Université Paris – Sorbonne (Paris IV)
École Doctorale 5 : Concepts et langages

Université de Californie à Berkeley
Department of Environmental Science, Policy, and Management

Doctorat en cotuelle :
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Jennifer Lynn Wells

Complexité et Changement Climatique :

Une étude épistémologique des théories de la complexité Transdisciplinaires et leur apport aux phénomènes socio-écologiques

Thèse soutenue en vue de l'obtention du grade de docteur le 23 juin 2009

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Mme Catherine Larrère	Professeur à l'Université Panthéon-Sorbonne
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Christopher G. Wells, Karen Wells, Rebecca S. Wells,

Ronald Powers, Catherine E. Bostock, David Bostock,

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Introduction

"[T]he twenty-first century will be the century of complexity."
Stephen Hawking[i]

“In the twenty-first century complexity is not a vague science buzzword any longer, but an equally pressing challenge for everything from the economy to cell biology.”
Albert-Laszlo Barabási[ii]

“Make things as simple as possible, but no simpler.”
Albert Einstein

As the urgency of climate change and other global issues has come to the forefront in recent years, many scientists and scholars have begun recasting these issues in terms of complex systems. This influential new perspective on social and environmental issues has major implications that have yet to be clarified. Climate change is an ideal case study of the utility of complexity theories, as it occurs at a planetary scale and involves interactions among complex systems essential to human civilization, such as food, energy, water, and economic systems. In the last ten years, just as mounting evidence has made climate change a top priority, literature on complexity theories has increased exponentially. A rising tide of books, journals and conferences focus on complexity indicating that yesterday’s buzzwords – chaos, nonlinearity, and networks – are today’s mainstream science and knowledge production. This presents an urgent need: to analyze advances in complexity theories and their implications in order to best inform decision-makers dealing with climate change.

The goal of this dissertation is to analyze how complexity theories are useful in addressing climate change. As climate change is awesome in its transdisciplinary scope, I necessarily address what complexity means in diverse disciplines, with their widely divergent methodologies and worldviews.

In lieu of a provable hypothesis, I explore a key proposition: complexity theories are likely unnecessary and inappropriate in some research, and yet substantial and useful in other areas, and I then assess this statement with respect to the case study of climate change science, ethics, and policy.

Complexity Theories – Definition Circa 2000

Complexity is a broad term referring to an overall scientific and philosophical perspective, based upon a large set of subsidiary ideas, sometimes referred to as 'complexity theories.' While the terms 'complexity' and 'complexity theories' continue to lack clarity for many, the considerable successes of the complexity theories proves their importance.

To begin with, I present the cursory, provisional definition of the field as it is still accepted as the last iteration of definitions for these terms, synthesized by various scientists and scholars in the period of around 1996-2000. While other views have grown considerably in the last ten years, the definition presented in 2001 by Stephen Manson and in similar accounts, is still broadly referred to, as it presents the most recent clearly articulated majority opinion of the field.[iii] Even this account was quite contentious at the time, yet it is perhaps the best general reference point against which to contrast the immense progress made in the last decade.

The circa 2000 account of complexity science or complexity theories roughly divided the field into three areas of research: algorithmic complexity, deterministic complexity, and aggregate complexity. Algorithmic complexity refers to two things. One, the measure of ***algorithmic complexity*** calculates *the effort required to solve a mathematical problem*. Spatial statistics and geographic information science face this kind of complexity. Problems such as enumerating all the permutations in a resource allocation situation or finding the shortest path through a network are very hard to solve in non-trivial cases. However, this form of algorithmic complexity has been utilized as an essential guide for practitioners in these areas.

The second form of algorithmic complexity lies in information theory, and is thus dubbed ***algorithmic information theory***. It has been attributed to independent contributions of three somewhat simultaneous founders, Solomonoff, Kolmogorov, and Chaitin.[iv] This body of work identifies complexity as *the simplest computational algorithm that can reproduce system behavior.* With information theory, one may condense the myriad interactions between systems components into simple measures. The use of information theory ranges from classifying remotely sensed imagery to considering the role of ecological community structure on biodiversity.

Algorithmic complexity may not be applicable to social or environmental phenomena as it may incorrectly equate data with knowledge. According to Manson, Vast realms of human endeavor, such as the lived experience and meaning given to it, lie beyond algorithmic expressions. Critics of geographic information science such as John Pickles claim that such shortcomings of computational representation are too great even for accurate analysis of spatial phenomena.[v]

The second main category of complexity theories is ***deterministic complexity***, which has four key characteristics: *1) the use of deterministic mathematics and mathematical attractors; (2) the notion of feedback; (3) sensitivity to initial conditions and bifurcation; and (4) the idea of deterministic chaos and strange attractors.* Prominent instances of deterministic complexity are chaos and catastrophe theories, which are quite successful with respect to some biophysical phenomena such as weather patterns and physical and chemical reactions.

Nonetheless, some debate persists about the overall value of chaos and catastrophe theories. A large amount of time series data is required to prove that a system has deterministic complexity. Even when data exists, fewer systems than anticipated are in fact deterministically chaotic or catastrophic. It appears that the instances are restricted largely to physical and chemical systems. Characterizing a human system through a few simple variable or deterministic equations is often just too simplistic.[vi] There are hazards in conflating pattern with process. For instance, urban land use may have a fractal pattern, but this knowledge only goes so far in aiding our understanding of how the land came to be that way, what this means for land use, or if that implies anything for land management.

Yet, effects such as sensitivity to initial conditions or strange attractors have spurred new thinking about everyday phenomena. This is often achieved by using these terms in an analogical manner. Postmodernists have embraced deterministic complexity this way (Hayles 1991). Deterministic complexity is characterized by contextuality, complexity and contingency; these themes have been said to exemplify postmodernism (Warf 1993). According to Nancy Cartwright, sensitivity to initial conditions and bifurcation undermine totalizing discourses by supporting unpredictability and the search for fragmentation and discontinuity.[vii] There are many other interesting parallels between discoveries in the complexity sciences and major concepts in postmodern theory, such as the use of scale, spatial hierarchy, boundedness, and economic attractors.

Finally, the third category has been called ***aggregate complexity***, or *systems of linked interacting components.* Algorithmic and deterministic complexity relies on simple mathematical equations and a number of assumptions on how complex systems work. Aggregate complexity instead assesses phenomena occurring at the scale of a system, resulting from the interaction of system components.

Key aspects of aggregate complexity include: a key set of interrelated concepts that define a complex system including relationships between entities, internal structure and surrounding environment, learning and emergent behavior and the means by which complex systems change, adapt, and develop. The heart of aggregate complexity lies in relationships, the relationships between components. Self-organization is the property that allows a system to change its internal structure in order to better interact with its environment, to learn through piecemeal changes in that internal structure.

Like deterministic complexity, aggregate complexity is explored in different fields via different means. While methodological difficulties have plagued aggregate complexity in the natural sciences, the development of computer simulation tools has allowed for substantial advancement in many areas of natural science, such as ecology. Once again, postmodern perspectives link aggregate complexity to issues of knowledge, language, and epistemology. Both aggregate complexity and postmodern theory have shown how entities and relationships within complex systems undergo constant interaction and development, supporting the postmodern view of localized, networked, social and political discourses.

It seems that all three forms of complexity present advances and insights at a cost. The three forms seem to gain in their power and reach in the order presented. Algorithmic complexity appears to be the simplest, yet the least fruitful and with the least real world applications. Deterministic complexity appears to be somewhat more difficult, but also bearing more tangible fruits. Finally, aggregate complexity is clearly more challenging than the other two areas. There is a very large literature on aggregate complexity, and a vast number of real world applications already developed and deployed. Numerous institutions, journals, academic departments and societies have formed to advance aggregate complexity theories. Clearly, many complexity scientists and scholars argue, aggregate complexity offers valuable perspectives on emergence, self-organization, social issues and environmental dynamics.

Many brilliant thinkers are currently devoting their careers to this field. At the same time, the field remains philosophically questionable. The relationship between the greater body of scientific knowledge and aggregate complexity remains elusive and uncertain. Despite new tools such as simulation models, aggregate complexity seems plagued with methodological shortcomings and deep misunderstandings.

Complexity Theories – Definition Today

This set of definitions, compiled and discussed about ten years ago, around the year 2000, now seems quite outdated. In this dissertation, I subsume the notions of algorithmic complexity and deterministic complexity under the much larger umbrella of aggregate complexity. Indeed, I give the prior two scant explicit attention, although they continue to play a major role within the field.

The main focus in this dissertation is on what was previously called aggregate complexity, and now is called simply, complexity. This has been the center of attention of what I conceive of as the main field of generalized complexity theories. I define ***generalized complexity theories*** as *the most encompassing view of complexity as it has been developing throughout the disciplines.* I expand on this definition in later chapters.

A greater deal of synthesis and rapprochement has taken place, not just between those involved in the proliferation of complexity theories in this last decade, but also due to considerable work to develop the field of generalized complexity theories, or complexity theories writ large. A growing number of scholars have tirelessly been drawing together the many precursors of complexity, the many disparate founding voices, and disparate fields, including: mathematics, cybernetics, biology, ecology, environmental issues, and various areas of postmodern analysis, social theory, and the philosophy of science.

My task is to assemble and assess this great body of work put together in the last ten years, and thus to advance our understanding of complexity, its relationship to the rest of knowledge, and its potential. My motivating questions include: Why it is that complexity seems to appear and make sense in every discipline, in a way that no former theory ever has? Is there something unique that merits this category of complexity theories? If so, what is the power, utility, and potential of this realm of theory called complexity theories? I use the word theory here in a broad, simple, general sense.

This dissertation is a sequel to the slurry of brief overviews of complexity written in the phase from around 1995-2000, when the importance and predominance of the field was becoming clear, but the sense of what it was or where it was going was anything but clear. At this point in the history of the field, I argue, it is possible and beneficial to greatly clarify major terms in the field, the parameters of the overall field, their relationship to each other, their relationship to science more generally, and their applicability to various real world issues.

In search of a more recent, better informed, and more synthesized definition of the complexity field, one simple place to begin is with the notion of a *complex system*, which has been defined as: a set of parts (Leibniz 1666); a set of unities with relationships among them (Bertalanffy 1956); and a global unity organized by interrelations between elements, actions, or individuals (Morin 1994). The key idea added to the definition of complexity in the Twentieth Century was the global character of the relational trait of the system, which has furthered our understanding of *emergent* and *self-organizing* properties. Today, some stress the multidisciplinary and epistemologically plural aspects of complex systems[viii], while others see complex systems as, "reality, untainted by the simplicity of models and other simplifying devices."[ix]

Mainstream notions associate complexity primarily with certain quite delimited instances from the natural sciences, which have been widely popularized. This includes captivating images such as fractals, strange attractors, and networks as in maps, food webs, or the internet. In fact, complexity has emerged in all the disciplines at different moments throughout human thinking, up until today. While some scholars still associate complexity theories more strictly with a few examples in the natural sciences, many others have begun to use the term more broadly to conceive of a large array of

phenomena and patterns that are now constellated into what many believe to be, in the Kuhnian sense, a new paradigm of human knowledge. In this sense, complexity theories emerged in all the disciplines, mostly since World War II.

While complexity has established itself widely and deeply in the last thirty years, both critics and supporters in both the natural sciences and social theory often still sidestep complexity terminology, because they find the definitions abstruse. Various troubling claims are made. Anything that you cannot define clearly is not worth studying. There is no such thing as complexity; what you call complexity is just standard science. Complexity is just a rag-bag of everything. Indeed, some natural scientists remain wary or are condescending of the term complexity itself.[x]

To these claims I would answer, many things we cannot define are clearly worthwhile, including love, hope, sustainability, healthy ecosystem services, and even the term science itself, which is actually also very difficult to define well. Complexity is in a sense an extension of standard science; but according to a vast new literature, there is more to the story than that. Therefore, complexity is not just a rag-bag of everything.

Mainstream analysis of the field has emerged almost entirely from just a few natural science institutes scattered in industrialized countries, largely starting with the Santa Fe Institute in New Mexico. These scientists advance basic science and consider applications in various niches, from spin glasses, pendulums, and sand piles, to food webs, and certain restricted examples of social and economic phenomena. This perspective is valuable, but may mask the more extensive implications in the realms of social science and global change. However, again, rather than recap the default mainstream perspective, this dissertation involves a full survey of the field, leading to the most wide-reaching ideas about what complexity is, what it implies, and if and how it is valuable.

This dissertation has been conducted, I believe, at just the right moment. By now, it is clear that complexity is here to stay, and the difficulty of defining it seems rather to indicate the breadth of its impact. Complexity has always been an aspect of our world, and there have always been complexity visionaries – Heraclitus, Blaise Pascal, Ludwig von Bertalanffy, Edgar Morin and many others. Since World War II, there have been a series of impressive new fields born under the umbrella, I argue, of greater complexity theories. By the mid-twentieth century, many leading philosophers had made important insights into complexity. By the turn of the twenty-first century researchers in most all disciplines had compiled enormous information about complex systems. In the last ten years work on complexity throughout the social science and social theory disciplines has become increasingly explicit and a coherent field of social complexity studies has been developing.

Aim, Rationale, and Methodology of the Dissertation

One of the main purposes of the first half of this dissertation is to connect the dots between various realms and disciplines, to explore just if and how complexity theories are transdisciplinary and useful. While the scope is necessarily transdisciplinary, the methodology I use is primarily philosophical analysis and interpretation. While I must tread at times into interpretation within different fields like the sciences, this dissertation is grounded in the philosophy of science and applied ethics. However, this dissertation also conforms to the views and methods of the following fields: environmental studies, environmental politics, science and technology studies, risk studies, and futures studies. It is no coincidence that such transdisciplinary fields have been proliferating in recent years; rather this trend has occurred directly in response to the increasing acknowledgement of the need to address greater degrees of complexity and transdisciplinarity in many of the major issues confronting societies and their environments today.

This dissertation presents a novel synthesis of contemporary complexity theories. While scholars have already delineated important work on transdisciplinary complexity, never before, to my knowledge, has someone brought together the most disparate areas of complexity studies in one synthetic interpretation. I include in this many important theses that have been based only implicitly and not explicitly on complexity theories. I attempt to show that making the many fruitful links to articulate complexity theories, both within and between the disciplines, represents a great advance for the field of complexity theories and for contemporary scholarship.

The novel contribution of this dissertation is the comprehensive, transdisciplinary, contemporary definition of complexity theories and its explicit application to climate change. There has been, notably, the transdisciplinary analysis of Edgar Morin.[xi] However, so much has evolved in just the last ten years that the two contributions presented here – this contemporary definition and the application to global change – are nonetheless notable advances.

I expect that secondary benefits will also accrue. Currently, many scholars in dispersed domains are exploring how complexity is essential to understanding the larger dimensions of various phenomena, social, technological, and environmental. This dissertation shows important links between their work: 1) elucidating the commonalities between different fields, 2) showing how lessons can and cannot be usefully adapted from one domain to another, 3) highlighting what, despite common principles, makes these fields distinct, and 4) analyzing when certain individual disciplinary approaches are appropriate, and when it is appropriate to employ complexity principles, theories, methods and analyses, whether stemming from the natural sciences, social sciences, transdisciplinary studies, philosophy, or ethics. Moreover, it sheds light on issues such as:

the role of scientists and scholars in understanding the science and technology of climate change; decision-making under conditions of inherent uncertainty; the place of science in the broader context of knowledge; the roles of different disciplines and different methodologies in relation to each other; and the essential social and ethical dimensions of climate change.

Outline of the dissertation

The dissertation is laid out in two parts and nine chapters in total. Part I is a transdisciplinary survey of complexity theories. Part II examines how complexity theories may be valuable in addressing climate change.

To begin, Chapter One explores the challenging but urgent question of defining and interpreting complexity theories. Hence, I attempt a lengthy definition and interpretation that I hope will be accessible and persuasive to the widest group of people, including natural scientists, social theorists, philosophers of science, ethicists, and others. While I offer a brief history of the field, I focus my efforts on synthesizing contemporary work, drawing upon major complexity scholars from the last fifty years. To accomplish this, I develop a Generalized Complexity Framework (GCF) that encompasses complexity theories in terms of six categories:

- Complexity ontological fundamentals I (COF I)
- Complexity ontological fundamentals II (COF II)
- Complexity epistemological fundamentals (CEF I)
- Axis I: Early classical science paradigm vs. complexity theories (AI)
- Axis II: Social theory, human sciences, and philosophy (AII)
- Axis III: Transdisciplinary theories and frameworks (AIII)

This GCF is revisited throughout the length of the dissertation. The two sets of ontological fundamentals include properties which are the basis of such complexity phenomena as nonlinearity, networks, feedback, hierarchy, emergence and self-organization, as well as descriptions of states of complex systems, such as the edge of chaos, degrees of connectivity, vulnerability, resilience, thresholds, and collapse. The epistemological fundamentals include the ways in which we are adapting to these ontological aspects, through new concepts, tools and forms of measurement. These include the observer and context, systems boundaries and openness, scale, grain, and issues such as the way that multiple systems coevolve or coproduce. This analysis involves a brief foray into the immense topic of what complexity implies for the way we understand terms and practices such as models, narratives, and other methods.

Each of the subsequent three 'axes' of Chapter One explores what appear to be fundamental ways in which complexity has been described and understood. For instance, I include a systems typology that provides one overview showing the elements that are added at each step between the simplest mechanical system and the most complex systems such as the human brain with its capacity to create new spheres of imagination, ideas, knowledge, and the creation of a virtual realm. And before proceeding through the individual realms of the natural sciences, social sciences and theoretical domains, I outline Edgar Morin's critical idea of restrained to generalized schema, which explains how the methodologies and worldviews of different disciplines end up framing and portraying particular aspects of complexity. These frameworks are helpful then, in reviewing the material throughout the rest of Part I.

Chapters Two through Five explore specific realms of the complexity field, examining how complexity is studied, understood, and applied in each area – the natural sciences, social sciences, social theory, transdisciplinary studies, and the philosophy of science. I track the Complexity Ontological Fundamentals throughout these realms, showing how their meanings intersect and diverge throughout. In Chapter Three I examine the prolific work of the Santa Fe Institute and other natural science institutes. In Chapter Four I examine work in the quantitative social sciences, and analyze the value of approaches such as agent-based modeling.

In contrast, in Chapter Four I analyze qualitative or philosophical approaches to the study of highly complex phenomena in the social and environmental spheres. In so doing, I engage in a comparison between the quantitative approaches of Chapter Three, and the much broader narrative approaches in Chapter Four. For this analysis, I utilize three influential social theories of the last two decades, exploring the way that the GCF does or does not contribute to these theories.

Chapter Five discusses the work of five different groups of scholars in different domains who independently have developed transdisciplinary approaches in order to adequately interpret current events. These groups are: specifically transdisciplinary complexity studies; interdisciplinary or multidisciplinary studies; ecologists and social scientists working on socio-economic systems studies; science and technology studies; and applied philosophy. Through the analysis of these five different groups, I explore how each group utilizes the GCF in the frameworks they develop.

In Part II, I apply the ideas of complexity theory to a particular case, climate change. Chapter Six explores how the broad perspective of complexity theories may be applicable, organized in two angles of approach. First, I look at the significance of the complexity fundamentals in the case of climate change. Rather than catalogue all the applicable fundamentals, I focus on two that have turned out to be particularly significant, feedbacks and thresholds, with obvious ramifications for sustainability, and

other aspects of the world's main systems, such as the systems of food, agriculture, energy, water, forests, soil, and transportation.

Second, I analyze two meta-assessments, the Fourth Assessment Report of the International Panel on Climate Change (IPCC), and the Millennium Ecosystem Assessment. Each of these massive assessments undertook sweeping international research and analysis on the state of the environment and its implications for climate change. I examine how the reports did and did not incorporate complexity terms and concepts into their analyses and conclusions, and the effects of this on the reports.

Chapter Seven engages in a reflection back over the main questions of the dissertation and the findings of the in-depth analysis of climate change. I explore how the GCF relates to climate ethics literature, which I break down into three groups relevant to this study. I analyze how the GCF this may inform and advance frameworks for climate change policy, politics and ethics, though I focus primarily on the case of climate ethics.

While the content and approach taken in this dissertation are quite bold, I believe this is justified by both the beauty of complexity theories and the depth of today's environmental crisis.

Notes

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PART I:

COMPLEXITY THEORIES:

A TRANSDISCIPLINARY SURVEY

Chapter One: Elucidating Complexity Theories

1.0. Introduction

Over the past twenty years there has been a great acceleration of so-called 'complexity studies', accompanied by increasingly powerful analyses of their meaning. Useful definitions have been available but not fully explicated and supported until recently. In this chapter, I describe the complexity field and define 'complexity theories.' My approach is to synthesize, reevaluate, and reframe the best definitions of the last fifty years, proposing a multidimensional definition that advances our understanding of complexity by presenting it in a comprehensive fashion.

I explore the propositional statement, to be explored throughout the dissertation, that transdisciplinary complexity theories may be very useful in some ways and some cases to the understanding and guidance of science, technology, ethics, politics and policy, even while it may be unnecessary, inappropriate, and problematic in other ways and other cases.

Generally speaking, ***complexity*** describes *systems composed of elements in dynamic interaction engaged in emergent, self-organizing processes.* Over the last century, scientists and scholars characterized complex systems in terms of nonlinearity, networks, feedback, and other common principles. Early systems and complexity theorists have laid significant 'foundations' and 'pillars' of the contemporary field. Yet ironically, a major claim of complexologists is that complexity offers proof of the death of foundationalism and absolute pillars as mechanistic metaphors that have given way to more dynamic ones. In rejection of these modernistic assumptions, I replace foundations and pillars with, respectively, *fundamentals* and *principles*.

The modern era has highlighted the extraction of the simple from the complex, overlooking the complex in ways that are at times useful, at times disastrous. I contend that seemingly innocuous oversimplification is the bane of contemporary knowledge, creating hyperdisciplinary blinders, dangerously decentralized and unguided motors of knowledge and technology production, and the lack of a direly needed useful sense of human place and agency within the knowledge and technology enterprise.

In the face of this situation, the reintroduction of appropriate degrees of complexity with its inherent transdisciplinarity, polyvalence, and context, is a challenging pursuit. An adequate definition of complexity theories, therefore, may be inherently longer, more complicated, and more qualitatively multidimensional than

thinkers in most disciplines are accustomed to. If the definition of complexity becomes too long, then it may risk becoming tautological, or arguably, no longer useful as a shorthand or heuristic.

The very fact that the definition continues to grow in length and complexity, however, indicates that there are aspects and qualities of our world which are highly complex, and that we may need to pay attention to this, with regards to some issues, in some ways, and at some times. The environmental crisis is one of these issues. Indeed, it seems that most or all of the multiple, contemporary global social and ecological crises fall into this category.

Complexity has taken time to emerge, it is still misunderstood and considered strange, untrustworthy or worse by some scientists, it is unknown to many social theorists, and the public is mostly completely unaware of it. The reasons for this are numerous, but a primary reason is that you can successfully study and manipulate many systems without ever using or understanding complexity theories. Airplanes fly, refrigerators cool, computers function, and printers print, without ever cracking a book on complexity. Linear equations, mechanistic concepts and methods, engineering and much of physics function perfectly fine without recourse to the extra study that complexity theories requires.

Indeed, classical science and technology have been immensely successful in many areas. However, they have proven to be grossly inadequate for comprehending and guiding contemporary human societies. As increasingly important issues of risk, uncertainty, unknowability, unpredictability, unintended consequences, and the environmental crisis itself show, classical science and technology do not provide sufficient insight and guidance in the realm of global environmental science, issues, policy, and ethics.

1.1. A brief history of complexity theories

The following is a brief account of the history of complexity theories. A few major challenges plague an accurate account of the history of systems and complexity theories. First, systems and complexity studies have been taken up in highly disparate disciplines with little accord between them over several decades, and the terminology is understood in different ways from the perspective of the different disciplines. Natural scientists and humanities scholars often have little accurate sense of each other's methodologies or disciplinary terminology. Moreover, the systems and complexity fields have developed in different languages, notably English, French, and more recently Japanese, Chinese, and other romance and Asian languages. For

instance, systems theory varies in some perhaps fundamental respects between American and French scholarship and interpretation. Therefore, I focus here on an account of the fundamental events, discoveries and figures in the field, without claiming to be comprehensive.

To clarify the parameters, I see systems theories largely as the precursor and core of what has more recently blossomed under the larger umbrella of complexity theories. Systems theories were influential from the 1920s through the 1970s; complexity theories have extended beyond and subsumed systems theories from the 1980s through today. Though this distinction is disputed, I believe it is a valid basic organization of the history, and in any case, whether or not we accept this as the relationship between the two sets of theories, it does not greatly change our understanding of the nature of the largest ensemble of these theories that I present in this dissertation.

As such, I divide the history of these studies into three major phases: pre-Systems Theories (ancient History to 1921), Systems Theories (1922 to 1981), and the contemporary phase of Complexity Theories (1982 to today). Of course there is much overlap. Seeds of complexity were planted in antiquity and again throughout the systems phase; systems theories still have growing credence and utility today, and at a deeper level, the distinction between the two may be ultimately inconsequential. I make the distinction, because it seems that the complexity scholars have put forth previously unarticulated aspects of the way the systems of our reality work, which are quite significant.

It is significant to mention the phase of pre-systems theories. Thinkers such as Heraclitus, Pascal, and many others, expressed core elements of complexity thinking. Heraclitus noted phenomena that today may well be called complexity, emergence, and self-organization. One could argue that Pascal was a complexity thinker to the very core, and has perhaps had more influence on the field than one could imagine, allowing the glimmering mystique of complexity thinking to reverberate in the background of the modern age. Distinguished from classical Western rationalist traditions in philosophy, Charles West Churchman identified the *I Ching* as a systems approach sharing a frame of reference similar to Heraclitus' pre-Socratic philosophy. Karl von Ludwig Bertalanffy traced systems concepts to the philosophy of Gottfried von Leibniz and Nicholas of Cusa's *Coincidentia Oppositorum*. Edgar Morin saw significant precursors of contemporary complexity theories in the works of Kant, Nietzsche and Heidegger. I lack space to defend each of these claims, but I offer a few such references to indicate the extent to which complexity has been judged throughout the history of ideas to have deep and multiple roots and sources.

One major strand of thinking that was influential to later complexologists was first articulated in modern times perhaps by the French Enlightenment thinkers, with

their desire to understand the disciplines in their growing ensemble, with some degree of rational articulation between them. Diderot's *Encyclopedia* spurred thinking on whether and how the sciences may ultimately be 'reunited.' Thus was born the precursors of the modern notions of interdisciplinarity, multidisciplinarity, and transdisciplinarity, and the unifying threads between disparate disciplines.

The Vienna Circle was a group of influential philosophers and scientists that met regularly under the guidance of Moritz Schlick, beginning in 1922, taking up the question of the unity of the sciences. Over time, they developed their main project, called *The Encyclopedia of Unified Science*. This was a pioneering attempt to construe a universal look at knowledge from a rigorous, empirical perspective. Regular members included Rudolph Carnap, Otto Neurath, and Hans Hahn. Ludwig Wittgenstein greatly influenced the group, associating with and meeting with them occasionally. Kurt Godel, W.V. Quine, and A.J. Ayer visited the group. Karl Popper was also influential in the discussion and criticism of their doctrines. The group based their ideas in the logical positivist philosophy that holds that philosophy should aspire to the same sort of rigor as the laws of the natural sciences. Philosophy should provide strict criteria for judging sentences true, false, and meaningless. Statements are meaningful only insofar as they are verifiable, and statements can be verified in two ways – empirical statements verified by evidence and experiment, and analytic truths, statements which are either true or false by definition. While their influence continued in subsequent years, the Vienna Circle disbanded with Hitler's rise, holding their final meetings in 1936.

The complexity concept emerged early on, perhaps as early as 1925 in Lotka's classic, *Elements of Physical Biology*. In the first half of the twentieth century many precursors to today's complexity theory were developed: in 1920 the theory of schismogenesis and netwar, in 1925 mathematical and theoretical biology, and in 1944 the study of biospherics. In the 1950s several significant domains developed including in 1950 cellular automata and in 1952 cellular dynamical systems, morphogenesis and self-organization.[i]

During and after the war, cybernetics became a second major branch of systems theories, complementing the work on the potential for a unified science, conducted by the Vienna Circle. Norbert Wiener and others worked on the field in the early 1940s. Wiener published what is considered the founding document, coining the term cybernetics, in 1948, called *Cybernetics: Or the Control and Communication in the Animal and the Machine.*

In the post-war period, from 1946 to 1953, major systems thinkers gathered regularly in New York City for a series of conferences on systems theories called the Macy's Conferences. They discussed general system theory, cybernetics and system

dynamics in diverse fields. These three areas of study can be seen as the major strands of what was to become known as Systems Theory and then Complexity Theories.

At the heart of these meetings was the biologist and philosopher Karl Ludwig von Bertalanffy, largely lauded as the founder of Systems Theory. Bertalanffy had been working throughout the 1940s on a unified view of the sciences. This work was partially a response and repudiation of the Vienna Circle's positivist approach. While Bertalanffy, originally from Vienna, shared the Vienna Circle's goal of discovering important transdisciplinary patterns in a rigorous modern fashion, he also developed a substantial argument against what he saw as the overly myopic and restricted approach of classical science employed by the Vienna Circle.

Bertalanffy saw systems concepts as a broad, interdisciplinary bridge that could ultimately unite all the sciences in a more inclusive fashion, with implications extending throughout the natural and social sciences. Bertalanffy is the founder of what he called General Systems Theory (GST), an attempt to theorize the connections between disparate types of systems, which provided the basis of much of the subsequent field of systems theories. Bertalanffy's work on General Systems Theory was published as a book in German in 1948, an article in English in 1951, and the book in English, *General System Theory: Foundations, Development, Applications*, which appeared in 1968, followed by two other books on systems theory, in 1975 and 1981.

Meanwhile, from 1956 to 1960, the Stanford Group was formed, consisting of von Bertalanffy, Anatol Rappaport, Ralph Gerard, Kenneth Boulding, and Ross Ashby. They officially called their group the Society for General Systems Research (SGSR). The span of the group's work was short but the results were prodigious, including four major tomes on GST. The journal they began continued to be published and was the most influential work in systems studies throughout the 1970s.

The SGSR influenced a group of Stanford philosophers who took up some of the questions lingering in the wake of both the Vienna Circle and the advent of systems theories, especially given the presence of SGSR at Stanford. This group, sometimes called the Stanford School of the philosophy of science, includes Nancy Cartwright, John Dupré, Ian Hacking, Patrick Suppes, and Peter Galison.

Meanwhile, the 1950s and 1960s was a fertile time for the systems sciences, during which various new strands were developing in parallel to systems theories, greatly expanding upon the initial ideas of the Macy's Conferences and the two Stanford groups. Several major fields were begun, including artificial intelligence (Herbert Simon and others, 1956), ecology (Rachel Carson, 1962), and catastrophe theory (Rene Thom, 1967). Some say ecology was founded as early as 1866, with E Haeckel's tome *General Morphology of Organisms, General Outlines of the Science of Organic Forms based on Mechanical principles through the Theory of Descent as*

reformed by Charles Darwin. Rachel Carson is not a founder per se, but in essence, many see her book as launching both the environmental movement of the 1960s and 1970s, and scholarly interest in the field.

Major dates for complexity theories from 1970 to 1982 included: chaos theory (Edward Lorenz, 1974), fractal geometry (Benoit Mandelbrot, 1975), the first book devoted to (what was to be later called) generalized complexity theories, *The Method, Volume I* (Edgar Morin, 1976, to be followed by five more volumes, between 1981 and 2006), the second, *Tools for Thought* and the field of operations research (Conrad Hal Waddington, 1977) , and a Cerisy Conference on Complexity Theories in France (1980).

Now the term complexity was coined and the synthesis of all of these major endeavors and fields began. The Santa Fe Institute formed in 1982. The same year, Jean-Pierre Dupuy published *Orders and Disorders: Quest for a New Paradigm* (*Ordres et désordres: Enquête sur un nouveau paradigm*).[ii] Maturana and Varela's concept of autopoesis emerged in about 1979. Popular books appeared on chaos in 1987 by James Gleick, and on complexity in 1992 by Mitchell Waldrop. Three new major complexity institutions began in the years 1998 and 2000, the New England Complex Systems Institute (NECSI), the Institute for the Study of Coherence and Emergence, (ICSE), and the organization Modeling of Complex Systems and the Association of Complex Thinking (MCX-APC). The interwoven and expanding notions of the nature of complex systems are certainly ongoing and active pursuits today.

1.1.1. Clarifications on Complexity Terms

Any highly complex theory will prove unsatisfying and even sacrilegious to those who wish to condense reality into one unified theory, one unified framework, one discipline, one ideology, one funding agency, one triumphant Nobel Prize.

In the last fifty years, many scholars have broken from these unifying notions, and begun to accept a messier and less satisfying picture of reality. Because it is messier and less satisfying than more coherent and elegant propositions, complexity terms seem inevitably to suffer from vagueness, incoherence, and inadequacy for tight and elegant logical arguments. One of the operating principles for this dissertation is to put aside the notion that for something to be worthwhile it must be simplifiable. Simplicity and brilliance are not always correlated; not every description of a universal trait can be as elegant as $E = MC^2$. By putting aside the assumptions of previous eras I attempt to open up thinking about complexity's definition, its successes, and its potential.

However, the field need not be as unruly as it currently has become, due largely to the transdisciplinary nature of complexity, and thus its development in very different domains. The field has evolved to the point that now there are four, equally unsatisfying and perhaps equally incorrect general terms for the description of research in the field of complexity: complexity, complexity sciences, complexity thinking, and complexity theories. This author has made some tentative personal choices that may very well not withstand the test of time, but I will give explanations sufficient for their use.

The term complexity has several connotations. First, as I mentioned at the outset, complexity is used in a broad, transdisciplinary sense as a synonym for complex systems, which is in turn a broad, transdisciplinary term for systems composed of elements in dynamic interaction engaged in emergent, self-organizing processes. In other words, complexity recognizes the intricacy and interactions within and between parts and wholes. Second, one can refer to complexity more generally as that which is devoid of overly constricting particulars: ideology, singular ideas, arguments, models or concepts that possess some degree of incompleteness as they represent but a tiny fraction of the reality of the world at any given moment. Third, complexity permits a distinction from past ways of knowing, primarily embodied in the categories of modern science, modernism and the scientific method. Complexity is used to evoke both the nature and the implications of the paradigm of complex systems.

I do not use the term *complexity sciences* as a general moniker for the whole transdisciplinary field because the history of modernistic assumptions underpinning the natural sciences has been so tenacious and influential that any term employing the

word science is too easily prey to confusion and distortion. I do use the term complexity science to refer to complexity studies in the natural sciences, such as the majority of work conducted at the Santa Fe Institute.

Nevertheless, I must distinguish in some way between the background status quo perspective that I contrast with the complexity perspective. Because the background status quo is greatly varied, with much of contemporary science and scholarship conducting research much in line with the complexity perspective I am presenting, this is no easy task. Following the lead of previous scholars, I utilize the terms ***classical science*** or ***standard science***, (as synonyms), to refer to *the dominant mainstream Occidental scientific worldview insofar as it is still not sufficiently 'complex'*. ***Classical*** refers to the perspective, the assumptions, and the ideas surrounding empirical science at the time of its inception in the 1500s. In this sense it is a classical view of what science is and means. ***Standard*** is a simple term to refer to how the majority of people perceive and understand science.

The term *complexity thinking* is useful in more general transdisciplinary discussion, and I employ it to mean:

1) The set of ideas, principles, fundamentals, models and conceptual tools used to study and describe the nature and the dynamics of systems of interacting elements in emergent, self-organizing processes.
2) An approach to perceiving and analyzing problems that incorporates the above ideas and tools.

Complexity theories also refer to any of the broad swath of studies in any of the disciplines studying complexity, which is thus defined as:

1) The use of one or more of the tools of complexity thinking, or 'complexity tools,' in the study of systems composed of a large number of elements in interaction.

I use of the word ***theory*** in the general, historical sense of the term, to mean, as in this definition from the mid-1600s *"contemplation, speculation, deepe study, insight or beholding."*[iii] This is in contradiction to more specific uses of the term within different disciplines. This is not an incidental, but rather a deliberate move on my part, to fortify the use of the term as it does and can apply in social theory, in philosophy, and in transdisciplinary analyses that involve a non-natural science dimension. This facilitates cross-disciplinary comparisons between these domains, which is useful in the case of the majority of today's major social issues.

Thus I employ the term 'complexity theories' most frequently. Unfortunately, like much within the complexity field, the term 'complexity theories' is likely to maintain its aura of messiness and incoherence to highly logical minds. However, such lack of precision and clarity may be necessary to descriptions of complexity at the largest scale.

Additionally, in this dissertation, I use the term 'study system' to denote the object of study, while shifting the focus from object, which connotes the outdated mechanical sense, to subject, which may include any kind of complex system under study, from natural, to social, to socio-ecological. So a ***study system*** is *any subject being studied*, and *a subject is any system, or any dynamic entity of study which is a system as defined in the complexity field – whatever type of system this may be, e.g. natural or social, and whether it be seen under the lens of natural science or social theory.* So a study system for an ecologist may be a puddle or a lake, for a sociologist it may be a particular prisoner or a prison system, and for an economist it may be the housing market in Topeka Kansas or the entire global financial crash of 2008.

Many times throughout this dissertation we will be confronting the issue of multiple connotations of cross-disciplinary terminology. For instance, complexity scholars at a natural science institute, the Center for the Study of Complex Systems (CSCS) describe their approach as interdisciplinary commenting that, "an important aspect of the complex systems approach is the recognition that many different kinds of systems include self-regulation, feedback or adaptation in their dynamics and thus may have a common underlying structure despite their apparent differences." They are using a common connotation of 'interdisciplinary,' that which is limited to the natural sciences.

In turn, many humanities scholars refer to interdisciplinary research to refer to work that spans disciplines solely within the human sciences and the humanities. Such varied connotations of seemingly clear terms such as interdisciplinary research are common. While these differences are unsurprising, given that one's training and expertise will limit one's associations and contributions, they are significant, because as human nature may perhaps dictate at first glance many readers assume that anything interdisciplinary must include her own discipline.

In the social sciences, a ***social system*** is defined as *any group of people who interact long enough to create a shared set of understandings, norms, routines to integrate action, and established patterns of dominance and resource allocation.*[iv] Examples of social systems are families and nations. According to Talcott Parsons, in 1951, a social system must: fulfill key functions, be oriented towards certain goals or objectives; create mechanisms for integration and adaptation; and create mechanisms for self-production.[v]

1.1.1. Towards an Evolving Definition of Complexity Theories

I approach a definition of complexity by means of a set of fundamental aspects, axes, methods, and implications of complexity theories, a synthesis of several past approaches. In this way, I admit my failure to discover a simple definition of complexity theories. However I claim that I have an even better discovery; it may only be possible to give incomplete definitions of complexity, but that these tentative definitions can be developed over time. This framework consists of seven areas of complexity theories including: seven fundamental features of complex systems; six axes of complexity; three views on scientific models; and four areas of knowledge reform (Table 1.1.). These complexity fundamentals have been developed by many scholars over the last century.

Complexity Ontological Fundamentals I (COF I)	• Complex adaptive systems, complex dynamic systems • Nonlinearity, chaos theory, and power laws • Network • Feedback • Hierarchy • Emergence • Self-organization
Complexity Ontological Fundamentals II (COF II)	• Equilibrium, phase state, attractor, edge of chaos • Connectivity, diversity • Network causality, interrelatedness • Unintended consequences, irreversibility & nonrenewability • Vulnerability, risk • Robustness, resilience, & sustainability • Threshold, tipping point, abrupt change • Collapse, catastrophe
Complexity Epistemological Fundamentals (CEF)	• Observer; context • System boundaries; openness • Scale • Grain • Co-evolution, co-production, co-evolving landscapes • Models, narratives, and other methods
Axis I: Natural sciences, and social sciences	Classical versus complexity sciences/ theories (Morin 1974; Merchant 1980; Dupré 1992; Norgaard 1994) • Mechanism, order, vs. organization • Atomism vs. network • Reductionism vs. synthesis • Essentialism vs. polyvalence, emergence • Universalism vs. pluralism, disunity • Determinism vs. intentionality, emergence
Axis II: Social theory, human sciences, and philosophy	• Compressibility vs. incompressibility; decomposability vs. nondecomposability; reducibility vs. irreducibility • Production vs. emergence; Complicatedness vs. complex • Thinness vs. thickness • Externalist vs. internalist • Uncertainty vs. unknowability
Axis III: Transdisciplinary theories and frameworks	• Transdisciplinarity • Systems typology (J-C Lugan 1983) • Reductive, emergent, holistic • Restrained versus generalized (Morin 2006)

Table 1.1. Generalized Complexity Framework: Six key aspects of complexity

Before delving into details, I give a general defense of this broad complexity framework, both a synthesis and an analysis of the major aspects of complexity theories as defined thus far today, intended to advance definitions in the field of complexity.

The order of the chart is chosen to represent a progression in aspects of complex systems that captures the nature and extent of change implied by 'generalized complexity' or complexity broadly construed. This will culminate with a definition of generalized complexity.

1.3.1. Fundamental Complexity and Overall Complexity

First I should distinguish between two important types of complexity, fundamental complexity and overall complexity. Fundamental complexity is possessed by any complex system; it has meaning only in distinction from overall complexity. In early modern times, atomistic thinking construed the atom as an inert, closed system and building block of the universe. This idea was reified during the founding of the Scientific Revolution and the Modern Era. In contrast, contemporary physics views subatomic particles as being complex and behaving in complex ways that are not fully understood. Today even subatomic particles, the smallest elements of physics, are considered to be complex.

Thus, overall complexity relates to the degree of complexity in relation to another complex system. Though complexity scholars do distinguish between simple systems and complex systems, there may be nothing in the universe which is entirely simple and composed only of simple things. A rock is composed of subatomic particles that appear to be complex. Nonetheless, a rock is vastly less complex than the human brain. Thus the second category is significant. A rock may be composed of complex particles, but a building made of rocks is nonetheless a simple system, in terms of the rocks, if it is a system at all. Moreover, even when we consider the complexity of the particles of the rock, the rock itself is still vastly less complex than the brain, because the brain possesses both complex particles and it is an extraordinarily complex system, producing hierarchical layers of increasingly complex kinds, whether in the realm of the material, biological or meaning. Indeed, it is the most complex type of relatively closed study system known to humankind, as described in Jean-Claude Lugan's typology of systems.[vi] Thus the spectrum that has often been invoked, with physics at the one end, and perhaps poetry at the other, is appropriate in portraying the spectrum of degrees of overall complexity. I choose to distinguish between these three sets of paradigmatic complexity fundamentals,

because I believe this accurately portrays one of the biggest and most troubling divides that have long plagued human knowledge, the culture gap between the natural sciences and the humanities, described by C.P. Snow in 1959.[vii] While numerous attempts have been made to reduce the negative impact of the culture gap on human knowledge and contemporary societies, the unresolved Science Wars of the 1990s reveal how little progress has been made in this arena.

Throughout the first few chapters of the dissertation I explore various definitions of complexity as it has been employed and applied within certain specific study areas. It is useful to understand the way that complexity has developed in a parallel fashion – and not a synthetic fashion – across multiple realms as well as disciplines of human knowledge. After first seeing how various scientists and scholars variously perceive complex systems and complexity, I return to this chart later in the dissertation to offer further insights.

1.3.2. Complexity Ontological and Epistemological Fundamentals

The first section, Complexity Ontological Fundamentals I (COF I), is not in any sense the 'simplest.' Indeed, self-organization, one of the seven complexity fundamentals, has proven as difficult as any of the aspects listed further down the chart. Similarly, and in inexplicable correlation with self-organization, emergence has been cited as one of the most difficult, unresolved problems in biology.[viii] These seven elements are the most common elements in the complexity literature. While they are mostly explicitly attributed to natural and social systems, I also discuss how they seem to be implicated in social theory, transdisciplinary analyses, and philosophy (chapters five through seven). I dedicate much of the next few chapters to the COF I.

These aspects of complex systems are often described in isolation, not just in the natural sciences, but in the other realms, the social sciences and social theories as well. I attempt to describe the major aspects or fundamentals of complex system in terms and descriptions that highlight their interrelationships. In complexity thinking, interrelationships between the complexity fundamentals and knowledge realms are as significant as the individual aspects. The second set of principles, Complexity Ontological Fundamentals II (COF II) can be seen as the results of the first set. It is through structures of networks, processes that are nonlinear, and feedback mechanisms that produce emergence and maintain self-organized patterns that systems maintain themselves in some kind of dynamic disequilibrium in a state

between order and chaos, or 'at the edge of chaos.' The states that systems are in are sometimes referred to as equilibrium, disequilibrium, phase states, or attractors.

How systems maintain themselves between states of order and disorder is somewhat determined by aspects such as connectivity and diversity. Because systems are composed of dynamic elements in dynamic interaction, they also are interacting not in simplistic, linear patterns, but rather in patterns of network causality. I define ***network causality*** as *multiple elements in interrelated causal interactions.* Nonlinear, network causality seems to be inherent to any study systems that cannot be explained by black box analytical methods, which explains why complex systems interactions generate multiple, unintended consequences, very few of which can be traced or predicted by the methods of classical science alone.

Once one sees that systems only possess emergence and self-organization of properties at certain time scales and within limited biospheric constraints, it becomes apparent that humans in relation to complex systems must consider properties of life in the biosphere such as irreversibility, nonrenewability, and limited resources. Thus, systems can be qualified as existing in various degrees along an axis that runs from, on the one hand, vulnerability and resilience, and on the other hand, robustness and sustainability. Two ultimate endpoints of complex systems are sustainability or collapse.

Complexity Epistemological Fundamentals (CEF) can be seen as the next iteration in consequences of construing life's systems in terms of complex systems; the ontological fundamentals lead directly to these epistemological fundamentals. The observer in the system presents a striking visualize shift, which permits one to better conceptualize the other epistemological fundamentals in turn. To even conceive this principle, is to redraw the schema of what systems are like and how we approach them. Classical science focused on discrete systems with no observer; the observer is outside of the study system and thus seen as not influencing the scientific study or experiment. In contrast, complexologists have reached consensus that this classical view is only fully appropriate to certain reductionist experiments. In many types of studies, one can draw the lines around the issue at hand, with the observer but one detail of the actual study. This permits one to highlight interactions: between observer and other drivers in the system, between the observer and the environment, and the like.

While natural scientists work almost entirely with complex systems today they rarely admit the extent to which their role as observer in the context of their experimentation or analyses has significance to their results. While the role of the observer is very constricted – located at some particular point and with only limited epistemological perspective upon the full reality of any complex systems dynamics – by recognizing the significance of observational perspectives and contexts, scientists

and scholars acknowledge potentially significant causal or contextual issues in their research.

This perspective of scientists and scholars locating themselves, their ideas, and their equipment within the sphere of complex systems, raises many new issues. One set of issues deals with the systems boundary delineations, including degrees of openness or permeability of study systems, that is to say, the nature of their interactions with their environment. Moreover, the hierarchical, networked structure of complex systems implies that issues of scale and grain are paramount to analyses. Feedback within and between systems as well as emergence and organization necessitate an understanding of co- production and co-evolution within and between systems.

Finally, such a set of epistemological fundamentals has implications for the general epistemology of various kinds of systems in disparate disciplines. Thus classical views of models themselves are called into question. Complexity scholars consider that the methodology of classical science must be radically reassessed and expanded to include both classical modeling as well as newer interpretations of both mathematical models and more comprehensive conceptual models – e.g. scenarios, narratives, and more.

1.3.3. Axes I-III

The remaining three areas of my complexity definition all stem from the shift from classical thinking to complexity thinking, in what I refer to as major realms of human knowledge, seeing a ***realm*** as *a cluster of closely related disciplines*.

Axis I: Natural sciences, and social sciences	Classical versus complexity sciences/ theories (Morin 1974; Merchant 1980; Dupré 1992; Norgaard 1994) • Mechanism, order, vs. organization • Atomism vs. network • Reductionism vs. synthesis • Essentialism vs. polyvalence, emergence • Universalism vs. pluralism, disunity • Determinism vs. intentionality, emergence
Axis II: Social theory, human sciences, and philosophy	• Compressibility vs. incompressibility; decomposability vs. nondecomposability; reducibility vs. irreducibility • Production vs. emergence; Complicatedness vs. complex • Thinness vs. thickness • Externalist vs. internalist • Uncertainty vs. unknowability
Axis III: Transdisciplinary theories and frameworks	• Transdisciplinarity • Systems typology (J-C Lugan 1983) • Reductive, emergent, holistic • Restrained versus generalized (Morin 2006)

In order to describe the three axes, I will first explain and justify the realms of knowledge that I delineate. Typically, one divides knowledge into the natural sciences, the social sciences, the humanities, letters and the arts.

Knowledge Realm	**Methodologies**
Natural science	experimentation or what is called the scientific method, and mathematical methods, including: modeling, statistics and probability applied to natural systems
Social science Quantitative	experimentation or what is called the scientific method, and mathematical methods, including: modeling, statistics and probability applied to social systems
Social Theory Qualitative	conceptual theory and analysis, and philosophical argumentation
Letters	Imaginative creation in the writing arts – literature, theater poetry, etc.
Arts	imaginative creation in the plastic and performance arts – drawing, painting, sculpture, dance, theatre performance, etc.

With respect to complexity thinking, and the next phase of human knowledge, I find it most useful to emphasize the differentiations and commonalities captured by these four categories and methodologies, which are generally aligned as follows: the natural sciences, the social sciences, social theory, the humanities, and the arts. Of these, I consider them to have a few major modes of analyses, including: the scientific method, replication of empirical and experimentation; mathematical modeling; conceptual theory and analysis; philosophical argumentation; and imaginative creativity. Of course, there is some overlap and similarity between these domains. Here, it is unnecessary to parse these details. What is significant is that the complexity fundamentals are expressed throughout the domains and throughout all of the methodologies.

Reconsideration of mathematical models touches the core of the project of modernity. Francis Bacon, Rene Descartes, Gottfried Leibniz, and Isaac Newton dreamed of a world in which all could be unveiled and revealed through the elegance of mathematics. The radical shift at the core of complexity studies has been the source of more contention than perhaps any other aspect of the complexity field. Thus, I include three sections on views of complexity as a shift away from the early classical science paradigm, though I do not see complexity as a paradigm, as I explain later. I divide this somewhat arbitrarily, along the lines of natural sciences and social sciences, social theory, and transdisciplinary perspectives. Seeing complex systems in light of shifts in all of these realms is highly significant. Therefore, I devote a chapter to each of them, (Chapters Two through Five).

The three axes of the GCF are aspects of one shift, the shift from simpler to more complex views across the realms of knowledge. I refer to this as the shift from the classical to complexity viewpoint. The physics to poetry spectrum can be seen as an axis extending from the discipline most legitimately studied through reductionist means, physics, through realms for which some reductionist methodology is helpful, but greatly insufficient, e.g. biology, statistical social sciences, to those for which reductionist methodologies are completely insufficient and often serve less to clarify than to create more confusion. These disciplines require social theory and philosophical argumentation.

The spectrum is useful, but aside from the above mentioned heuristic, there is no reason for this particular order, which should not be assigned undue significance. In fact, while many randomly assume that complexity began or emerged from the natural sciences, there is no reason to believe this. It may well be that modern era complexity emerged first in philosophy, as Edgar Morin has said.

Axis I is the shift from classical to complexity thinking is pronounced in the quantitative sciences. Reductionism is most debated in this arena. In this sense, reductionism is often equated with analytical thinking, when comparing analytical to

synthetic thinking, the prior referring to that which breaks down parts to analyze them individually, the latter which combines parts to analyze them collectively. Thus, a significant aspect of Axis I is an expanded understanding, without any loss in significance, of the nonetheless narrower role and place of reductionist experimentation. Reductionist experiments are defined briefly as those meant "to analyze or account for a complex theory or phenomenon by reduction." More specifically,

> [I]n philosophy, the practice of trying to show that certain entities may be eliminated by reducing all reference to them to reference to some other entities. In more general use, the practice of describing a phenomenon (particularly one involving human thought and action) in terms of an apparently more 'basic' or 'primitive' phenomenon, to which the first is then said to be equivalent; for example, the practices of describing mental states in terms of the behaviour that expresses them, of describing organic processes in terms of the physico-chemical reactions which underlie them, of describing social and political transformations in terms of the economic changes which engender them. In each case it is supposed that 'reduction' both explains, and also simplifies; 'reductionism' is therefore often used as a term of abuse for those theories which simplify too much, by reducing one phenomenon to another that is too basic to explain it.[ix]

Reductionism is an often contested concept. Yet it is central to my view presented in the GCF of the three axes of complexity theories. It is significant both because it speaks to both the nature of the methodologies, ontology and epistemology of the oft noted gap between the natural sciences and social theory and because of its apparent significance in the shift from the classical and the complexity paradigms.

Thus, we can group certain social science research with the natural sciences, as work that utilizes what I will call the primarily reductive methodologies: the scientific method, empirical studies, statistics and probability. These social science fields include: demography, social economics, and some areas of: sociology, political science, and the like. Of course, some areas of fields such as sociology or political science, utilize a mix of scientific and theoretical methodologies.

Axis II, social theory, includes research in the social science disciplines that do not utilize the explicit, quantitative reductive methodologies, relying instead on conceptual theory, analysis, and argumentation. Disciplines that produce primarily social theory include much of sociology, geography, anthropology, political theory,

and history. In this dissertation I cover some social theory disciplines – geography, sociology, and political science, and the humanities discipline of philosophy, including its subsets of the applied philosophy, philosophy of science, ontology, epistemology, and ethics. While there is a now substantial literature in the area of complexity and the arts, I omit this realm from the dissertation.

Axis III literature, unfortunately – in part because transdisciplinary work is eschewed by the academy – is often decentralized and dispersed. Transdisciplinary analyses are produced by renegade and pioneer thinkers in all disciplines, all areas of knowledge. Certain transdisciplinarians become interested enough to produce work that is explicitly transdisciplinary. Arguably, Axis III strategies treat the most complex issues the most adequately, most of the time, as they draw together and combine multiple methodologies and means of analysis.

As I mention above, these axes are far from a sufficient delineation for many purposes. For instance, many domains such as psychology, neuroscience, cognitive science, and linguistics, fall somewhere between the three axes. Again, for the purposes of the argument made in this dissertation, it is unnecessary to treat such difficult philosophy of science questions on this particular point. The three axes serve their aim for this dissertation well, which is to make the critical distinction not typically articulated or appreciated, between the various methodologies within the so-called 'social sciences.' I argue that it is not complexity theories, but social sciences, which are the real rag-bag of everything. The social sciences, if they are to advance, must be parsed more delicately. The crude distinction I make here between quantitative and theoretical studies of social systems makes possible an important perspective necessary to the further elaboration of complexity theories.

These three axes are presented in this order, as it has been used by many scholars in the attempt to look at knowledge more comprehensively, and in the extensive philosophy of science debate regarding how the disciplines are unified or disunified. The order is thus a useful heuristic for treating interdisciplinary phenomena, the assumptions of modernity, and the disunity of science.

The physics to poetry axis, more or less susceptible to reductionist methodology, evokes some useful differentiations. For instance, it has been argued that physical systems are the simplest, chemical systems a bit more complex, biological systems more complex still, ecological systems are highly complex, the human brain is more complex than many ecosystems, social systems composed of multiple humans, and their institutions, more so, and finally, socio-ecological systems at the global scale are the most complex systems possible on our planet. Ultimately, it may be more complex than that, but taking overall complexity as a guide, there appears to be some truth to this view. Significantly, this sheds a special light on the

fact that the realm of socio-ecological phenomena, the subject of this dissertation, is the most complex.

1.3.4. Ontological Complexity Fundamentals I

Ontological Complexity Fundamentals I	• Complex dynamic systems • Nonlinearity • Network • Feedback • Hierarchy • Emergence • Organization

Many scholars have defined complexity in terms of complex system functioning: complex systems, nonlinearity, networks, hierarchy, feedback, emergence, and organization. These fundamental features of complex systems are ubiquitous in the complexity literature (Richardson 2006; Gunderson and Holling 2002; Barabási 2002; Allen and Hoekstra 1992; Dunne 2003; Dumouchel 1983; Morin 1977). Observing that study systems throughout all realms of the world, thus throughout all types of knowledge disciplines possess these characteristics creates a kind of backbone to the corpus of complexity theories. This perspective highlights the way in which complexity theories seem to represent a transdisciplinary corollary to the disciplinary nature of our human knowledge. Clearly, if these traits are what distinguish the characteristics of complexity as transdisciplinary, but if we believe that all the disciplines are treating the same general real world in a basic sense, then these seven complexity fundamentals stand both in contrast and corollary with the traditional or classic view of distinct areas of knowledge – scientific and humanities fields or disciplines.

The ubiquity of these characteristics of complex dynamic systems in physics, biology, sociology, politics, engineering, and philosophy – indeed it seems in every discipline in a significant sense – provides a rather convincing basis for defining complexity theories in part as composed of these attributes.

This first set of ontological complexity fundamentals has been central to the first several decades of the field of complexity studies. As such I mention them only briefly here and discuss them in more detail in Chapters Two through Five.

1.3.5. Complexity Ontological Fundamentals II

Complexity Ontological Fundamentals II (COF II)	• Equilibrium, phase state, attractor, edge of chaos • Connectivity, diversity • Network causality, interrelatedness • Unintended consequences, irreversibility & nonrenewability • Vulnerability, risk • Robustness, resilience, & sustainability • Threshold, tipping point, abrupt change • Collapse, catastrophe

In addition to these elements, complex systems seem to possess a set of aspects which define their status or state of being through time, what I call complexity ontological fundamentals II.

Unlike the former category of functional fundamentals, this set does not extend quite so unquestionably across disciplinary boundaries. Some of these terms have not been, and perhaps could not be extended, for instance, from physical to social sciences. The meanings of some of these terms seem not to be quite comparable between natural science and social theory. However, while the precise nature of how certain systems or aspects of systems function may differ across disciplines, nonetheless, there seems to be strong transdisciplinary validity to the majority of these terms. As I describe these, I will make these distinctions.

What seems to legitimate the dubious exercise of making somewhat artificial distinctions across disciplines, some of which seem from the outset so different as to require different terms, is the realization that it is useful to get the best possible sense of the similarities between different systems. Moreover, as I say, many, perhaps even the majority of these terms seem to have valid and important resonance or even sameness across even the major disciplinary divides, natural, social and theoretical.

1.3.5.1. Equilibrium, disequilibrium, phase state, attractor, and the edge of chaos

Every kind of system can be described as having a range of stability and instability. It is possible to make significant distinctions between degrees of equilibrium or stability in various kinds of systems, from the physical to the political. Likewise, all systems undergo phases that can be described by degrees of vulnerability, resilience, robustness and sustainability. Precise measurement may not always be possible, but the knowledge that a system is in a relatively vulnerable or

resilient state with regard to certain impacting forces, is certainly still useful and significant.

Equilibrium has been a source of fierce debates, particularly in ecology. Frederic Clements held a singular ascensionist narrative of ecosystem development. The theory was in line with how we viewed the world generally. Since Aristotle it had been widely accepted that systems were entirely stable or entirely unstable. Religious and political institutions and the general populous long wished to find stability and safety in the world, maintaining millennial wishes to rid ourselves of chaos, uncertainty and risk. Throughout history, the world was divided into unsafe places (wilderness, hell) seen as chaotic, uncertain, and dangerous, and safe places (the church, the world of believers). Modern science set out to correct the pervasive sense of chaos and uncertainty, and to find and create the bases of stability, order, and controllability. It is unsurprising that ecologists copied this motif. Henry Gleason was an early detractor, opposing Clementsian ascensionist views in 1926. Since this time, the concept of equilibrium has been debunked and the predominant view in theoretical ecology is one of dynamic disequilibrium or ongoing non-equilibrium.

Knowledge of ecosystem dynamics is increasing rapidly, yet many important kinds of dynamics are still unknown. For instance, with respect to climate change, scientists do not know how to gauge when overall ecosystem vulnerability can lead to collapses beyond very narrow margins of environmental change, such as atmospheric temperature change. Research on the rainforest has shown that it is possible that a one or two degree shift in overall equatorial temperature could lead to a collapse of the rainforest. This is one of the major nightmare scenarios that has not and cannot necessarily be cleared up by science in the short time frame in which we must react to the current change.

1.3.5.2. Connectivity, diversity

Similarly, scientists and humanities scholars alike have been thrilled and mystified in recent years by study of systems as interconnected networks. Definitions of both terms vary slightly between fields.

In brief, connectivity refers to the degree of interconnectedness in a system, measured in various ways. Connectivity has long been defined as "the characteristic, or order, or degree, of being connected (in various senses)."[x] In ecology, connectivity is "A measure of the degree to which landscape units are linked to one another. For example, hedges that have intact and frequent lateral branches have a high degree of connectivity."[xi] Network causality I define as, "interconnected cause and effect relationships as they manifest in a network." In contrast to linear causality or unicausality, network causality evokes a much greater degree of difficulty or impossibility in determining exact causality in highly complex systems. This phenomenon is very familiar to doctors, lawyers, and others working in environmental health, where linking cancers back to original sources has proven highly difficult and often impossible.

Intriguing debates about diversity and other aspects of complex systems as demonstrated in various ecosystems is just one example of the import of diversity to complexity, which seems to be understood with respect to very limited issues. Clearly, the great biodiversity found in tropical regions has been shown to be of critical importance to the maintenance of life on earth. Rainforests and coral reefs are two of the most biodiverse ecosystems of land and sea, respectively. They are touted for their significance in various ecosystem services including carbon sinks, maintenance and rapid creation of highly diverse life forms, and air and water filtration. Indeed, rainforests and coral reefs are the earth's greatest pollution filters, referred to respectively as the lungs of the earth and the lungs of the ocean. Clearly, there is some correlation between biodiversity and such critical ecosystem services as carbon sinks and the stabilization or maintenance of these carbon sinks. So lack of understanding about the significance of complexity to diversity in ecosystems is a debate that in fact may be relatively inconsequential to our greater understanding of global environmental sustainability.

1.3.5.3. Network Causality, Interrelatedness

This view alters our perspective about many aspects of the systems in our world. Causality is increasingly understood to have not just linear or direct, but also networked and indirect manifestations. The concept of network causality provides a

substantial change to analyses in many fields. Scientists studying Arctic climate change in the last thirty years have shifted from an appreciation of isolated single causes, to vast interconnections of bio-geo-physical changes manifested through highly complex and intricately interconnected network causality. The ice albedo effect was at first seen to be highly significant, however, now it seems just one cause of warming among many hundreds or thousands or others, and perhaps even a relatively insignificant one.

Likewise in the humanities, there has long been a common sense understanding that if you pull one string, as the saying goes, you will eventually unravel the whole ball. This metaphor, like many, seems to only evoke complexity, without adequately capturing it. After all, a ball of string is a very simple system. Yet, such common metaphors do evoke this familiar quality. Even in somewhat simplified representational democratic politics, for instance, there may be several large drivers in an election season – corporate campaign contributions, personal networks of relationships to wealthy and powerful elites, and the possession of the critical skills and infrastructure to tap into these resources. However, from another perspective this may also be overly simplistic. There is also a large and highly diverse public, with strong attachments not only to singular ideologies, but to hundreds of particular issues and policies, with factors such as emotions, and psychology driving whether and for whom they vote. Single events, perceptions or analyses about candidates can sway large blocks of voters overnight.

Beyond such basic analyses, new research questions emerge. Those wishing for federal as well as local governments to take a stronger role in climate change, while confronting complex financial ties that bind governments more or less to the very corporations, institutions, and individuals who benefit most from our carbon intensive energy systems, may inquire into the utility of complexity analyses in understanding or perhaps anticipating how persons or groups may behave in conditions of interconnected systems and networked causality.

1.3.5.4. Unintended consequences, irreversibility and nonrenewability

As a result of connectivity and network causality, we have begun to clarify the common characteristics of unintended consequences, irreversibility, and nonrenewability in various kinds of social and environmental systems. If causes are complex, then so are effects; if causes exist in networks, then so do effects. As a result, imposing singular actions or interventions in systems rarely has the singular or clear impact initially sought.

Secondly, along with network causality is the basic issue of network structure, one of the functional fundamentals. Network structure and network causality both differ from the dominant classical model of seeking singular causes and effects, in a striking way; the multiplicity of the network obscures certain system-scale characteristics, such as overall resilience or vulnerability, as mentioned above. Logically, obscuring vulnerability also obscures irreversibility. This would seem to imply that clarifying and better visualizing degrees of vulnerability in systems may alert us to aspects of irreversibility in those systems, and their relative significance.

Another system-scale characteristic that may be less legible with reductionist lenses is the distinction between irreversibility and nonrenewability in systems. Irreversibility refers specifically to trends that reach tipping points of no return, such that the system enters a new phase and cannot return to the prior state in some in terms of some critical characteristics. In contrast, nonrenewability refers to the depletion of finite resources. This in turn can be divided into the category of substances that can be renewed but only a time-scale much longer than that of current human demands versus substances that just cannot necessarily be renewed at all.

Upon closer examination, insofar as changes occur on a planetary scale, these categories may either collapse into each other to a certain extent or at least become more difficult to discern. The formation of various fossil fuels depends upon the accretions of certain kinds of plant matter. Most of these kinds of structures are likely to reappear in future iterations of climate changes on Earth regardless of human impacts. However, it is wise to acknowledge that at least to a certain degree, human impact is now at such a scale and of such novel characteristics, that we are entering somewhat new territory; now we could alter long-term as well as short-term cycles on the planet. Candidates for possible radical changes to earth systems that remain unknown include: nanotechnologies, atomic technologies, and massive toxicity, perhaps causing some long-term alterations to planetary systems.

1.3.5.5. Vulnerability

If we define sustainability as the maintenance of biodiversity and natural resources across time, then ***vulnerability*** most simply put is *the degree to which a system is unsustainable.* Of course, on a smaller scale or within a more restrained research area, vulnerability may be seen as *the susceptibility of a complex entity, e.g. a whirlpool, to the kinds of disturbances that may disrupt, alter and destroy its structure altogether.* The tenuous but useful parallel that I am drawing between more

restrained and more generalized systems is that of this degree of weakness in the face of disturbance.

It should be noted that resilience, robustness, sustainability and vulnerability are some of the many complexity fundamentals that, while practically unheard of prior to the environmental movement of the 1970s, today are widely-used terms in academic publications across a spectrum of natural science disciplines, as well as throughout popular discourse and media.

1.3.5.6. Resilience, Robustness and Sustainability

As indicated in my comments on diversity and sustainability, complexity is often seen as one realm that could yield critical insights into resilience, robustness and sustainability. ***Resilience*** can be defined as *the capacity of a system to recover after a disturbance.* ***Robustness*** is *the degree of resistance involved in resilience, or the degree of strength a system possesses allowing it to recover after a disturbance.*

Sustainability is another term, like the words nature and complexity, which prove extremely difficult to adequately define. A simple definition of ***sustainability*** is *the capacity to maintain particular landscapes or the entire biosphere in such a state that the same amount of biodiversity and natural resources that exist at the present will be available to future generations.* While sustainability is not typically framed as a complexity term, I claim that not only is sustainability a key element of the complexity perspective, but that defining and describing it as such is necessary and valuable in clarifying the links between the fields of complexity and environmental issues.

Actually, the link between the two is intrinsic and inherent. Sustainability is but the larger-scale term for the edge of chaos which is seen as central to the definition of complex systems by so many scientists and scholars alike. In a physical system like a whirlpool in a stream, the phase state is typically that of maintaining the form of the whirlpool. In social systems, maintenance structures can vary greatly in degrees of stability, conformity, or chaotic vacillations. For instance, in a small monarchical system, one family may retain tight control over manipulation of resources for long periods of time. Whereas, in stock markets, vacillations can at times be extreme and unpredictable.

Thus, seen in a thoroughly transdisciplinary light, sustainability is but the larger-scale term for what is an essential aspect of complex systems studies, that of the nature of systems in states of maintenance.

1.3.5.7. Threshold, Tipping Point, and Abrupt Change

Threshold is a term with a long etymology, which has taken on a new significance in recent years. Generally, a ***threshold*** is *a fixed value (such as the concentration of a particular pollutant) at which an abrupt change in the behaviour of a system is observed,"*[xii] *or "the minimum intensity of a stimulus that is necessary to initiate a response."*[xiii]

Only in recent years have various new definitions of the term emerged, related more specifically to issues of ecological and global change. In the last twenty years, as use and definitions were increasingly being produced by the complexity scientists and scholars, these terms quickly became established in ecology. A recent review undertaken by twenty leading ecologists analyzed the meaning and significance of the term threshold in ecology. Echoing the often repeated question that I explore in this dissertation – that complexity theories seem at once highly significant and in some sense perhaps inapplicable – the article was entitled, "Ecological Thresholds: The Key to Successful Environmental Management or an Important Concept with No Practical Application?" The authors define and discuss the term ecological threshold:

> An ecological threshold is the point at which there is an abrupt change in an ecosystem quality, property or phenomenon, or where small changes in an environmental driver produce large responses in the ecosystem. Analysis of thresholds is complicated by nonlinear dynamics and by multiple factor controls that operate at diverse spatial and temporal scales. These complexities have challenged the use and utility of threshold concepts in environmental management despite great concern about preventing dramatic state changes in valued ecosystems, the need for determining critical pollutant loads and the ubiquity of other threshold-based environmental problems.[xiv]

However, the authors conclude by saying, "We argue that the examples presented above suggest that we are poised for major advances in this area and that ecological thresholds will soon be commonly used in the analysis of environmental problems and will be important in improving the quality of environmental management and our ability to predict the behavior of ecosystems over the next 10–20 years."[xv]

A tipping point is a particular kind of threshold. In a recent study related to climate change, edited by Harvard scientist William C. Clark, the authors wrote, the term ***tipping point*** commonly refers to *a critical threshold at which a tiny perturbation can qualitatively alter the state or development of a system*.[xvi] In step

with the ecologists' appraisal of thresholds, the authors of this study claim that tipping point is an invaluable concept that is advancing climate science and policy. They say, "We critically evaluate potential policy-relevant tipping elements in the climate system under anthropogenic forcing, drawing on the pertinent literature and a recent international workshop to compile a short list, and we assess where their tipping points lie. An expert elicitation is used to help rank their sensitivity to global warming and the uncertainty about the underlying physical mechanisms. Then we explain how, in principle, early warning systems could be established to detect the proximity of some tipping points.

The term ***abrupt change*** has evolved within the context of rapid global change, and it refers specifically to *a sudden large-scale tipping point*. The related term ***surprise*** is used in ecology and global change literature to refer to "*the condition in which an event, process, or outcome is not known or expected.*"[xvii]

1.3.5.8. Catastrophe and Collapse

In a similar vein, there has been a dramatic increase in literature on possibilities for overall system catastrophes and collapses in recent decades. As connectivity and network structure and causality relates to resilience and vulnerability, the latter relate to catastrophe and collapse. In a complexity framework, ***catastrophe and collapse*** are but *ultimate manifestations of vulnerability; at a certain point, a system that reaches a certain degree of vulnerability will collapse.*

In terms of complex systems analysis, there is a useful way to distinguish these terms. Catastrophes can be due to either natural or human causes. It is arguable at this point just how interconnected natural and human causes are. At the least, there are most often both natural and human causes, due to the connectivity of natural and social systems. Our current climate change may be induced almost entirely by human actions of burning and emitting greenhouse gases. Nonetheless, once the carbon is released, it sets into motion an intricate set of further environmental changes that must be understood as well.

Catastrophes can be further defined as *endpoints of a nonlinear process*; it may be valid to define catastrophes as threshold events. A hurricane in one sense is a nonlinear process that proceeds from a stirring of warm air over water to a greatly accelerated intensity of wind and moisture patterns that culminates in heavy winds and rain. As such, the intensification can be seen as a nonlinear buildup of air and water patterns, and the hurricane itself, as the climax and release of this process.

We also refer to disease outbreaks, stock market crashes, and human genocide as catastrophes. The increase of vulnerability to disease closer to Polar Regions due to climate change is another kind of nonlinear pattern set in motion. Likewise, a disease outbreak itself starts as a single human death, but can quickly spread to numerous cases. Once one begins to see nonlinearity, it appears everywhere. In the example of stock market crashes, multiple factors influence public confidence and speculation about stocks. Some of reasons why people buy and sell are based upon natural factors, such as hurricanes, gas shortages or climate change predictions. In turn, of course, surges and drops in stocks can quickly impact actual human activities involved in the manipulation of the natural world. Genocide is another example of a nonlinear pattern.

Understanding what triggers such events becomes critical in the interconnected and apparently crisis-ridden twenty-first century. A small literature is now developing to examine the unfortunate subject of interconnections between catastrophes. An obvious example is the overall intersection of climate change stresses, surging population, dwindling natural resources, increasing vulnerability to disease and famine, and historical tendencies towards war. Network catastrophe theory may seem grim. However, it may help us to prevent or diminish networked catastrophes.

As I will argue further in Chapter Nine, it appears that complexity theories help to illustrate not only human vulnerability with respect to catastrophe, and not only our responsibility in this regard, but also that we possess significant degrees of free will and agency. The concept of interconnected, networked, crises or catastrophes, may spur critical thinking and institution building on the subject of an ethics appropriate to such complex, interlinked causality and change.

1.4. Epistemological Complexity Fundamentals

Epistemological Complexity Fundamentals	• Observer, context • System boundaries, openness • Scale, Grain • Co-evolution, co-production, co-evolving landscapes • Methodology → Models, conceptual models, narratives

1.4.1. Observer and context

Function and nature of complex systems would not be complete without considering the way that we perceive, know and measure these phenomena, or the epistemological complexity fundamentals. A great distinction between the classical scientific lens and the complexity lens is that the former generally excludes the observer from the system, while the latter includes it. For instance, most climate change models are based upon the fact that human activities have spurred climate change. We would not want, however, the complication of attempting to include all of the related human dynamics within the model, or frame the model from the perspective of humans precipitating climate change. When we create climate models we have specifically delineated and sufficiently complex concerns on the table, such as: how to derive the best approximations of expected degrees of temperature increase related to extent of carbon emissions, and estimated effects to other systems as a result of approximate degree changes in average global temperature.

In contrast, for some kinds of study systems it is desirable to frame things from the perspective of complexity, including the observer in the system. For instance, if we want to better grasp more complex interactions between natural and social systems, we may need to include human agents or subjects or both in that analysis, whatever the precise method of analysis. If we want to conceptualize potential unintended consequences, we may need to include the observer and its perspective in the context of the whole, to study what may affect the observer.

In both the natural sciences and the humanities, the issue of the observer in the system and the context of the observer have become paramount in recent decades. While it is arguably a stretch, I view the post-Freudian literature on identity and self in psychology and philosophy as one critical realm of analysis regarding the "observer in the system" in the humanities. Indeed, the individual has been one of the main themes that distinguish the twentieth century.

Likewise, context has been a major theme in the social studies of science, which facilitates or even permits analyses of the ways that science and technology increase harms as well as benefits, rendering both the individual and the environment increasingly vulnerable within the 'risk society.' I explore these themes further in Chapter Four.

1.4.2. Systems boundaries and openness

Considerations of the observer and the context of systems naturally lead to distinctions regarding system boundaries and degrees of openness. By nature, the distinction of individual and context raises the questions of more precise boundaries. Every element is more or less permeable and interrelated within and across tiers of a general system hierarchy.

In observing a system, says Timothy Allen, there are two considerations for observation. One is the criterion for observation, which defines the system in the foreground away from all the rest in the background. The criterion for observation uses the types of parts and their relationships to each other to characterize the system in the foreground. This is the issue of ***system boundaries,*** *a criterion establishing the limits of the system, with respect to the relationships of the systems' parts.* The second is the spatiotemporal scale at which the observations are made, which I discuss next.

1.4.3. Scale and grain

Scale and grain are terms that allow us to explore hierarchical structures. Once one has established the parameters of a system via hierarchy structure, system boundaries, and degrees of openness, two essential tools for studying the system more closely are scale and grain. ***Scale*** is *a level of representation.* In mathematics and physics, the term scale means "a marking of values along a line to use in making measurements or representing measurements."[xviii] In the earth and environmental sciences scale has traditionally been applied to cartography, where scale is "the ratio between map distance and distance on the ground." A representative fraction of 1:25,000 indicates that 1 cm on the map represents 25,000 cm on the ground.[xix]

In ecology, scale is a parameter that translates a dimensionless description into dimensional terms. A common use is the expression of a system relative to some point of reflection. It is often used to mean: the extent of space and or time imposed

either on an observation, or on a system by means of observation, or an identification of the grain or finest distinction in a measurement protocol.[xx] Thus, scale and grain are sometimes conflated.

The term grain may have evolved from an English measurement, in 1575 the smallest measurement of weight was "a grayne of corne or wheate, drie, and gathered out of the middle of the eare," or from the sense of the texture of any substance, such as flesh or wood.

Grain is now used in ecology to mean *the first level of spatial resolution possible in a given data set, as opposed to 'extent,' which is the total area of study.* The need to consider scale and grain in ecological analyses was made prominent in the 1980s. Parameters and processes important at one scale are frequently unimportant or non-predictive at another scale, and information is often lost as spatial data are considered at coarser scales of resolution. Nonetheless, ecologists must often use fine-scaled measurements extrapolated to the analysis of broad-scale phenomena.[xxi]

1.4.4. Coevolution and coproduction

Emergence and self-organization are processes that involve intricate relationships within and between systems. Some of these relationships are at times referred to as coevolving or coproducing. An area in which such relationships are playing out is sometimes called a coevolving landscape.

Co-evolution in ecology refers to *mutual interactions between species over time, in varying degrees of symbiosis, mutualism, or antagonism.* In broad transdisciplinary contexts co-evolution implies highly complex socio-natural interactions. In ecological economics, Richard B. Norgaard employs the term co-evolution to mean "a process of coupled change between practices, values, and the biophysical environment." Humans change environments both materially and cognitively and in turn new environments change human practices and ideas. Norgaard explored dynamic socio-environmental feedbacks and substitution of ecosystem by economic services. However, he stresses that relationships between the entities affect the evolution of the entities involved.[xxii]

Coproduction has been used *to refer to co-evolution within social spheres, or between social spheres and the natural resources that they manipulate and transform.* In science and technology studies, the term has been prominent for about fifteen years, to refer to "the simultaneous making of the natural and social worlds."[xxiii] "In broad areas of both present and past human activity, we gain explanatory power by

thinking of natural and social orders as being produced together. The texture of any historical period, and perhaps modernity most of all… can be properly appreciated only if we take… co-production into account."[xxiv] Harvard professor and science and technology studies leader Sheila Jasanoff defines co-production broadly within science and technology studies:

> Briefly stated, co-production is shorthand for the proposition that the ways in which we know and represent the world (both nature and society) are inseparable from the ways in which we choose to live in it. Knowledge and its material embodiments are at once products of social work and constitutive of forms of social life; society cannot function without knowledge any more than knowledge can exist without appropriate social supports. Scientific knowledge, in particular, is not a transcendent mirror of reality. It both embeds and is embedded in social practices, identities, norms, conventions, discourses, instruments and institutions – in short in all the building blocks of what we term the social. The same can be said even more forcefully of technology.[xxv]

Such a view of evolving interrelationships within highly complex systems seems necessary but necessarily difficult. Some argue that the complexity this speaks to profoundly affect the way that we should understand models and other analytical tools.

1.4.5. Mathematical models, conceptual models, narratives, etc.

One of the reasons that complexity writ large seems too audacious to be taken seriously, is that it both inhabits and encompasses classical science, and in so doing some complexity theories create tension with core tenets of classical science, while they do not negate their utility in certain spheres of knowledge. I will explore this topic more in the next section, the major axes of restrained versus generalized complexity.

Here I would like to come full circle, giving some of the implications of the significance of the observer in the system. As I started my analysis of epistemology by discussing the observer in a contextual realm, I will end with a brief examination of methodology. I will discuss three groups with divergent views on models.

The first group is the many physicists and other natural scientists that hold to the strict classical view of models. As conceived by classical science, the model is a mathematical representation of reality. Disciplinary training in physics and other natural sciences still supports the view that mathematical models are the sole viable

method to describe and predict all natural phenomena. Most scientists at the Santa Fe Institute are swayed by the dominant view of physicists there, that mathematics is the only language of nature. While many scientists continue to see mathematics as the only 'language of nature,' social theorists have repeatedly objected that mathematics is an abstract language that can decipher only a restricted realm of natural phenomena.

A second group of scholars views models as representations of reality that capture as much of the complexity of a given system as possible, while remaining efficient and appropriate to the study system. They view the mathematical model as a tool that allows for the best possible analysis and prediction about complex phenomena. Most of the IPCC scientists would likely define themselves as being part of this group.

So, while some natural scientists, continue to think that mathematics is capable of modeling all reality, at least in some ultimate sense, many social theorists and humanities scholars claim that contemporary discoveries, including complexity theories, show that this is far from true. Scholars such as Naomi Oreskes and Kristin Schrader-Frechette argue that, on the contrary, mathematics is inappropriate to some realms, e.g. those that involve emotion, value, and meaning. Social theorists have presented valuable arguments about the restricted value of mathematical models.[xxvi] However, complexity scholars may be even better placed to develop more poignant arguments or proof of the restricted value of mathematics to what are, from the point of view of social law and policy, essentially transdisciplinary and often rapidly evolving phenomena.

The third group is mostly advanced complexity scholars, and they define complexity as that which cannot be modeled. The biologist and complexity scholar Robert Rosen argued this in 2000.[xxvii] In Rosen's view, models can capture complication, but not complexity. Models can be used to predict only non-complex phenomena, phenomena that follow precise a-contextual rules, for which we possess the capacity to accurately and completely replicate and predict. In this sense, the capacity to model a system is a primary indicator allowing us to define which systems are merely complicated and which are complex.

Debates between the strong advocates of the first and last of these groups appear to be intractable. Many natural scientists would object that complex phenomena is exactly what they model, and that in fact, models are the only way to access complex phenomena. The two arguments could not be more divergent. However, this seemingly deep disagreement is reconcilable. What Rosen and others argue is that mathematical models are often the best possible tool, but what they are really modeling is the complicated system that the scientist envisions can best capture certain functions of the complex phenomena under study. So it is not that

mathematical models don't capture complex phenomena, in a sense, they are often the best tool for describing and predicting in complex systems. However, this is because the complication which they capture is quite close to the complexity of the real world at least in some essential ways.

The difference between complicated things and complex things is significant. Indeed, it is one of the way in which we can foreground better definitions of complexity theories. According to Paul Cilliers, South African philosopher and complexity scholar,

> If a system – despite the fact that it may consist of a huge number of components – can be given a complete description in terms of its individual constituents, such a system is merely complicated. Things like jumbo jets or computers are complicated. In a complex system, on the other hand, the interaction among constituents of the system and the interaction between the system and its environment are of such a nature that the system as a whole cannot be fully understood simply by analysing its components. More, these relationships are not fixed, but shift and change, often as a result of self-organisation. This can result in novel features, usually referred to in terms of emergent properties. The brain, natural language, and social systems are complex.[xxviii]

Complexity scholars argue that acknowledging that what the model actually captures is just the complication that is closest to the complexity of the study system, allows researchers to remain cognizant of the often highly significant qualities and implications of complex systems that are not necessarily fully, adequately captured by the model – and remain cognizant that even when there is great accuracy in the model's data, if part of what it fails to capture is essential to the study questions, then it could still be insufficient. While this view retains the key and irreplaceable role of the mathematical model at the heart of large-scale studies, this distinction by Rosen and others provides a kind of meta-argument for the significance of the complexity framework to contextualizing and guiding research.

Like most scientists, Robert Rosen's followers would agree that the IPCC models are the best that we possess, and of course they are a very significant element in climate policy today. What they disagree with is that the IPCC's mathematical models are actually truly capturing complex phenomena. They argue that while these mathematical models are necessary in order to conceive of climate change on the large scale, it is helpful to make numerous distinctions about the nature and qualities

of these models, and to understand mathematical models in the context of a broader complexity perspective.

Timothy Allen, biologist, philosopher, complexity scholar, and founder of hierarchy theory in ecology, upholds Rosen's view. Allen employs the term narrative from the humanities, in counterpoint to mathematical models. Allen argues that:

> …a realist view of ecology does not pay sufficient attention to the role of the observer dealing with complex systems. Complexity after Rosen... is something that cannot be modeled. Conventional properties ascribed to complex systems are in fact prescriptions for what it takes to make a complex system yield to a model structure, to make it a simple system, albeit a complicated one. Complexity is not a material property, but turns rather on the question that is posed. It is normative to the degree that complexity arises from the lack of a paradigm, lack of an accepted set of modeling assertions. We develop a scheme for making complexity tractable.[xxix]

While there has been a great amount of valuable literature on narratives, the scheme that Allen suggests (with co-authors Zellmer and Kesseboehmer) offers the most useful, explicit use of narratives as complex systems methodology that I have seen. Timothy Allen bases his thesis on three principal ideas: Howard Pattee's concepts of laws and rules in biology and sociology[xxx]; Timothy Allen and Thomas Hoekstra's scale versus type and observation protocol versus observed structure[xxxi], and Robert Rosen's essence versus realization.[xxxii] I explore Timothy Allen's theory in more detail in Chapter Five.

For the moment, suffice to say that within Allen's framework, change can be described as occurring in a pair of two, intertwined cycles. The first cycle reinforces patterns of model building, while the second cycle deals with the changes that occur in the essence of that which was modeled. Thus, mathematical models run into constraints as they cannot conceive of emergent changes to essence, but only prescribed changes. The methodology of narrative is used to rise above these local constraints of models. In this view, complexity is "the ultimate semantic argument. If one has a paradigm, then the system is simple, perhaps complicated…, but still simple rather than complex. If one does not have a paradigm for it, then the system is complex." Thus for Allen, complexity is not a paradigm but what the world looks like when taking away all paradigmatic filters and lenses. This does not imply that a process can be complex at time-A and merely complicated at time-B; though it could

be the case that a particular aspect of phenomena-A (at any time) is merely complicated.

1.6. Axis I: Natural sciences -- Classical to complexity perspectives, shifts in the underlying assumptions of natural science, social theory, and the humanities

Axis I: Natural Sciences	Classical versus complexity sciences (Morin 1977; Merchant 1980; Dupré 1992; Norgaard 1994) • Mechanism, order vs. organization • Atomism vs. network • Reductionism vs. synthesis • Essentialism vs. emergence • Universalism vs. disunity, pluralism • Determinism vs. evolution, change

Numerous scholars have written about a shift in the underlying assumptions of science, from the modern to the contemporary eras, e.g. Morin (1994), Norgaard (1994), Dupré (1993), and Merchant (1980). They have remarked on this shift under a number of different titles and theories. What is notable is that they discuss the same underlying assumptions, which appear to be the incomplete antecedents of contemporary complexity principles. In themselves, these underlying assumptions of the classical era of science each had merit, and are not entirely wrong, but they are critically incomplete; taken as a way of seeing things more generally, they became greatly distortional when applied to complex systems.

