Complexity: A Gentle Guide

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## Introduction

“The 21st century is the century of complexity”.

Stephan Hawking

We are currently in transition from industrial to digital economy and the ensuing increase in *connectivity* and, consequently, in *complexity* causes living conditions to be volatile and unpredictable – shortages, mismatch between jobs available and applicants’ skills, unpredictability of supply and demand.

Uncertainty is understandably annoying, and scapegoats are usually politicians who are blamed for not being able to provide desired stability. But they are powerless – the turmoil due to the transition is not under their control.

To understand what is happening, let’s make an effort to master the basics of *complexity*.

## What is Complexity?

The word *complex* derives its meaning from the word *plex* (interwoven or interconnected) and should not be confused with similar words such as “complicated” (as a jet engine), “cumbersome” (as bureaucracy), “unwieldy” (as an aging empire), “chaotic” (as a disorderly administration) or “difficult to understand” (as a verbose document).

Complex is a scientific term [1]. It is the defining characteristic of a group.

*A group or, more formally, a system, is complex if it consists of a large number of diverse, partially autonomous participants (agents), engaged in intense interaction among themselves and with their environment, without being centrally controlled*.

In a complex group, *autonomy* (freedom to decide what to do) of participants is restricted by membership rules, the legal system and norms of behaviour.

The overall behaviour of a complex group is *uncertain* (unpredictable) because it emerges from the interaction between participants, and yet, it is not random – it follows *discernible patterns*.

### Sources of Complexity

Complexity increases with *connectivity* and *autonomy* of participants. The greater the participant’s ability to connect with other participants and the greater their freedom to choose how to act, the higher complexity [2]. The *strength* of connections between participants is also important. Weak connections, which can be easily broken and new ones established, increase complexity.

Complexity is as old as the world. What is new is the *current sharp increase* in social connectivity and, therefore, in complexity, driven by the widespread use of digital technology, primarily the internet and smartphones.

### Examples of Complexity

Here are two examples of complex systems, one from the 18th and another from the 21st century.

A moderately complex system is a cattle market with, say, 100 sellers and buyers negotiating sales of 100s of cows. The interaction of sellers and customers is not centrally controlled and the outcome of a market day – which cattle will be purchased by whom and which will remain unsold – is uncertain. A typical complexity of the 18th century.

A typical complexity of the 21st century is exemplified by the internet-based global market, with billions of participants negotiating deals, with a click of a mouse. The dynamics of such a system is such that the supply and demand equilibrium is impossible to reach. The system, when disrupted, has no time to return to the initial state - the system operates “far from the equilibrium” or even “at the edge of chaos”.

Examples of complex systems, which have emerged through evolution, rather than by design or planning, include biological systems (human brain), natural ecosystems (forests, grasslands, rivers, oceans) and social systems (democracy, mass migration, terrorist networks, markets).

### Complexity and Uncertainty

Every activity around us is either deterministic, or complex, or random.

Let’s use uncertainty as the demarcation criterion for distinguishing complex systems from deterministic or random [3], as shown in Table 1.

|  |  |  |
| --- | --- | --- |
| RANDOM | **COMPLEX** | DETERMINISTIC |
| uncertainty = 1 | 1 > uncertainty > 0 | uncertainty = 0 |
| full autonomy | participants have partial autonomy | no autonomy |
| disorganised | selforganising | organised |
| unpredictable behaviour | emergent behaviour | predictable behaviour |
| examples:  movement of molecules, roulette | examples:  game of football, gig economy, climate | examples:  jet engine, clock |

Table 1. Complex versus deterministic or random systems

Uncertainty is a consequence of complexity, and it increases with complexity. Low complexity systems have uncertainty close to 0, whilst highly complex systems have uncertainty close to 1 – they are *at the edge of chaos* [4] (the word chaos is used here to mean random behaviour).

## The Power of Complexity

Certain properties of complex systems are almost miraculous and can be used to substantially improve performance of any organisation. Selforganisation, *emergence* and *coevolution* belong to this category.

Let’s explore this further.

### Selforganisation

Every complex system when disrupted or attacked, has the propensity to autonomously re-organise its resources to adapt to the disruption or defend itself. It doesn’t matter whether the disruption/attack is malevolent (hacking), criminal (fraud), a mistake (human error) or a failure (a broken physical resource) [5], [6].

