The *Changing* Nature of Invention in Computer Science

Dennis Shasha

Based on two books with journalist Cathy Lazere

Great Inventor 1

- ***"I flunked out every year. I never studied. I hated studying. I was just goofing around. It had the delightful consequence that every year I went to summer school in New Hampshire where I spent the summer sailing and having a nice time."***

John Backus/inventor of Fortran

Late Start on a Career

- Graduates at 25 from Columbia's College of General Studies. No idea what to do.
- Gets job at IBM programming astronomy problems on a vacuum tube computer
- Likes the physics. Finds the programming difficult (no floating point numbers; just fixed width integers).

What it was like

"You had to know so much about the problem--it had all these scale factors--you had to keep the numbers from overflowing or setting big round off errors. So programming was very complicated because of the nature of the machine."

What to Do?

- Grin and bear it.
- Work harder/just get it right.

Not Backus

- First a floating point to fixed length compiler.
- Second, suggests the design of a programming language for IBM's next machine – FORTRAN.
- *"It would just mean getting programming done a lot faster. "*

Atmosphere of Invention

- Designing the language was “easy”
- Making it run fast enough so people would use it was hard.
- Linguists, mathematicians, logicians…
- Backus describes his role: ***break up the chess games that were still going at 2 PM.***

Upshot of FORTRAN

- Tremendously popular in industry (engineering and the beginning of data processing).
- Academics liked it less – no recursion, hard to do symbolic manipulation.
- Led to Lisp and also to Algol.

Design of Algol

- European-led meetings to design a new language.
- ***"They would just describe stuff in English. Here's this statement --- and here's an example. You were hassled in these committees enough to realize that something needed to be done. You needed to learn how to be precise."***

Context-Free Grammars (Backus and Naur)

- **S::= ASSIGNMENT | IFTHEN | IFTHENELSE**
- **IFTHEN ::= if EXP then S end**
- **IFTHENELSE ::= if EXP then S else S end**

Last Challenge

- Backus complained about his own inventions:
- ***"Once you've written a FORTRAN program, you can't tell what's going on really. It takes these two numbers and multiplies them and stores them here and does some other junk and then makes this test. Trying to do that calculation in a different way [is very difficult] because you basically don't understand what the program is doing."***

Backus's Solution: Functional Programming

- Side-effect free functions
- Clarity
- Composition
- Parallelism
- E.g. dotprod: {[x;y] sum x*y}

Backus Style

- Annoyed?
  - Don't grin and bear it.
  - Change it!
  - "The best way to predict the future is to invent it" Alan Kay
- If you still don't like what you see, then change it again.

Inventor 2:
What Makes Him Tick

- Our second inventor was an outstanding student, a strong mathematician, and logician.
- Institute for Advanced Studies after his master's.
- Full professor of mathematics early on.

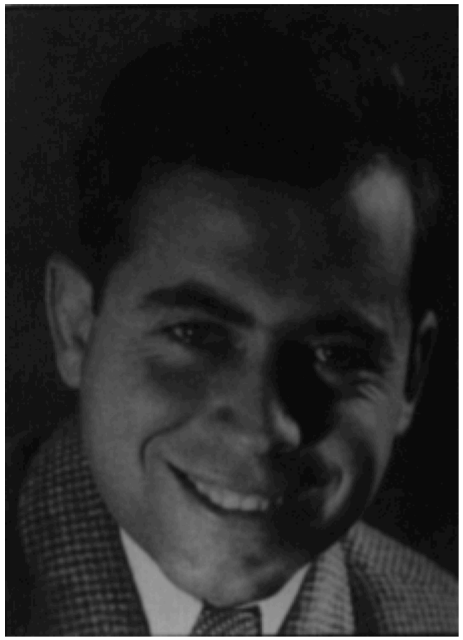
Some of his Best Known Work

- Non-deterministic finite state automaton (with Dana Scott): take Turing's model, simplify it, but add a smidgeon of choice.
- Randomized algorithms: throw dice in the middle of a computational recipe to speed things up.
- Numbers almost certainly prime….[i.e. method might declare a number is prime with small prob or error]

Against the Grain?

- Nothing in the computational culture encourages this way of thinking.
- Typical operations have names like “do”, “assign”, “end”, “add”, “copy” – a dance of imperatives.
- Rabin’s work involved giving the machine choice.

