Medical microsystems from moths to man

Joel Voldman
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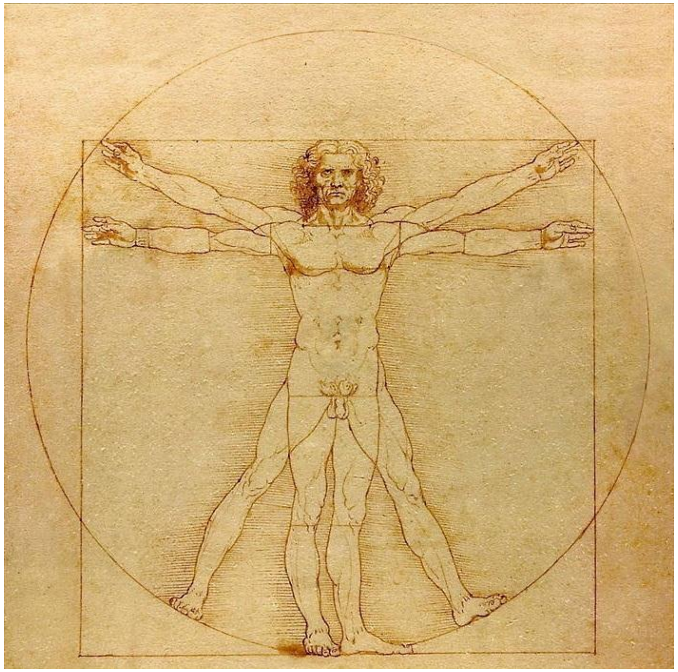
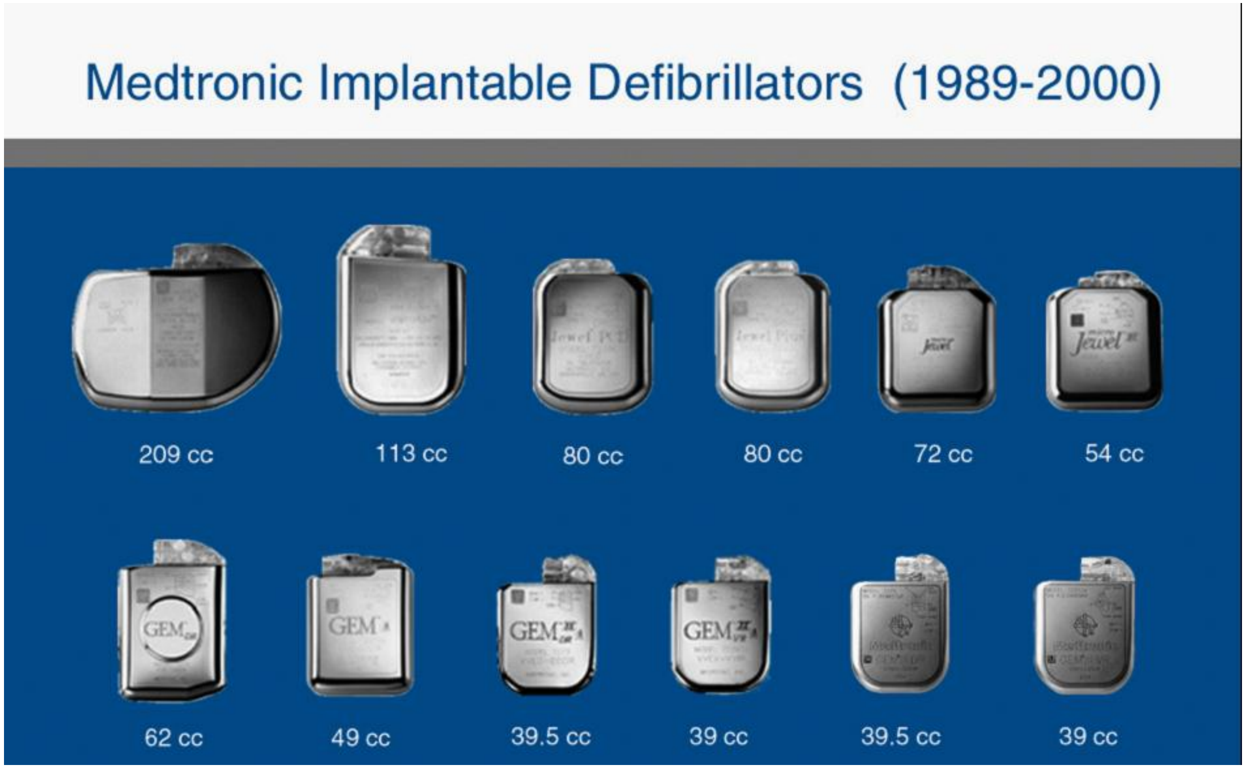


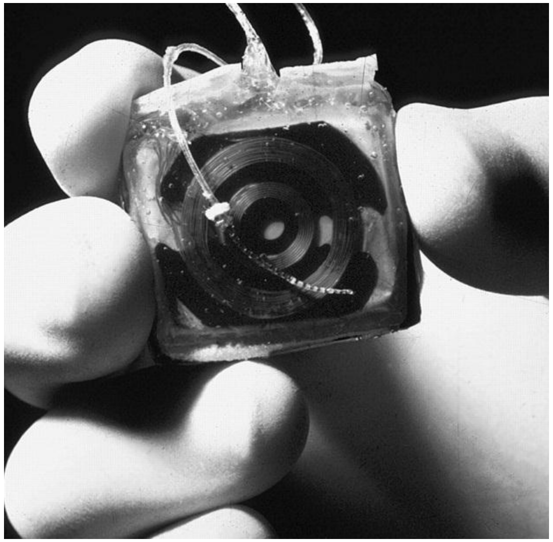
The progression of medical systems

Early (1958) and current pacemakers



The progression of medical systems

Early cochlear implant (~1979)



Clark G M Phil. Trans. R. Soc. B 2006;361:791-810

Cochlear Nucleus 5 (today)

Advanced Bionics Implant systems

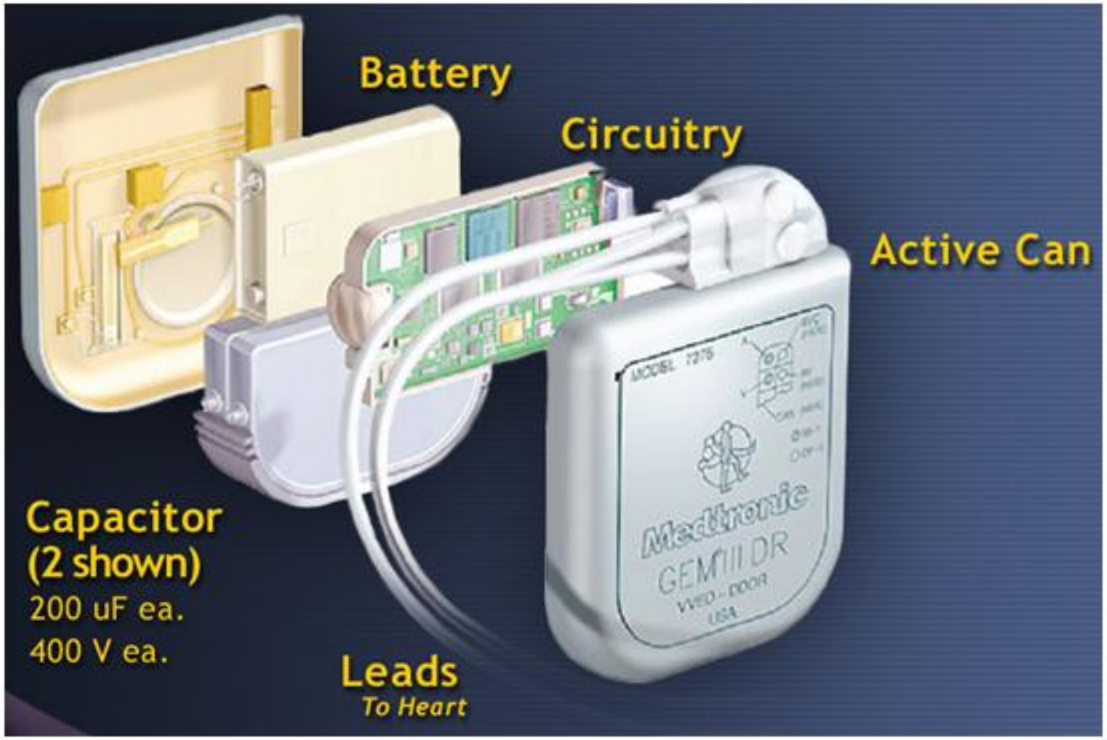
Medical devices are getting smaller

The progression of medical systems

- Lifetime of first implantable defibrillator (ICD) ~2 yrs
- Lifetime of current defibrillators: ~5-7 yrs

