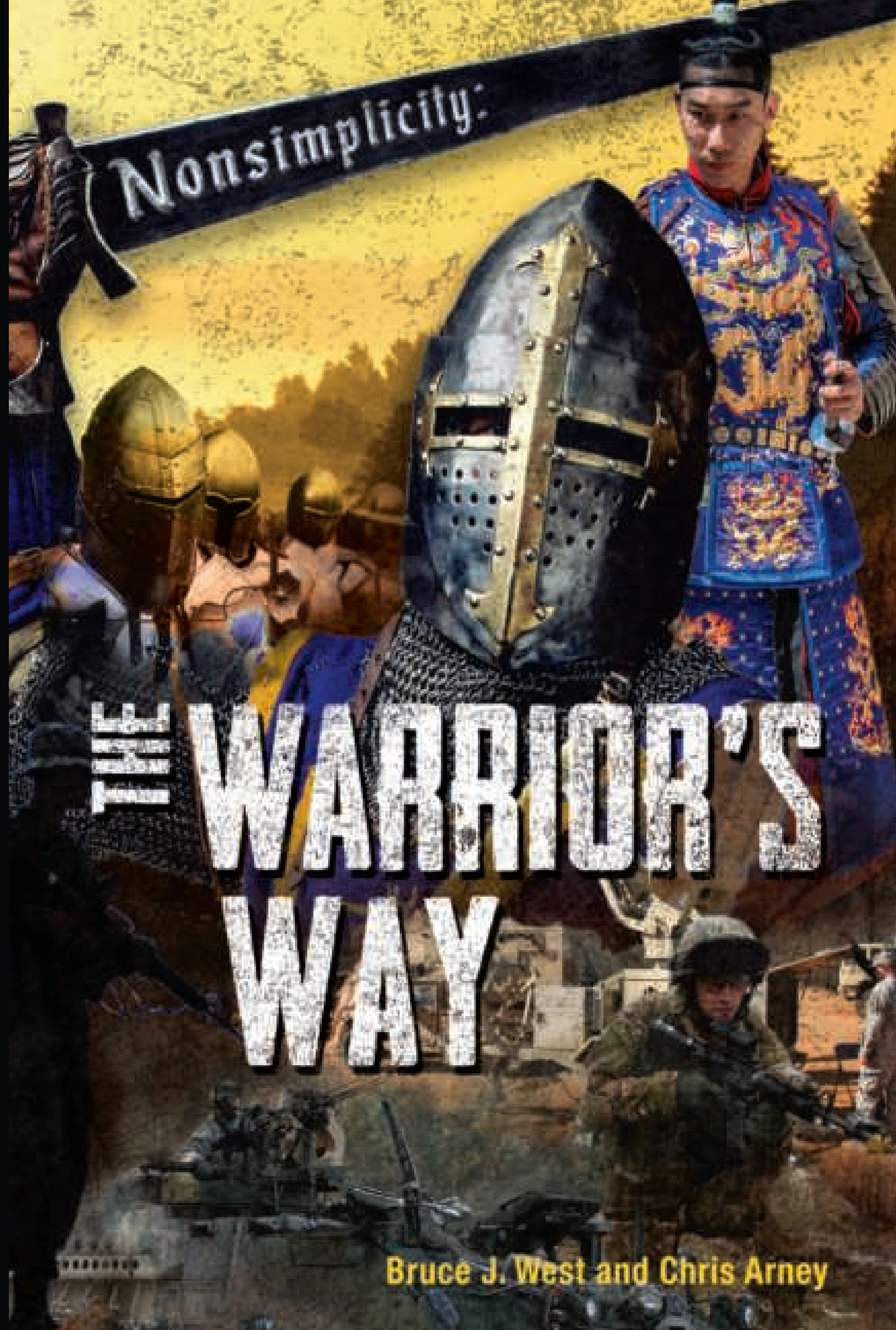
NONSIMPLICITY: THE WARRIOR'S WAY

Bruce J. West and Chris Arney



NONSIMPLICITY:
THE WARRIOR'S WAY

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FOREWORD

It is uncommon for an Army Officer to find himself surrounded everyday by some of the most brilliant scientific minds our country has to offer. But this is where I have found myself for the second half of my career and it has led me to work with one of the most unique thinkers to ever serve with our Army, Dr. Bruce J. West. Dr. West is literally the top 1% of the top 1%; he holds the top Army Scientist grade of ST (Scientific Professional) and he was awarded an honor held by only 1% of the Army's Senior Executive Service: the Distinguished Presidential Rank Award for 'sustained extraordinary accomplishments.'

In this latest work, *Nonsimplicity: The Warrior's Way*, Dr. Bruce West of the Army Research Office and Dr. Chris Arney of the United States Military Academy take on the task of challenging the US Army to 'think about the way we think.' The 4th Industrial Revolution is well under way and the unknowable implications of a world of "smart," connected devices will change how life is lived and wars are won. The US Army must change the way we think in order to change the way we fight. West and Arney state the problem precisely as: "How do we shed the cognitive constraints of Machine Age thinking and learn to apply nonsimplicity thinking to Information Age problems?"

Drs. West and Arney are not alone in educating the world to this coming challenge. I was first truly introduced to this paradigm in Dr. Nassim Nicholas Taleb's best–selling book, *The Black Swan*. As a scientist, I am very well grounded in the laws and theories of parametric and nonparametric statistics, but until I read Taleb's work, I did not see how consistently linear my thinking actually was. The US Army needs to grow a generation of leaders who can not only think in nonlinear terms, but can build and lead formations based on nonsimple principles. The best example of the successful application of this theory is found in the unparalleled success of the Joint Special Operations Command (JSOC) under the leadership of General Stanley McChrystal. McChrystal is arguably the first military leader of the modern age to successfully apply the principals of Complexity Science as best summarized in his 2011 article in Foreign Policy, "it became clear to me and to many others that to defeat a networked enemy we had to become a network ourselves."

The first half of this book provides the necessary depth and breadth of examples to help the reader identify everyday phenomenon that are best described by Complexity Science, Networks, and Nonsimplicity. Readers looking for elegant mathematical proofs, such as Bra–Ket notation and complicated derivations may be disappointed as there is exactly one set of equations explaining a simple geometry problem in the entire book. Instead, the authors focus on visualizations, analogies, and allegory to communicate to an audience that includes the most junior Noncommissioned Officer, the most senior Combatant Commander, policy makers, and everyone in between.

The military utility of a concept or gadget is normally best conceived via examples that play out on the battlefield. The power of the concepts conveyed in this book extend beyond battlefield application and may have a dramatic effect on the Army's requirements to Organize, Man, Train and Equip. This book is particularly timely as the Army undergoes a massive transformation of the "Material Enterprise" used to equip the Army. July 2018 marks the first time in over 40 years that the US Army has stood up a new 4 Star Command: Army Futures Command. Army Futures Command will lead the Army's future force modernization enterprise. US Army leaders made the decision to change how the Army Equips itself because they saw the stratospheric success of America's innovators juxtaposed to the continued failure of the Army's current equipping (acquisitions) processes. The impetus for change was evident but the mental map for how to change remains unclear. In *Nonsimplicity*, West and Arney have provided the cogent, consumable paradigm that Army Futures Command and the US Army as a whole can use to lead in the future and demonstrate the warrior's way.

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PREFACE

This book is a collection of ideas regarding how failures in complex systems differ from failures in simple systems, particularly how such failures may influence how we think and make decisions in military operations. A failure is typically a breakdown in a system's functionality initiated by an internal fluctuation of unexpectedly large magnitude, or an equally unexpected external shock. A simple, but complicated system like a formation of troops during the Napoleonic wars, has fluctuations characterized by a normal probability density function, that is, a bell–shaped curve, for which the theory of extrema, the basis for the theory of failure, is well established.

On the other hand, the fluctuations in a complex system, like the Internet or a modern aircraft carrier, cannot be represented in this way, typically have an inverse power–law probability density function, which is a different type of distribution. The implied differences in the failure modes, between exponential and inverse power-law processes, as they relate to the military, are discussed without the necessity of presenting the underlying mathematical formalism.

Perhaps discussing how an understanding of the complexity of modern society molds individual behavior may be as important as that of failure, particularly since such understanding can provide insight into the polarization of world views and decisions. The intransigence of right versus left political ideologies in Western countries; the diametrically opposed politically correct positions within democracies and theocracies on the world stage; the US military's response to violence and oppression; the growing acts of terrorism as well as imperialism—all with their modern dependencies on social media and cyber conflict, are symptomatic of the growing complexity of psycho–social networks in today's society.

Nearly half a century ago the Physics Noble Laureate Philip Anderson wrote the remarkable paper "More is Different" in which he speculated on the collapse of reductionism in science. The central problem of broken symmetry that he identified as the shift from the quantitative to the qualitative, which he gathered under the heading of broken symmetry. In physics, symmetry refers to the existence of different formal viewpoints from which a system appears unchanged. This changing view of science had a great effect on the US military, its systems and its doctrine. We will assess the changes and effects in military operations in light of tomorrow's science and the evolution of the world's military balance. Newton appears to have been the first scientist to recognize the significance of symmetry in his study of the relationship of space and time. Symmetry breaks as the complexity of a system increases with size, the clearest example of which is a sharp, singular phase transition at its critical point. The emergent, collective behavior that arises once criticality is reached breaks symmetry. Herein, we discuss a new kind of phase transition, one that is not singular so it lacks the mathematically sharp transition observed in physical systems. However, these new transitions do result in collective dynamics on the macro scale, just as certainly in military and cyber systems as they do in physical systems.

Complexity is more than complicated simplicity, although it took a number of generations for scientists to distinguish between the two. Complexity is nonsimplicity, which violates the fundamental assumptions of physical science. For example, time becomes non–uniform in psycho–social phenomena and space is deformed by the heterogeneities in processes, both of which produce inverse power–law fractal functions. In each nonsimple situation, the main element (independent variable) cannot be represented by a characteristic scale, but requires multiple interwoven scales, resulting in phenomena that lack the simplicity of the classical equations of motion when deterministic, as well as, lacking good behavior (ergodicity) when random. Nonsimplicity becomes a delicate balance between regularity and randomness, with neither dominating, but both always being present.

Modern military systems are nonsimple and show these dynamics. This book attempts to both show and explain the underlying science for this fog of war, while avoiding a reliance on mathematical formalism. Even if one of the principles of war is simplicity, there is very little in any military operation that could be considered simple from a scientific perspective. This book provides the science and mathematics to better define nonsimplicity and to quantify the fog of war.

The way ahead is to not to try to make things simple – that cannot be done, nor can it lead to success. So we will learn to overcome and deal with the complexity, and to ultimately own or embrace the complexity in military and cyber operations. The force that best learns to cope with complexity will often be the most successful on the battlefield, no matter what operational domain, what type of conflict, or where the conflict takes place.

NOMENCLATURE

5GW: 5th Generation of Warfare
AFC: Army Future Command
AI: Artificial Intelligence
AP: Altruism Paradox
AR: Augmented Reality
AUV: Autonomous Unmanned Vehicle

C4ISR: Command, Control, Communication, Computers, Intelligence, Surveillance, Reconnaissance
CAS: Complex Adaptive System
COG: Center of Gravity
COIN: Counterinsurgency
CS: Complexity Science

D2D: Data to Decision
DA: Data Analytics
DIKD: Data, Information, Knowledge, Decision
D2IKD: Data, Information/Intelligence, Knowledge, Decision
DIME: Diplomatic, Information, Military, Economic
DMM: Decision Making Model
DoD: Department of Defense
DIUx: Defense Innovation Unit (Experimental)

EMP: Electromagnetic Pulse
ERC: European Refugee Crisis

FCW: Fog of Cyber Warfare

GWOT: Global War on Terrorism

HIC: High-Intensity Conflict

IAPW: Information age Principles of War
IoBT: Internet of Battle Things
ISIS: Islamic State of Iraq and Syria
ISR: Intelligence, Surveillance, Recognizance
IW: Information Warfare

JIM: Joint, Interorganized, and Multinational
JSOC: Joint Special Operations Command

LFoE: Law of Frequency of Errors
LIC: Low-Intensity Conflict
LOAC: Law of Armed Conflict

MDB: Multi–Domain Battle
MDMP: Military Decision Making Process

NAO: Nonsimple Adaptive Operations
NATO: North Atlantic Treaty Organization
NCO: Network centric Operations
NCW: Network-Centric Warfare
NS: Network science

OODA: Observe–Orient–Decide–Act

Pareto PDF: 80/20 Principle
PDF: Probability Density Function
PCM: Principle of Complexity Management
PME: Professional Military Education
PMESII: Political, Military, Economic, Social, Information, Infrastructure
PTSD: Post–Traumatic Stress Disorder

RG: Renormalization Group
RMA: Revolution In Military Affairs

SOC: Self–Organized Criticality
SOTC: Self–Organized Temporal Criticality
STE: Synthetic Training Environment
SW: Synchronization Warfare

TBI: Traumatic Brain Injury
TRADOC: Army Training and Doctrine Command

UAV: Unmanned Aerial Vehicle
UGV: Unmanned Ground Vehicle
USMA: United States Military Academy
USMPS: United States Military Philosophical Society
UUV: Unmanned Underwater Vehicle
UWV: Unmanned Water Vehicle

WMD: Weapons of Mass Destruction

ACKNOWLEDGMENTS

The authors have collaborated on many projects and events over the last 15 years, but this is our first collaboration on a book. We appreciate the support we have received from our families and colleagues. We also thank the leadership and staff of the Army Cyber Institute and *Cyber Defense Review* for selecting our book to be the first in their new series. We emphasize that the opinions expressed in this volume are our own and although those opinions may have, in part, been formed out of research supported by the Army, they do not reflect the official positions of the Army Research Office, United States Military Academy, United States Army, Department of Defense, or the US Government.

PROLOGUE

It is an honor for the Army Cyber Institute (ACI) at West Point to publish *Nonsimplicity: The Warrior's Way* by Dr. Bruce West and Dr. Chris Arney. Unique within the US military, the ACI is an innovative mix of academic think tank and operational laboratory. The intellectual thrust of this scholarly work aligns with the ACI's vision to enable the nation to outmaneuver its adversaries in cyberspace. This book discusses and explains in a nontechnical, informal style of how the military can grow and change to prepare itself for its future. *Nonsimplicity: The Warrior's Way* describes the strategies, tactics, doctrine, tools, systems, and weapons that modern warriors need to develop, refine, and use. We are excited that it is the first ACI book in a series that will tackle the strategic aspects of the cyber domain. I want to thank the two authors, the CDR, and FedWriters for their exceptional work on this project.

COL Andrew O. Hall
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ABOUT THE AUTHORS

Chris Arney is a professor (Emeritus) of the United States Military Academy at West Point, NY where he taught undergraduate mathematics, network science, operations research, and cyber security for more than 27 years as an officer and civilian. He graduated from West Point and served in the Army for 30 years in the Military Intelligence Branch before retiring as a Brigadier General. His PhD is from Rensselaer Polytechnic Institute. Chris Arney has served as a Dean and acting Vice President for Academics at the College of Saint Rose in Albany, NY, and a Program Manager and Division Chief at the Army Research Office in Research Triangle Park, NC. His academic research focused on pursuit-evasion models, cooperative systems, information networks, complexity, intelligence and information processing, artificial intelligence, and language for robots. He is the founding director of the international undergraduate interdisciplinary modeling contest which celebrated its 21st year in 2019. Chris Arney has authored over 20 books and written over 100 technical articles.

Dr. Bruce J. West is the Chief Scientist, Mathematics at the US Army Research Office (ARO), 1999-present. Over a 50 year career, he has authored, coauthored, or edited 37 books and 36 book chapters, and published in excess of 310 scientific articles in referred scientific journals and magazines that have garnered a total of over 21,000 citations with an h-factor of 70. Before coming to ARO he was Professor of Physics at the University of North Texas from 1989-1999, Chair of the Department of Physics from 1989-1993, and Associate Director Center for Studies of Nonlinear Dynamics at the La Jolla Institute from 1979-1989. He has received numerous awards for his research including being elected a Fellow of the American Physical Society in 1992, accepted the Meritorious Presidential Rank Award in 2012, elected a Fellow of the American Association for the Advancement of Science in 2012, and recipient of the Distinguished Presidential Rank Award in 2017.

CHAPTER 1

OUR COMPLEX WORLD

> Both sides in the arms race are...confronted by the dilemma of steadily increasing military power and steadily decreasing national security. It is our considered professional judgments that this dilemma has no technical solution. If the great powers continue to look for solutions in the area of science and technology only, the result will be to worsen the situation. [266]

The above quote is a clarion call, over a half century old, for a new way of thinking made necessary to solve complex human problems. It inspired one of the more influential academic articles on the implications of complexity [105] in addressing human questions that have no technological solutions. In 1968, Hardin [105] challenged the nearly universal assumption that social problems, such as national security in a nuclear world [266], have a technical solution. He defined a technical solution as one that only requires changes in the natural sciences and which does not require changes in the social sciences and/or philosophy. His article does not address the nuclear arms race, but focuses on the broader strategy of how to solve complex human problems for which there are no technical solutions, using the spectre of over–population as the exemplar. History has endorsed Hardin's generic observations, in that what brought the nuclear arms race to an end and the Cold War to a peaceful climax was a change in strategic thinking, not in technology. It is this change in thinking that we come back to again and again in this book, but first let us identify the starting point for our discussion.

Hardin [105] introduced into the discussion of human problems, that have no technical solution, an argument called the tragedy of the commons. The original form of the tragedy argument appeared in 1833. [145] We subsequently update this argument in which individuals, with competing interests must share a common resource. If individuals act in their own self–interest without regard for the others sharing the resource, the unavoidable result appears to be the depletion of the resources and subsequent tragedy.

"Commons" is an old–English term for a land area whose use is open to the public. Lloyd [145] considered a pasture that is a commons and shared by a number of cattle herders, each one of which tries to retain as many cattle as possible. Hardin explains that external factors such as wars, disease, poaching and so on, may keep the numbers of men and beasts well below the carrying capacity of the commons for a long time. Eventually, however, social stability arrives and, instead of enhancing the wellbeing of the situation, inevitably leads to tragedy.

In the commons argument, the assumption is made that rationality leads to a herdsman acting in his own self–interest in order to maximize the gain made from grazing and selling his cattle. The herdsman reasons that to grow his herd he incurs certain costs: the purchase price and the incremental cost of overgrazing, by adding another animal to his herd. On the upside, the overgrazing cost is shared by all the herdsmen on the commons. Consequently, since he does not share his profit from this additional animal with the other herdsmen, it makes economic sense for him to add the animal to his herd. This argument is valid for adding additional animals as well.

The other herdsmen reach this same conclusion, since they are also rational. This compelling logic results in tragedy, since the commons grazing capacity will eventually be destroyed. Each herdsman is trapped in a rational system that logically compels them to increase, without limit, the size of their herd and to do this in the face of limited resources. Disaster and failure is the end point of this logical sequence in which all participants act in their own self–interest. Hardin summarizes the tragedy of the commons with the phrase, “Freedom in a commons brings ruin to all.”

Hardin sought ways to avoid the tragedy using the top–down approach of imposing social constraints, but in the end, he concluded that for his exemplar, over–population, the notion of the commons in breeding must be abandoned and that “Freedom to breed will bring ruin to all.” From the luxury of a historical perspective, it is easy to point out that Hardin did not follow his own advice regarding how to solve a human problem that does not have a technical solution. Instead, he framed the human problem of over–population in the tragic form that allowed him to propose, analyze, and reject technical solutions in clever ways.

One can find a number of weak points in his argument, which we pose here as questions. Do people always (or ever) behave strictly rationally? Do individuals ever act independently of what others in their community are doing? Do typical folk totally disregard the effects of their actions on the behavior of others? We subsequently answer each of these questions and others in a more general context. For the moment, it is sufficient to point out that the "straw man" of the tragedy of the commons is an example of a linear logical construct and its ultimate flaw is the inappropriate way it is applied to resolving paradoxes in our complex world. If Hardin had recognized the linear nature of the assumptions in his straw man and replaced them with more realistic complex interactive forms, he could have reached very different conclusions.

Altruism is one concept that was missing from Hardin's tragedy of the commons discussion, but which seems to us to be no less important than the notion of selfishness, which was key to his argument. Moreover, if selfishness is entailed by rationality in decision making, as he maintained, then altruism must be realized through irrationality in decision making. In point of fact, the competition between the two aspects of human decision making [10], the rational and irrational, may well save the commons from ruin. Adam Smith indirectly posed the altruism paradox (AP) in a social setting over two and one-half centuries ago, in *The Wealth of Nations*, by maintaining that people act in their own self–interest and in so doing, society as a whole benefits [217]:

> It is not from the benevolence of the butcher, the brewer, or the baker that we expect our dinner, but from their regard to their own interest.

Science typically follows a logical train of argument from a model–based premise to an entailed conclusion in the form of a prediction, which is then tested by experiment to determine if nature follows the same logic. When the two paths diverge towards conflicting results, the experimentalist questions the theory and the theoretician examines the experiments more closely. However, the purpose of the experimentalist and the theoretician is ultimately the same, to make the two paths dovetail, leading to a deeper understanding of the phenomenon being investigated. When multiple, well-designed experiments yield outcomes that do not match prediction, it is time to formulate a new model of the phenomenon under study. The new model yields a new prediction and the testing cycle is started again. This seems to be where we are in resolving the empirical compatibility of the intellectually conflicting social concepts of selfishness and altruism. The resolution of the altruism paradox will be discussed subsequently, but for the moment the take–home lesson from this discussion is the importance of complexity in solving human problems, particularly in the modern military. The goal is to understand how complexity has shaped and continues to shape today's military, by clearly distinguishing between those problems that do and those that do not have a technical solution. Therefore we stop for a moment and focus on some of the fundamental concepts that we find useful in this pursuit. Of particular importance is how the coevolution of the military and society has led to the identification of a number of paradoxes within the distinct, but related, organization of the military and the society to which it owes its allegiance. Another is the robustness of social organizations, from the scale of a megacity down to that of a military squad and how they can be supported, protected, disrupted, or destroyed.

1.1 Implicit Failure

The fact that businesses go bankrupt, markets crash, and people lose their jobs are examples of economic failure on either a system or individual level. Transportation disasters happen in the forced landing of airplanes, trains being derailed, and cars crashing; security breakdowns take the form of large data sets being stolen from corporations, or government agencies, and your personal computer being hacked or infected by a virus; healthcare collapse occurs when identified social groups are excluded from coverage, co-payments are so large as to make access unaffordable, and physicians refuse to accept a patient's form of payment; communications are corrupted when receivers are jammed on the battlefield, misinformation is slipped into transmitted messages, and emails are hacked. The list of potential failures is virtually endless and can be applied to every aspect of life, and is of particular importance to the military. Not because the military is more sensitive to such failure than is society in general, but because the repercussions of a failure within the military may be more far–reaching, in part, because the military is more tightly interconnected than most parts of society are.

The technological advances that make life so comfortable in modern society, also make it less stable. As society evolved from being agrarian, to industrial, to informational, its separate pieces have become more interdependent. Consider what would happen in the event of an electromagnetic pulse (EMP) generated by a nuclear explosion high in the atmosphere, say, above Pennsylvania. The EMP would fry the electrical circuits of the power grid, causing a blackout over the northeast corridor. The time needed to repair the power grid would be weeks to months, assuming the huge power generators would be available from a remote location and could be delivered.

The loss of electricity would, in turn, lead to all fresh food in urban areas rotting in the first week, due to lack of refrigeration. The food could not be replaced, because the trucks needed to deliver it would not be able to move, due to a combination of the onboard computers not operating and a lack of available fuel. The fuel pumps at many, if not most, gas stations would no longer work. The only food available to urban dwellers would be that in their homes and in the markets within walking distance. Within a week there would be food riots, with the populace overpowering the dismounted police force.

After the first week people would begin dying in large numbers, with the death toll determined by the season of the year. The old and infirm would die first, due to medication shortages, but there is no reason to go on with this description of the horrors resulting from a significant fraction of society abruptly losing power and not having the ability to regain it for a long time. The interconnectedness of modern complex society, one of the features that make it so attractive, would ensure maximum civilian casualties. The very complexity necessary for society to function also guarantees its fragility, that is, its increased sensitivity to disruption.

Failure is an implicit feature of complexity, the more complex a system, the more ways it can fail; whether it is the financial collapse of the stock market, a heart attack, a power grid shutdown, or the actions of a military unit that results in mission failure or casualties. The implication here is that each of these examples is related to a complex system: the physiology of a single individual, the decision making within and operations of a military unit, as well as the interconnectivity of complex physical, social, and informational networks.

It follows that the greater a system's complexity the more important is the need to anticipate its various failure modes, bearing in mind that not all such modes can be predicted. In fact, most failure modes are unanticipated, and surprise the policy makers. To be fair, anticipating a failure mode is not the same as predicting its occurrence. A prediction is a precise foretelling of the when and where of an event, generally based on some theory of the process, mathematical, scientific or otherwise. If the theory is sufficiently mature it may even forecast the magnitude of the event, as well as its time and place.

On the other hand, anticipating an event can be a somewhat vague feeling that something debilitating is about to happen, and it may concern anything from a collapsing bridge due to aging infrastructure, to ending negotiations based on the threat of a terrorist attack. The feeling can provoke a plan of action to reduce the recovery time from a failure, should it occur, and/or reduce its influence on subsequent failure modes. This intuitive response on the part of an engineer may result in a plan to avoid such a failure mode altogether, through enhanced design in anticipation of certain well defined failures. Military leaders are definitely caught in the dilemma of accomplishing the mission and/or exposing their soldiers to danger. However, in some situations failure cannot be avoided, while in other situations, it should be encouraged. For example, the purpose of studying the dynamics of terrorist networks is not solely for psycho–social understanding, but to determine how to disrupt their plans, if not to destroy the terrorist network altogether.

This book proposes a way of thinking about how to solve certain problems critical to society in general, and to the military in particular. It is a way of thinking made necessary by the demands of contemporary science to overcome the complexity barriers to understanding the modes of failure that are present in virtually every aspect of life and within every scientific discipline. Complexity entails the quantitative and qualitative richness of nonlinear dynamic phenomena so the scientific understanding of how phenomena fail must encompass both the qualitative and quantitative. To garner such understanding in a systematic way requires going beyond the traditional methods of modeling and simulation, as the only ways of transforming data into information and subsequently into knowledge and into more complex methodologies.

We know that today's models of reality have been pushed to the limits and beyond. Those which were developed and applied so successfully to the explanations for, and understanding of, physical phenomena, in the nineteenth and twentieth centuries, are no longer adequate to describe the emergent phenomena of the twenty–first century. For example, the Internet of Battle Things (IoBT) [129] predicts that the future battlefield will consist of multitudes of intelligent things that will be communicating, acting and collaborating with one another, as well as, with human warfighters. One aspect of this added complexity is discussed in the Fog of Cyber War (FCW) [130], which involves the chopping and shuffling of transmitted messages in order to confuse the enemy. These kinds of military operational issues are complex, nonsimple, and significant, because people's lives often hang in the balance.

1.2 Complexity Science

We propose adopting a fresh perspective for solving complex problems that do not have a technical solution and which enhance more traditional methodologies. We use the power of Complexity Science (CS) to advance this work. By a fresh perspective, we mean applying a point of view that has been pushed to the forefront in the past quarter century, or so, and which is summarized through a presentation of brief defining statements in *43 Visions of Complexity* [243], each one made by a leading complexity scientist. These statements stand as tributes to the formation of the Complexity Science Hub, Vienna, from many who have long-time affiliations with the Santa Fe Institute. We draw freely from their pregnant remarks and hopefully inspire some novel applications of CS to understand the modern military.

Our intent is to review a number of problems of crucial importance to society and the military, showing how complexity in its myriad forms is responsible for the scientific barriers that have previously blocked their solution. Complexity builds up intellectual blockades, digs emotional ditches and otherwise obscures understanding. Overcoming these impediments requires new mathematical tools to clear up the resulting ambiguities. Figure 1.1 indicates some of the research areas where new mathematics has contributed significantly over the years to various scientific disciplines. It also highlights some of the researchers whose work has established connections across multiple disciplines.

Many consider new technology a boon to the military and society. The value of science is often considered to lie the building and fielding of prototypical gadgets, as well as in teaching the consumer and warfighter how to effectively use them. Some technology fundamentally changes the way we live, while others barely makes a noticeable difference.

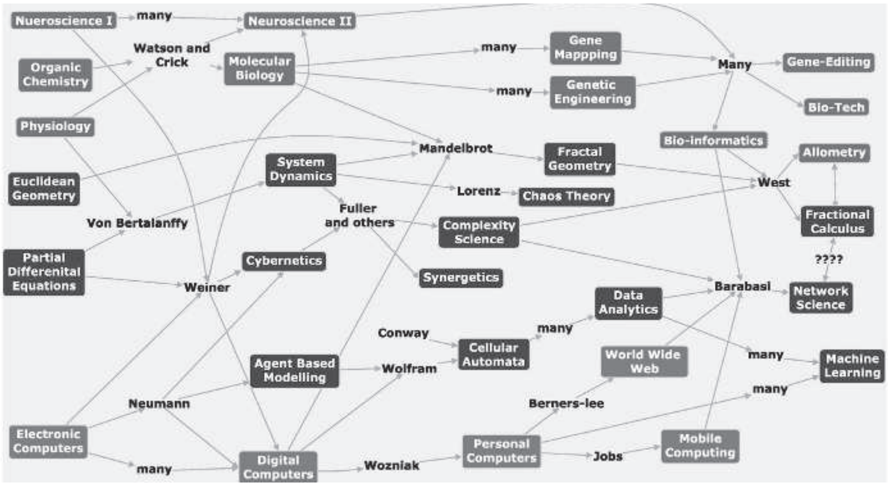

Figure 1.1: Here we interconnect some of the major areas of complexity research to some of the major contributors to those areas [158].

The distinction between evolutionary and revolutionary science and technology dates back to the 500-year-old inventions of the prolific artist, scientist, and military engineer, Leonardo da Vinci. Figure 1.2 shows the difference between da Vinci's evolutionary and revolutionary science in his weapon designs. The giant cross–bow (note the man in the foreground of the sketch for scale) was an incremental improvement over sixteenth century weapons and exemplified only an evolution in scale. Da Vinci's developmental design of a helicopter, on the other hand, was totally bizarre without precedent and is an outstanding example of what was at the time revolutionary science and technology [67].

Leonardo da Vinci was able to conceive of the helicopter, tank, and dive suit centuries before civilization had either the science or technology to effectively engineer them, much less the imagination to need or want them. He intuitively used the design elements of CS drawn from nature in his thinking. In the same vein, today, we use CS to form future military scenario planning and cybersecurity conceptual developments and it is as important for the future success of the military as designing new weapon systems to rigorously set engineering specifications. CS has been a force exponentiation factor, since the beginning of human conflict even though it has not been until now that we are able to formalize its role in applications, systems, algorithms, models, and products. The one lasting issue for any military is the need to adapt to the existential security challenges of their modern environment. Certainly autonomous armed military robots, heavily armed drones, and destructive cyber operations lie within this set of challenges. The Army has an excess of people who are capable of being a combat commander, but too few who are capable of managing the logistical challenges, conducting diplomacy, or understanding and putting to use the flood of data, science, and technology.

Evolutionary design ripples through society and the military, incremen–tally improving technology as it goes. By contrast, revolutionary design starts small, like the millimeter displacement of the ocean surface at the epicenter of an earthquake, gathers amplitude as it propagates toward land, along the upward tilted ocean bottom, until a tsunami crashes against the shore, smashing everything in its path. Unlike evolutionary ideas, revolutionary ideas require new ways of thinking about old problems, entailing totally new areas of scientific investigation in order to be realized.

The commonly accepted notion of science has become so interwoven with technology that the way most people think about science is almost inseparable from that of technology's products—products that facilitate the mission of the military and have fundamentally changed society. In the twenty–first century, the notion of an end product is an overly restrictive view of how the military and society can benefit from the fruits of contemporary science. Another, more subtle benefit, is the way people think about the world and how their way of thinking is tempered by scientific and technological advances. This is the perspective of doctrinal change and the role of information and knowledge in the military and society.

Science seeks to understand the world as it is, whereas engineering develops ways to use science to bend the world to carry out prescribed functions and specific tasks. The interweaving of new social media, new manufacturing and computer technologies, as well as global financial networks is, in part, how the United States expects to retain social, economic, and political superiority throughout the twenty–first century. The weaving together of new weapon systems, information and sensor networks into the fabric of the military is part of how the United States is expected to maintain its military superiority throughout the twenty–first century. Thus, science for society and the military is not only concerned with creating new devices, but also with how those devices change the networks to which they contribute, as well as how these networks are subsequently used in military doctrine and decision making.

Figure 1.2: Evolutionary research (top two figure reproduced from da Vinci's Notebooks [67]) and the analogous ripple effect is put in contrast with revolutionary research and the crushing tsunami effect.

We now recognize that all networks are interconnected and an advantage achieved in one sub–network does not necessarily produce an overall advantage in the host network. The enhanced performance of one sub–network may instead degrade the overall performance of the host network. It might even initiate a network failure, thereby forcing an ever deeper exploration into understanding how complex networks interact with one another and exchange information.

Revolutionary mathematics—totally new strategic and tactical thinking—can also have a tsunami effect, necessitated by the existence of disruptive scientific concepts. Mathematics establishes the conceptual infrastructure for science to express theory and to guide technology as the engineering fulfillment of that mathematical and theoretical reasoning. The seventeenth century differential calculus of Newton and Leibniz enabled natural philosophers to quantitatively reason over the changes in physical phenomena and laid the groundwork for the Industrial Revolution. The nineteenth century statistics of Gauss, Adrian, and Galton enabled social and life scientists to quantify uncertainty in their respective domains, following the lead of physics. Today we require even more creative techniques to either circumvent or directly overcome research challenges that block progress in a number of disciplines, all of which influence the typical civilian, as well as the warfighter.

Complexity can be given an intuitive definition, but we acknowledge that there is no universally accepted way to characterize it [243]. A quantitative measure of complexity can be associated with the dynamics of a system and is related to the number of interacting fundamental or microvariables. Consider the dynamics of one, or a few, such variables. Denote them as simple, see the lower left corner of Figure 1.3. As the number of microvariables increases, the mathematics of such systems, includes spectral decomposition, linear control theory, integrable and non–integrable Hamiltonians (generators of mechanical motion), nonlinear dynamics (chaos theory), algorithmic complexity, among other more specialized methodologies. Each of these techniques is relatively well understood by specialists, but do not be put off by the jargon, it is probably the last time we refer to them. Take solace in the fact that most of these specialists could not repair an internal combustion engine, nor fix an electric motor, nor remodel a home, nor accomplish any of the myriad other technically related tasks a typical non–mathematician can.

However, in the abstract world of scientific theory, the effects of non–locality in space, memory in time, as well as other such complications, are not well understood, in the case of a few microvariables. As the number of microvariables continues to increase, as shown moving from left to right in Figure 1.3, a system's complexity rises by the notional curve, and these established techniques become less exact and less useful. The methods come up against what we do not yet know, understand, or have the language to discuss.

On the far right side of the complexity curve, where the number of microvariables is very large (effectively infinite), we have equilibrium thermodynamics, and the system is again considered simple. The mathematics describing thermodynamic systems involve partial differential equations in terms of macrovariables that capture the evolution of probability density functions (PDFs), renormalization group (RG) relations and scaling of the coupling of macrovariables across scales; all of which bolster our understanding of the physical, social, and life sciences. Here again, the effects of heterogeneity in space and time are captured by the fractional calculus in terms of these macrovariables. As we ascend the curve, moving from right to left, the number of microvariables decreases, but the number of macrovariables increases, such that the phenomena being analyzed increases in complexity, and the mathematical tools available again become less useful.

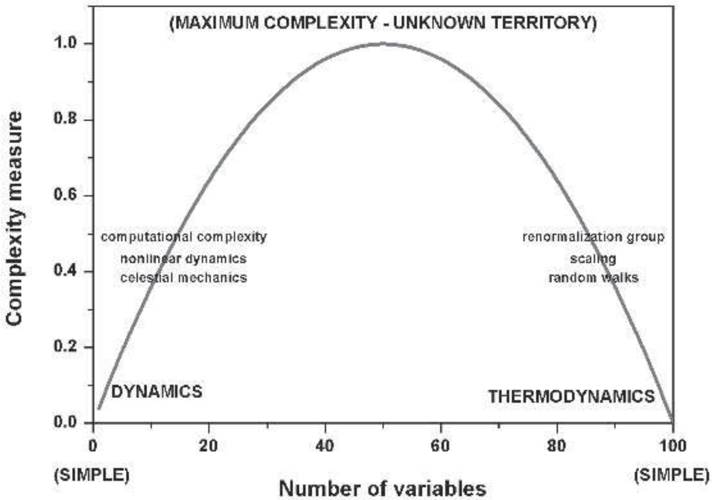

Figure 1.3: This figure, reproduced from [267] with permission, presents a conceptual nonlinear measure of complexity; one that categorizes networks with one or a few degrees of freedom and that are described by deterministic trajectories, as being simple. In the same way, systems that have a very large number of degrees of freedom that are not described by individual trajectories, but rather by distribution functions, are also simple. Complexity (nonsimplicity) lies between these two extremes of description.

The unknown territory in science and engineering lies between these two extremes of simplicity. The region of maximum complexity is where we know the least mathematically and have the least ability to make reliable forecasts.

It is where neither randomness nor determinism dominates; nonlinearity is everywhere, all interactions are non–local in space and time and some things are never completely forgotten. Here is where turbulence lurks, where the mysteries of neurophysiology take root, the secrets of psycho–social behavior are hidden, and the fog of war determines the fate of the battle. All the problems in physical, social, and life sciences that have confounded the best analytical minds for centuries are here waiting for the next mathematical-scientific concept to provide some light to guide the development of engineering control.

It appears that one of the better definitions of complexity is nonsimplicity for many of the same reasons that scientists tagged the complicated dynamic phenomena that were not linear as being nonlinear. This seemingly trivial shift in nomenclature enabled a way to discount the linear world view with a single phrase and form with what became a new mathematical discipline. The strategy was criticized, at the time, as consisting of a “zoo of non–elephants” since it was defining a concept by what it was not, but since the last half of the twentieth century it has grown into a respectable area of mathematical-physical science. In the physical sciences, this non–elephant definition appears under the rubric of nonlinear dynamics of chaos theory.

As a working definition, we consider nonsimple phenomena to have multiple interacting components, with emerging behavior that is entailed by, but cannot be immediately inferred from, the dynamics of its component parts, as would be the case using reductionistic descriptions. The nonlinear interactions generate a blend of regular and erratic variability in nonsimple phenomena, which enable them to adapt to a changing environment. At a minimum, it requires replacing ordinary calculus with scaling and fractional calculus [273].

The dynamics of nonsimple phenomena demand that we extend the research horizons beyond analytic functions and classical analysis. These forays suggest that the functions necessary to describe nonsimple phenomena lack traditional equations of motion, whether in extreme, nonsimple, extreme phenomena, (where Newton’s law does not describe the dynamics such as to the collapse of a bridge) to social phenomena (where Newton’s law is not expected to apply, such as to the downfall of a country). Consequently, replacing ordinary differential equations with alternative descriptions, whether linear or not, need to be developed, applied, and tested against empirical data. But perhaps, just as importantly, the reasoning forming the foundational understanding of the dynamics of extrema needs to be developed. It is, after all, this understanding that we want to use and communicate in this book, without explicitly introducing any mathematical formalisms.

Of course, there is another way to think about nonsimplicity, and that has to do with the number of scientific disciplines required to describe the behavior of a given phenomenon. Consider the altruism paradox (AP), which identifies a seemingly self–contradictory condition regarding the characteristics of species that Darwin originated. Some individuals in a number of species act in a manner that although helpful to others, may jeopardize their own survival and yet this property is often characteristic of that species. He also identified such altruism as contradicting his theory of evolution [64] and proposed a resolution to this problem by speculating that natural selection is not restricted to the lowest element of the social group, the individual, but can occur at all levels of a biological hierarchy, which constitutes multilevel selection theory [277].

The theory of sociobiology was developed in the last century and explains how and why Darwin's theory of biological evolution is compatible with sociology. Wilson and Wilson [277] were able to demonstrate the convergence of scientific consensus on the use of multilevel selection theory to resolve the AP in sociobiology. The resolution of such fundamental problems as the AP may be identified at the birth of each scientific discipline when new perspectives designed to ignore sciences thought to be irrelevant to new discipline. The nonsimplicity of a given phenomenon can, therefore, be measured by the number of different disciplines interwoven to describe its behavior.

One way to estimate the increase in the nonsimplicity of the phenomena being investigated is to count the number of published journal articles that have the word "interdisciplinary" in their title as done in Figure 1.4. The analysis pointed out by van Noorden [171], is based on journal names of more than 35 million papers in the Web of Science. These papers address 14 major conventional disciplines and 143 specialties. In the middle of the last century, the disciplines within the natural sciences and engineering appeared to be completely insulated from one another, whereas approximately 0.5% in the social sciences and humanities acknowledged the need to cross the barriers separating their own disciplines. By the present decade, 1% papers in natural sciences and engineering acknowledged the growth in nonsimplicity, whereas this number is 5 times greater in the social sciences and humanities. In both cases, the trend over this 60-year interval has been towards the study of phenomena with ever-increasing nonsimplicity.

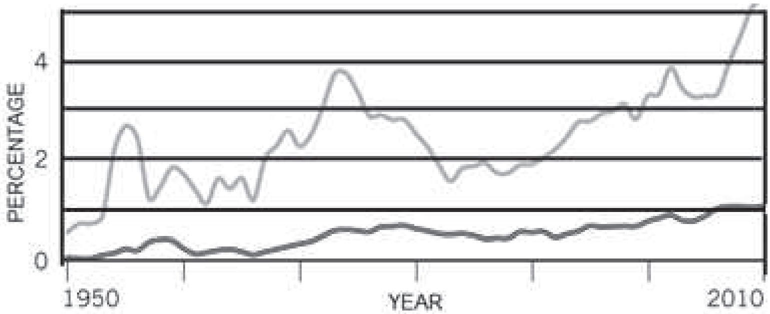

Figure 1.4: The percentage of scientific papers that have interdisciplinary in the title is graphed versus the year of publication. The two general categories are social sciences and humanities (upper curve) contrasted with natural sciences and engineering (lower curve). Reprinted with permission from [134].

1.3 Quantitative reasoning revisited

The implementation of the fractional calculus in the physical, social, and life sciences has languished because, until recently, the larger scientific community did not acknowledge a need for it and to a large extent, resisted its implementation. The calculus of Newton and Leibniz, along with the analytic functions that solve the differential equations resulting from Newton's force laws, have historically been considered sufficient to provide a proper and complete description of the physical world we see around us. Just to be clear, for this book, the point of view adopted is restricted to the classical world and quantum effects are ignored.

On the other hand, experiments indicate that a broad range of physical, biological, and social phenomena cannot be understood using the analytic functions we have come to rely on in the physical sciences. These functions do not capture the full nonsimple dynamics of common physical phenomena such as earthquakes and hurricanes [225], everyday social phenomena including group consensus [250], transitions from peaceful demonstrations to riots [98], the economic unpredictably of stock market crashes [153], high frequency finance [64] and the stability of healthcare networks [232], the familiar psychological activity of cognition and habituation [269], or the understanding of why networks fail [183], both locally and catastrophically. The inherent nonsimplicity of these phenomena and many others is beyond the scope of familiar nineteenth-century analysis, which, to a large extent, forms the mathematical foundation of present day physics and engineering. Understanding nonsimplicity as an extended class of problems, with common structural and mathematical properties, requires a new way of modeling and consequently more innovative thinking [243].

Phenomena that require the notions of non–integer dimensions, non–integer derivatives, and non–integer integrals for their interpretation were believed by most investigators to be interesting curiosities that lay outside mainstream science. We know that space has three dimensions. When time is included in the count, we have the four dimensions of the space–time continuum. But what does a 3/2 dimension look like? Ducking this question for the moment, we shall find that most phenomena do not conform to the simplifying fiction. Integer dimensions turns out to be one of those arcane notions whose time has run out.

The increased sensitivity of experimental tools, the enhanced data-processing techniques, the vast amounts of data made available by social media, and the ever-increasing computational capabilities have all contributed to the extension of science in such a way that those phenomena once thought to be outliers are now center stage. These curious processes are now described as exotic scaling phenomena [270, 271], whose descriptions quantify the coupling of variations in phenomena, processes and networks, across widely separated scales in both space and time.

An apparently different strategy, that of network science (NS), an out–growth of CS, has recently been used to model physical, social, and life science phenomena, in part because the nonsimplicity of phenomena in these disciplines emerges from nonsimple network dynamics. The nonsimplicity of networks may be broadly partitioned into structural nonsimplicity that relates to how the elements of a network are interconnected into a scale–free distribution, and process nonsimplicity that relates to the timing of significant events within network dynamics that is also scale–free. The scaling structure of networks has been widely adopted by the network science community as a measure of nonsimplicity and is a topic of discussion in textbooks, for example [169, 270]. Whereas what we call “process nonsimplicity” has been labeled “temporal complexity” and has only recently been identified as a significant measure of nonsimple network dynamics [271].

We note the lack of traditional dynamic equations in modeling nonsimple phenomena outside the physical sciences, which we explore by introducing fractional thinking. Such reasoning is a kind of liminal thinking that deals with moments; between the integer–order, such as the mean and variance. Then there are fractional moments, required when empirical integer moments fail to converge and between the integer dimensions there are the fractal dimensions that are important when data has no characteristic scale length. Between the integer–valued operators that are local in space and time are the non–integer operators necessary to describe dynamics that have long–time memory and spatial heterogeneity. Nonsimple phenomena require this in–between way of thinking, as well as modeling and scaling, along with fractional calculus [273].

The essence of our working definition of nonsimplicity is a process that balances regularity and randomness. We avoid using an overly constrained definition, because, like nonlinearity, nonsimplicity is defined by what it is not. In this way, we consider phenomena or structures to be nonsimple when traditional analytic functions are not able to capture their full richness of dynamic behavior. It was believed for centuries that physical theories, such as classical mechanics, could be used to describe the dynamics of highly idealized systems with absolute certainty and exactness. However, Poincare [185] found the flaw in that attractive clockwork view of the universe. It took over half a century for his discovery of the significance of nonlinear dynamics, including the non–predictability of chaotic trajectories, to influence the theories of mainstream physics. Historically, it was left to statistical physics to restore the mechanical description of nonsimple systems that uncertainty observed in actual measurements and to construct the associated probability density function (PDF) could be used as a measure of that uncertainty. The probability calculus provided the first universally accepted systematic treatment of physical nonsimplicity.

The shift in thinking from predicting a certain future for a dynamic object to a future filled with uncertain alternatives was accomplished by introducing probabilities to describe nonsimple systems. Empirical exemplars of such nonsimple phenomena are the time intervals between: earthquakes of a given magnitude [174], solar flares of a given size [98], breathing intervals [239], events recorded by electroencephalograms (EEGs) [94], events for optimal storage in human memory [8], and on and on. Many, if not all, empirical PDFs are inverse power-law. The average time between events, the first moment, often diverges. For these PDFs, there is no characteristic time scale for the underlying process, so the traditional assumption that time averages will coincide with PDF averages doesn’t work.

Empirical Power Laws	
Sociology	**Physics**
Actor networks	Earthquake magnitude
Alliance networks & firms	Earthquake time intervals
Blockbuster drugs	Ore size
City size	Solar flares
Citations	Temperature anomalies
Casualties of War	WWW connectivity
Co-authorships	**Physiology**
Consumer products	Bronchial trees
Copies of books sold	EEGs
Deaths of languages	Heart rate variability
Delinquency rates	Inter-breath variability
Distribution of wealth	Inter-stride variability
Distribution of family names	Mammalian brain
Firm size	Motivation and addiction
Growth rates of firms	Neuronal networks
Growth rates of GDPs	Radioactive clearance
Global terrorism events	Vascular networks
Internet links	**Psychology**
Italian industrial clusters	Decision making
Labor strikes	Cognition
Number of emails	Forgetting
Salaries	Psycho-physics
Social networks	Sexual relation
Supply chains	Trial and error

Figure 1.5: A non–exhaustive list of nonsimple phenomena having empirical inverse power-laws is given for four distinct disciplines. Adapted from [270].

It must be stressed here that one of the ubiquitous assumptions made in physics, as well as in most other science disciplines, is that the statistics of real phenomena described by an ensemble PDF have averages that are equal to time averages. Systems with this property have even been given a special name. They are called ergodic. The ergodic property is almost never realized in empirical data sets, however. It is one of those working assumptions made for mathematical convenience more than a century ago and is still accepted today, even when the data show it to be wrong. The argument, often given in the latter case, is that the process is only weakly non-ergodic, and consequently, the parallel assumption is made that ergodicity is not too wrong. But the size of the error made in a particular research context, outside narrow mathematical confines, is almost never checked, except by the most mathematically sophisticated. This particular failing is presently being changed in science, but the rate of change is not keeping up with the rate of change in society. Consequently, the application of nonsimplicity thinking, particularly within the military may have to drive the science, as it has so often done in the past.

It is important to have a perspective regarding the ubiquity of phenomena whose statistics are inverse power-law. They appear to be independent of context, occurring in geophysics, economics, sociology, medicine, astrophysics, and urban growth. In short, in every scientific discipline from Anatomy to Zoology. West and Grigolini [270] compiled a non-exhaustive but impressive list of empirical laws. These empirical distributions fall into the domain of ten distinct disciplines. Here we list some of those referenced [270] in Figure 1.5, but extend the examples listed within the social category, because they are most directly related to the purpose of this book.

1.4 Revolution in Military Affairs

The Revolution in Military Affairs (RMA) was a widespread movement in the military from the 1990s to 2010 that sought to improve and modernize military performance. The US military used the RMA phrase for its modernization efforts that rewrote doctrine, overhauled force structures, and developed new systems [229]. Military leaders used the term to convince Congress and other stakeholders that there was a reasoned, compelling, and logical rationale to perform their modernization tasks. However, the politics of the movement overpromised, and the RMA's conception of perfect situational awareness and full spectrum dominance never occurred. On the other hand, there was considerable real progress and potential remains in the RMA philosophy of nonsimplicity of warfare. The content of the Third Offset (the technological thrust involving the development of new military architectures) owes its character to RMA's reliance on nonsimplicity and its focus on information. The Third Offset represents a strong commitment to innovation and nonsimplicity in numerous information–based military systems. This paradigm shift in advanced technologies and modern doctrines is in the process of changing the fundamental character of the military.

Enhanced systems, technologies, and doctrines (e.g., precision strike capability, accurate and timely intelligence, situation awareness, reliable mobile communications, and distributed command and control capabilities) are elements of RMA that are now dominating modern warfare. These improvements in military operations have changed the face of modern irregular warfare and seek to do the same for conventional warfare. The RMA doctrines and processes for waging war (e.g., observe–orient–decide–act (OODA) loop, information warfare, network–centric warfare (NCW), mission command, system of systems (SoS), multi–domain battle (MDB)), are all powered by nonsimplicity modeling and information technology and influence elements of diplomacy and security affairs. These elements will be discussed in due course in this book. RMA needs to be understood not only by military officers, but also by strategic planners, diplomats, funding agencies, and military contractors. The RMA military now includes the cyber domain to add to land, sea, air and space, which combine to form the full range of military warfare domains. Military planners also consider political, military, economic, social, information, and infrastructure (PMESII) aspects in making policy recommendations [48, 76]. RMA built a new perspective of warfare, where valuable systems are less determined by raw kinetic power than the quality of their information collection, agility, mobility, communication links, stealth, targeting, sensitivity, resilience, and precision. Next on the RMA agenda are the inclusion of nonsimple capabilities of artificial intelligence, autonomy, and robotics. Through RMA, the United States military forces are preparing for modern nonsimple battle environments where speed, agility, intelligence, and versatility are of the essence.

At the practical level, RMA turned into an assembly of nonsimple innovations to achieve new capabilities, and in many ways, it accomplished its goals. It helped inspire innovative research and a deeper study in doctrine for all forms of operations, dazzling new high–tech equipment, and profound changes in military organizations. RMA has given the US military an informational advantage over potential adversaries and made the US military a more capable and versatile force. However, there are still questions about the effects of RMA: Is there more to do to build on RMA successes? Has the US military really fostered a culture that exploits these kinds of change? Did the military learn enough so it can develop and produce the next generation of nonsimple systems, leaders, and forces? Can visionary leaders use the new nonsimple doctrines and thinking to turn existing systems and forces into effective systems to fight future wars? Can the military cope with its internal competitive service parochialism to allow all services to grow and contribute to the RMA?

