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# What complexity science can teach us about illness and organisation

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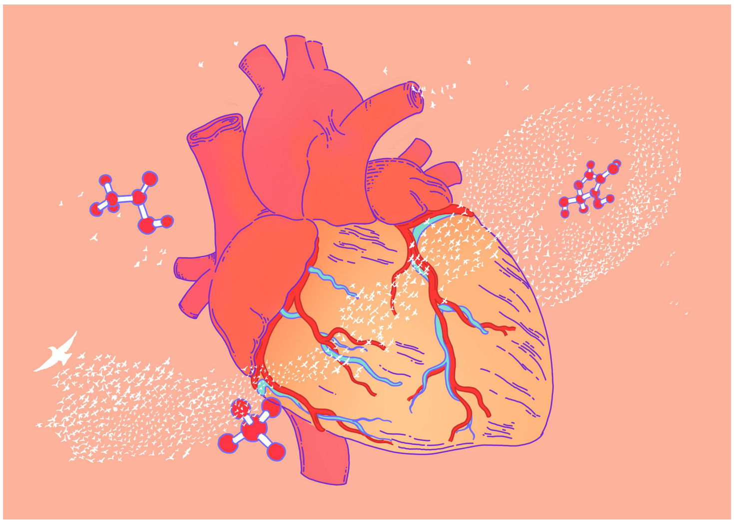
The movement patterns of migratory birds, Chinese philosophy of war and classical music shed new light on our understanding of biological and organisational systems. Complexity science explains complex adaptive systems and is useful both as a fundamental philosophy and a practical clinical aid.



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Medical science encompasses complex systems that range all the way from molecular biology to hospital organisation. Such systems cannot be understood only in terms of reductionist explanatory models based on mechanistic and deterministic causalities. Complexity science represent a new mindset that responds to these challenges (1).

Exact diagnostics, correct treatment and precise prognoses are crucial for high-quality patient treatment. An understanding of organisational structures and financial insight are cornerstones of good health management. Good health services require detailed knowledge about these systems. For example, haemodynamic models help us understand how we can increase cardiac output in critically ill patients; knowledge of the immune system can help us predict how the infection will develop in a patient with severe sepsis; biochemical and pharmacological knowledge is required to develop effective drugs; psychological insight promotes collaboration in the department and efficient organisation; academic methodology is the basis for research and quality enhancement; and management theory tells us how to organise a department or the scene of an accident. One question, however, remains unanswered: how well do we *really* understand these systems? Complexity science describes associations where traditional methods fall short.

## What is complexity science?

Complexity science is a collective term for theories that describe complex systems. The core idea is that systems should be understood holistically. A system cannot be explained by studying its components in isolation, as traditional reductionist methods often do. Complexity science is concerned with characteristics of the interplay and interactions within the system, more than with the characteristics of the component parts (1). Complexity science has its roots in general systems theory and includes chaos theory, for example (1).

The main component of complexity science is called a complex adaptive system. A classic image of a complex adaptive system and a good basis for understanding the theory is the following: imagine an enormous flock of birds – thousands of individuals – flying across the sky. It sweeps back and forth like a huge curtain and splits into smaller units to evade obstacles before it reunites. The flock of birds constitutes a *system*, because it consists of interacting individuals. It is *complex*, because of its high number of individuals and because it moves in unpredictable patterns. It is *adaptive*, because it is robust and adapts to environmental influence.

Does this mean that complexity science is primarily interesting to ornithologists? Fortunately not. Complexity science is relevant for most scientific disciplines. It constitutes a comprehensive framework of concepts, theoretical descriptions, mathematical models and practical tools for use in clinical practice, research and management (1). It has given rise to a new understanding of systems as (apparently) different as neuronal networks, cardiac physiology, sepsis, intensive care, healthcare service organisation, global economics, management philosophy and organisational psychology – to name but a few (1).

## System properties

Complex adaptive systems have characteristic properties. First, they are often self-organising. Self-organisation is a process by which order and functioning spontaneously arise in a system without any superior authority, such as when a flock of birds function with no particular leader. We can see similar mechanisms in ant colonies, social media or in organisations where cooperation and networks are formed across formal structures (1).