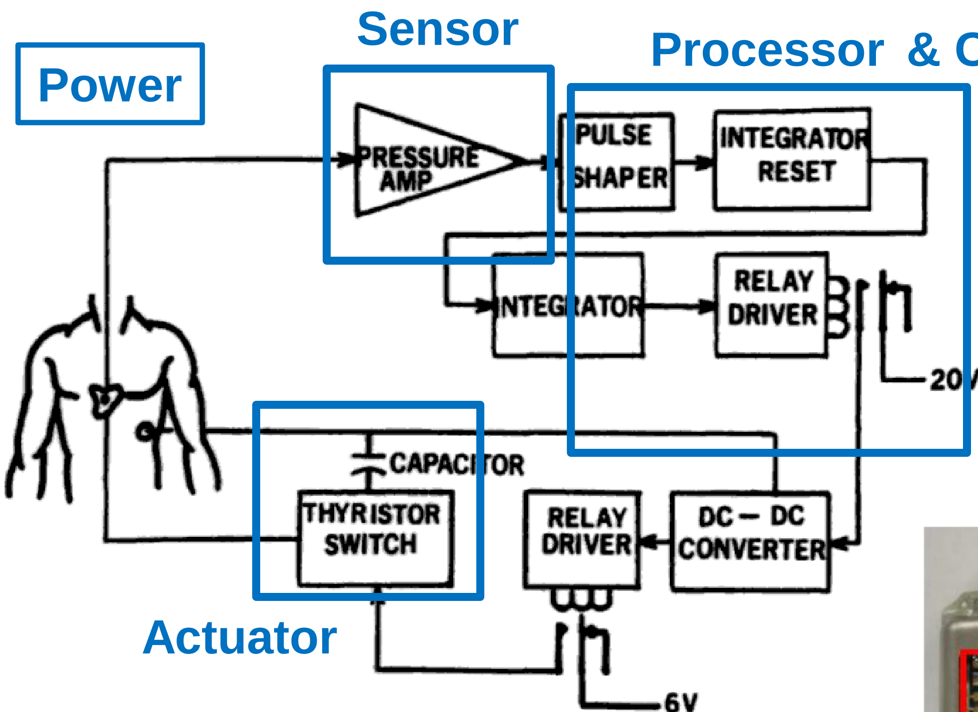
…but the battery is still a significant fraction (~50%) of the device

Schematic of ICD

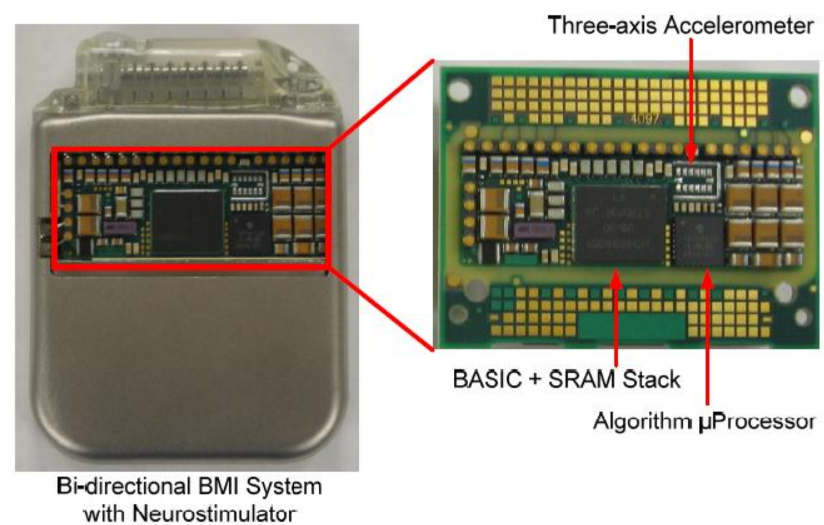


Batteries are getting better, and devices more power-efficient

The progression of medical systems



Block diagram of first implantable defibrillator (~1980)



Medtronic bidirection neurostimulator (today)

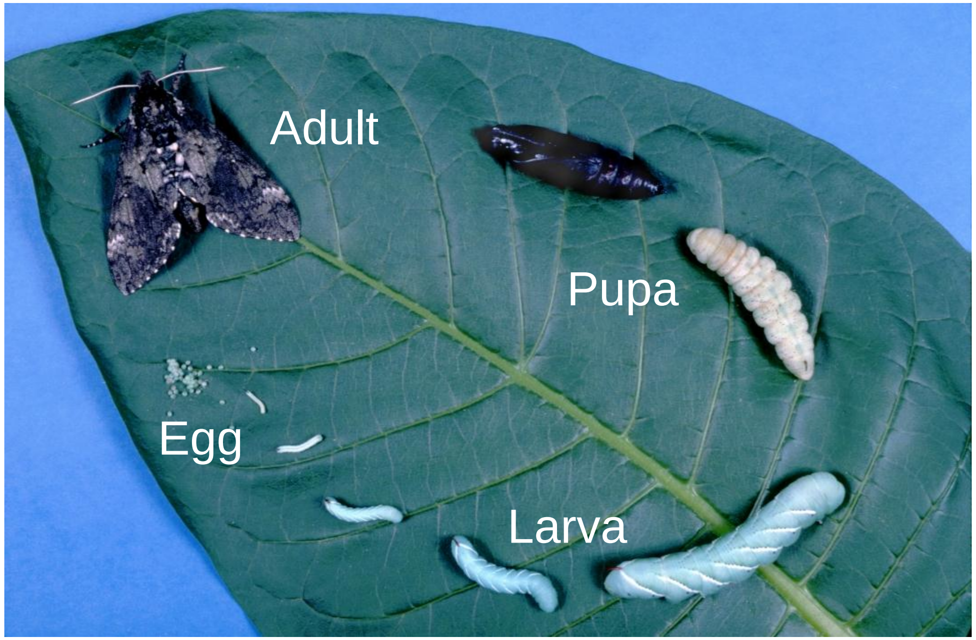
Medical devices are getting smarter: more sensors, more inference

…but this is not enough

- Major challenges remain
  - Size: can we go smaller?
  - Power: can we harvest energy from the person?
  - Functionality: what *else* can we sense to better close the loop?

How can a moth help?

Manduca sexta: the “tobacco hawkmoth”



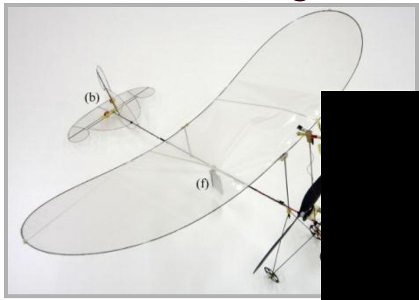
Hildebrand

- Average adult weight: ~2.5 g
- Wing span: ~110 mm
- Maximum flight speed recorded in captivity: ~5 m/s
- Load capacity in flight: ≥ 1 g