These assumptions of classical science include: mechanism, objectivism, positivism, monism and universalism. Various deep philosophical questions are embedded in these six aspects of the shift from the early classical scientific worldview to the complexity worldview. Though I lack space to adequately address these issues, most of these issues will be further elaborated if indirectly, in the elaborations of complexity fundamentals throughout the dissertation.

Just as early scientific methods of isolation and experimentation will always be the appropriate tools for certain aspects of study, so are these assumptions proper to some aspects of contemporary science. However, over the twentieth century we gained a deeper understanding of the ways in which these assumptions can be distortional when applied to inappropriate subjects. To give just one example here, the idea that systems were ‘mechanistic’ for the most part worked very well during the early Industrial period, for instance, in designing tools, engines, and buildings. However, deep problems arise in applying a mechanistic view to: human bodies, social theory, ecosystems, ideas and meaning, social institutions, decision-making, art, and cultures.

While scientists in the twentieth century largely embraced increasingly less mechanistic and more complex views of their objects of study, this shift has been incomplete. Many scientists maintain underlying assumptions that fit the mechanistic

paradigm, even while advancing sophisticated contemporary research based largely in complex systems.

In fact, and this is a major subject on its own, even the most talented complexity thinkers have to fight the natural tendency to fall into what I call simplifying devices or simplifications of thought that at times distort their otherwise good ideas. In the natural sciences, where complexity thinking is relatively new, researchers must consider various aspects of their work from the complexity perspective. First one needs to choose and frame questions with the insights of the basic nature of complex systems. But additionally, one needs to be cognizant of nature of complex systems when pursuing each of the subsequent steps of the scientific process, including and especially the context and parameters of their study system throughout experimentation and in the final analyses.

Even simpler aspects of complexity theories are still foreign to many trained in scientific disciplines. The more difficult, nuanced, paradoxical issues I sketched here are even less familiar. Thus, in many domains, scientists and scholars continue to utilize familiar 'mechanistic' methods and concepts insofar as it works, until coming up against the obstacle of complexity. For one to even recognize these obstacles is not obvious.

Scientists in the new life sciences industries can have considerable successes, all the while navigating and skirting potential disasters, often unknowingly. At some point, people have to grapple with complexity in their study systems. Though this might be seen as an inevitable part of the scientific process, it is also a choice, and many would argue, at times an unwise choice.

One argument for advancing complexity studies is the hope that by better conceptualizing and understanding complexity in systems, we could avoid waste of research time and funds that occur as we navigate these shifts independently, partially, and myopically. Rather, with better understanding, we should be able to clarify significant patterns and principles that would permit a more efficient and less dangerous advancement of the processes of science and technology. Studying what we are shifting towards – understanding of complex systems – should help to elucidate the shift itself. I will assess whether this holds true or not in the case study.

The immense successes of modern science, such as engines, antibiotics, and computers, attest to our assurance of the functioning of classical science. It is imperative that critics of science and technology be clear on the Janis-faced nature of such critiques. The project of modernity has been immensely successful – producing enormous freedom and opportunity, increasing life spans, enabling extraordinary improvements in agricultural efficiency and abundance, and amazing achievements in improving quality of life for a great number of people.

The complexity shift entails refutations of essentialism, reductionism and determinism as they were largely understood to underpin modernity. What I call for sake of simplicity the classical science worldview is described by John Dupré: "The metaphysics of modern science, as also much of Western Philosophy, has generally been taken to posit "a deterministic, fully law-governed, and potentially fully intelligible structure that pervades the material universe."[xxxiii] Note that he is speaking of the underlying metaphysics of science and not everything else about the way scientists see their study systems. A resulting claim is that of ***scientism***, *the view that natural sciences have primacy over other fields of inquiry such as the social sciences***.** Dupré refutes the main axes of this classical metaphysics, essentialism, reductionism and determinism.[xxxiv]

Dupré and his colleagues describe related changes to ontology and epistemology.[xxxv] Scholars espousing these views of modern science are clear on the idea that the way that science functions in the natural sciences has not changed. However, complexity theories reveal that the way we frame and understand the world beyond this essential science must shift, both in terms of how we understand the world to be (ontology) and the ways we can know it (epistemology).[xxxvi] It appears that complexity reveals both how our world is ontologically complex and how our epistemology must evolve to better reflect this complexity. Indeed, recent science and humanities' literature is replete with examples of these shifts, which I will discuss throughout Chapters Three through Six. What has been missing is for both more scientists in their disciplines, as well as some scientists working transdisciplinarily, to recognize and utilize the interconnecting web of the complexity theories that run throughout many of the influential ideas of our times. In this view, recent advances in complexity research have led to a major shift in the way we can perceive and interpret traditional science in the broader context of human knowledge.

1.6.1. Strong realism versus realist constructivism

> One cannot properly understand complexity with modernist, reductionist postures, because of the lack of ultimate self-consciousness embodied in those positions. Modernist reduction is insistently realist, and that eventually stalemates even the boldest assaults on complexity. There is not direct access to external reality, and that always leaves an out against the most definitive statements about reality. In the end one must take something of a constructivist stance to win the game outright. In a constructivist framework, the object of study is not external reality, but is rather the complex that holds the observer in relation to the observation. The relationship to an external observed is always indirect, and so it cannot be pinned down. However, the observer actually does experience the observation, and so that can be fixed. The constant self-reference in constructivism is ultimately realistic, the reality of experience itself.[xxxvii]
> Timothy F.H. Allen

Complexity scholars and others sometimes become engaged in philosophy of science debates on the subject of strong realism versus weaker realism or forms of hybrid realist constructivism. While I do not subscribe to most any of the labels (epithets) attributed to postmodernism, this debate is a critical one that emerges in complexity studies. This is because, as Allen's graph displays, the role of the observer in the system does lead to deeper inquiry about the nature of knowledge discovery and production. It seems that knowledge is both discovered and produced. Complexity seems to necessitate a realist constructivist hybrid view of the relationship between the observer and the observed. Again, I discuss this in more detail in Chapter Six.

1.7. Axis II: philosophy, human sciences and social theory

Axis II: philosophy, human sciences, and social theory	• Compressibility vs. incompressibility; decomposability vs. nondecomposability; reducibility vs. irreducibility • Production vs. emergence; Complicatedness vs. complex • Thinness vs. thickness • Unity vs. Disunity of the sciences • Uncertainty vs. unknowability

Embedded in Axis Two are a variety of quite deep and fascinating debates in philosophy and the humanities. While these topics are of considerable interest and fascination, I have deemed the first two sets, while interesting, to be slightly less relevant to the present dissertation. I have already addressed the issue of complicated versus complex systems. The latter three I discuss here. The last topic, uncertainty and unknowability, is intimately related to the focus here on socio-economic systems and climate change. Therefore, I expand upon this at some length at the end of Chapter Six, where I related the topics of uncertainty and the limits of science.

1.7.1. Thinness versus thickness

Clifford Geertz added a groundbreaking concept to the humanities when in 1973 he described the aim of interpretive anthropology as "thick description," a term he took from British philosopher Gilbert Ryle. While a "thin" description evokes only one layer of cultural behavior, a physical act, a "thick" description, by interpreting multiple aspects of behavior, such as physical gestures, but also layers of symbolic cultural meaning, captures a sense of a culture.

Geertz uses an example from Ryle between a blink and a wink. A blink is an involuntary twitch, a thin description, while a wink is a conspiratorial signal to a friend, a thick description. While a blink is just a physical act, a wink is open to considerable interpretation, possessing alternative or multiple meanings. By creating a taxonomy that combines analysis of blinks with the various possible meanings of winks, an anthropologist comes closer to adequate analysis of another culture.

One criticism of Geertz' concepts came from cultural ecologists, who argued that symbolic anthropologists are "fuzzy-headed mentalists, involved in unscientific and unverifiable flights of subjective interpretation."[xxxviii] This is a lovely example, to my mind, of the way in which thinkers ensconced on one shore or another of the void between natural science and humanities methodologies sword fight across the void.

1.7.2. The unity versus disunity of the sciences

The theory that the sciences are unified is associated with the quest for a theory of everything (TOE) in physics, i.e. an acontextual explanation for the existence of everything. While I cannot do this debate justice here, ultimately I think that the conjuncture of complexity theories and the unity-disunity debate may be quite useful. Complexity seems to militate against this common view of the unity of sciences. The TOE in physics would provide "an acontextual explanation for the existence of everything," says Kurt Richardson, who received two PhDs in physics before becoming one of the leading complexity philosophers.

The theory remains strong amongst many of the most prominent physicists. Stephen Hawking's claim that the Twenty-first Century will be the century of complexity was said in the context of his view that we are getting ever closer to a Unified Theory. In essence, the view of the sciences as unified turns on mathematics. What remains unclear at times is whether or not physicists mean to imply that everything, e.g. everything in social systems, environmental systems, and phenomena such as emotions and meaning, can be encompassed in such a theory. But even the milder version, that the natural sciences will find a mathematical theory that will ultimately unify them, seems problematic to many complexity scientists. Kurt Richardson says,

> The search for… over-arching laws and principles was /is one of the central aims of the general systems movement. Any such Theory of Complexity, however, will be of limited value. In Richardson (2005) I suggest that even if such a theory existed it would not provide an explanation of every 'thing' in terms that we would find useful. If indeed such fundamental principles do exist they will likely be so abstract as to render them practically useless in the everyday world of human experience – a decision-maker would need several PhDs in pure mathematics just to make the simplest of decisions.[xxxix]

Again, while the topic appears to be too intricate to tackle here, I suggest that complexification and limits to knowledge do support the view of philosophers such as John Dupré who argue for a coherent but disunified view of human knowledge. Whatever the case may be, the results of this debate may bear influence on our greater understanding of complexity theories.

1.7.3. Uncertainty versus unknowability

One of the deeper implications of complexity theories is that every time we impose classical constrictions on complex systems, without adequately acknowledging the complexity of the system, we are distorting our ideas to some degree. This sheds light both on why I have added the term 'unknowability' to the common term 'uncertainty,' and why in the short term, complexity theories' most significant role may be the logical support they offer to the precautionary principle.

I argue that both phenomena exist. While the prior is evident and accepted, I make an argument for the latter at the end of Chapter Six. For the moment, let's accept that our knowledge is limited, fundamentally limited, let's say for the foreseeable future. Just to admit this serves several purposes. For one, as we take unknowability into consideration, it changes the status and treatment of uncertainty. If we reduce our expectations of scientific results, we can also increase our appreciation of those uncertain but nonetheless poignant and substantial results that we do obtain.

1.8 Axis III: Transdisciplinary frameworks

Axis III: Transdisciplinary Frameworks	• Transdisciplinarity • Systems typology (J-C Lugan 1983) • Reductive, emergent, holistic • Generalized versus restrained (Morin 2006)

1.8.1. Transdisciplinarity

Transdisciplinarity and complexity are highly correlated subjects, two faces of one subject, in a sense. As such, the study and understanding of transdisciplinarity is an essential axis of apprehending complexity. I devote an entire chapter to the subject. Here I offer a brief introduction. I borrow and modify another table from Stephen Jay Kline, to evoke the significant correlation between transdisciplinarity and complexity at the levels of socio-ecological systems.

References in Kline's book seem to indicate that he had deep insights during the troubling science wars, raging just before he published the book. He was at the end of his career and may have written his last book partly as a sign to a way out towards peace between natural scientists and humanities scholars. Certainly, he seems to present a persuasive argument for the way in which complex systems appear to dissolve and bypass the difficult debates that have arisen between natural scientists and humanities scholars in recent years.

Arbitrary number indicating relative scale	**Representative objects**	**Disciplines**
9	Unknown	
8	Universe	Astrophysics
7	Galaxies	Astronomy
6	Solar systems	Astronomy
5	Stars, planets	Astronomy, astronautics
4	Continents, oceans	Oceanography, meteorology, geology, international relations, …
3	Geologic features such as mountains, valleys, watersheds, including socio-technical-ecological systems, societies, laws, etc.	Geology, ecology, aeronautics, forestry, marine biology, molecular and cell biology, biotechnology, agriculture, sociology, economics, political science, education, geography, business, public policy, operations research, history, food research, law, ….
2	Groups of people, large hardware	Engineering, medicine, urban studies, feminist studies, history of ideas, literature, poetry, English, art, math, ethnology, psychology, philosophy, film studies, cultural studies, ethnic studies, ….
1	Families, colonies, simple hardware	Linguistics, paleoanthropology, …
0	Multicellular plants, animals	Zoology, botany, anatomy, biology
-1	Unicellular plants, animals	Parasitology, biology
-2	Individual molecules	Materials science, chemistry, biochemistry
-3	Individual atoms	Atomic physics
-4	Subatomic particles	Subatomic physics
-5	Unknown	

Table 1.2. The hierarchy of constitution and disciplines – Note that many of the disciplines may apply to the levels just adjacent to them

1.8.2. Systems Typology

A typology of systems has been an integral aspect of the definition of systems theory and I believe it is useful as well to the articulation of complexity. Various authors have discussed this. I begin with the description of the archetype model of nine levels of complex systems, in the 1983 classic, *La Systémique Sociale*, by Jean-Claude Lugan. Lugan defines systems theory as the discipline that studies three sets of theories, the theory of open systems, the theory of general systems, and the theory of organization. The aim of systems theory, according to Lugan was, "to elaborate the methods of modeling phenomena by and as systems in general."[xl]

The first level consists in nothing but the distinction that there is a system and an environment. At the second level, the system is active; the activity of the system includes the perception of phenomenon in its environment. This involves any throughput or exchange between the system and its environment. The third level the system's activity appears to persist over time in such a way that one could speak of regularity if not stability; it is presumed to be regulated. The modeler posits the emergence of some pattern of internal regulation.[xli]

At the fourth level there is a leap up to a minimal intelligence on the part of the system; the system informs itself about its own behavior to regulate itself. It is clearly a self-regulating system. In order to regulate itself, the system produces information endogenously, systems of signals that assure the mediation of the systems regulation. This emergence of symbolic information, an artifact or artifice of internal communication, constituting a leap in the complexification of the system modeled.[xlii] The fifth level is another step up in intelligence; the system makes decisions about its own behavior. The system proves capable of treating information and based upon the cognitive exercise to elaborate its own behavioral decisions. This supposes that there is a sub-system enabling autonomous decision-making, producing, transmitting and treating information and only information. At the sixth level, the system is capable of memory. In order to elaborate upon its decision, the system not only considers instantaneous information, but also information that it has memorized. Thus at the sixth stage the system has three sub-systems: one for action, one for decision-making, and one for memorizing.

The seventh level involves interactions between all three of these sub-systems. The system can coordinate decisions regarding actions, decisions, and memorized information. At this point, the system can juggle numerous decisions regarding actions at each instant. At the eighth level the system displays imagination; it can conceive and imagine new possibilities for decisions. Not only can the system coordinate its actions, but it becomes possible of elaborating new kinds of actions. It can imagine new solutions and alternatives. Thus a whole new sub-system is added,

which is the capacity for the processing of ideas in such a way as to allow for imagination.

Finally, the most advanced stage of Lugan's systems typology is the system develops the capacity for self-realization or what Morin might call self-organization, in its more profound sense. In analytical modeling phenomena are determined and would not be capable of self-realization. The systems model is a proposition; the ideal of the model is thus not objectivity in the model, as in analytical modeling, but rather, the projection of the system into the model, into the future. This kind of system is itself capable of modeling, to explicate its projects through modeling or thinking, which is to say, to realize its projects. The system that can self-realize in the sense that it elaborates and develops its own projects is projective. The projects of the system are not given; the system itself constructs them. This illuminates the issue of determinism and freedom. The system is capable of reacting not just to pre-determined problems, but also to novel problems that it determines are pertinent to resolve.[xliii]

The beauty of this typology is that it permits us to simplify complex systems while at the same time maintaining some clarity about the fact that the system is multifaceted and transdisciplinary. For instance, a human being, a ninth level system, is clearly a transdisciplinary thing; one needs all the disciplines to study and understand a human: physiology and anatomy, but also psychology, sociology, and ultimately, all the disciplines. So this typology serves to demonstrate the links between the model and the multifaceted, transdisciplinary reality.

Similar kinds of models have been developed to describe various aspects of complexity theories. For instance, physicist turned multidisciplinary scholar, Stephen Jay Kline, developed a five-level model, called the "Hierarchy of Systems Classified by Complexity of Feedback Modes."

Type of System	Feedback modes and source of goals	Examples
Inert, naturally-occurring	None of any kind; no goals	Rocks, mountains, oceans, atmosphere
Human-made inert; without controls	None, but with purposes design-in by humans	Tools, rifles, pianos, furniture
Human-made inert; with controls	Autonomic control mode usually of a few variables; cannot by themselves change set points of variables	Air conditioner / furnace with thermostat, automobile motor, target-seeking missile, electric motor with speed control
Learning	Human control mode. Humans in system can learn and improve operations; systems can themselves change set points since they contain humans	Automobile with driver, chess set and players, piano with player, plane and pilot, tractor and operator, tank and driver, lathe and operator
Self-restructuring	Human design mode. Human scan look at system and decide to restructure both social and hardware elements via designs.	Human social systems, human sociotechnical systems; household, rock band, symphony, manufacturing plant, corporation, army

Table 1.3. A Hierarchy of Systems Classified by Complexity of Feedback Modes[xliv]

1.8.3. Holistic Complexity

Holistic complexity is simply a term I coin to indicate one place where complexity thinking can easily go awry. Holism refers to a set of philosophical theories, and is unrelated to the term as I use it here. Holistic complexity is a fictitious entity, but represents a trap that is easy to fall into. Based on the separate work of Edgar Morin and Kurt Richardson in this area, I propose my own such framework to categorize contemporary complexity studies, composed of three categories. I keep Morin's Restrained Complexity and Generalized Complexity, explained below, while adding "Holistic Complexity." I incorporate Richardson's neo-reductionism in Morin's category of restrained complexity.

My goal in thinking about a three-point framework of restrained, generalized and holistic complexity is to envision generalized complexity as the ultimate goal, while speaking to the other two reference points. There may be highly valuable work to be done in both of the other categories; however, to understand the full power of complexity, it is necessary to thoroughly grasp these three areas and how they interrelate.

Holistic complexity describes the various ways in which scholars err in the direction of holism rather than reductionism, and likewise fail to capture complexity accurately. In this sense, I create two general reference points with respect to complexity, one on either 'side,' which serve as umbrella categories for the two main ways in which human thinking tends to eschew complexity.

In contraposition to Morin's restrained complexity, holistic complexity speaks to all the kinds of ideas that fall prey to 'overshoot.' One type of holistic complexity is a theory that just lumps everything together, a unifocal or unicausal theory.

Some objects of study – the earth or an ensemble of disparate societies – exist at a scale beyond the elegance of the emergence and self-organization found at the level of particular systems. Hypotheses are made based on the subject of study to which we can assign arbitrary greater 'wholes.' Thus, if our subject of analysis is desertification, and we think in terms of the scale of the planet, rather than the particular desert ecosystem, we are using a holistic lens. Seeing subjects in this way is neither a reductive exercise, in the sense of an isolated, empirical study of a sub-unit of a study system, nor a study in complex systems, as when we look at properties at the scale of the system or systems under study. As opposed to 'restrained complexity' or 'generalized complexity,' this broader designation can be called the 'holistic approach.'

A holistic theory can correlate both with Stephen Jay Kline's concept of the false leap in the use of cross-disciplinary metaphors, or with Richardson's conception of both useful cross-disciplinary metaphors, versus confusing and even fallacious cross-disciplinary metaphors. A holistic theory makes a very broad claim, which is not adequately articulated. Such a broad claim can be relatively true, and useful in getting across messages in a powerful format that reach and move people. But broad claims can also be fallacious and harmful, wasting large amounts of time and energy by sending numerous researchers down confusing and unhelpful paths.

James Lovelock's Gaia Theory strikes me as a great example of a holistic complexity theory. Lovelock, an atmospheric chemist, argued that the planet is one large organism. He posited that the earth's atmosphere co-evolved with life forms to allow for and support life on earth. Thus, several chemical substances in the atmosphere are maintained within a small range that allows for life. If these chemicals were raised to a certain threshold, more or less, life on earth would perish. Therefore,

he concludes, the earth's atmosphere and the creatures on earth have co-evolved in mutual interdependence.

This seemed to ring true, ironically, with many natural scientists trained to accept the strongly established notion of the TOE. Lovelock's theory is a different kind of TOE, in which viewing the true aspect of complex systems, e.g. interrelationships, leads to conflating necessary distinctions. The strategy consists not in reducing to the point of losing critical aspects through distinctions, but rather one of losing distinctions through excessive lumping.

Lovelock's Gaia Theory makes a good example because it caused *both* a large amount of constructive research, consciousness, and even artwork, *and* a negative influence, as it was distracting, perhaps false, and not necessarily useful or applicable to the environmental crisis in concrete ways. Interestingly, perhaps even though current consensus seems to view the theory as false, it still has had a net positive influence on society.

Lovelock's Gaia Hypothesis captured the imagination of both earth scientists and the public. Academics published widely on the theme and held a conference, a kind of trial of the Gaia Hypothesis. While the theory seemed to capture the environmental imagination in a similar way that the first astronomical photographs of the planet earth had in the early 1970s, when one particular photo showing the earth from afar, with green and blue forms, surrounded by black space, became the photograph the most reproduced in photographic history. Paul Winters captured the public's love of the Gaia Hypothesis with his successful symphony, Missa Gaia.

While in this example I chose a topic which some see as conclusively provable, some holistic theories may concern topics that are unknowable, which raises interesting philosophical questions about when broader claims and studies are more or less useful in addressing, sometimes indirectly, critical social and environmental issues.

1.8.4. Restrained versus Generalized Complexity Framework

This distinction is perhaps the most significant framework within which to conceptualize the current state of complexity theories. The restrained-generalized distinction is a major step towards reconciling three major issues in the philosophy of science – the nature of the classical-complexity shift, the 'culture gap,', and the validation of transdisciplinarity as a realm of knowledge as significant as the natural sciences or the humanities. I will discuss these three ramifications after explaining the framework.

Restrained complexity versus generalized complexity, an analysis put forward by Edgar Morin in 2007, distinguishes between two major categories of complexity theories and their relationship to classical scientific theories.[xlv] Morin makes several distinctions useful in seeing the relationship of classical science and contemporary complexity sciences. First he distinguishes between classical sciences and complexity theories as distinct categories. The former is still largely intact, but transformed by the former. And within the latter, he distinguishes between restrained complexity and generalized complexity. Restrained complexity is that which studies complex systems from within mathematical and abstract means alone, with the assumptions of classical science intact. Generalized complexity, on the other hand, encompasses all aspects of complex systems, those which can be effectively understood through classical techniques, as well as those which cannot.

Some sets of issues can be studied in the delimited context and methods of classical science. For instance, looking at the chaotic patterns in the path of a waterwheel or pendulum is an empirical, laboratory based study of physical movement. On the other hand, many phenomena cannot be fully understood in isolation because they involve emergence – or dynamic, whole-system properties that cannot be understood through such approaches.[xlvi] Examples are the whole system level dynamics involved in emotions, hurricane patterns, and social movements. These fit into what Morin would call general complexity. It can be argued that most things do fit into this category, and that the process of trying to make them fit into the other two is a main source of distortion in our understanding. This distinction is still greatly misunderstood and contested.

Morin explains further by means of detailing the way in which classical science eschews three explanatory principles of complexity.[xlvii] One is universal determinism, Laplace's Demon, who is capable of knowing all past events and all future events with precision. Another is reductionism, which I have described above. One can say that reductionism consists in studying composites based upon the elements that constitute it. Finally, there is disjunction, the practice established by founders like Bacon and Descartes, based upon isolating and separating cognitive

difficulties one from another, one reason that separate disciplines become increasingly enshrouded and obscured from one another.

These principles have led to important developments in the history of modern science and technology in the last five hundred years. Nonetheless, ultimately, the limits to science may be as great, or greater, than their elucidations. Science and policy are increasingly confronting these limits.[xlviii] Indeed, this is the essential source of Ulrich Beck's theory of risk, elaborated in Chapter Four. In other words, classical science created great clarity and useful distinctions in the overall field of knowledge, as well as permitted considerable inventions and technologies thanks to the very reductive methods and predictive power of systems that function with relative deterministic certainty. However, the dawn of the twenty-first century is an era in which the problems amassed due to the obscurity, misunderstanding and poor estimation of the consequences of viewing our non-modern technologies in modern light as Latour would say – that is to say with modern assumptions of strict determinism, reductionism, and disjunction – is becoming more detrimental than beneficial.

In support of this perspective, Morin cites two qualities that escape classical treatment and are ubiquitous aspects of reality; two qualities of reality that classical science has ignored to the detriment of societies and their environments. These are irreversibility and emergence. Irreversibility fell into the chasm of the omissions of classical science. While classical scientists came up against the issue repeatedly, the assumptions inherent to classical science have kept these particular aspects of reality at bay. Irreversibility became evident with the discovery of the second law of thermodynamics, indicating that energy degrades over time in heat. This principle is embedded in temporal irreversibility. Until that discovery physical laws were in principle reversible; even in the understanding of life species were seen as fixed outside temporal exigencies.

Yet, irreversibility would keep returning to haunt modernist assumptions. Irreversibility involves disorder; the disordered movement of each molecule is unpredictable, except when one considers these movements together on a statistical scale, the law of distribution. In physics, such statistical laws were largely able to bypass disorder for many purposes. In the biological and human sciences, however, disorder became more and more evident and impossible to eschew from analyses. Irreversibility was embraced somewhat by the life sciences and human sciences, but far from sufficiently for the purposes of adequately addressing complexity in natural and social systems.

Restrained complexity has developed in the last ten years in France, limited to systems that one judges complex because empirically it presents itself in a multiplicity of interrelated processes, interdependent and retroactively associated.

However, complexity is not studied or understood epistemologically. This failure creates an epistemological break between restrained and generalized complexity, because all systems, of whatever type, are at least in part complex by nature; even complicated systems are made up of complex components. Restrained complexity has permitted important advance in formalization, possibilities of modeling, which themselves support interdisciplinary potentialities. However, it rests in the realm of the epistemology of classical science. When one searches for the laws of complexity one attaches to complexity like a wagon attached to the true train. It creates a kind of hybrid between the principles of classical science to which it clings, and to the advances beyond this realm. In reality, despite the advances, restrained complexity avoids the fundamental issue of complex systems – which is an epistemological, cognitive, and paradigmatic issue. In a sense, restrained complexity describes complexity, but only in de-complexifying it. One opens the gap to see beyond the old paradigm, but then one attempts to sew it shut again. Thus, the paradigm of classical science remains, in a somewhat disguised state.[xlix]

Yet Morin laments, "Certainly, now, more than a half century later, the word complexity has made an eruption, but it remains cloistered in a domain – the complexity field – that rests as impermeable to the social and human sciences as the natural sciences."[l] Rather than open up knowledge to reveal more of its transdisciplinary nature, restrained complexity has largely created a new cloistered field of knowledge.

Closely correlated to Morin's conception of natural science complexity as "restrained complexity," is Richardson's "neo-reductionist school" of complexity studies, which is,

> …strongly associated with the quest for a theory of everything (TOE) in physics, i.e., an acontextual explanation for the existence of everything. The sub-community seeks to uncover the general principles of complex systems, likened to the fundamental field equations of physics. The search for such over-arching laws and principles was /is one of the central aims of the general systems movement. Any such Theory of Complexity, however, will be of limited value. In Richardson (2005) I suggest that even if such a theory existed it would not provide an explanation of every 'thing' in terms that we would find useful. If indeed such fundamental principles do exist they will likely be so abstract as to render them practically useless in the

> everyday world of human experience – a decision-maker would need several PhDs in pure mathematics just to make the simplest of decisions.[li]

Throughout both Part I and especially in the case study I analyze this framework, and whether or not it provides advancement and clarity to the philosophy of science, and thus to the current state of knowledge with respect to complex global issues. Generally speaking, by showing more clearly the relationship between the natural sciences and the humanities, the restrained-generalized distinction appears to reconcile the disjunction between qualitatively different methodologies treating different aspects of singular, multifaceted phenomena.

I explore whether, by permitting reconciliations between various cross-disciplinary tensions, this framework help to articulate the significant, indeed inseparable, relationship between complexity and transdisciplinarity. This again, is but a framework, but a highly useful one. It is Morin's contention that both the classical paradigm and the methodological paradigm of the natural sciences reside completely within the broader perspective of complexity theories.

It may be helpful especially if one construes the 'restrained' and 'generalized' not as separate, constrained domains, but rather as symbolic reference points at two ends of a spectrum, which clarify the multi-disciplinary distinctions that exist within one disunified but imbricate singular field of reality. This perspective reveals the paradoxical nature of the shift towards complexity. On the one hand, one must acknowledge and account for disciplinary dissimilarities, as John Dupré has done. On the other hand, one must also acknowledge and account for the role of the generalized complexity framework and the correlation between disciplines that complexity permits, as Morin has done. These two aims are not only not mutually exclusive; they are also closely conjoined in presenting a clearer picture of reality.

1.8.5. Building on the Restrained-Generalized Complexity Framework

Whereas Morin spoke of the three underlying assumptions of classical science most broadly, universal determinism, reductionism and disjunction, Richardson delineates a more specific underlying assumption of the classical scientific method, which ultimately describes the assumption that results from Morin's three prior assumptions. Richardson describes the problem in terms of a syllogism:

- Premise 1: There are simple sets of mathematical rules that when followed by a computer give rise to extremely complicated patterns.
- Premise 2: The world also contains many extremely complicated patterns.
- Conclusion: Simple rules underlie many extremely complicated phenomena in the world, and with the help of powerful computers, scientists can root those rules out.

Naomi Oreskes and her colleagues refuted this syllogism and the authors warned that "verification and validation of numerical models of natural systems is impossible."[lii] Nevertheless, this position still dominates the restrained or what Richardson calls, the neo-reductionist, realm of complexity studies. To confuse matters, many of these complexity scientists use the same rhetoric as humanities scholars about shifting from the mechanistic paradigm to a complexity perspective, while in actuality they have inherited many of the assumptions of their more traditional scientific predecessors by simply changing the focus from one sort of model to another. There is no denying the power and interest surrounding the new models (e.g. agent-based simulation, genetic algorithms), but it is still a focus on the model itself. Rather than using the linear models associated with classical reductionism, a different sort of model – nonlinear models – have become the focus.

The caveat that many skeptics of restrained or neo-reductionist complexity mention, but few elaborate on, is that the new mathematics of this realm, developed the Santa Fe Institute, NECSI, and elsewhere, is "rather more sophisticated than traditional mathematics." Morin seems to address this when he speaks of several aspects of generalized complexity missing from the good work achieved in restrained complexity, namely, contextualization in society, culture, and environment. Again, each quantitative contribution may be valuable, but the complexity perspective seems to belie assurance of any innate superiority in types of models, supporting rather the view that models and narratives must really be designed for their study system on a

case by case basis; complex systems eschew universal application of methodologies.[liii]

What the restrained complexity scholars are doing then is advancing knowledge about what Morin and others would call *dynamics* of systems and calling that *complex*. Actually, insofar as irreversibility and emergence are omitted they are just dynamic systems. This in no way negates the challenges to advance systems dynamics. Systems dynamics are significant and constitute their own domain within the natural sciences.

In a different perspective, the term generalized complexity carries two very different connotations. Generalized complexity concerns not only all of these domains of knowledge, but also concerns knowledge about us as humans, individuals, persons, and citizens.[liv] American ecologists operating within the broader view of generalized complexity would perhaps add to that list, that only generalized complexity is truly capable of creating conceptual models or narratives able to grasp the dynamics between human impacts and environments.[lv]

Still, this distinction is extremely important and would deflate what might be seen as overly hubristic or exaggerated claims about the ultimate significance of systems dynamics with respect to the greater field of human knowledge. Clearly, if the complexity scientists believe that their mathematical work is the only method for accessing information about complexity in the more complex areas of social interactions, meaning, and human experience, and if in fact, that mathematical work extends only to complexity within natural systems, but cannot accede the types of complexity found in systems of emotion, meaning, and experience, then the work, as significant as it may be, does not have the grandiose ramifications that many scientists have argued it does. By the same token, this doesn't mean that all glory will be shifted to social theorists, philosophers, and their ilk, because one of the greater implications of generalized complexity theories is that the study of complexity in the realms of meaning and experience is an extremely difficult endeavor. The more complex a system is the harder and after a certain point less reliable the analysis is. While the socio-ecological realm may be inaccessible by means of scientific methodologies alone, it may likewise, in the case of many issues, be ultimately equally unfeasible even with the more appropriate theoretical methods due to the relative difference of complexity in the world and the likely constrained degree of the human capacity to capture it. But I will not speculate on this here. Perhaps the possible advances are quite substantial. The point here is not to speculate, but to acknowledge more realistically the true nature, capacity, and role of the various realms of knowledge.

Guidelines or principles for going about this remain unclear. I end this section with a note of caution. Many complexity thinkers call for the development of a

widely agreed upon language for complexity so that scholars in different disciplines speak the same language and can understand each other more easily. As I tend to support John Dupré's view of the coherent but disunified ensemble of human knowledge (discussed briefly above), and Nicolas Rescher's view of the complexification of knowledge, (discussed in Chapter Five), it seems to me that a universal complexity lexicon is not feasible or desirable. Richardson also critiques this approach.

> Promulgating that a 'language of complexity' needs to be defined and widely adopted is the first step towards another journey down the modernist path. This belief that an alternative language (or narrative) is required to explain complex systems is, as Daniel Dennett said in his criticism of Darwinism, 'reductionism incarnate'. If the mathematics of non-linearity tells us anything it is that complex systems are incompressible, i.e. there exists no model with lesser complexity that can completely explain a complex system. In addition to this, any understanding derived from a model of lesser complexity concerning the complex system of interest must be considered as provisional. By imposing a developed language we are effectively imposing a definite perspective; or model, which by definition will not be as complex as the complex systems we seek to explain, i.e., it will not have the requisite variety.
>
> Though a complexity lexicon may provide a useful starting point for the analytical process, it is not necessary to adopt it in order to consider complex systems. In fact, like any model/perspective/ontology/language/viewpoint, it will limit exploration by forcing the analyst to consider those aspects accommodated by the language of choice. Exploration should not be seen as some fancy sensitivity analysis, but of a more general paradigm exploration. Through paradigm exploration a resulting eclectic language will emerge which will be specific to the problem context, yet might be wholly inadequate for similar contexts let alone very different contexts. It is not possible to determine beforehand what aspects of the problem need to be considered. Only through allowing the language to evolve will it be possible to 'see' more, and develop a representation that is more context-specific. Pre-selecting the language, and more

importantly, not allowing it to evolve, is the same as shaping the problem to fit the available tools. Definition needs to be fluid (the late Wittgensteinian view) not static.

In summary, a pre-occupation with the search and implementation of a complexity lexicon needs to be avoided given the incompressibility of complex systems. Note, however, that I am warning against a pre-occupation with definition. The process itself of developing such a language will be of value, but more to those involved in the endeavor than those who later learn the language. There is no truly global framework that in itself has the 'capacity' and flexibility to describe all complex systems. What is needed is possibly a form of critical pluralism in which we critically review the assumptions of different paradigms, which manifest themselves in the paradigms associated language, in order to allow a context specific paradigm, and therefore language, to emerge.[lvi]

1.9. Conclusion: The Six Frameworks as an Ensemble

These six frameworks demonstrate quickly that complexity involves many disciplines. Ultimately, complexity must be considered as non-disciplinary, and it must be addressed both through each of the disciplines we have developed, perhaps with some exceptions, through many uni-disciplinary lenses. And perhaps it should be addressed by some scholars, at some stages, of some research projects, on some kind of study systems, as ultimately a transdisciplinary ensemble.

I view contemporary complexity theories though all of the primary areas of literature: (1) natural science, focused on work from the Santa Fe Institute (SFI), and related work; (2) human sciences and social theory, from the Institute for the Study of Coherence and Emergence (ISCE) and related work; and (3) the transdisciplinary view, based on work synthesizing disparate disciplines such as that of Edgar Morin and Timothy Allen. I argue that these three areas of complexity research are significant, and that by expanding into increasingly complex domains – material to natural to social to societal – each adds a dimension of understanding to the former.[lvii]

By nature of the breadth of such topics this may still sound abstract. Some scholars seem to conclude that since complexity requires some abstract thinking, it must be inessential, or worse, a hoax. This dissertation plumbs the gap between the claims that complexity is alternately a hoax or, as Stephen Hawking claimed, we are now entering, "the century of complexity."[lviii] I survey the bare facts and the best analyses on such essential topics as the uncertainties inherent in nonlinear dynamics in innumerable systems key to human well-being such as stock markets, ecological population dynamics, and weather patterns; the newly discovered rules of network structures such as 'small worlds,' six degrees of separation,' and the roles of 'strong' and 'weak' nodes, in the Internet, traffic, blood cells, and currency rates; or the emergent properties we now see as key to understanding evolution, cities, brains, and political movements.

Obviously, it is vast and expanding daily. While I have been working on the reading for this study on and off over the past ten years, before and during graduate school, I could not possibly cover it all fully. Yet, I persist in the contention that a somewhat superficial survey is necessary and adequate to the nature of this research, and does not dilute its potency. Rather, the potency of a complexity literature survey is found in the ultimate breadth and widespread applicability of the set of essential ideas that seem to fall out from these diverse fields and case studies. My approach to such a vast survey has been to attempt to read broadly, yet focus determinedly on the work of leading scientists within these subfields, and pursue the best elucidation of their most significant ideas and theories. Gradually, an extremely interesting view

emerges of a skeletal structure of complexity principles that changes the way we see the world.

Still, given the ubiquitous nature of complexity, the question arises, if everything is complex, how helpful are complexity theories? This dissertation aims to address this question, by examining perhaps the most complex and significant issue facing the international community today.

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Chapter Two. Complexity and the Natural Sciences

2.0. Introduction

For most natural scientists, ***complex system*** has a precise formal definition: *a system of many parts, which are coupled in a nonlinear fashion, which may be discrete or continuous, e.g. difference equations or differential equations.* Because they are nonlinear, complex systems are more than the sum of their parts. In a nonlinear equation, the two sides of the equation are disproportional. This disproportionality amounts to some degree of unpredictable behavior, the nature of the unpredictability depending on the type of system involved. This definition will be further explained throughout the chapter.

For scientists using this formal definition, it follows logically that a definition of complexity is based on the distinction between systems with and without these aspects – nonlinearity and unpredictability – respectively, biological and engineered systems. ***Biological systems*** are most often seen as *a system of parts, coupled nonlinearly, discrete or continuous, exhibiting emergence, in which small changes can lead to larger changes in a system, producing unpredictable behavior.* Whereas ***engineered systems*** are *systems of parts that do not display these other characteristics; they do not exhibit emergence, nonlinearity, or unpredictable behavior.* While ***complex systems*** in the natural sciences are closely related to nonlinear dynamics, the former specifically *consist in a large number of mutually interacting dynamical parts.* Examples of complex systems include: cells, nervous systems, brains, anthills, forests, human cities, and human economies.

2.1. The Complexity of Complexity Definitions in the Natural Sciences

While this initial largely mathematical definition may seem straightforward enough, complexity is famous for defying simple definitions in any domain. Yet, after over a half-century of development, more elaborate and still substantial definitions are now available, which explain how natural scientists view and study this field. Nonetheless, up until very recently, or perhaps still, many natural scientists, even leaders in the field of complexity studies at institutes like Santa Fe, say that they lack a satisfying definition of complexity or complex systems.[1] Lest one make too much of the difficulty in defining complexity, Physicist and philosopher Kurt Richardson has argued that while complexity is difficult to define, in fact, the word science is also

quite difficult to define; we have just grown to think of it is clear. Indeed, when we posit science against the backdrop of – past ways of thinking such as beliefs in alchemy, superstitions and mythologies taken as literal – then in contrast science seems clear. However, in comparing the definitions between science and complexity, then science begins to appear to be as difficult to define as complexity.

The complexity field has been developing rapidly in several rich and influential directions. Indeed, for a growing number of scientists and scholars from every possible discipline as well as public commentators of every stripe, complexity is seen as, if somewhat elusive or unclear, increasingly significant to contemporary societies. Some complexity scholars have called it the defining feature of contemporary life. President of the Santa Fe Institute Geoffrey West said, "Complexity Science, with its tentacles stretching across an astonishing spectrum of fundamental problems, is now viewed as a legitimate, exciting frontier…. [Complexity scientists can address such questions as] are there general principles and conceptual commonalities underlying robustness, resilience, innovation and evolution – concepts that are ubiquitous and central across the entire spectrum of science and technology? .... How are energy, resource, and information networks integrated in living systems, in engineered systems, in societies? Such questions are of fundamental importance, sometimes requiring a new way of thinking." While complexity scholars in philosophy and social theory, Francis Heyleighen, Paul Cilliers and Carlos Gershenson, who share a more transdisciplinary, multi-methodological school of complexity thinking, say that, "Complexity is perhaps the most essential characteristic of our present society."[2]

In order to give an adequate definition of complexity theories within the natural sciences, it is necessary first to make several critical distinctions and observations. Here I will present three distinctions which will be fundamental to our understanding in this and subsequent chapters with respect to just what we are defining when we define complexity theories in different domains of human knowledge. The three distinctions are:

1. Types of complex systems
    - Mechanical, living, social, meaning, virtual
    - These types of systems also exist intertwined within each other
    - A definition of most systems must in itself be transdisciplinary
    - Natural systems often can be studied without reference to social systems, but social systems must often consider the natural, mechanical, living, social, meaning, and virtual systems affecting the study system.
2. Methodology employed vis-à-vis the complexity
    - Reductionist or synthetic ontology and epistemology (study system and study method)

- Complexity science is also reductionist; complexity theory is partially synthetic

3. Ontological and epistemological complexity
    - All kinds of systems in the world exist within and intertwined with each other.
    - Therefore, reductionist and synthetic methodologies are entwined, partially inseparable

I discuss these three distinctions in turn, to provide the basis upon which to begin defining complexity in the natural sciences. In the distinctions that follow, I will give two examples of the ways in which complexity complexifies upon deeper analysis. That is to say, for every simple principle we discern to describe complexity, upon further investigation the principle becomes more complex.

2.1.1. Distinction One – Types of Systems

Distinction One, in studying complexity theories, it helps to be absolutely clear on one thing from the outset: *There is nothing simple – in nature, in reality, or in any of the major realms of reality – mechanical, living, social, meaning, and virtual.* It seems that to find anything simple about them, one will soon find an additional point that renders the same issue once again more complex. Complex systems are first and foremost complex, a tautology, but nonetheless a helpful anecdote to the very human tendency to simplify. If they were but a tautology to humankind, the dissertation would stop here.

In the first example, it is often said that mechanical systems are simpler than biological ones. This seems true in a significant sense, which is that mechanical systems are composed of less components that we can detect and describe, while clearly biological systems are far more complex both in number of components and in the degree and types of their nonlinear interactions. However, it is also true that mechanical systems, like everything on the planet, are comprised of material substances that at the most minute scales known to us, quantum mechanics, once again become complex to the point of incomprehensibility.

Therefore, ultimately, can we truly say that the mechanical system is less complex than the biological one? In one sense yes, in one sense no. As I mentioned in Chapter Two, ***fundamental complexity*** refers to the *ultimate complexity* of a study system, while ***overall complexity*** designates *relative complexity* that can be so ascertained to the best of our current knowledge. Clearly, as far as we know, the overall complexity of a rock is far less than that of the human brain. It seems unlikely

that greater knowledge of the fundamental complexity of the rock or the brain would change this designation.

One thing that this example illustrates is that often complexity theory definitions are based on at least one aspect that is not yet fully understood. In this sense we could say that all complexity definitions appear to be at least in part incomplete, indiscernible, or unknowable. If we are going to try to fully distinguish standard science from newfangled complexity science, however, it is fair to observe that science has the same kinds of incompletion, indiscernible and unknowable aspects. Thus, in this narrow sense, one could say that there is no difference between standard science and complexity science. The distinction collapses.

Meanwhile, Henri Atlan observes that while many non-natural scientists claim that complexity scientists are not doing 'reductionist science.' in fact the science of nonlinear dynamics and adaptation is also reductionist. In fact he says, complexity in the natural sciences, e.g. nonlinear, adaptive dynamics, are in an important sense more reductionist that standard science. Nonlinear dynamic adaptive systems are shown to exhibit both chaotic and patterned behavior, unpredictable in terms of specific particular pathways, but highly predictable in terms of types and patterns of pathways. For instance, when we examine the chaotic swinging motions of a pendulum tracing marks in a sandpit, we can say with great accuracy what kinds of patterns may occur, but we cannot predict with any accuracy which ones will play out how in a particular instance. This is ubiquitous across types of chaotic behavior in physical and chemical systems.

2.1.2. Distinction Two – Methodological Approaches, e.g. Reductionist verses Generalist

A second example of the way that complexity principles complexify will be illuminating throughout the dissertation. One of the essential distinctions made to distinguish standard science from complexity science, is that the prior is reductionist and the latter is generalist. This turns out to be partially very false and altogether problematic. However, it is still necessary to find some fashion in which to articulate this critical distinction, as it is significant whether reductionist methodology is used, what kind of reductionism, to what end, understood in what sense, etc.

The question of what reductionism is and what to think about it are rife with confusion, yet central to ultimately grasping a clearer picture of complexity theories in the sciences as much as elsewhere. Systems exist only in interrelation; therefore what has been generally classified as the methodology of standard science – isolation

and analysis or parts – does not necessarily capture the significant fact that these parts are complex. Sometimes this complexity is irrelevant to the study at hand, which would succeed equally well regardless of whether you label it as reductionist or not. At other times, to neglect or fail to acknowledge complexity inherent to parts will lead to flawed results.

2.1.3. Distinction Three – Ontological and epistemological complexity

Complexity theories touch on phenomena that are necessarily transdisciplinary or affected by and enmeshed in transdisciplinary phenomena. Therefore, defining complexity, even within one area of knowledge, e.g. the natural sciences, requires a certain amount of transdisciplinary inquiry and consideration.

It is important to recognize the specific view that most scientists at SFI, NECSI, CSCS and similar organizations have of their work. Santa Fe scientist John Holland is a computer scientist, engineer, and psychologist. Holland described the goal of SFI scientists as the search for a unified theory that would explain the dynamics of all living systems, be they groves of trees, colonies of bacteria, communities of animals, or societies of people. All are systems of many agents, each of which interact with its neighbors and, most importantly, adapt to change. What distinguishes complexity science from standard science is simply the study of interactions and adaptation. For this, SFI scientists must employ some "new theoretical frameworks, mathematical tools, and computer simulations," which enable them to study the essence of complex systems. Thus, according to Holland, SFI scientists look at the ontological novelty of interaction and adaptation, and the epistemological novelty of developing theoretical frameworks, mathematical tools and computer simulations capable of empirically studying these interactions and adaptations. In every other respect – including the basic methodologies of empirical observation and experimentation, grounding in mathematical models, the advancement of pure science or our understanding of the way systems function, and in the search for universal and generalizable principles – complexity science at Santa Fe and other natural science institutes is very similar to standard science, providing its extension into the realms of dynamics and adaptation of the world's many kinds of systems. ***Complexity science*** is *science that focuses on interaction and adaptation.*

For some natural scientists, like Alfred Hubler or Geoffrey West, complexity is only truly developed in the natural sciences. Whereas, for social theorist and complexity scholar Ray Cooksey said,

> What is complexity science? This question invokes systemic and dynamic thinking at many levels, which means that arriving at a coherent answer will be a complex process in and of itself.… [A] coherent answer to the question must, of necessity, draw on a diverse range of disciplines, while at the same time demanding a reconceptualization of those disciplines in the context of the new science we are describing. A coherent answer must also address the theoretical, methodological, and practical implications of the emergent science. Finally, a coherent answer must, itself, be contextually shaped and sensitized so that complexity science in the context of organizations and management will look, operate, and feel somewhat different to a complexity science for medicine or engineering.[3]

While a "reductive" analysis can focus on any type of subsystem, including types within types, e.g. mechanical system^{A} in interaction with mechanical system^{B} or mechanical system^{A} in interaction with biological system^{A} etc., in some cases it may be relevant or necessary to consider how X or Y interaction is constrained by or is constraining mechanical system^{C} or biological system^{C}. If this is the case, one cannot do this without focusing at least temporarily on various particular aspects of the study question. Thus, in fact it is difficult to conceive of any scientific research in any way other than reductionist. What methodology other than the reductionist would permit the sorts of inherent and fundamental distinctions and sorting that must be done in any kind of inquiry whatsoever?

Yet, at the exact same time, part of most or all research is synthetic. One cannot carry out an analysis entirely in reductionist terms, or entirely in synthetic ones. However, as I describe in subsequent chapters, while it is the nature of physics and chemistry to advance via such reductionist analysis, this process is very different in the social sciences, where knowledge does not advance via reductionist analysis of any kind of law-like behaviors. In the social theory disciplines, knowledge is substantially different yet again. There is no fixed knowledge to 'advance,' but rather shifting theories, ideas and foci as systems are studied over time.

2.2. The Edge of Chaos and Other Definitions

A few definitions of complexity have maintained considerable influence in the natural sciences. Perhaps the most influential defines ***complexity*** as *the edge of chaos*. And ***the edge of chaos*** as *the point at which chaos and order in systems are in tension*.[4] This is associated with the main description of complex systems as perceived in the natural sciences, complex adaptive systems. And these systems are often described with one of several characteristics that are unique to the natural sciences (though sometimes the vocabulary is transferred and used in other ways in the other knowledge domains), including "attractors" or "basins of attraction," and "chaos."

The edge of chaos – the dominant overall definition of complexity in the natural sciences – was developed and coined by Christopher Langton, an early SFI scholar and founder of the University of California at Santa Cruz "Chaos Group," a group of doctoral students who developed chaos theory in the wake of Edward Lorenz' 1974 discovery. It was Christopher Langton in the mid-1980s who conceived the idea and coined the term the edge of chaos. The point at which chaos and order are in tension is an ontological definition, focusing on what features of complex systems in physics and chemistry is most readily generalized. In a sense it is a truism; most all living systems exist in a state between that of order and disorder. Henri Atlan clarified this view in *Crystal and Smoke.*[5] On the one end there are highly ordered systems like crystal, on the other highly disordered systems like smoke. Everything living must live in a state that is between these extremes – partially ordered and partially disordered. A living thing requires structure and differentiation from its environment, and at the same time it requires the kinds of reactions, responses, novelty of ideas and approaches, necessary to respond effectively to a changing and at times hostile environment.

Natural science definitions of complexity fall into a few categories – ontological behavior, ontological characteristic, or epistemological characteristic. That is to say, respectively, complex systems can be defined with respect to their intrinsic nature (ontological) or relative to knowledge (epistemic). Next, some definitions describe one aspect of complex systems dynamics, while other definitions attempt to describe what is common to them in their entirety. Finally, natural scientists focus on the aspects of dynamics or adaptation, hence the reference to complex dynamic systems (CDS) and complex adaptive systems (CAS). I will discuss each of these in due course. Table 3.1 catalogues a few definitions that have remained influential, and catalogues them in terms of the three distinctions.

Though it appears to be inconsequential, it is interesting to note one point on which complexity thinkers in the natural sciences and in social theory differ on how

they do or do not distinguish between complex systems and complex adaptive systems. Natural scientists refer to their study systems as complex adaptive systems, calling them a special subset of complex systems. For social theorists, it is fine to call complex adaptive systems a subset of complex systems; however the reason for this is not the capacity for adaptation, but rather the types of elements under study. The types of study systems familiarly associated as complex adaptive systems exist in computer science, artificial intelligence, or neural networks. These types of natural systems are amenable to computer based simulation models. Thus ***adaptive*** refers to *agents who act in parallel, continuously acting and reacting in response to the reactions of other agents.*

Authors or Domain	**Definition**	**Categorization**
Brian Arthur[6]	A system that constantly evolves and unfolds over time.	Ontological behavior
Whitesides and Ismagilov[7]	A system whose evolution is greatly sensitive to its initial conditions, consists in a great number of independent interacting components, and evolves by multiple pathways.	Ontological behavior
Goldenfeld and Kadanoff[8]	A system that displays high degrees of structure with variation	Ontological characteristic
Hierarchy theory[9]	Hierarchical complexity = the diversity displayed by the different levels of a hierarchically structured system	Ontological characteristic
Entropic criteria[10]	Entropic complexity = the amount of entropy or disorder of a system as measured in thermodynamics (pertains to physical/ chemical systems only)	Ontological characteristic
Fractal theory[11]	Fractal complexity = the degree of the 'fuzziness' of a system, that is, the degree of fractal detail it displays at smaller and smaller scales (pertains to physical/ chemical systems only)	Ontological characteristic
Weng, Bhalla, and Iyengar[12]	A system that by design, function, or both, is difficult to understand and to verify	Epistemological characteristic
Computer science/AI e.g. Bar-Yam[13]	Informational complexity = the capacity of the system to surprise or inform an observer.	Epistemological characteristic

2.1. Definitions of Complex Adaptive Systems in the Natural Sciences

Beyond the edge of chaos, the dominant general definition of complexity, a great range of definitions related to scientists' particular foci has evolved. SFI physicist Alfred Hubler for instance, defines complexity as "a large degree of throughput in a system, which eventually leads to an explosion, a release, and later a slow buildup of tension as throughput again is greater than a system's capacity."[14] In fact, I was present at SFI when Hubler closed all the window blinds and proceeded to demonstrate this concept of explosion by creating lightning bolts at the podium. As noted in Table 3.1, scientists have defined complexity with reference to measures of such features of physical systems as degrees of entropy, information, and fractal detail. In 1995 John Horgan catalogued thirty-two such definitions based upon measuring different aspects of complexity.[15] More commonly held are the following two definitions of complex adaptive systems, by prominent complexity scientists John Holland and Kevin Dooley. Such definitions are supplemented with examples of the kinds of complexity dynamics which exist only in the natural sphere.

John Holland	A dynamic network of many agents (which may represent cells, species, individuals, firms, nations) acting in parallel, constantly acting and reacting to what the other agents are doing. The control of a CAS tends to be highly dispersed and decentralized. If there is to be any coherent behavior in the system, it has to arise from competition and cooperation among the agents themselves. The overall behavior of the system is the result of a huge number of decisions made every moment by many individual agents.[16]
Kevin Dooley	Three principles of a CAS: order is emergent as opposed to predetermined (c.f. neural networks), the system's history is irreversible, and the system's future is often unpredictable. The basic building blocks of the CAS are agents. Agents scan their environment and develop schema representing interpretive and action rules. These schemas are subject to evolution.[17]

Table 2.2. Definitions of Complex Adaptive Systems

Attractor	A point or an orbit in the phase space where different states of the system asymptotically converge.
Self-organized criticality	A phenomenon whereby certain systems reach a crucial state through their intrinsic dynamics, independently of the value of any control parameters. e.g. the point at which lightning starts a forest fire
Phase space	A multi-dimensional space that represents the dynamics of a system. For a system with N-variables, a phase space is a 2N dimensional space composed of N-variables and their time derivatives.

Table 2.3. Examples of phenomena that only exist in natural science systems

What all these definitions have in common is an adherence to the complexity fundamentals. Each one defines complexity according to one aspect or quality of the study system. As mentioned in Chapter One, I reiterate that in this dissertation I use the term ***study system*** to denote *the system being experimented upon, observed, tested, or otherwise studied. This may include any kind of complex system under study, from natural, to social, to socio-ecological.*

2.3. Complexity Fundamentals in the Natural Sciences

The Santa Fe Institute (SFI) was the first major complexity institute, founded in 1984.[18] Several other complexity centers have begun since that time, the largest being the Center for the Study of Complex Systems (CSCS) at the University of Michigan in Ann Arbor; the New England Complex Systems Institute (NECSI) in Boston; the London School of Economics (LSE) Complexity Group; and the European Union sponsored group, the Open Network of Centres of Excellence in Complex Systems (ONCE-CS). Scientists at these institutes and others like them throughout the world – for instance, complexity research has been increasing in China, Japan, and Korea – have discovered and developed the bases of the complexity sciences, emphasizing the importance of heretofore largely omitted aspects of scientific knowledge – including nonlinearity, adaptation, networks and other dynamical processes.

The scientists in these institutions – SFI, CSCS, NECSI, CI-LSE, and ONCE-CS – primarily practice basic research, as opposed to applied research, are trained primarily in physics and the other natural sciences. For the most part these scientists share the methods and underlying assumptions of mathematical modeling, and accreting empirical knowledge, and agree that "mathematics is the language of nature."[19]

In this natural science context, the view of complexity and complex systems is both more precise and more delimited than the definitions portrayed in mainstream literature. SFI scientists largely see their work as having a broad horizon and implications, but consider many of the current broad-ranging mainstream musings about complexity to be invalid. Rather, Santa Fe scientists currently divide their work into six foci: cognitive neuroscience, computation in physical and biological systems, economic and social interactions, evolutionary dynamics, network dynamics, and robustness.

Thus, while their work is largely motivated by societal problems and challenges, it remains basic and not applied; natural science and not social theory; driven by mathematical modeling, computer simulation, and empiricism, and not too much by theoretical analysis or interpretation. So when they refer to their work as interdisciplinary, they refer to research that can be based in mathematical methods. For physicists and chemists, bringing a bioinformatics scientist and a biogeochemicist together is interdisciplinary. While SFI strives to retain almost ten percent social scientists on their staff, their projects are based entirely in quantitative data and modeling. Social scientists on SFI teams utilize primarily mathematical methods.

2.3.1. Complexity fundamentals in their ensemble

Over the twenty-five years since the founding of the Santa Fe Institute in 1982, definitions and descriptions of complexity have revolved largely around the terms mentioned above: complex adaptive systems (CAS), nonlinear, network, feedback, hierarchy, emergence, and self-organization or self-organized criticality (SOC).

Complexity aspects	***Founding Scholar***
Complex systems, systems	Ludwig von Bertalanffy (biology), Kenneth Boulding (economics, philosophy of science, etc.)
Complex adaptive systems	John Holland, Murray Gell-Mann
Nonlinear Dynamics	Henri Poincare, Edward Lorenz, Christopher Langton
Networks	Stuart Pimm, Steven Strogatz, Albert-Lazslo Barabasi
Feedback	Claude Bernard, Norbert Wiener
Hierarchy	Simon Levin, Timothy Allen
Emergence	Numerous predecessors* and recently John Holland, Harold Morowitz
Self-organized criticality	Per Bak
Self-organization = order ←→disorder	Ernst Mayr, Ludwig von Bertalanffy, W. Ross Ashby, John von Neumann

Table 2.4. Key Complexity Terms and Founders in those fields
* One could name: Alfred North Whitehead, Henri Bergson, Georges Canguilhem, Arthur Lovejoy, Rene Thom[20]

I will briefly attempt to clear up some common confusion surrounding the vocabulary of complexity terms sometimes transferred across knowledge realms, e.g. from natural systems to social systems. Several terms that appeared in the natural sciences have been adopted in the social and human sciences. In some cases, this is an abuse and falls from use, however in a few cases the term takes on a substantial meaning in the new domain.

For instance, ***phase transition*** has a precise meaning in physics, *the transformation of a thermodynamic system from one phase to another.* At phase transition points, physical properties may undergo abrupt change, e.g. for instance volume may be very different in the two phases. An example is the transition of liquid water into vapor at the boiling point. In contrast, sometimes people use the terms *phase* or *state* to refer to a state or phase of some phenomena in social systems that can reach social tipping points, and shift into a system dynamic with quite different qualities. An example would be a transition from one phase of government to the next, or one state of mind to another. Again, the opportunities for confusion in the transdisciplinary sphere may seem daunting, but it need not, which I aim to show in Chapter Six.

In what follows, I start a more detailed survey of complexity concepts with this list of the complexity ontological fundamentals and the founders of each of the areas. I list the thinkers by the chronological dates when they published on these areas. Describing the complexity fundamentals themselves in either chronological order or order of importance is perhaps impossible. The reason for this relates back to the character of complex systems, which is an intricate one; the complexity fundamentals have no innate ordering precisely because these phenomena are so interconnected. The nature of complex systems is that each of these aspects is involved in tandem.

Thus, I describe them simply in a logical order: ***complex dynamic systems*** or ***complex adaptive systems, nonlinearity, networks, hierarchy, feedback, emergence,*** and ***self-organization,*** the latter of which in the natural sciences is often called ***self-organized criticality.*** This is logical in a loosely narrative way. In contrast to the classical mechanical perspective, this lists focuses on the dynamical and adaptive aspects of complex systems. In contrast to the linear, isolated, and atomistic features we are used to seeking, the complexity perspective focuses on the nonlinear, interconnected, and nested aspects of the systems. In contrast to static studies we are accustomed to it stresses the dynamical characteristics of feedback, emergence, and self-organization.

In this sense, I see the first set of three fundamentals (nonlinearity, networks, hierarchy), as simpler concepts than the second three (feedback, emergence and self-organization), which represent the more sophisticated or deeper aspects of complex

systems. While it is possible to conceptualize nonlinearity, networks and hierarchy in a static sense, this is not even possible in the case of feedback, emergence and self-organization. Hence, we might say that the first three are Level I dynamics, and the second three are Level II dynamics. In the living world, these distinctions seem to mean little, when we see all living entities as fundamentally dynamic and evolving. Moreover, the inextricability of the first and second set renders this hard to articulate.

Many significant lessons emerge from this study of complexity in natural systems. Nonlinear relationships in complex systems imply that small perturbations may cause large effects. These relationships contain feedback loops, both negative (damping) and positive (amplifying), meaning that effects of an element's behavior are fed back in such a way that the element itself is altered. Moreover, due to relationships between different types of systems – social, natural, industrial, economic, etc. – feedback occurs not just within but also between different types of systems. Thus, biospheric feedback systems may appear more as undulations or breathing of networks of interactions, carrying influence, for instance, between biological, hydrological, chemical, and geological systems. To envision such pluralistic dynamics, one must understand that complex systems are open; they exist in a thermodynamic gradient and dissipate energy. Therefore, they are usually far from energetic equilibrium, but despite this flux, there is often pattern stability.

An almost ubiquitous feature of complex systems is that they comprise a network structure. Networks are systems composed of nodes with links of interactions between them. 'Small worlds,' also known as 'scale-free networks,' have many local interactions with a smaller number of inter-area connections. Natural and human-made systems often exhibit such topologies. In the human cortex, for instance, we see dense local connectivity and a few very long axon projections between regions inside the cortex, and to other brain regions.

Complex systems are often nested, such that the components of complex systems are themselves complex systems. For instance, an economy is made up of organizations, made up of people, made up of cells – all of which are complex systems. Or a human contains a nested set of living processes – the body, body parts, organs, cells, and sub-cellular parts. Within this nested hierarchy, complex systems' boundaries are indeterminable, ultimately decided by the observer. The economist decides what sub-systems are affecting an economy; the doctor decides what sub-part of the body to diagnose.

Further, complex systems have history; they are dynamic systems that change over time, so that prior states may have an influence over present states. More formally, complex physical systems often exhibit 'hysteresis,' a term from physical systems, with analogues in social systems such as economics and history. Hysteresis in physical systems, often referring to magnetism, occurs when systems do not

instantly follow the forces applied to them, but react slowly, or do not completely return to their original state. In other words, it is "a retardation of the effect when the forces acting upon a body are changed (as if from viscosity or internal friction); especially a lagging in the values of resulting magnetization in a magnetic material (as iron) due to a changing magnetizing force,"[21] according to Jim Sethna, researcher at the Laboratory of Atomic and Solid State Physics at Cornell University.

To put it simply, *complex systems* are ***dynamic, nonlinear networks with emergent properties, open to their environment, operating via feedback mechanisms internally and externally.*** Starting by examining the views of natural scientists at the Santa Fe Institute, the first institute dedicated to complexity studies, we will now examine each of these aspects of complex systems in greater detail.

2.3.2. Complex Adaptive Systems

As noted above, various definitions have been put forward for the ***complex adaptive system*** (CAS). Again, a CAS is *a dynamic network of many agents – as diverse as cells, individuals, species, societies, and ecosystems – acting in parallel, constantly acting and reacting to what the other agents are doing*. The control of a CAS tends to be highly dispersed and decentralized. Coherent behavior in the system arises from competition and cooperation among the agents. The overall behavior of the system is the result of a huge number of decisions made every moment by many individual agents.[22]

Many complexity scientists favor algorithmic complexity as a measure of complexity because it is grounded in their primary method of computation. They define complexity as the minimal length of the algorithm that can model, or at least simulate, the system at hand. Chaotic systems in computation were a great surprise in the early 1970s. In one sense, chaotic systems may be simulated with short equations, suggesting that they are not complex at all, even if the output never actually repeats itself.[23] Meanwhile, random systems are highly algorithmically complex, because one needs an algorithm as long as the string of output values. Completely random systems are simulated only by the full list of the output. So in these terms, random systems are more complex according to their algorithmic measure.

For the most part, complexity scientists focus on natural systems amenable to computer based simulation models. ***Adaptive*** refers to *agents who act in parallel, continuously acting and reacting in response to the reactions of other agents.* SFI distinguishes *complex adaptive systems* from all other systems, which fall into the category of *multi-agent systems*. The key difference is that multi-agent systems are

interactive, whereas complex adaptive systems are also dynamic. What distinguishes a *complex adaptive system* (CAS) from a pure *multi-agent system* (MAS) is the focus on top-level properties and features like self-similarity, complexity, emergence, and self-organization. Thus, a ***multi-agent system*** is simply defined as *a system composed of multiple, interacting agents.* Whereas, a ***complex adaptive system***, is *a system in which the agents and the system are adaptive.* In this respect the system is what scientists call ***self-similar***. In mathematics, *a self-similar object is exactly or approximately similar to a part of itself (i.e. the whole has the same shape as one or more of the parts).* Coastlines are statistically self-similar; parts of them show the same statistical properties at many scales. Thus, a ***complex adaptive system*** is *a complex, self-similar collective of interacting adaptive agents.* Complexity scientists continue to study self-similarity. The phenomena may not have obvious utility value. The fact that coastlines are self-similar does not appear to impact on human land management of coastlines, for instance. Though perhaps there are exceptions. Nonetheless, the widespread presence of fractal, self-similar patterns in the natural world seem to be a significant insight into the fabric of the natural world.

With all this in mind, the critical aspect is certainly, dynamics. Flowing from the focus on dynamics other important properties of CAS are: ***communication, cooperation, specialization, spatial and temporal organization,*** and ***reproduction.*** They occur at all scales: both cells and the whole animals they compose specialize, adapt, and reproduce themselves. This is what is meant by self-similar behavior at different scales. Communication and cooperation also take place on all levels, from the agent to the system level.

The consensus in complexity science is that complex adaptive systems that can be usefully studied and provide scientific advances include computer science, artificial intelligence, game theory, and neural networks. Some scientists also think that the feature of adaptability can be usefully studied with respect to: the stock market, termite colonies, cities, and many other domains. Indeed, the complexity science literature touches on all of these topics, but the vast majority of study has been conducted in the prior areas. Only most recently have some scientists begun to expand into the latter topics. For instance, after accumulating and studying data on complexity in city dynamics, Geoffrey West has still only published in the Santa Fe Bulletin.[24] Other Santa Fe scientists have been collecting and interpreting data on economic systems as complex systems for a number of years. As of yet, some of these scientists themselves see their analyses as highly hypothetical and thus far without any definitive results.[25]

Nevertheless, many SFI scientists think that with more time there is potential for extending the work or that it follows logically that is should be possible. For instance, John Holland, to reiterate, who has written on a restricted group of natural

systems, describes what is unique to complex adaptive systems as follows: "A dynamic network of many agents (which may represent cells, species, *individuals, firms, nations*) acting in parallel, constantly acting and reacting to what the other agents are doing. The control of a CAS tends to be highly dispersed and decentralized."(my italics)[26] Nevertheless, few complexity scientists publish on social science topics.

2.3.3. Nonlinearity, Chaos, and Power Laws

Nonlinearity is *disproportionality between causes and effects*. It is thus related to the later discovery of ***chaos theory***, which is *the study of small causes leading to large effects, or sensitive dependence on initial conditions.* A particularly common nonlinear pattern in the world is that of the power law. A ***power law*** is *a kind of mathematical relationship between the size and the frequency of an event, following a consistent mathematical ratio.* For instance, an earthquake that is twice as large as another earthquake will be four times as rare. This pattern holds for earthquakes of all sizes, thus the distribution is said to scale. Power laws effectively describe various natural phenomena such as Kleiber's Law, the metabolic rate of a species and its body mass.

Perhaps the most familiar expression of nonlinear phenomena in the case of climate change is the commonly illustrated in science journals and popular media, sometimes referred to as the 'hockey stick' chart, an X-Y grid showing a long gradual phase followed by a short abrupt change. In Al Gore's movie, *An Inconvenient Truth,* hockey stick charts were used to show the strikingly ahistorical nature of the current anthropogenically driven temperature increase resulting from climate change, which began its sharp upswing in around 2000. This upswing in this chart was so high that Gore needed a large step ladder to climb to show what the curve would look like in a few years time. Ironically, while we have been swimming in a nonlinear universe from the beginning, it seems that these climate change images are among the most striking ones, bringing home the significance of nonlinearity.

Nonlinearity is certainly not new; it has been long noted in the sciences, and is the very basis of calculus. We have long known that nonlinearity is more frequent than linearity in mathematics and in the natural world. As the mathematician Stanislaw Ulam quipped, "To call the study of chaos 'nonlinear science' was like calling zoology the study of non-elephant animals."[27]

The mathematician Henri Poincaré discovered chaos theory at the dawn of the Twentieth Century. Poincare came upon nonlinearity while analyzing the three body

problem, in order to address the question of whether the solar system as modeled by Newton's equations was dynamically stable. The three body problem consisted of nine simultaneous differential equations. In 1903 Poincaré wrote:

> If we knew exactly the laws of nature and the situation of the universe at the initial moment, we could predict exactly the situation of that same universe at a succeeding moment. But even if it were the case that the natural laws had no longer any secret for us, we could still only know the initial situation *approximately*. If that enabled us to predict the succeeding situation with *the same approximation*, that is all we require, and we should say that the phenomenon had been predicted, that it is governed by laws. But it is not always so; it may happen that *small differences in the initial conditions produce very great ones in the final phenomena.* A small error in the former will produce an enormous error in the latter. Prediction becomes impossible, and we have the fortuitous phenomenon.[28] (My italics)

Further evidence and understanding of nonlinearity evolved over time. In the early Twentieth Century, nonlinearity first appeared in mathematics, in physics, quantum mechanics, chemistry and then meteorology, and finally in the field named Chaos. In 1974 Edward Lorenz published a paper on his discovery of chaotic properties in weather patterns, which spawned the famous metaphor 'the butterfly effect.' Lorenz' recognition was that certain systems, such as the hydrodynamical systems in weather patterns he studied, exhibit steady-state flow patterns, others oscillate in a regular periodic fashion, and still others vary in an "irregular, seemingly haphazard manner, and even when observed for long periods of time, do not appear to repeat their previous history."[29] The public imagination was sparked by chaos theory, captured by the image of the tiny flapping of a butterfly's wings in one country causing a great hurricane in another.

Like most major aspects of complex systems, the notion of nonlinear effects – small initial changes leading to large outcomes – captured the public mind in part because it was a contemporary scientific expression of an age-old truism. While the concept had not yet found legitimacy in scientific experiments, common sense long had held that small changes may lead to larger ones. For instance, sociologists long recognized that a small group of activists could bring about major social reform, as evoked in a famous quotation from Margaret Mead, "Never doubt that a small group of thoughtful, committed citizens can change the world. Indeed, it is the only thing

that ever has," or in popular expressions like 'the straw that broke the camel's back." Even if such pieces of traditional wisdom are not directly related to the scientific phenomena, non-scientists tend to seem to make such conceptual associations. This is a value neutral observation, but it may be important to note with respect to the way that ideas about nonlinearity uncertainty, and adaptation are taken up and spread back and forth across realms with quite different precise meanings.

Natural scientists usually say that the behavior of systems that exhibit chaos appear to be random, even though the system is deterministic in the sense that it is well-defined and contains no random parameters. Examples of such systems include the atmosphere, the solar system, plate tectonics, and turbulent fluids. There also exist non-random behaviors in economic and demographic systems which exhibit deterministic chaos. Systems that exhibit mathematical chaos are deterministic and thus orderly in some sense; thus, this technical use of the word chaos is at odds with common parlance, which suggests complete disorder. Though nonlinearity had perhaps always been apparent to scientists in one form or another, the powerful asset of computers helped scientists to acknowledge its significance, and begin to see it as the norm of nature.

The Santa Fe Institute and similar institutes focus mostly on nonlinearity in the fields of physics and other natural sciences. They stem from discoveries such as Ilya Prigogine's theory that stable stationary states of certain open dissipative systems are minimum-entropy-production states. The overwhelming majority of natural science studies of nonlinearity take place in journals of mathematics or physics. The most studied examples of chaos theory include patterns to be found in the behavior of: water wheels, sand piles, heart beats, and spinning disks of particles or glass beads. Finally, ecologists have benefitted from the use of power laws in ecosystem studies. For instance, James Brown, Brian Enquist and others studied power laws neatly describe the ratio of metabolism to size of animal species.

Though results are shared between the physics complexity community and the ecologists, there has been less agreement between these natural scientists and the social science environmentalist community. However, that nonlinearity plays a significant role in both natural and social systems became increasingly apparent to many mid and late Twentieth Century scholars considering the large-scale issues of population, technology, and environmental change. For the greater public, recent images such as the shocking images of nonlinear patterns, e.g. the hockey stick graphs in Al Gore's movie, *An Inconvenient Truth*, brought the connection between nature and society – between nonlinear phenomena and human security in the biosphere – into sharper focus.

2.3.4. Networks

Networks are another aspect of the natural world which was perhaps always somewhat apparent, but not taken up by certain branches of the natural sciences until recent times. Only recently with the emergence of ecology, cybernetics, and other fields in which networks are highlighted, has the ubiquity of networks and their significance to contemporary life in a globalized, interconnected world, been increasingly acknowledged.

Simply put, ***networks*** are *systems composed of links of interactions between nodes.* Yet they seem to appear in every realm – abstract (e.g. mathematics, concepts, ideas), material (ecosystems), ecological (food webs), biological (living matter), digital (a computer), virtual (e.g. the Internet), and social (friendships).

The bulk of network studies in natural science fields occur in mathematical fields such as network theory or graph theory, in computational ecology, and in social and virtual network studies. Analysis includes descriptions of structure, such as the key concepts of small-world networks or scale-free networks, and tools for observing and managing networks – such as critical path analysis and PERT (program evaluation and review technique).

As mentioned above in the discussion on self-similarity, natural scientists employ network analysis in the study of natural patterns, such as much recent work done by physicists studying ecological systems. For instance, recent papers on self-similar patterns in complex ecological networks cover topics such as fractility in ecological networks, e.g. the patterns of fractals in such natural objects as broccoli-like vegetables, seashells, and mountain ridges.[30]

Network scholars unearthed the important and ubiquitous phenomena of the clustering coefficient, or the number at which synchronous behavior begins to occur. Examples include clapping in a theater, insects calling, and fireflies lighting. The discovery that clustering is common throughout networks elevated it from an observation about social behavior to a generic property of complex networks. According to Barabbas, this posed the first serious challenge to the view that real networks are fundamentally random.[31]

The concept of ***scale-free networks*** took network theory by storm because so many real-world networks possess this quality. These are *networks in which some nodes act as highly connected hubs, while most nodes are much less highly connected.* In contrast, in ***random networks*** *nodes are more evenly connected.* To get a sense of the distinction, an aerial map of airports and airline flights is a scale-free network. Airports are all hubs, but airports in New York, Chicago and L.A. each have large clusters of links, whereas airports in Scottsbluff, Chattanooga, and Harveyville have quite few links. In contrast, imagine an aerial map of roads. While there may

seem to be nodes, they are in fact qualitatively much smaller than the nodes in the air flights map. The links are all random. The prior are called scale-free because this pattern of larger nodes exists at both larger and smaller grains (within a medium range in this case). Whereas, there is no such pattern that persists across scales in a random network. Therefore, the fact that many real-world networks are scale-free is quite significant, with various significant implications.

A ***hub*** is defined as *a highly connected node*. In a social network, a *hub* might be a famous or very popular person; on the Internet, a hub is a website like Google; and in an ecological system, hubs are often keystone species that can eat or be eaten by many different species, such as sea otters or coyotes, which, though a tiny part of the ecosystem play a disproportionately large role in ecosystem dynamics because they eat many other species. Ecological hubs were first known as *keystone species*, a term coined by zoologist Robert Paine in 1966.[32]

Ecological network studies have focused on ***food webs***, *the 'who eats whom' of the natural world.*[33] Darwin discussed ecological networks, in terms such as predator-prey relationships, so ecological network study has existed at least since his time. Numerous food web diagrams exist from the 1930s. By the 1990s food web scientists had created dynamic models of food webs and the research expanded greatly, in somewhat fractious groups. For instance, a debate raged over the significance of food web structure versus food web dynamics, or what structure can tell you about dynamics. By the time of writing, this fraction was merged.[34] Important discoveries in recent food web studies include the dynamics between food web connectivity and dynamics, such as biodiversity maintenance. These studies have given insights, for instance, into how many species must be removed from an ecosystem before the onset of an escalation of extinctions, or "an extinction cascade." Thus significant implications include potentially crucial clues to areas such as conservation biology and restoration ecology.

2.3.5. Feedback

Perhaps unsurprisingly, feedback is at once increasingly seen as the critical factor in both natural and social dimensions of climate change and other major socio-ecological problems, at the same time that it has been one of the least studied aspects of these social issues. Feedback has been extensively discussed in the fields of cybernetics and control theory, and to varying degrees in biology, engineering, architecture, and economics. Nonetheless the concept has been with us for a long

time. Similarly to nonlinearity, it is a term that takes on new dimensions and understanding in the context of climate change, as I will explore in Chapter Eight.

In modern times, feedback was popularized by Claude Bernard, father of modern physiology (1813-1878). For Bernard, *feedback* – the looping causality by which systems adapt and maintain themselves – was a central, issue in physiology and by extension throughout medicine and the life sciences. Bernard was a strong champion of the scientific method in the field of physiology – observation, hypothesis, experiment, confirmation and new information – noting the basic feedback pattern in both the method and content of his research. He made major discoveries both in physiology and neuroscience. Perhaps the largest contribution was to understand the fundamental principle of organic life that is homeostasis, or controlled stability of the internal environment of cells and tissues through feedback interactions with the external environment. In this sense Bernard was the father of modern study of the basic physiological feedbacks in the human body. He and others of course also saw links between their work on feedback in physiology with feedback in states of homeostasis and equilibrium.

Feedback was also an early, core concept in cybernetics, where it is defined as a process whereby some proportion or in general, function, of the output signal of a system is passed (fed back) to the input. Often this is done intentionally, in order to control the dynamic behavior of the system. In 1943 feedback was defined in the philosophy of science.[35] The authors defined ***positive feedback*** as *the force that adds to the input signals of a system, but does not correct them.* Whereas they defined ***negative feedback*** more strictly: *a process by which the behavior of a system is controlled within a margin of error relative to a fairly specific goal of the system*.[36] Therefore, positive feedbacks lead to escalating of forcing or change in a system, whereas negative feedbacks dampen or equilibrate forcing or change in a system.

Norbert Wiener, one of the founders of cybernetics, also acknowledged feedback as the central feature of cybernetics, defined feedback as "the science of control and communication."[37] Warren McCulloch defined negative feedback as, "the art of the helmsman, to hold a course by swinging the rudder so as to offset any deviation from that course. For this the helmsman must be so informed of the consequences of his previous acts that he corrects them."[38] Yet, a great contribution from cybernetics was the definition of feedback as the processes that allow a system to adapt to its environment as if there were a helmsman, when in fact there is none. Rather, they recognized that feedback is by nature occurs at the scale of the whole system. There is no control central. Thus, the metaphor of the helmsman was called into question as the cybernetics scientists debunked the notion of an 'actor' doing the steering in various kinds of systems. Later, founder of organization management Stafford Beer defined cybernetics as, "the science of effective organization."

Examples of feedback can be found in every kind of system. In ecology, a well-known example of feedback is the population dynamics cycles of snowshoe hares and lynxes. In this instance there is no one helmsman, but rather both 'sides' influence each other, that is to say they co-evolve in tandem with each other and with other species and systems in their environment. In the life sciences, a much noted example of positive feedback driving climate change is the albedo effect, in which melting ice leaves the surface of sea and land darker shades of color, shifting from white snow and ice to dark browns, greens or blues. Since these darker colors absorb more heat, this leads to a vicious cycle of accelerated melting.

2.3.6. Hierarchy

Hierarchy is another highly transdisciplinary aspect of complex systems. Hierarchy is the structure of a system, composed of nested sets of interrelated, somewhat independent entities. Hierarchy is rooted in the work of economist Herbert Simon, chemist Ilya Prigogine, and ecologist Timothy Allen. It appears that hierarchy theory offers a powerful set of principles to understand better complex structure and behavior of many kinds of systems.

In 1962 Herbert Simon published, "The Architecture of Complexity," a classic paper in which he argues for the ubiquity and importance of hierarchies in complex systems. [39] He argues that in terms of evolution, it is more efficient for complex systems to be composed of hierarchically organized subsystems. Thus he begins to argue that hierarchy is not a coincidental or accidental feature of complex systems, but an essential one.[40]

Just as the concepts of feedback and homeostasis had already proved essential features of diverse systems, so was hierarchical structure important. Herbert Simon expanded the meaning of the term, which had existed previously, referring to a system in which each of the subsystems is subordinated by an authority relation to the system to which it belongs. In a hierarchical formal organization, each system consists of a 'boss' and a set of subordinate subsystems; each of the subsystems has a 'boss' who is the immediate subordinate of the boss of the system. Unfortunately, social scientists transferred this definition into the social sciences, where it has much darker connotations, e.g. associated with totalitarian regimes, which hindered attempts to develop this otherwise perhaps neutral and useful descriptor of social phenomena.

From this formal organizational hierarchy, Simon expanded the term to include systems in which the relations among subsystems are more complex than in

the formal organizational hierarchy, and systems in which there was no relation of subordination among subsystems. Thus he defined *hierarchy* as a feature of all complex systems analyzable into successive sets of subsystems. Again, this could not appear to be a more perfect example of standard science. However, it is the recognition that the levels of the hierarchy than become significant due to both the position of the imperfect position and capacity of the observer with respect to the study system, and also the emergent and self-organizing properties taking place across various levels of the hierarchy, and difficult to account for from the perspective of any one level or one subset alone.

Simon noted some of the key features of hierarchies, later developed by Timothy Allen and others. For instance, he noted that physics pursued "receding elementary particles"; while the atom used to be an elementary particle, for the physicists of the 1950s they had become complex systems. Whereas, for some purposes of astronomy, whole stars or even galaxies can be regarded as an elementary subsystem. And while in one area of biological research an elementary subsystem would be a cell, in another area a protein molecule would qualify, and in still another, an amino acid residue. Hierarchy theory helps both to identify such seeming incongruence, and to see why it occurs.

At the same time, Simon moved beyond some of the all-encompassing grander hopes of early general systems theory study, and pointed to the significance of hierarchical structure as one feature that may merit larger claims. He pointed out that systems of greatly diverse kinds cannot be expected to have any nontrivial properties in common, and that metaphor and analogy across the disciplines can be helpful, but also misleading. All depends, he says, on whether the similarities the metaphor captures are significant or superficial. Indeed, this insight can be usefully applied to many areas of transdisciplinary understanding of complex systems dynamics.

Hierarchy theory has been very helpful in the field of theoretical ecology, where Timothy Allen and Thomas Hoekstra presented a model that maps and explains the interrelated concepts of hierarchy and scale in ecology.[41] They showed the importance of the observer to the system in ecology, or how the observer defines the system. A given entity may belong to any number of levels, depending on the criteria used to link levels above and below. An individual human being, for instance, may be a member of the level, i) human, ii) primate, iii) organism or iv) host of a parasite, depending on the relationship of the level in question to those above and below.

Two terms mentioned in Chapter Two are critical in ecological hierarchy theory: scale and grain. *Scale* pertains to size in both time and space; size is a matter of measurement, so scale does not exist independent of the scientists' measuring

scheme. Something is large-scale if perceiving it requires observations over relatively long periods of time or across large parcels of space or both. With all else equal, the more heterogeneous is something, the larger its scale.[42] Scale is thus intrinsic to grasping hierarchy. Levels of organization vary according to the object of study. Thus we can talk about: hierarchical levels, organizational levels, observational levels, levels of criterion of observation, and ordering of levels. The related concept of *grain* refers to the degree of detail we wish to examine at a given scale, in the sense of the grain of a photograph. Study systems are fine-grained – requiring more details at a smaller scale; or coarse-grained – requiring details at a larger scale.

Another set of important terms are *nested hierarchies* and *non-nested hierarchies.* The distinction between them divides two large groups of hierarchical systems. The most general kind of hierarchies are *non-nested*, or a collection of parts. An army is a nested hierarchy, a collection of soldiers. However, a military commander is a non-nested hierarchy; a general does not consist of a collection of his soldiers. Other common non-nested hierarchies include pecking orders and food webs. *Nested hierarchies* are rarer. Like a set of Russian dolls, for most purposes, they are completely ensconced in distinct levels of the hierarchy. Examples are the layers in highly structured systems, such as crystals or frozen amber. Such structure is impossible in social systems, probably impossible in biological systems, and thus found only in physical systems.

Moreover, hierarchy theory helps us frame and understand function and processes in systems. For instance, fundamental concepts are constraints and possibilities. Constraints are mechanisms from the bottom up in a hierarchical living system; while possibilities are purposes emerging at higher hierarchical levels in a living system.

