Science of the Total Environment 626 (2018) 684–688

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Total systemic failure?

Philip Garnett

York Cross-disciplinary Centre for Systems Analysis & School of Management, University of York, Heslington, York YO10 5GD, United Kingdom

HIGHLIGHTS

- Is the potential for total systemic failure something that we should be actively concerned about?
- Complexity theory and complex networks should be part of the methodological tool kit that we use to model and understand the Anthropocene.
- Artificial intelligence could be used to help us measure and intervene in complex systems.

ARTICLE INFO

Article history:
Received 8 November 2017
Received in revised form 8 January 2018
Accepted 8 January 2018
Available online xxxx

Editor: D. Barcelo

Keywords:
Complexity
Networks
Systemic
Failure
Anthropocene
Artificial Intelligence

ABSTRACT

While the world argues about whether climate change is real, what if *all* systems are failing? This paper seeks to ignite further discussion concerning human impact on all aspects of our environment as we move further into the Anthropocene, not only in terms of the pressure we produce, but also how our activity changes the nature of the relationships between Earth's systems. The paper suggests that we currently lack the tools and analytical capacity to understand the significance of these changes and therefore we cannot answer the question, "are all systems failing?". We discuss how complexity theory, complex networks, and Artificial Intelligence, could contribute part of a solution.

1. Introduction

Helbing (2013) proposed the establishment of a Global Systems Science as a response to the problems of instability in our highly connected world. This proposal was partly in recognition that there needs to be greater focus on the consequences of increasing connectivity between (and perhaps within) systems for the stability of the global system-of-systems that is our environment. These real-world complex adaptive systems often display resilience to, and the ability to adapt to, internal change and external drivers (Gunderson, 2000; Walker et al., 2004). However, what we do not know is how far these systems can be pushed before they either radically shift (into a perhaps unrecognisable state), or fail altogether, although some work has started to try to address, or at least draw attention to this issue (Carpenter et al., 2011; Dai et al., 2012; Brook et al., 2013; Hughes et al., 2013; Lenton and Williams, 2013; Bentley et al., 2014). We lack sufficient knowledge in a number of key areas, including the extent to which global systems are threatened, the degree to which systems are inter-dependent and connected, and significantly how this complex network of systems will respond to change or failure in connecting systems. We lack detailed understanding of the nature or character of the connections between and within systems, and therefore the significance of their loss is also unknown. Put simply our systemic understanding of the world needs improvement if we are to understand the consequences of the changes that mark the Anthropocene.

If we accept that we live in a global system-of-systems, where it is not unreasonable to suggest that feedbacks exist within and between all systems that have a significant role in the security of human civilisation, abandoning any possibility that the global environment is a set of discrete systems. We have to accept that changes or failures in one system feedback into the other systems; that *all* systems are intimately connected in ways that we currently do not fully understand (Buldyrev et al., 2010; Helbing, 2013). For global systems that are increasingly under pressure from human activity, what are the

E-mail address: philip.garnett@york.ac.uk.

https://doi.org/10.1016/j.scitotenv.2018.01.075
0048-9697/

potential consequences of this connectivity and feedback for system stability, and what are the consequences of our lack of knowledge of how systems respond to internal dynamics and external drivers to our understanding of how systems might fail in the real world? This paper seeks to promote discussion of these problems, and will explore the possibility that human civilisation could undergo total systemic failure. Failure that could in part be due to the connectivity in global systems. Lack of knowledge means that we do not know if this failure is inevitable and already happening (perhaps on a temporal scale what we are not sensitive to), or if the global system-of-systems will prove resilient. Perhaps most likely, and therefore most importantly, our future security as a species will require significant changes in our behaviour, and interventions in global systems. Knowing how and where to make those interventions is essential.

2. Complex adaptive systems, networks, and chaos

One definition of a system is a set of elements or objects that act together as part of a process or mechanism (Turcotte and Rundle, 2002), or form part of an network (Boccaletti et al., 2006). For example the financial system is the result of the interactions of a set of financial organisations, such as banks, hedge funds, and regulators. The complexity comes in the form of the difficulty (or potential impossibility) of predicting how that system will behave by looking at the interactions (or relationships) of the parts alone. We may think that we understand the types of interactions occurring between the banks, hedge funds, and regulators for example. However, complexity theory shows us that this is not enough to predict the behaviour of the financial system. Simple interactions between the parts of a complex system can result in emergent behaviours (Funtowicz and Ravetz, 1994), a property elegantly demonstrated by Conway's Game of Life (for description see Schulman and Seiden (1978)). The global behaviour of the system is often referred to as its state, and we talk about systems changing state and therefore changing behaviour. Complex systems are able to adapt to changing external inputs from their environment, the parts can change the way they interact with each other, and the parts themselves can also change, without there necessarily being a significant change in the emergent global behaviour or system state (Holland, 1992).