Building the doctrines to exploit RMA was a challenge, because there was very little experience to base these new concepts on–a result of the new revolutionary features of modern warfare being so different from what it had been previously [187]. This innovative process (paradigm shift) was difficult for the military, which takes pride in being historically based, with consistent principles and an experienced–based promotion system. These challenges and limitations are what made RMA only partially successful and still haunts its innovators. The paradigm shift from a traditional, simple, ordered, hierarchically structured military to a modern, nonsimple, agile, network–centric military is the ultimate transition challenge for an organization steeped in its history.

In many cases, the technological innovations are directly connected to doctrinal and organization change. Since the recent US experience is in low-intensity conflict (LIC) and mostly irregular, there is less confidence in RMA for high-intensity conflict (HIC). Some of the RMA innovations have been tested in their intended applications, but others have not been completely fielded or tested. Leonhard [138] argues that to create a technical advantage the military needs to adapt to prototype warfare, perhaps best described as a perpetual form of RMA and technology offsets, where many systems are in the form of experimental prototypes. Leonhard's vision of prototype warfare requires a new dynamic, where military forces are comfortable with deploying novel weapons and using novel tactics. The advantage of prototype warfare is its surprise to the enemy.

An example of a prototype system was the first set of unmanned aerial vehicles (UAVs). They were developed and used in LICs, but the newer, nonsimple UAVs (drones) will need to be more capable to join with many other new modern prototype systems in a HIC [101]. The Air Force has recognized the value of unmanned platforms and has trained and professionalized their operators. Through these new career fields for nonsimple, highly technical systems, the military is beginning to recognize itself as a nonsimple profession. There are still questions about the future since these new HIC systems have not yet been tested in a contested operational environment. Other examples of nonsimplicity RMA–initiated technologies are the networked command, control, communication, computers, intelligence, surveillance, reconnaissance (C4ISR) capabilities that have given the US military the ability to see the battlefield like never before. However, these C4ISR systems have operated solely in safe combat environments and have not been tested against enemy systems that could degrade their effectiveness [228].

What are the roles that cyber will play to protect the nation from threats such as Russian information operations, China's rapid advancement in information science education and research, and North Korea's hacking? Terminology and nonsimple modeling can help the military with system development and decision making. As Sulmeyer suggests in [233]:

> Maybe it's time we get away from using "cyber" as the description of what needs to be done, and instead think about what an Information Warfare Command would look like. The United States is really in an information war and it still does not have a plan on how to fight it? AI can help cyber.

The US should soon be able to significantly expand its powers of attack and defense in a cyberwar by automating capabilities such as probing, deceiving, and targeting enemy networks. Cyber operations are nonsimple by nature, yet they are a powerful and important part of today's RMA military force. As the military embraces its cyber forces and builds cyber doctrine and principles, perhaps cyber science will help the rest of the military embrace and understand nonsimplicity. As Cyber Command becomes a full combatant command and the incentive programs for service members who choose cyber-related fields are implemented, there will be more appreciation for the role of cyber and nonsimplicity in the military.

Several other long–term nonsimple technical and doctrinal development projects are finally entering defense spending and planning. Military innovations, such as the technologies of the Third Offset, have been informed by nonsimplicity and its role in military operations. Research and technological advances that enable the nonsimplicity of systems to function in a military setting have played major roles in these advances. For instance, technological and doctrinal innovation unfolded rapidly in the intelligence communities.

Analysts have shown, using nonsimple modeling and cognitive science, that information overload produced by sensor–rich, net–centric warfare may overwhelm soldiers and systems [43]. The operational control and decision making systems become bogged down from the sheer volume of information flow and processing. So even when technological and doctrinal improvements are fielded, their application can have an unexpected impact on the entire highly–connected, nonsimple system. This information–deluge situation indicates RMA was never at the full operational level that it was intended to reach, but it is well on its way to improving military capabilities.

The character of future war remains predicated on the development and understanding of new doctrine, the insights of national leaders into the international security environment, and the emerging technological and leadership capabilities. RMA has given the military a robust set of tools that can be rapidly adapted to meet unforeseen requirements in future conflicts, but are the military and national leaders ready and able to use these tools [194]? Even with all this progress, the fog of war and its stochastic nature leave nothing as certain. Modern military innovation is nonsimple and nonlinear. RMA technological or doctrinal improvements does not guarantee success in a future war. The United States military must ready itself to respond to potential near–peer, as well as, asymmetric conflicts.

The concept of the Fourth Generation of Warfare was first outlined in a 1989 *Marine Corps Gazette* article titled “The Changing Face of War: Into the Fourth Generation” [140] expanded in 2006 in *The Sling and The Stone* [102]. The previous generations of warfare show a steady increase in nonsimplicity. Characteristics of the generations are:

- 1st Generation: Line and column formation with smoothbore muskets. Troops fought in close order and advanced slowly. (seventeenth through nineteenth centuries)
- 2nd Generation: Linear fire and movement with some use of indirect fire. (World War I)
- 3rd Generation: Bypass enemy forces when possible and build defense in depth through speed and initiative. (World War II)

Fourth–generation is nonsimple and asymmetric, and often involves insurgents attempting to establish their own government. Fourth–generation warfare is often seen in civil wars with low–intensity conflicts, guerrilla operations, and terrorism. Technology, religion, cyber hacking, and politics can play major roles. Often the weaker adversary is decentralized and merely seeks to outlast the more powerful national military force through survival, slow attrition of the military, and erosion of its enemy’s purpose in fighting. The insurgents hope to convince the nation’s population and political leaders that their goals and reasons for fighting are too costly. The fourth-generation warfare is a blend of several different kinds of warfare, along with the use of new technologies.

1.4.1 Artificial Intelligence

> The complexity of warfare under conditions of intelligentization will necessitate a great degree of reliance on artificial intelligence. Artificial intelligence is expected to replace information technology... as the dominant technology for military development. [120]

Artificial intelligence (AI), machine learning, and autonomy are central to the future of the US military. Short–term goals in these fields are to develop systems that can absorb more information from sources than a human can, analyze data and information, and either advise the human decision-makers or take action. AI is becoming the main player in both the RMA and the Third Offset. The ultimate goal is collaborative human–machine networks that form smart, agile teams. AI will have a tremendous impact through its nonsimplicity on the modern military. AI technologies such as autonomous aircraft, cruise missiles, robot hackers, and machine analyzed video will make the military more powerful and much quicker in its decision making. AI also physically and informationally creates moral, political, and diplomatic issues. The US military has been funding, testing, and deploying various shades of AI that are similar to the AI that invigorated companies such as Google and Amazon. This kind of knowledge and capacity are poised to boost military innovation and capabilities. In the near–term, America's strong public and private investment in AI may give the US new ways to hold on to its position as the world's leading military power. For example, more intelligent and mobile ground, aerial, underwater, and surface–water unmanned vehicles that collaborate with troops will benefit from the expertise developed from drones and uncrewed ground vehicles used in Iraq and Afghanistan. Using these advanced systems will allow fewer humans to be on the frontline battle. The US already has AI–powered technologies such as intelligent report writing, advanced interactive visualizations, virtual reality, rapidly updated maps, and automated situational awareness reports and broadcasts. And logistics technologies such as drone delivery, self–driving vehicles, and 3–dimensional printing could become valuable military enhancements for asymmetric warfare.

There are still many important issues in AI to resolve. AI makes it possible that smaller nations and non–government organizations can threaten and potentially succeed against greater powers, such as the US. Debate in the military over the use of autonomous AI systems to kill people, without having a human in the decision–making loop, is presently taking place and will be a significant issue for society to resolve. A major concern is that a set of autonomous killer robots will one day be on the loose. The laws of warfare consider issues like proportional action against an enemy. Can AI make these judgments as well as humans do? Scientists are concerned that the development of autonomous weapons systems could lead to indiscriminate killing, or a new kind of military AI arms race.

Even if we wanted to, we would not be able to slow down the advancement of AI [83]. The competition for this powerful technology is too great to put any constraints on its development. AI will not be exploited by one military force without the development of other AI or cyber systems. However, once built, AI systems should be subject to the full extent of the laws that apply to its human partner or operator. AI should be sufficiently regulated that it is apparent that it is not human. The theory and application of nonsimple modeling for decision making enables AI algorithms to combine experts' advice that can be captured in the form of a causal network and then combined into a summary. Many nonsimple elements of information science contribute to the development and use of AI.

The future battlefield will be about data, its flow and the ability to manipulate data. Data will be a powerful weapon and intelligent nonsimple systems that collect, move, filter, process, and decide will constitute the military's most lethal systems. Use of this kind of AI in processing data is just beginning to reveal its usefulness to the military. One of the most difficult parts of integrating current AI with the military culture is the reluctance to fully trust AI that is created by machine learning. AI is able to process and fuse the influx of Big Data from many kinds of sensors and collectors. As stated in Romeo Ayalin II and Megan Brady's article titled "Visualizing Multi-Domain Battle 2030-2050" [18]:

> The key is to find ways to use data processing, exploitation and dissemination with fewer people.

One of the fastest growing fields in nonsimple military modeling is computational intelligence, which is a subset of AI. Journals such as *Mimetic Computing, Machine Learning & Cybernetics, Ambient Intelligence & Humanized Computing,* and *Computational Intelligence Journal* are leading efforts to build the science to enhance nonsimple AI for the military. AI tools for big data analysis still need nonsimple modeling and mathematics to enable the real-time processing of large volume, high velocity, and multiple variety data streams. Big Data AI processes are capable of more comprehensive and integrated analysis than human analysts. Therefore, the military needs AI to become integral to its entire intelligence process [17, 20, 23, 27, 29, 36].

1.4.2 Hyperwar

In its extreme utilization, AI helps to produce a form of hyperwar. Hyper–warfare is about the dramatic speed increase enabled by automating decision making and concurrent processing of data [7]. Hyperwar will go beyond current capabilities in several important ways, as it eliminates human decision making inside the OODA loop. The time delay associated with a human decision cycle will be reduced to near–instantaneous decisions. Up until now, the decision to take military action depended on human thinking and tedious decision making. However, human decision making has tremendous limitations in terms of speed and attention to detail. Two basic variables in the decision making process are time and information space. The time to form and execute kinetic action and the position or knowledge of the information space where the action is executed. Nonsimple operations take significant amounts of strategic, operational, and tactical data, information, and doctrinal decision making. Taking into account possible contingencies about the enemy's capabilities, AI ensures that plans are able to quickly become hyperwar operations and battles. At the tactical level, the hyperwar AI uses its data to identify targets, move forces, direct fires, coordinate actions, and keeps everyone informed. The concurrent actions of AI systems outpace even the most efficient human command and control.

In modern hyperwar, Autonomous Unmanned Vehicles (AUVs) of various types and sizes will be the agile, nonsimple force that serves as foot soldiers, helicopters, tanks, aircraft, ships, submarines, and aircraft carriers. Swarming and mobility will allow forces to coordinate, assemble, act, and dissipate rapidly [7]. Their sensors will provide vision to share and their decision algorithms will operate in appropriate ways on the AUV, in its swarm, and in centralized locations. These systems only require energy and ammunition and, therefore, can operate for extended periods of time without rest or recovery. The logistical demands for an AI–based AUV force are reduced.

Through its use of AI, modern hyperwar is the next great shift in warfare. The fusion of distributed AI with mobile AUV systems produces speed and concurrency for the hyperwar technologies. The rise of these capabilities was sparked by RMA. The ability of AI to improve weapon systems is happening in many militaries around the world. The speed of battle will accelerate to give the advantage to the side with better AI. At the operational level, AI will enable engagement with enemy formations far more quickly and thoroughly. At the strategic level, near-instantaneous analysis of information will provide better situational awareness and options.

It is interesting that the Russian Chief of the General Staff, Valery Gerasimov, articulated the parallel development of Russian military thinking regarding modern warfare. He observed that the very "rules of war" have changed and endorsed the historical observation that war is diplomacy by other means, but emphasizes that Russia must develop non–military means beyond those of physical conflict. Taking into account the protest potential of a target population, the applied means of conflict ought to include "the broad use of political, economic, informational, humanitarian, as well as other non-military measures." In this way Gerasimov proposed a strategy that combined military and non–military means to weaken from within an adversaries' cohesion and like the new rules of war proposed new theories of victory.

Consequently, the change in the character of warfare entails looking beyond technology and for the military professionals and social leaders to engage in a dialogue to determine new and different ways to impose a nation's will on its adversary [88, 91].

> ...A scornful attitude toward new ideas, to nonstandard approaches, to other points of view is unacceptable in military science. And it is even more unacceptable for practitioners to have this attitude toward science...Any academic pronouncements in military science are worthless if military theory is not backed by the function of prediction.

There is considerably more to develop and understand to make RMA–inspired hyperwar a reality. We need to understand the moral dimensions of these advances, educate leaders, develop nonsimple AI–powered information systems, and build entire forces of AUVs. Moreover, to make RMA a reality, the US needs to invest more in basic research (nonsimple modeling, CS and information science) to develop the tools for hyperwar.

1.5 Historical Context of Military Nonsimplicity

History is not the only tool to understand warfare, but it can provide context and insight for the military professional.[1] The history of warfare must be continually reassessed, since the understanding of events continuously evolves with the discovery of additional information and the inclusion of new and diverse perspectives. In this section, we include background on military nonsimplicity from a historical and theoretic perspective. We attempt to set our nonsimplicity theories and analysis in this context of the evolving intellectual profession of military doctrine and philosophy. It could be said that military professionals too often take lessons from historical events and turn them into fixed principles that create a too–structured, too–doctrinally static force. Taleb writes [240] that "humans are great at self–delusion" because they are able to make "historical events seem logical, orderly, and inevitable." Military leaders have often failed when they blindly followed a historically–based framework that was not analyzed with intellectual scrutiny for the military operational situation that was being contested. History itself is a process that does not conform to a linear logic, nor to simplicity. Believing that history is orderly and static hinders military professionals from understanding new contexts and using nuanced principles of warfare. Torrence [246] was clear in describing the role of nonsimplicity in history when he wrote:

> Officers must avoid self–delusion when studying history. To avoid self–delusion, military professionals need to challenge existing hypotheses and keep an open mind. Military professionals benefit from long–term studies devoted to military history. Analysis of military history creates an opportunity for military professionals

[1]The major portion of this section was contributed by J.T. McCormick.

to identify abstract principles of warfare that apply to evolving problems and to deepen their understanding of the military profession.

In recent years “winning” and “complexity” have become buzzwords within military circles. *The Army Operating Concept, Win in a Complex World* [247] and *The Army Vision –Strategic Advantage in a Complex World* [251] both emphasize the growing chaos and nonsimplicity of the current operating environments, as well as the necessity of the US Army to become agile and adaptable enough to respond to these challenges. Although technological and social trends are certainly making the world a much more nuanced place, warfare has always been among the most intricate and captivating of human endeavors and its recognition as such is hardly new. Military affairs can be understood from many distinct perspectives and analytic frameworks, demonstrated by the abundance of martial theories and doctrines put forth across history. Most doctrines have merely approached the problem from a specific point of view and, though the best often acknowledge the limitations of this approach, the majority of theorists present the resulting conclusions as universal truths of war.

The military theories that have endured the test of time are those that distinguish themselves by grappling with the nonsimplicity at the heart of warfare. Specifically, the two works that most clearly embody this trend are Sun Tzu’s ancient text, *The Art of War* [236], and Carl von Clausewitz’s masterpiece, *On War* [56]. Anyone passably familiar with military theory would recognize these two books as the most influential, renowned, and widely read of the field. Likewise, they are perhaps two of the most misunderstood and most frequently misused. Clausewitz and his work have been criticized for promoting an extreme form of total war devoid of political oversight; yet, this is not the reality of his theory [103]. Alternatively, Sun Tzu’s staccato style of presenting concise, insightful observations made his positions particularly easy to distort and misrepresent [103]. In a 2011 article discussing *The Art of War* and Chinese soft power, *The Economist* [78] described Sun Tzu as “the author of pithy aphorisms beloved by management gurus worldwide” and later stated “The Art of War is widely used by after–dinner speakers short of ideas.” Regardless of this abuse, scholars and warriors still widely consider the strategic theories of Sun Tzu and von Clausewitz as among the most important and influential.

It is interesting to consider why these two works have maintained such prominence over the years. Without even mentioning the vast differences between the men, history, and cultures that produced the works, the two could not be more superficially different. The standard English translation of *On War* stands at more than 600 pages and is accompanied by a 70-page "Guide to Reading *On War.*" The Art of War is little more than 6,000 Chinese characters and translates to only 10,000 words in English. This brevity is not because of a lack of content, but a reflection of Sun Tzu's highly polished and concise language. In contrast, Clausewitz at his death considered his own work unfinished, writing, "The manuscript . . . can be regarded as nothing but a collection of materials from which a theory of war was to have been distilled" ([56], 70). Anyone who has struggled through the turgid behemoth that is *On War* would agree with this sentiment. Beyond these transparent differences, there are notable differences in the authors' methodologies, conclusions, and general opinions. Though these discrepancies have perhaps been exaggerated, they are mostly well documented and studied [103]. Indeed, for the most part, scholars study the works separately, as almost completely alien perspectives on warfare.

While acknowledging these differences, we would contend that there is a common element in both works that explains why they have intellectually captivated readers for centuries and justifies their continued relevance today. This key similarity is nonsimplicity. Both Sun Tzu and Clausewitz recognized that warfare is neither fully probabilistic, nor fully deterministic, that all outcomes are the result of many intricately connected factors, that there will never be a single optimum operational approach to warfare, and that each war's results are contextual and cannot be generalized. Both authors would agree that nonsimplicity is an inherent element of warfare. Without this understanding of nonsimplicity as a general principle of warfare, it is doubtful that any work written hundreds or thousands of years ago would have any relevance to the modern warrior. Examining the texts with complexity science in mind makes these connections evident. Additionally, understanding Sun Tzu and Clausewitz from the perspective of nonsimplicity highlights key differences in their martial theories and how they recommend dealing with the inherent and nonsimple elements of uncertainty, interconnectedness, and contextuality of warfare.

In the case of *On War*, we are hardly the first to make the case that modern complexity science shows deep connections with this earlier text. Beyerchen [29] made the case that Clausewitz not only intuitively understood the nonsimple (nonlinear) nature of warfare, but also that this nonsimple nature inhibited reliable predictions of the military outcomes and prevented the creation of a universal theory of warfare [29]. Indeed, anyone familiar with nonsimple mathematics and its theoretical underpinnings will instantly recognize how nonsimplicity is thoroughly ingrained into Clausewitz's understanding of warfare. Yet, as Beyerchen points out, this begs the question as to why this connection has not been more widely noticed. Perhaps the siloing of military academics into STEM and humanities, preventing complexity theoreticians from reading *On War* or vice versa, at least partly explains why this perspective has not gained more traction. Alternatively, this divide may explain the pervasiveness of linear, simple, and reductionist thinking in military circles that Clausewitz explicitly fought against [29].

Examples of nonsimplicity in Clausewitz's theories abound, and it is illustrative to note some of the more significant ones. The most straightforward example is the inclusion of chance in the famous Clausewitzian trinity of passion, chance, and reason. More so than the other aspects of the trinity, Clausewitz sees uncertainty as ubiquitous, describing warfare as "continuously [and] universally bound up with chance" ([56], 85). As highlighted in Beyerchen's work, Clausewitz repeatedly discusses the difficulties of deriving general theories or Newtonian–like deterministic laws for warfare. In one such digression, Clausewitz states, "As we have seen, the conduct of war branches out in almost all directions and has no definite limits; while any system, any model, has the finite nature of a synthesis" ([56], 134). Rejecting generalized principles of warfare, Clausewitz instead argues that each conflict should be understood contextually and holistically. Here Clausewitz's argument sounds like an excerpt from a modern network science book, or complexity science paper ([56], 158):

> But in war, as in life generally, all parts are interconnected and thus the effects produced however small their cause, must influence all subsequent military operations and modify their final outcome to some degree, however slight.

Undoubtedly, many people familiar with Clausewitz will instinctively take issue with the notion that his theories share the intellectual ancestors with modern complexity science. Indeed, one of the most cited Clausewitz quotes is the trite, "Everything in war is simple, but the simplest thing is difficult" ([56], 119). Some might suggest that if everything in war is simple, then war itself is simple, or ought to be simple. Moreover, these same critics would likely also assert that the US Army should be more oriented towards precepts of Clausewitzian total war. However, these arguments are flawed for a number of reasons. First, the quote is taken from the chapter introducing friction, a concept Clausewitz uses to explain why war may be simple in theory, but rapidly becomes nonsimple when enacted in real life. Moreover, arguing that because the individual tasks of war are simple the whole task of war can be made simple is an inherently flawed form of linear and reductionist logic; it is this type of thinking that we, in the tradition of Clausewitz, discourage.

There may be several reasons why Clausewitz often seems incredibly reductionist and simplistic (for example, his guidance to always seek the destruction of enemy forces, focus on a center of gravity, and his belief that defense is a stronger form of warfare than the offense). One reason is the difference between a descriptive and prescriptive reading of Clausewitz, as noted by Martin [154]. A prescriptive (or pragmatic) reading for specific answers and guidance on how to win wars (treating Clausewitz as a scripture of warfare), leads to the application of Napoleonic principles to modern wars. Clausewitz himself rejects this notion, but nonetheless many of the arguments lead to such a conclusion. On the other hand, a descriptive (or theoretical) reading builds an analytic model that develops a nonsimplicity–based understanding of the abstract nature of war. This descriptive perspective suggests that one must understand the nonsimple elements of war since all conflicts are different.

For many years, the US Army encouraged a pragmatic interpretation of Clausewitz, leading to a doctrinal dogmatism in which *On War* is the Old Testament prelude to a gospel according to Army Training and Doctrine Command (TRADOC). Another reason to interpret Clausewitz as simplifying reductionism lies in Clausewitz's method of dealing with battlefield nonsimplicity by placing the mitigation and management of chance strictly under the commander's auspices. This explains Clausewitz's emphasis on commanders possessing coup d'oeil (the ability to cut through extraneous and false information straight to the heart of events) in order to break through nonsimplicity and understand things simplistically. When Clausewitz reverts to this explanation, it plays to a nonexistent form of magic, or military genius. Of course, this obfuscates the truth of military decision making and hides the modern scientific reality—no one possesses cyber coup d'oeil–even though they may have a great understanding of complexity science.

Arguing that Sun Tzu's military theories are embedded with nonsimplicity will likely draw less criticism. Sun Tzu predates Clausewitz by a millennium; and while there are many connections and similarities in their writings, Sun Tzu represents an almost opposite worldview and perspective to those of Clausewitz. Sun Tzu describes warfare with complicated terminology and ideas, but his mismatch in actually understanding nonsimplicity is ultimately displayed in his emphasis on the deterministic elements of war. Sun Tzu writes that nothing should be left to chance. If something is unknown or unpredictable, then it is the fault of the commander. Therefore, rigorous control of intelligence, reconnaissance and planning are the essential elements of operational success. Acute knowledge of one's own forces is essential as well. Of course, they are nonsimple tasks and Sun Tzu describes them in that manner. He goes on to encourage commanders to manipulate the presence and occurrence of nonsimplicity. In particular, he promotes the use of deception, asymmetrical and irregular tactics, psychological warfare, and counterintelligence. Perhaps most importantly from a nonsimplicity point of view is that the military force must remain inscrutable and enigmatic at all times. For these reasons Sun Tzu's theories are often lumped into a category with other early insurgency theorists, such as the twentieth century theoretician T. E. Lawrence.

Using mathematics–based terms and conceptions, Sun Tzu proposes that by sowing confusion and chaos, a commander may throw his opponent into a stochastic state, in which actions and outcomes seem completely random. Sun Tzu requires his force to remain in the more orderly deterministic state where he is (mostly) in control. This is almost the exact opposite of the Clausewitzian relationship to nonsimplicity. Rather than reducing nonsimplicity through simplifications and the mental heuristics of commanders, as Clausewitz would recommend, Sun Tzu recommends increasing the nonsimplicity of the conflict and then relying on flexibility, mental agility, and physical maneuverability to gain an advantage. In his framework, the adversary will never be able to control the nonsimple situation, like the friendly force is able to do. In practice, this is achieved by:

- Synchronization of apparently disparate forces (self–organization)
- Disruption of enemy intelligence, surveillance, and reconnaissance (ISR), while building a massive and effective friendly ISR system
- Inclusion of espionage and information warfare
- Psychological attacks on morale
- Highly mobile and flexible forces
- Battle avoided until success is all but guaranteed

New theories and frameworks like ours on nonsimplicity and complexity science can be oversold, misunderstood or misapplied. This was probably the fate of network-centric warfare (NCW). Encouraged by the rapid success of the first Gulf War, many theorists jumped on the bandwagon of the concept of RMA, with its associated technological offsets. The central idea was that a combination of technological advances and doctrinal changes created a force that would achieve strategic success with little cost. After the initial success did not sustain, some argued that NCW was never fully developed or implemented and that is most likely the case. The Army, despite enhancing some of its communication systems, never successfully enhanced its information–processing systems or made changes in force structure to produce effective networked communication or information processing.

Prior to the Global War on Terrorism (GWOT) and during the time that NCW/RMA theorists reached their peak, another camp of military thinkers was pushing the importance of the human angle in future conflicts. This school of thought is associated with the notion of the 5th Generation of Warfare (5GW) in which conflicts are increasingly politicized and focused on stability operations (for example, Kosovo, post–invasion Panama, and post–genocide Rwanda). The 5GW theorists and other counterinsurgency thinkers set a precedent for the Army's transition to counterinsurgency (COIN) approaches in the Middle East. Many of these theorists and historians served on General Petraeus' committee for writing the FM 3–24 doctrine for COIN. After a long period of floundering and misunderstanding of the conflicts in Iraq and Afghanistan, COIN was finally adopted in Iraq and later in Afghanistan. COIN is a form of nonsimplicity doctrine in that it acknowledges the nonsimplicity of pacifying a foreign population with the diffusion of ethnic, tribal, and personal ties that are pulling in many diverse directions. It also decentralizes intelligence assets and decision making to self–adapt the force and its operations to the continuous nonsimple situations of counterinsurgency operations. The COIN doctrine sought to maintain cohesion and focus of effort by designing an adaptive system with self–organization and resilience.

Though the issues of cultural nonsimplicity were a focus of COIN, there was little analysis using deeper organizational or mathematical perspectives. For most Army officers executing COIN operations, complexity simply meant complicated. The concepts of COIN and the implications of the GWOT for advancing military theory were summarized, analyzed, and enhanced by Simpson in *War From The Ground Up* [214]. These theories were found wanting by some military scholars, not because either was wrong, but because both were only partially correct, or partially implemented. The political and cultural dimensions of war have become heightened, and 5GW forces need better and deeper collection and analysis of information, using more powerful and nonsimple network and computational technology. Most importantly, today's nonsimple threats and information operations [11] have merged into an increasingly widespread operation known as hybrid warfare [71].

To meet these threats, hybrid warfare fuses conventional, irregular, and cyber operations into an agile, synergistic fighting force. Both Russian and Chinese military doctrines have embraced and adopted a form of hybrid warfare. Hoffman explains [111]:

> Hybrid threats incorporate a full range of modes of warfare, including conventional capabilities, irregular tactics and formations, terrorist acts that include indiscriminate violence and coercion, and criminal disorder. These multi–modal activities can be conducted by separate units, or even by the same unit, but are generally operationally and tactically directed and coordinated within the main battlespace to achieve synergistic effects in the physical and psychological dimensions of conflict.

The US military services were slower to advance these concepts and were reluctant to address it in doctrine. That has changed with hybrid warfare's success in the Ukraine and South China Sea. By refusing to identify the nonsimplicity of hybrid threats or addressing the need for a new form of warfare, the US was committing the cardinal sin of reductionism—assuming the whole is equal to the sum of the parts. The US tried to glue together the elements of NCW, COIN, mission command, and OODA loop to cope with hybrid threats. Finally, in 2010, the Army began to acknowledge this shortfall by authoring a 75–page pamphlet on hybrid threats [71]. This is undoubtedly a new form of warfare, which will push the limits of the still simplicity–based Army and will necessitate philosophical, organizational, and doctrinal changes in the form of nonsimplicity.

The Navy has similar concerns and reactions as the Army [106]:

> Maritime hybrid warfare is simply hybrid warfare conducted at sea or in coastal regions and resides in a grey zone of conflict short of open warfare. This is generally achieved through deniable operations, such as cyber–attacks or irregular forces.

Others see CS (complexity science) as the fundamental evolutionary principle for future improvement of the military. Calhoun [46] sees the current Army RMA transformation in conflict with the principles of complexity science, network science, and dynamic systems. He is an advocate for change—just a different kind of change than what he sees happening in the Army or what is projected for the future. To the complexity scientist change based solely on technologies to better prediction and provide more certainty is doomed. He writes that "complexity science is the one possible source of sound theoretical principles that could provide a guiding framework to the transformation process." He would like to see more innovative change efforts at all levels, more education in nonsimplicity, and cultural change in addition to advances in weapons and information technology. Rather than using technology as the change agent to lift the fog of war, Calhoun seeks nonsimplicity–based cultural innovations in organization, doctrine, and operational design. Calhoun's form of nonsimplicity seeks to embrace a form of military nonsimplicity that operates on the edge of chaos.

How does nonsimplicity affect the levels of warfare? Classical military theorists who rely on simplicity as a military principle suggest that most tactical situations have only a few potential alternatives and an even smaller set of right answers for tactical actions. Therefore, military professionals recommend a specific tactical maneuver to be employed in specific situations. The US Army, for instance, heavily relies on the basic concept of Battle Drill 1A. This would suggest that there may be little role for new conceptions of nonsimplicity in conventional tactics. However, that point of view has been changing dramatically with the increasing nonsimplicity of modern operating environments, such as megacities and space–cyber operations, and the integration of autonomous systems at the tactical level, such as surveillance drones.

Nonsimplicity, and AI in particular, directly effects the selection of operational formations (COIN, conventional, special operations, etc.) and the design of logistic and communication networks and the use of specific operational processes. In particular, nonsimplicity plays a very clear role in force structuring, unit movement, and force positioning. Many of these functions are currently performed by operations research analysts using computational tools, predictive analytics, and stochastic forecasting, but more and more of these functions will be performed in the future by AI systems.

At the highest levels of warfare, nonsimplicity dominates the future landscape of decision making. AI will help determine strategic goals and policy objectives. Strategy, as the interaction between political ends and operational means, is subject to a number of highly complex elements that do not lend themselves easily to simple analytics and quantization and are more appropriate for complexity science and qualitative modeling. Simpson's [214] suggested strategy is as much about crafting a forceful narrative as it is about achieving concrete goals. Strategy becomes even more nonsimple when the conflicting sides do not agree on what the war is about, and therefore asymmetrical, nonsimple narratives are involved in military operational decision making. Since nations rarely go to war for one reason, or with one goal in mind, adversaries' goals compete along with the military forces. Often internal politics within competing nations complicate war efforts. When coalition warfare is factored into the operational situations, the issues include the structure and operation of the collation network and strategy becomes more nonsimple to design and execute. In future warfare, nonsimplicity in the forms of machine learning and AI predictive analytics will help strategists unravel the multitude of interlocking interests and craft the strategic narratives.

1.6 Future Context of Military Nonsimplicity (Futures Command)

The United States Army Futures Command (AFC) was established in July 2018 with the intent of being fully operational by July 2019 [75]. The Command's headquarters will be in Austin, Texas, with operating agencies in many locations around the country. AFC will lead the Army's modernization efforts by integrating the future operational environment, threats, and technologies to develop new concepts, requirements, opportunities, and force designs. AFC will ultimately build the concepts, requirements, and designs of combat and information systems.

AFC seeks to unify the modernization efforts using a combination of research innovation and practical military needs. In addition to the new headquarters, the AFC will include many of the current Army analytic and research agencies such as Army Capabilities Integration Center, the Capability Development and Integration Directorates with their battle labs, TRADOC Analysis Center, Research, Development, and Engineering Command with its numerous laboratories such as Army Research Labs and Army Research Office, Army Materiel Systems Analysis Activity, Center for Army Analysis, and many other agencies.

To cope with the nonsimplicity that is inevitable in such an effort, AFC has an integrating structure in the form of cross-functional teams. These small coordination teams will be led by military officers and filled with experts from the military and civilian research communities. The first eight of these teams are: long-range precision fires; next generation combat vehicle; future vertical lift; command, control, communications, and intelligence; assured position, navigation and timing; air and missile defense; soldier lethality; and synthetic training environment. Much of the emphasis on future science and technology has no choice but to determine and promote nonsimplicity's role in the future. All the sciences—especially operations research, network science, systems engineering, cyber science and high–performance computing—will shift their paradigms to the holistic form of nonsimplicity to work on the most complex and demanding military problems. Several of the AFC sub–agencies are data–focused; therefore, nonsimplicity will play an important role in the success of many of the endeavors of this command. Using innovative research and development, realism, and practicality, along with the Army's new concept of a streamlined acquisition process, AFC hopes to produce new modern doctrine and new modern systems that can be rapidly developed and fielded. A form of sustainability is desired as well, where whatever is developed in the future will have the potential to be expanded and updated as technology shifts and improves.

Military service members, scientists, and analysts need to shed the cognitive constraints and simplicity of Machine Age thinking and learn to apply nonsimplicity thinking to modern Information Age problems. One way to start is to modernize and enhance the services' professional military education (PME) programs and schools with deeper thinking and rigorous problem–solving curricula. These PME programs need to embrace nonsimplicity to inspire their students to engage in complex modeling and interdisciplinary problem–solving challenges. Members of the Army's Futures Command will need to develop and deliver concepts and force designs, model new force structure, integrate cyber operations and new technologies, and ask, if not solve, many of the military's most vexing problems.

Education of service members and the intellectual development of scientists, analysts, and technical leaders are the primary instruments of modern military power. A military force cannot be successful without smart people making wise decisions, talented thinkers solving challenging problems, and insightful leaders building sustaining infrastructure. Smart, dedicated, and hardworking people make a military strong and capable. Modern data science with its elements of nonsimplicity, modeling, problem solving, and interdisciplinary learning must play significant roles in PME. In today's world, digital generals who understand nonsimplicity have become as important to national security as military generals. The modern military needs people who are digitally and technically savvy, understand the science of nonsimplicity, and are strong leaders. Hopefully, these future leaders will use nonsimplicity to build the US military's advantage. Perhaps one of Future Commands' most compelling decisions will be to decide on the future resource allocation between artificial intelligence and human education and the role of cyber operations in military conflict and diplomacy. These are extremely important to the future of not only the US Army and military, but for all of society.

CHAPTER 2

THE MILITARY IS NONSIMPLE

> Solutions to military problems are complex and convoluted, are seldom self–evident and may actually be contradictory...[w]arfare constantly evolves and reconstitutes itself...mangling and ruffling itself in new and wondrous ways that are rarely evident. [138]

The United States military is a highly–structured, hierarchical institution that operates advanced and complicated Industrial Age technological systems and equipment. That unto itself is a dangerous, unbalanced, combination. Hierarchy was fine for the military of 1955, but it is less than ideal for the twenty–first century. The United States government often gives its military nonsimple missions typical of the modern Information Age (post–industrial age) world such as modernizing Afghanistan, keeping peace in the Middle East, curing Ebola in Africa, and stopping piracy along the African coasts. Yet, through the discernment of nonsimplicity modeling, we reveal that we have the wrong organizational structure, with the wrong people (especially the leaders), trying to accomplish the impossible. The US military needs to be revamped and modernized on all levels: from private to general officer, from pistol to drone, from submarine to satellite, and from basic training to the war college. The 1955 vintage version of the US military, which we currently have, even with more money, advanced technology and weapons, huge logistical facilities, and uncounted improvements and modernizations, cannot accomplish the modern nonsimple missions with which it is tested.

Contradictory demands increase as organizations and their environments become global, more dynamic and increase in head-to-head competition. The subsequent tensions between conflicting alternatives can be understood and explained by viewing them through the lens of paradox. One definition of paradox involves the logical contradiction of two elements that are interrelated, exist simultaneously, and persist over time. Smith and Lewis [219] highlight the two components of paradox: 1) underlying tension—elements that logically seem to be individual, but are contradictory when placed together in a common context and 2) responses that embrace tensions simultaneously. In Chapter 5, we introduce a model, called the self–organized temporal criticality (SOTC) model, which takes into account the fact that tensions (paradoxes) are inherent and persistent in nonsimple organizations, like the military, but can be simultaneously manifest without contradiction.

Paradox resolution does not entail suppressing one or the other side of the tension, but instead requires dynamically determining a way of complying with both demands, or considering divergent ideas, at the same time. The SOTC models a continuous motion across opposing forces, to achieve a steady state by adapting to a continuous pull in opposite directions.

Military institutions are grounded in the past (leaders focused on history) and preoccupied with the present [93]. This results in great difficulty in considering the future. The units, organizations, agencies, and the services are involved in an intense competition for funding that provides an unhealthy parochial scramble for resources. But the worst element in the military's look to the future is that it has the wrong focus. Military leaders still believe that kinetic lethality, platform firepower, survivability of systems, and battlefield mobility are all that matter [93]. There is little consideration of cyber, intelligence, communications, or logistics. So the services still believe in programs that provide power systems and platforms in their focus areas and rarely think about overall capabilities. This concentration of decision making based on winning resource allocations is stifling to progress and sets the stage for problems in future operations.

2.1 Paradox: private and public

> But one must not think ill of the paradox, for the paradox is the passion of thought, and the thinker without the paradox is like the lover without passion: a mediocre fellow. But the ultimate potentiation of every passion is always to will its own downfall, and so it is also the ultimate passion of the understanding to will the collision, although in one way or another the collision must become its downfall. This, then, is the ultimate paradox of thought: to want to discover something that thought itself cannot think. [121]

If you belong to a military organization you probably find that the other members of your organization have more stamina, can run farther, climb faster, jump higher, are in all around better physical condition, and are overall more capable than you are. Consequently, you are probably less capable than are your military friends. A Capability Paradox arises from the fact that your military friends are probably less capable than are their military friends, as well. The implication is that everyone in the military is probably less capable than everyone else in the military, and therein lies the inconsistency that constitutes the paradox. How can everyone in the military probably be less capable than everyone else in the military?

This new paradox is similar to the Friendship Paradox, or Happiness Paradox, both of which are a consequence of the network structure of social media [34]. The Friendship (Happiness) Paradox asserts that within a social network most individuals have the experience of being less popular (happy) than their friends on average. The connectedness of individuals on social networks has been used to explain the counterintuitive nature of the paradox, often relying on the arguments of graph theory to make the point. Here we use statistical arguments that are hopefully more intuitive and, if nothing else, their familiarity will be increased through repeated use. Consequently, we explain the Capability Paradox in terms of how we map out the world within our brains, including the treatment of uncertainty and gaps in knowledge. Using that cognitive map, we think of the distribution of physical capabilities among people as being statistically normal, which is to say that its statistics are determined by the mode and width of a bell–shaped curve. A simple characteristic, such as height, has a variable data set over a large collection of soldiers. These data when ordered into equal sized bins, from smallest to largest, form a bell–shaped distribution, from which it is possible to determine an average height. This is typical of the collection and a standard deviation, which quantifies how well the average characterizes the distribution of heights. The heights of young adult males in the United States are empirically determined to be normally distributed as depicted in Figure 2.1. Presumably, the normal distribution does so well in this case because an individual's height is determined by stringing together a number of bones, each of which is statistically independent of the others, but each having a typical length.

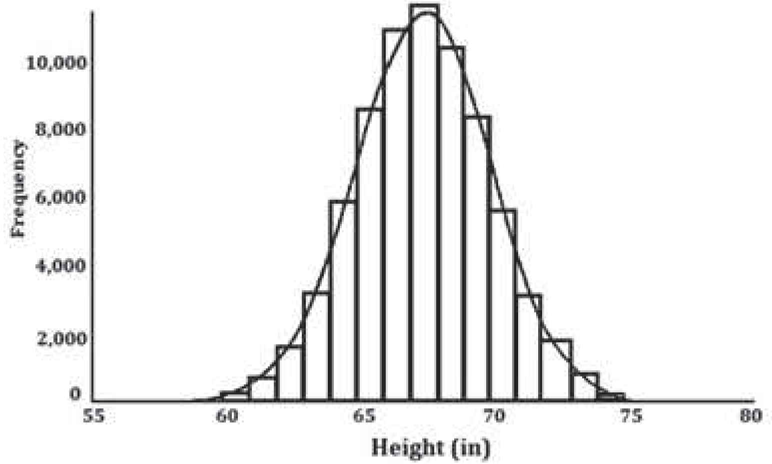

Figure 2.1: A histogram of heights of young adult males is fit with a normal distribution (solid curve).

However, the distribution of heights does not carry over to nonsimple characteristics, such as the distribution of athletic capabilities. For example, the evaluation of the performance of individuals was, for a long time, based on the normal distribution, but it turns out that the distribution of performance looks nothing like the distribution in Figure 2.1. In fact the bell-shaped curve in the figure artificially restricts the number of those that would excel, and when used in an evaluation process promotes mediocrity. The distribution of performance looks more like that given in Figure 2.2, where 80% of the weight is in the central region and 20% is in the tail of the distribution. This distribution with a long tail is named after its inventor, the nineteenth-century engineer-turned-sociologist, Vilfredo Pareto, who discovered this behavior in his analysis of the distribution of wealth within European city-states.

Why is it that the Pareto distribution resolves the Capability Paradox? It is because the paradox is based on the linear thinking of normal statistics inappropriately applied to capabilities. In this paradigm, it is assumed that the limited number of individuals that excel should be rated high—in school this would be the top 2.5% that would earn As, and the 13.5% who earn Bs. In turn, these individuals would be followed by 68% of the group who receive an average score of C, and 16% who earn Ds and Fs. But according to the 2012 study of O'Boyle and Aquinis [173], this is not at all the observed distribution of capabilities. O'Boyle and Aquinis conducted 5 studies with 198 samples, including over 600,000 entertainers, politicians, researchers, as well as amateur and professional athletes. Their results are consistent across industries, types of jobs, types of performance measures, and time frames, indicating that individual performance follows a Pareto distribution. Thus, these results have implications for all theories and applications that directly or indirectly address the performance of individuals, including performance measurement and management, training and development, personnel selection, leadership, and the prediction of performance.

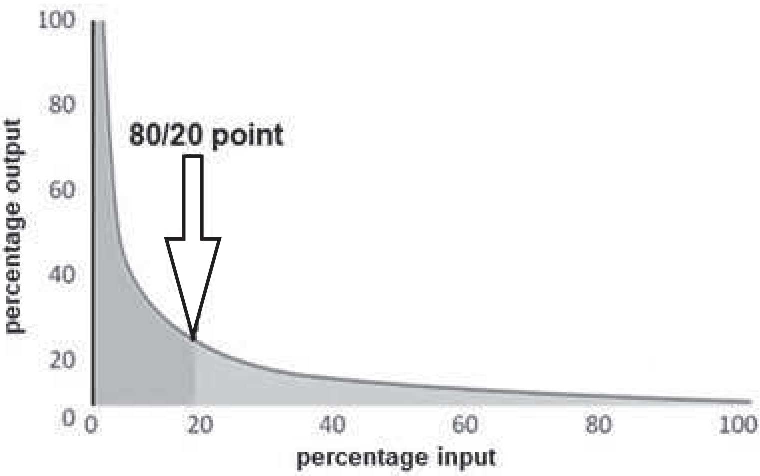

Figure 2.2: A sketch of the Pareto distribution is presented, in terms of percentages, emphasizing the inverse power-law nature of its tail. It is also referred to as the 80/20 Law, because in many applications, 80% of the results are obtained from the efforts of 20% of the people. A more complete discussion is given subsequently. Adapted from [173].

The Pareto distribution is skewed towards the extreme, indicating that the cohort is more capable than would be expected based on the bell–shaped curve. Consequently, you are likely to be less capable than your military friends on average, a member of the "rest," based on the analysis of athletes [173], unless you are one of the capability leaders, a member of the "best," out in the tail of the distribution. Yes, a significant majority of those being measured are below average; the size of this majority depends on what ability is being assessed. Therefore, it is not a mystery that when the average performer is thought to be representative of the group that a paradox results, emphasizing the empirical imbalance. Pareto labeled this, "The Law of the Unequal Distribution of Results," and referred to the inequality in his distribution more generally as a "predictable imbalance," resulting in a social inequality [272].

But it is not just at the level of the individual that paradox is encountered. A paradox is seen at the organizational level, deeply embedded within the bureaucracy, which has significant implications for both civilian and military organizations. Martin [155] observed that the rule governing how human institutions behave is paradox and the way devised to handle paradox in the social domain is politics. Politicians are often excoriated for being liars, or for abandoning their principles, which they all too frequently do. However, such behavior is not always capricious, or arbitrary, but is often a necessary step in resolving a paradox in order to reach an accommodation: a compromise that requires adopting conflicting points of view, simultaneously. But the paradox is an apparent contradiction that occurs because the observer is viewing the scene through the bell–shaped lens of linear thinking.

Martin [155] proposed three examples of bureaucracy as paradox in a military context. One involved junior leaders' understanding of the gap between the problems identified and the solutions being implemented. Many junior leaders are convinced that increasing the resources for solving a problem could make things worse, such as the Mission Command's solutions of using more technology. The second paradox involved teaching and adopting new ways of CS thinking, accomplished, in part, by unlearning the traditional ways of linear thinking. This was the Design concept, which paradoxically used the insight gained from the process to inform the military decision making process (MDMP) and the deterministic planning programmatically unlearning the old ways became relearning the old ways. The symbol for this could be the Ouroboros, the snake that eats its own tail.

His final example of bureaucratic paradox also presented a new way of thinking, one that avoided the false dichotomy of peace and war as the only solution, recognizing that when something intermediate between the two occurs, Western nations are ill-equipped to manage things to a successful outcome. The concept of the Gray Zone was introduced to handle such situations–except that it did not. It did what the other two exemplars did, revealed a bureaucracy co-opting attempts to change itself. Martin [155] summarizes his thoughts on the matter this way:

> In short, if one is expecting a conventional war to break out in Southern Iraq over who should control Kuwait, then a bureaucracy is the best way to go about preparing for such an eventuality. If, however, one does not know what to expect, but is reasonably sure it will not be a conventional war, then a bureaucracy is perhaps the least likely organization to prepare one for whatever is to come.

Bureaucracy is rampant in the US military, as it probably is in every military throughout the world. A military officer may be personally responsible for enforcing hundreds of thousands of rules and regulations. With modern leaders heavily fortified with a staff of lawyers, every problem and issue brings about mountains of new policies, rules, laws, e-memos, e-forms, and training requirements.

For instance, the US Army hasn't advanced (in the sense of making things more efficient, with fewer bureaucratic layers) its administrative bureaucracy very much in 60 years. It has been using the same form for leave (off duty time) requests for all those years. There is one difference: today's form no longer contains carbon paper between multiple copies (although the old carbon–copy forms still exist). What other organization could still be doing business the way it was in 1955 and be successful? The recruitment poster from that decade is depicted in Figure 2.3 and captures the soldier's continuing reliance on technology, but does not anticipate the disruption soon to be brought on by the technology of the computer revolution.

Using a decades–old form to manage Army leave time may not seem significant, in the face of the information explosion, but the volume of manpower, energy, and effort to manage every single form is staggering. With so many people at its disposal and a mindset that military manpower is essentially free once troops are recruited, the military still uses Industrial Age, brute-force manpower as its first choice against all tasks. However, the reality is that today's soldiers are some of the most expensive employees in the world and today's military missions are the most nonsimple actions in the world. Being bureaucratic is not the best way to build a modern military.

With this dilemma, of the contrast between the 1955 delusion and the 2018 reality, there are no incentives to fix overly-simplistic, even dysfunctional bureaucratic procedures. The Department of Defense (DoD) has spent billions of dollars on information technology, but many parts of the defense enterprise still depend on brute-force manual processes. As global security challenges multiply, defense budgets fall, and military end strength declines, wasting scarce manpower and fiscal resources on outdated procedures and processes comes at the expense of combat and operational capabilities. The military culture still sees bureaucracy as more valuable than modern nonsimple thinking and this is what CS needs to change.

Figure 2.3: United States Army recruiting poster circa 1955.

The full cost of individual service members increased by 46 percent between 2001 and 2011, and the percentage of the defense budget consumed by pay, benefits, and healthcare grew even more. Antiquated enterprise processes generate excess work time, consume energy, and cost millions of dollars. The administrative bureaucracy needs to be streamlined for more and better use of information to learn what the real issues are that need to be solved for successful operations. The modern military needs to be more like today's Google in organizational structure than it does the hierarchical military of 1955.

Many of the nonsimple missions given to the military today could be defined as challenging problem-solving. Brute force often does not work in these situations, even for the most combat-relevant tasks. The military, like other modern organizations, needs to define the problem associated with the mission's tasks, generate possible solutions, build a model or plan, test, get feedback on the progress, validate, and implement. We will see in the ongoing discussion that all these elements have CS components, which is to say that the relatively simple approaches of the past are no longer adequate for solving today's nonsimple problems.

Success or failure in war was traditionally measured in terms of territory gained from, and losses imposed on the enemy. These measures do not always reflect success in our latest experiences of modern warfare. It is often more effective to impose delays, disruptions, and inefficiencies on the adversaries' networks to cause their loss of capacity than to adopt traditional attrition tactics. There are important systems collaborations needed to overcome the adversarial confrontationally in all the military domains. This issue will continue to arise in the twenty–first century. Some of these collaborations to overcome challenges are:

- control of airspace through air defenses and strike aircraft
- control of water and logistics through submarines, battleships, carriers, and anti–submarine forces
- control of urban centers, airports and ports through mounted or dismounted warfighters and cyber–based sensors
- control of satellite access through physical and electronic shields, deception and stealth space operations
- securing networks and information systems through encryption and firewalls

There is always tension between what the military can do (its capabilities), what the military is asked to do (its assignments), what it does (its actions) and what it should do. Warfighting is important, but there is a full spectrum of military missions that call on skills other than warfighting. Having the right warfare measures for nonsimple operations, in all the domains (air, cyber, land, sea, and space), is critical to success in present and future conflicts. The mission of the services is to train and organize agile forces for potential use in the full spectrum of military missions.

2.2 Technologies

Over the next two decades, the advancement and widespread use of unmanned, robotic, semi-autonomous, and autonomous weapons, platforms, and even combatants will dramatically change the role of the human on the battlefield of 2030 and beyond. [234]

Former Secretary of Defense Ashton Carter, who was trained as a physicist and was a professor at Stanford University, used the planning for the Third Offset strategy to establish a strong connection of the military with the CS of Silicon Valley. The relationship was seen by Carter to be a logical fit between the nonsimple military and the best nonsimple technological problem solvers in the United States. The Silicon Valley-based Defense Innovation Unit Experimental (DIUx) focused on the use of high technology as a partner in developing CS. The belief that undergirds these initiatives is that CS and nonsimplicity lead to greater defense capability and innovation [206].

Policy within the United States and elsewhere often focuses on technology as a surrogate for military capability. However, militaries with the technological edge are not always able to translate that edge into operational success. The military needs to transition the CS advantage that has been successful in technology into its training, doctrine, operations, and strategy. The literature on military innovation is clear on this point: technology only goes so far in providing military effectiveness. Instead, the militaries that combine the development of new technologies with CS organizational or doctrinal improvements ultimately succeed in operations.

According to Davenport [66]:

> The Pentagon is increasingly focused on the notion that the might of US forces will be measured as much by the advancement of their algorithms as by the ammunition in their arsenals. And so as it seeks to develop the technologies of the next war amid a technological arms race with China, the Defense Department has steadily increased spending in three key areas: artificial intelligence, big data and cloud computing.

Arms races today are not always over weapons and technology, but can also involve the pursuit for enhanced operational connectivity. At the heart of the connectivity competition are smart, effective, structures and flexible, agile, processes. New systems are needed to keep up with the crush of urbanization, the growth of international trade, the nonsimplicity of supply chains, and the interdependencies on digital services. The allocation of resources to transportation, energy, and communications must continue to increase. The world's connections are made through nonsimple networks of computers, machines, and human organizations. The age of territorial conquest by the military is nearing its end and nations, if given a choice, rather than obtaining more land would prefer better connections. Nations and military forces compete to gain leverage within the connected international world.