And this is not all. During periods between disruptive events, the system is analysing its past behaviour to find ways of improving its own performance.

Selforganisation makes complex systems adaptable, resilient and sustainable.

Can we ask for more

*Adaptability* is the capacity for selforganising in response to a *disruptive event* (cancellation or modification of a demand, arrival of an unexpected demand, failure of a resource, a no-show). The adaptive system autonomously identifies a disruptive event and reschedules affected resources to neutralise, or at least reduce, the consequences of the disruption.

Example – an adaptive scheduler, in response to a request, allocates a minicab to a passenger and continues monitoring traffic conditions; if it detects a sudden traffic congestion, it reschedules the affected minicabs to avoid the delay in collecting the passenger.

*Resilience* is the capacity for selforganising in response to a fraudulent or malevolent attack. The resilient system autonomously identifies an attack and reschedules affected resources to neutralise or, at least, reduce the consequences of the attack (approval of a toxic loan, illegal transfer of money, hacking, cyberattack).

Example– A bank experiences during the night an attack by hackers, who manage by the morning to withdraw money from thousands of customer accounts (a real case). It is a clear instance of negligence – the bank neglected to build resilience into its systems. An AI-based protective systems would monitor transactions by customers 24 hours a day, would immediately note that the repeated emptying of accounts is an irregular activity, and would rapidly close the bank website.

*Conflict resolution* is a capacity for selforganising to resolve a conflict caused by two or more demand agents requesting access to the same set of resources at the same time. A complex system resolves a conflict by trial-and-error, it (1) identifies a conflict, (2) assumes that certain adjustment in the demand will resolve the conflict, (3) makes the adjustment, (4) evaluates results and, if necessary, modifies the initial assumption, (5) repeats steps 3and 4 until a mutually agreed resolution of the conflict is achieved or resources available for conflict resolution run out.

Example – Two clients asked for their cargos to be delivered to a warehouse at the same time. The complex system that managed deliveries autonomously decided to ask one of the clients if the delivery could be delayed. Permission was not given and the system approached the other client, who agreed. The conflict was simple but the important point here is that the system was not instructed by programmers how to resolve the conflict. It made a sequence of autonomous decisions.

*Spontaneous self-improvement* is the capacity for selforganising to improve own performance. A complex system self-improves by trial-and-error: it (1) detects a weak aspect of system performance, (2) assumes that a certain change in resources will improve system performance, (3) implements the change, (4) evaluates results and, if necessary, amends the starting assumption, (5) repeats steps 3 and 4 until the desired performance improvement is achieved or resources available for self-improvement run out.

Example - A complex scheduler, which allocates trucks to transportation orders, after completing the schedule with some time to spare, discovered that some large trucks were not fully loaded; it autonomously found newly available smaller vehicles and rescheduled the transportation order using the more appropriate trucks.

*Creative destruction* is a capacity for selforganising when the system realises that its performance cannot be improved piecemeal. The system destroys offending part of itself and then rebuilds it using a different building method.

Example – A complex system for the allocation of aircraft to air charter flights found that it could not match an available aircraft to any flight demand. It destroyed the schedule and began the allocation from the beginning, now matching flights to aircraft (rather than aircraft to flights) and the problem was solved.

### Emergence

Complex systems have remarkable *emergent properties* – properties that are present in the system as a whole and not present in any constituent component. Human intelligence is an emergent property of the human brain. No part of the brain is intelligent – intelligence emerges from the interaction of neurons.

Example- You can imagine the excitement when the author’s team discovered emergent intelligence in a *complex software* designed to schedule a rather difficult road transportation business [7]. The complex software in question, consisted of thousands of short algorithms, called *agents*, which were exchanging messages among themselves discussing how to produce the best schedule under unusually difficult circumstances. At some point, the agents unexpectedly decided to try a brilliant, original move that at a stroke solved a difficult problem.

Let me emphasise, agents were not instructed by the programmers what to do – on the contrary, they surprised the programmers with their decision. A clear proof that artificial complexity can create artificial intelligence.

*Emergent digital intelligence is the “silver bullet” of the digital age*.

### Coevolution

Complex systems have a propensity to *coevolve* with their environment – they selforganise to accommodate changes in their environment and the environment selforganises, usually almost imperceptibly, to accommodate the changes in constituent systems.

Example - Through coevolution, natural ecosystems (forests, rivers, oceans) have achieved *sustainability*, many with the lifespan of millions of years.