2.3.7. Emergence

Emergence has been defined as the process by which relatively simple rules lead to complex pattern formation.[43] John Holland, a complexity theorist specializing in genetic algorithms, attempted to clarify the founding assumptions of emergence in mathematics and the natural sciences. Holland is quite clear about the reach of his research. He wishes to dismiss all cases in the social sphere, the majority of cases, since his aim is to begin with an analysis of the most fruitful, most easily examined systems, saying, “I will restrict study to systems for which we have useful descriptions in terms of rules or laws. Games, systems made up of well-understood

components (molecules composed of atoms), and systems defined by scientific theories (Newton's theory of gravity), are prime examples."[44]

Among the important instances of emergence he omits he mentions for instance, "ethical systems, the evolution of nations and the spread of ideas." Reflecting the sentiment that naturally accompanies experimental methodology, he says, "The prohibitive factor of these domains is that they "presently have few accepted rules…. Most of the ideas developed here have relevance for such systems, but precise application to those systems will require better conjectures about the laws (if any) that govern their development." [45]

Regarding the abundant examples within the natural sciences Holland remarks, "there may be other valid scientific uses for the term emergence, but this rule-governed domain is rich enough to keep us fully occupied.… Recognizable features and patterns are pivotal in this study of emergence. I'll not call a phenomenon 'emergent' unless it is recognizable and recurring; when this is the case, I'll say the phenomenon is 'regular.'" Understanding the origin of these regularities and relating them to one another, offers our best hope of comprehending emergent phenomena in complex systems. The crucial step is to extract the regularities from incidental and irrelevant details… This process is called 'modeling.'"[46]

Holland synthesizes his findings about emergence in such rule and law-bound systems in eight key lessons. First, emergence occurs in systems that are generated. Examples include eddies in streams, chess games, a set of neurons, an organism over time, and cellular automata. The systems are composed of copies of a relatively small number of components that obey simple laws. Typically these copies are interconnected to form an array – such as checkerboards, networks, or points in physical space – that may change over time under control of the transition function.[47]

In these generated systems, the whole is more than the sum of the parts. The interactions between the parts are nonlinear, so the overall behavior cannot be obtained by summing the behaviors of the isolated components. Thus, there are regularities in system behavior that are not revealed by direct inspection of the laws satisfied by the components. These regularities both explain parts of the systems behavior and make possible activities and controls that are highly unlikely otherwise. An example is the way in which a strategy, based on uncertain pawn structures, may enable a player to win consistently at chess. Evaluating emergence requires extended or repeated examination and experiment, as the results are not evident from the starting point. In this sense "more comes out than was put in."[48]

Typically, emergent phenomena in generated systems are persistent patterns with changing components. A simple and elegant example is the way in which water in a fast-moving stream forms a standing wave pattern in front of a rock, where the water particles are constantly changing though the pattern persists; in this they differ

from concrete entities, such as rocks or building that consist of fixed components. Other examples include the pattern of a moving, changing, pawn formation in a chess game, or the reverberations in a set of neurons. Another familiar example is an organism, also a persistent pattern; organisms turn over all their constituent atoms in something less than a two-year span, and a large fraction of their constituents turn over in a matter of weeks. Only persistent patterns will have a directly traceable influence on future configurations in generated systems, and thus lend themselves to a consistent observable ontogeny.[49]

The context in which a persistent emergent pattern is embedded determines its function. Because of the nonlinear interactions, a kind of "aura" is imposed by the context. Holland's example is from the mathematical field of cellular automata, the brainchild of two of the renowned mathematicians of the twentieth century, Stanislaw Ulam and John von Neumann. Ulam's idea was to construct a mathematically defined model of the physical universe, within which to build a wide range of "machines."[50] Holland uses the example of the uses of a glider in interaction with other patterns in Conway's automaton. Within the field of cellular automata, a glider is a simple, mobile, self-perpetuating pattern as shown in a time series of graphs. They are used to show a sequence of changes in the patterns over successive time-steps. Thus, Holland was referring to a much delimited mathematical kind of context.

Interactions between persistent patterns add constraints and checks that provide increasing "competence" as the number of such patterns increases. A simple example is the way in which DNA code facilitates correction of local errors in the duplication process. A more sophisticated example is that in ant colonies and neural networks, as the number of individuals increase, so does the emergent competence of the network. Nonlinear interactions, and the context provided by other patterns (at times simple copies of a given pattern), both increase this competence. In particular, the number of possible interactions, and hence the possible sophistication of the response, rises extremely rapidly (factorially) with the number of interactants.

Persistent patterns often satisfy macrolaws. When a macrolaw can be formulated, the behavior of the whole pattern can be described without recourse to the microlaws (generators and constraints) that determine the behavior of its components. Macrolaws are typically simple relative to the behavioral details of the component elements.

A typical consequence of the laws that generate emergent phenomena is differential persistence, or the persistence of emerging novel attributes and strategies over a period of time long enough to allow for the development and verification of the most successful attributes and strategies. The emergent traits that prove to be the most useful and successful persist tend to persist and be adopted over time. Thus

emergence is a means by which a system learns. Therefore, Holland concludes, learning appears to be a key topic for any study of emergence.

A good study system of a relatively simple system is the game of checkers. In the program called Samuel's checkers player, for example, new strategies (new weightings) come from revisions of weightings of strategies that have been persistently successful against opponents.[51] Holland compares this with studies of living systems. In neural networks, it is the persistent reverberating patterns that become the elements of more sophisticated behaviors. This refers to the patterns of neuronal firing in what are called Hebb's cell assemblies, or the units that interact producing neuronal networks, know as neuronal engrams. And in Darwinian evolution, the patterns that persist long enough to collect resources and produce copies are the ones that generate new variants.

The differential persistence takes a variety of forms. This differential persistence can have strong effects on the generation procedure. The patterns that are likely to take a significant role early in the generation process are those that persist through many kinds of interactions. Many possible combinations are sampled, increasing the likelihood that some more complex persistent patterns will be discovered. These generalist patterns can provide a niche for specialist patterns that have a more restricted range of interaction. Occasionally a specialist will fit with a generalist in a kind of symbiotic way, with the specialist protecting the generalist from interactions that would cause its dissolution.

This kind of interactions takes the form of a default hierarchy of decision rules. For instance, imagine that an ant is guided by a general rule – Rule #1: If an object is moving (e.g. a falling rock), flee. This rule serves well in many contexts and will be tested frequently, often saving the ant's life. However, this same rule will cause the ant to avoid other moving ants, with deleterious effects. Here a second more special rule corrects the first rule. Rule #2: If the object is moving and small and exudes a "friendly" pheromone, then approach the object. If a specialist rule such as this holds whenever these more particular conditions occur, then a symbiotic relation results; in other words, the ant cooperates with the other object – be it ant, plant, etc. The specialist rule prevents the generalist rule from resulting in too many mistakes that could cause long-term damage to the whole, while the generalist acts to prevent dissolution in a wide range of situations that would not invoke a response from the specialist.

Finally, higher-level generating procedures can result from enhanced persistence. Cross-supporting interactions, (e.g. symbiosis) often provide enhanced persistence for the component patterns. When these patterns with enhanced persistence satisfy simple macrolaws, a new generating procedure is overlaid on the original.

Darwin's discussion of the origin of the mammalian eye provides a fine example of an induced higher-level generating procedure, a procedure that makes likely a pattern which would be quite unlikely on an a priori inspection of the basic elements. Before Darwin, many argued that something so exquisite as an eye could only have been produced by a designer – it could not have been produced by a chance assembly of parts. It does seem that most biologist objects as complex as eyes are extremely unlikely if one looks to their likelihood only as a random selection from the vast number of objects that can be formed from atoms.

Darwin's macroargument is nowadays bolstered by the deeper layer provided by the molecular biology of the eye, a set of factors unknown at the time he was writing. It is now understood that the energy of light alters the bonds of certain relatively simple biomolecules, setting off a chain reaction that can, for instance, cause neurons to fire. Light-sensitive compounds, lens-like crystalline compounds, neurons, and so on, serve as building blocks (generators) for the higher-level generating procedure that eventually produces eyes. Darwin's step-by-step procedure for the origin of eyes can be recast in terms of this overlaid generating procedure. Once we take into account the formation of a higher-level generating procedure, what had been extremely unlikely when taking into account only the lower-level generating procedures – interactions of atoms to form molecules, etc – becomes likely, indeed, perhaps inevitable.

Looking across systems at different evolved groups, we see that the eye-generation process has been repeated at least twice in evolution, in mammals and in cephalopods, using different building blocks (compounds, cell morphologies, and so forth) to achieve the complex design of an eye with the familiar parts (lens, adjustable focus, retina). In some ways, Holland conjectures, the eyes of cephalopods (e.g. squid, octopus), are better designed than those of mammals. Comparing across living systems, it seems that once such "building blocks" are taken into account, eyes are not so unlikely.

For my purposes, I wish to point out that the change in viewpoint – seeing eyes as extremely unlikely to seeing them as likely – results from the study of emergence. If the system runs long enough, even when the simplest persistent patterns are infrequent in a generating procedure, they will eventually occur. Once they occur, they will persist, making them candidates for combination with other persistent patterns (other copies or variants). Thus, larger patterns with enhanced persistence and competence can occur. Once some initial building blocks are discovered – simple membranes, Krebs cycle, differential adhesion of components, etc. – the number of combinations yielding viable organizations increases dramatically. The common argument that evolution is slow, requiring long sequences of improbable discoveries, misses the point. The unlikely will become likely, if one

allows for a layered series of generating procedures. Understanding and incorporating emergence moves us from a theory of natural selection to a more realistic, plausible theory of evolution.

By studying the varieties of emergence in the natural world, other biologists have expanded on Holland's view of emergence. Emergent behavior in natural systems includes the dynamics of social species such as insects and birds. Canonical examples include the processes by which social insects develop and work in colonies, by which bird flocks form and maintain the V pattern in flight. In fact, emergence appears to be ubiquitous. Everything emerges, from physics to philosophy, from the primordial stars and elements, through biological evolution, social evolution, and agriculture, to "technology, urbanization, philosophy and the spiritual."[52]

Harold Morowitz organizes the study around the chronological development of emergences throughout natural and human history. I'll focus on just a few of his 28 examples to evoke his thinking. In this chapter I'll address stars and multicellularity, and in Chapter Three, tool making, technology and urbanization.

After the big bang, the universe was in a state of change affording clear examples of emergence. In this early phase, before stars, there occurred a decoupling of photons and charged particles and a joining of electrons and nuclei. But there were not yet stars. The universe could be described as a vast sea of hydrogen atoms helium atoms, neutrinos, photons, spreading out and developing, for presently little understood reasons, variations of density over a whole range of sizes. Within this space, filled with the simplest molecules, were molecular clouds, held together by gravity, surrounded by zones of lower density. Universal and space-filling attractive forces moved hydrogen and helium molecules closer together. Energy was conserved. Atoms got closer. Molecules moved faster. As a measure of kinetic energy of moving molecules, the temperature then also increased. The condensing clouds of gas thus became even hotter and denser with time. As gas clouds became hotter and denser, they emerged into protostars.[53]

Any object hotter than its surroundings begins to glow, emitting "black-body radiation." The higher the temperature of the object, the shorter is the wavelength of the radiation maximum. Thus, nucleosynthesis or fusion reactions come into play. The temperature of the core rises; the constituent atomic nuclei begin to move with sufficient very high speed that when they collide they undergo nuclear fusion reactions. In turn, these nuclear fusions have two effects: they release more energy making the core even hotter, and they produce new kinds of atomic nuclei. This is a crystal clear example of emergence: star formation creates a whole new array of elemental nuclei, changing the composition of the cosmos. Newton had it only partially correct. Matter in its present form is not eternal, it emerged![54]

Because there are nuclei of different kinds, matter is informational in addition to its other properties. In general, the larger the mass of the cloud that gives rise to a star, the higher the temperature of the star and the shorter the time that it stays in a radiation-steady state. First-generation stars are made entirely from hydrogen and helium. As these stars explode, they create an array of other elemental nuclei through fusion, which then spreads as space debris. The subsequent generation of stars takes up this debris, and therefore will have more complex chemical composition and thus more complex processes. After the steady state period stars may change type due to internal processes involving the utilization of hydrogen, helium, carbon, or other processes involving the utilization of hydrogen, helium, carbon, or other elements, or they may explode catastrophically.

Therefore, chemistry is another realm of diverse emergent phenomena. The periodic table of elements is a framework for the many emergent relationships within chemistry, such as the properties of atoms bonding and crystal behavior. All of chemistry proceeds from nuclei and electrons interacting by a rule set that are pruned by the exclusion principle. In this case, the selection principle is a non-dynamic rule that selects a certain small set of states of matter from the inconceivably vast array of possibilities. Entities now interact as chemicals, subject to the set of rules that govern all chemical behavior. The periodic table is a different kind of emergence because it involves a new physical principle not derivable from dynamics. The Pauli principle, by defining all chemical interactions, organizes all subsequent emergences.

As a result of stellar emergence, the universe consisted of a great variety of stars, galaxies, occasional novas, pulsars, quasars, black holes, and an array of unknown entities generated by the laws of gravity, mechanics, thermodynamics, and nuclear synthesis. Along with this vastly complicated cosmic collection of entities, something else has emerged: the nuclei of the periodic table of elements, with its' vast potential for making new structures.[55]

In the biological world, a major emergent event was the advent of multicellularity, such as the multicellularity in fauna that was a precursor for our own development. Antecedent to multicellularity, prokaryotes emerged via macromolecular chemistry; chemical networks emerged with metabolism and three main areas of early biological emergence were: autotrophy (largely photo-autotrophy), ingestion of soluble molecules excreted into the environment by other organisms, and eating of other organisms.

Multicellularity arose as adult organisms consisting of many cells with different functions began resulting in more complex forms.[56] Meiotic replication already resulted in the single-celled stage of an organism. Morphogenesis arose, a subsequent series of cell divisions, starting with the unicellular diploid form, and transforming, with differentiation taking place to produce the multi-celled form of the

organism. At each stage of emergence to more complex forms of organisms, the hereditary material had to contain the program for the entire life cycle of an organism. In one elaborate example, the butterfly genome must contain the specification for the butterfly, but also for the caterpillar.[57]

Such elaborate cases of emergence begin to present greater challenges to scientists. While scientists have successfully described several major processes in emergent behavior, many argue that there are other aspects of emergence that remain quite difficult or perhaps impossible. For some scientists, even the simplest instances of emergence in biology have been seen as one of the hardest problems in the field. Jacques Monod stated this in 1970, and scientists like Richard Strohman maintain this position today.[58]

Differentiation and multicellularity are two key emergent properties in biological systems. A clone of cells is derived from a single fertilized egg. The interactions and internal instructions lead to cell differentiation. Some kinds of seemingly new types of emergence actually occur repeatedly. For instance, in the evolution of the taxonomic tree multicellularity occurred not just once, but on many independent occasions.[59]

2.3.8. Self-Organization and Self-Organized Criticality

There is something more than emergence going on in the many kinds of evolution on our planet, a further process leading to individuality and autonomy both biologically and socially known as self-organization. Among the natural scientists there has been much discussion of order, disorder, and the edge of chaos; some discussion of self-organization; and an increasing focus on the more delimited concept of self-organized criticality. We now turn our attention to these natural science reflections on self-organization.

Self-organized criticality (SOC) is a specific technical term first used in physical and chemical systems, coined in 1986 by physicist J.S. Katz to describe a property of (classes of) dynamical systems which have a critical point as an attractor, and therefore their macroscopic behavior displays the spatial and/or temporal scale-invariance characteristic of the critical point of a phase transition, but without the need to tune control parameters to precise values. It is considered to be one of the mechanisms by which complexity arises in nature, in chemical and thus living systems.[60] While the concept derived from physics, it has been applied in fields such as: geophysics, physical cosmology, evolutionary biology and ecology, quantum gravity, solar physics, and plasma physics. SOC is typically observed in slowly-

driven non-equilibrium systems with extended degrees of freedom and a high level of nonlinearity. Many individual examples have been identified since a seminal 1988 paper by Per Bak, Tang Chao, and Kurt Wiesenfeld, but to date there appears to be no known set of general characteristics that *guarantee* a system will display SOC.

The physicist Per Bak is famous for his use of the term to describe the common example of a sand pile as a model for self-organization. Sand dripped continually onto a surface eventually produces a sand pile that will wax and wane, fluctuating around a critical value. It will remain around a critical value as avalanches of varying sizes are followed by reorganization phases. Similar examples include the self-organizing processes of rice, coffee, beads, and liquid drops.

As we move from physics to biology a new perspective has been needed to distinguish the very different processes of emergence in biological systems, adding a new dimension that has long been missing from our understanding of biological evolution. Since Darwin's work was first published, various scientists have attempted to show that self-organization is a part of evolution.

Recently complexity scholar, physicist and biologist Stuart Kaufman has claimed that the self-organizing properties of organisms are a significant aspect of evolution. His book on the topic is called, *At Home in the Universe*. We are not merely the results of accidental natural selection, devoid of meaning in the universe. By meaning Kaufmann refers to the whole humanist dimension of our physical beings, such as ideas, purpose, or intention. Rather, the fate of all complex adapting systems in the biosphere – from single cells to (Kaufmann claims) large economies – involves evolving to a "natural state between order and chaos," a grand compromise between structure and surprise. As Shakespeare said, "We will find a place in the sun, poised on the edge of chaos, sustained for a time in the sun's radiance, but then disappear – untold actors may come and go; each strutting and fretting its hour upon the stage."[61]

Kaufmann holds that life itself initially emerged as a self-organizing whole. Sufficiently complex mixes of chemicals can spontaneously crystallize into systems with the ability collectively to catalyze the network of chemical reactions by which the molecules themselves are formed. Such collectively auto-catalytic sets sustain themselves and reproduce. This is what we call a living metabolism, the tangle of chemical reactions that power every one of our cells. Life is an emergent phenomenon arising as the molecular diversity of a pre-biotic chemical system increased beyond a threshold of complexity.

Stated purely in systems terms, this analysis is in fact saying that life is systemic and that life is emergent. Life does not exist in the form of some elemental part; it only exists as sets of systems. Life is nothing less than the collective processes that develop in cohort as systems evolve. Life is not located in the property of any

single molecule; we cannot discover the meaning of life in the details alone. Rather, life is a collective property of systems of interacting molecules. Life emerged whole and has always remained whole! Thus life is not located in the parts – but in the collective emergent properties of the whole they create. A set of molecules either does or does not have the property that it is able to catalyze its own formation and reproduction from some simple food molecules. Democritus and all of his followers have been wrong; there is no elemental particle, and the world is not composed like a set of Lego blocks building slowly in intricacy. The first chemical reactions were intricate, as has been everything since.

Nonetheless, no vital force or extra substance is present in the emergent, self-reproducing whole. Kaufmann claims that life itself is the force and substance in this emergent, self-reproducing system, to which some may object that this metaphorical usage of the words force and substance belies an extant gap in knowledge that perhaps weakens his theory.

However, Kaufmann argues that insofar as this discovery in contemporary biology is correct, it would go a long way in explaining both the incredible intellectual excitement, and the ultimate failure of the earlier biological notion of vitalism, and its echoes in the philosophy of Henri Bergson. Bergson catapulted to fame with the great popularity of his notion of "élan vital" or a vital life force that transcends the explanations of reductionist science. The brief firestorm of interest lasted from 1907 to 1914 and was later sharply refuted. Perhaps the utter rejection of vitalism helped spur even stronger reductionism to guide the first phase of microbiology and genetics research in the latter twentieth century.

Studies of self-organization may reconcile these views. Both atomism and vitalism are dead. There is indeed something 'vital,' but it is not an extra or mysterious force, it is found in the self-organizing emergent properties at the level of the whole organism. The collective system possesses a stunning property – it can reproduce itself and evolve. Parts are just chemical, but the collective system is alive; life is a natural property of complex chemical systems. When the number of different kinds of molecules in a chemical soup passes a certain threshold, a self-sustaining network of reactions – an autocatalytic metabolism will suddenly appear.[62]

Thus emergence leads to self-organization. Life is the natural accomplishment of catalysts in sufficiently complex nonequilibrium chemical systems. Relatively simple behaviors of nonequilibrium chemical systems are well studied and may have varied biological implications. Systems can form a standing pattern of stripes of high chemical concentrations spaced between stripes of low chemical concentrations. Examples include the stripes of the zebra and the banding patterns on shells. Such chemical patterns – zebra stripes – are intriguing, but not yet living systems. By what laws, what deep principles, might auto-catalytic systems have emerged on the primal

earth? In Kaufmann's view, aside from reconciling atomism and vitalism, we are also reconciling science and myth; study of self-organization may be seen as the search for a new creation myth.

The diversity of molecules in our biospheric system increased. The ratio of reactions to chemicals (or edges or nodes) increased. Molecules are themselves able to catalyze reactions by which the molecules themselves are formed. As the ratio of reactions to chemicals increases, the number of reactions that are catalyzed by the molecules in the system increases. Through ongoing catalyzing reactions, a giant catalyzed reaction web forms, so that a collectively auto-catalytic system snaps into existence. Thus, in a splendid phase transition, a living metabolism crystallizes and life emerges![63]

The self-organizing nature of life has been noted by great biologists for some time. In nature, qualities are born of associations and combinations. The association of an atom of carbon in a chain of molecules promotes stability, a quality indispensable to life. As Francois Jacob noted, nature makes more than additions, it makes integrations. Similarly, the living cell has emergent properties – to nourish itself, to metabolize, and to reproduce.[64] While this notion goes all the way back to Aristotle, it seems that the concept today – as expounded by Monod in 1970 and scholars like Kaufmann today – takes on a new sense of significance and centrality in biology. These emergent properties, whose cluster is called life, imbibe the whole as whole and retroact on the parts as parts. The genetic pool of a species arises from its genome and the qualities of an organism arise from its cells. In general, it appears, emergent qualities arise not from interactions of parts in their isolation, but from the whole-systems scale of systemic processes. Emergence somehow begets emergence.

2.4. Conclusion

The natural scientists have played a major role in the development of complexity studies over the last few decades. While complexity study began thousands of years ago, the flourishing of natural science complexity studies since the 1940s, and especially since the 1980s, has developed into a major new field.

In retrospect, we can look at the development of complexity theories throughout the natural sciences and see that they are interrelated. In the early twentieth century, physics and weather forecasting did not seem to have much in common. Now however, advances in nonlinearity highlight the commonality between nonlinear dynamics in physical, chemical and meteorological systems. In this way, the inherently multidisciplinary nature of complex systems studies slowly comes to light. This reveals some of the deeper conceptual shifts brought about by complexity theories, which can help to explain some of the confusion surrounding their development.

Principle concepts in the natural science study of complexity include: complex adaptive systems, nonlinearity, networks, feedback, hierarchy, emergence, self-organized criticality and self-organization. Since I will revisit these concepts from the quite different perspective of the social realm, it behooves us to briefly recap these definitions:

Complex adaptive systems are systems composed of multiple interacting agents exhibiting system-level properties like self-similarity, complexity, emergence and self-organization, or a complex, self-similar collective of interacting adaptive agents.

Nonlinearity is the common aspect of natural systems that small initial changes lead to large outcomes, or the disproportion between cause and effect due to multiple, intervening factors.

Networks are simply systems composed of links of interactions between nodes, appearing in every kind of system from the abstract (math, words), social (friendships), material (waste), ecological (food webs), digital (a computer chip), or virtual (the Internet).

Feedback is the way in which an output signal is passed (fed back) to the input in a given system. Examples are physiological systems, thermostats, and climate systems.

Hierarchy is the structure of a system, composed of nested sets of interrelated, somewhat independent entities. It is a key spatiotemporal organizing principle that takes into account such critical factors in systems dynamics as scale, grain, and whether a system is ‘nested’ or not.

Emergence is the process by which relatively simple rules lead to complex pattern formation. It has more recently been described by Harold Morowitz as the way by which life has remained ubiquitously self-organized, from as yet unknown processes at the smallest scale, to stages of evolution, the formation of stars, the advent of multicellularity, tool making, and the development of modern cities and technologies.

Self-organized criticality is the term natural scientists have favored with regards to self-organization, or the ongoing state by which systems emerge as whole functioning systems, possesses qualities such as individuality and autonomy. Self-organized criticality refers to the self-organizing properties in systems as simple as a sand pile, which remain around a critical value as phases of change are succeeded by periods of reorganized stabilization.

Clearly, complexity studies in the natural sciences are important to seeing and understanding the ubiquity of the above principles in the natural world. The complexity scientists rightly see their work as an extension of standard science into certain less developed areas – nonlinearity, processes of feedback, emergence and self-organization in systems, and thus the way in which systems are able to receive, react, and adapt to changes in their environment, interrelate, and evolve over time.

Natural scientists have advanced both in articulating particularities of the complexity fundamentals, and in beginning to interpret interconnecting aspects of these fundamentals. Advances are being made on particular rules or laws regarding nodes, hubs, and power laws in natural networks, e.g. within and between cells, physiology, food webs, and virtual systems like the Internet. At the same time, scientists analyze the way that these rules may have significance across and between systems, and implications for impacts and interventions with respect to these systems.

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Chapter Three. Complexity Theories and the Social Sciences

3.0. Introduction

If the dispersion and isolation of complexity concepts have diluted the message of the complexity fundamentals in the natural sciences, this is perhaps even more the case in the social sciences, which are less bounded by quantitative guidance or conceptual legitimation as the experimental method of the natural sciences. The social sciences share the same splintering disciplinary situation as the natural sciences; similarly, complexity has developed within different branches of the social sciences, without any automatic way to see the ensemble of insights or implications throughout the social sciences.

Social systems are notably complex. I contend that complexity theories provide a missing framework that could take the social sciences to a stronger new basis of autonomy, maturity, and authority. To study this hypothesis, I examine how complexity is currently deployed, explicitly and implicitly, throughout the social and human sciences. In the last few decades there has been a great proliferation of complexity concepts, theories and approaches in the social sciences. I will explore some of the early successes and promising indications of these studies. The synthetic, philosophical exploration of these ideas could provide major insight and innovation in the social sciences, and it has only just begun.

As noted in the history of the field in Chapter Two, there have been various different starting points and parallel trajectories of complexity theories in various fields, including within the social sciences. As mentioned in the Chapter Two history section, the history goes far back and has a wide reach. Oriental thinking is more open to systems thinking in some ways, and that large tradition is outside of my scope. Recall for instance that C. West Churchman described the I Ching as a key reference in systems theories, presenting a systems approach similar to Heraclitus' pre-Socratic philosophy. Additionally, many major modern philosophers have also been called precursors of systems thinking. The list is so inclusive I will not even attempt to defend it, though it is important to note.

Instead, I will mention a few of the most influential thinkers from the 1940s to 2000 considered precursors for the work to be presented throughout chapters Four through Six. Earlier thinkers, 1940s through the 1970s, include: Russell Ackoff, W. Ross Ashby, Gregory Bateson, Kenneth Boulding, C. West Churchman, Niklas Luhman, and Margaret Mead. Leading scholars writing into the 1980s and 1990s include: Manuel Castells, Paul Cilliers, Francisco Para-Luna, and Immanuel

Wallerstein. Of course, a comprehensive list would also draw from the more explicit complexity scholars, like Edgar Morin.

Such lists are hard to derive, because the work one could potentially include under the category of complexity in social systems is quite vast. A relatively large group of scholars contributed to the increasing awareness of the complexity fundamentals in the social sphere. While the approaches have varied considerably, these scholars have tended to highlight implications of social complexity such as: general interconnectedness, the many facets of socio-ecological systems, coevolution, coproduction, unintended consequences, risk, degradation, and the potential for abrupt changes and collapses.

Advances in complexity theories regarding social systems include the publication of Edgar Morin's first volume of the Method (1977) devoted specifically to complexity theories writ large. Other dates include the founding of societies and journals devoted to greater complexity studies; Santa Fe Institute and then NECSI were publishing work on social science complexity studies in the 1980s and 1990s. The Journal *Emergence: Complexity + Organization* (*E: CO*) began a significant forum for complexity studies in the social sciences in 1999. Though *E:CO* is geared toward organizational theory and business management, the editors aim for transdisciplinary perspectives, uniting studies in the areas of social systems, natural sciences, and philosophy. In 2004 the journal *Ecological Complexity* pronounced the importance of that disciplinary juncture. With the advent of systematic inquiry into what Edgar Morin calls, *generalized complexity*, it seems that a significant philosophical wedge was levied under the entire enterprise of the social sciences and is slowly altering the position and attitude of discourse.[i]

The study of complexity in social systems reintroduces a rich dimension of society that has been often touched upon and yet never fully acknowledged and integrated into the social sciences or social theory. According to historian Frank E. Manuel, five important founders of the social sciences in the eighteenth century – Anne-Robert-Jacques Turgot, Marquis de Condorcet, Henri de Saint-Simon, Charles Fourier and Auguste Comte, who he named the "prophets of Paris" – founded their systems primarily on the classical science worldview. Conceiving their work in relation to the natural sciences, these social theorists stated that their primary goal was to establish order.[ii] Throughout the Eighteenth Century, according to Manuel, the early classical worldview of the natural scientists was still firmly ensconced in much of social theory. Using excerpts from their writings, Manuel shows that each of these five founders of the social sciences was explicit both in the goal of finding order in society, and in eschewing the disorderly. They shared a strong conviction that social science was closely allied with the natural sciences and must strive for the same clarity and simplicity found in the natural sciences. As the historian Alan Spitzer

wrote about the book in 1964, "It is not so much that the prophets had to construct a substitute for the lost theology or even for God, but that they all attempted to reconstruct the shattered order of the universe and thus restore meaning to it."[iii]

In contrast to these origins, complexity theories began to more truly infuse the social sciences in the last half century. For sake of organizing this vast literature, I examine what appear to be three important groups of scholars that began developing complexity theories (often implicitly and not explicitly): social scientists, social theorists, and transdisciplinary scholars. I include work that does not explicitly but only implicitly advances complexity, by showing how the authors rely on complexity fundamentals to make their arguments. In this Chapter, Chapter Four I examine the work of *social scientists* who use classical social science tools, with its mathematical basis, including statistics and mathematical methods, and methods such as surveys, focus groups, and demographics, which mostly remain within the procedures and mindset of the natural sciences. In Chapter Five I examine the work of *social theorists,* the name I give to all those scholars in the social sciences, humanities, and in societal discourse, who employ theoretical and philosophical methodology. In Chapter Six I discuss the third group, the *transdisciplinary scholars*. While almost all scholars working in complexity theories recognize and highlight interdisciplinary dimensions of their work, these transdisciplinary scholars fully embrace the concepts of complex systems and interdisciplinary dynamics.

You might say that in the current literature specifically on what complexity is and what it means, there is a broad range of positions, but some degree of convergence around certain views. The principle views I have encapsulated and represented as chapters throughout Part I. The range of positions could be best charted with a hierarchical graph of concentric circles. At the core is complexity in natural systems – whirlpools, chaotic weather patterns and dripping sand piles. It appears that nobody disputes that these are complex systems. Some people think that complexity theories refer only to this inner circle of natural science research. Others extend this to quantitative social science but not beyond. Still others extend it to social theory. Moreover, there are references to complexity in every sphere of human interest – ideas, meaning, virtual worlds, literature and art. Finally, there has been a large literature about the complexity fundamentals in philosophy. Issues of emergence, organization, and self-organization have become major issues in philosophy. Some philosophers have a narrower definition of complexity theories, largely based on the natural sciences, while other philosophers have a very broad view indeed. The philosophical theories that describe complexity theories in the broadest way have spurred the common critique that complexity theories end up being nothing but 'a rag-bag of everything.'

Chapter	Angle of Approach	Areas of Study, Theories, Fields
Three	Classical social science tools and methodologies and the study of the complexity fundamentals and their implications	Mathematics – models, formulae, Simulations – agent-based models, virtual futures studies Social science methods – surveys, interviews, case studies, conceptual models, comparisons Indices and indexes – sustainability indicators, statistics Agent-based models for synchronous social behaviors
Four	Social theory methodologies and the study of the complexity fundamentals and their implications	Risk– Ulrich Beck, *Risk Society* Critique of modernity – Bruno Latour, *We Have Never Been Modern* Sustainability – Jared Diamond, *Collapse: How Societies Choose to Fail or Succeed*
Five	Transdisciplinary methodologies and the study of the complexity fundamentals and their implications	Full transdisciplinary complexity theories – Morin, Allen, Rescher, etc. Successful applications: ▪ organization and business management ▪ environmental management ▪ economic models and practices ▪ education models and practices

Table 3.1. Complexity Theory Approaches to Social Systems: Three Realms

3.1. Social Science, Social Theory and Transdisciplinary Theory

The advent of complexity theories has brought to all three groups – social science, social theory, and transdisciplinary theory – a sense of new potential. There is much work to do – first, to clarify, differentiate, and categorize the different groups of complexity studies within the social sciences; second, to recognize what unites them across their interdisciplinary expanse; third, to recognize and reconcile their widely divergent viewpoints and methodologies; fourth, to facilitate interdisciplinary exchange and diverse research approaches within this fast-growing area of social science research; and finally, to describe and analyze this literature. This body of research is quite diverse and there is no quick way to sum it up. In order to do justice to considerable changes to what topics in social science, social theory, and

transdisciplinary studies, I first study these three angles separately. I analyze what complexity says about social systems, and the way that knowledge has advanced in these three areas in the last fifty years. This lays the groundwork for speculation and analysis about how these three approaches each may or may not contribute to global issues today, e.g. to climate change policy.

In this chapter, then, on social science complexity, I first follow up the threads of the last chapter exploring how the six complexity principles have played out in the social sciences. Each of these fundamental aspects of complex systems – complex systems, nonlinearity, network, hierarchy, feedback, emergence, and self-organization – has emerged powerfully throughout the social science disciplines. Throughout the chapter there will be many examples that could be judged to be either standard science or complexity science. I take the position that these are all examples of complexity science, not standard science. But recall that in distinguishing between these two, I refer to complexity science as an extension of standard science, which utilizes primarily the same essential methodology of reductionism, isolation and analysis. In contrast to standard science, complexity science focuses upon especially upon whole systems interactions in one area or another – nonlinear, network and hierarchical patterns and structures, feedback, emergence and organization – and is in this way related to complexity theories of a slightly different nature because they utilize the methodologies of social theory and philosophy, which is the complexity theories found in those domains.

In these three chapters I will give examples of both failures and successes of complexity theories. Failures and successes both can be found amongst very talented leading scholars in both the natural science and social theory. I list both failures and successes for several reasons. First, this helps to reveal some of the true nature of complexity theories, what they can and cannot be, how they can be useless or distortional, as well as ways in which they have proven to be enormously successful. This spectrum highlights some of the challenges of transdisciplinary research. Notably, both natural scientists and social theorists have made huge errors by transplanting tried and tested methodologies and assumptions from their own disciplines and projecting them onto another discipline. This happens both in the transfer of methods and assumptions from physical systems into social systems, and vice versa. Mistakes in the field in no way debunk the value of some approaches in complexity theories. Pioneers and visionaries often step into pitfalls.

There are perhaps three distinctions between standard science on the one hand, and complexity science and thinking on the other hand. First, transdisciplinary links that can be made between complexity science and complexity theories, uniting some body of knowledge into a new kind of domain, a coherent transdisciplinary domain called complexity theories. Second, there is a difference in focus between

standard science and complexity science, which is parallel to the difference in focus between standard theory and complexity theory. In other words, what distinguishes all complexity studies from all classical scientific thinking, is the focus on the whole systems dynamics. Whole systems dynamics including the: structure, functioning, dynamics and processes of systems. Third, due to the transdisciplinary nature and dimensions of complexity theories, the field creates not just an extension of standard science, but it appears to be the means (the only means it would seem) to articulate the interconnections between the various fields of knowledge. As such, it provides not just extension of the whole project of human knowledge, but perhaps clearer understanding of the way that disciplines relate to each other, and whether and to what extent they are ultimately unified, disunified, intertwined, coherent or incoherent. With all this in mind, I analyze the development of complexity fundamentals in contemporary social science literature.

3.2. Complexity Fundamentals in the Social Sciences

3.2.1. Complex systems

The term complex system itself has different meanings in the natural and social sciences. Recall that in a general nondisciplinary or transdisciplinary context, ***complex system*** means, *a global unity organized by interrelations between elements, actions, or individuals*; and in the natural sciences the term complex system means: *a system of many parts, which are coupled in a nonlinear fashion, which may be discrete or continuous, e.g. difference equations or differential equations.* In the social sciences, the transdisciplinary definition applies, ***complex systems*** means *a global unity organized by interrelations between elements, actions, or individuals*. This seemingly simple definition includes challenging elements. One must delineate a given global unity, decipher what is meant by organization, which in the case of complex systems is actually the more elusive self-organization, choose how to parse out and conceptualize the interrelations, and keep in mind the possible interactions between such disparate groups as elements, actions, and individuals. Like many other significant concepts – love, sustainability, integrity, beauty – the phrase complex systems captures a lot. Some argue that it encompasses too much, a rag bag of everything. Making this differentiation between what is and is not useful is one of my major goals. Here I tease out the distinctive and useful meaning of the term in the social sphere.

There appears to be minimal debate on the effectiveness of various methodological and analytical approaches within the quantitative social sciences. Yet some of the initial approaches in the quantitative social sciences appear to be more fruitful than others. Throughout these three chapters on social systems, I will discuss a sampling of complexity research that includes both approaches that appear to be of dubious utility or feasibility, and other approaches that have been clearly both successful and socially useful. I will begin here with highly mathematical approaches, and lead up to, in Chapter Six, various highly transdisciplinary approaches to social systems.

First, I give an example of one prominent complexity scientist, the founder and leader of the New England Complex Systems Institute (NECSI), who treads on extra-disciplinary territory and conducts two studies, one of which appears to succeed while the more ambitious one fails. In terminology introduced in chapter one, Bar-Yam attempts to apply information theory to writing, humans and societies. While the theory of information applies to books, describing quantities of bits of information, it is less clear what it may reveal about the complexity of persons. The calculation of

the complexity of a human being is a complicated affair. In each case, words, language, people and societies, Bar-Yam attempts to quantify complexity in terms of units of mathematics. Such an analysis, applying information theory to social dynamics, I consider to be the extreme reference point in social science complexity. Bar-Yam postulates:

> If we are to consider the behavioral complexity of a human being by counting components, we must identify the relevant components to count. If we count the number of atoms, we would be describing the microscopic complexity. On the other hand, we cannot count the number of parts on the scale of the organism (one) because the problem is determining the complexity remains in evaluating C_0 [by which he means complexity of zero, or the absence of complexity]. Thus the objective is to select components at an intermediate scale. Of the natural intermediate scales to consider, there are molecules, cells and organs.[iv]

Despite such challenges, Bar-Yam arrives at one number. He calculates the microscopic complexity of a human being to be in the vicinity of 10^{30} bits, while the macroscopic complexity estimates are much lower – language-based 10^{16} bits, genome-based10^{10} bits, and component-based (neurons) counting 10^{8} bits. One difficulty is that there is a difference between the spatial component-counting estimate and the time-counting upper bound of 10^{12} bits. After reviewing these discrepancies, Bar-Yam concluded with an estimate of 10^{10+2} bits.

Amount of text	**Information in text**	**Text with figures**
1 character	1 bit	-
1 page = 3000 characters	$3x10^3$ bit	10^4
1 chapter = 30 pages	10^5 bit	$3x10^5$
1 book = 10 chapters	10^6 bit	$3x10^6$

Table 3.2 Information Estimates for Straight English Text and Illustrated Text[v]

Organism	Genome length	Complexity (bits)
Bacteria (E. coli)	10^8-10^7	10^7
Fungi	10^7-10^8	10^8
Plants	10^8-10^{11}	$3x10^8$ -$3x10^{11}$
Insects	10^8-$7x10^9$	10^9
Fish (bony)	$5x10^8$-$5x10^9$	$3x10^9$
Frog and Toad	10^9-10^{10}	10^{10}
Mammals	$2x10^9$-$3x10^9$	10^{10}
Human	$3x10^9$	10^{12}

Table 3.3. Estimates of Complexity – Primarily Based Upon Genome Length[vi]

In Table 4.3 Bar-Yam calculates the amount of complexity in a given entity based upon genome length. In the case of plants, where there is a particularly wide range of genome length, a single number is given for the information contained in the genome, because the accuracy does not justify more specific numbers. Genome lengths and ranges are representative.[vii] Speculating further, Bar-Yam turns from purely quantitative estimates of human complexity "to some more philosophical considerations" of the significance of complexity for "human beings, artificial intelligence, and the soul."[viii] One way to define the concept of soul, according to Bar-Yam, is the information that completely describes a human being. He sees this as possible based on the many numerical calculations allowed by complexity theories, such as his estimate of the complexity of a human being at 10^{10+2} bits. From this, he says, we can see that a scientific definition of a soul is possible, and that such a concept is not necessarily in conflict with notions about the soul in the field of artificial intelligence.[ix] Such considerations lead him to conclude that while there is at present no proof of the capacity to predict the behavior of a human being, that with understanding of the information necessary to describe an organism and its environment, it may be possible to predict its behavior.[x]

On a more global level, Bar-Yam argues, as social theorists do, that human civilization is a complex system, by which he means that societies are complex systems.[xi] His explanation is based in the complexity ontological fundamentals. Civilization consists in many elements, says Bar-Yam, including such sub-complex systems as humans and machines. Links or interactions between these nodes include: communication such as oral and written languages, mail and telecommunications, and economic activities. Each of these areas has produced successful, useful research at both SFI and NECSI. We will revisit these areas throughout this chapter. In this sense, Bar-Yam and leading social theorists are in agreement.

For instance, there is consensus in both social science and social theory, as I mentioned in my description of Jean-Claude Lugan's theory in Chapter Two, that

both machines and humans are complex, though with quite *substantial differences between both kinds and degrees of complexity*. In the case of machines, thermostats are considered complex because they utilize feedback control mechanisms to regulate temperature. In contrast, only living beings possess properties of self-regulation and self-organization. While the feedback mechanism may perform the same task, in the first case it is controlled entirely by human programming of machines, while in the latter case, the feedback involved is the result of millions of years of evolution resulting in humans. Bar-Yam agrees with this overall view of complexity, but comes to very different conclusions than social theorists as to the potential scope and use of methodologies.

Bar-Yam analyses some possibilities and challenges of applying complexity in social systems. He admits that the social and professional reality of one individual "may be" qualitatively different from the social and professional reality of another individual and that this implies, for example, that "decision-making strategies cannot be transferred in a simple way from one such reality to another." From which he extrapolates, "it will be difficult if not impossible for an individual to be suited to more than one such reality. It will be impossible for an individual to address all possible realities. The specific skills inherent in performing a particular task become of crucial relevance to the ability of an individual to perform it. This also implies that education should be directed toward specific and individualized professions…. These professions must be well suited to the individual's talents in order to enable success."[xii]

Computations of complexity can lead to very different conclusions. While Bar-Yam has produced a large body of leading work, his calculations of the complexity of humans and societies appear to be fruitless. In contrast, another computational study of societies and environments seems more useful. While Bar-Yam and Kline both use computational methods, they are measuring different things. While Bar-Yam estimates information, Kline estimates the degree of complexity as the number of components times the number of interactions. Bar-Yam measures data; Kline measures degrees of interactions, aimed at the processes of emergence and self-organization in a thing or a person.

Kline's method also is not fail proof and his more ambitious calculations, naturally enough, seem debatable. Nevertheless, with this method, Kline shows both the significance of transdisciplinarity, and the significance of the qualitative differences between the disciplines, by demonstrating that social and biological systems are vastly more complex than physical systems. Thus, he demonstrates a hierarchical relationship between the disciplines: from the smallest degree of complexity in simple physical systems, to greater degrees in machines, greater in

biological organs, greater still in whole humans and then societies, with the most complex systems being ecological systems containing social systems.

Kline starts from the same vantage point that I outlined in Chapter Two, that each person is complex, comprised of many scales of complex systems, such as the scales of the: atom, molecule, organ, body system, and body. The scales continue to enlarge through the social system, as scholars of emergence have evoked in their description of the social emergence from small to large-scale societies. From this it follows that all social groups and institutions are complex systems, and indeed, every kind of social system and society is a very complex system, when compared with many of the narrower examples of the natural sciences – sand piles, cell growth or bird flocks. By comparing these to much more complex objects such as human brains, and social spheres, Kline creates shorthand for ballpark estimates of the degree of complexity in diverse systems. By estimating complexity at various scales from small inanimate objects to large socio-natural systems, Kline reveals how complexity increases by orders of magnitude.

Entity	**Complexity x # of interactions (C x I) = degree of complexity**
A small inanimate object	C^1
A small machine, e.g. a toaster	C^3
A large machine, e.g. an airplane	C^4
A human brain	C^8
One human	C^9
The social sphere of the United States	C^{11}
The natural sphere of the United States	C^{12}
The entire socio-natural entirety of the United States	C^{13}

Table 3.4. Kline's Estimations of Degrees of Complexity at Different Scales

3.2.2. Nonlinearity, chaos theory, and power laws

Nonlinearity in natural systems is defined as *disproportionality between causes and effects.* The sister science of ***chaos theory*** is defined as *the study of small causes leading to large effects, or sensitive dependence on initial conditions.* Again, nonlinearity is more frequent than linearity in the natural world. Similarly, nonlinearity is the rule in social systems and linearity the exception.

Two classic papers in the area of nonlinear behavior in social systems were authored by Mark Granovetter. "The Strength of Weak Ties" published in 1973,

followed by “Threshold Models of Collective Behavior” in 1978. In the latter paper, Granovetter suggested computational methods to better understand such social subjects as riots, rumors, strikes, voting, innovations, and migration patterns. Granovetter was careful to exclude many social phenomena from his studies. He described the distinct case, apt for modeling, as situations in which groups of people face only two choices. In theory, the costs and benefits of each choice depends on how many other people choose choice A or B. Perhaps the great popularity of the article was due to the introduction of a dearly held intuitive concept, in newly legitimized language, ***threshold,*** defined as *the number or proportion of others who must make one decision before a given actor does so; or the point where net benefits begin to exceed net costs for a particular actor.*

In “Threshold Models of Collective Behavior,” Granovetter broke new ground in sociology. Whereas most previous sociological theory tended to explain behavior by institutionalized norms and values, and individual drivers, Granovetter suggested a new source of decision making, group dynamics. He argued that norms, preferences, motives and beliefs can provide a necessary but insufficient condition for the explanation of social dynamics. To explore this, Granovetter argued, one needs a model of how these individual preferences interact and aggregate.

Since Granovetter’s 1978 paper, hordes of quantitatively talented young social scientists have worked on such approaches. However, thirty years later, the utility of this kind of modeling is still somewhat unclear. In fact, our better understanding of the extreme complexity found in an individual human and in social interactions, seems to suggest that such approaches may not be as useful as once hoped. Could it be that once again social scientists fell prey to science envy and misused natural science methodologies, by transporting them over into impossibly complex domains in which they are less effective? I cannot do justice to the question, but its great significance merits a mention.

I suspect that the view of complexity as both transdisciplinary and indicative of qualitative differences across realms of knowledge – material, organic, meaning, wisdom – may lead the social sciences away from Granovetter’s approach. The qualitative differences between the natural sciences and the human sciences are such that the projection of quantitative methods in the social arena historically, often has been disappointing. A detailed study of the disparate cases in which cross-disciplinary transfer of methods does and does not work is in order, which is beyond my limited purview here.

3.2.2.1. Power Laws in Social Systems

Another potential mathematical tool may be more useful for social scientists. Complexity scholars were intrigued from the start with the possible potential of power laws in social systems. Perhaps, many wondered, power laws would provide some highly impressive discoveries, some laws of complex systems. Since power laws have been proven to hold up in substantial ways within ecosystems, the thought that they might provide some predictive order to the more challenging societal systems was tantalizing. Once ecologists determined strict power laws in size and metabolism of other species, it appeared possible to pursue Howard T. Odum's questions about the faster (unsustainable) metabolic rates of industrial human developments and cities, which might illuminate powerful rules and guidance in areas like energy studies, post-petroleum planning, and urban planning.

With colleagues at SFI and NECSI, I conducted two studies in this vein, searching for potential role of power laws in the field of sustainability studies.[xiii, xiv] My first work on this topic was conducted with a research group at the New England Complex Systems Institute. We focused on the *white flight* threshold hypothesis, first published by sociologist Thomas Schelling, or *the threshold number of African-Americans homebuyers moving into a neighborhood at which white homeowners will move out.* The idea was that at a given moment in the era succeeding the Civil Rights movement in the U.S., roughly from the 1950s phase of suburbanization to the year 2000, one could accurately generalize about the flight of whites from mixed race neighborhoods. The threshold was defined at ~15% African-American home ownership. Our limited study reviewed existing literature, and fueled our own complexity model, Netlogo, a modeling system developed for studying complexity phenomena in social systems.

In our limited study we concluded that the 15% threshold held up, however, that this was just as likely due to the crude nature of the tool with respect to the real phenomena, and specifically, the nature of the variables we input into the study. Surely, the considerable differences across times and places that were not captured by our study would be more than sufficient to invalidate the study. Great particularity of contexts and variables seems to militate against generalization. For instance, in Oakland California during the same time a minority of the town's population was white, and many stated that the goal of moving there was in large part to live in an African-American neighborhood. White flight thresholds cannot seem to account for factors such as measures preventing blacks from buying properties in strictly all white towns, as in former President Bush's new neighborhood in Texas. Such concerns continue to haunt efforts to make generalized models about extremely complex social phenomena.

During my fellowship at the Santa Fe Institute, I conducted a similar research project with complexity scholars Debora Hammond and Timothy Foxon. We used a slightly more sophisticated approach, still focusing on the application of power laws to social systems. We critiqued Pareto's Law in economics – the theory that an industrial society must have a certain proportion of poor people – using arguments from ecological economists such as Herman Daly. Simply comparing countries such as the United States and Sweden reveals the fallacy of any strict law across times and places. Our second argument was that metabolic rates of social systems and natural systems vary considerably, and that if this could be expressed in power laws then it would lend some predictive power to the stress of human impacts on nature. Most species of animals, aside from humans, are intimately wedded to a certain scale of impact occurring within their ecosystem and thus there is a correlation between their size, body weight, and consumption of natural resources or metabolism of energy in the system.

In contrast, through ideas and technologies, humans have vastly magnified their consumption. Humans have broken with the relatively more consistent patterns found among other species, as our powers of ideas, communication and technology impose a very different ratio of metabolism on natural resources. Our powers of reflexivity, both in terms of thought and in the construction of tools have allowed us to have an unprecedented impact on nature. For instance, in the 1970s Howard T. Odum calculated that the metabolism of human cities is four times the background natural rate of metabolism of human settlements in the countryside. In other words, in urban systems, humans require four times more energy for the maintenance of all the social-material systems – food, housing, transport, etc. – then human settlements dispersed in the countryside. This kind of analysis may provide another interesting indicator for the general study of human impact on environments.

Our study showed that while power laws do exist in both natural system and social systems, that they cannot be applied to human social systems in the same way, due to greater variability introduced by factors such as the variable human use of technologies. However, our study was brief and surely insufficient. It still appears that power laws may hold in social systems with surprising frequency and regularity. Geoffrey West, President of the Santa Fe Institute has done considerable work in the area of power laws in social systems, and I look forward to his results with much curiosity.[xv]

3.2.2.2. Patterns in Social Behaviors

According to leading social network theorist Duncan Watts, ***nonlinearity in social systems*** occurs when *"individuals in a population essentially stop behaving like individuals and start to act more like a coherent mass."*[xvi] Examples include such disparate events as cultural fads, financial bubbles, and sudden outbreaks of cooperation. These events can occur with regards to something as vapid as teenage girls' t-shirt styles to those as substantial as the weekly mass protests towards the end of 1989 in Leipzig Germany that catalyzed the reunification of Germany. Over a period of thirteen weeks the protests grew, from thousands to tens of thousands to hundreds of thousands of protestors, leading to toppling the East German Socialist Party, the fall of the Berlin Wall, and the beginning of the reunification of Germany. Leipzig quickly became known as the "city of heroes" as these crowds of ordinary people risked imprisonment, physical harm and possibly death, but spontaneously spread in numbers until the massive crowds of hundreds of thousands worked in unison to bring down the Berlin Wall.[xvii]

One may ask if there are really substantial similarities between such vastly different events as clothing fads and political uprisings. Social science nonlinearity and network researcher Duncan Watts argues that there is "a common thread." To see it one must "strip away the particulars of the circumstances and slog through a thicket of incompatible languages, conflicting terminology, and often opaque technicalities."[xviii]

The answer lies partly in one of the basic and early human propensities – to emulate others. Watts says that from choosing graduate programs to movies, many people consistently opt to minimize potential risk, whether to their career prospects or their evening's entertainment, by observing and emulating the actions of others.[xix] It would seem to me that there is more to say about our choices based upon our psychology, sociability and emotional attachments, indicating much higher complexity still. But perhaps there is utility in focusing on more obvious factors, as Watts does. Whether compensating for a lack of information, succumbing to peer pressure, harnessing the benefits of a shared technology, or attempting to coordinate our common interests, Watts says, humans continuously, naturally, inevitably, and often unconsciously pay attention to each other when making all manner of decisions, from the trivial to the life changing. This occurs despite strong cultural belief in the United States that we act in a highly individual way.

Some examples illustrate such trends more clearly than others. While body piercing is ultimately an independent decision, such body art may be based mostly in a desire to relate socially to peers and to develop an identity within the greater society. In contrast, the choice of whether or not to own a cell phone is more clearly

linked to the choices of social networks and is a good demonstration of the functioning and strength of social networks. The choice of when to buy a cell phone provides an explicit example of a certain social threshold. If all of your friends have cell phones it becomes increasingly inconvenient to remain without one.

Cell phones also provide an explicit example of how social and economic networks can be intertwined and coevolve, with various coercion and cooption between them. Businesses have adopted certain mechanisms to manipulate the choices of actors in social networks. Cell phone companies created incentives for customers to use the same network, e.g. giving two friends on the same network free minutes. Thus, people can be pressured to buy into a certain company network, or conversely, people's individual dependence on one cell phone company can affect how much time they do or do not spend talking to friends on or off that network.

Thus far, none of Watts' examples of social thresholds and tipping points seems to have too much obvious social utility. After all, we intuitively know about social tipping points, we more or less consciously react accordingly. It wouldn't seem to necessarily change our behavior just to know about the theoretical aspects of these daily realities. However, there is a strong argument that most of the social complexity research provides the basic science source from which many useful applications may emerge.

Next I will explore a few of Watts' examples of social networks and thresholds that seem to offer more applied interest and utility. One example of the great successes of complexity theories is the creation of a whole new series of networks. President Obama provides a good example. There is a very good reason that President Obama battled to save his Blackberry, built his campaign on internet participation, and produced weekly podcasts for two years before his election, posting each podcast meticulously to his pre-campaign website and then campaign website, the largest such operation in U.S. campaign history.

3.2.2.3. Virtual-Social Networking

In April 2009 the White House had added two more first-time achievements – the first White House Facebook and White House Flicker pages, each of which offered extensive and sophisticated exchange between White House staff and any web user who linked to these pages. The first day the Flicker page went up, one could find over three hundred photos of Obama, White House cabinet, advisors, staff, family, prominent politicians, lobbying groups, foreign leaders, and policy groups. Here one could see Obama engaging with presidential duties of all sorts – Oval office phone calls, Congressional sessions, White House receptions with public interest

groups, Obamas schmoozing with Kennedy's, health care unions, school assemblies, and any number of other frenetic first one hundred day activities. All of this was set against the backdrop of many beautiful White House rooms and chambers never before shown to the general public. The websites were designed to provide a new kind of forum of open democratic discussion and commentary. Within twenty-four hours the pages were filled with thousands of user comments and discussions.

Again, one could argue that these kinds of networked technologies are the produce of standard science. Complexity scientists such as Albert-Laszlo Barabbas, Duncan Watts, and many other following this very popular area of research, argue that it is a new field, or perhaps the coevolving development of standard and complexity science. They see this field of complexity science as the source of a wide array of new technologies improving every area of social life, such as the work, communications, travel, commerce, and more rapid, easy exchange of ideas.

Are computers a product of standard science or of complexity science? The answer seems to be that among the public at large and most scientists, the computer is product of standard science, while most scientists at SFI, NECSI and elsewhere would describe computers in part as a fruit of either complexity theories or the precursors of complexity theories. Indeed, most people accept the historical lineage I describe in Chapter Two, which describes cybernetics as a precursor or early realm of complexity studies. If cybernetics is a branch in the tree of complexity theories, then are computers not complex?

A second area of successes is the potential to define, distinguish, and describe coevolving processes in socio-ecological systems. Just as one can overlay evolving social networks and communications systems, so could one study the interactions and coevolution of systems, how they tend to relate and how they tend to develop. In some cases, researchers argue, this leads to more systematic and reliable understanding of both pitfalls and potential for planning, designing and living in contemporary societies.

A recent example of major benefits of our highly networked societies includes the global responses to the threat of a potentially radically worsening Swine Flu virus. Because of highly effective networking of the institutions involved, and the many network technologies involved, responses have been rapid and effective thus far. Global communication systems, politicians, media, hospitals, health care networks, and disease control center facilities staff and funding, all whirled into motion within a matter of days. This does not prevent the potential of a highly virulent strain creating a pandemic; however, it seems that it greatly reduced the chances of such an event.

More generally, as various social, technological, environmental, economic, political, human health, religious, and other systems interrelated, what risks might be

generalized? What pitfalls might be relevant across various systems, or at regular junctures between certain systems? What synergistic patterns might be established?

If more scientific study and evidence of brain tumors were to be linked to cell towers in poor neighborhoods, it may lead to the emergence of new social, political, economic, health, and technological networks. If a correct information cascade created news of serious health risks, actor network constellations may shift suddenly, with consequences for social, economic, and political networks and trends. For instance, a certain threshold is reached during growing evidence of a new cancer cluster before the predictable results of community organizing, shifts in property value, and legal battles with industrial polluters.

3.2.2.4. Coevolution of Societies, Environments, and Economies

More importantly, as the patterns of coevolution between industry, environments and human health become clearer over the decades of industrial activities in the landscape, this predictable pattern leads to strong and more effective responses, larger networks of organizations with better knowledge, expertise, and capacities to react more quickly and accurately. The industrial scandal at Love Canal New York which led to one of the first major local environmental battles was fought by pioneers who struggled to invent the means with which to fight big industry. Today's local environmental leaders have vast amounts of previous case studies, role models, information, expertise, support, laws, and lawyers at their disposal.

Watts offers many examples of how patterns of social coherence and the cascading of ideas can be harmful or helpful. In the case of the Branch Dividians, their strange and rigid religious beliefs are maintained through strict social isolation and internal reinforcement. In contrast, information that reaches many different groups can have immense impact, for the good or bad. United States television, among the worst quality in the world, is often blamed for its impact on American passivity and ignorance. Simple technological shifts towards higher Internet use or digital television may alter allegiances and consensuses on social and political ideas.

When an idea gains sufficient press and support in society, a tipping point is reached at which a critical numbers of actors join or participate. Such was the case of the alternative currency called Ithaca hours or Ithaca dollars, which have been in use since the early 1990s and can be earned and spent in a local, economic bartering system at a number of businesses in downtown Ithaca, New York. In contrast, an attempt to institute a similar alternative currency on the Upper West Side of New York City, lacked sufficient support and was a complete flop.

There are many differences between these two examples, but the one relevant to cascade studies is that "in Ithaca, the network of customers and vendors is sufficiently densely connected to be self-sustaining" whereas, "the Upper West Side, by contrast, is too integrated into the rest of New York for any individual to have enough stake in a purely local alternative to cash." If however, the cash cards had caught on on the Upper West Side, it seems plausible that, unlike Ithaca hours, the innovation would have spread, for precisely the same reason that it failed. "…the success of an innovation appears to require a trade-off between local reinforcement and global connectivity. And this requirement renders social contagion significantly harder to understand than its biological counterpart, where connectivity is all that matters."[xx]

3.2.3. Networks

As the nonlinear network behavior in the last section highlights, networks may be the most longest-lasting, trendiest buzzword in the social sciences. Social networks appear intriguing and promising to a wide range of social scientists. Many claims are made about the utility of networks to the ordinary and extraordinarily challenging problem of nonlinearity in social systems and decision-making. Social network researchers specialize in studying social behaviors from the perspective of large-scale group dynamics.

The definition of ***network*** from Chapter Three holds in social systems: *a set of nodes with interactions between them.* Perhaps though, combining this definition, with the definition of complex systems adopted in Chapter Two, and some details to render this more explicit, would be even more appropriate. As such, ***a social network*** would be *a set of social elements, agents, technologies, events, or phenomena, with interactions between them.* While this simple definition reveals what is in fact extraordinary complexity, social scientists are exploring what appear to be somewhat law-like behavior unique to social networks. As social nonlinearity studies are intriguing and merit study, mathematical tools in the case of social network studies are even more obviously compelling.

While social networks may or may not prove to have much mathematical power, they also present quite powerful images, perhaps even more than the hockey stick graph exemplifying nonlinear power laws, or a set of Russian dolls embodying the concept of hierarchical scales. Even more than these metaphors, networks are concrete, tangible, visible, and ubiquitous in both biological and social systems. In a few decades, the term network has come to evoke innumerable images: medical photos of arteries and neurons, aerial views of interconnected roads and highways,

maps of branching waterways in a watershed, or graphs showing the spread of disease. Like fractals, images of networks capture the eye and the imagination. Unlike fractals, it seems, networks are rich with numerous societal implications.

One widespread example was the red and blue political map of the United States that dominated the 2004 election season, with the red and blue states swelling or shrinking to represent percentages of population, votes and other statistics. Such graphics quickly revealed trends that were previously less obvious to some groups, such as the extent of evangelical voters in some states. The creator of these headline grabbing maps was social network scientist Mark Newman of the SFI and U Michigan's CSCS.

4.2.3.1. Small World Networks, Degrees of Separation

Yet social networks have gained considerable interest not just because of the graphics they generate; network theory is perhaps the most advanced area of the complexity fundamentals. Significant discoveries in the field include: small-world networks, scale-free networks, and hierarchical clustering. A ***small world network*** is *a network derived from the theory that any two people in the world can be connected via 'six degrees of separation.'* Illuminating the transdisciplinary nature of complexity fundamentals, the six degrees of separation concept was perhaps discovered, or at least first published, by a novelist – the Hungarian writer Frigyes Karinthy. In his short story, "Chains," ("Láncszemek" in Hungarian) one of the fictional characters proposed a bet. Karinthy wrote, "To demonstrate that people on Earth today are much closer than ever, a member of the group suggested a test. He offered a bet that we could name any person among earth's one and a half billion inhabitants and through at most five acquaintances, one of which he knew personally, he could link to the chosen one. Karinthy's 1929 insight that people are linked by at most five links was the first published appearance of the concept we know today as "six degrees of separation." The story was written just before the great stock market crash that began on October 24th 1929, which might have otherwise been attributed as a possible source of insight for Karinthy.

The concept of "six degrees of separation" entered the scientific literature in 1967 when Harvard professor Stanley Milgram published a groundbreaking study on social interconnectivity. Milgram's goal was to find the social "distance" between any two people in the United States. His study revealed that any two random people are linked by a chain of only about 5.5 others, which he rounded up to six. He picked far-off, random cities and estimated by calculating the results of chain letter experiments. Today, due to highly interlinked aspects of early twenty-first century life, including

cheap long-distance travel, the Internet, and our global economy, the number of our links is estimated to be closer to three or four.

3.2.3.2. Scale Free Networks, the 80-20 Rule

Mark Granovetter's classic 1973 sociology paper called, "The Strength of Weak Ties" argued successfully that weak social links are more important than our close cherished friendships when it comes to many phenomena of social networking – finding a job, getting news, passing rumors, or spreading a new fad.[xxi]

This view of the social sphere revealed something important, the presence of ***scale free networks*** *–highly connected clusters with a few external links to other highly connected clusters*.[xxii] In one case, a strong power law seems to arise in numerous kinds of networks, natural as well as social networks. This is called the 80-20 rule. It appears that in many systems, functions break down along the lines of 80 percent to 20 percent of the system. Vilfredo Pareto, an economist of the early twentieth century mentioned earlier in this chapter extended this to other domains less successfully, claiming that while eighty percent of a population tends to be financially comfortable, the other twenty percent is necessarily poor.

While Pareto was wrong with respect to poverty, strangely, the principle seems to hold with regards to various phenomena. Pareto was also an avid gardener. In his garden he made a striking observation: 80 percent of his peas were produced by only 20 percent of the peapods. This curious 80 to 20 relationship is now called Pareto's Law, or the 80/20 Rule, later formulated as Murphy's Law of management. In social systems it appears that 80 percent of profits are produced by 20 percent of employees, 80 percent of consumer service problems are produced by only 20 percent of consumers, 80 percent of decisions are made during only 20 percent of meeting time, and so on.[xxiii] Additional examples have emerged: 80 percent of links on the Web point to only 15 percent of WebPages, 80 percent of citations go to only 38 percent of scientists, 80 percent of links in Hollywood are connected to 30 percent of actors.[xxiv]

It is unknown why such diverse systems follow similar power laws. It may be that the natural science phenomena follow this pattern more closely, and there is some other explanation for a relatively accurate correlation in the case of interrelated social phenomena. In any case, complexity social scientists think that discovering the answers to these questions may provide breakthroughs in various areas, including perhaps social organization, management, and understanding complex change in socio-ecological systems.

Despite these remaining uncertainties, network scholar Laszlo Barabbas sees great promise in these seeming laws to network behavior. One subset of network analysis that has already had significant and widespread utility in social systems is ***link analysis***, which *the study of the relationships between actors in a network.* Link analysis has proved a very powerful tool in a number of ways. Computer-assisted or fully automatic computer-based link analysis is increasingly employed by banks and insurance agencies in fraud detection, by telecommunication operators in telecommunication network analysis, by the medical sector in epidemiology and pharmacology studies, in law enforcement investigations by search engines for relevance rating, conversely by businesses for search engine optimization techniques, by spammers for spamdexing, and in many other fields where interactions between many actors in a network must be studied.[xxv]

Already, the scale-free model has been critical to network studies; it was the first to account for the power laws characterizing real networks. The discovery of scale-free networks induced a paradigm shift, in that scale-free networks taught us that many complex webs surrounding us are far from random, but rather characterized by highly similar robust and universal structures. These insights came about with the World Wide Web, which offered the first chance to examine the intricate anatomy of large complex systems and established the presence of power laws.

Again, some standard scientists object that power laws are a part of the mathematics of standard science. Complexity scientists retort that while the methodology is the same, the focus and the goal are unique, revealing patterns at a different scale than standard science – the scale that incorporates the dynamics of the system. While power laws are old, the projects for which they are taken up are new. Complexity social scientists see the unique quality of their work –dynamics, adaptation, emergence and self-organizing processes – as a field to its own.

3.2.3.3. Social Network Maps

Complexity social scientist Mark Newman began examining many of the kinds of networks that crisscross contemporary society. He developed for instance, large maps, of applicable interest to wide groups of scientists, researchers, and citizens. Computer models of social network dynamics advanced maps in many areas practical interest – language, transportation, and relationships – shaped by these universal laws by which they appear to share the same hub-dominated architecture. The significance of hubs has prompted epidemiologists to seek new strategies to stop the spread of AIDS and small pox.[xxvi] Venture capitalists start companies based on

the insights from network theory. Historians use network structure to study genealogical webs. Indeed, social applications seem endless.

Ironies emerge. While military strategists look to network structure in their study of terrorism and warfare, peace activists are using network studies to advance social movements against militarism. Previous UC Berkeley postdoctoral student Skye Bender deMoll, for instance, has been using network research to advance the international peace movement. DeMoll took data from the researchers Michael Heaney and colleagues regarding antiwar movements in the United states, collected at five large-scale public demonstrations in 2004-2005.[xxvii]

Similarly, a considerable number of sociologists and other social scientists have pursued the concept of social networks as a tool to promote unity amongst relatively disparate, dispersed progressive social, environmental, and political groups. Previous progressive coalitions have long suffered from tendencies to decentralize and disintegrate. Progressive movements around the world have been rallying under the banner of the Movement of Movements, or the Network of Networks. Student activists have made efficient use of mobile technologies in organizing spontaneous demonstrations around the world. With many groups coalescing in the greater alter-globalization movement, the hope has been growing that such networking understanding and technologies will help the great multitude of interest groups on the left to better organize to promote united goals, as expressed in environmentalist Paul Hawken's recent book, *Blessed Unrest*.

What is striking about social network studies is how many different groups are utilizing them, including as I mentioned – computer systems operators, telecommunication analysts, medical researchers, epidemiologists, venture capitalists, genealogists, historians, military planners, peace activists, right wing think tanks and left wing activists. The examples seem endless. But even with the area of basic research, results have been encouraging, and researchers in the field are making bold claims. Lazslo Barabbas states that networks play a role in the mystery of life, seeming to agree with Kaufmann's view that perhaps networks were present and functioning in cohort from the very beginning of life. Without explicitly stating it, Barabási's work on biological networks also seems to support much that other biologists have postulated about self-organizing properties and emergence in biological organisms. In any case, Barabbas stresses the ubiquity of networks in biological processes, which began with intricate webs of interactions, and are able to articulate millions of molecules within each organism. Similarly, he notes, the enigma of society started with the social network.

While some economists have seen the significance of some aspects of complexity theories, like networks, dynamics have had a hard time entering the mainstream economic discourse, which has long remained remarkably dissociated

from various real world phenomena. Perhaps the current global economic malaise and indeed, considerable collapse, could have been better predicted had economists and other social scientists paid more attention to the many kinds of interacting network dynamics involved in the global economy.

Barabasí noted that in our current globalizing stage of societal development, the unpredictability of economic processes is rooted in "the unknown interaction map behind the marketplace." Therefore, "networks are the prerequisite for describing any complex system, indicating that complexity theory must inevitably stand on the shoulders of network theory."[xxviii] Perhaps it is more important to note that, indeed, *all* of the complexity fundamentals existed since the beginning – the beginning of the molecular soup that became life, and the beginning of the species that became homo sapiens. Indeed, nonlinearity, networks, hierarchy, feedback, emergence and self-organization have likely all been present since or before the birth of life on earth. Perhaps then, it is more accurate to say that complexity theory must inevitably be understood in terms of all of these fundamentals qualities of our living world.

3.2.4. Hierarchy

As I mentioned in Chapter Two, hierarchy in the social sciences became a loaded term. Paul Cilliers referred to this in a reintroduction to Simon Levin's classic 1962 paper, "The Architecture of Complexity," saying the term has been associated with rigid top-down social structures, and with reductionism that utilizes crude top-down pathways to understand social phenomena solely by physical activity at the lower level, lacking social and environmental phenomena and constraints.[xxix] For instance, as biology and genetics have increased exponentially in recent decades, misplaced focus on top-down reductionism in the social sciences has caused errors such as sociobiology and genetic determinism, spurring costly, lengthy debates.

Nevertheless, beneficial, democratic social structures and institutions can also be described in hierarchical terms, devoid of the negative connotations. Indeed, the concept appears to be value-neutral in essence and hierarchies of various kinds are common or universal to most social systems. Therefore, the impasse of this negative connotation must be surpassed. The word should be re-appropriated and imbued with new connotations.

3.2.4.1. Hierarchical Clustering, Hierarchical Modularity

In the above section on networks I explored some of the work by Laszlo Barabasí and others on recent network theory. Barabasí has also worked to highlight the importance of hierarchical structure in many networks. For instance, it turns out that a large number of the networks studied in recent years possess the generic property of what is called ***hierarchical clustering*** or ***hierarchical modularity****,* synonyms for *networks having a modular structure or hierarchical modularity.* Many phenomena exhibit modularity, from natural phenomena such as the cell, to social networks such as institutions, businesses, economies, and political groups. Thus, hierarchical clustering is what occurs when a web made of many highly interlined four-node modules, in turn forms fewer interlinked sixteen-node modules, which are the building blocks of an even looser sixty-four-node module.[xxx]

Hierarchical modularity has various advantages. First, modularity has a strict architecture – numerous small but highly interlinked modules combine in a hierarchical fashion into a few larger, less interlinked modules. Thus, modularity shows that there are no "typical" or "characteristic" modules in either living systems like cells, or social ones like institutional groups cell.[xxxi] Second, hierarchical modularity shows the features of hubs. Hubs maintain communication between modules; small hubs have links to nodes belonging to a few smaller modules; and large hubs act like a state governor, having jurisdiction over many departments and modules, bringing together communities of different sizes and cultures. Moreover, hierarchical modularity has design advantages. It permits parts of a system to evolve separately. In evolution, it allows organisms to experiment separately with individual functions. In institutions, it spurs and buffers disparate branches.

Various challenges illuminate the way for future social network studies. For instance, there is a paradoxical tension between modularity and scale-free structures, which fundamentally questions our understanding of how complex networks are organized. Current network studies reveal that many real networks are clearly scale-free, and appear also to be modular. Modularity is a defining feature of most complex systems. It is departmentalization that allows large companies to create relatively secluded groups of employees who work together to solve specific tasks; the Web is fragmented into heavily interlinked communities, mimicking the same structure in social spheres.

Curiously though, a modular architecture appears to be at odds with everything learned thus far about complex networks. Most networks are scale-free, held together by a few hubs. By virtue of the many links hubs possess, they must be in contact with nodes from numerous modules. Thus, says Barabasí, "Modules cannot be that isolated after all, resulting in a fundamental conflict between the known scale-

free architecture and the modular hypothesis. Current network models fail to resolve this contradiction."[xxxii]

Despite such puzzles, social network studies have yielded practical uses including sustainability models. Contemporary scholars are picking up where complexity founders left off.[xxxiii] Herbert Simon theorized that the relative stability of intermediate levels enables social systems to emerge more quickly through evolutionary processes. A transition to more sustainable technological systems will be facilitated by the promotion of relatively stable intermediate levels of more sustainable techno-institutional systems. For instance, stable mid-levels may promote niches in which radical innovations can occur.

Hierarchical structures also serve the task of portraying the true dynamics of coevolving, intersecting different types of human systems more accurately. Analysis of hierarchical scales helps to reveal the points at which different aspects of social systems coevolve. Several leading scholars in both the areas of ecology and in science and technology studies have increasingly noted the co-evolution of technologies and institutions, e.g. Sheila Jasanoff, Richard Norgaard.

3.2.4.2. Hierarchical Context and Coevolution in Societies, Technologies, and Environments

René Kemp created a framework for understanding how the existing technological and institutional system constrains the evolution of technologies. A three-level framework – technological niches, socio-technical regimes and landscapes. His thesis was that each higher level has a greater degree of stability and resistance to change than the level below due to the interactions and linkages between the elements forming that configuration.[xxxiv] The central level of a socio-technical regime represents the prevailing set of technologies, institutions and their interactions. For example, the rule-set or grammar embedded in a complex of engineering practices, production process technologies, product characteristics, skills and procedures, all of which are embedded in institutions and infrastructures. The higher landscape level represents the broader political, social and cultural values and institutions that form some of the deep structural relations of society.

According to Kemp, whereas the existing regime generates incremental innovation, radical innovations are generated in niches, the lower level.[xxxv] As a regime will usually not be homogeneous, niches occur, providing spaces that are at least partially insulated from 'normal' market selection in the regime, e.g. specialized sectors of the market, or locations where a slightly different rule-set applies. Niches provide locations for learning processes to occur and space to build up the social

networks – that support innovations – such as supply chains and user-producer relationships.

Frank Geels used this three-level framework to examine historical transitions between technological systems. Novelties typically arise in niches, embedded in, but partially isolated from existing regimes and landscapes. This work suggests new thinking about transitions of technological systems with a greater appreciation and application of ideas of hierarchical complexity, developed in ecological complexity and ecological economics.[xxxvi]

The actors and elements of the technological system in power, then, have many reasons strongly to discourage radical changes that would fundamentally alter the system. The development of a fossil-fuel-based energy system and associated abundant supplies of cheap energy to industrialized countries has led to rapid improvements in material affluence. Increasing concerns over the severity of human-induced climate change have led some governments including the United Kingdom and Germany to commit to a transition to a more sustainable, low carbon energy system. This commitment leads to a confrontation with the process of technological and political lock-in that has taken place over the last half-century. Herbert Simon's ideas on bounded rationality and hierarchical complexity are useful to understanding and promoting the transition to a renewable energy society.[xxxvii]

Some policy conclusions drawn from such work include the following managerial aims: (I) stimulate development of sustainable innovation policy regime – brings top appropriate standards of current innovation and environmental policy and regulatory regimes, (ii) apply systems thinking and practice, engaging with the complexity and systemic interactions of innovation systems and policy-making processes, (iii) advance the procedural and institutional basis of the delivery of sustainable innovation policy, (iv) advance the procedural and institutional basis of the delivery of sustainable innovation policy, (v) develop an integrated mix of policy processes, measures and instruments that cohere to promote sustainable innovation, and (vi) incorporate policy learning as an integral part of sustainable innovation policy processes.[xxxviii]

3.2.5. Feedback

Feedback, as discussed in Chapter Two, can be defined as *the signal that a system sends and loops back to receive again, in order for the system to regulate itself.* This *looping back process* is called the ***feedback loop***. In other words, any system that regulates itself has some kind of input and output systems; when the output of the system is fed back into the system as part of its input it is called

feedback. The purpose of feedback is to recognize, adjust and adapt to the dynamic behavior of the system, to itself, or in relation to other systems.

As described by Jean Lugan in Chapter Two, feedback is one of the first stages in the complexification of a system, and in this respect it exists in all kinds of advanced systems, including many physical systems such as weather patterns, all biological systems, and social systems. Examples of feedback are rampant in social systems: interpersonal relationships, organizations, stocks markets, ideas, economics, and computers. In the social sciences, feedback gained agency as a central concept in the field of cybernetics in the 1940s. While this 1940s' phase of cybernetics was immensely influential, bringing about the computer and Internet revolutions, the original field itself remains largely a mystery to mainstream America.

The two major types of feedback discussed in natural systems also apply to social systems. ***Negative feedback*** *tends to maintain status quo in system functioning*, whereas ***positive feedback*** *tends to alter functioning, and can lead the point of tipping a system into another state.* In other words, negative feedback tends to reduce output in order to stabilize system functions, whereas positive feedback usually tends to increase output, or in some cases creates a kind of "bipolar" output that can either increase or decrease output in the short term, but tends towards a greater oscillation of output. This is what produces the annoying high-pitched sound when audio feedback is improperly tuned.

3.2.5.1. Feedback in Cybernetics

Since early discussions of feedback theories there have been debates about how the metaphor plays out in the social arena. George Richardson distinguished between two strands of feedback in the social arena: *cybernetic* and *servomechanistic* feedback. When Warren Weaver defined ***communication*** as *"the means by which one mind may influence another*," the question became: does this definition have optimistic or pessimistic implications for society? Weaver focused on the negative social connotations of feedback, while Richardson described its positive social connotations. For Weaver, cybernetic thinking applied to society lends itself to manipulative models of social control. The mechanistic underpinnings of cybernetics would naturally conflict with humanist social concerns.[xxxix]

On the other hand, Richardson saw what he termed servomechanism as socially positive. He defined ***servomechanism*** as *the process of analyzing potential consequences of different possible interventions in dynamics of systems to ascertain the best courses of action.* He saw servomechanism as inherently antimechanistic and antibehaviorist, with an emphasis on internal, evolving dynamics. Hammond suggests

that this interpretation was perhaps more similar to the humanistic orientation of Ludwig von Bertalanffy's General Systems Theory. Bertalanffy saw this humanistic orientation as providing a starting point for participatory models of decision-making in social systems. In this sense, feedback and information provide critical roles in democratic forms of social organization.

3.2.5.2. Feedback In and Between Societies, Environments, Technologies, and Politics

One socio-ecological feedback debate concerned ecology as an example of systems theory. The work of Eugene and Howard Odum in systems ecology was perceived as furthering the cybernetic side of feedback implications. Social theory and complexity scholar Peter Taylor made two criticisms of the Odums' concepts of social feedback. First, echoing Warren Weaver, he argued that cybernetic theory of feedback mechanisms reinforced a machine view of nature and legitimated the notions of capacity of so-called scientific control of society. "A social feedback system, he wrote, implied the existence of systems scientists under whose controlling hands the system would run for the benefit of the rest of society."[xl] Second, he criticized the reductionism of the Odums' approach, warning that in so aspiring to the theoretical status of the physical sciences, the Odums' were fundamentally distorting our view of less law-like social systems.

In the last two decades these issues have been hashed out in many contexts as feedback became a central concept in many new systems and complexity approaches, in diverse social sectors. As indicated in Chapter Three, finally in the last few years the critical significance of feedbacks in climate change has begun to be acknowledged. However, pushing through sufficient policy for massive, unpredictable positive feedbacks remains one of society's greater challenges.

Another significant aspect of feedback in social systems is how feedback operates in terms of patterns of coevolving phenomena in socio-ecological systems. Coevolution is a concept capturing the transdisciplinary dynamics that are significant in the study of global change. It refers to the way in which feedback occurs in the interactions between many disparate phenomena and activities – ecosystems, species, natural resources, materials, technologies, ideas, organizations, economies, and ideologies – which mutually interact and affect each other as they change over time. In this fashion, cultures affect which environmental features prove fit and environments affect which cultural features prove fit.[xli]

Trajectories of social and institutional behavior are significant to any sustainable policy endeavors. Feedback, like nonlinearity and network structure, is

another way to break down the highly complex puzzle of societal, technological paths, and consider how societies may be more intelligently designed. ***Lock-in*** is one useful term used to study such patterns, coined by the Santa Fe economist Brian Arthur, defining it as *the tendency of the early choice of one technology to favor its dominance over time.* This seems to be an instance of a describing the way that feedbacks are a part of greater nonlinear patterns. That is to say, small decisions can lead to major outcomes. Moreover, feedback plays out in network structures. For instance, one technology choice may dominate in one social network, while another choice dominates in another social network; cars in the U.S. versus bikes in China, up until recent years, for instance. In this case, small decisions on a technology choice can lock a society into a certain techno-institutional systems can play a large role in the development of a society over time.[xlii] The reliance of industrial societies on oil is a striking contemporary example.

The term lock-in was taken by Gregory C. Unruh to examine ***carbon lock-in****, the stronghold of carbon-based energies and others systems in industrial societies*.[xliii] Unruh argues that industrial economies became locked-into fossil fuel-based energy and transportation systems through path dependent processes driven by technological and institutional increasing returns to scale. These technological systems become established through a co-evolutionary process among technological infrastructures, organizations, society and governing institutions, culminating in what was termed a techno-institutional complex (TIC). The concept of carbon lock-in was introduced to illuminate self-reinforcing barriers to change created by TIC that inhibit policy action even in the face of known global climate risk and damage, and the presence of at least cost-neutral, if not cost-effective or quite advantageous technological alternatives.[xliv]

Unruh admits that what he calls his technocentric analysis is just one approach to such a challenging topic as how to alter some of the main systems underpinning today's large industrial societies.[xlv] I suspect that it is useful to frame the search for solutions to our post-carbon economy in terms of such co-evolving feedbacks. The area of coevolution is a potentially highly rich one for the social sciences. It may more usefully even be considered as an entire sub-field of complexity theories, in which many more concepts like lock-in may be discerned. This may help in considering how to best approach the next round of potential technological lock-ins, as we contemplate energy alternatives. Better understanding of the potential boons and banes of coevolution and lock-in may help us to address questions such as: how to create long-term solutions to more sustainable societies, and how to set up systemic win-win solutions in the next round of large-scale social and environmental organization for what most hope will remain energy-intensive societies.[xlvi]

The positive feedbacks of increasing returns both to the high carbon technologies and to their supporting institutions, including rules, ways of thinking and

incentives, has created rapid expansion in the development of this carbon-based social system, so that it now incorporates massive technological infrastructures and a small number of powerful actors such as producing firms and rich nations.[xlvii] The actors and elements of this carbon-based social system came to depend on this system's oil supply for their livelihoods.

Actors often filter information in conformity with such strong dependencies, which in turn contribute to developing their personal identity, political bent and ideological ideas and biases. Politicians act in cohort and response to such actors, their views, and their economic needs. This creates a co-evolving tie between industry and government. In countries such as the United States, such ties and the rigidity with which they promote certain industries and technologies at the expense of others is compounded by further ties, at times mutually beneficial, but usually more or less manipulative, transparent, and legal. These ties can include media monopolies, advertising, lobbying groups, and even propaganda campaigns, all aimed at promoting one or another technology in the interest of massive profits and aggrandizement for the leading actors of these groups. As these links are tightened over time, amounts of money at stake tend to grow, and along with that money, political persuasion and manipulation campaigns. Seeing feedbacks in socio-natural systems in terms of co-evolving systems may be a useful concept with which to untangle and understand the forces that undermine the elusive goals of democracy and freedom.

Changes in business management have interpreted the term feedback in both positive and negative ways in different contexts. For the most part, however, the positive connotation of democratic process has been dominant in the business literature, widely adopted through the work of the 'soft systems' tradition, as in the work of Russell Ackoff, Stafford Beer, and Peter Checkland.[xlviii]

3.2.6. Emergence

In contrast to nonlinearity, networks, and feedback, in the case of emergence there seems to be a more substantial difference between the natural science definition and the social science one. Recall that emergence is defined in the natural sciences, as "the process by which relatively simple rules lead to complex pattern formation."[xlix] In social systems, ***emergence*** is defined as "*the processes whereby the global behavior of a system results from the actions and interactions of agents*."[l]

Throughout these three chapters directed at complexity in social systems – social science, social theory, and transdisciplinary social systems research, one faces a difficult challenge. On the one hand, there are sufficient distinctions to merit

analyzing them separately. On the other hand, ultimately the definition and understanding of some of the complexity fundamentals may require a re-synthesis between these areas. Amongst all of the complexity fundamentals, this difficulty seems especially poignant in the case of the last two cases, emergence and self-organization.

Certainly, the nature of these two phenomena or should one say categories of phenomena, remain an open question in all of the fields discussed throughout these three chapters, Chapters Four, Five and Six. This encompasses a vast range of academic fields, including: social sciences, social theory, transdisciplinary perspectives, and notably the philosophy of science, which I have included at the end of Chapter Six. Moreover, there is a veritable Renaissance of emergence studies in philosophy. Edgar Morin offered over two dozen different definitions of emergence in his book *Method*.

Furthermore, it seems that emergence and self-organization are the most difficult to define of all of the complexity fundamentals. They two seem to be very closely linked. There is a sense of chicken and egg question between the processes of self-organization and emergence. It does not seem easy to clearly distinguish, for instance, whether emergence occurs through self-organization or vice versa.

Therefore, in the attempt to define emergence and self-organization in social systems, significant challenge arises in at least three ways: 1) the definition of emergence across the broad swath of disciplines treating social systems, 2) the definition of self-organization across this same broad swath of disciplines, 3) the relationship between emergence and self-organization. In fact, there may be inextricable overlap in the true nature of these realms, in some areas. Surely, this is a subject that merits much more attention than I could give here.

