# Intelligent Autonomous Robotics

## 2. Exploiting physics

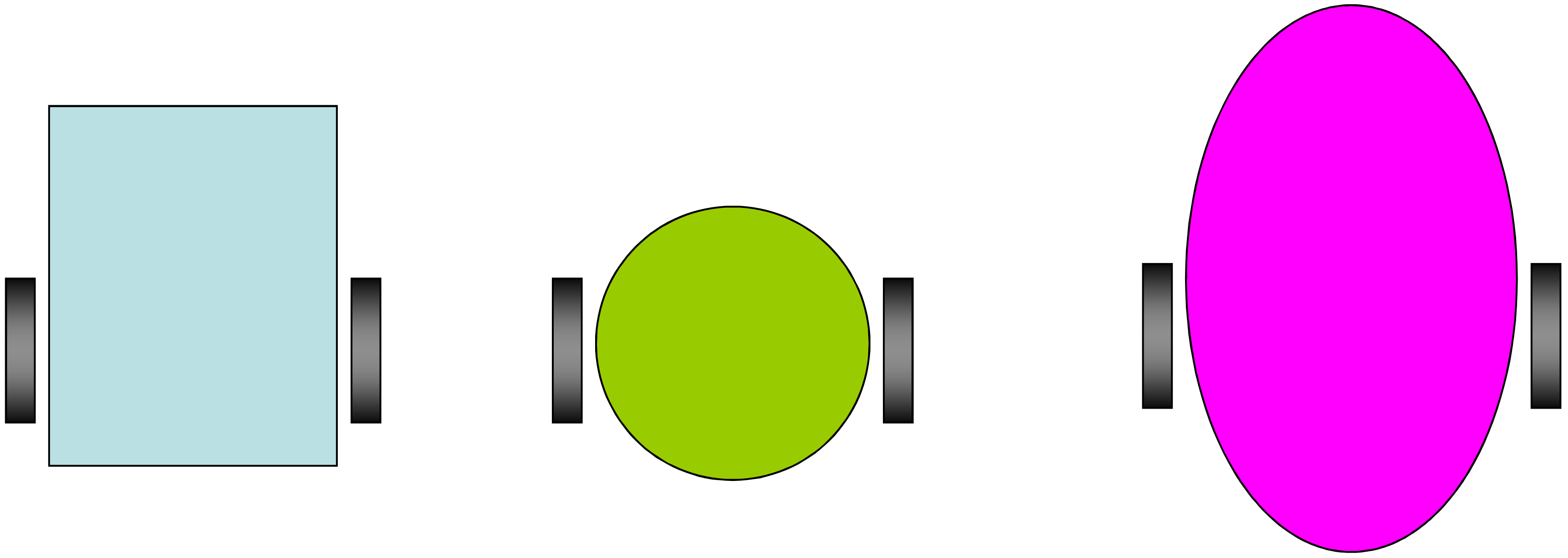
### 2.1 Shape and compliance

Barbara Webb

# Physics

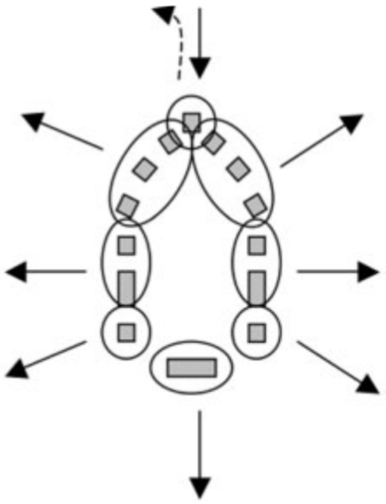
- Our aim is robots that interact with the world.
- The physics of this interaction are a hard constraint; we can’t beat it; and its better not to fight it.
- Sometimes the structure of the robot and the world can be used directly for successful interaction
  - Use the mechanical forces exerted on the robot to shape its movement
  - Design and position sensors to match the world and thus extract the immediate information needed for control

# What shape would you choose for a robot that must not get stuck in an office environment?

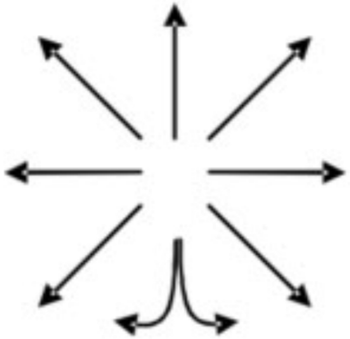


# The right shape can solve the problem.

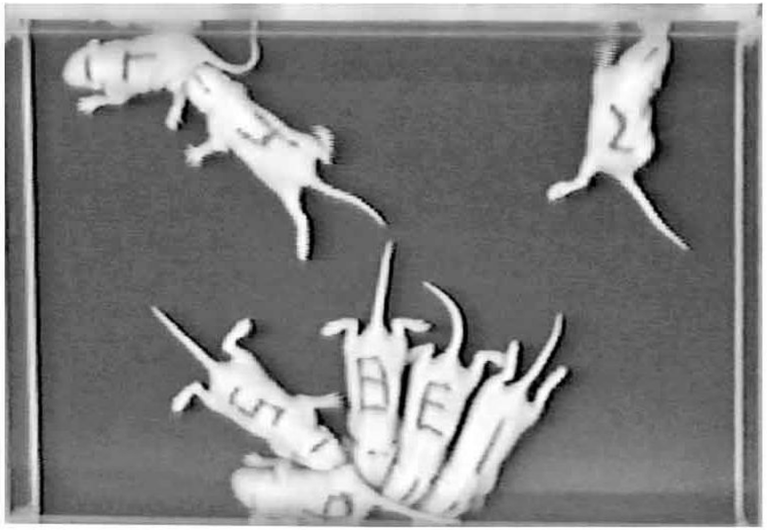
- May et al (2006)
- Infant rat pups huddle together and in corners
    - Assumed to be thigmotaxis behaviour: orientation towards contact with objects or other rats.
- Robots designed to replicate this behaviour:
    - Scale robot and arena size at 4:1
    - Shape robot with rounded snout
    - Tactile sensing clustered around the nose
    - Differential drive at rear like rodent back legs
- Programmed to react to touch by turning in that direction
- *OR* (as control experiment) to move in a random direction every 2 seconds (i.e. ignoring sensors)
- Random robots produced very rat-like behaviour!