Man-made flying microsystems

EPFL, Switzerland

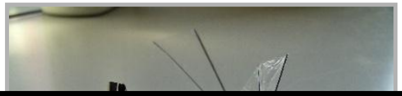
74 cm, 10 g



10 minutes

TU Delft, Netherland

10 cm, 3 g

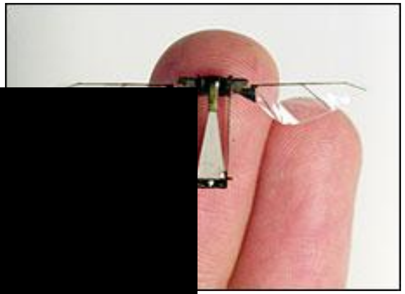


Prox Dynamics, Norway

8.5 cm, 0.9 g

Harvard Microrobotics Lab

3.2 cm, 0.06 g

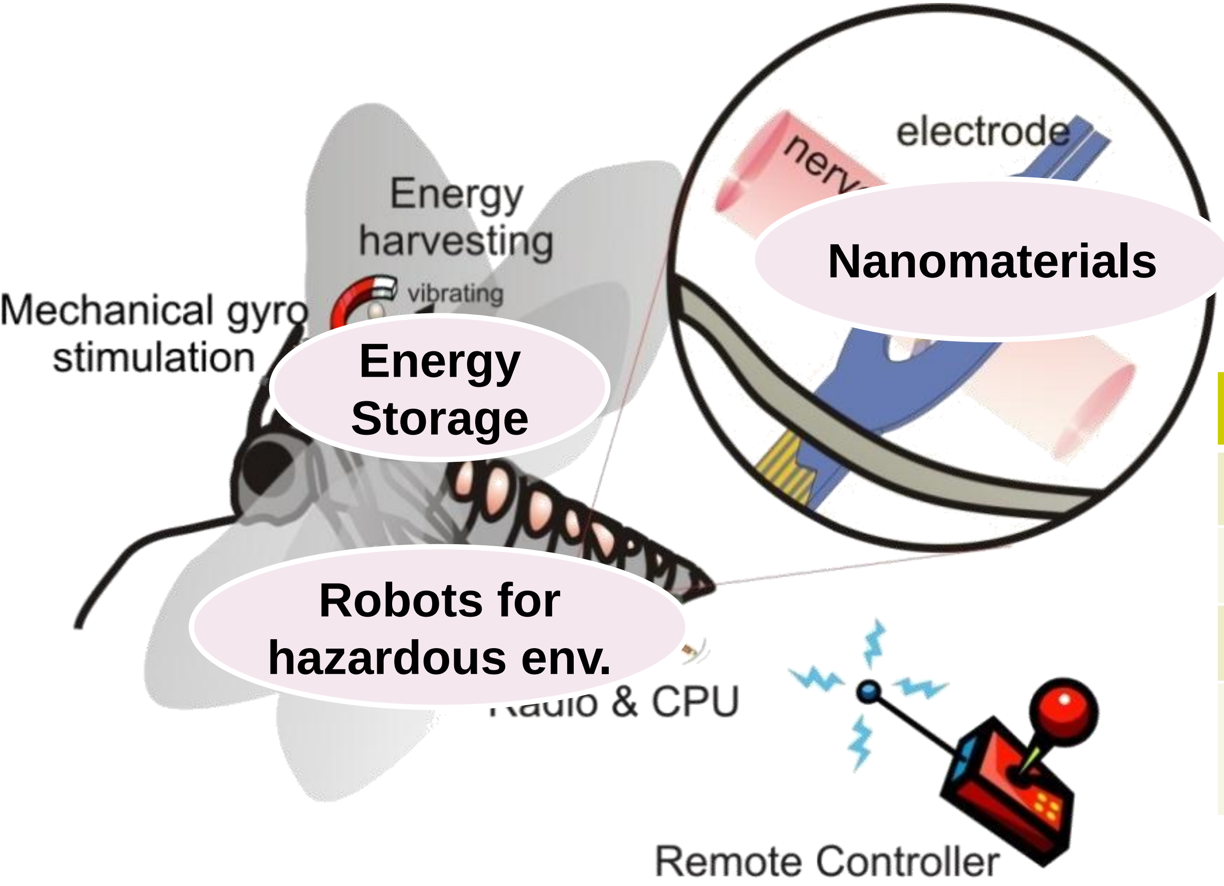


thered

etime

nctionality

Can we integrate man-made components onto a moth to combine the best of man and nature?



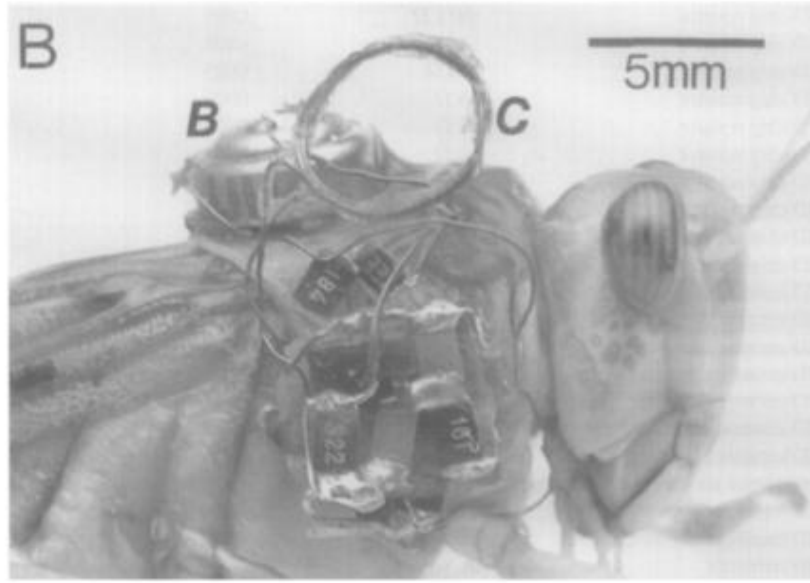
Spec.	Value
Size	~ 1 cm^3
Weight	< 1 g
Power	~1 mW
Data rate	1-10 kbps over 10-100 m

Technological challenges relevant to implantable microsystems

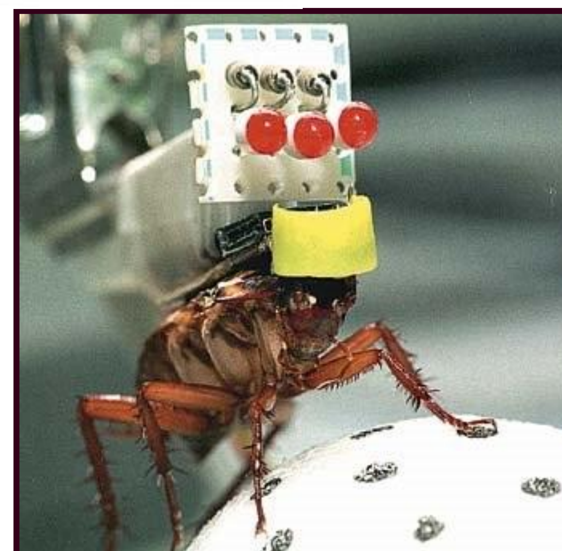
Insect microsystems

Researchers have long wanted to interface with insects in order to understand insect biology

Universität Konstanz, Germany, 1996



University of Tsukuba, Japan, 2002

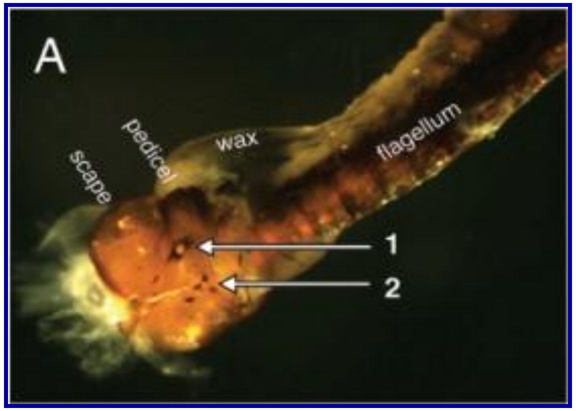


University of Tokyo, Japan, 1997

Different approaches to flight control

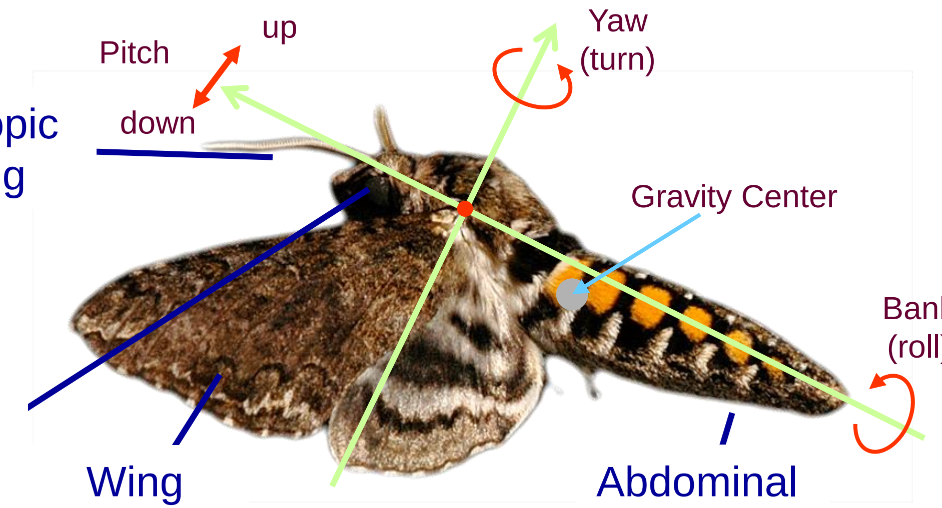
Balance sensory input with animal computation

Antenna muscle (Electrical)