Perhaps it will help to make a few key distinctions which will carry through these three chapters. Emergence One (E1) refers to the extension of a pre-existing phenomenon. For instance, cells continue to reproduce identical or replacement cells in plants or animals. In social systems, people renew and thus maintain such social phenomena as language, tools, or customs.

Emergence Two (E2) is novelty; something new occurs. In the nature sciences an example is the growth that occurs in stem cells. Embryonic stem cells found in most, if not all, multi-cellular organisms, are characterized by the ability to renew themselves through mitotic cell division and *to differentiate into a diverse range of specialized cell types.* In social systems, I give several examples in the text that follows: one example is the invention of a new tool or technology, e.g. the wheel, the motor, or the printing press.

Emergence Three (E3) may be used to refer to what occurs when E2 events undergo coevolving processes that create an escalation effect, resulting in numerous

and compounding instances of emergence. A new technology may permit rapid transformation of some natural landscape, leading to other instances of natural and social emergences. Human lifestyle can be greatly impacted, leading to further emergences. A major example is the advent of agriculture, described in what follows.

3.2.6.1. Examples of Emergence in Social Systems

Examples in social systems include creation of new social groups and movements; patterns of group movements like panicking crowds and traffic jams; development of new social patterns or behaviors, traffic jams; and the evolution over time of words, symbols, and meanings in a language. Historians of language have documented that languages have changed frequently throughout history, with vocabulary and even grammar changing radically over the centuries.[li] In the social system the lower level consists of the individual speakers' interactions and the individual conversations, and the higher level is the collective social fact of language as a group property.

Emergence is a central theme for most all of the major complexologists. Kurt Richardson and colleagues named their interdisciplinary complexity journal *Emergence = Coherence + Organization;* Edgar Morin explained the importance of emergence and self-organization in his early volumes on complexity theories in the 1970s and 1980s. In the 1990s, anthropologist Stephen Lansing noted the importance of emergence in natural and social patterns in the long-term sustainable water and agricultural systems in Indonesia. In a subsequent work, he added the importance of feedback to these patterns in sustainable agro-ecosystems in Bali.[lii]

Common to these examples is the observation that emerging at the global system level are patterns, structures, or properties that cannot be explained in terms of systems' components and their interactions.[liii, liv] According to some scholars, properties are emergent when they are unpredictable, or we could say unpredictable phenomena stem from emergent properties. In other accounts, system properties are said to be emergent when they are irreducible in any lawful and regular fashion to properties of the system components.[lv] What these scholars agree upon is that complex systems may have autonomous laws and properties at the global level that cannot be easily reduced to lower-level, more basic sciences.[lvi] In this, Sawyer sees the implication so commonly evoked and yet so often misunderstood, is the way in which emergence contradicts some of the foundational tenets of classical science. This is one example of evidence that the complexity reveals something significant about reductionism, a subject I turn to at the end of Chapter Six, on the philosophy of science.

Several natural scientists associated with the Santa Fe Institute have looked at emergence in both natural and social systems. In Chapter Two I described broad views of emergence shared by Stuart Kaufmann and Howard Morowitz. Here I expand upon his description of emergence in social systems. According to both Morowitz emergence occurs in every kind of system. A human being possesses the emergence proper to the hyper-complex cerebral system of an evolved primate. Society cannot be understood as a sum of individuals; rather, society constitutes an entity endowed with specific qualities. Discourse is not just an ensemble of words, but possesses the emergent property of meaning. Developed ideas are deployed into larger global ideas, which then are used when reflection retroacts on the basic unities have made them emerge (the initial ideas). In short, life emerged whole and has been whole ever since.

3.2.6.2. The Nature of Social Emergence

If the elaborate burials of the Neolithic humans showed signs of spirituality and self-awareness, the first proof of philosophy comes with the Ancient Greeks and then again in modern societies. Morowitz calls philosophy "the ultimate emergence of social humanness."[lvii] With philosophy there was a closing of the spiral of the history of social emergences, in that philosophers reflect back on all other instances of emergence. Philosophers think about big bangs, protons and all the other hierarchies connected by emergent phenomena. The emerging world turns inward and thinks about itself. As George Wald said, "a physicist is the atom's way of thinking about atoms."[lviii] With philosophy and the development of human knowledge we invented a new type of emergence, thinking, giving a new depth to the interconnections between different kinds of social emergence, and providing a source of reflection on all these emergences. Through reflective thinking, we went through a kind of transcendence, developing a new degree to volition and free will. We will return to such reflections upon reflections later, when we discuss transdisciplinary views on emergence.

The parameters within which emergence emerges remain constant from natural to social phenomena; emergence occurs in systems in which: (1) many components interact in densely connected networks, (2) global system functions cannot be localized by any one subset of components but rather are distributed throughout the entire system, (3) the overall system cannot be decomposed into subsystems and these into smaller sub-subsystems in any meaningful fashion, and (4) the components interact using a complex and sophisticated language. Not all complex systems have all of these features (e.g. interaction between birds in a flock involves

very simple rules), but it manifests emergence because of the large number of birds.

Conversely, complex musical communication among the four musicians in a jazz group leads to emergent properties, even though there are only four participants, says Sawyer. I extrapolate that perhaps this is due to the high number of potential combinations of notes, tones, styles, and rhythms by the musicians, just as, despite the simple rules of flock formation, there is relatively large number of birds per flock.

These properties of emergence – many components, dense networks, nonlocalization of global system functions, non-decomposability into subsystems, and sophistication of medium of exchange – are found in social systems, according to Sawyer, "perhaps to an even greater extent than in natural systems."[lix] Moreover, these properties are interrelated in most complex systems. Social systems with a densely connected network are less likely to be decomposable or localizable. Network density is progressively greater as communication and transport technology has increased the number and frequency of network connections among people.

Some complexity theorists claim that this is a cause of "swarm intelligence."[lx] Sawyer traces the concept of swarm intelligence back to Emile Durkheim, who called it "dynamic density." Generally, Sawyer argues that Durkheim was the first social emergence theorist, and that "contemporary complexity theory sheds new light on several poorly understood aspects of Durkheim's writings."[lxi] Of course, as I mentioned, Sawyer did clarify that Durkheim was one in a long line of social emergence theorists dating back in writing to Heraclitus, and no doubt orally beyond.

Sawyer distinguishes six waves of social emergence theory. First would be intimations of emergence in ancient writings, such as the fragments of Heraclitus, an early champion of complexity. Second were the early modern sociologists. According to Sawyer, Durkheim is the first "social emergence theorist." Durkheim worked on "dynamic density," for instance, the equivalent of today's "swarm intelligence".[lxii] Other visionaries of emergence include Auguste Compte, (1842), Emile Durkheim ([1895] 1964), William James (1890), and English philosopher George Henry Lewes (1875), several German social organicists, and psychologists such as Wundt and Gestalt.[lxiii] At this point the reader may ask how I include a thinker like Compte in both the anti-complexity and pro-complexity camps. In fact, Compte was both. In some ways he eschewed complexity, while in other ways he attempted to embrace and explain it.

Not only can one thinker be engaged in both non-complexity and complexity research. Indeed, academia is replete with simplifying forces – singular disciplines, dominant methodologies, pressure to constrain research within certain limited boundaries, and the like. Academic rewards go much more to those who obey the norms and constrictions. In fact, many if not most researchers struggle to some extent

with issues of boundaries. What is missing is the explicit and systematic understanding of the connections between various areas of complexity research.

3.2.6.3. Tools

The use of tools is a striking example of emergence in social behavior. For instance, humans invented the wheel, and chimpanzees learned to carry large stones several meters to crack open nuts, clearly demonstrating anthropoid tool use.[lxiv] Just as novelty may emerge on multiple disparate occasions in natural systems, so may they in social systems. Moreover, recent ethological studies have demonstrated that it is incorrect to associate tools solely with humans and our chimpanzee ancestors; tool use occurs in many different species. Herons drop small pieces of twigs to attract minnows, which they then swoop down to eat. Could it be that humans learned their fishing method first from birds? Other birds and many insects use sophisticated techniques to acquire and transport materials to build nests. While beavers build dams, plug water leaks, and make holes to lower water levels.

For humans, tool making began over two million years ago and continued up to the present. About 2.5 million years ago, Homo sapiens and homo neanderthalensis both engaged in simple tool making. Homo sapiens began to advance faster, engaging in stone working, making tools from bone and antler, making musical and artistic instruments, and conducting elaborate burials – indicating belief in spirituality, greater self-awareness and a higher degree of social organization. With the emergence of modern cognition came the advent of symbolic thought.

3.2.6.4. E3: Multiple, Codeveloping Emergent Capabilities and Social Progress

Strikingly, in the history of emergence of human behavior, several major types of emergence came into play together, not in a linear series, but in a co-evolving array of advancing social capacities and organization – tool-making, language, agriculture and social organization – all developed in interrelation. With Homo sapiens, social activities became highly complex. Man is not just a thinking animal, but an animal that forms constructs to explain the observed world. The mental feature of explaining the surrounding world became central in tool-making.

Morowitz describes the meta-history of technology and urbanization throughout human history. Technology began with tool-making, with Homo habilis living in East Africa and chipping stone rocks, the Paleolithic or Old Stone Age, from

two million to 10,000 years ago. Over this long stretch of time, technological advance came slowly to small groups of hunter-gatherers.

A large leap forward began 10,000 years ago (give or take a few thousand years in different parts of the world), involving a triple transition: from the Pleistocene to the Holocene, from hunter-gathering to farming, and from the Paleolithic to the Neolithic Age. These three emergences seem to be interrelated. Better tools may have made tilling the soil easier, aiding agriculture. Social relations of settled communities may have provided the circumstances to develop new tools and new technologies. Suddenly there were coevolving armies, police unites, religious institutions, priestly classes, colleges, medicine, engineering, astronomy, monuments, and large engineering projects. Biological emergence had led to massive social emergences.

Most of the early technologies in the Neolithic Age were mechanical. Several major changes took place in the second millennium A.C.E. In 1200 humans invented explosive powder. In 1045 Bi Sheng in China invented the first movable type. In 1440 Johannes Gutenberg in Germany devised the first printing press. From the 1600 through the 1700s scientists were laying the foundations of electromagnetic discoveries. Some of these may have been made much earlier in other societies. For instance, the first battery is attributed to scientists in Iraq in 250 B.C.E., which resembles a galvanic cell and is believed by some to have been used for electroplating. It is called the Baghdad Battery. Benjamin Franklin made observations that aided later scientists such as Michael Faraday, Alessandro Volta, André-Marie Ampère and George Simon Ohm, founders who were honored by naming the fundamental unites of electrical measurement after them. In 1800 Volta constructed the first device with a large electric current, the electric battery. From 1850 onwards there was an avalanche of technologies, including the motor, the steam engine, mass printing systems, and other major industrial machines.

3.2.7. Self-organization

Like emergence, self-organization remains an elusive and challenging complexity fundamental. For some, either emergence or self-organization or both seems to speak to the essence, certainly the least explained, most ubiquitous feature of complex systems.

As noted in Chapter Two, the general transdisciplinary term ***self-organization*** is defined as *the spontaneous often seemingly purposeful formation of spatial, temporal, spatio-temporal structures or functions in systems composed of few or many components.* The process of self-organization can be found in many fields, seemingly in all complex systems, e.g. physics, economy, sociology, medicine, technology.[lxv]

Also noted in Chapter Two, self-organizational processes are highly significant to complex systems: "We know today that everything that ancient physics conceived as simple element is organization. The atom is organization; the molecule is organization; the star is organization; society is organization. But we know nothing at all of the meaning of this term: organization."[lxvi] When Morin says that an atom *is* organization, he provokes us to accept the difficulty of the concept he is reaching for. By saying the molecule, star and society each is organization, he also refers to self-organization, as these entities are changing over time via self-organizing principles. By calling an object a process, Morin underscores the need to reverse the incorrect but strongly entrenched Western lens with which we tend to see processes as objects. Thus, in a significant sense, "things" are "organization."

In the natural sciences, self-organization and emergence are arguably among the harder problems, one that scientists only rarely turn to, once their career is already soundly established, or they received a Nobel early in their careers. For instance, in his classic *Chance and Necessity*, Jacques Monod said that self-organization is one of the hardest problems in biology. According to the broad view, self-organization, more than any of the other complexity fundamentals, gets at the heart of complexity and of life itself.

If Kaufmann is correct about the complex dynamics occurring at the origin of life, perhaps self-organization was the driving force. Though focusing on the term emergence, Stewart Kaufmann wrote additionally about the closely conjoined notion of self-organization. Kaufmann's broader thesis is that through the new sciences of complexity we may find our place anew in the universe, we may recover our sense of worth, our sense of the sacred and perhaps of meaning. Order is not merely tinkered, but arises naturally and spontaneously because of fundamentals of emergence and self-organization – what he calls the "laws of complexity" – that we are just beginning to uncover and understand. The past three centuries of science have been

reductionist – attempting to break complex systems into simple parts. But to understand the whole we must understand more than these parts, but also the collective properties, the emergent features in their own right.

What Kaufmann calls the laws of complexity, I might call more broadly the complexity fundamentals. Whatever the moniker, these complexity fundamentals appear to generate much of the order found in the realms of nature and meaning, as well as disorder. Spiders make a pre-nylon web, gnats swarm in cohort, and many natural objects develop not just functionally but in aesthetic correlation – shells, leaves, and waves. Biological evolution may be a deeply historical process as Darwin said, but at the same time bound by rules and patterns.

Patterns of speciation and extinction avalanching across ecosystems and time are somehow, (1) self-organized, (2) collective emergent phenomena, and (3) natural expressions of the laws of complexity we seek. These laws of biological evolution may also offer a new and unifying intellectual underpinning for social aspects of our lives – economic, cultural, and social. Similar small and large avalanches of change occur in social systems.

One must ask if it is truly intelligible to make links between such disparate phenomena. In one sense, all these phenomena fall loosely under labels of self-organization stemming from processes of emergence, as indicated by Harold Morowitz. It seems to me that there may be abstract generalities necessary to understanding systems dynamics, which form an ensemble of interdisciplinary processes, by which self-organization is the best term to describe that which is shared in the processes that create and maintain systems stemming from the universe to the diverse life within it.

Some have critiqued this view. The biologist, complexity theorist, and philosopher Henri Atlan analyzed self-organization within the biological and physical sciences. Additionally, he critiques the view of self-organization put forward by Kaufmann and Morowitz. Atlan takes as starting point theories of self-organization as developed in the cognitive sciences, which make liberal use of cellular automata that are applied to diverse systems from molecules to organisms to ideas, and construe self-organization as a broad umbrella term.

Atlan questions the breadth of this usage, taking place under the auspices of "evolutionary epistemology," and claiming neo-Darwinism as a unique paradigm that would explain: the complexification of matter since the Big Bang, the evolution of species, the apparition of humans, and the emergence of thinking, of consciousness, or scientific knowledge and of the theory of evolution itself. On the one hand, he agrees that there is some substance to this view.

On the other hand, Atlan argues, the global theoretical notion of self-organization is also a trap, pointing to pitfalls regarding their interpretation.[lxvii]

Folding all of self-organization under the theory of neo-Darwinism stems from the need to unify, at any price, our reason. This trap ignores the irreducible specificities between different levels of organization, which confuses the identity of formal models with those of processes that obey different constraints and follow different concrete substrates. What is remarkable, says Atlan, is that by falling into this trap one is led back to what he refers to as "strong reductionism." One can take two symmetrical forms as false one from the other. One error is reductionism of the psychic or physics. Another error is the inverse, the reductionism of biology to the psychic by way of the cognitive. The process of self-organization of matter would be in some sense a cognitive process. This inverse reductionism, despite its appearances and the normalizing jargon referring to Darwin or Lorenz, he says, is actually quite distortional, a kind of neo-vitalism.

At the risk of sounding too vague or apologetic for the complexity fundamentals, I would say that such controversy would not undermine what I have discussed here to be significant organizing principles provided by these fields of research: feedback, emergence and self-organization. I argue that serious attempts to confront complexity and transdisciplinarity in the wake of greater scholarly capacities, e.g. computing and word-processing technologies that allow single researchers to achieve greater transdisciplinary breadth and depth, have only just begun. Time and much hard work may yield more satisfying analyses of some of the core, most complex concepts, such as self-organization.

3.3. Remarks on the seven principles as they apply in social systems

Summing up this section, Table 3.x outlines the major areas of complexity research and their lead proponents in the social sciences:

Complexity aspects	Social science scholars
Complex adaptive systems	Yaneer Bar-Yam, T. Takaki, C.S. Holling, Lance Gunderson
Emergence	Kurt Richardson, Kevin Johnson
Feedback	Debora Hammond, Fritjof Capra, Timothy Allen
Hierarchy	Timothy Allen, Simon Levin, Yaneer Bar-Yam
Network	Mark Newman, Albert Laszlo Barabbas
Nonlinear Dynamics	Mark Granovetter, C.S. Holling, Lance Gunderson
Self-organization = order ←→disorder	Henri Atlan, Yves Barel, Jean-Pierre Dupuy, Pierre Livet

Table 3.5. Complexity Fundamentals and Major Thinkers

With respect to complexity fundamentals, both substantive similarities and differences arise between how they function in the natural sciences and in the social sciences. Generally, in the social sphere as opposed to the natural world, complexity becomes vastly more complex. The human brain is the most complex singular entity that has been discovered in the natural world. Moreover, the ensemble of the world's computers may have already surpassed the human brain in complexity, or will likely do so soon. The complexity of vast modern industrialized societies – comprising both the natural and social spheres together – dwarfs that of many of natural systems alone. Further, there are qualitative differences between complexity that can be modeled and predicted in certain ways in mathematics and the natural sciences, as compared to "unruly complexity" of the unmanageable, hardly imaginable complexity of our social worlds. Though ironically, in our incapacity to live lightly, the growth of human societies is currently causing a massive loss of biodiversity, the complex flesh of the natural world.

In tackling this, in analyzing the vast complexities of socio-natural systems, one quickly runs into Morin's obstacles: incalculability of too many variables evolving too quickly too fast to be captured and known, never-mind fully understood.

Nonetheless, complexity's challenge renders it no less significant and irresistible for the study of social systems and today's extraordinarily complex global change. Though it may appear merely tautological, it is significant that complex systems are defined in part by their complexity and thus social systems by their extraordinary complexity. Complexity theories aid in explaining how consciousness

appears to emerge from the natural world as an attribute of living beings. This would seem to aid in moving beyond framings that are dualistic, atomistic, or socially alienating, and thus help in conceptualizing future society as both more ecologically sound and more humane. Moreover, the hallmarks of contemporary societies that we have been discovering throughout the last century – interconnection, uncertainty, unknowability, unpredictability, unexpected consequences, and network causality – all appear to be most directly understood with respect to the study of complex systems.

Complexity was evident or inescapable in the social sciences long before the appearance of a true field developed in the social sciences. Emile Durkheim saw the importance of emergence in the 1800s. Yet, at that time natural scientists held to a strict view of reductionism, and imposed this across all the disciplines. As a result, social theorists such as Durkheim had to expend considerable energy merely in defending his broad conceptual lens. Those social scientists that have focused on whole systems have always faced the difficult task of ontologically grounding their antireductionism, said Sawyer. This meant various intensive expenditures for the holists over time. Social scientists developed dualist ontologies in an effort to account for their holist theories, leading to the unfruitful paths of vitalism, dualism, spiritualism and idealism, which they then eventually refuted. It was not until complexity theories developed that we have a resolution for these previous problems. For instance, emergentism provides a form of nonreductionism that accepts the ontological position of materialism.[lxviii]

It is likewise clear that complexity in the social sphere is a vast subject; the more we understand social complexity and its implications, the more it seems to extend far beyond our analysis. Yet, in the last half century tremendous progress has been made in clarifying some of the main aspects of the complexity of social phenomena and its implications.

3.4. Conclusion

In this chapter I argued that complexity theories provide a missing framework for understanding many developments and concerns in the social sciences in recent years. It became obvious that disparate analyses in the social sciences in the last few decades have some intriguing commonalities.

Social complexity does not seem to fit well into natural science categories, reductive categories, and formal analytical or mathematical methods. Articulating the work in the realm of social sciences because of the questions they address affect the social sphere. Scholars in diverse fields are expanding old concepts and methods, and formulating new ones, in ways that "escape the drawback of (classical, purely rationalistic) analytical approaches."[lxix] Moreover, in ways that can start to better capture key aspects of complexity in the social sphere: uncertainty and unknowability; multidimensionality; continuous change due to emergence; dynamics with the potential for both collapse and resilience; and the tools we use under these uncertain circumstances for making decisions and value judgments. One outcome of these implications of complexity in the social sphere is the emerging consensus that to conduct human affairs in ways that lead to resilience rather than collapse, that lead to sustainability, we need to use lenses and methodologies that highlight plurality and multidimensionality, matching the polysemous nature of our world and our social dynamics.

I have approached these revolutionary changes in the social sciences from three angles. First, I considered the complexity ontological fundamentals, as I did for the natural sciences: complex systems, nonlinearity, networks, hierarchy, feedback, emergence, and self-organization. This exploration reveals some of the great fascination of complexity studies: these same principles are ubiquitous through systems that are otherwise qualitatively very different. Thus, the fundamentals themselves manifest in ways that are at once similar (enough to be called by the same terms – complex systems, nonlinear, networks, etc.), and yet maintain substantial qualitative differences. We will see these principles once again as we explore the topics of transdisciplinary and the philosophy of complexity.

Next I examined methodological and disciplinary approaches to complexity in the social sphere. This vast section only scratched the surface of a rapidly proliferating set of concepts, methods, viewpoints and theories regarding complexity inherent to social dynamics. Yet, straight away it becomes obvious how widely this realm expands as we shift our gaze from the natural to the social sciences.

Finally, I began the exploration of what seems to be complexity's greatest implications – unpredictability, uncertainty, and unknowability – central themes to complexity studies, which I develop further in the following chapters.

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Chapter Four. Complexity Theories and Social Theory

4.0. Introduction

Complexity theories have also been taken up in the more theoretical realm of social systems research. The three theses I explore here discuss the topics of postmodernity, risk, and collapse, and are by the authors Bruno Latour, Ulrich Beck, and Jared Diamond.

I argue that each of these three theses is significant and influential due to the complexity fundamentals. In each case, the main argument is based upon one of the main complexity epistemological fundamentals (CEF), also drawing in and relying upon the complexity ontological fundamentals (COF). In my analysis, I will focus upon the complexity fundamental that I perceive to provide the major support to the author's thesis, and then discuss the set of secondary complexity fundamentals that explain and develop the thesis. The main and secondary complexity fundamentals utilized in each book are summarized here:

Author	**Theory**	**Main complexity fundamental**	**Secondary complexity fundamentals**
Bruno Latour (1996)	We Have Never Been Modern	Axes I: Classical vs. complexity sciences and theories	Uncertainty, incommensurability, networks, hybrids
Ulrich Beck (1992)	Risk Society: Toward a New Modernity	COF II: Risk	Vulnerability, unintended consequences
Jared Diamond (2000)	Collapse: How Societies Choose to Fail or Succeed	COF II: Collapse	Vulnerability, resilience, unintended consequences

Table 4.1. Three Theses in Social Theory and the Main and Secondary Complexity Fundamentals Supporting these Theories

This argument aims to support my overall dissertation claim: the complexity conceptual framework is significant, and acknowledging this is beneficial for addressing climate change and other major issues of global environmental change. The three theses described here serve as interpretive lenses for the recent use and utility of complexity in socio-ecological spheres. In each case, the links between the fundamentals in the theory, and between these three theories, is as significant as the

main argument being made. While the complexity framework embedded in these theories remains almost entirely implicit, I argue that it is valuable to render it explicit, helping to highlight the development of the generalized complexity framework in social theory.

Complexity theories reveal something deeply significant about social theory. A large body of work has grown up around the seven COF I in social theory. Much of this work is quite promising, however it remains somewhat inchoate, dispersed, inexplicit, and a bit less relevant to the case study of this dissertation. What becomes highlighted in the realm of social theory is that the theoretical methodology is favorable to the rendering of the generalized complexity framework in its coherent ensemble. In other words, while it appears laborious if not impossible to provide adequate descriptions of the interactions of all of the realms of the GCF in the natural and social sciences, in the realm of social theory this appears to be more accessible. For this reason I have chosen to focus more in this chapter on the way that a few social theories have developed in the last two decades that have taken up the complexity fundamentals in a broader, more comprehensive, more interrelated fashion, which is also more reflective of real world issues, and more applied in both content and goal.

4.1. Beyond the modernity that never happened – Bruno Latour

In *We Have Never Been Modern* (1996), Bruno Latour suggests that society has entered a "non-modern phase," in which we have become aware of the failures of modernity. In fact, the myth of modernity is breaking down, and we are realizing that our past notion of modernity was illusory, and in fact, "we have never been modern." Latour focuses on rectifying two false premises of modernity: that reality collapses into one kind of realm, the physical, and thus that nature and culture are distinct and can only be approached as separate entities.

More specifically, the term modern designates two sets of different practices that must remain distinct if they are to remain effective, but have become confused. The first set of practices is the biophysical practice of altering natural forms, the creation of new hybrids through the processes of science and technology production. The second set of practices creates distinct ontological zones and thus 'purifies' the real world. Two important zones thus purified by practices of mind and management are nature and culture. The first set involves hybrids and networks, the actual intricacies of the natural world that explain how change is really occurring, at local or global scales. The second set involves the way we think about this world, an abstract, purifying process.

The second process – the false purification of the real networks of the world – has made the first process possible. The more we purify and imagine an order that is not there, the more impurity and disorder we set loose. In other terms, the more we ignore networks and imagine them into neat categories, the more we create hybrids, and complexify networks.

Latour navigates the tricky waters of distinguishing between natural and human-induced increase in earth and social systems complexification and simplification. He speaks to general and systemic problems with the modern vision, thus illuminating a broad spectrum of the ideas presented by complexity theories. Most broadly, Latour's two processes can be defined in terms of the classical science worldview versus the complexity worldview. The first process represents the way that complexity theories explain reality, with the true principles of incongruence, uncertainty, and incommensurability. The second process represents the way modernity construed reality – presupposing atomism, linearity, and universalism, and layering on false assumptions about certainty, congruency, and commensurability.

Latour covers some similar points as Beck, e.g. parallels between risks and hybrids, the tipping point from wealth production to risk production and the tipping point from illusory modernism and confusions over post-modernism. Similarly, a link between Beck's quest to find the meaning of 'post' and Latour's quest to find the meaning of modernity; and between Beck's 'reflexive modernity' and Latour's attempt to use network interactions and dynamics to overcome the analytical paralysis that remains after a delusional modernity.

Breaking down Latour's main concepts, we find complexity at the heart of each one: hybrids, immutable mobiles, incommensurabilities, the Gordian knot, and the very term modernity. Next, we can examine Latour's definitions and my reframing for each of these terms in turn.

Latour defines ***hybrids*** as *new types of being that are part nature and part culture*. I would frame this within the concepts of c*oevolution, emergence* and *self-organization*, to explain the relationship between classical thinking and dualistic thinking, and to explain in more detail how and why modern simplifications have so misconstrued the interrelationships of nature and culture. It is not so much that classical science was incorrect about nature or culture, legitimized faulty dualistic thinking, or misunderstood nature and culture. Rather, classical thinking, with its focus on atomism, reductionism and universalism, tended to omit, overlook, and thus also negate the significance of continuous and critical processes of interrelationships and coevolution.

The term *immutable mobile*, refers to the conjunction of two classical science moves, *reductionism* and *universalism*. In the creation of an ***immutable mobile***, *a model or experiment is reified in one context, replicated only in that context, and then*

transferred for use across highly heterogeneous social and ecological lines – across cultures, norms, and environments. In this way, classical science falsely projected truths obtained from the parameters of a model or experiment within one context to another one. Laboratory science proceeded as a self-legitimizing phenomenon, reified as law and treated as a tool with which to manipulate and dominate across time and space, and across socio-economic and cultural borders. Frequently, this flawed interpretation was transferred from wealthy nations to poor ones, at the expense of the latter.

Latour first defined immutable mobiles in his 1987 book *Science in Action,* where he says that Tycho Brahe, through his scientific experiments, reversed the notion of what counts as *center* and what counts as *periphery*. Brahe worked from a well-equipped observatory writing down the positions of the planets, gathering sightings made by other astronomers, and becoming master of a virtuous cumulative circle that unfolds as the different places and times are gathered together and synoptically displayed. Through assembling these observations of previously disparate points in space-time into one synthetic meta-observation, Brahe created a correct model of planetary positions and relations. Brahe was thus, "the first to sit at the beginning and at the end of a long network that generates what I will call immutable and combinable mobiles."[i] A scientist in a center of observation and calculation was then endowed with the extraordinary power of creating immutable mobiles that draw from and act at a distance.[ii]

Latour also uses the term incommensurabilities. ***Incommensurabilities*** means what it sounds like: *things that cannot be compared or commensurated, or incongruent things.* Latour sees incommensurabilities as one of the products of casting a modernizing (simplifying) gaze on the natural (complexifying) world. One scholar boiled down Latour's entire oeuvre to the study of the "hyper-incommensurability of postmoderns."[iii] Latour describes incommensurability in this excerpt:

> The same article mixes together chemical reactions and political reactions. A single thread links the most esoteric sciences and the most sordid politics, the most distant sky and some factory in the Lyon suburbs, dangers on a global scale and the impending local elections or the next board meeting. The horizons, the stakes, the time frames, the actors – none of these is commensurable, yet there they are, caught up in the same story.[iv]

Placing Latour's ideas within the greater complexity framework highlights significant relationships between related or consequent concepts. One group of related concepts relates to the complexity epistemological fundamental – risk. Synonyms for risk and terms closely related to risk include: the environmental term *environmental externalities*, the medical terms *side-effects* and *unintended consequences*, the military term *collateral damage*, and what we call in common parlance, *risks* or *repercussions*. Contemporary parallels include: the incommensurable aspects of a complex system Timothy Allen outlines with respect to the axes of hierarchy and scale, and the focus on *unintended* and *irreversible consequences* that have become a focus in the wake of the convergence of multiple forces of environmental degradation, such as desertification, pollution, development, and global warming.

Finally, Latour describes the "Gordian knot" as the impasse between realism and constructivism.

> Whatever label we use, we are always attempting to retie the Gordian knot by crisscrossing, as often as we have to, the divide that separates exact knowledge and the exercise of power – let us say nature and culture. Hybrids ourselves, installed lopsidedly within scientific institutions, half engineers and half philosophers … without having sought the role, we have chosen to follow the imbroglios wherever they take us. To shuttle back and forth we rely on the notion of translation, or network. More supple than the notion of system, more historical than the notion of structure, more empirical than the notion of complexity, the idea of network is the Adriane's thread of these interwoven stories.
>
> Yet our work remains incomprehensible, because it is segmented into three components corresponding to our critics' habitual categories. They turn it into nature, politics or discourse. Yet this research does not deal with nature or knowledge, with things-in-themselves, but with the way all these things are tied to our collectives and to subjects. We are talking not about instrumental thought but about the very substance of our societies.[v]

In complexity terms, the Gordian knot might be seen as that which we get into because in our scientific views and institutional structures we have not developed ways of adjusting to our world as a set of interlocked, complex, dynamic systems. I

would contest Latour's differentiation of network and complexity as more and less empirical, a minor point.

I will restate some of the above points and their implications. Latour debunks the proposed opposition between ***realism*** or *the view that the facts of science exist independently of us* and ***constructionism*** or *the view that scientific entities are socially influenced or created.* Latour says that both parties in this war share the fallacy that *real* and *constructed* are opposites or are mutually exclusive in some way. In fact, *real* and *constructed* are naturally interrelated facets of the real world. I would add that real and constructed are the two sides of what complexologists call the process of emergence and organization – variably referred to in terms of feedback, recursivity, tetralogical loop, panarchic loop, etc. – by which the real is reconstructed and the reconstructed becomes real. The process by which, in complex systems terms, entities evolve through continuous self-organization, interrelation, and emergence, to maintain certain qualities over time, while continuously rejuvenating and renovating them.

In social network analysis it appears that what I refer to as a typology of knowledge realms – material (or mechanical), biological (or living), social (or cultural), meaning (or noology), and virtual – is indeed significant. These differences are in part explained and framed by emergence and hierarchy theories. As Harold Morowitz' timeline of biospheric emergence showed, the four or more realms of reality emerged in that order – first the material earth was formed, then biological life came into being, followed by consciousness and thinking, meaning, and finally the creation of virtual realms.

In an interesting twist, Bruno Latour argues that part of network analysis can be the acknowledgement of the lens that different social scholars use in analyzing their study systems. Latour alludes to three scholars who exemplify three realms of knowledge, in this case focusing on the material, social and meaning via analogous concepts the "naturalized, sociologized and deconstructed."[vi] The scholars he mentions with regards to these are, respectively, E.O. Wilson, Pierre Bourdieu, and Jacques Derrida, "emblematic figures" of these three approaches to environmental knowledge. When E.O. Wilson speaks of naturalized phenomena, societies, subjects and all forms of discourse vanish. When Bourdieu speaks of fields of power, then science, technology, texts and the contents of activities disappear. And when Derrida speaks of truth effects, then to believe in the real existence of brain neurons or power plays would betray enormous naiveté. Each of these forms of criticism is powerful in itself; yet it is discussed in isolation.

Latour feigns horror at a hypothetical study that would treat the ozone hole as at once naturalized, sociologized and deconstructed. Such a study might be firmly empirically established, with predictable power struggles, "but nothing would be at

stake but meaning effects that project the pitiful illusions of a [separate] nature and… speaker…. Such a patchwork would be grotesque."[vii]

Latour has called the modernist epistemology based in the concepts of separation, isolation, and purification, the "asbestos" of our intellectual world; we put it everywhere without thinking, and everywhere it wreaks havoc on our understanding and analyses. "Our intellectual life remains recognizable to us only as long as the epistemologists, sociologists and deconstructionists remain at arm's length." We have been trained to believe that the realms of the material, the organic and meaning are separate and to strive to see their interconnections and true hybridity and mutually influenced development is to mix "three caustic acids."

If we incorporate Latour's view of networks into the complexity framework, we can legitimize the view that networks are indeed transdisciplinary and these transdisciplinary and disparate realms of the same network must somehow be acknowledge and articulated. We can answer Latour's question about the implication of his network study. Either, he says, networks that we have traced in science studies do not exist – and critics are right to marginalize or segment them into three distinct sets – facts, power, and discourse, or, the networks are as we describe them. They do cross the borders of these great fiefdoms. They are neither solely objective nor social, nor the outcome of discourse. Rather, they are at once real, and collective, and discursive.[viii]

Latour employs the example of the ozone hole, which is too social and too narrated to be truly natural; the strategy of industrial firms and heads of state too full of chemical reactions to be reduced to power and interest; the discourse of the ecosphere is too real and too social to boil down to its meaning alone. What we must realize and work from, says Latour, is the fact that networks are simultaneously real like nature, collective like society, and narrated like discourse. I would add that we must see the complex systems that make up the study systems of the social sphere in a more realistic fashion than classical social theory permitted; we must acknowledge that they are far more pluralistic, polysemous, and multifaceted.

It is a useful exercise to compare two examples: the ozone hole and climate change. What is striking is that while the ozone hole is radically simpler to resolve than the climate crisis, already the ozone hole is firmly stretched throughout these entirely disparate realms of knowledge. Yet we were able to resolve the ozone issue with highly simple mechanisms: work with a few industries to replace the CFCs in their products with what turned out to be a cheaper and better alternative that did not deplete the ozone hole. Obviously, one does need to invoke complexity theories to grasp replacing one chemical used in hairsprays and refrigeration products with another.

In the case of climate change, networks come even more boldly into view. There is no one answer to climate change as there was to the ozone hole. Any solution involves necessarily highly challenging radical reductions in the production and emission of greenhouse gases into the atmosphere, which involve just about everybody on the planet, in highly intricate networks. Therefore, it seems that complexity principles and lessons become even more critical. While the solution to the ozone hole would involve complex, interdisciplinary realms, the mechanisms to resolve the problem could be located and analyzed within the field of chemistry and the political reality of a handful of compliant businesses, willing to change their products.

Climate change presents a vastly different challenge. The systems involved are truly global, fully interdisciplinary and highly complex in scope. But the mechanisms to address and change the climate balance are also global, interdisciplinary, and complex. Whereas a couple of dozen critical players had to make changes happen with regards to the ozone hole – policy leaders, engineers, and business leaders, with respect to climate change, many commentators have pointed out that a successful outcome will involve practically everyone in the world. Everybody uses energy and contributes to carbon emissions in some form. While perhaps policy leaders, engineers and business leaders will play critical roles in the case of climate change as well, successful emissions reductions scenario will almost surely involve billions of people making conscious energy conservation choices in their homes and lifestyles; the contributions of untold swarms of entrepreneurs, engineers, and small businesses; the understanding brought about from ethicists, politicians, community leaders, students, and many more sectors and groups. Whereas the ozone hole was caused by a replaceable chemical, CFCs, with limited source points, aerosols sprays and refrigerants, the climate crisis is caused by innumerable industrial activities, as well as the degradation or destruction of carbon sinks, and the innumerable dynamics of hydrological cycles and other phenomena impacted by humanity's daily activities.

Thus the many aspects of complexity theories provide tools. Latour's actor network theory, for instance, helps gain a more realistic picture of climate change policy by highlighting the necessity of moving beyond archaic epistemological and metaphysical underpinnings of traditional scientific thought, and rather acknowledging the very different realms of knowledge and the radical epistemological shift this implies.

Latour's epistemological shift seems to be one of many such shifts taking place within the context of the greater complexity shift. Just as Beck has attempted to pin down the date of the tipping point when Western societies passed from being wealth producing to risk producing societies, Latour identifies the date of a similar

tipping point. In 1989 the Berlin Wall fell opening the way to fuller globalization and with it the globalization of the capitalist and neoliberal policies. Also in 1989, the IPCC had just begun exploring the worrisome issue of climate change, and wealthy nations held their first conferences on the global state of the climate. For some observers, said Latour, these warning calls about the environmental crisis symbolized for some the end of capitalism and its vain hopes of unlimited conquest and total dominion over nature. In 1989 capitalism began to truly overreach itself. Ironically, by seeking to reorient humankind's exploitation of people towards the exploitation of nature by people, capitalism magnified both the exploitation of people and nature beyond measure.

Yet, he supposes some would see these as innocent errors. We were focusing on making progress. We wanted to end human exploitation of other humans. We wanted to become both nature's owner and its master. We enlisted our noblest virtues in the service of the twin missions, one in the political arena and the other in the realm of science and technology. Perhaps it was easy to believe that these missions were undertaken with noble goals in sight. And yet, with retrospect Latour asks, highlighting the profound lack of ethical, social, or ecological self-regulating or self-organizing processes at the level of global societies, "What criminal orders did we follow?"[ix]

In large part, our misguided goals were shaped and legitimized by the false underlying assumptions of the modern era, detailed by Carolyn Merchant, Richard Norgaard, Edgar Morin and others: atomism, mechanism, universalism, and their resultant beliefs in our power to create, control, and manipulate, with foresight and prediction. Our misguided goals can be found in the strange separations embedded in Cartesian metaphysics and an inappropriate transfer of the reductionist aspect of the scientific method, to the entirety of human knowledge, instead of recognizing the deep qualitative differences of the highly complex dynamics of the social sciences, humanities, and domain of human ideas and meaning. The impacts of our science and technology has had such profoundly negative unintended consequences as the concurrent crises of climate, pollution, population increase and mass extinctions of biodiversity, because we believed we could separate nature and society and evaluate them as two separate sets, and because we were unable to integrate the warnings of some of the great minds about the need for humility, constraint, and precaution.

Latour cites Heidegger, who pointed out that our socio-natural networks are pregnant with Being. Machines are laden with subjects and collectives. A Being is incapable of losing its differences, its incompleteness and its Being. Heraclitus stopped at a common baker's oven to warm himself and said, "Here too the gods are present." Yet modernity tried to separate scientific practice and technological objects entirely from other spheres of human lives – emotions, values, and meaning. This

view has had inestimable impact on the way we perceive and act in the world. Why don't we recognize the political, sociological, psychological anthropological, historical and ethical aspects of everyday "scientific objects" of our material world? According to Latour, it is because people "believe what the modern Constitution says about itself." Thus the moderns believe that technology is nothing but pure instrumental mastery, science nothing but pure enframing and stamping, and the subject pure consciousness. Through the modern lens, we look everywhere and see purity.

They claim this, but we must be careful not to agree with them. What they are asserting is only half of the modern world – the work of purification that distils what the work of hybridization – the actual interdisciplinary nexus of our reality – supplies. When we see scientific objects parading as purely scientific, we must reveal the truth: that scientific objects are circulating simultaneously as material, organic and meaningful; in Latour's words, as "objects, subjects, and discourse."

Once again, we benefit more from this influential social theory and amplify its meaning and messages, by framing it within the larger complexity picture. The complexity perspective reveals the inconsistencies of the modern worldview, and the relationships and interrelated implications that flow between them and from their ensemble. We see that science came to be seen as doing pure enframing and stamping through the inappropriate extrapolations of the scientific method, through the inaccurate understanding of the lack of relationships between disparate disciplines, and through learning to see slices of our reality through uni-disciplinary lenses. We have learned to see and evaluate issues through the lenses of classical science – distorting our vision of the overall picture through our tendency to extrapolate from the slices of reality we can manipulate and experiment with, to our greater understanding of certain systems. In so doing, we have failed to put the pieces back together again, failed to see the greater dynamics such as emergent properties, hierarchical relationships, and nonlinear surprises. By extension we have missed the crucial implications of these principles: unintended consequences, uncertainty, surprise and the need for precaution.

Latour's argument is that networks of great significance to us in our world are highly interdisciplinary and traverse all realms of knowledge. To what extent may complexity theory illuminate the lack of coherence between these realms and further the distinctions between them? By being explicit regarding the fact that they are all referring to one reality, and yet qualitatively different realms of knowledge, we may develop better means of adapting and reacting to global change.

4.2. Ulrich Beck – Risk Society

Ulrich Beck's *Risk Society* (1992) argued that the gain in power from techno-economic 'progress' is being increasingly overshadowed by the production of risk and harm. Generally speaking, there has been a major shift from the modern era to today's era, and we have trouble defining what the shift is, but it involves a shift towards reflexivity of industrial society. While in the classical industrial society the logic of wealth production dominates the logic of risk production, in today's society, this relationship is reversed. Hence, we can refer to our current era in Western societies as the "risk society."[x]

It is my contention that Beck's description of the shift from net benefits to net risks associated with industrial society is one piece of the overall framework of the shift from the classical science worldview to the complexity worldview, and thus is best explained within that framework.

Many of Beck's main terms fit neatly in the complexity paradigm. Once again, *reflexivity* is a term for *feedback* in the social sphere. Beck intends this term to employ a general usage throughout social and institutional realms, as well as material and organic ones. As we have seen throughout the first few chapters, complexity fundamentals have a ubiquitous quality and we can begin to define and describe how they exist and function throughout different realms and different scales. Progress in the context of classical scientific assumptions and metaphysics was seen as pure, certain, and linear. In contrast, evolution in a complex system is necessarily much less definable and absolute.

Rather, it is generally acknowledged that what benefits one aspect of a system may harm another, and that finding overall progress for any one part of a system is far from simple. Feedback in interrelated systems results in both beneficial and harmful output, some integrated into a system, some becoming 'externalities' to that system.

When the human population was smaller our technologies less developed and far less in number, nature still dominated on the planet. As our population skyrocketed in recent decades, we have come to dominate the planet. Humans now compose about fifty percent of the planet's organic biomass, consume forty percent of planetary biomass, have altered eighty percent of the earth's land surfaces, and have polluted one hundred percent of the earth's surfaces in some form, including all surfaces – land and water – whether it be, as Bill McKibben pointed out almost thirty years ago, only the buildup of greenhouse gases affecting the temperature, vitality, and future of the entire planet.

In 1992 Beck wrote that as they become globalized and subjected to public criticism and further scientific investigation, risks "came out of the closet" and achieved "a central importance in social and political debates." Now, over fifteen

years later, we can say that risks have achieved a secure central place in social and political debates. Even two years ago the techno-optimists and doomsday doubters were loudly contradicting the risks. In 2006, a wave of awareness about climate change changed this, fully marginalizing the skeptics. Debates turned to focus on the details of climate change, carbon emissions reductions, and the energy transition. One could even say then that the mainstream discourse in the United States surpassed the phase of the risk society, jumping directly into a 'crisis society'; Americans somehow transitioned directly from denial of crisis to coping with crisis.

But for those who were minding the horizon, when did the shift from modern optimism to concern with risks take place? Beck cites 1950. The tipping point occurred a few years after the war, with the ironic combination of war riches and peacetime lifestyles that allowed for a tremendous boom in both population and industrialization. At this time, the relationship of wealth production to risk production shifted from greater wealth production to greater risk production. Other such tipping points have been cited. Some scholars have cited 1970 as a time when society surpassed the ecological footprint of the earth and began a process of net environmental decline. 1970 was also a tipping of ecological consciousness, with the first Earth Day marking the upswing in consciousness. In analyzing the ways in which social systems lack the kind of efficient and sustainable kinds of self-regulation of some less complex natural systems, the issue of time lags between social consciousness and social action is significant.

It should be noted that Beck's tipping point of wealth production and risk production correlates more or less directly with related critical social tipping points, including: the ratio of human population to natural resources, lack and attainment of environmental consciousness, reversible and irreversible externalities or side effects, and thus the lack and then necessity of understanding complex systems, and the insights, lessons, and tools that they provide.

Similarly, part and parcel of the shift from *wealth production* to *risk production* is the shift from *local effects* to *extra-local effects*. Examples abound. Pollution was once contained locally, but with processes extending the reach of technologies and their effects, along with increased human population, pollution is now often cross-border. Acid rain produced in Detroit falls in Quebec. Manufacturing of luxury items destined for wealthy Americans pollute rivers and soils in Mexico. And perhaps most significantly for the coming years, the history of industrialization in the wealthy northern countries has created the dynamics of climate change that will wreck the greatest, most immediate havoc in non-industrialized, impoverished regions like sub-Saharan Africa, war-torn Middle Eastern countries, and vastly overpopulated and poor countries like Bangladesh.

Therefore, many or most risks are now global. As Beck said, "In view of the universality and supra-nationality of the circulation of pollutants, the life of a blade of grass in the Bavarian forest ultimately comes to depend on the making and keeping of international agreements." Risk society in this sense is a *world risk society*. In complexity terms, Beck is arguing that the collateral consequences of social systems' prolific manufacture of industry, science, and technology, is also a global ensemble of interconnected complex systems.

Again, I extend my complexity-based thesis in relation to Beck's expanded thesis on risk: reflexivity is one part of the complexity puzzle. Thus, the policy answer to the reality of increasing global risks is to recognize the importance of feedback in our institutions and policies, but also to recognize the other dynamics of complexity that become tools for constructive policy and change: understanding network dynamics, nonlinear dynamics, and the resultant, ever-present lessons of uncertainty, unpredictability and the need for precaution. A tool for coping with this shift is reflexivity. Once we grasp the dynamics of reflexive thinking and management, we are better placed to cope with the multiple facets of global change.

This may lead us to another tipping point, to which Beck alludes: the shift in the feasibility and vulnerabilities of the capitalist free market system. There is much to say about this topic, which is in the headlines more than ever before. Here I note only that if the earth was somehow an infinitely open system, then unlimited capitalist production and exchange might be ideal. Ironically, while the early classical scientists discovered the heliocentric theory and the closed boundaries of the earth, they also maintained assumptions such as linearity and progress, which hampered the development of a more realistic vision of limits to natural resources and environmental systems.

Whether or not the environmental crisis calls for a complete break from capitalist logic is a topic well beyond my scope here. Beck notes that the modernist thinking asserts that risks are big business opportunities that will profit some, and the logic goes, somehow then creates a so-called ripple-effect that will benefit the majority. In the declensionist era of the last thirty to fifty years – depending upon where you place the major tipping point into the risk society – we see increasingly how flawed this logic has been. In the current dual crisis in which global economic malaise meets the rapid acceleration of climate change, our highly production and profit oriented, natural resource rapacious, capitalist system is looking increasingly flawed. One could say with Niklas Luhmann that with the advent of risks the economy becomes self-referential, independent of human needs. With the economic exploitation of the risks it sets loose, industrial society produces the hazards and political potential of a risk-based society.

Results of the shift to a risk society are numerous. One can possess wealth, but one can only be afflicted by risks.[xi] Mirroring Latour's analysis of the multidimensionality of social life – at once material, biological, social, meaning, and virtual – Beck also says that what was considered the domain of science is now suddenly acknowledged as thoroughly multidimensional – social, economic and political. The spheres of life, long clinically separate in our minds, come crashing back together in the realities of the present crises. The acknowledgement of this polysemous quality involves numerous profound shifts in thinking. Scientists must give up hubris and territorialism, not only is their work no longer necessarily for the good of society, it may be, and it often is, detrimental.

In some instances this has been hidden by the marginalizing effects of the combined capitalist and utilitarian logics that have largely ruled contemporary American society. Exposure to lead is not dangerous *on average*. Wishful modeling results in statistical 'proof' that nuclear accidents would only be a marginal cost to the overall project of nuclear energy production. Recent studies on nuclear energy have shown that as few as one medium-sized nuclear accident would cancel out the economic and environmental benefits of the possible shift towards nuclear power in Europe, in the coming decades.

However, the level of lead that is harmless 'on average' constitutes a mortal danger to a minority.[xii] Moreover, this is true for isolated risks, before we even begin to account for the escalating risks resulting from the magnifying effect of interconnecting and escalating environmental risks and damages. Many proofs for so-called free market capitalism and utilitarian calculus have been offered. It would seem that few of these arguments have adequately framed these social, economic, and political systems within the contexts of finite, sensitive, complex, socio-natural systems.

If I am correct, then the entire logic of our predominant decision-making apparatus is at stake. From the point of view of the complexity scholar, this tendency throughout the industrial age through today to allow risks to seem contained or controllable was not just coincidence, but an intrinsic part of the ontological and epistemological problems embedded in the ideas and assumptions of early classical science and metaphysics.

Training in these old concepts believed to underlay natural science is so strong, and unidisciplinary thinking so ubiquitous, that "What is astonishing about the industrial pollution of the environment and destruction of nature with their multifarious effects on the health and social life of people, which only arise in highly developed societies, is that they are characterized by a loss of social thinking. This loss becomes caricature. This absence seems to strike no one, not even sociologists themselves."[xiii]

Further implications are so substantial as to at first seem overwhelming. This shift places us in a critical category error. What were seen as insignificant for single products seems all the more significant if we see people in the advanced stage of total marketing as *consumer reservoirs*. Taking several medications can either nullify or amplify the effect of each individual one. Additionally, since we now consume multiple pollutions through breathing, drinking and eating, these insignificancies can add up quite significantly. Contextualing the risk society within a complex systems framework, arithmetic progressions of risk are the exception; in a highly interconnected world, risk effects may become exponential.

4.3. Jared Diamond -- Complexity, Sustainability and Preventing Collapse

In 2005 Jared Diamond's *Collapse: How Societies Choose to Fail or Succeed* was a best-seller, one of the rare books to remain for many months in both the academic and popular limelight. Diamond's thesis was that societies like the Easter Islanders, the Greenland Norse, the Anasazi of the American southwest, and others collapsed because in the process of exhausting the natural resource base they depended upon they either failed to anticipate the consequent collapse, or they saw it coming but failed to adapt and thus to prevent catastrophe. Meanwhile, other societies in similar situations, such as the Tikopians and Tongans of the South Pacific and the Highland tribes of New Guinea survived because they were able to see the problems and thus discard their previously tightly held "core values," which in fact had brought about long-term environmental degradation. Thus they were able to change behaviors and replant forests, conserve soil, change diets, and adopt the necessary reforms to maintain a sustainable environmental base for future generations.

Diamond draws parallels between these historical examples and societies today, and concludes that moderns are now on a precipice, engaged in activities that are putting our very existence at risk. Modern modes of consumption and destruction have already driven several societies towards collapse, including Somalia, Haiti, Rwanda, and Congo. Perhaps most remarkable, is that the advanced industrialized societies appear to be pushing the entire planet towards collapse. For the first time in history, Diamond says, "We face the risk of global decline. But we also are the first to enjoy the opportunity of learning quickly from developments in societies anywhere in the world today, and from what has unfolded in societies at any time in the past."[xiv] Diamond states this as his motivation in writing the book, to realize that we have the advantage over past societies, like the Maya and Easter Islanders, to reflect on these failures and successes, and to follow positive examples in order to make the choices necessary for our own survival.

Diamond lists *four principle reasons* for the collapse of societies: (1) *failure to anticipate problems, (2) failure to perceive problems, (3) failure to engage in problem-solving* and *(4) failure to solve problems despite engaging with them*.[xv] I will discuss each of these four factors in turn, including Diamond's historical examples, and then how each factor exemplifies and is clarified by complexity theories. Generally speaking of course, the failure to anticipate, perceive and manage problems has to do with the inability to successfully understand systems that are complex and changing.

Several causes lead to the failure to anticipate, according to Diamond. First, a group may have no prior experience of the problem at hand, so may not be aware that such a possibility could occur. British explorers took great pains to bring foxes and

rabbits with them to Australia, believing this would improve the environmental situation there. The age of major long-distance exploration and settlements was new at that time, printing presses were relatively new, and the field of ecology had yet to be created. As such, they had no real knowledge of exotic plants and their high ecological and economic costs. It turned out that these two introductions have subsequently cost Australia many billions in damages and in environmental problems that continue today.

Similarly, but slightly different, societies often eschew or forget critical lessons, once learned. Many U.S. citizens were impacted by the oil shortage crisis of 1973. Throughout the 1970s and early 1980s many people drove small Japanese and German cars. However, by the 1990s these lessons were largely forgotten, or willfully overturned as Americans opted for the largest vehicles yet: light trucks, jeeps and SUVs. In another example, Arizona went through a severe drought in the 1950s, and people became aware that water usage would always be an important issue in that natural desert. It did not take too long however for people to forget, to exercise wishful thinking, and to begin to systematically drain water tables in order to water imported grass lawns and golf courses.

The final category of anticipation failures is *reasoning by false analogy*. People form habits and sometimes remain semi-cognizant of the exact circumstances of the patterns of habits they develop. Often, habits that are successful in one situation become disastrous in the next. Many people from the East Coast moved to Arizona in the 1960s and 1970s, and they wanted the same lawns and golf courses they were accustomed to. So they created them, never considering the vastly different ecological realities between a wet, grassy eastern climate and a desert. Diamond gives the example of the Greenland Norse, who were accustomed to heavy wet soils in their previous landscapes. When they arrived in Greenland they attempted to deforest and plant crops as they had at home. In the drier new environment however, the exposed topsoil simply blew away. Whereas in their former habitat their actions may have enhanced ecological diversity and food supplies, in the new situation they reduced these natural resource bases, and with them, their ability to survive.

Climate change offers various examples in the failure to anticipate. Much about industrially-driven climate change is novel. While researchers did predict the process of greenhouse gas global warming in the Nineteenth Century, so much about the industrial era was so overwhelmingly novel, that it seems that the process for moderns of the Nineteenth and early Twentieth Century to adequately think through risks and effects was quite challenging. When a society is undergoing rapid change so much constant adaptation is taking place that there is little capacity left over to think through the complex ramifications of the ensemble of changes. Or perhaps, rather, we are just not accustomed to having to expend the extra capacity. This leaves people

vulnerable to making Diamond's second instance of the failure to anticipate – forgetting lessons learned, or failing to connect up the dots and see issues as systematic rather than particular.

The second of Diamond's four major reasons that societies collapse is the failure to perceive that a problem exists. Diamond notes various ways that this can take pace. Some problems are literally imperceptible. Nutrients responsible for soil fertility are invisible to the naked eye; only in modern times did they become measurable by chemical analysis. Nutrient-poor soils often bear quite lush-looking vegetation. It was an easy mistake to assume one could clear this and grow crops. In many places where soil had already been seriously degraded before human settlement, settlers fell into this trap.

Societies also fail to perceive a problem when they depend upon distant managers who are unaware of what is going on at the scene. This reiterates Latour's concept of ***immutable mobiles****,* or *models or tools taken from one context and unwisely, universally exported to any number of foreign contexts*. Many companies have degraded their lands by overlooking some of the realities only visible on-sight.

Finally, societies fail to perceive slowly occurring problems concealed by wide vacillations. Similarly, many examples of collapses indicate that people were looking at the near future while ignoring the long-term. The GCF highlights such issues as these time lags between different systems processes.

Many of these perceptual errors are exemplified in the case of climate change: (1) industrially-induced climate change is novel, (2) any changes that are part of climate change also exist naturally and thus in a sense the particular events of climate change are invisible or debatable, and (3) because of the fluctuations over time, industrially-induced climate change did not become more readily apparent until the 1990s and early 2000s, when a steady rise in annual temperatures became evident.

The third reason that societies fail is that people perceive the problems, and apply rational techniques to resolve them, but fail in this task. Surprisingly, says Diamond, this is the most frequent cause of collapse, assuming a wide variety of forms. Diamond categorizes these problems as *rational behaviors*, in the sense that social scientists and economists speak of rational behavior in the clash of interests between people. *People are accurate in their portrayal of facts, amount of resources and conflicts over resources, but they fail to effectively cooperate and resolve the problems.* As Diamond states it,

> Some people may reason correctly that they can advance their own interests by behavior harmful to other people. Scientists term such behavior "rational" precisely because it employs correct reasoning, even though it may be morally reprehensible. The

> perpetrators know that they will often get away with their bad behavior, especially if there is no law against it or if the law isn't effectively enforced. They feel safe because the perpetrators are typically concentrated (few in number) and highly motivated by the prospect of reaping big, certain, and immediate profits, while the losses are spread over large numbers of individuals. That gives the losers little motivation to go to the hassle of fighting back, because each loser loses only a little and would receive only small, uncertain, distant profits even from successfully undoing the minority's grab.
>
> Examples include so-called perverse subsidies: the large sums of money that governments pay to support industries that might be uneconomic without the subsidies, such as many fisheries, sugar-growing in the U.S., and cotton-growing in Australia (subsidized indirectly through the government's bearing the cost of water for irrigation). The relatively few fishermen and growers lobby tenaciously for the subsidies that represent much of their income, while the losers (all the taxpayers) are less vocal because the subsidy is funded by just a small amount of money concealed in each citizen's tax bill. Measures benefiting a small minority at the expense of a large majority are especially likely to arise in certain types of democracies that bestow "swing power" on some small groups: e.g. senators from small states in the U.S. Senate, or small religious parties often holding the balance of power in Israel to a degree scarcely possible under the Dutch parliamentary system.[xvi]

Beyond this, Diamond notes a few types of rational bad behavior: everyday selfishness – I will do this even though it hurts others because it benefits me. This is a form of the tragedy of the commons, in which everybody benefits individually from resource use that is destructive at the collective level. This occurs for instance, in situations in which consumers have no long-term stake, or they fail to perceive the long-term stake they have, in the community they extract from, as well as in numerous situations in which the interests of the public good clash with those of the powerful elite.

The fourth and final reason that societies collapse is that people may correctly perceive problems, attempt to resolve them, but fail in this task due to what sociologists term *irrational behaviors*, or *behaviors that are harmful to everyone.*

Many of these sets of ideas are rational in one instance but not in another. In this sense, these mistakes are similar in nature to the false analogy, in that in both cases one forms an idea of what is a good or useful concept, frame of reference, or value system, and then one holds onto this strict, reified idea despite changes in an evolving environment and society. Irrational behaviors are based on irrational beliefs, religious or secular, that anchor one to a certain view and prevent one from thinking and acting rationally. "Religious values tend to be especially deeply held and hence frequent causes of disastrous behavior," says Diamond. Much of the deforestation of Easter Island was done for logs to transport and erect the giant stone statues for which they held deep religious beliefs. The Greenland Norse held strong Christian values, that helped them succeed in a tightly-knit community for centuries, but also perhaps distracted them from focusing on making the major adaptations to lifestyle that would have let them survive in the far North.[xvii]

Diamond also offers secular examples. For instance, Montanans forged their strong economy initially through mining, logging and ranching, and these industries have remained closely associated with their pioneering identity and values of individual freedom and self-sufficiency. While these industries and related behavioral and policy values were greatly helpful in the first phase of their history there, they have since become the source of considerable political battles and environmental degradation. Thus Diamond muses, "Perhaps a crux of success or failure as a society is to know which core values to hold on to, and which ones to discard and replace with new values, when times change."[xviii]

Now I look briefly at one of the criticisms of Diamond's work, before turning to reframe both Diamond's views and those of his critic, in my broader complexity analysis. Richard Smith's review of *Collapse* was called, "The Engine of Eco Collapse." Smith accepts much of Diamond's historical analyses, but questions the way Diamond relates his insights to the contemporary environmental crisis. He suggests that Diamond is clinging blindly to his own destructive core values, and he argues that the failure to resolve problems that we see clearly lies partly in our ability to see how our political institutional structures support destructive patterns in complex ways. As such, Diamond questions who is able to "choose" to succeed or fail, and just how such agency would play out in the greater socio-political-economic relations.

More specifically, Smith argues that "the engine of eco collapse" in our current worldwide crisis *is* the dominant system of capitalism. While agreeing with most all of Diamond's historian analyses, and many of his contemporary arguments, Smith offers a Marxist reframing, accepting Diamond's analyses of Montana, but highlighting the capitalist relations underlying the ongoing environmental destruction in the state. It's a great paradox, says Smith, that Montana is renowned for both its

beauty and the utter despoliation of that beauty – deforestation, deteriorating water quality, seasonally poor air quality, extensive toxic wastes, degraded soils, loss of biodiversity, and various deleterious impacts, most of which arose from "mining, logging and other heavy industries that scarred and polluted the landscape and often left poverty and unemployment in their wake."[xix,xx]

Diamond sees the beauty and destruction of that beauty a curious paradox. He says that early industrialists valued freedoms to pursue their industry and thus successful, held up the ideal of self-sufficiency. In contrast, Smith sees this paradox as an intrinsic part of capitalist processes that have played out similarly throughout the country, producing wealth for some and leaving poverty and pollution for others. In fact, Montanans would benefit from governmental zoning and planning to protect the quality of life they enjoy so much from unplanned, chaotic development.

Smith sees Diamond's thesis that "societies" are in a position to freely "choose to fail or succeed" as ill-formulated and unsupported by his own historical case studies. In many instances, he argues, Diamond has shown rather that laws, regulations and institutions, trade relations, and the like were framed around early capitalist relations that served short-term private interest at the expense of the public over the long-term.

Diamond himself does use a neo-Marxist class conflict model to partially account for collapse, although he never uses the word 'class.' Smith cites examples throughout Diamond's narrative that decry individuals' ability to choose, and help to explain the seeming irrationality of the collapse by showing how it is embedded in the greater economic social framework. For instance, Easter Island's systematic deforestation was significantly driven by inter-ruling class "competition between clans and chiefs driving the erection of bigger statues requiring more wood, rope and food."[xxi] Moreover, "Easter Island chiefs… *were trapped in a competitive spiral* such that any chief… who put up smaller statues or monuments to spare the forests would have been scorned and lost his job." (Smith's emphasis)[xxii] Smith suggests that Easter Islanders perhaps saw clearly the suicidal logic of their systematic deforestation of the land, but that the members of that society, ordinary Easter Islanders, were in no position to change policies dictated by their chiefs. Smith cites other instances in which ruling classes made systematically destructive decisions that may have been completely beyond the power of the citizenry to prevent.

Mayan kings and nobles, for instance, were "evidently focused on their short-term concerns of enriching themselves, waging wars, erecting monuments, competing with each other, and extracting enough food from the peasants to support all those activities. Like most leaders throughout human history, the Mayan kings and nobles did not heed long-term problems, insofar as they perceived them."[xxiii] Similarly, in the Greenland Norse society, "key decisions… were made by the chiefs, who were

motivated to increase their own prestige, even in cases where that might conflict with the good of the current society as a whole and of the next generation."[xxiv]

The discrepancy in Diamond and Smith's analyses seems to lie in assumptions about the power and functioning of communal or democratic decisions. Diamond's omission of this critical issue seems to belie a naïve belief in the capacity of democratic decisions to supersede elite power structures. It seems that he believes that some kind of self-regulating functioning may emerge naturally in democracies. For Smith, this is a substantial error. Parallels to today's large-scale, international alter-globalization movements – popular social movements battling against corporate constellations of power over sub-national and international relations, and hegemonic military-industrial complexes – appear to highlight the importance of Smith's critique.

Diamond asks "Why aren't we 'choosing to succeed?'" To which Smith replies, "The short answer is that under capitalism, the choices we need to make are not up to 'society,'" while the ruling classes are incapable of making sustainable choices."[xxv] In support of this view, Smith argues that Diamond's success stories – the highland society of New Guinea and others – have no chief, decisions are made by common consent, and thus they are more truly democratic. "Decisions were (and often still are today) reached by means of everybody in the village sitting down together and talking, and talking, and talking. The big-men couldn't give orders, and they might or might not succeed in persuading others to adopt their proposals."

In contrast, decisions in most contemporary industrial societies are enmeshed in complex networks of power and special interest, where corporate lobbyists, advertisers, politicians and other special interests promote private gain at the public expense through complex and expensive campaigns of spin, distortion, and extortion of public powers and imagination.

Such issues lead Smith to dismiss Diamond's solutions, what he calls the "standard tried-and-failed" strategies of: lobbying, consumer boycotts, eco labeling, green marketing, asking corporations to adopt best practices, and so on – the stock-in-trade strategy of the environmental lobbying industry that has proven so impotent to date against the global capitalist juggernaut of eco-destruction. While reforms and campaigns have made significant impact on environmental issues, and even some significant victories, the overall trend is towards global ecological degradation.

The underlying problem, for Smith, is that the big problems – climate change, deforestation, overfishing, pollution, resource exhaustion, species extension, and environmentally caused human health problems – are getting worse. And they are getting worse generally, despite successes here and there, "because environmental reforms are always and everywhere subordinated to profit and growth."[xxvi]

4.3.1. Complexity Analysis of Jared Diamond's Collapse and Richard Smith's Critique

Next I want to step back and reconsider a complexity analysis of these views of ecological collapse – first Diamond's and then Smith's. I have given a fairly extensive review of the various four factors in the way we think that contribute to societal collapses. Now I explore the thesis that complexity principles lie at the core of these factors, and thus a complexity framework brings invaluable insights to Diamond's overall argument.

Diamond speaks of four major problems, which I list as follow, analyze generally, and then break down in turn:

1. failure to perceive problems
2. success in perception, but failure to try to resolve problem
3. success in perception and in trying to resolve problems, but failure in resolving problems due to rational ideas and behaviors
4. success in perception and in trying to resolve problems, but failure in resolving problems due to irrational ideas and behaviors

These four failures of thinking and acting can all be fore-grounded first and foremost as existing within and partially explained by, their nature, context, and dynamics as part of complex systems. A first step in breaking down this new view of Diamond's analytical failures is to explain how the concept of feedback helps explain the basic function of perceiving, acknowledging, and reacting to problems.

A semiotic analysis might break down the process in terms of the simplest units of observations, clues, facts, symbols and ideas. Examining the process at the scale of the process of thinking and reflecting, we could elicit numerous qualitative axes along which a complexity analysis is helpful. One is how we see the context of analysis – whether it be through the traditional scientific lens of focusing on units as nouns, static entities such as "an observation" or "a thought." Invoking the complex dynamic systems perspective would first bring out the verbs behind the nouns. Assuming a unit of any measure of time, this would instead elicit, "observing" and "thinking."

A relatively simple *dynamic unit of analysis* is what appears to be a simple or short series of analyses or reflections in the dialectic or dialogic between observations and thoughts. In a very basic, essential way, perception and engagement are based upon the feedback processes inherent to thought and between our observations and our thoughts.

At a larger scale, complexity offers insights into the many ways that one can fail to perceive. One way we fail to perceive, Diamond points out, is that something

may be literally invisible to us, a weakness that greatly preoccupied philosophers at the time of the inventions of the microscope and the telescope. Descartes famously lamented that the naked eye cannot estimate either the true size or distance of a planet or star, and instead could foolishly believe the sun to be of a much smaller size and only a hundred miles away, for instance. It is perhaps largely because of the hubris associated with our use of such powerful tools in our scientific laboratories that we do not adequately fear the ways in which we fail to perceive dangers and harms in our industrial societies. In recent decades many of these kinds of risks and harms have come to light, such as: non-point source pollutions, noxious gases, health risks associated with chemicals, toxics, and new substances such as nanoparticles, hidden in many products we use for food, hygiene, clothing, and household products.

Other failures of perception arise from our incapacity to master the complexity in our surrounding system adequately to understand what we do see. It was only through decades and centuries of observations and experimentations that we gained the basic knowledge we possess in chemistry, agronomy, ecosystem science, and so many other fields. And yet, this knowledge is limited. As much as we master, there seems always to be possible new ecosystem evolutions, system state transitions, technologies, introductions, combinations, and juxtapositions that we cannot foresee, predict, understand, or even acknowledge when we first observe it. Novelty seems to present a more impressive challenge to us than we are accustomed to admitting.

For instance, we have commercially managed honeybees for centuries. If honeybees were to disappear, about two-thirds of our food crops would be left without bee pollination. Throughout the era of expanding industrial agriculture and human developments in the United States, people worried about the honeybee – alternatively that they would become virulent and pursue innocent children, or that they would disappear and disrupt our food cycles. Indeed, in early April 2007 observers reported the sudden disappearance of up to seventy percent of the bees from commercial hives on the East Coast. Innumerable theories emerged – the bees must be afflicted by magnetic fields from cell phone towers, from high speed long distance travel, or by any number of the synthetic and biotech chemicals with which they come into contact. By 2008 it became fairly clear that a new pesticide was a primary driver of the disorder, though other factors like general stress and systemic poor nutrition weaken and stress bees in contemporary industrial agriculture.

While this crisis may be resolved, it reveals how simply any one element could wreak havoc and yet remain difficult to disentangle from multitudinous forces driving highly impacted environmental systems. Despite extensive knowledge, practical mastery really, of many aspects of the social and ecological lives of honeybees, it seems like that we will never exhaust nor foresee the ways they could unintentionally be harmed or driven to extinction. This is just one of many ways in

which the complexity framework carry encompasses real concerns in environmental management.

I reiterate Diamond's four major problems:

1. the failure to perceive problems
2. success in perception, but failure to try to resolve problem
3. success in perception and in trying to resolve problems, but failure in resolving problems due to "rational ideas and behaviors
4. success in perception and in trying to resolve problems, but failure in resolving problems due to "irrational ideas and behaviors

I contend that our there are two general ways that the seven complexity ontological fundamentals help to illuminate Diamond's four problems: (1) direct lessons from the fundamentals themselves, and (2) indirect lessons via the implications of those fundamentals.

First, I will give a few examples of how the fundamentals themselves help to explain Diamond's observations of these four major problems in our thinking. It would be possible to give examples for each of our seven fundamentals. I will only mention a few, related to the concepts of hierarchy and scale. The problem of our literal capacity to perceive is just one of many problems illuminated by hierarchy and scale. Another issue is that when multiple problems exist in a nested hierarchy, some may be partially or totally obscured by others from a particular observer's position. Also, we may perceive things but not immediately see a complex interplay of causality across levels of a hierarchy. To bring the concept of network into the mix, factors or agents in a system may be linked in more or less obvious or visible networks, which may or may not coincide with other hierarchies we may be focusing our attention upon.

Scale is also implicit in Diamond's example of time frames and human awareness. At the dawn of the twenty-first century, when media brings events from across the planet immediately to our computer screens and radios, we are learning the hard way about the significance of planning for the long-term. As we witness from day to day villages built in earthquake regions, floodplains, or arid areas suffer during the rare incidences of nevertheless inevitable cyclic events of large quakes, serious flooding or prolonged droughts.

While the fundamentals that Diamond's work is based upon are greatly useful, so too are the set of implications that accompany them, as well as the acknowledgment and recognition of these implications as a coherent set of phenomena that help to explain the complexity fundamentals. Diamond himself does not make all the necessary links in analyzing how the fundamentals and the implications are related.

Here I will attempt to make a few of these critical links. I will restate three major implications of complex systems that are included in Diamond's analysis, though not explicitly linked to complexity:

1. Uncertainty
2. Unpredictability
3. Precaution

Uncertainty seems to stem from all the other implications, and to assume a somewhat dominant position. Evidently, uncertainty is related to the four ways our thinking contributes to ecological collapse. The systematic uncertainty of complex systems both explains and is explained by three of Diamond's four errors in thinking.

Uncertainty seems unrelated to perception. However, once a problem is perceived, uncertainty is closely related to the second two errors. In terms of the failure to engage with a problem, overwhelming uncertainty in the systems that we are trying to more successfully manage can lead people to: a rational impasse, an overwhelming analytical puzzle, or even a sense of paralysis and hopelessness.

Uncertainty is also closely related to the third problem, the failure to successfully address a problem rationally. This relationship has haunted the quest for knowledge throughout human history and remains a deep concern in philosophy and science today. It is also at the heart of this dissertation, and the question of how to rationally address the climate change.

Here I will just comment on a couple of obvious points related to *Collapse*. First, when there is high uncertainty, it may be difficult or impossible to make a decision on strictly rational terms. This is discussed by the philosopher Alasdair MacIntyre, who argues that in the absence of the means to make a strictly rational decision, sometimes the rational choice is to make the best possible irrational choice. [xxvii] In other words, rationality is a more malleable concept than we may wish; sometimes it is only through a complex mix of non-rational emotions and intuitions that we can find the most rational response to a situation. Secondly, ubiquitous uncertainty belies our long-held desire for the contrary – a certain, controllable, knowable world, and our related strong tendency towards that which our wishful desire for such a certain world nurtures all too much our strong tendency towards disaster-provoking hubris.

Finally, there is the question of how we fail in our attempts to resolve problems, and instead cling unwisely to outmoded irrational ideas and behaviors. In a more indirect, but nonetheless quite powerful way, pervasive uncertainty may be a driving force causing us to develop and cling to such irrational ideas and behaviors. Fragile and mortal in an uncertain world, we search constantly for a sense of

reassurance and protection. We tend to seek religious and ideological concepts that provide what seems a reassuring framework in an uncertain world.

When we look throughout human history and see how common such examples are, it raises red flags for us. It should remind us main lesson of the complexity paradigm: we must keep clearly in sight the world's ubiquitous uncertainty and unpredictability, which calls for us to act with precaution.

Finally, I return to Richard Smith's critique of Diamond. I want to say several things about Smith's critique of capitalism as the engine of eco collapse, and the complexity paradigm. To discuss the vast literature on green economic, political and institutional structures is to write another dissertation. However, Diamond and Smith's ideas may be a good source for one major thread of this dissertation: to develop typologies of thinking – concepts, frameworks, and intellectual approaches – based in complexity thinking.

More specifically, we need to develop typologies of complex thinking and typologies of simplistic thinking, analyze how various ways of thinking help or harm in our environmental thinking, and how to encourage the helpful varieties. In the complexity lexicon, words that encompass highly complex meanings are politically dangerous and easily manipulated. Concepts that attempt to greatly simplify complex ideas, concepts, institutions and practices must be counterbalanced with the democratic processes of critique, evaluation, and reflection. In short, complex ideas are only valid, as Morin put it, "at the temperature of their own destruction."

Words that simplify highly complex phenomena and then achieve a reified and static meaning are perhaps the most dangerous; these can be called ideologies. Insofar as terms like: capitalism, free market, communism, state-control, nation state, and the like are extracted from their messy and quickly evolving socio-natural-political context and transformed into singular and unchanging explicators, they do more of a disservice than a service to us. Ideologies, reifications, and essentialisms cripple our thinking, while critiques, problematizations, and complexifications enhance it.

Moreover, we need to systematically reconsider the way that we consider the intersections of the various worlds we inhabit –material, mechanical, organic, semiotic and virtual. We must begin to be more fully cognizant of the implications that arise each time we transpose one onto another, e.g. the mechanical on the organic. From the multitudinous debates and discourse of the many environmental literatures of the last five decades, from Rachel Carson to today, we can distill various key references that help us to bypass prolonged engagement in partisan squabbling and ideological debates.

One significant disjuncture between our observations and our ideologies lies between the reality of high levels of extinctions, biodiversity loss, and natural

resource depletion, and the ideology of infinite growth. The earth's finite ecosystems and natural resources are in varying states of rapid degradation, while our socio-political-economic ideas and structures – even with the sharp upswing in the rate of climate change and the current global economic crisis – our social institutions are still largely aimed to increase sale, profit, and consumption. Within this framework, debates continue about the most important factors in this picture and how to best confront them. Thus complexity theories appear to be useful both in understanding how our reality and our ideas remain so out of sync and in conceiving of ways to reconcile them.

A lesson to be drawn from Diamond's book that appears neither in the book nor in the hundreds of reviews of it is as follows: *collapse* is but one end of an axis between complete failure and 'optimal' maintenance of diverse living systems, it is one aspect of complex systems dynamics, and thus if we aim to avert collapse in the case of the current global environmental crisis, it may be best to contextualize the issues in terms of the complexity framework, in order to better map and articulate the most dangerous drivers, interactions, feedbacks, trends, and means to exercise our social and natural systems' resilience and aim for sustainability.

Thus, by proposing that collapse and sustainability be seen as essential reference points in the GCF, I am linking the literature about ecological sustainability, including its reference to social justice, and many issues, as well as the literature on collapse and catastrophe, and how to prevent them, into one greater literature on how to advance and facilitate our perception and understanding of global change. Through this exercise, perhaps we may come closer to providing the missing elements that Richard Smith seems to lament, which is the practice and theory of self-regulation or self-organization on a planetary scale. It may be possible to develop such a theory based upon the GCF.

Complexity theories may us to better analyze the natural world with its dynamics, phase states and tipping points, and its numerous coevolving nonlinear networked structures, its varied scalar levels and nested hierarchies, fully explicable only at the intersections of multiple disciplines, brought together by various researchers of differing expertise to bring their study to bear upon critical aspects of the environmental crisis.

4.4. Conclusion

Social theorists have begun taking up concepts that are in fact correlates of complexity theories. Several prominent social theories of the last two decades appear to be based upon complexity fundamentals. Many of the complexity epistemological fundamentals have been thoroughly discussed in social theory, albeit almost always implicitly. It seems, therefore, that my argument for the development of more explicit explanations of complexity theories is justified.

Such results are just the tip of the iceberg, to use a now unsettling metaphor. Given these results – the significance of both the presence of social networks and the lack of social self-organization, the perils of modernity, the rise of risk, and the risk of collapse – appear to provide support for the significance of complexity theories in the social sphere.

Notes

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[xi] _____. 23
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[xiv] Diamond, Jared. (2005). *Collapse: How Societies Choose to Fail or Succeed.* Viking Books: New York, p.23
[xv] _____. 421-440
[xvi] _____. 427
[xvii] _____. 432-433
[xviii] _____. 433
[xix] Smith, Richard. (2005). "Review Essay: The Engine of Eco Collapse." *Capitalism, Nature, Socialism* 16(4): 19-36, pp.31-32.
[xx] _____. 21
[xxi] Diamond, Jared. (2005). *Collapse: How Societies Choose to Fail or Succeed.* Viking Books: New York, 119.
[xxii] _____. 431.
[xxiii] _____. 177.
[xxiv] _____. 190.
[xxv] Smith, Richard. (2005). "Review Essay: The Engine of Eco Collapse." *Capitalism, Nature, Socialism* 16(4): 19-36, p.27.
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Chapter Five. Complexity, Transdisciplinary Theory, And the Philosophy of Science

5.0. Introduction

A number of scholars have begun to provide portraits of complexity studies writ large. These scholars tend to utilize the methodologies of the humanities and philosophy, but hail from disciplines across the board – social theory, theoretical ecologists, the humanities, and the philosophy of science. What they share in common is a desire to get a better sense of overall social and environmental dynamics in the world today. The vision of these scholars tends to extend beyond the differences described between the natural and social scientists, developing several comprehensive interpretations of complexity studies. I call this field *transdisciplinary theory*.

While often based in one discipline, for the most part these scholars have developed expertise in more than one discipline; many of them have backgrounds bridging more than one of the three major categories of knowledge – natural science, social science, and the humanities. With this transdisciplinary knowledge, these thinkers are able to look more comprehensively across the major realms of knowledge and their interrelationships. There may be no unified framework of knowledge, certainly in the biological and human sciences. However, most of these scholars argue that telling a story about large socio-natural issues, such as climate change, requires the inclusion of at least intermittent transdisciplinary framework and analyses. Many of them also speak to the utility of philosophical argument and analyses in creating bridges between their disparate epistemic communities.

It is instructive to consider how transdisciplinary work relates to the approaches mentioned in the last few chapters, the more common, disciplinary approaches. The work of the SFI provides one firm basis, of which mathematics and the physical and natural laws are essential. The work of the social theorists is also important; while it may be more challenging and controversial, lacking the qualities of mathematical equations and replicable experimentation inherent to the natural sciences, analyses in the human sciences are inescapably necessary in addressing many of the social and ethical dimensions of societal challenges, beyond being inherently fascinating.

Hence I study several wide-ranging works of transdisciplinary scholarship, to assess how well they are positioned to articulate complexity theories. In the last few decades, some of these thinkers have focused on how complexity theories relate to transdisciplinarity, and have taken major steps towards a new framework for human

knowledge, *complexity thinking*, that they say helps to address increasingly complex societal challenges.

5.1. The Need for Transdisciplinarity

One of the major messages to emerge from most science and scholarship in the Twentieth Century is that the kaleidoscopic ensemble of the individually myopic, highly specialized disciplinary niches is often greatly inadequate to the increasingly urgent need to understand and guide our highly complex, interlocking, global societies. In brief, today's issues demand a great sophistication of transdisciplinarity. First, I address the issue of terminology. There remains some confusion around the distinctions between inter-, multi-, and trans- disciplinary research. Increasingly, it seems that consensus is being formed within much of academic study, and it is in the context of common discourse that the terms are still confused.

Still, there remains no precise scholarly consensus on these definitions. Today, the three terms are still listed essentially as synonyms in most dictionaries. The Oxford English Dictionary defines interdisciplinary as "of or pertaining to two or more disciplines or branches of learning; contributing to or benefiting from two or more disciplines." Whereas multidisciplinary means "Of or pertaining to more than one discipline or branch of learning; interdisciplinary." Transdisciplinary is not listed.[i] Perhaps having two false synonyms struck the editors as enough already. Generally speaking, the minor distinction made in most dictionaries is largely irrelevant – interdisciplinary and transdisciplinary research must pertain to two or more disciplines or branches of learning, while multidisciplinary research pertains to three or more disciplines or branches of learning.

Nonetheless, the literature has grown immensely and it appears that in the last decade the majority has begun to shift toward a consensus of sorts, which holds that transdisciplinary is much more involved than either of the others:

> … in multidisciplinary research, each discipline works in a self-contained manner and that in interdisciplinary research, an issue is approached from a range of disciplinary perspectives integrated to provide a systemic outcome.
>
> In transdisciplinary research, however… the focus is on the organisation of knowledge around complex heterogeneous domains rather than the disciplines and subjects into which knowledge is commonly organised.

> … [T]he difference between interdisciplinary and transdisciplinary contributions stems from the Latin prefix "trans" which denotes transgressing the boundaries defined by traditional disciplinary modes of enquiry. They make a distinction between the research group, which will always remain interdisciplinary by the very nature of disciplinary education, and the research itself which, if transdisciplinary, implies that the final knowledge is more than the sum of its disciplinary components. Lawrence compares interdisciplinary approaches to a "mixing of disciplines" while trandisciplinary ones would have more to do with a "fusion of disciplines"…. Ramadier argues that transdisciplinarity entails an articulation among disciplines, while multidisciplinarity or interdisciplinarity simply implies the articulation of different types of knowledge…. Ramadier argues that trandisciplinarity should not simplify reality by only dealing with parts of it that are compatible at the crossing of multiple disciplinary perspectives, as is often the case with interdisciplinary research…. [He argues] that transdisciplinarity is at once between disciplines, across disciplines and beyond any discipline, thus combining all the processes of multidisciplinarity and interdisciplinarity.[ii]

Examples of scholars whose preferences tend towards transdisciplinarity then, according to the editors of this special issue, include: Erich Jantsch, Michael Gibbons, Jürgen Habermas, Jean Piaget and Donald Schön. The reasons for the preference of transdisciplinarity over the other two older modes of analysis include some of the following:

> First, transdisciplinarity tackles complexity in science and it challenges knowledge fragmentation. It deals with research problems and organizations that are defined from complex and heterogeneous domains. Beyond complexity and heterogeneity, this mode of knowledge production is also characterised by its hybrid nature, non-linearity and reflexivity, transcending any academic disciplinary structure. Second, transdisciplinary research accepts local contexts and uncertainty; it is a context-specific negotiation of knowledge. Third, transdisciplinarity implies intercommunicative action. Transdisciplinary

> knowledge is the result of intersubjectivity. It is a research process that includes the practical reasoning of individuals with the constraining and affording nature of social, organisational and material contexts. For this reason, transdisciplinary research and practice require close and continuous collaboration during all phases of a research project, what is called "mediation space and time", or "border work". Fourth, transdisciplinary research is often action-oriented. It entails making linkages not only across disciplinary boundaries but also between theoretical development and professional practice.

Transdisciplinary contributions frequently deal with real-world topics and generate knowledge that not only address societal problems but also contribute to their solution. One of its aims is to understand the actual world and to bridge the gap between knowledge derived from research and decision-making processes in society. However, transdisciplinary research should not be restricted to applied knowledge. This common interpretation is too restrictive, because there is no inherent reason why theoretical development – especially the analytical description and interpretation of complex environmental questions – cannot be achieved by transdisciplinarity. This is a basic necessity if advances are to be made in this vast and complex field of research.[iii]

It is necessary to unravel some of the disciplinary articulations in order to understand how the concepts are playing out in a given realm. This is increasingly true with the shift of focus from issues in physical and natural systems to issues in social and conceptual systems. Scientists studying isolated aspects of physical systems generally do not need to incorporate social issues in their experiments. Yet even scientists immersed in the most purely physical sciences need to be aware that their human ideas, values, and ethics affect every stage of their research, from the objects they choose to study or technologies they choose to create, to considerations of funding, technologies, and safety and policy protocols.[iv]

With this in mind, I address concepts in the closely related fields of transdisciplinarity and complexity. In transdisciplinary complexity terms, feedback occurs at small scales very effectively, but decreasingly well at greater scales in human societies. That is to say, particular organisms develop intricate feedback mechanisms over evolutionary time. Bacteria have developed processes of feedback, emergence and self-organization that are so sophisticated, that they often succeed in out-competing our best medical science. Shifting one's gaze up the evolutionary timeline, organisms had decreasing increments of evolutionary time in which to

develop processes of feedback, emergence and self-organization, therefore, these processes are less and less sophisticated as we approach the present. Human societies spent a very long evolutionary period in warring tribes, and relative to this, an exceedingly short period of time learning how to respond and organize societies to the complexities of massively increased interconnections and globalization.