Kamienski explains the role of technology in the military as [119]:

> Knowledge-intensive military technologies enable a more precise, effective, less costly, and more humane American way of war. DARPA's inventions have, paradoxically, made it much easier for the US to both get involved in and carry out military operations (with drones, stealth, precision–guided munitions, GPS, etc.) and deal with the consequences of war (i.e., new methods of treatment of injuries, prosthetics).

Other countries are now able to develop the cutting edge technologies that in the past gave the United States its advantage. This is happening now because some other nations have recognized scientific research and CS as the main highway into the future and have embarked on that passage without looking back. The United States' lead in science and technology is rapidly shrinking. Dan Arvizu, chairman of the National Science Board, remarked [172]:

> The first decade of the 21st century continues a dramatic shift in the global scientific landscape ...Emerging economies understand the role science and innovation play in the global marketplace and in economic competitiveness and have increasingly placed a priority on building their capacity in science and technology.

If and when the US does take a technological lead, it is often achieved by buying foreign scientists and engineers to do the research [172]. In those cases, the technological edge quickly evaporates, because the developers, or fast followers in other nations, are able to quickly advance through innovative applications to match our breakthroughs. It goes without saying that the United States military is trying to establish a high-tech advantage in the form of unmanned technologies such as drones (unmanned aerial vehicles, UAVs), robot ships, above and beneath the surface of the sea (unmanned water vehicles, UWVs), and autonomous driving vehicles (unmanned ground vehicles, UGVs). However, the edge is razor thin as the adversaries quickly incorporate these technologies from the US prototypes.

2.3 Agility in thinking

> War is a thinking man's game. [201]

With regard to the full-spectrum of operations in the modern information environment, the DoD must incorporate and exploit nonsimplicity-based methodology in the forms of NCW and multi–domain battle (MDB) doctrine. CS helps to integrate the multiple capabilities of United States' smart, advanced technological systems into a military advantage. The knowledge that agile units and flexible actions are the domain of nonsimple systems provides an opportunity for planning to be innovative and superior in the future. The nonsimple thinking entailed by CS is critical in diplomatic, informational, military, and economic power constructs, along with supporting America's rule of law, liberty, and self–determination. The US military cannot rely solely on new technological developments, however. We need better thinking, deeper data science and expert problem solving as well [60].

> There are but two powers in the world, the sword and the mind. In the long run the sword is always beaten by the mind – Napoleon Bonaparte

Smart (ability to learn) and knowledgeable (ready access to information) are advantages for any system–physical, informational, social, biological, or hybrid. Together, smart and knowledgeable can create intelligence. Intelligence drives the design, planning, and execution of military operations. The military's ability to mass forces, communicate over long distances, achieve dynamic coordination of operations, manipulate and exploit enemy weaknesses, and effectively employ psychological warfare tactics are based on a superior intelligence network that gives the leaders and their service members the situational awareness that leads to success. This form of a nonsimple environment is possible in the modern informational world.

CS through nonsimple network modeling makes thinking about the whole important again after the Industrial Age trend had made disciplinary expertise the most important skill. Planning, strategy, and facilitation are important aspects of military operations. Orchestrating large units to provide insight into its smaller teams, which then feedback intelligence into the larger units, is the key to the design of systems nonsimplicity approach to military operations. In the modern military, these CS ideas are found in network-centric operations (NCO), the OODA loop, mission command, nonsimple design, gray zone, data-to decision, and MDB.

General David Perkins [182] calls for a more complete and comprehensive nonsimple strategy to “encompass more than delivering decisive battlefield firepower.” To him, this additional nonsimplicity is like pivoting the strategy from checkers to chess. Future warfare is nonsimple and the focus needs to shift from the simple, concentrated model of decisive firepower to nonsimple, broader, more flexible capabilities. Another oversimplification that must change is the view that military operations have of three distinct, simplistic, hierarchical levels: tactical, operational, and strategic. As levels, they correspond to the hierarchical levels in the military chain of command. However, as integral doctrines of warfare, these three components are much more fluid and nonsimple. Handel [104] describes a “complex model of interaction,” where each doctrinal component can influence the others before, during, and after a battle, as well as during an entire war. Within this framework, the battlefield and its processes are much more networked and responsive than they are hierarchical. This form of nonsimplicity in process requires junior officers to live and work in the tactical realm, but also think and understand operational and strategic environments. Likewise, senior officers may primarily engage in operational design and planning, but need to know strategy and tactics to design potentially successful operations.

Biddle [30] called for modern nonsimple systems that include:

> ...a tightly interrelated complex of cover, concealment, dispersion, suppression, small-unit independent maneuver, and combined arms at the tactical level, and depth, reserves, and differential concentration at the operational level of war.

Some nonsimple operations could be characterized as taking an indirect approach, using strengths against weaknesses [30, 52]. The modern military is developing tactical and operational capabilities that seek to avoid the enemy’s strength of significant and lethal long-range fires. This concept is the direction of the Army’s MDB doctrine. Cavanaugh [52] also suggests using intelligence, cyber, electronic, space, and special forces, that combine to form “an unequal blend of overt and covert actors prepared to conduct hybrid actions in gray ways to achieve national objectives.” In any case, the trend is to form nonsimple combinations and integrations of joint, coalition, and specialized forces conducting tactical, operational, and strategic operations. Each component of the specialized force would be selected for its synergism to amplify the others, so that the final nonsimple force is not only greater than the sum of its parts, it is different.

In many ways, modern nonsimplicity in warfare is an iteration of what Sir Basil Liddell Hart labelled as the indirect approach. Hart believed that "...brains were a more effective strategic lever than brawn, arguing that indirect methods "'endow warfare with intelligent properties that raise it above the brute application of force'" [165]. His theory required a force to attack the psychological will of the enemy and emphasized the principle of surprise. Much of modern counterinsurgency warfare is a manifestation of Hart's indirect strategic approach.

2.3.1 Network–Centric Warfare (NCW)

Modern wars are fought between entities through confrontations of their systems-of-systems. This holds true for nations, non-state actors, and insurgent groups. Networks-of-networks are a representation of nonsimple networks of informational, social, communications, and physical layers with feedback loops and environmental factors as depicted in Figure 2.4. The networks have interdependent components (nodes and edges) with intelligent and mission-based behaviors. Understanding the nonsimple nature of such systems-of-systems is important for US network-centric doctrine. Large-scale systems are often multipurpose with many roles and sometimes conflicting goals. The idea of security and resiliency is to protect from a decisive action against your own system. Security-focused systems possess redundancy and adaptability, while protecting the nodes and links inherent within the network. Protection can be more important than efficiency for some networks-of-networks as they become too big and too important to fail, or so it is believed by some military leaders.

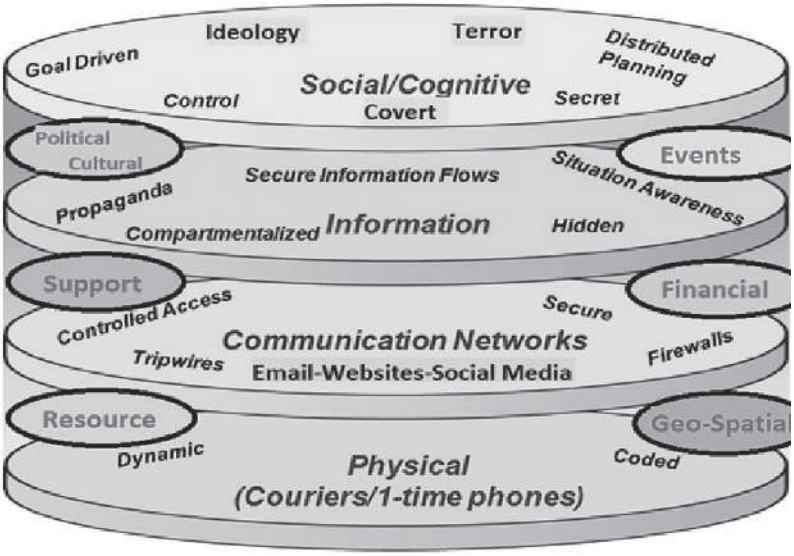

Figure 2.4: This is a notional sketch of how different kinds of networks are interconnected. These include physical, communications, information, cyber, social, and so on. Each one is interleaving with another to modify and presumably enhance the functionality of the separated networks.

NCW is an information-enabled concept of military operations that describes the way the US military forces organize and fight in the Information Age [162]. The main thrust of NCW consists of networked organizations and information-based doctrine that enable military forces to conduct effects-based operations at all levels (tactical, operational, and strategic) and in all domains of warfare. NCW translates its information superiority over an adversary into combat power by effectively linking friendly forces within the battlespace environment, enabling more rapid, more effective decision making and more dominant maneuverability. The NCW capacities are vital to successful operations and are created at the intersection of the information, cognitive, and physical elements of the battlespace. NCW enables shared situational awareness and tactical innovation through the capabilities of agile networked forces. This agility creates a decisive warfighting advantage with increased combat power forged from the networking of sensors, automating intelligence systems, identifying high-value targets, informing decision-makers, and effectively employing appropriate weapons systems.

The results of the NCW efforts are shared situational awareness, increased speed of command and control, higher tempo of operations, greater lethality of weapons, increased survivability, and powerful synchronization of effort. NCW has a profound impact on the planning and conduct of war by providing methodology to get inside an adversary's OODA loop, thus dictating the pace of military operations. Shared situational awareness and connectivity enables units of all sizes and functions to collaborate and synchronize. These enhanced capabilities create sustainability and rapid operational speed–both are critical to the success of modern, full–spectrum operations. Having the ability to make decisions and to act faster than the enemy is the foundation of military operations that produce favorable conditions for US forces. Networking is the key enabler of battlespace speed and is thus critical in military operational success.

One obvious goal of NCW is to develop the decision algorithms to take into account the multi-domain parameters to achieve a desired outcome. Much like the IBM Watson computer on Jeopardy, a rapid decision-making, AI-based framework could ultimately reduce the time window for both the information required to make a successful decision and the time window for the ultimate effects of the decision. Two important issues are knowing whether the intervention is feasible and will it have an effect on the improvement of the situation. Using its machine learning and rapid information processing frameworks, AI is able to conduct complexity modeling to develop a range of possible decisions, targets, and operational tactics along with their likely outcomes.

The equivalent of average (linear) thinking in warfare is the von Clausewitz concept of center of gravity (COG), the main unit or most significant operational element in the traditional battle plan and its implementation. Identifying a single COG is not conducive to analyzing, or measuring importance in modern warfare, because it is derived from overly simple linear thinking in combat operations. However, this outdated concept is still codified in joint doctrine as Joint Publication 5–0 (Joint Operational Planning [252]), which states:

> A COG, at the operational level, is usually a powerful element of the enemy's military capability.

Adhering to the COG strategy makes the main objective of the operation the COG. This linear path from the initial positions at the start of the operation to the COG is the main thrust of the operation and makes the operations linear and predictable–combat operations at their very worst. COG analysis uses reductionist logic to map the capabilities, requirements, and vulnerabilities of the enemy to the COG, ignoring the NCW concept that war is a highly nonsimple dynamic interaction between military forces. The result is that the COG, a concept used to simplify and focus the battlefield dynamic is not relevant to modern warfare. The COG concept is static and linear and consequently cannot adequately address warfare's nonsimple systems and dynamic interactions. The advent of NCW moves the US military beyond the COG concept. This nonsimplicity framework is part of a systems-centric methodology in planning and execution that is the primary transition to NCW in modern military operations.

> [The] name of the game [in warfare is to] preserve or build-up our moral authority while compromising that of our adversaries in order to pump-up our resolve, drain-away adversaries' resolve, and attract them as well as others to our cause and way of life. [60]

2.3.2 OODA Loops

The OODA loop is the planning-decision-action cycle of Observe, Orient, Decide, and Act that was developed in the 1980s and 1990s by Air Force Colonel John Boyd. The concept seeks to organize an effective combat decision making and operations planning and execution processes [162]. The approach generally favors intellectual agility, resulting from CS thinking, over physical power in military operations. OODA is a set of interacting loops that form a feedback and interconnected system of continuous communications and operations. One part of the loop that may need explanation is the Orient stage. The main components of orientation include cultural elements: values, heritage, tradition, laws, and experience. The Orient stage seems most important since the orientation of effort influences the way we subsequently Observe, Decide, and Act. Important to many operations are the teams of analysts who orient and observe. Commanders and decision-makers Decide and Act. The main point of the OODA loop is to work fast–faster than the enemy to get inside the adversary's OODA loop. The faster tempo generates beneficial conditions that prevent the enemy from good planning, or reacting well to the events of the operation. The OODA loop also serves to explain the nature of surprise in a way that unifies the Principles of War with NCW, NS, nonsimplicity, and evolutionary game theory.

The full and effective implementation of OODA has been stymied by bureaucratic politics and Boyd's own confrontational nature. By the time OODA was put into doctrine, it was overly simplified and of little use to commanders. The OODA construct had suffered from the Army's bureaucratic system remaking it simple. For instance, OODA doesn't take into account scale. It has no role for subordinates or sub-groups to coordinate or contribute to the OODA elements. Without more refinement, OODA does not connect individual decision making with group decision making and certainly not with higher-level national or strategic decision making.

2.3.3 Mission Command

The US military introduced a new command and control concept and methodology called Mission Command in the early 2000s. The Army defines Mission Command as [155]:

> ...the exercise of authority and direction by the commander using mission orders to enable disciplined initiative within the commander's intent to empower agile and adaptive leaders in the conduct of Unified Land Operations.

Mission command seeks to empower subordinate leaders with the agility to adapt to a dynamic environment to accomplish nonsimple missions by providing a common understanding, a shared vision, and a framework for implementing the operation. Subordinate leaders need wide latitude in combat. A recent issue that needed to be fixed immediately by mission command was the too-frequent micro–management of conflict by commanders thousands of miles away from the battle. Technology enabled the commanders to believe that they had situational understanding based on watching a video feed taken from a drone flying over the battle. Operating from this belief, remote commanders began giving detailed orders to soldiers on the ground. This was the opposite of distributed mission command operations, which was embraced and implemented just in time to stop these out-of-control micro-managers.

Network-centric information sharing seeks to improve situational awareness and ultimately organizational effectiveness. However, the volume and pace of information and communications received through computer networks can overwhelm individuals, resulting in data overload and reduced situation awareness. It takes informed and refined mission command and OODA thinking to obtain a reliable positive feedback loop resulting in greater situational awareness and mission effectiveness in military operations [5]. However, this data deluge often challenges the capacity of humans in the networks-of-networks. The result can be the retrograde situation where more information suppresses individual situational awareness. These potential results highlight several major growing-pains for networked organizations in general and military organizations in particular [43]. One solution is to automate the decision making process and take the humans completely out of the loop. This situation is related to the hyperwar concept discussed in Section 1.4.2. Overall, the US military has been hesitant to adopt nonsimplicity and networking theories into its doctrine and practice, even though there were serious efforts beginning in 2005 to introduce nonsimplicity into the design of military operations at various levels of education in the services. The initial thrust was that some military operations, such as stability operations, humanitarian aid, rebuilding infrastructure, and nation-building, needed new concepts like nonsimple systems design and CS thinking. The new doctrinal concepts of NCW, OODA loop, and mission command are some of the results of these efforts, which were generally part of the RMA.

The military's effort to introduce CS and nonsimple systems thinking into its education system for several years was hampered by many officers and soldiers being too set in their linear thinking ways [126]. They viewed the world as reductive, deterministic, and hierarchical. The military education systems had problems in educating these mid-range professionals in the deeper conceptual skills. Some military learners thought this was simply a more detailed part of the Military Decision Making Process (MDMP). Some were willing to tweak the traditional methods, and others were unwilling to change their well-established traditional methods, see, for example, [148, 223]. Among the service members and civilians who were willing to learn ways to improve design and planning were early adaptors, who thought fundamental change was beneficial. Snowden's Cynefin decision–making framework was introduced into the Professional Military Education (PME) system at the Army Command and Staff College. The framework uses systems theory, complexity theory, network theory, and learning theories to look at situations with simple, complicated, complex, chaotic, and nonsimple lens. However, most Army officers were unable to make that kind of change. The result has been a slow adaptation of CS to modern warfare.

The paradigm shift is taking place in the military force in other countries at a similar rate.

Nonsimplicity modeling, which implements CS into decision-makers' education, is based on concepts such as the following:

- Develop a mental model as a nonsimple adaptive system, not as a static system.
- Use the model, with its feedback loops, to think through potential second- and third-order effects.

- Use the model in an evolutionary game theoretic mode to think through not just your actions, but also to anticipate the inter–actions of all players' actions in an interconnected system-of-systems approach.
- Since military decision-making environments are nonsimple, high-dimensioned, fractal, fractional, and human–based, nonsimplicity modeling must be integrated into the intelligence, operational, and logistics systems, as well as, the operational decision-making system.

2.3.4 Gray Zone

> The Gray Zone was first described by Kissinger more than six decades ago as he detailed the complexities of the emerging Cold War. Kissinger highlighted those areas where neither clear military superiority could deter aggression, nor could diplomacy resolve all differences. [142]

Another example of linearity (in this case simple duality) that has restricted the military to limit military operations to be either at peace or at war. The Gray Zone terminology sought to change that archaic military mindset. The Gray Zone argues that different thinking, planning, structuring, and resourcing are required when units are involved in different kinds of operations and are neither at peace, nor at war. This idea is associated with a whole–of–government approach for military engagements. Using this idea, there is some support for the State Department to take the lead within the Interagency and develop approaches to the various forms of noncombat military operations. The military would then take the lead only in kinetic warfare.

The nonsimplicity tenets of NCW [5] provide an influential conceptual framework for increased networking, which can enhance human collaboration and organizational performance. This framework is enhanced by communication and information sharing, acting as a positive feedback loop, with increased information sharing resulting in greater situational awareness and mission effectiveness. The problem is human education, which is needed to understand the distinct roles of information and knowledge, in order to trust machine learning and artificial intelligence (AI). The positive effects of increased information sharing are reduced when individuals reach a state of information overload. The data-to-decision (D2D) initiative [207] shortens OODA–loop time, seeks to improve the processes of synthesizing data into information and subsequently into knowledge to support decision-making and action-taking. Managing the OODA loops and D2D processes require network collaboration, as well as CS agility. A critical process in OODA and D2D is data or information fusion through AI tools. This form of AI, similar to the IBM Watson system, synthesizes information in an adaptive, context-aware manner. Data fusion is a term typically used to describe computational frameworks for constructing a comprehensive data aggregation system that processes information to support user decision-requirements [207, 230].

2.3.5 Multi–Domain Battle (MDB)

> There is a need to change . . . organizational unit designs that will allow the Army to operate on the battlefield of the future, which will be dispersed and dangerous across all domains. [234]

As is always the case, the United States faces a challenging and changing military future. The military dominance that the United States established following the Cold War is no longer assured. Potential adversaries are developing capabilities and ways of conducting war that challenge existing American strengths. The US military must develop new concepts and capabilities to forge future military strengths. MDB with its nonsimple system agility seeks to develop these advanced concepts and capabilities, and additionally seeks to provide agile operational forces and a flexible doctrine to counter adversaries' newly formed systems and techniques. MDB has the potential to use CS to integrate, deepen and expand current military doctrine. It allows the services to move beyond linear synchronization and enables them to share their capabilities and collaborate in all domains to obtain an advantage in needed domains of operation.

> It is time for the institution [US military] to reestablish its intellectual curriculum vitae. [32]

MDB entails coordination by the ground forces to coordinate the full-force operations, much like Air-Land Battle. Additional nonsimplicity is often contributed by cyber and space elements during land, air, and sea action [108, 212]. A multi-domain ground force can project its influence into all domains, as well as seizing key terrain in all domains. These multi-capable MDB forces integrate and synchronize efforts throughout the battlefield to seize, retain, and exploit the initiative and achieve military objectives. Based on RMA, MDB uses military capabilities in innovative, nonsimple ways to overcome modern warfare challenges. MDB also involves CS and advanced technologies to integrate the forces using NCW to advance in all domains. The use of AI controlled autonomous unmanned vehicles (on land, sea, air), advanced electronic warfare systems, networks of swarming space systems, and highly disruptive cyber weapons enables MDB to provide the United States military's doctrinal advantage. To make MDB work, progress must be made in leaders' understanding and integrating nonsimple multi-domain assets. This new form of command and control uses the CS concepts through Mission Command, OODA loops, and NCW.

It is often the doctrine written in manuals and followed by commanders that slows and limits the transition to nonsimplicity in operations. The military culture continues to emphasize a linear form of Synchronization Warfare (SW). This top-down decision-making architecture has been embraced in military doctrine since World War II. Today, SW seeks to glue the sensor, communications, data processing, and precision-guidance technologies together with detailed standardized operating procedures. There is little flexibility in this architecture. The feedback control loops are hard-wired and static in order to have a single mechanized OODA loop fitting all levels of the organization. Being a highly linear, yet complicated, mechanical concept, SW emphasizes precision and order over flexibility and adaptability. This Industrial Age, techno-centric control element overrides the agility of CS, as well as, not being optimized for the Information Age.

Another obstacle is that the nonsimplicity ideas are intellectual and often lead to counter-intuitive decisions. Therefore, these cultural shifts for the military must be developed through education. Unfortunately, the military takes a training perspective to this mission by prioritizing, synchronizing, and focusing efforts. The central problem is that much of this traditional linear military thinking is bureaucratic. Bureaucracies are simple rule-following organizations that provide synchronization, standardization, control, and prediction. They seek efficiency and focus on effectiveness for carrying out known tasks. The hidden costs they incur are in the barriers to innovation and the suppressed ability to adapt to new phenomena. When the military does not know what to expect next, which is the common situation given the uncertainty of the battlefield, its bureaucracy makes it unlikely to handle whatever new situation does arise. One goal of CS is to reduce and circumvent the deceptive simplicity of bureaucracy, where that simplicity is actually counter-productive. The bureaucratic culture and synchronization approach to operations undercuts the much needed renovation of military affairs and restricts the implementation of MDB.

2.3.6 Nonsimplicity and Virtual Reality in Training

The US military uses formal education in academic military subjects as an important element in many levels of training and readiness. Officers and enlisted members attend various training and education courses as their careers advance. Eventually, the education becomes nonsimple as it relates to military strategy and logistics. Former congressman Ike Skelton's desire for PME was "to develop an exceptionally rigorous system of joint selection and education that will produce a cadre of superbly gifted strategic leaders capable of anticipating, planning, and leading in future wars" [202]. Our desire would be to rewrite Skelton slightly to have PME educate officers to have an understanding of the nonsimplicities of the modern battlefield. Unfortunately, in today's modern military there are too few leaders who know what nonsimplicity means, much less understand or cope with modern systems and combat. Likewise, reality has occurred for Ridgway and Martin's prediction [202]:

> A career officer [or soldier] is going to school as long as he [or she] lives.

A Synthetic Training Environment (STE) is an immersive augmented reality system, where soldiers are placed in diverse operational environments that stress them physically and mentally. These unit- and operator-specific training opportunities can help build readiness and skill. STE is sufficiently flexible to conduct unit training, rehearse missions, and test new combat formations and doctrine. STE can also save money, reduce training injuries, and protect real equipment and systems. Augmented reality simulations seem to perform well compared to many field training exercises. ONR research suggests that repeated use of simulations prepare soldiers' and Marines' cognitive abilities, which facilitates speed and efficiency without sacrificing quality.

The military is in the process of developing and testing digital platforms and gaming systems to empower its members to build their intellectual capacity needed for the nonsimplicity of the profession of arms. Digital learning platforms have become important for sharing ideas, disseminating information, developing skills, and obtaining knowledge [47]. The digital platform provides opportunities for operational-simulated interactions among system military members. The Army's gaming systems, like Operation Overmatch, enable soldiers to test virtual versions of gear, doctrine, and operational concepts that could be implemented in the nonsimple operations of the future [80].

The military is building many immersive augmented reality (AR) systems, designed to place soldiers in diverse operational environments with stressful scenarios to enhance readiness [58]. As the services use hybrid systems of manned and unmanned teams with AI-enhanced and cyber capabilities, AR systems are ideal to train and rehearse missions, as well as to test new nonsimple doctrine.

2.3.7 Cyberspace Operations

> Warfare is a human social activity. The workplace of warriors is society, the societies of those engaged in combat and the societies of active and passive spectator groups. Because it is a human activity–and one dependent on human action, reaction, and interaction-the outcomes of some warfare activities may be unpredictable [238].

Cyber science is interdisciplinary and requires skills, concepts, and problem solving from a variety of disciplines, such as mathematics; information, social, behavioral, network, computing and communication sciences; engineering; and humanities. Modern, global society is producing a deluge of virtual and networked information with associated security issues that call for special skills to understand the issues and solve the problems. Integrative skills are needed because the problems and issues in cyberspace do not follow disciplinary and intellectual boundaries and need many perspectives and levels to understand and solve. The modern military seeks to operate in cooperative team settings to accomplish a full-spectrum of challenging missions in all the warfare domains, where the complexity of the human dimension can never be separated from the technical and physical elements of the military profession.

Information, computer, and network sciences are foundational to the elements of cyber science. Defensive cyber operations seek to maintain network performance and reliability while protecting and securing information and communication validity. Many applications in cyberspace involve the Internet and the World Wide Web (physical, communication, information, and social layers). These layers of worldwide networks affect critical infrastructure and information used for national and global commerce and communications. Disruptions in the Internet or worldwide web or lapses in their security place at risk the infrastructure and economic health of the US and all of society.

The US military has a significant cyber security challenge. Many military systems depend on fast, immense, secure, data-sharing and information processing. The challenge is to share accurate, timely information no matter the intensity of adversarial cyber attacks. The military's networks have to survive intrusions and ward off the disruptions caused by hackers to remain connected and secure. Cyber capability has become an important element of national power. Cyber science affects the diplomatic, informational, military, and economic (DIME) elements of national power. Therefore, understanding cyberspace and building capability in cybersecurity are critical to reduce the vulnerability of information systems and protect critical infrastructure that exist on national networks. Understanding the nature and execution of cyber warfare is necessary to forge a strong military and strong nation. This realization has led to an increasing requirement for cyber military forces and personnel.

Cyber has become significant in all domains of military operations. For example, cyber can affect the use of small drones that are ubiquitous on the modern battlefield. Therefore, to be successful, the military must be able to attack or disable adversary drones and adequately protect US drones. This is especially important in urban warfare where drones are used to conduct surveillance and intelligence gathering against US forces in the hemmed in areas above city streets. Another example is maintaining an advantage in Wi-Fi service. This capability is essential in urban settings. Disrupting or hacking the adversary's Wi-Fi while protecting the US forces' Wi-Fi can give the US forces access to surveillance cameras and building security systems while denying the adversary knowledge of US forces location or movement.

There will be many more innovations on both the offense and defense fronts in cyber operations. Army Research Laboratory and Army Research Office scientists have presented an intentional cyber fog concept where the data stored is dispersed into fragments much like real fog [130]. These fragments are then stored on multiple end-user devices. Modern database systems employ similar algorithms both for security and scalability, but these nonsimple ideas are intended to be mobile and available to units in combat. These ideas soon become fog computing, fog networks, and fog storage. Cyberfog presents challenges with respect to network complexity and storage.

Another nonsimple innovation is the Internet of Battle Things (IoBT) [129]. These same authors present the cyber issues associated with the myriad devices in military units all securely connected to military battle networks. The future battlefield network will hold myriad cyber-connected devices and systems performing important tasks such as sensing, communicating, acting, and collaborating. When all this is done collaboratively, these devices will need to communicate and coordinate continually in a nonsimple network. The IoBT's large size with tremendous computation and communication demands require new models, concepts, and technical approaches. Indeed, cyber is nonsimple from almost all perspectives of the structures and processes associated with its operations and future requirements.

Progress has been made by all services in establishing cyber as a fully operational domain of warfare. However, the effort is still in its beginning and much more is needed to be accomplished, especially in terms of doctrine, education, and operational planning for a nonsimple military component. In addition to standing up cyber units and organizations, education and training courses at all levels are being established by all the military services. The Army, like the other services, has its own cyber think tank and research center to seek out future needs in the cyber domain. This think tank, the Army Cyber Institute (ACI), is building a talented and diverse community of interest in cyberspace. This community of service members and civilians plays an important role in education as well as research and operational planning. The ACI is located at West Point where it can help directly with the education and recruitment of cadets for cyber service. The Naval Academy has an equivalent Center for Cyber Security Studies and the Air Force Academy houses the Academic Center for Cyberspace Research. The Army's ACI also provides advice and assistance to the war colleges in instruction and research in the cyber domain. The cyber officers and service members who serve in this field often go to graduate schools to learn the technical skills for their service. The military has a long way to go to build its talents in cyber, but there have been many good initial strides that give hope to build a strong science-based, cyber-fluent culture in the military services.

Developing cyberspace knowledge and skills are requirements for all service members. As the Department of Defense Cyber Strategy (April 2015) states:

> The increased use of cyber-attacks as a political instrument reflects a dangerous trend in international relations. Vulnerable data systems present state and non-state actors with an enticing opportunity to strike the United States and its interests. During a conflict, the Defense Department assumes that a potential adversary will seek to target US or allied critical infrastructure and military networks to gain a strategic advantage [141].

Therefore, the military has missions to mitigate cyber risks to US networks and engage in operations to improve information security.

Military cyber analysts and operators train in cyber wargames and simulations of various types [74]. Cyber ranges and combat simulations are designed to test and exercise the requirements of cyber tasks during unit deployments and in garrison training classes. However, many more and better cyber training facilities and events are needed. Cyber ranges allow for service members to train and operate in closed, for-training-only networks in order to test capabilities used exclusively within the cyber domain. In this closed setting operators are able to use their tool sets to attack targets in the network and disrupt within a simulated internet infrastructure, but not the real thing. Therefore, large-scale, multi-domain cyber capabilities are somewhat limited on current cyber ranges. To remedy this, some Army cyber forces are able to train with tactical units at the National Training Center at Fort Irwin, California, as part of multi-domain battle training [186]. This training helps the military shore up its weaknesses in offensive cyber operations. Similarly, on the defensive side, network administrators link up with expert commercial cyber defenders for assistance. As the military cyber forces discover flaws in their own networks, they request assistance for the repair of current systems and improved design for future systems.

The Army Research Office has developed a project to establish a cyber agility framework to develop skills in countering cyberattacks. This could advance cyber tactics and strategies in meaningful ways.

2.3.8 Information Warfare

Information Warfare (IW) is a form of nonsimple conflict where the attacker influences the beliefs of an adversary by communicating information. The goal is to influence people to change their beliefs and then take action to change the policies of the people's leaders for the benefit of the attacker. The targets of IW can include individual people, organizations, and governments of the adversary. IW has been part of society and international relations for centuries. The major weapons in IW are deception, propaganda, imagining, marketing, lying, misinforming, charming, and social psychology. Modern technology, in the forms of social media, social networks, websites, Internet media, electronic communication, and even robocalls, have dramatically increased the intensity and capacity of IW.

In modern international politics, IW is becoming a pervasive, almost constant, form of conflict that requires a whole-of-government, and often a whole-of-society, response. The US military, the government, and American citizens must build a strong and active defense to deflect, neutralize, and mitigate the effect of foreign information influence.

The US has recently been under considerable IW attack from foreign entities and has often come up on the trailing side. The effects of these attacks have endangered and perhaps changed the US [128]. By using effective IW, the one who wins the war of words can defeat an adversary with much more powerful kinetic weapons [179]. In this nonsimple asymmetric form of conflict, individuals using social media can be more powerful than institutions, or even nations.

Modern technology enables the attacker to provide continuous streams of information for the adversary's citizens to consider. In IW, these streams of information are designed to influence the way people think. Given that at least some of the attacker's information is false and intended to deceive the recipient, IW weapons are often nonsimple systems with ethical issues. The proliferation of computers, smart phones, Wi–Fi, broadband, and global networks have enabled IW combatants to exist in all corners of the world. IW has close relatives on the spectrum of conflicts that include cyber warfare, network-centric warfare, information operations, network warfare, financial warfare, political warfare, voting warfare, narrative warfare, and religious warfare. Through considering the nuances of information actions, these can be considered separate forms of conflict, but there are considerable overlaps in all these kinds of non-kinetic warfare.

A virtual information-laden environment now exists where individuals receive ideas and viewpoints without validating the quality or truthfulness of the information being exchanged or knowing the source of the information. Technology provides tremendous access to information, but its uncertainties and impersonal nature also threaten democratic open society.

A quarter-century ago, this mode of modern, technology-enabled, information warfare was predicted by a US Air Force officer Richard Szafranski [238]. His outline of this kind of nonsimple conflict and his prediction of its use were extremely accurate:

> Information warfare is a complex notion. It is complex because the weapons employed are and always have been as common as words, pictures, and images, even though today these may be communicated or manipulated in uncommon ways. It is complex because the attacks are crafted by minds to affect minds. In addition, it is complex because the attacks can be direct or indirect, aimed at internal or external constituencies, the only constant being the effect sought. The desired effect of information warfare is to influence and change what the adversary believes.

Described in military terms, this type of conflict, along with social psychology, produces casualties with new beliefs that align with those of the attacker. In many ways, the recent Russian disinformation campaigns affecting US elections are just the beginning of the IW challenges in multi-domain future wars. Szafranski warns [238]:

> The United States should expect that its information systems are vulnerable to attack. It should further expect that attacks, when they come, may come in advance of any formal declaration of hostile intent by an adversary state. When they come, the attacks will be prosecuted against both knowledge systems and belief systems, aimed at influencing leadership choices. The knowledge and beliefs of leaders will be attacked both directly and indirectly. Noncombatants, those upon whom leaders depend for support and action, will be targets. This is what we have to look forward to in 2020 or sooner.

Szafranski added another ominous warning about US political warfare that can and does use similar IW techniques. In [238], he writes:

> While most often employed against external adversaries, many of the weapons of information warfare are equally well suited for employment against internal constituencies. For example, a state or group would not normally use guns and bombs against its own members; however, the weapons of information warfare can be used, have been used, and very likely will be used against both external and internal adversaries.

2.4 Future Warfighting Threats, Trends, & Challenges

In the report, “The Operational Environment and the Changing Character of Future Warfare” [248], TRADOC outlined a prediction of future warfare. Until 2035, the expectation is accelerated human progress with adversaries developing new technologies, new doctrine, and new strategic concepts. Between 2030 and 2050, the character of warfare will undergo revolutionary change, and the Army will monitor this change in warfare by watching the following 12 trends:

- big data
- power generation and storage
- cyber and space
- collective intelligence

- technology, engineering, and manufacturing
- climate change and resource competition
- artificial intelligence
- human computer interaction
- demographics and urbanization
- increased levels of human performance
- economic rebalancing
- robotics

The prediction is that the United States will, by 2050, have laser and radio frequency weapons, swarms of drones, rail guns, and synthetic biology. Likewise, the adversaries will also have many nonsimple capabilities and doctrines to include [248]:

- Multi-domain threats
- Operations in complex terrain, including dense urban areas and even megacities
- Hybrid Strategies–Gray Zone Operations
- Weapons of Mass Destruction
- Sophisticated anti-access/area denial complexes
- New weapons, taking advantage of advances in technology (robotics, autonomy, AI, cyber, space, hypersonics, etc.)
- The relationship and trade space between precision and mass Information as a decisive weapon

The US Army Warfighting Challenges are a set of enduring problems, which the Army seeks to solve in a continuous dynamic fashion, in whole or in part, to enhance the combat effectiveness of the future force. Many of the challenges are related to nonsimplicity, as is indicated in this brief summary of challenges [234]:

1. Develop Situational Understanding: Developing and sustaining situational understanding while operating in nonsimple environments against determined, adaptive enemy organizations, which will stretch the capabilities of modern forces.

2. Shape the Security Environment: Shaping and influencing security environments by engaging key actors in the defense network to help give the US military operational advantage at all levels.

3. Provide Security Force Assistance: By providing security to support policy goals and increasing local, regional, and host nation capability, capacity, and effectiveness, the US military has made connections around the world. Often nonsimple cultural understanding and partnering are need to be successful.

4. Adapt the Institutional Army: Future programs can be made by maintaining a nonsimple (agile) Army with combat effectiveness that can support other Services.

5. Counter Weapons of Mass Destruction: Determining the possibility of using WMD, or preparing to respond to and recover from adversary employment of WMD, are ways to ensure long-lasting peace. This may be the most complex challenge for the military.

6. Conduct Homeland Operations

7. Conduct Space and Cyber Electromagnetic Operations and Maintain Communications: Maintaining access to critical communications and information links, and ensuring intelligence, surveillance, and reconnaissance (ISR) across a multi-domain architecture are critical to operating in a nonsimple environment.

8. Enhance Training: Training and educating soldiers and leaders to accomplish the mission while operating in nonsimple environments are necessary steps in military force modernization.

9. Improve Soldier, Leader, and Team Performance: By developing adaptive leaders and cooperative teams that accomplish the mission in nonsimple environments of uncertainty and danger is the goal of modernization.

10. Develop Agile and Adaptive Leaders: The military must develop agile, adaptive, and innovative leaders who thrive in nonsimple conditions of uncertainty and chaos and are capable of visualizing, describing, directing, leading, and assessing operations in nonsimple environments and against adaptive enemies.

11. Conduct Air–Ground Reconnaissance: This is an important nonsimple capability to integrate two domains in modern warfare.

12. Conduct Entry Operations: The Army, working with the Marines, will have many nonsimple tasks in modern warfare.

13. Conduct Wide Area Security: Establishing and maintaining security across wide areas in coordination with other military and civilian elements is a nonsimple mission.

14. Ensure Interoperability and Operate in a Joint, Inter-organizational, and Multinational (JIM) Environment: Integrating JIM partner capabilities to accomplish missions across the range of military operations is a challenge to US forces.

15. Conduct Combined Arms Maneuver: The modern US military will conduct combined arms Air-Ground maneuver to defeat enemy organizations and accomplish missions in nonsimple operational environments.

16. Set the Theater, Sustain Operations, and Maintain Freedom of Movement: US forces must provide agility to the joint force and maintain freedom of movement during nonsimple operations with extended lines of communication in austere environments.

17. Integrate Fires: This is a critical nonsimple mission task.

18. Deliver Fires: The nonsimple nature of weapon systems and targeting increases the challenges of the task.

19. Exercise Mission Command: Understanding and directing operations consistent with mission command to seize the initiative is important to success in future operations.

20. Develop Capable Formations: The critical structure of the fighting force is nonsimple in geometry, topology, and capability.

Many of the elements fall into the human domain as related to the Gray Zone. As Linder explains [142]:

> Effectively confronting Gray Zone threats in the human domain requires an emphasis on warfighter as much as the technology that supports them, for this is at the core of the character of war. As Maj. Gen. (ret.) Robert Scales argued in his assessment of current and future conflicts (“Scales on War”), “the human element of conflict requires a broad spectrum of resources. Prevalent among them are abilities to adapt to diverse cultures, while preserving core objections” [202A].

The TRADOC G–2 adds other elements related to intelligence to watch and analyze. A recent report provides the following trends [248]:

- Evolving geopolitics
- Resurgent nationalism
- Changing demographics
- Unease with globalization
- Competition for resources
- Challenges to structures, order, and institutions
- Rapid development of technology
- Disparities in economic resources and social influence
- Perceived relative deprivations

However, of most concern in the report is the concepts of convergence and the AI singularity. The report [248] described these issues as follows:

> Convergence: The impact of the development of so many new and potential revolutionary technologies is made all the more disruptive by the convergence phenomenon. Virtually every new technology is connected and intersecting to other new technologies and advances. The example of the contemporary smart phone, which connects advances in cellular telephones with a camera, gaming, miniaturized computing, and the Internet has completely transformed and, in many ways, disrupted contemporary life. Future convergences between various technological advances are likely to be equally disruptive and equally unpredictable, but the areas in which we foresee the most likely convergences are:
>
> - Biology and bioengineering, including optimizing human performance
> - Neurologic enhancement
> - Nanotechnology
> - Advanced Material Sciences
> - Quantum Computing

- Artificial Intelligence
- Robotics
- Additive Manufacturing

Singularity: Singularity is the point at which artificial intelligence (AI) exceeds the collective intelligence of mankind, which will radically and irrevocably change the relationship between man and machine. There are several divergent possibilities regarding the singularity:

- As optimistic singularity advocates, such as Ray Kurzweil have suggested, AI improves human life in every way, from health–care, to emotional evolution, to intergalactic space travel.
- While not entirely apocalyptic, unboxed general artificial super-intelligence improves and evolves at such an exponential rate it escapes human restrictions, perspectives, and morality. It threatens the very existence of humanity.
- Humans evolve their own cognitive abilities through learning developments, brain implants, artificial stimulants, and non-AI, high performance computing to match, or at least keep pace with AI.

CHAPTER 3 FOG OF LIFE

> The general unreliability of all information presents a special problem: all action takes place, so to speak, in a kind of twilight. . . like fog. War is the realm of uncertainty; three quarters of the factors on which action in war is based are wrapped in a fog of greater or less uncertainty. . . The commander must work in a medium which his eyes cannot see, which his best deductive powers cannot always fathom; and which, because of constant changes, he can rarely be familiar. [56]

Carl von Clausewitz was a Prussian general and military theorist, who is famous for his insightful writings on the nature of war, in particular his understanding of the cognitive fog of uncertainty present on the battlefield. The phrase “fog of war” indicates the limited knowledge of the battlefield that is available to the warfighter at any given time and how blind they can be to its development over time. The result is nonsimplicity. By way of contrast, the clarity of a walk in the park is a consequence of its simplicity. You walk, perhaps with a close friend, talking about how lovely the trees are, reflecting in the afternoon light, feeling the sun on your face. All these things conspire to relax the body and mind, allowing thoughts to drift. A distant explosion, or a nearby gunshot, collapses the reverie and focuses the mind to the here and now. The broad expanse of the park constricts to the immediate view of the battlefield and the search for the source of gunfire. The fog sets in, because we realize how uncertain the situation is and how much we do not know. On the battlefield, knowledge determines survival and lack of focus resulting from uncertainty can kill you. The walk in the park is no longer simple.

It is not even that we know less than usual during a battle, it is that the lack of knowledge that is tolerable in ordinary life can make the difference between living and dying on the battlefield. But is it really true that we understand so little about our world and the basis on which the decisions we make every day, when we are home? In this chapter, we argue that the fog of war is an enhanced perception of everyday uncertainty in an extreme environment, where lack of clarity often results in disaster. We demonstrate below that our natural state can be characterized as the fog of life, as most of what occurs in our life goes unexplained and we understand remarkably little about how we make decisions, or how we extract information from data and knowledge from information. This is analogous to decision making in combat, enveloped by the fog of war.

3.1 Uncertainty of thought

The warfighter's way of thinking is a crucial element for combat success. We argue that a shift in thinking will enhance success in the future. In this pursuit, we examine one of the fundamental ways in which we frame questions, using nonsimplicity and network theory, along with what Westerners consider to be evidence for the logic of decision making. In particular, we focus on the extent to which a warfighter is influenced by cultural bias in making decisions. We will not concern ourselves with any specific aspect of Western culture; instead, we will focus on what surprises us. After all, it is what surprises warfighters on the battlefield that can get them and their friends injured or killed.

What surprises us is the unexpected–what we did not predict or anticipate. But we are not able to predict many things and life is filled with such events: what the weather will be tomorrow, how our significant other will respond to a gift or the lack of one, whether our boss will say yes to a raise, and so on. Even with this everyday uncertainty, some things are significantly less predictable than others because of their inherent variability. How we handle this variability is typically a measure of how well we make decisions under stress, given that stress is often the physiologic response to uncertainty. One common coping mechanism to uncertainty is setting up limits to expected variability. Many decide that a certain amount of uncertainty in their lives is not only acceptable, but is desirable, since small surprises lend spice to the daily routine. Once these borders have been established, we are sanguine, even interested, so long as things stay within these confines. However, surprise can still be overwhelming, such as when we encounter extreme events, for example, the loss of a child or spouse, or a surprise attack by an enemy. It is at such moments that traditional thinking fails. So let us examine uncertainty a bit more carefully. Consider the simple question: Will it rain tomorrow? It has been known for hundreds, if not thousands, of years that the best indicator of tomorrow's weather is today's weather, with maybe a little of yesterday's weather as well. It was cold and clear yesterday, and it is the same today, the odds are high that tomorrow will be cold and clear. A direct proportionality of the recent weather gives one of the most reliable predictors of future weather. But the forecast has built-in uncertainty. Let us be generous and say, based on today's weather, the prediction of tomorrow's weather will be accurate 70% of the time, but if yesterday's weather is also taken into account, then the percent accuracy might increase to 80%. Before large-scale models, computer calculations, and satellite observations, such simple calculations are what constituted weather forecasting. Temperature, humidity, precipitation, and so on were made by linear extrapolation of what had occurred in the recent past.

But as everyone knows, weather forecasting is not an exact science. There is always an element of uncertainty in the predictions, in large part because linear extrapolation does not faithfully capture the nonsimplicity of weather. The turbulent fluctuations in wind speed and direction, the erratic variability in the local temperature, and other variations in meteorological variables to which they are coupled, are artfully modeled. However, this variability is included in one form or another in weather forecasting computer codes, into which satellite data are fed, calculations done, and predictions read out. The computer forecasts are also not 100% accurate either, because of the erratic behaviors of the input variables and the chaotic nature of nonlinear dynamics. In fact, the weather report usually has a probability associated with it; perhaps a 50% chance it will rain tomorrow, unless that cold front changes direction.

OK, so maybe predicting the weather with certainty is a hard call. What about the spread in temperature: the high and low temperatures for the day. Numbers that are certainly useful to farmers and may be the determining factor as to whether or not you wear a sweater today. Even using modern computers, with the most advanced mathematical models of meteorology, the variability in air temperature is not reliable and predictions focus on the average air temperature and how that changes over the day. Therefore, the probability of a reliable prediction is based on the variability in the temperature being relatively small, in which case the deviation of the empirical average temperature from the predicted average temperature is also expected to be small.

It seems that uncertainty, or randomness, is at the heart of what we know and, in fact, is central to what we can know. Consequently, this is the most basic problem that CS addresses, which, as we saw in the last chapter, is central to our understanding of the modern military. If we are to disperse the fog of war we must first embrace uncertainty and then make it work for us.

3.2 Uncertainty and natural law

Why is it that some variability is acceptable and we can adapt to it, whereas other changes are considered abnormal and may result in our being momentarily shocked to the point of being paralyzed and unable to respond? The key word here is abnormal, with the implication that there is normal or typical behavior. Let us examine this notion of normality a little. It is our contention that this benign sounding word is at the heart of the fog of war and poses the greatest danger to the individual warfighter and to the mission. For clarity, we go back two hundred years to a time before statistics, when erratic fluctuations were thought to be the result of inferior experiments and generated by the fundamentally unknowable causes of randomness.

How can a collection of measurements, each one of which is individually wrong, lead to a result that is right in the aggregate? What is truly remarkable is that it has been found that random fluctuations follow an empirical law in the physical world. This natural law is every bit as precise as Newton's law of universal gravitation that predicts the orbits of celestial bodies. Here it is necessary to not confuse precision with accuracy, in fact, the empirical law gives a precise quantitative measure of the potential inaccuracy of each and every measurement. The unfortunate name of this law is the Law of Frequency of Errors (LFoE). The name is unfortunate, because error connotes mistakes, which leads to an often improper interpretation of what the law actually means.

At the turn of the nineteenth century, the German polymath Gauss [89] and the American mathematician Adrian [1], independently explained the mystery of why physical experiments never give the same result twice. Their academic discussion did not influence how soldiers fought in battle, nor did it change the views of most commanders, but in the cities where invention and innovation were flourishing, the intelligentsia was listening, including von Clausewitz. The imaginations of the nineteenth century Natural Philosophers were captured by the idea that random variations obey a law in the same way that deterministic phenomena obey laws. The bell-shaped curve depicted in Figure 3.1 peaks at the center, where the majority of experimental values occur, so that the largest fraction of results is concentrated at the variable's average value. The further a value is from the peak, the fewer times it is observed in the experimental data. This observed ordering of data points is captured by the natural law.

A natural law is shorthand for a vast amount of empirical data, usually expressed in concise mathematical form. What students of science and engineering find out later, if ever, is that all the simple mathematical expressions they learned, do not involve physical variables directly, but instead they involve tracking the behavior of the averages of those variables. Every measurement of a physical variable, such as temperature or pressure, actually yields a different result, but those differences are small, and the measured values close together in time tend to cluster around a typical value. This representative value of the observable is the arithmetic average, around which most of the measurements fall. This is where the notion of error enters our thinking.

Because many phenomenological laws are expressed in terms of average values, which can be predicted from physical theory, the average is considered to be the right answer and deviations from this value are interpreted as errors.

The nineteenth-century statistician, Sir Francis Galton, put it this way [87]:

> I know of scarcely anything so apt to impress the imagination as the wonderful form of cosmic order expressed by the “Law of Frequency of Error.” The law would have been personified by the Greeks and deified, if they had known of it. It reigns with serenity and in complete self-effacement, amidst the wildest confusion. The huger the mob, and the greater the apparent anarchy, the more perfect is its sway. It is the supreme law of Unreason.
>
> Whenever a large sample of chaotic elements are taken in hand and marshaled in the order of their magnitude, an unexpected and most beautiful form of regularity proves to have been latent all along. The tops of the marshaled row form a flowing curve of invariable proportions, and each element, as it is sorted into place, finds, as it were, a preordained niche, accurately adapted to it.

It was, and still is, remarkable that the random variations in measurement are not capricious, but follow an unexpected law. The LFoEs described what, in earlier centuries, was the mysterious variability observed in the measurements from all physical experiments and whose explanation had eluded generations of scientists. The mathematical form for this statistical effect has the one humped shape depicted in Figure 3.1 and became known as the normal distribution, which is another unfortunate choice of name. The name is unfortunate because it eventually leads to the mistaken impression, on the part of working scientists who are not statisticians, that all the world’s uncertainties are (normally) of this form, which is devastatingly far from the truth. In fact, the statistical distribution that describes the way we live, like the distribution of income, the frequency of stock market crashes, and bed availability in emergency wards, look nothing like the LFoE.

Our two mathematicians, Gauss and Adrian, hypothesized that the average was the best representation of the data and the bell–shaped curve depicted in Figure 3.1, with a width that characterizes the variability in the data, never repeating, always varying. This invention of statistics and its adaptation to the interpretation of experimental data revolutionized not only how scientists thought about the physical world, but how nonsimplicity and uncertainty were understood. In this way, uncertainty was shifted from the domain of the unknowable unknown to the knowable unknown, and the magnitude of that unknown could be quantified. The greater the nonsimplicity, the greater the uncertainty, as measured by the width of the LFoE. In this world view there exists a correct value for the outcome of an experiment and although this interpretation of uncertainty may be accurate for simple physical systems, generally it imposes an unrealizable restriction on how we understand the real world. Science was stuck in this rut for nearly two centuries.

It became evident from the LFoE that measurements ought to have a proper value, one determined by the dynamics of the observed phenomenon.

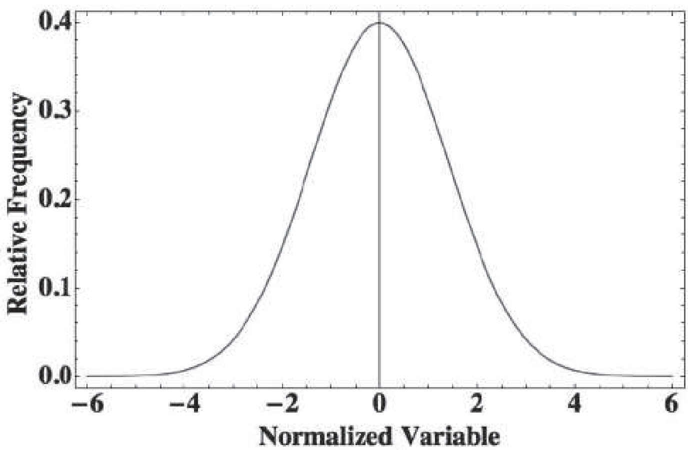

Figure 3.1: The bell–shape curve of Gauss and Adrian concerns errors. Consequently, the average of the experimental data is subtracted from each data point so the curve peaks at zero, and the data are divided by the standard deviation of the data (width of the distribution) so that the normalized variable is dimensionless. This is the universal curve for the LFoE. The peak occurs at the point of zero error, that is, the average of the data. The Region 2 standard deviations above and below the average value contain 95% of the errors.

