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Thinking Systemically About Complex Systems

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Abstract

As machine age problems have given way to systems age messes, the underlying complexity associated with understanding these situations has increased exponentially. Accordingly, the methods we use to address these situations must evolve as well. Unfortunately, many antiquated methods for dealing with situations remain prominent. Systems engineering, traditionally, is the practical application of procedural problem solving, typically geared toward the acquisition of large-scale systems. The underlying paradigm for solving these problems can be characterized as *systematic thinking.* While quite appropriate for machine age problems, this approach lacks the theoretical rigor to deal with systems age messes. Thus, a new paradigm of *systemic thinking*, conceptually founded in systems theory, is necessary. This paper briefly discusses systems engineering, contrasts it with systemic thinking, and introduces practical guidelines for the deployment of a systemic thinking paradigm.

Keywords: Complex systems, systemic thinking, holism

1. Introduction

Systems engineering, as it is traditionally understood, is founded in a process. That is, traditional systems engineering, most appropriately, can be characterized as *systematic engineering*, where *systematic* connotes the methodical, process-based nature of standards for systems engineering. Major systems acquisition-oriented organizations such as the Department of Defense [1] and NASA [2] are steeped in the application of systematic methods and their practice and *engineering* reflects this notion Thus, systems engineering, traditionally, is the practical application of procedural problem solving (most traditionally problems concerning acquisition). Further, the underlying paradigm for solving these problems can be characterized as *systematic thinking.*

While systematic thinking is appropriate for machine age systems, it loses its effectiveness when problems increase in complexity as we transition to a systems age. Thus, a new paradigm of systemic thinking, conceptually founded in systems theory, is necessary. The major differences between systematic thinking and systemic thinking are outlined in Table 1, with a discussion of each element to follow.

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Table 1. Comparison of Systematic vs. Systemic Thinking

	Systematic Thinking	*Systemic Thinking*
Age	Machine	Systems
Unit of Analysis	Problem	Mess (System of problems)
Stopping Criteria	Optimization	Satisficing
Goal	Problem Solution	Increased Understanding
Underlying Philosophy	Reductionism	Constructivism
Epistemology	Analysis	Synthesis
Discipline Scope	Multidisciplinary and Interdisciplinary	Transdisciplinary
Approach	Prescriptive	Exploratory

2. Age

The first distinguishing characteristic separating systematic and systemic thinking concerns the age of problems each is designed to address. The machine age was concerned with simple systems and the systems age is concerned with complex systems, or more appropriately for purposes of systemic thinking, messes (where a mess is a system of problems). Ackoff [3] speaks of the inability of machine age paradigms to appropriately handle systems age messes. The relevant takeaway is that, when we are faced with a mess, we will be unable to appropriately address it with methods designed for solving machine age problems. While these methods, such as operations research and systems engineering, certainly have their place, this place is not in addressing systems age problems, which require methods, and an accompanying theoretical basis, that appreciate their complex nature.

3. Unit of Analysis

Systematic thinking focuses on a singular problem. Due to its broader scope, systemic thinking has a larger, more abstract unit of analysis, that of a mess [3]. A mess represents a system of problems. Thus, many problems are contained in a mess, but their analysis is not merely summative. Thus, analysis of a mess is exponentially more complicated than a singular problem. This relationship is depicted in Figure 1.

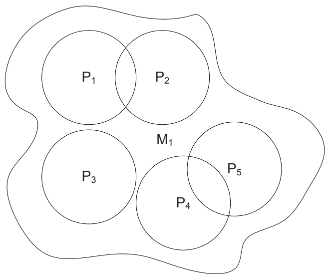

Fig. 1: Depiction of Mess and Constituent Problems

In Fig. 1 there are five problems, P_1, P_2...P_5 and a mess, M_1, consisting of these five problems and their problem context. Succinctly, $M_1 = f(P_1, P_2...P_5)$. It is in the interaction of these constituent problems and their associated context where the mess truly arises:

> *Problems are elements abstracted from messes; therefore, problems are to messes what atoms are to planets....the behavior of the mess depends more on how the solutions to its components problems interact than on how they act independently of each other*. [4]

Viewing this mess as a whole truly requires a systemic perspective.

