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Looking at Coronavirus Epidemic through the Lenses of Complexity Science

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Abstract

Our research shows that coronavirus epidemic models, at the time of writing, were inadequate because the modellers attempted to model a complex process (epidemic) without paying attention to laws of complexity science. Fundamentals of complexity science are then reviewed and a design of a complex adaptive simulator capable of predicting infection rates under various social contexts, as well as calculating cost-effectiveness of different protection policies taking into account the capabilities of coronaviruses to adapt and mutate, is described. The final section suggests how complexity science can help us to understand what the "new normal" will look like.

Why current models of coronavirus epidemic are inadequate?

In the article entitled “In Bed with the Supermodellers”, published in the Sunday Times on 10 May 2020, Bryan Appleyard described a chaotic situation in which diverse and often conflicting models of coronavirus epidemic are proposed by academics, based on guesses and opinions rather than real data, and concluded “we follow the science, the politicians say, but there is no such thing as “the science””.

How appropriate, I thought at the time. We certainly don’t have *the* science – we have, in fact, two different sciences.

The first is a traditional science, with roots in physics, the Queen of Sciences, often referred to as Newtonian Science, which is based on the assumption that the world is deterministic, in other words, predictable. And if we don’t know how to predict an aspect of world’s behaviour, for example, how coronavirus epidemic works, it is because we do not know enough about this particular subject, but we could be sure that the further research will provide us with the answer. “God doesn’t play dice with the world” is a famous way in which Einstein asserted determinism.

However, Newtonian science cannot deal with many issues in biology, social sciences and chemistry. Primarily because the key processes connected to life are irreversible. The tipping point was reached when Ilya Prigogine in his laboratory at Free University of Brussels created organic elements from an inorganic mixture, modelled on the primordial soup. This astonishing discovery of autocatalytic properties of a mix of chemicals, could not fit into deterministic understanding of our world. It was, clearly a paradigm shift.

From Prigogine’s work, particularly his book “The End of Certainty: Time, Chaos and the new Laws of Nature” [1], emerged the new science of complexity, the second, quite different, science to which I referred above.

Santa Fe Institute in the US developed their own influential version of *complex adaptive systems* [2, 3]. The latest book by Stuart Kauffman, “A World Beyond Physics: The Emergence and Evolution of Life” [4]. is a blueprint for the new scientific paradigm, fit to investigate the complex, irreversibly evolving world.

There is not much cross-referencing between these two powerful schools of thoughts, but then, according to Kuhn [5], a scientific paradigm shift is always preceded with rivalry among paradigm shifting actors.

The philosophical foundation of the new science is expressed in the assertion that the world irreversibly evolves, and future is not predictable. Future is created by the accumulation of everyday actions and interactions of all living and non-living constituent components. Every infection, war, scientific discovery, trading transaction, financial crisis, erosion, earthquake, tsunami and procreation, changes the world in a small and unpredictable way. “Future is not given” wrote Prigogine [6], in sharp contrast to Einstein’ assertion of determinism.

The subject which complexity science investigates is behaviour of complex groups, exactly what is required to understand an epidemic, but also other critically important issues, including immigration, global warming and Brexit.

The contention of this research report is that current models of coronavirus pandemic are inadequate because modellers have attempted to model a complex process – epidemic – ignoring principles of complexity science.

Shortcomings of current coronavirus epidemic mathematical models, as perceived by the author, are:

- Different models provide radically different values for the average reproduction number R (infection rate)
- Reproduction numbers for different social contests are not calculated
- Virus adaptation and mutation are not covered
- Group behaviour of viruses and potential victims is ignored
- The effectiveness and cost of various protection policies are not covered

Let’s review some fundamentals of complexity science to support the above contention.

Complexity science

Complexity science investigates behaviour of *complex groups* or, more formally, of *complex systems*. For the purposes of author's research "complex group" and "complex system" are synonyms.

Complex groups

A group is called complex if it is open (interacts with other systems) and if it consists of a number of diverse partially autonomous members, known as agents, which are engaged in intense interaction and may compete or cooperate among themselves.

