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HARNESSING THE POWER OF SELF-ORGANISATION

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ABSTRACT
Complexity of our social, political, economic and technological environment has increased recently to unprecedented levels creating frequent disruptive events (and occasional extreme events) that affect our lives and work. As a contribution to the knowledge on how to cope with complexity, the paper reports research on self-organisation. A practical approach to designing self-organising systems, based on author's substantial experience, is outlined.
Key words: agent autonomy, business processes, complex social systems, emergent creativity, emergent intelligence, emergent leadership, self-organisation.

1 INTRODUCTION

There exists ample evidence that social, political, economic and technological environments in which we live and work are *Complex*; and that complexity is relentlessly increasing [1]. This condition puts a considerable stress on our traditional institutions and organisations, which were developed to operate under conditions of a stable and predictable, rather than complex, environment.

It has been shown that for organisations expected to operate under conditions of complexity, the best way of coping with complexity is to develop a capacity for *Self-Organisation* [2], i.e. the ability to autonomously adjust own connectivity and behaviour in order to eliminate, or at least reduce, consequences of unpredictable external or internal *Disruptive Events*.

And since only complex systems can exhibit self-organisation, it follows that we shall have in the near future to design complexity into our institutions and organisations to enable them to become adaptive in order to survive and prosper in complex environments.

2 COMPLEX SYSTEMS REVISITED

2.1 Definition

Complex Systems are open systems consisting of large numbers of diverse, partially autonomous and richly interacting components, known as Agents, which are not centrally controlled. Global behaviour of complex systems emerges from the interactions of agents and is unpredictable but not random. Complex systems are characterised by the following seven properties: connectivity, autonomy, emergence, nonequilibrium, nonlinearity, self-organisation and co-evolution [3].

2.1.1 Connectivity

Agents are interconnected. Complexity of the system increases with the number of links that connect agents to each other. The strengths of agent links also affects system complexity; the weaker the

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links, the easier is to break them and form new ones, which increases system complexity. Adjusting agent connectivity is an effective method for tuning complexity. Complex systems often consist of regions of high connectivity (and high complexity) interconnected by low-connectivity (and low complexity) links, as exemplified by clustering of activities in the human brain.

2.1.2 Autonomy

Agents have certain freedom of behaviour (autonomy), which is always limited by norms, rules, regulations, and/or laws (natural or man-made). The increase in autonomy of agents increases complexity and if all constraints on agent behaviour are removed the system switches from complex to random behaviour. Inversely, if autonomy of agents is reduced (by tightening of laws and/or regulations), the system complexity will decrease, and in the extreme, the system will become deterministic. Agents are not centrally controlled.

2.1.3 Emergence

Behaviour of complex systems emerges from the interactions of agents and is not predictable and yet it is not random. Uncertainty about the outcome of agent interactions is always between 0 and 1. Emergence, in general, denotes a property of a system that is evident in the system as a whole but it is not present in any of its components.

2.1.4 Nonequilibrium

Complex systems are subjected to perpetual change experienced as a succession of discrete disruptive events and/or as a slow, almost imperceptible drift into failure. Frequency of disruptive events varies with complexity. In systems of high complexity disruptive events occur so frequently that the system has no time to return to stable equilibrium before the next disruption occurs. When complexity levels are very high the system is said to be at the edge of chaos because the uncertainty of behaviour is close to 1.

2.1.5 Nonlinearity

Relations between agents are nonlinear. Nonlinearity may amplify a small, insignificant disruptive event and cause a catastrophic outcome (an extreme event), the property called butterfly effect. The butterfly effect increases with complexity. In complex systems outcomes are, as a rule, consequences of numerous interacting causes, and therefore, the cause-effect analysis is inappropriate.

2.1.6 Self-organisation

Complex systems have a propensity to react to disruptive events by autonomously self-organizing with the aim of eliminating or, at least, reducing consequences of the disruption. This property is called *Adaptation*. Self-organisation may be also caused by a propensity to improve own performance, the property called *Creativity* or *Innovation*. To initiate and perform adaptive and creative activities the system must be *Intelligent*. Intelligence, adaptation and creativity are emergent properties exclusive to complex systems; their levels increase with complexity. The Artificial Intelligence (AI) found in complex adaptive software is normally referred to as *Emergent Intelligence*. It emerges from agent interaction and it is greater than the sum of agent intelligence.