## Complexity Issues

The main problem created by the increased complexity of our social environment is the increased uncertainty of living conditions, caused by

1. *frequent unpredictable disruptive events*
2. *occasional extreme events*, and
3. *a* drift into failure.

Let’s look at the causes one by one.

### Frequent Unpredictable Disruptive Events

As referred to earlier, the internet-based global market in which 3 billion suppliers, customers, middlemen, investors, bankers, consultants, advisers and speculators negotiate new deals and alter or cancel previously agreed deals, at unprecedented speed, represents a typical present-day high-complexity system.

Organisations operating in this market experience frequent, unpredictable *disruptive events* - nonarrival of expected orders, arrivals of unexpected orders, cancellations and modifications of orders, delays, human errors, failures of resources and electronic fraud and hacking [1].

The frequency of disruptions is such that these organisations, unless equipped with rapid decision-making AI systems, suffer losses.

Example – Early in the 2000s, the author was invited to advise one of the largest car manufacturers in Europe on how to deal with the high volatility of car markets. The client had, at the time, 45 car factories around the world, including some of the biggest mass production plants in Europe, supported by very large and expensive computer-based production planning systems, which had to work all night to plan the daily production. The problem was that as production went underway, every hour or so the client would receive a stream of messages from dealers cancelling or modifying orders. Since the car production could not be changed as quickly as orders, but had to proceed as planned, a certain percentage of manufactured cars could no longer be delivered to car dealers and had to be parked outside, waiting to be sold at discount. The author rapidly assembled an international group of highly competent software developers and built for the client a prototype real-time scheduler, driven by artificial intelligence, which managed to demonstrate that it is feasible to re-schedule affected parts of the production within minutes of the arrival of a modification or cancellation of an order (disruptive event). But the client was unable to switch to the new, real-time scheduling because the physical production infrastructure, built following principles of the industrial economy, could not be adapted to cope with frequent changes of production schedules. And it was much too expensive to develop a new adaptive production system.

There are exceptions, as always, factories producing baby nappies or car batteries do have a continuous and stable demand even in complex markets.



Fig. 2. An illustration of complexity of the internet-based global market

### Butterfly Effect: Occasional Extreme Events

In complex systems with nonlinear relations between components, such as the climate, the smallest disturbance - movement of a butterfly wing - may cause, at the other end of the planet, an extreme event – a storm – the phenomenon known as *butterfly effect* [8] or *black swan* [9].

Butterfly effect is the most dangerous aspect of a complex system. The amplification of small disturbances is difficult to discover and there is uncertainty as to when the accumulation will reach the *tipping point* and create an extreme event.

Example - The most dramatic case of the butterfly effect was the recent coronavirus pandemic - a single meal of an infected animal or, possibly, a single mistake in a virus laboratory, which enabled a population of viruses to escape - triggered a rapid propagation of the virus through the highly connected “global village”, causing worldwide infection, millions of deaths, and economic disruption on a huge scale.

### Drift into Failure

A drift into failure is another dangerous aspect of complexity but easier to handle than the butterfly effect [10].

When a complex group operates successfully over a long period of time, a tendency may develop among constituent participants to neglect some of their duties or engage in small-scale illegal activities, which can be individually easily concealed. However, the consequences accumulate over time and when the tipping point is reached, an extreme event (a failure) is triggered.

Example - The financial crisis of 2008 was caused by a drift into a failure [11]. The accumulation of small toxic loans (loans that could not be repaid), approved to gain bonuses, gradually reached the tipping point and turned into an unstoppable global crisis.

The evidence gathered from experiments with complex digital systems shows that to prevent drifting into failure, it is necessary to impose strict control of the behaviour of complex system participants when the operation is going smoothly but to allow them a considerable freedom of action to encourage creative thinking, during the recovery – the exact opposite to what was done by the UK and US financial authorities during the build-up to the crisis and during the recovery.

Complexity science provides a strategy for managing butterfly effects and drifts into failures in large, densely connected man-made complex systems, such as globalisation or the internet-based global market. The idea of clustering is at the core of this strategy. We consider this topic further in the section on managing complexity.

## Complexity Resists Control

*Controlling complexity* means attempting to make a complex system behave exactly as prescribed by restricting autonomy and connectivity of participants. Let’s consider an example – how contemporary social systems behave when their members consider the imposition of control unjust.

