Toward a System Types Model

Introduction

The Ultimate Whole

A system can only be understood as a whole. This fact makes holism fundamental to systems thinking. It also make synthesis, looking upward to a system's broader encompassing systems, the preferred approach for understanding the roles a system plays and so its greater purpose and meaning.

The logical end to the upward path of synthesis is the universe, the greatest whole and the one encompassing all known systems. Hence the meaning of all systems is dependent in some degree on understanding the universe as a whole. This implies that better understanding the universe should be an important aim of all systems thinkers.

True, as many have stated, a complete understanding of the universe may be forever beyond human capabilities, nevertheless, this approach can provide great value. It can provide a common whole into which must fit all of the work upward from individual systems. It can also reveal the universal architecture that applies to all systems.

Unification

An enormous amount has been learned about both the universe and systems. The knowledge, however, is highly fragmented, generally not systems oriented, and not presented in a coherent form. Much valuable knowledge is available but not in the form conducive to systems understanding. We have many pieces of the puzzle in various shapes and sizes but no systems-oriented big picture.

The system concept provides a basis for unification. Von Bertalanffy addressed the potential of system-oriented unification more than forty years ago.

"... the systems concept seems to present a welcome new point of view. It suggests that the unity of science is to be sought in the uniformity of conceptual constructs or models applicable to diverse disciplines and hints at a unity of the world which these disciplines conceptualize. Evidently, whenever entities are studied and compared, there are diversities as well as uniformities. Both must be given equal weight and the specificity of the observable is reflected in the specificity of the corresponding branch of science. ... There are isomorphies or uniformities at a high level of abstraction. Of special importance are those which concern 'system' in general, irrespective of their nature and their components. Such isomorphies indicate a unity of the observed universe and hence of scientific knowledge."

The assumption of a uniform universe underpins all science. All our observations show that the laws of science apply consistently across the entire universe. The universe is coherent; it is our descriptions of it that are not. But this problem is fixable -- at least in principle -- by integrating and unifying our knowledge into a common coherent description.

Bertalanffy suggests that the unity of science must be built on "uniformity of conceptual constructs", and calls for the identification of isomorphies. The greatest uniform conceptual construct may be the system concept itself. Since the concept extends across the known universe at all scales and transcends all disciplines, it is a prime candidate to be the foundation upon which a unified science can be built.

The systems concept has been widely recognized as an important breakthrough and one that implies a profoundly different view of the universe. The task at hand is to define this new view and do so in a form that can be improved and extended indefinitely. We need a comprehensive, holistic, system-oriented, and adaptable description of the universe. Such a model would provide unification in the form of a common framework and dialect into which all other knowledge can be fit and made coherent.

Meeting the Holism and Unification Imperative

Unification is the only remedy for fragmentation. Unification implies a common representation, i.e., model, that integrates all relevant knowledge based on a common set of concepts, among which the concept of a system is primary. Unification also implies a common structure of system types that recognizes "uniformities at a high level of abstraction" and defines "diversities as well as uniformities".

Achieving holism and unification at the highest level presents a daunting challenge but one so central to systems thinking that it cannot be ignored. Lack of progress in this direction may well be responsible for much of the malaise that is evident in the systems community and the lack of impact of systems thinking in the broader community.

Process

Unity requires a common model, and a common model requires a process to create and perfect it. The process must be designed to address the inherent nature of systems and importance of wholeness.

In the words of Gharajedaghi "we need a preconceived notion of the whole before we can glean order out of chaos". Unfortunately, an accurate and complete conception of the whole is exactly what we don't have at the start. Worse, we have preconceived notions that are inaccurate, incomplete and vary considerably per individual. Hence the task of modeling must be approached with humility as a voyage of discovery in which our preconceived notions are likely to change and change repeatedly.

The lack of an accurate notion of the whole, together with the immense range and highly interrelated nature of systems demands an incremental approach to model building. The process can proceed in general as follows. Some part of what is known is clearly specified and presented so as to be understandable and enable critical review. Additional content can then be added, repeatedly, with the proviso that with each increment the old and new are reviewed together to ensure coherence, i.e., that they are "true as a whole".

It is important to understand how critical maintaining coherence is for the process. The holistic understanding must always reflect all of the known information and vice-versa. This means new information cannot just be tacked on or forced into the previously conceived structure. Instead, the totality of information, both old and new, must be reconsidered as a whole with each change, and as necessary the model adjusted accordingly. Of course, any change at the top must be reviewed for impact on the parts, etc., recursively. In this way new information can generate a new "notion of the whole", which in turn may generate a "new order out of chaos".

Circularity and how to handle it is clearly the issue here. New information can drive a new holistic understanding which in turn drives a new appreciation of the parts which can then impact the holistic understanding, etc. Coherence can only be achieved by following this loop until it settles down and everything fits. This requires patience, open-mindedness, a desire to learn, and willingness change from all involved.

Of course, this is a big task but it reflects the inherent nature of systems and so must be faced. The best we can do is to learn to address the challenge systematically and efficiently and to strive to traverse the loop rapidly.

Reductionism is surely the easier path, which explains why it has been practiced for centuries to the virtual exclusion of holism. A dedication to systems means we must take up the challenge of holism and find a viable way to address it. Doing so implies a profoundly different modeling approach which is a secondary topic of much of this paper. The tentative nature of the modeling examples shown must be understood in the light of this new approach.

Aims of Document

The primary aims of this paper are (1) to raise the issue of the need for a common, coherent, comprehensive system model, (2) show that doing so can be a viable and valuable enterprise with the right approach, and (3) stir interest in anyone who might want to contribute or collaborate. This is done by providing examples of an early type structure as a step toward a comprehensive system model. The paper also addresses (4) some parts of the necessary process and modeling techniques, especially to show that barriers some see to this approach can be surmounted, i.e., that there are no "stoppers". A complete and perfect model is not provided; the work shown represents a beginning not the end of the process.

Developing a coherent systems-oriented view of all existence would appear to be the logical goal of systems thinking, and would make a fine ongoing project for the systems community.

The Model and Coherent Modeling

System Types

The notion of a system is extremely general and so has a great many variants. Many thinkers have noted distinctions among system types along various dimensions, and some have suggested type structures, albeit partial and from a parochial perspective. To my knowledge no complete type structure has been attempted, at least not as addressed here.

Dealing with both the many concrete types and abstractions presents a serious challenge. An effective management approach is to organize all the variants into a type structure, i.e., a generalization-specialization hierarchy. In such a hierarchy "diversities as well as uniformities" (specializations and generalizations) can be rigorously defined and given ”equal weight". Generalizations can help to recognize isomorphies. If desired, specializations could be related to their "corresponding branch of science".

A system type structure fits what Bertalanffy calls for in his statement: " First, we must find out the 'nature of the beast.' This is systems ontology -- what is meant by system and how systems are realized at the various levels of the world of observation."

Over time, the structure can be developed into a comprehensive, coherent model rigorously defining all types and generalizations, perhaps including examples. Such a structure would go a long way toward supporting the development of a unified view of "the observed universe and hence of scientific knowledge."

