Chapter 2 – System Ontology

Abstract

Given the physical history of the Universe as we understand it now there are a number of questions we need to address having to do with how 'things' come into existence and how is it that things seem to be getting more complex over time, going from the fundamental particles and energies that seem to have been created in the Big Bang to systems like the Earth and its complex 'spheres'. What exists is a matter of record. How the Universe proceeded to evolve toward greater complexity and organization is another matter. The things are organized into categories based on similarities and differences. That organization points to a hierarchy of complexity.

In this chapter we will propose an ontology of systemness that accounts for the organization. We say 'an' ontology because there have been many attempts throughout human history to establish such an organization. This chapter focuses on an ontology that is guided in formation by the principles of systems science covered in the last chapter. Again, this is not a first such attempt. We will acknowledge a few more recent attempts in this chapter but will not present a history of the developments in ontology as this can be found in many sources.

In all such ontologies the starting point is a metaphysical perspective, a point of view or world view. As metaphysics, one has to assert some basic 'substances' that are universal in nature and make commitments to derive all that exists from those. We start the chapter making such commitments at the most fundamental level of existence and then derive all else from there. The process that leads to increasing organization and complexity is essentially a universal evolution, which is an evolution theory that is not just about living systems. We call it "Ontogenesis" and describe the mechanisms (like variation, combination, emergence, and selection) that generate new things and new levels of organization. This is done in preparation for elaborating a systems language (names of the things and their dynamic relations) to be pursued in the next chapter.

2.1 What Exists

Ontology is the study of what exists. Its objective is to identify and name those categories of 'things' that are found in reality[1]. It is not concerned with specific instances of things themselves, e.g. your pet dog. Rather it is the "about-ness" of things, e.g. your dog shares many characteristics with every other dog, a group of characteristics we might call 'dog-ness'. It

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[1] We need to clarify that ontology is not just a list of things that exist, it is a guide to fundamental existence (the most basic things that exist) and to how other more complex things composed of these can come into existence. We are concerned not only with a claim of what basically exists (e.g. quarks) but what can be generated into existence from those few basics.

involves things that are general in nature, not specific instances of those things. For example, a biological entity that has some level of volition, it moves in order to obtain food, is an animal. Animals, defined by a set of properties (such as volition) exist. There are numerous instances of animals, from simple flat worms to whales. The concept of an animal is a category[2]; ontology deals with categories given names for identification purposes. More general categories sit atop a tree graph, sub-categories are linked below. The implication of the linkage is that the lower category is a type (or kind) of the higher category. A good example of an ontological category tree is the one implied by the animal example – a phylogenetic tree[3]. The root of the tree is the most general category, e.g., 'Animal' (kingdom) with all of the kinds of animals (phyla, e.g. vertebrates) forming nodes linked to it. Each of these then has subsequent sub-sub-category nodes (classes, e.g. mammals), and branching further down (see footnote 2) to yet lower levels (less generality). The lowest category in this tree is the species[4]. So we have, within the tree the logical relation, 'IS-A-KIND-OF' from the bottom up – a pet dog is a kind of canine, is a kind of mammal, is a kind of vertebrate, is a kind of animal.

The philosophical study of ontology delves into questions such as: "How do we know these characteristics define a category?" Or: "Is this characteristic particular to this category?" Or better still: "Is this a valid characteristic, and if so why?" For the most part we will leave these kinds of questions to the philosophers[5].

The concept of 'an' ontology is adopted in the field of information science primarily for the purpose of categorization and logical linking as in the above example of 'IS-A-KIND-OF'. In the computational world of information science the purpose of what is called "domain ontology" is to represent knowledge in a *computable form*. That is, the representation should be able to be

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[2] We will be using concepts from a field of mathematics called category theory. However, we will not delve into the more arcane aspects of the field. In Chapter 3 we will be developing a mathematical description of systems using set and graph theories. Those familiar with category theory will grasp the derivations. Our position, for the present, is that category theory is a little 'too' abstract for the development of a theory that can be grasped by the average reader – for whom this book is intended. For readers interested in knowing how to apply category theory to the structures we will be exploring, see the Wikipedia article: https://en.wikipedia.org/wiki/Category_theory for a basic explanation and lots of links to external resources.

[3] See the Wikipedia article: https://en.wikipedia.org/wiki/Phylogenetic_tree. Accessed: 10/4/2017. Note that phylogenetic trees generally are represented as branching upward. At the risk of confusing the reader, this differs from a conceptual tree which inverts the relations in having the root above and branching downward. There is no real difference in these representations. They come from different disciplinary origins (i.e. biology vs. logic). Yet another example of how systems theory is meta-theory for science!

[4] The term species is not quite as cut and dried with respect to categories. There are sub-species, and hybrids that can cause a little confusion. In the next chapter we deal with the notion of such fuzzy situations using fuzzy set theory.

[5] Consider, for example, the concepts put forth by philosopher Roberto Unger (Unger & Smolin, 2015) who asserts that ontology in philosophy is ultimately an empty concept. He holds that everything in the Universe is subject to change, including the 'laws' of nature; time being the only inclusive aspect of the Universe as a whole. What he proposes instead is a 'proto-ontology,' with three basic 'attributes' (section starting on page 239). The first is an existence postulate – something has to exist. The second is a plurality postulate – there has to be more than one kind of anything. The third postulate is that everything that exists must be connected causally. These three postulates are fundamental to systemness.

manipulated with time efficient algorithms to derive new knowledge[6]. The approach taken in this book is something between the philosophical and the computational one. The reason will become much clearer toward the end of Chapter 3 and as we use the language of system developed there to work with concrete systems. Basically, we assert that the language/ontological representations need to be a hybrid between algorithmic computation and natural language so that the ideas of systemness can move freely between the world of computer simulations and human understanding.

One thing that needs to be stated clearly, at this point, is that 'an' ontology cannot make a claim of truth – that the things and relations declared to be existing truly are the things and relations that truly do exist. Or more to the point, these are the only things that exist and matter. Any ontology is just a 'best guess' based on hopefully unbiased observations. What is being claimed is not ultimate truth but a *commitment* to a set of categories and relations that are treated as complete and internally consistent. Any metaphysicist is free to make other commitments and then show how those lead to our phenomenal experience of reality. For once commitments have been made, it is what we do with the sets subsequently to build descriptions of the world. Once the commitments are made, we can then turn attention to the nature of knowledge and how it is acquired, to epistemological pursuits. We begin this chapter with a few commitments to what we believe is the fundamental underlying nature of reality and how that nature gives rise to the things and relations we actually find in the Universe (ontogenesis). We then use the logic of ontogenesis (section 2.3) to derive the systems that have come into existence in the history of the Universe, how those systems give rise to new, more complex systems, and that produces all of the things that exist today (that we know of).

The purpose of this chapter is to explore and develop a system ontology in the service of developing a language of systems in the next chapter. The terminology developed in this chapter will form the basis of a lexicon and syntax of this language (Chapter 3) and establish the semantics of that language, its meaning with respect to descriptions of systems in the real world. The language will be used to build our knowledge of the world and how it works.

Before developing a means of saying what exists we need to consider several higher-order concepts that shape our thinking about systems. These concepts are at once phenomenological, that is we can perceive their reality, and metaphysical, that is they exist outside, above, and beyond our merely phenomenological treatments of things that exist.

The first is what we will call the 'category' of things. Categories are abstract types of things. A common example of categories is the phylogenetic tree of life. The binomial nomenclature method of naming species is predicated on a hierarchy of types. We humans are a type of primate. Primates are a type of mammal, and so on.

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[6] See the Wikipedia article: https://en.wikipedia.org/wiki/Ontology_(information_science) for background.

The second concerns the reappearance of certain patterns of forms and relations throughout the hierarchy of organization – the levels of organization[7] from sub-atomic particles and forces to atoms, to molecules, to geophysical and biological systems, and so on. There are a set of archetype patterns that recur at all of these levels. These have been labeled ‘isomorphies’ in that they seem to possess the same formal structures and functions whenever they occur. A deep form of an isomorphy is the existence of networks or objects that are composed of components that have strong interactions with one another and can be represented in graph theoretical terms. This form can be found at all levels of organization in nature and dominates human system designs (c.f. Mobus & Kalton, 2015, Chapter 4).

2.1.1. Categories and Type Hierarchies

Below we will argue that the nature of the process of ontogenesis naturally produces a hierarchy of elaboration of patterns we recognize as categories. As mentioned above, humans are a kind of primate. There are, extant, many concurrent versions of primates that are the leaf nodes in an evolutionary tree, having arisen from a common primordial primate archetype. Humans are contained within the category of primate (actually in the category of hominin which includes our cousin humans such as *Homo neanderthalis*). Primates are a *type* of mammal. The terms category and type are somewhat interchangeable with caution[8]. A category is a generalized grouping of systems that have a subset of similar characteristics. All mammals, for example, have hair and the females possess mammary glands for lactation and feeding the young. If you are asked to ‘categorize’ an animal that has hair and mammary glands, you would put it in with mammals. At the same time, mammals are a type of animal (and animal is a category). So, the distinction between type and category can be difficult. Our position is that we will not try to make a distinction explicitly. What is important is to recognize that types represent evolved individuations from categories. The latter are recognized by us humans from a process of inductive learning whereby we find representatives possessing common traits and lump them together into said categories.

Ontogenesis, the process of construction of things, as described below, is what gives rise to type hierarchies and subsequently our notions of categories.

2.1.2. Patterns and Isomorphies

We find, in the elaboration of what exists in the Universe, repeating patterns of process and form at each level of organization. For example, we will find that certain work processes such as ‘combining inputs’ or ‘temporary storage of substance’ are repeated at molecular or societal levels of organization. As mentioned above, the use of networks is replicated at all levels of

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[7] For a graphical view of levels of organization, along with an explanation of their dynamics, see Volk, 2017.

[8] In the dictionary they are considered symmetrical synonyms. The explanation given by WikiDiff does little to clear up the semantics and usage. See the WikiDiff explanation: https://wikidiff.com/category/type. Accessed 8/9/2018.

organization. We will argue below, in the section on ontogenesis that this is a natural consequence of the way systems are composed at the different levels of organization.

There are a set of universal patterns of organization that will be found at whatever level of organization we explore. In this book we will use the concept of an archetype model or a generalized (and abstract) model of process that can be shown to be applicable to any level of organization with appropriate elaborations. As an example, consider the notion of an *economy*. In later chapters we will demonstrate that the concept of an economy is a universal pattern of how energies and materials interact to produce stable, sustainable complex adaptive systems. Those systems emerge from the same process of ontogenesis we have been alluding to. They seem to be natural consequences of the process. In anticipation of our explication, we assert that metabolism is a fundamental form of an economy and that what we call 'the' economy of human society is nothing more than an expanded version of metabolism at an obviously larger scale of organization.

2.1.3. Origins of Things – A Universal Process

Where do hierarchies of organization come from? Why are cells complex organizations of biochemical processes (e.g., metabolism)? Why are communities complex organizations of humans, who are, in turn complex organizations of cells!? Indeed, how do 'things' come into being and, over time, the complexity of things increases? Our answer is a that a recursive process of auto-organization, emergence and selection, and evolution (variation and selection) operates from the most simple level of organization (quantum fields) through successive levels of organization (typified by the interests of the sciences, i.e. sub-atomic, atomic, molecular, etc.) to produce the Universe we see today (Mobus & Kalton, 2015, chapters 10 & 11; Volk, 2017; Morowitz, 2004; Smith & Morowitz, 2016; Bourke, 2011).

When the Universe was 'born' it was a super-hot mixture of fundamental particles and energies (we don't really know what these were, strings, monads?). Somehow, as the Universe expanded (through 'inflation' then 'ordinary' expansion) and cooled, matter condensed. Matter interacted with energies (photons) and having inherent interaction potentials formed structures under the influences of gravity, strong and weak forces, electromagnetic attraction/repulsion, and radiation. From the very beginning the Universe engaged in a process of *ontogenesis* – the process of combining lower-level entities to form complexes that could then interact at a higher scale – that led to the origin of living forms (at least on one planet we know of for certain; see section 2.3 below). Living forms continued the process of ontogenesis to form multicellular forms, and then societies. Human societies created cultures, a combination of biological and technological complex systems[9].

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[9] Tyler Volk (2017) has described a clear progression of increasingly complex stages on what he calls the "Grand Sequence" from free quarks to our current states of civilizations. He calls the process "Combogenesis" wherein ontological elements within any stage (e.g. quarks, nucleons, atoms, molecules, prokaryotic cells, etc.)

Universal evolution appears to be driving matter and energy toward greater levels of complexity. This in seeming opposition to the nominal account of the increase of entropy. In fact, so long as stars produce energy flows that affect disequilibria (i.e., energy gradients) in planetary systems there will be a drive toward greater organization. Locally, entropy decreases as life evolves elaborately. Globally, i.e. the whole Universe, entropy increases as it should. There is no contradiction. High potential energy does work to increase organization at the microscopic level of life on a planetary surface even while the Universe tends toward equilibrium (Morowitz, 1968).

2.2 What is ‘a’ System Ontology, and Why Does It Matter?

We have claimed that systemness, the ‘property’ of being a system, as described by the twelve principles in Chapter 1 and to be formally defined in the next chapter, is the fundamental organizing principle of the Universe. This is a very audacious claim on its face. So, it will be prudent to examine the basis of this claim because it is fundamental to everything that follows.

One way to see how this claim comes about we will describe the process of auto-organization of smaller, simpler system objects into larger, more complex systems with emergent properties and behaviors. Once stable properties and behaviors have come into being, the cycle of auto-organization and emergence at the next higher level of organization proceeds. This is the grand cycle of universal evolution that occurs on all levels of size and time. This is what we call ontogenesis, the evolution of forms of organization that become progressively more complex over time. The Universe that we observe today, especially our own world, came into being by this process.

If the concepts being explored by cosmology and quantum physics are reasonably close to reality, then the cycle would seem to “start” at some fundamental scale (the Planck scale?) of space and time with pre-particle entities (Unger & Smolin, 2015). These have attractive and repulsive interactions that lead to primitive structures (perhaps quarks and leptons) with emergent properties and behaviors. Those, in turn, led to interactions resulting in the particles of the Standard Model (or something reasonably close to it). And then everything from that point on is, as we say, history. This description may recount the bootstrap of physical reality. However, much research is needed to be done to reveal it. For our purposes we will need to assume that something like this had to have happened to get the whole process started[10].

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interact with one another forming combinations that effectively become the new entities at the next stage. So quarks combine to form nucleons and the latter combine with electrons to become atoms, and so on up the sequence. This is the same process as described in Mobus & Kalton, 2015, and again later in this chapter. See Section 2.3.2.2 below.

[10] Parenthetically, we harbor a suspicion that a key to understanding sub-atomic phenomena (quantum world) might very well end up being helped by systems science! But also large-scale phenomena like gravity. It is amusing to think that a resolution to the ultimate amalgamation of quantum and gravitational theories might have a root in systems thinking!

Regardless of the details at the quantum level, the fact is that the Universe has evolved into a very complex and complicated place. Here on our planet Earth that evolution has included the emergence of life, complex multi-cellular plants and animals, social structures, human beings, and civilizations. The latter includes a remarkable non-biological aspect – complex artifacts, or technology and cultures. Our starting point for understanding the Universe is already problematic. We exist in extreme complexity (as compared with atoms or subatomic particles). We have a major task ahead of us to grapple with that complexity, to understand how the world works.

The main topic of this book is the description and explanation of a *methodology* (set of methods) that can be used to acquire knowledge of how things in the Universe work. Further claimed is that this methodology rests on understanding ‘things’ as *systems*, that systems interact with other systems and in doing so form a larger, encompassing *supra-system*, that systems are composed of subsystems (down to an atomistic level), and that this hierarchical structure encompasses everything from the Universe as a whole (closed) system down to the uncountable number of fundamental particles and energy packets that have auto-organized to form the complexity of the Universe that we (as systems that can contain models of other systems) observe in the present.

The claim(s) thus made is (are) unprovable and, more importantly, un-falsifiable as it (they) stand. This puts the whole issue of systemness into the realm of philosophy, metaphysics, as a starting point. Systems science begins at the point where falsifiability of hypotheses becomes possible. That is after we have established a set of ‘axioms[11]’ generated from the claim of systemness and then set out to test whether this or that aspect of a specific system of interest fails, upon proper testing, to be falsified. The program for generating axioms from the principles of systemness is beyond the scope of this work. However, we do need to ground the rest of the book in a philosophical treatment to show the justifications for what follows.

2.2.1 System Philosophy

Following the tradition of philosophies, particularly those of the Western World (e.g. ancient Greeks), we will discuss the general ideas of systemness as a metaphysical domain, followed by briefs on what counts as a philosophical ontology and epistemology. This chapter will use this philosophical starting point to transition to what might be called a more practical version of ontology (and epistemology) as it relates to doing systems science. The term ‘ontology’ has been appropriated by the computer science/information sciences communities to mean a set of terms that name what exists in a domain of interest (e.g. diseases in the domain of medical science). The main use of domain ontologies is, for example, providing keyword tagging for documents, especially graphics that contain objects for which the name applies (e.g. X-rays of lungs with

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[11] The term is in quotes to note that these are more like assumptions than logical or mathematical axioms in the rigorous sense. However, their treatment as true axioms is not precluded (indeed it is expected).

cancerous tissues). World Wide Web developers have proposed a standard for use of such ontologies in what is called the “Semantic Web.[12]”

In this chapter we will develop a set of terms that cover *objects*, *relations*, *actions*, *transformations*, *quantifications*, and *categorizations* that constitute at least a beginning of a system ontology[13]. In the next chapter we use that ontology, along with a formal definition derived from the principles and reflecting the ontological development presented below to produce a language of systems. This language will then be the basis for everything else that follows, namely the extraction of knowledge about systems in the world through systems analysis, the modeling of systems for various purposes, and the generation of system designs.

But first we start with the metaphysical aspects of systemness as a basis for what we do.

2.2.1.1 Metaphysics

Systems as we will be describing are real things in the real world of material and energy. By definition they are physical. This even applies to ‘thoughts’ in the mind, which we now have solid evidence are patterns (spatial and temporal) of synchronized neural excitations of particular (though fuzzy[14]) clusters that encode representations of sub-patterns across the neocortex of the brain[15].

The position being taken here might be termed “practical physicalism,” or a philosophical stance that only matter and energy exist and all phenomena can be known in terms of these substances and their *interactions* (however see below for an extension of this position with respect to information and knowledge[16] as “non-physical” substances having causal powers). It is “practical” in the sense that the stance is taken because all we seem to be able to actually say we

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[12] See the Wikipedia article: https://en.wikipedia.org/wiki/Semantic_Web

[13] One of the reviewers of an earlier draft of this chapter introduced the author to a more universal approach to an upper ontology, the General Formal Ontology (GFO). After a review of its approach it appears that there are many aspects of GFO that map to the system ontology developed here. It is certainly conceivable that both approaches have many aspects in common because both are attempts to find the ultimate nature of what exists. One substantive difference, however, is that the GFO started out with an assumption of formality, using first-order logic. The system ontology presented in this chapter started with an assumption that imposing such a formality too soon might foreclose the exploration of interesting ideas that cannot be immediately captured in a formal language of that sort. The use of formalism (set and graph theories) in the next chapter are used primarily to capture descriptions of systemness without the restrictions imposed by an axiomatic system. We believe that at some point such a system will be developed but hope it will be after there is a broad understanding of the general terrain.

[14] The pattern of clusters contributing to any concept are under constant revision due to learning and forgetting attributes at the periphery of a concept. For example the concept of a ‘house’ may need considerable modification after one sees a geodesic dome-shaped dwelling.

[15] This view rejects the Cartesian dualism, matter vs. mind. What happens in the mind can be explained by the physical activities in a person’s brain. Using functional magnetic resonance imaging (fMRI) methods, neuroscientists are able now to view the brain in the act of thinking specific thoughts. Some kinds of thoughts, or activations of concepts, appear to be found in similar locations in the brains of different people.

[1616] Throughout this book and in Mobus & Kalton (2016) we differentiate between information and knowledge. The former is seen as the content of a message whereas the latter is seen as the content of a structure, See below, main text for explanations.

know objectively is that which we can measure by physical means. It is thus somewhat meaningless in developing a philosophy of physical systems to admit to other substances at the base of our phenomenal universe. We do not deny other possibilities but take this stance for the simple reason that we have nothing we can say, systemically or otherwise, about some other existence. On the other hand, we will soon introduce other aspects of reality that we will call "ethereal substances." Like matter and energy these are real in the sense that they participate in causal relations with the former two, i.e., constitutes their interactions. These are 'information' and 'knowledge' (see Figure 2.1 below).

Once we find ourselves in the realm of physical phenomena we can pose scientific questions and hope to answer them via the process of science. But questions such as: "What is matter?" or "What is energy?" or "What makes them interact as they do?" are on the edge of metaphysics (meta- beyond or above). An even more difficult-to-contemplate question is: "Why do they exist?" These kinds of questions are beyond the capabilities of science to answer. They are currently solidly in the realm of metaphysics.

Systems metaphysics is based on a worldview as previously described. We simply assume that the Universe is a closed system[17]. That is, the Universe has all of the properties of a system except the input and output of anything. Further we assume that the Universe came into being in a state of ultimate simplicity (in the Big Bang) and has been evolving toward higher levels of internal organization (at least in quasi-isolated pockets of space-time) and complexity through the interchanges of substances between emerging subsystems. Our main piece of evidence for this proposition is the existence and state of affairs on the Earth. We have at least one example of an evolved complex system (c.f. Morowitz, 2004).

The metaphysics of systems can be summarized by looking at the philosophical ontology and epistemology of a systems-based worldview.

The starting point is that the Universe is composed of matter and energy, that both come in discrete packets. Matter can be thought of as compressed energy. We know that the two substances are interchangeable[18]. Let us assume (as one of our axioms) that at the Big Bang matter was created out of some of the energy, itself contained in the singularity described by the standard model in cosmology[19]. There are many additional aspects of this 'creation' such as time, space, the four fundamental forces, and randomicity that are important in a full description but go far beyond the scope of this book, so will be left to another time. We will simply assume them.

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[17] We have to assume since as things stand we have no access to the boundary of the Universe due to the finite speed of light and the distance to the presumed 'edge' of the Universe. The assumption is considered reasonable even under so-called 'multi-verse' interpretations of cosmology (Unger & Smolin, 2015).

[18] Of course, thanks to Albert Einstein's famous equation: $E = mc^2$.

[19] Not all cosmologists are in agreement about the 'pre-history' of the Universe. See (Unger & Smolin, 2015).

2.2.1.2 Cosmological Ontology

As a first step in delineating what exists from the standpoint of systems we need to establish the overall context. Our planet is a system in the Cosmos. It is a subsystem of the Solar System and that is a subsystem of the Milky Way Galaxy. We find systems at increasing scales of size and time (c.f. Smolin, 1997). The Earth is our local ‘global’ system, mostly closed (at present) to material flows but luckily very open to energy flow, in particular solar radiation coming in and waste heat radiated out to space. In order to begin the construction of a system ontology we need to at least examine aspects of a cosmological ontology as it supports and constrains what we can say about systems.

Figure 2.1 shows a conceptual framework for the basic constituents of reality as we currently understand it from physics. In addition to matter and energy the figure shows ‘substances’ discovered and characterized in the 20th century, information and knowledge. It also shows the somewhat speculative situation with regard to what are called dark energy and matter. These substances are real enough by virtue of their observed causal impact on the long-term dynamics of the Universe (Primack & Abrams, 2006; Smolin, 1997). At this time all we can say is that dark matter is responsible for keeping galaxies from flying apart and dark energy is responsible for accelerating the expansion of the Universe as a whole. They are shown next to regular matter and energy with dotted lined boxes to indicate their still uncertain status.

Our metaphysical claim is that the entire universe is comprised of these substances interacting with one another such that structures composed of matter and energy evolve toward greater organization over time through a process of auto-organization, emergence, and subsequent selection[20].

This despite a seemingly countervailing process of randomness that appears universally. In reality this randomness is a result of the interactions of particles and lower potential energies that result in unpredictable changes in behaviors of the particles observed from a more macroscopic perspective. Thermal noise and various other sources of uncertainty, such as non-linear interactions driven by energy flows result in a stochastic process of combination as well as a stochastic environment. Without this stochasticity, combinations of particles (the term being used generically to represent an aggregate of independent objects at any level of organization) would not explore the space of possible combinations. Also, the stochasticity of the surrounding environment of the combinations can act to break up such combinations that are “weakly bound” so that the particles can be recycled. Only the most stable combinations in any particular environment will persist – their internal bonds are stronger than the forces that bombard them. This can be described as a search through the space of stable configurations,

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[20] Mobus & Kalton (2015, chapters 10 & 11) explicate these processes as they pertain to how matter and energy interact, mediated by information to produce more complex dissipative structures that, in turn, interact at a new level of organization. The degree to which such structures are dissipative is a measure of the entity’s “knowledge” of the interaction. See also the sections below regarding ontological information and knowledge.

A second and ultimately more important process is at work as well. That is the propensity for energies to equilibrate throughout the available space; that is the tendency toward energy equilibrium over time. This tendency, known as the 2nd law of thermodynamics, means that systems, even if they are stable against the vagaries of their environments, can, nevertheless, lose organization – become more disordered – and their components dissociate by losing energies that formed the bonds that held the components together.

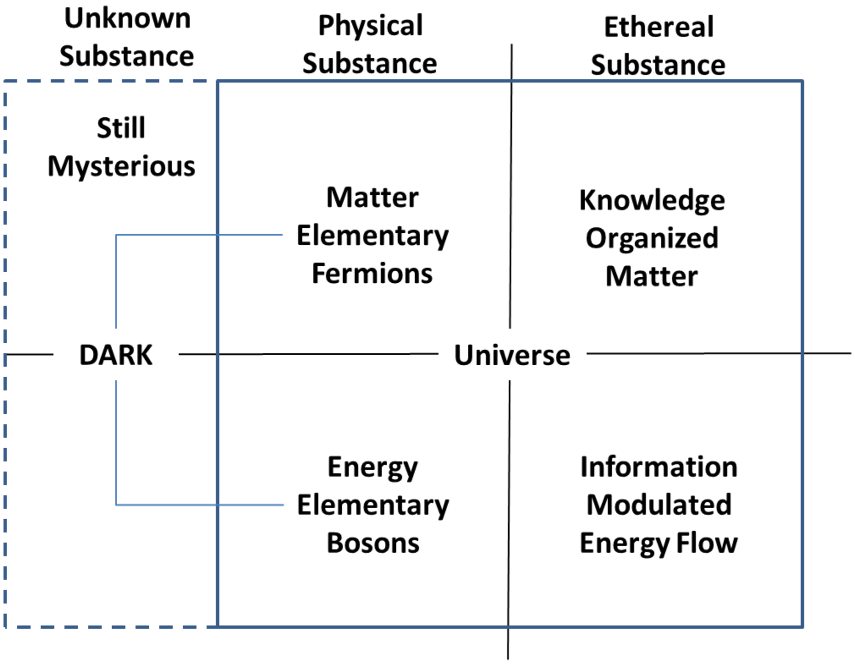

Fig. 2.1. These are the claimed substances that exit (have ontological status). The substances in the solid boxes have understood relations and interactions. The dotted lined box indicates that our knowledge of these substances is still developing.

