Model Archetypes for CAS, CAES

Abstract

9.1 Models of Complex Systems and Model Archetypes

In Chapter 5 we provided a brief introduction to the nature of a complex, adaptive, and evolvable system (CAES) and its precursor lacking evolvability the complex, adaptive system (CAS). This was necessary in order to proceed with the use of the methods of Chapter 5 in several complex system examples in Chapter 6. And again, useful in the more elaborate example of those methods working on the example of the human social system (HSS) economy in Chapter 8. We now turn, in this Part 3, to a fuller explanation of the CAS/CAES models and their sub-models because, in Part 4 we turn our attention to the design of CAESs.

In this chapter we will explain the different model archetypes of subsystems of a CAS/CAES that are needed to produce a viable, long-enduring system. But in order to grasp the significance of these models, the reader needed to first be exposed to the whole theoretical construct of systemness and how the process of ontogenesis led inexorably to complex adaptive systems and then to complex adaptive and evolvable systems (CAS/CAES). Chapter 8 was an anomaly in that we sought to show how the understanding of that construct and the analytical method derived from it would lead to sensible knowledge. We also wanted to demonstrate this for a very complex system to convince the reader that the concepts and methods work.

Now we have to revisit the inclusion of all of those references to this chapter by examining the larger picture of how they all relate in general to the concepts of CAS/CAES. The method to be used in this chapter is to bit-by-bit unpack the details of the archetype models as if we were doing a systems analysis (without formally doing the procedures of Chapter 5). We will first provide a summary view of the models and their relations. Then we will start unpacking the overall concept of a CAS/CAES archetype and how the other archetypes (agents, economies, and governance) interrelate to form the whole. Finally, we go into the details of each of these three models in the next three chapters.

All CAS/CAES share a fundamental organization of subsystems and functions that allow them to persist over the long haul and continue to serve a useful purpose in their environments even when those environments, themselves, evolve over time. We will start with the general model of a CAS/CAES and then examine the major component subsystems that make these systems possible. Then, in subsequent sections, we will provide more details of the subsystem archetype models so that you, the reader, will be able use these to analyze and, if tasked with creating a new system, design real systems.

The word, ‘model’ has many meanings but in the context of this book we restrict our concerns for the nature of models to the scientific and mathematical modeling of real phenomena and systems. In short a model can be any abstract representation of a real phenomenon or system (hereafter we will use the single word, system, to mean both general physical phenomena and systems as we have been describing throughout the book) that captures the “essence” of that reality but does not attempt to represent all of the details of the system that are not cogent to the system’s behavior in terms of understanding it. We are interested in the system’s behavior in terms of how it affects the rest of the world (or us), so minute details may not be relevant and can safely be left out. Leaving out unnecessary details while still accomplishing our goal of understanding is also pertinent to computational tractability[1]. The nature of the abstraction allows for various kinds of manipulations of the model parts such that the whole model behaves in a general way just like the real system.

The purpose of a model is to provide that abstract representation in a way that a human mind can comprehend all of the working parts without getting bogged down in superfluous details that do not affect the final results. For example, if our major interest is in predicting some future state of the system, any model that captures the main variables and transition functions may serve. But, at the same time, if our intent is to deeply understand how these transitions and behaviors are accomplished, then it might be necessary to include more details than are necessary for mere prediction. Science might be viewed as a process of discovering the details to the minutest level for just this purpose. On the other hand, when engineering a system we might be just as happy with major behavioral outcomes from more abstract models.

The “natural” sciences have considerable experience with dynamical systems models in which the main features of behavior are captured in a set of ordinary differential equations. When such equations are solvable then a future state of a system is a simple matter of solving the equations for a given set of initial conditions and specifying a time interval. As it turns out, the vast majority of interesting complex systems models cannot be handled in this way. It works very well for “simple” physical systems (like a few gravitationally coupled bodies) but does not work for intricately complex systems like human societies.

With the advent of the digital computer we have developed a whole new way of building dynamical models and simulating the ‘systems’ in order to determine what their states will be in some future time. We still need to specify starting conditions. But it is unnecessary to derive a set of formulas that compactly capture the dynamical behavior of the system. System dynamics modeling and computer simulation allow us to iterate over time rapidly (at the speed of digital computation) and arrive at an end state of even extremely complex systems with multiple kinds of internal feedback.

[1] For example, we do not need to include all of the details of quantum mechanics when building a model of a chemical reaction. They are de facto included in the overall behavior of the atoms, molecules, and their interactions.

1 ## 9.1.1 Representing Models

2 Equation 3.1 provides a basis for representing a model of any system. It uses the language of
3 graph theory, or more to the point, the language of flow networks as mentioned in Chapter 1.
4 However, it expands that basic language in order to capture the semantics of processes and
5 subsytemness. It is asserted, without a formal proof, that any system, no matter how complex,
6 can be represented by Eq. 3.1 which captures both structural and functional information down to
7 some level of detail. In other words, a model of any system (having the requisite systemness
8 properties) can be represented by a flow network where the nodes are work processes that
9 observe the laws of conservation (mass and energy) along with the 2nd law of thermodynamics.

10 ## 9.1.2 Systems Dynamics Models – Simulations

11 Many systems investigators have been concerned with system behaviors or dynamics.
12 Models built from principles of systems dynamics (SD, Forrester, 1979) are the basis of
13 simulations run on computers that can trace the behavior of systems over time and generate end
14 states of the system.

15 System models are often developed from ad hoc understanding of systems. Analysis is used
16 to decipher interactions between system components, but often boundary conditions are
17 determined by the modeler rather than emerging from a deep analysis (Meadows, 2008, p. 97).
18 Modelers are frequently faced with making somewhat arbitrary choices regarding boundaries
19 because how a system interacts with its environment is extremely complex and absent a
20 principled method for analysis, they are forced to select the boundaries. Most interesting systems
21 are, recall, fuzzy and therefore obscure as to where a boundary exists. As we showed in chapters
22 5 and 6, dealing with fuzzy boundaries is not trivial and is definitely necessary in order to get a
23 firm grasp on the nature of very complex systems. In SD projects the problem is somewhat
24 avoided by making those arbitrary decisions about where a boundary exists and what is inside a
25 system and what is external.

26 SD models/simulations have been hugely helpful, even given the problems with boundary
27 selections, in showing how complex systems behave in non-linear ways even when the inputs
28 ramp up (or down) in apparently linear schedules. These models are highly successful in
29 capturing the feedbacks (negative and positive) that give rise to non-linearities in behavioral
30 parameters.

31 SD has had several implementations since the first SD language, DYNAMO, was developed
32 at MIT. The language(s) however do not provide representations for all of the terms derived in
33 Chapter 2, nor does the language provide a process semantics or a hierarchical structural
34 organization[2].

[2] Actually, there are some newer SD modelling environments that are moving in that direction. Some support modular or object-oriented models that can be combined or re-used. Some also support a hierarchy of models, i.e.,

9.1.3 A General Systems Model

In Chapter 3 we presented a specific mathematical description (or definition) of a general system in Equation 3.1 (and subsequent explanatory equations). In Chapter 7 we demonstrated how the analysis of a real system, based on Eq. 3.1 (Chapter 3), could be captured in a knowledgebase for further analysis but ultimately for constructing models. In the next chapter we will show how this is to be done. We will demonstrate how the knowledgebase contents can be used to generate models at various levels of abstraction. And by models, here, we mean models suitable for computer simulation. The model can be as detailed as the analysis produced. If the intent was for deep scientific understanding then the model might similarly be extremely detailed and require extensive computing resources to simulate. On the other hand, because of the way Eq. 3.1 is structured (recursively) it is possible to generate system models that are more abstract and, hence, useful for engineering or management purposes.

A user of the modeling interface with the system knowledgebase need only indicate what level of abstraction is needed for a simulation. Since the transfer functions for any given module subsystem has been captured, it should be possible for the software to construct a simulation using those functions indicated in the level of the simulation requested.

9.2 What are Model Archetypes?

A model archetype is a generic version of a specific kind of system model. Some authors have used the term 'meta-model' in a synonymous sense. In general, we will stick to the term 'archetype' since 'meta' can take on several senses that might not always work.

The models to be presented in this chapter are archetypes of three complexly interrelated work processes that constitute the 'workings' of a functional and stable complex system that is able to maintain itself in a fluctuating and possibly non-stationary environment. Each of the three plays a necessary role in the whole and are highly integrated with one another to achieve completeness.

The concept of an archetype comes from observations of a large number of complex systems across the spectrum of levels of organization, but particularly from the first levels of living systems (bacteria and archaea) through the highest levels of human societies. We have devised the categories of complex adaptive (CAS) and complex, adaptive and evolvable (CAES) systems to hold all of the living systems representative categories (c.f. Miller, 1978, for the array of these systems). All individual organisms (i.e. single cells and single multicellular organisms) are complex and adaptive. Adaptivity to changing environmental conditions is a basic attribute of

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models within larger time domain models. But these have been developed in what looks like an ad hoc, needs-based manner rather than from a theoretical basis as provided in Part 1 of this book. See the Wikipedia article: https://en.wikipedia.org/wiki/Comparison_of_system_dynamics_software for an overview of several SD implementations.

living systems. Evolvability is also seen in living systems from cells (bacteria able to allow mutations in critical functional genes under certain environmental stresses) to more complex individuals possessing brains able to learn. The details of what these designations mean will be discussed below.

These archetypes are effective guides to analysis and design since they tell us what subsystems and components are to be found in all instances of CAS/CAES[3]. In this chapter we develop an archetype model of a CAS/CAES, identifying all of the subsystems that must be found in any instance of such a system. Whether we are decomposing an existing system or determining what is needed for a to-be-designed system, these archetypes act as guides to analysis and design. In the scientific reductionist decomposition of a particular system, such guides tell the scientist what structures/functions to look for at the next level down. In engineering, they tell the engineer what structures/functions need to be incorporated into the designs.

As used here a model archetype is a pre-defined model of the general architecture of a particular kind of subsystem that is common to all CAS/CAES systems[4]. It is so general that it can be used in any number of different contexts or specific CAS/CAES models. The governance model archetype, for example and introduced below, is one such model that describes a general governance process for any CAS or CAES. In this chapter we introduce four such archetype models. We expand the description of the CAS and CAES and then describe the three major subsystems that are vital to all CAS/CAES, agents, economies (as previously examined in Chapter 8), and governance.