Types are important but represent just one aspect of a model. A complete model must also address the structure of each type, the relationships among the parts and with the context, and the process of interactions, and importantly ensure coherence among all of the aspects. Any type structure alone must be considered especially tentative until a more complete model is in place.

Perfectibility

Many views into a model are provided in the following pages. The model is not perfect but strives to be perfectible. That is, the model is not now perfectly accurate, coherent, complete and understandably presented. However, it is constructed in such a way to be improvable so it can over time approach perfection ever closer (if never quite reaching it). Perfection may not be a realistic expectation for humans, but perfectibility is certainly achievable. Perfectibility is an important factor for dealing with a large, complex domain not yet fully understood, in which many changes and new insights must be expected.

Clarity First

Clarity before accuracy is a valuable modeling adage. Both, of course, are important goals. In striving for both it is better to be clearly wrong than unclear. If a statement is clear but mistaken, its flaws can be recognized and eventually corrected. If, on the other hand, a statement is unclear and it can be interpreted in multiple ways, its flaws are likely to be overlooked, and problems left to fester indefinitely.

Moreover, clear statements invariably elicit a response from reviewers which drives the process forward. So even when accuracy is in doubt it is better for a modeler to make, than not to make, a statement and to make it clearly. A response, especially one that points out a gap, flaw, or ambiguity, should be considered a sign of progress, and necessary for a continuously improving model. So if you notice flaws or can suggest improvements, by all means, inform the author. All are invited to be reviewers.

An Initial System Types Model

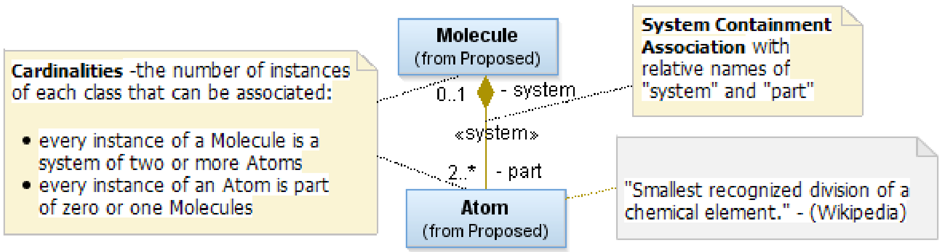
This section provides examples of a type structure and how it is developed, proceeding from simple to complex. The structure is using Unified Modeling Language (UML), using only a few simple constructs, all of which are clearly explained.

System Containment - Wholes and Parts

This section introduces one of the important relationships to be addressed, the one that associates a system as a whole with all of its parts, referred to here as a *system containment association*.

Figure 1 is a simple model diagram that declares two classes (types), Molecule and Atom and a relationship between them. The relationship, depicted as a line with a black diamond, is defined in UML to be a *containment association*, a strong form of aggregation. For our purpose, this standard association has been specialized (as indicated by the "<<system>>" marking) to be a system-parts association. (The meaning of which depends, of course, on how *system* is defined.)

The example states that a Molecule is a system whose parts are two or more Atoms.



Cardinalities -the number of instances of each class that can be associated:

- every instance of a Molecule is a system of two or more Atoms
- every instance of an Atom is part of zero or one Molecules

System Containment Association with relative names of "system" and "part"

"Smallest recognized division of a chemical element." - (Wikipedia)

Figure 1. System Containment Example (with Annotation)

Two notes (yellow background) have been included to explain other UML symbols. Other features of this diagram are briefly described in the following sections.

Class Names

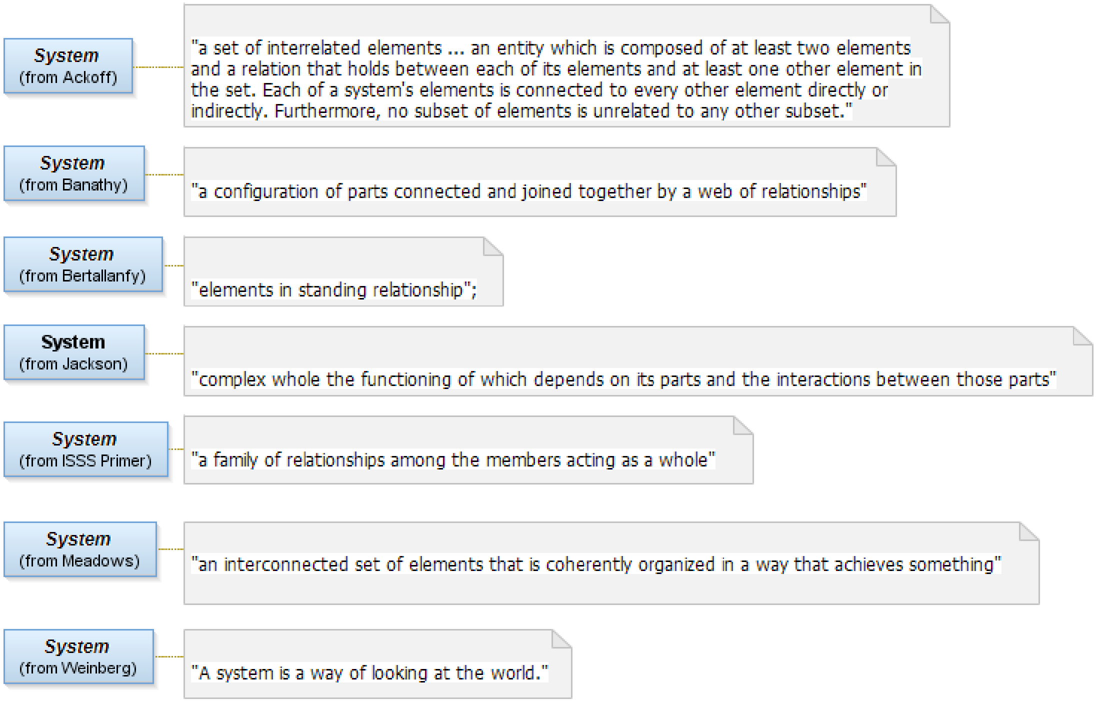
It is natural to assume we know what a class is from the class name. Because molecule, atom, and most natural systems are already well defined, that may well be true in this case. However, to achieve model coherence, a modeler must have control over the definitions of the model elements and not be constrained by predetermined definitions or existing names. A model must be considered its own unique dialect (or ontology), in which the elements mean only what they are defined to mean in the model, distinct from any implications the names might carry outside the model. Thus, it is important to distinguish a model term and its definition from any other definition for the same term. A distinct font (one that matches the model font) is used for this purpose for model terms.

Textual Documentation

Every element of a model can be documented with text and the text can be optionally displayed on a diagram, as shown here for Atom (grey background). However, the preferred definition of an element is by means of its relationships to other rigorously defined elements in the model. Nevertheless, text, although not rigorous, can be useful especially in the early modeling stages.

Tagging

Some types, such as *system*, have been defined in many ways by various people, some of which are show in Figure 2.



"a set of interrelated elements ... an entity which is composed of at least two elements and a relation that holds between each of its elements and at least one other element in the set. Each of a system's elements is connected to every other element directly or indirectly. Furthermore, no subset of elements is unrelated to any other subset."

