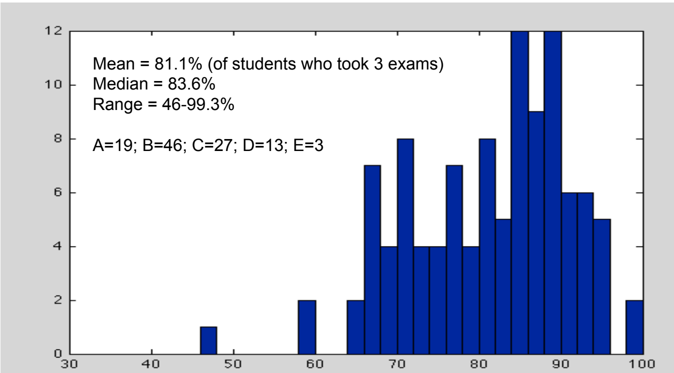
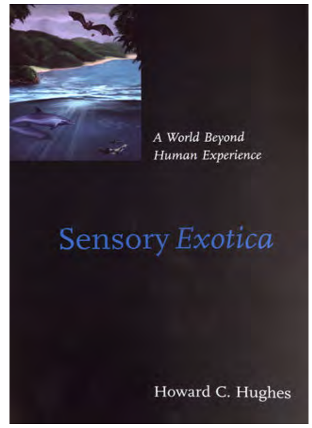
## Announcements

-Grades are on BB
-Exam is next Tuesday
-Final grade curve will be **0.1%** (which effectively will round up xx.90 grades)

- **NO** other adjustments will be made for final grades.
- E.g., 89.90 will be A- (after the final curve), but 89.89 will be B+

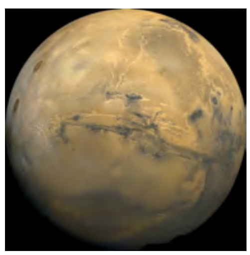


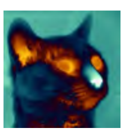

**A world beyond human perceptual experience**

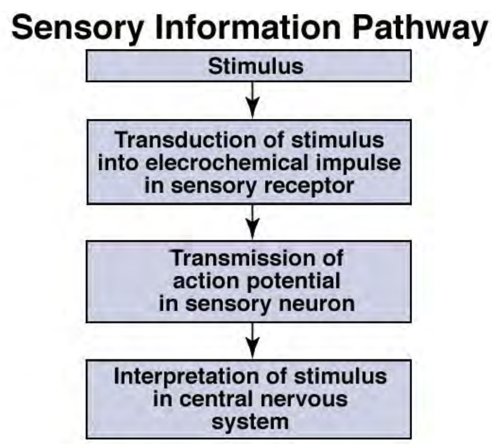



2

Perception = fundamental freedom
Perception = fundamental limitation







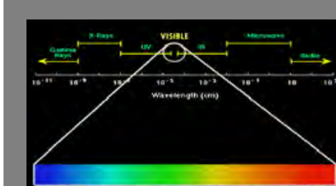

4

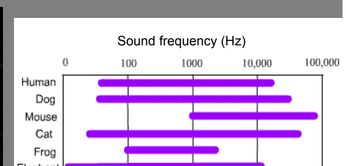
| Sense | Organ & receptor | | PHYSICAL quality of stimuli |
|---|---|---|---|
| vision | eye & photoreceptors | | light = visible electromagnetic waves |
| hearing | ear & hair cells | | sound pressure waves, traveling through a medium, eg air |
| touch | skin & mechanoreceptors | | physical surface properties (e.g., texture) |
| smell | nose & olfactory sensory neurons | | scent = airborne chemicals |
| taste | tongue & taste cells | | dissolved chemicals |
| ??? | ??? | | ???? |

**+ neural mechanism(s) to process info from the receptors**

## Ways to go the world beyond human experience…

- **Extend existing senses**
  - Ultraviolet vision (bees, finches)
  - Infrared vision (snakes)
  - Super-touch (star-nosed mole)
  - Infrasound (elephants) & ultrasound (dogs)




6

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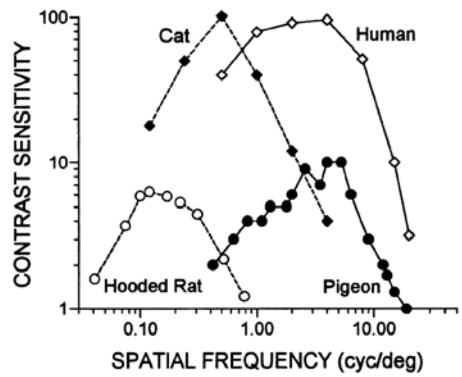
    - Biological sonar (bats, dolphins)
- **Technology: All of the above**

