A UNIFIED SYSTEMS HYPOTHESIS

by

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THE NEED FOR A U.S.H.

Introduction

Science is steadily losing the esteem with which the general public formerly regarded it. Scientific method applied to social issues such as nuclear energy, genetic engineering and to complex socio-technical facilities such as information, economic and stock-market systems, has often fallen far short of the mark as seen from the public's viewpoint. This is leading in turn to disaffection for science, a feeling that it is inappropriate for such complex social and moral issues. The classic scientific method, which has contributed so much to man's progress, is itself seen as inappropriate to issues with significant moral or ethical content. Scientists and engineers must address this loss of confidence by developing new methods appropriate to the wider world into which they are being drawn. The Unified Systems Hypothesis (USH) is presented in this wider context.

Some forty years ago there was a hope that the science of systems would offer a way forward. This hope was engendered in General Systems Theory

General Systems Theory

General Systems Theory, however, originated by von Bertalanffy (1950) et al, has not fulfilled its promise of a single approach to all systems. The social, behavioural and management sciences are still essentially separated from the traditional, harder sciences such as physics and chemistry. It is in the social and management sciences in particular that advances in methods have been made, but often without the mathematical rigour seen as fundamental by the physical sciences. Independent schools have grown up, the so-called “hard” and “soft” advocates corresponding broadly to the physical / mathematical and to the social and management schools respectively. Von Bertalanffy did highlight the vital Open System concept, and in so doing presented a new and exciting perspective on systems, which has subsequently influenced the softer sciences particularly to consider the whole, as well as the parts, of systems.

Addressing Complex Issues

The softer sciences have gained some success in their approach to the delicate subject of addressing issues, using so-called soft methods, organization development interventions and so on. They seek often to understand complex situations and perhaps to improve situations, rather than to proffer optimal solutions—the goal of the so-called hard systems practitioners. Soft methods are often procedural, frequently interactive, encouraging commitment through participation, developing consensus rather than solving problems. Soft and hard systems methods alike lack a theoretical base, so that the undoubted reasonableness of their several approaches is more in the nature of a theology than a science. This is particularly so of systems engineering

Systems Engineering

Systems engineering has made some advances since the introduction of General Systems Theory galvanized systems theorists in the fifties and sixties, but not many, and few seemingly related to the theory. Indeed, it is hard to find a theory of systems engineering, although there is plenty of empirical, ad hoc method and, of course it has its roots in operations research with its optimization ethic. Human Factors or human engineering, ergonomics, anthropometrics, etc have crept into the systems engineering scene, but there still exists something of a gulf between the human factors specialist, focused on the human in his working environment and relating to machinery, and the engineers who design that machinery. They lack a common language; the human factors specialist finds it difficult to be precise in engineering terms about matters of engineering concern, while the design engineer might like nothing better than a transfer function describing a human that he could plug into his calculations.

Systems engineers exist in, and are concerned with the creation of, socio-technical systems—that is, systems which are social as well as technical. Current approaches to systems engineering tend, however, to treat design as concerned with Closed Systems, or systems which exist in isolation from inflows and outflows of energy, materials and information. To be sure, systems engineers create interfaces to other systems, but they generally enquire little about activities beyond the interface—it is not, after all, their concern. Or is it? If von Bertalanffy is correct, then the principles he expounded concerning Open Systems should have relevance to today's complex systems engineering projects, be they hard, soft, closed or open.

Introducing USH

If systems engineering is concerned with socio-technical systems, and if there is a split between the social and the technical in terms of practice and theory, then it is to be expected that the systems created by systems engineers may be less than satisfactory. So it turns out. While there have been many spectacular successes, engineered systems are increasingly failing to live up to their promise as they become more complex. By comparison with their human counterpart, they are inflexible, non-adaptable and difficult to operate and understand. The Unified Systems Hypothesis (USH) presented in this paper is intended to bridge that gap by introducing a view of systems and a set of systems principles that are common to all systems. It is for others to judge the success of the USH, but it seeks to pave the way to greater harmony between man and his systems and, perhaps, offer the softer sciences a new perspective on their domains of interest and practice.

A visitor from space would see networks rather than systems: —

- Great Wall of China
- Rivers
- Roads
- Power Grids
- Reservoirs

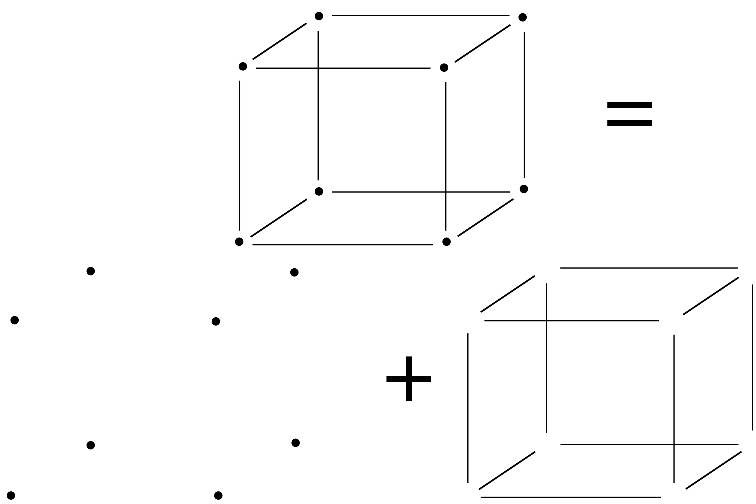
In this perspective of networks lies the foundation of USH—it looks at systems from the viewpoint of their interactions, interconnections and relationships, rather than from within any one system. In so doing, USH implicitly assumes that all systems of interest are essentially open, that is there is a flow into, out from, and between systems.