This view of physical phenomena was and is consistent with Newtonian mechanics, which determines the ballistics of rifles, the inertia of tanks, and the lethality of IEDs. The universe is understood to be determined by clockwork mechanical processes and, therefore, variables ought to be quantifiable, measurable and predictable, even those referring to an individual's life and to society. However, the nonsimplicity of the world manifests itself in predictions that are not as certain as those described by Newton's laws, unfortunately for science.

All experimental data is compacted into the universal curve depicted in Figure 3.1. Of course, the curve did not start out as universal, but depended on whether the measurements are the heights of soldiers on an Army base, the spacing of vehicles in a convoy, the fluctuations in the distance to where the round impacts the target, and so on. Each distribution has a different average value and a different width depending on what is being measured.

The procedure for obtaining the universal form is to subtract the average value from each data point and then divide the resulting data by the width of the distribution (the standard deviation). Consequently, the bell-shaped curve peaks at zero (the average has been removed) and the width of the universal distribution is unity (the units of the data have been divided out). In terms of this shifted and normalized variable the LFoE is universal.

Thus, even when statistics enter our understanding of the world, where uncertainty blurs what is expected, the scientist or engineer believes there ought to be a proper value that characterizes the process. In this interpretation statistical fluctuations do not invalidate the mechanical world view; rather, they complement it, often making predictions only slightly less certain than the ticking clock. The universal distribution peaks at zero error, corresponding to the “correct” average value, and consequently this is the most likely outcome of an observation. How accurate the average is in characterizing the full data set is, in turn, determined by the distribution width. A high-quality prediction has a narrow distribution, where the anticipated future is not too dissimilar from the one eventually experienced. On the other hand, a low-quality prediction has a broad distribution, where the experienced future can be quite different from the predicted one. The latter is filled with surprises. A year after Gauss and Adrian introduced the normal distribution, Marquis Pierre-Simon de Laplace presented a mathematical proof of the central limit theorem, which established that the validity and applicability of this distribution are much broader than anticipated by the LFoE. The Marquis showed that there are four conditions on which the central limit theorem rests. These conditions are expressed in the language of the law of errors as: 1) the errors are independent, 2) the errors are additive, 3) the statistics of each error is the same, and 4) the width of the distribution is finite. These four assumptions were either explicitly or implicitly made by Gauss, Adrian, and Laplace in their discussions of statistics.

The normal curve describes how we deal with the world's complications in order to keep from becoming frozen in the grip of uncertainty. But as we show, the LFoE applies to complicated phenomena; nonsimple phenomena require something else altogether. Consider that most people would like to retire someday and towards that end they make financial decisions, such as investing money in a 401K retirement account. But consider the daily variation in the profit of a particular stock in the stock market. If your stockbroker forecasts an upturn in the stock market, and it occurs, he is a genius and you commend yourself for selecting him. If the stock does not follow his prediction, he becomes suspect and you question the wisdom of choosing him to invest your money. But his success, or failure, is not the same as being able to predict with certainty how the price of a particular stock will behave.

The dominant view among market professionals is that the erratic motion of a stock is a random process driven by external events. The events are international and national issues, related to war and peace, crop failures, shifts in the geopolitical perspective, rising interest rates, falling interest rates, and so much more. All these activities (causes) tend to mask any underlying market mechanisms, which might have the characteristic of an economic law, as well as the intrinsic value of a company whose stock is being discussed. An individual broker may be successful in this random environment, but for each broker that succeeds over the long term, there are hundreds, if not thousands, that fail. The stock market is the battlefield of the broker, where they fall victim to life's fog of uncertainty with poor thinking, much as most military forces have done historically in the fog of war.

3.3 Machine Age world view

> [The United States] is still undergoing a transition from the industrial age of warfare to the Information Age. And, even if [...] the military could achieve a fully functioning combat cloud today... And, what I mean by combat cloud is achieving a means of rapidly and seamlessly sharing information, it is highly unlikely that the military would make the most of that new system. The reality is the Department of Defense and its respective service branches are still aligned in an industrial age fashion with employment doctrine still based on traditional attrition and annihilation strategies of warfare.
> – LTG David Deptula, USAF (Ret.)

In Western countries most people believe that they control their lives, and it is only in particularly nonsimple situations, such as in anticipating the price of individual stocks in the stock market, over which they have no control, that even the illusion of predictability is lost. Like many nonsimple things in life, this is both true and false at the same time. The truth lies in the plan they adopt for their life, the linear trajectory from college, to the top of their chosen profession, to retirement. The plan is also false, because life itself occurs while the plan is being executed and consists of the unpredicted side roads and detours that mark the deviation from the plan. These unpredicted and usually unpredictable deviations make life both interesting and disruptive, sometimes leading to abandoning the original plan altogether.

Plans are typically linear, proceeding from point A to point Z by means of the most direct route, through B, C and all the letters in between. Some plans are more elaborate than others and take into account contingencies, delays, and shortages, according to the experience and prescience of the planner. Linearity is necessary in order to define how the plan is structured. For example, the plan might be focused on economic stability, with suitable savings, provisions for promotions, and, of course, retirement. Or the plan might focus on how to advance a career through obtaining the proper education, making the appropriate contacts, and aligning with the winning side in professional disagreements. The planning variable, economic stability in one case and career advancement in the other, require linearity, because a variable can only be measured when it is not influenced, or only weakly influenced, by the rest of the world. Otherwise, it can be washed out by stronger effects and lose its identity altogether.

In the linear additive world of the LFoE, the average value is king, which is a view that was eventually adopted by a large fraction of physical and human scientists in the last two centuries. Linearity causes predictability: small initial changes in a process produces relatively small changes in its final behavior. The output is proportional to the input. The result is that linear phenomena can be controlled in a straight forward way, assuming that the world is stable and the appearance of instability is an illusion. But that is not the world of market crashes, staggering recessions and the failure of diplomacy–the actual world in which we live.

If linearity is so far from reality, why is it so important?

The concept is important, because a linear world has simple rules and yields simple results, even though it is not the world in which we live. In its most basic form, linearity determines that output is proportional to input, and response is proportional to stimulus. Linearity does arise in various guises in a number of distinct contexts and, although the various manifestations are in some sense equivalent, they do provide slightly different shades of meaning.

An example of a linear model can be drawn from the geopolitics of the last century. One frequently issued rationale for the United States to send military advisors and vast numbers of troops into Vietnam was to prevent governments from falling to communism. A popular argument was based on a simple metaphor. Each of Vietnam's neighbors was represented by a domino standing on end, in close proximity to one another, forming a tightly configured chain receding into the distance. Pushing the end domino (as depicted in Figure 3.2) causes it to fall (become communist) and strike its neighbor, which causes the next domino to fall, inducing a cascade of government transformations. The domino theory, as it is known, is a linear model of a nonsimple geopolitical situation whose sole virtue was that it could be readily understood by a mass audience. Other geopolitical theories of the time, although certainly more accurate, could only be understood by experts and lacked mass appeal.

Figure 3.2: The domino theory of geopolitics circa the middle 1960s.

This is an example of the pyrrhic victory of form over substance and the attractive simplicity of the argument has nothing to do with its validity. It is merely an example of how the world's nonsimplicity can be replaced and misunderstood by a simple linear model. Notice that all the nonsimplicity and nuance has been scrubbed clean from this model of reality. There is no fog to detract from the direct deterministic additivity of the effect of the cascading dominoes. What could be simpler? Wouldn't the military want this to be the reality of their profession?

Linearity underlies the assumptions that errors are additive and independent, necessary for the validity of the central limit theorem. Consequently, a linear world view is entailed by the LFoE, with the error (ambiguity) produced by limitations in information and/or knowledge. The linear view was adopted by sociology, psychology, and various branches of the life sciences nearly two hundred years ago. This view provides insight into nonsimplicity, which relies on understanding the elementary laws governing the underlying elements. Once the separate parts of a process are understood, it is implicitly assumed they can be joined together to understand the whole. In physics, this principle is used to explain everything from music to munitions. It arises from the separation of a system into its fundamental linear components. In other words, like the error law, the world consists of networks of linear additive processes, but unlike that law, these parts are inherently knowable. The linear world is predictable; it is a simplified version of Newton's mechanical clock, which is a view that helped to transform Western Society from an agrarian culture into a manufacturing one.

In any event, the success of the normal curve in physics led to its adoption in explaining non-physical phenomena as well, which resulted in the introduction of the "average man" in socio-physics, the "rational man" in economics, and the "reasonable man" in jurisprudence. The LFoE captured and held captive the imagination of scientists throughout the world for over two centuries. The bell-shaped curve was accepted, in part, because it allowed practitioners of the various non-physical disciplines to insert uncertainty into their discussions in a manageable way. A little uncertainty was not only tolerable, but was welcome.

The ideas of Adrian and Gauss found fertile ground in the manufacture and operation of the devices of the Machine Age. From the tolerance of a crank-shaft to the quality control of widgets coming off the assembly line, the artifacts of the Machine Age lent themselves to the description by the normal curve. Two hundred years of gathering data have taught us the properties of systems described by the normal curve. First and foremost, such systems are linear, so a system's response is proportional to the strength of the stimulation. A 10% excitation produces a 10% response, or maybe a 20% or 5% response, but nothing too crazy. The system remains stable when excited, and therefore, in principle, its behavior can be predicted, at least in a fairly narrow, probabilistic sense.

Secondly, such systems are additive, and they can be reduced to fundamental elements, which weakly interact and recombine after being perturbed to reconstitute the overall system. Consequently, linear additive phenomena that are stable when stimulated describe the world of Adrian and Gauss. These two conditions support the von Clausewitz' COG perspective of warfare.

This is the world view of yesterday's and today's warfighter. The machines that populate their world are the result of the normal curve dominating manufacturing to reduce variability. They have come to expect that refrigerators, dishwashers, automobiles, rifles, tanks, and all other machines of a given make and model are identical. But not only machines, the clothes and shoes they wear share a similar uniformity. Variability is under control and can be extinguished by the process of manufacturing. This anticipated controllability seeps into the individual psyche to reinforce the normal curve description of the variability in virtually everything.

This model of the world is based on the idea that variability is bad (un–wanted) and standardization is good (wanted). The historical success of Western Society reinforces this linear world view and conspires with the human desire to be in control of one's life to make suppression of variability attractive. But is this strategy for attaining uniformity indicative of a deep truth about our world, or does it merely impose an apparently desirable property that is useful in some contexts, but destructively harmful in others? It certainly simplifies manufacturing, as long as human beings are excluded from the process. Keep it linear, keep it simple, and thereby increase productivity. However, the culture does even more to reinforce this idealized view of the world. Every college student who has taken a freshman course in the sciences has been graded on a curve, which is to say, the grades received were forced to conform to the normal curve depicted in Figure 3.1. Grading on a curve means that 68% of the students in the class receive Cs, another 27% are equally divided between Bs and Ds, and the final 5% share the As and Fs. After taking enough of these classes, a student generally accepts the "reality" that something as nonsimple as learning can be represented by a linear additive process. This is a gross distortion of the learning experience, but the education establishment, including the military educational system, cannot be weaned from its use.

As we said, in the linear additive world of the LFoE, the average value is king, which is a view eventually adopted by a large fraction of the physical, human, and military sciences in the last two centuries.

Thus, Western culture, both directly and indirectly, has taught the same lesson to the soldier mechanic, or combat infantry soldier, as it did to the officer managing a motor pool or leading a platoon into battle, as it did to every person up the chain of command. The repeated lesson is that there is always a best way to accomplish a task or mission, that a small amount of variability can be tolerated, but not too much. This is the lesson of the normal curve and is how Westerners are enculturated to adopt a Machine Age way of thinking. The military warfighter is no exception. Unfortunately for the warfighter, this way of thinking, particularly in extreme situations, is dangerous, can be fatal, and is very seldom questioned.

The Machine Age view of the world certainly conflicts with the Middle Eastern tradition of maintaining amenities even in the middle of the battlefield. The importance of ritual, in the form of hospitality, is that it makes the world stable and understandable, at least to those in that culture. Hospitality is one of those social constructs that is often disconnected from everything else and must therefore be conserved. Good manners, like good discipline, are most important in extreme situations with uncertain structure as they have a stabilizing influence in a chaotic world. This perspective was one of the casualties of the industrialization of our society in the nineteenth century. The Irish statesman and philosopher, Edmund Burke, who supported the American Revolution, but was in opposition to the French Revolution, said it best [44]:

> Manners are more important than laws. Upon them, in a great measure, the laws depend. The law touches us but here and there, and now and then. Manners are what vex or soothe, corrupt or purify, exalt or debase, barbarize or refine us, by a constant, steady, uniform, insensible operation, like that of the air we breathe in. They give their whole form and colour to our lives. According to their quality, they aid morals, they supply them, or they totally destroy them.

Good manners, with their ability to stabilize social structure and their refining influence on even the coarsest among us, have survived within military culture as Military courtesy, which is one of the defining features of a professional military. Military courtesies include proper forms of address and when each should be used; the salute, and the related concept of standing at attention; proper wearing of military headgear and a dress code; as well as, the rules for behavior in various ceremonies. Specifics vary depending on the country and on an individual's rank, location, and circumstances. Manners, along with other social mores, are what constrain the variability of human social interactions to a manageable size.

As we mentioned, while the manufacturing paradigm was being constructed, a number of ideas that caricatured humanity were also developed: economics conceived of the "rational man;" jurisprudence invented the "reasonable man;" and sociology gave us the "average man." These concepts derive from the average of the LFoE, having been invented, developed and forwarded by the sciences. Of course, today, we consider such labels to be sexist and replace them with "average person," "reasonable person" and "rational person." But such replacements miss the broader point that the importance of variability in being human has been eliminated; a trait that some would argue is one of the more attractive aspects of the species. Such a parody of being human has found its way into serious popular discourse and its removal is not evident in the foreseeable future.

In counterpoint to this apparent historical misuse of statistics, consider Florence Nightingale, the socialite turned nurse, who was considered by some leading academics of the day to be the "prophetess" for the development of applied statistics. She led a group of thirty-eight nurses to Turkey during the Crimean War, where British soldiers were coming down with cholera and malaria in staggeringly large numbers. Of the 21,000 soldiers who died in this three-year conflict, only 3,000, or approximately 14%, were the direct result of wounds received in battle. The remaining 86% awaited nurse Nightingale for their explanation.

On arrival, Nightingale's nurse cohort discovered that hospitalized soldiers retained their army uniforms, "stiff with dirt and gore," and lacked decent food or blankets. Her efforts and eventual success in turning around these appalling conditions and her fame as a reformer of hospital sanitation methods are unparalleled. Less well-known was her use of the then-new techniques of statistical analysis to quantify the evidence of preventable deaths. She directly related the number of deaths to the lack of hygiene in the Army hospitals and single-handedly revolutionized the notion that social phenomena could be made objective through statistical analysis of data. Once measured, such data could be mathematically analyzed to draw inferences that could be used to form the basis of new, improved policy. She applied statistics to the life and death situation of soldiers in war and conclusively demonstrated that lives could be saved through acting on a proper interpretation of the statistical data. It is also worth mentioning that her family had the social connections to get that evidence to those in the British hierarchy who could actually affect this important social change.

3.4 Time to reflect

We have covered a lot of ground, so let us summarize the main points discussed. We examined how nonsimplicity, through uncertainty, blurs the predictions of deterministic models, such as those resulting from Newton's force laws. The LFoE was the first theory to directly treat CS in the modeling of the physical and subsequently the social and biological world from a unified perspective. Much of our experience of forces rely on the notion of linearity, even in such a general setting as the proof of the central limit theorem. Subsequently, we combined the arguments that enabled us to construct a linear representation of a nonsimple phenomenon and the random influence of the environment using the LFoE. In such a linear model of the world, a system's output is proportional to the input. The input to a system is typically under our control and is therefore known fairly well. However, there is uncertainty in what the system does with the input information, resulting in some uncertainty in the output. It is the output that is measured and therefore these data cannot be exactly predicted. This type of stochastic modeling fills our lives and dominates how we think about the world and our place in it.

Most people muddle through the fog of life, making decisions without complete information. Uncertainty shrouds both what they know and what they expect to happen. In the modern world, elusive cause and effect chains are sought at every turn, encouraging us to make the same decisions we made in the past, when the situation looks similar, provided we lack reasons to change. Consistency follows this Pied Piper of low expectations: if the cause remains unchanged, then so too will the effect. For example, a casual greeting while passing a friend in the hall usually elicits a smile, nod, or some other, equally non-committal response. However, if there is no acknowledgement, or the person mutters to themselves, or quietly sobs, there is probably something wrong.

The response is significant because it deviates from the acceptable response of linear proportionality: a smile in response to a smile and a nod acknowledging a nod. How to respond to the new behavior is determined by whether the person is a friend, a colleague but not a friend, or someone we barely know. However it is handled, it is clear that the outcome is determined by how we have interacted in the past and how that past interaction is projected onto the present circumstance.

Perhaps the significance of the overwhelming influence the LFoE has on our thinking is not yet fully appreciated, so let us consider an extreme situation where linearity all too clearly breaks down.

According to General Charles Krulak [132], in order to describe the overwhelming complexity of urban battle, the Marine Corps coined the phrase, “the three block war,” over which the entire spectrum of tactical challenges are unleashed, within a few hours and within a few city blocks. What this means is that on one block of this war, Marines might be fighting a lethal battle with an entrenched, unrelenting enemy. On an adjacent block, they might be rendering humanitarian aid to local people who have lost their homes or been injured in the conflict. Finally, on the third block, they may be attempting a peace mission by separating feuding local factions. All these aspects of the military’s mission spectrum are unfolding on the same day, involving the same troops and in the same urban area. Smith [218] comments that each of these one-block operations is closely linked with the others, so that the failure or success of one affects them all. This is the situation that exists in many Middle Eastern countries today. Not with just Marines, but with all our warfighters and allies alike.

The mutual influence of the activities on the adjacent blocks is not proportional, as it would be for a linearly connected network. For example, the success of the humanitarian effort could have multiple effects on the psychology of radical jihadists. It could discourage them, causing them to lose heart and withdraw. On the other hand, it could stiffen their resolve, resulting in them fighting even more ferociously. The response to the peace making effort is equally uncertain as the effort may either support or inhibit the behavioral change from the shift in the intensity of the fighting. Whether activities move cooperatively, or in opposition to one another; whether the cooperative response of one activity depends on the magnitude of another activity; or how any of the other combinations of responses are realized cannot be predicted. Uncertainty is the reason that accurate and timely information is so important in orchestrating the three block war as the shards of information chip away at the uncertainty buffering the separate blocks. Each action taken engenders a response, some that can be anticipated, others that cannot. The seasoned warfighter must be continually on the alert for the unexpected occurrence.

Cushman and his commander, William E. DuPuy, had a debate about developing leaders [190]:

> In 1974, the fundamental difference between the two men, as Cushman saw it, was that DuPuy was teaching the Army how to fight, while Cushman was complementing that work by teaching Army officers how to think about fighting...Cushman told Ricks that DuPuy’s old school methods would create “a generation of idiots who all know how to clean a rifle but who don’t know why we have an Army.”

CHAPTER 4

THE LOGIC OF FAILURE

> Critical and complicated situations are not always available for study, and in the real world, the consequences of our mistakes are slow in developing and may occur far from where we took action. After a long delay or at a great distance, we may not even recognize them as results of our behavior. We therefore have few opportunities to learn from our mistakes. [77]

Just as error follows a law, failures follow a logic, and ultimately so do catastrophes. The existence of such a logic implies that failing is not solely the result of happenstance, but is often the foreseeable consequence of decisions made and actions taken. A recurrent contributor to failure is the mistaken belief that the desired outcome of a nonsimple process can be achieved by actions that follow a linear chain from one cause to the next, like the falling dominoes. The typical linearity assumption, even if unconsciously made, regulates how we think about formulating ways to achieve a given outcome. In a linear world such an approach would guarantee victory, since the choice of action would be directly linked to the cause of the outcome. However, as we now know, we do not live in that world and more often than not, taking a linear approach almost guarantees catastrophic failure rather than victory.

Taleb and Blyth [241] recently examined, in a geopolitical context, the implications of artificially suppressing volatility in order to achieve stability. Their arguments were general, with exemplars of unintended consequences drawn from the world's political stage. In any event, they concluded that pushing natural variability from the central region of the probability density function, assuming a LFoE of potential outcomes, out into the tails of the probability distribution, as depicted in Figure 4.1 has two effects. First of all, the ubiquitous, naturally occurring, low-level variability, to which the processes could adapt, disappear from the policy makers field of vision, making everything appear calm and trouble free. Secondly, when a fluctuation does appear it is completely unexpected and devastating.

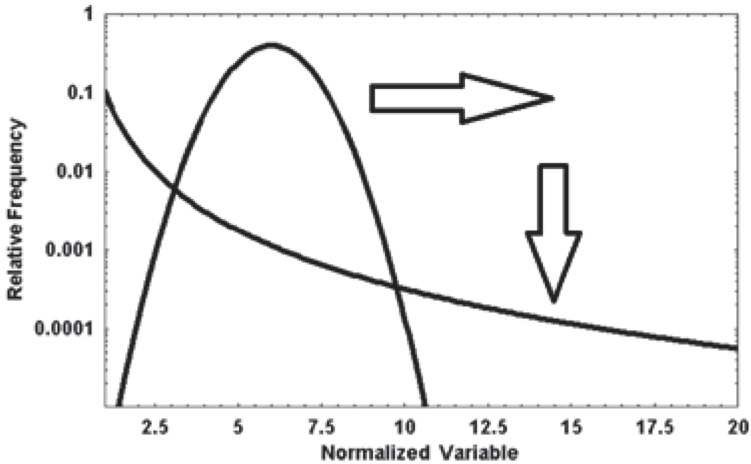

Figure 4.1: The Gaussian distribution is depicted as the Bell–shaped curve and the Pareto distribution is the long–tailed curve, both on log–linear graph paper. The arrows indicate a control strategy that pushes the frequently occurring low amplitude events out into the tails of the distribution.

The catastrophic consequence of such high–impact, low probability events, they argue, results from nonsimple systems becoming extremely fragile when their natural volatility is artificially suppressed. Such controlled systems simultaneously exhibit no visible signs of impending catastrophe [241]:

> In fact, they tend to be too calm and exhibit minimal variability as silent risks accumulate beneath the surface...These artificially constrained systems become prone to “Black Swans”–that is, they become extremely vulnerable to large-scale events that lie far from the statistical norm and were largely unpredictable to a given set of observations...Such environments eventually experience massive blowups, catching everyone off-guard and undoing years of stability or, in some cases, ending up far worse than they were in their initial volatile state.

As they point out, seeking to dampen all variability to achieve short-term stability, runs the risk of guaranteeing long-term instability by means of enhancing the probability of massive failure. One strategy to counter this effect is captured by the mantra of the innovator: “fail fast, fail often.” In this way, local failures are induced by the natural variability of the process; kept small through correction by human intervention; catastrophic failure is avoided and the nature of the process is sometimes revealed. Note that catastrophe is a system property and not a property of individual events; it may be the final straw that breaks the camel's back, but it is the cumulative effect of many straws and the camel together that make up the system to bring the animal down. It is not the final straw, but a lifetime of straws, plus the final straw. This is especially noteworthy in military systems.

4.1 Information Age world view

> The achievements of the industrial and information ages are shap–ing a world to come that is both more dangerous and richer with opportunity than ever before. Whether promise or peril prevails will turn on the choices of humankind [170].

In the Machine Age world view of Adrian and Gauss, everyone should make the same amount of money for the work they do. Some might make a little more, and others a little less, but the average salary ought to be a good indicator of the state of the economy. In such a world everyone would be considered a mediocre artist, play a musical instrument badly, all sports would result in a tie, and there would be no heroes. No one would be outstanding and everyone would be nearly equal and equally uninteresting. But that is not the world in which we live. In our world there is Michael Jordan who destroyed the competition in basketball; Picasso, who turned the art world on its head; Miles Davis, who captures the soul with his music; as well as people who make a staggering amount of money as income, whether deserved or not. In the real world, there are stock market crashes and economic bubbles, earthquakes, brain quakes, peaceful demonstrations that become riots, some children die, and others live to be very old. There is extreme variability everywhere, which would be considered outliers by the normal curve, but are, in fact, no different statistically from the rest of the population. They are the disrupters of the status quo, Taleb's Black Swans [240].

The point is that we live in a nonsimple world [247], but our understanding of and way of thinking about that world have their roots in the simple models formulated to function in the Machine Age. The distribution of income is not a bell-shaped curve, with a well-defined average and standard deviation. It is a curve that has a very long tail, as shown in Figure 4.1. This distribution, first discovered at the end of the nineteenth century by the engineer-turned-sociologist, Vilfredo Pareto [178], is one more appropriate for the Information Age. It captures the extreme variability that defines not only the boundaries of our life, but the unexpected events that take us by surprise.

What makes the research of Pareto so remarkable is that it contradicts all the understanding of social phenomena developed in the nineteenth century. Prior to his studies, it was believed that data sets gathered from social phenomena have a normal distribution, such as measured by the English scientist and eccentric Sir Francis Galton, the cousin of Charles Darwin. Galton was convinced that social phenomena could be understood by counting, so he counted the number of times people coughed at the opera, the number of illegitimate children conceived by the aristocracy and other obscure phenomena. He believed that the frequency with which an event occurs and the duration of its persistence determined the nature of the underlying causes [87]. So let us briefly examine how society and its members were understood in the 1800s.

At a time when most travel involved horses, reading was done during the day or by candlelight, and gentlemen drank, gambled, and whored, Natural Philosophy—now called Physics—was being transformed. Consequently, prediction emerged as science's hallmark and scientists, or natural philosophers, emphasized the predictability of phenomena. John Herschel, wrote in the Edinburgh Review, in 1850 [108A]:

> Men began to hear with surprise, not unmingled with some vague hope of ultimate benefit, that not only births, deaths, and marriages, but the decisions of tribunals, the result of popular elections, the influence of punishments in checking crime–the comparative value of medical remedies, and different modes of treatment of diseases–the probable limits of error in numerical results in every department of physical inquiry–the detection of causes physical, social, and moral–nay, even the weight of evidence, and the validity of logical argument–might come to be surveyed with that lynx-eyed scrutiny of a dispassionate analysis, which, if not at once leading to the discovery of positive truth, would at least secure the detection and proscription of many mischievous and besetting fallacies.

Herschel was addressing the new statistical way of thinking about social phenomena that was being championed by social scientists such as Quetelet, among others. As Cohen [57] pointed out, one way of gauging whether the new statistical analysis of society was profound enough to be considered a revolution was to consider the intensity of the opposition to this new way of thinking. One of the best-known opponents to statistical reasoning was the philosopher, John Stuart Mill. He did not believe that it was possible to construct a mathematics that would take the uncertainty that prevails in the counting of social events and transform uncertainty into the certainty of prediction required by science. Of course, there are many that today share Mill's skepticism and view statistics as an inferior way of knowing [159]:

> It would indeed require strong evidence to persuade any rational person that by a system of operations upon numbers, our ignorance can be coined into science.

One example of the LFoE, or the bell-shaped distribution, is given in Figure 2.1, where we indicate the frequency of occurrence of adult males of a given height in the United States. Such bell-shaped curves, whether they are from measurements of heights, or of errors, are described by the well-known LFoE in which it is clear that the larger the error (deviation from the mean) the smaller is the probability of that value occurring in the population.

But what does it mean?

Consider a slightly different example from that of measuring a physical phenomenon. Suppose I wanted to evaluate the quality of teaching of a university professor. One approach would be to ask a number of students to estimate the teaching capability of that professor on a scale of 1 to 10, to quantify their opinion of the complex process of teaching. How reliable is the estimate of the teaching capability if the average ranking received is 8.5? We assume that this score suggests the students think the professor is a good teacher.

Two distinct cases are of interest. In the first case, the lowest grade received is 7.5 and the highest is 9.5. From this narrow span of scores we conclude that the students' opinions are in close agreement. In the second case the students' estimates range over the full interval, 1 to 10. There would be more of the higher scores, in order for the professor to receive the average of 8.5, but there must also be a significant minority that strongly objected to the way the course was taught. Without making a judgment as to which teaching method is preferable, the professor in the second case is certainly more controversial, since the responses are so varied.

Thus, these two situations in which the student population thought the professor was a good teacher are really quite different. The single number (average) is not adequate to give a clear picture of the professor's teaching ability and the average does not distinguish between these two cases. A second number, the degree of variability in the students' responses (standard deviation) gives more insight.

In fact, the standard deviation provides a measure of the width of the bell-shaped curve, so that, together with the average value, we know all we can about the phenomenon.

Even though individuals in a population vary, here the population is the sequence of measurements; the characteristics of the population are themselves stable. The fact that statistical stability emerges out of individual variability has the appearance of order emanating from chaos and has inspired a number of metaphysical speculations. On the other hand, CS does show that randomness is lawful in the scientific sense. It constitutes a shift of focus from the individual, who is quite variable, to that of the system, which can be stable even when consisting of aggregated unstable elements.

Another way to interpret Galton's paean to the submission of uncertainty to the lawfulness of nature, with which we began Section 3.3, is Quetelet's regression to the mean. By regression to the mean, Quetelet meant that as more and more biological data is gathered, a species is better and better represented by the average value in keeping with the mathematics of error theory. From this he inferred that society is best represented by the "average man". Quetelet went so far as to claim that the mean value is the archetype that underlies all actual individuals and this archetype is revealed with the acquisition of large amounts of data.

Without going into the mathematical details, it is clear from Figure 4.1 that at the extremes the probability for a normal variable drops precipitously, as a consequence of the exponential nature of the normal curve. On the other hand, the inverse power-law of Pareto follows the more gentle downward slope depicted in Figure 4.1. The Pareto distribution corresponds to those in the upper few percent of the income distribution, and that distribution persists into the twenty-first century in Western Society. The Pareto distribution reveals a disproportionately small number of people, claiming a disproportionately large income. These are the individuals out in the tail of the income distribution. The imbalance in the distribution was identified by Pareto to be a fundamental social inequality and he concluded, after much analysis, that society was not fair [178, 273]. The Pareto world view, with its intrinsic imbalance, is very different from the balanced view of the normal curve. The Pareto imbalance is a fundamental feature of the Information Age and is a manifestation of the modern world's nonsimplicity.

The nonsimple phenomena of biological evolution, letter writing, turn–taking in two people talking, urban growth, and making a fortune are more similar to one another statistically and to the distribution of

Pareto than they are to the normal curve of individual heights within a population. The chance of a random child, selected from a large group, becoming famous or wealthy is very small, but it is still much greater than the chance of that same child becoming tall. A person's height is a hard ceiling determined by nature, whereas a person's wealth or fame is a much softer upper limit that allows for the dedicated to overcoming the social barriers imposing an artificial cutoff. But no matter how much you stretch you cannot become taller. On the other hand, many racially biased individuals have attributed characteristics to enslaved people that were, in fact, socially determined, such as the inability to read or do arithmetic. Consequently, once the social barriers were eliminated the apparent inability disappeared.

The Pareto distribution burst into the general scientific consciousness at the turn of this century with the realization that it described the connectivity of individuals who use social media and the World Wide Web (WWW). This was followed by a flood of applications, showing that such inverse power-law, scale-free networks could model the failures of power grids, explain consensus formation during group decision making, describe how small groups collapse into groupthink, characterize the collective neuron discharge in brain quakes, clarify the turn-taking in conversations, make transparent the mechanism of habituation, quantify the variability in stride intervals during normal walking and a broad range of other phenomena in the social and life sciences.

The inverse power-law of Pareto also defines the nonsimplicity of military operations: bombs that go astray, leaders that misalign, or decisions that never get implemented. The understanding has been growing that it is the network structure of social organizations that manifest their nonsimplicity in the non-intuitive statistics of Pareto. Results are non-intuitive because inverse power-law statistics are so different from that of the LFoE. For example, it is often the case that the second moment diverges, so that the standard deviation is ill-defined and the traditional measure of the mean as the best way to characterize a data set breaks down. This can be observed in the bursty behavior of a time series, which is a manifestation of the Pareto statistics, such as depicted by the exemplars in Figure 4.2.

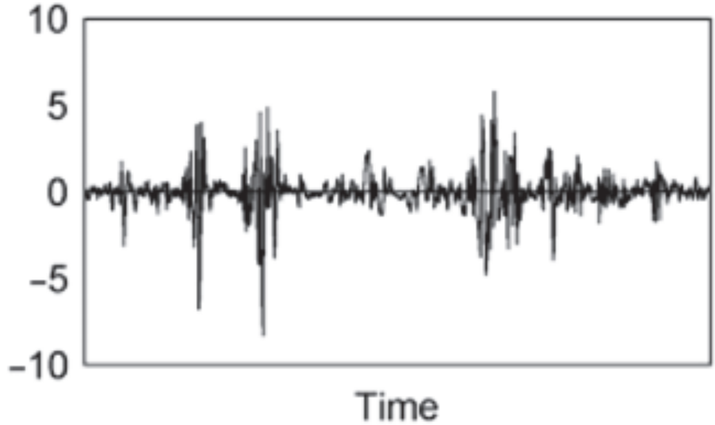

Figure 4.2: Depicted is the generic bursty behavior in naturally occurring time series of nonsimple phenomena such as turbulence, solar radiation, EEG, and hypoxia, among myriad others.

What caught the attention of many who were attempting to interpret the bursty behavior of network time series, was the fact that scale-free networks are robust against attacks for which they had been designed, but are fragile when confronted with unanticipated challenges. A common feature of all these nonsimple networks is their dependence on information and information exchange, rather than on energy exchange, which dominated the physical modeling of the Machine Age. The new Information Age dynamics entail a new way of thinking because of the inverse power-law distribution and the associated nonsimplicity-induced information imbalance. Understanding the implications of this transition is a challenge for the military policymaker.

A word of caution is in order before we continue. Inverse power-laws arise in a wide variety of venues, and the causes for the imbalance may be as varied as the phenomena in which they arise. There is one road to the normal curve of the Machine Age and it is straight and narrow, if somewhat steep. However, there are many roads to the Pareto distribution of the Information Age: some are wide and smooth, others are narrow and tortuously convoluted, but they are all the result of nonsimplicity in its various guises. We consider a number of familiar examples to highlight these differences and show the behavior of nonsimple phenomena.

4.2 Nonsimplicity and failure

The empirical distribution of income has, as we said, the inverse power-law form given by Pareto. Let's look at how income is distributed among the members of a society. As with most such discussions it is best to begin with data. Figure 4.3 depicts income data for the years 1914 to 1933, inclusive, for the United States.

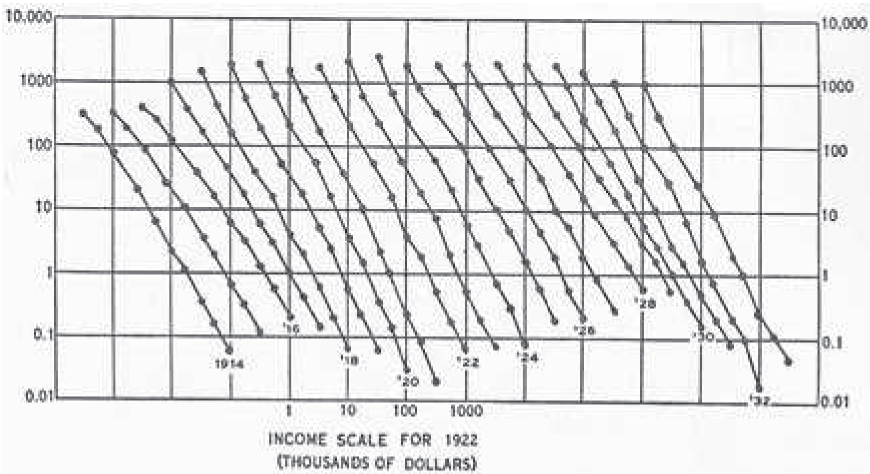

Figure 4.3: Comparison of income distribution in the United States from 1914 to 1933, inclusive [68]. Both the scale of the recipient population and the scale of the income are the logarithm of the appropriate variable. The vertical lines are one cycle (factor of ten) apart, as are the horizontal lines, with the scale shifting one-half cycle to the right for each successive year of data. The point nearest the date in each case measures the number of incomes in excess of $1,000,000 in that year [164].

Note that the data is displayed on log-log graph paper, where the variables' logarithms are recorded, rather than the variables themselves. On such graph paper, each factor of ten in population is one division and each factor of ten in income is also one division. In terms of logarithms, the yearly income distribution is a sequence of straight lines, each with a negative slope. The slope of the inverse power-law distribution yields the Pareto parameter, which is often referred to as the inverse power–law index. The yearly distributions in Figure 4.3 are remarkably similar from 1914 to 1929, and are a sequence of parallel line segments. The date is recorded at the end of the curve, which corresponds to the number of incomes in excess of one million dollars in that year. The years are separated in order to better compare them visually.

There is evidently an almost steady increase in the location of the end point of the income distribution curve, starting in 1921 and ending with the year of the stock market crash 1929. This vertical increase in the location of the end point of the distribution, from one year to the next, indicates an increasing number of people making in excess of one million dollars as the years went by. It was the Roaring Twenties and economic times could not be better. But then the bubble burst with the stock market crash of 1929. No one saw the train wreck coming.

In 1930, the end point of the distribution curve plummeted and the fraction of society living the good life decreased by a factor of ten. For every hundred people on the gravy train before the crash, there were only ten enjoying that ride after the stock market stabilized in 1932. It is interesting that throughout this time frame of prosperity, the number of poor seemed to be constant.

You probably noticed that the slope of the income distribution curve was approximately constant before the crash, but changed after the crash. The 1930 distribution is steeper than the 1929 distribution, indicating that the value of the power-law index is greater after the crash than it was before. But by 1933, the slope had regained its pre-crash value. The slope parameter, or inverse power-law index, is responsive to the nonsimple internal dynamics of society occurring as a consequence of the catastrophic market failure of the crash.

One must shy away from the conclusion that there was something unique about the stock market of the early twentieth century that led to its crash. Of course there have been multiple analyses itemizing the individual events that produced this particular economic disruption, leading some to believe that they truly understand what caused the crash. The failure of this particular market was not a singular event, however. It was just one more failure in a long history of social failures, or as Charles Mackay put it in his preface to the 1852 edition of *Extraordinary Popular Delusions and the Madness of Crowds* [149]:

> In reading the history of nations, we find that, like individuals, they have their whims and their peculiarities: their seasons of excitement and recklessness, when they care not what they do. We find that whole communities suddenly fix their minds upon one object, and go mad in its pursuit; that millions of people become simultaneously impressed with the delusion, and run after it, till their attention is caught by some new folly more captivating than the first.

This remarkable nearly-two-hundred-year-old book remains relevant in that it records in readable detail the formation and bursting of economic bubbles throughout history that could just as easily be describing the recent misadventure with the technology or real estate bubble of the past few decades. By way of example, consider the lowly fragile tulip, which was introduced into Europe via Constantinople circa 1550 and over time, attracted the attention of the gentry. The tulip's reputation grew until in 1634 it was not just fashionable, but mandatory among the wealthy to have a tulip collection. The intensity of the Dutch tulipomania was so great that as Mackay points out: ". . . the ordinary industry of the country was neglected, and the population, even to its lowest dregs, embarked in the tulip trade." The mania continued to mount until, in 1635, the following list of articles were delivered in compensation for one single root of a rare tulip species:

	florins
Two lasts of wheat	448
Four lasts rye	558
Four fat oxen	480
Eight fat swine	240
Twelve fat sheep	120
Two Hogsheads of wine	70
Two tuns of butter	193
Four tuns of beer	32
One thousand lbs. of cheese	120
A complete bed	100
A suit of clothes	80
A silver drinking cup	60

The total cost of the root of this one tulip was 2,500 florins, a staggering amount whatever the rate of exchange to US dollars. This is not the end of the story, however. The next year tulip sales went up on the big trading boards: the Stock Exchanges in Amsterdam and other towns in Holland, as well as those in London and Paris. The market provided the amplification mechanism for fluctuations in price speculation, which accelerated the destabilizing growth of the failure mode across the social divide [149]:

> Nobles, citizens, farmers, mechanics, seamen, footmen, maid-servants, even chimney-sweeps and old-clotheswomen dabbled in tulips. People of all grades converted their property into cash, and invested it in flowers. Houses and land were offered for sale at ruinously low prices, or assigned in payment of bargains made at the tulip-mart. . . the more prudent began to see that this folly could not last forever. . . .prices fell, and never rose again.

We selected the Dutch tulipomania as the exemplar of economic bubbles, in part because the idea of selling your home to buy flowers seems so ludicrous to the modern mind. The 1720 Mississippi Scheme that overwhelmed France while, simultaneously, thousands in England were being devastated by the South Sea Bubble could just as easily have been presented, but the intrinsic value of land might have obscured the speculation-induced failure mode. In fact, it does not matter if we discuss economic fiascoes, the wholesale burning of witches, or entering religious wars, the historical evidence indicates that individuals abandon their rationality in large groups, which eventually leads to the failure of certain social modalities.

4.2.1 Computer games

In his book *The Logic of Failure*, Dietrich Dörner [77], describes the general conclusions he was able to draw from his studies of people playing nonsimple computer games. The purpose of each game was to solve a particular set of problems and to reveal and assess the various problem-solving strategies people adopt. In watching how successful the strategies were in achieving the goals of the games, he determined how effective these strategies were in avoiding failure. The games differed significantly from one another, from that of keeping a refrigerator at a fixed temperature, when the thermostat had a built-in time delay, to stabilizing the society of a primitive agrarian tribe. It is worth pointing out the military has found the use of wargames invaluable in evaluating various strategies and will be discussed subsequently.

The computer game format enabled players to explore the consequences of what they believed to be perfectly reasonable approaches to problem solving, but which over the long term lead to unforeseen, but perhaps foreseeable, disasters. A refrigerator that did not prevent food from spoiling, a tribe that was plunged into famine, and a small town whose main source of income went into recession were all imposed by players with the best of intentions, but who misread the nonsimplicity of the system they were guiding. They also missed, or failed to observe, how the nonsimple system would respond to their interventions. Most people, including experts, were not skilled in situational awareness, or in reading the nonlinear relation between policy decisions and their effects.

A nonsimple system is one in which the smallest change can be amplified over time, leading to completely unexpected results. The outcomes are surprising, because in such systems new patterns can emerge; patterns that are not directly tied to the original configuration, as they are in simple, linear, LFoE, systems. The connection between the emergent pattern and the stimulus that induced that pattern can follow intricate routes within the system dynamics, which are impossible to know before they are observed. This was, in large part, the utility of the computer game approach, that both the ubiquity and failure of linear strategies became abundantly clear through their unfolding in the real time of the computer game world.

One lesson learned from watching the delayed response of the refrigerator temperature to the thermostat adjustment, was that most people live in a perpetual now-time system. Something as uncomplicated as a time delay of the system response to an input confuses most people to such an extent that they cannot learn to compensate for the delay and even those that eventually learn, do so poorly. This is an interesting result, because it can be argued that nothing in today's world responds instantaneously to correction. There are always some delays in every response. Anyone who has ever gone hunting knows that a miss is certain if one fires directly at a fast moving target. Another example drawn from our experience is running after a fly baseball in an open field. Space and time must be balanced, such that the rifle "leads" the target, so that the rifle's bullet and target will be at the same point in space at the same instant in time and the runner will be at the right spot just before the baseball strikes the ground. The time delay of interception translates into a spatial interval to be covered at a given speed.

Both the hunter and the outfielder are examples of the conceptual basis for describing how to adjust the input of a system to achieve a desired outcome. A linear system has mathematics that can directly connect the stimulus to the response: the bell rings and the dog salivates, the test is announced and the class moans, the graduation formation is dismissed and the cadets toss their caps in the air and cheer. However, when the system is nonsimple, there can be unforeseen consequences that occur at some substantial interval of time after the initial response is observed. It takes time for the activity to work its way through the various dynamic modes of the nonsimple system and generate multiple emergent effects, often produced by local cooperation. This clustering of effects is what makes the three block war not only feasible, but inevitable. The cause of these unexpected failures is often the result of "taking your eye off the ball," or thinking and acting in a simple linear way. The mathematical modeling of such systems will be considered in the next chapter.

Another aspect of nonsimplicity is critical behavior–a qualitative change in the dynamics as a crucial system parameter reaches a critical value. In a physical system, criticality is manifest as a material change of phase, say with water disappearing as steam over a boiling teapot, or water crystallizing to ice on a window pane. The adjustable parameter is the temperature. The nonsimple transformation is described mathematically, using a type of scaling involving temperature, which tightly couples the particle dynamics across scales, with no one scale dominating.

Dynamic models of the behavior of groups of people, collections of neurons within the brain, and other dynamically interacting aggregates indicate a phase transition from relatively independent to collective behavior. This transition occurs under relatively benign assumptions regarding how the network elements interact with one another. The decision-making model (DMM) is typical of a large class of mathematical models that share the scaling properties of physical systems [271]. In the DMM, the assumption is made that an interacting network of people tend to imperfectly imitate one another. This imitation hypothesis is sufficient to ensure the existence of a critical value of the strength of the imitative interaction. Once the critical value consensus is reached, where the members of the network act as a coordinated group and not as a loose collection of individuals, the separate microvariable behaviors are replaced by that of a single macrovariable that manifests emergent behavior seen as a phase transition [250], consensus [271], flock evasion of a predator [257] and so on. We encountered this strategy previously, when the microvariable was the individual and it was replaced by the LFoE, so that the probability for the occurrence of a value of the microvariable was the macrovariable.

The military strives to achieve such a coordinated outcome from basic and advanced training by replacing the undisciplined, individual perspectives of recruits with the organized disciplined perspective of newly minted warfighters. Consequently, it is not just the collective behavior of the group that is important, but the influence of the group on an individual's behavior is critical. Though it does not indoctrinate the individual, the group still influences the individual because, as human beings, we want to be accepted and liked. Consequently, both consciously and unconsciously, humans adopt the behavior of those around them, even those who are iconoclastic stay within socially accepted bounds of disruptive behavior. A typical example is the accepted idiosyncratic behavior of artists and scientists within otherwise conservative social groups.

Military units build a "band of brothers" culture that underlies the broader military system of values and successful unit actions in operations.

4.3 Deception, misdirection, and expectations

Information is contained within the data patterns and those patterns are rarely as unambiguous as we would like, or as we so often pretend they are.

There are typically multiple sources of fluctuation within the patterns, whose statistics are oftentimes described using the LFoE. Some of the limitations associated with such a statistical description of the variability of measurements, particularly those in nonsimple systems, were discussed previously. We have not, however, considered the consequences of deliberately distorting patterns through deception: the willful introduction of misleading bits into the data stream which, when processed, suggest a complete misinterpretation of the information. It is far easier to predict the actions of one's adversary when their thinking can be anticipated. This was understood by Adolf Hitler, who in *Mein Kampf* (1925) introduced the notion of The Big Lie, in which he explained that people would believe any distortion of the truth that is so large that it exceeds the accepted bounds of a normal lie. The lie would be "too big to fail." The science of propaganda has become more subtle, since this century-old introduction of one of its core principles; the sleight of hand that transforms a huge lie into a simple truth.

Sleight of hand and magic are popular with people of all ages, perhaps because they provide diversions, in which the art of misdirection exploits a fundamental weakness of human observation. Making objects disappear into, or appear out of, thin air, provides an entertainment for children, because it is a new kind of reality. Later on, the same diversion fascinates adults, because they know it is a trick, but they are confounded by how it is done. The secret of misdirection in the magic act is that it requires the cooperation of the innocent, and is based, at least in part, on a baby's understanding of the game of peek-a-boo.

In their primitive mental map of the world, a baby does not anticipate the persistence of objects. This is the development of an expectation that an object exists, even when it is not being observed. This persistence is not obvious to the child, for if it were, they would not be continuously surprised when the parent's head reappears after being lost behind the back of the couch. This primitive mechanism is, in part, the basis of our fascination with magic and our willingness to be surprised. It also suggests why it is so difficult for humans to see beyond the obvious and understand the implications of nonsimplicity. The persistence of objects over time is a fundamental property of our subjective map of the world.

Of course, nonsimple systems are also nonlocal in space, as well as in time, with the result that a stimulus delivered at one location may have multiple unforeseen responses at various other points in space. Any of these unexpected responses can be a precursor to a failure mode. Dörner points out that we must learn to deal with such unintended consequences, or side effects of mistakes, and observes that it is sometimes difficult to do this in the real world, where our failures can be spatially and temporally distant from the point where they were initiated. As a consequence, crises that incapacitate a friend are uncommon in the real world, so there is little occasion for individuals to learn from others' mistakes, except on a very superficial level. Although this observation may be accurate in ordinary life, at the site of a catastrophe, such as on the battlefield, or the scene of an accident, the situation is entirely different.

A mistake on the battlefield is not just an inconvenience, it is potentially fatal. The Army notion of situational awareness is intended to promote and develop nonsimplistic thinking to reduce the number of failures that result from unanticipated outcomes. Nonsimplicity or CS thinking abandons the linear paradigm and takes into account the reality that no two situations are ever exactly the same. Consequently, the illusion of doing the same thing under the same conditions and always getting the same result is avoided. The word illusion is selected with care, because on the battlefield no two situations are ever exactly the same. It is no wonder that a magician is also called an illusionist. The small differences in perception that are dismissed out of habit as being unimportant make causality the illusion and being unaware of misdirection dangerous.

The circumstances of ostensibly similar situations are always different. A warfighter needs to be able to identify and adapt to those differences. If the warfighter keeps his eye on the ball, nonsimplicity thinking may enable him to minimize the most negative effects of making mistakes. The idea that mistakes can be eliminated entirely is a fallacy of linear thinking. In a nonsimple world, people will always make mistakes and in a nonsimple world, there will always be failures. The trick is to anticipate and avoid the failure cascades that lead to catastrophes by identifying and correcting the mistakes that are made as quickly as possible. Overcoming an array of forces with advantageous maneuver of forces can change a developing defeat into a hard-earned victory on the battlefield.

For example, a situation may look the same as one previously encountered but which of the system's many characteristic modes responds most strongly to a given stimulus often changes from one encounter to the next. The change in response is a consequence of the many differences that were thought to be negligible, or had gone unseen, but in fact, turn out to be important. Consequently, closely observing the early response to a stimulus, while it is still manageably small, is crucial to understanding just how different the present situation is from what it was believed to be.

Situational awareness is therefore not just seeing the big picture, which it most certainly does, but, perhaps even more importantly, it includes an awareness of how the battlefield responds to an individual's actions and being keenly sensitive to any response that is new, or if not completely new, at least unanticipated. In one sense, it is like looking at a garden and noticing the one thing that has a sharp corner, or the barren patch within the bright colors and lush greenery. In the garden, an anomaly is a curiosity in the classroom, it is an annoyance, but on the battlefield, it is a warning of potential catastrophe. Anything that is anomalous, which means it does not have an immediate explanation, is a signal to take cover, or at least to proceed with extra caution, until the anomaly is understood and resolved. But how is an anomaly identified?

Whenever one enters a new situation, whether it is a committee meeting to discuss a colleague's promotion, a private sit-down to confront your boss about his most recent evaluation of your work, or engaging the enemy on the battlefield, the outcome is, more often than not, determined by the level of advanced mental preparation. What is required is an ability to anticipate and observe the situation, and the flexibility to adjust as the environment changes. How thoroughly you have gone over the situation in your mind and how deeply you have considered alternative scenarios. It is essential that what needs to be accomplished is clearly in mind, perhaps made clearer by having been written down. Greater clarity is achieved through specificity: the more detailed the list of desired outcomes, the greater the contrast resulting for any response that is inconsistent with them. As the list grows, the interconnectedness of goals coalesce into a mental model of the system and a picture takes shape around how the distinct objectives can be achieved. Success is invariably determined by how faithfully the nonsimple model mimics the actual situation.

Of course, not all goals are of equal value and they cannot all be realized at once. Consequently, when the situation calls for multiple objectives, an ordering of priorities is useful. Not a rigidly structured list, but one that allows for a certain flexibility to achieve completion of what needs to be accomplished. This flexibility is particularly important in nonsimple situations, because unintended consequences will most certainly emerge that require a real-time reshuffling of the ordering of priorities. In the heat of battle, priorities shift as the warfighter gains more information, which is transformed into knowledge and acted on. But there is a cautionary note. At some point in time, a decision must be made based on the information in hand. Such information is always uncertain and incomplete, so subsequent knowledge is tentative. Therefore, the decisions based on that knowledge are, in their turn, provisional, which is an academic way of saying that all decisions are fluid and should be taken with a grain of salt. Agility and flexibility are the trademarks of good decision-makers in nonsimple situations characteristic of military operations.

