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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.
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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 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.

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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 parthenogenetic 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

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