The Automation of Invention: Implications for Education

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Center for Curriculum Redesign

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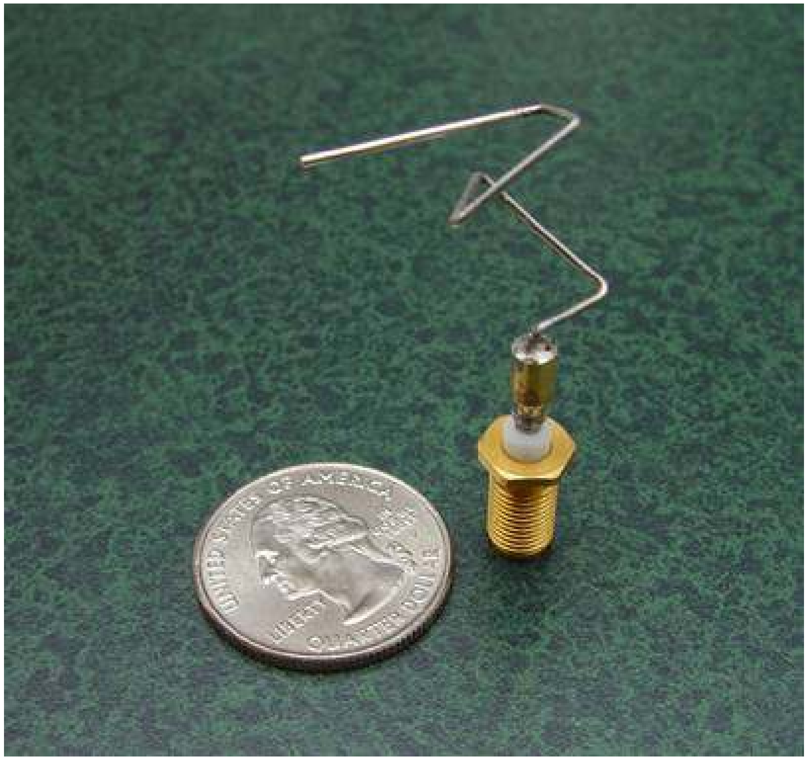
Overview

- Examples of invention automation ("artificial invention")
- Interlude: automatophobia
- Framework for invention automation (and a cure for automatophobia)
- Implications of invention automation for invention
- Implications of invention automation for education

Examples of "Artificial Inventions"

- Antenna on NASA's Space Technology 5 mission
  - Software: evolutionary algorithm
  - People: Jason Lohn, Greg Hornby, Derek Linden at NASA Ames Research Center
- PID controller
  - Software: genetic programming
  - People: John Koza et al.
  - Patents granted on controller and method of designing it
- Oral-B CrossAction toothbrush
  - Software: Creativity Machine
  - People: Stephen Thaler



Some more examples

- NuTech Solutions:
  - Technology: combination of genetic algorithms, neural networks, simulated annealing, evolutionary computation, and swarm intelligence
  - Result: Improved car frame for GM
- Natural Selection, Inc.:
  - Technology: evolutionary algorithm
  - Result: software for finding improved drugs
- Matrix Advanced Solutions:
  - Technology: proprietary software
  - Result: anticoagulant
- Hitachi:
  - Technology: genetic algorithm
  - Result: improved nosecone for bullet train

How invention automation technology works

- Many kinds of technology
- Just one example for now
- Many more at www.geniemachine.com

How the NASA antenna was invented

- Evolutionary algorithm, so-called because it "evolves" designs in a way that is analogous to how biological evolution evolves organisms
  - Generated initial "population" of potential antennas
  - Largely random, therefore largely useless
  - Let "unfit" antennas die
    - **"Fitness" defined by "fitness criteria" provided by human engineers**
  - Note: fitness criteria did *not* describe shape of antenna
    - Role is to be an abstract description of the problem to be solved by antenna
    - In the case of the NASA antenna, the fitness criteria favored characteristics such as the ability to transmit and receive signals at certain frequencies, and the ability to physically fit within a 6" cylinder.

