Chapter I

From Reductive to Robust: Seeking the Core of Complex Adaptive Systems Theory

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Abstract

This chapter seeks to identify the core of complex adaptive systems (CAS) theory. To achieve this end, this chapter introduces innovative methods for measuring and advancing the validity of a theory by understanding the structure of theory. Two studies of CAS theory are presented that show how the outer belt of atomistic and loosely connected concepts support the evolution of a theory; while, in contrast, the robust core of theory, consisting of co-causal propositions, supports the validity and testability of a theory. Each may be seen as being derived from differing epistemologies. It is hoped that the tools presented in this chapter will be used to support the purposeful evolution of theory by improving the validity of intelligent complex adaptive systems (ICAS) theory.

What is the Core of CAS Theory?

Where other chapters in this book may use intelligent complex adaptive systems (ICAS) theory as a framework to understand our world, we strive in this chapter to understand theory, itself. Through this process, the reader will gain a new perspective on the theory that is applied elsewhere in this book. To gain some perspective on ICAS, we will study the literature of complex adaptive systems (CAS) as developed in the field of organizational theory. As such, this chapter may be of interest to those discussing organizational theory and organizational change, multi-agent systems, learning methods, simulation models, and evolutionary games.

CAS theory originated in the natural sciences as a tool for understanding non-linear dynamics (Kauffman, 1995) and has gained popularity in organizational studies through the efforts of many authors (i.e., Axelrod & Cohen, 2000; Brown & Eisenhardt, 1998; Gleick, 1987; Stacey, 1996; Wheatley, 1992). As CAS expanded into this discipline, every author seems to have placed a personal mark by revising CAS for interpretation and publication. Indeed, in researching the literature, 20 concise, yet different, definition/descriptions of CAS theory were found.

Within these 20 definitions, "component concepts" were identified. For example, Bennet & Bennet (2004) note (in part) that a CAS is composed of a large number of self-organizing components. The concepts of "self-organization" and "large number of components" may be seen as conceptual components of CAS theory as described by those authors. These conceptual components might also be thought of as the authors' "propositions." It is important to note that among the 20 definitions, no two contained the same combination of component concepts. This raises a serious question: When we talk about CAS theory, are we really talking about the "same thing?" After all, if one author states that a CAS may be understood through concepts "a, b, and c" while another author states that the relevant concepts are "c, e, and f," there may be some conceptual overlap but there are also inherent contradictions.

In the social sciences, this issue has been of concern for decades. In one attempt to make sense of the issue, theory has been described as consisting of a "hard core" of unchanging assumptions, surrounded by a more changeable "protective belt" (Lakatos, 1970). When a theory is challenged, a theorist may rise to defend it with a new proposition that changes the belt, but presumably leaves the core intact. Phelan (2001) suggests that complexity theory has its "hard-core assumptions;" however, among the 20 definitions discussed here, there is no one concept that is held in common by all of the authors. If there is no concept, or set of concepts, held in common, where then is the core of CAS theory? Motivated by this apparent lack of commonality, we seek to identify the core of CAS theory.

A Chinese proverb states, "The beginning of wisdom is to call things by their right names." (Unknown, 2006, p. 1). The difficulty of engaging in conversations with imprecise definitions was famously illustrated when Plato called man a "featherless biped." He was forced to add, "with broad flat nails" in response to Digenes, who arrived with a plucked bird, proclaiming "Here is Plato's man." (Bartlett, 1992, p. 77). We may speculatively ask if it was the atomistic nature of Plato's definition that left it so open to misinterpretation. In short, we must wonder how we can know what we are talking about, if the name keeps changing. In contrast to Plato's rapidly evolving definition, Newton's laws (e.g., F=ma) have proved effective, and unchanged, for centuries.

As scholars, of course, we are continually engaged in the discovery (or social construction, depending on your view) of understandings and definitions. And yet, we need some level of shared understanding of existing concepts, so we may communicate effectively as we work to understand new concepts. In short, as scholars, we might see the increasing clarity and stability of our definitions as an indicator of "progress" in a given field. We dig the clay, form it into paving stones, place them in front of us, and walk on them to find more clay. In this chapter, we will suggest some tools for identifying the milestones along our shared road.

Central to the exploration presented in this chapter, we must ask, "Is it possible to ascertain the legitimacy of a theory through its structure?" Dubin (1978) suggests that there are four levels of efficacy in theory; and these levels do reflect the structure of the theory. They are: (1) presence /absence (what concepts are contained within a theory). (2) Directionality (what are the causal concepts and what are the emergent concepts within the theory). (3) Co-variation (how several concepts might impel change in one another). (4) Rate of change (to what quantity do each of the elements within the theory effect one another). Parson and Shills note four similar levels of systemization of theory--moving toward increasing "levels of systemization" (Friedman, 2003, p. 518). Reflecting the validity of these assertions, Newton's formulae might be seen as residing at the highest level because it is possible to identify quantitative changes in one aspect (e.g., force) from changes in other aspects (e.g., mass & acceleration). Such a high level of understanding has been long sought in the social sciences but has, as yet, remained elusive. One goal of this chapter is to advance CAS theory along this scale—and identify how further advances might be enabled for similar forms of theory.

