ADDRESSING THE WHOLE WHOLE

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ABSTRACT

This paper argues the need to develop a comprehensive, coherent, system-oriented description of the universe, and that doing so over time is quite feasible with the right approach.

Charles Francois has stated: "*We are indeed still - and mostly unconsciously - subservient to the general Cartesian reductionist model, which, after destroying the relationships network for the sake of 'simplicity', does never reconstruct it as an organized whole*." This implies that the most important mission of the systems movement is to reconstruct the organized whole. We are deterred from this mission because of its apparent difficulty. It has long been recognized that "*the whole*" must be addressed to understand a system. But what exactly is *the whole*? The whole includes all of a system's parts. It also includes the relationships and processes of interactions among the objects and with the environment. And it requires addressing all in concert. (Let's call this *all of the whole*.)

Furthermore, since a system's environment consists of other systems, these other systems must be considered part of the whole. This line of thinking expands the scope of the whole and when taken to its logical conclusion encompasses the entire universe. Hence the whole must be interpreted to mean not just a single system but the universal system of systems (*the whole whole*). While instances of the system pattern are interesting individually, the system pattern is most significant as a key element of the architecture of the universe.

Finally, the universe is evolving, not static. The deep hierarchies of systems existing today provide clear evidence of continuing system evolution since the Big Bang. Hence the universal process of system evolution (*whole history*) must also be included in the whole.

The whole means all of the interconnections within the broadest scope of space and time. It means the universe viewed as a system of systems, including *all of the whole*, *the whole whole*, and system evolution over the *whole history*.

How can a system so large and complex be addressed? The system pattern, being fundamental to the functioning, structure, and evolution of the universe, provides a basis for organizing a universal description. While we can never describe the universe completely, we can develop and persistently improve and extend a description of the web of interacting systems. To do so we must systematically integrate, unify, and generalize the relevant nuggets filtered out of the existing vast sea of available information. With modern tools and techniques the complexity of such an effort can be managed.

The dominant approach for centuries has ignored systems in order to avoid complexity. The opposite trade-off is now required: we must embrace complexity so as to understand systems. By embracing and learning to effectively manage complexity, it is possible to describe the whole in the broadest sense and so to develop an unprecedented understanding of the universe as a system of systems. This paper aims to show that doing so is now viable.

Keywords: Systems, System Types, Ontology, Taxonomy, Modelling

INTRODUCTION

System understanding has advanced radically since the middle of the last century. We have become better able to understand the behaviour of individual systems and deal with particular system problems. More importantly, we have developed a new system-oriented perspective on the universe. By this perspective the universe is revealed to be a coherent whole of which the system pattern is a central architectural element: the universe is seen to be a "system of systems".

The potential impact of this idea is difficult to overestimate. A system-of-system perspective heralds a new world view which threatens to overturn completely the mechanistic clockwork view that has dominated the West since the time of Newton. Ackoff has described this change as the transition from the Machine Age to the Systems Age (Ackoff 1981). Such a shift would have profound consequences and propel the systems approach to the forefront of science.

It is well accepted that synthesis is required together with analysis to understand a system. Synthesis teaches us to look upward and outward to view a system in the environment of the systems in which it is embedded. Parts can only be understood in the context of the whole. Synthesis, by proceeding upward and outward, leads inevitably to a system-oriented view of the universe. Because of its size and complexity, understanding the universe is deemed by some to be impossible, and in some sense it is. We can, however, understand it much better than we currently do and so cannot ignore a promising approach to doing so.

A system-of-systems view offers a unique opportunity to better grasp reality and our place in it. It would provide a common framework in which to describe the universe comprehensively, integrate fragmented human knowledge, harmonize the many diverse disciplines, show the universe to be a coherent whole, and facilitate more productive collaboration. Moreover, better understanding of the universe would support better understanding of every other system for which the universe serves as its environment.

The systems community has shown frustration with the scant recognition of the importance of systems and their correspondingly slight influence on policy. The systems approach is dismissed by many as being too abstract, scattered, unscientific, and impractical. The systems movement also seems to embody a deep inconsistency between its principle of wholeness and the lack of a holistic description of the universe. Practice appears not to follow principle, and this may help to explain the lack of traction for systems.

Addressing the Whole Whole

Developing a holistic description of the universe based on a system-of-systems perspective would seem to be the obvious way to exploit the potential of systems and so a natural step for the systems community. It is difficult to imagine any other way in which the fragments could be integrated, the disciplines harmonized, and the universe addressed holistically, a science-based world view developed, and the power of system principles demonstrated. Nothing would better show the value and importance of the systems concept. Nothing would have greater impact.