9.2.1 The General CAS/CAES Architecture

The concept of complex adaptive and a complex adaptive and evolvable systems (CAS/CAES) is an amalgamation and integration of concepts that have come from many different writers (see below, Section 9.4). At least on Earth, the concept starts to take shape with the first living cells emerging perhaps 3.8 billion years ago, just shortly after the condensation of the planet out of the solar debris (Smith & Morowitz, 2016). All living systems taken as individuals, which includes single cellular organism (both prokaryotes and eukaryotes), colonies of cells, multicellular organisms (comprised of eukaryotic cells, and in more complex forms, tissues and organs), and groups of multicellular organisms (populations), constitute the CASs, all able to adapt to some extent to variations in environmental conditions. Starting with species as a Darwinian evolutionary system, but including animals with modifiable cortices (i.e., capable of learning), especially human individuals, and then moving into groups of humans or societies

[3] We have found some aspects of these archetype models effective in non-adaptive systems as well but will refrain from trying to make the case for it in this book.

[4] The three model archetypes of subsystems within a CAS/CAES are necessary, but may not be sufficient (Mobus, 2017).

with cultures we recognize systems that are not only adaptable but are also evolvable. That is, they can undergo modifications that permanently change their structures and behaviors to meet the demands of a longer-term change in their environment. Alternatively, evolution may involve, as it often does in Darwinian biological evolution, fortuitous alterations that when tested by the environment, changed or not, are found to imbue increased fitness on those individuals that possess the alteration[5]. They out-compete and out-reproduce their conspecifics.

Another kind of evolvability enters the picture with human cultures, organizations, and institutions. We have termed this "intentional modification" as opposed to "chance modification" that is the hallmark of Darwinian evolution. Intentional means that some human brain recognized that a change in a subsystem of the culture (i.e. artifacts) or organization or institution would either improve on the existing structure/function or make them preadapted to perceived future conditions in the environment. A marketing manager sees a new market opportunity if the company would slightly alter the characteristics of an existing product that they manufacture with enhanced features. A young human being chooses a major in college and pursues changing their own minds with new and, to them, useful concepts and skills.

CAS/CAESs constitute a new phase of organization of systems. Life was such a new phase of matter when it emerged from prebiotic chemistry on the ancient Earth[6]. The CAES is yet a further phase transition to higher organization and potential for yet newer and more complex emergences (Smith & Morowitz, 2016; Morowitz, 2002).

9.2.1.1 Our Model of CAS/CAES – A Synthesis

The CAS/CAES scheme presented here is a synthesis that incorporates concepts arrived at by many researches in systems science but especially in the biological sciences. It primarily maps onto the general schema of living and supra-living (e.g. human societies) systems developed by James Miller (1978) as outlined in Chapter 2. It incorporates the concepts developed by Stafford Beer (1959, 1966, and 1972) and expanded by Eric Schwarz (1997, 1992) involving the *governance and management* of complex adaptive and evolvable systems based on principles from *cybernetics and hierarchical organization* (see Section 9.2.2 below) It incorporates concepts developed by Howard Odum (1983, 2007) regarding the trophic exchanges that occur in complex systems, the *flows of materials, energies, and information*. In other words, their *economies*. It also involves concepts of the modeling relation and anticipatory systems of Robert Rosen (2002) in the treatment of *decision agents*. These are all conditioned by concepts

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[5] The alterations referred to here are genetic mutations that lead to phenotypic structural and/or behavioral modifications. This mode of evolution depends on a large population of individuals in which the various blind experimental trials (mutations) can be tried out without jeopardizing the entire species.

[6] While there are still some debates regarding source of life, whether seeded on Earth from somewhere else in the Milky Way galaxy (a theory called panspermia) or actually started on Earth, we will assume the latter case as being the most likely given what is understood today about prebiotic chemistry and metabolism. C.f. Smith and Morowitz (2016).

1 developed by Harold Morowitz (1968, 1992, and 2002) regarding the organizing influence of
2 energy flows through systems (and Smith & Morowitz, 2016, already cited) and providing a
3 grounding for the *ontogenic cycle* from Chapter 2. These authors were central shapers of a
4 universal picture of complex adaptive and evolvable systems as we find them on the present
5 Earth, including the cultural addenda for the human social system. What we offer here is a new
6 way to categorize these systems and a synthesis, an approach to unifying the many various
7 views, if not the terminologies employed.

8 Figure 9.1 provides an overall scheme for the CAS/CAES archetype model. It shows that the
9 model is comprised of three generic archetype models, the 'Agency', 'Governance', and
10 'Economic[7]' system archetypes. Below we will describe each of these and how the whole
11 CAS/CAES archetype is composed. The agency (or agent) model is shown in the center and
12 overlapping both the governance and economic models since agents are the key decision-makers
13 in both subsystems (as represented in Figure 9.2 below).

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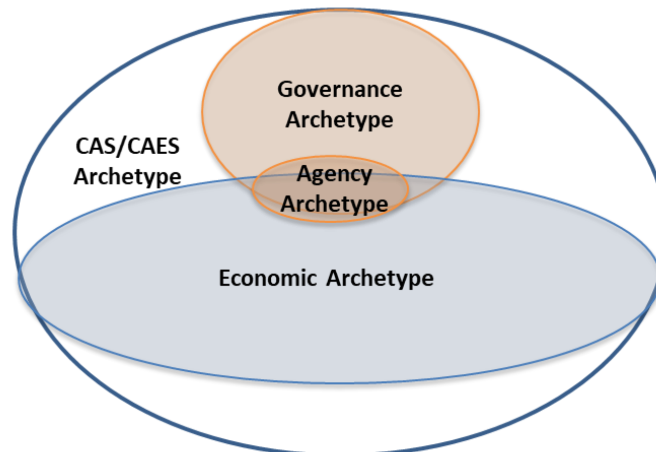

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16 **Fig. 9.1**. An architectural overview of a CAS/CAES. The model archetypes for 'Agency', 'Governance', and
17 'Economic' superstructures can be shown to be isomorphic across all such systems. These archetypes are fuzzy and
18 yet can be delineated in accordance with Chapter 5 and demonstrated in Chapter 8. The relative sizes of the ovals is
19 merely meant to be suggestive of the amount of work (for example the amount of energy devoted) that the process
20 involves. Note too that the actual distribution of these processes in a concrete CAS/CAES is not represented here.

21 The claim being made here is that all known exemplar CAS/CAESs can be explained by
22 reference to these subsystem archetype models, though for specific application domains there
23 may be some number of auxiliary subsystems that are part of the whole particular system. For
24 example, in Chapter 6 we identified a few subsystems in the HSS that were specific to the human

[7] We were tempted to call this the 'Metabolism' system archetype since cell metabolism is an instance of the economy of a cell and as we show physiology, the HSS economy, and the chemistry, energy flows of the ecosystem are just larger scale extensions of basic metabolism. But we decided that the term 'Economic' was the more general and would cover all of the subsystems of interest.

society system, such as the Science and Technology subsystem. Any such particular subsystems will interface and be integrated with the specific version of the archetypes discussed here. They can be treated as specialized processing modules but are still based on the three archetypes presented here.

Below we examine the roles of each of the three archetypes and explicate the most general features of each. The central claim we make is that in order for any complex system to be long-term stable in a changing environment it must have this architecture with the details worked out pertinent to the environment in which it is embedded and the interchanges it has with those conditions. When faced with the task of understanding complex systems, the *a priori* knowledge that this is the relevant architecture we should look for will make the analysis (and subsequently the design if that is the objective) far more efficient compared with casting about blindly trying to figure out what is happening and why (Chapter 12 will be devoted to a new approach to systems design and engineering based on these archetypes and including an ontogenic approach where the auto-organization process is replaced by an “intentional-organization).

9.2.1.2 A Note on Stafford Beer’s Viable System Model (VSM) and Its Relation to CAS/CAES Model

Readers who may be familiar with Stafford Beer’s VSM model (Beer, 1972) will begin to see some resemblances between that model and the CAS/CAES model. That is largely due to the fact that VSM played a huge role in this author’s research for a Master’s thesis in early 1980s. That thesis, titled “A Cybernetic Model for Use in the Development of Formal Information Systems”, describes the model of an organization and its needed management and control subsystems that strongly resemble Beer’s VSM, including many of the decision functions requisite to sustain viability.

But there are also a number of differences that, in this author’s mind, puts the CAS/CAES model in a whole new level of detail and meeting a new set of necessary and sufficient conditions. At one point this author considered naming the CAS/CAES model VSM 2.0 because of some of the ideas in its origins and some of the strong similarities. The advantage might have been that for people already familiar with VSM, the learning curve might be foreshortened. But after a side-by-side comparison of the two we realized that this would cause more confusion than clarity.

For example, Beer’s choice of labels for various management decision functions (System 2, System 3…, System 5) did not impart a sense of what the system actually was. In the CAS/CAES model, as one example, the Strategic Management function is labeled just that.

Other differences in the governance architecture revolve around the distinction between tactical and logistical coordination managements (see below and Chapter 11) and how the decision ‘types’ and ‘categories’ are different and thus require different kinds of agents and agencies.

What the CAS/CAES model incorporates, in addition, are important aspects of energy flow. When Beer was developing his ideas, energy (e.g. fossil fuels) was seemingly abundant and cheap. It hardly ever factored into decisions. Now, both from a cost standpoint and from an availability standpoint, not to mention the carbon releases from burning the fuels, energy acquisition and internal optimal distribution are playing significant parts in coordination and strategic management decisions. This isn't just a new kind of factor that can be treated as other already existing ones, but is a fundamental aspect of viability and is governed by the biophysical realities we saw in Chapter 8.

Finally, one of the biggest differences has to do with the terminology dealing with "adaptation". Beer seems to have conflated the idea of an adaptive system with that of an evolvable system (a concept not yet understood at that time) as did many thinkers. It is extremely important to recognize the difference because each involves very different kinds of management mechanisms and work processes (see Sections 9.3.2 and 9.3.3 below).