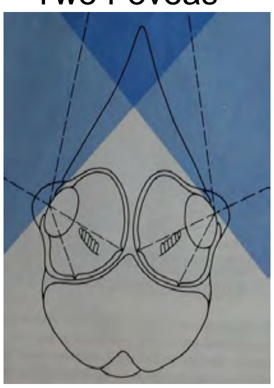


# Comparing Vision in Species



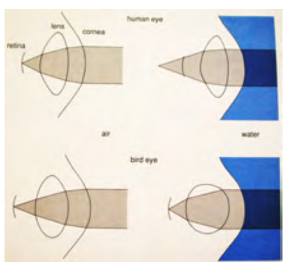



## Two Foveas



Barn Swallow

## Underwater Vision




Water birds have specialized muscles which alter the curvature of the eye to bring the image into focus

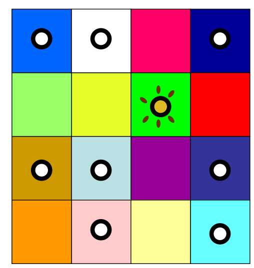
Waldvogel, 1990



## Can bees see colors?

- Place a patchwork of colored squares. Cover the squares with a glass plate. Place a dish of unscented sugar syrup on one color. Place empty dishes on the other squares. After bees regularly visit the syrup laden dish, rearrange the colored squares and place empty dishes on each square.

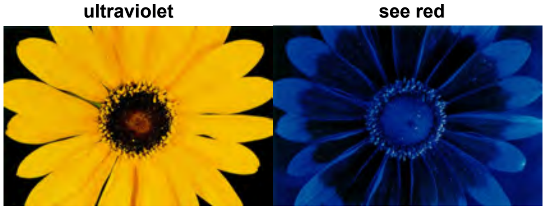
- Bees can see green, blue and yellow
- **Bees cannot distinguish red from black**
- This experiment will not show another important aspect of bee vision – that bees can see ultraviolet



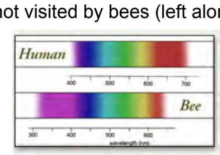


## Ultraviolet vision in bees

| **Humans cannot see ultraviolet** | **Bees can see ultraviolet, but cannot see red** |
| --- | --- |



- UV markings are like runway lights - pointing toward the nectar
- red flowers are not visited by bees (left alone for hummingbirds).



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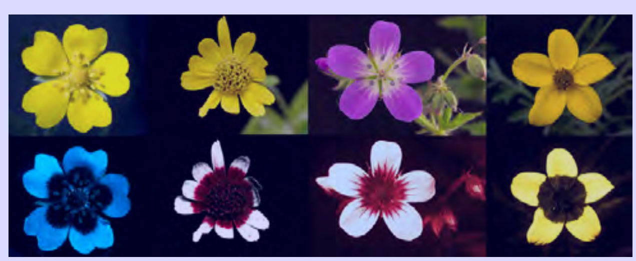
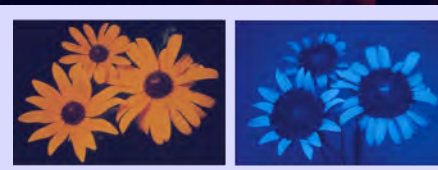
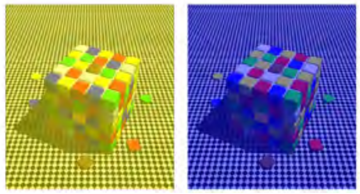




## Color constancy in bees



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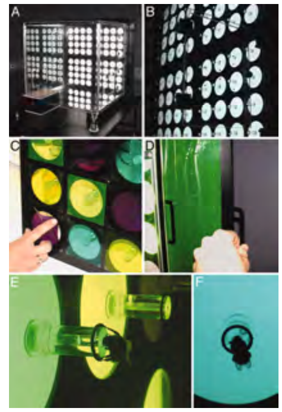
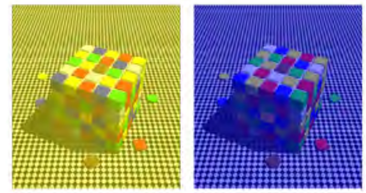
## Color constancy in bees




**Bees encode behaviorally significant spectral relationships in complex scenes to resolve stimulus ambiguity**

R. Beau Lotto* and Martina Wicklein

Institute of Ophthalmology, University College London, 11-43 Bath Street, London EC1V 9EL, United Kingdom

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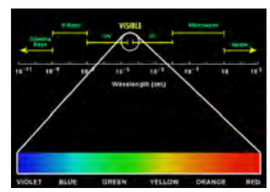
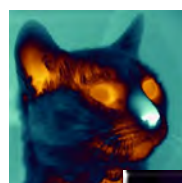
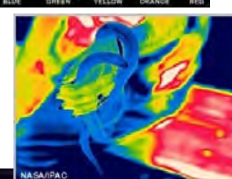
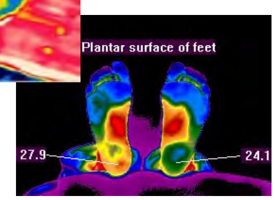
## Infrared “vision” in snakes



