Regulation of Complex Systems

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Preferred format: Poster

Complex systems abound. Yet there is little insight on how to do optimization. The most spectacular example of a complex system which could benefit from optimization is the economy. In the free market a large number of agents compete, collude, and - interact, to cause some global effect on the social well-being of citizens. This paper suggests a method for optimizing complex systems using a combination of cheap local and more expensive global dynamics.

Two extrema for Optimization strategies

There are many possible strategies which could be used to optimize a complex system. We will abstract away from these and allow only two:

- greedy search $\dot{x} = l(x)$, and
- enumerative search $\dot{x} = g(x)$

These will be termed *eigenstrategies*.

Combination of Eigenstrategies

Assume optimization is restricted to some linear combination of the eigenstrategies $\dot{x} = ml(x) + ng(x)$, and let $n=1-m$. What is the optimal setting for m? A metric called *local-global correlation* λ, can provide information on the what value to set for m, to achieve optimal search.

λ is simply the observed correlation between greedy and fitness on a particular landscape,
$\lambda = \frac{[1, 2, \ldots, n] \cdot [f(l(x)), f(l(l(x))), \ldots, f(l^n(x))]}{|[1, 2, \ldots, n]| \cdot |[f(l(x)), f(l(l(x))), \ldots, f(l^n(x))]|}$ where f is a special fitness function which combines speed and quality. Other forms for λ are also possible.

The hypotheses put forward in this paper are that (1) in a normal optimization problem, optimal search can be achieved by setting the ratio of exploitation to exploration equal to the λ metric of the landscape. The second hypothesis is that (2) for a complex system, optimal search can be achieved by setting the ratio of local to global update proportional to the landscape's λ metric.

1. The More-Garbow-Hillstrom test suite

The first hypothesis is tested on the More-Garbow-Hillstrom test suite (Gurwitz, 1994). This is a set of 30 optimization problems originally devised for the Argonne National Laboratory. A prototypical greedy and enumerative strategy (hillclimbing and uniform random sampling) were devised to run on these problems.

A Monte-Carlo procedure tested the performance of a combined greedy-enumerative optimizer at every value of m from 0..1 in increments of 0.05 with multiple starts. Results for speed and quality were then collected for each value of m.

The correlation between the λ metric (sampled on the landscape), and the optimum setting of m, was 0.6216 for N=30 problems, giving a significance of p<0.01. (fig. 4). This suggests tha thet λ of the landscape *predicts* the optimum combination of greedy versus enumerative strategies.

2. The US Economy

Census data was collected from the US Dept of Census over the period 1992 to 1996. Data was split into two sets, "economic state" and "social state". Economic state consisted of ecnomic indicators such as GDP, industrial production, foreign trade, whilst social indicators consisted of poverty, crime, income, and so on. (figs. 1,3). Using this data, a function mapping from economic state to social state was interpolated (fig. 2)

Next, starting from an initial state, (ie. the economy as of January 1992), the economy was allowed to move according to its favoured trajectory, that is, the actual path taken through economic space from 1992 to 1996. The question was, what level of intervention would be optimal.

Greedy search was set to be the favoured trajectory vector, and enumerative was set to be hillclimbing. Again a monte-carlo simulation was performed to test values from m=0..1 for the ratio between these two dynamics. Results forthcomming.

This strategy, of regulating a system proportional to observed λ correlation, is applicable across the board to other complex systems as well.

Discussion

In order to harness complex systems, the approach taken to-date (eg. Mitchell, 1996), has been to look for local behaviours which result in good overall effects such as global synchronization. The approach taken in this paper has been to avoid the problem of local dynamics, and instead treat the system like a black box and concentrate on facilitating or braking the system and imposing external dynamics.

The mathematics of trial allocation (ie. finding the correct ratio of m) are general, and instead of "regulation", an equally valid interpretation is that m is the magnitude of change needing to be effected to local dynamics to bring about desired outcomes. Therefore, instead of global changes, we use m as a measure for how much to mutate the local behaviour generating dynamics.

An application for this work is in identifying how much mixtures models should be rewarded locally versus globally (Jordan, 1992), and more speculatively, applications in the rational control of economies.

