A Discussion on Basic Notions

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Abstract What do basic notions in systems and ecology mean? Several papers in this book propose specific ways of viewing systems (in particular ecological systems) and offer definitions and notions related to their proposed views. These often very compact "conceptual models" aim at providing a means to understand the behavior and evolution of real-world systems, be they economic, social, or ecological. The way real-world systems are viewed by people and politicians influences considerably how humanity deals with their natural surroundings and how they may decide to act in an ecologically favorable direction, given the fact that humanity's actions obviously have major significance for the global earth's well-being. The proposed conceptual models used by various authors in this book differ considerably from each other, making a discussion of their respective merits and shortcomings very meaningful. Six authors joined in the discussion, proposing, supporting, or criticizing points of view and aiming at clarifying the notions they use, while putting them in perspective. The discussion has been ordered as a question and answers session around the main themes. We hope readers will enjoy the clash of ideas and develop further insights motivated by them.

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1 What Is Meant by a *Complex Ecological System*?

Peter: As defined in the Glossary to Patrick's chapter, a system is "a set of entities having constitutive structural relationships". Thus, an ecological system is characterized by the structural relationships of a multitude of organic elements (microorganisms, plants, animals) forming a bio-community.

Patrick: A system is said to be complex if its evolution is unpredictable due to chaotic behavior. In a system with few state variables, chaotic behavior is due to non-linearities, in particular, the occurrence of bifurcations, "strange" limit cycles, and unpredictability of evolution. However, most ecological systems have a large number of independent agents each with its own state variables, and with a corresponding large number of accidental interactions between them. One very common particular source of complexity in an ecological system is random arrival times of interactions between agents. E.g., pro-creation is the result of such unpredictable interactions.

Mathis: Indeed, Earth is covered by ecosystems, with many layers of complexity: vastly differing time constants, climate zones, and large numbers of loose or tight feedback loops, stretching from quick and local to slow and global, and strong human influence. These ecosystems are also exposed to random events (asteroids, volcanos) and highly predictable patterns (annual seasons), amplifying the complexity of the overall system dynamics. Hence, the opportunity to see complexity is near infinite, given that even simple pendulums with merely two degrees of freedom can produce chaotic movements (e.g., Rott's pendulum). But the trick is to also stay actionable in this nearly overwhelming context. It actually is possible to guide meaningful action even in the context of this enormous complexity, because some aspects of the biosphere are quite basic and straightforward. Ignoring engaging with those opportunities while hiding behind complexity does not serve humanity. It only decreases the likelihood of a sustainable future. For instance, there are some basic quantitative constraints that are true no matter the complexity of the ecological systems. If one entity (the human economy) demands more from the host ecosystems than those ecosystems can renew, this poses a quantitative threat that inevitably undermines the long-term prospects for this entity. It is possible for economic entities to overshoot their supporting ecosystems for some time due to accumulated ecological stocks that can be depleted (or sinks that can be filled), but this level of human demand cannot be sustained. This is where much of the attention needs to be. I recognize and emphasize that getting the quantities right is no guarantee for a sustainable future. Nor does it guarantee avoiding surprises. But for sure, not meeting basic quantitative conditions will undermine the ability of the complex ecological systems to provide for that human sub-system, and undermines its resilience.

2 What *Mechanisms* are at Work in a Complex Ecological System?

Peter: The unique property of ecological systems is the interdependency and interactivity of the various elements. In effect, an ecological system exhibits a functional total, often referred to as "super-organism". The physical and chemical conditions at the respective locations dictate which organisms are present at the time of observation. This means that an ecological system is not static in character but is as dynamic as the environmental conditions are. Moreover, diversity and redundancy of the biocommunity act proactively to sudden and gradually developing perturbations. This reminds me of the adaptive cycle proposed by Walker and Salt (see reference at the end). In summary, an intact ecological system might therefore be addressed as a self-organized sustainable system.

