Digital Healthcare: How to Transform a Traditional Health Service into a Healthcare Ecosystem

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Abstract

The report demonstrates how a traditional health service can be transformed into adaptive, resilient and sustainable healthcare ecosystem providing high quality, low-cost health service to clients and ready for the outbreak of the next pandemic. Intelligent digital technology developed by Rzevski Research is outlined and an evolutionary digital transformation method is presented. The report also describes a new approach to modelling coronavirus epidemic, which takes into account various way of slowing down the rate of infection and considers virus mutation.

Digital Healthcare

Digital Healthcare is a health service that is *adaptive, resilient* and *sustainable* and which offers to clients a high-quality reasonably priced medical care.

The key point of using the term "digital" is that any traditional health service to become adaptive, resilient and sustainable, must undergo Digital Transformation, as described below.

Natural and Digital Ecosystems

Natural ecosystems (forests, rivers, oceans, grasslands) are naturally adaptive to changes in their environments, resilient to catastrophic events, such as earthquakes or tsunamis, and sustainable for periods lasting, in some cases, millions of years.

We have developed now digital technology capable of transforming man-made systems into adaptive, resilient and sustainable "digital ecosystems". This represents a major breakthrough in improving how we live, work and provide healthcare.

Adaptability

Adaptive healthcare means a health service capable of

- Instantly detecting an internal or external disruptive event (such as a change of demand, a cancellation or change of an appointment, a failure of a medical resource)
- Rapidly identifying which part of the service will be affected and
- Quickly rescheduling affected resources to eliminate or at least reduce, consequences of the disruption.

A good example is adaptive ambulance service – if a call is cancelled after an ambulance has already left the hospital to answer that call, an adaptive service would be capable of rapidly rescheduling ambulance and divert it to answer a different call.

Sustainability

Sustainable healthcare means a health service capable of coevolving with its environment (natural, political, social, medical or economic).

For example, the increase in infection from a new virus, detected from data on hospitalisation, triggers the slowdown of non-life-threatening hospital admissions. The adaptive planning system rapidly picks up the trend and, if necessary, initiates opening of additional temporary hospital facilities and hiring of additional staff. When data show the infection slowing down the system begins a return to normal conditions. All these processes can be controlled by AI more productively, faster and more precisely than by human decision makers. To ensure accountability, AI-based systems should be designed to provide user-friendly interfaces which enable human decision makers to check and correct the decision made by the system, if necessary.

Why Digital Healthcare?

Ready for the next pandemic

The essence of the current problem with pandemic is that, due to globalization, any infection, even if it starts in the remotest corner of the glob, will be rapidly transferred to the whole planet (butterfly effect). And in a pandemic, demands for healthcare are unpredictable.

Only adaptive healthcare systems, as defined above, will be able to reschedule their resources in time for an effective patience care.

Since the outbreak is unpredictable, we must be ready for the next pandemic by increasing ability to rapidly react to an unpredictable outbreak.

Also, we have a problem with modelling of epidemic. Spread of infections is a complex process which includes virus mutation and cannot be effectively modelled without the use of intelligent digital technology, as described in section below.

Reducing Cost of Healthcare

Quite apart from pandemic, it is well known that the current healthcare service is too expensive and that it is essential to improve the utilisation of high-value medical personnel and resources to enable its widespread use. And in the UK, it is very important to reduce waiting for the appointment in the free National Health Service.

Our research shows that the largest cost reduction can be achieved by the intelligent real-time allocation of resources to everchanging demands. Intelligent real-time schedulers reduce waste by rapidly rescheduling affected resources (doctors, nurses, operating theatres, beds, specialist equipment) whenever a cancellation, a change in demand or a resource failure occurs.

Technology for Digital Healthcare

The basic premise of Complexity Science (see below) is that only complex adaptive systems can operate effectively within a complex environment [1]. Rigid structures, such as large administrations, tend to stall when placed under conditions of uncertainty. In contrast, interconnected small systems easily adapt to changes, are resilient to attacks and coevolve with their environments, which makes them sustainable.

We have developed technology for transforming conventional healthcare into an adaptive, sustainable and low-cost Healthcare Systems, which we shall call here Healthcare Ecosystems [2].

The philosophy behind the new healthcare technology is: *if you cannot predict demand, you must be able to rapidly adapt when it unexpectedly changes*.

Intelligent Real-Time Schedulers

Adaptability, resilience and sustainability can be designed into a digital healthcare by using intelligent real-time schedulers to allocate health service resources to demands.

