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Total Systemic Failure?

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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.

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. Both 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.

Keywords: complexity, networks, systemic, failure, Anthropocene, artificial intelligence

1 Introduction

Helbing[26] 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 [23, 50]. 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 [12, 13, 10, 28, 33, 6]. 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 [11, 26]. For global systems that are increasingly under pressure from human activity, what are the 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 as a set of elements or objects that act together as part of a process or mechanism [47], or form part of an network [7]. 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 [21], a property elegantly demonstrated by Conway's Game of Life (for description see [44]). 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 [27].

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 [10, 6]. 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 [34]. 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 supports 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 [5].

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[49]. 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 [2]. 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 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 serve 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.

Propagation of failure, and therefore how systems fail, is difficult to predict [1]. A system could lose nodes (parts of the system), or numerous edges (relationships between the parts) could be broken, and very little visible change may occur. However, at some point the loss or breakage might get to a point where the system's failure stops being solely caused by external forces and starts been driven by the internal dynamics of the system itself. The failure could then propagate rapidly throughout the entire system [51, 53]. The 2007-8 banking crisis could potentially have been a systemic failure of this type, parts started to fail in isolation at first but it quickly started to look like the whole banking system was under threat [24].

Failure can become even more unpredictable when we think in the context of systems-of-systems. The interaction between two semi-discrete systems may make it even more difficult to determine that a system is under threat and how significant that threat is. It could be the breakage and losses in a different but connected system that causes the sudden and unforeseen failure of a system that was thought to be robust [49, 38]. We also have to consider that relationships between systems might be the product of relationships between emergent processes, rather than the interactions of simple elements. An intuitive example of this would be human society, where each individual is a complex system, and the society is a emergent property of the interactions of the individuals. This complexity at multiple scales (both physical and temporal) makes the system level behaviours even more difficult to predict, as they are emergent properties of emergent relationships.

There is one further feature of complex systems that we should consider, inertia. System inertia is where it would appear that subsequent to a shock a system does not appear to change. This could either be because the system is resilient to the shock, or because there is sufficient inertia in the system that the change does not register immediately, but it could come at some point in the future. We should entertain the possibility that the inertia in global systems is the reason why we are not witnessing significant changes in response to the forces and shocks imposed by human activity. It is not because they are resilient, but because system inertia simply means that the reaction to our action has just not arrived yet, failure could be coming. Here it is the multiple temporal scales that is significant, failure could be occurring on a different temporal scale to human life. For decades the composition of the atmosphere has been changing, and for decades very little seemed to be happening. Only now are we starting to see the system react as average surface temperatures have started to change [36], potentially therefore it happening at different temporal scale. We could easily be seeing the very beginning of the reaction to our action, and that reaction could massively accelerate in future decades.

3.1 Total Systemic Failure?

If we accept that we exist within a complex systems-of-systems, built by the interactions between parts that produce emergent system behaviours, and that the emergent behaviour of the supra-system is therefore an emergent property of the interactions between subsystems. Then what can we say about whether, at least from the point of view of human civilisation, we are likely to be confronted with total systemic failure? Or indeed whether we are already experiencing total systemic failure?

Real world examples of systemic failure in social, ecological, and physical systems are thankfully historically rare, although unfortunately not historically absent [30, 32, 31, 20]. However, this is small comfort as we do not have to look very hard to see that numerous systems are under significant pressure [18, 22, 8, 46], and understanding safe operating spaces for social-ecological systems is non-trivial [41, 14]. How close these systems are to failure is difficult question to address, as "we do not know exactly where to locate thresholds of irreversibility" [19].