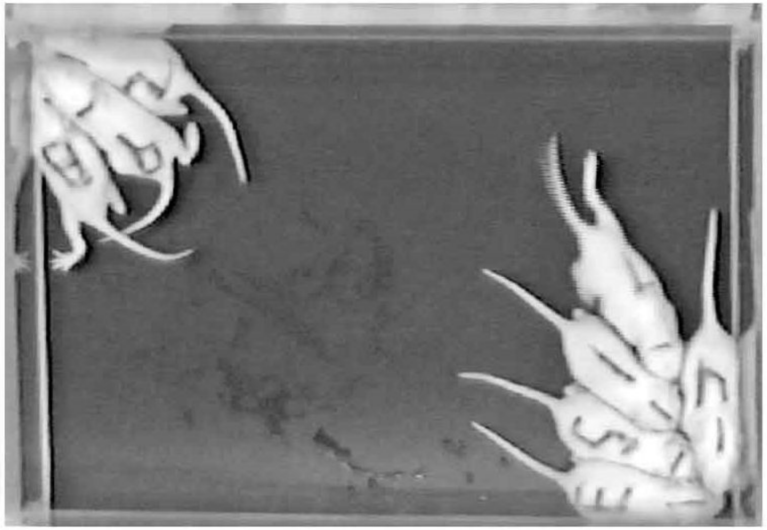


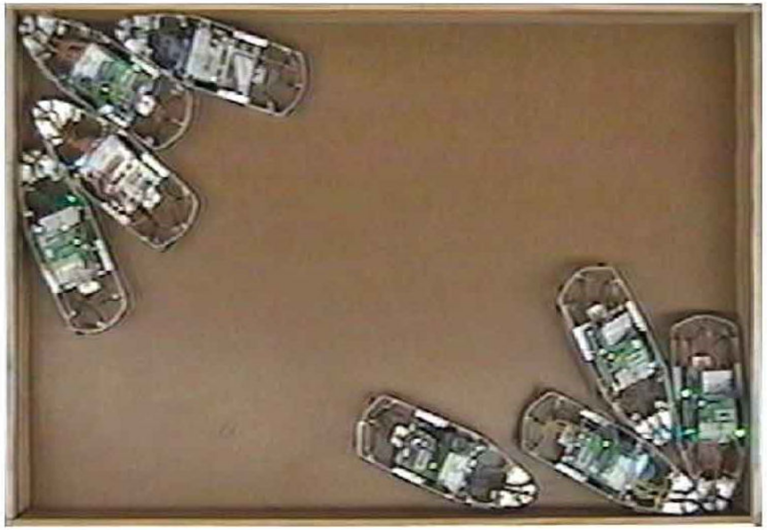
Respond to touch



Make random move

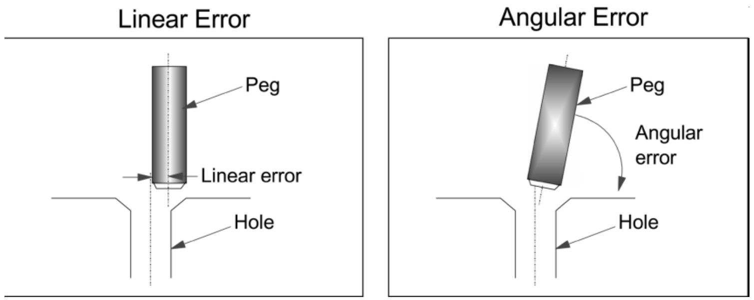






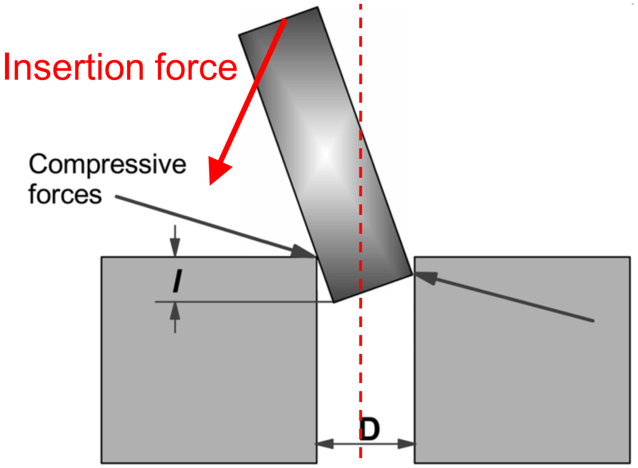
# Peg in hole – exploiting compliance

- Basic assembly task is made simpler by adding chamfer
- Still risk of wedging or jamming
- Ideally, forces produced by the alignment errors would act directly to correct them