A digital health service, as shown in Fig. 1, consists of

1. Real World of human and physical resources and demands that delivers the service to patients
2. Digital World of Digital Agents engaged in real-time scheduling of Real-World resources
3. Knowledgebase containing knowledge how to run the service
4. Interfaces between the two worlds, primarily concerned with the transmission of
    a. information about disruptive events from the Real to Digital World and
    b. instruction how to reschedule human and physical resources in reaction to disruptive events, from Digital to Real Word

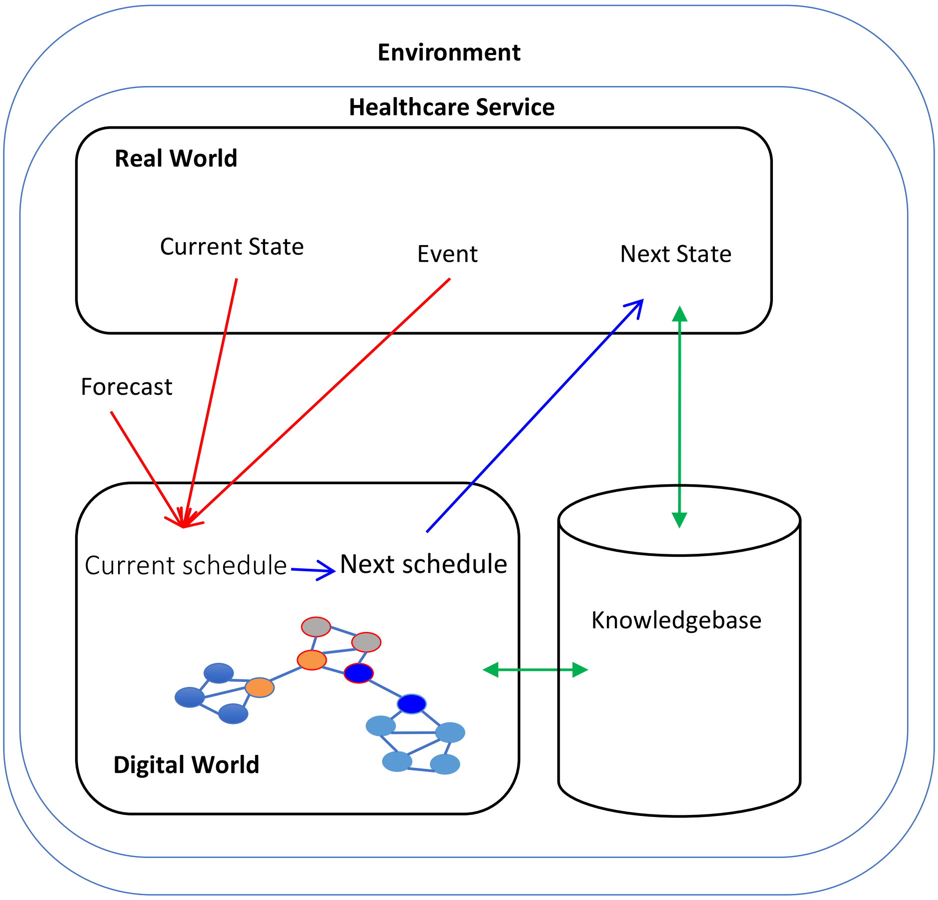

Fig. 1. Architecture of a Digital Healthcare scheduled by an intelligent real-time scheduler

Transformation of a Traditional Health Service into a Digital Healthcare

The conventional wisdom is to approach the problem top-down by attempting to perform requirements specification for the whole health service before starting the work on transformation.

Such approach would be unacceptable under current dynamics of the political, social, economic and technological environment within which the health service has to operate. Requirements would be obsolete before completion.

In contrast, an evolutionary transformation method would enable a seamless transformation.

Evolutionary Digital Transformation Method

Under conditions of frequently changing requirements, it is advisable to adopt an evolutionary method:

1. Consider all aspects of a health service with a view to identifying the one whose improvement will bring the highest value
2. Complete a requirements specification for the improvement of the selected aspect of the service
3. Design and implement an adaptive real-time scheduler for the selected aspect of the service only
4. Evaluate and update the solution demonstrating the achieved increase in the value
5. Select the next aspect of the service and repeat steps 2,3,4, ensuring that the newly added digital service cooperates, and if necessary, competes for resources with the previously installed digital services
6. As the number of digital services increases, continuously monitor and, if necessary, adjust the overall Digital Healthcare design

In theory, the evolutionary improvement of the health service should never stop. In practice, contractual arrangements between clients and urban ecosystem designers cannot be indefinite and will have to be limited to the improvement of one or more aspects of the service at a time.