J. Tse, SICB 2009

Gyroscopic sensing



Visual Biasing

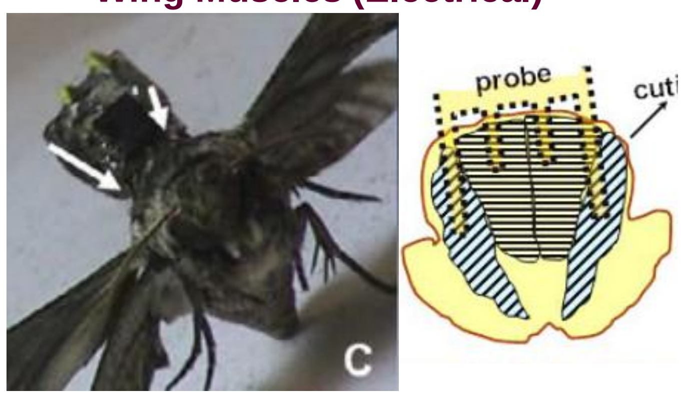
Wing Flapping

Abdominal Ruddering

Optical Stimulation

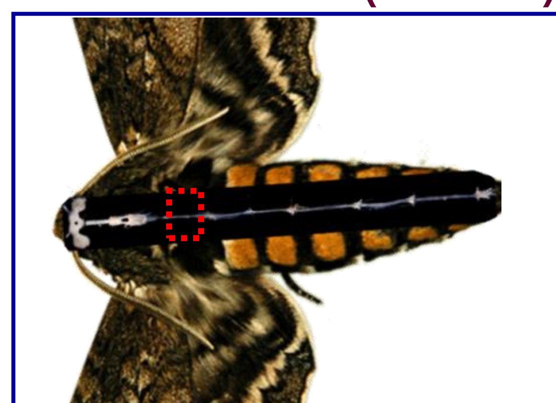
H. Sato et al., MEMS 2008, p. 164

Wing Muscles (Electrical)



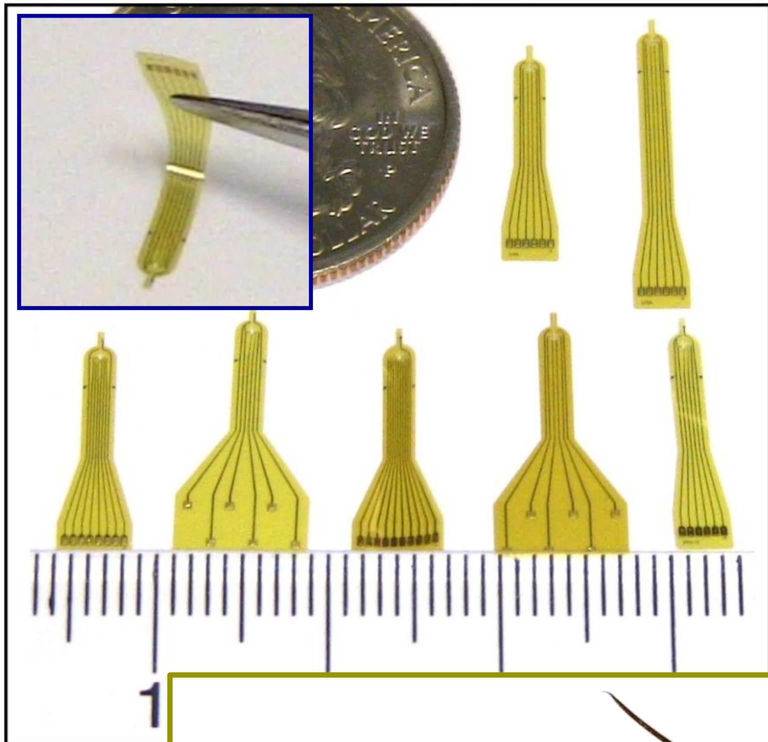
A. Bozkurt et al., MEMS 2008,

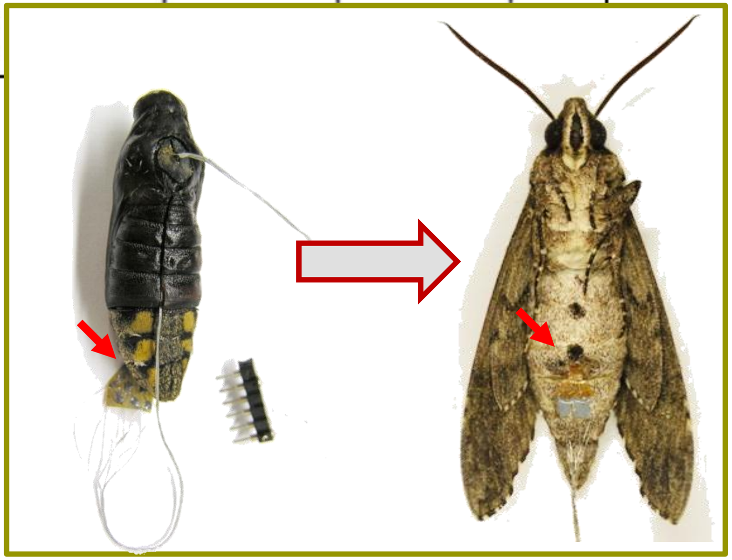
Ventral nerve cord (Electrical)

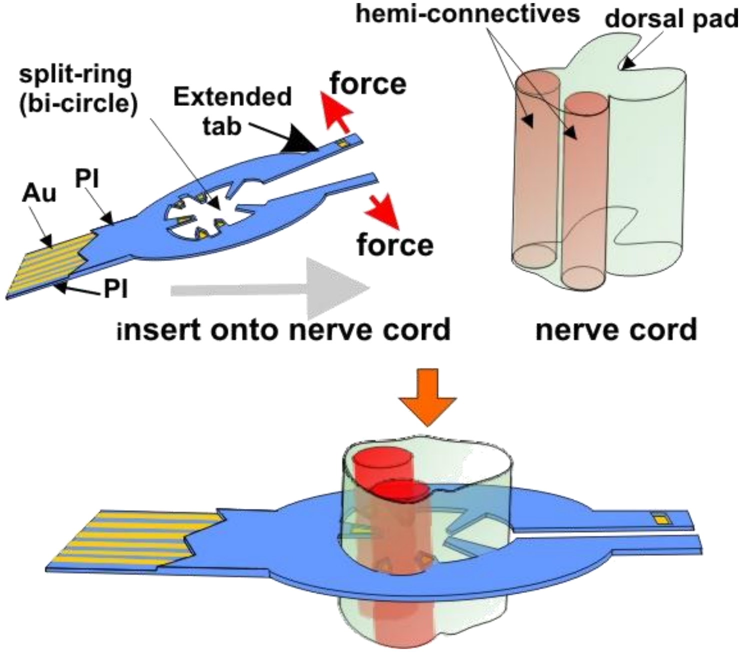


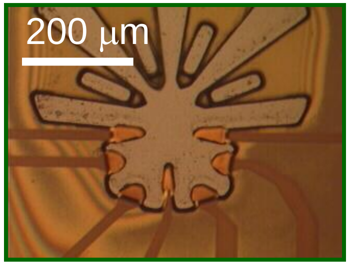
M. Enstom et al., SICB2003

Actuator: flexible implantable electrodes







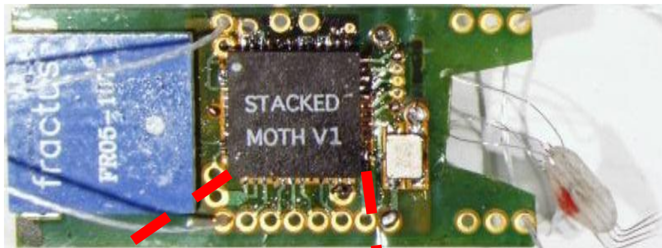


Bi-cylinder
8 sites

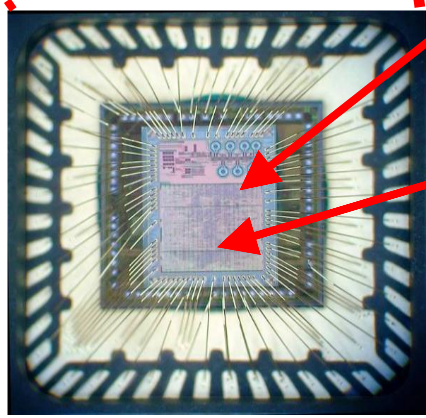
Connection with
FPC connector

How to communicate with moth?