To find the core of a theory, two studies are presented in this chapter. One study is based on content analysis (essentially, looking at the words used by the authors as reasonable representations of the concepts that they are conveying). The second study uses a more traditional narrative analysis. The first study is a reductive look at CAS theory—focusing on the axiomatic propositions of the authors. This method will be seen as adding to the outer belt. The second study focuses on the relational propositions of CAS theory. This method suggests that there is a core to CAS theory. However, it also shows that the core (based on the current state of CAS theory) has only a limited internal integrity. A path for developing a more robust CAS theory is then suggested. The process of developing a robust theory is expected to provide great benefits to scholars (based on the successful use of Newton's robust formulae).

Due to limitations of space, the studies in this chapter will be focused on the level of "concept" (with concepts presented as they are named by the authors and as they may be generally understood by most readers) and theory (as a collection of concepts). These studies will generally avoid the sub-concept level of interpretation and what might be called a post-theory level of application and testing.

The next section includes a relatively linear and reductive analysis of the concepts of CAS theory. This process might be seen as a thought experiment--a cognitive construction that represents the creation of new definitions in an ad-hoc manner.

A Reductive Study of CAS Theory

In this section, we engage in the development of new theory where theory might be seen as a collection of concepts. This process identifies the range of concepts in CAS theory and develops new versions of that theory. The new versions of CAS theory created here may be seen as newly evolved definitions. Although such definitions may be tentatively used to identify various perspectives of CAS theory, they may also be seen as adding to the outer belt of theory rather than clarifying the core.

We begin with a review of literature. Searches of the ProQuest database yielded nearly 100 articles in academic journals where CAS theory was discussed in the context of a human organization. Within those articles, 13 were found to contain concise (less than one page) definitions of CASs. Additionally, those journals (and other sources) suggested other scholarly publications. Promising books were reviewed and seven additional concise definitions were found. In all, this study (although not exhaustive) found 20 relatively concise definitions of CASs. Concise definitions were used so that the study could cover as much ground as possible. It is also assumed that a concise definition includes the most important aspects of each author's version of the theory. It is also expected that a sample of this size will provide a sufficient representation of the body of theory.

Although the authors' definitions are not listed for reasons of space, this study uses concise definitions from Ashmos, Huonker, and McDaniel (1998), Axelrod et al. (2000), Bennet et al. (2004), Brown et al. (1998), Chiva-Gomez (2003), Daneke (1999), Dent (2003), Harder, Robertson, & Woodward (2004), Hunt & Ropo (2003), Lichtenstein (2000), McDaniel, Jordan, & Fleeman, (2003), McGrath (1997), McKelvey (2004), Moss (2001), Olson & Eoyang (2001), Pascale (1999), Shakun (2001), Stacey (1996), Tower (2002), Yellowthunder & Ward (2003).

In the process previously described, the study deconstructed each definition into the authors' propositions, or component concepts. For example, Daneke describes a CAS as, "A simulation approach that studies the coevolution of a set of interacting agents that have alternative sets of behavioral rules" (Daneke, 1999, p. 223). The concepts describing the CAS here would be coevolution, interaction, agents, and rules. While another reader might develop a different list, it is expected that such lists would be substantively similar to the one developed here where a total of 26 concepts were identified, consisting of:

Agent, non-linear/unpredictable, levels, co-evolutionary, adaptive, agents evolve, far from equilibrium/edge of chaos, self-organizing, many agents, interrelated/interacting, goal seeking, decision-making, emergence/surprise happens, act in rules/context of other agents and environment, simple rules, permeable boundaries, evolves toward fitness, boundary testing, iterative process, agents are semi-autonomous, evaluate effectiveness of decisions/results, self-defining, identity, morality, irreversible, time.

This list might be seen as representing the whole of CAS theory from an atomistic perspective. It should be noted that at this "survey" stage, no component appears to be more "important" than another and no component seems to be closer to the core than any other.

Of the 20 publications, three could clearly be seen as the "most cited" (each having been cited by hundreds instead of tens, or fewer). Between them, there are six concepts used by at least two of the three, including:

Co-evolutionary, many agents, interrelated/interacting, goal seeking, emergence/surprise happens, simple rules.

This focus on what might be considered the "authoritative" versions essentially creates a new definition of CAS theory built on the shared conceptual components of the authors. However, it should be noted that this new definition has lost some conceptual breadth when compared to the whole body of CAS theory. Moving from one form of popularity to another, the following is a list of those six concepts that seemed most popular among the 20 definitions:

Non-linear/unpredictable, co-evolutionary, many agents, interrelated/interacting, goal seeking, emergence surprise happens.

Again, a new definition of CAS theory has been created with a new focus. Again, the conceptual components have shifted--both in comparison to the whole body of CAS concepts and in comparison to the authoritative version.

