# Three evolvability requirements for open-ended evolution

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By categorising artificial evolutionary systems into three levels of complexity, according to their selection mechanisms, it is possible to separate out issues of evolvability and so to produce three requirements for open-ended evolution. The three levels of artificial evolution, in order of increasing similarity to real-world evolution, are:

1. Searching a static fitness landscape (for example a fixed fitness function with single-individual input)
2. Searching a dynamic fitness landscape (for example coevolution)
3. Open-ended evolution

At the first level, the problem of evolvability centres on the *genotype-phenotype* mapping. Harvey's '*Species Adaptation Genetic Algorithm*' (SAGA) theory (Harvey 1992) addresses this issue. In this paradigm a population evolves for many thousands of generations, with gradual changes in genotype information content. The population should be nearly converged, evolving as species. Therefore the fitness landscape must be sufficiently correlated for mutation to be possible without dispersing a species in genotype space, or hindering the assimilation of beneficial mutations into a species. At this level, any difficulties with the phenotype-fitness mapping tend to be concerned with the specification of an appropriate mapping for the relevant problem, rather than in making the mapping well correlated. SAGA theory is equally relevant to systems with dynamic fitness landscapes, although it is worth noting that a dynamic genotype size does not imply a dynamic fitness landscape, for example "fitness = genotype length".

At the second level, we still have the problems of the first, plus now the *phenotype-fitness* mapping is no longer simply a function of one individual's phenotype, but involves *interaction* between phenotypes. So ensuring sufficient correlation in this mapping becomes a problem.

At the third level, we still have the problems of the first and second, plus now the requirement that the genotype-fitness mapping must be *open-ended*. That is, it must be possible to evolve evermore novel phenotypes with non-neutral variations in 'fitness'. What class of selective pressure can achieve this? Artificial selection can only select for that which it is specified to, whereas *natural selection* retains 'better' individuals, without any explicit specification of what it is to be better; this changes as the system evolves. Because artificial selection lacks this feedback in the selection process, open-ended evolution requires natural selection. A more detailed discussion of this can be found in (Channon and Damper, 1998).

Having recognised natural selection as one requirement for open-ended evolution, we can now look back at the first and second levels for two more. First, SAGA principles must be adhered to, in order to achieve the phenotypic variability required for open-ended evolution. Much has already been achieved on the evolvability of "brains" (controllers), especially neural controllers, but far less research has been carried out on the evolvability of complete phenotypes, that is brains plus "bodies" (morphologies) – the topic of a sister workshop.

Second, interaction between phenotypes must be open-ended, so as not to limit the number of possible behaviors. One of the main advantages of the above categorisation of artificial evolutionary systems, and the resulting decomposition of evolvability issues for open-ended evolution, is that it highlights the need for research into the evolvability of interaction systems. Perhaps the best initial approach is to use direct (body-based) interaction, leaving us with just one major research hurdle: the evolvability of *embodied* creatures.

In conclusion, the three evolvability requirements for open-ended evolution are:

1. Adherence to SAGA principles, for both "brains" and "bodies"
2. Open-ended interaction systems
3. Natural selection

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