Without a process to unify all knowledge, fragmentation will surely continue to proliferate and the contrast between the principle of wholeness and its practice become ever more stark and distressing.

To be sure, such a project presents challenges. However, given the evident importance of the mission, it deserves serious consideration.

An earlier paper, **TOWARD A SYSTEM TYPE STRUCTURE**, for the ISSS 2014 Conference (Marzolf 2014), described initial work done to implement such a description. This paper takes a step or two backward from implementation to better address the need for a universal system-oriented description, how it can be done, and the benefits of doing so.

RATIONALE

The rationale for this paper can be stated succinctly:

- Humans want and need to understand the universe and our place in it; the survival of civilization may depend on it
- The universe appears to be a system of systems
- A system can only be understood as a whole
- Thus to understand the universe as a whole, it must be addressed as a system of systems, i.e., by means of a system-oriented description
- Great knowledge of the universe is already in-hand but is likely to remain fragmented, flawed, and lacking coherence until it is integrated with the system pattern as the fundamental organizing principle
- Producing a better understanding of the universe through the development of a comprehensive, coherent, system-oriented description represents a historic opportunity
- Doing so would manifest the holistic principle of systems and so seems an obvious project for the systems community
- Such a description would provide great benefits attainable no other way
- Such a project is challenging but feasible; in any case, system principles demand that it be seriously considered.

THE DRIVE TO UNDERSTAND

"*Analysis focuses on structure; it reveals how things work. Synthesis focuses on function, it reveals why things operate as they do. Therefore, analysis yields knowledge;* ***synthesis yields understanding****. The former enables us to describe;* ***the latter, to explain***." (Ackoff 1981)

Humans have undoubtedly struggled to understand the universe in which we find ourselves ever since the requisite awareness evolved within us. Synthesis, an upward-looking approach applied to systems, offers a new and evidently more potent means to do so ("*synthesis yields understanding*").

A coherent understanding of the universe based on science and facts is of more than just academic interest. Humans, along with their enormous number of structures, machines and domesticated animals now dominate the Earth. We have the power to cause disasters of several types. We have taken control of many hitherto natural processes and consequently now bear heavy responsibility for our world. We need to learn how to wisely manage what we have taken control of - and do so quickly.

Human power has been developed largely through science. Human management, on the other hand, is rooted in diverse, mutually incoherent, and often dogmatic world views. It is imperative to develop a world view that, like science, is fact based and amenable to testing and continued learning, and thus can support wise policies that can be broadly accepted. A compelling case can be made that the race between growing human power and wise management is a race for human survival. Our continued existence may depend on the development of a better world view derived from a better understanding of the universe which can only come from a better understanding of systems.

THE UNIVERSE IS A SYSTEM OF SYSTEMS

"*The assertion of the continuous development and evolution of the universe is the most important general truth established by science. Everywhere we turn we observe irreversible changes subordinate to a majestic general plan or to the basic law of evolution, which manifests itself in the growing complexity of the organization of matter. Reason emerges on Earth as a part of this plan.*" (Turchin 1977)

"*... the real world is the system of all systems.*" (Bunge 2003)

New system types have been evolving from preexisting types ever since the Big Bang. The many existing hierarchies of system types provide clear evidence of it. This is the "*continuous development and evolution*" mechanism underlying the "*growing complexity of the organization of matter*" to which Turchin refers. All of the existing system hierarchies have been created by this process. All of the existing properties, including life, consciousness, and culture, have apparently emerged from systems that evolved through this process (except for those few properties inherent in primitive particles).

"*Everything in the universe is a system or part of one*", according to Bunge (or both, I would add). Evidently the system pattern and system hierarchy (aka., holarchy) are fundamental elements of the architecture of the universe. The universe is best viewed as a vast network of interacting and evolving systems, that is, as "*the system of all systems*". The universe, seen this way, provides the grand encompassing environment for all other systems. Understanding any system depends to some degree on how well this universal environment is understood.

To paraphrase and quote Dobzhansky (about Darwinian evolution): Nothing in the universe makes sense except in the light of system evolution. "*Without that light it becomes a pile of sundry facts some of them interesting or curious but making no meaningful picture as a whole*." (Dobzhansky 1973) Trying to understand individual systems without considering system evolution and the broader universe of which they are a part would seem to be like struggling to understand biology without the benefit of Darwinian evolution.