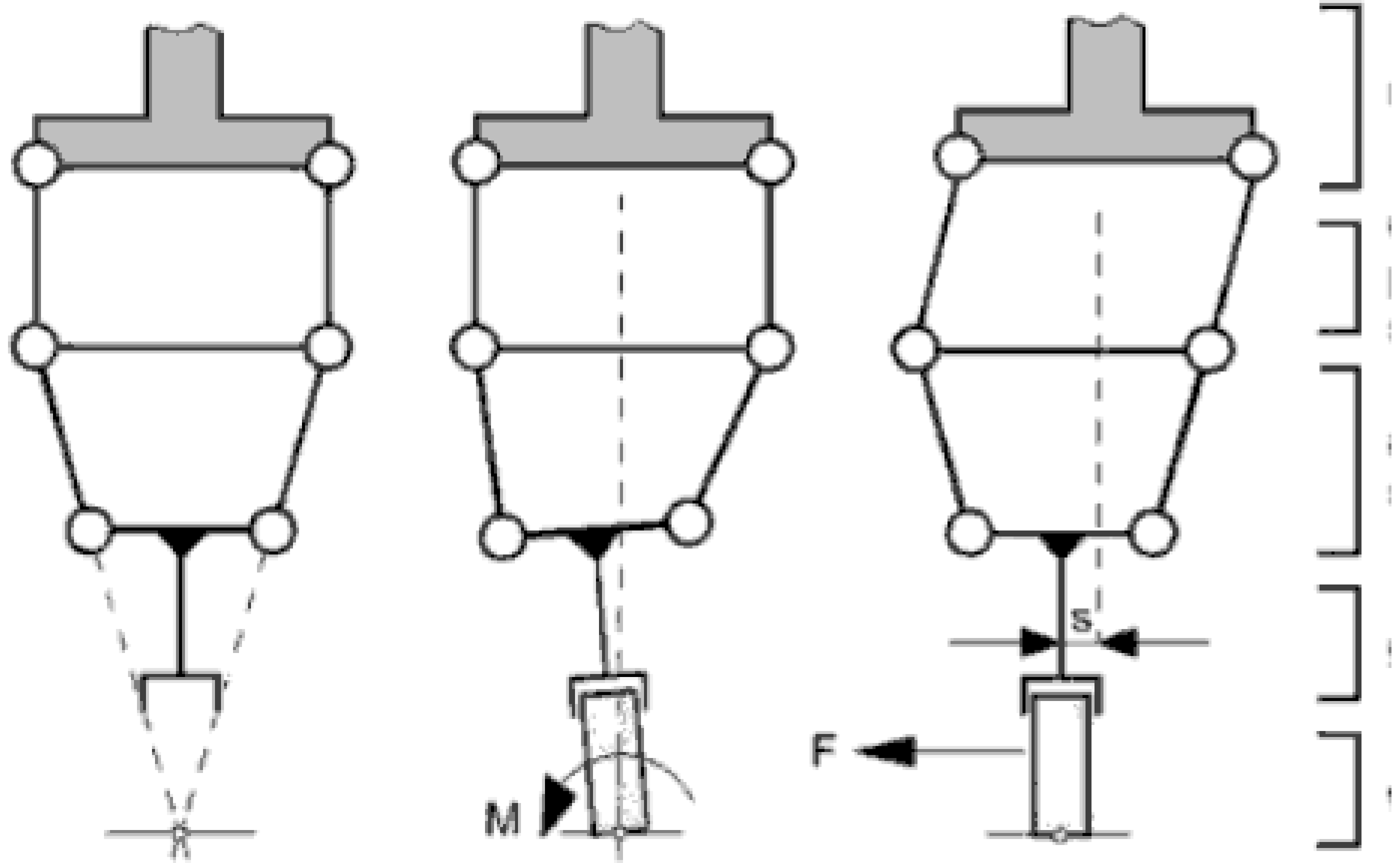
Peg in hole with chamfer

- Centre of compliance: point where six components of force (X,Y,Z and three torques) produce only directly corresponding translations and rotations (e.g. rotation force produces no translations)
- Centre of compliance at tip of peg would solve problem
- Can use linkages or compliant structures between end effector and part to produce ‘remote’ centre of compliance at tip of peg



***WEDGING*** = $l / D < \mu$

***JAMMIMG***: I/D > μ but insertion force vector too far from hole axis



construction torque loading shear force loading

From Robot Grippers, Monkman et. al (2007)

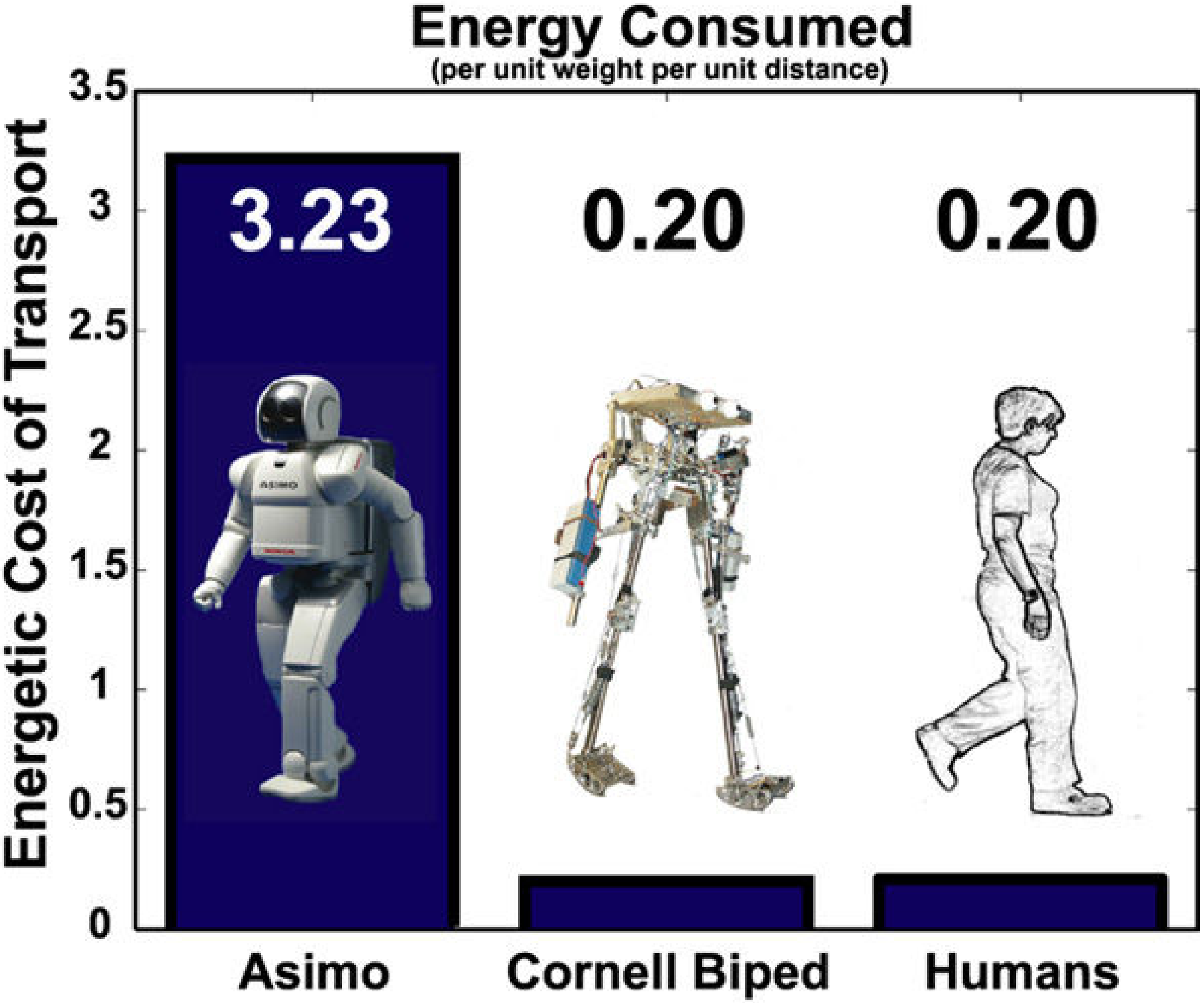
# Universal robotic gripper based on jamming of granular material
(Brown et al, 2010)

