EVOLUTION OF COMPLEX SYSTEMS

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Abstract
The strength of physical science lies in its ability to explain phenomena as well as make prediction based on observable, repeatable phenomena according to known laws. Science is particularly weak in examining unique, nonrepeatable events. We try to piece together the knowledge of evolution with the help of biology, informatics and physics to describe a complex evolutionary structure with unpredictable behavior. Evolution is a procedure where matter, energy, and information come together. Our research can be regarded as a natural extension of Darwin's evolutionary view of the last century. We would like to find plausible uniformitarian mechanisms for evolution of complex systems. Workers with specialized training in overlapping disciplines can bring new insights to an area of study, enabling them to make original contributions. This paper describes evolution of complexity as a basic principle of evolutionary computation. We joined parallel evolutionary structures with a grammatical evolution.

1 Introduction

Naturalistic explanations of life's origin are speculative [1]. But does this mean such inquiries are impotent or without value? The same criticism can be made of any attempt to reconstruct unique events in the past. We cannot complete our knowledge without answering some of the fundamental question about nature. How does life begin? What is turbulence? Above all, in a universe ruled by entropy, drawing inexorably toward greater and greater disorder, how does order arise? Although the various speculative origin scenarios may be tested against data collected in laboratory experiments, these models cannot be tested against the actual events in question, i.e., the origin. Such scenarios, then, must ever remain speculation, not knowledge. There is no way to know whether the results from these experiments tell anything about the way life itself originated. In a strict sense, these speculative reconstructions are not falsifiable; the may only be judged plausible or implausible. In the familiar Popper sense of what science is, a theory is deemed scientific if it can be checked or tested by experiment against observable, repeatable phenomena. Behavior of complex nonlinear systems with unpredictable behavior can be explained by a relatively simple and transparent system – a magnetic pendulum [8]. The idea is to set the pendulum swinging and guess which attractor will win. Even with just three magnets placed in a triangle, the pendulum's motion cannot be predicted. In the pendulum energy is transformed between the potential energy and kinetic energy. Assuming that we have removed all magnets from the platform, the pendulum will eventually stop swinging and come to rest in perfectly vertical plane. When we pull the pendulum up off that vertical axis, we create potential energy. When we release the pendulum from our grip (from an initial state), this potential energy converts into kinetic energy. The first law of thermodynamics is the conservation of energy that state that energy may neither be created nor destroyed – it is simply transformed from one state to another. In the magnetic pendulum, the forces of gravity and magnetism act on pendulum to convert back and forth between potential and kinetic energy in wild form.

The second law of thermodynamics states that the entropy (disorder) of closed system must always increase. There is friction on the pendulum caused when it pushes through the air (air resistance). This friction prevents anything from having perpetual motion. The potential and kinetic energies of the pendulum will transform into heat until the pendulum stops swinging. By placing varying numbers of magnets in varying positions on the base plate, we can create different movements and patterns in the swing of the pendulum. By flipping the magnets so that the north or south poles face up further creates different movements and patterns in the swing of the pendulum. By using the combination of varying position of the magnets on the plate, varying the number of magnets on the plate, and varying the up-facing poles, we can create virtually an endless pattern of crazy and unpredictable swings of pendulum.

Autonomous agent is a physical system, such as a bacterium, that can act on its own behalf in an environment. All free-living cells and organisms are clearly autonomous agents. Autonomous agent must be displaced from thermodynamic equilibrium. Work cycles cannot occur at equilibrium. In complex chemical reaction systems, self-reproducing molecular systems form with high probability. Life is an emergent collective behavior of complex chemical networks [1-4]. Enzymes catalyze, or speed up, chemical reactions. As the molecular diversity of a reaction system increases, a critical threshold is reached at which collectively autocatalytic, self-reproducing chemical reaction networks emerge spontaneously.

Another example of complex system is a sand pile. If we drop the sand slowly on the table the sand will gradually pile up. We will obtain many small avalanches and progressively fewer large avalanches. These huge avalanches are exactly the signature of the famous "butterfly effect" seen in the weather, where a small initial change can have large-scale consequences. The spreading avalanches constitute sensitivity to initial conditions. The same body of theory predicts that most species go extinct soon after their formation, while some live a long time. The predicted species life-time distribution is a power low [3].

