A FRAMEWORK FOR UNDERSTANDING AND ACHIEVING SUSTAINABILITY OF COMPLEX SYSTEMS

George Mobus
University of Washington Tacoma, Institute of Technology, 1900 Commerce St. Tacoma WA, 98402

ABSTRACT

This paper takes a systems approach to outlining a framework for the sustainability of complex systems. Complex systems have one or more functions that strongly interact with their environments, or the supra-system in which they are embedded. The success of the system in interacting with its environment over an extended time frame depends on that system's ability to regulate its activities, both internal and external so as to remain 'fit'. The concept of fitness derives directly from the evolutionary theory of phenotypic traits and capabilities (behaviours) being selected for or against by the environment of the system. But it is generalized beyond the standard neo-Darwinian biological process. The roles of adaptivity and evolvability and the mechanisms of a hierarchical cybernetic governance subsystem in maintaining these are advanced as necessary conditions for achieving sustainability in all types of complex systems.

An operational definition of sustainability is advanced along with a set of necessary conditions that must obtain in order for complex systems to achieve it. Several systemic dysfunctional conditions are explored to show how complex systems fail to achieve sustainability by failure of the hierarchical cybernetic governance subsystem. Examples from several natural and human-built systems are used to demonstrate these conditions.

Clarification of the meaning of complexity across a spectrum of system types is given. A definition of complexity based on hierarchical levels of organization is given to ground the discussion of the hierarchical cybernetic governance subsystem and justify its necessity to achieve and maintain stable dynamics in unstable environments.

The purposes and uses of this framework are discussed and examples provided. A brief description of the use of systems analysis to explore and discover functional and dysfunctional subsystems within the hierarchical cybernetic governance subsystem and how this might provide insights for the design of better performing subsystems is also provided.

The paper concludes with a projection of the benefits of applying this methodology to the governance of the human social system (HSS).

Keywords: Human Social System, hierarchical cybernetic governance, sustainable systems, operations governance, coordination governance, strategic governance, adaptivity, resilience, evolvability.

INTRODUCTION

The Concept of a Sustainable Complex System

The definition of a complex system is somewhat problematic owing to the unsettled situation with the definition of complexity itself. In this paper I shall be following the definition used in Mobus & Kalton (2014, chapter 5), which is an amplification of Herbert Simon's definition based on the properties of a partially decomposable hierarchy (Simon, 1996). In Mobus & Kalton we provided some amelioration between various views of complexity (e.g. chaos theory – functional complexity, and hierarchy theory – structural complexity).

In this paper I will be addressing the highest order of complex systems, those that are adaptive and evolvable (referred to as CAES). Examples of CAES include:

- A local ecosystem within the Earth Ecology (the Ecos),
- The Human Social System (HSS) as a subsystem of the Ecos,
- The Economic subsystem of the HSS,
- An organization like a corporation,
- An individual human being,
- Genera (from which species emerge).

By comparison, biological entities like single cells or more complex organisms up to more recently evolved mammals and birds are complex and adaptive, but not evolvable. That is, they do not create ad hoc internal structures/functions to solve problems. Later mammals and birds have brains capable of learning concepts, which in many ways represents a form of evolvability with respect to behaviours. Humans, of course, show the highest level of concept learning and adaptive behavior. They invented clothing and shelters to protect them against conditions in climates outside of the evolutionary birthplace.

In this paper I will provide an operational definition of sustainability and then show how three capabilities within CAESs provide for the greatest assurance the system will be sustainable. These capabilities, I will argue, can only be deployed through a properly functioning governance subsystem. The nature of that governance subsystem has been explored using systems science principles (Mobus, 2015).

A Principled Systems Approach to Sustainability

All CAES are structured according to a set of principles (Mobus & Kalton, 2014). Chief among these, insofar as the concept of sustainability is concerned, is that of internal regulation based on cybernetic principles. The claim made here is: CAESs are long-term sustainable (have duration) if they have a hierarchical cybernetic governance subsystem (HCGS) and that system is functioning properly as described in (Mobus & Kalton, 2014, chapter 9, and Mobus, 2015).

Systems that have such a HCGS are called purposive systems. They are goal oriented in the teleonomic sense. A generalized schematic of a purposive complex adaptive and evolvable system is shown in figure 1. The term 'purposive' signifies that the system actively seeks a goal that will provide it with some kind of reward (e.g. access to resources).

Not all CAESs are purposive. For example an ecosystem cannot be said to be goal oriented. Ecosystems do go through a natural progression of composition evolution that leads to what is called a 'climax' condition subject to the constraints of the larger embedding environment (e.g. climate conditions and bounding geography). But there are no active decision processes involved. In fact it might be argued that though such systems evolve toward the climax composition they are not really 'adapting.' These systems progress by the gradual colonization of plant and animal species (as well as components like soil bacteria and fungi) from remote similar systems. The governance of an ecosystem is based on mutual constraints between species and individuals through the trophic layers of the food web. Stability comes from the balance achieved in the material flows through the system from primary producers up through consumer layers and back to recyclers when living organisms die.

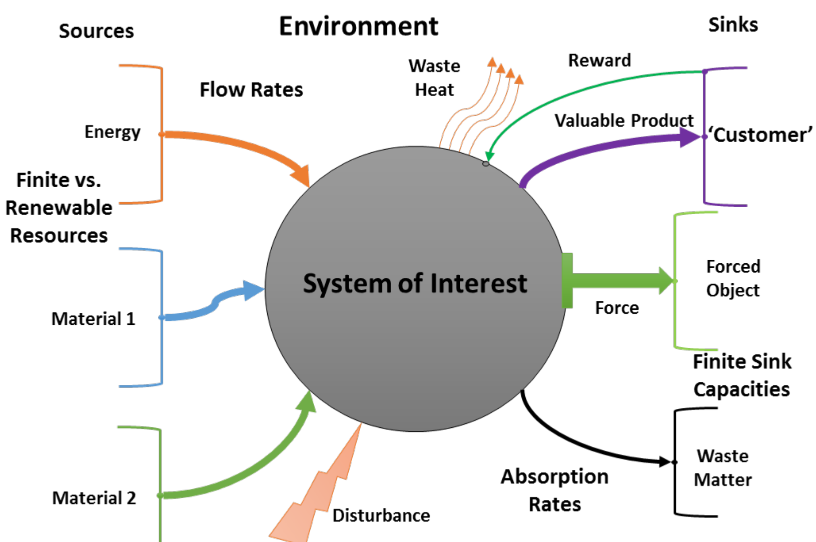

Figure 1. A purposive complex adaptive and evolvable system produces outputs that are acceptable to environmental sinks.

The CAES we are all seeking sustainability for is the HSS. As things stand today the governance subsystem for the global HSS looks more like an ecosystem than an HCGS. The section below, entitled "Why the HSS is Presently Unsustainable" provides the evidence for this situation.

All truly purposive systems interact with their embedding environment. They actively obtain resources such as material and energy from sources. They do real work using energy to transform materials for their own internal use and exporting some kinds of products and wastes to sinks. The energy that is used in work processes is dissipated as waste heat. They are capable of recovering from stochastic disturbances within limits.

Every kind of purposive system can be modelled in this fashion. The system 'intends' to produce outputs that fit the criteria of acceptance by environmental entities by virtue of their structures and functions arrived at by either evolution or design. If successful, the system is 'rewarded', that is, it will receive a valuable resource from the 'customer' entity. This is the basis of exchanges or transactions. The receipt of reward need not be direct from the customer entity. Rather it may come from a more distant source that is positively impacted by the customer as a result of the customer getting the right product from the system (e.g. a supply chain). The key notion, however, is that the system is producing something that is useful to other systems that act as sinks. In this sense the system *serves* a purpose in the larger supra-system and is positively reinforced. It is, in essence, selected for by its environment.

The HSS needs to have a purpose that serves a purpose in the Ecos. The meaning of sustainability of this mega-system of human civilization needs to be carefully considered, especially in light of the substantial changes to the global environment defining the Anthropocene. The typical interpretation of sustainability for the HSS, largely promulgated from the Brundtland Commission report's (1987) definition of "sustainable development," calls for the continuation of the global civilization with an emphasis on restrained growth of resource demand while allowing the development of regions not yet having a standard of living assumed (by most political and economic pundits) to be acceptable. The crux of the Brundtland report is summarized thus:

> Sustainable development is the kind of development that meets the needs of the present without compromising the ability of future generations to meet their own needs[1].

