The Many Roots of Complexity Science

Joseph K. DeRosa
MITRE Corporation, Bedford, MA USA
jderosa@mitre.org

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Preface

The Roots of Rock and Roll go deep into Gospel, Rhythm and Blues, Folk and Bluegrass - even the familiar I-IV-I-V-IV-I chord progressions can be found in Bach and Beethoven. When Elvis Presley and the Beatles appeared on the Ed Sullivan Show in 1956 and 1964, it was significant because huge audiences tuned in every Sunday night at 8:00 PM. Rock and Roll became a legitimate part of the culture. When the Rolling stones hit the concert circuit in 1969, it was significant because they were billed as the greatest rock and roll band in the world, but also because they became drugs-sex-rock-and-roll cultural icons of the new social norms. Decades later, the rock and roll trajectory has led us to unimagined places like MTV and the iPOD.

Here at the Santa Fe Institute (SFI) Complex Systems Summer School (CSSS), we are all swaying to the beat of **Complexity Science's Rock and Roll**. Our roots are in physics, biology, sociology, etc. Collectively we know the "who, what, when, where and why" of the key milestones from our respective our fields that constitute **the Roots of Complexity Science**. This is a project for all those from the CSSS Class of 2007 (as well as any wishing to continue it in coming years) who have a passion to help capture those roots for posterity. Who knows where the complexity trajectory will lead several decades from now?

Introduction

This is a simple project aimed at capturing the multidisciplinary roots of complexity science. It set up a Wiki at SFI to which any member of the CSSS 2007 could contribute. A Wiki is a collaborative website which can be directly edited by anyone with access to it.[1] Thus, the project attempted to leverage the diversity in the CSSS 2007 to expose some of the strong roots in the evolutionary tree of complexity science. The class of 2007 consisted of 61 students from around the world, e.g., Australia, China, Europe, Israel, Pakistan, South America and the United States. People came from academic disciplines as diverse as Engineering, Biology, Physics, Medicine, and Social Science. The project goal was to extract the roots of complexity science from the wisdom in this crowd. [2]

The Wiki

The "Many Roots of Complexity Science" Wiki resides at the Uniform Resource Locator

http://www.santafe.edu/events/workshops/index.php/The_Many_Roots_of_Complexity_Science

It contains four simple headings:

1. Post Your Favorite Roots (in Chronological Order if you can)
2. Use This Simple Template: (or refine it)
3. Team Members and Contributors
4. Explanation of Project

The template asked for the Date of the milestone, it's Creator, it's Name and a Brief Description telling its significance. It also asked for the Contributors Name so we could backtrack if desired. One example from the Wiki is:

> **1976 - Richard Dawkins** publishes *The selfish gene* Caused a massive stink at the time, and is still highly debated now, but remains a brilliant book no matter how right or wrong you think it is. (Contributed by Hannah Cornish).

As of 14 August there were forty entries, sixteen of them anonymous and the rest from eight known contributors. One other person, Rhonda BeLue, had enough passion for history to sign up to be on the Wiki Project team, - although the team never really met. Most entries came during the last week of the CSSS and ranged from an 1832 milestone (Carl von Clausewitz, On War) to a 2003 milestone (Lempert, Popper, Banks, Shaping the Next One Hundred Years: New Methods for Quantitative, Long-Term Policy).

The contributions span the fields of Political Science, Physics, Biology, World History, Networks, Turbulence Theory, Cybernetics, System Dynamics, Management Science and Systems Theory. **Go there now and see if your favorite "root" is listed. If not, add it!**

Content of the Wiki as of 14 August 2007

1832 - Carl Von Clausewitz (well, his widow) published **On War**. One of the two most important works in the history of military and strategic thought. Clausewitz's *On War* marks the introduction to warfare as an act of politics, which is non-linear in nature. While frequently criticized as a proponent of attrition and total warfare, such interpretations miss the fact that Clausewitz rejected total war as a practical model of conflict by noting that real-world experience shows that few conflicts are carried to their logical and absolute extreme. Instead, Clausewitz sought a theory that coupled violence of politics, human emotion and judgment, and complex interactions and probability (Contributed by Aaron Frank). On War

1937 - Landau published *On the Theory of Phase Transitions... [Landau1937]* The history of the theory of critical phenomena and phase transitions starts with Landau's works of 1937, where he introduced fundamental notions of spontaneous symmetry violation and the order parameter as a measure of this violation. It is impossible to exaggerate the impact which this idea had on practically all branches of physics and non-linear mechanics. Due to the concept of the order parameter, phase transition theory became a cross-disciplinary branch of science, much like the theory of oscillations. Landau gave simple prescriptions, how to describe order in terms of irreducible representations of the symmetry group. Around 1960 Landau formulated the general problem of fluctuation-driven phase transitions via a calculation of the path integral over all configurations of the order parameter. [Landau1937] L.D. Landau, ZhETF 7, 19 (1937); Phys. Zs. Sowjet. 11, 26 (1937).