"Partial autonomy" in this definition means that members of a complex group are not controlled centrally – they are free to decide what to do within the constraints imposed by group membership.

Such a group is labelled *complex* because its behaviour is inherently uncertain (unpredictable), although not random [7].

Overall behaviour of a complex system *emerges* from the interaction of participating agents and is very smart – complex groups rapidly adapt to disruptions, are resilient to attacks and, under certain conditions, exhibit collective intelligence and creativity.

Here are some examples of complex systems

- The human brain is the most illustrious example of a complex system in which 100 billion neurons are potentially connected into a vast neural network characterised by emergent intelligence and creativity
- The Internet of Things is a network of 30 billion "things" (physical objects), each containing a digital processor enabling them to exchange messages with each other (your car sending outputs of sensors monitoring its performance to your car service station and receiving diagnostic messages)
- The Internet-based global market, together with social websites, constitutes a complex system in which nearly 5 billion people conduct business or engage in social interaction
- A team of several designers discussing value of a design proposal – this example illustrates that complexity is present even in small groups if members are creative and have a considerable autonomy

A good example, highly relevant to the topic of this paper, is a group of viruses deciding if they should stay longer in the cells of a victim or switch to a new host [8].

Here is how the article "The Secret Social Lives of Viruses", published on the website of the prestigious journal, Nature, on the 18th of June 2019, depicts a group of viruses making decisions: "*the viruses …. were chattering away, passing notes to each other in a molecular language only they could understand. They were deciding together when to lie low in the host cell and when to replicate and burst out, in search of new victims*."

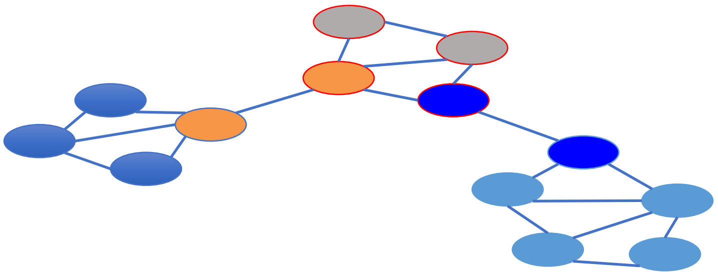

Fig. 1. A typical complex system with clusters of agents engaged in intense interaction

All living creatures – from microorganisms to humans – organise themselves in complex groups (cells, cultures, colonies, swarms, herds, packs, flocks, gangs, communities, families) and viruses are not an exception. In fact, living in a group is essential for cost-effective gathering, cultivating, and distributing among members resources for life.

Complex groups have some remarkable properties [9], [10]. Let's mention just those that are the most relevant to epidemic.

Adaptability

Adaptability is the capability to selforganise (reschedule available resources) or to mutate (bacteria, viruses) with a view to neutralising consequences of a disruption.

Two highly relevant examples of coronavirus adaptation are published recently.

The first shows that when viruses have no opportunity to infect new victims (e.g., because of a lockdown) they become more aggressive and mean serial intervals (time intervals between the infection and symptoms) get reduced from 7.8 days to 2,6 days in a month [11].

The second shows that when SARS-CoV-2 infect new victims with commonly elicited neutralizing antibodies, SARS-CoV-2 tend to mutate to a variety capable of resisting the antibodies [12].

Nonlinearity

Relations between agents in a complex group are nonlinear and they include amplification, acceleration, and autocatalytic properties.

Butterfly effect is a colourful metaphor for consequences of nonlinear relations between members of a complex group and describes how a disturbance, as small as motion of a butterfly wing, at one point on the planet, may, if conditions are right, cause an *extreme event*, as dangerous as a heavy storm, at a faraway place or, indeed, on a truly global scale.

The most striking example of the butterfly effect is the coronavirus pandemic – it began by one person eating infected bat (or, maybe, by one mistake made in a laboratory investigating coronavirus) and rapidly infected millions of people worldwide, caused a huge number of deaths and initiated a global economic crash.

