The Primacy of Paradox

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1 Introduction

Our world today is rife with systems and it's my bet that no amount of revolutions, IT or social, will rid us of them. *Au contraire*, all of our efforts are being directed at bigger, better, smarter systems. Special effort is being directed at a kind of system that makes ready use of a plethora of existing or legacy systems, having them work together in new ways forming what people are calling a Systems of Systems (SoS)[1]. These are new wholes greater than, smarter than, and more potent than not only any of the constituent systems but even the sum of them, however sum is defined.

Systems are ineluctably here to stay. Science however, which gave them to us and allegedly for our benefit, may not be able to lay claim to such permanence. Science, like so many of our present day institutions, systems all, is being rudely and inescapably visited by change, and of a kind that may even sweep science away or minimally make it unrecognizable from that which we know and love today. It is one of my goals in this presentation to say why I believe this and how to prepare accordingly.

2 A Systems Roadmap

Figure 1 shows a roadmap with several notable landmarks. In the top left corner we have systems engineering. This is both a body of scientific knowledge and a rational practice emerging from craft that many argue is the principal delivery vehicle for our contemporary systems. And not merely delivery; systems engineering also take care of maintenance, refreshment, renewal and timely retirement or recycling of these same systems. It is endemic to systems engineering to take care of systems from cradle to grave, or, as we are discovering from the energy-climate era [2], to learn to take care of systems from cradle to cradle.

In the top right corner is the new science, the science of complexity [3], which embraces diverse worlds such as the human brain, colonies of red harvester ants, sexual attraction mechanisms of Papua New Guinea fireflies, weather, climate change, biodiversity, and urbanization.

The remoteness of these two sciences is symbolic of their lack of communion and a spur to those committed to forming, if not a more perfect union of the two, at least a necessary unison of distinct harmonics.

M. Ulieru, P. Palensky, and R. Doursat (Eds.): IT Revolutions 2008, LNICST 11, pp.79–110, 2009.

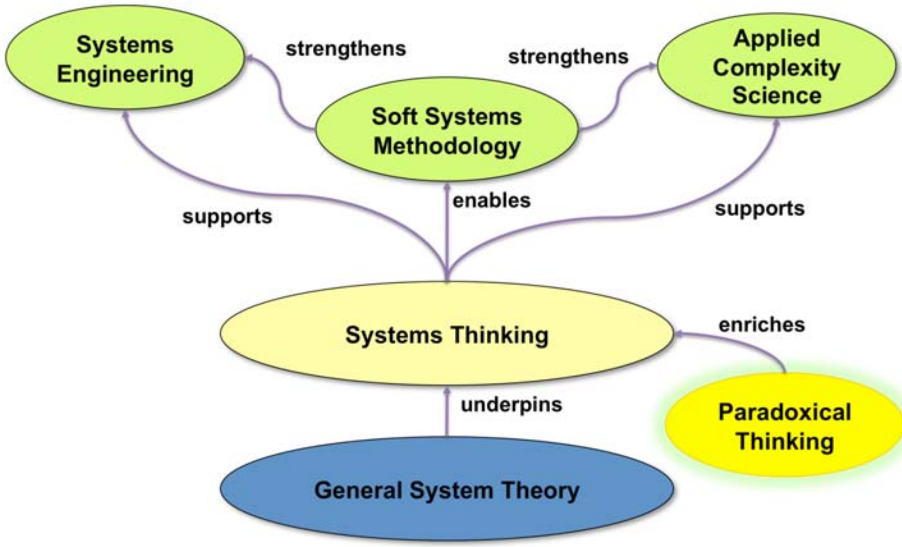

Fig. 1. A Systems Roadmap

Soft Systems Methodology (SSM) occupies the middle ground. This, as I see it, is both a migration of systems engineering, its developer Peter Checkland argued as such [4], and a precursor to the application of complexity science to the most challenging of all systems – ourselves. Perhaps I don't really mean *ourselves* quite as much as I intend to mean *communities of ourselves*, what Checkland termed human activity systems (HAS) and what some are referring to latterly as socio-technological enterprises.

All of these endeavors are underpinned by systems thinking, which is itself underpinned by General Systems Theory.

Thus while each micro-discipline of science, courtiers of the science king or stovepipes within the science park or industrial landscape, support and inform specific scientific endeavors, it is, in my view, systems thinking that provides a specialism in breadth or a horizontal integration mechanism for the universe of systems; a universe that comprises the physical, cyber, intellectual and sociological systems which populate and even crowd our planet and our minds.

A second major goal of my presentation is to validate this underpinning and relate how the horizontality of systems thinking operates and how it might even rescue science from being completely swept away by these irresistible winds of change, though its purposeful dethronement cannot nor should not be avoided.

The final noteworthy piece of this first slide sits unobtrusively to one side. It is paradoxical thinking. Symbolically marginalized, this piece of the landscape is neither innocent nor innocuous. It represents both the winds of change and a source of steering the scientific movement away from dangerous rocks which threaten sinking and drowning. It may even be a sail to direct our intellectual endeavors towards new currents that will take us to fresh discoveries, of knowledge and of ourselves, helping us to create systems better suited to communities of ourselves.

My third and final goal is to describe how paradox is endemic in these systems that heat, flatten and crowd our world, and how paradoxical thinking needs to be incorporated in the systems thinking toolkit or repertoire in order to rescue science from itself and to produce systems better suited to our new world.

3 Thinking about Systems

What can you make of the following assortment: a map of Yellowstone park, an elk, a wolf, a Toyota Prius, and an abstract network? This seemingly arbitrary collection would hardly qualify to be called a system, and yet these elements, and unobvious combinations of them, are precisely what we have chosen to exemplify that term.

If you think about these objects it doesn't take a lot of imagination to come up with a long list of stakeholders with interest in any one or more of them. Here are a few suggestions: geographers, ecologists, biologists, engineers, hunters, campers, metallurgists, and motorists. It might seem obvious at first which stakeholder attaches to which graphic but there are always surprises here.

Stakeholders have an interest in the system; to design it better or to exploit it more to their advantage are two conceivable interests. With that said it is evident that there are at least two kinds of system – the designed, for example the automobile, and the natural, for example Yellowstone.

In recent years there has been some interesting 'leakage' between the two. Designers of systems, having gained new respect for the qualities of design found in natural systems, be this a product of intelligent design or evolution, have sought to produce designed systems that in some way or other tap into these qualities, of resilience, agility or longevity. Designers seek to emulate the inherent, intrinsic attributes of natural systems.

Likewise the designed systems we create increasingly have an impact on nature, with global warming being a prime example of the effects of the so called 'dirty fuels system'. However, on much smaller scales, the increasing population of the automobile and of motorists has impact in terms of road infrastructures, suburbanization, family lifestyles, and so on. All of these changes inevitably leave their fingerprints on nature. Some argue that these effects have removed the invariance of the laws of nature themselves to the presence and interventions of mankind, a premise which has fundamentally underpinned scientific method. If this holds true we are really confronted by a mammoth revolution.

In addition to these points about stakeholders and of the intercourse between natural and designed systems, both of which begin to remove the arbitrariness of these graphics and lead us to see a variety of systems in their own right, I might point out one final and rather crucial point which refers back to the notion of systems of systems (SoS) above.

Both elk and wolf can be found in Aspen; one is prey and the latter is predator. Elk like to feed on young aspen leaves and these disappear rapidly as the elk population increases. Plentiful prey for the wolf ought to reduce the elk population and cause the aspen leaves to flourish. However, scientists have seen more subtle effects than predator becomes prey. In regions of Yellowstone where it appears to elks they have little room for maneuver or probable escape from predatory wolves, these will go untouched by elks and so aspen leaves will shoot up prolifically. It is the fear of the wolf, not merely the presence of wolves that has an effect of Yellowstone's ecology. This is a classic illustration of a system of systems where the relationships between constituent systems – wolves, elks and aspen, have a dynamism that transcends static traditional relationships.

Historically the automobile has been seen as a system, an integrated whole of subsystems, assemblies and parts. There are those who argue that this is a system of systems if the pieces of the system, for example the assemblies, can rightly be termed systems in their own right. But for others this lexicological argument is insufficiently strong. The Toyota Prius however can be truly regarded as an SoS. How so?

This is because the Prius designers recognize and respond to the reality that an automobile, as a system, is playing an adverse role in the wider system that is our planet. By wastefully consuming energy and dumping large quantities of carbon dioxide into the atmosphere the quality of life on the planet is diminishing for all, including the motorist. So these folk have exercised their design skills not only to realize personal transit in the automobile but also energy conservation in that very same system. And they have done this by opening up the functions of the automobile's assemblies to enable each of them to share in a collective responsibility of energy conservation on behalf of the system as a whole. This is turning parts into systems (technically they are called holons) so that these systems now not only provide their autonomous functions, e.g. braking but they have a sense of belonging and connectivity with one another sharing in the system's (i.e. the automobile's) additional responsibility to conserve energy.

Two actions the designers took were firstly to use the energy from braking to generate electrons which could then be stored in the battery and then use that, as opposed to gasoline, for driving as many miles as possible; and, secondly, to convert the kinetic energy realized by the car going downhill to generate more electrons to be stored in the battery for …. well you know. Some call this changing design thinking from focusing on a problem fix i.e. make a car get better gas mileage, to a transformational innovation i.e. make a car produce energy as well as consume it, one consequence of which is better mileage per gallon of gas. Other call this thinking systemically. At some point it will be called a revolution (and the Prius certainly gives many more revolutions per gallon than traditional automobile design!)

The significance of the network icon is to indicate the fundamental difference between a system and an SoS. Whereas the former is patterned conveniently on a hierarchical structure in which even part of a system can be further broken down into sub-parts, the latter is better signified by a network in which there is a greater sense of community at all levels and between levels, and this enables greater belonging of parts and an increased connectivity between them in addition to the sense of autonomy that each does its part but can now execute that role on behalf of the system and whatever revolutionary requirements are placed on that system.