The freedom of exercising choices in any social system is limited by social conventions and norms, ethical standards, rules and regulations imposed by social system statutes, and by national and international laws. Restrictions on the autonomy of individuals are normally enforceable by punishment, which can be severe (expulsion from a school, club, business; deportation from a country), or very severe (imprisonment, capital punishment).

In most cases, the motivation for limiting individual autonomy is reasonable, aimed at ensuring that the system (school, club, business, nation) behaves as closely as possible to what was intended.

However, if attempts are made to impose a full control on individuals (political dictatorship, military occupation), the social system will not be able to selforganise when hit by disruptive events, which in time will lead to disintegration (centrally planned economies have perished, military occupations, with some exceptions, have ended badly for the occupiers).

Also, the system is likely to resist the imposition of unreasonable control by creating an unofficial parallel social system (underground movement, guerrilla warfare) where dissidents are able to participate in prohibited activities (exchanging illegal books, discussing forbidden topics, planning or executing attacks). Unofficial, parallel social systems exhibit all the features of complexity, including selforganisation, which ensures its long-term success over the rigid control.

Even if controls are considered acceptable by the majority of members, opinions of some individuals and groups may differ on what the desirable autonomy should be, and some will practice what they believe, probably, in a covert manner (political dissent, infidelity, lying, theft, murder), or organise resistance aimed at changing the official order (rebellions, revolutions).

The idea that it is possible to control a social system by highly restricting the autonomy of constituent agents may be temporary possible only if the system is closed to external influencies. Such situations do not exist naturally but may occasionally be artificially imposed (Berlin Wall).

However, although complexity cannot be controlled, it can be managed.

## Managing Complexity

*Managing complexity* is a term that covers various ways of resolving issues created by increased complexity.

It is important to note that we can manage only those complex systems that are under our control – systems which we own, which we manage on behalf of owners or which we design. For example, a board of directors of a private company may decide that complexity of the company needs to be modified and may launch a complexity design project. And, of course, designers engaged in the design of complex adaptive software will deal all the time with the issue of how complex their software should be and how to achieve the desired level of complexity.

*We cannot manage complexity of our environment* which, by definition, is not under our control. There is nothing we can do about, for example, complexity of the internet-based global market.

What we can do is to match the complexity of organisations that operate in a such an environment to the complexity of the environment.

### Law of Requisite Complexity

The law of requisite complexity is the fundamental law of complexity management.

*A system can survive and prosper only if its complexity is matched to the complexity of the environment in which it operates.*

An alternative way of expressing the same idea would be:

*If a business operates in a complex market, its complexity must match complexity of the market.*

*If software supports a complex business, its complexity must match complexity of the business.*

It follows that rigidly structured corporations and administrations, which were designed to operate in a stable, predictable environment and are currently exposed to increased complexity of the internet-based global market, must be *injected with requisite complexity* using appropriate digital tools – the process integral to *digital transformation*.

This clearly spells the end of the road for deterministic software – in time, we shall use only *complex adaptive software*.

### Matching Complexity of an Organisation to Complexity of its Environment

The most practical way of matching complexity of an organisation to complexity of its environment is to *match the speed of scheduling of resources to the frequency of disruptive events*. In other words, in high complexity markets, the scheduling of resources must be done *in real time*.

The required speed can only be achieved by *replacing human decision makers with artificial intelligence*.

Human intelligence, although mighty, is slow.

At the strategic levels human intelligence will dominate artificial intelligence for a very long period, possibly for ever. The broad understanding of the world in which we live and work, necessary for developing the strategy for maintaining adaptability and sustainability is at present beyond artificial intelligence.

To be adaptive at the strategic level, it is necessary for decision makers to widen the scope of deliberations to be able to *anticipate* new, complexity-induced patterns in supply and demand, which is best done as a teamwork by participants with diverse knowledge profiles.

The adaptive strategy requires teams of strategists to

Monitor social, economic and political trends relevant to the environment in which the enterprise operates.

Analyse possible consequences of identified trends.

Review the strategy of the enterprise, based on analytical results.

To summarise, because of the requirement for faster decision-making at lower levels and wider understanding of the rapidly changing big picture at higher levels of management, the traditional hierarchical management structures are not suitable for operation under conditions of complexity.

*Distributed decision making – the interconnected clusters of decision makers, each cluster working on a well-defined problem* *is the model for the future.*

Hopefully, we now understand what to do to be adaptive. But how do we make organisations resilient?