How the NASA Antenna was invented

- Surviving antennas “mate” to produce offspring
- Some offspring “mutate”
- The process repeats for many “generations”
- Result (not guaranteed): a solution that satisfies the specified fitness criteria

Summary of some invention automation techniques

- Population-based
  - Evolutionary algorithms, Creativity Machine
- Top-down substitution
  - Hardware description languages
  - Traditional computer programming
- Bottom-up combination
  - Musikalisches Würfelspiel (music-writing software)
- These and others can be combined with each other

Interlude: The Fear of Automation (automatophobia?)

- Common reactions to examples above:
  - Computers are replacing humans
  - Humans will become obsolete

"I have created a machine in the image of a man, that never tires or makes a mistake. Now we have no further use for living workers."

-- Rotwang, in Fritz Lang's *Metropolis*

Interlude: The Fear of Automation

- Automatophobia is not unreasonable. Sometimes it is borne out.
- The fallacy of automatophobia, however, is that it assumes that automation, by its very nature, automates a process *completely*.

Automation is partial in practice

- Consider a process that consists of three manual steps A, B, and C.
  - A: crack egg
  - B: scramble egg
  - C: fry egg
- If only step B is automated, then steps A and C may continue to be performed manually by a human.
- If steps A, B, and C are automated, there is always some larger process that contains the process A, B, C as a sub-process, e.g.:
  - 1: Obtain egg (manual)
  - 2 (A, B, C): Crack, scramble and fry egg (automated0
  - 3: Season, present, and serve egg (manual)
- The larger process continues to require human involvement. A cure for automatophobia is in sight…

Partial Automation: Always a Place for Humans

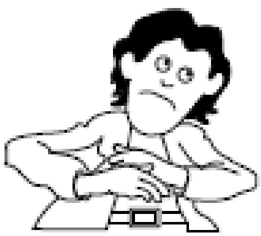
Interpolate

- Computer automates step B of process A, B, C:
  - A: Manual
  - B: Automatic
  - C: Manual
- Result:
  - Human performs A & C
  - Computer performs B

Extrapolate

- Computer automates steps A, B, C of process A, B, C:
  - 1: Manual
  - 2 (A, B, C): Automatic
  - 3: Manual
- Process A, B, C is always part of a larger process:
- Result:
  - Human performs 1 & 3
  - Computer performs 2

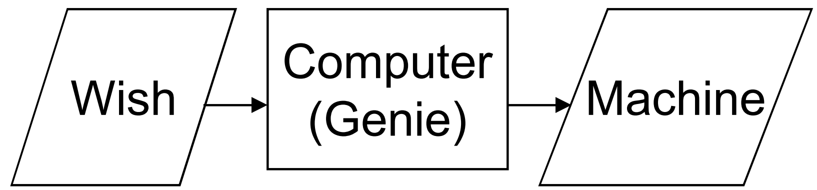
How invention automation technology is like a genie



How Invention Automation Technology is Like a Genie

Computers as Genies

- Human writes wish
- Computer grants wish by producing
  - design for a machine; or
  - an actual machine
  - that solves the problem described by the wish.

