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Enterprise Systems Engineering Theory and Practice

Volume 2: Systems Thinking for the Enterprise: *New and Emerging Perspectives*

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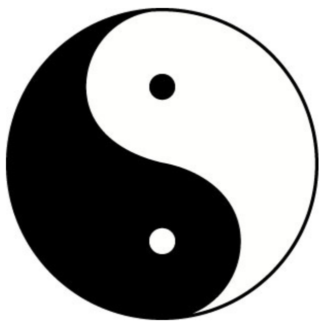

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Abstract

This report introduces and discusses new and emerging modes of thought that are increasingly being recognized as essential to successful systems engineering in enterprises. This new systems thinking is emerging at the intersection of seminal ideas from modern system thinkers, the broad discipline of information technology, and the theory of complex adaptive systems, particularly those from evolutionary biology and social systems. Part of this new systems thinking requires a replacement of the notion that specific engineering outcomes or goals can always be assured with one that seeks to shape, improve, or increase the value of engineering outcomes through thoughtful interventions in the ever-increasing numbers of circumstances in which we are not fully in control.

This report is one of a preliminary series of nine volumes that define and examine key building blocks of the evolving field of enterprise systems engineering:

Volume 1: Enterprise Characteristics and Challenges
Volume 2: Systems Thinking (New and Emerging Perspectives)
Volume 3: Enterprise Architecture (Application Across the ESE Spectrum)
Volume 4: Enterprise Management (Processes to Bridge Theory and Practice)
Volume 5: Enterprise Opportunity and Risk
Volume 6: Enterprise Activities (Evolving Toward an Enterprise)
Volume 7: Enterprise Analysis and Assessment
Volume 8: Capabilities-Based Planning Analysis
Volume 9: Enterprise Research and Development (Agile Functionality for Decision Superiority)

The volumes are intended as guidance for researchers and practitioners who are expanding their horizons from traditional to enterprise systems engineering. The volumes range from the complex characteristics and behaviors of enterprises to the challenges they pose for engineering and technology. They examine the impacts of enterprise processes and leading-edge technologies on the evolution of an enterprise. No attempt has been made to tightly integrate these documents - some material is repeated, some approaches may be slightly different. They were produced under a D400 effort to "Write the Book" on enterprise systems engineering, and at this juncture, they are being published as various works in progress - loosely coupled and evolving.

Preface

In his elegantly written *Wonderful Life* evolutionary biologist Stephen Jay Gould notes that:

> *When we set our focus on the level of detail that regulates most common questions…contingency dominates and the predictability of general form recedes into an irrelevant background.*[1]

Gould was making a point about natural evolution and history as it played out in the Burgess Shale[2] over the past half billion years, but his observation rings true in 21st century civilization and our complex human social systems.[3]

In our increasingly connected and complex world we must set our focus on the right "level of detail." In part, this requires we differentiate between questions whose answers we can control in a deterministic way from those we are unable to control but whose outcomes we wish to influence or shape. It is the latter to which we must bring our knowledge of "the predictability of general form[s]" to the foreground. The use of general forms to influence or shape systems engineering outcomes is largely the focus of this report.

Part of our knowledge of general forms comes from the emerging field of complex adaptive systems. Complexity encompasses a number of disciplines but two among them – evolutionary biology and social systems – seem particularly relevant to questions and problems of "enterprise as social system" and the role of systems engineer in it.[4] Complexity, with its roots in biology and sociology, together with seminal ideas from modern systems thinkers like Ackoff and Garajedaghi, form the basis for what is called the "new systems thinking" in this report.

Many systems engineers at MITRE are the products of educational and work experiences rich in the engineering disciplines, computer science, physics, mathematics, and the like with their emphasis on deterministic problem formulation and solution. A number of systems engineers may therefore assume the modes of thought found in evolutionary biology and sociology are largely *terra incognito* to them. But each of us is, in fact, the product of evolutionary biology, as are our physical environment, the culture in which we live, and the various social systems in

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[1] *Wonderful Life* .W.W. Norton & Company, New York, NY. 1989. p. 290.
[2] The Burgess Shale is a small limestone quarry high in the Canadian Rocky Mountains which was formed more than 500 million years ago.
[3] Consider this quotation in the context of a human lifetime. The level of detail that regulates most common questions are day-to-day concerns like "will I make it to the office before the 8:00 AM meeting starts?" That contingency dominates this kind of question can be seen by considering the myriad, unforeseeable events that could influence its answer, e.g., personal illness, traffic jams, automobile engine trouble. When we focus on the level of detail that regulates our daily lives, the general form of our life (e.g., childhood, adolescence, formal schooling, work life, retirement) and its essential predictability can easily recede into the background of our thoughts.
[4] Complexity theory forms a framework for understanding difficult problems and applying multiple disciplines to their solution.

which we operate daily. So while some of the terminology may be unfamiliar, many of the concepts should find deep resonance with our daily lives.

We live in a complex world. It is time to acknowledge and even embrace the idea so we can harness the power of complexity to improve or increase the value of engineering outcomes in a world in which we are not fully in control.

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1 Introduction

Our society and business are in the midst of a major transformation driven by and deriving its character largely from advances in information technology (IT). The rate of technical change in processing, storage, bandwidth and sensing is enormous. Expansions in other technologies (e.g., biotechnology) have been fueled and shaped by these changes. By dramatically decreasing the cost of information storage and propagation the information revolution is reducing barriers to interactions among people, businesses, organizations, nations, and processes that were previously isolated in space or time. At the same time, almost paradoxically, future events in this information rich world are harder to predict and control with the result that our world and our business are becoming increasing complex.[5] Why is this so?

Systems, societies and organizations become increasingly complex when changes occur that intensify interactions among their elements. By reducing barriers to interactions the information revolution is doing precisely that. In this way, information can be viewed as a mediator of interaction. Thus the information revolution gives rise to the complexity revolution. For example, financial networks allow buying and selling based on global knowledge of price movements that could not be assembled in the past. One consequence is that this ability to exploit capabilities, such as linking financial markets, for better short-run prediction and control could create longer-run difficulties of prediction and control, such as global propagation of financial crises. The cumulative effect is that the exploitation of new information technology to create changes viewed as desirable increases the breadth and depth of linkages and interactions which result in a large diversity of actors becoming part of the same community, thereby increasing overall interdependence which fosters complexity.[6]

In any age, the view we hold of our world is disrupted and threatened by new technologies of the era. But ultimately we synthesize them into a new and more powerful perspective. For example, astronomy threatened the view of a geocentric universe but it ultimately led to a more powerful view of the cosmos and our place in it. And so it is in our day that IT has both revealed the complexity in our social systems and accelerated it.[7] How do we form a new and more powerful perspective for dealing with this complexity?

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[5] A system is <u>complex</u> when there are strong interactions among its elements so that current events heavily influence the probabilities of many kinds of later events.

[6] Axelrod, Robert and Michael D. Cohen. *Harnessing Complexity: Organizational Implications of a Scientific Frontier.* New York, NY: Basic Books, 2000.

[7] Malone, Thomas W., *The Future of Work.* Harvard Business School Press. 2004. Malone argues a similar view. A key element of his thesis is that the cost of communication has dropped dramatically, thus precipitating major social changes.

What is needed is a new way of thinking – a systems thinking[8] that captures the fundamental relationships of information to complexity so that designers of every kind of enterprise can secure the benefits and avoid the pitfalls of this enormous change. This new systems thinking is rooted in several distinct fields but one of them – evolutionary biology – is a tap root. The use of evolutionary concepts to deal with complexity has grown in recent years because biology has changed from a passive, *descriptive* science to an active, *constructive* one.[9] Knowledge of genetics is used to manipulate and modify chromosomes to avoid or cure human diseases by creating new drugs or, in some cases, by altering the genetic makeup of individual humans. We clone life forms and not just simple organisms but some profoundly complex ones. These advances and others like them have fundamentally changed our view of and relationship to biology and its modes of thought.

As a consequence we find ourselves poised at the leading edge of a new systems thinking which is emerging at the intersection of IT and evolutionary biology.[10] As will be seen, part of this new systems thinking requires a replacement of the notion that specific engineering outcomes or goals can always be assured with one that seeks to shape, improve, or increase the value of engineering outcomes through thoughtful interventions in the ever increasing numbers of circumstances in which we are not fully in control.

The purpose of this report is to introduce and discuss new and emerging modes of thought that are increasingly being recognized as essential to successful systems engineering within an enterprise. The emphasis is on those that are substantially different in kind or degree from those in traditional system engineering. Traditional systems thinking and processes will always be relevant to the degree that the problem is or can be constrained to a system or system-of-systems problem. But they do not equip the systems engineer to deal with all that is going on in an enterprise. This new way of thinking is meant to supplement traditional systems thinking, not supplant it.

The presentation approach taken in this report is to discuss the principles of a concept followed by an "everyday" example of it. Examples are drawn from diverse sources and situations including organizational, social, technical, political, military, educational, governmental, financial, medical, and even board games.

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[8] Systems thinking is the ability and practice of examining the whole system rather than trying to fix isolated problems (P. Senge). It requires a systems perspective which is the act of taking into account all the behaviors of a system as a whole in the context of its environment. This puts a focus on the interactions and relationship between the system and its environment (Y. Bar Yam, NECSI). More fundamentally, thinking refers to how one organizes and uses knowledge to cope with situations: it mediates the perception of a problem and the production of a response (*World Book Encyclopedia*).

[9] Kenneth R. Miller, *Professor of Biology*, Brown University.

[10] Some make the case that ecology is more to the point than evolutionary biology. An ecology evolves itself through replacement of its elements and is in a dynamic equilibrium which is akin to the development of a system of IT systems (from a discussion with D. Norman, The MITRE Corporation).

2 The Enterprise

By *enterprise* we mean an entity comprised of interdependent resources (e.g., people, processes, organizations, technology, funding) that interact with each other (to, e.g., coordinate functions, share information, allocate funding) and their environment to achieve goals, as depicted in Figure 2-1.[11]

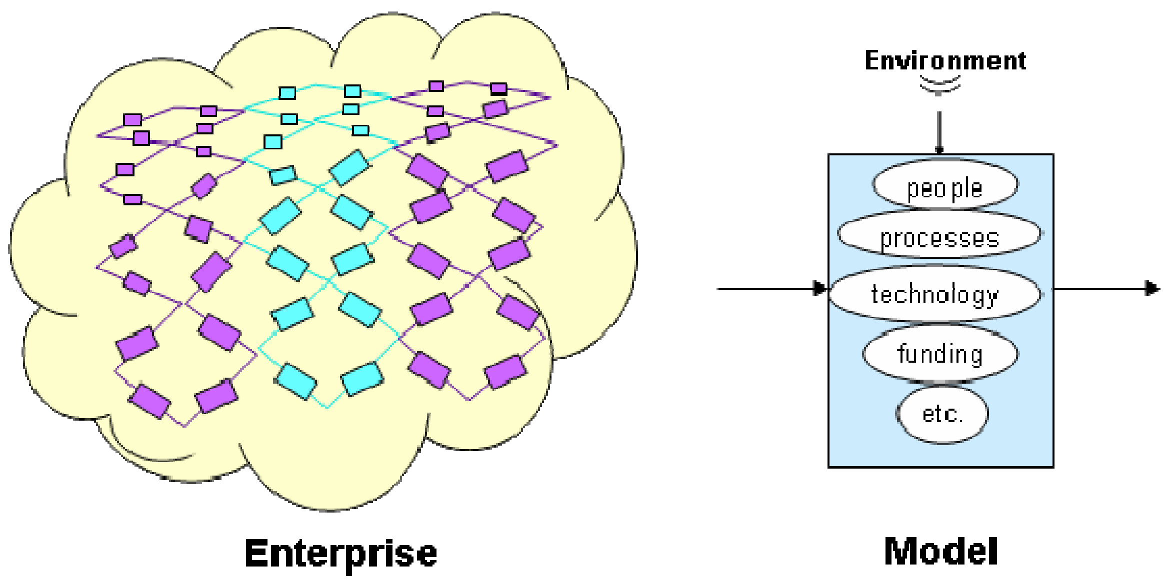

Figure 2-1. Enterprise Model

Historically, our focus has been on the technologies which have enabled the development of the piece parts - systems and subsystems – contained in the enterprise. Modern systems thinkers like Ackoff and Gharajedaghi are increasingly taking a holistic view of an enterprise as[12]:

- a multi-minded, socio-cultural entity,
- comprised of a voluntary association of members who can choose their goals and means,
- an entity whose members share values embedded in a (largely common) culture,
- having the attributes of a purposeful entity[13], and

[11] This definition is similar in its essentials with that of *Enterprise* in the *Net Centric Implementation Framework*, v1.0.0, 17 Dec 04, NESI.
[12] Gharajedaghi, J., *Systems Thinking: Managing Chaos and Complexity*. Boston, MA: Butterworth Heinemann, 1999.

- an entity whose performance improves through alignment of purposes across its multiple levels.

There has been a steady progression towards this enterprise model in both MITRE and its sponsors. Witness the reorganizations over the past decade that have eliminated various forms of stove-piping in MITRE (e.g., Center for Air Force Command and Control Systems matrix organization) and its sponsors (e.g., Air Force Electronic Systems Center (ESC) movement to an enterprise engineering and integration-based organization), as well as performance alignment initiatives within MITRE, like the P&D partnership.

There is a nested nature to most government enterprises.[14] At every level, except the very top and bottom, an enterprise itself is part of a larger enterprise and contains sub-enterprises, each with its own people, processes, technologies, funding and other resources. As depicted in Figure 2-2, the family of Airborne Early Warning and Control (AEW&C) systems is an enterprise which is nested (or contained) in the Command and Control (C2) Constellation enterprise which is contained in the Air Force C2 enterprise.

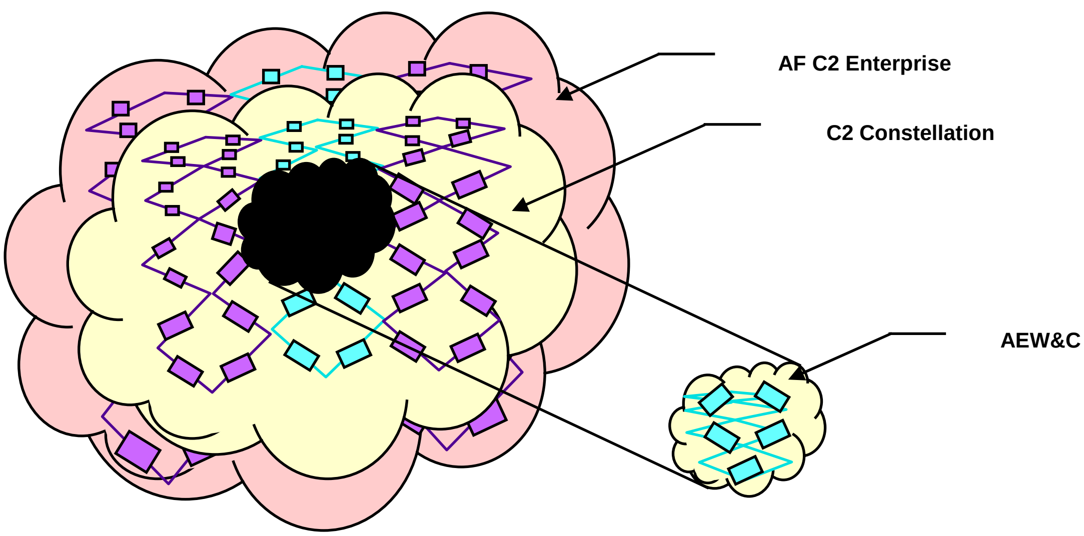

Figure 2-2. Nested Nature of Enterprises

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[13] A purposeful entity can achieve the same outcome in different ways (in the same environment) and can achieve different outcomes (in the same or different environments).

[14] The property of nestedness derives from the goal oriented, hierarchical nature of most government organizations. These kinds of enterprises are the focus of this report. This property is not seen in or to be expected of all enterprises. For example, many chain hotel enterprises are, in fact, associations of independent properties that operate as agents of and on behalf of the hotel enterprise in providing lodging and related services. The hotel corporation has little or no control of and assumes limited responsibility for the agent properties. In these arrangements either party can readily terminate the affiliation of the property with the hotel enterprise.

Alignment of purposes across the levels of the enterprise can improve overall enterprise performance: the sub-enterprises contributes to the goals of the containing enterprise. This view has profound implications for how systems engineers must think about their activities within an enterprise setting: it puts a premium on synthesis.[15]

For example, at the AEW&C system program level, the view must be that an AEW&C system builds an air picture that serves the higher goal of achieving situation awareness within the C2 Constellation. This requires the AEW&C systems engineer to ask (and answer) how the AEW&C piece parts being developed serve situation awareness in the C2 Constellation *in addition* to how they serve the AEW&C system specification. At the next level[16], the view must be that the C2 Constellation develops integrated capabilities to serve the higher goal of providing net-centric C2 for the Air Force C2 Enterprise. The implication is that the systems engineer must address how the C2 Constellation piece parts serve the Air Force C2 Enterprise in addition to how they serve the C2 Constellation. At the highest level[17] in this example, the view must be that the Air Force C2 Enterprise develops Air Force Net Centric capabilities to serve the higher goal of providing net-centric C2 for the Joint/Coalition C2 Enterprise. The implication is that the systems engineer must address how the Air Force C2 Enterprise piece parts serve joint and coalition net-centric C2 in addition to how they serve the Air Force C2.

This discussion leads to an operational definition of enterprise viewed from the perspective of an individual (system engineer or other participant) or team in the enterprise. It aims to answer the question, "what is my (our) enterprise?"

The enterprise is the set of interdependent elements (systems and resources) that a participating actor or actors either control[18] or influence.[19] The remainder of the elements constitutes the enterprise environment.[20] This is depicted in Figure 2-3.

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[15] Synthesis is the ability to identify the whole of which a system is a part, explain the behavior or properties of the whole, and disaggregate the whole to identify the role or function of the system in the whole. Ackoff, R., *Systems Thinking and its Radical Implications for Management.* IMS Lecture/Boston, 15 February 2005.
[16] Wing level at the USAF Electronic Systems Center.
[17] Electronic Systems Center Command level.
[18] To control means that an action we can choose to take is necessary and sufficient to produce an outcome.
[19] To influence means that an action we can choose to take is necessary but not sufficient to produce an outcome; our action is a co-producer of an outcome.
[20] Gharajedaghi, J., *Systems Thinking: Managing Chaos and Complexity*. Boston, MA: Butterworth Heinemann, 1999, p. 31.

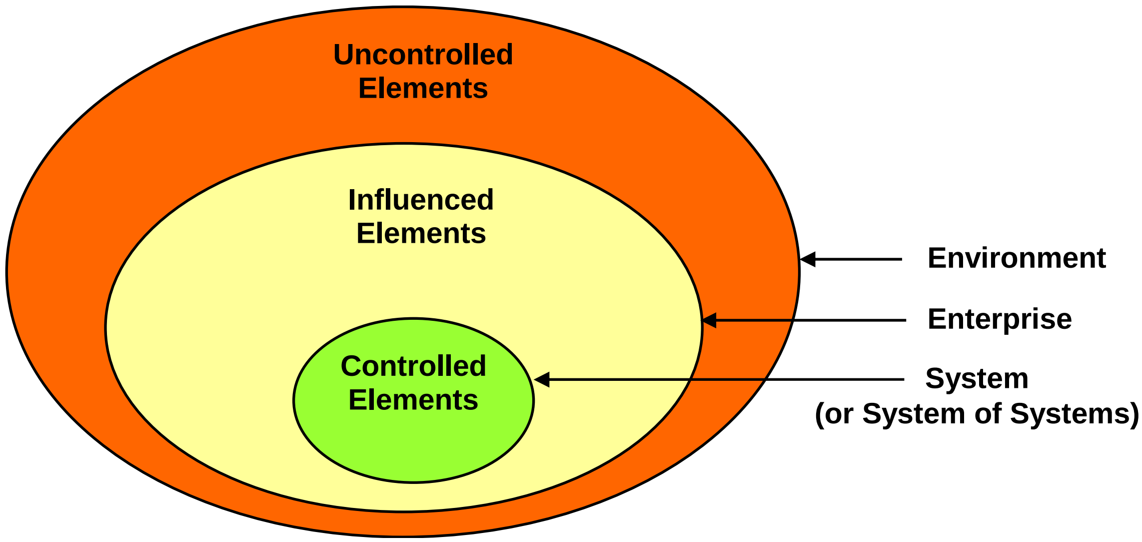

Figure 2-3. Operational Definition of Enterprise

Note that this definition of enterprise and its boundary are virtual constructs that depend on the make-up, authority, and roles of the participating actors in a community of interest. For example, the program team of a system managed by ESC may have virtual control of most engineering decisions being made on the system's day-to-day development activities. If the system is required to be compliant with standards developed by the Defense Information Systems Agency, the program team may have representation on the standards team but that representation is one voice of many and so the standard is a program element or variable that the program team can influence but not control. The Federal Acquisition Regulation requirements, which apply to virtually all government acquisitions, are elements or variables that apply to our example program but since they are beyond the control of the team, they are part of the program's environment.