"a configuration of parts connected and joined together by a web of relationships"

"elements in standing relationship";

"complex whole the functioning of which depends on its parts and the interactions between those parts"

"a family of relationships among the members acting as a whole"

"an interconnected set of elements that is coherently organized in a way that achieves something"

"A system is a way of looking at the world."

Figure 2. Various Historical Definitions of a System

Existing work is valuable so we want to capture and may want to refer to such definitions. When we do, we will want to be able to specify the source and distinguish them from our own current definitions. We will do that by tagging them by author as in the figure, and our current working definitions by "(Proposed)". This will also emphasizes that our definitions are all tentative and invites suggestions for improvements. This technique eliminates confusion about which definition we are referring to.

Model Diagrams - Views Into a Model

Figure 1 was referred to above as a *model diagram* to distinguish it from a conventional diagram. A *diagram* with no qualification is assumed to be a standalone picture in which the diagram elements are not necessarily well-defined; a name used across multiple diagrams cannot be guaranteed to refer to the same definition, and the set of diagrams is not necessarily coherent as a whole.

In contrast to a diagram, a *model diagram* is a view into a model with a single non-redundant set of well-defined elements. The same name used in multiple model diagrams always refers to the same entity and definition. This architecture provides critical advantages. Non-redundant definitions establish single points of change, i.e., a change to a definition changes it across all diagrams. This enables many overlapping views without sacrificing adaptability. Overlapping views can in turn be employed to depict multiple perspectives and levels of abstraction and thus produce understandable presentations of even great complexity.

High adaptability allows a model to be improved over an extended period by many incremental changes. Such a model gains permanency, i.e., it need not go out-of-date and be discarded, and perfectibility, i.e., it can be improved in all respects indefinitely.

Finally, the ability to see and understand all elements and their relationships, and to make an indefinite number of changes makes coherence ("true as a whole") possible. Understandability, coherence and adaptability are essential for modeling a complex domain but impossible to provide with conventional diagrams.

System Containment Hierarchy

The notion of a system goes back a long way, at least to the Greeks. Aristotle reportedly stated "a whole is different from the sum of the parts". The idea of system hierarchies also has a long history. The one depicted in Figure 3 has often been cited.

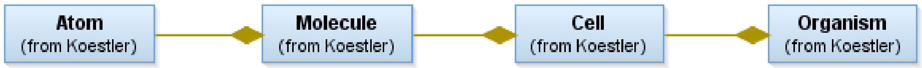


Figure 3. Often-cited System Hierarchy (or Holarchy as termed by Arthur Koestler)

A structure such as this has been termed a *holarchy* consisting of *holons*, where the distinguishing characteristic of a holon is that it is both a whole itself and part of a larger whole, and a holachy is a hierarchy of whole-parts. Ideas similar to early systems thinking were developed around holarchies notably by Jan Smuts (1920s) and Arthur Koestler (1960s).

Today we would call a holon a system, and a holarchy a system hierarchy. Figure 4 depicts a more current version of a system hierarchy, more rigorously modeled.

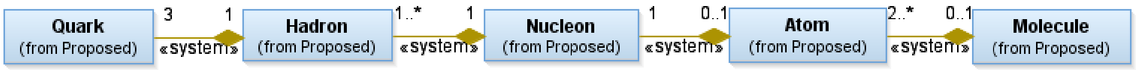


Figure 4. A System Containment Hierarchy

This figure specifies unambiguously that a Molecule is a system of two or more Atoms, which is a system of a Nucleon (and also electrons, not shown), which is a system of one or more Hadrons, which is a system of exactly three Quarks. The hierarchy shown here is only a small fraction of the known system containment hierarchies.

This simple figure already begins to expand our concept of a system from a standalone unit into a pattern manifested at multiple scales within a hierarchy of many interrelated types.

Subtypes - Generalizations and Specializations

Having examined the system containment association we now turn to a different but equally important relationship: the generalization-specialization relationship. Where the system containment relationship relates a whole and its parts, this relationship relates a generalization and it specializations. Like the whole-parts relationship, it is a transitive relationship and so also can generate a hierarchy. Although both relationships generate hierarchies, the two hierarchies are quite different and so must be clearly distinguished. Considered together the two types of hierarchies can provide a more complete picture and fuller grasp of systems. Such a view requires succinct representation.

The generalization-specialization relationship is less familiar than the whole-parts relationship, so let's consider a familiar example. The best known such hierarchy is the Linnaean System of living things, a simplified portion of which is shown in Figure 5.

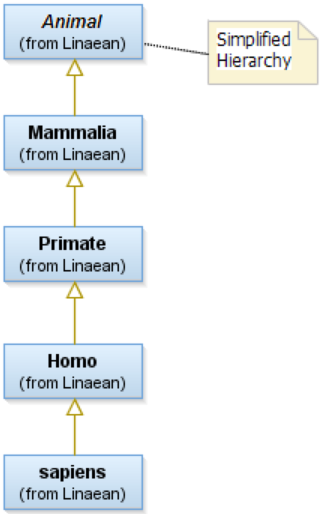


Figure 5. Example Generalization-Specialization (type-of) Hierarchy (much simplified)

The open-headed arrow points toward the generalization. The rule is that each specialization is "a type of" its generalization, and thus of all its generalization's generalizations. In the example a sapiens is a type of Homo, all Homos are types of Primate, all Primates are types of Mammals, and all Mammals are types of Animals, so a sapiens is also a subtype of all of the types above it.

An important distinction can be made between classes that can have instances and those that can't (termed *concrete* and *abstract*, respectively, in UML). The sapiens (concrete) class has instances, you and me, for example. The same could be said of all of all leaves, i.e., end-points in a generalization hierarchy; all of the other classes are abstract.

The primary purpose of an abstract class is to generalize across other classes. Identifying such generalizations establishes well-defined, uniquely-named concepts that provide intellectual leverage, essential for managing complexity. An abstract class, instead of having instances itself, has subtypes which have instances. Thus, you can refer to Primate or Mammal but neither can have an instance;

every instance of Primate or Mammal must also be an instance of a species, such as sapiens and must be so represented.

The Linnaean System, with its structure of generalizations, contains much more information and is much more useful than a simple list of species. The generalizations make important distinctions, defines new concepts, and groups species. It provides a framework for managing domain information in which each species has a unique name and one and only one location in the hierarchy. It is also adaptable, so that new species, or generalizations, can be accommodated, or even large reorganizations can be made (important in light of our ignorance, i.e., only a fraction of species have even been identified).

A structure of relationships such as a generalization-specialization hierarchy promotes a holistic view. A species in the Linnaean System, for example, is not viewed as an independent item but as one of many branches of the tree of life or a member of the family of all living things on Earth. Tree of life and family of all living things are, of course, new holistic concepts.

My contention is that defining type hierarchies is an essential function of modeling to provide a general structure to enable unification of knowledge, develop a holistic view, eliminate fragmentation and redundancy, and promote adaptability.