Small human groups develop more or less effective social methods – stories, myths, mores, moral systems, beliefs in praises and punishments, etc – in order to serve a parallel role of feedback, self-maintenance, and self-organization in social order, maintenance, and well-being. But as Jared Diamond pointed out, even at the small scale with tightly interlinked dependence on ecosystems small societies often made fatal errors and perished. Various indigenous tribes throughout the Americas for instance, practiced highly sustainable land management, but eventually made bad choices such as overproduction or overpopulation. At times bad choices were combined with bad luck such as draught or warfare and the civilization perished. Thus meta-regulation or meta-self-organization of human societies is dangerously underdeveloped with respect to our current biophysical impacts on the planet.

In the absence of the more effective self-organization, larger human social spheres are largely driven by social systems that prove frequently incapable of being guided by common interests – economic, demographic, and technological. In fact, many now believe that these massive and complex social systems are currently driving us towards some degree of global catastrophe. This raises many questions all of which are far beyond our scope here, such as: What kind of guidance can be greater at the international scale? Should humankind strive to develop an international governmental body or a set of peaceful interlocking communities that behave more cooperatively?

Thus, one of the promises of transdisciplinary research is to more effectively ascertain and describe the meta-scale decision-making processes as they stand, and how they might develop in ways that would better regulate questions of survival and thriving. Increasingly over recent decades, scientists and social theorists alike find that the work of transdisciplinary scholars is the only or the best manner to compensate or adjust the myopic nature of our increasingly hyper-disciplinary sciences and our societal systems. Indeed, it seems that perhaps our social systems have a decreasing capacity for rational self-preservation of humanity in correlation with increasing scales of societal and global complexity. Yet we are living in an era of globalization. It is increasingly evident that both many of today's pressing issues are transdisciplinary and that often these transdisciplinary issues are often embedded and interwoven with other transdisciplinary issues. It is increasingly evident that the transdisciplinarity of many issues must be taken into account, and that their even more complex transdisciplinary context must often be taken into account.

Social theorists in all areas have increasingly reacted to these shifting realities. Especially in the evidently highly transdisciplinary field of environmental studies or environmental sociology social scholars have tried new approaches. Many have chosen to become issue-based, meaning that they give the issue they work on priority over academic or disciplinary demands. Thus, whatever their initial or primary discipline may be, they define their work in relation to an issue, phenomena, or study system. Thus transdisciplinary scholars may actually define themselves first by the issue they are focusing on, and only secondarily, if at all, by discipline. As environmental scholar Isha Ray said, "It has been a long time since I called myself an agro-economist. Now I simply call myself an expert on water issues and that is increasingly what I am. When I go to agro-ecology conferences I cannot possibly keep apace in all the conversations dealing specifically with the writing in agro-ecology. I prefer to read more broadly so that I am more effective on water issues. And that's working. Increasingly, I am more effective on water."[v]

These scholars are shifting the nature of scholarship in many areas. Not only do they often eschew disciplinary careers, but also constraints on methodology. The majority of these issue-based scholars may employ some methodologies classical to an initial discipline; however they lend greatest legitimacy not to any one methodology or analytical approach, but again, to their issue. They first choose their issue, usually quite interdisciplinary, and in order to best theorize about that issue they adopt whatever methodologies are more appropriate.

The need for transdisciplinary analyses was often stated in past centuries, as when Rabelais said, "Science without conscience is but the ruin of the soul." When he uses this same phrase, Edgar Morin has said that he intends to refer not just to moral conscience, but to conscience period! Conscience in this instance referred to the aptitude of the whole scientific project to provide analyses that conceive of the nature and directions of the ensemble of scientific research, the aptitude to conceive itself.[vi]

5.2. Complexity's Big Picture: Perspectives, Frameworks and Definitions

Surveying the fields of knowledge pertinent to the subjects of global change generally, I have discerned five substantial transdisciplinary fields that have emerged in recent decades, which offer broad views of complexity. These five fields are: specifically transdisciplinary complexity studies; interdisciplinary or multidisciplinary studies; ecology and socio-ecological systems studies; science and technology studies; and applied philosophy. While the subject is vast, my aim here is to assess these broad-based approaches to treating issues of greater complexity, and how they do or don't take up complexity theories.

In grasping for a sense of generalized complexity and its relation to the rest of human knowledge, it is useful to see these various transdisciplinary approaches as five approaches to the same global system, with five different foci. In this manner, it is possible to highlight the very strong links between these seemingly disparate fields of endeavor. The common element between the five fields is the attempt to most directly address issues in terms of generalized complexity, as discussed in Chapter Two, which also amounts to the most inherently transdisciplinary of the approaches discussed in this chapter. Rather than using the simplifying and prioritizing lenses of one or another disciplinary niche, these fields apply lenses which encompass greater portions of the complex systems involved in the issues under study.

Generalized complexity permits one to study urgent policy issues regarding societies and environments, regardless of their metaphysical nature, e.g. regardless of how a highly complex socio-ecological ensemble may be unified or not. This provides the significant benefit of acknowledging and yet bypassing challenging, perhaps impossible philosophical questions, to effectively address urgent policy issues for which it becomes necessary to think more systematically, about more comprehensive details of global issues than is usually the case within the confines of certain disciplinary traditions, without falling prey to pitfalls such as endless debates about realism and relativism.

With this in mind, we can see that these five areas are simply approaches to reality from five points of view. Transdisciplinarity, inter or multi-disciplinarity, ecology, and science and technology studies, and philosophy of science, are simply angles focusing on, respectively: (1) all disciplinary perspectives, (2) some critical disciplinary perspectives, (3) environmental issues, (4) social issues, and (5) the nature of complex systems and their general implications for science and policy. By distinguishing the five fields in this way, I provide the grounds for some of my arguments about them.

#	Field	Founding Scholars	Foci
1	Transdisciplinary complexity studies	Edgar Morin, Nicolas Rescher, Basarab Nicolescu	All disciplinary perspectives
2	Interdisciplinary & multidisciplinary	Julie Thompson Klein, Stephen Jay Kline,	Some critical disciplinary perspectives
3	Ecology, biology, social ecology	Timothy Allen, C.S. Holling, Lance Gunderson,	Environmental issues
4	Science and technology studies	Sheila Jasanoff, Bruno Latour, Brian Wynne	Social issues
5	Philosophy of science and applied philosophy complexity studies	Nicolas Rescher, Mario Bunge, Kurt Richardson	The nature of complex systems and their general implications for science and policy

Table 5.1. Five Transdisciplinary Fields, Leading Scholars, and Major Foci

The main argument I wish to make here, is that the transdisciplinary complexity theories field provides the largest possible conceptual framework. This may or may not be the most effective or necessary for a given research project. However, I argue that regardless of its capacity, effectiveness or utility with respect to a given issue, as the framework explicitly aims to include both the greatest scope and grain of analysis, this should provide a significant reference point for global and socio-ecological issues. Moreover, it would seem that this might be the most powerful approach for issues involving the most highly complex global and socio-ecological systems.

In what follows, I outline these five areas, which encompass many theories that have emerged in the last few decades and contribute to a re-visioning of science, knowledge, progress, and society. I will remind the reader of the areas of knowledge discussed in the introduction such as the critique of 'progress' and the development of future studies – and briefly discuss how these two sets of ideas present an interconnected extension of the fields of study which are co-developing with the field of complexity theories.

In a variety of ways, these studies and theories have contributed to our understanding and interpretation of complexity. Together, presenting a wider picture of both the fields and theories advancing in correlation with complexity studies, I propose a framework for understanding complexity theories. In Chapter Nine, I show how these fields represent the great spectrum of work which then co-develops with the concepts of Generalized Complexity, as discussed in Chapter One, and how this in turn leads me to the creation of a disunified but coherent framework within which

to contextualize all these disparate branches of complexity research, what I call the *Generalized Complexity Framework*.

5.3 Transdisciplinary Scholars

5.3.1. Edgar Morin

The work of French sociologist and philosopher Edgar Morin provides a good starting point for any study of complexity, but especially for truly comprehensive, and thus transdisciplinary, perspectives. Edgar Morin's method is at once a call for a new metaphysical worldview, an exposition of the central ontological premises of complexity, and an exploration of complexity as method, a new epistemological approach to knowledge. He is seen by many as a founder of the philosophy of complexity and of transdisciplinary research. Along with major works in sociology, he is best known for his six-volume treatise on the philosophy of complexity, *The Method*, a transdisciplinary work regarding complexity in all areas of human knowledge.

Insights and explanations of complexity lead Morin to several main arguments. The first is the need for integrating complexity into all areas of knowledge, acknowledging the limits of lingering assumptions of early classical science. Second, the replacement of this limited classical science tradition, with a more realistic, fully encompassing, transdisciplinary conception of knowledge, what Morin has called science with conscience, or science guided by ethics.

Morin aims to show the limits of reductionism produced by the foundations of classical science. He argues that a fuller, more realistic vision of the world necessitates a much fuller project than encompassed solely by the methods and lenses of classical science. He demonstrates how complexity permeates all areas of human knowledge and thus cannot be captured by natural science alone, but necessitates understanding in social theory and humanities. In other words, the social sphere cannot be what philosophy of science refers to as 'naturalized,' understood with the methodology and worldview of the natural sciences alone. Finally, he argues that a more complex view of the world necessitates integration of ethics into science.

Morin makes these arguments from a transdisciplinary perspective. His main conceptual framework is a re-articulation of knowledge in a greater framework that both encompasses the disciplines and also shows the rich conjecture of their ensemble as one revealing the significance of central concepts such as self-organization and the subject. He analyses the notion of *subject* as opposed to object, *organization* as opposed to assembly, and *process* as opposed to product. He takes material previously described in at least partially static, at times mechanistic terms, and reinterprets them in light of the dynamic processes that belie the simplicity of static interpretations, ubiquitous dynamics such as emergence and self-organization.

Edgar Morin, perhaps more than the other scholars of general complexity, explores complexity *as method*. Morin names his major life's work, *Method*, playing with words, as he is wont to do, to establish a break with Cartesian atomism, universalism, essentialism, and reductionism. He views not just his content but his method as anti-method or anti-Cartesian. Morin's goal is to avoid Descartes' foundationalist approach, which he sees as reifying truth and certainty from the outset. Morin identifies three such Cartesian modes of simplifying thought: (1) ***to idealize*** – to believe that reality can be reabsorbed in the idea, that the intelligible alone is real; (2) ***to rationalize*** – to want to enclose reality in the order and the coherence of a given system; to forbid reality to overflow the neat boundaries we conceive; to need to justify the existence of the world by conferring on it a patent of rationality, and (3) ***to normalize*** – to eliminate the strange, the irreducible, and the mysterious.

In contrast, Morin cites Friedrich Nietzsche who said in the *Antichrist*, "The method comes at the end." This need not entail a vicious circle, says Morin, if we and our knowledge come back changed by the voyage. Thus Morin's vision of method is quite similar to that of philosopher Bernard Lonergan who defines method as, "a normative pattern of recurrent and related operations yielding cumulative and progressive results. Discovery and synthesis ensue, but neither discovery nor synthesis is at the beck and call of any set of rules. Both logical and non-logical aspects are at play; while the logical tend to consolidate what has been achieved, the non-logical keep all achievement open to further advance."[vii] Whereas Descartes sought all knowledge that cohered with his initial premises, for Morin, as San Juan de la Cruz famously said, "To reach the point that you do not know, you must take the road that you do not know."[viii]

Foundationalism failed repeatedly and is now dead, says Morin. We must begin with the opposite approach. We must proceed with analyses that always pose greater questions. We must learn to keep our analyses "at the temperature of their own destruction." We can only achieve a more realistic, more complete view of life by acknowledging its inherent lack of absolute truths and absolute certainties. Rather, most phenomena are pervaded by profound degrees of uncertainty, process, and change.

Morin advances complexity as method through an exposition on complexity *as* transdisciplinary. He begins by spelling out an array of fundamental rules guiding the knowledge of fuller complexity. For instance, complexity is the base; hence you cannot reduce the complication of developments to rules with a simple base. All knowledge takes place within a larger hierarchical system of phenomena and its knowledge. Some may object that this larger hierarchical system is simply order. Morin argues that we need to make more distinctions, due to qualitative differences

with respect to order or processes of ordering at different scales. According to Morin, the study of disciplines, including the organization of science into disciplines, emerges from the sociology of sciences and knowledge, from a reflection internal to each discipline and from a reflection of knowledge external to that discipline.

This leads to Morin's view that in the great scheme of things, complexity, hence reality is inherently embedded in transdisciplinary phenomena. Some degree of transdisciplinary analysis is often necessary. Thus, one can't know the study problem solely from within a single discipline. A fuller understanding always emerges from consideration of a study system within its next higher order of hierarchical organization. In advancing understanding, the frontiers of disciplines are as important as the disciplines. To limit analysis solely to singular disciplines obstructs thinking that will resolve human social challenges, which tend to be almost always transdisciplinary.

Again, Morin sees complexity as a generalized shift in the way the world is and in the way we study and know the world; Morin focuses on advancing core concepts in the ontology of complexity. If there is a central concept in Morin's work it is perhaps *organization*. More specifically, Morin sees organization, particularly self-organization, as a central feature of the universe. Morin's primary conceptual framework consists in a tri-part schema, what he calls a ***tetralogical loop*** of *organization, order, and disorder in mutual and constant interaction*. While at first it may appear abstract, the concept points to *the feedback of feedbacks*, operating in so many of the kinds of systems of everyday life and contemporary concern. Again, some philosophers may object that the tetralogical loop is merely order writ large. However, Morin see this as an essential distinction in more fully articulating complex processes, and ultimately, in advancing our understanding of organization.

Likewise, his use of the term organization has a large-scale quality that is both abstract and at the same time of first order significance in defining organizational processes more fully. Morin defines ***organization*** as *interactions in a circular or spiraling triangular relation [the tetralogical loop], in which no one particular force acts independently of the others.* Almost everything we initially saw as simple element we now see as organizational – atoms, molecules, stars, lives, and societies. But we know nothing of the (true) meaning of this term – organization.[ix]

Nonetheless, Morin has established several things about organization. First, it is not an ensemble of elements, as the term previously implied. Organization is comprised of ordered and disordered processes. Organization is in mutual correlation and co-relation with diversity and complexity. This is understood through recent developments in many areas of complexity study, notably ecology.

Ultimately, at the heart of organization lies ***self-organization***, *the processes involving order, disorder and interactions in a complex system, in their complex*

ensemble.[x] There is some "radical self" at the heart of organizational processes that science has yet to demystify. As I discussed earlier, one of the hardest problems of biology is the auto-generation of living systems. Leading biologists have mentioned this as a difficult problem, such as Nobel Laureate Jacques Monod[xi]. Moreover, biologist and complexity scholar Robert Rosen devoted his life's work to this question.[xii]

Indeed, many of Morin's core concepts are considered to be amongst the harder problems within the various disciplines they touch. This in part explains why Morin at times resorts to definitions some may find frustrating or worse. He defines organization through an elaborate discussion of related process concepts with which organization is intimately related, e.g. order, disorder, and interactions. I argue that the perhaps abstruse quality of Morin's work that some may perceive from their more detailed disciplinary niches is due partly to the difficulty of the issues Morin analyzes. When his work is framed in its transdisciplinary context, it appears that he has advanced some of the hard problems in fundamental complexity, e.g. in biology and ecology.

Natural scientists working on complexity fundamentals argue increasingly for the significance and the mysterious quality of self-organization as well. For instance, theoretical ecologist and network researcher Albert-Lázslo Barabási describes the relationship between complex systems, the need for synthetic analyses, transdisciplinary study, and the significance of the ineluctable role of self-organization. To Barabási, networks are as much about reconnecting the disparate disciplines, as they are about reconceptualizing a system's interrelations. He says, "Reductionism was the driving force behind much of the twentieth century's scientific research. To comprehend nature, we first must decipher its components. The assumption is that once we understand the parts, it will be easy to grasp the whole.… [Yet] we are as far as we have ever been from understanding nature as a whole. Indeed the reassembly turned out to be much harder than scientists anticipated. The reason is simple: Pursuing reductionism, we run into the hard wall of complexity…. In complex systems the components can fit in so many different ways that it would take billions of years for us to try them all. Yet nature assembles the pieces with a grace and precision honed over millions of years. It does so by exploiting the all-encompassing laws of self-organization, *whose roots are still largely a mystery to us*."[xiii] (my italics)

Morin's principle tetralogical loop of complexity – again, *organization, order, and disorder in mutual and constant interaction* – appears to be central to all complex systems. In a sense, this presents the philosophy of a deeper layer of the disciplinary work of some of his critics. Morin gives examples from every discipline, including: stars and suns in physics, vortices in chemistry, the formation and maintenance of

living organisms in biology, the evolution of patterns that make up ecological systems, processes in social institutions, human psychology, cognitive processes, and ethics.

Like the tetralogical loop, Morin systematically explores the meta-concepts of complex systems. These include: emergence, self-organization, eco-organization, and the relation between self-organization and eco-organization. For emergence alone, Morin offers over thirty definitions in the *Method*. It seems that to extract any one or few of them from context misses the message of the rich nature of this central aspect of so many systems. Understood in this light we began to see the richness of complexity concepts.

Along with the many of the scholars mentioned in earlier chapters, Edgar Morin views complexity as a new perspective, and more specifically as the result of the tremendous shift away from the underlying assumptions of early classical science to that of emerging contemporary knowledge of complex systems. This is at times called the shift from the mechanical universe to the complexity universe. From the cold, chilling universe of celestial spheres, perpetual order, moderation and equilibrium – the universe of Kepler, Galileo, Copernicus, Newton, and Laplace – to a radically new acentric and polycentric universe, opened up to quantum mechanics, systems biology, and the great complexity of social systems.

In arguing for this shift in worldview or perspective, Morin is certainly not alone. Carolyn Merchant, Richard Norgaard, and a great number of other social theorists from the 1970s until today have described this shift from early scientific to complexity in similar terms. Merchant in her famous book, *The Death of Nature,* and Norgaard in his *Redefining Progress*, echoes almost the same terms as Edgar Morin in their descriptions of new views of science, the universe and their implications. The old view fought for clarity and certainty, laws and consistency, while the new view is more accepting of what seems to be a ubiquitous consistency of flux, evolution, and emergence of novel, unpredictable states and effects. The old view tried to reify and build upon knowledge, while the new view accepts the accumulation and complexification of knowledge, while finding it more revelatory to de-reify knowledge, construing phenomena – the material, biological, virtual, and noological – as entities in perpetual process, decomposition, and genesis.

5.3.2. Nicolas Rescher

Nicolas Rescher was the only graduate of Princeton philosophy department to have received his PhD by the age of 22. He is a prolific American philosopher of science at the University of Pittsburg who has written on a broad range of topics

within the philosophy of science. Among this impressive list, he has devoted several books to complexity and its implications. Rescher defines ***complexity*** according to *the quantity and variety of a system's constituent elements and the interrelated elaborateness of their organizational and operational make-up*.[xiv]

The goals of Rescher's work then are similar to those of Morin. However, while Morin has developed a vastly more sophisticated systematization of the knowledge of complexity – from physics to ethics – Rescher offers broad, cursory accounts, with great focus and detail given to explanations of the implications, socially, politically and especially scientifically, of our dawning awareness of complexity. His account is largely an account in the philosophy of science. Rescher focuses on such subjects as: the growth of science and law of logarithmic returns; technological escalation as an arms race against nature; the theoretical unrealizability of perfect science; the difference between complication and complexity found between computers and humans or the "human element" missing from even the most powerful computers; and the daunting dilemma that thus far, complex problems outpace complex solutions.

Rescher offers a truly transdisciplinary definition of complexity theories, including advances regarding the effective conceptualization of transdisciplinary phenomena. As such, his definition of ***complexity*** has several useful dimensions. First, complexity is itself *a complex notion that combines compositional, structural and functional elements.* Second, it is also *a profound characteristic feature of the real*. The world we live in, he says, is an enormously complex system – so much so that nature's complexity is literally inexhaustible. In the end, the descriptive, explanatory project of natural science is something that cannot be completed. Third, *complexity is the inherent force in its own elaboration, as all aspects of the world tend towards increasing complexification.* This definition is quite substantial, and I expand on it at some length at the end of Chapter Six.

Not only complexity complexifies, but science itself complexifies over time. Progress in scientific research, says Rescher, ***complexifies***, which is to say that *as science develops it acquires a growth in technical sophistication that renders science itself increasingly complex.* Thus, the term ***complexification*** refers to *ever-increasing complexity*. Thus, in the course of scientific and technological progress, increasingly, we can see ever-expanding complexity. Therefore, the term *progress* is not only a fallacy of early modern thinking, it is also a misnomer, as advances in science possess a down side, which has become increasingly evident, and is perhaps also occurring to a greater degree, as the furtherance of scientific knowledge takes humankind into realms of ever-greater difficulty.

This is an elegant example of the use of complexity theories to advance philosophical theory with pragmatic applications. While many scholars have critiqued

progress and pointed to unintended consequences, Rescher goes a step further, an explanation of the limitations of progress and the inherent inclusion of unintended consequences, due to the inherent clash between our singular introductions and experiments, and the networked effects that result. Our singular actions are introduced in a world that is profoundly characteristically complex, a world which is at once compositionally, structurally and functionally complex. The action may be simple, but the result will be complex.

This ongoing complexification makes for increasing sophistication, diversification, and indeed disintegration of science itself. The ongoing development of natural science, Rescher points out, requires technological escalation – an ascent to ever-higher levels of sophistication and power. In turn, this escalation is achieved only by means of vast and ever-increasing effort and cost in the generation and processing of information. There are limits to our cognitive capacities, to the capacities of computers or biological robots, and to how much research we can afford to do.

I want to add a few thoughts, complementary to this analysis. In addition, and compounding the problems that Rescher raises, there are several limits that he does not mention, also central to this dissertation. These are limits of *natural resources*, *research funding*, and *time* – especially in relation to the actual progression of the phenomena that are the subject of applied research, e.g. climate mitigation. In light of the potential for intersecting positive feedbacks and tipping points leading towards more degraded and dangerous phase states, the current rapid global crises – food shortages, economic shrinkages, ecological degradation, worsening climate change, and wars – there are also limits to time relative to the changes going on in the world. For instance, climate scientists are all too aware that climate change possesses a time lag of thirty to forty years, so that the policies we put in place now, will only impact the build-up of emissions forty years from now, and the massive emissions of the last thirty years have still not added their full impact to the degree of warming the earth will undergo. Given climate change time lags, much current research may be late or obsolete with respect to the scientists' initial goals. For all of these reasons, notions of perfecting or completing scientific knowledge appear quite out of tune with contemporary understanding.

Additionally, the very conception of what rationality is has been shifting. Making rational decisions in a complex world is an increasingly understood to be a difficult and risky business, as well as an increasingly impracticable one. Increasingly we see that we are incapable of addressing issues beyond a certain degree of complexity, and yet, paradoxically, due to the interconnected, globalized nature of our era, our problems have become more complex than ever. Moreover, due to the novelty of our current late industrial phase, we have a mind-boggling accumulation of

unintended consequences from decades of intensive experimentations in industry and infrastructure. The ability to understand and cope with global issues today – given their increasing complexity, the limitations of our knowledge and control, and the dwindling of energy and resources – seems to slide away from us in an infinite regress. As highly complex problems intersect and accumulate, the way out appears increasingly obscure. This growing complexity thus inhibits our goals and policies through the growing obstacle of confusion and political gridlock.

The infinite regress of our true understanding and control of the world is precisely the opposite of the nature of knowledge accumulation predicted by the eager early classical modern scientists. In his poem Choruses From the Rock, the first stanza ends with a series of lines which have become among the most quoted of T.S. Eliot's poetry. He laments that accumulated information alone does not result in knowledge; knowledge alone does not result in wisdom. These lines are now legitimized and explained by the complexity theory notion of complexification, demonstrating that knowledge complexifies and therefore, that highly reductionist approaches and related technocratic policies appear to lead not to certainty or completion of knowledge; rather, overly reductionist approaches and policies seem to lead to an infinite regress in our knowledge and understanding of the world.

Opening Stanza of T. S. Eliot's poem
***Choruses from the Rock,* 1934**

The Eagle soars in the summit of Heaven,
The Hunter with his dogs pursues his circuit.
O perpetual revolution of configured stars,
O perpetual recurrence of determined season,

O world of spring and autumn, birth and dying
The endless cycle of idea and action,
Endless invention, endless experiment,
Brings knowledge of motion, but not of stillness;
Knowledge of speech, but not of silence;
Knowledge of words, and ignorance of the Word.
All our knowledge brings us nearer to our ignorance,
All our ignorance brings us nearer to death,
But nearness to death no nearer to GOD.
Where is the Life we have lost in living?
Where is the wisdom we have lost in knowledge?
Where is the knowledge we have lost in information?
The cycles of Heaven in twenty centuries
Bring us farther from GOD and nearer to the Dust.

In addition to Rescher's list of the obstacles to coping with complexity, I add several more obstacles, more challenges to knowledge. A major example is that of unintended consequences, and the related concept of vicious circles. Unintended consequences in turn interact in networks, bringing about further unintended consequences, or a vicious circle. There is a vast literature on unintended consequences; major areas of scholarship include the philosophy of science, medical research, health care, economics, political theory, management theory, etc. According to Robert Merton, "virtually every substantial contributor to the long history of social thought" has dealt with the matter.[xv] While Sartre stated that, "everybody has always known that the consequences of our actions always end up escaping us."[xvi]

How should people manage human affairs in a complex world? Rescher says, "very carefully." Again, this affirms Edgar Morin's view that the ultimate implication of understanding the world's complexity, therefore, is that ethics must become fully integrated into the scientific enterprise. In fact, it must in part *guide* scientific research and analyses. If so, our limitedness in the face of a world ultimately too complex for our understanding may not necessarily become an unmitigated tragedy for us.[xvii]

Again, like Morin, Richardson, and complexity scholars, Rescher addresses how complexity operates and affects diverse aspects of our lives. Again, one phenomenon that permeates our lives is that of ***complexification*** or *ever-increasing complexity*. Rescher points out that all of the different projects that are characteristic of the human condition – specifically including the cognitive, the productive, and the social – embark us on such a journey of increasing complexification.

This complexification everywhere produces the same results: increased diversification and specialization and increased difficulty in operation. As doing things becomes easier in the course of so-called progress, the management of affairs-at-large becomes more laborious, costly, and past a certain scale of efficiency, eventually serves to sap its own forces and spur its own demise. Despite the seemingly endless direction of choices, the individual must make delimiting decisions. Yet resources are finite – especially as regards time, labor, and energy. This limitation indicates the significance of personal choice in guiding values and priorities in an increasingly complex operating environment.[xviii] This principle, so significant in socio-economic systems, is at the heart of Timothy F. H. Allen's prescient book *Supply-Side Sustainability* (2002). This book follows in the tracks of Edgar Morin's *Homeland Earth* (1999), which one could say launched the new genre of "***environmental complexity"*** books, *books that utilize complexity concepts to explain or analyze socio-ecological phenomena*.

Nicolas Rescher has laid the groundwork for the philosophy of science arguments regarding the limits to science and knowledge, which I explore in the next chapter.

5.3.3. Basarab Nicolescu

In his book, *Manifesto of Transdiscplinarity*, Basarab Nicolescu states, "As is the case of disciplinarity, transdisciplinary research is not antagonistic but complementary to multidisciplinary and interdisciplinary research. ***Trandisciplinarity*** is nevertheless radically distinct from multidisciplinary and interdisciplinary work because *its goal, the understanding of the present world, cannot be accomplished in the framework of disciplinary research.* The goal of multidisciplinarity and interdisciplinarity always remains within the framework of disciplinary research.[xix] In this way, Nicolescu has perhaps affected, and in any case remains in line with, contemporary consensus on the distinctions between the three main alter-disciplinary terms, and the rationale for developing transdisciplinarity.

Nicolescu's point seems salient, insofar as one considers complex systems to be such that you can never be sure that some aspects of the areas of consideration you omit may in fact be critical to your research questions. This definition of transdisciplinary research may be somewhat dangerous; after all, the scholars engaging in it are just as limited in their capacities with respect to complexity, as outlined by Nicolas Rescher, that one may fairly put all alter-disciplinary research, all research explicitly beyond the bounds of single disciplines, in almost the same category. After all, if one conceives of transdisciplinary research as that which encompasses all aspects of a research question, we would surely never finish any research projects.

Nicolescu's comments on complexity speak to the need for a deeper consideration of transdisciplinary research. Nicolescu says various forces have led to the death of the classical vision of the world, among them the emergence of complexity. In this analysis, then, complexity is seen in a slightly different light – as a source and means of overturning anachronistic aspects of the conceptual framework of science, the font of a richer transdisciplinary framework.

Supplementing this argument, he argues that complexity has overturned early notions of logic *as we have known it*. The ancients considered a fairly comprehensive view of causality – notably Aristotle's four types of causality: material, efficient, formal and final. Early modern science, however, reduced viable causality to one kind: efficient causality. While this works for determinist phenomena, such as physical states, it fails for the majority of phenomena in all other disciplines, such as

social and ecological spheres. Nicolescu laments, "The cultural and social consequences of such reductionism, justified by the success of classical physics, are incalculable."[xx]

Many prominent scholars such as Rene Thom have further discussed this topic. For instance, in evaluating the concepts introduced by Waddington, Rene Thom provided the essential features distinguishing and relating epigenetics and genetics.

> If you were to follow Aristotle's theory of causality (four types of causes: material, efficient, formal, final) you would say that from the point of view of material causality in embryology, everything is genetic – as any protein is synthesized from reading a genomic molecular pattern. From the point of view of efficient causality, everything is also 'epigenetic' as even the local triggering of a gene's activity requires – in general – an extra-genomal factor.[xxi]

Nicolescu supports the view of complexity as both epistemological tool and ontological reality. Complexity in science is first of all the complexity of equations and of models. It is therefore the product of our mind, which is inherently complex. But this complexity is a mirror image of the complexity of experimental data, which proliferate endlessly. Complexity is therefore also a characteristic of the nature of things.[xxii]

Echoes are also heard from the natural sciences, describing complexity phenomena as strikingly multidisciplinary. Albert-Lázslo Barabási said, "We are witnessing a revolution… as scientists from all different disciplines discover that complexity has a strict architecture." In other words, Barabási thinks that patterns of networks are revealing a rule-based method of interpreting structure in a cross-cutting, transdisciplinary fashion. Recall that Barabási's examples of networks include: the World Wide Web and the Internet in computer sciences, social networks of big businesses or Hollywood Stars in the disciplines of business management or sociology, liquid reactions in chemistry, viruses in biology, food webs in ecology, ant colonies in insect biology, and the human brain in neurology. According to Barabási, each of these issues can only be fully understood in terms of varied disciplinary networks within which they are embedded.

5.4. Interdisciplinary and Multidisciplinary Studies

The fields of interdisciplinary and multidisciplinary studies have waxed and waned over the decades. Unfortunately, these three terms are often confused, with each other and with transdisciplinary studies, and used as synonyms. I will try to distinguish these fields as they are commonly used, and how they each relate to complexity studies. It seems likely and useful that these fields will continue, playing a role in the interpretation and understanding of complexity in both social and natural systems. Each one of these areas contributes to complexity studies in distinct and useful ways. Nonetheless, in describing complexity theories, certainly transdisciplinary theory is the most useful, for the reasons that Nicolescu described above. My premises:

- Transdisciplinary research is one of the key epistemological bases of complexity studies
- In large-scale, e.g. socio-ecological systems, many significant study systems must be addressed with transdisciplinary approaches
- Most environmental issues take place at these relatively large scales
- Therefore, transdisciplinarity is necessary to interpreting most environmental issues

Interdisciplinary research is *"a type of academic collaboration in which specialists drawn from two or more disciplines work together in pursuit of common goals."*[xxiii] Interdisciplinary programs sometimes arise from a shared conviction that the traditional disciplines are unable or unwilling to address an important problem. For example, as it became clear that the social analysis of technology was increasingly necessary, many social scientists with interests in technology have joined Science and Technology Study (STS) programs, typically staffed by scholars from diverse disciplines (including anthropology, history, philosophy, sociology, and women's studies.)

Multidisciplinarity, on the other hand, could be described as *collaboration between researchers of different disciplines that does not involve altering ordinary disciplinary approaches or developing a common conceptual framework.* Scholars doing multidisciplinary research interact and discuss the same goal, whereas engaged in interdisciplinary research must go further and actually integration research methods or a common conceptual framework, compromising their usual disciplinary protocol to some degree.

Others distinguish between interdisciplinary research and multidisciplinary discourse. This view would seem to coincide with the main view that interdisciplinary research involves more intimate engagement on the part of two or more scholars from

different disciplines. In contrast, the goal of multidisciplinary discourse is not to do basic research, but to examine the appropriate relationships of the disciplines to each other and to the larger intellectual terrain.

I define ***transdisciplinarity*** as *the study of reality in its multifaceted totality*. While ***transdisciplinary research*** is *research that utilizes whatever disciplinary, inter and intra disciplinary lenses, methodologies, and theories necessary to accurately portray that multifaceted reality.*

5.4.1. Steven Jay Kline

Prominent Stanford physicist Steven Jay Kline devoted a lifetime's career to his love of physics. However, he wrote his last book on how to a kind of philosophy of multidisciplinary systems, a manifesto on why multidisciplinarity is essential to many of today's urgent applied issues. In this last book published in 1995, *Conceptual Foundations of Multidisciplinary Thinking*, Kline argues that it is essential to advance multidisciplinary discourse and that this should cover, at a minimum:

1) The description of one or more overall frameworks that exhibit the place of the disciplines of knowledge with respect to each other.
2) The delineation of what a given discipline can (and cannot) represent in the world. The word "represent" here includes such things as descriptions, taxonomies, understanding, and possibly predictions.
3) The development of insight into the similarities and differences of the disciplines in matters such as the complexity of paradigmatic systems, the invariance of (or variation in) behaviors and principles over time, and the typical variables used in analyses.
4) And study of questions such as:
   A) How the disciplines ought to constrain each other when applied to problems that inherently require knowledge from many disciplines, including examples or specific difficulties that have arisen from lack of this kind of discussion.
   B) Some ways in which scholars can judge when subfields or research programs have drifted into error, nonproductive triviality, or approaches that inherently cannot produce the results sought.
   C) Application of (a) and (b) to at least a few important historical and current examples.
   D) Implications of (a) and (b) for methodology in various disciplines, and in our total intellectual system.[xxiv]

Regarding these four categories, Kline writes that no work he knows of covers all of the four topics listed, or any part of item 4. These gaps, he says, reinforce the idea that we have neglected the area of multidisciplinary study. As I have done repeatedly throughout the dissertation, Kline also stresses that multidisciplinary research is only an addition to the continuation of disciplinary science.

Some would object that these four objectives are impossible. From the perspective of Willard Quine's argument for anti-foundationalism, for instance, Kline appears to be trying to assess a vast scope of issues with a kind of impossible Archimedean point.[xxv] Innumerable scholars have pointed to such issues of the limits of scientific study or the limits of knowledge, as I discuss at the end of this chapter.

Yet, Kline states in his introduction that we must find ways to address applied issues in complex social systems. Kline offers several reasons why advancing multidisciplinary research may advance this goal. First, at least developing multidisciplinary frameworks will give us a better sense of the bigger picture, thus assuaging what he sees as the pervasive anxiety in contemporary society due to the inability to perceive human knowledge as a whole. The plethora of experts seems to us like a tower of Babel, in the face of which we feel confused and disempowered.

Another reason we need multidisciplinary discourse, says Kline, is the existence of emergent properties. While we may be able to understand the parts of a system by looking at them individually, this level of understanding will likely omit key principles of how the system functions as a whole. In other words, the whole does not equal the sum of the parts. That is to say, parts of systems in a disconnected state often cannot do anything like they can when they are all functioning as part of one system. Qualitatively different kinds of parts, when hooked together and wired up, often can do things that precisely the same parts cannot do when they are unconnected. It's true that even systems with homogeneous composition sometimes exhibit emergent properties, although far less commonly.

Again, some would argue that within physics, Kline's principle occupation for over a half century, entire branches of the field have made extraordinary advancement in the articulation of emergent processes. However, while Kline is renowned as a physicist, in this last work he positions himself as a multidisciplinary scholar and wishes specifically to address the distinction between emergence in physical systems with emergence in more complex socio-ecological systems.

The process whereby interactions between parts produces emergence at the level of the overall system is true for animate and living objects as well as inanimate ones. For instance, if you lay out all the bits and pieces of your car in your driveway, the bits and pieces will no longer carry out the main function of a car – to move and thereby transport passengers and belongings. Transport is only a function of the entire car and not of the parts individually.[xxvi] In the case of a living organism like a human being this becomes *all the more obvious*. Take a human apart, and not only will that person not be able to swim, write poetry, or fall in love, rather, he or she will also die, because the body requires a good number of its parts working together in conjunction, for survival.

Type of System	Feedback modes and source of goals	Examples
1. Inert, naturally-occurring	No feedback of any kind; no goals	Rocks, mountains, oceans, atmosphere
2. Human-made inert – without controls	None, but with purposes designed in by humans	Tools, rifles, pianos, furniture
3. Human-made inert – with controls	Autonomic control mode usually of a few variables	Air conditioner/ furnace with thermo-stat; automobile motor; target-seeking missile; electric motor with speed control
4. Learning	Human control mode. Humans in system can learn and improve operations; systems can themselves change set points since they contain humans	Automobile with drive, chess set and players, piano with player, plane and pilot, tractor and driver, lathe and operator
5. Self-restructuring	Human design mode. Humans can look at system and decide to restructure both social and hardware elements via designs	Human social systems & human socio-technical systems: household, rock band, manufacturing plant, corporation, army.

Table 5.2. A hierarchy of systems classified by the complexity of feedback modes[xxvii]

According to Kline, as interdisciplinary work creates more integration than multidisciplinary discourse, transdisciplinary work is seen to create even greater integration, requiring joint methodologies and conceptual frameworks. Again, it goes a degree further than multidisciplinary discourse in that researchers must have intimate familiarity with aspects of a project in order to accomplish a joint task.[xxviii]

5.4.2. Robert Rosen

Biologist and philosopher of biology Robert Rosen, born in 1945 in Brooklyn, New York, became another pioneer of complexity theories. Rosen began his intellectual career studying biology, mathematics, physics, philosophy and history, especially the history of science, and eventually became a student of physicist and

theoretical biologist Nicholas Rashevsky. Throughout his career, Rosen was driven particularly by the question "What is life?" Impassioned by the 1950 article in which Erwin Schrodinger poses this question, Rosen had found his life's quest, which drove his theory of the complexity of biology. His focus was on developing a specific definition of complexity that is based on relations and principles of organization, and a rigorous theoretical foundation for living organisms as what he called anticipatory systems.

Rosen argues that biology requires a "new physics" – a term and an argument he borrows, he says, from Erwin Schrödinger's book, *What is Life?* Schrodinger, says Rosen, was emphatic that biology requires such a new physics to accommodate it. This assertion has been rejected by some as 'vitalism.' However, Rosen argues, attempts to factor the provenance of biology through the provenance of physics (e.g. to factor Mendelian fractionations through molecular ones) have proven impossible, indicating that Schrodinger was correct. Rosen finds that reductionism proves a flawed and inadequate strategy for biology. The modes of analysis used in reductionist accounts have little to do with how organisms are actually put together or with how they work. In particular, in contrast to mechanical systems, organisms cannot be "run backwards," because they do not rely on purely syntactic algorithmic, machinelike modes of entailment.[xxix]

As attack on misplaced reductionism belying the need for transdisciplinary complexity theory is a theme throughout the dissertation, I quote Rosen at length.

> As we have seen, the Mendelian approach [in molecular biology] started from the phenotypic end, and proceeded by fractionating a phenotype of a living organism (e. g., one of his pea plants) into a finite bundle of discrete "characters", each of which was to be separately explained in terms of underlying hereditary, particle-like "factors" or genes.
>
> On the other hand, as a material system, a pea plant can also be structurally fractionated into material constituents, like cells, or nowadays, into molecules, or atoms, or even into more elementary particles. The resulting population of constituent units is regarded as a surrogate for the original pea plant, not because it behaves in any way like the intact plant, but because it consists of (presumably) exactly the same particles. This kind of fractionation is very different from Mendel's, based on phenotypic characters; a set of such characters is a surrogate for the plant, not because it is

> composed of the "same particles", but rather because it behaves somewhat like the original plant does.
>
> Both of these processes are different ways of "reducing" the plant; one to a set of "characters" governed by hereditary factors, and the other to a population of constituent particles. In quite different ways, then, these modes of reduction or analysis could presumably be inverted, to obtain the original plant from the various reductionist fragments arising from the application of the analytic procedures to it.
>
> The central claim of molecular biology is that these different modes of reduction are equivalent. In particular, it claims that it does not matter whether you argue backward from phenotype, as Mendel did, or forward from genome, as embodied specifically in the "sequence hypothesis" which identifies genome with DNA. In fact, it does matter deeply. The question is whether the obstructions which have always beset either line of argument are mere technical difficulties in actual execution of a strategy correct in principle, or whether the strategy itself is wrong.[xxx]

In effect, says Rosen, organisms, as material systems, raise profound questions at the foundations of physics, the science of material systems, itself. There are many reasons to ignore the condemnations of such biologists as Jacques Monod, who was vicious in his attacks on ideas from systems biologists such as Ludwig von Bertalanffy and Robert Rosen. For instance, Rosen argues, "there is nothing 'vitalistic' in asserting that algorithms are the special cases in mathematics and not the reverse."[xxxi]

This is well exemplified in the sequence hypothesis, Rosen claims, which is today widely regarded as completely embodying the mechnicanization of the organism, and as an illustration of the mechanical character of physics itself. Of course, no physicist would make this last claim today. This is important, because we can now overturn the sequence hypothesis, says Rosen, in turn overturning the mechanistic characteristic attributed as a foundation of science, touching upon some of the deeper foundational issues in science.[xxxii]

5.4.3. Timothy Allen

Timothy F.H. Allen is known for his work as a leading theoretical ecologist and for his development of ecological hierarchy theory. In recent years he has also been one of a few complexity thinkers making critical links across C.P. Snow's culture gap, and related disciplinary gaps, alongside Morin and Rescher. As a biologist, Allen's main work began within the principal conceptual framework of theoretical ecology, and in recent books, has moved towards more applied interests such as the implications of complexity for environmental sustainability.

Allen's recent work develops complexity fundamentals – particularly hierarchies and feedbacks – as well as overall complexity theories in both natural and social systems, with respect to applications regarding pressing socio-environmental problems. Allen draws upon Robert Rosen's definition of ***complexity***: *a system is complex when it cannot be modeled.* While many have contested this definition, as of yet there seems to be no argument that has succeeded in debunking the basic idea, which in no way denies the power of models, the need to model, or the ability to effectively model complex systems. Simply put, all models are attempting to model some aspect of complex systems, yet none can capture the full complexity of the system, without being so elaborate as to copy the system, which is impossible. It is in this sense that Rosen and Allen argue that complexity is that which cannot be modeled. Arguments to the contrary seem to collapse. Paul Cilliers, in his excellent book, *Complexity and Postmodernism*, states that ***complexity*** is *that which can be modeled*; however, he follows with a caveat that appears to undermine that statement, namely, that no complex system can be fully modeled, due to the extent, degree and rate of change of complexity in most systems.[xxxiii]

A system cannot be modeled, says Allen, when:

- parts have multiple identities – e.g. citizens and terrorists
- units of measurement are incommensurate
- scale changes become so large as to have qualitative implications – as in gas liquification
- adequate description demands more than one level of analysis – with the vast majority of systems, only by including an upper level, constraining context, can we give a full description of the lower level, and, generally speaking,
- the adequate description of a system demands multiple levels of analysis.[xxxiv]

While the concept remains that reduction and models are necessary to all knowledge, in fact, argues Allen, in the instance of highly complex issues, one may require lots of reductionism and models in initial phases, but in order to interpret that data, one must use analogy and tell narratives. Allen goes on to describe ***narrative*** as: *a set of elaborate scaling operations that make things of different sizes commensurate – earthquake, pestilence, and drought – you can make them commensurate by turning them into events.* Thus, in a general sense and over the long-term but in a sense still present in everyday science, the point of science is to improve the quality of the narratives it tells.

Explaining both scientific and literary methods in terms of narrative indicates the commensurability between scientific and literary methods. One could say in this sense, that a model is a synonym for a narrative, or more specifically that a ***model*** is *a scientific form of narrative*, and a ***persuasive essay*** is *a literary form of a model*. Addressing what they see as the fuzzy line between models in the natural sciences and social theory, science and technology scholars have shown that no scientific process is devoid of the biases, worldviews, and values of the scientist, which may skew the choice, procedure and delineation of her scientific research.

In this way the issue of commensurability seems to be significant across all of the disciplines. We see that in a significant sense, the natural and social sciences as well as the humanities are all ultimately engaged in the same process and ultimately limited and falsified to some degree by the constraints between our observations, perceptions, and interpretations, and the much greater complexity of the real world. Thus, quantitative and qualitative, formulae and words, the components of all three sets of disciplines involve what can be called narrative.

For Allen, the role of models and narratives is multifold. Models: improve the quality of narratives, such as the structural quality, give quantified precision to narratives, provide unequivocal constraints, explicate boundary conditions, define dynamical qualities, emerge from alternatives, and challenge the narratives on which they are based.

True narratives for science must be compatible with what we know or suspect happens. But that does not make a story true. A full chronicle would not only be impossible to capture, it would not be a narrative. (It would be a precise copy, which is abstract and impossible to model.) If no decisions for a narrator exist, then there is no story! Thus, narratives are not about objective truth. They are about conveying interpretation and experience. What narratives do is to develop commensurate experience, not of an external observed object, but of unified observer-observation complexes. Narratives link incommensurate situations. Modeling without a narrative is dangerous. Systems thinking links narratives to models, so as to find trans-disciplines to address a complex post-modern world. In this way, Allen highlights

another quite significant role of complexity theories – they link narratives to models, that is to say, they provide a way of communicating and coordinating between the quantitative and qualitative methodologies. It is possible that in this analysis, Allen has at once proved the significance of complexity theories to both science and philosophy, and also provided an intriguing hypothesis about how we may overcome the gap between science and culture.

Like Nicolescu and others, Allen has his own view of breaking down the barriers between quantitative and qualitative approaches to knowledge – C.P. Snow's famous science – culture gap. Allen says one breaks down the barrier between quantitative and qualitative when one models processes or when one models narratives. Allen and his co-authors attempt to unveil complexity as the everyday commonsense world around us, while speaking to the amazing job society has done so far in covering this up.[xxxv]

Complexity is in full view, in the commonsense world where people encounter it all the time. Unfortunately, there have been some early miscalculations regarding complexity's terrain and claims to fame. For instance, emergence has been rightly outlined as a critical piece of the puzzle. But emergence misses exactly half of the issue, says Allen. Recently, Allen and his colleagues outline what that other half is, and how it provides an overarching view for the rest of the literature on complexity.[xxxvi] One key to understanding the greater picture, Allen says, is that unfortunately, complexity cannot be addressed by putting more effort into what we are doing already. According to Allen, what Jerome Ravetz and Silvio Funtowicz have called 'normal science,' which I refer to as standard science or classical science – the worldview and assumptions of the founders of moden science, Francis Bacon, Descartes, and their cohort – is in strategic error on the matter of complexity. Therefore, technical improvement alone will not do the trick. It is going to take many different sorts of people working in consort.

This is in line with the argument made by Richard Norgaard and Paul Baer in their article, "Collectively Seeing Complex Systems: The nature of the problem."[xxxvii] Norgaard and Baer argue that reductionism cannot account for essential aspects of biological and social systems, therefore a more adequate grasp of highly complex systems must come from collective and collaborative efforts between large groups of scholars from many disciplines. Norgaard for instance participated in this kind of collaborative effort to better 'see complex systems' in his work on the Millennium Ecosystem Assessment, discussed in Chapter Six.

Unfortunately though, says Allen, engagement in this approach so far has been limited**.** In his view, in the United States at least, the business world has made the best efforts to grasp and utilize complexity, where success is achieved through "quick wits, intelligent caution, and real time practice." Sciences dealing with self-

evidently complex situations, such as ecology, have avoided engaging the real thing, "remaining content to engage often less helpful, more routine enterprises." Although complexity requires new ways of thinking philosophers have remained aloof preferring to detail the "niceties of normal science." Moreover, Allen laments the influence of big money on much of the spheres of scientific research and development and the resulting influence of technocratic analyses and industrial, technological pressures. Allen postulates that in a world of "gadgeteers, masquerading as scientists" – a phrase he borrows from a 1931 quote of Robert Maynard Hutchins, revealing how long the ties of industry and science have been problematic in the United States – "many humanities scholars seem too demoralized to even enter the complexity field."[xxxviii]

In the end, however, all these actors and all these disciplines are needed to engage in a new system of thought wherein science interpreted in the narratives of the humanities is applied to real time issues of people in business and elsewhere. Complexity is a new frontier, wherein humanity must be bold enough to break with the past, and dare to imagine beyond simple, if complicated, analyses. Complexity matters, claims Allen, for the survival of the most important human enterprises, and a mastery of it may even be required for a continued civilized existence.

5.5. Environment and Ecology

Ecology was popularized by Rachel Carson's 1962 book *Silent Spring*. Many systems thinkers were struck with the fact that ecology seemed to be the systems science par excellence. Ecology treated living systems, small and large, automatically delineating concepts of systems within systems. Indeed, theoretical ecologists have in many ways taken the lead in adopting the complexity framework for approaching social-natural issues. Timothy F. H. Allen is but one theoretical ecologist who has worked increasingly on applied environmental issues. A number of prominent theoretical ecologists have shifted their focus similarly, including: Frank B. Golley, Fikret Berkes, C.S. Holling and Lance Gunderson, among others.

Of this group, the prominent ecologists C.S. Holling and Lance Gunderson coordinated and wrote much of a large compilation of essays on socio-natural systems called *Panarchy*. In this book and related literature, ecologists alongside some social theorists elucidate many complexity terms. To these transdisciplinary ecologists, ***complexity*** consists in *self-organized systems created and maintained by a small set of critical processes, which make up living systems of people and nature. Those critical processes include cycles of carbon, water, nitrogen and other substances that play a key role in ecosystem functioning, as well as ecosystems services.*

Characteristics of complex systems include: diversity and individuality of components, localized interactions among components, and an autonomous process that uses the outcomes of those local interactions to select a subset of those components for enhancement. These processes establish a persistent template upon which a host of other variables exercise their influence. Such "subsidiary" variables or factors can be interesting, relevant and important, but they exist at the whim of the critical controlling factors of variables.

Complexity can be seen to be increasing in terms of both interactions of systems and the creation of new ecological problems. The social theorist and complexity scholar G Gallopin, who collaborated on *Panarchy*, points out three facets of complexity that represent a broad view of the field: ontological, epistemological and political, or decision-making. For Gallopin, the complexity of the interactions and problems in human and ecological processes is increasing for reasons associated with each of these facets of how we can understand complexity itself. First, we are impacting the ontological complexity of the world – human-induced changes in the nature of the real world are proceeding at unprecedented rates, resulting in growing connectedness and interdependence at many levels. Carbon from fossil fuel burning mixes with carbon from deforestation, and join together to force global climate change.

Changes in our understanding of the world include the modern scientific awareness and behavior of complex systems. Using more complex concepts and models, we come to see that unpredictability and surprise may be woven into ontology, the fabric of reality, at both the microscopic level (shown by Heisenberg's uncertainty principle) but also at the macroscopic level, as abundantly illustrated in questions of socio-natural changes and challenges.[xxxix]

These ecologists and their colleagues are largely motivated to understand complexity due to the need to resolve critical issues of social and natural sustainability. They suggest that the study of complex systems and their characteristics may help to answer such questions as: How are self-organized patterns created and sustained in ecosystems and on landscapes at different scales, from meters to months to thousands of kilometers and millennia? How do such patterns, the processes that produce them, and species' adaptation, sustain critical ecological functions across those scales? How can we understand the role of diversity in allowing and modulating adaptability in a wide range of settings, from biodiversity to evolution to the diversity of ideas and its influence on human adaptability to changing circumstances?[xl]

Despite explosive scientific advances, they say, the dynamics of complex ecological and socioeconomic systems are difficult to understand and predict. Yet our ability to anticipate and change the future depends largely on our ability to comprehend complexity. Both ecological and social systems share complexity characteristics such as the absence of a global controller, a hierarchical organization, dispersed interactions, and the ongoing creation of novelty, selection, and adaptation.[xli] Dynamics depend on history and lead to multiple possible outcomes. Therefore, a fundamental question is the degree to which system properties are environmentally determined versus the degree to which they are self-organized.[xlii]

A fundamental problem with current research is that in both ecology and in social science, linear tools dominate empirical research. Linear methods almost always prove superior to nonlinear ones for practical analysis and policy implementation. There is evidence of important nonlinearities in alternate states of ecosystems[xliii], spatial patterning of ecosystems[xliv], and clumped or discontinuous size structure of ecological communities.[xlv] Current paradigms seem to fall into two clusters: one consisting in gradual reversible change described by adaptations of linear methods; the other embracing surprises, hyteresis, and irreversibilities that imply fundamental nonlinearities. Thus, scientists should be asking themselves when the weight of evidence indicates that complexity-based approaches add significant value for understanding or forecasting the system. Policy analysts should be asking when plausible nonlinearities create risks and opportunities that have low (but nontrivial) posterior probabilities but extreme utilities.[xlvi]

Ecologists concerned with sustainability have made serious inroads into multidisciplinary studies as well. *Panarchy*, for instance, makes an argument for creating sustainability based mostly on complexity concepts and how they help us to better define, understand and manage complex socio-natural systems. ***Sustainability***, according to the authors, *is the capacity to create, test, and maintain adaptive capability,* so it is a concept based largely on the concepts of resilience and adaptation in complex systems.[xlvii] Likewise, ***development*** is *the process of creating, testing and maintaining opportunity, thus applying the same concepts in human systems*. Seen in this light, the term sustainable development is not an oxymoron at all, but rather a logical partnership of forces present in a complex system as it evolves. ***Sustainable development*** can thus be defined as *the goal of fostering adaptive capability and creating opportunities.* Other ecologists have corroborated this view, defining ***sustainability*** as *the maintenance of the small set of critical self-organized variables and the transformation that can occur in them during the evolutionary process of societal development.*[xlviii]

Panarchy is focused on questions that involve both social and natural systems, and therefore on complexity concepts as applied to both natural and social systems. For instance, their discussion of adaptive cycles is geared toward application to complex socio-natural systems. As such, after their definitions and initial analyses, they give concrete thoughts regarding application in both natural and social systems.

A chapter on discoveries for a sustainable future is co-authored by two ecologists and two social scientists. In it they discuss alternate states and adaptive cycles. Alternate and alternating states arise in a wide variety of ecosystems, such as lakes, marine fisheries, wetlands, and forests.[xlix] Some economic and social systems also exhibit multiple states. One example is the concept of convergence clubs in economic growth theory; another is pluralist politics involving different scales of government and different organizational frameworks.[l]

The authors site three complexity characteristics universal to many disciplines: potential acquired, connectedness, and resilience or "its opposite, vulnerability."[li] Next, they give examples in the various disciplines. Physical systems lack chance inventions and mutations and have limited potential for evolutionary change. There is little or no accumulation of novel potential (mutation, inventions, or exotics) that can subsequently act to change system response. Examples include plate tectonics and sand pile experiments. These systems exhibit periods of instability and reorganization, but not novelty or mutation.

In contrast, living systems vary greatly with regard to the question of their adaptive cycles. Some ecosystems – pelagic, open water communities, or eroded semiarid savannas exposed to rare, unpredictable rain events – are neither controllable nor predictable. In such systems, individuals develop extensive adaptations to

variability. One example is the lifestyle of elephants living in African desserts, traveling some fifty miles per day in search of less frequent and more diverse food sources, such as the nutritive roots of grasses ignored by elephants in more abundant ecosystems. Some living systems however can control variability over some scales, and thus show the full cycle of four phases of adaptation – growth, rigidity, collapse and reorganization. Examples include productive temperate ecosystems and large bureaucratic social organizations.[lii]

5.6. Science and Technology Studies

Science and Technology Studies (STS) is one of several transdisciplinary humanities fields examining the intersections of society, environment, and technology which have proliferated in the last two decades. Science and technology studies (STS), also known as the social studies of science (SSS) is a major field boasting several journals. Moreover, the field has drawn a great number of academics in dispersed fields of the humanities and social theory that identify with the field's topics and tactics.

In a recent overview of the field Mario Biagioli said that while on the face of it, the definition of science studies would appear to be a simple matter, in reality, "practitioners are dispersed over the widest range of departments and programs."[liii] Science studies is a profoundly transdisciplinary approach to appreciate some of the greater issues at play in social, technological and global environmental change today. Biagioli also notes how the field of science studies has been demonstrating the qualities of complexification noted by Nicolas Rescher, which I describe at the end of this chapter.

> As science studies produces more empirical work, it further 'disunifies' itself methodologically while producing increasingly complex and 'disunified' pictures of science, a double trend toward disunity that dissolves neither the field nor its subject matter.[liv]

The central premise of science studies or STS is that in the wake of certain failings and dangers inherited from the modernist project, we must study science itself, and the technologies it produces, and we must reevaluate our perspective on our enterprise of knowledge-making. Failed fundamental assumptions of modernism are still largely operative within the major projects of science and technology. While scientists, engineers, and technocratic experts have become engaged in many areas of complexity and other sciences that are at odds with the core assumptions of early classical science, nonetheless, they have not always adequately revised their views or methods. The impact of the ongoing modernist assumptions has a tremendous impact on the processes of science and knowledge creation, technology, and on societies and environments.

Still, as initially perceived, science is the purview of trained elite conducting experiments via empirical observation. However, the objectivism and certainty ascribed to science has largely given way to a more nuanced view. Science does yield 'objective' truths that can be invaluable in guiding society. However, science is also co-opted by powers guided by sundry biases and values at each phase in any

enterprise – in the choice of systems studied, the framing and worldview of scientists overlaid on the formulation and procedure of study, and the response to results, including omitting and ignoring them.

The process by which values and biases of scientists and the public – through choices, funding, voting on research funding, and other mechanisms – that allows science research and development to evolve in some ways and not others is known as *scientific constructivism* or *social constructivism*. ***Scientific constructivism*** is thus that view that *science is an enterprise that is constructed by human decisions and manipulations, in which some more or less objective data are favored over others, directed through a series of increasingly complex choices, which requires an increase in democratic regulation, in accordance with the increase in complexity.*

One of the cornerstones of Nineteenth Century science has now been uprooted by insistent uncertainty. As high degrees of uncertainty become internalized as inherent to science, this calls for a shift in the focus of policymakers, focus uncertainty to risk. Hence the need for Ulrich Beck's groundbreaking 1992 book, *Risk Society*, one of the classics of STS, discussed in Chapter Four.

Shortly after *Risk Society* appeared, two scholars published an influential article on this new risk framework. Silvio Funtowitz and Jeremy Ravetz called their topic 'post-normal' science. In redefining the boundaries of science and policy, enlarging them to include that which lies external to the disciplinary work of modern science, Funtowitz and Ravetz focus on several key axes: Kuhnian puzzle-solving vs. Kuhnian paradigm-shifting; basic science vs. applied science; and the axis of risk and ethics. They also make critical qualitative differentiations in the study of science, such as the orthogonal relationship in scientific data between uncertainty and quality. Uncertainty, they point out, is an attribute of knowledge, while quality is a pragmatic relation to knowledge. Thus one can distinguish between information of high certainty but little value versus information of low certainty but high value. In other words, study systems comprising high certainty often translate into information that is of little quality or value for analyzing or acting upon complex events, while information about which there is little certainty may nonetheless be of good quality for a certain function or understanding of complex events. Indeed, highly uncertain information about climate change may yet be very high-quality information, in our quest for sustainable societies.[lv]

The authors develop a chart encapsulating this principle, broken into three tiers of less to greater degrees of certainty (and corresponding drop in quality) in knowledge-making. This heuristic tool delineates the range of narrow to broad types of problems in relation to degrees of uncertainty, showing that uncertainty is orthogonal to significance of content or quality of information for interpreting content.[lvi]

Zones of scientific work defined in this conception range from basic science, to applied science, to ethics. First, is the inner core of puzzle-solving in the Kuhnian sense, or basic advancement within the scientific disciplines. A great mass of research yields information on behavior of materials or processes, in controlled settings. Second, is the realm of professional consultancy, in which scientific data is plugged into cost-benefit analyses. As every local environment has novel features, scientific 'universal principles' are parsed through analysis of uncertainty versus necessity of policy. Third, beyond professional consultancy lies the realm of post-standard, post-classical, or 'post-normal' science.

Indeed, in this realm lie our most complex social and environmental issues, many of which rank as critical issues facing humanity. Here we see that uncertainty is orthogonal to significance. So this realm encompasses issues of both extreme decision stakes and extreme uncertainty. Therefore, contemporary approaches to knowledge or 'post-normal science' requires that we integrate narrowly defined problems into the larger encompassing issues.

Some scientists use science studies literature to express the arguments they make based on complexity. One aspect of 'post-normal science' is the increasing frequency of issues that require timely policy despite a lack of scientific certainty. As I will describe in greater detail in the next section, leading climate scientist Stephen Schneider argues that the deep uncertainties – in both probabilities and consequences of the climate problem – has been underestimated and very poorly integrated into leading climate analyses. Moreover, these uncertainties may not be resolved until the objective data is available, that is to say, long after policy decisions must be made to mitigate the effects of climate change. In fact, the climate change debate is likely to remain in the realm of the highly uncertain for decades to come. clearly beyond the maximum acceptable time needed to change policy.

Therefore, says Schneider, decisions must be made not based on resolving uncertainties, but rather, based on weighing risks.[lvii] Decisions about climate policy require subjective judgments regarding the weighing of risks, where ***risk*** is defined as *the probability of harm.* This implies that not only the conclusion but also each part of the equation requires some subjective analysis. Examples of significant uncertainties about climate change include the highly debated climate sensitivities, as well as the outcome of several poorly understood possibilities of abrupt nonlinear feedback events, such as the collapse of the circulation conveyor belt in the North Atlantic Ocean[lviii] or the rapid deglaciation of polar ice sheets. Such abrupt changes or ***surprises*** are defined as *rapid, nonlinear responses of the climatic system to anthropogenic forcing*.[lix]

Science studies scholars Simon Shackley and Brian Wynne go farther in explaining the distinction between uncertainty and risk in climate change policy.

Shackley and Wynne point out, for instance, that the complexities of socio-natural issues such as climate change policy are mired in uncertainties, and how scientists and others must learn to "allow for a discussion and negotiation of uncertainty that spans the boundary between science and policy and defines the discourse of a common science-policy culture."[lx] However, the damaging effects of uncertainty can be limited if certainty about uncertainty can be achieved.[lxi]

Many science studies scholars argue that scientists must achieve greater clarity on how much uncertainty climate change policy makers must cope with. For instance, Shackley and Wynne claim, most current long-term climate change modeling is treated as if the potential for prediction has been realized, even though the expressed aim of the World Climate Research Programme, set up in 1980, was to test this question. All such modeling "begs the question of whether the particular model used is sufficiently realistic to display the nonlinear dynamic properties of the climate system… The key uncertainty as to whether the long-term climate is predictable is obscured in the ambiguous identity of models as both predictive truth machines and useful intellectual conventions or heuristics."[lxii]

When we must make decisions about feedback in climate change before the data are all in the science cannot cover enough of the larger issue to affect control or an appropriate public response. When values enter the discourse, all bets are off as to scientific findings. Scientists finding themselves in the arena of governance must take their best shot without doing the definitive science. Issues including large uncertainty bands with high potential risks are increasingly causing scientists to rethink the wisdom of basing policy on degrees of certainty. Such dilemmas have led to an interest in STS and other fields in making ethical decisions, in cases where definitive science is not an option, but the stakes are high.

The science produced on such complex topics is interpreted in a new light. Thus, it is not that science is new (it's not), but rather that certain types of study systems and interpretations of them are new. This occurs when science addresses highly complex study systems. Thus it might better be named, 'post-normal topics or analyses.' At any rate, what is implied by 'post-normal science' is not a new kind of science, but how our interpretation and understanding of scientific results changes in some kinds of cases, for instance when it is employed to understand increasingly complex systems of study such as climate change.

Some make a stronger distinction between normal and post-normal science, questioning whether science *can* address complexity, in the full sense of the term. Some critics object that global climate models (GCM), for instance, cannot sufficiently predict climate change. Another issue is the realization that searching within complex systems for universal causal mechanisms is fruitless. Crick's search for the true mechanism of consciousness, says Allen, is the search for the "true linear

approximation" of consciousness. A true linear approximation is an oxymoron; it makes no sense. While it may be hard to get most scientists to admit to being mechanists in this sense, the logic of this objection, Allen says, is sound. He sees this as both the Achilles heel of contemporary science, and the demonstration that standard science does not address complexity, at least not in the full sense of the term. Based on arguments such as these, Allen supports Morin's distinction between restrained and generalized complexity.

5.7. Philosophy, Philosophy of Science, and Applied Philosophy

Complexity has been present in philosophy from the earliest history and remains central to philosophy today, albeit often under the guise of different terminology. At the same time, philosophers increasingly are working with and advancing the field of complexity theories. I contend that complexity theories are essential to the advancement of philosophy, and that philosophy is necessary to the advancement of complexity theories. Yet, few scholars have explored these potentially significant contributions of complexity theories to philosophy and vice versa.

I analyze how complexity may contribute to philosophy, hypothesizing that complexity is essential not just to the substance of major debates in philosophy, but to their articulation and development. I laid the groundwork for this in Chapters Two through Four, in which I showed the significance of complexity theories in the natural sciences, social sciences, and various approaches to transdisciplinary studies. I pursue the argument of complexity and philosophy in three parts. First, I argue that complexity has a major role to play in each of the four major areas of philosophy – ontology, epistemology, ethics, and phenomenology. Moreover, it seems that these influences are not coincidental, but rather interrelated.

In the second part of my argument, I explore just one of these debates in-depth: the role of complexity in debates regarding the limits to knowledge. I explore how uncertainty and unknowability as understood in the complexity framework relate to philosophical debates about the limits to knowledge and knowability. I argue that the ways in which complexity theories reveal greater types and degrees of uncertainty and unknowability not only serve to debunk early classical assumptions of certainty and the potential for deterministic knowledge of all of reality, but also, it changes the basic register with which one should see such arguments in the philosophy of science. In short, if one agrees with the basic need to shift from the early classical perspective to the complexity perspective, it follows that this shift will reveal itself throughout the major debates in the philosophy of science. In other words, complexity theories help us to assess if our world is one of certainties, uncertainties, or both. Questions regarding how much certainty science can provide, for what kinds of questions, and how well this may work, belong to the domain of philosophy.

Finally, third, I give a very brief survey of what the implications of this argument with respect to the limitations of knowledge, discussing Nicolas Rescher's concept of complexification, and touch on the major and wide-ranging implications of this view, for complexity theories, and for knowledge more generally.

There is a coevolution taking place between complexity theories and the philosophy of science: complexity theories are being developed throughout

philosophy, while at the same time philosophical analyses are helping to explain the nature, significance, and place of complexity theories in human knowledge. The discussions in this chapter evoke the significance of uncertainty and unknowability while they also help to explain, contextualize and show how scientists and scholars can adapt to advanced understanding of uncertainty. The lesson of these analyses of complexity in philosophy today is that complexity theories both reveal and explain the inherent uncertainty in science, in knowledge, in the world, and therefore in many of the important issues facing societies today.

5.7.1. The fields of philosophical knowledge – ontology, epistemology, logic, ethics, and phenomenology

The sub-disciplines that make up philosophy have changed over the course of human history, in relation to new ways that we see the world, and thus new fields of philosophical study. In ancient times, all of philosophy was organized within the catch-all category of ***metaphysics***, literally *the nature of life at the broadest level*. By the Middle Ages philosophy had broken down into three fields: metaphysics, epistemology, and ethics. In the last few hundred years this splintered again into: metaphysics, ontology, epistemology, logic and ethics. In recent times, according to some philosophers, the umbrella field of metaphysics was subsumed by ontology, effectively vanishing, and a fifth branch was added, phenomenology.

According to this new set of distinctions, ***ontology*** is *the study of what is*; ***epistemology***, *the study of knowledge* or *how we know*; ***logic***, *the study of valid reasoning* or *how to reason*; and ***ethics***, *the study of right and wrong*, or *how we should act*; and finally, ***phenomenology*** is *the study of our experience, how we experience*.[lxiii] These distinctions are interesting in assessing where complexity lies concealed by other names. My main goal in this section is to argue that complexity is found in each of the above areas.

Indeed, complexity theories and the quality of unknowability that they reveal seem to inform the very criteria used to differentiate philosophy into its subfields. Degrees of complexity and knowability underlie the criteria that distinguish the branches of philosophy into a hierarchy of lesser to greater complexity. Mathematics and logic form the base of this hierarchy, the study of the most verifiable aspects of our world, largely the material aspect of metaphysics. Mathematics can and has become incredibly complex, indeed, beyond a certain point they it appears elusive to most of us, yet it still seems that mechanical physical systems are the least complex systems as compared to other realms of knowledge. Perhaps mathematics ultimately are just as complex as consciousness or tangled ethical quandaries, or perhaps Kline

is still correct that they are in a significant sense less complex. Ontology stacks atop this base, as the study of other aspects of the world that are not entirely verifiable, but not the most complex. Thus, we could conceive of a typology of less to more complex objects of ontological study, according to the numbers of variables and interactions that they contain, as Kline has done. Epistemology could almost be seen as a bridge between ontology on the one hand, and phenomenology and ethics on the other hand, in the sense that through a kind of feedback of understanding between our world and ourselves, we increasingly must refine epistemology to incorporate greater complexity as we discover it. As we do so, we gradually absorb more complexity into our ontology as well.

Viewed in this light, phenomenology is the study of the most complex aspects of reality, which cannot even be conceptualized without exploring the most complex aspects of life – such as the brain, again, the most complex object known – and without recognizing the extraordinarily complex phenomena that brains give rise to – such as consciousness, emotions, and ideas. By adding the fifth category of phenomenology, philosophers are acknowledging one of the complexity fundamentals, which is to say, the fundamental aspects of complex systems, more or less ubiquitous to reality – feedback or ***reflexivity***, which is *the corollary used in the human sciences and philosophy to refer to a force affecting its environment in such a way that it is fed back and reinforces the initial force*. Phenomenology highlights the reflexive interactions between experience and intelligence.

Finally, the apex of the hierarchy of philosophical studies is ethics, as ethics necessitates understanding and synthesis of all of the other domains of philosophy. One requires understanding in ontology, epistemology, and phenomenology, as well as many other disciplines such as politics, social sciences, and environmental studies, in order to make decisions about how to best conduct human lives. In this sense, ethics seems to be the most complex field of study.

Eventually, if complexity were to fully infuse philosophy, ontology might become best defined as the study of complex systems; phenomenology the study of ongoing dynamics and experience of complex systems; and ethics the study of how to act in such a complex world. Therefore, incorporating complexity theories fully into the study of these philosophical fields, in turn, might help to explain the nature of each of these areas.

The value of the meta-perspective of complexity theories and their transdisciplinary dimension is vast, as the myopia of current more specific training, far from the initial scientific goals of giving more unification and validation to a particular perspective on where we are headed, seems to allow just the opposite. The discourse of popular futurology still holds that there are no limits to human inquiry and ingenuity. For instance, some hold that medicine will prevent the human aging

process, prolong life indefinitely, and that civilization will fully occupy distant planets. Meanwhile, where most scholars studying the social and environmental realms see no limits, is in the problems that the progression of knowledge, science, and technology has brought about – long-term toxicity, climate change, deforestation, oceanic dead zones, and concerns such as the potential collapse of rainforests. Some think that human societies are clever enough to successfully inhabit space, while astrophysicists have begun to note that if even as many as five more satellites were to be destroyed in space, the degree of space debris would be so great as to disallow the further use of satellites or spaceships altogether. Gregg Easterbrook postulates that the 21st Century is a paradise, while Sir Martin Rees argues that we only have a fifty percent chance of even surviving it. After years or these two completely dissonant voices in public discourse, the more educated public increasingly seeks more sophisticated synthesis of knowledge today, in hopes of more realistic analyses.

5.7.2. Limited versus Limitless Science

Complexity appears to be essential in informing the debate regarding the present and ultimate limits or limitlessness of science, in terms of assessing uncertainty versus unknowability and in terms of the potential for ultimate explanations. First, in shifting from the early classical views, we see that science does not result in an accumulation of truths, an accumulative knowledge, at least not in the way we had conceived it. According to philosopher of science John Barrow, science with complexity is still accumulative: we accumulate more facts, broader theories, better measurements and advances in the creation of ever more powerful machines. Though, this rate of growth is limited by the increasing costs. On the other hand, philosopher of science Nicolas Rescher distinguishes between the classical view of knowledge accumulation versus Barrow's notion of it. It's not just that there is knowledge that remains 'veiled.' It's that the very direction of science is not one of accumulation, in this critical sense, at all! Through the development of science, knowledge is not accumulating more truth.

Rather, through the development of science, knowledge is ***complexifying***. Again, Rescher argues that the major characteristic of the real world and of our knowledge, is that it ***complexifies***, or that *as science develops it acquires a growth in technical sophistication that renders science itself increasingly complex.* Thus, the term ***complexification*** refers to *ever-increasing complexity*. Thus, in the course of scientific and technological progress, increasingly, we can see ever-expanding complexity.

I add that the more that science proceeds along the course of complexification, the more the vision of the completion of science becomes absurd. The more science proceeds, the further we are from knowing everything. One could argue that the more science proceeds, the less is known, the less certainty there is, or that the more one has understanding of particularities, the less one has general understanding. Therefore, the more science advances, the more the notion of understanding recedes. In stark opposition to early classical hopes of accumulating truth or understanding, in the sense of acquiring and integrating more knowledge, in fact, it seems that the more we accumulate knowledge, the less understandable that knowledge becomes.

Some might argue that this is a case of complexity science gone awry; complexity theorists have a complex peg, and so all they see are complex holes, or problems that require complex pegs. Some physicists in the complexity field still see science as an accumulative process that can eventually know everything. Geoffrey West, President of the Santa Fe Institute, and many of his colleagues at SFI share this view.

> Look at how much we have understood in the last 300 years! It's fantastic. Imagine if we continue for another 300 years, another 3,000 years, how much we may understand! Yes, I do think it is unlimited. You might say that there are some subjects – love, poetry – that science cannot understand fully, but I don't think so, and we cannot say that it cannot know everything. There is no reason to think that science cannot continue to progress as much as it has been. Science has proven to be incredibly powerful. Eventually, science can explain everything.[lxiv]

Others, such as Yaneer Bar-Yam of the New England Complex Systems Institute, demonstrate more caution. As a physicist, Bar-Yam is far more optimistic about the ability to understand human civilization than more experts in the humanities, yet he thinks that complexity reveals limits both internally and externally to scientific studies.

> It should be understood that a mathematical model that is used to capture a particular aspect of two systems does not necessarily capture other aspects. Similar to qualitative analogies, the relevance of mathematical models to describing a system is limited. This is particularly true when we consider the modeling of complex systems where by their very nature simplified mathematical models cannot capture the full description or complexity of the system being modeled.[lxv]

In this context, he says, while the more highly complex systems, e.g. human civilization, poses the greatest challenge to complexity theories, this also implies that the more highly complex study systems are, the more that complexity analyses of these systems find their greatest opportunity for contributing to our understanding. "It is precisely the application of general principles of complex systems that can teach us about human civilization." Moreover, "rather than rejecting the qualitative analogies between human civilization [and other highly complex systems such as environmental systems] and other [simpler] complex systems, the theory of complex systems may reveal both their validity and their limitations." Analogies should not be dismissed out of hand; neither should they be taken beyond their realm of validity. In this respect, he is in accord with generalized complexity scholars such as Stephen Jay Kline and Kurt Richardson.

However, Bar-Yam notes, "It should be emphasized, however, that there is a realm beyond which science cannot go." Neither, the unique aspects of the existence

of a single organism, nor the unique aspects of an organism's environment, can be predicted by science. There will always be aspects of the human environment that cannot be predicted, but rather, can only be experienced.[lxvi] Of course, some humanities scholars and philosophers go much further. Along with the philosopher Nelson Goodman, many ask, "How do you go about reducing…James Joyce's world-view to physics?"[lxvii]

One way to try to disprove the optimism of physicist complexologists such as West is to prove the argument that science is in fact not accumulating but ***complexifying.*** If science is becoming increasingly more complex, than it is becoming increasingly less comprehensible to us, and it would seem, increasingly less comprehensible period.

As reference points, it is useful to recall various claims to simplicity that have been successively overturned from the early scientific period until today. Early on, a fundamental wedge was levied beneath the cornerstone of simplicity, the early classical view that the universe is composed of simple elements. Founding fathers of early classical science – Leibniz, Descartes, Locke and Hume – thought of three elements as simple: colors, elemental particles, and numbers. Since they thought these elements were simple, therefore they thought that the simple must be regarded as an ontological category. So they held that understanding that which is simple also must be simple, because it is easily recognizable. Therefore, simplicity was seen to describe two categories – the ontological and the cognitive. However, a colorless nature is not nature. Nature is not colorless when not perceived of in interaction with minds. Therefore, color is not a simple element. Rather, it is at once, a chemical interaction, an experience, and an aspect of our experience of nature. It does not exist as a simple entity in any way.[lxviii] Similarly, of course it is now known that the atom is neither elemental nor simple, but rather highly complex, and that numbers are but abstractions for complexity.

Not only has science proven that simplicity does not exist, but moreover, according to Rescher the history of science is "an endlessly repetitive story of simple theories giving way to more complicated and sophisticated ones." Of course, we constantly seek to simplify science, striving for an ever smaller basis of ever more powerful explanatory principles. But through simplicity we discover complexity. In fact, complexity theories present the attempt to do this at the next greater level of detail and sophistication. This is one way to explain clearly the fact that complexity in no way replaces science or the scientific process, but is merely a new, transformative, accretion.

What Rescher wants to point out is that in the course of this endeavor, the attempt to simplify, we invariably complicate the structure of science itself. And I would add, it is through this process of simplifying scientific studies, that we also

complicate the nature and structure of knowledge itself – create the need for ever more finely spliced disciplines, ever more information, and even means of storing and transmitting information. So, we do secure greater power, e.g. functional simplicity, but at the price of greater structural complexity. As Rescher says, by the time the physicists get that grand unified theory what they will have will be so complex as to be likely far beyond comprehension. The math gets ever more powerful and elaborate; the training time to understanding only increases; etc. So despite its quest for greater operational simplicity (economy of principles) science itself is becoming ever more complex (in its substantive content, its reasoning, its machinery, etc.). Therefore, simplicity of process is more than offset by complexity of product, and so this ongoing complexification exacts a price of diminishing returns. Nicolas Rescher describes this process:

> The Greeks had four elements; in the 19th century Mendeleev had some sixty; by the 1900s this had gone to eighty, and nowadays we have a vast series of elemental stability states. Aristotle's cosmos had only spheres; Ptolemy's added epicycles; ours has a virtually endless proliferation of complex orbits that only supercomputers can approximate. Greek science was contained on a single shelf of books; that of the Newtonian age required a roomful; ours requires vast storage structures filled not only with books and journals but with photographs, tapes, floppy disks, and so on. Of the quantities currently recognized as the fundamental constants of physics, only one was contemplated in Newton's physics: the universal gravitational constant. A second was added in the 19th century, Abogadro's constant. The remaining six are all creatures of twentieth century physics: the speed of light (the velocity of electromagnetic radiation in free space), the elementary charge, the rest mass of the electron, the rest mass of the proton, Planck's constant, and Botzmann's constant.

Therefore, Rescher concludes, the course of scientific progress is not one of increasing simplicity. In fact, just the reverse is true! Scientific progress is a meter of complexification because overly simple theories invariably prove untenable in a complex world. The natural process of scientific inquiry impels researchers to ever more complex, ever more sophisticated descriptions. Our methodological commitment to simplicity and systematicity is necessary, but it is ontologically unavailing. Science over the last three hundred years may have proceeded by

simplification, but it has resulted in complexification. We should not let method blind us to the ever more complex ontological picture that science has presented us with, the substantive discovery of complexity.[lxix]

It would seem that the vast complexification of science should in fact be obvious by now. After all, in every discipline, scientists and social theorists alike are aware of the ongoing splintering and subdividing of disciplines; the ongoing escalation of jargon and incomprehensibility between even the closest scientific niches; the massive accumulation not just of quantity of information, but of its increasingly disparate, unarticulated nature. Every area of human lives becomes more complex with the concurrent development of science and technology.

First there was the tree branch torch, then the candle, next the incandescent mantle light, and finally the electric bulb. Each advance created with it a growing infrastructure. For the tree branch all you needed was a tree branch and a spark. For a candle, a knife, string, beeswax, and a simple match suffice. For the incandescent mantle light, you need factories producing lamps, matches, kerosene, and kerosene bottles. Thus, for incandescent mantle lanterns, it is natural to produce trucks and gas stations to haul them. Moreover, the electric bulb requires a bulb factory, the wiring of houses, and the dispersion of power stations and major manufacturing of electrical power. Similar patterns can be discerned for most discoveries and advances.

A distinction between the advances of knowledge in different realms is very instructive. Newtonian physics of course continues work for innumerable mechanical operations like flying airplanes. In such systems laws do work and prediction is essentially perfect and unchanging. In stark contrast, as we have seen throughout the earlier chapters, in other kinds of systems, more complex systems of the natural and social realms, systems do not remain unchanged, and there are no reliable means of prediction of this sort. When natural scientists and social theorists argue on this point, it is most often not because one group is wrong, but because both groups are correct but they are talking about quite different kinds of systems as if they were similar. It is easy to confuse natural science nonlinear studies as being non-reductionist because they are nonlinear. This is in fact a common mistake made by social theorists and others. In fact, as Henri Atlan points out, nonlinear studies within the natural sciences is just an extension of reductionism. They exhibit perhaps a richer degree of description, but not by means of different methodology but because of different subject matter.

In contrast, self-organizing and evolutionary systems truly are substantively different. While successful reductionist studies can be done on various aspects of self-organizing and evolutionary systems, those studies are not being done on the *self-organizing and evolutionary aspects* of those systems, but rather on phenomena that occur within the concurrent patterns of self-organization and evolution – *phenomena*

that can usefully be studied as if they were in equilibrium or nonlinear dynamics, which are in fact reducible and predictable. A chart that I have modified from Paul Allen illustrates these last points.

Assumptions and Type of Model	**Equilibrium**	**Nonlinear dynamics (including chaos)**	**Self-organizing**	**Evolutionary**
Type of system	Fixed	Fixed	Can changes its configuration and connectivity	Can change structurally
Composition	Yes	Yes	Can lead to new, emergent properties	Can change qualitatively
History	Irrelevant	Irrelevant	important at the system level	Important in all levels of description
Prediction	Yes	Yes	Probabilistic	Very limited; high inherent uncertainty
Intervention and prediction	Yes	Yes	Probabilistic	Very limited; high inherent uncertainty

Table 5.3. Systematic Knowledge Concerning the Limits to Systematic Knowledge* (* Table was adapted from Paul Allen, "What is Complexity Science: Knowledge of the Limits of knowledge")[lxx]

5.7.3. Results of Knowledge as Complexifying and Science as Limited

Generally, one major result of perceiving the pervasive complexifying process of the development of knowledge is that science does not describe successive truths, but rather successive destabilization of truths or theories. The science of biology, ecology, and human civilization will not look like the science of physics and mechanical systems. While there is always interest, value and purpose in pursuing knowledge in these domains, it comes at a cost. The cost is the increasing resource requirement of digging into ever deeper layers of complexity. Successive triumphs in our cognitive struggles with nature are only to be gained at an increasingly greater price. The world's inherent complexity renders the task of its cognitive penetration

increasingly demanding and difficult. Due to the complex nature of our reality, scientific knowledge is a process of drastically diminishing returns. Grappling with ever greater bodies of information in the construction of an ever more cumbersome and complex account of the natural world is an unavoidable requisite of scientific progress.[lxxi]

The same observation about the complex systems that make up the world has led physicist, philosophy, and complexity scholar Kurt Richardson to describe the limits of modeling complex systems.

> The best we can hope for is a method that would allow investigators to identify the causal loops that are primarily responsible for enabling complex behavior, for a particular study system only, during a particular period of time. From this, investigators could identify ways in which the system could be manipulated to be complicated or complex. But, it is important to bear in mind that such tests would only work for idealized and well-described systems. The benefits that such a test would bring to our understanding of real life systems are not at all clear cut. There are significant difficulties confronting the design of such a testing apparatus.[lxxii]

To my mind this is not bad news. It is actually very good news, for the future of human knowledge and sustainability. This perspective shows clear reasons to exercise much greater precaution, regulation, speculation, and skepticism with regards to some aspects of science and technology research and development. I would go so far as to say that insofar as the view of complexification proceeds, it gives explicit support for the necessary integration of ethics and science, as a basis for future research and development funding.

In no way do the limits to science suggest that science should cease, but it does lend merit to the appreciation and greater support for the humanities and social theory. In no way do the limits to science suggest that we are worse off, in an existential or fundamental sense. In fact, there are many positive aspects of these discoveries. First, it provides extremely useful reference points with respect to the understanding, policy and guidance in politics and the public sphere. Seeing the world in this more mysterious light allows us to see ourselves in a more mysterious light as well. Perhaps at long last this could diminish the hubris in human societies and worldviews, or reverse the process of alienation, with a re-enchantment of the world.

