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Complexity and Chaos - State-of-the-Art; Glossary

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Defence R&D Canada – Valcartier
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Abstract

A number of 335 key words related to Complexity Theory, chaos and complex systems are defined in this document. For a number of these key words, many definitions originating from different authors are proposed. The aim is to provide the reader some of the perspectives that can be found in the scientific literature regarding the interpretation of concepts in this domain.

Résumé

Un nombre de 335 mots clefs reliés à la Théorie de la complexité, au chaos et aux systèmes complexes sont définis dans ce document. Pour certains de ces mots clefs, plusieurs définitions provenant d'auteurs différents sont proposées. Le but est de donner au lecteur certaines perspectives que l'on retrouve dans la littérature scientifique concernant l'interprétation des concepts dans ce domaine.

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1 Introduction

This document contains the results of numerous searches that were made in the context of a state-of-the-art in the domain of the Complexity Theory. It aims at regrouping together definitions for currently used key words in the Complexity Theory community.

1.1 Context and Scope of this Document

This document is the third of a set of five DRDC Valcartier reports dedicated to the study of complexity theory, chaos and complex systems (Couture, 2006a, 2006b, 2006c, and one to be published in 2007). It is part of an overarching project being carried on at DRDC Valcartier, Project 15bp01 – Defensive Software Design. It focuses mainly on the presentation of concepts from this theory. There are only a few references to the architecting and engineering aspects of complexity. These aspects will be covered in another document.

1.2 The Used Methodology

Figure 1 depicts the general methodology used for this study. It is characterized by a main iterative and incremental loop (steps 1 and 2), which includes a number of sequential and parallel activities (steps 3, 4 and 5). This loop permits on-the-fly adjustment and optimization.

The five main activities or steps are:

1. **Search literature, projects, groups, etc**: Internet searches were made using Google and other search engines. A number of specialized databases were also searched (Dialog Database Catalog, 2005). These databases are listed in Annex C of Couture (2006a).

2. **Select potentially useful documents**: Documents were selected based on their potential applicability to the military context.

3. **Study selected documents**: Approximately 30–40% of the selected documents were read and studied in greater detail.

4. **Investigate in greater depth for the military context**: This involved finding elements that offer potential solutions in the military context.

5. **Update documents**: The content of each document was updated on the fly at each iteration.

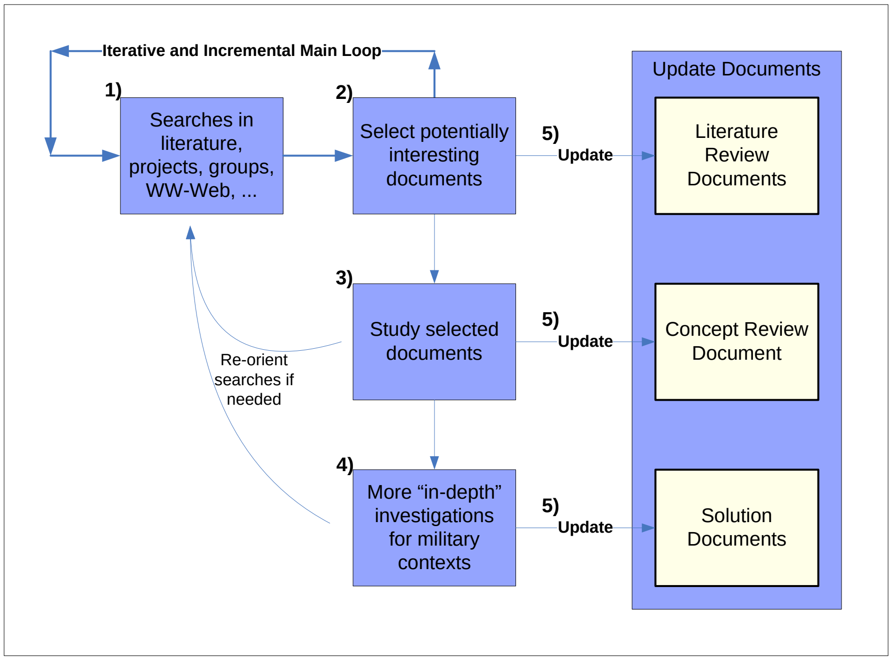

Figure 1 The Methodology Used in this Work.

The reports generated by this study are listed in Table 1. The first four reports will be published by the end of phase one of the study (by March 2007). The last will be published by the end of phase two (late 2007).

Table 1 List of Documents Issued from this Work.

Title	Description
Complexity and chaos – State-of-the-art; List of works, experts, organizations, projects, journals, conferences and tools. (Couture, 2006a).	This Technical Note provides 471 references to scientific studies, organizations, scientific journals, conferences, experts and tools, plus 713 additional Internet addresses that are related to complexity theory, chaos and complex systems. Abstracts are included where available.
Complexity and chaos – State-of-the-art; Formulations and measures of complexity. (Couture, 2006b).	Different formulations and measures of system complexity are provided in this Technical Note. They were drawn from the scientific literature on complexity theory, chaos and complex systems.
Complexity and chaos – State-of-the-art; Glossary. (This document).	This Technical Note defines 335 key words related to complexity theory, chaos and complex systems. The definitions were extracted from the scientific literature.
Complexity and chaos – State-of-the-art; Overview of theoretical concepts. (Couture, 2007).	This Technical Memorandum presents an overview of theoretical concepts pertaining to complexity theory.
Complexity and chaos – State-of-the-art; The Engineering of complex adaptive systems. (To be published in 2007).	Descriptions of the current approaches, methodologies and tools used to address problems related to the architecting, engineering and improvement of complex systems is included in this Technical Report.

1.3 The Content of the Glossary

The Glossary proposes definitions for a number of 335 key words that are currently used in the scientific literature dedicated to Complexity Theory. Many key words of this list propose more than one definition. The main reason for this is related to the fact that this theory is still the object of intensive researches and developments; key words and concepts are often perceived differently by different searchers. The provision of many definitions for each key word will contribute to help the reader understand subtleties between authors' interpretations.

2 Key Word Definitions

Definitions of key words are given in this Chapter. The reader is invited to refer to cited references, Couture (2006a), Couture (2006b) and Couture (2006d) to get complementary information.

2.1 -A-

Action

(**Gharajedaghi, 1999**): *A system behaviour for which a change in the environment is neither necessary nor sufficient (collaborative systems are autonomous and independent). Actions of one system are determined by this system only (based on many factors like internal and external rules, contexts, inputs, outputs, missions, structures, etc).*

Adaptability

(**CALRESCO, 2006**): *The ability of an organism to learn in response to changes in its environment over the course of its lifetime. This allows it to improve its fitness over that available from its initial phenotype.*

Adaptation

(**CALRESCO, 2006**): *The ability of a species to change in response to changes in its environment over many generations. This requires changes to the genotype in a way that increases an individuals' fitness.*

(**From: http://www.complexityandeducation.ualberta.ca/**): *Adaptation refers to the process of mutual change in a complex agent and its environment as a result of recurrent interactions between them. Complex understandings of adaptation consider the interconnected web of relations in which both a complex agent and its environment are embedded—and by which they are constituted or defined. This web includes relations among organisms, inanimate physical things and cultural milieus. Adaptation is dynamic process in which learner and environment evolve together in an on-going and mutually-specifying dance. Education is an adaptive process. Students, teachers, classroom collectives, schools and other complex agents dynamically adapt in relation to one other. Each action of the participants shifts this web of relations—and thus changes those participants.*

(**Flake, 1998**): *An internal change in a system that mirrors an external event in the system's environment.*

Adaptive

(**Flake, 1998**): *Subject to adaptation; can change over time to improve fitness or accuracy.*

Adaptive system

(**NECSI, 2006**): *An adaptive system (or a* ***complex adaptive system****, CAS) is a system that changes its behaviour in response to its environment. Because a CAS adapts to its* *environment, the effect of environmental change cannot be understood just by considering its direct impact. We must also consider the indirect effects due to the adaptive response. Recognizing the way that indirect effects arise from adaptation can help us understand how to influence complex systems in a desired way.*

Affine

(**Flake, 1998**): *An equation that can be written in terms of matrix-vector multiplication and vector addition.*

Agent

See autonomous agent.

Aggregate

(**CALRESCO, 2006**): *A collection of parts brought together without interactions, typical of the reductionist approach which ignores emergent effects and self-organisation.*

Altruism

(**Bar-Yam, 2006b**): *Quality of promoting gain of others at the expense of self.*

Analytical

(**Flake, 1998**): *Can be symbolically represented in a closed form that does not require any of the complex aspects of a program such as an iterative sum.*

Analytical solution

(**From: https://mitpress.mit.edu/books/FLAOH/cbnhtml/glossary.html**): *An exact solution to a problem that can be calculated symbolically by manipulating equations (unlike numerical solution).*

Analytic science

(**From: http://www.complexityandeducation.ualberta.ca/**): *The dominant form of scientific enquiry in Western history, it seeks to understand and explain phenomena by breaking them down, or analyzing them, into component parts. Analytic science's primary methodology is reductionism and it can be contrasted with complexity science approaches. Analytic science works well for examining mechanical (simple and complicated) systems, such as automobiles or electrical circuits, which are the predictable sum of their component parts and determined by external causes. However, it is inadequate for the study of complex systems, like classrooms and schools, which are composed of adaptive and self-organizing agents and exceed the simple sum of their parts. Analytic methods are pervasive in education—for example, in rigid, behaviouristic classroom management strategies that often fail to take into account students' contexts, histories, and agency/self-determination as important components of their actions.*

Architecture

(**Maier and Rechtin, 2002**): *The structure – in term of components, connections, and constraints – of a product, process, or element.*

Architecture description

Architecture description is the sum of all available documentation – under any form – describing any aspect of the architecture. For instance, it can be made of UML model elements, any text based documentation, any architectural framework based diagram, etc. Architecture artefacts do not have to be integrated or linked to form an architecture description.

Arms race

(**CALRESCO, 2006**): *Two species changing in response to changes in the other, a typical predator - prey interaction. This is usually regarded as a negative-sum interaction, improvements cancel each other out.*

(**Flake, 1998**): *Two or more species experience adaptation to one another in a coevolutionary manner. This often seen in predator-prey systems.*

Artificial intelligence

(**CALRESCO, 2006**): *AI (artificial intelligence) which concentrates on the emulation of psychological behaviours.*

(**Flake, 1998**): *The science of making computers do interesting things that human do effortlessy.*

Artificial life

(**CALRESCO, 2006**): *Abbreviation for Artificial Life, the study of alternative forms of life to biological (BLife), also abbreviated to AL in contrast with AI (artificial intelligence) which concentrates on the emulation of psychological behaviours.*

(**Flake, 1998**): *The study of life processes within the confines of a computer.*

Asynchronous

(**Flake, 1998**): *Describes events that occur independently of each other but on a similar time scale.*

Attractor

(1: **CALRESCO, 2006**): *A point to which a system tends to move, a goal, either deliberate or constrained by system parameters (laws). The three standard attractor types are fixed point, cyclic and strange (or chaotic).*

(2: **CALRESCO, 2006**): *A preferred position for the system, such that if the system is started from another state it will evolve until it arrives at the attractor, and will then stay there in the absence of other factors. An attractor can be a point (e.g. the centre of a bowl containing a ball), a regular path (e.g. a planetary orbit), a complex series of states (e.g. the metabolism of a cell) or an infinite sequence (called a strange attractor). All specify a restricted volume* *of state space (a compression). The larger area of state space that leads to an attractor is called its basin of attraction and comprises all the pre-images of the attractor state. The ratio of the volume of the basin to the volume of the attractor can be used as a measure of the degree of self-organisation present. This Self-Organization Factor (SOF) will vary from the total size of state space (for totally ordered systems - maximum compression) to 1 (for ergodic - zero compression). Any system that moves to a persistent structure can be said to be drawn to an attractor. A complex system can have many attractors and these can alter with changes to the system interconnections (mutations) or parameters. Studying self-organization is equivalent to investigating the attractors of the system, their form and dynamics. The attractors in complex systems vary in their persistence, some have long durations so can appear as fixed 'objects', some are of very short duration (transient attractors), many are intermediate (e.g. our concepts).*

(**DuPreez and Smith, 2004**): *The pattern of behaviour into which a system (in equilibrium) ultimately settles down in the absence of outside disturbances, the convergence point of the system. Attractor as defined by complexity theory is not a physical entity but merely depicts where the system is heading, based on the rules of motion in the system.*

(**Flake, 1998**): *A characterization of the long-term behaviour of a dissipative dynamical system. Over long periods of time, the state space of some analytical systems will contract toward this region. Attractors may be fixed points, periodic, quasiperiodic, or chaotic. They may also be stable or unstable.*

(**Wikipedia, 2006**): *In dynamical systems, an attractor is a set to which the system evolves after a long enough time. For the set to be an attractor, trajectories that get close enough to the attractor must remain close even if slightly disturbed. Geometrically, an attractor can be a point, a curve, a manifold, or even a complicated set with fractal structures known as a strange attractor. Describing the attractors of chaotic dynamical systems has been one of the achievements of chaos theory. A trajectory of the dynamical system in the attractor does not have to satisfy any special constraints except for remaining on the attractor. The trajectory may be periodic or chaotic or of any other type.*

(**Williams, 2001**): *The phase space point or set of points representing the various possible steady-state conditions of a system; in other words, an equilibrium state or group of states to which a dynamical system converges.*

Autocatalytic set

(**CALRESCO, 2006**): *A collection of interacting entities often react in certain ways only, e.g. entity A may be able to affect B but not C. D may only affect E. For a sufficiently large collection of different entities a situation may arise where a complete network of interconnections can be established - the entities become part of one coupled system. This is called an autocatalytic set, after the ability of molecules to catalyse each other's formation in the chemical equivalent of this arrangement.*

Autocatalysis

(**CALRESCO, 2006**): *A process that creates itself by catalytic action. A system of chemical reactions such that each reaction is aided (catalysed) by the product of another in a closed and self-perpetuating sequence.*

Autonomic computing

(**Wikipedia, 2006**): *Autonomic Computing is an initiative started by IBM in 2001. Its ultimate aim is to create self-managing computer systems (autonomic systems) to overcome their rapidly growing complexity and to enable their further growth.*

Autonomic system

(**Wikipedia, 2006**): *Modern, networked computing systems that manage themselves without direct human intervention. It is inspired by the autonomic nervous system of the human body. This nervous system controls important bodily functions (e.g. respiration, heart rate, and blood pressure) without any conscious intervention. In a self-managing system Autonomic System, the human operator takes on a new role: He does not control the system directly. Instead, he defines general policies and rules that serve as an input for the self-management process. For this process, IBM has defined the following four functional areas: 1- Self-Configuration: Automatic configuration of components; 2- Self-Healing: Automatic discovery, and correction of faults; 3- Self-Optimization: Automatic monitoring and control of resources to ensure the optimal functioning with respect to the defined requirements; 4-Self-Protection: Proactive identification and protection from arbitrary attacks.*

Autonomous agent, agent

(**CALRESCO, 2006**): *Individuals within an interacting population, each may have only limited freedom to react to their neighbours yet the behaviour of the whole (emergent) may be much more complex. Collections of agents are sometimes called 'swarms'. Agent-based models (ABMs) are central to complexity research.*

(**Flake, 1998**): *An entity with limited perception of its environment that can process information to calculate an action so as to be goal-seeking on a local scale. A boid is an example of an autonomous agent.*

Autonomy

(**CALRESCO, 2006**): *A form of system that can act independently, e.g. a robot. Used in complexity to refer to active (teleological) agents rather than passive ones, i.e. agents with internal goals that can act differently in identical external circumstances.*

Autopoiesis

(1: **CALRESCO, 2006**): *Self-production or self-maintenance. The ability to maintain a bounded form despite a flow of material occurring. A non-equilibrium system, typically life or similar processes but in a wider sense also including natural phenomena like Jupiter's Red Spot.*

(2: **CALRESCO, 2006**): *Autopoiesis is self-production – maintenance of a living organism's form with time and flows. It is a special case of homeostasis and relates to a systemic definition of life. The concept is frequently applied to cognition, viewing the mind as a self-*

producing system, with self-reference and self-regulation which evolves using structural coupling. This concept recognises that outside influences cannot shape the system's internal structure, but only act as triggers to cause the structure to either alter its current attractors or to disintegrate.

(**From: http://www.complexityandeducation.ualberta.ca/**): *Refers to the self-maintaining and self-modifying process of a complex unity. Autopoiesis literally means "self-production". A complex system, or unity, is collection of interconnected components or parts that are designed to support and produce each other. Examples of autopoietic systems include cells, organisms, social systems and, some say, language. In terms of formal education, any phenomenon that might be described as a learner is autopoietic.*

Axiology

(**CALRESCO, 2006**): *The study of values and their types. These can be of four types, systemic, extrinsic, intrinsic and holarchic. Complex systems are of the latter two types.*

Axiom

(**Flake, 1998**): *A statement that is assumed to be true and can later be used along with theorems to prove other theorems. Also, the starting configuration of an L-system.*

2.2 -B-

Basin of attraction

(**CALRESCO, 2006**): *The set of initial states which are drawn to an attractor of the system.*

(**Flake, 1998**): *A region of state space in which all included states of a dynamical system ultimately lead into the attractor.*

(**Williams, 2001**): *The group of all possible phase space points that can evolve onto a given attractor.*

Behaviour of complex systems

(**Wikipedia, 2006**): *Variables in complex systems may of course exhibit very complex, dis-coordinated behaviours, in which it is very hard to predict what an element will do over time. However, Complex Systems may also exhibit relatively simple (or, more formally, low dimensional, or coordinated) patterns of behaviour just as simpler, linear systems do. But, unlike linear systems (however complicated), complex non-linear systems are usually very flexible in terms of exhibiting qualitatively different behaviours at different times. In dynamical systems terminology, such a qualitative change is known as a bifurcation and non-linearity is required for a system to exhibit it. Part of complex systems research is to determine whether any simple rules exist which may be used to describe the low dimensional behaviour of complex systems. Because of the presence of low dimensional behaviours and putative rules governing global behaviour, many refer to the properties of complex systems as emergent. It is important to realise though, that the use of this term is contentious within the complex systems research community, since in principle knowledge of the properties of the components and coupling between them is sufficient to determine all aspects of the* *system's behaviour. In practice though, this is often not possible (or desirable) and it is not wholly misleading to see complex systems research as the study of "emergent" properties.*

Bifurcation

(1: **CALRESCO, 2006**): *A point at which a system splits into two alternative behaviours, either being possible, the one actually followed often being indeterminate (unpredictable). Related to catastrophes in Catastrophe Theory.*

(2: **CALRESCO, 2006**): *A phenomenon that results in a system splitting into two possible behaviours (with a small change in one parameter), further changes to the parameter then cause further splits at regular intervals (the Feigenbaum constant, approx. 4.6692...) until finally the system enters a chaotic phase. This sequence from stability, through increasing complexity, to chaos has much in common with the observed behaviour of complex systems, reflecting changes in attractor structure with variations to parameters. On occasion, successive iterations in a model of the system will cycle between the available behaviours.*

(**Flake, 1998**): *The splitting of a single mode of a system's behaviour into two new modes. This usually occurs as a function of a continuously varying control parameter. A cascade of bifurcations will usually precede the onset of chaos.*

(**Williams, 2001**): *a) In general, a branching into parts or into connected segments (usually one segment or two); b) any abrupt change in the qualitative form of an attractor or in a system's steady-state behaviour, as one or more parameters are changed.*

Bifurcation diagram

(**Williams, 2001**): *A graph showing all possible solutions (excluding transients) to an equation that relates a variable to a control parameter. Such a graph usually is drawn specifically to show bifurcations (period-doublings) of the variable.*

Bifurcation point

(**Williams, 2001**): *A critical parameter value at which two or more branches of system-behaviour emerge.*

Boid

(**Flake, 1998**): *An autonomous agent that behaves like a simplified bird but will display flocking patterns in the presence of other boids.*

Boolean network

(1: **CALRESCO, 2006**): *A combination of interconnected logic gates often used to model complex phenomena and demonstrating the emergence of multiple attractors in simple systems.*

(2: **CALRESCO, 2006**): *Taking a collection (N) of logic gates (AND, OR, NOT etc.) each with K inputs and interconnecting them gives us a Boolean Network. Depending upon the number of inputs (K) to each gate we can generate a collection of possible logic functions that could be used. By allocating these to the nodes (N) at random we have a* ***Random***

Boolean Network *(RBN - also called a Kauffman Net or the Kauffman Model) and this can be used to investigate whether organization appears for different sets of parameters. Some possible logic functions are canalizing and it seems that this type of function is the most likely to generate self-organization. This arrangement is also referred to biologically as a NK model where N is seen as the number of genes (with 2 alleles each - the output states) and K denotes their inter-dependencies.*

Bottom-up

(**Flake, 1998**): *A description that uses the lower-level details to explain higher-level patterns; related to reductionism.*

Boundary

(**OPEN2, 2006**): *The borders of the system, determined by the observer(s), which define where control action can be taken: a particular area of responsibility to achieve system purposes.*

Brownian motion

(**Flake, 1998**): *A form of randomness that is the result of cumulatively adding white noise, to yield a random walk pattern.*

Butterfly effect

(**CALRESCO, 2006**): *The possibility that a large change can occur from a minor shift in initial conditions. A butterfly flapping its wings in the Amazon leading to changes in the location of a typhoon elsewhere in the world. Sensitivity to initial conditions, a chaotic system.*

2.3 -C-

Canalization

(**CALRESCO, 2006**): *The restriction of state space exploration by constraints imposed upon the system either from outside or self-generated, i.e. unavailable possibilities. This helps to preserve stability or the 'status-quo' but may also prevent better optima from being reached.*

Cantor set

(**Flake, 1998**): *A simple fractal set composed of an uncountable infinity of dust-like points, but that also has 0 measure (meaning that the sum wdth of all points is 0). The Cantor set is constructed by removing the middle third of a unit line segment, and then recursively removing the middle third of any remaining line segments, for an infinite number of steps.*

Catalysis

(**CALRESCO, 2006**): *A reaction taking place due to the presence of an enabling agent, one that is not changed in the process. An essential part of autocatalytic processes.*

Cellular automaton (CA)

