In Search of the Biology of Systems

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Abstract—This paper will propose to do as von Bertalanffy once did, and that is to draw on the biological sciences, now hugely advanced beyond that ever imagined by von Bertalanffy and his peers, and use its findings, architectures and emergent behaviors, to argue for a biology of technology and enterprise systems. We seek a science and approach that we believe will provide richer insight into system failure, ‘health’ maintenance, repair, replication, growth, and mutation, all those features of the evolution of systems which constantly challenge us and which thus far we have only been able to explain via macro-level models and tools.

We propose to go deeper into the structure of these systems and to discover the "DNA" (building blocks) of these systems. Thus establishing a foundation to understand their behavior using biological analogies which we believe will turn out to be more than metaphors. We assert that these systems have micro-structures which will explain their individual life cycle and their communal ecology.

I. INTRODUCTION

In an earlier paper [1] we presented characteristics that enable differentiation between a System of Systems (SoS) and a system that is not a SoS (i.e. autonomy, belonging, diversity, connectivity, emergence). It was proposed that a SoS is a system, but not every system is a SoS. In this paper we will explore these proposed characteristics to a deeper level, one that defines the genesis of systems or SoS. The objective is to provide a pragmatic basis for better decision making during the conception, realization, and operation of systems while exploring their utility and purpose.

Many professionals, having specialized in a specific engineering micro-discipline, have gravitated towards a community of systems which uses many of the constructs from general systems theory to develop bodies of knowledge and practice which are essentially specialization in breadth, and are manifest in every area of technology e.g. telecommunications, aerospace, computing, and the military. In fact, these communities have done much to advance the systems approach on behalf of a broad range of professionals from general systems theory to develop integrated phenomena of study in any of a number of different disciplines [7]. It is these eight fundamental constructs that underlie all systems and provide a basis for unification: (1) system-environment boundary, (2) input, (3) output, (4) process, (5) state, (6) hierarchy, (7) goal-directedness, and (8) information [3]. Despite these constructs, they do not define fundamental building blocks of systems, but functional and physical states of what we may define as a system.

Therefore, we propose to do as Ludwig von Bertalanffy [3] once did, and that is to draw on the biological sciences, now hugely advanced beyond that ever imagined by von Bertalanffy and his peers, and use its findings, architectures and emergent behaviors, to architect a ‘concept exportation’ [4] for a biology of systems. While systemic and cybernetic theory focuses on processes and the bringing together,[5] we want to focus on the core of what is brought together. As general systems theory sought to “more fully understand the intersection between values and assumptions or a particular framework and its theoretical formulation,”[6] we seek a science and approach that we believe will provide richer insight into system failure, ‘health’ maintenance, repair, replication, growth, and mutation, all those features of the evolution of systems which constantly challenge us and which thus far we have only been able to explain via macro-level models and tools.

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II. THE SEARCH FOR SYSTEMS “DNA”

To define a living cell or a computer we use differing and diverse definitions based on fundamentally different building blocks, but to describe them as systems, we use equivalent distinguishing constructs first presented as general systems theory. When Ludwig von Bertalanffy wrote about systems as general systems theory in the 1940s, he described eight fundamental constructs that provide for a unification of all systems across domains. General systems theory addressed the transdisciplinary study of the abstract organization of phenomena, independent of their substance, type, or spatial or temporal scale of existence, while in a continual attempt to develop integrated phenomena of study in any of a number of different disciplines [7]. It is these eight fundamental constructs that underlie all systems and provide a basis for unification: (1) system-environment boundary, (2) input, (3) output, (4) process, (5) state, (6) hierarchy, (7) goal-directedness, and (8) information [3]. Despite these constructs, they do not define fundamental building blocks of systems, but functional and physical states of what we may define as a system.

