Theories of Non-linear Systems: A Paradigm for Organizational Thinking

Roché Francois Myburgh

Thesis presented in partial fulfilment of the requirements for the degree of Master of Arts at the University of Stellenbosch.

Professor Johann Kinghorn
December 2003

Stellenbosch University http://scholar.sun.ac.za

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously in its entirety or in part submitted it any university for a degree.

Signature:
Date:

Stellenbosch University http://scholar.sun.ac.za

An Assessment of the Application of Complex Systems Theory as a tool for Organization Strategy Development in the context of the Global Informational Economy

The advent of the computer age has seen many fundamental changes in the economics. The ease with which organisations can store and transmit information in unprecedented quantities and speeds has changed the face of the economy as well as the way in which organisations conduct their day to day operations. Information has become the primary resource for organisational competitiveness and this has seen an increasing drive for efficient information generation and management in an economy that is interconnected on a global scale. The demand for better information management practices is driven by the realisation that the global economy is susceptible to sudden and unpredictable changes that can potentially have global consequences. The more information organisations have at their disposal, the better their chances are of remaining competitive and relevant in the global economy. The informational economy confronts organisations with two very significant problems, the first is information overload due to the sheer volume of information that is available to them. The second problem is that despite the volume of available information organisations still are not privy to all the information that is required to lessen the impact of uncertainty that is so characteristic of the global economy. Organisations therefore always run the risk of becoming irrelevant if they do not change constantly. This drive for continuous change and the dependence on information has led some organisational theorists and economists to compare the global economy and organisations to nonlinear systems found in nature. Examples of nonlinear systems are living organisms, ecologies and solar systems. All of these systems are characterised by high levels of interconnectedness and interdependence among individual units within a shared environment, which they co-create. Nonlinear systems are of particular interest to organisational theorists because these systems process information about the environment to adapt in an unpredictable way to unpredictable changes. Such systems are incredibly resilient because they are able to learn and adapt to different conditions. Another notable aspect of nonlinear systems is the clear structured and complex organisation that they exhibit in the absence of centralised control mechanisms. Every unit has the liberty to experiment with new designs and from the success of individual units an organised and stable system emerges with a strong link between the success of individuals and the whole system. The order that exists within nonlinear systems is known as self-organisation because it is not superimposed but emerges instead in a spontaneous manner. Nonlinear systems are therefore more than just the sum of their parts. The notion of nonlinear systems and self-organisation has seen authors such as Stacey, Wheatley and Senge develop new ideas about organisational development, leadership and organisational strategic thinking. Their ideas are based on what is popularly known as 'The New Science'. These ideas attempt to encourage organisations realise that the global economy functions as a nonlinear system and that organisations stand a better chance of success if they learn to understand the principles of nonlinear systems and to utilise the inherent creative and organising characteristics of such systems.

Die aanvang van die rekenaar era het verskeie fundamentele veranderinge in ekonomie mee gebring. Die gemak en snelheid waarmee organisasies informasie kan stoor en versprei is ongekend en het terselfde tyd die voorkoms van die ekonomie verander asook die wyse waarop organisasies op 'n daaglikse basis funksioneer. Informasie het die belangrikste hulpbron geword vir organisasies in terme van kompetering en dit het 'n groter dryfkrag vir doeltreffende informasie ontginning en bestuur mee gebring in 'n ekonomie wat op 'n wêreldwye skaal in mekaar gevleg is. Die aanvraag vir beter informasie bestuur praktyke word gedryf

Stellenbosch University http://scholar.sun.ac.za

deur die wete dat die wêreld ekonomie vatbaar is vir skielike en onvoorspelbare veranderinge wat potensieel 'n wêreldwye impak kan hê. Hoe meer informasie organisasies tot hul beskikking het hoe beter is hul kans om relevant en kompeterend te bly in die wêreld ekonomie. Die informasie ekonomie konfronteer organisasies met twee fundamentele probleme. Die eerste gevaar is dat organisasies oorlaai kan word met informasie as gevolg van die absolute volume van beskikbare informasie. Die tweede probleem spruit voort uit die feit dat ten spyte van die beskikbare informasie, lei organisasies steeds aan 'n gebrek aan algehele informasie, organisasies kan dus nooit toegang hê tot al die informasie wat benodig word om die impak te verminder van die onsekerheid wat so kenmerkend is van die wêreld ekonomie. Organisasies loop dus altyd die gevaar om irrelevant te raak as hulle nie konstant aanpas by nuwe omstandighede nie. Hierdie soeke na konstante verandering en die afhanklikheid op informasie het verskeie organisasie teoretici en ekonome daartoe gelei om 'n vergelyking te tref tussen die wêreld ekonomie en organisasies aan die een kant en nie-linïere sisteme wat in die natuur voorkom. Voorbeelde van sulke sisteme sluit lewende organismes, ekostelsels en sterre stelsels in. Die komponente van al hierdie sisteme is op 'n komplekse wyse inmekaar geweef en interafhanklik op mekaar binne die raamwerk van gemeenskaplike omgewing waarvoor hierdie komponente mede verantwoordelik is. Nie-linïere sisteme is van besondere belang vir organisasie teoretici omdat die betrokke sisteme informasie verwerk aangaande hul omgewing om op 'n onvoorspelbare wyse aan te pas by onvoorspelbare veranderinge in die omgewing. Sulke sisteme is uitsonderlik standvastig deurdat hulle kan leer en aanpas by verskillende omstandighede. Nog 'n merkbare aspek van sulke sisteme is die duidelik gestruktureerde en komplekse organisasie wat bestaan ten spyte van 'n algehele gebrek aan gesentraliseerde beheer meganismes. Elke komponent is vry om met 'n nuwe ontwerp te eksperimenteer en vanuit die sukses van die komponente spruit die sukses van die sisteem. Die organisasie wat sigbaar is in nie-linïere sisteme staan bekend as self-organisasie omdat dit nie voortspruit uit 'n sentrale beheer meganisme nie maar instede spontaan onstaan as 'n gevolg van die aksies van komponente. Nie-linïere sisteme het die potensiaal om meer te kan wees as die somtotaal van hul komponente. Die beginsel van nie-linïere sisteme en self-organisasie het skrywers soos Stacey, Wheatley en Senge daartoe gelei om nuwe idees te ontwikkel rakende organisasie ontwikkeling, leierskap en strategiese beplanning in organisasies. Hierdie idees is gegrond in wat algemeen bekend staan as 'The New Science'. Die idees van hierdie skrywers is gemik daarop om organisasies aan te moedig om raak te sien dat die wêreld ekonomie soos 'n nie-linïere sisteem funksioneer en dat organisasies asulks 'n beter kans staan om sukses te behaal as hulle sou leer om die beginsels van nie-linïere sisteme te begryp en die inherente kreatiewe en organiserings eienskappe van sulke sisteme uit te buit.

Stellenbosch University http://scholar.sun.ac.za

Contents

Stellenbosch University http://scholar.sun.ac.za

Introduction

The Information Era

1. The Informational Economy

No one could fully have anticipated the degree to which information technology would drive change in the global economy. At the moment, no one has been able to produce an adequate solution for dealing with the information overload that faces the 21st century. This issue is of the utmost importance for organisations given the significant role that information processing has come to play in the day to day activities of organisations world-wide. Technological development over the last 20 years has undoubtedly ushered in a new era in all aspects of human society. Technology also continues to shape this era as immense improvements in miniaturisation, processing power, memory capacity, transmission speeds and system reliability, along with falling relative costs and mass market diffusion have seen computing and telecommunications incorporated into every facet of people's daily existence. Within a matter of a decade or so, personal computers have become universal and essential properties of day-to-day activities (Cronin & Davenport, 1988, 6). It is nothing short of a technological revolution, centred on information technologies, that has reshaped, the material basis of society at a pace that is both astonishing and unprecedented. Throughout the world, a global integration and interdependence introduced a new form of relationship between economy, state, and society. The result is a system where economies are characterised by a continuously changing geometry. Capitalism itself has undergone a process of profound restructuring, characterised by greater flexibility in management styles, decentralisation and networking of firms with regards to their internal structures, as well as their relationships to other firms (Castells, 1998, 1).

The information technology revolution has given rise to exponential growth in interactive computer networks in the corporate world. In so doing, new forms and channels of communication were created, which are shaping life, and being shaped by it at the same time (Castells, 1998, 2). The information technology revolution has been instrumental in allowing the implementation of a fundamental process of restructuring of the capitalist system from the 1980's onward (Castells, 1998, 13). Technology is changing very rapidly, but nothing changes in isolation in the informational economy. As such, changes in technology occur in conjunction with markets and structures (Harris, 1995, 224). The onset of the Information Era has connected the world markets to such an extent that geography and time have become diminished constraints in the corporate world. Castells characterises the techno-economic system as informational capitalism. Technological innovation and

Stellenbosch University http://scholar.sun.ac.za

organisational change – based on flexibility and adaptability – were essential in ensuring the speed and efficiency of this restructuring (Castells, 1998, 18 – 19).

In the changed world economy, the sources of higher productivity are increasingly dependent on knowledge and information applied to production and this knowledge and information is increasingly science based. Production in the advanced capitalist societies shifts from material goods to information-processing activities, fundamentally changing the structure of these societies to favour economic activities that focus on symbol manipulation in the organisation of production and in the enhancement of productivity (Carnoy & al, 1993, 5).

Castells (1998, 21) offers an important and relevant distinction between the terms, information and informational. Information as used in the term Information Society emphasises the role of information in society. In contrast, the term informational indicates the attribute of a specific form of social organisation in which information generation, processing, and transformation become fundamental sources of productivity and power, because of new technological conditions emerging in this historical period. The use of the terms, Informational Society and the Informational Economy attempts a more precise characterisation of current transformations, beyond common-sense observation that information and knowledge are important to our societies.

Castells also identifies five characteristics of the new paradigm. He identifies information as its raw material, and that the technologies are shaped to act on information. The second feature refers to the predominance of effects of new technologies. All processes of individual and collective existence are directly shaped by the new technological medium. The third characteristic refers to the networking logic of any system or set of relationships using these new information technologies. The fourth feature is the fact that the information technology paradigm is based on flexibility. Like processes, organisations and institutions can be modified or even fundamentally altered by rearranging their components. Castells identifies their ability to reconfigure as a distinctively decisive feature in a society characterised by constant change and organisational fluidity. The fifth characteristic of this technological paradigm is the growing convergence of specific technologies into a highly integrated system, within which old, separate technological trajectories become literally indistinguishable. Castells points out that microelectronics, telecommunications, optoelectronics, and computers are integrated into information systems (1998, 60 – 63). The ongoing convergence between different technological fields in the information paradigm results from their shared logic of information generation. A logic that is most apparent in the working of DNA and in natural evolution and that is increasingly replicated in the most advanced information systems, as chips, computers, and software reach new frontiers of speed, storage capacity, and flexible treatment of information from multiple sources. From

Stellenbosch University http://scholar.sun.ac.za

the observation of such extraordinary changes in machines and knowledge of life, and with the help provided by machines and this knowledge, a deeper technological transformation is taking place. This constitutes categories under which all processes are thought. Castells quotes Bruce Mazlish's rendition of the increasingly inseparable co-evolutionary path of mankind and the machines, which he has brought forth. The culmination of this path is the development of the computer and it emphasises the development of an inseparable co-influential relationship between humanity and information technologies (1998, 64). Perhaps the easiest way to summarise what is meant by the Information society is to say that on the one hand, labour is being intellectualised, and on the other automated. In the Information Era, technology causes occupational displacement, but at the same time, it facilitates new job creation. An increasing proportion of the workforce will be involved in activities, which entail the processing and handling of information in one way, or another (Cronin & Davenport, 1988, 9).

Economic and organisational transformations are taking place in the midst of one of the most significant technological revolutions in human history. Its core is information technology – informatics, microelectronics, and telecommunications. All this has been stimulated by economic and organisational transformations on a global scale; and, simultaneously, the information technology is indispensable for such transformations. The revolution in information technology has combined with organisational change at the global level to produce a "new world economy." Within the emerging global system, the structure and logic of the Informational Economy defines a new international division of labour. This division places less emphasis on the location of resources, cheap and abundant labour, or even capital stock. In the new division of labour, the emphasis is more on the capacity to create new knowledge and to apply it rapidly, via information processing and telecommunications, to a wide range of human activities in space and time that is becoming increasingly extensive (Carnoy & al, 1993, 6).

There is widespread appreciation of the value of information as a social and organisational resource. Society has become increasingly dependent on the effective acquisition and use of information, and the means by which these goals are achieved have become key components of the planning and policy-making cycle (Cronin & Davenport, 1988, 112). The organisation of production and of economic activity in general changes from standardised mass production to flexible customised production and from vertically integrated large-scale organisations to vertical disintegration and horizontal networks between economic units. The new economy is global, and there is an abundance of evidence for that. Investment, production, management, market, labour, information and technology are organised across national boundaries. What is new is not so much that international trade is an important part

Stellenbosch University http://scholar.sun.ac.za

of each nation's economy, but that national economies now work as units at the world level in real time (Carnoy & al, 1993, 6).

Societies as such, have always had to deal with information, and information control has always been a large part of organisational and social management, but never before on a scale such as is the case in the present. Populations have grown, social structures have become immeasurably more complex, international trade has become much more competitive, government regulations are multiplying at an astonishing rate in an attempt and regulate an environment where many events are unforeseen and some may never happen again. The stock of knowledge that is floating around in the world is expanding at a rate that never been experienced (Cronin & Davenport, 1988, 9). Successful functioning is ever more dependent on the individual's ability to diagnose information needs, respond to others' demands for information, and identify, access and exploit appropriate sources of information. In the global economy information is a resource, and it confers a competitive advantage on those who have achieved the necessary blend of regulation and stimulation (Cronin & Davenport, 1988, 10). Organisations are increasingly becoming information-communicating systems, which are routinely challenged with information of various sorts. Organisations have to generate, store and access information on a routine basis, and they have to distinguish between what is essential knowledge and what is potentially distracting. The way in which they manage the information resources has a direct bearing on organisational effectiveness (Cronin & Davenport, 1988, 112).

A competitive edge in the information sector has become crucial in overcoming economic difficulties, both for nations and organisations. Cronin and Gudim quote Stonier's reference to Japan and Switzerland as examples of countries, which do not have large land or mineral resources, but both are economically strong. Stonier attributes their power and wealth to their human resources. It is apparent that the economic health of developed countries throughout the world is increasingly dependent on the productivity of the information sector. Changing patterns in employment indicate a continuing movement from manual to mental, and from less to more highly trained labour (Cronin & Davenport, 1988, 113).

Technological progress, which is responsible for the increase in information, also increases the complexity of the economic system. Castells notes that the increasingly important role of applied information is a characteristic of advanced economic systems, transcending the historical characteristics of their modes of production. It would also seem that the salient role of knowledge and technology is not exclusive to the late twentieth-century economy, nor has this economy resulted simply from a change of production techniques. He proposes then that there is evidence of a secular trend because knowledge has always been important in organising and fostering economic growth. But the greater the complexity and productivity of an economy, the greater its informational component and the greater the role

Stellenbosch University http://scholar.sun.ac.za

played by new knowledge and new applications of knowledge in the growth of productivity (Carnoy & al, 1993, 16). Jonscher[1] states that increased work specialisation and improved operating efficiency are two of the consequences of technological progress. The consequences for the economy as a whole are increased output and complexity reflecting the introduction of more roundabout production methods, the spread of specialisation and the increasing division of labour. Since a larger variety of inputs are needed for each production stage, the number of transactions grows, resulting in an increase in the informational tasks of managing and co-ordinating the economy. Jonscher further suggests that there will be an increase in the information sector as a result of increased output and greater complexity. In turn, improvements in information handling efficiency will lead to further increases in output.

The growing awareness of the value of information as a social and organisational resource, combined with the progressive commercialisation of information services and the willingness of the market to pay for high-quality, value-added information products have all contributed to a perceptible shift in public attitudes. A new sophistication and competitiveness characterises the information complex (Cronin & Davenport, 1988, 114). According to Castells, the real transformation of the economic structures of advanced economies is the emergence of the "information economy". In this economy, the majority of employees will increasingly be engaged in information-processing activities (Carnoy & al, 1993, 17). The quality of the information and one's efficiency in acquiring and processing it, now constitute the strategic factor in both competitiveness and productivity for organisations and countries.

As an economy develops, and as society becomes increasingly complex, an expanding proportion of the workforce is required to operate on the production of knowledge (as opposed to physical goods) in order that the organisation of production and administration may be accomplished efficiently (Cronin & Davenport, 1988, 112). Peter Drucker calls this "the Age of Discontinuity.[2]" This term is the result of the continuous fundamental changes, which are occurring as a subset of the Information Era. The Information Era challenges the basic assumptions on which organisational practice has relied over the past decades. However, in an economy, which is no longer built on the exploitation and depletion of natural resources, old styles of organisational practices are increasingly coming under pressure. Traditional management styles have become inadequate in dealing with a new economy in which knowledge is the new source of wealth and the basis for a competitive advantage. The economy in the Information Era has resulted in the need for a fundamental redefinition of organisations. It has become clear that in order to leverage knowledge

[1] Quoted in Cronin & Gudim (1988) *Information and Productivity: A Review of Research* 114

Stellenbosch University http://scholar.sun.ac.za

assets, a fundamental transformation in the ways organisations organise has to take place[3]. The future of potential winners and the large continental economies depends largely on how they transform their economic and educational organisation and how they relate their existing but rudimentary R&D to production (Carnoy & al, 1993, 7).

2. Adapting to the Informational Economy

The technological revolution has forced fundamental transformations upon organisations. There is a shift from standardised mass production to flexible customised production, and from vertically integrated large-scale organisations to vertical disintegration and horizontal networks between economic units. The organisational pattern of decentralisation and flexibility is characteristic of large corporations, both in their internal structure an- [illegible] d relationship to a network of ancillary firms. The outstanding characteristic of the Informational Economy on organisations is the transformation of all economic activity, emphasising flexibility and adaptability in response to an ever changing and diversified market (Carnoy & al, 1993, 18). In the global information economy, organisations will have to learn how to manage situations where there is no command authority, no one will be in control, and no one will be controlled, instead, as Drucker points out, information has emerged as replacement for authority (Harris, 1995, 222 – 223).

In 1988, Peter Drucker published an article entitled *The Coming of the New Organisation*. In the article, Drucker describes the characteristics of organisations of the Informational Economy. These organisations will have fewer than half the management levels of current organisations and a third of the managers. These organisations will be knowledge based and composed largely of specialists. Performance will be directed through organised feedback from colleagues, customers and headquarters. And for that reason, these organisations will be knowledge-based. The centre of gravity in employment is fast moving from manual workers to knowledge workers who will resist the command-and-control system. Organisations will also change, because of the need for innovation and entrepreneurship demanded by the Global Economy. But the most important driving force behind the required change is information technologies. As advanced technologies become more and more prevalent in the organisations, they will engage in intensified diagnosis and analysis to avoid being swamped by the information they generate. The decision processes, management structure of the organisation, as well as the way in which the organisation operates will be transformed as a result of engaging in transforming data into information. The organisation structure changes as it focuses its data processing capacity on the production of information. The need for more management levels decreases, as does the

---

[2] Quoted in Lancourt and Savage (1995) Organizational Transformation and the Changing Role of the Human Resource Function www.kee-inc.com/article.htm

Stellenbosch University http://scholar.sun.ac.za

number of managers. There is a greater requirement of knowledge specialists in the *information*-based organisation. But in the central management, the information-based organisation needs few specialists. The knowledge is primarily at the bottom in the minds of the specialists who do different work and direct themselves. Traditional departments serve only as centres for training and the assignment of specialists. The work however, is done largely in task-focused teams. In the information-based organisation, there is a greater emphasis on individual responsibility for relationships and communications (Cash & Al, 1993, 85 –87). Drucker believes that, individuals will have to take more responsibility for themselves instead of depending on organisations. In an organisation that is reengineering itself around information, the majority of management levels will become redundant, resulting in the remaining layers acquiring more responsibility for information. The result will be a horizontally networked organisation, according to Drucker (Harris, 1995, 223 – 227).

One only has to take note of the current trend in corporate advertising to notice the shift, which has occurred in the focus of major organisations in the global economy. In the global economy, the most important resource is knowledge. Organisations constantly have to contend with an enormous flow of information, and act on or react to the moves of other organisations in the global economy. It has become exceedingly important for companies to be close to the markets in which they operate. Two catchphrases employed by CNN illustrate this point: "*Because there is always a market open, we never close*" is a fair indication that the world's markets are integrated on a truly global scale. Another phrase points to the emphasis placed on information, "*In the new global economy, you are what you know.*" Further examples of the emphasis placed on innovative thinking in the global economy are two catchphrases used in advertisements for Rand Merchant Bank, "*Traditional values, innovative ideas,*" and "*Perhaps the right idea is the one you haven't thought of.*"

The global economy has indeed forced onto organisations a new way of thinking about organisation. Organisations will have to learn to organise for information. A further problem is that in a constant flux it is dangerous to apply one solution to problems other than the one it was designed for. Not only do organisations have to adapt to the global economy, but they also need to survive in it. It is in this aspect that organisations are facing the greatest challenge. In the global economy, the only constant is uncertainty. Change is the central concern in today's business. Generating a continuing flow of innovative activity to build and sustain competitive advantage is consequently the most important general task facing organisations. The challenge is to creatively develop and control the complex behaviour of that highly interconnected system which is the modern organisation. The problem is that

---

[3] Lancourt and Savage (1995) Organizational Transformation and the Changing Role of the Human Resource Function www.kee-inc.com/article.htm

Stellenbosch University http://scholar.sun.ac.za

there are no clearly defined ways as to how to solve this problem (Stacey, 1993, 2). The most effective resource that organisations have in the global economy is information. The knowledge which employees possess and the way in which it is applied to create solutions has become the greatest key to organisational survival. The key issue which, remains, is how to effectively stimulate the innovative application of knowledge to generate working solutions.

Productivity and innovation, both applications of knowledge to work, now create value in the Informational Economy. The economic challenge of the Informational Economy is the productivity of knowledge work and knowledge workers (Drucker, 1993, 7). Knowledge needs to be applied to knowledge itself, in what Drucker calls the Management Revolution. The application of knowledge to work greatly increases productivity and productivity can only be increased through applying knowledge to work. Formal knowledge is seen as both the key personal resource and the key economic resource. Knowledge in this new meaning is knowledge as a utility, knowledge as the means to obtain social and economic results. Knowledge is being applied to knowledge. Drucker in fact defines management as the supply of knowledge to discover how existing knowledge can best be applied to produce results. At the same time, Drucker points out that knowledge is being systematically and purposefully applied to define new knowledge requirements, whether it is feasible and what has to be done to make knowledge effective. Knowledge is being applied to systematic innovation (Drucker, 1993, 38). This change emphasises that knowledge has become the essential and primary resource in the Informational Economy.

Knowledge changes and restructures social dynamics and creates new economic dynamics (Drucker, 1993, 41). Organisations that have survived the past two decades and are still thriving today have demonstrated a spectacular ability to adapt. These companies have downsized, right-sized, reengineered, embarked on cost containment campaigns, introduced integrated product design teams, integrated service teams, embraced diversity in the workplace, advocated change in corporate culture, preached acting locally and thinking globally, adopted global business outlooks, empowered, inspired, motivated, trained, partnered, transformed into learning organisations, and introduced new products and services at regular intervals. Along with that, these organisations have managed to form mergers, make acquisitions, consolidate some parts of the organisation, and spin off others (Rubinstein & Firstenberg, 1999, xiv). These steps were taken to optimise the organisation's ability to deal with information and generate working solutions in the Informational Economy. In other words, to transform the organisation into a knowledge-based organisation. Drucker proposes that knowledge, which is now considered knowledge, proves itself in action. What is meant by knowledge is information effective in action; information focused on results. To accomplish anything this knowledge has to be highly specialised (Drucker, 1993, 41).

Stellenbosch University http://scholar.sun.ac.za

Drucker proposes that organisations will increasingly have to plan abandonment, rather than trying to prolong the life of successful policy, practice, or product. Organisations will increasingly rely on the creation of the new (1993, 53).

Organisations, which are succeeding in the complexity and uncertainty of the unconventional and largely unpredictable global business world, have transformed themselves into learning organisations. Drucker (1993, 53) proposes three systematic practices, which companies in the Informational Economy should incorporate into their systems. These are, the practice of continuing improvement of everything it does; exploitation, the development of new applications from its own successes; and learning to innovate. Drucker warns that without the act of continuing self-renewal, organisations risk losing performance capacity and the ability to attract and hold knowledge specialists, which is crucial in the Informational Economy. Drucker also emphasises the importance of being able to make decisions fast, be based on closeness to performance, the market, technology, changes in society, environment, demographics, and knowledge which must be seen and utilised as opportunities for innovation. In short, organisations should be decentralised (1993, 54).

It is not surprising that companies, which, have adapted successfully to the new economy exhibit significant changes in the way they think about their business and customers. In a study done by Lancourt and Savage[4], the companies, which were examined, showed a complete redefinition of their entire business. There was a shift towards focus on the importance of identifying core competencies, teaming to combine and recombine competencies as business opportunities arise. Another hallmark of the transformation process appeared to be teaming across organisational boundaries. Some of the companies sampled by Lancourt and Savage entirely eliminated many of the traditional organisational boundaries. Work was organised in project teams and people join teams based on their competencies and interests. A defining characteristic of these teams is their ability to reorganise themselves as the nature of their work changes.

The very language used by companies in the Information Era is changing. Some of the companies in Lancourt and Savage's study refer to associates or co-workers instead of employees, managers are called co-ordinators, leaders or sponsors, and executives are known as counsellors[5]. The changes in the language used signify a shift, which is of even greater importance, in that it refers to an entire redefinition of the roles of the people occupying these positions. It is an indication that the new economy has redefined the roles of employees, on all levels of the changing organisation. Drucker advises that organisations

---

[4] Lancourt and Savage (1995) Organizational Transformation and the Changing Role of the Human Resource Function www.kee-inc.com/article.htm

Stellenbosch University http://scholar.sun.ac.za

need to go beyond senior/junior polarities to a blend with sponsor and mentor relations (Harris, 1995, 233). In addition to this, the change in the language used also signifies the great emphasis, which is placed on effective communication. Without an effective communication basis, the transfer of information is jeopardised and it loses value. Information-based organisations require clear, simple, common objectives that translate into particular actions. At the same time focus on one objective, or at most a few, is required. But an information-based organisation is composed of specialists, which makes it difficult to tell them how to do their work (Cash & al, 1993, 88). This necessitates mutual understanding and responsibility in organisations to ensure the essential and efficient co-operation (Harris, 1995, 233).

A subset of efficient communication of information with everyone in the organisation is the creation of the alignment necessary to maintain order without having to impose control from the top (Lancourt and Salvage, 1995). Production and trade units can function autonomously, and yet be reintegrated functionally through information networks (Carnoy & al, 1993, 20). In the Informational Era, power comes from transmitting information to make it productive, not from hiding it. Lancourt and Savage note that the core attractor, which kept the systems in their study from disintegrating, was a shared set of values. These shared values shaped organisational as well as individual behaviour, and when truly shared, it results in order without the need for external control mechanisms. It is essential that everyone in the organisation makes himself or herself understood, and that everyone, including the manager must be eager to understand others (Harris, 1995, 231). If employees have a clear concept of how the organisation functions, they find it easier to act creatively and innovatively. An information-based organisation should be structured around goals that clearly state management's performance expectations for the enterprise, for each part, specialists, and around organised feedback that compares results with these performance expectations so that every member can exercise self-control (Cash & Al, 1993,88). The Information Era has forced the realisation that it is more effective to design organisations in such a way that they are able to act in innovative ways rather than to try and control or direct all organisational activities. One implication of the information race is that every organisation of today has to incorporate an approach of the management of change (Drucker, 1993, 53). In the Informational Economy, it is essential to acquire new knowledge on a regular basis, or else, become obsolete.

Innovative strategic management, however, leads organisations into unfamiliar terrain. The future destination of an innovative organisation is not easily determinable. However, in an environment as unpredictable as the Global Economy, applying management practices,

---

[5] Lancourt and Savage (1995) Organizational Transformation and the Changing Role of the Human Resource Function www.kee-inc.com/article.htm

Stellenbosch University http://scholar.sun.ac.za

which are based on the concepts of instability could provide the answer to many of the problems facing modern organisations. Organisations cannot escape the uncertainty, which is the Global Economy; hence, it is imperative that they find ways in which to utilise their own innovation in a way, which combines with this uncertainty to achieve successful business results. Organisations have to learn to cope with uncertainty as a real part of their environment, it is not something, which can be organised away. The information-based organisation requires that everyone in the organisation take information responsibility. Everyone in the organisation should constantly be thinking through what information is needed to do the job and contribute (Cash & Al, 1993, 89). The focus has shifted to a person's performance and it has become the responsibility of individual employees to accept responsibility for defining what their contribution to the organisation will be (Harris, 1995, 228).

The question remains that if organisations have to change, what should they change to? Drucker (1993, 84) states that in order to improve the productivity of knowledge workers, fundamental changes in the structure of organisations are required, to such an extent that it could require a completely new organisation. For Drucker the key to success in this regard, is to get knowledge workers to concentrate on the real assignment. Drucker calls it the learning organisation. To be information literate, an organisation must begin with learning what it is that one needs to know (Harris, 1995, 229 – 230). Rubinstein and Firstenberg call it the minding organisation. The minding organisation behaves like a living organism, in which adapting is central to vitality and survival. The metaphor of the minding organisation relates the organisation to a living, developing entity, and it is based on the assumption that an organisation has a mind. It possesses a clear sense of purpose and adapts with agility to change. Rubinstein and Firstenberg propose that for an organisation to keep up with the complexity and uncertainty of the Informational Economy they should develop similar strategies of flexibility and adaptability to those found in living organisms. They propose that in the Information Economy organisations should abandon overly rigid and detailed planning and rather adopt strategies that combine less planning and more adapting (Rubinstein & Firstenberg, 1999, xiv). Old management practices are not designed for carrying organisations in the informational Economy. Organisations require a new approach.