This notion of community is an exciting one. We know it better in application to people systems and perhaps more broadly natural systems rather than the designed ones that people invent. However, it is not always that straightforward to engender serious community among people systems and that brings us to our next section.

4 The Boardman Conceptagon

An important question to ask is "How can systems people, practitioners and academicians, form a community of interest that is mutually supportive and collectively potent as opposed to remaining as a set of stove pipes littering the scientific and industrial landscape?" Put another way, "How can they act like parts of a Toyota Prius rather than the way in which regular parts in a conventional automobile act?" It is true that the latter do a good job, but in our complex world of systems there is more, much more expected of us than was once the case. Because the things that systems people do in their silos affect what others do, and maybe in counter-intuitive and counter-productive ways, it behooves all systems people to use their transcendental talent to work together, as a system, and anticipate the ways in which the systems they produce inter-relate, interact and emerge effects that often counter-point their intended good. My response to this challenge is shown in Figure 2 which is coming to be known as the Boardman Conceptagon.

One of the more important books for systems engineers to read is a work by Harry Goode and Bob Machol entitled, *Systems Engineering*. This is a foundational text, one to which contemporary writers and leading practitioners in this important and rapidly evolving subject area should pay due respect.

A key feature of that work is the distinction made between Interior Design and Exterior Design, a separation that in no way drives a wedge between the two. Rather, systems engineering is concerned not merely with each, but as importantly with the communion between the two.

Thinking abstractly, the words *interior, exterior* and *boundary* (the last being a notional demarcation of the two former) form an essential trio of concepts in the systems engineering lexicon. Likewise, the triple *inputs, outputs* and *transformations*, and another: *wholes, parts* and *relationships* convey ideas that inspire analysis and synthesis of a system's design, both the technical detail within and its suitedness to the system's operating environment.

Not only do these concepts aid the systems engineer in her personal efforts, they represent a bridge to other communities for whom the very same terms also bear much relevance, albeit interpreted vastly differently via specialist make-up.

An abstract thinker might ponder, 'What is the minimal set of triples, covering a sufficient variety and depth of intellectual effort to engage in purposeful systems design and analysis, that would not only support specific technical programs but would also support cooperation and collaboration between several specialisms needed to ensure mission success?'

The reason for asking such a question is twofold: first to form a basis for intelligent debate and effective collaboration between systems people of all walks of life; and, secondly to take a holistic view of the entire mission ensuring that whatever specific pieces the specialists provide, the whole itself is coherent, efficient, and suited for purpose. This collection of ideas is both scale free, covering multiple levels of systems effort, and horizontally integrative, uniting multi-disciplinary labors at any given scale, hence the Boardman Conceptagon.

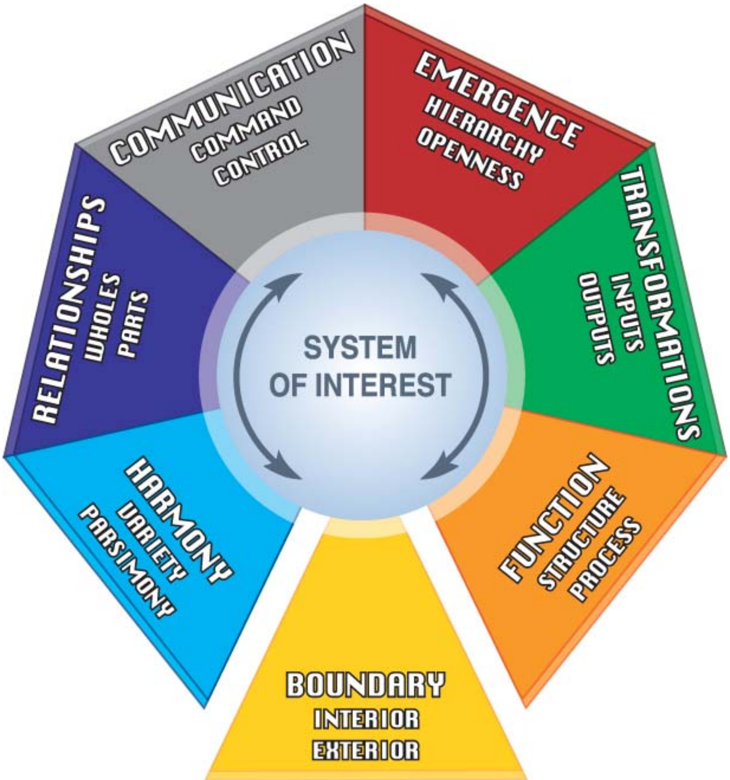

Fig. 2. The Boardman Conceptagon

At the center of this icon is a specific system of interest (SoI). This can be captured initially in a variety of ways: block diagram, flow chart, process map, SysML [5] diagram, or prosaic system description. (Within the systems engineering community and latterly the enterprise architecting community, frameworks exist to guide the overall capture of a system of interest as a collection of models using a variety of modeling paradigms.). Wrapped around this center are seven triples, three of which we have already introduced. The intention is to use each in turn, in any order and with several iterations to explore the system of interest – either analyzing a pre-existing system or synthesizing a new one.

Thus for example consider the triple: boundary, interior, exterior. If we argue that the name of the SoI is the system boundary, e.g. an iPhone, then the inside of the system ought to be obvious, e.g. integrated circuits and the Apple OS X software, or some variant thereof. A crucial element of the exterior would be iTunes with which the iPhone might connect in order to enrich the interior.

One would like to argue that the iPhone was systems engineered. What if systems engineering was the name of the SoI? What then is on the inside? What exactly is systems engineering, and what is on the outside, in the exterior? In other words where does this SoI, systems engineering, prosper and where does it do less well? We will address this issue in the next section.

What if the SoI was a question, e.g. "Who came after Harry Truman?" It would be relatively simple to guide the person being asked this question along a line of reasoning that strongly suggested the pattern to be succession of US Presidents. (Harry Truman was 33rd in the list). Doing so makes it obvious that the answer is Dwight D. Eisenhower, 34th US President. However, a valid response is Doris Day, who was never US President. However, her name comes immediately after that of Harry Truman in Bill Joel's hit record *We didn't start the fire* [6]. Here we see how the interior, the answer to a question in this case, adapts to the exterior, the context of the question. This responsiveness is not an unknown phenomenon to natural systems, and increasingly to designed systems purported to be agile [7].

At first sight it would appear that all the boundary is is a demarcation between the interior and exterior, a concept of little consequence. But then one observes that the interior is what the system is and like all systems it needs to be protected, it needs to be preserved, it needs to prosper. The boundary has a role in all three functions. The exterior may be hostile or docile; it may contain elements which would injure the systems, especially if they got into the interior, or it may contain elements which would be good for the system. Likewise the system may produce waste that may need to be ejected, or recycled, possibly by some other system. The point is that the boundary must permit the ingress and egress of elements in both interior and exterior. And it must do so intelligently. To all intents and purposes this makes the boundary of a system a part of the system (and a part of the exterior) and a system in its own right even, perhaps belonging to both.

This leads to a boundary paradox, our first hint at the paradoxical thinking landmark on our systems roadmap, which can be stated as follows: "You must have a boundary (to nurture and develop specialization in functional expertise, for example). BUT you must also NOT have a boundary (to allow that specialization to be rendered as a service [otherwise why have it] and to allow that expertise to be resourced via interactions with others). So it is possible that a good boundary must both exist and not exist simultaneously. The boundary must *keep* things out and in, but it may also have to *let* things out and in.

This triple and others like it begin to make a line of thinking more formally accessible by their mere existence. Just think what could happen if systems professionals from different walks of life shared their knowledge via this medium! Who knows what new ideas would be generated, possibly even of a transformational nature.

Let us turn to a 2nd triple: command, control and communication – one that is very familiar to the defense community at large and the military services in particular.

When Thomas Stallkamp, former VP of Chrysler, asked his line managers, "How many people and how many firms do you think are involved in the end-to-end process of conceiving, making and selling a Jeep Grand Cherokee?" it took them a while to find the numbers. The answer: 100,000 firms and 2 million people from initial product concept through to a satisfied customer driving her new purchase off a dealer's lot [8]. This answer is startling to most people who have never been involved with the entire life cycle of a product.

But once he recovered from the shock of that answer, Stallkamp posed a telling follow-on question, "Who's managing this enterprise?" The real answer is a paradox – no one is and lots of people are, our second hint at the paradoxical thinking landmark on our systems roadmap.

We must accept the fact that no one sits atop the Chrysler Jeep Grand Cherokee "experience." Perhaps in a titular sense someone does, but in no way can they be said to be its manager. Whoever occupies that office, they are neither a Washington nor a Napoleon commanding thousands and controlling affairs according to their grand strategy. Littered throughout the management hierarchy, or network if you prefer, are hundreds of people, each with their individual spans of influence and concern. But in what ways can this diverse collective be said to be in control of the whole experience when it is probably the case that they are largely unknown to one another? Do these managers perform like ants, somehow supporting excellent behavior for the Cherokee colony? Can control be just as effective, if not more so, if it is distributed rather than precisely located in a central commander? Can we really trust distributing control to a constituency that is largely unaware of the affairs and actions of its neighbors and upon whom a mighty burden of communication must fall in order to rescue order from the grip of chaos?

It is critical to understand whether when we ask "can we really trust distributing control to …?" we are even asking a useful question. When Stallkamp asked who (in particular rather than plurality) is in control of this vast extended enterprise, he was doing what any experienced executive or manager would have done—attempting to establish organizational accountability. A different question, however, may have proved both more illuminating and more useful. The questions we ask are largely a function of our mindset, and that the purpose and benefit of paradox is to confront that mindset—to make us challenge our reliance upon the "conventional" questions and position us to change our mindsets. In so doing, we can release the tension revealed by the paradox and move to the kind of breakthrough thinking that can offer solutions to problems long thought intractable.

Control is to engineers (and managers) what power is to politicians—the ability to influence actions, whether in hard systems or soft ones. Tennyson's The Trinity of Excellence in Leadership, cited by Emile Brolick [9], was neither the first nor the last work to observe that, paradoxically, effective control of others begins with control of self. "Order givers" must not abuse their authority lest they lose it, while "order takers" must exercise self-control when responding—the whole system relies on it.