Hierarchy Integration

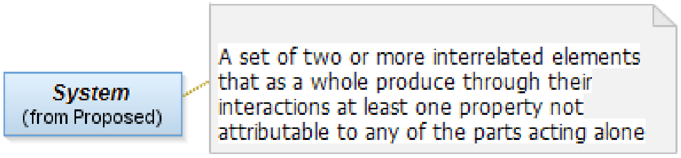
We have now addressed two important but quite different hierarchies. A system containment (part-of) hierarchy and a generalization-specialization (type-of) hierarchy. We will now present these two aspects together in the same views.

System

Finally, we get to system, that is, our proposed System. System with no qualifications represents in the model the most general possible notion of a system and so is positioned at the top of the System type hierarchy. The definition of System must meet two strict requirements. It must :

- be general enough to encompass every conceivable type of system
- be specific enough to distinguish a system from a non-system.

This requires us to think carefully about what we want our System to mean (we are the masters here). What are the minimal characteristics that distinguishes a system from a non-system?



A set of two or more interrelated elements that as a whole produce through their interactions at least one property not attributable to any of the parts acting alone

Figure 6. System - Most General Definition

Accepting (for now) the common definition of a system as a whole that is more than the sum of its parts, I conclude that all systems must have at least two interacting parts and a new (emergent) property.

Without at least two parts you can't have interacting parts; without a new property, the whole will not be more than the sum of the parts. The term "emergent" was deliberately not used in the proposed definition to avoid for now the controversy surrounding it.

At the top, System does not define everything about a system, only what must be true of all systems. The many other characteristics of system will be defined in specialized subclasses down the hierarchy.

Consider this to be only a working definition at this point, one that may well be revisited many times. We are most interested in establishing a holistic view. To do so it is important to get started, keep expanding the picture, and avoid getting hung up on any single issue. Assuming an adaptable model, all parts are modifiable indefinitely. We can go forward with this definition with the understanding that it may change as a fuller picture emerges, and our understanding matures.

So where are we at this point? We have a very general concept of System and the previously defined partial system containment hierarchy of Molecule, Atom, etc. How are they related?

The subtypes in the containment hierarchy, with the possible exception of Quark (which has no known parts), are all systems and so are subtypes of System; they could be shown that way, i.e., as direct subtypes in a hierarchy of only two levels. However, a number of fundamental distinctions can be made by defining several intermediate generalizations. One distinction is between nature-created and human-created systems, and another is between systems bonded by natural forces and those kept together through membership in a dissipative system. Further, the existence of four natural forces are well-recognized and each bonds different System subtypes, so it is useful to depict each force and show the system types it bonds.

Figure 7 depicts the subtype hierarchy that results from these distinctions.

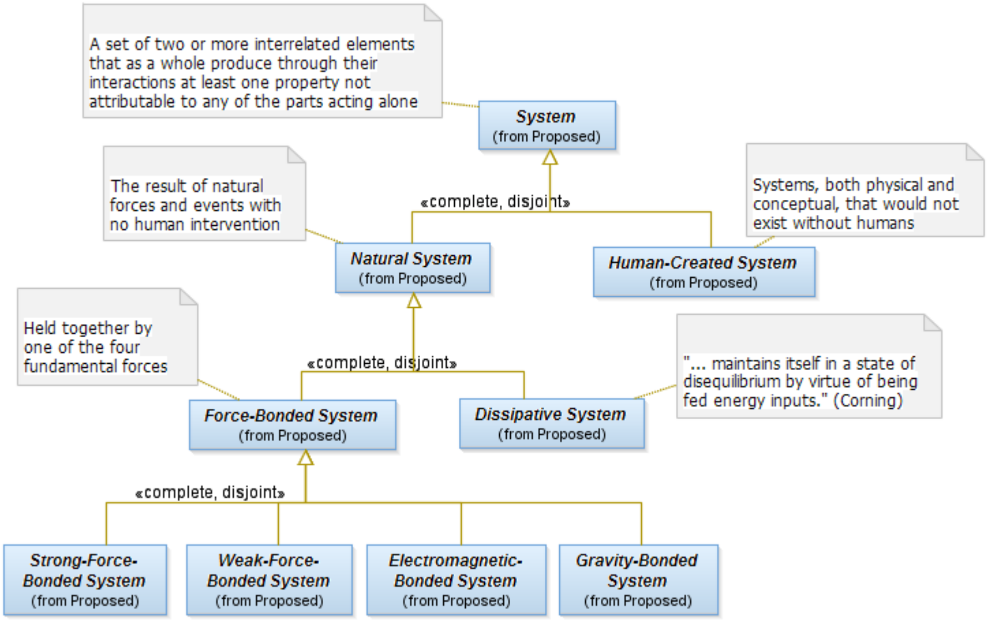


Figure 7. System Subtypes (with Natural System Branch Expanded)

All three of the generalization relationships include the marking (UML stereotype) "<<complete, disjoint>>". "Complete" specifies that all of the subtypes are shown; "disjoint" states that every further subtype must be specializations of one and only one of the indicated subtypes. Thus, Natural System and Human-Created System are the only two direct subtypes of System, and every System is either a Natural System or a Human-Created System but cannot be both. These are unambiguous statements that can be refuted with a single counter example, which would rightfully require a model update.

Unlike containment hierarchies for natural systems which are well understood and non-controversial, generalizations can be made in more than one way and are to some degree arbitrarily. The hierarchy here may not be the one best way to generalize. Nevertheless, I believe that some generalizations are more useful than others. The distinctions between nature-created and human-created, and between force-bonded and dissipative, systems are significant, important, clear, and nicely partition the universe of subtypes. These are good signs, although that does not necessarily mean it is the best structure. In any case, putting forward a generalization structure is a step forward irrespective of how well it holds up (so long as the model is modifiable).

Integration of Hierarchies

Now we can form a more holistic picture by presenting together the two hierarchies. Figure 8 integrates and unifies a lot of information and depicts it rigorously yet succinctly in a single diagram. Such views into a model can provide a holistic understanding not otherwise possible.