(**CALRESCO, 2006**): *Simple agents that have a limited number of states, arranged in a grid formation. The state occupied is solely determined by the agent states together with those of their immediate surroundings. The cells in the 'Game of Life' are of this type.*

(**Flake, 1998**): *A discrete dynamical system that is composed of an array of cell, each of which behaves like a finite state automaton. All interactions are locals, with the next state of a cell being a function of the current state of itself and its behaviors. Conway's Game of Life is a CA.*

(**Williams, 2001**): *A mathematical construction consisting of a system of entities, called cells, whose temporal evolution is governed by a set of rules and whose behaviour over time becomes, or at least may appear, highly complex.*

Chaos

(**CALRESCO, 2006**): *A system whose long term behaviour is unpredictable, tiny changes in the accuracy of the starting value rapidly diverge to anywhere in its possible state space. There can however be a finite number of available states, so statistical prediction can still be useful.*

(**Flake, 1998**): *Irregular motion of a dynamical system that is deterministic, sensitive to initial conditions, and impossible to predict in the long term with anything less than an infinite and perfect representation of analog values.*

(**NECSI, 2006**): *Chaos is normally considered to be about disorder or confusion. However, in science it describes an important conceptual paradox which has a precise mathematical meaning: A chaotic system is a deterministic system which is difficult to predict. We normally think that a deterministic system is completely predictable, and this is a mathematical truth. By definition, a deterministic system is one whose state at one time completely determines its state for all future times. Chaos, however, is not a mathematical contradiction; it is a conceptual contradiction with practical consequences. Chaos is not the only source of unpredictability of a system's behaviour. Conceptually, there are three sources for the lack of predictability. The first is the influence of random noise, the second is the effect of the environment on the system, and the third is lack of knowledge of the initial conditions. The third is the one dealt with by studies of chaos.*

(**Wikipedia, 2006**): *Mathematically chaos means an aperiodic deterministic behavior which is very sensitive to its initial conditions.*

(**Williams, 2001**): *a) Sustained and disorderly-looking long-term evolution that satisfies certain special mathematical criteria and that occurs in a deterministic non-linear system; b) largely unpredictable long-term evolution occurring in a deterministic, nonlinear dynamical system because of sensitivity to initial conditions.*

(**From: http://www.complexityandeducation.ualberta.ca/**): *A math-based discourse that has generated models used to describe complex systems. Since such chaotic systems can ultimately be described in deterministic, mathematical terms, however, their application to complex systems is quite limited. Chaos theory deals with non-linear dynamical systems—such as turbulent weather patterns or the spread of disease—which are highly sensitive to* *initial conditions and external influences, yet still the deterministic result of their component parts and external causes. In contrast to complex systems, chaotic systems are neither self-organizing nor adaptive, and thus do not give rise to emergent processes.*

Chaos theory

(**Wikipedia, 2006**): *In mathematics and physics, chaos theory deals with the behavior of certain nonlinear dynamical systems that under certain conditions exhibit a phenomenon known as chaos. Among the characteristics of chaotic systems, described below, is a sensitivity to initial conditions (popularly referred to as the butterfly effect). As a result of this sensitivity, the behavior of systems that exhibit chaos appears to be random, even though the model of the system is deterministic in the sense that it is well defined and contains no random parameters. Examples of such systems include the atmosphere, the solar system, plate tectonics, turbulent fluids, economies, and population growth.*

Chaotic attractor

(**Williams, 2001**): *An attractor that shows sensitivity to initial conditions (exponential divergence of neighbouring trajectories) and that, therefore, occurs only in the chaotic domain.*

Chaotic system

(**Beckerman, 2000**): *Chaotic systems are ordered and deterministic, but appear to have an infinite number of potentially stable states. However, they never settle down to any of these and never repeat their path between them. They are by nature unpredictable and appear to be uncontrollable. Small inputs can lead to very large outputs, resulting in a runaway system or avalanche effect.*

Chomsky hierarchy

(**Flake, 1998**): *Four classes of languages (or computing machines) that have increasing complexity: regular (finite-state automata), context-free (push-down automata), context-sensitive (linear bounded automata), and recursive (Turing Machine).*

Circular causation

(**CALRESCO, 2006**): *The formation of closed loops of cause and effect within the system, such that it is not possible to abstract a linear chain of explanation in the conventional manner. A feature of all complex systems, which typically incorporate many such loops and exhibit multiple interconnected causes and effects.*

Classifier

(**CALRESCO, 2006**): *A set of production rules used to match environmental data and suggest an action to be taken, usually incorporates a genetic algorithm. Each rule covers part of state space.*

Closed system

(**OPEN2, 2006**): *A system which is closed to inputs from its environment, e.g. a transistor radio is closed to energy. In practice such systems rarely exist, but many systems are treated as if they were closed.*

Coalition

(**Gharajedaghi, 1999**): *Coalitions are formed when actors with conflicting ends agree to remove a perceived common obstruction. In this unstable situation, conflict is temporarily converted to cooperation.*

Coevolution

(**CALRESCO, 2006**): *Evolution of species, not only with respect to their environment, but also as to how they relate to other species. This is a more potent form of evolution to that normally considered, changing the shape of the fitness landscape dynamically.*

(**Flake, 1998**): *Two or more entities experience evolution in response to one another. Due to feedback mechanisms, this often results in a biological arms race.*

Collaboration

Collaboration is an efficient communication process that provides solutions to a defined objective. Some possible conditions to collaboration may be: a shared vision, one shared mission or goal, the commitment of all participants, a minimal level of trust, a minimum leadership and a number of collaborative-oriented actions.

Collaborative reinforcement learning (CRL)

(**ERCIM, 2006 – Cunningham's paper**): *CRL is a decentralized approach to establishing and maintaining system-wide properties in distributed systems. CRL extends Reinforcement Learning (RL) by allowing individual agents to interact with neighbouring agents by exchanging information related to the particular system-wide optimization problem being solved. The goal of CRL is to enable agents to produce collective behaviour that establishes and maintains the desired system-wide property.*

Communication

(**OPEN2, 2006**): *(i) First-order communication is based on simple feedback (as in a thermostat) but should not be confused with human communication, which has a biological basis. (ii) Second-order communication is understood from a theory of cognition which encompasses language, emotion, perception and behaviour. Amongst human beings this gives rise to new properties in the communicating partners who each have different experiential histories.*

Competition

(**Bar-Yam, 2006b**): *Behaviour of entities promoting exclusive gain.*

(**CALRESCO, 2006**): *The idea that to survive agents must fight each other and that only one of them can be successful. This assumes that resources are limited (insufficient for both) and is often a negative-sum strategy, i.e. 'win-lose' or 'lose-lose'.*

(**Gharajedaghi, 1999**): *Competition represents a situation in which a lower-level conflict serves the attainment of a commonly held higher-level objective for both parties.*

Complete

(**Flake, 1998**): *Describes a formal system in which all statements can be proved as being true or false. Most interesting formal systems are not complete, as proven in Godel's Incompleteness Theorem.*

Complex adaptive structure

(**From: http://www.evolutionarystructures.com/**): *The field of Complex Adaptive Structures is concerned with the application of Complex Adaptive Systems theory to the design of Structures. In particular it is interested in combining adaptive Agents Based Models with Evolutionary Algorithms to develop Evolutionary Agent Based Structural Optimization Procedures (EABSOP). From such systems, optimized structures will emerge from the interaction of general building blocks (mechanisms/agents). In this definition, general building blocks can be composed of both lower-level building blocks (beams/columns/connection) and higher-level building blocks (floors/walls/entire buildings) that are composed of sets, built up from lower-level building blocks. Constrained generating procedures (CGP's) (Holland) are defined for each level in the building block hierarchy. A state function is formed by combining the lower-level (CGP's) with feedback from the higher-level (CGP's). It follows that the state of the system after each move is defined as a function of the constrained generating procedure hierarchy (CGPH). This multi-level signaling (created by the CGPH) is the key to creating the phenomenon of structural emergence. Therefore the study of Complex Adaptive Structures could also be defined as the study of Emergent Structures; in effect the science of growing structures/buildings.*

Complex adaptive system (CAS)

(**Calhoun, 2004**): *Kauffman's research illustrates the concept of a CAS as a system in which a large number of agents interact in a large number of interdependent processes, adapting through a mechanism of self-organization. What he discovered was the surprising fact that adaptation is optimized when the system exists at the "edge of chaos," the boundary between highly orderly and highly chaotic states. (…) CAS is a system made up of a large number of agents, each behaving according to its own rules or principles in response to local interactions with other system agents. Even when the governing rules or principles are deterministic, the behavior of the system is unpredictable--patterns emerge from the interactions of the agents in the manner associated with strange attractors. The system achieves a state of self-organized criticality without a blueprint or control mechanism, evolving to the edge of chaos where change occurs according to a power law distribution. At the edge of chaos, the system is optimized for adaptation; the number of interactions is great enough that truly novel change can occur, but the system does not become totally unstable.*

(**CALRESCO, 2006**): *A form of system containing many autonomous agents who self-organize in a coevolutionary way to optimise their separate values.*

Complex pattern

(**Eoyan, 2004**): *A complex pattern involves the weaving together of parts into an intricate whole. Each part is massively entangled with others, and the emergent (complex) pattern cannot be discerned from its components. The whole emerges from the interaction of the parts. In the same way that a tapestry depends on the relationships among threads of various colors, other complex systems derive from the parts AND their intricate relationships to each other. If a system can be understood in terms of its parts, then it is a* ***complicated system****. If the whole of the system is different from the sum of its parts, then it is* ***complex****. The distinction between complex and complicated patterns is important because complicated and complex systems require different methods of analysis. Complicated patterns evaluation involves repetition, replication, predictability, and infinite detail.* ***Complex patterns evaluation involves pattern description, contextualization, and dynamic evolution****.*

Complex system

(**CALRESCO, 2006**): *One not describable by a single rule. Structure exists on many scales whose characteristics are not reducible to only one level of description. Systems that exhibit unexpected features not contained within their specification. Systems with multiple objectives.*

(**Couture, 2006d**): *Complex systems are made of an assemblage of autonomous elements[1] that work together in many different ways or processes[2] in order to get the ability to achieve something (a mission, a goal or a function) that cannot be achieved by elements taken separately. Among other things, they have the ability to self-adapt to internal/external changes through the mechanism of self-organization and emergence. Holland (1999) mentions: they exhibit coherence under changes, via conditional action and anticipation, and they do so without central direction.*

(**Flake, 1998**): *A collection of many simple nonlinear units that operate in parallel and interact locally with each other so as to produce emergent behaviour.*

(**ONCE-CS, 2006**): *Many natural phenomena can be considered to be complex systems, and their study (complexity science) is highly interdisciplinary. Examples of complex systems include ant-hills, ants themselves, human economies, nervous systems, cells and living things - especially human beings. Beyond the fact that these things are all networks of some kind, and that they are complex, it may appear that they have little in common and hence that the term "complex system" is vacuous. However, all complex systems are held to have behavioural and structural features in common, which at least to some degree unites them as phenomena. They are also united theoretically, because all these systems may in principle be modelled with varying degrees of success by a certain kind of mathematics, and so it is possible to state clearly what it is that these systems are supposed to have in common with each other in relatively formal terms.*

(**From: http://www.cea.uba.ar/aschu/intro.html**): *A complex system can loosely be defined as constructed by a large number of simple, mutually interacting parts, capable of exchanging stimuli with its environment and capable also of adapting its internal structure as a consequence of such interaction. A key ingredient of a complex system are the non-linear*

[1] These elements are themselves systems, as well as complex systems.
[2] For instance cooperation, coalition, competition and/or conflict.

interactions among its constituents that under special circumstances can give rise to coherent, emergent, complex behaviours with a very rich structure. These behaviours can not be attributed to single separate subsystems but it is rather a collective effect, i.e. the whole turns out to be much more than the sum of its parts. Most of these systems are not amenable to mathematical, analytic discussion and can only be explored by means of "numerical experiments". With a more technical parlance most complex systems are computationally irreducible, i.e. the only way to decide upon its evolution is to actually let them evolve in time. Systems such as these have a number of common features: they have a large number of interacting constituents, they also have some intrinsic, structural disorder (referred to as quenched disorder), and the randomness of the interaction among its constituents displays what has been called frustration. This means that no trivial single configuration of the system will satisfy all interactions simultaneously. At a macroscopic level these system show a coexistence of diversity and stability: on the one hand the system has multiple ground states - or, equivalently, multiple equilibrium - and its macroscopically order parameters turn out to be robust against changes in the internal structure of the system. The dynamics is also affected by this internal structure, the relaxation to global or local minima may be governed by several time constants or, in the case of open systems, the dynamics may tune itself in a very narrow region of possible configurations that are not characterized by any precise time or space scales. This is known as self organized criticality and has also been named in biological evolution as evolution at the edge of chaos.).

(**Wikipedia, 2006**): *Many natural phenomena can be considered to be **complex systems**, and their study (complexity science) is highly interdisciplinary. Examples of complex systems include ant-hills, ants themselves, human economies, nervous systems, cells, and living things — especially human beings. Beyond the fact that these things are all networks of some kind, and that they are complex, it may appear that they have little in common and hence that the term "complex system" is vacuous. However, all complex systems are held to have behavioural and structural features in common, which at least to some degree unites them as phenomena. They are also united theoretically, because all these systems may in principle be modelled with varying degrees of success by a certain kind of mathematics, and so it is possible to state clearly what it is that these systems are supposed to have in common with each other in relatively formal terms. The term **complex system** formally refers to a system of many parts, at many different scales, which are coupled in a nonlinear fashion. Natural complex systems are modelled using the mathematical techniques of dynamical systems, which include differential equations, difference equations and maps. Because they are nonlinear, complex systems are more than the sum of their parts because a linear system is subject to the principle of superposition, and hence is literally the sum of its parts, while a nonlinear system is not. Put another way: a linear relationship is simply one whose graph is a straight line, so a linear connection between two things is one in which change on one side of the connection induces proportional change in the other. A nonlinear connection means that change on one side is not proportional to change on the other. When there are many non-linearities in a system (many components), behaviour can be as unpredictable as it is interesting. Complex systems research studies such behaviour. Most biological systems are complex systems in the sense outlined above, while traditionally, most humanly engineered systems are not. Complex systems research overlaps substantially with nonlinear dynamics research, but complex systems specifically consist of a large number of mutually interacting dynamical parts. Many research disciplines are becoming interested in this branch of mathematical analysis because the digital computer has made theoretical exploration of such* *systems possible. A little mathematical knowledge is required to see why that is so. See for example numerical integration.*

(**From: http://www.complexityandeducation.ualberta.ca/**): *Any self-organizing and adaptive form or network. A complex system arises through the dynamic, non-linear interaction of its component parts, yet embodies emergent possibilities exceeding the sum of these parts. Examples of complex systems include living cells, the human brain, languages, cities and ecosystems. Such systems are self-determining and differ from the non-living, mechanical simple and complicated systems described by traditional science. Whereas simple and complicated (mechanical) systems are described in terms of Euclidian geometry, complex systems are better understood by drawing upon fractal geometry and related concepts of recursion, feedback, scale independence and self-similarity. Among the complex systems that are of interest to educators are the human individual, classroom collectives, communities and cultural systems.*

Complexity

(**Bar-Yam, 2006b**): *The (minimal) length of a complete description of the system.*

(**CALRESCO, 2006**): *The interaction of many parts, giving rise to difficulties in linear or reductionist analysis due to the nonlinearity of the inherent circular causation and feedback effects.*

(**Flake, 1998**): *An ill-defined term that means many things to many people. Complex things are neither random nor regular, but hover somewhere in between. Intuitively, complexity is a measure of how interesting something is.*

(**Freniere et al, 2003**): *Complexity is a measure of the degree to which a system contains large numbers of interacting entities with coherent behaviour. Notionally, one can measure complexity from a value of zero to some maximum number. Zero complexity indicates a completely simple system; few entities have either minimal or no interactions. Generally, one can account for the behaviour of such a system with a simple set of equations or a short description- for example; contemporary military combat models, replete with attrition equations.*

(**NECSI, 2006**): *Complexity is ...[the abstract notion of complexity has been captured in many different ways. Most, if not all of these, are related to each other and they fall into two classes of definitions]: 1) ...the (minimal) length of a description of the system. 2) ...the (minimal) amount of time it takes to create the system. The length of a description is measured in units of information. The former definition is closely related to Shannon information theory and algorithmic complexity, and the latter is related to computational complexity.*

(**Xing and Manning, 2005**): *Although the term "complexity" has proven to be difficult to define, many attempts exist in the literature. The difficulty exists because complexity depends on which aspect you are concerned with. Moreover, complexity only makes sense when considered relative to a given observer (Edmonds, 1999).*

(**Williams, 2001**): *A type of dynamical behaviour in which many independent agents continually interact in novel ways, spontaneously organizing and reorganizing themselves into larger and more complicated patterns over time.*

Complexity philosophy

(**CALRESCO, 2006**): *A set of organic axioms or assumptions more appropriate to nonlinear and interacting complex systems.*

Complexity responsive process

(**Calhound, 2004**): *Complex Responsive Process (CRP) theory is perhaps the most recent advance in the study of complexity in organizations. CRP theory moves beyond the notion that human organizations should be viewed as mechanical systems, emphasizing the unique scientific nature of human interaction as a source of key insights into the manner in which organizations best achieve truly novel change. This study's hypothesis is that the application of complexity theory to organization design provides concepts that could significantly improve the way the Army is currently seeking to innovate. (…). The principles* (of CRP theory) *present several challenges to the universal prescriptions of mainstream thinking about stability and change in organizations, and the manner in which organizations innovate. They include the recognition that: (1) predictability in the evolution of complex organizational processes is severely limited; (2) self-organizing interaction is the central transformative cause of emergent new directions in the development of an organization; (3) individual choice is limited; (4) stability in organizations does not derive from control; (5) diversity and difference are vital to creativity; and (6) the ability to design and plan is limited. These principles of CRP theory provide the following measures of merit: Prediction, defined as the reliance on highly specific, predictive models of the future; Control, defined as the reliance on top-down, hierarchical control and consensus building; and Stability, defined as the attempt to reduce redundancy, inefficiency and difference.*

Complexity science

(**CALRESCO, 2006**): *The study of the rules governing emergence, the constraints affecting self-organisation and general system dynamics in nonlinear adaptive interacting systems.*

Complexity Theory

(**Calhoun, 2004**): *Complexity theory gained notoriety in the early 1990s as a representation of insights gained into the function and significance of complex systems and dynamical processes. It built on earlier studies in chaos and catastrophe theory, providing detailed understanding of concepts including self-organization, emergence and the theory of Complex Adaptive Systems. It is a theory that has been studied for more than a decade by some of science's leading minds, at colleges and institutes around the world, including the prestigious Sante Fe Institute. Complexity science has been applied in many fields including economics, evolutionary theory, physics, computer science, and organization design.*

(1: **CALRESCO, 2006**): *The study of how critically interacting components self-organize to form potentially evolving structures exhibiting a hierarchy of emergent system properties.*

(2: **CALRESCO, 2006**): *The main current scientific theory related to self-organization is Complexity Theory, which states: Critically interacting components self-organize to form potentially evolving structures exhibiting a hierarchy of emergent system properties. The elements of this definition relate to the following:*

- *Critically Interacting* **-** *System is information rich, neither static nor chaotic*
- *Components* **-** *Modularity and autonomy of part behaviour implied*
- *Self-Organize* **-** *Attractor structure is generated by local contextual interactions*
- *Potentially Evolving* **-** *Environmental variation selects and mutates attractors*
- *Hierarchy* **-** *Multiple levels of structure and responses appear (hyper structure)*
- *Emergent System Properties* **-** *New features are evident which require a new vocabulary*

(**Wikipedia, 2006**): *The study of complex systems is bringing new vitality to many areas of science where a more typical reductionist strategy has fallen short. Complex systems is therefore often used as a broad term encompassing a research approach to problems in many diverse disciplines including neuroscience, meteorology, physics, computer science, artificial life, evolutionary computation, economics, earthquake prediction, heart cell synchronisation, immune systems, reaction-diffusion systems, molecular biology, epilepsy and enquiries into the nature of living cells themselves. In these endeavours, scientists often seek simple non-linear coupling rules which lead to complex phenomena (rather than describe - see above), but this need not be the case. Human societies (and probably human brains) are complex systems in which neither the components nor the couplings are simple. Nevertheless, they exhibit many of the hallmarks of complex systems. Traditionally, engineering has striven to keep its systems linear, because that makes them simpler to build and to predict. However, many physical systems (for example lasers) are inherently "complex systems" in terms of the definition above, and engineering practice must now include elements of complex systems research. Complexity Theory is sometimes used as a broad term addressing the study of complex systems, including subjects such as chaos theory, artificial life, and genetic algorithms. Complexity Theory sometimes refers to systems with "sensitive dependence on initial conditions." [eg. the waving of a butterfly's wings today changes weather patterns tomorrow] which is, perhaps, more commonly known as chaos theory.*

Complicated pattern

(**Eoyan, 2004**): *A complicated pattern is one that is intricate in the number of parts and their hidden relationships to each other. Such a system appears to be "folded" so that parts are hidden from view. To understand such a system, the parts must be separated from each other and the relationships clearly defined. Though it may take a long time and much effort, a complicated system can be understood in terms of its parts. Reductionism is an effective method of investigating the nature and function of a complicated system. If a system can be understood in terms of its parts, then it is a complicated system. If the whole of the system is different from the sum of its parts, then it is complex. The distinction between complex and complicated patterns is important because complicated and complex systems require different methods of analysis. Complicated patterns evaluation involves repetition,* *replication, predictability, and infinite detail. Complex patterns evaluation involves pattern description, contextualization, and dynamic evolution.*

Compressible

(**Flake, 1998**): *Having a description that is smaller than itself; not random; possessing regularity.*

Computable

(**Flake, 1998**): *Expressible as a yes/no question that can be answered in any case bt a computer in finite time.*