Stacey proposes that in the uncertainty of the global economy organisations cannot determine before hand how to achieve their long-term goals. Organisations that prize innovation will discover ways in which to realise their long-term goals as they set about achieving it (1992, 1). Innovative strategic decisions result in unfamiliar terrain, which results in a predominantly unknown future. Stacey advises that organisations should create, invent and discover their destinations as they go along. This approach, however, has far reaching consequences for the control mechanisms of such organisations, since if no one knows the

Stellenbosch University http://scholar.sun.ac.za

destination the organisation will reach, then no one can steer it down the right path to that destination[6]. To this, Stacey proposes that organisational managers should facilitate conditions in which behaviour within the organisation is controlled, though it is not controlled by anyone. To achieve this outcome, Stacey suggests continual questioning of the current, and the generation of new perspectives through contention and conflict. This will result in the developing of new strengths and the partial creation of their own environments. To succ-eed in the Informational Economy, Stacey proposes that organisations drop the mindset of stable equilibrium and develop new ones, which recognise the positive role of instability, and the fact that long term futures are, effectively, unknowable (1992, 4). Instead of attempting to counteract the issue of unknowability, organisations should learn to face it head on. It implies that trying to develop a concept of the long-term future of an organisation is effectively impossible. It diminishes the idea that any one person or group can be in control of an organisation's long-term future. It implies that organisations should sustain contradictory positions and behaviour within the same organisation. Stacey summarises this point of view by saying that in the new way of thinking about organisations, a key concept is that of sustaining, rather than trying to resolve the paradox of control and freedom (1992, 7).

The recent trend is towards the development of organisations, which exhibit characteristics different from those of a few decades ago, but to develop the required characteristics to survive and thrive in the Informational Economy. The purpose is to develop innovative organisations, which are equipped to deal with the turbulent uncertainty of the Informational Economy. The internal structures of organisations are being examined, questioned, redefined, re-examined and questioned again. If business is to be conducted in a predominantly chaotic and uncertain global market in which change occurs at the speed of a thought, how should organisations shape to be able to survive in it? It is insufficient to prompt organisations to merely alter certain aspects of their organisations in order to increase control of the organisation. It is necessary to redress the very nature of an organisation if it is to adapt and thrive in the Informational Economy. Organisations should employ instability in a positive way by allowing people to use own initiative in the development of new ideas before referring it to management. By allowing instability in the organisation, new perspectives can be generated and provoke the continual questioning and organisational learning through which unknowable futures are discovered and created. This approach results in less comfort than traditional practices based on rigid planning and control, but applied to an economy which is itself turbulent and uncertain, it is much more dynamic and far more useful (Stacey, 1992, 7 – 8).

[6] Lancourt and Savage note the apparent lack of control mechanisms in this adapting system of organisation. The information technologies are the critical factors allowing for flexibility and decentralisation in production and management.

Stellenbosch University http://scholar.sun.ac.za

Stacey points out that if organisations are complex systems in which it was impossible to identify the specific ideas and actions that led to specific outcomes, then there has to be some other way of explaining the success of companies in the Informational Economy. He defines the approach of bounded instability as a required approach for coping with the unknowable future in an organisational environment where the old approach is no longer effective (Stacey, 1992, 9 – 10).

3. A Change of Reference

Scientists from various fields of study in the natural sciences have developed a new frame of reference within which they attempt to explain the workings of a world, which is characterised by incredible levels of interconnectedness at all levels. It is a frame of reference, which stresses uncertainty, unpredictability, irregularity, discontinuity and self-organisation. These are characteristics of complex systems. This frame of reference is aimed at providing tools for understanding a world in, which turbulence and chaos are as much part of the world as order and stability. Chaos is no longer seen as a reflection of human ignorance, but rather as a reality generated by simple laws. Chaos and turbulence are the essence of reality and there is often no cause when events unexpectedly change direction. This has led to the realisation that the development of most of nature's systems is a continuing process of creation, which depends significantly on chance, so making it impossible for man ever to control all of the outcomes. The focus has shifted from the view of order and pre-planned paths of development to a nature where disorder, irregularity and chance all combine in a creative and constructive way (Stacey, 1993, 21).

In a world where order and disorder are inseparably intertwined, the links between cause and effect can be extremely complex, distant in time and space and difficult to detect. This world is not unfamiliar to organisations where unintended and counterintuitive results are often produced even after meticulous planning. The dynamics of even a simple nonlinear feedback system can be so complex that the links between cause and effect are lost in the detail of what happens. Tiny changes can escalate to have massive consequences. The result is that virtuous and vicious cycles are generated, which can be very difficult to break out of. It is therefore totally impossible to predict the specific long-term future of such a system. Its future is truly unknowable (Stacey, 1992, 11). Even, though the specific behaviour is unpredictable when a system is far from equilibrium, the unpredictable behaviour still falls within the boundaries of recognisable categories. The dynamics of nonlinear feedback systems are characterised by a combination of regularity and irregularity, of stability and instability. Systems of this kind develop over time by passing through periods of instability, crisis, or chaos and then spontaneously making choices at critical points, producing new directions and new forms of order.

Stellenbosch University http://scholar.sun.ac.za

Advances in the fields of mathematics and natural sciences in recent years are shedding some light on this kind of dynamic interaction. The understanding of complex dynamic feedback systems in nature has been advanced by two scientific developments. The first is called chaos theory and the second self-organisation theory. In the 1990's a movement emerged which sought to create a shared epistemological approach, identified by the code word "complexity". The focus was on understanding the emergence of self-organising structures that create complexity out of simplicity and superior order out of chaos, as a result of several orders of interactivity between the basic elements at the origin of the process (Castells, 1998, 64).

Authors on organisational theory have in recent years sought to incorporate the principles of nonlinear systems theories into various aspects of organisational theories in an attempt to develop management practices, which are designed to steer organisations through the turbulent environment of the global economy. Peter Senge advocates the practice of five disciplines for learning organisations as a means of understanding dynamical complexity. Senge's five disciplines have proven to be very popular in management circles and a numerous organisations that have adopted a systems thinking approach based on Senge's five disciplines, have collaborated on a fieldbook for the five disciplines. The fieldbook suggests that systems thinking is widely applicable in the turbulent informational economy and the authors, many of whom are managers in organisations, refer to their own experiences with systems thinking to show how systems thinking benefits organisations. Among those proposing the application of complexity theory to leadership and management practice are Margaret Wheatley and Ralph Stacey. Their theories on management practices based on complexity theory have drawn considerable attention, and are claimed to be greatly successful when applied to organisations. The application of complexity theory in the business field is still in its infancy and still has to prove itself an efficient approach, but the concepts touched upon by the authors are of such a nature that it merits closer examination. In a vastly interconnected world characterised by unpredictability, the study of complex systems in nature might just result in the necessary understanding of such systems to establish a more suited theory of organisations. Senge, Wheatley and Stacey all share on fundamental belief, the global economy today is a nonlinear complex system where the rules for business can change very rapidly with no real warning before the time. To make sense of this business world today, organisations have to change the way they look at themselves and the world around them. One cannot understand a complex system through linear thinking, but when one learns to see the world systemically, one increases ones capacity for surviving in a world that changes in many directions at the same time.

Stellenbosch University http://scholar.sun.ac.za

4. Summary of Contents

The thesis consists of three chapters. The first chapter deals with the subject of Chaos theory. It presents a brief background of the development of nonlinear systems theory and elaborates on some of the most important aspects of nonlinear systems. It illustrates the view that the universe is composed of many different components that interact with each other a myriad of different ways. It also illustrates how the simple mathematical equations that describe the dynamical behaviour of nonlinear systems, can produce tremendously divergent patterns within the behaviour of the system. The principles of feedback that operate within nonlinear systems are responsible for the dynamical instability that is associated with systems when they enter a state of chaos. Nonlinear systems are very sensitive to the conditions that they exist in, and when these change, feedback can cause the system to become unstable. The instability that is the result of positive feedback causes the system to reorganise itself around the new conditions, but the outcome of this process is totally unpredictable. Chaos theory also shows that how systems use positive feedback and instability as an adaptive mechanism for bringing about changes in its structures. Chaos theory has shown that there is a very intricate relationship between order and disorder, and stability and instability in nonlinear systems. Chaos theory has shown how nonlinear systems reorganise themselves in relation to their environment. Through exchanges of energy or matter with the external environment, nonlinear systems can produce very complicated structures. When conditions in the environment change, the system is influenced because of its exchanges with the environment, and as a result the system's organisation is also changed. Nonlinear systems are therefore dynamical systems and operate in far from equilibrium conditions. The internal dynamics of the system enable it to use energy from outside to produce coherent structures that are more organised than equilibrium structures. Such systems are known as dissipative systems and their capacity for enduring in changing conditions is greater than that of equilibrium conditions. The further such a system is from equilibrium, the greater its organisation becomes despite the increased instability resulting from the high level of activity within the system. Chaos theory therefore shows that there is a different type of order within stability and disorder. This order is brought about through self-organisation in the system and it is maintained through a constant flow of energy from outside the system. Chaos theory shows that wherever nonlinear dynamics operate, chaotic behaviour can be found. It also shows that by understanding the way nonlinear feedback mechanisms operate, one gains a deeper insight into the way that systems such as ecologies, the weather and economies behave.

The second chapter focuses on the theory of complex adaptive systems. Complex adaptive systems are nonlinear dynamical systems that are comprised of any number of interdependent agents that are interacting within the boundaries of the system. Complexity

Stellenbosch University http://scholar.sun.ac.za

theory shows how simple components that interact according to relatively simple rules can produce systems of tremendous complexity. Complex systems are nonlinear systems, and as such feedback plays a significant role in the internal dynamics of the system. Every agent in a complex system shares connections with other agents and through feedback, the actions of different agents can influence other agents at other locations in the system. The agents in complex systems also learn about their environment and their neighbours. The information that they gain about the environment or the actions of their neighbours influences their behaviour. When any given event within the system or outside it influences the actions of a sufficient number of the components, the system starts to display co-ordinated behaviour. In this way, the individual actions of the components become synchronised to the point where the system displays recognisable structures. These structures emerge spontaneously through self-organisation of the components and through the intervention of external control. Complex systems also interact with their environments in various ways. In this way, the system and its components adapt their structures and behaviour in relation to the environment. However, complex systems also maintain their internal structures despite constant fluctuations in the external environment. Complex systems display both stability and instability at the same time. The actions of individual components may be very difficult to predict since they often appear to be acting in a chaotic manner, but when they interact with other components, their combined actions can result in the emergence of very distinct structures. Complex systems use both positive and negative feedback. Negative feedback maintains stability in the system by suppressing disturbances, however when a disturbance becomes sufficiently strong to warrant a change, the system uses positive feedback amplify its effects through the system. The amplification of disturbances through the system creates tension between the stable and unstable elements of the system and as a result of this tension, the system reorganises itself so that new structures can emerge which might be better suited for dealing with the disturbance. New structures come about through self-organisation of the component. The interactions of components in complex systems give rise to emergent properties in the system. Emergent properties are aspects of the system that cannot be directly linked to any of the components. These properties exist because of the convergent nature of dynamical behaviour in complex systems. Emergent properties in complex systems illustrate that these systems are in whole more than the sum of its parts. Examples of this are food webs in ecosystems, consciousness in the human brain, and strategic plans in organisations. Complex systems are information processing systems that learn about their environments, and adapt their structures as a result in order to facilitate a better match between themselves and the environment.

Stellenbosch University http://scholar.sun.ac.za

The third chapter looks at the perspective of three authors on the application of nonlinear systems theories to organisational thinking. Peter Senge, Ralph Stacey and Margaret Wheatley have used nonlinear systems theories to develop new methods for understanding organisational processes. All three of the authors focuses on the nonlinear feedback loops and time delays that influence the actions of people and organisations. Senge has developed five disciplines that he believes are useful for organisations in the interconnected global world where knowledge is the primary resource. As such, he has named it the five disciplines of the learning organisation. The combined practice of these five disciplines enables people in organisations to learn in an effective and combined manner in groups. Both Senge and Stacey emphasise the importance of group learning as the fundamental way for organisations to learn in uncertain situations. However, Stacey places a greater emphasis on the creative capacity of instability in organisations. Stacey's perspective is that organisations can be creative and innovative only when they operate in a far from equilibrium state. Stacey suggests that organisations should look at ways to maintain a far from equilibrium state through sustained instability. For Stacey, the main drive for instability in organisations comes from the shadow system. Shadows systems are the informal groups that organise themselves around new information and ideas in an attempt to bring about change in the organisation. Stacey emphasises the need for both stability and instability in the organisation. Stability in the form of the legitimate system enables the organisation to perform its daily functions, whereas instability in the shadow systems works to undermine the stability of the shadow system in order to bring about change. Stacey sees innovative and creative organisations as operating at the boundary between order and chaos, where the system is both stable and unstable. This is the edge of chaos, and for Stacey this is the state where organisations are at their most creative with the greatest capacity for information processing and learning. Wheatley's applies nonlinear systems theories to the concept of leadership in organisations. Like Stacey, she believes that organisations as nonlinear feedback systems produce their own forms of control through learning and self-organisation. Both Wheatley and Stacey believe that managers who want their organisations to be creative have to let go of attempts to control activities in groups or organisations. Activities in learning organisations are controlled by the learning process and interactions of individuals in groups. For Wheatley, creativity in organisations depends on autonomy. For Wheatley, creativity in groups requires information instead of control over activities. Control in the organisation results from and information flow that is made possible by relationships between employees across different levels of the organisation. Wheatley sees in the theories of nonlinear systems a message about creativity, innovation, and self-organisation that is changing the role of leadership in organisations from directing activities to facilitating information flows as a means for encouraging innovative business practices. Wheatley believes that leaders who allow employees to self-organise are more likely to be

Stellenbosch University http://scholar.sun.ac.za

surprised by higher levels of order and innovation than ones that prefer to maintain strict control over the activities of individuals. The work of these three authors represents new means for understanding the forces that create structure and influence behaviour in organisations, for promoting learning and creativity in organisations that enable organisations to adapt and learn through the growth of individuals as they engage in group learning.

Stellenbosch University http://scholar.sun.ac.za

Chapter 1

A Theory of Order and Chaos

1.1. Discovering a Nonlinear Universe

The 16th and 17th centuries saw a number of fundamental alterations in the fields of astronomy and physics. The new sun-centred astronomy and inertial physics formed the foundation of what came to be known as the Newtonian Worldview. Newton was the main scientific contributor to the new worldview, but it should be noted that he was not the only contributor. The underlying philosophical assumptions were to a greater extent developed by Descartes and Galileo. These men sought to explain the world in terms of its components, which resulted in a focus on the simplest and smallest components of matter, the atom. These men adopted the approach that nature could be reduced to its individual parts. Newtonian physics depicted a world in which everything could be described in mathematical or mechanical terms. Descartes suggested that the basic principles ruling nature could be obtained by a combination of pure reason and mathematical logic. This reductionism was based on the belief that phenomena could essentially be reduced to a collection of independent components, and that the study of these individual components would reveal the nature of the phenomenon as a whole.

In the Newtonian worldview, the fundamental physical reality is atoms. It was believed that everything happened because of the motions of atoms and that physical laws determined these motions. The universe was presented as one composed of independent parts. The actions, which occurred in this universe, would do so independently of human influence. It was assumed that humans did not really interact with the physical universe in any essential way. The universe was pictured as an ancient giant machine, which after its creation was set in a motion from which it would not deviate. The motion of the universe was determined by the physical laws, which govern the universe, underlying these laws was the principle of a universe resistant to change (Hobson, 1995, 132). Even God would not interfere with the universe after the act of creation. The system would run itself. The founding fathers of physics envisioned the universe as a giant clockwork mechanism, composed of independent atoms and operating according to the laws of nature. There would be no need for further intervention from the Creator.

According to Newtonian physics, every physical system is entirely predictable, hence the clockwork analogy. It was believed that if one could accurately account for all the specific positions and velocities of all particles at a specific time, then one could accurately predict the entire future of that system using Newton's theory of motion. In other words, the precise position and velocity of every one of the particles could be predicted, forever.

Stellenbosch University http://scholar.sun.ac.za

The predictability of the Newtonian universe does not end at particles, though. According to the Newtonian worldview, everything is made of atoms, and these atoms obey precise laws of nature, including Newton's theory of motion. The entire universe is made up of atoms, including living organisms, which according to the Newtonian worldview follow these precise laws. From this follows that the future of the entire universe is predictable, that the future is entirely determined by what all the atoms of the universe are doing at any given moment in time. It was thought at the time, that if one could account for all the forces of nature, and the positions of its parts, it would be possible to develop one formula, which would explain the movements of the universe from the largest bodies to the smallest atoms. This formula would then rid the universe of its persisting uncertainty. There would be no further surprises in the clockwork, since the universe is required to do precisely what it has done and what it will do for all time to come, to obey the laws of nature without deviation.

Newton remained the most important figure in the development of mechanics, with his three laws forming the foundation of mechanics before the 1900's. Newton developed a theory of how bodies move through space and time as well as the mathematics for analysing these motions. To this, he added the law of universal gravitation according to which every body in the universe is attracted to every other body in the universe by a force, which varied in strength in relation to the size and proximity of the celestial bodies. Newton developed a picture of an infinite universe in which gravity is always attractive. By assuming, that two masses attracted each other with a force inversely proportional to the square of the distance between them, Newton proved that the mechanics, which govern how bodies fall on earth also, explained the periodic motions of the planets. Newton's approach to physics was based on the separation of space and time. It was believed that one could accurately measure the interval of time between two events, and that anyone who measured this interval would get the same result as other persons measuring the same event (Hawking, 1989, 18).

The result of this reductionist approach was a universe, completely separable into its components, which would continue to operate according to the same patterns within which it was created. From this was deduced that if one could take the system apart and break it into its smallest components, then it would be possible to understand the whole. The universe was nothing more than the sum of its parts. Newton's crowning achievement was the application of his mechanics to show that the entire universe obeyed the same laws of nature as published in his *Philosophiae Naturalis Principia Mathematica*[7]. To understand this world, one had to understand the components and the way in which they were joined. From this understanding, one would be able to make accurate predictions of what would

---

[7] Slavin, A (1994) A Brief History and Philosophy of Physics, www.trentu.ca /academic/physics/depinfo/history_895html

Stellenbosch University http://scholar.sun.ac.za

happen at any specific point in time. Everything could be accounted for, so there would be no surprises. The clockwork framework seemed assured. In this classical picture of the physical world, space and time are absolute, and every bit of recognisable matter is at every instant at some definite place, moving with some definite velocity along some definite path, all governed by the relevant force laws according to Newton (Treiman, 1999, 4).

The static universe envisioned by Newton would however, be very unstable. The slightest variation in the gravitational pull between two celestial bodies would result in them either falling in on each other, or flying apart. The static universe of the reductionists would have started to contract under the influence of gravity. Equilibrium in the universe seemed a very unlikely state for its components to develop to. Despite this, attempts were made to rectify this resistance of a static universe by modifying Newton's theory so that gravity would be repulsive at greater distances. During the last two decades of the 19th century, several experiments yielded results, which proved to be impossible to reconcile with Newtonian physics (Hobson, 1995, 134).

The nature of the universe, as discovered at the turn of the 20th century, required a change in the mathematics, which was used to describe it. Already near the end of the 19th century, the French mathematician, Henri Poincaré suggested that the reductionism of the Newtonian worldview might be inadequate. Poincaré worked on the mechanics of closed systems, the epitome of Newtonian physics. According to classical physics, such systems are perfectly orderly and predictable. Objects in such a system are free of friction and air resistance and can hence conserve its energy. Any randomness or chaos in such a system could only come from outside chance contingencies. Poincaré challenged this idea when he started to think about the stability of the solar system and realised that there was a problem with the equations used to describe the motion of bodies within the solar system. Poincaré accepted that for any two-body system, such as the earth and moon, Newton's equations could be solved exactly. The orbits would be stable. Poincaré however, included the effect that the sun would have on the earth-moon system. In 1890, Poincaré showed that the simple step of moving from a two-body system to a three-body system rendered Newton's equations unsolvable. The three-body equation required cannot be worked out exactly. It required a series of approximations in order to get closer to an answer (Briggs & Peat, 1990, 27).

The many-body problem that Poincaré was working with is nonlinear in mathematical terms. The effect of every additional body in the system on another body has to be considered when attempting to solve an equation of the system. Poincaré added a term that increased the nonlinear complexity of the equation and corresponded to the small effect produced by the movement of an additional body in the system. In trying to solve the equation for a two-body system in which a third body was introduced, Poincaré discovered that most of the

Stellenbosch University http://scholar.sun.ac.za

possible orbits of the two bodies in his equation were not altered severely by the motion of the third body that was added to the equation. That much was expected. A small perturbation produces a small effect, but the orbits remained intact. However, Poincaré discovered that even with the slightest perturbation, some of the orbits in his system behaved in an erratic, even chaotic way. His calculations showed that a minute gravitational pull from a third body might cause a planet to deviate in its orbit, it could even result in the planet flying out of the solar system altogether. This was a devastating blow to Newton's stable universe, for if such a strangely chaotic orbit could occur in reality, then the solar system as a whole might be unstable. Until Poincaré, chaos had been assumed an entropic infection that comes from outside a system. Poincaré revealed that chaos, or the potential for chaos, is the essence of a nonlinear system, even a completely determined system could have undetermined results. He had found that small differences in the initial conditions of a system can potentially produce very great differences in the final phenomena, and the situation would then defy prediction. Poincaré had shown how the smallest effect could be magnified through feedback in unexpected and unforeseen ways[8]. Poincaré had looked for order in a system where none could be discerned, and had instead discovered how a simple system can erupt into incomprehensible complexity.

Newton's physics proved to have limitations, it was incorrect under certain conditions. However, Newtonian physics had become so ingrained into scientific thinking that it was not easily swept aside. The static universe description of Newton prevailed until the 20th century, even influencing Einstein's initial formulation of the theory of relativity. However, it had become necessary to develop new theories to deal with the situations where Newtonian physics fell short. The first few decades of the 20th century saw just that in the development of special relativity, general relativity, and quantum theory. Th- se theories dealt with very high speeds – special relativity; very strong gravitational forces and very large distances – general relativity; and very small distances – quantum theory. Newton's law of motion and views concerning time and space collapse at high speeds, though there is no noticeable disagreement at low speeds. Special relativity however, proved accurate at both low and high speeds. The predictions of general relativity corrected the errors, which occurred when Newtonian physics were applied to very strong gravitational forces, but once again show no variation from Newtonian physics when gravitational forces are not too strong and distances not too large. Quantum theory had far reaching implications for Newton's views on the predictability of the universe. It showed that individual atoms or molecules behave differently from macroscopic objects resulting from the combination of large numbers of atoms (Hobson, 1995, 134).

---

[8] Petree, J, *History of Chaos*, www.wfu.edu/~petrejh4/HISTORYchaos.htm

Stellenbosch University http://scholar.sun.ac.za

Modern physics proved to be incompatible with the mechanical universe that Newton had conceived. Relativity theory and quantum theory contradict both the specific predictions and the conceptual underpinning of Newtonian physics (Hobson, 1995, 228). It should be mentioned though, that the transition from Newtonian physics was not based on the discovery that Newton was wrong, but instead on the realisation that Newtonian physics was of limited validity. Classical physics continues to provide an accurate description of the physical world under conditions where velocities are small compared to the speed of light, and relevant dimensions are large compared to the size of atoms. Relativity theory and quantum theory were invented to deal with aspects of the physical world that fall outside of the Newtonian range. To this end, relativity theory and quantum theory have been responsible for the development of deeper conceptions of space-time and objective reality.

Max Planck introduced the quantum idea onto the scene in 1900 when he formulated his quantum hypothesis, and so initiated the post-Newtonian era in physics. In 1905, Albert Einstein announced relativity, the second substantial post-Newtonian idea. Relativity altered the perceptions of Newtonian physics in a number of fundamental ways. It implied different spaces and times for observers moving in different ways. Matter is recognised as made up of energy, motion and fields. The clockwork universe along with the accompanying determinism and objectivity was destroyed. In 1926, Werner Heisenberg formulated the uncertainty principle, based on the discovery that the more accurately one attempted to measure the position of a particle, the less accurately one could measure the speed of the particle. And inversely, the more accurately one intended to measure its speed, the less accurately one could measure its position. Heisenberg's uncertainty principle turned out to be an unavoidable part of the world, and had far reaching implications for the way in which thought about the world. The uncertainty principle invalidated the idea of a completely deterministic universe, for how could one venture predictions about the future if one could not even accurately measure the current state of the universe without disturbing it? The perception slowly dawned that reality was in fact somewhat dependent on the observer. These discoveries led Heisenberg, Erwin Shrödinger and Paul Dirac to reformulate mechanics during the 1920's into a theory called quantum mechanics, which is based on the uncertainty principle. In this theory, particles were depicted as being without separate, well-defined positions and velocities that could be observed. Instead, they had a quantum state, which constitutes a combination of their position and velocity (Hawking, 1989, 59). Quantum mechanics, however, is probabilistic. The quantum state of a system does not precisely specify particle positions and momenta, instead it specifies probabilities. The probability distribution of a particle's position is sharply localised, so that the position at the given time may be said to be almost definite for states. But there are other states for which the probability distribution could be tremendously broad, to the extent that when it is

Stellenbosch University http://scholar.sun.ac.za

measured, the particle could be located at almost any position. In between, there are infinitely many possibilities. The same holds for momentum. For some states the momentum is almost definite, for others, it is broad, and in between there are infinitely many possibilities. Even full knowledge of the quantum state does not allow one to predict an outcome event by event, only the probability distribution (Treiman, 1999, 7).

Physicists have used quantum theory to study the microscopic world since about the late 1920's. Although it had a fairly quiet start, its impact went beyond that of special relativity, and it is still not completed. There is still some uncertainty about the actual meaning of quantum theory. The practical impact of quantum theory extends to every device or idea that depends on the details of the microscopic world. Quantum physics represents a more radical undoing of the Newtonian worldview than relativity theory. Contrary to the deterministic worldview of Newtonianism, quantum physics implies that randomness or chance is inherent in nature at a microscopic level. It would appear that nature does not know what it will do next. The result is that the mechanical predictable universe of the reductionists is not an accurate depiction of reality. Nature is in fact deeply connected, and parts like electrons, protons, and light waves cannot be separated from their surroundings without fundamentally altering their character. Quantum physics describes a microscopic world that immensely delicate and can be altered significantly by the mere act of observation, even by observations that might not physically disturb the measured object. These discoveries have led to a collapse of the idea of an independent and knowable microscopic reality, instead it seems that a participatory reality exists and that this participatory reality includes macroscopic observers (Hobson, 1995, 333).

The idea of objectivity was crucial to scientific progress in Galileo and Newton's time. But over time, objectivity received a revered status as scientists thought that natural phenomena could always be separated from their surroundings. But since the time of Einstein's relativity theory in 1905, the observation process intruded on the belief in the possibility of complete objectivity. It became essential to specify exactly how quantities like space and time can be measured. In quantum theory, the entire experimental context becomes essential to the defining properties of the objects being examined. Answers lose their significance when seen outside of their experimental context. In the microscopic world, relativity is not quite dependent on the observer, but it is dependent on observation, which is different for every type of observation. Science was confronted by the realisation that identical causes do no lead to identical effects. Individual events are not predictable, even in perfectly controlled experiments. The universe is not at all like a clock. Statistical patterns are predictable though, but single events are not (Hobson, 1995, 185).

Stellenbosch University http://scholar.sun.ac.za

Quantum theory contradicts the notion that it is possible to divide phenomena into parts without changing it, instead it revealed a microscopic system that is not necessarily made of separable parts. An electron changes its nature when its environment changes. Quantum entanglement is the most striking example of this. Two entangled particles are so closely connected that it is not possible to think of them as independent particles, although they could be on separate planets. A measurement performed on one of the particles is correlated instantly with the result of a measurement on the distant one, even if there is no mechanism for communication between them. There is a microscopic wholeness that is not so easily discernible at the macroscopic level. Quantum physics suggests that natural systems are closely tied to their surroundings. These systems cannot necessarily be separated without fundamentally changing their nature. The universe as depicted by quantum physics seems less like a mechanical universe and more like an organic one (Hobson, 1995, 386).

Quantum theory is considered one of the most successful physical theories in history. The extent of phenomena described by quantum theory is exceptionally broad and extends to physics, chemistry, biology and technology, fields, which were considered completely unrelated. Quantum theory is the basis of atomic and molecular physics, the physics of interaction between electromagnetic radiation and matter, nuclear physics, and the physics of elementary particles. Quantum theory explains systems such as the laser, the transistor, a DNA molecule, a neutron star, or even the whole universe (Bialynicki-Birula & al, 1992, 30). It reveals a universe, which is interconnected at the smallest levels, yet through the interactions of its different components defies predictability of the system as a whole. A picture emerged of the universe as a nonlinear system within which the traditional differential equations introduced by Newton no longer sufficiently describe the workings of the system. It was realised that in the universe, systems could not be studied in separable parts without any consideration of the whole.

Poincaré's discovery went virtually unnoticed due to the astonishing significance of the other discoveries of the early part of the 20th century. During the years following Planck's quantum hypothesis and Einstein's publications on relativity, physicists tried to sift through the differences between Newtonian physics and the view from the perspectives of relativity and quantum theory. The universe had changed from a giant clock with separable independent parts, into a fundamentally indivisible one, a flowing wholeness in which the observer cannot be separated from the observed. The results from Poincaré's calculations pointed in the same directions as Planck and Einstein's work, but in the ensuing tumult following the discovery of relativity and quantum theory, Poincaré fell into the background. However, in the 1960's Poincaré's investigations merged with recent work on discoveries in the fields of nonlinearity and feedback, entropy and the inherent non-equilibrium of orderly systems.

Stellenbosch University http://scholar.sun.ac.za

These volatile elements started to come together forming the foundations for what would be yet another fundamental discovery for science in the 20^{th} century. To this end, Poincaré's work caused a positive consequence in the creation of the theory of chaos. The first theorists of chaos shared an interest in patterns. They were particularly interested in patterns that appeared again and again on different scales at the same time. They shared an interest in apparent randomness and complexity, in concepts such as determinism and free will. There was a feeling among those who adhered to the science of chaos that it had become necessary to reverse the scientific trend of reductionism. These scientists were interested in systems as wholes and not just the parts that the whole is made up from (Gleick, 1988, 5).

1.2. Nonlinearity and Chaos

The discovery and study of the inherent nonlinear characteristics of natural systems was bound to force a fundamental rethinking of the way scientists approached nature, as well as the way in which scientific results were interpreted. To this end, chaos theory can be described as making a definitive break from classical physics. Chaos is the name given to the irregular and unpredictable time evolution that occurs in nonlinear systems of various sorts (Baker & Gollub, 1996, 1). Chaotic dynamics as such are not part of any single and specific physical model, and therefore not limited to one specific area of science in application, instead it is a consequence of mathematics and hence appears in a broad range of physical systems. Chaotic dynamics refer to deterministic development that leads to chaotic outcomes. This means that from moment to moment the system is evolving in a way that is closely determined by the current state of the system and is dependent in a rigidly determined way on the previous states of that system. Despite the fact that a system exhibiting chaotic dynamics evolves in a deterministic way, measurements made on the system are still inadequate for accurate predictions about the state of the system even moderately far into the future. If a system is nonlinear, it means that in a later state the measured values of the systems properties are in a complicated way dependent on the measured values of the system in an earlier state. Complicated in this case should be seen as implying something that is different than proportional to, differing by some constant, or in some way a combination of these two. Chaotic behaviours are found only in nonlinear systems, since chaos is not possible without nonlinearity. Nonlinear relations are not sufficient for chaos though, but some form of nonlinearity is necessary for chaotic dynamics (Rasband, 1990, 1, 2).