In his book *Origins of order*, the complexity theoretician Stuart Kauffman extends this line of reasoning even further (2). Perhaps life itself is a result of self-organisation? Atoms and molecules interact on the basis of their electric charge and size. They form compounds with complex structures and functions. For example, phospholipids organise into cell membranes and enable chemical reactions with increasing complexity: metabolism, DNA replication, cell division and development of organs. In a large organism, coagulation cascades, immune responses and neuronal networks occur in a similar manner. Neuronal networks in the central nervous system form a physical substrate for consciousness and behaviour that promotes social interaction, new DNA replication and care for offspring. Kauffman summarises this as follows:

'The origin of life, rather than having been vastly improbable, is instead an expected collective property of complex systems of catalytic polymers and the molecules on which they act. Life, in a deep sense, crystallized as a collective self-reproducing metabolism in a space of possible organic reactions. If this is true, then the routes to life are many and its origin is profound yet simple.' (1, p. 285).

Second, such systems have emergent properties that cannot be explained only by analysing their constituent components. The movement pattern of the flock of birds arises from interaction between the birds and cannot be explained by studying the individuals in isolation. Similarly, the structure and electrochemical functioning of the brain have been amply described. This notwithstanding, we know little about the way in which our subjective perception of consciousness occurs. Innovative organisations create surprising solutions that we cannot predict based on the composition of the group. The astounding effect of colour in a great painting is the result of a few base colours in the right combination. A superb piece of music grows out of harmonies between a small number of basic tones. Although an analysis of the artist's composition and technique may be intriguing, we are rarely able to address what lies at the very core: why do we perceive this as so astounding? This is an important reminder of how the whole of a system is more than the sum of its parts.

Third, the system works best at the edge of chaos. A totally ordered system is stable and predictable, but rigid and with no capacity for flexible adaptation. A system in chaos is unstable and unpredictable. In the middle we find systems that have struck the right balance. In such a flock of birds, the interaction is sufficiently strong to keep the birds together, but loose enough to maintain flexibility. An effective immune system needs to balance on the edge between order and chaos in the same way. It must be sufficiently flexible to react to a large number of unknown antigens, but without being activated by the body's own structures. An ineffective and rigid system (such as in case of immunosuppression) is just as inappropriate as an unstable and chaotic system (such as in case of autoimmune disease). An approach to such dysregulation drawn from complexity science can yield a new understanding of the body's response to sepsis and autoimmune diseases (1).

The notion that effective organisations balance between order and chaos is nothing recent. President John F. Kennedy became known for actively cultivating contradictory opinions for the good of the group. He understood that effective organisations grow from constructive disagreement, and made provisions for this in his staff (3). More than two thousand years ago, the Chinese general and philosopher Sun Tzu (544–496 BCE) described how small, self-governing groups of warriors may outmanoeuvre a far stronger enemy. He understood that the desire for control was counterproductive and therefore provided his soldiers with a lot of latitude. He emphasised the importance of flexible planning and that leaders need to accept uncertainty (4). These remain fundamental principles in operational management and may form the basis for how we design contingency plans or organise a chaotic accident scene (5). These two were probably unaware of complexity science, but they demonstrated an intimate knowledge of how people interact in complex adaptive systems. Complexity science therefore postulates that robust, flexible and effective systems function best at the edge of chaos.

Fourth, the system often has fractal patterns. Fractals are patterns that are (approximately) identical at the microscopic and macroscopic level in the same system. Fractals are thermodynamically stable structures and exist everywhere in nature. Snowflakes, river deltas, waves, the bronchial tree, coronary arteries and purkinje fibres are *geometric* fractals. Time intervals and variability in heart frequency and EEG signals are *statistical* fractals (1).

## The human body as a complex adaptive system

So what benefits can be had from describing human physiology – the interplay between neural connections, immunodefence, organ systems and hormones – as a complex adaptive system?