Universal Gripper

U. Chicago, Cornell, iRobot
May 2010

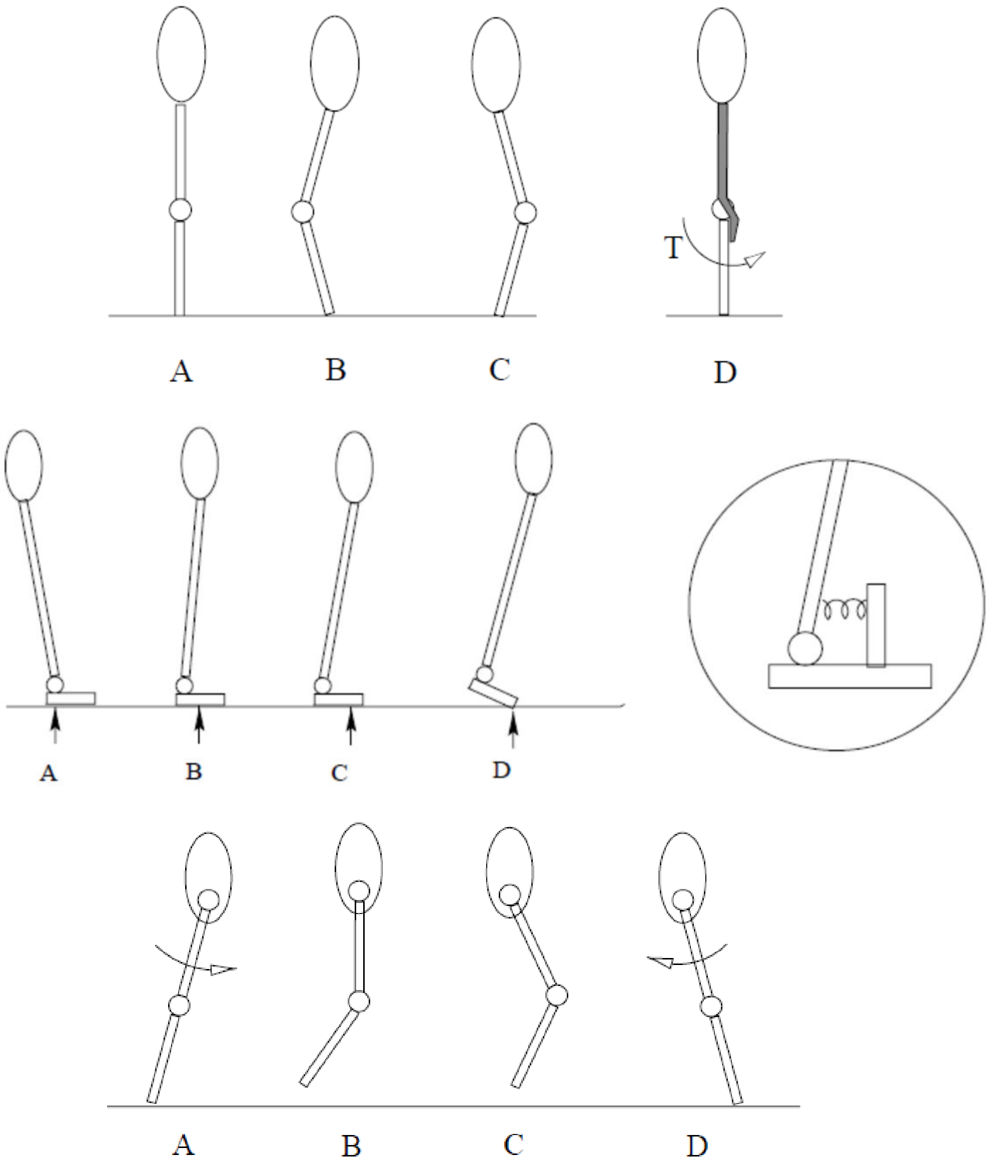
# Passive walking robot

# Using gravity (Collins, et al 2005)



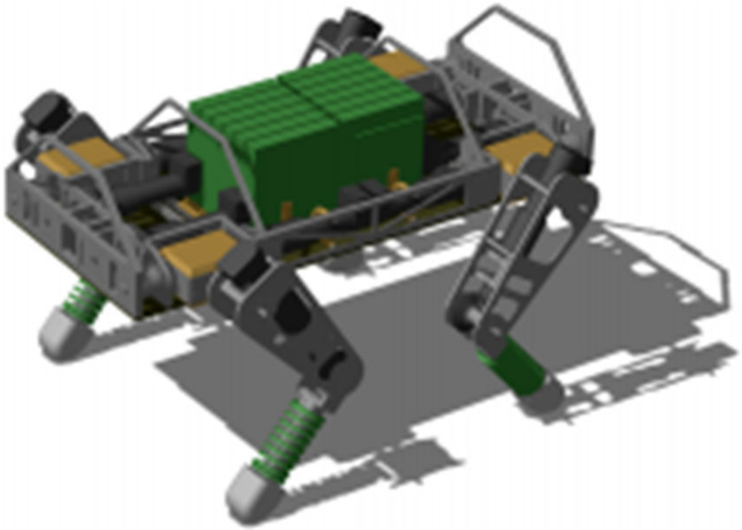
# Natural dynamics for bipedal walking

- Pratt & Pratt, 1998
- Keeping knee straight is difficult, unless add knee cap
- Foot allows support for moving centre of mass, compliant ankle deals with increased torque and provides ‘toe off’
- Exploiting passive swing in two part leg, get natural stride from actuating only hip joint
- Get low power robot, and stable speed without explicit speed control