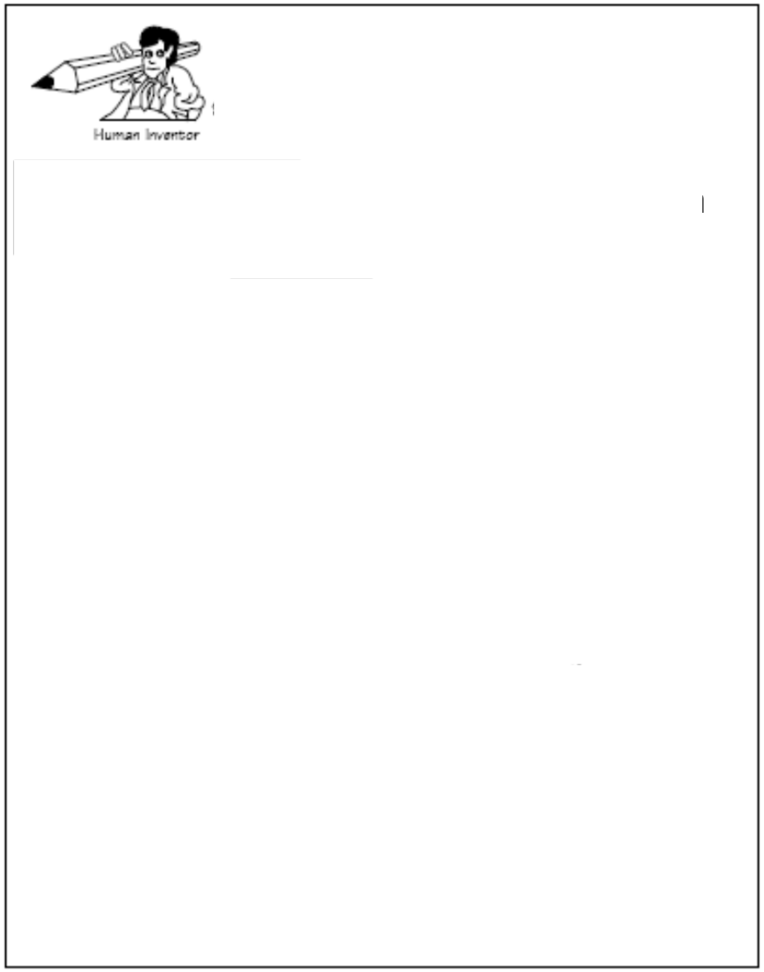


- Wish is:
  - an abstract description of the machine; or
  - a set of instructions for creating the machine.

What’s New Here?

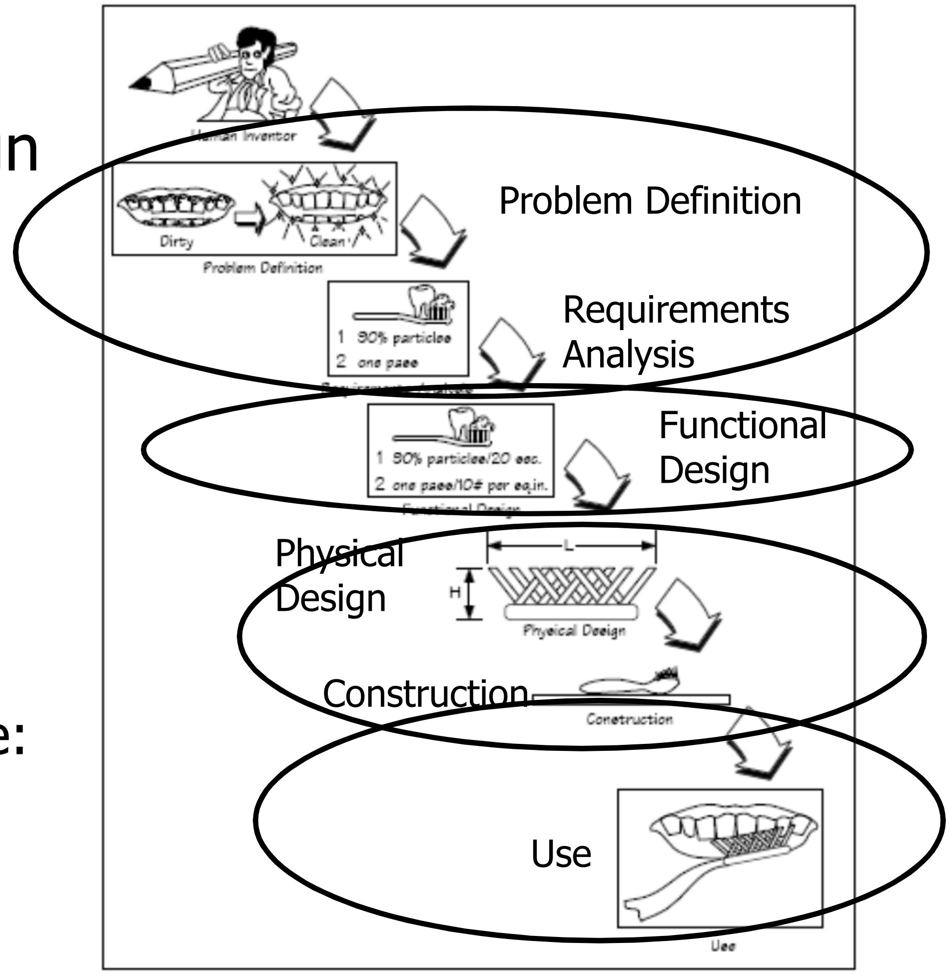
- What was “automated” in these examples?
  - Transformation of problem description into problem solution
- We can be more precise than that . . .