While well intentioned in its tone, if short on explanation of "needs" and "kind of development," this definition fails to address the necessary conditions that would have to be met for the HSS as a whole to persist, i.e. what would be needed for us to say the HSS is sustainable as a whole. Given the existential threats that human activity has created (i.e. the Anthropocene signature) the question of the whole HSS sustainability, let alone the development of pockets of the HSS is far from assured. The more global question, from a systems perspective, is: What are the necessary conditions for the sustainability of *all* complex systems? Given that I count as sustainable the fact that a system persists in structural, functional, and purposive conditions into an indefinite, but presumably finite, future, here are a set of necessary conditions:

1. The governance subsystem for the whole system must function within tolerances,
2. The capacity of the system to adapt to environmental changes must match the range of variations in the conditions which impact any of the subsystems.
3. The system must be evolvable and "lucky" or have strategic foresight in its governance subsystem.
4. The embedding supra-system must not alter so radically that either 2 or 3 can compensate.

---

[1] From the Wikipedia article on the Bruntdland Commission: https://en.wikipedia.org/wiki/Brundtland_Commission

I should emphasize that 1, 2, and 3 are indeed necessary but not sufficient. With 4 added the conditions might be sufficient but 4, colloquially the asteroid/comet impact possibility, is outside the control of the system itself, and therefore I will focus on 1, 2, and 3[2].

A Properly Functioning Hierarchical Cybernetic Governance Subsystem

As described in Mobus (2015) and Mobus & Kalton (2014, Chapter 9) an HCGS is found in many CAES (e.g. all but the ecosystem in the list above). Here I will provide a quick review of the HCGS principles from Mobus (2015). Figure 2 shows some of the essential elements of an HCGS. The opaque SOI of figure 1 is transformed by systems analysis (top-down deconstruction) into a transparent view showing some internal details.

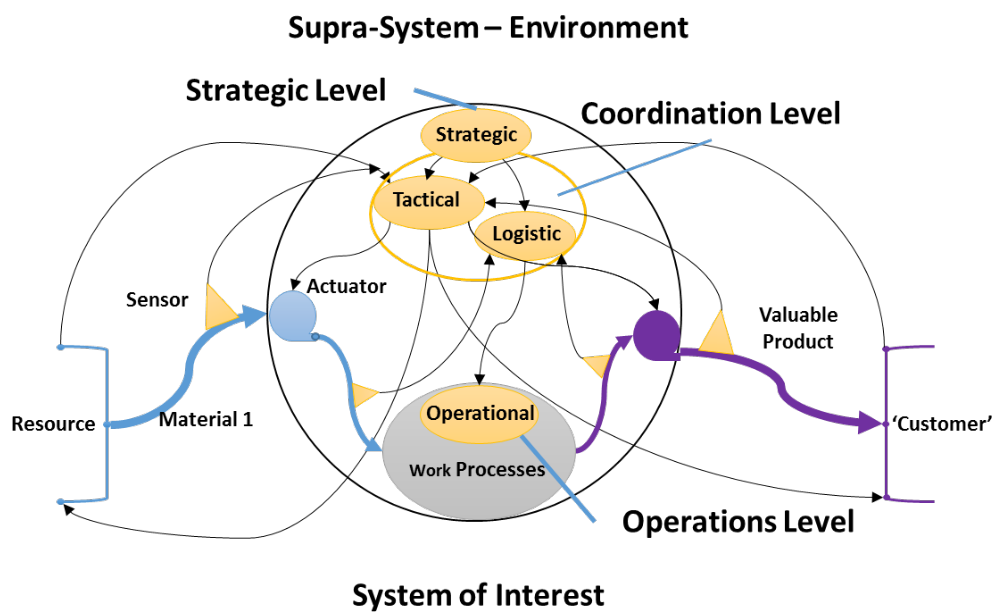

Figure 2. This transparent view shows the essential aspects of a purposive system with respect to the hierarchical cybernetic governance systems (yellow ovals). Yellow triangles are sensors that supply flow rate and substance quality information.

To summarize, the nature of the HCGS is an agency (information processing and decision-taking) subsystem that works to coordinate the behaviours of all work process subsystems in the whole system. Work processes are those where matter and energy are transformed into more usable forms under the influence of information flows. The latter are signals coming either from other work processes (in cooperation) or from coordinator processes higher in the hierarchy. Each work process has its local "management"

[2] Interestingly, however, some scientists are exploring the possibility of detecting and diverting threatening extraterrestrial bodies from crashing into Earth.

function, generally in the form of a feedback regulator to ensure quality and proper quantity flows of output products. This is called the "operational control" function. It may also employ feed forward from sensors monitoring inputs for quality and quantity. The regulation of a "physical plant" is the realm of standard control theory. Cooperation obtains between tightly coupled work processes when the managers are capable of using higher order computations to interpret and use signals coming from near neighbour processes. That is for process pairs where the outputs of one process are needed inputs to another process there are generally channels of communications between manager processes that allow one process to notify the other of variations in supply or demand. These channels can form a fabric of communications coupling in which pairwise cooperation might be extended to all work processes in the structural network of material and energy flows. I call this fabric a "market-based" regulation system in which the messages that affect one process are necessarily propagated to other nodes in the network. When systems are relatively simple, e.g. only a few cooperating work processes, and the decision-making agents are "honest" the market fabric can be a reasonable way to coordinate activities such that the whole system maintains its basic functions.

The problem is that for more complex systems, especially those in which the decision agents are behaving selfishly[3], or as systems evolve to greater complexity, the information flow through a large fabric tends to get distorted and time lags take their toll. These are well known phenomena in communications theory and cybernetics. At some point in the complexity evolution, it becomes mandatory for a new kind of information processing process to intercede in message passing and employ higher-order models to provide coordination services to the work processes. The operational regulators need help in anticipating larger scale fluctuations that will impact their operations but are not immediately signalled from near neighbours.

There are two basic kinds of coordination processes that conceptually sit "above" the operations level and observe the operations of work processes. One type is the logistics processor that works, in general, to modulate the activities of work processes within its span of regulation such that the overall system work is optimal in terms of the whole system's product outputs. The other type of coordinator is the tactical process, the main function of which is to coordinate the whole system's behaviours with those of external entities, specifically the sources of resources and the sinks for products and wastes.

Operations regulation and coordination processes constitute the general HCGS for the first kind of complex systems described below, the organic systems. For supra-organic and evolvable systems, a higher-order level of the HCGS is required, the strategic management level. Organic systems such as individual animals (and all plants) do not have a part of their brains dedicated to strategic decision making (great apes, cetaceans, and humans may be the only creatures that make decisions of a strategic nature!). Evolution has provided the strategies they will use in their life cycles (what to eat, when to procreate, etc.). Supra-organic systems (other than ecosystems), as described below,

---

[3] In Mobus (2015) I describe the situation with human decision makers in HCGSs. In this paper I will consider how the weaknesses in human capacity to make wise decisions needs to be taken into account in any question about sustainability.

exist in extremely complex and non-stationary embedding supra-systems (over longer time scales than mere organic systems). Changes are unpredictable in the ordinary sense but operate over longer time scales so that such systems have the opportunity (if they have the ability) to observe and learn and anticipate the changes in some fashion. They have the opportunity to modify their internal structures and functions to accommodate these changes. Whether they do so or not is sometimes a question of chance and circumstances[4].

Governance subsystems are critical to sustainability. Work processes need to be adaptable (condition #2) but they also need to be properly coordinated. For organic systems like individual animals the entire physiology and behaviour control systems are elegantly designed to function properly at least until the individual has passed its prime reproductive ages. Evolution did not equip such systems with maintenance processes beyond this duration since the strategy for such systems to propagate into the future is reproduction. They do not have repair subsystems that operate indefinitely. It is the species that sustains, not the individual.