Consider the range of typical networks: —

• Radio & TV • Newspapers • Rivers • Canals • Sewers • Gas Pipes • Timekeeping • Postal Deliveries • Veins and Arteries • Arterial Roads • Railways • Undersea Oil Pipes • Electronic Circuit Boards • House Wiring • Computers • Bus Services • Corridors, Stairs & Lifts • Mines • Spies • Contacts • Banks • Informers • Tasks • Power Grids • Trees & Roots • Management • Chain Stores • Burrows • Suppliers • Cracks • Teaching • Food Chains • Forces • Telephones • Carrier Pigeons

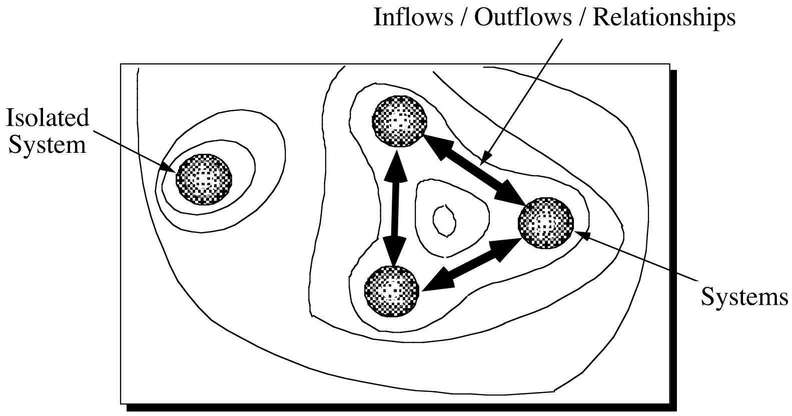
The list is endless. Many of the above might be thought of as systems and so they are at one level of hierarchy. A chai-store is clearly a system, but it is also part of a retailing network which interconnects manufacturers and consumers.

Is this network viewpoint tenable? Consider the following: —



The cube at the top is made up of dots at each corner and links, as shown below. Looking at the lower diagrams, we see that presenting the corner entities is insufficient to tell the whole story, since their inter-relationship is uncertain—they could be connected through the cube centre, for instance. Similarly, presenting the links only, while locating the entities, fails to describe them. Interestingly, as the simple diagram shows, a more coherent picture, in terms of the degree of order of the structure, might be said to emerge from the links alone than from the corner entities alone. This is particularly interesting. since it is more common practice to concentrate on the corner entities—the systems—than on their inter-relationships.

Interest in order is interest in reduced entropy. The figure is a highly notional representation of an entropy contour map in which are embedded four systems, represented by the four balls. The system at the left is isolated from the other three, and makes a simpe depression in the entropy fabric by virtue of its local order and as shown by the contours. The three systems at the right are mutually interconnected and both the systems themselves and their interconnections—since these represent order too—are shown as creating a depression (reduction) in the entropy fabric.



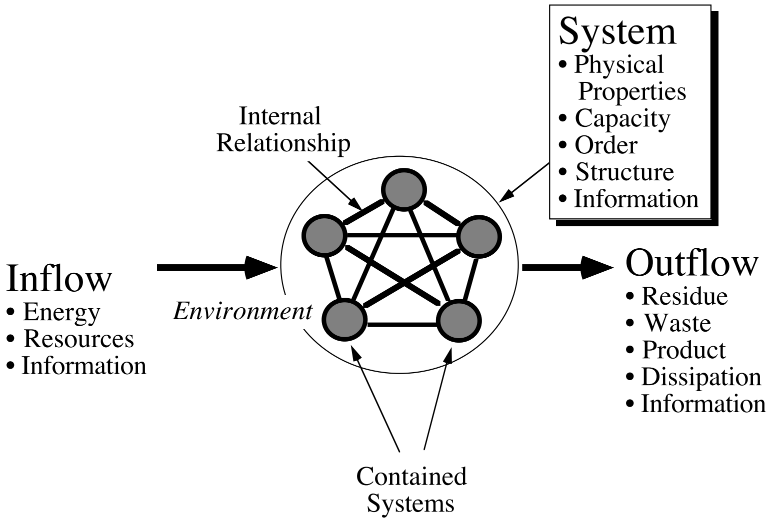
N.B. Both the Systems *and* their Inter-relationships create depressions in the entropy "fabric"

That entropy may be reduced by the existence of networks is further justification for the USH viewpoint.

U.S.H. SYSTEM IMAGES

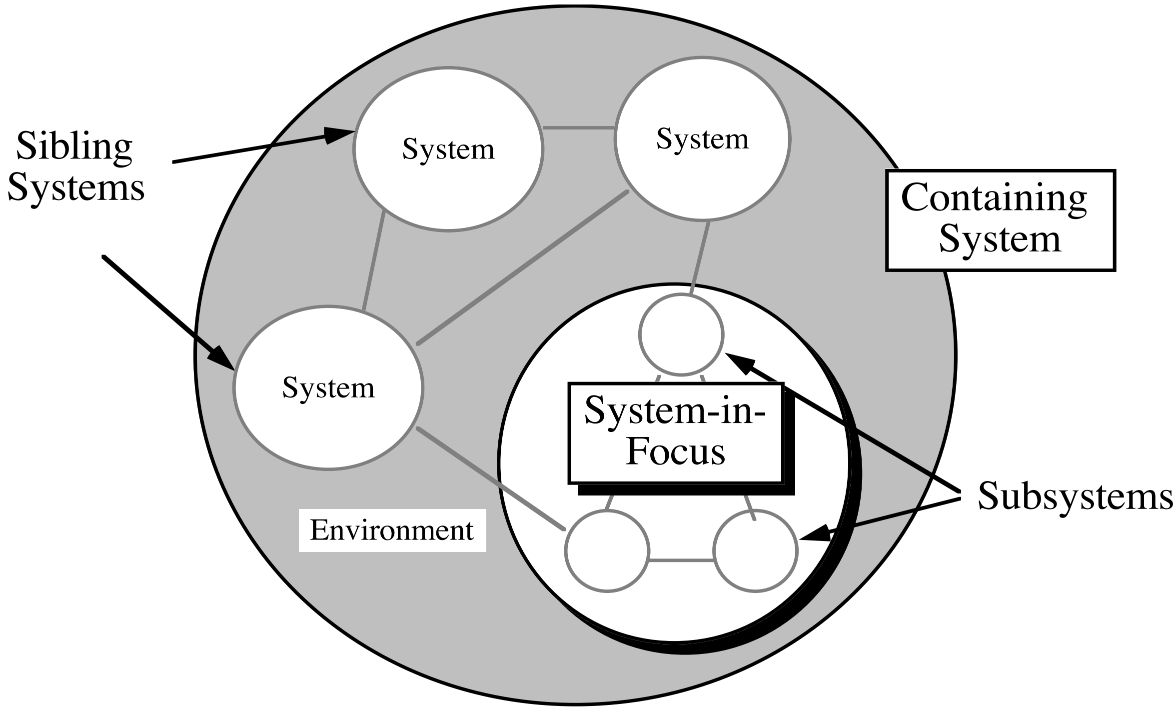
Sachs (1976) asks "Given an entity about which we know nothing, what should we presuppose about its nature in the process of conducting an enquiry?". He argues that the best strategy "to conduct the enquiry is to examine the entity under consideration simultaneously with its parts and a larger whole in which it is embedded, and never to assume that all its relevant properties may be obtained analytically from its properties already known". In other words, it is most prudent to assume that any entity under investigation is a System, is Open and is Inductive (as opposed to deductive). This is sound advice for all systems analysts, and has been observed throughout in the USH, particularly in forming the following systems images, which all apply simultaneously to any system.