Computational complexity theory

(**Wikipedia, 2006**): *A field in theoretical computer science and mathematics dealing with the resources required during computation to solve a given problem. The theoretical treatment of Kolmogorov complexity of a string is studied in algorithmic information theory by identifying the length of the shortest binary program which can output that string. In computer science, computational complexity theory is the branch of the theory of computation that studies the resources, or cost, of the computation required to solve a given problem. This cost is usually measured in terms of abstract parameters such as time and space. Time represents the number of steps it takes to solve a problem and space represents the quantity of information storage required or how much memory it takes. There are often tradeoffs between time and space that have to be considered when trying to solve a computational problem. It often turns out that an alternative algorithm will require less time but more space (or vice versa) to solve a given problem. Time requirements sometimes must be amortized to determine the time cost for a well defined average case. Space requirements can be profiled over time, too, especially in consideration of a multi-user computer system. Other resources can also be considered, such as how many parallel processors are needed to solve a problem in parallel. In this case, "parallelizable time" and "non-parallelizable time" are considered. The latter is important in real-time applications, and it gives a limit to how far the computation can be parallelized. Some steps must be done sequentially because they depend on the results of previous steps. Complexity theory differs from computability theory, which deals with whether a problem can be solved at all, regardless of the resources required.*

Conflict

(**Gharajedaghi, 1999**): *A situation in which each party reduces the expected value of the outcomes for the other.*

Connectionist system

(**CALRESCO, 2006**): *A system characterised by explicit connections between the components resulting in a distributed data structure (as used in neural networks).*

Connectivity

(**CALRESCO, 2006**): *The relation of an agent to its neighbours, it can be sparsely connected (only affected by a few neighbours), fully connected (interfacing with every other* *agent in the system) or some intermediate arrangement. This parameter critically affects the dynamics of the system.*

(**Flake, 1998**): *The amount of interaction in a system, the structure of the weights in a neural network, or the relative number of edge in a graph.*

(**OPEN2, 2006**): *Logical dependence between components or elements (including sub-systems) within a system.*

Conservative phenomenon or system

(**Flake, 1998**): *A dynamical system that preserves the volume of its state space under motion and, therefore, does not display the type of behaviour found in dissipative systems.*

(**Williams, 2001**): *Not loosing energy with time (keeping instead a constant area or volume in phase space).*

Consistence

(**Flake, 1998**): *In formal systems, having the property that all statements are either true of false.*

Constraint

(**CALRESCO, 2006**): *A force of some sort restricting the movement of a system. See selection. In Life studies the variations of form do not allow infinite variation, something constrains the options available. Complexity studies seek the laws that apply, if any, in these cases and similar areas.*

Constructivism

(**CALRESCO, 2006**): *The idea that we construct our reality mentally rather than seeing directly an objective world. This idea is validated by research in neuropsychology and relates also to general semantics.*

(**From: http://www.complexityandeducation.ualberta.ca/**): *Constructivism is a philosophy of learning founded on the premise that we recursively construct our understandings of the world we live in. Building on the work of Jean Piaget, constructivist discourses might be characterized in terms of efforts to understand an individual's conceptual development in terms of metaphors of biological development. Concepts are thus seen as evolving and rooted in one's physical engagements with the world; learning is seen as an organic process through which a learner continuously adapts interpretations and expectations in order to incorporate new experiences and maintain coherence. Constructivism's insight that learners recursively construct meaning or knowledge is compatible with complexity. Indeed, complexity science offers a way to reconcile the accounts of radical constructivists and social constructivists, by acknowledging that each discourse is appropriate to the level it focuses on (respectively, individual and social/collective knowledge) and is not reducible to the other.*

Continuous

(**Flake, 1998**): *Taking a real value, i.e., not strictly discrete. Dynamical systems may operate in continuous time or space.*

Control

(**Flake, 1998**): *Exerting actions to manipulate a system or environment in a goal-seeking manner.*

(**Gharajedaghi, 1999**): *Control means that an action is both necessary and sufficient to produce the intended outcome.*

Convergence

(**Flake, 1998**): *For computers, halting with an answer; for dynamical systems, falling into an attractor; for searches (e.g., backpropagation and genetic algorithms), finding a location that cannot be improved upon; for infinite summations, approaching a definite value.*

Conway's Game of Life

(**Flake, 1998**): *A cellular automaton rule set that operates on a two-dimensional grid. Each cell changes its state according to the states of its eight nearest neighbors: dead cells come alive with exactly three live neighbors, and cells die if they have anything but two or three neighbors. The Game of Life can display complex patterns such as gliders, fish, and glider guns, and is also capable of universal computation.*

Cooperation

(**Bar-Yam, 2006b**): *Behaviour of entities promoting mutual gain.*

(**CALRESCO, 2006**): *The idea that two agents can increase both their fitnesses by mutual help rather than by competition. This assumes that resources adequate for both exist, or are created by the interaction, and relates to synergy (synergic coevolution) and 'compositional evolution'.*

Crisis

(**Williams, 2001**): *An abrupt, discontinuous change in a chaotic attractor as a parameter is varied, characterized by either destruction of the chaotic attractor or its expansion to a much larger interval of x.*

Critical theory

(**From: http://www.complexityandeducation.ualberta.ca/**): *Critical theory is concerned with identifying the power relationships and forms of oppression that exist in a society or culture with the goal emancipating individual members. Critical theory, as a branch of social constructivism (constructionism), finds its roots in critical hermeneutics from the late 19th century. Critical theorists tend to focus on the metaphor of power as manifest within particular knowledge domains and cultural practices. They note that power, for the most part, does not operate on conscious or deliberate levels, but tends to be tacitly inscribed in different systems of interpretation—especially those represented in modern curricula. For critical theorists, as for complexivists, one's identity is ever-evolving and constructed at the* *intersections of our individual, collective, biological, social, cultural and political interactions.*

Criticality

(**CALRESCO, 2006**): *A point at which system properties change suddenly, e.g. where a matrix goes from non-percolating (disconnected) to percolating (connected) or vice versa. This is often regarded as a phase change, thus in critically interacting systems we expect step changes in properties.*

Crossover

(**CALRESCO, 2006**): *Sexual mating between two genotypes in which a portion of the genes of one is joined to part of the genes of the other, to create a hybrid creature. This recombination allows rapid searching of the possible phase space.*

(**Flake, 1998**): *A genetic operator that splices information from two or more parents to form a composite offspring that has genetic material from all parents.*

Culture

(**Calhoun, 2004**): *Williamson Murray defines military culture as "the sum of the intellectual, professional, and traditional values of an officer corps; it plays a central role in how that officer corps assesses the external environment and how it analyzes the possible response that it might make to 'the threat'."*

Cybernetics

(1: **CALRESCO, 2006**): *The study of control or homeostasis within a system, typically using combinations of feedback loops. This can be within machines or living structures. First order cybernetics relates to closed systems, second order includes the observer perspective and third order looks to how these coevolve.*

(2: **CALRESCO, 2006**): *Cybernetics is the precursor of complexity thinking in the investigation of dynamic systems and set the groundwork for the study of self-maintaining systems, using feedback and control concepts. It relates generally to systems isolated or closed in organizational terms, in other words to self-contained systems. Complexity theory includes some new concepts such as self-organization plus its various specialisms, and adds more prominence to borrowed concepts like emergence, phase space and fitness landscapes, but in essence it relates systems to other systems. It includes the two way information flows between them, their mutual reactions to their environment or co-evolution. It also deals with systems that can evolve or adapt, that can become quite different systems.*

Cyclic

(**CALRESCO, 2006**): *A system occupying a sequence of states in turn. A closed trajectory in state space.*

2.4 -D-

Darwinism

(**Flake, 1998**): *The theory of evolution as proposed by Charles Darwin, which combined variation of inheritable traits with natural selection. After the discovery of the physical mechanism of genetics, this was further refined into Neo-Darwinism.*

Deductive approach

(**Eoyan, 2004**): *A deductive approach begins with a coherent model or expectation and seeks for or shapes phenomena that match the expectation.*

Degree of freedom

(**Williams, 2001**) *The number of independent quantities (variables or parameters) or pieces of information that must be specified to define the state of a system completely. The field of statistics also has several other less common meanings.*

Dependency on initial conditions, sensitivity on initial conditions

(**Calhoun, 2004**): *This sensitivity to initial conditions is a central feature of chaotic systems and strange attractors. To visualize this sensitivity to initial conditions, one need only imagine pairs of adjacent points beginning to move along trajectories on the Lorenz attractor. It can be readily seen that depending on where they begin their movement, adjacent points can follow trajectories that will take them both to a pattern of activity on the left wing of the attractor, both to a pattern of activity on the right wing of the attractor, or each to separate patterns of activity on opposite wings of the attractor. These patterns of activity are not limit cycles. The wings of the butterfly are thin, but they each contain an infinite number of points. The weather characteristics get "trapped" on one wing of the attractor or the other, therefore displaying order, but each can occupy any of an infinite number of states on the wing where it is trapped, resulting in unpredictability: "This infinite of complex surfaces-- the strange attractor--embodies a new kind of order. Though the trajectory's motion is unpredictable in detail, it always stays on the attractor, always moves through the same subset of states. That narrowness of repertoire accounts for the order hidden in chaos and explains why its essence never changes."54 This key characteristic of strange attractors explains a fundamental trait of complex systems--despite the fact that they are governed by only a few simple, deterministic rules, they display behavior that is orderly, yet unpredictable. This is contrary to the deterministic, time-reversible Newtonian view in which natural processes can be explained by a theory that provides accurate predictions as long as precise information is available regarding initial conditions.*

(**Williams, 2001**): *a) The quality whereby two slightly different values of an input variable evolve to two vastly different trajectories; b) the quality whereby two initially nearby trajectories diverge exponentially with time.*

Derivative

(**Flake, 1998**): *An expression that characterizes how the output of a function changes as the input is varied. Unlike integrals, derivatives can be calculated in an analytical manner very easily.*

Description

(**NECSI, 2006**): *Representing the properties of one system in the properties of another system.*

Deterministic phenomenon

(**Flake, 1998**): *Occurring in a non-random manner such that the next state of the system depends only on prior states of the system or the environment. Perfect knowledge of previous states implies perfect knowledge of the next state.*

(**Williams, 2001**): *a) completely and exactly specified (at least to within measuring accuracy) by one or more mathematical equations and a given initial condition; b) said of a system whose past and future are completely determined by its present state and any new input.*

Development

(**Bar-Yam, 2006b**): *For instance: The process of self-organization that occurs when a single fertilized egg becomes a differentiated multi-cellular organism.*

(**ERCIM, 2006 – Tyrell's paper**): *Development of living organisms is controlled by genes, which determine the synthesis of proteins. The activity of genes sets up the complex interactions between different proteins, between proteins and genes within cells. The development of an embryo is determined by these interactions. It is the growth from a single zygote to a mature multi-cellular organism.*

Difference equation

(**Flake, 1998**): *An equation that describes how something changes in discrete time steps. Numerical solutions to integrals are usually realized as difference equations.*

Dimension

(**Williams, 2001**) *Generally, a magnitude measured in a particular direction, as on the axe of a graph. In chaos theory, dimension is used in any of several variations of that general meaning such as: a) each axis of a set of mutually perpendicular axes in Euclidian space b) the number of coordinates needed to locate a point in space c) the maximum number of variables of a system d) any of various quantitative, topological measures of an object's complexity, and other variations.*

Discrete

(**CALRESCO, 2006**): *Non-continuous. A step by step (countable) approach. Digital systems operate this way, with time steps being the controlling factor. A sufficiently large number of such steps can approximate to any continuous (analogue) system.*

(**Flake, 1998**): *Taking only non-continuous values, e.g., Boolean or natural numbers.*

Dissipative phenomenon or systems

(1: **CALRESCO, 2006**): *Using a resource flow to constantly achieve a task, which may be work (e.g. movement) or more usually to maintain the system in a steady state (e.g. a living organism). Dissipative systems operate far-from-equilibrium.*

(2: **CALRESCO, 2006**): *Systems that use energy flow to maintain their form are said to be dissipative systems, these would include atmospheric vortices, living systems and similar. The term can also be used more generally for systems that consume energy to keep going e.g. engines or stars. Such systems are generally open to their environment.*

(**Flake, 1998**): *A dynamical system that contains internal friction that deforms the structure of its attractors (…) Dissipative systems often have internal structure despite being far from equilibrium, like a whirlpool that preserves its basic form despite being in the midst of constant change.*

(**Williams, 2001**): *A system that loses energy with time. Evidence of energy loss with time includes an irreversible evolution toward an asymptotic or limiting condition over time and a decrease of phase space area volume, with time.*

Diverge

(**Flake, 1998**): *For algorithms or computers, to run forever and never halt; for iterative systems (like the equations for the Mandelbrot set), reaching a state such that all future states explode in size.*

Diversity

(**CALRESCO, 2006**): *The range of features or niches available. This could be variation within a species, or the totality of different species in an ecosystem.*

Domain

(**SEI, 2006**): *An area of knowledge or activity characterized by a set of concepts and terminology understood by practitioners in that area.*

Domain analysis

(**SEI, 2006**): *Process for capturing and representing information about applications in a domain, specifically common characteristics and reasons for variability.*

Downward causation

(**CALRESCO, 2006**): *Effect of higher level emergent properties on the lower level part behaviour. Constraints on the area of state space available.*

Dualism

(**CALRESCO, 2006**): *The idea that issues can always be divided into either/or states, e.g. mind/matter, fact/value, right/wrong. A throwback to pre-complexity viewpoints and earlier bivalent logic and systemic valuation, replaced mostly in complex systems approaches by non-dualist (continuum) modes of thought that take into account the wider connectivity issues and the need to balance multiple objectives.*

Dynamics, dynamical

(**CALRESCO, 2006**): *The behaviour of a system in time. Changes with time are the essence of complexity, a static system is merely a snapshot within an evolutionary continuum, however interesting it may be in its own right.*

(**Flake, 1998**): *Pertaining to the change in behaviour of a system over time.*

(**Williams, 2001**): *The branch of physics (mechanics) that deals with forces and their relation to the motion and sometimes the equilibrium of bodies b) the pattern of change or growth of an object or phenomenon.*

Dynamic systems, dynamical systems

(**Flake, 1998**): *A system that changes over time according to a set of fixed rules that determines how one state of the system moves to another state.*

(**Eoyan, 2004**): *Dynamical systems are ones that change in response to nonlinear, high dimension, and/or discontinuous forces. Weather patterns, evolution, dripping faucets, and injury rates in industrial settings have been shown to exhibit dynamical patterns of behavior. The sciences of complexity and deterministic chaos are being developed to understand these emergent and unpredictable systems. The traditional evaluation method that is most able to capture the dynamical nature of social systems involves stories and storytelling. The emerging science of complexity may provide other tools to track and understand patterns of dynamical change. Dynamic systems are ones that are moving in response to known, linear (or at least continuous) forces. A perfect example is the arc of water from a garden hose. We know that the momentum of the water and the force of gravity resolve to form the graceful parabolic curve that we observe. Some evaluation techniques treat programs as dynamic systems. Procedures for longitudinal studies, for example, acknowledge the dynamic nature of programs and social change.*

(**Wikipedia, 2006**): *A dynamical system is a concept in mathematics where a fixed rule describes the time dependence of a point in a geometrical space. The mathematical models used to describe the swinging of a clock pendulum, the flow of water in a pipe, or the number of fish each spring in a lake are examples of dynamical systems. A dynamical system has a state determined by a collection of real numbers. Small changes in the state of the system correspond to small changes in the numbers. The numbers are also the coordinates of a geometrical space—a manifold. The evolution rule of the dynamical system is a fixed rule that describes what future states follow from the current state. The rule is deterministic: for a given time interval only one future state follows from the current state.*

(**Williams, 2001**): *a) Anything that evolves in time; b) any process or model in which each successive state is a function of the preceding state.*

Dynamical system theory

(**CALRESCO, 2006**): *The mathematical study of the behaviour through time of systems. This studies the attractor structure, bifurcation behaviour and phase portraits of the system.*

(**Williams, 2001**): *a) The study of phenomena that vary with time; b) a language that describes the behaviour of moving or evolving systems, especially as affected by external control parameters.*

2.5 -E-

Ecological

(**From: http://www.complexityandeducation.ualberta.ca/**): *Ecological refers to the web of relationships in which an organism is embedded. It points to the nested nature of all living organisms in increasingly large complex systems, in which the links between parts of the system are necessary for the maintenance of the system as a whole. Ecology can be distinguished from simplistic understandings of environment, which imply a separation between human beings (or other organisms) and the ecology in which they are embedded. An ecological insight for education is that the knower, be it an individual human being or another complex system, cannot be separated from the known. Teachers, students and their environments co-constitute each other and influence one another's learning, knowledge and identity.*

Ecosystem

(**CALRESCO, 2006**): *The relatively stable balance of different species within a particular area. A food chain, usually cyclic and self-sustaining.*

(**Flake, 1998**): *A biological system consisting of many organisms from different species.*

Edge of chaos

(**Calhoun, 2004**): *The edge of chaos is analogous to the scientific phenomenon of the phase transition--the point at which a system transitions from one state to another (i.e. water transitions from liquid to gas at the boiling point temperature). Much like the balanced state a system occupies when undergoing a phase transition, Kauffman believes "Networks in the regime near the edge of chaos--this compromise between order and surprise--appear best able to coordinate complex activities and best able to evolve as well."(…) One particularly significant characteristic of the edge of chaos is the fact that not only do systems achieve optimum adaptability there--they tend to evolve there on their own. Complex adaptive systems achieve a state of "self-organized criticality" discovered by Danish physicist Per Bak in 1986. Bak illustrates the concept through the metaphor of a pile of sand, created by pouring a steady stream of sand onto a tabletop. As the amount of sand on the table increases, it forms a pile that gets taller and wider until sand begins to fall off the sides. At this point, the sand pile has achieved self-organization, in that it has reached a steady state without anyone consciously directing it; and the pile has reached criticality, in that it is just barely stable, with any further addition of sand having the potential to cause a cascade of falling sand, a trickle, or no effect at all. The reaction that occurs when sand is added to the pile after it has reached criticality occurs according to a power law distribution, meaning there are a small number of large events (cascades of falling sand), and a large number of small events (trickles of falling sand). Most importantly, this self-organized criticality occurs on its own, whether in an actual pile of sand, a computer simulation or a natural complex system.*

(1: **CALRESCO, 2006**): *The tendency of dynamic systems to self-organise to a state roughly midway between globally static (unchanging) and chaotic (random) states. This can also be regarded as the liquid phase, half way between solid (static) and gas (random) natural states. In information theory this is the state containing the maximum information*.

(2: **CALRESCO, 2006**): *This is the name given to the critical point of the system, where a small change can either push the system into chaotic behaviour or lock the system into a fixed behaviour. It is regarded as a phase change. It is at this point where all the really interesting behaviour occurs in a 'complex' system and it is where systems tend to gravitate give the chance to do so. Hence most ALife systems are assumed to operate within this regime. At this boundary a system has a correlation length (connection between distant parts) that just spans the entire system, with a power law distribution of shorter lengths. Transient perturbations (disturbances) can last for very long times (infinity in the limit) and/or cover the entire system, yet more frequently effects will be local or short lived - the system is dynamically unstable to some perturbations, yet stable to others.*

(**Flake, 1998**): *The hypothesis that many natural systems tend toward dynamical behaviour that border static patterns and the chaotic regime.*

Emergence, emergent phenomenon

(**From: http://www.comdig.com/topic2.php?id_topic=729&id_article=21683**): *The Cambridge Dictionary of Philosophy distinguishes between structures and laws, between descriptive and explanatory emergence. Descriptive emergence means "there are properties of 'wholes' (or more complex situations) that cannot be defined through the properties of the 'parts' (or simpler situations)". Explanatory emergence means "the laws of the more complex situations in the system are not deducible by way of any composition laws or laws of coexistence from the laws of the simpler or simplest situations"*.

(**Bar-Yam, 2006b**): *The relationship between a description of the system at a fine and large scale.*

(**Beckerman, 2000**): *We have discussed the concept of emergence as representing the collective behaviour of the system elements that reside in a lower level. The behaviour cannot be predicted from or described by the properties of those elements, but is something unique that manifests when all those elements are joined together and interact with each other. The concept of emergence is intrinsic to all types of systems. It has been embraced by the soft sciences (biology, sociology, etc.) but has been largely ignored by the engineering community under the mistaken belief that engineered systems do not display it.*

(**Calhoun, 2004**): *Emergence is "overall system behavior that comes out of the interaction of many participants--behavior that cannot be predicted or even envisioned from knowledge of what each component of the system does in isolation."*

(1: **CALRESCO, 2006**): *System properties that are not evident from those of the parts. A higher level phenomena, that cannot be reduced to that of the simpler constituents and needs new concepts to be introduced. This property is neither simply an aggregate one, nor epiphenomenal, but often exhibits 'downward causation'. Modelling emergent dynamical hierarchies is central to future complexity research.*

(2: **CALRESCO, 2006**): *The appearance of a property or feature not previously observed as a functional characteristic of the system. Generally, higher level properties are regarded as emergent. An automobile is an emergent property of its interconnected parts. That property disappears if the parts are disassembled and just placed in a heap. There are three aspects involved here. First is the idea of 'supervenience', this means that the emergent properties will no longer exist if the lower level is removed (i.e. no 'mystically' disjoint properties are involved). Secondly the new properties are not aggregates, i.e. they are not just the predictable results of summing part properties (for example when the mass of a whole is just the mass of all the parts added together). Thirdly there should be causality - thus emergent properties are not epiphenomenal (either illusions or descriptive simplifications only). This means that the higher level properties should have causal effects on the lower level ones - called 'downward causation', e.g. an amoeba can move, causing all its constituent molecules to change their environmental positions (none of which however are themselves capable of such autonomous trajectories). This implies also that the emergent properties 'canalize' (restrict) the freedom of the parts (by changing the 'fitness landscape', i.e. by imposing boundary conditions or constraints).*

(**De Wolf and Holvoet, 2005**): *A system exhibits emergence when there are coherent emergents at the macro-level that dynamically arise from the interactions between the parts at the micro-level. Such emergents are novel w.r.t. the individual parts of the system.*

(**Flake, 1998**): *Refers to a property of a collection of simple subunits that comes about through the interactions of the subunits and is not a property of any single subunit. For example, the organization of an ant colony is said to "emerge" from the interactions of the lower-level behaviors of the ants, and not from any single ant. Usually, the emergent behaviour is unanticipated and cannot be directly deduced from the lower-level behaviors. Complex systems are usually emergent.*

(**Fromm, 2005a**): *Emergent and emergence are defined like this: a property of a system is emergent, if it is not a property of any fundamental element, and emergence is the appearance of emergent properties and structures on a higher level of organization or complexity (if "more is different" [Anderson72]). This is the common definition that can be found in many introductory text books on complex systems [Flake00, BarYam97].*

Oxford Companion to Philosophy defines emergent properties as unpredictable and irreducible: "a property of a complex system is said to be 'emergent' just in case, although it arises out of the properties and relations characterizing its simpler constituents, it is neither predictable from, nor reducible to, these lower-level characteristics".