Michael Rabin (a few years ago)

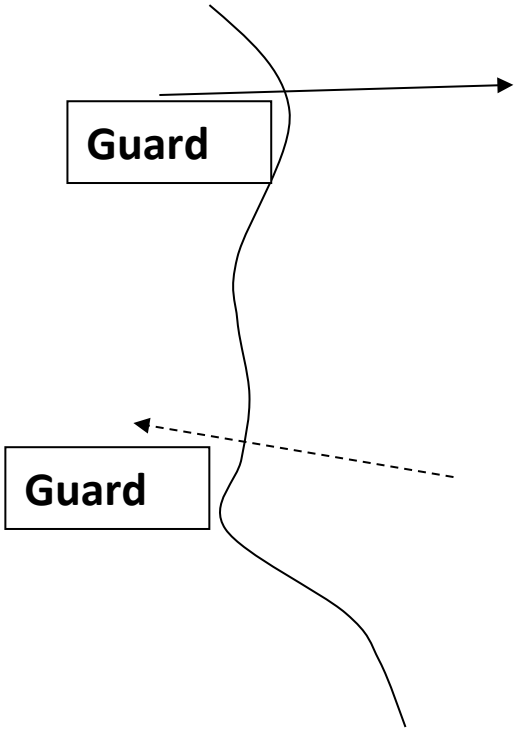


Small sampling of prizes:
Turing Award
American Academy of Sciences
French …
British…
Numerous Honorary Doctorates

Spy vs. Spy

- In 1958, John McCarthy proposed the following puzzle to Michael Rabin.
- ***There are two countries in a state of war. One country is sending spies into the other country. The spies do their spying and then they come back. They are in danger of being shot by their own guards as they try to cross the border.***

Spies Enter and Leave



Spy vs. Spy Goal

- ***"So you want to have a password mechanism. The assumption is that the spies are high caliber people and can keep a secret. But the border guards go to the local bars and chat---so whatever you tell them will be known to the enemy"***

Spy vs. Spy Goal

- ***"Can you devise an arrangement by which the spy will be able to come safely through, but the enemy will not be able to introduce its own spies by using information entrusted to the guards?"***

Spy vs. Spy (BIG hint)

- Rabin made use of the following procedure first introduced by Von Neumann to generate pseudo-random numbers: take an n digit number x, square it and take the middle n digits yielding y.
- E.g. x=341 → 341*341=116281→162=y
- Easy to go from x to y, but hard from y to x….

Implications of Spy vs. Spy puzzle

- Difficulty can be useful to help share secrets.
- Whole notion of complexity goes beyond decidability and undecidability to feasibility and infeasibility.

Rabin Style

- Find (usually through discussion) simple to understand problems that others consider too difficult to solve.
- Find an algorithm that was hard to come up with but simple and efficient to implement

Problem We Solved

- Can one prevent software piracy while
  - Allowing freeware/fair use/exchange
  - Encouraging viral distribution
- And without
  - Infringing on privacy
  - Involving the courts

