Bringing up Robot: The Quest to Grow an Artificial Mind

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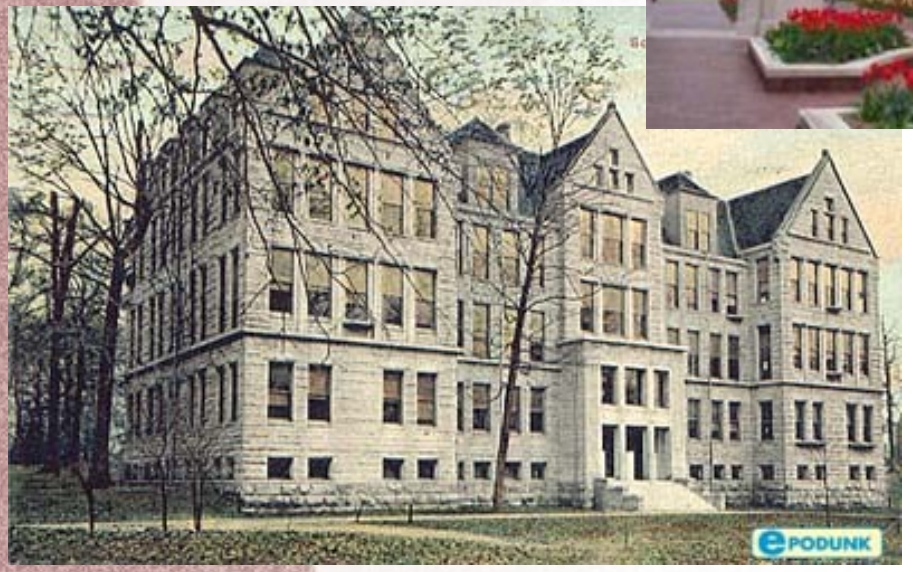
Director, Institute for
Personal Robots in Education
Associate Professor and Chair
Computer Science

Overview

- My path into Computer Science
- An interest in Robotics
- A crisis in Computer Science
- A sidestep into Education
- A new field, Developmental Robotics

My path into CS

- Indiana University, Purdue University at Indianapolis (IUPUI)
- Indiana University, Bloomington



Anthropology vs CS

- Anthropology
  - Physical
  - Cultural
  - Linguistic
  - Archaeology
  - Indiana Jones
- Computer Science
  - Simulated Evolution
  - Machine Learning
  - Computational Linguistics
  - Programming Languages
  - Artificial Intelligence

Anthropology vs CS

- Anthropology
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Education

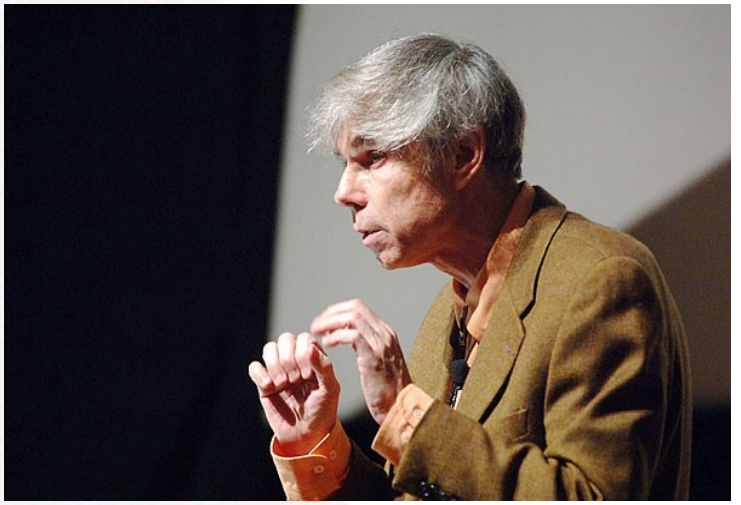
- B.A., Anthropology 1986

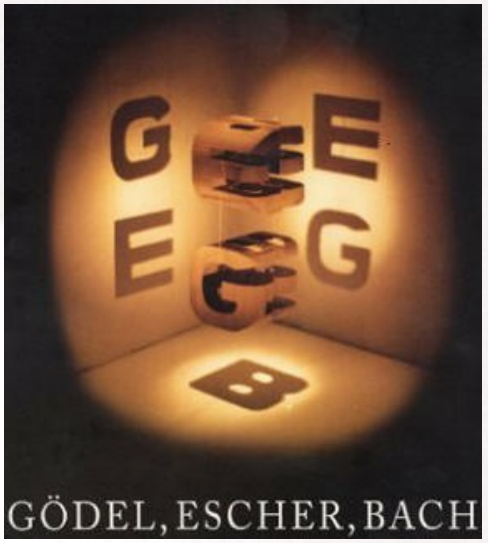
Education

- B.A., Anthropology 1986
- B.A., Computer Science 1987

A Doug Returns

- Douglas Hofstadter
- Pulitzer Prize, 1980
- Gödel, Escher, Bach: An Eternal Golden Braid
- Returns to IU



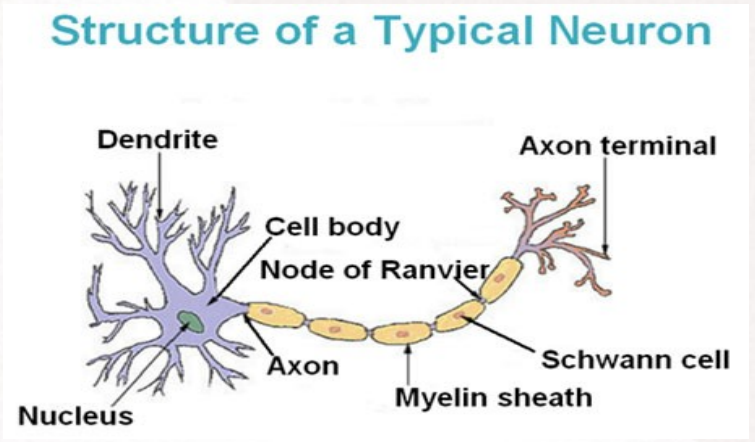


Education

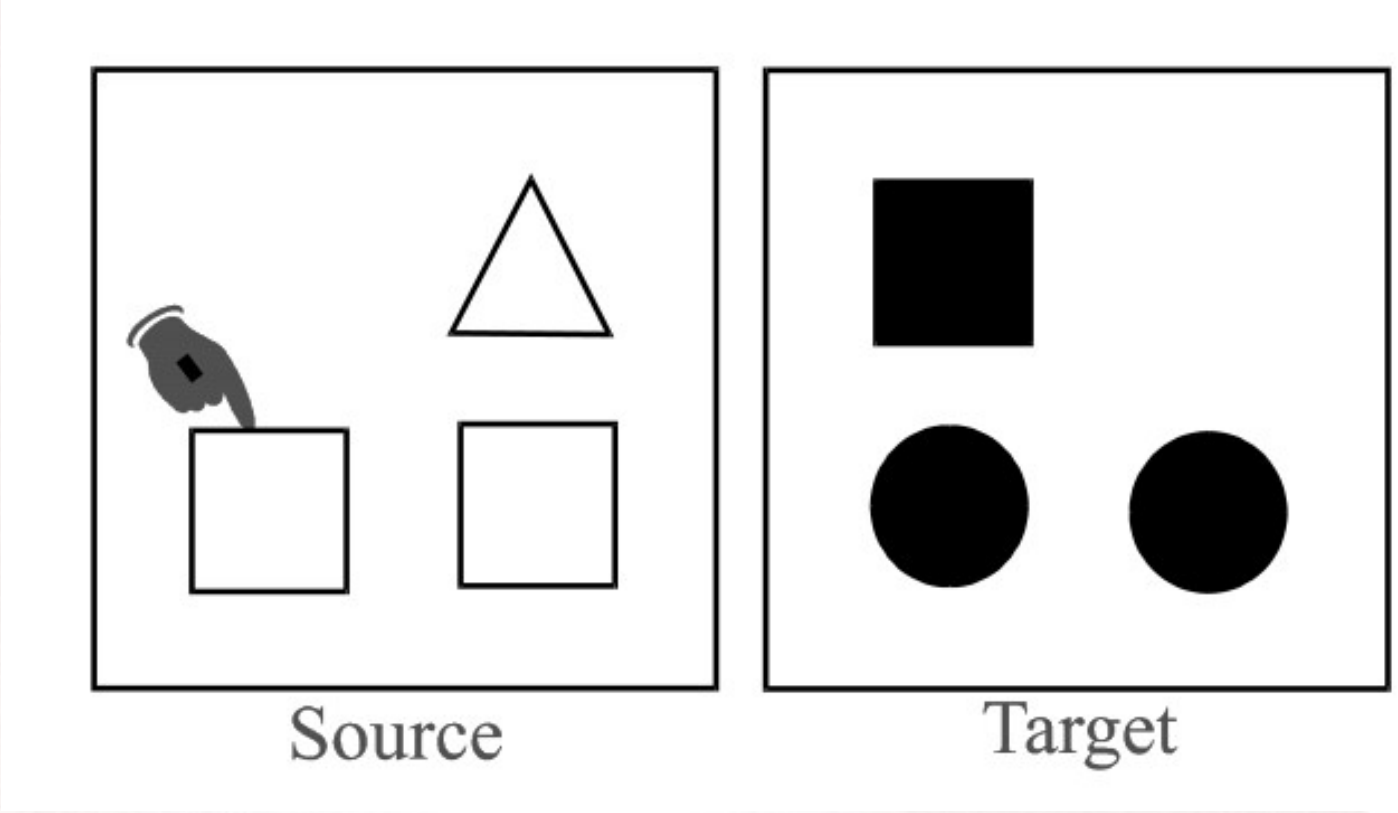
- B.A., Anthropology 1986
- B.A., Computer Science 1987
- M.A., Computer Science 1990

Cognitive Science

- Philosophy
- Psychology
- Computer Science



Visual Analogies



Structural Analogies

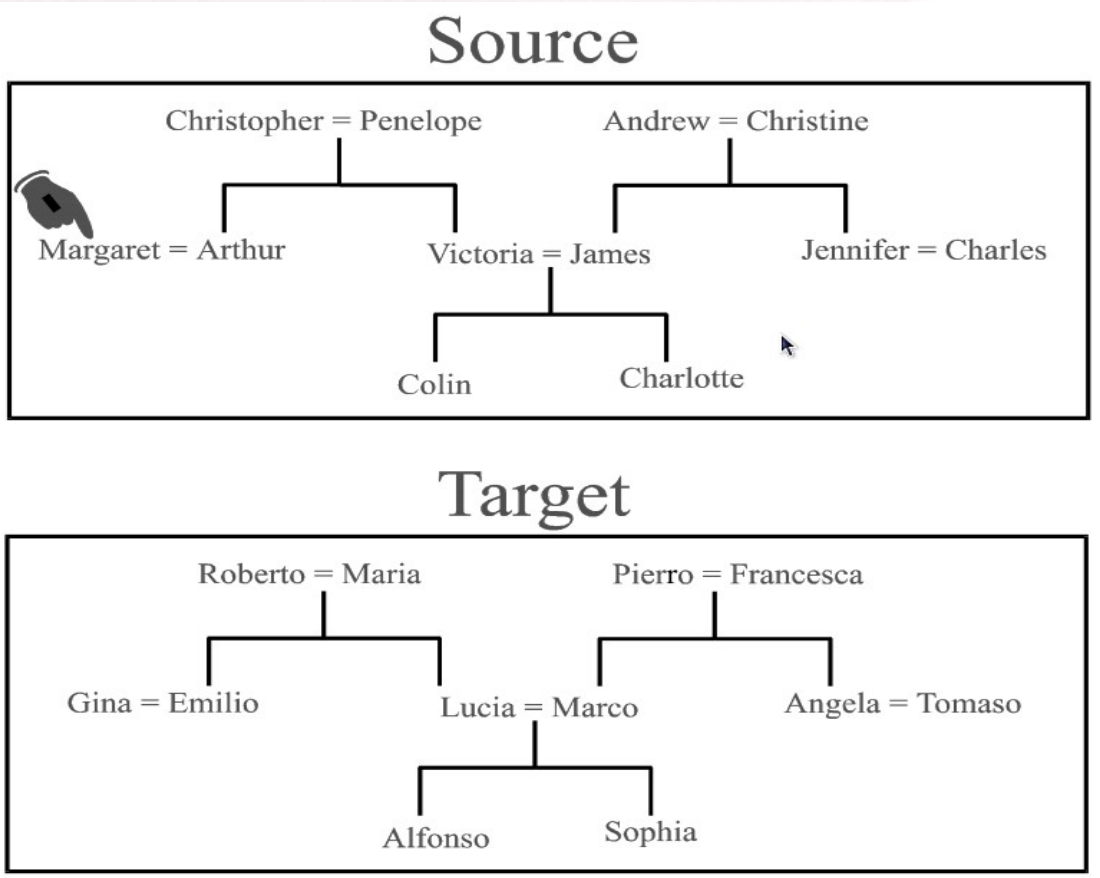
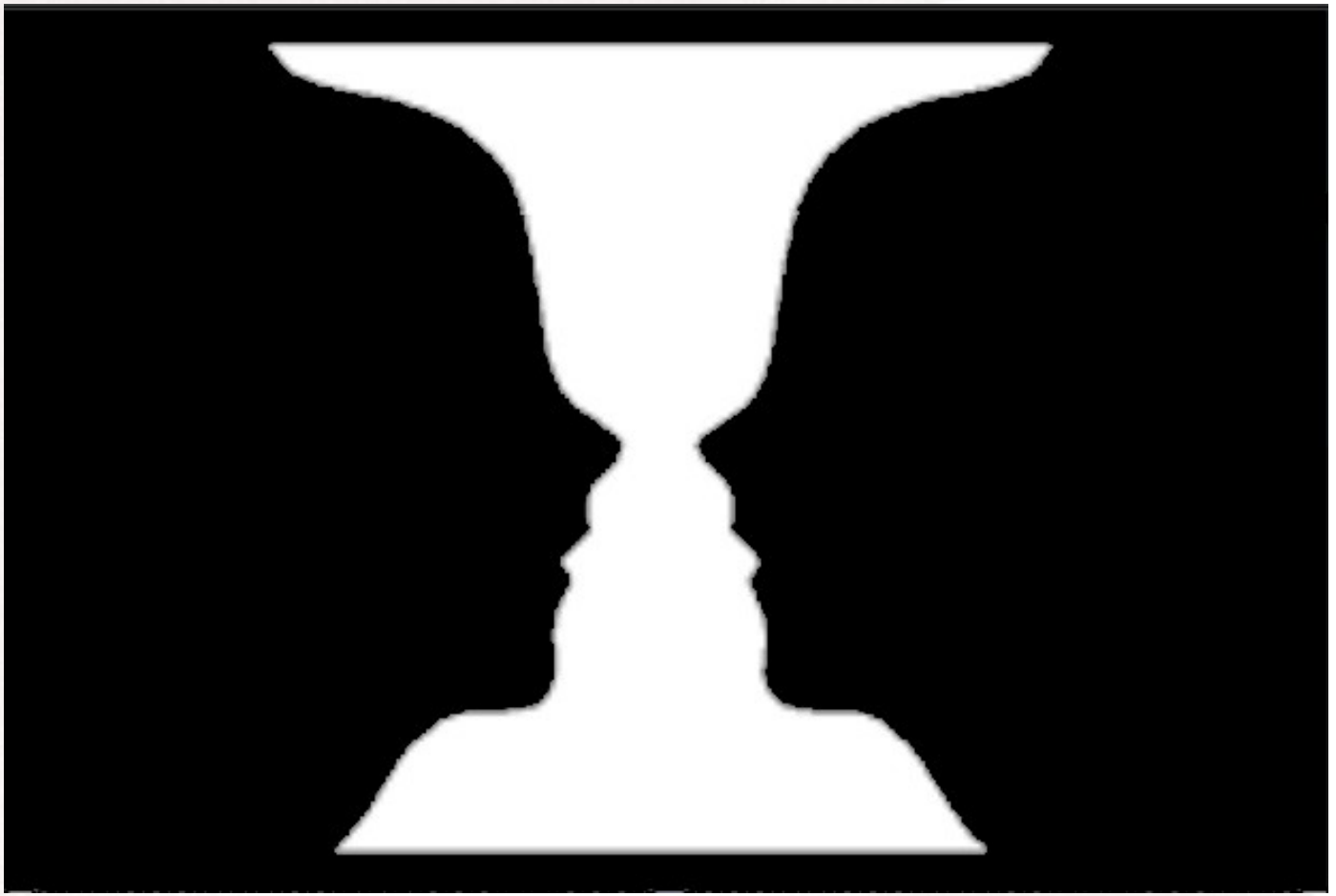


Figure 1-9. Sample #6: two isomorphic families. Who, in the lower family, can be seen as analogous to Margaret? (After Hinton, 1986).