Current theory includes two poles: "command and control," by which authority "at the top" issues directives that get resolved into executive action by a large group of people; and the "self-organizing" notion of an idea that infects (from the bottom), propagates and galvanizes a group of people who then take action as though they were a unit and had been commanded by a governing authority [10]. These polarities lead to a control paradox: "You must have command and control (to ensure orderliness and conformity to strategic direction). BUT you have must also NOT have command and control (and instead have ground-zero intelligence to foster innovation, tactical opportunism and preservation of self-awareness)."

Put differently:

- authority must exist at the top (for order), but it must also exist at the bottom (for autonomy);
- command must exist (and orders from an external source must be obeyed), but so also must the power to be insubordinate operating alongside a self-will that knows its own order and orders;

- control must operate within a framework that grants liberty to its constituents, but control must also be manifest in the self—as self-control and self-discipline to make the framework work.

The trick for both leaders and managers is to figure out how to embrace and resolve this paradox. Horatio Lord Nelson understood and leveraged it well [11]. He exercised and gave his subordinate commanders:

- **Ordered liberty and Creative disobedience.** To ensure he would be able to seize the initiative in battle, Nelson gave his subordinates (and himself) a clear articulation of his intent and the freedom (within that intent) to deal with situations as they came up, even if it meant ignoring orders.
- **Reciprocal loyalty.** One must give loyalty down the command hierarchy to gain true loyalty (vice obedience through fear). Nelson cared about the welfare of his men, they knew it and reciprocated.

5 Soft Systems Methodology (SSM)

When we introduced the triple of *interior, exterior* and *boundary* we coupled this with the question, "What if systems engineering was the name of the SoI? What then is on the inside? What exactly is systems engineering, and what is on the outside, in the exterior? In other words where does this SoI, systems engineering, prosper and where does it do less well?" We said at that time that we would address this issue in the next section; well, here we are!

Peter Checkland was invited to join the Department of Systems at the University of Lancaster by his close friend Gwilym Jenkins, a noted control systems engineer. The intention was for Peter to do scholarly work that would extend the reach of systems engineering to problems that lay beyond traditional boundaries, more in the socio-technical areas in which culture, politics, and the messiness of humans left its mark.

In retrospect this was a bridge too far, but in fairness to Peter Checkland and in keeping with his strongly scientific approach, rooted in inorganic chemistry and honed in the research laboratories of ICI he began his studies with the codified versions of systems engineering at that time and attempted some form of migration of their essence to a form that better suited the aforementioned messiness of what he later called *human activity systems* (HAS). What finally emerged was Soft Systems Methodology (SSM) and after more than 30 years of exposure to the pernicious currents and howling gales of the messy realities of HAS, which Gwilym Jenkins sought to tame, it has proved rather durable if not the answer that all would wish. Evidently there is room for further development of technique, as one might expect. But this is an excellent opportunity to take stock of Peter Checkland's work, in terms of the essence of its interior and the nature of the exterior to which it has been exposed.

Starting with the latter, this has variously been described by terms such as 'wicked problems [12]', multiple simultaneously tenable viewpoints (STV), ill-structured problems, counter-intuitive behavior [13], and problems that require problem definition. What this means is that the environment has many stakeholders each with valid perspectives on the problem but none in agreement as to what this is precisely. It also means that sincere remedies thoughtfully formulated often have a counter-productive effect since the problems, however defined, have a habit of either ignoring interventions intended to eliminate them or worse responding adversely producing a worsening situation.

Clearly, this is not a happy situation for the would be problem solver, now confronted by a serious dilemma; she is damned if she does nothing and damned when she does. It does little good, though it offers a degree of relief, to read rather humorous accounts of how systems, of both the solution kind and the problem kind (it is often helpful to regard a problem as a system), have a will of their own![14]

Given the fact that SSM has endured, in the face of such perversity, it must at least be intriguing to know what exactly is its essence, what is on the interior of this SSM system, to have given it such fortitude and reasonable popularity. I am happy to give my personal account of this fascinating interior.

The most important feature of SSM is the divide that Checkland promotes between the real world and the systems thinking world. It is as if the only chance of success lies in keeping these two separate. Of course were this separation to be an unbridgeable divide separated by a bottomless abyss which none dare cross, it would add little value. However, bridges are the secret of Checkland's methodology. They are crossed with care and due circumspection as befits the messiness of the real world and the sanctity of the systems thinking world. They are respected by citizens of each world.

Two things never cross this bridge: problems and solutions. This is vitally important, and gives us the 2nd feature of SSM: that the people working away in the ST world are NOT problem solvers; it also means that people battling away in the real world are THE problem owners. They own the problem and the problem remains with them. If the problem is ever solved it is solved in that real world and curiously enough not by means of a solution but rather by means of the problem owners' executive action - which can intelligently be nothing! – that treats whatever problem has been defined arrived at by whatever enlightenment appears, hopefully as a consequence of what does cross the northbound bridge.

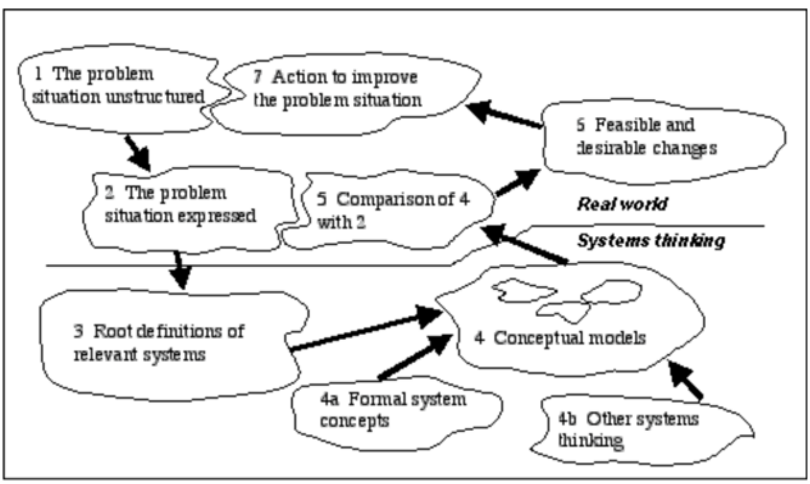

Fig. 3. Checkland's Soft Systems Methodology

If the problem stays permanently as it were in the real world, what is it that crosses the southbound bridge of which systems thinkers can make some sense and give something back, in the form of enlightenment hopefully, to the problem owners? This is a good question. An inspection of Figure 3 might suggest that what heads south is some form of expression of the problem situation, and that is true. But it is only part of the truth. Because in order for the systems thinkers to be effective they must be part of the real world and yet remain aloof from it! They must be accepted in the real world, as legal citizens, when in fact they are more accurately legal permanent residentaliens who never naturalize!

What systems thinkers take with them into their hallowed sanctuary is as deep an understanding of: the problem situation; the problem owners themselves; and, the very culture in which the problem and owners are immersed. Yet the systems thinkers must not be drowned by this understanding; it must not overwhelm them nor bias them in the way that it inevitably does the problem owners. Being part and yet not part of the real world for the systems thinkers is a paradoxical property of the SSM which gives it vitality.

Therefore what accompanies the problem situation expressed on its journey south is this deep understanding held by the systems thinkers and practiced by them in their own world. This leads naturally enough to another question, “What is this practice?”. The answer to this provides our 3rd feature of SSM: that the models which the systems thinkers come up with are of IDEALITY NOT REALITY.

It is as if Checkland gave up on building models of reality, the stock in trade of systems engineers, and if this was the case, then it was surely based on this line of thinking. Reality is very messy and any abstraction of it is never going to be informative as to its true nature. This messy reality is subject to enormous subjective interpretation by various stakeholders so even an abstraction of reality based on one perspective will be unrecognizable to a stakeholder with a widely differing perspective. Finally, building models of reality simply does not help since they can in no way advise you what to do – the reality is, you’ve guessed it, far too messy! Checkland’s response was to posit an unreachable ideality which would at least capture, in pure form, a world-view that was indeed idealistic but whose virtue would be to draw people towards the realization of that ideal. Wherever this brought them would still be real but ostensibly far better than the conditions they faced which was giving serious cause for concern.

The technical details of the SSM Practitioners need not concern us at this point, save to say that the effort is twofold: to build, via the problem situation expressions, those ideal systems whose very being would seem to directly follow and whose eventual realization would give rise to an ideal situation. From these statements of systems being follows a practice to define what these systems need to do in order to be. The former effort, leading to root definitions, is strictly definitional with emphasis on nouns, e.g. agents, agencies, and artifacts; the latter effort, leading to conceptual models, is operational, requiring emphasis on verbs. E.g. transactions and transformations.

It is this collection of definitions, models and renewed understanding that heads back north, giving the systems thinkers (aka analysts) an opportunity to play a full part in the real world via their dialogue with the problem owners. Once again there is a key pointer to bear in mind as the dialogue unfolds among analysts and stakeholders, a dialogue enriched by the conceptual models. This refers to the manner of making comparisons between the original problem expression and the conceptual models, and Checkland suggests four distinct ways.

First, the models can be used to suggest a line of ordered questioning. Quite possibly what takes place in the model in no way resembles what presently transpires – but that can be a good thing, and it stimulates fresh thinking by the stakeholders. A second way is to reconstruct the past and compare history with what would have happened had the conceptual models been followed faithfully. In both these cases, the models themselves can be hidden from the stakeholders, so that they are not seized upon as either the answer to their problems or absurd notions that can be flatly rejected bringing an intransigence among stakeholders and a resignation to cope with what they have. A third way is to reveal the models and accompany their presentation with questions about how they differ so much from present reality and why. Finally, an approach known as 'model overlay' can be tried. Here a new set of conceptual models are created this time they are based on reality and are designed to capture as much as possible the way things are. The only rule is that so far as possible they should have the same form as the 'divorced' conceptual models. What this overlay approach does is to highlight the distinctions, which of course is the source of discussion for change. What's more these new models can be reverse engineered into root definitions, and then that can be compared with the one that was obtained from phase 1.