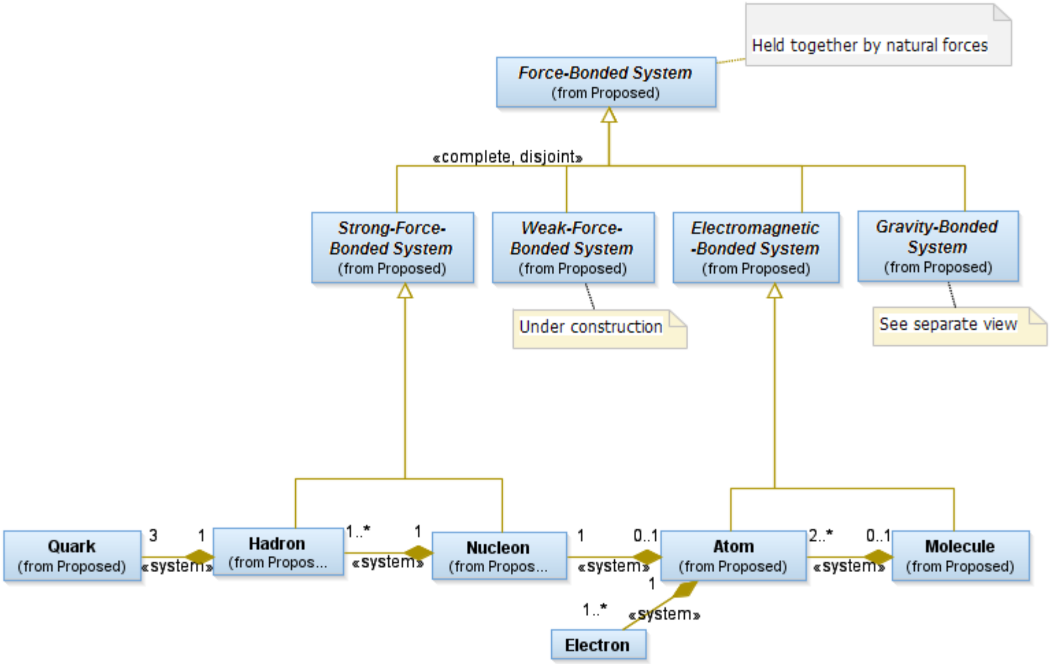


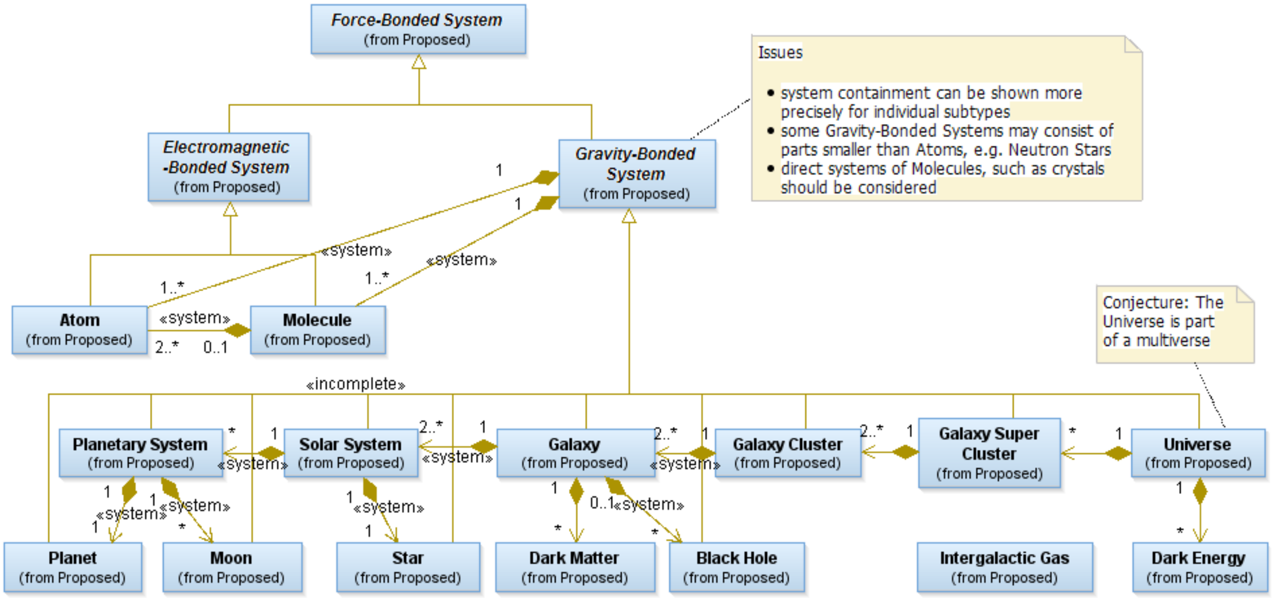
Figure 8. Force-Bonded Systems (Not complete)

In this figure the system containment hierarchy is presented horizontally and the generalization hierarchy vertically. Orientation on a diagram has no semantic significance and so could be shown vice-versa without changing any meaning. Although arbitrary, it is helpful to establish an orientation convention and be consistent across views.

Note that neither Gravity-Bonded System nor Weak-Force-Bonded System subtypes are shown. Many of the former exist but are deferred to a later view (see next section). More research is needed to clarify the role of the latter.

Gravity-Bonded Systems

Figure 9 presents Gravity-Bonded Systems. All of the Gravity-Bonded Systems are systems whose parts are in general Atoms and Molecules, with some caveats as indicated by the note labeled "Issues".



Issues

- system containment can be shown more precisely for individual subtypes
- some Gravity-Bonded Systems may consist of parts smaller than Atoms, e.g. Neutron Stars
- direct systems of Molecules, such as crystals should be considered

Conjecture: The Universe is part of a multiverse

Figure 9. Gravity-Bonded Systems

Raising and eliminating questions and issues is a normal part of an iterative process, and should be handled efficiently and transparently. Notes, which can be associated with any modeling element, provide a convenient way to present them in the pertinent context. The questions and issues are captured in the model, become part of its current state, and can be presented at the most suitable point. Instead of delaying in search of perfection, the model can be presented at any stage of development, along with any in-progress discussion. Disagreements and alternate interpretations could be handled in this way as well. Even imperfect views can be valuable and should be published but with known imperfections noted.

Figure 10 depicts all levels of the system containment hierarchy of Force-Bonded Systems from Quark to Universe. The elements are oriented differently in order to present all levels in a single view. This is an alternate view of the content of the previous two diagrams and shows how multiple overlapping views can be employed to provide different perspectives and/or levels of abstraction for better understanding.

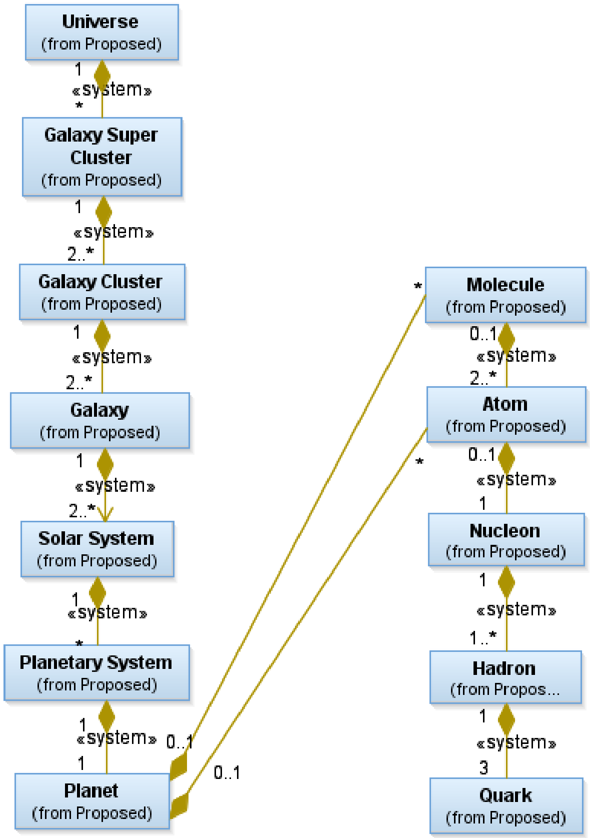


Figure 10. Force-Bonded Systems Containment Levels

This view presents Force-Bonded Systems in a generally known but seldom seen view. It is unusual because it brings together in a single diagram a large number of entities and relationships, and an enormous range of sizes. The remote ends of the spectrum are unfamiliar to most humans, who exist at mid-scale.