For supra-organic systems that are evolvable the situation is different. They are able to compensate for age-related deterioration through either extended repair functions or by behavioural modifications (e.g. grandparents retiring and helping out with the grandkids!) Commercial organizations (a kind of supra-organic system) can recover from product demand falls due to changes in customer preferences or obsolescence if they are strategically sharp.

Any failures of the HCGS to fulfil its role in operational regulation or coordination will expose a whole system to failures of overall process. In that case the system is vulnerable to environmental exigencies. It will not sustain its existence. The question of whether the HSS is sustainable could easily be answered given the state of the global HCGS. Put simply there is none. Even on national levels the way HCGS local governments operate does not provide the kind of management that would be needed to sustain a civilization. More on this later.

Two Kinds of Complex Adaptive and Evolvable Systems

I have been using the terms ‘organic’ and ‘supra-organic’ with respect to types of systems that employ HCGS management. There is another distinction that applies to complex, adaptive, and evolvable systems (CAES) that helps to show why systems that employ HCGS are capable of long-term sustainability. Let us differentiate between two basic kinds of systems that are CAESs yet operate via two very different internal regulation mechanisms. One is purely reactive to externally applied forces. It has no *purpose* other than to exist. It does not “reproduce,” that is creating a full-blown copy of itself in the conventional biological sense. It does not grow or expand its boundaries except when the surrounding supra-system (its environment) allows it to do so. It does evolve through a process of succession over time in reaction to supra-system changes imposed (e.g.

[4] A slight variation on Jacques Monod’s “Chance and Necessity.” See https://en.wikipedia.org/wiki/Chance_and_Necessity

climate change). This is the *eco*system model. Ecosystems (which includes versions of commercial societies) are internally regulated by market mechanisms, the fabric of information flows that allow entities (i.e. subsystem processes) to coordinate their activities with one another. Such systems have a high diversity of subsystems but a common messaging fabric. In living ecosystems the internal regulating mechanisms are mediated through the trophic levels and food webs. It is the flow of energy which is being optimized through multi-way mutual constraints. See below for more explanation.

The other kind of system performs actions meant to counter its supra-system's actions. It seeks to maintain the integrity of its basic structures and functions. It has a *purpose* to not just exist but to expand and replicate if it can. It can seek to change its supra-system such that it is more conducive to its own future. Such a system, if its internal regulation capabilities are up to the task, can sustain its self and its purpose over extended time scales. *Bio*systems (e.g. individuals, populations, and genera) are of this kind. So are many human organizations like corporations, which we call supra-organic systems in that they have both biological and mechanical subsystems in their structures. Generally speaking, individuals are not evolvable per se, though populations, genera, and human organizations are. A case can be made that the human brain, with its considerably expanded capacity to represent just about any concept (especially in the expanded prefrontal neocortex) and consequently alter its behaviour is an evolvable system, but that will be the subject of another paper.

This paper will explore the case of the purposive system and what form of internal governance processes are needed to increase the likelihood that the system will sustain its existence and purpose over extended time scales. I argue that the HSS is a purposive system and not an ecosystem. Therefore, the sustainability criteria involve maintaining structural and functional aspects in their essential forms, i.e. forms that support the purpose. As to what that purpose is, I assert that the HSS exists to support the needs of all of its biological members, at least in the ideal sense. That the ideal is far from realized in the present situation is a reflection of the same failures of the system that have resulted in the existential threats mentioned above. Put simply, the HSS has evolved structures and functions that are far from optimal in their ability to support the purpose.

Ecosystems are Reactive and not Long-term Sustainable

In order to fully appreciate how the right kind of governance subsystem can improve the capabilities of a purposive system to continue existing and flourishing (succeeding at its purpose) over extended time we should examine the first kind of system. We need to recognize what differences exist between how an ecosystem operates and what kind of regulatory or governance subsystem lends to its achieving a quasi-stable existence.

One reason this is relevant is that the form of ecosystem governance is very similar to what we see in the human social system, in the commonly asserted theory of the 'free' market as the only needed mechanism for societal stability and long-term sustainability. There is a prevailing belief that the free market (to the extent it can be free) has all of the necessary means for self-regulating the economy and that that is all that is needed to provide for human well-being and growth in living standards into the future. This is a dangerous conception. We need to understand how a ‘free’ market fails to make the kinds of overall system behaviours that would make the necessary adjustments to counter the supra-system’s tendency to change the rules of the game. Ecosystems change at the whim of the Earth’s larger scale milieu. Change the climate and the existing ecosystems come under varying degrees of stress, reacting by simply changing their own composition and processes. They just as readily go out of existence or substantially change such that they are no longer the same system. Though many neoclassical economists would doubtless argue vehemently to the contrary, the same phenomena apply to societal economies operating with market-based self-regulation. Near-neighbour cooperation using monetary signals breaks down under both internal failures and disruptive changes in the environment.

Ecosystems and market-based economies cannot anticipate changes. They cannot initiate actions in advance of harmful inputs that would act upon the supra-system’s mechanisms (its other subsystems that act on or against the ecosystem). Ecosystems do not adopt a defensive action when the climate changes. All that happens is that those species that are susceptible to the change will die off altering (sometimes critically) the food web. Then the ecosystem will become something quite different from what it was.

Market-based systems suffer exactly the same phenomena. When there are, for example, major new energy sources found, or new technologies invented, the forces that ripple through the economy often displace many members of the society. This may seem different from the ecosystem case at first glance. After all humans did the finding and inventing, so it looks, on the surface, like a purposive action. But it was the purpose of smaller subsystems (e.g. companies), not the whole economic system that produced the change. Second, during a phase of social evolution in which the population and the economies are growing both of these tend to dilute the impact of the displacements. We notice them less if we are not the ones affected. Nevertheless, the social fabric is no longer what it was. Values and mores get displaced as well. The video gaming and mobile communications technology developments have led to what might be described as zombie-like behaviour in the population. How else would you describe people walking along intently texting and walking into each other or some obstruction[5]?

Ecosystems and market-based systems can be said to “go with the flow.” They are at the mercy of whatever new developments occur. And in a seriously complex world like ours something is always developing. The world is non-ergodic, especially so as far as human affairs are concerned. It is important to recognize that these systems rely on internal feedback loops for regulation. As they evolve these feedback channels are selected for the stability they provide to the whole system. An extensive internal network of checks and balances (e.g. between predators and prey) comes to dominate the climax system. And that system might easily remain stable for as long as the environment in which it is embedded doesn’t substantially change. It might even be basically stable in the face of

[5] Working on a college campus and walking between office and classes gives one a chance to observe the new zeitgeist at first hand. Several days ago I witnessed two collisions between people who were so engaged in texting (or reading) that they just failed to check to see if their path was clear.

invasive species from time to time. Their incursions might trigger re-balancing but the system as a whole might well sustain even so. In the Pacific Northwest forests the invasion by blackberry plants has changed the understory, but not the overall fabric of the forest; as far as we have observed.

There is an additional twist to the market-based economy of the HSS in that humans, through their inventiveness, create their own changes in the embedding environment. That is, new technology is a major source of changes that force the direction of the flow. For the market-based ecology of commerce it is our own devices that change the conditions and to which the ecosystem of organizations must then adapt. Global warming and climate change are clear examples of this phenomenon.

Ecosystems are meta-stable and stability seeking even when it means changing their basic composition. The concept of sustainability is not even meaningful in this context. There is no purpose to sustain and the structures and functions are determined by change to whatever they need to be.

Purposive Systems are Proactive and can be Long-Term Sustainable

We contrast a reactive and quasi-stable system with a proactive and resilient one that is able to maintain its core purpose in spite of the kinds of changes the world throws at it[6]. The paradigm system is a single individual organism. Its purpose is not merely to exist but to reproduce. It has been "designed" by evolution to achieve this. It has been imbued with goals encoded in its genetic fabric. Its brain (in the case of animals) is wired to pursue behaviours that will maximize its chances of existing and procreating. It is optimized to live long enough to ensure offspring have successfully promulgated into the world[7].

Proactive, purposive systems do not merely react to changes in their environments. They make attempts to change the conditions if that is what is necessary to carry on with their purpose. The mechanisms for supporting this kind of behaviour require a form of adaptivity that is able to anticipate changes before they occur and initiate actions that pre-empt the supra-system. The Gaia theory invokes this notion on a grand scale. Perhaps the Earth as a whole *is* a proactive system. This is an interesting open question.