When Ashby further defined these constructs of general systems theory he stated that a system has a self-organizing process where the organization of a system spontaneously increases with a decrease in statistical entropy and an increase in redundancy, information, and constraints [8]. This too does not tell us what the fundamental building blocks of systems are, but expands our understanding of the state relationships that may occur in a systems life cycle. The
evolution of general systems theory from von Bertalanffy in the 1940s has seen the fundamental concepts applied to many areas and brought about new disciplines and phenomena: systems engineering, systems design, systems analysis, systems approach, cybernetics, and systems science to name a few [9]. While the theory of systems is still evolving, there are still no defined and developed building blocks of systems.

Most sciences have fundamental building blocks by which they can define and build upon the scientific study of their discipline (e.g. biology, genomics, DNA). The traditional approach in the sciences has been a reductionism and discovery approach to understand what the fundamental building blocks of their discipline are. For systems, it has been this same reductionism and discovery applied to understanding what makes them function, not what are they made of, to define what they are. Biologists have used this approach to take a holistic look at biology which is termed systems biology. But in biology we know the fundamental building blocks of all biological systems, DNA. These building blocks are assembled based on an architecture that is dictated by their behavior. The architecture of DNA comprises a double-stranded helical structure in which the two twisted legs of the ladder are made of phosphates and sugars, and the rungs made of nitrogen bases. The work of many scientists contributed to this definition but it was Watson and Crick [10] who discovered what the rungs were made of and how they joined together and to the legs. From the biological perspective the crucial questions to be resolved were those of growth and reproduction. The architecture settled this with the particular sequence of nitrogen bases in the rungs containing the coding or instructions for growth and the bonding within bases, being limited to specified pairs, conveying the reproductive signature.

What might it mean to speak of “A Systems DNA (sysDNA)?” If such existed and were possible it could mean that we had access to the vitality of a system in terms of its growth and reproduction, in and of itself, and possibly a means or perhaps the means to adapt it at a genetic level with some guarantee of the out turn, which perhaps we do not normally have by traditional systems studies. But why should it exist? There are many reasons why it should not. For instance we know of no body of knowledge for systems that is equivalent to chemistry for physiology or biology. Perhaps it is mathematics but the application of this to systems per se rather than to models of particular systems is notoriously lacking. Another primary reason for the non-existence of a systems DNA is that there is no prima facie reason for it to exist. It is one thing to explore natural systems, since life is what they have in common. But what do designed systems have in common that is a mystery we might believe will yield to an equivalent biology, physiology, chemistry or physics? How can so very many ad hoc man-made designs possibly bear a common imprint that would suggest an underlying DNA. It’s unlikely if not inconceivable. And yet we search!

Then for systems, which are mostly technology intensive, can we define the fundamental building blocks by which we can then apply a systems study to? One thing that systems do have in common or at least is said that they do is an architecture. However this is codified and there are multiple instantiations. What this does convey is conceptual design from which the detailed system later takes its form and thence its function. Is system architecture the systems DNA? Unlikely since it is almost certainly specific to each system, although patterns might be observable across the spectra of system architectures, certainly across given types of systems. So somehow or other the system architecture may have something to do with a systems DNA, but revealing the independent existence and nature of the latter is still what we desire. If it exists. Traditionally, the attempts to understand the lifecycle of systems has been through the engineering of systems or systems engineering. Some have stated that systems engineering provides us with a process by which we can design, develop, and manage systems, but it does not tell us what makes up a system. What are the systems building blocks, so we can define and study the biology of all systems?

We want to be able to rely less on reductionism and discovery to understand systems, but move to a more hypothesis-drive and discovery science approach to systems. Most systems are fundamentally complex with multiple parts, and it is almost impossible to fully understand and study something with so many parts. In reductionism we would reduce that down to the lowest level possible, but leaving ourselves with the improbable task of trying to relate this to the original problem. Systems biology has attempted to apply general systems theory to being able to explain the integrated and interactive nature of biology from the molecular level to the macro level. The study of systems has no molecular level, there is no “systems systology.” General systems theory has given us the architectural constructs to understand, design, and describe the behavior of systems at a level comparable to the study of proteomics, and general systems theory has allowed us to architect at higher levels of functional, physical, and environmental. We present here that we contend that there is a molecular level below general systems theory that we have not fully discovered or defined, which we define as systomics, the study of sysDNA. Therefore, we are asking the fundamental but not trivial questions, “What is the DNA of systems?”