Confronting the boss about that latest evaluation may lead to a discussion regarding an expected promotion, or elicit concern over a switch to the executive retirement plan, or draw out mention of those stock options that had been promised so long ago, but never materialized. All of these objectives and more are part of your job plan, but the order in which they are realized, or the conditions under which any, or all, of them are brought up in a discussion, depends on your mental model of that plan. These concerns lack the immediacy of the battlefield's life and death decisions, but they are still important in the lives of most people.

Thus, it is crucial to know which goals can be shifted or abandoned and which must be achieved in a predetermined order. In dressing oneself, the order in which you put on your shirt or pants does not matter; however, your pants always go on before your shoes and after your underwear. If you experiment with other orderings, after the age of about five, you will likely be escorted from your office to a place where professionals will dress you. In an analogous way, it is probably not appropriate to bring up the executive retirement plan with your boss before he has offered you the promotion, that is, assuming success in the workplace is part of your job plan.

The ordered list of goals, constructed for a new situation is, therefore, dynamic and may be revisited not just once, but a number of times, as the situation unfolds and new information is revealed, validated, or contradicted. Consequently, your situational awareness, of which the detailed list is a part, evolves into a strategy for long-term success. Success is defined as the realization of a predefined set of objectives. The strategy follows from your situational awareness that includes side effects and unintended consequences, and takes misdirection into account.

After making and implementing a decision, a warfighter must be more sensitive to changes on the battlefield, not less sensitive. He ought to be alert to potential responses, resulting from the implementation of his decision.

In other words, his nonsimplicity thinking ought to include anticipation of unplanned side effects. Here, again, an individual has to guard against over-thinking, or second-guessing decisions, which is often a consequence of having data collection, in and of itself, as a goal, rather than the collection being a tool to realize a specific goal on the list. An indispensable survival skill is knowing when to stop gathering data and when to start up again, through knowing the variability of the battlefield. The on-off switch for data collection is tied to being sensitive to anomalous changes, that is, to changes that are surprising and which cannot be readily explained–things that do not feel right.

Situational awareness, as part of nonsimplicity thinking, is not a compilation of what to do and what not to do, although on the page it might come across that way. We have that impression because of the serial nature of writing. This is another of those insidious traps of linearity that people fall into–they mistake the mode of communication for what is being communicated. In the 1970s, Marshall McLuhan famously said, “The medium is the message.” He was right, but not for the reasons he articulated. The properties of different media unintentionally emphasize different aspects of a message, due to the preconceptions of the sender and the receiver. The medium not only determines how information is transmitted, but what the information is that is exchanged. Music rendered by computer does not convey the same information as the same notes played by a human directly on an instrument; the unconscious modulation of the music by the human is absent from the stark adherence to the notes made by the computer. This loss of the human factor is measurable in music and elsewhere, even when not consciously recognized.

Nonsimplicity thinking shares many features with gambling at cards, like poker. In a poker game, some rules define the play of the game and cannot be changed. Other factors, such as those that determine when and how much to wager, or reading an opponent’s reaction to the cards held, are only loosely defined. However, both must be mastered in order to develop a winning strategy. The latter rules often have more to do with the behavior of the other players under uncertainty than they do with the cards. A person who understands and plays the odds of having certain cards minimizes the uncertainty of play and can become a competent player. But until they learn the strategy of the larger game, which incorporates the psychology of the opponents into the play, they will probably never be a champion player, or make a living playing poker.

The difficulty in learning the larger game is that the calculus of predicting the probable outcome of the cards is only part of the overall strategy necessary to win consistently over time. The importance of deception in the form of bluffing cannot be overstated in this regard. The inventors of game theory, von Neumann and Morgenstern, in their magnum opus *Theory of Games and Economic Behavior* [261] devote a 30-page section to "Poker and Bluffing," as well as multiple references to the various consequences of bluffing throughout their ground-breaking text.

Another aspect of situational awareness and decision making, which is all too often neglected in discussion, is the reliance, some might say the over-reliance, on rationality. Human beings make decisions based on feelings, impressions, biases and other irrational motives, at least as often as those based on cold, hard reason. The 2002 Noble Laureate in Economics, Daniel Kahneman, estimates this partitioning to be skewed toward intuition [118]. So let us examine how these two ways of deciding what to do, help to make up the world we experience.

4.4 Rational versus irrational decisions

> One might say that the physical seem little more than the wooden hilt, while the moral factors are the precious metal, the real weapon, the finely-honed blade. [56]

Sometimes we are too quick to explain the unexpected. Jumping to conclusions can be traced to culture, religion, and discomfort with uncertainty, or any other non–rational factors that short circuits the process of cognition. When examined in detail, it is often found that, in this rapid explanation process, there is a fundamental cause to which all events are being related. This is another of those insidious consequences of linear thinking that misses the subtlety of system nonsimplicity. It is apparently a trap into which all human beings fall, including radical jihadists, as well as those working to defeat radical jihadists.

It helps to obtain insight into the thinking of the adversary, beyond the superficial analysis of professional news outlets. This nonsimple insight is valuable in organizing a warfighter's thoughts about the conflict with radical jihadists. This analysis promotes mental models that not only have survival value on the battlefield, but contribute to strategies for winning the conflict, both on and off the battlefield. The battlefield is seldom a barren no man's land between opposing armies, but is all too often a downtown area of an urban center, where innocent civilians vastly outnumber the combatants. An abstract, but no less real, the battlefield is that of cyberspace, where cyberwar is conducted in deafening silence [129].

The radical jihadist profile promoted by Western media makes them out to be bad or mad, brainwashed, immature, ignorant, lacking in responsibility, isolated, and/or being sexually frustrated. Marc Sageman, a forensic psychiatrist, has shown these characteristics to be, at most, a small contributor of the profile, if not altogether absent in his book *Leaderless Jihad* [199]. Keeping in mind that his book was published in 2008, before the advent of the Islamic State of Iraq and Syria (ISIS), he found that 62% of jihadists had attended university, compared with less than 10% of the general population of which they are a part. He refers to this group as the first wave, which composed of the pre-9/11 terrorist groups. The majority studied technical fields such as medicine and engineering, as did the al Qaeda leadership, who had surprisingly little training in religion. However, as Sageman points out, all the good jobs in their chosen professions were only available in their homeland through graft, corruption, or nepotism. Unable to find technical outlets for their mental gifts and idealism, they railed against their governments and society.

In seeking answers, these technically oriented individuals returned to first principles to reconstruct their mental model of the world and, often for the first time in their life, encountered religion. Lacking strong religious backgrounds, they were not prepared to put what they encountered into a broader context. Sageman maintains that the first wave of Islamic terrorists found religion in their mid-twenties and did not have the religious training to accurately interpret the material they read. This resulted in a devotion to a literal reading of early Islamic texts, without the mitigating interpretation of the intervening millennium of Islamic scholars, which resulted in a quite barbaric perspective.

Radical jihad, like all other social movements and armies are susceptible to the logic of failure. The radical jihad social movement is a nonsimple network of geographically dispersed individuals, who share a radical view of Islam, have a flexible strategy for realizing a set of unchanging and unchangeable goals. In battle, as in social discourse, the radical jihadist is uncompromising, which means the list of priorities does not change as new information becomes available. The on-off data switch remains in the permanent off position, because the truth is intolerant; once the truth is attained, all other data, information, and knowledge is irrelevant, unwanted, and ignored. This mind-set, once adopted, is impervious to a reasoned argument or to experiential adjustment.

On the battlefield, when a warfighter makes an error in attribution, he subsequently fails to identify a potential failure mode. In not recognizing the effect of the mistake, the warfighter will not be able to draw the conclusions necessary to reorganize his thinking to correct the mistake. The next error in this logical chain is the failure to modify the decision and change subsequent behavior. This sequence of mistakes can be averted by nonsimplicity thinking, which has a built-in mechanism to self-correct, along with the on-off switch for gathering data. These are perhaps the most important aspects of nonsimplicity thinking, along with the truism that nothing is ever as simple as is appears.

In the radical jihadist's mental model, a failure mode cannot be accepted as a consequence of decisions made, due to the fundamental belief that such decisions are guided by a divine power. Therefore, an observed failure is not perceived to be a consequence of a decision made earlier, but to be a manifestation of the world's corruption. These failures, like earlier ones, only provide further evidence of the truth of their belief system and the necessity to be even more adamant in the pursuit of their goals.

On the other hand, a disaster befalling an innocent Muslim, due to an unintended consequence of a decision made by a United States warfighter or ally, is seen quite differently. The media portrays the event as a morality play about good and evil, not the inevitable consequence of the fog of war. Sageman rightly explains the template of the media story as being that of an evil-minded person who caused a grave injury to an innocent victim, with little or no analysis of the larger societal factors. This situation might have contributed to this unplanned and unwanted result. Such stories may incrementally move a young, disillusioned Muslim further along the trajectory of radicalization, but will not, in all likelihood, initiate the process of transformation from moderate to radical Islam.

In a first-ever event, the anthropologist Scott Atran addressed the United Nations Security Council in April of 2015 [15] on the insights gained from his research on young people who had joined radical jihad. This was the third wave of violent extremism and included ISIS, the majority of who have less than a primary school education. As in the first wave, they had little or no formal religious education. What religious training they did have was provided by al Qaeda and ISIS propaganda. Atran maintains that radical jihad is not a clash of civilization, Islam against the West, but is the very collapse of traditional cultures, undercutting the nation-state system represented by the United Nations itself. Neither interpretation of the present situation is tolerable for the stability of Western civilization.

Atran proposed three conditions necessary to harness the energy and idealism of youth in a way to counteract the attraction of radical jihad [15]:

- Offer youth something that makes them dream of a life of significance through struggle and sacrifice in comradeship.
- Offer youth a positive personal dream, with a concrete chance of realization.
- Offer youth the chance to create their own local initiatives.

These are the very things that ISIS offers, however malignant the implementation. It is the appeal to the adventurous spirit of the adolescent, the young, with the hope for glory, adventure and significance. It is neither an intellectual appeal, nor a religious one. It is an emotional appeal that promises a shared destiny with one's friends. A positive analogy might be to John F. Kennedy's formation of the Peace Corps, a successful government program started in another time, and for a different purpose.

Atran makes a compelling case for these three conditions, using arguments that are based on the failure of large-scale government programs. These government programs, although intended to counteract radical jihadi recruitment, completely ignore or misinterpret, the circumstances of the youth being recruited. One failure mode of these programs is their focus on the negative social aspects of radical jihad, rather than on the positive moral aspects of the West, thereby missing the point that "scared values must be fought with other scared values." Another failure mode is not taking into account that "all politics are local," and consequently attempting to reduce radical jihadi recruitment, through government programs that focus on the big picture-national or global-rather than on local initiatives are doomed at the outset. Like other people, jihadists live locally and this is where they are the most effective and the most vulnerable.

The majority of analyses of radicalization do not distinguish between the passive nature of the WWW and the active character of the internet. On the WWW, information is provided to the user on everything from radical jihadi manifestos, how to make bombs in the kitchen, and everything in between. However, it is unlikely that such passive material does anything more than reinforce previously held beliefs. On the other hand, social media constitutes a vast, interactive communications network, between two or more individuals in the form of e-mail, tweets, Facebook posts and comments, teleconferences, and so on. People change their minds through discussion, arguments, and by hearing different versions of the same refutation or defense, from friends, relatives, and complete strangers, not by reading scholarly discourse. Social media is where radicalization takes root, is nurtured, and grows [15]:

> The true leader of global Islamist terrorism is the collective dis–course of the half-dozen influential jihadi forums.

Is there a way the lack of leadership in the third wave of radical jihad can be understood at a computational social science level? The tentative answer is yes. The mathematical models on which such understanding is based are for the experts, but the conclusions drawn from them, along with the resulting entailments, are straightforward and can be understood without a mathematician's vocabulary.

Various mathematical models of nonsimple networks have been constructed. Each model provides insight into the workings of social groups, with varying degrees of success at explaining dozens of nonsimple networked phenomena, whose properties are described by inverse power-laws and not the LFoE. These are the events that potentially dominate our lives. This is why in referring to the catastrophic devastation of an earthquake, a reporter quotes it to be of magnitude 4, where a person barely feels a tremor, or a magnitude 6, where significant damage can be done. The number is the index in the power law in the size of the earthquake. A magnitude 6 quake is 100 times stronger than a magnitude 4 quake, as each unit increase in the index corresponds to a factor of ten increase in magnitude. Once you know the code a good deal of information can be condensed into a terse statement.

Of course, it is not only the magnitude of earthquakes that have Pareto's inverse power-law, but the time interval between earthquakes of a given size, also has inverse power-law statistics. In this way earthquakes are doubly nonsimple, as they have inverse power-laws in both size and the time interval between quakes of a given size. In a similar vein, West et al. [271] have examined how such intermittent statistical behavior intertwines itself with the organized activity of social groups.

"The threshold," "the tipping point," "the final straw," "the game changer," are all slightly nuanced catch phrases for configurations that have an enhanced sensitivity. One push and the car goes over the cliff, the wall topples, or the armed sociopath fires his weapon into the crowd. This is the leverage provided by the Pareto imbalance, it is the leverage produced when the collective effect of the network either amplifies or suppresses the intent of the warfighter. At the tipping point, survival often requires an ability to adapt to make the appropriate preparations. The latter enables the warfighter to use the imbalance to his advantage, or failing that, to deny the enemy the use of that leverage.

All this may be true, but it provides little solace to the warfighter on the battlefield. A large number of questions remain to be answered. How does this mathematical insight into the radicalization of youth to radical jihad enable warfighters to be weaned from linear mental models and facilitate the development of nonsimplicity thinking? How does this understanding provide them with an advantage when they are on patrol in an urban center known to be infiltrated by an enemy hiding in plain sight?

Answering such questions is no simple matter. However, certain strategies do lend themselves to thinking about problems that are unique to the military and suggest ways of solving them. We now turn to these strategies.

CHAPTER 5

MILITARY MATH MODELING

> Since all models are wrong, the scientist cannot obtain a "correct" one by excessive elaboration. On the contrary, following William of Occam he should seek an economical description of natural phenomena. Just as the ability to devise simple but evocative models is the signature of the great scientist so over-elaboration and over-parameterization is often the mark of mediocrity. [37]

We will demonstrate that even the most obvious of the mathematical models of importance to the military are not linear and ultimately are nonsimple. Figure 5.1 emphasizes this nonsimplicity by characterizing the social conditions leading to conflict as an ecological system [122]. Therefore, an elementary, dynamic, military engagement consists of one entity in pursuit of another, which is evading capture. We give a somewhat extended discussion of the considerations of the hunter and hunted for the purpose of revealing the kind of thinking that goes into constructing such a model. We include some equations, but they are only recorded to provide an example of how the abstract considerations are turned into tractable mathematical expressions, which is not difficult to do if you do not have to solve them.

This discussion sets the stage for more general considerations regarding the mathematical modeling of nonsimple military operations. For example, a Complex Adaptive System (CAS) is an interactive system that has the ability to adapt and coevolve with its environment and generate nonsimple behavior patterns. CAS behaviors are often surprising or unexpected. These behaviors include self-organization and the emergence of seemingly random patterns. A CAS can consist of interconnected elements that act according to rules and decisions that, in the aggregate, are labeled networks or systems that react or builds connections to the other elements in the aggregate, for example, military forces in an operation. The most significant element of a CAS is its chaotic, non-reductive nature, where small changes can produces large, unpredicted and significant changes in the system's behavior. Something very different can happen in the behavior of these nonsimple systems than what is expected or normal.

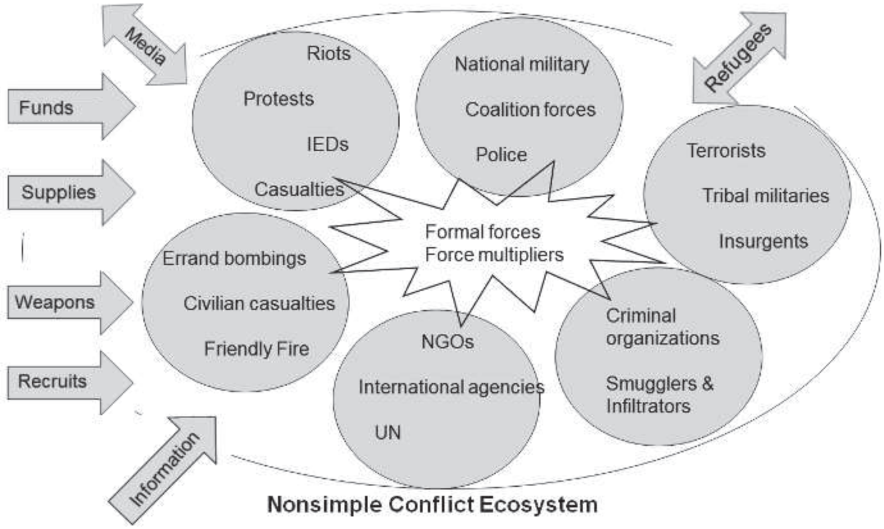

Figure 5.1: One view of the social context leading to war is given here as a conflict ecosystem. This is done to emphasize the conceptual overlap of warfare with a network view of an ecological system.

Traditional math modeling processes have been used successfully many times on problems involving physical systems. While these physical systems were often intricate with many parts, they could be modeled with known functions and connected in well-known reductive ways. For these reductive problems, stated in a scientific vernacular, macromodels could be built from known micromodels. On the other hand, for many problems in the information, life, and social sciences, reductionism is neither appropriate, nor possible, and the classic modeling approach fails. The human-element, along with system autonomy and adaptation, no longer follow the rules of reductionism. Aristotle's maxim that the whole is more than the sum of its parts voids reductionism for these kinds of problems and calls for a different approach. This different approach is nonsimplicity, which can be found under a wide variety of labels including, but not restricted to holism, emergentism, cybernetics, complexity science, or systems theory.

In nonsimple systems, causality, rationality of thought, and strict rules are trumped by self-organization, irrationality, capricious behavior, and adaptation. Nonsimple models often have multiple ways of interacting, such as feedback loops, dynamic rules, evolutionary changing parameters, stochastic elements, super-nonlinearity, or multiple scales and fractal dimensions. These phenomena result in new functional relationships and entirely new mathematical operations. We see nonsimple systems in ecosystems (forests, rivers, lakes, mountains, and plains), in species (beetles, mammals, insects, amphibians, and birds), in space (planets, moons, asteroids, black holes, and galaxies), in weather (storms, tornadoes, hurricanes, and droughts), in sociology (crowdsourcing, riots, elections, and terrorist attacks), and in psychology (post-traumatic stress disorder, traumatic brain injury, radicalization, and adaptation).

The key to strategic military modeling can be demonstrated using one of the simplest of dynamic military games: The Fox and The Hare. More generally, it can be called the pursuer and the evader, which differs from its country cousin by the number of strategies available to the players.

5.1 Pursuit and evasion

Pursuit and evasion involve movement of the players to achieve maneuver and position or location goals on the battlefield no matter what the domain of conflict (land, air, sea, space, or cyber). In some sense, pursuit-evasion is the fundamental operation of all military operational engagements. Pursuit- evasion (sometimes called seek-flee, hunter-hunted, predator-prey) is often played by people of various ages in the form of games and activities, such as tag on the playground, later on replaced by football and many other team sports, finally maturing into search and rescue, as well as, police chases. In the predator-prey relationships of the natural world, pursuit and evasion are the very essence of survival. While the overall concept seems simple enough to comprehend and is quite intuitive to humans, understanding the details of the action-reaction interplay and implementing optimal, or even competent pursuit-evasion strategies in algorithms are complicated, nonsimple and challenging. Finding proper measures for the properties of pursuit-evasion models and algorithms are a challenging and important step in this area of study.

Classical pursuit-evasion modeling and algorithm development have always been of interest to mathematicians and the military. On the mathematical side, dynamic models were directly formed from physical relationships and sometimes solved in closed-form, and, as the models were refined and amplified, approximations were made to solve the more elaborate models. Further development of mathematical analysis led to optimal solutions for some special cases.

On the military side, pursuit-evasion models help engineers to design and develop control systems for target-tracking missiles, as well as, evasion controls and maneuvers for high-speed combat aircraft. Often, the assumptions made for these phenomena were limited by the mathematical capabilities of the investigator and therefore the models and algorithms were naïve–one pursuer and one evader, or possibly a handful of one or the other, and simple or non-existent maneuver constraints for the participants. Seldom were realistic constraints or tangible scenarios successfully considered in the linear-based modeling world. Even less often were coordinated pursuit or evasion scenario considered for combatants who sought to pursue, but evaded only as necessary (playing alternating or simultaneous roles of pursing and evading). Despite the simplicity of the assumptions, models, and the depth of the research into this problem, there remain many unresolved issues in naïve pursuit–evasion, such as inclusion of goal-seeking participants (evade only as necessary yet still seek to reach a specified goal); optimal methods of movement and operation (except in special cases); the conditions under which capture by the pursuer is guaranteed; the conditions under which escape by the evader is guaranteed; and, most importantly, the proper performance measures for understanding the situation and gauging the utility of the algorithms.

As we approach an era of autonomous robots, such as UAVs, UGVs, UWVs, and AI-based cyber probes along with information-centric approaches in military operations, there are many scenarios of pursuit-evasion to consider, with nonsimplicity-embraced mathematical modeling and nonsimplicity-based analysis. Certainly, nonsimple systems of many pursuers and evaders who have varying goals, can be envisioned. Coordination and cooperation among the participants on each side need to be considered and understood. What kind of communication and control are needed to help the participants achieve their goals? Can swarming phenomena be understood and included in the basic models? Are there optimal strategies to follow? Can an intelligent player learn new strategies as the pursuit or evasion takes place and details of the environment are learned? How are the more sophisticated pursuit-evasion scenarios modeled and analyzed and what can we learn now so we can build proper algorithms and equipment (robots) for future success? These questions and many others are on our minds as we seek to understand and design the future autonomous military partners. Our tools are mathematical modeling methodologies, new conceptions of nonsimple systems, and a modern language to facilitate this new way of thinking.

5.1.1 Basic Concepts & Assumptions

There are many situations where one entity–a military vehicle, person, animal, or robot–chases another vehicle, person, animal or robot. Applications in the military are: missiles intercepting planes (or other missiles), smart munitions seeking evaders (anti-tank rounds seeking a tank), units or soldiers pursuing and closing in on enemy units or soldiers, ships closing in on other ships, and torpedoes tracking and exploding on enemy ships. There are many non-military applications as well: dogs running after cats, tacklers chasing and tackling ball carriers in football, and hunters after their quarry (predators pursuing prey). These applications are in reality three-dimensional, but some scenarios are more readily visualized in two dimensions, because the vertical dimension, height, may not be as significant as the other two. Consequently, we confine our discussion to two dimensions for convenience. The study of pursuit–evasion games with a single pursuer and a single evader began in the 1950s at the Rand Corporation. Fighter planes, such as the F-86D, had electronic solutions to these equations as part of their fire control systems during the Korean Conflict.

The first problem we consider is determining the movement path for the pursuer, given that we know the location of the evader. We start with the assumption that the pursuer has complete vision of the evader and knows the evader's position exactly. Of course, this is a substantial and often unrealistic assumption because even with excellent sensors such vision is prohibitively difficult to achieve. The pursuer's position is represented in two-dimensional Cartesian coordinates by $(x_p(t), y_p(t))$, with time t measured from the start of the chase.

The evasion component of the problem is just the opposite of pursuit: determine the movement path for the evader, given we know the location of the pursuer. For example, a rabbit zig zagging to avoid the fox's jaws, or the running-back eluding tacklers on his way to a game winning touchdown. We start with the assumption that the evader has complete vision of the pursuer and knows the pursuer's position exactly. Again, this is not reality, since such perfect vision is never possible. The evader's position is represented in two-dimensional Cartesian coordinates by $(x_e(t), y_e(t))$, with time t measured from the start of the chase. The subscript e indicates the evader.

We can model the pursuer-evader movements as continuous graphs or discrete points in time. There are at least two reasons why we model the movements discretely: 1) our final model may have to be implemented with discrete sensors or controllers, and 2) we will build highly nonlinear, complex models that ultimately require discrete computational computer methods to implement or solve, even if we initially use continuous models or not. The main reason continuous models may be preferred is they sometimes lend themselves to more powerful analysis and allow the calculation of property metrics (especially for optimization). However, most of what we ultimately need in the model falls into the area of hybrid systems, with both discrete and continuous elements. We discuss that technical point later.

Under the assumption of a discrete event model of time periods (intervals of length Δt), we use n to indicate the number of the time step in the model. During a small time interval Δt beyond the time t, the pursuer moves to a new position denoted by $(x_p(t + \Delta t), y_p(t + \Delta t))$. We convert these two functions of the variable t to discrete functions of our discrete time interval n. If we use the generic relation that $t = n\Delta t$, we can represent $x_p(t)$ by $x_p(n)$, $y_p(t)$ by $y_p(n)$, $x_p(t + \Delta t)$ by $x_p(n + 1)$, and $y_p(t + \Delta t)$ by $y_p(n + 1)$. The evader's position is modeled in the same way with a change of subscript, that is, $(x_e(n), y_e(n))$ and $(x_e(n + 1), y_e(n + 1))$.

5.1.2 First–Principle Modeling

Returning to the problem of determining the movement path for the pursuer for a time interval given that the pursuer knows the exact location of the evader, we also assume that the pursuer moves at a constant speed (given by s_p). One technique to use for the pursuer model is to have the pursuer move directly towards the evader. This means that the pursuer senses or receives information as to the exact location of the evader and heads in that exact direction for the time period Δt at speed s_p. As the location of the evader changes over time, the pursuer adjusts its path over each time interval to continue to move directly toward the evader. We can diagram the movement relationship by plotting the points and showing the geometry of each movement. This visual model is given in Figure 5.2.

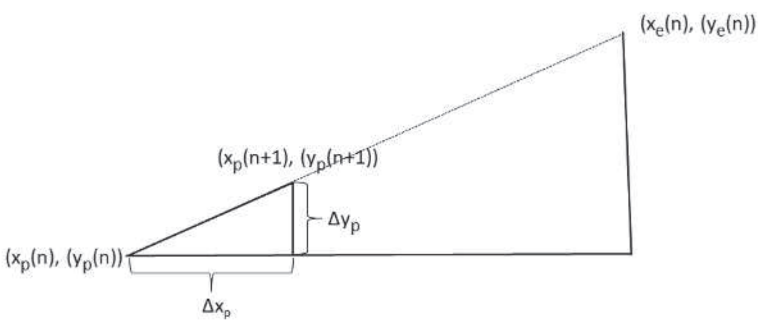

Figure 5.2: Movement of the pursuer during the time interval n to n + 1, while tracking the evader.

The result is a system of two nonlinear difference equations for the unknowns $x_p(n + 1)$ and $y_p(n + 1)$,

$$x_p(n+1) = x_p(n) + \frac{[x_e(n) - x_p(n)]s_p\Delta t}{\sqrt{[x_e(n) - x_p(n)]^2 + [y_e(n) - y_p(n)]^2}} \tag{5.1}$$

$$y_p(n+1) = y_p(n) + \frac{[y_e(n) - y_p(n)]s_p\Delta t}{\sqrt{[x_e(n) - x_p(n)]^2 + [y_e(n) - y_p(n)]^2}} \tag{5.2}$$

This is our basic pursuit model, which provides a means of determining the movement of the pursuer when we know the location of the evader. This system of equations can be solved by iteration from a known starting location of the pursuer and evader.

Determining the movement for the evader can be performed in the same way by assuming that the evader moves at a constant speed (given by s_e) directly away from the pursuer. As the location of the pursuer changes, the evader adjusts its path at each time interval to continue to move directly away. The evasion equations are similar to those of the pursuer, with s_p replaced with s_e, and $x_e(n + 1), x_e(n), y_e(n + 1), y_e(n)$ in place of $x_p(n + 1), x_p(n), y_p(n + 1), y_p(n)$.

It is worth noting that this model bears a strong similarity to elementary control systems, one in each direction. The control process is intended to zero out the difference between the system output (pursuer position) and the control signal (evader position). A one-variable control process is the thermostat in your home, adjusting the flow of warm air to maintain a preset temperature level.

One lesson to be drawn from the pursuer-evader model is its nonlinear nature. As rudimentary a model as it is, since it only involves line-of-sight vision and moving to minimize the distance between the pursuer and evader, it is still not linear. However, one simplifying property of the system is easily determined. If $s_p > s_e$, then the pursuer will eventually catch the evader. If $s_p < s_e$, the evader escapes.

The assumption that both the evader and pursuer have complete vision of one another is not realistic, no matter how good, or how redundant, the entity's sensors are. Possibly, the closer the two agents become, the better the sensor's vision and, therefore, the better the data. Though there are several ways to model the fog of the sensors and the inaccuracy of measuring direction and distance from one viewpoint to improve the models, we will have to do better sensor modeling as it relates to data collection and information flow. Networked sensors that synthesize their own data with that of their neighbors promise to revolutionize event detection and decision-making, but this promise cannot be fulfilled without substantial progress in the nonsimple tasks of analyzing data locally, communicating efficiently, and integrating analyses performed locally and globally. Deciding what data to collect and process locally, when to share data, which sensors should play differing roles, and when sensors should request data from other sensors, or pass data to another sensor, are important issues for many problems, including pursuit-evasion and cyber detection algorithms.

There are also various systems to determine how a pursuer should “lead” an evader. Using approximations for future movement, we take into account both the speed and the velocity of the evader, then use that information to predict where the target will be when the chaser catches the target. We can use this approximation for the two functions $x_e(t)$ and $y_e(t)$ representing the two coordinates of the evader’s path to approximate the value fltc (time to catch) the time advance to the location where the target is predicted to be, in order to have a proper lead. Then the “phantom” projected location to aim for is the point $\{x_e(t + \Delta t_c), y_e(t + \Delta t_c)\}$. Since we assume that we only know the location and not the velocity, we can approximate the time derivatives of the path with differences. Therefore, we modify the model using this “phantom” lead point in place of $\{x_e(n), y_e(n)\}$. The geometry of this lead algorithm is shown in Figure 5.3.

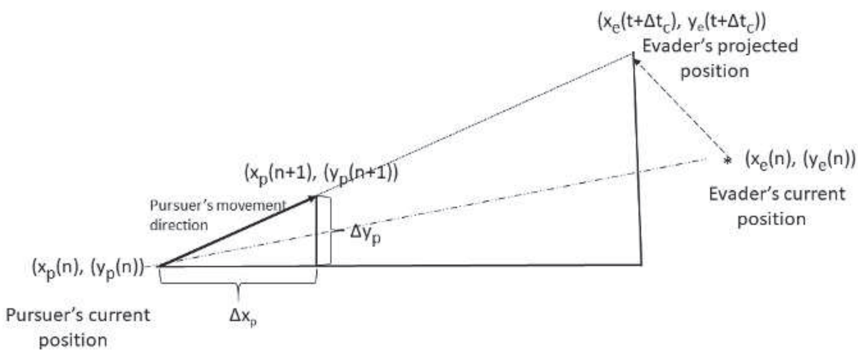

Figure 5.3: Path of the pursuer when moving in step n to n+1 towards the evader’s projected position.

Many ways exist to determine the value for Δt_c (the time to catch). We could approximate the “catch” time by using the time for the chaser to reach the target's current location. Therefore, a possible formula for it is the current distance between the chaser and the target given, divided by the pursuer's speed s_p. This would make the equations more formidable. We do not need to know their specific form for our purposes, but suffice it to say, there is plenty of nonlinearity.

How does the evader deceive the pursuer into slowing its approach or missing completely? Can we use the pursuer's lead strategy against it? One idea is to oscillate the path of evasion, so that the pursuer is oscillating even more violently than the evader as it tries to lead the evader. One way to implement this idea is to randomly vary set angles from a direct path away from the pursuer. At each time step, the evader randomly moves directly away, moves away at an angle clockwise, or moves away at an angle counter-clockwise from the direct path (a random walk-like evasion). In this model, the pursuer may become confused and either lead the evader by too much, or slows up to get a clearer view of the evader's path, thus slowing its forward progress toward the evader. This could definitely adversely affect the pursuer when there are maneuverability constraints on its movement.

Ideas are plentiful for modeling evasion, especially if the evader has obstacles to hide behind or mechanisms to blind its pursuers. Locally greedy algorithms that minimize immediate capture should be compared to globally-based models that seek to reduce the likelihood of capture over long time horizons.

There are multiple maneuverability issues for the pursuer and evader. Can either of them turn fast enough to make the necessary moves of the algorithm? This question merits study from a nonsimple modeling point of view. We have already assigned different, but constant (maximum) speeds to the evader and pursuer. Now we need to place constraints on the maneuverability of the players. For instance, if the evader is allowed to oscillate its path at specified angles, the pursuer may try to oscillate at even greater angles in an attempt to lead the evader. One idea is to allow the evader to move without constraint, because the evader could be proactive in its movement, whereas the pursuer is reactive. Constraining the pursuer's maneuverability is one realistic limitation to the reactive approach. From the nonsimple model constraint, one approach is to restrict the angle of the movement during a time step. Another would be to slow the pursuer's speed proportionally for any time step for which there is a large angular change in its movement. In any case, maneuver constraints are a nonlinear reality of pursuit and evasion.

Often evaders are also trying to accomplish a mission and they evade pursuers only to the extent to which they can still accomplish their mission (plane dropping ordnance, torpedo striking target, football players scoring touchdowns). Or, for a less focused mission, the evader tries to accomplish the mission, but once threatened by the pursuer, abandons the mission and evades in an attempt to escape (mission-evade-escape-survive). The interplay of the mission, evasion, escape, survival function is definitely a place where nonsimplicity measures can assist the algorithm and potentially even dominate.

How close does the pursuer have to get to the evader to make the catch? The type of scenario along with the nature of the pursuer and evader dictate the rules of the catch. There could be very different strategies for the pursuer and evader when they are very close (within a few time steps of potential catch) compared to when they are far away from one another. Close, we all know, counts in horseshoes and hand grenades, but perhaps sometimes the pursuer does not want to be too close.

With the advent of swarms or teams of UAVs, UGVs, and UWVs, systems of many pursuers and evaders can be envisioned. In modern military operations, the need for systematic studies of nonsimple pursuit-evasion scenarios, with multiple pursuers and multiple evaders, becomes increasingly important. What happens when N pursuers ($N>1$) try to catch K evaders ($K \geq 1$)? Complicated questions arise, about which evader does an individual pursuer chase, which pursuers does an evader run from, and how do the pursuers ensure they chase all the evaders? These are just some of the nonsimple issues to resolve. It's hard enough just to determine which of the adversaries is the closest. How can a pursuit or evader team implement an effective strategy when the situation environment seems so chaotic?

In the N-vs-K case, communications between the pursuers, or between the evaders, can be important in setting and implementing the strategies and tactics of the teams. What kind of information is valuable, how does it get to the right place, and how is that information used to control the movements of the players? These and many other nonsimple information issues need to be studied. One approach might be for the pursuers in a pursuer-heavy scenario to communicate about which evaders they should chase (perhaps an equal division of sub-teams) and then each of the sub-teams move to surround their designated evader. Once the teams of pursuers surround their assigned evader, they can close in for the catch. This is the reductive approach.

There are different deception strategies for the evaders when there are multiple pursuers after them. How can communication and group strategies help the evader? Can sentinel evaders pass the word of oncoming pursuers to give the other evaders an advantage toward escape? Can some evaders sacrifice themselves for the good of the team mission?

Even with communications between pursuers and information getting to the right places, networked teams of pursuers and evaders need to coordinate their actions. There are many strategies to consider and members of the team have to know their roles and share their information to achieve good situational awareness. Centralized control may require considerable communication from the team members to the centralized controller and vice versa, but this type of control may allow for very organized global behavior. Distributed control, where the decisions are made locally could reduce communication requirements, as well as, the possibility of messages being intercepted.

One model is to assign pursuers a region (grid zone) to cover and let the local pursuers in that zone pursue evaders in the zone and then when an evader escapes their zone, they just ignore that evader, because that evader has become someone else's responsibility. This is an adaptation of the zone defense from basketball and soccer. Complete and rapid communication is necessary in this zone approach. If there are issues involving communication overhead in the forms of decision delays, refresh rates of sensors, and stability of the system for adequate time step size, the nonsimplicity issues dwarf the others. Sensors and agents that synthesize their own data with that of their neighbors can revolutionize event detection and decision-making, but this promise cannot be fulfilled without progress in the algorithms to analyze data locally and combine analyses globally. Deciding what data to process locally, when to share data, the roles the agent plays, and when agents should communicate, or change roles, are some of the important nonsimple issues to make autonomous systems smarter and more productive.

The nonsimplicity condition calls for decentralized control mechanisms for many situations. The nonsimplicity associated with swarming (for example, fish, birds, or insects) are appropriate models for unit pursuit engagements and operations. The majority of the evaders could escape while the swarm of pursuers is after the first few unfortunate victims or sacrificial lambs. For the evaders, a flocking behavior could help protect enough agents to accomplish the mission.

Can we achieve optimality for simple scenarios and use simple optimal algorithms to help us understand the nonsimple scenarios? Machine learning models may achieve optimality for some conditions of N-K pursuit-evasion. This kind of nonsimplicity is part of the future advancement of modern military systems.

We demonstrated these concepts in two dimensions, but real applications are in three or more dimensions. What difficulties do additional dimensions cause for the models, theories, and algorithms? So far we have not mentioned geometric nonsimplicity, such as varying ground heights affecting line of sight in the third dimension, obstacles that can provide cover for evaders, and other factors that obscure sight and detection such as fog (the physical kind), evader-induced smoke, stealth from radar, and electronic or acoustic jamming.

As the pursuit-evasion game is played, there appears to be changing strategies for both kinds of players as the distance (or time to potential capture) changes. Let's look at this idea of the 1-vs-1 case once again.

5.1.3 Changing strategies

Let's consider changing strategies of the pursuer. See the regions in Figure 5.4 for regions of changing strategies. When the pursuer is far away (Region 5), it looks for evaders, but hasn't seen any yet. When the pursuer enters Region 4, it detects an evader to chase. In Region 4, the pursuer wants only to close the distance between them, so it moves directly toward the evader (no leading). As the pursuer enters Region 3, it realizes that the evader has detected it and needs to be smarter to further close the distance. In this region, the pursuer tries to lead the evader to shorten the distance (time) to catch. In Region 2, the pursuer decides to continue leading, modifies the lead distances, or goes straight for the evader depending on the evader's tactics (random oscillations, hiding, running, etc.). The pursuer is in Region 1 when it believes that the catch is inevitable and close. In this region, it moves directly at the evader (trying not to miss or be faked out by the evader's maneuvers). Region 0 is within the radius of the catch (the chase is over).

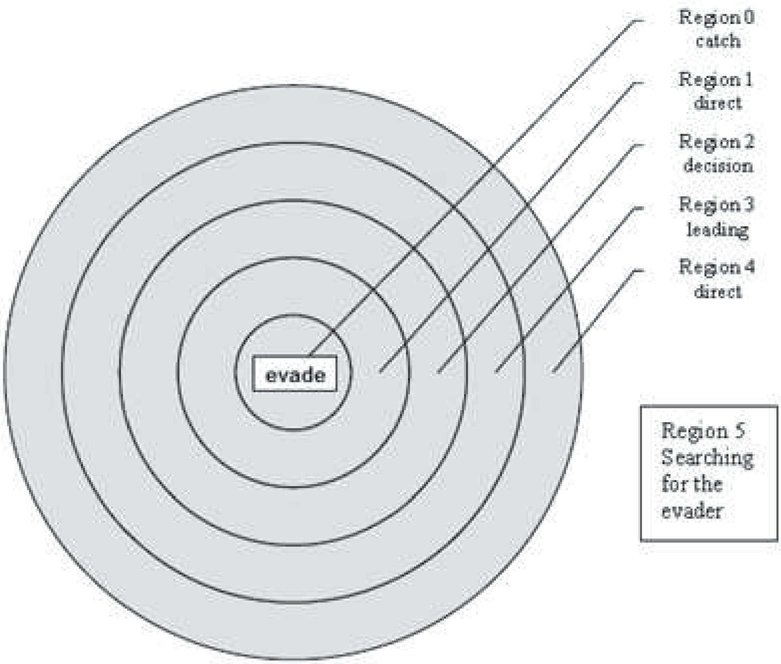

Figure 5.4: Pursuer's potential regions of changing strategies depending on distance (or time to catch) between the pursuer and the evader.

Now, let's consider an evader on a movement mission. We'll continue to use a circular model with the evader in the center; we could also just reflect the radial distances to define the regions. When the evader is far away from pursuers (Region 5), it looks for pursuers, but hasn't seen any yet, so it continues with its mission. The evader enters Region 4 when it detects a pursuer. However, in Region 4, the pursuer is still quite far from the evader so the evader continues the mission and just watches the pursuer. The evader enters Region 3 when it realizes that the pursuer is threatening its safety and it decides to actively evade. In region 2, the evader decides to use maneuver and/or deceit to evade (oscillate, smoke, hide, etc.). When the evader sees the pursuer in Region 1, it believes that the catch is probable. In this region, it attempts all maneuvers to include drastically changing tactics (go directly toward pursuer and execute a final oscillation, etc.). Region 0 is within the radius of the catch (the chase is over).

When we produce and analyze similar regions for the N-vs-K scenario, there are many more regions and strategies to consider as the groups of agents need to communicate, collaborate, decide as all the many distances between closest enemies change. We won't lay out a regional scenario for changing strategies in this case, but these are some of the things to consider: types of data to transmit and to whom to transmit them; who makes the decisions and when; when to identify who will be chased; when to change targets; who should be evaded; and should there be sacrificial lambs and, if so, who identifies who will be sacrificed?

We have previously considered a few elements of pursuit and evasion to show the nonsimplicity of the issue in a basic movement element of a military operation. We haven't resolved many of the nonsimple issues in this foundational military task and there are many more that we have not yet considered. The special cases, with goals like herding rather than capture, need to be studied in as much detail and may produce quite different strategies.

Our models and simulations have used discrete-motion, dynamic models and have taken a computational geometrical differential games approach to the problem. Others have approached the nonsimple optimality issues of pursuit-evade through nonlinear programming, or optimal control. We haven't discussed those approaches, but these are good references to them [49, 92, 100, 109, 188, 198, 259, 280]. There are other approaches that include a probabilistic approach involving stochastic pursuit-evasion, a graph theory approach, a state space and information space approach, and a machine learning (genetic algorithms) approach [35, 79, 110, 123, 189, 210, 228, 237, 282]. CS seeks to compare and contrast the different theories and results. Most importantly, developing and identifying the proper nonsimplicity measurements and performance metrics are necessary to develop the future of automated pursuit and evasion systems.

It is evident that the deployment of mobile interactive agents (robots, UAVs, UGVs, UWVs, cyber bots) will become increasingly important in the surveillance and pursuit of adversary forces in future military operations. Mobile agents will be equipped with sensors and wireless communication capabilities to coordinate among the friendly agents in order to pursue the enemy evaders or to evade enemy pursuers. In order to achieve operational goals, using nonsimplicity systems to understand group coordination must be achieved. The resolution of various physical and informational constraints of the battlefield must be taken into account as well. Studies of group coordination and the formation of these interactive agents in dynamic environments are just beginning. Many important issues and challenges still need to be resolved. Due to the nonsimplicity in the formulation and analysis of information flow and the challenging issues related to the vision and decisions of the agents, the progress made in this area has been challenging. Research efforts in hopes of developing theories, processes, tools, and algorithms for efficient pursuit-evasion strategies are needed. As a consequence, the ultimate designers and manufacturers of robots, UAVs, UGVs, UWVs, and cyber bots will be better informed for efficient pursuit-evasion strategies. It is probable that nonsimplicity modeling of pursuit-evasion operations will have a significant impact on the future of military operations.

5.2 Mathematics of the nonsimple

Models are abstract constructs of reality that stem from inherent assumptions about the nature of the phenomenon being investigated. These assumptions are necessary components of modeling. In traditional mathematical modeling, assumptions are made to simplify the representation of the process to enable closed-form, linear solutions that can be analyzed, generalized, and validated. In nonsimple modeling, assumptions are reduced to a minimum to achieve an often intricate model that attempts to include many, if not all, of the system's nonsimplicity elements, but which often has no closed-form, elegant solution to be generalized or proven. The modeler then uses new data-science tools to make sense of the solution and provide utility in analyzing their results. The modeler has to choose the appropriate level and number of assumptions made for the model. Nonsimple modeling is being used to represent and solve for more and more problems and is finding its place in applied mathematics, operations research, and data science.

Models can inspire mathematicians to create new mathematical relationships to process data to solve the model equations. Often the collection of models for a nonsimple system results in one-of-a-kind algorithms or simulations that sometimes need newly developed functions and processes. One way to categorize nonsimple systems is that they are not a reductive assemblage of known functions using known operations. Embracing nonsimplicity involves creativity to put together a viable model and to build new measures, methods, functions and algorithms. The recent developments of new mathematical and computational methods, enable modelers to abandon historically simplifying and limiting assumptions.

By the nature of the process, even using nonsimple models, math modelers are unable to create genuine models that faithfully match reality. Researchers attempt to model the essence of problems by building processes and structures that are nonlinear and otherwise not simple. But once the modeler constructs an algorithm, or creates a structure, it is no longer as genuine or nonsimple as reality. Embracing nonsimplicity is the approach for the modeler to confront the nonsimplicity issues as closely and accurately as possible. In the end, the model still consists of functions, operations, measures, algorithms, and structures that are intended to capture the full nonsimplicity of the empirical system.

Serious progress in interdisciplinary problem solving was made in the 1940s. In 1947 Warren Weaver's introduction to CS established a foundation for others to follow. He started by asking questions that had not been contemplated by classic science. The questions were about important societal issues, such as [265]:

> ..it is equally obvious that . . . something more is needed than the mathematics of averages. With a given total of national resources that can be brought to bear, what tactics and strategy will most promptly win a war, or better: what sacrifices of present selfish interest will most effectively contribute to a stable, decent, and peaceful world?

Weaver concluded his article with a new philosophy for science and problem solving that featured nonsimplicity:

> We must, therefore, stop thinking of science in terms of its spectacular successes in solving problems of simplicity. This means, among other things, that we must stop thinking of science in terms of gadgetry. Above all, science must not be thought of as a modern improved black magic capable of accomplishing anything and everything.

At the same time as Weaver's contributions, the science of Cybernetics was being developed by Norbert Wiener. This science professed that the consequential communication and control in systems, and therefore accurate models came from feedback loops. In the 1960s, systems theory emerged from the cybernetic foundation to take an interdisciplinary view of systems to describe the many ways that components interacted with each other, much like modern networked systems. In the 1970s, chaos theory formalized nonlinear dynamic systems, including bifurcations, strange attractors, and chaotic behaviors. These advances were the paradigm shifts needed to make modern science and problem solving amenable to nonsimple thinking.

The term “wicked” was originally used to describe problems that are challenging to solve because of incomplete, erratic, complicated, and unique requirements [191]. Because of system interdependencies, solving one aspect of a wicked problem often creates other problems. Wicked problems cannot be solved by applying known methods. They require inventive models that are often elaborate, adaptable, and nonsimple. Wicked problems include many of the compelling and seemingly capricious issues involving economics, environment, politics, and people’s behavior. Other wicked problems come from government and political issues for public planning and policy where large numbers of diverse issues are involved in the solution (for example, natural disasters, epidemics, homeland security, and nuclear energy). Wicked problems also occur in warfighting and military operations. These problems often stem from the following partial list of issues:

- Different and possibly contradictory views of the problem by different groups (e.g., competition and combat)
- Data are often uncertain or missing (hidden and dark networks)
- Ideological and cultural constraints are extremely important
- Political constraints that are dynamic
- Economic constraints that are controversial
- Numerous possible intervention points
- Considerable uncertainty, ambiguity in many of the possible assumptions (the fog of war)

Where do metrics fit into nonsimple modeling? Metrics are the measures that modelers use to help the model quantify properties and ultimately determine decisions. The metrics by which modelers measure “distance” between phenomena for a nonsimple model will likely be nontraditional in form and nonsimple in computation. To be used in models, metrics must be computationally feasible; mathematically and scientifically justified; and based on known or hypothesized physical, biological, sociological, or socio-cognitive principles and properties. Ad hoc or purely heuristic metrics, with arbitrary parameters, are limiting and can weaken models and their results. The best metrics are derived from the context of the situation and the decisions to be made, not assumed or assigned and are verified by data. Quantification and metrics need to maximize reliability and accuracy, since often uncertainty, falsification, and deception are present in the input data from social media that are influenced by humans.

Technologically-enabled social interactions and social media have had explosive growth over the past decade. Social media facilitate interaction and information exchange. They create enormous amounts of data (text, image, and video), information, and intelligence that can be used to develop wisdom, situational awareness, and facilitate wise decision making. The traditional models and analytical tools used for physical phenomena often do not work for the modeler of social and informational phenomena. An emerging goal of nonsimple modeling is to produce forensic and predictive models from calculating and analyzing human-based data and metrics. This analysis includes models that extract information from social media and find the patterns of information across a variety of sources to improve decision-making results. The nonsimplicity of this problem comes from the open-world context of social media data that is significantly different from the usual closed-world context of physical sensors and their models. One important element of the nonsimple modeling is the representation of uncertainty that is applicable for the poorly understood, nonsimple, open-world situations that occur in social-media. Using technology-based social network models and tools will help enhance and resolve information and social challenges and issues.

To enhance the decision making in military operations, modelers work to quantify the elements and their nonsimplicity within the operations. The traditional metrics in war: casualties or materiel and land seized or destroyed often have reduced significance in modern operations. In addition, political, cultural, and ethical values of the combatants lead to different goals that make any utility measures difficult to construct. In modern insurgencies, a cogent measure is the amount of local support the counter-insurgency force obtains and is an often appropriate measure for the kind of conflicts happening today. However, this entity is very difficult to measure, so we may not be able to gauge success very accurately using this measure, or other nonsimple measures.

One way that systems are nonsimple is in their geometry. Probably the most significant issue is the inclusion of multiple scales. As an example, water flow in an ocean may take place in several different geometric scales (e.g., deep ocean water, water in the shallower coastal shelf, turbulent flow near a beach or shoreline). Most fluid flows (water in pipes, air around airplanes, coolant in cars) involve modeling on multiple scales. There is a famous joke (among scientists) in the math community spoofing the oversimplification of real-life geometry in physical models. “Consider a spherical cow,” the joke goes,“ in which the milk is uniformly distributed.” This simplified geometry may be a little hard to imagine and starting the modeling process with such an assumption is certainly the very antithesis of embracing nonsimplicity.

Our world is full of diverse systems–people, organizations, governments, networks–with behaviors that produce unexpected, nonsimple phenomena. In today's world, it is not unusual to have political uprisings, economic crises, and new social trends. People who use models to help them think about and solve problems can gain more insight into the behavior of nonsimple phenomena than those who do not. Models make us better thinkers because they help us organize information as well as make sense of data overload and challenging issues that arise from the internet. Models improve our ability to predict, design, explain, formulate strategies, and make better decisions. These are the elements that, in part, mold the thinking of the modern military leader.

5.2.1 New paradigms

Applied mathematics (and science, in general) has a rich history of progress in modeling and analysis methodologies that have resulted in the advancement of knowledge and solutions to important problems. The utility of sociology is a recent beneficiary of this progress. Thomas Kuhn [133] proposed an episodic model in which revolutionary advances, or paradigm shifts, are the driving forces for scientific advancement. According to Kuhn, paradigm shifts are more important than the steady, inch-by-inch incremental progress of scientific methodology and thinking. Kuhn's theory credits some of the twentieth-century paradigm shifts for the success of sociology and the introduction of humanism into modern science. According to his theory, when a paradigm reveals significant anomalies, new revolutionary ideas emerge that lead to an entirely new methodology that eventually gains followers. An intellectual contest between the new and old paradigms takes place and sometimes a new or different scientific system emerges as a result.

During the twentieth century, a number of significant interdisciplinary scientific disciplines emerged from major paradigm shifts–operations research, information science, computer science, network science, analytics, decision science, and data science. These modeling disciplines relied on, and continue to rely on, nonsimple modeling and analysis for their progress. Over the twentieth century, more and more modelers found the traditional reductive approach limiting for many of the most cogent and capricious problems. The new paradigms of nonsimplicity and complexity modeling emerged as they became more effective at solving important problems.