Invent with an Amplifier

- So far, we have seen inventors that use clever design.
- Computers are later put to work.
- Major tradition of engineering: ever-increasing precision and control.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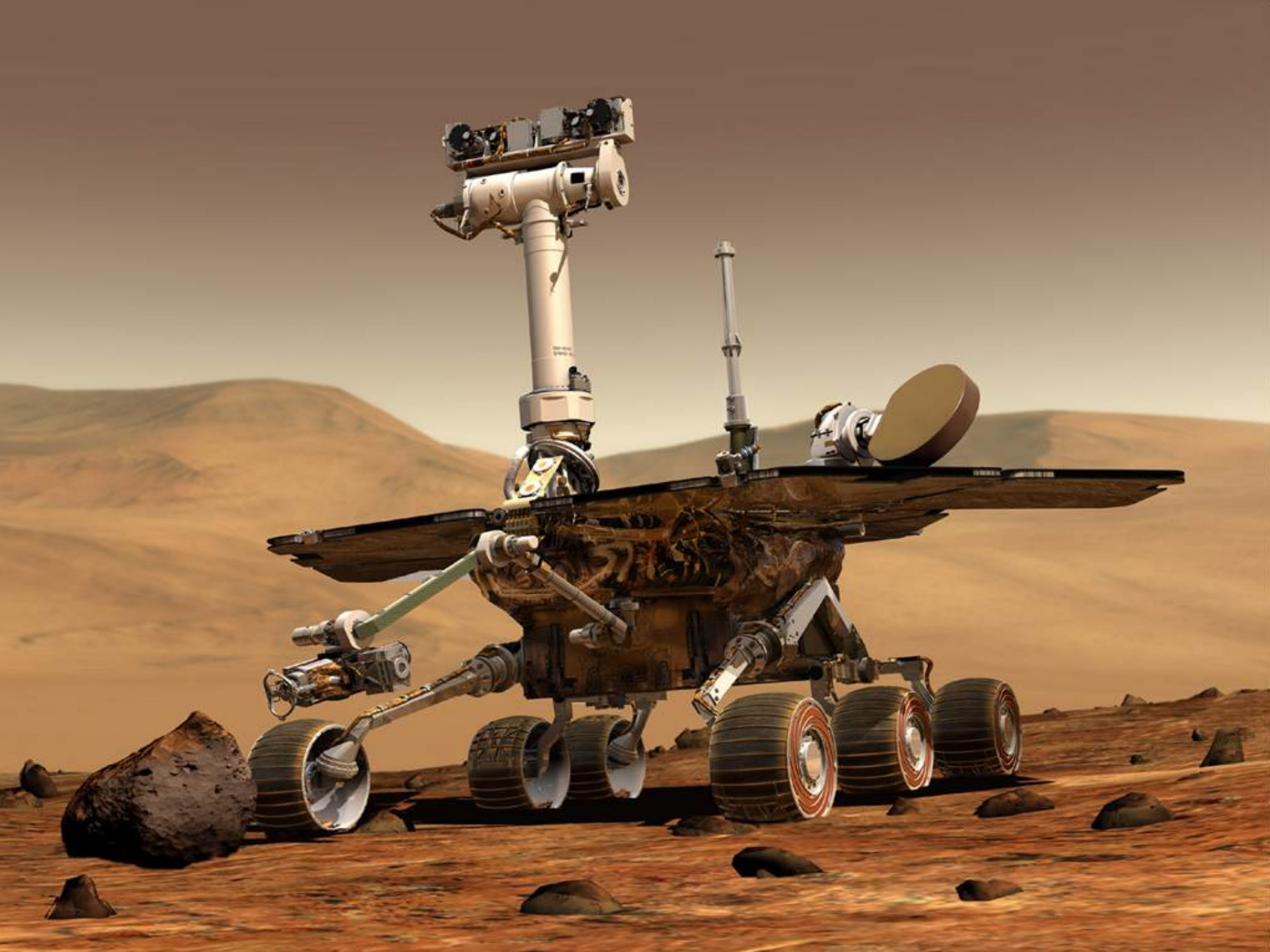
But What About New Environments?

- Spacecraft: bombarded by particles.
- Everything could go wrong … unknown unknowns
- Can't anticipate everything



When Something Goes Wrong, what should a spacecraft do?

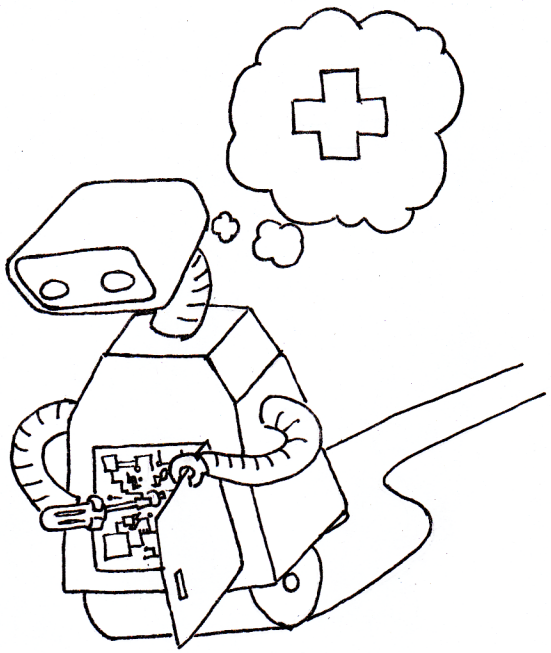
- Call home
- Like a kid who scraped his knees while playing with Billy