Nonlinear systems stand in contrast to linear systems. The magnitude of a linear system's response to a disturbance is proportional to the magnitude of the disturbance, so that small causes have small effects, and one cause has one effect. Thus, linear systems are mostly stable. The presence of a nonlinear term, however, is often responsible for certain

Stellenbosch University http://scholar.sun.ac.za

parameter values becoming unstable. This makes the existence of chaos possible, though it does not necessarily ensure chaotic behaviour (Baker & Gollub, 1996, 1).

The motion of a linear system can be analysed as the sum or superposition of certain standard motions. Here the normal modes can be thought of as individual parts that are not interdependent, the superposition principle is analogous to the aggregation of these parts. Linear systems obey the superposition principle, in which the combination of solutions yields another solution. Therefore a complicated problem can be analysed by breaking it down into many simple ones, and once solutions for them have been found, they can then be superposed and the answer will correspond to the original problem. The superposition principle usually fails for systems operating far from equilibrium, where nonlinearity is an inherent attribute of the system. Since two solutions of a nonlinear system cannot be added together to yield another solution, the nonlinear problem must be solved as a whole. In nonlinear systems, the superposition principle breaks down. The nonlinearity of a system makes the system highly complicated and its analysis difficult since nonlinear systems can exhibit seemingly random behaviour with no clear relation between cause and effect (Crutchfield & al, 1986, 38). In a nonlinear system, one cause can start a chain reaction of several consequences and often these consequences cannot be easily retraced to the original cause. This gives the appearance of randomness, though this is only an appearance. Nonlinear systems are therefore far more complex than linear systems. In a nonlinear system, the output from the system is not proportional to the input, therefore such systems are subject to periods of instability, the smallest of disturbances can under certain circumstances produce huge effects on them, sometimes transforming their behaviour from regular to chaotic (Auyang, 1998, 234). Nonlinearity constitutes the foundation for chaotic and unpredictable behaviour in deterministic systems, and because the constituent parts are so tightly coupled to the behaviour of the other parts, it is virtually senseless to examine the individual character of any single part without consideration of the whole. Hence, a more holistic examination of the system is required in order to gain a better understanding of the inherent interconnectedness that characterises the constituent components of nonlinear composite systems (Auyang, 1998, 178).

However, chaos is not entirely malicious. Understanding of the possible behaviour of nonlinear systems has lead to the possibility that systems, which previously seemed hopelessly random, may be predictable, even if only in the short-term. Traditionally, it was assumed that random behaviour was resulted from extreme complexity. Chaos has shown that this is not necessarily so. Irregularity can result from deterministic behaviour and does not necessarily involve an enormous number of independent degrees of freedom. In the presence of nonlinear dynamics, only a few independent variables are sufficient to generate chaotic motion. When only a few degrees of freedom are involved, the short-term behaviour

Stellenbosch University http://scholar.sun.ac.za

can be modelled deterministically. Chaos therefore has two sides to it. On the one hand, it implies that long-term predictions are impossible, but on the other hand, it implies that in some cases short-term predictions are possible (Eubank & Farmer, 1996, 56). It should also be noted that nonlinearity as such is neither desirable nor undesirable. Nonlinearity in the form of turbulence can endanger aircraft travelling through the air. However, by entering different values into nonlinear equations, systems theory scientists are able to picture the effects that various policies and strategies would have on the evolution of cities, the growth of corporations, or the operation of economies. Using nonlinear models makes it possible to locate pressure points that can potentially be critical in the evolution of such a system, since at these critical points a small change can have a disproportionately large impact on the rest of the system. But perhaps the greatest discovery of chaotic dynamics is that, due to the inherent determinism involved, seemingly patternless behaviour may in time become comprehensible through the application of appropriate techniques (Stewart, 1989, 47). Chaos has shown though, that nonlinear models must be considered for short-term predictability if any benefit is to be gained from prediction at all. Conventional linear statistical measures are just inadequate to describe nonlinear processes. A chaotic process can be uncorrelated over short times, although it is quite deterministic, or the collective behaviour of the component parts may transform the system completely. With this mind, it becomes clear that the property of linear correlation simply does not provide the proper information to adequately characterise chaotic behaviour (Eubank & Farmer, 1996, 56).

What then, is chaos exactly? There is no easy answer to this question, and as yet, no single universally accepted definition. What is certain though, is that all systems exhibiting chaotic dynamics are sensitively dependent on initial conditions, possess elements of feedback, and are capable of self-organisation. When examining chaos, it becomes clear that it does not refer to aimless disordered ranting and raving within systems. Chaotic dynamics forms part of a very delicate process within dynamic systems that leads to a determined outcome. The following sections present a brief introductory description of these processes and emphasise in particular the intricate relationship that exists between irregularity and organisation that arises from chaos.

1.2.1. Sensitive Dependence on Initial Conditions

Sensitive dependence on initial conditions is the technical term for Chaos. Edward Lorenz, a meteorologist at MIT, discovered sensitive dependence on initial conditions in the early 1960's while working on a system displaying seemingly random behaviour. Lorenz had created an artificial weather system on a computer by using three connected nonlinear differential equations to describe a simple mathematical model of a weather system. The answers to these equations were printed out on paper every minute in rows of numbers to simulate a real weather system on earth. The numbers created repetitions, but always with

Stellenbosch University http://scholar.sun.ac.za

slight differences. There was a discernible pattern, but there were disturbances within this pattern. The sequence formed recognisable cycles that would come around and around, but were never repeated in the same way. Wanting to repeat the cycle some months later, Lorenz started midway through the simulation, entering the numbers directly from the printout to recreate the sequence. The printout exhibited three decimal places, and in contrast to this the computer on which the simulation was conducted stored six decimal places. The second pattern Lorenz received diverged very quickly from the initial one, leaving Lorenz with two completely different weather patterns. Lorenz assumed that the shorter rounded-off numbers would be of no consequence, but this ultimately turned out to be a flawed assumption. The remaining three decimals, which were left out, proved to be of the utmost importance for the recreation of the original system. Sensitive dependence on initial conditions therefore, refers to an exponential divergence in patterns formed from different initial conditions (Gleick, 1987, 13). Where sensitive dependence on initial conditions applies, any change, no matter how small, will eventually be amplified and lead to fundamental changes.

Sensitive dependence on initial conditions is a trademark characteristic of chaos, and it is found in abundance in nature. In a later publication, Lorenz (1993, 8) refers to chaos in the following way:

> *"Returning to chaos, we may describe it as behaviour that is deterministic, or nearly so if it occurs in a tangible system that possesses a slight amount of randomness, but does not look deterministic. This means that the present state completely or almost completely determines the future, but does not appear to do so."*

Chaos has an appearance of randomness, but is in fact deterministic. Precise laws govern the evolution of deterministic systems from specific initial conditions. Specific initial conditions will follow a determined sequence, which means that there can be only one event that can follow a current one, in a truly random sequence anything that can possibly happen can do so next (Lorenz, 1993, 7). This is clearly not the case with chaos. Chaos as a dynamic phenomenon occurs when the state of a system changes over time. The entity that changes, as Lorenz discovered, is some variable, or set of variables, which determine the state of the system. The values of this set, at that particular point in time, determine everything that there is to know about the system (Stewart, 1989, 42). The system is sensitively dependent on those specific variables, if the variables are changed the system is transformed in accordance with the new variables. Such a transformation, though, is not a random process, it occurs according to the defined rules of the system. In principle, the future is completely determined by the past, but in practice, small uncertainties that can

Stellenbosch University http://scholar.sun.ac.za

creep in are amplified, so that behaviour may be predictable in the short term, but will be essentially unpredictable in the long term. The system's course of development is determined by a dynamic rule, but the rule can only be traced if the initial conditions are specified. Initial conditions though, are seldom exact in that it pinpoints a unique state out of all the possible states of the system. Inexact initial conditions will cover a group of states within its margin of error. With increasing accuracy, the group can be reduced in size, but it can never be reduced to a single point. Therefore, the solution of a dynamic equation with inexact initial conditions does not yield a single path of development, but results instead in a group of paths originating from proximate states. If the system is chaotic, these paths will diverge exponentially so that the accuracy of prediction based on the dynamic rule deteriorates (Auyang, 1998, 245).

Poincaré's mathematical analysis of the many-body problem has already shown that simple systems, which obey Newton's laws of motion, have the potential for displaying chaotic behaviour, the key to this lies in the fact that simple deterministic equations are capable of yielding complicated unpredictable results. Where systems are exposed to small uncertainties, such as the effects of other systems, it is subjected to persistent instability. This persistent instability can alter the state of that system and so set in motion a chain of events, which can in time change the behaviour of, or even the system itself. If such an error goes by undetected, it becomes completely impossible to predict the future of that system, even if the sequence leading to chaotic dynamics is totally deterministic (Percival, 1989, 42). Nonlinearity in any system implies that any small disturbance, such as a slight change of the initial conditions, can result in a big difference in the behaviour of the system at a later stage. This makes the behaviour of nonlinear systems very complex. This is further complicated by the fact that the system's initial conditions can be measured or determined only approximately in practice, since any measuring instrument only has a finite resolution (Lam, 1996, 5). In an environment, where conditions can suddenly change as a result of external interference or internal dynamics, it becomes quite impossible to determine initial conditions. The practical implications of these limitations are quite profound. Incomplete knowledge about the initial conditions of a specific sequence will serve as 'complete' initial conditions for a completely different sequence. Sensitive dependence on initial conditions, therefore, implies more than a mere increase in the difference between two states as each evolves with time. Different initial conditions imply different systems, and an immediate consequence of this is the impossibility of making any accurate predictions sufficiently far into the future (Lorenz, 1993, 10, 12).

All nonlinear systems are sensitively dependent on initial conditions. To realise this, is also to realise that in a world where nonlinear systems are subjected to persistent instability, the scenery can change very rapidly and most unexpectedly. With only limited or inaccurate

Stellenbosch University http://scholar.sun.ac.za

knowledge about the world and events, it is virtually impossible to anticipate such changes until they have come to bear. Where a system is sensitive to initial conditions, long-term prediction crosses the threshold of redundancy.

1.2.2. Feedback in Nonlinear Systems

Nonlinear equations have their own unique ways of developing, and they are very reluctant to reveal these ways. Nonlinear equations have more than one solution with no method to solve most of them in general. In nonlinear systems, the relationships between the components are of such a nature that any given cause or action can have a great number of different effects. If one adds two elementary actions to one another in a nonlinear system, it can induce dramatic new effects that are a reflection of the onset of synergy between the constituent elements. This can give rise to unexpected structures and events with properties very different from the ones constituted the elementary laws of the system to which they belong. Nonlinear systems are prone to abrupt transitions, they display a multiplicity of states, complicated pattern formation and follow and unpredictable course of evolution. To understand these properties of nonlinear systems requires a holistic approach to the dynamic behaviour that is produced by the system as a whole (Nicolis, 1995, 1,2).

A very important feature of the dynamic behaviour of nonlinear systems is the phenomenon of feedback. In nonlinear equations, there are terms, which are repeatedly multiplied by themselves. This process represents the feedback that is present in nonlinear systems, and an increasing awareness of this phenomenon is part of the driving force that fuels the development of chaos (Briggs & Peat, 1990, 24). In a sense, feedback contributes to nonlinear systems' resistance to the superposition principle. In a linear system, one can remove and later replace part of a set without altering the outcome of the whole. If one removes part of a nonlinear sequence, not only does it change the outcome, but it also creates an entirely new sequence with a character distinctly different from the original. Equally so, if one adds something to a nonlinear sequence, it also transforms the sequence into a completely new one. In a nonlinear world, any alteration in a system is fed back into that system, so that local disturbances do not necessarily remain local or isolated, but are amplified onto a global scale. Therefore, the different weather sequences that evolved from Lorenz's differing sets of initial conditions can be attributed to feedback. Feedback plays a very significant role in nonlinear systems, but it is a role that has two parts.

There are two types of feedback, positive and negative. Negative feedback loops were recognised as such during the 1940's and show up in mathematical models depicting the relationship between predator and prey. The feeding back of the discrepancy between predator and prey serves to close the gap between the two species and so maintains a delicate balance between predator and prey. In the 1950's, scientists began to take note of the existence of feedback loops other than negative feedback loops. The popular example

Stellenbosch University http://scholar.sun.ac.za

of positive feedback points to the sound that is produced when a microphone is placed too close to a loudspeaker. The chaotic sound is the result of an amplifying process where the output of one stage serves as the input for the next stage. The terms negative and positive indicate that one type of feedback regulates while the other one amplifies. These basic types of feedback are inherent to nature and are found at all levels of living systems, in ecological evolution, in the human body, in the moment by moment psychology of social interaction, in the competition characterising economies, and in the mathematical terms of nonlinear equations. Feedback embodies an essential tension that exists between order and chaos in all of the above systems and in every other nonlinear system (Briggs & Peat, 1990, 25, 26).

One need not look further than population biology to find examples of the regulating and amplifying aspects of feedback. Where species occur naturally, they appear to be intricately linked to their environment in such a way that they regulate their own population numbers. Populations naturally exist in limit cycles, tending to increase after dropping to unusually low densities, at which point conditions again become optimal for maximum growth, and after reaching unusually high densities, they tend to decrease again. The regulating aspect of feedback prevents populations of plants or animals from growing indefinitely and so preserves the delicate order that exists within systems. Even a population of animals, free from external interference such as predators, would not expand without constraint. In the real world, exponential growth does not continue unchecked because any population system is dependent on other systems in the food chain. Systems are interrelated, so the population size in the end depends on the environment in its totality. This implies that the size of a population free from predators would still be influenced by the support potential of the environment, since the amount of available food, also determines the level of competition within the population (Vivaldi, 1989, 46; Briggs & Peat, 1990, 56). In a nonlinear world though, species are rarely free from external interference. In the real world, relationships among species become very intricate because of complex feedback loops. Populations usually interact with other species, which in turn interact with others, creating a sort of biological many-body problem (May, 1989, 39). For a population biologist, all of these factors have-to be brought into consideration when attempting to describe the evolution of populations. Despite all the intricacies involved in population dynamics, it still possible to capture its essence in the relatively simple formulas that depict population growth. In his 1987 publication entitled *Chaos*, James Gleick employs what he calls, "*possibly the simplest*" mathematical equation that can be applied to population growth, $x_{next} = rx(1 - x)$[9]. The apparent simplistic appearance aside, the equation still captures the essence of population growth with all its many intricacies. The term $(1 - x)$ represents feedback and is

Stellenbosch University http://scholar.sun.ac.za

responsible for regulating growth, since as x rises, (1 – x) falls. The population growth of successive years now depends in a nonlinear way on the population size of the previous year. The term r represents the rate of growth that can be set higher or lower and is particularly important. In the physical systems from which the equation is borrowed, the parameter r represents the amount of heating or friction impacting on a system, in short the nonlinearity or environmental noise. In population biology, it refers to the population's capacity to both boom and bust. With these variables in place, a population biologist can now enter some starting value for the terms, and by iterating the equations over a length of time, can see the course that the population will run (Gleick, 1998, 63; Briggs & Peat, 1990, 57).

The continuous iteration of the equation from the selected starting values will, under certain conditions, eventually settle the population into a steady state of growth. Negative feedback will keep the population growth in check, and prevent the population from exploding. In reality though, conditions do not remain unchanged indefinitely. The number of predators may vary, the available supply of food may be affected by drought, or some fatal disease may strike the population. These factors all influence the growth rate parameter r in Gleick's equation. The equation is nonlinear and therefore sensitively dependent on initial conditions. If the growth rate parameter is changed, the entire sequence will reflect this change. The change in initial conditions is amplified through the entire system, and so transforms it into a different sequence. This amplification of the differences in values (errors) is the result of positive feedback. The amplification process of feedback ensures that tiny variations in the environment are fed back into the system, and this ensures that small disturbances do not necessarily have small consequences. In environments that are constantly changing, feedback prevents any system from settling down into a long-term equilibrium state. As the environment changes, so does the system, and if the environment is constantly changing, then the system will also be constantly changing.

An immediate consequence of the presence of feedback is the potential for chaos. By entering different starting values into the growth rate parameter in Gleick's formula, one can observe the effect that various degrees of nonlinearity, or environmental noise, can have on the development of a population. By slowly increasing the amount of nonlinearity acting on a system, one can clearly observe the changes that the system undergoes as it tries to balance between stability and instability. If the starting value for the growth rate parameter is too low, for example below 1, the population will steadily decline. At r = 2, the sequence will develop towards a value that is neither too large nor too small. If the growth rate parameter is further increased to 2.5, a slight oscillation occurs between two competing growth terms,

[9] For simplicity's sake, the equation is applied to a population where successive populations do not overlap.

but eventually the system will return to a steady population size. At r just slightly smaller than 3, the oscillation already observed at 2.5 lasts longer, but the system nevertheless succeeds in returning to a steady size. If the growth rate parameter is pushed up to 3, the system enters a new pattern of behaviour. Instead of approaching a single steady population size, the system now oscillates around two stable values. At this value for the growth rate parameter, the feedback within the system causes an over-correction, producing a population number that is too small, and then followed by one that is too large. The configuration of the system at this point is of such a nature that the opposite over-corrections balance each other precisely to produce regular oscillations around two fixed points. As the growth rate parameter is further increased, the system continues to display increasingly erratic behaviour. When the growth rate parameter is pushed up to a value just smaller than 3.5, the two fixed points become unstable and produce another bifurcation and the population now oscillates around four different points. The system now becomes unstable over increasingly shorter periods, the first stable oscillation occurred at r = 3, the next one required an increase of nearly 0.5 in the growth rate parameter. From 3.5 onwards, the required increase in the growth rate parameter quickly becomes smaller, and at every successive bifurcation, the number of fixed points around which the population oscillates, is doubled. Initially there were two attractors, this doubles to four, then eight, sixteen and thirty two until it reaches a virtual infinite number of different attractors at r = 3.57. At this stage, there is almost no discernible order within the system. The system has collapsed into chaos. This process of successive bifurcations is known as the 'period-doubling route to chaos' (Briggs & Peat, 1990, 58; Vivaldi, 1989, 47, 48). The increased pressure applied to the system forces it to change its structure, much like the way water changes to ice when it is moved from a refrigerator to a freezer.

The increase in nonlinear interference on the system leads to an increasingly erratic pattern of behaviour within the system. Feedback prevents the system from settling down to a steady state, but very significant, though the behaviour of the system is quite disordered, it still stays within certain bounds. As the nonlinearity is increased through the growth rate parameter in the equation, the system becomes increasingly unstable, suddenly small causes have explosive consequences. The increasing nonlinearity has another significant consequence though. Through the period-doubling sequence, the system can also develop a regular pattern again. Mixed into the disorderly behavioural patterns of nonlinear systems are regions where the system once again becomes stable. If the growth rate parameter is increased to 3.8, the system suddenly becomes predictable again. These periods of stability and predictability within the otherwise erratic pattern are called intermittency. Intermittency casts a different light on the relationship between order and disorder. It suggests very strongly that a single system can contain the whole range of order from simple oscillations

Stellenbosch University http://scholar.sun.ac.za

to the complexity of full chaos with each extreme surfacing alternately. It would seem that chaos and order are all part of the same indivisible process (Briggs & Peat, 1990, 62). In fact, it has been noted that both spontaneous oscillations and adaptations of internal activities to cyclic changes in the environment play an important role in the temporal organisation of life. It is therefore, not surprising that this type of dynamical behaviour occurs on various levels of organisation in biological systems (Marek & Schreiber, 1995, 177).

The bifurcations that emerge when a disturbance moves a system into a state of far from equilibrium indicate that a qualitatively different solution to the equations for a nonlinear system has suddenly appeared as a result of a variation in one of its parameters (Rasband, 1990, 217). This is accompanied by an increase in irregularity in the pattern of behaviour displayed by the system. Successive period doublings, or bifurcations are the result of increased pressure on the system, and the system can approach chaos through a series of bifurcations. As such, bifurcations can be seen as one of the important precursors to chaotic dynamics (Rasband, 1990, 108). Bifurcations in the description of a system imply that the same system contains both deterministic and probabilistic elements. Between bifurcation points, the system can be found to obey deterministic laws, but in the region of a bifurcation point, the internal fluctuations become increasingly important in determining the evolutionary course that the system will follow from that point onwards (Prigogine, 1980, 105, 106). At the bifurcation points, the system can be described as choosing between several possible futures and the internal feedback of some of those optional futures is so complex that there is a virtual infinity of degrees of freedom to choose from, hence the system becomes unstable at this point. The number of possible choices at a bifurcation point is so high that it forces the system into a chaotic state. Sensitivity of this magnitude has serious implications for the wholeness of systems, to such an extent that the entire state of the system could under appropriate conditions depend on the most minuscule of parts. Of equal importance here, is the development of pattern, coherence, stable dynamic structures, networks, coupling, synchronisation and synergy that develops out of these bifurcations. The energy, which flows through complex dynamic systems along with fluctuations cause continuous change, which can either constrain or amplify the effects. In chaotic flux, these systems can vacillate in a phase transition, and it can reorganise the system completely in an unpredictable manner[10]. In instances such as this, the significance of individual action on the part of the components becomes crucial for the whole, for through the local actions of any single component, chaos or transformational change can emerge on the part of the whole system (Briggs & Peat, 1990, 74 – 75).

At the centre of these transformational processes is feedback. It is responsible for iterating local variations back into the system until it reaches global proportions, constantly pushing

[10] Petree, J, *History of Chaos*, www.wfu.edu/~petrejh4/HISTORYchaos.htm

Stellenbosch University http://scholar.sun.ac.za

the system harder and harder, and further away from an equilibrium state. Feedback can therefore be seen as a destabilising factor in nonlinear systems. However, increased disorder that stems from this destabilising effect appears to be essential for a greater constructive purpose in the organisation of nonlinear systems. The apparent random motion that characterises chaos is in fact part of a determinate self-organising process that gives rise to higher levels of order within systems as they deviate from equilibrium.

1.2.3. Self-organisation in far from equilibrium Systems

At first glance, it might seem strange to associate the irregular motion of chaotic dynamics with the concepts of order and stability. However, recent work on non-equilibrium systems by the Nobel Laureate, Ilya Prigogine, has shown that, not only is there a definite relation between non-equilibrium processes and order, but that non-equilibrium processes are essential for the self-organisation processes of dynamic systems. Prigogine's work on far from equilibrium systems in thermodynamics, first led to the concepts of *equilibrium* and *far from equilibrium* to categorise the state that a system is in. In a variety of dynamic systems, the flows are nonlinear functions of the forces having an effect on that system. Under these circumstances, the system is in a far from equilibrium state. Far from equilibrium means that a system is so far removed from its thermal equilibrium that the linear laws of cause and effect break down under the effects of interaction among individual components with a large degree of freedom regarding their behaviour. In far from equilibrium conditions there is a great deal of energy involved and this energy flows into the system from outside its boundaries (Briggs & Peat, 1990, 136). In the previous section was illustrated how these external energy inputs can cause a system to become unstable and so deviate from equilibrium. This section will illustrate that non-equilibrium systems not only use the external energy for a process of self-organisation, but that the structures that appear as a result of such processes are characterised by a higher degree of order and are far more complex than equilibrium structures.

At this stage, it should become clear that non-equilibrium systems are characterised by an exchange of energy and matter between the system and its environment. Most non-equilibrium systems are made up of a large number of relatively simple components such as molecules or cells, animals or humans. A common feature of these constituent components in non-equilibrium systems, is their ability to – under suitable conditions – interact and self-organise themselves to give the system a collective behaviour or state (Lam, 1996, 359). Hydrodynamics provides a suitable example of the process of self-organisation in Rayleigh-Bénard convection. The experiment consists of a fluid between two close horizontal plates being heated from below so that the temperature of the lower plate would be higher than the temperature of the upper plate. Originally the heating is by conduction, but as the temperature gradient increases, the hot water rises and mixes with the cooler water levels.

Stellenbosch University http://scholar.sun.ac.za

This collision causes the hot water to cool down and tumble over. The increasing temperature gradient signals the departure from equilibrium and the onset of far from equilibrium thermodynamics. During this process, the random motion of the constituents at the elevated temperature destroys the macroscopic structure, and creates a new structure in the form of hexagonal convection rolls, which are formed spontaneously through far from equilibrium thermodynamics (Çambel, 1993, 52, 53; Auyang, 1998, 184). These cells constitute a higher degree of molecular organisation within the system and their formation is a result of the transfer of energy from thermal motion to macroscopic convection currents. The motions of the currents that appear after the system has become unstable and convection has been established are more highly organised than the microscopic motions in the state of rest. Large numbers of molecules must move in a coherent fashion over observable distances for a sufficiently long time for a recognisable pattern of flow to develop. The essential point then is that beyond the instability of the thermodynamic branch, there is a new type of organisation relating the coherent space-time behaviour to the dynamical processes inside the system. However, for this coherent behaviour to emerge it is necessary that the appropriate feedback conditions are satisfied so that the thermodynamic branch can become unstable at a sufficient distance from equilibrium. The new structures that appear in this way differ substantially from equilibrium structures, they are more sophisticated and considerably more complex in their organisation. Furthermore, these structures can only be maintained in far from equilibrium conditions through a sufficient flow of energy and matter. Once the system no longer receives energy from outside it becomes impossible to maintain the non-equilibrium processes and the macroscopic convection structures disappear. To distinguish non-equilibrium structures from equilibrium structures, the term '*dissipative structures*' was introduced. These dissipative structures provide a striking example of the way in which non-equilibrium processes can be a source of higher order. An order that corresponds to macroscopic fluctuations that become stabilised through exchanges of energy from the outside (Nicolis & Prigogine, 1977, 3, 4,5; Prigogine, 1980, 88, 89).

The processes of self-organisation occupy a special place among the diverse processes, which occur in open systems. They can only take place in nonlinear systems, since only these display the diverse and sophisticated motions that are necessary for the processes of self-organisation to set in and develop. Importantly, the processes of self-organisation can only take place in dissipative systems. Dissipation, though, can play a constructive role in the processes of self-organisation. Stable space-time structures, whose sequences essentially constitute the process of self-organisation, are impossible without dissipation (Klimontovich, 1991, 1, 2). The nonlinear energy exchanges between the system and its environment allow the system to replenish energy lost to '*friction, mixing, heat transfer, or*

Stellenbosch University http://scholar.sun.ac.za

unrestrained growth'. It is essential that these energy exchanges are maintained if the system is to continue existing. In this context, nonlinearity and the distance from equilibrium can both be sources of order capable of driving the system to an ordered configuration. In a world of complex dynamical systems, the equilibrium state is often the temporary state of being, since the dynamic processes required for self-organisation can only take place when the system is driven away from an equilibrium state (Çambel, 1993, 47, 56). In the process, the connection between order, stability and dissipation appears to be profound, and to clearly indicate this relation the ordered configurations that emerge beyond instability of the thermodynamic branch are called dissipative structures. These dissipative structures provide a striking means for understanding the coherence and organisation that is characteristic of the non-equilibrium world (Nicolis & Prigogine, 1977, 60; Prigogine 1980, 84).

Dissipative structures are distinguished from conservative structures by the fact that in the former energy is exchanged between the structure and its environment, whereas a conservative structure does not. In this context, the role of energy exchange becomes very important for determining stability or instability in the structural state of dissipative systems. Dissipative structures occur in open systems where energy is taken in from sources outside of the system and the entropy that is produced is in turn dissipated into the surrounding environment. Dissipative structures, therefore, are systems that are only capable of maintaining their structures as long as they are continually exchanging energy with their external environment (Briggs & Peat 1990, 138, 139). Most systems in nature are open, dissipative systems, characterised by nonlinear interaction and capable of chaotic dynamics. Such systems are extremely resilient though, and seem to indicate that the relation between chaos and order serves to enhance their resilience. The nonlinear dynamics of such systems enable them to adapt with remarkable success to sudden changes in the environment, and in the process ensure that the system can survive in an unpredictable world. This survival though, is not based on the rigid preservation of existing structures, but rather on the preservation of an adaptable structure, which is sensitive to changes in the environment. By responding to outside changes, the system is able to reorganise itself into an improved state that will be capable of enduring under the changed conditions. This ability of self-renewal or regeneration is responsible for the unique characteristics that are found in living systems and is defined as autopoiesis. Autopoietic structures are essentially highly autonomous structures, despite being inextricably linked to their environment through far from equilibrium energy flows. Each autopoietic structure has its own unique history, but this history is linked to the history of the larger environment and the histories of other autopoietic structures. Autopoietic structures have definite boundaries, but these boundaries are open and connect the system in a very complex way to the world

Stellenbosch University http://scholar.sun.ac.za

around it so that the structures form part of a larger interrelated system. The movement of individual parts is therefore closely related to the collective movement of the system, and as is characteristic of nonlinear systems, feedback underlies this collective movement (Briggs & Peat, 1990, 154).

The phenomenon of self-organisation seems to indicate that in an unpredictable nonlinear world, dynamic instability is a great advantage. By maintaining a flexible structure, dynamic systems are able to replace lost energy, and so ensure survival. In the process, systems actually become increasingly ordered, despite the great freedom that is afforded to individual components within the system. In fact, the system as a whole seems to benefit from the individual meandering of its components. As each component responds to an outside disturbance, feedback reinforces that response through the system, causing other individual parts to become excited and finally when critical number these individual parts have been excited, they start to behave in a collective fashion. From this collective behaviour stems the increased order that the system exhibits as a whole. Since this sequence of events can only occur when the system deviates from equilibrium, it suggests that the equilibrium state would be characterised by a lack of temporal and spatial order. It also suggests that when it comes to complex motions, it becomes very difficult to distinguish between order and chaos since the two seem to be very closely tied to one another (Nicolis & Prigogine, 1977, 57; Klimontovich, 1991, 5). These discoveries make it less strange to describe turbulent flow as more ordered than laminar flow, and all the more likely that processes characterised by complicated motions afford greater stability to systems undergoing such processes.