Patrick: A major effect in a complex ecological system is the generalized occurrence of *emergence*. In such a system, new, coherent but complex entities arise that are not covered by the constituting properties of the original system. For example, the fact that a cell reproduces by cell division is not derivable from or contained in the laws of physics or chemistry, although these laws are instrumental in the process (they are necessary for it but not sufficient). As another example, humans use sound to convey meaning, but the meaning a sound has does not derive from its physics. The emergent complex entities obey new laws of their own. They are forming novel complex systems by themselves, utilizing properties of the basic system on which they are grafted (for example, humans form societies with specific state variables and laws, while humans themselves are organisms based on cells, which also have specific state variables and laws. Social science is therefore fundamentally different from cell biology and even more from physics). Often, the time scale of the emergent system is largely different from the original, so that state variables of the emergent system are often slowly varying in terms of quantities from the participating original. It is this effect that produces existential stability or identity to the emergent species or system.

3 What Mechanisms are at Work in *Economic and Societal Systems*?

Michael: One of the most important questions for the future is that of economic growth and environmental protection. How do we bring that together (for example, economic growth versus climate policy). But the politicians do not dare to act, because it is a very complex topic. A second topic is the distribution of income and financial/productive assets. Again, the politicians do not dare to do the right thing.

Patrick: Economic growth is mostly measured purely by tallying financial data, like the gross national product (GNP) of a country or of the world, or the gross domestic product that measures the total income of a country. Talking about the GNP, the issue is: "what does it consist of"? It is supposed to measure the monetarized total of “goods” and “services”. The ecological issue with that is that the monetarized value of goods has a much too large component of value obtained from natural resources. This is in a large part due to the fact that these resources (like oil, minerals, water, or even human labor) can too easily be exploited because they are generally much too cheap at the source (a more correct measure would discount exhaustion of natural resources!). The way economic output is measured definitively has to change. Such a redirection (to be done with a whole number of measures to be discussed elsewhere) does not diminish economic activity, it may even be instrumental in increasing GNP and thereby generating more economic growth than what is achieved through conservatively protecting existing, natural resources-based industries. The actions to be taken have to influence both the demand side and the supply side. Demand has to be conditioned by emergent, ecologically sound products (a good example is the recent emergence of Photo Voltaic and Wind Energy), while the supply can be influenced by regulations, taxation, and other protecting measures.

4 What is Meant by *State Variables* of a Complex System?

Peter: According to Walker and Salt, the state of a system is defined by the numerical values of the state variables that constitute the system. Typically, complex systems have a multitude of state variables, but only a few control the performance of the system. As an example, the availability of resources (raw materials, energy, talented employees, etc.) defines the extension and the limits within which an economic system can remain active. As soon as the system gets exposed to certain thresholds, the system loses its identity and integrity.

Patrick: I believe there is often confusion in what is meant by “state variables”. The detailed state variables of a large complex system are usually not directly available for control by an emergent actor, only some conditioning factors can be influenced, and then only by proxies. For example, mammals have internal regulatory systems for their body temperature, which they can only influence indirectly, e.g., by avoiding infections. The body temperature is itself a complicated function of the detailed state of the organs that constitute the respective body. When talking about control, always at least two systems have to be considered: a base system on which control is exercised and a controlling agent, which is emergent in most cases (there are also intrinsic control mechanisms, but these are seen to be automatic from the perspective of an outside controller), and has its own state variables. That only a few variables can control the performance of a system is largely incorrect: it is the emergent controlling agent who is limited and can access only a small collection of potential controlling parameters using a proxy. This is due to the fact that the laws governing the emergent species (its structure and evolution) do not allow direct interference with the laws of the base system.

5 How do Such State Variables *Evolve*?

Peter: We have to differentiate between sudden and slowly developing state variables. A break-down of an economy or the sudden change from a planned to a market economy (see East Germany after the political change) generates a dramatic threshold, and therefore a loss of identity and integrity of the system affected. Slow changes of state variables such as the rise of the sea level in millimeter scales caused by global warming are not readily visible to the agents in charge. Equally dangerous is the unnoticed descent of the groundwater level caused by over-extraction of water for agricultural irrigation, for instance in Northern India. No precautionary actions have been taken, and this might eventually lead to dramatic consequences.