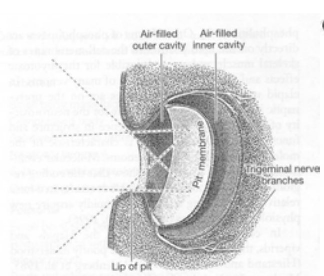


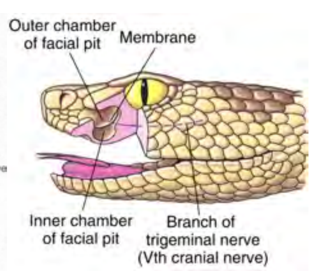





## Infrared “vision” in snakes

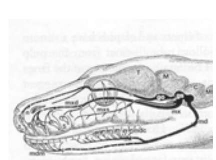
- Infrared “heat” sensing is highly developed in pit vipers.
- Heat-detecting sensors are concentrated as two large pits between nostril and eyes
- Allows them to strike at warm-blooded prey in the dark

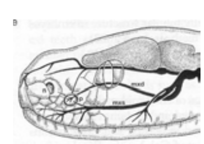


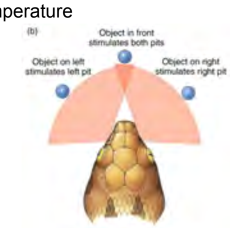




## Infrared “vision” in snakes

- Infrared sensitive snakes can
  - detect temperature differences as slight as 0.003 degrees C
  - Senstivie 40 cm from head – if body is >10 C above room temperature
  - can judge distance & direction of the target (how?)
  - may even create an "image" of the size and shape of the prey
  - some snakes can superimpose the infrared image on a visual image
  - snakes that prey on "cold-blooded" creatures detect the "heat void" created by the prey in the background temperature







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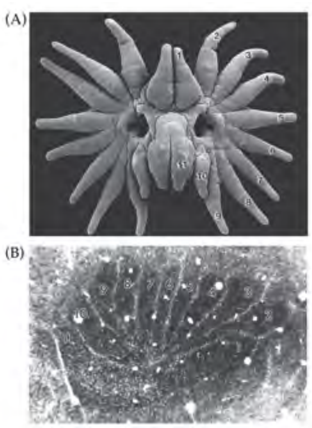
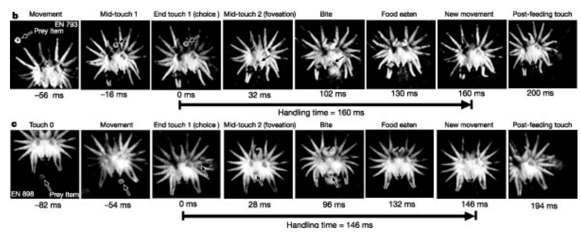
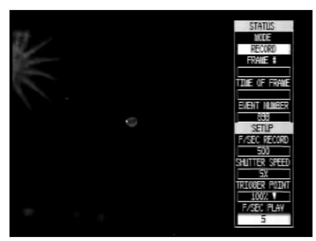
**Super touch in star-nosed mole**

**Cortical representation of 22 pink, fleshy tentacles (star-nose)**

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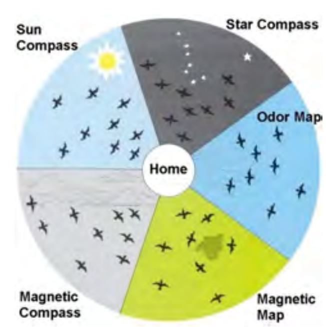
# Navigational Strategies

- Trail following/route learning
  - Visual and/or olfactory routes
- Piloting
  - Using landmark cues to find a known location
- Path integration
- Compass navigation
  - Celestial navigation
  - Magnetic navigation
- **Map vs. compass navigation**

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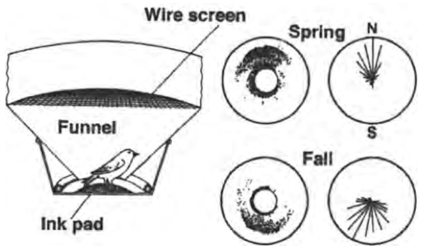
# Navigational Strategies

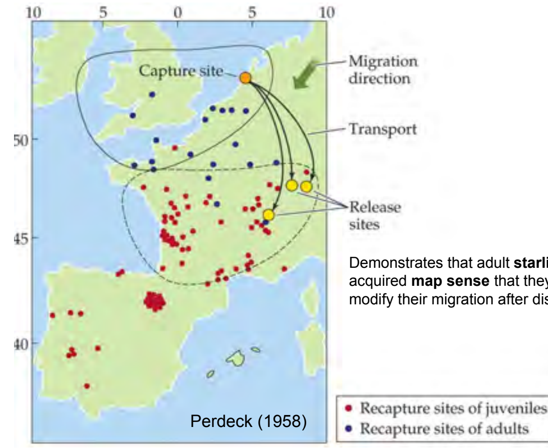
Often studied using the:
**Emlen funnel**