1.3.1 Order from Chaos

Chaos conveys a very definite message. In the presence of nonlinearity, simple systems are capable of extremely complicated behaviour. The concept of nonlinearity is essential to chaos since the creation of order is primarily a product of nonlinear dynamics. When one considers that nonlinearity can produce amplifying or dampening effects in the form of feedback, stability or instability, as well as coherence or divergence, it becomes increasingly clear that nonlinearity cannot as a whole be ascribed to one type of effect. And this is an essential understanding of nonlinear systems, single systems can contain opposing tendencies (Goerner, 1995, 19, 20). A major consequence of these contradicting characteristics is the incredible versatility that it affords system characterised by these motions.

In addition, chaos reveals that systems may be physical and determinate, but this does not necessarily imply that these systems are predictable, controllable or even completely knowable. Nonlinear dynamic systems create patterns, coherence, stable dynamic structures and synergy because of the reciprocal influence that interdependent variables

Stellenbosch University http://scholar.sun.ac.za

have on each other. The result is an underlying holistic pattern, which cannot be deduced from individual components. The concept of self-organisation underscores the idea that order can be generated from chaos. Stability and instability in the structure of a dissipative system is closely related to the way that irregular behaviour turns disorder into order. Order in a nonlinear context though, is not a final destination, but is instead another state that the system reaches in its continuous evolution. As long as a dissipative system is exchanging energy with the outside environment, it will continue to evolve and adapt to differing circumstances. This suggests that the creation of order is driven by the rules of energy flow. Chaotic dynamics will drive the system away from its current state and into a new state, better suited to endure interference from the external environment, in the process the system goes from a state of being to a state of becoming. When the flow of energy is terminated, the system will slowly wind down, and the state that it is in will eventually succumb to erosion. Equilibrium therefore, implies an uncomfortable state for a dissipative system. Since its organisation in equilibrium is at a minimum, the system's resilience declines and it loses its adaptability. Chaotic dynamics therefore serves as a measure of a system's ability to weather change. This suggests that as a system evolves, it increases in complexity, but within this complexity, order and disorder are inseparably intertwined. Such systems are active, creative, and move in a definite direction. These systems are strewn with irregularity, but at the same time, they are determinate and patterned. Change is not a gradual phenomenon, but is intermittent, moving the system through periods of stable uniformity and qualitative change. The universe that chaos reveals, is a vastly integrated, holistically interconnected unity, quite different from the universe that Newton envisioned (Goerner, 1995, 22, 23).

1.3.2 Life with Chaos

The obvious question at this point is what role, if any, does chaos play in people's daily lives? Where does feedback and self-organisation fit into society? Perhaps the best way to approach these questions is by asking a question relating to the political and economic scene at the end of 2001. Why were 43 commercial aircraft grounded at the end of 2001 by the German airline, Lufthansa? The answer, though disturbing, raises some interesting points about the structure of the global economy. On the 11th of September 2001, the United States suffered the worst attack on its domestic territory since the attack of Pearl Harbour in 1941. The fact that commercial aircraft were used as weapons against civilians rocked the world, and within days, global air-travel was in decline. Suddenly, people whose preferred mode of transport had been air-travel became reluctant to make use of it. Airport companies around the world stepped up security levels in an unprecedented fashion, airlines increased security checks on all baggage, and safety protocols dealing with hijackings onboard aircraft were under review with the possibility of adopting a more aggressive strategy in the event of

Stellenbosch University http://scholar.sun.ac.za

hijackings. Due to the sudden and unexpected decline in air-travel, airlines around the world had to take drastic measures in an attempt to keep their losses to a minimum. For many airlines, like Lufthansa, this involved a decrease in the number of flights, and the grounding of aircraft that had suddenly become excessive. Along with the decline in the number of passengers on flights, was a decline in the number of tourists, not only to the United States, but also to countries around the world. In turn, this affected many developing countries whose economies depend in a large part on their tourism industries. The attack on the political and economic principles of the United States was quickly amplified to a global crisis. Around the world leaders described the event as an attack on the '*free world*' and what started out as an attack directed at the United States, transpired into an internationally organised US led war against terror. This is just one aspect of the incident. The decline in air-travel and subsequent economic losses to the global air-travel industry is but another. Along with this, there are many other examples of individual losses as a result of a single act of terror. One act, many consequences. This one example has all the trademark characteristics of a nonlinear feedback system, and it serves to illustrate in a very profound way, that chaos is not just a mathematical oddity in the world of science, but an everyday reality. With the world as it looks at the beginning of the 21st century, one action can have many consequences, and those consequences need not be close to the point of action. If it is difficult to anticipate events, then keeping track of their consequences may turn out be a virtual impossibility. This is just one example of the consequences of the complex structures that interact to shape the global economy. The nonlinear dynamics of the global economy has serious implications for the way that organisations approach strategy and policy formulation.

Consider the impact that the sudden slump in the value of the Rand at the end of 2001 had on the South African economy. In this regard, the negative impact of the Zimbabwean political crisis on the economies of the SADC members played a significant part, though it was almost certainly not the only contributing factor. This also indicates that in the global economy, it becomes very difficult to trace consequences back to their cause.

If one considers the sudden impact that unpredictable events can have on the operations of organisations, then one would be excused for asking whether long-term planning can contribute in a positive way to today's organisations[11]. These are but two examples that strongly suggest that the global economy may be a nonlinear evolving system, and if that is the case, then it is very probable that chaos will also be a part of the global economy. Against this background, the flexible structures exhibited by adaptive systems in nature holds an appropriate example for organisations operating in the global economy, in an

---

[11] An important feature of nonlinear systems is after all, the essential unknowability of its long-term evolution.

Stellenbosch University http://scholar.sun.ac.za

uncertain environment, flexibility is a key part of survival in a world of bounded instabilities. The example of the airline industry also serves to illustrate this point. After the sudden decline in air-travel following September the 11th, there was a gradual increase in the number of airline passengers. Airlines were forced to adopt unforeseen measures in an attempt to respond to declining numbers of passengers. The grounding of excessive aircraft formed a part of their response, and through these measures major airlines adapted to the changed environment. Gradually, there was an increase in the number of people making use of air-travel since the September 11th attack. This was reflected by the gradual reintroduction of temporary excessive aircraft into the active fleets of major airlines like Lufthansa, who announced at the end of the first quarter of 2002 that several of the 43 grounded aircraft had been reintroduced into service. In an environment that is constantly changing, the ability to adapt successfully played a substantial part in the recovery that airlines experienced in the first half of 2002.

Can one then infer from examples like this that human structures, economies and organisations, are indeed complex evolving systems? There appears to be a lot of support for this approach, and it seems to be a valid approach if one considers the inherent unpredictability, which forms so great a part of the modern global economy. If this is indeed the case, then the concepts developed in chaos theory, become a very promising tool for organisations operating in the global economy and indeed merit further attention. The question here though, is what can the study of nonlinear systems in nature contribute to the understanding and enhancing of social dynamics, and in particular, to organisations competing in the global economy.

The concepts of chaos have given rise to another field of study, which in time took on an identity of its own, an identity quite different from chaos. Complexity is a field of study that, in a way, is exactly the opposite of chaos. Complexity theory studies the way in which complex systems spontaneously organise themselves in such a way that it is capable of generating structures and behaviour well beyond the reach of the individual components that it is comprised of. The key to this sort of behaviour is the ability of its components to self-organise, and by acting in a coherent fashion, giving the system a distinct character that is not recognisable at individual levels.

To call complexity a fascinating scientific subject, would be an understatement, and an inaccurate one at that. The systems that are the focus of complexity studies extend far beyond the realms of science, for complex systems form an integral part of the everyday life and actions of everyone. In this regard, it reveals the essence of chaos as an everyday reality in the life of the common person. Human beings are not only capable of producing complex social structures, but we are ourselves the result of a long history of evolution characterised by complexity, from the development of the first cells through to the incredible

Stellenbosch University http://scholar.sun.ac.za

structures that make up the human body. Complexity, like chaos, is a field that spans across many scientific disciplines, including social dynamics like politics, economies and organisations of every kind. The concepts of complexity form the topic for the next chapter, and with it, the focus shifts from the natural sciences to the life sciences and the way that nonlinear dynamics contribute to the formation of organised wholes at various levels of complex systems.

Stellenbosch University http://scholar.sun.ac.za

Chapter 2

A Theory of Complex Systems

2.1 Aspects of Complexity

Chaos theory has contributed significantly to the understanding of many systems that had previously seemed virtually incomprehensible. However, the full range of dynamics present in many nonlinear composite systems seems to fall beyond the scope of chaos (Ruthen, 1993, 112). Despite the immense unpredictability that appears to characterise many systems in nature, a large measure of order is also visible throughout the universe and its many components. An order that seems remarkable when one considers that nature is composed of numerous systems, each one made up of individual components. The components of these systems act and react in many different ways with little regard for anything but their own benefit and, additionally, have no concept at all of the larger system within which they exist. The order that characterises natural systems is even more intriguing when one considers that there is no mechanism for control, from which a design for order might be superimposed on these systems. Any visible order therefore, is likely to emerge from within the system without any preconception from an external designer. Additionally, it would appear that in the absence of central control even chaos contributes to a sense of order that exists in the universe (Goodwin, 1995, xi). Poincaré did after all discover that celestial bodies, subject to the gravitational effects of more than one other body are susceptible to chaotic behaviour, and yet clusters of stars combine to form galaxies in the distinct shape of spirals. This order develops despite the gravitational forces of millions of stars on one another. The process, however, requires millions of years to shape galaxies into an ordered state. Although organisation in dynamical systems requires time to develop, the amount of time involved varies according to the properties of the system, even though the processes involved might not. The amount of time required for termites to construct a lodge is insignificant when compared to the amount of time it takes for a galaxy to develop into a spiral, but the results are an impressive example of the phenomenon that has been labelled self-organisation. Termites display no planning committees or executive management during the construction of a lodge – or any other activities that termites engage in – yet the remarkably intricate engineering efforts involved in the construction of a lodge are well beyond the means of any single termite (Goodwin, 1998, 32). The Australian compass termites, for example, construct their lodges so that the two elongated sides are always lined up north to south.

Stellenbosch University http://scholar.sun.ac.za

This is done to gain maximum exposure from the morning and afternoon sun, while only a small part of the surface is exposed to the harsher noon sun (Dawkins, 1997, 12, 13). When faced with such accomplishments, it seems very implausible to maintain that the behaviour of a colony of termites can be equated simply to the sum of the activities of its individual members. It is also quite notable that the lack of central command does not imply a lack of order; instead, it suggests that individual components are actively involved in the process of emerging order within systems. This process, which gives rise to emerging order in systems, is self-organisation.

The notion of self-organising systems, which spontaneously crystallise into an ordered state, might sound strange and unnatural, but it would appear to be nature's preferred mechanism for putting systems of various sorts together. It would seem that the various '*classes of recognisable things*' such as galaxies, organisms and ecologies have arisen in the universe through a sequence of processes that have led to self-organisation and increasing complexity (Davies, 1990, 61). It was, however, necessary for significant advances in computer technology to be achieved before scientists were able to develop a better understanding of systems where interaction among its constituents results in complex structures emerging at a higher level within the system. The human imagination though, seems to be resistant to the idea of surface order emerging from underlying disorder in a spontaneous manner and without the guiding hand of preconception. Additionally, complex systems are essentially beyond standard mathematical representation, which makes scientific analysis of such systems very difficult under any circumstances. Despite advances in computer technology, the processes of self-organisation and emergence are still poorly understood. However, through the efforts of various scientists, the field of complexity theory started to emerge as a science in its own right. Although it has not matured sufficiently for a universally accepted definition to emerge, it is thought, in general, that a complex system is one where the behaviour of the system cannot be described in a concise manner despite the presence of definite elements of organisation (Stewart, 1997, 368). As a science, there are few fields that complexity does not extend to. Biology, be it on the level of cells or entire populations, economics, physics, chemistry, all of these fields are, in one way or another, involved in the study of systems with nonlinear dynamic processes. In all of these different fields there are dynamic systems where multiple agents interact in an unpredictable way, yet through their actions, the system as a whole can spontaneously crystallise into an ordered state characterised by higher-level behaviour. From the perspective of complexity, the truly fascinating aspect of all the various types of systems found in biology, physics or economics, was the discovery that all of these systems, though differing in their components, appear to follow the same principles for the emergence of structure and order. Hence, complexity's interest extends to the level of these systems as wholes. Its focus falls

Stellenbosch University http://scholar.sun.ac.za

on the intricate relationships that develop between the constituent parts of a nonlinear dynamic system, where local interaction gives rise to complex global coherence in a fascinating interplay between complexity and simplicity. One might say that, in essence, complexity theory is an attempt to elucidate the relation between the laws of nature, which are often quite simple and the resulting behavioural patterns, which can often be very complex (Stewart, 1993, 2).

This chapter examines how complexity arises from local interactions among diverse agents and that, despite the appearance of disorder, complex systems develop recognisable structures through a process of self-organisation. It is an attempt to show that complex systems combine simplicity and complexity, stability and instability, and order and disorder within the organisation of a single system.

2.2. Complex Adaptive Systems

Complex systems are found across many different scientific fields, which make it very difficult to formulate an exact description for a complex system. Complexity is many faceted and hence has different meanings to different people from various fields of study. What is complex for one person is potentially complicated for another and *vice versa*. Also, given the variety of fields where complex systems are found, it is not surprising that such systems come in various forms. Stewart, for example, distinguishes between three different types of complex systems and each one has distinctive characteristics, which separate the systems from one another. There are spatial complex systems, which display complicated patterns, although these patterns remain unchanged over extended periods of time, as in the case of a DNA molecule. The second type of system is characterised by patterns that appear relatively simple when examined at any given point in time, but the system as a whole may in time be transformed in a complicated way, therefore it is referred to as a temporal complex system. The trading markets for commodities would be an example of a temporal complex system. The third type of system is complex both in space and time, such systems display complex patterns and are at the same time capable of producing immensely complex processes within, and a prime example of this type of system is the human brain (Stewart, 1993, 2). A system can then be classified as complex in either its construction or in its processes. Irrespective of the classification though, complexity in any system arises from rule-based interactions that develop among the component parts of the system and the environment and leads to self-organisation. From this perspective complexity can be seen as an emergent phenomenon of the large-scale patterns created by every component of the system and at all levels of interaction (Stewart, 1997, 368).

Stellenbosch University http://scholar.sun.ac.za

2.2.1. Simplicity: The Foundation for Complexity

One of the primary concepts of complexity is the concept of complex systems as interactive nonlinear wholes. Although any complex system is clearly comprised of many individual components, the system as such exists as a whole as a result of all the individual components combined. This, however, does not imply that the degree of complexity in any system is dependent on the complexity of its components. It may seem strange, but the combined interactions of a few relatively simplistic components are quite capable of producing a system of immense complexity. In terms of complexity, the degree of interconnectivity among the components is of greater importance than their own complexity. In this regard, the human brain is a spectacular example. There are few, if any, more intricate examples of interconnected systems than the human brain. Comprised of a hundred billion neurons with as many as a million times as many synapses, it is an ideal example of individual agents interacting to produce a complex whole (Greenfield, 2000, 12). At the cellular level, neurons are the primary information processing units of the brain but they are not the only cells in the brain, in fact, another type of brain cell called glial cells, actually outnumber neurons in the brain. However, glial cells do not participate in information processing in the brain, but rather perform a vital supporting role for the functioning, nourishing and protection of neurons (Purves, Orians & Heller, 1992, 817). Glial cells are, therefore, no less significant to the existence and functioning of the brain than neurons are. Yet given the context, when compared to the remarkable complexity of the brain, neurons and glial cells are somewhat simplistic both in structure and function. The most remarkable aspect of the brain then, is not the immense number of brain cells, but the high degree of interconnectivity among them. The complex character of the brain is then a result of this high degree of interconnectedness that exists between the different neurons. It is obvious that no single neuron can compare to the abilities of the brain, yet the brain and all of its abilities stem from the combinations made from simple neurons. The obvious question then is how this becomes possible.

Compared to the brain, neurons are simplistic in structure and limited in abilities, however, by itself every neuron has a sufficiently complex structure. This complex structure is of such a nature that a single neuron can have synaptic connections to thousands of other neurons, according to some estimates even as many as ten thousand (Eiser, 1994, 191). Regardless of the actual number though, it is evident that neurons have developed in such a way as to facilitate the efficient communication of information from the various senses. Communication among components is then the first step from neuron simplicity to brain complexity. However, the process of communication between neurons is also nonlinear, which means that even if a single neuron is connected to ten thousand other neurons, not

Stellenbosch University http://scholar.sun.ac.za

all of them will be stimulated into activity if that particular neuron is stimulated. The process of signal transmission between neurons is made possible by a variety of different chemicals involved. Each one of these chemicals impacts on a specific receptor in the target neuron to the extent that different transmitters have different effects on the final strength of any signal transmitted between neurons. The chemical transmission of signals within the brain is also varied in that chemicals function at varying levels that lead to different actions at different times, depending on the strength of the signal and the type of information it transmits. By using different combinations of chemicals in this way, the brain attains a very flexible and versatile structure that is based on co-operative but nonlinear interaction (Greenfield, 1997, 80 – 82). The process of neuron stimulation is undeniably nonlinear, which means that the outputs from any given circuit within the brain will not be proportional to the input. In this way, interaction and communication between neurons can have very unexpected consequences. It is doubtful whether attributes such as language abilities or the capacity for creative thinking would be possible without nonlinear interaction in the brain. In addition, the processes in the brain are also entirely self-regulating. Self-regulation follows from the immense interdependency among neurons, as a result, every process through which neurons are stimulated is dependent on the combined activity of the other parts of the brain, which are involved in the processing of a specific stimulus (Eiser, 1994, 191). Although there is still no clear understanding of how the brain's higher abilities actually arise from neuron activity, it is clear that the transmission of signals between neurons as they perform their local information processing functions is the foundation for the emergence of any higher-level abilities in the brain.

Interconnectedness is then an essential aspect of the brain's structure and functions. A clear indication of this notion is to be found in the fact that the astonishing growth that the brain undergoes after birth is not related to the number of neurons in the brain, these are, by and large, all present at birth. The growth of the brain up to the age of sixteen, when it reaches its mature size can be attributed to changes in the connections between neurons. During this phase of development, the external inputs that the brain receives from experiences with its environment plays an important role in the formation of structures in the brain. The connections between the different neurons are strengthened in accordance with activities, which are frequently performed. Hence, neurons that are used on a regular basis with regard to certain activities tend to have stronger connections with other neurons than is the case with ones that are less frequently used (Greenfield, 2000, 61). The emergence of brain complexity from neuron simplicity, therefore, builds on the communication of signals between neurons in a way that gives rise to greater organisation. If there is a sufficient

Stellenbosch University http://scholar.sun.ac.za

degree of interconnectivity, simplicity combined with nonlinear interaction can go a long way in generating structures of immense intricacy.

The description so far creates the impression that the brain is nothing more than a collection of a large number of neurons interacting in a variety of ways. The description is true, the brain is a large collection of neurons, but according to Stewart's definition of complex systems, it is not concise (1997, 368). Nor can it be, for compared to the intricacies of the brain neurons appear somewhat simplistic. A description of neurons can therefore, not encompass an accurate description of the brain. A brain can interpret images and sounds, it can remember with emotion, or solve complicated mathematical equations through the application of logical reasoning. A neuron can obviously not. A brain is capable of producing a sense of itself. Neurons have no concept whatsoever of the brain. If the brain dies, its neurons will die, but if a million or so neurons die, the brain can normally continue to function without deviation. It is obvious then that there is more to the brain than just interactive neurons, but at the same time, as complex as the brain is it, is comprised of relatively simplistic components. The emergence of complexity in a system therefore, is not dependent on the complexity of its components. A few simple units, such as neurons, interacting according to simple rules are equally capable of producing complexity. This principle is true for many different types of complex systems, and equally so at various levels of a single entity. It is within the boundaries of the overall system that intricate interrelationships develop, irrespective of how simplistic the individual components are. Complexity in any system, according to Cohen and Stewart (2000, 219), emerges from simplicity '*through the sheer multiplication of possibilities*' relating to the outcome of interaction among the components. Within complex systems, the scope for possible connections among the components can be vast, but it is dependent on the capacity of the components to interact in different ways under different conditions. Within the context of any complex system, simplicity lies at the foundation of complexity, and they are inextricably intertwined in the development of possibilities within the system.

2.2.2. Differentiation and Integration in Complex Systems

The brain is a collection of simple neurons, but it is obviously much more than that. If neurons cannot process images or produce emotion by themselves, then what is required for the brain to be able to do so? At the lower levels of a complex system, the individual components are constrained in their abilities, but the problem of individual constraint is resolved by integrating the abilities of the various individuals through interaction. In other words, the various individuals build on each other's capabilities leading to the development of sub-systems within the overall system. Within any interconnected system, the potential development of sub-systems is a very important feature. Sub-systems develop where certain components within a complex system have particularly strong connections, usually

Stellenbosch University http://scholar.sun.ac.za

as a result of certain shared properties. These sub-systems differ very distinctly from the components they are comprised of and display distinctive features, which are unique to it in comparison with the rest of the system. The development of distinct features in sub-systems adds variety to the system's structure and functional abilities. An increase in the variety of abilities within an interrelated system would therefore also contribute to an increase in the potency of the overall system. Sub-systems can therefore be seen as a very necessary condition for complexity.

If one considers the larger structure of the brain, it can be divided into three distinct regions. These are the forebrain, the midbrain and the hindbrain, which are themselves made up of different parts such as the medulla, the thalamus and the hypothalamus (Purves, Orians & Heller, 1992, 819, 820). At the cellular level, every region of the brain is comprised of neurons, which are quite similar. At the next level though, these individual neurons are organised into various sub-systems such as the four cortices within the cerebral hemispheres. At this level, the various sub-systems start to display properties, which are more sophisticated and not found at the level of individual neurons. Every region also differs very distinctly from the other regions of the brain with regard to function. One does not have to examine every part of the brain to realise that within the overall structure, there is a tremendous divergence of structure and functions among its components. This can be seen in a comparison of the functions of the four cortices located within the cerebral hemispheres. The temporal cortex is responsible for processing auditory information and the use of language, while the occipital cortex is responsible for processing visual information. The parietal cortex is involved in the processing of sensory information, which is received from the body. The primary somatosensory cortex aids this process, a region contained within the parietal cortex. The primary somatosensory cortex consolidates information received from the thalamus regarding touch and pressure sensations from the entire body, before transmitting it to the parietal cortex for further processing. The fourth one is the frontal cortex, which is involved in the stimulation of muscle movement in the body. This is done through a region called the primary motor cortex, which has connections with muscles in specific parts of the body. Yet, despite these connections the frontal cortex does not co-ordinate complex behaviour (Pruves, Orian & Heller, 1992, 822). The four cortices are largely responsible for processing information about the external environment, however, it is only when the association cortex receives and processes this information that it acquires a fuller meaning. In this region, which lies outside the somatosensory and motor cortices, information from the memory stores is added to the primary sensory information. The sequence of information processing within the brain shows a divergent distribution of functions among sub-systems and across levels of organisation. Information processing in the brain, therefore, also follows a hierarchical sequence, which leads to increasingly

Stellenbosch University http://scholar.sun.ac.za

sophisticated information processing as one moves up this functional hierarchy. This effectively enables the cerebral cortex at the uppermost level of the brain's functional hierarchy to better interpret events in its external environment (Starr & Taggart, 1989, 345). It is in the cerebral cortex, the outer grey layer of the cerebral hemispheres, that the highest functions of the brain are located. These include memory, decision-making, thinking and reasoning, but for the cerebral cortex to perform these functions, it is dependent on information from the various other regions of the brain, such as the four cortices, which by themselves cannot perform such integrated functions (Cohen & Stewart, 2000, 172).

As one studies the structural organisation of the brain, it becomes clear that within the overall system, various sub-systems are specialised to perform distinct functions. From the cellular level up to that of the cortices and even further to the level of the two hemispheres, the structure of the brain displays a very apparent divergence in functions and abilities. The divergence of function within the brain is of such a nature that neurons grouped together within one region can have stronger connections with neurons grouped together at another region located further away, than with a group located in closer proximity, but specialised for different functions. Divergence implies that within each region of the brain, various groups of neurons are specialised for processing certain aspects of stimuli, while other regions located in close proximity are dealing with other aspects of the same stimuli (Edelman and Tononi, 2000, 42). For example, the simple act of observing a green tennis ball travelling through the air relies on certain neurons in the primary visual cortex to respond to the shape of the ball while other neurons respond to its colour. After the primary visual cortex received this information, it is processed by another region of the brain that is specialised for the further processing of colour and movement. Every mental function that is performed by the brain is then the result of different parts of the brain working in parallel with a clear correspondence between any given macroscopic region and the neurons that constitute that region at a microscopic level (Damasio, 1999, 115, 116).

Despite the divergence of functions among many different regions, the brain is without a doubt a single structure, but one that is comprised of multiple layers of organisation within the overall structure. The different levels of organisation within the brain implies that units within the brain can form part of more than one sub-system, as is illustrated by the fact that the neurons comprising the primary motor cortex forms an integral part of the frontal cortex. A consequence of this organisation is that the processes that occur within the brain are the result of simultaneous actions taken by various neurons located at different places within the brain. The ability of neurons within the various regions of the brain to communicate with one another allows the brain to function in this fashion as a correlated and interdependent whole. Although sub-systems within the brain are clearly responsible for certain processes within the overall structure, those sub-systems cannot be seen as independent units since

Stellenbosch University http://scholar.sun.ac.za

their processes can only occur in parallel with the whole interactive structure of the brain. If there is a breakdown in communication between these units, it influences the functioning of the levels above, consequently the brain would not function properly. Although the brain consists of two clearly defined hemispheres, they are linked into a single structure through several connections of which the corpus callosum is the largest, but not the only one. An interruption of communication between the two hemispheres would imply that the brain would no longer efficiently function as a unit. The right hemisphere would then only exert control over the left-hand side of the body and the left hemisphere over the right-hand side, consequently any activities that require parallel functioning of the two hemispheres would be negatively affected. The large degree of interconnectedness among the different units of the brain is then a clear indication that not every part of the brain is capable of performing every function (Cazzaniga, 1998, 52, 53). Instead, the elaborate divergence of functions among the various regions is characterised by a high degree of interdependency. This interdependency leads to the integration of these functions as one moves up the hierarchy of the brain's organisation. Interaction among the various units therefore, is not only essential in systems with interdependent units, it is also a very successful way for every part to benefit from the effective functioning of the whole as the overall system increases in functional abilities and complexity. Without the integration of functions from the various regions, higher-level behaviour such as learning or language would be completely impossible. Therefore, although the various regions of the brain can be distinguished anatomically, these regions do not function autonomously, but form part of a cohesive and integrated whole, which is dependent on the elaborate divergence and integration of functions among these regions (Greenfield, 1997, 31; Greenfield, 2000, 6).

The co-operative efforts of these regions at one level enable the next level of organisation within the brain to perform its functions. Without the integration of the processing output from the various regions at a higher-level, thought processes in the brain would just be a collection of incoherent activities. At the same time these higher-level regions are more specialised. The different functions of various regions are dependent on the hierarchical organisation of units, which enables the next level of the system to perform increasingly complex functions. These functions are not possible at lower levels since neither the amount of information that is available nor the structures at that level are sufficient to enable higher-level information processing. Higher-level information processing can therefore, be described as the consolidation of multiple output signals from various lower-level information processing regions into a single coherent output. It is clear then that the incredible abilities of the brain do not reside in any specific region or unit of the brain, but is a product of the way in which the functions of various parts are integrated at various levels of the entire brain.

Stellenbosch University http://scholar.sun.ac.za

The integration of outputs from differentiated information processing units is typical of parallel processing systems. Parallel processing in any system depends on a significant amount of interconnected units involved in the simultaneous processing of information. In such systems information is distributed through various parts of the system instead of being stored at a single location, thus allowing multiple units simultaneous access to the same information (Eiser, 1994, 191). Functional distribution of this type implies that the activity levels of the various units exert an influence on the activity levels of other units. Interdependence among the various components of the brain therefore, also extends across hierarchical levels. At one level, the activity levels of sub-systems determine the activity of the next level to the extent that the activity levels of its sub-systems determine the activity levels of the system as a whole. However, the way in which the components of a complex system such as the brain give rise to increasingly specialised properties is still unclear. This follows from the difficulty presented by the correlation between lower-level interaction and higher-level properties. The most obvious example of this obstacle relates to the question of how a brain comprised of unconscious neurons can attain a conscious state of *I am*. There are so many different states of mental activities involved in any conscious experience, that it becomes virtually impossible to determine exactly at which point a person consciously experiences encountered events. Parallel processing in any system implies that it becomes virtually impossible to define the state of such a system at a fixed point when it has crossed a certain critical threshold of information distribution and processing (Eiser, 1994, 192). It is quite possible to pinpoint the various components in the brain, which are responsible for processing information about the body and how it relates to the external environment. However, even with this knowledge, the exact sequence that leads from sensory perception to a conscious experience of the body and the environment is still elusive. A parallel processing system such as the brain may be very difficult to analyse, but the segregation of behavioural activities among various computing circuits within the brain effectively allows more functions to be placed within the same structure (Cohen & Stewart, 2000, 150). The diversity of structures, which contribute to similar functions within the overall system is also immensely advantageous since it increases the potency of the brain as well as its ability to adapt to unpredictable events in its environment (Edelman & Tononi, 2000, 87). It can therefore, be concluded that optimal functioning in complex systems depends on the interaction of diverse components across various levels of organisation where the simultaneous information processing activities of the various components influence each other's behaviour at various levels within the system. This type of operation results in an integrated output in the form of coherent and recognisable structures that emerge at the levels above the interactive components.

Stellenbosch University http://scholar.sun.ac.za

Complex adaptive systems can then be described as a class of system that is comprised of multiple interactive components. The components of such systems are engaged in nonlinear interaction, which allows for the development of sub-systems from their interaction and indicates that the individual components are functionally specialised. The sub-systems that emerge from the interaction of the components exceed the capacities of the individual components. In this way, complex systems acquire increasingly sophisticated abilities at every level of functional integration. At every such level within the hierarchy of the overall system, attributes emerge that are not found at the levels below. The fact that the various sub-systems of the brain can make a difference in the functioning of the rest of the system indicates that the system is integrated at all levels (Edelman & Tononi, 2000, 130). This process of functional integration culminates at the level of the system, which effectively means that at the level of the system, complex systems are more than just the sum of their parts. It is also an indication of the inseparable character of complex systems, within the context of the system it is impossible to view the system and its components as separate entities.

