

Chapter 9: Beyond Engineering

CS105: Great Insights in Computer Science

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.

Software Problems



The screenshot shows the CNET News.com website interface. At the top, there is a search bar and navigation tabs for 'Today on CNET', 'Reviews', 'News', 'Downloads', 'Tips & Tricks', 'CNET TV', and 'Compare Pr'. Below these are category links: 'Business Tech', 'Cutting Edge', 'Green Tech', 'Access', 'Threats', 'Media 2.0', 'Markets', and 'Per'. The main article is titled 'Injury risk prompts recall of all Segways' by Caroline McCarthy, published on September 14, 2006. The article text begins with: 'Once touted as a landmark innovation in transportation, the Segway Personal Transporter has suffered another setback: The self-balancing scooter's parent company has recalled all of its currently available models because of a potentially dangerous software glitch. After six Segway riders complained of head and wrist injuries, the U.S. Consumer Product Safety Commission announced Thursday in conjunction with Segway Inc. that all 23,500 of the vehicles sold between March 2002 (when they were first introduced) and mid-

Segway Spill

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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.

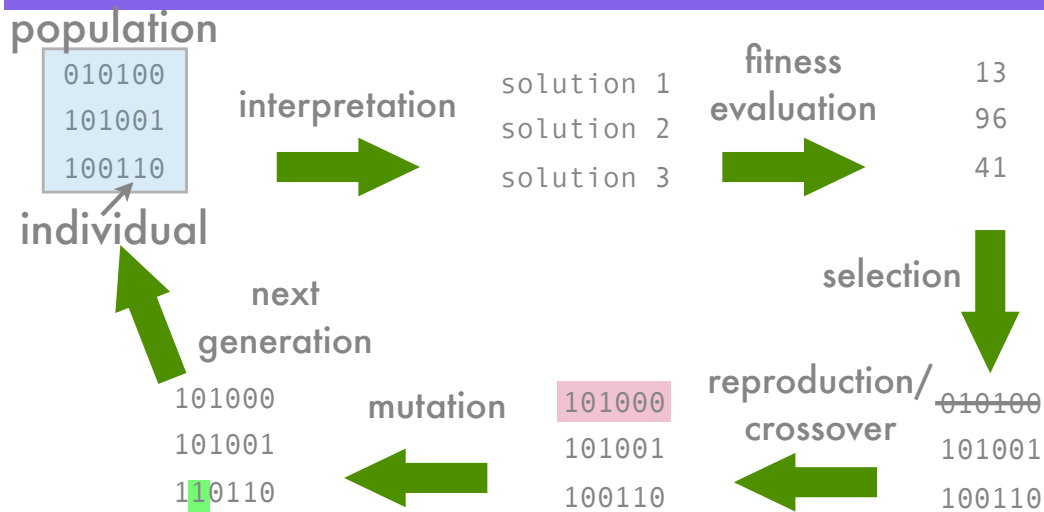
Engineering Methodology?

- 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 these examples: *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!

GA Circle of Life



- Each generation tends to improve on the previous ones.

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)?

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
- graph search / hillclimbing
- formal problem
- objective function
- parallelism



Karl Sims' Accomplishments

**Evolved Virtual
Creatures**

**Examples from
work in progress**

Creatures

- In each case:
 - Sims wrote a program to turn bit sequences into creatures (bodies and behaviors).
 - Fitness was evaluated by “running” creatures in a simulated 3d world.
 - Higher scoring (more fit) individuals replicated.
- Surprisingly interesting creatures created!

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 a 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** (biochemist): "...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 the Creator, he'd design his creation via evolution.
- An interesting perspective on the debate:

Evolution... Choice of The Intelligent Designer