Figure/Ground



PhD Thesis

- Learning to Make Analogies: A Connectionist Exploration
  - Learning
  - Analogies
  - Generalization

Can a computer do something for which it wasn't program to do?

Education

- B.A., Anthropology 1986
- B.A., Computer Science 1987
- M.A., Computer Science 1990
- Joint Ph.D., Computer Science and Cognitive Science 1997

Bryn Mawr College

- Joined Deepak Kumar, fall 2001
- With Lisa Meeden, Swarthmore Computer Science & Deepak began brainstorming on developing general artificial intelligence (AI)

My experience with AI

- Initially, excited that I could program a game that could beat me (and I learned moves from it)
- Slow realization that **I** put all of the intelligence in there with clever representations and search algorithms
- Finally, admitting that it's a lot of work! Fun, but not heading toward general intelligence

Problems with Traditional AI

- “Brittle” - breaks very easily
- Inputs and rules must be defined precisely
- Doesn't handle “sort of”, “almost” or “kind of”
- Really requires the programmer to solve the problems through data structures and algorithms (eg, computer science)
- Each of these could be addressed, but...
- ...Biggest problem is that it doesn't **surprise** me!

“New AI”

- Trainable and generalizable (neural networks)
- Create novel solutions (evolutionary systems, ant algorithms like Hofstadter's codelets)
- Ability to deal with imprecision (fuzzy logic)

Two AIs

- Formal system
- Tokens and Rules
- Discrete
- Centralized
- All or none
- Distinct syntax and semantics

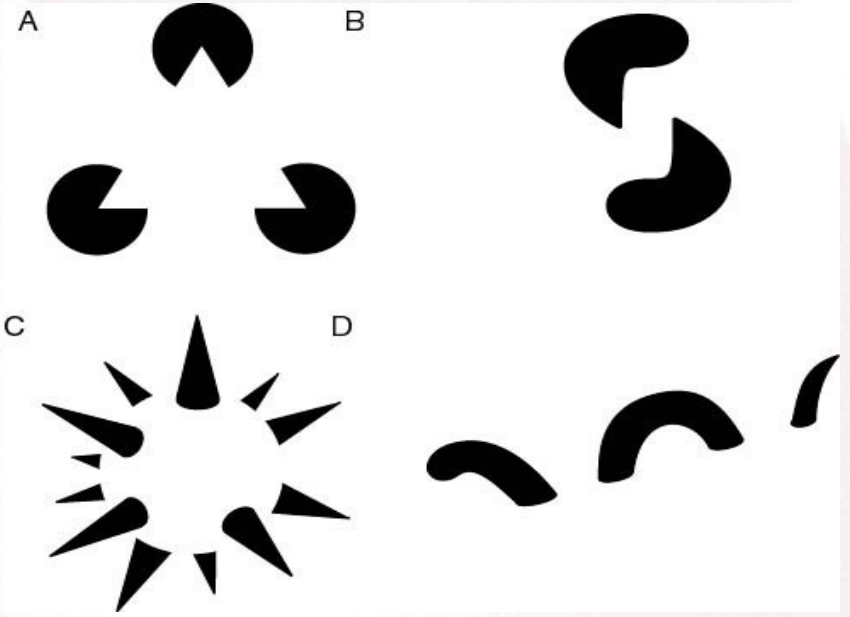
- “Informal system”
- Patterns and generalizations
- Real-valued
- Distributed, self-organized
- Graceful Degradation
- Blurred syntax and semantics

The essence of New AI?

- Based on numbers rather than symbols
- Often, based on biological metaphors (such as brains, ants, and evolution)
- Sometimes called “embodied AI” because of focus on body and experience

Emergence

"the whole is greater than the sum of the parts"



Emergence

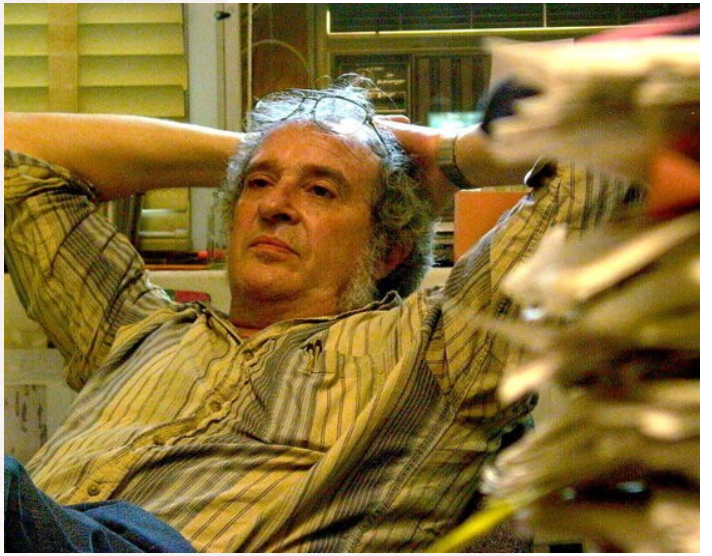
- Composed of small, simple interacting parts
- Results cannot be “predicted” (no closed-form equation)
- Multiple levels of processing, understanding, and effect
- Not easily understood using standard reductionist methods
- Is everywhere in the real world
- Is rare and limited in simulated worlds

How to use emergence in AI?

- Trained, not programmed: Learning
- Experienced, not programmed: Robots
- Simple, interacting parts: Neural networks
- In my lifetime: Not evolutionary systems
- Resilient to noise and variations: lots of experience/time
- Creative: should surprise me, in a good way

Bryn Mawr College

- Created the Emergence Group
- Met every week for 5 years
- Breakfast Club
- Created an interdisciplinary course



Bryn Mawr College

- Joined Deepak Kumar, fall 2001
- With Lisa Meeden, Swarthmore Computer Science & Deepak we formed the **Developmental Robotics Research Group**
- Outlined our philosophy in a paper “Bringing up Robot” in 2002



Bringing up Baby

"a 1938 screwball comedy, ... an **infamous box office catastrophe**, causing Hawks to be fired from his next film and forcing Hepburn to buy out her contract. As time went on, however, the movie gained more and more attention and is now revered as a **sophisticated classic** decades ahead of its time, and it continues to **generate revenue for Hepburn's estate**."

- wikipedia.org, Bringing up Baby

Bringing up Robot

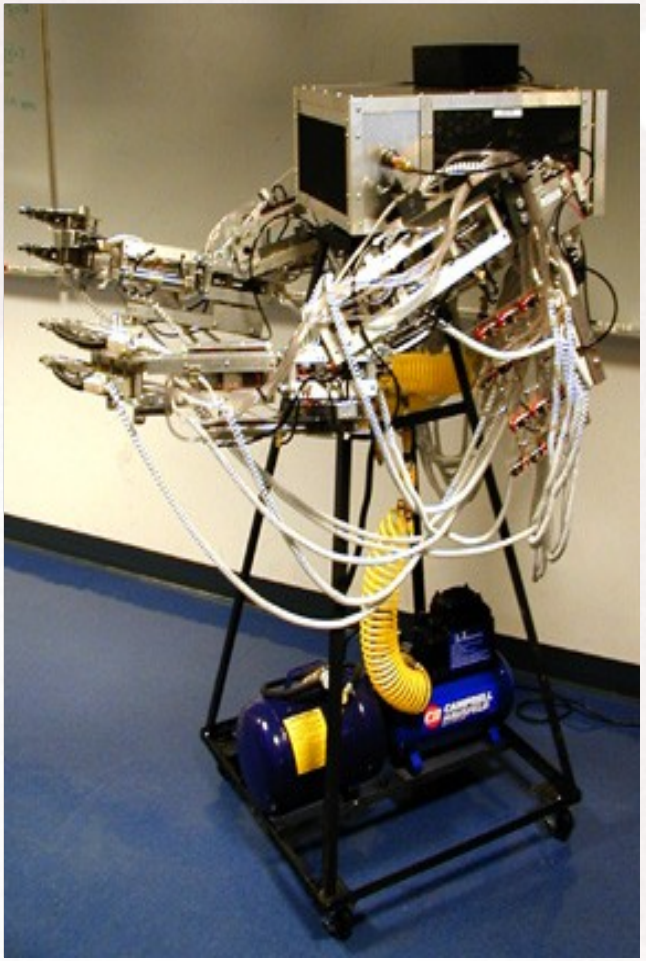
- **Robot**, with sensors and motors
- **Seed program**, Intrinsic Developmental Algorithm
- Engaging Environment
- Can the robot + program + environment + time **develop intelligence**?

- We coined the term “Developmental Robotics”

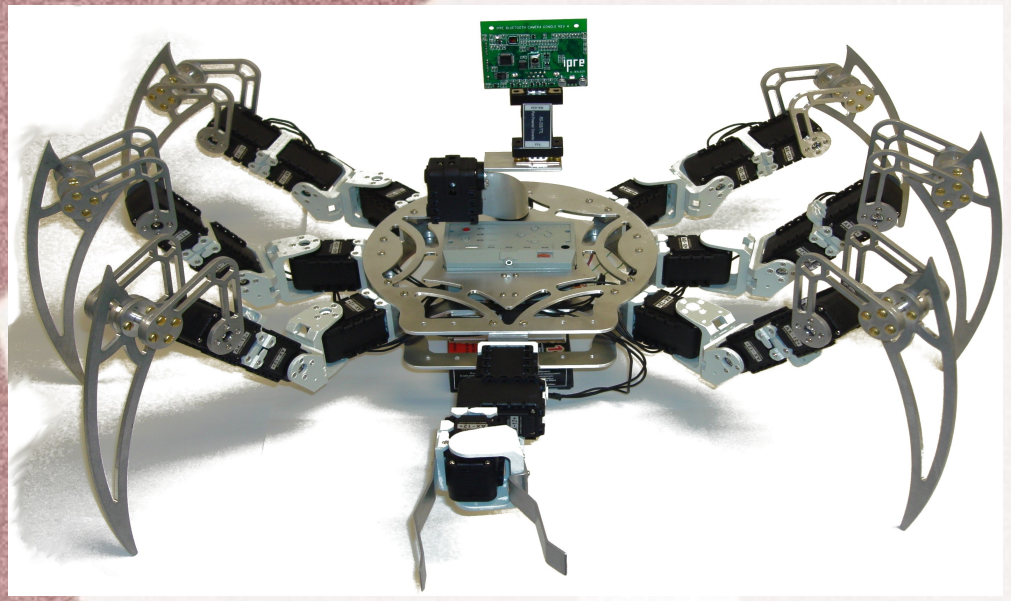
Developmental Robotics

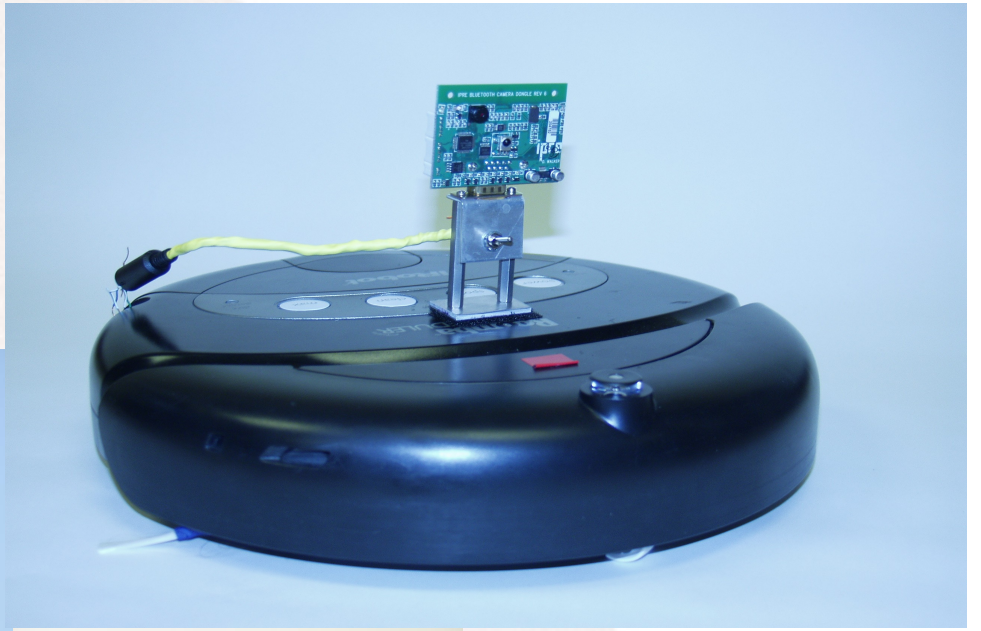
- Focuses on the autonomous self-organization of general-purpose, task nonspecific control systems
- Gets its inspiration from developmental psychology and developmental neuroscience
- Explores the kinds of cognitive capabilities that a robot can discover through self-motivated actions
- Relies on experience and internal “conceptual” organization

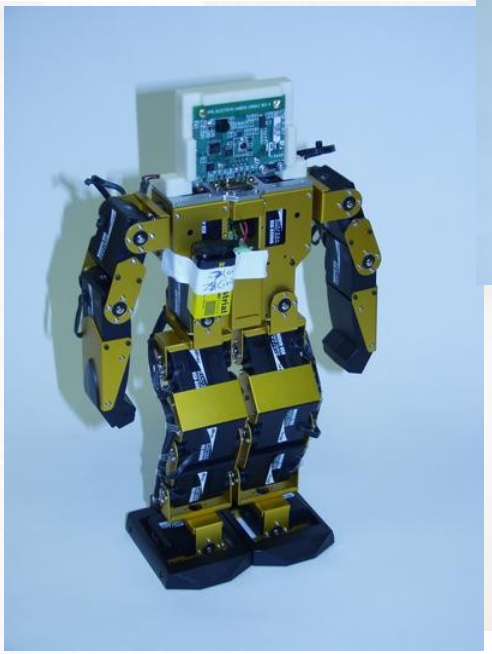
Robots



Robots

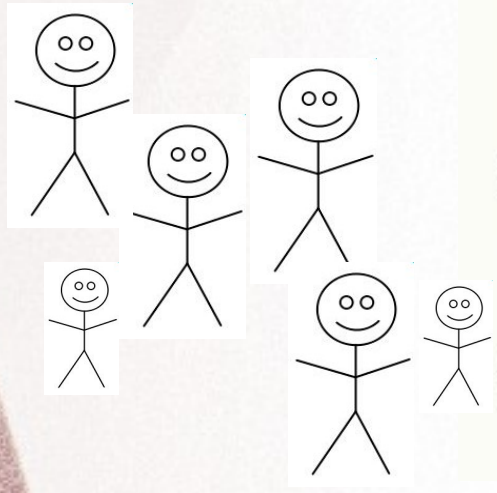




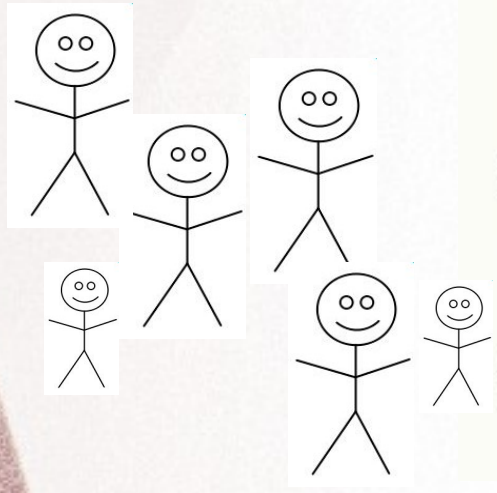


Crisis in computer science!