This provides a bridge to physics and a cosmological process of ontogeny (development). The origin and evolution of systems in the Cosmos is cosmogony (or cosmogeny[21]). Once the existence of fundamental particles and energies was established, presumably in the Big Bang, the development of increasing levels of organization (i.e. particles to assemblies, their interactions, to supra-assemblies) took over. This describes an upward spiraling process of auto-organization wherein components at a given level of organization, say atomic elements (nuclei of hydrogen and helium), would combine in nucleosynthesis[22], to produce more complex systems of protons and neutrons – the heavier elements. After the Cosmos cooled sufficiently nuclei could attract electrons to form atoms with the emergent properties that allow yet further combinations in the

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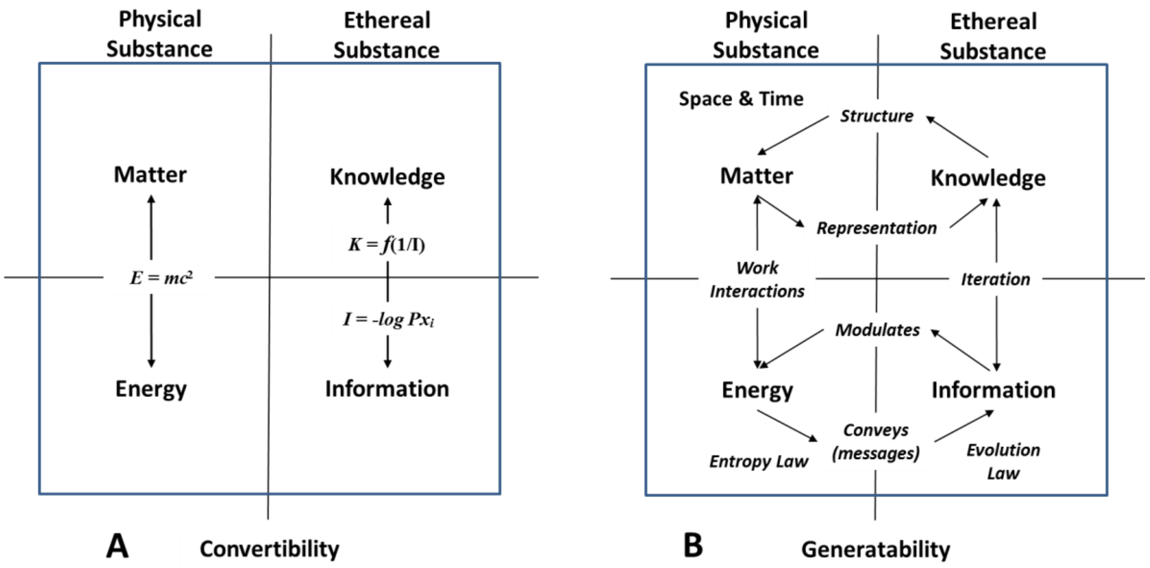
[21] The suffix, '-geny' derives from the same root as 'generate' and 'gene', referring to birth and development. The term 'cosmogony' appears to be a derivative therefrom. C.f. the online etymology site: https://www.etymonline.com/word/-geny for reference. Accessed 1/8/2018. Also see the Wikipedia article on cosmogony: https://en.wikipedia.org/wiki/Cosmogony. Accessed 1/8/2018.

[22] The fusion of simpler nucleons to form heavier elements. See the Wikipedia article: https://en.wikipedia.org/wiki/Nucleosynthesis for background. Retrieved 6/21/2018.

form of molecules. We now enter firmly the realm of increasing complexity and the emergence of new properties and behaviors.

Auto-organization is a result of the capacity for some fundamental units of matter to possess interaction potentials of varying kinds. Namely, these units may interact by binding (attraction) or mutually repelling each other, using or giving up energy (e.g. photons) as appropriate. Moreover, we posit that these interactions are determined by geometry, the potentials exist only at certain points on the 'shell' of the matter. An atom is a model of this matter-matter interaction relation. Atoms (elements) are already systems, meaning they are composed of simpler subsystems (e.g. quarks, organized as subsystem components of protons and neutrons, and electrons). Our assumption is based on the idea that we will see this pattern of matter-energy-matter interactions (with the structures of matter exhibiting 'personalities' that condition the kinds and dynamics of interactions) as we go 'up' the organizational hierarchy[23].

But remember this is metaphysics at this stage. We are not compelled to 'prove' this conjecture, only to make clear what we are conjecturing because of our position that systemness obtains therefrom. The happy fact is that from atoms, and chemical interactions, up the hierarchy we are clearly dealing with the interactions of matter and energy and the "ordinary" sciences. Below we will review the roles of information and knowledge in this interaction and as they pertain to the on-going process of evolution. For completeness Figure 2.2 shows some of the relations that exist between matter, energy, knowledge, and information.



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[23] What we are describing is reminiscent of the Marx-Engels theory of dialectical materialism. See: Spirkin, Alexander (1983) by Progress Publishers. https://www.marxists.org/reference/archive/spirkin/works/dialectical-materialism/index.html Retrieved 10/28/2016.

Fig. 2.2. A) Matter and energy are inter-convertible according to Einstein's formula. Information and knowledge are similarly inter-convertible (see text). **B)** The relations between information/knowledge and energy/matter constitute the cause of dynamics and the evolution of all structure.

In Mobus & Kalton (2015, Chapter 7) the subjects of information and knowledge are explicated. Here we summarize the main points covered in that chapter.

2.2.1.2.1 Ontological Information

The term 'information' is used so broadly in everyday language that it is often misused, even by those who work in a field related to information theory (e.g. computer science)[24]. Partly this is because those working in a field have developed a culture of mutual understanding of their subject in which they all know what meaning should be attached to any particular instance of the use of the term by virtue of the context in which it is used. Outside of that culture, other cultures or laypersons, do not share this contextual distinction so the real meaning can get lost.

For example, the word is often used when referring to a subject that is actually about 'knowledge' (explained below). Information and knowledge are *not* one in the same in a technical sense, but are often interchanged in casual use. Take the case of genetic coding in DNA. The actual codes (nucleotide triplets, called codons, corresponding to specific amino acids) are embodied in the structure of the gene and are, technically, *knowledge*. The sequences are the result of evolutionary learning[25] – variability tested by natural selection. Many authors indiscriminately refer to the genes as 'information' because they know that the gene is the source of a message (messenger RNA) that will be sent out into the extra-nuclear cytoplasm where it will be decoded by a ribosome to construct a polypeptide (or protein). The message is informational to the ribosome as will be explained shortly.

In this work we follow the basic insight of Shannon (Shannon & Weaver, 1949) that information is the *measure* of uncertainty regarding the state of a message, or the next 'symbol' to be received in a message stream, which is a property of the receiver (e.g., the ribosome) and not of the sender (the DNA). The DNA codes, read and interpreted by DNA sequencing, as in the Human Genome Project, are informational to the gene researchers in the same way the message carried by mRNA is informational to the ribosome. When the genome is first sequenced the researchers cannot know with better than a 1 in 20 chance what the next codon will be (unless they already knew what the amino acid sequence of the protein was so that they could make a prediction – but it wasn't until after the genetic sequences were discovered that researchers could

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[24] For a thorough and extensive review of the complications involved in the usages of the term, see the Stanford Encyclopedia of Philosophy review at: https://plato.stanford.edu/entries/information/. Accessed 1/10/2020.

[25] The use of the word 'learning' is a bit risky in that it is usually associated with what animals do mentally. However, it refers to any change in a structure resulting from the information exchanges going on at an appropriate time scale. In the case of evolution, a mutation can cause a change in the phenotype that result in different form or behavior, essentially an informational message to the rest of the environment. The latter, then has an opportunity to act upon that new structure, positively or negatively. If positive then the species has "learned" something that will be retained.

match up genes and proteins more rigorously). Hence the sloppy use of the word information when describing the actual structure of the gene.

The measure of information in a message is strictly a result of the properties of the receiver – the entity that uses the message to instigate a change in its own structure. This is the essence of learning in its most fundamental form. A message is received that reduces uncertainty in the receiver, which, in turn, results in a modification of its own structure, thus producing a new level of knowledge in it[26]. The inter-conversion relation between information and knowledge is shown in Figure 2.2A. The formula for information, I, comes from Claude Shannon's (Shannon & Weaver, 1949) formulation of the amount of information conveyed by the receipt of the next symbol (from an ensemble of symbols possible) in the message (Mobus & Kalton, 2015, Chapter 7, Quant Box 7.2)[27].

Another mistake made in the use of the word information in common usage is to intermingle the notion of 'meaning' with information. Meaning is actually quite separate from the measure of information. Meaning comes from the *a priori* arrangement of senders and receivers that involves the interpretation of messages. This in turn depends on the prior agreement on the symbols, rate of message flow, and other factors. The receiver is predisposed to act (make internal changes) on the message. However, the information measure of the message determines how much action ensues. Meaning tells the receiver *what to do*. Information tells the receiver *how much to do*. In Chapter 11 we introduce a macro-model of governance, the Hierarchical Cybernetic Governance System (HCGS), in which we will further demonstrate the nature and role of information in forming and maintaining structures and functions in systems.

The ontological status of information derives from the fact that messages have causal power to change a physical structure. This is, however, a strange kind of causal power. It is not a result of the intentions of a transmitter/sender, but rather it is based on the ignorance of the receiver. This ignorance is a function of the structure of the receiver relative to other possible structures that could obtain with the accomplishment of work. That is, the receiving structure already has the capacity to alter itself so as to better facilitate the dissipation of energies, to become more thermodynamically stable. It will only do so, however, as a result of receiving messages that trigger such a reaction. Real work is accomplished in making these alterations, so energy is consumed and heat dissipated. Afterward, the structure is a priori prepared to dissipate future

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[26] In Mobus & Kalton (2015) it is explained that messages are carried in energy streams that are modulated in one form or another to encode the content. The energy variations in the message flow (the code) then may be amplified by the receiver so that effective energy flow can be directed to the site of work on the receiving structure so that it is modified based on the informational content of the message received. This is the resolution to the difference between information and meaning that Shannon and Weaver (1949) pointed out. Meaning derives from knowledge, information derives from improbability.

[27] Shannon got his inspiration from the work of Ralph Hartley (1928) who developed the idea that the members of a set (of symbols, say) represented an amount of uncertainty proportional to the size of the set. This notion closely aligns with that of physical entropy and so in subsequent developments of formal information theory, the term message entropy and information have become confusingly intertwined!

flows of energies without having to do additional work. Information is the capacity to cause changes in receiving systems that better prepare that system for future messages (minimize surprise). The change in the structure of the receiver that reflects this preparation is what we call knowledge.

2.2.1.2.2 Ontological Knowledge

As noted above many authors conflate the notion of information with what we are calling here knowledge. Whereas information is the measure of uncertainty reduced when a message is received by a competent recipient (i.e., able to decode the modulations appropriately) knowledge is the *a priori* structure (which channels energy flows) of the recipient. The latter will undergo changes in structure in proportion to the 'amount' of information in the message. Figure 2.3 provides a diagrammatic depiction of the interrelation between information in a message and knowledge gained.

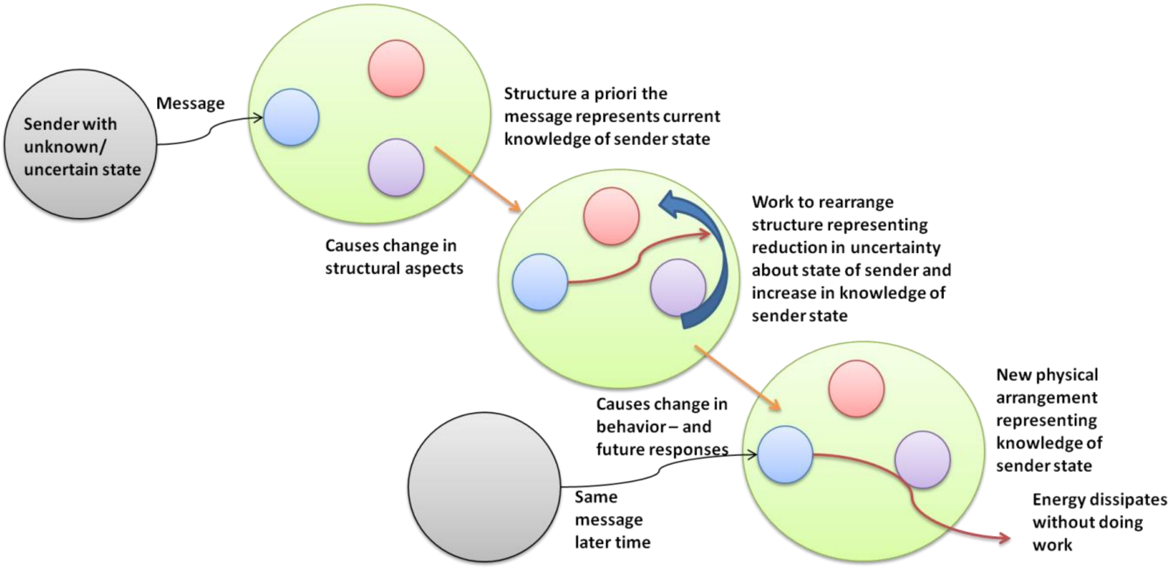

Fig. 2.3. This figure shows the time course events when a recipient receives a message from a sender. A sender encodes a message based on its current state which may be different from the recipient's knowledge of the sender's state as coded in the recipient system's internal structure. The message would therefore contain an amount of information representing the degree and direction of difference. The interpreter (blue small circle) uses that information to direct a work flow modifying the internal structure. If at a later time the very same encoded message is received again it does not contain information because there is no difference and the energy that would have gone to do additional work is simply dissipated, or conserved for future use.

According to the Upanshads[28], "Knowledge is *structured* in consciousness." The key word here is 'structured'. The theory of knowledge, ordinarily the subject of epistemology (discussed below), is rising to the level of science with the recognition that knowledge is encoded in the

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[28] Ancient Vedic texts such as the Bhagavad Gita (in which this sentiment is given). See the Wikipedia article: https://en.wikipedia.org/wiki/Upanishads. Accessed 11/2/2016.

actual physical structures of systems[29], and thus acquires ontological status (Principle 7 in Chapter 1). Knowledge is acquired through experiences that a system has. Internal structures change in organized work processes in response to the informational qualities of those experiences. Once changes in the structure have been made the result is that the system has internalized the experiences and if exposed to similar conditions in the future will receive less information from the same situation in those subsequent experiences.

Leaving aside the nature of consciousness for the moment, we note that it is nevertheless a phenomenon of the brain. Knowledge is encoded in the structure of the brain (as one example). The brain contains knowledge from three basic processes: evolution, development, and experiential learning, along with a facility for persistence – memory (Coen, 2012)[30]. These correspond with the time domain of information generation and knowledge production. They could be renamed as “species learning,” “maturation learning,” and “autonomous agent learning.”

In Figure 2.2B we see some of the transformational (generation of) relations. The right side of the diagram shows that information receipt generates knowledge construction in the receiver. This means that the receiving system possessed an *a priori* low expectation of the messages communicated from sender to receiver. Since the ‘amount’ of information in a message is inversely proportional to that expectation, the receiver has to respond by reconfiguring its own structure to become more dissipative (Mobus & Kalton, 2015, Chapter 7). That is, it is better able to pass through the energy flows that are the result of information (perhaps through amplification) so that next time the same message is received it is less likely to cause a similar amount of change in the structure.

What Figure 2.2B shows is the iterative cycle of information-knowledge construction mediated by the roles of matter and energy. In essence the configuration of matter (structure) holds the knowledge of the system. Energy conveys the message from the sender to the receiver. Usually a very small amount of energy (and possibly matter) are involved in the message. What makes it a message is the modulation imposed on the flow by the sender. That modulation encodes the symbols (a set of patterns) into the message flow.

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[29] There is a somewhat widespread misapprehension about the nature of knowledge, especially among biologists who assert that information is an emergent phenomenon in living (and possibly prebiotic) systems as opposed to a fundamental substance. Many of these authors also prefer to use the term ‘information’ more broadly than seems appropriate. For example some use the adjectives ‘latent’ and ‘semantic’ to name what we are calling here, “knowledge.” For example see Grisogono (2017) for arguments for the emergence (vs. primacy) of information with the advent of life and the conflation of ‘semantic’ information with what we call here, ontological knowledge.

[30] In the above example of a ribosome receiving information from the DNA it is using that information to build a polypeptide structure. However it, as a system, does not really learn anything since once the polypeptide transcription is complete the polypeptide is released to wander off into the cytoplasm. The ribosome has no memory of what it did!

In the figure, the term ‘Entropy Law’ refers to the fact that work needs to be accomplished in order to change the structure and to maintain it if it is to be retained. Forgetting is a loss of structure resulting from non-maintenance. This phenomenon can be found in living and supra-organic systems quite readily. The term ‘Evolution Law’ is the reciprocal phenomenon. Where work is done to maintain newly acquired structure (or where the structure is highly stable under the extant environmental conditions) the change in structure has a ratcheting effect. In essence the gaining of knowledge is progressive so long as suitable energy flows through the system (c.f. Morowitz, 1968).

The concept of learning and knowledge encoding is not limited to living beings and certainly not limited to human beings. Any time one system sends a message that is received by a second system, and that second system is altered by its receipt, learning has occurred. Knowledge has been increased.

This is true across all scales of space and time. It begins when the Universe cooled sufficiently to allow, for example, quarks to begin signaling each other through the mediation of gluons (the strong attractive force), Quarks that end up moving toward one another, reacting to the information value (say based on separation distance and relative direction) undergo a structural combination (three quarks to a proton, for example) that constitutes the knowledge of the subatomic particle. As will be seen later, this is the beginning of ontogenesis, but it also illustrates that as soon as the constituents of the early Universe could form structures and react to signals information and knowledge attained their ontological positions.

At the scale of atoms we see photons being the mediators of information. The outer electrons are perfectly “happy” buzzing around in their orbitals. But the receipt of a photon of the right energy can boost an electron to a higher energy state causing it to step up an energy level (or even completely away from its atom). The atom as a whole is now in a new configuration and will react. Eventually the electron will fall back to its normal place emitting another photon as a message to the cosmos. Of course when atoms are aggregated closely together they have multiple different ways to communicate with one another, like the sharing of electrons to form covalent bonds in molecules (another instance of ontogenesis!) Each atom achieves a new configuration (knowledge) and behaves differently as a result.

The pattern of message receipt and reconfiguration (even if marginal or miniscule) embodies the gaining of knowledge (even if fleeting) repeats at every level of organization in the Universe.

One further note on the nature of knowledge as structural configuration; it does not generally persist. Entropy prevails in the end. Except for the configuration of quarks in a proton, which appears to be eternal, all systems at higher levels are subject to decay or destruction. Atoms are relatively stable, except if radioactive, but molecules are subject to many chemical and physical conditions that can change them. Protein molecules degrade with time at physiological temperatures and need replacing in living systems. DNA molecules are among the most long-lived biomolecules, which is why we can recover genetic information from Neanderthal bones. But even they have a tendency to occasional degrading (this is especially the case when DNA is being copied). In human-scale terms, our memories, which are configurations in neural networks, the strength of connections between neurons participating in an engram, do tend to fade with time unless reinforced through recall from time to time. In terms of the situation shown in Figure 2.3 it would amount to a slow decay back toward the initial state with the emission of waste heat. Mobus (1994) provides a mathematical model of ‘forgetting’ or memory trace fading in neural networks as a perquisite for learning new associations in a non-stationary world. Paradoxically, the entropy law is what makes it possible to learn new things and build new knowledge.

2.2.1.2.3 Panpsychism[31]

Recall the last section opened with a quotation from the ancient Vedic texts, the Upanishads, regarding knowledge, structure, and consciousness? There has been an on-going debate, mostly among philosophers of science but also some physicists, that consciousness is a property of the Universe, indeed probably the key property. That is every physical thing in the universe possesses some level of consciousness. The interplay between matter, energy, information and knowledge suggested in Figure 2.2 hints at what might be called a micro-panpsychism or a concept of how the most fundamental physical substances can be considered conscious. If we define consciousness broadly as an ability to receive messages and change our internal configuration in accordance with the amount of information contained in the message, then it would be true that consciousness is possessed by the most fundamental units of reality. And, if the most fundamental units, say Leibnitz’s or Smolin’s (1997) monads [32] were able to receive information and change their behavior then it seems reasonable that the composition of more complex entities (quarks, nucleons, atoms, molecules, etc.) would possess more elaborate forms of that property. It would then be reasonable to argue that the consciousness that is so evident in living systems is actually rooted in a basic capacity of elements in the Universe to “sense” and change in accordance with what they sense.

We might not be able yet to say anything about strings or monads, but we do know that nucleons are able to change in response to weak interactions (*W* and *Z* bosons conveying messages) that can result in nuclear transmutations[33]. Atoms can be ionized by the receipt of photons knocking out outer electrons (and potentially lead to chemical bonding). Change of structure due to “unexpected” energetic flows, messages, starts at the lowest known levels of material organization. So it is not a stretch to claim that the given definition of consciousness is

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[31] See the Wikipedia article: https://en.wikipedia.org/wiki/Panpsychism. Retrieved 6/21/2018. Also the Stanford Encyclopedia of Philosophy article: https://plato.stanford.edu/entries/panpsychism/. Retrieved 6/21/2018.

[32] See the Wikipedia article: https://en.wikipedia.org/wiki/Monad_(philosophy) for background. Retrieved 6/21/2018.

[33] See the Wikipedia article: https://en.wikipedia.org/wiki/W_and_Z_bosons for background. Retreived 6/21/2018.

operative at every level in the complexity structure of the Universe. It becomes really interesting in the realm of living things, and even more so in the realm of sentient beings such as ourselves.

How the fundamental units of reality combine and construct higher levels of organization, complexity, and capacity to construct knowledge is a central concern of ontology or ontological development.

2.2.1.3 Ontogeny – First Pass

Ontogeny (also ontogenetic process) is the process of something becoming or coming into existence[34]. The central question here is: How do systems of increasing complexity arise out of the four (or six) fundamental substances in the first place? In other words, where and how do systems originate and develop into their stable forms and functions? How does complexity increase over the history of the Universe?

This question had little meaning in the time before Charles Darwin put forth an evolutionary development process. For most, existence was simply a given; God created heaven and earth and all therein. Scientist had begun to question the firmness of this stance before Darwin but it was Darwin who provided a mechanism for biological evolution in which new characteristics, in the form of new species, could emerge from existing forms[35]. Biological evolution, especially with the addition of Mendelian genetics and the theory of genetic mutation goes a long way in explaining how biological systems change over time, but it does not directly address the problem of origins, or how things got started, nor does it address the ‘apparent’ trajectory of evolution, that is by producing more complex biological systems over the course of time. In the realm of biology, we need to examine the origin of life problem, the emergence of living cells from non-living chemical reactions, in order to consider how life got started prior to neoDarwinian evolution. Then we have to address the issue of why biological evolution, over the course of time, has led to increasingly complex life forms, and ultimately to human intelligence and consciousness[36].

Today we now also understand the process of embryonic/fetal development as an unfolding of potential, coded in the genes, but influenced by environmental factors that have the effect of turning on or off genetic expressions at key points. There is a new amalgam of neoDarwinian

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[34] The term ontogeny is generally associated with biological development, i.e. embryonic or fetal development. However, the term can also refer to any development process in which a new, more complex form (and function) develops from more primitive or simpler forms (and functions).

[35] Alfred Russel Wallace developed a very similar thesis at the same time as Darwin, but the priority of publication goes to the latter. See the Wikipedia article: https://en.wikipedia.org/wiki/Alfred_Russel_Wallace for background. Accessed: 6/1/2017.

[36] Of course not all species became ‘more complex’ over time. The Earth is still full of less complex forms such as prokaryotes, single-celled critters, and worms, etc. Only a few evolutionary lines lead to greater complexity in terms of body forms, organs, and behaviors. However, the increase in complexity in those few forms also contribute to the overall complexity of the whole planet. For example, the human invention of antibiotics has worked back on prokaryotes to force the selection of antibiotic resistant strains. The Ecos is thus more complex overall.

evolution with embryonic development (known as Evo Devo, Carroll, 2006) that has gone a long way to explain ontogeny much better than Ernst Haeckel's recapitulation theory[37].

From the systems standpoint, we need to understand how do systems originate (biological or not) and how do they evolve to achieve a stable existence in which they can be observed to behave in particular ways. The solution to this question is found in the nature of auto-organization, emergence, and contextualized selection on what emerges. We assert that there is a universal form of evolution, of which biological evolution is just one example (Mobus & Kalton, chapters 10 & 11). This is the process, composed of those three sub-processes working in concert, that, starting at the most fundamental level of matter and energy, creates new objects or entities at a new level of organization. We call this process Ontogenesis. Once the new entities are formed they are subject to ambient conditions that select for or against various configurations. Those that remain stable can then interact with each other in new ways. And the process starts over again at this new level.

Briefly, (from Mobus & Kalton, previous reference) before systems as such exist there are components – particles with various personalities[38] – contained within a volume of space that, under the influence of energy flows, mix and interact (Morowitz, 1968, 2004) to form more complex structures[39]. Some of these structures will prove to be stable under the ambient conditions (a kind of selection process) and demonstrate new, emergent, behaviors. They become, in effect, new components capable of new interactions at a new, higher level, of organization. This is how new things come into existence. And once a new level of organization obtains, the *ontogenic* cycle starts again to produce the next level of organization. There are components at each level that have potentials for interactions (e.g. atoms, molecules, cells, etc.) and energy flows that supply the capacity to do the work of combination (as well as dissociation), and when combinations are made, they are selected for their stability in the ambient conditions. The history of the origin of life will be written in this scenario. So, too, will the origins of eukaryotic cells, multicellular organisms, and societies (Bourke, 2011). Biological evolution accounts for the micro-steps of biological development. But the emergence of species, genera, and all of the subsequent divisions of life as well as the nature of social systems comes from a universal process of auto-organized subsystems, the emergence of higher-order structures and functions, and the ultimate selection of that which works under the prevailing conditions. This is universal ontogeny.