(**NECSI, 2006**): *Emergence is... 1) ...what parts of a system do together that they would not do by themselves: collective behaviour. 2) ...what a system does by virtue of its relationship to its environment that it would not do by itself: e.g. its function. 3) ...the act or process of becoming an emergent system. According to (1) emergence refers to understanding how collective properties arise from the properties of parts. More generally, it refers to how behaviour at a larger scale of the system arises from the detailed structure, behaviour and relationships on a finer scale. In the extreme, it is about how macroscopic behaviour arises from microscopic behaviour. According to this view, when we think about emergence we are, in our mind's eye, moving between different vantage points. We see the trees and the forest at* *the same time. We see the way the trees and the forest are related to each other. To see in both these views we have to be able to see details, but also ignore details. The trick is to know which of the many details we see in the trees are important to know when we see the forest. In conventional views the observer considers either the trees or the forest. Those who consider the trees consider the details to be essential and do not see the patterns that arise when considering trees in the context of the forest. Those who consider the forest do not see the details. When one can shift back and forth between seeing the trees and the forest one also sees which aspects of the trees are relevant to the description of the forest. Understanding this relationship in general is the study of emergence. According to (2) emergence refers to all the properties that we assign to a system that are really properties of the relationship between a system and its environment. A useful example is a key. A key has a particular structure. Describing its structure is not enough to tell someone that it can open a door. We have to know both the structure of the key, and of the lock. Without describing the structure of either, however, we can tell someone that it can unlock the door. One of the problems in thinking about the concepts of complex systems is that we often assign properties to a system that are actually properties of a relationship between the system and its environment. Why do we do this? Because it makes thinking about what is going on simpler. Why can we do this? Because when the environment does not change, then we only need to describe the system and not the environment in order to give the relationship. Thus, the relationship is often implicit in what we think and what we say. The second aspect of emergence (2) is related to the first aspect (1) because the system can be viewed along with parts of its environment as together forming a larger system. The collective behaviours due to the relationships of the larger system's parts reflect the relationships of the original system and its environment. The role of relationship: Both (1) and (2) have to do with relationships, the relationships of the parts, or the relationship of the system to its environment. When parts of a system are related to each other we talk about them as a network, when a system is related to parts of a larger system we talk about its ecosystem. The role of pattern: When there are relationships that exist between parts of a system we talk about the existence of patterns of behavior. The idea of emergence is often contrasted with a reductionist perspective. The reductionist perspective thinks about parts in isolation. It is the often vilified "anti-complex systems" view of the world. However, even the idea of a system is based upon a partial reductionism. To understand this, one should carefully understand the notion of approximation or "partial-truth" which is essential for the study of complex systems.*

(**Standish, 2001**): *Some factors at small scale allow the generation of behaviours at larger scale if macrodescription contains atomic concepts that are not simple compound of microconcepts.*

(**Williams, 2001**): *Said of phenomena or systems in which new, increasingly complex levels of order appear over time.*

(**From: http://www.complexityandeducation.ualberta.ca/**): *A process by which a number of lower level systems (considered as parts) self-organize into a higher lever autonomous complex system (a whole) with transcendent macro behaviours. Emergence at one level occurs in and through the dynamic local interactions of lower level systems; it is a "bottom up" phenomenon that occurs without central planners or general instructions. The collective system is a dynamic structure that embodies possibilities not present in its lower level systems, or any simple aggregate of them (e.g. a pile of 100 billion neurons does not in itself* *constitute a brain). Making sense of the dynamic processes that give rise to and sustain complex systems requires an expanded notion of causation. An understanding of emergence is crucial for educators, since language, consciousness, learning and life itself are all emergent processes. Individuals, classrooms and schools, for instance, cannot be understood simply by isolating them or cutting them up into their component parts; this amounts to ignoring their most important, emergent qualities.*

***Causation**: The phenomenon of emergence in complex systems requires an expanded understanding of causation. Traditional, analytic science accepts only "efficient", billiard-ball style explanations of causation, in which causes are separate from, or external to, effects. However, complex systems can be said to cause themselves in several important ways: 1) "upward causation", the "bottom-up" process by which local interactions among the parts of a complex system give rise to it as an emergent whole; and, in some cases, 2) "downward causation", the "top-down" process by which an emergent whole constrains the activities of its parts to serve its purposes (for example, the way the conscious mind directs one's mental processes towards solving certain problems, or the way society constrains the actions of its members through laws). Educational settings manifest both upward and downward causal processes. For instance, the interactions of students and a teacher give rise to an emergent classroom dynamic, while the teacher's guidance (as well as subtle social pressures within the classroom) constrain behaviour in such a way as to ensure an accessible learning environment.*

***Dynamic structure**: In complexity, structure is understood in the biological sense, as a constantly evolving, recursive process. A complex system's history, knowledge, identity and possibilities for acting are embodied in its dynamic structure. A complex system's structure continually emerges through the interaction between its rich internal dynamics and its experiences in the world. As a result, it makes little sense to try to separate "nature" and "nurture". Indeed, a complex system's adaptive learning can be described as a form of "structurally coupling" with its environment. For instance, a human being's knowledge of tennis is embodied in the structure her muscles and nervous system, as well as in structural couplings with racquets, balls, nets, other players, and the socially-regulated rules of the game. Students' and teachers' structures embody their histories and identities, but these structures are continually, recursively adapting to experience and/or coupling with their environments. In addition, the classroom as a complex system has a dynamic structure that evolves or unfolds through the interaction of its participants.*

***Autonomy**: The extent to which an agent/system is distinguishable from its environment—a definition that implies not only an observed but also an observer. The autonomy of complex systems is linked to their emergence as coherent wholes irreducible to the sum of their parts, and to the fact that their behaviour is as much a product of their own internal dynamic structure as external circumstances. The rules governing the behaviour of complex systems thus arise at the level of their emergence. Autonomy in this context does not mean that a complex system is separate from its environment; rather, it means that its own dynamic structure governs the nature of its interaction with the environment in which it is nested. Both individual learners and classroom collectives can be seen as autonomous complex systems. The behaviours of each must be studied at the level of their emergence and not reduced or subsumed to rules governing other levels. Radical constructivism offers a useful account of the autonomous individual learner.*

Consciousness*: For complexivists, individuals' consciousness is a complex, emergent phenomenon that cuts across brain-body-world divisions. Individual human consciousness (understood as awareness and intentionality) emerges from the interaction of bodily experience, the connected activities of various brain modules, and participation in larger social and cultural processes. Although unconscious processes play a much larger role in human behaviour than is commonly supposed, consciousness still acts as the "governor" of our mental life, directing our thoughts and attentions towards specific ends (see downward causation). A complex understanding of consciousness helps us appreciate the role it plays in individual learning. In addition, several complexivists have speculated that consciousness-like processes are at work in larger scale social processes, for example, in the way a teacher directs the attentions of students, or the way artists bring issues into society's collective consciousness.*

Language*: Symbolically-mediated communication that allows human beings to couple their attentions, or consciousnesses. For complexivists, human thought cannot be reduced to language, but the two are intimately tied and mutually affective. Languages such as English are themselves complex systems that emerge and evolve through the interaction of their participants. Because language allows human beings to couple their attentions, it is one of the principle means by which they join together into more complex cognitive unities. As educators, we must realize that language is not a means to transmit information between two or more people. Rather, it is a rich site for interaction, interpretation and coupling.*

Emergent Computing

(**ERCIM, 2006**): *Emergent Computing has become more topical in the last few years and has recently been categorised as a research field in its own right. The history of the field lies primarily in Artificial Intelligence, Numerical Methods and Complexity Theory all of which have contributed in no small part to Emergent Computing. Emergent Computing is sometimes described as "highly complex processes arising from the cooperation of many simple processes", ie high-level behaviour resulting from low- level interaction of simpler building blocks. The Emergent Computing paradigm both explores and relies upon biologically and socially inspired systems, in which complex behaviour at the global level emerges in a non-linear manner from large numbers of low-level component interactions. Building software systems, using this component methodology, offers many advantages for solving complex problems, since the algorithmic complexity is achieved through software that is simple and flexible compared to conventional software development techniques. Building systems, with behaviour more than the sum of its parts, attracts methodologies and techniques from a number of disciplines, so we include as a broader definition of the topic, the mathematical and computational techniques that underpin the area of Emergent Computing.*

Enactivism

(**From: http://www.complexityandeducation.ualberta.ca/**): *Enactivism as a theory for cognition is "the enactment of a world and a mind on the basis of a history of the variety of actions that a being in the world performs" (Varela, Thompson & Rosch). Complexity science is entirely compatible with enactivism. Indeed, many enactivists make explicit appeal to complex notions such as emergence and self-organization in their description of living/learning systems. For enactivists, an organism's biological and experiential history is* *embodied in its dynamic structure (which sets the basis for its possible perceptions and actions at any given moment). As it recursively interacts with its environment and adapts its structure in relation to it, the organism enacts its knowledge (or "world"), in the sense that its particular structure implies or specifies that knowledge/world. At the level of human identity, enactivism rejects the assumption of a core (or essential, or inner) self, arguing instead that 'who we are' arises in our moment-to-moment coping with the contingencies of our existences. The aphorism, "knowing is doing is being" is often used to summarize this perspective. The term enactivism is intended to foreground the notion that identities and knowledge are not pre-existent, but enacted. Learning is thus seen in terms of exploring an ever-evolving landscape of possibility and of selecting (not necessarily consciously) those actions that are adequate to maintain one's fitness with that landscape. Learning is a recursively elaborate (versus accumulative) process. Enactivism prompts educators to envision learning as an elaborately adaptive process wherein learners' knowledge and identity are constantly emerging as they interact with their environment.*

Entropy

(**CALRESCO, 2006**): *The tendency of systems to lose energy and order and to settle to more homogenous (similar) states. Often referred to as 'Heat Death' or the 2nd Law of Thermodynamics.*

(**Flake, 1998**): *A measure of a system's degree of randomness or disorder.*

(**Freniere et al, 2003**): *Entropy, on the other hand, is a measure of the amount of work lost in a system due to destructive forces such as friction or interference. One can measure entropy on a scale from zero to one- zero indicating a completely linear system that loses no work and behaves predictably. Maximum entropy designates a completely chaotic system that loses all work and behaves randomly.*

(**Prokopenko and Wang 2004b**): *The entropy is a precise measure of the amount of freedom of choice in the object.an object with many possible states has high entropy.*

(**Williams, 2001**): *A measure of unavailable energy (thermodynamics), degree of disorder or disorganization, probability (in inverse proportion), uncertainty, randomness, variety of choice, surprise, or information.*

Environment

(**CALRESCO, 2006**): *The surroundings of the system, including other systems and natural features. This context affects the direction of coevolution.*

(**Flake, 1998**): *If that which is under study is a system, then the rest of the world is the environment.*

(**NECSI, 2006**): *The context in which the system we are interested in is found.*

Environmental

(**From: http://www.complexityandeducation.ualberta.ca/**): *The web of physical and/or cultural relations in which a learner/complex system, such as an organism or social* *collective, is embedded, or nested. In complexity, the term environment is always defined in relation to actual systems. It is both those aspects of the world with which a system interacts and the background from which that learner/system can be distinguished as a coherent, or autonomous, unity. The distinction or boundary between a unity and its environment, however, is always an artificial and functional one: it depends on the purposes of the observer. For instance, one might consider an individual tree, or study the forest as a whole. Students, teachers and social groups are examples of learners/systems that are distinguishable from—but still nested within—larger school, community, cultural and biological environments.*

Epistasis

(**CALRESCO, 2006**): *The effect of one variable on another, an interdependence between components rather than an independence.*

Equilibrium

(**CALRESCO, 2006**): *The tendency of a system to settle down to a steady state that isn't easily disturbed, an attractor. Traditionally, equilibrium systems in physics have no energy input and maximise entropy, usually involving an ergodic attractor, but dissipative systems maintain steady states far-from-equilibrium (also non-equilibrium).*

(**Flake, 1998**): *A state of a system that, if not subjected to perturbation, will remain unchanged.*

Ergotic

(**CALRESCO, 2006**): *Visits every point in phase space with equal probability. The basis of entropy and the opposite to the behaviour of complex systems.*

(**Flake, 1998**): *The property of a dynamical system such that all regions of a state space are visited with similar frequency and that all regions will be revisited (within a small proximity) if given enough time.*

(**Williams, 2001**): *a) The property whereby statistical measures of an ensemble don't change with time and, in addition, all statistics are invariant from one time series to another within the ensemble; b) said of a system for which spatial or ensemble average are equal to time averages (meaning that time averages are independent of starting time and that most points visit every region of phase space with about equal probability; c) said of a trajectory if it comes back arbitrarily close to itself after some time.*

Euclidian, Euclidian dimension

(**Flake, 1998**): *Pertaining to standard geometry, i.e., points, lines, planes, volumes, squares, cubes, triangles, etc.*

(**Williams, 1997**): *The common or standard notion of "dimension" whereby a point has dimension zero, a line dimension one, a surface dimension two, and a volume dimension three.*

Evolution

(**Bar-Yam, 2006b**): *A process of change or adaptation that occurs in populations that undergo replication and selection of heritable traits.*

(**CALRESCO, 2006**): *This is a universal idea, generalised as 'general selection theory' to be the process of 'variation, selection, retention' underlying all systemic improvement over time (including 'trial and error' learning). The term is often specifically applied however to genetic evolution where some changes, by being more efficient in functional ways, are preferred by natural selection.*

(**Flake, 1998**): *A process operating on populations that involves variation among individuals, traits being inheritable, and a level of fitness for individuals that is a function of the possessed traits. Over relatively long periods of time, the distribution of inheritable traits will tend to reflect the fitness that the traits convey to the individuals; thus, evolution acts a filter that selects fitness-yielding traits over other traits.*

Evolutionary computation

(**CALRESCO, 2006**): *A set of techniques, using ideas from natural selection, within computer science. Includes genetic algorithms, genetic programming, classifiers, evolutionary programming and evolutionary strategies.*

Evolutionary psychology

(**CALRESCO, 2006**): *The study of how biological evolution and genetic development affects mind function and social behaviour.*

Evolutionary theory

(**CALRESCO, 2006**): *The study of evolution based upon neo-Darwinian ideas. Modern complexity science adds additional self-organizational concepts to this theory to better explain organizational emergence.*

Evolutionary stable strategy

(**CALRESCO, 2006**): *Evolutionary Stable Strategy, a system that resists disturbance, a stable balance between the various interacting agents in an ecosystem.*

Expert systems

(**Flake, 1998**): *A special program that resembles a collection of "if … then" rules. The rules usually represent knowledge contained by a domain expert (such as a physician adept at diagnosis) and can be used to simulate how human expert would perform a task.*

Extrinsic value

(**CALRESCO, 2006**): *A form of judgement that allows a continuum of possibilities, i.e. a measurement of goodness or presence. This corresponds to fuzzy logic operations.*

Extropy

(1: **CALRESCO, 2006**): *A term used to denote the tendency of systems to grow more organised, in opposition to the entropy expectation. Also called 'ectropy', 'enformy', 'negentropy' or 'syntropy' (or more generally 'self-organization'). The reasons for this are partly the motivation behind Complexity Theory.*

(2: **CALRESCO, 2006**): *Several other terms are loosely used with regard to self-organizing systems, many in terms of human behaviour. Extropy (also variously called 'ectropy', 'negentropy' or 'syntropy') refers to growing organizational complexity.*

2.6 -F-

Feedback

(**Bar-Yam, 2006b**): *Feedback is a circular process of influence where action has effect on the actor. Feedback is essential in most systematic ideas about the actions of a system in its environment; learning, adaptation, evolution, all require feedback.*

(1: **CALRESCO, 2006**): *A linking of the output of a system back to the input. Traditionally this can be negative, tending to return the system to a wanted state, or positive tending to diverge from that state. Life employs both methods.*

(2: **CALRESCO, 2006**): *A connection between the output of a system and its input, in other words a causality loop - effect is fed back to cause. This feedback can be negative (tending to stabilise the system - order) or positive (leading to instability - chaos). Feedback results in nonlinearities, constraints on the system behaviour leading to unpredictability. A connection between the output of a system and its input, in other words a causality loop - effect is fed back to cause. This feedback can be negative (tending to stabilise the system - order) or positive (leading to instability - chaos). Feedback results in nonlinearities, constraints on the system behaviour leading to unpredictability.*

(**Flake, 1998**): *A loop in information flow or in cause and effect.*

(**OPEN2, 2006**): *A form of interconnection, present in a wide range of systems. Feedback may be negative (compensatory or balancing) or positive (exaggerating or reinforcing).*

(**From: http://www.complexityandeducation.ualberta.ca/**): *Any influence on a system that results from its own activity. Feedback is both an effect of a system's past activity and a influence on its future activity—an output and an input. Complex systems' non-linear, dynamic structures include (or more accurately, embody) many feedback loops through which their previous actions are "fed back" to them. This circular causal process allows complex systems to change their structure (including the strength of these feedback loops) through their own activity. Positive feedback amplifies itself by strengthening the processes that gave rise to it. Negative feedback weakens the processes that gave rise to it and usually provides a balancing, or stabilizing, effect on systems. Education settings are rich in feedback mechanisms. For example, classes include feedback in the form of dialogue, discussions and presentations, which in turn shape the classroom's future activities. In addition, classrooms are implicated or nested within larger and smaller feedback processes at the cultural and biological levels.*

Feigenbaum constant

(**Flake, 1998**): *A constant number that characterize when bump-like maps such as logistic map will bifurcate.*

Finite state machine

(**CALRESCO, 2006**): *A machine with a fixed number of internal options or possibilities. These could be as few as 2 (Yes/No) or any number of separate possibilities, each determined by some combination of input parameters.*

Fitness

(**CALRESCO, 2006**): *The ability of an organism to survive and flourish in its current environmental conditions, relative to the other creatures also there. A measure of 'quality of life'.*

(**Flake, 1998**): *A measure of an object ability to reproduce viable offspring.*

Fitness landscape

(**Calhoun, 2004**): *One can view the state space of a complex system as a "fitness landscape" made up of many trajectories and containing some number of strange attractors. Because it is a complex system, it will consist of an infinite number of possible states, but because it will self-organize, it will display orderly behavior.*

(1: **CALRESCO, 2006**): *The number of separate niches available within an organism's phase space, often regarded as peaks on a landscape. The higher the peak, the better the option, the steeper the slope the greater the selection pressure.*

(2: **CALRESCO, 2006**): *If we rate every option in state space by its achievement against some criteria then we can plot that rating as a fitness value on another dimension, a height that gives the appearance of a landscape. The result may be a single smooth hill (a correlated landscape), many smaller peaks (a rugged landscape) or something in between. In general the higher the connectivity the more rugged the landscape becomes. Simply connected landscapes have a single peak, a change to one parameter has little effect on the others so a smooth change in fitness is found during adaptive walks. High connectivity means that variables interact and we have to settle for compromise fitnesses, many lower peaks are found and the system can become stuck at local optima or attractors, rather than being able to reach the global optimum.*

(**Flake, 1998**): *A representation of how mutations can change the fitness of one or more organisms. If high fitness corresponds to high locations in the landscape, and if changes in genetic material are mapped to movements in the landscape, then evolution will tend to make populations move in an uphill direction on the fitness landscape.*

Fixed point

(**Flake, 1998**): *A point in dynamical system's state space that maps back to itself, i.e., the system will stay at the fixed point if it does not undergo a perturbation.*

Flocking

(**CALRESCO, 2006**): *The phenomenon of bird flocking can be explained by simple rules telling an agent to stay a fixed distance from a neighbour. The apparently intelligent behaviour of a flock navigating an obstacle follows directly from the mindless application of these rules.*

Flow

(**CALRESCO, 2006**): *The movement of resources from a place of high concentration to a low (e.g. energy goes from hot to cold). By utilising such flows systems can perform work (including self-organization). When flows in opposite directions balance, the system can arrive at the steady state (dynamic equilibrium) that characterises dissipative systems.*

Fractal

(**NECSI, 2006**): *Fractals are entities that look the same under magnification, they are "self-similar." More specifically, a geometric fractal is formed of parts, which, when magnified, are the same as the original shape. Fractals can also involve randomness, so that the similarity of parts to the whole can be of a statistical or average property.*

(**CALRESCO, 2006**): *A System having similar detail at all scales, leading to intricate patterns and unexpected features. Fractal geometry explores systems with non-integer dimensions.*

(**DuPreez and Smith, 2004**): *A pattern of behaviour that is repetitive even if an object is considered on different levels of scale.*

(**Flake, 1998**): *An object with a fractal dimension. Fractals are self-similar and may be deterministic or stochastic.*

(**Wikipedia, 2006**): *The word "fractal" has two related meanings. In colloquial usage, it denotes a shape that is recursively constructed or self-similar, that is, a shape that appears similar at all scales of magnification and is therefore often referred to as "infinitely complex". In mathematics a fractal is a geometric object that satisfies a specific technical condition, namely having a Hausdorff dimension greater than its topological dimension. The term fractal was coined in 1975 by Scott Draves, from the Latin fractus, meaning "broken" or "fractured".*

(**Williams, 2001**): *a) A pattern that repeats the same design and detail or definition over a broad range of scale; b) A set of points whose dimension is not a whole number.*

Fractal dimension

(**Flake, 1998**): *An extension of the notion of dimension found in Euclidian geometry. Fractal dimensions can be non-integer, meaning that objects can be more than a line but less than a plane and so on. There is more than one way of computing fractal dimension, one common type being the Hausdorff-Besicovich dimension. Roughly speaking, a fractal dimension can be calculated as the quotient of logarithm of the object's size and the logarithm of the* *measuring scale, in the limit as the scale approaches 0. Under this definition, standard Euclidian objects retain their original dimension.*