One system that did at least appear to be close to systemic failure was global finance during the crash of 2008, where according to media reports banks in the UK were perhaps only hours away from switching off the cash machines. The experience of the financial and banking sector during the financial crisis allows us to make a number of important points and draw a number of comparisons. The crash of 2008 was an unexpected systemic crisis, that was at least in part due to the connectivity of the system and a lack of understanding of how the parts were interacting. There was a global response to the crisis, and the world mobilised very quickly in response to the existential risk of financial catastrophe, with large bail-outs and other forms of liquidity being provided to the sector. An exact total cost of the financial crisis would be difficult to calculate, however the reported total EU bailouts of member states is approximately €544 billion (from successive rounds of financial support [17]). The UK National Audit Office reports that peak support for UK banks was around UK£1.162 trillion [39], the US treasury's Emergency Economic Stabilization Act of 2008 provided US$700 billion to banks [15], and the Chinese economic stimulus program was reported to be US$586 billion [4]. In addition there has been successive rounds of quantitative easing in the US, UK, Japan, and Sweden. Was this the best response to the crisis? Perhaps not, and it could be argued that the financial system has not fully recovered, and we do not know what might be coming in the future. Had we had a better understanding of global finance as a complex system, then (assuming that the crisis was not simply avoided) perhaps a more targeted response could have been made.

What is also interesting about the response to an existential risk to the financial system is that there was in fact a global response, with similar tools being deployed by multiple nations together. It has also been noted that bailouts dwarf spending on other global crises [3]. This again highlights the significance of the interactions and feedbacks between global systems. Different social and political systems (which are tightly linked to the financial system), allowed for the intervention in the financial system. There was resistance (from the 'people') however it was not enough to stop the response (or change its nature) and for better or worse the financial system was bailed out. Social and political systems are also tightly linked to the climate system, however in this case we seem to be struggling to respond in a coordinated way, or on a sufficient scale, and the resistance this time seems to be more political.

The Stern Review on the Economics of Climate Change, produced for the United Kingdom Government late in 2006, made a central recommendation that 1% per annum of then global GDP should be spent to stabilise global atmospheric CO_2e at around 500 to 550 ppm, which was then later revised to 2% of global GDP per annum in 2008 [45, 29]. In 2006 global GDP was reported by the World Bank to be approximately US$51.3 trillion, rising to US$63.4 trillion in 2008, and it currently stands at about US$75.8 trillion [52]. 2% of $70 trillion dollars would be roughly US$1.4 trillion per year for 8 years, or about US$11.4 trillion. Not an insignificant sum of money, however not beyond what countries could afford should 'they' want to, and is not that different in magnitude to the funds provided to the financial sector. The exact comparative cost is not the important issue, both cost calculations are fraught with difficulties because it is not simply the case that money is spent but assets are also acquired and economies stimulated in complex ways (its a complex system). What is an important issue is that in the case of the financial system we were unable to see the crisis coming, and therefore were not able to respond appropriately, and now must hope that in the long term our intervention proves to be successful and not actually have done more harm than good. In the case of the climate system it would seem that in all likelihood we can see the crisis coming but are unable to collectively respond. Our thinking is not systemic.

At present we do not have the tools (computational or otherwise), language, or understanding to address this problem of knowing how and when a system is going to react. Our ability to even map complex systems, particularly in the real world, is limited, and the holy grail of complexity science of being able to then make precise interventions that produce predictable changes remains elusive [9, 2]. It might even be the case that the level of precision dreamt of is impossible; there are no levers to pull. We should also be mindful that intervention might also have its own unintended consequences, knowing when not to act because a system is in the process of adapting is as important. What therefore can we do?

4 Complex Networks and Artificial Intelligence

Complex networks are an intuitive method by which complex systems can be characterised and perhaps understood. Networks are made up of nodes that often represent objects, such as a bank, or person. Edges (connections) between the nodes capture some relationship between the two objects; Bank A *owes money* to Bank B, Alice is *friends with* Bob, Bob *owes money* to Bank B. For this reason complexity theory maps well onto complex networks [37].

