# “The Genetic Algorithm in Economics”

J. Lucas Reddinger, Professors Rob Fleck and Joe Atwood

Department of Agricultural Economics and Economics

Montana State University, Bozeman, MT 59717

## Abstract

In computer science, the genetic algorithm (GA) is known as a very useful optimization technique. The GA uses the theory of natural selection to weed out the less desirable data and arrive at the optimal solution. In economics, the GA can be used as a model of social learning, which is how individuals get information from others.

The GA does this analogously to natural selection, with economically beneficial information in place of preferable traits for selection. This project explores the use of the GA to model the spread of new agricultural technologies in Ghana during their green revolution. When technology adoption is thought as a necessary trait for survival in a competitive environment, technology diffusion is analogous to traditional evolutionary theory. The GA can be used to model such learning environments, as it simply imitates natural selection. Such a model may be extremely useful for modeling many economics problems, including fertilizer and high yield variety seed adoption in developing countries.

# The Genetic Algorithm

The GA is simply a computer program that simulates an evolutionary process. The program has a population of organisms which sexually reproduce, passing their traits on to their children. Consistent with Darwin's theory of natural selection, the fittest organisms are the most likely to pass on their genes. In addition, mutations occur randomly in the gene pool, allowing for significant adaptation to the environment.

## An Analogy

Suppose that we have an environment consisting of a series of hills. There are 30 hamsters, some sitting in the valleys, and some near the tops of the hills. If we move all of the food toward the tops of the hills, the hamsters will eventually migrate there (those that don't will die). Mathematically, the hamsters are our independent variable (say $x$), and the food distribution can be represented in the form of

$$food(x) = \ c \cdot sin(x), c > 0.$$

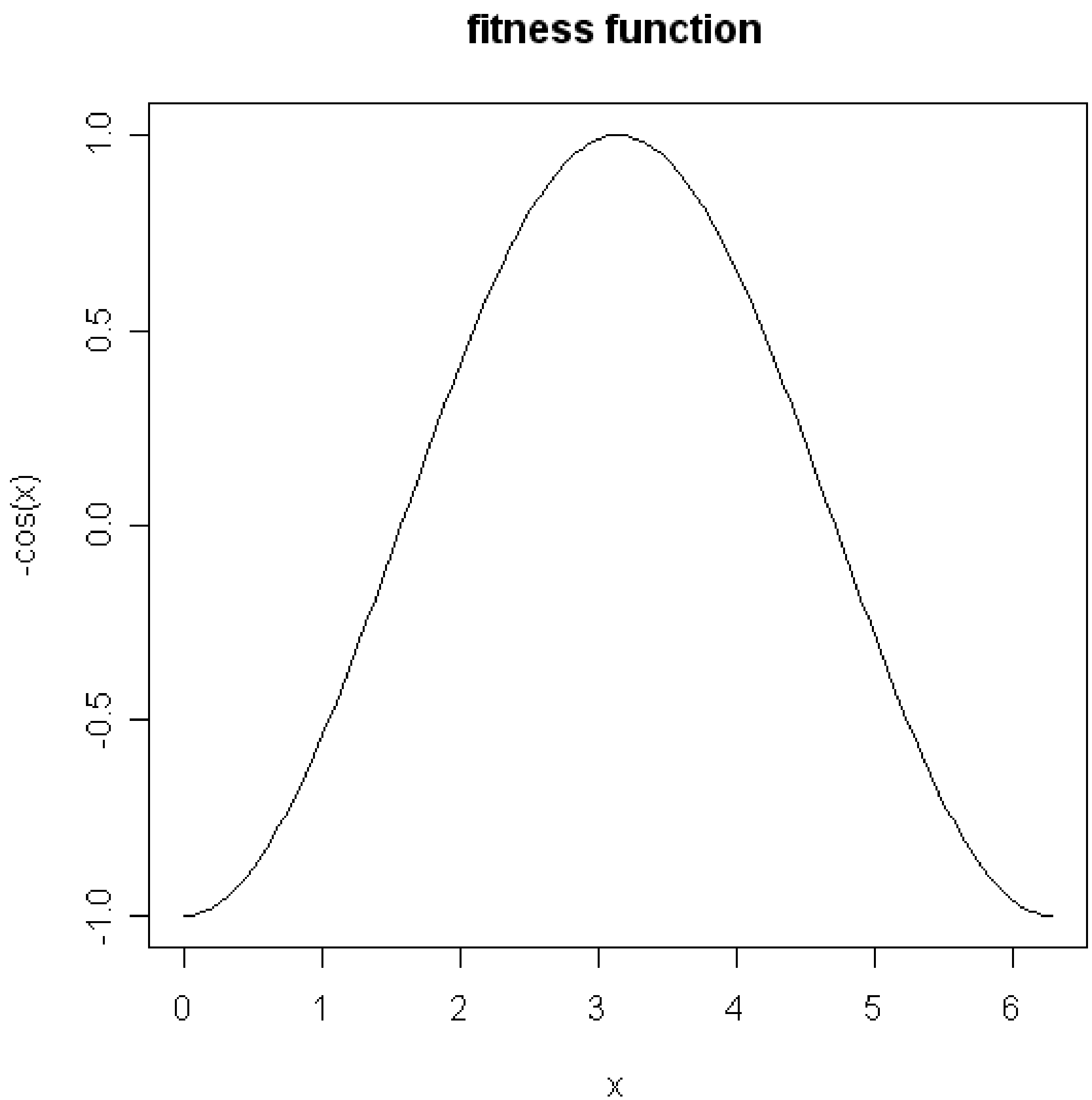
We then have a mathematical framework for our migration problem.