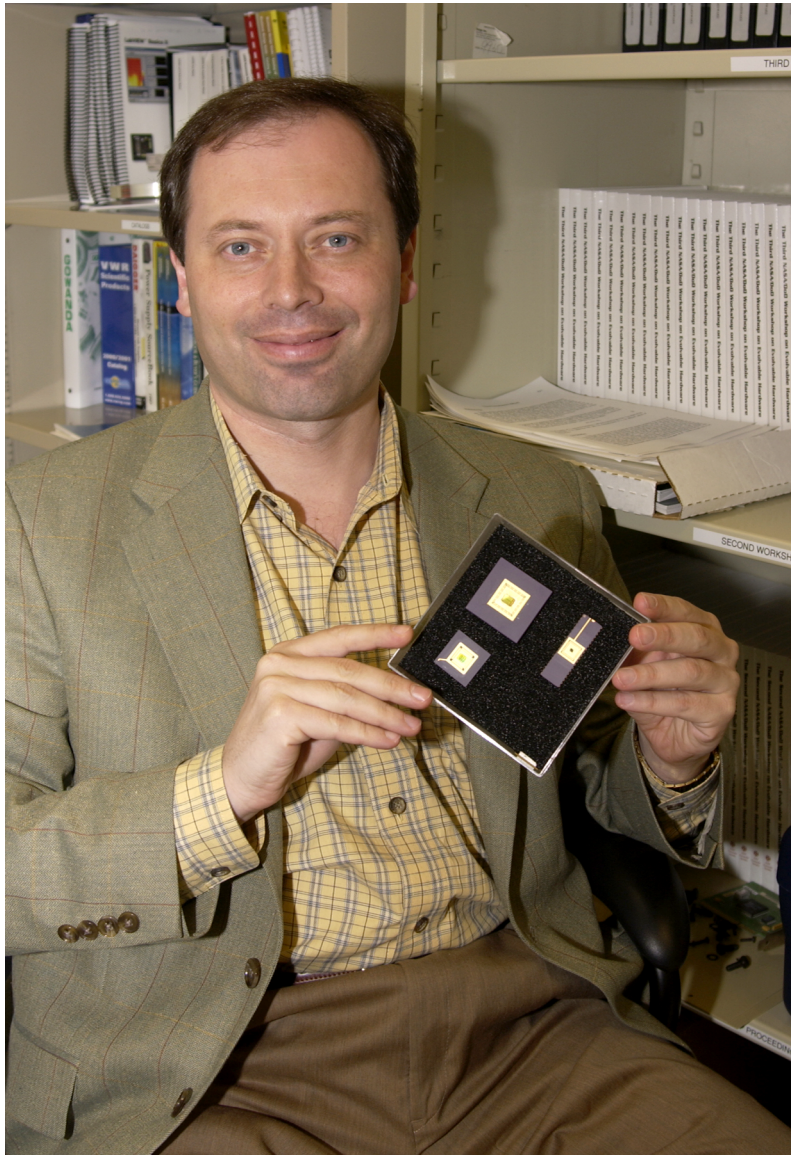
What Does Glenn Reeves Do?

- Try to duplicate the problem on local hardware.
- If so, send “code patches” to spacecraft.
- This works … kind of (messages take 10+ minutes to arrive)

Is There Another Approach?