Although a distinction is sometimes drawn between qualitative and quantitative modeling, many times the two go hand-in-hand. Quantitative work enabled fruitful modeling and analysis in the physical sciences. Qualitative research was used to gain a general sense of nonsimple phenomena in the social and behavioral sciences. The goal of nonsimple analysis is to dovetail the quantitative and the qualitative so that the quantitative measures of the rainbow blends with the aesthetic judgment to form beauty and the nonsimplicity of music can be matched to the pleasure in the brain.

The information content and nonsimplicity property are influenced at all scales, so mathematics must either embrace the nonsimplicity with computationally detailed models (large-scale, stochastic, discrete-event simulation); build smart, autonomous models that refine themselves (machine deep learning–a rising, modern branch of AI); develop better models and logic systems (homotopy type theory–a modern replacement for set theory); or develop the ability to find the right scales at the right time (renormalization theory with an associated dynamical modeling using fractional mathematics). In essence, nonsimple models must incorporate the dynamic with the static, the microvariables with macrovariables, the discrete with the continuous, and the big with the small-data phenomena. Some examples of applications being modeled using nonsimplicity of interest to the military are cybersecurity, unanticipated failures, and tipping points.

Given scarce resources, identifying sectors and areas of the population that need the most help is crucial in implementing policies and programs that do the most good and prevent the most harm. The traditional approach in public policy and development work is to triage areas of concern by comparing discipline-specific measures of well-being (poverty for economists, burden of disease for doctors, etc.). While useful for initial evaluation and assessment of a population, such measures are often insufficient for designing future intervention programs, because of the single dimensional and disciplinary nature of these data. The nonsimple approach spans that gap by developing a multidisciplinary index (nonsimplicity measure) of household vulnerability based on the relationship between the identified factors of vulnerability and its measurable manifestations. An AI-driven, nonsimple model learns the characteristics of vulnerability using a form of machine deep learning, by assigning known vulnerable areas (slums) as a training set. After learning, a neural-like network model can be used to predict the vulnerability of households within other city areas, such as the suburbs, or within the vulnerability areas of other cities. Vulnerability maps of urban areas can be generated so the military can use them to launch humanitarian aid operations in the most critical and warranted areas.

It has been over half a century since the creation of America's modern day immigration system and, over that time, people have become increasingly globally connected. Yet policies from a much earlier environment still dictate who can enter the United States. Researchers have struggled to evaluate and predict the consequences of immigration on American society and to provide definitive policy recommendations. Nonsimple models using the relationship between American citizens and immigrants, as measured by changes in living standards and wages, seek to determine what immigration policies best improve the US economy and culture. Multi-objective integer programming can then be used on the results to find Pareto optimal policies and illustrate the various trade-offs between economic and social objectives. The result is a better understanding of how immigrants affect the living standards of American citizens. This nonsimple model has the potential to provide data-driven policy recommendations to improve the economic opportunities for all current citizens of and future immigrants to the United States.

While much analytic work has been done in an attempt to resolve the European refugee crisis (ERC), traditional mathematical modeling methods have not yet shown how to alleviate the problem. With millions of refugees and just as many constraints that seem to be continuously changing, the ERC is a timely example of a big-data, wicked problem. Big data connotes that the volume and dimensionality of the measurements make the data set impossible to analyze statistically, because existing statistical methods have not been able to effectively account for the relationships and synergistic effects manifest by different components of the problem. By using nonsimple modeling techniques like renormalization group theory, modelers can scale down this problem from big data into a manageable networked system to do the analysis with network science tools, or dynamic systems techniques. Once again, the goal of resolving the ERC is to formulate viable policy recommendations to alleviate the stresses produced by the mass immigration into Europe.

In the modern world, with multiple different types of adversaries ranging from conventional to non-conventional enemies, from insurgent groups to rogue nations, the United States can no longer rely on traditional methods of warfare to ensure national security. America needs to consider and develop deterrence strategies to combat state actors that strategically employ non-state actors as proxies that counter US military forces. A deterrence model is developed by showing how the enemy perceives the value of their aggressive actions, or restraints based on each decision the US leaders make. This modeling, when successful, allows analysts and policy makers to estimate the effectiveness, cost, benefit, and speed of each action, as done using the computer games discussed in Chapter 4 and its future generations. The goal is to determine the probability of non-aggression from the adversary, based on each possible action that the United States could consider. This nonsimple model provides military analysts detailed insight into possible enemy behaviors and good ways, if not the best way, to counter those threats and actions.

Operational planning needs good models and tools to ensure success. One valuable tool is the categorization of cities into how they operate and function so military operations can avoid urban obstacles and restrictions and take advantage of knowledge of the overall situation within the city. Urbanization increasingly means that the poorest and most vulnerable people move into large, highly distressed slums. In many rapidly growing cities, the majority of the population lives in slums. The United Nations estimates that 55 million new slum dwellers have been added to the global population since the turn of the century. These areas exhibit high levels of poverty and inequality. The risk is that these slums will detach themselves even further from effective government service and control and build local political and military power structures that may come to constitute a threat to the city and the nation. Military operations need to take into account the urban geography and the existing processes and structures of urban functions. Many of these informal areas are also the most susceptible to natural disasters because they are located on marginal lands, unsuitable for further development, and often become the ground-zero of disaster relief efforts.

Nonsimple techniques can help military analysts categorize and understand large sprawling cities. Understanding both formal and informal structures and processes in governance, economics, communication, social functions, and space and infrastructure utilization is critical in measuring a neighborhood's vulnerability, as well as operating in dense urban areas. A nonsimple model can build a framework for measuring factors for operations and decision making. The model helps to identify regions with less-developed infrastructure and decentralized, missing, or ineffective governance and identifies key players in informal governance.

5.2.2 Network Science (NS)

> Few would argue with the proposition that the world is becoming increasingly connected. In fact, humanity is on the cusp of what futurists call the 4th Industrial Revolution, in which the physical, biological, and digital worlds will merge. . . . Connectivity favours speed, freedom, sharing, delegation, and individuality, attributes the digital natives of today take for granted. Can the strengths of connectivity be made to work in military command systems emphasizing hierarchy, control, integration, and coordination? Integration, for example, is one of the buzzwords of those advocating Multi-Domain Battle, and its achievement is absolutely critical. [177]

Networks are not only ubiquitous, but they also lie at the core of the economic, political, military, and social fabric of modern society. As stated in the National Research Council report [167]: "...society depends on a diversity of complex networks for its very existence." Analysts are beginning to perform nonsimple network modeling and data analytics for many applications and issues. NS and data analytics (DA) seek to build a framework for understanding military-relevant issues, such as communication flow, command and control, managing unit operations, implementing information assurance, modeling terror cells and their processes, gathering and processing intelligence, maintaining security in physical and informational systems, enabling engagement within the Army's Global Landpower Network, and decision making [39].

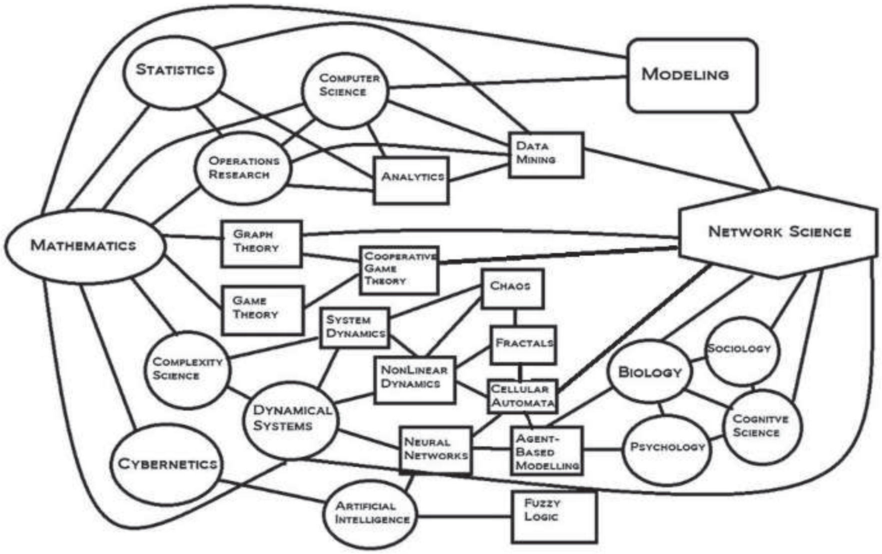

Figure 5.5: The development of network science over the past quarter-century has incorporated many new mathematical techniques. A number of the new techniques have been refined in making models of nonsimple phenomena in a number of scientific disciplines. Reproduced from [159] with permission.

In the life sciences, network applications include, but are not restricted to, mapping genetic and protein networks and their roles in disease, mapping rudimentary brain networks by identifying and validating network processes within the brain, forecasting disease contagion, and analyzing various levels and regions of ecosystems, see Figure 5.5. Network-based applications involving physical networks include managing communication and computer systems, operating logistics and transportation systems, and designing infrastructures in various buildings, structures, and systems, e.g., water, waste, and heat. The network models associated with social processes involve conducting collaborative decision making and group learning, modeling collective and team behaviors that involve coordinated activities, modeling the meanings of textual and spoken language to understand influence, and tracking the emergence of societal impact and achievement [61].

Network models can merge the social, informational, communication, and physical layers of a system or organization into an interconnected, unified system for a broad, integrated analysis [13, 14]. Figure 5.5 indicates some of the mathematical ideas that have been incorporated into the modern modeling of networks. The network layers collectively produce an all-encompassing, non-reductive, nonsimple model that permits multiple scaling, processing of tremendous volumes of data, finding suitable measures of system nonsimplicity, and builds appropriate diversity and specializations within the system or organization. Network modeling enables the dynamics in the structures and processes of the phenomenon being modeled to build usable knowledge and make viable decisions. One of the recent results in NS shows the impossibility of perfect control over organizational and entity behavior in social networks [271]. A subtle hand of delicate management through shared vision and autonomy is often more powerful than rigid micro-control through rules, regulations, and detailed instructions. This result is significant for military networks. As Roehner [193] reflected about these data-driven contexts:

> The real challenge is to do real physics and real sociology in the framework of network theory.

A major issue in using modeling to build military systems, or to analyze military doctrine, is that hidden or opaque networks create a sinister form of nonsimplicity in systems that cannot be overcome by current methods and tools. Finding these networks and their dependency structures has been the ultimate challenge for analysts, so military planners often perform traditional simplifications and approximations, using current methodologies that unfortunately still do not provide the accuracy and reliability we desire. As an example, large organizations have many networks that relate people in numerous ways. We are often able to find and analyze a few of these networks in the organization such as formal management, friendships, and information flow networks. However, many of the networks in the organization are hidden, such as speaking accents, politics, trust, social, interest, parking location, influence, and tastes in fashion, food, music, TV, and movies. All these undetected networks, along with hidden characteristics and traits of individuals affect the thinking and behavior of people, teams, units, and the entire organization. Therefore, information processing for decision making, influencing people, collaborating, maintaining loyalty, and building motivation do not follow simple, rational, or logical patterns. Likewise, behavior analysis of elements such as work habits, eating, supporting, helping, smiling, do not follow rules that can be used to determine consistent, predicted actions. Can we do better in understanding organizations and their operations by modeling them as nonsimple systems to understanding their complexity? A goal of nonsimple network modeling is to quantify the intrinsic properties of groups such as happiness, influence, communication quality, intelligence, and/or cooperation. These attributes often make a difference in many issues in society.

Figure 5.6: A boy perhaps imitating the body language of his father and grandfather while walking. The basis for the imitation hypothesis used in DMM. Reproduced from [271] with permission.

The decision-making model (DMM) [271] was constructed to provide insight into how groups make decisions under conditions of uncertainty, which is particularly useful in the present context. This nonsimple model is based on the assumption that human beings, when allowed to choose freely, imitate one another, as depicted by the small boy imitating the body language of his elders in Figure 5.6. This single assumption is sufficient to establish a tipping point between competing alternatives, for dynamic groups ranging from democratically formed political parties to radical jihadists. The model establishes the logic behind the answers to such questions as how the stability of a society may be undermined by zealots and committed minorities, as well as how that stability can be reestablished. Of course, it is a model and, as such, its implications must be tested against data, which largely remains to be done.

One of the surprising properties of the DMM is that, even though a group can reach consensus, it can do so without a leader. At any given point in time, that the model predicts there is a leader, with the leadership role defined by having the largest number of connections with other members of the network. The relative number of connections for members of the group follows an inverse power-law distribution. However, the length of time any member of the group is in the leadership role is always short as the position of leadership is transient, even though the inverse power-law does not change in form over time. It is surprising that, like the third-wave radical jihad movement, the DMM can display large-scale, long-time agreement and does so without a persistent leader. The model predicts a relatively rapid turnover in leadership, while at the same time the connectedness structure of the group remains unchanged. Thus, we have a leaderless, but stable social group. This may also suggest the need for an alternative policy or strategy to that of killing off the leadership in an attempt to defeat radical jihad, since who the leader is at any given point in time may, in fact, be immaterial.

A tipping point stands out most clearly when there are only two states; black or white, yes or no, up or down, for or against, and the slightest touch or smallest piece of information induces an unexpected transition between the two states. Consequently, tipping points are uncertain and surprising. They can be described after the fact, but they are not predictable. The inability to predict when a tipping point will be activated is not the same as not knowing it exists. One can know that a situation has come to a head and still not know how to predict the size of an outcome, or when exactly it will occur.

The surprising aspect of tipping is like that of getting a joke or the moment of having an insight. There is no linear algorithm to indicate how, after thinking for a given length of time, understanding will suddenly emerge. The insight is unexpected and its exact source is unknown, but the process is certainly not linear. Sometimes it comes by retracing familiar unsuccessful arguments that ultimately reveal a hidden contradiction or inconsistency. A contradiction is attractive, because the truth lies on one side or the other, hence the contradiction reduces the number of options to two. In the face of uncertainty, this is as good as it gets. At other times insight comes by abandoning the traditional approaches and trying something that on its face cannot work, such as accepting the truth of a proposition and its negation, simultaneously, and thereby embracing paradox. But such a path is not for the faint of heart, as we explain in the next chapter.

5.2.3 Cyber

Cyberspace is different from the other military war-fighting domains, in that it is not a natural domain but, a man-made one. Every element of cyber science is so nonsimple that cyber science is different from the traditional sciences. There is no set of basic principles that serve as a foundation on which to build. Interdisciplinarity is the primary factor of the cyber domain and its associated operations. The avoidance of patterns through the inclusion of randomness and diversity are the fundamental elements of cyber science. Its analytic elements are more interdisciplinary and diverse than the natural sciences. Cyberspace itself is the combination of many digital-related components that store, process, secure, protect, transmit, and use information. There are technical aspects of cyber, along with the involvement of many human-based disciplines such as philosophy, ethics, law, psychology, policy, and economics. Together many disciplines and interdisciplinary off-shoots contribute to the nonsimplicity of cyber analytics. To develop this science, we seek to investigate the questions: Why and how does cyber science eschew patterns? What roles do randomness and diversity play? In a world that is increasingly connected through expanding digital networks, cyber science offers tools to understand the nonsimple issues and solve the challenging problems that this expansion is creating. Cyberspace is nonsimple, dynamic, interdisciplinary, fractional, and chaotic, where the use of structures and processes are challenged to represent and conceptualize its elements and capture the dynamics of the basic attacker-defender (pursuer-evader) interface. Additionally, the issue of security of information in cyberspace and military cyber becomes the ultimate nonsimple science and profession.

Cyber science must develop ways to enable military cyber analysts to contribute to the nonsimple realities of the fast-paced worlds of digital communication and information processing. Cyber analysis is highly interdisciplinary because its elements involve many forms of science relevant to the goals, perspectives, and principles of network-based operations. Computing, modeling, and networking are important underlying elements, as are fundamental processes and structures in mathematics and operations research. Big Data, Evolutionary Game Theory, and AI are the applied components of the present day digital cyber world.

The first element of the nonsimplicity of cyberspace is understanding the problem to be solved, or the issue to be confronted. Often the issues and problems that need to be addressed are hidden, and only the symptoms are visible. The cause of the problem–a bug, an innocent human error, bad hardware, a multi-layered firewall, a dynamic fast-acting AI, or a malicious attack is often undetectable, yet critical in the success of a military operation. The balancing relations among security, performance, privacy, and information availability are delicate. Cyber analysis is needed for fast, time-sensitive problem solutions and robust network designs that are not as common in other domains. Since the cyber world is developing at an incredible rate, we need to ask: Can analysis keep pace with computing, math, and AI, which are often component parts of the issues and problems?

Another element of cyber nonsimplicity is the underlying competitive nature of the attacker-defender dynamic. Hackers and malicious systems are pitted against defenders of information and system's performance. However, there is much more to cybersecurity than a formidable firewall and good virus protection. In addition, these attacking elements often try to hide their true identity or their plan of attack. Defenders try to hide or change their patterns so attackers cannot identify patterns, find seams, and exploit weaknesses. This game theoretic setting takes nonsimplicity modeling to new heights in terms of the what-if, cause and effect, and who-did-what questions. Cyber problem solving is an unstructured process that often requires high-dimensional, nonlinear models, yet still need dynamic modification to adapt to the continuously changing situations. Moreover, the implementation of a cyber-model must always consider speed in order to retain the advantage. This need is where AI is so critical in cyber systems.

Cyber modeling benefits from the art of war gaming of the basic elements of the cyber competition. Models that can test capabilities, probe for vulnerabilities, fix performance degradation, and exercise cyber systems, are needed to enhance cybersecurity. Artificial intelligence techniques like machine learning and reinforcement learning are valuable tools to many cyber modelers for maintaining the fast pace of attacking and defending.

On a larger scale, the science of information security, which has as a goal building effective systems for information assurance, is a component of cyber science. A major challenge is that the same elements of the information network that create its positive attributes (effectiveness and freedom) also produce its negative attributes (vulnerability and lack of privacy and security). What makes the network robust, survivable, and hard to kill paradoxically makes it inefficient, difficult to manage, and vulnerable to penetration. Evolutionary biology shows that inherent diversity provides reliability at a price of loss of efficiency. The key is to find the right balance of acceptable performance and vulnerabilities.

Evolutionary biology also teaches that change (adaptation and randomness) is needed in order to survive. Today's cyber systems can be vulnerable and unpredictable–a place where actions and events happen fast. To survive on the network you have to be able to react quickly and effectively–sometimes proactively and sometimes reactively. Diversity is the model attribute that best provides the potential for resilience to vulnerabilities and yet maintains the agility to change fast. One natural way to create diversity in cyber systems is through randomness (explicitly designed, random, yet efficient processes). Nature provides diversity in its DNA and cells; cyber scientists need to build this kind of diversity and randomness into their systems.

There is a well-defined and useful definition of what it means for information (numbers, words, symbols) to be random–an impossibility to establish a pattern to compress its information content. In order to build smart systems, cyber scientists need to include that kind of randomness and its consequential diversity into cyber architecture. Designing diversity into a network can make it robust, secure, inefficient and difficult to control. The goal is to have randomness and diversity nearly everywhere, such as in the following:

- Authentication Procedures
- System Connections
- Operating Systems
- Protocols
- Topology of the Architecture

The analogy between cyber and biological systems is powerful. Monocultures are efficient, but vulnerable. The basic concept is that uniformity creates a form of patterned weakness, due to its predictability. Poly-cultures are inefficient, but usually robust to a changing environment and therefore have enhanced survivability. The result is that diversity creates a form of strength. The ultra-efficiency of uniform precision often indicates, and will ultimately produce, system fragility. This idea of adding randomness and diversity is not intuitive to modelers who have worked in other, simpler domains. Fortunately, despite efforts to make the internet more uniform and efficient, its architecture has resisted all of these efforts, and remains nonsimple. The Internet works precisely because of its inherent diversity and randomness. Yet, we continue to follow our intuition and design military networks and systems primarily for efficiency. The result can be super-efficient networks that are often rigid and brittle. When things go wrong in our carefully designed systems, we react by enforcing rigid discipline and control that destroys diversity and ultimately degrades the security of the network.

So when weaknesses are found, cyber scientists may need to include in their designs more intentional randomness into the network, as long as it still meets its operational demands. Then modelers can use the system's diversity for improved survivability at the cost of efficiency. Randomness means that no one (not even the designer or builder) has precise control, but overall performance will still be higher than highly-patterned, over-programmed, inflexible, but broken systems.

Based upon technological and cultural advances, we see an evolving threat of an increase in cyber-attacks and breaches in data security. More and more people are affected through both an increase in soft attacks on unprotected information and a rising level in the severity of the attacks. Hacking and cyber-attacks have become weapons in an ongoing and perhaps never-ending cyber war. Blended attacks, where cyber is connected to other forms and domains of warfare, have the most potential for devastating effects. Fortunately this hasn't happened often, but the future is ripe for a massive increase in attacks on infrastructure and large-scale service networks (e.g., energy, communication, entertainment, business and water resources).

Autonomous systems of all types depend upon data. When these data are corrupted, manipulated, or denied, the system performance is degraded. Without good security decisions, data collection, storage, and processing systems can be weakened or destroyed by cyber–attacks. Since AI will be the backbone of our autonomous systems, the AI must be healthy and secure to operate and make wise cyber decisions for both offense and defense. The weaponization of AI means that it can also be used as the decision-maker and coordinator for an attack, or as the first responder in defense of a network under attack. On the offense, AI can be used to monitor the expanded cyber environment, assessing vulnerabilities in the adversary's defense, or taking autonomous action. On the defense, AI can block and mitigate cyber probes and hacking attacks. AI along with highly automated defense systems become the key components in thwarting these attacks, usually because humans are too slow to monitor the entire cyber environment and take a long time to decide and implement action. For the human-in-the-loop defense systems, the offense-based adversary using AI can overwhelm the slow-acting human defense.

Counter-intuitively, the main vulnerability of cyber systems is frequently too much efficiency. When simplistic efficiency is the driving factor of the system, it is often easy to attack the patterned, smooth-running, predictable network. Efficiency is easy to hack because there is no redundancy or randomness to delay or confuse the hacker. The attacker

AI just finds the system's efficient pattern and determines a seam to enter the system by covering its entry with the same pattern. Once the AI-enabled attacker learns how the system is constructed and operates, it can find the valuable data and hijack system control, or use the system as a part of a more significant attack. Unfortunately, most current systems were designed with security as an afterthought and rely too heavily on humans to detect and block cyber-attacks. Nonsimple cyber and AI are a tough combination to stop by simple efficiency, slow human skills, and even military diligence.

There is a need for accepted international norms for cyberspace. Information technology is designed to operate across multiple physical boundaries and domains, as well as, across different cultures. For example, the military's cyberspace operators in cyber-dense urban areas will need to confront tremendous nonsimplicity in every element. The numerous urban networks will vary greatly in software, protocols, formalities, and integration between systems. Every urban or operational area will have its own physical and virtual cyber terrains. The number of computers, smart devices, sensors, and communication systems will be so significant that all data collections will include Big Data challenges. The most hyper-connected cities could have millions of small networks, with millions of AI programs and human users. Military forces will have to interact with these cyberspace networks to succeed in their operations. The cyber domain is a form of man-made information terrain that is much more dynamic than the environments of the other domains. The nonsimplicity of these vast global networks make cyberspace difficult to visualize as operational terrain. However, within the framework of modern joint, multi-domain battles, the nonsimple cyberspace terrain must be considered, analyzed, understood, used, and exploited to the US military's advantage.

Cyber science seeks to build models and algorithms that help to defend or attack systems, predict and defend against attacks, respond to problems, design flexible systems, protect the valuable information, and otherwise carefully watch over and monitor their respective portions of cyberspace. Future cyber service members will need to provide just enough organized framework to prepare courses of action for identifying potential problems and create game plans for resolving both the forecasted and the unforeseen events. There is an active and evolving future for cyber science in the military. Through the biological analogy, cyberspace requires new, original ways of thinking and model building for the tasks that are part of this rapidly changing science. It is not often that the way ahead in science is to embrace randomness, diversity, inefficiency, nonsimplicity, and interdisciplinarity. Yet these are the hallmark of modern cyber systems. Cyber science in this nonsimple form will be a challenge for our cyber community to accept, understand, develop, and learn. The military will need to teach diversity, randomness, and nonsimplicity modeling to its military cyber scientists and operations research analysts. In addition, new forms of Computer Science, Nonsimplicity Modeling, Operations Research, Fractional Mathematics, Network Science, Game Theory, Big Data, and Artificial Intelligence will need to be incorporated into this highly nonsimple cyber education.

The warfare of the future will be multi-dimensional, multi-domain, and nonsimple with planning, intelligence collection, and decision making happening simultaneously with kinetic action. Some systems will be manned or remotely operated, but most will be autonomous. These autonomous weapons, sensors, reconnaissance technologies, and intelligence processing systems will be in all domains of warfare–air, land, sea, space, and cyber. These systems will also be linked to hybrid teams of people and other machines.

We need the collaboration of the government, military, industry, and universities to overcome and ultimately prevent cyber hacks and attacks [31]. Interdisciplinary collaboration is needed to overcome the obstacles of bureaucracies and their inherent nonsimplicity. Today's cyber operations are both bureaucratic (full of rules and laws) and nonsimple, combine to make it the ultimate challenge for modern military forces.

Though human beings have naturally pondered the ethical limits of warfare for thousands of years, only recently have people tried to codify these principles into laws. Despite countless attempts to limit violence through creeds and oaths, the first international conferences that bind nations to follow the principles of Jus ad Bellum and Jus in Bello were the *Geneva Convention of 1864* and later, the *Hague Conferences of 1899 and 1907* [227]. *The Law of Armed Conflict (LOAC)*, as we know it, was solidified in 1945 by the ratification of the *United Nations Charter* [227]. Thus, in the scope of human history, the LOAC is a relatively recent development.

Yet, recent technological advancements have seriously challenged the general applicability of LOAC. Cyber Operations, including on-net activities and information warfare, have muddied the water concerning what is classified as force and redefined the nature of interstate competition and coercion. Just as the Additional Protocols expanded the legal restraints of the *Geneva Convention*, LOAC scholars worked at the behest of NATO to put forward the *Tallinn Manual* in 2012 [204], as well as a more recent update [205]. This legal work has been challenging due to both the rapid advances in cyber technology (requiring frequent updating and revisions), the adjunct nature of these codes to the LOAC, and the nonsimple nature of cyber operations. Since the LOAC was conceived prior to the invention of Cyber Operations, nesting the two together in a meaningful way certainly requires mental gymnastics to reign in the ever-expanding nature and methods of modern warfare.

One such explicative work is the article in the *Small Wars Journal,* "A Beginner's Guide to the Musical Scales of Cyberwar," by Smith [221]. In the paper, Smith uses the analogy of musical scales called octaves to illustrate basic classes of cyber operations in terms of legality. In the analogy, the further notes are from Middle C, the less permissible the notes (actions) are. The first octave above Middle C contains actions that are clearly acceptable. In this category are military responses to a state-on-state attacks that cause damage to persons or property above the "de minimus damage/injury threshold" [221]. The second octave consists of Anticipatory Self-Defense, actions taken to eliminate imminent threats that would cause serious damage to persons or property or constitute a serious violation of sovereignty. Such responses are "likely to be permissible." The third octave is the final gray area of legality, composed of operations taken against foreign non-state actors who launch attacks and cause serious damage. Responding to non-state actors with full military force is obviously a violation of sovereignty, though this can be circumvented by obtaining permission from the governing body of the country. However, such permissions may compromise a cyber-attack's effectiveness. The final octave represents actions that are clearly not permissible under LOAC, such as raw aggression, coercion and preventative strikes aimed at eliminating potential attackers.[1]

Cyber Operations are particularly difficult to place precisely within the Musical Scale of LOAC. It is important to note that cyber operations very rarely break "de minimus damage/injury threshold," despite famous examples such as Estonia in 2008 and Stuxnet in 2010. Some of the most damaging attacks have been in the realm of information warfare, combining espionage, propaganda campaigns, and coercive force. Such Cyber Operations do not break the traditional limit outlined under LOAC. Second, the challenges of attribution in cyberspace fundamentally change the nature of the debate. When nations responding to a cyber-attack cannot confirm whether the attacker is a state or non-state actor, retaliatory strikes naturally are raised to a higher pitch on the analogous

1 This analysis was adapted from J. McCormick's work in an undergraduate modeling course at USMA.

LOAC scale. The third, and perhaps most important, challenge to legally classifying Cyber Operations is that, unlike traditional military operations, cyber-attacks can be conducted while otherwise normal relations are going on between countries. An example is the sporadic cyber conflict between the US and China. This is because cyber-attacks are often one-off operations, unlike the sustained military invasions of the past. In practice, nations can conduct infrequent cyber-attacks against one another while still maintaining normal, yet nonsimple relations.

The analogy of musical scales provides a base for the analysis of cyber operations. Rather than imagining interstate behavior as a single finger jabbing at a keyboard, playing individual notes one at a time, let us consider military, operations as chords and national (grand) strategies as chord progressions. Those familiar with music theory will instantly recognize that chord progressions may span across several octaves, just like long term strategies may incorporate legally acceptable actions and somewhat dubious behaviors as well. Under this analogy, escalatory strategies such as an arms race can be equated to a chord.

We can take this analogy further and identify the significant shifts that cyber operations have brought about. Classical chords are those that stay within an octave and maintain a harmonic relationship between the notes. An inverted chord is one that consists of notes mostly from one octave, but may contain one note from another octave, while still maintaining the same chord relationship.[2] In our analogy, cyber operations are the higher octave notes in the inverted chords, consisting of illegal acts that are embedded within a chord of acceptable behaviors. As long as these high pitch notes are played in conjunction with a legitimate lower range narrative structure, states can perform legally dubious acts without triggering international alarms.

Using this expanded music-cyber framework, we can see why constraining cyber operations within legal limits has been so difficult thus far. As long as nations can conduct illegal operations with impunity, the incentives will not exist to encourage nations to change norms and move from the current game's theoretic status of a Nash Equilibrium, that is, no player has an incentive to deviate from his chosen strategy after considering all opponents' strategies. Unless we create serious improvements to the technology of attribution and properly address the recent attacks in the form of information warfare properly, the cyber landscape will continue to be characterized by the inverted chords of cyber-warfare (il)legality.

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[2] The musical rock band Chainsmokers have based their music on this technique. Almost every Chainsmokers beat drop consists of an inverted chord progression with one note being played at a much higher pitch with a "synth" reverb.

5.2.4 Adaptive operations

> As we have seen, the conduct of war branches out in almost all directions and has no definite limits; while any system, any model, has the finite nature of a synthesis. [56]

> If you don't like change, you are going to like irrelevance even less. Army Chief of Staff General Shinseki to his commanders.

The United States is no stranger to adaptation and change at the operational level. To build on this foundation, a flexible adaptive approach to operations, based on nonsimplicity, could be a force multiplier in many military operations [26]. One way could be a doctrine using nonsimple models for tactical actions that change the current state to a more desired state through the ability to learn and adjust faster than one's adversary. This use of OODA loops to provide the advantage would be a doctrinal goal of the force. The steps to do this entail defining the mission and developing an understanding of the nonsimple systems, including ways to achieve situational awareness, understanding contextual variables, and identifying the various elements within the environment that can change and impact the operation.

Nonsimple adaptive operations (NAOs) would seek structures and processes at the lowest level possible to allow for autonomous organization, action, resiliency, and rapid adaptation and maintain a general direction of action. Within a broad strategic intent within the NAO framework, commanders would use mission command to empower subordinate units to ensure total freedom of action in order to rapidly confront and confuse the enemy. NAO forces seek to out-pace and out-think the adversary by developing an emerging, yet random-looking, sequence to shift the adversary's OODA loop capabilities. Taking away and reversing normal military control measures is outside military cultural norms, yet those actions have more adverse effects on the enemy. The greatest change in NAO is that the military would have to invest human capital to train and build sets of soldiers (not necessarily units) to fight in this fashion. This sort of change would be a difficult challenge.

Modern war is the acquisition not only of the adversary's territory, but also the adversary's information systems. The result is that the OODA loop is not just a human system, but also an informational system as well. Military leaders and the military systems need to observe the situation, orient to the dynamics of the situation, decide on a response, and act on that decision. Military command and control must confront the OODA loop challenges and maintain the advantage in the realm of information warfare. Military tactics, strategies, and operations are continually adapting to improve their OODA performance. However, the reality of operations means every design has a weakness, every plan has a mistake, every system has a flaw, every action has a reaction.

These dynamics are relentless–improvement and change are always at work. Every step in the flow and evolution of the OODA loop shows a new perspective to the adversaries. Both sides look for patterns, phases, seams, delays, and weaknesses to exploit. The rigid and overly simple cultures, structures, and processes of the military are ripe for exploitation by innovation and nonsimple thinking. Hierarchical and simple systems are too predictable and are therefore fragile. The resulting requirement is that modern military operations need a nonsimple methodology and doctrine to forge an advantage. Unfortunately, nonsimplicity is often the last thing the structured traditional leaders of the military consider. Many military leaders entered and flourished in the military because they wanted order and structure and avoided chaos and nonsimplicity. They were the best linear thinkers, and not the ones who embraced the new nonsimple ideas and methods. This disconnect in talent management and training must change soon in order for the modern American military organization and force structure to succeed.

In recent years, various adversarial militaries have developed asymmetric operations that use the ideas behind nonsimple thinking and nonsimple adaptive operations to their advantage. In naval operations, weapons such as torpedo boats, fast attack craft, fast attack interdiction craft, midget submarines, anti-ship ballistic missiles, mine-laying ships, and contact mines can rapidly converge in an unpredictable fashion, thereby overwhelming a technologically superior enemy. In air operations, drones and unmanned aircraft of various sizes and capabilities, stealth radar-resisting aircraft, and highly maneuverable pursuit aircraft change the dynamics of the battlefield. On land, the infiltration of bogus agents and false ideas change the environment to favor one side, or lead to misunderstanding of the other's operational intent.

These forces using nonsimple doctrine seek to overwhelm the enemy in a way that is unpredictable, lacks the vulnerability of centralized control, and is relatively low cost. Through deliberate disorganization and random behavior, these military pioneers have developed an effective way to perform nonsimple modeling for tactical actions to accomplish operational objectives connected to their desired end state. Their goal is to get inside their enemy's OODA loop by faster processing of the cycle. The military forces of developed powers have often favored a deliberately simple approach using simple hierarchical command and control in hopes that their technological overmatch could win the operation. However, as we see in many modern operations, the asymmetric nonsimplicity can prevent that overmatch from ever being a factor in the operation.

A nonsimple adaptive operational framework may not be suited for every operational context. However, developing forces that are able to conduct nonsimple adaptive operations may provide an advantage in some of the asymmetric situations we face in many operations. Military forces can gain advantage on the battlefield by using nonsimple thinking by conducting nonsimple adaptive operations. By its very nature, war is a nonsimple adaptive system. Therefore, using nonsimple techniques in the doctrine of NAO to fight should be the natural response. Asymmetric approaches like NAO do not need to reside with the smaller force. This might be the perfect time for the US to build NAO doctrine and seek an advantage in the nonsimple operations that the military has been performing for several decades. Thinking about nonsimple adaptive systems and how the military could use them has value. Understanding how NAOs work may provide a military advantage in future operations. It could be the key to achieving our goal of operational omnipresence.

The US military is the one force that has the power and resources to consider operational omnipresence. Wald defines operational omnipresence as [262]:

> The perpetual, networked presence that enables operations and awareness anywhere in the world. It consists of three primary interconnected components: physical assets, virtual capabilities, and information. It's the culmination of where you are, where you can be quickly, and awareness of what is occurring everywhere else.

Achieving this capability gives a military force a substantial competitive advantage in almost every military operation. However, it will take considerable progress in all three of the essential components of military presence: physical, virtual, and informational. In the past, the United States has only concentrated on the physical. As Bazin indicates [26]:

> Supercomputing power is necessary. Artificial intelligence across the system is critically important. Human-machine pairing is vital.

There will always be gaps in the physical presence by a national force on the worldwide stage of operations. However, virtual presence can help fill those physical gaps. Virtual presence allows force to be applied from a distance through cyber, electronic, information, and space-system warfare. Informational presence starts with collecting information and monitoring events where physical and virtual presence are not possible.

The mere perception of being watched through information collection influences behavior. Cyber-, sensor-, and satellite-enabled surveillance means that a near-global electronic vision is possible. The use of the vast amounts of information, as it is processed to become intelligence, influences the decisions of the decision-makers of the side being watched and deters their confidence in operational planning and execution. Secrecy is no longer considered possible for the enemy. The side with operational omnipresence knows everything, is everywhere, and cannot be surprised or deceived. With physical, virtual, and perceived presence established, operational omnipresence becomes a possibility. In addition to the acquisition of more ships and planes, bombs and missiles, cyber and space capabilities, and surveillance satellites and sensors, offsetting the capabilities of other nations' militaries has become also about how these various systems are interconnected and organized into a super-fast information network. Nonsimple system designs and doctrines provide tremendous operational advantage for achieving operational omnipresence.

The most challenging technological issues in achieving omnipresence are in data and NS. The need is for real-time analysis of massive amounts of data and information. Since action is needed in real-time, AI must be trusted to perform much of the analysis and decision making. There is too much information for humans to analyze, or manage, in a timely fashion for effective OODA loop operations. The AI collects, filters, reviews, summarizes, and makes recommendations or takes action based on the data. At every level, AI, along with the human-machine connection, executes the nonsimple military operational roles to achieve omnipresence. Wald concludes [262]:

> Operational omnipresence seems to be the logical next step in the progression of the changing character of warfare.

Militaries are beginning to understand the roles of nonsimplicity in warfare. Military operations involve nonsimple paths and feedbacks with no limits in structures and processes. NAO and operational omnipresence may be the next scientific steps in warfare to regain the OODA loop advantage in asymmetric and NCW. The supporting concepts for this method of warfare are NCW, Mission Command, OODA loop, nonsimplicity (systems) design, gray zone operations, D2D, and MDB.

5.3 Wargaming

Wargaming has become a valuable method to foster innovation and to build an understanding of the elements of nonsimplicity that exist within military operations. Wargames must be designed well and used appropriately to achieve these objectives of improving the military mind. The human brain will be a prominent facet in future operations. The wargame simulations can involve combat forces engaging in mock combat as part of their training, video or virtual reality games played by service members to learn basic skills, or computer-based to quantify the value and impact of a new system [181]. These games can range from high-level interagency decision making that involves strategic negotiations and diplomacy evaluated off-line by experts to small unit force-on-force tactical warfare, where the scenario and outcomes are determined in real time, by precise computer simulations.

As is often the case with DoD, the current wargames are overly focused on specific historical battles. While historical scenarios can provide context and content, they do not allow for the full range of nonsimple decision making and doctrinal application often needed in a viable modern wargame. For military leaders using wargames as human-in-the-loop simulations to improve nonsimple decision making, the scenario must provide useful insights into their current problems and future situations. Wargames can provide a sense of whether new doctrine is feasible and whether new systems will help the force achieve its objectives. Playing out a new doctrinal plan under competitive conditions can reveal the potential doctrine's implicit benefits and vulnerabilities. Wargames cannot provide a complete understanding of system or doctrine performance, but they often facilitate leaders' decision making and staff members' information processing. Forces have often done well learning from wargames, but it is a more difficult challenge to independently verify concepts or quantitatively evaluate systems precisely using wargames. The goal for modern wargame simulations is a design to provide measurable, repeatable results that produce useful, predictive outcomes.

Broad scenarios calling for higher-level strategies can generate areas for potential modernization or further doctrinal analysis. Focused scenarios generate vulnerabilities for specific systems or further training needs for units. Some wargames as simulations are designed to focus on specific technologies in order to identify issues that can be explored further with follow-up research and development. Good wargames select appropriate competing players or teams and provide each team with appropriate resources based on the goals of the game. Sometimes wargame results inform the researchers associated with system development and allow researchers to compare results with other games, simulations, or other analytical findings. In this way, wargames can be a valuable tool in the research and processes. The results can motivate further analysis to test identified issues, or induce digging deeper into areas of uncertainty.

From 2014 to 2017, former Deputy Secretary of Defense Robert Work wanted more wargames and more information from games for system development and testing [181]. His plan was for the military to develop nonsimple, highly analytic wargames to explore how conflicts might be waged, what systems and doctrines adversaries might use, and what systems, as well as, doctrine the US military needs. This wargame-based research was envisioned to assist military planners to understand the potential impacts of the Third Offset. The Third Offset Strategy seeks new systems and doctrines to neutralize threats, which can be used to build a more capable modern nonsimple force. The wargames to support the Third Offset concentrated on nonsimple elements, such as AI, cybersecurity, space operations, undersea systems, unmanned systems, air dominance, and long-range strike capabilities. As the United States seeks to design its force structure for the next war, the results from wargames can provide helpful information to guide force structures designers, systems developers, and decision-makers. The game data offer insights and guidance on what systems to buy or develop, how to use the systems, where to locate units and equipment, and how to train the combatants. In moving toward nonsimple games [116]:

> [A] group of Marine, Army, and Air Force officers in the Marine Corps University, Advanced Studies Program are constructing a series of campaign-level decision games to hypothesize new manned-unmanned teaming concepts.

Military wargames often focus on the action-reaction-counteraction cycle of operational planning for combat training. Other wargame designers have produced numerous nonsimple scenarios for the leaders and unit staffs within the force. Networking then makes it easier to bring together the players, decision-makers, and experts for these games. The human dimension makes wargaming play very valuable, because the leaders and staff members use their individual and teamwork skills to compete and win the game. The human players garner valuable experience. The mathematical models support the efforts by building good scenarios, managing the play of the game, collecting the right data, performing analysis, and producing valuable quantified results.

As an example of a productive use of military-designed wargames, *Unified Quest*, Army's wargame series is designed to identify issues and explore future force development. This series of major games has given many years of constructive feedback to Army leaders. Unified Quest is managed by the Training and Doctrine Command's Future Warfare Division, and involves many Army senior leaders, along with hundreds of staff officers and soldiers. These games give the players and the Army leaders an assessment of potential improvements to the systems and doctrines of the future force. Unified Quest uses a nonsimple, future resource-informed perspective that is not limited by current resource constraints. The games have helped the Army's Campaign of Learning on how best to develop the Army to *Win in a Complex World*. The website for Unified Quest lists the following goals:

- Understand threats, enemies, and adversaries in the context of the future operating environment and future missions.
- Refine concepts to maintain a strong foundation for Future Force development.
- Evaluate the Future Force under realistic scenarios.
- Identify capability gaps and opportunities to improve Future Force effectiveness.
- Design the Future Force and develop strategies to ensure that Army forces are prepared to accomplish missions while operating as part of joint, inter-organizational, and multi-national teams.

5.3.1 Evolutionary game theory

The nonsimple analytic foundation of a wargame comes out of the science of game theory. A robust game theory model can provide more scientifically compelling results than the play of a wargame, but that might be a bias on the part of the scientists. Game theory models interactive systems, where the outcome of a person's action depends on the actions of all the other people and the environment or situation in which that person comes in contact. There are many applications in the form of social, political, business, and military interactions: real estate transactions, campaigns by candidates, local business competition, the arms race, international negotiations, and warfare. The players do not have to be people; they can be any entity capable of making a choice, such as a country, business, or military unit. It is believed that people are rational, so that in interactive situations they try to determine what behavior yields the best outcome for themselves and act in their own best interest. Game theory models the situation and recommends rational choices for these situations, thereby predicting peoples' behavior in them.

This is a form of agent-based modeling where the players in the game (agents) and their interaction (the rules of play of the game) are known. In game theory, players assess the likelihood of their reward (benefit or loss) from an outcome by figuring out what the other players are likely to do. Simple situations are represented by static games, in which each player chooses a one-time (fixed) action without knowing the choices of the other players. Nonsimple situations are much more realistic and dynamic, where players choose their actions through many iterations and can adjust their decision making based on many factors. This is known generically as evolutionary game theory, wherein other forms of nonsimplicity can be considered as well, such as stochastic elements, the influence of the choices of the other players, or even changing the rules of the game over time.

One defense objective that is ripe for analysis using game theory is deterrence. However, many tactical and strategic doctrines can be analyzed and modeled for their value using game theory. The models are often analyzed using a technique called backward induction [99]. Unfortunately, the military often limits its use of games theory models to static games because of misconceptions and unneeded limitations. These self-imposed limitations include:

- The simpler the model, the better it is. Sometimes, military analysts limit the game models to two decision alternatives (e.g., attack/defend; cooperate/defect; aerial assault/amphibious assault) or only allow two competitors.

- Both sides' interests are symmetric. The values and rewards are the same for both sides. The reality is that game theory rewards and decision options may be very different for each side.

- Simple models forbid communication between competitors and often are played for one static decision and not multiple dynamic iterations.

These are not necessary conditions for nonsimple evolutionary game theory. More realistic nonsimple scenarios can be analyzed using evolutionary game theory, which is dynamic and can include game structures with asymmetric information, as well as asymmetric incentives played indefinitely by more than two communicating competitors.

Nonsimple game theory modeling and analysis can add value to wargames and provide an accurate evaluation of military operations, doctrines, tactics, strategies, and systems.

Nonsimplicity has enhanced game theory in several ways. One way is redefining rationality and the idea that sometimes the players are unable to either compute their best strategy, or unable to perform that strategy, yet the game is still a viable model for realistic situations. The other is that while rationality is still being considered, there are other hidden or related factors that influence the game. We consider how to implement this nonsimplicity by considering the notion of paradox introduced earlier and how evolutionary game theory may play a role in its resolution.

5.3.2 Altruism paradox resolved

> How wonderful that we have met with a paradox. Now we have some hope of making progress. Every great and deep difficulty bears in itself its own solution. It forces us to change our thinking in order to find it. [33]

We previously observed that decision making is not an entirely rational process. If humans were strictly rational, then such things as the Altruism Paradox would not exist. The paradox goes like this: Individuals act in their own self-interest (selfish), but in so doing contribute to the observe well-being of society (altruism). The paradox was first identified in this form by Adam Smith at the time of the American Revolution in *The Wealth of Nations* [217]:

> It is not from the benevolence of the butcher, the brewer, or the baker that we expect our dinner, but from their regard to their own interest.

The two alternatives, selfishness and selflessness, stand in such sharp contrast to one another that their incompatibility appears irrefutable. But this logical tension is clearly resolved at the operational level, otherwise we would not have heroes. Medals for bravery are an objective acknowledgement of the resolution of the altruism paradox at the operational level. So how does that work? For one thing, paradox is the result of logical inconsistency between the ways we believe people think, as opposed to how they act. The paradox is a consequence of the belief that we humans are rational animals. So let us examine this assumption.

The failure of people to think rationally and consequently to act in the same way was commented on in the discussion of the tragedy of the commons in the first chapter. To follow up on those remarks, let us consider the research findings of the two Israeli psychologists, Daniel

Kahneman and Amos Tversky. These investigators achieved such remarkable research success in the closing quarter of the last century that Kahneman was awarded the 2002 Noble Prize in Economics [118]. Their research focused on quantifying the empirical economic behavior of people and emphasized the balance between the rational and irrational in decision making, rather than just assuming people are rational, as had been done previously. A remarkably consistent finding from their studies is the existence of three robust regularities in human decision making; regularities that we find complement the empirical observations of military historians and scholars.

The first of these regularities is that people are more sensitive to losses than they are to gains. This empirical finding is in agreement with von Clausewitz, who argued that military losses affect the loser more than they do the winner. Thus, the way the individual responds to wins and losses appears to scale from the individual warfighter up to the collectives within the Army. The social-psychological response of an Army to wins and losses seems to be a scaled-up version of the typical response of the single warfighter. The second generic result of Kahneman and Tversky is that individuals respond more strongly to changes in the amount of stuff they have that is of value than they do to the absolute amount of stuff they possess. Suppose that you and a friend both invest in the stock market and each receive a profit of $100. Your friend invested $1,000 and you invested only $100. You have doubled your money and your friend has made a 10% profit. Who do you think is happier with the outcome? The answer is obvious. Isn't it? You and your friend gained the same amount of what you value, but it is an aspect of human nature that we respond more strongly to the larger percentage change in what we value and not to its absolute level. This peculiarity in how people respond is actually experimental verification of an assumption about the psychology of people made by the mathematician, Daniel Bernoulli, nearly three centuries ago.

This second generalization is related to, but is different from, the first one. Taken together they would imply asymmetric responses to percentage wins and percentage losses of equal size. In the example of investment used above, it would suggest that a 10% loss in investment would be experienced more strongly than a 10% gain so that the negative response is not compensated for by the positive. We can take this observation to the extreme environment of the warfighter. We observe that the devastating experience of a close friend being killed in battle is in no way balanced by the exhilarating experience of saving a friend's life in battle. The psychological experiences of the important events in life are not to be measured by a zero-sum game, or the mode of the LFoE.

The last of the general findings is that the estimation of subjective probabilities made by people is severely biased by the first piece of information received (anchoring). This is a fundamental mechanism for the way we make decisions under uncertainty, or with insufficient information. The information someone gives us about a person, for example, that they won an award or were released from jail, just before we are introduced to them for the first time, biases our first impression. It might well determine whether we interpret their smile and light hearted manner, as an attempt to be friendly and sociable, or as insolence and insubordination. Anchoring is cognitive bias that identifies an all too human tendency to rely an inordinate amount on initial information. The first piece of information anchors our decision making process and disproportionately influences subsequent judgments. Once an anchor is established, other judgments based on incomplete information are formulated to accommodate the truth of that fixed point. Like precedent in the law, the anchor colors subsequent interpretation of other information in the light of the anchor.

The last finding lies at the heart of all military training. The intent of Basic Training is to erase, or at least overcome, the cognitive biases, opinions, beliefs, prejudices, and tenets of civilian life or, at least those that are incompatible with good military discipline and order. The purpose is not just to destroy, but to replace this cacophony of civilian views with a single, self-consistent, set of anchors, which prepares recruits for the physical, mental, and emotional elements of military service. The training provides recruits with the basic tools necessary to carry out the roles in which they will be cast for the duration of their tour. An exemplar of a set of anchors is the USMA motto: Duty, Honor, Country.

The empirical regularities established by Kahneman and Tversky [118] can be used to construct a calculus, based on nonsimple network theory, to replace the qualitative arguments used in resolving the capability paradox made in Chapter 2 with a quantitative model. The resolution of paradox that arises in decision making on the part of the individual is tied to the dynamic behaviors of the rational and irrational parts of the brain. West et al., building on the research of Mahmoodi et al. [151], developed a composite, two-level, dynamic network model of the functionality of the brain equivalent to two interacting subnetworks to resolve the Altruism Paradox [274].

One subnetwork, based on the DMM [271], leads to strategy choices made by the individuals under the influence of the choices of their nearest neighbors. The other subnetwork measures the Prisoner’s

Dilemma Game payoffs of these choices. The interaction between the two subnetworks is established by making the imitation strength increase or decrease, according to whether the average difference of the last two payoffs increased or decreased. Although each of these imitation strengths is selected selfishly, which is to say the individual choices of imitation strengths are made in the best interest of the individuals making the decision, the social system is driven by the resulting internal dynamics towards the altruistic state, which has the greatest social benefit, and not the selfish state. In this way, the Altruism Paradox is resolved using the internal dynamics of the composite network.

CHAPTER 6

UNCERTAINTY AND NETWORKS

> Tao is the proper path in life, the one the sages follow spontaneously, and others strive to follow...Your way is not who you are, but what you do, not the species of a tree but how it grows... the Tao of a robber is not his deviance but the skill with which he loots your house. [147]

How do we shed the cognitive constraints of Machine Age thinking and learn to apply nonsimplicity thinking to Information Age problems? Learning how to change the perceived uncertainty of a process from the Gauss-Adrian normal curve to that of a Pareto inverse power-law may provide at least a partial answer. Putting this question in the context of the distribution of wealth, we ask: How do we make the conceptual transition from the eminently fair normal curve of income, which is not observed, to the demonstrably unfair, but universally observed inverse power-law distribution of income obtained by Pareto?

One way to understand how such a transformation between distributions can occur is by shifting attention from the income of an independent individual to one that includes the effects of collections of individuals joining together for a common purpose, for example, to form a company. An initial income distribution, with a finite variability (variance) can be adjusted to incorporate an additional income component. The new component has greater variability (a broader width) and is included by means of additional people involved in forming a small company. Of course, these small companies may, in turn, join together to form a larger company, so that the newly modified distribution can be further modified to incorporate an even broader width distribution due to the aggregating of small companies.