The purpose of this dialogue phase is to generate debate about possible changes which might be made within the perceived problem situation. In practice the work done so far can itself become the subject of debate and change! This requires humility on the part of the analyst: how can he expect stakeholders to change when she herself won't? Changes can be to any of the artifacts of the process, or to the process itself. (But then thinks can only get better!)

Checkland suggests there are three types of change: in structure, in procedures, and in attitude. Structural changes may occur to organizational grouping, reporting structures, or functional responsibility. Procedural changes are to the manner of getting things done, for example the periodicity or medium for reporting. Attitudinal change is of the mind and the heart, and usually less easy to accomplish than the former. The criteria for suggesting and effecting change must be whether they are systemically desirable and culturally feasible. The former refers to a respect for the integrity of the SSM and of all the artifacts this generated; in other words change ought not to be arbitrarily effected simply because 'something has been done' but that something has not been acknowledged. The later criterion shows respect for the problematique and for the stakeholders themselves. Even when change is obvious and agreed upon, it may not actually be deemed implementable simply because of 'conditions'. That is political (and economic) reality. The analyst hasn't necessarily failed; after all he is no longer dealing with buttons in the engineering sense, but belly buttons.

6 Paradoxes of Complexity

We come now to the top right hand corner of our systems roadmap, to the science of complexity. Our interest here has little to do with admiring or recounting the enormous and remarkable achievements in this space over the past half decade or so, summarized sublimely and with unique elegance and authority by James Gleick [15].

It has more to do with revealing the inherent paradoxes that complexity science holds. In this way we can begin to see how the terms *system, complex* and *paradox* form an amazingly powerful trinity.

Our summary of these paradoxes is as follows:

- Complexity is simpler than it first appears
- Simple things exhibit complex behavior
- Little things mean a lot
- Large worlds are smaller than we think
- Significant things are vital and obscure
- Weak relations bring strength and security
- The rich get richer and the poor
- A complex is one and many simultaneously

What we will do is to take a cursory glance at our complex world, with its 6 billion plus people, its intricate food webs, the behavior of some of its less obvious animals – fireflies of Papua, New Guinea, and our own human brains, among many other of life's complexities and in so doing illustrate the paradoxical summaries we cite above. In so doing we hope to emphasize the primacy of paradox as a way of life, our way of life, and set a new direction for scientific thinking, a way that not only benefits from complexity science but also from systems thinking, one that has paradoxical thinking in its core.

6.1 A Weakness Stronger Than Strength

How many people do you know? Is it 10, 50, 100, or more? Some of us know lots of people, others very few. In reality it is harder to really know many people very well. So some of our relationships, relatively few, are deep and regularly maintained. Others are more on the acquaintance level and it is often difficult or too bothersome to keep these latter relations going. Over time they usually whither and die. Their demise at least can be considered at the expense of strengthening the few that really matter, however those are decided.

Some of your 'circle' will know people you don't know, which in a way extends your network. But most of the people you know will know one another. These circles are probably better referred to as a cluster, a reasonably tight knitting together of a close group of friends. Clusters make up a world but they do nothing to make it small. Strong ties hold a cluster together but it is the weak ties that turn a collection of clusters into a small world [16].

It is this paradox, that weak ties are what gives a small world its strength, that for us typifies complexity and systems thinking. It is one of many, as we shall discuss. But lingering with this a little is worthwhile for we must continue to break out of a mindset that insists a network is either a circle of friends or a circuit of transformers, power lines and switchgear. Weak ties explain the computing power of our human brains and the synchronicity of fireflies in a tropical rain forest in Papua, New Guinea. From friends and fuses to fireflies and firing neurons. We are beginning to explore the groundbreaking science of networks, and with it immense opportunities for complexity understanding and systems thinking.

The articulation of a small world architecture using the mathematics of graph theory is comprehensively captured by Duncan Watts [17]. A paper by Watts and his thesis advisor Steve Strogatz, largely free of mathematics, set ablaze huge interest in the phenomenon of small-worldness with its architectural fingerprints being found in diverse fields as ecosystems, natural language and the World Wide Web [18].

At the outset of their work together they sought to introduce random links between a fully ordered network of clusters. Suppose an initial circle (of friends say) has 1,000 dots, each connected to its 10 nearest neighbors. This gives in all about 5,000 links. To this let's add 10 links at random (0.2%). The network is still essentially ordered but is now lightly splashed with randomness. More and more links can be added gradually at random and the effect on clustering and on any perceived small worldness calculated. This is a form of network evolution with strict order being updated with random rewiring. They found that whilst small disturbances had no noticeable effect on clustering it had a devastating effect on small worldness. Initially the degrees of separation was 50 but with a few random links it plummeted to 7. Skeptical of their findings their experimentation continued with greater scrutiny. No matter what they did however they always found that the lightest dusting of the ordered network with random links produced a small world.

In a planet of 6 billion, with each person linked to their 50 nearest neighbors, the number of degrees of separation is of the order of 60 million. Throw in a few random links, a fraction of the total being 0.02 % and the degree of separation drops to 8. If the fraction is slightly increased to 0.03% it falls to 5. Clustering, a social reality, persists but small worldness, a counter-intuitive phenomenon appears. Courtesy of random encounters, forming relatively weak relations, but strong enough to tie a planet together. Little things do mean a lot! Now what about those fireflies and fiery neurons?

6.2 Ready, Fire, Aim

Imagine a 200 yard stretch of forest bordering a river in Papua New Guinea. The trees are forty feet tall. The scene whilst verdant and panoramic is nothing extra-ordinary. A firefly decks each leaf but you see none. Night falls. Speckles of light dapple the stretch and interest awakens. Soon there are clusters of blinking lights as near neighbors get accustomed to their fellow flashers. The scene crescendos in a series of single solid flashes, about twice per second, along the entire stretch. Millions of fireflies have synchronized themselves into an orchestra of light in the darkness. It is a vista to rival anything that Walt Disney pulls off at EPCOT. The scientific term is terrestrial bioluminescence [19]. But let us not allow technical nomenclature to obscure an inexplicable phenomenon.

How is this possible? How is synchronicity achieved? Is there a conductor for this orchestra? The ant, we are told, has no commander. Are fireflies somehow a brighter species, that a leader emerges from their uniform ranks? And if so, is it possible for millions of fireflies to notice a single leader and be smart enough to subordinate themselves to this single command? Perhaps not. By the same token it appears unlikely that fireflies have the bandwidth to tune into all their neighbors. If there were say 10,000 fireflies the total number of communication paths between them would be 50 million. Can a single firefly monitor 10,000 chat lines in the context of 50 million traffic lanes? Unlikely. The motivation is high. The flashing is the means by which males attract females as a prior to mating. It makes sense to produce a series of single blinding flashes. That will get the females' attention. Going it alone is risky. But can a forest of fireflies produce the collective consciousness to synchronize in order to maximize mating potential? Who has that idea? Some of them or all? And how do they share that notion?

To make progress with these questions we need again to turn to the seminal work of Duncan Watts and Steve Strogatz. It seems possible that near neighbors will somehow get their flash act together. By comparison two grandfather clocks near to one another in a room have exhibited a synchronism of their pendulums, the explanation being the interaction of rhythms each transmits to the other via the floor. Let us argue then that each firefly responds mostly to the flashing of a few of its nearest neighbors. The computational burden on a firefly is now more realistic, tuning in to say 5 neighbors. The traffic lanes are now reduced to 0.1% of what they were when each firefly could communicate with any other of a population of 10,000.

A rare few fireflies might also feel the influence of a fly or two at a longer distance. A few fireflies might have a particularly brilliant flash, and so be visible to others far away, or few genetic oddballs might respond more to a fainter flashes than to bright ones. In either case, some fireflies make it possible for long-distant links to exist between evident clusters. This argument begins to present the opportunity of a small world pattern.

Watts and Strogatz carried out computer simulation using this small world architecture and repeatedly found that the insects were able to synchronize almost as readily as if each one had the power to speak to any other fly. In essence the pattern is a breakthrough in computational efficiency.

No one really knows how fireflies are 'connected'. Only a few species in Malaysia, New Guinea, Borneo and Thailand have the power to synchronize evidently. So the terrestrial light orchestra is still shrouded in mystery. But a fingerprint of computational speed and power may have emerged. Armed with that it does not seem unreasonable to ask whether our human brains, computation engines par excellence, might possess a small world architecture.

Phrenology is thoroughly discredited as a body of knowledge. But it was not entirely without purpose. The notion that the brain is somehow arranged into organs, functional building blocks each devoted to specific tasks such as memory, sight, sound, emotion and so on, is one that has usefully carried over from the hocus pocus of feeling the lumps and bumps on our skull as a pattern match with personality traits, into modern day neurological science.

The cerebral cortex is held to be the locus of our higher capabilities. This thin gray intricately folded and delicately packed outer layer of the brain, just a few millimeters thick, contains the precious neurons from among the 100 billion that make up the brain's tissue. The cortex is the part of the brain that lets us speak, perform mathematics, learn music, and invent excuses for being delinquent. It is what makes us distinctively human. And it is indeed organized into something like a set of organs. MRI scans are ways of detecting neural activity based on oxygen content in the blood flow patterns around the brain. They can therefore act as a lens into the modular decomposition of the brain relative to various tasks in which we are engaged, e.g. responding to a verbal command, recognizing a taste, or recalling a friend's address.

Squeezing 100 billion neurons into a 3 pound lump inside the skull seems far fetched but not when you consider that you can get more neurons into a thimble than there are people in the United States. Crudely, a neuron is a single cell with a central body from which issue numerous fibers. The shortest of these called dendrites are the cell's receiving channels. Longer fibers known as axons are the transmission lines for the neuron. Most of the neurons link up with near neighbors within the same functional region. Signals from axons are received by dendrites and so neural activity is myriad signaling along these channels of which there are hundreds of trillions. The brain is interwoven like nothing else we know. It is complex. But is it simpler than it seems?