Regardless, there is now a substantial body of knowledge showing that animals and even some plants anticipate their environments and act in advance of actual changes that might turn out to be costly in terms of causing damage to tissues that would need to be repaired (Mobus, 1999). Assuming a level of effectiveness in action, i.e. the organism has the power to affect the outcome, biosystems are able to maintain their integrity so as to carry out their purpose, on average. No such system is perfect. But given an adequate

---

[6] Noting, however, that an event such as the Chicxulub meteor at the end-Cretaceous extinction (dinosaurs) is such a radical change that few biosystems could accommodate it. There are limits to everything.
[7] Whether the species are K-selected or r-selected, the objective is the same; produce enough viable offspring to improve the chances of the gene pool to promulgate into the future.

population of similar purposive organisms, the odds are in favour of success for the population.

SUSTAINABILITY

Sustainable processes are those that can continue into an indefinite future. Systems fall into four categories of process dynamics: Growing, Developing, Steady State Maintenance, and Contraction (or collapse). Growing dynamics imply that the system is getting larger in some way. It is obtaining extra resources from its environment in order to construct new structures. Developing has two basic modes. One mode goes along with growth and constitutes remodelling of internal functions as the system enlarges. This is ontogenic development. Examples are embryonic development and small businesses growing to larger size adopting more sophisticated business processes. The second mode of development is progressive development. It is not necessarily associated with growth. It is marked by improvements in internal processes for efficiency and/or effectiveness. Examples are technological inventions and learning in the brain.

All natural systems are constrained by their environments insofar as the extent to which they can grow and develop ontologically. Growth potential is ultimately a function of availability of resources and the capacity for waste sinks to absorb and nullify wastes. Resources are generally utilized by multiple competing systems. Even supposed renewable resources are flow-limited. Finite resources are stock-limited. Either way all systems working to obtain those resources are constrained in achieving growth or ontogenic development by the limits of the resources.

Progressive development may also be constrained by resource limits, in particular limits in exergy availability. Exergy is the amount of energy in an energy source that is available to do useful work. Unlike matter, which in principle can be recycled, energy that is used to do work is transformed into waste heat according to the 2^{nd} law of thermodynamics. Thus constraints on energy flows or stocks will result in constraints on how much work can be done in actually constructing better subsystems in progressive development.

Steady state maintenance is more correctly described as bounded oscillations around a steady state mean value of size (also called a stationary process). Most real systems that grow toward their limits approach this dynamic. So long as the external environment is relatively stable over time, then such systems can enjoy a sustained existence. The oscillations around the mean are a natural consequence of small perturbations in resources or temporary internal disequilibria due to time lag effects. Under ideal conditions the peaks and valleys will not be so extreme as to cause internal damage to parts of the system.

What is Sustainable Growth?

The only sense in which this term has meaning is when a system is small compared to its potential for increasing its size. Infants grow to become adults. Organizations grow as long as there are new members that want to join. But eventually growth ceases and the system enters a dynamical steady state.

The fallacy of economic growth is that a supposed measure of income, a surrogate for accumulated wealth, the Gross Domestic Product (GDP), measured in dollars, can go on growing forever. The standard belief among neoclassical economists, and just about everyone else, is that exponential growth of GDP is the sign of a healthy economy. The fact that so many people hold this belief is stunning and shows how poorly most people grasp basic systems principles. Indefinite sustainable growth of real systems is impossible on many levels, but the most determining is the limits of energy availability. Real wealth is created by work on natural resources to produce usable (that is valuable) artefacts and services. Since energy is used up in doing work and since 80% of the world's energy supply comes from non-renewable fossil fuels the notion of an indefinitely growing economy is laughable.

What is Sustainable Development?

Ontogenic development, by definition, reaches an end point when the system is mature. As with sustainable growth the only sense in which ontogenic development is sustainable is when the system is immature and is in the process of maturing.

Progressive development can, in theory, go on regardless of growth or state of maturity. Since the basis of this development is invention and innovation, it is possible, in principle, to find new, better ways of doing things. Biological genera, as systems, are presumably finding better species (that is those that are more fit) through neo-Darwinian evolution. A human can learn better skills throughout her lifetime. A company can find more efficient procedures for handling work. None of these developments need cost the system as much in energy invested as growth or ontogenic development. And they are investments in that they are expected to have returns in the energy savings to be made in the future.

However, progressive development can only be accomplished so long as there is some energy available to do the work needed to change old components into newer ones. Constraints on energy flows will constrain the rate of progressive development.

What is Sustainable Steady State?

If a system has successfully entered into a mean steady state dynamic it is conceivable that it could be sustained in that dynamic into the indefinite future. What is required is that the system meets three necessary criteria or has three capabilities. A fourth necessary condition is outside of the control of the system but will be mentioned as it establishes the boundary conditions for a sustainable dynamic. The three system capabilities are adaptivity (or adaptability), resilience (or self-repair), and evolvability (a form of progressive development). The fourth condition involves the dynamics of the embedding supra-system or environment. Systems that meet the three criteria and as long as the environment is reasonably stable can enjoy long-term sustainable lives. Of course, systems that are growing or developing may be subjected to environmental conditions that require at least the first two capabilities but for simplicity sake I will discuss these in terms of a steady state system.

THREE NECESSARY CAPABILITIES

Preliminary – Average Lifespan of the System Type

Complex purposive systems must be capable of these capabilities in order to persist into an indefinite future. By ‘indefinite’ I do not mean infinite, of course. Every system has a natural life span with a range of variation in duration. Among organic systems the specification is relatively simple. Individual humans have a lifespan (depending on their lifestyle situation) of, say 70 years +/- following a distribution curve on either side of that norm. Species, in general, are thought to have a duration of about 1 million years +/-, again following a distribution curve on either side. Local populations of species are possibly somewhere in between, with the lifespan dependent on the local ecosystem.

Among supra-organic systems, such as corporations, many also have average durations, but these are more difficult to characterize by a simple norm and variance statistics (too many confounding variables). Civilizations, likewise, seem to have normal lifespans with a distribution curve, centered at about 2,000 years but with huge variances. This is more an observational number rather than saying anything instructive about civilization durations (Tainter, 1988).

The real point is that nothing lasts forever in the limit. Systems that are not evolvable (see below) are always at the mercy of their embedding supra-system as well as the ravages of entropic decay (aging). Evolvable systems, on the other hand, could have a longer, if not indeterminate, duration if they undergo internal changes that keep them fit with respect to that embedding system. But evolution depends on luck (chance and circumstance) for non-sentient-based supra-organic systems like genera. For sentient-based purposive systems luck is still a big factor. But forethought and intentional design and construction of anticipatory modifications (e.g. planning a new product line for a company) help these systems sustain their existence, if not their original purpose, into that indefinite future. Since chance and circumstances still prevail (e.g. a comet hits the Earth), nothing is ultimately guaranteed.

All complex systems, in order to persist, need the following capabilities. These are related to the hierarchical cybernetic governance subsystems levels.

Adaptivity

Adaptivity is the capacity to continue operations of subsystems when inputs to a system vary in quantity or quality from a normal (or nominal) value. Adaptivity is built into operations and coordination levels of the HCGS. The system must be able to adjust its internal workings such that it compensates for these changes in input values. Values above or below a nominal range may have deleterious effects on the system and so require responses from its operational level subsystems that act to rebalance internal operations and oppose the deviations. At the same time the logistics coordinator needs to rebalance the inter-process flows to compensate for one or several operational subsystems being affected. The tactical coordinator comes into play to attempt to correct the situation with respect to the external inputs.

Consider the purposive system $\boldsymbol{S}$ whose output is the set, $Y = \langle y_{j,t} | y_j \textit{ is an output type} \rangle$, composed of products and wastes[8]. For each $y_j \in \boldsymbol{Y}$ there exists a range of values $[y_{j,lo} \ldots \widehat{y_j}, \ldots y_{j,hi}]$, called the acceptable range of quantity (or quality), with a norm, $\hat{y}$, and an impact distribution around that norm such that approaching the low or high values result in negative consequences insofar as fitness is concerned; that is the environment will react negatively to outputs outside the nominal ranges. The system will strive to keep all of its outputs within the acceptable range and as close to the norm as possible. This is generally achieved through standard monitoring of outputs and feedback control by the tactical coordinator. However the ability to achieve this depends, in part, on the quality/quantity of resource inputs.