# Spring flamingo
http://www.ai.mit.edu/projects/leglab/

leggedrobotics.ethz.ch

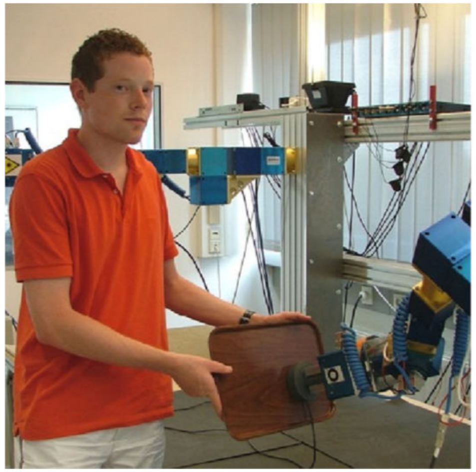


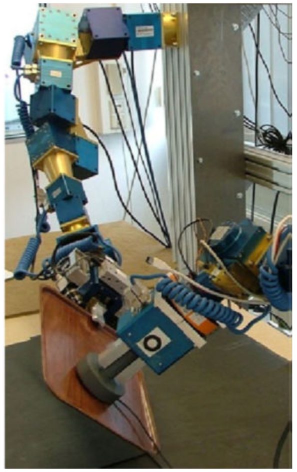
# Converting energy for control

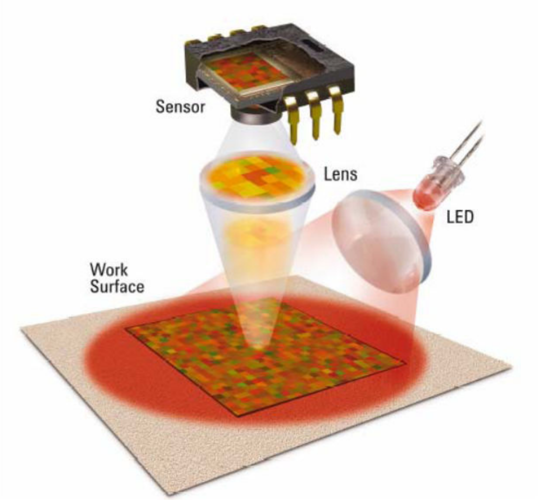
- So far discussing examples of harnessing forces and energy in the world for direct robot control
  - E.g. using gravity to produce leg swing
  - E.g. using shape of robot and environment to force diversion towards or away from something
- But we have a lot more flexibility if we can use energy and forces indirectly
  - E.g. convert light energy to wheel speed to approach lamp
  - Have input-output connections that are positive, negative, thresholded, or any other arbitrary relationship
  - Have input-output connections dependent on circumstances, or dependent on the past or future…

# Designing and distributing sensors

- Installation or invention of a new sensor might solve a robotics problem
- Example: robot arm following a trajectory to finish or wipe a surface, greatly simplified by end-effector-mounted slip sensor based on optic mouse principle (Milighetti & Kuntze, 2008)





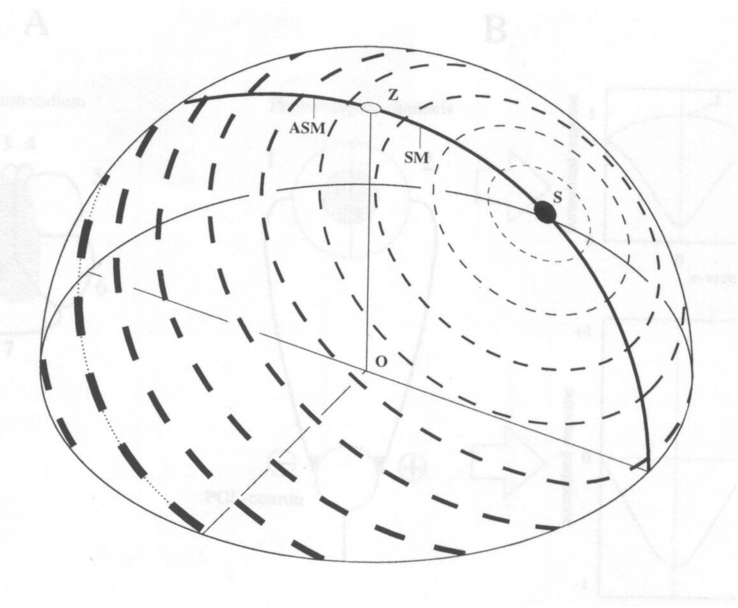


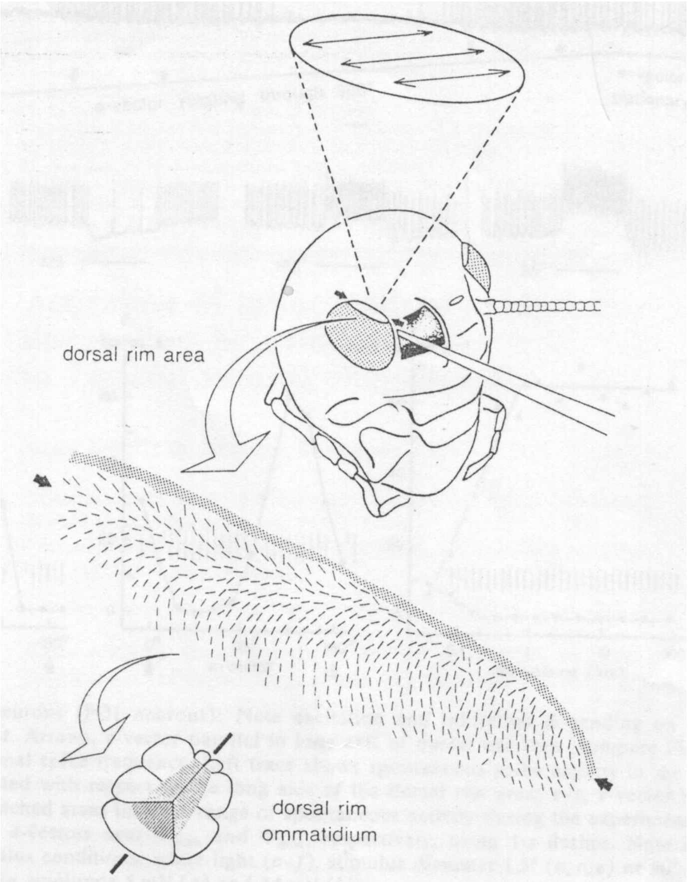
- GPS has made significant difference to the robot navigation problem

# Polarised light compass

Desert ants (and many other animals) have visual receptors tuned to the polarisation plane of light.

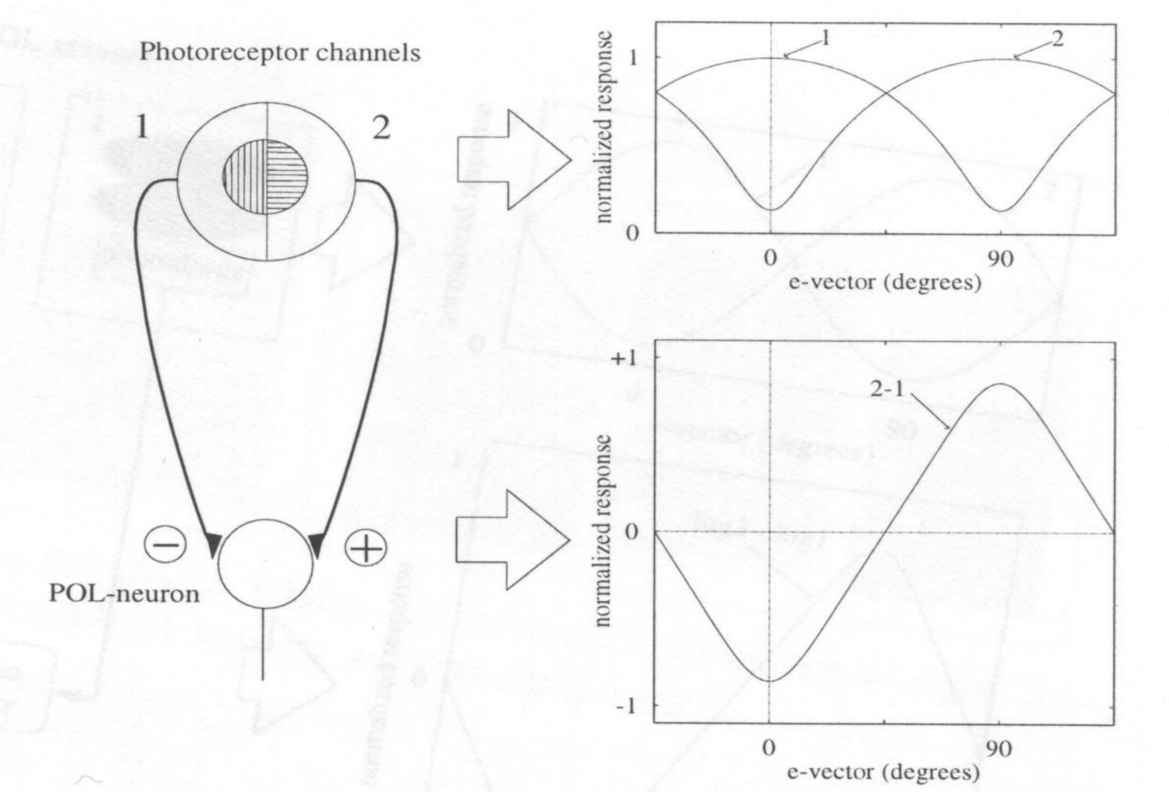
Skylight has a natural polarisation pattern





