Quantum Genetic Algorithms

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Abstract

Recent developments in quantum technology have shown that quantum computers can provide a dramatic advantage over classical computers for some algorithms. Since most problems of real interest for genetic algorithms (GAs) have a vast search space [Holland, 1975], it seems appropriate to consider how quantum parallelism can be applied to GAs. In this paper we present a simple quantum approach to genetic algorithms and analyze its benefits and drawbacks. This is significant because to date there are only a handful of quantum algorithms [Williams and Clearwater, 1997].

1 QUANTUM GENETIC ALGORITHM

There are two significant differences between a classical computer and a quantum computer. The first is in storing information, classical bits versus quantum *q-bits*. The second is the quantum mechanical feature known as *entanglement*, which allows a measurement on some q-bits to effect the value of other q-bits. Figure 1 describes the generic quantum genetic algorithm (QGA).

set $Reg1_0$ through $Reg1_{n-1}$ into superpositions

apply fitness function to $Reg1_{0,n-1}$
storing result in $Reg2_{0,n-1}$ (producing the entanglement)

measure each of $Reg2_{0,n-1}$ (all $Reg1_i$ and $Reg2_i$ collapse)

repeat

> **crossover** of $Reg1_i$ to generate new population (Reg2i is still entangled)
>
> **apply** fitness function as before
>
> **measure** $Reg2_{0,n-1}$ (producing collapse)

until population converges or termination condition met

Figure 1: QGA

A q-bit differs from a bit in that it can either be a 1, 0 or a *superposition* of the two. In this example, Reg1and Reg2 are two registers of q-bits. Both registers are of length n.

2 ANALYSIS OF THE QGA

One may ask, what is gained by the quantum genetic algorithm? Currently this answer cannot be quantified. The apparent advantage for a QGA is the increased diversity of a quantum population. A quantum population can be exponentially larger than a classical population of the same "size".

However, it is unclear exactly how the additional diversity will influence the result.

3 CONCLUSIONS

We have presented a quantum GA that uses the quantum features, superposition and entanglement. Our simple analysis of the algorithm suggests that it should have two advantages over a normal GA. First, because "individuals" in the QGA are actually the superposition of multiple individuals it is less likely that good individuals will be lost. Secondly, and more significantly, the effective statistical size of the population appears to be increased. This means that the advantage of good building blocks has been magnified. Presumably this will greatly increase the production and preservation of good building blocks thereby dramatically improving the search process.

Unfortunately, these implied advantages can not be presently proven. Therefore, a good direction for future research would include providing a mathematical analysis of the convergence time of the QGA

References

Holland, J.H. (1975). Adaptation in Natural and Artificial Systems. Ann Arbor, MI: University of Michigan Press.

Williams, C., Clearwater, S. (1997). Explorations in Quantum Computing. Springer-Verlag New York, Inc.