The process of making an organisation resilient is the same as the process of adaptation. The difference is in which data to monitor and what to look for. To achieve adaptability, we monitor flow of orders and behaviour of resources, and for resilience, we are trying to spot unexpected deviations from normal behaviour of both the organisation as a whole and of each of its members.

A section of a digital system which protects the system from attacks and fraud the author calls a *digital Immunity system*.

Artificial Immunity systems protects organisations from electronic attacks and fraud, and build resilience into organisations by:

Continuously monitoring all the relevant data streams and databases and instantly detecting a deviation from normal behaviour, possibly due to an attack or fraud.

Performing a quick analysis to assess the consequences and to check if the unexpected behaviour is an attack, fraud or a random disturbance.

Rescheduling the relevant resources to foil the attack or fraud without disturbing unaffected parts of the system, if possible.

Protecting organisations from drift into failure is not much different. However, it includes continuously monitoring activities of certain participants and, therefore, may interfere with privacy. The aim is to detect human errors or illegal activities, which although insignificant by themselves, if undetected, may accumulate and reach the tipping point.

Coevolution of a complex system and its complex environment results in sustainable systems which are always “in tune” with their environment. It is sufficient to ensure that complexity of a system is matched to the complexity of the environment.

### Clustering

*Clustering means* *partitioning a complex group into sparsely connected smaller groups of participants* [3], as depicted on the right-hand side of Fig. 2.

Clustering is of immense importance in managing complexity – it prevents, or at least reduces, negative consequences of butterfly effects and drifts into failure and, at the same time, increases the effectiveness of the interaction between participants.

All living creatures live in small groups (clusters) – they selforganise into swarms, colonies, herds, packs, tribes, families, communities, nations.

In a group where all participants know each other, it is easier to collectively create and distribute resources for life, grow and age together and experience a feeling of comfort and security.

A good example of clustering is the way in which recent immigrants to London selforganised themselves into cultural clusters – the French in Kensington, the Indian in Southall, the Polish in Ealing and the Russians in Knightsbridge, to mention just a few.

cluster 1

cluster 2

cluster 3

cluster 4

Clustered Complex System

Densely Interconnected Complex System

Fig. 2. Two contrasting configurations of complex systems

Among biological systems there are many examples of clustering. The human brain, a beautiful creation of natural selection, consists of connected regions (clusters), each focused on performing a particular function. Fig. 3 shows regions of a human brain engaged when people lie and those when they are truthful.



Fig. 3. Green regions are engaged when people are truthful and red regions when they are dishonest

There are good examples of designed clustered complex systems. Founded in 1096, the first English university, Oxford, was, and still is, organised as a system of connected colleges - each college being a cluster of intense educational activities where academics and students live and learn in relatively small groups. Cambridge, 100 years younger university, functions in the same way.

In contrast, modern universities are as a rule organised like corporations, run by administrators – a type of organisation unsuitable for operating in a complex world.

Brexit is an example of voters preferring to live in a cluster – in a traditional sovereign state.

We really should ask ourselves why we ignore the clustered configuration, which emerged from natural selection and is so successful in biological and natural ecosystems.

## Complexity Science

Our traditional education prepares the young to be successful in an orderly and slow-changing world in which the future is predictable and where the source of uncertainty is often ignorance and, therefore, can be reduced, or even eliminated, through learning. In such a *deterministic word*, according to Newton, natural laws are valid independently of time and location. Einstein asserted determinism by stating “God doesn’t play dice with the universe”.

As recently as 1990’s, a different worldview was articulated by the Belgian Nobel prize winner, Ilya Prigogine [12], [13] and by the US Santa Fe Institute researchers, Stuart Kaufman [14] and John Holland [15] - a *complexity worldview*. Many eminent authors have also made important contributions to the idea of a complex evolving world, without necessarily mentioning the term complexity. Among them, Charles Darwin [16], Carl Popper [17] and Marvin Minsky [18]. Eric Beinhocker authored a comprehensive account of the complexity of the global market [19].

The essence of the complexity worldview is that the world, far from being created to a great design, irreversibly and unpredictably evolves from early beginnings, through the stage of primordial soup to the current state, and will continue to evolve, driven 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 or procreation, changes the world in a small and unpredictable way. *Uncertainty* is a result of unpredictable evolution and cannot be reduced or eliminated.

