Introduction to Complex Adaptive Systems and Risk Analysis

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This article presents various concepts for security managers and directors to get a brief introduction to complexity theory and its relevance to risk analysis. The first part of this article is to introduce the concept of complexity in various environments, and the second part presents how it relates to risk analysis.

The structures and tools that we have developed in the area of risk identification and risk management are fairly well developed. Most of us in the security industry understand that risk is fundamental to our profession. How we assess risks, identify risks and analyze risks are all already part of standardized processes. One of those frameworks is known as the ISO 31000, "Risk Management – Principles and Guidelines" standard. How we treat or manage risks as they are applied to business operations is another known standard, ISO 22301 "Business Continuity Management Systems". The application of the two standards together with the consideration of "opportunities" is considered Enterprise Risk Mangement (ERM). Consensus of definition defines ERM as the "methods and processes used by organizations to manage risks and seize opportunities related to the achievement of their objectives."

However, one consideration that is not well known for security directors and managers is when and where do we apply those tools. What types of risk assessment and identification are scientifically valid in terms of the context to which they are applied? In what operating environments do they work or do not work well? Are we sufficiently informed as to which environment we are currently operating in? To answer these questions we must understand the operating environment. Is it an "ordered" environment or an "nonordered" environment?

The best framework that I have seen over the years comes from a physicist and philosopher, David John Snowden. He proposed back in 2009 a framework on understanding complexity, known as the Cynefin Framework. This framework gives us insight as to distinctions between operating environments based upon their respective level of complexity. "Cynefin" is a Welsh term that means habitat, or your place of multiple belongings. The Cynefin Framework is represented by four quadrants, much like the four quadrants we learned about in algebra in high school. Don't worry, we will not go into algebra here in this article, but we will use some mathematical representations such as the Cartesian plane to help better visualize the this innovative framework.

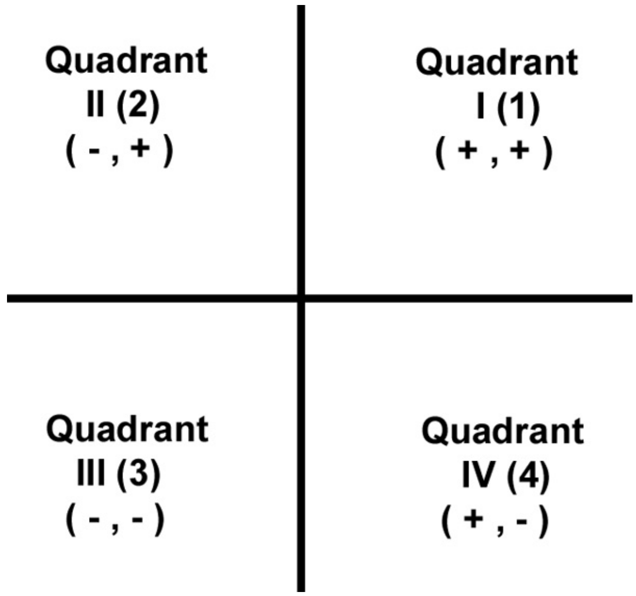
“Chaos was the law of nature; Order was the dream of man.”
- Henry Brooks Adams (1838 -1918)

Orientation and Coordination

René Descartés, (1596-1650), a French mathematician, helped us orient ourselves with respect to two variables. The Cartesian coordinate system is a coordinate system that specifies each point uniquely in a plane by a set of numerical coordinates, which are the signed distances to the point from two fixed perpendicular oriented lines, measured in the same unit of length. Each reference line is called a coordinate axis or just axis (plural axes) of the system, and the point where they meet is its origin, at ordered pair (0, 0). The coordinates can also be defined as the positions of the perpendicular projections of the point onto the two axes, expressed as signed distances from the origin.

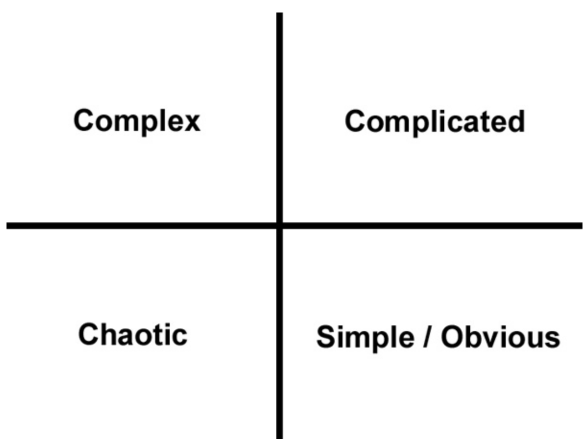
The axes of a two-dimensional Cartesian system divide the plane into four infinite regions, called quadrants, each bounded by two half-axes. These are often numbered from 1st to 4th and denoted by Roman numerals: I (where the signs of the (x ; y) coordinates are I (+ ; +), II (- ; +), III (- ; -), and IV (+ ; -). And for those of you who actually enjoyed trigonometry and the functions of sine and cosine, appreciated the I, II, III, IV, quadrants as they helped us make more sense of those functions over time.

This simple two dimensional framework helps us understand relations between two variables (x and y), or the behavior of a mathematical function $f(x) = ax^2 + bx + c$. But the Cartesian plane is represented here to give us a known framework, something familiar from our educational past, a sort of “cultural or technical literacy” reference if you will.



Visualizing Levels of Complexity

The level of complexity increases in a counter-clockwise fashion starting from the lower right-hand quadrant (Quadrant 4) with the “Simple / Obvious” in the Cynefin Framework.