The implication and view being advocated here is that all actors or teams in an enterprise setting should know "their" enterprise and be aware of which enterprise elements or variables they control and which they influence. Environmental elements or factors cannot be controlled or influenced. But the individual or project team may very well need to be aware of and understand implications of environmental factors.[21]

We will return to this controlled-influenced-uncontrolled framework in Section 5 where the discussion focuses on approaches to shaping, improving, or increasing the value of outcomes for the ever increasing number of enterprise elements that can be influenced but not controlled.

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[21] A simple but clear example of the need to understand the uncontrolled elements of an environment can be seen by considering an individual standing on a railroad track with a locomotive bearing down on him. While he may not be able to stop the train, the individual can and should get off the track.

3 Moving from Traditional Systems Engineering to Enterprise Engineering

Systems engineering can be defined as a process that integrates multiple disciplines to define and transform requirements into a system while involving environmental, economic, political, and social aspects. Traditional systems engineering (TSE) is a term used to describe engineering of sub-systems, systems and systems-of-systems.

TSE is a sequential, iterative development process whose goal is to produce products, many of which are of unprecedented technical complication and sophistication. The INCOSE (ANSI/EIA 632) Systems Engineering model, depicted in Figure 3-1, is a widely recognized representation of TSE.

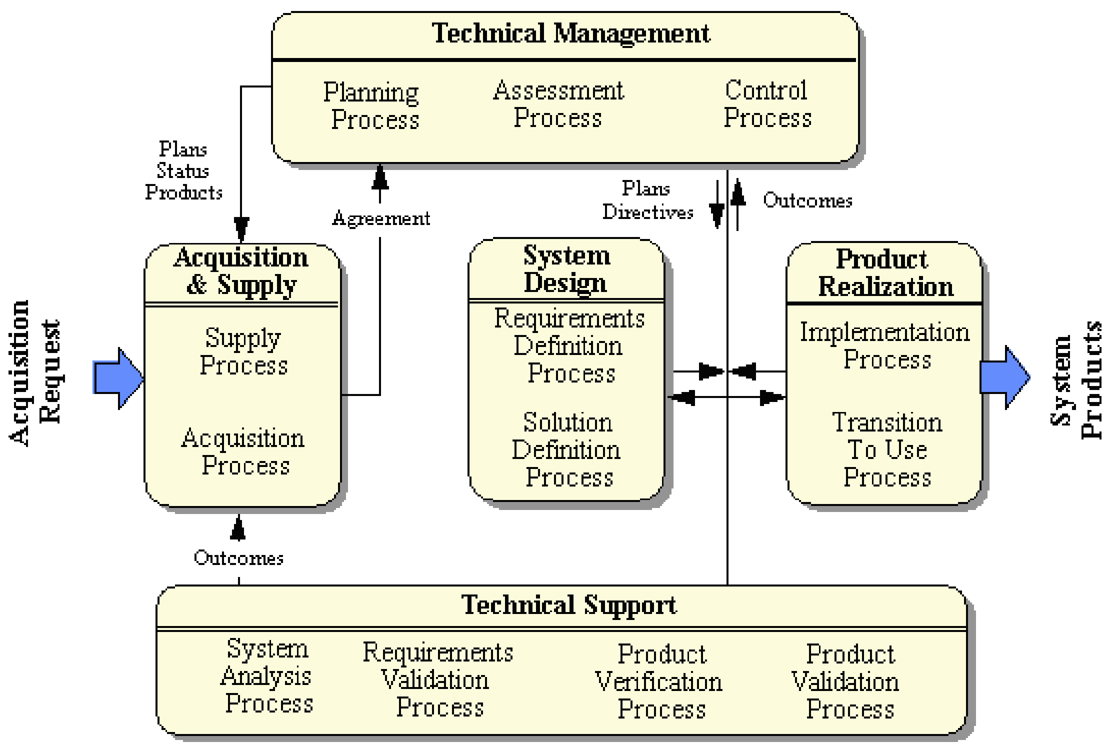

Figure 3-1. INCOSE (ANSI/EIA 632) Systems Engineering Model

An implicit assumption of this TSE model is that all relevant factors are largely under the control of or can be well understood and accounted for by the engineering organization, the system engineer, or the program manager. The culture and processes in a TSE organization normally reflect this assumption.

There are fundamental differences in an enterprise. While some factors may continue to be well understood by or remain under the control of the system engineer or program manager, others are not. Because enterprises frequently embrace diverse agencies, sponsors and operational communities, there is increased emphasis on working across and bridging organizational cultures, agendas, and socio-political-economic differences. Enterprises exhibit attributes of a complex system. As a result there arise questions of how to deal with enterprise processes that approximate natural evolution and, in some cases, how to deliberately mimic, encourage, facilitate and channel them in constructive directions. Adjectives that are used to describe system engineering and other processes in an enterprise expand to include: *evolutionary, emergent, adaptive, self-organizing, competitive and cooperative*.

For many, even most systems engineers the reality of their existence is that they inhabit and must perform well in two different system engineering environments at the same time: a local, program office environment in which the culture, norms, expectations and rewards may be more influenced by a TSE culture and an enterprise engineering (EE) culture in which the focus is on enabling the broader enterprise, in some cases even at the expense of the smaller system.

Every system engineer must bring enterprise perspectives, behaviors, skills and competencies[22] to their activities whether they are executed at the sub-system, system, system-of-systems or enterprise scale. In that sense, every system engineer operating in or working on an enterprise must consider themselves as an enterprise engineer, who is required to perform systems thinking for the enterprise.[23]

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[22] A behavior is a specific action. A skill is an ability to perform a complex collection of actions with ease, precision and adaptability to changing conditions. Knowledge is a body of understood information possessed by an individual which is in accord with established fact. A competency is a cluster of job-related behaviors, skills and knowledge that affects a major part of one's role or responsibility; correlates with success; can be measured against accepted standards (that relate to success); and can be improved via training and development. (Adapted from S. Parry, *The Quest for Competencies*.)

[23] Thus an Enterprise Engineer is a system engineer who brings an enterprise perspective to his or her activities. The Enterprise Engineer may work on problems at any scale of the enterprise: sub-system, system, SoS or Enterprise. The individual who does not (or is not required to) bring an enterprise perspective to his or her activities is termed a subsystem engineer; SoS engineer, enterprise system engineer, etc. (from a discussion with R. Swarz, The MITRE Corporation).

4 Modes of Thought

The purpose of this Section is to introduce concepts which are fundamental to a discussion of the emerging views on the new systems thinking in the following Sections.

4.1 Analysis

Give a child an object she has never seen before and just leave it with her. It can be a radio, a clock or a toy. If she wants to determine what it is (and she usually does), what is the first thing she does? She takes it apart. Her second step is to determine what each part does, and the third step is to assemble her knowledge of the parts into knowledge of the whole. This three step process is *analysis.*[24]

This example motivates a more formal definition of *analysis* as the ability to decompose an entity into deterministic components, explain each component separately, and aggregate the component behaviors to explain the whole.[25]

Analysis results in knowledge of an entity: it reveals internal structure. If the entity is a system then *analysis* answers the question, "how does the system work?" For example, to know how an automobile works, you analyze it: that is, you take it apart and determine what each part does. This is essential to important activities like repairing automobiles or diagnosing and repairing problems of other, more complicated systems.

Analysis, as one of our earliest and most natural modes of thought, is so fundamental to human thinking that it has almost become synonymous with it. But is *analysis* the only mode of thought required to answer important questions about a system?

That the answer to this question is "no" can be seen by considering the automobile, again. The automobile was originally designed for six passengers. Why? Take apart as many automobiles as you like and no amount of analysis will lead to an understanding of the six passenger capacity. Why is it not seven, fifteen, or twelve? The answer is that the automobile was designed for the

[24] Ackoff, R., *From Mechanistic to Social Systemic Thinking*. System Thinking in Action Conference, November 1993. This is a classical definition of systems analysis and a very simple one at that. New modes of analysis are emerging. The forces at work in this development are many. Part of it comes from the evolution to net-centric systems in which one can neither state, *a priori*, the extent of a system nor decompose it into deterministic parts which perform specific or guaranteed roles or functions. Yet the need to perform analysis continues, unabated. Additionally, the view of systems and enterprises as socio-cultural entities suggests that analysis should include social or human dimensions, not just technical ones. This implies that systems analysis may have important similarities with (and much to learn from) fields as diverse as intelligence analysis, medical analysis, stock market analysis, and weather forecasting. Lastly, the role of conceptual framework, limits in cognition, and biases in human decision-making are increasingly being recognized as forces which are shaping how we view and do systems analysis: it is not just about the data, it is also about how we, as humans, perceive the data. It is not the intent of this report to address these new and emerging aspects of systems analysis, which would require a paper every bit as long as this one.

[25] Ackoff, R., *Systems Thinking and its Radical Implications for Management*. IMS Lecture/Boston, 15 February 2005.

average American family size, which was 5.6 at the time. This example is an illustration of *synthetic* thinking. Every MITRE systems engineer who has defined a system performance specification against mission or operational requirements has engaged in synthetic thinking.

4.2 Synthesis

Synthesis is the mode of thought that results in the understanding of an entity: i.e., an appreciation of the role or function an entity plays in the larger system of which it is a part. Just as *analysis* answers the "what is it?" question about an entity, *synthesis* answers the "why is it what it is?" question.

Synthesis is the ability to identify the whole of which a system is a part, explain the behavior or properties of the whole and disaggregate the whole to identify the role or function of the system in the whole.[26]

If you are attempting to understand a college synthetically the first step is to identify the larger system of which the college is a part, e.g., a state higher education system. The second step is to explain the containing system (e.g., the state higher educational system delivers high quality educational programs, available to all its citizens, with an emphasis on disciplines important to the state's economy). The third step is to disaggregate the whole to identify the role or function in the system of which it is a part (e.g., the state's economy is based on agriculture, mining, and information technologies which are reflected in the state higher education system organization structure and emphasis. The college in question has a focus on academic disciplines and technologies related to mining.). Taken together, this synthetic view explains why the state has a mining college and provides a basis for asking and answering "what if?" questions about the college, like: what if the state's economy shifted away from mining (or moved more towards it)?

If we had attempted to *analyze* the college, we would have decomposed the college into particular departments which consist of faculty who educate students to earn certain degrees in specific majors, and so on, down to a level of sufficient granularity to answer the question at hand.

Systems thinking requires knowledge *and* understanding - both analysis and synthesis – represented in the same view. That is precisely the point of the AEW&C/C2 Constellation example in Section 2. The ability to combine analytic and synthetic perspectives in one view is an enabler of alignment of purposes, which is so important to successful engineering in nested or hierarchical enterprises. It allows the systems engineer to ask purposeful questions and trace the implications of potential answers across the enterprise. Would a change in performance at the subsystem level result in a change at the enterprise level? If so, how, and is it important? How would a new enterprise level need be met?

[26] Ackoff, R., *Systems Thinking and its Radical Implications for Management*. IMS Lecture/Boston, 15 February 2005.

There is another reason why *synthesis* is such an important *systems thinking* concept. It expands the solution space of a problem in a way that can make intractable problems solvable. The following example illustrates how.

Example: In the early 20th century the City of Chicago ran a large trolley car system. The General Manager (GM) of the trolley system had a goal to improve its performance and efficiency. Trolley cars were run by two operators: a driver and a conductor. The driver was responsible for maintaining the trolley's schedule: i.e., arriving and departing the route stops on time. The conductor was responsible for collecting fares and assuring that passengers paid the correct fare and departed at the right stop (fares were based on geographical zones). Both driver and conductor were paid fixed hourly salaries.

The GM reasoned that if the operators' salary structure were changed to a lower hourly base rate plus a performance-indexed rate this would motivate operator performance improvement which would translate into improved overall trolley system performance and efficiency. This was done. The performance-indexed part of the drivers' salary was tied to on-time schedule performance and that of the conductor to assuring fare equity.

But this change immediately caused a conflict. The driver was motivated to depart a stop quickly (to stay on schedule)while the conductor was motivated to more carefully (and, hence, more slowly) issue tickets, collect fares, and check that departing passengers had not gone beyond the zone for which they paid (inspectors, masquerading as ordinary passengers, evaluated driver and conductor performance). The relationship between drivers and conductors became antagonistic with the result that overall trolley system performance actually decreased. The problem, of course, was that the new performance system had created an inherent conflict between the operators.

Many solutions were tried. They all focused on improving the efficiency of one or the other of the trolley operators' job as a mechanism for deconfliction. For example, different internal configurations of the trolley were tried in an attempt to reduce the time it took to execute conductor responsibilities. Nothing worked and the conflict continued.

A consultant was finally brought in. The problem was explained to him in great detail, including all the options that had been considered for improving operator efficiency. The first question the consultant asked was, "how many trolleys are in the system?" The GM thought this was a curious and not particularly relevant question given that the problem was a conflict between two operators on a trolley but he answered, "1,250." The consultant wrote that down and asked, "how many trolley stops are in the system?" The GM answered, "850" and went on to express his disappointment in this line of obviously irrelevant questioning. The consultant wrote down 850, looked up at the GM and said, "I have a solution to your problem. There are more conductors than stops. Take the conductors off the trolleys, position them at the stops where they can collect fares from customers lining up at the stop *before the trolley arrives and check fare zones from passengers after they exit the trolley. In this way you will completely separate the contentious timelines of the two operators."* [27]

The consultant had used a counterintuitive principle to solve the trolley problem. When faced with an apparently intractable problem the usual response is to make it smaller, contain, or constrain it. The consultant in this example was going down a line that appeared to make the problem space larger in seemingly irrelevant ways. But, in fact, he was making the *solution* space larger by viewing the problem in the context of its containing whole. This is a form of *synthesis*.

This example also touches on and leads into the next topic, *multidimensionality*.

4.3 Multidimensionality[28]

Much of traditional systems thinking has been dominated by a view that opposing tendencies are to be treated as a duality in a zero-sum game: order/complexity; change/stability, and so on. These pairs are viewed in a way that a gain for one invariably results in a loss for the other.

In this view, opposing tendencies are formulated as either mutually exclusive, discrete choices or a continuum. In the former, depicted on the left in Figure 4-1, choices are expressed as dichotomies, *X* or ~ *X*, which is an *exclusive or* relationship: a win/lose situation in which the loser, usually declared "incorrect" is eliminated. In the latter, depicted on the right in Figure 4-1, opposing tendencies are treated as intermediate shades of grey between polar opposites of black and white. Resolution is achieved by compromise which normally results in an unstable mix of elements of the two extremes. The instability comes from the constant struggle between groups which each continue to see different "clear and present" urgencies that come from their view of reality. Opposing tendencies need not be constrained to pairs as the familiar acquisition trade-space trio of cost, schedule, and capabilities demonstrates.

Figure 4-1. Traditional View of Relationship Between Opposing Tendencies[29]

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[27] Ackoff, R., *Systems Thinking and its Radical Implications for Management*. IMS Lecture/Boston, 15 February 2005.
[28] Gharajedaghi, J. Systems Thinking: Managing Chaos and Complexity. Boston: Butterworth Heinemann, 1999, pp. 38–43; 67–71.
[29] Ibid., p.38.

The principle of *multidimensionality* holds that seemingly opposing tendencies not only coexist, overlap and, hence, interact, but they also form a complementary[30] relationship. More formally, *multidimensionality*[31] is the ability to see complementary relations in opposing tendencies and to create feasible wholes with seemingly unfeasible parts.[32]

This definition changes the characterization of opposing tendencies from an *or* to an *and* relationship, and results in a view of them as being separate, mutually interdependent dimensions that can interact and be integrated into a new way of thinking. It expands the duality-based solution space from choices between win, lose, or unstable compromise to one in which opposing tendencies can both (or all) "win." A generic representation of this is depicted in Figure 4-2. This perspective provides the opportunity to interpret opposing tendencies in a new relationship with a logic of its own. This is particularly relevant to the enterprise-as-social-system problem space: in social systems, the formulation of problems into the dichotomy of *X* or *not X* rarely appears to be an important solution approach.[33]

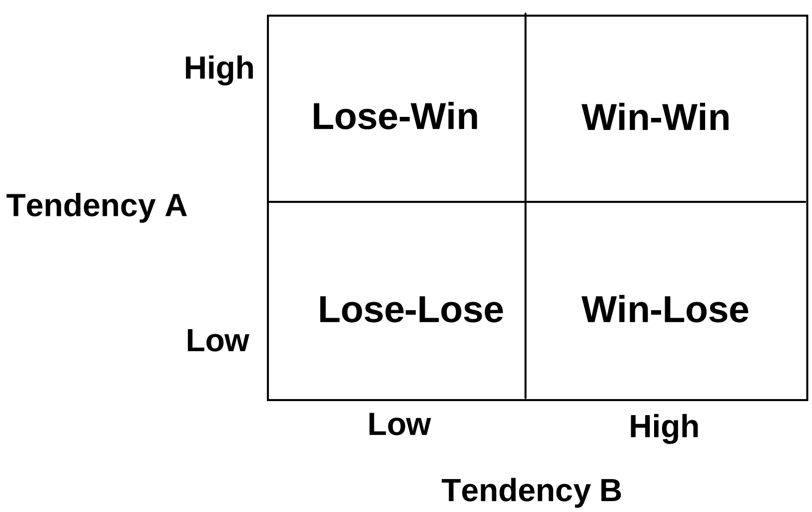

Figure 4-2. Complementary View of Relationship Between Opposing Tendencies[34]

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[30] A <u>complement</u> is that which fills out or completes a whole.
[31] <u>Dimension</u> may refer to either mathematically quantifiable variables or aspects or facets of a system.
[32] Gharajedaghi, J., *Systems Thinking: Managing Chaos and Complexity*. Boston: Butterworth Heinemann, 1999, p. 38.
[33] Churchman, C. West. *The Systems Approach and Its Enemies*. New York, NY: Basic Books, 1979.
[34] Op. Cit., Gharajedaghi, p. 39.

Figure 4-3 shows an example complementary relationship between concern for stability and concern for change. The interactions of high and low concerns in each of the dimensions produce completely different modes of behavior.[35]

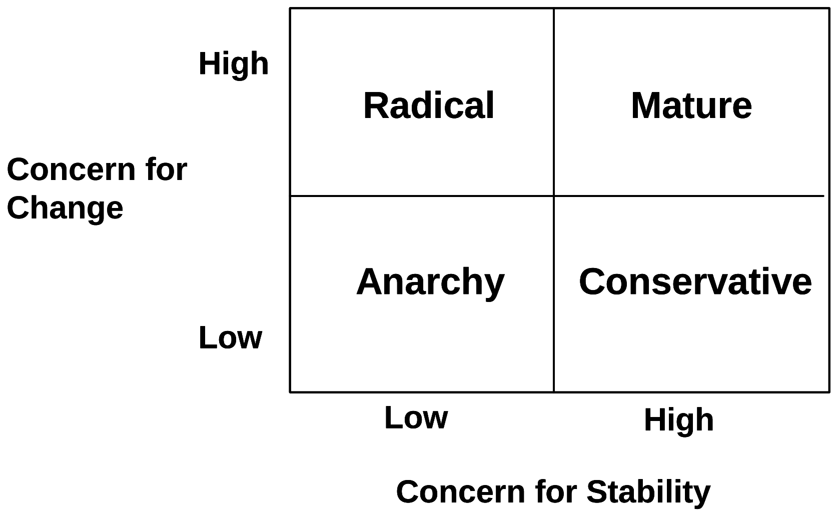

Figure 4-3. Interactions Produce Different Modes of Behavior[36]

Figure 4-4 shows another complementary relationship and uses it to differentiate among styles of management based on the manager's concern for production and concern for people. Although the upper left and upper right quadrants both show a high concern for people, the expressions of that concern are quite different. The upper left quadrant represents a paternalistic, populist leader whose concern for people is basically a concern for their weakness which is often expressed as a protective nature towards them. The upper right quadrant represents a leader whose concern for people stems from a respect for their ability which is directed at assisting them to achieve their on-the-job potential. Similarly, Figure 4-5 portrays the results of a study of factors conducive to innovation.[37]

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[35] The boundary between high and low levels of a tendency is the point at which the behavior of an aspect of the system changes qualitatively. This may be thought of as an inflection point or phase change. For example, if an individual has $100 a week to spend on transportation she may own an economy car. At $200 per week, she may own a luxury sedan and with $300 a week she may have a high-end sports car. But if she has $10,000 a week to spend on transportation she may not own a car at all but get her personal transportation by helicopter or chauffeured limousine. For an expanded discussion see Gharajedaghi, pp. 40–41.

[36] Ibid., p. 41.

[37] Gordon, G., et. al., *A Contingency Model for the Design of Problem Solving Research program*, Millbank Memorial Fund Quarterly (1974): 184-220.