Patrick: Most "state variables" one considers in Earth's ecology are globalized, often statistical functions of the huge variety of individual state variables of the largely independently acting agents that constitute the system. Such globalized state variables are often conditionals for the existence of an emergent species, and therefore also "slowly varying", because the time scale of the emergence is many orders of magnitude different from the time scale of its base system. E.g., the life span of an organism is many orders of magnitude larger than the time scale of chemical reactions that take place in it. The bodies' temperature is a conditional for the existence of its organs. Control by an emergent species on such global quantities can only be exercised through proxies, i.e., using one or the other mechanism of the base system accessible to the controlling agent and capable of producing the perceived benefit. Such controls may or may not succeed at preserving conditionals essential to the respective species (its resilience). Moreover, emergent species compete with each other for control and may annihilate each other. That some (actually many) variables are slowly varying is often due to inertia or conservation of some quantity (mass, energy, momentum, capital, goods, knowledge...), but it is also true that our global ecological systems are not "closed", so that many quantities are slowly varying thanks to exchange processes in relative equilibrium (e.g., the temperature of the earth, the constitution of the atmosphere or oceans). An emergent species can only be resilient if the control exercised by it on the base system keeps the conditioning quantities within acceptable ranges.

6 What Defines the *Identity of a System*?

Anastassia: While one can argue that the system can retain "identity", without a proper definition of identity, this argument clarifies little. For example, the atoms of gold are identical and they don't age and change in time. On the other hand, identity may refer to a particular trajectory the system follows in space and time. For example, a person retains his or her intellectual identity as long as the brain and memory function normally. If they don't, the intellectual identity is no longer retained, but the genetic identity, fingerprints, etc. are still retained. So what is the identity of a resilient system? Once we define it, in measurable terms, I argue that these characteristics should remain stable and it is this stability that defines the system.

Peter: Identity means the complete agreement of one thing with another thing. Strictly speaking, a thing or in our case a resilient system can only be identical to itself. Strong disturbances might violate the identity of a system. It is no longer the same as before, but might still be resilient but under a different regime, though. Retention of identity has therefore nothing to do with stability.

Patrick: The notion of "identity" and in its wake "resilience" are relative notions. "Identity" requires a differentiation between the subject being identified and its environment. Often even a third instance is involved, namely the agent which identifies. For example, as humans, we recognize the identity of a species within an ecological environment (i.e., both terms "species" and "ecological environment" have been defined and their use is recognized as conformal to our definition). Moreover, identity goes in "layers": we can talk about the "identity of a species" vs. the "identity of a specific member of that species", etc. A dynamic system (as considered by us) is characterized by a number of evolving parameters (its "state") and its identity of a specific system is then, as Anastassia rightly observes, seen as its "trajectory" (in technical terms: the "trace" of its joint state variables). The trace a species leaves behind in the world's evolution (its "identity" according to the definition of "species") is a different thing than the identity of a member of that species. Different types are characterized by different state parameters, different evolution mechanisms, and different time scales: systems that have isomorphic parameters and evolutions belong to the same "species" (this constitutes the species identity of a given member, while the individual trace identifies the member itself). State parameters of a given organism appear, produce traces, and then disappear again. Species have appeared and disappeared on a much larger time scale. Each of these types of systems needs a good amount of resilience just to keep existing, because the environment they live in is perpetually changing, while they want their identity, i.e., the "existence" of their states and its traces, in short, their existence, to remain valid at least for a significant period of time. In the ecological cases we are considering, the thesis is that the resilience of the human species is dependent on the resilience of the system Earth, including the resilience of other species.

7 How Computable are *chaotic* Dynamical Systems?

Klaus: In my paper *From Anthropocene to Artificial Intelligence? Challenges of Machine Learning for Science, Life, and Society*, I considered applications of modern machine learning to ecological dynamical systems. Ecological systems are highly complex, non-linear, and often chaotic. Therefore, the crucial question arises how computable are chaotic dynamical systems in principle. Chaotic dynamical systems model turbulence in ecological systems which are crucial for current debates on climate, population dynamics, and long-term predictions of our planet Earth. Therefore, I supplement some comments and results concerning the computability of dynamical systems from a mathematical and epistemic point of view.