- Compass navigation
  - Celestial navigation
  - Magnetic navigation
- **Map vs. compass navigation**



## Map vs. compass navigation



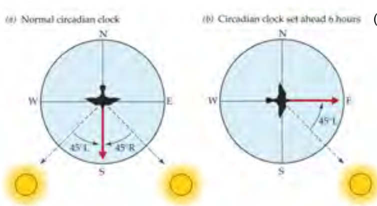

Demonstrates that adult **starlings** have an acquired **map sense** that they use to modify their migration after displacement



## Biological compass: Sun

Used by birds (pigeons) and insects (bees)

- **Sun position**
  - must be combined with an internal clock
  - you need to know where the sun is
- **Tested by "clock shifting"**
  - Can confuse homing pigeons:
    - shift clock ahead +6 h; release them in the field, and their bearing is 90° off course (sun moves 15°/hr)



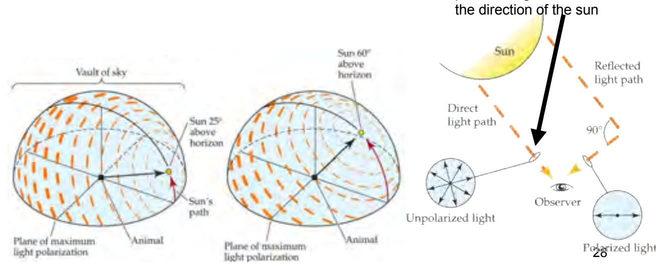

(that is, at 9am pigeon thinks it is 3pm)



## Biological compass: Sun

- Use of **polarized light**
  - Used for orientation
  - Useful under partially overcast conditions
    - E.g., Savannah Sparrows - nocturnal migrants that use polarized light patterns from setting sun to orient (shown with the Emlen funnel)
  - Still needs an internal clock

The direction from which this polarized light comes indicates the direction of the sun






## Biological compass: Moon & Stars

- **Stars**
  - constellations rotate around "north" star.
  - Must be combined with an internal clock
  - Used by nocturnal migrants (indigo bunting)
  - Evidence come from Emlen funnel studies

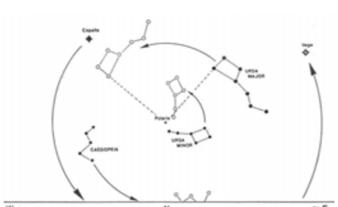
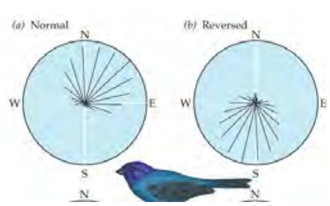


Figure 4. Changing star positions: view to the northern sky in spring from 30°N latitu Solid star symbols: early evening, open star symbols: 6 h later.






## Biological compass: Moon & Stars

Emlen funnel study

- 3 groups of indigo bunting raised:
  - G1: In windowless room, constant dim light
  - G2: Under normal night sky with normal rotation of celestial features around Polaris (North star)
  - G3: Under night sky with rotation of celestial features around Betelgeuse (Orion's 'right shoulder', 180° from Polaris)

- Grp. 1 - randomly (did not learn about stellar sky patterns)
- Grp 2 - normal southward orientation (used Polaris to define North)
- Grp 3 – 180° away from Betelgeuse (as if using Betelgeuse to define N)

## Biological compass: Moon & Stars

- Moon – not as useful as aid to navigation (moves more slowly than sun (24.83 h cycle);
- need for 2nd internal clock)
- Some nocturnally active animals do have a moon compass (e.g., sandhoppers (crustacean), sockeye salmon)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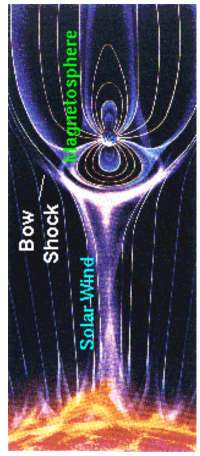
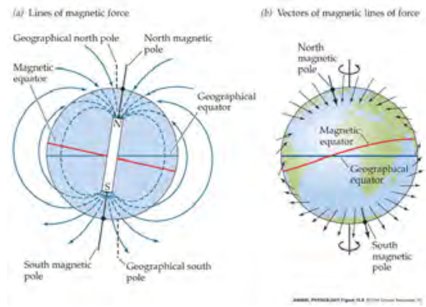
## Biological compass: Earth's magnetic field




- direction and inclination

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## Biological compass: Magnetoreception

- Ringed-bill Gulls have a tendency to move in a southward direction
- Birds released in a strange location with magnets on their backs showed random dispersal
- Controls (no magnet) preferred to travel South