Thus, while the VSM played a hugely influential role in this author's thinking, over the years as that thinking evolved and more elements from other threads were integrated into the basic model of complex, adaptive, and evolvable systems, it seemed legitimate to offer a new concept with a new name. See Section 9.4.1 below for more comparisons between VSM and the sub-models of CAS/CAES.

9.2.2 Archetype Models Overview

Here we present a brief overview of each of the archetype models. In the next three chapters we will provide descriptions of each of the sub-models in more detail.

9.2.2.1 Agents and Agency

Agents are specialized decision-making information processes the outputs of which generate control activities. Agents have "agency" in this respect. Any decision-making mechanism that affects the state of the system and/or its environment is an agent. To be a successful agent its agency must cover the possible actions that would be needed to adjust itself and/or its environment so as to maintain a suitable relation (Ashby, 1956, 1958). The agent archetype includes simple mechanical devices such as the old bi-metal coil thermostat as well as more complex devices such as the auto-pilot on jetliners and all instances of homeostatic processes in living systems.

The effectiveness of an agent depends on it making veridical decisions. That is, it decides to take the action that will satisfactorily maintain that suitable relation (c.f. Simon, 1996, page 27). Faulty decisions will make the agent and its embedding system subject to selection processes (as described in Chapter 2). The decision selection process is based on an internal model of the relations between the incoming signals and the appropriate output control signal(s).

Another aspect of agency is the degree of autonomy or flexibility the agent has in making the decision. The degrees of freedom an agent possesses in arriving at a suitable decision will, in general, match the complexity of the decision environment. Agents operating in highly complex environments cannot have access to all of the state information that they would need to arrive at a certain decision. The decision model the agent uses to compute a solution will tend to be more probabilistically-based and use auxiliary heuristics to make a choice. In other words, the more autonomy the agent needs, the more it will need to rely on learning to modify or adapt its model in order to continue making reasonably good decisions.

Chapter 10 will delve into agents and agency in greater depth, especially as pertains to humans as decision makers where biological and psychological factors complicate the decision process.

9.2.2.2 Economy

CAS/CAESs may be viewed as a whole coordinated group of work processes that produce the products and services needed internally to maintain the system (autopoiesis). The system, as a whole, needs to have processes for obtaining resources and expelling wastes. It may also produce exported products or provides services that are of value to other entities in its environment and part of the supra-system in which the CAS/CAES is a subsystem.

An example of an early evolved economy in nature was the metabolism of early cells (Morowitz, 1992). But we may also consider the various cycles of materials in the whole Earth system as a kind of economy (Volk, 2016). Below we will briefly look at some aspects of the metabolism in cells as representative of a living economy. Multicellular organisms expand on this notion of an economy of the body through the multiple interactions between cells in tissues. We will generically refer to this as “physiology,” but we should point out that it is really a coordinated system of extra-cellular metabolism. Ecosystems are yet further expansions of this basic notion in the trophic food webs and waste recycling processes. Finally, in human societies we come to the economy of society. This, too, is an expansion of the basic cellular-body metabolism. That is, the activities of the human social economy (recall Chapter 8) are all part of the most complex CAES we know of and all intended to support human life (even when some humans turn destructive toward other humans it is with the intent of preserving one society over another).

Below we will provide the archetype model of a generic economy. The model can be seen to be applicable to metabolism, physiology, trophic flows, and the human economy[8].

[8] All but the last listed economy work properly. As we saw in Chapter 8, the HSS economy has some serious design flaws; it does not fully conform with the archetype model.

9.2.2.3 Governance

The on-going maintenance of a CAS/CAES requires management and regulation of internal economic processes but also of agents.

The hierarchical cybernetic governance system (HCGS) model is the basic architecture of how a CAS/CAES in managed and regulated to achieve stability in the face of an uncertain and changing environment (Mobus, 2015, 2017; Mobus & Kalton, 2015, Chapter 9). The hierarchy aspect refers to the fact that the governance subsystem is organized in layers (and possibly sub-layers), of which there are two (in CASs) or three (in CAESs). The bottom layer is devoted to real-time operational controls and between-processes cooperation (feedforward) at the level of the economic work processes mentioned above. The second layer contains agents that are responsible for coordination of the lower layer when cooperation between processes is not reliable or even feasible, in some instances. There are actually two kinds of coordination managed in this layer. Not only must the lower layer work processes be coordinated amongst themselves, but the whole system has to achieve coordination with external entities, resources, and sinks. The internal coordination is termed "logistic" and the external coordination is termed "tactical." Examples will be provided below.

The top layer, when present, applies to the most complex and evolvable systems that can learn from experience and modify themselves or their behaviors accordingly – CAESs. This is termed the "strategic" layer and it is involved in, among other forms of governance, assessing the trajectory of changes in the external environment and planning what internal changes need to be made to continue to succeed (exist) in that future situation.

Each of these layers operates in different time domains. The operational layer, as mentioned, operates in real-time, meaning that it responds to the changing conditions in the same time frame in which those changes take place. The coordination layer operates in, possibly several longer time scale, working on changes in the time-averaged changes in overall operations or accounting for time lags in changes in upstream processes. The strategic layer operates over very long time scales relative to the operations and coordination layers.

These three archetype models interoperate to produce a viable system, stable and survivable, over long periods of time, effectively what we would think of as the lifetime of the type of system of interest. After describing and explicating the nature of CAS/CAESs, and then comparing the basic CAS/CAES framework to several former models, we will take each of the three sub-models in turn for description and explanation in detail.

9.3 Complex Adaptive and Evolvable Systems – The Archetype Model

The most complex systems that we know of are living and supra-living entities. Cells and individual people are living systems. Species, ecosystems, and societies are supra-living systems.

1 So is the whole planet geosystem, which we call the "Ecos[9]." Any identifiable system that
2 includes living components, like a society or a corporation, is an example of this category. Table
3 9.1 provides some exemplars of CAS and CAES along with notes on the archetype models to be
4 found in each. The first column names exemplar systems ranging from the protocell thought to
5 exist at the emergence of life through examples of living and supra-living systems all the way up
6 to the Ecos. In the latter case we are speculating about what an Earth system with humans and
7 ecosystems living in balance might be like. Humans and human societies are situated between
8 the extremes of economies and governance of single cells and of ecosystems. In this hypothetical
9 world of 'harmony' human societies might take on the role of the *brain* of the Earth (c.f.
10 Grinspoon, 2016). One way to state this as a reasonable expectation is that, by the CAS/CAES
11 archetype assertion, unless the Earth does achieve a kind of 'consciousness' it cannot be long-
12 term viable. Perhaps it would be wise to recognize what it would take to manage the planet
13 wisely.

14 **Table 9.1.** Examples of CAS/CAES and their instantiations of agents, governance, and economy models.

Exemplar	Agent Model	Governance Model	Economy Model
Protocell – emergence of life from geochemistry	Operational primarily with auto-organization and selection	Coupled organic-mineral reactions networks and auto-catalytic cycles	Energy supplied by various reducing reactions in an anoxic environment
Single cell	Operational, logistical, and tactical phenomena embodied primarily in enzymatic control of production of structural and enzymatic proteins	DNA knowledgebase, RNA mediated transcription and translation into proteins and various active messaging and transfer RNAs	Metabolism and cellular physiology Mitochondria energy supply, ribosomes as factories, consumption to grow and reproduce
Multicellular Organism	Tissues and organs processing chemical information to decide on the responses, release of hormones, the brains of animals with specialized modules	Brains, endocrine, and immune system in animals	Physiology in which multiple organs participate in maintaining the body, blood system for main transport

[9] James Lovelock and Lynn Margulis (1974) have called the planetary ecology 'Gaia', the name of the Greek goddess of Earth. The Gaia hypothesis stipulates that the interactions between the biosphere and all other 'spheres' constitute a self-regulating entity that maintains balanced flows (over geological time scales) of the major substances in a kind of planetary physiology (Volk, 1998). The use of a goddess's name to invoke the Earth system has been somewhat controversial in the past, but has become more acceptable in recent times. This author chose to use the term 'Ecos' (from the root of ecology, meaning 'home') to be somewhat less invocative of a mysterious process. But, as demonstrated by Tyler Volk's 1998 book, Gaia's Body, the mysteriousness is much less an issue.

Human being	Prefrontal cortex orchestrating activities in conscious mind, localized special modules for processing sensory input, perceptual processing, and conceptual manipulations	Same as for animals but with the addition of strategic level processing, thinking about the past, the present, and the future, imagination and affordance recognition, language	Same as for animals but with the addition of creating an external physiology (tools, shelters, etc.) to allow incursions into non-physiological environments
Organization (e.g. family, tribe, enterprise)	Individual human beings, motivated by biological mandate but able to hold beliefs	Hierarchy of authority, power relations	Obtain resources, increase order, consume, expel wastes
Society	Officials, representatives, bureaucrats, and other human beings	Hierarchies of authority, various models of authoritarianism and seat of power, still very much experimental	Evolving, not yet stable, possibly self-destructive
Ecosystems	Primarily operations level	Mutual constraints, distributed competition	Trophic flows, producers, consumers, recyclers
Ecos	Fully sapient beings	Human society as strategic and highest levels of tactical/logistical combined with cooperation with global ecosystems	Energy (power) applied judiciously only necessary consumption Recycling

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2 As discussed in the Introduction, complex adaptive systems (CAS) are able to respond to
3 changes in their nominal environmental conditions and operate to counteract any ill effects of
4 those changes, thereby extending their viability. The main subsystem of the CAS that
5 accomplishes this is the homeostatic process. As further discussed, a CAS that is also evolvable
6 (CAES) can make internal permanent restructuring in response to long-term non-stationary
7 alterations in the environment[10], thereby keeping the basic system viable in the long-run. Below,

[10] Such restructuring may be due to either accidental (trial and error) or serendipitous discovery, as in Darwinian evolution, with subsequent testing for efficacy by the environment (selection) or intentional as in the case of a human social organization that invents new mechanisms and new behaviors. In the latter case, the environment will still be the final arbiter of what is efficacious or not.

