# Chapter 6 – Analyzing Various Kinds of Systems

## Abstract

This chapter examines the application of the methods of Chapter 5 to analyze a variety of systems at increasing scaled of complexity and hierarchical organization. We start with an example of a ‘merely’ complex system and then proceed to complex adaptive and then to complex adaptive and evolvable systems. We end this chapter with an examination of the human social system (HSS) as a CAES subsystem of the Earth, of the Ecos. The purpose of these examples is to show how the methods of Chapter 5 can be applied to all varieties of system types and complexities. These examples provide, essentially, starting points for the top-down deconstruction process and do not attempt an in-depth analysis. However, they should provide directions for others to endeavor more in-depth analyses in the future.

Appendix A provides additional examples in terms of the uses of the formal definition given in Chapter 3, showing how the analytics work for simple systems.

## 6.1 Analysis of Example Complex, Complex Adaptive, and Complex Adaptive and Evolvable Systems

While the methods of analysis described so far are applicable to all systems, no matter how simple, the real benefits of using this principled methodology will be in coming to understand complex systems, and in particular complex adaptive and evolvable systems[1]. Examples of a complex adaptive system come directly from the biology of cells. These systems are extraordinarily complex when compared with most designed systems. This is because they have a large number of levels in their organization tree as well as a breadth of component types. Thus, cells have a Simonian complexity exceeding any machines (even computer networks).

Ecosystems and human organizations have yet higher Simonian complexity simply because the biological components of each includes cells (of plants and animals or of human beings) as levels in their organizations. The human brain represents an interesting intermediate system in the CAS/CAES spectrum. It is comprised of ordinary adaptive cells (neurons) but organized in a way to allow the networks of those cells to have evolutionary properties similar to those of species/genus systems. Human organizations, subsequently, have an uncommon degree of

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[1] These types of systems were outlined in the Introduction. Unfortunately, we will not describe their specific attributes until Chapter 9, which is devoted to the explication of what we call archetype models, large-scale patterns of phenomena that interoperate to produce CASs and CAESs.

Simonian complexity since they are composed of multifarious components, but most importantly among those components – human brains.

In the next several sections, we will explore a series of increasingly complex, adaptive, and evolvable systems. The normal process of scientific investigations along lines of specialization and the reductionist methodologies employed have gone a long way toward producing a tremendous amount of knowledge about phenomena at all levels of organization. The disciplinary sciences, practicing the general science process, have accomplished the decomposition of systems within their domains such that we already have a general body of knowledge about what things are and how they work at many different levels of complexity and organization. What has been missing in the scientific methods is the knowledgebase construction that allows everything discovered and documented within the disciplines from being connected. The difference between a knowledgebase and a set of separate, and sometimes isolated facts will be demonstrated in the next chapter.

So much of the knowledge from the disciplines remains as islands of understanding bits and pieces, rather than a comprehensive view of how the world works. In this chapter we seek to demonstrate how the same kind of knowledge as developed by normal science could be better discovered and organized in a more transdisciplinary way. We claim that the use of systems analysis as described in the last chapter would lead to this result. Specifically, in this chapter we will reexamine knowledge acquisition from several different levels of organization involving the most complex systems we know of. In the following chapter we shall complete the vision of how knowledge gained through analysis can be organized in a universal knowledgebase based on the structure of system knowledge.

A single chapter in a book could not begin to do justice to anything like a full systems analysis of these systems. We will examine several real-world systems that have been analyzed by the method of Chapter 5 and show some samples of the end products, maps and trees, for example, to show how each demonstrates the properties of systems even though each is in a different domain. What we can do, in this single chapter, is to show how the analysis work begins and take the process sufficiently deep to give a good accounting of the first few levels of organization of the example systems. The analysis will be taken far enough to establish how the procedures given in Chapter 5 produce the systemic knowledge needed to gain deep understanding. What we seek is a global view of knowledge. We want to see how any of the islands that currently exist fit with one another, how they relate in both a hierarchical fashion (levels of organization) but also as co-relating subsystems of the whole world. The vision for how to achieve this latter will have to wait for our examination of the knowledgebase structure in the next chapter, but a clue for how this is realizable has already been given in the way in which a systems analysis of a particular SOI can be expanded in scope and even reversed such that the supra-system (environment of the current SOI) may become the new SOI.

The five systems demonstrated in this chapter represent increasing scales of size, complexity, adaptivity, and evolvability. The examples chosen are all, with the exception of the last one, systems that have proven stable and productive. At this writing the jury is still out on the long-term prospects of the lase example.

We start with analysis of a basic computing system, a machine that is capable of some rather impressive processing. The hardware, coupled with modifiable software, is an example of a complex system (as defined in the Introduction). If we were to include the role of software engineers and the projects seeking to modify the software components in response to changes in the environment of the computer product, then we would have to classify that expanded SOI as a CAES. We will, however, stick to an analysis of just the machine with a (temporarily) fixed program.

Next, we will examine a living cell, a very special one in the evolution of animal species, the neuron. Our analysis was motivated by a desire to emulate the biological neuron in the course of emulating natural intelligence, as it was understood in the mid-1980s. The hypothesis was that it would be necessary to build artificial (that is simulated) neural networks out of much more biologically-realistic models of neurons to obtain the same kinds of dynamics in processing and learning. For deep analysis of neurons, we turned to the then understood neurological and physiological science but integrating it with cybernetics and network theory as discussed below. Those efforts produced the Adaptrode mechanism, a synapse emulator, and an artificial neuron that produced some important neurodynamics in simulation. It also, eventually, led to the construction of an artificial agent (a robot) that behaved in many ways like a simple gastropod (a snail) in foraging for rewards and learning to avoid threats.

The third example, also a biological system, is the human brain. This system is clearly a subsystem embedded within not only the organism (a person), where it is directly responsible for the full range of hierarchical cybernetic governance of the body (Appendix D) and behavior, but also the cultural/social larger supra-system, which has a substantial impact on the adaptability and evolution of the brain structure (and the knowledge encoded within). This is a great example of a system that has a seemingly clear physical boundary, but in fact is so highly porous and fuzzy that identification of real boundaries is a major challenge. It is also an example of a system that is just now becoming amenable to transparent-box analysis through advanced imaging technology and increasingly clever probes of the correspondence between brain structures and thoughts and behaviors.

The fourth example steps up to the social system level in which multiple brains and cultural artifacts constitute the main components, the social organization, such as a corporate enterprise. Here the scales of size, complexity (e.g. more than just an aggregation of brains), adaptability, and evolvability range dramatically. For example, in size and complexity alone the scales may reach global levels (i.e. international corporations). If the brain represented a challenge in analyzing boundaries, that challenge is multiplied many times over for social organizations.

Finally, we will take a quick look at the systems analysis of the entire human social system (HSS). Although we speak casually about the human species and its cultures as social *systems*, so far there has not been a systems analytic attempt to understand ourselves comprehensively. The social sciences, like all of the physical and biological sciences, are an aggregate of loosely coupled sub-sciences that investigate very different topics regarding different aspects of being human and living in a social world.

There will be no serious attempt to delve into an actual analysis of the entire HSS in this chapter. The point of that section will be to demonstrate how the process might be used to actually tackle such an undertaking. A key issue discussed here, however, will be how being inside the system and still analyzing it objectively is another kind of challenge, but how it might be achieved as a result of the systematic process. The reason for its inclusion here is that it strikes this author that understanding ourselves, our particular kind of system, is extremely important if we are to grasp the nature of the biophysical problems the HSS is clearly causing in the whole Earth system. A grasp of the HSS is also a prelude to Chapter 8 in which we take a specific subsystem of the HSS, the economy, and demonstrate a much more thorough systems analysis process that will show a better understanding of economic phenomena than is currently accomplished with neoclassical economics. We introduce the forbearer of a *systems economics*.

## 6.2 The Computing System

We will start by showing the results of an analysis of a very simple computer by the methods of chapter 5. In engineering terms, we are doing a “reverse engineering” process to find out what the computer is made of and what pieces are connected to what other pieces. This system borders on the line between mere machines and adaptive systems because of the nature of software. Similarly, it approaches a kind of evolvability in that computers are generally designed for expandability, of memory and input/output (I/O) capabilities. But both adaptivity and evolvability[2] are totally dependent on the machinations of engineers, hardware and software. Still, the capacity to reconfigure some aspects of a computer, even when deployed in the field, make it a reasonable candidate for what we might call “primitive” CAES status.

In truth the analysis of a computer like this is not terribly useful since computer designs already exist and the design processes already in place can readily produce any new functions without going to the trouble of a full, deep analysis. The purpose for putting this example in the book is just to provide a starting place using something fairly simple, but complex enough to demonstrate how the procedure works.

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[2] There is a very active area of research in reconfigurable hardware such as the wiring between components and self-modifying programs. For more background on hardware that is reconfigurable see the following Wikipedia articles: https://en.wikipedia.org/wiki/Field-programmable_gate_array and https://en.wikipedia.org/wiki/Flash_memory.

## 6.2.1 A Simple Computer

Many beginning computer architecture textbooks include a design of a very simple (minimal) computer along with a simulator that students can practice writing assembly language programs and run them. The design is simple enough to be covered in a single semester but nevertheless includes the major principles and design techniques used in real computers. Here we borrow a variant on one of these computers, developed by the author to teach computer architecture to first- and second-year computer science students. The original design is owed to Yale N. Patt (University of Texas at Austin) and Sanjay J. Patel (University of Illinois at Urbana-Champaign) (2004). It is a minimal Von Neumann computer that demonstrates most of the features you will find in any computer, just scaled down to size and complexity that students can handle. In this section we will not be getting deep in details of the computer itself (called the LC-3) since our objective is simply to demonstrate the kinds of results that are obtained from a deep systems analysis of a machine. The author's revised design (called the SC-2) is shown in Figure 6.1 below. It borrows many of the features of the LC-3 but has expanded the instruction set and I/O capabilities. For those interested in the design of one of these simple computers we recommend you take a look at Patt & Patel (2004, chapters 4 and 5).

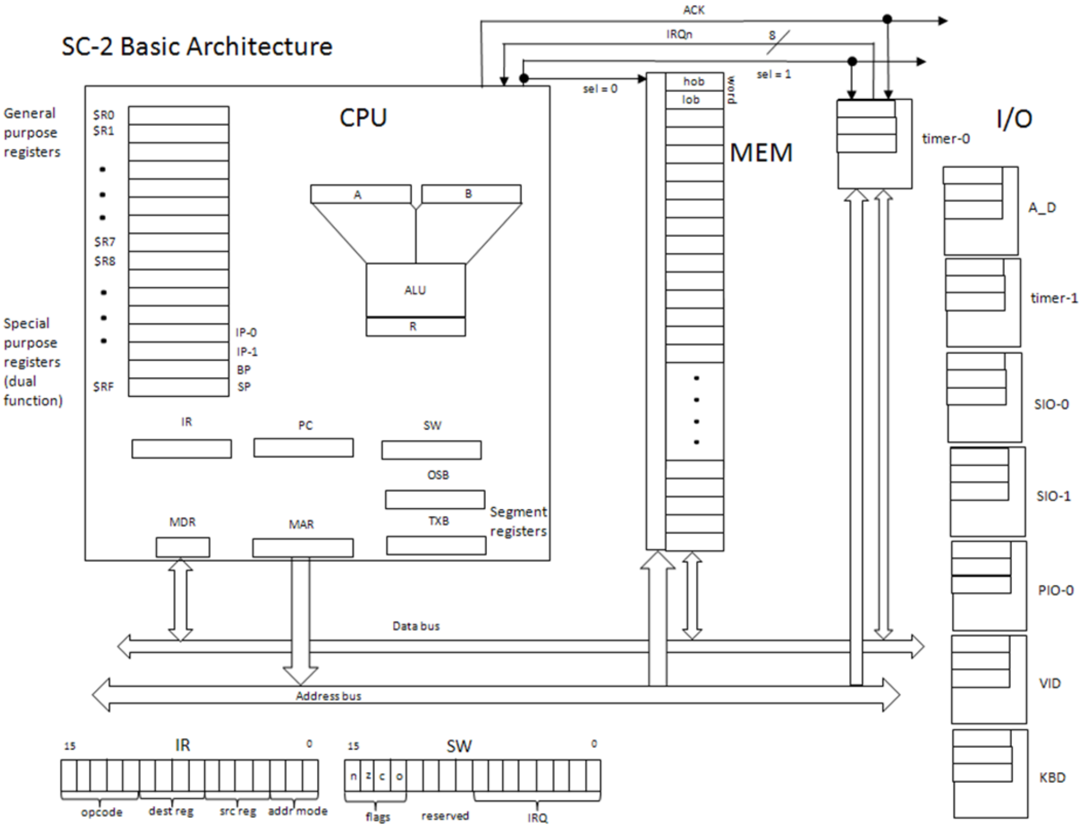

**Fig. 6.1.** The SC-2 computer architecture is a 16-bit (register sizes and addressability) computer inspired by the design presented by Patt & Patel (2004). This machine doubles the number of instructions, but uses basically the same general design as the LC-3.

