

A Genetic Algorithm Model of Mutation and Evolvability

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ABSTRACT

It is clear that in any dynamical environment, the long-term evolutionary success of a lineage is due not only to the fitness of an individual relative to its competitors at a given time, but also due to the lineage's ability to adapt to the changes in its environment over the course of many generations. Such factors that influence an organism's future evolutionary path can be termed as affecting its evolvability.

Both the specific properties of an individual, and its relation to its environment and other individuals, can affect its evolvability. An example of the former is the evolution of mutation. Many organisms have evolved mechanisms that allow them to control, to some degree, the manner in which mutation is effected (see for example [2]).

The work to be presented here involved using a genetic algorithm (GA) based computer simulation to investigate the evolution of mutation and its effects on evolvability. A simple GA was employed, using single point crossover and tournament selection, on a fixed length binary state chromosome (more information about these basic mechanisms of GAs can be found for example in [1]). Further, a mechanism was provided for an individual chromosome to affect its own mutation. This was done by assigning to each locus on the chromosome one of two functions – either the bit contributed directly towards the fitness of the chromosome, or it acted as a mutation control site. Each control site was responsible for controlling the mutation of the successive series of fitness-coding sites. The fitness of an individual at a given time was given by comparing the fitness-coding bits in its chromosome to an 'environmental template'. Dynamics in the environment were introduced by periodically re-assigning the values in this environmental template.

At the boundary of each environmental change, mean fitness in the population dropped abruptly. This was then followed by a sharp increase during the subsequent generations, followed by a slowing down as fitness approached its maximum. The level of mutation control can be considered in relation to this fitness dynamic. It could be seen that the level of control very quickly rose to near maximum, that is to say that mutation was almost entirely eliminated. At each point of environmental change, mutation control then immediately began to subside, allowing increased mutation and more rapid adaptation to the new environment. As fitness again neared its optimum, the control bits again kicked in suppressing mutation.

The effects of this dynamic can also be seen by considering the variance of fitness across the population. As mutation control reduced, the fitness variance could be seen to increase in the following generations. With the resumption of mutation control as the population neared the fitness optimum, fitness variance could again be seen to fall as the population converged on this optimum.

These dynamics can be understood most explicitly in terms of genetic drift. For a highly adapted organism, a low mutation rate becomes desirable in order to minimize the error catastrophe limit on fitness due to genetic drift away from the fitness peak. For a poorly adapted organism, a larger gene pool results in more rapid genetic movement towards the fitness optimum. An increase in mutation will produce just such an enlargement of the gene pool. In highly adapted organisms, therefore, there will be a strong evolutionary pressure to contain mutation, while in less well-adapted organisms the evolutionary pressure will be for reduced mutational containment.

For moderate values of mutation the behavior is as above. As mutation rate is raised from this point, a transition can be seen into a chaotic behavior. Level of mutation control appears to no longer be related to fitness or environment, changing in an essentially random manner. Clearly, a certain level of mutational stability is required for mutation control to be of evolutionary use.

As mutation rate is lowered from the default value, a transition in the mutation control dynamic can be observed to a steady state. Again, mutation control appears to no longer bear any relation to fitness or environment, converging in this case on a static level. In this case, it appears as though mutation is the evolutionary drive for mutation control, and without a sufficiently high level of mutation, this drive is insufficient to produce the control dynamic described above.

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