Whilst functional regions are in effect clusters of neural connections. The brain also has a smaller number of truly long-distant axons that link brain regions that lie far apart, sometimes even on opposite sides of the brain. Consequently the human brain has many local links and a few long-distance links, something that starts to resemble a small-world pattern. Research has shown that the degrees of separation in a cat's brain is between two and three, identical with a macaque brain, while at the same time regions are highly clustered. So it seems that what is true of social networks is also true of what Mark Buchanan charmingly calls a thoughtful architecture [20].

Some biological advantages of this small world architecture in the human brain are compellingly clear. If you accidentally hit your thumb with a 5 pound hammer instead of the intended nail, several things happen in coordinated fashion. You drop the hammer, draw the offended thumb to your mouth and suck it, let out a scream, and do a jig. At least that's what we do! Several parts of the brain are called upon to engage this kind of bodily function and that orchestration is achievable only because of the long-distance links that tie the various clusters responsible for separate actions together. A second advantage lies in the fact that brain clusters provide huge redundancy so with the wear out and/or fall out of neurons the functional blocks can still perform their functions. Even if functions are degraded or rendered impotent their separation means each block can still function so that loss of speech understanding does not necessarily mean loss of memory or the ability to make future plans. Even if communication links are broken between say the visual cortex and the hippocampus, that could result in a slight degradation in short-term memory of visual information, the small-world architecture takes care of that by providing alternate longer less direct routes. It's as if people remain neighbors even though gulfs well up; they simply use go-betweens. After all, these neurons are all in it together, all 100 billion of them!

There's one final thing to say about the brain's magic imparted by this thoughtful architecture. After construction and coordination comes consciousness. No-one knows where this resides. It is one thing for neurons to be ready and to fire, they deserve their 5 millisecond reset time having unloaded, it is another thing to take aim, to say, "I am a conscious human being, I am me, and I am unique". How does this come about? The orchestration of billions of neurons might be addressable in terms of small-world architecture and synchronicity, but how does this self-organization at the *many* level lead to self awareness at the *one* level? State of the art research seems to suggest that there are connections between the two and it is all a matter of the simultaneity of the many and the one, the ultimate paradox of complexity.

Thinking of consciousness requires us to address two aspects: conscious states and conscious organization. Consider the scenario of being a student in a class room and briefly, while being unengaged by your instructor, you glance though a window to see someone running toward your building. What do you make of this? More particularly what does the brain make of this? It engages in the generation of multiple states: of pattern recognition, movement detection, context setting, generation of emotions, awareness of sounds, selection of possibilities. All at the same time and all concluding in a single integrated picture.

This is made possible by neural synchrony: the coherent engagement of neurons and in many regions of the brain and *at multiple levels* into one overall pattern. Research has found that when the brain is confronted by two distinct views, of some simple patterns, neural activity is not synchronized when the patterns are seen separately but when they are made to merge and become one pattern, neural activity is synchronized. It is synchrony that creates conscious integration. Moreover in synchronous movement individual neurons maintain a subtle but defined lead or lag behind the group's average firing so that the whole orchestration is information rich in what it provides to upper echelon neural circuitry. It's the equivalent of hearing the orchestra and the violins and the flute. The one and the many.

One of our paradoxes in coming to an understanding of the term complex is that complexity is far simpler than it looks. Behind the apparent confusion lies a hidden order. So this proves in the small world architectures of Watts and Strogatz. That order can be summarized by tightly-knitted clusters and random connections between these. It's as if the randomness gave rise to the order we find in the computational efficiency and resilience that instances of these architectures produce, e.g. finding female fireflies and mind magic. This is encouraging. We turned the paradox to our advantage. Let's not leave it there. What else? Is it possible that order lurks behind pure chaos? Are there invisible forces at work to shape our lives, our technologies and our environment regardless of happenstance, uncertainty and accident? Can there exist a design presence that steers a course while chance itself holds sway? This is not merely an academic question or idle philosophy on our parts, though we do take great enjoyment in posing these questions for their own sake.

There are many instances of networks that exist in the real world that simply do not conform to or are shaped by the forces that give rise to the small world architectures we have thus far enunciated. Inspired as we were to abandon our stereotypical networks of electrical grids and social circles to go on and discover new varieties of this key notion, the firefly flocks and neural networks being prime examples, we can find many more examples – river, networks, air transport networks, the Internet, and the chemistry from which we humans are made. None of these exhibit the pre-existing clustering that our small world examples have required. These are all products of two forces – growth and chance. Who knows when it is going to rain, how heavily and where? Water that fills our rivers. Who decides what airports there shall be served by what kinds of aircraft traveling to who knows where? Planes that fill our skies. What determines which servers will attach to the Internet, publishing material to the Web and providing access to countless millions? Servers that thrill our surfers. As much as we might imagine we have an involvement in these things, in no way can we say we determine outcomes. These are governed by growth and chance. Do these dance? And is there a discernible choreography?

6.3 Snowballs and Seesaws

What do the great Mississippi, the Internet and a computer game, inelegantly named diffusion limited aggregation (DLA), have in common? At face value the answer is surely nothing. But that's because we are looking for a simple explanation. To find what we are looking for we must subject ourselves to paradox, and find the complexity in each of these systems.

The Mississippi River stretches 2315 miles from its source at Lake Itasca in the Minnesota North Woods, through the mid-continental United States, the Gulf of Mexico Coastal Plain, and its subtropical Louisiana Delta. Its river basin, or watershed, extending from the Allegheny Mountains to the Rocky Mountains, including all or parts of 31 states and 2 Canadian provinces, measures 1.81 million square miles, and covers about 40% of the United States and about one-eighth of North America. Of the world's rivers, the Mississippi ranks third in length, second in watershed area, and fifth in average discharge. That's the big picture. How it got formed is largely by accident.

Over however many years, the clouds gathered, the rains came, the ground washed away and the mighty Mississippi began to take its shape. We do know gravity played a part, that's why the rain comes down! As the soil erodes by the washing of rainwater, channels are formed. This has a positive feedback effect in enhancing that flow of water. Grid lines are carved on the earth as fingerprints of the rain's reign, the watermark of myriad deluges. An invisible force is at work influenced by gravity and history, that of what has gone well before will be welcomed back again. What is the imprint of this force? To answer that question we need an imaginative leap into data capture. What is the relationship between sectional lengths of the river and the amounts of water these drain? Why should we bother to ask this question? The reason for that is because the imprint of the Mississippi bears marked similarities with many other great river basins. There exists a pattern in the formation of river systems and this cannot be explained by comparing the details of their environs or history. But it can be accessed by this imaginative question.

This data conforms to what mathematicians call a power law, or what engineers call log-log. And it is this power law relationship that holds true for all river systems. It becomes attractive to think of this as the architecture for river systems, a design whose architect eludes us, without faith.

We cannot improve upon Mark Buchanan's eloquence: "The real importance of the power law is that it reveals how, even in a historical process influenced only by random chance, law-like patterns can still emerge. In terms of this self-similar nature all river networks are alike. History and chance are fully compatible with the existence of law-like order and pattern."[21]

Does this power law have ubiquity? Can it be that this architecture shows up in the Internet and this clumsily named computer game?

The Internet has its origins in many ideas including a DoD need to build resilient infrastructures, as well as the need of many researchers to share information reliably and efficiently, initially confined to California. Its origins are however of far less importance than its history, as remarkably brief as this is. That history has been governed by spectacular growth and inordinate randomness. No one determines the Internet even though its protocols are well published standards that are fully-obeyed. Is a pattern possible for such a system? Consider the relationship between the number of nodes in the Internet and the number of links these nodes possess to other nodes (indicated by the number of routers located at these nodes). Once again this relationship conforms to a power law – it is log-log.

Apparently rain falls where it will causing rivers to flow where they will, and routers sprout wherever they will creating information flows where they will. But in both cases their will be done according to a higher power law.

What about the DLA game? Imagine a blank screen and an insignificant anonymous object drifts across. A second one does likewise, both appearing and traveling perfectly at random. If they bump into one another they stick together. If they miss, they carry on their random walks perhaps disappearing from view. Millions of these objects appear over time. A figure appears. It should, according to our intuition, be an anonymous insignificant blob – an aggregation of myriad identical objects. But there is a pattern,. It is tentacled, from which we infer that it's hard for new objects to get to the centre of this non-blob. The tentacles are self-reinforcing. More than this they are self similar. What mathematicians call fractal. Just like the river systems. Our power law just won't go away! Growth and chance keep it alive and well. It shows up in the most surprising places. In our body chemistry, one or two specific molecules take part in several hundred chemical reactions involved in the bacterium's metabolism, whereas many thousands of other molecules take part in only one or two reactions. The distribution of molecular interactivity against the number of molecules with a given interactivity is yet another power law.

Given its irrepressible nature, might we dare to ask 'Does the power law provide us with a network signature? What is this like? And what rules are in operation that create or govern these 'power networks'?

Though a little naïve, it is hard not to equate the power law with 'To the victors the spoils' That is how power operates right? A colloquial expression for this is 'the rich get richer'. As much as one might despise this it seems to be a law of the universe. Is it the power law? Barabasi and his colleagues [22] answer this for us by their experiments with 'preferential attachment'.

Consider a green field situation – several nodes and no links. Gradually links are added entirely at random. With some new links come new nodes as they enter the growing network. Inevitably a few nodes will gather a few more links than others. Now consider that as new links are added they have a preference towards connecting to nodes that already show a preponderance of links to other nodes. The process of adding links is still random but the probability that these now attach to the more popular nodes is slightly increased. With such a set of rules these experiments produced a similar pattern repeatedly. What is more, the architecture of these patterns always conformed to a power law with a few nodes acting as powerful hubs and myriad nodes having relatively few links. The numbers of nodes plotting against the population of links that these nodes support falls off in log-log fashion.