A system is said to be deterministic if its future and past are determined by its present state. An example is classical mechanics with Newton's laws of motion. But, in practice, complex dynamics can often be indistinguishable from chaotic motions. In this case, predictions of the future are practically impossible, although the system is in principle deterministic. A simple case of a deterministic system is a harmonic oscillator with the equation of motion

$$\frac{d^2}{dt^2} + \omega^2 x = 0$$

It is an integrable system with the solution

$$x(t) = x_0 \cos(\omega t + \phi_0),$$

where x_0 and ϕ_0 are the initial conditions. For a given time t, a computer provides a solution $x(t)$ which needs $O(\log t)$ operations. It can be proven that chaotic motion requires a number of $O(\log t)$ operations. Therefore, an integrable system is completely computable and predictable. For a chaotic system, a prediction is not possible, before the future arrives. In the chaotic case, the system is its own best predictor and there is no predictive algorithm with a computational complexity better than $O(\log t)$.

The transition to chaos can be illustrated by the logistic map which was historically introduced in 1837 by Pierre F. Verhulst as mathematical model of demographic growth. It is a mapping of the unit interval [0, 1] on itself which is defined by the first-order difference equation

$$x_{n+1} = ax_n(1 - x_n)$$

with $0 \leq \alpha \leq 4$. The transition from regular to chaotic behavior depends on the growth defined by the parameter α. For $\alpha = 4$, the map is chaotic. If $x_n = \sin^2(\pi y_n)$ is substituted in the difference equation of the logistic map for $\alpha = 4$, one gets

$$\sin^2(\pi y_{n+1}) = \sin^2(2\pi y_n).$$

Therefore, in the case of chaos with $\alpha = 4$, the logistic map is equivalent to

$$y_{n+1} = 2y_n(\text{mod}1)$$

with the analytic solution

$$y_n = 2^n y_0(\text{mod}1).$$

Now, consider a digital representation of y_0 with $y_0 = 0.1101001100010101\cdots$. Each iteration of the map $y_{n+1} = 2y_n(\text{mod}1)$ moves the point in the binary representation one digit to the right and drops the part to the left of the decimal point. In short: One bit of information is erased at each step.

It can now be shown that the solution of $y_{n+1} = 2y_n(\text{mod}1)$ (and that means any prediction) is completely unpredictable. If the first t digits of the initial condition are known, the subsequent digits cannot be determined. The solution for future predictions will depend on ever diminishing details of the initial condition. In general, the set of all possible binary initial conditions corresponds to the set of all possible random sequences of coin tossing (with 0 for head and 1 for tail). Therefore, the development of the system is also random.

These results illustrate the restrictions of even our best supercomputers. In the state of chaos, no prediction is possible in principle. No algorithm could help us to influence and prevent our fate. In other words: In this case, it is too late. Therefore, we must be sensitive to critical signals during the transition of complex dynamical systems. The debate on climate change is a dramatic example.

Patrick: Klaus' examples show that very common systems with only one state variable can show chaotic behavior, i.e., become totally unpredictable after a relatively short time lapse. The more so when the system under consideration consists of a large number of state variables, which, moreover, have interactions that happen at unpredictable times. So: chaos is ubiquitous. Does that mean that predictability disintegrates totally? The answer is: not totally, depending on 1., the complexity of the system (the number of state variables involved), and 2., the time scale. For example, although the laws of gravity of more than three bodies (like our solar system) are known to produce chaotic behavior, we also know that the ephemerides can be predicted orderly in time spans of millenniums, which are short range with respect to the time scale of the universe. Chaos is ubiquitous, but so is emergence, which provides for a (limited) way out of chaos (it was mentioned before by Matthis that not all variables characterizing the state of a system evolve chaotically—in particular quantities that are conserved remain stable). But emergence allows for more. For example, intense traffic (say in Paris) is chaotic, but a taxi driver knows how much time it will take approximately to go from A to B (because he uses information from his peers who are scattered in the jam). This shows emergent control at work in a chaotic situation. Nature is a great performer in generating emergence out of chaos (think about the generation of species). Emergence means that new, often globalized state variables appear for which new laws hold, and which become reliably predictable on a different time scale than the originals. The task of ecological modeling is to properly identify the properties of emergences and utilize those to generate "well-being" of the more comprehensive system, which consists of the original (or base) system and its emergences.

8 What is the Object of *Resilience* and What are the Relevant Parameters?

Peter: The International Resilience Institute at Stockholm defines resilience as the ability of a system to continuously adjust to changing ambient conditions, to absorb disturbances while retaining its basic function, structure, and feedbacks. A system remains in a permanent dynamic state characterized by its identity and integrity. Thus, resilience should not be confused with stability or equilibrium. Resilience is rather a dynamic property. The relevant parameters characterizing a resilient system are the readiness to release, to monitor ambient changes, and to respond by means of reorientation.