Complex adaptive systems also interact with their environment. These interactions consist of energy and information exchanges, which are vital for the survival of the system since it enables the system to acquire information about the external environment. In this way, the system can gather information, which will assist it in adapting to changing conditions in the environment. To this end, diversity in the structure of the system is a great adaptive advantage, since it contributes to the flexibility of the system's overall structure. A flexible structure is adaptively more versatile than a rigid structure. However, in any complex system, the greatest adaptive feature is without a doubt the ability to gather and process information about the external environment. Within the context of survival, information becomes the key component. If a system is able to process information about its environment, its ability to respond to changes is increased by its ability to manipulate the information for personal gain (Lewin, 1994, 37, 39). Consequently, computational capacity becomes an accurate indication of a system's ability to organise itself in such a way as to ensure the best match with its environment. However, this also emphasises the importance of integrating information from various components, since if information processed among diverse components is not integrated at higher-levels, it loses its significance as an adaptive advantage to the system as a whole and the process is made redundant. All complex systems are then characterised by a specialisation of functions in diverse components, but such specialisation only acquires a functional value in the system when it is consolidated into the integrated structure of the system as a whole. If the components of the system are not integrated or specialised, the system will have only minimal complexity (Edelman &

Stellenbosch University http://scholar.sun.ac.za

Tononi, 2000, 131). The complexity of the system is therefore, closely related to the organisation of the system at various levels.

2.3. Self-organisation and the Emergence of Structure in Complex Systems

Within complex systems of any kind, recognisable structures are a certainty. What is less certain though, is how these structures emerge as a higher-level property of the system through the interactions of simple agents. The answer to this question can be related to the organisation of the system's components, and specifically to their organisation in relation to the external environment within which they operate (Johnson, 2002, 19 – 20). Since complex systems are dependent on their environment for resources, either in the form of tangible resources such as food, or intangible resources such as information, it is evident that the environment has a significant impact on the organisation of the system's components. Self-organisation then refers to the way in which the components of a system arrange themselves in such a way as to facilitate the best possible match between the structure of the system and the environmental conditions to which the system is subjected. Structure in a complex system then becomes a consequence of self-organisation, which in turn, follows from interaction between the various components and the conditions prevailing in the environment.

The importance of the environment in the evolution of complex systems extends the sphere of interdependence beyond the components of the system to incorporate the components of the environment as well. In this way, the system and the environment evolve together. Although environmental influence on complex systems is a familiar concept that abounds in nature, the exact extent of environmental impact is more obscure. The nonlinear nature of complex systems distorts the correlation between any given cause and its effect with regards to the impact that environmental conditions may have on complex systems. Interaction in complex systems is then subject to time delays, which shrouds the notion of cause and effect in obscurity. This immediately adds an element of unpredictability to the evolution of structure in complex systems. If one takes into consideration that environments are constantly changing as well, then one is confronted with a situation where complex systems are responding in unpredictable ways to influences that are also unpredictable in that they are removed from their cause. Consequently, it is very difficult to predict the structures that can emerge in complex systems since neither the future conditions of the environment is known, nor is it possible to know how the system will react to any changes in the environment. The emergence of structure in complex systems should then be seen as an unpredictable consequence of interaction between an interdependent system and environment. In this regard, self-organisation is the process that leads from changing environmental conditions to the emergence of new structures as an adaptive response.

Stellenbosch University http://scholar.sun.ac.za

2.3.1.Self-organization in Complex Systems

Complex systems owe their structures to the integration of its components. In most complex systems, the components differ very distinctly from one another with regard to form and function. Each component within the system is actively pursuing its own ends, which effectively makes the dynamical behaviour of the system immensely more complicated (May, 1981, 197). At the level of individual components, complex systems can appear quite the opposite of organised and structured. It is, however, important to bear in mind that individual components, even while pursuing their own selfish ends, are doing so within the context of a shared environment. Individual components are not isolated from each other, but form part of an overall whole. It is within the constraints of the overall system, be it an ecology, an economy or a colony of insects, that collective behaviour of individuals shape the structures, which become apparent at the level of the system.

Complex systems, as dynamical systems, are typically structured to facilitate a flow of resources from one part of the system to other parts. The structure of any organism, for example, is of such a nature that nutrients can be spread from the digestive system through its entire body. However, the organism is also dependent on its environment for those nutrients and in that dependence lies the foundation for self-organisation. As each organism goes about in its quest for survival, it forms part of a flow of energy through all layers of the ecology to which it belongs. The primary source of energy for anything on this planet is of course the sun. Within a community of organisms, plants then become the primary intake points of energy from the sun and from there, it becomes available to other members of the community. The myriad of herbivorous creatures which feed on plants, extending from insects all the way to larger organisms such as antelope or zebra form the next stage of the flow of energy through the community. As prey for carnivorous organisms, the flow of energy is extended from herbivores to carnivores and insectivores. Waste from all organisms within the community, including the remains of organisms that have died, form the final stages for the flow of energy. At this point, dung beetles or burying beetles recycle vital chemicals, which are contained in the waste or remains of animals, before it is finally made available again to plants through soil bacteria (Dawkins, 1997, 245, 246). The flow of energy through any community of organisms is therefore, very necessary for the survival of the organisms within that community. At the same time, without the organisms comprising the community, the flow of energy cannot exist. In terms of complex systems, it then nonsensical to see the system and its components as separate from each other.

Stellenbosch University http://scholar.sun.ac.za

There are a number of significant aspects about the flow of energy through ecological communities. One of these would be the appearance that the structure of the community is so well adapted to facilitate such a flow as to seem the result of an intended design. This is, in fact, not the case at all. The structure of the community is an unintentional consequence of the way the different organisms interact with one another. At no point in this flow of energy is there any organism that willingly wants to pass on energy from itself to another organism since, under most circumstances, the energy flow implies the demise of the source of energy. However, despite the obvious risk involved for any individual organism, the benefits of forming part of this flow of energy are effectively beyond measure. Life outside of this flow is not possible. It is then quite obvious that no organism is involved in this flow for any other reason than its own personal gain. Any benefits that they might add to the broader community through the continuation of this flow, is purely incidental (Dawkins, 1997, 246). The community as such is also an unintended outcome of this flow of energy. It goes without saying that none of the organisms intended to develop a community where a flow of energy among species can be facilitated so that the organisms can share in the benefits of such a flow. The community, with its flow of energy, is made possible entirely through random interactions among individual organisms. That is a result of self-organisation.

Another notable aspect of the flow of energy through communities in ecologies is that the description seems one of perfect stability. Energy will flow from plants to herbivores to carnivores and back to plants and the result is a stable community of organisms. The interaction between different types of species, i.e. vegetation, herbivorous or carnivorous, that comprise the community is therefore, organised and to a certain extent predictable. This follows from the fact that interaction within the system is subject to certain constraints that is in place as a result of the organisation of the system. All organisms within the system fill certain niche roles. This becomes apparent at the level of species, where classifications can be made such as hunters, scavengers, or herbivores. Once it becomes clear how these different types of species interact with one other, it becomes possible to discern recognisable patterns in their interaction. Different organisms from the same class will display similar behaviour under similar conditions. If one can then identify the patterns of behaviour among the various classes of species, the systems to which they belong become predictable to a certain extent. Therefore, at species level, one can say that foxes will eat rabbits, but at individual levels, it is uncertain which fox will eat which rabbit. That is determined purely by random interaction between individual organisms. The predictability of species interaction is therefore, constrained by the unpredictability that characterises individuals interacting. The stability, and hence predictability, of large-scale structures in complex systems is further constrained by the number of individuals

Stellenbosch University http://scholar.sun.ac.za

interacting within the system. To this end, it can be said that increased complexity, in the form of an increased number of components interacting within a shared environment, works against the notion of stability in the community (May, 1974, 172). At individual levels, the pattern of behaviour in the system is characterised by random interaction, but there is nothing random about carnivores consuming herbivores. The organisation that emerges in the system is therefore, at the level of species and above. Complex systems can then be said to incorporate elements of order and randomness within a single structure, which makes the system stable and predictable at the level of the system, but unstable and unpredictable at the level of individuals (Stewart, 1997, 368). Since the interaction of individual components is the foundation for the emergence of structure in a complex system and these interactions are unpredictable, it follows that the emergence of structure in a complex system will be unpredictable. The consequences of interaction between various components cannot be determined in advance. It is only when the structures that emerged from these interactions have been established as part of the system that one can start to recognise certain predictable aspects in the system's behaviour. Prior to this though, it is impossible to predict the consequences of interaction between individuals within the system. The unpredictable behaviour of individual components within complex systems implies that it would be quite impossible to attempt a description of a complex system based only on individual behaviour. The complexity generated by the interaction of individual components is simply too overwhelming to yield any sensible description of the system beyond the notion that individual components that interact can generate tremendous complexity in systems. It also becomes clear that with a greater number of interacting components, the system is also inclined to decrease in structural stability, as the interactions between the components will continuously alter the relationships among the various components. As such, the dynamical behaviour within the system will display increased instability. Persistent instability, though, would prevent the system from developing the coherent structure, which is a prerequisite for the system's endurance. It is then essential for the existence of complex systems that there should be some mechanism for collapsing the chaotic interactions among diverse components into a single structure and so afford the system long-term stability. This collapse of chaotic interactions into stable recognisable structures is effectively accomplished through self-organisation. Self-organisation therefore, is a means of bringing order and structure into a system.

The external environment also largely influences the flow of energy through a community of organisms. The total niche volume available in the environment determines the total number of species that can comprise the community. Variety of typical species within the community is in turn determined by the effective niche volume that is available to species

Stellenbosch University http://scholar.sun.ac.za

of certain types for exploitation (May, 1974, 175). Environmental conditions are therefore, very important in terms of the emergence of structures within the community. By influencing the variety of species that can exist within the community, the environment is in effect influencing the structures that can emerge in the system from the interaction of species. The community will therefore, evolve in close relation to its environment. Complexity therefore, involves both internal and external influences (Lewin, 1992, 148). To this end, the structure of complex systems retains a reference of its interaction with the environment. Although, given time this reference is likely to become obscure. The obscuring of the environment's impact in no way diminishes the importance of the system's history and is instead an indication of the system's capacity to learn about its environment, to act on relevant forces, and to 'forget' the ones that are of lesser significance. Organisation within the system requires some form of selective learning, for without selection, the system would be unable to stabilise its components. The impact of the environment on the structures of complex systems and the system's reaction to the impact is then visible in the numbers and different types of species within a community. From this, one can deduce that the emergence of structure in complex systems is greatly dependent on a suitable match between the system and its environment. Mismatch can, among other things, result in the demise of the system. If the flow of energy within the community is disrupted at one point along the line, it influences all other components with detrimental consequences to the system as a whole. However, self-organisation appears to prevent this from happening by rearranging the components of the system whenever changes in the environment require the system to adapt. As such, the ability to learn about the environment and to act accordingly makes complex systems vivaciously adaptive phenomena.

The final significant aspect about the flow of energy through the community is that it remains unchanged despite the various types of changes that the community undergoes. This is due to the fact that the flow of energy is not an attribute of individual components or even individual species, it is an attribute of the community. Any ecology exists as a result of the species that inhabit it, without those species, there is no ecology. Yet, different aspects of the ecology change as the species that inhabit it change. But the ecology will not change if a tree somewhere falls over or a butterfly migrates into the region. The reason for this is rather obvious. Ecologies are not made up of single organisms, they are instead organisations of entire interacting species (Cohen & Stewart, 2000, 367). To this end, individual components are expendable, because they change on a regular basis. Whether any given organism dies is irrelevant, if there is an identical one to replace it. This is the basis for the perpetuation of species. If one accepts species as the fundamental organisational components of an ecology, it means that the perpetuation of species

Stellenbosch University http://scholar.sun.ac.za

results in the perpetuation of the ecology. But even if an entire species becomes extinct, it will not undermine the community if there is, and there usually is, another species that occupies the same niche as the extinct species. The components of an ecology are constantly renewed, but the ecology as such remains unchanged despite the flow of components. From this perspective, one can describe an ecology as a fluent entity. The structure of a complex system is, therefore, not dependent on the individual components or the number of components in the system *per se*. Components come and go and their numbers vary, however, what does not change is the organisation of these components in the context of the system (Goodwin, 1995, 36). Within the ecology, herbivores will still be dependent on vegetation, carnivores will still be dependent on their prey, and all species will be dependent on a means for perpetuating their existence. The structures that develop through these relationships are the emergent structures of an ecology. These relationships extend beyond individual organisms, and as such, become properties of the system. Self-organisation and emergent properties are therefore, indicative of higher-level behaviour that arises within the system. Higher-level organisation in complex systems is a way of creating large-scale visible patterns on the level of the system through the integration of individual interaction. These are the attributes of complex systems that develop on the level of the system where they are clearly discernible and possible, although they are not implicit in any of the individual components (Cohen & Stewart, 2000, 231). Therefore, when referring to structure in a complex system, one is referring to a state of organisation that has emerged as the coherent result of the combined activities of interacting components. This type of higher level organisation reflects the intentionless order that emerges at the macro-level of the system and is an indication of the interdependency that exists among a variety of components that share a specific region over a specific period of time (Khalil, 1999, 11, 18). Emergent structures, as a consequence of self-organisation, can then be described as the simplifying of the complexity that is generated by a variety of individuals pursuing their own ends (Cohen & Stewart, 2000, 232).

Self-organisation then is the process that leads to the emergence of ordered structures at the level of the system where random interactions among components generate disorder at the level of components. Through self-organisation, definite patterns of organisation start to emerge from within the system, although these patterns are only visible at the level of the system. This tendency towards the creation of recognisable patterns in a system suggest that complex systems tend to simplify the underlying complexity at individual levels, and that this simplification results in emergent properties at the level of the system (Stewart, 1997, 368; Cilliers, 1998, 90). Self-organisation, in itself, is then an emergent property of the system as a whole. It is an indication that in complex systems, the unitary operation of the system is of greater importance than any of the components and as such, the system

Stellenbosch University http://scholar.sun.ac.za

determines to a large extent what takes place within its boundaries (Luisi, 1993, 19, 20). It becomes clear that on the level of the whole, a complex system displays properties, which are not found in any of its components. At this level, the properties of the system are beyond those of its components, and often it can be very difficult to relate these properties to any of the components. Despite the remarkable insight that the study of complex systems have yielded thus far, there are still numerous aspects about complex systems for which the science of complexity has not yet been able to find plausible explanations. Among these are how the brain creates the conscious mind from unconscious neurons, or how the components of a developing organism generate its form. The emergent properties of complex systems are the defining properties of these systems, but they are also the most poorly understood attributes of complex system.

2.3.2. Emergence: From Complexity to Simplicity

At the foundation of all complex systems, one finds relatively simple components interacting in various ways. The simplicity of the components though, becomes lost in the complexity of their interactions. Yet, when one looks at a complex system, the appearance is invariably one of a single coherent entity. It is a recognisable structure. Despite the complexity generated by the many components of an organism, the organism itself appears quite simple and to a certain extent predictable. Organisms are born and, with a certain amount of luck, they will mature and reproduce before eventually dying. They will interact with other organisms and be part of a flow of energy through a community interacting species. The apparent simplicity of the overall system forms part of the most puzzling aspect of complex systems, namely emergent properties. Emergence is the philosophical core of complex systems. It is the concept that bears testimony to the fact that at the level of the system, complex systems exceed the capacities of their components and the whole becomes more than the sum of its parts (Stewart, 1997, 367). The conscious mind illustrates this point immaculately. In the region of a hundred billion neurons in the brain, none of which are capable of a conscious experience. The capacity for consciousness is therefore, an attribute of the brain, an emergent property that cannot be traced to any of its components. It starts from the complex interaction involving the many different units in the brain's neural network and emerges from the rapid selection of the most appropriate coherent state from a large repertoire of possible states for the individual units within the active neural network (Edelman & Tononi, 2000, 134). In between the activities of neural networks and conscious experiences is something that is as yet not understood. Scientists are beginning to understand that emergent properties are the end results of random interaction, and as such, they indicate that the chaos produced by random interaction has collapsed into new simplicities. Emergent properties in complex systems are examples of order that emerges from chaos. Although emergence

Stellenbosch University http://scholar.sun.ac.za

is currently a poorly understood concept, it is the most important indication that numerous interacting agents, which are seemingly lost in incomprehensible chaos, can spontaneously develop properties that are neither implicit in any of the individual components, nor predictable from their interactions (Cohen & Stewart, 2000, 232). Emergent properties in complex systems have no single cause. Emergence is then also evidence that in nonlinear composite systems, the activity within the system is not just a sequence where one event follows another, but is part of a process where every action contributes to the incidental existence of something larger within the system. It illustrates the convergent nature of complex systems.

The concept of emergence has also forced the realisation that current scientific methods are inadequate to conclusively answer questions about the consequences of interaction between two or more rule-based systems. At the level of systems, new high-level regularities emerge from their interaction, which result in the creation of new possibilities for the development of both systems. These possibilities did not exist prior to interaction, as such, there is no way to anticipate it. The rules that emerge from new interaction between these systems were not previously contained in the rules of either system. These rules only came into existence once interaction between the systems occurred. From the point of interaction and onward, the two systems will co-evolve in ways, which were impossible and inconceivable up to the moment of their interaction (Stewart, 1997, 381, 382). Since there is no way to predict the rules that will emerge from the interaction between two complex systems, there is also no way to predict or prepare for the consequences of their interaction. Co-evolution of this type abounds in nature where species develop certain attributes as a direct consequence of their interaction with other species. This phenomenon is widely known as 'arms races' between species. It closely resembles the type of reciprocal antagonistic behaviour that is displayed between hostile nations where every nation expands its respective arms in response to expansions made by other sides. The actions of any one side force reactions on the part of the other sides, which in turn necessitate a further response from the first actor. The result is a vicious circle with an unpredictable outcome. A significant aspect of co-evolution among species though, is the lack of clear advantage gained by any species despite the increased sophistication of evasion or predatory skills. Through co-evolution, species effectively shape their own fitness landscapes, and this landscape, despite the instability of individual interactions, is characterised by constant stability and increased complexity. In certain cases, co-evolution can change the attributes of the components and leave the landscape stable, but in other cases, co-evolution not only changes the attributes of the components, but also destabilises the entire landscape. Emergence therefore, is by no means always associated with stability in complex systems. The rules emerging from new interaction

Stellenbosch University http://scholar.sun.ac.za

between two systems can effectively destabilise the entire system. This instability will persist until the system is able to adapt existing structures to new emergent ones. The alternative to adaptation of existing structures is extinction, therefore, the collapse of instability through emergent structures is a vital attribute for survival. Emergence then is the point where instability gives way to stability, and regularity develops from random interactions. This in effect boils down to the creation of new rules governing the interaction between all the affected agents. The creation of new rules following the interactions of two or more complex systems makes prediction in any complex system a risky affair. At the best of times, it is exceptionally difficult to predict emergent properties even with a fair understanding of the system's rule for interaction, but predicting outcomes becomes impossible when there is a total lack of knowledge about the rules governing interaction between components or systems. This is a tremendous challenge for proponents of complex systems theory, for what is the use of a theory claiming that individual components can generate incomprehensible complexity from which regular and stable structures can emerge, but without being able to explain or predict how it happens.

Complexity has a long way to go to prove itself as being a worthwhile development in science. Many of the discoveries made by complexity scientists regarding the behaviour of complex systems are the result of intense simulations done on computers. The complexity of real systems such as the brain or entire communities within ecologies yields so much information and would take up so much time to interpret that it is questionable whether it would be worth the effort. Computer simulations are faster, which is an advantage, and because the simulations are designed around the rules of interaction within the system, it cuts through the complexity generated by the individual agents. This allows the researcher to see the patterns of organisation that is generated within the system. It also yields better insight into the loops that exist among various components and how these influence behaviour within the system. In this end, computer simulations also assist in showing the unintentional outcomes of interaction under conditions where feedback is an important attribute of the system. However, this has resulted in people questioning the validity of the relation between the results of simulations and the actual verification of their results in real world systems. Additionally, the results of computer simulations are sometimes very contradictory to what people intuitively believe about the world around them. For most part, humans would like to believe that it is possible to develop general ideas, which can be applied to nearly similar situations. It is a comforting thought to believe that it is possible to understand everything about the world we live in, and that we can attain certainty about something by gathering more information about a subject when we are confronted by uncertain outcomes in that subject. Complexity challenges this notion by showing that nonlinear systems cannot be perfectly understood by gathering more

Stellenbosch University http://scholar.sun.ac.za

information about the components of the system. As such, people are often resistant to the ideas of complexity. People simply don't feel comfortable with the idea of uncertainty, and as it is, uncertainty is an unavoidable part of systems characterised by nonlinear feedback loops. The idea of order emerging from chaos sounds fashionable, except for the part where the theory claims that chaos does not go away. Complexity forces the realisation that ambiguity is part of nature and that it is embedded in natural systems, but also in the social structures that humans have developed. It is part of any system where individual agents have a substantial degree of freedom in terms of choices for interaction, but where the choices exercised by individual components result in reactions on the part of other components. Complexity has led to the realisation that a single system can incorporate stability and instability, regularity and irregularity, large-scale predictability and micro-scale unpredictability, and coherence and incoherence alongside one another. It has shown that complex systems behave as a multiplicity of individuals or as a single entity, and it does so in a way that makes it impossible to separate the system from its components or *vice versa*. However, complexity has also shown that in a constantly changing environment, it is an advantage to be as complicated as possible and that complexity bound within a stable structure is a huge evolutionary edge (Stewart, 1993, 3).

2.4. The Edge of Chaos

Complex systems appear to develop naturally towards a state where complexity of interaction is balanced with structural stability. This region between stability and instability is popularly known as 'the edge of chaos'. It is called the edge of chaos because it is a state where complex systems hover on the brink of structural collapse without actually doing so. It appears that the system is driven towards the edge of chaos through learning or selection, and that it is at this point, the edge of chaos, where complex systems display maximum computational capacities and optimal adaptability. It is in this narrow region between order and chaos that complex systems achieve the greatest potential for productive change (Lewin, 1993, 11). The system is at its most vibrant when it is poised at the edge of chaos with the creative freedom of individuals enabling the system to change without the need for an external driving force behind their efforts. At the edge of chaos, the processing of information about the environment by individual components changes their behaviour as each one learns and reacts to the environment and the actions of other components around them. The swift flow of information at the edge of chaos enables the components to evaluate how other components responded to their actions, and to subsequently adjust their own actions in response to the reactions of their neighbours. At this point, information processing results in the emergence of new patterns within the system as all the components within the system adjust their actions to the actions of surrounding components. The ability of individual components to rapidly produce new

Stellenbosch University http://scholar.sun.ac.za

structures in response to changes in their surroundings effectively allows the coherent structure of the system to endure amid changing environmental conditions. To this end, individual freedom contributes significantly towards the survival of the overall system. Each individual explores their surroundings, learning from and reacting to experiences as they are encountered. The surrounding components are influenced by changes in other components, and also adapt under the influence of adaptations by their neighbours. As every individual component adapts to their surroundings, the system as a whole also changes in an adaptive way as a result of changes in the components. The individual actions within the system generate tremendous complex patterns, but these patterns are a creative attribute of the system in the sense that the future state of organisation within the system emerges from the collective behaviour of all the components at that point. The edge of chaos therefore, represents the point where information processing forges organisation from chaos.

It is effectively an act of adaptation on the part of the system, since as each individual component becomes better adapted for its environment, the system becomes better adapted for its environment. As such, adaptation of the system to its environment is a consequence of the adaptation of every individual component that the system is comprised of. At the edge of chaos, the freedom that individual components have becomes an advantage for the system's survival, for at this point, information flows freely through the entire system and begins to gain the upper hand over energy (Lewin, 1992, 51). The edge of chaos therefore, represents a critical point for structural evolution in complex systems. At this point, positive feedback drives the system towards instability and creates conditions where small inputs in the system can have large outcomes (Lewin, 1992, 51). However, because the system reaches maximum computational capacity, information processing resulting in emergent properties prevents the system from total structural collapse. The role of information processing then becomes a critical factor influencing the structures that emerge from complex interactions at the edge of chaos. In a way, the act of sense making stands between the system and structural chaos. Learning within complex systems therefore, represents a critical point of control within the system. As such, evolution to the edge of chaos as the point where computational capacity is at an optimal level, is an important part of the survival of complex systems.

Information processing in the components of the system is limited to information about their immediate environment and their neighbouring components, which implies that components within a complex system have a very limited range of influence. However, this short-range transfer of information ensures that individual components are not inundated with information that may potentially be irrelevant for their existence. To this end, the diversity that exists on the part of various types of components is also an

Stellenbosch University http://scholar.sun.ac.za

important attribute for systems poised at the edge of chaos. A greater diversity of components effectively allows for a broader distribution of information processing among the different types of components. Although an increase in the types of components that interact also results in a decrease in structural stability, the increased complexity that emerges from their interactions is essential for the evolution of possibilities within a complex system. Increased diversity that leads to increased complexity is in essence a catalyst for increased creativity among the interacting components.

The system's creativity is reflected in the networks that develop from interaction at the edge of chaos. It is an indication that connections between the various components are at an optimal level for creativity in generating structure and organisation. If individual components shared connections with too many other components, the system would be in a constant state of chaos as every component attempted to deal with the overflow of information. The system as such would then be prevented from developing stable structures, which ultimately, would result in the structural collapse of the entire system. However, at the edge of chaos, the networks that emerge between components sharing particularly close connections and interaction between different networks compensate for the limited range of information transfers between individual components. The networks of interactions that emerge among the components of the system then become of vital importance for the structural stability of the system. The stability that emerges from the collective dynamics of all the interacting networks prevents the actions of any single component or network from collapsing the organisation of the system into chaos. These networks form the transition between the incoherence of individuals interacting and the coherence of a stable structure and as such, constitute the balancing act, which characterise complex systems poised at the edge of chaos. In effect, control over the system is then made possible through the emergence of multiple networks of interactions among a variety of different components as each component processes and responds to the information that is locally available to it (Lewin, 1992, 51). The various components that comprise each network within the system act to regulate one another's behaviour to the extent that control within the system is highly dispersed. This dispersed nature of control within the system though, effectively allows the system to rapidly change from one state of organisation to another state at every point where it is required. The edge of chaos as the state where information processing and adaptability are at an optimal level therefore, appears to be the ideal state for complex systems to exist at and thrive in an environment that is uncertain and constantly changing. At the edge of chaos, systems are at an extreme complexity with a fine balance between stability and instability. At this point, flexibility within the system stops short of rendering the system without structure, but for

Stellenbosch University http://scholar.sun.ac.za

adaptive purposes in an ever changing world, it an ideal state to be in (Stewart, 1997, 370).

The edge of chaos as the preferred state of existence for complex systems emphasises important aspects regarding control in complex systems. It emphasises the important role of information processing and learning by the components of the system. To this end, it is in the system's best interest to be in a state where the flow of information through the system is of such a nature that the various components can easily gain access to the information they require. The edge of chaos also emphasises the flat hierarchy that characterises organisation in complex systems. This flat hierarchy affords individual components and networks a large degree of freedom in their choices of interactions. This freedom of choice in interactions benefits the system in that as each component or network pursues its own individual ends, they are essentially ensuring the survival of the system. However, the networks that emerge among components are an indication of the importance of diversity as a means of controlling the system at the edge of chaos. A larger variety of types of components are accompanied by an increased number of potential networks that can emerge. The edge of chaos is the point where interaction among components generates creative structures from the choices made by the various components and if the potential number of structures that can emerge is increased, then the system becomes adaptively fitter. Diversity works for the notion of creativity, and with creativity forming an essential part of adaptive behaviour, the significance of diversity becomes apparent (Stacey, 1996, 99).

2.5. In the Face of Uncertainty

Complex systems theory emphasises uncertainty as an unavoidable part of all nonlinear composite systems. It explains that unpredictable behaviour can emerge from the interactions of interdependent components within a shared environment irrespective of the system or the components. It shows that interacting agents can produce stable properties within systems, and that the ability to generate such structures implies that interacting individuals can shape the environment around them. As such, many of the discoveries regarding the behaviour of ecologies are resonating with recent perspectives in economic thinking. Some people have come to see organisation in economies as species interacting within an ecology. In both ecologies and economies, the interactions of individual agents are responsible for creating large-scale regular patterns, although underlying these patterns are unpredictable events that occur as a result of the interaction among components. The future state of an economy is therefore, just as unpredictable as the future state of an ecology, and for much the same reasons. Like ecologies, economies are nonlinear composite systems with elements of feedback. Organisations operating in economies form part of networks of interactions, and in the rapidly changing informational

Stellenbosch University http://scholar.sun.ac.za

economy, these networks have become tremendously complex as organisations constantly adapt their products, strategies, and alliances in an attempt to prevail under variable conditions (Lewin, 1997, 32).

Complex systems theory is an attempt to understand how the structures that are visible in nonlinear dynamic systems are formed from the interactions of different types of components and what is responsible for different types of systems displaying similar properties. This focus on the understanding of organisation within systems is a key attribute of complexity. Although it is impossible to control complex systems such as an economy, it is possible to exert a measure of influence on the system if one understands the nature of interrelationships among the components. Influencing though is not to be confused with control. Because complex systems are the result of many different components interacting, it follows that no single component can control the system, which would constitute one component dictating the behaviour of all the other components. Feedback in effect makes this impossible. The components are sensitive to each others behaviour and the interdependence that exists among these components creates conditions where any action by one component X can have a negative impact on another component Y. Consequently, if component Y is of significant importance for component X's survival, any action taken by X that negatively impacts Y, will be to X's detriment. Even if components are not directly linked to each other, the interdependence among all the components implies that at nothing in a complex system happens to one component in isolation from the rest of the components. Complexity as such, explains patterns of interrelationship among interacting components, but it does not attempt to predict the consequences of interaction.

The value of complex systems theory lies in the insights it generates regarding patterns in organisation. Since many of the patterns that emerge in complex systems are in one way or another valid across various types of systems, it is useful to understand the nature of complex systems as a class of system. To this end, many of the images that have appeared about patterns of behaviour in ecologies can be of use for organisations in economies. Through understanding of the actions of components living in uncertain conditions, one can learn from it and attempt to incorporate elements such group learning within a system, flexibility, dispersed control, and adaptability into organisations in economies. These concepts are not necessarily new to organisations in the global informational economy, but their implications are as yet, relatively poorly understood. The next chapter examines the application of complex systems theory as a means for strategic and competitive advantage in the uncertainty of the information economy, and takes a look at how systems thinking in organisations can change the perspective people have of the dynamics of organisations.