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[37] See the Wikipedia article: https://en.wikipedia.org/wiki/Recapitulation_theory for more background. Accessed: 6/1/2017.

[38] As explained in Mobus & Kalton (2015) the term 'personality' refers to interaction potentials expressed outwardly from the boundary of a component. These potentials provide the points on the boundary where components may connect (see 'Interfaces' below). Components may have multiple potentials and thus combine with multiple other diverse components to form structural complexes. These personalities are also referred to as affordances elsewhere

[39] Morowitz also emphasized the geometric aspects of energy flow in which energy enters the system at one point and exits, as heat, at another point, leading to convective cycles that further act to organize the structure, providing another dimension to the selective environment.

The process of ontogeny is a natural consequence of the interplay between matter, energy, information, and knowledge, which is the final product of the process. Knowledge is encoded in the structures of matter, bound by energy, and stable in the face of testing by on-going energy flux. Systemness is the natural consequence of ontogenesis. The construction of higher order systems from lower order, but tested ones, gives rise to the principle of systemness (Mobus & Kalton, 2015, Chapter 1). It is what produces the hierarchy of physical forms and interactions that constitute the world. It gives us a Universe interactions, a network of entities that behave. In section 2.3 we will expand the explanation of the ontogenic cycle.

2.2.1.4 System Epistemology

The bulk of this book is actually about system epistemology or more specifically how we humans gain knowledge of systems. Using the to-be-developed ontology and formal definition of system (Chapter 3) we will generate an organized structure that is modifiable in the sense of learning described above. This structure, which we will implement in a database, like our brains, will be predisposed to receive information about a specific system, the system of interest, generated from the act of analysis (in the broad sense). We call this structure a knowledgebase. In Chapter 4 we introduce the mechanics of how system information will be generated, how it results in the encoding in the knowledgebase structure, and how that knowledge may be "recalled" and used for multiple purposes, such as refining its own structure, testing hypotheses (through models), and constructing/generating designs for physical implementations. The latter will include not just engineered products, normally associated with systems engineering, but organizations and organizational processes, and policy recommendations for public action (e.g. water distribution policies for regions experiencing severe drought).

The key to system epistemology is recognizing that the gaining and storing of knowledge in the knowledgebase is accomplished using a language of system that is completely comprehensible to human beings. In the next chapter where we develop this language we show how the language of system is already grasped subconsciously by humans and thus becomes accessible consciously by making the nature of the language explicit through systems science and the ontology (terms) translated into a spoken language (in this case English).

Thus, the knowledgebase, an artifactual system, can converse with a human mind (actually many minds) through a language facility to share knowledge about other systems. We use systems science to build a system of communication between machines and people that will, hopefully, enrich our totality of knowledge.

2.2.1.4.1 The Role of Modeling

All systems are initially observed from the 'outside.' That is, the scientist has access to monitoring the inputs and outputs (behavior) of the system but does not immediately have access to internals of the system that generate that behavior[40]. The first task of gaining knowledge is to produce a formal description of the behavior in the form of a model of the system that can be used to generate the same behavior as witnessed in the system itself. Very complex and/or fuzzy bounded systems may require considerable observation before the researcher arrives at the set of variables that adequately describe the system's behavior. Once a model's results conform to the behavior of the system of interest, empirically determined, the scientist may claim to have a certain degree of understanding of the system.

More often than not, however, the first several attempts at models will not produce conforming results and the model builder will seek to resolve the discrepancies by looking for unrecognized variables and/or presumed internal relations between variables or other factors (e.g. rate constants) that might cause the model to perform better. The traditional approach to scientific epistemology has been along these lines. Observe the phenomenon, develop a hypothesis regarding how the system works, build a model with the 'right' variables and relations, and then run the model to see if its behavior conforms to the real phenomenon. If it does, write a paper and submit it to a journal!

In the history of the sciences, however, this has not been a satisfying process. Eventually models fail to provide the kind of knowledge that we really seek. Whether due to changes in the environments of the systems, insufficient precision or accuracy in the solutions, or, in the case of evolvable systems, to some alterations inside the system boundaries that change the transformation functions that are hidden from view, models become obsolete. Or, the scientists are just curious about what is really going on inside the system (see below)!

Models are, thus, themselves evolvable systems. They tend to get more complex as scientists seek to explain more about complex phenomena than the original model could provide. More than that, the discrepancies between models and the real systems provide the motivation for opening up the black box and attempting to deconstruct the internals. In other words, science has proceeded to explore phenomena more deeply as a result of not getting the models 'right' in the first place.

We can understand this tradition in terms of the tools that the sciences have had to work with. This includes the kinds of sensors that were available for monitoring systems, mostly from the outside. They had to 'infer' the internals based solely on the observed behaviors (or they may have settled on simple correlation when no hypothesis of causality was available). And then they had to take great care to make sure their observations were complete and accurate. The use of models, whether statistical correlations between variables, or sets of ordinary differential equations, or, more recently, system dynamics and agent-based methods, has been considered a "strong inference" method for saying we understand a system. When the models fail to predict

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[40] This is even partially true of systems in which humans are components such as an organization or the economy (see Chapter 8). The scientific approach requires objectivity, which can be gotten, in theory, by the scientists removing themselves from the system and pretend to be an outside observer.

new or different phenomena they need to be changed, or guide the eventual deconstruction of the system.

This has been the typical pattern in the sciences: develop a hypothesis about how something works based on its behavior, generate a model to test the hypothesis (especially if normal experimental approaches cannot be used), collect additional observations for analysis, and see if the model helped predict the system's future behavior. Today this methodology is pervasive thanks to the ease of building models for computer-based simulation. Many scientists race to construct a model as early as possible and then spend the next several years tweaking the models until they seem to produce the appropriate outputs.

The problem with this approach is that a model is not necessarily the same thing as understanding the system itself. It is reasonable to say it is understanding *something* about the system, but that is all one can say with any kind of certainty. Yet, for many sciences, this has been the best that could be done until someone proceeded with deconstructions that clarified the internal mechanisms and produced better causal models[41].

2.2.1.4.2 Inquiry

In the description of information and knowledge from the prior section one might conclude that the communication act is all 'set up' prior to any messages being sent and result in knowledge encoding. However, this is not always the case. Just above we described knowledge acquired by the method of analysis. In a sense there is no 'sender' of messages in the case of inquiry into a subject. The act of gaining knowledge is initiated by the actions of the one seeking to gain knowledge. A scientist proposes a hypothesis and then does experiments to (ideally) refute it if it does not correspond to the truth of the matter. The messages being received originate in a phenomenon that the scientist is actively observing. There is no sender encoding the message as described above in a strict sense. The scientist, in setting up the experiment and then observing the results, has constructed the sender (the experimental medium) and designed the code (measurements).

Experimental science is not the only possibility. Many sciences have to rely on observations of naturally occurring phenomena and employing various methods, mostly statistical inference and modeling, in order to obtain their observations. Again there is not an a priori communication connection between a sender (in this case the phenomenon) and the receiver (the observer). However, in both of these cases there is a flow of information from a source (experiment or phenomenon) to a receiver (scientist), usually via instrumentation. The scientist, as the receiver in this case, has an a priori expectation associated with the results of the observation and whatever reduction in uncertainty of the outcome constitutes information. The scientist gains

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[41] In Chapter 8 we will see a specific example of a science that has relied on modeling heavily as it attempted to explain very complex phenomena. We will also show how the approach can now migrate toward that being put forward in this book.

knowledge and conveys messages (via journal articles) that are informational to a broader audience. The knowledge acquired is encoded into structured literature where it is accessible by future receivers.

What is interesting about this situation is that the motivation for the messages derived from experiments or just observations is the curiosity of the scientist. The scientist wanted to understand something and set up conditions whereby they could get the information necessary to construct new knowledge. Where does this curiosity come from? Humans are by no means the only animal to demonstrate curiosity-driven exploration. Usually such explorations can be related to searches for food or other rewards but they are undirected (foraging for example). But in humans exploration and inquiry seem more opportunistic; that is there is no direct benefit sought, but just some information that might come in handy some day! Humans have been labelled “informavores!”[42]

2.2.1.4.3 Knowledge Gets Refined and Expanded

Principle #12 in Chapter 1 says that systems can be improved. This has many versions, but in the present case we are referring to the improvement of knowledge, which is, in fact, a system of encoded forms. In fact we are referring to principle #9, which relates to systems containing within their structures *models* of other systems. In the human brain these mental models are what we mean by concepts. And concepts can not only be learned, they can be improved with additional experience. They can be refined (finer resolution, correction, etc.) and they can be expanded (incorporate more perspectives).

Learning in this sense is motivated by discrepancies between what a currently held concept (model) predicts and what actually happens. Predictive ability is the key to fitness in a changing or non-stationary and uncertain environment. Ergo, if a concept currently held is failing in some way to make sufficiently accurate predictions, the mind is motivated to find out why.

This is what is behind the scientific quest for more and better knowledge and it is what is behind individuals being curious. There is reason to suspect that many mammals and birds have this same facility (as in the cat’s curiosity being a source of loss of one of nine lives.)

In the next chapter we will examine the idea that the brain contains a natural template of system structure and function that it applies to observations of the real world and uses to make primitive predictions, as when a newborn is starting life. The real-world systems that are observed deviate in multiple but normal ways leading to the triggering of learning. The template model is used to construct a specific instance model, which then will be refined and expanded as the young person gains experience with that kind of system. When real systems are encountered that deviate more significantly from already encoded models, this is a trigger to cause the brain to create a new category of system and start building from the prototype template anew.

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[42] See the Wikipedia article: https://en.wikipedia.org/wiki/Informavore for background. Accessed 2/19/2019.

2.2.1.4.4 Learning Systems Learning Systems

No this is not a typo. Here we refer to the idea of systems that can learn actually going through the process of learning other systems (improve their models of other systems; principle 9 in Chapter 1). This is the basic model of systems epistemology. Systems of sufficient complexity (like our brains) are capable of constructing models of all other systems, including supra-systems by improving and expanding on a fundamental 'system' template. Our effort will be to show how this basic model can be replicated in an artifactual system (the knowledgebase fed by systems analysis).

One remaining question is: "Where did the template system model come from in the first place?" The answer, one that would require several volumes to explain in detail, is the evolution of brains. Animals have to behave, move, react to, and otherwise negotiate a dynamic world of systems. Brains evolved from simple reactive sensor-decider-actor subsystems to the complexities of the human brain by virtue of selection favoring those brain structures that were better able to learn and work with systems in the world. Even the simplest sensor-decider-actor brain (in flat worms for example) are themselves input-process-output devices and that is the fundamental template definition of a system! By virtue of having a primitive brain, a flat worm possesses a model of self and a primitive model of its world (e.g. mud as a medium/food).

This being so, we are now in a position to tackle the problem of developing a universal ontology of system. That is, we will need to identify all of the existing elements that make a system what it is. The simple input-process-output model is a good starting place for our understanding, just as it was a good starting place for the evolution of brains and for the development of knowledge in an individual human being.

2.2.2 Examples of Developing a System Ontology

The desire to construct an ontology that captures the essence of human thinking is not at all new. For example Gottfried Leibniz (1646 – 1716), who we will refer to below, pursued a "*Characteristica universalis*", or a universal language of science that would unify all of the pursuits of the sciences[43].

In this section we will briefly look at several representative but more modern, methodological approaches used to develop a system ontology. These have been and are being employed by several researchers in system science, linguistics, and systemic applications in the sciences. We should hasten to note that not all of the work that has been done is couched in terms of 'ontology' per se. Most of the work done to date has been, rather, the exploration of frameworks, lexicons, and semantics aimed at grasping an organization of systems knowledge that can be used to further the cause of systems inquiry. We offer this sample of work as, nevertheless, examples of attempts to establish a common language of what exists based on a

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[43] See the Wikipedia article: https://en.wikipedia.org/wiki/Characteristica_universalis.

conceptualization of systemness. We would assert that these examples are oriented toward the same goal even if perspectives are somewhat dissimilar. Therefore, with deepest respect for the efforts examined here we hope the authors (those still alive) will permit us to aggregate their insights into this concept of ontological development. This is only a small survey of approaches to developing the ontology of systems. We believe that this is a fruitful area of open research. What we present here is just the beginning (but hopefully an extremely useful one). The objective of the development methods is to define a clear and concise *framework* (next section) for then examining system-related phenomena to assess their ontological status.

The key questions asked in developing such a framework revolve around discovering common features and patterns of features that are found to be true in all systems, or at least those that we have a deep interest in. The principles given in Mobus & Kalton (2015) and replicated in Chapter 1 are examples of this kind of study. The listed principles in Chapter 1 are, however, only the most general features and patterns. Many more are believed to exist and will be the subject of much research in the coming decades (c.f. Rousseau, et al, 2016). As presented below, the ontology framework is based largely on the principles, but there have been several additional important influences.

2.2.2.1 Miller's Living Systems Theory

James Grier Miller (1978), in his monumental tome, *Living Systems*, did not address the idea of an ontology as such, however he outlines 12 critical system concepts relevant for life and a number of terms referring to commonalities across kinds of living systems (e.g. from cells to societies). Table 2.1 provides the list of top-level concepts from his Chapter 2. Each one of these has a number of sub-concepts (details and sub-sub-concepts!) This list is similar to the Ontology Framework in Section 2.4 below.

Table 2.1. Miller's basic concepts include what we are calling a system top-level ontology for living systems (complex adaptive and evolvable systems).

Miller's Basic Concepts (Chapter 2)
Space and Time
Matter and Energy
Information
System
Structure
Process
Types
Level
Echelon
Supra-system
Subsystem and Component
Transmission in Concrete Systems
Steady State

Missing from Miller's list is the concept of *knowledge* as separate from but related to information as shown in in figures 2.1, 2.2, and explained above in the section on Cosmological Ontology. Otherwise the reader will already recognize some of these items from our prior discussion and will encounter more as we proceed. Another difference between Miller and Mobus & Kalton (2015) is that the former includes the term 'steady state' as having principle ontological status whereas the latter establish a general concept of 'dynamics' of which steady state dynamics are only one kind. The reason is likely to be that Miller was only concerned with *living* systems that continued living over time, which would require a steady state dynamic condition, at least so far as the then state of knowledge of what being alive meant. Other biologists tackling the distilling of principle terms, such as Len Troncale (see below) have included more general forms of dynamical systems such as chaotic processes.

Along with these basic concepts Miller listed 20 critical subsystems of a living system (page xix of the preface, Table P-1), and a select number of components (Table P-2, pages xx-xxiii). His approach was to examine all of these across multiple levels of living system organization, e.g. cells to supranational systems. Even though Miller was concerned with living systems as a biologist and medical scientist, he recognized the life-like characteristics of human-based organizations[44]. So most of the subsystems/components are found in all levels.

Miller grouped his critical subsystems into three categories, subsystems that process matter, energy, and information, subsystems that process only matter and energy, and subsystems that process only information. A fourth quasi-category holds a single critical subsystem – the boundary. A few representatives in categories 2 and 3 are listed here (with notes on relations to what will be covered later in this book in square brackets). Examples of category 2 include: "Ingestors" [later to be seen as acquisition processors], "Distributors" [as the name implies], "Producers" [later to be seen as sub-subsystems]. Category 3 examples include: "Input transducers" [later to be seen as message transducers, e.g. amplifying receivers], "Channel and nets" [later to be seen as flow networks], "Memory" [as the name implies], and "Decider" [later to be seen as an agent subsystem (Chapter 11)]. His category 1 also contains a single element that combines categories 2 and 3 along with the boundary element – that is a "Reproducer" [later to be seen as a specialized work processor for repair and propagation]. All of these critical subsystems are to be found in all levels of Miller's hierarchy of systems [later to be seen as levels of organization] from a single cell (lowest level of organization in his vision) through organisms to societies and supranational systems[45].

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[44] In Chapter 8 and again in Chapter 11 we will look at the economy and its governance as a form of exosomatic metabolism, thus reflecting Miller's notion of a supra-level of organization that is still reflective of a living system.

[45] At the time of Miller's writing and up to the present there really are no examples of supranational systems that would meet his criteria. Neither the United Nations, nor NATO or any other such organization is vested with decision making authority. State powers that approximate a supranational, such as the former Soviet Union and the current European Union were and likely are unstable arrangements. The former already has disintegrated, and the latter seems on the brink as of this writing.

2.2.2.2 Troncale's System Process Theory

Lenard Troncale (1978; Friendshuh & Troncale, 2012; 2006) with co-workers have been working on the concept of systems as processes (SPT and SoSPT see, below). He and his co-workers have been leading an effort to build a true science of systems through the rigorous examination of a large number of 'processes' or transformations and relations between elements that give rise, for example, to stability, structures, or products[46].

System-level processes (originally called "systems field axioms"), and how they interact, called 'linkage propositions,' act to produce higher order processes. The latter leads to what he calls "Systems of Systems Process Theory" (SoSPT) reflecting the hierarchy of organization from simple relations (at the bottom of the hierarchy) to much more complex multiples of processes and realized linkage propositions at the higher levels.

These workers emphasize the importance of the concept of 'process,' which they define as, "…a series of steps of change through which a set of objects proceeds." (Friendshuh & Troncale, 2012). They argue that the concept of process is so important because change (transformation of objects) is what the world is fundamentally about. But not just any change; they emphasize that changes that lead to organization or structures is the basis of systems and should, thus, be the main subject of systems science. Hence, they look for fundamental process archetypes that are 'isomorphic' across many if not all systems that come under study. In other words, they are looking for processes that underlay all of nature. These would be the ontological elements of systems. Friendshuh and Troncale (2012) explain isomorphisms:

> A process is isomorphic if its abstracted, generalized "form" or "pattern" can be found at many scales in many phenomena (Gr. iso- = same as, equal; morpho- = form).

Some examples of processes that are isomorphic are[47] (from Friendshuh & Troncale, 2012):

- Boundaries
- Competition vs. Cooperation
- Cycles and cycling
- Emergence/Origin
- Feedback
- Hierarchy
- Networks

The ontology that emerges from the Troncale et al work consists of major system states and progressions, such as system 'form' and system 'linkage', each with its own set of 'isomorphic

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[46] Troncale has noted many similarities between his own work and that of Miller mentioned above. Both researchers had very similar goals and methodologies by which to arrive at general theory. See (Troncale, 2006).

[47] Many of Trocale's processes correspond with what Mobus & Kalton (2015) call principles of systemness.

processes' and cross-connected through the linkage propositions which are paths of influence between the isomorphies. For example, Troncale defines a system state as 'origin.' In this state he defines the isomorphy of 'boundary conditions' (see Figures 1 and 2 of 2006). In other words, the system comes into existence as a system when a boundary appears that distinguishes it from the background environment in which it is embedded. The boundary condition isomorphy is linked with the 'input/output' isomorphy that is part of 'system linkage.' In other words, there is a direct relation between inputs and outputs with boundary conditions established earlier in the sequence of system ontogeny (to be discussed below). This very important relation will be developed more explicitly in what follows.

Troncale also points out a basic problem with ontologies: "Texts have many words. Words are notorious chameleons. They change with the intent and background of each user. Unless there is a consensus about the meaning of the words in a proposition or process, little is accomplished" (Troncale, 1993). The selection of a lexicon that is truly representative of an ontology is not a trivial problem.

2.2.2.3 INCOSE – Systems Science Working Group Effort

The International Council for Systems Engineering (INCOSE) has had difficulty describing a discipline of systems engineering owing, in part, to a poor consensus on what systems science actually is and what parts of systems science should inform the engineering of the products systems engineers produce. And this comes from a poor consensus on what a system is! Within the ranks of INCOSE a number of systems engineers recognized this failing and set out to correct it[48]. The INCOSE Systems Science Working Group (SSWG)[49] was formed to address this problem. They sought alliances with existing systems science organizations such as the International Federation for Systems Research (IFSR)[50] and the International Society for Systems Science (ISSS)[51] to begin the process of constructing definitions for systems, systems science, and, eventually, a bases for systems engineering. As part of that effort, members of the INCOSE SSWG have been working on defining an ontology of systems that could provide a basis for inter-group communications about systemness (though they do not use that term explicitly).

It is a little cart-before-the-horse to have engineers define a scientific subject area in this way. However, given that the need is extremely great (systems engineering is going to happen regardless of the state of a system ontology!) it is not entirely unprecedented. And, as it happens,

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[48] It was also motivated by a growing number of systems engineering projects that had 'failed' in one sense or another and the growing awareness that systems engineering, unlike other engineering professions that were solidly based on physics or chemistry, had no scientific base to build upon.

[49] See the INCOSE SSWG web site: https://www.incose.org/ChaptersGroups/WorkingGroups/transformational/systems-science for more information. Accessed 1/26/2018.

[50] See the IFSR web site: http://www.ifsr.org/ for more information. Accessed 1/26/2018.

[51] See the ISSS web site: http://isss.org/world/ for more information. Accessed 1/26/2018.

many high-level systems thinkers have been involved in the effort so there is a high degree of expectation that the work will produce useful insights. As of this writing, the author's own efforts are being invited to be incorporated in the effort. So this chapter and the next will become part of the process within INCOSE to build a universal ontology (and language) of systems.

2.2.2.4 Natural Semantic Meta-language

The idea that there might exist a common lexicon (of concepts) pointing to a fundamental ontology has been explored by Anna Wierzbicka and Cliff Goddard (Wierzbicka & Goddard, 2014) in terms of a minimal set of semantics that are common across 'all' natural languages and are used as a base set of terms to define other terms in a language. They have identified a set of terms, called "semantic primes," that they claim are common to all investigated languages (meaning that cross language interpretation is straightforward). There are words in every language that are used to express these prime concepts, e.g. "mother" (in English) is found in all studied languages.

The idea that there might be a meta-language containing universal concepts lends some weight to the idea that mentalese exists and is subconsciously being used in thought. Further, that there are universal concepts suggests that the proposition that the human brain comes hardwired with a set of templates for those concepts – that they are not a product of cultural indoctrination provides support to the more refined proposition that the human brain is wired to perceive systemness.

2.2.2.5 System Dynamics (SD)

One of the most well-known systems modeling methods was developed originally by Jay Forrester at the Massachusetts Institute of Technology (MIT). Forrester sought to construct a computer modeling language that would be general enough to encompass any arbitrary dynamic system process (Radzicki & Taylor, 2008). His original targets were related to management of organizations and economics, but the language he developed could be applied to a wide variety of systems, such as ecosystems, and engineering projects. DYNAMO, his early language, used a lexicon based on the idea that all systems involve flows of matter, energy, and messages, or, more generically, just flows of stuff and influence. It also involves the states of reservoirs or 'stocks' of stuff that rise and fall relative to the flow rates of inputs versus outputs. He defined regulators or 'valves' that controlled the rate of flows as well as sensors and control decisions that would change the settings on the valves.

Subsequent versions of SD have continued to view the universe as being comprised of stocks, flows, regulators, and influences determined by decision functions. Newer languages with graphic front-ends have been developed to help researchers build complex models of systems in these terms. Donella Meadows in *Thinking in Systems* (2008) provided a summary of SD lexicon, syntax, and semantics for building models out of the simple ideas of stocks and flows.

Indeed, a significant number of issues involving system dynamics can be handled using this ontology. Just about everything you see is composed of stocks of something and flows into and out of those stocks. The generality of the language (and its basic ontology) allows it to be useful in any number of systems models. A great advantage of SD is that it is immediately translatable into computer code for simulation.

On the other hand, there are still many aspects of systemness that are beyond mere dynamics. As important as dynamics are, they are not the end all of system modeling or understanding. In the last decade, work has been done on combining agent-based modeling languages with SD in order to produce more realistic models of systems involving cognitive processes (instead of mere decision functions) and social interactions. Thus the ontology of SD is being combined with the ontology of cognitive science and sociology to arrive at a much richer definition of reality.

2.2.2.6 H.T. Odum's Energese

Howard Odum is recognized as one of the fathers of systems ecology. He made an incredibly significant contribution to that field but also to our general understanding of how the whole world works with his introduction of the study of energy flows in ecological systems.

His focus was on how energy enters the systems (through primary producers capturing solar energy and producing biomass) to how that energy is then distributed among the participant species in the ecosystem, and finally dissipates to the embedding environment (heat transfer to exiting water and radiation to the atmosphere).

Odum recognized that these principles of energy flow applied equally to the human economy (Odum, 2007, and see Chapter 8 for a further explication). He developed an implicit ontology and lexicon called "energese.[52]" What he recognized and used to great effect is, in Len Troncale's terms, the isomorphic relations between energy flow-through in ecological systems and that in human economic systems. An economic system is, after all, a process for doing useful work to produce wealth for human's to exploit (see Chapter 8). This is no different than primary producers making biomass for exploitation by the consumers in an ecosystem.

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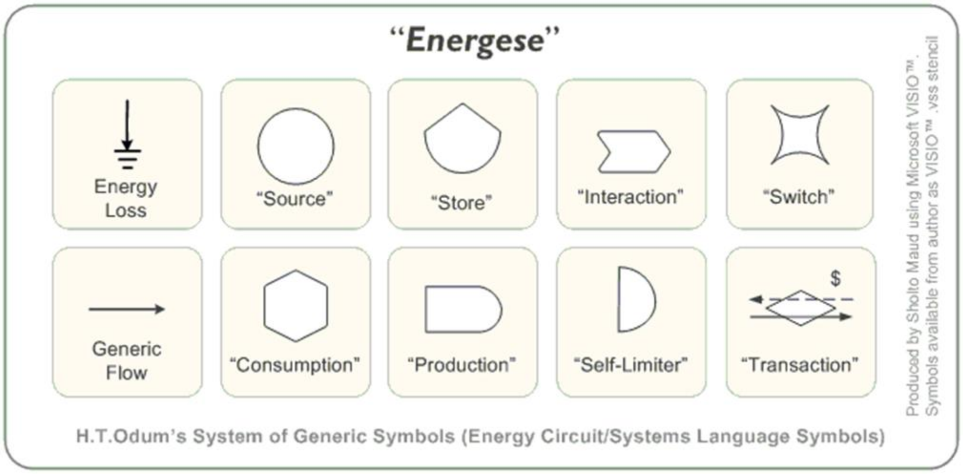
[52] See Wikipedia article: https://en.wikipedia.org/wiki/Howard_T._Odum#Energese:_Energy_Systems_Language.