The Waterfall Model



Swimming Up the Waterfall

- Critical (last required manual) step in design process:
  - Stone age: use/construction
  - Industrial age: construction/physical design
  - Information age: functional design
  - Artificial Invention age: requirements analysis/problem definition



Old Skills, New Skills

- When a waterfall tier is automated, critical skill needed to be an inventor shifts up one tier in the waterfall
  - Industrial Age: physical design
  - Information Age: functional design
  - Artificial Invention Age: problem definition

Inventors as wish writers

- Inventors in the Artificial Invention Age will need to be skilled wish writers
  - Necessary: ability to describe the problem to be solved in a language that a computer can understand
  - Not necessary: physical design skills
- Necessary:
  - abstract mathematics
  - physics
  - computer programming
- Existing inventors' skills shift higher
  - Note: abstract ≠ vague
- May make it possible for non-inventors to become inventors

Humans and computers: inventive partners

- Recall NASA antenna example:
  - Genetic algorithm produced potential designs
  - Engineers noticed varying signal strengths
  - Engineers modified fitness criteria to favor smooth signal strengths
  - Re-ran algorithm: results were better than initial run.
- Example of collaborative inventing.
  - Really? Yes . . .

Collaborative inventing

- Two types of computer-facilitated collaboration:
  - between humans; and
  - between human and computer.

Human-computer collaboration

- NASA antenna: human-computer collaboration
  - Why?
  - Interaction between human engineers and software resembles that between human collaborators:
    - Software: generated, evaluated, and refined potential designs
    - Humans: defined problem, reviewed designs, gave feedback to software
    - Feedback loop involving both collaborators

Human-computer collaboration: product package design

- Affinnova
  - IDEA: Interactive Design by Evolutionary Algorithms
  - Designed product packaging for 7-Up Plus
    - Decomposed design into components: images, color, materials, text
  - Software presented millions of designs to consumers online
  - Consumers selected their preferred elements
  - Software evolved designs in response
  - Cadbury picked one design from six best

Human-computer collaboration: features

- Like any team, human-computer collaboration is most successful when human and computer each contributes what it does best:
  - Human: formulating problem, making aesthetic judgments
  - Computer: generating, simulating, and evaluating large numbers of potential solutions quickly
- End products can be better than could have been produced by either partner acting alone

Human-human collaboration: examples

- Open source software
  - Open source programmers often volunteer
- Companies are now using same model for profit:
  - “Crowdsourcing”
  - InnoCentive: online innovation marketplace
    - Companies post technical problems online with a bounty
    - Anyone, anywhere can try to solve the problem to win bounty
    - Result: return of the garage inventor
- No more “Not Invented Here” syndrome
- Paraphrasing Raymond: with enough eyeballs, all technical problems are shallow
- Open innovation and crowdsourcing examples:
  - Louis von Ahn GWAPs: www.gwap.com
  - Paid crowdsourcing platform: www.humangrid.eu
  - LEGO factory: factory.lego.com
  - Large list of examples: tinyurl.com/3vc3mh

Open innovation

- These are examples of “open innovation” (Henry Chesbrough)
- Two effects:
  - enabling existing innovators to innovate more efficiently
  - enabling non-innovators to join the game
- Examples of latter:
  - iRobot “Robot Development Kit”
  - MIT Media Lab “scratch”
  - Customer innovations documented by Eric von Hippel
    - http://web.mit.edu/evhippel/www.books.htm

Distributed inventing

- Most examples above are distributed
  - Collaborators are geographically dispersed
- Facilitated by fast, high-quality, low-cost networking technology

Technology Facilitating Distributed Inventing

- Not just networks!
- Improved CAD and simulators
  - Reduce time/cost of prototyping/testing
    - Autodesk “Inventor”
  - Spread of “design by coding”
    - E.g., HDLs for processor design
    - Nanotech and biotech?