4. Stopping Criteria

When analyzing a complex situation, it is imperative to think about global criteria associated with the desired end state of the analysis. That is, as an analyst, am I searching for a globally optimal, "best (maximum or minimum) value of the objective function" [5] solution to a problem, or am I merely seeking a satisfactory solution to my problem? The answer, as always, depends.

Given the relatively constrained perspective of a singular problem, it is easy to conceive that the stopping criteria for a problem analysis using a systematic thinking paradigm is optimization. The end goal of this machine age problem is to develop a best answer to the problem at hand. Thus, we speak of the *best* design for a structural component of a larger system, or the *best* portfolio selection from among a number of choices. Systemic thinking, however, requires a more delicate balancing act to be observed.

Given that any systemic thinking effort will involve two or more constituent problems, and the solution to each problem assessed independently represents a unique global solution to the mess, we must consider the principle of suboptimization [6] in our analysis of these messes. Maximizing overall mess performance (i.e., optimizing the mess) requires that its constituent problem solutions be constrained, thus violating the notion of suboptimization. Ackoff [4] echoes the difficulty in achieving an optimal solution to a mess:

There is an important systems principle, familiar to all of you, that applies to messes and problems: that the sum of the optimal solutions to each component problem considered separately is not an optimal solution to the mess....It is silly to look for an optimal solution to a mess. It is just as silly to look for an optimal plan. Rather we should be trying to design and create a process that will enable the system involved to make as rapid progress as possible towards its ideals, and to do so in a way which brings immediate satisfaction and which inspires the system to continuous pursuit of its ideals [4].

Thus, if each system (i.e., problem) chooses to pursue (and thus, optimize) its own interests, then the mess will necessarily operate at less than maximum performance. Balancing the interests of constituent problems is one of the most difficult aspects of systemic thinking. A mechanism for doing so is known as satisficing. Satisficing is a term coined by Herb Simon [7, 8] to describe how individuals make rational choices between available options and within a constrained environment. Simon argued that decision makers are rarely able to obtain and evaluate all the information which could be relevant to the making of a decision. Instead, they work with limited and simplified information to reach acceptable compromises (you satisfice, a portmanteau of satisfy and suffice) rather than to obtain a globally optimal strategy where a particular objective is wholly maximized. This relaxation from optimal-seeking problem solution approaches represents a departure from traditional operations research solution techniques, one appropriate for mess analysis.

5. Goal

Given systematic thinking's focus on the problem as a unit of analysis and optimization as its desired end state, it is clear that the goal of a systematic thinking endeavor is to determine a problem solution. As such, a problem solution effort aims to determine the globally best answer to the particular problem of interest and recognizes that there is a preferred solution for the endeavor in question. Systemic thinking endeavors, however, are not so straightforward. Given their focus on satisficing and messes, it is clear that a singular view of “best” is not only not achievable, but also not necessary. Instead, the goal of a systemic thinking endeavor is achieving increased understanding of a mess. Increased understanding does not presuppose that our situation will reach a conclusive state. Rather, we may end up trapped in a do-loop until conditions within our situation's environment change. Thus, the question we must ask is, how are we going to move toward increased understanding of our situation? This exploration may lead to a set of solutions, each of which may apply to the constituent problems of a mess, or it may lead simply to a greater understanding of the mess being faced. This increased knowledge may manifest itself in a recognition that we cannot do anything to improve or alter the current state. More importantly, perhaps, is the understanding that we may not want to intervene, for fear that we'll upset the dynamic equilibrium [9] of the underlying system. The field of cybernetics and the systems principle of homeostasis (Cannon, 1929) inform systems practitioners that systems have the ability to self-regulate to maintain a stable condition. Often times, intervention will cause negative feedback rather than improvement. Understanding of this concept helps us to avoid the Type IV error [10]. Boal and Meckler (2010) elaborate on the problems caused by a Type IV error as:

Acting to solve a problem, be it the right problem or the wrong problem, can create other difficulties. Sometimes solutions are 'iatrogenic,' meaning that they create more, or bigger problems than they solve. Faced with such a possibility the decision maker should thoroughly examine all the potential system effects, and perhaps refrain from action.