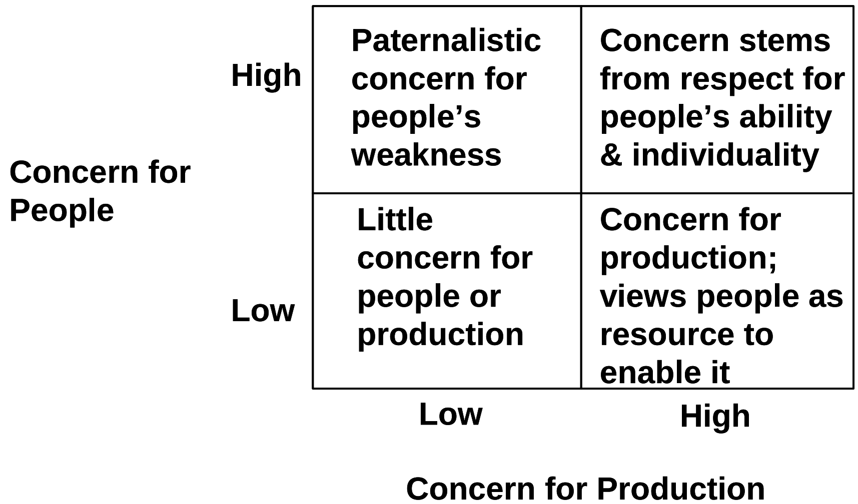

Figure 4-4. Management Style[38]

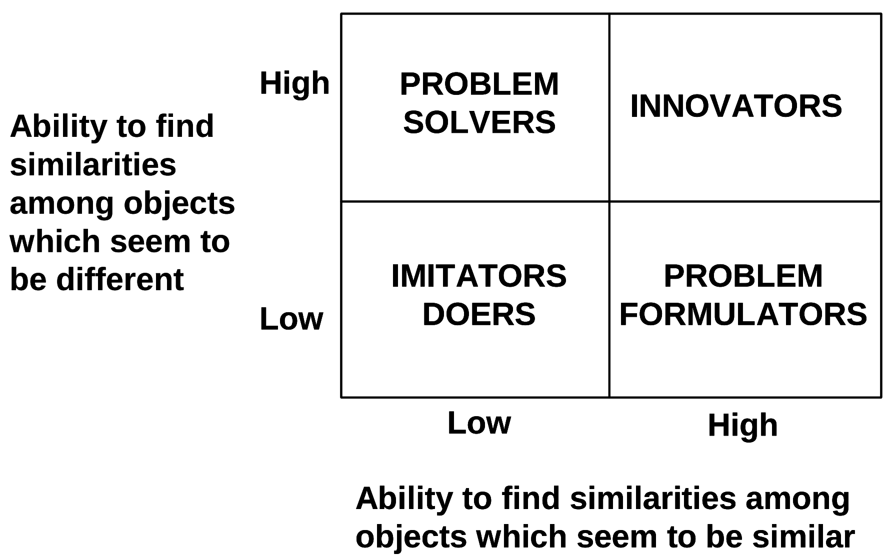

Figure 4-5. Innovative Abilities[39]

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[38] Op. cit., Gharajedaghi, p. 42.
[39] Ibid., p. 43.

Example: Westville (fictitious name) is a suburb of a large New England city. The community has had a long history of quality in its educational system. The reputation is justified. By any measure – results in academic contests, SAT scores, or placement in the most competitive universities – Westville consistently outperformed its more affluent neighboring towns and even most nearby prestigious private schools.

The quality education Westville schools provide was a consequence of several factors: strong parental involvement; the percentage of local taxes that are devoted to the schools; and the effectiveness of school system administrators in applying monies to programs of excellence.

Life in Westville revolved around the children and schools so much so that after their children graduated "empty nesters" in large numbers would migrate out of town in search of communities better aligned with their new interests. They were replaced by younger families eager to take advantage of Westville's quality schools.

But something changed in the early 1990s. Adults whose children had graduated from the school system increasingly viewed Westville as their retirement community of choice. These active seniors began looking to the town for services and facilities that served their needs.

At the same time, education costs began rising faster than the economy. Families with school age children advocated additional taxes to maintain the quality of education while retirees, particularly those on fixed incomes, became apprehensive of their ability to afford living in "their" town. Over time, a conflict emerged and grew as a consequence of the shifting demographics of the town. Families with school-aged children and empty nesters had different priorities. Town meetings became heated.

Town members framed the discussion as a contention concerning the amount and distribution of financial resources. The "solution" took the form of an unstable compromise (reference Figure 4-1) between opposing factions representing "quality schools" and "senior livability." The school administration would find and implement incremental efficiencies year after year until it became clear to a majority of the town that additional monies were needed for schools at which point the town voted an increase in taxes, to the great consternation of the seniors. Seniors got a few programs aimed at them but they were always judged "too little, too late." Both sides were unhappy most of the time.

A small number of citizens formed a group aimed at asking the question, "what would a solution look like that maintained school quality <u>and</u> improved senior livability?" The question suggested an interdependence between what had been viewed as two opposing tendencies and opened up new solution possibilities beyond win, lose, or compromise.

In discussing this question it became clear that many empty nesters and retirees:

- *came from the knowledge industry,*
- *understood the value of education,*
- *wanted to give something back to their community, and*

- *had a "pipe dream" of contributing to education in some way.*

An idea emerged out of the group for a program in which empty nesters and retirees could become teacher assistants or even teachers (if certified or willing to undergo certification). Individuals in the program could participate as volunteers (no remuneration), for a tax credit (to be applied against local taxes) or be paid a small salary. Many participated. Most volunteered, some took a tax credit, and a few opted for the salary.

The program became popular and spread to other Westville town services (library, recreation center, after school sports and other activities). The cost savings reduced educational and other town expenses. Tax increase requests reduced in frequency and magnitude. Seniors became more integrated in the community. They felt less of a need for separate senior programs and so those demands decreased. What remained of them was adequately met by a portion of the town's cost savings.

Westville succeeded in transforming a win, lose, compromise situation to one in which the vast majority of citizens were happy. It did so by reframing an "or" situation into an "and" one using the principle of multidimensionality.

We will return to multidimensionality in Section 5 where it will be used with the controlled-influenced-uncontrolled framework to illuminate the complementary relationship between innovation (or differentiation) and integration, and how complexity can be harnessed through thoughtful intervention in processes that are beyond our direct control.

4.4 Interdependence[40]

Classical systems thinking has focused on analysis and analysis has focused on problems in which the variables are independent or may reasonably be assumed to be so. When the variables are, indeed, independent this is a powerful framework since it allows the systems engineer to logically decompose a system into its variables and examine the response of the system to changes in each variable, one at a time.

A common pitfall is not recognizing that a system may contain slack between its variables and it is the slack which allows the analyst to treat the variables as though they are independent *but only in a number of circumstances* or *up to a point.* The performance of the variables in a system can be improved until the slack among them is used up at which point the variables become interdependent and improvement in one comes only at the expense of others. The sequence in Figure 4-6 illustrates this idea. In (a) the three circles represent three variables whose interdependence is not evident, as suggested by the wavy lines which join them. (Picturing this sequence as three children tied at the waist by ropes may help in the visualization.). In (b) the top circle moves but the slack is not yet used up and so the interdependence among the circles is still not evident. In (c) the top circle has moved sufficiently so no slack remains between it and the other two circles. The interdependence between the top circle and the other two becomes clear.

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[40] Ibid., pp. 13–16.

Note that the slack between the bottom two circles is not used up and so interdependence between them is not yet apparent.

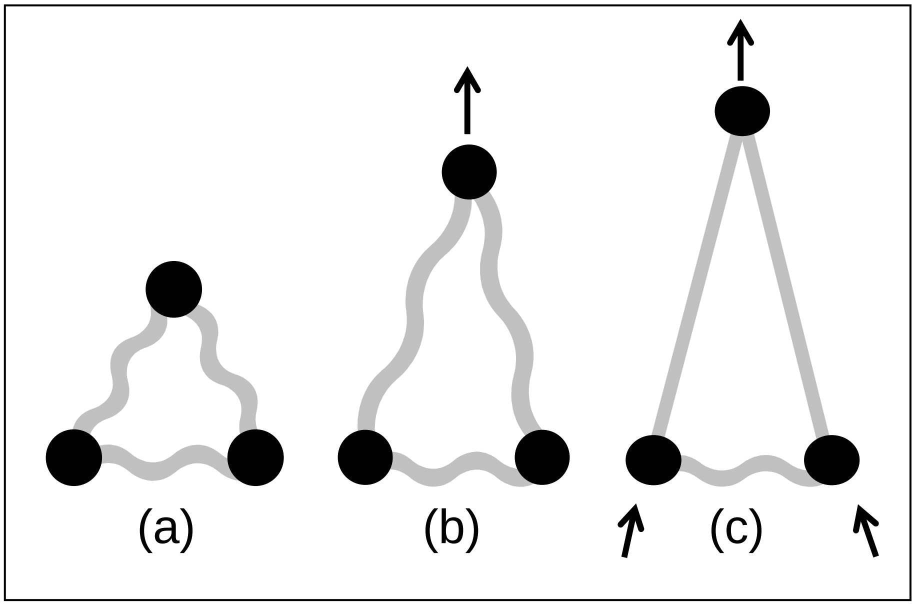

Figure 4-6. Slack in a System May Appear as Independence

Enterprises or other large, complex organizations may run into interdependence as an issue when engaged in quality or other system-wide improvement campaigns. In these situations it is customary to gauge improvement as performance increases in multiple variables (shorter development time, better cost containment, increased customer satisfaction, reduction in product defects, improved safety, etc.). Often, these campaigns reach a plateau, stall in their progress, or even regress as measured by the variables of interest. When this happens it is usual to think that the organization needs to be re-energized in the improvement campaign and, of course, this may be the case. However, plateauing may be a symptom that the enterprise or system – in its current form – has reached its potential. It has used up all its slack. Further progress can only come from a redesign of the organization or operation of the enterprise or system.

> *Example: The trolley example in Section 4.2 is an illustration of a situation in which further progress required a redesign of the system. As long as the design of the overall trolley system kept the driver and conductor on the trolley, it created an interdependence between driver performance and conductor performance that traded improvements in one at the expense of the other. Moving the conductor from the trolley was – in essence – a redesign of the system that provided additional slack between the two performance variables.*

5 A Framework for Harnessing Complexity

Section 2 introduced an operational definition of enterprise based on the notion that the elements or variables in our world could be partitioned into those we control, those we influence, and those beyond our control. A consequence of MITRE and its sponsors evolving towards an enterprise model is that each of us, as participating actors in our enterprise, are losing the ability to control many elements while at the same time we are gaining in our potential to influence many others. Systems engineering, therefore, is becoming more and more about the ability to influence in our increasingly complex environment.

5.1 A Systems View of Development[41]

Development[42] is a purposeful transformation towards higher levels of differentiation and integration at the same time. Development is an evolutionary process by which a social system (e.g., individual, team, community, enterprise) increases its ability or value (as gauged by performance, effectiveness, impact, influence, profitability, etc.). *Differentiation* refers to deviations among entities that are apparently similar and *integration* refers to the similarities among things that are apparently different. The former emphasizes tendencies toward increased complexity, variety and autonomy while the latter tends toward increased order, uniformity, conformity, and collectivity.

Note the similarity in concepts and terminology used in the discussion of Figure 4-5. The basic idea is the same: the seemingly opposite tendencies of differentiation and integration complement each other to create *innovation* which is both a destination (in Figure 4-5) and a journey or process (in Figure 5-1).

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[41] Gharajedaghi, J., *Systems Thinking: Managing Chaos and Complexity*. Boston, MA: Butterworth Heinemann, 1999.

[42] This development model is quite general and can be applied to individuals, teams (large or small), systems, and enterprises as defined in Section 2. Our focus will generally be on teams, systems, and enterprises which will be generically referred to as "organizations." The other terms will be used where appropriate.

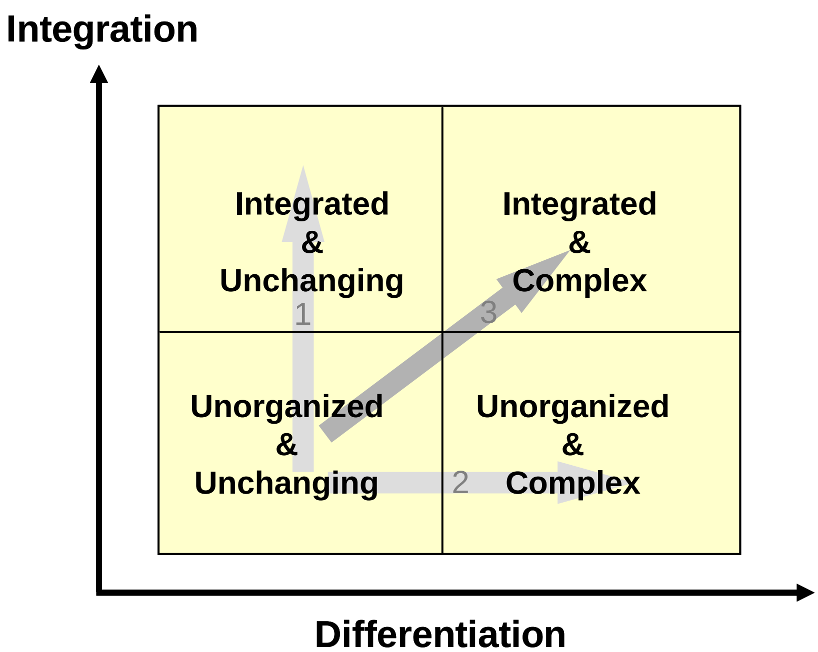

Figure 5-1. A Systems View of Development

The discussion that follows in the next several paragraphs will step through Figure 5-1 using an enterprise as an example, but it should be kept in mind that this developmental model is applicable to individuals and teams as well as enterprises.

An enterprise in the lower left quadrant of Figure 5-1 is static and unorganized. Change is infrequent or non-existent and the piece-parts that are there are unorganized into any semblance of a coherent whole. Movement or evolution is generally possible, of course, so the question becomes one of direction.

One evolutionary path is to organize all the elements and processes that currently exist in the enterprise, that is, integrate straight up to the upper left quadrant, as indicated by arrow 1 in Figure 5-1. The result is organized simplicity: a highly integrated organization which knows how to do things very well in essentially one way. Change in the way things are done is difficult to effect. The organization is rigid and inflexible in how it responds to problems, opportunities, and other changes in its environment.

Another possibility for evolution is towards unorganized complexity, as indicated by arrow 2. This is an organization that proliferates many ideas for accomplishing activities or developing products (differentiation) but never integrates them into a coherent process or product. Frequently, there is an element of innovation in this differentiation but what keeps it from being true innovation is that the good ideas never get realized. Examples of unorganized complexity are some of the early internet inventors who produced numerous elegant and novel approaches to solving internet technology problems but never put them together into a coherent, financially profitable business package.

The last possibility for evolution is towards integrated complexity, as indicated by arrow 3. This is a movement towards complexity and order at the same time. This is an organization that proliferates many new ideas about its processes, products, and solution approaches and then selects and integrates the best of them into subsequent versions or entirely new incarnations. Some organizations develop elaborate and detailed 10-year plans and then execute to that plan. An integrated, complex organization is not like that: instead, it "reinvents itself" through continual differentiation and integration to higher levels of value and performance. This "continuous reinvention" provides adaptability to environmental changes.

5.2 A Systems View of Development – Examples

Complex entities like individuals, teams, or enterprises do not develop in straight lines, as suggested by the arrows in Figure 5-1; nor are specific developmental outcomes necessarily guaranteed when an individual, team or enterprise embarks on a developmental program. So, how do complex entities develop? The following examples motivate a general developmental framework which will be elaborated in the remainder of this section.

> *Example: John is a capable performer who wanted to improve his value and impact at work. In collaboration with his supervisor and mentor John decided to achieve his goal by improving his communication skills, technical currency, and visibility within his organization.*
>
> *John looked into several opportunities for improving his communication skills including a variety of courses on effective writing and effective briefing preparation. He enrolled in one of each. John also joined a debating club. He soon realized that he communicated adequately in prepared situations and so he dropped the courses and increased his involvement in the debating club. John integrated his debating club experiences into his on-the-job impromptu and extemporaneous discussions.*
>
> *John explored different ways of increasing his technical currency: evening classes at a local university; e-Learning; and in-house courses at his place of employment. His frequent business travel made the evening class schedule untenable. The e-Learning environment was too unstructured for John. The in-house courses provided the right balance of flexibility for his travel schedule and structure, so John focused on that approach to improve his technical currency.*
>
> *John was known and well regarded in his business unit. But it was a small and established part of the company's overall operations. John diversified his individual work portfolio so that he and his work became more widely known in the company. He also sought out and contributed to initiatives perceived as vitally important to the company's future. As a result, John got visibility at higher organization levels.*

Example: Jane runs an engineering consulting group that is geographically divided between two locations. One part of the group is collocated with the client and the other is located at a facility 400 miles away.

The client was generally pleased with the consulting services provided but began to question the contributions of the part of the group that was physically separated from them.

Jane took several actions to remedy this perception. She began having weekly teleconference meetings that included the client and group members at both locations. She made a point of having group members away from the client location lead and brief activities to the client. Jane also rearranged some of the work so the away location had sole staffing and product responsibility for it.

These actions succeeded in changing client understanding of the away location staff and perception of their value to the existing contract. It also led to an unexpected, positive consequence: the client contracted with Jane's company for a different consulting activity based on the abilities and experience of the remote location staff.

Example: Linda is the general manager of a large and diverse business enterprise. Each division, by itself, has been successful in its niche and each has a reputation for innovating within its product area and market. The divisions' tendency, however, is to innovate incrementally in fairly predictable steps along their separate, various product lines.

Linda understands the importance and value of this "directional" innovation but she sees enormous potential for transformational innovation that develops fresh, groundbreaking ideas for new products and markets by associating concepts and technologies from one division with those from another division.[43]

Linda's vice presidents pay all the right lip service to her vision but they never seem to get around to putting together any creative cross-division proposals. They are not opposed to Linda's idea: they are each just "too busy" managing their own successful operations. Linda has held focus group sessions and off-sites in an attempt to generate some ideas and enthusiasm. She even considered a major reorganization to break down interdivisional barriers and better align operations with transformational innovation. But Linda understands that such a reorganization risks undoing the current organization's incremental innovation ability, which is also very important to future business.

Linda decided to leave the current organizations in place but to add a small but important business process. Approval for full scale development of a division's new product now requires the usual documentation and briefings and, in addition, the division is required to

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[43] In *The Medici Effect* (Harvard Business School Press, Boston, MA. 2004) Frans Johansson differentiates between two types of innovation – directional and intersectional. The former represents incremental development and the latter represents transformational development which requires the removal of *high associative barriers* between different cultures in an organization.

arrange and present an agreed, funded, cross-division collaborative proposal aimed at transformational innovation.

With this small change, Linda linked success within a division to collaboration across divisions. In effect, her new policy changed the rules of success for the divisions and reshaped the interaction patterns of her vice presidents and the divisions they lead to place a premium on collaboration. Linda cannot predict the exact details of the cross-divisional collaborations (nor would she necessarily want to), but she can assure that they will happen if the vice presidents and their divisions wish to remain successful. The strategy became so successful that it was copied by other general managers in the company.

5.3 A General Development Framework for Complex Systems

The three very different examples in Section 5.2 all involve the development of a complex entity or system (individual, team, enterprise). In each example, we can see movement towards the integrated complexity depicted in Figure 5-1. How did it happen? Clearly, each of the central characters in the examples *intervened* in their complex situations in ways that helped bring them to a "future" they were seeking.

What was the nature of these interventions? The first example concerned an individual who explored a *variety* of opportunities for developing his communication skills and technical currency before selecting specific approaches that served his needs. The second example illustrated how a line manager solved a perception problem concerning part of her team by changing the *interaction* patterns between them and her client. The last example illustrated a general manager *selecting* a strategy[44] to improve innovation, which worked so well it was copied across the corporation.

While simple, these examples illustrate the key elements of a guiding developmental framework for any complex adaptive system: [45] variation, interaction and selection. These are interlocking concepts that can generate productive actions in complex situations that cannot be controlled but can be influenced (reference Figure 2-3). The framework will help us ask and answer the question, "what interventions in our complex system are likely to bring us to a future we would prefer?"[46] This moves us from being passive observers in complex situations to active

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[44] A strategy is the way an agent responds to its surroundings and pursues its goals. The usage includes deliberate choice in the sense of business strategy and patterns of response that pursue goals with little or no deliberation.

[45] A complex adaptive system is a complex system (ref. footnote no. 1) that contains agents or populations that *seek* to adapt. An agent is entity that has the ability to interact with its environment, including other agents. It can respond to what happens around it and can do things more or less purposefully. A population is a grouping of entities (e.g., agents, strategies) that have a common attribute, affinity or bond (e.g., population of business managers, population of coworkers).

[46] The framework provides a systematic way to analyze complex systems that suggests useful questions and illuminates promising possibilities for action and it can clarify relationships among seemingly separate issues. Analyzing complex adaptive systems within this or any other framework does not assure the ability to produce or predict *specific* outcomes. But it can foster an increase in value, impact or

participants who *manage* variation, *shape* interactions and *make* selections to guide, even accelerate[47] improvement over time.