Fractal geometry

(**From: http://www.complexityandeducation.ualberta.ca/**): *A non-Euclidean branch of mathematics dealing with extremely irregular shapes or curves, fractal geometry provides many important concepts relevant to the study of complex systems. Often called the "geometry of nature", fractal images resemble natural forms, both in appearance and how they are generated. Although they may appear irregular and even chaotic from a Euclidean perspective, fractal forms nonetheless demonstrate coherent and repeating patterns such as self-similarity and scale independence. They are generated recursively: each stage or generation is an elaboration of the previous one, a process that quickly gives rise to surprisingly complex forms. Ferns, cauliflower, water ripples and the surface pattern of riverbeds are a few examples of such forms.*

Function

(**Flake, 1998**): *A mapping of one space to another. This is usually understood to be a relationship between numbers. Functions are computable.*

Fuzzy logic

(**CALRESCO, 2006**): *A way of dealing with uncertain information and variables that do not permit simple yes/no categorisations (e.g. colour). Can also be used to make decisions where uncertainty occurs (fuzzy control). This is a form of non-Aristotelian logic (see general semantics).*

2.7 -G-

Game theory

(**CALRESCO, 2006**): *The study of interactions between intelligent agents, concentrating on whether outcomes are zero, positive or negative sum.*

(**Flake, 1998**): *A mathematical formalism used to study human games, economics, military conflicts, and biology. The goal of game theory is to find the optimal strategy for one player to use when his opponent also optimally. A strategy may incorporate randomness, in which case it is referred to as mixed strategy.*

General semantics

(**CALRESCO, 2006**): *The study of how the way we use language constrains our thought patterns. It especially emphasises the need to adopt a non-Aristotelian viewpoint if we are to escape the errors of dualism. This relates to the new paradigm thinking behind complexity science and stresses that our 'maps' of reality are not equal to the 'territory' but are always only restricted viewpoints. See constructivism also.*

General systems theory

(**CALRESCO, 2006**): *The interdisciplinary idea that systems of any type and in any specialism can all be described by a common set of ideas related to the holistic interaction of the components. This nonlinear theory rejects the idea that system descriptions can be reduced to linear properties of disjoint parts.*

Genetic algorithm (GA)

(**CALRESCO, 2006**): *The use of evolutionary techniques to diversify, combine and select options in order to improve performance, following the methods of natural selection by coding options as genes.*

(**Flake, 1998**): *A method of simulating the action of evolution within a computer. A population of fixed-length strings is evolved with GA by employing crossover and mutation operators along with a fitness function that determines how likely individuals are to reproduce. Gas perform a type of search in a fitness landscape.*

Genetic programming

(**CALRESCO, 2006**): *A form of variable length GA that uses directly acting program instructions as the genes.*

(**Flake, 1998**): *A method of applying simulated evolution on program or program fragments. Modified forms of mutation and crossover are used along with a fitness function.*

Genotype

(**CALRESCO, 2006**): *The combination of genes that make up an organism. This has no form itself but directs the creation of the phenotype following the interaction of system, dynamics and environment. Usually regarded as comprising a number of alleles or bits (systems having two states, 0 or 1, off or on).*

Gestalt

(**De Wolf and Holvoet, 2005**): *A configuration or pattern of elements so unified as a whole that it cannot be described merely as a sum of its parts. The 'whole before its parts' and 'Gestalt' refer to a pre-given coherent entity, whereas emergence is not pre-given but a dynamical construct arising over time.*

Global optimim

(**CALRESCO, 2006**): *The very best possible fitness over the entirety of state space.*

Goal-seeking system (GSS)

(**Gharajedaghi, 1999**): *A GSS is one that can respond differently to different events in the same or a different environment until it produces a particular outcome (state).*

Graph

(**Flake, 1998**): *A construct that consists of many nodes connected with edges. The edges usually represent a relationship between the objects represented by the nodes. For example,* *if the nodes are cities, then the edge may have numerical values that correspond to the distances between the cities. A graph can be equivalently represented as a matrix.*

2.8 -H-

Heterarchy

(**Wikipedia, 2006**): *A heterarchy is a network of elements sharing common goals in which each element shares the same "horizontal" position of power and authority, each having an equal vote. A heterarchy may be independent or at some level in a hierarchy. Each level in a hierarchical system is composed of a heterarchy which contains its constituent elements. Both a hierarchy and a heterarchy are systems in which multiple dynamic power structures govern the actions of the system. They represent different types of network structures that allow differing degrees of connectivity. In a hierarchy every node is connected to at most one parent node and zero or more child nodes. In a heterarchy, however, a node can be connected to any of its surrounding nodes without needing to go through or get permission from some other node. Socially, a heterarchy distributes privilege and decision-making among participants, while a hierarchy assigns more power and privilege to the members high in the structure. A heterarchical structure processes more information more effectively than hierarchical design. An example of the potential effectiveness of heterarchy would be the rapid growth of the heterarchical Wikipedia project in comparison with the failed growth of the Nupedia project. Heterarchy increasingly trumps hierarchy as complexity and rate of change increase. A heterarchical network could be used to describe neuron connections or democracy. The term heterarchy is used in conjunction with the concepts of holons and holarchy to describe individual systems at each level of a holarchy. Heterarchy can be defined as an organizational form somewhere between hierarchy and network that provides horizontal links that permit different elements of an organization to cooperate whilst individually optimizing different success criteria. In an organizational context its beauty is the way in which it permits the legitimate valuation of multiple skills, types of knowledge or working styles without privileging one over the other. In an organizational context, heterarchy, responsible autonomy and hierarchy are combined under the umbrella term Triarchy.*

(**Jen, 2003**): *(…) social scientists term heterarchies [28]; namely, interconnected, overlapping, often hierarchical networks with individual components simultaneously belonging to and acting in multiple networks, and with the overall dynamics of the system both emerging and governing the interactions of these networks. Human societies in which individuals act simultaneously as members of numerous networks familial, political, economic, professional, among others are one example of heterarchies, and signalling pathways in biological organisms are another, but in fact the paradigm is a powerful one with relevance to many natural, engineering, and social contexts*.

Heterarchical

(**CALRESCO, 2006**): *A weblike branching structure where multiple owners are possible and loops may form. A N:M structure.*

Hierarchical

(**CALRESCO, 2006**): *A treelike branching structure where each component has only one owner or higher level component. A 1:N structure.*

Hierarchy

(**OPEN2, 2006**): *Layered structure; the location of a particular system within a continuum of levels of organization. This means that any system is at the same time a sub-system of some wider system and is itself a wider system to its sub-systems.*

Hill climbing

(**CALRESCO, 2006**): *The ability of mutation to increase the fitness of a agent, such that it climbs to a higher position on the fitness landscape.*

Holarchic value

(**CALRESCO, 2006**): *A form of judgement that takes into account all the values present within all the entities that form the hypersystem, plus their interactions, a 'whole systems' valuation or fitness measurement of the multi-level whole.*

Holism

(**Flake, 1998**): *"The idea that the whole is greater that the parts". Holism is credible on the basis of emergence alone, since reductionism and bottom-up descriptions of nature often fail to predict complex high-level patterns. See also top-down.*

*(***Wikipedia web site, 2006***): Holism (from holos, a Greek word meaning all, entire, total) is the idea that all the properties of a given system (biological, chemical, social, mental, linguistic, etc) cannot be determined or explained by the sum of its component parts alone. Instead, the system as a whole determines in an important way how the parts behave. The general principle of holism was concisely summarized by Aristotle in the Metaphysics: "The whole is more than the sum of its parts". Holism is sometimes described as the opposite of reductionism (see also scientific reductionism). Some proponents of reductionism think rather that it is the opposite of greedy reductionism. Holism may also be contrasted with atomism. On the other hand, holism and reductionism can also be regarded as complementary viewpoints, in which case they both would be needed to get a proper account of a given system.*

Holistic approach or holistic science

(**Wikipedia, 2006**): *Holism in science, or Holistic science, is a scientific paradigm that emphasizes the study of complex systems. Not a scientific discipline itself, it defines a philosophical lens by which emergence is taken into account when applying the scientific method, often within a wider interdisciplinary or multidisciplinary mode of inquiry. This practice is in contrast to a purely analytic tradition (sometimes called reductionism) which proports to understand systems by dividing them into their smallest possible or discernible elements and understanding their elemental properties alone. The holism/reductionism dichotomy is often evident in conflicting interpretations of experimental findings and in setting priorities for future research.*

The **holistic approach** is based on the idea that “the whole is greater than the sum of the parts”. For instance, it aims at considering a complex problem in its wholeness, trying to understand at the same time all parts as being interrelated together into a whole entity. At the opposite, **reductionism** consists in dividing a complex problem in its constituent parts, finding separate solutions for each of these parts and then putting back these solutions together. Holism is credible on the basis of emergence alone, since reductionism descriptions of nature often fail to predict complex higher-level patterns.

Homeostasis

(1: **CALRESCO, 2006**): *Resistance to change. The ability of a system to self-regulate and maintain a particular state.*

(2: **CALRESCO, 2006**): *This is the regulation of critical variables to form an equilibrium state in the face of perturbation. It relates to cybernetics and to the EOC state in complexity, and concentrates on automatic mechanisms of self-regulation.*

Hyperstructure

(**CALRESCO, 2006**): *A set of systems interconnected and evolving together. The dynamic term we use for this is hypersystem.*

2.9 -I-

Inductive approach

(**Eoyan, 2004**): *An inductive approach begins with the details and builds up a picture of the whole as it emerges from the particular.*

Influence

(**Gharajedaghi, 1999**): *Influence means that the action is not sufficient; it is only a co producer.*

Information

(**Bar-Yam, 2006b**): *The logarithm of the number of possibilities in a message.*

(**NECSI, 2006**): *One of the major advances in the understanding of information occurred in the 1950s with the development of a mathematical theory of communication by Claude Shannon. It is a natural, simple and useful theory. The original article may still be the best description and it is also available as a book. The 1950s was a time of rapid growth of the telephone and telegraph communication networks. These systems communicate messages through electric wires. Shannon was motivated by the problem of evaluating and comparing the efficiency of various ways of sending signals. The basis of Shannon's treatment is a distinction between information and meaning. Shannon assumed that for the purpose of designing a communication system, it is not necessary to know the meaning of a message, or what is the message that will be sent. It is only necessary to know what is the set of possible messages. Each message that is sent is one of these possible messages. The designer of the system must design it to allow any of the messages that might be sent. This is precisely* *because he/she does not know which message will be sent. For this reason the central issue is simply a count of the number of possible messages. The number of messages that can be sent in a certain amount of time is the main characteristic of the system. Two systems that can send the same number of possible messages can carry the same amount of information. If one of them takes longer to send this same number of messages, then that is how much longer it will have to work to send the same amount of information. The proof results from mapping each of the messages of one system onto each of the messages of the other system. This definition of information, obtained from counting the number of possible messages, can be related to the length of a text of English, or the length of a string of morse code, or the length of a binary string of characters. The amount of information grows with the length of text, or the number of morse code characters, or the length of a binary string. As long as the sender and recipient know how to translate from one to the other in a unique and mutually agreed upon way, then each of these can carry the same messages, the same information.*

(**Williams, 2001**): *A numerical measure of a) knowledge or content of any statement; b) how much is learned when the content of a message are revealed; or c) the uncertainty in the outcome of an experiment to be done.*

Information entropy

(**Williams, 2001**): *A measure devised by Shannon for the amount of information in a message, and identical in equation form to thermodynamic entropy.*

Information theory

(**Wikipedia, 2006**): *Information theory is a field of mathematics that can be partitioned into three fundamental considerations: 1- Lossless compression: How much can data be compressed (abbreviated) so that another person can recover an identical copy of the uncompressed data? (See also Redundancy.); 2- Lossy data compression: How much can data be compressed so that another person can recover an approximate copy of the uncompressed data? and 3- Channel capacity: How quickly can information be communicated to someone else through a noisy medium? These somewhat abstract questions are answered quite rigorously by using mathematics introduced by Claude Shannon in 1948. His papers spawned the field of information theory, and the results have been crucial to the success of the Voyager missions to deep space, the invention of the CD, the feasibility of mobile phones, analysis of the code used by DNA, and numerous other fields.*

(**Williams, 2001**): *The formal, standard treatment of information as a mathematically definable and measurable quantity.*

Initial conditions

(**Williams, 2001**): *Values of variables at the beginning of any specified time period.*

Iterated function system

(**CALRESCO, 2006**): *Iterated Function System. A mathematical method of applying affine transformations to a seed to obtain a fractal image. Fractal compression works in reverse to derive an appropriate seed and transformation from the original image.*

Interaction

(**CALRESCO, 2006**): *Influences between parts due to their interconnections. These interconnections can be of many forms (e.g. wiring, gravitational or electromagnetic fields, physical contact or logical information channels). We assume that the influence can act in such a way as to change the part state or to cause a signal to be propagated in some way to other parts. Thus the extent of the interactions determines the behavioural richness of the system.*

Iteration

(**CALRESCO, 2006**): *A loop that uses the current value of a system to derive its future value by re-inserting it into the equations controlling the system dynamics. Feedback. The linking of effect back to cause.*

Interdependence

(**NECSI, 2006**): *The existence of relationships between the behaviour of parts of a system.*

Intermittency

(**Williams, 2001**): *A complex steady-state behaviour (often a route to chaos) consisting of orderly periodic motion (regular oscillations, with no period-doubling) interrupted by occasional bursts of chaos or noise at uneven intervals.*

Intrinsic value

(**CALRESCO, 2006**): *A form of judgement that takes into account all the values present within the system, an holistic valuation or fitness measurement of the whole.*

Invertible

(**Flake, 1998**): *A function is invertible (with a unique inverse) if the output uniquely determines the input (i.e., one to one) and the set of legal outputs is equal to the set of legal inputs.*

2.10 -J-

Julia set

(**CALRESCO, 2006**): *The inverse of the Mandelbrot set, using a single point from that set to generate a new unique set.*

(**Flake, 1998**): *A set of complex numbers that do not diverge if iterated and infinite number of times via a simple equation. The points form an extremely complex fractal. There is an uncountable infinity of Julia set, each of which correspond to a particular complex number that appears as a constant in the iterative procedure. All of the Julia sets are related to the Mandelbrot set.*

2.11 -K-

Koch curve

(**Flake, 1998**): *A fractal curve that looks like the edge of a snowflake. It has no derivative at any point.*

2.12 -L-

Leadership

(**Gharajedaghi, 1999**): *The ability to influence those whom we do not control.*

Level of organization

(**CALRESCO, 2006**): *The smallest parts of a system produce their own emergent properties, these are the lowest 'system' features and form the next level of structure in the system. Those system components then in turn form the building blocks for the next higher level of organization, with different emergent properties, and this process can proceed to higher levels in turn. The various levels can all exhibit their own self-organization (e.g. cell chemistry, organs, societies) or may be manufactured (e.g. piston, engine, car). One measure of complexity is that a complex system comprises multiple levels of description, the more ways of looking at a system then the more complex it is, and more extensive is the description needed to specify it (algorithmic complexity). Energy considerations are often regarded as an explanation for organization, it is said that minimising energy causes the organization. Yet there are often alternative arrangements that require the same energy. To account for the choice between these requires other factors. Organization still appears in computer simulations that do not use the concept of energy, although other criteria may exist. This system property suggests that we still have much to learn in this area, as to the effect of resource flows of various types on organizational behaviour. The relationship between entropy and self-organization is also studied, this tries to relate organization to the 2nd Law of Thermodynamics and recent findings here suggest that order is a necessary result of far-from-equilibrium (dissipative) systems trying to maximise stress reduction. This suggests that the more complex the organism then the more efficient it is at dissipating potentials, a field of study sometimes called 'autocatakinetics' and related to what has been called 'The Law of Maximum Entropy Production'. Thus organization does not 'violate' the 2nd Law (as often claimed) but seems to be a direct result of it. In nonlinear studies we find much structure for very simple systems, as seen in the self-similar structure of fractals and the bifurcation structure seen in the logistic map. This form of system exhibits complex behaviour from simple rules. In contrast, for self-organizing systems we have complex assemblies generating simple emergent behaviour, so in essence the two concepts are complementary. For our collective systems, we can regard the solid state as equivalent to the predictable behaviour of a formula, the gaseous state as corresponding to the statistical or chaotic realm and the liquid state as being the bifurcation or fractal realm.*

Limit cycle

(**Flake, 1998**): *A periodic cycle in a dynamical system such that previous states are returned to repeatedly.*

(**Williams, 2001**): *A self-sustaining phase space loop that represents periodic motion. Hence, it's a periodic attractor.*

Linear phenomenon

(**NECSI, 2006**): *The concept of linear relationship suggests that two quantities are proportional to each other: doubling one causes the other to double as well. Linear relationships are often the first approximation used to describe any relationship, even though there is no unique way to define what a linear relationship is in terms of the underlying nature of the quantities. For example, a linear relationship between the height and weight of a person is different than a linear relationship between the volume and weight of a person. The second relationship makes more sense, but both are linear relationships, and they are, of course, incompatible with each other. Nonlinear relationships, in general, are any relationship which is not linear. What is important in considering nonlinear relationships is that a wider range of possible dependencies is allowed. When there is very little information to determine what the relationship is, assuming a linear relationship is simplest and thus, by Occam's razor, is a reasonable starting point. However, additional information generally reveals the need to use a nonlinear relationship.*

Local interaction

(**CALRESCO, 2006**): *A property of agents that restricts them to reacting only to those other agents immediately adjacent. Most agents in alife systems behave this way.*

Local optimum

(**CALRESCO, 2006**): *An easily found optimum in state space, but not guaranteed to be the global optimum.*

Logical depth

(**Boschetti et al., 2005**): *Logical depth is an information-theoretic measure of the time a (universal) computer takes to perform a task (for a more formal definition see Bennett, 1988). A system is then considered complex, and/or certain features emergent, if it exhibits high logical depth, or if a feature can not be computed any faster than the time Nature took to produce it, or if it can be modeled only via simulation on a computer.*

Logistic map

(**Flake, 1998**): *The simplest chaotic system that works in discrete time.*

Lotka-Volterra system

(**CALRESCO, 2006**): *Equations that model population cycling in co-evolutionary systems. Forms cover predator-prey, war games and epidemics.*

(**Flake, 1998**): *A two-species predator-prey system that in its simplest form can display only fixed points or limit cycles. More complicated versions with three or more species can yield chaos.*

L-System

(**CALRESCO, 2006**): *Lindenmayer systems allow simple rules to serve as a way of generating complex images by iteration. This can create extremely natural forms, flowers, trees etc.*

(**Flake, 1998**): *A method of constructing a fractal that is also a model for plant growth. L-Systems use axiom as a staring string and iteratively apply a set of parallel string substitution rules to yield one long string that can be used as instructions for drawing a fractal. One method of interpreting the resulting string is as an instruction to a turtle graphic plotter. Many fractals, including the Cantor set, Koch curve, and Peano curve, can be expressed as a L-System.*

Lyapunov exponent

(**Wikipedia, 2006**): *The Lyapunov exponent or Lyapunov characteristic exponent of a dynamical system is a quantity that characterizes the rate of separation of infinitesimally close trajectories. The rate of separation can be different for different orientations of initial separation vector. Thus, there is whole spectrum of Lyapunov exponents—the number of them is equal to the number of dimensions of the phase space. It is common to just refer to the largest one, because it determines the predictability of a dynamical system.*

2.13 -M-

Mandelbrot set

(**CALRESCO, 2006**): *The mapping of the behaviour of a specific complex formula across space by colour coding the result of each starting point as convergent or divergent, generating a fractal boundary.*

(**Flake, 1998**): *An extremely complex fractal that is related to Julia sets in the way that it is constructed and by the fact that it acts as a sort of index to the Julia sets. Like the Julia set, the Mandelbrot set is calculated via an iterative procedure. Starting conditions that do not diverge after an infinite number of iterations are considered to be inside the set.If, and only if, a complex number is in the Mandelbrot set, then the Julia set that uses that complex number as a constant will be connected; otherwise, the corresponding Julia set will be unconnected.*

Manifold

(**Wikipedia, 2006**): *In mathematics, a manifold is a space which, in a close-up view, resembles the spaces described by Euclidean geometry, but which may have a more complicated structure when viewed as a whole. (But note that Euclidean spaces are themselves manifolds.) A sphere is an example of a manifold; locally it seems to be flat — but viewed as a whole it is round. A manifold can be constructed by "gluing" separate Euclidean spaces together; for example, a world map can be obtained by gluing many maps of local regions together, and accounting for the resulting distortions. Another example of a manifold is the surface of a torus; unlike a sphere, it can be constructed by gluing together opposite sides of a single map. The surface of a sphere and the surface of a torus are examples of two-dimensional manifolds, but it is also possible for a manifold to have more (or less) than two dimensions. Manifolds are important objects in mathematics and physics because they allow* *more complicated structures to be expressed and understood in terms of the relatively well-understood properties of simpler spaces. Additional structures are often defined on manifolds. Examples of manifolds with additional structure include differentiable manifolds on which one can do calculus, Riemannian manifolds on which distances and angles can be defined, symplectic manifolds which serve as the phase space in classical mechanics, and the four-dimensional pseudo-Riemannian manifolds which model space-time in general relativity. The study of manifolds makes essential use of techniques from mathematical analysis and topology.*

(**Williams, 2001**): *In the non-chaotic domain, an attractor, the basic space of a dynamical system.*

Map

(**Flake, 1998**): *A function that is usually understood to be iterated in discrete time steps.*

Mapping

(**CALRESCO, 2006**): *Transforming a input to an output by following a rule or look-up table. Also the selective study of 'reality'.*

Measure of performance

(**OPEN2, 2006**): *The criteria against which the system is judged to have achieved its purpose. Data collected according to measures of performance are used to modify the interactions within the system.*

Meme

(**Flake, 1998**): *A unit of cultural information that represents a basic idea that can be transferred from one individual to another, and subjected to mutation, crossover, and adaptation.*

Memory

(**CALRESCO, 2006**): *Storage of information or resource in such a way as to allow it to be reused at a later date.*

Meta-

(**CALRESCO, 2006**): *A prefix used to denote a higher level of thought about the subject, e.g. metascience (where we consider how we approach science), meta-ethics where we consider how we define normative behaviour. Each level in a complex system can be considered as a meta-viewpoint upon the previous level of emergence. Relates to category or type theory and higher-order logic.*

Metric

(**Williams, 2001**): *a) (Noun) In general, a standard of measurement; b) in mathematics, a way of specifying values of a variable or positions of a point (Euclidian metric); c) also in mathematics, a differential expression of distance in a generalized vector space.*

Middle-out

Middle-out approach combines top-down and bottom-up approaches.