This aggregation occurs with an ever smaller probability. In this way, the resourceful individual constructs a geometric series for the income distribution, each term of the series given by the initial normal distribution, with a geometrically increasing variance to incorporate the influence of more and more groups of people. Each increase occurs with an algebraically decreasing probability. The resulting series of factors contributing to the income distribution defines the entrepreneurial effect [272].

The entrepreneurial effect not only applies to businesses, but to the military, as well. The single individual is the modern warfighter, who is also a member of a firing team, which in turn belongs to a squad that is part of a platoon, and so on. The warfighter is part of a hierarchy of larger and larger commands. In this way, the defining characteristics of the modern warfighter are enhanced. It is clear that the broader distribution, the one that includes the amplification factors, through the formation and leveraging of ever larger groupings, places more and more of the variance into the tail of the distribution. The amplitudes of the additional terms become smaller and smaller, because the probability of their directly influencing the warfighter is decreasing, but as the series of amplifying terms becomes longer, the contribution to the tail builds up.

This buildup is schematically depicted in Figure 6.1, where the initial distribution was taken to be exponential. We see the formation of an inverse power-law tail from the infinite series of the leveraging mechanisms, obtained in the way outlined, transforms the behavior of the warfighter from an exponential to a Pareto inverse power-law. In becoming part of this hierarchy the way of the warfighter is transformed from what they would do if operating on their own, and what they choose to do as a member of this "band of brothers." So what does this imply about the changed behavior of the warfighter?

This entrepreneurial mechanism, under different names, has been used to generate the Pareto tail in a number of contexts. One area of particular interest is that of cognition. The phenomenon of cognitive adaptation has been modeled using multiple exponential processes to account for the observed range of time constants in neuronal networks. Just as the economy uses this mechanism to leverage investment, the brain may well use it to leverage how we think. We propose to understand how the cognitive map of the modern warfighter must be transformed from the world view of small linear, variations implied by the normal curve to that of the nonlinear, richly nonsimple variations entailed by the inverse power-law distribution. To identify what needs to be done to change the cognitive map that determines how the warfighter thinks requires that we examine more carefully what is entailed by Pareto's identification of the imbalance in the underlying processes.

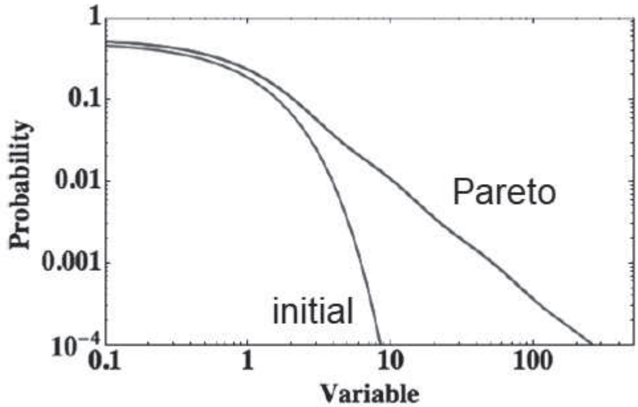

Figure 6.1: The initial exponential distribution is given by the lower curve on log-log graph paper. The upper curve is the superposition of an infinite number of such exponential terms that give rise to an inverse power-law distribution asymptotically: the Pareto distribution.

6.1 Pareto's Law

Thus, the data on wealth, language, urban growth, biological macroevolution, and other nonsimple phenomena have distributions that are long-tailed, not bell–shaped, and consequently entail an imbalance in the underlying process. The important question is: What does the imbalance imply about the underlying process? For example, why should a few percent of the population have the largest fraction of the wealth? A related question is whether they ought to have that wealth at all, or whether society could function with the wealth more evenly distributed across society?

For convenience, suppose that 20% of the population owns 80% of the wealth, which is the kind of imbalance Pareto recognized. Note that this compares two data sets: size of wealth and number of people. The normal curve would require 50% of the population to have 50% of the wealth. Of course, in the real world, much less than 20% of the population owns more than 80% of the wealth, but historically these percentages have been descriptively used to discuss the imbalance implied by the Pareto inverse power-law distribution and we continue in that tradition [125]. The actual numerical value of the partitioning is not important for the present discussion; what is important is that the data show the existence of the Pareto imbalance. The actual size of the imbalance between the rich and the poor is determined by the size of the Pareto index. The larger the index, the smaller the imbalance, and the smaller the index, the greater the imbalance; this is known as the 80/20 Rule, or Pareto's Law. Modern warfighters can be taught how to leverage this imbalance in the appropriate variables to his advantage, as we shall see.

A rationale for the 80/20 imbalance, in addition to the entrepreneurial effect, has been established using network theory. The DMM network shows that when people imitate one another, they reach consensus of opinion when a critical level of imitation strength is achieved [271]. This is the tipping point, or critical point as it is called in the physics journals–the point where the network undergoes a phase transition. The existence of this social transition, along with identifying its defining characteristics and strategies for leveraging it, will eventually be part of Army training. Consequently, when only a small, but critical, fraction of the force learns a new effective behavior, that behavior will be rapidly adopted by the total force. This fraction can be significantly less than 20% in a trained force of modern warfighters.

Of course, the appropriate training methods do not presently exist. A large part of the challenge in developing such methods is transforming the mathematics of CS into a form that can be readily communicated to those not grounded in mathematics. People in various specialized occupations learn to talk and think in specific ways that facilitate information exchange with others in their field. Of course, it might also be the case that those who think in certain ways are attracted by activities that utilize that way of thinking.

6.1.1 Scratch a soldier, find an engineer

It is not an accident that the first engineering college in the states was the United States Military Academy at West Point, founded in 1802 by the then-newly formed Army Corps of Engineers. In one sense, a military person thinks like an engineer or a mathematician, with an intrinsic affinity for order and hierarchical control. They utilize a systematic short-hand way of thinking about the nonsimple problems they encounter and have a certain amount of similarity in the two world views. The two views have incrementally developed over millennia and have, to a large extent, expunged the emotional from the decision-making process emphasizing the rational over the irrational. This comfortable picture of how we make decisions, based as it is on rationality, has been called into question by the behavioral economist Dan Ariely who, using carefully crafted scientific arguments based on decades of experiments, concludes humans are "predictably irrational" [10].

The beginning of an engineering-mathematics world view might be traced back to Euclid's 2,300-year-old text on geometry, which cast in stone the theorem-proof discourse in mathematics. The origin of the military view is less clear, but Sun Tzu, with his emphasis on strategy, espionage, deception, and military tactics, is probably a reasonable place to start [236]. In his equally ancient handbook for the military, a premium is placed on what can be quantified and demonstrated to be true, a tradition that has only grown stronger with time. In both engineering and mathematics and military operations, the idea of speculation is unwelcome–except under very tightly controlled conditions–when decisions must be made in the absence of complete or reliable information.

Every commander wants to exercise command and control in a manner that most effectively accomplishes their mission. In order to accomplish this, the commander needs as much information as possible about the environment of that mission, in as-near-to-real time as possible. In an urban setting, this requires obtaining data regarding the number of enemy and how they are distributed through the city, where they are dense and where they are sparse, who is in the leadership, which streets they control, and so on. The patterns within the data constitute the information that is passed along, but receiving and understanding such information and trusting its validity are quite different things. Command does not need to know the details of data gathering, but it must be confident in the information extraction processes and how that information is minted into intelligence and knowledge.

The critique of such data analysis begins with identifying the sources of error, along with error size, and frequency of occurrence. The sources of error can be traced to the noise in sensor inputs and outputs, or to the inconsistency and ambiguity of human reporting, such as making a count of the enemy in the middle of a firefight. In the stress of the moment, it would be all too human to exaggerate the size of the opposing force. For these and other reasons, the data itself lacks fidelity and is never completely accurate. The question remains concerning how to determine the level of uncertainty in the raw data. In data analysis terms: is the observed variability in the data the signal (the important variation in the number being reported), or is it noise (random fluctuations containing no useful information), covering up the signal? The signal-to-noise ratio is an important measure of the level of uncertainty in the data. For example, a signal-to-noise ratio of one would mean equal amounts of both, indicating roughly a 50-50 chance that the piece of information just received is wrong. Time-dependent patterns in the data often constitute critical information. For example, is the size of the adversary increasing or decreasing in time? The trend in the data would constitute the information. The comfortable, but simplistic separation of the data into signal plus noise, where the signal is given by the apparently regular behavior of the driving process, the noise by the fluctuating random behavior, and their separation according to differing time scales, is no longer satisfactory for the battlefield.

Consider an acrobat dancing on a wire high above the crowd in a circus. Her movements are both fast and slow, to keep her balanced, as well as to control her locomotion from one side of the circus tent to the other. The flowing movements, sharp hesitations, and changes in direction of the wire-walker are all part of the spectacle. This metaphor captures the control of various subnetworks within nonsimple networks that regulate, maintain, and guide stability and locomotion. The wire-walker does not walk in a slow measured step, nor do the subnetworks operating in a nonsimple process, as in a battle, act in a steady hierarchal fashion. Both phenomena leap and change in unpredictable and unexpected ways to perform their respective functions.

One would be hard-pressed to separate the signal from the noise in the wire-walker's movements, yet that is exactly what we require from the analysis of nonsimple systems for the warfighter. What constitutes signal and what constitutes noise, often depends on who is doing the analysis, that is, whether that analysis is carried out in the brain of a mathematician in a comfortable office back in the States, in the brain of the commander at headquarters far from the battlefield, or in the brain of a soldier, seeing a flash in the building off to his left and smelling the residual smoke of live fire. The term "signal" signifies what is important, or more accurately, what is important in the eye of the beholder. What is not important is called noise, and the noise must be filtered out, or otherwise suppressed, to enhance the clarity of the signal. Filtering as a means of separating the unwanted from the wanted parts of a data stream has become part of our culture's vocabulary, whether it is removing dirt from the fuel line in an automobile, or suppressing random fluctuations in the input to a computer. Filtering is the technical process of removing unwanted erratic fluctuations from the signal. The trick, of course, is knowing what filter to apply, in what context, and recognizing that nonsimple systems do not lend themselves to linear filtering.

Engineers know how to filter and control linear systems, assuming the two propositions: (i) changes in output are proportional to changes in input and (ii) the total change in output results from the sum of the changes in individual inputs. As noted earlier, a typical person almost invariably expects a linear response to a change in the input to a system.

For example, politicians argue that if a little foreign aid slightly increases a country's economic growth, then additional aid should stimulate even more growth. This argument sounds reasonable to the man on the street, but it does not account for such nonlinear properties as saturation or threshold effects, where a little additional stimulus may be all that is needed to push the country's economy into a new dynamic mode and thereby harm it significantly, or activate a corruption mode that will kick into motion once the threshold is reached. Proportionality and additivity are violated in all nonsimple systems, as observed by von Clausewitz [56] regarding war:

> The scale of a victory does not increase simply at a rate commensurate with the increase in size of the defeated armies, but progressively. The outcome of a major battle has a greater psychological effects on the loser than the winner. This, in turn, gives rise to additional loss of material strength [through abandonment of weapons in a retreat or desertions from the army], which is echoed in loss of morale; the other two become mutually interactive as each enhances and intensifies the other.

Nonsimplicity is deeply embedded in the nature of the real world, which implies uncertainty and unexpected changes, such as in the asymmetric response to loss in battle, as observed by von Clausewitz. The asymmetric response is another manifestation of Pareto's Law. This way of thinking avoids undue expectation, surprise, and disappointment, which are three precursors to failure. Expectations are typically formed by extrapolating linearly from the present situation into the unknown future and therein lies its vulnerability. The occurrence of an unexpected event is the source of surprise, which if sufficiently bizarre, may inhibit an appropriate response, resulting in a catastrophically negative outcome. Alternatively, the response may be disappointment, resulting in a clouding of the needed situational awareness, setting the stage for a delayed catastrophe.

6.1.2 Information and security

The security of a nation is not infrequently reduced to how much its government can rely on a particular piece of intelligence data. Other than scale, this situation is similar to that of the Commander in the field, where decisions must be made based on the provided information, both of which suffer from the same shortcomings in credibility. One distinction that might be drawn is that in the intelligence community the data may be a one of a kind event that must be accurately interpreted or the consequences could be dire. Such interpretations are a blend of psychology, sociology, and geopolitics. Lacking the quantitative guidance provided by the mathematics of hard science or engineering, this transition from data to reliable intelligence has historically had a significant artistic component that fills the gaps in scientific or engineering-based analysis.

Cybersecurity is one area of national importance where the reliability of data can often be quantified. But even here the information value of the data remains elusive, regarding how much is lost, the degree of corruption due to aggregation, and the extent to which it is transformed into misinformation by misguided data processing, or inappropriate filtering. Changes made in a nonsimple network introduce planned-for effects that are desirable, as well as unplanned surprises that may not be so desirable. In a nonsimple network, it is practically impossible to illicit a single isolated response to an action and consequently there is an ever-present need to remain flexible and anticipate the unpredictable, since we inevitably modify the systems or networks in pursuit of the control we desire.

Organizations and other nonsimple networks are like people, in that they change with experience, including changes they have consciously chosen to undergo, such as installing computer updates. Analogously, just as personal growth depends on the situations in which a person is placed, so too does the security of a cyber–network depend on the networks to which it is connected. Often times, the security assessment fails to take into account how the changes made in a cyber subnetwork results in changes in the larger cyber environment. The cyber policy makers understand that changes in response times, capability, and other fundamental properties of hardware and software, in turn, produce changes in the dynamic cyber environment. However, it is not possible, at present to predict the influence of a positive change in a subnetwork on the overall behavior of the host network.

In his discussion of the deterioration of nation states, Rosenau [3, 194] points out that national landscapes can be more aptly described as ideoscapes, ethnoscapes, mediascapes, technoscapes, and finanscapes, each being a different functionality of a nation. For our purposes, we recognize that these new-scapes entail a change in the way we think about how the mission of the military is realized: the linear predictable trajectory of the past must be replaced with an erratic, nonlinear trajectory to capture the international chaotic dynamics of the present. This is particularly true if we include radical jihad as a category of ethnoscapes [195]:

> ...the long-standing inclination to think in either/or terms has begun to give way to framing challenges as both/and problems. People now understand, emotionally as well as intellectually, that unexpected occurrences, that minor incidents can mushroom into major outcomes, that fundamental processes trigger opposing forces even as they expand their scope, that what was once transitional may now be enduring, and that the complexities of modern life are so deeply rooted as to infuse ordinariness into the surprising development and the anxieties that attach to it.

There is general agreement that CS is not likely to provide a method for predicting specific events, particularly failures, now, or any time in the foreseeable future. In and of itself, this scientific consensus suggests that we ought to reexamine how science and the quantitative models it provides are used by policy makers and those that implement decision science in the real world. This is particularly important for modern warfighters as they develop and employ a new kind of situational awareness. Nonsimplicity theory serves the purpose of cautioning anyone who makes decisions, from the policy maker down to the warfighter, on and off the battlefield, against looking for a panacea. The simple linear solution to the problem does not exist, so the warfighter must be more circumspect and less certain by using the nonsimple alternative.

The theory of warfare has been updated to what is called NCW [4, 5], through the Department of Defense (DoD) adapting to our information-rich society. This theory is the embodiment of an Information Age transformation of the networked DoD. NCW is discussed here because it dovetails with nonsimplicity. The networking incorporated into NCW requires a new way of thinking about how the military accomplishes its missions, how it organizes and interrelates, how it acquires and fields the systems that support it and how it develops operational doctrine.

A synopsis of NCW tenets is given in a report to the United States Congress [5]:

- A robustly networked force improves information sharing.
- Information sharing enhances the quality of information and shared situational awareness.
- Shared situational awareness enables collaboration and self-synchronization, and enhances sustainability and speed of command.

After more than a decade of thoughtful discussion, this new view of warfare is still not fully developed, nor is it a deployable warfighting capability. In fact, the NCW tenets are the result of carefully argued scenarios based on combat experience, not the result of experimentally verified mathematical modeling and analysis. However, the first tenet is consistent with the Principle of Complexity Management (PCM) [268, 271], which has established, under a variety of conditions, that maximum information transfer occurs between two networks, having comparable levels of nonsimplicity. It is worth pointing out that unlike the information transfer in communications, as measured by the Wiener/Shannon entropy, which is independent of the properties of the sender and receiver, the dependence of the information transfer between nonsimple networks is crucially dependent on the properties of the sender and receiver-more nonsimplicity in smart systems. Increasing the information transported through a network channel is often a waste of resources, unless the receiver has the nonsimplicity of the sender. Otherwise, the mismatch in nonsimplicity inhibits the information transfer. This analytic result was anticipated by the aphorism: “Do not cast pearls before swine.”

As was emphasized in its initial development and is still true today, far more needs to be done to get us from the platform-centric force (such as trucks, tanks, submarines, and planes) into a comprehensive, network-centric one: a networked Army of sensors, computer networks, smart weapons, and intelligence gathering social webs. The operation tempo of the modern military has increased to match that of our networked society. This increased tempo permeates all from flag officers to the newest recruit. In the Information Age, there is no mitigating influence to lengthen the time between decisions, such as the necessary interval between receiving a letter and composing a written response. Technology has eliminated programmed downtime to consider response alternatives, or to devise a backup plan in case of failure. There is only what we know now and the need to make a decision.
Right now!

The military, as well as society in general, needs a fundamental understanding of how the physical, social, cognitive, and information networks exchange information. To achieve this understanding, research has provided insights into how processes and parameters in one nonsimple network affect and are affected by those in other nonsimple networks. The underlying desiderata are to optimize human performance in NCW and greatly enhance the speed and precision of information transfer in nonsimple military operations.

The insights and new mathematics, resulting from network research, enable us to achieve these goals. The new mathematics provides the tools to predict and control the behavior of collections of individuals.

In the second half of the twentieth century, it became clear to an increasing number of scientists that the deterministic clockwork universe of Newtonian physics was not only unsuitable for describing the nonsimple systems in the social and life sciences, but it was not even appropriate for modeling nonsimple physical systems. Without belaboring the point, the traditional analysis of mechanical systems was replaced with nonlinear dynamics, which in the last quarter of the twentieth century became commonly known as chaos theory. If these results had been confined to physical processes, chaos theory would not have had the wide-ranging impact that it did. For better or worse, it was determined that most nonsimple phenomena are basically nonlinear and what had been so mysterious about biological and sociological processes in the past could, more often than not, be traced back to the misapplication of linear concepts to the interpretation of their behavior.

The application of chaos theory to social and biological systems in the eighties and nineties led to the development of the discipline of CASs [243]. We might choose to rename this “nonsimple adaptive systems,” but that would only cause confusion, so we will stay with the accepted nomenclature. For some, CASs provided the scientific proof that social phenomena are intrinsically unpredictable, or at least not predictable in the way physical processes are. For other scientists, the restrictions found in the predictions of nonsimple physical phenomena freed their imaginations from the rigid constraints of Newtonian physics to a less certain, but richer tapestry of possible futures, more compatible with what is observed in the social and life sciences. Consequently, nonsimplicity became a balance between the regular and the random, where measures of this balance between the two are at the forefront of research.

CAS, as a discipline, has morphed, at least in part, into the fledgling discipline of Network Science over the last ten years, which incorporates the giant strides made by its predecessors into a new scientific perspective [243]. The critical behavior that has become evident in nonsimple networks is traced to the phenomena of consensus in social networks, to the discharge avalanches in neuronal networks, and to phase transitions in physical networks. We are now poised to address the emergent properties of real-world situations, where these kinds of networks–the physical, social and informational, and others–with different functionalities, interact with one another.

The NCW perspective of the operational Army supports the full spectrum of missions, including humanitarian, peacekeeping, and full combat operations. For instance, there are too many types of warfare to mention them all, but here are some of the types from a book written by Chinese military scholars [144]:

> psychological warfare (spreading rumors to intimidate the enemy and break down his will);
>
> smuggling warfare (throwing markets into confusion and attacking economic order);
>
> media warfare (manipulating what people see and hear in order to lead public opinion along);
>
> drug warfare (obtaining sudden and huge illicit profits by spreading disaster in other countries);
>
> network warfare (venturing out in secret and concealing one's identity in a type of warfare that is virtually impossible to guard against);
>
> technological warfare (creating monopolies by setting standards independently);
>
> fabrication warfare (presenting a counterfeit appearance of real strength before the eyes of the enemy);
>
> resources warfare (grabbing riches by plundering stores of resources);
>
> economic aid warfare (bestowing favor in the open and contriving to control matters in secret);
>
> cultural warfare (leading cultural trends along in order to assimilate those with different views);
>
> international law warfare (seizing the earliest opportunity to set up regulations).

The new perspective emphasizes the need to understand how nonsimple networks interact with one another and adapt, rather than only react in the face of a changing enemy.

The physical domain is where events take place and are recorded by sensors to create data. These data may contain identifiable patterns, which, when they exist, can be communicated with little distortion, between networks. The information, or data patterns, are explained by theory and thereby turned into intelligence, which is further processed in cognitive networks, where knowledge is constructed and assessed and decisions are made. How this data-information/intelligence-knowledge-decision (D2IKD) process, starting in the physical domain and ending in the cognitive domain of decision making, is where network science has had its greatest impact.

As we mentioned, the tenets of NCW have not been scientifically established. The qualitative and quantitative evidence for these tenets, however, have been used to argue that [3]:

> ...warfighters employing Network Centric Warfare concepts can leverage shared situational awareness and knowledge to achieve situational dominance and dramatically increase survivability, lethality, speed, timeliness, and responsiveness. This evidence also points to the fact that the source of the transformational combat power enabled by Network Centric Warfare concepts can only be understood by focusing on the relationships in warfare that take place simultaneously in and among the physical, the information, and the cognitive domains.

The implications drawn from the interactions among the three kinds of networks, along with the assumed increased efficiencies of the functions of these networks, are presently being tested through mathematical modeling, analyses, and computation. One of the few results that is sufficiently general to bear on the above comments is related to the PCM, which requires the degree of nonsimplicity of interacting networks to be comparable in order to maximize the transfer of information from one network to the other. In turn, it is reasonable that increasing the reliable information that is exchanged decreases the likelihood of making mistakes.

6.1.3 Cognitive conflicts

The physical domain is where warfare traditionally unfolds. Our world of sight, sound, smell, and sensation is the backdrop for maneuvering over and within the ground, sea, air, and space environments. It is the realm of physical platforms interconnected by communications networks. The elements of this domain have been established to mimic the networking of human sensor modalities, and are therefore the most directly measurable. Consequently, measures of combat power have traditionally been made in this domain. However, this is becoming less true with the advent of cyberwar, which is the recruitment realm of the leaderless radical jihad movement and our growing ability to measure the value of information.

The domain of cognition is the realm of the warfighter's mind. As mentioned earlier, many military historians believe battles, perhaps even wars, have been won or lost in this realm, long before any physical conflict. Unlike the physical domain, the elements of cognition consist of such intangibles as leadership, morale, unit cohesion, level of training and experience, situational awareness, and the effects of societal opinion. This is the realm where commander's intent, doctrine, tactics, techniques, and procedures guide the warfighter when confronted with uncertainty.

The social domain describes the necessary elements of any human enterprise. It is where people interact, exchange information, form shared awareness and understandings, and make collaborative decisions. This is also the domain of culture, the sets of values, attitudes, and beliefs held and conveyed by society's leaders, whether military or civilian. It overlaps with the information and cognitive domains, but is distinct from both. Cognitive activities by their nature are unique: they occur in the minds of individuals. However, shared sensemaking—the process of going from shared awareness, to shared understanding, to collaborative decision making—is a socio-cognitive activity, because the individual's cognitive activities are directly influenced by the social nature of the exchange and vice versa.

Perhaps the most elusive domain is where the abstract concept of information resides. In this realm the elements of information are created, analyzed, and shared. It is this domain that facilitates the exchange of information among warfighters, but unlike the communications network, which is physical, the information network is the realm where command, control and the commander's intent is conveyed. Consequently, it is increasingly the information network that must be protected and defended to enable a force to generate combat power in the face of an adversary. In the all-important battle for information superiority, the information domain is ground zero.

Multiple-scale and cross-scale couplings are recurrent themes in the study of physical, informational, and social and cognitive nonsimple networks. Existing mathematical formalisms address one, two, or a continuum of scales, but the underlying problem consisting, as it does, of a finite number, greater than two, but less than infinity, of interacting scales, remains open for the adventurous explorers of data science to make their mark. Existing mathematical approaches offer insights into the quantitative aspects of nonsimple phenomena, with multiple scales (no characteristic scale) in stationary and near-equilibrium dynamic networks, but what is needed now is a way to describe the dynamics of such nonsimple phenomena and networks, when the underlying processes are neither stationary, nor near-equilibrium. Network macrocharacteristics cannot be deduced from the microproperties of individual components; they emerge as a consequence of the nonlinear dynamics of the network's macrovariables.

Consequently, a mathematical framework is needed to characterize the interactions between the dynamic network macrocomponents, the temporal evolution of the network, and its response to external stimuli, including attacks. The framework must take into account heterogeneity, which is manifest in the fact that averages over ensemble distribution functions, such as the LFoE, may differ from averages taken over long time series, as well as satisfying conflicting constraints and objectives. In short, the fundamental assumptions, historically made for mathematical expediency in the physical sciences, are now coming back to haunt us, because the nonsimple phenomena, which we are now encountering, strongly violate those assumptions. These limiting assumptions, once thought to be so valuable, have left us in a hole that we are now digging our way out of. A few scientists have reached the mathematical high ground, from which they see that the road is long and only lightly traveled.

Science is an increasingly social activity, which is a consequence of the fact that the nonsimplicity being addressed now and in the future involve phenomena belonging to distinct and non-overlapping disciplines. The problems arising in these multidisciplinary phenomena entail the collaboration of multiple scientists with a variety of disciplinary skill sets necessary for their solution. Consequently, scientists must learn to communicate with one another in order to better understand problems from multiple perspectives. One way to characterize network macrodynamics is by modeling how information propagates within, and is transferred between, nonsimple adaptive networks. To achieve this understanding, we need to know how information (in a general sense) flows across a network, so as to maximize utility (for example, as perceived by a decision-maker), under constraints (such as timeliness and resource usage). Upon examining the interface between two networks, how is the transfer of information facilitated, for example, between physical sensors and cognitive networks? The most nonsimple network in the military is the warfighter, who is continuously being inundated with new sights, sounds, sensations, and smells–some of which are meaningful for the mission, most of which are not. If humans gave each and every input the same level of attention they would be overwhelmed and would very quickly shut down and flick off the information gathering switch. However, over many millennia humans have evolved a kind of sensor selectivity that automatically sorts out, at any time, which sensor signals contain useful information and which are noise. This phenomenon has been given the name habituation.

The noise of the crowd, so evident on entering a packed social event, fades away after a few minutes, making normal conversation possible. Hot bath water seems to cool as you lower your body into it, but it is not the temperature of the water that adjusts, but your sensitivity to it. The sharp pungent odor of sweat permeates training camps, but the smell all but vanishes from consciousness soon after stepping off the bus. These are examples of habituation, which indicate how nonsimple networks, such as the human brain and nervous system, adapt to simple stimuli of various kinds. This is a fundamental process of control and suppression of noise; noise being identified here as stimuli containing no useful survival information [269].

The sound of water droplets striking the sink, from the unsteady dripping of a faucet, can be irritating to the point of losing sleep. Why can't some people block out the erratic sounds of the splashing water in the same way they habituate to traffic noise outside the window, or to the smell of strong cheese in the kitchen? One reason has to do with the fact that the intermittent dripping is not a simple stimulus. A simple stimulus is one that is predictable and, as such, is determined to not be a potential threat since it has not been one in the past. However, under certain physical conditions the time interval between a faucet's water droplets become unpredictable and, from one drip to the next, that interval can shift from very short to being arbitrarily long. It has been shown experimentally that the time interval between drips is chaotic, with no finite average time between drips [209]. This lack of predictability is experienced as a potential threat and, consequently, many individuals anxiously anticipate each and every drop. The nonsimplicity of the stimulus has been experimentally determined to match the nonsimplicity of cognition. Maximum information is transferred from the acoustic time series of the splashing water to the cognitive network within our brain, in spite of our best efforts to suppress it. But it is not just annoying stimuli, such as a dripping faucet that fixes our attention and refuses to fade with time. Certain song lyrics and melodies not only do not fade away easily, but often command our attention to the exclusion of more important stimuli.

At a societal level, it is possible for most of us to recall one or two teachers we were fortunate enough to have in our schooling, whose voices still reverberate in our brains. The simple teacher, who spoke in a flat monotone, without moving either hands or feet, we cannot recall. What was her name? However, the nonsimple teacher, who used dramatic gestures, fiery language, paced up and down the aisles of the classroom, while regaling us with the wonders of history, English, or mathematics can be effortlessly remembered. These properties of information transfer between nonsimple networks, from the teacher to the student and from the faucet to the brain, are captured by the PCM [268, 270]. This principle states that maximum information is transferred between nonsimple networks, when the measures of nonsimplicity of the two interacting networks are individually maximum and comparable to one another.

The networked military exists in the physical, informational, social, and cognitive domains of the society of which it is a part. Consequently the overarching goal of nonsimplicity and NS research, within the Army has been to develop the fundamental principles and procedures that can enable modeling, design, analysis, prediction, and control of the behavior of secure communications, sensing, and command-and-control (decision-making) networks to optimize the information exchange among the members of this nonsimple network-of-networks. Many barriers to realizing this goal exist, including the lack of an adequate mathematical formalism to facilitate logical discourse. This lack hinders the development of efficient simulation and modeling tools. The basic research advances over the past few years have been in building the foundation of a science of networks by developing a mathematical and scientific framework with proper metrics, language, structures, and processes to provide a constitutive understanding of nonsimple networks possessing a broad spectrum of functionalities.

The science of nonsimple networks is unlike the traditional scientific disciplines in that it identifies a particular structure–that of a network–as the basis for the science. Since structural webbing exists within and among all scientific disciplines, the overarching goal of this nascent science is to develop a body of principles that enables modeling, design, analysis, prediction, and control of the behavior of the underlying phenomena in physical (sensors and wireless webs), information (communications and knowledge management), social (people, organizations, and cultures), and cognitive networks (perceptions, beliefs, and decision making), to name only a few. The emphasis is not restricted to the network structure within a given discipline, but is focused on networked phenomena containing many disciplines and how such nonsimple and functionally different networks interact with one another. As a nascent science, its underlying principles are still missing, so that a fundamental challenge for this effort is to develop the science to create and organize the fundamental knowledge upon which to base these principles. Moreover, NS is intended to bridge the knowledge gap between disciplines and to break down the artificial barriers scientists have created between disciplines, which were initially erected to facilitate understanding using simple models.

The existing research strategy has been to develop a unifying scientific framework that merges multiple theories and applications across disciplines, which had not previously been connected and whose merger has produced some remarkable results. For example, in the real world, information occurs in intermittent bursts in both space and time; propagates across links that vary in quality and that connect elements with multiple properties. Each property, in turn, invalidates one or more foundational assumptions made in the past for the purpose of tractability. Such arcane assumptions include, but are not limited to LFoE, whose realization does not display the bursting quality so often observed in real data. The importance of not assuming the LFoE was previously emphasized, but now it is time to see what can be learned from the statistics that are observed.

The US military has entered a new era of warfare–an era that is a consequence of the transition that society has made from the Machine Age to the Information Age. Modern society connects humanity in more ways than at any time in world history, using technologies that could not have been imagined in previous generations. Part of society's evolution was the developments of network interoperability, such that networks of different functionality can be interwoven and, in one way or another, connect national and global networks. This network-of-networks is the engineered webbing of humanity that covers the globe. This often invisible web has comparable structures within the military. These fundamental changes in society have led to the current drive to transform the military, especially the Army, with the concept of NCW at its center.

6.2 The Vital Few

A significant controversy has sprung up in the past decade or so, over whether all children should obtain an award for participation in a sport, or whether such awards should be restricted to those who run the fastest, jump the highest, throw the farthest. At the heart of the controversy is the question over whether competition is a good thing that ought to be rewarded, or it ought to be discouraged. One side argues that the positive response to the encouragement of the children receiving a participation award far outweighs the negative reaction to being labeled a loser, by not coming in among the top three in a more traditional competition. Of course, one can gather psycho-social studies whose conclusions support either side of the controversy, resulting in zero minds being changed. So let us take a parallax view and approach the question on a tangent.

A linear, or simple, world view suggests that there ought to be no a priori preference for targeted or participation awards, so that we can arrange our reward system to satisfy whatever we decide gives the best outcome. This would support the participation award position. On the other hand, the nonsimple world view would say that nature has evolved á priori preferences and, if we establish procedures that go against these preferences, we encounter natural boundaries and resistance. This would support the competitive award position. The more fundamental question then arises: When are society's protocols arbitrary and when are they a reflection of who and what we are as evolved human beings?

A partial answer to this question can be distilled from the fact that most people like to know the relative size of things. They are more comfortable knowing that things fit together into the natural order of how they think they ought to be. For postadolescent males, the significant question to be answered might be: Who has had the most sexual liaisons? This question is often replaced during the last years of college with: Who is the smartest guy in the room? As their careers begin to take shape, it might morph into: Who makes the most money? Or in the case of the academic, the concern might be who has published the most papers or received the most citations or awards. Society often characterizes this wanting to compare, contrast, and order events as a strictly male trait, reducing it to Freud's identification of penis envy. But women have historically had their own versions of the same syndrome.

Let us examine how such concerns fit into the nonsimple world view implied by Pareto's Law and attempt to at least partially resolve the participation-award controversy.

6.2.1 Preparing for extremes

> In a study of rock climbers, surgeons, chess players, factory workers, and dancers, psychologist Mihalyi Csikszentimihalyi found that when faced with extreme challenges they entered a state of elevated concentration–one he called flow–in which time seemed to stand still, one moment blended into the next, and doing the right thing became almost effortless [84].

When a data set is arranged in descending order of size, from the largest to the smallest, something remarkable often occurs. The size, or rank ordering, of the data reveals an inverse power-law distribution, which is to say, on log-log graph paper, the data orders itself along a straight line with a negative slope. This is not the same kind of inverse power-law observed by Pareto for the distribution of wealth, because the size itself does not matter, only the relative order, that is, the assigned rank of the datum. Consider a thick book, filled with many words, such as Dostoyevsky's *Crime and Punishment*, and determine the number of times each word appears in the book. The words have been counted, not for this Russian classic, but for books of comparable length. In this word count, rank one is given to the word used most frequently, rank two to the next most frequent word, and so on. Zipf was the first to carry out this procedure, explore its implications, and note that the product of the relative frequency of a word and its rank number produces a constant. Such a count of word use in English is depicted in Figure 6.2.

This hyperbolic relation, between the word frequency and rank order, implies that the rank-order distribution of words is inverse power-law, with a power-law index of one. This simple distribution of the ranking in the frequency of word usage is known as Zipf's Law, which states that a rank-one word (the), occurs twice as often as a rank-two word (of), three times as often as a rank-three word (and), and so on. A similar relation is found for many languages, as well as for the sizes of cities (Auerbach's Law), the number of new biological species (Willis' Law), and a myriad of other biological, physical, and social phenomena, many of which can be found in Zipf's book [281].

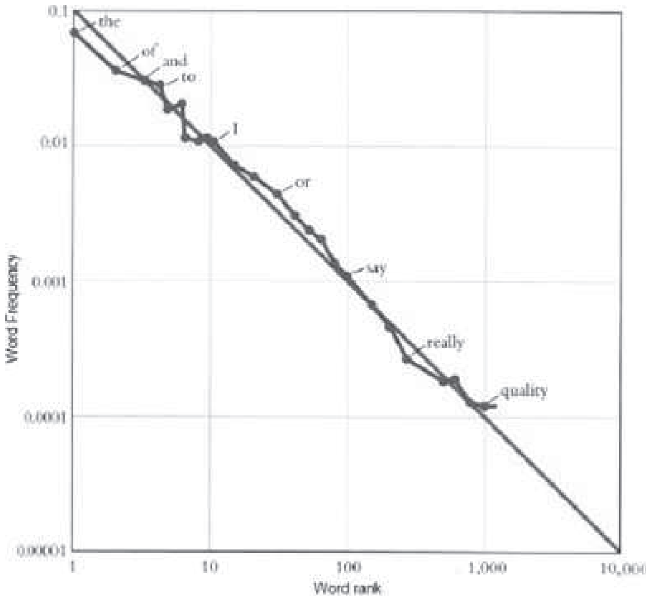

Figure 6.2: Zipf's Law: The relative number of words is plotted on log-log graph paper versus the rank order of that word for the first 8,728 words in the English language. The inverse power-law of Zipf [281] is given by a straight line segment whose negative slope is the power-law index. The line with unit slope is the best fit through the data.

Consider the difference between the inverse power-laws of Pareto and Zipf. In the case of Pareto, the number of people having a given level of income determines the distribution of wealth. To express the same income data in terms of rank, we could parse the data into discrete income levels, with the highest level being rank one, the second-highest rank two, and so on. The two ways of displaying the data constitute a change in representation from the relative number of people with a given level of income, to the rank order in the level of income. The fact that the data yields inverse power-laws in both representations implies that the power-law indices in the two representations are simply related. Consequently, the nonsimplicity of phenomena in the real world and how they are ordered according to rank are deeply connected.

How the rank ordering done in biological and social evolution relates to the comfort level in having things ordered properly in a cognitive map is still a mystery, however. But it is reasonable to assume that the rank ordering of things in the world is related to how the brain organizes and orders its representation of those same things. People's experience of events is condensed into cognitive mapping processes and, regardless of the representation used, their relative ordering and, perhaps even their relative separation in space and time is maintained, see Figure 6.3. Thus, the feeling of satisfaction or excitement experienced by a person may be a consequence of a matching between the pattern in a person's mental map and the ordering of data in the world. That resonance is captured in an author's use of language and the frequency with which certain familiar words are used, such that the story flows at an uninterrupted pace and it is a pleasure to lose oneself in the tale. This resonance might also reflect the experience of "being in the groove," where an individual can carry out complex tasks in effortless fashion that at other times might require the expenditure of great effort.

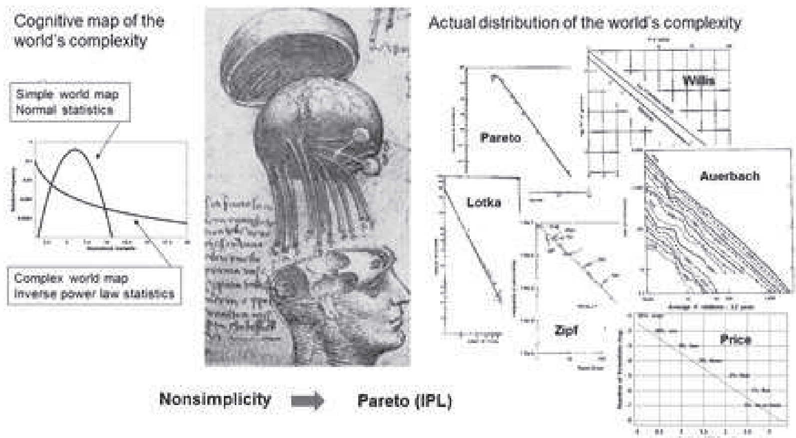

Figure 6.3: Here, we use an image from da Vinci's anatomical studies to emphasize the mapping of the world done in the brain, reproduced from [67]. On the left, the world map of normal statistics is contrasted with that of inverse power-law statistics. On the right are a half dozen empirical inverse power-laws along with the names of the scientists who did the original analysis, reproduced from [267] with permission. In each case it was determined that the nonsimplicity of the underlying phenomenon implied the Pareto inverse power-law distribution.

A simple life is satisfied by balance in which "all things done in moderation" is key. A nonsimple life needs a different kind of balance, one that comes from being able to exploit the intrinsic imbalance in the distribution of things that are desired. For example, since people do not share the same ordering of values, it is possible for two people to leverage one another to mutual advantage. If the distribution of talent and income were distributed as prescribed by the LFoE, then leveraging a piece of talent for a piece of wealth would not be possible. An asymmetry is necessary to achieve leverage. In a simpler time, such exchange was manifest in patronage, where a wealthy individual would support an artist, often lavishly, while the artist gave expression to their art. With this exchange, the artist could create, and the benefactor could reap the social benefit of "unselfish giving" and displaying the works "he" had provided. Admittedly this arrangement had some drawbacks, but, by and large, it was mutually beneficial to the artist, to the benefactor, and to society. If you have a chance, visit Michelangelo's masterpiece, the marble statue David, in Florence, then reassess your conclusions concerning the potential benefit to society of leveraging such talent.

The benefit of such an arrangement to humanity can be determined by tracing the works that resulted from such philanthropy throughout history. Churches, synagogues, temples, and mosques attest to the interleaving of past civilizations and the contribution of spiritual expression to the fabric of present-day society. It is the display of interdependence revealed by such historical monuments that motivate the radical jihadist, at least in part, to destroy every symbol of non-Islamic achievement. This is often in preparation for the Caliphate, the radical jihad social plan.

One thing a warfighter has in common with a social planner is what is called the Planner's Dilemma. The concept is a familiar one. The probability of the occurrence of an extreme event decreases with the size of the event–for example, the magnitude of an earthquake or a flood. The larger the magnitude of the extreme event, the less likely it is to occur. The social planner must design structures that can withstand an earthquake of a given magnitude or build a levee to hold back the flood waters of a given height. But there is a cost associated with each design, as the size of the event increases, the probability of its occurrence goes down, but the cost associated with implementing the design to survive that magnitude event goes up. A sketch of these conflicting considerations is given in Figure 6.4. Often the best design decision is where the two curves cross.

The more difficult curve to empirically determine is the probability of the occurrence of a given size extreme event, whether the focus is on natural disasters, or the casualties resulting from battle. If the probability curve falls sharply to zero, the survival costs are relatively small. They are small because the size of the extreme–within, say, a 100-year window for a flood–is not too large. However, if the probability continues to be non-zero for very large values of the extrema, so that the probability of a very large magnitude event is significant, the survival cost might be prohibitive. The extrema from a non-exponential distribution, such as an inverse power-law, could have such very large extreme values occurring within a relatively short interval of time.

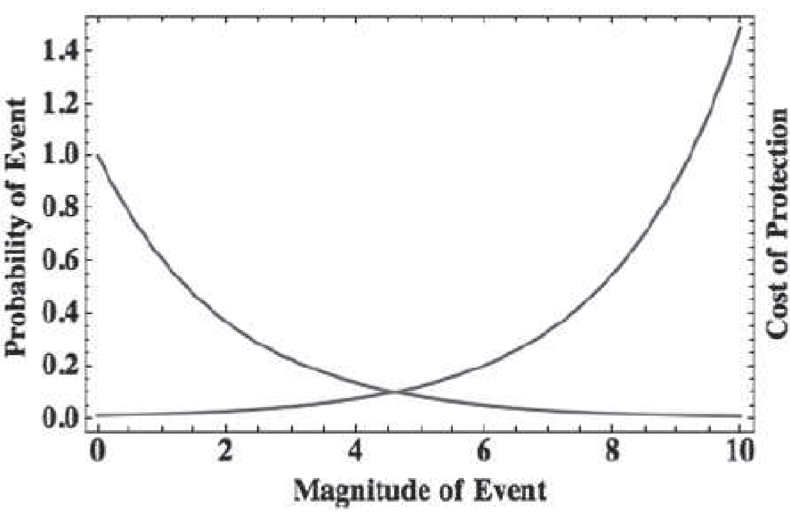

Figure 6.4: The Planner's Dilemma: the protection cost increases (right vertical axis) as the probability of a rare event decreases (left vertical axis), both as a function of the magnitude of the event.

The warfighter, like the urban planner, is faced with the prospect of spending an ever-increasing amount of resources to protect against an ever less-likely disaster and must make decisions by balancing the two. The immediate difficulty is determining how to balance the likelihood of a catastrophic event against the cost of mitigation against it. The only way to rationally construct such a trade-off between the cost and peace of mind, is to have a systematic estimate of the probability for the occurrence of an extreme event, an estimate that may never have been measured. To accomplish this trade-off, the urban planner uses the fact that the waiting time T (S) for an event of a given size S is inversely proportional to the probability of an event of that size occurring p(S), which is formally given by $T(S) \propto 1/p(S)$. For example, the city might wait ten years for the occurrence of an event that had a 0.10 probability of occurring, but it would wait 100 years for an event whose probability was 0.01. In other words, if the underlying process is exponential and the probability of an extreme event not occurring changed from 0.90 to 0.99, then, typically, the city would be safe for a factor ten longer period of time before the event arrives.

The bell-shaped curve of the LFoE can be related back to Newton's laws and simple dynamical systems, so that the curve can be used to describe the distribution of experimental errors. In the same way, the inverse power-law curve can be related back to unstable dynamical systems. The inverse power-law, depicted in Figure 6.3, is seen to have a long tail, which extends far beyond the region where the bell-shaped curve is confined. This long tail often indicates a lack of scale and this lack of scale can be manifest in the divergence of the average value of the dynamical variable. Note that if the data has an average value that is proportional to the size of the data set, then such things as a mean response time cease to have meaning. This drives engineers crazy, because the traditional ways to characterize a process are no longer available.

Very often the heavy-tailed distribution is a consequence of intermittency in the underlying dynamics, so that large values of the observable occur more often than would be expected from the stable dynamics of simple systems. So what does an engineer do when the statistics of the underlying process are not exponential? Or what does a warfighter do for that matter?

The first thing of consequence to note is the difference between the frequency of occurrence of a given size extreme event for exponential and non-exponential statistics of the underlying process given in Figure 6.3. The inverse of the probability of occurrence of an extreme event of a given magnitude is plotted in Figure 6.5, as the return time. In the latter figure, it is clear that the return time for non-exponential statistics (in this case, inverse power-law) is significantly shorter than that for exponential phenomena. For Gumbel distributions, named for the mathematician who first systematically studied the behavior of the extrema of exponential processes, suppose a magnitude 50 event occurs every 100 years. By way of contrast, an inverse power-law process might have an extreme event of magnitude 50 that recurs every 10 years or so. It is evident that it is much easier to develop protection against an exponential process than against the significantly more frequent inverse power-law process.

The difference in how long it takes for an extreme value of a given size to occur for a second time explains, in part, why levees built to withstand the 100-year flood are successful; the frequency of occurrence and duration of rainfalls contributing to floods are exponential processes, statistically. This is in sharp contrast to the distribution in the number of casualties in a battle, conflict, or war, whose statistics are not exponential, but inverse power-law. Simple phenomena with exponential statistics have extrema that are relatively easy to prepare for because they are so rare. Nonsimple phenomena with inverse power-law statistics produce extrema of a given size much more frequently than do exponential statistical processes and require special consideration along with major investments of resources in preparation for their occurrence.

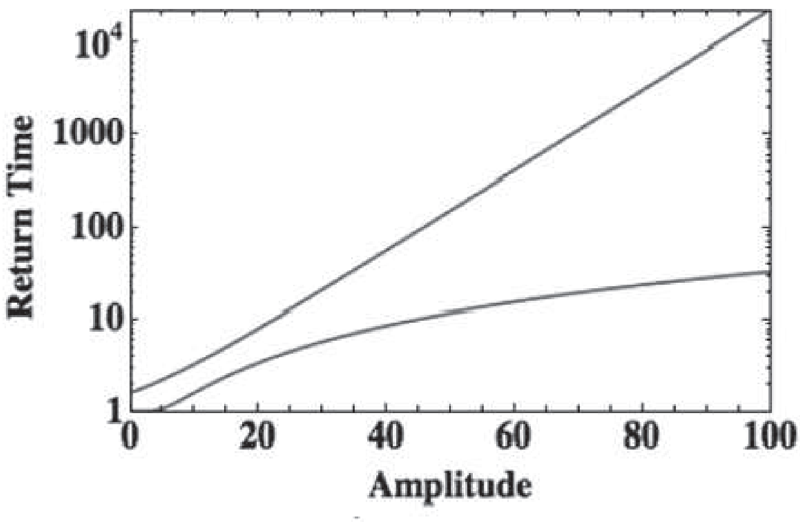

Figure 6.5: The upper curve is the return time for a given amplitude extreme event when the underlying process is exponential and corresponds to a Gumbel distribution. The lower curve is the return time for a given amplitude extreme event when the underlying process is inverse power-law.

Unfortunately, when nonsimple phenomena are mistakenly described using exponential statistics, society is ill-prepared for the extreme events when they occur. This is what has happened repeatedly with the stock market crashes of the last century and early in this century; each time a market crash occurs, it is treated as an anomaly. Such events ought to have been anticipated, but they never were even though their existence is an intrinsic part of stock market dynamics. This shortsightedness must be avoided on the part of the warfighter and it can be by using nonsimplicity thinking. For example, anticipating when the next attack will occur is like waiting for the next drop of water from the leaky faucet to come crashing down–the cost of survival is eternal vigilance, increased sensitivity, and a touch of paranoia.

Thus, the data on the distribution of wealth, the frequency of word use in language, city sizes, biological macroevolution, and apparently most other nonsimple phenomena have distributions that are more like the inverse power-law, than they are like the bell-shaped curve. The existence of the upward mobility observed in social development, as opposed to biological development, is a consequence of the nature of the intrinsic constraints on the underlying process. The ceiling is hard wired in biology, but the constraints are much more flexible in society. One consequence of this difference is the imbalance in the underlying process for inverse power-law phenomena, first observed by Pareto, and prompted the sociologist Joseph Juran to capture the essence of the imbalance with the phrase “the vital few and trivial many.”

6.2.2 Statistics and nonsimplicity

In an earlier chapter, we asked the question: Why should a few percent of the population own the largest fraction of the wealth? The answer was given in terms of critical properties of nonsimple networks, in which the imbalance was related to the scale-free structure of the network connectedness. For the sake of argument, we assumed that 20% of the population owns or controls 80% of the wealth. Of course, income data show that in Western countries, the distribution of wealth is partitioned at approximately 3% and 97%, depending on the country. The 80/20 nomenclature has been used historically to denote the separation into the have and have-nots, implied by the inverse power-law distribution, across a broad spectrum of phenomena outside wealth. We either refer to the imbalance in this way, or as Pareto's Law. The 80/20 Rule was independently identified by the science fiction writer Theodore Sturgeon, in a form that in literary and artistic circles became known as Sturgeon's Law [231]:

> Using the same standards that categorize 90% of science fiction as trash, crud, or crap, it can be argued that 90% of film, literature, consumer goods, etc. are crap. In other words, the claim (or fact) that 90% of science fiction is crap is ultimately uninformative, because science fiction conforms to the same trends of quality as all other art forms.

This might have been hyperbole on Sturgeon's part, or it might have been intuitive insight, based on long experience as an exceptional science fiction writer. In any event, he offered a fundamental principle on the statistics of nonsimplicity, not only as it applies to the art world, but to the world in general and the military in particular.

Note that we have explicitly identified the imbalance resulting from the inverse power-law in the spread of wealth and talent or capabilities. The former appears to be determined by the nonsimplicity of society rather than by some natural constraint; this suggests we should be able to modify the distribution. This has been attempted through the implementation of all manner of social regulation intended to redistribute wealth more equitably; the graduated income tax comes to mind. However, a minimal imbalance seems to resist all efforts at equalization and its removal: either by equalizing all income levels, or putting virtually 100% of the wealth in the hands of the few; appears to destabilize society [200]. On the other hand, the distribution of talent is determined by biology and, consequently, it is less amenable to social intervention, even when we make social adjustments as to what constitutes the positive expression of that talent. But what do these observations have to do with the warfighter?

One intersection of the inverse power-law with the experience of the warfighter is in the distribution of the number of casualties resulting from conflict. For the present discussion, we count the number killed due to terrorist attacks. Between 1968 and 2004, there were 19,907 terrorist attacks worldwide. The number of dead and injured follows an inverse power-law distribution, as depicted in Figure 6.6. In this figure, the logarithm of the number of those injured, or killed, is given on the horizontal axis and the vertical axis is the logarithm of the probability that this number exceeds the number on the horizontal axis. It is noted that rare catastrophic attacks are not outliers of an otherwise exponential process, nor are they exceptions to the rule: they are the rule [263].

It has been known for a long time that the distribution of casualties, in wars around the world, is an inverse power-law, when the casualty rate is adjusted for population growth. When the data is adjusted in this way Roberts and Turcotte [192] find that the casualty rate per 10,000 of the combined populations of the warring nations follow an inverse power-law, with an inverse power-law index of 2.5. The index is greater for wars than it is for terrorist attacks depicted in Figure 6.6, where the solid line segment has a slope of -1.7 and a power-law index of 1.7. Consequently, a typical terrorist attack kills a handful of people and the maximum number of casualties in single such attack, so far, was 2,973 on 9/11.