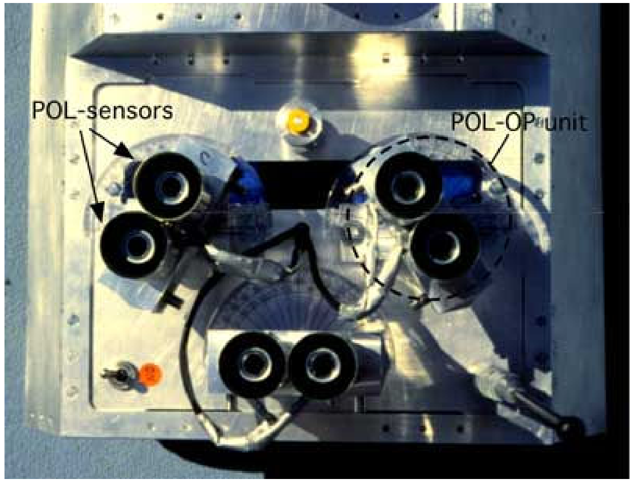
# Polarised light compass

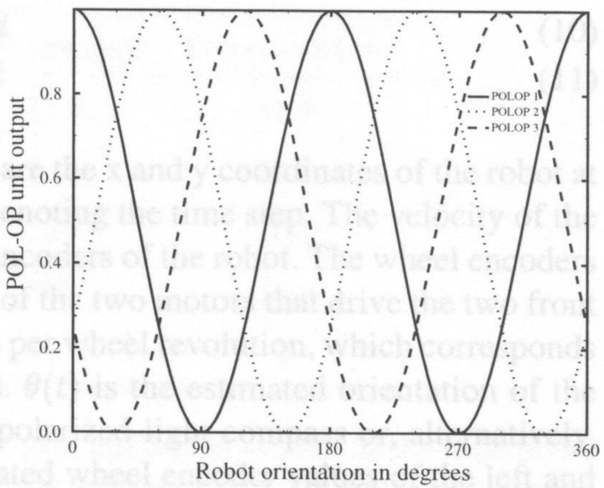
The receptors are tuned in orthogonal directions, and opponent processing by ‘POL-neurons’ produces an intensity-independent response.



# Polarised light compass

This mechanism has been replicated on the Sahabot. Uses three pairs of sensors oriented at 60 degree axes.