# Example: A Canonical Simple GA

Let us use the following as our fitness function:

$$f(x) = -\cos x$$

$$\forall x \in [0, 2\pi]$$



# Step One: Initialization

A population of size *pop_size* is generated with random genes.

| Organism[1] | Organism[2] | Organism[3] | … | Organism[*pop_size*] |
|---|---|---|---|---|
| 0 | 1 | 0 | | 1 |
| 0 | 0 | 1 | | 1 |
| 1 | 0 | 0 | | 1 |
| 0 | 1 | 0 | | 1 |
| 1 | 1 | 1 | | 1 |
| 1 | 0 | 0 | | 1 |
| 0 | 1 | 1 | | 0 |
| 1 | 1 | 0 | | 1 |

## Step Two: Evaluation

Each gene is converted into a value which is then used to evaluate the fitness of the organism.

| Organism[1] | |
|---|---|
| 0 | *eval* |
| 0 | 180 |
| 1 | |
| 0 | *x* |
| 1 | 4.42 |
| 1 | |
| 0 | *f* |
| 1 | 0.29 |

| Organism[2] | |
|---|---|
| 1 | *eval* |
| 0 | 217 |
| 0 | |
| 1 | *x* |
| 1 | 5.33 |
| 0 | |
| 1 | *f* |
| 1 | -0.58 |

| Organism[3] | |
|---|---|
| 0 | *eval* |
| 1 | 82 |
| 0 | |
| 0 | *x* |
| 1 | 2.01 |
| 0 | |
| 1 | *f* |
| 0 | 0.43 |

…

| Organism[*pop_size*] | |
|---|---|
| 1 | *eval* |
| 1 | 191 |
| 1 | |
| 1 | *x* |
| 1 | 4.69 |
| 1 | |
| 0 | *f* |
| 1 | 0.02 |