A General System View



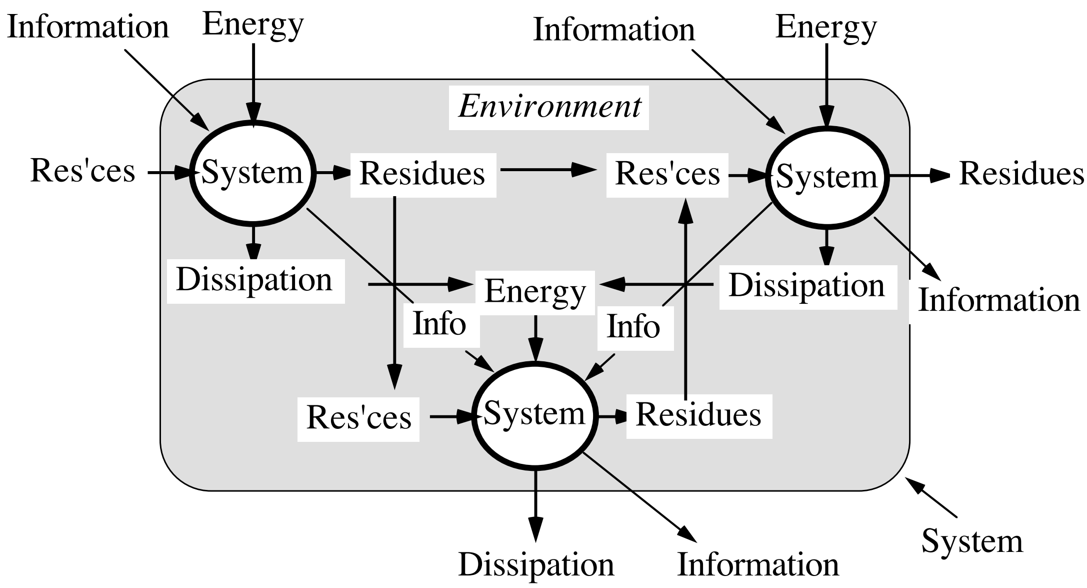
The first image is of a system receiving inflows, passing outflows and containing related and intra-connected systems. The inflows generally comprise energy, matter and information. The outflows are similar in substance but attract different titles. The system exhibits physical properties, it has order, structure or hierarchy, and it has capacity, intrinsic or explicit, to store/process energy, matter and/or information. Environment pervades and impinges upon the system and its contained systems. Evidently, this system image is of an Open System, connected to other systems not shown.

Systems Hierarchy



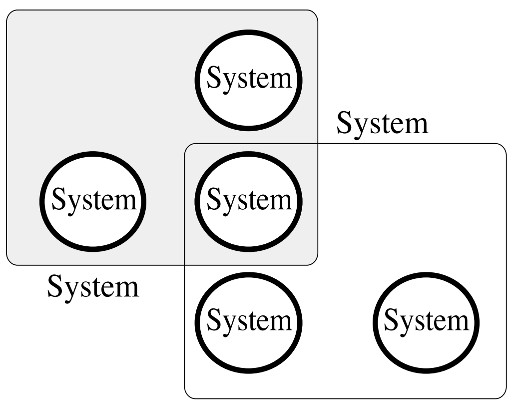
The second image presents a three-level system hierarchy in which a "System-in-Focus", that in which an observer has immediate interest, both contains systems (subsystems) and is, itself, contained in a Containing System along with other Sibling Systems. These siblings are related / interconnected to the System-in-Focus; its contained systems are intra-connected. Environment pervades the Containing System, but need not be homogeneous. Environment exists within the System-in-Focus, but need not be identical with that outside in the Containing System. Boundaries, shown as hard edges, may in fact be soft and fuzzy.

Interacting Systems



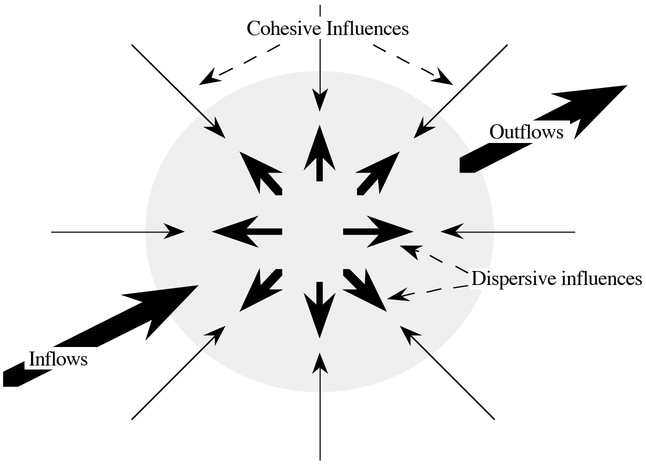
The third image combines the first two into a networked set of contained systems with mutual interflows, such that the outflows from some form the inflows to others. One system's residue becomes another's resource; one system's dissipation becomes another's energy source. Information is, unlike energy and material, exchanged without significant loss to the supplier. The interacting systems exist within a container that also receives, dissipates and exchanges, so providing hierarchical consistency.

Simultaneous Multiple Containment



The fourth image presents a different thought; that a system may be simultaneously contained within more than one container, as a bus-driver is simultaneously within a transportation system, a family system and a social system with his passengers. The potential complexity engendered by this image is staggering; if each system at each level of hierarchy can be simultaneously in a variety of containers then the resulting n-dimensional weave could be beyond untangling.