The Cynefin Framework on Complexity, created by David John Snowden, a Welsh philosopher and physicist in the area of knowledge management.

Complex Visualization: game of poker	**Complicated** Visualization: game of chess
Chaotic Visualization: warfare, battlefield conditions	**Simple / Obvious** Visualization: game of Tic-Tac-Toe

Simple / Obvious domain:

A simple game of Tic-tac-toe represents the simple and predictable outcomes. One can win, lose or draw, the outcomes are finite. We all remember from our childhoods playing the simple game of Tic-tac-toe (also known in the UK as “noughts and crosses”). Most Tic-tac-toe games will end in a draw if both players are experienced. However, there are a lot of possible games to be played. There are 255,168 possible games of Tic-tac-toe excluding symmetry. But now that you are thinking about that number, you realize it is not that simple, eh? But it is a start!

Complicated domain:

Chess can be very complicated. The possible combinations and permutations are numerous. The “Shannon Number”, named after Claude Shannon, is a conservative lower bound (not an estimate) of the game-tree complexity of chess moves of 10 to the power of 120, based on an average of about 10 to the power of 3 possibilities for a pair of moves consisting of a move for White followed by one for Black, and a typical game lasting about 40 such pairs of moves. That is to say that after each player has moved 5 times each (10 total moves) there are 69,352,859,712,417 possible games that could have been played. That is a lot of moves, a lot of possible outcomes! Can it get even more complicated?

Complex domain:

The game of poker is complex. The game of poker is usually represented here to help people visualize complexity. But this game is a complex adaptive system as the players (agents) within the system are “interconnected” as they are in communication with each other. They are also “interdependent”, they depend on information captured from the other opponents. Good poker players understand the importance of the “poker face” and thus deny information to the other players. Professional players, like professional investigators understand the importance of microexpressions and their relevance given certain stimuli. The number of possibilities in a in a 52 card deck Five-Card Poker, there are 52 cards of which we choose 5, with 2,598,960 ways of drawing a hand. So not only do you have to deal with the mathematical combinatorics, but you have to deal with human psychology as well.

Chaotic domain:

This is the complexity domain that people, be they CEOs, presidents, managers or battlefield commanders do not wish to stay in for very long. This is the domain of chaos, where linearity and predictability is not readily apparent. This is a nonordered domain that is very different than the ordered domains of the Complicated and the Simple/obvious. The idea is that when one finds himself or herself here, move out of this domain as soon as possible. This is the domain in which there is no order, there is no linearity, there is no clear sequence of causality. However, there is or are deeper levels of order that do occur in this apparent randomness. This is the domain of “Chaos Theory” a branch of mathematics focusing on the behavior of systems that are highly sensitive to initial conditions, yet exist underlying patterns, constant feedback loops, repetition, self-similarity, fractals, self-organization… One might have heard of the “Butterfly Effect” of Chaos, a paper presented in 1972 by Edward Lorenz to the American Association for the Advancement of Science in Washington, D.C., entitled Predictability: Does the Flap of a Butterfly's Wings in Brazil set off a Tornado in Texas?. Yes, this is the domain where causality is not very clear!

To summarize, the Cynefin Framework gives us greater insight as to the complexity of the environment that we are operating in. Again it is about deterimining the level of cause and effect in terms of predictability. And this is based on the behavior of the agents within the system. In the domain of Simple/Obvious, the agents are predictable each and everytime you conduct the experiment. In the more complicated domain, the domain of Complicated, there still exist “order” as we have in the Simple/Obvious domain, and the interaction between the agents in the domain or system are still predictable. This all changes when we move out of the “ordered” domains, and into the “nonordered” domains of the Complex and the Chaotic. Now in the nonordered domain of the Complex the level of interaction between the agents of the system are not so easily predictable. In fact, the interactions are almost different each and every time. However, more general patterns become discernable, and this is referred to as “emergent” behavior. Finally, we have the Chaotic domain, another nonordered domain, where again the interactions between agents are completely undeterminable, and therefore unpredicable. Cause and effect do occur, but we can not know or determine the exact process.

Complex Material Science: Silicon Dioxide, SiO_2 Form: Amethyst crystal Impurities due to Transistion metals	**Complicated** Material Science: Silicon Dioxide, SiO_2 Form: Quartz crystal
Chaotic Material Science: Silicon Dioxide, SiO_2 Form: Glass	**Simple / Obvious** Material Science: Silicon, “Si” number 14 Oxygen, “O” number 8

Material Science Analogy

To further the explain of the Cynefin Framework let us try the superimposition of material science to the framework and see possible correspondences or similar structures using a more concrete example. Let us use silicon dioxide, one of the most common minerals on Earth as an example. Silicon dioxide (SiO_2) is the major ingredient in sand so to speak. It also has beautiful manifestations in the form of crystals. Remember a crystal is an ordered form or “iteratively” repeated structure at the molecular level. Atoms of silicon and oxygen combine to form unit cells (molecules) in an orderly fashion (a “lattice”), which create what we know as crystals. In a very pure form, the quartz crystal is hexagonal and clear visually. But when there is presence of other “impurities” you get wonderful color variations, such as impurities of iron (Fe 26) in the matrix of silicon dioxide to get the purple amethyst crystal.

Just remember, crystal structures are highly ordered at the molecular level, the three-dimentional structures are repeated over and over again in the lattice. On the other hand, we have nonordered structures. When you have nonordered structures of silicon dioxide you have what we know as glass. Glass is clear and translucent, but not as clear and translucent as crystal. So from the simple components of silicon (Si 14) and that of Oxygen (O 8) we have many different forms or manifestations of a simple compound.

