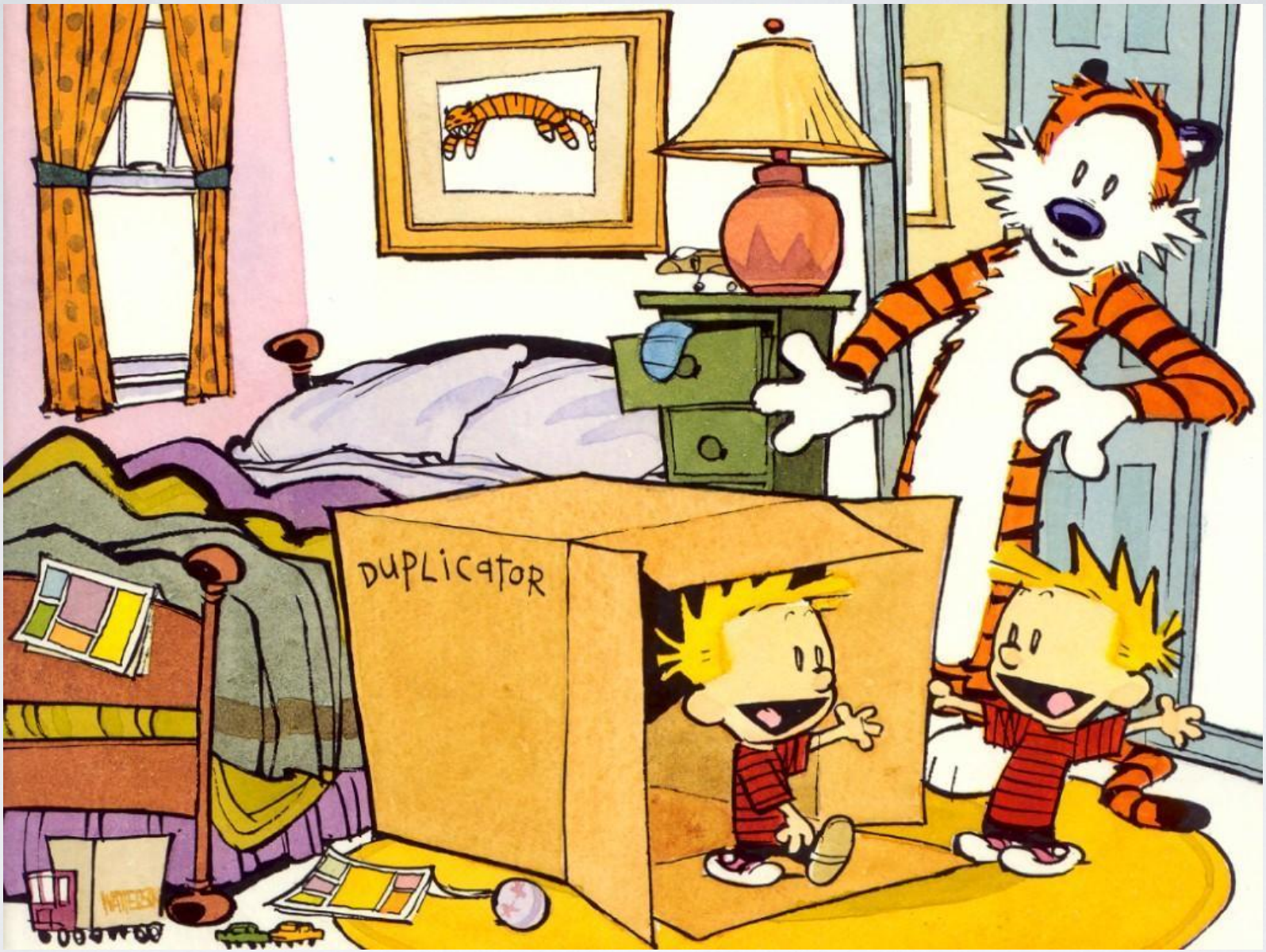
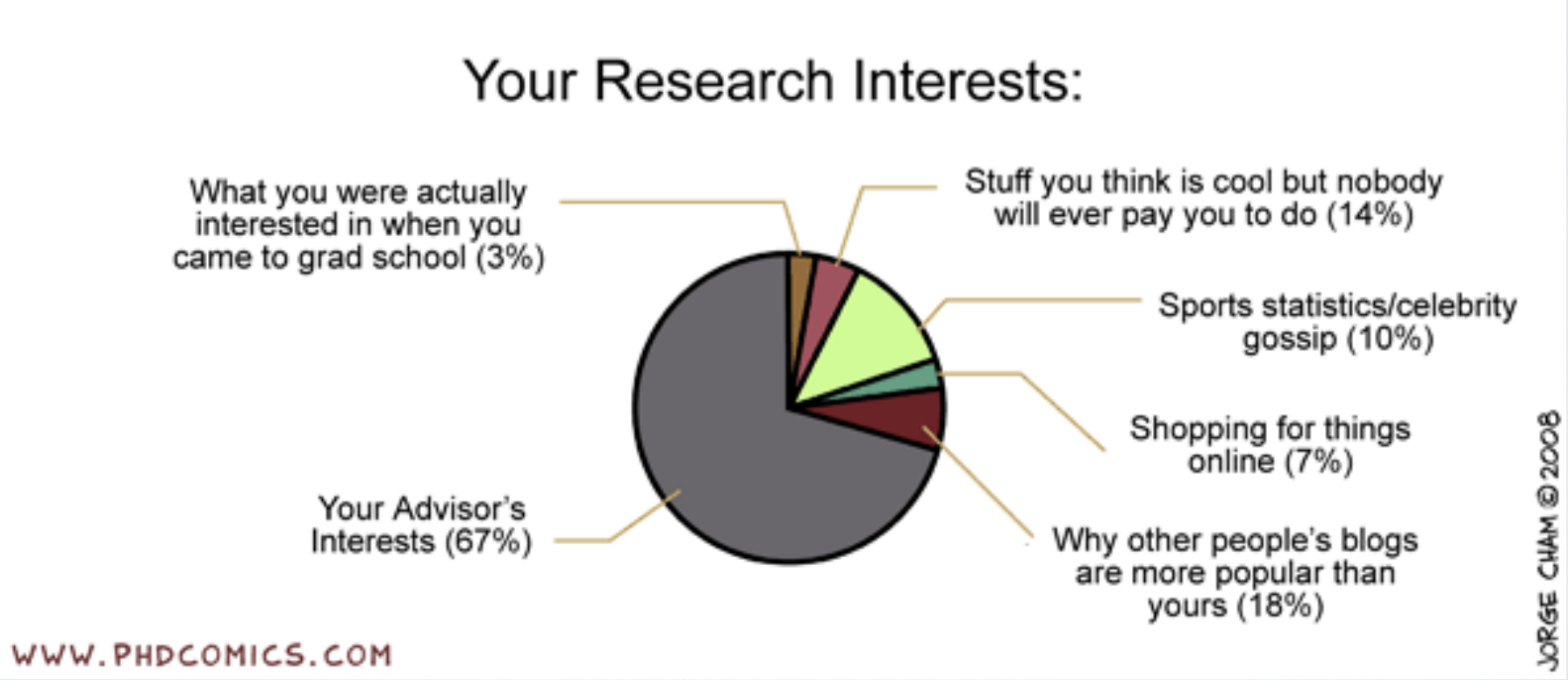
THINK BIG:

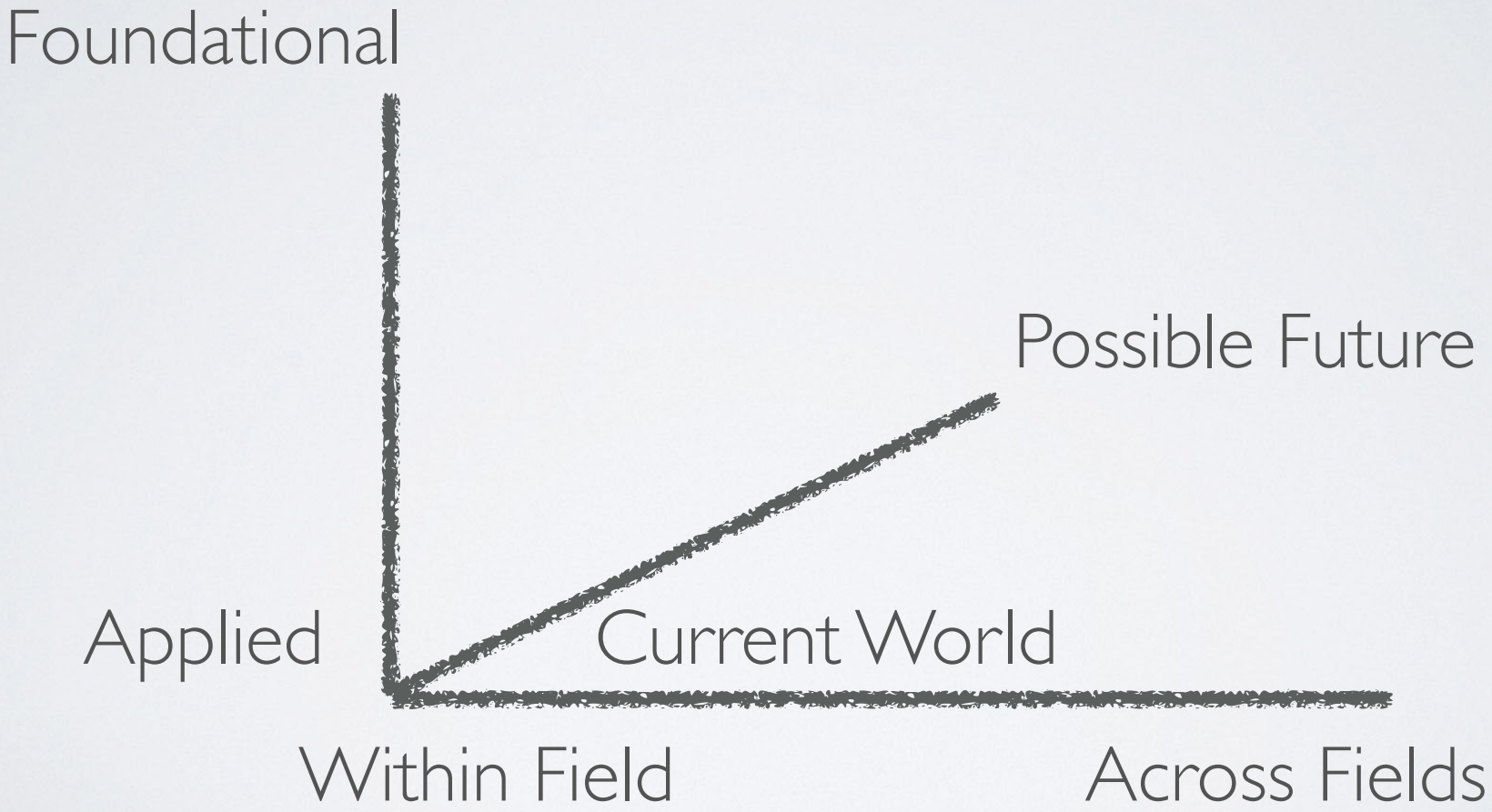
SOME CRAZY THESIS IDEAS


DUPLICATOR

GRAD SCHOOL


Your Research Interests:
What you were actually interested in when you came to grad school (3%)
Stuff you think is cool but nobody will ever pay you to do (14%)
Sports statistics/celebrity gossip (10%)
Shopping for things online (7%)
Why other people's blogs are more popular than yours (18%)
Your Advisor's Interests (67%)
WWW.PHDCOMICS.COM
JORGE CHAM © 2008

BALANCED PORTFOLIO



ONE TRICK

Predict the trends:

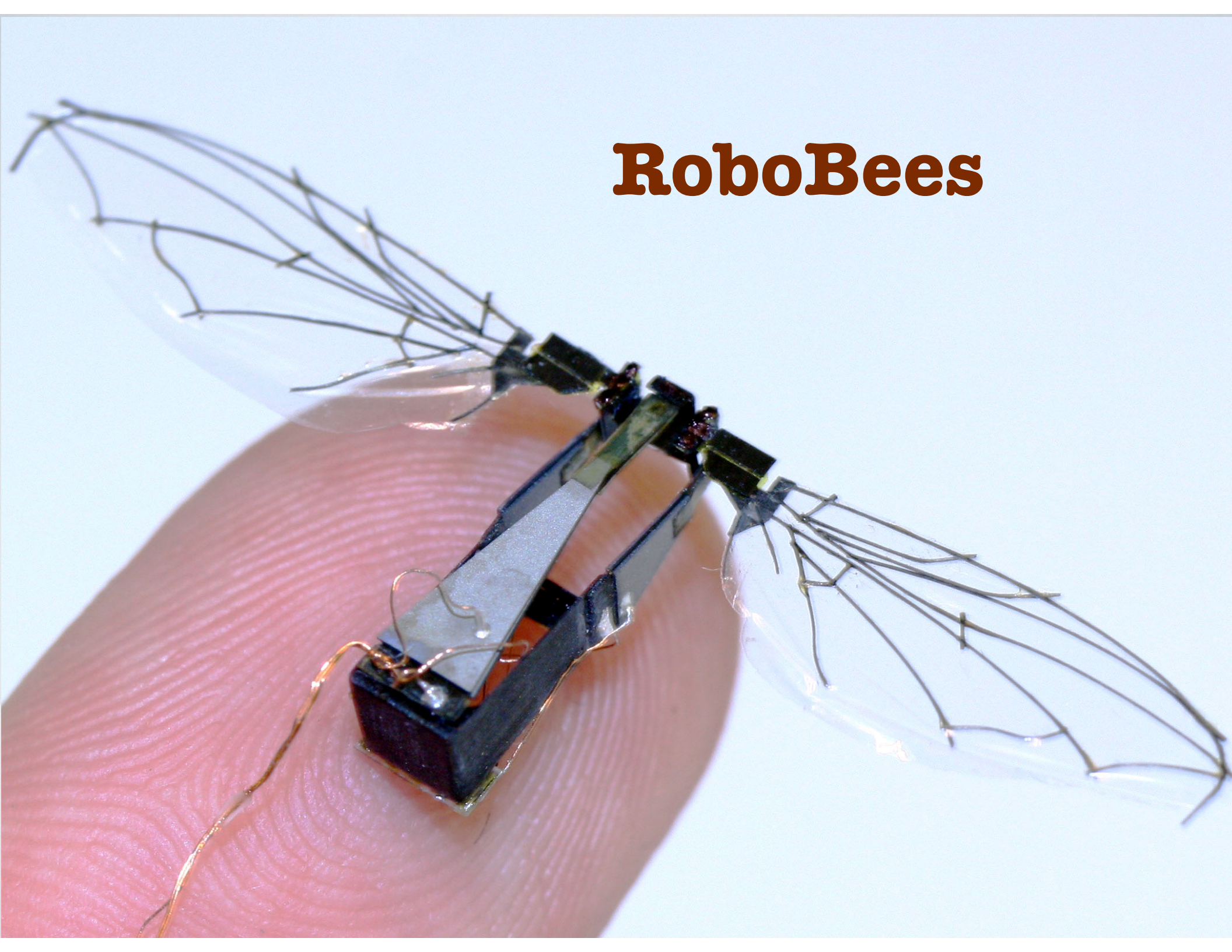
- sequential -> parallel, concurrent, distributed
- digital -> faulty, noisy, analog, quantum
- pure computation -> sensors, actuators

FOR EXAMPLE

Language & compiler support for:

- faulty chips
- DNA hairpin assemblies
- 10,000 robotic bees

RoboBees



COLONY COLLAPSE DISORDER

"In the winter of 2006, a strange phenomenon fell upon honeybee hives across the country. Without a trace, millions of bees vanished from their hives, leaving billions of dollars of crops at risk and potentially threatening our food supply."

http://www.pbs.org/wnet/nature/episodes/silence-of-the-bees/introduction/38/

A SOLUTION?