2.1.7 Co-evolution

With time, complex systems change as their environments change and, in turn, they affect their environments. Co-evolution is irreversible.

2.2 Further readings

Literature on Complexity is very extensive. Nevertheless it is best to start with real pioneers and founders of the Science of Complexity, Prigogine [4, 5], Kaufman [6] and Holland [7].

3 SELF-ORGANISING SOFTWARE

3.1 Introduction

Conventional computer programs (software) are deterministic systems with strictly predictable behaviour determined by instructions specified and written by the designers and coders.

Can we design software to be complex?

And if we could, why would anyone prefer complex software with unpredictable behaviour more than deterministic computer programs, which behave as instructed?

The answer to the first question is: yes, we can. During the last 20 years the author and his team have designed and implemented a large number of complex adaptive computer programs [1].

The answer to the second question is counterintuitive and not widely known or accepted. *Complex adaptive software is capable of self-organising in a way that eliminates consequences of disruptive events and therefore it is perfectly suited for modelling (and/or managing) business, social, economic, political, geopolitical and many other complex systems.*

Conventional software is not suitable for operating in a complex environment because it cannot cope with unpredictable disruptive inputs.

3.2 Architecture

Complex adaptive software is an open system. It interacts with its environment, which is also complex and it consists of three key components: *Ontology*, *Virtual World* and *Connections to the Environment*, as depicted in Fig. 1.

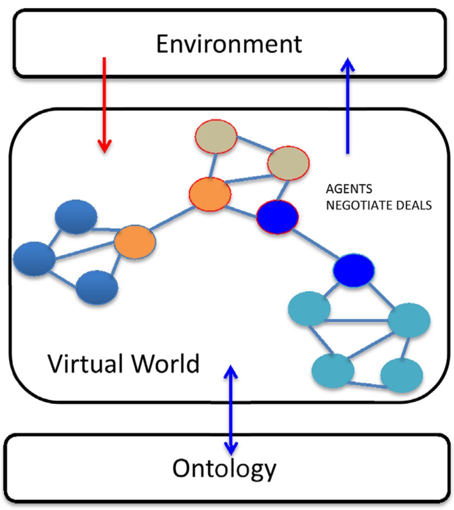

Figure 1: Architecture of a complex adaptive software system.

Ontology contains conceptual domain knowledge organised as a network of Agent Classes and their Relations. Agent Classes are defined by their attributes, which include patterns of behaviour. Virtual World is a network of Agent Instances and their relations. Agent instances are defined by the values of their attributes. Complex software being open, is always connected to other systems – its environment.

3.3 How complex software works

Complex software components are computational objects known as Software Agents.

The key feature of complex software is that its components, software agents, accomplish given tasks by exchanging messages with each other rather than by computation.

Typically, agents negotiate deals, they match supply to demand, allocate resources to orders, determine which word will have which meaning, which record will belong to which cluster, etc.

Whenever a disruptive event occurs agents autonomously and rapidly re-negotiate affected deals and thus eliminate consequences of the disruption.

The re-negotiation of deals amounts to self-organisation.

3.3.1 Connectivity

Which agents are designed to communicate with each other is determined by Agent Class Relations in Ontology. When two agents agree on a deal, they form a Connection, as depicted in Fig. 1 above.

These connections are not permanent and agents can cancel or modify existing connections and/or establish new ones, if necessary. By varying connection strength and the number of connections between software agents we can tune software complexity.

3.3.2 Autonomy

Agents' autonomy is constrained by the set of Standard Messages that each Agent Class is permitted to exchange with other agents and which is specified in Ontology. Before acting agents consult Ontology where they select from the set of Standard Messages a message that is appropriate for their task in hand. If no message is fully appropriate, agents select a message that appears to be most appropriate. In other words, if domain knowledge stored in Ontology is incomplete, agents will try to overcome this limitation by informed guessing. By varying the degree of autonomy of software agents we can tune software complexity. However, the autonomy of software agents is bound to be restrictive and therefore it is far more effective to tune software complexity by varying agent connectivity.