Here we apply the procedures for decomposition to the computer as a system. Engineers should perhaps take care in what follows. They are used to something called “block diagrams” (as in Figure 6.1) to show the components of a machine. But recall that the diagramming representations in deep systems analysis is meant to convey much more information than just the relative geometric relations between parts. It is also used to show functional relations through input/output flows. So, for those used to block diagramming methods, please bear with us as we approach the problem of understanding a computing system from a systems perspective. In the next major section, we will be looking at the neuron as another kind of computing system, so the methods used here, while perhaps strange looking, will hopefully make more sense once we see how they apply to other domains.

### 6.2.2 Decomposition

The decomposition of a computer system is aided by the fact that computers are designed in a modular fashion. That is, modules embedded in larger modules! We take advantage of this fact to show how decomposition can be applied. In what follows we have elected to leave out the numbering identification scheme discussed in Chapter 5 so as to not clutter up the figures unnecessarily. The reader may want to review the procedures in that chapter for assigning the dotted number identifiers to components in the course of decomposition. Below we only show verbal identifiers (names) of components as we suspect this will be sufficiently clear.

### 6.2.3 Environment and SOI Identification

The first steps involve determining the boundary of the system, identification of the system of interest (SOI) and doing an environmental or context analysis. In Figure 6.2 we show the results of these analyses for the computing system as SOI. Remember this is a very simple machine, essentially similar to a pre-Internet CP/M or DOS computer[3].

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[3] See the Wikipedia articles: https://en.wikipedia.org/wiki/CP/M and https://en.wikipedia.org/wiki/DOS for background on these ‘simplistic’ operating systems.

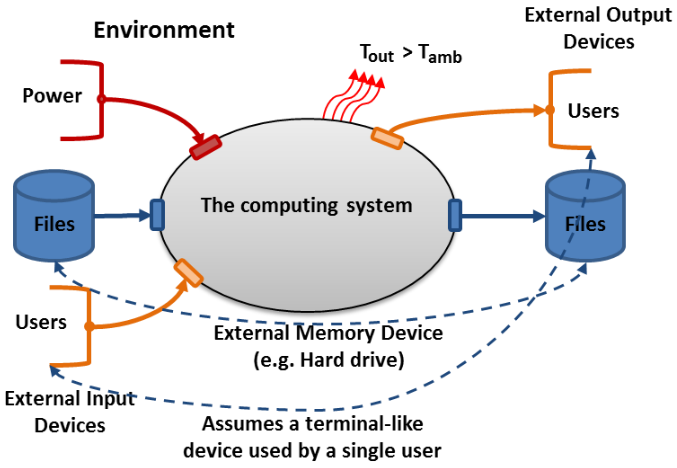

**Fig. 6.2.** A computing system (simplified) can be analyzed through decomposition.

Here we see that energy is supplied via a power source (A/C wall socket!). An external file device contains programs and data files. The computer will read programs/data from the files and write new programs/data back to the files (or create new files as needed). Users can be either programmers who write software (to be stored in files) or so-called end-users who work directly with the data (e.g. accountants). Note that all computers generate some heat as they do the work of data processing, which must be removed from the device either by radiation or in larger systems by convection (e.g. a cooling system). All of the shown interfaces are handled through specific cable attachments that, essentially, keep the wires straight.

### 6.2.3.1 SOI Internals

An initial decomposition of the computer itself reveals several important details. The flows are all conducted by wires carrying electricity modulated between a maximum voltage (e.g. 3.5 volts D/C) and ground (e.g. 0 volts). A computer consists of the hardware that makes the computations possible, the software or programs that guide the hardware in doing so, and an intermediate hardware/software hybrid component called “firmware” that couples the software to the hardware. Within the software is a program that has primary responsibility for interfacing all other programs with the hardware through the firmware component, called the operating system. The details of how this works will not concern us since we are going to pursue a decomposition of the hardware.

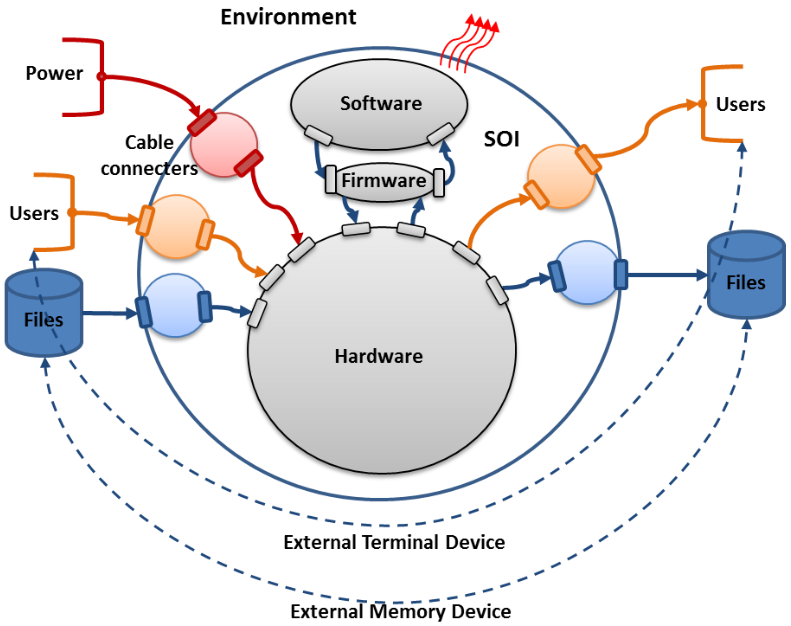

**Fig. 6.3.** The first level decomposition reveals the major components of a computer includes the hardware, software (programs), and an intermediate kind of hardware/software hybrid that interfaces the software with the hardware – firmware. The interfaces with the outside world are through cable connectors.

### 6.2.3.2 Hardware Decomposition

We now pursue a depth-first decomposition of the hardware. The main results are shown in Figure 6.4. For a sense of completeness, similar pursuits of either the firmware or software components would reveal, first, the existence of an operating system (OS) in software that interfaces with the hardware control programs embedded in the firmware. This is a complex relation, beyond the scope of our current exercise. However, we should note that a similar decomposition of the OS and firmware components (e.g. what used to be called the "basic input output system (BIOS)) would demonstrate the same modularity and hierarchical structure.

Rather, we will focus on the hardware decomposition as it demonstrates the overall scheme as well as any aspect of a computing system. Figure 6.3 illustrates this for the SC-2[4].

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[4] Actually this is generic of all computers!

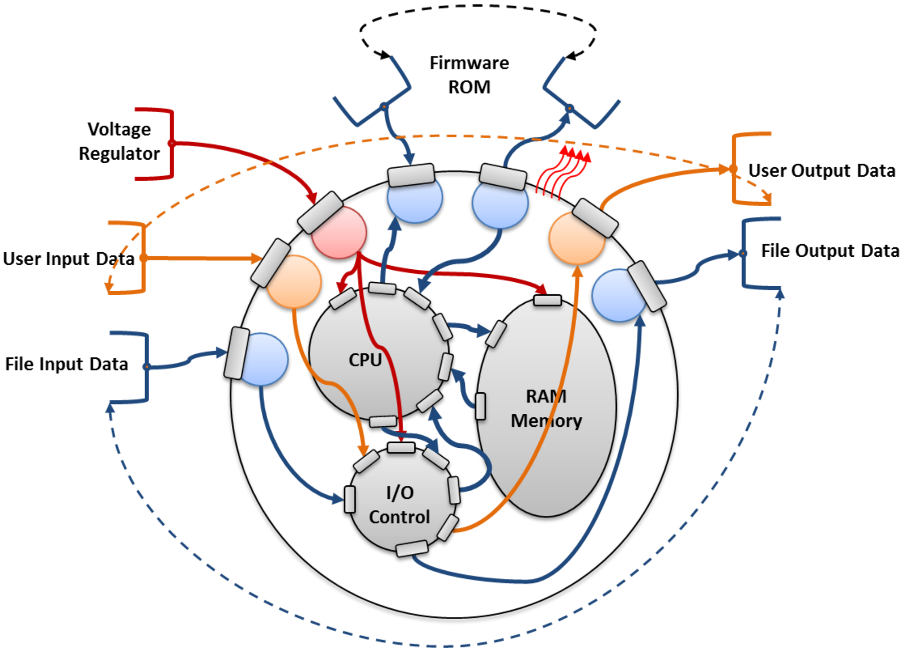

**Fig. 6.4.** Decomposition of the hardware component from level 1 reveals the main component subsystems of hardware and the flow paths of energy and data/messages.

As the decomposition proceeds, we select the CPU as the next module to be analyzed. The CPU becomes the SOI at level 2 and is shown in Figure 6.5. In this figure we identify the main internal components that make up the CPU function, identifying a few of the interfaces that mediate the flows of data through the CPU.

The CPU is comprised of a number of subsystems, some simple, like the register file, others complex like the arithmetic logic unit (ALU). The figure identifies the major component subsystems at level 3 in the decomposition. It also shows some limited flows of power and data, e.g., between the cache memory and the pipeline processor. The analysis would proceed by identifying the flows from CPU interfaces on its boundary to or from all of these elements and then between them as was done in Chapter 5.

That which flows within the computer is messages and energy. The latter is relatively easy to account for. All work performed in the various components is simply managing energy flows (switching of transistors) and results in heat. No energy is actually stored except in capacitors for very brief periods. Messages are coded in binary streams and are synchronous, i.e. all flow controlled by an on/off clocked signal. So the various metrics used to characterize the message flows boil down to bit rates. For example, all data flows from these components to one another are handled via the internal busses (there may be several) which operate at characteristic speeds. Thus once characterized at data rates, there isn't much else to specifying the flows (no material flows!)

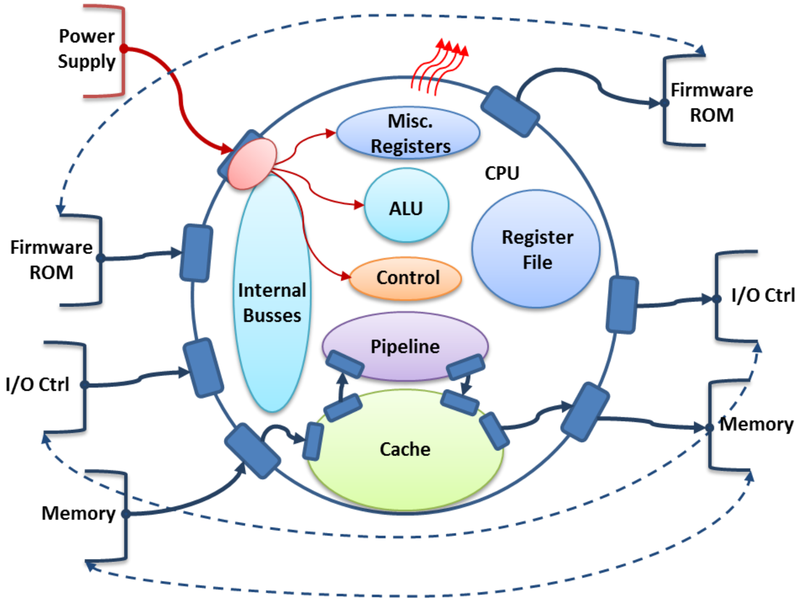

**Fig. 6.5.** Further decomposition of the CPU subsystem, now treating the other computer subsystems as sources and sinks. Only a few power and data flows are shown.