By Mdd at the English language Wikipedia, CC BY-SA 3.0,
https://commons.wikimedia.org/w/index.php?curid=38159397

Fig. 2.4. H.T. Odum's energese lexicon and iconography used to model both ecological and human economic systems. Source: Mdd at the English language Wikipedia, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=38159397.

2.2.2.7 WordNet

George A. Miller (Miller, 1995), at Princeton University Department of Psychology, started a lexical database of English words that are linked semantically. The resulting network can be searched for meaningful relations (they call "synsets") that have deep conceptual structure. From the WordNet website:

> WordNet® is a large lexical database of English. Nouns, verbs, adjectives and adverbs are grouped into sets of cognitive synonyms (synsets), each expressing a distinct concept. Synsets are interlinked by means of conceptual-semantic and lexical relations. The resulting network of meaningfully related words and concepts can be navigated with the browser. WordNet is also freely and publicly available for download. WordNet's structure makes it a useful tool for computational linguistics and natural language processing.[53]

Using WordNet's online search tool for the word "container" links to full hyponym words like: bag, basket, bowl, bin, and many others, including vessel, are produced. A subsequent search led to 'reservoir' and a search for the inherited hypernym (superordinate inheritance) produced the display below (Figure 2.5).

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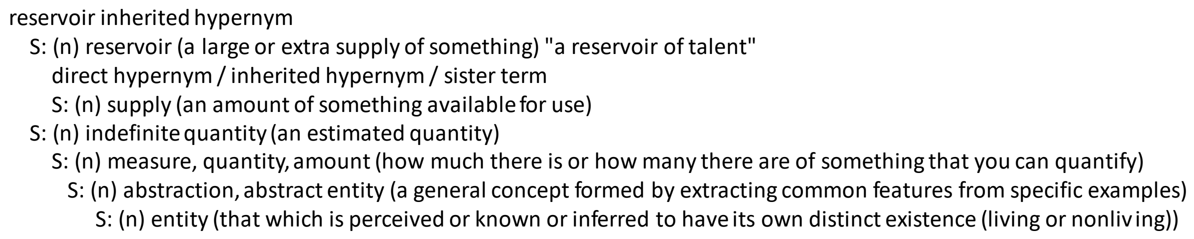
[53] See the WordNet website at: http://wordnet.princeton.edu/wordnet/. Accessed 11/3/2017.



reservoir inherited hypernym
  S: (n) reservoir (a large or extra supply of something) "a reservoir of talent"
    direct hypernym / inherited hypernym / sister term
    S: (n) supply (an amount of something available for use)
  S: (n) indefinite quantity (an estimated quantity)
    S: (n) measure, quantity, amount (how much there is or how many there are of something that you can quantify)
      S: (n) abstraction, abstract entity (a general concept formed by extracting common features from specific examples)
        S: (n) entity (that which is perceived or known or inferred to have its own distinct existence (living or nonliving))

Fig. 2.5. The inherited hypernym display from WordNet shows the inheritance of the concept of a reservoir from the concept of an entity. It acquires traits of ‘measure’ and ‘supply’ along the way. Source: http://wordnetweb.princeton.edu/perl/webwn?o2=&o0=1&o8=1&o1=1&o7=&o5=&o9=&o6=&o3=&o4=&r=1&s=reservoir&i=1&h=10000#c. Accessed 11/3/2017.

Hyponyms are subcategories of a more general class (according to Dictionary.com).

What the synsets in WordNet demonstrate is how terms used in English are semantically related and how they are organized in a category hierarchy from most general sense to specific meanings. A reservoir holds something as ethereal as talent or as physical as drinking water. It has some sense of an associated quantity of that something (e.g. a talent agency has 13 actors). It is an entity that performs a particular function (holding, at least temporarily). Thus, a reservoir is essentially what we called a stock in chapters 2 & 3. The term stock did not, surprisingly, relate to reservoir in this sense in WordNet. One might question then if it is advisable to continue to use the word stock as our semantic primitive. This is an open question that will deserve more investigation as the practical tools deriving from the use of systemese are developed.

2.2.2.8 Strong Movement Toward a General (Universal) Ontology of System

In all the above cases we see the researchers making concerted attempts to accomplish two things. The first is the establishment of a framework for understanding systemness in terms of what sorts of ‘things’ exist and participate in the patterns of objects being systems. The second is to use that framework to generate terms that can be interpreted universally as having the semantics we attach to the things, performing their functions, within the patterns of systemness.

There is clearly a desire to derive such a set of terms. The underlying motive would seem to be the desire to have a common language of systems that would describe the systemness (“domain of system knowledge” according to Klir, 2001) into which the particular terms of disciplinary terms (domain of thing knowledge) could be mapped. With good reason.

At the base of this motivation is the need, becoming more perceived as time goes on, to have a true basis for transdisciplinary communications. Efforts such as presented in this chapter and by the workers described above will continue and likely strengthen as this need deepens.

2.3 Ontogenesis: The Origin and Development of Systems

In a previous section (2.2.1.3), we provided an introduction to the notion of ontogeny of things that exist. We asserted that auto-organization, emergence, and selection, the ontogenic cycle, accounted for the existence of things in the Universe. The mechanisms by which this is accomplished are the subject of Mobus & Kalton (2015), chapters 10 and 11. The argument we now advance is that this is the basis for systemness evolving in the Universe, the organization of matter, the levels of organization, and the increases in complexity of systems as new levels emerge. That is, the process of ontogeny in the Universe is responsible for the fact that all systems are constructed of subsystems, which, in turn, are themselves systems amenable to further decomposition until we reach a most fundamental "particle" level[54]. What we find in the Universe today is a very complex structure of systems and their subsystems. The Earth is a system comprised of numerous subsystems (see chapters 8 and 11 for example). This complexity evolved through the ontogenic cycle driven by the availability of high potential energy flows (e.g., from the Sun) through the Earth structure, doing work to complexify[55] the system, and radiated as low potential waste heat to outer space (Coen, 2012; Morowitz, 1968, 2004; Schneider & Sagan, 2006).

The Earth, indeed, the whole Universe, is what it is today because electromagnetic energy has been flowing from stars through intermediate systems, planets like the Earth for example, to deep space since the gravitational formation of bodies undergoing nuclear fusion reactions[56] capable of radiating these energies (stars). On this planet we observe systems comprised of subsystems that are, themselves, comprised of subsystems (i.e., sub-subsystems), down to the level of subatomic particles precisely because the pattern of systemness is the natural outcome of ontogeny.

2.3.1 The Ontogenic Cycle

The ontogenic cycle is the process whereby 'things' that exist at a level of organization interact with one another. Some things interact strongly, for example forming strong bonds or mutual dependencies that will hold them together in space over time.

2.3.1.1 The Basic Process

We recapitulate the descriptions of auto-organization, emergence, and selection that underlay universal evolution from Mobus & Kalton (2015). Figure 2.6 is a simplified view of the

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[54] A most fundamental particle or most "atomic" particle is posited at the quantum level. Loop quantum gravity theory (see Wikipedia: https://en.wikipedia.org/wiki/Loop_quantum_gravity, accessed 1/27/2018, and Smolin, 1997; Unger & Smolin, 2015, for background) and string theory (see Wikipedia: https://en.wikipedia.org/wiki/String_theory , accessed 1/27/2018) both seek to explain how things come into being based on such fundamental particles or strings. These subjects are far beyond the scope of this book. Our conception of such particles and their interactions with quanta of energy is based on inference and the need for an ultimate stopping condition for downward recursion of the system-subsystem relation more fully explained in the next chapter.

[55] This term implies that the work of combination of subsystems and components through auto-organization increases the Simonian complexity of the whole supra-system.

[56] Nucleosynthesis is, itself, a version of ontogenesis in which lighter atomic nuclei are brought together to form heavier nuclei. See the Wikipedia article: https://en.wikipedia.org/wiki/Nucleosynthesis for background. Accessed 1/5/2019.

process as presented in that source by adding the explicit flow of energies that drive the cycle and adding a third loop representing a different and significant mode of organizing we call "intentional-organization," which we will encounter in Part 4 of the book in chapters on artifactual systems and their design by human intention.

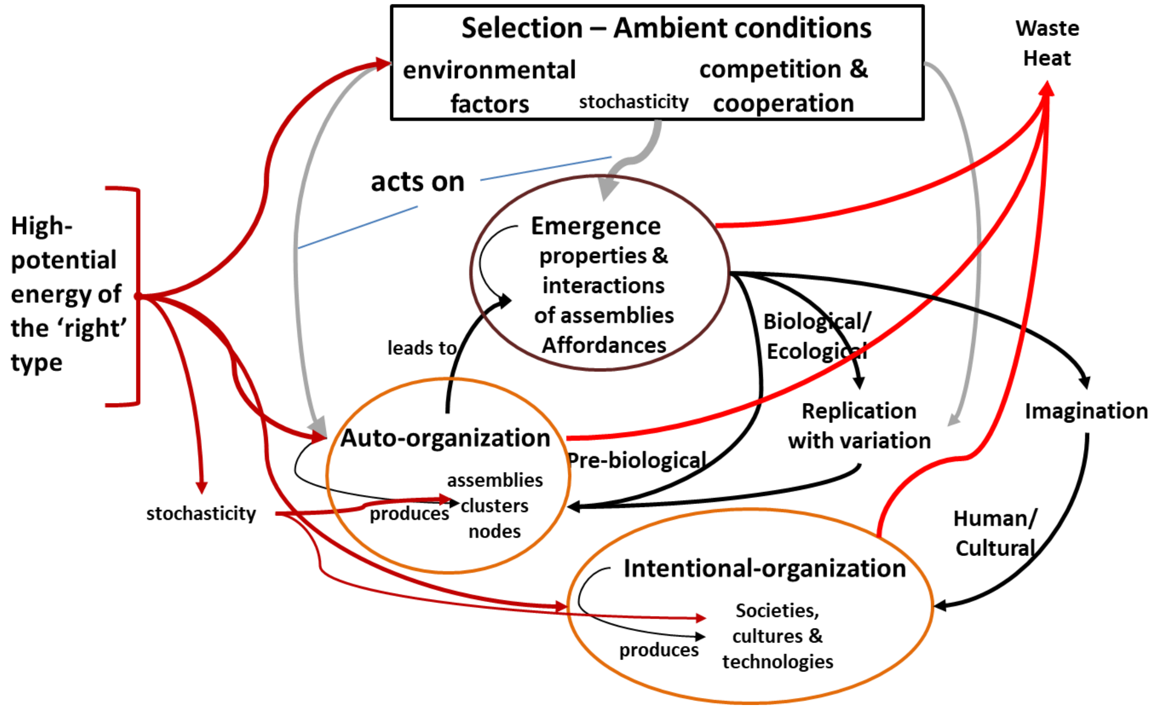

Fig. 2.6. The ontogenic cycle is depicted. This cycle produces ever more complex systems from simpler systems as long as there is a flow of high potential energy from a localized source through the system and out to a general sink, as is the case for the earth system. Figure modified from Mobus & Kalton (2015), Figure 10.3, page 471.

The figure depicts three loops, from left to right, that represent ontogenesis in three different regimes (or dynamic realms, as Volk, 2017 terms them), The inner-most loop is labeled pre-biological and entails ontogenesis of systems from the subatomic level of organization up to and including the pre-biological chemical level. Upon the emergence of life (described by Smith & Morowitz, 2016, as a major phase transition of matter) we enter the realm of biological evolution which inserts a new subprocess, the methods of replication with variation (genetic mutation, for example) to the overall process of emergence followed by a new round of auto-organization. This significantly expands the range of possible variant entities (e.g. species) and thus the opportunities for auto-organization to generate many new kinds of entity relations, including symbiotic and ecological (e.g. food webs). This new level of organization offers entities with vastly increased numbers of affordances, and hence, greater or longer-term stability for the new systems emerging. Finally, once hominids evolved through the operation of this biological loop, and transcended ordinary consciousness, that of the state of the body, of the state of the immediate environment, and the state of the coupling of these two (Mobus, 2019) and mere signaling communication, a new kind of organizing process comes into play. Humans invent things that they can imagine and intend to construct and use; they are conscious of possible future worlds (Mobus, 2019). This latter process, here identified as “intentional-organization” will be explored further in Part 4, as mentioned. We introduce it here in preparation for that discussion.

The flow of high potential energy[57] through a potential system, that is one that is not particularly organized but contains ‘particles’ or individuated entities with complimentary affordances that have the potential to form interactions requiring the doing of work, drives the auto-organization, or realization of those potentials, in the form of new assemblies of particles, i.e. particles form selective bonds, or in the case of the biological loop, species relations. In the case of intentional-organization this is realized in the actual work of humans inventing and constructing new cultural artifacts (see Chapter 13). Since work is being done, the energy eventually flows out of the system as waste heat when a steady-state condition is achieved. The figure also depicts a smaller flow of energy that is not necessarily driving work directly but contributes instead to stochastic disturbances or the “shuffling” of the particles to increase the opportunities for disparate kinds to interact. Note that in the Auto-organization process this stochasticity is a relatively important component of the process (e.g. in the chemical system, this is in the form of thermal vibrations and variations in momenta of the atoms, such as Brownian motion). In the Intentional-organization loop, stochasticity plays a role, to be described further in Part 4 as the novelty element in imagining designs, but much less so as in the pre-biological and biological loops.

The most notable version of this process, to provide an explicit example, might be the chemical interactions between molecules that were thought to be involved in the origin of life on Earth (Morowitz, 1968, 1992, 2004; Schneider & Sagan, 2006). During this phase ambient conditions (such as temperature, salinity, pH, and other physical forces in the case of pre-life chemistry) tend to select for more stable assemblies and disrupt lesser stable ones. If the geometry of the boundary conditions is favorable, the flow of energy through the system will also drive convective, mixing, and sorting cycles that might favor the interactions between these new assemblies. The assemblies have different interaction potentials than their components had possessed before forming bonds. For example, larger organic molecules may have very different bonding potentials for exposed valence shells when some of the valence opportunities have already been subsumed under the formed bonds. Some of these new potentials are “stronger” than would have been the case for a “naked” atom. They also can exhibit very different behaviors. More complex molecules may show affinities for other molecules that would not have been present in the pre-molecular state. This is the phase of emergence – new structures and new behaviors emerge from these new potentials.

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[57] High potential energy refers to a specific form of energy that is capable of coupling with specific forms of work within the potential system. Different forms of energy will couple with bonding activities in the different levels of organization. At subatomic levels the energies are inherent in the fundamental nuclear and electromagnetic forces. At the molecular level energies may involve thermal modes or electromagnetic quanta (i.e. photons). At the social level these same forms of energy are now operating in the form of behaviors such as eating and replicating.

Lest the reader think this general pattern of the ontogenic cycle only applies to atoms and molecules, think about social situations. There are many instances where strangers are gathered into a new potential social situation, like a new organization (the containment boundary), where they enter a phase of “getting to know one another.” People have personalities and have affinities for certain other personalities in forming relations of trust, friendship, or being repelled by some. The organization may have an “official” organization network, but here we can see the “unofficial” social network auto-organize. The resulting relations, in particular the bonds that are forged, provide the bound participants with much more social power than any of them might have had as individuals.

Consider the rings of Saturn, or, for that matter, the orbits of planets around the sun. On the scale of the solar system we see interactions mediated by gravitational coupling that lead to new structures. Planets like Earth are condensed and structurally organized aggregations of dust, water, and gasses that form new organizations during planetary evolution. The final (or semi-final) states of the solar system and planets demonstrate considerable organization through the selection force of gravity (e.g. the various geo-layers from the Earth’s core to its outer atmosphere based on densities of the materials) pulling mass toward the planetary center versus the flow of high temperature heat outward toward the surface and into deep space.

As important as the emergence of new structures and behaviors, the stable assemblies represent a new level of complexity, i.e. complexity of the whole system has increased. The pre-biotic chemical “soup” underwent a phase change when self-replicating cells emerged and has increased in complexity ever since with the rise of eukaryotic cells, like paramecia, then multicellular organisms, and eventually up to human societies. The Earth, as a planet is far more complex as a whole, than any one society. Figure 2.7 depicts the spiraling upward over time of the results of the continuous application of the ontogenic cycle. The width of the spirals represents increasing complexity. The spiral shape represents the auto-organization and emergence of new more complex assemblies through time. As long as there is a flow of free energy, i.e. energy in a form that can drive the useful work of forming new combinations of assemblies at any given level, the spiral will continue upward and wider. This increasing complexity is corresponded with the increasing levels of organization that we have witnessed on our planet (after Volk, 2017; c.f. Morowitz, 2002; Troncale, 1978a).

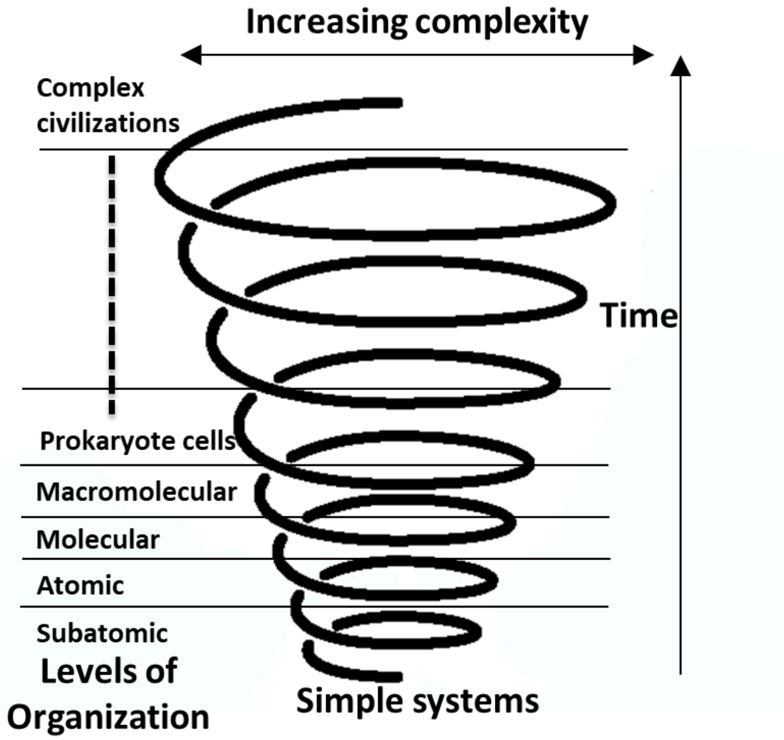

Fig. 2.7. The continuous pass through the ontogenic cycle produces a spiral of ever-increasing complexity as the general ontology of the Universe.

Here we present a summary of the mechanisms involved in the ontogenic cycle as far as auto-organization is concerned (as mentioned above we will consider intentional-organization later in the book). Figure 2.8 shows the situation prior to the onset of auto-organization. This shows schematically a multiset of components (possibly themselves subsystems as described in the next chapter). Each component possesses what we have called "personalities" which make them unique kinds of entities. The objects in the figure represent these entities and each has a set of bidirectional arrows representing their potentials to interact with other components (potential affordances). These entities are shown contained in some fashion that ensures their potential for interactions (later we will discuss boundaries and boundedness). Also shown is the existence of a high-potential energy source providing energy input into the container at a particular position. The figure also shows the dissipation of low potential energy (not shown are the actual source and sink entities for simplicity) and a pathway for energy to flow through the system.

The state of the system at this primordial situation is that the components may interact, say through collisions or bumping; we assume motion degrees of freedom. The situation shown can represent a wide range of entities in the levels of organization in Figure 2.10 below. It can represent, for example, the simple molecules available for interactions leading to the construction of macromolecules, the precursors of living systems. Or it can represent individual human being brought together in a social situation in which personalities (as the word is normally used) have the potential to interact.

This model of auto-organization follows closely and was inspired by the work of Harold Morowitz (1968) and amplified by Smith & Morowitz (2016). Morowitz developed the concept of how energy flow, under particular conditions of containment and configuration, could act to organize the system in a molecular environment. He was one of the premier workers in the field of biogenesis (origin of life).

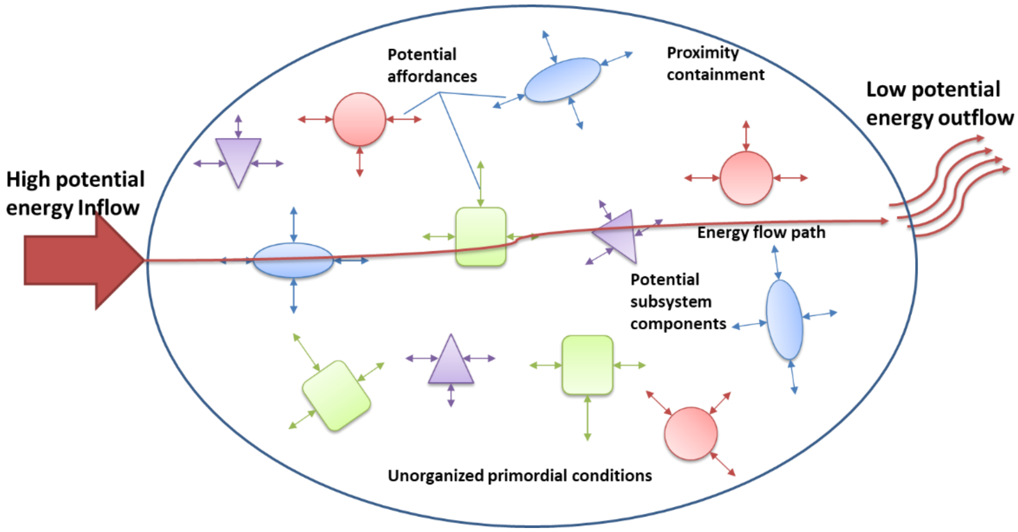

Fig. 2.8. The primordial conditions before the onset of the ontogenic cycle just at the onset of auto-organization.

We use the term 'affordance' in a very general way. More specifically, mutual affordance means that two entities are able to couple unidirectional flows (of material, or energy, or messages), which will be explained later in this chapter and more thoroughly in the next chapter; for convenience these two-way flows are here represented as bi-directional arrows for brevity. An example is the coupling of a positive charge from a proton with the negative charge of an electron. Another is a dialog between two people.

What we see in Figure 2.8 is a 'potential' or latent system. Each entity's potential affordances are matched to one extent or another with affordances on one or more of the other entities, by type. That is, each entity has a potential to bond[58] with some other entities under the right circumstances. Principally that means an availability of the 'right' kind of energy (also known as exergy) available in the energy flow to do the work of forming the bond. Another 'right' kind of energy might involve that needed to move the entities about within their containment. In the work Morowitz did he noted how aqueous molecular systems (under conditions of temperature and pressure) respond to heat flow by forming convective cycles, assuming the waste heat can escape the system as shown in the figure. This keeps the potential system at relatively constant temperature and pressure. Moreover, the convective cycles carry the entities about in a stochastic manner making the probability of finding matches higher than equilibrium chance alone.

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[58] For completeness we should also understand that some affordances may involve repulsion and not just attraction. To keep the explanation simple we are only considering attractive forces here.

Though the process of auto-organization can most easily be pictured for molecular formation, as the entities in Figure 2.8 represent atoms of different kinds with different configurations for valence electrons, it is important to note that this picture represents the general dynamics of auto-organization and is valid for all levels of organization. For potential systems higher in the levels of organization the same phenomenon can be seen but with differences in the details of containment, configuration, and what the specific form of energy flow is involved. For example, in the case of people brought together at a social meeting, the containment might involve the event (like a wedding) and a room. The energy flow is clearly much more complex involving both the energy each person uses to move about which they brought into the situation from the food they consumed at home, but also things like the temperature controls for the room.

From the initial primordial state, we now consider the actual process of ontogenesis, the combining of these entities as a process and how it leads to more complexity and increasing levels of organization (see section 2.3.1.2 below).

Figure 2.6 above shows three pathways from emergence back toward the next phase of auto- or intentional-organization. One pathway, the purely physical, involves auto-organizations of things such as nucleons, atoms, and molecules, but also covers auto-organization (via the gravitational force) of stars, planets, and galaxies, in other words, pre-life systems. The second, middle pathway routes through the special kind of evolution that applies to living systems. Mechanisms that can be viewed as generators of unbounded diversification, such as mutation and duplication create opportunities for new living systems to emerge. The third, right-most pathway will be covered later. Figure 2.9 provides a pictorial representation of the auto-organization pathways. Here we see the entities from Figure 2.8 beginning to interact and follow a time course of such interactions, thus becoming components of a system. These are shown as bonding at the mutually compatible affordances.

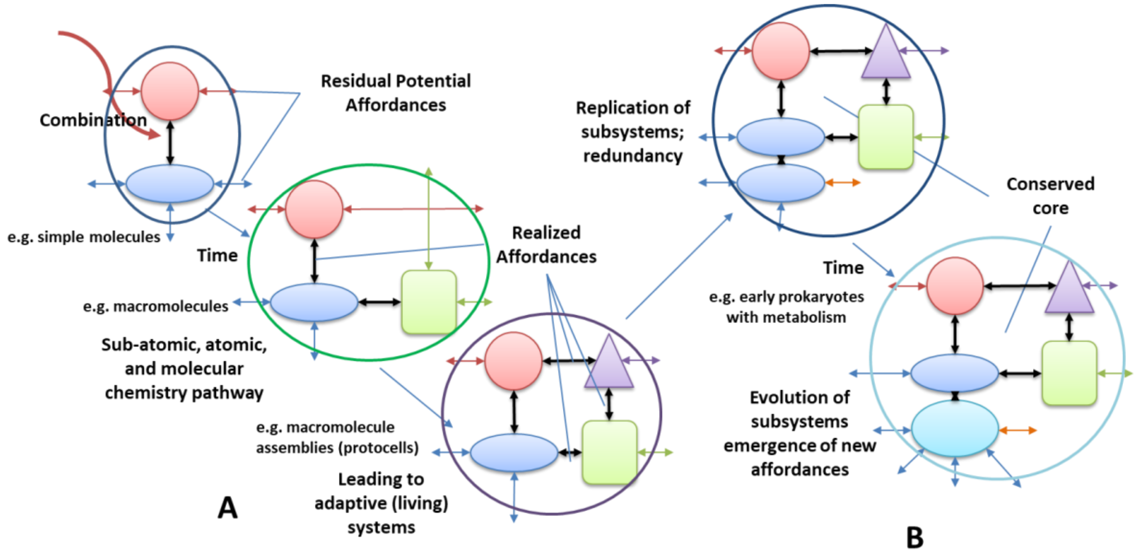

Fig. 2.9. Ontogenesis: A) the pre-life pathway to greater complexity; B) the evolutionary pathway to greater complexity of living systems through biological evolution. The surrounding ovals in the A sequence represent effective boundaries where the connections between entities as components create a unity. The boundaries indicated in the B sequence may represent actual boundaries like cell membranes. This figure depicts just the formation of stable structures, those having significant duration given the milieu in which they formed. A more complete picture would show many unstable formations (at a specific time) hovering around the stable ones that will later disaggregate and many components that have not been incorporated into more complex structures owing to the specific conditions of the milieu.