Producing Computer Scientists
The Pipeline Model

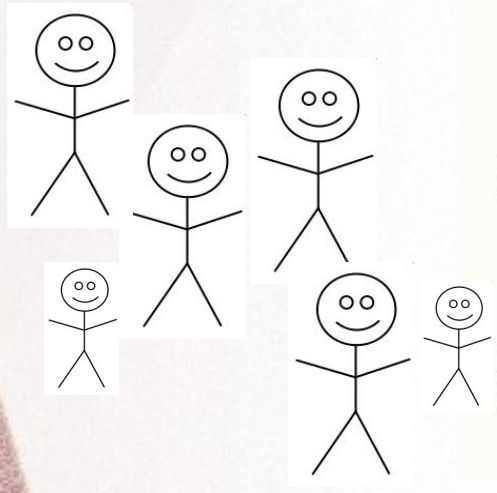


Producing Computer Scientists
The Pipeline Model



Producing Computer Scientists
The Pipeline Model

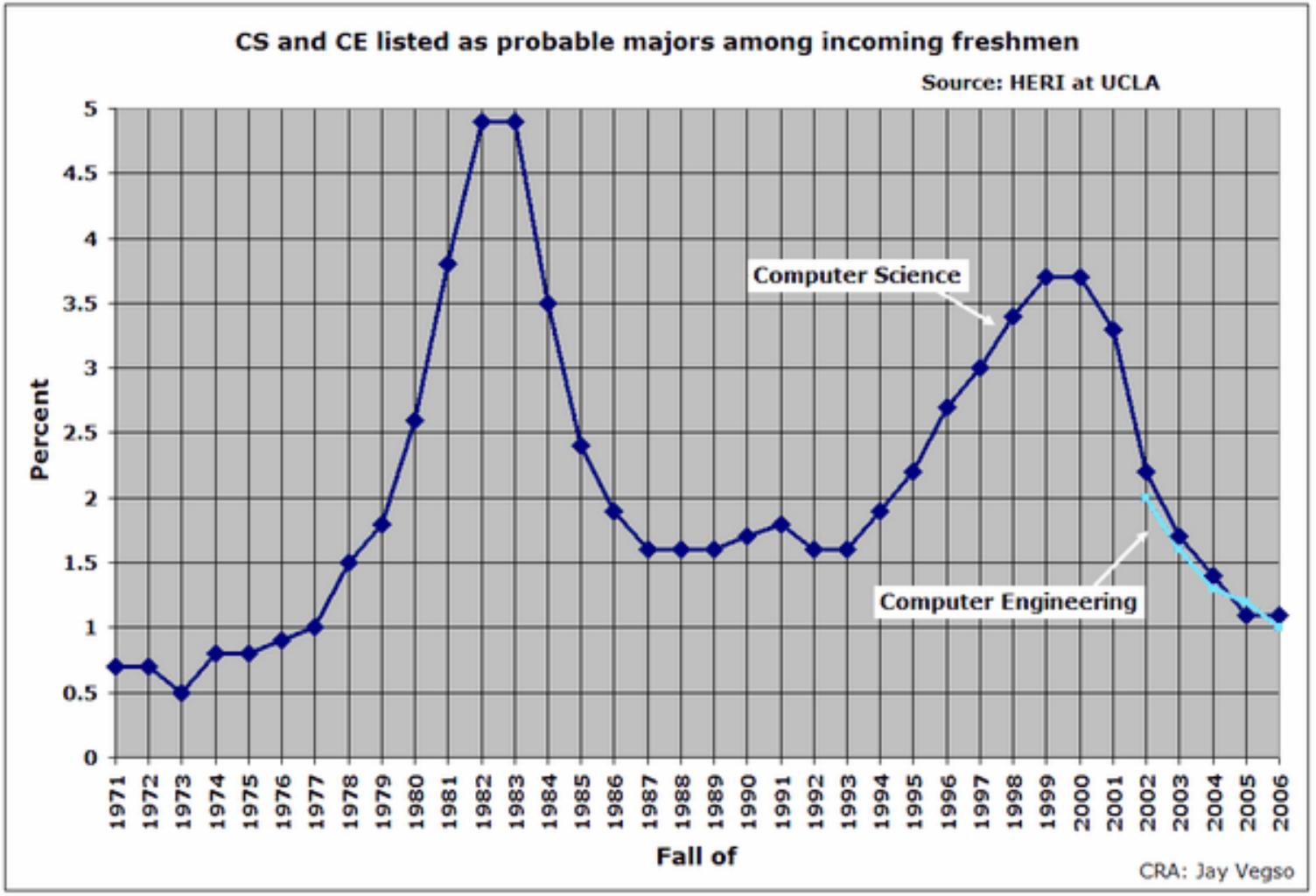
1. Attraction



2. Retention

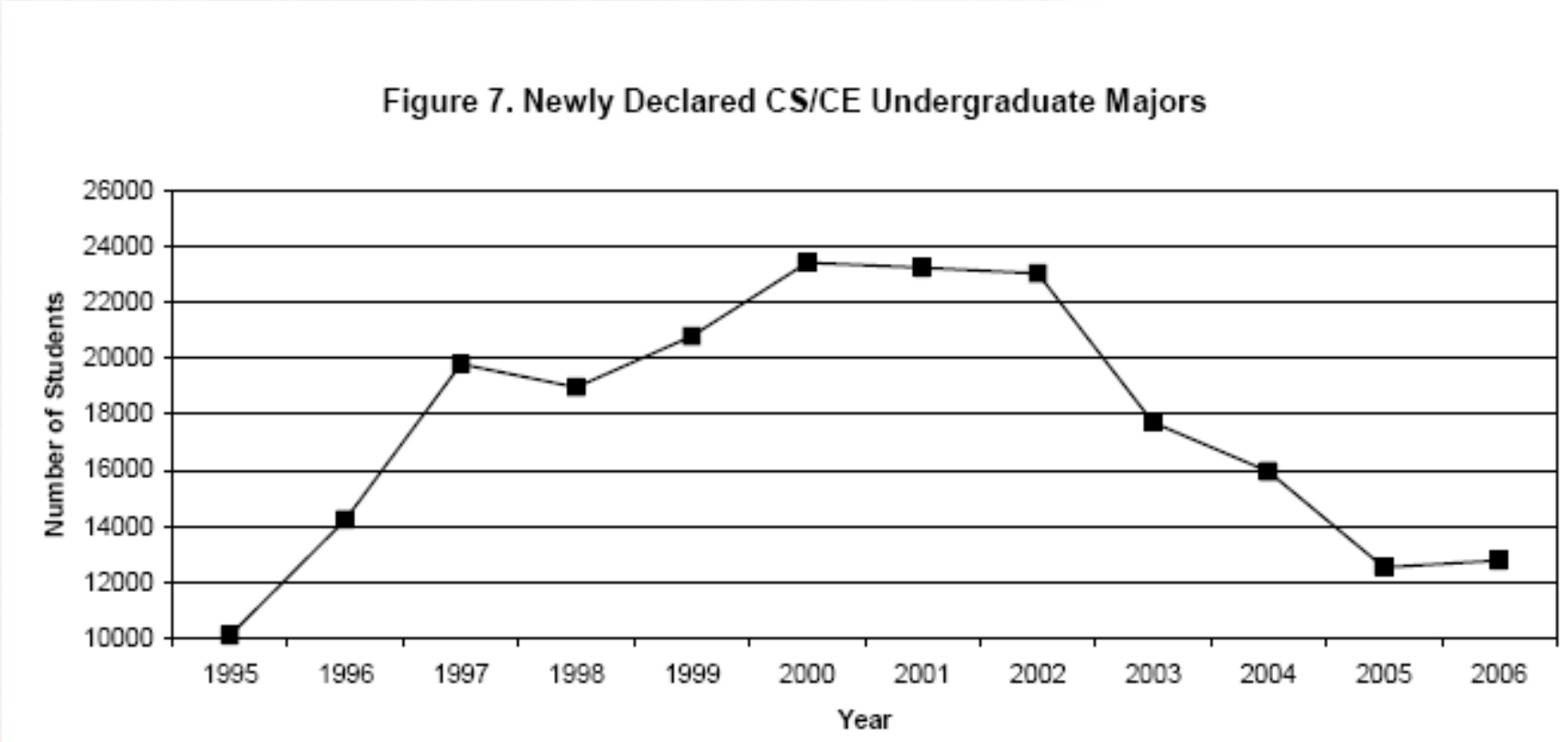
3. Diversity

1. Attraction



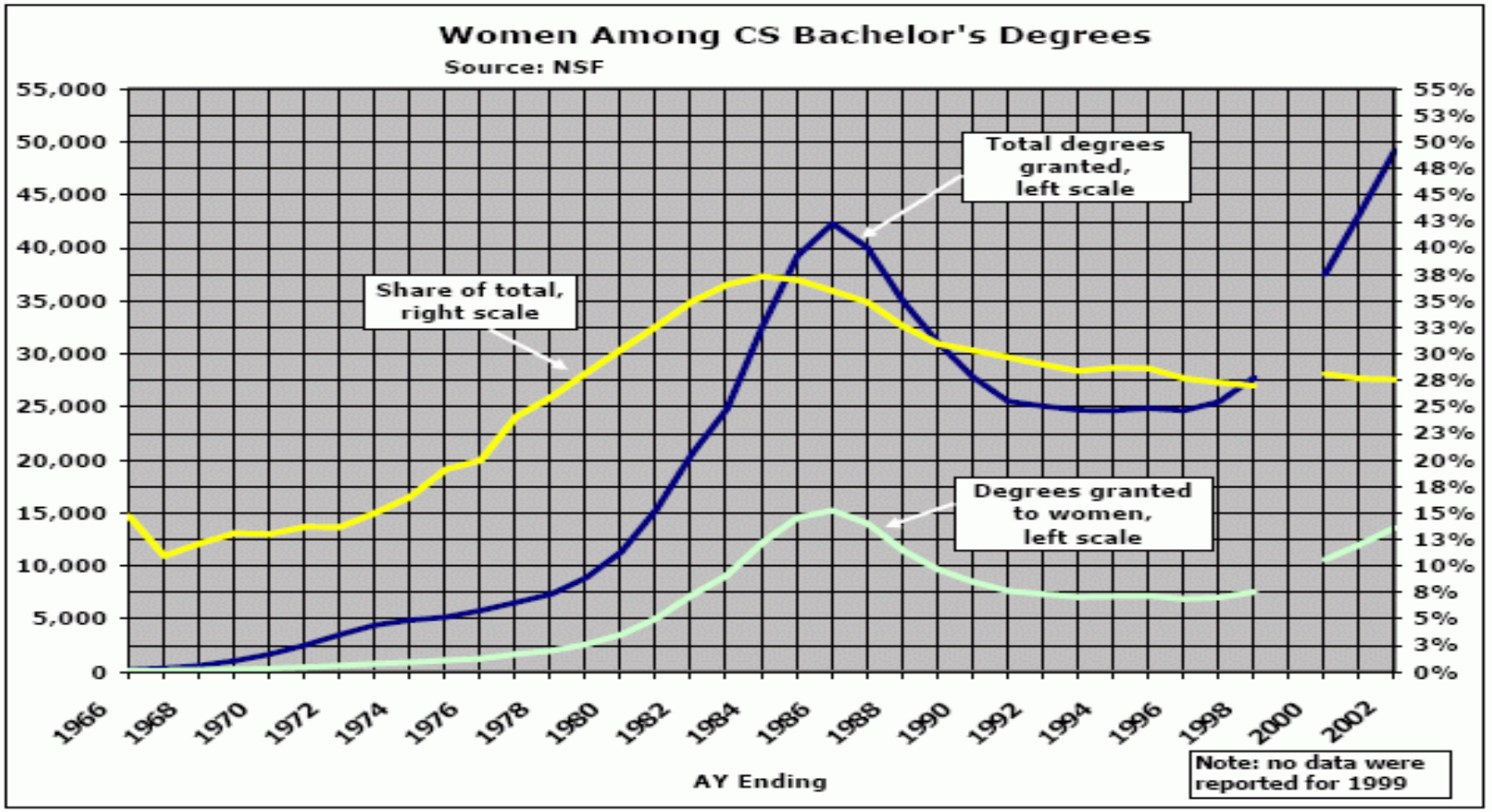
From: Low Interest in CS and CE Among Incoming Freshmen, CRA Bulletin, 2/6/2007.

2. Retention



From: CRA Taulbee Survey Report 2005-06, March 6, 2007.

3. Diversity
Women and Underrepresented Groups



From: Computer Science Bachelor's Degrees Granted to Women, CRA Bulletin, April 5, 2006.

Why?