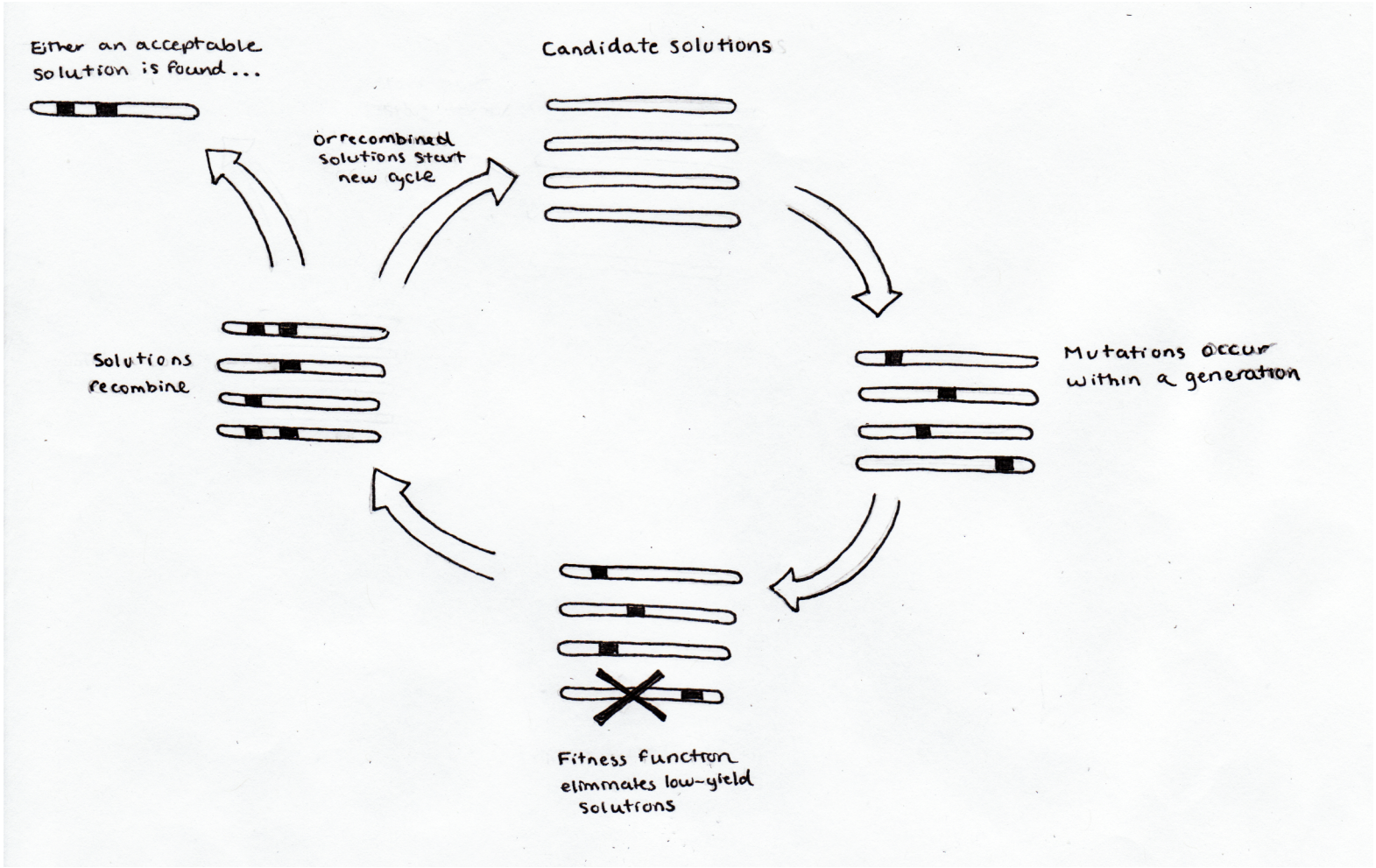
- When your kid gets older, you expect him to fend for himself/herself.
- Can we ask spacecraft to do the same thing?




THIRD
SECOND WORKSH

Circuits Redesign Themselves

- Just like an older kid who has a bruise, the circuit tries to make itself operational, by tweaking its circuit connections.
- No human intervention.
- Human role: new age parenting rather than the spare-the-rod-spoil-the-child style


Either an acceptable solution is found...
Candidate solutions
Or recombined solutions start new cycle
Solutions recombine
Mutations occur within a generation
Fitness function eliminates low-yield solutions

Any Applications Closer to Home?

- How about just a few blocks/few kilometers away?