3.3.3 Emergence

The global behaviour of complex software emerges from agent negotiation but the task is never fully accomplished as long as disruptive events continue to occur. Complex software keeps adapting to its environment throughout its life.

3.3.4 Nonequilibrium

The perpetual occurrence of disruptive events does not allow software behaviour to stabilise. After every disruption software moves to a different state.

3.3.5 Nonlinearity

Nonlinearity of connections between agents may cause the propagation and amplification of instabilities. Insignificant disruptions may cause extreme Events, such as destruction of a carefully built agent network. We can vary the resistance to extreme events by modifying properties of connections with a view to restricting propagation of instabilities, e.g. oscillations.

3.3.6 Self-organisation

Software self-organises by autonomously changing connections between agents whenever such change helps to accomplish a task. Typically, software self-organises in order to eliminate consequences of disruptive events. Here is an example.

Let assume that the software task is to schedule the delivery of cargo to the International Space Station (ISS) in real time, and that after a considerable activity of agents they have agreed on a schedule that meets all requirements. If then a message is received that one of the items scheduled to be delivered by the next spacecraft is no longer required, the message will activate the relevant Item Agent, which will send a message to the relevant Container Agent that the cargo capacity, which was occupied by the cargo item that is no longer required, can be used for delivering an alternative item. Container Agent will immediately start negotiations with agents representing cargo items on the waiting list to select which of them will be scheduled for delivery by the next spacecraft. The decision is typically reached in a few milliseconds.

Self-organisation aimed at eliminating consequences of the occurrence of an unpredictable disruptive external event enables software to adapt to changes in its environment.

Adaptation results may not be optimal if time available for adaptation (negotiation between agents how to adapt plus all the actions required to implement the required changes) is too short to search for the optimal solution. In such cases agents will accept, for the time being, the first feasible solution and would attempt to improve this solution during intervals of time without disruptions, if possible.

Self-organisation aimed at correcting nonoptimal adaptation decisions can be interpret as a creative or innovative activity, which enables software to improve it's own performance.

3.3.7 Co-evolution

In time, the pattern of disruptive events generated by the complex software environment will change and, inevitably, because of perpetual adaptation, the changes in the environment will cause changes in software. The process is reciprocal, the changed software will cause changes in its environment.

4 SELF-ORGANISING BUSINESS

4.1 Introduction

Business is all about the allocation of available resources to demands – people to tasks, projects or departments; money to departments, projects, teams or individuals; machine tools to manufacturing processes; transportation facilities to cargos; storage capacities to parts and components; etc. A typical business has a massive amount of resources: human, financial, physical and knowledge resources (imbedded in data) and it is not surprising therefore that Enterprise Resource Planning (ERP) systems are a backbone of every enterprise.

ERP systems and various planners and schedulers, which work in batch mode, do the allocation effectively under stable market conditions. They typically require 8 h to calculate the optimal allocation schedule and then the business is expected to work according to the schedule for the next 8 h. Any changes in demand and the availability of resources during this 16-h period are ignored.

When the environment in which business operates is seriously complex (as is the Internet-based global market) and characterised by the frequent occurrence of unpredictable disruptive events, the allocation of resources to demands must be done in real time, which implies the capability of the business processes to self-organise.

For real-time scheduling we have to have systems capable of performing autonomously the following activities:

1. Rapid detection of a disruptive event
2. Immediate identification of demands and resources that will be affected by the disruption, and
3. Autonomous re-scheduling the affected demands and resources with the aim to eliminate, or at least reduce, consequences of the disruptive event before the next one occurs.

Note that autonomous re-scheduling of resources to demands amounts to self-organisation.

Only complex systems are capable of self-organisation, and therefore, businesses supplying products or services to the Internet-based global market should have complex resource allocation systems [8–10].

When complexity of the environment is reasonably low, the real-time allocation of resources can be done by human operators (dispatchers) but, with complexity on the rise, the periods of time between consecutive disruptive events is becoming too short to allow people to gather relevant information, make decisions and implement actions.

4.4 Domain knowledge

In business systems the domain knowledge (knowledge how a business should work) is contained in business constitutions, rules and regulations; business process specifications; operational manuals; skills of managers and employees; national and international laws; and norms of business behaviour.