A wise client would ensure that they have priority access to a skilled team for continuously maintaining and improving the new urban ecosystem. And that would represent an extension of the health ecosystem with the introduction of additional self-maintenance and self-improvement services.

Concurrent Transformation Mode

In addition to approaching the transformation in an evolutionary manner, the work on (a) requirements specifications, (b) the design, and (c) the commissioning of digital services should be done *concurrently*, timing the work in such a way that

- Whenever the design of the improvement of a n aspect of the health service is completed, the requirements specification for the improvement of the next aspect is ready for design
- Whenever the commissioning of the improved aspect of the health service is completed, the design for the improvement of the next one is ready for commissioning

The concurrent design is especially convenient if the design is conducted by cooperating teams located at several different geographical locations.

Illustrative Example

Let’s assume that the critical service selected for the improvement is the ambulance service.

Designing Ontology

The transformation begins with outlining ontology for the ambulance service, which involves:

- Selecting Object Classes (Ambulance Vehicle, Ambulance Crew, Crew Member, Ambulance Equipment, Route, Road, Hospital, Patient, Relative)
- Identifying Relations (Crew belongs to Vehicle, Equipment belongs to Crew, Vehicle follows Route)
- Defining Properties of Object Classes (for Crew Member: id, qualifications, availability)

It is prudent at this stage to write scripts for agents, which should be also stored in ontology and ready for agents to pick them up when given a task to perform.

All relevant policies, rules and regulations guiding the delivery of healthcare services should be also stored in ontology.

In addition to ontology, the knowledge base also contains all data on Object Instances, which are normally stored in client databases.

Designing Digital World

Digital World is a place where digital agents negotiate among themselves how to allocate resources to demands. The process is rapid and, in principle, not repeatable. The conditions, under which negotiations between digital agents are conducted, often change during the negotiations. In this respect, Digital World is like Heraclitus’ river.

To design the Digital World means to design the whole digital infrastructure that supports the exchange of meaningful messages among, potentially, hundreds of thousands of digital agents.

The choice of coding technology is vital and recent advances in Python and Microservices brought considerable gains in the transformation speed.

In the Ambulance Service Virtual World, the matching of crew members to crews, crews to ambulance vehicles, ambulance vehicles to hospitals, roads to routs, patients to hospitals, etc. is done by exchange of messages between relevant digital agents.

To achieve adaptability, the matching of demands to resources is done by agent communication rather than by computation. If, for example, a road to selected hospital is blocked by excessive traffic, Road Agent of the blocked road will immediately let affected agents know of a problem and trigger a wave of renegotiations between affected agents to determine a new route to the hospital. If a new route is too long, agents may try to negotiate a switch to a different hospital.

The key advantage of this type of rescheduling is that parts of the Ambulance Service Ecosystem not affected by the road closure, continue functioning as though no disruption occurred.

What is described here is just a minute part of the design process, hopefully sufficient to demonstrate how our new technology offers a considerable advantage over conventional batch-mode optimizers. Many more design details may be found in [1].

Designing Interfaces between Real and Digital Worlds

Information on disruptive events occurring in the Real World must be transmitted to the Digital World and all scheduling decisions, made by digital agents in the Digital World, have to be conveyed to the Real World.

Initially, the exchange of information is likely to be implemented by messaging between digital agents and human operators (e.g., drivers), using their smart phones or specially designed handheld communication devices. However, the preferred method is to exchange information directly between digital agents and physical resources of the Real World (e.g., vehicles, robots, conveyors), using The Internet of Things technology.

Extending the Initial Design

Scheduling of ambulance vehicles is easily extended to cover, for example, the scheduling of hospital staff and facilities that are required by patients brought in by ambulance vehicles. We just need an additional swarm of digital agents to do this job. And then, of course, we can add more swarms of digital agents to schedule other hospital resources such as operating theatres, etc. The design should advance step by step, each step proven in practice before the next one is commissioned.

Modelling Virus Pandemic

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

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.

The technology used for designing intelligent real-time healthcare schedulers has been used to design epidemic simulators. Architecture of an Epidemic Simulator is shown below.