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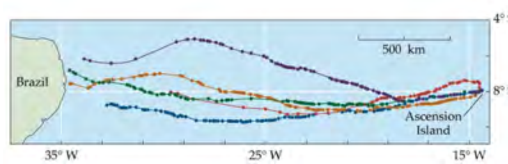
Green turtles can navigate thousands of miles (using Earth's magnetic field)



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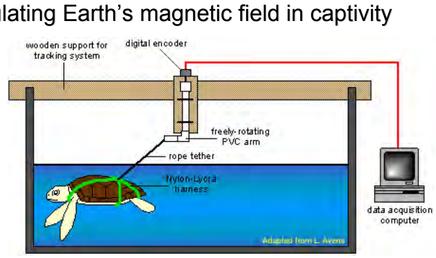
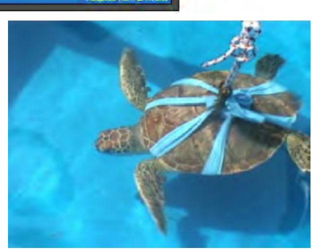
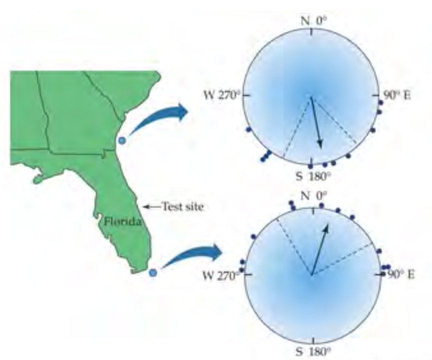
Simulating Earth's magnetic field in captivity

Turtle treadmill










turtles have "map-sense".

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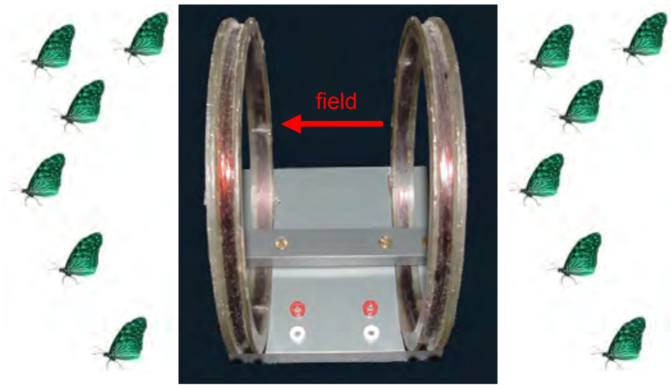
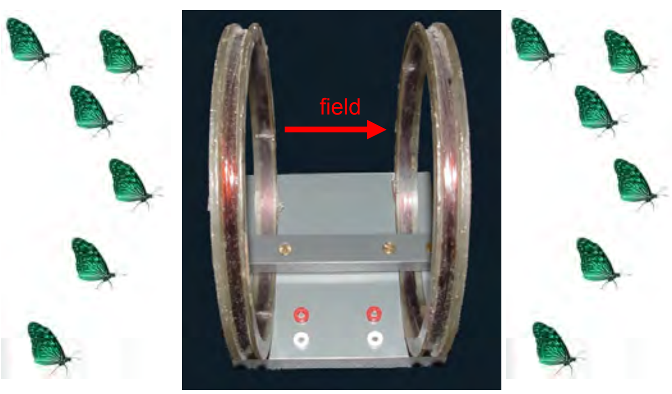
**Biological compass: Magnetoreception**


**monarch butterfly**

• experiment with butterflies flying through an Helmholtz coil !




• experiment with butterflies flying through an Helmholtz coil !

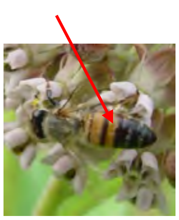


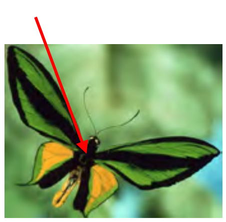

**Biological compass: Magnetoreception**

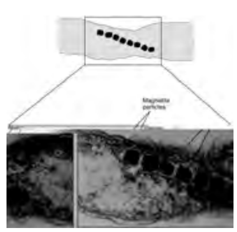
| | | |
|---|---|---|
| **vision** | eye & photoreceptors | light = visible electromagnetic waves |
| **bio-compass** | ????? | earth's magnetic field |



**Biological compass: Magnetoreception**







magnetite particles found in some birds, turtles, salamanders, bees, butterflies.. along with associated nerve endings (even in bacteria)

BUT, how is the magnetic material used as a magnetoreceptor?



# Magnetic responsive neurons

Recordings for the trigeminal ganglion of the bobolink that responds with altered electrical activity to changes in the ambient magnetic field.