The figures on the left side (labeled A) represent a time sequence (blue arrow labeled Time) of pre-life auto-organization. In this figure we represent a shortened sequence leading to biological evolution, but independent of scale, the various objects could represent quarks, or nucleons, or atoms, or molecules (or planets, or stars, etc.). In that sequence higher complexity is obtained when various entities with different personalities and having different, but compatible potential affordances (thin two-headed arrows) combine owing to mutual attraction to produce realized affordances (thick black two-headed arrows). In this sequence we see the emergence of increasing complexity by ‘accretion’ at the same level of organization. The combinations may lead to the emergence of new possible affordances or, as shown, residual affordances from the original components and newer combinations (middle object in A). The success, of course, depends on the ambient conditions that add or subtract energy from the process (as shown above and detailed in Mobus & Kalton (2015, Chapter 10). Those conditions select for stable configurations and select against weak bonds. The third object shows another round of auto-organization that leads to a chemical system sufficiently able to exploit the energy disequilibria and be able to adapt to minor shifts and retain stability. This is the beginning of ancient metabolism (Smith & Morowitz, 2016) and probably coincident with the building of the first genetic code. At some point subsequent these systems acquired an ability to replicate themselves and internal parts of themselves (the two similar blue ovals in the upper object in B). Replicated internal components may have the ability to evolve differently from the original component[59]. We have now entered the pathway of biological evolution where when such events occur the redundant part is free to evolve into something new, sometimes also evolving new affordances (bottom object in B).

Atomic auto-organization proceeded along a fixed pathway by merely combining nuclei via nucleosynthesis. Residual affordances took the form of increasing positive electric charge as protons were fused to form higher atomic number. New affordances took the form of creating additional (potential) electron shells with increasing ‘slots’ for electrons to occupy when nuclei captured electrons (in cooler conditions). These new affordances of atoms, valence shells, not just nuclei, created the potential for chemical interactions between atoms, e.g. covalent or ionic bonds. Of course, when a valence shell has all of its electrons and the atom is electrically neutral the atom system is essentially closed to further interactions; no residual affordances are available at the boundary, except under very extreme conditions.

Chemical evolution (and here we can include planetary construction) begins to introduce more elaborate combinations of atoms and under the right circumstances leads to molecular mixes of sufficient complexity and organization that they live. We suppose that the process of ontogenesis continues apace. Biological evolution eventually produced our clever species which has proceeded to change the dynamic of ontogenesis by introducing intentions into the combination business (and into the business of reshaping material resources for advantage) They create systems for their use and combine with a spectacular array of those artifactual systems (see Chapter 13) to form a multiplicity of cultures, organizations of societies with seemingly unlimited affordances. At this writing there has been some hint of these cultures further combining by a process of blending. You can find a McDonalds™ almost anywhere in the world.

In the following section we sketch the elaboration of structures, forms, and functions in a hierarchy of complexity as ontogenesis produced the Universe we witness today.

2.3.1.2 Levels of Organization

The Universe, as we find it contemporarily, is rather complex in terms of heavenly bodies (stars, planets, galaxies, and even more exotic bodies). But in addition, there are islands of exceeding complexity (at least one that we are sure of) on planets with living systems[60]. This complexity pertains to the fact that there exist nested levels of organization. Atoms might seem relatively “simple” compared with molecules, especially organic molecules. In turn molecules are relatively “simple” compared with living cells, prokaryotes like bacteria. And bacteria (or cells in a multicellular organism) are much “simpler” than a tree or a goat. When we recognize

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[59] In Chapter 9 we will address the issues of what is required within a complex, adaptive, and evolvable system to implement these mechanisms.

[60] Recall that the kind of complexity we are talking about is that suggested by Herbert Simon, a hierarchically organized object composed of subsystems and those composed of smaller subsystems, what he called a “partially decomposable” system.

that all organisms are participants in larger-scale ecosystems including geophysical aspects as well as a large-scale stable set of other living species we can see that the whole Earth is exceedingly complex.

Figures 2.10 through 2.12 show some relations between "things" that show progressively greater complexity as new levels of organization (to which they belong) emerge. We will discuss the progressive origins of these things below as well as the levels of organization and emergences. Figure 2.10 presents the purely physical (i.e. subatomic and atomic entities that end up producing both large-scale entities (like galaxies) and small-scale entities like gasses and rocky bodies through chemical interactions.

The figure shows the transition from non-living to living systems through stages that involve the co-evolution of primitive ecosystems (believed to be primitive thermal vents in the new oceans, Smith & Morowitz, 2016). The events that had to occur for the origin of living matter are only now beginning to be understood. Morowitz (1992) considers the origin of metabolism and some primitive form of it providing clues as to what sorts of chemical interactions must have been transpiring that would produce a substrate for full-on living metabolism in true cellular structures.

The exact mechanisms involved in the origin of life, what the processes of auto-organization and autocatalysis that led to the first biological entities (prokaryotic cells) are still unknown but many clues have been discovered (Smith & Morowitz, 2016). But once living systems emerged in the ancient Earth, a new capacity for self-maintenance emerged as well, the capacity for individual cells to adapt within boundaries to changes in their extant environment. We now enter the realm of the complex, adaptive system (CAS) insofar as individual organisms are concerned. But something even more interesting co-emerges with living cells. They reproduce and form populations of cells. They transmit their genetic materials via copies to descendants, but sometimes with minor errors in the code. Most of the time the errors are either harmful and kill the individual descendant, or they may be neutral, having no substantive effect on the phenotype of the offspring and so are invisible to selective forces. What this does do, however, is introduce a completely new kind of system in the form of a population of individuals that share the same basic genetic code but for a few errors in copying here and there – a species. And the population constitutes a new kind of system. It, taken as a whole, is a complex, adaptive, and *evolvable* system. Not only are individuals capable of adapting within limits to short-term changes in environments, but due to some individuals possessing mutations that, by chance, give them the capacity to become adaptive to larger changes, the species gains the ability to survive on the whole when things really do change substantially. The capacity to evolve modified and more fit phenotypes, when things change, gives the species resilience in the face of change and makes it long-term sustainable.

So with the origin and development of life we go into the realm of the complex, adaptive, and evolvable systems (CAES) mentioned in the Introduction, again in Chapter 1 and to be refined in Chapter 5.

It is the CAES that intrigues us the most. Each of us, even as individual biological entities, turn out to be CAES, at least in terms of our ability to 'learn' new ideas and behaviors. But so are our social systems, our organizations, and, increasingly, our artifactual systems (Chapter 13).

The horizontal blue line in Figure 2.10 marks the point at which systems types transitioned from simple and merely complex to complex adaptive and then complex, adaptive, and evolvable systems. In this book we will be mostly concerned with CAS and CAES instantiations, and, in particular, those at the high end of the chart in Figure 2.12 below.

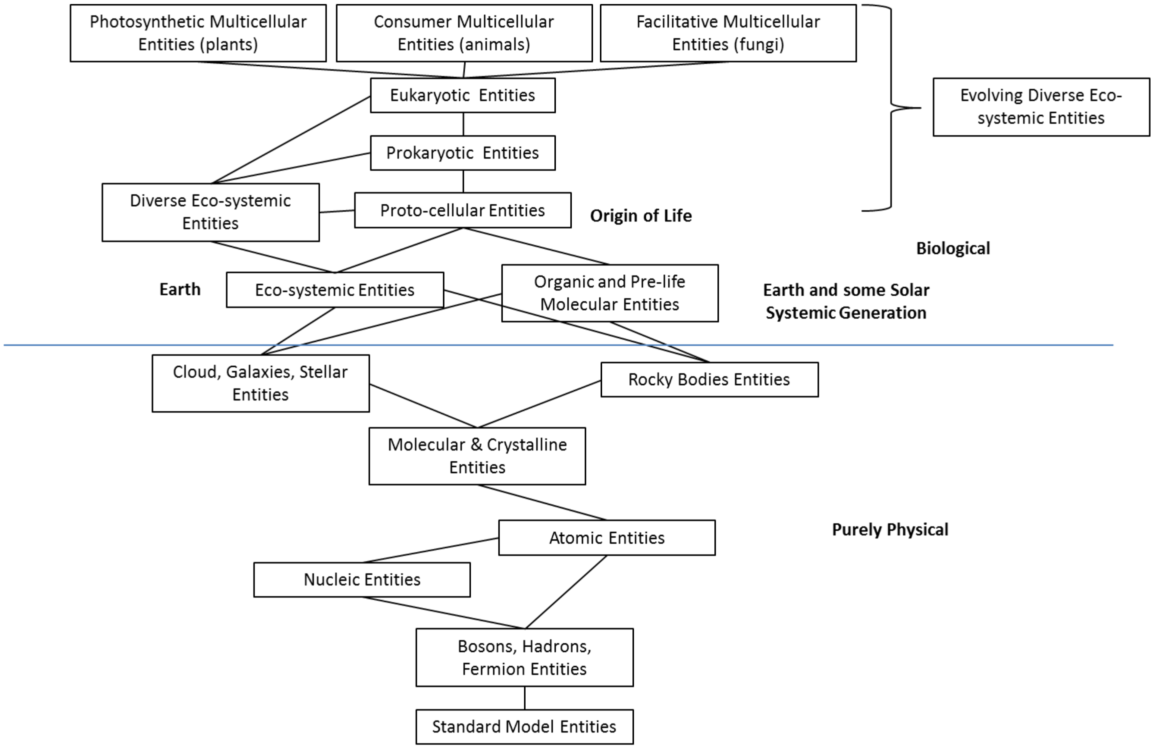

Fig. 2.10. Levels of Organization starting with the lowest levels – the "Purely Physical" – and showing the generation of the biological levels. Note that this does not reflect a simple linear evolution, but that multiple kinds of subsystems have emerged and co-evolved over time. The boxes are labeled with the kinds of "things" that exist at any given level. Those things tend to continue to exist at higher levels although things like "Proto-cellular Entities" at the origin of life stage may have been consumed by living organisms after the "Prokaryotic Entities" stage emerged. Also see below sections under 2.3.2 Other Takes on Ontogenesis.

Ontogenesis has continued unabated from the production of simple systems like atoms, complex systems like planets, complex, adaptive systems like biological individuals, and complex, adaptive, and evolvable systems like species, human individuals (the capabilities of their neocortex), ecosystems, and human social systems like tribes and agro-villages (Figure 2.11).

Each turn of the cycle traces out the spiral increase in complexity pictured in Figure 2.7, focused on the Earth as a whole (and presumably many other planets in the Universe able to support living systems). We will refer to the whole Earth system as the Ecos[61] – the home. The human species (as with all species of plants, animals, fungi, bacteria, etc.) are subsystems of the Ecos. The human social system is a particularly interesting subsystem of the Ecos. We shall have very much more to say about it in the following chapters.

Figure 2.11 continues the evolution of higher levels of organization within the biological domain, but focuses mostly on the line of animal evolution, particularly the development of complex nervous systems leading to complex behaviors. Of course, of significance in this evolution is the origin and evolution of human beings. The figure represents a number of unnamed stages with dashed lines. We jump up to *Homo sapiens* from Primates (in general) through a number of species of pre-*Homo* and early *Homo* (e.g. *erectus*).

Sapience is defined as the cognitive ability of humans to form communications networks using complex symbolic representations (words and sentences – language). But it also involves the hyper-social capacity to cooperate (with more than just altruistic actions), to think both systemically (see Chapter 3) and strategically (into the future). And it involves moral reasoning. So far as we know, these capacities evolved in the human line of great apes, though we cannot be certain which in the several predecessor species they first became operative.

One of the earliest indications of rising sapience in the Homo genera was the reliance on small group interactions, extended families and fission-fusion dynamics (Sapolsky, 2018, pp 429-430) leading to “bands” or extended groups that obtained stability, leadership hierarchies and a cohesion that supported what is called group selection (Sober & Wilson, 1998; Wilson & Sober, 1994; Wilson & Wilson, 2008; Wilson, 2013) in which competition between groups in which cooperation between members of groups led to increased fitness. That is, in groups that excelled in cooperation internally, their ability to outcompete other groups led to a higher rate of success in exploiting resources and reproduction.

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[61] The Ecos is an alternative and broader name for the whole Earth system (which includes Luna and Sol having major input influences on what happens on the surface of the Earth) not in opposition to the popular term, Gaia (Lovelock & Margulis, 1974) but as a way to situate Gaia as the physiology of a larger phenomenon (c.f. Volk, 1998).

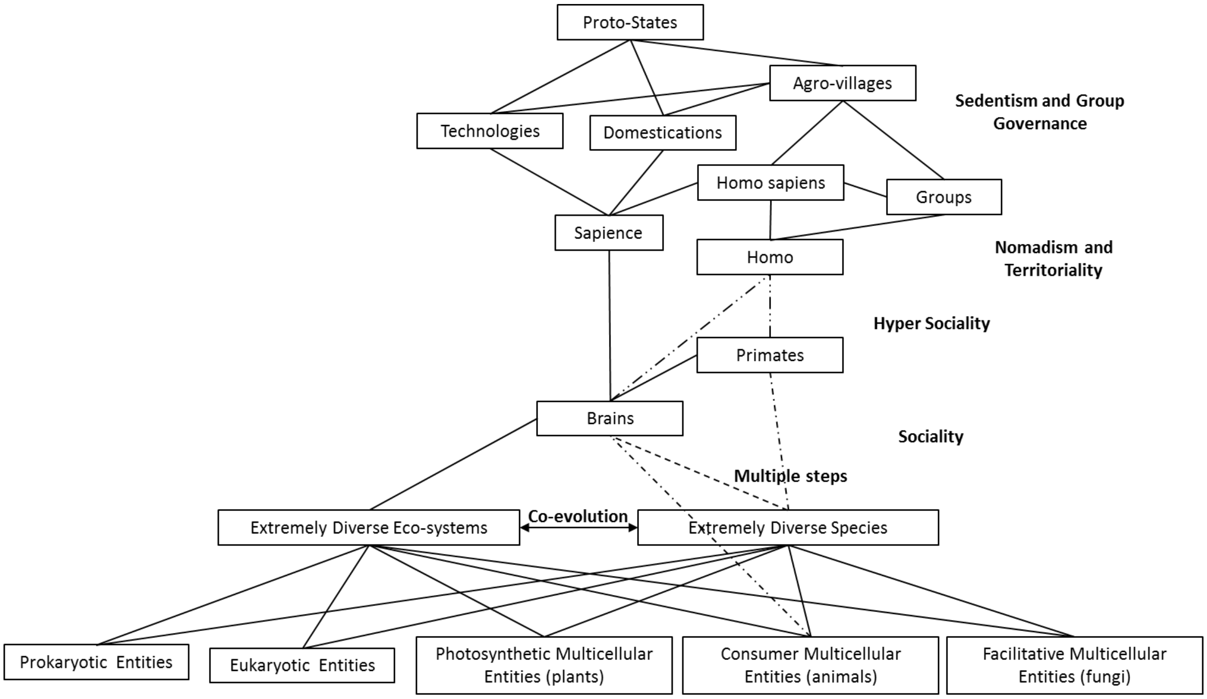

Fig. 2.11. The continuation of emergence of levels of organization after the emergence of life. Living cells rapidly diversified through the Darwinian mechanism of descent with modification (i.e. gene mutations). The great Linnaean Kingdoms (along the bottom) originated during the earliest era of life as a result of modification and selection (discussed below). The various dashed lines represent progressions that include many more intermediate steps that have been left out. Also, the diagram only follows the Animalia line of evolution; being very anthropocentric!

Homo sapiens proceeded to invent new technologies in stone, wood, and bone tools, along with improved clothing and shelter construction. The process of domestication of plants and animals (e.g. a wolf-like ancestor to a dog) also led to more reliable food sources. In particular the domestication of various grains and living in uniquely abundant ecosystems that promoted sedentism (areas like the Fertile Crescent in the Middle East and the Nile River Valley) gave rise to increasing group sizes and new kinds of social organization that ultimately put emphasis on the logistical management of planting fields and irrigation. A new level of organization emerged involving humans, tools, other living organisms, and a new relation to territory – the agro-village (Scott, 2017, c.f. Volk, 2017, Chapter 13).

Early agro-villages entered into a number of kinds of relations with each other and with the remaining hunter-gatherer-herding cultures that still lived around them (Scott, 2017). Some of these relations involved trade and mutually beneficial interactions (e.g. a source of “fresh” genetic material). Some were more aggressive and destructive. It seems a lot depended on the weather! Climate variations over the centuries determined crop successes, and needs to raid other villages’ grain stores. Basically, the Mesolithic and Neolithic ages, right into the Bronze-Iron age saw a fluctuation of proto-state formations followed by dissolutions (due likely to plagues and wars, ibid).

In Figure 2.12, we pick up the continuing story of the ontogenesis of complex human social systems from Agro-villages and Proto-States to what Scott (2017) calls "Grain-core States" such as Mesopotamian Ur and the united kingdom of Egypt to the rapidly developing cultures of humans.

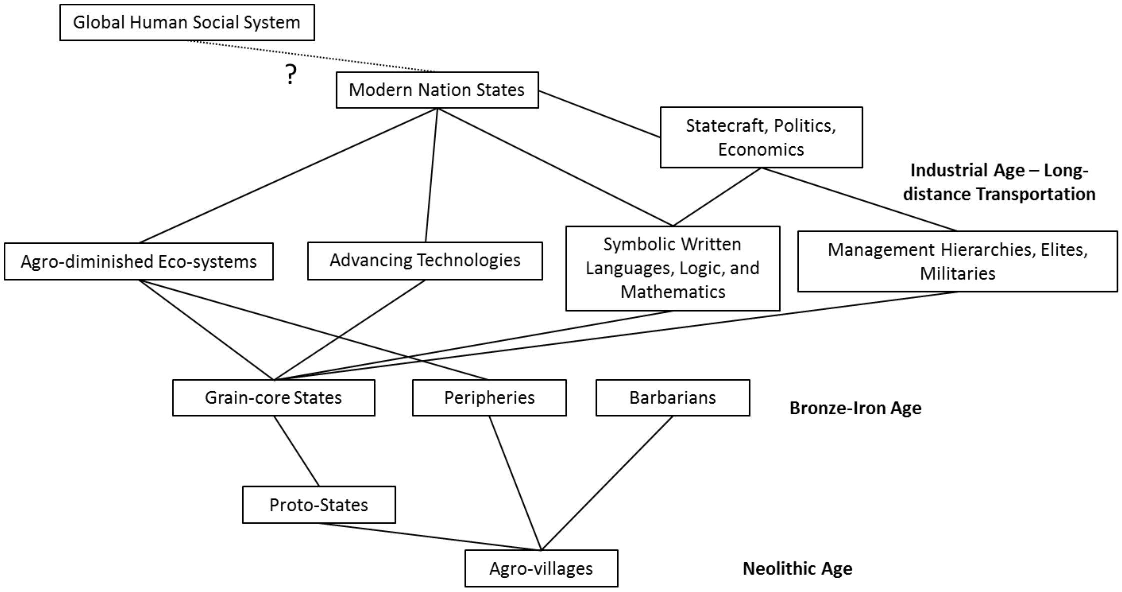

Fig. 2.12. The levels of organization for humans grows quite complex but can be summarized by the historical "ages" that paleontologists and historians consider. This characterization of the Neolithic and Bronze-Iron ages is derived from Scott, 2017. The highest level of organization is represented by a world in which the whole of humanity is integrated into a single "Global Human Social System," which will be addressed in chapters 6, 8, and the Postscript.

A lot goes on in terms of the auto-organization and emergence of new forms once early states come into existence and show some relative stability. Writing, logic, geometry and mathematical reasoning come into existence in the context of managing the grain-core. Management hierarchies (see Chapter 11) emerge. So does religion and its coupling to those management hierarchies – various forms of what is called "statecraft".

Money is invented as a form of "promise to pay" backed by real commodities. Those promises are increasingly taken over by the evolving nation states. Coinage is invented as a form of messaging – the state promises that you can use this coin to buy commodities that you need; trust us!

The modern nation state, indeed the whole global system of nation states interacting with one another has been the result of emerging entities engaging with each other and forming coupling interactions that are both super complex and yet wholly understandable in light of the ontogenic cycle. Below, we review the major components of that cycle.

2.3.1.3 Energy Flow: A Prerequisite to the Generation of Structures and Levels of Organization

The key proviso of the ontogenic cycle is the fact that energy is needed in any physical, chemical, biological, and social/ecological system in order to do work. That is, to bring material components together, to force or induce them to interact (e.g. bind or communicate) and to provide an on-going source of binding energy, there needs to be an input of the right kind of energy from an external source as well as an external sink to which "spent" energy can dissipate.

Harold Morowitz (1968) provided an exquisite model of how energy flow through an unorganized chemical system provided the motive force to facilitate the auto-organization of that system, to produce combinations of elementary things that would then give rise to a new level of organization, prebiotic molecules. His approach was to focus on the processes that gave rise to the origin of living systems (see also, Smith & Morowitz, 2016), the prebiotic regime of complex molecular formation that occurs as a result of the "right" kind of energy (i.e. light photons or heat differentials) flowing into a highly constrained geometric "container" at a particular point, and then out at a diametrically opposite point as waste heat. What Morowitz showed is that given the right energy flows and geometry, complex molecular forms would emerge that could then interact further.

Morowitz was[62] an eminent scientist dedicated to strict rules of empiricism. In a personal meeting with this author, he was unwilling to leap to non-empirical implications of his energy flow principle beyond its role in pre-biological chemistry (he later would actually venture out into other domains, c.f. Morowitz, 2004). Yet, what systems science deals with is patterns and after many years of examination it is clear that the notion of energy flow is at the heart of driving increasing complexity. We propose to call this aspect of ontogenesis the Morowitz principle.

2.3.1.4 Auto-Organization: Creating Structure

At any level of organization, one finds elemental entities. Whether these be atoms or individuals in a society, the fact is that the world contains individualized entities or objects that have the capacity to interact with other (perhaps diverse) entities in either attractive or repulsive interactions. Potential systems, that is systems that are composed of multiple independent individuals of various types prior to the flow of energy generally will have some form of random or semi-random distributions, subject only to the chance interactions (think of a container of a mixture of gasses at thermal equilibrium). Every type of entity will possess what we called a "personality" (Mobus & Kalton, 2015), or the range of interaction potentials or affordances exposed to the other entities. These may be outward exposed potentials such as valence shells on atoms that have already formed bonds with other atoms in molecules and then proceed to form more complex molecules (e.g. polymerization of repeating chains of smaller molecules).

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[62] Harold J. Morowitz (December 4, 1927 – March 22, 2016). See the Wikipedia article: https://en.wikipedia.org/wiki/Harold_J._Morowitz for background. Accessed 1/13/2019.

However other kinds of potentials may develop as a result of increased complexity and geometry. Following the molecular story, once proteins (a heteromer of amino acids) evolved they took on folding into new shapes that gave them abilities to manipulate other kinds of molecules, such as carbohydrates.

The personalities of human individuals are extremely more complex and diverse, of course. By personalities, here, we don't just mean the standard psychological personality profile, e.g. extroverted vs. introverted. We mean the whole range of behaviors and appearances that are perceived by other humans. Some are going to be perceived as attractive and followed by potential formation of bonds (friendships, romance, trading relations, etc.) Others may put off any such relations, be essentially repulsion. These are clearly not forces, like nuclear or electromagnetic/electrostatic, but they are real and it can be argued are derivatives of those simpler forces. Furthermore, any bonds forged between individuals (including those between parents and children) require the direction of biophysical energy toward maintenance.

Attractions lead to aggregations, groupings. Repulsions lead to increasing distances between entities and separation of these entities[63]. Combining through attraction creates new entities at what we have called higher levels of organization. Repulsions between these new entities leads to competitions and sorting. That is, the new entities are engaged in pulling together and pushing apart dynamics that tend to group attractive entities into interactions.

These patterns of interactions mediated by forces and energy flows should not be thought of as merely analogous. The energy flows in biological groups is exactly the same as in, for example, cellular metabolism, but now channeled through more complex mechanism (psychology and brain physiology). To insist that they are different is a grave category error that only perpetuates the belief that somehow humans are different from the rest of nature and beyond the laws of physics and chemistry (not to mention the laws of biological systems).

Auto-organization operates at every level of organization bringing diverse personalities (that is objects with various affordances) into proximity and interactions that, if stable under ambient conditions, are the basis for the next higher level of organization as depicted in figures 2.8 through 2.10. Attraction (e.g. exothermic and exergonic reactions) or forced interactions (e.g. endothermic or endergonic reactions) along with the sorting and organizing influences of repulsion under the excitatory influences of an energy flow (and that energy's interactions with the material forms of the entities in the system) produce a stochastic mixture of higher-order structures that can then interact and form a new level of organization. This is an on-going and recursively generative process that, as we track it from the simplest subatomic entities (i.e.

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[63] Unless the energetic environment includes forces that can overcome the repulsive force, for example as occurs in nucleosynthesis inside a massive star where the effects of gravity and pressure overcome the electrostatic repulsion between two positively charged nuclei, bringing them close enough together that the residual strong nuclear force causes them to fuse. On the scale of human interactions the requirement for economic viability frequently forces parties to cooperate to achieve a common goal.

quarks, electrons, and photons), meaning considering the history of the Universe, has led to the kinds of complex structures (living systems and societies) that we observe today.

2.3.1.5 Emergence: New Structures and New Interactions

Auto-organization is fundamentally a randomized process of combination and sorting (or segregating). It is *chance*[64] because there is no *a priori* organization in the distribution of entities throughout the volume of a potential system. The Big Bang saw to that. Entities at a level of organization tend to be distributed in a random, mixed manner. Energy flow and auto-organization then tend to generate randomized combinations of more complex entities. Energy flow drives segregative movements and material flows, like convective cycles. But in the end, new structures are formed and these have new potentials for interactions with each other. The example of the emergence of enzymes (or ribozymes in RNA world) that have shapes that facilitate catalytic reactions in other molecules in metabolism enabled the emergence of life processes is a case in point (Smith & Morowitz, 2016).