What do these three processes do? *Variation* produces raw material for adaptation.[48] *Interaction* makes or changes the rules and strategies agents play by and their interaction patterns. *Selection* promotes adaptation.

What questions do these processes help answer? A variation-interaction-selection framework clusters the discussion of change mechanisms in a complex system on three central and connected questions:[49]

- What is the right balance between variety and uniformity in a system?
- What (or who) should interact with what (or who) and when?
- What should be maintained or proliferated and what should be eliminated?

Much of the intellectual content of this variation-interaction-selection framework[50] comes from seminal work[51] done by Robert Axelrod and Michael Cohen (who, together with Arthur Burks and John Holland, comprise the original members of the BACH group).

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performance of the system over time. It provides a basis for inquiring where leverage points and significant trade-offs of a complex system may occur and it suggests what kinds of situations may be resistant to policy interventions and when small interventions are likely to have large effects (like the third example in Section 5.2).

[47] The idea of manipulating a complex system through regimens to *accelerate* improvement comes from discussions with and writings of M. L. Kuras (The MITRE Corporation).

[48] Adaptation is said to occur when a selection process leads to an improvement according to some measure of success.

[49] Although not mentioned explicitly, the change mechanisms may be in response to changes in the environment.

[50] Axelrod, Robert and Michael D. Cohen. *Harnessing Complexity: Organizational Implications of a Scientific Frontier.* New York, NY: Basic Books, 2000.

[51] The foundation for the variation-interaction-selection framework comes from three distinct fields: evolutionary biology, computer science, and social design. *Evolutionary biology* provides insights into how adaptations come about through the reproduction of successful individuals (with their successful strategies) in populations. *Computer science*, particularly evolutionary computation, has fostered an engineering approach to adaptation in which one asks how systems can be designed to be more effective over time. The rapid growth of the Internet (with its distributed and network-mediated computing) has led computer science into deeper analyses of what it takes to make systems of many agents work together and grow. *Social design* provides insights into people and their activities in political, economic and social systems. In particular, organization theory provides insights into how and why institutional structure *matters* and game theory provides insights into how people choose strategies to maximize their payoffs in the presence of other people who are attempting to do the same.

The perspective that is presented in this report is one which overlays Axelrod and Cohen's variation-interaction-selection construct onto Gharajedaghi's systems view of development, as depicted in Figure 5-2. Gharajedaghi provides the destination. Axelrod and Cohen provide mechanisms for moving towards it. Figure 5-3 is the same as Figure 5-2 but with callouts that show the organization of the discussion that follows on variation, interaction and selection.

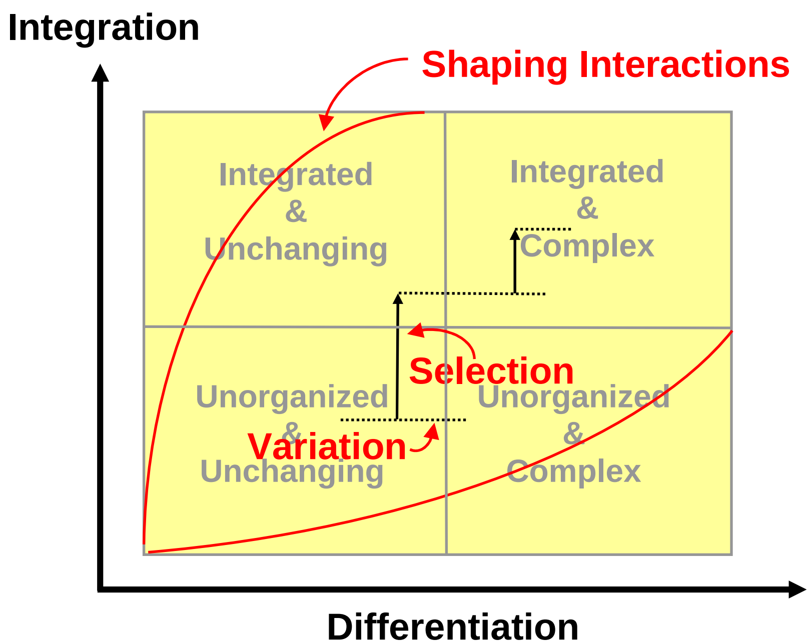

Figure 5-2. A General Development Framework for Complex Systems

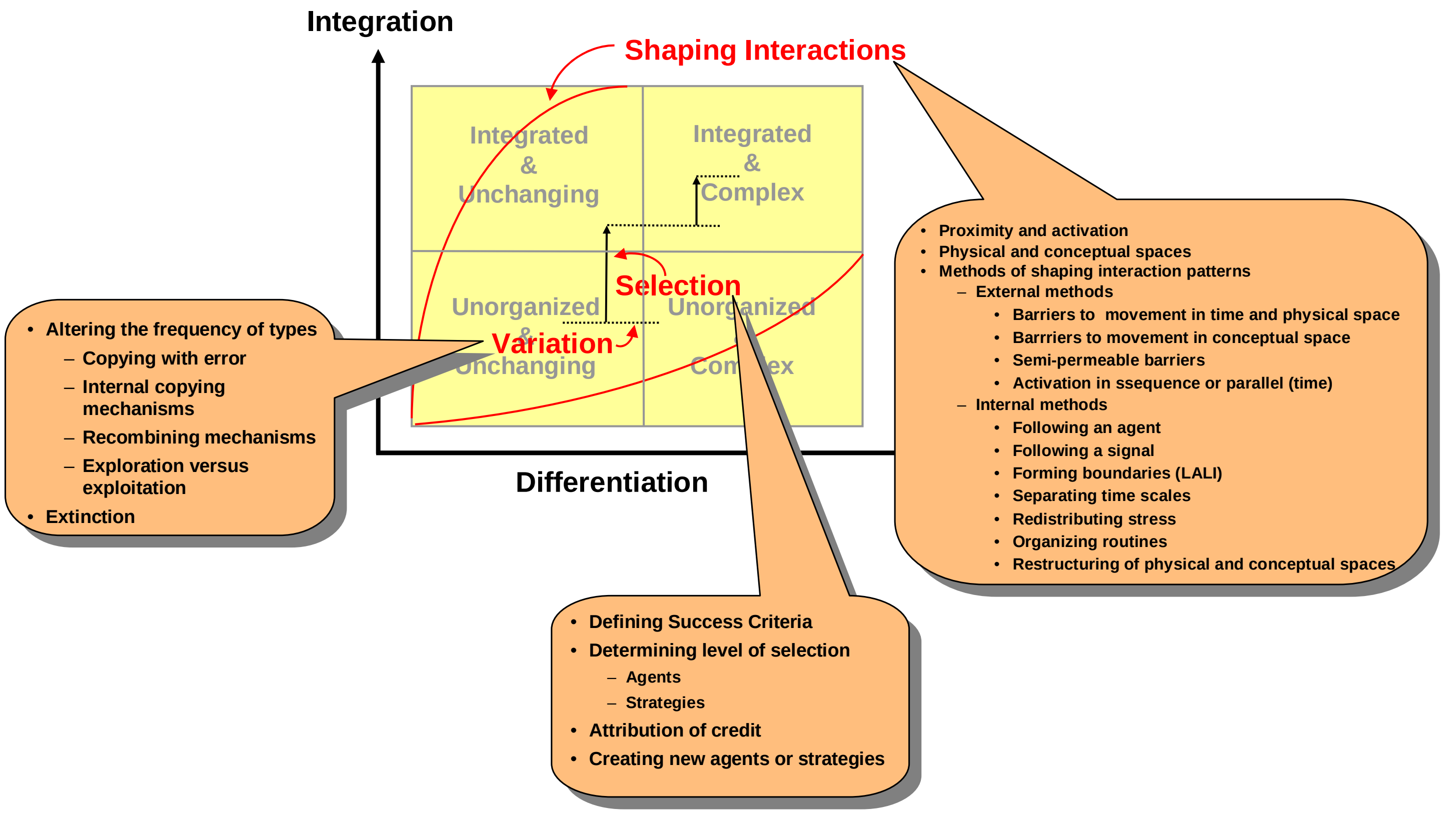

Figure 5-3. Organization of Discussion on the General Development Framework

5.4 Variation[52]

Variation produces the raw material for adaptation.[53] Variety is not only desirable to development of a complex adaptive system, it is essential. And it is essential not only in the popular "survival of the fittest" sense in which a "best-of-breed" artifact or agent is identified and selected from among a set of "also rans" which are then eliminated. That which is not currently best may be a critical resource for the future of a complex adaptive system. For example, without variety, the introduction of a new threat, such as a parasite or virus, can wreak havoc whether in crops, computers, or other monocultures.

But to take advantage of what has already been learned, some limits must be placed on the amount of variety or diversity in the system. Otherwise, there is the risk of expending resources generating options for achieving a goal and never actually choosing and using one. These factors and trade-offs were at work in the example in Section 5.2 of the individual who explored a variety of opportunities for developing his communication skills and technical currency before selecting specific approaches that served his needs.

The actions available to shape the behavior of a complex system often work not just by accommodating variety; they also work by actually increasing or decreasing the variety of agents in a population (e.g., internet standards, product designs under consideration for development). Variety turns up repeatedly in complex systems as a crucial factor in their development. But the situation is not always as simple as saying that homogeneity is bad and variety is good. Homogeneity can be very useful indeed, as the following example shows.

> *Example: Consider a C2 Enterprise built on a layered architecture in which IP is a chosen point of convergence for all network implementations.*[54] *The standardization of IP is a form of homogeneity imposed on the enterprise. Differentiation is lost at that particular level of the architecture and innovation is – if not lost – seriously affected because the inertia of a widely accepted and adopted standard can only be overcome by the most compelling reasons. But that same standardization enables innovation to flourish above and below the standard and is therefore a net gain for the enterprise.*

So, the key question in variation surrounds choosing the right balance between variety and uniformity. What are mechanisms for managing that balance?

5.4.1 Altering the Frequency of Types

There are several basic ways in which populations in a complex system can be created modified, or eliminated. Within a given population we will differentiate among subpopulations and call

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[52] Op. cit., Axelrod and Cohen, pp. 32–61.

[53] *Variation* produces artifacts which are objects that are used by agents (e.g., a systems engineering process). Artifacts can have important properties (e.g., location or capabilities). Artifacts usually do not have their own purposes or powers of reproduction.

[54] Electronic Systems Center Strategic Technical Plan (STP) v 2.1.

them *types*. A *type* is a category of artifacts or agents within the larger population which share some detectable combination of features.[55]

5.4.1.1 Copying with Error

In the simplest case copying can be viewed as a primitive reproduction process. When it functions without error the result is an increase in the frequency of one of the population types.

Copying is rarely perfect. In nature, genetic mutation is a copying error that is an important source of variety. It can create new types as well as alter the relative frequency of existing types.

There are many mechanisms in human social systems that are similar to genetic mutation. Process error (in systems engineering organizations, factories, or research laboratories) is one. These introduce variation into a system from sources like the misunderstanding of a system engineering process by a new employee, or deliberate shortcuts in established processes by an individual because of deadline pressures. Most variants introduced by mutation are detrimental. There is the occasional small improvement and the rare spectacular improvement. An example of the latter is the ink jet principle which was discovered as a result of a research laboratory malfunction.

Exploring (or expecting) new possibilities via copying with error is slow and costly.

5.4.1.2 Internal Copying Mechanisms

Mechanisms that produce new types or changes in type frequency in a targeted fashion tend to be triggered by events internal to the system in which they operate. An example is when a personal computer manufacturer offers two models and consumers buy one enthusiastically a kind of selection process takes place in which one type will become rare. Selection processes, discussed in Section 5.6, create copies of some agents or strategies from a population and eliminate copies of others.

Benefits to individual users that derive from the large number of other users (e.g., personal computers that enjoy robust file compatibility) can be a strong force in accelerating convergence and reducing variety. When a lead type becomes the *de facto* “best” and environmental

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[55] A type has five important aspects:

a. Types are generally defined by some detectable feature(s) of the agents in the population;
b. Many other dimensions of variety in the population may persist in the population without being recognized as types by the agents themselves;
c. The features that distinguish types usually provide only an imperfect indicator for the actual differences in action among the agents in the population;
d. Types are often endogenous in complex systems – agents within the population may detect types and act conditionally (and even change type definitions if the system is adaptive);
e. Types can be exogenous as well – defined only in the minds of those analyzing a CAS from the outside.

Op. cit., Axelrod and Cohen, pp. 37–38.

conditions are not changing, rapid convergence on a standard can result in large economy of scale benefits to both the user and the industry producing it. But in changing environmental conditions or when types available so far are not the best possible, loss of variety can result in potentially superior alternatives never being developed.

Conventional examples of premature convergence include the competition between VHS and BetaMax systems of video recording and the QWERTY and Dvorak keyboard arrangements.[56] Within a C2 enterprise there is the question of whether and when to converge on an IT standard.

5.4.1.3 Recombining Mechanisms

The process of selection only alters the relative frequencies of existing types (unless copying errors are also occurring). In biology the process of *crossover* recombines genetic contributions from both parents by splicing together pieces of already viable genetic material. This mechanism creates novel types in a way that is very different from the random changes made by mutation. As a consequence, *crossover* is more likely to yield an improvement than mutation.

Conceptual recombination, as a form of invention, has similar properties. Examples abound and many (though not all) have resulted in transformational or intersectional innovations including: the motor and wagon combination of the first automobile; Pixar's combination of computer technology and traditional filmmaking to create 3D animation with lifelike emotion (e.g., *Shrek*); and Richard Garfield's combination of board games and trading cards to create the popular collectible card game *Magic: The Gathering*.[57]

Another kind of *conceptual recombination* (that represents the more common incremental or directional innovation) comes from the traditional design analysis of a complex C2 system in which the system to be developed is decomposed into sub-problems that can be independently addressed. Potential sub-problem solutions can then be recombined in different combinations to address the system problem.

Constraint relaxation and *assumption reversal* are other mechanisms practiced in human problem solving. The former seeks solutions to a hard problem by generating variants that relax one or more of the situation's constraints. It introduces new variants by starting with materials of established feasibility and modifying them. *Assumption reversal* takes the idea one step further: it requires solutions to actually violate one or more assumptions about the solution space.

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[56] David, Paul, "Clio and the Economics of QWERTY." *American Economic Review 75* (1985): pp. 332–335.
[57] One view of transformational innovation is that it flourishes in organizations that enable and encourage different fields and cultures to meet to purposefully combine diverse concepts for problem solving. The interested reader is referred to Frans Johansson's *The Medici Effect*, Harvard Business School Press, Boston, MA. 2004.

Example: The RSA cipher (used as the basis for commercial internet encryption) was developed by reversing the 2500 year old basic law of cryptology that required two parties in a secure exchange to have the same key.[58]

The important point about this example is that *assumption reversal* encourages a perspective of a problem from a completely different viewpoint, breaks problem solving out of traditional patterns of thought, and allows the generation of unexpected combinations.[59]

Crossover, conceptual recombination and *constraint relaxation* provide mechanisms that can both create new types and change relative frequencies. They work with portions of strategies or agents already in use to introduce new types by internal processes that have some degree of correlation with the system's other conditions.

5.4.1.4 Exploration Versus Exploitation

Exploration versus exploitation is an important trade-off between the creation of untested types that may be superior to that which currently exists as compared to the copying of tested types that have so far proven best. This trade-off is important across a wide range of situations in which the testing of new types comes at some expense to realizing benefits of those already available.

This is similar to the relationship that exists between differentiation (as a form of exploration) and integration (as a form of exploitation) in Figures 5-1 and 5-2. Too much exploration can leave an organization permanently disorderly so that striking new ideas have their underpinnings swept away in subsequent change before it is known whether the new ideas will work. Aggressive exploitation risks losing variety too quickly which can happen when fast imitation of an initial success cuts off future exploration and possible improvement.

These are not just two ways that good concepts can go wrong. The two possibilities form a fundamental trade-space. Investments in options and possibilities associated with exploration often come at the expense of obtaining returns on what has already been learned. This trade-off sometimes has a temporal aspect to it.

Example: In the C2 Constellation example of Section 2, the enterprise leadership will, at some point, need to decide whether to invest resources, like capital, engineering talent, and management attention, in developing ideas for new constellation capabilities or in extending the service life and performance envelope of existing assets.

5.4.2 Rules of Thumb on Encouraging Variety

There are no hard and fast rules for when one would reliably do better with more variety. In an "ideal situation" where the current approach to a problem is judged the "best possible" and the problem or environment is unlikely to change, exploration is not indicated. For other situations there are some broad conditions in which exploration is likely to be of value. These are

[58] Ibid,, p. 55.
[59] Ibid., pp. 54–55.

summarized in Table 5-1, along with rules of thumb for them. The anecdotes from the Linux open source software development experience illustrate how its development philosophy favors exploration and variety.

Table 5-1. Rules of Thumb on Encouraging Variety[60]

Condition	Rules of Thumb	Examples from Linux
When problems are long-term or widespread	• The more use that can be made of an improvement, the more it pays to bear the costs of searching for one.	• Operating systems are among the longest living elements of IT. Unix – of which Linux is a free version – dates to 1969. • Improvement to an OS is likely to bear fruit over a long period. • The gains from an improvement to an OS can benefit thousands or millions of users.
Problems that provide fast, reliable feedback	• If you can learn quickly and reliably whether an alternative solution might be better then you have more chances to find an improvement and you have longer to gain from what you might discover. • Where fast and accurate feedback channels don't exist, try to create them so the benefits of exploration can be gained.	• In server environments, Linux features are exercised at high rates and defects are evident quickly. • Open distribution enables every contributor of a proposed variant to make a functional new version that can be tested locally. This increases the rate of feedback. • Quality of proposed variants can be assessed with relatively high reliability.
Problems with low risk of catastrophe from exploration	• If the risk of an extremely bad result from exploration can be judged as low then consider increasing the amount you are willing to do. • Try to create ways to lower risk of extremely bad results so the benefits of exploration can be gained.	• The Linux culture has a well-developed philosophy of modular isolation. Interdependence among components is strictly governed in a way that limits the chance of catastrophic consequences from exploration.
Problems that have looming disasters	• If continuing to exploit the best solution found to date will likely to lead to disaster, then explore. • The relative attractiveness of exploring comes from the negative yield of exploiting.	• This condition is a property of the motivation of some developers more than a property of Linux open software development, per se. • Many Linux contributors fear the extinction of the Unix OS family in which they have invested their expertise. • Others fear the hegemony of Microsoft OSs.

[60] Op. cit., Axelrod and Cohen, pp. 50–58.

5.4.3 Extinction

Ignoring the sharp effect of extinction can have profound implications in many complex social systems.[61] Real populations have finite numbers of discrete agents or artifacts and the difference between having a few and zero is not just a little extra waiting time. Recreating a type lost to the population can be unlikely. It is more likely that its niche will be occupied by another type which may not have an important feature of the original.

The reverse issue is that it matters enormously whether the number of people who have thought of an idea is one or zero. We see this in small ways all the time. For example, once a difficult and long-standing mathematical conjecture is finally proved subsequent and usually shorter, more elegant proofs quickly emerge.

This suggests that there is real risk in a view that assumes all that is needed for an idea to emerge are circumstances that will bring it rapidly to prominence. The distinction between this view and one that understands the effect of extinction has relevance for policy strategies. For example, "counting on the market to find a solution," can be expected to work more rapidly and reliably in domains where several approaches have been partially worked out as opposed to a domain in which a feasible approach is yet to be conceived.

5.4.4 Summary

Variety plays a critical role in the evolution of a complex enterprise. The focus in this section has been on managing variation through mechanisms that create and destroy variety in a population. These are fundamental to changing the composition of populations over time. There is a fundamental trade-off between exploitation and exploration. The former creates agents or strategies similar to types that have already been successful. The latter creates types that are likely to be substantially novel. Extinction of types may be significant in a complex enterprise.

5.5 Interaction[62]

Interaction among agents shapes the creation and destruction of variety and produces the events that drive attribution of credit. When thinking about the variety of agents and their strategies one is led to the question of the right balance between variety and uniformity. This balance is achieved partially through interaction which seeks to answer, "what or (who) should interact with what (or who) and when?" Interaction patterns and their influences are all around us, as illustrated by the familiar example below.

[61] Many conventional theories for analyzing populations are based on assumptions of continuous modeling traditions (the so-called nano-fox property in which predator-prey models grow and shrink by proportionality constants). In these theories there is no complete extinction so no matter how severe the starvation, the predator population will rebound as soon as the prey return.

[62] Op. cit., Axelrod and Cohen, pp. 62–116.

Example: Our individual networks of current acquaintances have a strong local bias because it is convenient to work, shop, attend school, and become affiliated with civic and religious institutions near home.

More fundamentally, and beyond manipulating variety and uniformity, interactions help shape the outcome space within which a complex system develops as depicted in Figure 5-2. Events of interest within a complex social system arise (or do not) from the interactions of its agents with each other and with artifacts, as illustrated by the example below.