Anastassia: I don't quite understand what the term "resilience" adds to the notions of stability and equilibrium, despite your caution. As long as we say that a resilient system retains its "basic function, structure, and feedbacks", this means that these system properties remain stable and do not change. If they do change, then what is it that the system retains?

Patrick: I fully agree with the definition and description given by Peter. A word of caution, however: resilience is often felt as a conservative attitude. For survival of a species, or, better even, for general ecological well-being, much more is needed. In particular creativity and gumption. These notions are not usually covered by the term "resilience". Why not create a "Gumption thinking Institute"?

Anastassia: Regarding creativity and gumption, by far the majority of species in the biosphere survive based on their genetic program alone and do not require any creativity, like birds don't need creativity to build nests. It appears more to be a matter of genetic luck at the moment of evolutionary origin: if the new genome fits adequately to the working ecosystem without disrupting its functioning, the new species will survive. If not, it is not a new species but a defective version of the older one. Our own species, uniquely, mostly bases its functioning on cultural rather than genetic information. We do need "creativity" only in the sense that we need to bring our governing cultural information in accordance with the ecological laws of nature that permit long-term persistence, something all other species already "know" from their genes.

Peter: Correct. Creativity and gumption are properties of Homo Sapiens only. If executed with caution, based on scientifically based knowledge and with respect to ethical norms, creativity and gumption give us the ability to understand changes of parameters, react accordingly, and manage a system in the sense of resilient thinking.

Anastassia: I don't disagree for the disagreement's sake. I honestly don't see what "resilient thinking" means as a general notion. More importantly, I believe that misunderstanding systems for "resilient" (as in the forest example) and mimicking their properties could make things just worse. It won't work. That is why it is important to understand what resilience is if it exists. Take, for example, the idea of "embracing change". Some changes can be embraced, some cannot. Cancer is a change to be fought with, not to be embraced. There are no generalities here.

Patrick: I think that many species of birds show quite a bit of creativity in how they build nests in unusual places! Hence I think that the statements given by Anastassia and Peter on this issue are way too strong. It does not seem true that the genetic program alone defines the behavior of the members of a species or its evolution. The genetic program only contains information on how an adaptive system like mammals and humans (or trees) is created (e.g., the genetic program only contains the necessary triggers for the growing mammal to create all the sorts of cells that will constitute the various organs in the developing fetus). To put it in my terminology: the purely genetic way of viewing things does not take ubiquitous emergence into account. What the brain of a mammal or a human is going to do is not programmed in the genes, only its structure is, and then only in "blue print", while much is left to environmental influences and accidental occurrences (like mutations). That human brains have more potential than those of most species is clear as far as we know, but I would not dare to say that "creativity and gumption are properties of human sapiens only". The notions of "creativity" and "gumption" are human defined with reference to what humans see as their own properties, and hence simply do not apply to other species, although some other species show remarkable properties that one could call great creativity and even gumption. They may survive our species thanks to that!

9 How Does Resilience of a System Differ from *Stability and Equilibrium*?

Peter: Being a civil engineer, I call a structure like a high-rise building or a bridge stable when it demonstrates the ability to withstand a significant disturbance such as a strong wind or an earthquake. In contrast, the resilience of a structure refers to the ability to balance the shock waves triggered by wind forces or an earthquake so that in effect the structure does not fall apart. Therefore, stability is a static, resilience a dynamic notion. The term equilibrium refers to a situation where disturbances are balanced by counter-disturbances as a result of resilience. Likewise, a forest consisting of a monoculture of spruce trees is unstable because it cannot withstand attacks of bark beetles. In contrast, through biodiversity and redundancy, an intact forest ecosystem possesses the means to avoid bark beetle infection of a single tree species. Such systems act as a resilient system with the ultimate effect of stability.