Additionally, while most authors identified themselves as scholars, others identified themselves as scholar-practitioners. Those whose affiliations were uncertain were left out of this ad-hoc, demonstrative study. The five concepts most commonly described by those authors who identified themselves as scholars were:

Non-linear/unpredictable, self-organizing, many agents, interrelated/interacting, emergence/surprise happens.

Among those who identified themselves as scholar-practitioners, the four most popular concepts used were:

Non-linear/unpredictable, many agents, interrelated/interacting, goal seeking.

There are obvious limitations to this ad-hoc study. However, a number of insights and benefits become apparent here. First, that this study creates a comprehensive view of the concepts within a body of theory. Of course, in this study, that view is limited to the level of the concepts, rather than delving deeper, which is another possible level of exploration. Second, that each group of concepts suggests those specific concepts that might be most appropriate for a given application or area of research. In a sense, each group of concepts might be viewed as a "school of thought" for CAS theory within its specific venue. Importantly, this brief study essentially began with 20 definitions and generated four more. The number of theories in the outer belt was easily increased, yet we do not seem to have increased our understanding of the core. Our lack of core insight may be related to the form of analysis, or the type of data used. Importantly, we approached the data as lists of concepts and rearranged them into new lists. Each attempt to identify a new perspective resulted in a new list. As with the broader survey (the first list), each subsequent list has no discernible core.

The analysis presented in this section has served to demonstrate some strengths and weaknesses of a reductive form of study. In the next section, we look at alternative approaches to the ordering of conceptual components and, in the section following, we apply those ordering ideas to clarify the structure of CAS theory.

Looking at the Structure of Theory

Drawing on Southerland, Weick (1989) discusses theory as, "an ordered set of assertions" (p. 517). If a theory is defined (in part) as consisting of ordered assertions, it begs the question of just how well ordered those assertions might be. By "ordered," we might understand those assertions to be arranged alphabetically, by apparent importance, or any number of possible methods. This “disposition of things following one after another” (Webster’s, 1989, p. 1013) do not seem to add much to our understanding of theory, however. It is not clear, for example, that a theory might be considered more valid if the assertions are in alphabetical order instead of ordered (for example) by the year each concept was added to the literature. However, based on that simple interpretation of order, there would seem to be no epistemological preference between ordering the assertions by their historical appearance in the literature, by the first letter in the concept, or ordering the assertions by the apparent importance ascribed to them by an author.

By ordered, therefore, it may be that Weick was implying something more significant than a list. A more useful (or at least an alternative) epistemological validity, therefore, might be developed by looking at the assertions or propositions of a theory as being “interrelated,” where the propositions might be seen as, “reciprocally or mutually related” (Webster’s, 1989, p. 744). With such a view, a body of theory might be seen as a kind of system and, “…any part of the system can only be fully understood in terms of its relationships with the other parts of the whole system.” (Harder et al., 2004, p. 83, drawing on Freeman). It seems, therefore, that every concept within a theory would best be understood through other concepts within that body of theory. Significantly, this perspective seems to fit with Dubin’s (above) assertion that theories of higher efficacy have explanations and concepts that are co-causal.

To briefly compare and contrast levels of interrelatedness, we might say that the lowest level of relationship may be found in some jumble of random concepts. A higher level of interrelatedness might be seen in a book where an author describes concepts (thus causing each to exist in closer relationship with others). Other authors have used a wide variety of methods for increasing relatedness such as placing them in a list (as above), a flow-chart showing a cycle (e.g., Nonaka, 2005, for social construction), a matrix (e.g., Pepper, 1961, for metaphors), or a combination of lists and flows to create a meta-model (e.g., Slawski, 1990). With each increasing level of relatedness, a given reader might understand a concept in relationship with other concepts, and so find new insights based on the relatedness between concepts. In short, an increasingly systematic relationship might be viewed as having increasing relatedness. One example of a systemic theory may be seen in Wilber’s integral theory of human development (e.g., Wilber, 2001). In his theory, Wilber describes four quadrants that represent categorizations of insights from numerous disciplines. Wilber claims that each of these quadrants is co-defined by the others—in essence, that no quadrant can be fully understood except in relation to the other three. This claim suggests a high degree of relatedness.

Another way to look at interrelatedness might be seen in the concept of "reflexive." Hall (1999) suggests that some forms of inquiry represent a "third path" of inquiry that is primarily neither objective, nor subjective; rather it is essentially reflexive, where meaning is created in a socially constructed sense. In contrast to reflexive forms used in the sense of the interaction between individuals, however, the second study of this chapter looks at reflexive analysis in the sense that suggests a relationship within, or between, the concepts of CAS theory.

Combining the idea of relatedness with the idea of theory having a tight core and a loose belt, we might see the concepts in the core as being more closely interrelated than the belt. For example, the above reductive study of CAS produced definitions with low levels of interrelatedness, as might be found in the loosely defined belt of a theory, because the new theories are presented essentially as lists of concepts.