If we continue the decomposition, we might choose the ALU component for the next level starting place. We would find it composed of a number of registers and computational operator circuits such as full adders, parallel OR gates, etc. Registers could be further decomposed to find D-latches lined up and connected to even more internal busses in the ALU. Finally, proceeding along this branch of the decomposition tree, we find that the latches are composed of transistors forming storage circuits. We can consider transistors as atomic components since they all work similarly and it is how they are wired up in logic circuits that determines functions beyond switching on and off (binary 1s and 0s).

Figure 6.6 presents a partial decomposition tree from the root (level 0) and environment (level -1) through the Hardware, CPU, ALU, Registers, D-latches, to transistors branches resulting from the depth-first analysis.

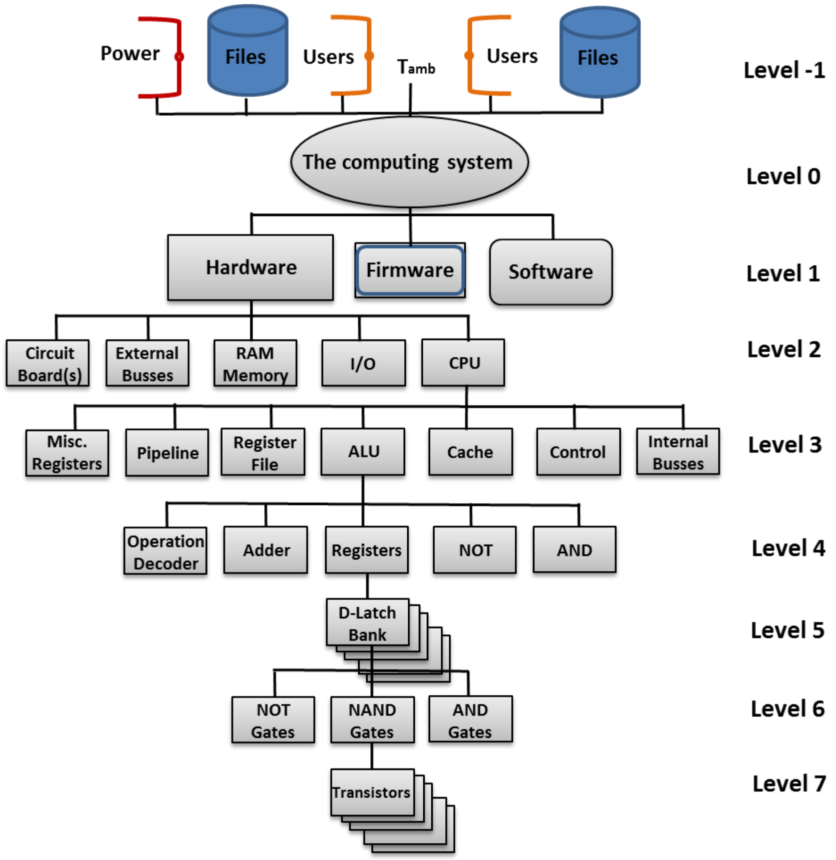

**Fig. 6.6.** A decomposition tree representation of several subsystems of a basic computer system down to the atomic component level (7 for the register implementation within the ALU). This tree shows the decomposition through the CPU branch and the ALU branch after that.

## Capturing Knowledge and Generating Models

In the next chapter we will consider the architecture of the knowledgebase used to capture the components and relations during the decomposition of a system. We have alluded to this capture in Chapter 5. All of the elements shown in figures 6.2 through 6.5 and summarized in Figure 6.6 are thusly captured in a knowledgebase.

In anticipation of those chapters, consider that if the design of a computer or a computer network were captured as a systems decomposition in the fashion just presented it would be possible to produce a simulation of the computer from this knowledgebase automatically. In fact, computer architects and designers, today, build elaborate models of their systems in advance of actual fabrication. They do this to test design alternatives and to gather metrics on performance before committing resources to building actual systems so as to make sure their design ideas are going to provide a net benefit. If an explicit systems knowledgebase existed, then modifications to specific modules at any given level could be undertaken and tested via model expression and simulation in a way that should be far more cost-effective than building such models manually. If Intel or other chip manufacturers were to formally adopt this approach, we suspect their costs of design to production would be significantly reduced more than offsetting the costs of capturing their current designs in a systems knowledgebase through deep systems analysis. What most companies (like Intel) don't realize is that they are already incurring those costs in what they currently do anyway. What the methodologies presented in this book do is organize the activities into a system of knowledge capture and deep understanding that permit significant savings in efforts in future design efforts.

### Transitioning the Complexity Boundary

A computer is one of the most complex machine examples of a system. It sits at the boundary of being a mere complicated machine and becoming a true CAS because of its reliance on software to control what it actually does. Software is mutable but only if a human programmer executes the changes. Self-modifying programs are on the horizon, however, with the advent of hardware that is reconfigurable as described earlier. We expect that within the next decade, especially with the understanding of hierarchical cybernetic management systems as described in Chapter 11, adaptive control algorithms and modifiable hardware configurations will elevate cyber-physical systems into the realm of truly adaptive machines.

For now, however, the best representative of a true CAS is the biological cell. And the ultimate representative of a highly adaptive system is the neuron cell in the brains of animals. Neurons are extremely adaptive systems that deal with computational problems not unlike the computer described here. The nature of the computation that neurons perform is quite unlike that done by computing machines (today). Neurons operate in a highly stochastic environment and, yet, provide a reliable computation translating input signals into stable output signals that contribute to the overall computation of large-scale patterns. Neurons are somewhat analogous to the transistor-based logic circuits of the computer example, but the analysis of how they work goes much deeper. We turn to the neuron now to see how an analysis can go much deeper into the biophysical phenomena that support the capacity for thought in the human brain.

## 6.3 The Neuron – A Complex, Adaptive System

The author's primary area of research involved building a computer model of a biological neuron with the thought that such a model would be useful in then constructing more biologically realistic neural networks (Mobus, 2000)[5]. The field of artificial neural networks (ANNs) was gaining increasing interest in the general area of artificial intelligence but the standard notion of a "neuron" among engineers and computer scientists was extremely simplified and, while useful in certain limited ways, in no way emulated biological-like learning.

At the time that this research began neurobiologists were starting to acquire considerable knowledge about the overall dynamics of neural plasticity and its role in learning. The field of

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[5] In contrast to the artificial neural networks (ANN) that were in vogue starting in the 1980s.

brain science, which included work on neurons as the primary units of function in the brain, pursued the work in the classical reductionist vein. Starting with noting how synaptic junctions changed their ability to generate a wave of depolarization of the local cell membrane; a synapse's "strength" was found to increase under certain conditions of prior excitation by incoming signals. So, neuroscientists naturally went looking for the biochemical details that accounted for this phenomenon. This was the reductionist approach of the sciences.

In this section we describe work on understanding the neuron and synaptic behaviors from a systems perspective, which, we assert, afforded some different insights than were coming from the neurobiological framework. Using the guidance of deep analysis given in Chapter 5, we will produce a system map and tree similar to what we did for the computing system above. As was true for the computer, we can only demonstrate a small portion of a neuron map and tree[6].

## 6.3.1 Identification of the SOI – the "Typical" Neuron

There are over 100 known types of neurons in the human brain. They vary in form and some aspects of their functions, but share a core of structural and functional features. Namely, the cell body has a set of inputs, either electrical or chemical *synapses*, usually arrayed on special protrusions called *dendrites*. They have a single output *axon* that may, nevertheless, branch so that the output signal reaches many other neurons through their synapses. We will not be concerned particularly with brain structure and the wiring of neurons into networks or circuits. Rather we will focus just on the common features of neurons representing a "typical" neuron. This neuron is based on the most abundant form in the neocortex of mammals, the *pyramidal cell*, so called because its basic shape resembles a pyramid with dendritic branches on each of the "corners" and the axon emerging from the center of the base. The geometry of cell types is thought to be a controlling factor in the temporal and spatial integration of input signals, typically pulses of currents.

## 6.3.2 Analysis of the Boundary and Environment

We will not attempt a full biological description of the environment in which neurons operate, the brain tissues that include many other elements besides other neurons, such as glial cells[7] and the fluid milieu. In short all of the factors that are involved in any living cell such as nutrient obtaining and waste disposal will be left out of our current interest. Here we will focus exclusively on the sources and sinks of a typical neuron that are other neurons. The interest here is communications between neurons and the consequences of those communications in terms of encoding memory traces (c.f. Alkon, 1987). Figure 6.7. depicts the nature of the communications channels between neurons. Signals that travel along axons are typically pulses of excitation

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[6] For those not already somewhat familiar with neurobiology and neuronal structure/function we strongly recommend you take some time and read the summary article in Wikipedia for background: https://en.wikipedia.org/wiki/Neuron. Accessed 10/21/2018.

[7] See the Wikipedia article: https://en.wikipedia.org/wiki/Glia for background. Accessed 9/5/2019.

called action potentials. They travel in one direction – away from the source cell body – toward other cells. As shown in the figure axons can branch to send the same signal to multiple other neurons. The axon forms a connection with the receiving cell through a synapse, which we will analyze as an interface below.

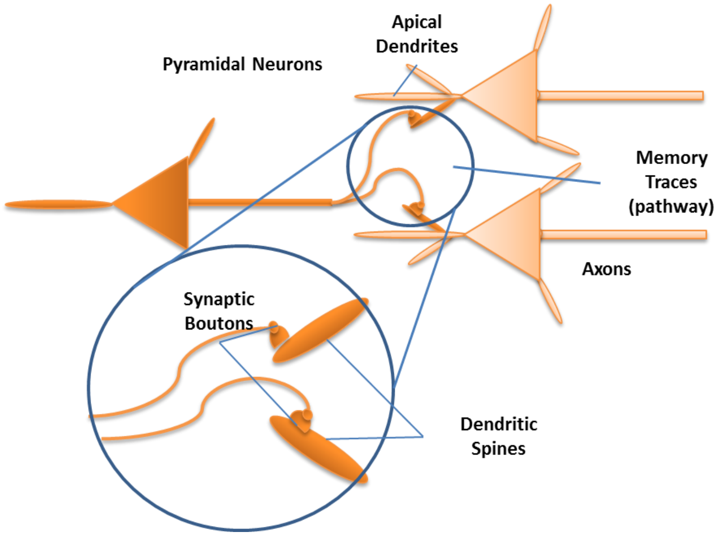

**Fig. 6.7.** Neurons communicate with one another.

Synapses may be formed directly on the cell body membrane, but more generally they terminate on dendritic protrusions, or spines, which act as integrators for signals from multiple neuron sources (only one source is shown in the figure). Each synapse is an interface between the incoming signal and the receiving neuron system. In the next section we will be describing the processing of a synapse in more detail. But, briefly the incoming signal, called an action potential, causes the release of molecular neurotransmitters that cross the small gap between the presynaptic and the postsynaptic membranes. The neurotransmitter then elicits an excitation in the receiving membrane. There are many different kinds of synapses even in the same cell. Again, we narrow our focus onto synapses that have modifiable reactivity to incoming signals. These are called ‘plastic’ in that they can be modified (strengthened or weakened) and then retain their level of reactivity for a time. This is the basis for encoding memories.