Automating manufacturing

- What good is a design if you can't build it?
- Recent advances in "personal fabrication"
  - Read *Fab* by Media Lab Professor Neil Gershenfeld
- New business models
  - Ponoko: manufacturing on-demand

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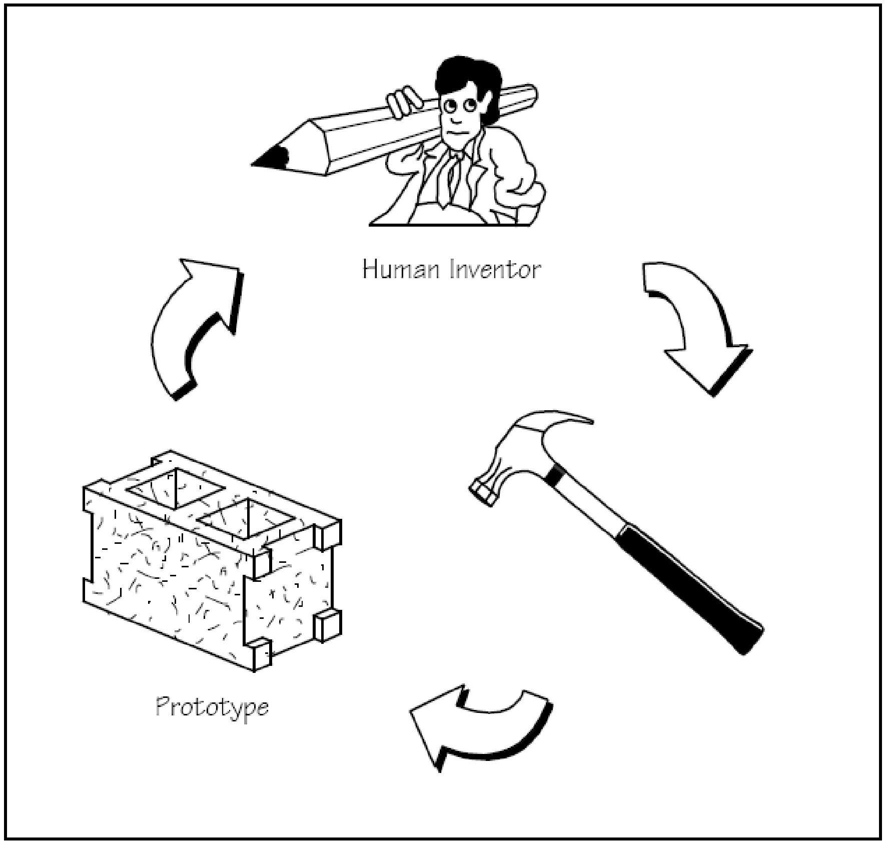
Human-Machine Collaboration: Phase I