An adaptive system is one that can continue to operate over a finite range of variations in input conditions, centered on an optimum for each type. Similarly to the output quality/quantity parameters, let $\boldsymbol{X}$ represent the set of input types for a complex system. That is $X = \langle x_{i,t} | x_i \textit{ is an input type} \rangle$ such as energy, matter, messages. $\boldsymbol{i}$ indexes the type and the value of any x_i at time t can be determined. Then for each $x_i \in \boldsymbol{X}$ there exists a range of values $[x_{i,lo} \ldots \widehat{x_i}, \ldots x_{i,hi}]$, called the nominal operating range, with a norm, $\hat{x}$, and an impact distribution around that norm (i.e. at the limits damage will ensue).

Adaptivity is achieved by having internal mechanisms that can compensate for variations in inputs around the norms for those inputs. That is, the mechanisms work to adjust the operations dependent on these inputs so as to protect the quality of their outputs. The paradigm example of this kind of adaptivity is homeostasis wherein the mechanisms operate to counter the effects of changes in inputs in order to maintain acceptable levels of outputs (quality/quantity). A number of mechanisms are well known. For example systems may be able to obtain substitute inputs or from alternative sources. They may have internal backup stocks of the input resource to compensate for fluctuations in quantities of the input. In the case of detrimental inputs the system may have abilities to retreat from the source.

Simple adaptivity involves a response mechanism that reacts to a change in inputs. A more advanced form of adaptivity involves forming a memory of the stimulus change that, if reinforced over time, results in the mechanism retaining its expectation of change in anticipation of future changes. This form is the basis of "learning" in which the organism or organization is prepared for the future (Mobus, 1999).

The point of adaptivity is that it is a capability that is already built into the system. It is not something that is created ad hoc (see Evolvability below). Living systems evolved to deal with variations in their environments that fall within limits. No system is capable of

[8] See Mobus & Anderson (2016), this conference proceedings. We provide a formal definition of system $\boldsymbol{S}$ in which inputs and outputs are defined mathematically.

adapting to extreme conditions or maintaining their basic capabilities in light of extremes that persist over time. In the first case systems need to have additional capabilities to repair damages that obtain as a result of long exposure to extremes. The second case is addressed by evolvability operating in a population context (to be explained below). However, in this case the results of exposure to extremes for extended time is the death of individuals when their internal capacities for adapting have been strained beyond their limits.

Resilience (Repair)

When adaptivity fails to adequately compensate for extreme conditions (at the high or low limits) the system must have a capacity for repairing the ensuing damage. That means it must have internal information on how to 'fix' the damaged components, stocks of extra materials and energy, and internal work processes that are dedicated to repair work.

Living systems exist because early in evolutionary history these capacities were inherent in the interplay between early metabolic chemistry and the genetic codes stored in RNA/DNA. Repair work processes are essentially the same as construction processes, which are used to replace decayed components and reproduction. This is autopoiesis as we now understand it.

Resilience in supra-organic systems likewise depends on spare construction capacity and knowledge of how to do the construction. We have, unfortunately, a cogent example of the failures of such capacity in the decline and failures of critical infrastructure. In the United States there is a growing worry about the state of roads and bridges, dams and power grids among other critical parts of the whole system.

Evolvability

There is a lot of confusion in the literature on adaptive systems between the terms adaptivity and evolvability. This is an unfortunate result of evolutionary biologists loose use of the former term when describing the capacity of a species (versus individuals) to be fit in an environment (with its variations in conditions) as an 'adaptation.' What they mean is that as a whole, and on average, the population of a species has characteristics that make it, in general, well adapted, *a prior*, to the environment. This has nothing to do with the mechanisms of adaptivity (as described above). What seems to have happened is some of the early pioneers in biomimic computing tended to use the terms adaptive and evolution interchangeably when describing, for example, adaptive agents and evolutionary programming. As described above, adaptivity is a capacity to compensate for variation in inputs that is built into the phenotype.

Evolvability has a much different meaning. In short it means that a system can alter its internal structures in multiple ways that give it significantly altered or entirely new capabilities. For example, the simplest form of evolvability would be the changes in the input range: $[x_{i,lo} \ldots \hat{x}_i, \ldots x_{i,hi}]$, such that x_{lo}, x_{hi}, or $\hat{x}_i$ (or all three) are permanently adjusted to accommodate the long term changes in the environment. In organic systems this is accomplished blindly by there already being some variation in the population regarding these parameters and natural selection to weed out the individuals unlucky enough not to have the 'right' preadaptation to the new conditions. For example, in the populations of Darwin's finches, there is a pre-existing range of bill sizes and lengths that allow the species to be sensitive to changes in climate that alter the kinds of seeds that predominate in their food sources. Some birds come pre-adapted to larger, harder shells and as those not so equipped succumb to the reduction in food, the lucky ones come to predominate in reproductive success.

A system evolves when the changes in the embedding environment trend over a longer time scale than the lifetime of single individuals. As mentioned previously large environments (like the Ecos) are non-stationary with respect to many attributes and causal relations. Throughout the history of the Earth large-scale changes in conditions like continental masses and climate have operated over fairly long time scales and the selection pressures driving speciation has been tolerable to life. Exceptions have given rise to the major extinction events that radically diminished biodiversity. Fortunately there have always been hardy species capable of adaptive responses to the changes. And after the die offs the rates of speciation have generally been spectacular. Evolvability is the backup plan when adaptivity is not sufficient.

We are presently watching in real-time a major shift in global average temperatures that are forcing climate changes of all types. All species of plants and animals are being affected to one extent or another. Some will be somewhat adaptable; they can move to new environs to compensate. Some, perhaps the majority, will not be able to adapt. That is where evolution comes to the rescue. Members of the species may be recipients of genetic variations that make them pre-adapted to climate changes and survive. If the selection pressures are strong we may witness evolutionary changes to rival Darwin's finches.

Supra-organic purposive systems such as organizations are also evolvable. They have the capacity to anticipate changing conditions and undertake modifications to their structures and functions, if not their basic purposes. This is dependent on having human decision agents with strong strategic thinking capabilities at the top of the HCGS. The organization doesn't undergo neo-Darwinian evolution; they do not produce offspring with variations in the genome in hopes of some surviving. They evolve more through intentional redesign of subsystems in the hope that doing so will make them more competent (for the commercial world that is more profitable!) Luck is almost always still a factor. The internal model of the world might be defective leading to bad choices in actions. Or the world could still hold surprises that could not be anticipated (the equivalent of the Chicxulub meteor). Since it is human beings that are in the roles of strategic managers and therefore are responsible for the models of the world, the former difficulty is what accounts for the high variability in organizations succeeding in remaining fit in spite of being evolvable.

WHY THE HSS IS PRESENTLY UNSUSTAINABLE

If all three of the above capabilities are available then the only question is whether the HCGS is up to the task of using them when needed. This is where we run into difficulty with social systems, especially the global HSS. The governance systems in place are too often dysfunctional with respect to their implementation of the hierarchical cybernetic principle, and the decision agents working within whatever governance structure is in place are increasingly incompetent as the complexity of the social system increases.

Since we can't address the problem of a completely unpredictable event affecting the Ecos, I will focus on the internal issues of the HSS that are presently deficient such that achieving sustainability of our current civilization (let alone further development) and possibly even our very existence is unlikely without some major changes in our approaches to governance. On the other hand, knowing what these deficiencies are at least offers some hope that by correcting them we might achieve some kind of sustainable condition.

Purpose of the HSS

Is the HSS a purposive system? If so, what is its purpose? These are central questions that need to be asked and answered before we can begin to address the questions of governance and sustainability. The current general belief about the HSS's purpose is fully anthropocentric. We believe that the HSS, indeed the whole Ecos, exists completely for our own benefit. This belief is at the root of our neoclassical economic model wherein the HSS extracts all of the resources it possibly can, grows exponentially without concern, and dumps waste products into the Ecos faster than the sinks can absorb them.