In addition to the concept of relatedness, another important concept for this chapter is that of "robustness." Wallis (2006a) explored a number of interpretations of this term. Following insights developed from Hegel and Nietzsche, Wallis settled on an understanding of robustness that might be familiar to those working in the natural sciences, where a robust theory is one where its dimensions are "co-defined." An example of this would be Newton's law of motion (F=ma) where each aspect (e.g., mass) may be calculated, or understood, in terms of the other two (e.g., force and acceleration).

It is very important to differentiate between theories whose structure might be seen as robust, and theories whose structure might be understood as an ordered list. For example, a list of assertions might be understood as an atomistic form of theory and might be represented abstractly as "A" is true. "B" is true. "C" is true. In contrast, the propositions of a robust theory might be seen as Changes in "A" and "B" will cause predictable changes in "C." Changes in "B" and "C" will cause predictable changes in "A." And, changes in "C" and "A" will cause predictable changes in "B." The interrelatedness of concepts in a robust theory suggests that the theory may be validated from "within" the theory.

In this book and elsewhere (e.g., Richardson, 2006), the concept of robustness is used to describe the stability of a network experiencing external perturbations. A system that is completely unstable would have a robustness of zero, while a perfectly stable system would be assigned a robustness of one. While it could be legitimately argued that no system can have its measure of robustness at the extreme ends of the scale (zero, or one), this chapter will use zero and one as approximations to facilitate discussion.

An understanding of perturbations might be used to determine what might be called the "dynamic robustness" of a system of theory by identifying the ratio of stable concepts to changing concepts. In this two-step proves, one first identifies the concepts contained in each form of the theory and assigns each a numerical value based on the component concepts. Next, the ratio between the two (earlier and later) versions of the theory is taken. If the two theories are identical, the robustness will be equal to "unity" (or one). If the two theories have no concepts in common, they will have a robustness of zero. For example, if theory "A" has four distinct concepts (a, b, c, d) and subsequently evolves into theory "B" with four concepts (c, d, e, f,), we may see theory A and B together as having a total of six concepts (a, b, c, d, e, f) with only two concepts held in common (c, d). This relationship suggests that in the process of evolving from theory A to theory B, the theory exhibited a robustness of 0.33 (two divided by six). Of course, such measures might only be considered valid when the concepts themselves are unambiguous. This method may be seen as responding to Hull's (1988) deep discussion on the evolution of theory--and providing a tool to aid in the mapping of that evolution.

If we look at each author's influence on CAS theory as a perturbation, CAS theory may be seen as having a low level of robustness. For example, Yellowthunder et al. (2003) describe a CAS using four concepts drawn from Olson et al. (2001) who used those four in addition to three additional concepts. This change suggests a robustness of 0.57 (the result of four divided by seven). Other times, CAS does not fare even that well. Dent (2003) states that he drew his conceptualization of CAS from Brown et al. (1998). However, between the six concepts listed by Dent and the eight concepts listed by Brown et al., there are only two concepts that clearly overlap. This suggests a low robustness of 0.14 (the result of two divided by fourteen). In contrast, Newton's formula of force (F=ma) may be seen as having a robustness of one as the formula is unchanged in any non-relativistic application. The widespread use of Newton's formula may suggest that theories of greater robustness are more useful (and may have more predictive power) than theories of less robustness.

While low robustness may be seen as enabling "flexibility" (where a theory changes and evolves with rapidity), it may also be seen as an indicator of confusion or uncertainty. It recalls our original question as to the core of CAS theory and suggests that axiomatic, atomistic, or reductive definitions (e.g., theories with concepts that are structured as lists) have shown too much flexibility to provide an adequate representation of the core. In the following section, we analyze the body of CAS theory to identify more robust relationships between the concepts.

Investigating Relational Propositions

In this section, we investigate the relational propositions described by the authors of the above 20 concise definitions to identify the core of CAS theory, where that core may be seen as shifting CAS theory toward Dubin's (1978) second level of theory efficacy (where concepts are directionally causal).

In this process, as with the reductive study, we deconstructed each of the concise definitions into propositions. Rather than use all of the available conceptual components, however, those statements that were essentially axiomatic are left out. For example, Bennet et al. (2004) state, "There are some basic properties common to many complex adaptive systems. Examples are some level of self-organization, nonlinearity, aggregation, diversity, and flow" (p. 26). Those concepts would be considered axiomatic or atomistic. In contrast, their statement that, "The term complex system means a system that consists of many interrelated elements with nonlinear relationships that make them very difficult to understand and predict" (p. 26) may be seen as a relational proposition because nonlinear relationships are seen to cause unpredictability.

Of the few relational propositions, the first is Stacey (1996) who states that agents follow rules (or schemas) in their interactions to improve on their behavior. This proposition shows that there is some relationship between the agents, their schemas, behaviors, and the subsequent improvement in behavior. Many authors echo this same general idea.