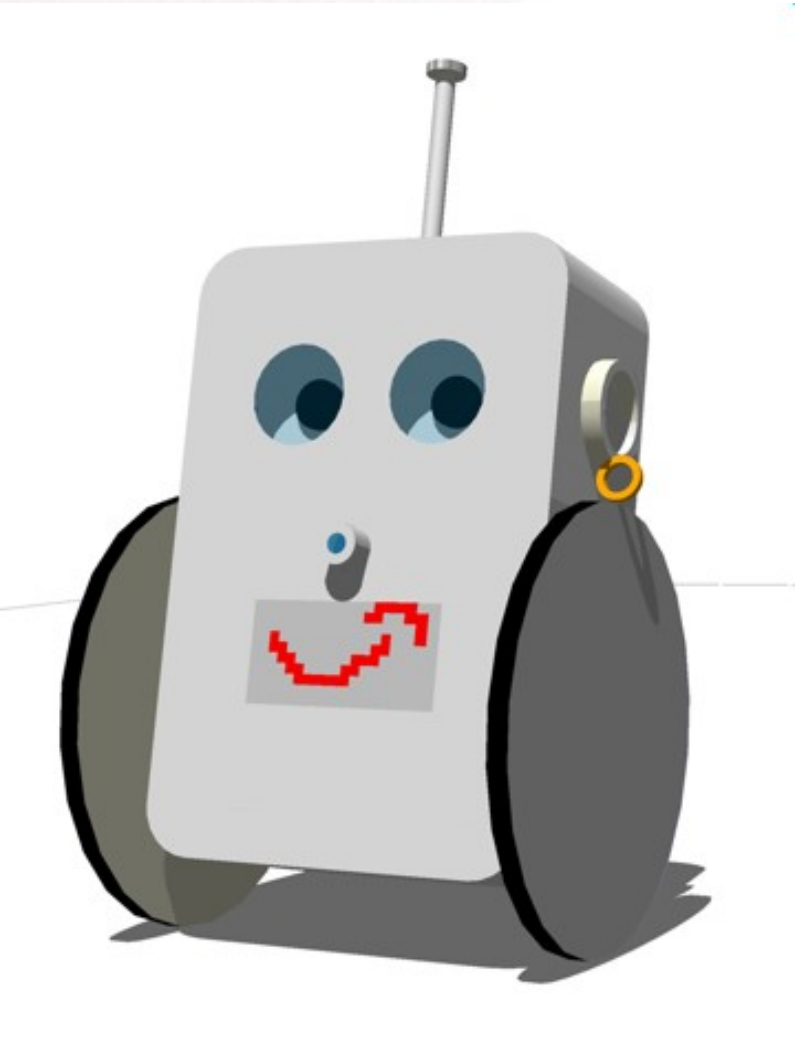
- "Intro to CS" became the "**Intro to Programming**"
- CS became more about where to put the **curly braces** and less about the science, less about the problem solving
- Without a real problem to solve
  - CS became **less authentic**
  - CS became **less relevant**
- Irrelevancy made it impersonal

Institute for Personal Robots in Education

- **Research Project**
  - Mission: explore making CS education more fun and effective through the context of a *personal robot*
  - Goal: Affect all levels, from middle school to graduate school
  - Initial Target: CS1
- 3-year seed funding provided by Microsoft Research (about $2M)
- Joint effort hosted at Georgia Tech with Bryn Mawr College
- **Special ingredient and hypothesis:**
  - **A *personal robot* for every student**

Personal Robot

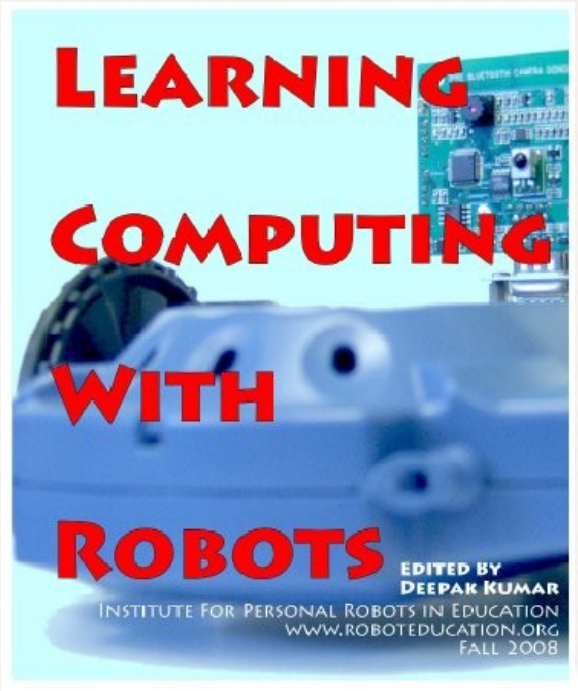
```
turnLeft(.5)
speak(“Hello, BMC!”)
playMusic(“madonna.wav”)
setFace(“smile”)
takePicture()
penDown(“red”)
```



IPRE Pilot Hardware Kit Featuring Parallax's Scribbler

- 6 Light sensors
- 7 IR sensors
- Stall sensor
- Speaker
- 5 LEDs
- 2 motors
- Bluetooth wireless
- Camera
- Gamepad

Available from Amazon.com, Kinkos, and lulu.com



$17.95

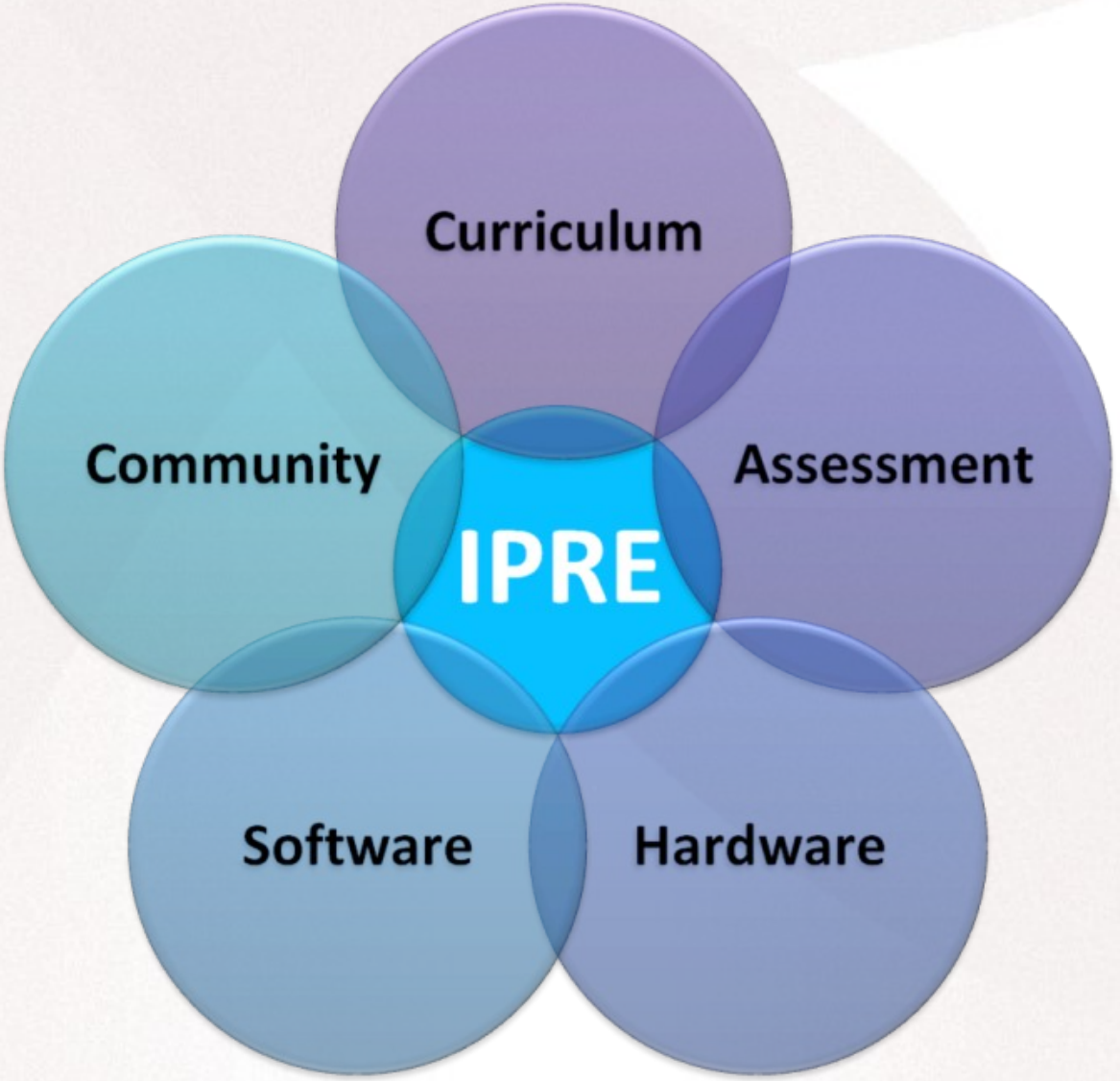
$199.95

Myro Software

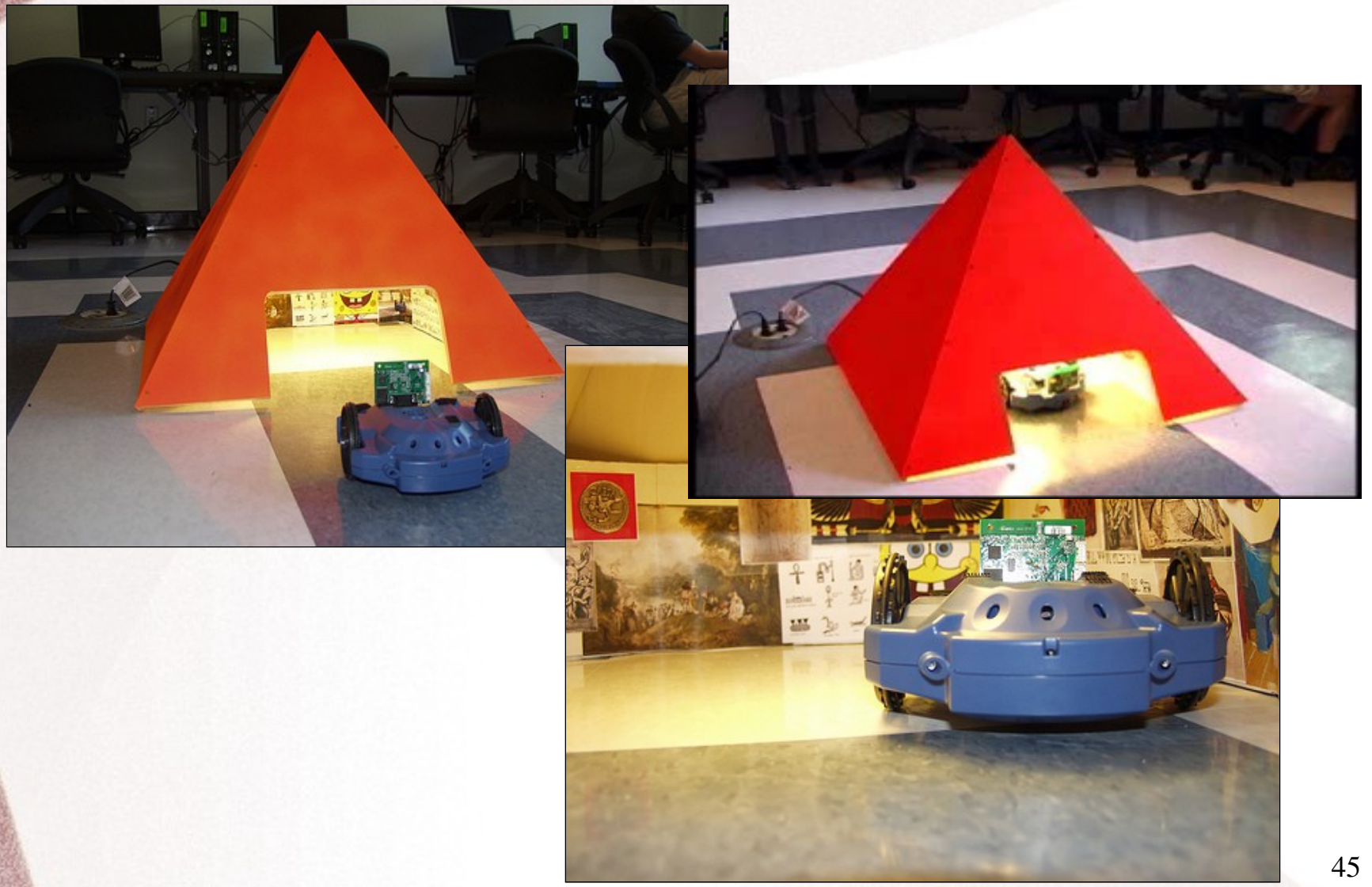
Free, and open source

Runs on Linux, Mac, and Windows

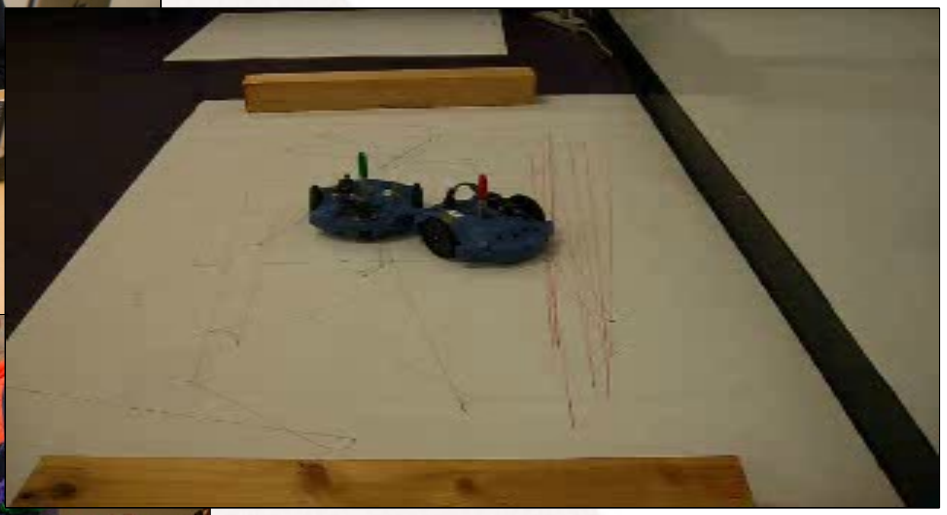
Can you really change an entire field with a curriculum?