The systems view of CAESs and purposiveness provides an alternate view. CAESs exist and thrive when they are serving a purpose to the embedding environment. They are producing products and/or services that are *useful* to the larger supra-system. Their internally managed purpose is to produce those products or services so as to continue to have evolutionary fitness and a continued reward within the larger system. In doing so they help to ensure their own sustainability. As an example of a valuable service, top carnivores are often keystone species in a given ecosystem[9]. They contribute to the biodiversity and general health of ecosystems by keeping their prey species, which have direct impacts on the primary producers, in check. At one time, before the invention of agriculture, human beings were cast in this kind of role. Their intelligence capacity for organizing hunting and gathering from diverse food sources probably made them valuable to the savannah ecosystem (). However, that very capability seems to have selected for more intelligence leading humans to break out of their role as a keystone species to become agriculturists, forever changing their relation to the Ecos. They became extractors and polluters.

---

[9] See the Wikipedia article: https://en.wikipedia.org/wiki/Keystone_species and the story of wolves in Yellowstone park at:
http://earthjustice.org/blog/2015-july/how-wolves-saved-the-foxes-mice-and-rivers-of-yellowstone-national-park?gclid=CLqGsoCz4s0CFZNgfgodOmQAOw#

In order to have a chance to become sustainable as a social system, humanity must have a purpose relative to the needs of the Ecos. What, then, should the purpose of the HSS within the embedding Ecos be?

What product or service could the HSS produce that is useful to the Ecos? This is not an easy question to answer. The HSS is currently producing many by-products of industry. As things stand, it appears that most of these are harmful to some part of the Ecos. The HSS is confiscating large portions of the Ecos for farming and extractive processes[10], leading to habitat losses for other species (and their subsequent demise). It is producing exotic chemicals that are altering the biology of the biosphere, including humans. Is it possible to say that the HSS is currently a contributing component of the Ecos? There is a school of thought that humans are supposed to be stewards of the Ecos – managing it in some fashion. But the reality is that the Ecos was doing just fine long before humans evolved. It might do just fine after humans have gone.

There is another, darker view of the human condition. Cancers occur when damaged DNA permits certain cell types to ignore their purpose and go on a growing rampage. The ultimate result is death of the embedding supra-system (the organism). Cancerous cells *forget* that their purpose is to serve the supra-system by fulfilling their roles. Has the HSS become a cancer in the Ecos body?

Clearly these are challenging questions. But from a systems perspective they must be addressed. If we are to come to grips with the major issue of sustainability of the HSS we must answer the question of what we are for, what purpose we serve, in the larger Ecos supra-system. If those questions can be answered the next issue is how do we adapt or evolve our HSS system to accommodate serving a purpose in the Ecos. From the current perspective that means building an adequate governance system.

Current Design of the HCGS

It will be impossible in the constraints of a paper such as this to do sufficient justice to the issue of what is wrong with our current system[11]. Here I will discuss just a few examples of where the HCGS that constitutes humanity's best attempt at self-governance deviates detrimentally from nature's model.

The Market Fabric

The prevailing belief that free markets can solve all economic problems (which are largely believed to be the only kinds of problems that matter) has guided human decision

---

[10] According to various forms of ecological footprint analysis humanity has exceeded its carrying capacity of Earth by 1.5 to 2 times. See Rees & Wackernagel (1994).

[11] In Mobus (in preparation 1), "Understanding the Human Social System: A Systems Analysis of the Global Civilization" I attempt to do better in terms of analyzing the problems we face and why we are failing to manage them.

making with respect to strategic thinking[12]. From individual beliefs as “consumers” and “tax payers” to institutional beliefs about the centrality of profit taking to the political milieu of neoliberal capitalism, the economic system we live in globally is based on the idea that the “invisible hand” and personal greed will work through the market to magically coordinate all that needs to be coordinated. As a result, we do mostly rely on market fabrics to distribute information and force cooperation among economic agents using prices (as measured using faith-backed currencies) and contractual agreements.

As a result of this dominating belief, bolstered by those who are likely to gain the most from it being dominating – the bankers and rentiers – governments are constrained to find policies that conform and make decisions that leave markets to operate unfettered. Remarkably this persists in spite of so many historical episodes providing evidence of devastating market failures. So dominant is the view that the whole political process is just an exercise in finding leaders who will more vociferously promise to keep the markets free while also promising to protect consumers and workers from exploitation.

Society also suffers a secondary but extremely problematic failure from a cybernetic perspective. The ideal of a free press is that information about failures of the system will be revealed to the electorate, who presumably will critically judge the effectiveness of those human agents in consequential positions. There are many reasons to think that this is not the case since so many news venues are now fully owned profit making organizations completely imbued with the neoliberal capitalist credo.

As discussed previously, a market-based interaction fabric can work very well if the system is not intentional or is merely reactive. It works perfectly well for natural ecosystems. But in the context of a system that purports to have the purpose of supporting all of its member agents in a community living in a reasonable standard it is clearly not sufficient. Indeed, it is easily shown to be at the root of destructive forces such as CO_2 emissions and ultra-extreme income disparities. Rather, a market-based fabric should be thought of as a first level mechanism for achieving multi-way cooperation among a small local group of operational level processes that are directly communicating. It works best when the work processes are mutually transparent and where the motives of the participant subsystems (agents) are also mutually supportive. In the context of the HSS this implies neighbourhoods and small communities. Good examples include farmers’ markets and organized supply chains[13]. On a global scale and at the levels of complexity of the modern organizations, with their emphasis on competition and proprietary knowledge, there is no physical way markets can solve much of anything.

Operations Level

---

[12] The reality is that there is so much more to human existence besides economic concerns like income and consumption costs. Market-based interactions occur in many non-economic contexts. We call it reciprocity and it is a natural part of human mentality. Unfortunately, due to the milieu of economic survival thinking today almost all of our thinking is directed toward considerations of “what’s in it for me?”

[13] This means supply lines of companies that are in direct communications with one another to permit supply and demand information to be accessible to all.

Complex organizations like corporations, NGOs, schools, and churches form the operational units of the HSS. Because they are complex they require their own HCGS. Below I will address a major problem with HCGSs employing human decision agents in critical roles. Most organizations suffer from distorted objectives. I will introduce only one kind of distortion to show how the modern organization is faltering in its role.

Consider the idea, generally accepted among economists and MBA students, that the purpose of a corporation is to maximize shareholder wealth production (as measured in monetary terms). The duty of the board of directors and the officers of the corporation is to ensure that stock prices increase. Given that the officers are often compensated with shares this produces a strong incentive to follow through with this objective being the most important. There are many ways that officers, e.g., CEOs and CFOs, can fix things to have this happen; think Enron. But how does this contribute to the general welfare of society?

The basic problem is that many organizations, particularly profit-oriented corporations, do not grasp their actual role within the social milieu. They are oriented to profit maximization (which can easily be achieved by reducing labour wages) and competition. Even in cases where they cooperate, say with suppliers through supply chain contracts, there is a tendency to take advantage of positions of power; think Walmart.

In a coordinated complex adaptive and evolvable system the operational level subsystems have to find ways to produce their products in ways that truly service the whole system. That is not happening in the modern economy. Moreover, the concept of competition between operational units is damaging the whole system. For example, consider the domain of education. The neoliberal capitalistic model of operations has become pervasive in the HSS subsystem of education. The scope of this paper does not permit a full hearing of the issues. But one example will serve to show the problems.

In the zeal of (in particular) American society to maintain something called a competitive edge in science, technology, engineering, and math (STEM) the culture has adopted the use of standardized testing to monitor and regulate (through financial incentives) public K-12 schools. An unintended consequence of this reliance on a “management” approach has been the shifting of emphasis in the classroom to “teaching to the test” and a general decline in teaching critical thinking. One might argue that the education subsystem of a society is one of its most critical ones. What will be the long-term effect of producing a generation of students who are only worried about what they should study (memorize) in order to pass the upcoming exam?

Operations level subsystems rely heavily on accurate feedback regarding their products or services and an error-free model of what to do when the product or service quality/quantity measures deviate from the desired values. If their models of what constitutes value and goals are distorted, then they cannot adequately contribute in the long run to the supposed objectives of the HSS.