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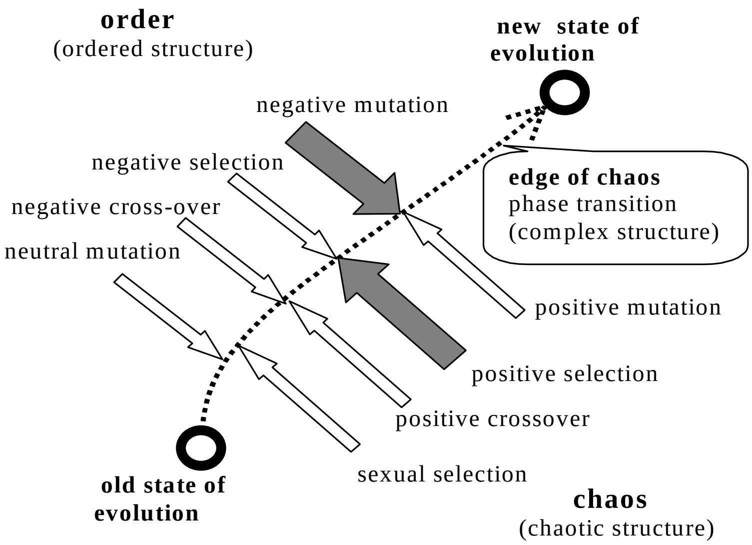

Fig.1: Evolution on the edge of chaos

One modern sense of a compact description of something is a computer program. Then the concept of a compact description becomes the concept of shortness of the program. To create such programs we can use grammatical evolution [10]. In order to maximize compression, we must get all redundancy out of both the input symbol string and the symbol string representing the program. But as the length of the most compact description increases, bit by actual bit, its information content increases, bit by bit. This is a quite different approach to compare with Shannon's information theory. Thus, for each bit in reduction of the entropy of the system by our measurement, the information content of the most description increases, on average, exactly as rapidly. The sum of the entropy of the system plus the observer's knowledge about that system is a constant for an equilibrium system.

2 Self-organization and adaptation of complex systems

In dynamical systems, transition can be found: order, complexity, and chaos. Analogously, water can exist in solid, transitional, and fluid phases [4], [9]. In nonlinear systems, a chaos theory tells us that the slightest uncertainty in our knowledge of initial conditions will often grow inexorably, and our predictions are nonsense. Complex adaptive systems share certain crucial properties (non-linearity, complex mixture of positive and negative feedback, nonlinear dynamics, emergence, collective behavior, spontaneous organization, etc.). In the natural world, such systems include brains, immune systems, ecology, cells, developing embryos, and ant colonies. In the human world, they include cultural and social systems. Each of these systems is a network of a number of "agents" acting in parallel. In a brain, the agents are nerve cells; in ecology, the agents are species; in a cell, the agents are organelles such as the nucleus and the mitochondria; in an embryo, the agents are cells, and so on. Each agent finds itself in the environment produced by its interactions with the other agents in the system. It is constantly acting and reacting to what the other agents are doing. There are emergent properties, the interaction of a lot of parts, the kinds of things that the group of agents can do collectively; something that the individual cannot. There is no master agent - for example - a master neuron in the brain. Complex adaptive systems have a lot of levels of organization (hierarchical structures), with agents at any level serving as building blocks for agents at a higher level. The immune system is governed by local interaction between cells and antibodies, there is no central controller in distributed control. Similar behavior can be found in the development of the Internet. We can use biological laws to describe the development of the Internet.

