Moving through the world.

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Learning outcomes

By the end students will understand that:

1. Direct perception is a way of thinking about what information is ”in the world” and can be extracted without lots of neural processing.
2. Looking at the neural circuits in the fly, we can see how animals can be tuned to Directly Perceive task relevant information.
3. Trying to “build-in” direct perception in robots is difficult because robots have to be tuned to their sensory ecology.
4. Eye movements in humans are task dependent and show how humans acquire information in a just-in-time and task dependent way.

Direct perception and JJ Gibson

"Perception of the world and of the self go together and occur only over time"

Gibson, 1978

Embodiment

"Robots and animals have bodies and experience the world directly."

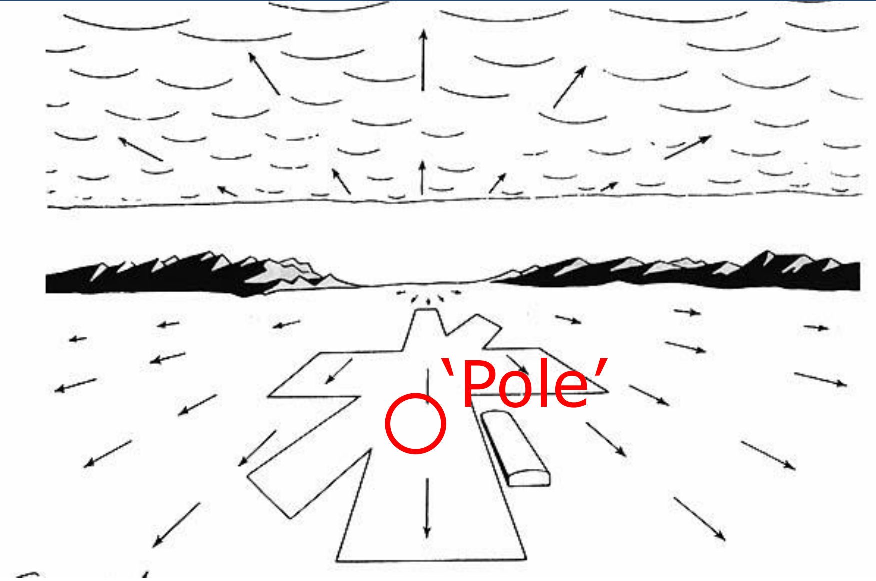
Brooks (1991) Intelligence Without Reason

Situatedness

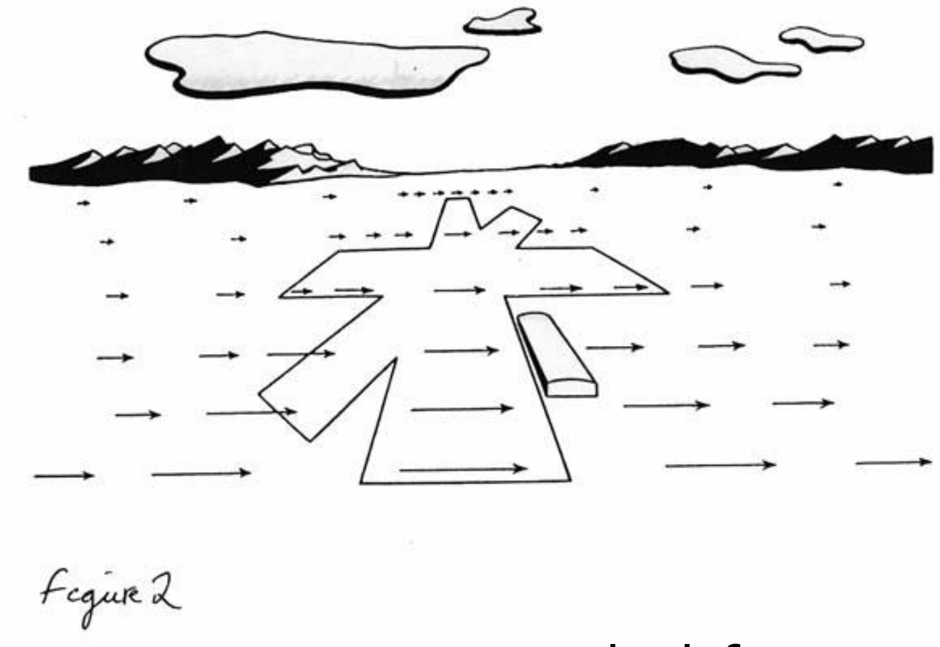
"The agent or animal is in the world: they do not deal with abstract descriptions but with the here and now of the world directly influencing the behaviour of the system"

Brooks, 1991, Intelligence Without Reason

Gibson realised that optic flow is the consequence of movement



movement and gaze aligned



movement to the left; gaze perpendicular

- Optic flow is the pattern of visual motion across the whole visual field
- Optic flow depends on the agent’s movement and the structure of the world

Direct Perception

- **Invariants** - properties of the sensory input that are always true.
  - Pole of a flow field tells you heading, change in the scale of a texture gives relative depth
- **Affordances** - the world affords (allows) actions.
  - Turning handlebars to align facing direction with pole of expansion
- **Resonance** - the brain is tuned to resonate with particular environmental patterns.
  - Visual system wired-up to efficiently extract optic flow information.