So there we have distinctions between ordered and nonordered systems using silicon dioxide molecules; simple molecules of silicon and oxygen are represented in the Simple / Obvious domain. Then we have ordered, structured, iterative molecules of silicon dioxide (SiO_2) that give us beautiful quartz crystals and we place them in the Complicated domain. Followed by a more complex situation where we have some added complexity of impurities from iron to form wonderful purple Amethyst crystals representing the Complex domain. Finally, in the more nonordered structures of silicon dioxide (SiO_2) in the form of glass to represent the Chaotic domain. To recap, the silicon dioxide molecule when it is in an ordered self-similar and repeating lattice structure forms a crystal, but that same molecule of silicon dioxide when not in that ordered state, forms what we know as glass. So, same material, but different states of order.

“In all chaos there is a cosmos, in all disorder a secret order.”
- Carl Jung (1875 –1961)

Understanding Competition between Agents using Game Theory

The use of the games previously as a metaphor is not by accident. Any time you have “agents” of a system in competition with one or another, an excellent tool kit to use is one found in “Game Theory”. Game theory is the study of mathematical models of strategic interactions between rational decisionmakers. In game theory, one looks first to which framework one is operating or where the interaction (“game’) is taking place. For example, in decision making situations, one first orients as to one of three possible situations: 1. Deterministic situation, 2. Probablistic situation, 3. Uncertainty situation. Again, the first thing you must do before you pick up this tool of “Game Theory” is to decide if there exists competition between the agents. Then you must decide in which of the three situations is this tool to be applied. Same for risk management, right? First you must orient yourself to the possible events that could affect your people, your installations and your information that you wish to protect (Remember, the first step in risk management is to identify the assets you wish to protect). Then once you have identified those harmful events, you assign the probability of occurrence of each event. At first face “prima facia” it seems fairly simple, no? But what about dealing with more abstract classes of things? If you want to talk about abstractions a great place to start is that of Systems Sciences.

Systems Sciences and Complex Systems Theory

Ludwig von Bertalanffy (1901-1972) was an Austrian biologist and founder of General Systems Theory (GST). General systems theory is about broadly applicable concepts and principles, as opposed to concepts and principles applicable to one domain of knowledge. It is a sort of “meta” or "super" template or framework that identifies similarities or similar structures between different systems and subsystems. Basically what GST does is to identify commonalities or "isomorphisms" between apparently different areas of fields of study. It is this superimposition of cross-disciplinary studies that generate new ideas within different fields of study. Personally, I have always visualized those transparencies of the “overhead” project (remember those?), and if you line up one transparency over another you will have a composite image. In otherword if you line up a model of social interactions of community with a model of political interactions of that same community, you will have a better composite of what the community is actually doing. So one tool that is applied to one field, is modified slightly to apply to another field, and so on. How again did the System Sciences evolve over time?

Notions and Emergence of Systems Consciousness

System Sciences essentially laid the ground work for Complex Systems Theory back in the 1934 with Bertlanffy's publication on GST. But GST had concepts already from other great scientists and mathematicians such as Issac Newton (1642-1727) and Henri Poincaré (1854-1912) in Dynamical Systems Theory in the 1940s and 1950s. Almost simultaneously in other disciplines such as Cybernetics from Claude Shannon (1916-2001), Walter Pitts (1923-1969) and Warren McCulloch (1898–1969) in Artificial Intelligence. Later in the 1970s and early 1980s we have the emergence of Chaos Theory from Tien Yien Li and James Yorke, and finally with David John Snowden in Applied Complexity in the mid 2000s along with many other such as Luca Bertonlini (Transportation / Urban Planning), Jennifer Wells (Sustainability/Transformative Studies), Yorghos Apostolopoulos (Population Health), Juniper Lovato (Complexity Education).

The most important thing to gather from this historical perspective of the systems sciences is that we see the principle of "emergence" in our collective consciousness. (Definition of emergence: the process through which the interaction between elements gives rise to something more than the sum of their parts in isolation.) We note historically that it was not a single scientist or engineer that had a complete picture of System Sciences, but rather it was the "interaction between these agents", these scientists, through the exchange of information that elevated our collective consciousness in this field of study. Can Systems Sciences be applied to Risk Management?

Risk Management and Categorization / Classification:

Placing events respectively in relation to their probabilities of occurrence and their severity helps us orient ourselves to our landscape of risk and is an excellent step in orienting ourselves to the situation at hand. The visual manifestation of this are matrices, such as the 4 x 4 matrices used in risk management (see below). Recall from Enterprise Risk Management and ISO 31000 where we start with assessing the risks so as to classify them with respect to the probability of occurance. On the Y axis we have Rare, Unlikely, Possible and Probable, and on the X axis we have Low, Medium, High, Very High.

Probable	4 Moderate	8 Major	12 Severe	16 Severe
Possible	3 Minor	6 Moderate	9 Major	12 Severe
Unlikely	2 Minor	4 Moderate	6 Moderate	8 Major
Rare	2 Minor	4 Minor	6 Minor	8 Moderate
	Low	Medium	High	Very High

Categorization of events and their respective likelihoods and severities helps us visualize or conceptualize order or level of order within a certain domain. The very nature of constructing the 4x4 matrix or even a 5x5 matrix starts us thinking ("categorizing") in terms of probability of occurrence and severity of an event once it occurs. But is this not the process of "orienting" ourselves to the situation? Is there a specific algorithm or sequence that we might use? Does there exist a step-wise procedure?