References

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Figures

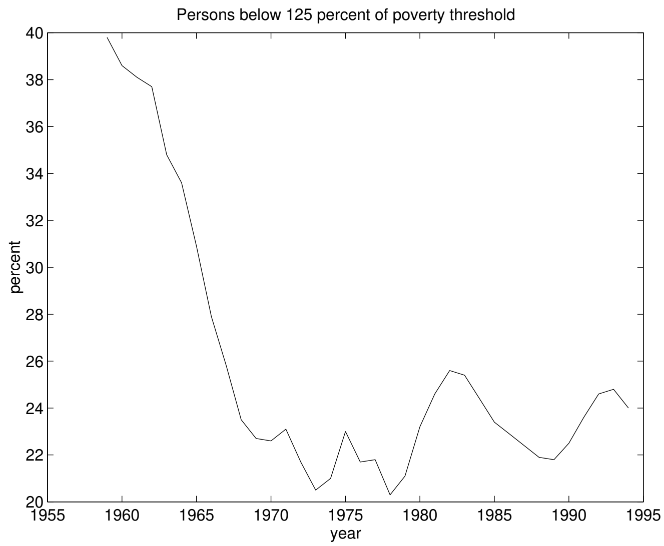

Figure 3

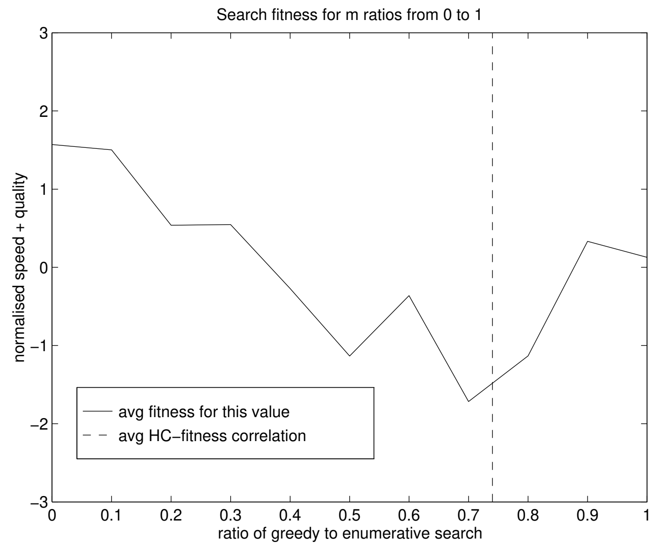

Figure 4

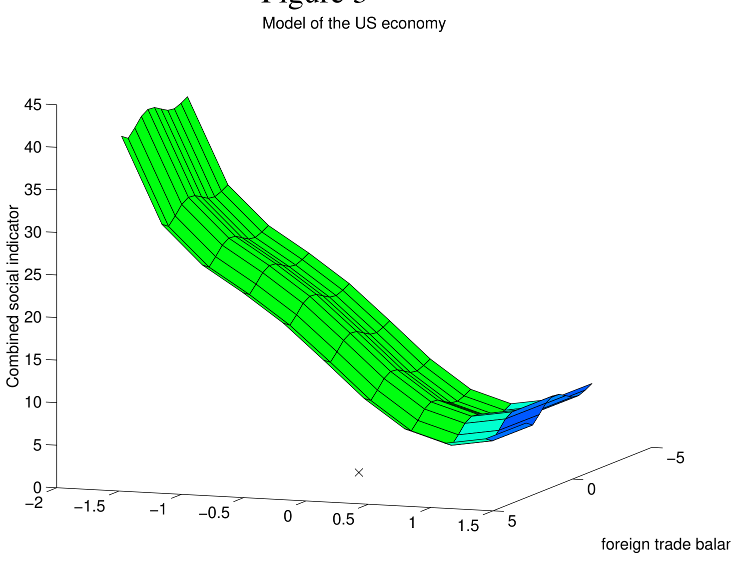

Figure 2

Figure 1

Figure 1: Economic points collected from 1992-1996. Six economic dimensions defined the "economic state". (source: US Census). **Figure 2:** Points are interpolated to give a model of the economic state to social state function. This example shows a 5th degree polynomial. **Figure 3:** Poverty rates in the United States from 1959 to 1994 (source: US Census). **Figure 4:** Search results on the More-Garbow-Hillstrom suite. The average λ for these landscapes (0.74) is very close to the average optimal setting for search (0.7).