Coordination Level

Every country (regional units and cities) has its own set of laws and regulations that constitute its coordination level management[14]. These are meant to coordinate the behaviours of organizations and individuals (though usually in the sense of preventing them from harming one another). Nations enter into trade agreements and treaties for cooperative tactical activities. Internally, logistical management is handled by loosely organized laws, rules, and regulations. Countries like the United States and other large, geographically-speaking, nations are broken into states or provinces that have their own regional governmental structures. The whole of a country might be governed by a constitution or similar overarching document (and states have their own versions) detailing the form of the government. In all cases the structure of the government follows the hierarchical principles showing that the division of labour among decision process types is at play.

Governments have evolved since the onset of the Agricultural Revolution and the beginnings of urbanization and what we call 'civilizations.' The forms of coordination, both logistical and tactical have developed in sophistication but to this day remain largely intertwined with the economic systems employed, i.e. political-economy. Laws and regulations are generally developed through reaction to some problems experienced as civilizations grew and became more complex (i.e. technologies, social arrangements, institutions, and customs evolved). Even in dictatorship-style governments there is little in the way of systemic organization to achieve some optimization of operations. As things stand today the overarching belief that neoliberal capitalism and market mechanisms are mostly all that is needed and work best if unfettered by government bureaucracies to achieve coordination among all entities has had a tendency to relegate the actual implementation of coordination to international corporations.

But the world as a whole remains uncoordinated to a large degree. The only mechanism that comes close to this involves the avoidance of conflict and war. NATO (North Atlantic Treaty Organization) and similar coalitions are constructed to produce a strong alliance against which other powers would not dare to attack. The United Nations, organized after the devastation of World War II, is the only global body that attempts to coordinate specific international workings. Many consider it a weak organization that barely has any real effect. It was instrumental in building an accord on curtailing the production and use of chemical refrigerants discovered to be causing the opening of a 'hole' in the ozone layer of the atmosphere over the Antarctic. But its successes in doing the same for the release of carbon dioxide from burning fossil fuels, leading to climate change, has thus far been very poor. The UN with its many directorates is the closest thing to a coordination process with respect to a global HSS. Its effectiveness is in question.

In some ways the evolution of coordination-level governance and the current state of it at both national and global scales is reminiscent of what must have taken place in the

[14] These comments apply equally to organizational and institutional governance.

auto-organization taking place in the origin of life. From the earliest versions of stable but simple bounded metabolisms it took many millions of years for the development of fully functional autopoietic mechanisms that provided early bacteria-like organisms the abilities to be resilient and enter into biological evolution fully. What seems to be missing from HSS governance is the kind of functional autopoiesis mechanisms that would complete the HCGS at the coordination level. Below I will address the central problem we face in achieving this condition and consider what would be necessary to change that.

Strategic Level

The question keeps coming up: What are the ultimate goals of the HSS? This is probably the most difficult question to answer. The majority of people might subscribe to some form of humanism – that the lives of human beings matter and should be the supreme factor in decisions on how to manage ourselves. The paradigm example is the conflict between saving a species from extinction versus jobs for people. It is not clear that there is any kind of consensus on these kinds of issues. But invariably it seems jobs win out and habitats for endangered species lose.

In essence there appears, from a systems perspective, a complete absence of strategic management in the HSS. The closest approach is the existence of the United Nations organization having the goal of preventing another world war. One would like to believe that the existence of "executive branches" of various national governments, e.g. presidents and prime ministers, provided some kind of strategic management for their countries. But other than diplomatic relations with other countries – avoiding wars and obtaining trade agreements – there does not appear to be any true strategic management. How many governments are actually answering questions about how best to serve the welfare of their citizens? How many governments actually know what questions to ask? The records of national governments on strategic management are spotty at best. The most typical pattern in governments today seems to be the neoliberal capitalism solution. If you can stimulate the economy to grow, then everything will be fine for the citizens.

Generally speaking, there really is no strategic level governance for the HSS. The closest we have come is the United Nations' Intergovernmental Panel on Climate Change (IPCC) that has been doing threat analysis. It has been providing the information input that a strategic management process could use to plan for mitigation and adaptation. But it has been struggling to get the countries of the world to come together in a consensus on climate change and what to do about it (i.e. reduce carbon emissions). The problems with accomplishing any meaningful action reflect the lack of understanding of how complex adaptive and evolvable systems really work. This may be a reflection of another systemic problem for our HSS; that human beings are very poor decision agents.

Humans as Decision Agents

The role of decision agents in HCGSs is that they must make veridical decisions about what needs to be done to manage their part of the system. Here we face a fundamental problem with the situation of the HSS and the core issue with respect to our existential threat. Human beings are remarkably poor decision agents from a systemic POV! For example, countless studies in behavioural economics have demonstrated the fallacy, at the heart of neoclassical economics, that humans are rational deciders. That is, they are supposed to make rational, utility maximizing, decisions with economic consequences. They should do this for their own benefits. They should do this as managers for the benefits to their organizations. They should do this as critically thinking citizens in democracies. But the sad truth is that humans are not such decision makers (Kahneman, 2011). We now realize that human beings are subject to all kinds of biases, use evolutionarily developed heuristics, and are prone to errors of judgement even when working hard to make decisions. The decision milieu for most governance (and political) decisions is what are called 'wicked problems.' These cannot be solved using algorithms or even heuristic programming.

Wicked problems require something that is seemingly rare in human cognitive capacity – wisdom. The nature of wisdom has been taken up by cognitive psychologists over the last several decades and has now been reasonably well characterized (Sternberg, 1990; Mobus, in preparation 2). The reason for the rarity of wisdom in individual humans can be attributed to several factors; education and the social attitudes toward age tend to downplay its importance. However, a stronger influence might be biological – sapience, the brain basis for acquiring wisdom, is a newly evolved trait (along with symbolic language and other aspects eusociality). As such it is still nascent in capacity among the vast majority of the population. Furthermore, in today's world there is little selective advantage to the ability. Wise people are rarely rewarded for being wise, nor do they tend to produce more offspring.

Wisdom is the use of tacit knowledge, acquired over a lifetime, to make veridical judgements. An area in the prefrontal cortex, Brodmann area 10 (BA10), an area known to be associated with future planning (that is strategic thinking), underwent radical expansion between 200 and 150 thousand years ago. This accords with what anthropologists have been able to decipher regarding the origins of symbolic thought and also correlates with the development of language (Tomasello, 2014). Strong strategic thinking in a group context is one of the major features of wisdom.

If it is true that the majority of human beings are relatively weak in their sapience, then it is the case that a majority of decision makers are not wise and are prone to the kinds of mistakes in decision making that Kahneman and other cognitive scientists have described. An HCGS cannot function well with defective decision agents. This is similar to the problem of designing a well-functioning machine using fault-prone components.

Wisdom, however, is not all that is needed. Decision agents use decision models to compute the control output required from the situation inputs (see Mobus & Kalton, 2014, chapter 9 esp. figure 9.18). For human decision makers in governance roles those models consist of, for example, explicit rules as in policies and procedures, their knowledge of those rules, their knowledge of how the system they are making decisions about works, and their capacity to make predictions of what will happen in the system as a result of their control actions.

Once again we see that the issue of complexity creates a fundamental problem. Humans may become experts over time, but the more complex the system being governed the less likely any one human being can understand it well enough to make decisions that will always be veridical. In Mobus (2015) I described a tribal model of governance thought to be the kind of situation most human groups were in at the end of the Pleistocene epoch. Tribal life for hunter/gatherers was reasonably simple and the human brain evolved especially to handle that level of complexity. It is unlikely to have evolved further since that time to handle the kinds of complexities we face in modern social systems. We have probably succeeded to the degree we have because of our ability to form bureaucratic hierarchies with higher levels being abstractions of many lower levels.

But whatever successes we have had appear to be unravelling as human decision makers are called upon increasingly to operate in the kind of complexity experienced in our modern world. Even the best designed governance structure is doomed to failure if the decision agents are making substantial mistakes or are maliciously deciding for personal gain.