Decision Making Processes and the OODA Loop

The OODA Loop from the 1950's was the framework of USAF's Coronel John Boyd, a military analyst that was assigned the task to reduce the number of fighter plane losses against the Soviet Union. The OODA Loop is an acronym for a decision procedure: Observe, Orient, Decide and Act. For the purposes of mapping one system to another (linkage), here the term "observe" is the same as "sense" (Snowden uses the term "sense" in referring to events). Here we are making the mental comparison between Boyd's OODA Cycle and the Cynefin Framework's decision processes: Obvious/simple domain has the decision process of: sense, categorize, act. The Complicated domain has the decision process of: sense, analyze, act. The Complex domain has the decision process: probe, sense, act. And finally the Chaotic domain has the decision process: act, sense, act. Here the final action is taken to move out of the Chaotic domain as soon as possible, with the goal to move into a more ordered domain such as the Complicated or Simple/Obvious domain.

This process of observation first and then orientation second is key. But remember, first you have to observe (or sense), before you can orientate yourself to the problem at hand. That simple decision process of Boyd's OODA Loop; Observe, Orient, Decide, Act "maps" or corresponds well into the Cynefin Framework's processess:

1. Observe first, "Which domain of complexity am I currently in?"

2. Orient, "How am I in relation to the "agents" of that domain? Are there many agents? Are they interconnected? Are they interdependent? Are they autonomous?"

3. Decide, "Sense, Categorize, Act" if in the Simple/Obvious domain, "Sense, Analyze, Act" if in the Complicated domain, "Probe, Analyze, Act" if in the Complex domain, "Act, Analyze, Act" if in the Chaotic domain.

4. Act: Implement those decision processes.

As we can see, the decision processes or sequences are very similar between those of John Boyd's OODA Loop and those of David John Snowden's Cynefin Framework, correct?

Decision Making and Management in Complex Environments

David Snowden is a well known consultant in the area of knowledge management. Having worked in programming and information management for many years, he apparently made very interesting observations and conclusions as to consulting in business management and especially in the field of software management (On YouTube you will find a lot of references to Cynefin and Agile, Kanban, and Scrum. "Scrum" is an agile framework for managing knowledge work, with an emphasis on software development, although it has wide application in other fields. Kanban means "billboard" in Japanese, and is a scheduling system for "lean" and "just-in-time" manufacturing.) Snowden's framework definitely helps those in software development.

Let us take Snowden's complexity framework into the field of business management practices. How do we do this? By superimposing the various types of business practices to the appropiate complexity domain in which we find ourselves. What are we looking for? What are we sensing or observing for? First we have to be aware and sense the system and its constituent parts, the "agents" of the system. Are the agents of the system following a certain level of linearity or predictability? If they are predictable then we are operating in a that so call "Newtonian" system, a system of classical physics, where cause and effect are clearly visible and knowable, an ordered system.

In that Newtonian system there exists order, linearity, and "clock-work" precision. We are comfortable in applying known tried and true management systems. Take for example the concept of "Six Sigma". Six Sigma literally refers to the the 6^{th} sigma or 6^{th} standard deviation (SD) in normal statistical distributions. So if you remember you college statistic class on finding 68% of the data in the first standard deviation (SD), 95% of the data in the second SD, and 99.7% of all the data within the third SD, then you remember correctly. It is also known as the 68-95-99.7 rule in normal distributions of data.

Recall the definition of deviation: a quantity calculated to indicate the extent of variation for a group as a whole. In statistics, the standard deviation (SD) is a measure that is used to quantify the amount of variation or dispersion of a set of data values. The equation associated with SD takes input from the variance from a set of data. The standard deviation of a random variable, statistical population, data set or probability distribution is the square root of its variance. Again, do not worry too much about the details of some mathematical tools, instead try to understand the tool's significance versus the intricacies of the tool itself. Remember, we don't all have to be automotive engineers to be able to operate a motor vehicle or even a automotive mechanic, we just need to get to where we are going.

Historical Notions of the Normal Distribution and Standard Deviation

Metrics actually go back a couple of thousand years at a conceptual level. Meaning that people had a "rough idea" of simple mathematics, measurement and deviation. Human metrics existed as well back in the days of the ancient Greeks, but not as we know it today. Today we have more experience in mathematics, statistics and engineering than we ever had before. But that does not mean that people in the time of the Greeks and Romans, were ignorant of human ability and categorical differences. An observation made back in the Punic Wars reveals:

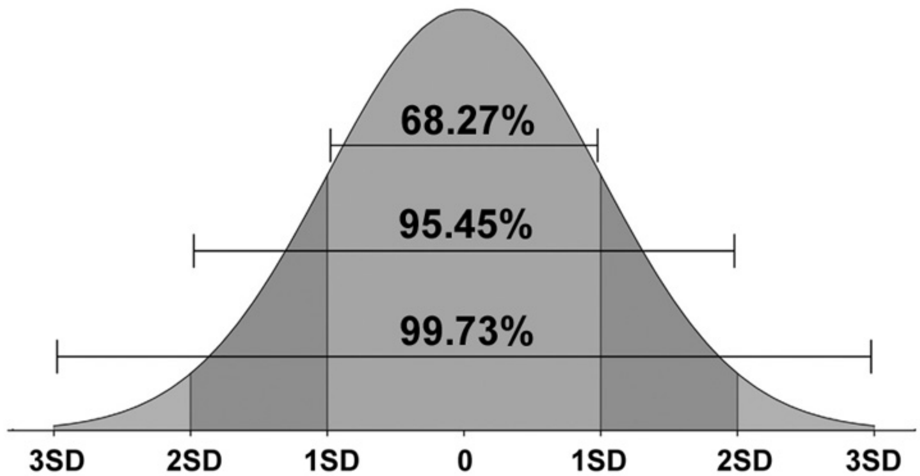
“Out of every one hundred men, ten shouldn't even be there, eighty are just targets, nine are the real fighters, and we are lucky to have them, for they make the battle. Ah, but the one, one is a warrior, and he will bring the others back.” - Heraclitus of Ephesus (535 B.C. - 475 B.C.)

