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What Do We Mean by Change?

We exist in four dimensions: the three dimensions of space and the dimension of time. Time only moves in one direction — forward — and it is because of time that we are aware of change. A change occurs only when something is different between two time states; when something moves in space or one of its attributes is altered. This is so much a part of life that we do not even question this definition of change. But there are some things that only form a pattern by changing along the time dimension — music, for instance. A series of changes or patterns in time, be they music or the movement of share prices, are only apparent after the event. It is important to note that change has a binary form, i.e., it happens, or it does not happen. It may be viewed as having the characteristics of a hole: you can have a small hole or a large hole but not a piece of a hole. Likewise, you can have a small change or a large change but not a piece of a change.

A few physicists have challenged the classical view of time flowing through a single universe. Tegmark writes,

> "Most people think of time as a way to describe change. At one moment, matter has a certain arrangement; a moment later, it has another. The concept of multiverses suggests an alternative view. If parallel universes contain all possible arrangements of matter, then time is simply a way to put those universes into a sequence. The universes are static; change is an illusion …."[1]

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By this he means what appears to be a change in this universe is actually movement to another, differently configured universe. We move from universe to universe and consider this movement as time. This is an intriguing thought and I will use a similar concept later, that of the design space. However, this multiverse concept provides no insight into the nature of change in this universe other than the conjecture that the probability of moving to a particular alternate universe must vary, some being more probable than others. It is reflected within this single universe by the probability of some arrangement of matter changing to another out of many different, possible arrangements. Whichever way it happens, we perceive this movement as change in our universe.

We, *Homo sapiens*, are a social species and when the first *Homo sapiens* picked up a stone and used it as a tool, complex socio-technical systems came into being. The existence and use of tools has shaped society and society, in turn, has developed tools to fit its evolving needs. These needs have continued to grow so that large, complex socio-technical systems are now found everywhere. Disappointingly, the record of deliberately designing such systems is marked by continual failure and we shall see that this failure occurs because the human designers fail to understand the nature of change.

An example of the unexpected results of change is found in the clearing of trees to make available more agricultural land.[2] This practice has led to rising water tables and increasing salinity that eventually reduces the amount of useable land. Another is the construction of the campanile or freestanding bell tower in Pisa. When the tower was built it was undoubtedly intended to stand vertical. It took about 200 years to complete, but by the time the third floor was added, the poor foundations and loose subsoil had allowed it to sink on one side. Subsequent builders tried to correct this lean and the foundations have been stabilised by 20th-century engineering, but at the present time the top of the tower is still about 15 feet (4.5 metres) from the perpendicular.[3] Along with the unexpected failure of the foundations is the unexpected consequence of the Leaning Tower of Pisa becoming a popular tourist attraction, bringing enormous revenue to the town.

A far more tragic example is the attempt to combat hunger in the Okavango Delta in southern Africa, where periodically the tsetse fly

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devastated the cattle herds of the native people, often resulting in subsistence-level survival. Western consultants acted to suppress the tsetse fly and replace the local cattle with European-style beef cattle. The increased cattle populations soon overgrazed the pasture, leaving the land an uninhabitable desert.[4]

The creation of unwanted and unexpected effects is a theme addressed throughout this book. It is my view that a major cause of these failures is a general lack of understanding that the people, organisations, hardware, software and any other technology are all part of the same complex system. Not accounting for the interaction among these very different parts of the system after a change is the underlying reason for unpredictable system behaviour. The economist Herbert Simon said many years ago,

> "It is typical of many kinds of design problems that the inner system consists of components whose fundamental laws of behavior — mechanical, electrical, or chemical — are well known. The difficulty of the design problem often resides in predicting how an assemblage of such components will behave."[5]

To understand what I mean, let us consider a traffic jam. A traffic jam is an event that we recognize and it results from the interacting behaviour of many vehicles — cars, bicycles, motorcycles, etc. — but the jam is not evident in the behaviour of any one vehicle; it emerges from the socio-technical interaction of the drivers and their machines. Hence, the effect where the behaviour of the whole system differs from the behaviour of the individual components is known as emergent behaviour. This emergent behaviour is an important characteristic of change and I will talk about it in more depth later. It isn't only technology that fails; Bhopal,[6,7] Chernobyl[8,9] and Three Mile Island[10,11] were all catastrophic failures of socio-technical systems, where human behaviour was an inherent part of the failure. What is more, socio-technical systems are complex systems, and the constant interaction between the system's components creates dynamic effects that are very far from the desired equilibrium. We are all aware of this effect in large information systems. Such systems are subject to this constant interaction: as the users become competent in using the