Task dependent direct perception

Affordances

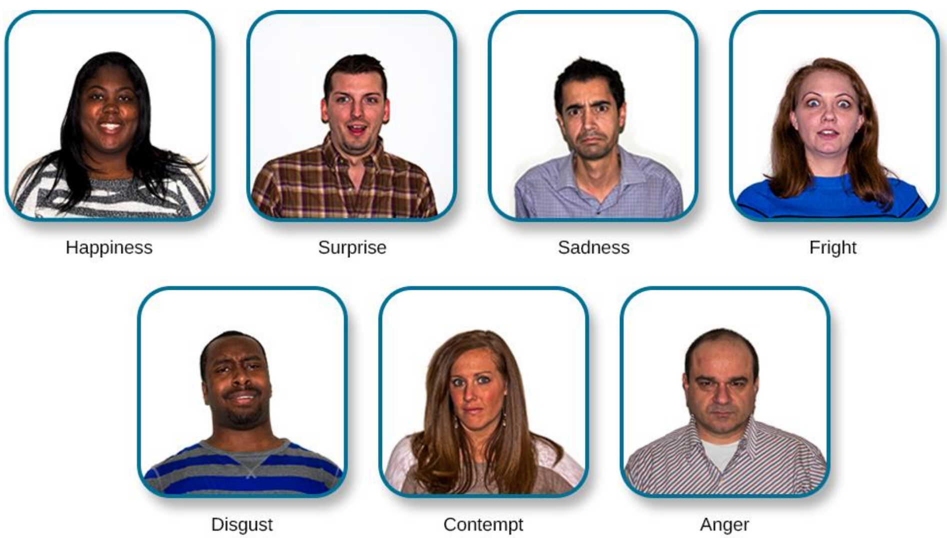
Invariants

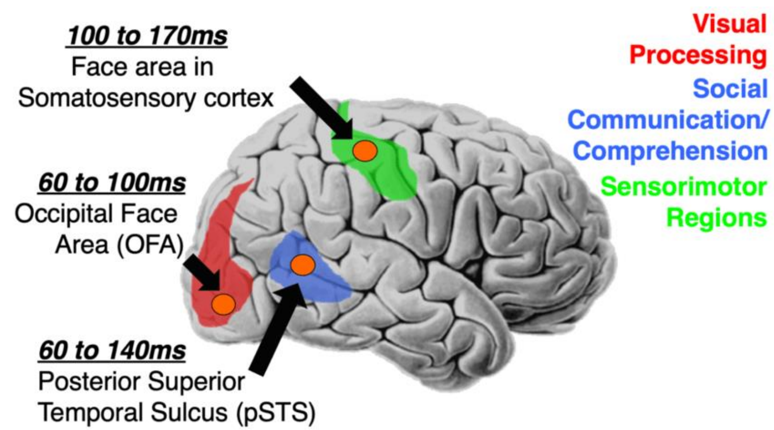
Resonance

Understanding social information Empathy

Culturally invariant facial gestures indicating emotion

Visual system that has dedicated matched filters for face information





Task dependent direct perception

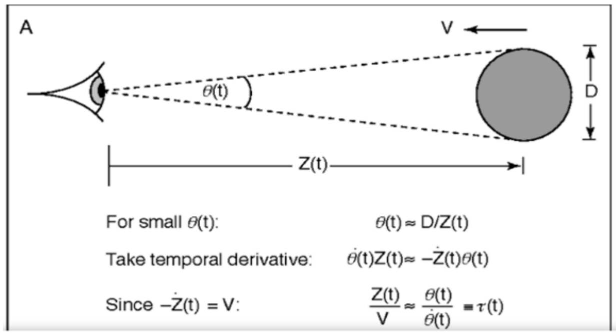
Affordances

Heading a football

Controlling a dive

Invariants

Tau – time to collision



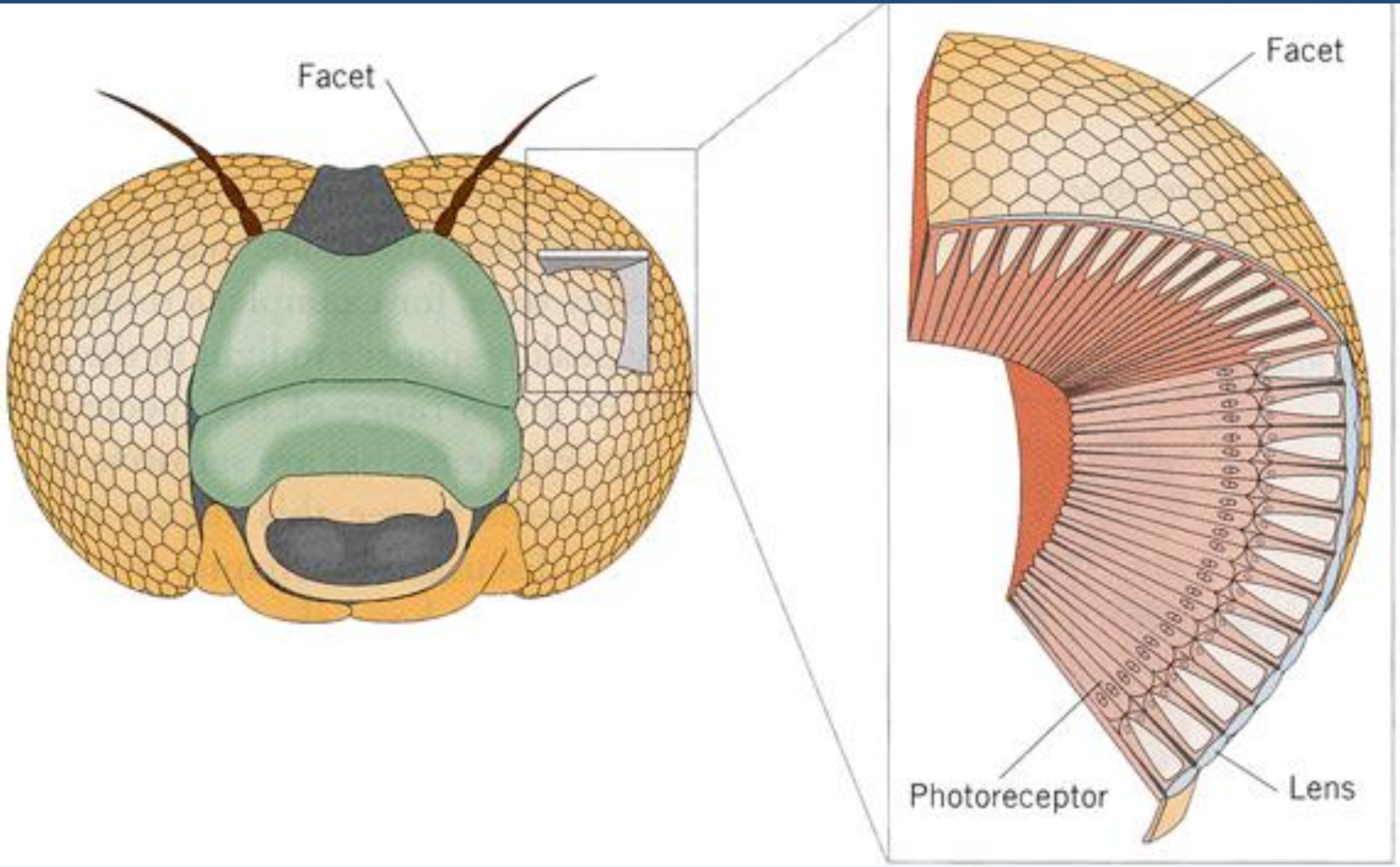
Tau = inverse relative expansion rate of the object's image on the retina

Resonance

Visual system that extracts edge information; neural circuits 'calculate' Tau + react to collisions

2. The fly, a Gibsonian animal

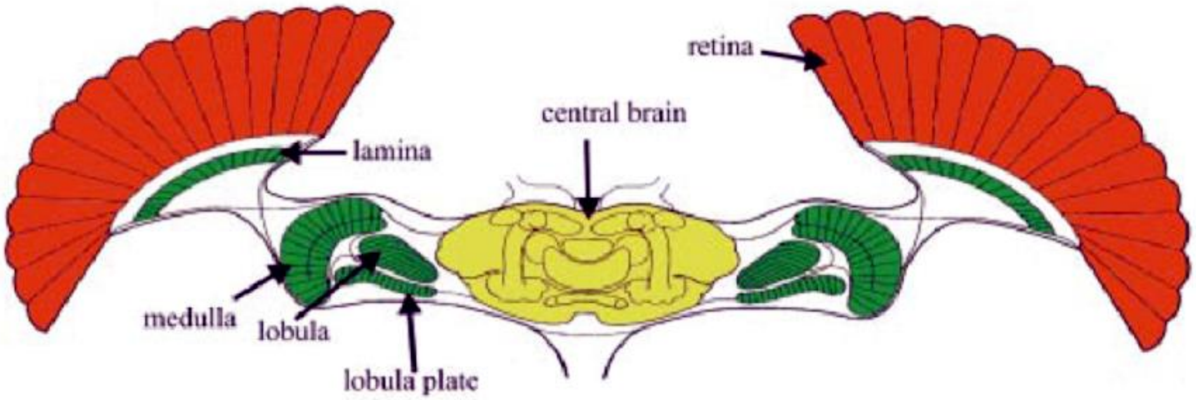
The Compound Eye



Each ommatidium has a lens and photoreceptors that receive light from the same direction.

Therefore, one ommatidium ≈ one pixel

Insect visual system

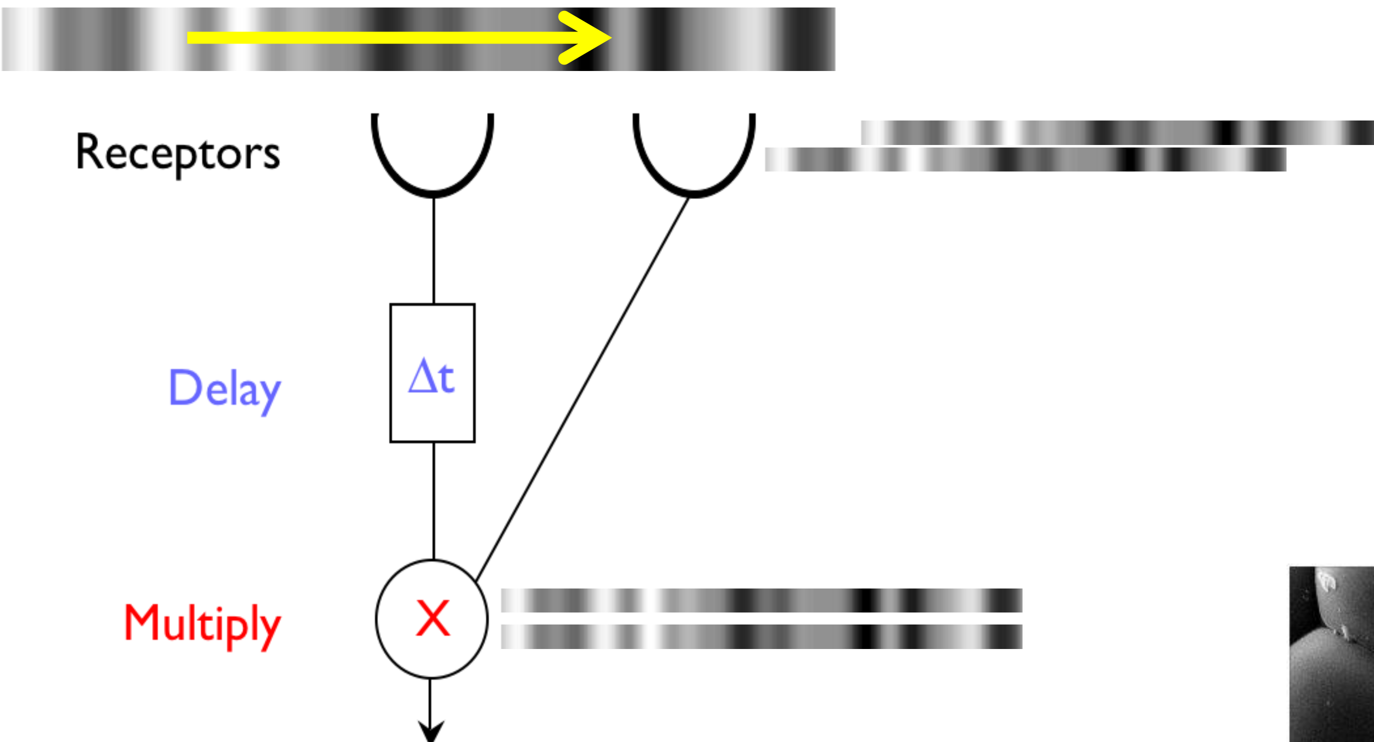


1. **Retina.** 1. Transduction of light
2. **Lamina.** 2. Local normalisation,edge detectior
3. **Medulla.** 3. Local motion detection
4. **Lobula/Lobula plate.** 4. Extract global patterns

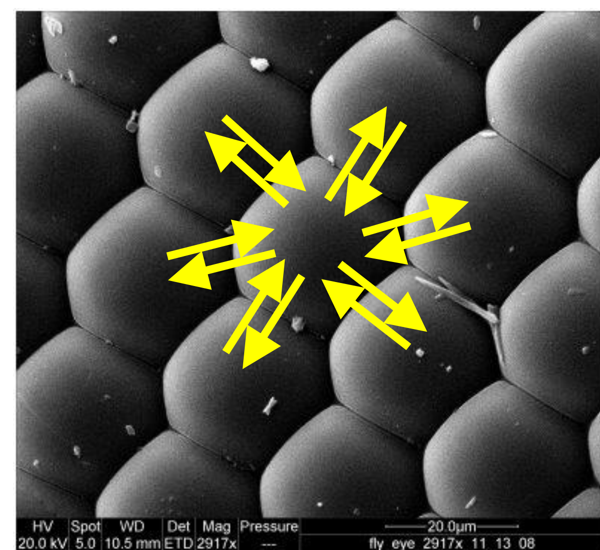
Borst and Haag (2002)

Local motion detection

Correlation of time-delayed signals

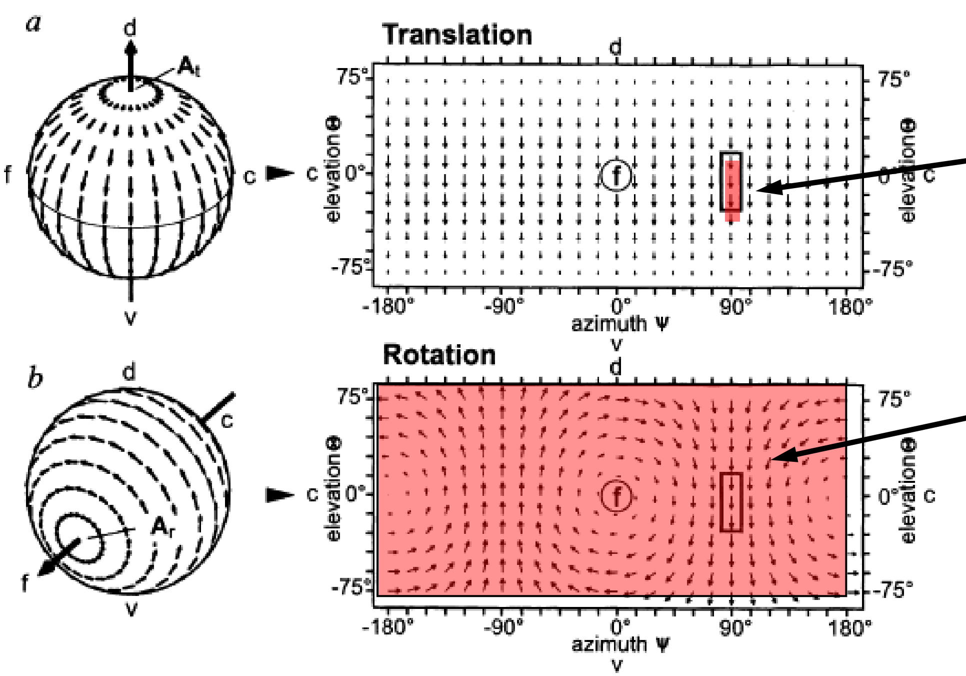


- Correlation implemented by multiplication of delayed signal
- Delay sets the temporal tuning
- Spatial organisation sets directional tuning