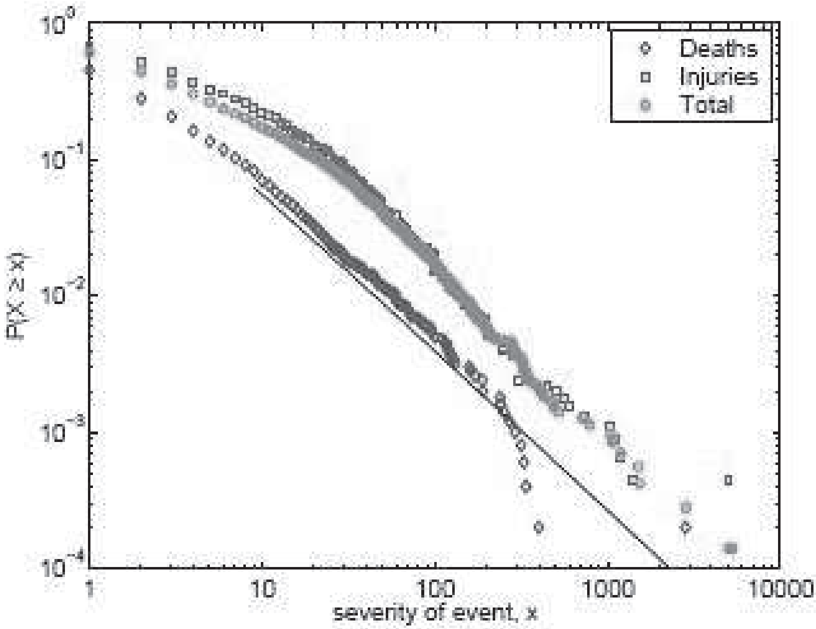

Figure 6.6: The probability, $P(X \geq x) \propto 1/x^{\alpha}$, that the severity of an event is greater than a given amount is depicted using data on the deaths and injuries due to terrorist attacks between 1968 and 2004 [263]. When graphed on log–log graph paper the inverse power-law yields a straight line with negative slope $-\alpha$.

The imbalance of Pareto's Law is seen to be operational in all manner of phenomena crucial to the modern warfighter. By way of example, let us return to our earlier discussion of radical jihadist computer forums set up for recruitment. The investigator Awan [16] determined that 81% of users had never posted on the forums, 18% had posted a few times, and only 1% had posted a substantial number of times–500 or more. This may be interpreted as a 99/1 imbalance between those who participate in the radical jihadist forums on the internet and those who merely observe what is being done. This rule states that the number of people who create content represents approximately 1% of the people actually viewing that content. This means that for every person posting on a forum, there are at least 99 others viewing that forum but not posting. The intellectual "wealth" is generated by the few and passively absorbed but actively used by the many [272]. This same 1% rule [175] has been observed elsewhere on the internet as well.

The most successful postings are not those that demonstrate the vast intellect of the individual providing solutions in the postings, but are the more subtle insights revealed in the questions being asked. The thought–out question often penetrates more deeply into the psyche of the reader than does the most careful analysis of a problem. This is one of the new ways of thinking that can be taught: Never accept an explanation without first turning it on its head, its side, and pulling it inside out, especially if it confirms something you already believe. Always ask questions. The modern warfighter will be a trained skeptic, but not necessarily a cynic; more like a venture capitalist than a typical investor in the stock market.

In large organizations, such as the military, the Pareto imbalance in the distribution of achievement translates into the majority of the accomplishments being generated by the minority of its members. The vital few have the talent and ability necessary to generate revolutionary ideas and carry them to fruition. These individuals provide the leadership to focus the attention and activity of the majority on the tasks required to produce results, whether these results are new ways to carry out old tasks or they are new tasks resulting in a totally different mission strategy and requiring totally new thinking. Sometimes, one of the many produces new methods and insights; this often catapults that individual into the ranks of the few. In any large group, 20% produce most of the results, but it is not always the same 20%. There is a flux from the many to the few and back again, as recognized by Pareto, and only the rarest of individuals remains permanently within the ranks of the few. Consequently, the modern warfighter will be trained to value the support role of the 80%, as well as being prepared to step into the 20% role at a moment's notice, when the need arises.

On the other hand, in any organization it is possible to identify a small group of individuals who produce most of the interruptions. These are the contrarians or gadflies that question things and demand accountability. Although they are typically a pain, they are also the individuals who keep the group from falling into the trap of groupthink. What they contribute is to be valued. It often seems that the 20% producing 80% of the interruptions have a certain sensitivity to what causes the organization's administrators the greatest discomfort, and is often the result of a disregard for efficiency and their focus on producing results. This skill can only be honed when it is repeatedly demonstrated that it is of value to the military and that it is an important part of the military culture. The modern warfighter must also be part gadfly.

As a large organization, the military is no different from any other large organization in its distribution of talent, achievers, troublemakers, and problem solvers. The nonsimple problems inhibiting the success of an organization or of a mission within the military often appear to be independent of one another but, in point of fact, they are not. Nonsimple problems, like results, are interwoven, however subtly, so that generating solutions is closely related to generating results. What this means in practice is that nonsimple solutions are connected to multiple, apparently unrelated problems within the organization; the distribution of solutions have the same imbalance in their influence on problems, as individual talents have on the distribution of income among people. This imbalance is manifest in 80% of the problems being resolved by 20% of the solutions. These are the nonsimple solutions the modern warfighter will be trained to identify and exploit. They must find the solution that not only solves the problem of immediate concern, but also facilitates the solution of problems that, although not immediately evident, can be anticipated.

In a complementary sense, the vast majority of the simple solutions do not have a substantial impact on the spectrum of an organization's problems. Moreover, their implementations are costly in the sense that the cost per problem resolution is approximately the same for all solutions generated. Thus, implementing 10 solutions to fix 10 problems might work, but it is much less efficient than implementing the one solution that fixes, in large part, all 10 at once. Consequently, it would be highly beneficial to determine up-front if a given solution is one of the

20% before it is implemented and thereby markedly increase the cost effectiveness of problem-solving. The modern warfighter must be this kind of problem solver.

These examples and more are discussed in a business context and recorded in Richard Koch's *The 80/20 Principle* [125]. The 80/20 Principle is simply Pareto's Law and has both positive and negative consequences in the business world. It should be emphasized that it is not always the same segment of the workforce that goes into these percentages. For example, the 20% that is providing the lion's share of productivity, probably has a small overlap with the 20% that is causing most of the consternation at town hall meetings. The two power-law indices may not be directly related, but both are a consequence of the organization's nonsimplicity, and one cannot be eliminated without losing the other.

The practical significance of Pareto's Law is that it is a continuing reminder to be attentive to the 20% that matters. Only 20% of what people do during the day actually matters, in the sense that it produces 80% of the results that are achieved. The mental trick is to identify and focus on those things that you have determined in advance to be significant. When daily minutia consume your time, try not to get overwhelmed, and remind yourself of the 20% on which you need to focus. If something isn't going to get done, make sure it's part of the 80% and, ultimately, its impact will be mitigated.

6.2.3 Paradox and Uncertainty

In Chapter 2, we briefly discussed Martin's [155] intriguing notion of military bureaucracy as paradox and mentioned three examples. We explained the emergence and resolution of paradox qualitatively, using the difference between the LFoE and Pareto's Law. In that interpretation, paradox results from the misperception that the erratic data generated by nonsimple phenomena, which are properly described by Pareto distributions, are instead interpreted as if they were simple and consequently described by bell-shaped distributions. The failure to take into account the full range of variability contained in the Pareto distribution of a process, due to this misconception, is what leads one into paradox and is a consequence of using linear thinking rather than CS thinking.

The distinction made between simple logical thinking and nonsimple (CS) thinking at the level of the policy maker within the bureaucracy is equally valid at the level of the individual warfighter on the battlefield. It is nonsimple thinking that resolves the paradox. In fact, the warfighter must be more adept at resolving paradoxes in his thinking than the policymaker. The advice from other policy wonks and panels of subject matter experts, followed by thoughtful critical analysis by military leaders, all enter into the determination of new policy to resolve an intellectual conflict, or paradox, within the bureaucracy. The warfighter does not have the luxury of such on-site support groups. The warrior's way directly confronts new paradox, either alone or in the company of a small band of other warriors, who, with more or less the same level of expertise, must resolve the paradox in a very short time frame: seconds to minutes of its being recognized.

It is useful to have in mind various ways paradox comes about in the military. Some representative paradoxes can be lifted directly from *The Army/Marine Corps Counterinsurgency Field Manual* and are presented here as examples of the different mindset required for their resolution. These COIN paradoxes, which are offered to stimulate, not limit, thinking, are discussed in detail in [184]:

- Sometimes, the more you protect your force, the less secure you may be.
- The more successful the counterinsurgency is, the less force can be used and the more risk must be accepted.
- Sometimes, the more force used, the less effective it is.
- Sometimes doing nothing is the best reaction.
- Some of the best weapons for counterinsurgents do not shoot.
- The host nation doing something tolerably is normally better than us doing it well.
- If a tactic works this week, it might not work next week; if it works in this province, it might not work in the next.
- Tactical success guarantees nothing.
- Many important decisions are not made by generals.

Computational social science relies on the assumption that criticality, such as reaching consensus, is a consequence of self-organization. The same can be said for nonsimple biological, physical, and sociological phenomena. A number of investigators have devised mathematical models by which to quantify critical phenomena in the physical, social, and life sciences. Such models, as reviewed by Sornette [226], describe the phase changes of solids, fluids, and gases; the frequency and magnitude of earthquakes; the flocking of birds; the crashing of markets; the onset of brain quakes; and the transition from demonstrations to riots, to name a few. These models can be widely separated into two groups. The first group models phenomena that achieve criticality through the external manipulation of a control parameter, such as the changing of temperature in physical phase transitions. The second collection models phenomena in which criticality emerges due to internal dynamics, without adjusting an external control parameter, and has acquired the name self-organized criticality (SOC) [263].

West et al. [274] generalized the SOC model using a two-level dynamic network model of decision making, the self-organized temporal criticality (SOTC) model, which has criticality as an emergent property. In the context of the Altruism Paradox, SOTC drives the selfish behavior of individuals within a social group to generate cooperation (altruism) and simultaneously achieve maximum social wellbeing. Previous models attempted resolution by placing the good of the individual and the good of society in competition, with a winner and a loser, making it an either/or contest. The SOTC model shows an individual can consistently act in his or her own self-interest while simultaneously attending to the social benefit of his or her decisions, independently of any specific physical, social, or biological mechanism, thereby replacing the either/or with both/and interactions. As discussed previously, the mathematics demonstrates that the intellectually conflicting notions of selfishness and altruism, are not logically inconsistent when treated dynamically. The dynamic model reveals that what is good for society need not be purchased at the cost of what is good for the individual.

To explain the resolution of the paradox, we emphasize that the SOTC model is a contribution to evolutionary game theory. The resolution of paradox is a consequence of scaling and criticality in the complex decision-making process. In the SOTC model, criticality is not forced upon the network by setting the imitation strength in the networked DMM to a suitable value. The critical value of the imitation strength is spontaneously reached without artificially raising or lowering its level within the network from the outside. Instead, criticality is dynamically attained by having each individual within the network select the value of their individual imitation strength that results in maximum benefit to themselves.

Individuals weigh each and every decision they make, using the two subnetworks of intuition and cognition, to adapt to the changing composite-network behavior. The SOTC model has the intensity of the imitation strength selected by the individuals on the basis of increasing their own benefit, rather than as a form of blind imitation. It establishes the emergence of cooperation through the mere use of the Prisoner's Dilemma payoff, thereby connecting the evolution of global cooperation with the search for agreement between individuals and their nearest neighbors. This balancing of the tension between intuition and cognition not only resolves paradox, but gives pleasure in overcoming the impossible.

More generally, within a bureaucracy, the role of leadership is to support opposing internal forces and harness the continuous tension between them, enabling the system to not only survive, but to continuously improve. Of course, this is the ideal case, as all too often bureaucracies become stuck at the level of survival and need to be jolted from their complacency. In a nonsimple organization, consider the paradox of having both A and $\bar{A}$ within a common context, where $\bar{A}$ is a proposition and A is its negation. This would be the Yin and Yang of Taoism; the thesis and antithesis existing together. The combination of A and $\bar{A}$ existing together manifest a duality in opposition to one another, but they are also synergistic and interrelated within the larger system.

Figure 6.7: In Taoism the fusion of the two cosmic forces, the light and dark, represent Yin and Yang respectively, each containing a 'seed' of the other.

The resolution of the paradox that is implicit in Figure 6.7 requires abandoning the either/or-thinking of Aristotelian logic that implies A or $\bar{A}$, but not both together, to embrace the both/and-thinking of A and $\bar{A}$ together, achieved by balancing the tension of contradiction dynamically. This management of the tension of paradox, whether within individuals, groups, or organizations produces flexibility and resilience, while fostering more dynamic decision making [220]. This replacement of Aristotelian logic entails new Principles of War, for example, the existence of a Gray Zone.

6.2.4 Paradoxical Leaders

Smith et al. [220] proposed a new way for leaders to address contradictory but simultaneous challenges, starting from a rejection of stability as being a necessary condition for an organization to prosper, which for the Army means to successfully carry out its spectrum of missions. Contradictions always exist is complex organizations, some of which form fundamental paradoxes which cannot be resolved by adopting to support one side of the conflict or the other. Both sides of the contradiction have value, and the successful leader is one who can devise strategies that enable the organization to cope with paradox without becoming doctrinaire.

The resolution of paradox demands that diametrically opposed alternatives be examined. It turns out that such alternatives not only contradict one another, but depend on one another as well. Of central importance to the military is the Strategy Paradox, which is a consequence of the need to commit to a strategy despite the uncertainty of the outcome, knowing full well that the strategies that lead to military success are the same strategies that can lead to military disaster. As summarized in a business context [220]:

> Strategic paradoxes are essentially dilemmas that cannot be resolved. Tensions continually arise between today's needs and tomorrow's (innovation paradoxes), between global integration and local interests (globalization paradoxes), and between social missions and financial pressures (obligation paradoxes).

The goal of the leader is to establish a dynamic stability within the organization that embraces paradox, one that persists over time. There always exists the tension between the short term needs of the warrior, especially in battle, and the long term needs of the military to prepare for addressing the challenges of the future. The seductive attraction of consistency in decision making, mistaking it for stability, must be avoided. A leader must recognize that inconsistency is often desirable and be capable of holding multiple, conflicting views, all of which are true. S/he must transition from either/or-thinking to both/and-thinking, which, in order to satisfy competing demands in the long term, requires a leader to frequently shift their short term positions [220]. Or as expressed by the poet [82]:

> A foolish consistency is the hobgoblin of little minds, adored by little statesmen and philosophers and divines. With consistency a great soul has simply nothing to do. He may as well concern himself with his shadow on the wall. Speak what you think now in hard words, and to-morrow speak what to-morrow thinks in hard words again, though it contradict everything you said to-day. "Ah, so you shall be sure to be misunderstood." Is it so bad, then, to be misunderstood? Pythagoras was misunderstood, and Socrates, and Jesus, and Luther, and Copernicus, and Galileo, and Newton, and every pure and wise spirit that ever took flesh. To be great is to be misunderstood.

There is a distinction to be made between the leader who analyzes disputes in the manner of a chess master and one who approaches conflict like a poker player. In both, there are well-defined rules of engagement, as well as strategies for gaining position, making sacrifices, and attacking. However, in poker, there is the added dimension of deceit. Since not all the play is visible to everyone, there is the opportunity to bluff and exploit your opponent's psychological reaction to uncertainty. In the real world, a "consistently inconsistent" devious player has an advantage over a predictable rule follower. This is where CS thinking, or a paradoxical frame of mind, can overcome an adversary hampered by the belief that cognitive dissonance is to be avoided. On one hand, an opponent seeks to minimize uncertainty through control and decisions that suppress nonsimplicity, thereby reducing flexibility and cutting down on the number of options available to them. On the other hand, the paradoxical leader's strategy is to cope with ambiguity and gain advantage by keeping the opponent off balance through uncertainty. As mentioned earlier, the mathematical models strongly favor strategies that incorporate bluffing into the play.

CHAPTER 7 PRINCIPLES OF WAR

> Peering into the future can be scary and surely is humbling. Events unfold in complex ways for which our brains are not naturally wired. Economic, political, social, technological, and cultural forces collide in dizzying ways, so we can be led to confuse recent, dramatic events with the more important ones. It is tempting, and usually fair, to assume people act “rationally,” but leaders, groups, mobs, and masses can behave very differently–and unexpectedly–under similar circumstances. For instance, we had known for decades how brittle most regimes in the Middle East were, yet some erupted in the Arab Spring in 2011 and others did not. Experience teaches us how much history unfolds through cycles and shifts, and still human nature commonly expects tomorrow to be pretty much like today–which is usually the safest bet on the future until it is not. I always remind myself that between Mr. Reagan’s “evil empire” speech and the demise of that empire, the Soviet Union, was only a scant decade, a relatively short time even in a human life [170].

> The change from atoms to bits is irrevocable and unstoppable [168].

Principles of science are the laws of laws and are intended to capture the systematic behavior of classes of empirical laws. In physics, one might draw together Ohm’s Law, Boyles Law, Coulombs Law, etc. as describing the empirical relations among physical observables. These empirical laws are then explained in terms of theoretical laws, such as Newton’s laws of motion, Maxwell’s electrodynamics laws, and so on. But at the top of this hierarchy are the physical principles from which these laws follow, such as the principles of symmetry and the conservation of energy. In biology, one can point to the principle of macroevolution, but like an axiom in geometry, a principle cannot be proven, it can only be disproven.

Outside the physical and life sciences, principles are the basic components defining frameworks that rarely change. However, as the environment changes, human knowledge grows; human perspectives and methodologies transform; and, consequently, all principles do ultimately evolve. There is no steady state in any element of life. Principles evolve and can, at times, during paradigm shifts, revolutionize how we see the world. The clockwork universe of Newton gained ascendancy during a time in which battles were fought in ridged formations, travel over long distances took days to months and was an adventure, banks gave letters of credit, and there was a porcelain bowl beneath the bed. The challenges of daily life seemed manageable when the new world view was applied to industry and the Industrial Revolution came of age. The horse was replaced by the car, the telegraph and telephone edged out letter writing and the naturalist view of an agrarian society yielded to the urbanization of the Machine Age.

Scientific principles change, mathematics changes, and morals and ethics change. The Machine Age, with its reliance on a world dominated by mechanical forces, gave way to the Information Age, an age dominated by the force of information. In today's world, technologies and their principles change at warp speed. But what about the military? Every aspect of military operations and warfighting has changed significantly over the past two centuries. So much so that the forces, the weapons, the people, and the methods of warfare are fundamentally different. Even the spectrum of military operations has grown and changed dramatically over the past two decades in the United States. So a natural question to consider is: should the Principles of War change to accommodate the changes in society?

The concept of warfare is difficult to comprehend; neither strategic abstraction of, nor tactical concentration on, details seems to give clear focus. War cannot be simply explained using logic, measures, or definitions. War is violent, dehumanizing, and nonsimple. It is dynamic, being both continuous and discrete. Changes are always made through countless social, political, economic, cultural, technological, and other factors, and the mere mention of or involvement in war changes the situation in nonsimple ways. All sides continuously devise strategies intended to confuse and disrupt one another. The philosophy of war as a nonsimple strategic factor has become a significant element of the United States foreign policy. Now the tactics and operational use of nonsimplicity have to advance to keep pace.

Sun Tzu wrote [236]: "Now the general who wins a battle makes many calculations in his temple ere the battle is fought. The general who loses a battle makes but few calculations beforehand." This dictum has been taken for granted by many contemporary militaries under the assumption that through detailed study and mathematical calculations victory in war can be guaranteed. Yet, military history shows that reality is not so simple, and often the best-laid military plans fail for no reason other than chance (or, in our terminology, nonsimplicity). Furthermore, there is a predominant school of thought in military history that believes no amount of calculation and modeling can compensate for inexperience and lack of talent. Perhaps, this view is best articulated by von Clausewitz, who argued that [56] “[military] genius . . . is above all rules.” If this has been the case for the majority of human history, why should we expect the nature of warfare to change and why should we believe that the new mathematical models of network science, computer science, and complexity science will be essential to success in modern cyber warfare?

It may run deeply against the grain of Western military thought, but analyzing the implicit assumptions beneath these contrasting views reveals that Sun Tzu’s assertion has become truer than ever. Network science and similar mathematical models have become key to the future of warfare because of two broad transitions. First, advances in technology have dramatically altered fundamental aspects of warfare to such an extent that von Clausewitz’s argument no longer holds in general and certainly not in the domain of cyberspace. Second, mathematics itself has also been transformed by the evolution of truly interdisciplinary fields, such as network and information science, which embrace the world’s complexity to a much greater degree than any previous field of research and study.

Though we might be hesitant to accept arguments that the essential nature of war has changed, it is hard to deny the fact that cyber operations and information-based warfare have dramatically changed the equation. Perhaps, in the very broadest sense, the fundamentals of strategy and competition have evolved slowly, but the actual conduct of war has been radically transformed to such an extent that we can no longer rely on notions of expertise, or genius, to carry a force to victory. Von Clausewitz’s own concept of genius relies on what he called coup d’oeil. The term literally translates to “blow to the eye,” referring to a commander’s ability to rapidly perceive reality through the fog of war and determine the best course of action [56]. We have shown that because of the nonsimplicity of warfare, such capability–and, therefore, genius, or even insightful intuition–does not and cannot exist in modern warfare. And the very notion that any human being possesses such intuition for cyber operations is even more absurd, because we are unable to directly perceive the “terrain” or “enemy disposition” in the cyber domain. Situational awareness is never fully achieved in cyber operations, and the entire system changes at the speed of electrons through the network. With the growing nonsimplicity of on-net activities and the challenges of big data, it is already impossible for human beings to interpret cyber operations without nonsimple network models and advanced mathematics.

Furthermore, the notion that mathematical models can never incorporate the nonsimplicity of human competition and real-world dynamics is truly out of date. Mathematicians and scientists from many fields have made significant strides in understanding and modeling nonsimplicity, even though such models are best used for understanding, and not necessarily for prediction. Many modeling advances rest on NS and other emerging, modern, interdisciplinary fields in the information sciences. NS has been so powerful in application because it brings together ideas from graph theory, mathematical physics, systems theory, statistical inferences, biology, and game theory into a holistic approach focusing on interconnectedness as the driver of nonsimplicity. By embracing nonsimplicity, network science allows modelers and warfighters to avoid the tragic mistakes of linearity and determinism which have held back previous applications of mathematics to military operations.

As modern warfare continues its advance into the cyber domain, armed forces can no longer rely on the ideas of historical-based expertise and legendary military genius to guarantee victory. These arcane elements have little to no bearing in the rapidly changing, intellectually-based cyber operations. NS and other nonsimplicity-based paradigms that embrace CS and interconnectedness are the best means available to military planners for conceptualizing the cyber battlefield. Though we should hesitate to do away with all previous theories on strategy and ignore centuries of military history, the answers the armed forces of the world are looking for cannot be found in the wisdom of the past. Instead, they can only be found in viewing that wisdom through the nonsimplicity models of the future.

7.1 Various options for new principles

The current United States Principles of War were influenced by the thinking and writings of military scholars, such as the Frenchman Antoine–Henri Jomini and the Prussian Carl von Clausewitz, from the early 1800s. When the British officer J.F.C. Fuller came out with his principles of war in the early 1920s, the American Army developed its own version and has used them since in doctrinal manuals and training. The current version is unchanged from 1948. However, there have been many changes in the conduct of warfare over these past 70 years that affect the efficacy of those principles. As modern-day warfare missions evolve to full-spectrum missions (stability operations, cyber warfare, peace-keeping, disaster relief, humanitarian aid), with new domains (cyber and space) and expanding roles of information and technology, it may be time to correspondingly change the US Military Principles of War. These principles were written long before we understood that bits of information are as important as atoms and that super-fast machines of warfare could sense the enemy, make decisions, and take action on the battlefield in the blink of an eye. Of course, principles are not substitutes for understanding and thinking, but are intended to enlighten and support those activities. Neither are they a complete checklist. But they are a convenient place to start when designing an operation or analyzing a situation.

Some military scholars believe that the Principles of War are fine the way they are written, and other scholars have proposed changes, some substantial and others more modest [90, 138, 254]. However, quality scholarship and insightful leadership always entreat questions on both the theory and its application, as changes in both theory and application are inevitable. So we ask: can the Principles of War be improved, given what we now know about operational nonsimplicity? What are the differences in warfare that have emerged over the past 100–150 years that ought to be incorporated into new Principles?

Some of the significant shifts in society's philosophy and military's functions that could affect basic principles of warfare and military operations include:

1. The Information Age made people embrace the nonsimplicity of human interaction, along with the information deluge overwhelming both. This information revolution and the accompanying revolution in military affairs have produced a dramatic shift in warfare and its underlying principles.

2. Military's operational framework's evolution through the development of NCW, MDB, and intelligent system technologies that also stem from the revolution in military affairs (RMA).

3. New domains of warfare with the advent of air, space, and cyber.

4. Evolving doctrines to include the latest developments in mission command, OODA loop, landpower, and air-sea battle. These elements combine with the rising role of non-state actors to produce highly asymmetric, hybrid, and irregular wars.

5. Increased technological capabilities resulting in better communications, better vision of the battlefield (sensors and video feeds), increased firepower (particularly nuclear), robotic systems, and artificial intelligence which produce the potential for increased speed and span of operational control (hyperwar).

6. Faster pace of action in all elements of warfare, including the pace of technological and doctrinal change through the adoption of new scientific and cultural paradigms.

Like the underlying theories in many disciplines, the Principles of War both directly and indirectly affect the conduct of operations, and in many ways, the current principles have stood the test of time and practice. Along with their direct effects on operations, perhaps their greatest values lie in the education of military professionals and as the framework for research models to analyze operational plans and exercises. So why might all these changes affect the principles? Society's transition from physically focused to information-centric focus impacts many basic and analogous operational elements of life.

Scientific thinking and methodology, business and finance, organizational structures and processes, and decision-making and analysis have all changed dramatically in this new era. This is mainly due to human–created information issues behaving differently from physical ones and new technologies and doctrines providing improved options. In many military operations, information collection is highly valuable until its flow is so plentiful that it becomes a deluge. As the military continues to enhance data collectors and sensors (e.g., drones, robots, and web sites), the result is an ever-growing, overwhelming data cascade that brings tremendous opportunity and challenge that affects the basic concepts of battle, warfare, and war.

Predictions for progress in future operations require broader, more flexible command structures to cope with this information nonsimplicity and creates a need for more operational agility to react or cope with intelligence processing and information actions. Situational awareness can be enhanced with technological and doctrinal improvements, the integration of modes of understanding (theory, application, and practice), and clearer perceptions (data, information, intelligence, knowledge, and wisdom). Mission Command, OODA loops, NCW and other doctrinal changes combine the art of command (using cooperation, information, and situational awareness to understand, visualize, describe, direct, lead, and develop operational teams), with the science of control (planning, preparing, executing, assessing, and conducting information-based actions). These changes enhance the need to understand and use the human dimension, in particular, interactions between the quantitative intelligence of the systems and networks with the intuitive and qualitative intelligence of the commander and staff. New doctrine builds information-savvy, adaptive teams that anticipate transitions, accept risk to create opportunities and conduct appropriate operations. In many modern situations, collaborative decision making might be better suited than unity of command. Embracing nonsimplicity of warfare, through autonomy and systems intelligence, may be more advantageous than making operations plans simple and detailed.

These answers seem to lead to more questions: which Principles of War need changing or replacing? Or is an entirely different framework needed? An analysis of the current principles shows some possible needs and suggestions:

1. Objective: Direct every military operation toward a clearly defined, decisive, and attainable objective, even though the objective may be multi-dimensional and nonsimple. Military operations, like all operations and activities, need proper goals and direction, making this principle still viable and necessary in the Information Age.

2. Offensive: Seize, retain, and exploit the initiative. Some objectives are not achieved through offensive operations. In some domains, such as cyber and space, or in some operations, such as counter-insurgency and counter-terrorism, the offense is not necessarily available. It is unlikely that commitment to offensive action helps [units] respond effectively to rapidly changing situations and unexpected developments. Quite the contrary, being too offensive-minded can create great difficulties in warfare, making this principle highly questionable. However, having the initiative, whether in an offensive or defensive situation, and taking advantage of it to achieve momentum are valid for all operations of warfare.

3. Mass and Economy of Force: Concentrate the effects of combat power at the decisive place and time. Allocate minimum essential combat power to secondary efforts. These two can be paired since one is somewhat dependent on the other. Having appropriate kinds and capacities of

forces at decisive places and times is a wise operational precept, but the terminology of appropriate balance or appropriate location may better describe the nonsimplicity of this highly functional, geographical, and topological concept. Other considerations, like appropriate organization, span of control, as well as size and organization of force, must also be considered, as these make the two principles questionable, as they are currently written. Maximizing mass or size (creating overwhelming power) comes in many forms. In the United States military, many leaders have thought mass–more time, more energy, bigger organizations, more money, more technology, and more people—can solve all problems. Perhaps this has become the American way of problem-solving. If a little is good, certainly a lot more is much better. But nonsimplicity greatly changes the equation. Perhaps being wiser, or being more appropriate, are better principles to consider.

4. Maneuver: Place the enemy in a disadvantageous position through the flexible application of combat power. The term maneuver is too narrow a concept in a broad, overarching framework such as Principles. Mobility or flexibility may be better concepts and terms to make the framework of Principles stronger and more applicable. Others would advocate for an even broader term such as agility, or another more definitive process, like synchronization.

5. Unity of command: For every objective, ensure unity of effort under one responsible commander. Perhaps the military is the last vestige of this concept, although some elements of mission command are attempting to move the military toward a less singular command posture. Nearly all other elements of organizational operations have moved to more shared leadership with some conception of coordination and cooperation. Of course, the ability to communicate is needed for any framework for command. Today’s way of implementing the nonsimple decision-making business of warfare makes this principle questionable.

6. Security: Never permit the enemy to acquire an unexpected advantage. This surely is an important principle that remains appropriate in the Information Age military and in all domains of warfare.

7. Surprise: Strike the enemy at a time or place or in a manner for which he is unprepared. This is also still an appropriate principle and an element where nonsimplicity modeling has a significant effect.

8. Simplicity: Prepare clear, uncomplicated plans and clear, concise orders to ensure thorough understanding. This concept is no longer valid in the era of nonsimple operations and systems. While making plans and orders clear and concise are valid elements of modern warfare, the goal of being uncomplicated is not viable. It is more important that plans and orders are appropriately designed and contain appropriate levels of nonsimplicity and flexibility, making this principle highly questionable.

Based on this brief analysis and using a more modern conception or terminology for the Principles, a direct one-to-one remake of the current (from 1948) principles might include the following in a more modern nine Principles of War:

1. Objective (unchanged)
2. Initiative (new)
3. Appropriate Balance (new)
4. Appropriate Organization (new)
5. Synchronization (new)
6. Cooperation (new)
7. Security (unchanged)
8. Surprise (unchanged)
9. Flexibility (new)

But there is nothing magical about the number nine. It was merely Fuller's original number. Perhaps it is also worth looking at Fuller's Principles from 1925. There are several different elements in this list to include an affective, human-based attribute: determination. We provide more analysis of these principles:

1. Direction: (Objective) What is the overall aim? Which objectives must be met to achieve the aim?
2. Concentration: (Mass) Where will the commander focus the most effort?
3. Distribution: (similar to Economy of Force) Where and how will the commander position their force?
4. Determination: The will to fight, the will to persevere, and the will to win must be maintained.

5. Surprise: The commander's ability to veil their intentions while discovering those of their enemy. Properly executed Surprise unbalances the enemy and causes demoralization of enemy force.
6. Endurance: The force's resistance to pressure. This is measured by the force's ability to anticipate complications and threats. This is enhanced by planning on how best to avoid, overcome, or negate them and then properly educate and train the force in these methods.
7. Mobility: (similar to Maneuver) The commander's ability to maneuver their force while outmaneuvering the enemy's forces.
8. Offensive Action: The ability to gain and maintain the initiative in combat. Properly executed Offensive Action disrupts the enemy, causing disorganization of the enemy force.
9. Security: The ability to protect the force from threats.

Now that dramatic improvements in weaponry, communications, sensors, and even the utility of individual combatants are the essence of a professional military, these adjustments all contribute to nonsimplicity. The network-centric battlespace hopes to provide for seamless communication, information-sharing, and the rapid response to support requests. A new set of Principles of War must be broad enough to readily accommodate the fast pace of development and operations as well as an increase in nonsimplicity fundamentals in military doctrine, technology, and capabilities. In 2007, van Avery [254] wrote:

> [T]he current principles of war require considerable revision and expansion. But they cannot be discarded wholesale. All of the current principles represent timeless, essential elements of warfare that will continue to be relevant in the future, although most are applicable now in more limited circumstances. Instead, the current principles must be developed into more complex principles that represent a better approach to the future of war.

The Principles of War that van Avery recommended are [254]:

1. Objective (all agree on this)
2. Speed (this depends on the purpose and context)

3. Concentration of effects, which replaces mass: van Avery's justification includes: With effects now taking primacy over force, successful military operations require a commander to focus first on the effect of networks and weapons, and second on the positioning of specific platforms. Military formations were developed to concentrate the effects of weapons. The dispersal of forces, beginning in the twentieth century, was designed to counter massing of fires and area effect weapons. In some circumstances, concentration may result in an asset being unavailable for more important concurrent conflict, when appropriately leaving the asset in a supportive mode is more helpful to overall success.
4. Economy of effects: This means employing the right number and combination of effects (an economy of force is replaced by an economy of effects). RMA shifts focus from forces to effects.
5. Pervasive awareness: This seeks to establish an exploitable, in-depth knowledge of the battlespace and the opponent.
6. Continuous planning: Units need ongoing development and redevelopment of courses of action, for both the current situation and future contingencies. Given the nonsimplicity of modern warfare, the old axiom that no plan survives first contact with the enemy is even more salient.
7. Flexibility: This Principle makes more sense than speed. Units need to adapt to new or different requirements or situations.
8. Sustainment: This entails ensuring the persistence of forces to see the conflict through, from entry to withdrawal.
9. Efficiency of command: Modern bureaucracy needs to be controlled by ensuring the force has no more administrative staff, or layers of command, than necessary. This also implies a conception of command that needs to be more like mission command.
10. Security: Unchanged and still needed.
11. Integration: This means connecting forces for appropriate participation in planning, and assigning useful tasks to these forces.
12. Surprise: Unchanged and still needed.
13. Feedback and evaluation: Collecting and analyzing of pseudo-information from the force, during operations are part of the American military operations.

7.2 Information Age Principles of War (IAPW)

The inclusion, so far, of only one affective attribute (Determination) leads to consideration of other affective elements such as resilience, courage, ethics, and morale. But none seem to rise to the level of a principle. Combining the most relevant of Fuller's principles, the current Army doctrine, the modern nine principles, and van Avery's principles produces our recommended set of principles of war for today's nonsimple operations. Our proposed Information Age Principles of War (IAPWs) are the following.

1. Objective (original): Properly identifying the objective may mean outlining a multi-component, multi-disciplinary goal that has dynamic qualities that evolve in both the short and long term. Much of the setting of the military objective will define the decision criteria for winning the war. Often the most challenging nonsimple aspects of the objective setting come from human and political elements that are nonsimple and often qualitative in nature.
2. Distribution of forces, assets, and energy (an expansion of Fuller): This principle supersedes the simplistic approach of concentration and economy of force that stems from the COG approach of Clausewitz. It also takes into account the logistics of assets and energy levels that affect force strength and capability. Larger forces may not be all that significant in the nonsimple battlespace, and sometimes balance is needed to achieve an objective, not overwhelming power at any critical point.
3. Endurance (Fuller): This principle is also related to sustainment and perseverance by the military forces, the government, and the citizens of the nation. Strong leadership is sometimes needed to produce these nonsimple attributes.
4. Mobility (Fuller): This principle includes speed and maneuver in both the physical and virtual worlds. The essential components of this principle are the use of AI to make fast decisions and implement fast actions and technology to make rapid, smart movements on the battlefield. Waiting for the human to decide every step and issue new orders slows the process and results in over-simplifying the operations.
5. Synchronization (modern): This principle is similar to efficiency of command and control, however, efficiency is not always possible and the operation still must be appropriately managed by the leadership and executed using the high-tech nonsimple military systems.

6. Cooperation (modern): This principle provides the concepts of mission command and shared leadership along with enabling joint and hybrid operations.
7. Security (original): The safety and health of US service members, citizens, and allies are paramount in every operation.
8. Surprise (original): This nonsimple concept is the one that often produces the most significant progress toward many military objectives.
9. Flexibility (Modern and van Avery): This principle is the essence of nonsimplicity in the processes of every operation and every organization. On the modern battlefield, this capability must be used and maintained for ultimate success.
10. Integration (van Avery): Modern operations are often multi–purpose and performed by a coalition of forces; therefore, special attention is needed to integrate these various forces. Integration is the method by which the command authority and staff maintain the synchronization of the operation.
11. Awareness (van Avery): This information–based attribute is essential to achieve the advantage of understanding the reality and nonsimplicity on the battlefield.

The new IAPW eliminate the following from today's Principles:

1. Offensive: too simple and single-minded for modern and future operations
2. Mass and Economy of Force: too focused on the linear concept of a center of mass
3. Unity of Command: the most constraining linear principle
4. Simplicity: impossible to achieve and inappropriate to seek on the modern battlefield because it can constrain the performance of a modern military force

Of course, any set of Principles, whether of War or Science, is interdependent. The elements of military operations have evolved and continue to evolve with changes in the military profession and its role in society. The following principles of joint operations are formed from the US Army Principles of War. Currently, there are three additional joint operational principles: restraint, perseverance, and legitimacy. These 3, added to the current 9, comprise 12 principles of joint operations, as outlined in Joint Publication 3.0. The goal of these principles is to provide the military the wherewithal to prevent, shape, and win a war. The rationales for these additional three principles of joint operation are in keeping with the elements of nonsimplicity and could be added to the IAPW or left as a separate list for joint operations.

> Restraint: This notion is intended to limit collateral damage and prevent the unnecessary use of force since a misguided act could cause significant consequences. Leaders of military operations have to ensure their personnel are properly trained and follow the rules of engagement.
>
> Perseverance: The force must have the commitment necessary to achieve the mission. Quite often, longer-term diplomatic, economic, and informational actions are needed to supplement the military efforts.
>
> Legitimacy: This concept is based on the legality, morality, and rightness of the actions in the operation. Sometimes restricting the use of force may be needed to have legitimacy.

7.3 Leadership & Asymmetric Warfare

> It should be obvious that the only way the US remains competitive is through a profound commitment to digital technology and the STEM education and training that enables it. [9]

The 9/11 attacks epitomized the concept of asymmetric warfare. It is the kind of conflict in which one side has far less power and resources than the other, but still manages to achieve important victories and may even achieve its goals in the war. Al-Qaeda was far weaker than the United States, but by using disruptive tactics and unconventional tools (suicide bombers, box cutters, and jetliners), it succeeded in inflicting great damage on its enemy. The increasingly fierce barrage of cyber-attacks against the governments of nations and their private firms, scientific centers, foundations, and civil-society organizations is a new form of asymmetry. One that exploits the intrinsic vulnerabilities of modern Western organizations and society. The vulnerability is not one of energy or power, but one of information.

Units need a competent and resilient network of team members that utilize the IAPW to operate in their nonsimple, interdependent, and interconnected environments. These IAPW provide organizational agility and capability. If leaders rely too heavily on strategies and workflow that provide rules and barriers or authoritative checklists for success, then they are doomed to failure in today's nonsimple environment. If organizations focus on empowering leaders with shared visions and collaborative skills that are able to establish and use innovative architectures and policies, then the organization can thrive and succeed in today's environment. Paul Van Riper [256] was a master of nonsimplicity thinking in military operations:

> It is past time to put our military thinking and writing back on firm ground.

The US military has built an information and decision-making superiority legend that needs to be made genuine. The United States relies on its command and control information systems and its intelligence gathering to provide operational coordination, situational awareness, and insightful leadership. These goals are enhanced with Complexity Science in the form of NCW, OODA loop, systems design, mission command, D2D, and MDB. Technology in the form of sensors provides the potential to understand the nonsimplicity of the battlefield. The IAPW could become the start point and focus for progress.

7.3.1 Future needs

Our world is changing at an incredible pace. Today, the US military has new operational missions on battlefields and environments that did not even exist in an earlier age. Faced with this inexorable march forward, more than ever, the US requires more than ever the opportunity for measured, reflective, and intelligent discourse to reinforce and grow the conception of military science, art, and leadership. In an era of nonsimple insurgencies and hybrid wars, shape-shifting and ill-defined enemies, and considerable cross-cultural friction, it is critical that our military leaders at all levels adeptly and intellectually navigate a wide range of strategic and tactical decisions. Our country needs leaders with military experience and skill to solve wicked nonsimple problems. The US Army seeks scholar-warriors who integrate their experience and skill with a deep intellectual and interdisciplinary approach and use Complexity Science to understand issues and to solve challenging problems. Using the Information Age Principles of War, the future force will be well-trained for many possible scenarios.

Military schools such as the service academies and war colleges exist to prepare these intellectual leaders for our nation and military. Many officers will continue their formal education through graduate-level schooling opportunities, both inside and outside the DoD, as their careers progress. War college graduates need to be the leaders in the Complexity Science effort, particularly since the role of a leader in the

Information Age is different from what it was in the Machine Age. It is encouraging to see military leadership recognize the need to modernize professional military education, but much more is needed [160, 201].

Intellectual engagement and deep thinking are not just the direct products of an educational degree. These traits are the hallmarks of a strong, adaptable, forward-thinking, and thoughtful professional leader. The US military should pursue opportunities to reinforce the role of scholarship and intellectual engagement among all military officers and leaders, while working to overcome the obstacles that restrict open discourse on the nonsimple challenges facing us today and in the future. We need intellectual engagement throughout the military with a regular program of events and cross-disciplinary networks designed to pursue and answer some of the large and vexing problems facing our nation today in the areas of military art, science, and leadership. As the IAPW indicate, future military success rests with the ability to think and adapt faster than the enemy and to operate effectively in a nonsimple environment of uncertainty, ambiguity, and unfamiliar cultural circumstances. With the complexity of cyberspace expanding its role in military operations, the very nature of military operations is changing, and the defense community is using nonsimplicity in inquiry and modeling as a paradigm for anticipating and reacting to those changes.

One way to do this is for the military to have its own learned society of inter- and multi-disciplinary scholars, military and civilian, seeking to impact military operations, structure, process, and networks. This community of scholars would continuously sift through alternatives and shift the paradigm to stay ahead of future defense issues and needs. Working with organizations like the Army's new Futures Command, such a society would endorse involvement from all disciplines at all levels of thought while seeking cooperation and collaboration to bring multiple perspectives to bear on the nonsimple issues facing the military. The United States had such a society in the early nineteenth century: the United States Military Philosophical Society (USMPS). All West Point cadets and faculty were members of the USMPS, along with the members of Congress. Even though the military struggled in the early years, the USMPS prospered, and by 1807, the Society was considered a focal point of scientific activity in America, especially in aspects related to military science (fortifications, ordnance, ballistics) and government organization. Regular monthly meetings were held and papers read. During that time, military science was firmly based on mathematics, mechanics, and science and thus the need for USMA to be a technology and engineering school. With today's warfare advancing of the cyber front, USMA faces challenges to remake itself as a new form of educational leader.

The USMPS was designed to support the study of science related to the military. Unfortunately, when the War of 1812 intervened, USMPS ended in November 1813, and that may have been the most significant loss of the war. It may well be time for the USMPS to again open its doors and guide the military into the nonsimple future of the Information Age. Building models and systems using nonsimplicity and CS will enable the future US military force to be prepared for the nonsimple events that will continually test our nation and the military.

POSTSCRIPT

The military strives to adopt strategies that work. Those strategies are extracted from previous military experiences and from the societies and services to which they belong. The new strategies are modulated to accommodate military values and missions. In the past, scientists explained why the adopted strategies worked or, as is more often the case, they apologized for why they did not work in the military in quite the same way as they did on society's broader stage. Recall that an apology is a formal, after-the-fact, justification for why things turned out the way they did. Scientists have rarely been in the position of being able to predict what will and what will not work in the human sciences and, therefore, they are reluctant to make socially grounded predictions.

However, the situation is changing. Scientists have only recently begun to address nonsimplicity head-on and have determined that information itself is uncertain, that it is only partly relevant as traditionally defined, and it has a limited shelf-life. An organization with information superiority can maintain that superiority for only a short time, during which it must decide what to do. This is the goal of the OODA loop as well. In that short time, it must determine how to implement the decision. This is as true in the military, as it is in the broader social context. In asymmetric warfare (unbalanced information warfare), information superiority ebbs and flows between adversaries, and those that anticipate what to do at the next stage of superiority gain a short-term advantage. Those that learn how to systematically use information superiority, increase the likelihood of their achieving it again at a later time, thereby gaining a longer-term advantage. The short time scale of cyber operations makes human decision making in cyber tenuous.

In asymmetric warfare, the force with the superior kinetics does not always win, because the battlespace often includes all of society and not just the traditional players on the battlefield. The battlespace is the entire Information-Age society, and the differences between the networking and cyber capabilities of the military and those of the adversarial, insurgent force become all-important. The rules and intent of each are different, so neither the enemy nor their purpose is always apparent. A Western society may build a large standing army to achieve a national policy objective, whereas a Middle Eastern group may infiltrate a series of schools and modify what is taught to the next generation. In this context, the distinction between combatant and civilian, as well as winning and losing are blurred to the point of indistinguishability, unless the intelligence process uses its nonsimple models to full effect.

NCW, of which the modern warfighter is the basic unit, converts information advantage into competitive advantage by creating processes and procedures through networking that otherwise could not exist. This network and cyber processing capability potentially leads to increased mission effectiveness. This military process involves the coevolution of the organization with the process. Without such coevolution, the organization and the modern warfighter would drown in an ocean of data. They would not be able to transform the deluge of data into a data-stream and then into information flow and ultimately into usable knowledge.

The multiple network interdependencies of NCW requires the 80/20 Rule, with its fully nonsimple way of thinking about how the military accomplishes its missions, how it organizes and interrelates, and how it acquires and fields the systems that support it. The road to success in warfare is based on nonsimplicity thinking, and it needs to be richly populated with analyses and experiments to recap the potential benefit and avoid the pitfalls of unintended consequences. Moreover, this new kind of warfare purports to facilitate the entire spectrum of military operations, from peacekeeping, deterrence, dissuasion, and cyber hacking, to violent clashes and sustained high-intensity conflict, including the countering of irregular catastrophic and disruptive threats.

The most vivid theatre of war today and into the foreseeable future is the downtown district of any city, which shields combatants behind civilians. The tactics, technology, and terrain of urban warfare are not those of traditional tanks and bombs. Rather, they include cyberattacks; cyber fog; booby traps; social media propaganda; remotely detonated, improvised explosive devices; and many more newly developed, urban tactics. In asymmetric warfare, the modern warfighter must determine in which houses the true enemy resides and destroy only those buildings, or attack only the correct apartment of the adversary. It is no longer the case that the enemy is on one side of a line and the allies are on the other, instead the two intermingle. The enemy is both far away and in the house next door. As part of the nonsimplicity of warfare being addressed in the twenty-first century, this requires a new kind of nonsimple situational awareness, one that finds and disrupts the connectivity of the enemy to social media and erodes its cyberspace. It is not the individual that is being identified; rather, it is the connection of the individual to a radical network that provides the modern warfighter with the certainty to engage, shoot, and kill. This is one of the lessons of warfare in the Information Age.

The military is not immune to the implications of Pareto's Law, so therefore, the warfighter on the battlefield must be trained to implement strategies that keep him and his unit in the 20%. Another way of putting this is warfighters need to implement strategies that keep them in the 80% that survive and still accomplish their mission. Sometimes you desire to be in the 20%; other times, it is the 80% that is preferred. We emphasize again the numbers in the 80/20 rule are not hard and fast, but are intended to denote the imbalance in the underlying process, nothing more. So the strategy is to minimize the friendly losses in any battle, with the goal of reducing them to zero, but in reality it is the imbalance in Pareto's Law that determines the outcome.

A phrase that may capture the ultimate strategy for the warfighter is Whack-A-Mole. As an arcade game, Whack-A-Mole players swing a mallet to strike toy moles and drive them back into their holes. There is a checkerboard of such holes and stealthy moles peak their heads out individually at random, so there is no way to predict where one will next appear. This image is applied to the practice of stopping something that occurs repeatedly and randomly at the point where it is observed. This is done to terminate a spam email; to close a pop-up advertisement; or to prevent phishing for private, sensitive information. But it is considered an inferior strategy because it only addresses the unwanted effect and not the underlying cause of the nuisance.

On its face, Whack-A-Mole seems to be a very poor strategy indeed. Would it not be better to have an overarching strategy that addresses the root cause in order to prevent the annoyances from occurring in the first place?

When the annoyance consists of a random sequence of uninvited interruptions to whatever you happen to be doing on the computer, the solution is straightforward. Write a few lines of code or buy some software to filter out the unwanted messages. This levels the playing field, keeping it free of disruption. But it is only a superficial solution since everyone else is still subject to the same sequence of uninvited interruptions. Here the simple, but annoying, problem is solved by filtering out your exposure to it. An in-depth solution would address the cause and suppress the random sequence entirely, rather than just adopting a technical strategy that still allowed the fluctuations to occur, but masked them from view.

What about nonsimple attacks upon truly nonsimple networks? Beyond a certain level of nonsimplicity, it appears that one is not able to smooth out the uninvited interruptions. But even if one were able to do so, would that be a smart thing to do? Taleb and Blyth [241] have argued that it would not. Their arguments address the fact that a truly chaotic network, by its nature, can neither be entirely deterministic, nor can it have simple statistical fluctuations. A nonsimple network has dynamics that retain a balance between regular and random behavior, with extreme values being more prevalent than in normal statistics. Now it is the extreme values that the observer regards as an annoyance, which he would try to suppress with an informed Whack-A-Mole strategy.

Having partial knowledge of the underlying process, a policy maker might institute regulations that eliminate annoyances. If successful, the new policies would suppress the relatively low-amplitude extrema, and it would appear that the playing field was now more level and mole-free. Government agencies are put into such positions all the time, being assigned tasks that are apparently desirable, but practically unrealizable. A charge given to the Department of Homeland Security is to completely suppress the number of terrorist attacks within the United States. But is that a sustainable steady state? A challenge assigned to the Center for Disease Control is to completely eliminate epidemics, large and small, throughout the country. But is that a realistic goal?

If these agencies temporarily achieved their assigned tasks it would only be an illusion. In the undetected, if not undetectable, background, the process would be suppressing extrema near the center of the distribution and forcing them out into the tails. Eventually, these previously released extrema would go into the making of catastrophic fluctuations in a Pareto distribution. These large extreme values, when they do occur, might completely destroy the fabric of the process. Consider an individual raised in a sterile environment. Being protected from low-level exposure to germs, the person never develops the antibodies necessary to survive more severe contacts. This disease-free upbringing looks attractive, but it has deprived the individual of the adaptive development that is the modern endpoint of evolution. He has traded a number of brief illnesses to which he could adapt, for a single large extrema that could be fatal.

We know that the size of terrorist attacks has a Pareto distribution, with the number of deaths in the 9/11 attack being the largest so far. Consequently, by completely eliminating the uncoordinated “lone wolf” terrorist attacks, the likelihood increases that the next attack will surpass

9/11 in sheer horror. With this in mind, Whack-A-Mole might seem like a mindless reactionary strategy, but it avoids the tragic illusion that anyone is in absolute control. It also acknowledges that nonsimple problems on the battlefield, or in cyberspace, are only solved in the short-term. The warfighter that embraces the intrinsic uncertainty in both the cyber and physical battlespaces, making them part of situational awareness, and decision-making components, greatly enhances the likelihood of successfully whacking the nearby moles that are an immediate threat and thereby surviving.

Recognizing the nonsimplicity of warfare will provide the context to improve the capabilities of both the warfighter and the policymaker and build the foundation for the evolution and revolution of modern military and cyber systems.

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