Cohesion and Dispersion



For a system to continue as an aggregation, it follows that there must be some cohesive influence attracting the contained systems one to another. That the system does not collapse to a point suggests that there must be counteracting influences tending to disperse the contained systems. Cohesive and dispersive influences must balance for a system to persist. Such balance could be static or dynamic (oscillatory). Since systems wax and wane, it must be possible for the balance to be changed in either or both directions. The fifth image presents system inflows and outflows as the mediators of change in this weakening or strengthening of binding influences.

U.S.H. DEFINITIONS OF "SYSTEM", "ENVIRONMENT" AND EQUILIBRIUM

System

Within a Unified Systems Hypothesis, the definition of "system" is of particular interest, since there have been many definitions. Sachs (1976) suggested, "a system is a set of related entities, referred to as constituents of the system". Jordan (1960) produced some 15 definitions, before contending that a thing is called a system when we wish to express the fact that the thing is perceived as consisting of a set of elements or parts that are interconnected with each other by discriminable, distinguishable principle. Hall (1962) defined "system" as "a set of objects with relationships between the objects and between their attributes".

Most satisfyingly, from my perspective, Russell K Ackoff (1981) defined as follows. "A system is a set of two or more elements that satisfies the following three conditions: (1) The behaviour of each element has an effect on the whole (2) The behaviour of the elements and their effects on the whole are interdependent and (3) However subgroups of the elements are formed, each has an effect on the whole and none has an independent effect.

Most commentaries agree that there are concepts both of parts, and of relationships between those parts, in the notion of system. I would contend that it is the *orderliness* of the systems concept that is appealing, in that it reveals pattern in complexity or from obscurity. Degree of orderliness is not evident in the plethora of definitions of system as a dominant feature. The following definition, used as a basis within the Unified Systems Hypothesis, is hopefully sufficiently vague to capture all kinds of systems, yet sufficiently explicit to be useful: —

> *A system is a collection of interrelated entities such that both the collection and the interrelationships together reduce local entropy.*

In this definition, the relationships receive a degree of prominence equal to that of the entities, because the pattern or network of relationships reduces uncertainty just as much as the collecting of entities. The definition covers all kinds of systems, human activity, man made, natural, etc., and is compatible with open as well as closed classifications. This is not to suggest a relational structural approach; Angyal (1941) suggested "systems cannot be deduced from relations, while the deduction of relations from systems still remains a possibility". Since systems could be related in many ways, a particular pattern of relationships carries information reduces uncertainty—the definition seeks parity for structure with entity, but not precedence.

Environment

Environment is a strange concept to define. It seems often to be thought of as a vague "soup" or medium in which systems exist. Kremyanskiy (1960) had a clear view of environment. "The external environment penetrates the entire living whole of...a group and turns in part into its internal environment....". Hall (1962), however, stated:— "For a given system, the environment is the set of all objects outside the system: (1) a change in whose attributes affect the system and (2) whose attributes are changed by the behaviour of the system." Sachs (1976) avowed "the environment of an entity is the collection of its envelopes relative to all its relevant properties. The entity itself is sometimes excluded by convention from the environment". The notion of envelope is one of co-production, in which the response of an entity to a stimulus is defined, not by the stimulus alone, but by other factors impinging on the entity at the same time. Ackoff and Emery (1972) hold similar views about environment and co-production. In Sachs' view, the environment was itself a system. Von Bertalanffy (1950), with his seminal Open Systems formulation, had little to offer on environment, causing Emery and Trist (1965) to introduce the notion of Causal Texture of Organizational Environments. In their view, "while Von Bertalanffy's formulation enables the exchange processes between the organism, or organization, and elements in its environment to be dealt with in a new perspective, it does not deal with all those processes in the environment itself, which are among the determining conditions of the exchanges"

Overall, it has to be said that the handling of environment seems to be either vague or inconsistent. And yet it is an essential feature from the most abstract of system levels down to the air we breathe and the situations in which we live. I therefore propose a seemingly new definition, designed—as with "system"—to be both vague, yet precise: —

Environment is that which mediates the interchanges between systems. Total environment is the sum of all such mediations

How does this definition work? Consider any two systems. Identify the exchanges between them. Identify that which mediates the interchanges; that is environment. For example, that which mediates the interchange between economic systems is money, barter and trade—we often speak of a "favourable trading environment." Consider a suburban dormitory system and a City business. That which mediates the interchange of people is the commuting facilities—we often refer to the travelling environment. Plants and animals exchange CO_2 and O_2 using the atmosphere and the biosphere as a mediator. In physics, forces are mediated by the exchange of particles. Conduction electrons mediate heat being con-ducted along a metal rod. Living, walking in the town and country, environment is that which mediates the multitude of interchanges between the surrounding fea-tures and us.

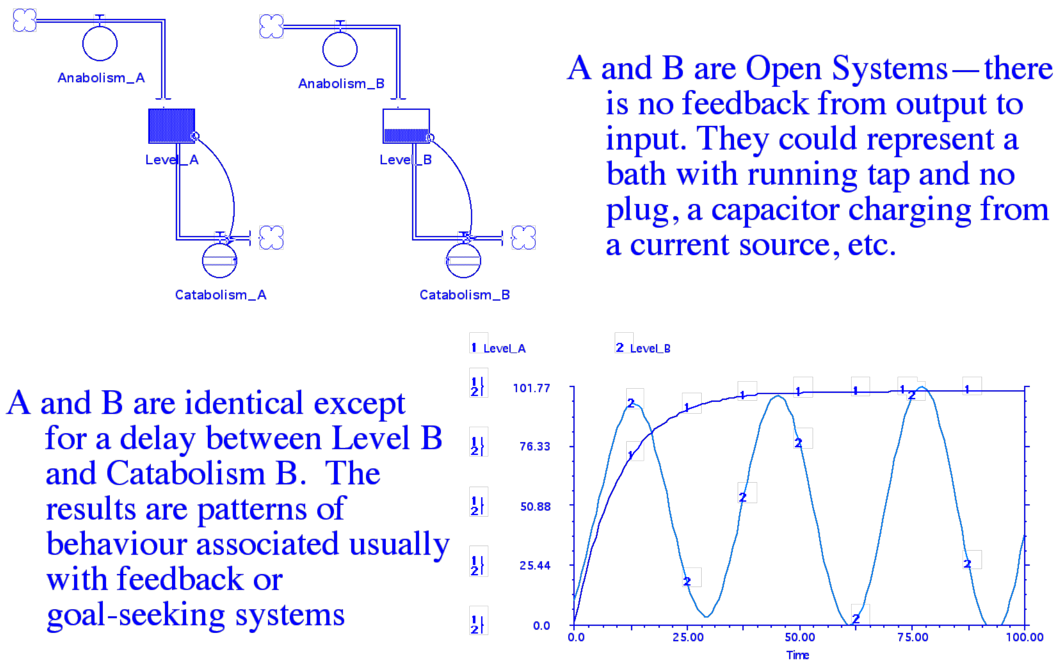
So the consistency with general understanding of the term arises. Kremyanskiy's "pervasive soup" can be seen as the sum of all the discrete one-to-one mediations going on at any time, some of which are interesting, others less so. And here is the value of the new definition. It enables identification of the environment of particular interest, part by part, so that we may be precise about those parts of the environment in which we have an interest, but may be vague about the other parts.