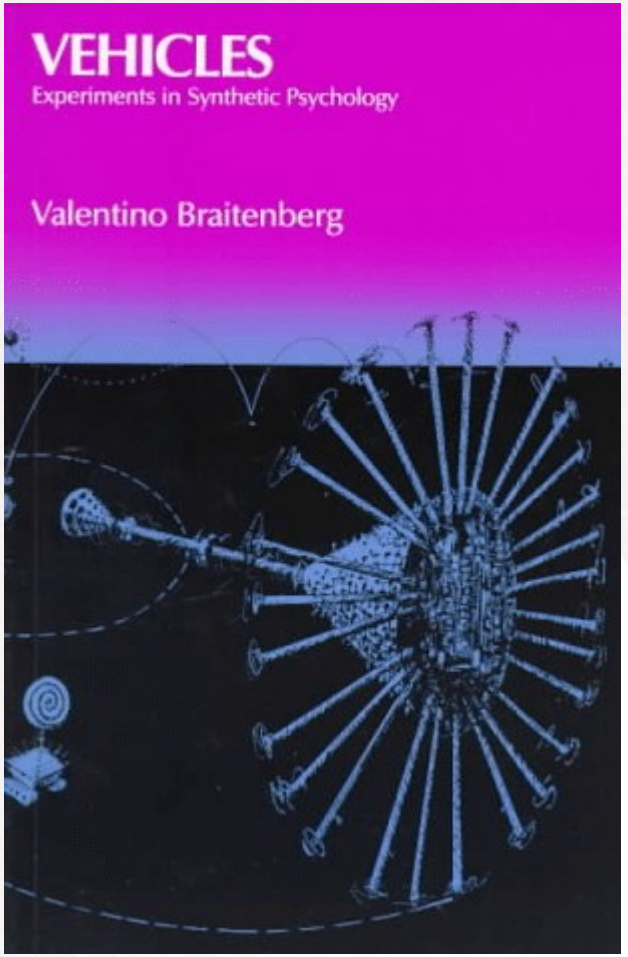
A CS1 Assignment: Exploring a Pyramid



Programming as a social activity



Connections to Biology and Psychology



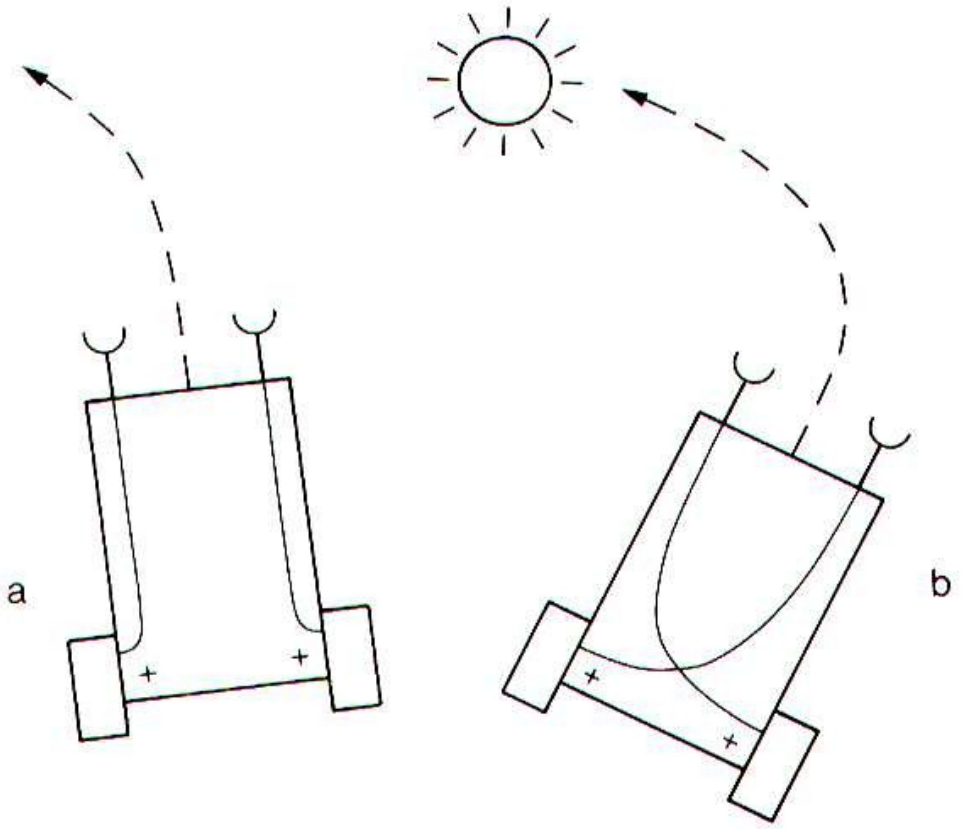


Figure 3
Vehicles 2a and 2b in the vicinity of a source (circle with rays emanating from it). Vehicle 2b orients toward the source, 2a away from it.

“Civic Computing”

BRYN MAWR

Gateways for...

NEWS
- Bryn Mawr Now
- Recent Issues
- Bryn Mawr in the News
- College Publications
- Public Affairs Office

EVENTS
- Campus Events Calendar
- Performing Arts Series
- Visiting Writers Series
- Library Exhibits & Lectures
- Alumnae/i Events Calendar
- Conferences and Events

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SEARCH

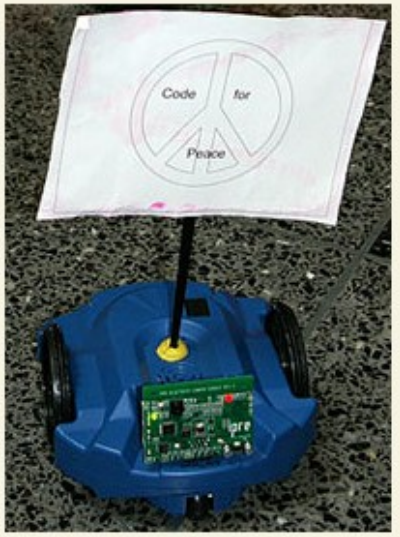
ADMISSIONS | ACADEMICS | CAMPUS LIFE | NEWS & EVENTS | VISIT | FIND

Bryn Mawr Now

XML

October 25, 2007

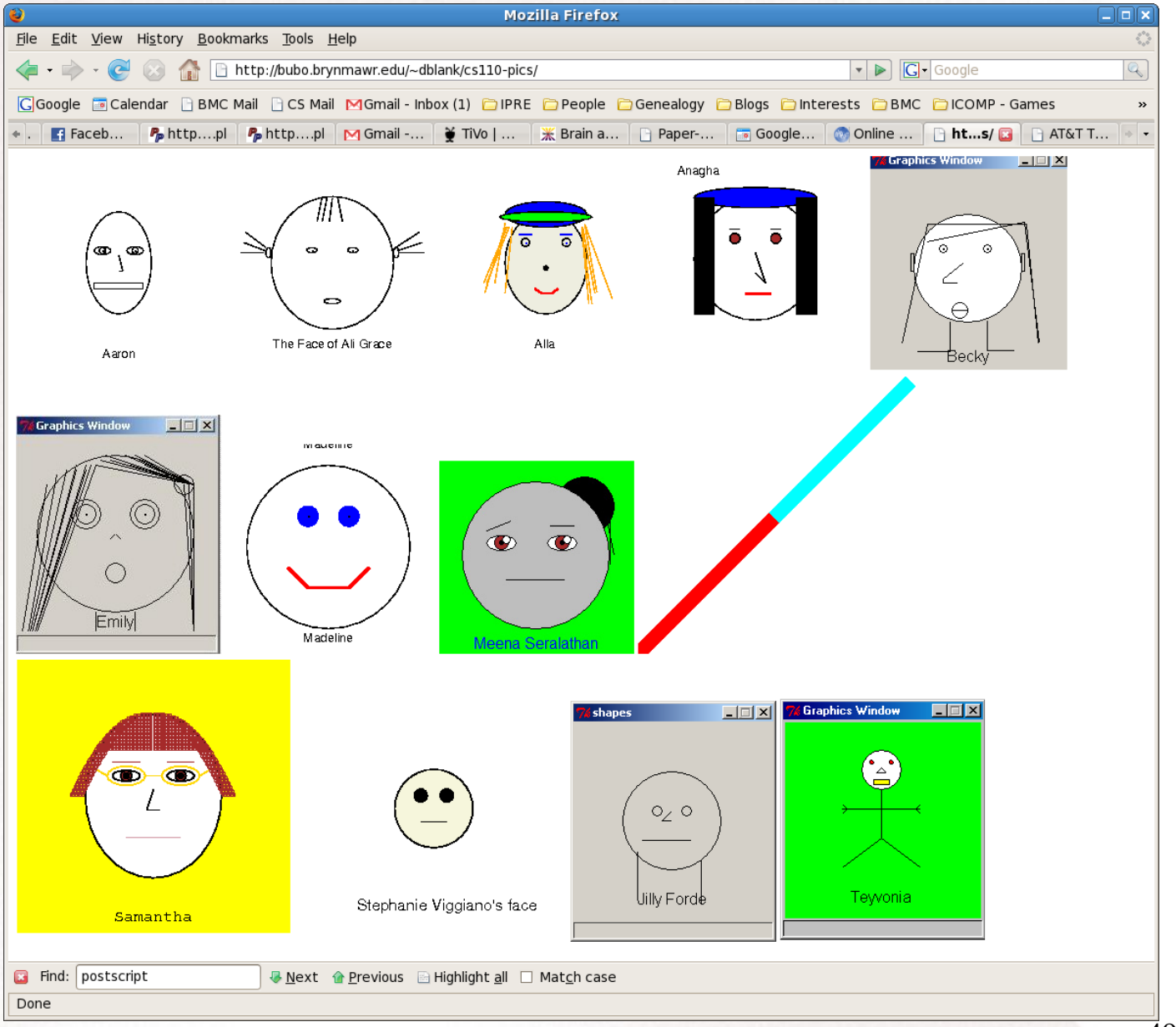
Peacebots Picket Robotic Violence



What do robots do in the real world? They vacuum floors, work on assembly lines, assist with laparoscopic surgery and, as of last Saturday, march for peace.

The peacebots that demonstrated at the Franklin Institute on Oct. 20 were programmed by four students from Associate Professor of Computer Science Doug Blank's introductory course in computer science, which uses

Graphics and Objects: Day 1



Games and Robots

YouTube game videos available at **cs.brynmawr.edu/games**

Music and Robots

Saxophone

A saxophone or similar wind instrument (*Saxofony* in ChucK)

- **setStiffness(*stiffness*)**: set reed stiffness (0.0 <= *stiffness* <= 1.0)
- **setAperture(*aperture*)**: set reed aperture (0.0 <= *aperture* <= 1.0)
- **setPressure(*pressure*)**: set pressure / volume (0.0 <= *pressure* <= 1.0)
- **setVibrato(*vibratoFreq*, *vibratoGain*, *noiseGain*)**: set frequency and gair <= 1.0)
- **setBlowPosition(*position*)**: set blow position / lip stiffness (0.0 <= *positio*
- **startBlowing(*strength*)**: start blowing (0.0 <= *strength* <= 1.0)
- **stopBlowing(*strength*)**: stop blowing (0.0 <= *strength* <= 1.0)
- **setAttackRate(*seconds*)**: set rate of attack (sound's beginning) in seconds

MoogSynthesizer

A Moog synthesizer (*Moog* in ChucK)

- **setFilterQ(*floatValue*)**: set filter's Q value (0.0 <= *floatValue* <= 1.0)
- **setFilterSweepRate(*rate*)**: set filter sweep rate (0.0 <= *rate* <= 1.0)
- **setVibrato(*freq*, *gain*)**: set frequency and gain of vibrato (*freq* in Hertz, 0.0
- **setAfterTouch(*afterTouch*)**: set aftertouch (0.0 <= *afterTouch* <= 1.0)

StruckBar

Struck bar instruments (*ModalBar* in ChucK)

Orchestrating

After you get familiar with a single instrument, then you migl instrument.

```
from myro import *
from myro.chuck import *

initChuck()

def playSaxophone():
    sax = Saxophone()
    sax.connect()
    sax.startBlowing(1)
    wait(1)
    sax.stopBlowing(1)

def playMandolin():
    mandolin = Mandolin()
    mandolin.connect()
    mandolin.pluck(1)
    wait(1)
```

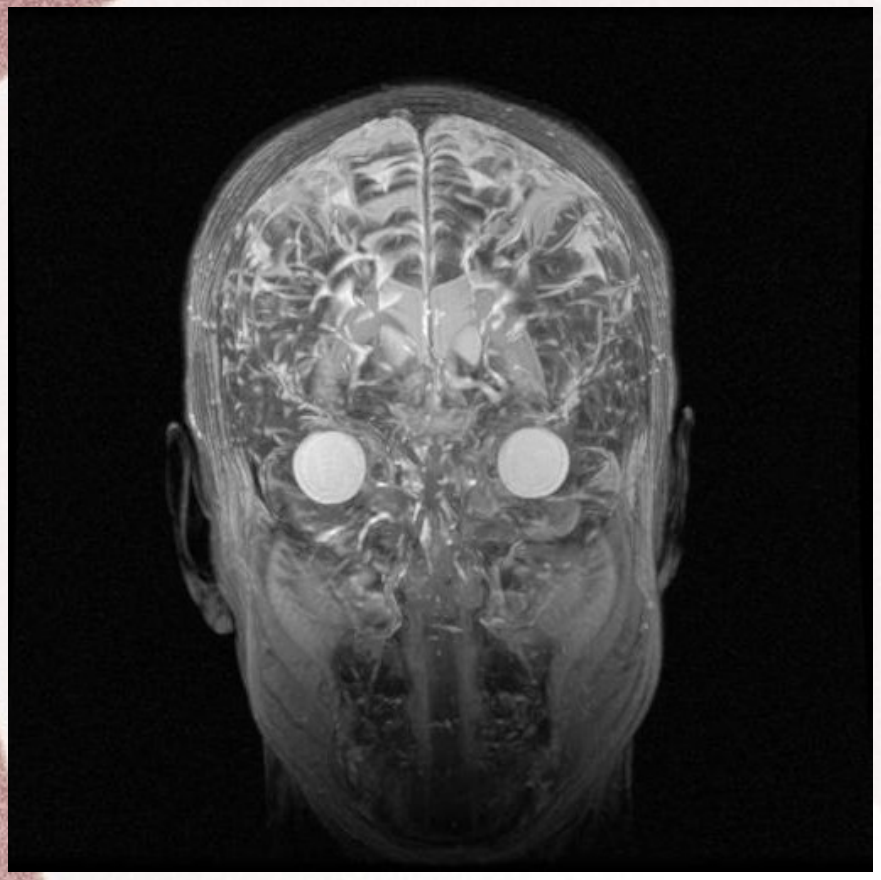
You can test each one of those independently by simply rur

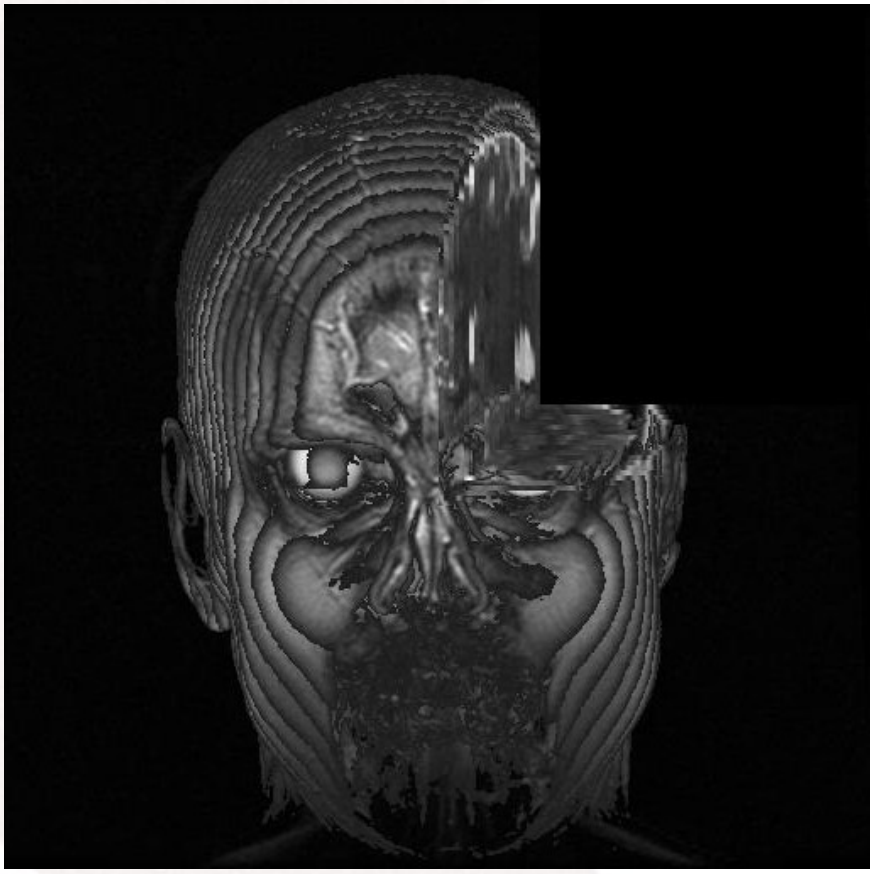
```
playSaxophone()
```

Once you have more than one intrument function written, yo

```
doTogether(playSaxophone, playMandolin)
```