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information system, they often see new ways of doing things and dream up new things to do with the information. Additionally, the information system attracts new users with different ideas of functionality. These new concepts change the organisation's (social) processes, structure and its perception of what is required from the information system. So, the technical system's environment changes. To derive the expected benefits, the technical component has to change, thus changing the users' environment. When the social and technical components change in step with each other, we call this process "co-evolution", hence the system's (socio-technical) design co-evolves with the problem space,[12,13] each continually changing in response to the other as the various users' requirements change and the technology changes.

So what controls change? I shall divide the question into two parts, namely what causes an individual component to change and how the propagation of the effects of change through the system affects the system behaviour. The answers to these questions go some way towards answering the key question: How will the system change over time? The concept underlying this book is that the widespread failure to understand or create successful systems (including socio-technical systems) is due to the unrecognised or, more likely, unaccepted fact that all systems are co-evolutionary in nature. I will give a more detailed definition of co-evolution later but I am sure you get the idea. In complex systems change is inevitable and small local changes propagating through the system can cause global changes in system behaviour. Recognition of and accommodation for change is essential to complex, co-evolutionary system design. Designers and implementers of systems demand some form of qualitative prediction of the result of the proposed design in order to create designs that meet the expectations of the system users. This is easier said than done.

Social and technology-based systems are built by lawmakers, engineers, shamans, economists, etc., i.e., almost everyone. System building is goal-directed; there are goals to achieve and requirements to be met. Thus building a system is concerned with plans for the future. These plans are based on predicting the system behaviour at specified times in the future. Indeed, complex systems are built, particularly, to meet an expressed need. But in a large, truly complex system, it is possible for this planned predictability to break down into a morass of unanticipated behaviour so that

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the need is not met. This unpredictability comes from the propagation of the effects of change through co-evolving components. The effect of a change in one component is often deterministic and generally predictable, but when one component has an influence on one or more of the other components, the effects become complex. In fact the situation is worse than this; the effect of the propagating changes originating from two or more initial changes interfere with one another and alter the outcome. The components' new states apply conflicting pressures for change on each other and can induce them to enter a cyclic or chaotic set of states. These changes to individual components or small groups of components are local in nature but their aggregate effect is evident in the behaviour of the entire system. The holistic system behaviour is unpredictable because it is dependent on a multitude of local changes.

Complex systems are dynamic, i.e., they change over time. Any one component exists in an environment of all the other components in the system. In general, these systems change because each component is influenced by the other components in its environment, as shown in Figure 1.

A simple example is a crossroad where the traffic flow is controlled by traffic lights. If we consider the traffic lights and the vehicles using the junction the system components, then at any given time if the lights change, the behaviour of the vehicles changes and so the system behaviour changes. In this case and generally speaking, there is a perception lag (Lp) between the environment changing and the various components perceiving this change

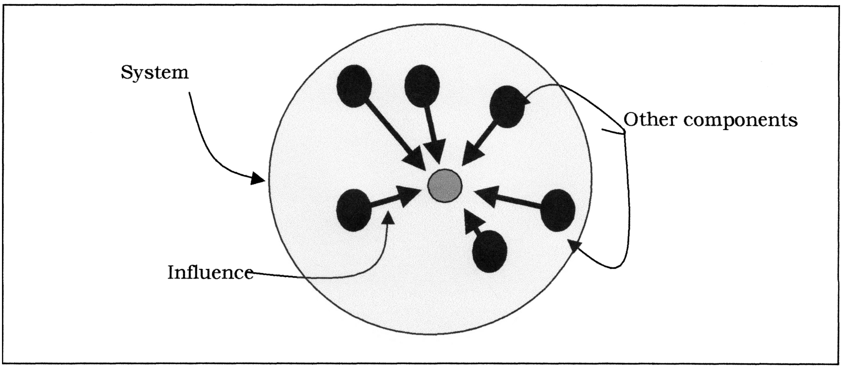

Figure 1. A component in its environment.