Custom radio

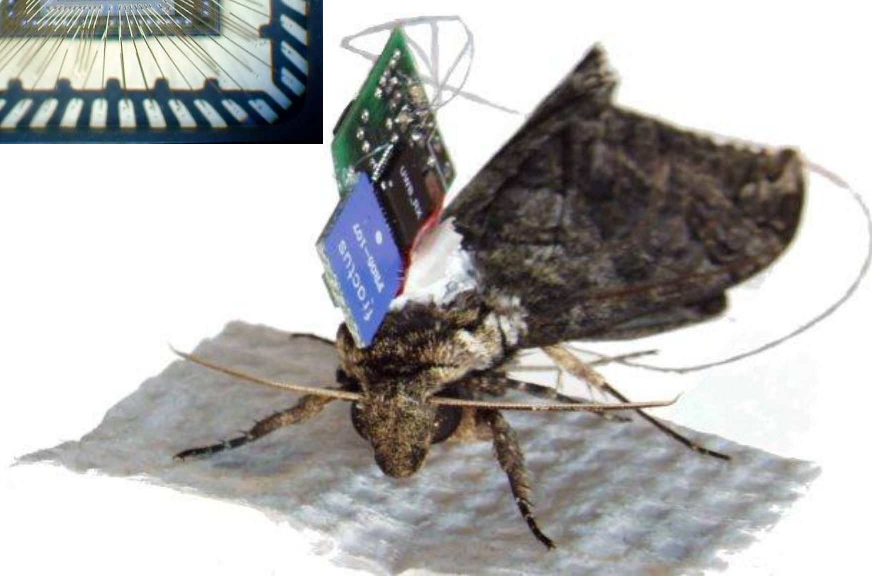


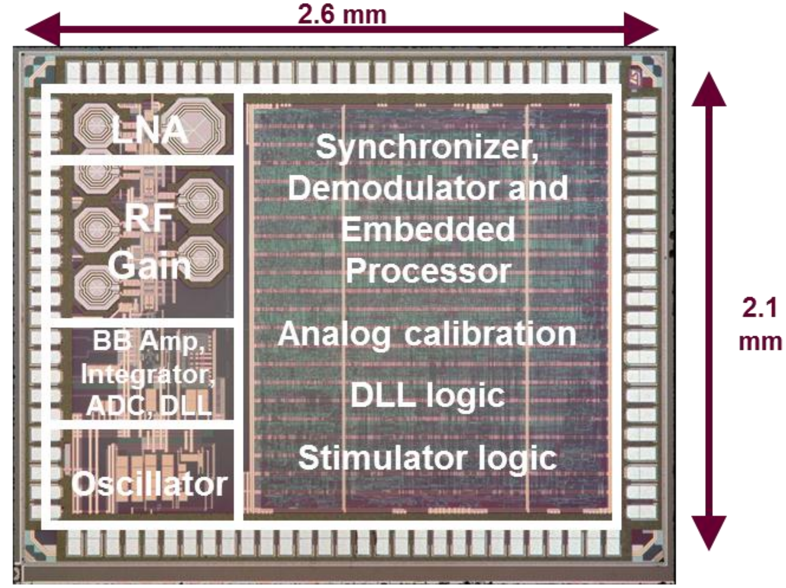
Stacked die



Radio

µController & Flash



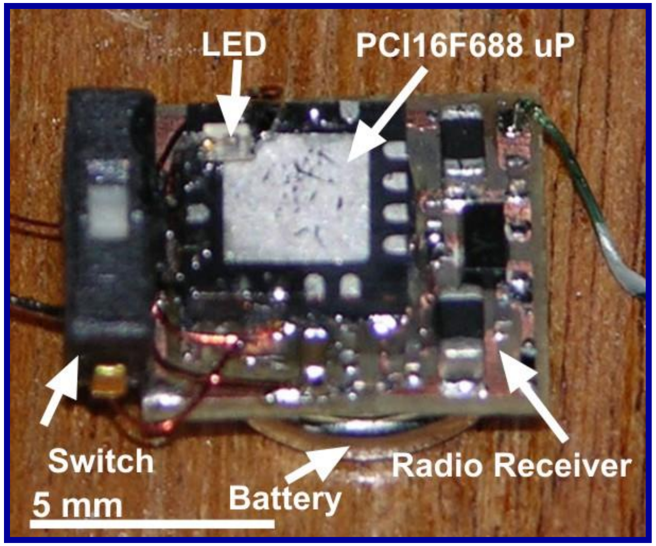


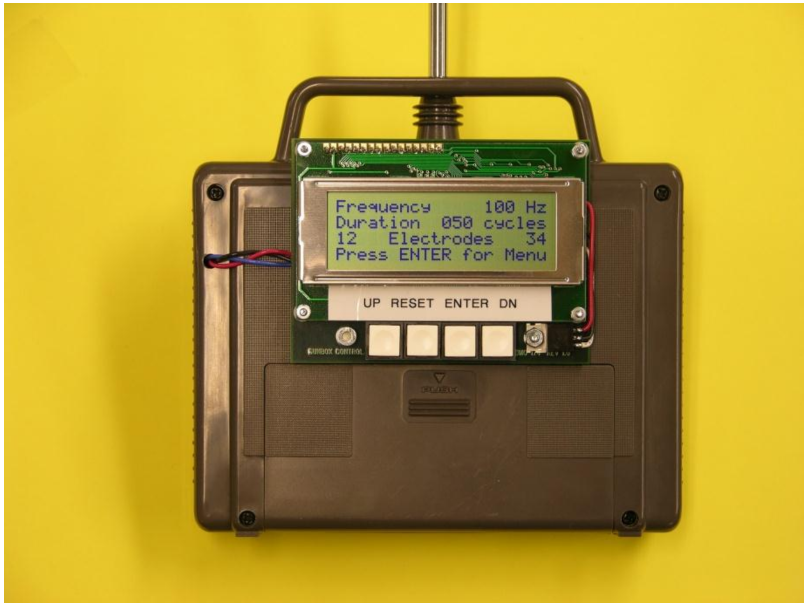
Component	Mass (mg)
Radio + Microcontroller	161
Printed ckt board	100
Antenna	164
Silver Oxide Battery	320
Harness	85
Other Components	170
Total	~1 g

Anantha Chandrakasan, MIT

Can we go even smaller?

- Semi-commercial AM radio for radio-controlled planes
- Combination of µcontroller, battery, and radio receiver
- ~0.5 g total system weight

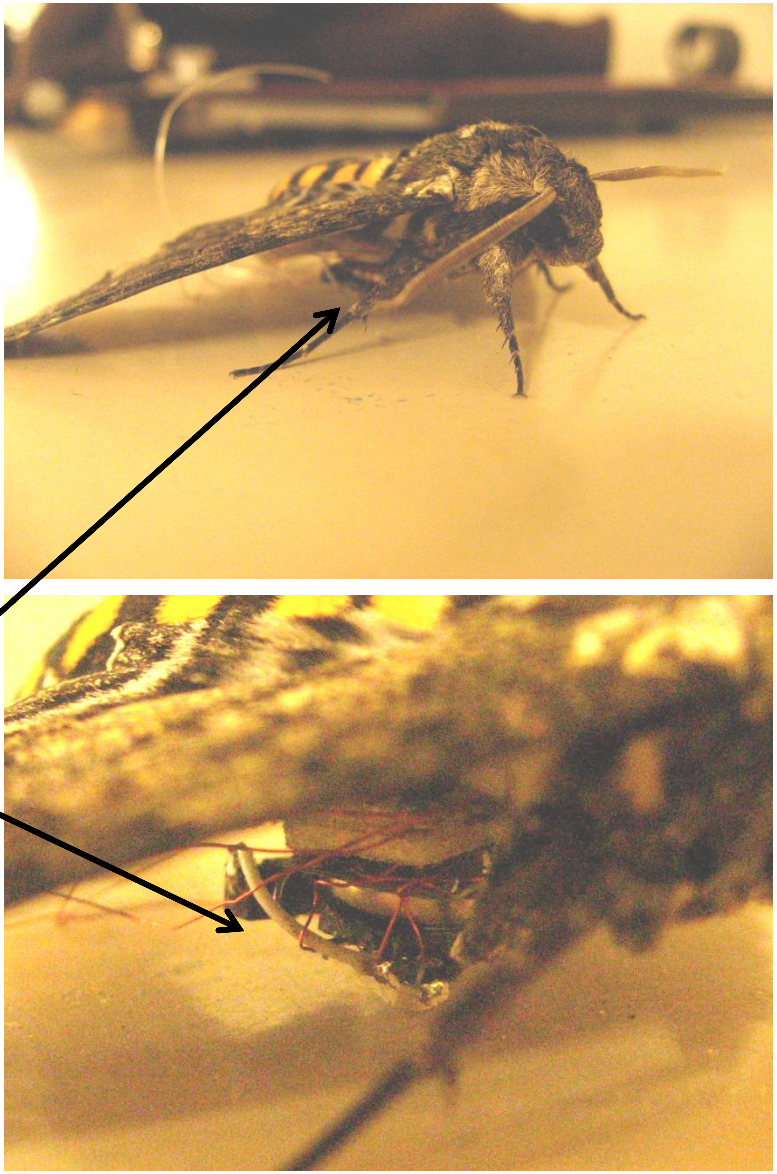




Component	Mass (mg)
3.0V lithium cell	251
Radio Receiver	48
PIC16F688 uP	41
Switch	50
LED	<1
resistor	<1
FNP	2
(solder, etc)	67
Total	460