1 in Section 9.4.1, we will expand on what this means. Evolution can be essentially happenstance
2 (Darwinian evolution due to mutations in a large population of individual representatives
3 followed by selection of favorable phenotypes), a blind search through design space. Or it can be
4 intentional/directed as when a corporate CEO decides to open a new line of product or an
5 engineer decides to alter a component of an artifact to get expanded or different performance.
6 This is evolvability as we have come to understand it. The internal restructuring that takes place
7 in response to changes in the environment will also be tested (selected) but, in our example of
8 corporation, by market forces rather than climate or predation. In Section 9.3.3.3 we will expand
9 on this

10 Complex adaptive systems as individual entities evolved on Earth through the same process
11 of ontogenesis described in Chapter 2. First the complex chemistry of carbon, hydrogen,
12 nitrogen, oxygen, phosphorous, and sulfur (CHNOPS[11]) and other trace elements and minerals
13 produced the first living systems, bacteria and archaea. Then, Darwinian evolution took over
14 producing myriad species of those first living cells and later multicellular lifeforms. Darwinian
15 evolution introduced the species as a system (along with populations as subsystems and genus as
16 supra-systems). These latter systems, aggregates of individuals, became evolvable thanks to the
17 fact that so many different (and thanks to mutation) diverse individuals were produced for
18 environmental selection (testing).

19 Evolvability describes both a system's capacity to change internal subsystems to attain
20 better adaptation and a capacity to regulate the *change in internal subsystem changes* on a needs
21 basis[12]. In other words, some evolvable systems have the capacity to either allow themselves to
22 undergo mutation of subsystems (some bacteria are able to 'permit' mutations when food
23 resources are non-ideal), or, as in the case of a human organization, cause an intentional
24 modification expected to provide a preadaptation to an environmental change (as when starting a
25 new product line in anticipation of market expansion). In the biological (Darwinian) case, this is
26 accomplished through massive reproduction with variation in the genotype due to chance
27 mutation. In the human-made artifact or institution case (Hughes, 2004) it is due to anticipatory
28 modification (strategic decision-making).

29 Natural ecosystems are a bit difficult to characterize easily. They can evolve over time in
30 terms of their component species until they reach (given enough time and stability of the climate)
31 their climax state. This is the state in which the balance of species interactions leads to a quasi-
32 stable dynamic. Once in such a state, an ecosystem resembles a CAS more than a CAES. A rain

[11] See the Wikipedia article: https://en.wikipedia.org/wiki/Gaia_hypothesis for background. Accessed 5/16/2018.

[12] See the Wikipedia article: https://en.wikipedia.org/wiki/Evolvability for background and explanation. Accessed 5/16/2018.

1 forest is an example of a climax system[13]. Their evolution is in concert with biological evolution
2 that is it relies on opportunity and chance, without intentional mechanics.

3 Intentional evolvability requires foresight and planning and apparently applies only to
4 human constructs[14]. The whole capacity to design future configurations of material, energies,
5 and messages – i.e. invention of machines, procedures, and policies – seems to be a uniquely
6 human capacity, though it also seems to have roots in human forbearer species (De Wall, 2016).
7 Nothing is new under the sun, it seems.

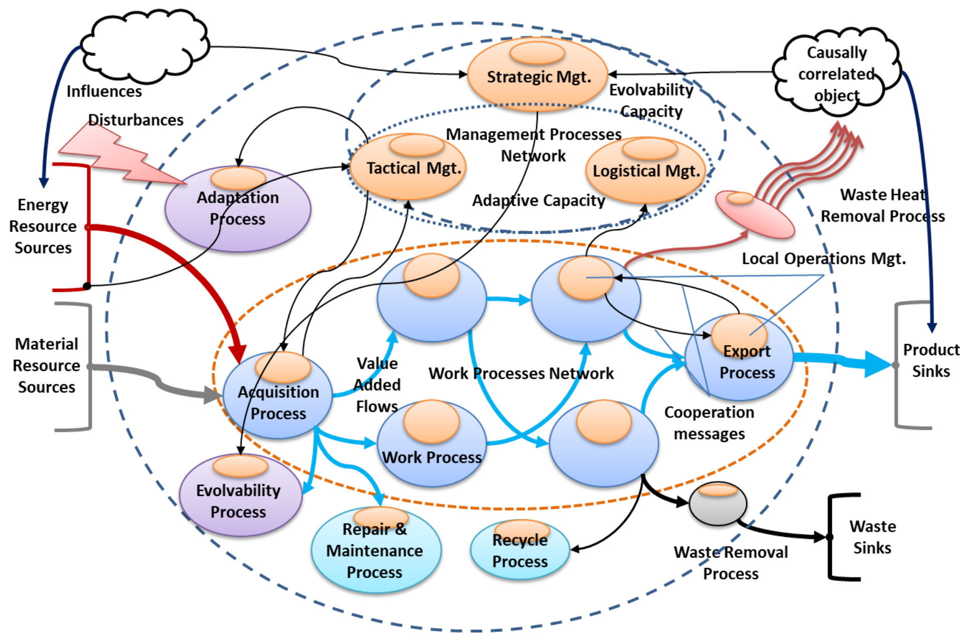
8 Figure 9.2 is a general schema for a CAES in our systemese iconic language. It applies to all
9 such systems we find on planet Earth. A CAS is very similar except that it lacks a strategic
10 management capability and an evolvability process capability. These differences will be covered
11 below. The figure shows a management process network, which constitutes a governance
12 structure for the whole system. It also depicts the basic economy of the system, or the work
13 process network where material and energy inputs are transformed into useful (low entropy)
14 goods and services. Each of the process ovals in these two major networks have internal agents
15 (smaller orange ovals) that are concerned with managing the processes. Further discussion of the
16 difference between governance and economic process agents will be presented below in Section
17 9.4.1.2 Governance Architecture.

18 Also shown in the figure are a number of auxiliary processes that are hard to qualify as
19 strictly economic or governance. In extremely complex systems these are themselves often
20 complex enough to be treated as CAESs having their own internal economic subsystems, etc.
21 These include processes that handle adaptation, that is they respond to disturbances to restore
22 balance in the system; repair and maintenance of existing work processes, often working in
23 concert with the adaptation processes; evolvability processes that are able to construct new work
24 processes under directions from the strategic layer of the governance system; and recycling
25 processes that are able to take waste material outputs and rework them into usable components.

26

[13] See the Wikipedia article: https://en.wikipedia.org/wiki/Climax_community for background. Accessed 5/16/2018.

[14] This is not *entirely* the case, though it is obviously the case. Brains of non-human animals possessing cortical structures, e.g. the neocortex in great apes, are also considered CAESs in that they have the capacity to process concepts that deal with the future possible states of the world. Or, in other words, they are anticipatory up to a point.



1

2 **Fig. 9.2.** The most complex kinds of systems we know are not only adaptive but also evolvable. This figure
3 represents the several main component models (archetypes) for a CAES. Basically, a CAS is most of what is in this
4 archetype except for the 'Strategic Mgt' component in the 'Management Process Network' and the 'Evolvability
5 Process' (lower left sector). Shown are just a few of the flows of matter, energy, and messages into the system and
6 between components of the system. Not shown in this figure, but not to be left out of the analysis are all of the
7 interfaces.

8 In Chapter 10 we will explore the nature of the agents and their agency (the orange ovals
9 within each process oval, including the management ovals). Chapter 11 will consider how these
10 agents are distributed through both the governance processes themselves and the economic
11 processes which are being coordinated by the higher-level governance layers. Then in Chapter 12
12 we will go deeper into the economy sub-model. All of these, to-be-explored, are archetype
13 models, meaning that they are generic patterns applicable to all CAS/CAESs.

14 What this figure shows is how the three sub-models, agents/agency, governance, and
15 economy interrelate. The Work Processes Network constitutes the basic value-adding economy
16 with peripheral processes for repair and maintenance, recycling, and waste removal as necessary
17 attendants even though they don't directly contribute to product production. The Evolvability
18 and Adaptation processes, likewise, are separate from the main economy but are closely related.
19 They are considered work processes – those that transform material using high-potential energy
20 – to accomplish the work of modifying other work processes to handle changes.

21 The figure also shows the relation to the global governance of the economy and peripheral
22 processes. The organization of governance is a hierarchy of decision types based on necessary
23 roles. Operational decisions for managing each work process is local to that process.
24 Coordination-level decisions are embodied in two kinds, logistical decisions which work toward
25 coordinating and balancing the internal work processes to keep the value-adding production
26 flowing, and tactical decisions which are about how to best interact with entities in the

environment. Finally, for CAESs the highest level of decision-making is at the strategic level where information from both logistical and tactical management along with information about the general environment (not just the sources and sinks) are used to build a model of the CAES and potentially relevant aspects of its environment to be used to anticipate future states of the world that might have a significant impact on the system. With these anticipatory scenarios, the strategic agent makes decisions about how the system should reconfigure itself to take advantage of possible new resources or avoid possible new threats.

This model of governance is called the hierarchical cybernetic governance system (HCGS, Mobus, 2017, 2018). It shows how decision types are organized in this three-level structure and addresses the kinds of communications that are required between decision processes. This will be the subject of Chapter 11.

9.3.1 Complexity

Put in the context of ontogenesis we see a progression of systems that start out relatively simple or, perhaps, not terribly complex. Here complexity refers to the Simonian complexity measure characterized by the heterogeneity of component subsystems at each level of organization in the system, the number of interactions between components within and entities in the environment, and the depth of the organization tree (see Section 3.3.3.7.2. Simonian Complexity). Systems become more complex, historically, by accreting additional components (sometime freestanding systems in their own rights), as when some large prokaryotic cells acquired other smaller prokaryotic cells that had well-established citric acid cycles that would later evolve into mitochondria via symbiogenesis or endosymbiosis (Margulis, 2011)[15] . Or multiple systems at a given level would form tight associations and develop into multi-unit organizations, such as the early forms of multicellular organisms (Bourke, 2011; Morowitz, 2002; Volk, 2017). Volk (op cit.) describes these processes with the term 'combogenesis' meant to evoke the vision of heterogeneous things coming together, somehow, to create a new larger, more complex thing[16]. In Chapter 2, we used the concept of 'auto-organization' to cover the same ideas but cast it in light of the actual kinds of mechanisms that enable the "coming together" of disparate components.