- Micro-sized robotic bees!
- Funded through $10M NSF Expeditions in Computing grant
- Ten faculty at Harvard, one at Northeastern, collaborators at Centeye, Inc.
- Collaboration across many areas:
  Computer Science, Electrical Engineering, Biology, Applied Math, Mechanical Engineering, Materials Science,...

HARVARD School of Engineering and Applied Sciences

WYSS INSTITUTE

THE TEAM

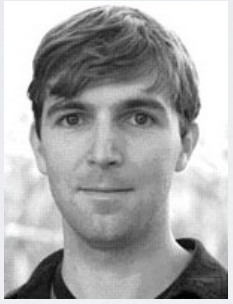
Northeastern

Centeye

Gu-Yeon Wei

VLSI

Rob Wood



Microrobotics

Radhika Nagpal

Distributed Control

Joe Ayers

Neurobiology Biorobotics

Stacey Combes

Insect biology

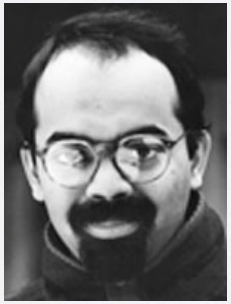
David Brooks

Low-power architecture

Programming languages

Greg Morrisett

L. Mahadevan



Bio-materials

Todd Zickler

Vision

Geof Barrows

Vision sensors

Matt Welsh

Sensor Networks

Micro fuel cells

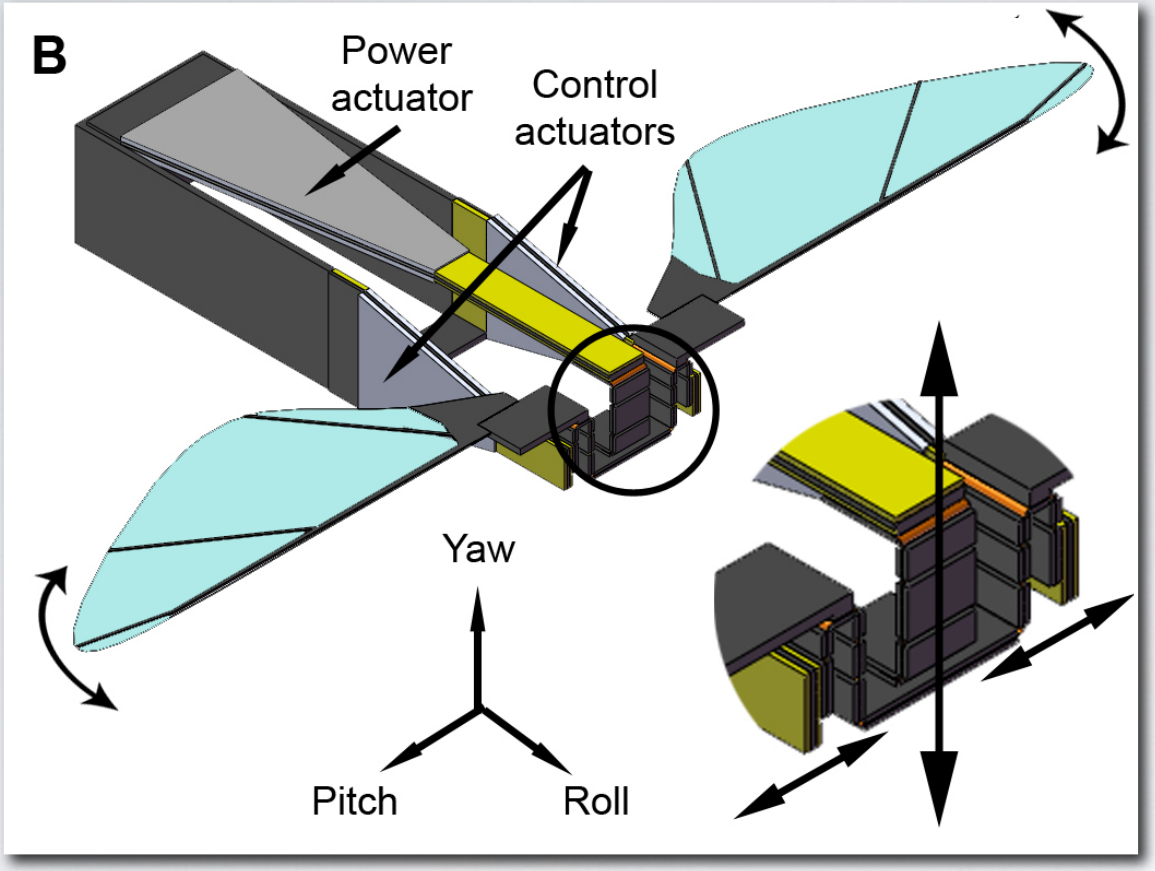
Shriram Ramanathan

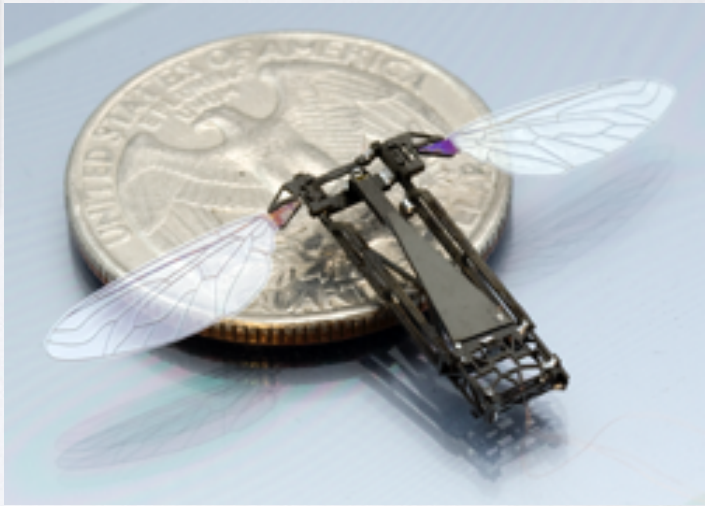
WHY CHOOSE BEES FOR FLIGHT BIOINSPIRATION?

- High payload
  > able to carry loads ≅ body weight
- High flapping frequency (~230 Hz)*
- Low stroke amplitude
  (~90° at hovering, increase up to 130°)*
- Non-wing control mechanisms
  > extend hind legs for stability†
- Able to fly in turbulent conditions†

(*Altschuler et al., 2005, ***PNAS;***
†***Combes and Dudley, 2009, PNAS***)

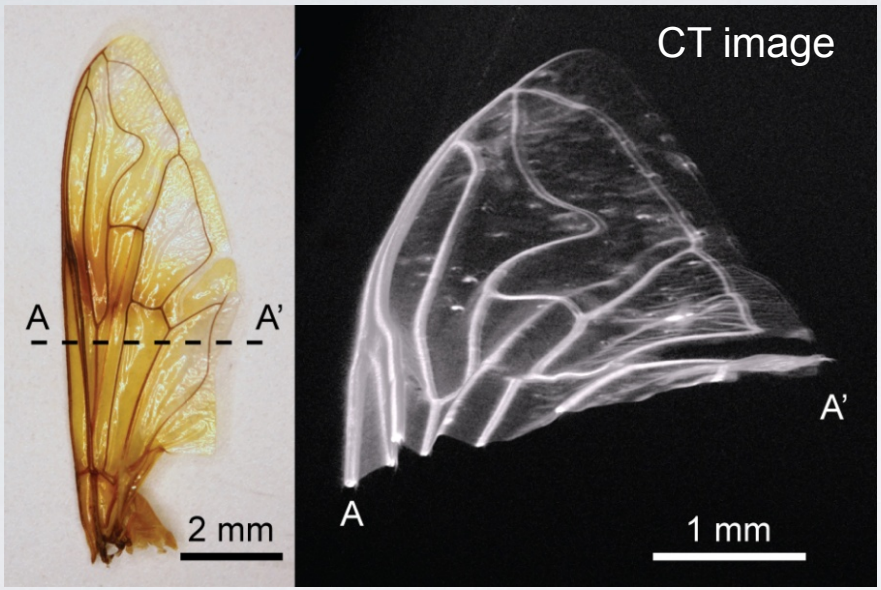
BASIC BODY DESIGN





[Wood]