Dave Otten & Jeff Lang

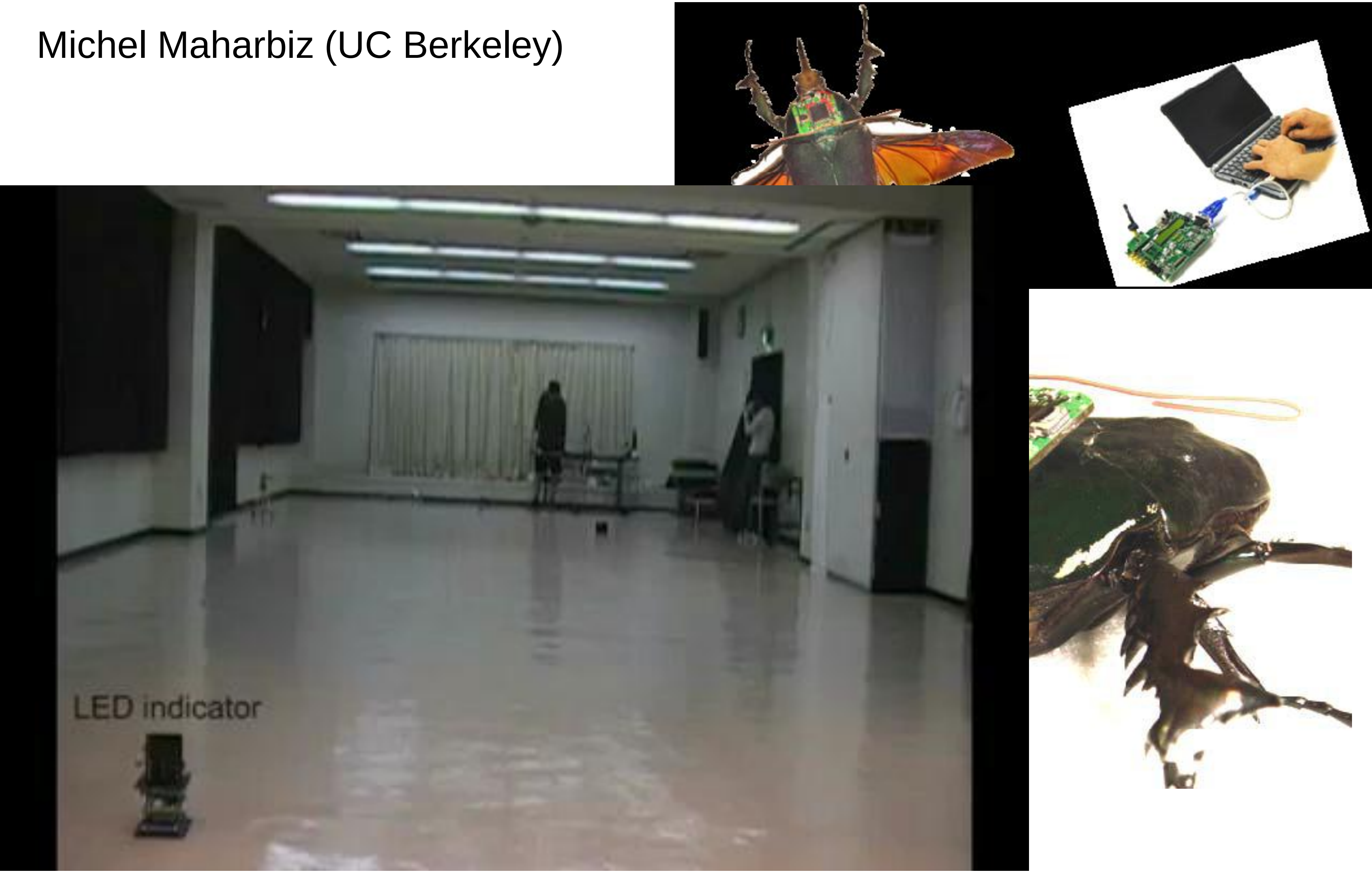
Flight control



Tom Daniel

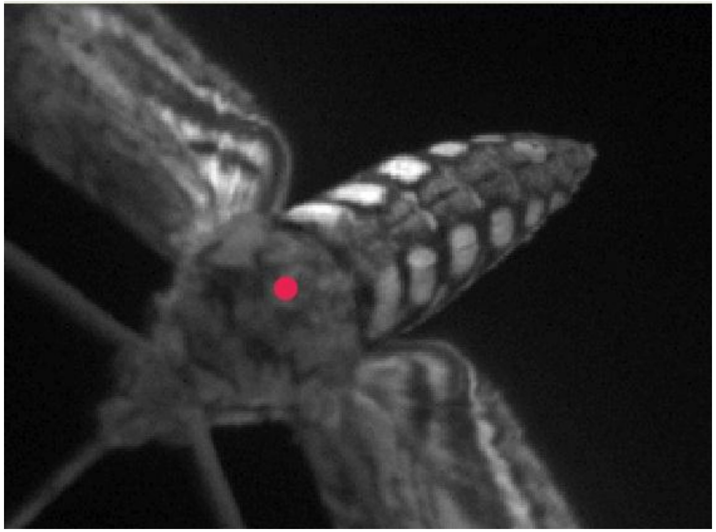
Flight control

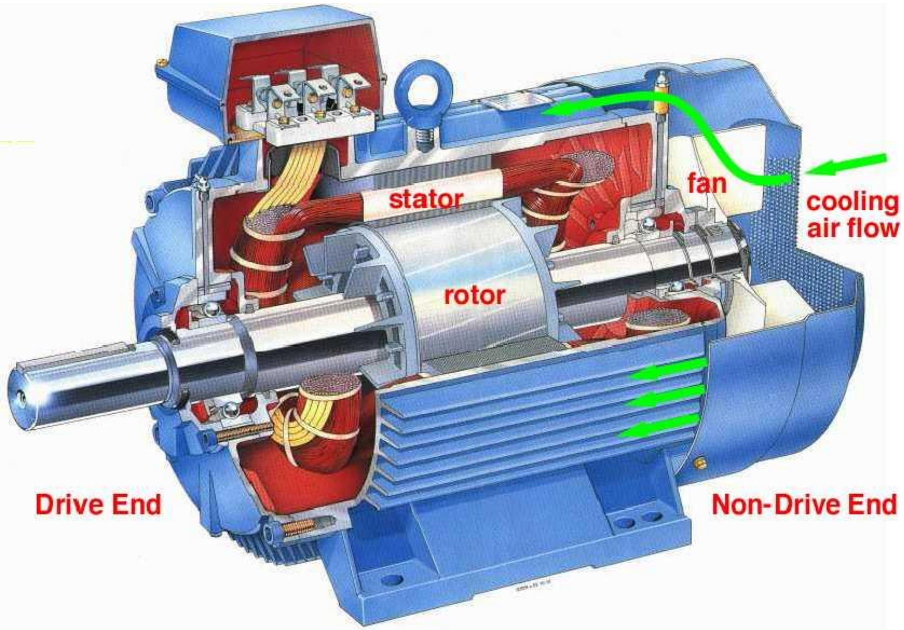
Michel Maharbiz (UC Berkeley)

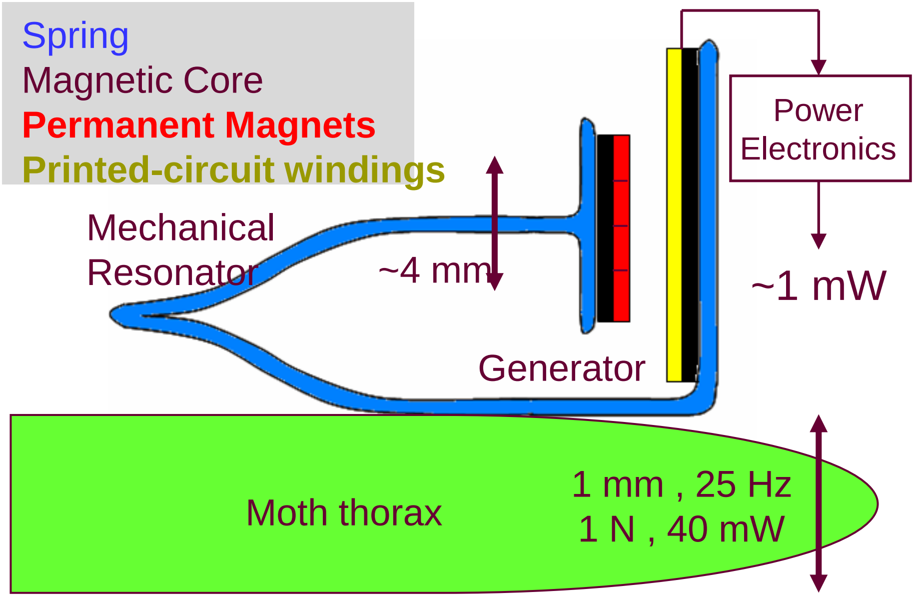


The energy challenge: how to power the system?