But auto-organization often gives rise to many more emergent entities, with new structures and new interaction potentials, than can achieve stable relations at a given level of organization. Nature is continually blindly experimenting with new forms to see what they can achieve as new systems. Because the emergent new forms are the result of chance encounters at the lower level of organization, not all of them are necessarily fit to contribute to the new level. In fact, most new experiments are doomed to failure. Only a few stable configurations of structure and their potential interactions are destined to survive a fundamental testing and, thus, provide the entity components that can enter the next cycle of ontogenesis. The environment that is extant for any given level of organization is a harsh taskmaster.

2.3.1.6 Selection

Every new structure, with its new interaction capacity, is a blind experiment (remember the "chance" part of emergence?) Structural configurations have to be subjected to tests like thermal stability (at the ambient temperature, can the entity exist?) They have to be stable against other environmental conditions (such as pH, pressure, social norms).

Consider the situation for the most elemental particles, the quarks. In the earliest phase of the Universe, shortly after the Big Bang, in an extreme temperature, all of the various generations of quarks (I up/down; II charm/strange; III top/bottom) could exist and potentially interact to form exotic kinds of hadrons. But as the Universe cooled radically (as it expanded radically) only the up/down quarks proved stable enough to form realized hadrons (protons and neutrons).

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[64] As in "Chance and Necessity", (Monod, 1971); the role of chance or stochastic process in evolution.

Or consider the conditions of the early Earth and primitive oceanic thermal vents where conditions may have acted to select for the stability of co-factor molecules that would eventually contribute to primitive metabolism (Smith & Morowitz, 2016).

Selection is, of course, a major aspect of Darwinian evolution. There are several candidate selection processes that are reasonably well understood; natural selection, or the selection of the phenotypes most capable of surviving and reproducing, sexual selection, or the capacity of certain body forms to be more attractive to potential mates, and multilevel selection, in which capabilities at the genetic, phenotypic, and group level of form and behavior act to provide advantage or otherwise to systemic entities (genes, individuals, and groups, respectively).

We view selection as an all-encompassing process in which the context or environmental conditions operate on emergent forms to destroy those that are susceptible (i.e. denature proteins that are not stable) and leave in place those that are thermodynamically or physiologically, or sociologically stable. The survivors are free to interact and start the next phase of ontogenesis; to produce the next level of organization.

The result of selection is the basis for the next round of ontogenesis. That which proves effective, and survives within the context of the environment created by the level of organization, participates in the next round of auto-organization. The ontogenesis of new levels of organization thus emerge and the Universe experiences new levels of complexity. Hence, figures 2.6 and 2.7 and the framework they invoke.

2.3.2 Other Takes on Ontogenesis

This view of increasing complexity is neither new nor unique to our conceptualization. In fact, many authors have examined this apparent trajectory of the evolving Universe. In this section we examine a number of previous or current concepts of how the Universe is evolving toward increasing complexity and, especially, as represented by the evolution of life and humanity on the planet Earth.

2.3.2.1 The Noosphere – Teilhard de Chardin

Pere Teilhard was a Jesuit priest living in the early 20th century who completely bought into the theory of Darwinian evolution applied to humanity[65]. For de Chardin, the mind of humanity represented a new level of organization above the mere animalistic capacity for cognition.

The mind of humans was a result of a continuing process of evolution (set in motion by the Christian god). But it was fundamentally different from the sentience of prior creatures (particularly the great apes). Teilhard's objective was to reconcile mental evolution with the

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[65] See the Wikipedia article: https://en.wikipedia.org/wiki/Pierre_Teilhard_de_Chardin for background. Accessed 1/13/2019.

Christian theology. He recognized that human mentation was apart from our ancestral apes but did not develop a firm empirical theory for how this was so.

Even so, Pere Teilhard provided some instructive insights with respect to how humans represented to new level of organization that involved mentation beyond basic ape-biology. Leaving his metaphysics and theology aside, he did give us a sense of humans as a new level of organization – that our species represented an emergence from the mere biological.

2.3.2.2 Combogenesis

Tyler Volk has coined a term to describe the process of forming combinations of simpler things to produce more complex things – Combogenesis (Volk, 2017)[66]. He describes how the process first kicks off in the early universe (right after the Big Bang) with the combining of subatomic particles (quarks) to form nucleons (protons and neutrons) as the ultra-hot universe began to cool down upon expansion[67]. Nucleons and electrons could then combine to form the early light atoms (e.g. hydrogen and helium). As gravity condensed gaseous clouds to form the earliest stars, combogenesis went to work in their interiors through nuclear fusion to produce heavier nuclei. Supernovae then produced even heavier nuclei which, when ejected into space, formed the atoms that we know from the Periodic Table.

Volk then describes a "Grand Sequence" of transitions in which combinations at the molecular level led to the formation of planets and the origin of living matter (see also Smith & Morowitz, 2016). The stages in this sequence represent major transitions in a hierarchy of complexity (i.e. from prokaryotic to eukaryotic cells, to multicellular organisms, to societies of multicellular organisms, and particularly human societies).

As with the ontogenesis cycle described here, combogenesis is acted upon by evolutionary processes. He does not include physical process selection, but once into the realm of living things, first the process of biological evolution and then, when humans enter the picture, cultural evolution, the role of selection becomes obvious.

In our reading of Volk's work, it seems that we and he have independently arrived at a concept of universal generativity for complexity and levels of organization. This is not really remarkable in that the seeds of thinking this way have been long germinating (Bourke, 2011; Coen, 2012; Miller, 1978; Maynard Smith & Szathmáry, 1998; Morowitz, 1968, 1992, 2004; Prigogine & Stengers, 1984; Troncale, 1978a).

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[66] Volk's work is perhaps the most similar to the results reported above. The author and Volk developed very similar conceptions of how the Universe got more complex over time. We have been in close communications to see if an integration of the two sets of ideas is possible.

[67] The picture is similar to the cooling of a hot gas in a volume that can expand. The expansion gives rise to fewer particle collisions per unit time, which is what we recognize as a lowering of the temperature of the gas.

2.3.2.3 Emergence by Continuous Integration and Diversification

Another perspective on how hierarchies of increasing complexity have emerged from a bottom-up process of things interacting at one level and then producing objects at a new higher level is provided by Len Troncale (1978a). The integration aspect seems to be fundamentally the same idea of combogenesis (above) and auto-organization of ontogenesis. Different entities, with different interaction potentials actualize those potentials to form more complex entities at a new level of organization.

Troncale's vision includes a phase of diversification or variation generation that seems influenced by the process in Darwinian evolution in which species diverge from a common ancestor in incrementally subtle ways. The mechanisms for generating diversity depend on the level of organization. In biology this is Darwin's famous decent with variation, now known to be due to mutations and chromosomal cross-over. It depends on making many copies of a genome wherein some configurations may be different (mutations) and lead to phenotypic variations that can then be tested in the crucible of selection.

What seems different between Volk's vision of a grand sequence of discrete stages and Troncale's model is that the latter sees the process as continuous and on-going, whereas the former sees what look like discrete jumps. Volk does offer that there might be a place in the model for micro-combogenesis events that, at a larger scale of resolution might reasonably appear to look like discrete steps.

What seems important here is not whether emergent new things and behaviors is due to a continuous or discrete stage process, but rather that both these views, along with the others mentioned all point to an obvious (but often contested) trajectory of universal evolution going from the simple (as in the Introduction) to the complex, to the complex adaptive (early life, cells and individuals), to the complex adaptive and evolvable (life, genera, and societies). The details of how this trajectory is supported by ontogenesis will be the subject of intense research in the coming years.

2.4 An Ontological Framework

In the section 2.2.1.2, "Cosmological Ontology," above we established a basic background ontology, claiming that all that exists in the Universe, or at least that part of it accessible informationally by we humans, ultimately is formed from matter and energy, organized by the influences of information and resulting in representation of knowledge. Under the influence of the ontogenic cycle above, the Universe has evolved from a primordial, simple state to what we observe today, a high level of organization and complexity that includes living beings such as ourselves capable of understanding that organization. We will take this as a starting point for 'that which evolves,' that is, all the 'things' we find in the Universe.

In this section, we will provide an ontological framework that asserts that what can exist in this evolving universe, made of matter and energy, organized by knowledge and information, is systems. Put differently, matter and energy interact according to the influences of knowledge and information to produce systems at all scales of space and time, at all levels of emergent organization, and complexity.

The claim, made in Chapter 1, Principle #1 (Systemness, and supported by the ontogeny arguments above) is that everything is a system, meaning that all things in existence are organized with system attributes and are, themselves, subsystems of larger supra-systems, up to the Universe as a whole (which we take to be the only true closed system). This claim must be counted as a conjecture as much as a premise at present. However, it is arrived at by induction over the examination of many actual concrete systems in nature, as indicated in the above section 2.2.2, on “Examples of Developing a System Ontology.” The framework offered here is as much a guide to future research in systems science as an outline of ways to view systems ontology.

2.4.1 The Framework, its Purpose, and its Justifications

A framework is a set of guides and organizing principles used to elaborate the details of a complex subject. This book is about a framework for understanding systems through the application of the principles in chapter 1 – its main structure being the method of analysis and knowledge capture. The framework we offer here is an approach to finding and defining a set of unique objects, relations, and actions that are found in all systems[68]. These objects, etc. are at once both concrete and abstract. They are concrete in that each is found to be a real thing. They are abstract in the sense that we are applying symbols, names and icons, for example, to denote the real object, etc.

The framework for the system ontology is shown in Figure 2.13. This may be called a conceptual model in that it not only demonstrates the ontological commitments but also how they are organized. The figure is a graph representation of elements (nodes) and their relations (edges) along with category names and organizing labels (levels).

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[68] Troncale (2006) proposes a similar notion of a framework for his SSP (system of system’s processes). Troncale does not call his approach an ‘ontological’ framework, but one can find significant relations between it and that given here.

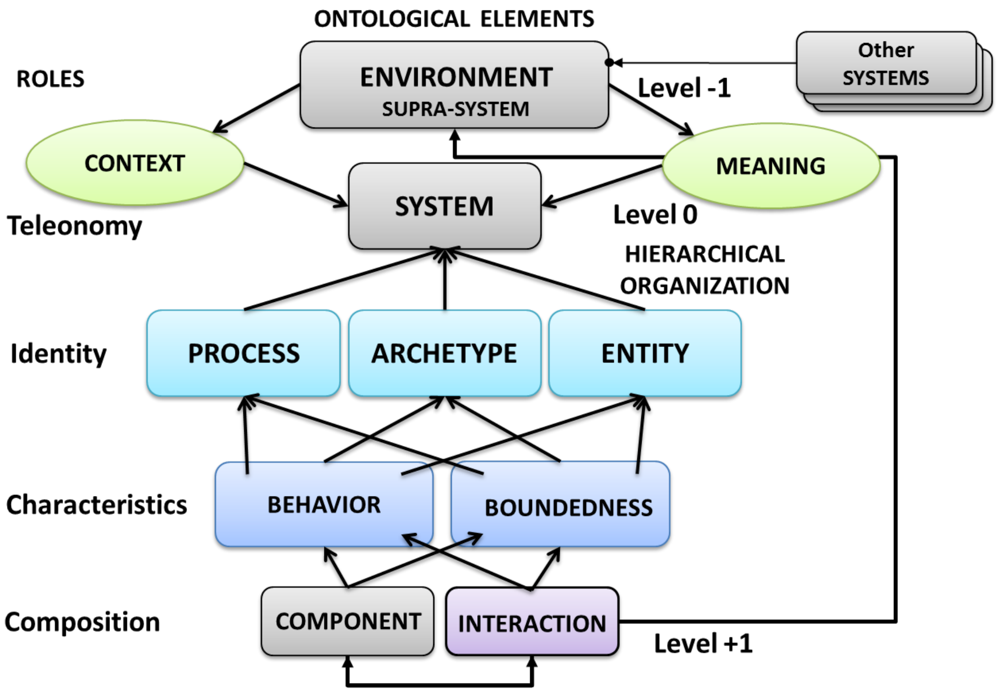

Fig. 2.13. A general framework for the system ontology identifies the relations between upper ontological elements. Grey elements are the main elements, i.e. the ENVIRONMENT/SUPRA-SYSTEM in which the SYSTEM is embedded and the COMPONENT(s) which comprise the system are the main structural elements. Ovals, CONTEXT and MEANING are logically imposed on the relation between the environment and its system component. Light blue rounded corner rectangles (PROCESS, ARCHETYPE, and ENTITY) are Identity attributes of any system. Dark blue rectangles (BEHAVIOR and BOUNDEDNESS) derive from the way a system's components interact with one another to form its internal structure/function. INTERACTIONS among internal components and between entities (Other SYSTEMS) in the environment involve exchanges or flows of matter, energy, and messages (or influences).

Elements (nodes in the directed graph) in all capital letters denote terms that will be used in the top-level ontology of systems. These are the things that exist by virtue of the Universe organizing as it does, through auto-organization, emergence, and evolution (Mobus & Kalton, 2015, chapters 10 & 11) which we are now calling the ontogenic cycle in section 2.3.1 above. These are the core things that we will look for in our analysis of systems regardless of the level of organization or complexity. As we will show in the next chapter, for example, the element labelled COMPONENT at Level +1 may be readily seen as a subsystem of the system at level 0. That component/subsystem would then be subject to the same analysis imposed by the framework in the figure. It will become the system of interest and be its own level 0. The analysis simply reapplies the conceptual framework with the previous SYSTEM becoming the new ENVIRONMENT.

The framework is composed of three *aspects*. The first aspect, the nodes in the graph, is the set of ontological elements themselves. The second, signified by the words on the left side of the graph is the ROLES that the items in that region (horizontal level) of the graph play. The third aspect shows the higher-lower relation that frames the system hierarchy; the level numbers are relative positions in the hierarchy.

Starting at the top, the ENVIRONMENT encases and defines both the CONTEXT and the MEANING of the system of interest (SOI). This is designated as level -1, or one level up[69]. It is also often referred to as the supra-system. Level 0 is that of the SOI, the system that we seek to understand and model. Level +1 is one level down from the SOI meaning the level of organization in which we find the internal components and their interactions – that which gives rise to the SOI behavior and define its boundary.

In the next section we will elaborate on all of the elements, relations, and categorizations illustrated in Figure 2.13.

2.4.2 The Aspects

2.4.2.1 The Ontological Elements of the Framework

In the section below, "The System Ontology", we will define and describe these elements and their expansion into sub-elements that exist. Here we provide a brief explanation of the major elements in the framework in preparation for that expansion.

2.4.2.1.1 ENVIRONMENT

In this structure the top or highest element is the environment. This is the supra-system that encloses the system of interest (see Figure 2.4). Environments are, by definition, more complex than the SOI. This is because that larger system contains the SOI, which is then a subsystem, as well as other systems interacting with the original SOI. Hence, the complexity of the environment includes the complexity of the various subsystems.

The environment is what gives context and meaning to the SOI. Both have to be considered in order to understand the roles, particularly that of *purpose* (see below).

2.4.2.1.1.1 CONTEXT

This refers to the set of conditions that obtain at a time instant relevant to the dynamics of the SOI. The environment in an evolving Universe is continually changing in so many various complex ways, so contexts also change[70]. The fundamental context is that of the various other

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[69] The author recognizes the irony of calling a level -1 as UP. This somewhat unfortunate condition is a result of adopting the computer science way of looking at 'tree' structures, which are inverted from our ordinary understanding of trees. The root is at the top and the level number is zero. To go down the tree level is to increase the level number. Thus to go back to something before the presumptive root means to go in a negative direction. What can one say? Conventions are conventions after all.

[70] This pertains primarily to the Universe as it appears to exist today, 13.5 billion years after the Big Bang. The environment of the first particles (e.g. quarks) and photons, indeed all of the elements of the Standard Model, started out in extreme temperature in which these elements likely existed as independent non-binding or interacting entities. But the Universe rapidly cooled and as the temperature came down elements began to interact and form the first

systems with which the SOI interacts in an on-going way. These are the sources of inputs and the sinks for outputs across the system boundary[71]. Other sources, not necessarily recognized as an identifiable nature may affect a system through what we will call a 'disturbance.'

Changes in context will occur in several ways. The first way is when a source or sink entity changes its behavior (e.g. the rate of supply or receiving) from a long-term average (if such ever existed). This is one form of what is technically called non-stationarity. We will be examining this phenomenon extensively. A second kind of change involves the appearance or disappearance of sources or sinks. A loss of a resource source or a shut off of a sink changes the context in which the SOI operates. This too is a kind of non-stationarity that can change slowly or rapidly. Both of these changes are part of the uncertainty factors that affect all concrete systems.

One source of uncertainty we will not be concerned with is that of purely random action of chaos in the vernacular sense. True randomness could only be achieved in closed system where there is absolutely no kind of gradient operating, e.g. an adiabatically isolated container holding simple gas near equilibrium and far from any gravitational influences. While such systems might exist in an idealized abstraction they are technically impossible. What has come to be called deterministic chaos, however, is not of this same sort of randomness. Supra-systems may have chaotic dynamics, meaning that one or more of their internal causal relations between subsystems (including the SOI) may operate on a chaotic attractor, this still counts as a form of organization. And that organization has implications for the organization and sustainability of the SOI.

2.4.2.1.1.2 MEANING

The concept of 'meaning' has always been problematic in philosophical terms. The ideas are tied up with things like human values, which are extremely variable and very often inconsistent even within a single individual.

In our system ontology, we consider MEANING to describe a set of conditions that have a trinary affective influence on a system. We use the term 'valence' to designate one of three influences, positive, negative, or neutral[72]. The changes described in the context could have neutral effect, in which case the system does not need to do anything differently, indeed it is free to choose a next state randomly. But some context states can be negative with respect to how the conditions will affect the system (e.g. part of a negative feedback loop). For example, a radical

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systems – protons, neutrons, electrons, and neutrinos, with their various interactions mediated by the bosons. Yet later cooling led to the formation of atoms that could then interact through chemistry. Thus one could say that the environment for these primary systems is no longer changing thus they are not compelled to make further adjustments.

[71] We have used the term boundary in a rather loose way so far. As will be explained in section 2.4.2.1.2.5, below, a boundary is an effective demarcation between what is in the system and what is not. It is realized in many ways and in many forms described there and in the next chapter.

[72] In psychology the term valence refers to the degrees of badness (and repulsion) or goodness (and attraction) with no reference to neutral. We are using the term in a broader, though inclusive, sense.

change in average temperature in a climate zone will require some response from the species affected or they will go extinct. Other contexts might be viewed as positive in that they support the system, as when the average temperature returns to that which was the norm for the species. An important aspect of this interpretation of meaning is that it is the ‘handshaking’ between an environment and the system in terms of interpreting messages (information) and computing decisions for action (if such is possible).

We assert that virtually all meaning ultimately resolves down to one of the three ‘valences’ and the magnitude of those changes that give urgency or motivation for action by the system. This assertion is based on work done by Antonio Damasio (1994) in the realm of human brain functions and decision making and by observations widely made in animal behavior. As well, the author has demonstrated this working in a robot’s brain (Mobus, 2000).

Throughout the book, we will provide examples of the context and meaning of an environment’s affect upon a system.

Note, in Figure 2.7 that we show an arrow from the INTERACTION element (at the bottom) going all the way back to the ENVIRONMENT element. This represents closing the loop between the SOI and the ENVIRONMENT via its interactions with the latter. If those interactions are inappropriate given the CONTEXT situation, then the SOI will incur a negative valence from the ENVIRONMENT. Conversely, if the interaction is appropriate, then the valence will be positive. If the interaction is neutral, then the valence will also be neutral.

2.4.2.1.2 SYSTEM

This ontological element is quite obviously the core of the whole enterprise. There are three ways to view a system of interest: as a process, as an object, and as an entity.

2.4.2.1.2.1 PROCESS

All systems within the Universe are open to input and output flows of at least one of: material, energy, messages (which are special forms of material/energy flows). Systems process or transform the inputs into outputs. The collective effect of the process is also called the “function” of the system. The processes inherent in the bits and pieces of a rock, strong chemical bonding, produce its qualities of hardness and stability over time (soft sandstone notwithstanding). The processes of digestion in your alimentary track function to acquire nutrients for your body’s maintenance.

2.4.2.1.2.2 TYPE

The ontogenic cycle (section 2.3.1) as it has proceeded over the history of the Universe, from simple, to complex, to complex adaptive, and to complex adaptive and evolvable systems has generated a plethora of diverse real systems as variations on common themes. These systems share a basic set of attributes that puts them in what we call a category. For example the evolution of the geosphere has produced an incredible variety of lakes (a category of entities) on almost all continents. These lakes vary in volume, depth, surface area, and other important features. But they are all recognizable as lakes. They all serve the same function of acting as reservoirs for water. Similarly, all mountains are recognizable as mountains, being in the category of mountain. Within the tree of life the relations and derivations are even more telling. Life has evolved into many different genera from some common ancestor, forming a complex tree-like structure. There is a continuity of genotypic information such that we can trace current living things back to their predecessors (in most cases). But the elaboration of the tree of life also created a set of categories, captured in the nomenclature system that designates, for example, phyla, classes, families, etc. down to the species level.

We are using the term ‘type’ here in a very general way. It can refer to a category, which is usually found in a hierarchical structure, or it can refer to what we are calling an ‘archetype’ (see Chapter 9 for an elaboration on the concept of archetypes). Generally the word is used to designate a derivation from abstract classification hierarchies. As such it places the system of interest within a larger evolutionary framework that is within a diversity generating ontogenic process. Its use here, in the framework, will become clearer in the next chapter when we introduce the mathematical concept of a system’s history.

Type corresponds with the way mental models are formed in the human brain.

2.4.2.1.2.3 ENTITY

An entity is a concrete system that does something actual, having causal effect on other entities or objects in its environment. Concrete systems are real and identifiable as unique, at least within a minimal category. That is, a system as an entity is an actual thing in itself and not something like a category (though it belongs to a type). The idea of a ‘house’ is a concept and a category of objects that exist in the world. ‘My house’ is an actual member of this category and particular in existence. Models of systems are abstract versions of real systems that are more like categories in action. On the other hand, a specific model instantiation, say in a particular computer memory, is an entity for the duration of its run.

2.4.2.1.2.4 BEHAVIOR

All systems display activity on some time scale. They interact with other systems by virtue of properties of their boundaries and their components (below).

2.4.2.1.2.5 BOUNDEDNESS

All systems are delineated from their environments by virtue of *coherence* of the components. We can talk about this as providing an “effective” boundary. In some systems this will manifest as a physical barrier demarking the insides of the system from its environment, such as the case of cell membrane. In other cases, there may not appear to be any such structure. The atmosphere is “bound” to the planet by gravity but we don’t conceive of a physical boundary keeping the gasses enveloping the planet. Indeed, some of the lighter gasses such as hydrogen may be light enough to escape the atmosphere if struck by an energetic photon. The effective boundary of the atmosphere is the gravitation field gradient where the pull of gravity is no longer able to keep the lightest gasses from escaping.

This type of boundary belongs to a class of fuzzy boundaries, to be explained more fully below in section 2.4.2.2.3 Attributes, and in Chapter 3. Other characteristics of boundary conditions, such as porosity will also be explained.

Boundedness is a property that, in the Universe of today, generally arises as a result of electromagnetic interactions between molecules or gravitational force for massive objects. But we can also count the bonds of love between people as a form of binding force that keeps, for example, families together. In this case the electromagnetic force is operating on several levels. It is behind the electrochemical operations in the brains and it mediates message flows between people. They don’t feel a physical force per se, but they do feel the effects of physical forces at play in their mental states and communications. Boundaries in social systems are extremely fuzzy and generally porous. People come and go and are members of a given system based on, for example, time of day or season of the year. Other membership relations are also possible, e.g. members of a religious persuasion based on common held beliefs.

Boundaries need not be crisp or clearly physical entities in themselves. For example, some boundaries are implications of the strength of interactions between components being such that the entity has a degree of ‘apartness’ from other entities in the environment (see Figure 2.8). Take a molecule as an instance. The boundary is provided by the chemical bond strengths between atoms and the lack of available bonding sites on the molecule. CO_2 is a good example. The four bonding sites available on the carbon atom are occupied by the two bonding sites on each of the oxygen atoms, thus leaving no additional bonding sites. The bonds established are quite stable so the molecule is established as an entity and will only interact with other molecules through physical collisions (i.e. temperature-related). That particular molecule is especially good at absorbing photons at characteristic wavelengths and becoming more agitated as a result.

Boundaries, when not completely explicit, can be determined by the relation between internal interaction strengths and densities in the network of subsystems compared to interaction strengths and number with external entities. Figure 2.14 shows a depiction of a system where the boundary is “effective” as a result of the bindings between internal subsystems are strong and dense as compared with interactions between a few components and some external entities. A graph theory-based analysis of the network depicted in the figure would reveal the ‘clique’ of grey nodes which, in turn, provides a strong argument that the components inside the blue oval constitute a delineated system even though no explicit physical boundary can be seen.

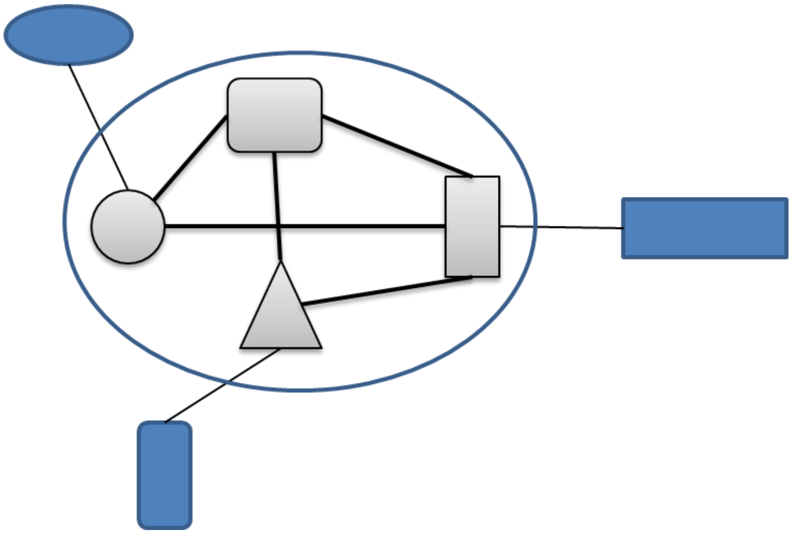

Fig. 2.14. The density and strengths of interactions (links) between components that are 'inside' the system are greater than those between external entities and a few components of the system. The effective boundary (blue oval) distinguishes between the system and its environment. Thicker undirected lines represent stronger links.