Local and global motion

A fly has to detect local motion and global patterns



So a vision system must:

Detect local visual motion

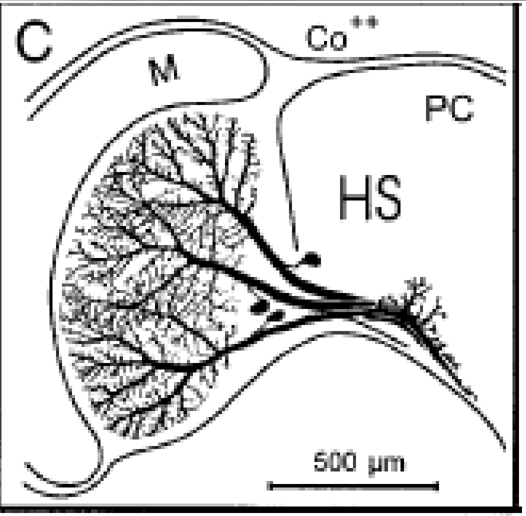
Identify wide-field patterns

Krapp et al. (1998)

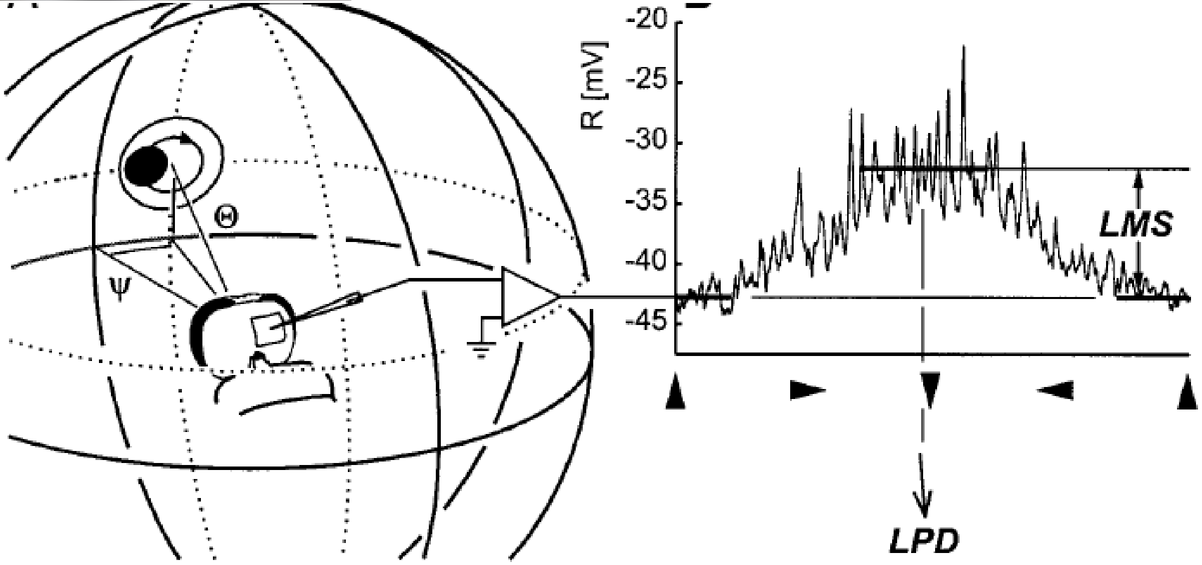
Lobula plate wide-field neurons

Neurons in the Lobula plate are large and have inputs from all across the visual field.

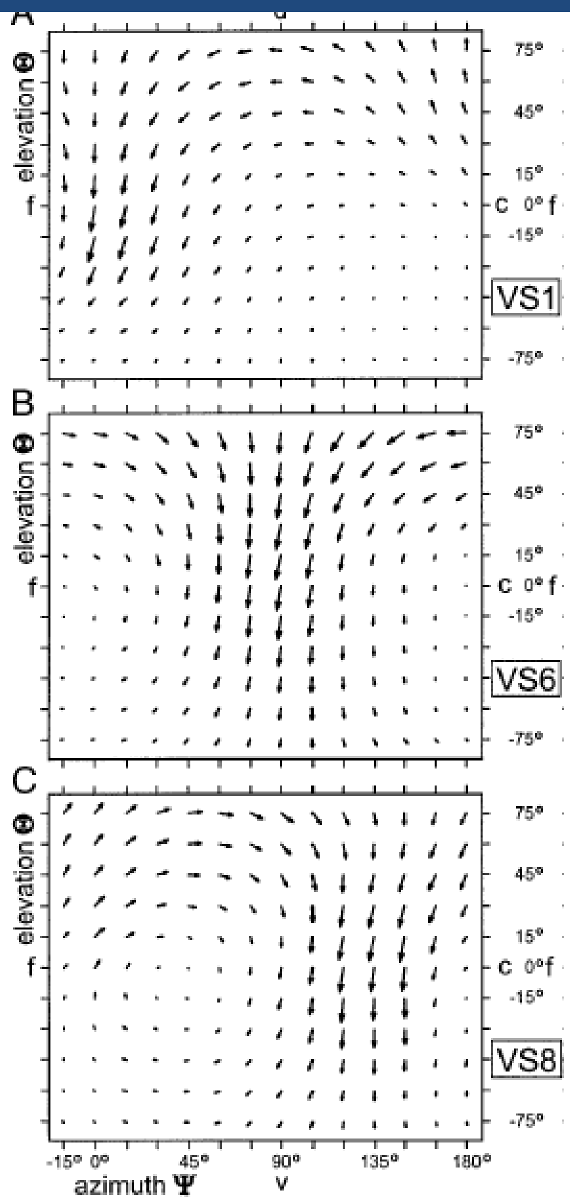
It is possible to map out the 'preferred' stimulus for these neurons.

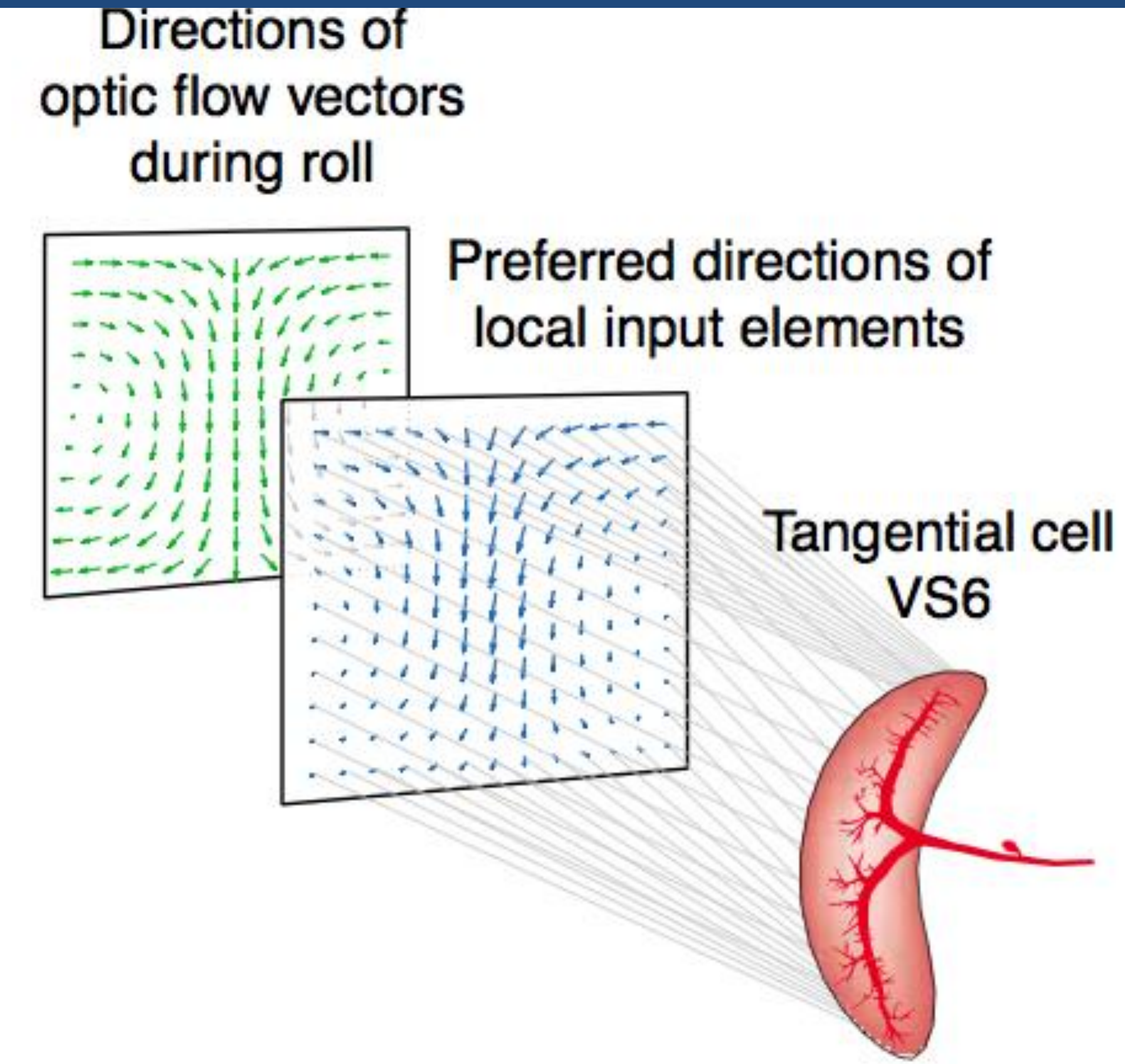


Krapp et al. (1998)