How could complexity science help to model epidemic?

Based on the notion that epidemic is a process of allocating victims to viruses and that viruses attack in groups it is possible to design a complex adaptive simulator, let's call it *Epidemic Simulator*, capable of calculating infection rates for a variety of contexts:

- open spaces (gardens, streets, beaches)
- closed spaces (homes, theatres, cinemas, restaurants, pubs, hospitals, care homes, slaughterhouses)

In addition, the simulator would be capable of answering questions (taking into account the capability of viruses to mutate) - how much, and at what cost, infection rate would be reduced

- By lockdown?
- By social distancing?
- By face masks?
- By testing?
- By other means?

Simulating wars between a group of viruses and a team of protection strategists would be an excellent way of learning how to manage an epidemic.

Architecture of an Epidemic Simulator is shown below.

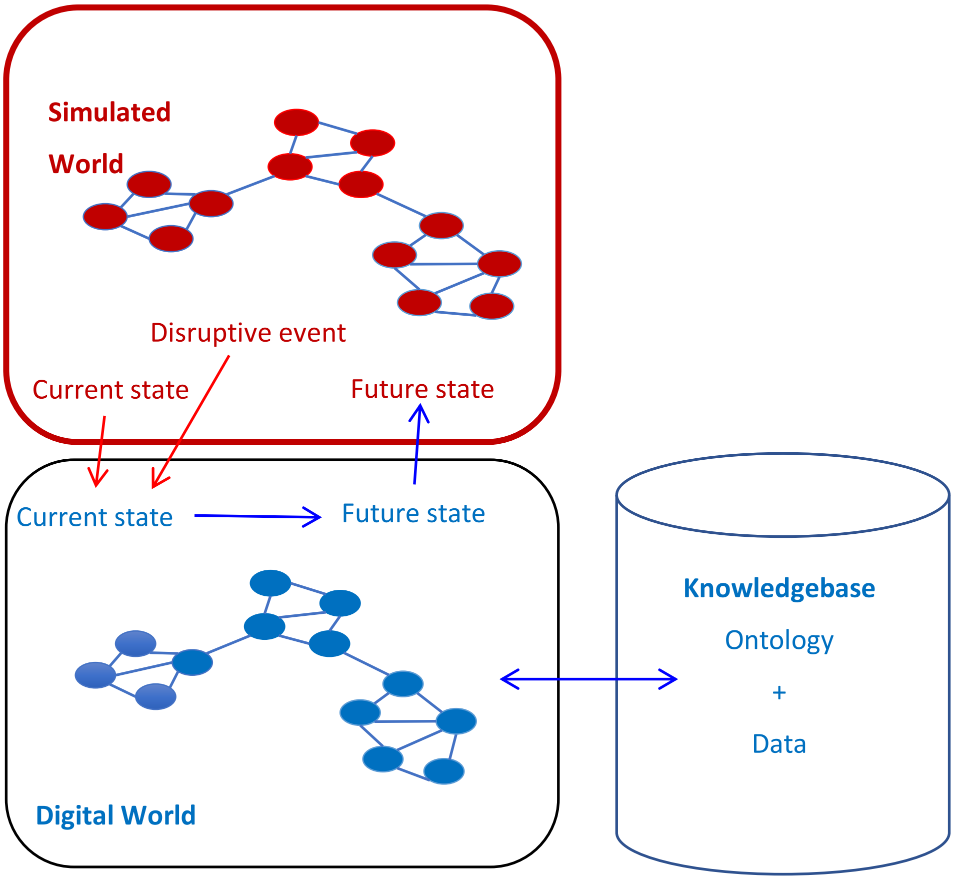

Fig. 2. Complex Adaptive Epidemic Simulator

The *Simulated World* is a computer readable dynamic description of the social context within which infection rate is calculated. For example, a group of restaurants is represented as a network with clusters. Each individual restaurant is represented as a cluster (in which infected and non-infected clients and employees interact). Connections between clusters represent flows of infected and non-infected clients and restaurant employees between restaurants.

