

Lecture 21: Genetic Algorithms

CS442: Great Insights in Computer Science
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Genetic Algorithms

- First scientific talk I went to (college): John Holland on Genetic Algorithms.
- Inspiring! (Try it sometime.)
- Haven't quite lived up to their promise, but still useful and interesting.
- Sometimes called "the second best way to solve any problem".

Brain

- 10^{12} neurons, 10^5 connections per neuron.
- That's 1,000,000,000,000 (a million millions) neurons, each with 100,000 (a hundred thousand) connections.
- Areas specialized: Example, Broca's area aids in producing grammatical speech.

Frog Experiment

There was this biologist who was doing some experiments with frogs.

He was measuring just how far frogs could jump.

So, he puts a frog on a line and says "Jump frog, jump!"

The frog jumps 2 feet.

He writes in his lab book: 'Frog with 4 legs - jumps 2 feet'.

Next, he chops off one of the legs and repeats the experiment.

"Jump frog jump!" he says.

The frog manages to jump 1.5 feet.

So he writes in his lab book: 'Frog with 3 legs - jumps 1.5 feet'.

He chops off another and the frog only jumps 1 foot.

He writes in his book: 'Frog with 2 legs jumps 1 foot'.

He continues and removes yet another leg.

"Jump frog jump!" and the frog somehow jumps a half of a foot.

So, he writes in his lab book again: 'Frog with one leg - jumps 0.5 feet'.

Finally, he chops off the last leg.

He puts the frog on the line and tells it to jump.

"Jump frog, jump!"

The frog doesn't move.

"Jump frog, jump!!!"

Again the frog stays on the line.

"Come on frog, jump!"

But to no avail.

The biologist finally writes in his book: 'Frog with no legs - goes deaf'

Specialized, And Yet...

- Functions can shift around.
- Some functions appear to have elements in multiple areas.
- Some areas appear responsible for only vaguely related functions.
- Doesn't seem to have a clean hierarchical functional breakdown like a human-designed processor might.

Engineering Failures

- **Therac-25:** Radiation-treatment machine overdoses patients if operator types too fast.
- **Patriot missile tracking system:** Time measured in tenths of a second, which cannot be accurately represented in binary. Round off error caused it to gradually lose precision.
- **Mars Climate Orbiter:** Lost on entry into the Martian atmosphere because code inconsistently used feet & meters.
- **Mars Polar Lander:** Software misinterpreted the extension of its landing legs as landing, causing engine shutdown.
- **Ariane 5:** Satellite launch missile software couldn't convert 16-bit real number to 16-bit integer and crashed in flight.

Engineering Methodology?

- Hillis argues that this type of catastrophic failure is traceable to the engineering process itself: modules built in isolation, often not fully tested together.
- Suggests a more holistic way of building complex systems: Genetic Algorithms.

GA: New Way To Search

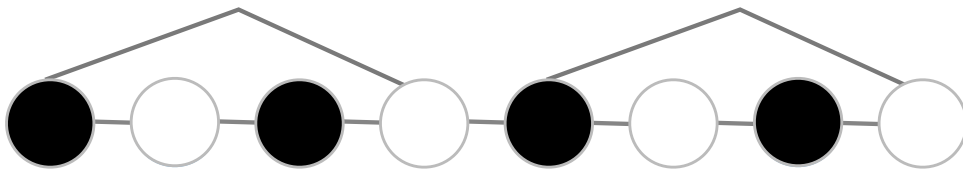
- Each solution is an *individual* and the set is the *population*. Set size is maybe 200.
- Objective function score is *fitness*.
- Higher objective function value solutions are replicated to allow more search to proceed from this steps: *asexual reproduction*.
- Local search steps are *mutation*. Optimization proceeds in a series of *generations*.
- Two solutions can be combined to create a new one: *crossover*.
- Fit individuals allowed to reproduce, unfit individuals don't. Inspired by Darwinian evolution!

Algorithmic Options

- What do you need to define to create a GA solution to a problem?
 - What is the fitness function?
 - How is an individual represented?
 - How are individuals selected for reproduction?
 - How are individuals altered (mutation)?
 - How do individuals combined (crossover)?

Example Problem

- Find a 2-coloring of this graph.
- *Reminder:* Nodes can be black or white. Two nodes that are linked cannot be the same color.