Example: The 1961 French military putsch against Charles de Gaulle, precipitated by his policies on Algeria, failed before it could get off the ground. None of the officers had taken more than a passing notice when thousands of transistor radios were issued to French troops several weeks before de Gaulle's Algeria policy announcement. The radios were regarded as a harmless comfort for the troops aimed at relieving their boredom. But de Gaulle used them to broadcast directly to the troops his reasons for the Algeria policy. Though the policy was wildly unpopular with most career soldiers in leadership roles, de Gaulle succeeded in convincing thousands of conscripts of the wisdom of his choice. This one-on-many interaction between de Gaulle and his troops, over the heads of their intermediate leaders, broke the back of the revolt before it started.[63]

Interaction patterns shape the events in which members of a complex social system become directly involved and they provide the opportunity for spreading and recombining of types that lead to creation and destruction. The events drive processes of selection and amplification that ultimately change the frequency and variety of agent types. Interaction patterns help determine what will be successful for the agents and the system and this, in turn, will help shape the dynamics of the interaction patterns themselves.

5.5.1 How Interaction Works: Proximity and Activation

When thinking about patterns of interaction it is useful to differentiate two classes of determinants: *proximity factors* and *activation factors*. The distinction between the two roughly equates to that between space and time.

Proximity factors determine how agents come to be likely to interact with each other (or not). Normally, we pay a lot of attention to physical proximity but we are all part of numerous other relational networks that establish proximity. Some examples are: organizational proximities, interest group affiliations, political parties, etc. These all influence the likelihood of whether particular agents or classes or agents will interact and the nature of their interaction.

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[63] Forsyth, F., *The Day of the Jackal*. New York, NY. Bantam Books, 1985, pp. 20–21.

Time scale affects our perspective on *proximity*. On a short time scale proximity focuses largely on the issue of how likely it is that a particular agent or group of agents will interact with a larger population.

Example: When looking for a new job it is common for an individual to interact with a network of peers who have similar business or technology interests, and work environment preferences (action-oriented versus contemplative; research versus production; academic versus applied, etc.) to identify companies with cultures compatible to the job seeker. The focus of this short-term proximity dynamic is on fit of an agent (job candidate) into what is perceived as a relatively fixed population (a company).

On a longer time scale, the focus on *proximity* can change. While in the short run, a place of work shapes what kinds of individuals join the company, ultimately the individuals who come on board shape the company.

Example: A company provides a technologically sophisticated consulting service to a large client. The company and the client both agreed that collocation with the client would form a stronger partnership and the change was made. It is natural and prudent for the company to place increased emphasis on the technical staffs' ability to interact with the client. But if it is done at the expense of technical know-how (for example, by hiring large numbers of staff who come from the client ranks and know its culture better than the needed technology) over time the company risks losing what attracted it to the client in the first place – its technological sophistication.

Thus, a structure that seems fixed in the short term (like a company's culture and expertise) can be changed in profound ways over time by co-evolutionary dynamics.

Activation factors determine the sequencing of activities. The term *activation* groups together many different processes that affect the timing of agent activity. It is useful to differentiate systems with periodic or "clocked" activations (e.g., budget or other calendar driven cycles) from conditionally activated processes in which the results of a current event control which events may occur next. In the former type of system events are activated by global, rigidly controlled mechanisms while in the latter events are activated locally and flexibly.

The distinction can be profound. To use a simple example, consider the difference between "ready, aim, fire" and "fire at will."[64] The decentralization inherent in a conditionally activated process like "fire at will" is normally assumed to be an advantage since the adaptive capacity of a system is increased when events can be activated locally and flexibly rather than globally and rigidly. But this is a *two-edged* sword: adaptive capacity can speed extinction as well as increase viability. Just as in *variation* where neither exploration nor exploitation is always preferable, neither greater internal control nor greater decentralization is necessarily better.

[64] Op. cit., Axelrod and Cohen, p. 63.

Example: Permitting financial traders to respond to local conditions can let them quickly exploit short-lived arbitrage possibilities. But when globally determined prices contradict traders' assumptions it can lead them to a rapid sequence of ever riskier trades to cover loses with the potential for financial catastrophe.[65]

A major question in structuring interaction patterns is whether interactions will be concentrated among a few pairs of types or will be spread across a wide range of type pairings. This involves a trade-off between *intense* and *diffuse* interactions among types. That is, over time, should the interactions of an agent repeatedly be with others from a limited number of types or with others drawn from a wider range of types?

Example: Engineers who stay together in a stable work group with the same leader as they progress through different projects experience intense interaction patterns. Those who change work groups and project leaders as they move among projects experience diffuse interaction patterns.[66]

Issues that arise in the *intense interaction* pattern are insufficient exploration and loss of variety. An issue that arises in the *diffuse interaction* pattern is that prior accomplishments may not be fully exploited in subsequent work groups. But there is nothing inherent about this alignment. Diffuseness can favor exploitation.

The point about the intense/diffuse trade-off is that it alerts us to a set of questions that need to be asked about how the shaping of *proximity* and *activation* in a complex social system will affect the exploration-exploitation balance, along with other aspects of the system.

5.5.2 How Interaction Works: Physical and Conceptual Spaces

A fundamental property of an agent is its *location*. Agents have *location* in the usual physical space and time sense. The movement of agents in space and time changes their proximity and hence their ease of interaction. When agents interact they are either physically co-located or the interaction takes place via technology. So the concept of *location* applies to interactions, as well.

Examples:

- *Learning news in a conversation at the town square.*
- *Discussing a work proposal via a teleconference.*
- *Purchasing a text from an on-line mail order catalog.*

Using the idea of physical space and time as an analogy we can consider the *location* of agents and their interactions in other kinds of spaces.

Example: A company organization chart provides a map of a conceptual space. The director of purchasing is "near" those who do purchasing in the sense that their interactions are likely

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[65] Ibid,, p. 63.
[66] Ibid,, p. 69.

to be frequent even though purchasing agents may be physically distributed across the company's business locations. At the same time, the purchasing director may be organizationally far from someone working in marketing even though that office is next door. It is the logic of roles in an organization that makes individuals more or less likely to interact.[67]

In fact, a way of thinking about organizations is as a deliberately designed conceptual space that will "organize" the interaction of agents toward some ends.

Example: Recall the geographically divided engineering consulting group of Section 5.2. The manager altered the roles of away location staff and began having weekly teleconferences between the two locations to increase the frequency and nature of interactions between her local client and away location staff. This increased the visibility of away staff and succeeded in changing the perception of their value to the client.

Organizations are a familiar example of conceptual spaces but they are not the only kind. All that is required is that the concepts convey a sense of multiple categories that can be *locations*, that agents in the population can be members of different categories (and thus have different locations), and that the locations convey something about the likelihood that agents will interact. Technical expertise, similarity of roles, rank or other forms of status, fluency in a certain foreign language, and similarity of work problems are a few examples of concepts that can also serve as conceptual spaces.

Differences in the timing of events in a complex system can have a large effect on outcomes. A change that increases proximity, that makes agents more likely to interact, means that on average the interaction will occur sooner. Reversing the order of events may change the character or likelihood of those events. The system can have an entirely different history, as a result.

Example: The D-Day results (and that of World War II) may have been dramatically different had the 3rd Reich learned of the true location of the main attack before it was launched.

5.5.3 Methods of Shaping Interaction Patterns

Specific mechanisms to harness complexity by shaping interactions fall into two classes: external and internal. *External* mechanisms are ways to modify the system from the outside (e.g., designing artifacts or policies that change the rules others play by). *Internal* mechanisms are ways to change the interaction patterns that are driven by processes within the system. Each can be thought of as a form of filtering that selectively allows more interactions with certain agents and less with others.

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[67] Ibid,, p.73.

5.5.3.1 External Methods

The principal mechanisms available to change interaction patterns from outside of a system are: barriers to movement in time and physical space; barriers to movement in conceptual space; semi-permeable barriers and activation in sequence or in parallel.

Barriers to movement in time and physical space: Examples of barriers to interaction exist throughout our social world including national borders, prisons, private clubs, computer networks deliberately disconnected from other networks, and middle schools that isolate juveniles facing the onset of adolescence from children who are either younger or older. The essential effect is to make some agents more proximate and others less. Examples of barriers include direct changes to physical space such as adding walls. Examples also include alteration of the technology of moving through physical space: building tie corridors among a corporations campus of buildings. Any barrier has an opposite, e.g., removing walls, or eliminating existing tie corridors.

Time can be altered by controlling the technology for moving through it. Writing is a means of interacting across space and with the future. Reading is a technology for interacting with the past. Many IT advances can be understood as reducing the barriers to interactions across space and/or time. Some have a 1-to-many broadcast property (e.g., radio and television).[68] When controlled by central authorities they have enormous power to make diverse and dispersed populations more homogeneous in their knowledge, loyalties and language, as evidenced by the example of de Gaulle's policies on Algeria.

A major limitation of these kinds of barriers is their imprecise selectivity. Crude physical boundaries rarely cluster together all the agents who would benefit and only those. Technological interventions that remove barriers often increase both wanted and unwanted interactions: for example, the world wide web which brings us closer to both desirable and undesirable groups.

Barriers to movement in conceptual space: This is an extension of the basic barrier approach that achieves greater selectivity. Conceptual spaces are used by agents themselves to make distinctions. Examples, previously noted in Section 5.5.2, include technical expertise, similarity of roles, rank or other forms of status, fluency in a certain foreign language, similarity of work problems and a host of other categories. The "location" of each of these conceptual spaces is delimited by boundaries to movement which are largely defined through a complex system's social conventions. For example, it would be an unusual junior staff member who chooses to sit in a company cafeteria at a table of executive directors.

These conceptual barriers place more refined and selective filters on patterns of interaction than physical barriers. This is an enormous advantage as a means of shaping interaction patterns. The disadvantage of conceptual barriers is under-exploration because they restrict interactions to homogeneous and familiar pools of other agents as suggested by the following example.

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[68] Ibid., p. 79.

Example: Members of highly specialized technology communities tend to advance their discipline in fairly predictable steps along a well-defined dimension because they primarily combine concepts within their field. This evolution via refinement and adjustment is what Paul Maeder[69] *calls "single-disciplinary incrementalism." It rarely leads to transformational discoveries in a field, which are more likely to occur when a multidisciplinary team addresses a problem.*

Semi-permeable barriers: A *semi-permeable barrier* is anything that prevents some kinds of interactions while permitting others. Examples include gates and guards who exercise selective access control; network firewalls; and V chips for televisions.

In a complex human social system many examples of semi-permeable barriers involve delegating a person to make choices which involve conditionally opening or closing a barrier to an agent wishing to move through it. Inserting a human in the loop is common since the desired selectivity is important and usually not easy to automate well. Examples include secretaries who control access to their supervisor's office and calendar; and certification boards that test, accredit and expel members of professions such as law, medicine, and teaching.

As a technique for shaping interactions, semi-permeable barriers are most useful when an overwhelming number of interactions that consume time and resources are possible, and the agents seeking access are not well known. On the other hand, semi-permeable barriers (as well as conceptual barriers) may admit the wrong agents or block the right ones.

The chief advantage of semi-permeable barriers is the increased precision of blocking and permitting movement in physical and social space. Semi-permeable barriers can allow passage where admission should be governed by momentary conditions or in situations where rules cannot cover well all the circumstances that may arise.

The disadvantage of semi-permeable barriers is the possible mismatch between the rules or criteria governing the selective admission and the long-term welfare of the system behind the barrier.

Example: A company which has succeeded for years using outmoded manufacturing processes may not survive economically if it continues to focus its hiring efforts on individuals who have only those skills.

Activation in sequence or parallel: Most mechanisms discussed thus far involve the deliberate manipulation of physical or conceptual spaces. But the individual, manager or policy maker may have the opportunity to manipulate time.

Example: When a new system is being developed, there may be many components of the overall design with the configuration of each one depending to some degree on the designs of others.

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[69] Paul Maeder is the founder of the highly regarded venture capital firm Highland Capital.

The conventional approach to design interdependence has been to work in sequence. Part of the art of managing sequential design is to choose a sequence in which the discoveries of problems at later stages do not force too many changes in the results of earlier stages. A major drawback is that it requires a long elapsed time from beginning of first design stage to completion of the last.

There has been a large move to parallel design of complicated products. The designers work on all components at the same time. The project is completed in the time required to design the most time-consuming single component. This rearrangement may offer a large improvement if the communication and coordination among the simultaneous design subprojects does not slow them or introduce inconsistencies.

The gain occurs (if it does) by a re-sequencing of the interactions among the agents in the design team. In the sequential design, designers of a component interact with designers of components "upstream" by receiving finished plans and perhaps even prototype artifacts.

In the parallel design the work of any one component design teams is contemporary with perhaps many others since all team are active simultaneously. Communications among the subprojects cannot be so much via finished plans and artifacts as it is in projections and models of what other components will be like in the end.

CAD tools, for example, enable coordination and communication, in parallel design. A "working" simulation of the entire product is built and each new version of a component is reflected in a change in the simulation which must continue to show that the overall product still "works." This shared model is a rich artifact that helps achieve the needed coordination.[70]

Increasingly, business processes within enterprises are moving towards greater automation and interconnectivity with the result that more information is becoming available to more individuals faster. A consequence is that the sequencing of events in complex social systems is being manipulated by advances resulting from the information revolution, sometimes in subtle but important ways. This has profound implications (legal, privacy-related, and cultural, to name a few) that are only beginning to be understood.[71]

Example: Company A has a well-developed intranet which includes a directory of all employees. The web page for each employee contains basic information such as office location, telephone number, position, and grade.

When an individual is promoted, company policy has been to inform the employee privately (preferably face-to-face) and then inform the rest of the organization (usually via email).

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[70] Ibid., pp. 84–86.

[71] While it is too early to say for certain, *Social Computing* systems may have the potential for transforming how we view and use enterprise tools. *Social Computing* includes people, organizations, and their activities as fundamental system components, with a goal of enabling identity, behavior, social relationships, and experience to be used as solution elements. See, for example, http://www.research.ibm.com/SocialComputing/.

But the process between approval of a promotion (or any pay grade change, for that matter) and posting to the corporate intranet had become so automated and efficient that changes began being posted before the individual had been informed.

Since most employees have little occasion to visit their own web page, their peers (who might be looking up the employee's telephone number) would notice a promotion and call to congratulate the unknowing recipient of the promotion. It was usually a pleasant, if somewhat perplexing discussion. Of course, learning of a demotion this way can be a devastating experience for an employee.

The company resolved the altered timeline by inserting a manual step in the approval-to-posting process to assure an employee had been notified of a grade change before it became publicly available.

5.5.3.2 Internal Methods

Internal methods for changing interaction patterns are mechanisms that depend on interactions within the system to stimulate further activation of agents. There are several major methods: following another agent; following a signal; forming boundaries; separating time scales; redistributing stress; organizing routines; and restructuring of physical and conceptual spaces.

Following another agent: One of the simplest mechanisms that can modify interaction patterns arises from one agent staying near another. The most basic examples involve staying nearby in a physical space. The general character of the mechanism persists even when the proximity is conceptual.

The biological prototype of this mechanism is *adhesion* in which one organism sticks to another or stays close to it. The effect is that the "following" agent experiences a pattern of interactions similar to that of the "leading" agent. Additionally, there is more interaction between follower and leader and the follower meets people (agents) the leader knows.

Examples: There are many examples of agent following including apprenticeships, big-brother/big-sister, aide-de-camp and general officer, and mentoring relationships. They all share an element of acquiring the interaction patterns and strategies of the leader, who serves as a kind of template.[72]

In following, an agent can tacitly pick up the contact pattern of a leader without necessarily understanding the theory of (or causes and effects of) that pattern. Good theories can be costly to

[72] In the world of computer networks this kind of mechanism has been generalized in "recommender" systems which allow users to "adhere" to the tastes of others, in order to interact with persons and objects the recommender system has encountered. This is used in the world of taste goods (e.g., books and music), for finding professional assistance (dentists, stockbrokers) and for finding discussion groups or web pages of interest. The information revolution makes possible recommendations based on a statistical synthesis of others that might be closer to predicting an individual's personal tastes than any other single user or even a professional critic.

create and share with others and they may not always be needed. Many, maybe most, well-executed human social interactions occur without benefit of explicit knowledge, let alone a theoretical understanding of why a pattern of behavior works well. For the most part, knowledge transmitted via agent following serves people well, even if it may carry along some counterproductive beliefs. The mechanism of copying the interaction patterns of other agents passes along vital social knowledge and allows an agent to adapt (to the environment which is new to him or her but not the leader) without requiring an explicit understanding of complex social systems.

Of course, problems can arise when interaction patterns learned by following are transferred to new contexts, including situations in which the current context changes, since the selectivity of a more precise theory is not available to sort out which features should be modified and which retained.

> *Example: Ways of interacting with a consulting client that evolved in an era of physical separation and communication via written report can work poorly when transferred to a collocated, interactive team environment.*

Copying another agent has a further effect in addition to picking up the other's patterns of interactions. At the population level, copying others' interaction patterns also introduces strong correlation among the contact patterns of the agents with the resulting social system having a strong cliquish property. An advantage of the formation of social networks with correlated properties is that agents in such a population will have a strong overlap with the contact patterns (and thus the strategies and knowledge) of most agents with which they interact. This overlap implies shared assumptions and common understandings and these, in turn, simplify transactions of all kinds. Explanations can be brief and result in few misunderstandings. Consequences of actions can be more correctly anticipated. The ease of communication helps build social capital.

There are disadvantages to a social structure that develops through pervasive *agent* following. It can result in a loss of information diversity. Frequent interactions of colleagues who all know one another can lead to reduced diversity of the information they hold as a group. This can have the effect of reducing an agent's ability to explore a wide space of options whether the agent is an individual, work group or enterprise. Surprisingly, important information usually does not come from a close circle of colleagues but from acquaintances at the edge of an individual's social world. If *agent* following mechanisms predominate in an organization, the culture may evolve to one of insufficient exploration and premature convergence.

A consequence is that a healthy professional social network should probably contain a mix of strongly and weakly clustered contacts to provide a balance of exploitation and exploration. This is similar in its essentials to an important *small world*[73] property, exemplified by Mark

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[73] Watts, Duncan J., *Six Degrees: The Science of a Connected Age*. New York, NY. W. W. Norton & Co. 2003.

Granovetter's circles of friends,[74] notionally depicted in Figure 5-4, where those within the same circle know each other well and communication with other circles is maintained by a few weak ties.

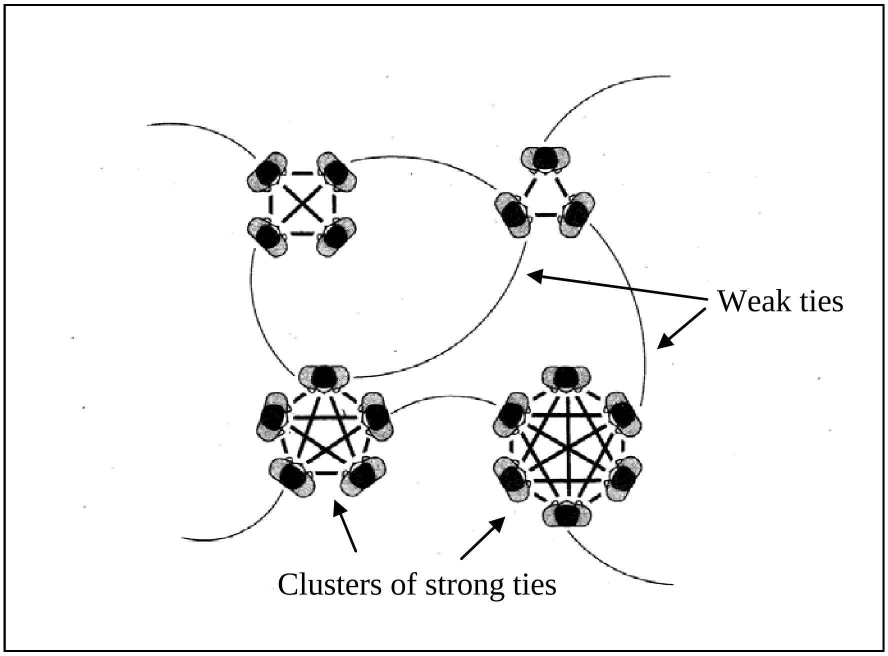

Figure 5-4. Strong and Weak Ties (Granovetter's Circle of Friends)

Following a signal: Another strategy that an agent can use to alter its interaction pattern is to follow some detectable *signal*, moving toward locations that have better value.[75] The movement creates new patterns of interaction for the following agent. From the perspective of an external designer, this strategy provides an opportunity to create or modify signals that agents follow in order to alter their patterns of interaction.