BIOMIMETIC MICRO WINGS



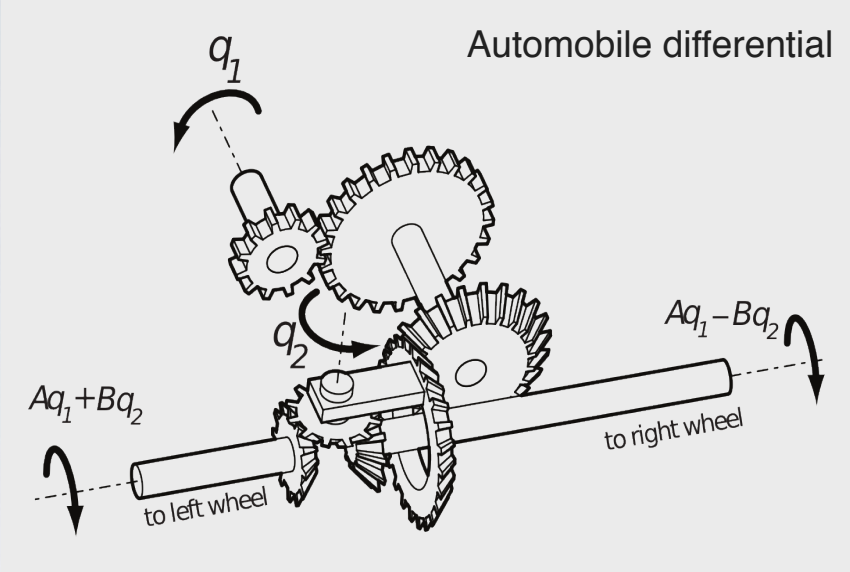
Morphology of natural wing (hover fly)

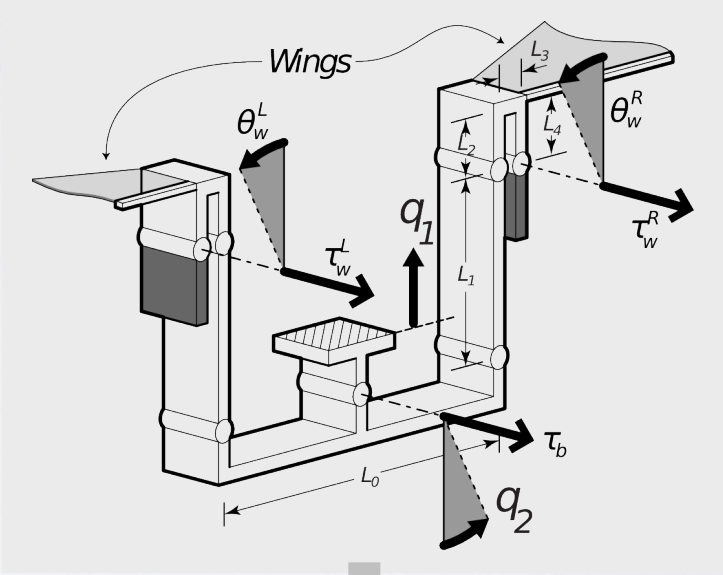
3D plastic micro wing [Tanaka *et al.*, in press]

- Engineer wings that mimic natural wing morphology
  - High stiffness, light weight, structural control of wing deformation
- Enables parametric experiments to better understand the functional morphology of insect wings

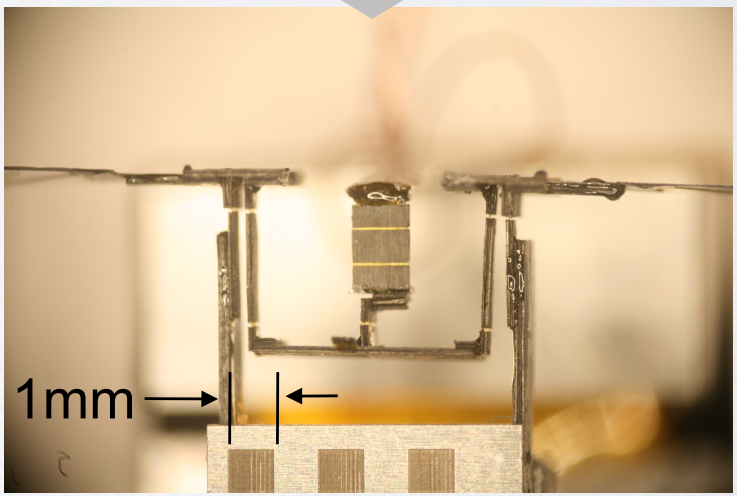
[Wood]

PASSIVE CONTROL





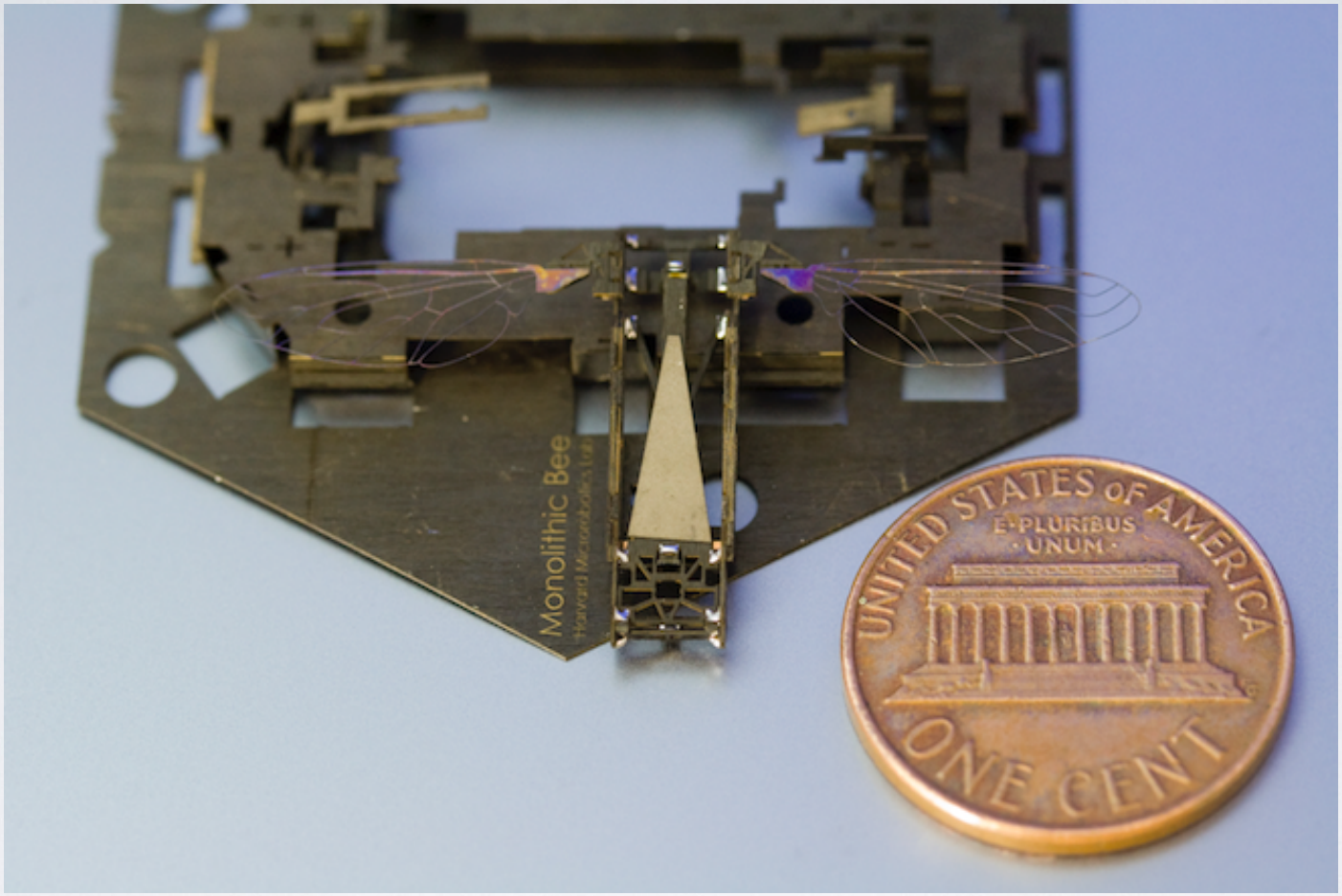
- Passive Aeromechanical Regulation of Imbalanced Torques (PARITy)
  - Balances drag torques by passively modulating stroke velocity