Network structure, as defined by connections between the nodes, tells us something about that system, e.g. friendship groups (communities) or information flow. These regions (along with other warning signals[42, 43]) might provide a way of characterising the state of a system. Different network structures could be associated with stability, or with instability. Others still might map to regions of structural dependency, and/or the propensity for failure. This is not a precise lever of change, but more a way of assessing the health of a system, and providing some indication of where we might intervene. Thus perhaps complex networks present an approach to modelling the Anthropocene [35, 48]. Networks of global systems could be built, and models developed to highlight areas of potential concern, computer modelling could then be used to simulate what could happen to these systems in the future.

Mapping and then analysing systems, particularly those on a global scale, is a significant challenge. The analysis of dynamic networks, where nodes and edges come and go, is particularly challenging as it is difficult to robustly attach significance to any one node or edge, or predict if any given node or edge might disappear or new one form [40]. Not only the network structure (topology) is of significance, but also the character of the components and how the network changes. The increasing capacity in artificial intelligence (AI) and computing power presents itself as an opportunity. Perhaps AI could be used to design the sensory networks, and build the appropriately abstracted models required to monitor and analyse global systems. We ourselves might struggle to determine the significant of connectivity in systems, however we might be successful in designing AIs that can.

5 Conclusions

Complexity, although not a new idea, perhaps offers both theory and method required to tackle the global problems of today. This paper is not an exhaustive discussion of the possible role of, and problems posed by, systems thinking. It seeks to highlight that complexity theory and complex networks could contribute to the solution, as both methods are aimed squarely at attempting to aid our understanding of systems composed of many interacting parts. The holy grail of complexity theory, an ability to determine which parts of a system should be altered to produce the desired systemic change, might not be impossible. However, complex networks might allow us to assess global systems as a systemic whole, rather than discrete parts, and AI could be used to assist with the design of the models to test hypotheses, and the analysis and collection of sensory data.

The possibility of the human civilisation undergoing systemic failure is not new, ideas such as the limits of growth and sustainable development have been discussed at least since the 1970s [16]. The central problem with this debate seems to be around whether or not human activity is having a significant impact on global systems. The idea that our environment is composed of isolated, discrete systems, that do not influence each other needs to be abandoned. From a complex systems perspective it simply makes no sense that our presence and activity is not impacting all global systems. The question should be to what degree are these systems connected, what feedbacks exist, and where is human activity creating the most pressure. Ultimately, we should seek to understand how global systems might fail, what systemic failure might look like in the real world, and how close systems are to failure.

Unfortunately that does not seem to be happening. The nature of our respond to the possibility of a given systemic failure would appear to be more dependant on ideology than systemic thinking, and in the case of climate change this could prove catastrophic. The possibility of severe changes in our climate should not be dismissed as 'fake news', a hoax, or conspiracies against economic development, and the fact that it is could prove to be a contributing factor in the failure of the climate system. From the point of view of a systemic response to the possibility of climate change, the paralysis in the political system could constitute a systems failure in its own right. A failure in the political system would feedback into the climate system. Could that result in a cascade failure of both systems?

To mitigate the possibility of total systemic failure regional interests would need to give way to global interest, and we would need to mobilise a response greater and even more coordinated than our response to the possible failure of the financial sector in 2008. The question is how? Such a response looks increasingly less likely, particularly in a world of increasing isolationism, self-interest, and social and media echo chambers. Global complex systems do not respect borders, making it hard to see how any state or group could act alone. Perhaps then we need to think more in terms of distributed interventions in systems, rather than top-down global regulation. Natural systems do not have centralised control systems, the control is decentralised and is in fact an emergent property of the interaction of the parts of the system. With gridlock and division in global politics [25], perhaps numerous adaptive, decentralised, smaller interventions (supported by data collection, modelling, and AI) offer a solution where no global consensus is forthcoming. If we can make creative use of technologies, such as sensory networks supported or designed by AI, locally deployed but globally linked, perhaps this could support a decentralised response to global systemic issues.

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