Darwin made a historic leap in understanding by addressing a broad generalization: living thing, over its whole lifecycle, since its appearance on Earth. We have the opportunity to do better by addressing a broader generalization, system, over its more extensive lifecycle, since the Big Bang. Darwin found a way to made sense of all living things on Earth. The system concept should help us similarly to make sense of everything in the universe.

If the universe is truly a system of systems, then any description of the universe that hopes to be coherent and understandable must be system oriented. Lack of system orientation helps to explain the fragmentary state of existing descriptions. Integrating the existing fragmentary knowledge into a common system-oriented description would greatly enhance its value and may be the most productive path open to us.

Turchin's "*most important general truth established by science*" provides the basis for a comprehensive, system-oriented, coherent description of the universe, which, in turn, promises to provide a better understanding of everything in it. This should be the goal.

ADDRESSING THE WHOLE

Together with system orientation any system description must address "*the whole*", which raises an important question.

What is "the Whole"?

"*In systems thinking, increases in understanding are believed to be obtainable by expanding the systems to be understood, not by reducing them to their elements. Understanding proceeds from the whole to its parts, not from the parts to the whole as knowledge does*." (Ackoff 1981)

It has long been recognized that "the whole" must be addressed to understand a system. But what exactly is "the whole"? The whole includes, of course, all of a system's parts. It also includes the relationships and processes of interactions among the objects and with the environment. As Ackoff states, a system cannot be understood without knowing its interactions, from which the properties of the whole are derived. Most importantly, all of the above must be addressed in concert. (*Let's call this all of the whole*.)

Secondly, since a system's environment consists of other systems, these other systems must be considered part of the whole. This line of thinking expands the scope of the whole incrementally and when taken to its logical conclusion encompasses the entire universe, whatever challenges that might entail notwithstanding. Hence "the whole" must be interpreted to mean not just all of a single system but the universal system of systems (*the whole whole*). While instances of the system pattern are interesting individually, the system pattern is most significant as a key element of the architecture of the universe.

Finally, the universe is evolving, not static, and has a long history of change. The deep hierarchies of systems existing today provide clear evidence of continuous system evolution since the Big Bang. Hence the universal process of system evolution (*whole lifecycle*) must also be included in the whole. We need to understand how the existing system hierarchies evolved and how new levels are evolving.

"The whole" means all of the interconnections and interactions within the broadest extent of space and time. It means the universe viewed as a system of systems, including all of the whole, the whole whole, and system evolution over the whole of history. This is a tall order, of course, but the need to address the whole cannot be avoided since it is inherent in the nature of a system.

No system is an island; all are part of the main, i.e., part of the universal system of systems, and can only be fully understood from that perspective. We must address systems not just by individual instance, but as the fundamental organizing pattern of the universe. This perspective could be termed *systems-in-the-large* or *Big Systems*.

Completing the Paradigm Shift

Charles Francois has stated: "*We are indeed still - and mostly unconsciously - subservient to the general Cartesian reductionist model, which, after destroying the relationships network for the sake of 'simplicity', does never reconstruct it as an organized whole*." (Francois 2000)

The universe is undeniably complex. The dominant approach for centuries has been to ignore systems in order to avoid their complexity. Now the opposite trade-off is required: we must embrace complexity so as to understand systems. By embracing and learning to effectively manage complexity, it is possible to describe the whole in the broadest sense and so to develop an unprecedented understanding of the universe as a system of systems. Is there any other way to do so? Apparently not.

While the difference between the "*Cartesian reductionist model*" and the approach needed for a system is now well understood, a compelling case can be made that the paradigm shift remains incomplete, even among those dedicated to the study of systems, and that we are still partly and perhaps unconsciously subservient to the old model.

Consequently, we continue to understate the scope of the whole because we are reluctant to accept the complexity implicit in its true scale. We avoid *systems-in-the-large*.

Learning to view systems as open rather than closed has been an important and well noted step forward. However, open systems are still typically addressed as single systems within an "environment", i.e., all else. Actually, each single system is a part of a hierarchy of systems, and its environment consists of other hierarchies of systems all within the universe. The conventional solitary open system view, while an advance, still represents a great simplification and so could be better called a system fragment or *system-in-the-small*. This represents progress but still falls short of a full systems view.

We must finally break completely with the old model and its pursuit of isolated simplicity, and develop systems understanding no matter what. That is, we must accept whatever complexity results, and learn how to deal with it effectively. We must realize that complexity can be managed and so it is possible to address the universe as a system of systems. We must stop separating and simplifying, and instead learn to integrate and unify, and to do so on the grandest scale. Rather than developing many fragmentary models separately we must learn to develop a single unified model collaboratively.