NYSE
NYSE
NYSE
NYSE
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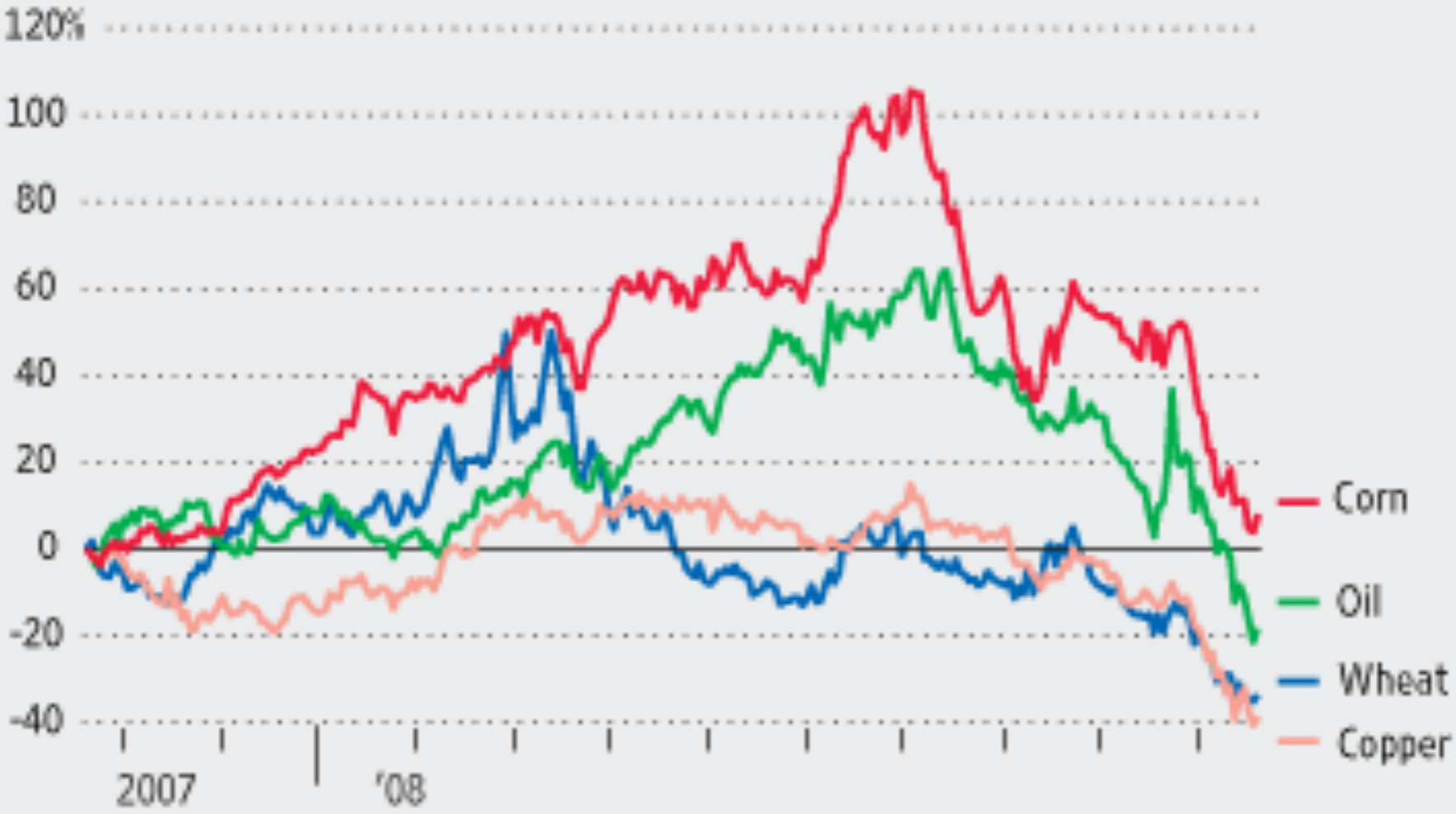
eSpeed
Production Support
eSpeed
Dmitriy Falberg

In Retreat

Cumulative change in commodity-futures prices over past year



Source: Thomson Reuters Datastream

Form of What They Want

- ***"If the price of a 10-year treasury rises by a certain amount over 2 minutes while the 5-year treasury doesn't move, then the 5-year treasury is likely to rise in the next 2 minutes."***

Problem of Finding Them

- ***"Amrut just handed me 28,000 attributes—the slope of the traded price over 2 minutes, the slope of the bid volume over 30 minutes, and so on. He said, 'The answer's in there somewhere.'"***
- If each attribute has 10 values, we're talking about 10000000000000000… <28,000 zeroes> possibilities.

How Should One Go About This?