In healthy individuals, the heart rate, respiratory rate, EEG signals, blood-sugar levels and the correlation between them vary in complex fractal patterns. In the sick, this complexity declines. In other words, complex patterns are an expression of a healthy organism, while declining complexity is an early indication of illness (1).

Such pathophysiological changes have been detected in a number of conditions (1): low heart rate variability predicts mortality and occurs before changes in ECG and release of troponin in myocardial infarction. Lack of correlation between vital parameters predicts exacerbation in cases of trauma, sepsis and burn injuries. It has been shown that in patients with diabetes, the variability in blood-sugar level loses complexity in the period before the disease manifests itself. Similar loss of complexity occurs in the EEG patterns in patients with mental disorders. In older people, we can see a decrease in the fractal patterns in neuronal activity and hormonal release, while loss of skeletal trabecular meshwork and pulmonary alveoli represent a loss of geometric fractal patterns (1).

This may have implications for the way in which we treat illnesses. By understanding the patient as a complex adaptive system, we postulate that the patient's physiological patterns show exactly such low variability and loss of fractal patterns. Good treatment attempts to re-establish the normal physiology. We scrutinise variations in blood pressure, respiratory rate, hourly diuresis and temperature fluctuations. We administer drugs, fluids and nutrients in finely tuned dosages and control the settings on the respirator in minute detail. Is it conceivable that exaggerated regularity counteracts (high) physiological variability and thus prolongs the course of illness? Some studies indicate that this may be the case (1). Concepts such as variability and fractal patterns may seem abstract, but with the appropriate technology it is a simple matter to measure variability in the heart rate, respiratory rate and EEG signals and show them as numerical values on the monitor above the patient's bed – for use in daily clinical work.

## The health services as a complex adaptive system

Hospitals and other large organisations in the health services can also be understood as complex adaptive systems (1). A hospital consists of a large number of employees, patients and their next of kin, who interact in networks of formal and informal structures, acquaintances, meetings, consultations, phone calls and patient record notes. Complexity science systematises knowledge from management and organisational theory, quality improvement work and conflict management. In combination, such knowledge may provide a better understanding of how we can build good and effective organisations (1).

Traditional organisational theory emphasises formal structures, rationalisation and standardisation (1). It is based on the assumption that detailed planning, top-down control and analyses can predict future outcomes. The organisation is regarded as a machine, in which initial values invariably produce the same result. Disagreement is seen as a disturbance that should be toned down. Errors are best prevented through directives, standardised procedures or adjustments in individual factors. Such a view of errors and deviations may be fertile ground for a culture in which the fear of failure overrides the joy of accomplishment. Thus, the risk of new errors increases.

Complexity science underpins modern management and organisational theory. It strives for flexibility, freedom of action and decentralised leadership (1). Formal structures are assigned less importance. The organisation is a dynamic unit undergoing continuous change. Planning frameworks are flexible and seek to strike a balance between micromanagement and delegation. Interaction arises across departments and in random forums. Disagreement is healthy and – if managed appropriately – a source of new knowledge.

It is obviously naive to establish a sharp distinction between two approaches that have been described here in a rather pointed fashion. Freedom of action and flexibility should never exclude clear leadership and targeted organisation when this is required. Determination of general priorities, economic frameworks, basic values and long-term strategy need to be centralised – not least for reasons of democracy. Complexity science cannot provide all the answers, but can provide valuable input to the question of how we can organise our health services in an even better way.

## The road ahead

Good patient treatment and good healthcare management – good health services – require sound knowledge of complex adaptive systems over the entire range from molecular-biological reactions to hospital organisation. Complexity science describes such systems in light of new explanatory models where traditional reductionist methods fall short. Internationally, complexity science is referred to as a key new scientific concept (1). There are some who claim that complexity science does no more than rename phenomena that wise people have described for centuries (6). Unfortunately, such arguments have given rise to distorted notions of what this science really represents. Modern complexity science emphasises practical usefulness, mathematical models and clinical relevance. In the right combination, complexity science constitutes a fundamental philosophy, a theoretical framework and a practical tool for use in management, research and daily clinical work.

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