Benefits of the Whole

Many benefits can be realized by combining information into a proverbial big picture, even irrespective of systems. Consider familiar examples of combinations: a map combining a location, destination, and the connecting routes; the complete solar system (both Ptolemaic and Copernican views); a food web that shows how nutrition flows through an ecosystem and similar cycles for water, carbon, energy, etc.; a weather map; global plate tectonics and related areas of geologic activity; Darwinian evolution; and evolution of systems since the Big Bang. All of these have provided important new understanding by *integrating and unifying knowledge into a common model, broadening the scope, and crafting views from new perspectives and at greater levels of abstraction*.

Consider some of the many benefits of combination.

Awareness
Having everything in one accessible and understandable description enables everyone to become aware of all knowledge and thus prevents needless ignorance, avoids duplication of effort, and enables building on existing work. It also develops a common understanding, i.e., mental model, that facilitates communications and collaboration.

Relationships
A relationship, by definition, exists between two or more entities. Without the entities themselves, relationships are unlikely to even be considered. Relationships normally lack visibility and can easily be ignored until the related entities have been both defined and represented in a way that enables them to be considered jointly.

Moreover, entities are related in multiple ways and many relationships continue through multiple entities forming chains in both space and time. A chain can only be recognized when all of the constituent entities and relationships have been brought together in a common description. Collectively the result is a complex network of entities and relationships in both space and time. Such a network is a more accurate view of reality and better basis for understanding but requires combining knowledge of all entities and relationships. Until we do so, our view will remain impoverished.

Generalization
Many of the entities that we recognize individually are in fact variants, also called subtypes or specializations, of a more general type or universal. For example, more than a hundred variants of atom are known, and millions of species - variants of a living system - have been identified.

Variants, when recognized to be such, by being brought together and considered collectively, can be related and generalized. They can be defined in a hierarchy such as the Linnaean system of living things. By so organizing, a large amount of information can be reduced to minimal size, and made consistent, non-redundant, and adaptable. Adaptability means it can be developed incrementally over time and kept up-to-date, which, in turn, means that large complex domains can be addressed.

Organizing in this way leverages all existing knowledge, defines useful generalization, and converts a haphazard set of variants into a single manageable structure. Such a structure may reveal gaps suggesting variants still to be identified as famously done by the Periodic Table of Elements. Moreover, the nature of the structure may provide insight into its genesis leading to new understanding, such as Darwinian evolution. Finally, generalizations provide intellectual leverage without which managing the complexity of the universe appears dubious.

Enable Selective Viewing
Combinations soon become networks too large to be grasped all at once. A larger diagram is not the solution. Instead, large domains must be viewed by multiple subset. The availability of a complete set of domain information enables the necessary subset views to be crafted to provide human understandability. Understanding and thus improvability require creative view development which to be done optimally needs full information.

Crafting the subsets for understandability is an art employing several techniques. Abstraction, i.e., detail management, is perhaps the most important such technique. Abstraction, is the art of deferring some information from a view so as to make other information more understandable. New understanding comes from viewing certain groupings of information while temporarily ignoring other information. Abstraction is critical for revealing patterns and especially for illuminating the big picture, which typically requires the deferment of a great amount of detail.

Information is typically grouped based on how it was gathered, initially organized, or by the goals of the gatherers, that is to say, arbitrarily in only one of many possible ways to view it. Having a complete set of information provides an opportunity to present it in less conventional ways, from different perspectives and at multiple levels of abstraction, yielding new understanding. Because of fragmentation and constrained view development, many such views have never been seen or possibly even imagined and so often spark new ideas and open new lines of investigation.

Combined knowledge enables development of the full set of coherent views essential for holistic understanding and critical-review-driven improvement. The ability to craft new views easily and quickly based on current interest, questions, and concerns is also highly advantageous.

Refinement
Experience shows clearly that fragmented descriptions contain many flaws. Worse, many flaws go unrecognized indefinitely. Users are unaware of the flaws because they are undetectable so long as the subsets of information remain isolated. Remarkably, most of the flaws can be readily recognized and resolved once the fragments have been integrated into a common model.

For example, a statement in one fragment often contradicts a statement in another. If the statements are integrated and reviewed, contradictions can be easily recognized and eliminated. Similarly, inconsistencies of other types become recognizable when all the inconsistent items are depicted together.