### 6.3.3 Internal Decomposition

Figure 6.8 shows a neuron using our systemese language. Other neurons are depicted as source and sink entities according to the boundary and environment analyses. Note that the “rest” of the cell’s internal subsystems have been subsumed under a single subsystem oval but is comprised of all the other living cell functions that keep the neuron alive and able to perform its primary function – processing and transmitting signals.

Input processors are the synaptic junctions receiving afferent axonal terminals (left side of figure.) These processes involve a complex set of chemical reactions that change the level of output from each one; the channels shown internally from each synaptic compartment to the central processor labeled, “Depolarization state.” The interface protocols are found to be comprised of various neurotransmitter activated channels through the cell membrane that, when opened, allow various ions to flow into the compartment[8]. In the resting state there is a voltage difference between the outside of the membrane and the inside. It is polarized with a net negative voltage outside. When the channels open and ions flow inward the local membrane is depolarized. The output from the synaptic compartments are actually states of local depolarization that spread out from the synaptic compartment on the membrane. The figure treats this spread of activation (depolarization) as directed channels to the central processor, which is the summation of the contributing depolarization events within a short time window. The small oval labeled with “Σ” represents this process and sends the result to the neuron output processor, the axonal hillock.

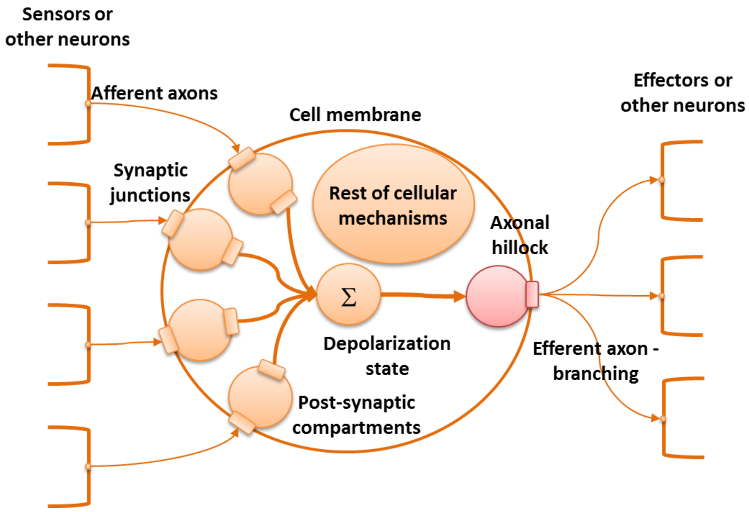

**Fig. 6.8.** A model neuron subsystem map.

The degree or strength of the depolarization events at each synapse depends on the history of activations at each one. In general if a synapse has been depolarized frequently in a short period of time and certain other time correlated events have occurred, the degree of depolarization with each subsequent incoming action potential will be greater (or in the case of inhibition, lower) and that synapse will contribute more to the summation.

### 6.3.3.1 Level 1 Decomposition – Message Processing

At level 1 of the decomposition we are primarily concerned with three basic subsystems. These are the set of synapses (perhaps arrayed in subsets by dendritic spines), the

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[8] In truth this is a little over simplified. Some channels are activated by the currents of sodium ions flowing inward. These channels allow for the passage of other ions to flow inward (calcium) and others outward (potassium). See Alkon, 1987; Squire & Kandel, 2009, for details.

polarization/depolarization processing of the cell membrane, and the axonal hillock which triggers the outgoing action potential signal when the total depolarization state of the membrane reaches a threshold value.

We will consider level 2 decomposition of the synapses below. For our purposes in this level 1, we simply note that the membrane acts as a temporal and spatial integrator of all of the synaptic depolarization states. What is important to understand is that the total depolarization of the membrane at any given instant is dependent on the temporal correlation of incoming signals at the synapses. This is how the neuron determines the correspondence between those incoming signals and provides a kind of internal feedback to the synapses that figures into the strength encoding of those that contributed (see below).

The hillock acts as a binary filter. If and only if the depolarization state of the membrane is sufficient will it pass through (and possibly amplify) that state to generate an outgoing action potential. This is how the neuron acts to coordinate its output with its inputs so that only meaningful signals are sent along to other neurons.

### 6.3.3.2 Level 2 Decomposition – Synapse Internals

The workings of synaptic compartments, how they receive and act on incoming action potentials from source neurons, and how they change their efficacy weighting – their response strength – is quite complex and we can only give a brief outline of it here as it pertains to the decomposition of neuron processing. In (Mobus, 2000), section 3 “Biological Synapses” the reader can find a more complete description of the internals of a synapse and a discussion of its dynamics with respect to its short- and long-term responsiveness.

In brief, what are called ‘learning’ synapses are influenced by the frequency of incoming signals. If a burst of high frequency incoming signals is received their degree of depolarization is increased exponentially fast. Each incoming action potential boosts the depolarization state of the local membrane. If the frequency is low, or during quiescent periods, the membrane is repolarized, as if starting from scratch. Now, if during a high frequency burst, while the membrane is maximally depolarized, the synaptic compartment receives a secondary signal (chemical) signifying that the current burst is “meaningful” then a chain of internal chemical reactions takes place which result in the synapse being “potentiated” or, in other words, it does not completely return to the polarized state after the burst is over. That is, the synaptic membrane retains a very short-term memory trace of a meaningful input signal.

If over the course of a short time (but longer than a burst period) additional bursts and secondary signals are received, the potentiation of the synapse is, itself, strengthened. And, the rate at which this new, secondary potentiation decays is much longer. In fact, much much longer.

This is the beginnings of the encoding of a memory trace. With many repetitions of the pairing of an incoming burst and a reinforcing secondary signal (which must come slightly after the primary burst starts) the potentiation of the synapse, that is its readiness to respond to future such signals, is greatly enhanced. The interpretation of this phenomenon is that the secondary signal came from a meaningful feedback, either from the cell itself, or from external sources such as neuromodulators. That means that the primary signal must be associated with the secondary and so its receipt is important. In fact, the author has shown that the primary input signal comes to represent an anticipation of whatever causes the secondary signal and so can be used to encode a causal relation and to be interpreted as a prediction of the latter.

The overall aspects of synapses and their dynamical behavior is discovered in level 2 of the decomposition. We have given a very brief glimpse of what would be found in level 3, decomposing the internals of a synapse.

For a more complete description of these functions and their consequences for learning and behaving see (Mobus, 1994, 1999).

### 6.3.3.3 The Decomposition Tree

Figure 6.9 shows the neuron decomposition tree down to level 2. Further decomposition of synapses (level 3) can be found in the above-mentioned references.

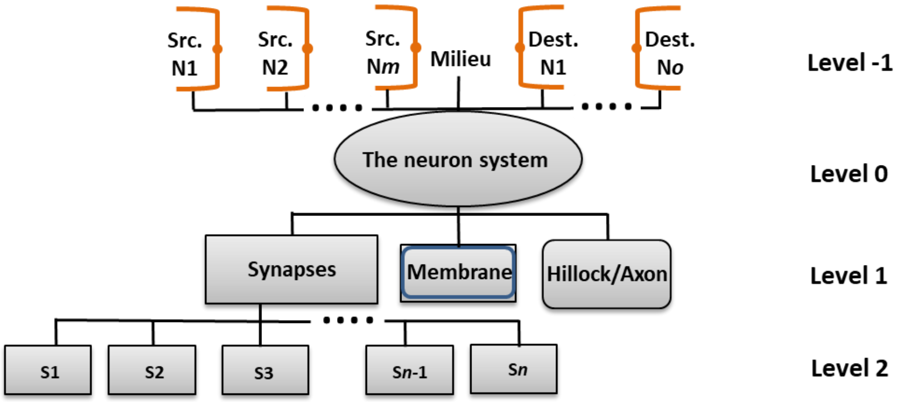

**Fig. 6.9.** The neuron system depicted in Figure 6.8 shown as a decomposition tree

As depicted in Figure 6.9, neurons interconnect in a complex network in the brain. In animals that have cortical structures, especially the neocortex in mammals, brains are able to encode memories of complex perceptions. The brain of animals able to do this kind of experiential learning are, by our definition of evolvable systems, CAESs. Just as with a single neuron, even a cursory demonstration of the use of the deep understanding process on more evolved brains (such as a human's) would require many volumes. These are actually very exciting times for neurosciences, including neuropsychology. New methods for exploring living brains as they process information are making unprecedented progress in analysis of brain functions. Improved methods of histology and neuroanatomy combined with functional imaging (e.g. magnetic resonance imaging – fMRI) data are helping neuroscientists get a much better picture of how brains work. In the following section we will briefly describe some of these methods with respect to understanding the brain as a CAES.

## 6.4 The Brain – A Complex, Adaptive, and Evolvable System

In this section we want to show how the deep systems analysis methods described in the last chapter apply even to an advanced field of science which has already discovered many aspects of its topic, and how that application can act to organize the already discovered knowledge into deep understanding of the whole system. The idea is to use the analytic technique not to discover facts in a science, but to take facts that are already known from the science and insert/organize them according to the structure of Equation 3.1 and as embodied in the deep system knowledgebase (to be described in the next chapter). This is a kind of post-reduction reconstruction of the systemic links between possibly isolated facts in any level of analysis and between the levels themselves. It attempts to reconstruct the systemness of the SOI from the current understanding of the pieces derived from normal scientific inquiry.

All of the sciences, particularly the natural sciences, have proceeded through often disparate reductionist methods to obtain bits and pieces of knowledge in specific realms of their disciplines. What is being suggested here is that the methods of deep analysis and knowledgebase filling using the already known facts of the subjects can help reconstitute the subjects as systems by showing the pathways to reintegration.

The example of the way in which the *Periodic Table* of chemistry has filled this role is instructive[9]. As chemistry became increasingly analytical (alchemy becoming an empirical science) chemist were discovering new atomic entities that had different properties. Thinkers who noticed relationships between element types, such as a progression of unit weights and repetition of forms of reactivity, began trying to organize these elements in some rational tabular form that took into account these properties. This led to the table form we see today, originally credited to Dmitri Mendeleev (1834 – 1907)[10]. Since chemists were working on specific elements, that did not represent the full spectrum of possible elements, gaps appeared in the table. The table itself had a regular format so these gaps were recognized as indicating that some elements had not yet been discovered. That regular format helped to ‘predict’ the properties of the undiscovered elements, especially, for example, what sorts of molecules or crystals the elements might form, which then helped chemist design assays that could isolate the to-be-discovered elements. In other words, the periodic table provided a way to predict the discovery of unknown elements and a structured way to go about their discovery. It was the organization of

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[9] This example has been used by others in a similar vein, but was first introduced to this author by Gary Smith, a systems architect at Airbus Defense and an active member of the INCOSE Systems Science Working Group.

[10] See the Wikipedia article: https://en.wikipedia.org/wiki/Periodic_table#First_systemization_attempts for a more comprehensive history of how the table developed. Accessed 9/29/2019.

the periodic table based on the properties of elements that formed a meta-chemical model of all of the elements.

This is another example of how systems science should be considered as metascience. This method of obtaining systemness in any scientific field, starting with what is already known, may provide the kind of roadmap to discover the gaps, where they exist, and suggest what to look for in those gaps. All of the subjects of the sciences are either systems in their own right, or phenomena that involve systemic behaviors[11] so should be amenable to this approach.

The choice of example, the brain, is made because this organ is lately the subject of intense study, is the mediator of human activity, and because it is representative of an archetype model system, the hierarchical cybernetic governance system (HCGS) that will be the subject of Chapter 11. The reader may want to peruse the subject of that chapter for background, but it isn't required reading to understand the treatment here. Our interest is in how to accomplish the task of deep analysis of a CAES representative system.