1941 - Kolmogorov proposed a scaling approach for hydrodynamic turbulence. [Kolmogorov1941] A.N. Kolmogorov, DAN SSSR, 30, 299; Ib. 31, 99 (1941).

1944 - Onsager published an exact solution of the 2-d Ising model [Onsager1944], a truly exceptional (even singular) accomplishment. As of 2007, despite numerous attempts, 3D Ising model has eluded exact solution. It is even conjectured that the exact solution is in general not possible. [Onsager1944] L. Onsager, Phys, Rev. 65, 117 (1944);

1944 - Erwin Schrodinger published *What is Life?* I'm not the right person to speak to it's biological significance, but apparently it was a source of inspiration for Watson and Crick. It is an amazing read regarding both the nature of science, the relationships between statistics and laws, and transitions between cells as matter and cells as life (Contributed by Aaron Frank). What is Life?

1948 - Norbert Wiener published *Cybernetics* He used the newly formed fields of statistical Information and Control Theory to establish the role of feedback and nonlinearity in engineering design and biology. [Cybernetics] *(Contributed by J. DeRosa)*

1948 - Claude E. Shannon published **A Mathematical Theory of Communication** The beginning of information theory. The paper is here [Information Theory] *(Contributed by Owen Densmore)*

1950 - Norbert Weiner published *The Human Use of Human Beings*

In this companion book to Cybernetics, Weiner expounded on the principles of Cybernetics with no equations and warned of the dangers of scientific research that did not consider the social implications of the technology and research. [Cybernetics] *(Contributed by J. DeRosa)*

1956 - W. Ross Ashby published by his estate *Cybernetics* Available online at http://prp.vub.ac.be/books/introCyb.pdf This book precisely defines the principles of cybernetics as applied to systems. It is a precursor to the work of Wiener and Shannon. A classic for anyone intersted in General Systems Theory. This is a deep root.

1958 - Norbert Weiner published *Nonlinear Problems in Random Theory* This book is decidedly mathematical and lays out the framework for the general functional analysis of nonlinear systems. For a clear exposition of the mathematics see the book written by one of his students M. Schetzen *The Volterra and Wiener Theory of Nonlinear Sy*stems [System Theory] *(Contributed by J. DeRosa)*

1959 - It is realized [Levanyuk1959],[Ginsburg1960] that mean field theory neglects fluctuations which grow rapidly near the phase transition point. Thus, mean field theory works well outside a small vicinity of the transition point and is invalidated by fluctuations within it. In this way the necessity to include fluctuations in phase transition theory was first recognized. Simultaneously Fisher [Fisher1959] approached the problem by attempting to generalize Onsager's results to non-exactly-solvable problems. By introducing critical exponents he made the decisive step to scaling. [Levanyuk1959] A.I. Levanyuk, ZhETF 36, 810 (1959); [Fisher1959] M.E. Fisher, Physica 25, 521 (1959); [Ginsburg1960] V.L. Ginsburg, Fizika Tverdogo Tela (Solid State Physics, in Russian) 2, 2034 (1960).

1961 -Industrial dynamics. Pegasus Communications. Forrester Forrester is the founder of System Dynamics, which deals with the simulation of interactions between objects in dynamic systemsIndustrial Dynamics was the first book Forrester wrote using System Dynamics to analyze industrial business cycles. '*Contributed by R. BeLue)*

1964 - Patashinskii and Pokrovskii in Russia formulated the field theory equations and conjectured correctly that the correlation functions of any order should obey scaling laws [Patashin1964]. Soon thereafter, they introduced the theory of scaling [Patashin1966], first presented at the International Symposium on Phase Transitions in Dubna, May 1965. The physical picture was that, for critical fluctuations the distribution of the order parameter remains invariant with temperature if the length scale and other observables are adjusted properly. The theory was physically equivalent to Kadanoff's formulation, which was published 4 months later[Kadanoff1966]. In addition, in his work Kadanoff first formulated a program of elimination of short-range degrees of freedom by decimation of spin blocks, an embryo of the Wilson Renormalization Group, though still not a practical tool for calculations. [Patashin1964] A.Z. Patashinskii and V.L. Pokrovskii,

ZhETF, 50, 439 (1964) [Sov. Phys. JETP 19, 677 (1964)]; [Patashin1966] A.Z. Patashinskii and V.L. Pokrovskii, ZhETF 50, 439 (1966) [Sov. Phys. JETP 23, 292 (1966)]; [Kadanoff1966] L.P. Kadanoff, Physics 2, 263 (1966).