In sharp contrast to Einstein’ assertion of determinism, Prigogine proclaimed “Future is not given”.

The idea is, of course, not entirely new, Heraclitus realised, as early as 500 BC, that the world is perpetually changing and expressed this notion in a memorable sentence **“**You could not step twice into the same river**”.** Karl Popper observed that in a deterministic world creativity would not be possible.

The subject of complexity science is the behaviour of complex systems, and the method is primarily experimental. Good results have been achieved by trial-and-error method.

## Complexity Mindset

*Complexity mindset* is a mindset which encompasses the complexity worldview. Developing a complexity mindset is essential for those who live and work under conditions of uncertainty. The contrast between deterministic and complexity worldviews is illustrated in Table 2.

The key difference is that the belief in determinism leads to the illusion that the future is, in principle, predictable. And although, in practice, we find that the key elements of our future (health, wellbeing, security) are uncertain, determinism leads us to believe that uncertainty is caused by lack of knowledge and, therefore, in time as we gain the required knowledge, we shall be able to predict the future.

The main consequence of believing that the world is complex is the understanding that the future is, in principle, unpredictable. However, since the world is complex, rather than random, the evolution follows discernible patterns. Therefore, although the future is not given, we may determine the likelihood of certain scenarios.

For example, it is highly likely that the digital economy will replace the industrial economy within the next 30 years.

Highly likely but not certain – a catastrophic event may stop or divert the current flow of events.

|  |  |
| --- | --- |
| DETERMINISTIC WORLDVIEW | COMPLEX WORLDVIEW |
| World is created according to a “grand design” | World irreversibly and unpredictably evolves from primordial soup to a global village |
| Future is predictable | Future is not given |
| There is universal law which predicts everything. We are waiting for it to be discovered | Future emerges from billions of interactions among constituent agents, living and non-living and is therefore not predictable |
| Uncertainty = 0 | 0 < Uncertainty < 1 |
| If we are uncertain, it is because of our lack of knowledge. Learning eliminates uncertainty | Uncertainty is an inherent property of complexity and cannot be eliminated by learning |
| Time and space are invariant | “Becoming” is as important as “being” |
| For every effect, there is a cause | Effects are triggered by reaching the tipping point due to the accumulation of many causes, which may be individually insignificant |
| 384 BC Aristotle  The world consists of matter and energy (information was ignored) | 600 BC Buddha  The mind is everything. What you think you become |
| 1643 Newton  Natural laws are valid at any time and at any location | 535 BC Heraclitus  You could not step twice into the same river |
| 1879 Einstein  God doesn’t play dice with universe  Time is an illusion | 1831 James Clerk Maxwell  Wrote about a new kind of knowledge that would overcome the prejudice of determinism |
|  | 1902 Karl Popper  In a deterministic world it would be impossible to choose or create |
|  | 1917 Prigogine – father of Complexity  The end of certainty  Future is not given |

Table 2. Deterministic and complexity worldviews, including worldviews of some of the intellectual giants throughout the centuries

## Key Points

1. Complexity is created by a large group of diverse participants that enjoy certain autonomy and are engaged in the intensive exchange of information with each other and with their environment without being centrally controlled.
2. The example of special interest is complexity of the internet-based global market whose billions of participants are engaged in agreeing, modifying or cancelling transactions with a click of a mouse.
3. Negative consequences of complexity of the internet-based global market are
   1. Volatility of supply and demand due to frequent unpredictable disruptive events
   2. Butterfly effect
   3. Drift into failure
4. However, complex systems have a remarkable property; they are able to selforganise when hit by an unexpected change in their environment (adaptability) or an attack (resilience).
5. According to the law of requisite complexity, organisations operating in complex environments, to be successful must be as complex as their environment
6. Although complexity is as old as the world, it was ignored by science until near the end of the 20th century, when it increased exponentially, driven by the widespread use of the internet and mobile phones, and began to create serious economic issues; the new science of complexity is still underestimated by the orthodox scientific community
7. We now have a rivalry between two contrasting worldviews
   1. The traditional belief that our world is deterministic and its behaviour is predictable, and
   2. The new belief that our world is complex, that its behaviour emerges from the interaction of its constituent elements - living (animals, plants, microorganisms) and non-living (erosion, earthquakes, tsunamis, tides, winds) - and that is unpredictable but not random – it follows discernible patterns.

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