Gaps can be exposed by composing views to show completeness. Such views can depict, for example, full life cycles, complete flows and processes, all of the variants of a type, and full networks of relationships. Boulding calls such wholes "gestalts" (Boulding 1956). Such views tacitly pose the question: what, if anything, is missing? Reviewers frequently answer this question spontaneously by pointing out an absent item. In this way gaps can be eliminated systematically until eventually no more can be found. But completeness can only be achieved through integration and with views that encourage and support serious review and improvement because they are understandable and claim to be complete. It is also important to be able to update views promptly in response to reviewers' comments.

Coherence

Coherence, defined as "true as a whole", is a concept that includes many of these issues. In addition to accurately describing reality, a description must be complete and true as a whole.

Coherence provides an invaluable test: all of the parts of a description must fit together flawlessly. Anything that doesn't indicates a flaw that must be addressed. However, a coherence test can only be applied effectively when all relevant items have been brought together. This means that coherence must always be considered most unlikely whenever no effective coherence test can be applied. It is important to recognize that since a coherence test cannot be applied to fragmented information, *fragmented information cannot be made coherent*.

The inescapable conclusion from this observation is that the basis of our world view is not coherent, and won't be until we succeed in integrating and unifying the fragmented descriptions of the universe, and applying an effective coherence test.

More troubling still is the fact that most informal discussions do not effectively communicate meaning because of the use of terms that are not well defined within a coherent structure and so are interpreted differently by each participant. The differences often escapes the awareness of the parties and so may never be corrected.

Integrating and unifying all domain knowledge makes it possible to document the full network of relationships and generalization hierarchies, eliminate flaws, ensure coherence, and develop creative views to render the domain understandable as a whole. It enables a comprehensive, coherent, and understandable description. Without integration into a common model, a complete and accurate description and full understanding remains out of reach.

CHALLENGES

Many challenges exist to describing the universe. Here we briefly describe some of them. In the next section we describe the techniques to address the challenges.

Preliminary

The first hurdle is that the whole idea of a universal description sounds outlandish and so is tempting to reject out-of-hand without serious consideration of its need, potential, and viability. Hopefully, the point has now been made that representing the universe as an organized whole is essential to advancing the systems view. Consequently, doubts must put aside long enough to consider how such a thing could be done.

Secondly, our natural instinct toward anything big and complex is to divide and conquer, i.e., break it into parts and address them independently. This action, of course, would surely defeat our goal at the very outset since just the opposite is needed. This challenge is to resist the intuitive and insist on addressing the universe as a single whole.

Incompatible Dialects and Mediation

Perhaps the greatest challenge to a universal description is incompatible dialects and the resulting fragmentation of knowledge and barrier to communications and collaboration.

Dialects
It is only natural for unique customized sets of terms and meanings - local dialects, so to speak - to evolve within working communities. In addition to specialized terminology, local dialects may embody tacit assumptions, goals, values, and world views all tailored to the group and its unique history. Such dialects provide value by capturing local meaning and facilitating group communications, but they form barriers among groups. New dialects continue to arise with new groups and new discipline specializations making the situation steadily worse. Many system scientists as far back as Kenneth

Boulding (Boulding 1956) have warned about the danger of overspecialization and restricted communications.

Dialects, in turn, reinforce isolation, which leads to further dialect specialization, establishing a vicious cycle. For example, it has been said that even hard rock and soft rock geologists no longer communicate. The result is many increasingly isolated groups and pools of incommensurable information often called *silos*.

This problem is referred generally to as fragmentation, meaning that the sum total of knowledge is being split into separate fragments preventing its use collectively. An unknown but undoubtedly large amount of valuable knowledge exists in this state, where it is inaccessible and includes much about which many are completely unaware.

In contrast, synthesis requires pulling together a broader array of knowledge, ideally all that is relevant. Specialization and isolation prevent doing so and so reinforce the use of analysis and a reductionist approach - quite the opposite of a systems approach. Fragmentation effectively prevents a systems approach to the universe and for that reason must be a primary target to change.

So what is the solution? It must be, as Francois puts it, to "*reconstruct the whole*" (Francois 2000) by integrating and unifying selected fragmentary knowledge. This requires a common, system-oriented, language capable of expressing all knowledge, unbiased by any single dialect, discipline, or fragment.

Mediation

Light has been thrown on this challenge by the design pattern community. This issue has been addressed abstractly by a design pattern called Mediator (Gamma 1995). A mediator is a mechanism to enable multiple disparate objects to communicate. For example, if the communicants use different languages or protocols, the mediator provides translation services.