[Wood]

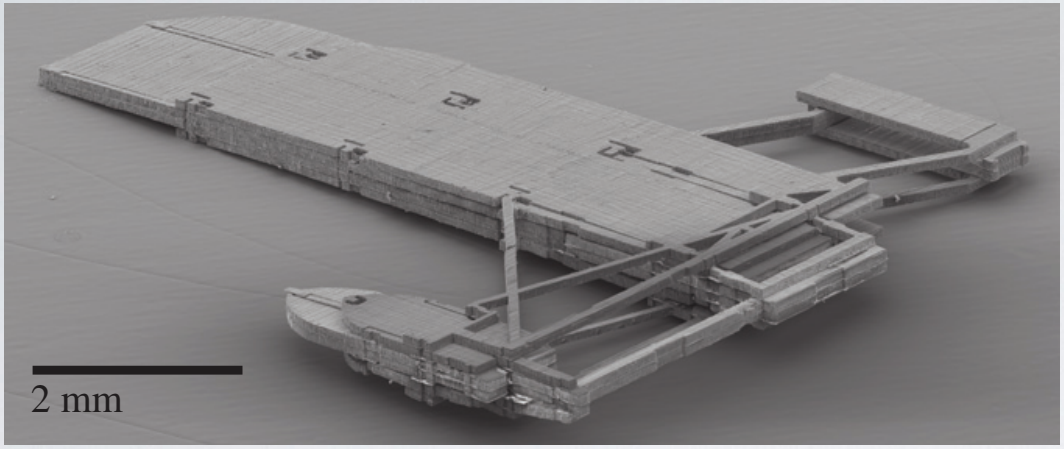
WINGS IN MOTION

POP-UP-BOOK ASSEMBLY

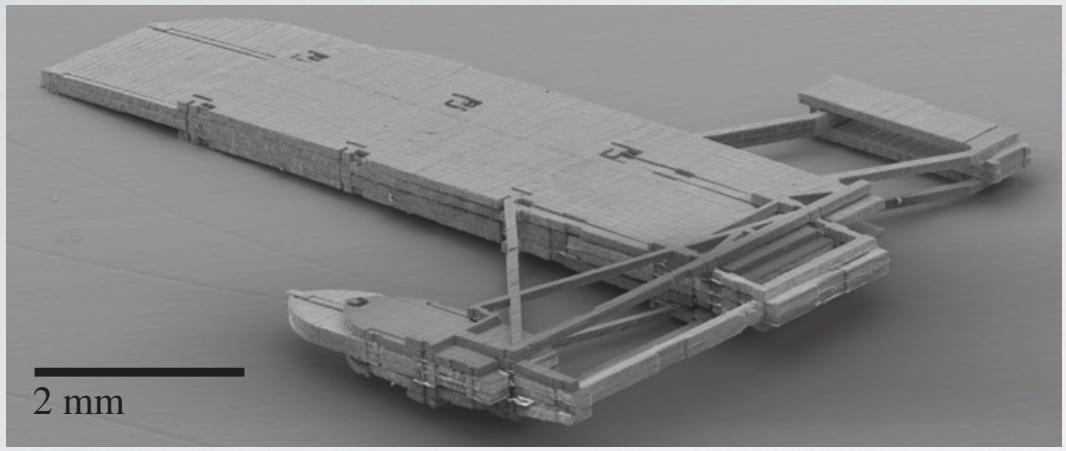


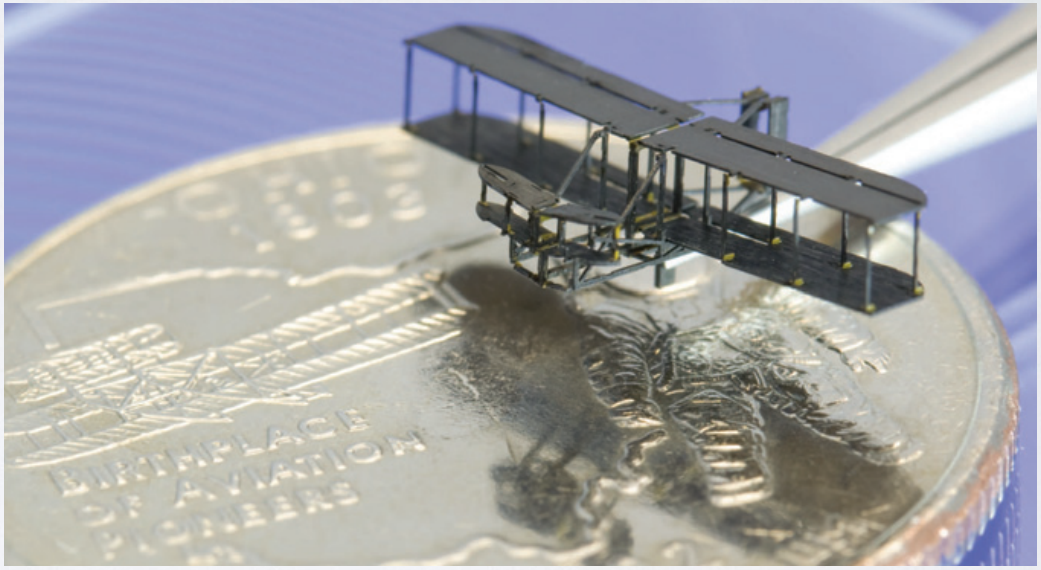
The whole structure is made like a printed circuit board. 18 layers of different materials (carbon fiber, a plastic film called Kapton, titanium, brass, ceramic, and adhesive sheets) are laminated together in a thin, laser-cut design.

Then the pins pop-up from the bottom to fold everything into place. The whole shebang is dunked in a liquid metal solder to bond tiny brass together, which lock the robot's joints in place. Finally, the scaffold is removed by laser cutting, releasing the tiny bee-bot.
[http://www.wired.com/wiredenterprise/2012/02/robotic-bee/]



GUESS?





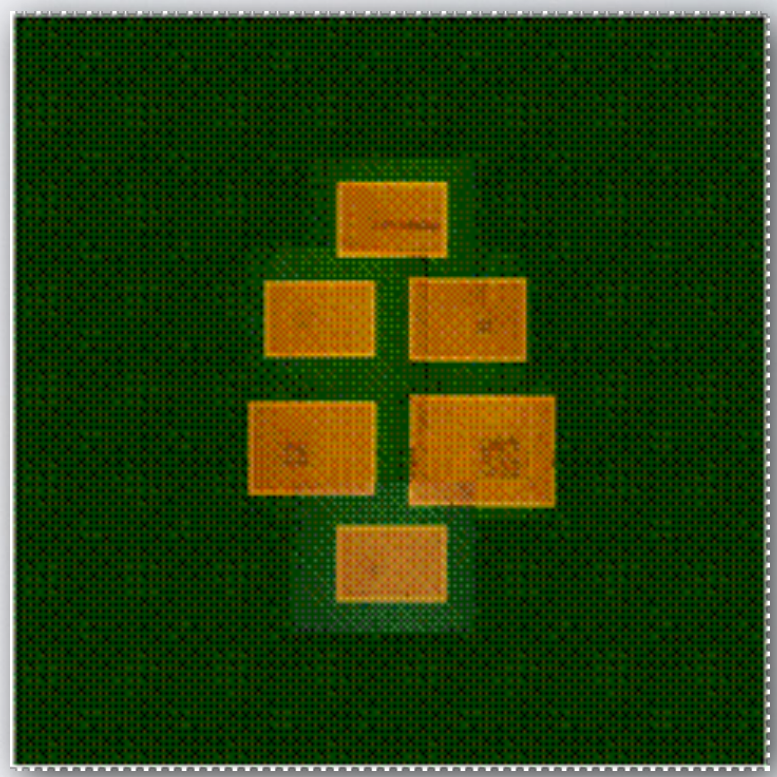
GUESS?