(1) spontaneous activity;

(2) response to 200 nT change (0.4% of Earth's magnetic field) ;

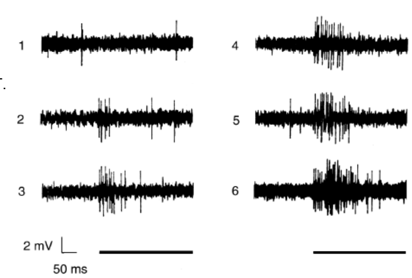
(3) response to 5000 nT change;

(4) response to 15 000 nT change;

(5) response to 25 000 nT change;

(6) response to 100 000 nT change.

The earth's field is approx 50 000 nT.

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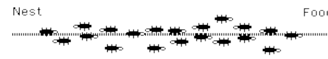
## Types of Pheromones

### Communication pheromones

**Trail pheromones**
- Commonly found in numerous social insect species
- Used for orientation to & from the nest for the establishment of foraging trails (highways)

**Alarm pheromones**
- Common in social insects & aggregate feeders
  - wasps, termites, bees, & some aphids
- Function
  - defense
  - Dispersal




**Aggregation pheromones**
- Signal that recruits conspecifics to a food source.
- Known in bark beetles & certain desert grasshoppers.
- Can also function in an anti-aggregation mode when sufficient individuals are present.

## Ways to go the world beyond human experience…

- **Extend existing senses**
  - Ultraviolet vision (bees, finches)
  - Infrared vision (snakes)
  - Super-touch (star-nosed mole)
  - Infrasound (elephants) & ultrasound (dogs)
- **Develop additional senses**
  - **Passive senses**
    - Biological compass (turtles, birds, insects)
    - Pheromones (insects, animals)
    - Electroperception (sharks)
  - **Active senses**
    - Electric fish
    - Biological sonar (bats, dolphins)
- **Technology: All of the above**

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## Ubiquitous bioelectric fields

- Cells maintain an electrochemical gradient of -60 to -80 mV across the cell membrane
- Nerve cells generate an action potential that causes a change of 130 mV over a ms.
- signals generated through cellular activity (especially muscles & neurons) of other animals
- mainly low-frequency signals (< 50 Hz)`
- Consequently, all living animals produce very weak electric fields. These can be detected by a variety of predatory animals, such as sharks, platypus, etc.
- Electric fields (around a dipole) fall off with the cube of distance: **Electric fields are, therefore, not useful over long distances.**

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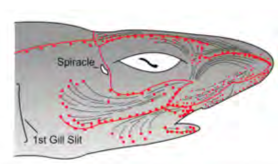
## Types of electroreception

- **Passive**
  - detecting fields from external sources
    - Animate (bioelectric, gills, muscle, heart)
    - Inanimate (electrochemical, geomagnetic)
  - Sharks, skates, rays, catfish, all electric fish
- **Active**
  - Detecting perturbations to fish's own field
    - Animate (other animals, predators, prey)
    - Inanimate (any object with an electrical conductivity differing from the water)
  - All weakly electric fish (knifefish, elephant-nose)
  - Some strongly electric fish (electric eel)

- *Strong* electric fields
  - 10's to 100's of volts (stunning)
  - torpedo rays (20 - 50 volts)
  - electric catfish (300 volts)
  - electric eel (500+ volts!)

## Passive Electroperception

- Passive electroperception (fields from external sources)
  - Animate (bioelectric, gills, muscle, heart)
  - Inanimate (electrochemical, geomagnetic for navigation)
  - **Very useful in water**!
- Found in sharks, skates, rays, catfish, all weakly electric fish **and Platypus**

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## Passive Electroperception: sharks and stingrays

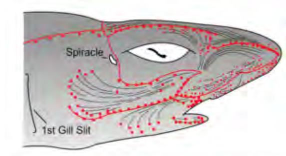
Experiment showing that sharks have electroperception:

| | |
|---|---|
| • One pool (fish pure added to water), hidden live flounder, one shark: | **flounder eaten** |
| • add algae to water (to eliminate vision): | **flounder eaten** |
| • repeat with a dead flounder: | **flounder NOT eaten** |
| • repeat with a live flounder wrapped in insulating plastic film: | **flounder NOT eaten** |
| • replace founder with electrodes mimicking flounder's electric field: | **electrodes attacked** |





| | | |
|---|---|---|
| **vision** | eye & photoreceptors | light = visible electromagnetic waves |
| **bio-compass** | ????? | earth's magnetic field |


| | | |
|---|---|---|
| **vision** | eye & photoreceptors | light = visible electromagnetic waves |
| **????** | ampullae of Lorenzini | ??????????? |

Respond to: touch, changes in water temp, changes in water salinity, & (1962) electricity



## What are **Ampullae of Lorenzini?**

- Bundle of sensory cells connected to several nerve fibers that are enclosed in a gel-filled tubule which has a direct opening to the surface through a pore
- In principle could be used to sense Earth's magnetic field while a shark is in motion