Moreover, the boundaries of science also describe certain boundaries of the universe, which, if unsettling in some ways, should be comforting in other ways. As Barrows points out, while Newtonian laws still work to run our mechanical systems

such as airplanes, it is because and not despite, the limits to the speed of light. Before Einstein, the Newtonian picture of the world placed no limit to the speed at which light or any other information could travel. In reality, such lack of limitations was impossible. A world that had no speed limit would have no humans. A world too simple to accommodate light would be too simple to accommodate humans. The recognition of the limits to the speed of light makes the self-consistency of the laws of Nature possible.[lxxiii]

Over the course of the last three hundred years, science has proven to have one major strength according to Nicolas Rescher: Science is "an endlessly versatile intellectual instrument capable of accommodating itself to ever-changing cognitive circumstances."[lxxiv]

At the same time, science has a number of limitations. Here I summarize and synthesize a list of the limitations of knowledge from the works of these three philosophers of science, Nicolas Rescher, John Barrow, and Kurt Richardson:

• Fallibilism
• Instability
• Inability to arrive at anything ultimate or definitive
• The pragmatic dimensions of progress
• The obstacle of the escalation of complexity
(Nicolas Rescher)[lxxv]
• Even correct theories are limited
• Knowing process has an inevitable by-product of every unveiling limits
• Understanding more leads to understanding more about limitations of previous understanding
• Human limits – arise from nature of our humanity and evolutionary inheritance
• Technological limits – rooted in our biological nature
• Limits on information – limits on human time, energy, resources
• Limits on speed of transmitting information
• Practical limits – we are surrounded by a host of practical problems
• Experimental limits – on what we can test
• Limit on the scope of questions – there is only so much we can approach in terms of major philosophical questions
(John Barrow)[lxxvi]
• qualitatively different behaviors and scale independence
• chaos versus anti-chaos
• incompressibility
• bottom-up limitations
• top-down limitations
• differences in the ontological status of behaviors
• the issue of emerging domains
• that of evolutionary phase spaces
• cellular automata and
• the position of the observer
(Kurt Richardson)[lxxvii]

Table 5.4. The Limits to Science

Table 5.4 lists these theoretical limits to science. I have discussed many of these briefly and I lack space to do each of them justice. So I have chosen to focus on complexification. It seems that the argument regarding complexification is sufficient for various goals here. One, it shows a significant break, not only from early classical scientific assumptions, but the evident residue and holdover of many of these assumptions even amongst scientists working almost entirely within the realm of complex systems. Two, complexification is the core source of many, or perhaps even

all, of the other major categories of the limits of knowledge on this list. For instance, complexification results directly in such challenges as human limits, technological limits, informational limits, practical limits, financial limits, and experimental limits.

Complexification sheds light on the seeming paradox that super computers can now cope with highly sophisticated models, and yet at the same time, on the sentiment that many in the public at large have been expressing about the fallibility of science and technology. As eminent molecular biologist Richard Strohman of the University of California at Berkeley said, "Science cannot even fully understand one single cell, so great is its complexity. How could that science ever 'understand' issues that are vastly more complex in natural and social systems?"[lxxviii] To conclude, it seems that complexification provides sufficient grounds to argue that complexity theories have major repercussions throughout many debates in the philosophy of science.

5.8. Conclusion

A broad swath of scholars is addressing complexity in transdisciplinary studies, multidisciplinary studies, social theory, and in various fields of philosophy of science and applied philosophy. Unfortunately, as we have seen, they are in many ways as isolated from one another as the natural scientists are. Optimistically, they share a stronger common language than some natural scientists, and several attempts have been made to advance terms and frameworks that may facilitate more shared understanding, albeit of a more complex picture of reality, ultimately not possible to unify by means of any one method or epistemology, e.g. solely via mathematical models or reductionist analyses, as many earlier philosophers and scientists had hoped.

I have presented a brief tour of deep, varied, and extensive literatures including: theoretical ecology and biology; interdisciplinary and multidisciplinary views; science studies and technology studies; transdisciplinary views of complexity; and the philosophy of science. In so doing we focused on founding scholars in these areas. The most prominent complexity scholar today, Edgar Morin, thinks that it is necessary to adopt a transdisciplinary view in order to understand the true and radical nature of complex systems and their implications for contemporary social issues. Philosophers Nicolas Rescher, Basarab Nicolescu, Kurt Richardson, and others have similarly suggested a need to articulate the transdisicplinary interpretations and implications of complexity.

In the fields of theoretical biology and ecology natural and social scientists have made significant inroads in both theory and application related to environmental sustainability. They have outlined frameworks such as Panarchy that help to conceptualize and operationalize management in complex dynamic systems, including the complicated components of social and natural systems. Various scholars based in the natural sciences have begun to comment on work emanating from their own throughout the social and human sciences. For instance, Albert-Lázslo Barabási has commented on implications of network theory throughout various social, medical, institutional and computer issues.

Additionally, scholars like Stephen Jay Kline have begun to look at the nexus of interdisciplinarity and complexity, and the nature and pitfalls of multidisciplinary and interdisciplinary perspectives. Kline for instance has catalogued an insightful laundry list of ‘fallacies of projection’ that have typically occurred between disciplines, a guideline for avoiding such fallacies while effectively articulating cross-disciplinary issues. By highlighting the fallacies of projection between disciplines, epistemologies, and worldviews, Kline also clarifies areas of research where it is both

possible and highly fruitful to develop links and understanding of multidisciplinary phenomena.

For their part, humanities scholars coalescing in transdisciplinary fields such as STS having employed complexity fundamentals in creating significant advances in understanding of the evolution and co-evolution of society, science, technology and the environment, highlighting the links between these, or in Morinian terminology, the continuous recursive loops between them. Following such influential books as Ulrich Beck's *Risk Society*, evolving concepts of risk, uncertainty, and unknowability have spurred major threads of work throughout the human sciences, focused on analyzing greater societal and environmental trends that require a transdisciplinary approach.

Moreover, concerns over global change and the new degree of risk in contemporary society have sparked increasing numbers of interdisciplinary conversations and collaborations. Scientists like Stephen Schneider, in the face of inexorably highly transdisciplinary challenges like climate change, have begun to amass literatures from a broad range of scholars, both theoretical and applied.

Even the most abstract and theoretical branches of knowledge in the humanities have responded to the pleas of global change commentators such as conservation biologists and climate specialists. These fields have brought about widely misunderstood and hotly debated topics such as the constructivist nature of knowledge, and the ultimate unknowability of certain areas of knowledge. In defining modernity and postmodernity with respect to what are now construed as many failed, as well as many valuable, assumptions, they have spurred broader incendiary debates about what postmodernism is and implies. Those debates aside, these transdisciplinary approaches are undeniably important to understanding and orienting policy to address global change.

Finally, I embarked in the vast areas of philosophy of science and applied philosophy, and extracted one major example to explore the thesis that complexity theories are making significant contributions to these realms. Philosophers like Mario Bunge of Harvard have explored the role of individual complexity fundamentals to philosophy of science inquiries. The prolific philosopher of science Nicolas Rescher has devoted several books to the conjuncture of complexity and philosophy, and has forwarded the intriguing theory that complexity helps to demonstrate a trend that has been noted throughout the history of ideas, that of the complexification of knowledge and the limits to knowledge. Rescher's views help to expand upon and contextualize the ideas of two philosophers whose views radically changed common perceptions of the nature of science, Carl Popper and Thomas Kuhn. Popper's falsifiability theory, and Kuhn's theory of paradigms are both better understood within the context of Rescher's theory of complexification.

NOTES

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PART II:

COMPLEXITY AND CLIMATE CHANGE

Chapter Six. Complexity in Climate Change and International Assessments

6.0. Introduction

I assert that complexity theories are useful to some facets of climate change study and policy and attempt to discern how they are most useful. I have shown the significance of complexity ontologically, epistemologically, and throughout the disciplines. Given this breadth, I have focused my research and analyses on what are considered to be urgent questions about climate change.

I pursue three arguments. First, I examine the significance of the complexity fundamentals to climate change generally. Second, in light of this, I compare classical science – of which some influential perspectives and assumptions remain dominant today – and the complexity perspective. Third, I look at the two major meta-assessments that have been carried out in recent years on socio-environmental issues, the 2007 report of the International Panel on Climate Change and the 2005 Millennium Ecosystem Assessment. I examine how these two reports have incorporated complexity fundamentals, how they have failed to do so, and the significance of complexity to their analyses and conclusions. Finally, I analyze the results.

In this chapter, wherever I do not otherwise state dates I will use the year 2007 and the data at the time of the IPCC Fourth Assessment Report as the reference point for statistics, e.g. ice melt has increased by 17% in the Arctic in the last 25 years (implied, from 1972 to 2007). At the end of the chapter, I will also consider some most recent data from 2009 on the degree of increase in climate change in the last two years, since this is significant to the discussion.

In the case of discussions regarding important transdisciplinary issues like climate change mitigation and adaptation, involving large numbers of people from all disciplines and backgrounds, one must just keep in mind that the vocabulary used is going to take on somewhat transdisciplinary meanings. In this dissertation, it is useful at times to distinguish the sense of a term as the transdisciplinary complexity theories (TDCT) sense, especially when the same term has a different meaning in other contexts, e.g. different disciplines. This neologism TDCT may have no other use outside this dissertation! It's just useful to distinguish it here. I tend toward agreeing with Kurt Richardson's argument against developing a detailed specific transdisciplinary complexity lexicon, seeing it as dubious both in terms of pragmatic value and philosophical possibility.

6.1. Fundamentals

I assert that all of the categories of complexity are significant to climate change, but that four of these are paramount. Three of the complexity ontological fundamentals are central terms in the climate change literature, whether in scientific, academic or popular literature: ***feedbacks, vulnerability,*** and ***thresholds.*** These terms are ubiquitous in the climate change literature and in the popular press. I include the term ***resilience*** as *the degree of a system's effective response to vulnerability*; ***nonlinear*** as *a quality of thresholds*; ***tipping point*** as *a particular variety of threshold*; and I note that the term ***abrupt climate change*** is a term used to describe *a global-scale climate change tipping point*.

Similarly, amongst the other complexity fundamentals, a few are obviously significant in the climate change arena***: uncertainty, unanticipated consequences,*** and ***transdisciplinarity.*** Behind uncertainty one finds the less utilized but not less significant word, ***unknowability***. Of course, much of the same implications stemming from transdisciplinarity are often analyzed in the name of multidisciplinarity, or interdisciplinarity, the latter of which is by now employed as an organizing principle by almost every environmental studies department or organization.

Related to all of these terms is another set of climate change complexity fundamentals ***sustainability, adaptive capacity,*** and ***irreversibility. Sustainability*** is the environmental studies term for *a meta-scale phase state,* in the theoretical ecologists' sense of these terms. Ecologists and other environmental thinkers use the terms ***phase*** and ***phase state*** as synonyms for: *a the state of an ecosystem for a period of time, before a set of conditions causes a qualitative change in the nature or dynamics of the system and it shifts into a different state.* This is completely different that the technical terms phase and phase state in physics.

In the case of the term threshold there is also room for cross-disciplinary confusion. Threshold in physics or mathematics has a different meaning than when it is employed in transdisciplinary complexity, where ***threshold*** refers to *what occurs between phase states,* (again, referring to the TDCT sense of the term phase state!)**.** An example is a rainforest turning into a savannah. In ecology, environmental conservation and related disciplines, there is a large literature with respect to resilience, vulnerability, robustness, etc.

In this sense, ***sustainability*** is *a synonym for a relatively stable environmental state at a relatively large scale.* You might have a robust, beautiful, or healthy garden or park, but you wouldn't say a park was sustainable. Sustainability tends to refer to larger spatial and hierarchical scales. This is at least in part because network causality can have effects across broad swaths of ecological hierarchical scales in many instances, e.g. the hydrological positive feedbacks in climate change. Thus, a robust

ecological patch in one place does not necessarily signal or support particular kinds of ecological robustness across the larger region.

Adaptive capacity is a synonym of ***resilience***, *the capacity of an ecosystem or social system to resist shifting to a more degraded state.* ***Irreversibility –*** *the incapacity of systems' dynamics to be reversed such that a system repossesses certain qualities, attributes, or characteristics that it has lost during a threshold to a new state of being, or phase* – means the same in common language, complexity lexicon, and climate change literature. As such, irreversibility is *a shift from one state to another that cannot shift back.* Many caveats can be made here. For instance, complex systems dynamics such as emergence imply that no living thing ever 'shifts back,' or as Heraclitus said, "You could not step twice into the same river; for other waters are ever flowing on to you."[i] More importantly here, while an irreversible shift could conceivably be positive or negative, environmentally beneficial or harmful, generally speaking it has a negative connotation. One could say the evolution of a new species in an ecosystem is an irreversible change, in a sense. However, the term is most often used with a negative value, referring to stages in a process of the degradation of ecosystems, often thought not always, in the latter phases of the degradation of an ecosystem, e.g. transformation of a savannah to a desert. Therefore, irreversibility describes a threshold, and it can be the precursor of a collapse.

To reiterate, in this chapter I primarily focus on these complexity fundamentals, as they seem most obviously significant to climate change: ***feedbacks, vulnerability, nonlinear, thresholds, sustainability, uncertainty*** and ***transdisciplinarity***, including the related terms ***resilience, adaptive capacity, tipping points, abrupt climate change, phase state, transdisciplinarity,*** *and* ***irreversibility.*** That these terms are found throughout climate change literature does not alone prove my point. In what follows I analyze the significance of these terms to climate change. Tables 7.1 and 7.2 catalogue these terms and some preliminary examples and suggestions of ways in which these terms appear to be central to understanding climate change. In the text that follows, I explain in more detail the significance of these examples.

Complexity Term	Climate Change Term
Adaptive =	**Adaptive Capacity** "The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences."
Vulnerability; lack of resilience =	**Vulnerability** "The degree to which a system is susceptible to or unable to cope with adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change, the variation to which a system is exposed, its sensitivity, and its adaptive capacity."
Diversity =	**Biodiversity –** Myriad life forms sustaining and sustained by climate and vulnerable to climate change.
Uncertainty =	**Likelihood and confidence language** Virtually certain > 99% probability of occurrence Extremely likely > 95% Very likely > 90% Likely > 66% More likely than not > 50% Very unlikely < 10% Extremely unlikely < 5% Very high confidence – a 9 out of 10 chance of being correct High confidence – an 8 out of 10 chance Medium confidence – a 5 out of 10 chance Low confidence – a 2 out of 10 chance Very low confidence – less than a 1 out of 10 chance
System state or phase state = (not the physics term 'phase state')	**Sustainability** Maintaining global systems in a phase state with at least as much ecological and social integrity as they currently possess.
Unintended Consequences =	**Surprises** Unpredicted, sudden shifts in climate regime.
Irreversibility =	**Irreversibility** The nature of a change of system state, or 'phase change,' in which parts of ecosystems undergo changes that cannot be reversed, e.g. desertification.

Table 6.1. Epistemological Fundamentals of Complexity and their Expression in the Climate Change Literature. All the climate change terms are from the IPCC report, Climate Change 2007.[ii]

6.1.1. Feedbacks

As the complexity fundamentals are inherently interconnected, there is not really a correct order to be used in describing them. Thus, once again I choose the order based upon its seeming *narrative* valor, the order described above. It is useful to recall, however, that in analyzing the case of climate change like many other complex issues the complexity fundamental do not tend to occur in an isolated fashion. Rather, once again we find that the complexity processes are ***interconnected***; *nonlinear feedbacks* lead to *thresholds* at which *system states* change and previously *robust* ecological systems become increasingly degraded, *vulnerable*, and may even *collapse*. Cumulatively, multiple feedbacks lead to more systemic *tipping points*, at which a greater quantity or expanse of related complex systems – ecosystems and societies – transform into *system states* in which more aspects of societies or ecosystems are degraded, diminished, or destroyed.

I will break down each of these complexity fundamentals in turn, explaining examples from climate change. In chapter three we defined ***feedback*** as *a force that through affecting its environment then loops back to affect itself*, and *positive feedback* as *a force that affects its environment, such that the initial force is then increased*. While, a *negative feedback* is, *a force that affects its environment, thereby causing the initial force to diminish or to remain equal*. The National Academy of Sciences (NAS) has defined feedbacks as "processes in the climate system that can either amplify or damp the system's response to changed forcings."[iii] In addition, the NAS has distinguished feedbacks as one of the two main drivers of climate change, along with forcings. A ***climate forcing*** is *an energy imbalance imposed on the climate system either externally or by human activities.* Examples include changes in solar energy output, volcanic emissions, deliberate land modification, or anthropogenic emissions of greenhouse gases, aerosols, and their precursors. A ***climate feedback*** is *an internal climate process that amplifies or dampens the climate response to a specific forcing.* An example is the increase in atmosphere water vapor that is triggered by an initial warming due to rising carbon dioxide (CO_2) concentrations, which then acts to amplify the warming through the greenhouse properties of water vapor.[iv] The basic greenhouse effect is based on this simple climate feedback mechanism.

Various feedbacks have already been proven to be among the most significant and influential to the process of climate change at the planetary scale. Other feedbacks have been identified as drivers of historical rapid climate changes, so there is reason to expect that they could be or become drivers in current climate change. Furthermore, there may be major feedbacks that no scientists have as yet identified. In 2001 scientists warned that "a substantial part of the uncertainty in projections of

future climates is attributed to inadequate understanding of feedback processes internal to the natural climate system."[v] Therefore, it is of central importance to understand, model, and monitor climate feedback processes.[vi]

According to some estimates generated by climate models, feedback mechanisms internal to the climate system will bring about over half of the warming expected in response to human activities.[vii] Feedbacks already occurring in the climate change processes include the albedo effect, glacier fissures, and sudden, rapid permafrost melting, with ensuing methane release. Worrisome potential feedbacks include the halting of the North-Atlantic thermohaline circulation belt, the conversion of the Amazon rainforest into savannah, and various other kinds of sudden releases of methane, e.g. giant methane bubbles emerging from the ocean.

Generally speaking, the global carbon and sulfur cycles contain the potential for numerous important feedback processes. This includes carbon uptake by the land and ocean, such as atmospheric, biospheric and oceanic processes that influence the abundance of CO_2. In other words, every area of the entire surface of the globe can be seen as a potential source of carbon sinks or leaks. Unfortunately, this would seem to leave plenty of room for the escalation of positive feedbacks. Scientists are exploring such carbon feedbacks as, for example: cloud, water vapor, and lapse rate feedbacks; sea-ice feedbacks; ocean heat uptake and ocean circulation feedbacks; and land hydrology and vegetation feedbacks.[viii]

The Polar Regions of course are seeing the most rapid and thus tangible climate change. The average temperature of the Arctic has risen more than four degrees, in comparison with the approximately one degree average for the globe. In the past few years, Arctic sea ice has been melting much faster than most scientists had predicted. On the one hand, there are quite simple explanations. On the other hand, some of these seemingly simple explanations turn out to be tremendously complex. For some scientists, this begs the question whether or not, in highly complex situations, complexity theories are useful or just another complication.

6.1.1.1. Feedbacks – The Ice Albedo Effect

I explore one example here, the albedo effect, which was one of the first hydrological positive feedbacks widely used as an example of climate change feedbacks. The albedo effect was one of the very first feedbacks to be widely reported and discussed. From about 1990 to 2004, or even later, the public and even a majority of climate scientists it would seem focused on this feedback as if it were the only climate feedback, or the only significant one. I argue that it has been in correlation

with scientific data and approach opening increasingly to acknowledge and integrate more complexity that this perspective on climate feedbacks has been shifting.

The albedo effect consists in a change of the speed of melting in the Arctic region due to the color of the land or water surface. Surfaces of a lighter color such as snow and ice reflect more heat, thus keeping the surface at a cooler temperature. The Arctic Ocean and landmasses are of darker hues, thus absorbing more heat than snow or ice absorbs. As snow and ice melt and expose more ocean and land surfaces the arctic region absorbs more heat. The increase in heat absorption in turn melts a greater quantity of snow and ice, which in turn leads to greater surface temperature, and more melting.

There are no satisfactory estimations for the amount of albedo forcing in the Arctic. What has been measured is the amount of sea ice decline – 17% over the last 25 years. As scientists noted such data they increasingly blamed the most obvious culprit, the albedo effect. Arctic scientists Roland Lindsay and Jinlun Zhang of the Polar Science Center at the University of Washington explain further, "There appears to be a feedback at work in the sense that increased open water and thin ice in summer absorb more solar energy during clear skies or produce more low cloud and increased long-wave absorption, leading to less ice growth the following winter. It has been proposed that the Arctic may be near a 'tipping point,' a new equilibrium state between increased radiative absorption in the ocean during the summer and the amount of first-year sea ice that can grow during the following winter."[ix] Thus, the authors imply that albedo is the main culprit.

Of particular note is the extreme reduction in summer ice from 2002-2005.[x] Scientists began to investigate what seemed to be the ice albedo effect due to a string of hot summers in the 1990s. Some suggested that the increased Arctic temperatures created observed shifts in wind fields, causing higher winds in certain areas, in turn blowing hotter air over the Fram Straight region. Thus, decreased ice thickness in the Fram Straight has been blamed on the high temperatures of the 1990s, which caused "a large volume of thick multiyear ice… to have departed from the Fram Straight… leaving the Arctic with more thin, first-year ice more prone to melt in summer."[xi]

Yet, the more scientists looked for feedbacks, the more they seemed to find. Just as the albedo effect may have triggered shifts in wind patterns so myriad other systems have been shifting, such as: changes in cloud cover, vapor, and terrestrial ecosystem emissions. Over the last ten years it has become evident that the *cumulative feedbacks between these numerous feedbacks* are significant. Increasingly, we must speak of cumulative networks causality of interacting feedbacks, in which multiple smaller-scale feedbacks feed back into each other, amplifying the amplification. An example of this is 'dynamical ice melting.' This term has been used to describe the way that ice itself melts in the Arctic, regardless of other factors like

wind. It came as a surprise to climate scientists in the early 2000s that massive glaciers do not just melt from the top down, but rather, various changes take place creating feedbacks within the pattern of the melting ice itself. For instance, fissures form, capable of rapidly creating channels that suck water down to the bottom of glaciers. Pools then form under glaciers, spreading, and so facilitating the growth of further fissures. This dual process is self-enhancing and soon there is a network of rivers and pools forming throughout the glacier, adding to the speed of its melting.

To some, such analyses of snowballing feedbacks may smack of alarmism. At least, it strikes some as unfamiliar. Scientists continue to look for empirical evidence of the impact of these effects individually and cumulatively. Generally, studies about networks of local feedbacks interacting within the Arctic region raise more questions than they answer. Finnish Arctic researcher Bruce Forbes and colleagues studied geographic variations in anthropogenic drivers throughout the Arctic, looking at how they influence vulnerability and resilience of socio-ecological systems.[xii] Forbes states hopefully,

> Evolving over long periods during the Tertiary and Quaternary, elements of the boreal and arctic tundra biota have adapted to high variability in climate and other variables, such as herbivory. Resilience is expressed at several levels from the individual to the ecosystem. Even when entire biomes have disappeared, as in the case of the steppe-tundra of Beringia, isolated relics or fragmentary analogues of ancient communities have persisted, albeit in impoverished forms, indicating that some inter-species relationships are resilient in the face of major, long-term environmental change.
>
> The range of adaptation among human cultures during the Holocene is similarly impressive. During this period the whaling and reindeer-dependent cultures of Eurasia were undergoing profound changes, partly in response to climate. More recently, contemporary cultures of the taiga and tundra zones have experienced intensive outside economic and institutional pressures, as well as relatively short-term but significant climate change in some regions. Overall, northern indigenous peoples are experts in adapting to shifting conditions (environmental, social, economic) and recognize their own abilities in this regard. Despite this record of resilience and the capacity to buffer against change, northern ecosystems have traditionally held a reputation for being 'fragile' and therefore vulnerable to immediate, long lasting and perhaps irreversible change. [xiii]

After surveying an impressive set of regional variation in drivers and likely system change, the authors attempt to discuss the cumulative impact of these individual regional changes. As is often the case in this instance – generalizing up from discussions of multiple intra-regional effects to some overall predictions about changes in the region – the reader is left with a sense of disorientation amidst the vast and interconnected possibilities. It is a difficult proposition to make socio-ecological generalizations at a small scale; at the regional scale, this can seem overly ambitious. While it is possible to write clearly on issues of such complexity, it can become increasingly vague and speculative. Moreover, the optimism in the following passage seems to belie the vulnerability discussed in the last passage.

> Climate change is the wild card in managing for resilience in the 21st century. While some high latitude regions have been stable or cooling in recent decades, northwestern North America and northern Russia have been experiencing significant atmospheric and subsurface (permafrost) warming. Melting of frozen ground may lead to acceleration of cryogenic processes such as thermokarst and solifluction, affecting the structure and function of forest and tundra ecosystems. Under enhanced fire regimes forests could be replaced by northern steppe vegetation. A major threat is accelerating disturbance regimes, in particular fire and insect outbreaks. Warming will inevitably increase variability of the climate system, and dry and warm periods will be more frequent and longer than under the current climate. In the short term, land use and, in Russia, ongoing social and economic upheavals are likely to be more significant and potentially tractable drivers of regional change. With or without a warming climate, certain geographic areas appear especially vulnerable to damages that may threaten their ability to supply goods and services in the near future. Climate change may exacerbate this situation in some places, at least in the short term, but may offer opportunities to enhance resilience in the long term.[xiv]

Studies that are able to rely on past evidence of specific, large-scale thresholds manage to give a somewhat clearer sense of urgency. Several scientists have postulated on the major causes of the Marinoan climate warming, occurring about 635 million years ago. One theory has massive methane release from equatorial permafrost as the greatest trigger in this global meltdown.[xv]

Indeed, other research focusing on equatorial changes in past climate changes also attempts to pinpoint relatively specific causality, e.g. global scale impacts, which may obscure which initial drivers were significant in bringing about the later, larger drivers. While policymakers prefer the apparent clarity that the focus on the greater past drivers provides, analysis of such acontextual focus that also acknowledges the significance of context thus reveals an alarming degree of the limits to knowledge in such cases. After all, of primary concern to policy makers today is not the ultimate result of biospheric change, but the initial set of drivers that if altered by current policy could substantially change or even altogether avoid that final result.

In Chapter Six I spoke of the limits to science and the limits to knowledge. One major aspect of the limits to knowledge in the case of climate science is the limitations in assessing systems dynamics beyond a certain degree of complexity and degree of flux in feedback dynamics over time. This militates against success of the classical science methods and goals with respect to precision, predictability and truth. Moreover, it forces natural scientists to concede, abandoning the hope of full knowledge of various climate change dynamics and instead accept the necessity of uncertainty language, including uncertainty bands and statistical probabilities.

> The Amazon rainforest is not an ephemeral feature of South America; rather it developed during the Cretaceous and has been a permanent feature of this continent for at least the last 55 million years. However, it seems that due to human activity the Amazon rainforest is entering a period with unprecedented disruption and climatic condition with no analogue in the past. Some modeled results suggest that a significant portion of the Amazon rainforest may turn to savanna by the mid to late Twenty-first century (e.g. White *et al.* 1999; Cox *et al.* 2000).[xvi]

This excerpt gives one significant illustration of the limits to knowledge. What this and other recent studies have shown is that there is a non-negligible probability that entire rainforests may undergo major phase shifts, e.g. transformation into savanna. Rainforests have high biodiversity and thus high complexity, the variables and factors involved in assessing the impact of both climate change on rainforests and deforestation on climate change are numerous. [xvii] Indeed the Amazon rainforest alone contains one-half of all biodiversity on Earth, one-half of all of the complex ecological interactions. [xviii]

As appears to be the case with the great variables and factors in positive feedbacks driving climate change, the great variables and factors within the rainforest suggest that prediction is highly difficult. Additionally, it may be that the more

interacting variables there are, the more potential drivers there are, the more potential for triggers of new positive feedbacks, the greater the degree of network causality amongst feedbacks, and thus, the greater the potential for major shifts in phase state. The implications of a rainforest collapse are mind-boggling. Losing such massive carbon sinks would throw into question the survival of human civilization. Rainforest ecologists agree that prediction about feedbacks from human impact and climate change endangering large rainforests remain among the most difficult, but that that difficulty renders a rainforest conversion or collapse no less probable. Is it not the case then, that complexity sheds light on the limits of science?

Moreover, it appears that the studies that most accurately report degrees of complexity are also those that shy away from making just about any causal conclusions or only quite general ones. In a recent study of the role of rainforest complexity in regional (and biospheric) sustainability, the scientists measured multiple aspects of vegetation characteristics, including biomass, density, height light/ leaf area index (LAI), and shade area index (SAI). They concluded that there is such an enormous degree of complexity in rainforest dynamics, that it militates against isolating out almost any causal factors over another. They state "there are multiple dimensions to the site variation in canopy complexity." Both the addition of new functional types, e.g. tall deciduous shrubs and Picea, and interactions among the functional types results in changes in this complexity across the biodiversity gradient. The addition of a full spruce canopy has the greatest effect on tall shrubs, leading to a 60 percent reduction in total shrub biomass. As for ground cover, the addition of tall shrubs and Picea reduced the Sphagnum mosses; however total ground cover remained fairly similar. However, even in the understory, where total biomass and cover extent remained relatively similar across sites, there was a complex pattern of change in abundance within and among functional types. Moreover, forbs and grasses had higher biomass and cover in the high-biomass sites (tall shrub, woodland and forest), where nutrients were presumably more available than in the low shrub and tundra sites. From this they conclude, "The functional types are responding to site characteristics other than to just canopy development, e.g. differences in nutrient cycling."

Such studies point to what would seem a truism of ecosystem dynamics – that sites of high biomass, biodiversity, and carbon storage seem more resilient than sites of lower biomass, biodiversity, and carbon storage. However, even this truism is not truly understood or verified – after all deserts can remain in a constant state of high biodiversity for very long periods – the drivers that can unravel such resistant ecosystems remain unclear. It seems that as some climate scientists attempt to tackle larger and larger types, degrees and scales of complexity in ecosystem dynamics they end up with increasingly vague, less certain and less useful results. It appears that

studying increasingly complexity in systems leads to increasing limits to knowledge. In this case, an increasingly comprehensive study of ecosystems correlates with a receding capacity for prediction and control.

Finally there is the issue of polar permafrost methane release. In June 2008 one of the worst nightmares of climate change prediction became a reality. Scientists in the Arctic observed massive release of methane from below the Siberian tundra in the form of numerous columns of rapidly rising methane gas.[xix]

Methane contributes twenty-five times more than carbon dioxide to global warming. Evidence of large quantities of methane is present in data on some of the past major global warming events. For instance, evidence seems to show that a massive methane release was one of the major causes of the Permian-Triassic extinction event, the largest one in the earth's history. The Permian-Triassic event, 251.4 years ago, was the Earth's most severe extinction event, with up to 96 percent of all marine species and 70 percent of terrestrial vertebrates becoming extinct. Moreover, it is the only known mass extinction of insects; 57 percent of all families and 83 of all genera were killed off.

Could it be the case that the release of permafrost methane that began in 2008 or before has begun a major tipping point, or *abrupt climate change*? This is unknown. Nevertheless, prominent climate scientists are taking positions. Later in 2008, the most celebrated climate scientist in the U.S., James Hansen, and several of his colleagues began to state publically that we have passed a critical climate change tipping point.

Many atmospheric feedbacks seem to be, on the face of it, quite simple. The albedo effect, in isolation, appears simple. Dark surfaces absorb more heat, and thus create a vicious circle of increasing warming. However, this assertion belies the lessons that the complex systems framework reasserts over and again. In fact, the more that the Arctic is studied, the more complex it appears to be. A series of simple feedbacks does not equal a large set of simple feedbacks, but rather, an immensely, perhaps impossibly complex puzzle.

At the same time, in highly complex puzzles it often appears that results are clear and relatively simple. When a house is on fire, we do not need to calculate all the complexities of wind, temperature, causality, and potential consequences. We just put out the fire. When the Amazon is at risk, we do not need to calculate all of the specifics. We simply must stop the known causes: deforestation, overharvesting, and massive carbon emissions. Perhaps there are more causes? Perhaps correcting these three would suffice.

6.1.1.2. Feedbacks – Multiple Intersecting Feedbacks

Princeton University atmospheric scientist Michael Winton now thoroughly debunks the widespread theory of the significance of the ice albedo effect. He says the albedo effect is insignificant, a feedback of minimal impact on warming, and of little interest. After attempting to estimate the role of albedo feedback with respect to the surprisingly rapid melting in the Arctic, Winton concluded that actually the role of albedo is probably only a negligible factor in accelerating arctic warming. More significant perhaps is Arctic-global long-wave feedback difference originating from *cloud, water vapor and temperature feedbacks*.[xx] Others have agreed, such as University of California at Berkeley professor and leading climate scientist, Inez Fung, who sees hydrological feedbacks as likely the most significant feedbacks involved in climate change.[xxi] Michael Winton thus suggests that "combining these feedbacks might lead to either an under- or overestimation of the relative role of SAF (surface albedo feedback)," but that, "a clearer picture of the mechanisms of Arctic amplification in the models will require application of more refined feedback analysis techniques."[xxii] Unfortunately, the biogeochemical feedbacks such as cloud, water vapor, and temperature feedbacks that he points to remain among the most difficult to calculate.[xxiii] Fung also sees hydrological feedbacks as likely the most significant feedbacks involved in climate change.[xxiv]

What seems to emerge from the flurry of studies on Arctic melting in the last decade is that cases of innumerable intertwined causal networks are perhaps the most significant but also the most challenging to capture empirically. It can become difficult to discern the degree to which each cause is contributing to the overall effect, and thus which are the areas of priority for further research and policy.

Furthermore, multiple interacting feedbacks are not the only driver of Arctic melting. Other causes are not necessarily feedbacks per se, but simply contributing factors adding to the overall dynamic. According to James Hansen and colleagues, another perhaps significant contribution to Arctic melting is the pollution emitted from nearby industrialized countries, which exacerbates the albedo effect. Soot, according to this theory, increases warming because snow retains aerosols, darkening the surface more in the late winter and spring when the sun is high in the sky and most effective, thus increasing absorption and lengthening the melt season. Hansen says the problem is perhaps more difficult than scientists thought at first, explaining, "Although laboratory experiments show that fine BC (black carbon) particles can escape with meltwater more readily than larger aerosols, there is a tendency for even the finest aerosols to be retained and enhance absorption in the melting season."[xxv] This example is one among many that signify that unanticipated interactions between

the human-driven environmental problems are greatly significant during the current era of unprecedented change.

Facing such challenges of highly complex dynamics, some scientists are directly employing complexity theories in order to address feedbacks more effectively. For instance, ecologists Lisa Belyea and Andrew Baird of the University of London have studied interwoven feedbacks within peat bogs. Because methane is a much more powerful greenhouse agent than carbon, and because much of the Northern permafrost covers such ecosystems, peat bogs could play a significant role in climate change. In this area, Belyea and Baird created a general complex adaptive systems (CAS) model based upon Simon Levin's CAS criteria and Timothy Allen's hierarchy principles.[xxvi]

Belyea and Baird's complex adaptive systems model and analysis seem to have been significant to the success of their research, which has been widely cited. The authors linked peat land properties to what they call four general properties of "complex adaptive systems" (CAS): spatial heterogeneity, localized flows, self-organizing structure, and nonlinearity. They also present a framework for modeling peatlands in terms of CAS.

> In this framework, the system is disaggregated, both vertically and horizontally, into a set of components that interact locally through flows of energy and resources. Both internal dynamics and external forcing drive changes in hydrological conditions and microhabitat pattern, and these autogenic and allogenic changes in peatland structure affect hydrological processes, which, in turn, constrain peatland development and carbon cycling.

Thus the authors link local dynamics regarding a common source of methane emissions with greater hydrological processes, and track how these hydrological processes in turn constrain peatland development and carbon cycling. Their work contributes directly to those researching larger hydrological patterns, such as Inez Fung and Michael Winton, and thus it seems to be an example of a successful application of a local-scale CAS model benefitting larger-scale research.

Yet it raises the question of how well and whether in fact such a small-scale study on peat bogs can be magnified to look at larger regions of such ecosystems. Further, while this particular line of research may be promising, what happens in adding up innumerable such small-scale research projects? Does it necessarily lead to more clarity on the macro-scale patterns such as hydrological and carbon cycles? It leads back to the question raised by many climate thinkers – scientists, philosophers,

and social theorists alike, which is the question of the limits of capacity and utility in aggregating immense amounts of data that ultimately will maintain some degree of uncertainty or unknowability with respect to the multiple interactions of a networked causality that one cannot possibly completely track. If one were to include most of the regional and global feedbacks involved in Arctic ice melting in a single model, the number and types of feedbacks and their interactions seems astronomical, an overwhelming task. It would require highly costly, complex models, leading back to the question: At what point is the pursuit of precision in modeling an unnecessary or uneconomical one?

To follow the example of peat bogs and potential methane release further, the following facts may be sufficient. As I stated, methane is a greenhouse gas agent about twenty-five times more powerful than carbon dioxide. Beneath the Arctic permafrost lie large expanses of methane, exactly how much remains unknown, but it is highly probable that there is enough methane to make it a moot point. Moreover, new evidence shows significant permafrost melting throughout large regions of the Southern Arctic. In Fairbanks, Alaska, problems resulting from permafrost melting have been everyday phenomena for over a decade. This includes 'drunken trees' – trees falling over because the permafrost holding them in place has melted; and 'wavy roads' – roads that have sunken in wave-like patterns due to permafrost melt, creating such undulations in the concrete that driving on them feels like a rollercoaster ride. With such substantial empirical evidence and high stakes it is reasonable to take into account even a small probability of such substantial feedbacks as methane release.

Once we accept this argument and see that network causality leads to a lack of sufficient evidence in complex cases, it becomes less important to fully clarify *which* feedbacks or combination of feedbacks causes the catastrophic outcome. Whatever the precise means by which multiple feedbacks lead to accelerating climate change, it is evident that past a certain threshold there is a high probability of catastrophic consequences. Empirical evidence of ice melt in the last decade is largely sufficient to show the merits of a strict precautionary approach to greenhouse gas emissions.

To accept a conclusion without knowing the precise causes goes against the grain of Western thinking. Yet, this seems to be precisely where complexity analyses lead us. This is one of the many useful shifts in thinking that a generalized complexity framework (GCF) seems to require and induce. It is as if our mainstream rationality – still infused as it is with early modern assumptions – reveals one face of current events, a largely comforting, workable perspective. While the General Complexity Framework (GCF) reveals the truer face of catastrophe.

While the IPCC scientists write that we have too little understanding about dynamical ice melt, leading climate scientists are making more and more ardent calls for rapid and drastic GHG reductions. While scientists cannot show precise details of

what will happen and where, they can state general effects within reasonable uncertainty bands. The overall diagnosis is that there is at least a 10% chance of biospheric, catastrophic climate change that would have massive negative impacts on all of humanity.

Network causality is a major aspect of what I call a more sophisticated brand of rationality than standard classical science rationality, or "complexity rationality." This is not a new concept. There has been significant attention to critiques of overly simplified views of rationality, such as the 'bounded rationality' began by Herbert Simon and others fifty years ago. More recently, precautionary principle scholars, environmental philosophers, risk and futures scholars, and many other have commented on the need for more nuanced view and practice of rationality.

I use the term ***complexity rationality*** to refer to *the ensemble of theories that demonstrate the influence of the GCF on rationality.* For instance, as in the above examples, network causality alerts us that without knowing precise causes, our reasons for acting are just as valid in the case of catastrophic climate change as they are in the case of the many types of insurance that we readily accept as highly rational. We do not hesitate to buy insurance against fire, theft, health problems, or death. As noted and early climate change scientist Stephen Schneider has pointed out, the rationality we have long employed to buy insurance against a theft of house fire is the same logic we can employ to act proactively with respect to climate change. The great majority of people will buy fire insurance even when there is only a five percent chance of harm, and most people will buy fire insurance with less than a one percent chance.

Since the best climate science tells us that there is at least a ten percent chance of catastrophic climate change in our lifetimes, rationally we should pay large sums to prevent that outcome. This was true ten years ago, when scientists already were predicting at least a ten percent outcome of catastrophic results of climate change. Major effects of that change were to hit many poor and disenfranchised in the current decade, began to affect everyone in the next twenty years, and likely have dire consequences across the board by 2050. Since that time, scientists have even better data on the risks of climate change. Over the last few years, as climate change scientists have had time to see the errors in their predictions, they continually increase the degree of catastrophe and push the date back further towards the present.

In one striking example, in 2008 geologists officially announced that humankind is no longer in the age of the Holocene and has now entered the Anthropocene. In fact, the scientific data supporting this distinction has been present for two or three decades. This is one more example of the non-objective value judgments surrounding data. It takes more than the data to make essential realizations. It requires emotional and psychological willingness to overcome ideological and

ideational barriers to new interpretations of the world. Thus, there are human time lags, as well as biophysical time lags, in the manifestation and acknowledgement of climate change.

The overwhelming scientific consensus asks us to grant the corollary between our willingness to pay individual fire or theft insurance with risks of only 5% or even below 1% and to pay our share of societal insurance for preventing catastrophic climate change, at least 10%, many leading climate scientists now would say is much higher. By accepting this statistical framework, we renounce the need for knowledge of more precise causality. To grasp complex systems dynamics, is to fully disband with notions of necessary certainty and to embrace probability as a basic and essential part of a wide range of social and environmental planning.

As University of California at Berkeley biologists Margaret Torn and John Harte report, "Experimental and modeling evidence is accumulating that terrestrial ecosystems could form positive feedbacks with global warming in the next century through changes in, for example, primary productivity, soil carbon storage, and methane emissions due to the influence of climate on, for example, length of growing season, soil moisture, and permafrost, respectively.[xxvii] All ten simulations in the recent coupled climate carbon cycle model intercomparison (CAMIP) show positive feedback by 2100 due to ecosystems."[xxviii] Torn and Harte argue that scientists should pursue better understanding of the feedbacks. But their principal message here was to state that the nature and urgency of interacting feedbacks must bring about a greater sense of urgency in climate policy. Once the nature of feedbacks is understood and more accurately included in climate scenarios it becomes more obvious that the stakes are quite high. Consequently, rational analysis militates for rapid emissions reductions.

6.1.2. Thresholds

The issue of feedback gains even more significance in conjunction with another term rampant in the climate change literature, another major ontological complexity fundamental: thresholds. Multiple feedbacks in cohort, or one more influential feedback, may lead to a threshold, perhaps even to a drastic threshold known as a tipping point or in the case of climate change on the global scale abrupt climate change. Again, I clarify the sometimes confusing terminology. It is possible on a regional scale to have a tipping point, or a series of tipping points, but only if it creates a significant shift in phase state at the local scale. Such a shift at the global scale is called abrupt climate change.

Another common term used to describe such thresholds is 'surprise.' Most generally speaking, the nonlinearities inherent in the hierarchy of the many systems

making up the global climate system lead to changes that humans, in an effort to predict, plan, and understand, do not grasp. Such *unanticipated consequences* are termed ***surprises***. According to Stephen Schneider, "Strictly speaking, a ***surprise*** is *an unanticipated outcome; by definition it is an unexpected event.* Potential climate change, and more broadly, global environmental change, is replete with this kind of truly unexpected surprise because of the enormous complexities of the processes and interrelationships involved (such as coupled ocean, atmosphere, and terrestrial systems) and our insufficient understanding of them. The IPCC (1996) defines surprises as "*rapid, non-linear responses of the climatic system to anthropogenic forcing* (e.g. greenhouse gas increases), such as the collapse of the 'conveyor belt' circulation in the North Atlantic Ocean or rapid deglaciation of polar ice sheets."[xxix] Note Schneider's distinction between a surprise and a "truly unexpected surprise." This is a logical error, but reveals a sensibility that seems to have some substance, as climate scientists discover what appear to be more or less 'surprising' surprises.

Thresholds are thus ubiquitous in the climate change literature as well, but under all of these terms: *surprise, tipping point, abrupt climate change, catastrophic climate change, sensitivity of system to disturbance, resilience of system to thresholds, vulnerability of system to thresholds,* and more. While local thresholds are significant, in the case of climate change many scientists focus on abrupt or catastrophic change for the obvious reason that it seems the most significant. This brings us back to the problem mentioned earlier, the seeming paradox that if the analyses are ultimately too complex to carry out, once there is a certain degree of complexity – with its accompanying certain degree of intertwining of feedbacks, unintended, unforeseeable consequences, and surprises – then it seems to lead to insurmountable obstacles in the traditional research model. Scientists are then forced to adopt a research method that is more tenable within the General Complexity Framework (GCF).

In discussing these possibilities, scientists resort to a variety of terms. For instance, Richard Kerr wrote in *Science*,

> A few years ago, researchers modeling the fate of Arctic sea ice under global warming saw a good chance that the ice could disappear, in summertime at least, by the end of the 21st century. Then talk swung to summer ice not making it past mid-century. Now, after watching Arctic sea ice shrink back last month to a startling record-low area, scientists are worried that 2050 may be overoptimistic." Kerr quotes John Walsh of the University of Alaska, Fairbanks, a polar researcher, "This year has been such a quantum leap downward, it

> has surprised many scientists. This ice is more vulnerable than we thought." And that vulnerability seems to be growing from year to year, inspiring concern that Arctic ice could be in an abrupt, irreversible decline. "Maybe we are reaching the tipping point.[xxx]

The following quotation, the conclusion of a study on Arctic change, is an account of the global scale threshold sometimes referred to as a tipping point or as abrupt climate change.

> The future of the Arctic region in the 21st century is highly dependent on the magnitude and rate of warming that actually unfolds, which is very difficult to predict with any degree of accuracy. However, if the last few decades and the projections of climate models are an indication of what is to come, the region will likely experience sustained and rapid warming well into this century. Under these conditions, it is clear that the risk of significant change in the Arctic in this century is large, perhaps larger than was thought just a decade ago. If indeed Arctic sea ice disappears during the summer and carbon emissions from high-latitude terrestrial ecosystems increase sharply, the Arctic will almost surely become more than the proverbial canary in the coal mine. It will provide major positive feedbacks to the earth system as a whole, pushing the earth system closer to a possible state change and perhaps providing the acceleration required to cross the critical threshold beyond which a state change is unavoidable and largely irreversible.[xxxi]

Schneider employs a slightly different use of the terms phase states and thresholds, speaking of them in terms of equilibriums, emergent properties, and irreversibility:

> Most global systems are inherently complex, consisting of multiple interacting sub-units. Scientists frequently attempt to model these complex systems in isolation often along distinct disciplinary lines, producing internally stable and predictable behavior. However, real-world coupling between sub-systems can cause the set of interacting systems to exhibit new collective behaviors – called 'emergent properties' – that are not clearly demonstrable by models that do not also include

> such coupling. Furthermore, responses of the coupled systems to external forcing can become quite complicated. For example, one emergent property increasingly evident in climate and biological systems is that of irreversibility or hysteresis -- changes that persist in the new post-disturbance state even when the original forcing is restored. This irreversibility can be a consequence of multiple stable equilibria in the coupled system – that is, the same forcing might produce different responses depending on the pathway followed by the system. Therefore, anomalies can push the coupled system from one equilibrium to another, each of which has very different sensitivity to disturbances (i.e., each equilibrium may be self-sustaining within certain limits).
>
> The foregoing discussion is primarily about model-induced behaviors, but hysteresis has also been observed in nature (e.g., Rahmstorf, 1996). Exponential increases in computational power have encouraged scientists to turn their attention to broadly focused projects that couple multiple disciplinary models. General Circulation Models (GCMs) of the atmosphere and oceans, for example, now allow exploration of emergent properties in the climate system resulting from interactions between the atmospheric, oceanic, biospheric, and cryogenic components.[xxxii]

Schneider wrote this in 2003. By 2008, as indicated above, James Hansen and other prominent climate scientists think we have already reached such a tipping point, that will play out inexorably in the coming decades, with little chance that we will conceive of a way to stop or reverse it. In an article entitled, "The Thinning of Arctic Sea Ice, 1988-2003: Have We Passed a Tipping Point?"[xxxiii] Climate scientists Lindsay and Zhang argue that we have already passed a critical threshold in global climate change. They cite the satellite data showing the record or near-record lows for ice extent in 2002-2005. Models of the melting have shown that since 1988 the thickness of the simulated basin-wide ice thinned by 1.31 m or 43percent greatest along the coast from the Chukchi Sea to the Beaufort Sea to Greenland. According to Lindsay and Zhang, thinning since 1988 is due to:

> …preconditioning, a trigger, and positive feedbacks: 1) the fall, winter, and spring air temperatures over the Arctic Ocean have gradually increased over the last 50

> years, leading to reduced thickness of first-year ice at the start of summer; 2) a temporary shift, starting in 1989, of two principal climate indexes (the Arctic Oscillation and Pacific Decadal Oscillation) caused a flushing of some of the older, thicker ice out of the basin and an increase in the summer open water extent; and 3) the increasing amounts of summer open water allow for increasing absorption of solar radiation, which melts the ice, warms the water, and promotes creation of thinner first-year ice, ice that often entirely melts by the end of the subsequent summer.

The further one goes forward along the chain of positive feedbacks and thresholds the more dramatic the effects can become, which is a critical aspect of the nature of these dynamics. Many patterns of system nonlinearity do not follow slight curvy paths, but rather exponential paths. To show the significance of this aspect of thresholds, I give examples of multiple-threshold cases.

Studies on past climate change events in the earth's history provide one approach to answering the question: If abrupt climate change were to happen what will it be like? What these studies of past climate changes suggest, is that the answer may be to trigger still other abrupt changes, resulting in a *cascade of tipping points*. At some point, no matter how great the global disturbance, the biospheric climate and life systems will settle out to a new kind of settled phase, and if the earth's history is a gauge, this new phase will likely eventually facilitate the development of a new phase of increasing biodiversity. (Though even for this there is no absolute guarantee, depending on the ways in which humans alter planetary systems.)

The dominant theories regarding the last two large-scale climate change events now hinge on an abrupt shift in which multiple thresholds were triggered. One theory is that abrupt climate change triggered volcanoes, which in turn blocked sunlight, in turn provoking major species loss, creating cascades of species losses, and greatly exacerbating conditions for all species. In an example of a cascade of tipping points, climate change itself, as well as seismic activity, can trigger volcanic eruptions, inducing further climate change.

> Abrupt climate change can trigger volcanic collapses, phenomena that cause the destruction of the entire sector of a volcano, including its summit. During the past 30 ka, major volcanic collapses occurred just after main glacial peaks that ended with rapid deglaciation. Glacial debuttressing, load discharge and fluid circulation coupled with the post-glacial increase of

> humidity and heavy rains can activate the failure of unstable edifices. Furthermore, significant global warming can be responsible for the collapse of ice-capped unstable volcanoes, an unpredictable hazard that in a few minutes can bury inhabited areas.[xxxiv]

Another interesting fact about the GCF is that by seeing the various facets of the framework in their mutual interaction, at times the complexity framework seems to redefine itself. One grasps the terms individually, and then as an ensemble, upon which one sees the interconnections between them, which ultimately leads to a certain redefinition of each of the original terms, and so on. In this instance, we understand the causal links between these three terms – feedbacks lead to thresholds which cause surprises. However, if we were looking for surprises in the first place, we may call them by a different name. As Schneider puts it,

> Events that are not truly unexpected are better defined as *imaginable abrupt events*. For other events—true surprises—although the outcome may be unknown, it may be possible to identify *imaginable conditions for surprise*. For example, if rate of change of CO_2 concentrations is one imaginable condition for surprise (i.e., more rapid forcing increases the chances for surprises), the system would be less rapidly forced if decision-makers chose as a matter of policy to slow down the rate at which human activities modify the atmosphere. To deal with such questions, the policy community needs to understand both the potential for surprises and how difficult it is for integrated assessment models, or IAMs (and other models as well) to credibly evaluate the probabilities of currently imaginable 'surprises,' let alone those not currently envisioned.[xxxv]

Thus far, the authors simply confirm the consensus. But they go on to say that "internal thermodynamic changes related to the positive ice-albedo feedback, not external forcing, dominate the thinning processes over the last 16 years. This feedback continues to drive the thinning after the climate indexes return to near-normal conditions in the late 1990s. The late 1980s and early 1990s could be considered a tipping point during which the ice-ocean system began to enter a new era of thinning ice and increasing summer open water because of positive feedbacks. It remains to be seen if this era will persist or if a sustained cooling period can reverse the processes." Clearly, positive feedbacks and the thresholds they lead to seem to be central to climate change science and policy.

6.1.3. Slouching Towards Climate Change

I propose that a major choice is at hand for thinkers of all kinds. To fully embrace the broader implications of the General Complexity Framework (GCF) is to acknowledge the paradox that there are limitations to what complexity we can capture, and yet we are best off capturing as much complexity as we can. There appears to be an ongoing complexification of knowledge, of the Universe, and yet we must find some delimited reality to extract. With respect to issues like climate change, the only rational choice is to embrace the bigger, richer, and more depressing challenge that includes the dimensions of vulnerability, unpredictability, and unknowability in intellectual pursuits.

To acknowledge climate change in an adequately complex light requires the recognition that things sometimes do fall apart – as in William Butler Yeats' famous poem, "The Second Coming," referred to in the title of Joan Didion's famous book, *Slouching Towards Bethlehem* – which is to say, they do sometimes transform in a manner that is more rapid and far-reaching than we seem to be conceptually prepared or emotionally eager to acknowledge. This is to acknowledge the tensions between order and disorder in social processes, eschewed by many thinkers who have sought order in the social sphere and in the Universe. This is not to blame the lingering forces of early scientific views as the only culprit; there are many reasons that the human mind is rigged to avoid complexity and to focus on order and on controlling what one can, having to do with not only limits to knowledge, but also with our historical cognitive, perceptual, and psychological limits.

The Second Coming
William Butler Yeats, 1919

Turning and turning in the widening gyre
The falcon cannot hear the falconer;
Things fall apart; the centre cannot hold;
Mere anarchy is loosed upon the world,
The blood-dimmed tide is loosed, and everywhere
The ceremony of innocence is drowned;
The best lack all conviction, while the worst
Are full of passionate intensity.

Surely some revelation is at hand;
Surely the Second Coming is at hand.
The Second Coming! Hardly are those words out
When a vast image out of Spiritus Mundi
Troubles my sight: a waste of desert sand;
A shape with lion body and the head of a man,
A gaze blank and pitiless as the sun,
Is moving its slow thighs, while all about it
Wind shadows of the indignant desert birds.
The darkness drops again but now I know
That twenty centuries of stony sleep
Were vexed to nightmare by a rocking cradle,
And what rough beast, its hour come round at last,
Slouches towards Bethlehem to be born?

Given the above argument with respect to feedbacks and thresholds, it may be tempting to see thresholds as the central issue to climate change science and policy. I argue that this is false. Rather, the focus on new tools as singular or singularly significant new solutions is in fact a holdover from the classical way of perceiving and conducting science and scholarship. It may be one of the greatest culprits in the hubris of Western thinking. As soon as researchers eschew the ensemble of complexity, not just in momentary analyses, but in the very orientation of what they will consider in analyses, they open the door to analytical traps. To argue that one must do so of necessity is to negate the significance of false, incomplete, or faulty assumptions upon analytical results. The paper may be published, the career advanced, and the society relatively functional up until a point. Yet, ultimately, those initial false, incomplete or faulty assumptions come home to roost. Today it seems that we are witnessing an exponentially rising return of initial flaws. Like the protagonist in Hitchcock's *The Birds* sitting on the park bench while a flock of menacing birds gathers behind him, we do not see anything, but we sense that a dark cloud that has been gathering for some time is now a full and present danger.

Such analytical traps must be studied. We could label this category of simplistic thinking traps as Rationality Traps, or RATS. The first problem with identifying RATS is that they appear to be so prolific. If the act of denying the significance of complexity and the failure to construe an adequately generalized complex theoretical framework has lasted into the twenty-first century, then our analyses must be overrun with RATS. Sadly, one could also say that no matter how much we integrate complexity fundamentals and advance complexity thinking, it seems likely that RATS are an inevitable aspect of human thinking. In fact, perhaps what is needed is to start to distinguish a typology of RATS, and then begin to make some important determinations, such as which RATS are most significant to all studies or to a study at hand, which are most common, and which most easily avoided.

In correlation, one would develop a list of Contemporary Rationality Tools, or CATS. What are the most effective complexity thinking tools, the most applicable, the most easily applied to particular cases, the most accessible and the most readily deployed. The innumerable complexity methods mentioned throughout the first half of the dissertation provide some examples. I spoke of complexity versions of nonlinear models and scenarios, decision making methods, network analyses, hierarchical models, and whole systems scenarios.

If one were to list the CATS, a good one to put in first place might be the validation of the long-held common-sense rule in the realm of sophisticated critical thinking, that the first answer one finds is probably not the only one or the last one. When presented with a highly complex social situation – climate change, or the current economic crisis – it is likely that there will be many, intricate causes, and only multifaceted solutions which touch upon many of these causes would begin to present a sufficient response. In complexity terminology this could be stated as follows: the greater the intricacy of social and environmental complexity and the richer the web of networked causality, the more significant it becomes to move away from analyses that search for the singular solutions and instead to focus on determining the significant early drivers and on reversing them.

Many scientists, upon acknowledging the significance of one or another climate feedback and or threshold, reacted to some extent within a unicausal or causal minimalist framework, e.g. focused on a few consequential and perhaps related drivers. At times they employ a degree of disciplinary blindness, either presuming the significance of their own discipline in the study system or simply omitting alter-disciplinary drivers and dynamics. While this is at times merited and at times produced the most significant research, quite often it produces sub-optimal, unnecessary, or even misleading or inappropriate research trends. In this sense, while unidisciplinary research is such an essential aspect of natural science research, in the

case of climate change it creates research patterns that are often replete with redundant, unnecessary, unfruitful, fairly irrelevant, or even misleading or inappropriate results and conclusions.

For scientists trained in and ensconced in singular disciplines deeply imbued with the training of the scientific method of analysis, a natural move is to see the helpful new insight as the most helpful tool *within the discipline X*. Climate scientists who discovered the significance of feedbacks and thresholds in climate change may fall into the trap of orienting all research efforts to analyses of feedbacks *within their research area Y*, in this case, feedbacks involved in climate change, often occluded within one micro-disciplinary framework. A correction for this tendency would seem to necessitate periodic transdisciplinary analyses, which would help uni and micro-disciplinary researchers to guide themselves towards the most fruitful and influential study systems and questions, in this case, the most significant and influential feedbacks. Many of the best researchers do just this, but even their useful results may be improved if the efforts at transdisciplinary analysis were more systematized or sophisticated.

What a shift to complexity thinking requires in part, is to move beyond singular tool approaches to guidance of empirical investigation, to approaches guided in part by a generalized complexity framework itself, which I explore in the next section. A GCT framework would be open to new insights about the field of complexity theories itself, flexible in integrating new information and insights about the way generalized complexity itself is construed, and open to ongoing evolving understanding with respect to various transdisciplinary challenges. Thus, to say that feedbacks and thresholds are the central issues in climate change is to miss the point. We go on seeking one monster on the horizon, but this purported monolithic monster would be as (un)useful to us as would be one monolithic reality. For instance, as mentioned in the complexification discussion, a reality that had no constraints and no limits, e.g. no speed of light.

6.2. The Value of the Generalized Complexity Framework

It is not just feedbacks and the thresholds that they lead to that are significant to understanding climate change. Rather, it is the entirety of complex dynamic systems with all of their ontological and epistemological fundamentals that are truly significant. It is not just that scientists did not foresee issues such as feedbacks and thresholds in climatology and related natural sciences. Rather, it is perhaps more significant that natural scientists *often cannot foresee* essential issues involved in socio-ecological systems (SES), and thus must rely in part on a GCF in the conceptualization, framing, prioritization, conduct, and analysis of their research.

A thought experiment can help to support this argument. Let's suppose that natural scientists had had the necessary instruments and awareness to focus on feedbacks and thresholds earlier. Let's suppose, further, that they had adopted a complexity framework for more of their research, on a more substantial basis, one hundred years ago. It is still possible and even likely that they would have overlooked all or some of the most significant issues to do with feedbacks and thresholds of the various geo-hydro-carbon cycles, or the technologies which have spurred the initial drivers and feedbacks. After all, large-sale or even small-scale climate change is an unprecedented event in the period during which humans have employed science and have had the instruments to detect changes. Moreover, it turns out that the largest initial climate impacts are happening at the farthest reaches of the planet, the two poles. Having never observed melting glaciers, scientists would likely still have overlooked issues such as dynamical ice melt.

The essential lesson here is not that we are missing certain fundamentals from the complexity framework. Rather, the main problem that has allowed us to remain so blind to climate change and interrelations of many environmental and social issues is the fact that what we may lack the most is the generalized complexity framework itself. Natural scientists mostly are unaware of it or refute it, and social theorists often utilize only fragmentary aspects of it, singular complexity fundamentals, rather than the ensemble. The extraordinary success and reliability of the scientific method with respect to so many domains, including not just physical and mechanical systems, but those in which complexity is more obviously present – biological, social, virtual, and meaning – blinded us to the way that complexity enhances all of these systems, and especially the latter four. Thus, scientific hubris has continued unabated in the last two centuries without the benefits of a more realistic, comprehensive vision of the world.

6.2.1. Classical Science versus Complexity Theory

In Chapter One I laid out distinctions between what I have been referring to as the classical science perspective and the complexity perspective. Here I develop this distinction further, and argue that it is necessary to incorporate a generalized complexity theories framework into climate change study and analyses, examining the case of how complexity is most useful in climate change science, analyses, and policy. I define the ***complexity theories framework*** as *the explicit and periodic use of the overall set of complexity fundamentals and their interactions as a reference point, conceptual framework, and guide to the processes of science, analyses, and policy.* In distinction, the ***Generalized Complexity Theories Framework*** is *a framework derived from the overall set of complexity fundamentals and their interactions, implications, and subsequent ontological and epistemological contradistinction from the set of assumptions held over from the early classical science era, employed to not just compensate for the errors in these assumptions, but rather to develop the more sophisticated conceptual tools that logically results once one fully incorporates the insights and implications afforded by the complexity paradigm.*

The GCF relates to both basic and applied science and both initial and latter stages of policy. It implies that one delineates and relates the complexity fundamentals of the study problem at hand to this larger complexity framework. This enables one to consider how various complexity fundamentals, which appear to exist ubiquitously across complex dynamic systems may be important to the particular study question. Such an approach permits efficacy and systematization of dynamics – under the rubric of the various complexity fundamentals – that one can expect may exist and may have significance in various study issues.

Classical science, traditional science, and similar terms have been employed to refer to *the general scientific worldview, assumptions, and modus operandi of the last two hundred years*. In Chapter Two, I defended in more depth what I mean by the distinction between the early classical science paradigm and the complexity perspective, and I now reiterate a few essential points. First, like Timothy Allen, Kurt Richardson, and others, I agree that complexity theories appear to attempt at least to describe reality without any paradigmatic lens or filter. Of course, it may turn out that complexity theories are seen as a paradigm at some future date, when a different perspective emerges. However, for reasons I have explained, such as the implications of Rescher's complexification discussed in Chapter Six, and the arguments provided by Allen, I see complexity as the lack of a paradigm. Second, by making a distinction between classical science and complexity thinking I in no way or form deny or disqualify the essence of the scientific method – as explicated by Francis Bacon and his contemporaries in the sixteenth and seventeenth centuries – central to the nature

and essence of scientific research today. Science, which has been so successful in the last few hundred years, is in no way reduced or diminished by recent complexity discoveries and perspectives. Rather, the complexity paradigm is but an *extension to* or *addition to* early classical science, if an essential one.

Third, just because unidisciplinary and reductionist methodologies are not sufficient for all types of inquiry, this does not in any way deny the power and necessity of reductionist analysis in many aspects and forms of inquiry. Again, to the contrary, such methods at times must be enhanced by other dimensions of analysis, particularly in the case of issues of high socio-ecological complexity. A quick look at the hierarchal structures of most study systems exemplifies the need to understand not just in a reductive, piecemeal approach, but also in a synthetic, systems approach. Table 6.3 sketches the basic contrast between these two frameworks.

Mainstream Analysis of Climate Change	Complexity Analysis of Climate Change
Usually constructed from the point of view of one discipline, with the accompanying somewhat constrained epistemology and methodology	Utilizing any or all of the knowledge disciplines applicable to a given area of study, as necessary; integrating various necessary epistemologies and methodologies
Synthesis consists in practice that is common to this discipline.	Synthesis consists in studying and determining which of the many disciplines, epistemologies, and methodologies involved, in what combination and what order, are most appropriate to the particular study at hand.
Contextualized primarily in one knowledge discipline, and thus within the context of its literature, assumptions and myopia.	Contextualized in multiple knowledge disciplines; with the potential of references to vast, often disparate though actually interconnected bodies of literature; with multiple counteracting assumptions, perhaps rendered more visible or perhaps reconciled through this process.
The policymaker must reintegrate the unidisciplinary result of a study back into its pluridisciplinary milieu. This process is perhaps more prone to inadequate previsions, unnoticed errors, and unintended consequences.	The policymaker reintegrates the pluridisciplinary result of a study back into its pluridisciplinary world. This process is perhaps more equipped for either adequate foresight or adequate precautionary measures, and thus vulnerable to less errors and unintended consequences.

Table 6.2. Comparison of Mainstream and Complexity Conceptual Frameworks

6.2.2. Assessing the Complexity Framework

I hope to assess these claims in support of the complexity framework against the experience of scientists studying climate change and other global environmental issues over the past ten years. Perhaps leading scientists who have spent years assessing climate change might benefit from a complexity theory approach. Particular phenomena such as methane release from permafrost or from the ocean viewed from

a complex systems perspective might advance public knowledge, political will, and climate policies. I will critique the meta-assessments of the last ten years as a means to advance this argument.

Other hypotheses act in support of these. If somehow scientists had incorporated complexity more fully into the scientific revolution from the start, it may have been possible to develop in such a way as to increase wealth, well-being, and opportunity, without rendering the earth's life support systems so fragile and vulnerable. The lack of complexity theories in the last few hundred years may have been a driving force in reducing resilience and robustness of social and ecological systems. What this implies is that with this knowledge, humanity can shift in that direction now, to the extent possible.

Second, and based upon this first, climate change could be described as a result of the exploitation of the complex dynamic systems that make up the planet. Thus by looking at these issues in terms of complex systems we see both where parts of our global system are most dysfunctional, and thus where they may be best revised and repaired, to the extent possible.

If the classical scientific framework is defined in relation to such new perspectives, in terms of reductionist viewpoints and methodologies, the complexity framework can be viewed as an overview of science that allows one to integrate this reductionist stance with synthetic views and methodologies.

At the end of Chapter Two I outlined Edgar Morin's framework of restrained versus generalized complexity. Leading complexity scholars have proposed similar distinctions between complexity schools, categories, and frameworks. To reiterate, Edgar Morin distinguishes between complexity theories he calls r***estrained complexity****, based in reductive and mathematical methodologies, as much of the work at SFI and NECSI.* He contrasts this with ***general complexity***, or *work that draws upon data and ideas from math and model-based complexity, but consists in the dimension of theory and philosophical analysis of complex system dynamics.* In other words, Morin defines restrained complexity as that which utilizes reductionist analysis principally in study of a particular system or set of systems of a certain kind. In contrast, generalized complexity is that which involves: reductionist data and analyses, whole systems data and analyses taking into account the parameters and phenomena at the largest scale within which we find the study problem, and finally synthesis of these points of view at individual scales within one greater whole-scale perspective. This permits one to examine not only the phenomena as seen from the reductionist and holistic points of view, but also how these phenomena interact together in their greater context.

Kurt Richardson gives another variant of this distinction, adding an additional category. Roughly equivalent to Morin's restrained complexity and generalized

complexity; Richardson speaks of, respectively, *neo-reductionist* and *critical pluralist* perspectives. His additional category is roughly similar to what I have called *holistic analysis* – whole system interpretations excluding any reductionist analysis – which Richardson playfully named the school of *metaphorticians.* Any holistic interpretation invites the use of metaphors. Holistic interpretation devoid of any reductionist analysis falls prey to false metaphors. This is the major shortcoming of holistic analysis as I outlined it, essentially that while reductionist methodology may be intrinsic to critical plural or generalized analyses, overly holistic analysis often leads to metaphors that are faulty, making inappropriate links or comparisons between disparate phenomena, or overly generalized analyses.

Such frameworks articulate the role that different methodologies – what one can, it seems, crudely distinguish as two sets of methodologies – play in relation with each other. They show why the various methodologies are necessary, where they surpass the strength of the scientific method by itself, the significance of the human sciences, and the weaknesses of holistic or overly broad analyses and the risk of ambitious or random transdisciplinary metaphors.

6.2.3. Rationale for the Complexity Framework

In the analysis of environmental meta-assessments to follow, I attempt to show that in some ways omitting the complexity fundamentals becomes problematic, even if in other ways their inclusion would be unwarranted. So, before proceeding with the analysis of the two meta-assessments, I explain three reasons why *in principle* the complexity fundamentals and indeed the whole Generalized Complexity Framework (GCF) should be included in the meta-assessments. As a caveat, I repeat that this is not meant to be exclusive of reductive analyses, but rather just one facet of study, complimenting reductive analyses where they fall short. Whatever perspective within the broadest complexity framework one may ultimately adopt, one is perhaps more likely to catch significant patterns of behaviors if one at least studies the broadest framework periodically.

First, significant analytical tools derive from the broader perspective of complexity theories that do not derive from study at a smaller grain and scale. For instance, due to the ontological fundamentals of hierarchical structure, emergence, and self-organization, one of the primary criteria that characterizes complex systems is that they possess qualities at the level of the whole system that are not found or understandable solely from the study of their parts.

Applying this rule to study systems at the scale of the biosphere, the rule becomes we cannot completely understand global issues solely by breaking down

those issues into their component parts. Some systems phenomena can only be understood at the largest scale, and often some phenomena that at first may appear to be disparate or inconsequential may in fact be significant to the study at hand. Therefore, it is reasonable to hypothesize that in the case of highly complex biospheric-scale issues, such as climate change, research questions should be framed at the largest scale and grain at some points, including prior to making definitive decisions regarding subsequent studies at smaller scale and grain. This process, beginning with the largest scale and grain in order to adequately assess and frame further, more delimited studies, permits one to focus on what may be more significant drivers in the overall system.

Second, forcing ourselves to at least refer to a complexity framework facilitates the work of those addressing any of the disparate areas of climate research. Even if one argues that diverse scholars must study their separate aspects of the climate issue, it is necessary to utilize the GCF at times for some purposes, e.g. for reviewing, assessing and guiding the totality of climate research over time. The best current GCF – as the GCF should be continuously advanced by scholars in various disciplines over time until perhaps it is replaced by a new perspective – is a necessary reference to remind us of the various interconnected branches relating to particular study issues, and this can render various activities clearer and more efficient, such as: systematizing the work of transdisciplinary research, such as to render it more efficient and more successful; quickly determining what disciplines, methodologies, conceptual tools, or models to employ; more effectively developing any necessary interdisciplinary models or analyses; more effectively identifying appropriate collaborators from other disciplines; and thus better linking, sharing and developing important data and research amongst disparate uni-disciplinary colleagues.

Third, a reason why the complexity framework would appear to be superior to the classical scientific framework for complex global issues is the great degree of uncertainty, unknowability, and risk involved in speculations and scenarios regarding the future. Until now, complexity theories have proven more potent and promising in the treatment of risk, uncertainty, and unknowability than any other major theoretical perspective. There is no doubt that global change, especially since 1950, has been unprecedented in types, degrees, and overall nature. The many unprecedented changes during the last sixty years are now co-evolving in mutual interaction. These co-evolutions themselves seem to be becoming thicker with complexity, at least until now, as new technologies proliferate, populations continue to increase, and continue to encroach further upon natural spaces. Perhaps at some future date, there would be such loss in terms of energy potential, species extinctions, and general biodiversity loss, that there would be a net decrease in overall planetary complexity, but the nature of this decrease itself may undermine the project of science. Seen in this context, it

becomes indisputable that there remains considerable uncertainty about even the climate change drivers that we know about. Moreover, the study of past climate changes began only in the last few decades. Climate scientists are still speculating over the causes of past disruptions, and even hypothesizing about and discovering new causes of past disruptions. Given the degree of complexity involved, and the degree of known unknowns, it is likely that there are substantial unknown unknowns. Thus, significant factors in any rational climate discourse will continue for the foreseeable future to include: risk, uncertainty and unknowability.

6.3. Meta-Assessments

In the last section, I argued that a complexity framework best facilitates the collection of significant data and analyses regarding the scale, grain, context, and nature of drivers, and finally the capacity to conceptualize the interactions between these drivers and influences, and thus to prioritize critical drivers and implementations to change them. In what follows, I test this hypothesis through an analysis of two meta-assessments of socio-ecological global change that have been conducted in the last decade. I analyze the way that these assessments did and did not incorporate complexity theories in their analyses, methodologies, and synthesis; considerations for future such assessments; and what these two examples signify for my hypothesis of the utility and necessity of the complexity framework when studying systems of such considerable complexity.

There remains a considerable challenge in studying phenomena of large-scale socio-natural complexity. Complexity theories and the framework they permit, as I have outlined above, is one conceptual tool. Various other tools have been developed in recent decades, as global phenomena took the front stage, and technologies such as computers have facilitated study of them. I attempt to conduct this analysis as much as possible without biases regarding the value of these conceptual tools, methodologies or frameworks for such varied and highly challenging subjects. My method is to evaluate the work that has been done in these two large-scale developments, looking at primary resources – the reports themselves, and the critiques written by the report writers themselves, as well as reviews and related literature by other scholars.

In brief, the two assessments can be described as follows. The International Panel on Climate Change is the main international scientific organization that has worked on climate change since 1988. Here I study their most recent comprehensive report, completed and published in three parts in the winter and spring of 2007, as well as an additional synthesis report published in November 2007.[xxxvi] *Climate Change 2007* is the most comprehensive synthesis of climate change science to date. Experts from more than 130 countries contributed to the report, which represents six years of work. More than 450 lead authors received input from more than 800 contributing authors, and an additional 2,500 experts reviewed the draft documents.[xxxvii]

> The main activity of the IPCC is to provide in regular intervals Assessment Reports (AR) of the state of knowledge on climate change. The latest one is *Climate Change 2007*, the Fourth IPCC Assessment Report. The IPCC produces also Special Reports; Methodology

> Reports; Technical Papers; and Supporting Material, often in response to requests from the Conference of the Parties to the UNFCCC, or from other environmental Conventions. The preparation of all IPCC reports and publications follows strict **procedures** agreed by the Panel. The work is guided by the IPCC Chair and the Working Group and Task Force Co-chairs…. The composition of author teams shall reflect a range of views, expertise and geographical representation. Review by governments and experts are essential elements of the preparation of IPCC reports.[xxxviii]

The second report I analyze, the Millennium Ecosystem Assessment (MEA), was the result of research begun in 2000 and completed in 2005, similarly written by a large group, 1,360 scientists who convened in locales around the world. In their words, they undertook this massive research report:

> … to assess the consequences of ecosystem change for human well-being and the scientific basis for actions needed to enhance the conservation and sustainable use of those systems and their contribution to human well-being…. findings on the condition and trends of ecosystems, scenarios for the future, possible responses, and assessments at a sub-global level are set out in technical chapters grouped around these four main themes. In addition, a General Synthesis Report draws on these detailed studies to answer a series of core questions posed at the start of the MEA. The practical needs of specific groups of users, including the business community, are addressed in other synthesis reports…. Each part of the assessment has been scrutinized by governments, independent scientists and other experts to ensure the robustness of its findings.[xxxix]

The IPCC report and the MEA have taken on unprecedented degrees of complexity in their planetary scale study of socio-ecological change. Surely, many scholars and scientists have studied a multitude of aspects of socio-environmental change in the last half century. Some precursors of these assessments focused more explicitly on how to grasp and evaluate change at the global scale and what it portends for human societies and for environmental sustainability. Examples are the documents and studies stemming from the first international environmental conference, the Rio Summit in 1992. But the four assessments of the IPCC, of which I focus on the most recent, and the MEA, are uniquely global in scope and ambition.

The IPCC researchers focused explicitly on climate change, while the MEA researchers covered the entirety of socio-ecological change. Since climate change involves many or all of the other major environmental issues we are facing, it is interesting to note how each of these foci plays out with relation to complexity. Again, the broad question I am asking here is how these two studies, the IPCC and the MEA, integrate or do not integrate the complexity fundamentals of climate change. Evidently, the MEA is a vast and detailed compendium, and provides a rich resource for various other kinds of study. Here I focus on three questions in turn: How do the two studies succeed in incorporating complexity? How do they fail to do so? What does this signify for future studies and policy regarding climate change?

6.3.1. Climate Change 2007 – The Intergovernmental Panel on Climate Change Fourth Assessment Report

In the IPCC reports, many of the complexity fundamentals are at play. These include, as mentioned above: feedbacks, vulnerability, thresholds, sustainability, uncertainty and transdisciplinarity, including the related terms resilience, adaptive capacity, tipping points, abrupt climate change, phase state, and interdisciplinarity. My inquiry has led me to focus largely on the issues of feedbacks, transdisciplinarity, and uncertainty with the correlated term unknowability. It is significant that uncertainty has become such a dominant theme in the science and discourse of climate change, as I will demonstrate in what follows. In various ways, the other prominent issues of feedbacks, vulnerability, thresholds, and sustainability, lead us back time and again to the issue of: uncertainty, its meaning and significance, what is signifies about our scientific method, beliefs, and frameworks, how to understand it, and how to cope with it. This may also raise some fruitful questions about the related, less frequently mentioned, but also significant term, unknowability.

Over the past ten years, several prominent climate scientists and scholars have begun to reveal in more depth the significance of uncertainties in climate change and how uncertainty is part and parcel of complex, dynamic systems. As Schneider and Azar wrote in 2001, "Uncertainty surrounds every corner of the climate debate. Moreover, because of the complexity of the climate system, surprises can be expected. (e.g. IPCC, 1996a, p.7; IPCC, 201b, Chapter 1). Low probability and catastrophic events, as well as evidence of multiple equilibria in climate system are of key concern in the climate debate."[xl] Similarly, in a 2002 paper, Stephen Schneider wrote, "Significant uncertainties plague projections of climate change and its consequences."[xli]

Similarly, adaptation and mitigation, which are directly dependent on highly complex socio-ecological interactions, introduce various types of uncertainties, many of them great. As Katherine Vincent, climate change social theorist writes,

> Assessing adaptation is fraught with uncertainties, as it requires future projections of whether adaptive capacity assets will be drawn upon in times of need. Instead the potential for a unit of analysis to adapt, or its adaptive capacity, tends to be considered, even though assessing this is still uncertain. The capacity to adapt to climate change is dependent on a wide variety of social, political, economic, technological and institutional factors. The specific interaction of these factors differs depending on the scale of analysis: from the level of the

> country down to the individual. Adaptive capacity is multidimensional: it is determined by complex inter-relationships of a number of factors at different scales.[xlii]

These uncertainties carry over into the study and evaluation of adaptations. Vincent writes, "Although controversial, the use of indicators and indices is one means of quantifying adaptive capacity for the use of policymakers. However, the process of identifying and deriving accurate indicators is [also] fraught with uncertainties." Three of these include: a normative selection of driving forces, the choice of an appropriate indicator of that driving force, and a determination of the direction of the relationship between indicator and driver.[xliii]

Indeed, as researchers have been confronted with increasing focus on highly complex systems in recent decades, they have developed a new sense of uncertainty, the view that highly complex socio-ecological systems have the *characteristic* of uncertainty. In examining the extent and depth of uncertainties in climate change, many scientists have remarked on the ubiquity of uncertainties in other large, socio-ecological phenomena. As Suraje Dessai and colleagues, another group of social science climate scholars, wrote, "Uncertainty, then, is pervasive in the climate change debate, but uncertainty is not unique to climate change. There is uncertainty associated with other global phenomena – the economy, geopolitics, and health – whether in relation to economic crises, terrorism, or influenzas and pandemics. In fact, uncertainty is a multi-dimensional concept that is omnipresent in our society."[xliv]

A related but slightly distinct theme is that uncertainty is an inherent aspect of the scientific enterprise, as philosophers such as Karl Popper have pointed out. It is in this sense that climate scientist Stephen Schneider notes that uncertainty, and more specifically, the level of certainty needed to reach a firm conclusion, is a perennial issue in science.

Uncertainty, like complexity, while ever present, did not interfere much with the progression of science and technology throughout most of the modern age. Like complexity, uncertainty is ubiquitous, and yet human scientists, technologists, and other social leaders did not have to confront it directly very often. But as human societies have become more global, usurped more of the earth's total biomass, land-surface, and natural resources, and as the impacts of human actions have increased, extending human impact in both reach and in interconnection of feedbacks, uncertainty – along with risk, harm, unintended consequences, and thresholds – has come increasingly to the fore. No longer are fire and theft insurance the only areas in which uncertainty is dealt with in a rational, that is to say probabilistic, manner. As Schneider notes, "the difficulties of explaining uncertainty have become increasingly salient as society seeks policy advice to deal with global environmental change."[xlv]

Such remarks reached the mainstream climate change scientific community and resulted in a widespread acknowledgement of the problem of uncertainty. Yet, clearer, more comprehensive incorporation of uncertainty into climate models and analyses is still largely lacking in the IPCC 2007 assessment reports. Historically IPCC assessment reports like other climate assessments made the mistake of mostly omitting events of what appeared to be low-probability but high consequence. As Stephen Schneider has suggested of climate change literature more generally, for the most part, IPCC assessment reports primarily consider scenarios that attempt to 'bracket the uncertainty' rather than explicitly integrate unlikely events from the 'tails of the distribution.'

Moreover, interactions between social and ecological systems, which are rapid, numerous, and carry significant impacts in contemporary times, are largely omitted. Schneider writes, "Not even considered in the standard analytical works are structural changes in political or economic systems or regime shifts such as a change in public consciousness regarding environmental values."[xlvi] These are numerous and work both to exacerbate and to correct for climate change. In other words, rapid and influential human responses to climate change must be integrated into climate analyses in order to be effective.

Various critics have found that the IPCC reports omit too much by way of nonlinear change and tipping points. Although researchers may recognize the wide range of uncertainty surrounding global climate change, their analyses are typically surprise-free. This omission produces a monumental policy failure. As Schneider said, "Decision-makers reading the 'standard' literature will rarely appreciate the full range of possible outcomes, and thus might be more willing to risk adapting to prospective changes rather than attempting to avoid them through abatement, than if they were aware that some potentially unpleasant surprises could be lurking (pleasant ones might occur as well, but many policymakers tend to insure against negative outcomes preferentially)."[xlvii]

Brian O'Neill, who Simon Levin has called, "one of the brightest young scientists out there," is one of the youngest scientists in the IPCC network, "trying to reformulate climate change projections that can cope better with uncertainty by accounting for 'future learning.'"[xlviii] O'Neill, a futurist, works on improving what he sees as major shortcomings in the IPCC work and hopes to improve upon the IPCC failure to adequately account for complexity, uncertainty, and tipping points. According to O'Neill, researchers "desperately" need a strategy for tackling climate uncertainties.[xlix]

Again, the weakness that Brian O'Neill is pointing to here is epistemological, the way that uncertainty is studied, perceived, and thus dealt with. And again there do exist precursors of more rational methods, such as the probabilistic method with

which we assess and allocate insurance in the case of fire, theft, and other unpredictable – meaning always possible but in any given moment utterly uncertain – future events. After noting the challenge of uncertainty in climate prediction for example, climate social scientist Suraje Dessai and colleagues argued for policy and action in the face of uncertainty.

> Given the deep uncertainties involved in climate prediction (and even more so in the prediction of climate impacts) and given that climate is usually only one factor in decisions aimed at climate adaptation, we conclude that the 'predict and provide' approach to science in support of climate change adaptation is significantly flawed.
>
> Other areas of public policy have come up with similar conclusions (e.g., earthquake risk, national security, public health). We therefore argue that the epistemological limits to climate prediction should not be interpreted as a limit to adaptation, despite the widespread belief that it is. By avoiding an approach that places climate prediction (and consequent risk assessment) at its heart, successful adaptation strategies can be developed in the face of this deep uncertainty. We suggest that decision makers systematically examine the performance of their adaptation strategies/ policies/ activities over a wide range of plausible futures driven by uncertainty about the future state of climate and many other economic, political and cultural factors. They should choose a strategy that they find sufficiently robust across these alternative futures. Such an approach can identify successful adaptation strategies without accurate and precise predictions of future climate.[1]

Similarly, in a co-authored chapter on research methods for the Fourth Assessment Report, Brian O'Neill echoed the epistemological concerns such as those of Dessai and Schneider mentioned above that IPCC assessment reports primarily consider scenarios that attempt to 'bracket the uncertainty' rather than explicitly integrate unlikely events from the 'tails of the distribution.' Bracketing the uncertainty may appear as the next logical step for those trained in mainstream policy methods involving certainty and clear delineations between outcomes. However, once one embraces uncertainty as a necessary aspect of normal complex systems functioning for issues such as overall social and natural trends in climate change, it is

necessary to shift to a methodology more in step with such complex dynamics and such inherent uncertainty. Bracketing the uncertainty is like Cuba deciding at the beginning of a hurricane season not to prepare for a level five hurricane at all, because there is less than a fifty percent change of a level five event. Obviously, with a ten percent chance of a level five hurricane, residents will be willing to pay for major preparations. Explicitly integrating extreme events would perhaps require that the island do as much as possible for a level five event, even with only a one percent chance. It is the insurance logic, again, with which we brace ourselves against any major risks. It is necessary to use that probability which captures these extreme events, avoiding those systems that omit these tails of the distribution.

In writing the IPCC chapter, O'Neill saw that in the effort to create consensus, important complexity analyses fell out of the final drafts. He warns that when scientists lacked knowledge of how accurately to describe probabilities of such unlikely but catastrophic events, they simply omitted them, or wrote them in utterly vague terminology. Granted, any large group writing effort is plagued by the need for compromise. And there does need to be consensus for climate scientists to be taken seriously and to send clear messages to policymakers. O'Neill says it is important for climate scientists to speak with a powerful, united voice. However, he says, this is counterproductive if it results in a misrepresentation and minimization of the most serious risks. "The extreme scenarios that tend to fall out of the IPCC process may be exactly the ones we should most worry about."[li]

To address this problem, O'Neill has been organizing interdisciplinary groups to work on the issues of feedbacks, thresholds and uncertainty in the assessment process. For instance, he assembled a team of a half-dozen demographers, economists, statisticians and physical scientists to try to sharpen the models to better account for uncertainty and thresholds. Early in 2008 he organized a meeting of top climate scientists, economists, and demographers to think about how they generate knowledge.