Axelrod et al. (2000) note that varied schemas (situational decision-making rules) differentiate, or provide variety, among agents. Agents are also differentiated by geography (differences in physical and conceptual space). These agents interact with one another (and with tools) in an essentially evolutionary process that might be seen as being based on the agent's fit with the environment. In that process, the agents are changed through changes in their schemas. Changes might be seen as increasing or decreasing the similarity of those agents. Similarly, Shakun (2001) states that agents take actions to reach goals. In this conversation, goals may be seen as generally similar to schemas as both seem to have some influence over the actions of the agents.

McDaniel et al. (2003) also suggest that agents interacting over time leads to self-organization. Time may be seen as important, although most authors include it only implicitly. Moss (2001) notes that members (agents) self-organize toward more stable patterns of activity. This may be seen as generally similar to the process of agents interacting to cause self-organizations--with the added idea that the process of self-organizing causes more stable patterns of activity. These stable patterns of activity are a result of common frames of reference, an idea that seems generally similar to rules or schemas as noted above.

Other authors (e.g. Bennet et al., 2004; Hunt et al., 2003) start from generally the same position—that the components (which might be seen as agents) of a CAS interact. However, according to these authors, the interactions lead to uncertainty. Dent (2003) also agrees and adds that the interaction is to find fit. Dent then notes the results of the agentic interactions may be seen as causing change (that may be thought of as a form of uncertainty).

Somewhere between, or combining, these camps, Harder et al. (2004) state that varied agents interact to maintain a system (homeostasis, in their words) rather than create a new system. However, their description of homeostasis is described by terms such as "dynamic equilibrium," "constant change," and "adaptation." Thus, it seems that the authors are suggesting that agents do not change—so much as they enable their CASs to interact, change, and evolve.

Pascale (1999) notes that the process of agents engaged in interaction will lead to more "levels" of organization. This idea of levels might be seen as conceptually similar to Axelrod et al.'s description of the geographic differentiation of agents (physically and/or conceptually). Additionally, it does not seem as though the creation of a new level of organization should be significantly different (within the context of this conversation) than the creation of a "new" system. It simply seems that this particular new organization is one that is already nested in an existing one. A larger difference between Pascale's version and that of other authors is that Pascale states that the agents are "shuffled" by the larger system.

Drawing on Dooley, Olsen & Eoyang (2001) note that agents evolve over time to reach fitness. Again, we may note the explicit surfacing of the temporal aspect of CASs that many authors leave tacit. Also, where most relational statements discuss agents interacting to achieve fitness, these authors might be seen as leaving the step of interaction as tacit. In both versions, however, agents do tend toward fitness.

Finally, Chiva-Gomez (2003) draws on Stacey to note that CASs that are closer to the edge of chaos (EOC) will experience more self-organization. This concept of EOC might be considered synonymous with "bounded instability," which Stacey describes as a balance between formal and informal systems. More broadly, EOC might also be described as the boundary between stability and ambiguity. In developing the OEC concept, Stacey (1996) notes Kauffman, Wolfram, Gell-Mann, and Langton among his influences. Seen from the perspective of the present conversation, Kauffman's (1995) description of bounded instability may be understood as occurring where the number of agents approximates the number of interactions. If there are too many agents, and insufficient interactions, chaos reigns. On the other hand, if there are few agents and many interactions, stability prevails. Therefore, it seems reasonable that we may integrate the EOC concept with the other co-causal statements above because the EOC may be understood as a ratio between the number of agents and their interactions.

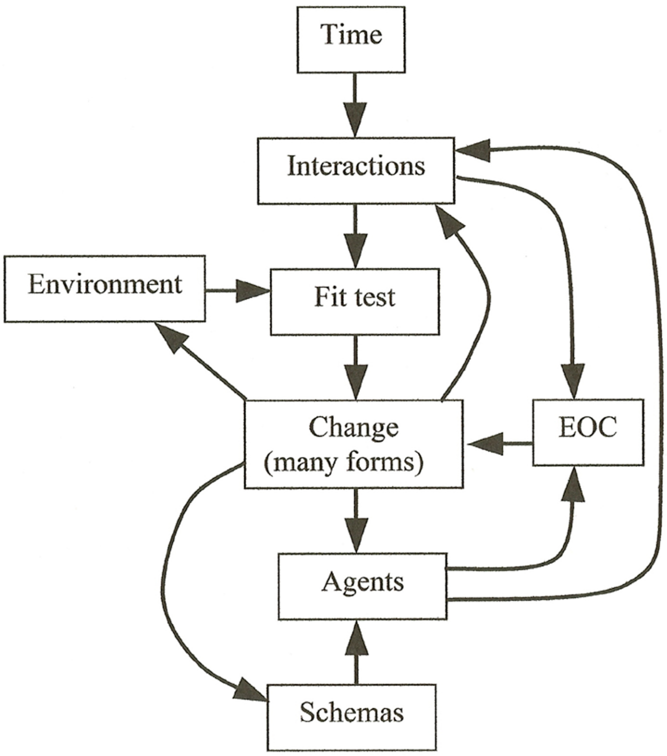
Generally speaking, there appears to be considerable overlap between many of the previous causal propositions. Specifically, many authors discuss the existence of agents (including parts), schemas (that may be seen as including goals, rules of interactions), interactions (that may include communication, and also implicitly or explicitly assumes the passage of time), and fit (including evolutionary tests of success). Additionally, it may be seen that the fit test is based on the existence of an external environment (although that environment may be seen as one or more other agents). There are a variety of changes that may result from a fit test including adaptation, change in interaction, change in schemas, increasing uncertainty, increasing certainty, self-organization, and the maintenance of existing organization. Also, as change is seen as a "general" result, change may also be seen to alter agents.