		49, 50	89, 90		
		46, 47, 48	86, 87, 88		
		41, 42, 43, 44, 45	81, 82, 83, 84, 85		
		36, 37, 38, 39, 40	76, 77, 78, 79, 80		
		31, 32, 33, 34, 35	71, 72, 73, 74, 75		
		26, 27, 28, 29, 30	66, 67, 68, 69, 70		
	08, 09, 10	21, 22, 23, 24, 25	61, 62, 63, 64, 65	97, 98, 99	
	05, 06, 07	16, 17, 18, 19, 20	56, 57, 58, 59, 60	94, 95, 96	
01	02, 03, 04	11, 12, 13, 14, 15	51, 52, 53, 54, 55	91, 92, 93	100

This is one of the many significant historical examples that are given in our leadership courses. It is the simple understanding that not all people are created and developed equally. A leader must understand diversity of knowledge, skills and abilities. And from that keen understanding allocate with efficiency those human resources, then know how to motivate each and every one of them!

”Mathematics expresses values that reflect the cosmos, including orderliness, balance, harmony, logic, and abstract beauty.” - Deepak Chopra

Gaussian or “Normal” Distributions, named after Carl Friedrich Gauss (1777 – 1855) was a German mathematician and scientist, that understood the implications of the “Law of Large Numbers” and the “Central Limit Theorem”. The importance of Gaussian distributions is significant as it fits many natural phenomena, for example, blood pressure, physical fitness scores, and IQ scores, all follow the normal distribution when the numbers are sufficiently large. Why is that important to us in data analysis or in knowledge management? Because we need to know if the data that we are observing are statistical aberrations (also known as statistical “outliers”). Understanding Gaussian or Normal distributions helps us answers the question of what we are seeing is “normal” (or average), or out of the norm.



Six Sigma is a set of techniques and tools for process improvement. It was introduced by engineer Bill Smith while working at Motorola in 1986. The etymology of the term comes from the 6th Standard Deviation or 6SD, and Sigma is the symbol used in statistics to denote standard deviation. What does it mean? In process engineering it is described by a sigma rating indicating its yield or the percentage of defect-free products it creates. A six sigma process is one in which 99.99966% of all opportunities to produce some feature of a part is statistically expected to be free of defects (3.4 defective features per million opportunities) or the time between expected failures, MTBF (mean time between failures).

Six Sigma is a statistical tool for modeling manufacturing and engineering processes, but can it apply to human being and human resource management? One would have doubts, as human beings are just not simple machines. David Snowden does not seem to really favor the Six Sigma as he knows that it is an all too often misapplied tool in process engineering when taken out of its context. Six Sigma is applicable in the Ordered domains of Simple/Obvious and the Complicated. But it is not for the Nonordered domains of Complex and

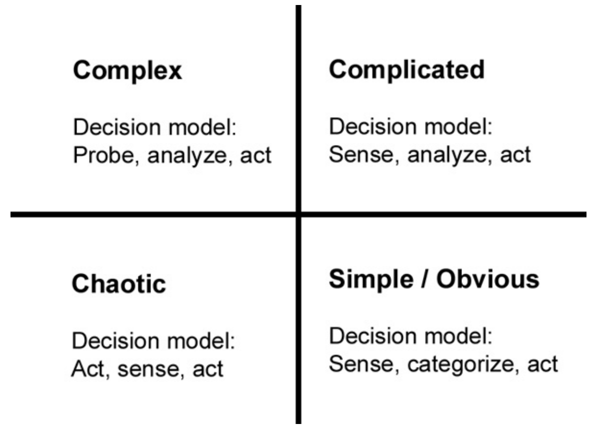
Chaotic. However when you move out of ordered domains and into nonordered domains, manufacturing “best practices” are not suitable for open systems.

“Be regular and orderly in your life like a bougeois, so that you may be violent and original in your work.” - Gustave Flaubert (1821-1880)

Human Resource Management is Complex Adaptive

Anytime you are dealing with human beings your are not in the Simple/Obvious domain or even in the Complicated domain. You are either in the CAS (Complex Adaptive Systems) domain or in the Chaotic domain. Why? Because individual people are not 100% predictable each and everytime. Even a human’s heart beat is never the same each time, nor are a human being’s patterns of thought exactly the same. Populations of people however do follow “emergent” patterns or “averages”. As the Law of Large Numbers suggests that as the number of samples gets larger and larger, approaching infinity, the average starts to approach a central tendancy. And that is a rather interesting questions: Is the Central Limit Theorem an emergent phenomenon?