The notion of a boundary as a natural element is still contentious in schools of systems thinkers. We define a boundary to exist when the sum of binding forces from within a given system act to establish long-term cohesion among the component parts of the system. Colloquially, "the family that plays together stays together."

Think Box 2.1.

The Boundary "Problem"

Over the last few years members of the systems science and system engineering communities have been holding regular discussions for the purpose of coming up with an agreed definition of systemness. One of the difficulties that have emerged from these discussions has been the recognition of little agreement on the nature of boundaries. Engineers, coming from a tradition of being the ones who define what a system is (i.e. they have to design a system to perform a given function) tend to prefer the notion that boundaries are more of less arbitrary, or, rather, that we humans determine what the boundary of a system is. They then transfer this sentiment to the existence of boundaries in natural systems as well, some claiming that boundaries (indeed systemness itself) are a construction of the human mind. Some systems scientists, especially the ones more inclined to pure formal definitions of systems, agree, thinking that the whole notion of a system is a mental construct (and, of course, the mathematical representation of a system *is* a mental construct – see Chapter 3). But the majority of natural scientists and especially those who do practice systemic thinking about their subjects, tend to hold the opposite view; that systems are clearly bounded even when the boundary is based on internal forces and interactions as opposed to a constraining physical container.

The boundary "problem" is one of world views rather than an actual problem in finding the so-called boundary conditions, the conditions that pertain to demarking a system from its environment. Where it becomes problematic for systems scientists who are trying to do analysis of real systems is when they are faced with finding those conditions and clearly differentiating the insides from the outsides of a system. A formal approach to the problematique is to use the concept of a fuzzy boundary, borrowed from fuzzy set theory. As will be shown in Chapter 3, a fuzzy boundary can be defined in which each component member of a system has its own membership function that can be based on location in space and/or time. This means a member component may be inside the system boundary to some degree at certain spatial coordinates and at certain times. At all other locations and times, the component is outside the system.

While there remain significant philosophical debates on the nature of boundaries and systems, in reality these debates have not seriously hindered progress toward understanding systemness itself. The main problem tends to be with the methods and tools used to resolve the question of what is a system, natural or engineered. For the most part this means how one goes about constructing a model of a system for purposes to be discussed in Chapter 10. One of the things this book seeks to show is how this difficulty can be mitigated.

2.4.2.1.2.6 COMPONENT

All systems contain components that internally operate (behave) to produce the process that the system entails. Components may themselves be systems, or atomic, i.e. irreducible.

2.4.2.1.2.7 INTERACTION

All systems interact with other systems to some extent or another. There are no isolated systems. Interactions result from properties of their boundaries and processes. Fundamentally all physical components/subsystems possess interaction potentials mediated by the electromagnetic and/or gravitational forces. Chemical reactions (exchanges of electron), radiative interactions, mechanical interactions, and convective cycles mediate the interactions between systems at all levels of organization above the atomic. Even love is mediated by chemical interactions (pheromones and brain receptors!)

At all levels of organization the entities which exist possess interaction potentials mediated by physical forces but possibly transmitted over long distances. Electromagnetic phenomena, especially photon transmitted, can be used to transmit messages at low energy costs over tremendous distances. And in fluidic media such as air and water, mechanical waves, when modulated effectively, can also transmit information that causes changes in the receiving system. Pheromones along with words of endearment, transmitted either by electromagnetic (writing) or mechanical (sound waves) can seal a bonding quite effectively.

Another term used to describe interactions is “relations.” An interaction is a relation, but the latter term captures the static situation more than the dynamic one. There are a number of kinds of relations that are temporary or transitory. They can be logical or situational, such as positional in space and time (“in front of”, “before”), or social (“dominant”, “submissive”). An interaction may incorporate a relation, but should do so as part of a functional description; that is the relation should be time-dependent at least but likely to depend on other factors. For example: a train engine can be “in front of” the trail of cars it is pulling as long as it is going from point A to point B, after which it is decoupled. The “in front of” relation only exists under certain functional conditions.

2.4.2.2 Roles

All of these elements play various roles within the framework.

2.4.2.2.1 Teleonomy

Referring to the interactions between the environment and the SOI (level -1 to level 0 in Figure 2.3): The term ‘teleonomy’ is used to designate something like a “purpose.” Purpose is a highly problematic concept, both philosophically and practically. Do systems have a purpose? Does the environment have a purpose? Does either *serve* a purpose? Purpose implies intention. Pre-Darwin, the organization of the world was easily explained by the intentions of God. Post-Darwin the situation has gotten more complicated.

Systems exist and persist in their environments as a result of performing some kind of *function* that is beneficial, ultimately to the supra-system. This is the meaning of ‘fitness.’ As long as a system fulfills its function and that function is of net benefit to the embedding supra-system, the system gets to enjoy the receipt of beneficial resource inputs. In other words there is a net benefit (profits minus costs) to both the supra-system and the system and thus, the system sustains.

A system performs its function in the sense that it produces outputs, some of which are products in that they are inputs to other entities in the environment that need those inputs as resources, while others might be actions, behaviors, that contribute to the success of other entities in the environment. The output of a system might be a physical substance or it might be a behavior. In either case that output is of value to some other entity or entities in the environment and, thus, a benefit to the supra-system as a whole.

Consider an ecosystem. This is a semi-closed system composed of multiple species of plants, animals, bacteria, fungi, and the geophysical substrates on which it is built. It is also dependent on a pattern of climatological regularity. Ecosystems achieve a more-or-less (quasi-) stable dynamic, called a climax state, in which the interactions between all of the various species act to mutually constrain one another. In this system, the purpose of a carnivore is to constrain the population of a prey species; the purpose of the latter is to convert photosynthetic (primary) production to animal biomass for the predator. The plants that feed the primary consumer have the purpose of converting solar energy into preliminary biomass. The predator’s purpose is to eventually return the biomass back to the bacterial colonies that return the nutrients to the soils so that the next generation of plants can fulfill their purpose. Every biological system depends on every other biological system for its existence and the steady-state flux of energy and material exchanges through the whole ecosystem maintain the organization of that system.

The purpose of a system is to ‘fit’ into its supra-system in the sense that it produces actions or products that keep the whole supra-system in dynamic stability. The supra-system’s purpose is to channel flows of resources to those subsystems that fit this objective. Subsystems that contribute to the long-term stability of the supra-system are favored by virtue of the fact that other subsystems will produce resources that they need as long as they produce resources that other subsystems need.

Thus, purpose is a mutual support phenomenon. You scratch my back and I will scratch yours. Or, I will scratch species A's back, they will scratch species B's back, etc. until species Z scratches my back. Subsystems that do not do so are ultimately not fit in the evolutionary sense and will be selected against in the long run. The environment of an SOI is a system seeking dynamic equilibrium so long as energy flows through it. An SOI that does not meet the purposes of a supra-system (environment) will be selected against in the long run.

A system can be said to have a purpose in terms of the environment. This does not necessarily mean that the system is purposeful (has its own purpose for existing) but if it does its purpose should be aligned with the "needs" of the environment in order for there to be any kind of long-term sustainability for the SOI. Context is the current state of the environment with respect to those interactions it has with the system. It affects the system from moment to moment and the system must behave in such a way that it accommodates that context. In the totality of interactions between an SOI and its environment, misalignments will invariably harm the SOI. Nature bats last, and always wins. Even if the environment is stressed by the actions of the SOI, the former will counter and select against the SOI in the long run. When the variables of the environment reach certain critical values they create a stressful situation for the SOI.

Meaning is based on the imposition by the environment of its requirements for the SOI, i.e., gives meaning to the existence of the SOI. The SOI should be viewed as a subsystem of the larger environment taken as a supra-system. Thus, the SOI at level 0 must behave in a way that fulfills the requirements imposed by the environment. This is the meaning of natural (and other forms of) selection in biological evolution, for example. This is the meaning of market factors in the economy as another example. Biological systems like species that fail to provide a service to the larger ecosystem niche, will be selected against in the long run. Those that provide a useful output (e.g. meat for carnivores or food for herbivores, or are keystone species[73] in specific ecologies) will generally benefit from the environment providing useful feedback. Carnivores work to keep populations of herbivores in check (a regulatory function) and receive food for doing so. Herbivores often spread seeds or manures and, similarly, receive food in the process. Companies that produce a product or provide a service that consumers desire are rewarded with sales and profits. Purpose comes from this matching of subsystem output to other subsystems' inputs in a way that is mutually beneficial through feedback loops (both positive and negative). Overall balance and stability of the whole supra-system depends on these kinds of matched interactions.

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[73] A keystone species is one that plays a critical role in the sustainability of an ecosystem. Their influence on the structure and function of the system is such that removal of representatives of the species from an ecosystem has been shown to cause a major change in the abundance of various other species. See the Wikipedia article: https://en.wikipedia.org/wiki/Keystone_species .

Environments have a tendency to change on longer time scales than that of the overt behavior of the SOI. This is the basis for the SOI to change (its composition and behavior) to remain in compliance with the new(er) requirements. This is what adaptation and evolution are about.

Living and supra-living systems (e.g. organizations) are certainly purposeful in doing what they have to in order to stay alive (operate) and procreate (profit/grow). They are adaptive and evolvable systems that can reconfigure their internals to meet new challenges.

2.4.2.2.2 Qualities

This refers to the set of aspects that confer systemness on a ‘thing.’ Every concrete system is, at once, a process, an object, and an entity. The process is a set of active internal transformation activities that are required for the system to obtain and manipulate resource substances and produce output substances (and forces). The process gives rise to the identity of the kind of entity an observer perceives. Object-hood entails the system being a unified, whole, identifiable body. All of its parts move in an orchestrated way.

2.4.2.2.3 Attributes

We attribute systemness to an entity (or process) based on the fact that what is perceived by another system (we humans for example) is the behavior of a bounded object. When we cannot know directly what is going on inside the object, we can still infer something is happening inside by virtue of sensing what is going in from the outside and what is coming out from within, or, in other words, crossing the boundary, and this includes the responses to forces as well as the production of forces applied to entities in the environment.

The behavior of the whole system is a function of the combined behaviors of its internal components (and cannot be predicted on the basis of individual component behaviors). It is recognized that the behavior “belongs” to the SOI by virtue of an effective boundary that demarks the system from the rest of its environment.

2.4.2.2.4 Composition

The boundary of the system keeps the contents in and the rest of the environment not needed as resources out. A system is composed of components that have interactions with one another. They are linked by various ways, forces and flows of substances. As we will see in the next chapter, but start to get a hint of here, is that a component of a level 0 SOI can be, itself, a system. That is it has the ontological status of a system, making it a subsystem of the original SOI. By a recursive rule of hierarchical organization (see Equation 3/4 in the next chapter), such a subsystem may be remapped into this same framework and treated as a system with an environment (the original SOI as supra-system) and composed of internal components and interactions giving rise to its behavior. This remapping is the basis for the process we will introduce in Chapter 4 as functional/structural deconstruction[74].

2.4.3 Levels

The concept of levels in a hierarchy is quite natural. In this framework, we define a three-level structure depicted in Figure 2.15. We label the SOI as level 0 (L 0) as it is the focus of our investigations. The environment of the SOI is labeled level -1, as in it is one level out from the SOI. The explanation for this comes shortly. Similarly, the components within an SOI are assigned level +1.

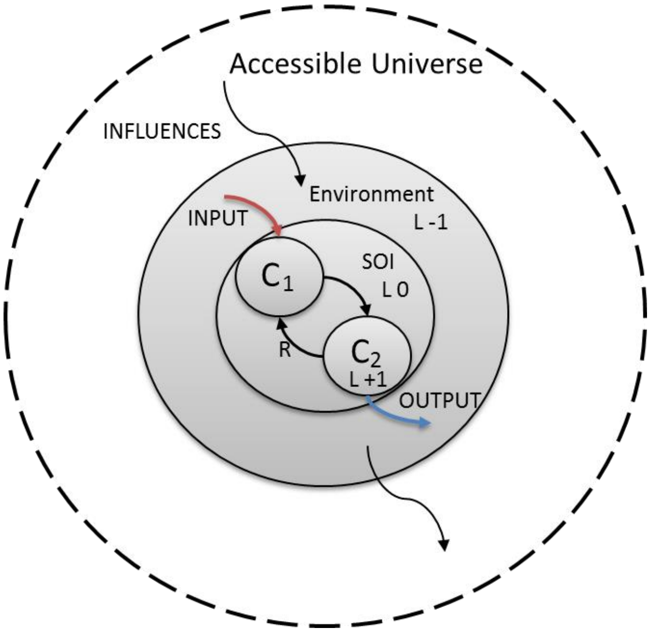

Fig. 2.15. This depicts a 'map' of system hierarchy (see Figure 2.14). Level 0 is the SOI. Components (C1 and C2) along with relations (arrows labelled R) constitute the next level down, L +1. The environment is the next level up, L -1.

Some possible confusion arises from this use of plus and minus symbols. It is logical, however, from the standpoint of a graph theoretical tree which has its root at the top and branches downward in levels. The root is generally said to be at level 0 and the branches to lower nodes are at level 1; those at the next level down (!) are at level 2 and so on. We will be using tree structures and graph theoretical math in formulating the structure of system representation in the next chapter, so it will become clear how this scheme works in practice. The assignment of -1 to the level of the environment will come into play when we are doing functional and structural deconstruction on levels further down in the hierarchy of composition.

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[74] The term 'decomposition' is often used to mean the same operation. In mathematics this is well understood. Unfortunately I have found that many naïve students or laypersons think of corpses rotting when the word is used, or at least that thought seems to lurk subconsciously, perhaps biasing their understanding of what we are doing, or creating a barrier of mild disgust that blocks understanding. We prefer the term 'deconstruction' since it evokes a mechanical operation of taking something apart and it sounds better than 'dissection.'

2.4.3 Using the Framework

2.4.3.1 Applying the Principles at Level -1 in the Framework

We are now in a position to attempt an organization of ontological elements using the framework and examining various proposed elements from the numerous methods discussed above and examined elsewhere. Our starting point is to use level -1, the ENVIRONMENT and level 0, the existence of a SYSTEM, with the role of CONTEXT and MEANING focusing our attention on the Purpose of the system. Taken along with the principles of organization, hierarchy (especially that the environment is a supra-system), network, and behavior we establish the existence of other systems as entities in the environment that interact directly with the system of interest through the flows of matter, energy, and messages. The entity-hood of the system is established by the existence of a boundary that acts to regulate the inflows and outflows and these, measured at points in time, establish the CONTEXT of the environment relative to the SYSTEM. The inputs to the system must necessarily be construed as resources (except for disturbances) and the system must necessarily have at least one output that is of benefit to the environment. Benefit to the environment has the same characteristics as benefits to the system from the context. The tri-valent values discussed earlier apply mutually to the environment and the system. We conclude that the value produced by the system must benefit some entity in the environment which through some feedback loop through the environment comes to support the continued availability of critical inputs to the system.

These are some of the objects, relations, and actions that have ontological status as a result of applying the principles to candidates within the framework.

Table 2.2. Examples of that which has existence (ontological status) at level -1 in the framework.

Existence of	
Objects (Substance)	System of Interest, Sources, Sinks, Channels, Material, Energy, Messages
Relations	Source-Of, Sink-For, Relative Position in Space, Relative Activity in Time
Actions (Work)	Applies Force, Moves, Accepts-From, Exports-To, Reacts-To

2.4.3.2 Applying the Principles at Level 0 in the Framework

We next address the qualities of level 0, the SOI, by examining the attributes that make an SOI what it is. An SOI is, by definition, a system. Our examination of level -1 established the input/output relations with environmental entities, so the SYSTEM status of the SOI is given. Also established, if the output(s) of the SOI are transformed aspects of the inputs (e.g. some of the high potential input energy appears at the output as waste heat), is that the system contains a PROCESS. Work must be accomplished within the SOI so that transformations are established. Finally, ENTITY-hood is given by locating the system in time and space relative to the other entities in the environment. In some environments, as supra-systems, a multiplicity of similar entities may constitute subsystems. That is, an SOI may be replicated within the environment multiple times. However, thanks to the fact that no two physical objects can occupy the same space at the same time, it is possible to establish the unique characteristics of a specific SOI by affixing the time and place of its existence. Note that the first element, time, is considered always sequential. However, space is established by fixing a coordinate system on the whole environment and specifying the coordinates of a given SOI. This operation is only sometimes necessary when doing a micro-scaled analysis, as will be demonstrated in Chapter 5.

The transition to the application of Level 1 begins with establishing the existence of the BOUNDARY and BEHAVIOR of the SOI. Boundaries establish the points of contact/interaction between the SOI and the other entities in the environment. The boundary also provides the frame of observation for the behavior of the SOI with respect to its position in the environment and the interactions it has with the other entities. The external or public behavior of an SOI is observed at the boundary first.

2.4.3.3 Applying the Principles at Level 1 in the Framework

The full establishment of the boundary and behavior of an SOI precedes and leads to the exposure of the internals of the SOI. The latter now becomes a new ENVIRONMENT in that the existence of COMPONENTs and their INTERACTIONS constitute the establishment of the internals of the original SOI. We now move the index up so that the new Level -1 is the entire contents of the original SOI and the new Level 0 applies to all of the subsystem components to be found there. And the new Level 1 will be reapplied to each of those that are not atomic.

Table 2.3. Examples of that which has existence (ontological status) at level 1 in the framework. Note that basically the same ontological items are repeated at this level. Sources and Sinks are replaced by subsystems and components.

Existence of	
Objects	Subsystems, Components, Atomic Processes, Channels, Material, Energy, Messages, Stocks/Reservoirs
Relations	Source-Of, Sink-For, Relative Position in Space, Relative Activity in Time
Actions (Work)	Applies Force, Moves, Accepts-From, Exports-To, Reacts-To

The differences between Table 2.2 and 2.3 indicated the key to understanding systems through analysis by deconstruction. Whereas in the original level -1 we started with unmodeled sources and sinks, at level 1 we designate the components of the original level 0 as subsystems and (possibly) atomic processes (those that need no further deconstruction). Systems are composed of subsystems, some of which are already known (e.g. atoms are already well understood as systems). This will be of help in deciding how to proceed in analysis in Chapters 4 and 5.

2.4.4 Upper Ontology

What we have accomplished at this point is the construction of an ‘upper’ ontology or the base concepts that are used to derive all other concepts of that which exists in the real world. The framework we employed has provided us with a basic vocabulary of highest order categories of those things that exist. The work ahead, then, is to construct the ‘lower’ ontology for systemness, e.g. identifying specific categories of things that have specific kinds of causal effect in the world.

2.4.5 System Domain Ontology

By the contention that all things are systems we can begin to recognize specific things that perform different, yet still general, kinds of functions in complex systems. For example we can differentiate INTERACTIONS based on the idea of a flow of influence and further differentiate those flows based on the real-world attributes (BEHAVIOR) of energy, matter, and messages. These latter are attributes of interactions at every level of organization in the Universe, so are not just attributes of disciplinary domains, but of all systems. In the former arenas we will make further distinctions, for example of different kinds of energies, e.g. electricity vs. gravitational potential. In the next section we develop the system ontology.

2.4.6 Discipline Domain Ontologies

Every domain of knowledge has its own peculiar identifications for things that are systemic. This is the key to understanding how to apply system science and, specifically, systems analysis to the understanding of domain-specific systems. Biology has its own terminology, but those terms can ultimately be derived from systems terms (the systems ontology). The same is the case for all the other natural and social sciences. We contend it is also the case for the humanities, though this is a bit more difficult to show[75].

2.5 The System Ontology

Thus, we will now develop the ontology of systems and derive a terminology that is applicable to any kind of system at any level of complexity. This ontology will be the basis for the development of the lexicon of a system language, to be developed in the next chapter.

2.5.1 Background Categories

These categories are not substances as such, but rather used to establish relative locations and relative times.

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[75] Consider, for example, a painting as a model of perceptions had by the artist. Even abstract art is representational. Moreover, those representations ‘speak’ to the observer of the work. If this were not the case then there would be little or no value in art as a means for human minds to connect.

2.5.1.1 Space

The existence of SPACE is problematic. In Newtonian physics, space is an absolute, a kind of lattice of locations. In Einsteinian (General Relativity) space is defined by the distance relations between objects. In this book we will use the notion of LOCATION-RELATIVE-TO, having identified a frame of reference. In most cases this will be a Cartesian frame with the center chosen as the center of mass of a system. This is strictly for measuring relative distances in some appropriate metric/scale which will be identified on a case-by-case basis.

Systems as real things in the Universe have extent, that is a volume occupied in space. In the next chapter, when we turn to the discussion of real systems and their boundaries, we will make more explicit what this means. In addition to the extent of a system, there is the issue of space between systems, especially with respect to the 'distance' that substances must travel between systems. As we will see, when multiple systems communicate and transfer substances between one another over an extended time we are really talking about a supra-system, a system of systems that constitute the supra-system being, itself, a system and thus, the spatial extent of all of these subsystems plus the distances between them form the extent of the supra-system.

2.5.1.2 Time

Time could also present special problems. Time scales vary with the level of organization. Things go more quickly in smaller scale subsystems; time constants are smaller relative to the larger supra-system. The shortest time interval for the lowest subsystem level is taken as the basic clock tick for the system as a whole. Ideally time constants that are integer multiples of this smallest time constant (Δt in discrete time) can be applied to subsystems higher in the hierarchy. This is advisable when one desires to run simulations of a higher level of organization as an abstraction of the lower levels. This will be discussed in Chapter 9.

Systems exist over some time scale. As with the extent of a system in space, they have extent in time as well. Indeed, the very notion of a system having duration means that during its lifetime it is recognized as an organized whole thing. But systems do not last forever, with the possible exception of protons and sub-nucleon particles[76]. Indeed, the Universe as a whole may not be eternal. The evidence is strong that it will either evaporate or ultimately contract back into a singularity (perhaps exploding in another Big Bang).

All systems above protons have a lifespan. Though it is difficult to make any causal claims at this time, there is reason to believe that lifespans, when lived in full measure, are related to the workings of entropy. Systems eventually simply fall apart. On the other hand, more likely scenarios involve systems being disrupted by other systems as when galaxies collide or a prey animal is eaten by a predator.

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[76] Protons may or may not be stable indefinitely. Some indications are that protons do decay with a half life of about 10^{32} years. As of this writing no one has detected a verifiable proton decay event. See the HyperPhysics article: http://hyperphysics.phy-astr.gsu.edu/hbase/Particles/proton.html for background. Accessed 4/5/2020.

2.5.1.3 Space-Time

As is now understood, space, with its three dimensions, and time, as a fourth dimension, constitute a singular framework for placing entities in relation to one another. In this book we will not dwell on the implications of a system's position in space time per se since that will always be relativistic with respect to other systems and will be particular to the kinds of systems with which we will be concerned. So, for our treatment, we will assume that systems have space-time extent, a location and time during which the system may be observed and recorded (as covered in Chapter 5). It is simply noted that this aspect of systemness, that it does occupy space for an amount of time, is a given.

2.5.2 Framework Elements

2.5.2.1 ENVIRONMENT

Every SOI is embedded in a larger system, the supra-system. Generally, the SOI will interact directly with only a few other subsystems of the same level of organization status and/or atomic components (see below). The environment contains all of the sources of inputs (matter, energy, and messages) and the sinks for outputs (same substances). It also contains all of the channels (or fields) through which flows occur. The entities of the environment connect directly with the boundary of the SOI.

2.5.2.2 SYSTEM: The Root Category

The SOI is the entity that we are most interested in understanding. It can be viewed as the root of a tree (inverted) with branches to nodes representing the subsystems at level 1. Figure 2.16 shows the basic tree structure of a deconstructed system.

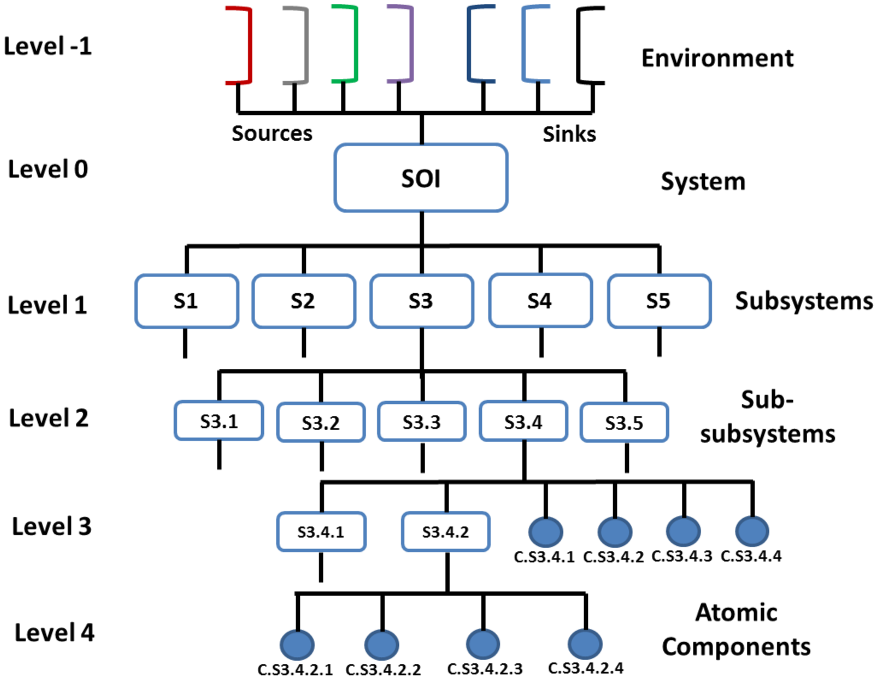

Fig. 2.16. The Environment-SOI-Subsystems hierarchy represented as a tree structure shows the levels of organization in a complex system. The labels in the various nodes below the root node (SOI) are used to distinguish each subsystem or atomic component and preserve the ordering of the tree. Branch lines that terminate are presumed to have children but are not shown. Note that level 3 shows a mix of both subsystems and atomic components. This tree is unbalanced in that node S3.4.2 is not a leaf node and has additional children atomic components.