Stellenbosch University http://scholar.sun.ac.za

Chapter 3

Perspectives on the Application of Nonlinear Systems Theories to Organisational Thinking

3.1. The Economics of Uncertainty

Traditional economics contains a notion called perfect rationality. The principle of perfect rationality maintains that in any economy, all agents have access to all the information that they require in order to make sensible strategic decisions on which the long-term future of that agent can be based. Certain reservations are made to accommodate adjustments as a result of unforeseen external interference, but these are not considered to be a reasonable threat to the long-term stability of the agent's future. Perfect rationality is based on the belief that economies are stable equilibrium systems, where everyone is able to reasonably predict the actions of any competitors in their industry. Perfect rationality though, is not taken seriously, but the concept that has given rise to perfect rationality is accepted. People feel comfortable with the idea that economies are stable, even though certain unforeseen events can cause havoc with that stability, it is believed that an economy will eventually return to equilibrium (Arthur, 1993, 7). The informational economy though, is not at all conducive to this type of reasoning. In the informational economy, the large influence of technology has drastically altered the perception of stability and equilibrium, since technology changes regularly and unpredictably so. New technology also changes the economic environment as a whole in unpredictable ways. Technology has the potential to create a new industry, or to eliminate an old one with little or no warning. The internal operations of the global economy is anything but certain and predictable. Even the application of information by one agent within an economy deprives the other agents of certainty, since they do not know what information is available to other agents, nor do they know how these agents will interpret the available information. Another aspect of the global economy that reinforces uncertainty among individual agents is a lack of understanding of how their own actions that are perceived as beneficial in the short-term can potentially be harmful to them in the long-term. Interdependence in the global economy implies that agents have to know how their actions influence not only their competitors, but also their co-operators. In the global economy where organisations can have a global base of operations, organisations develop along with other organisations, and whatever influences one, will influence the others too. The global economy of the 21st century has a distinctive biological appearance to it. Instead of organisations competing with other organisations in a one-to-

Stellenbosch University http://scholar.sun.ac.za

one manner, images are emerging of clusters of organisations that are constantly adjusting their strategies, products or management styles in an attempt to stay ahead in an economy that is continuously changing under its own influence. Information and technology has made the modern economy an untidy place to operate in, and it has changed the image of the organisations that are operating in the global economy. The image of today's organisation is one of adaptively intelligent agents, constantly looking for patterns within the mess of interacting agents. Today's organisations are generating information at an accelerated pace, they are constantly testing ideas in their industry, evaluating how their actions are influencing the other agents and reacting to reactions by other agents. When their world changes again, those ideas are discarded and the process starts again. In the global economy, organisations are constantly learning and constantly evolving (Arthur, 1993, 8). They are doing so in conjunction with other organisations in an interdependent environment that is shaped and reshaped by the actions of each agent operating within the economy. Under conditions where individual agents are actively shaping their environment, and where the information that is available to each agent does not include the reactions of other agents to their actions, it is impossible to know how the future of that system will look. The global economy of the 21st century has all the hallmarks of a complex adaptive system. If that is the case, then the implications for organisations operating in the global economy are profound. For one, the whole linear way of thinking about organisations and economies has to be evaluated. Organisations will have to embrace a way of thinking that emphasises the interrelationships and patterns that emerge in economies. The focus should be on seeing the bigger picture and where we fit into this bigger picture. The organisations that will succeed in the interdependent global economy will be the organisations that have mastered the art of sustained learning.

The concept of systems thinking has been around for some time and a number of authors have made valuable contributions to various aspects of organisational thinking in terms of complex systems theory. This chapter will examine the work of three authors relating to complex systems theory as a means for understanding the dynamics at work in organisations and their environment, as well as the implications of complex systems thinking for leadership in learning organisations. The focus will be on the work of Peter Senge, Ralph Stacey and Margaret Wheatley.

3.2. The Learning Organisation

The tremendous drive for information has given rise to the concept of learning organisations. Organisations are becoming more and more shaped around information gathering and processing, and applying the knowledge gained to their daily routines. To this end, organisations have to find new ways for learning. These ways have to complement individual learning with group learning. In the global economy, it is no longer sufficient to

Stellenbosch University http://scholar.sun.ac.za

have one person in a group doing the learning and strategy formulation. Under the intense uncertainty of the informational economy, group learning is the only way to thrive in an ever-changing environment. Organisations are then becoming agents of learning themselves, displaying a type of behaviour that is similar to the behaviour of an organism. Organisms adapt to their environments through learning, and they continue to learn about the environment each time it changes. The learning organisation is part of a complex web of interactions in the economy, but at the same time, organisations are the result of complex interaction on the part of its components, the employees. Just like the structures in the human brain are constantly altered as the brain learns and adapts to its environment, so too, are the interrelationships among employees capable of adapting if circumstances require them to do so. The importance of continuous learning in organisations is clear but in the process, the interrelationships that exist between employees as the fundamental resource of the organisation are emerging as a fundamental aspect of organisational development. The abilities of employees are at the core of an organisation's capacity to develop, to learn and to adapt. To this end, it is important that organisations embrace a perspective that encourages people to see themselves as part of a system that is functioning within a larger system. It is important to understand how the actions of individuals influence both the behaviour of other individuals and of the organisation, and how the actions of the organisation influence other organisations within their environment. The learning organisation is built on the concept of wholeness, where new and expansive patterns emerge from the awareness of interdependence among agents and where collective aspirations are encouraged. With this perspective, it becomes possible to create conditions where people can learn how to learn as a group. This systems thinking perspective is fundamental for the development of a learning organisation (Senge, 1999, 3). Learning within an organisation, however, has to extend beyond merely becoming familiar with information, to actually leading to a change in the behaviour of the organisation and the people who comprise the organisation. A basic aspect of learning in complex systems is that it leads to changes in the system. Adaptation occurs as a result of learning. To this end, Peter Senge has developed five disciplines, which are intrinsic to an organisation's capacity for adaptive learning.

3.2.1 The Five Disciplines of The Learning Organisation

For Senge, success in a learning organisation depends on the incorporation of five disciplines in the learning process of the organisation. These five disciplines are systems thinking, personal mastery, mental models, building shared visions, and team learning. It is however, of vital importance that these five disciplines are practised in unity within the organisation, since each one builds on and complements the values of the other four.

Stellenbosch University http://scholar.sun.ac.za

A systems thinking perspective is responsible for changing people's perception of events as isolated or unrelated to perceiving the world and events around them as intrinsically indivisible and interconnected. Systems thinking in organisations enable people to see how different events influence one another in various ways, and how events can often take a substantial amount of time to play out their effects on various other aspects of the system. Systems thinking is intended to reveal the full patterns that exist among interrelated components within a system and to assist people in seeing how they can effectively facilitate changes in those patterns. Systems thinking is then about seeing the bigger picture in a world where events and consequences can become separated in time and space (Senge, 1999, 7).

Personal mastery refers to the attainment of a special level of proficiency among employees. Although it is dependent on the efforts of each individual, the advantages for the organisation follow from the group wide practising of this discipline. Personal mastery among individuals enables them to realise the results that are most important to them and to continuously do so. Personal mastery though, requires a commitment to lifelong learning on the part of the individual. It literally becomes a process without an end. However, this commitment should lead to the continuous clarification and deepening of personal vision. It enables an ongoing focus of energy, cultivates patience and encourages people to see reality from an objective point of view without losing their concept of being part of that reality. An organisation's commitment to and capacity for learning is connected to the commitment and capacity of its employees, to this end, the discipline of personal mastery is intended to facilitate a deepened reciprocal commitment between employees and the organisation, and *vice versa*. Personal mastery is beneficial to an environment comprised of committed learners (Senge, 1999, 7, 8).

The third discipline pertains to the mental models that people have of the world around them. These mental models are influential in the perception that people generate about reality and how they should act within that reality. The success of the learning organisation depends on the capacity of managers to change their mental models of '*the company, their markets, and their competitors*' in an environment that is continuously changing. The organisation's capacity to continuously adapt and grow is therefore, dependent on the capacity of its employees to learn how to share their personal views of the world and to continuously question those personal views in relation to the world around them. In so doing, people share their own perceptions with others in such a way as to open it up for influences from other people (Senge, 1999, 8, 9).

The fourth discipline is building a shared vision. Shared vision is fundamental for encouraging people to '*excel and learn*' based on their own personal desire to do so. A shared vision is the result of the ability to bring ideas about the future that are shared by

Stellenbosch University http://scholar.sun.ac.za

individuals into the open in such a way that it results in a commitment to that future by the participating individuals. It is about encouraging people to engage in the making of their own future, instead of having someone decide the future for them and asking them sign up for it (Senge, 1999, 9).

The last discipline is team learning. Team learning is about fostering conditions of co-operation where the intelligence of the team will exceed the intelligence of any individual within the team. Team learning facilitates an extraordinary capacity for co-ordinated action in teams. Where individuals are learning as a team, individual members grow at a faster pace than would have been the case if individuals learn by themselves. Team learning follows from dialogue where individuals engage in group thinking, which results in actions or conclusions that do not come from an individual, but from the group. Team learning fosters changes in the behaviour of individuals through the collective behaviour of the team. Team learning is essential for learning in organisations, considering that teams comprise the fundamental learning unit in an organisation. Organisations therefore, learn only when their teams learn (Senge, 1999, 9, 10).

Senge distinguishes the five disciplines of learning organisations from other management disciplines by pointing out that the five disciplines are personal disciplines. They involve the personal thoughts and desires of individuals and the way individuals interact and learn from one another. Senge also points out that convergence of the five disciplines does not create the learning organisation, but facilitates new means for experimentation and advancement in organisations (Senge, 1999, 11). Learning then takes place through a process of continuous discovery. Senge's depiction of the relationship between organisational learning and employee learning resembles the concept of individual components within a complex system whereby the interactions and information processing of the components give rise to self-organisation and emergent properties within the system. The difference though, is that where individual components within a complex system, for example ants in a colony, are unaware of the implications of their actions for the existence of the system, humans can be very much aware of how their co-ordinated actions can determine the structures and future state of an organisation. Our inability to effectively know the outcome of our actions though, should not discourage people from adopting a systems thinking approach to organisations. On the contrary, by developing a deep understanding of the principles of complex systems, people are in effect empowering themselves in way that gives them a measure of control over their own destiny. People can learn how to become active agents in the construction of their own future by integrating the five disciplines into their organisations.

Senge emphasises the importance of developing the five disciplines in unity. To this end, he explains that systems thinking is the discipline that integrates all the disciplines into a coherent theory and practice. Systems thinking enables people to see how the different

Stellenbosch University http://scholar.sun.ac.za

disciplines are interrelated, and that by enhancing all the other disciplines, it becomes a constant reminder that in complex systems, the whole is greater than the sum of its parts. Systems thinking enables people to understand the fundamental forces that are at work in a complex system, and that, by being aware of those forces, people are better able to determine how those forces should be manipulated for moving the organisation from one point to another. However, Senge also indicates that systems thinking requires the other four disciplines if it is to reach its full potential. Together, the other four disciplines encourage people to realise how their actions are necessary if the organisation is to excel. This happens when every individual is committed to the long-term development of the organisation through shared visions. Organisations excel when individuals realise that an organisation can adapt and grow only when people challenge the deficiencies of their current perceptions through constant scrutiny of their mental models about the world. The organisation will learn better when people develop their potential and skills for learning as groups, and that these groups are capable of constructing larger pictures of the world than individuals. Personal mastery in individuals is the motivation for continuous learning about the effects of their actions in the world around them. When people realise the value of these four disciplines, the value of systems thinking as the fifth discipline should encourage people to practice all five disciplines in an integrated way. Systems thinking therefore, challenges people's perceptions about themselves and the world. The learning organisation is essentially a '*shift of mind*' where people are forced to see themselves and the world around them not as separated from each other, but as interdependent units of an interconnected system. From a systems thinking perspective, people can see how they are responsible for creating their own problems, and that learning organisations are places where people can become aware of how they are responsible for creating their own reality (Senge, 1999, 12, 13).

Senge's five disciplines of learning organisations emphasise the implications of learning in complex systems. Senge describes learning as a source for recreation. Learning is an act of personal empowerment in that it enables people to accomplish things, which they could not do before. It is also an act of self-enrichment in that it is responsible for changing people's perceptions of the world and how individuals relate to it. Learning is a creative influence in the lives of people in the sense that it increases people's capacity for creative action through which they contribute to the processes that shape the world around them. No complex system is a passive bystander in the development of its environment, and no component within a complex system is uninvolved in the process that shapes the system that it is part of. In similar vein, Senge defines the learning organisation as one that is '*continually expanding its capacity to create its future.*' Senge's description of the learning organisation incorporates '*adaptive learning*' and '*generative learning*' both as enhancing attributes of the

Stellenbosch University http://scholar.sun.ac.za

organisation's capacity to play a creative role in the unfolding of its future. The learning organisation is continuously experimenting, testing, discovering, learning and adapting. Senge emphasises that creative generative learning is the difference between merely surviving, and actually taking a part in shaping the environment around the organisation (Senge, 1999, 13, 14).

3.2.2. Systems Thinking: A Departure Point for The Learning Organisation

The global economy today is interconnected on an incomprehensible scale. Yet, the implications of the tremendous interdependence that has emerged within industries and economies are poorly understood. Part of the uncertainty that hampers organisational planning is an inability to see or make sense of the patterns that emerge from the interrelationships between different agents within economic environments. Organisations are still undermined by a tendency to perceive events as isolated and unrelated. Decision-making is then based on a collection of what Senge calls '*snap shot*' views of events. With such an approach, it is not surprising that organisations fail to see the patterns that emerge from interaction between organisations. The development of systems thinking as a paradigm for organisational learning is recognition of the inadequacy of organisational practices that attempt to deals with events as unrelated occurrences. It is also an indication of a growing perception among organisation theorists that actions taken by organisations can have a direct albeit unanticipated impact on future events that impact on the organisation. As such, systems thinking emphasises the significance of feedback loops that operate in economies. The principles of systems thinking adhere to the same principles that were developed in the natural sciences where complex systems such as organisms, colonies of social insects, or ecosystems are treated as integrated and essentially indivisible wholes. Systems thinking is aimed at helping people to deal with the dynamic complexity that is generated in nonlinear feedback systems. As such, it is a paradigm for understanding interrelationships among agents and for seeing processes with patterns of change instead of a '*snap shot*' slide show (Senge, 1999, 68).

Considering the tremendous complexity that characterises the global economy, systems thinking presents a unique approach for dealing with the often obscure connections that exist among economic agents. For Senge, systems thinking is an '*antidote*' for people's inability to make sense of the unparalleled interdependence of the new economy. By developing people's sense for the structures that underlie dynamical complexity, systems thinking enables people to recognise the leverage points that exist naturally in complex dynamical systems. Systems thinking further offers a means for people to distinguish low leverage points from high leverage points so that they are better able to judge at which point they should attempt to influence the system. Applying systems thinking to organisational thinking essentially requires a shift in mindset, but this shift in mindset is the incentive for the integration of all five learning disciplines when they have been put into practice. Within the reality of complexity, Senge calls systems thinking *'the cornerstone of how learning organisations think about the world'* (Senge, 1999, 69).

The obvious value of a systems thinking perspective lies in its propensity for elucidating major interrelationships underlying the problems organisations face and in so doing, new insights are generated with regards to the appropriate steps that could be taken to alleviate those problems. Essentially, systems thinking encourages people to develop an understanding of the nonlinear character of complex systems. By doing so, people start to recognise flows and loops of influence between agents and that these flows and loops lead to recognisable patterns within the system. In the end, systems thinking leads to the simplification of complexity by encouraging people to look for patterns within the complexity of interaction (Senge, 1999, 73). From this perspective, people will come to see structure in complex systems as a result of the convergence of processes in a flow of interaction.

3.2.3. Understanding Structure as a Flow of Processes

Structure in complex systems always involves some form of flow. To a certain extent, structure becomes a by-product of this flow. However, this flow does not have a neatly defined beginning or end. Senge describes this flow as circular, with events converging and influencing each other in an ongoing way to produce the structures that underlie reality. Systems thinking is a means for explaining the processes that are at work in this flow. In any flow, there are typically certain processes, which determine the course of the flow. However, the processes are not always apparent and as such, it becomes very difficult to determine how one should intervene to bring about a desired change. Systems thinking is then intended to point out the underlying forces that influence the interrelationship between components. It is a way of seeing where we are in relation to other agents and how everyone is involved in the flows that exist in the structure. As such, systems thinking encourages people to understand the dynamics of the system.

In any nonlinear system, feedback is an inherent part of the system's dynamics. Human systems are no exception. Feedback is at the heart of the reciprocal nature of interaction, to the extent that every action in a complex system can be understood as both a cause and an effect simultaneously. Feedback challenges the conventional concepts about causality, by illustrating that the underlying forces, which are inherent in the structure of the system, can cause a certain type of behaviour to prevail within the system. Systems thinking enables people to see how they and their actions are integrated into this feedback process in such a way that they are both influencing and influenced by reality. Influence in complex systems can then be described as flowing in more than one direction. Feedback in human systems leads to the realisation that no single agent is responsible for what happens in systems, outcomes are instead generated by everyone within the system and because so many

Stellenbosch University http://scholar.sun.ac.za

agents are involved, the exact influence of any individual is difficult to determine (Senge, 1999, 78). Additionally, actions and outcomes in complex systems are subject to time delays. Every action takes time to disseminate through the system, and the impact of action on other components will then not become apparent within the immediate future. It is important to incorporate the element of time delays into the concept of feedback in order to understand why the consequences of actions emerge only gradually afterwards. The concept of feedback also helps people to understand why actions sometimes appear to have no effect and sometimes appear to have explosive consequences. The effects of positive and negative feedback create different types of consequences. By understanding that positive feedback and negative feedback are both parts of the processes within a system, people are encouraged to try and see the system as the fundamental operating entity. In so doing, people realise that they can often influence how the system behaves (Senge, 1999, 80).

Understanding how feedback operates enables people to determine the most appropriate interventions in the system's processes. Reinforcing feedback and balancing feedback are then the two basic elements of systems thinking. Reinforcing or positive feedback is responsible for small events growing under their own influence. Senge points out that reinforcing feedback is not necessarily bad. Although it is responsible for instances where something that starts out bad continues to get worse, it can also be utilised to reinforce processes in the desired direction. Senge describes the results of positive feedback loops in organisations as either accelerated growth or accelerated decline (Senge, 1999, 81, 82). By recognising reinforcing feedback in the structure of a system, people are able to better judge the circumstances that are responsible for their growth or decline and can then make better judgement regarding the actions that should be taken to correct this.

Accelerated growth or decline rarely goes unchecked since there are limits in either direction. The consequences of these limits are varied, from slowing the process down, to stopping it, pushing it in a different direction, or reversing it entirely. This is the effect of balancing or negative feedback. Positive and negative feedback therefore, operate alongside each other, although the relationship is not a symmetrical one. Positive feedback can cause a system to become unstable, but at a critical point of instability, negative feedback starts to pull the system back towards stability. Negative feedback therefore, works to balance the system, to keep it stable. Senge points out that balancing feedback is most apparent in goal-oriented behaviour. It yields a balancing process whereby the system gradually adjusts towards a desired level. However, Senge also points out that the balancing process often goes unnoticed in organisations because some goals tend to be implicit and are subsequently easily overlooked (Senge, 1999, 84, 85). He also points out that if balancing processes go unnoticed, it can lead to surprising and problematic results.

Stellenbosch University http://scholar.sun.ac.za

This often happens because balancing processes create the impression that nothing is happening, and are as a result more difficult to detect than the explosive consequences associated with reinforcing feedback. Balancing feedback can cause an organisation to resist change even if the participants are changing, and so create an impression that resistance has suddenly appeared from somewhere. The resistance is in fact an internal response from the organisation in an attempt to maintain an implicit goal. Balancing feedback therefore requires an organisation to recognise the implicit goal and to change it before further attempts are made to bring about changes in the organisation. If this is neglected, then any attempts to push the system into changing will only result in increasing resistance. It is in this regard, that a subtle intervention at an appropriate point in the system can be more successful in bringing about changes than a forceful push, particularly if the system is going to meet the push with proportionate resistance. Systems thinking therefore encourages people to look for the source of resistance and the forces that maintain it as the point of intervention (Senge, 1999, 88).

Feedback is a significant aspect of the dynamical behaviour of complex systems, it is therefore important to understand how feedback can cause havoc during the execution of strategies no matter how well intended they are. Unless one considers the role of feedback in a complex system, one will not be able to fully appreciate the processes in an interdependent system that are responsible for turning good intentions into bad consequences. Feedback also increases people's awareness of the impact of time delays in complex systems. Time delays impair our ability to assess the consequences of our actions and as such are responsible for miscalculations in our actions. Without an appreciation of time delays, people leave themselves vulnerable for instability and if no action is taken to account for time delays, the processes in the system can break down. In this regard, Senge describes time delays as the '*third basic building block*' of systems thinking (Senge, 1999, 89).

Systems thinking is then built on the concepts of reinforcing loops, balancing loops and delays. These three blocks constitute the vital influencing factors on the processes that result in the emergence of structures in complex systems. It is essential to understand how feedback loops operate in a system and to recognise how the various loops can dramatically alter the course of processes within the system. Without an understanding of the role of feedback loops, people will be left with a sense of powerlessness when their actions yield unintended outcomes. An understanding of the impact of loops and time delays will also enable people to make better assessments regarding the corrective actions that should be taken. Systems thinking is a very effective foundation for action in complex systems, in particular since it allows people to understand the forces that are responsible for the prevailing uncertainty in complex systems. It also leads to the realisation that people

Stellenbosch University http://scholar.sun.ac.za

contribute to those forces through their own actions. This realisation encourages people to take responsibility for their actions for in that responsibility people accept that they can actively shape their own future by working within the system's structures instead of against it.

3.2.4. Systems Archetypes: Finding Leverage Points for Intervention

Systems thinking encourages people to see that they and their actions are part of a larger system. By recognising that their actions contribute towards the existence of structures in the system and that they are not only influenced by structure, people realise that they are able to manipulate the structure of the system for their own benefit. Once people understand the forces that are at work within a system, they gain insight into the development of structure, and with that perspective they can see what they should do to work within the processes of the system and significantly, how people are able to change those forces. Systems thinking allows people to recognise that complex systems display certain recurring structural patterns. Senge calls these recurring patterns '*systems archetypes*'. Senge has identified 9 such archetypes and he describes them as the essence of mastering the ability to recognise structures in both the personal and organisational lives of people. For Senge, the archetypes portray the simplicity that underlies the complexity of issues in organisation management. He encourages people to learn how to recognise these archetypes as they represent the points of leverage in the difficulties that arise from complexity. For Senge, organisations embark on a course of practising a systems perspective when people master the ability to recognise systems archetypes. Senge insists that systems thinking can only yield insight into the way people create their own reality when managers in the learning organisation start to think in terms of the systems archetypes. In this sense, the systems archetypes are a means for reconditioning people's perceptions in such a way that they are able to see the active structures in a system more clearly, and from this point, they are able to identify the leverage points in the system. Senge states that by identifying systems archetypes, people can see how reinforcing loops, balancing loops and time delays affect the system, and through that they gain insight into the location of the high and low points of leverage in the system (Senge, 1999, 94, 95). The systems archetypes are intended to elucidate the '*circles of causality*' that exist within systems. They are a means for seeing how the actions that people take combine with the inherent forces operating in the system to generate the structures that people see around them. In this sense, people gain insight into how a system is likely to respond to their actions, but also where to intervene in order to bring about meaningful changes in the structure. In the process people learn to look for the points where their actions meet resistance from structures as the points to intervene in the system. Using the archetypes, according to Senge, is the starting point for mastering systems thinking, and through increased

Stellenbosch University http://scholar.sun.ac.za

application of those archetypes people will naturally start to think in a more systemic way (Senge, 1999, 113). The system archetypes are meant to encourage people to look for leverage points as the points where small changes can have large outcomes, instead of trying to force the system into something that apparently works against its structure.

Senge views leverage points as the '*bottom line*' of systems thinking. For Senge, the best results of intervention follow from actions, which are '*small and well-focused*'. The most effective way of inducing significant change in a system comes from finding the points where action will lead to enduring changes. Senge does admit though, that the nature of complex systems makes such points reasonably obscure. Leverage points in organisations are not obvious to the majority of people, but Senge ascribes this to an inability to recognise the structures that underlie their actions. It is for this reason though, that organisations should endeavour to use archetypes as a means for making structures and their leverage points apparent (Senge, 1999, 114). Systems thinking helps people to see how everyday interactions result in increasingly complex but subtle structures, but it does so in way that teaches people to recognise these structures. Systems thinking empowers people to act within these structures by helping people to see patterns instead of isolated event, but also to recognise the events and forces that are involved in those patterns (Senge, 1999, 126). When people are able to look through complexity and to see the underlying structures and the forces that operate to shape them, it becomes possible for them to see how high and low leverage points cause change in complex systems. By using systems thinking, people can apply these insights to facilitate meaningful and enduring change through subtle interventions. This is accomplished, according to Senge, through the organisation of complexity into coherent stories. These coherent stories serve to elucidate the forces that underlie problems faced by organisations and through that, people discover enduring solutions to those problems instead of trying to deal only with the symptoms produced by such problems (Senge, 1999, 128).

3.2.5. The Core of The Learning Organisation

Any organisation that operates in the global economy of today will eventually reach the conclusion that there is no permanent solution for the problems faced by the organisation. Systems thinking represents a means for making sense of the processes and underlying forces, which are responsible for creating constant change in the environment. It shows people that these processes and forces are always at work and that it is then essential for the organisation to continuously grow amid changing conditions. Growth in an organisation follows from the application of theories, methods and tools, which contribute to an increase in skills for dealing with conditions of perpetual change. Continuous growth leads to the discovery and implementation of new guiding ideas. Along with continuous growth comes experimentation for new designs about the organisation's infrastructure. The learning

Stellenbosch University http://scholar.sun.ac.za

organisation is built on the concept of continuous growth, and as such, it is equipped for dealing with the challenges and opportunities of the present while simultaneously building its capacity for the future. Growth in the learning organisation is a result of a commitment by its members to the continuous focus on enhancing and expanding the collective awareness and capabilities. The existence of the learning organisation is then based on the vision of a shared collective experience and imagination on the part of its members (Senge, Kleiner, Roberts, Ross, & Smith, 1995, 4, 5).

The five disciplines are effectively a means for creating an environment within the organisation where its members are able to transcend individual constraints and to interact in new ways, which contribute to the collective benefit of the organisation and all of its members. The collective benefit is however, dependent on a lifelong commitment to the five disciplines on the part of employees. The benefits of practising the five disciplines in unity are enticing though. Through personal mastery, people realise that if they learn to expand their personal capacity for creating the results that they desire the most, their actions can create an organisation that encourages people to develop themselves toward the goals and purposes that they have chosen (Senge & al, 1995, 6). People are constantly reminded of the interconnectedness between themselves and the environment and this leads to an increasing awareness of the interdependence between people's actions today and the reality they experience tomorrow (Flood, 2000, 26). By using mental models, people realise the benefits of reflecting on the images they have of the world, and by realising how these internal images influence their actions and decisions, people realise the necessity of continuously clarifying and improving these images. The discipline of shared vision encourages people to develop shared visions of the future that they desire, and by developing the principles and guiding practices for those shared visions within a group, people become increasingly committed in a group. The discipline of team learning shows that a transformation of conversational capacities and collective thinking skills can lead to group collaboration where the intelligence and abilities of the group exceed the capacities of any individual (Senge & al, 1995, 6). Team learning in organisations encourages collective learning, which benefits both the organisation and its members. And as the fifth discipline, systems thinking presents an organisation with a platform for change that is built on its capacity for transformational learning (Flood, 2000, 27). When people think systemically about the forces and interrelationships that shape the behaviour of the system, they are able to see how they can change the system more effectively. With an understanding of they dynamics involved in complex systems, people learn how to act in a way that corresponds to the larger processes at play within the world (Senge & al, 1995, 6, 7). The five disciplines of the learning organisation encourage people to empower themselves and their organisation in the world by learning how to learn in a world where not everything is as

Stellenbosch University http://scholar.sun.ac.za

fixed as they might appear from a non-systemic perspective. The five disciplines are in effect a method that, when applied in unity, enable organisations to cope within the uncertainty of the interconnected global economy. The application of the five disciplines is in essence an act of transformational learning within an unknowable environment. As the fifth discipline, systems thinking does not purport to predict outcomes, instead it promises clarification through learning and understanding of the processes that are responsible for creating the very structures that make people feel so powerless. To this end, the greatest value of systems thinking is found in its capacity for changing the way people see the world around them and their connectedness to the world. When people realise that they and their actions are part of what happens in the system, they also realise that it is within the abilities to influence what happens in the system. When people learn to think differently, they also start to act differently.

Systems thinking shows that the primary leverage for learning in an organisation lies in the capacity of its members to collectively engage in transformational learning. The application of the five disciplines is intended to encourage people to consciously learn in a way that continuously tests their previous experiences, and to transform those experiences into knowledge that is both relevant to the core purposes of the organisation and easily accessible to everyone in the organisation. This implies that all values or assumptions are subjected to constant examination and challenges. Scrutinise it even if it works. A key attribute of a learning organisation is the constant generation of knowledge. This knowledge though, proves its worth in its capacity for effective action. Knowledge creation is therefore intended to enable an organisation to acquire capabilities, which it did not have before. Knowledge creation though, is complemented by the organisation's capacity to disseminate knowledge through all areas of the organisation. Knowledge that is shared has a greater application potential. It is essential though, for organisations to determine the relevance of knowledge. This helps the organisation to learn around its core purpose. People can use relevant knowledge to improve the organisation's abilities. Learning in an organisation encourages '*study*' and '*constant practice*'. Learning in this way is an ongoing process aimed at mastering the ability of constant '*self-improvement*' (Ross, Smith, Roberts & Kleiner, 1995, 48). The five disciplines encourage people to set out on a life long journey of learning and to apply what they have learnt in their capacity as individuals to complement other people working with them. In this way individual learning flows through to group learning, which is the foundation for effective organisational learning. The core of the learning organisation therefore, is group learning. As people challenge each other's perceptions about the world, new ideas emerge within the group, which lead to different perspectives and a new way of doing. For organisations to learn continuously, it is essential that group learning within the organisation is continuous. Through group learning, the

Stellenbosch University http://scholar.sun.ac.za

organisation is constantly renewed, and constant renewal is a necessary ingredient for organisational survival in the turbulent informational economy.