Complexity of systems has increased over geological time on Earth as larger organisms evolved. As this has progressed the need for internal regulation of cooperation, i.e. coordination among the components in their interactions, has also developed. But so has the ability for the systems to become more flexible and resilient against external disturbances through the emergence of adaptive capacity. Adaptivity comes from the emergence of response choices in components coupled with external influences (a consequence of increasing complexity!). In the

[15] See the Wikipedia article: https://en.wikipedia.org/wiki/Symbiogenesis for background and additional information. Accessed 7/30/2019.

[16] Of course, this is what we described as auto-organization in the ontogenic cycle in Chapter 2.

origin of life, for example, proto-metabolic processes may have included an ability to switch between several mineral sources of redox coupling for energy (Smith & Morowitz, 2016). One of the most fundamental forms of adaptivity is in an ability to buffer inputs against a fluctuation in flows. Systems that could store surges in energy, would be better able to withstand lags in energy inputs.

Adaptivity evolved as a result of increasing complexity in systems along with the selection imposed by the environment – the systems that evolved adaptive mechanisms survived[17].

9.3.2 CAS

Complex adaptive systems (not capable of evolving in their own right) are systems that have degrees of freedom in operations that allow them to adapt to a corresponding range of changes in environmental conditions[18]. In living systems, this is the case for homeostasis as has already been noted (and c.f. Miller, 1978). A subsystem can respond to changes in a key environmental parameter like temperature, or salinity, with internal changes that counter the change in the environment. The purpose of this response is to maintain nominal operations.

Human organizations, likewise, usually are built with adaptive capabilities in several of their internal functions. When there are fluctuations, for example, with supply shipments, or customer demand, an organization can respond by shifting internal operations so as to compensate. In modern automated supply-chain management systems, for example, many of these response mechanisms are built into the software itself so that the computers are the decision agents and provide very rapid responses to such fluctuations. In other cases, human decision agents, relying on their particular agency (power to make alterations as needed) are the adaptive mechanisms. But note that either machine or human agents can only respond with their a priori built-in agency. They cannot restructure their work domain on their own (we wouldn't want software to be able to modify itself for certain!)

9.3.2.1 Adaptivity

There are three levels of adaptivity that living systems and organizations use to adjust to fluctuations in their various environments. Mobus (1999) analyzed these three based on the notion of cost reductions (in energy requirements terms) in dealing with the changes. The objective is to minimize the costs of responding to change so that the energy resources can be

[17] The other aspect of fitness is reproduction. Little is understood about when and how reproduction of systems emerged from proto-living systems. The current favorite hypothesis is that RNA autocatalytic cycles coupled with protein synthesis "somehow" managed to encode patterns of organization of proto-metabolic processes. As always, more research is needed.

[18] This was noted by W. Ross Ashby (1958) as the 'Law of Requisite Variety.' Our inclination is to avoid the word 'law' in considerations of matters in systems science given the still nascent state of the science. The concept is, however, well recognized in systems circles. See the Wikipedia article: https://en.wikipedia.org/wiki/Variety_(cybernetics)#The_law_of_requisite_variety. Accessed 11/28/2016.

conserved and thus reduce the need to acquire additional resources. In both living systems and organizations there are four basic costs associated with responding to the environment. These are costs above the direct costs of nominal operations (e.g. basal metabolic rate in organisms or overhead in organization operations).

The first is the direct cost of responding to a change, the homeostatic cost. The increased cost in energy for responding to a critical parameter is essentially proportional to how far from nominal the excursion of the parameter (both negative and positive value excursions are the general case) and how long the excursion lasts. This is called the response cost, $C_{response}$. In the social world of humans this is the cost of responding to a crisis situation.

The second cost involves the drain on autopoietic support systems, the stores of materials and energy along with the work needed to restore those stores. For example, after a prey animal exerts extra energy to escape a predator it must eat a bit extra to replace the energy used up in the chase. This cost may be paid back over a longer time frame, but it is still a real cost, $C_{restore}$. In the human world this is the costs associated with re-acquiring stores of resources that were used up in responding to the crisis, such as replenishing inventory after 'Black Friday' sales stampedes.

A third cost arises when the excursion is more extreme or lasts for a long enough time that damage accrues to the system. For example, if a warm-blooded organism is subjected to very cold temperatures for a long enough exposure, it can suffer hypothermia or frostbite with possible damage to some of its tissues. These tissues will need to be repaired (assuming the creature survives) and that takes up additional energy – higher costs, C_{repair}. Suppose the Black Friday stampede at a department store resulted in physical damage to the facilities. Those would need to be rebuilt.

The fourth cost involves the autopoietic maintenance of the responding mechanism itself. This can be thought of as the cost of maintaining some emergency response equipment, like a sprinkler system in an office or plant. In biological systems, it corresponds with the maintenance of tissues above that needed for ordinary operations. For example, humans that are called upon from time to time to lift heavy weights maintain extra muscle mass for the occasional demand (see extended example and explanation below). We designate this expenditure as $C_{prepare}$, the cost of being prepared. Think of this as the premium costs for having insurance.

The levels of adaptivity provide ways to minimize these costs, thus reserving resources for the entity system giving it maximal capacity to survive (and thrive) in its environment.

The objective function for response systems would be:

$$min_{t-stimulus}^{t-restored}\left[C_{response} + C_{restore} + C_{repair}\right] \qquad \text{Eq. 11.1}$$

The time of stimulus onset is *t-stimulus* whereas *t-restored* is the time at which the system is completely restored and all costs have been paid. The cost attributed to being constantly prepared to respond is amortized over the *t-restored* interval.

Minimization of the total cost depends entirely on the efficiencies with which response, restoration, and, if needed, repair can be done. Of these costs the cost of repair can be quite large as can that of response. Clearly one strategy for reducing costs would be to avoid damage by responding to the stimulus more quickly, i.e. minimizing the time lag between onset of stimulus and the onset and magnitude of the response. This, however, often results in higher preparedness costs and restoration costs. Another strategy involves anticipating a stimulus in time to reduce its effects or avoid it entirely. Any mechanism that would allow this would likely have a slightly higher preparedness cost due to having to maintain the extra control equipment needed (see below). But preparedness costs are the least component in total costs. Whatever additional costs might be involved are more than offset by the substantial reductions in response and repair costs. Details of this approach are given in (Mobus, 1999), reviewed in (Mobus & Kalton, 2015, Chapter 9, section 9.6.3.1) and outlined below.

Stimulus-Response

The first level is a simple stimulus-response capability. In this capability the system responds as quickly as it can to changes in its environment (the critical parameters). The system has a subsystem dedicated to making a response to the stimulus. In the general case the response acts to counter the effects of the stimulus signal and is reactive. In biological systems, this can be seen in what are called reflexive responses. The system maintains a minimal capacity to respond to the episodic[19] changes in stimuli that are encountered. For example, an animal's musculature is maintained at the level necessary to handle 'ordinary' sorts of work effort. An organization might maintain a basic inventory of parts for manufacturing to handle normal fluctuations between supply and demand for production. The system activates its response mechanisms in proportion to the stimulus and experiences costs accordingly.

A fundamental problem arises when a stimulus situation is greater than the kind of normal that has generally prevailed over the history of the system. If the temperature fluctuation is greater than ordinary, the biological system has to draw down its reserves more than usual. Similarly, an organization might need to draw down inventory more than would ordinarily be the case. The question then is how often might such extraordinary fluctuations be expected in the future? There is no good answer to that question on the basis of a single event. But, suppose such events occur with greater frequency than had been the case in the past? That is, the external processes that are generating the stimulus are non-stationary and thus not necessarily predictable. This calls into need the second level of adaptivity, a more permanent change in the capacity to respond to such events.

The cost associated with response is just the amount of resources drawn from stores, e.g. energy stores that are needed to activate and sustain the response mechanism. In addition, there

[19] Stimuli occur not only episodically, but also with varying intensities and varying durations so that the response mechanism is designed to 'track' the episode and respond in kind.

is an additional cost associated with restoring the resource stores to a ‘safe’ level. If the drawdown has been significant then the restoration activities need to be undertaken quickly, thus also requiring more power. The time lag between stimulus onset and response onset as well as response magnitude are critical factors in determining the extent of costs accumulated over the duration of the stimulus.

Adaptive Response

Living systems evolved to be able to change their capacity to respond to changes in the environment based on the frequency with which extraordinary demand (stimuli) occur, at least within limits. This means that a system can increase the responsiveness of its mechanism by increasing standby resources dedicated to it and/or by growing more response tissue. A good example of this phenomenon is the case of an ordinary person who decides to take up weight lifting to gain muscle bulk (perhaps thinking this will make him/her more fit!) Starting out, the person has an ‘ordinary’ musculature needed for ordinary life. Over time, training with weights, a person can enjoy an increase in muscle mass as the periodic but frequent demand on lifting causes the muscles to respond by becoming stronger. The muscles are adapting to a change in long-term demand on their ability to respond. If the training is sustained then the muscles will bulk up and the person will be more able to lift heavier weights on demand.

Biological systems have this capacity to adapt on the basis of reinforced demand. They do this by increasing their efforts to obtain necessary resources, material and energy, and they commit more resources to maintaining the acquired capacity to respond. If the demand for continued ability to respond declines (the weight lifter stops training) the tissues will eventually revert to their baseline capacity – a rule of biological systems is “use it or lose it.” This is because the energy and material economics of life are such that a system cannot afford to maintain something it doesn’t really need. It is ‘willing’ to pay the cost if the demand is reasonably expected in the future. But if on-going experience shows that the demand was just a short-term phenomenon it will revert to the baseline capacity.

Human organizations basically follow this same rule, or try to. If an organization increasing its inventory to handle long-term disruptions in parts receiving, it will order larger batches and keep them in inventory so as to have parts on hand to meet demands from manufacturing (meeting demands from customers ultimately). The organization keeps track of costs (in dollars) for maintaining such an inventory stock and continually matches that against the actual demand being experienced. Should either demand decrease or the parts supplies are no longer subject to disruptions they will most certainly reduce the size of their inventory to reduce operating costs.