Business would be deterministic if knowledge how the business should work were precise and explicit and neither managers nor employees were allowed any initiative. In the past many corporations almost succeeded in achieving such a goal by strict Command and Control management approach, although a fully deterministic (predictable) business never existed.

Modern approaches to business management increase complexity of businesses by

- Wider distribution of decision-making powers
- Drastic reduction of levels of managerial hierarchies
- Replacement of individual problem solving by teamwork and consultation at all levels of management.

And the increase in complexity enables businesses to self-organise under conditions of frequent disruptions

4.5 Disruptive events

Let's look closer why do we need self-organisation in business. To answer this question we have to look into complexity of the contemporary global market. The biggest issue here is market dynamics resulting in the unpredictability of demand and supply.

Under conditions of frequent unpredictable demand failures (nonarrival of the expected order, the arrival of an unexpected order, modification or cancellation of an accepted order) and resource failures (failures of resources allocated to demands) it is very difficult to conduct a business unless we have a mechanism in place ensuring that the business will self-organise *rapidly* in reaction to any demand/resource failure and eliminate the consequences.

4.6 Conflict resolution

In addition to demand/resource failures, in complex environments businesses often experience conflicting demands. A typical conflict arises when two or more different demands each requests the same time slot to perform two or more different activities. An alternative conflict arises when two or more different demands request to perform a joint activity each proposing a different time slot.

4.7 Adaptive business

A business is Adaptive if it is capable of achieving specified results under conditions of frequent disruptive events and conflicting demands.

Conditions for adaptability are certain degree of business complexity, which enables self-organisation, and complex adaptive resource allocation systems, which ensure that self-organisation is sufficiently rapid to eliminate consequences of a disruption before the next one occurs.

The same conditions apply for a business to become *Resilient* to electronic attacks.

4.8 Drifting into failure

When a business operates successfully and manages to increase its value over a long period of time (measured in years), a subtle change in behaviour slowly emerges: increased tolerance of reduced thoroughness, mistakes, laziness and even of small-scale fraud. And then everyone seems surprised when the accumulation of small incidents reaches the Tipping point and the business is hit by an extreme event – loss of a significant client or even insolvency.

Perhaps the best example of a drift into failure of the global scale is the widespread cheating with subprime loans among financial institutions during a long period of global economic growth, which led to the global financial crises of 2008/2009.

A self-organising business can eliminate the drift into failure by tightening up control over behaviour of agents during the long periods of prosperity and relaxing controls when the going is tough in order to enable emergent creativity.

4.9 How complex adaptive business works

A diagram how a Real World of business is managed by a Virtual World of software agents engaged in the real-time allocation of resources to demands, is shown if Fig. 2.

5 SELF-ORGANISING SOCIO-POLITICAL SYSTEMS

5.1 Introduction

For the purposes of this paper socio-political systems are communities, towns, regions, nations and unions of nations. The largest socio-political system of them all, the geo-political constellation will be considered separately.

It is assumed here that the goal of a socio-political system is, or it should be, to provide for its members an environment conducive to satisfactory existence, as defined by members themselves, directly or through their representatives.

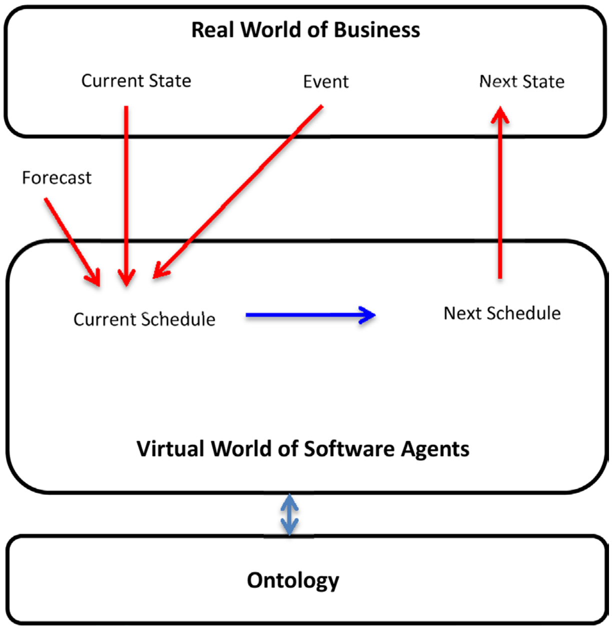

Figure 2: Virtual world manages in real time the real world of business.

