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Editorial

Complexity science and sustainability transitions

Many, perhaps most, would agree that society is a “complex system”, and that sociotechnical transitions are complex phenomena. This suggests that complexity science may contribute to our understanding of how sustainability transitions work and can be stimulated.

But what does it mean that society is a complex system? The contributions to this Special Section clearly demonstrate that there can – and probably should – be many answers to that question. The most basic distinction is perhaps that between structural and dynamical complexity (e.g., Érdi, 2008); or, as some might say, between complexity and complicatedness. An illustrative example of the first is the space shuttle, and of the second a flock of birds (e.g. Eriksson et al., 2010). Is society more like a space shuttle, or is it more like a flock of birds? It clearly appears to partake in both of these qualities, and does not emerge as a central example of any of them.

The first contribution by Zeppini et al. reviews a collection of seven model types to address threshold dynamics, i.e. dynamical systems that undergo sudden non-linear change. This has been a central issue in complexity research since its inception, and it continues to represent one of the most salient needs for complexity models due inherent problems in understanding such dynamics either intuitively or mathematically. The models are presented as sequence of brief reviews of the types of problems and dynamics that the models can address, how they do it, and how they are related – presenting the reader with something like a palette of tools.

The first model of “hyperselection” describes a transition mechanism triggered by the fraction of adopters of a new technology in a population exceeding a threshold value. This is driven by increasing returns to adoption, i.e. a technology getting more attractive the more common it is. *The second model* is a variant of the influential increasing returns model of Arthur (1989). This is a well-known model of path-dependency in social systems and it relates thresholds in adoption to behaviour of individual agents. *The third and fourth models* address situations in which increasing returns to adoption stem from bilateral interactions between the agents. This creates unique dynamics since increasing returns will be local rather than global. This brings out the coordination problem associated with transitions. *The fifth model* emphasizes dynamic effects of transmission of information due to switching technologies in a population. If the outcomes of switching are shared in the population, and decisions are based on this information, the adoption of a new superior technology can lead to information cascades which may accelerate. *The sixth model* is based on the so-called NK fitness landscape model introduced by Kauffman (1993) in evolutionary biology. Here adaptation of technologies or agents is represented as points on a topographical landscape where peaks are attractive (high fitness) and valleys are unattractive (low fitness). The transition question can be seen here as: how do you get from

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a low peak (e.g. an unsustainable state) to a higher peak (e.g. a more sustainable state) if you need to pass a valley on your way there? The NK model allows us to explore these aspects systematically. *The seventh model* is percolation – originating from the study of diffusion of liquid through a porous material. Well-known non-linear phenomena in percolation processes resemble transition dynamics. *Finally*, Zeppini et al. consider social network theory from sociology. Threshold effects on the spread of ideas and technologies in a social network are relevant here: how many interacting agents must act before the system will change. Altogether, complexity as studied by Zeppini et al. is clearly focused on dynamical complexity: a stationary dynamics of interacting entities/agents.

The second contribution, by Laland et al., introduces Niche Construction Theory (NCT) as a source of theoretical inspiration for sustainability transition researchers. This involves discussing transitions from a highly general perspective that recognizes deeply congruent principles of innovation in different sorts of complex adaptive systems. Their view of complexity is quite different from that of Zeppini et al. Complexity from the perspective of NCT involves structural complexity – or complicatedness – and the emergent organization that arises in the system. Innovation here constantly changes the very rules of the game. Within this view, complicatedness and complexity are dynamically tangled up and hard to delineate. The radical implication of NCT in biology is that it challenges the old strict delineation between what adapts and what gets adapted too; i.e. between organisms and their environments. This view is representative of a recent "developmental turn" in evolutionary biology (e.g., Wagner et al., 2000; Laubichler and Maienschein, 2013).

Finally, the third contribution by Arapostathis et al. presents a historical case study of the evolution of the UK natural gas system from 1960 to 2010 using the familiar Multi-Level Perspective approach. They emphasize the integrative nature of the process: a co-evolution of multiple different actors and multiple components. As a result, the authors argue that one cannot readily and easily identify "prime movers" of a transition. Rather, it is a question of actor and components interacting and, most importantly, changing in parallel and across many levels of organization. The approach further clearly brings out the historical contingent nature of transitions. Path dependency is important in every phase: even very small events can be important as they may have strong cascading downstream consequences. Narrative historical case studies have since long embodied important features of complex adaptive systems; namely that they are historically path-dependent and that they tend to involve a multitude of heterogeneous subsystems and levels of organization, which both can alter over time. As Arapostathis et al. put it, the narrative approach "...enables us to highlight the roles of actors, institutions and technologies in the co-evolutionary processes of change relating to 'system integration'..." This view clearly emphasizes the structural type of complexity. Methodologically and ontologically it challenges the micro-macro dichotomy expressed in many formal models (as discussed in Zeppini et al.). It is interesting to note that there is a similarity between the evolutionary developmental reasoning of Laland et al. and the historical case study approach adopted here.

The three contributions point at similarities in studying and conceptualizing innovation and transition in biology and the social sciences. They clarify the usefulness of formal modelling and narratives to benefit from this connection. Both connections involve evolutionary theory, but focus on different types of mechanisms.

In a recent series of workshops at the European Center for Living Technology (Venice, Italy),[1] we have explored the potential of a recent connection between biology and the social sciences (e.g. Erwin and Krakauer, 2004; Wimsatt and Griesemer, 2007; Andersson et al., 2014), with participants from innovation research, biology, archaeology, complexity science, etc. This new potential has emerged with the rise of developmental theories of evolution in biology, combined with an increasing interest in multi-level complex systems where organization acts as a scaffolding structure for the dynamics that generates it (e.g., Lane et al., 2009; Byrne and Callaghan, 2014). What has emerged with clarity in these workshops is that innovation researchers, developmental evolutionary biologists and complexity scientists understand each other well with a minimum of "translation"; there is a striking

[1] (1) "Innovation, society and complexity: a dynamics of detecting, solving and creating problems" March 21–13, 2012; (2) "Transition and Stasis in Society and Biology: models, theories and narratives" March 18–22, 2013; (3) "New Data – Old Theories: The Future of Theorizing about Innovation in Complex Adaptive Systems" May 5–8, 2014. All these workshops were held at the European Centre for Living Technology in Venice, Italy.