### 6.4.1 Brain Science

We will use the term *brain science* to denote the totality of various subfields such as brain anatomy (the gross structures such as hemispheres and lobes), neuroanatomy and neurocytology (the distribution of various neuron types in modular clusters), and connectomics (how neurons and modules communicate). All of these subfields have attacked the analysis of different levels of complexity, more or less in parallel and often without reference to the discoveries in other areas. An exception to this would be the remarkable work of mapping cytoarchitectonic regions to the cortex as accomplished by Korbinian Brodmann (1868 – 1918), a German neuroanatomist. Brodmann mapped out areas of the whole cortex based on cell types and microstructures of connections found there, leading to a set of 'areas' having differences that appear consistent across individuals and, to some degree, across species. Even with this kind of integration across spatial dimensions (from gross anatomy to microanatomy) there are still many holes in our understanding of relations.

Other neuroscientists focus on the functions of regions from whole lobes (e.g. the visual processing of the occipital lobe, the most posterior part of the cerebral cortex) to patches that correspond with Brodmann areas (e.g. rational decision processing associated with Brodmann area 10). There are still many gaps in our grasp of what smaller processing modules are doing in relation to larger areas, but the science of connectomics is starting to fill some of these in[12].

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[11] By phenomena, we mean the subsystem processes that are a part of a larger system process. For example, we can study the flow dynamics of a fluid, the characteristics of which may include turbulence regardless of the fluid type and physical arrangement of the source and sink. Turbulent flow is an isomorphic phenomenon that is found in many different kinds of systems.

[12] Connectomics, roughly speaking, is the application of network theory as discussed in earlier chapters and in Mobus & Kalton (2015), Chapter 4, to neural connectivity between regions of varying scale, both structural (which

The brain is easily seen as a complex adaptive and (with the capacity to encode arbitrary patterns in neocortex[13]) evolvable system. It is the governance system for an individual, for logistical, tactical, and strategic decisions and actions[14]. So, it will provide a good test of the applicability of deep analysis. In the next section, below, we address the issue of brain complexity and how it may be resolved via taking the data already grasped by the various subfields and putting it into the knowledgebase format. There are a number of projects currently underway attempting to build models of the brain. We suggest that by applying the procedures of deep analysis and capture of data in the knowledgebase, described in the next chapter, would greatly advance this effort.

One of the most exciting developments in neuroscience and neuropsychology is the application of systems modeling to the human brain and correlating its workings with human behavior. This is an enormous field of study that we could only feebly present in this volume. Rather we will remark on a few recent developments that demonstrate how the brain and its activities are representative of a CAES.

A key development in brain science has been the development of new instrumentation capabilities, including the ability to visualize living brains as they work and produce behavior. Recall the discussion of instrumenting the inputs and outputs of a system in section 5.5.2.3.1 *Flows, Sources, Sinks, and Interfaces* in Chapter 5. There have been major breakthroughs in instrumentation of the whole brain as well as subsystems (i.e. neurons and networks of neurons). By now most people are familiar with the functional magnetic resonance imaging (fMRI) pictures of activity zones in areas of the brain “lighting up” when the subject is exposed to various kinds of sensory and emotional stimuli. The field of correlating, for example, patient ‘thoughts’ with brain activities has produced some remarkable results, helping to explain many different mechanisms involved in ‘kinds of thoughts.’

But there are many additional imaging techniques that can be used at various scales of space and of time[15]. Some of these allow unprecedented looks at individual neurons (both visually and electrical activity. Others are being employed to map the connectivity between both short-range and long-range modules and regions. The technologies being employed allow non-invasive and non-destructive observation of brain components at multiple levels of organization. This is the

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neurons are talking to which other neurons) and functional (what are the neurons saying to one another). See the Wikipedia article: https://en.wikipedia.org/wiki/Connectomics for background. Accessed 9/29/2019.

[13] In this discussion we are primarily interested in the mammalian brain with the obvious intent to apply this approach to the human brain. However, this approach is as applicable to all animals.

[14] In what follows we will be treating the brain proper as the SOI. The rest of the central nervous system and the peripheral nervous system will be treated as parts of the input-output sources and sinks. Under some circumstances it would be prudent to use the reverse analysis methods of section 5.7.4 *Reverse Deconstruction* of Chapter 5, for example when analyzing the visual system and discovering that ‘eyes’ are actually more complex sensory organs than simple light detectors.

[15] Both temporal and spatial resolutions are still not co-extensive, that is one instrument’s scale does not necessarily shade into another’s that is used to explore a different scale.

ideal situation for systems analysis where we seek to preserve functional relations even as we decompose the structure.

### 6.4.2 Brain Complexity

There are actually several ways to view the complexity of the brain. Figure 6.10 provides a summary of structural and functional complexities that need to be kept in mind when analyzing brain systems. In the figure we show the structural nesting of increasingly smaller componential elements, down to the synapse.

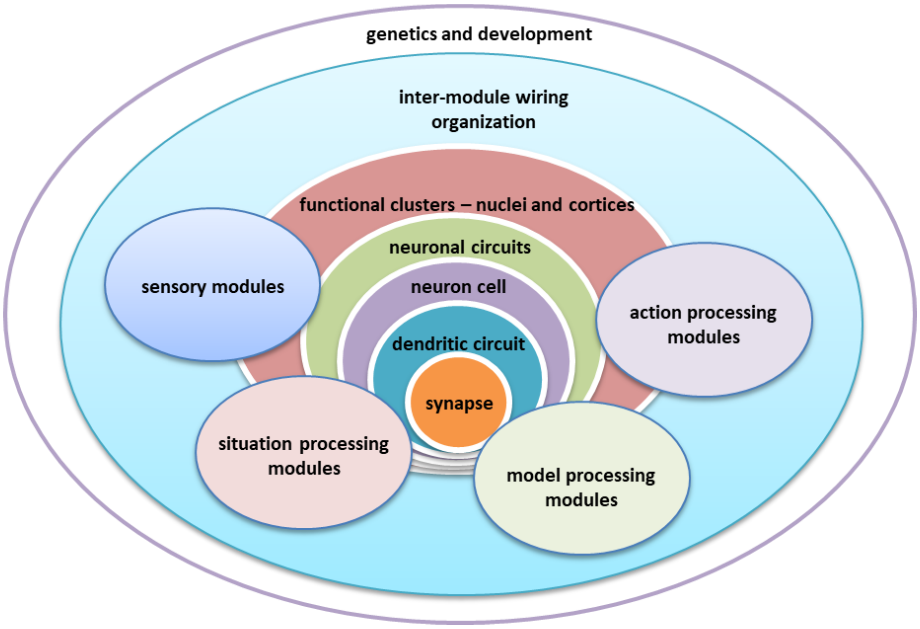

**Fig. 6.10.** Brain complexity can be viewed from the structural hierarchy (nested organization) or /the functional processing modularity.

The brain is an information processing system – a biological computation engine (Mobus & Kalton, 2015, Chapter 8, section 8.2.6). In fact, it is a set of computational modules, each using the same basic processing elements (neurons) but processing different inputs to produce different outputs relevant to the module's purpose. More primitive modules of the brain (see diagram below) are in the form of clusters, often called "nuclei." They receive inputs from various sources, including other nuclei and sensory organs. Their internal 'wiring' determines what they compute[16]. More lately evolved cortical structures are more plastic in terms of their wiring. That is, cortical modules (such as the Brodmann areas mentioned above) are able to encode variations

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[16] In cognitive science the term 'algorithm is often used, but, in fact, these biological computations are heuristic; the term algorithm is reserved for procedures that are guaranteed to produce a specific result.

in patterns of connections based on changing experiences. Cortical modules still have specific processing jobs to do, but many internal options with respect to how[17].

### 6.4.3 Overall Organization – Mammalian Brain

Figure 6.11 provides a diagrammatic layout of the architecture/organization of the mammalian brain. All animals (with brains) have the basic processing capacities to compute appropriate motor/glandular responses to the sensory inputs (both exteroception and interoception). This is the core capabilities of brains. Over evolutionary time, as environments and body forms increased in complexity these basic processing capacities needed to expand to handle the expansion of messages coming from the outside world and the internal body (Striedter, 2005). In addition, as the environment became more complex it also became more stochastic, that is associations between input signals became far less deterministic. Cortical structures, essentially sheets of grey and white matter, using repeating low-level modules (e.g. the cortical columns discussed below) provided a mechanism for encoding variations in associations. Animals could 'learn' associations that might vary over time and place.

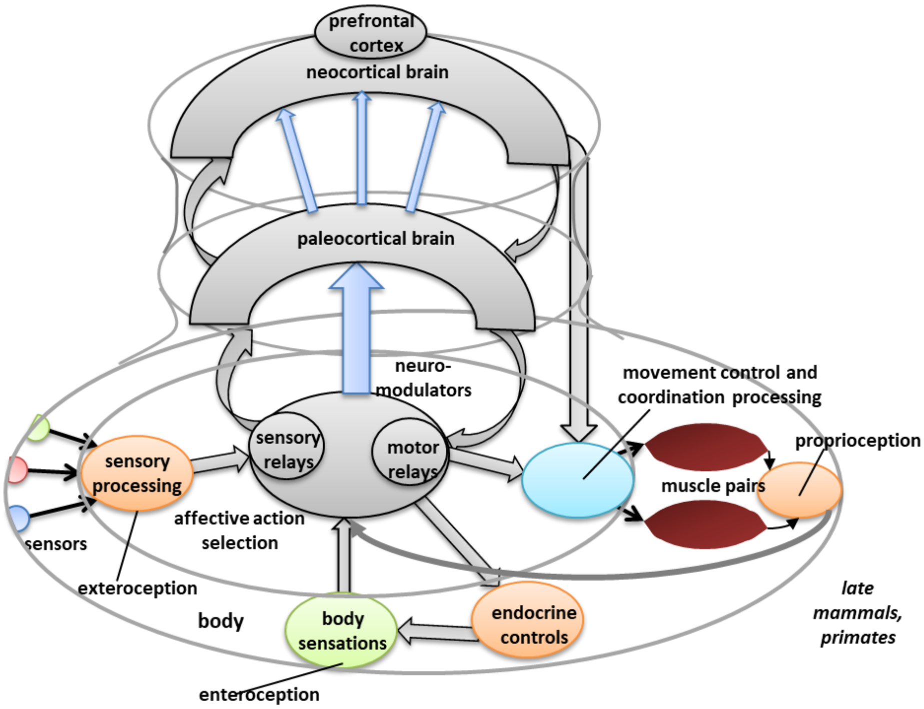

**Fig. 6.11**. The mammalian brain architecture is organized as a series of more lately evolved layers of cortical structures overlaying the basic, limbic, or primitive brain.

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[17] This is an example of the 'law' of requisite variety described by Ashby (1957). See also, the Wikipedia article https://en.wikipedia.org/wiki/Variety_(cybernetics) for background. Accessed10/3/2019.

## 6.4.4 Levels -1 and 0 (Preliminary Look)

In this section we take a look at a partial decomposition map after doing a level -1 and level 0 analysis followed by the start of an internal discovery of subsystems at level 1. Figure 6. shows an outline of the analysis at this stage. What is shown is not following the suggestion in Chapter 5 to start with the outputs (i.e. motor control and glandular control), though that rule of thumb still would apply. For illustration purposes, however, it is easier to show the internal message flow mapping from a sensor (in the retina), through a relay nucleus (thalamus), to the primary vision processing cortex in the occipital lobe.