In the case that it was an attempted solution to the right initial problem, one important problem is now replaced by another, perhaps worse problem. (p. 333)

So, in achieving increased understanding we may learn that inaction is the best action.

6. Underlying Philosophy

Philosophy is based in a world view which ultimately drives the understanding of a mess. Aerts, et al. [11] define world view as “….a system of co-ordinates or a frame of reference in which everything presented to us by our diverse experiences can be placed” [11].

Ackoff [12] defines world view as:

Every culture has a shared pattern of thinking. It is the cement that holds a culture together, gives it unity. A culture's characteristic way of thinking is imbedded in its concept of the nature of reality, its world view. A change of world view not only brings about profound cultural changes, but also is responsible for what historians call a "change of age." An age is a period of time in which the prevailing world view has remained relatively unchanged. [12]

This consistency in world view is what Checkland [13] refers to as *weltanschauung*, the image or model of the world that provides meaning. Each of these definitions hints at the idea of a world view as a shared perspective or frame of reference for understanding the world. Ackoff's [3] talk of a transition in ages implies a shift in philosophical world view. The philosophical worldview has changed from reductionism in the machine age to constructivism in the systems age.

Reductionism, first introduced to Western civilization by René Descartes (1596–1650) in his *Discourse on Method* and later expanded by Isaac Newton (1643–1727) in his *Principia Mathematica* focuses on reducing a system to its barest elements in order to provide for an understanding of the system. Focusing on biological complexity, Mazzocchi [14] discusses several limitations of applying a purely reductionist perspective to understanding complex systems:

- "...the reductionist approach is not able to analyse and properly account for the emergent properties that characterize complex systems..." [14]
- "...reductionism favours the removal of an object of study from its normal context. Experimental results obtained under given particular conditions or from a particular model—such as a mouse, *in vitro* cell cultures or computer models—are often extrapolated to more complex situations and higher organisms such as humans. But this extrapolation is at best debatable and at worst misleading or even hazardous." [14]
- "...reductionism is also closely associated with determinism—the concept that every phenomenon in nature is completely determined by preexisting causes, occurs because of necessity, and that each particular cause produces a unique effect and vice versa. This, naturally, also sustains the idea of predictability.... Nonetheless, complex...systems cannot be fully understood on a purely deterministic basis." [14]
- "...to better understand complex...systems and their adaptive behaviour, we need to consider the phenomenon of self-organization...." [14]

Mazzocchi [14] continues, "An epistemological rethink is needed to instigate a paradigm shift from the Newtonian model that has dominated science, to an appraisal of complexity that includes both holism and reductionism, and which relaxes determinism in favour of recognizing unpredictability as intrinsic to complex systems" [14]. It is clear that much is to be gained from adapting a world view focused on holism [15], or constructivism. This perspective focuses on assembling system components into a purposeful whole in order to provide for an understanding of the system as a whole. This unique world view underlies systemic thinking and helps to provide for its epistemological basis, discussed in the following section.

7. Epistemology

Epistemology refers to the theory of knowledge and thus, addresses how knowledge is gained about a particular situation. It is informed by a particular worldview and thus, given their divergent world views, the epistemology underlying systematic and systemic thinking is quite divergent as well. Ackoff (1979) succinctly describes the steps in analysis as:
"...(1) taking apart the thing to be understood, (2) trying to understand the behavior of the parts taken separately, and (3) trying to assemble this understanding into an understanding of the whole..." (p. 8)
Analysis relies on observation, experimentation, and measurement for its knowledge gathering. It is largely quantitative in its attempts to explain and understand the world.

On the other end of the epistemological spectrum is synthesis. Synthesis involves identification of a system to be studied. It then explores the environment in which the system resides, in order to understand its behaviors and purpose. Thus, rather than decomposing the system, synthesis aggregates into larger and larger systems in order to infer meaning. Synthesis relies on understanding, complementarity of perspectives [16], and social construction for its meaning. Its emphasis on understanding (vice solution) and complementary, subjective evaluation of meaning should be comforting to individuals who focus on messes.