Anastassia: In my perspective, a high-rise building and a bridge likewise balance the waves triggered by wind forces, and the effect is that the structure does not fall apart. The only difference with the resilient system (of which I cannot think a vivid example to be compared to a bridge or building) might be in the amplitude of counterbalances, or the rigidity. If the object is rigid, even a tiny change in the distance between its molecules brings about a huge tension force, which balances the wind force. If the object is less rigid and more elastic, the changes in the location of its parts become macroscopic and visible. But this is a purely quantitative difference, not qualitative. Thus, stability is the resilience of a rigid system, or resilience is the stability of an elastic (flexible) system. This quantitative difference does not have an absolute meaning, one and the same system can be viewed as stable or resilient. Then why use a different word, what does it add? Regarding the forest example, I see it differently. Bark beetles are not a disturbance, they are part of the ecosystem disturbed by clear-cutting and then by artificial replanting which interferes with the natural process of forest succession. Monoculture: this is the disturbance. Bark beetles attack this "wrong biota" to kill it and to initiate normal succession and recovery toward a healthy ecosystem on the place currently occupied by the disturbance. Furthermore, it is not that an intact forest ecosystem somehow "copes" with bark beetles due to redundancy, etc. The intact ecosystem does not have any redundancy. Bark beetles are part of the intact ecosystem, and they just simply never attack it, like normally our immune cells don't attack us. Can you give an example of a real-world resilient ecosystem?

Peter: As said before a real-world ecosystem is resilient as long it demonstrates its ability to continuously adjust to changing ambient conditions, to absorb disturbances while retaining its basic function, structure, and feedbacks. Take global warming as an example of a change of ambient conditions. As long as forestry does not interfere and provides time for adaptation, the forest ecosystem keeps its basic function (e.g., serves as a biotic pump to transport humidity to habitats even in far distances). In contrast, the ecosystem loses its identity when forced into a direction non-compatible with the system's inherent capability of self-organization.

10 What is the Meaning of *Resilience Thinking*?

Peter: Resilience thinking is methods of viewing ecological systems as a reaction to environmental changes by measures of self-regulation. In the case of economic and societal systems, resilience thinking assists agents in operating such system to the benefit of their long-term existence. It appears that resilience thinking is key to sustainability and sustainable development.

Patrick: One should be careful not to restrict the notion of resilience to a single species or emergent entity. Resilience of one emergent system is dependent on the resilience of others. E.g., the resilience of an economic system may be achieved at the expense of the overall resilience of humanity, at least for some time, facilitated by the long-term time scale of controlling variables. The economic exploitation of earth's resources threatens the long-term resilience of the earth's ecology, while it may appear to enhance resilience in a shorter time span. Resilience Thinking must harmonize global and longer time effects of the various interacting entities.

Mathis: In 1972, the tagline of the Stockholm conference, the first large scale UN conference on environment and development, was "Only One Earth". This tagline was a clear recognition that humanity is bound to live within the resource budget of our one planet. Over the years, while Earth science and the ability to track and measure metabolisms and regeneration rates have vastly improved, the conceptual frames to interpret these trends have become ever more fuzzy. One big step in this direction came 15 years later, when *sustainable development* got "defined" by the Brundtland report. The word "defined" is in quotation marks, because that definition is unmeasurable, or untestable, and keeps the idea fuzzy. Whether this was on purpose or not, we can speculate. But it did help avoid conflicts with the "business as usual" trajectory and its proponents, at the cost of inaction. The more recent concepts such as *sustainable growth* or *green growth* are even more confusing, suggesting that there are no trade-offs, and no need for a fundamental adjustment to the physical reality of planetary constraints. Whether the word *resilience* is part of this confusion, we could debate. I have not found many meaningful definitions. The use of the concept feels often like a soft reinterpretation of sustainability, an effort to keep the door wide open so all can participate and no conflicts need to be faced. In fact, if resilience truly means "to absorb disturbances while retaining its basic function", it may not even apply to the current context where the biological metabolism of humanity is so vastly out of scaled compared to the size of its ecological host (i.e., the planet). Humanity's outsized metabolism is driven by The massive use of finite fossil fuel—at a scale that is unlikely replaceable. It might be euphemistic to call the massive overshoot humanity is facing "a disturbance". There have been many books published on resilience, with lack of clarity of how one can observe such "resilience". They tell little about measurable, quantitative conditions that need to be met in order to enable the possibility of resilient outcomes. Few recognize the profound dynamic of global overshoot. My interpretation is that such uses of the resilience concept distract from what seems such an obvious, massive priority: to reduce the human metabolism to a level that Earth's ecosystems can cope with. And again, this reduction of metabolism is not sufficient for a sustainable future, it is merely necessary.