We observe this phenomenon in many walks of life and instances of science. A power law fits the number of non-executive company directors with a precious few holding more than 100 offices and very many just one or two directorships. It is clear why. Corporations need savvy to inform their strategic planning. So much of this can come from non-executive directors. The ones that are most coveted are the ones that are already popular with companies, i.e. who are already serving in many capacities. It makes sense. Each corporation gains via the wildly popular non-executive director the enhanced experience that person is gaining courtesy of serving on several boards already. These folk are in effect conduits of corporate knowledge around the landscape. Conduits embodied as hubs. It is the old boys' club writ large.

We see the power law in sexual-contact networks. Inevitably a few people are more sexually active than others in terms of the partners they have. There are forces at work here. With success at gaining new partners comes an acquired skill to gain yet more. With more partners gained comes the need to practice that skill more extensively in order to keep up a good image. With that motivation comes more skill and more partners. It is a cycle that Pete Senge would call a reinforcing loop and characterize by a snowball rolling down the side of a mountain potentially producing an avalanche. A hit song from Queen [23] could not be more apposite to capture this momentum –

I'm a rocket ship on my way to Mars
On a collision course
I am a satellite
I'm out of control
I'm a sex machine ready to reload
Like an atom bomb about to oh oh oh oh oh explode!

This type of network also has the small world property. It is another flavor of small which causes us to differentiate between the Watts & Strogatz variety and that of Barabasi [24]. The former has been termed egalitarian and the latter aristocratic. Examples of the nouveau riche are the in-demand non–executive directors and the sexually prolific. A more obvious example are the wealthy themselves. Here is quite literally a case of the rich getting richer. Money flows between people are essentially transaction based – you give me work, I give you money. You give me money, I give you goods. This works for all of us alike. But money in return for time or goods is very limiting. It is an activity that characterizes egalitarianism. The real power comes when money works for you [25]. This involves risks but it carries rewards. Big risks carry huge rewards. Two things characterize rich thinkers. First, they put less value on their money because they have so much of it. Risks are reduced accordingly. But risks are further reduced by focusing the time that is not spent working for money on being smarter about what will work and what won't. Investment to the rich does not equate with gambling by the poor. There will always be risks since uncertainty rules but you can minimize these by investing your time wisely.

Is there an end in sight to these gains? Does reinforcement continue endlessly? Or are there limits to growth as Peter Senge found. Does the snowball meet any obstacles that can prevent the avalanche? Is a seesaw in sight?

Left unchecked the air transportation network in the USA would become aristocratic by nature with the major hubs being of course Atlanta, Chicago, and Dallas. The hub and spoke system much favored of airlines serves their needs to carry as many passengers as possible wherever they want to go, provided it is via their hubs. It makes economic sense for them to concentrate resources and facilities at major airports at the inconvenience to passengers of switching flights and layovers. But the 80 million passengers that pass through Atlanta's Hartsfield Jackson International Airport annually represents a limit to growth. The airport is often running beyond maximum capacity and when bad weather shows up, not only in

Atlanta but at connecting cities, life gets hairy. Passengers vote with their feet which explains the growth in regional airports, smaller aircraft and point-to-point travel. People are not electrons. There is a distinct difference between atoms and bits [26]. And whereas there appears no limit to how many web sites can point to and be pointed at by others, this is not the case for mere mortals with luggage and a persistent need for burgers, bathrooms, and beds.

So there are balancing forces that will arise to keep in check the rich gets richer snowball. The interesting thing for us to consider is how these network architectures, aristocratic and egalitarian, can switch. What are the factors that determine this and what are the consequences for people, corporations, species, and technology systems in terms of reliability, security, safety and resilience?

6.4 Significant Others

The persistence of the small world architecture is impressive. That it comes in these two flavors is also charming. Both types emphasize the paradox of revealing a hidden order to apparent chaos and of providing a simple elegance to what otherwise seems immensely complex. Who can be satisfied though with leaving matters there when the urge to find deeper meaning through higher order patterns has been stimulated by successes thus far? Isn't it the case that we are in a process of understanding significance, of meaning itself?

In the egalitarian networks the significance lies in the weak links, another extraordinary paradox. In the aristocratic network, more evidently the significance lies in the (super) hubs, also known as the vital few (compared to the trivial many). What exactly is the nature of this significance? That of course depends on the real world situations whose apparent disorder and complexity is elegantly captured by small world architectures.

In the case of the world's ecosystem, aristocratic small world structure is a natural source of security and stability. Yet the super hubs or 'keystone species' represent crucial organisms the removal of which might bring the web of life tumbling down like a pack of cards. Removing even 20% of the most highly connected species fragments the food web almost entirely splintering it into many tiny pieces doing untold permanent damage to a web of life. Culling of one species send out 'fingers of influence' that in a few steps touch every last species in the global ecosystem. Strong links between species set up the possibility of dangerous fluctuations therefore since the vital few are the vulnerable feet of an aristocratic giant. By sharp contrast the weak links between species act as natural pressure valves in communities. The weak had once again gone unnoticed since our concentration was focused on the vital few hubs. Paradox demands wisdom and complexity often finds us lacking in that department.

A smart David spots the temple of his opponent. An agile youth unencumbered by heavy protective armor for which no need is foreseen casts the first stone. And it is enough.[27] The lesson for us is to find the simplicity behind the complexity, recognize what is significant and, in the case of food chains, be smarter about what we can and can't cull.

Resilience, the ability to withstand major disturbances and quickly restore order is now a matter of architecture in the face of specific threats. Random networks, despite their redundancy, fall apart quite quickly in the face of an uncoordinated attack. The aristocratic network, like the real world Internet, falls apart gracefully under random attack, and doesn't suffer catastrophic disintegration. But the very feature that makes an aristocratic network safe from random failure could be its Achilles heel, in the face of an intelligent assault. As far as the Internet's wholeness or integrity is concerned, the destruction of 18% of the most highly connected hub computers serves to splinter the network almost entirely into a collection of tiny fragments.

Complexity science is the latest of King Science's courtiers but its arrival might spell the end of that monarchy. Reason has been the prime mover behind all science, the force that swept away superstition and dogmatic religion. Yet scientific method's exploration of this vast phenomena of complexity has revealed a new simplicity, a collection of elementary paradoxes that defy reason! Can science keep its principles in the face of this usurper whose initial disguise was the clothing of its own king? Or can science safely abandon its principles, in a principled way, and so extend its reign even to beyond the borders of unreasonable paradox? This is the battle now for science, one in which its only means of achieving victory is by means of surrender!

7 Paradoxical Systems

The predominant thought pattern of systems engineering is that of *choice*. Basically SE is excellent at defining a solutions space given a tenable set of constraints. What engineers are superb at is identifying candidate solutions that lie within that space, these being forthcoming on the basis of the merits they proffer relative to the criteria imposed or implied by the stakeholders. The final piece of this process, given a solutions space and a set of candidates, is the selection of the best candidate, or optimal solution. The notion of choosing, from a set of candidates, is a powerful thinking pattern, continually reinforced by the SE paradigm.

When it comes to soft systems methodology (SSM) we are stopped dead in our tracks by the multiplicity of choice, each one of which appears to take on a personality of its own demanding unique attention and requiring that no other be chosen above any one. Here is a case of damned if you do and damned if you don't. We stand at the doorway of paradox. The practitioners of SSM know full well the simultaneity of tenable viewpoints and accept the role of facilitating debate amongst the stakeholders to arrive at a course of executive action that is both systemically desirable and culturally feasible. That arrival may very well call for the abandonment of all the original viewpoints, accepting instead the emergence of fresh thinking as part and parcel of the SSM approach. In the mix, contradictions and controversies are dealt with, the force of consensus being mobilized as a product of the stakeholders' emerging sense of community, and therefore an acceptance of collective wisdom (not groupthink) that appreciates the initial set of STVs, has a maturity that knows which to abandon why and when, and a fundamental change in thinking to envision new possibilities and new strategies for realizing these. It is as though SSM transforms the multiplicity of choice into a consensus that at the outset was never a choice!

Latterly, what complexity has done is to reveal hidden threads of interconnections between hitherto remote and apparently disconnected entities and to show us how insignificant changes in any one of these can have tumultuous effects on others. In systems engineering the choices were straightforward and inert to being chosen. In

SSM the choices contended with each other each forcing themselves on the decider, to the exclusion of others. In complexity the choices are far from obvious and when they do come into the light they are massively interconnected, making it a case of choose all or none. What we have witnessed as science has progressed is a gradual erosion of the very reductionism which has powered the science revolution. It is indeed unusual for that which has wrought a revolution to secure it. However it is inexplicable that this property to be so belated, in the order of half a millennium! And now comes the final nail in the coffin!

Our scientific knowledge has brought us finally to the realization that in nature and in design our ultimate challenge to the intellectual pursuit of all mystery lies in an apparent abandonment of reason. Here we confront paradox itself. In its most generic form, a paradox is a stark choice between two clear alternatives – systems engineers would love that - but the existence of both choices denies the plausibility of either. This is not mere contention. It is the rational denial of choice based on the very existence of the same.

In the rest of this paper we seek to better understand, by exploration of an eclectic collection of exemplars, why paradox exists, what its existence means, and how revolutionary thinking, of a kind that parallels anything we have seen throughout mankind's history, must be perpetual in our world of systems.

7.1 Energy

In his brilliant book *Hot, flat and crowded*, Tom Friedman describes the Dirty Fuels System. This system has powered the industrial revolution and is indispensable to the western world for maintaining the extensive infrastructure and accustomed lifestyle of hundreds of millions of people. Naturally this system is coveted by the rest of the world and is accordingly being widely adopted and deployed in developing nations, principally India and China, that have seen the virtues this system has bestowed in the past. It is a system that has fueled growth, delivered prosperity, and affords huge influence to a nation state in the world's eyes.

However, the first name of this system heralds a note of caution. The system is seen as hellish since the fuel comes from below (the earth's surface) - in the form of oil and coal, pollutes the earth, and is exhaustible – no future in hell (other than an unwanted one). By contrast the heavenly fuel comes from above, in the guise of wind and solar, does not pollute (has a purity to it), and is inexhaustible (at least until the sun is extinguished). This dramatic comparison serves at least to draw attention to the now incontestable fact that the dirty fuels systems is bad – for all of us. It is especially bad if it is going to be adopted by all of us. However, how can anything be so bad if it has brought so much good?