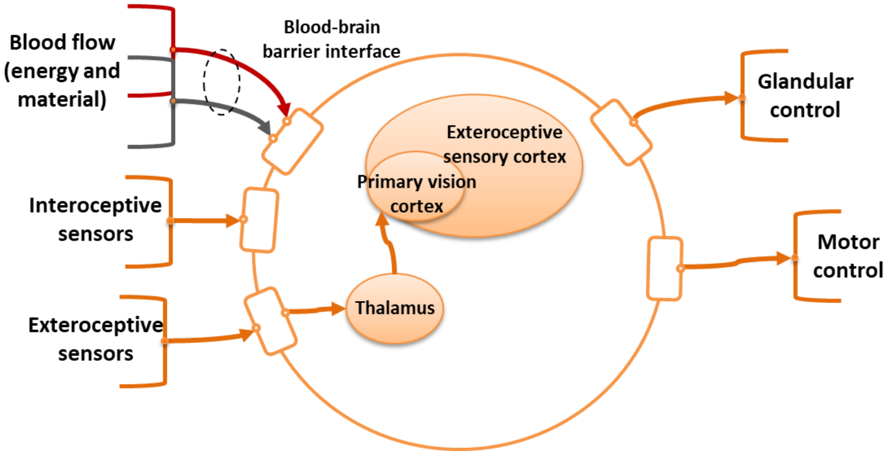

**Fig. 6.12.** The starting point for deep analysis is similar for all systems.

## 6.4.5 The Brain Structural Decomposition Tree

Figure 6.13 should not be taken as complete by any means. Again, it is just representative of the structural decomposition tree that would be produced by the deep analysis. Note that at the lowest level shown (labeled Level ?), many different neuron types are present in the cortical column modules[18]. Every neocortical area (the various lobes) is comprised of very similar columns but the various processing modules, such as Brodmann areas, may have different neuron types or mixes. The columns are organized in several layers that are continuous across the neocortex (think of the cortex as a layered sheet that is composed of side-by-side columns).

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[18] See the Wikipedia article: https://en.wikipedia.org/wiki/Cortical_column for background. Accessed 9/30/2019.

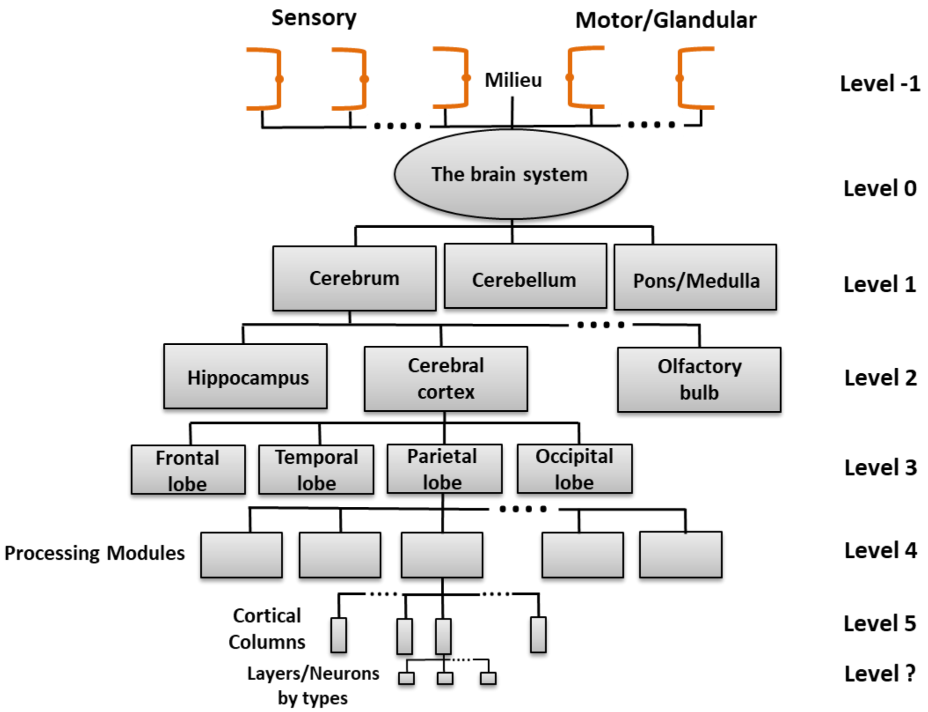

**Fig. 6.13.** A brain system decomposition tree (showing components only) shows the overall organization of the system.

The general way these columns are internally wired is thought to provide the mechanism by which memory engrams are encoded and activated (Hawkins, 2004). Columns in the sensory cortices encode features relevant to the various sensory modalities. Columns in the initial association cortices receive inputs from the sensory columns that are activated by the presence of those features during perception and encode percepts based on correlated features, e.g. roundness and redness are associated in the perception of something that will eventually be conceived as an ‘apple’.

The tree is not complete in that it is lacking the details of neurons, dendrites, synapses, etc. from Figure 6.9. And it should be noted that that figure is not really complete in that each synapse will have a subsequent decomposition tree showing the biochemical components that make it up. This could, of course, be extended down to the atomic level (or even the elementary particle level!) but if the reader recalls the argument from Chapter 5 about what constitutes an atomic process (ultimate leaf node in the tree), then it should be clear that only the specific molecular components of synapses (as with all other aspects of the neuron) need be considered.

Even in its incompleteness it should be clear that something as complex as a human brain can be amenable to a complete deep analysis following the methods given in Chapter 5. The singular advantage of undertaking such a project would be a reintegration of all of the functional aspects of brains with a very likely discovery of insights into how the operations of the brain give rise to the mind and cognition.

### 6.4.6 Behavior

The brain is the mediator of the behavior of the organism. For highly evolved organisms like great apes, and especially human beings, this especially includes social behavior – the ability to work in groups to achieve mutually beneficial objectives and support the lives of all in the group.

## 6.5 The Organization System

Human beings have an ability to be social in a variety of situations. One person can be a member of multiple ‘tribes’ simultaneously, as long as each is different from the others, have different purposes and cultures. A person can be a family member, a church member, a sport team member, and a working member of an organization.

One could reasonably argue that we have more experience with analysis of complex systems in the realm of various kinds of organizations like businesses. This has been the result of the computerization revolution in which business processes, previously conducted using paper-based data processing, were automated starting back in the 1960s. We will not belabor the points of deep analysis for business processes. We simply claim that organizations like businesses and other institutions can be analyzed in the same way that any other system would be. Here we will only reflect on how the analysis of business processes has evolved and then on where things stand today. The reader is invited to apply the methods of Chapter 5 to a business (or other kind of organization) as an exercise.

The form of organizations had evolved gradually over the history of commerce. They have always been hierarchical in nature, with an upper ‘management’ and a set of work processes. In the course of growth, successful organizations needed to expand the breadth and depth of this hierarchy. The best understood subsystems in organizations, and thus least questioned by analysis, were the accounting systems, financial and managerial. These systems had a long history of successful mechanisms for keeping track of assets, liabilities, costs and benefits of operations. So, naturally, they were among the first to be automated by computing systems. Unfortunately, because these systems were so well understood a form of analysis emerged that sought not a deep understanding of the systems (or the firm’s operations they were meant to subserve) but rather on the approach to mechanizing the paper-based methods. The efficacy of the systems was presumed and the only task at hand was to convert the methods to algorithms and reports. The question of the goals of management of the work processes was never questioned.

This approach worked reasonably well for accounting systems, which, as stated, had undergone a long evolution that had already selected for best practices so the assumptions made when automating them were not unwarranted. The problems started to emerge when other management information structures were automated. By the time computers were infiltrating the corporate world, businesses had already become very complex with deep and broad hierarchies. Moreover, many then-current business practices, such as finance and marketing, had not undergone the same kind of evolution and selection of best practices that accounting had. Thus, they were not as well understood. Nevertheless, in seeking increased efficiencies in other parts of their operations, firms sought to automate these other functions, or at least parts of them that would provide managers with the information they needed to make decisions.

Case studies in MIS and other computerization/communications projects attempted to replace paper-based data/information processing. Today, computerization (including informatics, big data analytics, etc.) is the basis of innovative organizational activities (e.g. new services). The perennial problem that computerization projects have encountered as automation projects were undertaken is that the analysis of the organization (or proposed organization) was not deep in any meaningful sense. The analysts hardly looked into the actual operations or functional organization of the firm. They relied almost entirely on the judgements of so-called ‘users’ or ‘stakeholders’ to create conceptual maps of the operations and then attempt to overlay information systems on top of whatever the users told them. And all too often the users were mid-level managers who might not have actually understood some important details of the operations they managed (managers notoriously leave the details to workers). Moreover, managers too often get confused about the nature of the decisions they are supposed to make, and as will be shown in Chapter 11, do not even realize the cybernetic purpose those decisions are supposed to serve. Over the history of business automation, there has been a gradual evolution driven as much by project failures as anything. If one analyzes the way the projects were conducted of both failures and successes one finds that the latter are marked by up-front analysis that delved much deeper into the actual business processes being managed.

The state of systems analysis for business processes has advanced considerably[19]. This is due in part to advancements in process analysis and a much clearer understanding of how these processes actually work, what sort of management is needed, and what information requirements are to support decision making. Today there exists a rich repertoire of process “patterns”, such as supply chain or flexible manufacturing cells that analysts can use to guide their designs with reasonable assurance of producing a good one. It is not necessary, in most cases, to start from scratch.

Even so, as businesses evolve and grow or develop new processes (or new products) there will always be a need to do a deep analysis with capture of knowledge in a knowledgebase to ensure the success of the enterprise. There are two basic reasons that the processes themselves and not just the information needs should be analyzed. First, the design of the process itself may be improved by such an analysis. Second, the actual regulation/control points in the process will be more readily identified and, thus, the decision agents and the “requisite variety” of agency will become visible (see Chapter 10 for an explanation of agent/agency archetype models). That will lead to a management structure appropriate to the process.

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[19] See the Wikipedia article: https://en.wikipedia.org/wiki/Business_process_management for background. Accessed 10/18/2019.

Humans associate and organize work processes – become a system – in order to accomplish a goal, they have a purpose. Throughout history the mechanisms employed for the organization have been more experimental than guided by systems theory. Local-scale organizations (which includes multi-national business and institutions) exist to fulfill their (socially agreed upon) purpose). We cannot say the same for the whole of the human species as a global-scale society/organization. The purpose that humanity serves is either very cryptic or non-existent. In the next section we will start an analysis of the global human social system, the human species along with its accouterments of complex cultures, as preparation for considering a new organization of humanity and a society that might serve an important purpose.

# 6.6 The Human Social System (HSS)

You and I are human beings. That means we are part of the system that is being analyzed. How do we handle the conceptual framework for modeling a system when the observer/modeler is actually part of the system? The methods of scientific inquiry come to our aid. The ideal of scientific investigation is objectivity in observations and analysis of data. Over the last 200 years or so we have learned quite a lot about achieving scientific objectivity even when the observer is part of the system being observed. There are no guarantees per se. But there are safeguards that have been built into the scientific process to allow evaluation of the level of objectivity achieved in any scientific inquiry. Figure 6.14 provides a view of the problem and its solution.

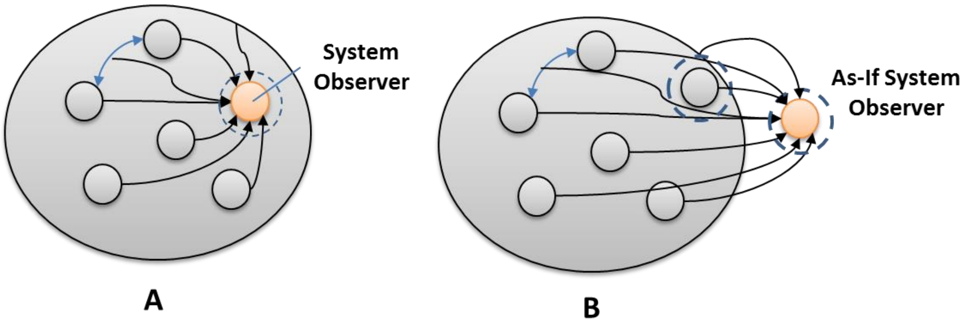

**Fig. 6.14**. The system observer is embedded in the system being observed. (A) The observer may well be able to gather data (black arrows) on the other entities and relations in the system, but does that exclude influences of those other entities on the objectivity of the observer? (B) Can the observer extract itself from the system in a meaningful way so as to pretend to be observing a system as-if from the outside? The figure shows the retention of a surrogate entity representing the observer as they would participate in the system.