11 Is the *Ball in the Bowl Model* too Simple to Explain Application of Resilience Thinking to Entrepreneurial Systems?

Peter: The Ball in the Bowl model is a metaphor. It is used to explain basic functions and properties of resilience to agents in charge of the operation and maintenance of economic and societal systems. It provides advice but must not be understood as a physical image of real systems. Depth, width, and curvature of the bowl are symbols referring to slow and fast changing variables. The rolling of the ball in case of a perturbation symbolizes the dynamic reactions of the system. The so-called point of attraction should be understood as a symbol of the ideal state of resilience under undisturbed circumstances. The ball does certainly not roll toward this point driven by the power of gravity but by the virtue of the state variables.

Patrick: In my view, the Bowl model is an incorrect rendition of the reality of a complex ecological system consisting of a large number of relatively independent agents. There are just too many degrees of freedom to produce a "bowl". Rather: everything evolves, although there are rapidly and slowly evolving characteristics, mostly depending on the inertia involved. The only way to achieve a modus of control on the evolution is by participating in it. I.e., by creating counteracting measures of the same type that tend to preserve needed conditions for the existence of the species concerned. One has to fight one emergence (like the use of oil for mobility) by another emergence (like what happened with nuclear power), which, in turn, has to be checked by a new to develop emergence (like solar or wind energy), which in turn will have to be checked when new deficiencies appear. There will always be competing emergences, like there are competing species. Long-term resilience is dependent on which emergence wins out.

Mathis: I agree with Patrick. The relative stability of the Holocene that some describe as a Goldilocks situation may come to an end, with more unpredictable climate patterns and shifting ecological productivities. Social stability is also more likely on an expansive trajectory, where "ever more" soothes potential social conflicts, and that trajectory may turn as well. Material contraction, eventually imposed by overshoot dynamics, whether by design or disaster, put more distributional conflicts on societies, adding social instability to the equation. Patrick's "competition of emergences" (possibly turning into a "competition of emergencies") could be a more accurate description of future states than finding another "equilibrium for the ball in the bowl" if humanity fails to proactively manage the overshoot dynamics.

12 Is it Fair to Assume that Persistence to *Outdated Business Models* Leads to Collapse, Chaos, and/or Bankruptcy?

Peter: With reference to an economic system, specifically a company, the adaptive cycle is assumed to keep revolving as long as the managers of the system monitor changes in science, technology, society, and political agendas, release outdated practices when appropriate, and reorient the production modes and sales practices. In case the management neglects ambient change, the company may eventually run into bankruptcy. Its collapse is caused by non-productive chaos.

Patrick: Companies can be destroyed by many effects, in particular non-adaptive management or problematic management decisions (like risky investments in technology), but a major threat to traditional companies in modern times has been emergent technologies like the internet, computers, genetic engineering, social networks, etc. An alert company may take up emergent signals and participate in the emerging growth, but it will usually not do so and expire at its own rigid sticking to its perceived equilibrium. Resilience for a company means to embrace change intelligently. Arie de Geus used to say "Shell does not exist to pump oil, it pumps oil to exist". Shell will stop existing if it keeps pumping oil!

Mathis: Overshoot, i.e., overuse of ecosystems beyond their regeneration, is possible, but leads inevitably to depletion and weakening of those systems. So, overshoot is possible in the short term, but not forever. How long it is possible depends on the size of the ecosystems' stocks. Therefore, economies that depend on overshoot and are unwilling to leave the overshoot zone by design will be forced to leave it by disaster (which might well include, or be anticipated by, financial collapse). That's the mathematically set dynamics of overshoot. Therefore, the answer to the question above is clearly affirmative, if the human economy is in overshoot. And the evidence that humanity is in overshoot seems overwhelming.

13 Does *the Adaptive Cycle* Preflect Reasonably Enough Sustainability Developments of Ecological, Economic, and Societal Systems?