WFCs are matched filters tuned to flow fields





Krapp et al. (1998)

Situatedness: Ecological tuning of matched filters

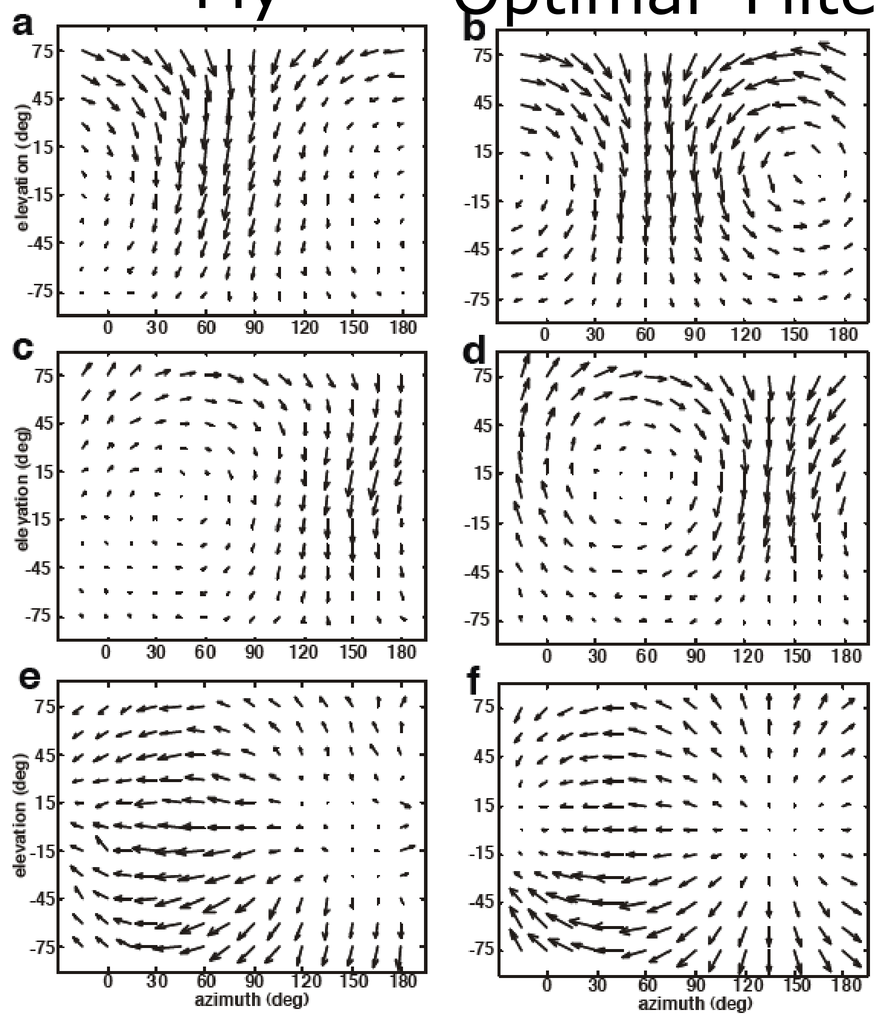
For rotation: objects at all distances move at the same speed

To detect rotation, look at distant objects, less contamination by translation.

In translatory motion: Close objects move faster than distant ones.

To detect translation, look at close objects, which move faster

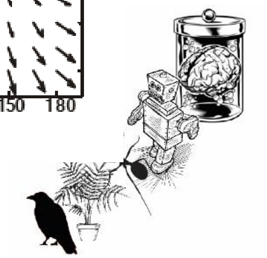
Fly 'Optimal' Filter



VS4

VS10

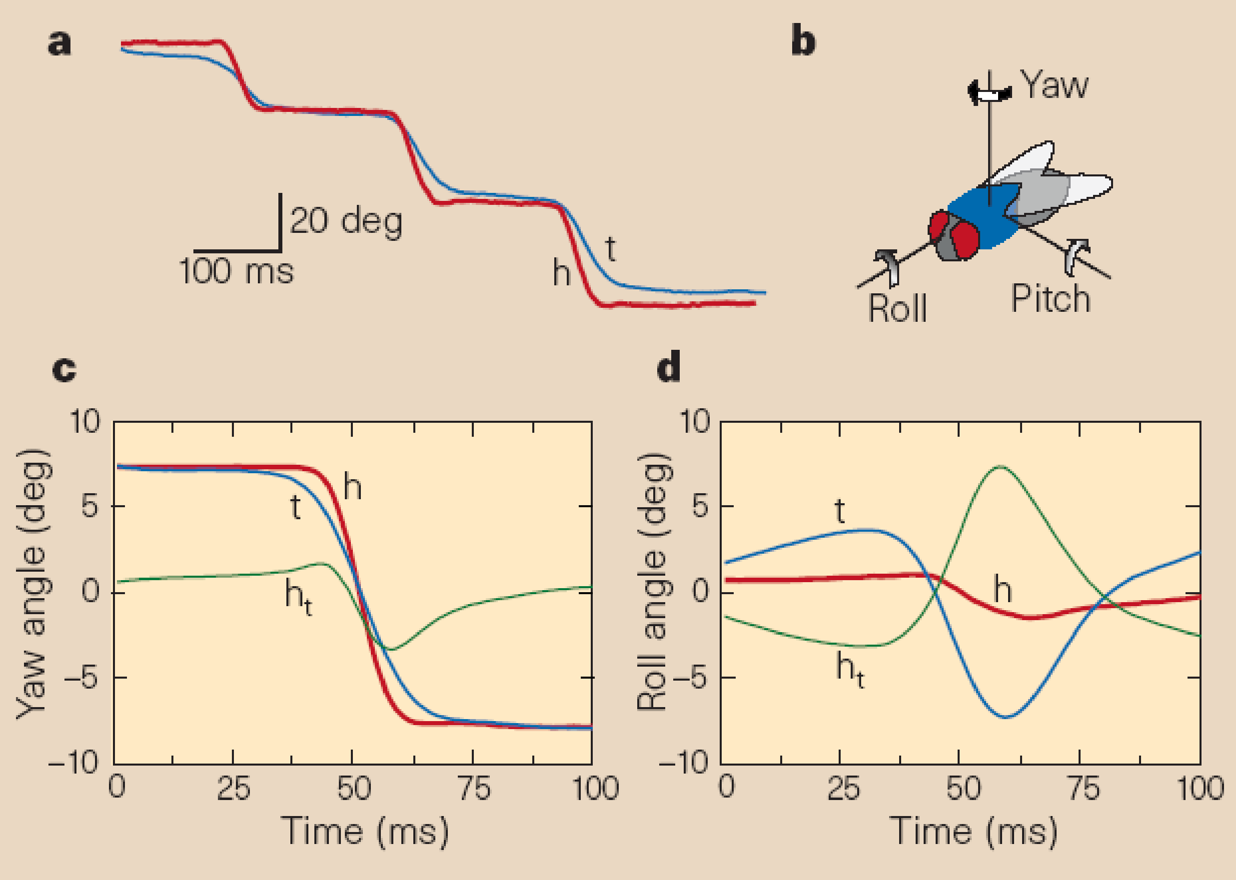
Hx



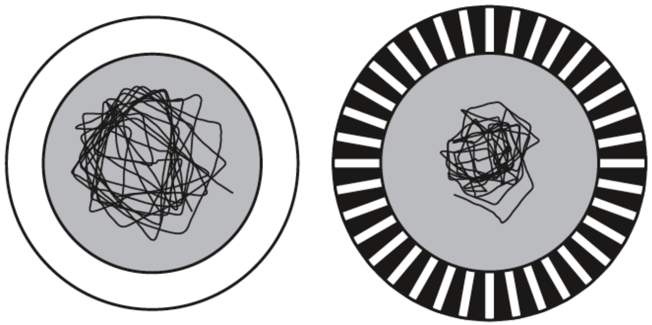
Franz & Krapp (2000)

Embodiment: movement style matters

- Flies judge distance to objects from optic flow
- Easiest if head is still as rotation swamps the signal
- So flies move in a way to keep the signal 'clean'



- Flies fly straight with sudden turns
- To make signal even cleaner, they counter rotate head to make saccades (red vs blue)

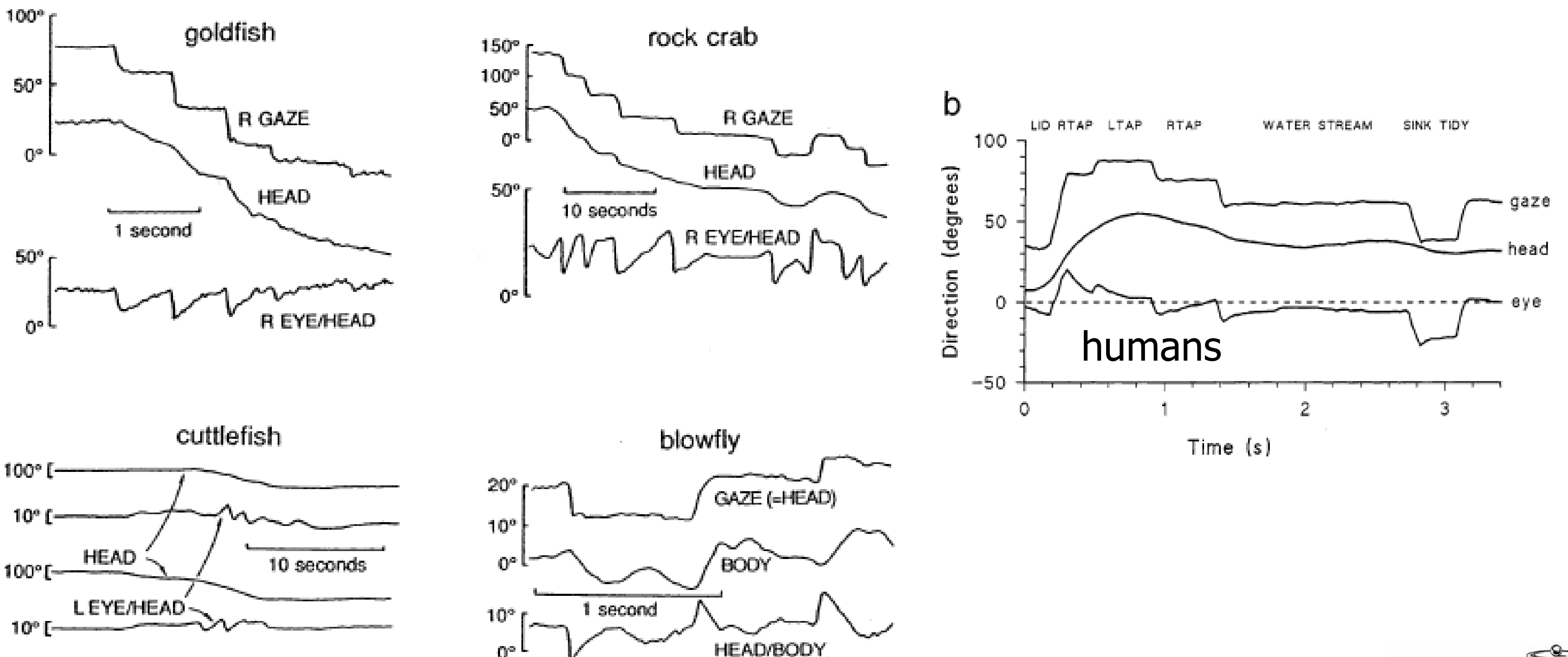


Schilstra and van Hataran (1998)