We humans tend to organize our environment into transport systems, communication systems, infrastructure systems and so on. This presents no problems within USH, since it is merely a hierarchy shift. It is, however, convenient to retain the notion of environment as mediating interchange between systems—it is a useful model.

Equilibrium

As with environment, so the notion of equilibrium has been disturbed by systems thinking. Koehler (1938) held the view that equilibrium was essentially associated with a low state of energy, as for a marble running to the lowest level in a saucer, while for many organisms what was frequently referred to as equilibrium corresponded instead to a heightened energy state. So, a horse stands while it sleeps and is clearly not at its lowest energy state, which would be lying down. A candle flame reaches its stable operating length from the wick when it is burning brightly, not at some minimum energy condition. Koehler referred to such phenomena as stationary processes, and his distinction is still valid. Nonetheless, the term ‘equilibrium’ is in general use and needs to be addressed.

The following figure[1] shows two models of an Open System, graphed alongside their dynamic responses to a constant inflow. The outflow is the same in each case in that it is proportional to the contemporary level, but in System B the outflow has been delayed—delay is not shown. System A behaves just like the candle flame—it grows rapidly, but growth rate levels off and it reaches a steady state. System B on the other hand oscillates and the oscillations will either diminish or increase in amplitude according to the amount of the delay. Boulding’s classification of systems (1956) places such open or self-regulating systems at hierarchy level 4, the level of the cell in biology, with the first three levels (Static structures, simple dynamic systems, control mechanisms) being closed in relation to their environment. And yet, as the figure illustrates, the model could be a representation of a simple physical system such as a bath or an electronic capacitor in parallel with a load resistor, charging from a constant current source. There seems to be some discrepancy with Boulding’s system classification, which is particularly interesting because it is often used as the basis for discriminating between living and non-living entities—see Kast and Rosenzweig (1973).



Evidently there can arise a static or dynamic balance between inflows to, and outflows from, an Open System such that it reaches a stationary or stable condition. I do not believe it necessary, as did Koehler, to give this a title other than equilibrium since there is clearly parity in operation, albeit not induced by feedback. The essential point that Koehler makes concerning energy wells is, however, important in Open Systems; the test for equilibrium cannot be one of minimum energy. Instead, I propose the following definition for all systems: —

[1] Using the STELLA notation for system dynamics modelling

Interacting systems can be said to be in equilibrium when their environment is stable, statically or dynamically

This definition of equilibrium employs the USH definition of environment, above. It should, to satisfy the objectives of USH, address all systems satisfactorily, including physical systems. The marble at the bottom of the saucer is subject to forces, mediated by their respective molecular structures. There is no movement and no friction. If the marble is displaced, it will roll back and forth under imbalanced forces, settling eventually at the bottom of the saucer again. While rolling, the frictional force is mediated by the adhesive forces between marble and saucer, and between marble and air, which are constantly changing until the marble is once again stationary.

The marble example shows a difference between the form of the usual definition of physical stability, based on a balance of forces, and the new definition. The balance of forces paradigm is prescriptive—if a suitable force is applied, it will result in equilibrium. The USH definition is descriptive—if the environment is stable, then it may be deduced that interacting systems are in equilibrium. In USH, stable environment is the litmus test of equilibrium.

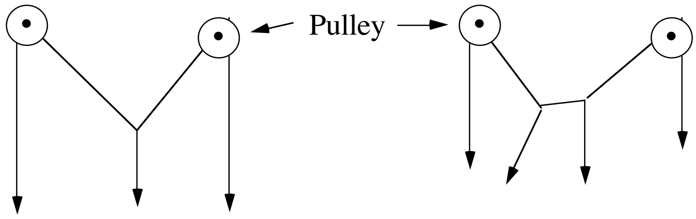
U.S.H. PRINCIPLES

We are now in a position to identify some simple systems principles, which are induced from observation, accepting Popper's (1968) admonition on the limited value of induction, but nonetheless presenting the principles in Popper's (1972) spirit of openness as the basis for progress. Later, predictions will be made from the principles that satisfy Popper's dictate of falsifiability, such that there is a potential for the principles to be refuted.

Interacting Systems

Le Chatelier's Principle is a general principle of interacting forces in classical science: —

"If a set of forces is in equilibrium and a new force is introduced then, in so far as they are able, the existing forces will rearrange themselves so as to oppose the new force"



In the diagram, the three forces at the left are in equilibrium. At the right, a fourth force is introduced and the original three readjust to a new point of equilibrium for all four. The example is of forces in a single plane, but the concept is seen so often in everyday life that a wider interpretation seems eminently reasonable.

The Principles of Interacting Systems flow simply from the images and definitions above, and are as follows: —

> *1. Interacting systems will tend to equilibrium.*
>
> *2. If a set of interacting systems is in equilibrium and a new system is introduced to the set then, in so far as they are able, the existing systems will rearrange themselves so as to oppose the new system*
>
> *3. Perturbation of a set of interacting systems at equilibrium need not be followed by a return to that equilibrium, but may instead result in a tendency to some other condition of equilibrium*
>
> *4. At equilibrium, the environment will be stable.*

These principles are unexceptional for physical systems, to the point that they may seem axiomatic; Le Chatelier (1850—1936) expounded them in 1888 in that context. Not so for all systems, however. The contention of the Unified Systems Hypothesis is that these principles apply equally to economic, political, ecological, biological, stellar, particle or any other aggregation that satisfies the definition, *system.*

An example of interacting systems seeking a new equilibrium can be found in urban commuting systems. Raising rail fares sharply to increase revenue in a supposed inelastic market can result in short term advantage, to be replaced by long-term loss as commuters switch to other forms of transport and companies opt out of the expense of urban operations.