What emerged as the most significant issue was how IPCC scientists have been failing to adequately incorporate what they called the "Wile E. Coyote effect" – the moment when the cartoon coyote doesn't realize that he is falling off of a cliff until he looks down, too late to turn back, which is a tipping point, or what climate scientists sometimes call abrupt climate change. In particular, scientists wish to clarify knowledge about climate thresholds such as the abrupt change or even shut down of the ocean's conveyer-belt system, the ocean's thermohaline circulation belt. O'Neill warns that while scientists need to know more about the natural variability of the oceanic Meridional Overturning Circulation (MOC), they still don't even know "how precise your measurements have to be" or how large an area must be studied before uncertainty could be sufficiently reduced to spot "the edge of the cliff."[lii]

Climate scientist Michael Schlesinger points to another example, polar ice sheets are melting more rapidly than anticipated.[liii] "Things are happening right now (2006) with the ice sheets that were not predicted to happen until 2100," says Schlesinger. "My worry is that we may have passed the window of opportunity where learning is still useful."[liv]

This is not to say that the IPCC has not addressed uncertainty. Certainly, scientists in and outside the IPCC have been trying to grasp and incorporate the role of uncertainty in scientific assessments; it has been a stage by stage process. The IPCC reports have increasingly included plenty of data on nonlinear change. IPCC reports include graphs that present numerous potential thresholds and tipping points, and are mentioned in the text. However, these same tipping points are then omitted from the more elaborate analyses. The IPCC has a history of mentioning terms like tipping points, giving data that points to them, and still omitting them from the conclusion. It is important to recall that I am speaking here of the terms tipping point in the TDCT sense as it has been used by IPCC scientists, and not the more technical meaning of thinkers such as Rene Thom.

While the reluctance to give dire news is very human, it may undermine the legitimacy of the IPCC to continue to omit their own facts from their analyses. The IPCC's innumerable threshold charts, in popular terms "hockey-stick charts," are a good start. To take the above account seriously, that feedbacks are nonlinear and interactive by nature, is to recognize the significance of both the hockey-stick graphs in various domains, their ubiquity across domains, and their intra and inter-domain interactions. It is striking to see the correlation between human impacts and adaptations, and in ecosystem functioning and services. As human impacts have surged upward in recent years, ecosystem services have taken a sudden turn downward.

Gradually, the IPCC authors have made progress in their approaches to uncertainty. Amidst the writing of the Fourth Assessment Report, some IPCC scholars made the following remarks about how the IPCC improved their uptake of uncertainty from 1990 to 2007.[lv] Their description of this transition makes several notes significant to the ideas put forward earlier in this dissertation. They note that different disciplines use different methods to study conditions of uncertainty. Thus, any hope of a universal approach to uncertainty management has been debunked; it is necessary to embrace methodological plurality of approaches to uncertainty throughout the myriad disciplines involved in climate change. Finally, scientists must learn to capture key uncertainties without oversimplifying the way different kinds of uncertainty appear at different scales.

As the authors state:

> Looking back over three and a half Assessment Reports, we see that the Intergovernmental Panel on Climate Change (IPCC) has given increasing attention to the management and reporting of uncertainties, but coordination across working groups (WGs) has remained an issue. We argue that there are good reasons for WGs to use different methods to assess uncertainty, thus it is better that WGs agree to disagree rather than seek one universal approach to uncertainty management. In the IPCC First and Second Assessment Reports, uncertainty was not addressed systematically across WGs. Uncertainty statements were not centrally coordinated, but left at the authors' discretion.
>
> In 1990, the WG I executive summary started with what the authors were certain of and what they were confident about, thus taking a subjective perspective. They used strong words like ''predict'', a term which would nowadays rightly be avoided. For WG II (Impacts) and WG III (Response Strategies), the review procedures were not very rigorous yet and uncertainties were not a major topic of debate. The formulation of key findings did take uncertainties into account, albeit not in any consistent manner. Two pages were devoted to scenarios—as a description of uncertainty about the future—used in the WG III report. The Summary for Policymakers contains a few sentences stressing several uncertainties, e.g. those related to the difficulty of making regional estimates of climate-change impacts.

Science studies commentators correctly noted some of the flaws of these approaches. As climate change opponents and detractors began using uncertainty against the IPCC scientists, science studies scholars the lack of clarity surrounding uncertainty. Analyzing an IPCC report in 1996, Simon Shackley and Brian Wynne suggested that, the potentially damaging effects of uncertainty in scientific knowledge could be limited if certainty about uncertainty can be achieved. Such attempts at clarification or 'auditing' of uncertainty is common in scientific reviews and assessments and plays a role in the process of achieving consensus around scientific knowledge claims. As Sir John Houghton, chairman of the scientific assessment Working Group (WGI) of the IPCC, stated, at the IPCC,

> [C]lear distinctions have been drawn between what is likely to occur (with appropriate ranges of uncertainty given) and changes which are much less likely and more speculative…. This clarity of approach very considerably aided the wide acceptance of the IPCC's finding by policymakers and the signing by nearly all countries of the Climate convention.[lvi]

While Houghton said that "the [quantitative] estimation of uncertainty is at the heart of the scientific method…. [e]ven when the uncertainties are large."[lvii]

Seeking to bridge the concerns of policymakers and scientists, leading STS scholars Simon Shackley and Brian Wynne analyzed the conundrum of finding sufficient certainty on uncertainties. They discussed the difficult navigation between the goal of objectivity and the false routes of positivism and relativism, following Kristin Shrader-Frechette's advice to not "throw out the baby of objectivity with the bathwater of positivism."[lviii] Without dismissing the authority of the IPCC scientists, they aimed to show how, to date, the IPCC was falling short of sufficiently articulating climate change uncertainties. It is worth quoting at some length.

> Although scientific uncertainty appears to be well articulated in such representations [as the IPCC's second assessment report], closer inspection suggests that climate scientists are unable to demarcate clearly or fully the extent and type of all forms of uncertainty by the methods and practices of climatology. For example, nowhere in the IPCC's reports of 1990 and 1992 is there a systematic discussion of what is meant by uncertainty in different contexts, of the different meanings of uncertainty, or of methods of analyzing it. In the absence of further explanation, therefore, it appears paradoxical that the IPCC reports rely so heavily on qualitative indications of certainty. It is also beguiling that while scientists apparently favor quantitative uncertainty ranges, Houghton (1994) reports that scientists have a difficult time agreeing on exactly what the ranges mean.
>
> For example, in assessment for policymakers, climate scientists usually give a range of estimate for the temperate response at the earth's surface to a doubling of carbon dioxide (CO_2), sometimes called the "climate sensitivity." This range of 1.5^{o} to 4.5^{o} Celsius is arrived at by using deterministic climate models and is not a

probability range. The most sophisticated models adopt fundamental laws, such as Newtonian laws of motion and the gas law, to simulate the circulation of the atmosphere and ocean at grid points in a three-dimensional space. These general circulation models (GCMs) have been developed from weather forecasting models and have a large computational requirement. They can be "run into the future" with a sudden or gradual increase in the prescribed atmospheric concentration of CO_2 as a means of exploring climatic changes. One of the scientists involved in preparing the IPCC's 1990 report commented in an interview:

> [W]hat they were very keen for us to do at IPCC, and modelers refused and we didn't do it, was to say we've got this range 1.5-4.5^{o}, what are the probability limits of that? You can't do it. It's not the same as experimental error. The range has nothing to do with probability – it is not a normal distribution or a skewed distribution. *Who knows what it is?* (emphasis added)[lix]

Such limitations in the articulation – and understanding – of uncertainty, as judged by climate scientists' own expressed standards, only emerge from more detailed enquiry and would not be apparent to most policymakers. Climate scientists, however, do understand such limitations of the analysis of uncertainty even if they do not always articulate them fully and consciously. Accordingly, most scientists can be satisfied about the validity of representations such as those in the IPCC reports even when the limitations are not made fully explicit. Policymakers can also accept this discourse of the management of uncertainty because it is sufficiently ambiguous not to threaten their authority as decision makers (e.g. accounting for uncertainty can be seen as a useful "service function" of science for policy).[lx]

In the summer of 2005 Arctic sea ice underwent very rapid and sudden melting, surprising most climate scientists. Chunks of sea ice the size of U.S. states began falling off glaciers into the sea. Such events may have spurred erstwhile reluctant scientists to take the questions of uncertainty and thresholds more seriously. Meanwhile, interdisciplinary teams of IPCC scientists had become increasingly aware that the initial aim of universal approaches to uncertainty was unattainable. In its place, methodological and epistemological pluralism amongst different IPCC disciplines had become imperative. This is the thesis of the IPCC scientists in the article "Agreeing to Disagree."[lxi] As scientists worked on ensuing IPCC reports, talk shifted from prediction to projection and from uncertainty to degrees or scales of uncertainty. This implied that uncertainty should be framed not as an inconvenience to be overcome, but as an inherent aspect of complex global systems that had to be understood in terms of degrees and scales. They wrote:

> In the Second Assessment Report (1996), WG I dropped the usage of uncertainty terms in its main policy messages, but added a special section on uncertainties. Efforts were made to reach consensus on appropriate formulations for uncertainty-laden statements. The key formulation "the balance of evidence suggests" was coined during the plenary meeting jointly by IPCC delegates and lead authors. "Predicting" was replaced by "projecting" climatic changes on the basis of a set of scenarios. In its concluding chapter "Advancing the understanding," WG I mentions the need for a more formal and consistent approach to uncertainties in the future. WG II, which covered scientific–technical analyses of impacts, adaptations and mitigation of climate change, assigned low, medium or high levels of confidence to the major findings of the chapters in the executive summaries, following again the subjective approach. Explicit reporting of uncertainties was not a key focus in the WG III assessment on the economic and social dimensions of climate change. They were captured through reporting of ranges from the literature and scenario-based what-if analyses of costs of response action. In preparation for the Third Assessment Report (2001), a strong demand for a more systematic approach to uncertainties was identified—as recommended by WG I in the Second Assessment Report. [lxii]

A more systematic approach to the uncertainties came in 2000 in the form of a cross-cutting guidance paper on uncertainties by leading climate scientists Richard Moss and Stephen Schneider.[lxiii] The paper summarized the relevant literature and built upon the Second Assessment Report's lessons. The team which prepared the book in which Moss and Schneider's report was found discussed the idea of organizing the guidelines on uncertainty around a general scale going from totally true, certain, or known, to totally unknowable. The known to unknown scale was seen as attractive from the perspective of the need for simplicity. But the writers decided it would be overly simplistic. In the end, they came upon a "two-dimensional, qualitative" way to qualify key findings based on *the amount of evidence* – the number of sources of information – and *the degree of the agreement* – how much the different sources point in the same direction. It was left up to individual author teams to calibrate the two scales – the amount of evidence and the degree of agreement.

Thus, the scientists found themselves in the position of an exercise that many of them must not have been well-trained for, the epistemological question of how to discern qualitative measures for certain uncertainty. The relationship between evidence and belief varies a lot between disciplines, according to Moss and Schneider. Presumably, a single available case study would score low on the first scale, while seven or more independent controlled experiments would score high. If seven or more experimenters' results were similar, they'd score high on both scales. Thus, the guidance paper proposed:

1. An analysis methodology (recommended steps for assessing uncertainty)
2. A common vocabulary to express quantitative levels of confidence, and
3. Terms describing qualitative levels of understanding, based on both the available amount of evidence and the degree of consensus among experts. [lxiv]

This is one major example of how the IPCC attempted to better incorporate uncertainty and extreme events into climate change science. Many scientists have reflected on appropriate ways to approach, capture, and describe uncertainties. It remains unclear just how successful this addition has been for the work of individual scientists. Uncertainty is much more present in the IPCC's Fourth Assessment Report. As O'Neill points out, however, it still seems to omit what may be the most important data of all, the more abrupt changes.

Again, such concerns are not completely new. A substantial literature on such questions at the conjuncture of uncertainty and catastrophe theory was produced in the 1970s and 1980s. Once again, it appears that the diversion of convergent analyses

– a phenomenon partially explicated by Nicholas Rescher's theory of complexification – plagues the contemporary scholar. Evidently, even transdisciplinarity cannot fully address this, as it becomes a question not of the willingness or the practicality of inclusivity or of synthesis, but rather of the sheer quantity of knowledge that one person can possess or process. This is one of the rationales behind the movement towards collaborative scholarly communities and epistemological communities, fostered by projects such as the MEA.

6.3.2. Millennium Ecosystem Assessment – The Millennium Assessment Report

While the IPCC was tackling the Fourth Assessment Report, another project was underway, the massive five-year study by 1,360 scientists around the world to assess the overall state of the global environment, the Millennium Ecosystem Assessment (MEA). In 2000 the MEA teams set out to assess the environment. By the time they were done in 2005, they had muddled through not only enormous quantities of data, but along the way also – substantial, difficult, at times novel, and to many, unfamiliar, unanticipated and pioneering – theory and philosophy. In the attempt to assess the health of the world's ecosystems, they came up repeatedly against the major theoretical challenges of epistemological, methodological, and conceptual pluralism, transdisciplinary discourse, and complexity.

A literature has grown up in the wake of the MEA report. One of these was written by a group of MEA scholars, attempting to engage in what I call, using Brian O'Neill's term, learning about learning. The scientists and scholars reflect on the MEA experience of what they call 'bridging scales and epistemologies.'[lxv] The authors call for the need to "reason together" as Harvard professor and leading STS scholar Sheila Jasanoff says, engaging in, "intentional deliberation, exchange, and comparative evaluation and critique among epistemic frameworks."[lxvi]

In their report, *Bridging Scales and Epistemologies*, the authors state that the MEA process highlighted that the need to incorporate and synthesize analysis from data at different scales and using different epistemologies is an essential part of global analyses, "particularly acute in global environmental governance."[lxvii] They go on to consider strengths and weaknesses of the MEA in addressing the interdisciplinary and pluralist aspects of the MEA and to highlight the enormous challenges of global assessments. Moreover, as Ian Hacking said, adequately studying issues of multiple scales and multiple disciplines is complex, costly and sometimes uncomfortable. This is true even amongst natural science disciplines, which already diverge greatly in preferences regarding models, instruments, methods and styles of reasoning.[lxviii]

Thus, bridging scales and epistemologies is not simply a matter of increasing spatial or temporal resolution, but of "stitching together multiple knowledge systems that encompass divergent paradigms and operate from distinct assumptions and evidentiary standards, ideological commitments, and frames of meaning."[lxix] In this sense, they note, bridging scales becomes a special case of bridging epistemologies, as epistemic frameworks emerge as a key difference across scales.[lxx]

While this suggestion already has great implications for the difficult and extensive nature of global assessments, it is just one piece of a complexity framework as discussed in the previous section of this chapter. The authors' analyses of lessons learned and improvements for future global assessments seem to support this

hypothesis. They suggest four challenges to overcome in future work, and five ways that global environmental assessments can in turn facilitate understanding of how "mutual learning occurs across scales and knowledge systems." The four challenges include:

1. building capacity for critical policy reasoning
2. promoting epistemic tolerance and pluralism
3. enhancing reciprocal dialogue and exchange, and
4. restructuring scientific assessments to serve as deliberative spaces within global governance, where this mutual learning amongst a plurality of scientists groups and disciplines can occur.

These suggestions may sound ordinary at first glance, but a closer examination reveals that with respect to the current state of academia, education systems and public media and discourse, and insofar as these are serious intellectual goals, these challenges would present radical changes. Major reform would be necessary not only in academia, but in the spheres of science and technology, the school systems, and even many businesses and corporations. It would seem necessary to increase funding for all levels of education, and implement serious regulation to protect universities from the encroachment of increasing economic pressures from science, industry and corporations. At the same time, these suggestions seem indispensable.

The authors of *Bridging Scales and Epistemologies* also suggest that environmental assessments facilitate this learning by:

1. making differences across styles of reasoning explicit
2. structuring comparative evaluation of reasoning techniques
3. promoting dialogue about the appropriate application of methods and frameworks on global contexts
4. facilitating cross-cutting evaluation, and lastly,
5. communicating these deliberations broadly.

Again, this may be more challenging that it seems at first glance. Most of these suggestions would require the work of epistemologists, requiring major advancement of a certain currently underdeveloped and perhaps underestimated school of epistemology. The last few suggestions require a great deal of dialogue and dispersal of ideas, that to effectively take hold would need major investment and years of development. With suggestion number five – communicating these deliberations broadly – the authors signal that pluralism is not just critical between scientists and scholars, but also between different parties and stakeholders of the public, confirming

notions of science studies scholars that science of this complexity can only be truly analyzed by an educated, general public who embody the diverse sets of knowledge, not just across disciplines, but across regions, ecosystems, cultures, and political and institutional groups.

Their conclusion offers ideas on ways to build upon the methods of the MEA. First, subglobal assessments should not fall back into the easy comfort of place-based assessments. Local assessments of local concerns are insufficient. Instead, the general approach must synthesize variations in causes and impacts of global environmental change. In practice this may be quite complicated. For instance, it would involve eliciting subglobal variations in frameworks of meaning and styles of reasoning for producing knowledge about global risks. Subglobal assessments should abandon fixation on geography as the sole defining organizational characteristic. The point of bridging scales and epistemologies is to find alternative ways to slice up global problems for analytical purposes as many sub-global processes are not confined geographically. I add that this seems very insightful, and that the way forward would seem to open a Pandora's Box or possible approaches to such complexity – a plethora of options that may seem daunting, yet it may be necessary to explore it in order to find analytical tools that are at once comprehensive and flexible enough to allow for varied use.

Second, assessments must reach out in their deliberative mechanisms beyond the experts who participate in the assessment itself. If global environmental assessments are to help reduce ideological fissures in global society, they must cease being isolated exercises of expert analysis and start becoming focal points by which whole communities can begin to learn to reason together.[lxxi] Much more needs to be done to fully evaluate the implications both reasoning together as an approach to democratizing international governance and of using regionalization as a strategy for achieving this democratization.

The vast complexity of these issues sheds light on the substantial challenges to improvement of global assessments of socio-environmental change. As such, it may indicate that ultimately such a brief report can do nothing more than frantic arm waving about the enormity of the tasks at hand. Thus, while the *Bridging Scales and Epistemologies* report produced by the MEA scientists seems to support my hypothesis that such analyses could go farther once grouped under the umbrella of a 'complexity framework,' it also indicates some of the potential pitfalls and even weaknesses or limits of a truly wide-reaching methodology that would have to be overcome in order for assessments utilizing a richer complexity framework to succeed.

For instance, while many of these goals sound laudatory and promising, as articulated in this brief report they are almost entirely abstract. The material, data,

epistemologies, peoples and ecosystems to be somehow synthesized reads more like a list than a set of ideas that might be "stitched together." Moreover, as natural scientists are already wary of the immense cost and challenge of effective global climate assessments, such additional challenges surely appear to some as overly costly. It is one thing to list challenging and novel epistemologies and methods; it is another to carry them out, finding ways to effectively synthesize quite different methods of modeling, experimentation, and theorization. If only a small cadre of scholars would have the requisite skills to conduct such syntheses, how then could a team of over a thousand IPCC scientists live up to the task of incorporating not just different disciplines, but effectively integrating the plural voices and ideas of the public at large?

Nevertheless, this path forward seems essential. It may be that achieving pluralistic epistemological communities is not just a buzzword but a realistic necessity. One can see it as an enormously complex, challenging, and difficult task. But one can also see it as a goldmine for the advancement to a truly exciting new phase of more sophisticated, systematized transdisciplinary science and ideas. It is possible and perhaps most rational to accept the theory of complexification, accept the limits to knowledge, and therefore, consciously choose to confront these challenges as well as possible.

6.3.3. Weaknesses of the Meta-Assessments

Against this backdrop – which I hope lends some realism to the comments to follow – I now attempt to catalogue some of the major failures of past global socio-environmental assessments. As noted above, perhaps the most significant shortcoming of both the MEA and the Fourth IPCC AR is their failure to adequately address the issues of abrupt climate change. With respect to the general climate models (GCMs) at the core of early IPCC reports, Stephen Schneider and economist and climate scholar Christian Azar noted in 2001, "Although these highly aggregated models are not intended to provide high confidence quantitative projections of coupled socio-natural system behaviors, we believe that the bulk of integrated assessment models used to date for climate policy analysis – and which do not include any such abrupt nonlinear processes – will not be able to alert the policymaking community to the importance of abrupt nonlinear behaviors."[lxxii] Climate scientists must manage to include risks of catastrophes in cost-benefit analysis, or find better forms of analysis. Schneider and Azar write, "[t]he complexity of the climate system implies, we have noted, that surprises and catastrophic effects could well unfold as the climate system is forced to change, and that the larger the forcing, the more likely there will be large and unforeseen responses."[lxxiii]

In what follows, I address some of the other omissions or weaknesses of the MEA and Fourth IPCC, and analyze whether these shortcomings are based in the early classical science paradigm, and whether a complexity framework might help to correct these areas. Generally speaking, as one noticed in the critique of the MEA above, abstraction about critical issues detracts from the effectiveness of the message. One hears much talk of the need for plurality in methods and analyses, but little concrete advice on how to achieve this with such vast data. Often throughout these global assessments the authors point to the need for synthesis between diverse disciplines, epistemologies, methods, and scales. However they usually fail to analyze or explain how to proceed, fail to state or underrate many of the implications of this work, and omit or underrate various aspects that become clearer within the context of greater complexity studies, including: unknowability, the limits of certain scientific methodologies to certain issues, irreversibility in ecosystems, network causality in socio-ecological systems, and the nature of systems state changes at multiple scales, e.g. cascade effects.

Another category of error in global socio-ecological assessments is that the authors often name and address problems clearly, but do so in a way that remains mostly within the classical science framework, and thus fails to achieve adequate understanding of either the degree of challenge or possible ways to view or to approach it. For instance, in the Fourth AR of WGI scientists use the term "dynamical

ice loss," mentioned in a way that can be read as a rather banal process, considering the risk that this appears to represent. In the summary for policymakers, the authors fail to note the acceleration in the speed of sea ice loss, particularly in the summer of 2005, but also in 2006. Instead, the authors say "Dynamical processes related to ice flow not included in current models, but suggested by recent observations could increase the vulnerability of the ice sheets to warming, increasing future sea level rise. Understanding of these processes is limited and there is no consensus on their magnitude."[lxxiv] Thus, while some of the critical information trickles down to summary reports, the essential messages of speed, irreversibility, tipping points, and cascade effects do not make it into the summary reports.

Similarly, the authors note that, "The resilience of many ecosystems is likely to be exceeded this century by an unprecedented combination of climate change, associated disturbances (e.g. flooding, drought, wildfire, insects, ocean acidification), and other global change drivers (e.g. land use change, pollution, over-exploitation of resources).[lxxv] And that, "Over the course of this century net carbon uptake by terrestrial ecosystems is likely to peak before mid-century and then weaken or even reverse" thus amplifying climate change.[lxxvi] And this is left without further comment. Thus, abrupt climate change is mentioned without its catastrophic quality coming through. Perhaps a natural scientist is trained to write in this fashion, but a broad public readership will not know how to read between, or beyond, the lines.

These omissions of the critical complexity elements in the final summaries often results in strangely vague and understated conclusions: "The large ranges of SCC are due in the large part to differences in assumptions regarding climate sensitivity, response lags, the treatment of risk and equity, economic and non-economic impacts, the inclusion of potentially catastrophic losses and discount rates. It is very likely that globally aggregated figures underestimate the damage costs because they cannot include many non-quantifiable impacts. Taken as a whole, the range of published evidence indicates that the net damage costs of climate change are likely to be significant and to increase over time."[lxxvii]

Furthermore, the summaries tend to underrate what scientists now understand to be significant interactions between various biophysical systems. Thus far, the assessments include little analysis of the interactions between different large-scale ecological issues, and their compounding or cascading consequences. Thus, factors that influence climate change are often omitted or insufficiently analyzed, including: pollution, human encroachment on ecosystems, human depletion of natural resources and subsequent biodiversity loss, feedbacks between biodiversity loss and climate change, and the like. Currently, biodiversity loss and extinctions are of a magnitude unprecedented in human history. Thus, the omission of interactions and feedbacks between other drivers of biodiversity loss and climate change as a driver seems quite

significant. Biologists and ecologists estimate that we will lose 40 percent of the earth's flora and 40 percent of the earth's fauna by 2050. Now, climate scientists are estimating that climate change alone will cause a similar degree of species extinction, about 40 percent.[lxxviii] This leaves open the question of what total biodiversity loss will be by 2050 or perhaps significantly earlier, given the nature of the multiple drivers of biodiversity loss, and the interactions and feedbacks between these drivers. What the IPCC summary authors do report is that these significant cross-cutting, biophysical interactions exist and should be analyzed, but that no one has done this as of yet.[lxxix] As climate scholar and economist Christian Azar points out, climate scientists capture these significant uncertainties implicitly, not explicitly, and too often omit their significance.

If we were to successfully synthesize those two sets of drivers, we would come closer to a true estimate of overall extinctions by 2050. A valid synthesis of this sort may be highly challenging or perhaps impossible to obtain. Yet, however difficult or impossible it may be to evaluate such interactions, since they are of a significant degree of probability, it seems imperative to discuss and analyze the implications of them much more thoroughly and effectively, in order that policymakers reading reports such as the those of the IPCC and MEA see a more realistic portrayal of the potential risks. If this has not yet been the case, it is not because these outcomes are not probable enough. It is at least partially because scientists are still largely thinking and analyzing within the partial and insufficient classical science framework. There are likely other reasons – political, psychological, and personal.

But these ideas are not new. Typically and logically enough, what many natural scientists recognize to be a significant necessity of philosophical analysis of the scientific process had been discussed by philosophers and social theorists for years or even decades. Also, there were a few natural scientists who were studying the potential significance of abrupt changes in the 1970s. To observe the poignant and early contributions of many social theorists, such as environmentalists, science studies scholars, philosophers of science, and social critics – in no way intends to slight the significance of the natural scientists contributions, without which we would not even have empirical evidence of climate change! Rather, it is meant to underscore the utter significance of dialogue and understanding between the social theorists and philosophers on the one side, and natural scientists on the other. It does seem to be the case that if hubris and scientism were not so strong throughout so much of the natural science communities in the last decades, and if more of these scientists had listened to numerous warning calls from philosophers of technology, social theorists, and environmentalists, and if these issues had been effectively taken up and

communicated to the public, we might have been able to begin implementing serious renewable energy and climate policy some years ago.

These drawbacks carry over into the IPCC's work on adaptation and mitigation as well. A very positive observation, the IPCC authors note is that, "There is a growing understanding of the possibilities to choose and implement mitigation options in several sectors to realize synergies and avoid conflicts with other dimensions of sustainable development (high agreement, much evidence)."[lxxx] Yet, they fail to discuss the complexities of this statement or how one might determine, address or implement such synergies. They do not discuss the role of network causality, either in the compounding of problems, or possibly in the compounding of solutions.

Generally, a shortcoming and source of error in the IPCC reports and the MEA report is that the authors, naturally enough, indicate the importance of complexity, while doing so almost entirely from the classical scientific framework. Thus, in the consensus process in writing synthesis reports, the authors end up deleting substantial claims such as "Unmitigated climate change would, in the long term, be likely to exceed the capacity of natural, managed and human systems to adapt."[lxxxi] The much milder version chosen in the summary of the same report, also by WGII, "The resilience of many ecosystems is likely to be exceeded this century by an unprecedented combination of climate change, associated disturbances (e.g. flooding, drought, wildfire, insects, ocean acidification), and other global change drivers (e.g. land use change, pollution, over-exploitation of resources).[lxxxii] Thus, to the attentive eye, the message of possible catastrophe seeps through. However, it does so without any discussion or analyses of essential political questions. Perhaps the IPCC felt it necessary to avoid thorny politics in the past. At this point however, climate change adaptation and mitigation is an accepted political reality. In the Fourth Assessment Report the authors of WGIII only lightly dabbled in such significant issues as to who will pay for mitigation and adaptation, e.g. expensive upgrades of facilities.[lxxxiii] In the future, such central political issues must be fully addressed.

Additional confusion in the report stems from what I call attempts to describe complex issues from within the early classical framework. For instance, the authors frequently confuse verb tenses, using the future or conditional tense where the present tense is accurate. The authors write, "If the damage cost curve increases steeply, or contains nonlinearities e.g. vulnerability thresholds or even small probabilities of catastrophic events, earlier and more stringent mitigation is economically justified."[lxxxiv] In this way, the authors often fall back on the more conservative conditional tense. This might possibly be considered accurate if it did not give the impression that we not already deep into such challenges, and have been for perhaps

several decades or more. Given the 30-40 year time lag of greenhouse gas emissions, effects should not be underestimated.

Another category of mistakes one can find through the IPCC reports, the MEA, and related literature, regards assumptions or statements about disciplines outside that of the given author. Global assessment authors are often called upon to write transdisciplinary material, even if they have had training in only one or two of the disciplines under study. As a result, these authors are forced into the position of speculation and analysis regarding disciplines they do not intimately understand and have no training in. Naturally enough, they are often susceptible to cross-disciplinary errors.

Cross-disciplinary errors are a broad category comprising various types, as complexologists like Stephen Jay Kline have discussed. Here I will discuss just two examples of cross-disciplinary errors. First, a category one might call the basic cross-disciplinary error. The authors mention just one paper in the outside discipline for which they lack knowledge. They make a fundamental error about the nature of the paper, speak of it out of the context of relevant literature, or discuss it without acknowledging a critical debate surrounding the issue at hand. For instance, in discussing the issue of interdisciplinarity, the authors write, "Achieving true Consilience (Wilson 1998) between natural and social sciences would be a giant leap forward in ability to understand the world and manage our activities within it in a sustainable manner."[lxxxv] E.O. Wilson's theory of consilience is purely theoretical; there is very little development of how to actually link the worlds of the sciences and the humanities. Obviously this is a laudable goal, and is in fact one of the goals stated in the MEA auto-assessment report mentioned above. However Wilson's theory is a bare bones approach that seems to inherently eschew the complex systems dimension of the tension between order and disorder, by eschewing the latter. Whatever one thinks of Wilson's theory, the point is that it is an undeveloped theory that has little to offer the immense and philosophically difficult task of developing greater understanding between the spheres of knowledge. As such the comment remains a nod in an unknown direction with no analysis, explication, or argument to back up any substantive research goals in this critical dimension of the Fourth Assessment Report results.

There is sufficient proof throughout the report that the authors are far too constrained by classical thinking to make the best analysis of such transdisciplinary theory. For instance, in a second example of a categorical error, the IPCC FAR authors write:

> Simulation models can be used as 'universal translators' that allow individuals with different backgrounds to access a model from their own perspective and then asses the output from this model in a form that can be understood from multiple perspectives. It is thus critical that models are well documented, summarized, and easily accessible to the general modeling community as well as to policy makers. Models also allow us to explore the realm of the possible, setting bounds on what we can realistically achieve with policy.[lxxxvi]

In the realm of social theory, anyone with the most minimal background in the literature would cringe at the notion of a 'universal translator,' which has been so thoroughly critiqued and debunked in the last several decades. In this case, the universal force of models also has been debunked by climate scientists in the last few years. Thus, it is not just a superficial statement, but likely a deeply flawed one. The quotation reveals the common myth of natural scientists, which I have called scientism (after John Dupré). Scientism can result in the logic used here, which holds that modeling methods that work well in a given natural science discipline would work the policy disciplines as well.

Such uninformed transdisciplinary analyses are doubly unfortunate. Not only are scientists more aware of the need for transdisciplinary work. For their part, social theorists have made considerable advances in this arena. Analyses of universalism and approaches toward more nuanced, pluralistic approaches have been abundant in recent years.

6.4. Analyses of the Meta-Assessment Reports

The IPCC and the MEA have undertaken bold and hard work, and I would argue that they have succeeded in their main goals – respectively, creating a legitimate basis for acting upon climate change, and gaining further insights into the vulnerable state of our global ecological health. The critique I have carried out has been merely to show that the methods used in these past reports would be insufficient for future ones.

To appreciate the significance of this chapter and the hypothesis regarding thresholds, one should consider the reports of polar ice melt not only from the period of 2002-2005, but also that of 2005-2009. The news has not been good. One has just to look to Julienne Stroeve, research scientist who has observed sea ice loss over the last seven years, whose articles each year bear approximately the same title: "Arctic sea ice decline is faster than previously forecasted."[lxxxvii]

As I write, an Antarctic ice bridge ruptured sending forth a gigantic iceberg. This represents yet another form of the dynamical ice melt which the 2007 IPCC report writers admitted that they largely omitted because it is "little understood." Given the presence of networks of fissures, streams, and pools forming throughout the glaciers, does this not send warning signals about the current creation of perhaps dozens or hundreds of icebergs to come, potentially further speeding the polar melting?

Meanwhile, just a few days ago in early April 2009, the BBC reported that another iceberg which they first reported on in 2002 as the largest iceberg ever recorded, had collided with glaciers in Antarctica, presumably causing a massive impact. One might ask if such impacts lead to further fissures and further cracking, exposing more glacial surface area to warming water and further melting. As the IPCC authors stated, it is little understood. However, within the framework of nonlinear logic perhaps one does understand a little better.

Reflecting upon these considerations and upon the main argument throughout this dissertation, that adequate treatment of complex systems necessitate at least some degree of complexity theories, I ascertain three reasons why the integration of complexity in future climate change analysis will provide stronger results. These are based upon three characteristics of climate change: immense scale and grain; highly transdisciplinary nature; and substantial and also novel inherent kinds of risk, uncertainty and unknowability. These facets of climate change render it truly an issue of unprecedented complexity.

This is not to say that some aspects of climate change politics, policy, mitigation and adaptation are not already crystal clear. Various aspects of climate change policy are quite clear and have been since the 1970s. I will discuss these

aspects in the next chapter. They include such imperatives as: the need for major greenhouse gas emission reductions now, the need for rapid and development of renewable energy technologies, and the need for social equity, justice, and international cooperation. These issues could all be argued for from within a complexity framework, but it is unnecessary!

Other issues do necessitate a complexity framework. First, perhaps the best example is the need to find synergistic solutions or virtuous circles to the multiple crises that confront us – blinding political and religious ideologies, flawed or outdated economic models, inadequate education systems and support, social inequities, the demise of industrial agricultural, food distribution problems, dissemination of toxic chemicals into global ecosystems, the near death of the world's oceans and coral reefs, massive pollution problems, human evil, and the list goes on.

Second, as I have argued throughout the dissertation, the role of transdisciplinary understanding cannot be underestimated. This is true both within the knowledge realms and between them. Complexity theories and transdisciplinary theories are intimately interconnected. As I hope Chapters One through Five demonstrate amply, you cannot study one without studying the other. This is in itself an explanation for the shift from the reductionist dominance of the early classical viewpoints to a more synthetic approach that embraces rather than eschews the characteristics of complex system that are so replete in the case of climate change.

Third, I want to make the argument that my preceding arguments in this chapter are just an indication of the greater troubles that lie underneath. As I show in Chapter Four, risk, thresholds, and collapse are closely linked. In what follows, I argue that any effective policy for climate must take into account all of the major crises we face today. This may seem overwhelming, but I would also suggest that the voice that sees this as overwhelming is in large part the voice of simplicity past, the echoes of hopes for simpler problems and simpler solutions. In fact, once one begins to accept a view of the world that encompasses greater complexity, the search for complex solutions may appear as a tremendous relief, putting to rest innumerable inane and inefficient practices based upon the drive for simple, atomistic, and linear solutions. Synergistic thinking is much more efficient, more effective, more social, and more humane.

What society and climate change leaders must face is that climate change is anything but an individual issue that might bring some degree of success by eschewing the other crises confronting society. Rather, if we look at the list of these crises, each one brings to bear rather strongly in the outcome of climate policy. Blinding political and religious ideologies risk undermining and undoing progress by diverting the energies of large blocks of people. Rather, if political and religious blocks begin to see the flaws in ideology itself, there may be more freedom to

engender more communal practices. Flawed economic models are problematic, but a great deal of brilliant thinkers has been working on more socially and environmentally adequate alternatives for a long time, and many of these ideas could spread quickly with the recognition of their effectiveness. Social inequities are at the heart of much conflict and strife. Yet insofar as it becomes clear to our leaders that this will directly unfurl our policy goals, the seriousness of our situation can lead the way to substantive change.

I will not exhaust the list, but I raise these issues in part to point to much more fruitful and optimistic thinking that can be derived from the mere exercise of validating and taking up the exercise of thinking about synergistic solutions, one of the areas of complex thinking. The question becomes what it will take for our leaders to think in such unprecedented ways. I suggest that the real threat of continuing high levels of greenhouse gas emissions can lead leaders to think in unprecedented ways.

Let me expand upon the unprecedented quality of our current situation. Generally, the unprecedented changes of the last two hundred years are based in the mix of scientific, industrial, technological, economic, and demographic revolutions, which have manifested not only unprecedented social and ecological changes, but the novelty of a human impact that has increased by many orders of magnitude, to the point of actually dominating – e.g. usurping from other species in the ecosystems on which life depends – the majority of the earth's biomass and ecosystem services. Breaking each of these categories down into some of their concrete components reminds us just how spectacular have been some of the principle drivers of change: the farm tractor, chainsaw and concrete mixer; the steam engine, internal combustion engine and individual car; the factory, the skyscraper, and the mega-shopping mall; the television, radio and Internet.

It is stunning to think of the ways in which these inventions have changed both society and the earth. While this may seem trite, there is an aspect of it that is relevant to the thesis, which is the considerable difficulty humans have in truly taking into account the novelty and the dimensions of contemporary global changes and of the subsequent new kinds and degrees of human and ecosystem vulnerability. Whatever the reasons for this, if climate change is an example of a subject that creates cognitive dissonance for people, then perhaps insofar as complexity theories help shed light on the functions and dynamics of systems sustainability and vulnerability, such research can provide some significant simplifications, some guidance and reassurance, in what are otherwise, realistically, daunting research projects.

Moreover, technological inventions have spurred not just ecological change but major transformations of the individual psyche, mind, and experience, as well as socialization, social institutions, and social movements, with co-evolving, far-reaching consequences far beyond what human thinking processes seem able to

readily distinguish, articulate, and understand. Thus, the subject of the interconnected feedbacks of social transformation via technological change, while enough for a lifetime of study, is deeply significant to the interconnected feedbacks of technological and demographic changes that make up the massive fossil fuel, profit and growth-based economy now dominating the planet and transforming the world ecosystems.

The existence and nature of unintended consequences has come more and more to the fore in recent decades. It is by now quite evident that technologies bring about negative impacts as well as positive ones. Yet the inevitable negative impacts – falling as they do outside the continuation of classically based logic – are not acknowledged nearly enough when it comes to funding for new research, development, regulation, and policy. Any ecological economist, such as Richard B. Norgaard, working on these issues since the 1960s and 1970s can attest to this. Those dealing with cleaning up the messes of past technologies are usually not the same people paid to lobby for the new ones. Though in the worst instance, regulators are *replaced by* or coerced by lobbyists, as in the extraordinary fashion with which the Bush administration ushered lobbyists into the majority of the federal posts previously held by regulators. In just one example, the EPA was headed by lobbyists whose last jobs served to officially protect the oil, coal or mining industries. This is another example of dispersion not just into academic hyper-specializations, but also in funding throughout institutions oriented toward profit. Simple division of labor and interests undermines at times elaborate efforts to assess and regulate science and technology.

Without the use of bulldozers, chainsaws, and fossil fuels, people would not be succeeding at razing such vast swaths of forests so rapidly in recent years. For a few years now, deforestation has been cited as responsible for one-fifth of net climate change. The combination of fossil fuels and intensive technologies has permitted admittedly radical changes to the earth's surface in the last fifty years. Moreover, also trite but still needing to be acknowledged, technologies such as highly efficient industrial agriculture have permitted a population boom of mass proportions, increasing population by five times in the last fifty years; yet that agricultural system promises only short-term efficiency or even *viability*.

Technological interconnections – phones, planes and the internet – have allowed for completely unprecedented social and market interconnections. Even millennia after the development of international trade, with the exception of world's numerous networks of trade routes, global societies have lived almost entirely autonomously and in isolation. In comparison, today the world has become fully interconnected, with all but the tiniest shreds integrated into its web. The wealthy portion of this web, with the poor dependent on them in frightening ways, has further

deepened the social interconnections by consolidating wealth into a single world market, with pulsing nodes around the world in the stock markets of New York, London, and Tokyo.

As a result of all these unprecedented human activities, environmental change has been unprecedented as well. Natural resource degradation, depletion and even irreversible changes to nonrenewable natural resources have shifted drastically. Even the definitions of irreversible change and nonrenewable natural resource have shifted, insofar as these terms are correlative to the degree of human impact in a region. A small band of Native Americans, whether they maybe be viewed as noble or savage, are not going to cause the kinds of damages created by industrial revolutions, with their toxic chemicals, heavy metals, massive production, waste, pollution, and myriad related issues. Depleting energy resources in one region was a relatively insignificant issue in 1800, when there were plentiful forests to use for alternative fuels. Depleting the last sources of the dirtiest oil in a world with disappearing buffers from pollution has not only a different *degree*, but a much different *type* of impact on human societies and the biosphere.

Such unprecedented changes bring into play differences in nature and degree of irreversibility and nonrenewability, and the capacity for last-straw thresholds bringing about snowballing threshold effects throughout global ecosystems. If western societies had begun to think and operate in terms of sustainable systems at any point before say 1950, many of the previous impacts on the environment, e.g. burning coal, could have been much more readily absorbed into the environment. The global commons was much more forgiving before industrial societies locked themselves into certain infrastructural, social, economic, and technological pathways that committed us to widespread environmental damage.

As a result, one of the significant if less evident environmental changes of the last two hundred years is that Western societies have shifted from local to global impacts not just in terms of particular environmental issues, as they are generally discussed in the mainstream academic discourse, but also as we must understand them in the complexity framework. Throughout most of human history, Westerners created a global set of quite local social and environmental thresholds, buffered by vast expanses of environmental systems, providing their significant potential for natural capital and ecological rejuvenation. Throughout the last two hundred years, exponentially so in the last fifty, a relatively small group of elite Westerners have turned this highly robust web into a very fragile one.

As the various human societies increasingly grew and connected at the seams, eliminating and degrading environmental buffer zones, humans have changed the resilient biosphere to one with greatly diminished and deteriorated buffers. Along with this came a shift from local thresholds buffered by natural expanses to a world of

intersecting local thresholds. These global shifts and their implications are only fully to be understood through a complexity framework permitting one to see how one can study how the interconnections not only connect, but also interact, and how one can gauge what one can effectively study and know, and what one cannot. As discussed above, interacting feedbacks create novel change. Generally speaking in our "fragile dominion" as Simon Levin called it,[lxxxviii] human impacts are increasing, positive feedbacks are accumulating, and the net effect is qualitatively different from what happens on a highly environmentally well-buffered, robust, and resilient planet.

6.5. Conclusion

I have asserted the utility of complexity theories to further climate change analysis and policy. I looked at this through three means. First, in reviewing the complexity fundamentals, I show how a few of them are quite significant in the case of climate change. Second, I compare what I have called the early classical science paradigm and the complexity paradigm, and discuss ways in which the latter may better capture these significant complexity fundamentals. I derive a list of fourteen complexity fundamentals that are critical to climate change understanding and policy: ***feedbacks, vulnerability, nonlinear, thresholds, sustainability, uncertainty, transdisciplinarity***, ***resilience, adaptive capacity, tipping points, abrupt climate change, phase state, transdisciplinarity,*** *and* ***irreversibility.*** This is not an exhaustive list, but a representative group of significant concepts.

Through several examples regarding feedbacks and thresholds, I showed that these issues are indeed central to successful policies for the mitigation and adaptation to climate change. The albedo effect, while an evident polar feedback, may or may not be playing a principal role in current temperature change and ice melt. Other feedbacks that may play as much a role or more include: shifting wind patterns, changes in cloud cover, vapor and terrestrial ecosystem emissions, dynamical ice melt, iceberg creation and collision, permafrost methane release, constitution of species types in global ecosystems, rainforest destabilization, or the cumulative effects of all of these and more. What is clear is that the interactions between and across many types of earth systems seems to be accumulating and is currently resulting in an exponential shift in polar ice melt.

I discussed the ways of thinking that might be seen as related to the early classical scientific paradigm, oversimplifications, or rationality traps. To describe these systematically it would seem necessary to create a typology of the success stories of complexity theories. What examples of successful concepts, models, frameworks, and other tools have been successful, and how might these be extended to more general uses? Throughout Part I of the dissertation I discussed numerous examples of successful approaches that incorporate greater degrees and aspects of complex systems, including: diagrams and models taking up complexity fundamentals, scenarios, narratives, transdisciplinary frameworks and analyses, indices, indicators, and more.

Third, I looked at the two major meta-assessments that have been carried out in recent years on socio- environmental issues, the 2007 report of the International Panel on Climate Change and the Millennium Ecosystem Assessment. I examined how these two reports have incorporated complexity fundamentals, how they have failed to do so, and the significance of complexity to their analyses and conclusions. I found that throughout the IPCC reports, uncertainty and unknowability were

acknowledged, and that in the latest report authors had gone further in describing these uncertainties. However, while the significance of the uncertainties was at times included in individual sub-reports, either the uncertainty itself, or usually also the attendant urgency and significance of the uncertainty, were omitted from the final synthesis reports. Moreover, throughout the IPCC reports, less probable, extreme, but possible events were all but left out.

In the case of the MEA, I found that as other reviewers have stated, one of the major weaknesses of the report was a failure to adequately conceive and carry out some of the highly challenging transdisciplinary aspects of both the empirical data collection and the analyses, or as one group of MEA authors themselves wrote in retrospect, to adequately "bridge scales and epistemologies." Using different epistemologies is an issue that is of particular significance in global assessments, and the MEA authors made much progress, but that this progress revealed how much more fundamental understanding is necessary of what transdisciplinary thinking is and how it operates.

After having begun this chapter by shifting the gaze from one feedback to multiple intersecting feedbacks, a highly complex case of network causality, in the analysis section I explored what happens when we shift from examining one unprecedented event that is climate change, to examining climate change within the context of so many other unprecedented global trends – social, demographic, economic, ecological, agricultural, and the like. Noting that so many of these areas are in some state of crisis, I argued that it becomes pivotal to consider climate change itself as embedded in a web of inextricable, unprecedented realms of global change.

NOTES

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Chapter Seven. Complexity, Ethical Theory and Climate Change: Implications for Climate Ethics and Policy

7.0. Introduction

If we concur that the world is complexifying through continuous spirals of emergence, self-organization and multifaceted coevolution, and that regardless our methodology of simplification our knowledge is in fact complexifying, it would seem that we need to integrate these ontological and epistemological realities of the world into the ethical and political realms.

Given that complexity theories produce interesting and useful results throughout all the disciplines; given that in doing so they prove to in fact possess and provide transdisciplinary power; given that they appear to present a new paradigm that acknowledges and adjusts for the fact that knowledge is not 'being completed,' but rather 'complexifying'; given, in short, that both our ontology and our epistemology are shifting to describe this complexity; and finally, given that resolving the greatest challenge of our era seems to require this new perspective or paradigm; should it not be the case that a similar shift to this new framework must occur in the realms of ethics and policy?

To assess this question, I examined the current literature on climate ethics and justice. In my analysis, I discover that the most effective, influential ethics and justice literature pertinent to climate change includes, and I would say often hinges on, the complexity fundamentals. While the entire GCF is represented in various ethical analyses, and alongside the shift from classical to complexity perspectives which is everywhere present, two areas of the GCF are particularly significant to ethics: the second set of complexity ontological fundamentals and the complexity epistemological fundamentals, GCF Axes II and III. It appears that climate ethics and justice literature benefits particularly from the incorporation of these two axes.

• Equilibrium, phase state, attractor, edge of chaos • Connectivity, diversity • Network causality, interrelatedness • Unintended consequences, irreversibility & nonrenewability • Vulnerability • Robustness, resilience, & sustainability • Threshold, tipping point, abrupt change • Collapse, catastrophe
• Observer; context • System boundaries; openness • Scale • Grain • Nature of development: co-evolution, co-production, co-evolving landscapes • Models, narratives, and other methods

Table 7.1. Axes II and III of the Generalized Complexity Framework (for the complete framework, refer to Table 2.1 in Chapter Two)

In this argument I will analyze various areas of climate ethics literature, showing how the complexity fundamentals factor into each case. I start with the mainstream climate ethics and justice literature. Next I examine eight groups of ethical theories emerging from scholars taking applied and transdisciplinary approaches to issues of social and environmental change. Finally, I examine the literature of a selection of thinkers whose work focuses more specifically on the GCF and climate change and examine their results.

While complexity may be relevant for all the realms of ethical theory – meta ethics, normative and applied ethics – I focus here on applied ethics and climate change. The challenges of co-evolving realms of social and natural spheres in increasingly inter- and intra-connected contemporary societies, underscores how the influence of complexity theories in science, social policy, social theory, and philosophy may also influence ethics and policy.

The coevolution of complexity and ethics seems to impact the relationship of science and ethics. Generally, thus far this dissertation supports and furthers the hypothesis that complexity theories validate ethics with respect to science in a newfound way, legitimizing the prioritization of ethics as a research agenda. During the shift towards the complexity perspective, a portion of the power of legitimacy and

significance of science is ceded to ethics. Additionally, in demonstrating the utility of the GCF in the case of climate change, Chapter Six also helps to illustrate the death of what you might call the purifying forces of modernization, pure or idealized notions of: foundationalism, essentialism, and reductionism and determinism. The debunking of these pure forms also brings about a newly revitalized understanding of the significance of freedom of will, human agency, and responsibility. As this fuller amplitude of human will power and agency come to light, this further validates the nature and the imperative of responsibility.

As older, more anemic and fragile notions of rationality are replaced with richer and stronger ones the opportunity arises to reassess notions of decision, action, indecision and inaction. A new force infuses ethics. As the old purifying forces of modernism and rationality are debunked, science cedes power to ethics.

The GCF serves to further this power shift by explicitly defining the roles of each sector of knowledge with respect to one another. This is the guiding hypothesis of this chapter. Complexity may serve to advance the nature, mechanisms, and power of ethical theory, rendering it more adequate to our contemporary planetary situation.

7.1. Complexity Theories versus Complexity Thinking

By now the concept of complexity thinking should be a little bit clearer. I restate the relevant definitions from Chapter Two:

> ***Complexity theories*** refers to any of the broad swath of studies in any of the disciplines studying complexity, defined as:
> 1) The use of one or more of the complexity fundamentals, tools of complexity thinking, or 'complexity tools,' in the study of complex systems.
>
> ***Complexity thinking*** is useful in more general transdisciplinary discussion, and I employ it to mean:
>
> 1) The set of ideas, principles, fundamentals, models and conceptual tools used to study and describe the nature and the dynamics of systems of interacting elements in emergent, self-organizing processes.
> 2) An approach to perceiving and analyzing problems that incorporates the above ideas and tools.

An antithetical definition is of use here. If I have convinced the reader that complexity is partly defined in juxtaposition with the paradigm of early classical science, then *complexity thinking* is partially *non-modernistic thinking*, where modernism refers only to those aspects of modernism that are transformed by complexity theories. It appears increasingly that brilliant thinkers are often as much trapped in their specialization as they are empowered by it. Again, many problems contribute to this, however overemphasis on reductionism and on specialization contribute considerably.

The results of the case study on climate science militate for a shift of balance from scientism to a balanced perspective of knowledge, in which ethics or one might say now, wisdom, is at the helm. To truly reform our education and our thinking in order to cope with the shift of scientist to ethical thinking requires people to first see how steeped they can become in their own discipline, and even to a certain degree trapped and diminished by it. Ironically, but naturally enough, the complexity natural scientists are at one and the same time on the cutting edge of natural science exploring the very new terrain of complex adaptive dynamic systems, and yet, due in large measure to their methodology and specialization, some of them are also largely

out of step with the radical shift taking place in the humanities. Meanwhile, many humanities scholars never manage to create connections between theory and action. Students around the globe spend years in a seemingly infinite regress of increasingly specialized training, over innumerable lattes. Meanwhile, the house is on fire.

This irrational and ironic situation illustrates the problematic surrounding Rescher's complexification, the challenge of complexity thinking, and also supports the need for complexity thinking, because as Einstein said, one wants to simplify a problem as much as possible, *but not more*.

How is this accomplished in the case of such an issue as climate change? I'll mention just three important considerations here: 1) putting the major ethical theories of the modern era in a more realistic context, 2) advancing beyond overly modernist thinking, which is to say, developing in the arenas of complexity and wisdom, and 3) the current coevolution of multiple, intersecting, highly challenging global crises.

7.1.1. Contextualizing Ethical Theories in Contemporary Societies

First, it is important to place climate ethics and justice in the context of the history of ethics and justice. The major ethical theories of the modern scientific era tend to suffer from various forms of inappropriate transdisciplinary transfer of reductionist hubris, which is to say ethicists, like the natural scientists, attempted to start with a blank slate, or a simple scenario, and from this basis build reliable ethical systems.

The major ethical theories of the modern era have been based on duty, utility, virtue, contracts, and rights. They have tended to be atomistic – they attempted to build singular principles for singular acts, duties, character traits and the like. While many modern ethicists attempted in one form or another to devise mechanisms for universal rules, rights, judgments and the like, these theories have largely remained mired in very difficult intra-ethical academic debates, and far from application to most of our daily lives.

Contemporary consensus seems to hold that none of the major ethical theories of the modern era are up to the task of global environmental issues or other contemporary societal issues. While each theory may have something to contribute, generally speaking they are grossly inadequate to issues like climate change. This is a problem that urgently needs to be addressed, since, in the last few years, the persistent inadequacy of ethical theories has hindered progress in international negotiations on climate policy. Determinism and inevitability are of great psychological convenience for many whose careers or lifestyles are trapped in ethical gray areas. Any of the

weaknesses in our best modern democratic, participatory institutions, are exacerbated by the lack of clarity in both academia and in public discourse, with respect to the realms of values and ethics.

7.1.2. Contextualizing Complexity Theories in Networked, Polycentric, Polysemous, Socio-ecological Systems

It is significant not to relegate climate change to one more environmental issue, even if one ranks it as a significant or the most significant one. A lesson of complexity theories is the interrelatedness and coevolution of various socio-ecological issues. Due to this interconnectedness, it behooves us first to step back and take a quick glance at the context of climate change.

As presented in Chapter 7, climate change, with its multitudinous drivers, extremely complex feedbacks amongst innumerable natural systems, and its inevitably biospheric-scale tipping points, seems to pose a policy issue of dastardly proportions. We must abandon the Promethean, modernistic framing of ethics, just at the moment that we must acknowledge that climate change drivers and feedbacks are intersecting in ways far beyond comprehension, never mind control. Indeed, propositions to control nature on the scale of the planet are more disturbing than most science fiction schemes. Geophysical engineering projects include projecting millions of tiny mirrors into space, lacing the ocean with heat absorptive metals, and trying to store carbon in huge underground tanks, to name just a few. Our belated recognition of climate change has led scientists like James Hansen to say that although he finds geophysical engineering plans potentially quite dangerous, the desperation of our current situation is such that we cannot yet afford to overrule such options.

7.1.3. Contextualizing Ethics in Multiple coevolving global crises, such as: social, biodiversity, agricultural, water, pollution, political, religious, and economic

There is worse news; we are facing multiple global crises. Along with climate change, the global community also faces: one billion people coping with daily hunger, rapid acceleration of habitat and biodiversity loss, the depletion of essential natural resources like fresh water and fertile topsoil at irreplaceable rates, the energy crisis, increasing problems from the massive build-up of long-term toxic chemicals and waste in the natural environment, worldwide food shortages, the global financial

meltdown, the spectacular failure of U.S. military adventures, the intensification of extremist militant groups in the U.S. and abroad, and a string of little-publicized, small-scale releases of radioactivity into the environment via over fifteen nuclear accidents in 2008 alone, casting a shadow on plans for nuclear energy to supplant fossil fuels.

Each of these crises is also intersecting in an unfathomable fashion. As the crises accumulate and the future of civilization dims before our eyes, more leaders around the world than ever are willing to employ ethics in the fight literally to save humanity. If one of the complexity implications is our socio-ecological systems interrelate and interact much more than we were accounting for through the modern lens, then we must start doing a much better job of accounting for this with respect to the mutually-intertwined interactions of the various other major global trends. Unfortunately, while various interrelated challenges have been building for decades during "the great acceleration" – the phase of massive population and industrial growth since the 1950s – many global challenges appear to be coming to a head. To put it more precisely, one could call some of these changes tipping points. To use an example that illustrates the magnitude of the crisis in Western thinking – the global gross domestic product – GGDP – is projected to shrink in 2009 for the first time in world history. Changes in every area from health of oceans, agricultural lands, forests are said to be in a state of crisis.

7.2. A Complexity Ethic as a "New Ethic"?

The field of environmental ethics is largely attributed to a few main sources. The first is the influence of indigenous or premodern peoples. Indigenous societies, and some argue sustainability itself, is largely based upon theories of environmental ethics developed over millennia and absorbed directly into the myths and mores of indigenous societies. Most indigenous societies had some kind of shamans and a deep knowledge of their natural environment. Before modernity, the whole world was steeped in environmental ethics. Of course, as Jared Diamond argues, this saved only a small percentage of them from ecological collapse. So apparently, indigenous ethics through myth, beliefs and mores, was often not enough to prevent ecological collapse.

Nonetheless, indigenous environmental, local and spiritual knowledge is a source of considerable value to environmental thinking today. Unfortunately, modern thinking has had the pervasive and pernicious effect of devaluing and even invalidating other forms and stores of knowledge. This is particularly true with respect to indigenous modalities of thought, ceremony, and other aspects of environmental management. It is indeed significant to recognize and remember that for the great majority of human history it was through these environmental ethics that humanity survived as often and to the extent that it has. One can point to the examples of past societal collapse – Easter Island, the Mayas, Ancient Mesopotamia, and the like – but ultimately, even if collapses were in the majority, the continuity of societies through the millennia is still explained partially upon successful strategies of environmental ethics such as ethnobotany, shamanistic norms and pharmacology, spiritual relationships with animals and natural resources sustained through mythical mores, intercropped and swidden agriculture systems, and other techniques that promoted the conservation of landscapes.

While keeping this foremost in our minds, environmental ethics as we know it should probably be understood as a term specifically referring to the ethics we need to develop in response to modernism, in other words, the ethics of late modern or postmodern societies. In addition to all the environmental thinkers above, there are of course hundreds or even thousands of other thinkers who environmental ideas contribute to environmental ethics today.

After Henry David Thoreau, John Muir, and Aldo Leopold, Rachel Carson articulated much about environmental ethics, which she perhaps consciously concealed in a more pragmatic and direct attack on the heavy use of petrochemicals in the modern American landscape. Other early influences included Arne Naess' deep ecology platform, which created a significant reference point in the discourse of human ethics vis-à-vis the natural world.

In 1970, Richard Routley published an article sometimes touted as the first explicit articulation of the contemporary field of environmental ethics, called "Do we need a new, an environmental ethics?" More recently, environmental ethicist Catherine Larrere wrote a sequel, "Do We Need a New Ethics?"

My answer to this question is that the nascent environmental ethics of today is at the same time new and old. It is old, in the sense that we find many of the main principles for it in the ethical theories that have developed in the last half century, which I outlined above, and can draw upon older systems, e.g. many indigenous belief systems. It is new in two ways. First, insofar as it clarifies the major theoretical framework of transdisciplinary complexity that provides a useful structure for so many socio-ecological issues like climate change. Second, it is new in the sense that ethicists have yet to fully acknowledge the proliferation of ethical theories that exist and discuss viable ways of deriving effective pluralistic visions from this great array. The way I suggest here involves drawing upon all the best alternative approaches to environmental ethics that have been articulated already, and find ways to use the GCF to frame and integrate some of these ideas into one more developed and expansive theory. Ultimately, as the pragmatists would likely argue, it would seem that we need one discourse within which the plural voices can come together for effective, concrete dialogue on specific issues.

The most viable means to giving this recombined ethical system credence and coherence would be the system that best captures the broad range of factors and parties involved, which appears to be complexity theories. While some ethicists have begun to pursue this implicitly or partially, it is preferable to advance this area explicitly, such that these parallel efforts find mutual support and credence.

Some of the essential new concepts include the now fully validated phenomena of uncertainty, unknowability, thresholds, new phase states, vulnerability, resilience, sustainability, and collapse. In this sense, the systematic and sophisticated new field of environmental ethics needed to address the climate crisis is indeed new. Thus, I call this "complexity ethics."

In climate change science, uncertainty bands are broad enough that we clearly need to act proactively to prevent climate change despite inexact prediction of the future. Moreover, the majority of leading scientists now clearly state that there is a considerable degree of unknowability with respect to the trajectory of climate change impacts, despite great advances in the science. In essence, recent climate science has proven degrees of *known unknowability*. I use this term to describe *the areas of uncertainty bands that scientists know that we cannot know, yet nonetheless know fall within the realm of catastrophic climate change.* The concept that much of highly complex systems phenomena is unpredictable is finally permeating social discourse of global change.

Moreover, in the past two years, leading scientists such as James Hansen, and leading social theorists such as Bill McKibben, have loudly and publically declared that we have already passed perhaps one of the most significant meta-thresholds – we have now stepped irreversibly into the realm of catastrophic climate change. What remains to be seen is only the degree of catastrophic climate change which will take place, which can still be influenced by human policy choices in the immediate future.

7.3. Ethics Literature Analysis

In what follows in the bulk of this chapter, I analyze three separate sets of climate ethics. The first consists in the first generation of climate change literature to emerge after it became evident that climate change was occurring and related scholars began to write on the subject, approximately from 1995 to 2005. I discuss both strengths and weaknesses in this approach, showing how some leading reports were still largely mired in modernist thinking. The second includes a number of contemporary ethical theories that are relevant to climate change, including many theories in the broader area of environmental ethics, developed since the 1970s. Finally in the third group, I explore leading work in applied climate ethics, and argue that its strengths are quite compatible and even correlated with the GCF.

7.3.1. Ethics Literature Group I: Mainstream Climate Change Ethics

Mainstream climate ethics literature combines two very fruitful tools – various aspects of the GCF and the use of quantitative indicators, such as global atmospheric emissions reductions targets. As I discussed in the last chapter, there is an emerging climate consensus about the need to incorporate not necessarily explicit positive feedbacks, but certainly the implications of intersecting global scale networks of positive feedbacks. Such intersecting positive feedbacks can lead to potential extreme or catastrophic aspects of climate change. Therefore, there is a need to develop and advance quantifiable criteria to use as goals and measuring sticks in the IPCC policy process.

7.3.1.1. The White Paper[i]

In 2004, an international meeting convened in Buenos Aires to discuss the ethics of climate change. Following the meeting, a group of 25 coauthors with input from sixteen major environmental and climate ethics organizations including centers at Penn State, Montana, Cardiff, Oxford, and the Tyndall Center, put together the first major international report on the ethics of climate change. The discussions in Buenos Aires had led to the following list of major ethical issues involved in climate change:

1. Responsibility for Damages: Who is ethically responsible for the consequences of climate change, that is, who is liable for the burdens of:
a. preparing for and then responding to climate change (i.e., adaptation) or
b. paying for unavoided damages?
2. Atmospheric Targets: What ethical principles should guide choice of specific climate change policy objectives, including but not limited to, maximum human-induced warming and atmospheric greenhouse gas targets?
3. Allocating GHG Emissions Reductions: What ethical principles should be followed in allocating responsibility among people, organizations, and governments at all levels to prevent ethically intolerable impacts from climate change?
4. Scientific Uncertainty: What is the ethical significance of the need to make climate change decisions in the face of scientific uncertainty?
5. Cost to National Economies: Is the commonly used justification of national cost for delaying or minimizing climate change action ethically justified?
6. Independent Responsibility to Act: Is the commonly used reason for delaying or climate change action that any nation need not act until others agree on action, ethically justifiable?
7. Potential New Technologies: Is the argument that we should minimize climate change action until new, less-costly technologies may be invented in the future, ethically justifiable?
8. Procedural Fairness: What principles of procedural justice should be followed to assure fair representation in decision making?

In light of the Generalized Complexity Framework, I look first at the weaknesses of their approach and next at their strengths.

7.3.1.1.1. Weaknesses of the White Report

The authors captured some of the dynamics of climate change and ethics in the first three points and in the last point. However, in the other four questions they erred by framing their questions in reaction to two separate, deterrent, authoritative forces of the time: science and propaganda. While the natural scientists were grappling with issues of uncertainty from the early 1990s through say 2006, from 1996 onwards the oil magnates were sponsoring a massive campaign of misinformation and manipulation. I am of course in no way equating science and propaganda. However, the ideology that held that only *certain* results were acceptable rendered the *authority* of science of the time as much an impediment as a source of information. In this case, the inability to get past the uncertainty debates sooner led to collusion, albeit unwitting, with big oil.

Questions Four is framed from the defensive, and is thus more disempowering than empowering: "What is the ethical significance of the need to make climate change decisions in the face of scientific uncertainty?" A framing that would incorporate the shift in authoritative power of science and ethics suggested by the GCF might be: What are the various ethical challenges obscured by the ongoing illusion that deep uncertainty makes rational action impossible in cases of fairly probable catastrophe? As I noted in Chapter Six, leading climate change scientist and thinker Stephen Schneider debunked the false focus on uncertainties early on, arguing that decisions must be based not on resolving uncertainties, but rather on weighing ***risks***, or *probabilities of harm*.[ii]

Likewise, question five misses the point entirely, essentially asking for permission to ask an ethical question rather than actually asking one. Already in 2004, scholars such as economist Christian Azar and climatologist Stephen Schneider had put forth strong arguments regarding the more than sufficient evidence that what was good for the environment was not necessarily detrimental to the economy, and in many areas could be quite good for the economy. Indeed, the GCF in shifting from atomistic causality to network causality militates strongly for synergistic approaches. Ecological economists have been arguing for thirty years about the economic benefits of environmental policy. Leading scholars supported much greater costs to national economies than have been adopted or even seriously discussed in international negotiations thus far. Similar remarks could be made regarding the weaknesses of the next two questions, six and seven.

While there are strengths to be found in the framing and response to the first three questions and the last, there are still weaknesses that tend to undermine the final analyses. In question two for instance, the authors follow all the right paths, but just don't reach very far in their conclusions. It seems that this is due not to any

negligence on the part of the authors, but rather to the extreme difficulty of the questions involved. Some of these same authors have subsequently provided much richer analysis of this point. In 2004 the authors stated, "The choice of lower or higher GHG atmospheric targets has great ethical significance particularly in light of differential impacts on the most vulnerable people. As alternative GHG atmospheric targets are proposed, ethicists need to identify the ethical significance of each alternative."[iii] While they include the concept of vulnerability and the implications that that entails, this question remains a very initial one, in what has taken years to get off the ground.

The introductory remarks, first three and last questions are often diluted with overly modernist language and perspectives. The introduction gives an overview of climate ethics parameters that demonstrate the magnitude of ethical issues, including a list of the challenges of distributional fairness based upon from the following facts about climate change**:**

1. Many of those who will be most harmed by climate change have contributed little to causing the problem;
2. Many of those who emit GHGs are least threatened by adverse climate change impacts;
3. Those that are vulnerable to climate change harms are often least able pay for adaptation measures needed to protect them from climate change impacts;
4. Because there is a need to set an agreed upon global atmospheric target, climate change policy makers will need to face the question of who should bear the burdens of reducing emissions so that an atmospheric GHG target can be achieved through national emissions limitations;
5. In allocating national emissions reductions targets, policy makers will need take a position on who has a right to use the biosphere as a carbon sink and in what amounts;
6. Emissions levels from human activity vary greatly around world and therefore the huge emissions reductions that will be needed to prevent dangerous climate change will fall disproportionably on some if equity is not taken seriously;
7. In responding to the threat of climate change, current generations will affect the interests of future generations.[iv]

The major limitations of this list revolve around its partial omission of various aspects of the GCF. Again several passages are infused with the language of linear, atomistic, singular causalities, which oversimplify the true picture, and as such, actually obscure positive opportunities for advancement, e.g. for reconciliation between poor and wealthy nations. For instance, phrasing focuses on individual parties with exclusion to others. Phrasing such as "many of those who emit GHGs….", "those that are vulnerable to climate change harms…." and "who has the right to use the biosphere as a carbon sink," are partly misleading.

For one thing, the entire surface of the planet is a carbon sink – soil, plants, and all bodies of water. Therefore, point #1 gives the misleading impression that poor don't participate in climate change. While the sentiment is correct, the phrasing is quite wrong. Everyone on the planet has responsibility with respect to climate change. The massive deforestation going on primarily in economically impoverished nations accounts for one-fifth of the entirety of climate change drivers. This fact opens the door to massive incentives for rich and poor to collaborate in finding more effective ways to stem the tide of deforestation and fund more effective and long-term conservation efforts in many forested areas. This process has been accelerating in the last few years and some small successes are beginning to flourish.

Point Two gives the false impression that the wealthy will not suffer due to climate change. This seems to stem in part from the persistent conflation of connectivity in very different types of systems, e.g. the wishful thinking that the wealthy can always protect their interests. In actual fact, connectivity and types of phase state changes are very different in economic and ecological systems. The international economic crisis of 2008 serves as a glaring reminder of the degree of economic interconnectivity. Yet, financial and economic crises may leave relatively strong safe havens for the wealthy. Ecological connectivity on the other hand proves to be more tightly interwoven still. In the ecological scenarios for the next few decades, there are a number of possible positive feedbacks that would have such a significant impact on the planet as a whole that life in all parts of the earth would change irrevocably. Predicted events such as the loss of roughly fifty percent of all species will certainly have effects upon the wealthy.

7.3.1.1.2. Strengths of the White Report

Strengths of the White Report are also numerous. The first question of the White Report, while framed in slightly atomistic fashion – asking *who* should be responsible, rather than the more obvious, to what degree are various parties

responsible – nonetheless poses the vast question of global responsibility that forces one to begin sorting through the polyvalent aspects of responsibility in a highly interconnected world. In Questions Two and Three, the authors implicitly argue for quantitative limits. As in the case of sustainability indicators and ecological footprints, simple quantified targets appear to be essential in managing any highly complex systems. Thus the authors are able to address directly two of the major challenges of climate change, despite the enormous complexity embodied in the questions. Question Three finds further strength in its inclusion of extreme events, and thus implicit acknowledgment of that which causes extreme events, e.g. nonlinear dynamics, thresholds, and abrupt changes. While the precise determination of "ethically intolerable impacts" may be an impossibly complex issue to calculate, one arrives at a useful conclusion.

The last question, "What principles of procedural justice should be allowed to assure fair representation in decision making?" There are many arguments for the significance of fair representation in decision making. One of these arguments is found in the fourth section of the GCF, Axis I, classical versus complexity theories. This axis supports the notion that good climate policy will not be mechanical, atomistic, or universal by nature. Rather, successful policy will fulfill the role of a self-organizing property at the national and international levels, devised and developed in rich, inclusive societal networks, through polyvalent perspectives, with multiple groups expressing the plurality of their needs, views and suggestions.

7.3.1.2. The Gordian Knot

Insofar as I am correct in the above analysis, it could go a ways towards undermining some of the early negative conclusions of mainstream climate ethics literature, in a period I define as dating from ~1995 to 2005. I call this first phase of climate ethics literature the decade of ***the Gordian Knot*** or *the conclusion that the ethics of climate change were too difficult.* The dominant view held that any ethical solutions run into the inevitable obstacles of too much complexity in politics, human nature, development rights, and other insuperable obstacles. Policy makers, scientists, and scholars turned ethicists during this period lamented that climate ethics was simply too difficult.

Michael Grubb, an academic serving on the IPCC Working Group III at the time, wrote an overview essay on climate ethics in 1995.[v] He wrote, "While the Western literature on climate change has been dominated by scientific and economic perspectives, political realities have already highlighted *the central role that equity*

considerations will play" (my italics).[vi] Thus, this article appeared early in what was to become a large climate ethics literature. Already, Grubb laid a sophisticated groundwork, capturing a sense of the unprecedented nature and the magnitude of the potential issue, and laying out most of the major ethical issues still debated today.

Grubb introduced the major ethical theories regarding climate change, showing the correlations between ethical theories and proposed emissions allocation schemes.

International justice principle	**Climate change policy principle**
Egalitarian rights	Per capita entitlements
Causal responsibility	Polluter pays/ historical responsibility
Utilitarianism	Willingness to pay
Kant/ O'Neill	Comparable burdens
Beitz/Rawls	Rawls/distributional effects
Barry	Status quo, basic needs

Table 7.2. Ethical Theories and Corresponding Emissions Allocation Schemes[vii]

However, as I critiqued other IPCC writers of doing in Chapter Seven, Grubb seems to eschew true consideration of extreme climate events. On the one hand, one could argue that this was just a sign of the times; in 1995 there was still considerable uncertainty about the degree of climate impacts on human societies. On the other hand, in fact the IPCC already had sufficient facts to describe most of the same ethical dynamics that persisted twelve years later at the time of the Fourth Assessment Report. The difference was, in 1995 most of the IPCC writers did not yet have a clear sense either of the nature of probability and extreme events, of the true nature of feedbacks and thresholds, or of their significance to climate change scenarios. It seems that these missing elements permitted many of them to cite extreme climate events without then integrating them fully into their analyses or conclusions.

Grubb tends to tell two stories. In one version there are great risks for everybody. He writes, "If the Gulf Stream were to shift its course, the United Kingdom could end up with a climate… like Newfoundland."[viii] In the second version, there are clear winners and losers, with the losers predominately in the poor countries and the winners predominantly in the wealthy ones. Similarly, these early climate ethics articles often emphasize the possible benefits. "Although food production can be maintained and perhaps enhanced under climate change, its

distribution will shift, with a relative decline of 10 percent or more in the developing world."[ix]

Grubb mentions a litany of climate ethics proposals and in so doing begins to reveal their complexities.

> Krause et al. (1993) suggest that an overall cumulative limit for emissions of 300 billion tonnes of carbon over the period 1985-2100 be established and divided equally between the current industrialized and developing countries. The general characteristics of this allocation are argued to be ethically appealing as it requires substantial cutbacks from the industrialized world and allows for some interim growth from developing countries, but no more detailed division is offered and no more formal justifications for a 50:50 aggregated division of future emissions are presented.[x]

Picking up on this trend in the mainstream climate ethics literature, an article in *Climate Policy* in 2003 asked the question: Can quantitative indicators serve as "a foot hold for [sur]passing the environment-development Gordian Knot?"[xi] The authors adopt a consequentialist view in which they frame the climate issue as one in which development equity prevents climate responsibility. Many ethicists and policy makers took up similar positions in this period, climate ethics was an impossible challenge.

Other mainstream authors bypassed this difficulty by simply shirking responsibility altogether. This was a favorite theme of American ethicists. In one article, Eric Posner and Cass Sunstein argue, "It is far from clear that GHG emissions reductions on the part of the United States are the best way to help the most disadvantaged people of the world."[xii] Evidently, the authors presume that an economically strong United States is best for the world. The irony is thick. Any last Bangladeshis awaiting the arrival of trickle-down economics will find only the trickling-up Indian Ocean; the IPCC predicts that within a matter of decades, the ocean will cover as much as one-third of Bangladesh, creating hundreds of millions more environmental refugees.

As time went on, more ethicists and philosophers began to enter the fray. In 2006, environmental ethicist Stephen Gardiner published a now classic article, "A Perfect Moral Storm: Climate Change, Intergenerational Ethics and the Problem of Moral Corruption."[xiii] Gardiner argued that climate change is so complex, with such prolific and dispersed causes, that it is likely to be irresolvable, the ultimate tragedy of the commons problem. Everybody is guilty and no one is responsible.

While I agree with most of Gardiner's points, I reject his conclusion. I see his argument as well-founded, largely on complexity fundamentals of network causality, unintended consequences, and Rescher's processes of complexification. Gardiner points out that every person on the planet is implicated in the carbon balance, usages of carbon vary extensively, and that people are embedded in broad and intricate systems and thus accountability is challenging. To his comments on network causality, one could add network effects and thus networks of positive feedbacks and rapid coevolution of societies and environments.

For these same reasons I disagree with his conclusion. Taking up his reasons, and even more fully employing the GCF in analyses, one reaches a more nuanced and paradoxical conclusion. Yes, the great proliferation and fragmentation of causality makes climate change in one sense the ultimate tragedy of the commons. Yet, the results of climate change will be more truly global and thus globally transformational than the White Report ethicists and others such as Gardiner admit. If we go farther with analyses infused with notions from the GCF, then it appears that there will be no true safe havens on the planet. It may still be safer to live on Central Park then it would be living in the South Bronx, but how well will either place be doing when one third of Manhattan – as well as one third of Florida, Bangladesh, and many other American and European cities and seashores – are below water, one of the IPCC predictions that at this point appears to be inevitable?

The mainstream climate ethics literature, focused as it is on climate change, cannot help to have set out with a rather realistic sense of the complexities of the problems posed. Nonetheless, without the aid of the specific GCF, many scholars demonstrate various ways in which modernist thinking creeps into their analysis, muddying the picture. If, in the end, even ethicists turn to dismay, this seems to be ironically based in a partial underestimation of the full negative impacts of climate change. By applying an even fuller GCF perspective in their analysis, it appears that greater global change, in being worse than they conceive, may actually foster greater social and policy responses than at first anticipated.

7.3.2. Ethics Literature Group II: Eight Promising Contemporary Approaches

I analyze eight approaches in contemporary applied ethics literature, most relevant and connected with climate change, and which further support the argument for the GCF. These eight ethical approaches are a representative sample, which seem sufficient to make the point within the constraints of this dissertation. Some of these scholars would likely describe their work in more or less different terms than I use. However, my goal here is partly to highlight the implicit connections that may have more analytical power when described explicitly. The eight groups are: common pool resource ethics, land ethics or ecocentric ethics, extensionist ethics or ethics of globalization, pragmatist ethics, ethics of responsibility and of catastrophe, the ethics of care, partnership ethics, and various ethical theories from the academic field of philosophy. Additionally, there are many other important and interesting ethical fields and movements, which are more or less relevant, such as the animal ethics field. My focus is on the fields bearing most directly on climate ethics.

Ethical theory	**Founder, leaders**
Common pool resource	Elinor Ostrom, Native Peoples
Land, Ecocentric	Aldo Leopold, Catherine Larrere
Extensionist, globalization	Aldo Leopold, Peter Singer
Pragmatist	Anthony Weston, Andrew Light
Responsibility, catastrophe	Hans Jonas, Ivan Illich, Jean-Pierre Dupuy
Care	Virginia Held, Sandra Laugier
Partnership	Carolyn Merchant
Ethics in academic philosophy: Contextualized Complex contractualist	Various: Harry Frankfurt Thomas Scanlon

Table 7.3. Ethical Theories, and their Founders and Leading Proponents

The rich integration of these eight schools of thought begins to look like a more promising basis for an ethics of climate change. Once again, I attribute the attractiveness of this set of theories to the fact that each of these, in its own way, has articulated visions that help to articulate the shift from an ethics based in the classical worldview to an ethics of the complexity worldview.

7.3.2.1. Cooperation and the Commons – Elinor Ostrom

The first of these approaches seeks to overturn Hobbsian, Malthusian, and Hardinien notions of the egoist nature of the net force of all human interactions and thus to overturn the very thesis of the tragedy of the commons. The general approach is to argue that Hobbes, Malthus, Hardin or others in a similar line of thinking err in ascribing too much mechanism, determinism, inevitability and egoism to the overall picture of human interactions. In fact, it seems that these three thinkers and others like them projected a partially scientist and modernist film over the analyses of quite complex, dynamic, human systems, and thus failed to incorporate the very human capacity to *adapt*!

It is a sad irony that up until this point in human history, humankind has been so uncertain of its own agency and capacity for communal organization and societal self-organization. The modern worldview obviously played a part, fostering as it did explicit and elaborate early arguments for determinism in both physical and societal systems. Another player was evidently the political power ensconced in monotheistic attribution of all power to heavenly sources. In any case, it is perhaps one of the greater discoveries of complexity theories, that, as Sartre and so many others throughout the Twentieth Century persuasively argued, humans have agency. One of the great benefits of the GCF is to validate and clarify this degree of human freedom, agency, and intrinsic responsibility. Humans are dynamic and adaptive, capable of changing direction, and imbued with strong forces to counter societal problems, forces of care, compassion and cooperation.

Elinor Ostrom's argument for this is to show the ways in which the tragedy of the commons has not occurred in various examples; by creating a typology of the ways in the tragedy of the commons does not occur, one can create constructive models for cooperative strategies. Ostrom holds that Hobbes' followers were wrong to construe human interactions as so inherently dominantly cruel. She points to the numerous examples from anthropology and sociology of groups and communities in certain times and places that find ways to live quite peacefully and sustainably. The San Bushmen of the Kalihari Desert in Namibia are a much touted example, although there are many others.

A prominent example with direct bearing on our subject is Elinor Ostrom's theories and models of cooperative strategies, which debunk the inevitability and determinism embedded in Garret Hardin's tragedy of the commons theory. This provides the secondary and perhaps the strongest attack on Stephen Gardiner's pessimistic Gordian Knot theory. This article and others in the same vein, construes Hardin's argument as unrealistically mechanical, deterministic, and inevitable. Derived from game theory or decision theories, such arguments may rely too much on

hidden mechanistic assumptions, and omit critical human tendencies for cooperation. Ostrom refutes Hardin, by showing that people in fact often resolve common pool resource struggles successfully.[xiv]

Specifically, Ostrom develops a six-part model describing how communities have successfully managed common pool resources in numerous instances around the world. Ostrom demonstrates that local initiatives and cooperative efforts often overcome the kinds of degrading patterns engendered in commons situations. What this implies is a special kind of coevolution, a promising topic for further research. I discuss this briefly in the conclusion of this chapter, on solutions and approaches. Ostrom envisions a coevolution in which people find ways to symbiotically alter course, develop innovative projects, policies, and new methods of cooperative commons management. Such endeavors in turn coevolve with larger-scale enterprise, which at times yield power to local successes, bringing about even larger-scale successes in common pool resource management. Indeed, one could also point to a few recent international treaties that have been, up until now, largely effective in protecting even planetary commons spaces, such as the International Treaty of the Seas.

7.3.2.2. Land Ethics, Ecocentric ethics – Aldo Leopold, Catherine Larrère

Aldo Leopold's essay, the Land Ethic, lays out a basic formula for developing an ethics of complex systems. The Land Ethic is based on the story of a mountain ecosystem. Characters in the story include the plants, trees, small animals of all kinds, as well as wolves, deer, hunters, naturalists, and people enjoying nature for reasons of scientific research, recreation, and aesthetic enjoyment. (Yale Professor Stephen Kellert would later add to this list: biophilia, spiritual enjoyment, psychological health, etc.)

The central ***ethical principle*** of the Land Ethic holds that: *A thing is right when it tends to preserve the integrity, stability and beauty of the biotic community. It is wrong when it tends otherwise*. Here are four excerpts from Leopold's Land Ethic (1949).

> [A] land ethic changes the role of Homo sapiens from conqueror of the land-community to plain member and citizen of it. It implies respect for his fellow-members, and also respect for the community as such.[xv]
>
> The ordinary citizen today assumes that science knows what makes the community clock tick; the scientist is equally sure that he does not. He knows that the biotic mechanism is so complex that its workings may never be fully understood.[xvi]
>
> Perhaps the most serious obstacle impeding the evolution of a land ethic is that our educational and economic system is headed away from, rather than toward, an intense consciousness of land. Your true modern is separated from the land by many middlemen, and by innumerable physical gadgets. He has no vital relation to it; to him it is the space between cities on which crops grow…[xvii]
>
> Wilderness is a resource which can shrink but not grow. Invasions can be arrested or modified in a manner to keep an area usable either for recreation, or for science, or for wildlife, but the creation of new wilderness in the full sense of the word is impossible.[xviii]

In each of these citations, Leopold evokes the shift from modern to complex thinking. Interwoven in these passages, one finds many of the implications of the

complexity framework identified throughout the dissertation. In the first, one finds the shifting relationship of authority between the science and ethics. In the second, Leopold highlights the issues of highly complex systems, certainty, and unknowability. In the third, he examines the way that the dovetailing, coevolving two forces of the process of complexification and the ideology of modernism have led increasingly into a sense of alienation, isolation, and confusion, and the significance of this for the relationship between people and their environment.

Finally, in the fourth, Leopold foresees the critiques of the slow growth, zero growth and sustainable development movements to emerge thirty years later; the wilderness can shrink but not grow. Indeed, he warned in advance that spending billions on the Biosphere projects was a flagrant waste; humankind cannot understand the complex mechanisms of single organisms, so much less can we "create wilderness."

Many successors have followed Leopold's example, including Holmes Rolston III and Baird J. Callicott in the United States, and Catherine Larrère in France. Larrère explains the evolution of environmental ethics from the 1970s through the 1990s. There were two early branches, biocentrism ethics and ecocentrism. The prior granted intrinsic value of all biological beings. The latter, following Leopold's example, saw the basic ethical principle as based in the fact that we are all part and parcel of a community of living beings, of the same biotic community, and thus we have obligations to all other members of the community.[xix]

In this way, Larrère describes a much more complex principle at the heart of the ecocentrism. By highlighting the entire community, ethical theory must move beyond the atomistic, individual components as each one valuable. More significant is treating the scale of the entire ecosystem, humans included, and thus addressing not just singular entities or relationships, but the entire web of interrelationships, with all the profound complexities that this entails.

By shifting the basis of ethical concern and principle from parts and partial relationships to wholes and all relationships, ecocentrism shifts from interdictions of harming individual parts, to principles for maintaining wholes, argues Larrere. As she puts it,

> In contrast to the deontological biocentric ethics, which primarily put forth interdictions (what one could call a "don't touch" principle), ecocentric ethics is an ethics of good practices, of good habits for human conduct in the natural world: those that Aldo Leopold presents in the essays in A Sand County Almanac. Ecocentric ethics permits links between respect for community members et the entire community, along with

> responsibility of those within it. What then, can ecocentric ethics bring to ethics, more anthropocentric, or more pragmatic, with respect to responsibility? Essentially, this brings us the capacity to situate ourselves in the natural world of which we are a part and to represent nature to ourselves. Yet, contrary to how it is often presented, ecological problems or environmental protection do not pose a conflict between humanity and nature (e.g. people against wolves, bears, etc.…) but poses the question of knowing in what nature we want to live.[xx]

Larrère considers the context of the evolution of environmental ethics in the United States, which has flourished precisely in response to the rapid and striking human impact on what was a vast and rich Wilderness, Native Americans included, at the time of conquest.

Whether the techno-natural world of cities is more or less complex than wilderness areas, one way to understand Leopold's development of ecocentrism is a response at the dawn of the massive boom in population, industrialization and technological transformation that the United States was to undergo in the next half century. At this dawn of great change, in the wake of prior critiques of modernism of which Leopold must have been somewhat aware, such as the Frankfurt School, Leopold hit upon the way in which coevolving systems of population, industrialization, technology, and other human systems would interact with environmental systems. He saw that social networks were increasingly inextricably ensconced in a growing web of techno-urban networks. As Thoreau had proclaimed in the last century, changes in the landscape provoked seemingly irrevocable changes not only in ecosystem biodiversity and integrity, but also in the way people think and live. It was in this sense, as well, that Thoreau proclaimed that in wilderness is the salvation of the world.