Looking at the concepts in their causal relationship, we may define the core of CAS theory as agents, with schemas, interacting over time. The results of those interactions are maximized at the EOC and are subject to a fit test with the environment. The result may be changes in schemas, changes in interactions, the creation or maintenance of larger systems, increased stability and increased instability. Finally, the status of the EOC may be changed by the creation of new agents, schemas, or CASs. This definition is represented graphically in Figure 1.

Each arrow represents causal direction, where one aspect of CAS theory will have an effect on another. As the concept of non-linear dynamics is an important aspect of CAS theory and complexity theory (e.g., Dent & Holt, 2001; Lichtenstein, 2000), it may be worth noting that the relationship between the causal aspects of this definition of CAS theory seems to support the idea of a non-linear or non-deterministic structure. This view is in contrast to an atomistic list of conceptual components.

The presented definition surfaces additional challenging questions. These questions might be seen as stemming from potentially contradictory statements by the authors. For example, Axelrod et al. note that changes occur at

Figure 1. Relationship between causal concepts



the level of the schema while Moss suggest that change occurs at the level of interactions. These should not, however, be seen as mutually exclusive. Instead, we might ask, "How much change will occur?" Then we might ask, "Where will that change occur?" For example, if a group of individuals self-organize into a corporation to take advantage of a new business opportunity, how much change is seen from the perspective of the business environment (with the inception of a new entity) compared to how much change is seen by the agents (as they organize themselves into new relationships and interactions), and how much change might be seen as occurring at the level of the schema of those individuals?

The structure of this model does not seem to be "perfectly" causal, however, in at least three areas. First, time (along with agents and change) enable the occurrence of interactions. However, nothing seems to "cause" (or alter) time. Therefore, time seems to be seen as an atomistic concept. To become more fully robust, this model should identify what causes (and alters) time or/and its perceived passage. Second, schemas seem to be caused by change, alone. Such a linear relationship would seem to suggest that any change in schemas would create a corresponding change in agents. This relationship would suggest that the concept of schemas might be bypassed. Alternatively, the concepts of schemas might be enhanced by adding causal influences. Finally, while the EOC seems to control the "quantity" of change, the variety of possible "forms" of change is still open to interpretation. Similarly, the environment seems to be changed only by change (another linear relationship, like schemas). However, the environment may represent numerous CASs--each with their own nested agents and schemas.

Although this model has left out many component concepts of CAS theory, the closely related nature of the included aspects suggest that it may be a good representative for the core of CAS theory. That is because that causal model more closely meets Dubin's requirement for stage two of efficacy of theory, while the reductive models only reach stage one. In the next section, we compare three models of CAS theory.

Comparisons and Insights

Drawing on Davidson and Layder, Romm (2001) suggests that researchers use "triangulation" (multiple research methods to reduce subjectivity in research). Thus far, we have presented two forms of analysis. A third form of analysis of the same data set may be found in Wallis (2006a) where reflexive dimensional analysis (RDA) was used to understand CAS theory as consisting of five related conceptual dimensions. Developed by Wallis (2006b) from grounded theory and dimensional analysis, RDA is a method for the investigation of a body of theory.

Looking at the broad range of concepts in CAS theory, the previous reductive study has the benefit of including all concepts of the body of CAS theory—presented as a list of atomistic concepts. The RDA version also purports to include all the concepts of CAS theory; however, it presents those concepts as "enfolded" so that concepts not directly represented by the theory might be understood indirectly by combining the dimensions of the theory. For example, the concept of "evolution" (not directly represented) might be understood as "change" over "time" (both of which are directly represented in the model). In contrast to either of the above methods, the causal model leaves out concepts that are considered to be axiomatically atomistic (although those concepts may be seen as still existing in the belt). This suggests some benefits and detriments to each method. Where the atomistic/reductive approach might be more complete, the RDA version might be understood as more abstract (and so has the opportunity to be applied to a wider variety of systems) and more parsimonious (where aspects are related by the minimum number of laws possible, per Dubin).

Comparing the flexibility of these forms of theory (setting aside their common requirement for scholarly justification), it seems that reductive forms enable the easy addition or removal of concepts, essentially adding or removing them from the list. In contrast, forms of theory that are reflexively structured (RDA and causal) are not so easily altered. For example, referring to Figure 1, if we were to remove the concept of interactions, our understanding of other concepts would be imperiled. Time would become "disconnected" from the model, agents would become linearly causal to change (thus eliminating the concept of EOC), and agents would go straight to fit test without interactions (a wholly unsatisfactory description).