People and other agents move in space toward desirable signals: spacious offices with privacy and quiet; roles perceived as having higher value and impact; jobs at companies with intellectual stature in a particular community. These are patterns of moving through physical or conceptual space by following a *signal*. The direct effect is to bring the agent into a situation that is perceived as more desirable. The indirect effect is to bring the agent into the interaction pattern prevailing in

[74] Barabasi, Albert-Laszlo. *Linked*. Cambridge, MA. Plume Books. 2003, pp. 41–44.
[75] Finding a new signal and moving towards it is the essential message of many self-improvement best sellers like Spencer Johnson's *Who Moved My Cheese?* G.P. Putnam's Sons. New York, NY. 1998.

the new location. The agent enters the social network of the new location. So, while agents generally move along a gradient for its own sake (to get a quieter office or make more money) they experience the indirect effects of these interaction patterns, which may not have been fully anticipated.

A disadvantage of following a signal is that an agent can get stuck at a local maximum and not find the global one. This is a common problem in complex adaptive systems. A strategy for dealing with a signal for the global maximum not being detectable from a current location is for the agent to make large exploratory moves to determine whether that signal can be picked up from a different vantage point.

> *Example: An individual may be in the "best job" in her current company but there may be a better one in another company which remains unknown unless she seeks outside opportunities.*

> *Example: During the 1980s, rival groupings of computer companies formed to advocate different standards for the Unix operating system. The several groupings seem to have developed their coalitions by a logic of considering only small changes in the space of possible coalitions.*[76]

There are differences between *signal* and *agent* following. Signals are usually associated with locations rather than agents. Following a signal relies implicitly – and sometimes explicitly – on a belief that the signal goes together with consequences an agent will prefer. Signal following leads to locations that attract others who follow the same or related signal. Agent following leads to others an agent interacts with, through whatever mechanism.

An advantage of s*ignal following* is that it can provide an explicit context for interpreting what happens. If an individual changed jobs because he perceived the new company as being intellectually distinguished and finds he is enjoying his new colleagues, the improved intellectual environment is a likely cause. Another advantage of *signal following* is that the consequences of the resulting patterns of interaction can be evaluated as reasonably specific criteria. One can say, "I wanted a more action-oriented environment and it is." In *agent following* it may be more difficult to know what criteria to apply to the resulting interactions since the signal may not be causally associated with the interactions experienced.

> *Example: An employee goes to a "better" job but has a bad year because of his new supervisor's unrecognized management style problems. Since the employee does not know the true cause he may incorrectly conclude that the problem stemmed from some distinctive feature of the new job.*

A disadvantage of *signal following* is that the signal may be a poor predictor of the quality of interactions that follow.

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[76] Axelrod, Robert. *The Complexity of Cooperation*. Princeton University Press. Princeton, NJ. 1997.

Forming boundaries: What is the similarity among a zebra's stripes, sharply defined ethnic neighborhoods in a large metropolitan area like Boston (e.g., Chinatown, North End), the concentrations of different merchants (e.g., gold dealers, rug dealers) in downtown Ankara, Turkey, and splinter groups in political wings, both left and right? They are all examples of striking patterns characterized by sharp boundaries.

How are these patterns formed? Different as they seem to be, these are all examples of pattern formation by local activation, long-range inhibition (LALI). The basic principle is that a pattern that has been "deposited" in one area makes it more likely that another, similar deposit will occur nearby and less like that a similar deposit will occur farther away.[77] Nearby areas will have many deposits and, as a result, areas farther away will have strong pressures to be clear. Together, these two forces lead to the formation of sharp boundaries.

As the examples suggest, LALI works across a wide range of spaces, both physical and conceptual: patchy ethnic neighborhoods in residential areas of cities, splinter groups on a political extreme wing, spots on a Dalmatian's back, groupings of ideologically like-minded individuals who attract those who share their views and oppose the "heresies" of those who do not.

> *Example: Archipelagos and networks of mountain valleys are examples of LALI at work. Research has shown that for biological populations they are the ideal breeding ground for novel life-forms. The Galapagos Islands are a familiar example. In these settings semi-isolated populations breed with relatively infrequent exchanges of animals. Improvements occur but spread slowly enough to avoid a rapid loss of diversity.*
>
> *Care must be taken in choosing actions for human social or organizational settings based on simple analogy to breeding biological populations. The mechanisms of reproduction are very different, as are the criteria for assessing change.*
>
> *Nevertheless, an organization that judiciously clusters networks (or facilitates their formation) may create a more favorable environment for diversity and adaptation. In this kind of organization early innovations spread more slowly and variety that can provide material for later improvement is retained. Premature convergence is less likely to occur. To the extent that the biological analogy is appropriate to human organizational settings, there are implications for how the organizational structure and policies of an enterprise facilitate or inhibit innovation and adaptation.* [78]

The point in presenting the above example[79] is not to recommend either resisting or facilitating the loss of variety in a complex social system. Rather, it is to pose the question in terms of the

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[77] Bonabeau, Eric. *From Classical Models of Morphogenesis to Agent-Based Models of Pattern Formation*. Santa Fe Institute Working Paper 97-07-063, 1997.
[78] Axelrod, Robert. *The Complexity of Cooperation*. Princeton University Press. Princeton, NJ. 1997.
[79] Note the similarities between the archipelago in this example and the strong and weak ties of Granovetter's Circle of Friends discussed in 5.5.3.2 and depicted in Figure 5-4.

structure of networks of human interactions in such a system, so that advantages, disadvantages, costs, and interventions can be considered.

Separating time scales:[80] There is a tendency of many social systems to assume hierarchical shapes. The upper layers of such systems typically involve processes that span longer time intervals while the lower levels are more often involved with processes that run relatively quickly. Generals and their staff concern themselves with the question of what campaigns should be entered in the weeks or months to come, while Army Brigade and Air Force Air Operations Center planners concern themselves with the production of ground operation and air mission plans for the next few days.

This hierarchical arrangement of time scales supports effective governance in complex social systems, which is why it is often seen in the military and industry. The slower activity at the upper levels establishes a stable context for faster processes at the lower levels. It helps in taking a defended hilltop if the definition of the enemy does not change while you are attacking it. It helps in providing a service if the definition of the client does not change while you are providing it. Hierarchies have the property that every element of the system (but the top one) has a supervisor. So, whenever a superordinate element acts, it establishes a context that allows its subordinates to act in concert. This is useful in achieving the benefits of coordination.

This separation of time scales in complex social systems is advantageous. Actions with long time frames tend to become assigned to positions that govern levels in which actions have shorter time frames. Systems that organize this way will have a competitive advantage.

In most organizations, the assignment of actions to different levels within the organization is done by agents within them. If those agents understand this principle, it offers them an opportunity to adapt their organization when changes occur to its environment.

> *Example: Consider a company that provides a technologically sophisticated consulting service to a client. If the client's consulting needs begin to change very rapidly, it may be advantageous for department and division managers to relinquish product quality oversight and reassign it to lower level managers or even individual staff. The department or division managers then focus on the long-term reputation of the company with the client and within the technology and business communities of which it is a part. In this way, management still continues to influence the products employees produce but they do it by shaping the company's reputation which attracts certain types of clients and employees.*

The point of the above example is not that the line of reasoning in it is always right. The point is it represents a perspective that comes from and leads to the right kinds of questions.

Redistributing stress: This is a mechanism that depends on interactions within the system to stimulate further activation of agents. Per Bak has studied a wide range of systems in which some kind of stress propagates through the system (sand piles, snow fields, underground rock layers)

[80] Simon, Herbert A. *Sciences of the Artificial*. Cambridge, MA. MIT Press. 1981, pp 193–229.

which release in avalanches and earthquakes.[81] The attribute of a system which gives rise to these events is called “self organized criticality.”[82] In Bak’s work the systems consist only of artifacts. Later work has shown that some of the results can apply to systems that include agents. Examples are traffic jams and the mass extinction of species.

What is happening in all these instances is that a small event may or may not trigger other events (such as avalanches or earthquakes). Bak’s group has repeatedly found that the events follow the power law distribution.[83] The principle can be illustrated by the distribution of the sizes of wars as well as the sizes of avalanches. There are many small wars, a moderate number of medium sized wars, and a very few large wars. Another important result about these systems is that after they build to their critical state, a long period without a large event does not imply that one is due soon. There is such a complex interdependence among all the elements of a system that it cannot be known whether small events are relieving or increasing stress.

The following extended example[84] illustrates the interplay of stresses in a highly interactive and interconnected large scale information system, how they can lead to catastrophic failure, and possible mitigation techniques.

> *Example: The possibility of large-scale failures in information systems is an especially important problem domain for three reasons.*
>
> - *Information in the information systems involve both new technology and new institutional arrangements which have not existed long enough for the development of a good empirical foundation for risk assessment and management.*
> - *Information systems continually undergo major changes, so a good empirical foundation for risk assessment and management may never become available.*
> - *Vital economic and military functions are highly dependent on these systems.*
>
> *Some types of failure in information systems are well understood and easy to design against. Others are much less understood and present substantial challenges.*
>
> *Independent failures are the simplest type. These may be thought of as local failures. If a room is lit by four lamps and one goes out, it does not make the others fail any sooner than they otherwise would and the others continue to provide light. As this simple example illustrates, the primary method of risk management against independent failures is to build*

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[81] Bar, Per. *How Nature Works: The Science of Self-Organized Criticality*. New York, NY: Springer-Verlag, 1996.

[82] Self-organized criticality is the tendency of a system to stay near its critical state.

[83] The power law distribution is an important characteristic of scale free networks which are as diverse as the World Wide Web, the U.S. Air Traffic System, the “acquaintance distance” between any two people (popularized in John Guarre’s *Six Degrees of Separation*), and the molecular network in biological cells. See, for example, the discussion in Barabasi’s *Linked*.

[84] Ibid., pp. 106–110.

redundancy into the system. This can be seen in the more sophisticated example of an information network in which reliable communication is assured by routing traffic around a failed node.

The situation becomes more difficult when local failures are not independent. Correlated shocks are failures that occur when elements of the system tend to go down at the same time for the same reason. For example, radio transmitters in an area would all likely fail at the same time due to the occurrence of sunspots. Typical solutions involve building new elements of the system that are not susceptible to the same shocks, for example landlines in the sunspot example. Monocultures, such as information systems that rely on widespread use of common hardware and software components, are susceptible to computer viruses and other virtual pests. Heterogeneous computing environments may be more difficult to manage for the IT staff in an organization but they can enable some knowledge workers to continue company operations while others wait to get their machines disinfected.[85]

Independent and correlated failures can both occur in systems whether or not the elements are connected to each other. In our efforts to stabilize systems against independent or correlated failures we often transform them into more tightly coupled systems that redistribute stress. An example is the U.S. electrical power grid system which allows regions to borrow power from each other to deal with local failures or shortages in capacity.

Stress propagation failure becomes possible when a system's elements interact naturally or are designed to interact. The risk is that a failure in one element can cause stress in another element, leading to failure of that element, as well. Eventually a cascade of failures could cause a large-scale failure, as shown by the 1977 blackout in New York City or the two outages of 1996 that affected millions of utility customers in the western United States show.

Of course, systems are coupled for many other reasons besides protecting against independent or correlated failures. One important reason is efficiency. For example, a just-in-time inventory system, which increases efficiency by reducing inventory buffers, means that a strike in a single plant can rapidly close a whole network of plants.

Unless the basic coupled nature of a structure is changed, interventions to stave catastrophic events can only be expected to be briefly effective. Short-term interventions are not effective. The relative frequency of big and small events (whether earthquakes or power grid failures) stems from the nature of the interdependence between the elements. It is the linkages among the artifacts or agents that give rise to events which influence the type and probability of future events.

While the principles for systems that propagate stress are not fully developed, ideas for mitigating stress tend to fall in one of three areas:

[85] The Windows operating system for personal computers is targeted by hackers orders of magnitudes more often than the Apple operating system.

- *The entire problem can be avoided if the elements of the system can be prevented from transferring stress to each other. This normally requires a major redesign of a system.*
- *Large stress failures can be prevented by partitioning the system in a way that prevents load transfers from one part to another.*
- *Build more slack into individual elements of the system so that they fail less often.*

All these methods work at some cost in lost opportunities for load sharing or other efficiencies.

Organizing routines: Another mechanism in which interactions within the systems stimulate further activation of agents is the formation of work routines in organizations. Work routines are recurring patterns of interactions among agents and artifacts. The interactions in a single routine may be quite diverse because they combine the distinctive skills of multiple human agents.

Examples: A simple example is an automobile assembly line but many examples are less structured and formal. An intricate division of roles and responsibilities in setting up a night bivouac can emerge among a squad of soldiers who have been patrolling with each other for months. Families develop similar patterns of behavior with respect to periodic activities like making dinner, washing dishes, and mowing the lawn.

Routines arise because interactions among agents increase the likelihood of later repetitions of those same interactions. Usually this happens through learning by the participants. They may become aware of a valued result from an overall routine in which their actions played a part.

Example: A systems engineer hears that the sponsor he referred to another colleague a few days earlier got exactly the information needed and was pleased with the systems engineering team. Referrals in future, similar interactions with a sponsor are more likely to occur.

Example: A systems engineer going on vacation prepares a work summary and spends an hour discussing a work activity a colleague will take over for the next two weeks. If when she returns from vacation she finds that the work has continued smoothly during the interim she will be more likely to use the same handover mechanisms for future absences.

We normally do not give much attention to how routines arise. They are important sources of organized productivity. Part of their value rests in accomplishing work while taking relatively little attention. As a consequence routines are noticed mainly when they do not work, when they resist needed change, or when they execute inappropriately.

The way routines form is important for organizations. The easier it is to create good ones and modify bad ones, the more productive organizations can be. Part of the success enjoyed in the "quality" field has come from making linkages between events (or cause and effect) clearer to participants. This motivates the use of routines and makes them easier to learn and improve. Tracing a defect to its upstream cause and fixing it at the source, rather than patching it locally, allows all participants to understand the interdependencies of a routine. While it can be costly in time or other resources to put into operation, particularly in the early stages of implementation, this approach can reap large future rewards for the organization.[86] It is the basis of Toyota's well-deserved reputation for producing quality automobiles.

Looking at routines this way, one can more easily envision devices for making the next step or the final result more visible to participants. These include feedback on weekly progress, and even procedures to highlight the absence of feedback or complaint.

It is important to note that all of these examples of propagating stress and of self-sustaining activity are about formation: of the potential for large-scale failures, of boundaries, of recurring action cycles. They are less about the details of the observed structures and more about how the structures arise.

When we look for insights into harnessing complexity we should ask how we change the pattern of sizes of large-scale failures, the shape and size of patches or other groupings that form, or the number and complexity of organizing routines that can be created. Note that these techniques do not necessarily give us control over specific events. Instead, they help us find interventions that may affect the averages of what happens, that may allow adaptation or learning, even without knowing in advance just what will change, or just what will be learned.

<u>Restructuring of physical and conceptual spaces</u>: In this mechanism the actions occurring within the system alter the very structure of the space in which the actors are located. The agents are not directly intent on changing the collective interaction patterns, but barriers are being created or reduced from the inside, as a by-product of agent actions.

The classical example from biology is speciation. The animals may have no intention to form a separate species, but their breeding decisions eventually have that result. Biological examples of mergers are less common but they do occur.

In the social world we see merging and division of groups and even nations. At the level of national politics such processes always have an explicit component. New nations declare their independence. Foreign governments recognize their existence. But frequently this is a late stage of what began as a more implicit and internally driven separation process. A group of people considered as part of some larger population find themselves interacting more strongly with each other and less with members of another grouping. They talk of their separate identity and this may lead them into a new dynamic that results in their separation from the larger population. An example on the national level is the peaceful division of Czechoslovakia into the Czech Republic and Slovakia in 1993. Of course, this restructuring of spaces can play out at much smaller organizational levels.

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[86] "People [in an organization] usually know some – but not all – [work process] dependencies and making them clear through activity maps, for instance, can dramatically improve the efficiency and effectiveness of a process." (Malone, Thomas W., *The Future of Work*. Harvard Business School Press. 2004, p. 141.)

5.5.4 Summary

There are numerous methods, rules and strategies for shaping interaction patterns. In turn, these interaction patterns among agents shape the creation and destruction of variety and produces the events that drive attribution of credit. Next we examine how selection itself works and how it feeds back onto variety and interaction.

5.6 Selection[87]

To this point the discussion has been on mechanisms that create and destroy types and processes and structures that govern interaction among agents. The discussion now turns to how selection can be employed to promote adaptation. This involves making decisions on which agents or strategies should be proliferated and which eliminated.

If one wants to design a system that is able to explore new possibilities while being able to exploit what has already been achieved, biological evolution provides an important benchmark. Of course, selection in a complex social system need not operate in the same way as evolutionary biology. But, natural selection provides a well-studied and familiar example of how selection can work. It requires three things.

- A means to retain the essential character of the agent. In biological systems genetic material preserves the key patterns.
- A source of variation. In simple biological systems this can be achieved by mutation. In sexual reproduction, novelty is generated through recombination of characteristics from parents and mutation.
- Amplification or changes in the frequencies of types. In biological systems this is the result of some individuals having many offspring while others have few or none.

Interestingly, biological evolution demonstrates that adaptation can be achieved without agents or anyone else having any understanding of how the system works. This has implications for human social systems. They, too, evolve with or without purposeful intervention.

Compared to more directed methods of achieving adaptation, natural selection has disadvantages since it occurs at the level of the agent. Whenever it is feasible to attribute success to something more specific than an entire agent, there is the possibility of selecting strategies, rather than whole agents.[88]

> *Example: Knowing that quinine-related compounds reduce malaria allows a strategy of spreading them through the world instead of waiting many generations for natural selection*

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[87] Ibid., pp. 117–151.

[88] Recall that agents have strategies. For example, an employee helps a co-worker in the hopes that the latter will reciprocate; someone needing a loan asks a friend to help; a nation seeking to promote favorable norms leads by example.

to breed malaria-resistant humans, particularly since the main anti-malarial solution nature makes the carrier susceptible to sickle-cell disease.[89]

When attribution is sufficiently precise it can be advantageous to make numerous copies of a good strategy in a short time that would be difficult, costly, or perhaps even impossible if complete agents had to be reproduced. Agent selection and strategy selection share the need to make copies that retain effective adaptations, to incorporate variation for further adaptation, and to amplify the success and cull the failures that do occur. But the two methods differ at the level at which they operate – and selection at the two levels can work very differently.

Example: Selection of one contractor from a population of competing firms (agent selection) can have quite different dynamics from selecting among a population of technical approaches proposed by a single contractor (strategy selection).

The view advocated here is one in which tradeoffs are made in an evolutionary context and considers factors like innovation versus exploitation and variety versus uniformity. Note that the tradeoffs may go beyond concerns surrounding the immediate decision (technical approach for a particular project, in the above example). For example, depending on the immediate decision, there may be implications concerning the survival or extinction of contractors and, hence, the variety of them available to do similar projects in the future.

A design for an adaptive system of selection must address four issues:

- Defining success criteria
- Determining level of selection (agents or strategies)
- Attribution of credit (for success or failure)
- Creating new agents or strategies

In application, these design issues do not necessarily separate neatly into four distinct factors.

5.6.1 Defining Success Criteria

The importance of defining success appropriately is the essence of the following story.

Example: After standing in a long line with fellow draftees to wash and rinse their dinner plates a recruit (who was an operations analyst in civilian life) approached his drill sergeant to explain that it is inefficient to use two vats for washing dishes and two for rinsing them. Since washing takes more time than rinsing, he explained, it would be faster to use three vats for washing and one for rinsing. The drill sergeant looked at the recruit incredulously and said, "You have it exactly backwards. I can't keep the platoon running all day but the longer

[89] Ibid., p. 118.

> *I keep you on your feet the better it is for your physical conditioning. I want you to stand as much as possible."* [90]

Selection of agents or strategies implies some metric of success. In most situations performance measures are active in the minds of designers, policy makers and other stakeholders whether they are acting in the system or contemplating it from the outside. In Linux software development, the thousands of individuals proposing solutions to specific operating system problems know that speed and stability are critical success criteria for new versions of the operating system. Typically, however, the assessment of alternatives in a complex social system is not easy: there is usually more than one criterion that can and should be used to assess results and some may even be viewed as being in conflict with each other.

For a business, profit seems a natural measure of success. For a checkers player, winning games is a natural performance measure. Yet, even in these simple examples, with a criterion that seems indisputable, complexity might be harnessed more effectively if other success measures are used.

In a business, market share provides an additional measure that can be a useful supplement to profits. Changes in profits may reflect factors beyond the control of a company, such as a change in national economy. Attributing credit (or blame) for a change in profits to a new marketing campaign may be the wrong inference in a national economy in which an entire industry either flourished or didn't. An increase in market share could provide a better indication than profits of whether a company was doing something right and what it was.

There are measures of success that may be more effective than waiting for the outcome of an event. These will be discussed later.

The view taken in this report is that performance measures are instruments for shaping which events are likely to occur in a complex social system. While performance measures are clearly important, they are not absolute and unchangeable. Nor is the attainment of any measure, *per se*, generally the highest goal. Goal setting is an intervention technique that creates performance criteria that govern the processes of selection.