In short while the precise development of an ecocentric ethical theory remains elusive and perhaps overly ambitious, this may serve environmental ethics much better than, for instance, the biocentric alternative. By encompassing greater complexity and challenge, the theory underscores: the complexity of human and natural interactions; some potential outlines of a more viable and realistic environmental ethics, including multiple stakeholders, ecosystem services, and issues of irreversibility, vulnerability, resilience and constant evolutionary and adaptive change. It also sheds light, perhaps, on some limits to ethics.

7.3.2.3. Extensionist ethics, globalization ethics – Aldo Leopold, Peter Singer

Extensionist ethics – as expressed by Leopold and later developed by ethicists like Singer – are an effective way to include much greater complexity in ethical analyses. While early modern ethical theories often had goals that extended to the societal level, in their substance, many focused a great deal on examples involving a very restricted ethical sphere. Indeed, to this day most advanced ethics seminars at Yale and Berkeley Universities almost exclusively utilize thought experiments involving no more than three people per experiment, at times a roomful, or occasionally a nation, but often constricted to some specific group, e.g. a nation of World Cup television watchers.

Leopold cuts straight past this by focusing his object of ethics not on relating solely between people, but on the all of the relationships involved in a certain area of land.

> All ethics so far evolved rest upon a single premise: that the individual is a member of a community of interdependent parts. His instincts prompt him to compete for his place in the community, but his ethics prompt him also to cooperate (perhaps in order that there may be a place to compete for.)
> The land ethic simply enlarges the boundaries of the community to include soils, waters, plants, and animals, or collectively: the land.[xxi]

The decades in which environment ethics has developed have been especially marked by the striking increase in both global population and global interconnectedness. Alongside and in relation to the concepts emerging from ecocentrism, as well as parallel scholarly fields such as conservation biology (begun in the 1980s), a wave of ethicists has approached environmental ethics as ethics of the conservation of whole areas. This also stems from either the preexisting philosophical concept of ethical extensionism, or Aldo Leopold's uptake of it in the Land Ethic. ***Ethical extensionism*** refers to *the shift in ethical theories from narrower to broader spheres.*

Pioneers include Yale School of Forestry and Environmental Studies professors Tim Clark and William Burch, who focused on the entirety of conflicts within a certain zone of struggle over environmental conservation. Tim Clark focused on analyzing the stakeholders in the highly contested and often deadly battles over land management in places like rural and wilderness areas in Montana and the

Rockies, while William Burch focused on urban Long-term Ecological Research Sites, such as Baltimore Maryland, showing the necessary and problematic process of including everything within watersheds inside of singular land management strategies.

In the sphere of ethics, Australian ethicist Robert Elliot articulated the nebulous and intensely conflict-ridden nature of environmental ethics on the ground, based upon case studies of conservation battle sites. His essay "Environmental Ethics," discusses the ethical questions involved in the fight over Kakadu National Park in Australia's Northern Territory.[xxii] Many elements of both environmental interest and political conflict are present. He lists them:

Important environmental landscapes – woodlands, swamps, waterways
Endangered species – Hooded Parrot, Pig-nosed Turtle
Ecological significance, e.g. ecosystem services
Recreational opportunities
Research opportunities
Great beauty, Aesthetic enjoyment
Spiritual significance to the Jawoyn aboriginals
Mining interests: gold, platinum, palladium and uranium

Table 7.4. Interests in Kakadu National Park, Australia Great Northern Territory. Adapted from similar list by Robert Elliot[xxiii]

Elliot hypothesizes about the types of harm that will occur if mining is permitted. The list encapsulates the major environmental issues of concern at the global scale, showing how significant each environmental struggle is in the greater framework of biospheric sustainability. Elliot's list of harms includes everything from species extinctions to further degradation of conditions leading to increases in endangered species, implying further possible extinctions. Ecosystems services will be diminished or in some areas even destroyed. Various opportunities for advancement in local communities and the international community will be reduced, compromised, or destroyed. Spiritual significance to one stakeholder group will be destroyed, and in the end, the mining is likely to profit only a small group of individuals and not the community at large.

Important landscapes will be degraded or destroyed; it will pollute rivers, poison wildlife, and endanger more species
Species will become extinct; biodiversity will decrease
Ecosystem services will be disrupted, degraded, diminished, or destroyed
Naturalness of the place will be compromised
Recreation opportunities will be reduced
Research opportunities will be reduced
Aesthetic opportunities will be reduced; beauty will be lessened
Spiritual significance to the Jawoyn aboriginals will be disrespected
Mining will profit some individuals, and probably only incur losses for locals

Table 7.5. Harms if Mining is Allowed in Kakadu National Park. Adapted from similar list by Robert Elliot[xxiv]

Next, Elliot denominates the steps in the process of ethical analysis. One must first determine validity of at times competing or contested empirical facts regarding causes and results. Arguments regarding the facts will then only make sense against a certain kind of background. The differences in this background give rise to different assessments of what should be done. What constitute this background are such things as: desires, preferences, aims, goals and principles, including moral principles.

This step reveals the profundity of difference, the ways in which values, aims and desires tend towards conflict in most cases of conservation management. One major element actually missing from Elliot's example, for which it might be even better to choose another example, is that question of indigenous people living in and depending on lands and resources enclosed within the contested conservation area. Much progress has been made on this issue in the last ten years, but it remains a highly difficult aspect of the work of would-be environmental conservationists.

Ethicists and citizens must then sort through the various profound ethical questions that result from this method of roping out an area of complexity, focusing on what kinds of principles in operation may offer moral guidance in our treatment and relationship with wilderness areas.

1. Would it matter if actions caused species to become extinct?
2. Would it matter if actions individual animals to perish?
3. Would it matter if actions caused widespread erosion in Kakadu?
4. Would it matter if the mining turned the South Alligator River into a watercourse devoid of all life?

5. Is it better to protect Kakadu or to generate increased material wealth which might improve the lives of a number of people?
6. Is the extinction of a species alright in order to increase employment?

Elliot points out that this calls for a variety of competing, including partially overlapping environmental ethical theories. These include:

1. Human-centered
2. Animal-centered
3. Life-centered
4. Biotic and abiotic together
5. Ecological holist
6. Combination of more than one[xxv]

I will give an example of Elliot's sixth ethical theory. One could conceive of an ethical theory that combines ecocentrism and human-centered rights. This is essentially the ethical theory with which conservationists have now framed fights between indigenous occupants and external environmentalists in recent years. In other words, this ethical theory would result in considering both the interests of animals and the goal of biospheric maintenance. Where these conflict, for example in the common case in which people's rights or lifestyles can only be saved by simplifying an ecosystem, then some kind of trade-off or balancing would be required.

In the end, Elliot does not offer any prescriptions in the case study of Kakadu. While he does not state it anywhere explicitly, he argues for points of view that I would say fall within a complexity ethics and his ethical theory is 'complex systems centered.' He writes,

> If it is organizational complexity per se that makes something morally considerable then some non-living things will be morally considerable; e.g. the bodies which make up the solar system, patterns of weathering on a cliff and a snowflake. The property of having a diversity of parts constituted by complexity, constituted in a more complex, richer fashion – this may be the best criteria for moral consideration….
>
> Understanding the rainforest is a complex system with interrelationships leads us to value it as a whole more than we otherwise might. Knowing how the parts work in concert to maintain the whole might assist us in

> seeing it as a thing of beauty. Counting these kinds of reasons as reasons for avoiding environmental despoliation provides the basis for an environmental ethic, which reaches beyond either a human or animal centered one and possibly beyond a life-centered one as well.[xxvi]

Finally, while he does not articulate it, he implies that there is a clear policy choice to be made in the case of Kakadu, because the harms outweigh the benefits. He states,

> It may not be correct to say that human should always come first or that preserving an ecosystems is always more important that protecting any set of human interests. Nevertheless there will be cases, such as Kakadu, where the morally appropriate policy is clear enough.[xxvii]

One could argue that while Elliot's approach throughout was the classic approach of the professional ethicist – empirical data, background story, specific ethical principles, and considerations about how to weigh them. He demonstrates throughout the difficulty and intricacy of the issues involved. And yet, the proceeding analysis is detailed enough perhaps to keep one's analyses from going too far awry. This is of course the nature of ethics. Ethics, like science, has limits, and resolves these limits through rational analysis and judgment. Ethicists, in contrast to many natural scientists, have always grappled with deep uncertainty; they have never had cause to presume or pursue truth and certainty in the way that natural scientists have. Rather it is presumed that in highly complex situations there may be no certainty and no way to conduct a 'complete' or ethical analysis. Sometimes "the morally appropriate policy is clear enough."

7.3.2.4. Pragmatist ethics – Andrew Light, Eric Katz

Another approach to effective incorporation of complexity is to give more weight to pragmatism than theory. I consider this the applied branch of applied ethics. These thinkers are primarily philosophers and ethicists by training. Andrew Light, Eric Katz, and Anthony Weston are all leaders of environmental pragmatism. The pragmatist school of environmental ethics developed in response to the inefficacy of two decades of environmental ethics deemed to be overly theoretical and incapable of its intended goal, saving the environment. As Light said,

> The intramural debates of environmental philosophers, though interesting, proactive, and complex, seem to have no real impact on the deliberations of environmental scientists, activists and policymakers…. It is imperative that an environmental philosophy as a discipline, address [the environmental] crisis – its meaning, its causes, and its possible resolution. [For this to occur] the fruits of this philosophical enterprise must be directed towards the practical resolution of environmental problems. Ethics cannot remain mired in long-running theoretical debates in an attempt to achieve philosophical certainty.[xxviii]

Through the 1970s and 1980s many applied environmental ethicists tried in vain to resolve certainty in theoretical debates. Here again one finds a wall of uncertainty. If knowledge is becoming increasingly complex, and scientific facts regarding many critical phenomena of our lives cannot be determined with certainty, then it would seem we have that much less chance of attaining certainty in ethical deliberations.

The more we elaborate arguments for certainty in complex systems the more we run into the walls of both uncertainty and unknowability. Indeed, to refer back once again to the question of overall versus fundamental complexity, unknowability prevents a precise answer to the question of the differences in degrees of complexity between these two kinds. However it appears to be the case from what we can tell that there is a typology of kinds of complexity, ascending from mechanical and physical systems as the least complex, through more complex biological systems, and finally the hyper-complex realms of ideas, meaning, and emotions. If this is the case, then ethics – which encompasses all of the above and attempts to assess and deliberate within hyper-complex contexts of socio-ecological change – is the most complex realm of knowledge. Though each used very different methods, any of which may be questionable, this is the conclusion of, for instance, Stephen Jay Kline and Yaneer Bar-Yam,[xxix]

The pragmatist philosophers move is to recognize that ethics appears to share this quality of uncertainty with science, and that paradoxically this renders ethics both more significant than previously realized, but perhaps no more capable than previously thought. More significant because ethics is a tool we use in cases of uncertainty, and no more capable perhaps, because ethics itself suffers from such profound theoretical uncertainties. Thus these discoveries go well hand in hand, as the lessening credence of science makes increases that of ethics. Given the reality of the reality of long-term uncertainty and purported unknowability in science, there is no

choice but to engage more seriously with ethics. The pragmatists take up this issue head on.

> The pragmatist goal is to find workable solutions now. Pragmatists cannot tolerate theoretical delays to the contribution that philosophy may make to environmental questions.[xxx]

> Environmental pragmatism is the open-ended inquiry into the specific real-life problems of humanity's relationship with the environment. The new position ranges from arguments for an environmental philosophy informed by the legacy of classical American pragmatist philosophy, to the formulation of a new basis for the reassessment of our practice through a more general pragmatist methodology.[xxxi]

Within pragmatism, one finds justifications, motivations, and goals outlined by many of the crosscutting analyses in social theory mentioned earlier in the dissertation. In this case, many of the critiques on which the pragmatists base their work seems to be based upon ideas drawn from sources such as the science and technology studies, theoretical ecology, and the philosophy of science, such as those discussed in Chapter Six, and those in turn were inspired by earlier social theorists and philosophers. For instance, some drew upon the Frankfurt School; a group that early critiqued the Enlightenment ideals and modernism. Pragmatists presume such issues as the non-duality of humans and nature, the intrinsic value of all natural things, and the necessity of ecosystem services. Based on drawing from these lessons of the past, they aim to focus more on environmental solutions.

Philosophers Sandra B. Rosenthal and Rogene A. Buchholz argue that pragmatism is a critique of the modern scientific worldview, which they call a view that objectifies Nature and posits a clear separation between humanity and the natural world. Pragmatism offers a "radical correction of modernity." Bryan Norton contrasts applied and practical (or pragmatic) philosophy. Applied philosophy applies a valid theoretical principle to a specific situation, and thus requires a commitment to theory before application. Whereas, pragmatic philosophy arises within a specific problem situation, deriving theories (if need be) from the problem context itself. The role of the applied philosopher in solving practical problems is thus much different from that of the pragmatic philosopher.

Key aspects of pragmatism include: the call for moral pluralism, the decreasing importance of theoretical debates, the placing of practical issues of policy consensus in the foreground of concern. This takes place is a few forms, such as 1)

the articulation of practical strategies for bridging gaps between environmental theorists, policy analysts, activists, and the public, and 2) developing general arguments for theoretical and meta-theoretical moral pluralism in environmental normative theory.[xxxii]

So not only do the pragmatists draw from the same sources and the same general theories as many of the transdisciplinary groups mentioned in Chapter Six and Chapter Seven – science and technology studies, the theoretical ecologists, philosophy of science, etc., as well as the policy conclusions of the IPCC, and the MEA – but they also seem to arrive at the same conclusions. The lists of criteria with respect to bridging gaps, including and negotiating between multiple stakeholders, and developing and applying theoretical pluralism, echoes the calls of such these other groups listed throughout the dissertation. Ultimately, says Light, environmental pragmatism is a new strategy for approaching environmental philosophy and environmental issues. It is not a single theory or view, but rather, "a cluster of related and overlapping concepts."[xxxiii]

In order to work on problem solving, Light says, one must strive for meta-theoretical compatibility between opposing theories. The commitment to solving environmental problems becomes not only the precondition for any workable and democratic political theory, but also a regulative ideal "emanating from practice" – from environmental activism and guiding the construction of political and normative theories. In an example of this, Light strives to reconcile ontological schools of environmental ethics, like Arne Naess' deep ecology, with materialist schools, such as Murray Bookchin's social ecology.[xxxiv] Ultimately, these are neither mutually exclusive nor incompatible; they simply require a broader, more pluralistic framework of ethical theory. For this reason, pragmatist environmental ethics strives for a "metaphysical tolerance of a multiplicity of approaches." In this way, the pragmatists hope to render environmental ethics ""a relevant participant in the search for *workable* solutions to environmental problems into the next century."[xxxv]

Pragmatist environmental philosophers such as Light seem to have caught on to something very important – if science is plagued by uncertainty, so is ethics. Yet that does not render either of them less significant, and perhaps renders ethics more so. As environmental ethicist Mark Sagoff has written:

> We have to get along without certainty; we have to solve practical, not theoretical, problems; and we must adjust the ends we pursue to the means available to accomplish them. Otherwise, method becomes an obstacle to morality, dogma the foe of deliberation, and the ideal society we aspire to in theory will become a formidable enemy of the good society we can achieve in fact.[xxxvi]

7.3.2.5. Responsibility and catastrophe ethics – Hans Jonas, Ivan Illich, Jean-Pierre Dupuy

A major current of thought has developed around the notion of responsibility. In recent years some of these thinkers have dealt increasingly with the responsibility not just to preserve the natural world, but to prevent the catastrophe of its destruction. This work builds upon extensive ethical theories and a rich literary history addressing the central place of the Promethean power of humans in the realm of morality.

Hans Jonas' elaborate ethics of responsibility proposed a reformulation of ethics around the core concept of responsibility in all of its facets, debunking notions of utopia and absolute progress, and developing a more realistic, forward-looking perspective. His work touched upon many questions that remain central to ethics today, such as this passage that sends shivers up the spine (1979).

> Yet the combustion of fossil fuels, beyond simply causing local air pollution, also presents the problem of global warming that may enter into a strange competition with the depletion of reserves. This is the "greenhouse gas effect" that remains after the carbon dioxide that has formed during combustion accumulates at the global scale in the atmosphere and acts as the glass cover of a greenhouse, which is to say it allows solar radiation to enter, but it prevents thermic radiation from leaving the earth. A worldwide temperature elevation set off and maintained by us (beyond a certain degree of saturation this will continue even in the absence of supplementary combustion) may put in motion long-term consequences for the climate and for life, which nobody would want – all the way to the extreme possibility of the catastrophic melting of the polar ice caps, the elevation of Oceans, the immersion of great swaths of lowlands… as such the frivolous and joyous party that humankind enjoyed during a few industrial centuries may be paid for by millennia of a transformed terrestrial world.[xxxvii]

In terms of complexity, what is striking is Jonas' acute sense of the *vulnerability* of the world, which appears visionary for his day. Student of Husserl, Heidegger, Bultmann, witness to both world wars, contemporary of Sartre, Arendt, and other great post-World War II intellectuals, Jonas seemed especially well placed to appreciate the fragility of both human civilization and the natural world.

Ivan Illich expanded upon the need for an ethics of responsibility. One or two generations after the rising critiques against the progress, modernity, and the lost hopes for utopia, and a generation before Ulrich Beck was to describe societies in the 1990s as crisis-ridden 'risk societies,' Illich described some of the peculiar ways in which progress could be unpacked. In complexity terms it is based upon unintended consequences. Illich also noted however, how unintended consequences seem to accumulate over time producing ongoing dilemmas. He noted that as modern societies developed technologies, human lifestyles and landscapes coevolved, and this coevolution interwove in ways that were at times beneficial, but at times perplexing and in fact nefarious. Obviously in some ways modern technologies were greatly beneficial, improved the quality of life, and saved lives. But as modernity evolved, the benefits became increasingly mired in the accumulation of unintended consequences. The nature of change slowly became distinguished from the dreams of progress. It is increasingly evident that many innovations, once introduced into the complex context of human lives, display degrees of dysfunctionality; the intended benefits undermined by myriad intersecting negative consequences. In every domain there was a unique term for it: in medicine – side effects; in the military – collateral damage. Illich studied the more global phenomena – unintended consequences and their accumulation over time, which he called, "counterproductivity."

"… [T]he Illichienne critique throws into doubt the stronghold that the logic of detour exerts on our thinking. He who is animated by the logic of detour may fall prey to its own trap; he can forget that the detour is, precisely, only a detour. He who retrenches the better to spring forward keeps his eyes fixed on the obstacle that he wishes to surpass. If he stands back while looking in the opposite direction, he risks forgetting his objective, and mistaking his regression for progress, taking the means for the ends."[xxxviii]

As technologies, in context, have this characteristic of counterproductivity, so does our very rationality take on the quality of counterproductivity. In the 1970s, Illich and Dupuy conducted a study and found that the average French person spends more than four hours per day in a car, of which the average speed comes to an astounding seven kilometers per hour. This is faster than a person walking on foot, but notably slower than a cyclist. Yet, the car owner spends a good deal of office time simply paying for the costs of the car, gas, and upkeep.[xxxix]

> The mathematical result [of our research] implies the following: The average French person, deprived of his car, and, let's suppose, freed from the necessity of working long hours to pay for it, would spend less of his "overall time" dedicated to transport if he made all of his trips by bicycle – and we do mean, all of his trips,

> not only those daily trips he makes between the house and the office, but also the weekend, going to his distant country house, and at the holidays, travelling to a distant seaside. This alternative scenario would be judged absurd, impossible. Nevertheless, it would economize time, energy and nonrenewable resources, and it would amount to a lesser impact on what we call the environment. Where is the difference then which makes it that in one case, the absurdity is patent, whereas it is obscured in the other? Since, in the end, isn't it more comical to work a great deal of one's life just in order to pay for the means of transport to go to that job?[xl]

Once again, reacting effectively to the environmental crisis seems to require a certain inversion of logic. In the case of the precautionary principle, this amounts to reversing the burden of proof, reversing the order of time, and reversing assumptions about progress. In the case of ethics, one has to shift rationality from linear to nonlinear, calm to chaotic, predictable to uncertain and likely to bear surprises.

In contemplating issues like counterproductivity and how it can lead to catastrophe, Dupuy developed an ethical theory which uses an inversion of time. An adequate environmental ethic entails a projection in the future in order to act as if the worst tragedy would occur, so as to prevent it. Like the authors of the Club of Rome, one has to assume the worst case scenario, in order to motivate society to perhaps not take that route.

In his book *For an Enlightened Catastrophism* Dupuy argues that we must reverse the logic of the place of the observer in time with respect to the harm or catastrophe. When the observer is in the present speculating about future harm, one utilizes wisdom, and is confronted with the difficult issue of how to cope with the probability of harm. When the observer is in the distant future – assuming harm in the near future – one also will turn to wisdom, in the sense of the need to balance conflicting ethical claims on the best way to proceed in many complex cases; however, one has a stronger rationality upon which to act than mere precaution. Once one assumes that the worst will occur, the rational choice is to take the fullest actions possible to prevent it, supposing that the ration of probability to harm is sufficiently alarming. Here is an ethics designed to address the extreme events that Brian O'Neill lamented so inevitably fell out of the IPCC reports. Here is an ethics for abrupt climate change.

7.3.2.6. Care-based ethics – Virginia Held, Sandra Laugier

The ethics of care emerged in the wake of Carol Gilligan's influential book in 1982, *In Another Voice*. In brief, this school of ethics holds that besides reason, duty, and rationality, there is another driver of ethical action that could be succesfully developed, which is simply the innate human tendency to care. While the ethics of care has diverged slightly from Gilligan's original thesis about gender difference, care ethicists have developed Gilligan's idea that care is a trait upon which much of the real ethics of everyday life is based, and thus a promising basis for ethical theory. One of the key questions, for Gilligan, is how care is then linked with responsibility.[xli]

Care-based ethics reflects the Generalized Complexity Framework (GCF) in various ways. First of all, while this may seem indirect, it is significant that care replaces the full observer back into the system. By focusing on care – rather than one rational criteria or another – we immediately include the full apparatus of the human as observer in the complex system towards which the ethical theory is aimed. There may be a number of strengths in this approach. First, it seems to reflect some of the truth about ethics that lay dormant during the modernist era when many leading ethicists attempted to base ethics in rationality in one way or another. As noted by various philosophers throughout history, and most notably recently Bernard Williams, the exercise of first utilizing rationality in order to then express caring is not really how we operate, nor how we should. As Williams points out, if his wife and a stranger are both drowning, he should not have to reflect before plunging in to save first his wife and only then the stranger. One might add, taking time to rationalize his love for his wife may even prevent the second rescue.

Care theory gets past such issues by recognizing that at the basis of much of real life ethics is the instinct and desire to care. The concept of care has been extended to the environment, for example in the concept of biophilia developed by Stephen Kellert and E.O. Wilson, environmental thinkers at Yale and Harvard respectively, who contend that human and other creatures possess biophilia, which is to say simply, living beings tend to have feelings of affection and care for other living things, across many species boundaries. Humans care about the environment. While there are innumerable *reasons* to care for nature to a certain extent they are irrelevant, because we just *care* about nature; we have feelings of love and stewardship for nature that arise in us naturally.

Second, care-based ethics is contextual. The metaphysical theory of contextuality constitutes an alternative model for moral theory. The philosopher Joan Toronto argues that care-based is one of what is called a set of contextual ethical theories, which eschew abstraction and require the incorporation of real actors and a

real society. According to Toronto, these theories are founded on the certain ideas about the nature of morality that differ from the meta-ethics inspired by Kant. In any contextual moral theory, one must situate ethics in a concrete fashion, which is to say regarding particular actors in particular societies. The simple enumeration of principles is not sufficient for understanding the theory. It thus also reincorporates Aristotelian virtue theory, as the contextual ethical theory "concentrates its attention not on the morality of certain acts but on the greater moral capacity of the actors."[xlii] Moreover, morality cannot be determined by posing hypothetical moral dilemmas or by affirming moral principles. Rather than being based in the hypothetical, care theory is based in the moral imaginary, the character, and the capacity of each person to respond to the complexity of a given situation. Toronto considers contextual ethical theories to include: Aristotle's moral theory, and the theory of moral sentiments of the Scottish enlightenment philosophers, e.g. David Hume and Adam Smith. Due to the initial interest in character, any contextual ethical theory must incorporate a portrait of the complexity of the subject.[xliii]

According to Toronto, modern a-contextual ethical theories utilize rational tests to verify egoistic tendencies. Hence, modern ethicists came to identify morality and rationality, falsely. In contrast, the contextual ethicists hold that moral sensibility and moral imagination are determining factors for the adult ethical life. Rather than creating the ideal of being the rational actor, moral contextualism explores the individual's capacity or incapacity for moral development, to the point of caring for others. The ethics of care is a framework capable of articulating the conciliation between one's own needs and the needs of others; balancing between forces of competition and cooperation; and maintaining the network of social relations in which one is placed.[xliv]

7.3.2.7. Partnership ethics – Carolyn Merchant

Carolyn Merchant has developed an ethics based upon partnership. She draws from various rich sources including eco-centric ethics, homocentric ethics, social ecology, deep ecology, feminist ethics, ethics of care, radical ecology, and various spiritual traditions.

> The partnership ethic I propose for consideration is a synthesis of the ecocentric approach based on moral consideration for all living and nonliving things, and the homocentric approach, based on the social good and the fulfillment of basic human needs. All humans have

> needs for food, clothing, shelter, and energy, but nature also has an equal need to survive. The new ethic questions the notion of the unregulated market, eliminating the idea of the egocentric ethic, and instead proposes a partnership between nonhuman nature and the human community.

A human community in a sustainable relationship with a nonhuman community is based on the following precepts:

1. equity between the human and nonhuman communities
2. moral consideration for both humans and other species
3. respect for both cultural diversity and biodiversity
4. inclusion of women, minorities, and nonhuman nature in the code of ethical accountability
5. that ecologically sound management is consistent with the continued health of both the human and the nonhuman communities.[xlv]

> A partnership ethic holds that the greatest good for human and nonhuman communities is in their mutual living interdependence. [xlvi]

Merchant explores the case of the fisheries of the Pacific Northwest, asking about the moral relationship between people and fish. She draws historical perspective into the way that through coevolution of people, land, resources, technologies, and cultures during the last hundred and fifty years, the material, spiritual and ecological relationships have been altered. Alongside this historical narrative, she traces the evolution of ethical theories.

> The Western idea of property stemmed from the Roman notion of bundles of sticks or fasces; symbols of authority and justice carried by Roman lictors as symbols of power, exemplified most blatantly in modern times by the fascist symbol of a bundle of sticks, emblem of the Italian regime of Mussolini. By contrast, the Yakima believed there were sacred bundles of magical objects given to an individual by a guardian spirit, defined, not as rights and privileges as in the Western system, but as relationships and obligations to other human beings, to the tribe, to nature, and to the spirit world. Thus under laissez faire capitalism, a very different ethic replaced the native American belief system for managing the commons in the Pacific Northwest.

Merchant traces the history of fisheries on the Columbia River in Oregon, sketching the coevolution of population, technology, ethics and legal codes from the mid-1800s to the present.

> In the 1850s, the first gill-nets were used on the Columbia River below Portland. They were combined with purse seines, traps, and squaw nets during the decades of the 1850s and 1860s. In 1879, fish wheels were introduced on the Columbia River; these were like ferris wheels with movable buckets, attached either to a scow or to rock outcrops along the edge of the river. They operated day and night scooping fish out of the river and dumping them down shoots into large bins on the shore to be packed and slated. By 1899, there were 76 fish wheels on both sides of the river. In 1866, the canning industry began operating on the banks of the Columbia near Eagle Cliff, Washington and by 1883, there were 39 canneries shipping to New York, St. Louis, Chicago, and New Orleans.[xlvii]

Fisheries from 1823 to the 1880s in the Pacific Northwest operated under a laissez-faire capitalism that was rooted in an egocentric ethic, an ethic that pertains to individual fishers or fishing companies. Individual had rights over of ownership over individual stocks of fish. The underlying ethical principle was: What is good for the individual is good for society as a whole.

From the late 1800s to the early 1900s, the fisheries employed a homocentric ethic, exemplified by the idea of the maximum sustainable yield, as the best approach to regulation and management. Fish wheels were outlawed and times of fishing curtailed. In 1877, says Merchant, Washington closed the fisheries from March through and again from August through September to give the fish a chance to reproduce. Oregon followed suit in 1878. The states regulated the kind of gear that could be used, the size of nets, and the area of the river on which they could be used. In 1917 purse seines were prohibited. In 1948 size regulations were imposed limiting catchable fish to those above 26 inches in length.

> A bigger threat to the fisheries, however, occurred in the 1930s. along the Columbia River and its tributaries. Dams for hydropower and flood control are examples ***par excellence*** of the homocentric ethic dedicated to the public good. Yet the public good did not coincide with the good of fish. Fish ladders and elevators had only

> limited effect in sustaining fish migrations, particularly those downstream. The Chief Engineer of Bonneville Dam initially proclaimed, "We do not intend to play nursemaid to the fish." In 1937, George Red Hawk of the Cayuse Indians observed, "White man's dams mean **no** more salmon" By 1940, the catch of Coho salmon amounted to only one tenth of that taken in 1890.[xlviii]

Here we see that with the advent of new technologies there is often both an unwitting backslide in ethical action, if not in ethical principle as well as a counterproductive and thus ecologically destructive phenomena. Advances in fishery ethics that occurred at the turn of the century were lost when larger commercial and financial interests were at stake.

Merchant addresses some of the obvious obstacles to the partnership ethics: the growth-oriented ethic of the free market economy and the property rights movement backlash against environmentalism. However, there is really is no choice but to attempt to overcome these obstacles, in the search for sustainability. "We might come back to the notion that Barbara Leibhardt-Wester proposed in her comparison of native and European Americans-the idea of the 'sacred bundle.' Like the Native American sacred bundle of relationships and obligations, a partnership ethic is grounded in the notions of relation and mutual obligation."[xlix]

7.3.2.8. Ethics in academic philosophy – Harry Frankfurt, Thomas Scanlon

Thus far, I have not said too much about the field of ethics, by which I mean ethics as it is being developed in academic philosophy departments. There is a consensus amongst contemporary environmental ethicists that the great modern opuses on ethics are completely inadequate to the kinds of problems that the globalized world requires today. Nonetheless, a number of contemporary philosophers have taken up more promising approaches. I mention just two here, though there are many examples.

Harry Frankfurt has developed a theory of care on a much greater scale than previously attempted by the original feminist authors. In his 1988 book *The Importance of What We Care About*, Frankfurt gives the concept of care an architectonic position that largely surpasses the scope of other ethics of care. Seeing the spectrum of good to bad as a problematic oversimplification running throughout modern ethics, Frankfurt hopes to overcome this dynamic by creating a theory that encompasses the entire spectrum. In his system, care and importance are tightly

linked. Frankfurt appears to have as driving motivation the desire to rid morality of the axis of good and evil.

The metaphysical concept of care is born in effect in the diagnostic of a lack in the familiar conceptual repertory, with respect to which moral philosophy attempted to justify the opposing objective of good and bad, making of this comparison the principle recourse of the definition of a human and the characterization of the normative good and responsible life. But this repeated attempt in the history of philosophy has simply failed, not in a contingent way, but due to moral and rationalist presuppositions that were completely in discrepancy with real human lives as they are concretely lived, in its diverse forms. [1]

I don't have space to do justice to Thomas Scanlon's substantial work, *What We Owe to Each Other*. However, in keeping with the argument here, I wish only to signal that this is another example of a leading contemporary ethicist chipping away at the edifice of modernism and revealing the more complex face of ethics beneath. In this case, Scanlon delineates a new contractualist theory, based on more of the concrete details and nuances of concrete personal choices. Scanlon focuses on difficult questions of how to determine our ethical choices when we are indeed unique individuals enmeshed in very complex social networks. As such, in contrast with past contractualist ethicists, Scanlon's work reveals much finer grain of detail in the questions of interpersonal interactions in a society of the size and scale of our times.

In a sense, although I suppose that he may never refer to it in this fashion, Scanlon's theory takes a big step towards developing precisely what Carolyn Merchant called for twenty years ago, and mentioned in her article *Fish First!.* I reiterate, "We might come back to the notion that Barbara Leibhardt-Wester proposed in her comparison of native and European Americans-the idea of the 'sacred bundle.' Like the Native American sacred bundle of relationships and obligations, a partnership ethic is grounded in the notions of relation and mutual obligation."[li]

7.3.3. Ethics Literature Group III: Transdisciplinary, Complexity Thinkers on Climate Ethics and Justice

Various scholars have laid a sophisticated foundation regarding the ethics of climate change. These ethical theories have some basis in complexity theories, transdisciplinary training and interests, an applied approach, and a pragmatist's urgency. In this section, in following with the past two sections, I will discuss the work and approach of a few leading scholars.

For the most part, these scholars succeeded in synthesizing much of the best ideas of the last eight sets of ethics. In writing about the particular and striking case of climate change, they began with solid comprehensive factual understanding of the subject, explored and developed many relevant quantitative criteria and indicators, and brought together numerous different ethical principles in deciphering the best approach. To give a full sense of their account, therefore, I will first take a step back and give an overview of what we have learned about ethics with respect to the very particular case of climate change.

7.3.3.1. Criteria for the Ethics of Climate Change

With regards to climate change, various criteria are central to ethical debates. There are three major criteria, all framed with regard to known risks, with estimates being placed on what levels of human impact that would likely prevent runaway catastrophic change.

The ***first criterion*** is *the permissible rate of carbon tons emitted per year per person.* The U.S. level is currently seven tons per person per year, while the average of Western societies is more like five. Suggested goalposts include 3 tons, to as low as 1/3 a ton. The ***second criterion*** employed is *the total degree of average global temperature increase.* From 1970 until about 2000, the global average was about 8/10 of a degree. However, from 1990 and especially since 2000, that level has been accelerating. Of course, change has been less at the equators and much greater at the poles, greatly exacerbating feedback patterns. At the North Pole since 1970 there has been over four degrees of warming. The IPCC warns of a five to seven degree average global warming over the 21st century. Unfortunately, in the last ten years the average global change has risen sharply. So it is looking increasingly difficult to pull back to stay under two degrees. Two degrees, however, is precisely what many experts feel would be the only reasonable way to reduce the likelihood of runaway catastrophic change.

Finally, the ***third criterion***, is *the measure of climate change in total carbon emissions in parts per million of the atmosphere.* All the statistics I will mention in this paragraph are taken from the organization Global Carbon Project.[lii] In 1751 the pre-industrial background quantity of greenhouse gases in the atmosphere was 280 ppm. Between 1970 and 1979 the world carbon output increased by 1.3 ppm per year. Between 1980 and 1999 it was just over 1.5 ppm per year. From 2000 to 2007 world carbon output increased by 2.0 ppm per year, and in the last two years it has increased still farther by 2.2 ppm per year. By the time of the 2007 IPCC report, the total was > 380 ppm. While some mainstream sources now call for stabilization at 450 ppm, best estimates seem to indicate that it is actually necessary to stay under 350 ppm or perhaps lower to prevent runaway catastrophic change.

These estimates have changed very rapidly. When Nicolas Stern employed his largely classical economic formulae to the questions of climate policy in 2007 he called for retaining emissions below 450 ppm. A rapid backlash from scientists and scholars using a more comprehensive complexity worldview persuaded Stern that he was wrong. When this author pressured one of Stern's colleagues presenting on the Stern report at Berkeley University, regarding the inadequate rationale behind the 450 estimate, she was told, "I know. We have been getting an enormous amount of complaints that we did not look at the most significant aspects of the science, including the issue of feedbacks. We know that we need to readjust our estimates. In April 2008, Stern officially recanted, admitted his failure, and corrected his estimate to 350 ppm.

Analyzing whether the basis of this change from 450 ppm. to 350 ppm. was scientific data or ethical concerns, I posit it is impossible to separate the two. However, the world's leading scientists have now come to consensus. We do not need more science; what we need is ethics, will-power, and political action. According to the best estimates, we have already gone beyond the major tipping point separating safe from dangerous degrees of climate change. The criteria for this evaluation are listed as follows.

Among these leading scientists, the debate has shifted. Old questions were: Is climate change real? Is it driven by human impact? Is it happening already? Due to feedbacks and rapid acceleration, just a few years later we are asking entirely different questions, such as: Exactly when did we pass over the threshold from human-induced climate change to dangerous anthropogenic climate change? How much can we evaluate about the nature and trajectory of accelerating, interacting feedbacks? Will there be a moment of abrupt climate change in the near future? If so, from what source – a 'singular' dramatic event such as a sudden methane release from the permafrost or from the ocean; an equatorial tipping point leading to a sudden collapse of the Amazon Rainforest; or the halting of the ocean's Thermohaline

Circulation Belt? Or would it be simply a combination of more anodyne individual feedbacks creating a vicious, biospheric, feedback snowball effect?

Scientists do not agree precisely on which criteria to use for political goals. Yet, most would say that their uncertainties about such figures have little to do with science and more to do with politics and ethics, or in some cases wishful thinking. Climatologists, geologists, and other leading scientists agree that we have had for years already sufficient science to merit a major shift in policy. In fact, many would argue, as Jonas' discussion of the greenhouse effect in 1979 demonstrated, that we had sufficiently compelling science to merit a substantial shift in Western societies thirty years ago. Today, in 2009, there is no longer any scientific uncertainty. What is needed is primarily not more science, but rapid advances in ethical theory and political action.

7.3.3.2. Ethical Issues in Climate Change

If complexity theories help stimulate advances in ethics, ethics also seems to advance complexity theories. As scholars confront the particular challenges of climate change, many important aspects of ethics in highly complex socio-ecological systems are being brought to light. Climate change and ethics are in a kind of mutual dialectic, a co-production.

At the same time, an overview of the literature on ethics in climate change, and of the arguments put forth by governments and other large parties in international negotiations, reveals tensions that correlate rather closely with the tensions between modernistic and complexity thinking. In other words, as long as the utility of complexity remains obscured and marginalized, the world is vulnerable to the potential repetition of the reach of modernistic assumptions, or lack of more realistic ones. I will outline a few examples of this as I proceed. While I have conducted a fairly extensive review, I have turned extensively to the work of Paul Baer, who, while not an ethicist by academic training is nonetheless one of the foremost scholars of the ethics of climate change.

The recognition that fossil fuels are putting planetary systems in danger has been acknowledged in various ***framings of climate ethics***. One is the issue of ***burden sharing***. This view frames the reduction of fossil fuel use as a burden that should be shared in some ethical manner. Those who rely on a strictly burden-sharing theory are likely to fall prey to obscuring the significance of historical issues such as responsibility for greater or lesser creation of and benefit of the climate problem, the history of colonialism, and other global justice issues.

A second framing of climate ethics is that of ***resource sharing***. Such a view must take into consideration tricky issues in common pool resource and tragedy of the commons issues. Moreover, unknowns such as the invention of new energy technologies and potentially rapid widespread uptake of these may greatly alter the course of future climate change, at least in some respects.

For these reasons and others, many have turned to the predominant climate ethics framework, ***allocation justice,*** what in the field of ethics is referred to as distributive justice. Peter Singer uses the concept of an atmospheric pie; everybody should get a fair share of the atmospheric pie. In this view, parties that have exceeded their share have obligations to parties that will therefore get less. This framing is open enough to incorporate various items for allocation, including fossil fuel use, emissions rights, costs, technologies, and trading rights, environmental rights, and the like. On the face of it, just allocation would seem to allow for strong ethical principles in key practical areas of climate change adaptation and mitigation. Analysts should be able to derive some fair quantities in the categories of allocating rights for amounts of

emissions, amounts of financial and technical assistance, rights for emissions trading schemes, and the like.

However, the flip side of this openness is that proposals that are very much at odds with each other co-exist under the same label of allocation justice. For instance, during the Bush Era of the last eight years, U.S. negotiators suggested that emissions rights should be allocated with respect to a country's capacity to produce; that emissions rights should be proportional to GDP. The irony in this proposition makes it grotesque. Similarly, first world negotiators, mostly in the U.S., have proposed that wealthy countries be granted grandfathered allocation rights, an elitist proposition that those who were lucky enough to benefit from the carbon intensive technologies for the last fifty years should be doubly rewarded by maintaining a better standard of living even while underdeveloped countries suffer through the brunt of the worst consequences of climate change in the next few decades.

In contrast, allocation theories may also promote concepts such as ***per capita emission rights***, which allow for much more equity in standard of living. Some theories go beyond this, arguing not only for per person allocation rights, but for also factoring in a principle of historical accountability, and even future accountability. Under such theories, wealthier countries that have more luxurious carbon-intensive histories would be required to pay more still as retribution based on the present, past and future. In the present, many wealthier countries continue to have radically better standard of living than in poorer countries, their past activities are much greater contributors to current climate change, and finally, future scenarios indicate that poor countries will be hit much harder by the worst climate catastrophes, and wealthier countries may even benefit more, as in the case of the potential for increased agricultural yield in Canada and Russia.

To summarize, it would seem that a start for climate ethics would include some *allocation justice system* based in some *equitable per capita rights*, incorporating issues of *historical responsibility* and *considerations for creating more equitable societies* as a basis for *more sustainable societies in the future*. How this would be worked out in actuality is a quite complicated proposition.

7.3.3.3. The Greenhouse Development Rights Framework

To reiterate, Paul Baer stated that a start for climate ethics would include an allocation justice system based in equitable per capita rights, incorporating issues of historical responsibility and considerations for creating more equitable societies as a basis for more sustainable societies in the future. In a subsequent report, Baer and his colleagues did just that: *The Greenhouse Development Rights Framework: The right to develop in a climate constrained world.*[liii] The four coauthors are Paul Baer and Tom Anasthasiou of EcoEquity, based in Berkeley, California, and Sivan Kartha and Eric Kemp-Benedict of the Stockholm Environment Institute in Sweden, all four leaders on the frontier of climate theory and action.[liv] They first published the report in 2007, and they issued an updated version in 2008.

The basic principle throughout is to build up principles that, we could all agree upon and that permit basic human rights and that extend humanitarian principles to everybody, while fairly distributing the costs and burdens of rapid deceleration of GHG emissions. The authors devise a few tools for this. First, they develop an indicator that captures both responsibility and capacity with respect to emissions reductions. Inevitably, based on the glaring facts of the last two decades of international discussions, this is based on achieving fair and feasible partnership between Northern and Southern nations.

> This paper argues that an emergency climate stabilization program is needed, that such a program is only possible if the international effort-sharing impasse is decisively broken, and that this impasse arises from a severe, but nevertheless surmountable, conflict between the climate crisis and the development crisis. It argues, further, that the best way to break the international climate impasse is, perhaps counter-intuitively, by expanding the climate protection agenda to include the protection of developmental equity, which can and should be specified in terms of the UNFCCC's notion of "common but differentiated responsibilities and respective capabilities." The Greenhouse Development Rights (GDRs) framework does exactly this, in the context of an extremely ambitious emission reduction pathways designed to hold global warming below 2° C. It defines national responsibility and capacity, and assesses national climate obligations, in a manner that relieves from the costs and constraints of the climate crisis those individuals who are still striving for a decent standard of welfare – represented by a

> "development threshold" defined at an income level modestly above a global poverty line. Moreover, it takes intra-national income disparities formally into account, stepping beyond the usual practice of relying on national per-capita averages, which fail to capture either the true depth of a country's developmental need or the actual extent of its wealth. By so doing, it provides us with a reference framework by which we can coherently estimate comparability of effort, across nations and regions and across disparate effort-sharing regimes. The GDRs framework, in other words, is designed to demonstrate how a global emergency mobilization to stabilize the climate can be pursued while, with equal deliberateness, safeguarding the right of all people to reach a dignified level of sustainable human development. We present in this paper an exposition of the GDRs framework and indicative quantification of its implications.[lv]

The second edition made major changes, both to adjust to greater complexity in data, and to mimic greater complexity in their methodology. Specifically, while the first report modeled two IPCC SRES scenarios (AIB and BI), using AIB as the "business as usual case" and contrasting it with B1 to estimate the size of the global "no-regrets" potential – the emissions reductions that could be made for free or in fact, even profitably. The SRES scenarios were overtaken by events, rendered obsolete by rapid climate change in 2007. So the authors adopted the International Energy Agency's 2007 World Energy Outlook reference projections as their new business as usual case. They estimated the no-regrets potential against the influential new McKinsey estimate, also based on the 2007 World Energy Outlook reference case.[lvi]

Moreover, they found a way to render their model dynamic. Rather than calculating the key metric, the Responsibility and Capacity Indicator (RCI) on the basis of current national data (GDP, population, cumulative emissions), it calculates them on the basis of projections of these indicators, projections that are derived, from the 2007 World Energy Outlook. While the World Energy Outlook is also imperfect, it has served to give them a more accurate analysis in light of major recent change, enabling the authors to reveal, as they say, "some intriguing and politically challenging results."[lvii] But while the results are certainly challenging, they present a path forward that is reasonably realistic, feasible, and fair.

7.4. Climate Ethics and the Generalized Complexity Framework

Following upon my close examination of the Greenhouse Development Rights Framework Report, Second Edition (GDR), I list here some of the Generalized Complexity Framework elements that seem to produce the best basis of climate ethics. These principles are found throughout all of the ethical theories I have examined in this chapter, which interweave in myriad fascinating ways. Nonetheless, what appears to be most essential is that the Generalized Complexity Framework is correlated with the major elements of the GDR paper.

It is interesting to note that nowhere in the GDR paper do the four authors discuss complex systems per se, complex fundamentals per se, or complexity science or complexity thinking. Yet, the report is completely consistent with the description of climate change as discussed. In fact, the report hinges on the very interpretation I outlined in Chapter Six, on the significance of positive feedbacks, thresholds and the probability of abrupt and catastrophic climate change. The authors assume catastrophic climate change as the basis of all of their following calculations and analysis.

This seems to reinforce the view that complexity fundamentals in themselves are only consequential insofar as they are consequential to a particular study system, a particular issue at hand. Nonetheless, if our world is indeed comprised of complex systems, as the scholarship described in Chapters Two through Six seem to indicate, and if climate change seems to hinge not on a mechanical worldview but on the mechanisms of the complex worldview, then it seems that the preservation and development of the GCF is a fruitful task in the accompaniment and perhaps guidance of the further advancement of climate ethics and policy.

I have argued that each of the above climate ethics and environmental ethics literatures has taken complexity fundamentals into account to some degree. And I have organized the chapter to show a progression of lesser to greater incorporation of these complexity fundamentals to ethical theories. Time will tell how well these climate ethics will hold up. Insofar as they fail, I rather suspect it will not be the fault of the theoretical basis. Even if ethics is limited, as presented by scholars like Paul Baer and his colleagues, it seems quite persuasive and sufficient to the task. At the end of the day, it is not the limits to science and ethics that endanger us, but our ignorance or denial of them. Many indigenous groups did survive despite their minimal knowledge of Western science and technology. What limits us currently seems to be social, psychological and political imagination and will power.

What follows gives a list of what seem to be critical complexity fundamentals that would be necessarily compatible to any climate ethics, as they are compatible to

the Greenhouse Development Rights Framework. For this list, I refer primarily to the large-scale, the planet Earth:

- Phase state – we have one (biospheric phase state); this was obscured by modernist rationality and perspectives, which held that the planet's ecosystems existed in a quasi-permanent equilibrium
- Connectivity – when we add together social connectivity and environmental connectivity, the degree of connectivity increases dramatically, also increasing degree of risk of large-scale regime change
- Network causality – as demonstrated in Chapter Seven, network causality plays a major role in assessing the world's situation, and is thus much more significant than previously recognized
- Unintended consequences, irreversibility, and nonrenewability
- Vulnerability – much greater than it was determined to be through the reassuring modernist rationality and thus perspective
- Robustness and resilience – also much greater than previously acknowledged, however also mitigated by rising thresholds of global change
- Thresholds, tipping points and abrupt climate change – as demonstrated in Chapter Seven, thresholds are play a major role in the development of climate change, and they define the advent of systems collapse
- Observers and contexts; scale and grain – evidently, if we see the context of climate change in its full complexity, this provides a radically different picture than seeing climate change solely with the anachronistic lenses of early modernism
- Openness of boundaries – between these various coevolving sectors
- Coevolution – environments and the various sectors of human societies
- Models, narratives and other methods – Given all of the above, evidently, our view of models changes considerably; the role of empirical, mathematical modeling is of course quite significant, but it cedes much of its imperial power back to other areas of knowledge, primarily to methods like the narrative, and the development of ethics and wisdom.[lviii]

Peering into the near future in this light, it becomes clearer that our individual daily choices carry a greater and greater global impact. If we have already passed the tipping point of catastrophic climate change, our choices are much diminished. Regardless, our only present choice is to proceed as if we have unlimited power to bring our policies and our lifestyles into line with the realities of climate change. If we no longer have the choice between 100% of the biodiversity we had in 1968 or 50% of it, nonetheless perhaps today we still have a choice between chaos and community.

Further, it seems that we are approaching a rather striking kind of bifurcation event! The turmoil and degradation surrounding climate change may lead citizen movements and world leaders to a real breaking point in the striking choice between a world primarily at war or one primarily at peace, between ruthless profiteering and individualism or advancing cosmopolitanism, between dictatorships or collaborations, between ongoing neoliberal usurpation or cooperative, green movements, between a Hobbseian world and a Rawlsian or Singerien one. All of these trends seem to continue to develop and flourish. Until what point?

7.4.1. The Generalized Complexity Framework: Objection and Reply

A major weakness of the approaches that stem from incorporation of complexity fundamentals, at first glance, is that they appear to be, not surprisingly, too complex, too difficult, and too impracticable. I argue, however, that rather than reject the GCF for this reason, it becomes all the more important to embrace and explore it, at least as a reference framework.

We have behind us two thousand years of recorded knowledge, massive indigenous knowledge about sustainability, and various resources for developing ethics and policy in the face of climate change. The GCF does not diminish or negate the invaluable knowledge base we already have. Ultimately, it seems that the most rational way forward is by embracing this, as well as all of the implications it brings about. These implications include a renewed validation and appreciation of various alternative perspectives on social and environmental management and lifestyles, including for instance some of the indigenous and early modern lifestyles and practices that were more sustainable.

Academia has seen a great movement in recent years of scholars acknowledging that humanity seems to be headed over a cliff, recognizing that science, technology and economic strength alone are not only insufficient for saving humanity, but to a degree, part of the problem itself. This has led to a movement of

academics interested in Wisdom, with prestigious grants and fancy conferences designed to steer a generation of scholars towards more fruitful thinking about how to steer away from the cliff.

My last argument here is that the perspective and tools I have presented and defended find a home in this movement towards advancing our lifestyles, social systems, environmental management, and ways of thinking, by infusing them with greater wisdom. Complexity may be a part, perhaps a central part, of this new path towards wisdom.

7.5. Is and Ought

In fact, I argue that complexity theories provide the means to refute Hume's argument for the inherent *separability of is and ought* by explicating the inherent *inseparability of science and ethics* in human societies and environments. What this implies for the treatment of complex systems is the intrinsic necessity of ethics to the project of human knowledge generally, including science and technology. It indicates the positive and negative, presence or absence, of proactive or reactive, ethical theories. The complexity worldview conjoins acknowledgement of great vulnerability and rapid change in social and natural systems, with that of the agency and responsibility of humans for their influential activities.

Thus by the simple fact of revealing the inherent nature of resilience and vulnerability in human and environmental systems, the GCF reveals that when science is proven to hit limits, the best contemporary rationalities point towards the development of ethics to infuse policy and management. The science, technology and policy equation that we have been implicitly following for generations – science, technology, policy, implementation – shifts to science, ethics, technology, ethics, policy, ethics, implementation, ethics. At every step there is uncertain, inability to fully calculate, fully control, fully understand and fully transform, and thus at each step our studies and actions should be embedded in ethical thought.

But what do we do when ethics also hits upon limits? It seems that the project we are setting out upon, a bit late in the game, is to develop the kinds of self-organizing properties at the global scale that have only previously been developed in evolutionary time, at the scale of the individual living organism, the clan, or the ecological system. What we need is biospheric level self-organizing properties. And this would require many radical shifts in human activities, such as the end of intra-planetary warfare.

7.6. Solutions and Approaches

Complexity fundamental	Ethics and Policy approaches
Interconnectedness	Symbiotic solutions, virtuous circles, win-win-win, problematization
Network causality	Network analysis
Uncertainty, unknowability	Probability of harm, weighing of evidence,
Dynamic, changing, evolving	Iterative, uncertainty expected
Hierarchical system structures	Multi-scalar and multi-grain analyses; transdisciplinary framework analysis at least iteratively
Observer in the system; significance of context	Transdisciplinary framework analysis at least iteratively
Complex dynamic systems	Generalized Complexity Framework good basis for developing ethics and policy
Pluralistic inclusion and approaches	Broad-based ethics and policy frameworks based in GCF
Unintended consequences	Precautionary Principle
Nonlinear change, thresholds, tipping points	Inclusion of low probability, high impact events,
Resilience, vulnerability, sustainability, potential collapse	GCF also a good bases for developing ideas in the realm of wisdom and related broad-based perspectives

Table7.6. Complexity Fundamentals and their Implications for Ethics and Policy Approaches

Here I present some corollaries between the complexity fundamentals and good policy principles. While this table is my concoction, it is supported by numerous scholars, e.g. the transdisciplinary groups discussed in Chapter Six.[lix] Looking at the right column, one rational reaction may be, this is far too complex. That may be, but it seems to be the best that we have for the moment. As highlighted in the *Greenhouse Development Rights Framework* and in comments by both Carolyn Merchant and Catherine Larrere, inclusivity, pluralism, recognition of interconnectedness and the kinds of dialogue, and partnership that this entail, appear to be central to any workable ethics of climate change. As Catherine Larrere said,

> The choice is not between man and nature, but between a uniform world modeled solely on economic interests, and a diverse world that leaves space for the plurality of human aspirations, lifestyles and approaches to be seen

> as a plurality of living beings. From this point of view, ecocentric ethics, which has the ambition of integrating human activities within the natural environment, can provide models of action. [lx]

This viewpoint about complexity, pluralism and participatory structures of democracy, ethics and politics, has moved in just a decade or so from largely being berated and marginalized, to perhaps the consensus view, not only amongst ethicists and most social and political theorists, but also amongst scientists, policymakers, the IPCC, and other organizations most implicated in climate change. Harvard science studies professor Sheila Jasanoff defends it in the field of science and technology studies; C.S. Holling and other leading ecological theorists support it; F. Stuart (Terry) Chapin, James Hansen, and other leading climate scientists argue for it; and ethicists and philosophers increasingly rally around these views, in groups ranging from the heart of ivory tower academia to the most marginalized. Thus even while the terms complexity, complexity theories, complexity thinking have remained considerably marginalized and misunderstood, the details and implications of complexity theories have had an immense influence on academia, policy circles, and an array of social institutions.

This position however, which recognizes complexity and supports pluralistic views and participation, is very challenging. Acknowledging complexity and complexification seems to require acknowledging that there are limits to science. Upon further examination, it also reveals that there are limits to ethics! Indeed, the more we examine complexity, the more it seems that every realm of human knowledge and understanding is riddled with uncertainty, unknowability, and thus each one has limits. It is ironic that just after we run up against the limits of science to help us in issues involving great uncertainty and unknowability, we turn to ethics only to discover that ethics has limits as well.

However, this does not dilute the power of ethics. A curious kind of see-sawing takes place, in which at first it seems that science cedes power to ethics, and then it seems that ethics cedes power back to science, as we alternately run up against the limits in either system. In the end, a new vision is emerging in which science is revalidated, but with serious caveats as to a new framing in which the limits of science may militate against its endless expansion. In turn, just as we see that ethics does have limits, we also reaffirm its power, and its essential relationship to science and technology. In many situations, especially highly complex socio-ecological situations, despite its limits, ethics nonetheless takes on new power and validation. In the case of highly uncertain and unknowable variables, ethics is essential.

7.7. Beyond Ethics: Contemporary Rationalities and Climate Action

> We are now faced with the fact that tomorrow is today. In this unfolding conundrum of life and history there is such a thing as being too late. Procrastination is still the thief of time. Life often leaves us bear, naked and dejected, with lost opportunity. The tide in the affairs of humanity does not remain at the flood, it ebbs. We may cry out desperately for time to pause in her passage, but time is deaf to every plea and rushes on. Over the bleached bones and jumbled residues of numerous civilizations are written the pathetic words, "too late." We still have a choice today, nonviolent coexistence or violent coannihilation. This may well be humankind's last chance to choose between chaos and community.
> Dr. Martin Luther King, Jr., February 1968[lxi]

Only a few years ago the oil magnates' disinformation stranglehold still held most Americans in the grips of total climate denial or worse, climate skepticism. As many observers wryly observed, up until about July 2006, most Americans were either ignorant – denying or skeptical of anthropogenic climate change – and then from August 2006 on (often the same people) were sadly resolved that climate change is so monumental and so advanced a problem, that it is too late to do anything about it. Quite evidently, as every action and inaction has ethical impact, it doesn't matter where you are on a threshold of system change; there is nothing to do but to act.

Today, just three years later, every leading climate scientist, politician and activist calls climate change primarily to be an issue of values, justice, and ethics. It is necessary and important to understand climate ethics, as it relates to science, and as it evolves. However, I would argue that a grasp of the adequate ethics and a thorough reasoning based upon them, leads to the conclusion that climate change truly is no longer an ethical issue, because the ethics of climate change are so clear. At this point, not only is the science of climate change clear enough. The ethics of climate change has become clear enough as well. What is left is merely the need for goodwill, generosity, courage, and leadership, otherwise known as political will.

In actual fact, the shift from the neo-modernist analyses to fuller perspectives such as the eight groups and the transdisciplinary complexity analyses, leads to a striking fact: the climate situation is advanced enough that actually, what we need to discern through ethical analyses of climate change is already relatively clear, if only because the situation is so advanced that the need for action tends to trump most any call for more precision about particularities! But while ethical theory may seem relatively clear, there is abundant need for ethical judgments in supporting, pursuing,

and assessing the results of these theories. We need ethics in pluralist collaboration and in policy analysis.

Thus, my argument in this chapter with respect to climate ethics ends up mirroring rather closely my argument with respect to the problem of enormous intricacies in network causality amongst positive feedbacks. In both cases, we must look at the current processes – positive feedbacks and serious social and environmental injustices respectively – not with the modernistic perspective that teaches us to isolate, analyze and understand, but rather with the complexity perspective that teaches us to focus on the complex ensemble of whole system dynamics *as much as possible*. In the case of climate feedbacks and thresholds, I argued that it is so highly complex that the best research focus is not necessarily on thoroughly understanding every last positive feedback. It may well be that a more productive line of research would be to focus on incorporating issues like positive feedbacks within the context of the GCF, into policy models.

Similarly, in the case of climate ethics, we may have a tendency to frame our analyses in the modernist fashion, saying that we need to isolate, analyze, and understand every nuance of every ethical question so that – and there is the false logical leap – knowing all of these particularities will somehow enable us to address all of them in their ensemble and *on the global scale*. Rather, emergence and self-organization teach us that we need to be paying attention to how processes are operating at the larger scales. The utilitarians can hardly figure out which trolley switch to pull, or how many Indians it may be morally correct to kill in order to save other Indians. It seems less likely still that from knowing some thousands or millions or infinity of such questions together, this will best prepare us for acting on climate change. Once again, it seems that the power of complexity theories lies in the greater framework and implications that it engenders more than any particular aspects of the framework. In the very act of reaching obstacles in the capacity to advance knowledge of whole systems, the GCF gains credence and power.

Thus, of two lessons one. Perhaps complexity theories can sometimes simplify. In much the same way that the endless search for precision with respect to climate feedbacks is unnecessary (and what we really need to do is to acknowledge that the probability of a catastrophic event is high enough that deciphering which factor is driving the escalation of positive feedbacks driving climate change is no longer significant), in much the same way, an appropriate approach to climate ethics is not to complexify it – not to isolate, analyze and explore every detail. Rather, complexity theories militate for recognition that the GCF appears to provide some antidotes to overly modernistic analyses that let us get so far and so deep into climate change already.

Applying the GCF to the various climate ethics questions raised earlier in this chapter leads to the following conclusion. Because the probability of a catastrophic effect of climate change is significant enough, the precise details of ethical arguments become a moot point, because at any rate sufficient advances in all realms of climate change action – prevention, mitigation and adaptation – require such extensive actions, that it renders most of the ethical arguments one could have moot.

From about 1996 until the present, the United States has been largely in the grips of the massive campaign funded by the oil industry to confuse and obfuscate necessary climate policy. Substantial data is now available on the actors, nature and magnitude of this campaign.

> A new report from the Union of Concerned Scientists offers the most comprehensive documentation to date of how ExxonMobil has adopted the tobacco industry's disinformation tactics, as well as some of the same organizations and personnel, to cloud the scientific understanding of climate change and delay action on the issue. According to the report, ExxonMobil has funneled nearly $16 million between 1998 and 2005 to a network of 43 advocacy organizations that seek to confuse the public on global warming science.
>
> "ExxonMobil has manufactured uncertainty about the human causes of global warming just as tobacco companies denied their product caused lung cancer," said Alden Meyer, the Union of Concerned Scientists' Director of Strategy & Policy. "A modest but effective investment has allowed the oil giant to fuel doubt about global warming to delay government…."

The logical next step in this progression is a wave of repressive obfuscation from a host of elites who believe that they have more to lose with strong climate policy. This could take the form of endless debates about climate ethics in an attempt to create confusion about the field of climate ethics, which, in fact, is becoming quite clear. In other words, the next logical anti climate policy campaign would conflate the clarity of basic climate ethics theory with the very challenging task of its ethical implementation.

However, we could accept the lesson derived from analyzing climate change under the complexity microscope. That lesson is that such considerable policy change is needed in order to sufficiently reduce the probability of catastrophic climate change, that there is actually no need to perpetuate ethical debates. While climate ethicists have developed the field with the best of intentions, it could rather quickly

be taken up, manipulated, and misappropriated by elites refusing to give up their fossil fuel toys.

The GCF already reveals that apparently massive emissions reductions must be made in such a short time span, that we have little if any window of opportunity for racially shifting gears to a sharp emission reductions pathway. There is every reason to put major funding into alternative renewable energy generation systems of many kinds, in the hopes that some of these new technologies would be so wildly successful as to permit a new era of luxury energy uses. But we are not there yet. And the issues of time lags, coevolving feedbacks, coevolving multiple stressors on increasingly fragile social and environmental systems – both of which are rendering ecosystems increasingly fragile and vulnerable in this era of multiple global crises – reminds us that stalling for time until new technologies exist is not an option.

This requires a much more serious engagement with some of the starker issues that ethicists have raised. This would include Henry Shue's early call for ethical principle based on the significant distinctions between the most ***essential emissions***, *emissions used for maintenance activities, such as emissions for cooking, clothes, housing, and the basic local transportation,* and ***luxury emissions***, *emissions for the myriad extravagant, luxury activities of the wealthy* Still further distinctions are needed rapidly. The category of luxury emissions is far too broad, spanning many useful distinctions to be made. Which areas of scientific research may actually be either extraneous or counterproductive? What degree of non-necessary travel may be judged beneficial, and how could this be weighted with respect to deep and challenging emissions cuts? Are there activities that may be deemed to be socially unhealthy, which could militate for extra penalization and disincentives for certain kinds of luxury emissions? At what point along the catastrophic road ahead might citizens and leaders put prohibitions on the production of luxury emissions such as the epitome of all irrationalities, the massive weapons industry? On what kinds of principles would we decide which scientific research, which educational courses, and such would be continued, if cuts had to be made?

7.8. Conclusion

I set out to describe the implications of complexity theories for ethics and policy. I explored three categories of climate ethics and justice literature, to check it against the complexity literature and the GC framework. What I discovered was that the most effective, influential ethics and justice literature pertinent to climate change includes and I would say hinges on the complexity fundamentals. While Axes II and III of the GCF are particularly apparent in ethical questions around climate change, the whole of the GCF is taken up in the ethics literature.

I have said that complexity ethics is not new – as it can draw from many aspects of many past ethical systems, not the least of which are the many indigenous ethical systems developed over millennia. At the same time, it is new insofar as it clarifies the major theoretical framework of transdisciplinary complexity that provides a useful structure for so many socio-ecological issues like climate change, and it helps to acknowledge and articulate a more effective pluralist basis for ethics.

In the first set of literature, which was the preliminary mainstream collection of climate ethics, starting in about 1995, many of the essential issues of climate ethics that were established quickly remain amongst the most significant today.

Next, I turned back to an examination of the generalized complexity framework as it is highlighted in environmental ethics. I derived my own list of the GCF elements it seems essential to include in any climate ethics project.

This led me to a daring final hypothesis about the capacity of complexity theories as I have presented them throughout the dissertation to not only recalibrate the appropriate relationship between science and ethics, but ultimately perhaps overcome the long-standing divide in moral philosophy between is and ought. The complexity worldview, I argued, conjoins the acknowledgement of great social and environmental vulnerability and rapid change, with that of substantial agency and responsibility that humans possess.

I drew upon the complexity fundamentals to suggest a major policy approach stemming from each. Complexity theories, and in their ensemble, the generalized complexity framework, provide a unique opportunity to synthesize and rearticulate many large and divergent bodies of literature that are all pointing ultimately to the same questions of vulnerability and resilience. Drawing from this, I hypothesize about what complexity reveals about the relationship of science and ethics, pointing out that one of the things complexity demonstrates is the limits in each of these realms.

Finally, I examined the great call for climate ethics. I argued that while we must continue applied approaches, as leading scholars like Paul Baer have done, nonetheless we may not really need armies of climate ethicists. To a certain extent,

just as the science is in, so the ethics is in. What is left is the imagination, optimism, motivation and political will to put climate ethics into action.

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Conclusion

Complexity is a fascinating subject, but more than that, a useful one. I set out to explore what complexity studies are, and what, if any, utility they have. I have demonstrated several things. One, complexity studies have considerable transdisciplinary breadth. Two, they have utility both in terms of providing fuller understanding of various aspects of our reality – dynamics, networks, hierarchies, emergence, and self-organizing properties – and also in providing an essential general overview of knowledge, a framework that serves as both a reference point and a rich theoretical lens.

In Part I, I set out to address the following questions: What is the nature of complexity science? What is the nature of complexity in the quantitative social sciences, and again in the realm of non-quantitative (qualitative or philosophical) social theory? What are transdisciplinary complexity theories? In other words, I examined complexity theories as a transdisciplinary subject, including one major debate about complexity in the philosophy of science.

In order to examine these diverse areas effectively, it seemed necessary to first address the question of defining or articulating complexity as thoroughly as possible, as I did in Chapter Two. In attempting to articulate what complexity means in a way that incorporates complexity in the very different disciplines it spans, I created a definitional framework, which, since it encompasses the whole transdisciplinary spectrum of complexity theories, I call the Generalized Complexity Framework (GCF), to cohere with Edgar Morin's system and his term, generalized.

Complexity Ontological Fundamentals I (COF I)	• Complex adaptive systems, complex dynamic systems • Nonlinearity, chaos theory, and power laws • Network • Feedback • Hierarchy • Emergence • Self-organization
Complexity Ontological Fundamentals II (COF II)	• Equilibrium, phase state, attractor, edge of chaos • Connectivity, diversity • Network causality, interrelatedness • Unintended consequences, irreversibility & nonrenewability • Vulnerability, risk • Robustness, resilience, & sustainability • Threshold, tipping point, abrupt change • Collapse, catastrophe
Complexity Epistemological Fundamentals (CEF)	• Observer; context • System boundaries; openness • Scale • Grain • Co-evolution, co-production, co-evolving landscapes • Models, narratives, and other methods
Axis I: Natural sciences, and social sciences	Classical versus complexity sciences/ theories (Morin 1974; Merchant 1980; Dupré 1992; Norgaard 1994) • Mechanism, order, vs. organization • Atomism vs. network • Reductionism vs. synthesis • Essentialism vs. polyvalence, emergence • Universalism vs. pluralism, disunity • Determinism vs. intentionality, emergence
Axis II: Social theory, human sciences, and philosophy	• Compressibility vs. incompressibility; decomposability vs. nondecomposability; reducibility vs. irreducibility • Production vs. emergence; Complicatedness vs. complex • Thinness vs. thickness • Externalist vs. internalist • Uncertainty vs. unknowability
Axis III: Transdisciplinary theories and frameworks	• Transdisciplinarity • Systems typology (J-C Lugan 1983) • Reductive, emergent, holistic • Restrained versus generalized (Morin 2006)

Table 8.1. Generalized Complexity Framework – GFC (Duplicate of Table 2.1.)

In a sense, it may appear that the GCF merely assembles all of the diverse definitions of complexity theories into one place, one page. However, throughout the dissertation I show that the GCF is valuable on at least two scores. First, it helps us to address phenomena that are essentially transdisciplinary, enough that disciplinary lenses do not succeed in thoroughly addressing study questions. This is the case with climate change, where science, ethics, political will, and wisdom all seem to be necessary ingredients to affect solutions.

Second, the GCF serves as a useful and also necessary conceptual tool for the difficult philosophical questions that arise from any attempt to advance a more sophisticated explanation of transdisciplinary complexity. This includes questions such as the nature of the limited or unlimited nature of science and knowledge. It would also be effective in addressing the philosophy of science debate regarding the unity or disunity of science and knowledge.

In Chapters Three through Six, I attempted to build towards a comprehensive explanation of complexity theories by way of disciplinary explanations. Beginning with the natural sciences, I show how in fact, scientists such as John Harte who have decried the labeling of complexity science as a 'new science' are quite correct. I think that the most essential aspect of a knowledge practice is its methodology. In any case, the methodology of complexity science does not differ from that of standard science. Rather, what is novel about complexity science is its subject matter, focusing on issues of dynamic, adaptive, emergent and self-organizing processes that were in truth largely eschewed by earlier generations of natural scientists throughout the last three centuries.

Nonetheless, complexity sciences reveal quite a stunning perspective on the way the natural world works. Through the many examples of advances in complexity sciences given in Chapter Three, I show how each of these has intrinsic value, many have significant applied value, for issues that affect us today. To reiterate but a few examples here, 1) network studies in the spheres of the material, ecological, social and ideas, illuminate the many challenges of globalization and our planetary interconnectedness in myriad useful ways, 2) hierarchical structures provide an invaluable reductionist framework within which to both create more awareness of the prominent issue of the observer in the system and also clarify how to carve out and frame scientific issues in light of the issue of the point of observation in the system, and 3) issues such as emergence and self-organization similarly alert scientists working in various realms of natural science to anticipate and integrate these significant aspects of all the majority of phenomena, including living systems, social dynamics, languages, ideas, and more. A longer or more thoroughly researched study could go even farther in bringing to light the specific benefits of each of these areas. However, I think that the many specific contemporary examples listed in Chapter Three would be sufficient to convince even a pessimistic reader of the utility of these major complexity fundamentals.

In Chapters Four and Five I engaged in a similar analysis with respect to the utility and interest of complexity studies in the quantitative social sciences and then again the realm which I have called social theory, meaning all social science research that is non-quantitative. As I discussed, this distinction is somewhat troubled and unstable, as quantitative studies always incorporate some degree of qualitative thinking, analysis, and theory in their creation, testing and analysis. Similarly, in much of what I call social theory, data, statistics, and quantification is included to some extent, even if the emphasis is on argumentation or analysis. However, this distinction was the best I could decipher, and it seemed necessary to make some distinction, since the quantitative side falls into the category of reductionist analysis and the philosophical analysis into the category of non-reductionist analysis, and this dividing line seems to be a critical one in describing the nature of complexity as it plays out in different disciplines.

Thus, I look at various approaches to reductionist or quantitative analyses of social systems, and I argue that attempts to quantify social phenomena in a strictly reductionist fashion as in some (not all) of the more daring studies by Yaneer Bar-Yam to quantify the most highly complex aspects of human systems, fall flat. But that other studies by Bar-Yam, and much of the approach of the Santa Fe scientists to address aspects of social systems – e.g. urban studies, economic dynamics, etc. – may be much more valid and illuminating.

Finally, the usage of quantification as a tool merely intended to provide data for what are essentially philosophical studies of human systems appears to be the most fruitful approach of the use of quantification in the social sphere. Philosophical theory, however, is generally more fruitful in more highly complex issues such as social and environmental global change. Thus my conclusion is that reductionist methods of mathematical modeling are perhaps the strongest analytical element in the natural sciences and some areas of social science, whereas, philosophical interpretation and argument are the strongest analytical element in the realm of social theory.

Each sphere has its predominant method, and each of those methods has its place. Ultimately, the results of these different spheres, when studying systems and phenomena at the scale of highly complex socio-ecological systems, only produces true coherent descriptions and meaning in relationship with the other. This is because at that larger scale, the results of various kinds of methodologies must be synthesized in such a way as to coherently conjoin different kinds of information and ideas, without unnecessary distortion.

Given those distinctions, the more specific results of study in the social sciences were as follows. As in the case of the natural sciences, the complexity ontological fundamentals and epistemological fundamentals appear throughout social science studies. However, in contrast to the natural sciences, in the social sphere these fundamentals are largely, implicitly and not explicitly stated. By showing the range of ways in which in

fact these complexity fundamentals have become useful and even indispensable, despite the stealthy non-explicit nature of their development in the social sphere, I have built the argument that various changes to the approach of social scientists and theorists towards the field of complexity theories would be quite beneficial.

These proposed changes include, 1) develop and advance transdisciplinary analysis within the social sphere, at least insofar as this enables scholars of social systems to acknowledge and incorporate the GCF framework, 2) work collaboratively to develop this framework with insights from across the social systems disciplines so that it becomes as systematic or universal as possible, without becoming too systematic or universal, (in line with Einstein's dictum: simplify as much as possible, but not too much), 3) render both the GCF and work in the individual aspects of the complexity fundamentals as explicitly as possible, so as to foster understanding between myriad social system scholars. It appears that complexity fundamentals are as present in social systems as they are in natural systems, thus making that presence explicit can only be beneficial for effective development and clarification of complexity theories.

Indeed, I set out to discover the nature of complexity theories in the various realms of knowledge, and what I discovered was that it is a full and quite challenging field. As in the natural sciences, complexity fundamentals amount to but an extension in the study of social systems, towards aspects of those systems which were previously somewhat (though not entirely) eschewed by social scientists in the past two centuries, including a more systematic or patterned appearance of: dynamics, networks, hierarchies, emergence, and self-organizing processes.

To some extent, this omission was due to an obfuscation of complexity by various assumptions underlying the fabric of modernity's worldview. These include the tendency towards: reductionism, determinism, universalism, However this story is a bit contentious. There are great differences between various proposed assumptions of the modern worldview, e.g. reductionism and universalism both are imbued with a negative connotation by some social theorists, while in fact of course the problem is not reductionism per se, but merely reductionism applied where it does not work really, as in hyper-complex systems in which researchers quickly run into significant problems due to the limits to science! It seems, however, that there may actually be a greater rationale to ascribing a negative connotation to universalism, as universalism seems to not work effectively in any kind of system.

At any rate, such philosophical questions stretch beyond the scope of this dissertation. I hope to have raised some interesting questions in these areas, which might lead to future directions in research in what appears to be a very fruitful area of study – complexity theories as interpreted within various major debates in the philosophy of science.

In the area of social theory complexity theories have proved useful in such areas as: possibly significant alternative explanations for group dynamics (e.g. the work of Mark Granovetter); potentially significant insights regarding power laws in complex systems (e.g. current research of Geoffrey West); powerful tools for sustainbility studies (e.g. work of Panarchy scholars, Timothy Allen, Timothy Foxon and others); specifically, principles such as technological, infrastructural or economic lock-in serve to articulate particular obstacles and thus opportunities for research on sustainability; and explanations or at least advances in distinguishing and understanding issues of emergence and self-organization. For the latter, Harold Morowitz' interpretation of the various 'breakthroughs' of human evolutionary history, e.g. the use of tools, as a kind of benchmark aiding to articulate the distinctions between social and biological evolution.

In Chapter Five, I attempted the difficult task of deciphering some essential distinctions between the kind of social system analysis that is at least largely based in quantitative issues, as listed above, and those theories based almost entirely in social theory, or theoretical argumentation. I discussed the nature of social science analysis in the case of the complexity ontological fundamentals, showing that interpretations in social theory have made ample use of them, even if this has primarily been only implicit. Next, I drew upon three examples of social theorists who have been amongst the most influential in the last twenty years, Bruno Latour, Ulrich Beck, and Jared Diamond. I showed that in each case, the authors main thesis was based upon one of the complexity fundamentals – networks, risk and vulnerability, and resilience or collapse, respectively. I show that in each case, the conclusions of the theorist hinged upon the complexity fundamentals, and that in their ensemble these scholars have succeeded in outlining and articulating some of the most pressing issues of our times. Each of these authors pulls out one significant thread in what we could call the major story of our era, the story of the planet's entry into the new and frightening era of the Anthropocene, in which Promethean fears of long gone literary masters have come home to roost.

Chapter Six took this argument a step further, by demonstrating that multiple diverse and largely unrelated, non-communicative groups of scientists and scholars are each describing some of the same phenomena of large-scale socio-ecological change. While they approach the issues from slightly different angles, I showed that in fact their ultimate interests are so common as to merit much greater collaboration and synthesis of their research and analyses. I described ways that transdisciplinary approaches have shed light on not just the complexity fundamentals, but also the interrelationships between the different fundamentals. My cross-disciplinary analysis also highlights how each of the fundamentals – networks, emergence, organization – has layers of varied meanings, but ultimately substantial rapport between them. Studying complexity in this broad fashion also highlights some of the challenges of the complexity fundamentals, and even offers

substantial arguments for the need to acknowledge what remains a 'mysterious' quality of the phenomena of emergence and self-organization.

In the last section of Chapter Six, I explored the debate in the philosophy of science about the possible limits to science and knowledge. This leads quickly to such issues as the nature of complexification, and the critical connection between complex systems, complexity theories, and complexification. Based upon the work of such philosophers as Nicholas Rescher, John Barrow, and Kurt Richardson, I argue that complexification is a dominant feature of contemporary knowledge and societies, and that it points not only to proof of the limits of science and knowledge, but also to the significance of ethics in the corpus of contemporary knowledge.

In Part II, Chapters Seven and Eight, I presented a case study of complexity with respect to climate change science and climate change ethics respectively. In Chapter Seven I explored the role of the complexity fundamentals in current understandings of climate change, and showed that the role of feedbacks and thresholds is very significant to scientific assessment of climate change. By examining the major planetary-scale scientific assessments of the last decade, the IPCC Fourth Assessment Report and the Millennium Ecosystem Assessment, I show that the need to include these two aspects of complex systems dynamics has been the central issue in climate change and general global environmental assessment in each of these studies. In the case of the MEA, the authors themselves also call for the urgent development of other critical features of the GCF, including finding ways to advance assessments across diverse scales, grains, epistemological communities, and other issues discussed in detail throughout Part I of the dissertation.

However, I put forth a major caveat, which is that the study of the particular complexity fundamentals falls into the trap that we can see an infinite regress due to the process of knowledge complexification. Thus, our understanding of what makes for true and most relevant scientific advance is shifting. While throughout much of the modern era any basic science was considered an advancement in knowledge, through our increased understanding of such qualities of knowledge as complexification, we see that in fact, not all basic science is merited. Indeed, endless study of particularities in climate feedbacks distracts us from the more important issue of the overall trends in climate change and the study of potential extreme events, technologies and knowledge relevant to short term emissions reductions, and other areas of applied research relevant to short term and long-term climate adaptation and mitigation.

Description of various processes and qualities of globalization are relevant to the discussion, as they help to extend the analysis of the extreme complexity of feedbacks and moreover, coevlution, in socio-ecological systems. Recognizing the role of high degrees of inextricably entwined processes of coevolution, helps us to see the powerful potential of the complexity framework writ large, with respect to the unprecedented

nature of so many of the major issues that our globalized societies face today. In the past years, discussion of risk and precaution has given way to increased discussion of crises and catastrophes. They are but two facets of one trend, as tightly entwined risks do actualize as harms and catastrophes. This includes the joint crises we face today, the coevolving crises of: economies, financial markets, ecological services, human population growth, and natural resource and biodiversity depletion. I argue that the GCF helps to highlight and emphasize how important it is to acknowledge that climate change is occuring within this context of not just globalization, but also global crisis.

Chapter Eight focused upon ethics. In this chapter I set out to analyze the role of complexity theories in the field of ethics. I end up making various parallels between my analyses of climate science and climate ethics, parallels which strengthen arguments for the advancement and prioritization of more sophisticated, complexity-based, climate ethics.

In Chapter Eight I approach an assessment of the import of complexity to ethics, by analyzing several groups of ethical theories relevant to climate change. These three groups of theories are progressively more attentive to the conjuncture of complexity fundamentals and climate change. I analyze groups of ethical theories from contemporary times that seem to have the most utility and effectiveness in addressing socio-ecological, planetary issues. I also review the major ethical issues in climate change as they have been laid out in the last decade, as in the synopsis by Paul Baer: allocation justice systems, equitable per capita rights, historical responsibility, considerations for creating more equitable and more sustainable societies. Finally I analyze some of the most advanced work in climate ethics, the report put out by Paul Baer et al, *Greenhouse Development Rights in a Climate Constrained World.*

From these analyses, I come to four conclusions. First, that the GCF is once again central to the main considerations in climate change, as much in ethics as in science. Second, that ethics, like science, faces the obstacle of limits in the face of advancing complexification, which one hits rather quickly when assessing planetary-scale issues. Third, this implies that complexity theories, in this sense, may help to overcome Hume's is-ought divide.

Fourth, based upon these last arguments, I argue that the GCF offers specific useful tools for climate policy approaches, and I list these approaches. Problematizing and resolving climate change seems to require a mix of the following complexity fundamentals and policy approaches listed in Table 8.2.

Complexity fundamental	Policy approaches
Interconnectedness	Symbiotic solutions, virtuous circles, win-win-win, problematization
Network causality	Network analysis
Uncertainty, unknowability	Probability of harm, weighing of evidence,
Dynamic, changing, evolving	Iterative, uncertainty expected
Hierarchical system structures	Multi-scalar and multi-grain analyses; transdisciplinary framework analysis at least iteratively
Observer in the system; significance of context	Transdisciplinary framework analysis at least iteratively
Complex dynamic systems	Generalized Complexity Framework good basis for developing ethics and policy
Pluralistic inclusion and approaches	Broad-based ethics and policy frameworks based in GCF
Unintended consequences	Precautionary Principle
Nonlinear change, thresholds, tipping points	Bayseian probability, inclusion of low probability, high impact events,
Resilience, vulnerability, sustainability, potential collapse	GCF also a good bases for developing ideas in the realm of wisdom and related broad-based perspectives

Table 8.2. Complexity Fundamentals and their Implications for Ethics and Policy Approaches (Duplicate of Table 7.6)

In my final argument, which built on the main argument of both of the case study chapters, I showed that the limits to both science and ethics, militates in fact for some prioritization of political action over further speculation. I ended with some speculations about the kinds of questions that the next phase of climate ethics, the 2009 pre-Copenhagen phase of climate ethics, could most fruitfully address. Building upon the work of scholars such as Paul Baer, climate ethicists need to address a new generation of ethical questions, lighting the way towards agreements in such challenging areas as the distinctions between kinds of essential and luxury emissions, and how to describe, argue, publicize, and integrate such distinctions in policy recommendations.

There is a very positive side of complexity's contribution to climate change: it shows us that although our knowledge may remain in some respects uncertain and limited, nonetheless: advances in ethical theories will be further legitimized; the rationale for greater responsibility at the base of our science, ethics and politics will be validated; more sophisticated and proactive interpretations of the precautionary theory will be

advanced; new understanding of rationality will be developed; and our analyses will be infused with evolving theories about complexity.

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Résumé :

Cette thèse propose une analyse épistémologique des théories de la complexité, une évaluation de leur portée générale et de leur utilité dans des domaines particuliers, et la mise au jour de leur contribution décisive à la question centrale du changement climatique. L'objectif est de cerner la nature de la complexité à travers tout l'éventail des disciplines, car les théories de la complexité ne cessent de s'éteindre et la liste des bénéfices qu'on leur attribue de s'allonger. L'étude de cas du changement climatique est riche, y sont impliqués de nombreux systèmes complexes d'importance décisive pour le genre humain, parmi lesquels l'agriculture, l'énergie, l'eau et l'économie. Le présent travail propose d'abord une définition de la complexité généralisée, comprise comme cadre général de la pensée fondé sur six grandes catégories. Il procède ensuite à l'analyse à travers ce cadre, des dimensions scientifiques, politiques et éthiques du changement climatique. Notre point de départ est constitué par un examen attentif du trois corpus importants : le rapport du GEIC « Climate Change 2007, » « le Millennium Ecosystem Assessment, » et l'éthique du changement climatique. Il s'avère, à travers la thèse, que la mise en œuvre des théories de la complexité est en fait nécessaire pour mesurer de manière précise et rigoureuse la portée non seulement des aspects multiples des différents systèmes complexes impliqués, mais aussi de l'ensemble dans toutes sa signification polyvalente. En s'interrogeant sur le rôle et l'utilité des théories de la complexité dans des domaines et à des échelles multiples, nous mettons en lumière une série de principes-clés sur la nature et l'usage de ces théories.

Title : Complexity and Climate Change : An epistemological study of transdisciplinary complexity theories and their contribution to socio-ecological phenomena

This dissertation presents an epistemological analysis of complexity theories, an evaluation of their contribution, both generally and to specific domains, and a demonstration of their important contribution to climate change. The objective is to provide a description of complexity theories across the whole range of disciplines, as complexity theories continue to expand and the list of their proposed benefits continue to grow. The case study of climate change is rich, as it touches on a number of complex systems of primary significance to humanity, such as agriculture, energy, water, and the economy. The present work proposes first a definition of generalized complexity, comprised of a general framework of the field based upon six major categories. It proceeds to analyze, in light of this framework, the scientific, ethical and political dimensions of climate change. Our point of departure consists in a thorough examination of three important bodies of literature: the IPCC report "Climate Change 2007," the "Millennium Ecosystem Assessment," and the ethics of climate change. Throughout the dissertation, it turns out that the use of complexity theories is in fact necessary in order to measure in a precise and rigorous manner the contribution, not only of the multiple aspects of different complex systems involved, but also of the framework as an ensemble, with its polyvalent signification. By examining the role and the utility of complexity theories in multiple fields at multiple scales, we reveal a series of key principles regarding the nature and usage of these theories.

Disciplines : Philosophie, sciences de l'environnement

Mots Clés : complexité, systèmes complexes, épistémologie, changement climatique, éthique environnementale, rétroaction, points de basculement, causalité en réseau, limites de la science

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