Tammero and Dickinson (2002)

This is a universal strategy

Determining structure of the world via direct perception … minimise rotation



Land (1999)

Insect-inspired biorobotic case-studies: Optic-flow based collision avoidance

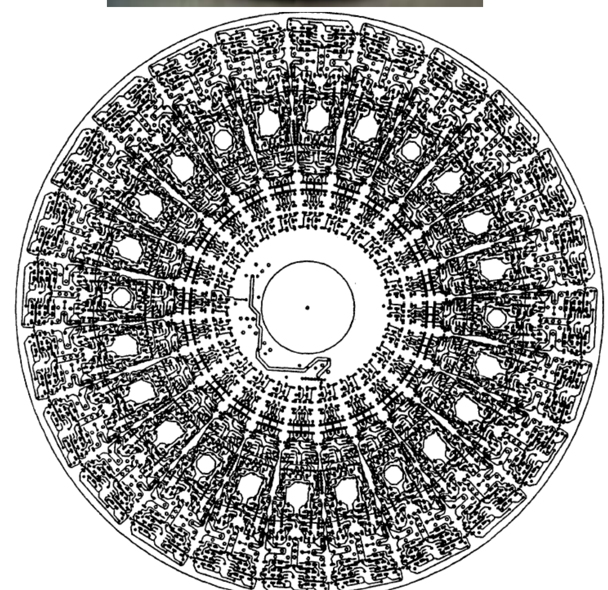
Case study 1: Franceschini neurorobotics

From Insect Vision to Robot Vision

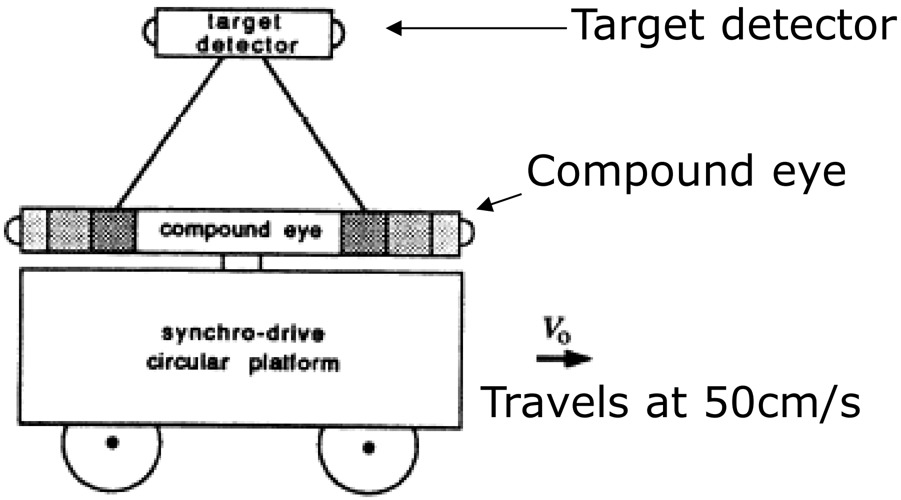
N. Franceschini; J. M. Pichon; C. Blanes

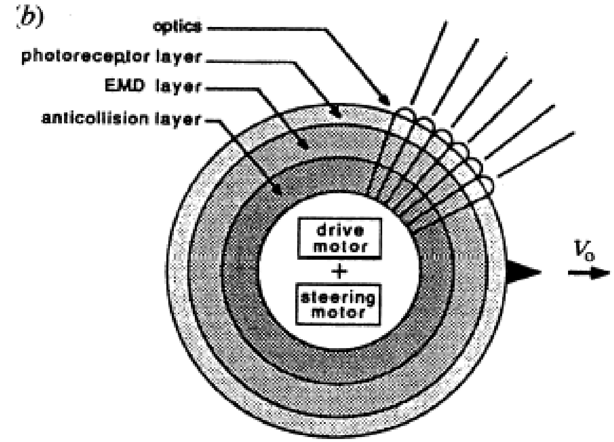
Philosophical Transactions: Biological Sciences, Vol. 337, No. 1281, Natural and Artificial Low-Level Seeing Systems (Sep. 29, 1992), 283-294.

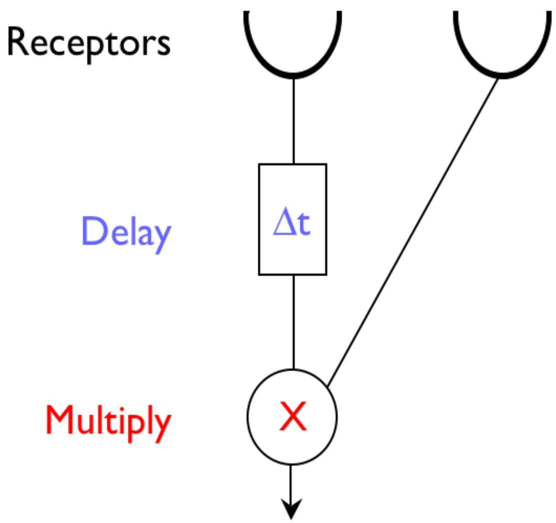
- Robot is a mobile ‘Compound eye’ with a panoramic 1D array of photodetectors.
- Analogue circuitry measures local motion signals using correlation type EMDs
- Uses output from these EMDs to avoid collision with obstacles

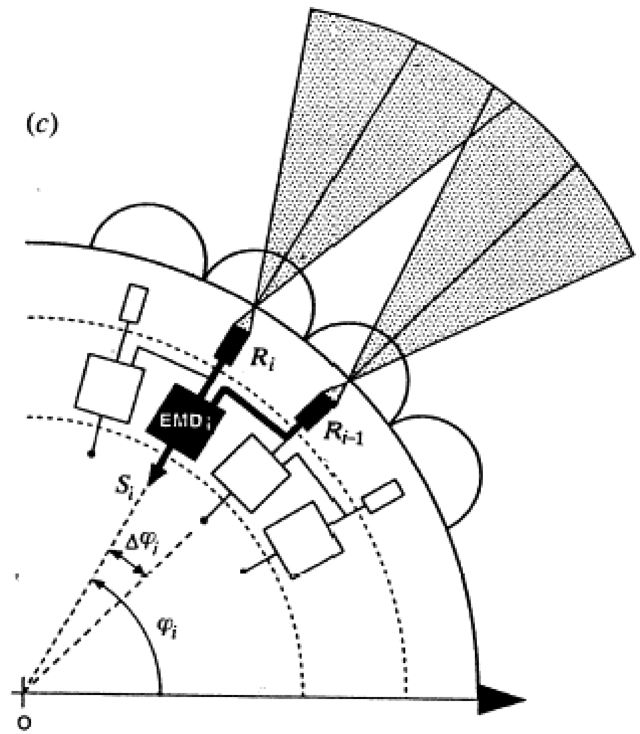


Eye is matched filter for objects 30 cm away









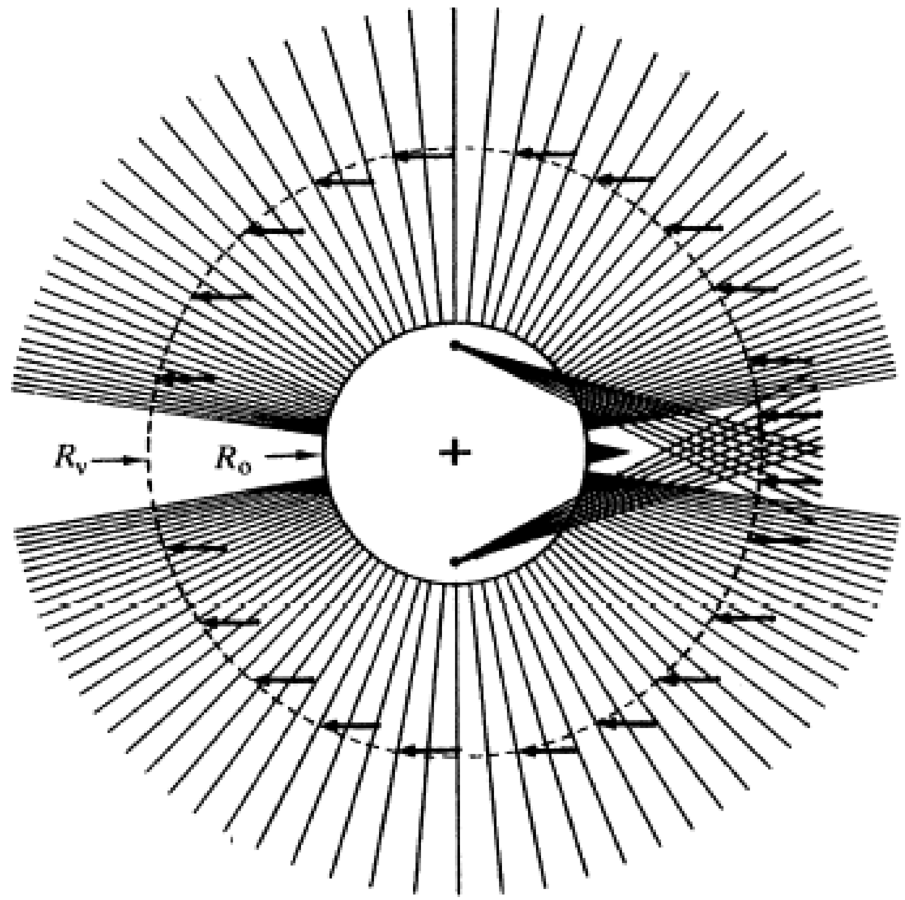
Delay tuned to get above threshold signal for object 30 cm away when moving at 50 cm/s