This view illuminates several points. One is the consistency of the systems pattern across many levels and a vast range of scales, and the resulting multi-level hierarchy. Another is the ability to produce mind expanding views by integrating and presenting diverse knowledge normally fragmented across academic disciplines.

Remaining Branches of Generalization Hierarchy

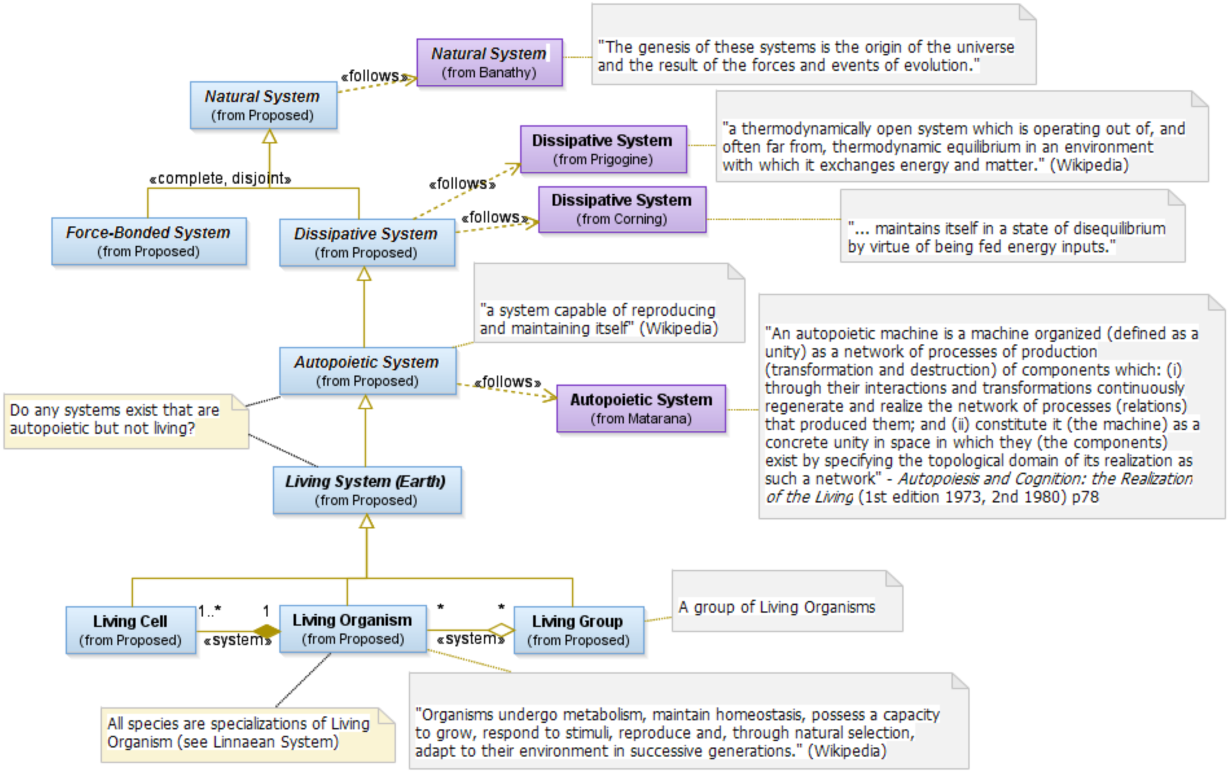
We have identified (see Figure 7) but not detailed several other branches of the system generalization hierarchy, specifically Dissipative Systems and Human-Created Systems. Both are large and diverse, and represent a considerable modeling effort. Neither can be addressed in detail here, but a few initial ideas will be offered.

Dissipative Systems

Dissipative Systems are the only type of Natural System other than Force-Bonded System. The two types of Natural System differ radically by architecture, and also by where they occur; Force-Bonded

Systems are found throughout the universe and Dissipative Systems are found only on Earth (to our current knowledge).

Figure 11 depicts a very early stage of development of Dissipative Systems, showing only a few key subtypes. Autopoietic Systems are significant because they can reproduce themselves making possible Darwinian evolution, the great variety of species on Earth, and us. Three important subtypes are shown. Humans, of course, are a key Living Organism subtype responsible for the creation of many new types of system.



"The genesis of these systems is the origin of the universe and the result of the forces and events of evolution."

"a thermodynamically open system which is operating out of, and often far from, thermodynamic equilibrium in an environment with which it exchanges energy and matter." (Wikipedia)

"... maintains itself in a state of disequilibrium by virtue of being fed energy inputs."

"a system capable of reproducing and maintaining itself" (Wikipedia)

"An autopoietic machine is a machine organized (defined as a unity) as a network of processes of production (transformation and destruction) of components which: (i) through their interactions and transformations continuously regenerate and realize the network of processes (relations) that produced them; and (ii) constitute it (the machine) as a concrete unity in space in which they (the components) exist by specifying the topological domain of its realization as such a network" - *Autopoiesis and Cognition: the Realization of the Living* (1st edition 1973, 2nd 1980) p78

Do any systems exist that are autopoietic but not living?

A group of Living Organisms

All species are specializations of Living Organism (see Linnaean System)

"Organisms undergo metabolism, maintain homeostasis, possess a capacity to grow, respond to stimuli, reproduce and, through natural selection, adapt to their environment in successive generations." (Wikipedia)

Figure 11. Working Diagram of Dissipative Systems

This view differs from earlier views because of its early stage of development. In early stages it is helpful to assemble available pertinent information, such as candidate types and relationships, existing definitions, and questions and issues. This diagram illustrates the ability to make a lot of fragmented knowledge visible so it can considered collectively and unified into a coherent model. Such a diagram acts as a work space where everything relevant can be considered, manipulated, and reviewed.

The diagram also exemplifies several modeling features. Notes, as previously discussed, can be used for questions and issues, reminders, provisional conclusions or any comments that may be helpful. Notes capture temporary information and keep it with the model.

Previously available terms and their definitions are also shown. Many thinkers have considered system types in the past, and in doing so developed important distinctions and insights. Such concepts should be captured, studied, and incorporated, albeit without necessarily accepting every definition verbatim. We should stand on any shoulders available to us and make use the of concepts and distinctions already on the record.

Here each such historical term has been distinguished by being tagged by author and rendered in a different color. The proposed system types are related to the historical definitions by a dashed arrow (<<follows>> dependency). In this way the source of definitions can be captured and both the proposed definition and its historical antecedent can be depicted.

Human-Created Systems

This extensive branch of system types will include everything physical or conceptual created by humans. Conceptual Human-Created Systems would include all concepts from the human mind including stories, literature, religions, mathematics, and science (and this model).

Physical Human-Created Systems would include all human tools, machines, buildings, and artifacts. Also included would be implementations of conceptual systems such as paintings, sculpture, books, and music recordings.