In rigidly structured socio-political systems where members (social agents) are centrally controlled (dictatorship) self-organisation is not allowed. Dictators make the assumption that society is deterministic and it will behave as instructed. Attempts to self-organise are nevertheless almost always made at least by some social agents (see section on dissident behaviour).

Whenever constituent agents are given certain freedom to make autonomous decisions (democracy), they will make use of this freedom to self-organise with a view to eliminating consequences of any disruption interfering with their work or life. In other words, by self-organising a complex socio-political system may achieve its goals in spite of disruptions.

5.2 Domain knowledge

In socio-political systems the domain knowledge (knowledge how the system works) is contained in constitutions, statutes, rules and regulations but also in precedencies, rituals and unwritten traditions (culture). And, of course, a considerable part of it is locked in member's memories, very often in a tacit form, and applied without a need for the formal representation.

It is important to realise that knowledge on how a social system works is never complete and without contradictions; and therefore, it cannot be literally applied, it is necessary to interpret it, which can be done only in the presence of considerable intelligence.

5.3 Disruptive events

Socio-political systems experience a variety of disruptive events with increasing frequency, although the frequency is nowhere as high as in business, where, the Internet-based global economy is in a real turmoil.

Examples of disruptive events are (1) changes in legislations concerning employment, pensions, holidays, working hours, minimal wage, etc., (2) changes in prosperity caused by the loss of employment, increase/decrease of remuneration, (3) changes in living costs, (4) disruptive actions of constituent agents aimed against each other (internal attacks), (5) disruptive actions generated by other social systems (external attacks).

Social systems as a whole, or parts of social systems, self-organise aiming to reduce consequences of disruptive events or to maximise own advantages.

5.4 Emergent intelligence

The key difference between social complex systems and biological, physical or chemical ones is in the degree of *intelligence* of constituent agents. For the purposes of this paper let us define intelligence as 'the capability to formulate and achieve goals under conditions of uncertainty'. Intelligence subsumes propensity for self-expression and the ability to learn, investigate and communicate. This feature of social systems is very important because intelligence provides agents with the ability to exercise choices. However, social agents may or may not be allowed (empowered) to use their intelligence, depending on the social order.

A social system comprising intelligent agents that are given the appropriate autonomy exhibits *Emergent Intelligence*, which is far greater than the sum total of constituent agent intelligence. The 'appropriate' autonomy here is the degree of freedom given to individual agents to make decisions, which yields the best global behaviour of the system.

The appropriate agent autonomy depends on intelligence of agents (not all agents have the same intelligence) and on complexity of the environment in which the social system is embedded. In that respect each system, at any given point in time, is different. We can ascertain only that the appropriate autonomy is always greater than none and smaller than total.

5.5 Emergent creativity

To survive and prosper in the complex world there is a need to perpetually review goals and invent new ways of achieving agreed aims and objectives. To satisfy this need agents should not just react to disruptive events, they should be *creative* – able to anticipate trends and generate new opportunities. Creative agents can be appointed (research & development staff) or allowed to emerge when creativity is required (emergent creativity). Experience shows that the latter approach is more promising. Any social agent appears to be able to exhibit certain degree of creativity when circumstances demand. It is worth remembering that in complex systems emergent creativity is greater than the sum of agent creativities. A good reason to encourage complexity.

5.6 Emergent leadership

To achieve difficult goals the available intelligence and skills may not be sufficient. A *Leader* is an agent that is capable of motivating, mobilising and advising other agents to undertake difficult tasks and, in particular, tasks that are critical for the achievement of system goals. Leaders can be appointed or they can be allowed to emerge at the time when leadership is required (emergent leadership). The idea of emergent leadership is rather new and untested but much more aligned to the complex thinking than the current practice of appointing leaders.

5.7 Social order

The freedom of exercising choices in social systems is never complete. Autonomy of social agents, and thus their freedom of choice, is limited by social conventions and norms, by ethical standards, by rules and regulations imposed by social system statutes and by national and international laws enforceable by punishment, which can be severe (expulsion from a school, club, business; deportation from a country), or very severe (imprisonment, capital punishment). The purpose of limiting agent autonomy has always been to eliminate or restrict the unpredictability of the emergent behaviour of social systems, in other words, to ensure that the systems behave as nearly as possible as intended by system creators. However the effort to control the system by controlling constituent agents is often self-defeating.