8. Disciplinary Scope

Although the terms are often erroneously used interchangeably, multidisciplinary, interdisciplinary, and transdisciplinary each have a unique meaning [see, e.g., 17, 18-20]. A succinct summary of the three is provided by Choi and Pak [21]:

> *We conclude that the three terms are used by many authors to refer to the involvement of multiple disciplines to varying degrees on the same continuum. Multidisciplinary, being the most basic level of involvement, refers to different (hence "multi") disciplines that are working on a problem in parallel or sequentially, and without challenging their disciplinary boundaries. Interdisciplinary brings about the reciprocal interaction between (hence "inter") disciplines, necessitating a blurring of disciplinary boundaries, in order to generate new common methodologies, perspectives, knowledge, or even new disciplines. Transdisciplinary involves scientists from different disciplines as well as nonscientists and other stakeholders and, through role*

release and role expansion, transcends (hence "trans") the disciplinary boundaries to look at the dynamics of whole systems in a holistic way. [21]

A graphical depiction of multidisciplinary, interdisciplinary and transdisciplinary is shown in Figures 2-4. Note that D_1 and D_2 in the figures refer to Discipline 1 and Discipline 2, respectively.

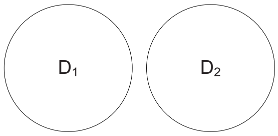

Fig. 2: Multidisciplinary Depiction

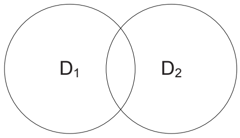

Fig. 3: Interdisciplinary Depiction

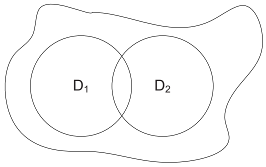

Fig. 4: Transdisciplinary Depiction

A truly transdisciplinary scope is required for systemic thinking. This is further demonstrated by the holistic worldview demanded by systemic thinking. Multidisciplinary and interdisciplinary perspectives represent too narrow a focus for understanding the bigger picture encouraged by a systemic lens.

9. Approach

The final distinguishing characteristic that separates systematic thinking from systemic thinking is that of the approach employed by each. As discussed earlier, systematic thinking is, quite obviously, systematic, and thus, procedural. This means it is largely prescriptive and largely holds to a detailed process for undertaking it. In the world of cooking, systematic thinking would involve strict adherence to a recipe; in driving, step-by-step navigation barked out by a GPS; in engineering, a standard such as IEEE Std. 15288 [22], with many rules and procedures to follow. Systemic thinking, on the other hand, is much more exploratory. It is normative in that it driven by a flexible way of thinking which adheres to norms, or general descriptors of behavior without strict rules. The emergent behavior [23] exhibited by the messes it is intended to support are well suited to an exploratory approach. Thus, returning to previous examples, systemic cooking would suggest a general framework for a meal and perhaps a set of suggested ingredients, but it would refrain from providing precise measurement quantities or detailed instructions. Similarly, systemic navigation would account for emergent behavior (e.g., traffic, weather, and road construction) expected by anyone who's ever gone anywhere in a car. It might exist on a continuum, at one end merely providing a map with a "You are here" sticker and leaving the explorer to his or her devices, and at the end other end providing a set of suggested routes, but leaving the explorer to determine deviations from the suggested route in an ad hoc fashion and adjusting accordingly. Finally, with respect to engineering, systemic thinking provides a general methodology for *thinking* about a mess, yet it stops short of detailed prescription necessary in traditional systematic endeavors. This lack of prescription allows for the analyst to adjust to real world nuances impossible to be captured by prescriptive approaches to understanding complex scenarios.

10. Conclusions

Systems age messes are much grander and more complex than their machine age problem predecessors. Thus, accompanying methods to understand them must also account for this additional complexity. Practice shows that this is not the case and systems engineering and its underlying paradigm of systematic thinking are still quite prevalent in today's world. This paper introduced a methodology for systems thinking and contrasted it with traditional systematic thinking. The hope is that this paper will spark discussion about the development of methods to encourage such a perspective be adopted by systems thinkers to put the approach into practice in a manner which will garner increased understanding for messes associated with the systems age.

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