1968 - Polyakov and Migdal used such physical requirements as causality and unitarity, which permitted, in principle, numerical calculations of the critical exponents [Pol1968], [Mig1968]. Unfortunately, the equations were too complicated to solve using computers of that time. [Pol1968] A.M. Polyakov, ZhETF 55, 1026 (1968) [Sov. Phys. JETP 28, 533 (1969)]. [Mig1968] A.A. Migdal, ZhETF 55, 1964 (1968) [Sov. Phys. JETP 28, 1036 (1969)].

1971 - Kadanoff and Wegner proved the universality hypothesis. [Kadanoff1971] L.P. Kadanoff and F.J. Wegner, Phys. Rev. B4, 3989 (1971). According to this hypothesis, the critical behavior is determined by symmetry and how it is violated. All phase transitions may be divided into universality classes.

1972 - Ackoff (updated in 2006) publishe **On Purposeful Systems** Ackoff is the Wharton School grand master of using puposeful (teleological) systems in the analysis of business enterprises. He has great anecdotes, like "why is it when you have a headache you put an aspirin in your stomach, but when there is problem in sales, they fire the sales manager?" COULD COMPLEXITY BE LURKING? [See the citation for Gharajedaghi for more in Ackoff]

1972 - Wilson introduced renormalization group approach, which elucidated the structure of the theory to the extent that standard methods could be employed. This effectively marks the birth of the theory of phase transitions, scaling and renormalization group as we know it today. Kenneth Wilson went on to receive a Nobel Prize in Physics, 1982. [Wilson1972] K.G. Wilson, Phys, Rev. Lett. 28, 548 (1972).

1976 - Richard Dawkins publishes *The selfish gene* Caused a massive stink at the time, and is still highly debated now, but remains a brilliant book no matter how right or wrong you think it is. (Contributed by Hannah Cornish).

1977 - Ilya Prigogine wins the *Nobel Prize in Chemistry* For his groundbreaking work in non-equilibrium thermodynamics-especially non-dissipative structures. [Chemistry] *(Contributed by J. DeRosa)*

1978- Thomas Schelling published **Micromotives and Macrobehavior** Contains the seminal article on racial segregation which is now referred to as the Schelling Model. The book marks a notable departure from Schelling's previous work on military strategy and deterrence, but retains his emphasis on strategic interaction and emergence (Contributed by Aaron Frank). Micromotives and Macrobehavior

1981 - Peter Checkland published *Systems Thinking, Systems Practice* but the 1999 edition has a 30 year perspective on the hard verses soft sciences applied to systems

thinking. Checkland represents a class of engineers who are applying complexity science to real-world problems.

1984 - Ilya Prigogine and Isabelle Stengers publish *Order out of Chaos: Man's New Dialogue with Nature* A brilliant account of the journey from Newtonian science to complex dynamical systems. An emphasis on thermodynamics and dissipative structures. One of the works that triggered the study of complexity science. [Chemistry] *(Contributed by J. DeRosa)*

1985 - Robert Axelrod published **The Evolution of Cooperation**. Probably the most famous analysis of the iterated Prisoner's Dilemma (IPD) game, conducted via a computational round-robin tournament (Contributed by Aaron Frank). The Evolution of Cooperation

1992 - William McNeill published **The Global Condition: Conquerors, Catastrophes, & Human Community**. This book is a series of lectures that McNeill delivered Clark University in 1979. They mark a concise description of his view of world history as the interplay between human purposes and worldly processes, and the interactions between three dissipative systems - physical, biological, and symbolic. A short and powerful read by the founder of modern world history, and former member of SFI's Research Board (Contributed by Aaron Frank). The Global Condition

1992 - M. Mitchell Waldrop published **Complexity: The Emerging Science at the Edge of Chaos**. This pop science book described the basic ideas, spirit, and driving forces behind complexity theory and the founding of the Santa Fe Institute. It brought the world of complexity science to the attention of the general public. –Contributed by Mpoynton 16:43, 27 June 2007 (MDT)

1995 - John H. Holland published *Hidden Order* This is the book in which John Holland made the famous quote "...with a careful research plan,under controlled conditions, using selected agents, complex adaptive systems do pretty much what they damn please." [Complexity]

1995 - Clifford Rogers published **The Military Revolution Debate**. This book is a collection of articles on military history. The articles review the definition and consequences of the *Military Revolution* in early modern Europe, a period of far reaching technological, social, economic, and political change - starting a process that ended feudalism in Europe, gave birth to the modern nation state, and European global exploration and colonization. Most importantly, it marks one of the first instances where Stephen Gould's concept of punctuated equilibrium is advanced as a hypothesis for explaining radical and rapid military and political change (Contributed by Aaron Frank). The Military Revolution Debate

1996 - Ervin Laszlo published **The Systems View of the World**. Like many of the books oulined here, this is about complexity and a holistic view of the world, but with one main exception: it is done from the viewpoint of the Systems Theorist.