- Thermal energy: moth heats up during flight
- Chemical energy stored onboard
- ~40 mW mechanical power during flight



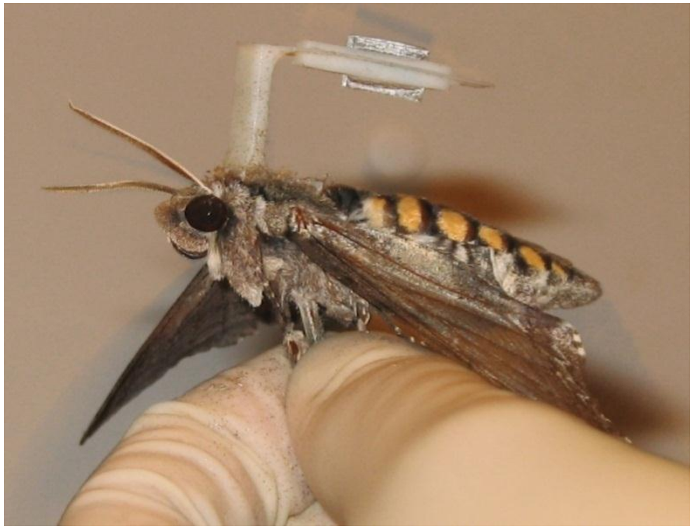


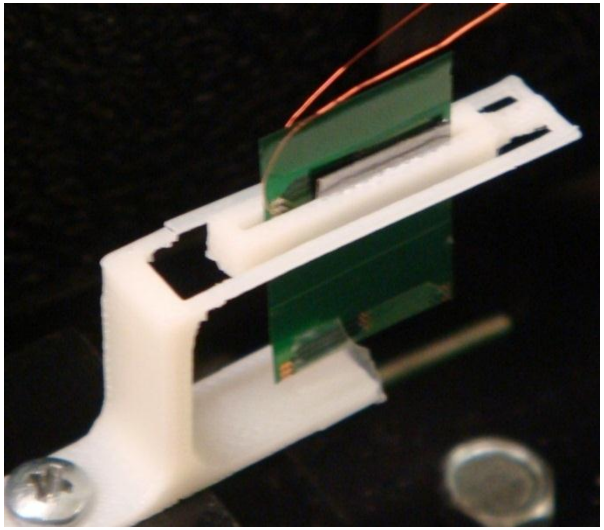


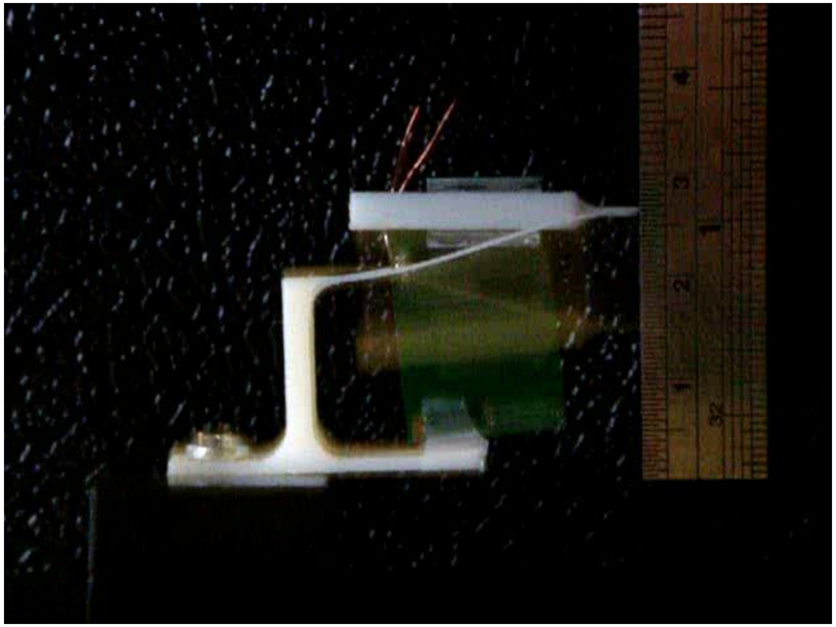
Jeff Lang

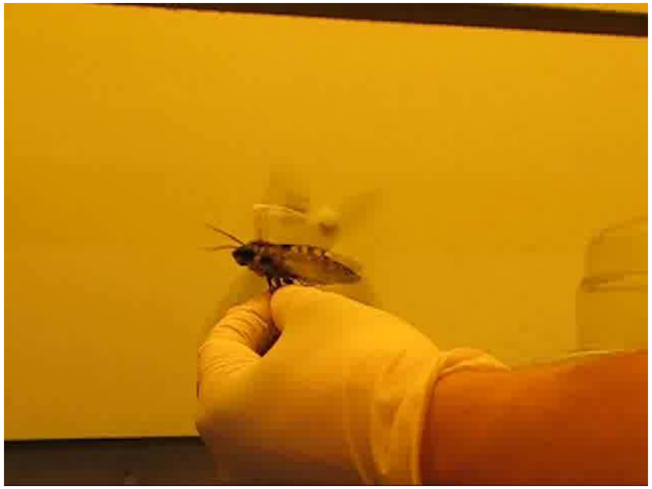
Energy harvesting

- 3D-printed harvester
- ~1 mW power out







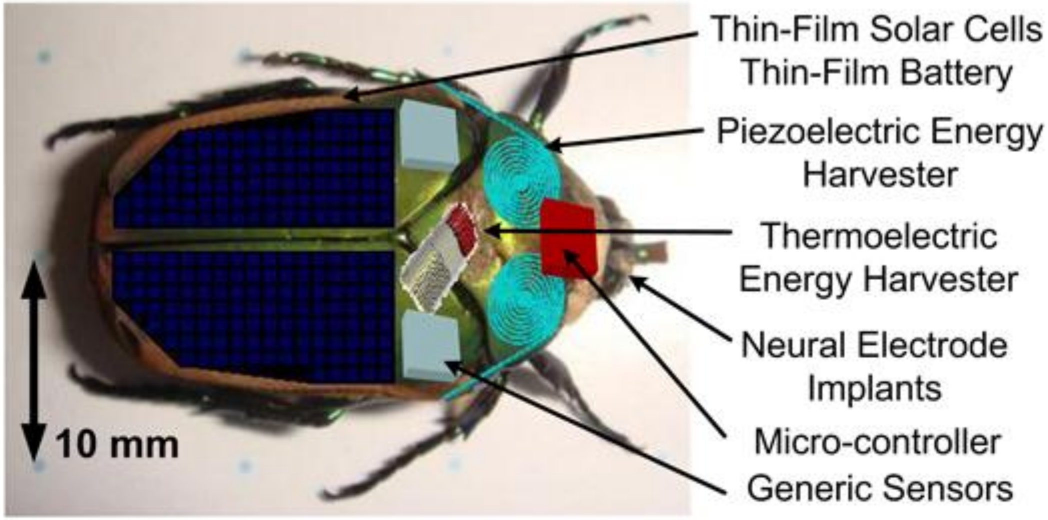


Jeff Lang

Energy harvesting

Univ. Michigan energy harvester from beetles

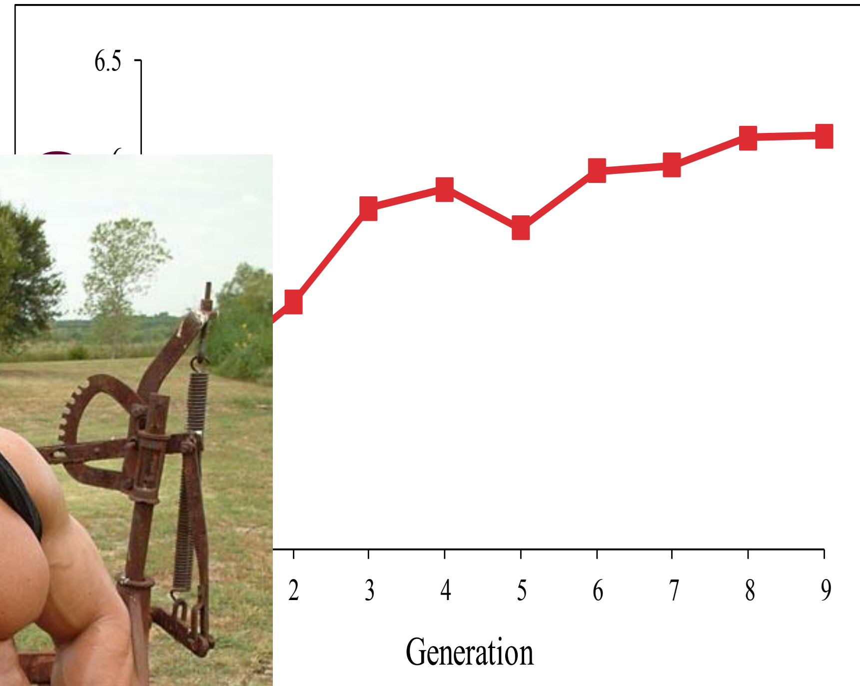
~20 μW



Engineering the animal

While we decrease system size & mass, can we push up payload capacity?