Two general mediation strategies have been identified. One is to provide translation from each communicant to every other one. The other is to develop a single common language and provide translation from and to it for every distinct language of the communicants. The latter approach has many advantages, especially in the case of a large number of communicants (the number of required each-to-each translations increases with the square of the number of communicants).

Interdisciplinary approaches are often touted. While undoubtedly useful in certain cases, they sound much like the first mediator approach described above. Integrating two disciplines or dialects with each other is plausible, but integrating every discipline with every other is not. The goal from a system standpoint must be not just integration of selected disciplines but development of a separate systems super discipline that subsumes all other disciplines; that is, adoption of the second mediator approach. This implies the development of a systems language into which all other dialects can be translated. We need one common system language not a host of joint languages.

So here is a outline of a solution. A common system-oriented language is developed. Information is translated from existing dialects into it, which can be done over time. In effect, a mediator function is established across all fragments of knowledge.

This will be similar to, but more extensive than, the creation of the Linnaean structure and the process that translates common and natural-language-specific species names into a single living-thing-oriented Linnaean language. However, the new systems language instead of being living-thing oriented must be system oriented, i.e., at a higher level of generality and addressing a broader domain.

Who will fill the mediator role? The systems community would seem to be the natural player of this role, and perhaps the only one qualified and motivated to do so.

A common system-oriented language does not mean that the other dialects need to go away, just as the common names for species have not been completely replaced by the Linnaean names. One common systems language and many specialized dialects could coexist indefinitely. In any case, eliminating dialects is not the goal and perhaps not desirable. The goal is holistic understanding through a universal model in a common systems language.

Ontology and System Taxonomy

The foundation of a system-oriented language must be a systems ontology, i.e., a definition of the systems domain universals and their relationships. I believe that an ontology is best developed as part of the domain modeling process. Universals and particulars are best defined as they are encountered, where they can be understood in context, and while related issues are being faced and resolved. In this way the ontology develops directly from the domain harmoniously with the model as it is extended, and both can remain consistent and adaptable indefinitely.

Taxonomies are essential parts of an ontology. A taxonomy is "*a representational artefact that is organized hierarchically with nodes representing universals or classes and edges representing the **is_a** or subtype relation*" (Arp 2015). The best known example is the Linnaean taxonomy of living things. A systems taxonomy must form the core of a systems ontology.

Many system scientists have put forward bits and pieces of a system taxonomy but, to my knowledge, no one has attempted to develop one comprehensively. The lack of a systems taxonomy is, in my view, a telling statement about the current state of a systems ontology and the systems field generally.

In other fields, especially biology and medicine, there has been a realization that the fragmentation of the fruits of expensive research and hard-won experience is intolerable. Consequently, much ontology work is now in progress, some with support from the U.S. government (Smith 2009)(Arp 2015). Examples include the Foundational Model of Anatomy, the Cell Ontology, and the Infectious Disease Ontology. The results of this work is publicly available, and is likely to provide examples, guidance, and possibly usable definitions.

The systems taxonomy will provide a great many straightforward mappings into the dialects. For example, many system types such as: atom, molecule, star, solar system, galaxy, cell, organism, family, etc., are core concepts in various disciplines and all map directly to well-defined universals within particular dialects. A system types taxonomy will provide an important initial systems ontology component.

All of this obviously represents a huge task but, as previously mentioned, it can be done incrementally over an indefinite period, can potentially be done by many people (although it must be centrally managed), and the work can be prioritized to provide early payback. Also, it can provide great value even while only partially complete, which means that once well started, it can become self-sustaining.

Clearly, to best understand the whole we need access to the combined knowledge in all fragments. We need to create, in effect, a superset of available knowledge. This requires integrating and unifying the knowledge currently fragmented. This, in turn, requires establishing a single common language, i.e., an ontology, built upon a systems taxonomy.

Doubts about the legitimacy and effectiveness of the systems approach is likely to persist until a legitimate system world view is developed based on a comprehensive, coherent, system-oriented description of the universe.

MEETING THE CHALLENGES

Although these challenges are daunting, it is my contention is that they can be met by an approach that includes the following techniques.

Develop Incrementally

Size and complexity is a great challenge, to say the least. How can we deal with the immense scope and complexity of the universe? Clearly, it can't be done immediately in a single stroke. So the first realization is that describing the universe must be a process, not an event. A description must be developed incrementally through many iterations of statement, critical review, repair, improvement and extension. In principle, such a process could continue providing improvement and extension indefinitely.

In other words, the challenge of size and complexity can be mitigated by distributing it over time. Even a long journey can be made in small steps. An incremental approach also provides staffing flexibility. Progress can be made by a single person or small team, yet scale up to a multitude. Successful similar large-scale, ongoing processes such as Wikipedia development might provide guidance.