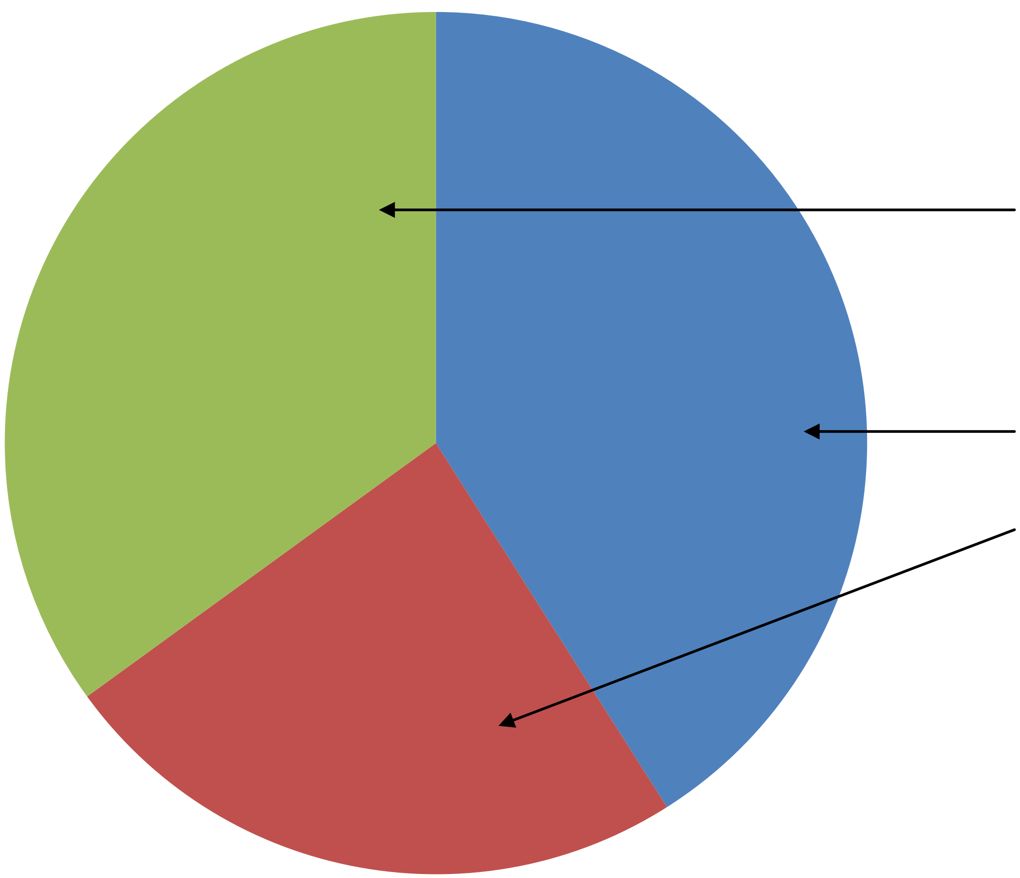
## Step Three: Selection

Organisms are stochastically selected from the population for reproduction. Each organism's chance of reproduction is proportional to its fitness.

$$f'(x) = f(x) - \ min_j \, f(j)$$

$$prob_{selection}(i) = \frac{f'\big(x(i)\big)}{\sum_k^{pop\_size} f'\big(x(k)\big)}$$

The chance of selecting organism $i$ for selection is equal to its share of the total fitness. Think about selection as tossing darts at a board:



$$p_{s,1} = 0.35$$
$$p_{s,2} = 0.$$
$$p_{s,3} = 0.41$$
$$p_{s,4} = 0.24$$
$$\sum p_s = 1.$$