The environment is shown as another upward directed tree with the sources and sinks as the nodes (level -1). The complexity of the system is indexed by the number of levels of sub-trees. Each subsystem of the SOI, at level 1, is, itself the root of a tree. Only the tree rooted at S3 is shown in the figure. At level 2, the sub-subsystems of S3 are shown. Similarly, S3.4 constitutes a sub-sub-tree root for children at level 3. Level 3 in this figure contains some atomic components (see explanation below) mixed with additional children sub-sub-subsystems[77].

The relation between the depth of a hierarchical tree and the concept of system complexity is explained more completely in Mobus & Kalton (2015, Chapter 5).

2.5.2.2.1 PROCESS

A process is a system that performs a transformation on its inputs to produce outputs that are different in form, quantity, or organization. The atomic work processes of figures 2.17 and 2.18 are archetypes. Systems are generally speaking compositions of atomic work processes and so accomplish more complex processes.

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[77] The extending of prefix ‘sub’ with hyphens for each level down in a tree is used here only for example purposes. In the future we will drop this kind of notation with the understanding that ‘subsystem’ means a child node of some sub-root in a tree like this. Where necessary the level of the subsystem will be given using the kind of dotted integer notation shown in the figure to make it explicit.

Every real system imports material and/or messages and energy. It does work on the imported matter, energy, or messages, converting some portion of the energy into a lower form – waste heat. The work performed will depend on the details of the system (or subsystem) but will involve some form of transformation or translation (moving). In general, the imported material, energy, or messages will be transformed from a high entropy form into a lower entropy form, having balanced the entropy equation by virtue of the lost heat. Messages are processed for their information content. This may involve work done in receiving, transducing, and interpreting the message for its information content. Further work done by an ‘information processor’ would include conversion of the information to knowledge for storage in the structure of the system. It may also result in encoding the information for re-transmission.

Material transformations involve processes that reduce the entropy of the material, such as refining or shaping mater for a new use. The work could be mechanical, electrical, thermal (high temperature), or chemical. In all cases energy is consumed to change the material from its ‘raw’ form into some form that is going to be more useful to clients or to the system itself (e.g. repairing structures internally). In most cases there will be some form of transport of the material from one location to another. One major form of transport is exporting products or wastes through the boundary.

Energy transformations involve work done on a low grade (low potential or quality) energy form to boost its potential or quality (with some loss as heat) so that the energy flow becomes, product-like, available to other work processes. Examples include refining oil to produce gasoline, or transforming water flow into electricity.

In all three cases (Figure 2.17 below) there are two types of high quality energy inputs. One type is the operations energy (as shown in the figure) which must flow into the process in real-time. The second type is the energy that was consumed constructing the energy work process (equipment) originally, plus periodic energy consumption for maintenance of the equipment. The former is, essentially, the operating costs, in high potential energy. The second is, essentially, the investment of high potential energy to make it possible to do the on-going work.

As per Figure 2.16, showing the subsystem hierarchy, each one is also a sub-process that is responsible for a smaller portion of the whole system process. Atomic components are also processes but perform the smallest unit of work. Components, including atomic components, are discussed below.

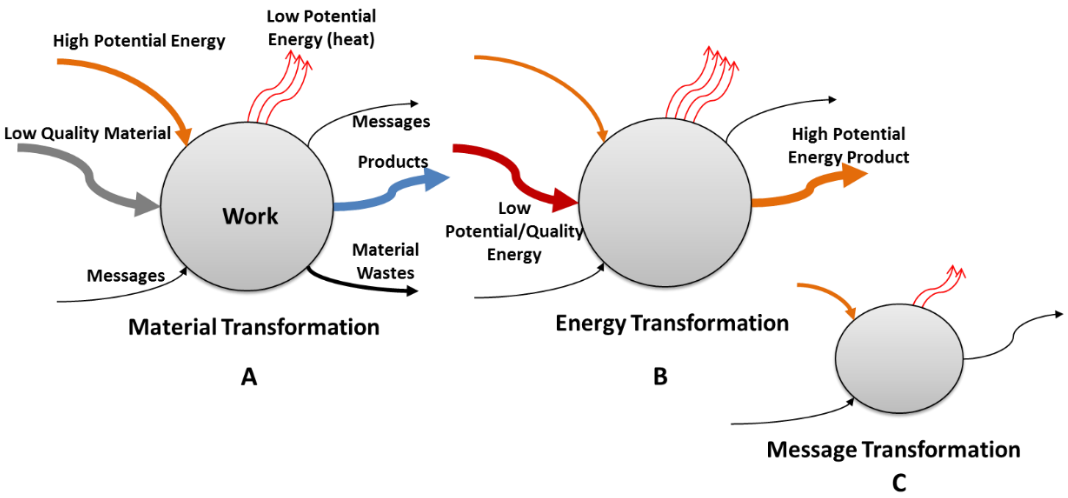

Fig. 2.17. All processes transform low quality material, energy, or messages, into high quality versions of the same. Work processes require the input of high potential energy to drive the work itself. In doing work, according to the Second Law of Thermodynamics, some of the energy does not accomplish work, but is transformed to a low potential form – waste heat. The work produces a 'product' or high-quality material, or high potential energy, or messages of greater use (higher information content) downstream. Material transformations involve some material waste products while energy transformations produce a greater proportion of waste heat.

Non-atomic processes are usually mixtures of various work processes, having multiple material, or energy, or message inputs and multiple outputs. Atomic processes are defined below.

2.5.2.2.2 OBJECT

Every real system has physical extent in an appropriate frame of reference. It takes up space and has duration. No two objects may occupy the same space at the same time.

There is, however, a situation in which some systems can 'seem' to occupy the same space. This occurs when the boundary of an object is fuzzy, that is, the boundary may soften or morph for some period of time. One of the best, and most dramatic, examples of this is when a single person (or a group of individuals) moves from one system in which they participate to another. For example, an individual goes to work in an office in the morning – they become a component in the business system. All of the individuals who arrive around the same time, in essence, expand the boundary of the business system. At the same time that they become part of the business system they have ceased to be directly participating in their own family systems (at least in body if not mind). The same argument applies to a person's involvement in various out-of-the-home activities. When someone is shopping, they are participating in the 'consumer' part of the economic system. When they are working (at the office) they are participating in the labor part of the economic system. An individual is a multi-capacity component of many different systems. What makes it even more complicated is that a single individual's mind can be involved in many different sub-processes, effectively, through subconscious mental activities. A father at work can be worried about a sick child at home while working at the office. However, no human can effectively actually be engaged in multiple activities at the same time (no matter what teenagers may think about their abilities to 'multi-task.'

The fact that boundaries may morph, or be fuzzy in this sense, they are no less real. But the issue of time needs to be accounted for. In the example of people going to work, each individual can be thought of as part of a flow (of an agent component – see below) between delineated subsystems. That is, for example, people going to work are outputs from the "human" subsystem flowing to input to the economic subsystem.

2.5.2.2.3 ENTITY

A system, through its behaviors, will affect other entities in its environment (level of organization in the hierarchy). This is what we call 'entity-hood.' In this perspective, entities affect each other, which is the same as saying subsystems interact with one another and, by virtue of their output/input flows affect each other's' behaviors. All entities are actors regardless how simple they may be. More complex entities have more latitude in making decisions and more impact on other entities by virtue of their degree of agency.

2.5.2.2.3.1 Actor

In a very real sense even a dead body is an actor. The very act of decay sends various chemical compounds into the environment and affect other entities. Every atom is an actor. Every system, by virtue of being a process with inputs and outputs is also an actor.

2.5.2.2.3.2 Agent

A special pattern of an information processing subsystem is a decision maker. The decision maker takes in information from the environment, processes this information in the context of a decision model, and generate a 'decision.' The latter is output that is coupled with an effector subsystem to cause behavior to occur. The nature of agents and agency will be covered in Chapter 11.

2.5.2.2.3.2.1 BEHAVIOR

Every system interacts with its environment in some fashion. What it does in reaction to forces or chemical interactions constitutes its behavior. This is the changes in space or composition that a system undergoes over time in response to those interactions. Even a pebble being buffeted in a mountain stream can be said to have some kind of behavior. The degree to which its internal constituent minerals retain their bonds and the overall shape of the pebble even in the face of the buffeting can be counted as 'doing something' even though we prefer to think of it as being inert. Behavior in this context may be just the dynamics of a solid object reacting to physical forces.

Things get more interesting for systems such as the Earth's mantle which continuously undergoes convective streaming and pushes continental plates around the crust. This too is behavior, but motivated by energy flows internal to the system.

Living systems are similarly motivated from internal energy flows that are even more highly constrained resulting in complex behaviors that are goal directed.

2.5.2.2.3.2.2 BOUNDARY

A boundary demarks the difference between the inside of a system and the outside, or environment. A boundary exists whenever components of a system are restrained in time and space to a particular location. Materials, energies, and messages may penetrate the boundary, but the components that interact with one another to make the system what it is, are kept together so that they will consistently interact.

Boundaries need not be separate objects or components though they certainly can be. For example, a cell membrane is a distinct and special substance that surrounds the cell interior allowing the influx of molecules that are (generally) good for the cell's metabolism, keeping out foreign molecules that would interfere with normal operations. And the membrane facilitates the expulsion of by-products that could be harmful to the normal operations of the insides.

Other kinds of boundaries may simply be implied by operational forces and interrelations between components that are much stronger than those between internal components and others in the environment. For example, the congregation of a church does not need a specific building (walls and roof) to maintain it as a system. The fellowship and bonds of shared beliefs are psychological forces that keep the congregation structurally and functionally unified. Of course, in this last example, the boundary is porous in that members may come and go over time. Moreover, it is fuzzy in that different members may have slightly different degrees of membership, say, based on their particular understanding of a bit of dogma.

Boundaries may or may not be solid, easily identifiable enclosures. However, everything that we could call a system has a boundary that makes it capable of maintaining system-hood over time.

2.5.2.2.4 COMPONENT

Every object element within the system boundary, including the interfaces, channels, stocks, sensors, and regulators are components of the system. At higher levels of organization in the SOI components will be found to be complex objects themselves, or, in other words, subsystems that will require further white box analysis (see Equation 3 in the next chapter).

Atomic components are those subsystems that need no further deconstruction in order to understand the SOI internals. What makes them atomic is that they involve a minimum of inputs and outputs and their transformative work is easily handled as an opaque-box. Four simple work processes are shown in Figure 2.18. The word substance, as used in these figures, can mean any of material, energy, or messages. However the forms operating on material inputs are shown. These all conform to the principle that all systems are processes that involve work being done, requiring energy flow and transform the shape, purity, rate of flow, or dynamics of materials. Simple work includes: combining two substances into a more complex substance (a product) with the loss of some heat and waste substance, splitting a single substance flow into two (or more) products with some loss of energy and substance[78], impeding a flow or slowing the rate of flow with a consequent back-pressure, and buffering a flow, used to smooth out the flow volumes over time.

Atomic components are most generally found at the lowest level of organization in the hierarchy. However, at lower levels it is possible to find mixes of atomic and complex components, the latter being subsystems that will still need to be deconstructed. The hierarchy tree, in such a case, is unbalanced.

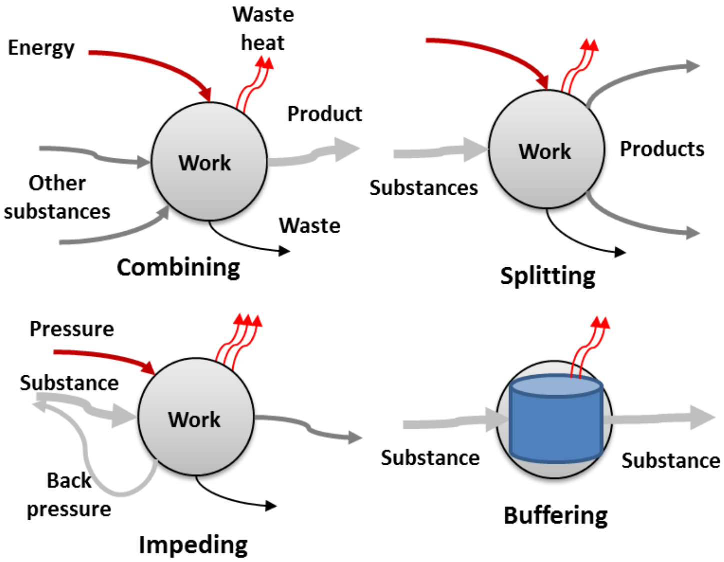

Fig. 2.18. Subsystems can be treated as atomic components when their work processes are simple and already understood.

Figure 2.19 shows some additional work processes that are atomic. Copying takes a patterned input substance and an un-patterned one, outputting the original input (think of it as a template) and a copy of the pattern in the second output (plus some waste from imprinting the pattern). Propelling is work done to push a substance against a gradient, like a pump pushing water through a pipe. Sensing is somewhat similar in that it responds to a modulated force or energy flow, where the modulation is a kind of pattern. It outputs a modulated energy flow, usually very low power, which encodes the modulation (or variation over time) in the applied

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[78] Note that in this scheme a product is any configuration that is more usable by downstream processes than the input substance would have been.

force. Amplification is related. It adds energy (power) to a weak but modulated energy input to produce a “copied” modulated high powered energy flow output. A modulator is in this same category in applying a modulated energy flow (signal) to a substance flow to produce a modulated output substance flow. Note that when the input substance is a force or energy flow we have the sensor or amplifier effect.

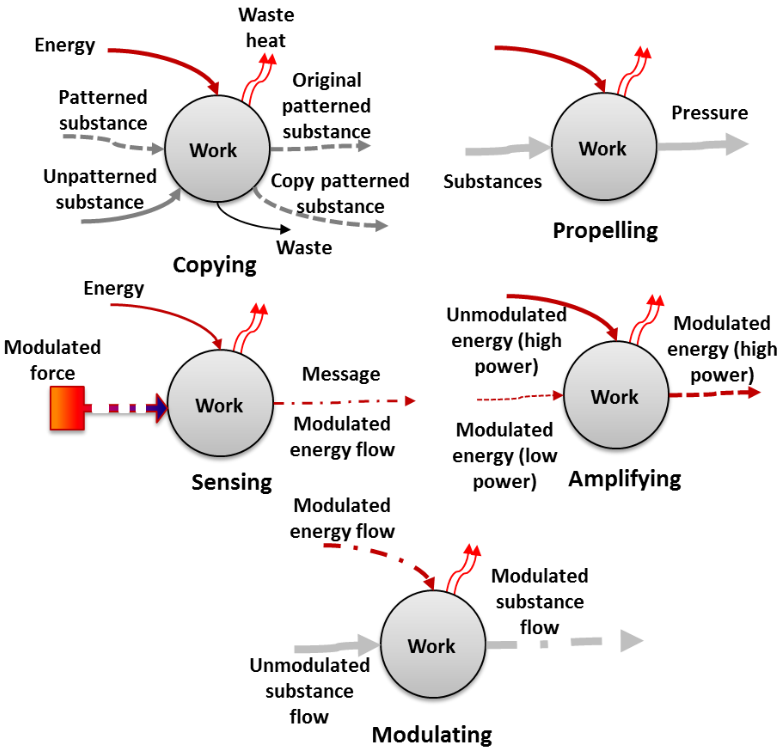

Fig. 2.19. Additional atomic processes are shown.

The term “component”, however, can apply to a subsystem within a system. As above we reserve the term “atomic component” to specify a leaf node in the deconstruction tree. Otherwise a component should be viewed as having internal structure that needs further deconstruction to elucidate its structures and behaviors. This is the basis, to be developed in the next chapter, for the recursive structure of systems. Component definitions apply at level +1 in our framework. But once all components in a given system are known, that system becomes the new level -1 insofar as further analysis of the components is concerned. Each component, in turn, becomes the system of interest where its environment includes all of the other former components in its supra-system (the old level 0). The net result of this is the realization of a tree structure as shown in Figure 2.8 above.

2.5.2.2.4.1 Personalities

Components of a system express different potentials for interactions with other components, what we have also called potential affordances. In other words, components have ‘kinds.’ They are differentiated by the fact that all components of systems are subsystems having internal structures that produce unique (to the kind) behaviors and interaction potentials. For example, elemental atoms have differing kinds of bonding potentials due to the effects of the Pauli Exclusion Principle and the atomic weight of the nucleus (leading to different valence shell levels). Amazingly different people have different personalities that have varying amounts of attractiveness or repulsion to other personalities. Both kinds of personalities lead to interactions between entities!

2.5.2.2.5 INTERACTION

There are various kinds of interactions between components and between components and entities outside the original level 0 (i.e. in the original level -1). The interactions between internal components are generally characterized as flows of substance, either channelized (through channels) or broadcast as fields. Material flows may be through constrained channels, like pipes, or through circulations such as convective cycles. Energy, similarly, may be delivered through channels or through general fields. Either way the laws of conservation and degradation (or diffusion) have to be observed. Interactions occur because the component receiving the flow is affected by it. The existence of complex systems depends on the fact that one component's output is a resource input to another component allowing the latter to fulfill its purpose, i.e. perform its intended work.

There are several aspects associated with interactions (see the higher-order aspects given above). These are related to several principles listed in Chapter 1. They have ontological status from the standpoint of being found in every system.

2.5.2.2.5.1 Networks (Principle 3)

The interactions between components in a system at a particular level of organization form a network, generally a flow network for different substances and influences. Relational networks are also part of the interactions, i.e., some components (nodes) in the system may have key roles in the system relative to other components. For example, upstream components in a supply chain can influence the behavior of downstream components by virtue of the quality of their products. Every such network can be modeled (Principle 9) as an abstract graph where the components are node (edges) and the links (edges) are the relational connections (Mobus & Kalton, 2015, Chapter 4).

The components of every system (every kind of system) form networks of relations.

2.5.2.2.5.2 Complexity (Principle 5)

As described in Mobus & Kalton (2015), Chapter 5, complexity is a measure related to the degree to which a system has both a multiplicity of components (subsystems) at any given level of organization (below) and the number of such levels forming a hierarchy. Every system may be characterized by this measure. Simple systems (e.g. elemental atoms) have very low measures of complexity relative to a living cell, which contains all of the complexity of elemental atoms, their various molecular compositions, and their interactions in complex molecular interactions, e.g. enzymatic reactions.

Complexity might be better characterized as a property rather than a “thing.” However, as we will see in coming chapters, this property is fundamental to systemness and thus we claim has ontological status as something that exists.

2.5.2.2.5.3 Hierarchies (Principle 2)

As with the related aspect, *Complexity*, the hierarchical structure of systems is a reality owing to the nature of the levels of organization that emerges from auto-organization (Principle 6). Hierarchies of systems and subsystems, etc. are also called “holarchies,” a term suggested by Arthur Koestler[79] to describe how a whole system is comprised of subsystems that are themselves essentially each one wholes in their own rights. No non-hierarchical system is known. Even so-called “flat” organizations turn out to have implicit hierarchical (power) structures if not hierarchical work processes. No mailroom clerk gets to decide if and when they will distribute the mail!

2.5.2.2.5.4 Messages (Principle 7)

Messages are specialized versions of energy (and often time material) flows. They are characterized by using very little energy in their transmission from a source to a sink. They are generally pushed out (actively transmitted) and received passively. Messages are flows that are modulated in a way that encodes symbols (e.g. frequency, amplitude, digital) that are a priori recognized by the receiver. They take little energy to propagate signals (inject into a channel or broadcast) and are most often amplified at the receiving end so as to have effect on the receiving system (i.e. result in work being done to modify the structure of the receiver).

Messages are used by active transmitter systems to influence receivers, to inform them and generally to control future behavior by receivers. However, receivers might also be receptive to naturally occurring signals, such as reflected light or naturally generated sounds or emanated molecules (taste and smell). Living systems have evolved to use ambient messages to observe and perceive their environments. They can observe entities that are not themselves actively sending messages but whose behaviors nevertheless transmit information.

2.6 Putting It All Together

2.6.1 Terminology

The point of an ontological study is to determine the existence of objects, their relations with one another, their effects on one another, and their overall structure in time and space. The second point is to assign terms (symbolic names) to these objects, relations, and actions, and to

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[79] See the Wikipedia article: https://en.wikipedia.org/wiki/Holarchy. Accessed: 2/28/2017

determine legitimate connections between the terms, in other words, the syntax of a language. That will be the task tackled in the next chapter where we elaborate an initial lexicon and syntax of the system language.

This work requires establishing a hierarchy of abstractions, such as the idea that there is a universal concept of a movement or “flow” of something (material, energy, or message) that sits atop a SPACE-TIME coordinate structure (a Newtonian version) or a set of distinctive kinds of channels (a relativistic version). A flow of material is distinguished from a flow of energy.

2.6.1.1 The Natural Language Version of Terms

We will be expressing our ontological terms in English. The choice should be completely arbitrary but was made for practical reasons. Most scientists today, regardless of their native language, speak English in conferences. Most journals in the Western world are in English. We will leave it to others proficient in other native languages to translate these terms to their language as needed. In the next chapter we introduce the idea that every human on this planet has an internal inherent mental language that is the same for everyone regardless of their public (spoken) language. The terms in this mental language (lovingly called ‘mentalese’) are at the core of natural public language, i.e. every word in every language has its root meaning buried in the subconscious use of mentalese. Thus, if this conjecture is correct (see the ideas of Natural Semantic Meta-language above and to be further explored in the next chapter) then the selection of a specific public language should be immaterial since every term in any one language is directly translatable into any other public language[80].

Thus, the terms in our ontology of system will attempt to be English words that represent the most abstract conceptualization of the system term relating to the systemese concept.

The lexicon of a language of system to be developed in Chapter 3 will be given in English. In chapters following Chapter 5 we will see several example systems using the derived English terms specific to the domain of the systems of interest. The language of systems may be viewed as a kind of Rosetta stone, providing a means of translating terms in one domain to terms in another domain; this may help provide a basis for transdisciplinarity.

Terms used in quantification and mathematical descriptions of functions, for example, are, at this point, relatively universal in the realm of discourse. Mathematics is its own language, as is logic. Visual images, e.g. icons representing the various terms, may or may not be culturally neutral. This is an area that requires more research. For example, the use of a barrel icon, , for the term “stock” may not convey the meaning in all cultures. Another term, “store,” is used

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[80] Not to imply that word-for-word translation between any two languages is trivial. Sometimes it takes a phrase in one language to convey the semantics of a single term in another language. However, here we are talking about systemess concepts which are innate in all human minds so the translation of those concepts between languages should be fairly straightforward.

by Odum (2007) to refer to the same concept. In some natural languages the translation of store might be more appropriate than stock. We will leave it to linguistic experts to make that determination. We don't think anything vital is going to be lost in this English text by using stock[81].

2.6.1.2 A Basic Example of the English Ontology of Systems

Finally, we list here a set of terms along with their hierarchical relations derived from using the framework described in section 2.4. This list is not meant to be exhaustive, but it includes some of what we believe to be the most useful concepts in understanding concrete complex systems.

- Environment
    - Entities
        - Source
        - Sink
        - Disturbance
    - Flows [MOVES-FROM-TO]
        - Input
            - Material
            - Energy
            - Message
        - Output
            - Material
            - Energy
            - Message
- System
    - Boundary
        - Type (e.g. porosity, fuzziness, etc.)
        - Interfaces
            - Receiver (of inputs)
            - Exporter (of outputs)
    - Subsystem

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[81] There is some difficulty in talking about this particular term since there needs to be a distinction made between the substance of the stock and the container in which it is held. The stock value is a measure of the amount of the substance, e.g. volume or weight for material, or charge in a capacitor for electrons. The confusion comes from the fact that a holding condition (e.g. a boundary) involves some kind of container having a capacity measure. Further complicating the distinction is the fact that some such containers are fuzzy. For example, a herd of cattle, while feeding in a free range are not physically contained in the conventional sense. When they are herded into a corral they are in a container. In both cases we can talk about the stock of cattle in terms of the number of heads. In the free range condition the cattle are still 'contained' but now by the geographical distribution of edible grasses. And too, many ranchers do erect fences to keep their cattle from getting too far away. The author is deeply indebted to Hillary Sillito for pointing out this important distinction.

        - Component
            - Sub-subsystem
                - Object
                - Entity
                - Agent
        - Interactions
        - Relations
    - Behavior
    - Hierarchy
    - Complexity

These basic concepts of what exists will be expanded throughout the book, but will be given more definitive status in the next chapter.

2.6.2 Accounting for Everything

This chapter has presented a pass at defining what exists insofar as systemness is concerned. The use of a framework in section 2.4 sought to provide a means for producing a full accounting of the attributes of systemness but as with all human endeavors, something is bound to have slipped through unnoticed. There are some ‘things’ in our Universe that have been missed. Our framework approach, based as it is on the principles identified in Chapter 1, will surely be found wanting at some time in the future. It may need revision or even a complete overhaul. But something like it will be needed to guide the identification of all of the unique things, interrelations, and actions that do exist.

What we hope will happen is that this ontology will be used to guide the process of understanding complex systems and when it fails or finds inconsistency those who understood the use of the framework will go back to that point and rethink as needed how the framework might have failed to determine whatever that something that is missing. The danger is that researchers may be tempted to simply add onto the ontology in an ad hoc manner without really working through the framework and finding out how to fix it. This would be unfortunate because just like in the sciences, guided by the scientific method, for example, improvements in the process of discovery of new domain knowledge are made to the scientific method itself, e.g. adding double blind experiments helps diminish biases. The framework presented in section 2.4 is to system ontology what the scientific method is to normal science. If it lacks something as shown by the discovery of an ontological object that did not come out of the framework, then the framework itself needs updating and improving.

2.7 Summary of Ontology and Ontogeny

This chapter has been an extensive examination of the concept of an ontogeny of systems starting from a cosmological level and developing the systemness properties and attributes that apply universally to all ‘things’ as we find them. All systems, we have asserted, are based on a few fundamental patterns of organization and behavior that work together to make a system a system. We have also examined the nature of the ontogenic cycle, which accounts for how systems emerge from lower levels of organization and complexity. We claim that all system components, at higher levels of organization, recapitulate the fundamental work processes depicted in figures 2.18 and 2.19. These represent atomic processes that are found throughout the natural and artificial world and their patterns are simply elaborations of higher-level assemblies of lower-level components.

It remains to now use the discovered concepts of things and their terms to develop a structured description of all systems at any level of organization and complexity. Then using our terminology and such a structured description, we intend to define a system language (SL) that can be used in analysis to obtain a deep understanding of any system of interest (and its environment) as well as be a basis for generating simulation and static models of those systems. This language will provide a single common way to describe all systems regardless of their specific disciplinary content.

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