It costs more to maintain a higher level of preparedness. But not doing so carries an even higher cost in the form of repairing damages accrued from not making an adequate or timely response. Biological tissues are damaged (degraded or disrupted) when the stimulus goes over some limit or remains high for too long a period, draining response resources. A business’s reputation can be damaged if it fails to supply customers with demanded products. These kinds

of damage may not result in death or going out of business, but they do need to be repaired as quickly as possible and that that will take additional resources and time. The strategy of building up and maintaining additional response capabilities is meant to minimize these costs which could otherwise be quite high depending on the extent of damage.

Anticipation

The most cost-effective strategy for both living and organizational systems to minimize costs due to responses to fluctuations in stimuli is to find ways to anticipate the onset of a stimulus before it happens and take preemptive (pre)adaptive actions. The trick is to sense other factors in the environment that might be causally connected with the factor that will produce the stimulus that demands a response. The other factors are essentially neutral in terms of direct impact on the system but may have a causal relation with the factor that does have a direct impact. As such, if a neutral factor is found to occur just prior to the impactful factor (the stimulus) then the system may preempt the onset of the stimulus by starting to respond even before the stimulus is detected.

A capacity to be anticipatory is based on the CAS having an internal model of the environment insofar as the relations between direct stimulus events and those that are neutral but have causative impacts on the stimulus entities (Principle 9 in Chapter 1). The nature of models was developed by Rosen, et al (2012) who showed that a model could be used to anticipate future states of the world and replace the more typical response mechanisms. The model used has to contain sufficient details about how entities and forces in the environment relate such that is reasonably veridical with respect to the real nature of those relations. It must be capable of accepting input states that are hypotheticals in time scales much shorter than real-time for the SOI. Today we use computer models with hypothetical input data to project what the state of the system will be at some point in the future. For example, we use climate models with hypothetical increases in CO_2 emissions to predict various scenarios of future warming and climate disruptions.

Anticipation serves a useful role beyond just reducing reaction-mode costs. When a negative consequence is anticipated the point is to take actions that will obviate the need to respond. As when a prey animal anticipates that a predator lies in wait around the corner it chooses to take a different path to the water hole. In this case you can’t quite call the anticipation a *prediction* that continuing along this path will lead to my death. Good predictions are supposed to come true in the future. In this case we use a seeming prediction (a possible scenario) to avoid the prediction coming true, therefore making the prediction false. A seeming contradiction.

In biological systems, the notion of anticipation can be seen in the effect of Pavlovian conditioning; a bell rung before a meal can cause a dog to salivate in anticipation of the meal. The dog learned to associate a bell being rung just prior to meals with the fact of an impending meal. The ringing bell then became a stimulus for the response (called a conditioned response).

Well managed companies have people who are monitoring the external environment and are able to associate movements in factors that might portend changes in, say, demand for their products. For example, sellers of household goods (furniture, stoves, etc.) might take note of a down trend in new housing starts and because they had learned from past experience, anticipate a downturn in demand for their products as well. We call these sorts of anticipatory clues, leading indicators of movements.

All of these capabilities are to be found in concrete complex adaptive systems. The long-term viability of any CAS depends on relative stability of the various critical environmental factors upon which the system depends for its existence. Supplies of resources, absorption of products (and wastes), and the general milieu of the environment must remain fluctuating within boundaries established over the evolutionary history of the system. As long as this kind of steady state condition exists, the systems that have evolved to fit in that environment can generally deal with occasional excursions to the limits. It is when some factor(s) in the environment are themselves changing over time that the capabilities for adaptation are tested. In those circumstances systems that are incapable of making the necessary internal adjustments to their structures and functions will eventually succumb because of the relentless accumulation of the costs discussed above. Some systems, however, have an ability to make the needed modifications and continue to be fit in the new environment. In the biological world those systems are the genera in which speciation permits evolutionary adaptation (not individual adaptation based on physiology or behavior as described above[20]) to take place. In human organizations, the capacity to alter internal structures and function in response to changing environments makes these systems *in situ* evolvable.

9.3.3 CAES

A complex adaptive and evolvable system (CAES) is one that is adaptive but also capable of changing its internal structures/functions in response to a changing environment. The changes here go beyond mere degrees of freedom in responding to nominal ranges of changes in environmental parameters. The kinds of changes we are referring to here involve permanent changes in the response mechanisms themselves or even creating new response mechanisms to

[20] There is an unfortunate confusion regarding the word 'adaptive' as used in much of the literature on CAS. In evolutionary biology writers often refer to the idea of 'evolutionarily adaptive' meaning that a species is adapted to a particular niche. The species, in this case, is a subsystem of the genus that has adapted to the niche via evolutionary mechanisms of mutation and selection. New species evolve from existing ones. Both may survive and undergo additional microevolutionary change. But the word adaptive in this respect applies to the species level of the genus. Adaptivity, used in the context of individuals within a species is the capacity of the individual to change its response but only within some a priori range, determined by its evolutionary adaptation. It cannot completely alter its physiology or behavior to fit wholly new conditions. Humans are both adaptive and evolvable, at least insofar as their behavior is concerned. Their expansive neocortex allows for the evolution of new concepts in response to new environments. This is why we are able to 'adapt' to completely new technology or live in extreme environments like the Arctic. Human organizations are also both adaptive and evolvable by virtue of being composed of human agents. We will make every effort to make clear when we are referring to individual adaptivity (as in a CAS) versus an evolvable system (CAES).

take advantage of some new potential resource or avoid some new kind of threat[21]. The latter involves changes to the architecture (or genome) that make a system more fit (if it works) in its environment. This is neo-Darwinian evolution in biology (applied to genera) and organizational change in human organizations (e.g. changes in policies and procedures).

The significant difference between adaptivity and evolvability is that the latter involves having internal mechanisms for effecting change beyond nominal changes in the environment (lower left-hand oval in Figure 9.2 labelled "Evolvability Process." That is, components within the system have to have the ability to be modified or created anew. Such modifications in a living organism, e.g. a mutation in the DNA of a single cell, usually lead to either cell death or potentially cancerous growth. These mutations are vigorously repaired where possible since they are generally detrimental. However, when we look at a species as a system the situation allows for evolvability. If a germ cell gene is mutated, resulting in a change in the phenotype of a descendant, and if that change is favorable – leads to increased fitness of the resulting phenotype – the species may undergo evolution assuming sufficient conditions of selection are present (c.f. Losos, 2017).

More complex systems, such as the neocortex of mammals, especially humans, or human organizations are evolvable by virtue of having internal mechanisms for wholesale changes in adaptive mechanisms. Brains can learn new concepts or forget (submerge) old ones that are no longer useful. Organizations can acquire new departments or dissolve those no longer useful. Both such operations serve the interest of increasing fitness of the system in its particular environment.

9.3.3.1 Adjacent Possible

Stuart Kauffman (2000, c.f. Chapter 7)) describes an evolutionary process in which the current state of the system (the genome, for example) can be tweaked minimally but yet allow the system to explore nearby possible states, or in our scheme, behaviors, that will either prove fit or not. In Darwinian evolution this results from, for example, point mutations leading to changes in the phenotype that can then be tested by selection. In human organizations we see experimentation with step-wise or incremental alterations of organization that lead to improved functions or behaviors that can similarly be tested by the economic environment. With enough of these steps, especially being taken in parallel in several adjacent dimensions, it is likely that the system is moved into an entirely new space of possibilities – new functions and behaviors.

All CAESs demonstrate the capacity to 'explore' their phenotypic space in a blind search for improvements, that is, incrementally better fitness. This is a necessary capability that keeps a CAES from getting stuck in a local minimum, a fitness capacity that is perhaps sufficient but not optimal. Of course, some exploratory moves may be more than just to the nearest, adjacent

[21] An excellent example of this is the acquisition of antibiotic resistance in microbe that result from mutations in genes.

possible state. Occasionally systems may be able to make large jumps out of their minima as in the case of punctuated equilibria phenomena in biological evolution[22]. Corporations may discover a new technology and develop a new product for a new market that is distinctly different from their ordinary products. But these events are relatively rare compared with the exploration of incremental regions of fitness space. The latter is a major source of variability across a gene pool in biological genera or between organization in societies.

9.3.3.2 Chance and Necessity[23] – Darwinian Evolution

In biological systems, specifically species, evolution proceeds by seemingly random modifications to genes (mutations, cross over, and certain epigenetic phenomena in the genotype) that then affect the phenotypical properties, structures and functions, of the individual in which the mutation occurred[24]. The mutation of any functional gene or any sequence involved in the control of expression of genes is thought to be a random event, a copy error or a result of a radiation knock-out event and is thus in the realm of "chance." The way that chance can have a role in evolution is because the events occur within a very large population of potential opportunities – a population. Many parallel chances can be tolerated due to the fact that there are many more cases of no chance (no mutation) so that the few that do occur do not put the whole species at risk.

Mutations and changes in the phenotype resulting must then be tested in the context of a dynamic environment. In biology this constitutes some form of selection (natural, sexual, and directed or breeding). Those that improve fitness of the system tend to be propagated into the next generation.

In human systems chance and necessity may still play a part of the general evolution of these systems. For example, a serendipitous discovery or a new idea that just popped into someone's head can lead to modifications not directly linked to external conditions initially.

9.3.3.3 Evolvability

We have come to realize that some organisms are able to modulate the mutation of certain genes in response to changes in their environments that facilitate ordinary Darwinian evolution.

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[22] See the Wikipedia article: https://en.wikipedia.org/wiki/Punctuated_equilibrium for background. Accessed 8/2/2019.

[23] The phrase is credited to Jacques Monod (1971) who characterized the process of biological evolution in terms of random modifications generating variability (chance) and environmental selection through constraints necessitating the viability of those individuals lucky enough to possess those variations that the environment permits.

[24] For clarity, the mutation occurs in one of the genes in one of the two gametes (in sexual reproduction) that then results in a phenotypic modification that will be subjected to environmental selection. Most mutations are believed to result in a detrimental configuration that is non-viable for the zygote. But those that are not will be subjected to selection in the Darwinian sense.