Unfortunately we cannot yet predict or measure how much change would equate to a perceptibly different system. A system could go through a slow and smooth transition over a period of time long enough that the systems around it adapt in the same way, and to us (with our short memories) they might fail to register as different. Alternatively a system could shift rapidly, causing a major disruption; a tipping point (Brook et al., 2013; Bentley et al., 2014). Whether or not a tipping point is more significant than slow evolution of a system is debatable. A slow and gradual change into a hostile state still brings you to that hostile sate, and slowness is merely a question of relative scale. Our obsession with rapid changes is more down to our relatively short-term outlook as a species, or a consequence of the shortness of our individual lifespans when compared with changes in the environment. If the result is a hostile environment we should be as concerned about slow systemic shifts as we are tipping points. Given time all state changes are significant to humans as a population, be they tipping point failures, collapse, or slow and relentless shift. The main differences being that if the change is slow and gradual it might be easier to reverse the change and steer the system back towards a more advantageous state.

This notion of changing of state is perhaps in itself problematic. To talk of maintaining a particular state, or one state being advantageous to another, makes sense from the view of a particular element of that system (i.e. humans), but does not really mean very much from position of the system as a whole. There is no central evaluator that has an opinion on the *value* of the current state. However we as elements in a system would like to have that ability, and with it the knowledge to steer a system into a state that is more advantageous to our survival. (In some ways this was the holy grail of systems research, the ability to make precise changes that affected system state.) Large global complex systems are at best quasi-stable, systems come under exogenous and endogenous influences all the time and as a consequence are never truly static. The current state might be enough of an attractor that the quasi-stability is relatively stable, or the system might be slowly moving through phase-space on a trajectory of changing state. Alternatively, as would be the case for something like a Lorenz attractor, the system might be orbiting an attractor, but have the capacity to jump and orbit a new attractor (Lorenz, 1963). Each representing different states for that system. The problem however, if we take the climate system as an example, there is nothing to guarantee that both states will support human life.

Climate change is potentially a good example of this. Our planet will likely have some sort of climate for a very long time, it might just not be one which can support life. The ever-increasing quantities of CO_2 in the atmosphere may result in a state change in the climate system. That could be a slow trajectory of ever-increasing temperatures (potentially reversible), or perhaps a rapid jump to a new state of significantly increased temperatures (potentially irreversible, or significantly harder to reverse), a process known as hysteresis (Barnosky et al., 2012).

System behaviour gets even more complex when we consider that systems do not stand in isolation, free from interference from their environment or other systems (their environment of other systems). They are highly connected, to the point where with many systems it is difficult to determine the start of one and the end of another, or the end of the system and the start of its environment (Vespignani, 2010). For global systems there is no outside; all global systems are connected, and we are in them. (It is often necessary, and advantageous, for researchers to draw arbitrary boundaries around systems to have any hope of understanding their system of study (Allen, 2001). These simplifications are a requirement of tractability, but could introduce flawed assumptions, possibly rendering the model of the system invalid).

3. Systemic failure

Here it is useful to consider two possible ways that a system can fail. One is from the point of view of the system, and the other is the point of view of some or all of the parts in the system. In the first instance a systemic failure would describe a situation where a failure in one part of the system, or parts of the system, propagates through the whole system resulting in the disappearance of the global system behaviour. The interacting parts can no longer produce that emergent global behaviour (or any other emergent behaviour), the parts are not interacting any more. This could be due to loss of nodes from the system, or the breakdown of the relationships between nodes. We have to be a little cautious in how we describe this disruption to the emergent system behaviour. It is not the same as a system changing state, it is the total loss of the systemic behaviour.

The second possibility for failure could be from the point of view of some parts of the system. Here the system becomes hostile to some of its parts, that might have severe consequences for those parts, but represents merely a process of adaptation or change at the system level. These events are undoubtedly happening all the time, particularly in natural systems. It is from our point of view (as a part) where these changes might appear as a systemic failure. Where a system that we rely on appears to fail catastrophically and can no longer perform the function on which we are dependent, but really it is carrying on in some other state.