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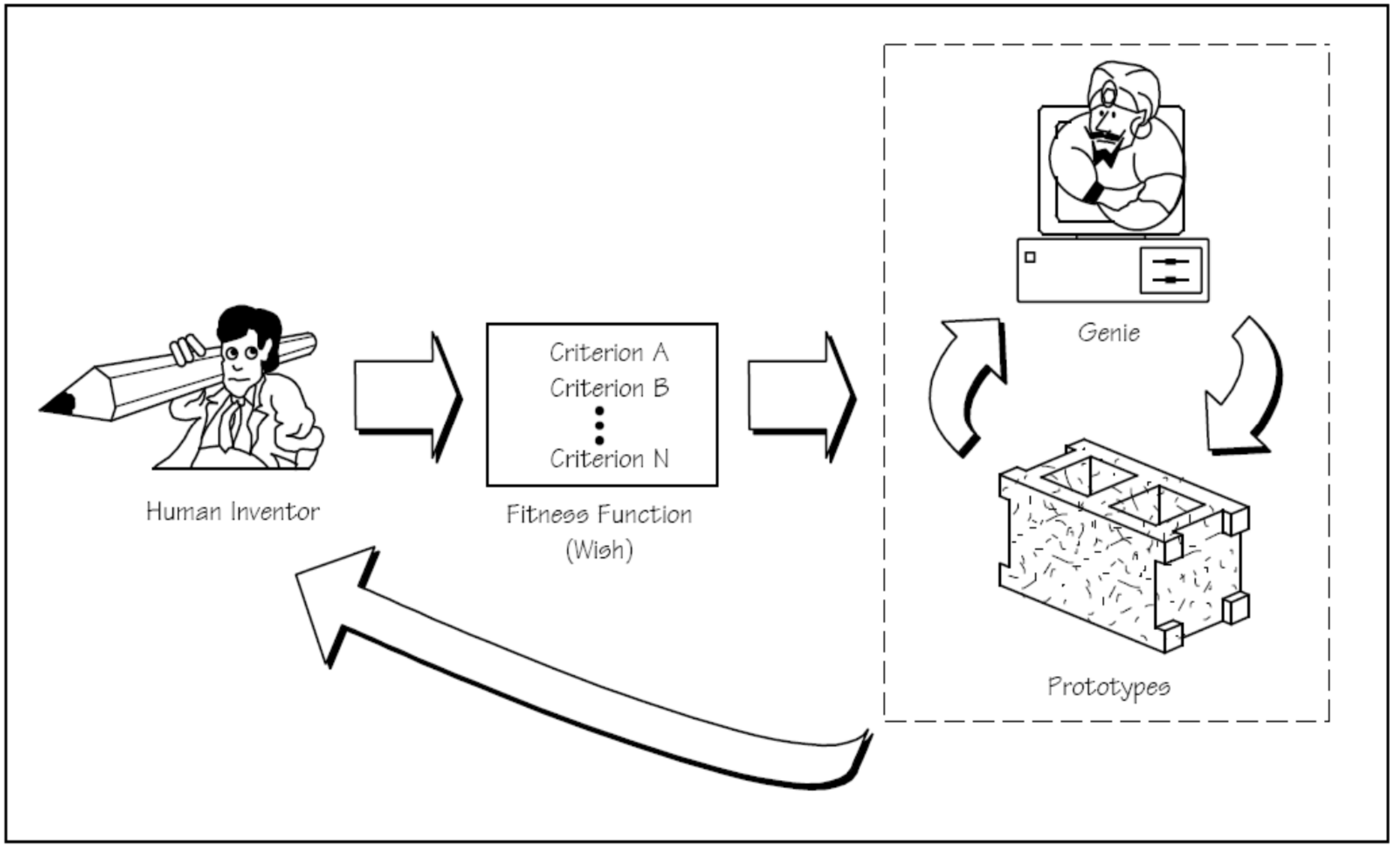
Human-Machine Collaboration: Phase II