A. The Chemistry of Togetherness

The cell and a system have three things in common: structure, function and lifecycle. The cell has the advantage of chemistry to explain structure. The system does not. The cell has its vitality encoded chemically. But this encoding, essentially deals with patterns of organizational form to which we can usefully impute anthropomorphisms. Carbon, for example, is very agreeable, more so than any other element. It happily builds relationships with other elements. Some architectural forms are rugged, difficult to break. Others are fragile. And yet both types may consist of the same elements, just differently arranged. This line of thinking gives us a clue as to how to build a conceptual chemistry and with that the fundamental building blocks of systems such as satellites, battleships and the product development teams that build them. We believe that the essence of a system is ‘togetherness’, the drawing together of various parts and the relationships they form in order to produce a new whole that
will have its own structure, function and lifecycle. That said, we want to embark on a discovery of ‘togetherness,’ our conceptual chemistry. Our conceptual chemistry set currently consists of five elements: autonomy, belonging, connectivity, diversity, and emergence [11].

For each of these elements, there are opposing forces or paradoxes that are influenced by fluxes in realizing or recognizing a system [12]. This balance is considered reversible. Reversible is conditions under which the forces are so nearly balanced that an infinitesimal change in one or the other would reverse the realization of the system. In any system we seek ideal conditions that the realization of the system is carried out reversibly. Under these conditions the realization of the system yields the maximum possible performance; although, reversibility does not hold true in practice. The flow of these forces and their relationship work in distinguishing types of systems and determines the togetherness of a system which fortifies its realization.

In biology energy plays a fundamental role in the chemical and physical process that help to realize all living systems. For systems, we contend that this energy is to biology as togetherness is to systems.

With these previously mentioned five elements we can begin to understand what they mean to togetherness. The first element is autonomy which defines the ability to make independent choices. There is nothing that is wholly independent for it would have no relationships; it would need none. The beauty of independence is to be able to pick and choose interdependence. Thus autonomy is less to do with the freedom of something, from all other things, and more to do with the exercising of choice among several decisions that affect and are affected by other things, including those that increase or decrease choice. Autonomy always finds, though it be argued that it never needs, context, and it is fully exercised within a forever changing firmament of contexts.

Our second element is belonging. There can be no system less parts be found therein and these in some sense belong. Nucleons belong in a nucleus, which belongs in an atom, which belongs in an element which belongs in compounds which .... make up life ... by belonging. Autonomy can determine belonging but belonging will surely affect autonomy. People choose to be married, and they choose to be faithful; independent and autonomous choices both. The choice to be then unmarried is thereby denied by the very autonomy that led to marriage. Yet, the autonomy continues. So does the belonging. Yet, this belonging itself changes since the partners change via the very nature of belonging together whilst sustaining their respective autonomy. Belonging and autonomy are independent, orthogonal in the logical sense, but they are interdependent in the true spirit of autonomy.

Thirdly we have connectivity. Some argue that belonging means being connected. True. Yet, autonomous systems can choose to unbelong and stay connected to the systems with which they once belonged in the system. Connections exist within systems and within the contexts of systems, and they may transgress system boundaries. Belonging is confined within a system boundary, of some description.

Our fourth element is diversity. Interestingly this is the first one of our notions that simply cannot be applied to a single entity, be this part, relationship or whole. Of necessity it must be a comparative notion and it is this kind of thinking that supports the integrative nature of a system, be it cell or satellite. We use this conceptual chemical to argue for the dependence of a system on its diversity, that is its own, that of its parts and that of its relationships. Diversity can affect belonging; for example, some will not join if the system is already too diverse, or not sufficiently diverse. Likewise belonging or not, affects diversity. Diversity can also affect connectivity; great diversity can cause huge technical challenges in supporting connectivity and with that, communication and hence control.