3.3. The Far from equilibrium Organisation

Systems thinking enables people to see that stability and instability form part of the same structures through the operation of reinforcing or dampening feedback within organisations. It also shows how feedback in the interactions of interdependent agents within a shared environment can be responsible for generating very unexpected and unintended consequences even from carefully planned and executed interventions on the part of organisations in an economy. It is therefore, impossible to fully anticipate the outcomes of actions in organisations or economies where agents are engaged in interrelated activities. Complex systems are therefore associated with open-ended change. As such, it is also impossible to accurately plan for the future of a complex system. This is the view that Ralph Stacey advocates. For Stacey, uncertainty is not something that organisations can side step, as such, he suggests that managers adopt an approach that faces up to an unknowable future. Stacey points out that in open-ended change conditions, no one can really be in control of the organisation's long-term future, hence flexibility becomes an essential attribute of organisational planning in open-ended change conditions (Stacey, 1992, 7).

Complexity theory has shown how complex systems such as organisms or ecologies use stability and instability in their structures to thrive in open-ended change conditions. Senge's learning organisation can be compared to an organism that learns from its environment, responds to changes in its conditions and adapts when it is necessary. Stacey believes that by understanding how complex adaptive systems incorporate stability and instability within a single flexible structure, organisations can learn to exploit the creative forces that are inherent in nonlinear systems. The organisation is then not merely adapting to its environment, but it also becomes actively involved in shaping the environment to suit its requirements. For Stacey, this starts when organisations are able to sustain the contradictory forces of stability through dampening feedback, and the creative instability of reinforcing feedback. This implies that organisations should focus on sustaining a paradox between the constraints of the system, and the freedom of individuals to change the system through constant learning. In Stacey's view, organisations should learn how to use instability in a positive way (Stacey, 1992, 7). Stacey's view of the successful organisations of the future is one of an organisation that operates in a far from equilibrium state. This is the state that allows nonlinear systems to act creatively in conditions of open-ended change through a sustained state of tension between the feedback forces that drive the system towards order or chaos. This tension between stability and instability in far from equilibrium conditions drive the organisation towards creative change. Stacey sees successful

Stellenbosch University http://scholar.sun.ac.za

organisations as passing through periods of instability, crisis and chaos. During this process, new directions and order will emerge from spontaneous choices that were made at critical points along the organisation's development (Stacey, 1992, 12). However, these processes are only possible in a non-equilibrium state.

3.3.1. The Shadow System as a Source for Creativity in Organisations

Systems thinking represents a viable approach for organisations that have to learn their way into an uncertain future. Ralph Stacey though, is of the opinion that learning organisations should do more to create their own future, instead of merely responding to changing conditions in an adaptive way. Stacey therefore, places a lot of emphasis on organisations' capacity for acting creatively.

For Stacey, the key to unlocking creativity in organisations lies in the realisation that organisations are complex adaptive systems. Organisations are nonlinear systems where feedback plays a vital role in the dynamics of interaction within the system. Stacey also distinguishes between the legitimate system of an organisation and the shadow system that operate alongside each other. The legitimate system is the formal bureaucracy of the organisation and is built around the core values and policies of the organisation. The core values and policies of the organisation are maintained through dampening feedback, as such the structure of the organisation is maintained through the suppression of threats to the structure. Dampening feedback in this instance can be seen as the mechanism that attempts to maintain an equilibrium between organisational structures and the people that have to adhere to the policies and values that maintain those structures. Stacey acknowledges the necessity of the legitimate system, without such a system, the organisation will collapse into anarchy. Stacey is, however, of the opinion that an equilibrium state in an organisation represents a real threat for creativity in the organisation. It is in this regard that Stacey emphasises the importance of shadow systems in organisations. Stacey suggests that creativity in organisations is found in the shadow system of an organisation. The shadow system according to Stacey represents a potentially wider range of dynamics than the order and stability that he associates with the legitimate system. Where the legitimate system exists primarily through the forces of dampening feedback, the shadow system is prone to instability and tension as a result of the forces of reinforcing feedback (Stacey, 1996, 168).

The shadow system of an organisation exists alongside the legitimate system. The two serve as counterbalances for each other and it is therefore essential that both systems are maintained if the organisation is to function at all. The legitimate system maintains the stability that the organisation requires to perform its day-to-day functions. It is, however, in the shadow system that real creative learning takes place. Within the shadow system, positive feedback creates tension between the accepted values, policies and ways of doing,

Stellenbosch University http://scholar.sun.ac.za

and new innovations that emerge from the political interaction that Stacey associates with learning in groups. Stacey states that group learning is the fundamental way for organisations to learn in open-ended change situations. For Stacey, groups in organisations learn through a process of discovery when future conditions are uncertain. The conditions that arise when a group is learning together creates the tension between stability and instability that Stacey believes is essential for the group to generate creative solutions.

With regards to group learning, Stacey emphasises two points. The first is that group learning takes place through conflict, dialogue and persuasion. It is predominantly a political process of tension between the accepted ways of doing and an emergent perception of new directions for the organisation. This political process is then a source of instability in the group. However, conflict, dialogue and persuasion open people's minds to new ideas and different ways of looking at their reality. From this, people within the group can develop an understanding for how other people within the group are thinking. Continuous dialogue is then essential if new ideas are to emerge from the group and not just from specific individuals. Continuous dialogue will also inevitably result in challenges to the accepted policies and values that are held in place through dampening feedback in the legitimate system of the organisation. Stacey therefore, encourages managers to develop instability and tension in the shadow system through conflict dialogue and persuasion in group learning. Group learning then employs creative destruction as a learning method. Stacey states that learning in an organisation essentially takes place when old perceptions are questioned and dismissed, and replaced with new ones (Stacey, 1996, 387). For Stacey, the tension that arises between the legitimate and the shadow systems are the result of the different effects of dampening and reinforcing feedback within the constraints of the organisation's structure. Stacey places a lot of emphasis on feedback within organisations and group learning. Where dampening feedback allows the system to maintain a structure within which day to day operations can take place, Stacey sees reinforcing feedback as the force that is responsible for new ideas growing beyond individuals or groups and to eventually replace structures, which are no longer suited for the organisation's development. When people discover new ideas or strategic directions through group learning, which results in the dismissal of dominant structures, they are in effect performing what Stacey calls complex learning or double-loop learning. Double loop learning in groups take place when people question the underlying assumptions and mental models that they have while at the same time examining the problem they face from different angles. For Stacey, the questioning process involved in double-loop learning is of greater importance than answers or outcomes. Results from any learning process are only temporary whereas the process of questioning is constant as a means of learning. According to Stacey, double-loop learning should result in the development of new mental models for newly perceived

Stellenbosch University http://scholar.sun.ac.za

situations and since double-loop learning takes place in groups, group learning then becomes the essence of strategic discovery and choice (Stacey, 1996 387).

This leads into the second point that Stacey emphasises about group learning. The ideas that emerge from discussions among individuals are emergent properties of the group. It is not the ideas or visions of one person that leads to new ideas. Stacey therefore, sees group learning as essentially devoid of central control. The outcomes for groups engaged in double-loop learning are uncertain, and as such, it is impossible for anyone to fully control the actions and outcomes of group learning. For Stacey, this implies that no one in the group can really be in control, as such, both the purpose and methods of the group have to be discovered through the learning process (Stacey, 1992, 111, 112). This however, does not mean that there is no control in group learning. For Stacey, there is a close relation between learning and political processes in groups to the extent that they amount to a form of control in the open-ended conditions that is associated with double-loop learning. Control in group learning stems from the complex political learning process in the group, which is responsible for the development of coherent behaviour in the group. No one in the group is then in control, but the learning process and the political maneuvering that is inherent in group interaction results in new discoveries, choices and coherent actions by the group and not through the influence of individuals (Stacey, 1993, 227). Outcomes in groups are then a result of the individuals of the group acting in coherence through dialogue, scrutiny and persuasion and control is associated with the process that leads to the emergence of coherent behaviour. Stacey therefore, believes that the outcomes of group learning are emergent properties of groups engaged in double-loop learning. In complex adaptive systems, new structures emerge when the system has become unstable as a result of positive feedback. From this tension and instability, new structures emerge through self-organisation. In accordance with Stacey's view of organisations as complex adaptive systems, conflict, dialogue and persuasion are the tools for generating instability that will result in self-organisation. New ideas or strategic directions are for Stacey the equivalent of emergent properties that arise spontaneously through group learning and self-organisation. From this perspective, the creative capacity of a group or an organisation is for Stacey similar to the creative abilities of complex adaptive systems in nature where the structures displayed by the systems are a consequence of the coherent actions of all the components. The individual components do no more than learn about their immediate environment and react to the actions of their neighbours. Structure in complex systems is unintended outcomes of the local interactions of interdependent individuals. For Stacey, there is an important lesson to be learnt from the study of the dynamics that lead to emergent order in complex adaptive systems. To this end, he emphasises the importance of reinforcing feedback loops as a means for generating new strategic directions through tension and

Stellenbosch University http://scholar.sun.ac.za

instability. Stacey, however, also points out that the learning process that results from this tension and instability creates its own form of control over the situation as people become involved in the political process of soliciting support for the ideas that emerged from the group. As such, Stacey believes that the source of control for managers is not the containing of instability in group learning, but the fostering of conditions where instability generates creative learning. Group learning according to Stacey, is the only viable form of control in open-ended change situations where outcomes are discovered rather than planned (Stacey, 1993, 227).

For Stacey, the paradox of stability and instability, and order and disorder that exists when a system operates under non-equilibrium conditions should be the primary aim of organisations that have to learn their way into an unknowable future. The non-equilibrium state is for Stacey a key attribute of organisations that want to be successful in the turbulent informational economy. In uncertain conditions, tension between the stability of the legitimate system and the instability of the shadow system can be a great source of creative innovation for organisations. For Stacey, organisations can engage in creative learning when they adopt the contradictory states of simultaneous stability and instability, tight and flexible control, and centralised and decentralised structures. For Stacey, these attributes are associated with an organisation that maintains a healthy tension between a stable legitimate system and an unstable shadow system. While the legitimate system attempts to keep uncertainty at bay, the shadow system embraces this uncertainty to provoke learning through tension, contradiction and paradox (Stacey, 1992, 40).

For Stacey, the essence of strategic management lies then in group dynamics that encourage the challenging of convention. It is about making the implicit explicit and exploring learning behaviour, interactions, obstructive barriers and political manoeuvring that can give rise to new mental models. This is the second loop of double-loop learning and it underlies people's ability for achieving different learning models that are better suited for new situations. Successful double-loop learning should give individuals the freedom to advocate their positions and to be open for allowing others to test those positions. Double-loop learning is a messy process, but this messiness is essentially, what provokes new insights from group dialogue. For Stacey, this messy double-loop learning is dependent on feedback processes that keep the group in a far from equilibrium state. Conflict, confusion and exploring that follow from dialogue based on a willingness to listen to and discuss other people's views are the breeding ground for innovation in group learning. This process, according to Stacey, is the only suitable group dynamics that can deal efficiently with open-ended change (Stacey, 1992, 119 – 120).

Stellenbosch University http://scholar.sun.ac.za

In terms of complexity, the shadow system in organisations represents the interactions of individual components within the overall structure of the system. It is in the shadow system that disorder plays a vital role for creativity and innovation. In any complex system, the dominant structures of the system are a result of the interactions between components and the environment. These structures can then be altered through changes in the actions of the individual components, but it is important to bear in mind that the system is likely to resist any attempts at changing the dominant structures. Stacey suggests that people, as the ones responsible for generating structures, should be aware of the nonlinear dynamics that are at work in the organisation. With knowledge of these dynamics, it would not only become easier to recognise the points where the structures are susceptible to change, but it would also become easier to recognise how one can use positive feedback as a means for reinforcing new ideas into the organisation in such a way that people will not be working against the legitimate system in counterproductive ways. For Stacey, this becomes possible only when organisations seek to maintain a non-equilibrium state. Complexity theory does not offer a means for making uncertainty and unpredictability disappear, but it offers insight into how people discover and create new strategic directions through interaction that leads to self-organisation. Complexity theory also encourages people to take responsibility for their actions, for in self-organising systems, every one plays a part in the never-ending process of continuous learning through discovery, contention, and dialogue. The shadow system of an organisation is about maintaining and operating in a non-equilibrium state to enable new strategic directions to emerge from the disorder and ambiguity of group learning (Stacey, 1996, 347). In the shadow system, nonlinear feedback mechanisms are used to destroy old structures and this destruction of the old allows new ones to emerge through spontaneous self-organisation. These processes though, can only take place through unstable dynamics, as such, the creative potential that is found in tension and instability dominates Stacey's view of the shadow system. Stacey though, maintains that this paradoxical state forms the basis for order to emerge from disorder. The operations of legitimate and shadow systems alongside each other are a way for organisations to operate in a state of bounded instability. For Stacey, a state of bounded instability is the state where positive and negative feedback lead to the emergence of innovations and strategic directions. Stacey then, associates bounded instability with creativity in organisations (Stacey, 1996, 348). For Stacey, this bounded instability enhances the existence of an organisation's shadow system, and the shadow system in turn enhances the organisation's creative capacity. As such, Stacey describes the shadow system as the mechanism that people use for dealing with highly complex and ambiguous situations with unpredictable futures. Because the shadow system is composed of groups that are easily changeable, it implies that new groups can form rapidly in response to unforeseen events without the need for it to be formalised. The shadow system can then also deal with a wider range of events

Stellenbosch University http://scholar.sun.ac.za

than the formal legitimate system. The shadow system therefore, represents a potential source for creative learning and innovation at a speed that is impossible for the legitimate system to match (Stacey, 1996, 381).

Stacey believes that by seeing organisations in terms of complexity theory, managers gain new perspectives about strategic thinking and group learning, which shift their attention to the learning processes and underlying assumptions that drive those processes. A complexity based perspective on organisations shifts the attention to a concern about the effects of group dynamics and learning behaviour. It emphasises the creative instability of contention and dialogue where consensus on particular issues is only a temporary state. Complexity based views of organisations encourage examination, understanding and dealing with dampening feedback that resists change and hampers innovation, and the intentional utilisation of reinforcing feedback as a mechanism for driving change in the organisation. Additionally, managers using complexity theory come to see group learning as a complex process that continually questions the way people, groups and the organisation learn with regard to different situations. For Stacey, this should assist people in dealing more readily with contentious and ambiguous issues associated with open-ended change in that they will become more adept at developing new mental models from which actions are designed for each new strategic direction (Stacey, 1992, 120, 121).

3.3.2. Control and Creativity in Organisations at the Edge of Chaos

Stacey's view of organisations is one of organisations as complex adaptive systems. It is in this regard that he places so much emphasis on an organisation's ability to maintain itself in a non-equilibrium state. In a non-equilibrium state, the organisation is optimally poised to facilitate flows of information from outside and within the structures of the organisation. Stacey, however, indicates the importance of both stability and instability in the nonlinear processes that he associates with organisations. He is clear on the importance of the constraints of the legitimate system as a mechanism for preventing the instability generated by the shadow system from collapsing the organisation into anarchy. At the same time, the creative results that emerge from the shadow system are important for preventing the organisation from becoming rigidly stable. It is important for the organisation's survival that it does not lean over to either of the opposing ends in the spectrum of dynamics. Stacey then proposes that organisations, like all complex adaptive systems, should endeavour to evolve towards a region between the extremes of stability and instability. In complexity, this is the edge of chaos. For Stacey, the edge of chaos for organisations represents the point where organisations are optimally balanced between stable formalised functioning and the instability of creative information generation, learning and adaptation, which is necessarily messy due to the informal nature of the shadow system's operations. The edge of chaos represents the point where organisations can learn and change creatively through

Stellenbosch University http://scholar.sun.ac.za

fluctuations in the shadow system without causing the organisation to destabilise completely (Stacey, 1996, 170 – 172).

At the edge of chaos, the system is at its most innovative because it is neither rigid nor devoid of structure. It is positioned neatly at the edge of structural collapse. At this point small changes, such as new ideas or strategic directions that emerge from group learning, can be rapidly amplified through the entire organisation as a result of reinforcing feedback in the political processes of the organisation. The effective application of reinforcing feedback prevents any specific structure from becoming an obstacle for change when conditions in the environment change. This implies that the organisation should be able to rapidly diffuse information through various levels of the organisation. If this is not possible, then new ideas will not gather sufficient support in the organisation to cause any relevant changes. This rapid diffusion of information is effectively aided by the informal networks that spontaneously emerge from political manoeuvring in the shadow system of an organisation. Information processing and learning that leads to the emergence of new structures through self-organisation is a key attribute of complex systems that are poised at the edge of chaos. Complex systems appear to naturally evolve towards the edge of chaos where information generation and sharing among components are at an optimal level. Stacey then, sees organisation displaying a similar capacity for performing complex behaviour when they are poised at the edge of chaos. The edge of chaos also emphasises the importance of individual information processing and learning in complex systems, and once again, Stacey draws a parallel between organisations and other complex systems. Stacey points out that organisations cannot learn or be creative if the groups and individuals that comprise the organisation are not learning or being creative. However, unless there is an opportunity for the learning and creativity of individuals or groups to replace existing structures, the organisation cannot adapt. In organisations, new structures emerge to replace old ones when information is shared within and between groups. For Stacey, this sharing of information is inherent in the non-equilibrium processes of systems operating at the edge of chaos, for it is at the edge of chaos that reinforcing feedback can potentially allow a single innovation to change the entire strategic direction of an organisation.

Stacey, however, also indicates that even while operating at the edge of chaos, organisations rarely display chaotic behaviour. Instead, organisations tend towards stability for long periods of time before suddenly becoming unstable for a while. This instability in the organisation is only temporary though, for from this instability the system develops a new legitimate structure, which is inherently stable. For Stacey, this is indicative of a legitimate system stabilising the organisation, while the shadow system in the background is always fluctuating through instability. Stacey suggests that this pattern of behaviour where the organisation moves through periods of stability and instability with order and disorder

Stellenbosch University http://scholar.sun.ac.za

flowing from one another is a result of the organisation's position at the edge of chaos. For Stacey, this intertwined relationship between stability and instability, and order and disorder in the process of change in organisations is essential. This is because the legitimate system of an organisation does not usually change through formal discussion. For Stacey, changes in the stable legitimate system follow from dialogue and political manoeuvring in the shadow system. As such, it becomes an example of order emerging from disorder through interaction and learning. When an organisation is at the edge of chaos, the formal policies and values of the organisation stabilise the organisation, while every once in a while, the processes of political interaction and double-loop group learning in the shadow system reaches a critical point of instability. This critical point is where new ideas, policies, values and strategic directions have gained sufficient support within the organisation to replace the existing ones. In this way, stability in the form of a new legitimate system emerges from the instability generated by reinforcing feedback in the shadow system (Stacey, 1996, 174, 177 – 179). The organisation is therefore, both ordered and disordered at the same time. For Stacey, this paradoxical state that is the edge of chaos represents a viable state of being for organisations to survive in open-ended conditions. The organisation requires an ordered structure to cope with closed or contained change, but at the same time its creative capacity for learning its way into an unknowable future requires the instability of the shadow system with its self-organising networks. For Stacey, the tension generated by the political processes of group learning adds to the formal structure of the organisation. The political process generates change in the legitimate system that is necessary if the organisation is to survive as a relevant functioning unit. The edge of chaos in organisations is then a state where the organisation can face closed and open-ended change simultaneously. It is a necessary state if the organisation is to operate simultaneously and alternately in the tightly structured hierarchies of the legitimate system and the loosely coupled political networks of the shadow system (Stacey, 1993, 261).

In complex adaptive systems, the edge of chaos represents the point in the internal dynamics of the system where information gains the advantage over the free flow of energy. At the edge of chaos, every individual has sufficient freedom to examine and process information that is received from other individuals around it and then to react to it by some output of its own. As every individual engages in this process, the combined activities of all the individuals take an affect on each other's actions and as the process continues, it becomes possible to discern a collective rhythm in the activities of the system. This collective rhythm generated by the individual interactions of every agent allows coherent structures to emerge from the dynamic instability of interaction. Because every agent is responding locally to the information that is available in their immediate environment, the actions of the system are designed for dealing with specific conditions. When conditions

Stellenbosch University http://scholar.sun.ac.za

change, the agents are exposed to new information and the process of learning is extended. This often requires the informal structures of the system to change in order to deal with new information. However, the ability of the system to change its structures when conditions require it to do so, effectively allows complex systems to operate and thrive under open-ended conditions where outcomes are unpredictable, cause and effect distant in time and space, and change is never ending. In short, complex systems deal with open-ended change through a process of continuous learning that takes the system through periods of stability and instability and ultimately leads to continuous novelty and adaptation. In terms of organisations facing open-ended change, this implies that new approaches to control have to be developed for dealing with the uncertainty of open-ended change, since adaptation involves changes in the organisation's rules and relationships. These changes though, cannot be anticipated before the time and have to be discovered through learning. For Stacey, learning as discovery is inherent to dealing with change and uncertain outcomes (Stacey, 1993, 35, 36). In Stacey's view, political interaction and double-loop learning are the only viable forms of control that can operate effectively in the boundary state between order and chaos in organisations, and are at the same time viable for dealing with situations of open-ended change. The reason for this according to Stacey, is because both forms of control drive the organisation away from equilibrium and closer to the edge of chaos where the organisation can be creative and innovative (Stacey, 1996, 163).

Stacey sees learning and political interaction as capable of producing a type of behaviour that is coherent and controlled in the uncertainty of open-ended change conditions. Despite the fact that learning and political interaction employ reinforcing feedback that destabilises the organisation, the instability is still contained within boundaries. The instability that results from learning and political interaction is controlled because the process of learning and political manoeuvring connects discovery, choice and action in groups (Stacey, 1992, 164, 165). For Stacey, this means that group learning is controlled behaviour that displays recognisable patterns. For Stacey, learning acts as a form of control because it results in clear connections that run between the different phases of group learning. Stacey describes this connection as originating from individual discoveries, leading to choices that arise from reflection, contention and dialogue by all the members of the group about those discoveries, and culminating in actions that explore the implications of those discoveries. At this point the connection leads back to discovery as the choices and outcomes of actions result in individuals making new discoveries. The process of group learning depends greatly on the group's ability to maintain tension between sharing discoveries and generating different views on those discoveries, and for Stacey learning as a form of control is a consequence of the constraints caused by this tension. This tension is a result of the interaction between individuals in groups. Interactions between people in organisations inevitably form part of a

Stellenbosch University http://scholar.sun.ac.za

political process. For Stacey, political interaction also produces controlled behaviour by the members of an organisation. Control results from the fact that when people make a discovery, any choices that determine future actions based on such discoveries require the gathering of support through persuasion and negotiation, and the use of power at different levels of the organisation. Political interaction constrains the instability of the shadow system because organisations are typically characterised by an unequal distribution of power and a hierarchy. As such, people are required to submit their discoveries and views for scrutiny by their piers and particularly by others who hold more power than they do. Hence, if any discovery or view is to be reinforced into the legitimate system, support about issues and actions gained from people higher up on the hierarchy is essential. Individuals are free to experiment, challenge, test and learn by themselves and in groups, but any emergent novelty still has to gain acceptance through the process of political interaction. In this regard, political manoeuvring forms a boundary around the instability of the operations of the shadow system without suppressing the creative capacity of individuals and groups engaged in double-loop learning (Stacey, 1992, 166).

Learning and political interaction encourage creativity and innovation in non-equilibrium organisations because they create a state of instability in the organisation. Both learning and political interaction create tension in the organisation and this sustained tension is the source for creativity and innovation. However, because both double-loop learning and political interaction take place beyond the individual in groups, the instability that is generated through challenges, contention, and conflict is constrained by the same process that gives rise to this instability, namely discussion and dialogue that leads to persuasion. For Stacey, this type of control is effective in open-ended situations because it does not attempt to deal with uncertainty by specifying actions that should lead to the realisation of specific intentions. Interaction based on group-learning and political manoeuvring does not set predetermined rules and directions, but allow these to emerge from the learning process. In this way, choices and actions are designed specifically around the relevant issues without anyone actually controlling the process that resulted in those choices and actions emerging from groups engaged in double-loop learning and political manoeuvring. This is for Stacey an example of control emerging through self-organisation in situations where organisations are required to learn along the way as they proceed into open-ended change. For Stacey, this type of control implies that managers should be less concerned about controlling the actions of individuals or groups, and more concerned about controlling the context within which groups can learn. Stacey believes that if the context for group learning is right, that is sustained tension in the bounded instability of the shadow system, the system will control itself. When there is sustained tension in the shadow system of an organisation, double-loop learning and political interaction produce both control and

Stellenbosch University http://scholar.sun.ac.za

emergent intention, which create a state of bounded instability. For Stacey, control in organisations should be aimed at coping with bounded instability and open-ended change, and this is exactly the type of control produced by double-loop learning and political interaction (Stacey, 1992, 167, 168).

3.4. Leadership: A Complexity based Perspective

Margaret Wheatley sees in the scientific branches of quantum physics, self-organisation theory, and chaos theory the potential for a new way of thinking about organisations, innovative business practices and leadership (Wheatley, 1994, xi). All three of these theories have been responsible for fundamental changes in the way science explains the workings of the universe. Wheatley believes that an understanding of the nonlinear, integrated and self-organising world described by these three theories will prompt people to realise that in the constant flux and unpredictable change of the global economy, there is an inherent orderliness with creative processes and dynamics that maintain an order that people seem unable to grasp. Until people realise that order and change, and autonomy and control are not extreme opposites but part of the fundamental processes of an interrelated and self-organising whole, Wheatley believes they will still attempt to operate organisations in ways, which are not only counterproductive but also destructive. To this end, she proposes that people need to start seeing their world in a whole new way. A way of thinking that is not based on a linear, uncoupled view of phenomena, but on a nonlinear, holistic systems view of the world (Wheatley, 1994, 2 – 4).

This new world view starts when people stop trying to divide the world into different pieces as if these were unrelated building blocks, and instead see that the world is an interrelated and interdependent flow of processes where everything has the potential to influence everything else (Wheatley, 1994, 27). In this world, boundaries are not impenetrable walls that protect the inside of a system from the chaos outside the system, but they are gateways that allow the system to draw energy from outside that can be shaped into recognisable and stable structures, which are both resilient and adaptive at the same time. Wheatley sees organisations as dissipative structures where, order, adaptation and creativity are the result of the relationships between all the agents and the way these agents self-organise under the influence of energy and information transfers from outside the system. Wheatley sees potential innovation in the relationships between people in organisations, and every variation of these relationships represents the potential for something new to emerge in the organisation (Wheatley, 1994, 34). For Wheatley, the implications of this type of worldview profoundly alter the way people organise in organisations. The priority shifts away from defining tasks and towards facilitating conditions where nonlinear processes can create their own organisation of relationships. This requires that managers learn how to construct relationships and to assist the growth and evolution of

Stellenbosch University http://scholar.sun.ac.za

emergent innovations. Wheatley sees organisations as organised around patterns of relationships and the capacities that are available for these patterns to form. Tasks, functions and hierarchies are less important and should be allowed to emerge as people become better skilled at listening, communicating and group learning facilitation, which contribute towards the building of strong relationships among people (Wheatley, 1994, 38, 39). For Wheatley, the role of leadership in the dissipative organisation is based on improvisation. Leaders have to improvise in a constantly changing world by creating conditions where individuals are invited to contribute to the creation of innovation as an emergent order from the interaction of all the participants. These leaders do not attempt to direct the processes that lead to innovation, they only attempt to create conditions where people can be creatively interactive. Control over the outcomes of these processes is placed in the self-organising abilities of the system (Wheatley, 1994, 44).

According to Wheatley, the creation of relationships between employees at all levels of the organisation becomes a primary focal point for leaders. Wheatley compares organisations to systems where interaction is controlled through fields of energy. Culture, values, vision and ethics as qualities of the organisation are not enforced from the top down, but are emergent properties of the self-organising capacities of interaction and feedback in the organisation. This creates a feeling of ownership of those ideas by everyone that participates in their development. This, according to Wheatley, allows organisations to exercise control through the '*formative properties*' of organisational qualities as these flow through the organisation, influencing the behaviour of every employee that comes into contact with them. These fields of energy can connect organisational behaviour that is discrete or distant, because unlike people, organisational qualities can be everywhere at once. Wheatley believes that organisational qualities as concepts are an excellent form of control, but it forces a shift in the attention of leaders. The creation of clear values or visions now becomes only half of the process. Of equal importance now is that these ideas are disseminated to everyone. This is essential if ideas are to be of any value whatsoever. The role of leadership is then broadened to include the creation of links between every part of the organisation. In this way, culture, values, vision and ethics can be used as '*conceptual control mechanisms*' because they can influence behaviour, and cohere and organise separate events into a structural unit (Wheatley, 1994, 52, 54, 55). For conceptual controls to be effective requires an active contribution from every employee in the organisation. This implies that the role of leaders is not to design and enforce conceptual controls, but to create conditions where every employee can be engaged to contribute to the formation of and adherence to conceptual controls. Employees should be able to submit and explain their ideas and concerns with others through open dialogue. This is the foundation for the emergence and perpetuation of conceptual controls. Conceptual controls emerge and

Stellenbosch University http://scholar.sun.ac.za

persist as a result of group learning. Individuals engage one another in discussions in groups, which helps people to acquire new knowledge and skills as the group learns together. Through group learning, individuals change, and as individuals change, so do their groups. This process is effectively double-loop learning and it enables conceptual controls to change as individuals and groups change through learning, application and reflection. Conceptual controls are therefore not dependent on any individual, but their existence and evolution is determined by the interactions of everyone in the organisation. As emergent properties of the organisation, conceptual controls can persist despite random fluctuations, yet they are changeable when learning renders them redundant (Wheatley, 1994, 55, 56). For Wheatley, conceptual controls as an example of fields of energy that determines behaviour, illustrate the correlation between order and disorder, and stability and instability that is responsible for a very subtle structure that controls behaviour without anyone actually being in control (Wheatley, 1994, 57).