It is important to realize how incremental development casts the whole project in a different light. The effort is neither to describe the universe in complete detail nor to instantly create an description using all of the best current knowledge, both of which are impossible. Rather, the effort must be to produce an initial description using a subset of the best current knowledge in such a way that it can be improved and extended indefinitely. This is a quite different and achievable proposition. The aim must be to approach ever closer to perfection, while accepting that perfection can never be reached. In this respect it would be similar to science which has been at work and improving for centuries with no end yet in sight. A long term "perfectible" project raises additional issues but ones that are all manageable. The design of the process is critical (Ackoff 2006).

Simplification and Minimization

Even with incremental development, it is essential to reduce the volume of information to make it easier to understand and manage. The can be done in several ways, such as by eliminating redundancy, exploiting generalization and abstraction, and prioritizing what is addressed. The remaining volume, so reduced, must be managed by means of modern information management technology.

The greater part of most existing descriptions is redundancy and so is not only unnecessary but detrimental generally and fatal to perfectibility. Known techniques can eliminate redundancy and thereby drastically reduce the size. Textual descriptions are highly redundant; their size can be significantly reduced by disciplined use of a specialized language. Fragmented descriptions are even more redundant collectively. By structuring to reduce redundancy a unified description can be made considerably smaller than the sum of the fragmented descriptions.

Generalization also reduces redundancy and bulk. For example, the Linnaean System describes millions of species succinctly by minimizing redundancy via a hierarchical structure. The structure enables the properties of a type, such as a mammal, to be defined once rather than redundantly for each of the many species that are subtypes of that type. Recognizing types (universals) and distinguishing between them and instances (particulars) is fundamental to generalization. Generalization can be applied not just to objects but to all types including relationships, processes, and interactions, an important technique not widely understood and seldom employed.

Systems provide an excellent target for generalization since the system is a quite general concept having many subtypes, is central to the effort, and system instances are ubiquitous at all scales throughout the universe. By defining system subtypes and organizing them into a generalization-specialization hierarchy (taxonomy) the total size of the descriptions can be minimized, not to mention the many other important benefits that doing so would provide. This makes the system type hierarchy the leading candidate for early attention.

Many significant pieces of the puzzle exist and just need to be integrated. For example, since living thing, the subject of the Linnaean, is a type of system, the system generalization structure would subsume the entire Linnaean hierarchy. In other words, a system taxonomy would simply be an extension of the Linnaean living system hierarchy.

In addition to the more than a million living organisms in the Linnaean, other significant well-defined parts of a system taxonomy exist and can be included more less "as is". These include atoms (more than a hundred subtypes), molecules (millions of subtypes), and minerals (several thousand subtypes). In most cases catalogues of such system subtypes are available or in development on-line and can be included in a system model. Moreover, with an on-line model, they can be included by reference via a simple hyperlink.

A firm rule for a description must be to define nothing more than once, and this ideal can be closely approached. By learning to do so, volume can be drastically reduced and important other benefits such as consistency, reviewability, adaptability, and extendibility, can be achieved. Consider, for example, the ease of adding a new species to the Linnaean because most of the description already exists within the extensive structure of generalizations.

Even with the best application of size minimization techniques, the volume of information will still be huge. Computer-based modelling tools supported by database technology will be essential. Modern tools support the management of large amounts of information. A modelling tool incorporating a data base is essential for managing, manipulating, and presenting the information. However, it is important to understand that such tools, while necessary, are insufficient by themselves. Much more than just loading a data base is needed. The essential element is the understanding and skill to use them effectively to achieve the defined goals.

Two aspects of modelling must be carefully managed: definition and presentation. To be able to support complexity, the two must be optimally decoupled. Definitions can be stored in a repository, i.e., data base, which presumably can scale as required and be managed to eliminate redundancy.

For presentation, detail must be filtered to facilitate human understanding, a technique often referred to as abstraction. Filtering can be done in more than one way to produce views from diverse perspectives and levels of abstraction. Such views will inevitably represent the same element multiple times. However, with proper decoupling, an element can be represented any number of times without being defined more than once. If only defined once, a definition can be easily changed across any number of representations and views. This capability is critical for complexity management and so a modelling tool that supports the decoupling of definition and presentation is essential.

Finally, prioritization can be applied so as to address the subject in the most productive order. Heuristics have been developed to provide guidance in this regard. One is to give priority to whatever appears likely to improve the understanding of the whole, since doing so may well have a profound impact.