- ***"We needed to think of something that was autonomous and could churn through billions of combinations. We didn't have time to think of what the actual relationships were…. We realized that in the end, this would be a truly black-box system. "***

Rubber Meets the Road

- They turned the algorithm on at 9:00 AM on a Monday. The system bought and sold $10 million worth of securities in a few minutes.
- ***"I was sweating. I used to bring two shirts to work for the first couple of months. It was exhilarating in a jumping-out-of-a-plane sort of way."***

Unintended Consequences

- Mostly autonomous systems, solving new problems in new environments
- Accidents happen.
- Can they be contained?

Problem Existed 100 Years Ago

- Titanic: “practically speaking unsinkable”
- It sunk
- No lookouts
- Going too fast
- Not enough rafts
- No training for mishap

A Gallery of Oversights

- Bhopal: designed for safety
- Blew up
- Methyl Cyanide mixed with water
- MIC not refrigerated
- Smokestack scrubbers out of service
- Population not told about wet cloth

Levels of Feedback

- Bad things happen
- Levels of feedback and correction
- Skin heals itself
- Other arm takes over
- Other people help out

Nancy Leveson: New Approach to Safety

- Levels of feedback and correction
- Make sure safety features stay operational
- Hierarchical design not only for functionality (what should happen) but for safety (what shouldn't happen)

The Place for Natural Computing

- Problems with many unknowns, requiring rapid reaction, and enormous search spaces.
- Aerospace, trading system design, …
- So much happening without human intervention.

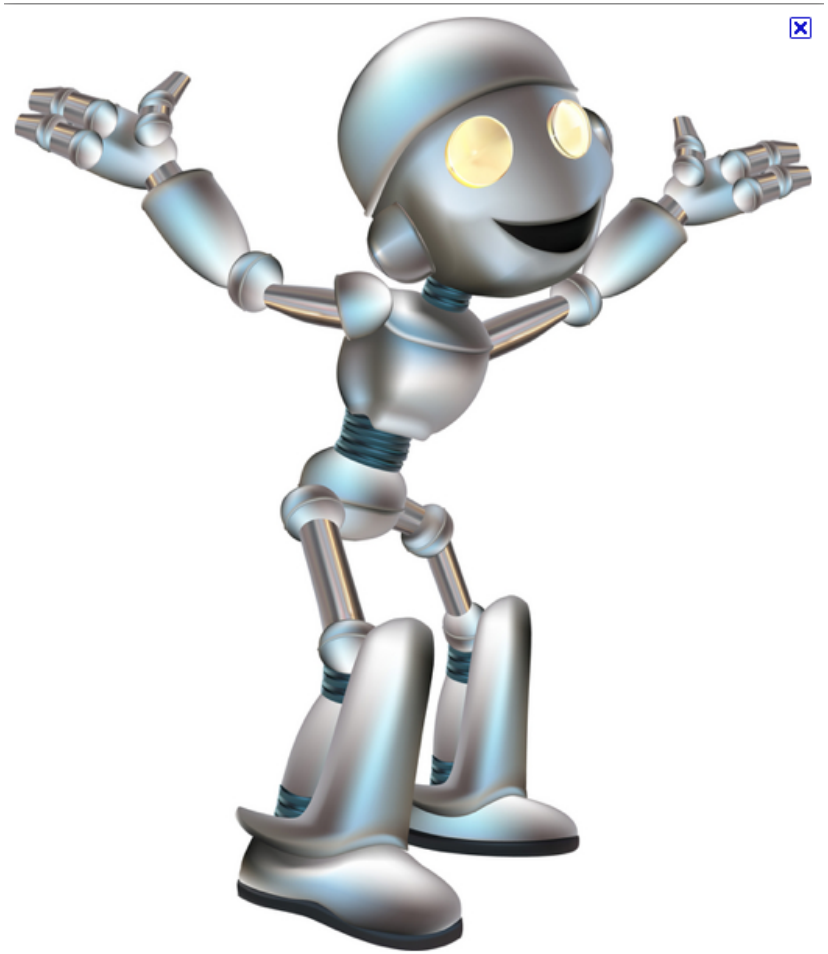
A Place for You

- You cannot be the inventor of the first computer language.
- You can however be ready when a new confluence of technologies requires creative solutions.