1996 - Herbert Simon published the 3rd edition of **The Sciences of the Artificial**. A critical examination of systems design, development, and adaption. Simon advances a science of design beginning from the simplest of systems and works his way through the relationship between complexity and hierarchy. In the process he travels through psychology, computer science, economics, policy analysis and engineering, and even the departmental architecture of modern universities (Contributed by Aaron Frank). The Sciences of the Artificial

1997 - Alfred Crosby published **The Measure of Reality: Quantification in Western Europe, 1250-1600**. Don't be fooled by the title, this is a fascinating book about how our very understanding of the world itself was transformed by shedding numbers of their qualitative properties, inventing systems of measurement, and devising tools and methods for information categorization and visualization. I suspect that our collective efforts in theorizing, measuring, and visualizing complex, non-linear systems may be akin to the challenges posed by the earlier efforts to conceive of time and space, and that similar breakthroughs may (hopefully) be evident in our own lifetimes (Contributed by Aaron Frank). The Measure of Reality

1997 - Yaneer Bar Yam, published **Dynamics of Complex Systems**. This is a highly technical and wide-ranging book on modern complexity theory. Yaneer operates the New England Complex Systems Institute (NECSI)and each year hosts the International Conference on Complex Systems. Think of him as SFI-East - only smaller.

1997 - Geoffrey West, Jim Brown, and Brian Enquist, published their first paper explaining the fractal origin of quarter power scaling in biology. This collaboration between an SFI/LANL physicist and two UNM biologists continues to rock ecology (from Paul H.).

1999 - Jamshid Gharajedaghi published the **Systems Thinking**. This is a must for those interested in the the management sciences. Gharajedaghi was Science Advisor to the Shah of Iran, who had lots of PhD's running the countries modernization programs. But something was wrong. Things were not working as planned. They hired Russ Ackoff from Wharton to help, and he and Gharajedaghi started what is today know as Systems Thinking in business. *(Contributed by J. DeRosa)*

1999 - Gary William Flake published the **The Computational Beauty of Nature**. Computer explorations of fractals, chaos, complex systems and adaptation. (Contributed by --Luciano Oviedo 19:03, 24 June 2007 (MDT))

1999 - Charles Perrow published the updated version of **Normal Accidents: Living with High Risk Technologies**. This is seminal work on the social aspects of complex technologies and technical systems that have become essential components of modern society, yet contain unknowable failure modes. Importantly, Provides a framework analyzing and characterizing complex technical systems, making the book more than just a historical accounting of well known accidents such as Three-Mile Island and the Challenger (Contributed by Aaron Frank). Normal Accidents

1999 - Duncan J. Watts published the **Small Worlds**. An SFI veteran from Princeton. You want ot know about the small world phenomenon in networks, go here. This is the Watts of Watts and Strogatz fame.

2002 - Stephen Wolfram published **A New Kind of Science**. A tome on using discrete dynamical systems (focussing on cellular automata) as tools to study complexity in real world systems and the nature of complexity itself. Note that much of the underlying science was published in Wolfram's journal articles in the 1980's. Important to note also is that many consider parts of the work as controversial for taking the ideas too far. (Contributed by Joseph_Lizier). See Wolfram Science

2002 - John Lewis Gaddis published **The Landscape of History: How Historians Map the Past**. An excellent examination of the theory and practice of history through the lens of complexity, with strong emphasis on the nature of evolution, the role of contingency, and the role of historian as an interpreter of past (Contributed by Aaron Frank). The Landscape of History

2002 - Philip Bobbitt published **The Shield of Achilles: War, Peace, and the Course of History**. Bobbitt puts forward a theory of politics and history that fuses international politics and strategy with domestic politics and constitutional law. Bobbitt argues that states exist between the competing demands of international survival and the constraints of domestic legitimacy and constitutional order. The book is both a large scale conceptual application of Simon's *Science of Design* advanced in **The Sciences of the Artificial**, and an examination of application of *evolution* applied to the creation and endurance of independent polities (Contributed by Aaron Frank). The Shield of Achilles

2003 - Robert Lempert, Steven Popper, and Steven Bankes published **Shaping the Next One Hundred Years: New Methods for Quantitative, long-Term policy Analysis**. A powerful revisioning of policy analysis under the condition of "deep uncertainty." The authors work the history of and methodology of thinking about the future, and then develop a method of computational analysis for coping with inevitable and irresolvable uncertainties in order to develop strategies and polices that a designed to robust and adaptive (Contributed by Aaron Frank). Shaping the Next One Hundred Years

EndNotes

[1] Wikipedia, http://en.wikipedia.org/wiki/Wiki
[2] See Surowiecki, The Wisdom of the Crowds, Anchor Books, New York, 2004