HOW DO THEY GET POWER?

THIN FILM MICRO-FUEL CELLS

Westinghouse SOFC

?

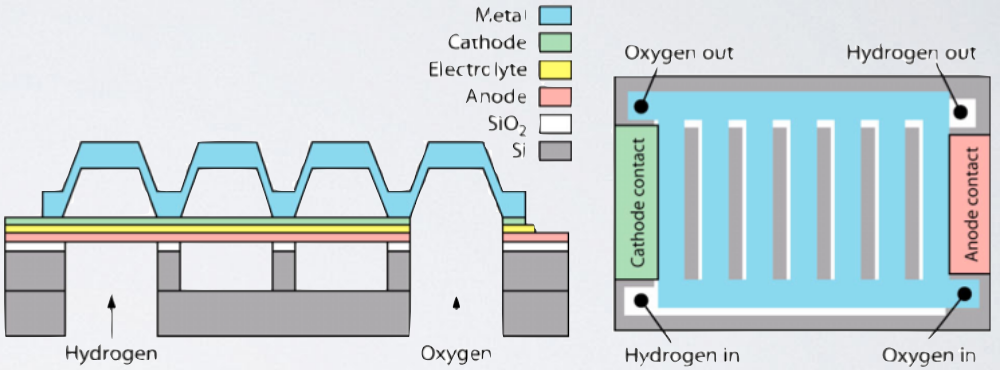


Johnson and Ramanathan, 2007

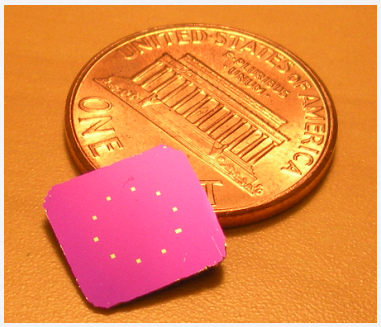
[Ramanathan]

POTENTIAL FOR MICRO FUEL CELLS

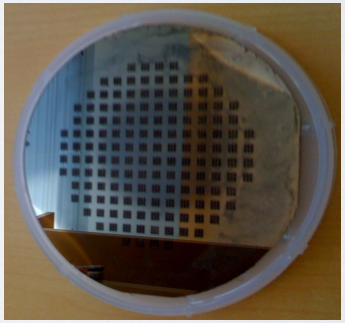
- Current limitations:
  Requires hydrogen fuel
  Operate at 200-500 °C
  Power output
  ~100 mW/cm^2



- Future goals:
  Continuous power generation, 1W, breathe air, ambient conditions!



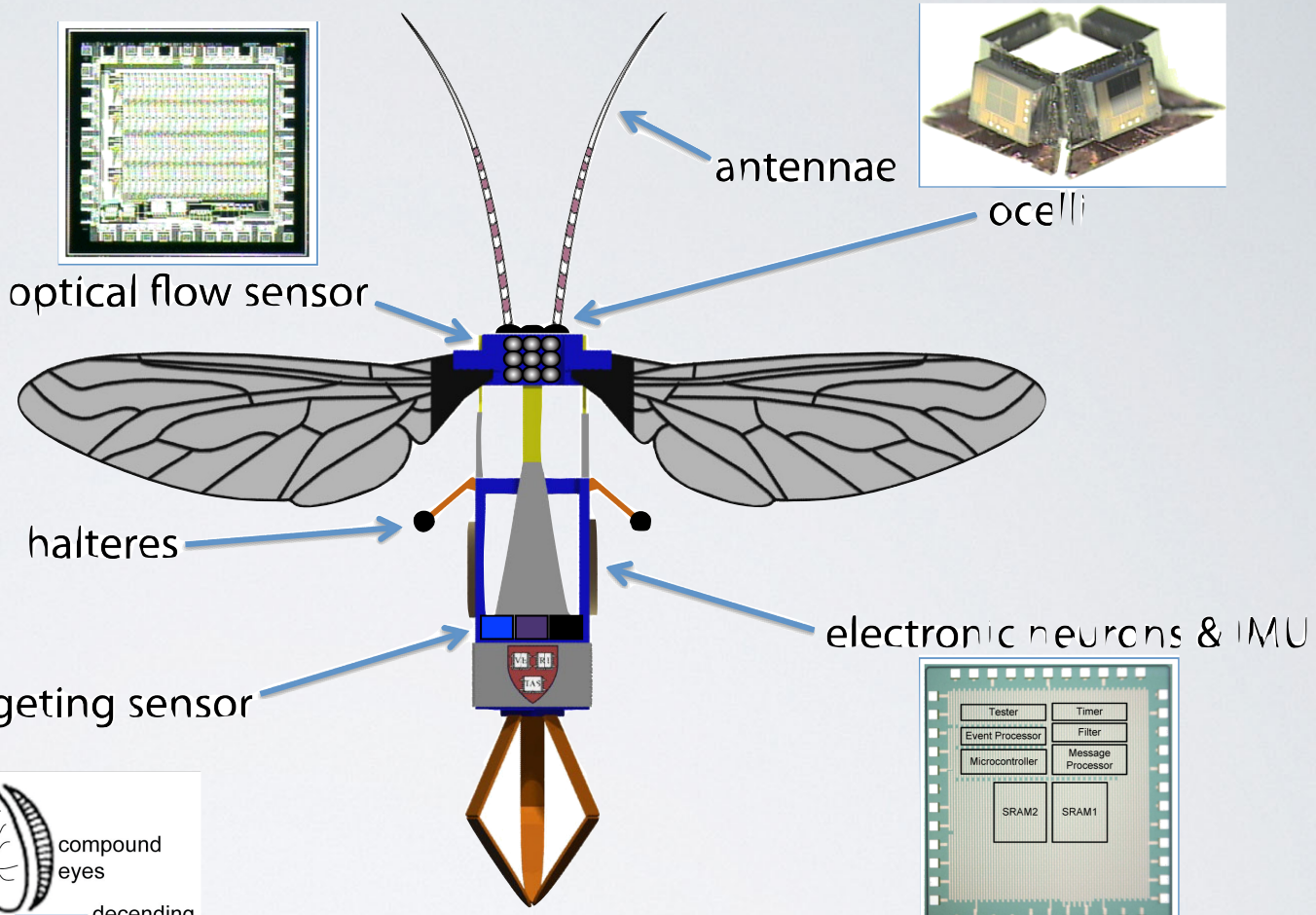
SOFC arrays



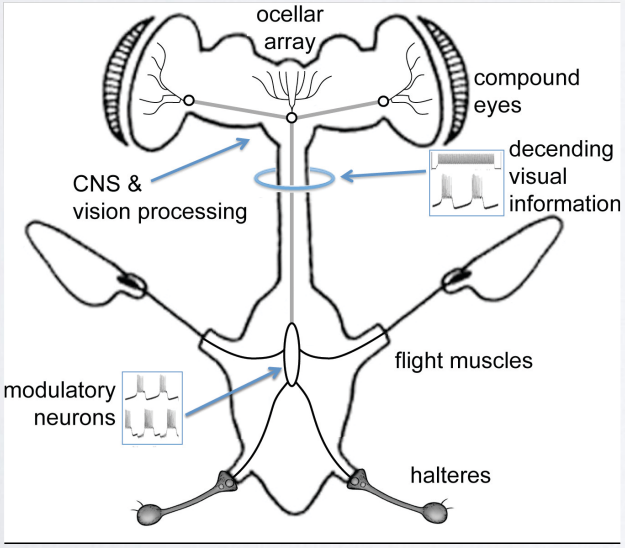
Wafer-scale functional fuel cell arrays

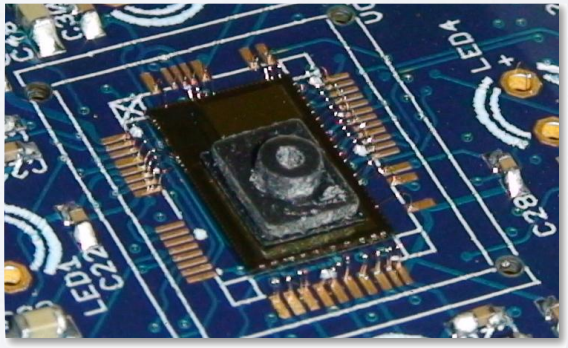
[Ramanathan]