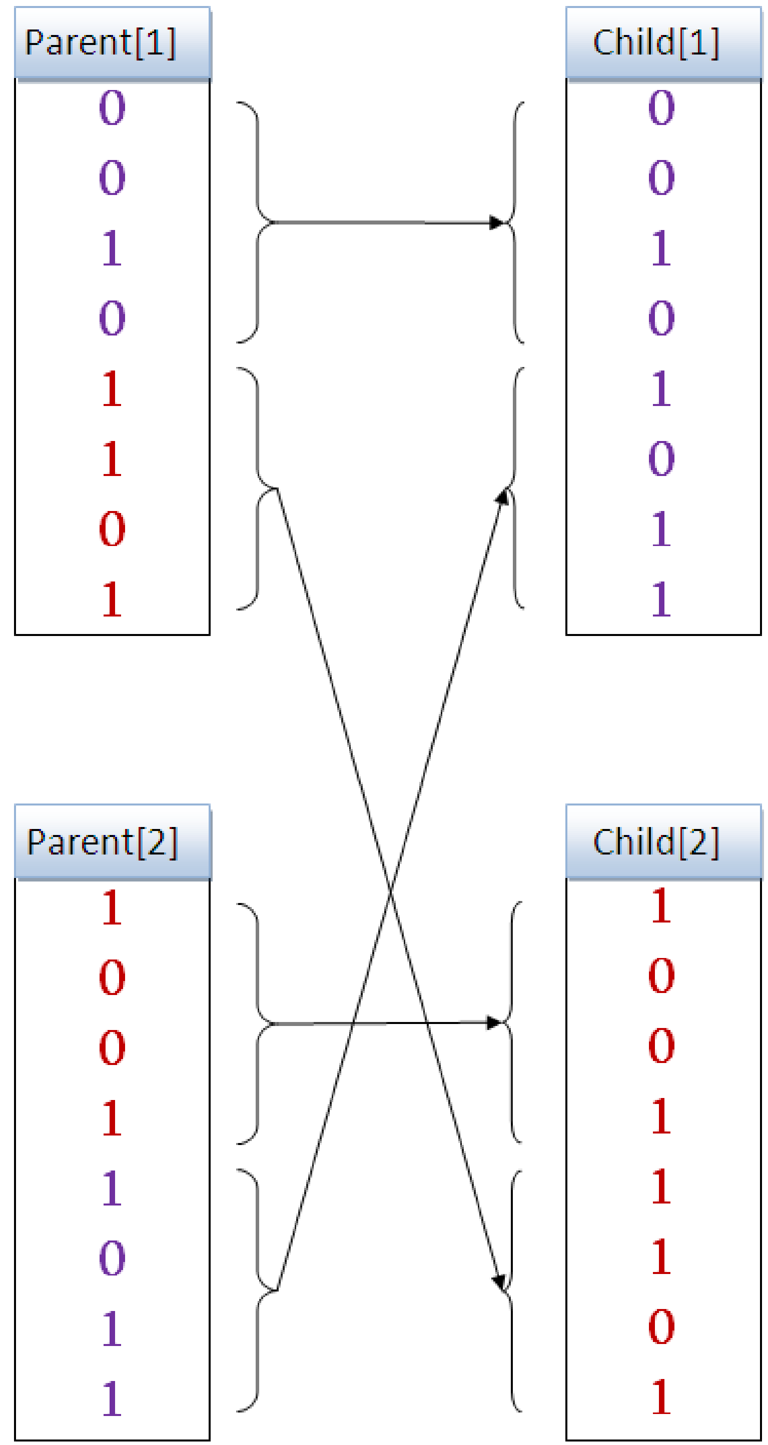
$$f'_1 = 0.87$$
$$f'_2 = 0.$$
$$f'_3 = 1.01$$
$$f'_4 = 0.6$$
$$\sum f' = 2.48$$

Note: We suppose that $pop\_size = 4$, and we use the fitness values from Step 3.

We pick parents by throwing darts at this board. This process is repeated *pop_size* times, so that we can maintain our population size (each two organisms produce two offspring.)

## Step Four: Crossover

Sexual reproduction will occur between two organisms through single-point crossover. A cross-over point $n$ is selected randomly. An example crossover is shown here with $n = 4$.



# Step Five: Mutation

We select a probability of mutation:

$$prob_{mut}(i) = 0.01$$

Applying this to every bit in every gene in every organism, there is a 1% independent likelihood that a given bit $i$ will be changed.

| Child[1] |
| --- |
| 0 |
| ~~0~~ 1 |
| 1 |
| 0 |
| ~~1~~ 0 |
| 1 |
| 0 |
| 1 |

### Step Six: Reiteration

The children generated through crossover and mutation become the new parents at Step Two. The process is repeated with another round of evaluation, selection, crossover, and mutation. Each iteration is called a generation, analogous to a rapidly evolving population. To optimize a particular function, anywhere from five to five hundred generations may be necessary.