Embodiment: sensor angles tuned to behaviour

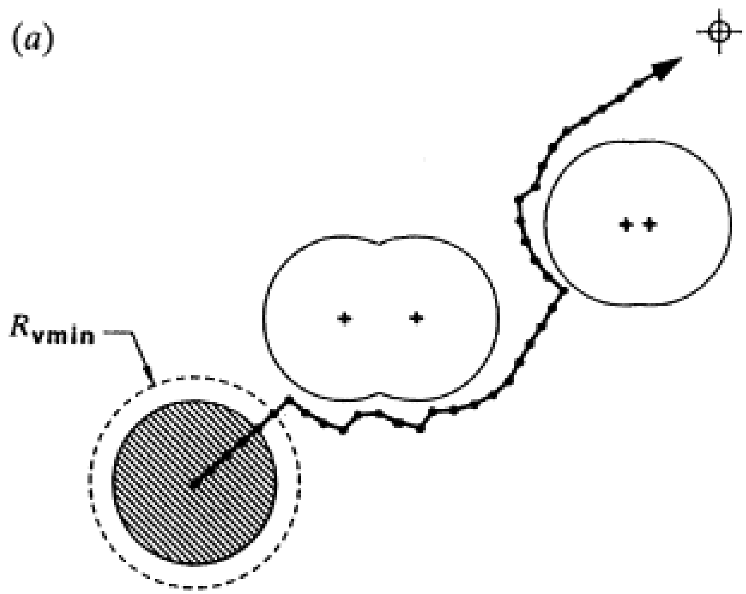
- Objects parallel to direction of movement move more than objects at front
- Delays set by hardware so fixed

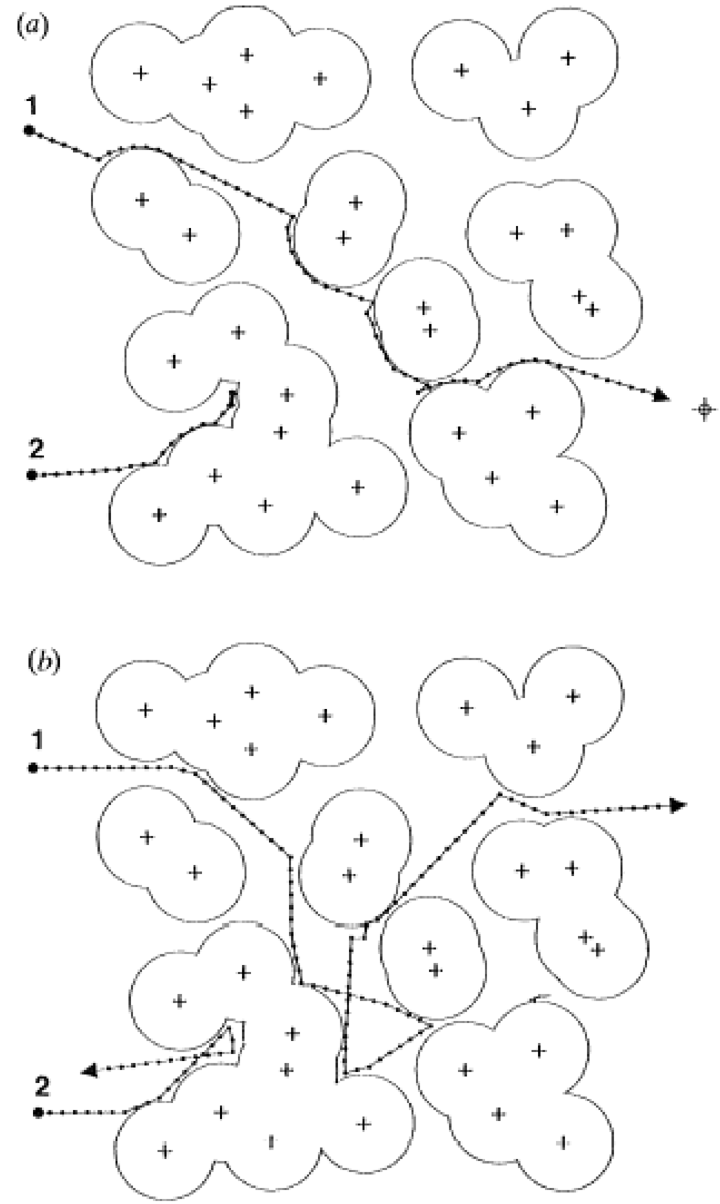
- Instead change spacing between EMD sensors so delay matches distance moved by objects (30 cm away) at different angles relative to direction of movement
- Sampling density matches local velocities of a translatory optic flow field (cf WFC matched filter)

- Increases physical complexity but simplifies computation
- Outsourcing computation to body



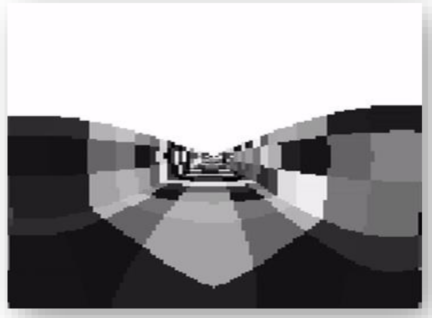
Translational vs Rotational Movements

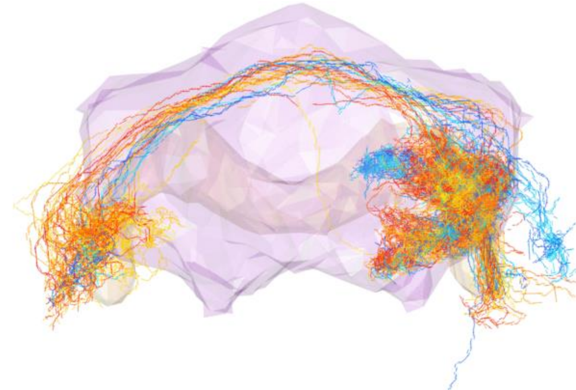




- Notice the maths only works if motion is in a straight line
- So robot moves straight and rotates quickly to avoid as in saccadic fly movement

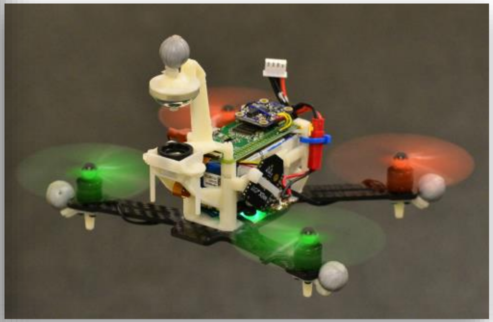
Neuromorphic collision avoidance: Opteran technologies





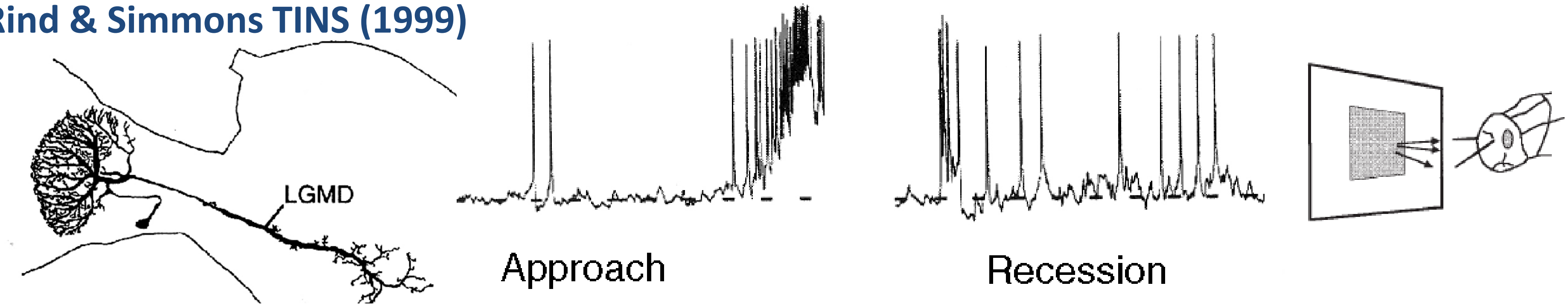
Vision
system =5kg

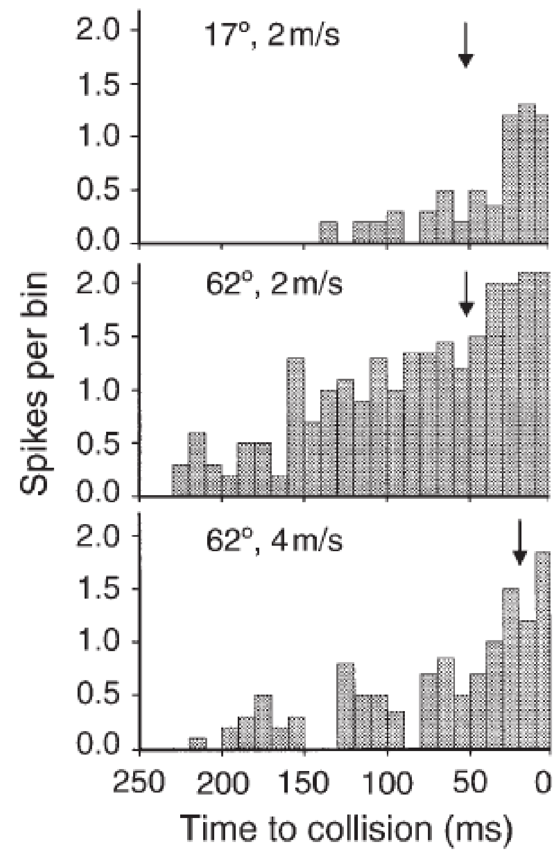
Good for small UAVs and motion stabilisation



Case study II: The LGMD a matched filter for collision

Rind & Simmons TINS (1999)





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BioSystems 87 (2007) 164–171
BioSystems
www.elsevier.com/locate/biosystems

A bio-inspired visual collision detection mechanism for cars: Combining insect inspired neurons to create a robust system