In Wheatley's view, organisations function through relationships among the employees. In this organisation, control is exerted through concepts that emerge from group learning and then flow through the entire organisation. The organisation is described as a nonlinear feedback system. In this organisation, individuals shape the structures of the system and as such, order emerges from the combined interactions of all employees across the various levels of the organisation. Order is essentially established through organisational qualities that result from self-organisation during group learning and information dissemination. However, self-organisation and emergent novelties are ascribed to nonlinear processes in systems that operate in non-equilibrium states, as such, Wheatley supports a view of the organisation as being creative when it remains in a non-equilibrium state. Although the non-equilibrium organisation employs both dampening and reinforcing feedback simultaneously, the organisation is maintained in a non-equilibrium state when new ideas or innovations can be integrated into stable structures of the organisation through reinforcing feedback. The necessity for employing dampening feedback to prevent the organisation from collapsing into anarchy is emphasised, however, reinforcing feedback is an essential prerequisite if the organisation is to remain adaptive. Reinforcing feedback becomes the mechanism through which new information can be amplified from its original local position through the entire organisation where possibilities for its application become potentially greater. The spread of information is aided by the nature of the relationships between employees. However, Wheatley also indicates that the nature of innovation and information generation creates tension between the new and the existing aspects of the organisation. This tension though, forces a response and the organisation deals with it by reconfiguring its internal structures accordingly. Organisations then respond to change through the novelties that emerge from group learning and not so much from the planning or control of leaders. For Wheatley, the

Stellenbosch University http://scholar.sun.ac.za

processes that drive change and adaptation in organisations effectively lead to self-organisation. Self-organising processes allow complex systems to adapt structural aspects while simultaneously maintaining its structural integrity. Self-organising systems are therefore, both stable and unstable at the same time. For Wheatley, the lesson to be learnt from this is that leaders should not fear instability in organisations. She proposes that when leaders succeed in maintaining instability in the organisation, they are enabling employees to act creatively. Organisations cannot be adaptive if its employees are not creative. When leaders attempt to contain instability through inflexible control mechanisms, creativity is stifled and the organisation moves towards equilibrium. For Wheatley, this equilibrium state represents a tremendous threat for the survival of the organisation. In the fast paced and open-ended change of the global informational economy, innovation and self-renewal are essential for organisations. However, innovation and self-renewal can only happen if an organisation utilises instability through constant complex learning. These conditions are essential if organisational learning is to give any indication of the expertise that would be required and the tasks that should be attended to for the organisation to survive. Under these conditions, the teams that are needed to meet changes can emerge through self-organisation, and an advantage of self-organisation is that these teams can change when conditions change. For Wheatley, self-organising organisations find it easier to operate in a fluctuating environment. Their structures are sufficiently resilient to endure while at the same time flexible enough to change without collapsing the organisation completely (Wheatley, 1994, 91).

Self-organisation though, requires a constant flow of information about external environmental factors and the internal capacity for processing and reacting to external factors. In organisations, this requires continual data processing guided by high levels of self-awareness, a wide array of data collecting means, and the capacity to engage in reflection about new information. This process aids the organisation in making sense of the information that is constantly flowing through the organisation, effectively enabling it to make better selections for actions from all the available choices. It also aids the decision making process that relates to the selection of resources which are applied in response to threats or new opportunities that suddenly emerge. Like all dissipative structures, the dissipative organisation develops and maintains its structure through an integrated flow of processes and it survives by learning about its environment and adapting its structures through changes in the flow of processes. In this way, the shape of organisation can be kept stable, even when the content that drives its shape changes from time to time (Wheatley, 1994, 91). For Wheatley, this openness and responsiveness to information does not erode the organisation, but actually contributes to the creation of a firmer sense of identity that is less vulnerable to external shocks. The self-organising dynamics of the organisation dominate its

Stellenbosch University http://scholar.sun.ac.za

structures, and by remaining open and responsive to information from outside and the potential application of this information on the inside, the organisation attains a higher level of autonomy and a stronger identity in a turbulent environment. Because the structures in the organisation are organised around information, the organisation of these structures is not threatened when the information content changes. As long as information flows through the system, irrespective of the actual content, structure can be maintained. For Wheatley, self-organising structures in organisations actually give the organisation more freedom from the demands of the environment. This is because self-organising structures can change as the conditions in the environments change, and they can do so more rapidly than structures that first have to be formalised before they can function legitimately (Wheatley, 1994, 92, 93).

Wheatley believes that like all complex systems, organisations require some means to prevent them from losing their character amid constant change. Stable equilibrium states will suppress organisations' capacity to evolve while unchecked instability will cause the system to behave in a way that would prevent stable structures from emerging and result in its evolution being undermined. The evolution of any complex system is influenced by its history, this places certain boundaries around the extent of adaptation through the actions of its components. It is a very flexible boundary that allows the system to maintain its stability while interacting with the environment. In organisations, Wheatley identifies this enabling constraint as core competencies. Wheatley believes that when an organisation is focused on its core competencies, it is defined as a portfolio of skills instead of predetermined business units. This allows the organisation to change in response to environmental fluctuations without first having to redefine itself in a profound way. The organisation remains dynamically stable amid constant change by reaching a level of autonomy within its environment where it need not always be reactive, but can influence the development of its environment for its own benefit. The organisation can then remain stable despite the tumultuous nature of its environment, because whenever it is required to adapt, it does so in a manner that corresponds to its history and identity. For Wheatley, organisations, which change with reference to their, values, competencies and culture can remain orderly even while they change. Wheatley sees identity that is based on values, competencies and culture as being more independent from its environment. These organisations maintain stability even when undergoing extensive changes, because when they change it always involves an act of self-reference. By looking at who they are and at what they have at their disposal, these organisations remain true to their identity when they adapt (Wheatley, 1994, 93, 94).

Stellenbosch University http://scholar.sun.ac.za

A remarkable aspect of systems that adapt through self-organisation is the lack of central control that co-ordinates the actions of individual components. The components of self-organising systems are allowed a great deal of autonomy. This enables the system to sustain a global stable state. Greater freedom in self-organising systems results in more order. Wheatley believes that this holds a profound lesson for leaders in organisation. Control in a constantly changing world is not in the hands of a select few individuals. For Wheatley, good leaders are the ones who recognise that individual freedom at all levels of the organisation can develop greater order through self-organisation. Employees, who understand and focus their actions on the core competencies of their organisation, can co-ordinate their behaviour in an organised way without having to be told to do so. The role of leaders is to provide individuals with a strong frame of reference that is conducive to independent but co-ordinated activity. Wheatley sees human organisations as self-organising systems, as such, she believes that control in organisations emerges when autonomous individuals are allowed to interact in creative ways. Control is generated through behaviour, and not in the hands of managers. This can create a certain level of anxiety and uncertainty within the organisation, but Wheatley believes that if control is distributed broadly through the organisation, it enables creative individuals to have a significant impact on the organisation. This creative learning by individuals also becomes a mechanism that contains the anxiety caused by uncertainty (Wheatley, 1994, 95). Wheatley believes that when leaders give individuals sufficient freedom in their actions, organisations are able to transform themselves in creative but controlled ways. This, however, demands that the thoughts and ideas of people are allowed to flow through the organisation, and ultimately to bring about self-organisation on the part of employees and organisations. This will effectively give the organisation a semblance of unpredictability, but it is not possible to predict the future behaviour of any system that is creative. To this end, Wheatley believes that the science of complexity is forcing leaders to think differently about their views on concepts like change and stability, autonomy and control, and relationships of independence and interdependence (Wheatley, 1994, 98, 99).

Wheatley believes that the new science will force leaders to rethink their role in organisations. Complex systems do not require stringent control mechanisms, they are capable of producing their own control mechanisms through self-organisation. Self-organisation in complex systems is dependent on a steady flow of information through the system and in this lies the fundamental shift in the role of leadership. It is no longer the task of leaders to direct activity within the organisation, for given sufficient levels of information, and the components of a complex system can direct its own activities. For Wheatley, this implies that leaders now have the role of ensuring that employees have sufficient access to information. When information flows freely through an organisation, it changes perceptions

Stellenbosch University http://scholar.sun.ac.za

and structures, and it guarantees new ideas and innovation. In complex systems, the key resource for creativity is information (Wheatley, 1994, 105) Information though, is generated through uncertainty, and in this regard leaders should realise that in a far from equilibrium organisation, creativity and freedom of action go side by side. It is therefore, important for leaders to understand how the activities and relationships in organisations employ uncertainty and ambiguity as a source for generating information. Instead of trying to control this uncertainty and ambiguity, leaders should give employees the freedom to explore it. Leaders should trust the capacity of information to produce a sense of direction and order amid uncertainty and constant change. In this regard, it becomes the task of leaders to distribute information across the organisation as broadly as possible. The free flow of information through the organisation changes the relations and connections between people, and from these new connections innovation emerges (Wheatley, 1994, 109, 113). The task of leaders is then no longer to direct activity, but to direct the flow of information through the organisation. For Wheatley, the process of information generation and creative innovation is greatly enhanced when leaders are willing to release control over people and to allow them to be guided by a shared sense of purpose. This will result in many internal fluctuations in the organisation because conflict and contradiction are no longer suppressed through tight controls. However, when conflict and contradiction are emphasised, the tension that follows becomes a source of new information. This newly acquired information will create a new order when it becomes processed. Wheatley believes that when information is effectively applied, it becomes the energy that turns disorder into order in the organisation. Once leaders realise how new knowledge emerges from variable relationships and nonlinear connections, they will realise that their task is to build organisations that facilitate and supports these processes. When people at all levels are encouraged to think and interact in ways that facilitate a flow of information through the organisation, people become exposed to new perspectives, different perceptions and constant discussion. These constant exchanges produce new information, allowing people to learn new things regularly, and in the process individual learning enables organisational learning (Wheatley, 1994, 115 – 117). Wheatley proposes that leaders start to see their organisations as flows of processes, where every person shares connections with many others in such a way that the different activities of individuals become integrated and this convergent behaviour by individuals allows a single complex structure to emerge within the organisation. Wheatley believes that the new science of complex systems is forcing people to look at the whole and not just parts of a system. When this happens, leaders can start to focus on the creative capacity of the processes that create whole organisations. When these processes are recognised, leaders can discover how these processes combined with information become potent source for creativity and order in organisations (Wheatley, 1994, 118, 119).

Stellenbosch University http://scholar.sun.ac.za

Wheatley feels that the same principles that are applied in nature to create a near infinite array of diverse structures apply in human organisations too. In this regard, she points out that a focus on relationships has become inherent in theories of organisations and management (Wheatley, 1994, 144). The result is the emergence of different perceptions about leadership. For Wheatley, there is a realisation that leadership is always dependent on the context that arises from the relationships that people value. In organisations, leaders can only influence results when they recognise that people who operate as complex networks where relationships are a fundamental property make contributions. Networks though, can be difficult to control, but when they operate with a sufficient degree of autonomy, they produce stability without the need for externally imposed control. The perception then is that leaders should focus their energies on understanding and promoting these nonlinear feedback processes that exist in complex networks, since these processes produce structures that are globally stable, yet locally they are flexible and can respond adaptively without the need for someone to control it. Leaders have to learn how to see organisations as flows of processes that merge individual actions into a coherent whole. This coherent whole remains stable because the organisation possesses a capacity for self-reference. Every individual is influenced by the organisations conceptual qualities, as such, their creative efforts are guided by a desire to adhere to these qualities even when they are working to change other aspects of the organisation. For Wheatley, self-reference is the most fundamental principle of complexity based leadership. Leadership as control through rules and co-ordination has expired in knowledge based organisations according to Wheatley. Wheatley sees the role of leadership as responsible for creating conditions where people can interact in different ways and still produce convergent behaviour. These relationships between people are at the same time a source for creativity, learning and adaptation, as well as a source for emergent order. Leadership then has to foster innovation and innovation requires autonomy. In Wheatley's view, leadership in the future will be less about tight control and more about fostering conditions for participation, relationships, innovation and learning. Organisations will be controlled through the commitment of individuals to adhere to the conceptual qualities of organisations as they act to change the organisation through their own creativity and interactions with others (Wheatley, 1994, 145 – 147).

3.5. Concluding Remarks on Nonlinear Systems Theories and Organisational Thinking

The value of nonlinear systems theories as a paradigm for organisational thinking is rapidly becoming apparent. However, people are still finding it difficult to see how nonlinear systems theories can be applied to benefit various aspects of organisational activity. Perhaps the greatest contribution that nonlinear systems theories make to organisations is the changes it causes in the way people view the world around them. Theories of nonlinear systems allow people to see how even the simplest of events can create havoc in the most stable of environments simply by being iterated through feedback. Theories of nonlinear systems give people a means for understanding the nature of change in complex systems like organisations and economies and it enables them to design business practices that can operate within rapidly changing conditions by tapping into the forces that drive change. Nonlinear systems theories bring a new dimension to the view on the importance of adaptability and entrepreneurship in organisations simply by illustrating just how unpredictable and unstable nonlinear systems can be (Parker & Stacey, 1997, 93). Without an ability to accurately forecast the future, the ability to react and adapt rapidly to events as they are encountered becomes a great asset. However, unpredictability and explosive instability are not necessarily detrimental to organisational success. In fact, nonlinear systems theories show how nonlinear systems use instability in a creative and adaptive way. The problem with unpredictability and instability is a mental one, in that people associate it with discomfort, anxiety and a loss of control. People are prone to seeing half-empty glasses when confronted by theories of nonlinear systems and miss the potential for creative change and complex stability that these theories contain. Theories of nonlinear systems therefore require people to have a different view of the world. This view starts when people recognise that the world is essentially an indivisible whole and that feedback and time delays are natural attributes of that whole. When people look at something from a different perspective, they are also likely to behave differently. However, before one can expect different behaviour, one must ensure that people understand why they are looking from different angles. This is essentially, what nonlinear systems theories do by showing people that an interconnected world can twist events around in unforeseeable ways and can produce consequences that could not easily have been anticipated. This different mindset can start people on the way of looking at relationships between phenomena as a meaningful way for making sense of the world. It is a means for seeing patterns of behaviour that are generated by many different units where everyone is influenced by the actions of the others. However, what nonlinear systems theories cannot do is allow people to predict the long-term future. Prediction is very different from pattern recognition. Recognising patterns allows one to see which key variables are influenced by certain actions. This allows one a certain degree of local leverage to influence those variables through the choice of actions. The amount of information that one would need to predict the future state of the system based on its patterns of behaviour is virtually infinite and as such quite impractical as a business tool. The mindset that is developed from nonlinear systems theories is one that accepts unpredictability as unavoidable, but it also presents one with an explanation for why this is the case. These theories ease the discomfort of unpredictability through an understanding

Stellenbosch University http://scholar.sun.ac.za

of the dynamic processes and interrelationships that underlie and characterise the unpredictability of complex systems.

By providing an understanding of the operations of nonlinear composite systems, the theories of chaos and complexity enable people to design organisations and strategic directions that utilise the relationships that exist between people within organisations. These relationships are essentially, where the creative edge of organisations is located. When it is impossible to anticipate the future, constant learning becomes of vital importance. Nonlinear systems theories provide organisations with a glimpse of how the components of complex systems in nature are organised to ensure creativity and innovation from their interactions. Apart from providing an explanation of the complex relationships in economies that give rise to unpredictability, nonlinear systems theories also provide organisations with a useful method for understanding how they can utilise the innate creativity that exists in individuals. It suggests that individuals interacting in meaningful ways can produce clearer and more realistic strategic directions in uncertain situations. The value of variable relationships between employees in organisations lies in their ability to produce unexpected novelties in unpredictable ways simply by having been allowed to experiment with different ideas and to self-organise themselves around the ideas that are most viable. However, the unpredictability that characterises organisations and economies implies that strategic directions have to be revisited on a continuous basis. The theories of nonlinear systems suggests that organisations should focus on managing local events by continuously considering outcomes that extend only over a small number of interrelationships and only over short periods of time into the future. Attempting to grab hold of more than this, would result only in being swamped by the complexity of the world (Flood, 2000, 90).

Theories of nonlinear systems have then transformed the way people think about organisations, about strategic planning, about control and autonomy, and about stability and instability. People are beginning to see order and disorder in new ways. It is likely that nonlinear systems theories may provide a more viable paradigm for thinking about organisations because it focuses on dynamic processes that generate patterns of behaviour within interrelated systems. It provides a more accurate representation of the dynamics that are at play in knowledge-based organisations and the informational economy. By showing that such organisations are in fact complex adaptive systems, people can see how they can use the inherent self-organising abilities of people in groups to foster conditions where creativity and innovation can result from a learning capacity in the group that exceeds the capacities of any of the individuals. Theories of nonlinear systems suggest that relationships between people in organisations might just be the most important source for creativity and innovation in organisations. These relationships promote continuous learning and provide a platform for the emergence of group capacities that exceed the capacities of the members.

Stellenbosch University http://scholar.sun.ac.za

It incorporates a sense of control in itself and does not require external controllers. These relationships also facilitate the flow of information that is essential for group and organisational learning and as such, it forms a conduit for new ideas to spread and influence various other aspects of an organisation. Relationships form the essence of groups in organisations. Through these relationships, individuals complement each other's abilities and make up for any weaknesses. Relationships between people also make it easier for people to work in groups and to actually function as a group and not a collection of people. Relationships foster trust, and this trust gives rise to a willingness to participate, to share information and views, to handle conflicting perspectives in the interest of shared values. This view of group interaction corresponds to Drucker's view of what he calls the most robust group that can operate in organisations (1993, 79). This type of group forms the foundation for emergent novelties in organisations.

The three perspectives on nonlinear systems thinking that have been presented share the view that the global informational economy demands new mindset and a new style of management that can cope with uncertainty, ambiguity and complexity. This style will have to be based on a perspective that treats the world as an indivisible complex whole where individual agents interact and evolve within the context of an interconnected world. It deals with events as they occur in a flexible way instead of attempting to dampen change through stability based on long-term planning. It will recognise the creative capacity of individuals that have been given the freedom to self-organise themselves around information, and it will encourage complex learning in groups as means for organisational learning. The new style of management will be based on control of boundary conditions and the processes that facilitate effective complex learning. It will be based on control over the processes of learning about and discovery of events as they occur in real time (Stacey, 1993, 364). The global informational economy has all the hallmarks of a complex adaptive system where organisations as its fundamental components evolve together. If organisations are to survive in the turbulent environment, they will require a means for constant learning, innovation and adaptation. Theories of nonlinear systems provide a mindset for understanding the processes that drive change in organisations in so doing they give an indication of the conditions that need to be fostered so that people can interact, learn and produce the innovations that can keep organisations competitive on a continuous basis. Given the fact that nonlinear systems theories have had a profound impact on the way scientists understand and explain the dynamics of order and disorder in the world, and that these dynamics are clearly discernible in the informational economy, it is likely that nonlinear systems theories will also have a profound impact on the way people think about organisations. Given the impact that these theories have already had when they have been applied to business practices, one might reasonably assume that the people who master a

Stellenbosch University http://scholar.sun.ac.za

systemic mindset are likely find it easier to make sense of the global economy. This could go a long way in ensuring that their organisations can survive and thrive in the global economy.

Stellenbosch University http://scholar.sun.ac.za

Bibliography

Arkin, A.P. (2000). '*Signal Processing by Biochemical Reaction Networks*' in J. Walleczek (Ed), *Self-organised Biological Dynamics & Nonlinear Control*, Cambridge: CUP

Arthur, W.B. (1993). 'Pandora's Marketplace', in *New Scientist* Vol. 137 Supplement No 1859, 6 – 8

Auyang, S. Y. (1998). *Foundations of Complex-System Theories*, Cambridge: CUP

Baker, G. & Gollub, J. (1996). *Chaotic Dynamics: An Introduction*, Cambridge: CUP

Bialynicki-Birula, I. & Cieplank, M. & Kaminski, J. (1992). *Theory of Quanta*, Oxford: OUP

Bohm, D. (1984). *Causality and Chance in Modern Physics*, Routledge & Kegan Paul: London

Briggs, J. & Peat, F.D. (1990). *Turbulent Mirror: An Illustrated Guide to Chaos Theory and the Science of Wholeness*. Harper and Row Publishers: New York

Çambel, A.B. (1993). *Applied Chaos Theory: A Paradigm for Complexity*, Academic Press Incorporated: San Diego

Carnoy, M. Castells, M. Cohen, S. & Cardoso, F. (1993). *The New Global Economy in the Information Age: Reflections on our Changing World*. Pennsylvania State University Press: Pennsylvania

Castells, M. (1993). 'The Informational Economy and the new International Division of Labor', in M. Carnoy, M. Castells, S. Cohen & F. Cardoso. (1993). *The New Global Economy in the Information Age: Reflections on our Changing World*. Pennsylvania State University Press: Pennsylvania

Castells, M. (1998). *The Rise of the Network Society*. Blackwell Publishers: Oxford

Cilliers, P. (1998). *Complexity and Postmodernism – Understanding Complex Systems*. Routledge: London

Cohen, J. & Stewart, I. (2000). *The Collapse of Chaos: Discovering Simplicity in a Complex World*, Penguin Books: London

Stellenbosch University http://scholar.sun.ac.za

Cronin, B. (1988). 'Telematics and Retribalisation', in B. Cronin & L. Davenport (Eds), *Post-professionalism: Transforming the Information Heartland.* Taylor Graham: London

Cronin, B & Gudim, M. (1988). 'Information and Productivity', in B. Cronin & L. Davenport (Eds), *Post-professionalism: Transforming the Information Heartland.* Taylor Graham: London

Crutchfield, J.P., Farmer, J.D., Packard, N.H. & Shaw, R.S. (1986). 'Chaos', in *Scientific American*, Vol. 255, 38 – 49

Damasio, A. D. (1999). 'How the Brain creates the Mind', in *Scientific American* Vol. 281, 112 – 117

Davies, P.C.W. (1990). 'Why is the Physical World so Comprehensible?' In W.H. Zurek (Ed), *Proceedings volume in the Santa Fe Institute Studies in the Sciences of Complexity: Vol. 8. Complexity, Entropy and the Physics of Information.* Addison – Wesley Publishing Company: Redwood City, CA

Dawkins, R. (1997). *Climbing Mount Improbable.* Penguin Books: London

Dixon, J.M. Tuszynski, J.A. & Clarkson, P.A. (1997). *From Nonlinearity to Coherence: Universal Features of Nonlinear Behaviour in Many-Body Physics*, Clarendon Press: Oxford

Drucker, P.F. (1987). 'The coming of the new Organisation'. In J.I. Cash, R.G. Eccles, N. Nohria & R.L. Nolan (1993). *Building the Information-Age Organisation: Structure, Control, and Information Technologies.* Irwin Inc: Boston

Drucker, P.F. (1993). *Post Capitalist Society.* Butterworth-Heineman Ltd: Oxford

Edelman, G.M. & Tononi, G. (2000). *Consciousness – How Matter becomes Imagination.* Allen Lane: The Penguin Press: London

Eiser, J.R. (1994). *Attitudes, Chaos and the Connectionist Mind*, Blackwell: Oxford

Eubank, S.G. & Farmer, J.D. (1996). 'Introduction to Dynamical Systems'. In L. Lam (Ed) *Introduction to Nonlinear Physics*, Springer – Verlag: New York,

Stellenbosch University http://scholar.sun.ac.za

Flood, R.L. (2000). *The Fifth Discipline Revisited: Learning Within the Unknowable.* Routledge: London

Gazzaniga, M.S. (1998). 'The Split Brain Revisited'.in *Scientific American* Vol. 279, 50 – 55

Gleick, J. (1988). *Chaos*, Vintage: London

Goerner, S. (1995). 'Chaos, Evolution and Deep Ecology.' in R. Robertson & A. Combs (Eds) *Chaos Theory in Psychology and the Life Sciences*, Lawrence Erlbaum Associates: Mahwah, New Jersey

Goodwin, B. (1995). *How the Leopard changed its Spots – The Evolution of Complexity.* Phoenix Giants: London

Goodwin, B. (1998). 'All for One, One for all.' in *New Scientist* Vol. 158 No 2138: PP 32 – 35

Greenfield, S. (1997). *The Human Brain – A guided Tour.* Weidenfeld & Nicolson: London

Greenfield, S. (2000). *The Secret Life of the Brain*, Penguin Books: London

Hall, A.R. (1993). *The Revolution in Science 1500 – 1750*, Longman: London

Harris, T.G. (1995). 'The Post-Capitalist Executive: An Interview with Peter Drucker.' in K. Ohmae (Ed) *The Evolving Global Economy: Making Sense of the New World Order.* Harvard Business School Publishing: Boston

Hawking, S.W. (1989). *A Brief History of Time.* Bantam Books: London

Hobson, A. (1995). *Physics: Concepts and Connections*, Prentice Hall: Englewood Cliffs

Horgan, J. (1994). 'Can Science explain Consciousness?' in *Scientific American* Vol. 271: 72 – 78

Johnson, S. (2002). *Emergence.* Penguin Books: London

Kauffman, S.A. (1991). 'Antichaos and Adaptation.' In *Scientific American* Vol. 265: 78 – 84

Khalil, E.L. (1999). 'Social Theory and Naturalism – An Introduction.' In E.L. Khalil, & K.E. Boulding, (Eds) (1999). *Evolution, Order and Complexity.* Routledge: New York

Stellenbosch University http://scholar.sun.ac.za

Kiel, L.D. & Elliot, E. (2000). *Chaos Theory in the Social Sciences: Foundations and Applications*, University of Michigan Press: Michigan

Klein, M. J. (1962). 'Max Planck and the Beginning of the Quantum Theory.' in S.G. Brush, (1988). *History of Physics: Selected Reprints*, American Association of Physics Teachers: College Park

Klimontovich, Y. L. (1991). *Turbulent Motion and the Structure of Chaos: A New Approach to the Statistical Theory of Open Systems*, Kluwer Academic Publishers: Dordrecht

Lam, L. (Ed). (1996). *Introduction to Nonlinear Physics*, Springer – Verlag: New York

Lam, L. (1996). 'Active Walks: Pattern Formation, Self-Organisation, and Complex Systems.' in L. Lam, (Ed). *Introduction to Nonlinear Physics*, Springer – Verlag: New York

Lewin, R. (1992). *Complexity: Life at the Edge of Chaos*. MacMillan Publishing Company: New York

Lewin, R. (1993). 'Order for Free.' in *New Scientist* Vol. 137 No 1860: 10 – 11

Lewin, R. (1994). 'A Simple Matter of Complexity.' in *New Scientist* Vol. 141 No 1908: 37 – 40

Lewin, R. (1997). 'It's a Jungle out There.' in *New Scientist* Vol. 156 No 2110: 30 – 34

Lorenz, E.N. (1993). *The Essence of Chaos*, University of Washington Press: Seattle

Luisi, P.L. (1993). 'Defining the Transition to Life: Self-replicating Bounded Structures and Chemical Autopoiesis.' in W.D. Stein & F.J. Varela (Eds) *Thinking about Biology: An Invitation to Current Theoretical Biology*. Addison-Wesley Publishing Company: Reading MA

Marek, M. & Schreiber, I. (1995). *Chaotic Behaviour of Deterministic Dissipative Systems*, CUP: Cambridge

May, R.M. (1974). *Stability and Complexity in Model Ecosystems*. Princeton University Press: New Jersey

Stellenbosch University http://scholar.sun.ac.za

May, R.M. (1981). *Theoretical Ecology: Principles and Applications.* Blackwell Scientific Publications: Boston

May, R. (1989). 'The Chaotic Rhythms of Life.' in *New Scientist* Vol. 124 No 1691: 37 – 41

McGlade, J. (1993). 'Alternative Ecologies.' in *New Scientist* Supplement Vol. 137 No 1859: 14 – 16

Nicolis, G. (1995). *Introduction to Nonlinear Science*, CUP: Cambridge

Nicolis, G. & Prigogine, I. (1977). *Self-Organisation in Nonequilibrium Systems: From Dissipative Structures to Order through Fluctuations*, Wiley Interscience: New York

Parker, D. & Stacey, R. (1997). *Chaos, Management and Economics: The Implications of Nonlinear thinking*, The Institute of Economic Affairs: London

Percival, I. (1989). 'Chaos: A Science for the Real World.' in *New Scientist* Vol. 124 No 1687: 42 – 47

Prigogine, I. (1980). *From Being to Becoming: Time and Complexity in the Physical Sciences*, W.H. Freeman and Company: San Francisco

Prigogine, I. & Driebe D.J. 'Time, Chaos and the Laws of Nature.' in E. Infeld, R. Zelany & A. Galkovksi (Eds). (1997). *Nonlinear Dynamics: Chaotic and Complex Systems*, CUP, Cambridge

Purves, K.P. Gordon, H.O. & Heller, H.G. (1992). *Life: The Science of Biology*, Sinauer Associates Inc: Sunderland

Rasband, S.L. (1990). *Chaotic Dynamics of Nonlinear Systems*, John Wiley & Sons: New York

Ross, R., Smith, B., Roberts, C., Kleiner, A. (1995). 'Core Concepts about Learning in Organisations.' in P.M. Senge, A. Kleiner, C. Roberts, R.B. Ross, B.J. Smith. (Eds) *The Fifth Discipline Fieldbook: Strategies and Tools for Building a Learning Organisation.* Nicholas Brealey Publishing: London

Ruthen, R. (1993). 'Adapting to Complexity.' in *Scientific American* Vol. 268: 110 – 117

Stellenbosch University http://scholar.sun.ac.za

Senge, P.M., Kleiner, A., Roberts, C., Ross, R.B., Smith, B.J. (1995). *The Fifth Discipline Fieldbook: Strategies and Tools for Building a Learning Organisation.* Nicholas Brealey Publishing: London

Senge, P.M. (1999). *The Fifth Discipline: The Art and Practice of The Learning Organisation.* Random House: London

Stacey, R.D. (1992). *Managing the Unknowable: Strategic Boundaries between Order and Chaos in Organisations.* Jossey-Bass Publishers: San Francisco

Stacey, R.D. (1993). *The Chaos Frontier: Creative Strategic Control for Business.* Butterworth-Heineman: Oxford

Stacey, R.D. (1996). *Complexity and Creativity in Organisations.* Berret-Koehler Publishers: San Francisco

Stacey, R. D. (1996). *Strategic Management and Organisational Dynamics.* Pitman Publishing: London

Starr, C. & Taggart, R. (1989). *Biology: The Unity and Diversity of Life*, Wadsworth Publishing Company: Belmont

Stewart, I. (1989). 'Portraits of Chaos'. in *New Scientist* Vol. 124 No 1689: 42 – 47

Stewart, I. (1993). 'A New Order.' in *New Scientist* Vol. 137 Supplement No 1859: 2 – 3

Stewart, I. (1997). *Does God play Dice? The New Mathematics of Chaos.* Penguin Books: London

Stewart, I. (1998). 'Rules of Engagement.'.in *New Scientist* Vol. 159 No 2149: 36 – 40

Treiman, S. (1999). *The Odd Quantum*, Princeton University Press: Princeton

Vivaldi, F. (1989). 'An Experiment with Mathematics.' in *New Scientist* Vol. 124 No 1688: 46 – 49

Wheatley, M.J. (1994). *Leadership and the New Science – Learning about Organisation from an Orderly Universe.* Berrett-Koehler Publishers: San Francisco

Internet Resources

Lancourt, J. & Savage, C. (1995). *Organisational Transformation and the Changing Role of the Human Resource Function* www.kee-inc.com/article.htm

Stellenbosch University http://scholar.sun.ac.za

Petree, J. *History of Chaos*. www.wfu.edu/~petrejh4/HISTORYchaos.htm

Slavin, A. (1994). *A Brief History and Philosophy of Physics.*

www.trentu.ac/academic/physics/depinfo/history_895html