## Ways to go the world beyond human experience…

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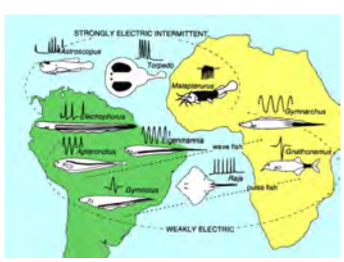
    - Electroperception (sharks)
  - **Active senses**
    - Electric fish
    - Biological sonar (bats, dolphins)
- **Technology: All of the above**



## Active Electroperception

Active (perturbations to fish's own field), can detect:
- –Animate (other animals, predators, prey)
- –Inanimate (any object with an electrical conductivity differing from the water)
- –Communication by other electric fish

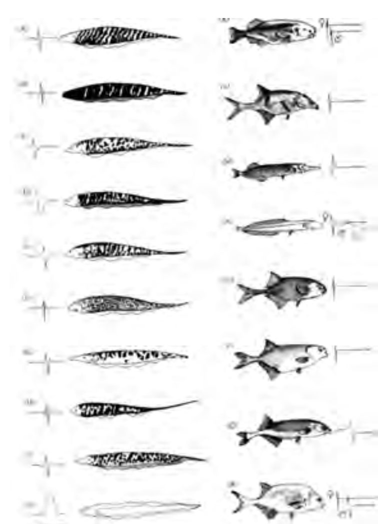
Used by:
- –All weakly electric fish (knifefish, elephant-nose)
- –Some strongly electric fish (electric eel)


## Electric fish

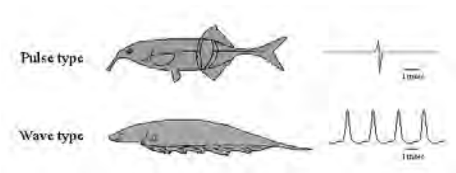
•Found in muddy or black water

•Signal is **EXTREMNLY** regular
- •Time error of less than 0.00000014 s
- •Needed for detection of small temporal phase differences (0.00000040 s!!!)



## Active Electroperception

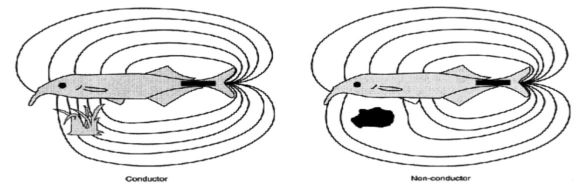
### Clickers vs. Hummers




**All weakly electric fish emit either "hums" or "clicks" as a means of exploring their environment.**
**<u>Clickers</u> emit a short, pulse-like discharges.**
**<u>Hummers</u> emit a constant, wave-like discharges.**



## Active Electroperception




**The electrical field generated by the fish is distorted by nearby objects.**
**A good conductor (i.e. a living organism) is conducive.**
**A non-conductor (i.e. a rock) blocks it.**

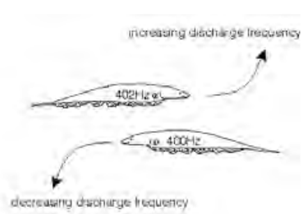
**The fish decides how to react to an object based on the distortion pattern it creates in the electric field.**



## Active Electroperception

### The Jamming Avoidance Response (JAR)

• When two fish with nearly the same frequency meet, one fish shifts its frequency slightly higher and the other fish shifts its frequency slightly lower.
• The shifts are simultaneous and reflexive.
• The process prevents the two frequencies from interfering and jamming each other's electrical signals, allowing the fish to operate in the same area.






## Ways to go the world beyond human experience…

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    - Biological sonar (bats, dolphins)
- **Technology: All of the above**



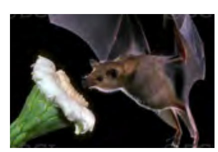
## Bio-sonar: Bat echolocation

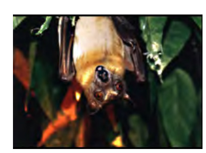
Sonar: sound navigation ranging

**Most diverse of all mammal species (~1000 sp = 25%)!**

www.batcon.org

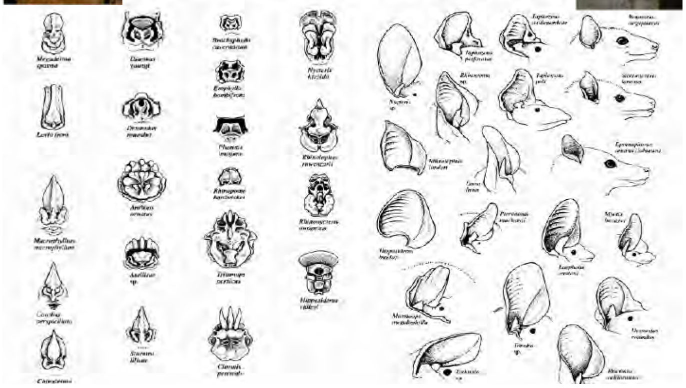
## Bat facts





- A single little brown bat can catch 1,200 mosquitoes-sized insects in just one hour (1 every 3 seconds)
  - Detection to eating time = 500ms
- the 20 million Mexican free-tails from Bracken Cave, Texas eat approximately 200 tons of insects nightly.
- The world's smallest mammal is the bumblebee bat of Thailand, weighing less than a penny.
- Giant flying foxes that live in Indonesia have wingspans of nearly six feet
- Nearly **1,000** species of bats account for about a quarter of all mammalian species
- **Not all bats echolocate**