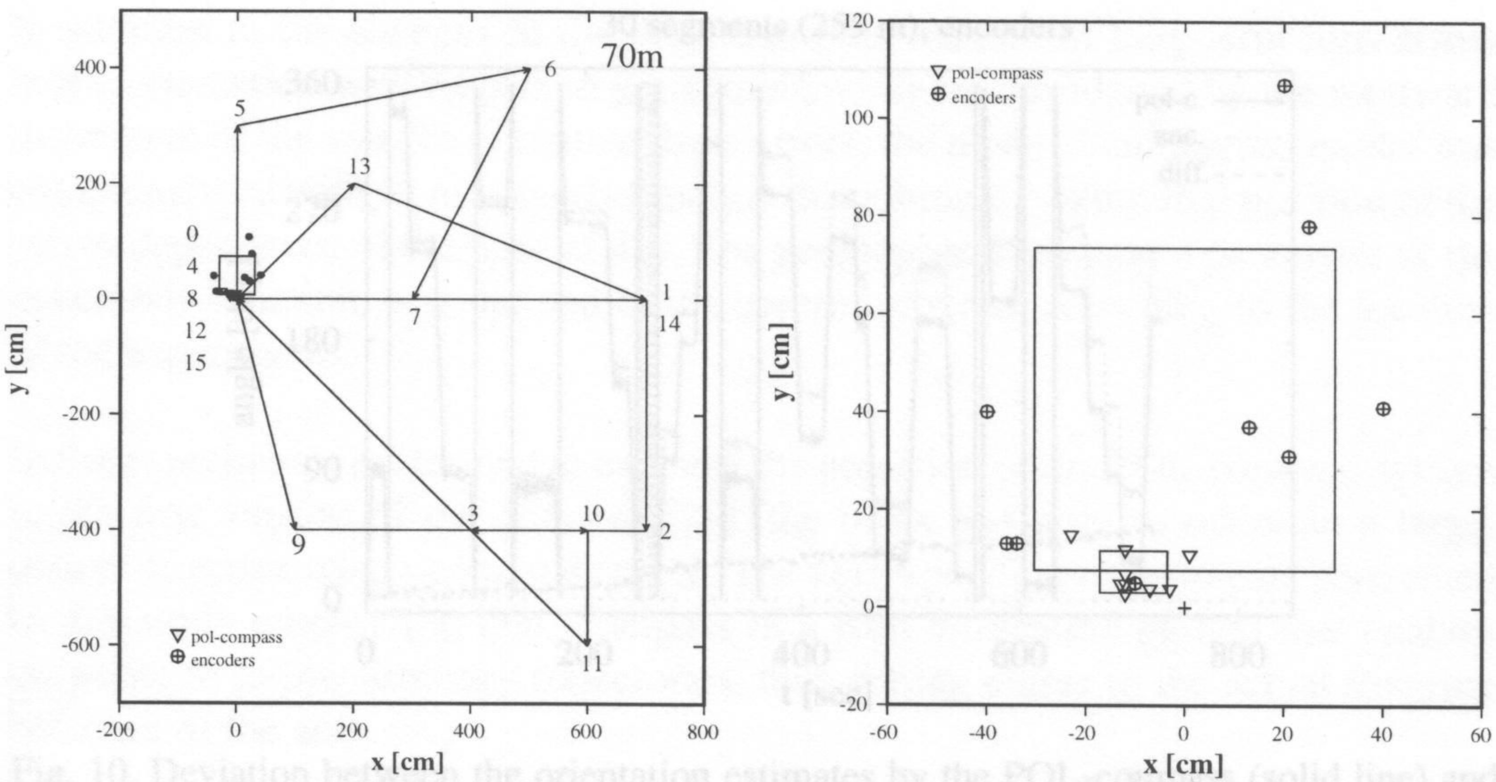




Can create lookup table to determine direction indicated by output ratios of the three sensors. 180 degree ambiguity resolved by sensing sun direction.

# Polarised light compass

Results of path integration using polarised light compass : much more accurate than odometry



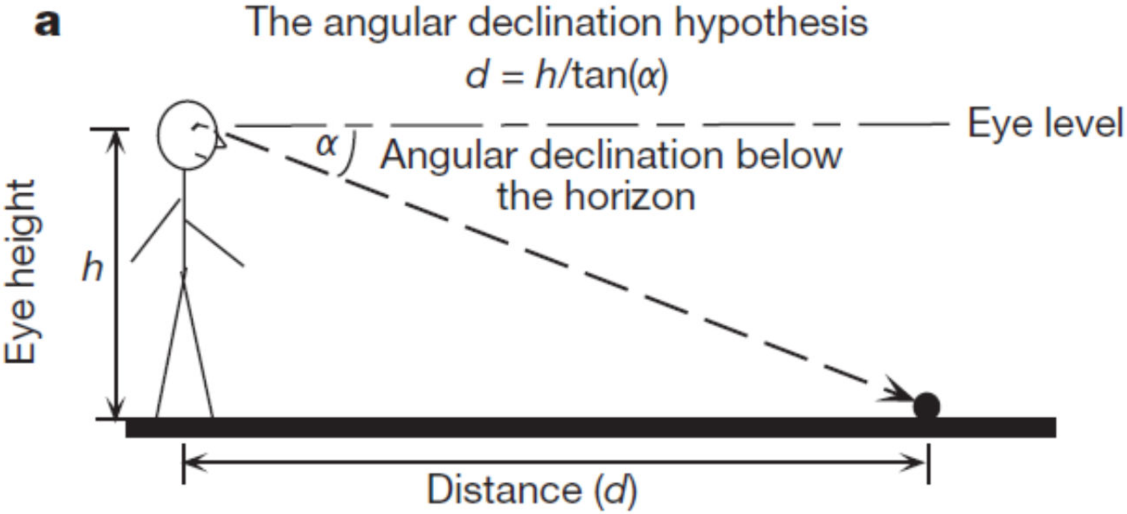
# Sahabot in the Tunisian desert

# Exploiting physics for sensing

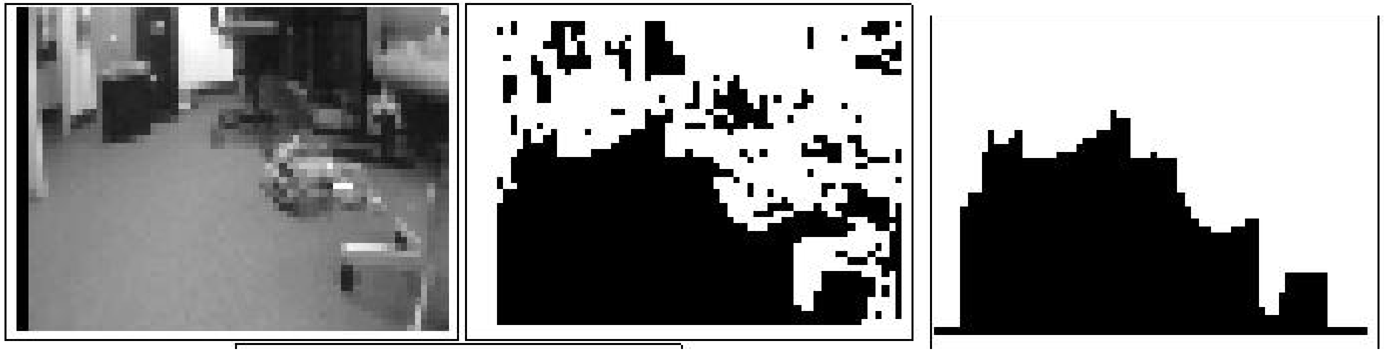
- A common mistake is to assume we must reconstruct veridical world properties from sensor data:
  - E.g. robot needs to map distance and angle of all obstacles; depth information requires range sensor or stereo
- Actually only need to extract whatever is required for execution of appropriate action:
  - Egocentric, robot-relative co-ordinates
  - May be simple/single property that suffices for control (but may still need to do some sensor processing to get it)

# How to determine distance without stereo

If the ground plane is flat, there is a simple relationship between visual angle and distance to the base of an object on the ground (Ooi et al, 2001)



Using on a robot: Filter image for ground vs. texture (=object); then height of ground in image gives distance to object (Horswill, 1993)