There exist now numerous tests of objectivity when making observations of systems in which the observer is a regular participant. Recall, too, from principle 10, (Chapter 1, section 1.3.10) that a sufficiently complex system can contain (or produce) a model of itself. In other words, there is nothing, in principle, that would prevent an ‘as-if’ external observer from being able to construct a model of itself as still being in the system of interest. This, we contend, is the basis for why we human beings, applying the tools and techniques of systems science, can step outside of our own system while maintaining fidelity of the composition and behavior of that system. This is why we can have social sciences and especially a science of economics.

The idea that the whole of the human species, taken along with all of our cultural accouterments, could be analyzed for deep understanding might at first seem daunting, if not completely foolish. On the other hand, the search for understanding of the human condition has been, if not the principle effort, then certainly a substantial effort in human history. While the natural sciences, based on empirical methodologies and mathematical modeling have sought knowledge of how the rest of the Universe works, many of the social sciences have tackled a more qualitative approach to gaining understanding of ourselves and how we conduct our affairs.

Biology crosses the boundary between our animal characteristics and our behavioral characteristics. Many feel this is the case for economics as well. Psychology has been pursued as a natural science with hints of hermeneutics when we had so little understanding of how the brain works. But now we have very rigorous neuropsychology with appropriate analysis tools. So, we are beginning to bridge the seeming gap between biology and psychology. And with that bridging, we are also beginning to see the possibility of a sounder basis for economic science (see Chapter 8 for a better glimpse).

The logic of deep systems analysis tells us that the context or environment of a system of interest is as important to understanding the SOI as the decomposition of subsystems making it up. If we want to understand any subsystem of the HSS, it suggests we must understand the other subsystems as well. We need to understand the larger world system (i.e. the planet), and, indeed, the solar system and galactic system. Fortunately, we can start our analysis at the level of the planet because it is effectively closed to significant material flows (dust and the occasional meteor coming in and some loss of lighter atmospheric gasses). It is open to energy flows, principally from the sun with heat radiated back into space. Thus, a great deal of knowledge about the structures and dynamics of subsystems of the Earth have already been explicated (see Figure 6.x below). We also have significant knowledge about the biosphere and how human beings evolved from earlier hominins.

With this in mind we argue that we can situate the HSS as the SOI within the whole Earth system – the Ecos.

Other authors, notably Immanuel Wallerstein (2004)[20] have already launched programs of analysis of the whole 'world-system,' defined to be the human social system and its embedding in the physical world. They treat the HSS as a system, considering its inputs and outputs from the Earth, and then decomposing its internals deriving the interactions between major subsystems.

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[20] See also the Wikipedia article: https://en.wikipedia.org/wiki/World-systems_theory for more background. Accessed 4/20/2018.

### 6.6.1 Looking Down from the International Space Station – A Brief Examination of the Earth Supra-system

In a thought experiment following the logic of extracting the observer from the system observed, lets imagine ourselves as astronauts aboard the International Space Station (ISS) looking down on our planet.

The Earth planetary system receives solar energy from the sun (Sol). Only a portion of the total solar flux makes its way to the surface of the planet owing to the filtering effects of the atmosphere. The energy that does make it to the surface drives a number of biophysical processes, from the hydrological cycle to the production of biomass. Because the potential complexity of the Earth has not yet reached fully realized complexity (Mobus & Kalton, 2015, section 5.4.2, page 203) the components of the surface are continually rearranging through the auto-organization and emergence cycle (the ontogenic cycle discussed in Chapter 2), bolstered by biological and cultural evolution to generate new levels of organization and complexity of systems. All of this emergence of organization is driven primarily by solar energy, both current real-time and historic or fossil sunlight in fossil fuels, with some contributions from tidal and tectonic cycles. The surface of the planet from several kilometers beneath the continental plates, the oceanic abysses, and up through several kilometers of atmosphere constitutes the active zone of life that through its activities and evolution work to dissipate the energy influx in the form of heat radiated back into space (see Figure 6.15 below).

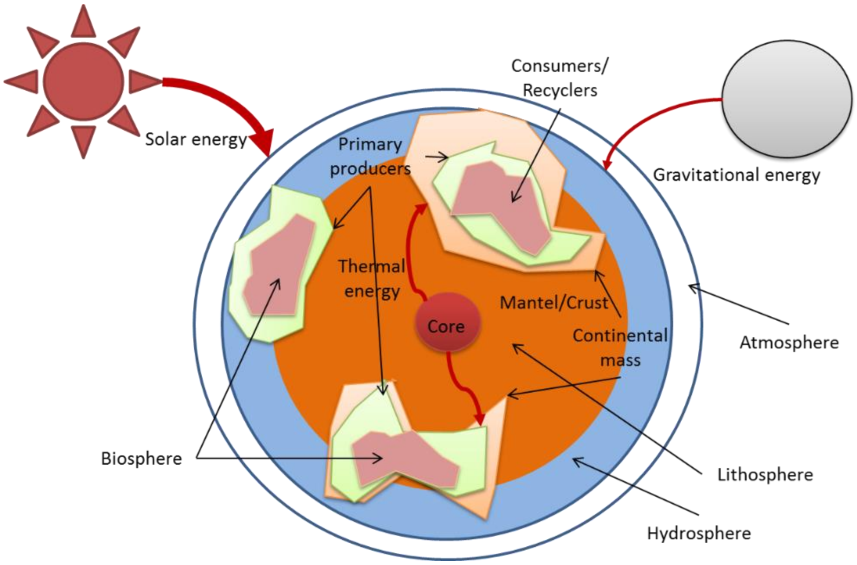

**Fig. 6.15**. The whole Earth system

Imagine that you are an astronaut aboard the ISS, looking out a view port on the Earth below. You see the really big picture. And, since the ISS orbits the Earth, over a few hours you will see the really big picture of the whole Earth. From that perch, you will see continents and oceans, maybe mountain ranges. At night on Earth (in the shadow side from the Sun), you will see clusters of lights, the cities of the world. However, you will not see people. There are no borders to delineate countries. It is possible, however, that you can detect the season of the year by noticing the coloration of areas on the continents. The Northern Hemisphere may seem greener during the summer months and browner in the winter. You can detect changes even with the naked eye.

This is actually a very good perspective to start a systems analysis of the systems that are of prime importance to humanity. The whole human enterprise, viewed as a system, is embedded in the Earth as its supra-system. We need to adopt a perspective that will ensure that we do not miss anything when we analyze the human system as a whole. Systems analysis is a process of digging into the details of a whole system from a preliminary perspective looking down on the whole. We have to start there in order to understand how the system is affected by its environment. We will do this in stages from the satellite view down to the subsystem view within the human system.

In Chapter 8, we will examine a very important subsystem for humanity, the economy, and demonstrate how the use of systems analysis as was covered in Chapter 5 will produce some important insights into how the world works not previously shown by classical economics[21]. In essence, our approach is to start afresh in constructing a science of economics. We will not be repackaging classical concepts from economics, such as Adam Smith’s description of the “invisible hand” or supply-demand curves. We will be tackling the problem of gaining understanding of this subsystem by starting from the high-level view of the whole human + culture system and deconstructing it without any preconceived notions of what we will find.

In this section, we will provide the environmental analysis for the economic system, the human social system. Our approach will be slightly different from the kinds of analyses previously discussed. We already know that the economy is embedded within the HSS and has extensive interactions with the other Earth subsystems. What we will do here is take a quick look at the whole Earth system, and then consider the HSS as a subsystem within that. This will set us up for the analysis of the economic system in Chapter 8.

### 6.6.2 The View from a U2 Spy Plane – The HSS

Having seen from the ISS that the human system can be seen from space, we now come down in altitude a bit to see some more details of what that means. Humanity is unlike any other species on the planet. It covers the planet and it has an exosomatic (outside the body) conglomeration of artifacts that dominate the scenery – it has a culture, defined as the set of artifacts, institutions, and behaviors, that has a major impact on the whole Earth. From this height we still see large aspects of the human system, but are starting to see some interesting

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[21] Today, economics is called “neoclassical” economics in an attempt to ameliorate classical economics (from the 19th century) with modern findings relevant to modernity.

details as well. We see that the human + culture system is comprised of many various subsystems.

## 6.6.3 The Human Social System in the Earth Supra-system

The seeds for obtaining a modern, systems approach perspective already exists in the work of Immanuel Wallerstein (2004, Chapter 2), which he calls “world-systems analysis.” By ‘world-system’ Wallerstein is referring to what we have called the HSS, the human social system. His approach isn’t quite the same thing as a deep systems analysis as promoted by this book, but it is guided by systemic thinking and he treats the world-economy as a whole, breaking down various components, such as markets and other institutions, as subsystems in a way very similar to what is being explored here. Thus, our efforts can be foreshortened by this previous work and we refer readers to it for clarification.

The human species is a monolithic genus (only one extant species) that occupies every continent and habitable island on the planet. In modern times, with travel and communications technology that we have, almost all human beings are in potential contact with all others, even if indirectly (since you are reading this you are likely a mere six degrees of separation from the film actor Kevin Bacon!)[22] Though there are still groups of humans living not too differently from our Stone Age ancestors in various pockets of the world, even they are affected from time to time and in various ways by modern technological societies. It is reasonable to argue that the human population of Earth constitute a single social unit over the long term. Figure 6.a shows a simplified model of the HSS[23] situated in the Earth system, which we have called the “Ecos,” a term derived from the Greek for ‘home.’

The HSS is, so to speak, a fully owned subsidiary of the Ecos[24]. Our entire existence depends on the physical nature of the Ecos, and its relative stability over the life of our species. That latter point cannot be too fine. Relative stability means that the major attributes of the Ecos, the climate variations, the pH of the oceans, the tectonic activity of the mantel, the major gas and hydrological cycles, and many more, must operate within narrow ranges that are conducive to life. The planet Earth is, perhaps, uncommonly fortunate to be the right mass and composition, situated in the ‘Goldilocks’ zone in the solar system, and orbiting a star that has been relatively stable itself over the four and a half billion years since its early condensation from the debris ring circling the sun[25].

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[22] See the Wikipedia article: https://en.wikipedia.org/wiki/Six_Degrees_of_Kevin_Bacon.

[23] Another term we will use for naming the HSS is the Anthroposphere. This term refers to the human species, but also our cultures, artifacts, and impacts on other systems in the Ecos (e.g. the atmosphere and hydrosphere). We will use these two terms interchangeably but more often go with HSS since it involves fewer characters!

[24] A phrase (paraphrased) attributed to the economist Herman Daly.

[25] At the time of this writing a number of Earth-like planets have been discovered in orbits around their stars that put them in their Goldilocks zones. By the time you read this we may know if any of those planets harbor some form of life!

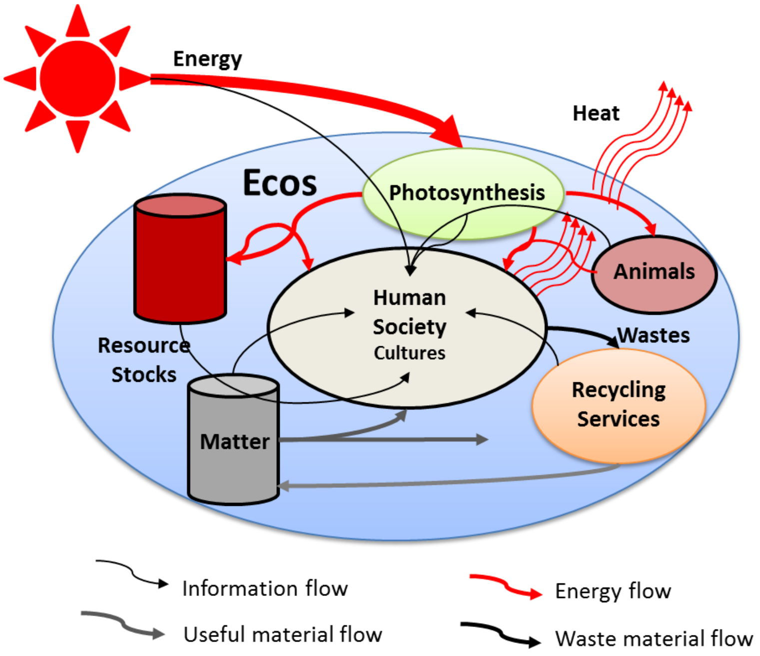

**Fig. 6.16.** Human society is a subsystem within the Earth supra-system, which we have called the "Ecos." Shown within the HSS is the very important sub-subsystem of "Governance." This will be the subject of Chapter 11 and will be discussed in overview in this chapter. See the text for details.