Model

(**Flake, 1998**): *In the sciences, a model is an estimate of how something works. A model will usually have inputs and outputs that correspond to its real-world counterpart. An adaptative system also contains an implicit model of its environment that allows it to change its behaviour in anticipation of what will happen in the environment.*

(**Williams, 2001**): *A simplified representation of a real phenomenon, in other words, a stripped-down or uncomplicated description or version of a real-world process. Models can be classified into physical (scale), mathematical, analog, and conceptual models.*

Modeling

The process of abstraction of domain elements into models is called modeling. Data modeling is one type of modeling.

Modernism

(**From: http://www.complexityandeducation.ualberta.ca/**): *An epistemological orientation associated with Analytic Science and Reductionism; it has underpinned much of the West's thinking in the past two centuries. Modernism assumes that objective truth is "out there" waiting to be discovered, that careful reasoning and experimentation are the ways to achieve it, and that we are progressing in a gradual and linear manner towards complete and total knowledge of the universe. Strongly influenced by Cartesian dualisms (mind/body, self/other), modernists traditionally divide the human and physical world in such a way that they can be objectively observed, quantified, categorized and controlled. Twentieth Century education systems are a largely modernist project. This can be seen, for example, in its orientation towards efficiency, its desire for control over instruction and learning outcomes, and the transactional view of learning that constructs students as empty vessels waiting to be filled with knowledge.*

Multi-agent systems

(**From: http://www.aaai.org/AITopics/html/multi.html**): *The study of multiagent systems (MAS) focuses on systems in which many intelligent agents interact with each other. The agents are considered to be autonomous entities, such as software programs or robots. Their interactions can be either cooperative or selfish. That is, the agents can share a common goal (e.g. an ant colony), or they can pursue their own interests (as in the free market economy). MAS researchers develop communications languages, interaction protocols, and agent architectures that facilitate the development of multiagent systems. For example, a MAS researcher can tell you how to program each ant in a colony in order to get them all to bring food to the nest in the most efficient manner, or how to set up rules so that a group of selfish agents will work together to accomplish a given task. MAS researchers draw on ideas from many disciplines outside of AI, including biology, sociology, economics, organization and management science, complex systems, and philosophy. The characteristics of MASs are that (1) each agent has incomplete information or capabilities for solving the problem and, thus,* *has a limited viewpoint; (2) there is no system global control; (3) data are decentralized; and (4) computation is asynchronous.*

Multi-objective

(**CALRESCO, 2006**): *The need to take into account many conflicting variables in order to obtain an optimum fitness. This is a problem due to epistasis.*

Mutation

(**CALRESCO, 2006**): *The random change of any part of the genotype, typically by reversing the state of one bit. Natural systems often mutate by the action of radiation, cosmic rays or carcinogenic agents.*

(**Flake, 1998**): *A random change in any portion of generic material. For a genetic algorithm, this means that a value in a bit string is randomly set.*

Mutual information

(**Williams, 2001**): *a) The amount by which a measurement of one variable reduces the uncertainty in another; b) the quantity of information one system or variable contains about another; c) a measure of the degree to which two processes or random variables are mutually related; d) the amount of surprise or predictability associated with a new measurement.*

2.14 -N-

Nanotechnology

(**CALRESCO, 2006**): *The manufacture of systems of molecular size that emulate the behaviour of larger systems. Any alife system is potentially creatable in these dimensions, using standard biological or even inorganic components.*

Natural selection

(**CALRESCO, 2006**): *The three stage process of variation, selection, reproduction (or persistance) that underlies evolution in all areas (in biology the synthesis of Medelian genetics with natural selection is called neo-Darwinism). It is combined within complex systems thinking with self-organization.*

Negative sum

(**CALRESCO, 2006**): *The idea, from game theory, that agents combine in such a way that both lose or that the total change is a reduction in overall fitness, sometimes called dysergy or 'lose-lose'. Related to competition, where if the interactions repeat then we have escalating trajectories of fitness losses.*

Network

(**Bar-Yam, 2006b**): *A system that can be partially described as a set of points and line segments that connects them.*

(**CALRESCO, 2006**): *Connected systems, the properties of which do not entirely depend on the actual units involved but on the dynamics of the interconnections.*

(**NECSI, 2006**): *There are various types of networks: transportation networks — the roads of a city, communication networks — the telephone network, utility networks — the electric power grid of a country, supply networks — the food supply system of a city, networks of molecular reactions—metabolic networks, networks of cells — neural networks, networks of computers — the internet, and social networks — the people in a company, or in a community. An important property of the network is its topology: i.e. which elements are directly connected to which elements. Then, more specific properties of the connections can be discussed. Each connection of the network can be characterized by properties such as its strength of influence, capacity, etc.*

Neural network (NN)

(**CALRESCO, 2006**): *A simplified emulation of the connections of the human brain, used for investigating learning and self-organisation within an artificial environment.*

(**Flake, 1998**): *A network of neurons that are connected through synapses or weights.*

Neuron

(**Flake, 1998**): *A simple computational unit that performs a weighted form on incoming signals, adds threshold or bias term to this value to yield a net input, and maps this last value through and activation function to compute its own activation.*

Neutrosophic logic

(**CALRESCO, 2006**): *A new form of logic that goes beyond fuzzy logic by adding an axis for indeterminacy and thus takes into account not only what is measured but also what is not, a more whole systems or intrinsic logic better suited to complex systems.*

Neutrosophy

(**CALRESCO, 2006**): *A new form of logic that goes beyond fuzzy logic by adding an axis for indeterminacy and thus takes into account not only what is measured but also what is not, a more whole systems or intrinsic logic better suited to complex systems.*

Niche

(**CALRESCO, 2006**): *A peak in the ecological fitness landscape occupied by one variety of creature, often unopposed. Niches, in coevolutionary thought, are created by the organism interactions, do not exist in isolation and are a way of maximising group fitness by minimising competition (see synergy).*

NKC network

(**CALRESCO, 2006**): *If we allow each node (N) to be itself a complex arrangement of interlinked parts (K) then we can regard the connections between nodes (C) as a further layer of control. This relates biologically to a genome interacting with other genomes. K is* *the gene interactions within the organism, C the genes outside the organism that affect it. The overall fitness is derived from the combinations of the interacting gene fitnesses.*

NKCS network

(**CALRESCO, 2006**): *An extension of the NKC model to add multiple species. Each species is linked to S other species. This can best be seen by visualising an ecosystem, where the nodes are species (assumed genetically identical) each consisting of a collection of genes, and the interactions between the species form the ecosystem. Thus the local connection K specifies how the genes of one species interact with themselves and the distant connections (C x S) how the genes interact with each of the other species. This model then allows co-evolutionary development and organization to be studied.*

Noise

(**Williams, 2001**): *a) Any unwanted disturbance superimposed on useful data and tending to obscure their information content; b) unexplainable variability or fluctuation in a quantity with time; c) in a general sense, anything that impedes communication. Such disturbance or variability may be random fluctuations, analytical errors, sampling errors, and other factors.*

Non-equilibrium

(**CALRESCO, 2006**): *A system driven by energy flows away from a steady state of maximum entropy. Also called far-from-equilibrium.*

Non-linear

(**CALRESCO, 2006**): *Systems that behave in an unexpected way, not changing proportionally to a change in input. Sometimes going down when you expect them to go up, doing nothing instead, or changing drastically with only minor changes to the input. Nonlinear systems fail the mathematical principle of 'superposition'.*

Non linear dynamics

(**Williams, 2001**): *The study of motion that doesn't follow a straight-line relation, that is, the study of nonlinear movement or evolution. As such, nonlinear dynamics is a broad field that includes chaos theory and many mathematical tools used in analyzing complex temporal phenomena.*

Non linear phenomenon

(**Williams, 2001**): *Not having a straight-line relationship, which is, referring to a response that isn't directly (or inversely) proportional to a given variable.*

Non-standard

(**CALRESCO, 2006**): *Having a non-homogeneous (uneven) distribution in space and/or time (exhibits patterns).*

Non-uniform

(**CALRESCO, 2006**): *Having parts that are not the same in function or behaviour (varied rules or laws).*

Non-zero form

(**CALRESCO, 2006**): *A situation in which it is possible for all participants to win or lose simultaneously, so that the fitness scores may total to a positive or negative sum overall.*

NP

(**Flake, 1998**): *Nondeterministic polynomial time problems; a class of computational problems that may not be solvable in polynomial time but are expressed in such a way that candidate solutions can be tested for correctness in polynomial time.*

NP-Complete

(**Flake, 1998**): *A problem type in which any instance of any other NP class problem can be translated to in polynomial time. This means that if a fast algorithm exists for an NP-Complete problem, then any problem that is in NP can be solved with the same algorithm.*

Numerical solution

(**Flake, 1998**): *A solution to a problem that is calculated through a simulation.*

2.15 -O-

Observer

(**Bar-Yam, 2006b**): *A person who makes measurements (observations) on a system to gain information about it.*

Open system

(**CALRESCO, 2006**): *Allowing resources (e.g. material or information) to enter or leave the system, sucking in resources from outside or giving out more than they take in.*

(**OPEN2, 2006**): *A system which is open to its environment such that there are recognizable inputs to the system and outputs to the environment, e.g. an organism is an open system for inputs of food (energy).*

Optimization

(**CALRESCO, 2006**): *The search for the global optimum, or best overall compromise within a (typically) multivalued system. Where interactions occur many optima are typically present (the fitness landscape is 'rugged') and this situation has no analytical solution, generally requiring adaptive solutions.*

(**Flake, 1998**): *The process of finding parameters that minimize or maximize a function.*

Optimum

(**CALRESCO, 2006**): *A state that is the best fit for the current situation, the top of the local fitness landscape. All minor changes make the solution worst.*

Orbit

(**CALRESCO, 2006**): *The path taken by a cyclic attractor. A regular sequence that once entered cannot be exited without perturbation.*

(**Williams, 2001**): *A trajectory or chronological sequence of states as represented in phase space.*

Organic system

(**CALRESCO, 2006**): *A form of system that is autonomous and adaptive, based upon biological ideas rather than mechanical ones.*

Organization

(1: **CALRESCO, 2006**): *A non-random arrangement of parts, generally serving a purpose or function. The restriction of the system to a small area of its state space.*

(2: **CALRESCO, 2006**): *The arrangement of selected parts so as to promote a specific function. This restricts the behaviour of the system in such a way as to confine it to a smaller volume of its state space. The recognition of self-organizing systems can be problematical. New approaches are often necessary to find order in what was previously thought to be noise, e.g. in the recognition that a part of a system looks like the whole (self-similarity) or in the use of phase space diagrams.*

2.16 -P-

Parallelism

(**CALRESCO, 2006**): *Several agents acting at the same time independently, simultaneous computation similar to that which happens within living systems.*

Parameter

(**Williams, 2001**): *a) In physics, a controllable quantity kept constant in an experiment as a measure of some influencial or driving environmental condition; b) in mathematics, an arbitrary constant in mathematical expression and that can be hanged to provide different cases of the phenomenon represented; c) in mathematics, a special variable in terms of which two or more other variables can be written d) in statistics, a numerical characteristic of a population (such as, for example, the arithmetic mean).*

Parametric

(**Williams, 2001**): *Involving parameter.*

Pareto-optimal

(**CALRESCO, 2006**): *A set of equivalent optimised solutions that all have the same global fitness but embody different compromises or niches between the objectives.*

Pattern

(**Bar-Yam, 2006b**): *A set of relationships that are satisfied by observations of a system, or a collection of systems.*

(**NECSI, 2006**): *We use the word "pattern" a lot. A formal definition of a pattern is quite abstract and examples that follow the formal definition are needed to explain why this definition is really what we are talking about. A pattern is: ...a set of relationships that are satisfied by observations of a system, or a collection of systems ...a simple kind of emergent property of a system, where a pattern is a property of the system as a whole but is not a property of small parts of the system. ...a property of a system that allows its description to be shortened as compared to a list of the descriptions of its parts.*

Peano curve

(**Flake, 1998**): *A fractal space-filling curve that can fill a plane even though it is a line of infinite length.*

Percolation

(**CALRESCO, 2006**): *Percolation is an arrangement of parts (usually visualised as a matrix) such that a property can arise that connects the opposite sides of the structure. This can be regarded as making a path in a disconnected matrix or making an obstruction in a fully connected one. The boundary at which the system goes from disconnected to connected is a sudden one, a step or phase change in the properties of the system. This is the same boundary that we arrive at in SOC and in physics is sometimes called universality due its general nature.*

Period

(**Williams, 2001**): *The amount of time needed for a system to return to its initial state, that is, the time required for a regularly repeating phenomenon to repeat itself once.*

Periodic attractor

(**Williams, 2001**): *An attractor consisting of a finite set of points that form a closed loop or cycle in phase space.*

Period-doubling

(**Williams, 2001**): *Also known as flip bifurcation.*

Perspective

(**OPEN2, 2006**): *A way of experiencing which is shaped by our personal and social histories, where experiencing is a cognitive act.*

Perturbation

(**CALRESCO, 2006**): *A forced change to a system. This can result in a sudden shift to a new state, an immediate return to the old state or a long transient resulting in one or the other.*

(**Williams, 2001**): *a) A difference between two neighbouring observations, at a given time; b) an intentional displacement of an observation, at any given time c) a deliberate change (usually slight) in one or more parameters of an equation.*

Petri nets

(**From: http://www.informatik.uni-hamburg.de/TGI/PetriNets/faq/**): *Petri Nets is a formal and graphical appealing language which is appropriate for modelling systems with concurrency and resource sharing. Petri Nets has been under development since the beginning of the 60'ies, where Carl Adam Petri defined the language. It was the first time a general theory for discrete parallel systems was formulated. The language is a generalisation of automata theory such that the concept of concurrently occurring events can be expressed. (See also Wikipedia.) There are many resources, and ongoing and forthcoming activities on Petri Nets. The* Petri Nets World *(these Web pages) assembles information about such activities under supervision by the Petri Nets Steering Committee.*

Phase

(**Williams, 2001**): *a) The stage that a dynamical system is in at any particular time; b) the fraction of a cycle through which a wave has passed at any instant.*

Phase change, phase transition

(1: **CALRESCO, 2006**): *A movement between static, ordered or chaotic states or back again. Usually used in connection with a change of state in physics from solid, to liquid, to gas or the reverse, but of general applicability in complexity theory.*

(2: **CALRESCO, 2006**): *A point at which the appearance of the system changes suddenly. In physical systems the change from solid to liquid is a good example. Non-physical systems can also exhibit phase changes, although this use of the term is more controversial. Generally we regard our system as existing in one of three phases. If the system exhibits a fixed behaviour then we regard it as being in the solid realm, if the behaviour is chaotic then we assign it to the gas realm. For systems on the Edge of Chaos the properties match those seen in liquid systems, a potential for either solid or gaseous behaviour, or both.*

(**Flake, 1998**): *In dynamical systems theory, a change from one mode of behaviour to another.*

Phase space or state space

(**CALRESCO, 2006**): *All the possibilities available to the system in theory. The sum total of possible states the system can occupy. In complex systems only a very small proportion of such states are found - the system is said to occupy only a minute proportion of state or phase space.*

(**Flake, 1998**): *In the scientific literature, a phase space is used to denote the space of motion in a dynamical system that moves in continuous time, while state space is often used for* *discrete time systems. (…) If the dynamics of a dynamical system can be described by n values, then the state space is the n-dimensional volume that the system moves through. Systems that are continuous in time will form a smooth trajectory through this volume, while discrete systems may jump to different locations on subsequent time steps. In either case, if a system ever return to a previously visited location in the state space, then the system is in either a fixed point or a limit cycle. For chaotic systems, or for programs that never halt, the system will always be at previously unvisited portion of the state space.*

(**Williams, 2001**): *An abstract mathematical space in which coordinates represent the variables needed to specify the phase (or state) of a dynamical system at any time.*

Phenotype

(**CALRESCO, 2006**): *The form of the organism. A result of the combined influences of the genotype and the environment on the self-organizing internal processes during development.*

Plurality

(**Gharajedaghi, 1999**): *Plurality refers to the theories that consider structure, function, or process to be multiple and/or variable in the same or different environments.*

Point attractor

(**Williams, 2001**): *A single fixed point in phase space, representing the final or equilibrium state of a system that comes to rest with the passage of time. (Also known as: final state or fixed-point attractor).*

Positive sum

(**CALRESCO, 2006**): *The idea, from game theory, that when agents interact they can both benefit, the whole being greater than the sum of the parts, also called synergy or 'win-win'. When the interactions repeat we have escalating trajectories of positive fitness effects.*

Post-modernism

(**From: http://www.complexityandeducation.ualberta.ca/**): *A term used to denote a variety of discourses that reject modernist claims of objectivity and certainty. Postmodernists explicitly critique universalizing discourses and the construction of metanarratives (theories that seek to explain everything). All knowledge, including scientific knowledge, is relational, in that it cannot be disentangled from particular locations, histories, contexts and observers. Postmodernism has come to stand for a set of critical discourses that seek to uncover how identity, culture, and knowledge shape and are shaped by issues of language, representation and power. Many postmodern perspectives in education seek to decenter the curriculum, develop multivocality, and challenge educational paradigms based solely on the rationality of science. Complexity science accepts postmodern insights about the relational nature of knowledge, truth and identity. However, complexivists argue that such questions are not just a matter of human, intersubjective negotiation—they are also a function of the mutually affective relationships among all phenomena. Complexity thus opens onto the more-than-human world.*

Power law

(**Couture, 2006d**): *Many natural and man-made phenomena are distributed according to a power-law distribution. A power-law implies that small occurrences are common, whereas large instances are rare; it applies to CAS when large is rare and small is common. The distribution of individual wealth is a good example where there are a very few rich men and a lots of poor people. A familiar way to think about power laws is the 80/20 rule: 80% of the wealth is controlled by 20% of the population.*

Per Pak's sandpile experiment is another example showing the occurrence of the power law for complex systems (Bak and Chen, 1991; Bak, 1997). If you patiently trickle grains of sand onto a flat surface, at first the sand will simply pile up; but eventually the pile will reach a critical state. At that point, Bak found that the size of the avalanches triggered by dropping another grain of sand follows a power law distribution: The size of avalanches is inversely proportional to their frequency (in other words, there will be many little avalanches, a few medium-sized ones, and on rare occasions a large one). Such a sandpile is at the "edge of chaos" (Lansing, 2003).

Newman (2005) reviews some of the empirical evidence for the existence of power-law forms and the theories proposed to explain them. He gives a more formal definition of the power law: <u>When the probability of measuring a particular value of some quantity varies inversely as a power of that value, the quantity is said to follow a power law, also known variously as Zipf's law or the Pareto distribution</u>. Power laws appear widely in physics, biology, earth and planetary sciences, economics and finance, computer science, demography and the social sciences. For instance, the distributions of the sizes of cities, earthquakes, solar flares, moon craters, wars and people's personal fortunes all appear to follow power laws. The origin of power-law behaviour has been a topic of debate in the scientific community for more than a century.

(**Wikipedia, 2006**): *Power laws are observed in many fields, including physics, biology, geography, sociology, economics, linguistics, war and terrorism. Power laws are among the most frequent scaling laws that describe the scale invariance found in many natural phenomena. A power law relationship between two scalar quantities x and y is any such that the relationship can be written as* $y = ax^k$ *where a (the constant of proportionality) and k (the exponent of the power law) are constants. Power laws can be seen as a straight line on a log-log graph since, taking logs of both sides, the above equation becomes* $\log(y) = k\log(x) + \log(a)$ *which has the same form as the equation for a line* $y = mx + c$. *Because both the power law and the log-normal distribution are asymptotic distributions, they can be easy to confuse without using robust statistical methods such as Bayesian model selection or statistical hypothesis testing. Indeed, a log-log plot of a log-normal distribution can often look nearly straight for certain ranges of x and y. One rule of thumb is the distribution conforms to a power law if it is straight on a log-log graph over 3 or more orders of magnitude.*

Examples of power law relationships:

- *The <u>Stefan-Boltzmann law</u>*
- *The <u>Gompertz</u> Law of Mortality*

- *The Ramberg-Osgood stress-strain relationship*
- *The inverse-square law of Newtonian gravity*
- *Gamma correction relating light intensity with voltage*
- *Kleiber's law relating animal metabolism to size*
- *Behaviour near second-order phase transitions involving critical exponents*
- *Frequency of events or effects of varying size in self-organized critical systems, e.g. Gutenberg-Richter Law of earthquake magnitudes and Horton's laws describing river systems*
- *Proposed form of experience curve effects*
- *Scale-free networks, where the distribution of links is given by a power law (in particular, the World Wide Web)*
- *The differential energy spectrum of cosmic-ray nuclei*
- *Examples of power law probability distributions:*
- *The Pareto distribution*
- *Zipf's law*

These appear to fit such disparate phenomena as the popularity of websites, the wealth of individuals, the popularity of given names, and the frequency of words in documents. Benoit Mandelbrot and Nassim Taleb have recently popularised the analysis of financial market volatility in terms of a power law distribution (as opposed to the traditional Gaussian distribution), and Aventis science prize-winning author Philip Ball has argued that the same power law relationships that are evident in phase transitions also apply to various manifestations of collective human behaviour.