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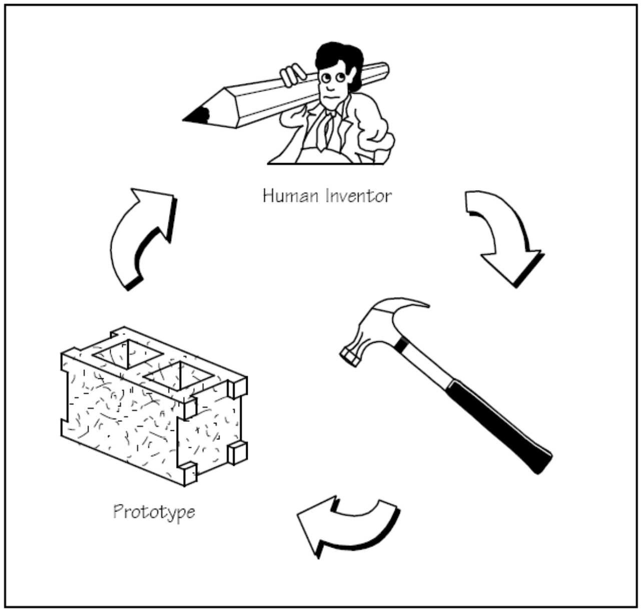
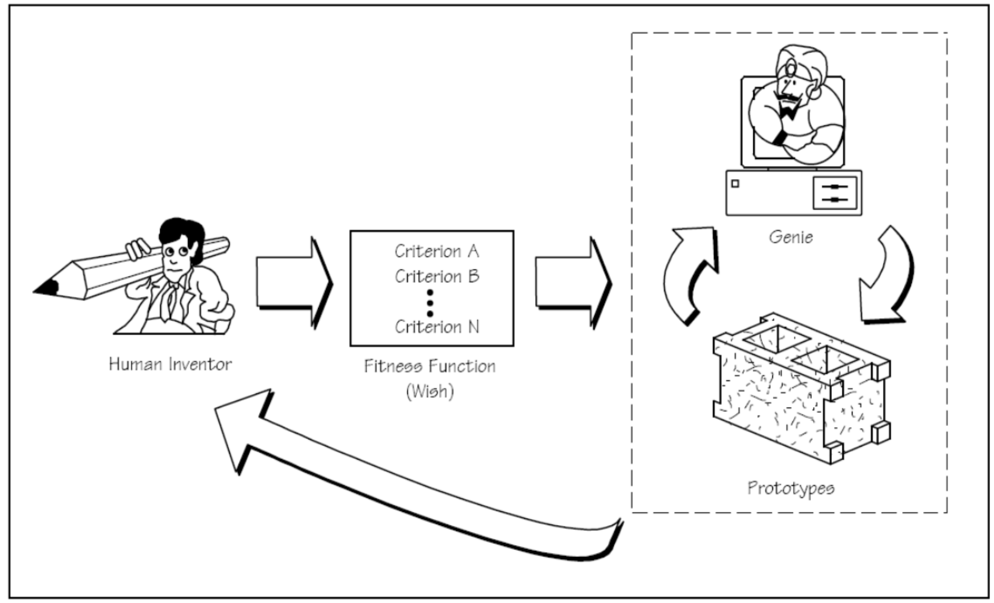
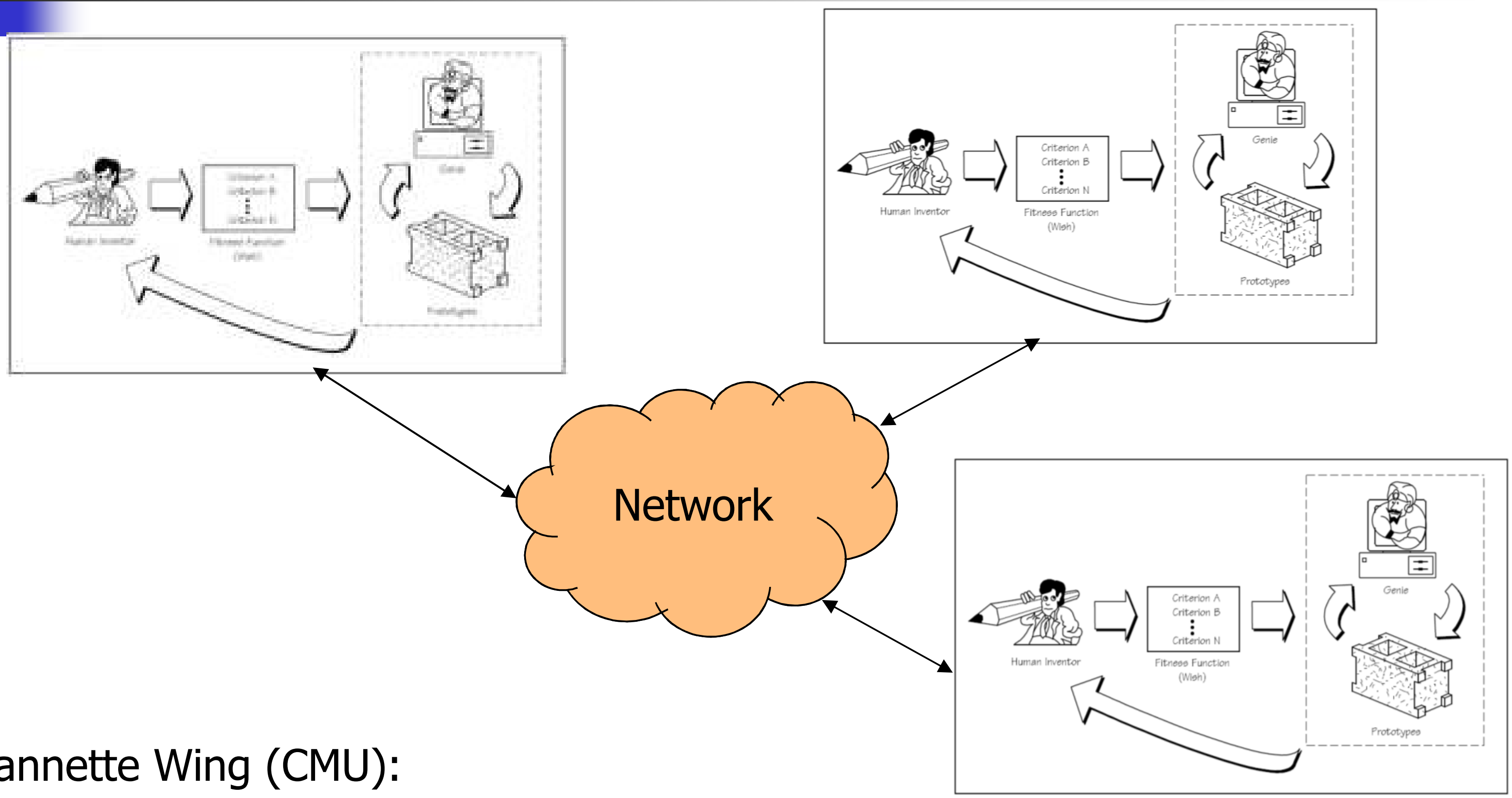
Comparing Phase I to Phase II