The Brain


antennae
ocelli
optical flow sensor
halteres
electronic neurons & IMU
UV targeting sensor

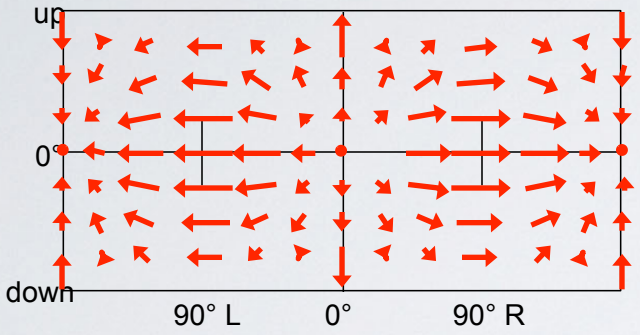
Tester
Timer
Event Processor
Filter
Microcontroller
Message Processor
SRAM2
SRAM1


ocellar array
compound eyes
decending visual information
CNS & vision processing
flight muscles
modulatory neurons
halteres



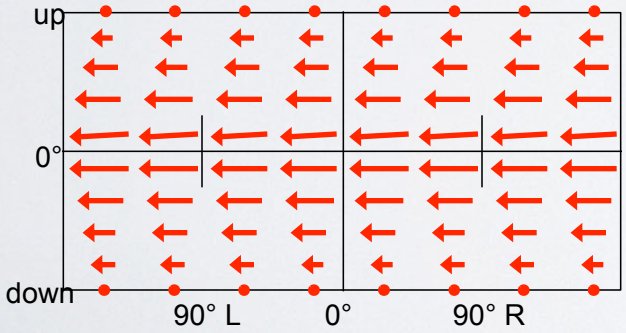
OPTICAL FLOW SENSING

Move Forward



Optical flow can directly sense velocity-related information

Yaw Right

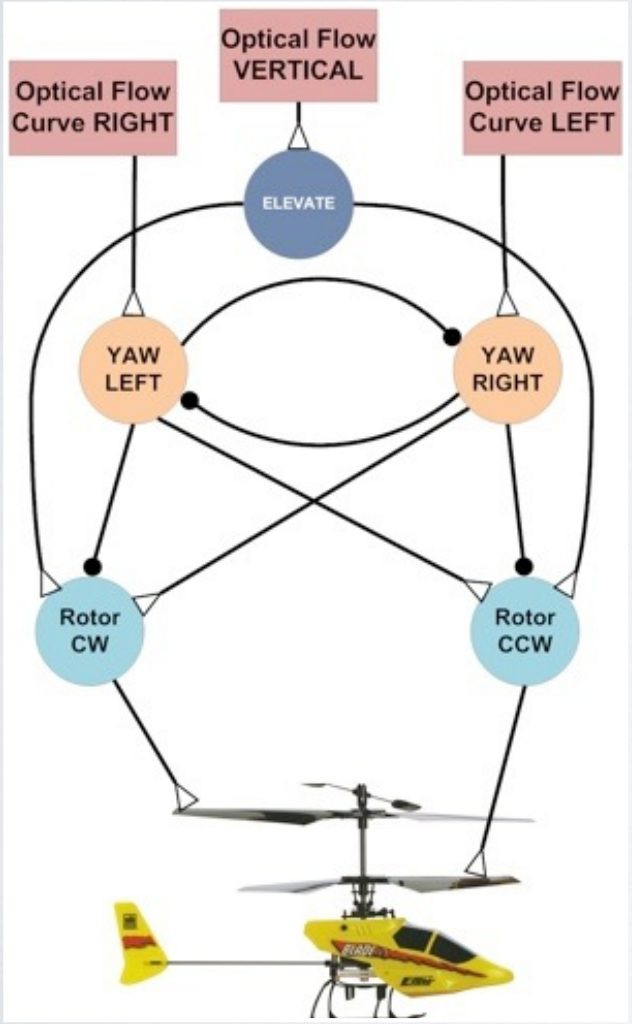


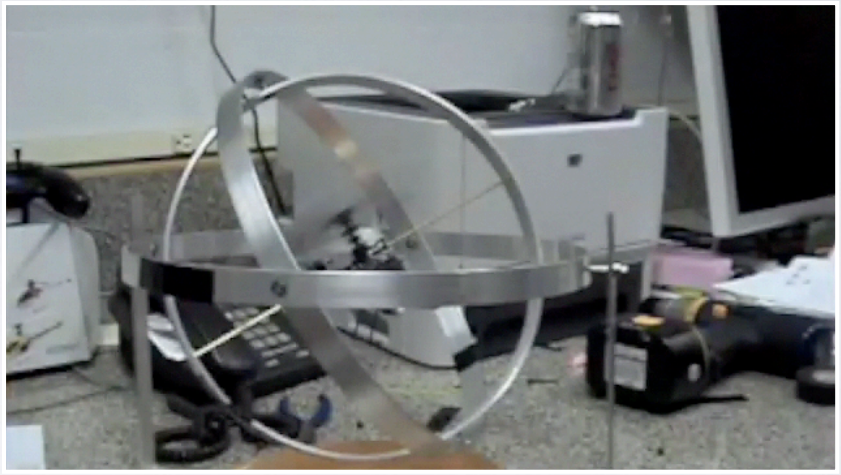
Optical flow can provide gyro-type information

http://www.youtube.com/watch?v=ckVQrwYIjAs

[Centeye]

ARTIFICIAL NEURAL CONTROL

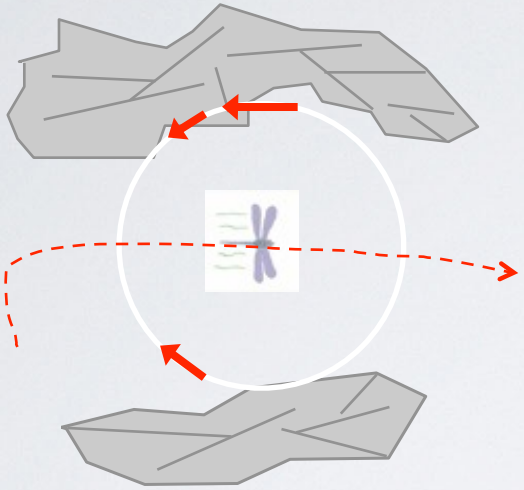




[Ayers]

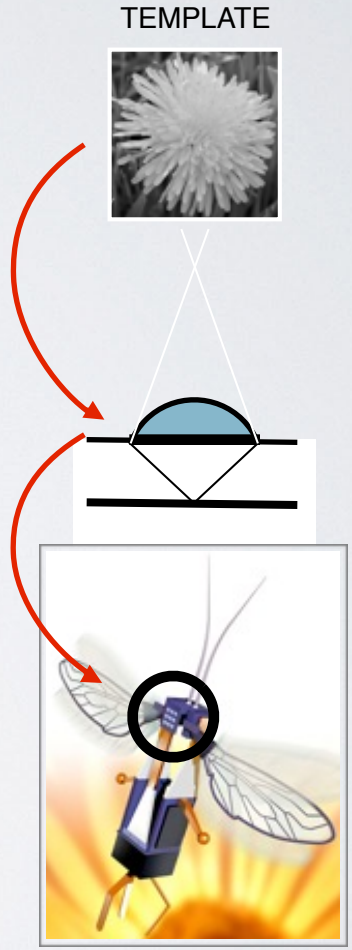
- Optical flow provides information on surroundings
- Discrete-time mapped (DTM) neurons, coded into microcontroller, controls rotors