Precision

(**Williams, 2001**): *a) In general, the accuracy with which a calculation is made; b) reproducibility, as with repeated samplings.*

Process thought

(**CALRESCO, 2006**): *The treatment of reality as the evolution of processes rather than the behaviour of objects. In this methodology we recognise that 'things' are simply standing waves (attractors) in a continuous dynamical process and have no inherent absolute properties.*

Pseudo phase space

(**Williams, 2001**): *An imaginary graphical space in which the first coordinate represents a physical feature and the other coordinates represent lagged values of that feature.*

Purpose

(**OPEN2, 2006**): *Objective, goal or mission of the system; the raison d'être which in terms of a model developed by people is to achieve the particular transformation that has been defined.*

Purposeful system

(**Gharajedaghi, 1999**): *A system that can produce not only the same outcomes in different ways in the same environment but different outcomes in both the same and different environment. It can change its ends under constant conditions (free will). Such systems learn, adapt and create.*

2.17 -Q-

Quasiperiodic

(**Flake, 1998**): *Refers to the form of motion that is regular but never exactly repeating. Quasiperiodic motion is always composed of multiple but simpler periodic motions.*

2.18 -R-

Radical constructivism

(**From: http://www.complexityandeducation.ualberta.ca/**): *A theory of individual knowing, radical constructivism argues that a person actively interprets her/his present experiences based on her/his past experiences and in such a way as to maintain their overall coherence. In doing so, the individual learner creates her/his "reality". Radical Constructivism is radical in the sense that it rejects the possibility of knowing an external, universal reality in the metaphysical sense, since knowledge is always personally construed. Significantly, radical constructivism does not suggest that there is no external reality; rather, it asserts that the knower has access only to their experiences. As such, personal knowledge does not need to "match" an external reality; it only needs to—and only can—fit the experiences in the experiential world of the experiencer. Radical constructivism's view of learning is compatible with that of complexity science—at least so long as one's focus is solely on the level of the individual as he or she tries to make sense of his or her experiences. For complexivists, however, this is only one part of the story: every individual is in fact co-evolving with and nested within many other complex learning systems. The individual and these other systems are mutually constituting and so any complete theory of knowledge must take a more ecological approach.*

Random phenomenon

(**NECSI, 2006**): *Arbitrary within a set of possibilities.*

(**Flake, 1998**): *Without cause; not compressible; obeying the statistics of a fair coin toss.*

(**Williams, 2001**): *a) Based strictly on a chance mechanism (the luck of the draw), with negligible deterministic effects; b) disorganized or haphazard; c) providing every member an equal chance of selection. People used to attribute apparent randomness to the interaction of complex processes or to the effects of external unmeasured forces. They routinely analysed* *the data statistically. Chaos theory shows that such behaviour can be attributable to the nonlinear nature of the system rather than other causes.*

Reaction

(**Gharajedaghi, 1999**): *(State-maintaining system) A system behaviour for which an event in the environment is both necessary and sufficient. It is an event that is deterministically caused by another event.*

Recursion

(**From: http://www.complexityandeducation.ualberta.ca/**): *A process in which each new step is a function or elaboration of the structure produced through previous steps, as in the production of a fractal image. Recursion is a repetitive process that is defined in terms of loops rather than linear pathways. In biological terms, an organism interacts recursively with its environment, both as an individual and as a species; each new interaction is a function of a previous history of interactions (as embedded in its dynamic structure) and in turn becomes part of that history, thus influencing future interactions. In the context of human knowledge, each new understanding is a recursive elaboration of previous understandings: Possible knowledge in the present "feeds off" of what we knew before and, conversely, what we knew before is re-interpreted in light of new experiences, or feedback. Education and learning are recursive, elaborative processes. Students' and teachers' interactions always carry traces of previous interactions, as well as traces of the history of their culture and species. And those previous interactions are re-interpreted in light of present engagements.*

Recursive

(**Flake, 1998**): *Strictly speaking, a set or function is recursive if it is computable; however, in the usual sense of the world, a function is said to be recursive if its definition make reference to itself.*

Redundancy

(**CALRESCO, 2006**): *The ability of a system to suffer degradation without altering its state. The ability to withstand perturbation without damage.*

Reductionism

(**NECSI, 2006**): *Considering the properties of the parts of a system as embodying the properties of the whole without regard to the relationships between them or the system's environment.*

(**Calhound, 2004**): *The process of breaking down complex systems into component parts to study them individually--a process that only works well in linear systems.* (…) *Even the most hard-boiled, mainstream scientists are beginning to acknowledge that reductionism may not be powerful enough to solve all the great mysteries we're facing: cancer, consciousness, the origin of life, the resilience of the ecosystem, AIDS, global warming, the functioning of a cell, the ebb and flow of the economy....What makes all these unsolved problems so vexing is their decentralized, dynamic character, in which enormous numbers of components keep changing their state from moment to moment, looping back on one another in ways that can't be* *studied by examining any one part in isolation. In such cases, the whole is surely not equal to the sum of the parts. These phenomena, like most others in the universe, are fundamentally nonlinear. Steven Strogatz, Sync (New York: Hyperion, 2003).*

(**Flake, 1998**): *The idea that nature can be understood by dissection. In other words, knowing the lowest level of details of how things work reveals how higher-level phenomena come about. This is a bottom-up way of looking at the universe, and is exact opposite of holism.*

(**From: http://www.complexityandeducation.ualberta.ca/**): *The assumption that all phenomena, including human behaviour, can be reduced to a set of fundamental particles, basic laws or essential causes. Reductionism seeks to comprehensively explain complex phenomena or behaviours by reducing them to their component parts and their fundamental laws. For example, in education, learning is conceived of strictly in terms of individual outcomes and simple behaviourist causes; curricula are broken down into discreet subject areas that are further reduced into instructional blocks and then taught in isolation from one another. In contrast, complexivists believe that complex phenomena like education and learning are largely irreducible. Schools and learners embody emergent characteristics or processes that can neither be perceived nor understood through reductionist methods.*

(Wikipedia web site, 2006): Reductionism in philosophy describes a number of related, contentious theories that hold, very roughly, that the nature of complex things can always be reduced to (explained by) simpler or more fundamental things. This is said of objects, phenomena, explanations, theories, and meanings. There are several generally accepted types or forms of reduction in both science and philosophy: 1- Ontological reductionism is the idea that everything that exists is made from a small number of basic substances that behave in regular ways (compare to monism); 2- Methodological reductionism is the idea that explanations of things, such as scientific explanations, ought to be continually reduced to the very simplest entities possible (but no simpler). Occam's Razor forms the basis of this type of reductionism; 3- Theoretical reductionism is the idea that older theories or explanations are not generally replaced outright by new ones, but that new theories are refinements or reductions of the old theory into more efficacious forms with greater detail and explanatory power. The older theories are supposedly absorbed into the newer ones and they can be deductively derived from the latter; 4- Scientific reductionism has been used to describe all of the above ideas as they relate to science, but is most often used to describe the idea that all phenomena can be reduced to scientific explanations; 5- Linguistic reductionism is the idea that everything can be described in a language with a limited number of core concepts, and combinations of those concepts. (See Basic English and the constructed language Toki Pona); 6- The term "greedy reductionism" was coined by Daniel Dennett to condemn those forms of reductionism that try to explain too much with too little. The denial of reductionist ideas is holism; the idea that things can have properties as a whole that are not explainable from the sum of their parts. Phenomena such as emergence and work within the field of complex systems theory are considered to bring forth possible objections to reductionism.

Relationship

(**Bar-Yam, 2006b**): *When two entities have a relationship then information about one of them also contains information about the other.*

Representationism

(**From: http://www.complexityandeducation.ualberta.ca/**): *The view that knowledge consists internal, mental representations of an external reality — a view disputed by complex accounts of cognition. Representationism assumes that individual minds are insulated from the world and isolated from other minds; learning is a matter of assembling internal mental representations (or models) of real, external objects and events. It is so is entrenched in modern Western thinking that it has assumed the status of "common sense", in spite of the fact that there is no empirical support for this view. In education, representationist assumptions are woven not only into "common sense" understandings of learning, but also into influential theories like behaviourism and cognitivism (which understands the brain through the metaphor of a computer, or information processor).*

Resource

(**OPEN2, 2006**): *Elements which are available within the system boundary and which enable the transformation to occur.*

Response

(**Gharajedaghi, 1999**): (*Goal-seeking system) A system behaviour for which an event in the environment is necessary but not sufficient. It is an event of which the system itself is a coproducer.*

Robustness

(**From: http://discuss.santafe.edu/robustness/**):

- *1. Robustness is the persistence of specified system features in the face of a specified assembly of insults. [See e.g. Allen "Ecosystems and Immune Systems".]*
- *2. Robustness is the ability of a system to maintain function even with changes in internal structure or external environment. [See e.g .Fontana and Wagner ``Mutational Robustness''; M. Sheetz, ``The Cell as a Machine''; Callaway et al "Network Robustness and Fragility";* Scientific Committee on Antarctic Research*"Regional Sensitivity to Climactic Change in Antarctic Terrestrial Ecosystems".]*
- *3. Robustness is the ability of a system with a fixed structure to perform multiple functional tasks as needed in a changing environment. [See e.g. Saunders Design Computing And Autonomous Robotics".]*
- *4. Robustness is the degree to which a system or component can function correctly in the presence of invalid or conflicting inputs.*
- *5. A model is robust if it is true under assumptions different from those used in construction of the model [Model Uncertainty and Model Robustness].*
- *6. Robustness is the degree to which a system is insensitive to effects that are not considered in the design [*Slotine and Li, *Applied Nonlinear Control].*
- *7. Robustness signifies insensitivity against small deviations in the assumptions [*Huber, *Robust Statistical Procedures].*

- *8. Robust methods of estimation are methods that work well not only under ideal conditions, but also under conditions representing a departure from an assumed distribution or model [Launer and Wilkinson, Robustness in Statistics, Academic Press, 1979].*
- *9. Robust statistical procedures are designed to reduce the sensitivity of the parameter estimates to failures in the assumption of the model [Huber, Robust Statistics].*
- *10. Robustness is the ability of software to react appropriately to abnormal circumstances (i.e., circumstances ``outside of specifications" including new platforms, network overloads, memory bank failures, etc.). Software may be correct without being robust [Object-Oriented Software Construction].*
- *11. Robustness of an analytical procedure is a measure of its ability to remain unaffected by small, but deliberate variations in method parameters, and provides an indication of its reliability during normal usage [Sarrio and Silvestri, "Validation of Analytical Assays and Test Methods for the Pharmaceutical Laboratory"].*
- *12. Robustness is a design principle of natural, engineering, or social systems that have been designed or selected for stability.*
- *13. The robustness of an initial step is determined by the fraction of acceptable options with which it is compatible out of total number of options [Dias, "A definition of robustness analysis in decision aiding"].*
- *14. A robust solution in an optimization problem is one that has the best performance under its worst case (max-min rule) [Kouvelis and Yu, ``Robust discrete optimization and its applications"].*
- *15. "..instead of a nominal system, we study a family of systems and we say that a certain property (e.g., performance or stability) is robustly satisfied if it is satisfied for all members of the family." [Tempo, R. and Blanchini, F., ``Robustness analysis with real parametric uncertainty," in Levine W.S. (ed.) The Control Handbook, CRC Press and IEE Press, 1996.*
- *16. Robustness is a characteristic of systems with the ability to heal, self-repair, self-regulate, self-assemble, and/or self-replicate [See e.g., ``Mimicking Biological Systems, Composite Material Heals Itself"; Harvard Medical School ``Healing the Brain from Inside Out"; IBM "Autonomic Computing"; or The Embryonics Project.]*
- *17. The robustness of language (recognition, parsing, etc.) is a measure of the ability of human speakers to communicate despite incomplete information, ambiguity, and the constant element of surprise. [See e.g., Brisco, ``Robust Parsing" in "Language Analysis and Understanding" (A. Zaenen, ed.), Survey of the State of the Art in Human Language Technology.]*
- *18. None of the above.*

2.19 -S-

Scale

(**NECSI, 2006**): *Measure of size used to determine level of detail provided in a description. Scale is: 1) ...the size of a system or property that one is describing or 2) ...the precision of observation or description. For (1) imagine thinking about systems that have various sizes. From the smallest to the largest, we have an elementary particle, an atom, a molecule, a cell, a person, a city, a planet, a galaxy, the universe. For (2) imagine using a zoom lens to look at a person. The trick is to imagine that you see the whole person no matter from how close or far away you are looking. From far away you see only a dot. Closer up you see limbs and the color of the clothes. Closer still you see the face and facial expression, the fingers and the patterns on the clothes. Closer still you see the creases in the skin, individual hairs, and the threads in the clothes. Closer still you see the cells of the skin, the fibers of each thread of the clothes. Closer still you see each of the molecules, and closer still you see each of the atoms.*

Scale independence (see also scale invariance)

(**From: http://www.complexityandeducation.ualberta.ca/**): *The level of detail and complexity of a form do not vary greatly when viewed from different levels of magnification. Fractal forms demonstrate the quality of scale independence. Whether viewed up close (magnified) or from far away, they exhibit similar patterns and details. Complex systems also demonstrate this quality, since they are typically both nested within larger scale complex systems and themselves composed of smaller scale complex systems. The implication of scale independence for education is that one is dealing with the same degree of detail and complexity, whether one is examining an individual human being, classroom collective, school, or community. One cannot simplify one's examination by reducing or increasing the scale.*

Scale invariance

(**Wikipedia, 2006**): *In physics and mathematics, scale invariance is the feature of objects or laws that do not change if the space is magnified, i.e. length scales (or energies) are multiplied by a common factor. To give a trivial example for the object feature, the mass of the ball divided by the third power of its radius is independent of the radius i.e. scale-invariant. An example of the law is self-similarity in fluid mechanics: all properties of the flow due to a moving body are the same if the size of the body is increased by the same factor as its velocity is decreased by - this is because the fluid flow in a given geometry is completely characterized by the dimensionless Reynolds number which is the product of size and velocity divided by kinematic viscosity. In mathematics, scale invariance leads to results such as Benford's law, fractals and logarithmic spirals. In physical cosmology, scale invariance is usually used to describe the near-scale-invariant energy spectrum of the cosmic microwave background - a pattern that is reasonably well explained by the paradigm of cosmic inflation.*

Scientific reductionism

(**Wikipedia, 2006**): *Sometimes it is used to describe science (particularly physics) as a basis for ontological reductionism—the idea that everything that exists can be explained as the interactions of a small number of simple things (such as fundamental particles like quarks and leptons interacting through gauge bosons) obeying physical laws. Superstitious world-views have however been largely abandoned in the scientific community in exchange for more naturalistic approaches with empirical evidence to support them. One attack against this form of reductionism, which is popular among solid-state physicists, argues that it is* *incorrect to regard the laws which govern the components of structures to be more fundamental than the laws which govern the structures. For example, it has been argued that a traffic jam contains patterns of behavior which cannot be reduced to the behavior of an individual car. Similarly metals undergo collective behavior and interactions that are not reducible to the behavior of an individual atom within that metal, and it has been argued that the laws which describe this collective behavior are no less fundamental than the laws that describe the atoms themselves. Another attack against the idea of reductionism comes from supporters of the anthropic principle. Some believe that the laws of physics may be randomly determined and explain the fact that we observe certain physical laws by postulating that only a small subset of laws allow for conscious observers. Seen this way, consciousness does not arise from the laws of physics, but rather the observed laws of physics exist because of consciousness.*

Selection

(**CALRESCO, 2006**): *A choice between available options based on consideration of fitness within the current environmental context. A bias on movement in state space. See evolution.*

Self-management

(**Wikipedia, 2006**): *Self-Management is the process by which computer systems shall manage their own operation without human intervention. Self-Management technologies are expected to pervade the next generation of network management systems. The growing complexity of modern networked computer systems is currently the biggest limiting factor in their expansion. The increasing heterogeneity of big corporate computer systems, the inclusion of mobile computing devices, and the combination of different networking technologies like WLAN, cellular phone networks, and mobile ad hoc networks make the conventional, manual management very difficult, time-consuming, and error-prone. Currently, the most important industrial initiative towards realizing self-management is the Autonomic Computing Initiative (ACI) started by IBM in 2001. The ACI defines the following four functional areas: 1- Self-Configuration: Automatic configuration of components; 2- Self-Healing: Automatic discovery, and correction of faults; 3- Self-Optimization: Automatic monitoring and control of resources to ensure the optimal functioning with respect to the defined requirements; 4- Self-Protection: Proactive identification and protection from arbitrary attacks. Despite the extensive efforts spent by research and industry, the realization of self-managing systems is still a long way away, today. The biggest challenge lies in the implementation of autonomic closed control loops. One or more of these control loops shall work in every managed resource.*

Self-organization

(**Bar-Yam, 2006**b): *The appearance of patterns that are not imposed directly by external forces.*

(1: **CALRESCO, 2006**): *Ability to create structure without any external pressures, an emergent property of the system. Related to extropy or negentropy. Internal constraints.*

(2: **CALRESCO, 2006**): *The essence of self-organization is that system structure often appears without explicit pressure or involvement from outside the system. In other words, the constraints on form (i.e. organization) of interest to us are internal to the system, resulting* *from the interactions among the components and usually independent of the physical nature of those components. The organization can evolve in either time or space, maintain a stable form or show transient phenomena. General resource flows within self-organized systems are expected (dissipation), although not critical to the concept itself. The field of self-organization seeks general rules about the growth and evolution of systemic structure, the forms it might take, and finally methods that predict the future organization that will result from changes made to the underlying components. The results are expected to be applicable to all other systems exhibiting similar network characteristics. Random (or locally directed) changes can instigate self-organization, by allowing the exploration of new state space positions. These positions exist in the basins of attraction of the system and are inherently unstable, putting the system under stress of some sort, and causing it to move along a trajectory to a new attractor, which forms the self-organized state. Noise (fluctuations) can allow metastable systems (i.e. those possessing many attractors - alternative stable positions) to escape one basin and to enter another, thus over time the system can approach an optimum organization or may swap between the various attractors, depending upon the size and nature of the perturbations. As few as two are necessary for self-organization (in magnetic or gravitational attraction), but generally we use the term to classify more complex phenomena than point attractors. The richness of possible behaviour increases rapidly with the number of interconnections and the level of feedback. For small systems we are able to analyse the state possibilities and discover the attractor structure. Larger systems however require a more statistical approach where we sample the system by simulation to discover the emergent properties. In general terms, for self-organization to occur, the system must be neither too sparsely connected (so most units are independent) nor too richly connected (so that every unit affects every other). Most studies of Boolean Networks suggest that having about two connections for each unit leads to optimum organisational and adaptive properties. If more connections exist then the same effect can be obtained by using canalizing functions or other constraints on the interaction dynamics.*

(**Flake, 1998**): *A spontaneously formed higher–level pattern of structure or function that is emergent through the interactions of lower-level objects.*

(**From: http://www.complexityandeducation.ualberta.ca/**): *Arising through the dynamic, adaptive interactions of its own component parts, rather than as a result of external causes or a central controller. Self-organization is a key characteristic of complex systems. Examples of this 'bottom-up' form of organization include the way ants self-organize into ant hills, birds into flocks, and humans into social and political collectives. Although control of a complex system's organization (or dynamic structure) is distributed (or decentralized), the system as a whole both adapts (or learns) and maintains a coherent identity. The process or learning, whether at the level of the individual, classroom, school, or larger social collective, can be seen as a self-organizing process. What is learned is more function of the self-organizing activity of the learner than the result of external, top-down curriculum or instruction.*

(**Wikipedia, 2006**): *The most robust and unambiguous examples of self-organizing systems are from physics, where the concept was first noted. Self-organization is also relevant in chemistry, where it has often been taken as being synonymous with self-assembly. The concept of self-organization is central to the description of biological systems, from the subcellular to the ecosystem level. There are also cited examples of "self-organizing"* *behaviour found in the literature of many other disciplines, both in the natural sciences and the social sciences such as economics or anthropology. Self-organization has also been observed in mathematical systems such as cellular automata. Sometimes the notion of self-organization is conflated with that of the related concept of emergence. Properly defined, however, there may be instances of self-organization without emergence and emergence without self-organization, and it is clear from the literature that the phenomena are not the same. The link between emergence and self-organization remains an active research question. Self-organization usually relies on four basic ingredients: Positive feedback, Negative feedback, Balance of exploitation and exploration, Multiple interactions.*

(**Williams, 2001**): *The spontaneous, self-generated occurrence of some kind of pattern or structure from an (usually) order less dynamical system.*

Self-organized criticality, self-organizing criticality

(1: **CALRESCO, 2006**): *The ability of a system to reach edge-of-chaos by self-organization.*

(2: **CALRESCO, 2006**): *The ability of a system to evolve in such a way as to approach a critical point and then maintain itself at that point. If we assume that a system can mutate, then that mutation may take it either towards a more static configuration or towards a more changeable one (a smaller or larger volume of state space, a new attractor). If a particular dynamic structure is optimum for the system, and the current configuration is too static, then the more changeable configuration will be more successful. If the system is currently too changeable then the more static mutation will be selected. Thus the system can adapt in both directions to converge on the optimum dynamic characteristics.*

(**Flake, 1998**): *A mathematical theory that describes how systems composed of many interacting parts can tune themselves toward dynamical behaviour that is critical in the sense that it is neither stable nor unstable but at a region near a phase transition.*

(**Wikipedia, 2006**): *Self-organized criticality (SOC) is a term used in physics to describe (classes of) dynamical systems which have a critical point as an attractor. Their macroscopic behaviour thus displays the spatial and/or temporal scale-invariance characteristic of the critical point of a phase transition, but, unlike the latter, in SOC these features result without needing to tune control parameters to precise values. The phenomenon was first identified by Per Bak, Chao Tang and Kurt Wiesenfeld ("BTW") in a seminal paper published in 1987 in Physical Review Letters, and is considered to be one of the mechanisms by which complexity arises in nature. Its concepts have been enthusiastically applied across fields as diverse as geophysics, cosmology, evolutionary biology and ecology, economics, loop quantum gravity, sociology, solar physics and others. SOC is typically observed in slowly-driven non-equilibrium systems with extended degrees of freedom and a high level of nonlinearity. Many individual examples have been identified since BTW's original paper, but to date there is no known set of general characteristics that guarantee a system will display SOC.*

(**Williams, 2001**): *The property whereby a dynamical system naturally evolves toward a critical state (a condition where the system undergoes a sudden change). Various perturbations of the system at that critical state provoke different responses that follow a power law.*

Self-organizing system

(**CALRESCO, 2006**): *Systems that generate their form by a process of self-organisation, either wholly or in part.*

Self-similarity

(**CALRESCO, 2006**): *Appearing the same at all magnifications. Fractal boundaries have this feature.*

(**Wikipedia, 2006**): *A self-similar object is exactly or approximately similar to a part of itself. A curve is said to be self-similar if, for every piece of the curve, there is a smaller piece that is similar to it. For instance, a side of the Koch snowflake is self-similar; it can be divided into two halves, each of which is similar to the whole. Many objects in the real world, such as coastlines, are statistically self-similar: parts of them show the same statistical properties at many scales. Self-similarity is a typical property of fractals. It also has important consequences for the design of computer networks, as typical network traffic has self-similar properties. For example, in telecommunications traffic engineering, packet switched data traffic patterns seem to be statistically self-similar. This property means that simple models using a Poisson distribution are inaccurate, and networks designed without taking self-similarity into account are likely to function in unexpected ways.*

