The Effect of Network Structure on the Spatial Coevolutionary GA

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Abstract
Using the simple one-max problem we will show the range of effects spatial networks have on spatial coevolutionary Genetic Algorithms (GAs). Non-coevolutionary spatial GAs have had their spatial reproductive structures tested to show that different structures can result in varying performance; Coevolutionary variants however have not. In this extended abstract we show that varying types of spatial structures can impact the coevolutionary GA differently than the standard GA.

Introduction
Spatial and Coevolutionary GAs are two fields that have received a fair amount of research, however their behaviour when combined is not well understood. Some preliminary work has been done showing that combining spatial and coevolutionary GAs can both greatly improve the GA’s performance and stabilize problematic coevolutionary behaviour such as fitness dissociation between populations (Hillis, 1991; Pagie and Hogweg, 1997; Weigand and Sarma, 2004; Mitchell, et. al., 2006). Looking at the behaviour of specific spatial structures on Spatial GA’s has been a topic of interest for many researchers (Sarma and De Jong, 1996; Bryden et al, 2006); however, none of the researchers we surveyed had tried any spatial structure on a coevolutionary GA other than a simple grid. We aim to look at the effects of a number of spatial structures and view their effects on the coevolutionary GA, including whether they induce the same performance as they do on a standard GA.

Background
The Spatial GA uses graphs structures that can be found in any introductory textbook on graph theory (such as Harry, 1969). The GA uses undirected edges, meaning that each connection implies that the both nodes are aware of each other. We will also discuss: the degree of a graph, the average degree (number of connections) of all nodes in that graph; the path length between nodes, the number of connections necessary to get from one node to another; and the diameter, the maximum shortest path length between any two nodes.

A GA with a spatial reproductive network is one that only allows an individual to reproduce with nodes within its direct neighbourhood. This, in effect, limits the amount of genetic flow which can occur through the population (Sarma and De Jong, 1996). A standard GA can be considered a spatial GA with a complete network, wherein every node is connected to every other node.

Methodology
GA Setup
We use the simple one-max problem to quickly and succinctly show that the impact of spatial structures on the standard GA is different than the same problem on the coevolutionary GA using a standard easy to understand function. The fitness of a chromosome solving one-max is simply equal to the number of ones it contains; this implies the maximum fitness is the chromosome of all ones.

The coevolutionary GA is setup so that each population is placed on identical reproductive networks and for the evaluative network each node from one population is paired with a node that has the same reproductive location in the other population. The fitness of each coevolutionary individual is set equal to the combined one-max score of itself and its partner, i.e we are examining a cooperative coevolutionary system. Our standard GA uses a chromosome length of 60 and the coevolutionary GA uses a chromosome length of 30 for each population. These values are comparable as the coevolutionary GA is mapping two chromosomes together. We are using an elite size of 2 (the members with the two largest fitness values are reproduced using local elitism), a 0.8 probability of crossing over using uniform crossover with a parameter of 0.3 and a mutation rate of 2/L where L is the chromosome length for both GAs. The GA is run until one-max is found up to 5000 generations when it is cut off; any GA that reaches 5000 generations is reported as reaching that number. We run 50 repetitions for each spatial structure on each GA configuration.

Spatial Structures
We will be comparing the performance of one-max on 8 different spatial structures for both GA types. These structures will include 2 grid type, 3 ring type and 2 random type graphs. Figure 1 shows the first of the grid type Grid 4 (so named here as it has a degree of 4), which is the structure most commonly seen in spatial coevolutionary papers. Figure 2 is Grid 8, connecting 8 nodes, the same 4 that Grid 4 is connected to and additionally the 4 nodes on the diagonal. ‘Ring 2’ is a standard ring. Ring 4 (Figure 3) is a ring where each node is also connected to its neighbor’s neighbor, implying a degree of 4. Ring 8, is the same as Ring 4 but connected to the 4 nodes on each side. Rand 4 and Rand 8 which are random graphs, are reconstructed for each GA run, with an average degree of 4 and 8 respectively; and finally the complete graph which simulates the standard GA.
The node’s degree provides the minimum time for genetic information to travel between individual nodes, while the diameter measures the minimum time for genetic information to travel everywhere in the population. Each structure has a degree equal to the number in its name and the following diameters: 9 for Grid 4, 4 for Grid 8, 50 for Ring 2, 25 for Ring 4, 13 for Ring 8, and 1 for Complete. For Rand 4 & 8 the diameter varies based on the run and can even be infinite if a disconnected graph is formed.

Results

The results for the experiments done on the standard GA can be seen in Figure 4, while the coevolutionary results are shown in Figure 5. We can quickly see that the worst result received was for the complete coevolutionary GA; it was the only GA to report any failed solutions within the 5000 generation limit and is much worse than every other GA tested. The spatial structures at each connection level have been tested using the Wilcoxon rank-sum test with a Holms-Bonferroni correction and 99% confidence level and they all show a statistically significant difference in performance. The diameters of the graphs appear to have no, or at least a very limited, effect. Notice that while the random graphs have a larger variance than the other graphs, it is nowhere near as large as we might expect if diameter was playing an important role. It is clear that for the one max problem on the coevolutionary GA the graphs with the lowest degree provide the best performance.

In stark contrast to the coevolutionary results, we see that the spatial structures have barely any effect on the standard GA for this one max problem; no structure is statistically significantly better than the rest. Somewhat surprisingly, we found that the GA with the best performance on the one-max problem is the Coevolutionary GA with a Ring 2 structure, the next best performing are the 3 graphs with 4 connections on the Coevolutionary GA; they have better performance than the Standard GA when compared with a 99% confidence level. Finally, it is clear that spatial locality does help stabilize the coevolutionary system, at least for the one-max problem, as evidenced by the poor performance when using the complete graph in Figure 5.

Conclusion

It is clear that the impact of spatial structures on the coevolutionary GA has different effects than on the standard GA. We have only shown the difference using the simple one-max problem, but it is clear that getting such a variation in performance on such a simple problem will likely imply similar performance differences on more complex problems; though more experimentation would be required to determine which structure is best. We have shown that, at least for the one max problem, connectivity is more important than diameter; i.e. local dissemination is more important than global dissemination. We hypothesize that this is due to a ‘locking in’ effect, wherein good genes are able to stay near each other in both populations and synergistically work towards the optimum. More evidence supporting this hypothesis through looking at elitism can be seen in McLaughlin and Wineberg, 2014. We believe that this should hold for more complicated problems run on a coevolutionary GA, and consequently, a more detailed study is required.

References

Harary, F. (1969). Graph Theory, Addison-Wesley, Reading, MA.