Remember, in systems that have these following characteristics where there exist “many agents”, there is “interdependence” among the agents, they are “interconnected”, and the agents are “autonomous” then most likely you are operating in a Complex Adaptive System. Typical examples of CAS are financial markets, geopolitical systems, global logicistical supply chains, the internet, cities. Even the human brain can be considered as a CAS; it has about 100,000,000,000 brain cells (many agents), and that these agents are highly interconnected, supposedly by trillions of interconnected synapses (estimates of 100,000,000,000,000 + synapses). So the sum of the parts is clearly much greater than the parts, eh? Is this consciousness an emergent state?



Cynefin with distinction to decision processes depending in which domain we find ourselves.

Cynefin and Levels of Complexity in Training Personnel

Preparing the workforce for levels of complexity

Here we have another picture of the Cynefin Framework but with respect to the hours of investment in training to achieve certain levels of competence. When we talk about training hours, we talk about approximations necessary to produce changes in the levels of knowledge, skills and abilities in people to make necessary changes. The acronym KSAOs refers to Knowledge, Skills, Abilities and Other (Other being the set of values, morals and ethics. Values, morality and ethics are a set how the individual perceives the correct action to be implemented) describes the characteristics of a person's ability to change the status quo. The ISO 17024:2012 standard is a guide on how to develop schemes to certify people. This standard serves as a decent scheme or framework regarding the KSAOs in our global economy for the purposes of interoperability.

Simple/Obvious:

That represents the basic or introductory levels to guide an employee new to the office or the basic induction to the institution. In the security area, most of the basic safety courses are based on this category. For example, the induction or basic orientation for a new security officer in a factory takes in 40 weeks to familiarize the officer to the risks/threats to occupational health (ISO 45001: 2018, Management of Occupational Safety and Health). But this level can be classified as "unskilled labor". The current distinction in terms of educational hours is not defined. However it normally corresponds to the people who achieved the second basic cycle of education, or attained a secondary education ("high school"), approximately 11 or 12 years of general education.

Complicated:

The more complicated the work is, the more training is needed. The people working in more technical areas, with a minimum of 200 to 400 hours for a Technician I, a Technician II between 1,200 to 1,600 hours. Regarding international levels there are still no established standards, but maybe we could have an approximation of hours?

The G20 (or Group of Twenty) is an international forum founded in 1999, to governments and governors of the central banks of 19 countries and the European Union. The European Union (EU) is a political and economic union of 28 member states, for a total of 47 countries and approximately 5 billion of people in 2018. Using the averages of hours studied in the stages of primary (grades 1, 2, 3) and before secondary ("lower secondary" in English (grades 4, 5, 6) and (grades 7, 8, 9) there is supposedly an average of total 8,000 hours of instruction. The school or secondary education (grades 10, 11, 12) represents another 3,000 additional hours of instruction, for a total of 11,000 hours for students reaching 18 years of age. This bases of education supposedly gives a certain level of "interoperability" for people in an economy.

Complex:

Education is not equal to training and instruction regarding to technical areas. General education is not "vocational" education, there are two different approaches, correct? Most instructional programs for a police are about 900-1,000 hours (six months) of vocational education, very similar to that of an infantry soldier in an army. Other vocations demand more hours, for example in the area of artisans or "tradesmen", such as welders, electricians, plumbers, carpenters. There are learning programs of this more experienced category that last 4 to 5 years to be certified in the industry. We calculate approximately 2,000 hours per year. So a 4-year program is an 8,000-hour scheduler to master and exercise your vocation without supervision. Obviously some technical programs are more complicated than others, for example a program to become a plumber may last 4 years while an electrician's program may last 5 years (or 10,000 hours). To handle levels of complexity one must have a certain level of experience in the field, to solve most cases. The other cases, cases that were never previously faced, are situations that must be apply the relevant principles to solve the problem.

Chaotic:

In chaotic situations, such as natural disasters or warfare, in cases where the causality is not clear, where things are not linear, not predictable, we could only anticipate the events. And with the anticipation of the events that may occur, prepare us. A doctor in the emergency room, he has no idea that he will see every day. But he only has his experiences for cases previously attended. He or she has to do pattern recognition, to better adapt a previous case to the new case in question. A doctor in the USA has approximately 24,000 hours of professional and vocational education (a four-year bachelor's degree (8,000 hours) from the university, also four years of medical studies (8,000 hours), plus time as a medical internship or four-year "residence" (another 8,000 hours), plus the 11,000 hours of schooling (K-12), for a total of approximately 35,000 hours. One can conclude that to face chaotic situations, more education and more experience are needed to solve problems in this domain. There may be a manual of protocols, procedures and instructions in crisis management, but they are only principles in general.

To describe or write a procedure for each and every problem to be solved would imply an “exhaustive” search strategy. It would like take years as you approach the “fractals” or fractal level of the problem. The other method might be that of the “heuristic” search strategy with the decision points on the Bayes’ Theorem likely determined on the “best-fit” pattern recognition algorithm? In other words the complexity in complex domain, each possibility can not be reasonabably defined (combination or its subset of permutations) of the incident or accident. You can not spend hundreds of hours analyzing the best solution while your patient dies, you have to act. So act, get some information on the chaos, and move out of the domain. For example, if this happens after a natural disaster and there are people waiting in the emergency room, the first thing to do is act. This act is usually in the form or "triage", categorizing patients in terms of severity; Green, Yellow, Orange, Red. Then, starting with the majority of severity patients (Red), first treat most of the life threatening conditions. Act on the conditions that affect the oxygen that reaches the tissues or cells; such as problems with the cardiovascular system and the pulmonary system, then treat secondary problems.

Management Principles and Practices in Complex Environments

Let’s take a look at the different management practices given the type of environment that one is operating. One would apply the respective management practice based on the level of complexity.