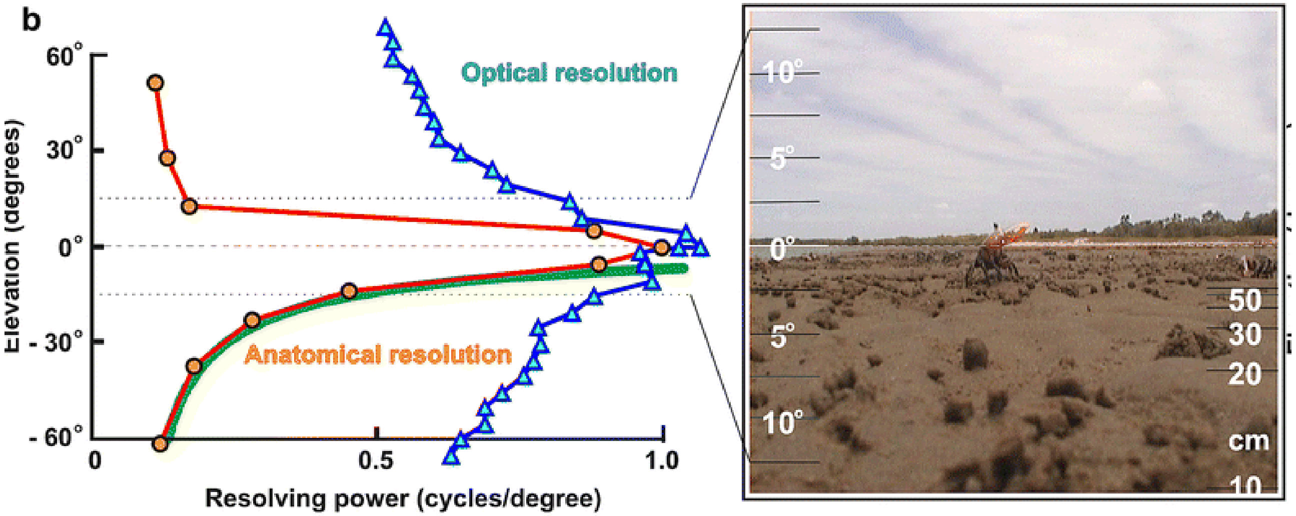
# Living in a flat world: the fiddler crab

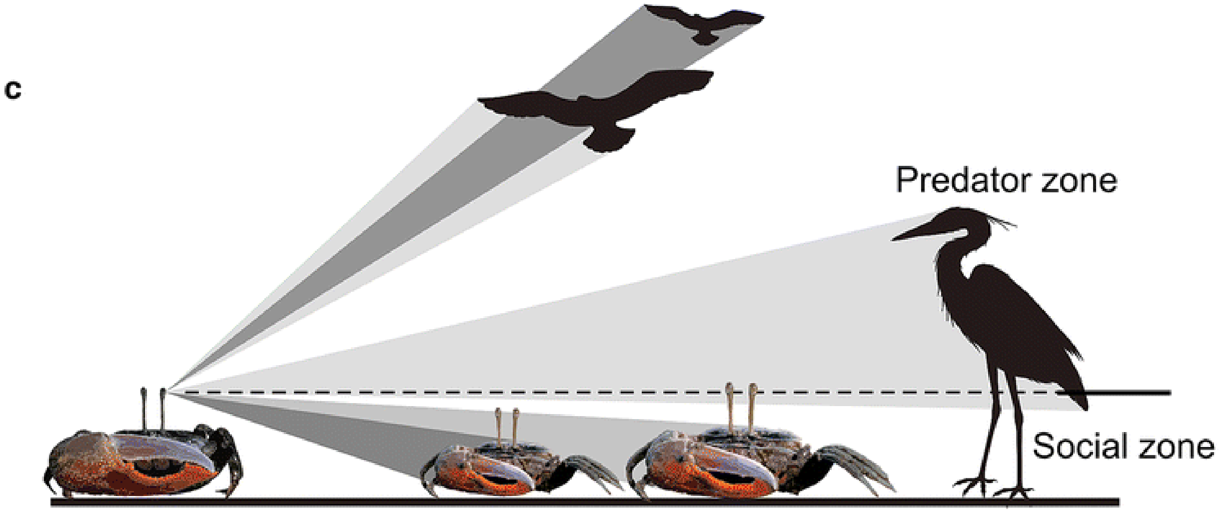
Zeil & Hemmi, 2005

-Raised eye stalk aligns eye with horizon

- Anything above the horizon is a predator, anything below a fellow crab

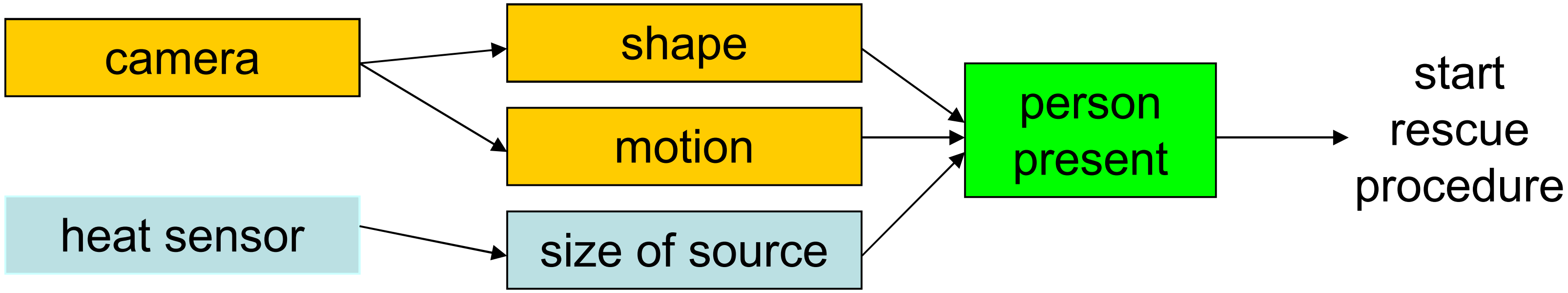
-Resolution (number of ommatidia) greatly increased around horizon, this gives effective *size constancy* for approaching animals





# Virtual/logical sensors

- An abstraction over the physics of specific sensors
- Task oriented definition: start by defining the property you want for robot control (e.g. ‘person detector’ for a rescue robot)
- Design set of input sources (may include other virtual sensors), and computation (may be in hardware) that produces appropriate output vector



- For robot control purposes can treat as ‘direct’ sensing of desired property
- Within the module, may be able to redesign, use different sensors to obtain same (or improved) effective sensing capability.

- In practice, usually need to take into account the real physics of the sensor

# Sensing for Action

- Sensors transduce energy from one form to another
- From the robot control point of view we have some information – a measured value – that represents some property of the world
- This relationship is rarely a direct one:

E.G. We say the IR sensor is a ‘range’ or ‘distance’ sensor:

Distance to object →
Light scattering →
Amount of light reflected →
Resistance of sensor element →
Voltage →
Analog to Digital Conversion→
Calculation →
Distance value

*But note! We may not need to know the actual distance to perform the appropriate action, such as “avoid”*

# For next week

## Practicals

- Monday 10am or 1pm, FH level 1 robot lab
- Will be assigned a robot (work in pairs)
- First demo (robot avoids obstacles and follows walls) due the following week

- Think of (or research) a sensory system (like polarised light detection) that some animals use, but humans don't. Find out if this has been used for robotics. Email me your example for discussion next lecture.

# References

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Collins, S. H., Ruina, A. L., Tedrake, R., Wisse, M. (2005) Efficient bipedal robots based on passive-dynamic walkers. *Science*, **307**, 1082-1085.

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