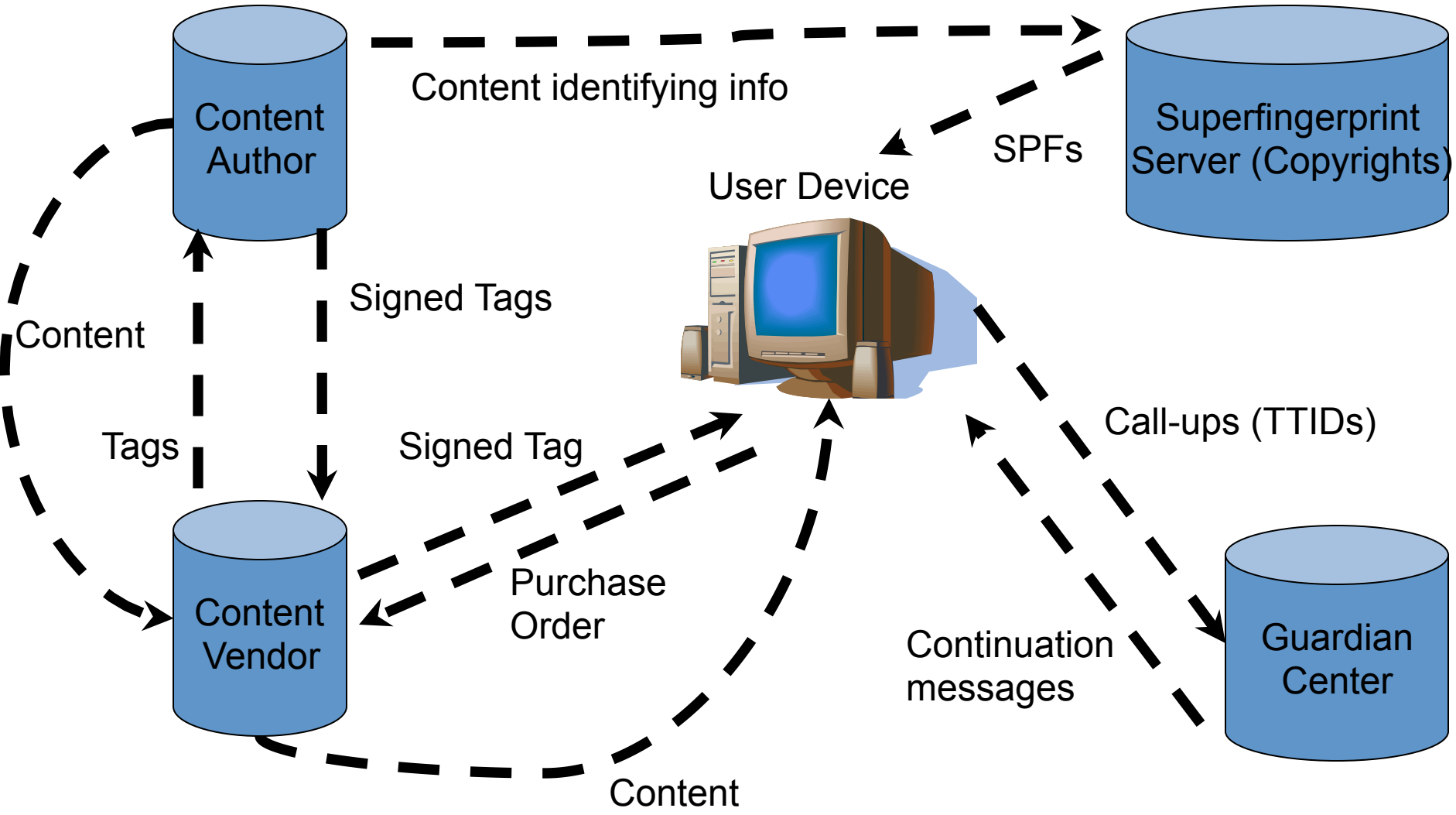
Invention Styles

- Easily angered (Backus)
- Like puzzles (Rabin)
- Repair stuff (Glenn Reeves)
- Encourage autonomay (Adrian, Glenn, Amrut)
- Exploit feedback (Nancy Leveson)

What is Your Style?



Overall System Architecture



Whither Human Creative Role?

- People lose monopoly on creative thinking.
- Creativity is redefined to exclude computer's role.
- People view machines as co-workers and co-inventors, very adaptive nimble ones at that …

Whither Invention?

- Invention in the future (human role):
  - model problem/design framework
  - design for safety
- Invention in the future (computational role):
  - explore search space
  - try stuff-test-try-test-try-…