In complex social systems performance measures are largely defined, modified (or maintained) and applied (or disregarded) by the agents themselves. While this is not a surprise to many experienced managers, it is striking how little explicit attention is given to this within a social system like an enterprise.

> *Example: Consider the case of profit. What counts as profit depends on many factors, including laws, what tax codes recognize as legitimate costs, what society's norms define as "fair" and whether actual practices conform to those norms, and whether society charges for disposal of byproducts of revenue-producing activities (e.g., used motor oil). Societies even regulate whether or not profit is a permissible goal in systems. For instance, in the early 20th century America largely removed profit as a permissible goal from social systems like*

[90] Ibid., pp. 119–120.

schools, hospitals, and prisons. There has been experimentation with it in all three sectors in recent years to address flaws that have been seen in the performance of these institutions in their core missions. [91]

A further consequence of performance measures being defined by the agents themselves is that there can be more than one measure active and the measures may be inconsistent and change over time. Change seen as an improvement by one type of agent may be viewed as a loss by others. There are issues in variety in performance measures just as there are in other characteristics of agents and their strategies.

The way in which success is defined affects the chances for effective learning. Consider the difficulties in learning checkers if the sole criterion of success is winning. The central problem is that victory or defeat comes only once per game. Getting more than one measurement of performance per game could dramatically improve the rate of adaptation.

The typical way to do this is to use intermediate criteria that can be measured in the course of the game. In checkers or chess this is possible by evaluating the current board to see who is ahead in pieces and aspects of position. This kind of evaluation allows intelligent choices in the middle of the game based on what promises to lead to a better board position in a few moves. Since one cannot precisely measure the consequences of early moves for an ultimate victory, the tack is to introduce metrics that are more easily predicted. Although it may appear somewhat counterintuitive, the chances of winning are increased by concentrating on criteria that do not explicitly include winning.

The use of intermediate criteria is evocative of *build-a-little, test-a-little* incremental system acquisition in which a focus on developing intermediate capabilities more readily leads to the successful deployment of a full capability. But incremental system developments are usually concerned with the ultimate goal of successfully fielding the full capability of a specific system and rarely put a spotlight on learning to improve intermediate performance criteria for future developments of other systems. In the following example, consider how this perspective, if adopted at an enterprise level, could evolve improved enterprise acquisition processes.

Example: In checkers, one can learn to improve the criteria by which one evaluates intermediate board positions. For example, having many pieces in the center of the board often leads to good results a few moves later. This suggests a strategy that focuses on dominating the center of the board early in the game.

But how does one learn these kinds of strategies and then improve on them? When arriving at a board position that subsequently proves to be surprisingly good (or bad), there is the opportunity to use this information to refine existing success criteria. In the future, the player can exploit the refined criteria to drive towards even better intermediate board positions. A long-term consequence of this type of learning is that the player accumulates a store of well-

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[91] Ibid., p. 121.

developed criteria for attributing value to a variety of board positions and thus evolves to a high skill level.[92]

It is common in system acquisitions to use intermediate measurements to give insight into questions such as "is the program on course" and if not "what are we doing wrong and how do we correct it." It is less common that the intermediate measurements are scrutinized with a view towards asking whether the criteria used accurately predict success and how they can be improved for future use.

This approach and technique for learning to improve performance criteria are of broad applicability. They can be summarized as follows:[93]

- When success is measured rarely, new measures taken more frequently can speed learning even if the measures do not perfectly reflect the longer-term goal.
- Whenever outcomes are better or worse than expected, the experience can help revise the criteria so that, in the future, the attribution of credit will produce more accurate results.

The above discussion is not intended to recommend this approach in all circumstances or to the exclusion of other considerations. If the challenges a program manager are facing are long-term or widespread in the organization, fine-grain and immediate measures of success may work against much needed exploration. The challenge for the organization and its leadership is to develop measures of success that promote learning by fine-grained and frequent feedback and appropriate levels of exploratory behavior.

Care must be taken in using indirect measures of success to guide action and learning. A measure may be correlated with results that matter without being causally related as suggested by the familiar relationship among fever, disease and aspirin. Aspirin can reduce the fever without affecting the disease and may even be harmful if elevated temperature is part of the body's way of fighting the disease.

Taken as a whole, these observations about criteria for success imply rich possibilities (and risks) for harnessing complexity by shaping the criteria by which agents or their activities are evaluated. Which measures are used profoundly affects which agents and strategies will be copied and combined and what adaptation will occur. This is what gives such power to what seem modest changes in measures, such as introducing on-time performance into airline regulation[94] and portfolio risk into financial management.[95]

Example: The core mission of public libraries is to provide information to their patrons. Libraries typically track circulation statistics as indicators of institutional success in this

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[92] Ibid., p. 122.
[93] Cohen, Michael D. and Robert Axelrod. "Coping with Complexity: The Adaptive Value of Changing Utility." *American Economic Review 74* (1984); pp. 30–42.
[94] Gartner, Scott S. *Strategic Assessment in War*. New Haven, CT.: Yale University Press, 1997.
[95] Sharpe, William F. et. al. *Investments*. Englewood Cliffs, NJ: Prentice Hall, 6th ed., 1998.

mission. The circulation statistics of the Washington (fictitious name) Town Library had steadily risen every month over the past two years. As at all libraries this increase in demand was viewed as good news. So, it came as a surprise when the town voted not to approve an override to increase library funding (and staffing level) the following year.

The library director reasoned that the library had not yet reached the right circulation threshold and if they did that in the ensuing months the town would "see the light" and approve the override next year. The circulation indeed continued to increase but, much to the surprise and dismay of the library director and the overworked staff, the override again failed to pass.

The director held an all-hands meeting with the library staff to discuss why demand continued to grow but did not translate into support for additional funding to increase capacity to meet that demand. This is a form of the question, "what predicted the surprise?" The staff member who kept the circulation statistics noted that of the 60 percent of town residents, who were library cardholders, 40 percent were occasional users and only 20 percent were "power" users. Further, the increase in circulation demand had been coming predominantly from the power users who understood and exploited the library's excellent capabilities. The reason for the failed overrides became clear: 20 percent of the town population was insufficient support. What was needed was not higher circulation numbers, per se, but a different distribution of existing circulation and broader awareness of the value the library brought to the community.

The library mounted an information campaign aimed at educating the occasional and non-user about library services and their importance to the intellectual life of the community, particularly to school-aged children. Demand increased slightly during the following year, as did the number of patrons. Appreciation of the importance of the library to town life grew. The override to increase library funding ultimately passed.

To see the intricate interactions within and among multiple populations of agents and their potentially profound effect on the definition of success in a complex system, consider an award system that recognizes, rewards, encourages, and defines excellence in an area of human endeavor. The area can be any from a range of possibilities that are relevant to a complex enterprise. Examples include best technical paper awards; department, director, or presidential awards for individual or team performance in a business unit; customer support awards; and the promotion or appointment of individuals to prestigious positions or ranks in an organization.

Traditionally, we think of awards as being exemplars and motivators of good performance and they certainly are. But the importance of awards and recognitions in a complex social system stems, in large part, from their utility in *changing* success criteria to ones that are *different* from current standards. Therefore, awards or recognitions based on *subjective* criteria are of most interest. In these situations it is usual that a "judge" or "panel of judges" makes assessments of quality. The term "judge" is meant broadly. Examples include a senior technical director recognizing a project team for success or a board of directors electing a new corporate officer.

A direct effect of an award is to recognize or reward an individual or team. An indirect effect is that it provides a model for others to emulate. This helps shape the perception of what is important to the individual's or team's peers within an organization.

Example: A project team recognized for a small success in a technology area new to a corporation sends a signal to others that growth in the new area is strategically important, valued, and will be rewarded.

Example: The election of a new corporate officer with a distinguished record of forging new business in a company that has a legacy of affiliation with one major client signals increased value in an ability to expand the client base.

Both these examples show how awards can redefine success within an organization. The goal in each instance is to provoke additional innovative exemplars of the new values.

The effect of awards can be even more widespread, extending beyond the organization.

Example: Organizational awards or appointments that are made known outside of the company provide signals to current and potential clients about what the organization values. The promotion of a knowledgeable client base, in turn, can help create a market or increase demand for the service or product the organization provides.

Awards that are made for explicit competitions (e.g., best proposal for rapid prototyping idea that works in partnership with existing programs for a client) can engender useful variety by identifying and promoting new and valuable ideas. When such an award is made it tends to legitimate and promote the entire field or genre of the winner. From the perspective of the winner having an idea chosen is a form of selection in which the winner's intellectual offspring survive for further development.

But there is a tension. Deciding who or what should win requires the application of standards of excellence. The judges invariably use standards that are shaped in part by the broader community of which they are a part. And judges are usually selected on the basis of their own standing in the community which, in turn, is often based on their adherence to current standards. Even if the judges wish to be leaders in the identification of what is new and worthy, they risk looking arbitrary or foolish. So the judges are also judged and they face the tension of a trade-off between a safe choice that reflects current standards (exploitation) and a bold choice that can transform the standards (exploration).

Although it may appear counterintuitive awards can even stifle variety, as the following example illustrates.

Example: One can view a succession of increasingly responsible positions within a company as a set of rewards leading to the ultimate reward of being elected CEO. If the corporate culture is one that acknowledges certain jobs as tickets to be punched along the way to the top, then this can be the dominant focus of would-be CEOs. The population of CEO aspirants in a company can create for themselves astonishingly similar career paths with the result that *the pool of likely CEO candidates has diminished variety. Examples of this phenomenon abound as can be seen by considering the preponderance of Air Force Chiefs of Staff who were rated pilots in their career.*

While each award sets up a competition among those aspiring to win it, there may also be a competition among the awards themselves.

Example: Is being the engineering staff director of portfolio A better than that of portfolio B? Put another way, which will accrue more "credit" to its incumbent? There may be a view in an organization of which portfolio has greater status based on the historical importance of the portfolio to company success. But that can change if an incumbent of a less important portfolio goes on to achieve a more prestigious position within the company.

Thus, awards in a complex social system create an intricate set of interactions within and among different populations of agents: award seekers, their peers, judges, the awards themselves, and even potential company clients.

5.6.2 Determining Level of Selection

The process of selection promotes adaptation by amplifying success at the level of the agent or of strategy. Selection at the two levels can work in very different ways. The former makes an entirely new agent without the need to determine or know the cause of success. The latter creates new strategies from an existing agent, which frequently requires an explicit decision about what strategy or part of the agent was responsible for success.

5.6.2.1 Selection of Agents

If an employee leaves a company another person fills the vacancy. Those who select the successor must pick one candidate or another. They are not able to pick and choose among the features they prefer from a group of candidates. This provides a straightforward basis for answering the question of what should be given credit for success in being appointed to the position. The answer is the whole candidate. As much as those who select the successor might want to ascribe credit and blame separately for a candidate's experiences or character traits, the decision requires selection at the level of the entire agent.

Filling positions in a company is an example of co-evolution in which both kinds of selection are playing out. Those who appoint are selecting at the level of agents. Active candidates are selecting at the level of strategies by observing attributes of recent appointees and adopting or moving towards those attributes themselves (e.g., by increasing skills in important attributes through training or experience) in an attempt to make themselves more competitive for future openings.

Agent selection can operate at many different scales. The economy can be viewed as selecting at the level of companies (some flourish, others go bankrupt) and even whole business sectors (airline travel suffered in the post 9-11 period while travel by personal automobile increased).

Example: Imagine a company that has a highly successful branch office. The company might use its earnings to reproduce the successful branch office in a way that duplicates its entire operation, as far as possible. If branches operate fairly autonomously, this would amount to creating a new agent. The company would have given credit to an entire branch (instead of any of its particular strategies or characteristics) and used it to amplify success by duplicating it.[96]

Agent selection usually requires a substantial accumulation of resources to create and proliferate new agents. As will be seen, this contrasts with strategy-level selection where the marginal costs of producing new copies may literally be almost zero (e.g., software algorithms).

Selection pressures in a complex social system are an important factor in deciding on the utility of selection at the level of agents. A high selection pressure produces a strong tendency for a small number of the very best agents in a population to be copied while others are copied very little if at all. A weak selection pressure produces a slight tendency for better agents to be copied more and thus provides some amplification to populations of agents who are somewhat or relatively successful. So, a strong selection pressure exploits success quickly but it can also destroy variety in a population that can be used to explore for even better results in the future.

Selection pressures at the scale of the world economy cannot be easily influenced. Within an organization, however, managers and individuals may have the opportunity to change them.

Example: Awards and recognitions for "top performers" in an organization can usually be adjusted so that more or fewer top performers are recognized. Recognitions that involve monetary awards are particularly flexible since their frequency and the amount of the awards can be easily adjusted, even within a fixed budget. On the other end, "zero-tolerance" of underperforming agents or artifacts reduces variety and favors exploitation over exploration. This is the familiar trade-off between exploiting that which is best currently and maintaining variety to explore for possible future improvements.

The perspective being put forth here is one that advocates neither strong nor weak selection pressures, *per se*, but rather a view which recognizes the role of variety in a population and harnesses selection pressures to secure their advantages.

5.6.2.2 Selection of Strategies

Strategy selection proliferates particular strategies or combinations of multiple strategies. In this section *strategy selection* will be discussed by exploring how it differs from *agent selection* in three key attributes: cost, waiting time and difficulty of inference. The different strengths of the two levels of selection are sometimes complementary and there can be advantages to a hybrid system of selection.

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[96] Ibid., p. 129.

If success can be assigned to a strategy rather than an agent the cost of proliferating the strategy can be substantially lower than that of acquiring whole agents. Assembling or acquiring a new agent (person, business unit or a new government organization) is typically more costly than copying a successful strategy used by the agent.

Example: The manager of a systems engineering organization can attempt to hire "star" quality talent from outside the company. But if the reason the outside talent is successful is because of expertise in new technologies or systems engineering processes it might be less costly to train engineers already on board.

Whether this is a promising approach or not depends on how readily the new technologies or processes can be learned. Are there educational resources for hire with success in teaching these skills? Does success really depend less on the new skills, *per se*, and more on the interaction and integration of the new skills with existing skills learned via previous education and work experiences? Then it may be necessary to pay the cost of hiring a systems engineer with the entire complement of successfully integrated skills.

A second difference that often occurs between strategy and agent level selection is waiting time. This can be thought of as an instance of higher costs (recalling the familiar adage "time is money") but even if the direct costs of agent copying were affordable the indirect consequences of delay might not be.

Example: Company A may have a proprietary process for certifying its engineering work force. It might be quite valuable and plausible for company B to develop its own engineering competency model and certification process. It would result in company B having a model and process that is tailored to its culture and "brand" of engineering. But if a potential client is demanding a form of certification as a condition of contracting with company B there is the risk of losing or delaying the contract. Company B may chose to license the company A certification process, in essence copying its strategy, not because of lower monetary costs but because of the value of elapsed time.

Although selection at the level of strategy is typically faster and less costly these differences are tendencies rather than inevitable consequences as the following example shows.

Example: A company asked by a existing client to take on a new contract with its unique set of stakeholders and technology issues may find it more advantageous to create a new division or a small spin-off firm to support the contract rather than modifying existing operations, activities and organizations to do so.[97]

A third difference between selection at the two levels is the difficulty in inferring exactly what is to be copied. This difficulty occurs at both levels but there is one important difference between the two. Whole agents may be thought of as a collection of strategies. Successful agents generally employ a set of strategies that are internally compatible. If selection is made at the level

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[97] Ibid., p. 133.

of the agent the interactions among the strategies do not need to be understood. Strategy level selection generally requires more precise inferences. How many of an agent's activity patterns and which ones must be copied to duplicate success? Agent level selection generally preserves context better and this can be an advantage in complex social systems where many results derive from interactions among multiple effects that are not fully understood.

The tendencies for selection at the agent level are to be more costly, slower, and more context preserving. The first two tendencies are often not wanted while the last frequently is. This can form the basis of a trade-space among these factors for a manager, policy maker, or designer who has some freedom to influence levels of selection.

> *Example: Most examples so far have involved selection for positive traits but there can be selection for negative ones. For example consider technology currency among the population of professional staff in a company that provides a technically sophisticated consulting service to its clients. For individuals who are not keeping current, selection at the level of strategy may correspond to low performance ratings and low or no pay raises. This does not remove the staff from the population (although some may choose to leave of their own accord) and it gives the individual time to reacquire technical currency through education or new assignments. On the other hand staff (as agents) could be negatively selected in response to their loss of technical currency by being reclassified to a lower pay grade or even terminated. This form of selection will make staff with low technical currency less likely to be copied or proliferated in the population. Of course, removing an individual from the population and replacing the individual typically costs more and takes longer than changing the individual's strategy provided the individual is willing to change strategy.*

Selection at the level of agents and selection at the level of strategies have somewhat complementary strengths. Agent selection often works on longer time scales. It generally preserves variation and context. Strategy selection is faster which is usually but not always better. Strategy selection isolates key patterns that can be more easily copied. Thus, one is led to consider hybrid systems where selection operates at both levels in a single population of agents.

> *Example: It is common for many companies to evolve the quality of their technical staff by a combination of activities that select at both the agent and strategy levels. Evolution of technical currency for employees is achieved through strategy level selection which focuses on providing in-house technology refresher courses and by subsidizing technical courses taken at local universities. Agent level selection occurs primarily through hiring highly qualified technically staff to fill vacancies as they occur.*

The complementary nature of the two levels of selection and the observation about hybrid selection systems suggest a strategy that diversifies selection processes to achieve a mix of fast and slow ones when there is the possibility to do so.

5.6.3 Attribution of Credit

Attribution of credit is the process by which an agent uses a performance criterion to increase the frequency of successful strategies or decrease the frequency of unsuccessful ones.

Attributing credit correctly is difficult and prone to mistakes. Large portions of academia (e.g., logic, statistics, science) and government systems (e.g., professional review boards, courts of law) are devoted to improving the extent to which conclusions follow from premises and evidence. These can all be viewed as contributing to improving the performance in credit attribution that drives important selection processes in our civilization.

The results of a survey of factors which make it easy to learn lessons from experience in decision making contrasts starkly with the properties of a complex social system. These are summarized in Table 5-2 below.[98]

Table 5-2. Decision Making Factors Versus Situations in a Complex Social System

Factors that Enable Lesson Learning in Attributing Credit	**Situation in a Complex Social System**
Clear rewards for appropriate choices.	Difficult to determine what should be rewarded or which choice is appropriate.
Repeated opportunities for observation or practice.	Infrequent measurements of success. Shifting context makes few observations comparable.
Small deliberation costs for each choice. Frequent choices become easier.	Deliberation costs become increasingly higher (scientific peer reviews, legal proceedings).
Good feedback on results of choices.	Feedback is ambiguous, even conflicting.
Unchanging circumstances that keep inferences valid.	Circumstances and goals change continuously.
A simple context that can be easily analyzed.	Complicated, changing context.

There are numerous examples that illustrate the attribution of credit and its limits.

> *Example: Lessons were learned by the American military in the Vietnam War. These include the need for decisive force in any future war, the need to avoid slow escalation,*

[98] Conlisk, John. "Why Bounded Rationality." *Journal of Economic Literature* 34 (1996): pp. 669–700.

and the need to avoid civilian interference in the conduct of war. These lessons were turned into strategies and applied to the planning and conduct of the Gulf War with apparent success.[99]

Example: The lesson the Soviet Union learned from the Vietnam War was that their North Vietnamese allies won because of their great will and courage, assisted by military aid from the Communist world. These lessons did not warn the Soviets about their later intervention and ultimate failure in Afghanistan.[100]

Example: Consider the project manager who grows a new business area, is promoted and singled out to be emulated. Years later more careful analysis may show that the business area led the company down an ultimately unfruitful road and had actually diverted resources and intellectual capital from other, more promising work areas.

The business literature is replete with stories of performance indicators that failed to capture important aspects of the complexity of an attribution of credit situation. What follows are suggestions on how the side effects of inevitable mistakes of attribution can be turned, in part, to an advantage.

The first type of mistake is crediting (or blaming) a part when a larger ensemble is responsible. This is common in complex social systems since they so often involve a number of entangled causal factors.

Example: It is easy for a department or project manager to notice when a single agent or strategy is associated with a series of successes or failures. If the manager is not positioned to observe other forces he or she may reach the incorrect conclusion that the agent (or strategy) alone caused the results. In the case of an individual agent, the manager should consider finding a way that provides the manager a different observation perspective of the agent to include even putting the agent with another team to see whether success really comes from the efforts of a single, prominent individual or the interplay among the contributions of a number of team members (i.e., group chemistry).

The second type of mistake is attributing credit or blame to one ensemble of factors when a different ensemble is responsible. Diagnosis of cause in complex, multi-causal situations is error prone.

Example: Consider the problem of examining customer or end-user complaints about a product malfunction or underperformance to discover defects or potential design improvements. Many companies and enterprises have sophisticated systems that track problems from notification by the customer or end-user through trouble ticket

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[99] Powell, Colin L. *My American Journey*. New York, NY. Random House. 1995.
[100] Zimmerman, William and Robert Axelrod. "The Lessons of Vietnam and Soviet Foreign Policy." *World Politics* 34 (1981): pp. 1–24.

generation, technical assistance assignment, and resolution. This problem and tracking system construct is common across enterprises as diverse as consumer product companies and military C2 and weapon systems.