Science raises an interesting issue. If Natural Systems have been elucidated by science, are they not human concepts and therefore Human-Created Systems? Science can be distinguished from other Human-Created Systems by the fact that it makes every effort to accurately represent nature by use of the scientific method, which has proven itself to be quite effective. Thus the model of Natural Systems could be considered to be both a Conceptual Human-Created System and a reasonably accurate, though never perfect, description of nature; by that argument we could justify classifying it separately.

Detail Management

Detail handling presents a dilemma for modelers. It is addressed here because without the proper approach it is impossible to manage great complexity or present holistic views, and so achieve holistic understanding.

Presenting an understandable view requires deferring detail not pertinent to the view. Yet much detail is important and cannot be ignored. Achieving a holistic and perfectible model demands effective detail management as described below. This is nearly impossible to do with only standalone diagrams but can be done with a model that includes independent views and repository of definitions.

The real world contains lots of detail. For any particular purpose, much of the detail available is not only irrelevant for a particular purpose but can be harmful because it detracts from understanding. Thus it is important to carefully control the detail presented so as to achieve clear understanding, a technique often referred to as abstraction.

This technique is especially important for modeling systems because much detail must be deferred to make a complex whole understandable, that is, presenting the whole understandably requires a high level of abstraction. By creative use of abstraction, a model can be presented from multiple perspectives and with differing degrees of detail (levels of abstraction) making even the very complex understandable.

It is important not to confuse less detailed with fuzzy or nebulous, a meaning sometimes associated with the term abstract. The definition of an abstract concept should be as rigorous and precise as the definition of any other concept, just less detailed.

Abstraction specifies deferring (with respect to a purpose), not to discarding, detail; detail may be valuable and useful for other purposes. Modern modeling tools, by an architecture that separates element definition and presentation, supports both capturing detail and applying abstraction to presentations. Detail can be captured in a model even when not presented in a view.

Deferring detail from a diagram raises the issue of how to make accessible the detail so deferred. One way is to provide multiple diagrams presenting different subsets of detail. This suggests providing groups of multiple diagrams focused on different purposes rather than ignoring detail or trying to include it all on one diagram. Multiple diagrams can be coordinated to collectively provide a comprehensive presentation. This can be compared with the traditional technique of presenting a three-dimensional figure using front, top, and side views of, although the technique need not be limited to only three views.

One valuable way of coordinating multiple views is to provide the same content at different levels of abstraction. This enables the viewer to drill down or bubble up to find the best level of abstraction for the current purpose. This allows both clearly viewing the whole without distracting detail and accessing as much detail as needed - the best of both worlds.

So good detail management approach can be summarized as:

- capture all useful detail
- apply abstraction at presentation-time to create purposeful views
- create as many purposeful diagrams as needed for complete coverage and understandability.

With these rules common poor practices, such as discarding potentially useful detail, presenting too much detail on a diagram, and even trying to depict everything on a single diagram, can be eliminated.

Generalization should be considered to be a form of abstraction. The concept of *Mammalia* enables the succinct representation of all of the many species who bear their young alive and have mammary glands while deferring the details. Natural System enables us to succinctly represent all of the many systems created by nature without human intervention. (And note that both terms are well-defined and not at all fuzzy.) Use of generalization in this way is essential for a holistic view.

Detailed Views

In this section we provide examples of views showing detail not provided in the previous more abstract views.

Figure 8 specifies that a Hadron is a system of exactly three Quarks. This is true as far as it goes but does not provide full detail.

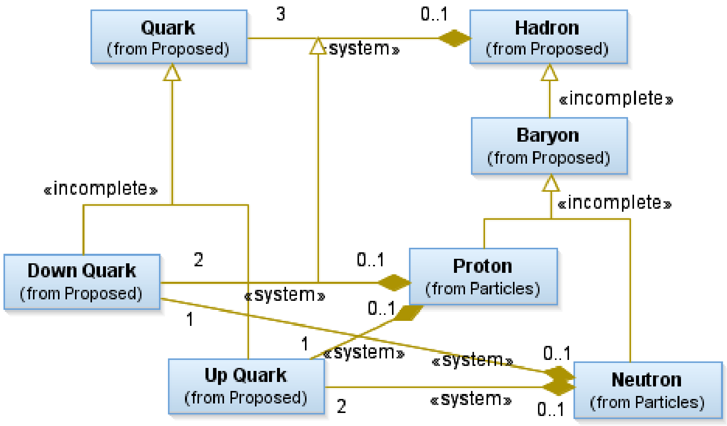


Figure 12. Detailed View of Proton and Neutron Subtypes of Hadron

Figure 12 shows that additional detail can be rigorously modeled, using the Hadron-Quark example. A Proton is shown to be a system of two Down Quarks and one Up Quark, and a Neutron to be a system of one Down Quark and two Up Quarks. The specializations here are all marked incomplete, i.e., there are more subtypes than shown in this view.

Generalization is a powerful techniques, and can be applied to elements other than classes. In the figure the associations among the Proton and Neutron, and the Up and Down Quarks are specializations of the more general association between the Hadron and Quark (which in turn could be considered a specialization of the most general association between a System and its parts).

Figure 13 provides another example of a view at a more detailed level.

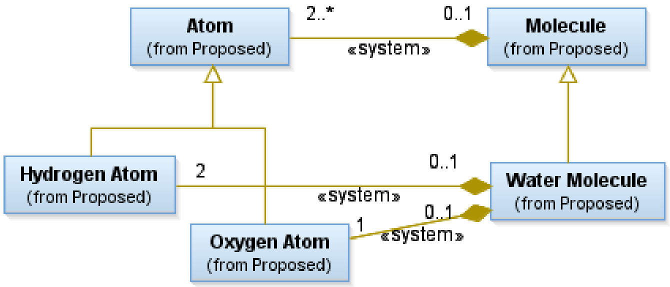


Figure 13. Detailed View of Water Subtype of Molecule

These detailed views raise the specter of an explosion of detail. Much detail is available about most system types. For example, more than a hundred types of atom exist and perhaps several million types of molecule. If our focus is the big picture, we must be selective and don't need to include all available detail. However, any detail that might be useful, perhaps for examples to prove a point, can be captured.

In the meantime, we can include in the model by reference detailed collections from outside of the model, such as the periodic table of elements or a catalog of species. Links can be included in a model to any information accessible locally or online. Of course, it makes no sense to duplicate in the model anything already available unless doing so provides value in some way.

On the other hand, detail to any degree can be added over time. A policy of gradual detailing makes sense assuming you can recognize the abstractions to start with. An adaptable model supports working the opposite way, from detail to abstractions, or some combination, as well. In any case, a holistic view is the goal and that is where the focus should be kept.

Modeling the next level of detail is not just about adding detail. Modeling detail often provides insights that generates changes in the overall model organization. Such changes are an integral part of an iterative modeling process.

Toward A Holistic View

Although we only have the rough beginnings of a comprehensive model, the views it provides already spark insights that could be steps toward a holistic systems-oriented perspective. Consider the following observations, partitioned into three categories: universal architecture, system types, and modeling.