In short, it seems that the reductive (and less integrated) forms of theory are more easily changed and therefore may be seen as more easily manipulated or evolved by theorists. That, in turn, suggests that the closer we get to a fully robust form of theory, the more difficult it will become to make further progress. The next few decades, therefore, may see the evolution of competing very-nearly robust theories. Those theories may then be tested (in real world and computer modeling venues). Then too, each version of theory may find its own specific niche (e.g., one model may be applied to organizations, another to individuals, and a third to schemas).

Additionally, the reductive study suggests a technique for identifying which concepts within a general body of theory might be more closely connected with a given focus (e.g., scholarly version of CAS). The RDA and causal versions, in contrast, are both highly integrated so that the researcher is encouraged (almost required) to utilize all of the concepts for any given analysis. In the causal model depicted in Figure 1, for example, a researcher focusing on interactions would be impelled to describe how those interactions are changed by changes in agents, change, and time. Additionally, the causal relationships would suggest that the researcher describe how changes in the interactions aspect altered the EOC and the fit test. In a sense, this creates a road map that might be of benefit to researchers and students alike.

Shifting our focus to the core, we should note that the core concepts of the RDA version of CAS are (atomistically) interactions, agentness, change, levels of difference, and time. The causal version of CAS may be represented as schemas, agents, interactions, time, fit test, change, EOC, and environment. The two models hold in common the concepts of change, interactions, and time. In the RDA version, the schemas, agents, and environment of the causal version might be explained as agentness seen at different levels. Both of these models suffer from understanding time as an atomistic concept. Where time enables change (for example), nothing enables time. This could seem to be a relatively innocuous concept; however, the concept of "flow" (Csikszentmihalyi, 1991) suggests that the idea of time, especially as a subjective representation of productivity, may be an important area for investigation. The RDA version leaves the idea of agents (and other forms of systems) loosely defined based on the idea that it is the observer who determines what the system "is." The causal version leaves the concept of Levels relatively tacit, seemingly accepting that there are three levels of systems (which may be broadly understood as schemas, agents, and environment). Similarly, there are differences within each causal concept (there are different forms of change, a variety of agents, and schemas include a variety of rules).

In contrast to what might be called the "dynamic" measure of robustness discussed previously in this chapter (where we quantified the level of robustness of a theory as it evolved between authors), we might apply here a more "static" measure of robustness. Static robustness might be applied to quantify the internal integrity of the structure of a body of theory and so provide a point of comparison between the two views of the core. Alternatively, it may be used to differentiate between core and belt concepts within a body of theory. A measure of robustness may be achieved by comparing the total number of aspects within the theory to the number of aspects that are both causal and emergent. On one end of that scale, a theory that simply lists its component concepts, without identifying how the concepts were related to one another would have a robustness of zero. On the other end of the scale, a fully robust theory (e.g., Newton's F=ma) might have three dimensions, each of which is both causal and emergent, and therefore would have a robustness of one (3 / 3 = 1). By "emergent," it is important to note that a given concept must be understood in relation to two or more other concepts, as in Newton's model. If changes in one concept were to be determined directly by only one other concept, that change would be seen as linear, and so adding little to the model. For example, if we were to say that changes in the environment cause changes in the agent that cause changes in the schema, we might as well say that changes in the environment cause changes in the schema. If, on the other hand, there is something about the agent that ameliorates, filters, or accentuates, the changes from the environment, we may then say that the changes in the environment and the effect of the agent result in changes to the schema.

In the previous reductive study, all lists have robustness of zero (e.g., 0 / 29 = 0). In the RDA CAS model, there are a total of five dimensions (agentness, levels, change, time, and interactions). However, of those five, only three are both emergent and causal (agentness, interactions, and levels). Therefore, we might understand this form of the theory as having a static robustness of 0.6 (3 / 5 = 0.6). In contrast, the causal version presented in this chapter contains eight concepts – only five of which may be seen as both causal and emergent providing a robustness of 0.625 (5 / 8 = 0.625). In short, the causal version may be seen as an improvement over the RDA version and this chapter serves as an example of theory-advancement towards a robust core.

Shifting to the relatively non-robust aspects, we see that time appears in the causal model to be atomistic. Schemas and environment are seen as linear/determinant. In the causal model, it seems that the more important area for investigation are the concepts of time, environment, and schema. Understanding how those concepts may be understood as emerging from two or more other concepts within the core should indicate how the model might be rearranged to make sense from a robust perspective. For example, the multiple levels of this model (including schema, agents, and environment) may each be seen, in some sense, as a CAS. That may indicate the opportunity to create a model where each level is represented by that same (simpler) model. Such repetition of simpler models might, in turn, allow the elimination of some redundancies from the model. Indeed, until such an investigation is undertaken, those linear components of an otherwise robust model might be seen as existing somewhere between the belt and the core in an intermediate, or connecting zone.