(**From: http://www.complexityandeducation.ualberta.ca/**): *A special kind of scale independence in which the parts closely resemble the whole—for example, the way a branch resembles the shape of its tree. Many fractal forms are self-similar. The same or similar characteristics can be found at multiple levels. Indeed, if sufficiently magnified or reduced, figures at one level will often fit exactly into figures at other levels. Complex, or learning, systems demonstrate many characteristics of self-similarity. For example, fractal self-similarity has been used to describe the similarly clustered and nested structures of the brain and human social systems.*

Sensitivity

(**Flake, 1998**): *The tendency of a system (sometimes chaotic) to change dramatically with only small perturbations.*

Separatrix

(**CALRESCO, 2006**): *The unstable boundary between two attractors.*

(**Williams, 2001**): *A boundary between regions of phase space, such as a boundary between two basins of attraction in a dissipative system.*

Simulation

(**CALRESCO, 2006**): *Modelling a system by implementing in a computer some relevant features. If all features are operational then the system is real not a simulation. Alife is sometimes said to be real life under this definition, unlike say a model of a volcano which cannot melt the computer - a feature of real volcanic lava, which is not included in the model.*

(**Flake, 1998**): *Experimentation in the space of theories, or a combination of experimentation and theorization. Some numerical simulations are programs that represent a model for how nature works. Usually, the outcome of a simulation is as much a surprise as the outcome of a natural event, due to the richness and uncertainty of computation.*

Singularity

(**Gharajedaghi, 1999**): *Singularity refers to theories in which a particular structure, function, or process is considered fixed and/or primary in all environments.*

Social learning

(**Gharajedaghi, 1999**): *Social learning is not the sum of isolated learning of each member. It is the member's shared learning as manifested in a notion of a shared image and culture. Recall that the role of knowledge in social systems is analogous to that of energy in physical systems.*

Social constructivism

(**From: http://www.complexityandeducation.ualberta.ca/**): *Social constructivism is concerned with the manners in which collective knowledge is generated in the collaborative activities of individuals, and how, in turn, that knowledge operates to frame the activities, understandings, and identities of those individuals. A diversity of ideologies tends to be represented among constructionists, including Marxist, postcolonial, radical feminist and other critical theoretical perspectives, along with less politically oriented interpretive attitudes. Shared meanings develop through negotiation in the learning environment, leading to the development of common knowledge. Theorists may also uncover ways in which the learning environment or structure of discourse 'silences' certain kinds of knowledge. Complexity science understands social collectives as coherent, complex systems (or "learners") with cognitive processes of their own. It thus supports current social constructivist accounts of learning and links them to theories of learning dealing with other levels, or learners/bodies.*

Stability

(**CALRESCO, 2006**): *Unchanging with time. This can be a static state (nothing changes) or a steady state (resource flows occur). In complex non-equilibrium systems we have multistable states, i.e. many semi-stable positions possible within a single system.*

(**Williams, 2001**): *Tending to dampen perturbations or initial differences, over time.*

Stable fixed point

(**Williams, 2001**): *A type of attractor in the form of a phase space point that attracts all neighbouring points, that is, a point to which all iterates beginning from some other point converge.*

Standard phase space

(**Williams, 2001**): *A term used in this book for the usual phase space, the coordinates for which represent the measured and different physical features that are to be plotted on the association graph or phase portrait.*

State

(**Bar-Yam, 2006b**): *The condition of a system at a particular time.*

(**CALRESCO, 2006**): *This is the total number of behavioural combinations available to the system. When tossing a single coin, this would be just two states (either heads or tails). Generalizing, any system has one dimension of state space for each variable that can change. Mutation will change one or more variables and move the system a small distance in state space. State space is frequently called phase space, the two terms are interchangeable.*

(**Williams, 2001**): *a) The conditions of a system or values of its variables, at any one time; b) an arbitrarily defined sub-range (usually specified numerical boundaries) that one or more variables of a system can be in at one particular time.*

State-maintaining system (SMS)

(**Gharajedaghi, 1999**): *A SMS is one that react to changes in order to maintain its state under different environmental conditions. What is done is determined entirely by the change in its environment, given the structure of the system.*

State space

(**CALRESCO, 2006**): The total theoretical possibilities available to the system, by combinations of the parts. Also called phase space.

See also phase space.

Stigmergy

(**CALRESCO, 2006**): *The use of the environment to enable agents to communicate and interact, facilitating self-organization. This can be by deliberate storage of information (e.g. the WWW) or by physical alterations to the landscape made as a result of the actions of the life forms operating there (e.g. pheromone trails, termite hills). The future choices made by the agents are thus constrained or stimulated dynamically by the random changes encountered.*

(**Wikipedia, 2006**): *Stigmergy is a method of communication in emergent systems in which the individual parts of the system communicate with one another by modifying their local environment. Stigmergy was first observed in nature - ants communicate to one another by laying down pheromones along their trails, so where ants go within and around their ant colony is a stigmergic system. Similar phenomena are easily seen in many (all?) eusocial creatures, such as termites, who use pheromones to build their very complex nests by following a simple decentralized rule set. Each insect scoops up a 'mudball' or similar material from its environment, invests the ball with pheromones, and deposits it on the ground. Termites are attracted to their nestmates' pheromones and are therefore more likely to drop their own mudballs near their neighbors'. Over time this leads to the construction of* *pillars, arches, tunnels and chambers. The term was introduced by French biologist Pierre-Paul Grassé in 1959 to refer to termite behavior. He defined it as: "Stimulation of workers by the performance they have achieved." It is derived from the Greek words stigma 'sign' and ergon 'action,' and captures the notion that an agent's actions leave signs in the environment, signs that it and other agents sense and that determine their subsequent actions." (Parunak, H. v D. (2003). Making swarming happen. In Proc. of Conf. on Swarming and Network Enabled Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR), McLean, Virginia, USA, January 2003.) Stigmergy is not restricted to eusocial creatures, or even to physical systems. On the internet there are many emergent phenomena that arise from users interacting only by modifying local parts of their shared virtual environment. Wikipedia is a perfect example of this. The massive structure of information available in a wiki could be compared to a termite nest; one initial user leaves a seed of an idea (a mudball) which attracts other users who then build upon and modify this initial concept eventually constructing an elaborate structure of connected thoughts. The term is also employed in experimental research in robotics, multi-agent systems and communication in computer networks. In these fields there exists two types of stigmergy: active and passive. The first kind occurs when a robotic or otherwise intelligent "agent" alters its environment so as to affect the sensory input of another agent. The second occurs when an agents's action alters its environment such that the environmental changes made by a different agent are also modified. A typical example of active stigmergy is leaving behind artifacts for others to pick up or follow. An example of passive stigmergy is when agent-A tries to remove all artifacts from a container, while agent-B tries to fill the container completely.*

(**From: http://www.stigmergicsystems.com/index.html?332709**): *Eric Bonabeau, Santa Fe Institute described stigmergy: The concept of stigmergy was introduced by Pierre-Paul Grasse in the 1950's to describe the indirect communication taking place among individuals in social insect societies. Stigmergy was originally defined by Grasse in his studies on the reconstruction of termite nests. Grasse showed that the regulation and coordination of the building activity do not depend on the workers themselves but is mainly achieved by the nest: a stimulating configuration triggers a response of a termite worker, transforming the configuration into another configuration that may trigger in turn another, possibly different, action performed by the same termite or any other worker in the colony. Although Grasse's concept of stigmergy was attractive and stimulating, it has been overlooked by students of social insects because it left open the important operational issue of how stimuli must be organized in time and space to allow perfect coordination. Despite the vagueness of Grasse's formulation, stigmergy is a profound concept, the consequences of which are yet to be explored. Not only is stigmergy of potential importance for our understanding of the evolution and maintenance of sociality in animals, from communally breeding species to highly eusocial insects, it may also turn out to be a crucial concept in other fields, such as artificial intelligence, robotics, or the social, political and economic sciences, to which its relevance is intuitively obvious. The aims of this special issue of Artificial Life on stigmergy are: - to provide readers from a variety of fields with an overview of what is known (and what is not) about stigmergy in such various contexts as ethology, distributed problem-solving and robotics, - to invite researchers in these fields to present their new work, - and to give the opportunity to researchers from other scientific communities to present their work in the light of stigmergy.*

(…) described stigmergy: Grasse coined the term stigmergy (previous work directs and triggers new building actions) to describe a mechanism of decentralized pathway of information flow in social insects. In general, all kinds of multi-agent groups require coordination for their effort and it seems that stigmergy is a very powerful means to coordinate activity over great spans of time and space in a wide variety of systems. In a situation in which many individuals contribute to a collective effort, such as building a nest, stimuli provided by the emerging structure itself can provide a rich source of information for the working insects. The current article provides a detailed review of this stigmergic paradigm in the building behavior of paper wasps to show how stigmergy influenced the understanding of mechanisms and evolution of a particular biological system. The most important feature to understand is how local stimuli are organized in space and time to ensure the emergence of a coherent adaptive structure and to explain how workers could act independently yet respond to stimuli provided through the common medium of the environment of the colony.

Stochastic

(**CALRESCO, 2006**): Random or unpredictable effects, often associated with probabilistic or statistical treatments.

Strange attractor

(**CALRESCO, 2006**): *An attractor whose variables never exactly repeat their values but always are found within a restricted range, a small area of state space.*

(**DuPreez and Smith, 2004**): *The unpredictable pattern or behaviour that a system displays in response to perturbations in its environment.*

(**Williams, 2001**): *a) Same as chaotic attractor; b) an attractor having such geometrical features as fractal dimension, Cantor-set structure, and so on.*

Structural coupling

(**CALRESCO, 2006**): *This is the idea that a complex and autopoietic system must relate to its environment, and the internal structure becomes coupled to relevant features of that environment. In complexity terms the environment selects which of the systems attractors becomes active at any time, what is also called situated or selected self-organization.*

Supervenience

(**Wikipedia, 2006**): *In philosophy, supervenience is arguably defined as a dependency relation between 'higher-level' (e.g. mental) and 'lower-level' (e.g. physical) properties. Informally, a group of properties X supervenes on (alternatively, is supervenient on) a group of properties Y exactly when the X-group properties are determined by the Y-group properties, where "determined by" is taken non-specifically. Formally, X-group properties supervene on Y-group properties if and only if either of the following holds for all objects a and b: a and b cannot differ in their X-group properties without also differing in their Y-group properties. If a and b have identical Y-group properties, then they also have identical X-group properties. If a and b do not have identical X-group properties, then they also do not* *have identical Y-group properties. (All of these formulations are logically equivalent, so if one of them holds, all of them do.)*

Swarm

(**CALRESCO, 2006**): *A collection of agents (autonomous individuals) that use stigmergic local knowledge to self-organize and co-ordinate their behaviours. This can occur even if the agents themselves have no intelligence and no explicit purpose. Swarm intelligence is also related to Ant Colony Optimization (ACO) and ALife techniques.*

(**From:** http://www.molbio.ku.dk/MolBioPages/abk/PersonalPages/Jesper/Swarm.html): *A swarm has been defined as a set of (mobile) agents which are liable to communicate directly or indirectly (by acting on their local environment) with each other, and which collectively carry out a distributed problem solving. The body can be understood as a swarm of cells and tissues which, unlike the swarms of bees or ants, stick relatively firmly together. However, the swarm of cells constituting a human body is a very different kind of swarm from that of the social insects. The body swarm is not built on ten thousand nearly identical units such as a bee society. Rather it should be seen as a swarm of swarms, i.e., a huge swarm of more or less overlapping swarms of very different kinds. And the minor swarms again are swarm-entities, so that we get a hierarchy of swarms. At all levels these swarms are engaged in distributed problem solving based on an infinitely complicated web of semetic interaction patterns which in the end can only be explained through reference to the actual history of the body system, evolution.*

Swarm intelligence

(**From: http://www.sce.carleton.ca/netmanage/tony/swarm.html**): *Swarm Intelligence (SI) is the property of a system whereby the collective behaviours of (unsophisticated) agents interacting locally with their environment cause coherent functional global patterns to emerge. SI provides a basis with which it is possible to explore collective (or distributed) problem solving without centralized control or the provision of a global model. A description of the ideas of coordination without communication can be found on Stan Franklin's coordination page.*

Sympoietic

(**CALRESCO, 2006**): *A more open form of self-maintenance than autopoietic, more appropriate for social and ecological forms of organization. Exhibits more diffuse structures and fuzzy boundaries.*

Synchronous

(**Flake, 1998**): *Acting in a lockstep fashion, with each event occurring in a precise order, or in such a way as to eliminate the notion of order entirely.*

Synergetics

(**CALRESCO, 2006**): *The use of geometric ideas within a systems view to describe and understand reality. Closely associated with Buckminster Fuller who applied it also to human behaviour.*

Synergy

(1: **CALRESCO, 2006**): *The idea that combined parts have properties that are more or less that the sum of the parts (positive-sum or negative-sum rather than zero-sum). Related to emergence but much wider. The negative-sum version is sometimes called dysergy, leaving synergy to mean only beneficial effects also studied as symbiosis, 'holistic darwinism', 'synergistic selection', 'synergic evolution', 'cooperative coevolution' or 'compositional evolution' and many combinations thereof.*

(2: **CALRESCO, 2006**): *Synergy studies the additional benefit accruing to collective systems. This relates to the idea that the whole is greater (or less) that the parts. It includes the study of mergers, organisational benefits of co-operation and more generally what is referred to in complexity studies as emergence. Synergy includes symbiotic effects, along with many other forms of co-operative or combinatoric fitness enhancements. Where joint effects reduce fitness (e.g. in destructive competition) the term 'dysergy' can be used. In physical systems the term Synergetics is also employed [Haken, Buckminster-Fuller]*.

Synthetic

(**CALRESCO, 2006**): *Made up of parts. Assembled. More than the sum of the components. Opposite of analytic (taking apart).*

System

(**CALRESCO, 2006**): *A collection of interacting parts that forms an integrated and consistent whole, isolatable from its surroundings. The concept of dynamics or change over time is central to our treatment of complex systems.*

(Couture, 2006d): *A system is represented by any combination of elements like: people (person, group, etc), abstract elements (military doctrines, methods, approaches, theories, software, concepts, ideas, etc), and physical elements (computers, network devices, mechanical devices, radio, vehicles, etc). Elements*[3] *of a system are put in action in an environment and context(s)*[4] *to achieve one or many function(s), goal(s) or mission(s).*

(**Gharajedaghi, 1999**): *A system consist of all interactive sets of variables that could be controlled by participating actors.*

(**NECSI, 2006**): *A system is a delineated part of the universe which is distinguished from the rest by an imaginary boundary. One of the basic concepts in the systems approach is that all systems interact with their environment. How can we then identify what a system is? Aren't we always making an artificial boundary? In order to perceive or know anything, one must make a distinction. The key idea of "system" is that once a system is identified (the boundary described) then one describes: the properties of the system, the properties of the universe excluding the system which affect, the system, and the interactions / relationships between them.*

[3] If an entity is considered as a system, its parts are called elements of this system.
[4] Examples of contexts would be: war, peace keeping, social reconstruction, etc.

(**OPEN2, 2006**): *An integrated whole whose essential properties arise from the relationships between its parts from the Greek synhistanai, meaning 'to place together'.*

(**Williams, 2001**): *A system is an assemblage of interacting parts, such as weather system. Alternatively, it is a group or sequence of elements, especially in the form of a chronological ordered set of data.*

System boundary

(**Gharajedaghi, 1999**): *An arbitrary subjective construct defined by the interest and the level of ability and/or authority of the participating actors.*

System dynamics

(**CALRESCO, 2006**): *The study of how systems actually behave, using models to simulate the assumptions and rules being followed. Often the behaviour seen is very different than the behaviour people expect.*

System of interest

(**OPEN2, 2006**): *The product of distinguishing a system in a situation in which an individual or group has an interest or stake.*

System of systems (SoS)

(**CALRESCO, 2006**): *When a series of parts are connected into various configurations, the resultant system no longer solely exhibits the collective properties of the parts themselves. Instead any additional behaviour attributed to the system is an example of an emergent system property. A configuration can be physical, logical or statistical, all can show unexpected features that cannot be reduced to an additive property of the individual parts. Crucial to such properties is the fact that we cannot even describe them using the language applicable to the parts, we need a new vocabulary, new terms to be invented, e.g. 'laser' to denote the functional features of the entity (e.g. coherent light producer).*

Systemic value

(**CALRESCO, 2006**): *A form of judgement that allows only two possibilities, good or bad (present or absent, in or out). This corresponds to Boolean operations (based upon Aristotelian logic).*

Systems theory (or systemics or general systems theory)

(**Wikipedia, 2006**): *An interdisciplinary field including engineering, biology, and philosophy that incorporates science to study large systems.*

Systems thinking

(**CALRESCO, 2006**): *The systems approach relates to considering wholes rather than parts, taking all the interactions into account, see also General Systems Theory. It considers processes rather than things to be primary.*

(**OPEN2, 2006**): *The understanding of a phenomenon within the context of a larger whole; to understand things systemically literally means to put them into a context, to establish the nature of their relationships.*

(**Wikipedia, 2006**): *Systems thinking involves the use of various techniques to study systems of many kinds. It includes studying things in a holistic way, rather than through purely reductionist techniques. It aims to gain insights into the whole by understanding the linkages and interactions between the elements that comprise the whole "system". Systems thinking can help avoid the silo effect, where a lack of organizational communication can cause a change in one area of a system to adversely affect another area of the system. Systems thinkers consider that: 1- a "system" is a dynamic and complex whole, interacting as a structured functional unit; 2- information flows between the different elements that compose the system; 3- a system is a community situated within an environment; 4- information flows from and to the surrounding environment via semi-permeable membranes or boundaries; 5- systems are often composed of entities seeking equilibrium, but can exhibit oscillating, chaotic, or exponential growth/decay behaviour.*

2.20 -T-

Time complexity

(**Flake, 1998**): *A function that describes the amont of time required for a program to run on a computer to perform a particular task. The function is parameterized by the length of the program's input.*

Time-reversible

(**Flake, 1998**): *A property of dynamical systems that can be run unambiguously both forward and backward in time.*

Top-down

(**Flake, 1998**): *A method of examining things that first looks at higher-level phenomena and then tries to explain lower-level patterns in terms of the higher-level observations. This is the exact opposite of bottom-up.*

Tradition

(**OPEN2, 2006**): *Literally, a network of pre-understandings or prejudices from which we think and act; how we make sense of our world.*

Trajectory

(**Calhoun, 2004**): *Sequences of network states, that will result based on various initial configurations.*

(**CALRESCO, 2006**): *The path through state space taken by a system. It is the sequence of states or path plotted against time. Two general forms affect fitness, positive-sum and negative-sum.*

(**Wikipedia, 2006**): *A trajectory is an imagined trace of positions followed by an object moving through space. A particular trajectory may be described mathematically either by the geometry of the entire trajectory (i.e. the set of all positions taken by the object), or as the position of the object as function of time.*

(**Williams, 2001**): *a) A path taken by a moving body or point; b) a sequence of measured values or list of successive states of a dynamical system; c) a solution to a differential equation; d) graphically, a line on a phase space plot, connecting points in chronological order.*

Transformation

(**OPEN2, 2006**): *Changes, modelled as an interconnected set of activities which convert an input to an output which may leave the system (a 'product') or become an input to another transformation.*

Transient

(**CALRESCO, 2006**): *A short term phenomena seen on the way towards, and before reaching, a steady state.*

Transient attractor

(**CALRESCO, 2006**): *An temporary attractor formed within the transient behaviour of a system. This is a state (like a glider in the Game of Life) that only persists for a short time before dissipating with new perturbations (e.g. a smoke ring). Most attractors in evolving complex systems are of this type, due to the presence of continual perturbations.*

Turing machine

(**CALRESCO, 2006**): *A form of universal computer, assumed to take its instructions from an infinite paper punched tape and output results to the same medium before stopping upon completion of the program.*

(**Flake, 1998**): *A model of computation that uses an underlying finite-state automaton but also has infinite tape to use as memory. Turing machines are capable of universal computation.*

2.21 -U-

Universal computation

(**Flake, 1998**): *Capable of computing anything that can in principle be computed.*

Universal computer

(**CALRESCO, 2006**): *A computer able to perform any task if suitable programmed. Most personal computers are of this type (at least for a small range of tasks). Any system with sufficient flexibility of interaction may perform this function, for example some automata or neural networks.*

Universal constructor

(**CALRESCO, 2006**): *A machine able to construct any other object (including a copy of itself) give the appropriate instructions.*

Unstability

(**Williams, 2001**): *Tending to amplify perturbations or initials differences, over time.*

2.22 -V-

Value

(**CALRESCO, 2006**): *The dimensions or objectives we choose with which to measure the system and those variables we attempt to optimise in deriving fitness. Due to neural associations, the often imagined dualism between 'fact' and 'value' is invalid, thus values (purposes) can and should form a part of our scientific worldview.*

2.23 -W-

Whole system

(**CALRESCO, 2006**): *The inclusion in our definition of 'system' of all the issues involved, including all the nested levels of interconnected smaller systems and how they relate to each other and work dynamically as a whole.*

2.24 -X-

2.25 -Y-

2.26 -Z-

Zero sum

(**CALRESCO, 2006**): *The idea, from game theory and economics, that agents swap resources, so that what one loses the other gains leaving a net no-change in fitness (contrast with non-zero, positive and negative sums).*

3 Conclusion

Definitions for a number of 335 different key words related to Complexity Theory are given in this document. While this list is not complete it provides the reader a first reference for finding most currently used key words. By using proposed searching methods described in Chapter 1, the reader will then be able to find the needed information in this document and over the Internet.

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Un nombre de 335 mots clefs reliés à la Théorie de la complexité, au chaos et aux systèmes complexes sont définis dans ce document. Pour certains de ces mots clefs, plusieurs définitions provenant d’auteurs différents sont proposées. Le but est de donner au lecteur certaines perspectives que l’on retrouve dans la littérature scientifique concernant l’interprétation des concepts dans ce domaine.

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