The Di*gital World* is a complex adaptive model of the Simulated World in which a Digital Agent (a computational object) is assigned to each infected (Infection Agent) and each non-infected human being (Victim Agent) of the Simulated World. The allocation of Victim Agents to Infection Agents (infection flow pattern) is calculated using domain knowledge stored in the Knowledgebase.

The *Knowledgebase* is the key element of the simulator, where all what is known about coronavirus epidemic is collected and organised as Epidemic Ontology, which can be updated whenever needed, without interrupting simulation.

Progress report and future work

The design of the Epidemic Simulator has been completed. The next stage is coding a prototype which must be comprehensively tested as a prove of concept. For this Rzevski Research needs modest investments.

When prototype is ready, a team of knowledge engineers will have to design fully working Epidemic Ontology before the simulator can be used in anger.

How could complexity science help to prepare us for the “next normal”?

Let’s consider how best to exit from the lockdown. To do this effectively, we should have a good idea how the “next normal” would look like. And here the complexity science can certainly help.

Remember the key philosophical premise of complexity science: the future is created by actions and interactions of all living and non-living components of the world. And one of the most powerful man-made components of our world is technology.

Society invest into creative minds to invent new tools, which are expected to help society to achieve prosperity, but inevitably by using new tools, society changes. New tools create new jobs and new jobs upset the old order. This process is known as the coevolution of society and technology [13].

We are currently in the middle of a rapid shift from *industrial society*, relying on the mass-production technology to generate prosperity, to *information society*, whose prosperity depends on the widespread use of digital technology (digital computing, digital communications and, above all, digital intelligence).

This process is unstoppable. All the efforts of those who resist the change are in wain. In the near future, we can expect the transition to digital age to accelerate. Here is a small sample of changes which will happen.

- We shall have lectures at all levels delivered online, supported with extensive tutorials, discussions and team-projects face-to-face
- We shall be choosing what to buy, whenever possible, face-to-face but we shall be buying online; town centres will be transformed with many large retail premises converted into apartments and smaller ones into restaurants and bars; many boutiques will survive.
- We shall not travel long distances to our offices; we shall be working from home, or in office spaces near our homes, where we can work both online and face-to-face with our colleagues
- About 50% of all current jobs will be taken over by artificial intelligence (intelligent digital real-time schedulers will control business processes such as supply chains, production, distribution, purchasing, order processing, invoicing and invoice payments) without reducing employment opportunities; retraining will be required and will be made available by entrepreneurs (for a fee)
- We shall be transforming huge mass-production manufacturing plants to flexible versatile manufacturing units served by robots and artificial intelligence and move them closer to consumption to avoid global supply chains this will substantially reduce energy consumption and generation of CO2
- We shall switch to electric cars, vans, lorries, busses, ships and even drones and aircraft, to help our environment
- AI will control agriculture, saving water (and money)
- The main impact on our wellbeing will come from extracting knowledge from data using artificial intelligence (AI). Here are just two examples:
    - The value of knowledge on healthcare hidden in NHS data accumulated since its inception was estimated to be in the region of £10 billion per year
    - Data collected worldwide on coronavirus pandemic is priceless as source of knowledge on how to manage the next epidemic
- The increasing elderly population will not be a burden for young; to the contrary, caring for elderly will be a growing market for intelligent digital technology (self-driving cars and trollies, household robots, solar energy, healthcare systems, autonomous food/medicine ordering and delivery systems, the Internet-based security and help alarms) and it will thus provide new jobs for new generations

The UK will be moving further into the digital era, that is inevitable, but will we move fast enough?

We have technology. The progress will depend on how quickly we can switch mindsets of decision makers from the economy of scale (a 20th century concept) to the economy of intelligence (the 21st century concept).

We have an opportunity to have a V shaped recovery if we focus on digital transformation of traditional businesses, administrations and healthcare [14].

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