Peter: The adaptive cycle as described above might be considered a process favoring sustainability of the system under consideration. It is a measure of sustainable development. This statement is supported by the following nine statements of Walker and Salt:

A resilient world

- promotes and sustains diversity in all forms;
- embraces and works ecological variability;
- consists of modular components;
- focuses on slow controlling variables associated with thresholds;

- promotes trust, well-developed social networks and leadership;
- places emphasis on learning, experimentation, locally developed and controlled rules (subsidiarity principle);
- embraces change;
- has institutions that include redundancy in their governance structure and a mix of common and private property;
- includes all un-priced ecosystem services in developments and assessments.

Patrick: I agree with the description, although I might formulate it somewhat differently (it sounds a little too conservative to me). I would put more emphasis on gumption and the creation of new emergences that are ecologically beneficial. I believe that is the key to moving economy in an ecologically productive direction: change economic activity in a massive way toward creating ecological well-being. I agree in particular on the importance of "slowly varying variables" as conditions for the systems' existence. The picture sketched in this Walker and Salt statement shows clearly that the "Bowl" model does not apply to the (global) ecological situation.

14 Is it Reasonable to Consider *Panarchy* as an Expression of System Dynamics Characterized by Creative Chaos and Subsequent Controlling Emergence?

Peter: Walker and Salt define *panarchy* as hierarchy of linked adaptive cycles active at different scales: "What happens at one scale can influence or even drive what is happening at other scales". On the other hand, Patrick defines "*emergence* as a property of a system that is not derivable from its structural dynamics, but exercises a controlling influence on its global evolution".

Patrick: The occurrence of emergence in a chaotic system is a fact of System Dynamics. It does not contradict the possibility of a collateral occurrence of panarchy as defined by Walker and Salt. In fact, emergence needs the panarchy. Emergence happens when a new order is created on top of a chaotic or panarchic system, using its evolution mechanisms, but creating its own evolutionary laws (in a non-chaotic system, evolution is fixed: there is no freedom for creative developments out of the blue). In all evolutionary processes, chaos is instrumental in producing the creative freedom potentially leading to novel developments. Computers, the internet, and the smartphone (all three good examples of recent emergences) would never have arisen if people had not been free to explore new possibilities in computing and communication. Resilience is a necessary property of a surviving species, but to ensure its continuing well-being, the species must develop new existential perspectives. Whole Earth Ecology is much more than a necessity for survival. It is an enormous opportunity for human development and well-being.

15 How Can or Should the Physical, Biological, and Engineering Context be Brought Into Economics?

Mathis: This is what I offer as a hypothesis: the lack of physics in modern social theories (including economics, sociology, and political sciences) are a legacy of an unreconciled, denied colonial past. Centers of colonial power operated with resources they were able to get from elsewhere, at low cost, without the consent from "elsewhere". The development theory did not question that resource appropriation, but framed it as "global trade". Therefore, a reconciliation with the colonial past may be necessary for the dominant economic and social theories to fully embrace again the physical nature of our individual and collective existence. Such a reconciliation could not just heal but also strengthen economic thinking. It would allow us to recognize that sustainability is a necessary ingredient for securing everybody's prosperity. It is stunning that the World Economic Forum now identifies 5 of the top 5 most likely global risks as environmental. Yet the same organization's competitiveness report, and much of the mainstream economic policy thinking largely ignores the significance of environmental trends for their own economies' long-term success. I have not found a better explanation as one rooted in a still prevalent, unspoken colonial attitude: "I can always get what I need from somewhere else".

Patrick: One should be careful not to limit the import of so-called natural sciences and engineering into social sciences and economics to "physics". Biology, system science, engineering, psychology play equally important roles in understanding ecological situations and, a fortiori, the global earth ecology as an integrated system. There is confusion in using the terms "physical reality" and "physics" as equivalent, due to the historical misconception that all phenomena in nature are reducible to effects that can be described by physics. In fact: most of them are not (and will never be). With "complex system science", an effort was made to overcome the belief in a rigid, deterministic world order ruled by physics. Both economic theory and "physical" science have to take each other's evolving paradigms into account. Since economics has been a massive contributor to the present ecological situation, the mutual impact of natural sciences and economics becomes crucial for their future as valid vehicles for understanding the earth's global system and its evolution.

Mathis: yes, physical reality is more than physics. Yet the laws of thermodynamics are fundamental drivers that social theory cannot afford to ignore.

Reference

1. Walker B, Salt D (2006) Resilient thinking. Island Press