The whole idea that it is possible to control a social system by excessively restricting autonomy of constituent agents should be carefully re-examined. The notion is fully valid only if the system is closed, or if its environment is stable and without disruptive events. Such situations do not exist naturally in the real world but are occasionally artificially imposed (Berlin Wall). When these conditions are not satisfied, i.e. when the system is open and its environment is complex (ever changing in unpredictable manner) attempts to control a social system by imposing excessive restrictions on agent autonomy are counterproductive. They prevent agents to react positively to disruptive events and thus stifle self-organisation, which in time leads to system disintegration (centrally planned economies).

Even more importantly, when perception of the desirable autonomy of agents by those attempting to control a social system and by constituent agents themselves, differ significantly, each agent tends to formulate a private (nondeclared) set of goals, which may not be compatible with the publicly declared social goals. Activities aimed at achieving nondeclared goals are often conducted in a covertly manner resulting in 'deviant' behaviour (infidelity, lying, theft, fraud and murder) and/or in organizing resistance aimed at changing official goals (rebellions and revolutions).

In large socio-political systems, such as nations, a greater autonomy is often given to a small number of elected agents, each representing a group of individual agents, rather than to individual agents themselves (democracy). This arrangement is a compromise, which may be satisfactory in a transient period from a dictatorship to fully participative democracy, where decision-making is prerogative of all society stakeholders.

5.8 Dissident behaviour

In social systems with strict centralised control there is a tendency of groups of agents to form an unofficial (dissident) system, which exhibits all features of complexity, including emergence and self-organisation. Complexity of a dissident group of agents ensures its long-term viability as a parallel social system, as experienced by disciplinarian businesses and totalitarian political regimes.

6 SELF-ORGANISING GEOPOLITICAL SYSTEM

The geopolitical system is the most complex social system encompassing all seven or so billions of people who live on our planet. At present, until we find our footing in this new field of research, it is wise to assume that the smallest component of the geopolitical system (its constituent Agent) is a nation or a large international movement. Then we could build models of geopolitical constellations using complex adaptive software and exercise them to gain understanding how adaptive and resilient they are.

A quick analysis shows that although we never had a global dictatorship, we had the geopolitical constellation of very low complexity in the 20th century after the World War 2, which exhibited equilibrium behaviour due to the existence of two powerful political blocks facing each other armed with nuclear weapons. We experienced a geopolitical system consisting of two antagonistic agents, both powerful because both possessed weapons capable of destroying life on the whole planet, and yet powerless, because they could not use these weapons without causing self-destruction.

With the exception of this period in the 20th century, the Cold War, throughout the recent history the geopolitical system behaved as a genuine complex system. Whenever a nation attacked another nation, the attacked side managed to self-organise and to successfully defend itself. According to my analysis, in recent history, no nation that started a war managed to win it. Consider the Napoleon's disastrous attempt to conquer Russia. As superior Napoleon's army approached Moscow, highly centralised state of Russia abandoned the defence of its capital and withdrew its army allowing Napoleon to enter into the city. But Moscow was empty, its *citizens decided* to abandon it and when Napoleon entered Moscow they set fires to their own homes and expelled the enemy without suffering any human losses. A perfect example of self-organisation in self-defence. Napoleon was then chased by partisans and regular army right back to Paris. Hitler's defeat at Stalingrad followed a similar pattern.

Current geopolitical conflicts are even more complex. Mobile phones and the Internet empower the side, which is attacked to rapidly self-organise into a formidable defence network. No recent military intervention by one geopolitical agent against another achieved its goals because of resilience created by social complexity.

Technology-driven complexity of the 21st century world calls for new geopolitical behaviour - conflict resolution rather than aggressive intervention.

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CONCLUSIONS

Under conditions of complexity, which currently prevail in our technological, business, social, economic and geopolitical environments, the power of self-organisation is evident. Since the trend is for complexity to increase, we shall have to learn to adjust our way of working and living to accommodate complexity rather than ignore it. And the best way is to re-design our organisations and institutions to make them self-organising.

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