Representation Choices

- What is the fitness function?
 - Number of mismatched edges.
- How is an individual represented?
 - n bits (0 = white, 1 = black)

Algorithm Choices

- How are individuals selected for reproduction?
 - Less fit half “killed”, remainder get to mate at random.
- How are individuals altered (mutation)?
 - Each generation, one individual chosen to have each bit randomized w.p. $1/11$.
- How do individuals combined (crossover)?
 - Each bit randomly selected from parent.

Code: Main Loop

```
def ga():
    p = population()
    gen = 0
    done = 0
    while (not done):
        p = thin(p)
        winner = fitness(p[0])
        p = reproduce(p)
        i = randint(0,m-1)
        p[i] = mutate(p[i])
        print gen, p[0], winner, sum([fitness(x) for x in p])
        done = (winner == n+1)
        gen = gen + 1
```

makes initial random population

sorts individuals by fitness, deletes bottom half

fills in missing half via crossover of existing individuals

picks an individual to mutate (set a bit at random)

Pop Ops

```
def mate(x,y):
    str = ""
    for i in range(n):
        if randint(0,1) == 0:
            str = str + x[i]
        else:
            str = str + y[i]
    return str

def reproduce(p):
    kids = []
    for j in range(m/2):
        x = p[j]
        y = p[randint(0,m/2-1)]
        kids = kids + [mate(x,y)]
    return p+kids
```

```
def mutate(x):
    str = ""
    for i in range(n):
        if randint(0,10) == 0:
            if randint(0,1) == 0:
                str = str + "0"
            else: str = str + "1"
        else:
            str = str + x[i]
    return str

def thin(p):
    p.sort(compareFitness)
    return p[:m/2-1]
```

And You Were There...

- loops, strings, lists
- sorting
- random numbers
- bits
- search / hillclimbing
- formal problem
- objective function
- parallelism

Karl Sims Accomplishments

**Evolved Virtual
Creatures**

**Examples from
work in progress**

A Virtual Debate

- **W. Daniel Hillis:** Ph.D. in Computer Science at MIT, invented of the 64k processor Connection Machine, the 10,000 year clock, Chairman and Chief Technology Officer of Applied Minds.
- **Michael J. Behe:** Ph.D. in Biochemistry from Penn, Professor at Lehigh, coined the phrase “irreducible complexity”, Fellow of the Discovery Institute.

Recognizing Design

- **Behe** (talking about a car): “... when he opens up the hood and sees the engine he immediately realizes that it was designed.”
- **Hillis** (talking about a monkey brain): “Looking at it appears as if everything is connected to everything else---unlike the neat, hierarchical diagram of an engineered computer.”

Role of Natural Selection?

- **Behe** (good for small steps, not big): “Some systems seem very difficult to form by such successive modifications -- I call them irreducibly complex. ... Natural selection can only choose among systems that are already working...”
- **Hillis** (good for big steps, not small): “Simulated evolution is a good way to create novel structures, but it is an inefficient way to tune an existing design.”

Irreducible Complexity?

- **Behe**: “...if a person were so unfortunate as to be missing one of the eye’s many integrated features, such as the lens, or iris, or ocular muscles, the inevitable result would be a severe loss of vision.”
- **Hillis**: “...building a nest requires a few dozen individual steps, such as locating a twig, picking it up with the beak, carrying the twig back to the nest... even if a single step is missing ... the bird...will derive no evolutionary advantage.”

Must We Understand?

- **Behe:** “In order to say that some function is understood, every relevant step in the process must be elucidated.”
- **Hillis:** “It is possible that a satisfactory description of what the brain does will be almost as complex as description of the structure of the brain---in which case, there is no meaningful sense in which we can understand it.”

Grass is Always Greener

- **Behe (scientist):** “...if the cilium can not be produced by natural selection, then the cilium was designed.”
- **Hillis (intelligent designer):** “Products of engineering are inherently fragile. ... The contrast in reliability between the brain and the computer illustrates the difference between products of evolution and those of engineering.”

Short Summary

- I think they are both being a little silly.
- In short, however, Hillis is saying that if he were God, he'd design his creation via evolution.
- An interesting perspective on the debate.

Next Time

- Simple Robotics
- <http://en.wikipedia.org/wiki/Robotics>