Complex Management Practice: Emergent	**Complicated** Management Practice: “Good” Practices
Chaotic Management Practice: Novel	**Simple / Obvious** Management Practice: “Best” Practices

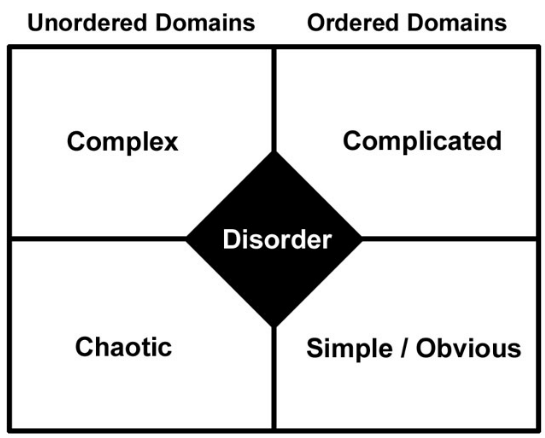
Simple / Obvious Domain: The manager has predictability within the system. Usually it is a system that is linear, predictable and knowable. This ordered or somewhat static environment is perfectly suitable for “Best Practices”. Also in this domain, standard operating procedures (SOPs) clearly are useful. Here in somewhat controlled environment such as a factory, and relatively “closed” systems. But what do we do when things get complicated?

Complicated Domain: The manager has reasonable predictability and the system is ordered. The system is nonlinear and linear but for the most part predictable and somewhat knowable. It is a dynamic environment with a lot of moving parts, but an environment where the manager applies “Good Practices”. Do we just modify our SOPs to become more abstract as we move upwards on the ladder of abstraction (See S.I. Hayakawa’s Ladder of Abstraction). So will the standard operation procedures now become Standard Operating Principles?

Complex Domain: Now the manager is in an environment where you cannot predict the future, just as one cannot predict the weather or predict the results of a football or baseball game. A complex domain is where the agents or components of the system are interconnected, interdependent, and autonomous upon one another. In this domain the end results of experiments are not predictable as they are not repeatable. You can not predict the outcome. And if you conduct the experiments again and again, your results are different each and every time. That simple “interative” function does not produce predictable results, it is nonlinear.

Chaotic Domain: In this Nonordered domain, the manager finds that linearity and nonlinearity characteristics do not help to orient oneself, that causality and predictability are not clearly evident. The recommended action here is to move out of the chaotic domain and into an ordered domain as soon as possible. Ordered domains again are “Complicated” and “Obvious / Simple”.

However, Snowden does recommend that to generate creative thinking strategies and tactics, it is important for CEOs and other leaders to enter into the Chaotic domain but with limited and controlled “probing”. This type of controlled entry into the Chaotic domain stimulates innovation and creativity for companies. It may lead to “First Mover Advantage” in the market place. So as we can see, its clear application in ERM of taking on certain risk to possibly access “opportunities”; the of balancing of risk and possible gains. For example, in Agile (Agile is a set of values and principles used in the management of software development. It has only a 68 word manifesto of which there are 12 principles). One of the important concepts to take away here is that in software development Agile uses the concepts of the decision process “probe”, “analyze” and then “act”. It receives information from the client “probing”, then “analyzes” it utility before further software development continues, then “acts” when there is a positive response from the client “Mikey Likes It” (culture reference from a cereal commercial in the early 1980’s). The cycle continues until the client is satisfied.



The Cynefin Framework with the inclusion of Disorder (Entropy)

Disorder is important to include so as to distinguish various states. This is also known as the “fifth” domain, the state of disorder that is neither unordered or ordered. It is the state of entropy to use the analogy from thermodynamics. Entropy is defined as “a thermodynamic quantity representing the unavailability of a system's thermal energy for conversion into mechanical work, often interpreted as the degree of disorder or randomness in the system.” Another definition for entropy: “lack of order or predictability; gradual decline into disorder”. And from information theory, “entropy is defined as a logrithmic measure of the rate of transfer of information in a particular message or language.” Those definitions are a bit difficult to wrap your head around. But I have always visualized entropy as a state where there no longer exists a “gradient” of energy or heat energy. Remember the principle that heat energy always moves from a hotter state to a colder state. So you move from a higher energy state to a lower energy state over time. The other more concrete analogy I like to use is that of surfing. For one to surf you need the water to be higher at one side and lower on the other side of your board. That’s right, you need a “gradient”, a difference in the height of the water for you to surf. If the surface of the water below your board is flat, you are not surfing… you are in a state of entropy (“and just paddling and waiting for the next wave”).

The same analogy we could apply to the “entropy of creativity” of a system. If everyone on your leadership team is thinking the same thing, and there does not exist a “gradient” of thought, then your team will not generate any new ideas. That is why it is important to have diversity on your team. Just remember, if there are no differences (no gradients), then there is no possibility of doing any real work. This is the “heat death” of a system, where there no longer exist temperature differences “gradients” or other processes may no longer be exploited to perform work. In the language of physics, this is when the universe reaches thermodynamic equilibrium (maximum entropy).

In a macro sense we have only three states of order: Ordered, Unordered (Nonordered) and Disorder. A manager or leader’s mission is to place order upon the state that one is operating. To accomplish this it is necessary to move out of nonordered states and move to an ordered state (Complicated or Simple) and avoid the disordered state. The modern manager or leader has more tools in front of him or her than any other time in history. The most important question before leaders is now which tool for what environment.