This is a kind of massively parallel random search for a solution to a problem in the interest of allowing life to go forward. Though the details of mechanisms are still sketchy, it appears that there is actually a kind of favoritism applied to critical genes, allowing them to mutate at above the background rate in a kind of hope-for solution[25]. This is to say that organisms can allow themselves to produce mutant offspring that might be able to be more fit in a changed environment. For biological organisms this is literally a "craps shoot." It is not a calculated risk but a result of having so many parallel attempts in play that the likelihood of one of them paying off (in terms of increased fitness for the lucky individual) is sufficient to ensure the survival of the species. Living systems have evolved to be evolvable. And that may explain the success of life in dealing with the huge variability of climate shifts and general environmental variations that have defined the history of the planet. Life has endured in spite of cycles of global warming and ice ages because some species have become evolvable.

9.3.3.4 Intentional, Volitional Modification

Birds build nests in order to have a place to hatch and raise their offspring. They do this quite intentionally. Beavers build somewhat more complex dam shelters for brooding. They too do this on purpose. In these cases, we assume that the intentional actions taken needed to complete the tasks are the result of instinctive drives but even so we can see a high degree of autonomy in terms of selecting specific building materials and fashioning the developing nest. Ant and termite colonies, are also the result of built-in programming to construct nests but carried out by a much more hardwired set of behaviors distributed through the colonies and coordinated by chemical signaling. Given the size of an ant brain it would be hard to attribute intentions to the individual ant as it follows the program based on the chemical signal inputs it is receiving. We can attribute much more in the way of intentional action to beavers as they have been observed to solve local problems that arise when attempting to, for example, gather building materials in a complex and challenging environment.

However, though we may see intentions in the individual behaviors and responses to challenges in some animals, we have never witnessed a beaver, say, try to build a two-story dam, or a bird decide that a multi-compartment nest would be more comfortable with a separate room for the chicks.

Biological evolution led to the emergence of the human consciousness, a wholly new kind of consciousness that enjoys a seemingly unlimited capability to modify its world according to imagination. This capability appears to arise from the symbol representation and processing capacity of the human neocortex, particularly in the prefrontal cortex of the brain. Human beings are capable of changing their minds, meaning that they can modify their thoughts, their symbolic

[25] When genes are being read out or copied errors occur all the time, which could lead to a mutated form. However, these changes are generally repaired by enzymes associated with the chromosomes. One possible mechanism for achieving a higher rate of mutation would be to just inactivate those enzymes associated with specific genes.

representations, and their behaviors. This ability has a number of evolution-like qualities. Changes in internal representation and relational connections can happen as a result of environmental change, i.e. the brain receives informational messages that alter its conceptions. Or they can be the result of accidental (that is stochastic) processing that leads to new insights. Dreams are sometimes credited with changing someone's perspective or understanding. Or they can be intentional, the result of thinking hard about something and developing a new conceptualization.

When humans change their minds, they change their behaviors, or the actions they undertake to make something happen. We then change something in our environment to make things work differently. After which, the larger environment will apply selection pressures on the new things/behaviors and some will prove worthy while others will fail (e.g., VHS vs. Betamax).

Intentional modification seems to be a phenomenon relevant only to mankind. We modify our instruments, tools, esthetics, and even ourselves intending to solve a problem or make something better, or more comfortable, or more efficient. Then we wait and see what happens. This is still a form of evolution. It is still an exploration of the adjacent possible. But now it is not really relegated strictly to chance as was the case for Darwinian evolution. Part 4 will be covering the various kinds of intentional modification/invention/artistic creation in which humans engage. There we will see that design and engineering of artifacts is a new kind of ontogenesis (as covered in Chapter 2) in which auto-organization is 'replaced' by what we will call "intentional-organization." We will also see that the term "intentional" does not mean "deterministic." Intentional-organization retains an element of chance (see Chapter 12) and so, is still in the realm of an evolutionary dynamic.

9.4 The CAS/CAES Framework and Prior Models

We will briefly describe several prior models mentioned above and compare them with the CAS/CAES framework to underscore why a general synthesis of many models is required.

9.4.1 Viable Systems Theory/Model

As mentioned above, what we have described as the CAS/CAES archetype model is quite similar to the theory of viable systems advanced by Stafford Beer (1972). Beer developed a model of a viable system that was applicable to human organizations of all types. Though he related the concepts involved back to biological models, his main insight was based on the application of cybernetics to the management and stability of a dynamic organizational system such that it would be capable of adapting to changes in the milieu. He recognized the fact that a system's viability depended on a hierarchy of management decisions, which he described as "Systems 1 – 5" (see below). He did not differentiate between adaptability and evolvability as we have done, owing largely to his focus on human organizations which, almost by definition, are evolvable. Our purpose was to distinguish those work processes and governance decision types that are needed to achieve adaptivity and evolvability when it is present. Beer's theory, viable

systems theory[26] (VST) was the basis of a model, viable systems model (VSM)[27]. Given the brief description of the HCGS above, we will review Beer's VSM and its relation to HCGS. Of course, the VSM is similar to the CAES model as a whole, which includes the other model archetypes to be described below. But its reliance on cybernetics will make it easier to discuss differences in the context of the HCGS.

The CAES model presented above possesses the necessary but not-quite sufficient conditions for long-term viability. Since the completely sufficient conditions include the fact that the system is *always lucky*, such as in no asteroids or comets of consequential size will crash into the Earth ever, the concept of viability (stability, resilience, and sustainability) must remain provisional. That is, unfortunately, the best any CAES can hope for.

But even absent the luck condition, a viable system can expect to enjoy a full life cycle if it is a CAS or be potentially eternal, in an abstract sense, if it is a CAES[28]. Examples of the latter are phyla in biology, perhaps.

Here we consider a mapping from VSM to the CAES archetype. As noted above, Beer's primary concern was for modeling a human organization, e.g. a commercial firm. He was most interested in how cybernetics played a role in management and management decisions. And he clearly understood that agent decisions and actions mapping onto a hierarchical organization.

9.4.1.1 Agents and Agency

A major concern for Beer was the regulatory capacity of the basic cybernetic model. Beer delved into autonomous agency theory. He relied heavily on W. Ross Ashby's (1958) "Law of Requisite Variety" in control theory. This "law," more an observation, states that a control system must be able to have a number of control options (and the power to enforce the choice) as there are variations in system states.

9.4.1.2 Governance Architecture

Beer described a five-level architecture that involved operations, measurements of performance (information), agent decision processes, and coordination/strategic processes.

Beer labeled each component in this five-level architecture as Systems 1 to 5 (S1 through S5), as mentioned above. S1 entities map onto the CAES conception of work processes. This is where the fundamental work gets accomplished. He does not elaborate on the actual work flows,

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[26] See the Wikipedia article: https://en.wikipedia.org/wiki/Viable_system_theory. Accessed 12/20/2016.

[27] Also, see the Wikipedia article: https://en.wikipedia.org/wiki/Viable_system_model for a description of the layered cybernetic system. Accessed 12/20/2016.

[28] Of course, it cannot be absolutely eternal! For example, we know the Universe seems headed for an entropy death in some distant future if our surmise of dark energy is correct. It is hard to imagine how life could continue under those circumstances, but since there is no theory to tell us what to expect we should probably prepare for the worst-case scenario.

that is the flow of transformed material from one S1 to the next in the value-added chain. Nor does he differentiate work processes in categories such as import or export processes versus internal transformation processes. He does not explicate special work processes such as recycling or adaptation processes. And, as stated earlier, he does not pay special attention to the role of energy flow as a driving force through work processes, that many operational level (S1) decisions are actually decisions about adjustments in energy flow.

Beer defines S2 more as communications channels or the network of communications between S1 entities (to be discussed in the next three chapters in terms of cooperation) and between S1 entities and an S3 entity. The latter is a reasonable mapping onto the logistics coordination manager. Here Beer seems to be more concerned with the optimization of groups of S1 entities; his research in Operations Research (OR) would certainly account for this focus. S3 also provides an interface with the higher levels, S4 and S5, whereby longer-term performance information is transmitted upward and command-like information is transmitted downward.

It is not clear that Beer distinguished tactical from logistical coordination decisions, though he discusses tactical vs. "synergies" (presumably between S1s) but his S4 was responsible for monitoring the environment. What is not clarified is the difference between tactical coordination between the whole system and its sources and sinks via observations of the latter by the tactical decision process and more broadly ascertained information about other entities or situations in the environment that would be relevant to strategic decision-making. He does link the activities of S4 entities with determining needs for adaptive responses, as when, for example, a supplier of critical parts suffers an internal problem and cannot provide shipments in a timely manner; the system will need to find a new supplier.

As with so many thinkers in this time period, Beer does not distinguish between adaptive processes and evolvable processes at S4 level activities. Level S4 is akin to the strategic level in CAES. It is tasked with monitoring the environment and making strategic decisions regarding changes to the organization. Beer labels this as "Awareness." But he defines a level above strategic, L5, which is tasked with establishing the "ethos" within the organization. He labels this "Identity," In CAES this is a long-term result of decisions made in the strategic management level and so, subsumed in that process.

One might conclude that most of the functions covered by the CAES model are also covered in the VSM but possibly distributed differently and with some blurring of boundaries between function types. One important similarity between CAES and VSM is the recognition that there is a recursive definitional relation of entities in both. For VSM, many of the Sx entities are themselves VSMs. Certainly, for very large organizations each of the Sxs would contain internal functions of the VSM sort. For example, large departments, like accounting, would have S1s like bookkeeping functions, S2s like consolidations of accounts with reporting to the controller, S3s like supervisors for various accounts, S4s and S5s in the form of the controller who has to be cognizant of the environment of the accounting department (the rest of the organization) and make decisions regarding changes in policies and procedures within the department.

Similarly, in a CAES we can distribute functions as just described. But CAES also recognizes a further level of recursion in that every human agent is itself a CAES. And this has interesting ramifications for the actual work that gets done given that humans are quite imperfect agents.

Finally, the VSM model situates the organization (SOI) within a larger environment that includes sources and sinks, as well as external markets with competitors, and reference to what he calls, "potential futures." S4 is responsible for considering these potential futures and making strategic decisions.