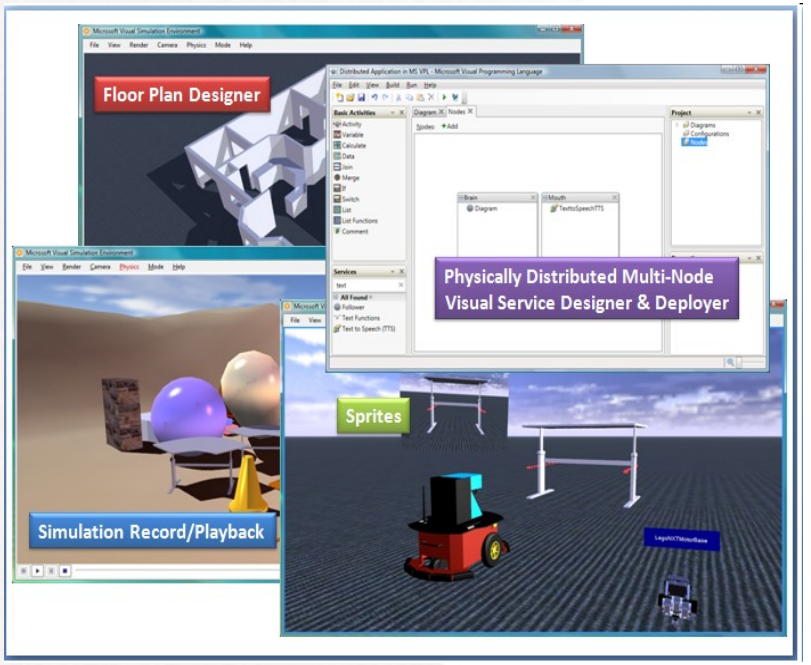
Vision and Image Processing





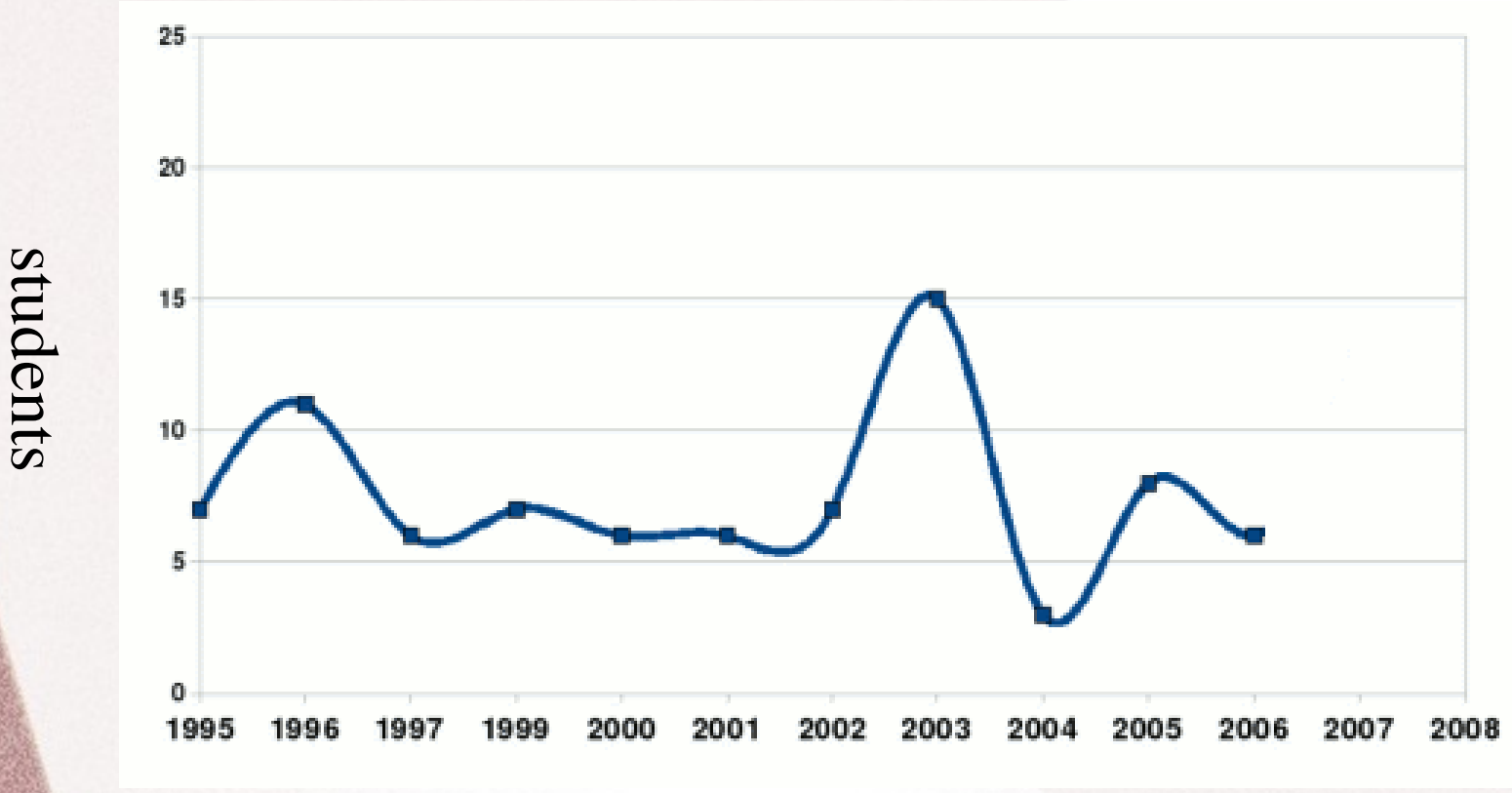
Advanced Robotics

- AI
- Neural Networks
- Vision
- Mapping
- Maze Following



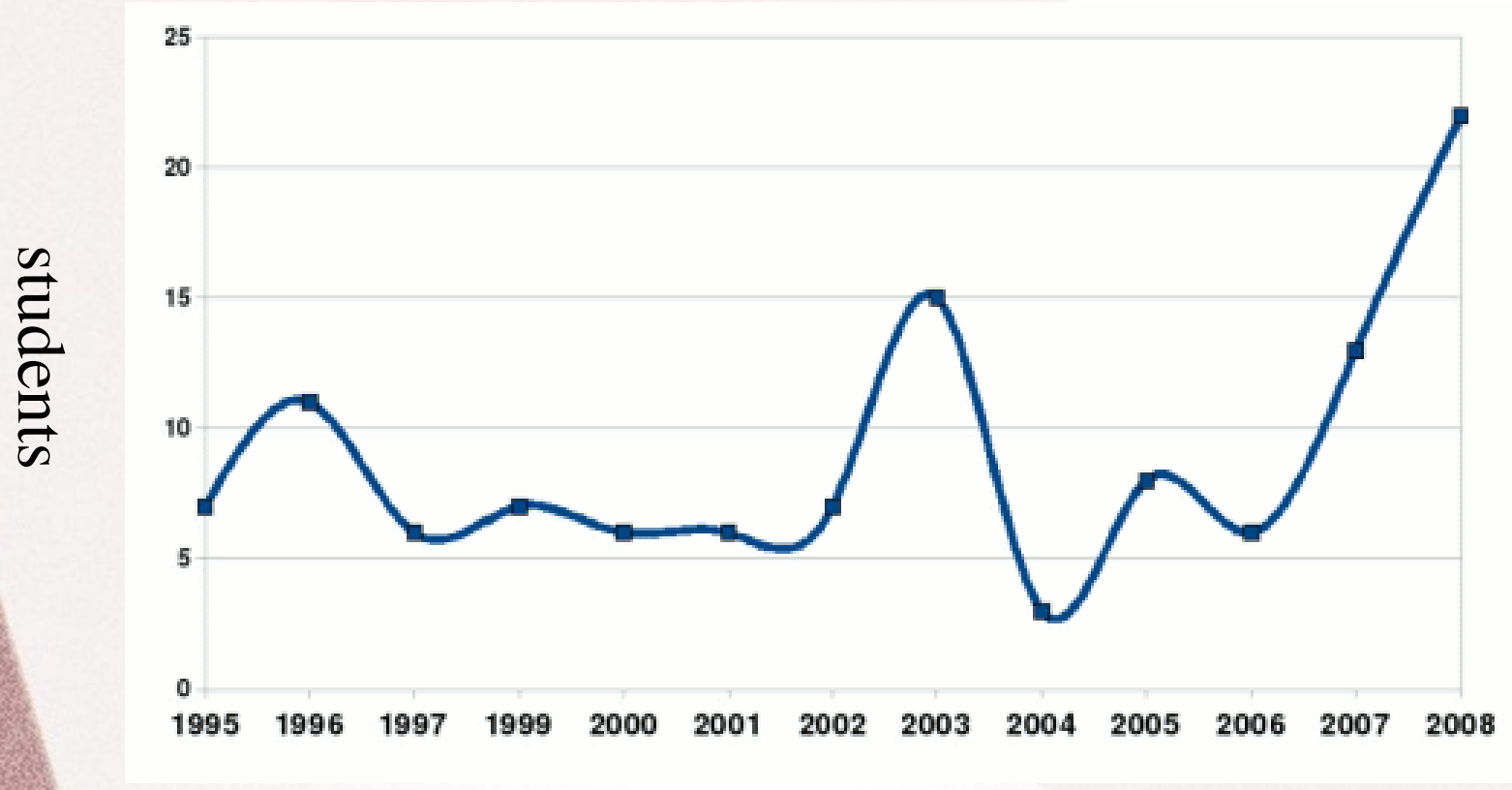
- ...and Developmental Robotics

Retention?



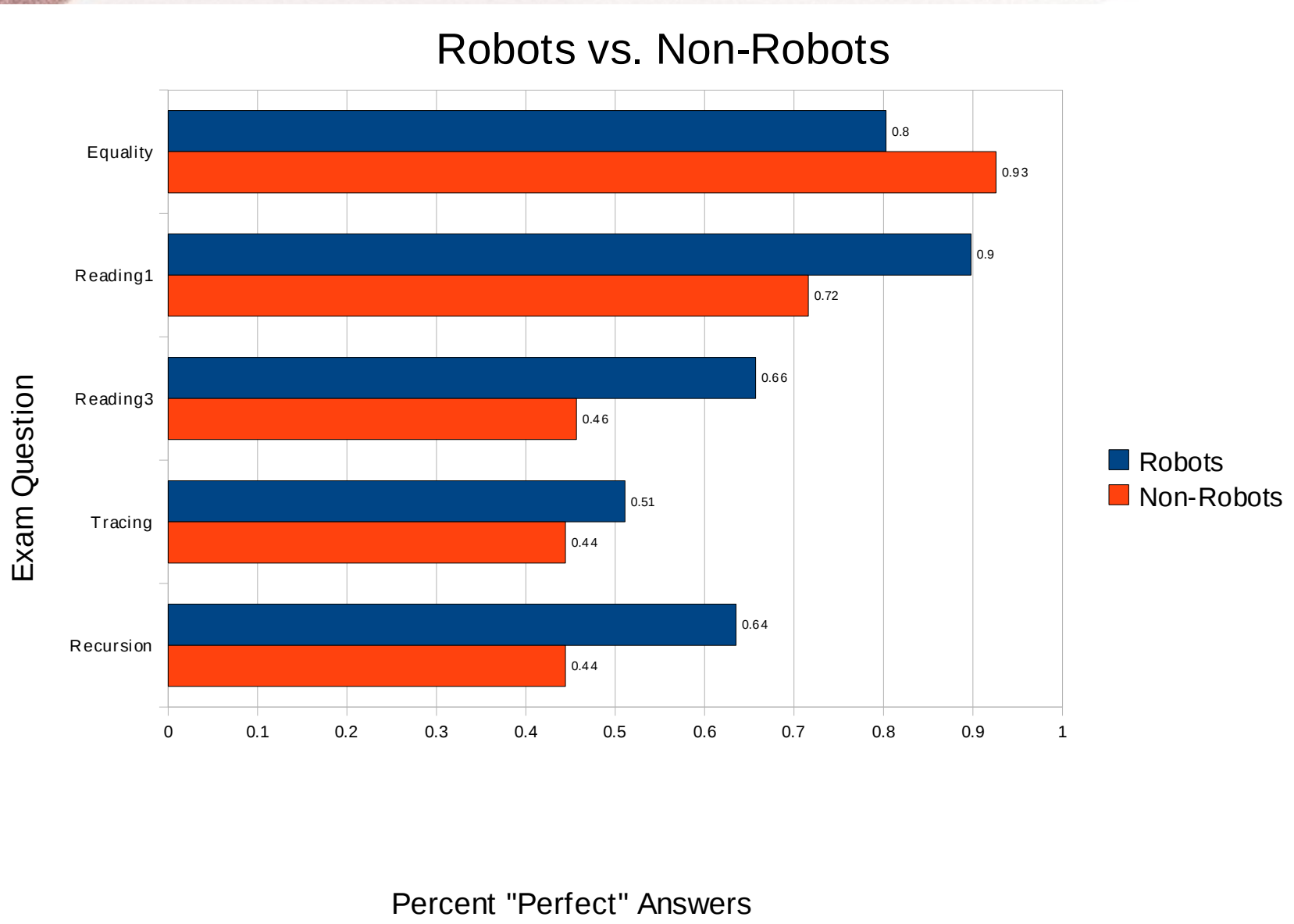
Bryn Mawr College – Population of CS2

Retention!