Our final chemical element is that of emergence. This is normally attributed to the system level rather than to the system’s or relationships, but then in one sense scale takes care of these. Our interest is also in knowing how parts emerge by belonging and having connectivity with others, in a diverse whole. The extent to which this occurs can have a dramatic affect on the type of system we have, including a special type many have referred to as System of Systems (or SoS). In the cell, the nucleus, part of the cell at some point grows, constricts in the middle and finally divides in two, an elegant piece of choreography that precludes the division of the cell itself. In this case two cells emerge from a single cell but before that occurs the nucleus emerges, merely by belonging to the cell.

B. The Biology of Systems

We are attempting to provide greater formalism to the notion of system ubiquity, that is to describe a system in the abstract so that system designers and managers of specific systems can take account of this abstract knowledge thereby ensuring that whatever they build is a system not merely because it carries that term in its description but also because it bears the marks of a system as we understand that term. We rely on the notion that a system is a collection of parts and their interrelationships assembled together to fulfill a purpose. Our differentiating elements have something to say about these parts, their interrelationships, the assembling together (process), and the fulfillment of purpose – all in the most abstract sense but in a way that this relates to the specifics of the system under consideration.

We now want to go a stage further from defining the elements and their specious use to making stark contrasts between systems (of parts and SoS). That step is to visit the notion of holon, that which is both whole and part simultaneously. We liken the holon to a spherical object and argue that as such it consists of an inner core and an outer coating, or series of coatings; coatings and core are in continual ‘communication’ or the holon ceases to exist and becomes either part or whole.

The core of the holon is its competence or competency set and we make the point that this represents the autonomies of the holon, i.e. its dependability to do what it is supposed to do without continual supervision or management attention (see Figure 1). A soldier in an army is not autonomous in the sense
that he is under authority. Yet, he is autonomous once he is given an order or command, part and parcel of the authority regimen. In fact, the very order itself signals and emphasizes the soldier’s competence to act and to act without further intervention by the authority figure. If this core did not exist no command could be given, otherwise, what would that command be? Similarly, when the driver of an automobile hits his brake pedal he is issuing a command to the braking sub-system having confidence that that sub-system has the competence to perform its duties, execute its autonomics, utilize its competence set, and altogether play its part. So we argue the core of the holon is its competence, its core non-existent. For a braking sub-system in an automobile, the degree of autonomy is changing as the vehicle becomes more intelligent and in principle able to do a better job than many drivers. However that superior performance relies on decentralized control in which sub-systems (aka holons) have not only superior cores (autonomics) but also superior coatings. Our search then is for how these coatings can be applied, how they can be changed, in light of experience and new knowledge, and how they interact with the core and with the higher-order system.

III. CONCLUSION

These then are our conceptual chemical components from which we believe we can construct ‘systems DNA’. Our proposition for this line of experimentation is simple to state but far from trivial to accomplish. It consists of proposing various models of ‘systems DNA’ comprising various arrangements of our conceptual chemical components, simulating these models using agent-based technology and then validating the results against the various real and hypothesized systems we use to develop the models. The latter model type will be a simplified abstraction of a real system so that in every case the model has traceability to some aspect of reality be this a battleship, a Boeing (aircraft) or the battle itself (episode in a military conflict).

We will endeavor to decompose each chemical concept into finer grain constituents by scrutinizing the meaning of each and exploring their various interdependencies. This decomposition will give us our system of agents. We will be careful to note valid architectures, forms of organization, for inter-relating the decomposed concepts, and these architectures will give us our agent-based model. The behaviors we obtain from simulation results will be compared to what we might have expected or what we know to be true in life-like situations.

The prize for this line of reasoning is to have a far greater understanding of the nature of a system and its distinction from other systems. But we shall also learn how a system that is not a priori a SoS might become one and thereafter, either maintain its identity as such or return to being just a system or indeed a ‘non-system of systems’. Mutation of systems, by nature or by design, becomes ‘genetically’ grounded perhaps leading to at long last not just more systems theory but a theory of systems.

REFERENCES