Selective breeding

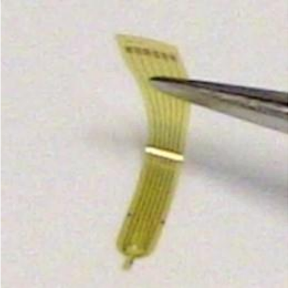


Goggy Davidowitz

So what do we learn?

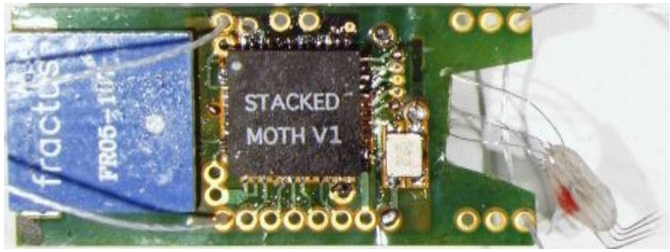
- The component technologies have translation potential

Neural interface



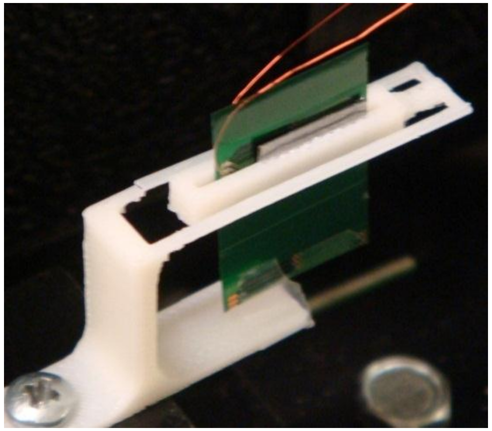
Peripheral nerves

Communications



Small, low-power wireless telemetry

Energy harvesting



Low-frequency human motion

Medical microsystems: challenges

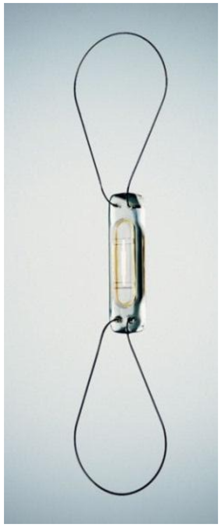
- Power is an enduring challenge
- There is abundant power available from humans
  - ~3-5 W from body heat
  - ~2 W respiration
  - ~1 W blood pressure
  - ~10's W from motion
- But biomedical energy harvesting is still mostly a promise

Knee harvester, ~5 W, *Science* 2008

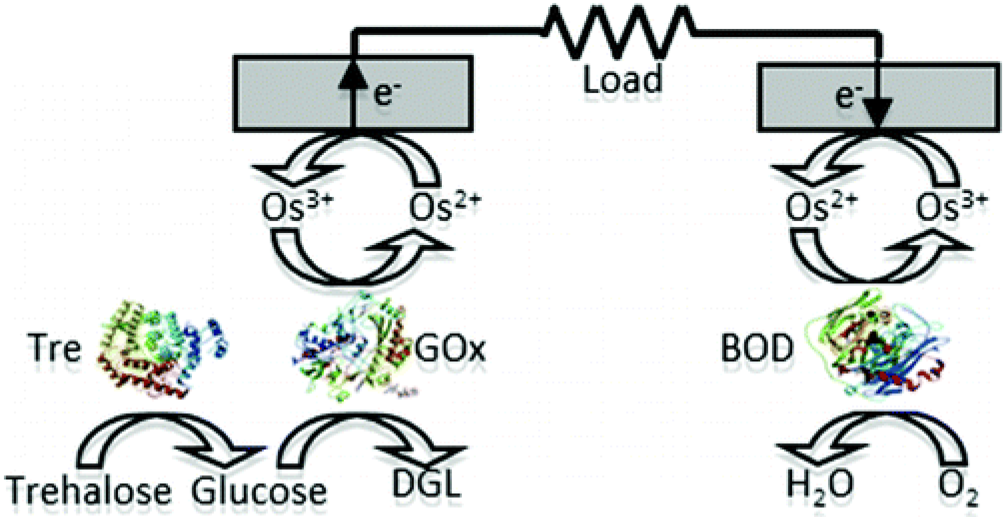
SEIKO Thermic watch

Medical microsystems: challenges

- One solution is to be passive
- Can we tap into stored chemical energy?
- Or will we just wait for electronics to catch up?



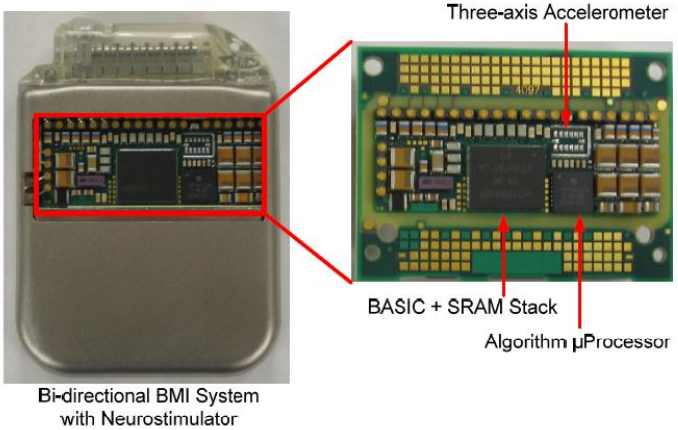
CardioMEMS passive pressure sensor



Biofuel cell for insects, *JACS* 2012

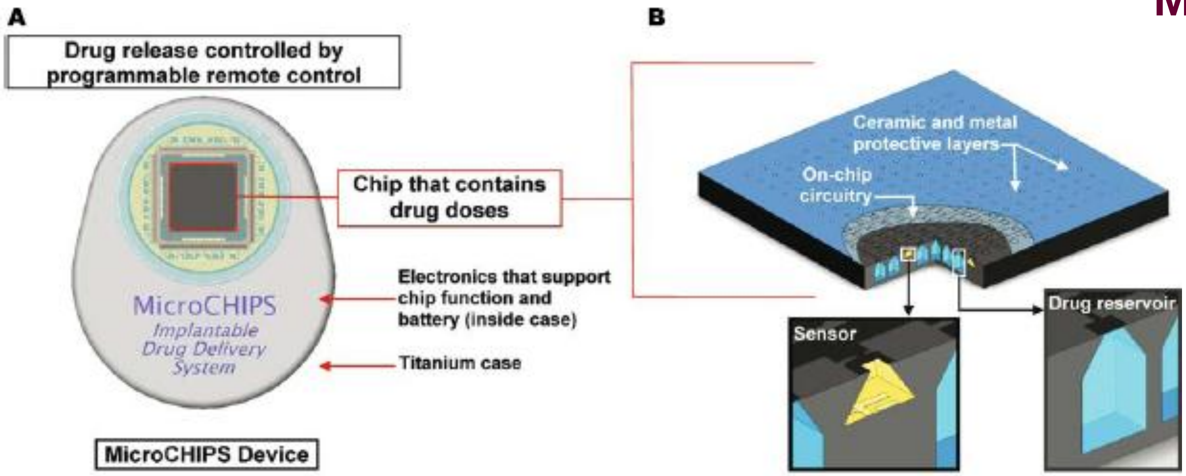
Medical microsystems: challenges

- Sensing
  - In order to close the loop, we need to sense
  - Motion is easy, but not necessarily informative
  - Molecules are hard, but more important



Medtronic bi-direction stimulator

MicroCHIPS device



Staples *et al.*, *Pharm. Res.* 23:847 2006

Medtronic Guardian Continuous Glucose Monitor

Requires calibration every 12 hrs via fingerprick test

3-6-day lifetime

Medical microsystems: challenges

- Algorithms: how to turn data into information?
- Security: how to prevent unauthorized read\write?