Bryn Mawr College – Population of CS2

Results: Robot students did on average 10% better

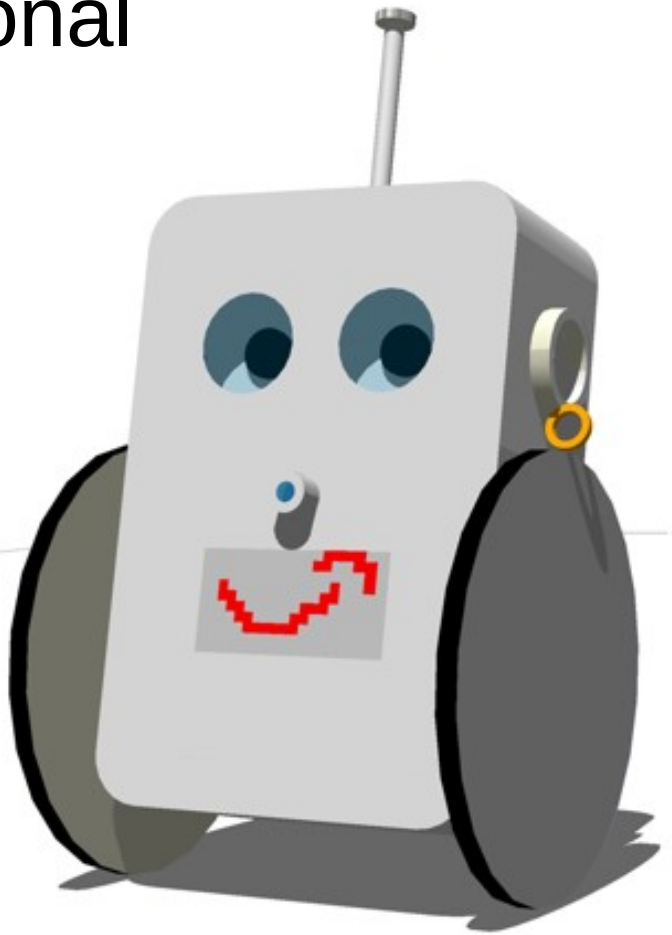


Analysis

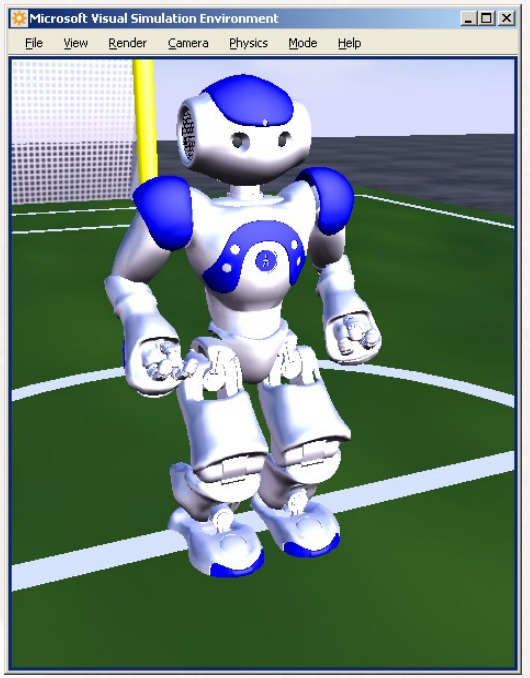
- **Learned CS concepts** through robots
- Robots made learning experience **more hands-on, tangible, and exciting**
- Most frustrating parts were dealing with robot **hardware** inconsistencies
- Viewed CS as a type of logic and **problem solving;** requiring patience & thought
- Discovered that CS and robots are **applicable to the real world**

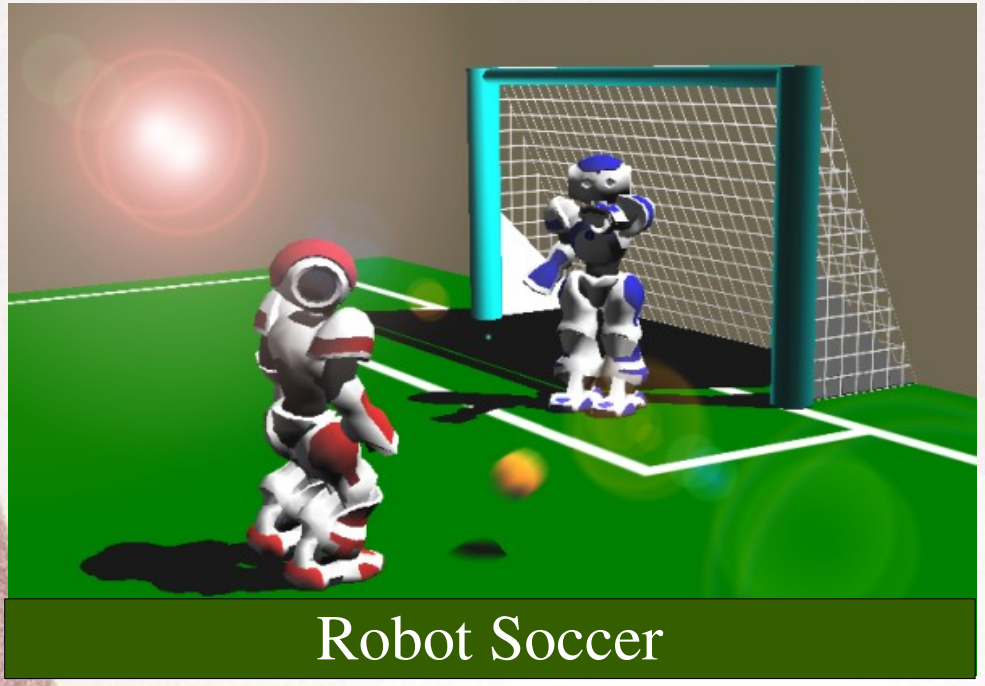
What's Next?

- NSF Funding for next two years
- Develop an infrastructure for many languages and additional libraries
- Further develop the robo-ed community
- Inform other scientists about results



Humanoid Robots





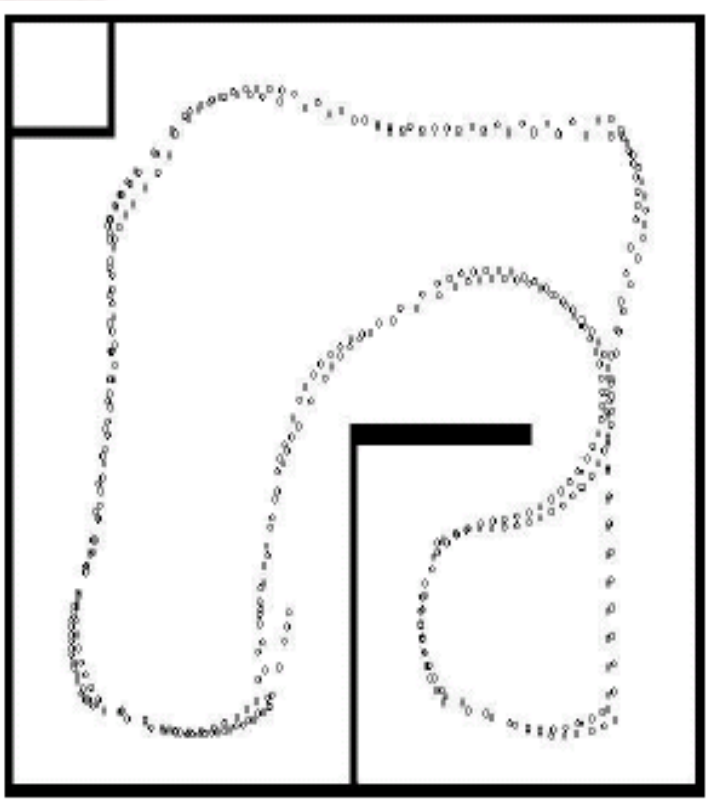
Robot Soccer

Developmental Robotics

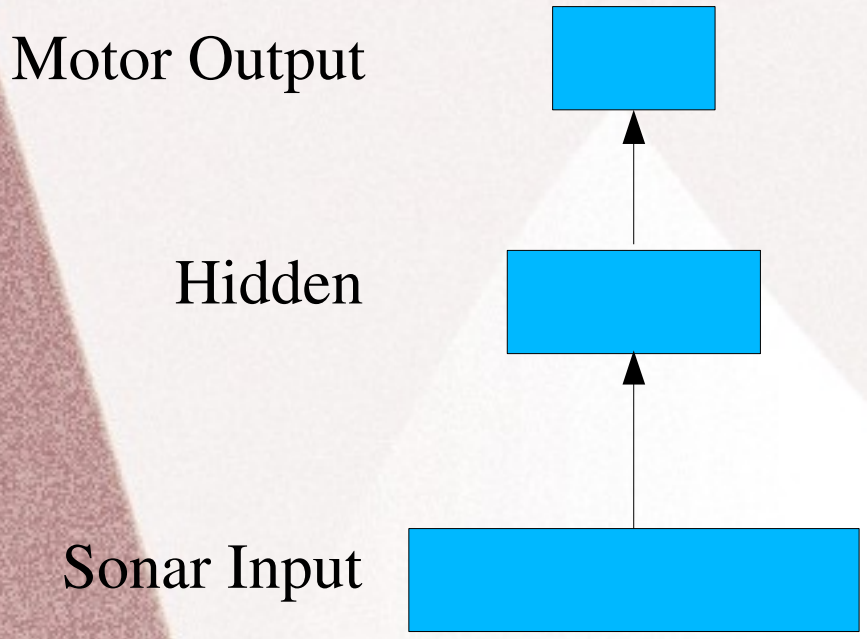
Now we have some nice tools to use in the classroom and in research

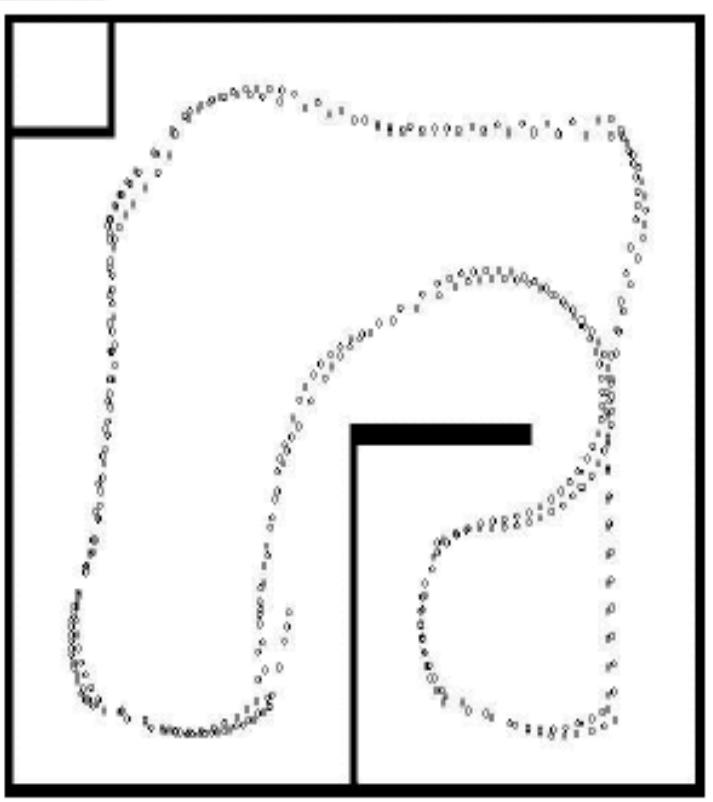
Simple Example

- Innate behavior
- Given sonar sensor readings, predict what my motors will do

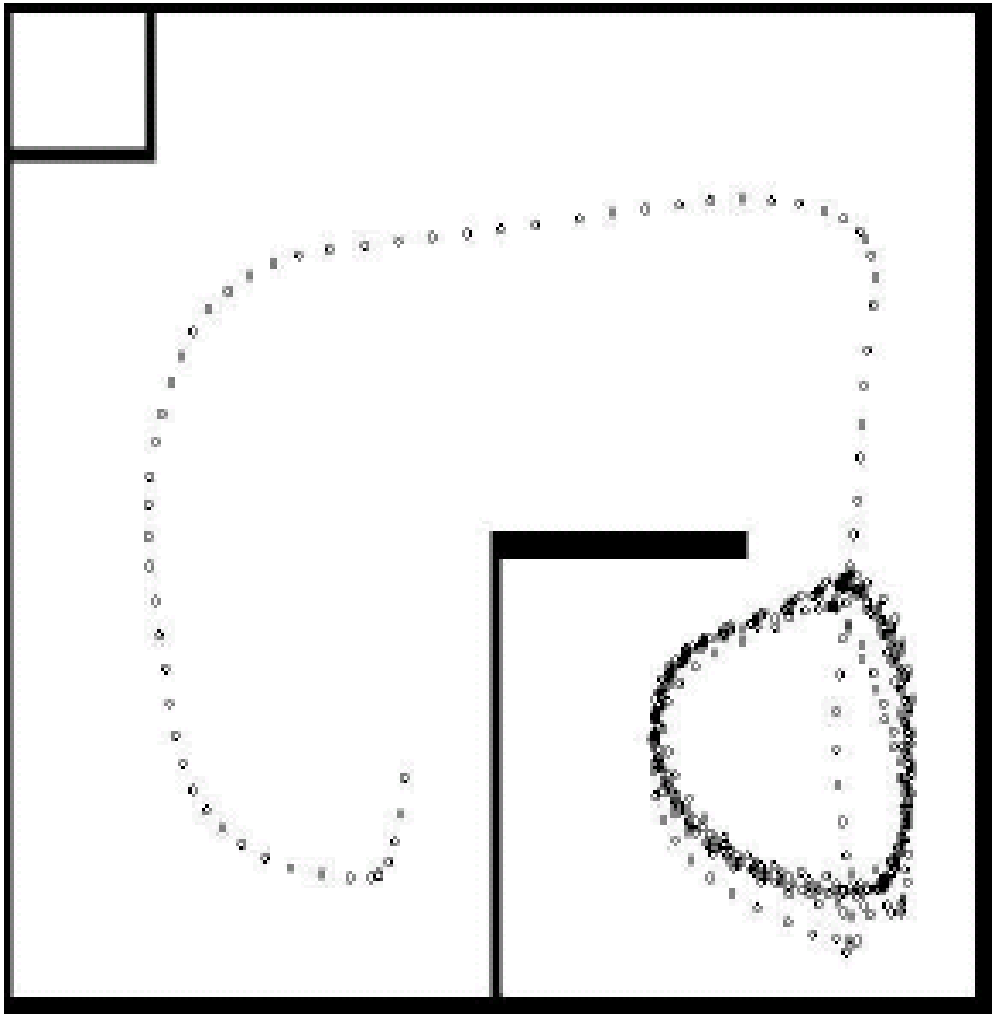


Simple Example





Wall-Following Task: Neural Network



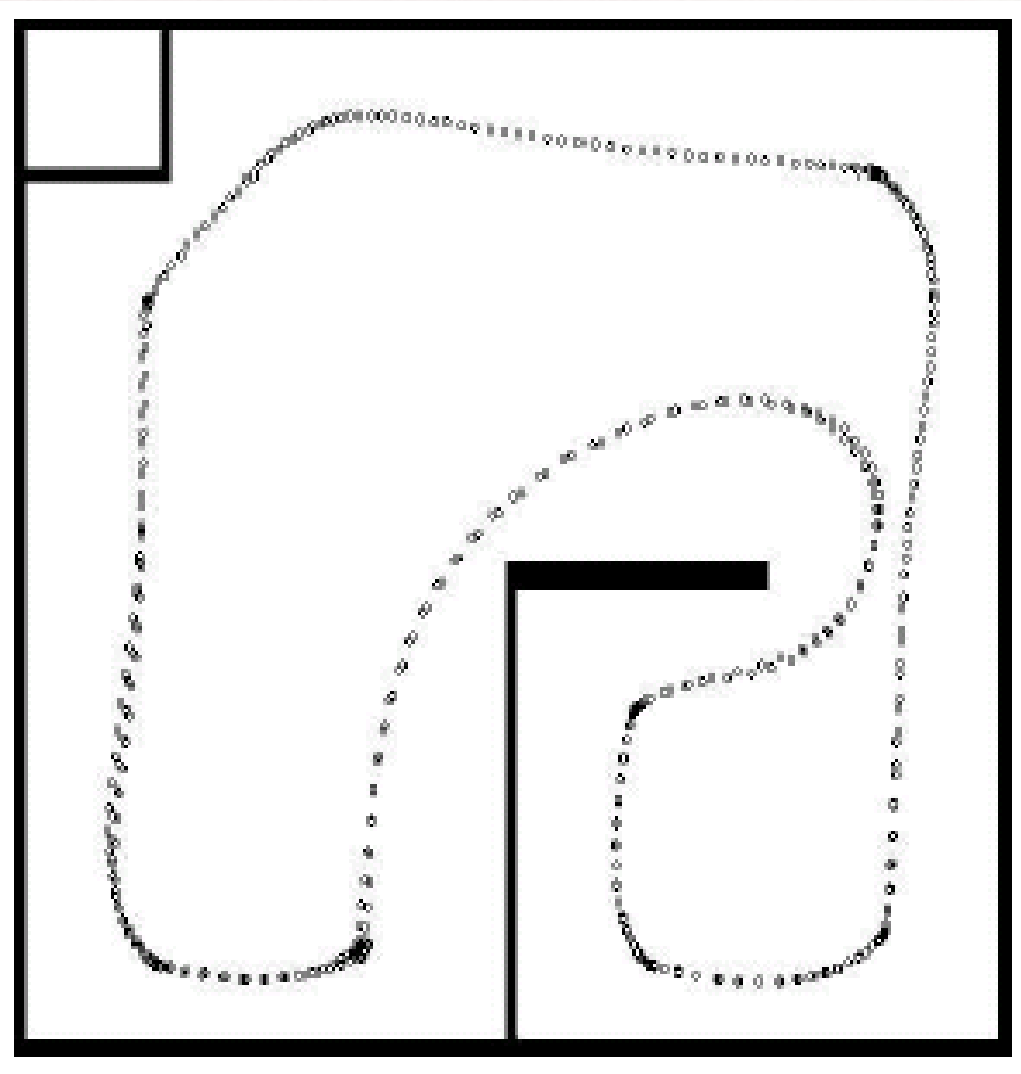
Catastrophic Forgetting

- On-line training requires on-the-fly learning
- Important events may be rare
- Mundane, long sequences overwhelm rare events
- Could be overcome by manually “balancing” data and training off-line, but that isn't Developmental Robotics
- Need an automatic, on-line data balancer...