Finally, based on Dubin's list (where increasing relatedness suggests higher efficacy of theory) and Weick's inference (that propositions should be effectively ordered, or interrelated), it may be suggested that increasing robustness suggests a higher level of epistemological validity of a theory. In general, however, it is important that the causal core may be seen as being derived from a different epistemological validity than the loosely related list of concepts that comprises the belt. Where the belt may find validation from any one of a wide range of research methodologies and points of view, the core finds validation only in the relationship between its own concepts. This is a significant epistemological shift that suggests a rich opportunity for additional study.

Will CAS and/or ICAS Theory Survive?

In this chapter, 20 concise versions of CAS theory were found in the discipline of organizational theory. The conceptual components were identified for each theory and subjected to two forms of analysis. The first, a reductive study, was beneficial in the identification of concepts representing the range of CAS theory, for linking specific concepts within the body to specific uses of the theory, and the creation of additional versions of CAS theory. Each additional definition was seen as adding to the outer belt of the theory rather than clarifying the core. The second study focused on the causal statements found within the body of CAS theory and identified the core of CAS theory by identifying relationships between those concepts. It is suggested that by focusing on causal relationships, we may be able to accelerate the evolution of CAS theory.

This chapter suggests that the flexibility of loosely connected forms of theory may support the spread of that theory through the social sciences. However, the very flexibility that allows CAS theory to grow may also obscure the core. The lack of core, in turn, may limit the effectiveness of that theory in application. Another significant contribution of this chapter is the creation of specific measures of robustness as tools for examining theory. These include measures of dynamic robustness (as an indicator of the evolution and stability of a theory as it passes between authors), and static robustness (a numerical indicator of how well co-defined a theory may be). The more static robustness a theory has, the more it may be considered to be part of the core.

Will CAS theory survive? Or, will it join the 90% of social theory that rises rapidly only to disappear just as quickly (Oberschall, 2000)? This chapter represents a significant step toward a new understanding of theory (in general) and CAS theory (in particular). If CAS theory is to retain its validity and even gain credibility in the face of the next wave of theory (that will, undoubtedly, arrive), it seems that it must develop a robust core. In an important sense, a robust theory might be seen as possessing epistemological justification, not from external testing, but internally, as the understanding of each aspect of the core is tested against the other aspects of the model. Conversations on the structure and construction of theory are likely to continue, and even increase, as our understanding of theory-creation increases. Measures of theory-robustness would seem to provide useful tools for advancing that conversation.

Looking to achieve a more optimal future of CAS theory, investigations should first clarify the causal relationships suggested in this chapter. With a fully robust version of CAS, the next step should be to test that model in the field and through computer modeling to clarify (or deny) relationships suggested by the co-defined aspects. Additionally, the "inter-testability" of the core aspects hints that such a model might be disprovable in the Popperian sense. For example, if the model pictured in Figure 1 were to experience a change in interactions that did not result in a change in the fit test, the model would be disproved. This would, of course, open the door to improving the model (Popper, 2002). Then too, if everything observable may be explained in terms of the robust aspects, then each application in the field becomes a test of the theory, and we have another opportunity to accelerate the evolution of CAS theory through practice.

This chapter has focused on CAS theory, but what about its close cousin ICAS? While this book may, or may not, contain all concepts related to ICAS theory, it certainly provides a cross-section of that theory. As such, the reader may apply the insights and techniques presented in this chapter as he or she reads other chapters. That way, the reader may identify the full breadth of concepts for ICAS theory. Similarly, within each chapter, the reader may find an emphasis on those concepts specifically related to that particular area of study and so suggest a "school of thought" within ICAS. Finally, the reader may range between the chapters seeking causal relationships between concepts, and so develop a robust model of ICAS theory. Each of these opportunities suggests how the reader might develop an alternative point of view that may be useful for further study and developing new insights.

In conclusion, we have presented three major insights that may support theory development and the progress of ICAS theory. First, a robust form of theory provides the best description of a solid core of a theory and so avoids the growing belt of loose concepts that obscures it. Second, it is possible and desirable to measure a theory's level of robustness and by so doing, to measure the progress of that theory. A corollary here is that measuring the progress of a theory opens the door to advancing that theory in a more rapid and purposeful way. Finally (although less deeply explored), robust theories may provide a path to more effective analysis and application. As the data for developing the core came from the belt, it should be noted that no core is possible without a belt. This suggests that both belt and core, with their separate epistemological justifications, are necessary to the advancement of theory.

Shifting to an evolutionary perspective, CAS might be seen as a recently evolved (and rapidly evolving) "species" of theory--derived from its fecund progenitors in systems theory and complexity theory. As a relatively recent species, it is well adapted to fit its niche as an insight-generator for theorists. Theorists, theory, and this book (as a representative of the conversation) may then be understood as three species--all engaged in a co-evolutionary process. This co-evolutionary process, in turn, suggests the opportunity to improve ourselves by accelerating the evolution of CAS. In the sense of an evolutionary landscape, this book might be seen as a path leading CAS off of the plains (inhabited by herds of "big-belt" theories) and up the slope of Mt. Kilimanjaro.

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