The Earth is effectively materially closed as a system. However, it is open, within the spectral window of radiation supplied by the sun and filtered by the atmosphere, to energy flows. That spectrum turns out to be optimal for driving photosynthesis as the primary basis of all life[26]. The flow of energy through the Earth system is the source of organization motivation (doing work) that drives biological evolution (Morowitz, 1968, 1992, 2002; Schneider & Sagan, 2005).

The HSS depends entirely on the material and energy resources afforded by the Ecos. All of the biological resources (food, wood, fiber, etc.) are renewable from the flows of solar energy being transformed into biomass through photosynthesis. Our current reliance on hydrocarbon and carbonaceous fuels are based on stocks that were stored in the Earth's crust in the distant past. They too came originally from biological sources that were buried in sediments and 'cooked' into their rich carbon and hydrogen compacted energy sources (c.f., Crosby, 2007, esp. Part II). The atmosphere and hydrosphere, along with soils, provide the gasses and water necessary for life. The tectonic activities of the Earth's crust provide a long-term recycling system that has produced the minerals that humans have come to rely on for metals and other elements that allow us to develop modern technologies.

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[26] Living systems derive primary energy from multiple sources. At present we have discovered that deep ocean hydrothermal vents provide a source of energy for a whole ecosystem that extracts energy from hydrogen sulfide spewing from the vents. See the Wikipedia article: https://en.wikipedia.org/wiki/Hydrothermal_vent#Biological_communities.

The Ecos is all we get for the time being. We have to find out what it needs from us (the HSS) in terms of a purposeful product[27]. We have to find out how to live in balance with the various cycles of resources and waste absorption that act over many different time scales.

Our sciences have made significant progress toward acquiring this knowledge. We have the broad outlines of what we should be doing to live successfully on the planet. In some cases we have very definitive knowledge. However, our knowledge of the real workings of economics as the fabric of our HSS contains many “beliefs” that are in contradiction with the scientific knowledge. For example, the neoclassical belief that an infinitely growing economy, as measured, for example, by year-over-year percentage increase in the Gross Domestic Product (GDP), is the ideal case[28]. This stands in stark contrast to the scientific fact that no system can grow indefinitely in a finite world. Every known biological system reaches a maximum size consistent with its access to flows of resources and its interactions with the rest of its environment.

Figure 6.17 translates the depiction in Figure 6.16 into the graphic systems language. The sources of our resources are shown as environmental entities along with the waste and heat dumps used. Resources that are technically renewable, e.g. plant and animal inputs, are dependent on solar energy and as living systems they are continually renewing their biomasses as energy flows through the ecosystems that support them (including farms). They are technically renewable but only if the draw-down rates are no greater than the production rates. Otherwise these resources become “flow-limited”; they cannot provide more resource than the rate of energy flow and the recycling rates for their material inputs.

Also shown in the figure is the character of the stored resources of energy (hydrocarbon fuels) and materials, such as ores and minerals. These are what are called “stock-limited”; they can be used up.

The figure is a cartoon representation of an environment and boundary analysis aggregating all inputs and outputs of each type into single arrows as well as sources and sinks being aggregated. The next step would be to begin deconstructing the environmental entities and the flows into individuated entities and flows. For example, the stored energy source would be divided into, say, the three major fossil fuels. The interfaces on the boundary of the HSS are likewise aggregated representatives of the means by which the flows pass the boundary.

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[27] Recall the discussion of purpose in Chapter 2. Long-term stability of a system depends on the fact that subsystems fulfill a function that contributes to the whole system.

[28] This is the case of exponential growth or compound growth. The latter sounds great when you are talking about money in the bank, but a very simple calculation would quickly show that the concept is absurd in the limit.

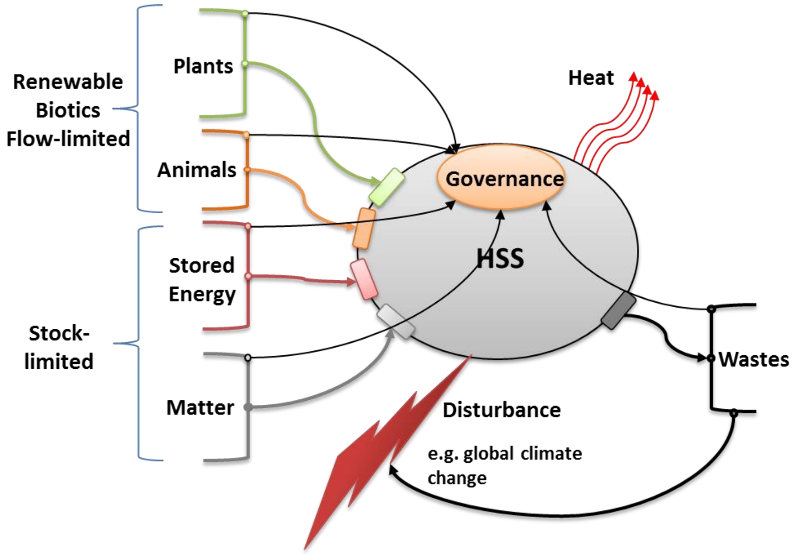

**Fig. 6.17.** The system language (graphic form) view of the HSS as the SOI. The Ecos has been reduced to those resource inputs and waste outputs in the environment of the HSS. As in the previous figure, we show the governance subsystem receiving messages from the external systems. The governance subsystem will be using the information in these messages to make decisions on what the various internal work processes in the HSS should be doing. Also shown is a representative disturbance (global climate change) resulting from HSS waste disposal ($CO_2$) into the atmosphere.

In the case of fossil fuels, the supply is considered essentially fixed and definitely finite. Material resources are limited by the quality of the matter. For example, ore quality has to do with the concentration of the desired resource in the rocks from which it is extracted. The physical processes of the lithosphere that tend to produce concentrations that are valuable operate over geological time scales. Therefore, if the rate of extraction exceeds the rate of replacement, then these materials are also flow-limited. This does not consider the possibility of recycling the material, which we will consider later.

Notice what is not shown in the figure. There is no “product” or “service” output from the HSS returning something of value back to entities in the environment. The reason it is not shown is that there would seem not to be such an output, at least not one that is sufficiently significant. Recall from Chapter 2, the section on Purpose, that every subsystem within a supra-system has a function to perform that provides product or service to other subsystems such that they are fit for their environment (the environment will provide useful resources through feedback loops or select against the subsystem that fails to meet its obligations). The HSS, both in its extraction of raw resources from the Ecos and its depositing its wastes (many of which are completely foreign) in the Ecos, is changing the world in ways nobody intended when they started doing so. The current scale of the HSS and the rate of its extraction/deposition processes are so great that geophysicists are seriously considering naming the current period the Anthropocene[29]. The HSS is producing effects in the Ecos but as of the present such effects seem largely negative.

What the HSS does for entities in the Ecos, such as the plants and animals (the biosphere) that might pass as some kind of service is to attempt the protection of some "hot spot" ecosystems in order to preserve species diversity[30]. But this is really just mitigation of damage to ecosystems already done; a reaction to perceived damage. The "management" of certain natural resources, as in various national parks and forests, is another attempt to provide a service, but it is currently based on fairly weak models of what that management should entail. For example, forest management, in the recent past, has included preventing fires that would burn out the understory fuels on a fairly frequent basis on the fear that any fire would be bad for the forest. The result was a buildup of those fuels such that when a fire did get started, it would burn the trees worse than had they allowed many small fires to burn. When fires ran through forests under nature's management, the understory was kept low and thin so that major fires could not destroy square miles of forest trees. The good news is that human foresters are learning this about forests and there is a shift in fire management practices[31].

**Question Box 6.x.**

What product or service should the HSS produce that would benefit the entire Ecos? Do wastes from the HSS constitute some kind of "product" of value to the Ecos?

Figure 6.17 also shows the flows of messages from entities in the environment to the governance subsystem of the HSS. The latter is considered as the agent that makes the decisions about how the HSS should behave relative to the resources and waste dumps. The messages received provide some information regarding the quality and capacity of the resources and their flows. In theory (see Chapter 11) the agent will regulate the internal operations of the system in order to not cause stresses in the supra-system. As we will discuss in Chapter 11, we humans have not done a stellar job of this function so far.

In Chapter 8 (see in particular Figure 8.1) we will decompose the HSS SOI into a few fuzzy subsystems. One of those systems is the economic system. In that chapter we will then further decompose the economic system as we find it today (though we will consider its history as a combined intentional and evolutionarily designed system – see Chapter 12 for consideration of human design processes). Since our objective is to demonstrate the analysis of complex systems

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[29] This proposal is in serious consideration and may even have been adopted by the time you read this. We will be discussing this subject in later sections.

[30] See the Biodiversity Hotspot Wikipedia article: https://en.wikipedia.org/wiki/Biodiversity_hotspot for a definition and explanation of the attempts at conservation. Accessed 3/8/2017.

[31] See, for example, this Wikipedia article regarding the forest fires in Yellowstone National Park: https://en.wikipedia.org/wiki/Yellowstone_National_Park#Forest_fires.

and not to necessarily explicate all aspects of the HSS economy, we will only begin the decomposition process in that chapter. We will, however, return to the idea of designing a well-working system (a better social system as a sustainable complex adaptive and evolvable system) in Chapter 15 where we will use concepts discussed here and in Chapter 8.

The HSS has already left it's not-so-positive mark on the Ecos. The proposal to rename this era the "Anthropocene" is based on the deposits of human artifacts throughout the world. Currently the distribution of plastic particles provides a telltale marker of non-biological processes that may prove to have biological consequences. The fact that we humans are recognizing the possible consequences is heartening. If we can come to deeply understand the governance subsystem for the HSS (Chapter 11) we may find a way to moderate our collective behaviors if not actually find a purpose for our existence in the Ecos.

This section has presented a preliminary approach to the analysis of the HSS just to show that such a deep systems analysis is, at least in principle, feasible. Already, the social sciences have made inroads in their siloed analyses (see: Bourke, 2011; Miller & Page, 2007; Mobus, 2018;  Polanyi, 2001; Rothschild 1990; Sawyer, 2005; Scott, 2017; Simon, 1957; Tainter, 1988; von Neumann & Morgenstern, 1944; Wallerstein, 2004 for a sweeping overview of findings in a number of these silos).

## 6.7 Summation

Everything in the Universe that can be described using the formulation given in Chapter 3 (Equations 3.1, 3.2, 3.3 and subsequent) is a system and can be analyzed accordingly. The methods of deep analysis, meant to lead to deep understanding of real systems can be applied to any kind of system, though one can argue quite reasonably that the ordinary sciences have done and are doing adequate analysis of the phenomena they investigate, but this is based on the fact that most such phenomena are relatively speaking, simple or merely complex. The deep analysis procedures given in the last chapter are not significantly different from ordinary scientific analysis (e.g. dissecting a formerly living system and probing the physiology of a still living system). Ecologists have been practicing a form of systems analysis almost from the beginnings of their discipline. What makes the Chapter 5 methods different are three things. First, the procedures are based on systems principles and are formally algorithmic (as opposed to the scientific method which is more heuristic). Second, the discovery process is associated with the capture of relational knowledge as it unfolds (see next chapter). And third, because of the isomorphic quality of the formulation mentioned above across all systems, these methods can be applied as well to complex adaptive and evolvable systems regardless of the level of complexity.

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