Governor


fuel to the machine. When less fuel flows to the machine, it slows down.
Governors are used to control the speed of many engines. Without a governor, a diesel engine would keep accelerating until it flew apart.

Wall-Following Task: Governed Neural Network



Neural Network Governor

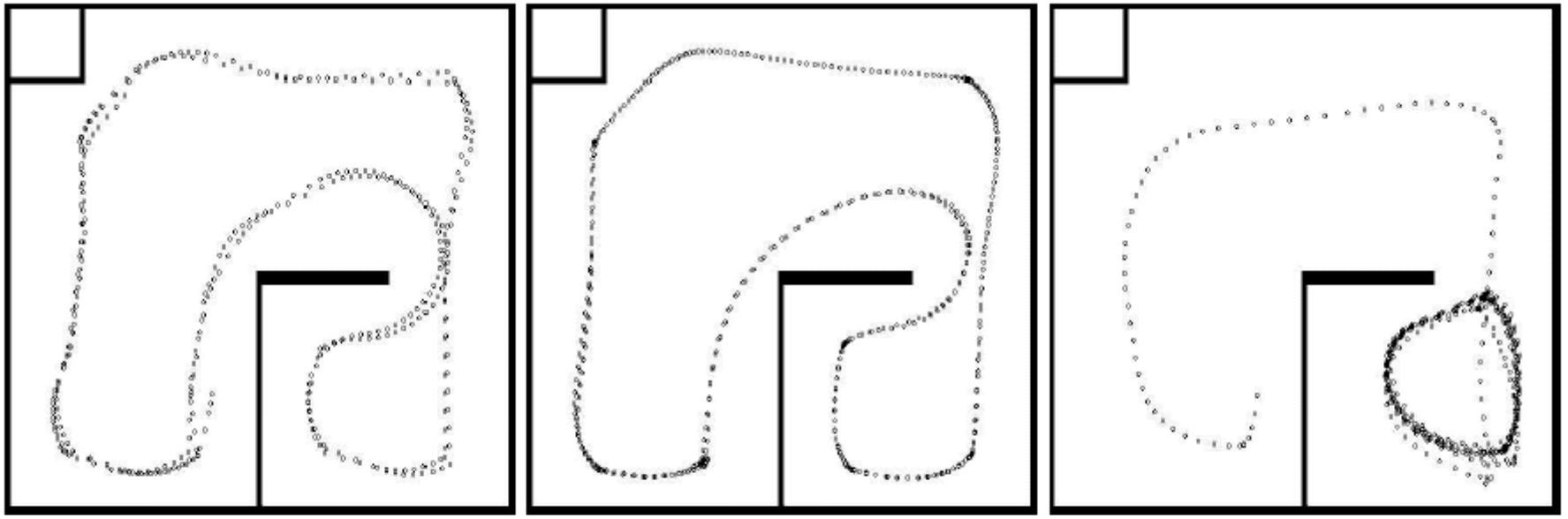
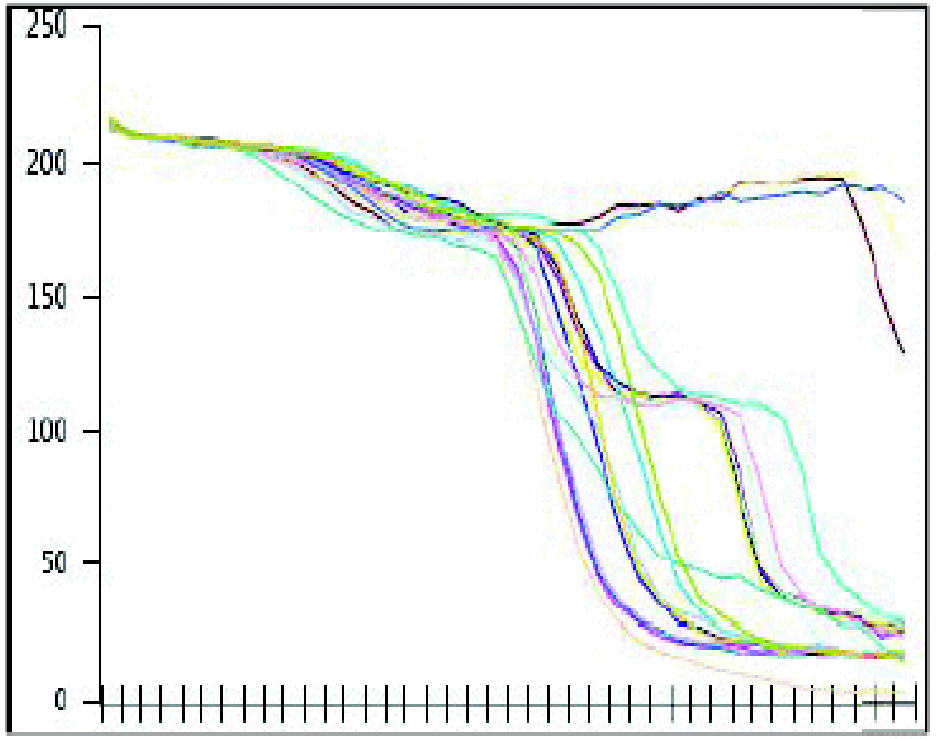


Figure 4: Example paths of the teacher, a governed neural network, and a standard neural network in the wall following task.

Learning to Predict Error Can Help a Network Learn Faster



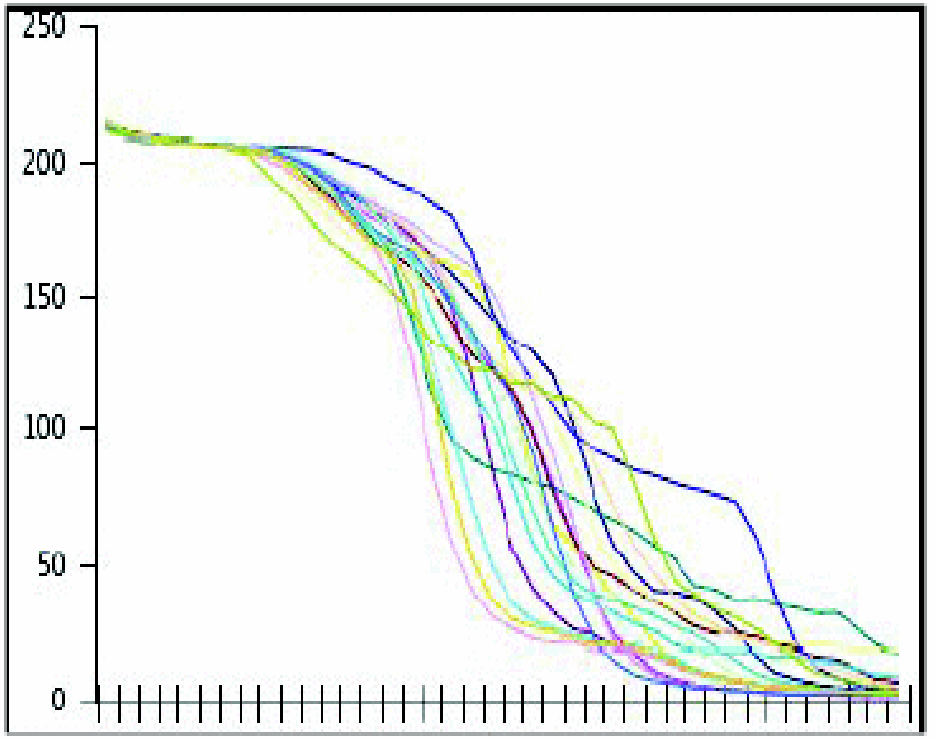
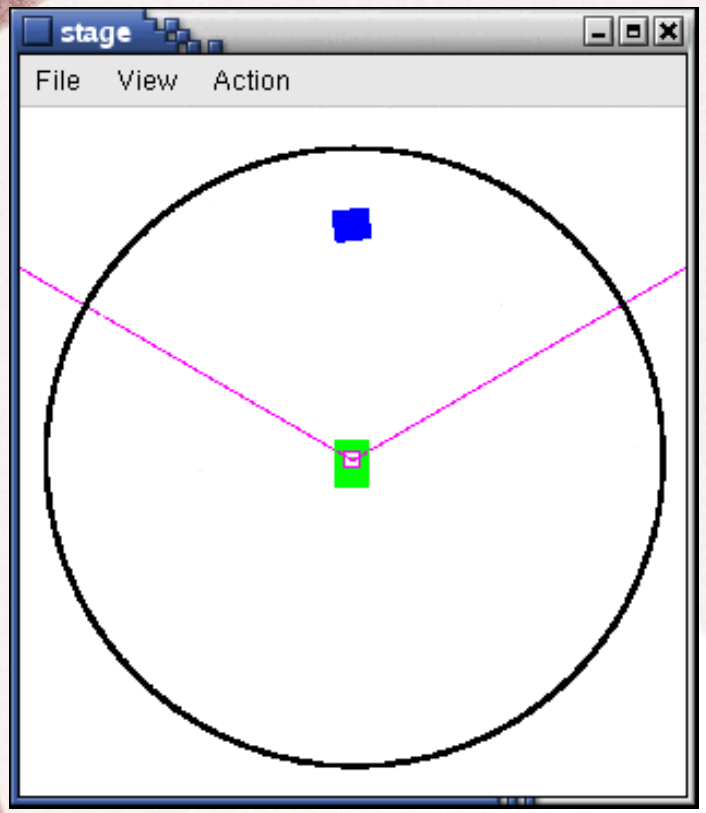


Figure 3. Performance of 20 artificial neural networks trained with back-propagation without expected error outputs (left) and performance of 20 ANN's trained with expected error outputs (right) . The X axis shows 1,000 sweeps though the corpus of 32 patterns. The Y axis shows the total summed square error for just the XOR outputs. The TSS error at sweep #1000 shows a significant difference in speed of learning, $p < (.05)$.

Developmental Robotics Framework

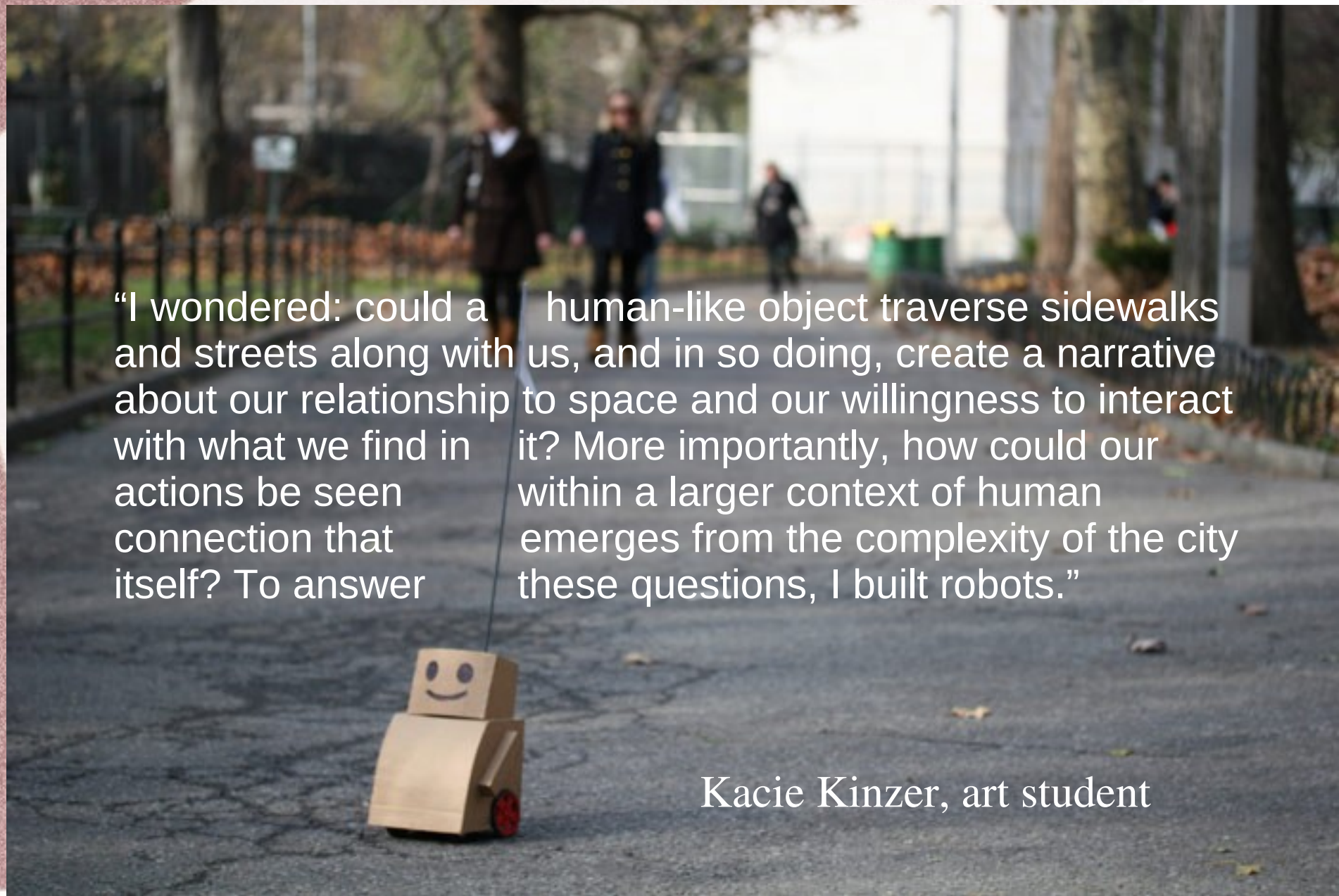


- Attempt to predict what comes next
- Focus on where you were wrong
- Repeat

Conclusions

- **Developmental Robotics** is a new, emergent approach to creating generally intelligent systems
- Computing is the new, liberal art
- CS at BMC is making an impact in research and education
  - May be seen by some as a screwball comedy
  - Sophisticated classic decades ahead of its time

Tweenbot
Anthro + CS



Tweenbot Anthro + CS