OPTICAL FLOW SENSING

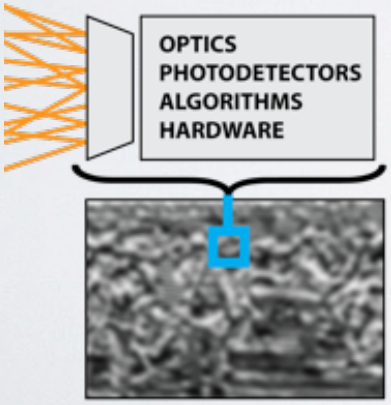


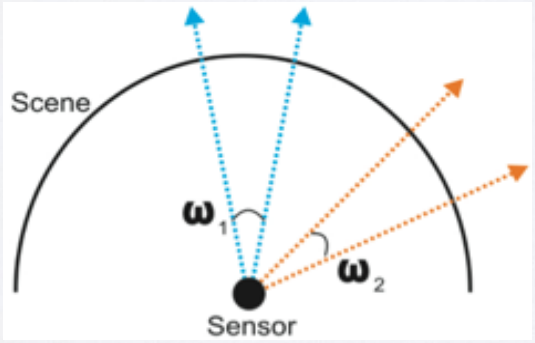
Optical flow

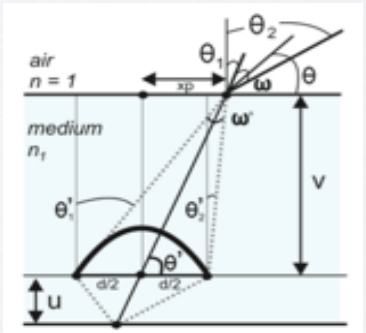
Target recognition



Optics/algorithm co-design



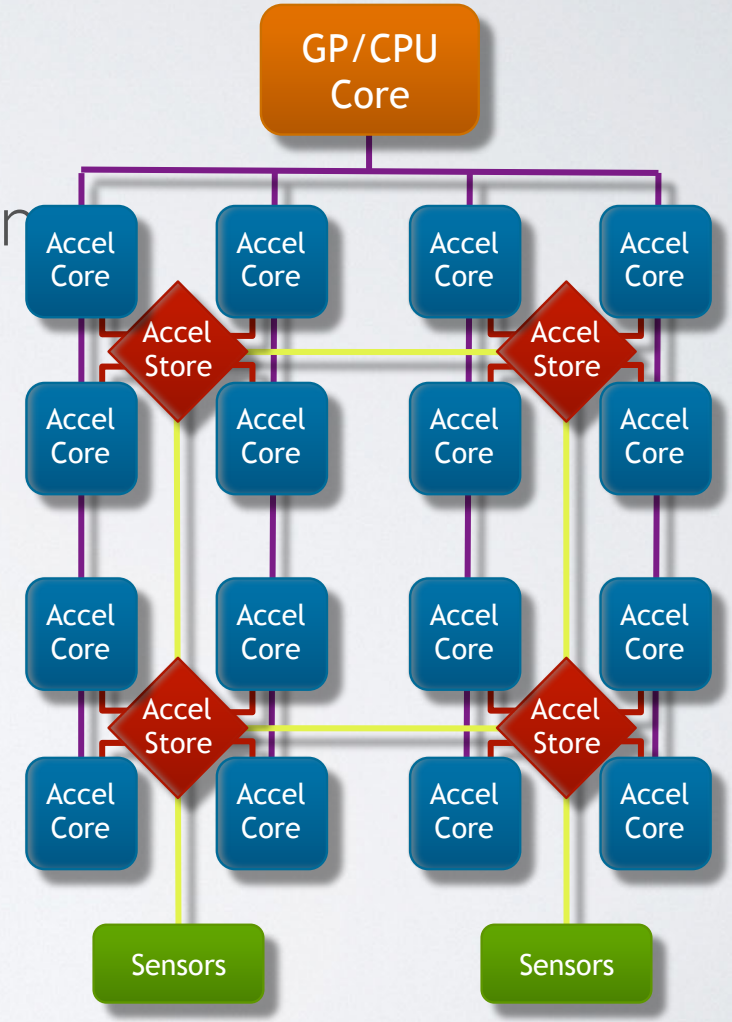




[Centeye & Zickler]

BRAIN ARCHITECTURE

- Accelerator-based processor design
- Ultra low power: microwatts
- General-purpose CPU core
- Accelerators for specialized tasks (navigation, vision, control)

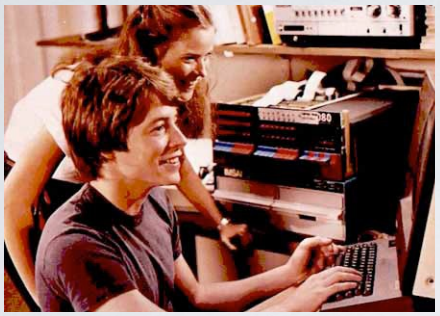


[Brooks & Wei]

The Colony

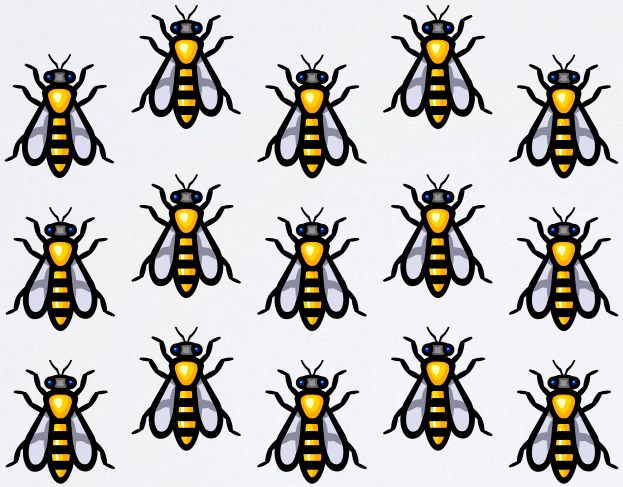
WAGGLE DANCE

THE OLD WAY...



C code

No doubt full of bugs

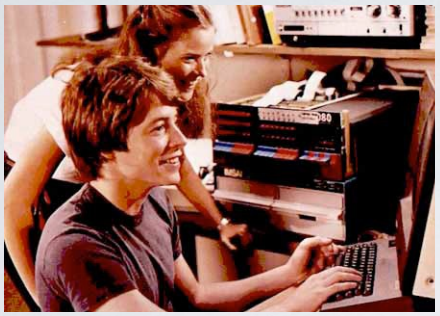


Box o' bees

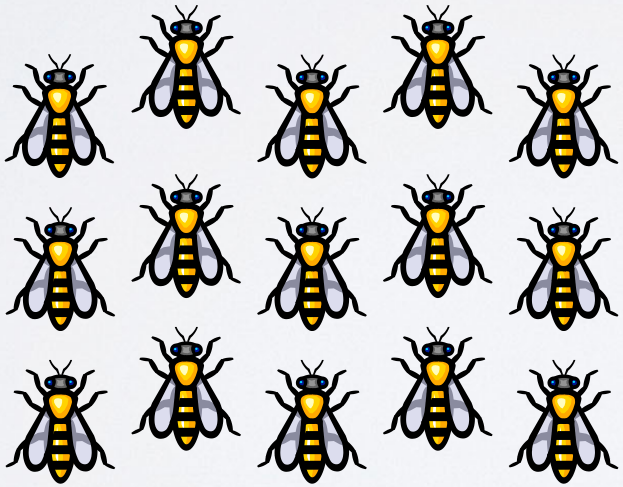
Havoc and mayhem

[Welsh, Morrisett]

THE NEW WAY...



Macroprogram



Box o' bees

Beautiful swarm behavior

MACROPROGRAMMING

- Program the swarm, not the bee
- Automatically compile swarm program to bee programs
- Compiler generates code to handle communication, failure detection, task assignment, and resource management

YER DOIN IT RITE

Sean Hannity "Waste 102" - March 12, 2010

Thanks!

http://robobees.seas.harvard.edu

greg@eecs.harvard.edu

Special thanks to the National Science Foundation