Modelling Defined

Many actions including simple diagramming is often referred to as modelling. As used here the term has a much broader and more specific meaning. Modelling is the management of the process of better understanding information collectively by capturing, rigorously defining, integrating, and unifying it. It includes an ongoing feedback process of improvement consisting of critical review, comment, update, and presentation to make it fully understandable. The result is a continuously improving, comprehensive, coherent, system-oriented description of the universe. Modelling includes the following functions:

- to accumulate descriptive information within a book-of-record where information can be officially registered, managed, and developed incrementally
- to establish a systems-oriented ontology and taxonomies for all significant objects
- to define relationships, interactions, processes, etc., i.e., "non-things", and to manage the complex networks so created
- to translate knowledge from the many existing dialects into a common systems-oriented dialect, which requires integration and unification
- to refine by eliminating flaws and gaps
- to enable the understanding necessary for critical review by crafting views to depict the information from multiple perspectives and levels of abstraction, especially to develop the "big picture" views necessary to understand a system as a whole
- to systematically generalize not just things, but all aspects of the domain (some of these generalizations may well turn out to be equivalent to isomorphisms)
- to ensure coherence by crafting the requisite views and reviewing them for global consistency
- to maintain model adaptability so that the model can be continuously improved indefinitely
- to manage the large and growing accumulation of data, including eliminating redundancy
- to manage the overall development process to achieve ever-closer approach to the ideal (i.e., perfectibility); especially to support an effective ongoing feedback process of review, comment, and update.

Many of the details of the modelling needed have been worked out and, in fact, significant parts of a systems model have been implemented. These will perhaps be the subject of a future paper. See Marzolf (2014) for an early example.

Forging a Macroscope

The challenge of complexity has sparked the idea of a "macroscope" (Rosnay 1979), a imaginary instrument related to the microscope and telescope, that would allow us to cut through complexity and to see the big picture hidden by a confusion of detail. I contend that a proper model, developed by use of the combination of tools and techniques described above, would constitute in effect a macroscope. Detail can be organized, filtered, and presented understandably with such a model. In this way, through systematic, disciplined effort rather than magic, complexity can be managed to allow mere humans to grasp the whole of even the largest and most complex domain.

So, despite the vastness and complexity of the universe and the undeniable challenge posed by it, no factor exists to make it impossible to systematically develop a comprehensive, coherent, and understandable description. The challenge of scope can be managed by developing the description incrementally, by systematically applying simplifying and size-reducing techniques, such as generalization, abstraction, and redundancy avoidance, by appropriately use of modern tools, and by prioritizing effort.

Final Thoughts

Two historic advances in human understanding have been made in recent decades. The first is awareness of the system as a distinct, important, and universal pattern. The second is the realization that a system can only be understood as a whole and to do so requires synthesis as well as analysis. These steps mark important progress but are far from the end of the system story.

I contend that more recently a third advance has occurred: recognition that the universe is a system of systems, or at least can be viewed as one to our great advantage. This observation opens a promising new line of investigation and the potential development of a better and more broadly accepted understanding of the universe and our place in it.

Far from being chaos, confusion, or a profusion of independent individual systems, the universe is one coherent whole of which the system pattern is a, and perhaps *the*, fundamental organizing principle. If true, then the system pattern provides the basis for a comprehensive, coherent, system-oriented description of the universe. Such a description would profoundly alter our understanding of the universe and our place in it. We don't grasp the universe as a whole because the universe itself is incoherent, but because our current descriptions are inadequate, being neither system oriented, comprehensive, nor sufficiently holistic.

Progress with systems depends on addressing the whole whole. To do that we must learn to manage great complexity. This represents the greatest current challenge, but one that can be surmounted.

Newton famously integrated heaven and Earth by showing that the same laws of mechanics apply everywhere. In so doing he forever changed our world view. The current generation has an opportunity to have a similar impact by "integrating the universe". This can be done by showing that it has evolved and continues to evolve through a common system-based process and is organized by a common system-based architecture. Such a achievement would likely alter our world view at least as radically as Newton did. This opportunity may well turn out to be the most significant impact of the advent of the systems concept.

Addressing the Whole Whole

Who is best positioned do this work? Who knows systems and strives to understand the whole? Who is cognizant of many disciplines yet least biased by any single discipline? The systems community, of course. A role is beckoning to be the synthesizer of fragmented knowledge, keeper of the global model, developer of a systems world view, and presenter of an understandable holistic vision. The systems community must grasp this historic opportunity.

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