That question is bound to be asked by those now wanting to adopt that system so that good might come to them, and is inevitably being asked of those for whom the system has brought much good but who are, ironically, the ones now saying that the system is bad. How would you feel if you were one of those to whom good had yet to come, but was now clearly within reach via the 'Dirty Fuels System', and was being told by those to whom much good had come that this is a bad system? It would tax your trust would it not, and possibly make you more resolute in choosing 'hell'?

This particular Gordian knot [28] is not easily sliced, and it forms the basis of a superb exemplar of a paradoxical system. Imagine a unit of energy consumption to be an Americum. This represents a group of 350 million consumers with a per capita income in excess of $15,000 and a growing penchant for consumerism. The USA is 1 Americum. For many years there were only two Americums in the world: the USA was one, the other in Europe. There were small pockets of Americum-style living in Asia, Latin America and the Middle East. Today Americums take shape all over the planet: China has given birth to one and is pregnant with another; India has one now and one on the way, due by 2030; another is forming in the Pacific rim, and yet another in parts of South America and one more in the Middle East. By 2030 we will have gone from 2 Americums to 9. These are America's carbon copies. The problem is that the filing system doesn't have room for all. Friedman quotes Jeff Wacker [29] as follows: "Our prosperity is threatened by the very foundation of that prosperity (the nature of American capitalism). We have to fix the foundation before we can live in the house again. China's foundation cannot be the same as the same foundation we built America on. And America can no longer be the same".

The problem is that we do not know what the new foundation is; and there's nowhere else to live while the old foundation is being changed. My question is, "How can SE, SSM and/or complexity science help us cut the knot?"

7.2 Geopolitics

Commentators refer to John Adams and Thomas Jefferson as 'the voice and the pen'. For sure John Adams knew to enlist the services of Thomas Jefferson in drafting the Declaration of Independence while he himself always rose to his feet at the Continental Congress with unbridled passion and convincing authority to ensure unanimity among the colonies in adopting a revolutionary posture. By the same token, Jefferson knew full well his own limitations as a public speaker preferring the solitude of his library and private moments of quiet inspiration to lend his unique skills to the revolutionary effort. And who can deny the magic of his prose as the ink flowed onto the pages with irresistible fervor and undeniable unction:

"When in the Course of human events it becomes necessary for one people to dissolve the political bands which have connected them with another and to assume among the powers of the earth, the separate and equal station to which the Laws of Nature and of Nature's God entitle them, a decent respect to the opinions of mankind requires that they should declare the causes which impel them to the separation.

We hold these truths to be self-evident, that all men are created equal, that they are endowed by their Creator with certain unalienable Rights, that among these are Life, Liberty and the pursuit of Happiness. — That to secure these rights, Governments are instituted among Men, deriving their just powers from the consent of the governed, — That whenever any Form of Government becomes destructive of these ends, it is the Right of the People to alter or to abolish it, and to institute new Government, laying its foundation on such principles and organizing its powers in such form, as to them shall seem most likely to effect their Safety and Happiness. Prudence, indeed, will dictate that Governments long established should not be changed for light and transient causes; and accordingly all experience hath shewn that mankind are more *disposed to suffer, while evils are sufferable than to right themselves by abolishing the forms to which they are accustomed. But when a long train of abuses and usurpations …"*

It is borderline sacrilegious to then say 'and so on'. These are not mere words but invocations to the soul of every man … of *all men*. At the time it was well accepted that *all* did not mean *all*. Almost a century later, in continuing pursuit of that more perfect union, *all* began to mean rather more than it once had … and yet more remained to be done. Jefferson's words have marched on with time embracing more minds and enfranchising more of us. They have torn down walls and infected many with thoughts of a better life. The American dream is not confined to the Continent in just the same manner that Jefferson himself foresaw America would not be confined to the eastern seaboard on which its fledgling from first saw the light of day. The words though few and simple are limitless in their scope. But are they? If growth is the vehicle for the advancement of these words, what of the limits to growth? If words are power unto themselves, what are the limits of power?[30]

The expected destination of all men being created equal is a middle class earth that cannot be sustained on planet Earth. Here is the inevitable geo-political paradox: if these words are true then their truth cannot be denied to those for whom they have not been true – they need to be made true; the application of these words lifts people out of despair and sets them on a road to prosperity; the sharing of that prosperity – by the means that has thus far provided it to all for whom the words are true must lead to despair for all.

Is this paradoxical situation beyond the scope of SE? Beyond the scope of SSM also? And, even, beyond the scope of complexity science? If this be the case, is it not just too much to hear of their impotence in this matter given that these very servants of science, by their application to technological, sociological, ecological, and political endeavors have brought us to this quandary? Are they, having got us in this mess, now to wash their hands of it? (Even though they continue to practice unaltered?) Is it conceivable that an exhibition of humility among these problem-solving giants, rendered by the introduction of paradoxical thinking - the nemesis of science, might be the wicket gate that leads from this world to that which is to come?[31]

7.3 Information

The history of computing begins inevitably with man, the first computer whose productivity soared with the invention of the place value systems and was enhanced by devices such as the abacus. Automatic engines came much later onto the scene but as in so many other developments a power law applies to the growth in capacity, productivity, and innovation of both man and machine. Calculation has given way to information for its own sake and latterly the strive is away from data towards knowledge and wisdom. Some suggest that man plays god by making machine in his own image via artificial intelligence. Today computing has even taken on an ethereal nature disappearing as it were from tangible machines into mysterious clouds. Users are uncaring of the location of computers, software and data as long as their needs are met in timely and reliable fashion on whatever fashionable boxes they attach to their person. The opposite is true for cloud providers who must locate vast server farms near sources of power and cooling and who are continually frustrated by security and privacy relative to the geography that applies to specific clouds.

One thing is for sure: that the information technology and energy technology media (or infrastructures) must come together (some refer to this as cyber-physical ecosystems). Only in that way can the energy crises, the geo-political challenges and the information futures be assured. That the way to this convergence is strewn with paradoxical systems must be regarded as a necessary blockage to the promised land and a sure sign that this is the only way, one guided by breakthrough thinking.

8 Principles and Their Principled Violation

Science is founded on reason and paradox appears to call for the abandonment of reason. Yet paradox, we assert, is the necessary road block to conventional wisdom and a portal to breakthrough thinking. As with any other road block you can ignore it, you can go around, under or over it, or you can find a different way to a different destination. This paper says when you come to the paradox you must treat it as a sign post that your current thinking, that brought you this far, will not work in future. If you're prepared to do that then the way will open up to where you want to go, and, respecting the paradox as a tutor, will lead to fresh understanding. In the end you don't abandon reason you jettison failed understanding and you add to the stock of wisdom.

A second rock on which science is built is that of principles. These are not easily formed and once established are seen as immovable and immutable. They serve as our fallback in all tricky situations. Were these to vanish, so the argument goes, all would be lost. What happens then when we are forced to abandon our principles? Are we acting in an unprincipled manner? Perhaps, but not necessarily. Groucho Marx, that most irreverent of comics, once said, “I have principles, of course I have principles. And if you don't like them, well, ah well, …. I have other principles”. Hilarious. But many a true word spoken in jest. Let's explore this.

8.1 Declarations

In his book American Creation (Ellis, 2007), Joseph J. Ellis reveals the centrality of paradoxical thinking in the founding of the Unites States of America. It is prominent in the Declaration of Independence, the Constitution, and the necessary actions of the founding fathers.

Like their contemporary Rousseau, the members of America's revolutionary generation rejected the long-held conventional wisdom that political sovereignty must be singular, indivisible, and vested in a single location. The Constitution created multiple, overlapping sources of authority in which the blurring of jurisdiction between federal and state power became an asset rather than a liability, transforming the idea of classical “sovereignty” and reserving it in a holistic repository—the people.

‘Problematic’, ‘blurring’, ‘elusive’, ‘endless’, ‘multiple’ and ‘overlapping’ were defining characteristics of this new generation, not in any paralyzing or disingenuous sense but, by the sharpest of contrasts, in a vitally paradoxical sense, that captures the imagination and brings hope for an expansively endearing and enduring empire of liberty. It is, after all, notably uncommon for the men who make a revolution to secure it as they did.

Many Americans fail to recognize the profound paradox expressed in two of our most cherished documents. The Declaration of Independence locates sovereignty in the individual; in some ways it depicts government as an alien force, and makes revolution against oppressive government a natural act. But, the Constitution locates sovereignty in a collective called "the people," values social balance over personal liberty, and makes government an essential protector of liberty rather than its enemy.

8.2 Washington

In the winter of 1777-78, George Washington selected Valley Forge as his encampment because of its abundant food supply, which he wanted to deny the British troops ensconced in nearby Philadelphia and claim for his own troops. Unfortunately, the bulk of the local farmers preferred to sell their crops to the British army in Philadelphia. A veritable caravan of grain and livestock flowed from the very productive countryside into the city to feed British troops. Women and children drove the wagons to minimize the likelihood of arrest by American patrols.

At least some of Washington's peers viewed his plight sympathetically. "I am the more chagrined at the want of provisions to which I am informed your Army is reduced as I believe it is partly owing to the boundless Avarice of some of our Farmers, who would rather see us ingulphed (sic) in eternal Bondage, than sell their produce at a reasonable price". So wrote William Livingstone, the governor of New Jersey.

Washington was caught between two equivalently incompatible courses: confiscate the food for his starving soldiers, alienating the very people the American Revolution was intending to defend, or maintain the revolutionary principles while watching his army dissolve. What a dilemma! What a paradox! What to do?

Washington took decisive action in multiple roles. As commander, leader, judge and problem solver, he chose to inflict short-term suffering to achieve a long-term outcome—free American people living according to American principles. He put his soldiers first by ordering the Army to intercept and confiscate the wagons, horses and food, but to leave the women and children driving the wagons unharmed. The Army arrested and hanged the ringleaders of the illicit traffic in public executions designed to make a statement, and shot men carrying food into Philadelphia, leaving their bodies on the road as warnings.