The principles do not indicate the *manner* of movement. There is certainly nothing in the principles to suggest that movement should be linear. According to the systems and to their interactions, movement could be slow, fast, and even explosive, as suggested by Catastrophe Theory and Chaos Theory. Both these theories would seem to interface with the Principles of Interacting Systems.

System Cohesion

This principle derives simply from the fifth image above, and may seem axiomatic, particularly for physical systems: —

A system's form is maintained by a balance, static or dynamic, between cohesive and dispersive influences.

The Earth is held in its orbit around the Sun by a balance between gravitational and centripetal forces; that orbit will change as the Sun's mass decreases through its emission as radiation and the solar wind.

Since the USH is intended to apply to all systems, this principle must apply not only to such physical systems, but also—for example—to social systems such as families or ethnic groups. It is, perhaps, an unusual thought to consider that the influences that bind a stable family together equate to the influences that tend to disperse them. The notions are appealing, however, in that they stimulate thoughts as to what those influences might be and how change might be associated with external influences permeating the family group.

An example from the world of bees is relevant. As hives get bigger, the pheromone emitted by the dominant queen who assures bees that all is well with the world has to spread further and each bee receives less in consequence, until the level per bee falls below a threshold. At this point bees swarm to find a new hive. The cohesive influence is carried by the pheromone. The dispersive influence is unclear, but may be an evolved response to anticipate reduction in food due to concentrated local foraging. Perhaps the example of the bees gives a clue about limits to growth, evident in organisms, structures, societies and organizations which exhibit tendencies to divide beyond a certain side, measured either dimensionally or in numbers in the system.

Connected Variety

The Principle of Connected Variety is concerned with stability[2] of interacting systems. The third image above showed a small set of three interacting systems. As the number of interacting systems increases, and as their mutual interconnections increase both in number and in the variety of energy, matter and information exchanged, they develop a closer and more cross-coupled weave in which it is increasingly likely that system outflows will match other system inflows[3], leading to a stable environment. These considerations lead to the Principle of Connected Variety: —

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[2] Stability is not always a desirable state. A set of stable interacting systems may be resistant to change. While such resistance may be admirable in the biosphere, it may be less so in, say, business or politics, where controlled change may be the objective.

[3] Implicit in the definitions of interactions is the sense of flow and interchange. Relationships and connections which disconnect, which bar interchange and flow, require to be reformulated before applying the Principle of Connected Variety

Interacting systems stability increases with variety, and with the degree of connectivity of that variety within the environment

Evidently, there are shades of W. Ross Ashby's (1956) Law of Requisite Variety in this principle, but it is not intended as a cybernetic statement. Instead, the image evoked by the principle is one of Complementary Systems, sets of Open Systems whose outflows and inflows are mutually satisfying. The balance between floral and faunal CO_2 and O_2 exchanges was mentioned in the discussion of environment above, and is an ideal example of Complementary Systems; the balance depends upon variety and connectivity, and is evidenced by a stable environment.

The value of this concept may be considerable; it may even provide a new ethic for systems engineering, where concentration on local optimization could be overtaken by the concept of Complementary Systems—see below.

Limited Variety

The Principle of Limited Variety is stated as follows: —

Variety in Interacting Systems is limited by the available space and the minimum degree of differentiation

The principle is axiomatic once "space" and "minimum differentiation" have been established. To explain, consider a guitar string. It can vibrate in a variety of modes limited by the need for nodes at bridge and stop. This maximum set of modes is the available space; the minimum differentiation is set by the need for each mode to comprise waves in integer half wavelengths only. Consider religions. There are only so many religions in the world. The principle suggests that this arises because religions, to be different, must have a minimum significant differentiation; in this case, the available space is set by Man's intellectual view of religion. The variety of basic ethnic types is similarly limited by our perception of differentiation. Consider lastly specialization in labour. Odum (1971) showed that specialization increases as the environment becomes more benign. In such benign environments, the "space" for increased specializations increases; what constitutes a specialization is determined by the minimum differentiation required for one role to be considered discrete from another.

Preferred Patterns

As the weave of interactions between systems becomes more complex, it is increasingly likely that feedback loops will be set up, some perhaps existing through many successive systems and exchanges. The occurrence of positive feedback loops is to be expected, and leads to the Principle of

Preferred Patterns:—

The probability, that interacting systems will adopt locally stable configurations, increases both with the variety of systems and with their connectivity.

Locally stable, interacting systems abound. Cities, computer giants, international conglomerates, thunderclouds and tornadoes, molecular microclusters, ecological niches, bat and moth sonar, bureaucracies—all are instances of positive feedback, or mutual causality as Maruyama (1968) described it, leading to stable configurations. The general expectation of positive feedback is that it will produce some form of regenerative runaway. That need not be the case when such positive feedback exists within a web of essentially negative feedback loops. Instead, multiple points of stability can occur.

Duncan and Rouvray (1989) discovered recently that small aggregates of atoms form a discrete phase of matter, and that they aggregate in particularly stable configurations. Such cluster species are referred to as "magic numbers" by analogy with the quantum model of atomic nuclei in which certain combinations of protons and neutrons are allowed and others are not.

A new economic theory by Arthur (1990) suggests that the long-held view of supply and demand as a moderating, or essentially negative feedback system, is untenable particularly where modern high-technology products are concerned, and that positive feedback could provide a much more convincing argument to explain the dominance of, particularly, organizations which entered into a new, high-tech field early in its development.