Universal Architecture Observations

- Systems and system hierarchies appear to be a natural and fundamental part of existence, pervasive throughout the entire universe at all scales.
- Systems and system hierarchies are intimately related; all system types except for the most primitive are in fact a hierarchy. Indeed, the primary unit could be considered to be the system hierarchy with the system relegated to a common recurring pattern within it.
- System hierarchies provide evidence of a system evolution process in which a new type of system develops via the integration of instances of preexisting types. This means that the system evolution process is also fundamental to the architecture of the universe. System hierarchy also implies dependencies among system types and an order of appearance of each type within the universe or a particular part of it.
- Systems, system evolution, and system hierarchies are, in effect, three sides of the same coin, i.e., aspects of the same systems phenomenon.
- Complexity, a controversial subject, can be defined objectively in several ways, including: number of hierarchy sublevels, number of parts, number of different types of parts, number and types of interactions, number of systems in which embedded, and type of bonding architecture.
- A system embodies the combined emergent properties from all its levels. Constituent sublevel properties can combine in multiple ways. They may simply accumulate, e.g., mass,

or cancel each other, e.g., electrical or color. Most common is for different properties from multiple branches of the hierarchy to interact so as to create new emergent properties. How these properties combine can and should be modeled and presented so it can be better understood.

System Type Observations

- The system pattern is extremely general having specialization in many dimensions, including size, number of parts, bonding, and how they are created.
- The most common Natural Systems have formed (self-organized) in response to the four natural forces, with each force bonding systems at the scale of its effective range. This process began soon after the big-bang. Force-Bonded Systems apparently exist throughout the universe and form the foundation of all other systems.
- A second distinct and profoundly different natural system architecture has emerged on Earth (and possibly elsewhere). Dissipative Systems, in contrast to Force-Bonded Systems, exist far from thermodynamic equilibrium and only in an environment with which they can exchange energy and matter. All (Earthly) living things and living groups are based on this architecture.
- Living systems could be considered system specializations based on a distinct system architecture existing only within a particular context.
- Darwinian evolution, which generates specializations of Living Systems on Earth is closely related to the more general system evolution, and perhaps should be viewed as a specialization of it.
- One important distinction is that instances of Force-Bonded Systems arise individually in response to natural forces while instances of Autopoietic Systems inherit their organization from their parents. Inheritance implies a system across generations of potentially interbreeding individuals (species), but no such system exists for Force-Bonded System types.
- Darwinian evolution has enabled a more holistic view of the place of humans in the universe as a branch on the great tree of life or member of the family of living things. An even more general view of humans would be as an Earthly system specialization, in which case our cousins would include not just monkeys and other living species but other systems such as hurricanes, fire, and more distantly molecules.
- Living things, although based on a distinct architecture, have an intimate relationship with Force-Bonded Systems. They are built on a foundation of Force-Bonded Systems (largely Molecules) and reside on a Planet within an environment of Force-Bonded Systems, e.g., a Solar System within a Galaxy.
- All systems built on a foundation of Force-Bonded Systems are subject to natural forces. Human-Created Conceptual Systems are not built on the Natural System foundation and so are not subject to natural, or any other, forces. Human-Created Conceptual Systems are the only known types independent of Force-Bonded Systems.

- The generalizations provide considerable explanation value. For example, cells and molecules are close level-wise but quite different in architecture. This partially explains why cells are more complex. Molecules and galaxies are quite different in size but similar in architecture as Force-Bonded Systems.
- Science could be considered a Human-Created Conceptual System but one that reflects Natural Systems as closely as humans can make it.
- Instances of most system types can be a part of only one other system at a time, e.g., an Atom can be in only one Molecule. Human complexity is partially due to the fact that a human can be part of many Living Group Systems at a time; e.g., species, family, economic unit, nation, sports team, etc.

Modeling Observations

- Modeling can present great complexity in a way to make it understandable and thus put understanding in reach of many people; it does so by the use of succinct representation, abstraction, and multiple complementary views; most importantly, it can present an understandable holistic view essential for understanding systems, and do so together with the capability to drill down to additional detail and show multiple perspectives, all while keeping all views collectively coherent.
- A model can be made and kept adaptable so that it can be changed quickly and easily; this means it can support an ongoing incremental improvement process, i.e., be perfectible, and so address complex, highly interrelated domains such as systems.
- A model can be organized so as to provide an effective repository to capture and organize information; it can provide a single place for every piece of information creating neither redundancy nor fragmentation.
- A model can capture historical information tagged so as to distinguish it by author and thus manage multiply-defined terms and collect related concepts.
- A model can provide examples in the form of instances constrained to be fully consistent with type definitions.
- A model can organize all of the many variants of system as specializations of the most general notion of a system (and so fit them into a generalization-specialization hierarchy); this enables them to be managed, understood, critically reviewed, and improved (and describes both diversity and commonality as Bertalanffy suggests).
- Modeling systematically recognizes generalizations and isomorphies by investigating distinctions and commonalities among system types
- A model provides a highly effective basis for collaboration by establishing well-defined and uniquely named concepts, relationships, and processes, and developing insightful presentations.

Conclusion

If we believe that understanding systems is important, and a system can only be understood as a whole, we must face and meet the need to understand the whole. This implies understanding the universe, the ultimate whole, and especially its fundamental architecture.

The universe can be understood -- to the degree doing so is possible by humans -- by integrating the great amount of available but fragmented knowledge. To do this requires a common model into which what is known and continues to be learned can be unified, coherence enforced, and understandability provided.

This, of course, is a huge job that can only be done over time. An incremental approach is required, which means that it must be possible to improve and extend the model indefinitely, a quality that could be called perfectibility. Certain uncommon modeling techniques will be needed to support such an effort, especially those necessary to maintain high model adaptability and support understandability . The needed techniques are well understood and adequately supported by available modeling tools.

Continual model extension and improvement depends on feedback from critical review. Effective review in turn depends on clear and unambiguous statements, understandable presentation and knowledgeable reviewers. A broad range of reviewers is desirable to provide in-depth coverage of the many disciplines and areas of expertise; many diverse reviewers are quite possible with the internet. The desired global understanding must emerge from a system of disciplined process, well-structured model, and reviewing community.

Such a model would bring many benefits. It would support more effective collaboration. It would bring out inconsistencies, gaps, misunderstandings and other defects in current understanding. More importantly, a new coherent and up-to-date view would show the universe in a new light, sparking new ideas and uncovering new opportunities. Hopefully, it would in time establish a broadly accepted systems-oriented view of the universe, bring order to some of the current confusion, and cause systems thinking to be taken more seriously.

The primary conclusion is that developing a global, systems-oriented model is a viable project, would provide great value, and would move forward the cause of systems thinking. At this point, integrating existing knowledge may well be more productive than discovering new knowledge. Examples have been provided that hopefully support that conclusion.

Developing a coherent systems-oriented view of existence would appear to be the logical goal of systems thinking, and would make a fine ongoing project for the systems community.

The author intends to continue along this path and would welcome comments and support of any form, especially references to others who have addressed this issue.

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