Energy Supplies

The final condition to consider in the sustainability of the HSS comes from both a failure of the HCGS and from a simple physical fact of life. We are running out of usable high quality energy needed to run the system.

No system can maintain itself, let alone grow or develop, without a reliable source of high quality energy. It takes energy to do real work and real work is needed to repair and refurbish the internal work processes of a system.

The HSS is currently running on about 80% fossil fuel sources. This is because we have developed an incredibly power-hungry technology-based civilization that requires increasing supplies of those fuels to keep operating. Even underdeveloped regions of the world are made possible (in their less than favourable environments) by supplies of fossil energy. The problem is those supplies are fixed, finite resources that we have been drawing down at increasing rates. And now the situation has turned on us.

It takes energy to obtain energy. There is a critical factor, energy return on energy invested (EROI)[15] that has been diminishing over time. The original fossil fuel sources were relatively easy to mine (drill, pump). As we used up the easy-to-get supplies, we turned to more expensive (in energy terms) supplies like off-shore oil. Today there are very few sources of so-called conventional (that is cheap) fuels and we are increasingly dependent on non-conventional sources (e.g. tar sands and fracked shale deposits), which are much costlier, yielding very low EROI values (Hall & Klitgaard, 2011). Hall & Klitgaard have estimated that a technological society such as the US needs to have sources with EROI values greater than 10:1 just to maintain critical infrastructure for

[15] EROI derives from a systems analysis of energy sources and the energy costs to extract the raw energy and transform it into a usable form.

transportation. The current sources of oil and natural gas tend to meet that criteria but they are also finite resources that are going to play out within the next several decades. What then?

There is a persistent belief in society that a "green" economy will be feasible. This is driven as much by the desire to stop using fossil energy because it is the source of carbon emissions that are causing climate change. The trouble with these beliefs is that they rely on solar influx as the power source for our continuing technological society. Technological solutions such as photovoltaics and wind turbines are held out as solutions to both the dwindling fossil fuels and the emissions problems. There is however a growing concern among biophysical economist (those who actually know thermodynamics!) that the EROIs of these technologies are inadequate to power modern societies. For example, a recent analysis of the EROI of actual deployment of photovoltaic power grids showed their values as closer to 2:1, two units of power for every unit input to derive that power (Prieto & Hall, 2013). This is not encouraging.

It is highly improbable that green technologies are going to provide enough energy to maintain the current materialistic consuming lifestyles of the OECD countries. Simply because of the physical limitations of energy flow, the HSS is going to have to reorganize and operate on very different principles. In other words, the current HSS is not sustainable in any sense of that word.

CONCLUSION – CAN THE HSS BECOME SUSTAINABLE?

Perhaps a better question is: Is there an HSS design that could obtain sustainability? The answer is probably yes, at least in theory. A follow on question, however, is harder to answer: How do we get from the current design to one that is sustainable with a minimum of pain and suffering?

Regarding the first question, the universal evolutionary model of increasing hierarchical complexity suggests that the HSS is following the pattern of cooperation among diverse components giving rise first to a federation of loosely coupled subsystems (our current state of affairs) and then the tightening of the relations through the emergence of coordinating functions (see Mobus, 2015, "Societies in Evolution"). There is hope that this pattern which has accounted for the range of societal units (e.g. societies of biochemicals to societies of macro-organisms) that transformed into more cohesive entities better fit for their environments, and hence, by definition sustainable, will pertain to the HSS as well (Bourke, 2011; Morowitz, 2002; Smith & Szathmáy, 1995).

In my paper last year (Mobus, 2015) I explained this process and pointed out that the only way it succeeds is with the emergence and evolution of a well-functioning HCGS. That means the governance structures that make it feasible for very complex social systems to operate as a single entity must be based on the HCGS principles as found in all such transitions. The most critical consideration for this to happen is addressing the questions about the purpose of the HSS in the Ecos. Once those questions have been answered then it is possible to design an HCGS with a strategic layer that constantly monitors the success of the whole with respect to fulfilling its purpose. We know what it should look like and how it should operate from the many examples in nature. We just have to decide to do it.

The question of technical feasibility of a properly functioning HCGS for the global HSS is not the problem (Odum & Odum, 2001). The question of how do we get to an HSS that works from our current state of affairs is the hard part. First there is the part about making the decision to do so just mentioned above. Here we run directly into the problem of poor decision making by human beings – their lack of wisdom. Political will is commonly invoked as lacking. Leadership is lamented as missing. Perhaps this is the case. But the reality is that it will take all human beings everywhere to recognize the nature of the problem and the solution. Otherwise there will be dissent that no amount of political will or leadership can overcome.

The problem? As described above, there is no way that the current HSS, at its size in population, its consumption of resources, and its production of pollution, can be made sustainable. There will need to be a major transition to a much smaller, much less consumptive, and much less polluting system. At the same time a much better governance subsystem will need to be implemented that will enforce these objectives. Given the nature of human beings in this scenario the philosophical questions of freedom and natural rights will likely come under review.

The alternative to an intentional process of transition is the purely evolutionary one of natural selection. This is likely to result in massive culling of the population and forced loss of energy/material resources. Conflicts between competing interests are a likely consequence. This is definitely not a minimum-pain path. Moreover there might not necessarily be an actual transition to entity-hood for the HSS after the dust settles. The HSS is an evolvable system even if presently devoid of strategic governance to intentionally find evolutionary solutions. Perhaps revelations coming from a systems science perspective could help to sway the general public regarding the extent of the problem and systems engineering might provide a pathway for an intentional transition pathway. The systems community has a responsibility to try.

REFERENCES

Bourke, A.F.G. (2011). *Principles of Social Evolution*, Oxford University Press, Oxford UK.

Hall, C.A.S. & Klitgaard, K. (2011). *Energy and the Wealth of Nations: Understanding the Biophysical Economy*, Springer, New York.

Kahneman, D. (2011). *Thinking Fast and Slow*, Farrar, Straus, and Giroux, New York.

Mobus, G.E., (1999). "Foraging Search: Prototypical Intelligence", *Third International Conference on Computing Anticipatory Systems*, August 9-14, 1999. Daniel Dubois, Editor, University of Liege, Belgium.

Mobus. G. & Kalton, M. (2014). *Principles of Systems Science*, Springer, New York.

Mobus, G. (2015). "A Systems Science Framework for Understanding the Nature of Governance", Proceedings of the 59th Annual Meeting of the ISSS - 2015 Berlin, Germany, Vol 1, No 1 (2015).

Mobus, G. & Anderson, K. (2016). "System Language: Understanding Systems", Proceedings of the 60th Annual Meeting of the ISSS – 2016 Boulder, CO, (accepted).

Mobus, G. (in preparation 1). *Understanding the Human Social System: A Systems Analysis of the Global Civilization*.

Mobus, G. (in preparation 2). *A Theory of Sapience: Using Systems Science to Understand the Nature of Wisdom and the Human Mind*, Available upon request.

Morowitz, H.J. (2002). *The Emergence of Everything: How the World Became Complex*, Oxford University Press, Oxford UK.

Odum, H.T. & Odum, E.C. (2001). *A Prosperous Way Down: Principles and Policies*, University Press of Colorado, Boulder CO, USA.

Prieto, P.A., & Hall, C. (2013). *Spain's Photovoltaic Revolution: The Energy Return on Investment*, Springer, New York.

Rees, W. E. & M. Wackernagel (1994). "Ecological footprints and appropriated carrying capacity: Measuring the natural capital requirements of the human economy", in Jansson, A. et al.. *Investing in Natural Capital: The Ecological Economics Approach to Sustainability*. Washington D.C.:Island Press.

Simon, H.A. (1996). *The Science of the Artificial*, The MIT Press, Cambridge MA

Smith, J.M. & Szathmáry, E. (1995). *The Major Transitions in Evolution*, Oxford University Press, Oxford UK.

Sternberg, R.J. (ed.) (1990). *Wisdom: Its Nature, Origins, and Development*, Cambridge University Press, New York.

Tainter J.A. (1988). *The Collapse of Complex Societies*, Cambridge University Press, Cambridge MA.

Tomasello, M. (2014). A Natural History of Human Thinking, Harvard University Press, Cambridge MA.