Richard Stafford*, Roger D. Santer, F. Claire Rind
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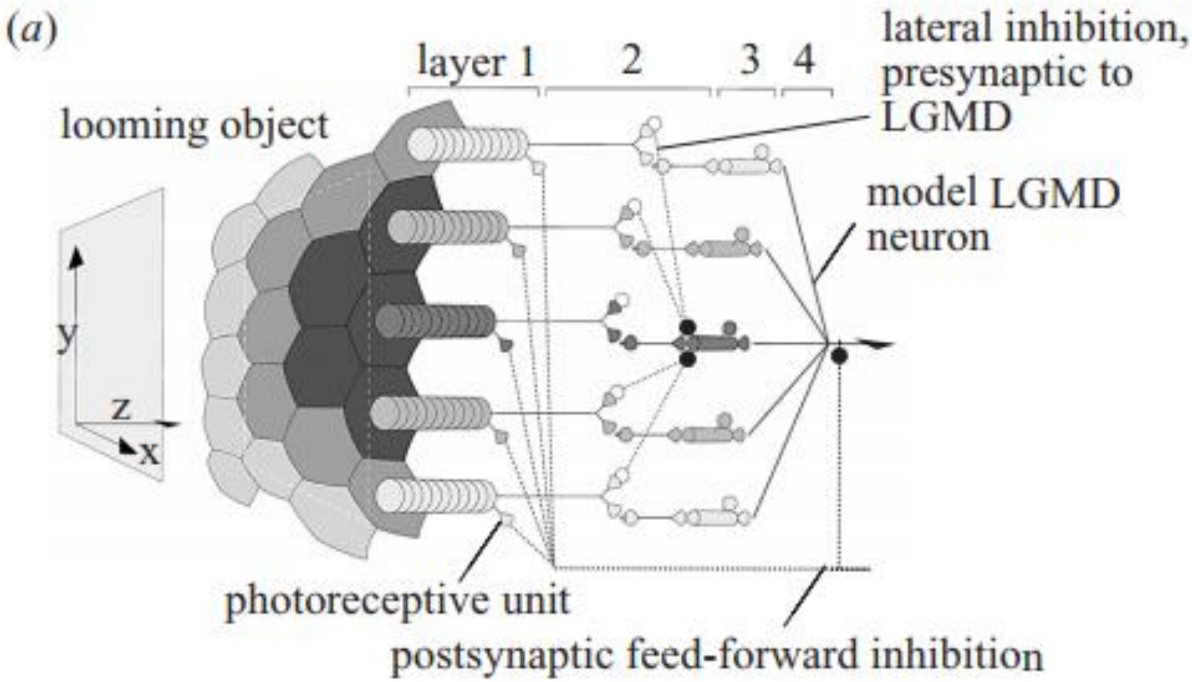
Received 28 February 2005; received in revised form 8 July 2006; accepted 15 July 2006

- Lobula Giant Movement Detector (LGMD) fires at similar time to collision for different stimuli
- General purpose collision detector?

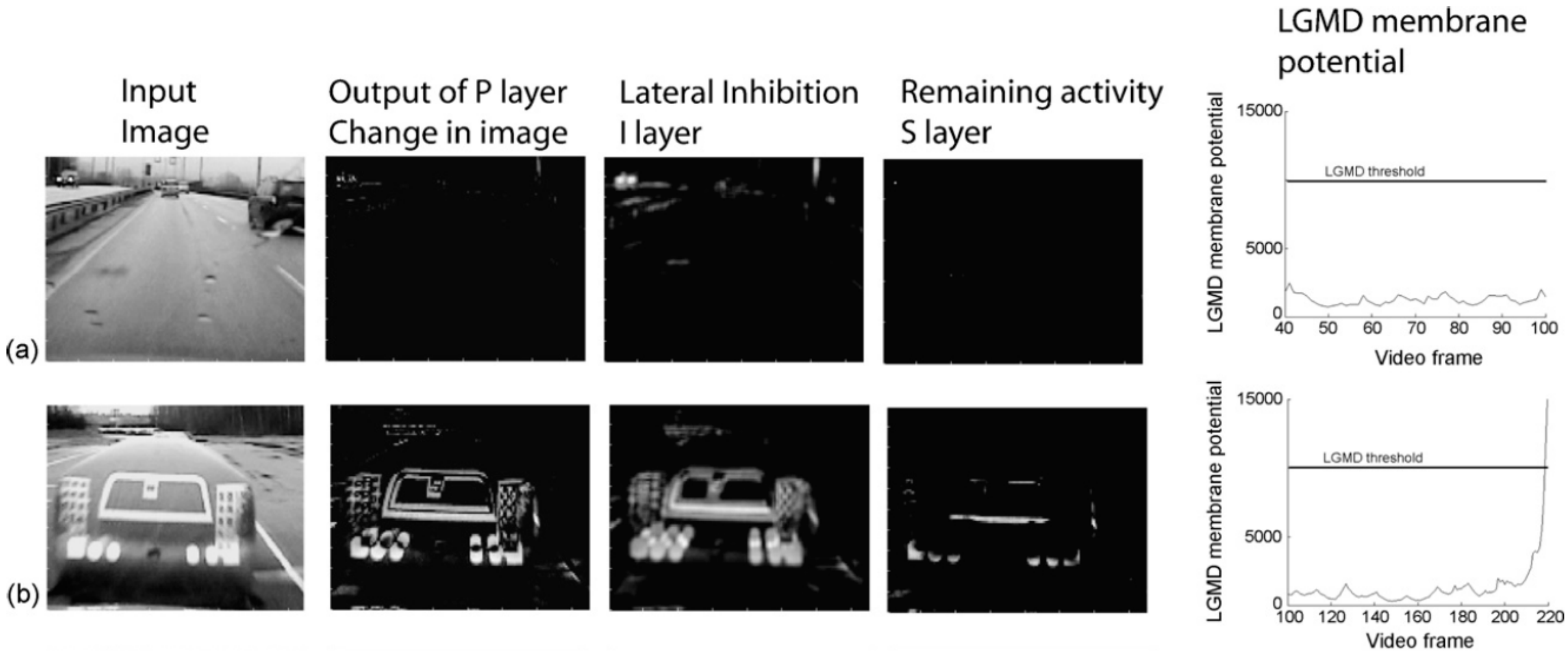
ANN implementation of LGMD

Rind + Santer, Proc Roy Soc, 2004



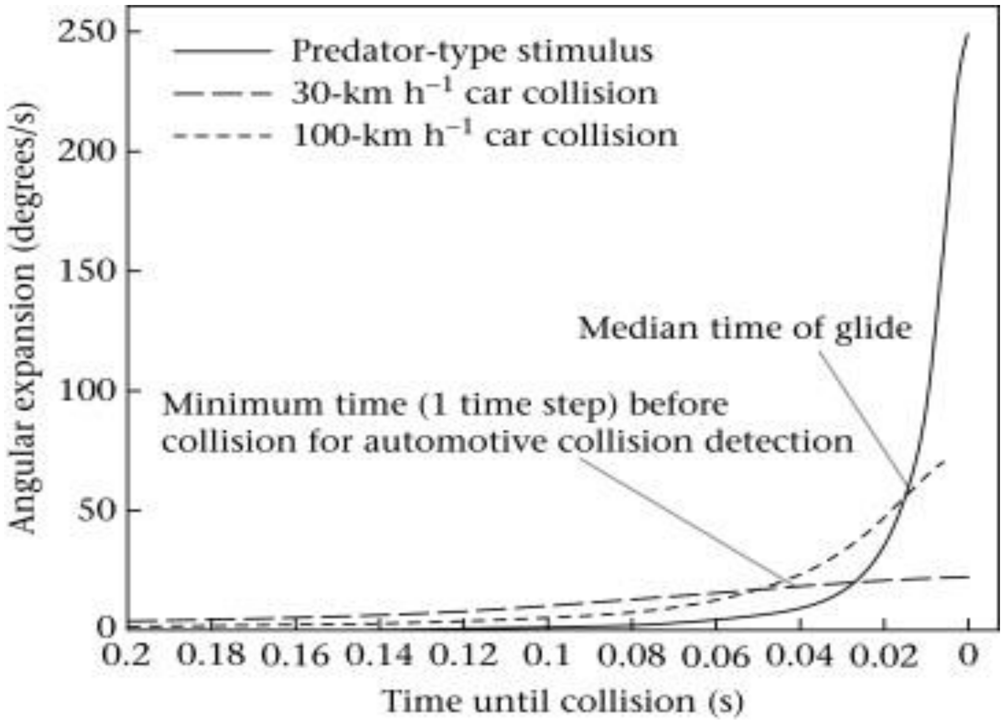
- ANN implementation based on known physiology
- Sums across inputs/neighbours (as in EMD) to detect movement of edges
- Has delayed global inhibition so if object moves but doesn't expand, it cancels excitation so responds to expanding stimuli only
- Above threshold signal triggers avoidance

