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Conference Title

Evolvability of natural and artificial systems

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Abstract

Evolvability in its simplest form is the ability of a population to respond to directional selection. More interestingly it means that some lineages show open-ended evolution by accumulating novel adaptations, and that some lineages complexity can increase indefinitely. Unlimited heredity is a precondition for such rich open-endedness, another one seems to be (analogous to) chemical combinatorics. The richness of matter seems to be a source of challenges and opportunities not yet matched in artificial algorithms. However, some "artificial" systems can be more evolvable than natural ones because for the former the whole population is not under the constraint to survive in the wild. A form of artificial selection may happen even in the brain of replicable patterns that yield complex adaptations within the lifetime of the individual.

Keywords: evolvability; open-ended evolution; complexity; chemistry; natural selection; artificial selection, mind

1. Introduction

In this session evolution means evolution by natural selection, as conceived by Darwin and Wallace. Although there has been considerable progress in evolution theory, it is fair to say that Darwinian Theory seems to retain a status similar to that of Newtonian physics: both are incomplete, but unlikely to be overthrown. Darwinian dynamics can be expected to unfold in a population of evolutionary units, having the features of multiplication, inheritance and variability. If among the inherited traits there are at least a few that affect the survival and/or the fertility of the units, then in the population natural selection can take place. Note that this formulation (by Maynard Smith) does not specify genes or organisms or any

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other concrete level of organization. It does not mention even living systems. This framework is indeed so general that it is applicable to molecules, computer programs or aspects of natural language [1].

Evolvability of a population in a broad sense refers to the ability of the population to respond to directional selection. A population that responds faster is more evolvable than a population that lags behind. But many people would prefer a more exciting approach to evolvability by asking the question: what allows open-ended evolution to occur in a population. Open-ended evolution means that there is no limit for the emergence of novel adaptive traits. An even more exciting version of open-endedness is that in the long run complexity (somehow measured) can increase indefinitely, at least in some lineages.

1.1. Evolvability is not trivial

Evolutionary genetics has dealt with some aspects of evolvability for a long time. The prime example is sexual reproduction, which shows that the problem of evolvability is a tricky question [1]. First, there is the “twofold cost of sex”: other things being equal, a pathenogenetic female would reproduce twice as fast as sexual females, simply because half of the offspring of the latter are males. Thus the advantage of increased genetic variation by sex should compensate for this disadvantage. Second, simple ideas why increased variability is advantageous do not necessarily work, as exemplified by the famous argument by Bernard Shaw to Isadora Duncan when she proposed Shaw to marry and produce superb offspring: as beautiful as she and as smart as he. Fine, but what if it turns out the other way round?

1.2. Artificial and natural selection

Crucial differences between artificial and natural selection can exist. For example, unnatural selection schemes (such as elitism) may work well in surprisingly small populations. Another relevant difference is that the genetic load (due to mutation or recombination for example) may be less important for artificial selection because the population is kept in a selection arena and thus does not have to survive in the wild.

1.3. The nature of inheritance

An important aspect of evolvability concerns the nature of inheritance [1]. It certainly does matter how genetic information is transmitted. There are some replicators (such as intermediates of the autocatalytic formose reaction network) that reproduce in a holistic way: there is no digit-by-digit copying of a replicator in such cases. This is in contrast to modular replicators where digital genetic information is copied during replication, such as of DNA or RNA. Whereas holistic replicators are attractor-based, modular replicators are like storage of information. Holistic replicators and short nucleic acids show limited heredity only, because the number of possible types is much smaller than typical population. Genes today for all practical purposes (FAPP) have unlimited heredity since the number of possible sequences is hyper-astronomically large, hence almost infinitely larger than the size of real populations. Thus unlimited heredity is a necessary condition for open-ended evolution, and it requires digital information storage.

1.4. Open-ended evolution

What else is needed, then, for open-ended evolution? We suggest a tentative answer: rich ‘chemical’ combinatorics searched by a natural selection algorithm in a population of units with unlimited heredity. The term “chemistry” is should be understood in terms of formal chemistry. Memes *sensu* Dawkins seem to have unlimited heredity but their underlying “genotypes” are not made of molecules, yet they are likely to be based on physical, replicable symbol systems [2]. Evolution may be a blind watchmaker but it is a blind watchmaker with a lot of experience of watch making, fond memories of a wide range of clients and their watch needs. We can speculate about possible substrates of evolution on this basis. What kind of materials can support the required stability, variability, flexibility, and combinatorial open-endedness [3]? The answer may be frustrating. As stressed by early writers including Schrödinger, carbon is the only currently known chemical basis with these properties. If carbon proves to be a unique precondition, this delimits but also empowers the search for an artificial evolution.