There are many, many more examples from many diverse spheres of the development of preferred patterns, sufficient for the principle to be established by induction and to be mathematically modelled

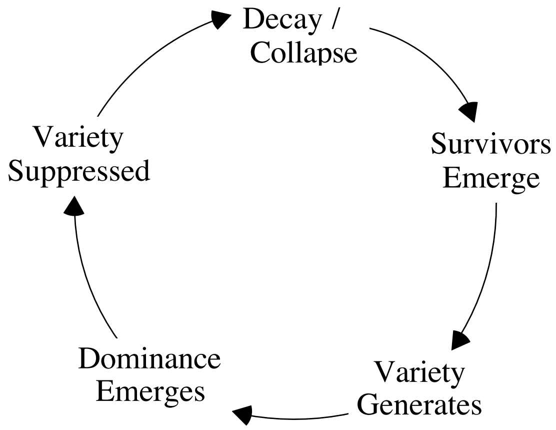
Cyclic Progression

The last of the USH principles addresses a phenomenon that we all recognize, that systems do not last forever. Civilizations may be considered as systems and as H. G. Wells (1922) noted, they come and go, as follows: —

> • Neolithic Civilization • Sumeria • Egypt, Babylon and Assyria • The Primitive Aryans • The Early Jews • The Greeks • Alexandria • The Romans • Carthage • China • The Barbarians • The Byzantine and Sassanid Empires • The Arab Nations • The Mongols • The Americans • The Industrial Revolution • And so on up to the present.

Such thoughts lead directly to the Principle of Cyclic Progression, expressed in words and graphically as follows: —

Interconnected systems driven by an external energy source will tend to a cyclic progression in which system variety is generated, dominance emerges to suppress the variety, the dominant mode decays or collapses, and survivors emerge to regenerate variety.



The principle does not imply that the *same* systems emerge. Clearly with civilizations, that is not so. Emerging systems may occupy the same "space" however, whatever that term implies in particular situations. Variety is generated in the space by influx from surroundings, or by mutation of systems (Maruyama (1968)), or both. Romme and Despain (1989) recently undertook an investigation into recurrent fires in Yellowstone National Park. The subject of interest was the relatively rare occurrence of major fires, although minor fires, initiated by dry weather and natural or man-made sources, occurred frequently. Between the early 1700s to the summer of 1988, there were major fires in 1690-1709, 1730-1749, 1850-1869 and 1988.

The suggested reason for the rarity was connected with ecological succession: each major fire created space in the locale. A few species were adapted to survive fire, and these grew. The space encouraged the generation of species variety, some from deep root varieties and some imported from surrounding areas by wind and animal. The varied flora encouraged varied fauna. The faster-growing tree species overtook the original, slower-growing survivors to form dense stands, intercepting the sun, and reducing the ground-level vegetation. Original survivors died out, to be replaced by second-generation varieties, letting in some sunlight and stimulating the growth of vegetation on the forest floor. Finally, matured trees died, small trees and dead branches accumulated, leaving the forest fully supplied with fuel for the next fire to become a major catastrophe, and so starting the cycle again.

The weight of evidence suggests that there may indeed be a repeating pattern in systems where variety, the mediator of stability, is suppressed by dominance[4], which in leads to vulnerability through inability to change. A

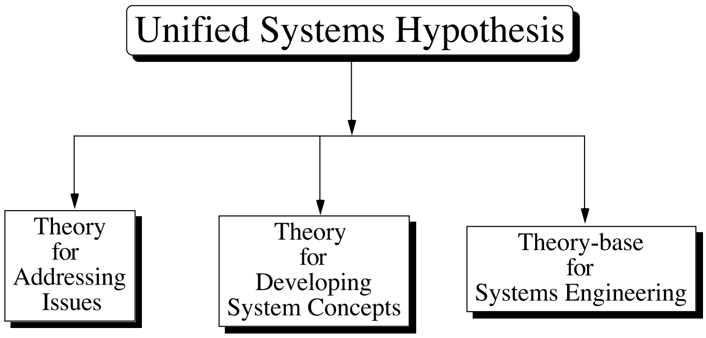
[4] *Dominance need not only be an indication of size, but may also refer to "pecking order", number of subordinate systems, absorption of total available resources, etc. Essentially, in interacting systems, dominance denotes substantial imbalance in favour of one system at a given hierarchy level.*

simple mechanical analogy might be that of plucking a guitar string off-centre, so as to create a wealth of harmonics. Gradually the overtones subside, leaving the dominant fundamental which decays in its turn. If the finger is moved along the fret board while the harmonics are present, any may be picked out. If only the fundamental is left, moving along the fret-board will suppress the vibration. Response to change is better where the variety exists.

U.S.H. PRINCIPLES AS A SET

The Basis for Systems Practice

As the figure illustrates, there are three areas in towards which the USH may contribute. At present, each of these areas is treated somewhat differently: —



- Addressing Issues. There appears to be no real theory for addressing issues, although there are many methods, some quite successful. As usual, such ad hoc methods, while pragmatic, may fall short of providing an ideal solution.

- Developing Systems Concepts. At present, system concepts are not always rigorously developed, the procedure being to go directly from a solution-transparent requirement into design. There appears to be a gap in the process, prior to formulating a firm requirement, in which creative, innovative concepts are developed, explored and assessed. In industry, for example, marketing staff quite often return from a visit to a customer having agreed with him the broad outline or architecture of a system, thereby setting in concrete one of the most important and difficult aspects of design without realizing the significance of their actions. There seems to be, moreover, no established theory for the development of traceable, supportable concepts

- Systems engineering itself is short on theory, as has been discussed

Complementary Systems—A Systems Engineering Method

Systems engineering is concerned with optimization. The concept of cost-effectiveness, often at the heart of systems engineering projects, is one of optimization. The USH images above present a problem in this respect. If systems exist in containers like Babushka Russian Dolls and if systems are interconnected and intra-connected, how can any one system be optimized in its own right without disturbing the similar optimization of siblings, contained and containing systems? Since the foundation of systems engineering methods and procedures, steeped in the original Operations Research (see Hitch (1955)), is fundamentally aimed towards optimization, this is a serious question.

Engineering in general, but systems engineering to a lesser extent, tries to operate in a closed system mode by defining sharp boundaries, interfaces and environment—this is practical and convenient, and can be applied successfully to products. It cannot be applied to the human activity systems within which engineers operate, nor to the due process of systems engineering (as opposed to product engineering) since, by its nature, systems engineering is concerned with interacting systems. Systems engineers tend to be graduated product engineers, however, and they can still attempt to see the system in isolation, like a product, by defining interfaces and minimising interest in what happens on the "other side". Thus, they may believe they are optimizing.