9.4.1.3 Economy

VSM does not explicitly treat the internal flows as an economy in the way it is defined in CAES (Chapter 12). It does consider value-added relations among S1 entities but does not categorize these S1 entities into necessary sub-functions such as import/export, production, and distribution functions (as will be delineated in Chapter 12). There was an explicit recognition of the supplier (source), system, and customer (sink) relations. In this he assumed that the purpose of an organization, like a firm, was to produce a product that could be exchanged with entities in the environment for equal value in some form (money). And thus, Beer does explicitly link the internal economy with the external embedding social economy.

It must be pointed out that in the late 1960s our knowledge of the isomorphic forms of work done in, for example, a living cell or a multicellular organism was a model of a generic process we would come to call an economy. We might as well call the social economy (e.g. as we discussed in Chapter 8) the social "metabolism," indeed some authors have done so. Volk (1998) likens the whole Earth's various processes in and between the major geospheres as "Gaia's Physiology" noting how the many cycles of materials, driven by the flows of energies, produces multi-timescale dynamic equilibria (sometimes those multi-timescale dynamics superpose to produce extrema, but in the long run the Earth has maintained a range of conditions conducive to life). So, it is with intermediate systems between Earth as a whole and cells in our bodies. The internal flows and transformations form a network of value-adding or restoring processes that collectively constitute an economy. Human organizations are no different.

Next, we look at another researcher's conceptions of this observation.

But, in summary, Stafford Beer provided an enormously valuable insight into, especially, the workings of an organization that would make it viable as an entity over an extended period of time. He identified numerous necessary conditions and, as far as human organizations were concerned, he felt those conditions were sufficient. Where CAES differs from VSM, aside from some distinctions in nomenclature, is the degree of refinement in both the architectural layout and the specification of particular functions. Beer alluded to how VSM was applicable to living systems but at the time of his work not as much was understood about the range and roles of mechanism isomorphic across the spectrum of complexity from cells to civilizations so this was

more a metaphorical modeling than a high-resolution analogic modeling. Still, it was visionary for its time and this author owes a debt of gratitude to Beer for pointing the way.

9.4.2 Living Systems Theory – James Grier Miller

Whereas Beer came at a theory of what a viable complex adaptive system involved from the standpoint of management science (operations research and cybernetics), James Grier Miller was a biologist first and incorporated systems science into his development of a generic model of functions that he found to be isomorphic across the spectrum from cells to civilizations. We introduced Miller's work in Chapter 2, Section 2.2.2.1, his "Living Systems Theory" in the context of the model of an ontology of systems. We noted there that the theory only concerned living systems and so could not provide an ontology of simpler systems. Nevertheless, it provides a superb example of developing a generic model of a complex, adaptive, and evolvable system.

Miller's theory is extraordinarily detailed and complicated. We could not begin to cover it as elaborately as it deserves. So, we will only provide glimpses of his treatment as it pertains to the CAES model we are putting forth. As with Beer's VSM there is much overlap in terms of isomorphic functions with CAES.

Miller applied his "basic concepts" as given in Chapter 2, Table 2.1 to the following levels of organization: Cell, Organ, Organism, Group, Organization, Community, Society, Supranational System. This list is similar in presentation as, for example, Tyler Volk's (2017) "Grand Sequence," covered in Section 2.3.3.2 of Chapter 2 in the context of ontogenesis from "prokaryotic cell" to "geopolitical states." But Miller is not really concerned with major transitions or emergences per se. Rather, he is interested in the functions that are isomorphic and found in all levels of his hierarchy. As mentioned in the Chapter 2 treatment, Miller lists 20 "Critical Subsystems" discretely identified for their functions. Most, if not all, listed by Miller can be found within the CAES model but have many have a system-subsystem relation rather than being identified on an equal basis.

9.4.2.1 Agents and Agency

Miller lists a number of functions as separate categories, e.g. systems that process material and energy versus systems that process information (and Miller's use of the term information did not recognize the distinction between information and knowledge as was covered in Chapter 2). The list of information processing functions is generally subsumed under the agent/agency model (Chapter 10). For example, he speaks of transducers (sensors in Chapter 2), channels and networks (messages in Chapter 2), memory (the H object in Chapter 3, Equation 3.1), and the decider (the agent along with the decision model in Chapter 10).

He then proceeds through each of the living system levels identifying each of these as they are instantiated in that level. For example, here is what he says about the "decider" structure in a cell.

> Components in both nucleus and cytoplasm which are involved in control of cellular processes constitute a cell's decider. The subsystems appear to have at least two echelons. These are described by Eigen as "legislative" nucleic acids (the higher echelon) and "executive" proteins, like enzymes (the lower echelon). [page 272, Section 3.3.7.1]

"Eigen" refers to Manfred Eigen (1927–2019), a German biophysicist, 1967 winner of the Nobel Prize in Chemistry. The term "echelon" refers to an aspect of the hierarchical cybernetic governance architecture we will cover below. Agents, in the CAES model, are situated in different levels of that hierarchy according to the 'types' of decisions they make. In the above example of the decider(s) at the cellular level, the nucleic acids (DNA) in the nucleus are roughly equivalent to the logistical coordinator in CAES. The enzymes are equivalent to the operations manager associated with the work processes, such as synthesis of lipids and carbohydrates.

Miller similarly goes through each level of organization delineating each critical subsystem in terms of the core concepts backed up with extensive empirical evidence. It is truly a massive amount of work. And no cursory summation like this can possibly do justice to it.

9.4.2.2 Governance Architecture

In Miller's conception of governance, like Beer, he arranges 'control' in a hierarchic fashion (as mentioned above) naming the levels "Echelons", by which he means 'steps in the "chain of command" (page 29). That is higher echelons have broader scopes of control or influence over lower echelons.

Within each level of organization, he then elaborates the roles played by each of the major components, giving extensive examples. For example, the 'decider' (agent) in an organization is, "Top executives, department heads, middle managers" (page xxiii). In the Preface he provides a table with level of organization (cells to civilizations) in the left column, critical subsystems that process information as column heads, and specific examples such as just given in the matrix entries. One can see from this array that there is strong evidence that his list of critical subsystems for processing information are truly isomorphic in that there are exemplars for each level and type subsystem.

9.4.2.3 Economy

The list of critical subsystems that process matter and energy are shown in Table P-2, pages xx and xxi in the Preface. These correspond to many of the low-level elements in the ontology of systems in Chapter 2 (see figures 2.17a & b, 2.18 and 2.19) and further elaborated in Chapter 3 (see figure 3.12).

These are elements that operate together to produce instantiated processors. Miller's list are actual categories of work types primarily related to biology whereas in Chapters 2 & 3 we focused on more generic work and function types from which specific types in Miller's list could be built (at any scale).

Thus, Miller's model of matter/energy critical subsystems correspond more closely to the notion of an economy as will be given in Chapter 12 in this volume. As an example, his "PRODUCER" critical subsystem example for an "ORGANIZATION" level is: "Factory production unit," by which he means a manufacturing company, its physical plant and personnel. I will be clear in Chapter 12 how this concept and many others that Miller describes, map onto the processes in an economy model.

Miller is much more explicit about the role of energy flow than Beer was but this is likely because he started from a biological point of view in which energy flow is of principal concern.

9.4.3 Synthesis and Incorporating Other Work

There have been many comprehensive models of complex adaptive systems proposed over the years but the two just given have seemed to this author to be the most comprehensive. Fundamentally the CAES model presented here started with an attempt to integrate these two versions. Along the way it was discovered that certain details needed to be drawn out more than either author had done and some concepts needed reorganizing and relabeling in order to be consistent and also to incorporate some more up-to-date understandings.

Both of these models incorporated some elements from many other fields of endeavor, for example, both include basic cybernetics, communications, information, and control theories. The CAES model synthesizes the two approaches (along with this author's distinction between information and knowledge and cleaning up some ambiguities regarding the definition of information in Chapter 2). At the same time, it goes deeper into the distinction of decision types as fundamental to the structure of the management hierarchy and integrates into the model some of the latest understandings of agent theory (especially humans as agents).

Finally, a major distinction that arises from the attempt to integrate and consolidate is that between a merely adaptive system and an adaptive and evolvable system. This distinction is essential to a deeper understanding of the life course histories of the different systems. CASs have life histories that are constrained by their a priori preparation to adapt to changes in the environment. Their evolution and construction assume a more or less ergodic, that is stationary over time, environment. The real environment of Earth is definitely not stationary in geological time scales. The environment will be forever in fluxes and when the changes go beyond what any merely adaptive system can handle it will die. On the other hand, evolvable systems have a much better chance of persisting for much longer life-times if they are able to reconstruct themselves to accommodate the changes. It is important to recognize this difference and to incorporate it more explicitly in our design models.

9.5 Expanding the CAS/CAES

In the next several chapters we will expand the concepts of the agent, economy, and governance model archetypes. In each chapter we will focus on the role of the sub-model

1 archetypes and give examples of their instantiation in real systems, somewhat in Miller's
2 fashion, at different levels in the hierarchy of organization.

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Rosen's Modeling Relation

Theoretical biologist, Robert Rosen developed a theory of how living (animal) systems were successful in evolutionary terms because they had an ability to anticipate contingencies in their environments and take preemptory actions to increase their advantage in survival, hence their fitness (see Mobus, 1999, for a model of how this happens in very simple animal brains). This is possible because animals construct causal models in their brains that allow them to anticipate a consequential outcome (say the attack of a predator) by running the models fast forward (simulation in the brain) based on a set of current input cues (e.g. a scent of the predator).

The nature of models in brains has only recently started to be explicated (c.f. Carey, 2009). Mental models are not just conceptual representations, but dynamical simulations of many aspects of the subject's environment. For Rosen (c.f. 2012) a key question is the formal structure of the relations between models (whether in the brain or a computer) and the real phenomena they represent. The success of a creature in anticipating its environmental contingencies depends of the veracity of its model (an abstraction) and the real phenomenon. Those creatures better able to build more realistic, and hence more veridical, models of their worlds were more successful in

survival and reproduction. The evolution of more complex brains in the animal kingdom might be driven by the needs to build better, more veridical models of an ever increasingly complex world.