It is natural to ask what can be learned from the records of a problem and tracking system that would contribute to product improvement. Closing the loop on this form of organizational learning has often been more difficult than expected.

An analyst working on a communication system problem might hypothesize that since all the customer reports on degraded voice quality of a particular military radio installed on a mobile command center occurred when traveling over dirt roads, shocks at a particular frequency may be causing an audio disturbance. A hypothesis is usually tested by checking whether its conditions are sufficient to reproduce the problem. Many of these tests may fail. For instance, someone from the radio product development company may subject the unit to low-frequency vibrations and observe that it still performs well. It may be that the complaint reports occurred during the winter and the problem arises only when the temperature is cold or perhaps involves an interaction between temperature and vibration. This more subtle and detailed hypothesis may emerge only from a direct dialog between the analyst and the front-line maintenance experts.

What this suggests is that it may be beneficial for a company or enterprise to pay attention to the contact patterns between its various organizations. It may be immensely useful in resolving misattribution of credit. The interactions of new contacts may result in other information flowing between the organizations and this may generate new and useful combinations of ideas.

The third type of error is a failure to appreciate the role of context. This normally involves crediting a misconstrued strategy, where actions actually produced success, but the conditions in which the actions should be taken have been misunderstood. This type of mistake is especially common when selecting at the level of strategies because, unlike agents, they normally do not preserve context and they often take the form of conditional action patterns (e.g., if circumstances X and Y occur, then do Z). The difficulty comes from the fact that actions can be much easier to observe than the conditions that gave rise to them. Particularly in competitive situations, an opponent may not be willing to fully or accurately disclose the context of an action.

Example: When a player in a chess game gives an opponent the opportunity to take a key piece, it may not be easy to determine whether this is a blunder or a clever sacrifice. The ultimate effect of the move may not be clear for some time.

Learning proceeds slowly in this type of situation. Efforts to emulate apparently successful strategies will result in mistakes because many factors determine success (e.g., other subsequent chess board moves) and knowledge about the conditional aspect of a particular strategy or move is limited.

A tack for dealing with this is along the lines of the "defining success criteria" discussion and checkers example of Section 5.6.1. Surprises (actions that apparently produce a result different - better or worse - than expected) can fuel improvement provided one can correlate factors that were observable or predictable in the short run with the surprise. The question becomes, "What observable criteria were often high or low when the result was better or worse than expected?" This is an important shift from a focus on "what predicted the outcome" to "what predicted the surprise," i.e., the deviation of what occurred from what was expected. It is a form of the adage "we learn best (and quickest) from our mistakes."

5.6.4 Creating New Agents or Strategies

The fourth part of selection is the creation of an existing agent or strategy through copying or recombination or its destruction. Many of the key points have been made in the discussion on creating and destroying variety.

Notions of copying are central to creating or destroying agents and strategies. The aim in discussing copying in general is to guide designers and policy makers to ask questions about how copies are made and how destruction happens for the agents and strategies in the systems they work in. There are many different processes that may be called copying.

Agent copying requires material resources to be assembled. Copies are made using the same materials as those of the copied agent. Strategy copying concentrates on the preservation of abstract form. The former is akin to natural selection and the latter shares similarities with copying of algorithms, software or processes in computer systems.

Just as the differences between copying strategies and agents matter, so too do the detailed differences among various copying processes. Errors and recombining processes depend on the details, and the character of the variation in the system is shaped by them in turn.

> *Example: Imitating an individual's method for making face-to-face charity requests is very different from photocopying and distributing fund-raising letters. Both involve a form of copying, but the former requires an integration of a pattern into one's own behaviors.*[101]

Making fund-raising calls using another's method is more akin to recombining strategies than is photocopying and mailing fund requests. Scale matters in copying, as well.

> *Example: Setting an example intended to trigger imitation as a form of copying is very different when the population is a group of local work-mates than it is when the population is comprised of various organizational stakeholders in a complex enterprise (developers, users, contracting and engineering management agencies, etc.) each with their own and very different metrics for success.*[102]

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[101] Ibid., p. 147.
[102] Ibid., p. 147.

5.6.5 Summary

The central question in selection is, "which agents or strategies should be copied or destroyed?" Four aspects of selection have been examined: criteria for success, focus on selection at the level of agents or strategies, attribution of credit, and mechanisms for creating new agents and strategies. The answer to the question is strongly intertwined with answers to two other major questions: "what is the right balance between variety and uniformity?" (variation) and "what should interact with what and when?" (interaction).

6 Application to an Enterprise

Section 5 discussed a framework for harnessing complexity in a world with many diverse, mutually adapting players, where the emerging future is difficult to predict. Increasingly, these are the situations systems engineers find themselves in. This section provides a brief summary of the ideas presented in Sections 2 through 5 and suggests how they might be applied in the design and evolution of improved enterprise organizations, strategies, and processes.

A highly compressed restatement of the variation-interaction-selection framework shows how it forms a working whole. Principle concepts introduced in Section 5 are italicized.

> *Agents*, of a *variety* of *types*, use their *strategies*, in patterned *interaction*, with each other and with *artifacts*. *Performance measures* on the resulting events drive *selection* of agents and/or strategies through processes of error-prone *copying* and *recombination*, thus changing the frequencies of the types within the *system*.[103]

6.1 Purposeful Questions

Systems engineering has always been about asking good questions, answering them and following their implications. What follows is a series of questions that can help the systems engineer harness the complexity of a particular system or enterprise.

6.1.1 Systems Thinking Questions

- What is my enterprise? What elements of it do I control? What elements do I influence? What are the elements of my environment that I do not control or influence but which influence me?
- How can a balance be achieved between optimizing at the system level with enabling the broader enterprise, particularly if it comes at the expense of the smaller system?
- How can analytic and synthetic perspectives be combined in one view to enable alignment of purposes across the enterprise? Would a change in performance at the subsystem level result in a change at the enterprise level? If so, how, and is it important? How would a new enterprise level requirement be met and how would it influence systems below it?
- How can the solution space of a seemingly intractable problem be expanded by viewing it in its containing whole?
- How can complementary relations in opposing tendencies be viewed to create feasible wholes with seemingly unfeasible parts? How can they be viewed as being separate, mutually interdependent dimensions that can interact and be integrated into an "and" relationship?

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[103] Ibid., p. 151.

- Is interdependence of variables in a system or enterprise hidden by slack? Is the inability to make progress in one variable except at the expense of others an indication that slack among them is used up? Can a redesign of the system or enterprise remove interdependence or provide additional slack?

6.1.2 Harnessing Complexity Questions

- What interventions in a complex system are likely to bring it to a future we would prefer? How can variation be managed, interactions be shaped, and selections be made to guide and accelerate improvement over time? What is the right balance between variety and uniformity? What (or who) should interact with what (or who) and when? What should be copied (or proliferated) and what should be eliminated?

6.1.2.1 Variation

- What is an appropriate balance between variety and uniformity?
- What processes of copying and recombining create and destroy the variety of types in the enterprise? What additional processes might serve copying and recombining functions?
- Can variety be created by combining portions of strategies or agents already in use to introduce new types that have some degree of correlation with the enterprise's other conditions?
- Can variety be created by relaxing or reversing assumptions about a problem or a solution?
- How do errors occur in current processes? Does the variety that results ever offer potential value?
- Where and how can homogeneity be used? Can homogeneity (e.g., convergence on a standard) be used to enable innovation to flourish elsewhere in the enterprise?
- How can premature convergence be prevented? Are the types available in a population likely to be the best possible? Are environmental conditions changing so that what is best now may not be best in the near future?
- What is the right balance between exploration and exploitation? Is exploration especially valuable because improvements can be widely applied or used for a long time? Is there a risk of disaster from trying a bad strategy?
- Will extinction eliminate from a population a type whose replacement may be lacking a critical feature of the original? Is the enterprise operating under the assumption that all that is needed for an idea or solution to emerge are conditions that will bring it rapidly to prominence?

6.1.2.2 Interaction

- What are events of interest whose likelihood should increase or decrease?
- What are the current patterns of interactions among types?
- How can interaction of agents with each other and with artifacts be used to alter the likelihood of events of interest in a complex system? What (or who) should interact with what (or who) and when?
- How is proximity influencing interactions? Can proximity be used to increase or decrease the likelihood of interactions?
- How does time scale affect the perspective on proximity? Is the nature of a given population shaping which agents are attracted to it? Will the nature of the population be shaped by new agents that join it? What are the dynamics of co-evolution?
- Are events of interest activated periodically or conditionally? What are the consequences of changing an event's activation mechanism? Will it favor viability or speed extinction?
- Are interaction patterns of an agent or type intense or diffuse? What are the consequences of changing the pattern? Will it alter an exploration-exploitation balance?
- Can changes to an organization structure be used to make some agents more proximate and others less? Will the resulting re-organization shape the interaction of agents towards some ends or goals?
- Can barriers to/enablers of movement in time and physical space be used to make some agents more proximate and others less? Is the imprecise selectivity of these methods acceptable?
- Can barriers to/enablers of movement in conceptual space (e.g., similarity of technical expertise or organizational roles) be used to make some agents more proximate and others less? Can the resulting refined selectivity be used to advantage? Is the risk of under-exploration acceptable or addressed in some other way?
- Is there a role for semi-permeable barriers in shaping interactions? Is the situation one in which admission is governed by momentary conditions or in which rules or criteria cannot easily cover all circumstances that may arise? Is the risk of possible mismatch between the admission rules/criteria and the long-term welfare of the system or enterprise acceptable or addressed in some other way?
- Have the implications of mechanisms that shorten, reverse or otherwise alter the timing of events been thought through and accommodated?
- Can agent following be used by a follower to pick up contact patterns of the leader? Is it important for the follower to understand the theory of the learned pattern because it is likely to be transferred to a new context? Is the risk of reduced information diversity

through pervasive agent following acceptable or addressed by assuring a mix of strongly and weakly clustered contacts?

- Can signal following be used to alter interaction patterns of an agent to move it toward locations that have a better value? How is the risk of getting stuck at a local maximum addressed?
- Can boundary formation (through organizational restructuring and changes in policy) be used to create an archipelago-like environment that favors diversity and adaptation?
- Can separation of time scales be used to organize operations so that activities with longer time frames govern or set the context of activities with shorter time frames?
- Can stress be distributed across a system in a way that does not increase the potential of a large-scale failure?
- Can good organizational routines be created and bad routines modified easily?
- Are actions of agents within a system or enterprise altering the structure of the system's or enterprise's physical and conceptual spaces even if the agents are not directly intent on changing their collective interaction patterns or erecting or eliminating barriers?

6.1.2.3 Selection

- How can selection be used to promote adaptation?
- Are selection tradeoffs being made in a context that goes beyond an immediate decision? Does the tradeoff consider factors important to future decisions, like variety versus uniformity and innovation versus exploitation?
- Are performance measures viewed as instruments for shaping which events are likely to occur?
- What criteria of success are used to select types that become more or less common over time? Are there multiple criteria? Is selection done by many agents or few?
- Is success defined in a way that enhances the chances for effective learning? Is success measured frequently enough to enable learning? When outcomes are surprising (better or worse than expected), is the experience used to revise the definition of success so that it will produce more accurate results in the future?
- If challenges are long-term or widespread, do the measures of success balance fine-grained and frequent feedback to promote learning with appropriate levels of exploratory behavior?
- When using indirect measures of success is care taken to assure that the measures are causally related to success and not just positively correlated with results that matter?

- Can modest changes in performance measures profoundly affect which agents or strategies are copied and what adaptation will occur?
- Can awards and recognitions be used to change success criteria to ones that are different from current standards?
- Should selection be performed at the agent level, strategy level or represent a hybrid?
- Can selection pressures be influenced? Is selection pressure high or can it be made high (which produces a tendency for a small number of the very best agents to be copied)? Is selection pressure low or can it be made low (which produces a slight tendency for better agents to be copied more and thus provides amplification for somewhat successful agents)?
- Do the factors of cost, waiting time, and difficulty of inference favor selection at the level of agents, strategies, or a hybrid?
- Do performance measures make systematic mistakes in attributing credit? If the likely mistake is crediting a part when a larger ensemble is responsible can a different observation perspective be found? If the likely mistake is attributing credit to one ensemble when another is responsible can different interaction patterns among subpopulations generate new combinations of ideas? If the likely mistake is a failure to understand the role of context can "surprises" fuel improvement through learning?
- What mechanisms should be used to create new agents or strategies?

6.2 Examples

It is the nature of a complex social system or enterprise that some of its important attributes do not scale from the system or system-of-systems level. What follows are examples of enterprise-level thinking and processes that may not have well-developed (or needed) system or system-of-systems level antecedents. Note how the thinking and questions come from the discussion in Sections 2 through 5.

6.2.1 Portfolio Management

A technologically sophisticated enterprise whose capital is knowledge and the ability to apply it looks at the future from the perspective of: "what hard questions or problem areas do we want to be working on in the next five to fifteen years" and "how do we position ourselves to increase our likelihood of being selected for and succeeding in them?" This is a form of the basic question, "what will bring us to a future we would prefer?"

The answer is similar to the familiar "what will bring me to a financial future I would prefer?" It is sound portfolio management. And it is portfolio management with a view that looks beyond the short-term performance or current value of the individual instruments which comprise the portfolio. It requires the right balance between different investment types. That balance can and does change over time due to factors like stage of life, other obligations and expenses (college tuition, car payments, unexpected catastrophic asset loss) and change in life goals. Viewed in this way, managing the “balance” or the “whole” is clearly more than the summation of managing the parts of the portfolio.

There will always be a need to look at and manage the immediate and short-term performance of the separate current programs within an enterprise portfolio. But it is future-oriented “hard problem areas” that focus our attention on managing a portfolio in a way that moves the enterprise towards various preferred futures.

Consider the following future problem areas from the perspective of enterprise portfolio management.

Example: The next generation of U.S. AEW&C system

What is the right amount of variety in the AEW&C enterprise portfolio when considering the next generation of U.S. AEW&C system? Does the current portfolio provide a mix of technical problems and experiences that will be applicable to the next generation U.S. AEW&C including those surrounding choice of platform, sensors, information systems, communications and networks? If not, how can that variety be created? Should an attempt be made to redefine engineering roles and technical focus of current work? Should new work be brought in that requires the assumption of less coveted task engineering roles instead of a general systems engineering and integration role if it provides the opportunity to acquire intellectual capital in a critical future technology?[104] *Should some programs in the portfolio be divested? If the portfolio itself cannot be changed in a way that brings in opportunities to acquire critical intellectual capital are there ways of changing AEW&C enterprise interaction patterns to increase the likelihood of acquiring it? For example, can exchange programs be initiated with other program offices (e.g., E-10A, Navy Hawkeye, GIG) in which intellectual capital is acquired via periodic meetings or engineer exchange programs? Is the population of AEW&C enterprise staff being viewed primarily through a lens of current problems? Or is the population of staff being assessed and modified through training and hiring to assure the right mix of technology skills and domain experience for addressing the next generation of AEW&C? What is the right balance between servicing current programs and positioning for the future?*

Example: The next generation of air situation awareness (SA) systems

The next generation of air SA systems has other solution possibilities beyond AEW&C options consisting of different combinations of airborne platforms, onboard sensors, mission system capabilities, and communications. Alternatives include space-based and unmanned aerial vehicle (UAV)-based sensors and different options for mission crew location. As a result, the variety in technology and mission experience required expands to include space-based

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[104] Note that the portfolio perspective permits a view of a low-impact/high-value activity as one that need never grow to high impact as a single program itself so long as it serves an enterprise-level high impact future need.

radars, UAVs, UAV-based sensors, control mechanisms for UAVs, and communications between a remotely located mission crew and space-based or in-theater air SA assets. These are longer-term possibilities than the next generation of AEW&C. How much intellectual capital in these areas is needed now? How much is needed later? Does it need to exist in the AEW&C enterprise or can it reside in a broader enterprise portfolio? If the latter, what should be the interaction patterns between them and the AEW&C enterprise? How should the interactions evolve over time?

Example: The next generation of SA systems

The next generation of SA systems goes beyond air SA to include ground SA and perhaps other domains. The variety in technology and mission experience needed encompasses both airborne moving target indicator (AMTI) and ground moving target indicator (GMTI) areas. Portfolio management questions arise concerning program, technology focus, and staff mix, as they did in considering the next generation of AEW&C and air SA systems.

But there are new and different questions, as well. Interesting interactions arise when thinking of solutions to problems that have been addressed separately in the past. For example, current AMTI (e.g., AWACS) and GMTI (Joint STARS) capabilities have completely separate sensors, mission systems, communication systems and platforms. Current day tactics, techniques and procedures for the two capabilities are incommensurate in a number of important respects (e.g., on-station orbits, sensor information exchange with other network participants and its timing). What does a solution look like in which both AMTI and GMTI missions are both well-served at the same time and not traded off against each other in a zero-sum game? How can the principle of multidimensionality (Section 4.3) be used to interpret these opposing tendencies as mutually interdependent dimensions that can interact and be integrated in a new way of thinking about situation awareness? Are there opportunities for transformational innovation at the intersection of the AMTI and GMTI domains – domains that have largely evolved along separate paths? Can AMTI and GMTI information be used to develop new and useful representations of interactions or relationships among objects in different domains? Does this then change the nature of situation awareness? Does it suggest unimagined cross-domain system operator roles, mission applications, and decision-support aids? Do these new areas need to be explored? By whom?

6.2.2 Evolving Enterprise Processes and Practices

Enterprises that develop products have an interest in measuring the progress of product development.

From a single program or product perspective, the focus of incremental system development is primarily concerned with the ultimate goal of successfully fielding the full capability of a specific system or capability.

As a result, it is common in system acquisitions to use intermediate measurements to give insight into questions such as “is the program on course” and if not “what are we doing wrong and how do we correct it.”

In developing products or capabilities, particularly highly complex ones, intermediate measurements are also the basis of *build-a-little, test-a-little* incremental acquisition approaches. Their focus on developing working, useful intermediate capabilities more readily leads to the successful deployment of a full capability.

In an enterprise that develops many products, systems, or capabilities, particularly over an extended time, there is an opportunity to examine intermediate development criteria to determine whether they accurately predicted development success and how they could be improved for future developments. The focus of this perspective is on improving the intermediate measurement criteria used to track the progress of product, system, or capability development not on the status of a particular product in development.

Surprises (results different - better or worse - than expected) can help revise success criteria so that, in future developments, attribution of credit is able to produce more accurate results, provided one can correlate factors that were observable or predictable in the short run with the surprise. The question becomes, “What observable criteria were often high or low when the result was better or worse than expected?” This is an important shift from a focus on “what predicted the outcome” to “what predicted the surprise,” i.e., the deviation of what occurred from what was expected.

This kind of process allows the enterprise to accumulate a store of increasingly accurate criteria for attributing credit to a variety of intermediate positions in developing products, systems or capabilities. The enterprise thus evolves its acquisition processes, learning from its own experiences. The enterprise becomes collectively more capable in a way that enables managers of future programs to make increasingly more intelligent decisions throughout the development cycle.

7 Postscript

What is the relationship between traditional system engineering as exemplified by the INCOSE model presented in Section 3 and the evolutionary development framework for complex systems of Section 5? Is there any? Are there more than one? There is no simple answer as of this writing, but the discussion in this report suggests some interrelationship and at least a partial nature of it.

The INCOSE model produces systems, subsystems, and systems-of-systems. For this discussion, call them all "products." There are many developers producing products which perform similar roles or functions. And there is variation or differentiation across these similar products. So, one view is that traditional system engineering produces artifacts that provide variety for the processes of interaction and selection that result in improved future products. To use the AEW&C example again, the current market of AEW&C systems provides the variety for the next generation.

But there are other artifacts that come out of executing a traditional system engineering process like the INCOSE model. Improved system engineering processes do. And there is variety in these processes which fuels the evolutionary model that produces improved future processes. So, clearly the traditional model feeds the evolutionary model.

It works the other way, as well. Changes occur in well defined, deterministic processes, whether introduced by mistake (e.g., misunderstanding of a system engineering process by an inexperienced employee) or by design (e.g., deliberate attempt to innovate). And so evolution is found in and part of the very fabric of the traditional system engineering process.

The relationship between the traditional system engineering and the evolutionary developmental framework is akin to the yin-yang[105] symbol which suggests that they are complementary elements. Both are needed to form the "whole" and each contains an aspect of the other.

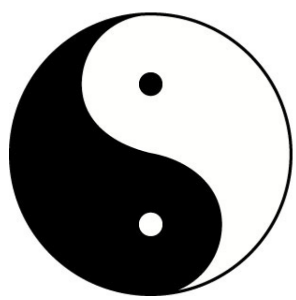

Figure 7-1. Yin Yang Symbol

[105] The Yin Yang is also called the Tai-Chi symbol. The Tai-Chi is from I-Ching, a foundation of Chinese philosophy.