## Extending the Example

- Only one dimension ($x$) was used above; GAs easily[1] operate on $n$ dimensions.
- The fitness function is not restricted to continuous/differentiable functions or single-modal functions—in fact, anything that can be programmed may be used.
- The mutation rate $p_{mut}$ may be coded as a gene, allowing its evolution as well.

---

[1] Computational costs are linear.

## The GA in Economics

- Learning in Economics is "a relatively permanent change in a behavioral potentiality that occurs as a result of reinforced practice" (Reichmann, 2001).
- Each genetic individual represents an economic agent's strategy.
- The economic agents are not fully rational—they possess bounded rationality $\{f\}$.

## Reichmann (2001)

- Crossover represents learning by imitation or communication: economic strategies are combined or disseminated.
- Mutation represents learning by experimentation: new economic strategies are discovered and tried.
- Coding $p_{mut}$ in a gene "endogenizes the individual propensity to experiment."

## GA Applications in the Literature

- $\max_q \pi$ for regional monopolies
- Operational Economics
- Portfolio allocation (equity vs. debt)
- Game theory (deviation from Nash equilibrium)
- No empirical study modeling social learning

# Technology Diffusion as Social Learning

- A new fertilizer lowers costs to farmers.
- Fertilizer use, an economic strategy, is analogous to a trait that increases an organism's fitness.
- At first, farmers will experiment with fertilizer use (mutation).
- Other farmers will learn of the beneficial strategy and adopt it (crossover).

# Ghana's Green Revolution

Farmers began using fertilizer and HYV[2] seeds for pineapple production in the 1990's. Conley and Udry (2001) provide adoption data. Unfortunately, the time-series data are not consistent with predicted adoption rates for a successful technology because use decreases over some time periods.

| time | HYV |
|---|---|
| 2 | 114 |
| 3 | 112 |
| 4 | 437 |
| 5 | 305 |
| 6 | 233 |
| 7 | 214 |
| 8 | 317 |
| 9 | 156 |
| 10 | 90 |
| 11 | 139 |
| 12 | 351 |
| 13 | 283 |
| 14 | 165 |
| 15 | 103 |

[2] High yield variety

## Empirical Modeling Problems with the GA

- Time for the GA is measured in generations, which is generally not useful.
- If variables are transformed (generations into time) then there is a scaling problem, and the model will not make useful predictions.
- The GA requires a fitness function. In many cases, this will be the firm's profit function. However, this is usually unknown.

## Agent-Based Modeling: Credit Markets

Our current research involves looking at farmers' yields as they vary with weather conditions. The GA will contain three genes:

- Risk aversion (varying degrees)
- Technology adoption (dummy variable)
- Accumulated wealth

The fitness function is designed stochastically to simulate weather conditions.

In crossover, parents will pass on their wealth to their children, in addition to their level of risk aversion and their adoption choice.

## Avoiding Previous Pitfalls

In this study, we can implement institutions such as credit markets in the GA and observe how they alter technology adoption trends. It is predicted that farmers with more wealth or with access to credit markets are more likely to adopt a beneficial technology, ceteris paribus.

## Future Exploration

- $p_{mut}$ as risk aversion
- The effect of estate taxes on adoption

## Conclusion

Our research will give insight into the effects of credit markets on technology adoption in developing economies. In addition, such an application will help garner more attention to the GA as a useful economic model.

# Acknowledgements

Special thanks to Rob Fleck and Joe Atwood. Insightful contributions made by Dave Buschena, Wendy Stock, Neil Cornish, John Paxton, Tomas Gideon, and Christina Hayes. This project has been made possible by generous funding by the Montana State University Undergraduate Scholars Program and the Montana State University Department of Agricultural Economics and Economics.

# References

Conley, Timothy, and Christopher Udry. "Social Learning through Networks: The Adoption of New Agricultural Technologies in Ghana." *American Journal of Agricultural Economics* 83 (August 2001): 668-73.

Riechmann, Thomas. *Learning in Economics: Analysis and Application of Genetic Algorithms*. Heidelberg: Physica-Verlag, 2001.