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in the environment, and a reaction lag (Lr) between the perception of an environmental change and the reaction to that change. In addition, these lags may vary across the components, with one reacting faster than another; $Lp1 \neq Lp2$ and $Lr1 \neq Lr2$. So we will often have a system of many components, each with a different perception lag and reaction lag. If this is so, then shortly after we make a change to one component, some of the other components will have perceived the change and a fraction of these may even have reacted to it. As soon as these components react, they change the environment for the rest of the system. Meanwhile, some of the slower components are now reacting to the earlier change, which also affects the environment. Because of the lags, the components react independently and one small change results in a system that is out of equilibrium. The system and its behaviour are changing over time and interaction is taking place between the components; in short, a typical complex system. I am sure you can relate this to the traffic/traffic lights analogy. Once the process has started, when, if ever, the system will return to equilibrium cannot be predicted by analytical means. However, as we will see later, computer-based simulation shows promise. The rate of change can vary widely but in general, where there are changes incurring small individual costs, you will get rapid rates of change. Changes with large costs tend to happen less frequently. Systems research has shown that for systems as unlike as avalanches in laboratory sand piles,[14] magnitude of earthquakes[15] and the number of deaths due to wars,[16] graphs of the size of the event against the frequency of the event all show a power law. It seems likely that all streams of events in complex systems conform to a power law, even death.

I define the process of change as: influence + decision + transition, but sometimes the decision is not to change and in this case there is no transition.

The Study of Change

Recognition of the importance of change as a phenomenon is not new. Probably the first published research into change was Gabriel Tarde's 1903 book, *The Laws of Imitation*. Tarde, a French judge, wrote about change in social systems from the perspective of a feedback loop between the criminal justice system and criminal behaviour.[17,18] In this approach, he was foreshadowing the better-known systems thinking of Ross Ashby, Stafford Beer and Jay Forrester some 50 years later. Ashby, in his book *Introduction to Cybernetics*, proposed the use of cybernetics, an offshoot of control theory, for the study of changing biological and social systems. He thought that cybernetics was a "theory of machines" but actually, it treats not things but ways of behaving. In keeping with this idea, which works primarily with the general case, cybernetics typically treats any given particular machine by asking not "what individual act will it produce here and now?" but "what are all the possible behaviours that it can produce?"[19]

In effect, Ashby is asking, "What happens when a change is made? How does it feed back into the system?" In the same year, Beer tackled the problem of understanding the organisation of social and socio-technical systems. He based his investigation on insights from neurophysiology, cybernetics and control theory. Initially Beer did not claim to have invented a new model; his aim was to discover and document the persistent pattern of organisations. Nevertheless, in 1981 he developed what he called the Viable System Model (VSM). His long-term goal was to develop a discipline of "management cybernetics" with the VSM as its methodology, and he continued to publish on this theme into the 1990s.[20–27] Forrester[28] introduced the concept of system dynamics, again using ideas drawn from control theory (mainly feedback) to organise information into computer simulation models. His first article based on this work appeared in the *Harvard Business Review* in 1958.[29] Forrester claimed that a digital computer acting as a simulator played out the roles of people in the real system and revealed the behavioural implications of the system that had been described in the model. Given the complexity of human behaviour the early simulations were highly abstract. However, Ashby, Beer and Forrester all accepted that change in one component in a system causes change in other components and, in time, the effects feed back to the initial component. Later, the ubiquity of change in computer-based systems was recognised by Frederick Brooks and in 1975, he wrote about it in his classic book, *The Mythical Man-Month*.[30,31] In the book he says,

> "The only constancy is change itself. Once one recognizes that a pilot system must be built and discarded, and that a redesign with changed

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> ideas is inevitable, it becomes useful to face the whole phenomenon of change. The first step is to accept the fact of change as a way of life, rather than an untoward and annoying exception."

Brooks perceptively pointed out that the programmer delivers satisfaction of a user's need rather than any tangible product, and both the actual need and the user's perception of that need will change as programs are built, tested and used. Brooks and others emphasise that when the need is poorly articulated and is continually refined as partial solutions are revealed, then change is inevitable. My colleague David Cropley aptly captures this as "the solution defines the need."[32] However, even now, more than a quarter of a century after Brooks published *The Mythical Man-Month*, many socio-technical systems are still not designed with the concept that they might be easily changed, even though the complexity of interaction within and between socio-technical systems may well have increased since 1975. Brooks' point, that the constancy of change in computer-based systems should be accepted as a fact, is clearly still not recognised or found acceptable by a large proportion of system sponsors and builders.