2. Open-ended evolution and open-ended thought

2.1. Embodiment

Classical 19th Century materialism knew that matter is, in a fundamental sense, *rich*, and because all things are material, all things are rich – we can find the origin of complex systems at this point, where many interconnected variables interact in nontrivial ways

So far humans have not produced any machine that within the time frame of its operation continues to make discoveries rivaling the capacity of a human infant to do so. Why is this? Some say it is because we have not understood the significance of embodiment. But what of embodiment? We do not think Penrose is right that it is the quantum properties of embodiment that is needed for an intuitive grasp of a theoretically un-provable fact. The intuitive feeling of something being true is not an indication that we have some direct access to platonic reality as he strangely assumes, instead, the feeling that something is true is a subjective experience rather like the feeling of something being red, or the feeling of something being loud, it is a result of sensorimotor contingencies as described by the theory of Noe and O'Reigan. For something to be true is for it to "stand" against a set of perturbations, the shaking of the foundational table upon which it stands. We learn such shaking tests of truth based on the culture we inhabit. Some tests appear more effective than others. No, we think the open-endedness conferred by embodiment in contrast to a formal system, e.g. a computer program, comes from the perversity of noise and variation found in physical systems. Everything varies; random numbers are not neatly assigned to particular dimensions as in a genetic algorithm. Furthermore, physical reality is rich and this is a variant of the environmental complexity hypothesis.

2.2. Ecology

There also appear to be deep ecological reasons for biological complexity, whatever that means. This is demonstrated by the failure of Tierra (Tom Ray) [4] and Avida (Chris Adami) [5] to produce open-ended adaptation. We think they fail because they lack a cost of information. In their system a predator organism does not gain prebuilt code from a prey individual; instead, there is only competition for one resource, CPU time. There is no capacity to produce an economics of open-ended competition for resources that are created by the units of evolution. We postulate that the addition of such a capacity would improve these simulations. Physical reality forces such processes; you cannot ignore it when making a real physical experiment, but you can do so in a simulation.

Evolvability is the ability of life for continued evolution, reaching ever-new stages. For evolvability, there are important material preconditions, which are now essentially complexity requirements. Firstly, we need interplay between stability (with propagation and generative variability, as in the DNA) and flexibility (as in ontogeny and the phenotype that "wraps" the DNA). Without the first, there can be no

Darwinian evolution, and without the second, there can be no environmental contingency as a source of information to act on the first [6]. But similarly, secondly, we need a proactive environment, acting as an open system, and supplying the conditions for new interactions, be they abiotic (climate, geography) or biotic (as in the co-evolution of species, or in niche construction) [7].

On this basis can evolution be open-ended in the sense that all (or sufficiently many) possible forms can be actualized – this generative completeness is increasingly seen as a co-product of inner and outer forces, and the mediator is the material complexity of both. Interestingly, this also means that mechanisms of evolution transcend the living, much as mechanisms of the mind transcend the brain. The extended mind hypothesis sees parts of the world and in particular artifacts as essentially parts of the human mind (a trivial example is a notebook). By analogy, evolution uses the extended organism that "contains" a large and variable part of the environment. Let us use complex systems notions again. Our conventional notion of system implies a radical clustering of variables into relevant and irrelevant ones, and this way we can efficiently "cut off" things from their environment – we can individuate the world into entities. That such individuation is just an approximation must be clear, and the emerging picture of the organism-environment unity shows that this approximation is not always applicable.

2.3. Open-ended thought

Considering the fact that the relations between open-ended evolution and open-ended thought are striking, we have proposed the neuronal replicator hypothesis which debugs Edelman's theory of neuronal group selection by actually explaining how patterns of synaptic connectivity and dynamical activity patterns could be copied from one neuronal group to another [2, 8, 9]. By doing so we hope to explain how open-ended evolution of neuronal information could take place in the brain itself during thinking processes. This provides a domain in which we can explore natural selection at human timescales, if only neuroscientists can be encouraged to search for replicators in the brain. Such replicators already are known to exist, for example the copying of receptive fields of orientation selective neurons in cat visual cortex after deafferentation by a retinal lesion. The question now is: can unlimited hereditary copying of receptive fields and groups of receptive fields be found. What is the copying fidelity in the brain and how does this limit information transmission in neuronal tissue?

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