LGMD algorithm in action



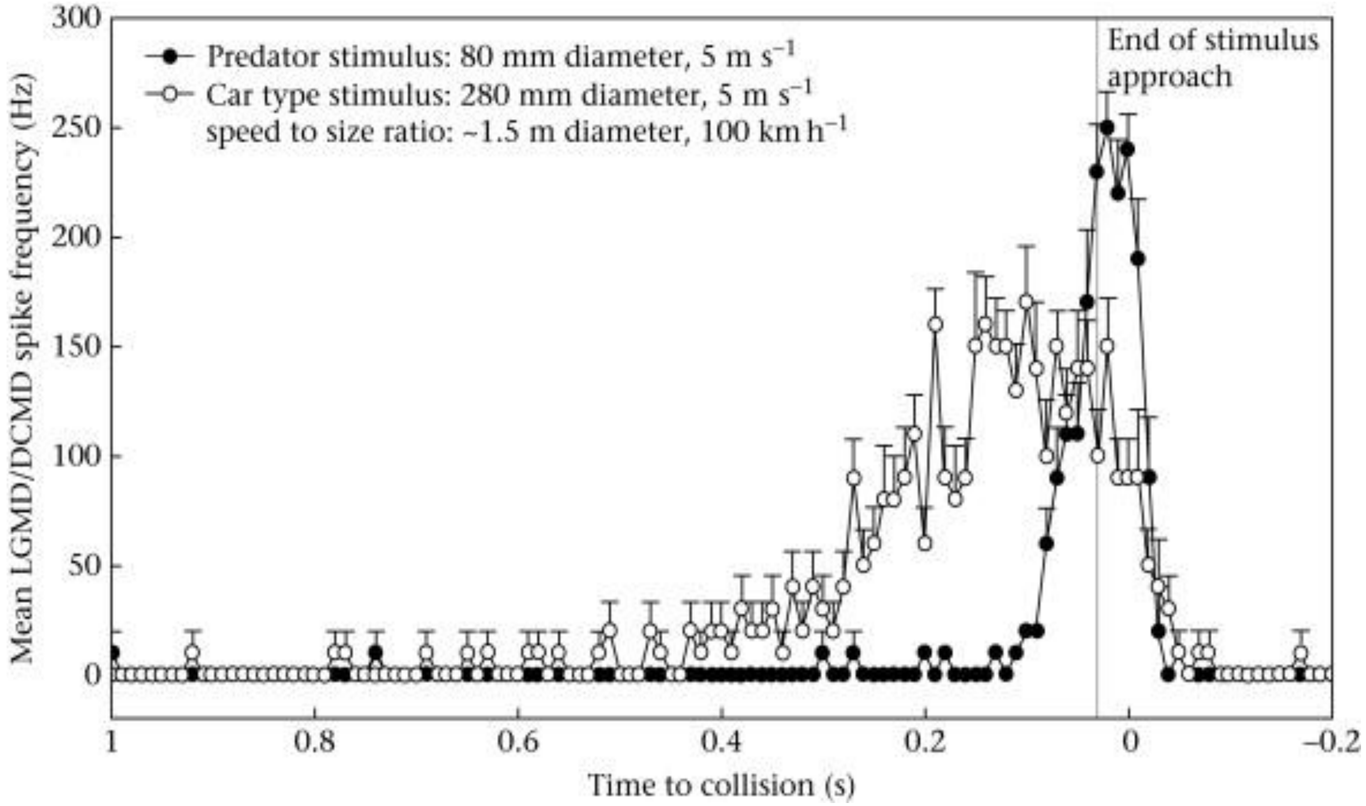
- After tuning delays, algorithm worked in most test cases
- But false collisions consistently made in response to cars translating across LGMD
- locust would react to other locusts + collisions
- Why? Consider behavioural ecology and interrogate model and LGMD with behaviourally relevant stimuli

Model responds differently to cars and birds



- Birds have very different movements relative to locust and so get fast expansion at end
- Cars expand smoothly so to trigger collision (<40 ms before collision!) need to make model more reactive meaning passing cars also trigger collisions

Is the model wrong?



- LGMD response shows the same pattern
- So how do locusts avoid birds AND other locusts while also not responding to general locust movement… ?

Predator NOT collision avoidance

- They don't!
- Locusts are small and light: collisions don't hurt
- Only need to avoid birds which are big
- And respond late as you don't need to avoid ALL bird just the beak
- Moral of the story: avoiding cars is not the same sensory ecology as locusts avoiding predation

- When modelling something, must consider animal's behaviour, morphology and sensory system in its natural environment
- Still useful to build/test the model: discovered that LGMD is beak avoidance NOT general collision avoidance

Santer et al 2011 Predator versus Prey: Locust Looming-Detector Neuron and Behavioural Responses to Stimuli Representing Attacking Bird Predators, PLOS One

Task dependent vision and direct perception in humans

Eye movements

- Saccades move our high resolution foveas over a scene.
- The pattern of movement is dependent on the task.

The eye-mind hypothesis

"there is no appreciable lag between what is fixated and what is processed"

Just and Carpenter (1980)

Surmise what the family had been doing before the arrival of the unexpected visitor.

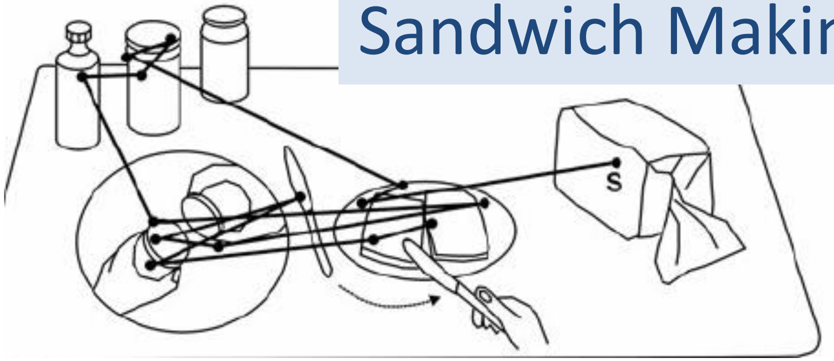
Estimate how long the v
been away from the fam

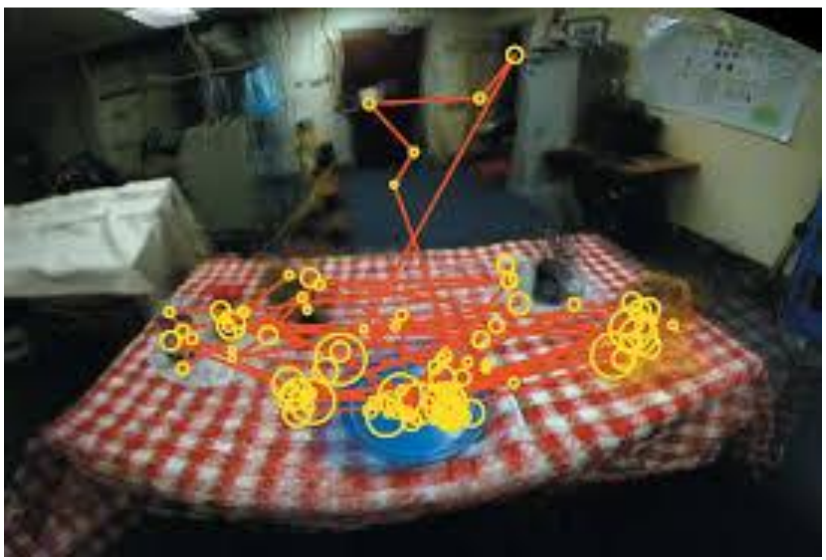
The boy the girl the cat bit scratched died

Yarbus (1967)

Task dependent direct perception

Sandwich Making



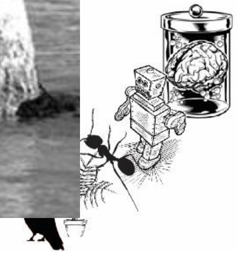


Walking

Laurent and Thompson (1998)

Eye movements are to the target for the grounded foot.

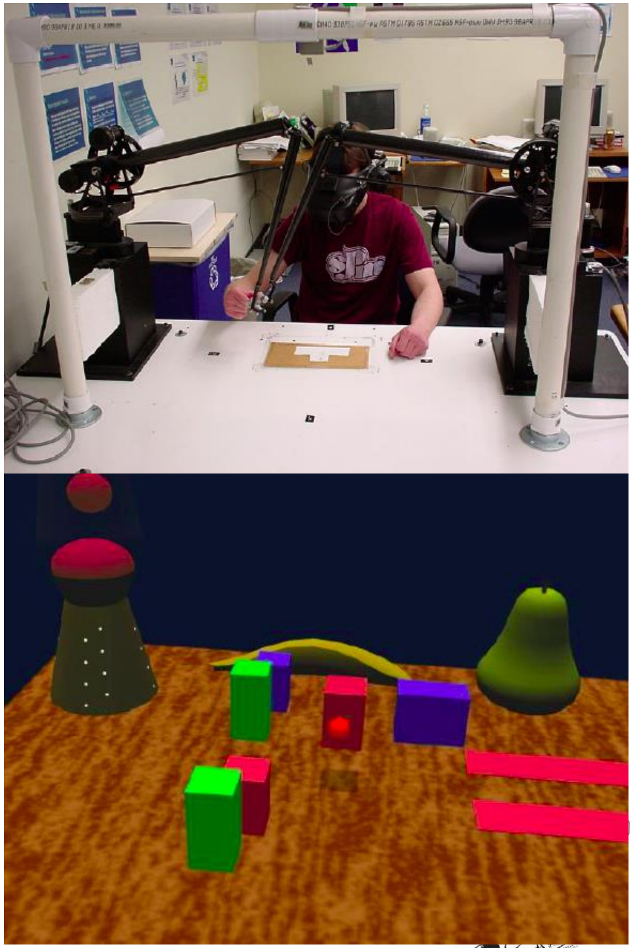
Visual information is required to set ‘thrust’ at take-off



Land (2009) Visual Neuroscience
Hayhoe (2007) TiCS

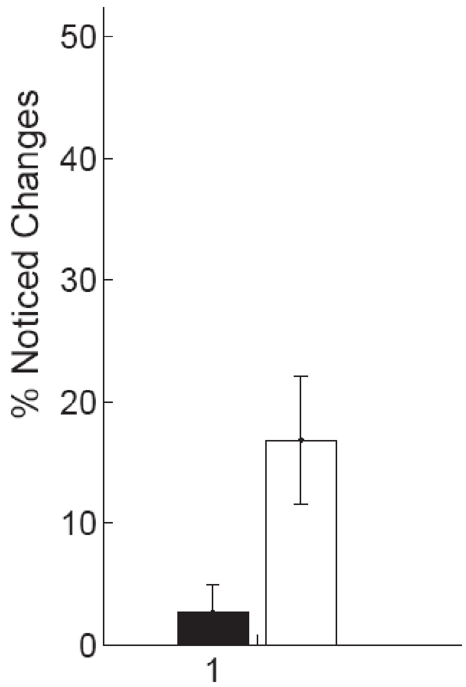
What you see is what you need

- Subjects have to sort bricks
- Fixation pattern is reliable:
  - Fixate block - Pick it up
  - Fixate belt - Hand brings block to belt
- Experiment measures subject's ability to detect changes.



Triesch et al (2003)

What you see is what you need



Subjects show change blindness. Reporting less than 20% of object size changes even in the task that required subjects to move objects onto the belt in size order.

Triesch et al:

"[this highlights the] highly purposive and task dependent nature of human vision. Information is extracted, for certain computations "just in time" when needed to solve the current goal."

Summary

- Recommended reading
  - Mary M. Hayhoe (2017)“Vision and Action” Annual Review of Vision Science
  - Mandyam V. Srinivasan (2021) “Vision, perception, navigation and ‘cognition’ in honeybees and applications to aerial robotics” Biochemical and Biophysical Research Communications
  - Stafford et al (2007) “The role of behavioural ecology in the design of bio-inspired technology” Animal Behaviour