- Control of tool by human: manual labor in Phase I, abstract instructions (wish) in Phase II
- Feedback loop: only in whole system in Phase I, in both system and *within the tool* in Phase II

Human-Machine Collaboration: Phase III



Jeannette Wing (CMU):

computer::= machine | human | machine + human | network of computers

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The Future of Inventing

- Automation
  - Role of human inventor:
    - describe problem to be solved
    - provide subjective judgments
  - Role of computer:
    - generate, simulate, and evaluate potential inventions
  - Resulting inventions often:
    - are surprising
    - contradict conventional wisdom about good design
    - are not understandable, even by human experts
  - May enable:
    - Existing inventors to become better inventors
    - Current non-inventors to become inventors

Implications for Education

- What do we need to teach students so that they can take maximum advantage of automated inventing, and of automation more generally?
  - Simple answer: all of the skills listed above (e.g., abstract problem definition—the ability to write wishes)
  - Complex answer: *ability to design solutions to problems within the framework of Phase III of human-machine collaboration*

Teaching Human-Machine Collaboration

- When faced with a problem to be solved, ask: what configuration of a Phase III system is best-suited to solve this problem? E.g.:
  - Which parts are best solvable by people?
  - Which parts are best solvable by machines?
  - How can those people and machines best interact to solve the problem as part of a system?

Solving Problems in a Phase III World

- Skills required include ability to:
  - Decompose problem into modules
  - Identify skills possessed by available:
    - Humans (oneself and others)
    - Machines
  - Identify cost/risk/time associated with each of above
  - Assign best human and/or machine to each module

Phase III Problem Solving is Teachable

- All of this can be learned, but it takes time, practice, and a shift in mindset
- Part of the problem is that it contradicts tenets of traditional education
  - Requires team-building skills taught only in business or engineering schools, if anywhere
  - Traditional education focuses on teaching *each individual* to acquire all skills necessary to perform a task.
  - Inability or refusal to acquire all such skills is viewed as a personal failure of the student and is penalized
  - Attempts to delegate subtasks to others (whether humans or machines) is not only frowned upon but explicitly punished as "cheating"
- Focus must shift from teaching students to think:
  - "How can *I* solve this problem by myself?"
  - "How can I design a *system*, including some combination of people and/or machines, to solve this problem as efficiently and effectively as possible?", where the resulting system may not include the student himself or herself.
- This is a momentous challenge but well worth the effort due to the potential reward.

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