Famous for both his personal reserve and scrupulous ethics, Washington had to fill another, perhaps far more difficult role—arbiter of his own conscience. Even here, circumstances prevented doing all he surely would have wished. The General ordered the Continentals who confiscated food to pay for it with certificates of debt. Unfortunately, these were essentially worthless to the bereft farmers and their families.

Washington simultaneously exercised and was blessed by wisdom, in that he knew the people's necessary suffering lay on a road to a destination they themselves had determined, yet had lost sight of: life, liberty and the pursuit of happiness. His difficult choices also exposed a new development in the strategic chemistry of the war. It became clear for the first time that the American Revolution, while still and always a struggle for independence, was also a civil war for the hearts and minds of the American people—the two contests were closely connected. Washington had previously viewed the war as a conventional contest between two armies, so he had focused on sustaining a fighting force in the field that could match and eventually defeat the British army. Conventional wisdom says “the longest purse” wins the war; paradoxical wisdom sheds new light. The new variable was not money but allegiance. Even the longest purse could not defeat the deepest resistance.

When faced with the challenge of how to deal with the farmers, Washington recognized that the real problem lay not with the farmers, but with how he viewed—and must conduct—the war. This recognition led the General to a profound change of strategy—from simply fighting the British army to “covering the country” by deploying the Continentals and local militia units as roving police who controlled the countryside. This essentially defensive or delaying strategy made control of the countryside as crucial as winning battles. Had he not faced the reality of paradox, he would have missed the opportunity to both shift the paradigm and create America.

8.3 Jefferson

On a single day in 1803, the United States doubled in size, adding what is now the American Midwest to the national domain—all the land from the Mississippi to the Rocky Mountains and the Canadian border to the Gulf of Mexico. This tract of land was the most fertile of its size on the planet. It made America self-sufficient in food throughout the 19th century and the agrarian superpower of the 20th. The fact that the man who made this monumental executive decision was on record as believing that the energetic projection of executive power was a monarchical act only enhances the irony; and irony is a close cousin of paradox, with humanity often playing the role of unwitting victim.

Jefferson saw the Louisiana Purchase as vital to the nation’s future. His response to James Monroe’s letter in response to a slave revolt said, “ … it is impossible not to look forward to distant times, when our rapid multiplication will … cover the whole northern, if not the southern continent with a people speaking the same language, governed in similar forms, and by similar laws …”. Jefferson’s vision rested on two assumptions: that the land would be settled (by multiplication and migration) and not conquered; and, that in the interim, the most docile of sitting tenants should be the Spanish, whose imperialistic enterprise was a thing of the past (after the defeat of the Spanish Armada by the British in 1588).

Jefferson was also emboldened by the military strategy lessons Washington had learned when it came to repelling a mighty invading force bolstered by a powerful economy, but setting foot on soil thousands of miles from home. For this republican to honor the breakthrough thinking of a federalist he had come to despise and almost think of as a traitor gives credence to his statement: “We are all republicans; we are all Federalists.” He pulled off the Purchase in the manner of a Caesar, negotiating directly with Napoleon, who was acting against the advice of his ministers. Concerned the emperor could change his mind, Jefferson had to act quickly, but lacked the authority to act alone. Or did he?

The Constitution’s inherently ambiguous definition of executive power can expand and contract like an accordion, making the music required by different historical contexts. Forced to choose between losing Louisiana and abandoning his Constitutional principles, Jefferson subverted the Congressional process, saying, "To lose our country by scrupulous adherence to written laws would be to lose the law itself." Jefferson had a vision of what 'our country' meant, what written laws – the letter of the law – meant, and what might be meant by something more 'spiritual,' even more fundamental than a principle. Of course in such matters, without the benefit of codification, we necessarily admit ambiguity, but for Jefferson this was less a problem than an opportunity.

This consummate republican paradoxically exercised supreme executive power to fulfill his vision of 'our country.' He thought that his action would not become a precedent, but history has proved him incorrect. Indeed, history has conclusively demonstrated that how one interprets and leverages the Constitution is perhaps far less a matter of principle than a function of one's power position and perception of the situation.

8.4 Gerstner

In the early 1990's IBM faced unprecedented difficulty. The unthinkable was in the minds of some – that IBM would go under or be bought out by an upstart. Even in their darkest hour however the reality was that IBM had unsurpassed technical expertise, to build exciting new products, and unrivalled business knowledge, to build lasting partnerships with their customers. It might even been said, paradoxically, 'Is this what got us into our troubles?' Or, 'If we have these assets and are still in trouble what's our future?' Lou Gerstner stepped up to the plate.

He announced what should have been already well known and was being leveraged by IBM's competitors to Big Blue's demise - that a revolution had occurred: Information Technology was no longer being driven by vendors but by customers!

That paradigm shift was what IBM needed to recognize and leverage if they were to survive. Accordingly they formulated four new models. A new industry model: innovate or integrate; a new business model: service-led; a new computing model: infrastructure plus ubiquity; and, a new marketplace model: an open playing field [32].

But I ask, 'What was the moment of breakthrough and how was this intuited?' My argument is that as much as IBM were being blindsided by the shift in IT driver – from vendor to customer, they were also being road blocked by paradoxes of their own making. The first was this: the more they invested in IT the less it impressed customers, (because the world had changed and IT was being customer-driven). The second was made up of these two components. That proprietary systems were good for them, it locked-in customers, but bad for customers ("we the customers" throw of the tyranny of proprietary systems, the kings of IT epitomized in IBM - and demand open architectures, industry standards, end-to-end solutions, services etc.). At the same time, open systems architecture, in the case of the IBM PC, gave Wintel its start and had done almost nothing, relatively, for IBM, for whom open appeared to be not the way. So for IBM it was a case of 'damned if we do and damned if we don't.' Perhaps these paradoxes went unobserved – I am speculating here. Perhaps they were noticed but not respected. But maybe they were articulated, with respect, and that made IBM realize more fully the dramatic shift that had taken place among customers AND that IBM still had much to offer. All that was needed was a change in thinking.

One that leveraged IBM's technical expertise and business knowledge to give the company an appropriate setting for the new wind direction.

9 Paradoxical Thinking

No one can ever be satisfied with leaving a problem exactly where it is. Maybe the problem is well defined. If so, then it is to be solved, by current or future methods. This is the approach taken by systems engineering. Maybe the problem is not well-defined. Then it is to be transformed until it becomes either well-defined or sufficiently well described that some form of action can be taken as remedy. This is the work of soft systems methodology. Maybe the problem is exotic with many threads interweaving throughout creating patternless chaos. In that case we might wait long enough to watch for patterns to emerge, in which case we can use the pattern as a means of describing the problem and hence formulate a solution to the original chaos. Or we adopt a simple stance on what might be the pattern and see if this simplified structure, that gives us our hypothesized pattern, does indeed create the chaos we originally witnessed for ourselves. This is the approach of complexity science.

Everything we have ever known concerning the existence of problems, however defined, described or presented, is action-oriented – problems simply cannot be left to themselves. To admire a problem and leave it at that is to risk castigation by scientists in particular and society at large. There can be no exceptions. Not even for paradoxes. There must then be an action-oriented agenda for paradoxes, what we might call paradoxical thinking, even if the very nature of a paradox is to produce a kind of problem paralysis, a torpor that incapacitates action, something that insists that the problem be perpetually preserved. Accordingly I close this paper by offering such an agenda for action, my perspective on paradoxical thinking.

My first point is that I choose to locate this agenda not as a body of knowledge that can be executed, to stand with SE, SSM or complexity science. Instead I offer it as a component of systems thinking. In that sense I make my agenda for action not as a doing entity but as a thinking entity, having regard for what Albert Einstein said, "In the brain, thinking is doing". I believe that a paradox IS a system and therefore doing something about a paradox requires thinking about it as a system.

Accordingly the value of systems thinking needs to be restored so that it is respected by systems practitioners, probably by the offerrings it provides to them for taking action. Thus icons such as the Conceptagon, the systemigram, causal loop diagrams (CLDs) and the system archetypes which emerge from CLDs e.g. 'fixes that fail', accidental adversaries', and 'tragedy of the commons' are the visible face of systems thinking to the systems practitioners. Seeing these icons in use by that community should be regarded as successful implantation of precious seeds the fruit of which ought to be a more horizontally integrated community, across all systems disciplines, one that will want to encourage the growth of new seeds and thereby esteem for systems thinking.

My second point is that I do not regard paradoxes as intractable problems. I do regard them as challenges to the way I have been thinking, a pattern of thought that has led us inevitably to the paradox. It is as though the paradox was a way of revealing ill-health, in thinking, and closes down future possibilities until that ill-health is treated. In other words the paradox is not the problem; the real problem lies within us, within our ways of thinking, that requires us to get out of ourselves, as it were. In some ways then there are similarities between paradox and the kinds of problems that SSM seeks to treat. Wherever paradoxes are to be found we will surely discover also one or more problems that are systemic. Systemic problems require systemic solutions. SSM itself is a systemic solution. The problems that SSM treats are likewise systemic, and SSM develops a system of 'solutions', more correctly idealized worldviews, the collective sharing of which with problem owners, by skilful facilitation grounded in systems thinking, conceivably produces executive action grounded in a holistic respect for the original systemic problem.

My third point is that whereas all forms of problem solving us force to make a choice, i.e. define solution, from all that is possible (amongst all candidates), all forms of paradox force us to make a choice that is impossible. The essence of all paradox leads us to the point of convergence of the impossible and the imperative. Since culturally, historically and reasonably one is eventually forced to make a choice, the same is true of paradox. But the curious thing about paradox is that unless you accompany that choice with breakthrough thinking that choice is nugatory. The paradox lives on and is only once and for all treated, not by the choice you make, but by the realization that it is the chooser who must change. In paradox, we are the subject matter, and it is against us that revolutions must come.

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