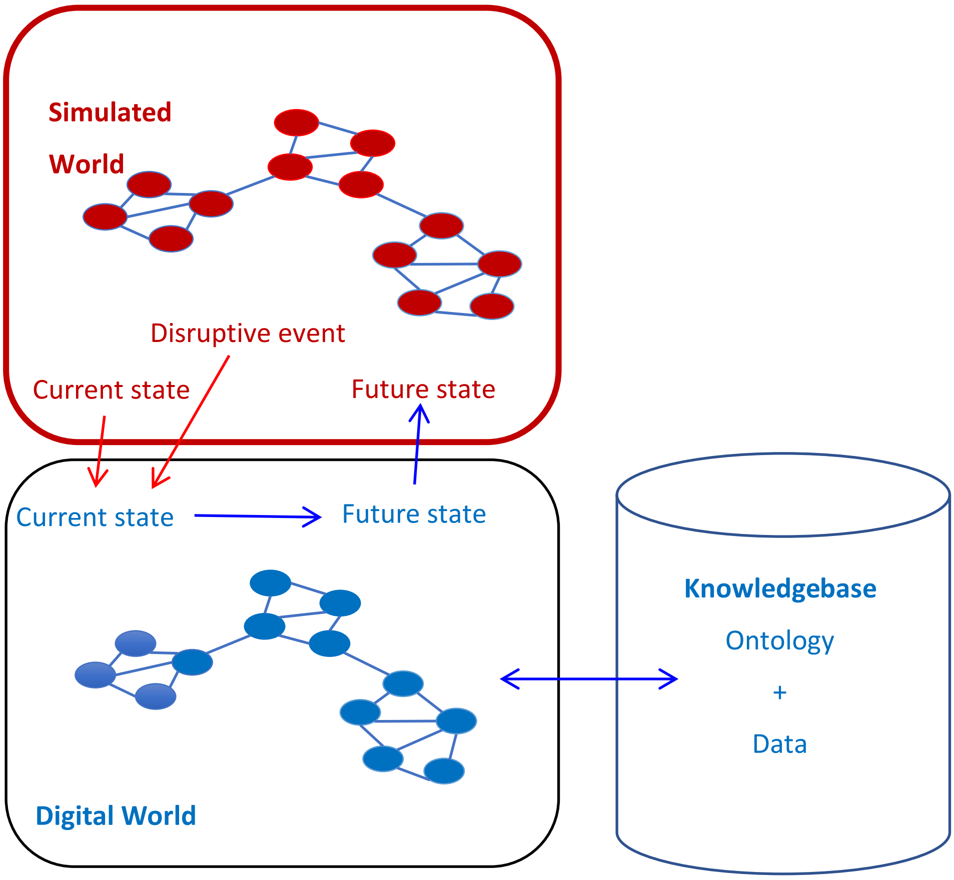

Fig. 2. Complex Adaptive Epidemic Simulator

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 invests 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 [3].

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 world 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 [2].

Complexity Science

For the benefit of readers who are not familiar with the science of complexity, let’s go over relevant fundamentals.

The traditional science, with roots in physics, the Queen of Sciences, often referred to as Newtonian Science, 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” [4], emerged the new science of complexity.

Santa Fe Institute in the US developed independently their own influential version of *complex adaptive systems* [5, 6]. The latest book by Stuart Kauffman, “A World Beyond Physics: The Emergence and Evolution of Life” [7] is a blueprint for the new scientific paradigm tailor-made for investigating the complex, irreversibly evolving world.

There is not much cross-referencing between these two, European and American, powerful schools of thoughts, but then, according to Kuhn [8], 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 [9], 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.

Complex groups

A group or, more formally, a system 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 [1].

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 [10]. 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*."

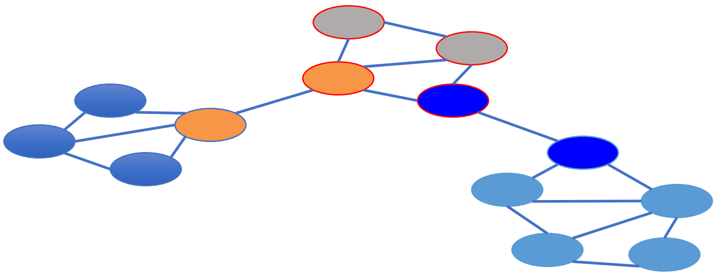

Fig. 3. A typical complex system with clusters of agents engaged in intense interaction

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 [11], [12]. 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 [13].

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 [14].

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.

Conclusion

The transformation from a conventional to a digital healthcare is urgent because of the huge gap between the increased complexity of the environment within which modern health services operate and their rigid administration and technological infrastructure unable to work effectively under the condition of complexity.

We have developed technology for transforming traditional health services into genuine health ecosystems. What we need now is the change of mindsets of decision makers, who still don't grasp the scale of the worldwide switch from mass-production of goods to the digital world of intelligent processing of information and extraction of knowledge from data.

We have proposed and described an evolutionary transformation methodology that ensures a minimum of disruptions to health services, enables a seamless transformation and can be carried out by several teams in parallel.

New modeling approach to coronavirus complex infection processes taking into account virus group behavior, adaptation and mutation is outlined.

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