Is an optimized car one which makes most profit for its manufacturer, goes faster, handles best, uses least fuel, causes least pollution, sells best, absorbs least natural resources, takes least energy in production, provides most work for suppliers in a depressed area, etc? Any attempt to answer will show that optimization can only be local. Does this matter? The question says it all—the motor car is a classic example of local optimization, causing widespread pollution, absorbing resources, providing great pleasure and satisfaction, and connecting individuals and groups within society so as to improve societal stability and cohesion. The car designer does not concern himself with much of this when "optimizing" his design, and the accumulated effects of many "local optimizations" can be either good or bad, according to situation and viewpoint.

Perhaps a better alternative exists, as seen from the USH perspective. A new interacting system perturbs the fabric of existing interactions in many ways when it is introduced. It is possible, using the Principles of Interacting System, to develop a simple, new and effective approach to systems engineering, as follows:—

DESIGN GUIDELINES: —

- Establish requirements by reference to Containing System(s)
- Design system to complement Sibling Systems
- Partition system to promote internal variety, avoid dominance
- Intra-connect that variety to promote stability, mutual reward
- Enhance cohesives, diminish dispersives
- Interconnect that variety to promote external stability
- Interconnect to promote mutual reward

IMPLEMENTATION GUIDELINES: —

Step 1. Identify Perturbed Systems and interactions
Step 2. Adjust / Establish Complementary Systems to neutralize the perturbations.

Consider the following simplified example: —

A new, fossil-fuel power station is to be introduced to an under-developed region. Perturbed systems include almost all of those in the region, social, economic, ecological, transportation, etc. Complementing Systems will be needed to absorb / reuse the waste / effluent / dissipation / pollution from mining, transportation, generation, distribution & utilisation. Complementing Systems will be needed to:

- *Prevent any reduction in ecological variety* □
- *Manage the move of the regional economy towards a new, enhanced, point of economic equilibrium*
- *Manage the consequent social imbalance and the resulting evolution to a new point of social equilibrium.*
- *In addition, the Principle of Connected Variety suggest that there will also be a need for systems to gather, organise and communicate information about all the above systems to other systems within the environment.*

The need for such systems may seem evident, but the concept of optimization does not lead to their identification, while the Complementing System approach does so with ease. The concept of Complementing Systems seems to be a worthy product of USH.

Consider a “hard” example, i.e. one seemingly without social context: —

An aircraft, part way through design, is to have an auxiliary power supply introduced. The Containing Systems for the new unit include the aircraft, which has Form and Function, and the economic system within which the aircraft manufacturer and the supplier interact. The systems to be perturbed include financial, management, structural, propulsion, fuel, electrical, cooling, control and display, stability, drawing, tooling, assembly, test, maintenance, storage, documentation, and many other systems. Complementing Systems will be needed to absorb / redistribute the load, reduce additional drag / increase thrust, maintain the Centre of Gravity within Limits, store additional fuel / decrease specific fuel consumption, redirect fuel and air flows, reroute cable systems, redesign controls and displays, and many more, not forgetting the communication systems necessary to communicate information about the new systems to all the other systems

This is systems engineering but, while choices clearly have to be made, optimization is not dominant. The philosophy of "absorbing the perturbation using Complementing Systems" is in operation. Indeed, using a USH philosophy and method may enable systems engineers to address a *much wider range of system classifications* than hitherto, since the principles at work in the examples were not confined to engineering but were addressing much wider issues.

PREDICTIONS FROM U.S.H.

The U.S.H. Principles as One

Each of the six principles has been presented independently. It is evident, however, that they address complementary aspects of interacting systems: —

- **The Principle of Interacting Systems** addresses the tendency to equilibrium
- **The Principle of Cohesion** addresses the changing form of an interacting system and limits to growth
- **The Principle of Connected Variety** addresses the bases of stability between interacting systems
- **The Principle of Limited Variety** addresses the limits to differentiation in interacting systems
- **The Principle of Preferred Patterns** addresses the emergence of dominance
- **The Principle of Cyclic Progression** examines life cycle.

The principles are best viewed in the context of system lifecycle. Interacting systems exhibit stability as a result of their (limited) connected variety, while the emergence of dominant systems—due to positive feedback—does not *necessarily* reduce either the variety or the connectivity. Where dominance does result in, or is associated with, a reduction in connected variety, then decay and/or collapse will follow because of the reduction in stability and / or the tendency to dissolution associated with excessive growth and ponderousness, together with the concomitant reduction in ability to respond to change. Dominance can reduce variety by reducing the cohesion of lesser interacting systems so that they lose viability, or by effectively isolating such systems from the interactions, or both.

Predictions

The previous section, Complementary Systems, suggested the value to be gained from a USH perspective, by considering engineering projects as open, interacting systems. All systems engineering activities are *de facto* Open Systems both as human activity systems, and in the tasks undertaken. Systems engineering is perhaps the archetypal socio-technical system (Emery and Trist (1960)), since it not only is an Open System of Men, Money, Machines, and Materials (Jenkins (1972)), but it seeks—or rather, should seek—to create Open Systems as its *raison d'etre.*

Predictions will be made on a broader front, in keeping with the principle of Popper's black swan[5]—Popper (1972)— since to choose particular examples proves nothing, being inductive. Instead, a broad prediction will be more falsifiable—and it is to be remembered that the USH seeks to address all classifications of system.

Prediction A. It should be possible to increase the stability of any set of interacting systems by increasing either the variety in their interactions only, or their connectivity only, or both together.

Prediction B. Collapse or decay of a dominated set of interacting systems will be succeeded by the generation of an increasing variety of interacting systems

Prediction C. Dominance will tend to arise in any complex set of interacting systems.

Prediction D. Dominance will lead to the decay of interacting systems only where interacting system variety has been suppressed.

Prediction E. It is not possible to reverse the process of decay, once dominance has suppressed variety. Decay and the subsequent regeneration of a variety of interacting systems must ensue in sequence.

CONCLUSION

The Unified Systems Hypothesis brings together views and concepts from a wide variety of systems thinkers, old and new, and presents a set of system images, definitions and principles which are intended to provide a common basis for the perception, understanding, analysis, design and creation of all systems. This is a bold aim and it is difficult to prove—or disprove—many of the contentions presented. But then, it is a hypothesis and not a theory. The USH will have value if it provides an evolving basis for all systems practitioners to work together, soft with hard, open with closed, so that we

[5] *Proof by induction that all swans are white would be confounded by a visit to Australia, where there are black swans!*

may jointly improve our practices.

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