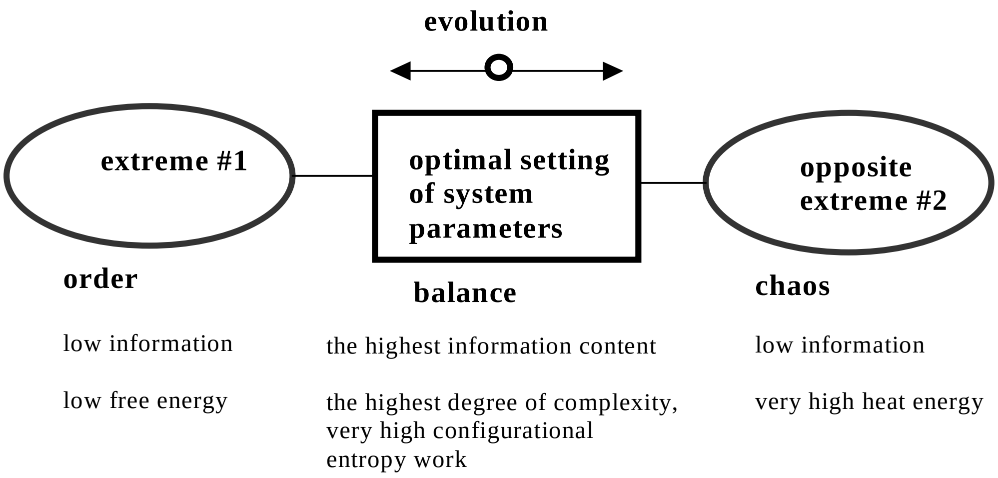

Fig.2: Evolutionary setting of system parameters

The edge of chaos is a special region onto itself, the place where you can find systems with lifelike, complex behavior (see Fig. 1 and Fig. 2). Living systems are actually very close to this edge-of-chaos phase transition, where things are much looser and more fluid. A natural selection is not an antagonist of self-organization. It is a force that constantly pushes emergent, self-organizing systems towards the edge of chaos from a chaos area. A mutation and a crossover are opposite forces pushing the systems from an order to chaos-areas. Evolution always seemed to lead to the edge of chaos. The complex evolutionary structure was described in [5 - 8]. A random genetic crossover or mutation may give a species the ability to run much faster than before. The agent starts changing, then it induces changes in one of its neighbors, and finally you get an avalanche of changes until everything again stops changing. Systems get to the edge of chaos through adaptation: each individual (agent) tries to adapt to all the others. Co - evolution can also get them there; the whole system co-evolves to the edge of chaos. In ecosystems or ecosystem models, three regimes can be found: ordered regime, chaotic regime, and edge-of chaos like a phase transition. When the system is at the phase transition, then - of course - order and chaos are in balance. There is an evolutionary metadynamics, a process that would tune the internal organization of each agent so that they all reside at the edge of chaos. The maximum fitness occurs right at the phase transition.

3 Parallel grammatical evolution

Grammatical Evolution (GE) [10] can be considered a form of grammar-based genetic programming (GP). In particular, Koza’s genetic programming has enjoyed considerable popularity and widespread use. Unlike a Koza-style approach, there is no distinction made at this stage between what he describes as function (operator in this case) and terminals (variables). Koza originally employed Lisp as his target language. This distinction is more of an implementation detail than a design issue. Grammatical evolution can be used to generate programs in any language, using Backus Naur Form (BNF). BNF grammars consist of terminals, which are items that can appear in the language, i.e. +, -, sin, log etc. and non-terminal, which can be expanded into one or more terminals and non-terminals. A non-terminal symbol is any symbol that can be rewritten to another string, and conversely a terminal symbol is one that cannot be rewritten. The major strength of GE with respect to GP is its ability to generate multi-line functions in any language. Rather than representing the programs as parse tree, as in GP, a linear genome representing is used. A genotype-phenotype mapping is employed such that each individual’s variable length byte strings, contains the information to select production rules from a BNF grammar. The grammar allows the generation of programs, in an arbitrary language that are guaranteed to be syntactically correct. The user can tailor the grammar to produce solutions that are purely syntactically constrained, or they may incorporate domain knowledge by biasing the grammar to produce very specific form of sentences.

GE system in [10] codes a set of pseudo random numbers, which are used to decide which choice to take when a non-terminal has one or more outcomes. Because GE mapping technique employs a BNF definition, the system is language independent, and, theoretically can generate arbitrarily complex functions. There is quite an unusual approach in GEs, as it is possible for certain genes to be used two or more times if the wrapping operator is used. BNF is a notation that represents a language in the form of production rules. It is possible to generate programs using the Grammatical Swarm Optimization (GSO) technique [11] with a performance similar to the GE. Given the relative simplicity of GSO, the small population sizes involved, and the complete absence of a crossover operator synonymous with program evolution in GP or GE. Grammatical evolution was one of the first approaches to distinguish between the genotype and phenotype. GE evolves a sequence of rule numbers that are translated, using a predetermined grammar set into a phenotypic tree.

There is a new method of GP [12], named chemical genetic programming (CGP), which enables evolutionary optimization of the mapping from genotypic strings to phenotypic trees. In biological cells information is derived from DNA to give each cell its functionality. This process is called translation. A series of metabolic reactions, catalyzed by several enzymes, translate genetic information into proteins. Each amino acid is a biochemical building block, so together the amino acids form the fundamental set of functional units in a cell. In the CCP a cell is evolved, and includes a DNA string that codes genetic information and smaller molecules for the mapping from DNA code to computational functionality. Genetic modification of a cell's DNA allows the DNA code and genotype-to-phenotype translation to coevolve. Building an optimal translation table enhances evolution within a population while maintaining the necessary diversity to explore the entire search space. The collection of grammatical rewriting rules, or translations, is stored in each cell's translation table. Using the breeding techniques of conventional GP, GE or CCP is effective alternative. In CGP however, the translation relation is dynamic, and the system is allowed to optimize both the combination of symbols in the genotypic string, as well as the translation set is used to create a cell's phenotypic tree. The genotype-to-phenotype mapping is a critical point in designing an evolutionary system. This mapping provides the building blocks that a system is allowed to work with progressing towards its objective.

We created multilevel distributed GE with parallel structure [5], [13]. This parallel approach can decrease the computational time and improve adaptation to the change of system parameters.

Conclusions

Parallel evolutionary algorithms (EAs) can increase the efficiency and robustness of systems, and thus they can track better optimal parameters in a changing environment. It is not easy to say which individual modifications in parallel and hierarchical structure are the best. If we join the GE together with the parallel EA, then - in the higher level - it is not important which a subpart will contribute more to the final solution of a parallel GE.

From the experimental result it can be concluded that modified standard GEs with two sub-populations can design parallel GE much better than classical versions of GEs. The parallel grammatical evolution can be used for the automatic generation of programs. We are far from supposing that all difficulties are removed but first results with parallel GEs are very promising.

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