In summary, Complex Adaptive Systems (CAS) in Risk Analysis are about first being sensitive to what is around us, “observe” just as the OODA Loop suggested back in the 1950’s. Reducing our cognitive biases in a consistent and frequent manner keeps us constantly aware. Second, the ability to analyze and correctly identify as to what operating environment is before us, in other words, “orient” ourselves. Third, apply the tool sets that correspond to the domain that we are operating, “decide” what tools to apply. And finally “act”, apply our knowledge, skills and abilities (KSAOs) to the situation at hand.

The same Cynefin Framework can easily help to orient us to situations of causality, and accident analysis. In the area of occupational health and safety, ISO 45001: 2018, Clause 9: Monitoring, measurement analysis and performance evaluation, is the area I would assign the process of accident analysis. Root Cause Analysis (RCA) was developed by the United States Department of Energy (DOE-NE-STD-1004-92) back in 1992. And it has its respective 5 step sequencial process:

Phase 1 - Data Collection
Phase 2 – Assessment
Phase 3 - Corrective Action
Phase 4 – Inform
Phase 5 - Follow-up

And to help visualize in the analysis of RCA, many common root cause analysis tools and methods are used:

1. Pareto Charts:
2. Fishbone Diagrams:
3. Scatter Plot Diagrams:
4. Failure Mode and Effects Analysis (FMEA):
5. Fault Tree Analysis:
6. Barrier Analysis:
7. Change Analysis:

Again, RCA is an excellent “cookbook” method of dealing with causality in closed systems and/or ordered domains (“Complicated domains and Simple/Obvious domains”). The problem is when the analyst tries to apply certain tools where they should not be applied. RCA is great for Complicated and the Simple/Obvious, but not when you are dealing with CAS and human beings (As Snowden alluded to with the analogy of Six Sigma and its application to human beings). In Enterprise Risk Managenment (ERM) and accident analysis, you can nominally encapsulate the attribution of cause to “human error”, but you can not have traceability to the exact erroneous thought process or processes of the human being that caused or contributed to that accident or incident.

Bertalanffy’s description two types of systems: open systems and closed systems is a useful oversimplification. The open systems are systems that allow interactions between their internal elements and the environment, a “system in exchange of matter with its environment, presenting import and export, building-up and breaking-down of its material components.” Closed systems, on the other hand, are held to be isolated from their environment. For example, a factory is more of a closed system than a flea market or a “farmer’s” market. A financial market such as the stock market is an open system.

”We adore chaos because we love to produce order.”
- M.C. Escher (1898-1972)

Seeing Incidents / Accidents as Emergent Phenomenon

To simplify, open systems have a lot of inputs (more then are sometimes possible to calculate) from one or more sources. Closed systems have very few or knowable inputs (you can count them on your hands in simple and obvious domains) and in Complicated domains you will need a computer and Subject Matter Experts (SMEs) to know all the inputs, but it is at the end of the day knowable!

In open systems, all the inputs are not knowable. There are just “too many moving parts” as the saying goes. A human being is a great example of an open system. There are physical constraints such as one is subject to the Earth’s gravity, that the body needs oxygen, that it needs water, and that it needs food (see Maslow’s Hierarcy of Need Gratification). But I am recalling a saying that they have here in Costa Rica, a colloquialism “Cada cabeza, un mundo”, which translates into “every mind is its own world”. That is a very appropiate observation from the System Sciences point of view. The human mind is a Complex Adaptive System, and thoughts and consciousness are most definitely “emergent” phenomenon.

All systems of accident and risk analysis take into account “human error”. And human thoughts and consciousness are in the CAS or Complex domain. Yet, these tools of analysis only apply to ordered domains, and not nonordered domains. So it is as if we are entering an operating room to perform an appendectomy on the patient, but we brought the tool kits of plumbers and electricians. If you encapsulate the attribution of cause to “human error” that is fine, you only nominally reach the domain of CAS. But to go further into CAS with diagnostic tools that only work in Complicated and Simple/Obvious domains is not rational nor productive. For us to traceout the the erroneous sequence of thought of a pilot in a deadly plane crash is just not possible. It is roughly equivalent to the “The Seven Bridges of Königsberg” problem in mathematics. Leonhard Euler (1707-1783), proved that there is no solution.

Traceability of root causes and accident analysis reaches a distinct boundary layer in the domain of Complex Adaptive Systems, it cannot go further as tools designed and developed for closed and linear systems cannot function here. We need to develop diagnostic and investigative tools that we can use in the Complex Adaptive and the Chaotic. Enterprise Risk Management and Risk Analysis needs to understand their limits of applicability, their respective limits of utility and validity.

Part of our insistence over the past decades of applying our linear tool kits to nonlinear problems is most likely due to our Western culture of analysis. On one hand, here in the West we like to break problems down problems into their respective parts (Atomism, from the Greek philosopher, Democritus who proposed that all matter was composed of small indivisible particles called atoms). In Eastern culture, on the other hand, they embrace or more correctly accept diversity and that of the nonlinear and nonorder as we see reflected in the “Tao Te Ching”:

> “The Tao that can be told is not the eternal Tao;
> The name that can be named is not the eternal name.
> The nameless is the beginning of heaven and earth.
> The named is the mother of ten thousand things.”
> - Lao Tzu (c. 6th – 5th century BC)

The world before us has both order and nonorder, yet we have such a difficult time in accepting this duality as Westerners. A more effective solution might be to balance both Western and Eastern perspectives in analyzing risks, especially in knowing which tool kits to use, their limitations, and when and where they can be applied.