# Nose leaf and ear diversity



- 1794: Lazarro Spallanzani first proposed bats could "see" without their eyes
  - Experiments with bats and owls in dark rooms
  - When he placed a sack over the bat's head it became disoriented.
- 1795: Charles Jurine
  - Inserted plugs in bats' ears
- 1795: Georges Cuvier
  - Elaborate touch theory
  - Became the "established" theory for over 100 years
- 1930's: Donald R. Griffin of Harvard coined term "echolocation"
  - showed that bats produce sounds above the human range of hearing
  - Revealed that they use the echoes of ultrasonic, high frequency calls to locate objects.

The Anabat II Detector

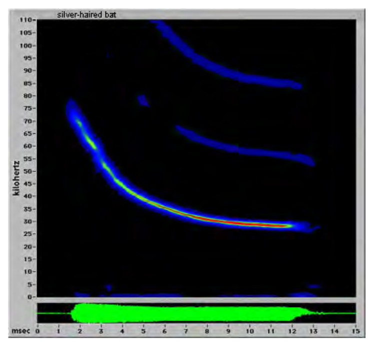


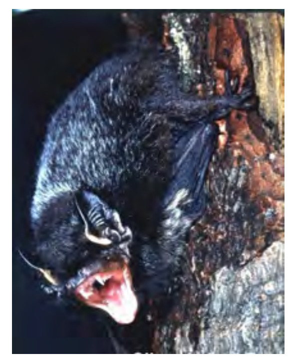
# How do bats echolocate?

•use their voice box and tongue clicking to produce the echolocating pulses. Bats move air through their vocal chords and the sounds is either emitted through their mouth or their nose.
•Sonar chirps of a typical bat utilize frequencies as high as 200 kHz.
•Long wavelengths penetrate further, giving a broad "view", while the shorter wavelengths detect tiny objects.
•Have a ~60 degree field of aural view (per pulse)
•Detect sounds as high as 200Khz (optimal freq is species specific)
•Detect objects less than a mm in diameter



Different bats have different calls with different spectral profiles



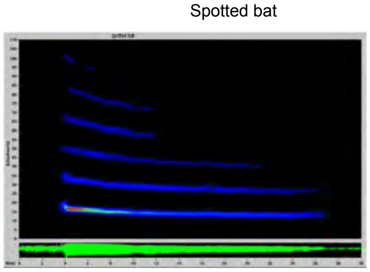





Source: http://www.sfsu.edu/~sierra/cavabats.htm

Different bats have different calls with different spectral profiles

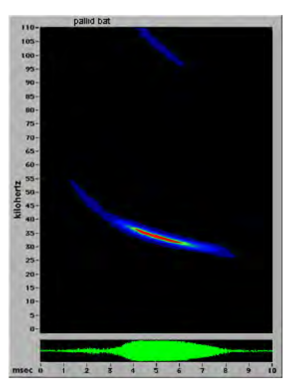
Spotted bat





Source: http://www.sfsu.edu/~sierra/cavabats.htm

Different bats have different calls with different spectral profiles

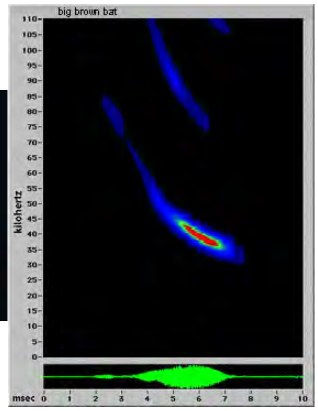



Pallid Bat



Source: http://www.sfsu.edu/~sierra/cavabats.htm

Different bats have different calls with different spectral profiles




Big Brown Bat

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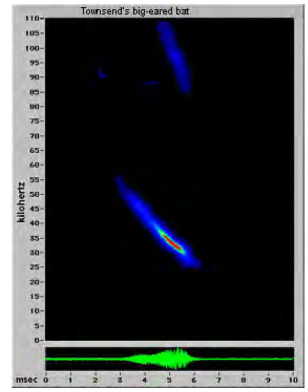
Source: http://www.sfsu.edu/~sierra/cavabats.htm

Different bats have different calls with different spectral profiles

Townsend's Big Eared Bat

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Source: http://www.sfsu.edu/~sierra/cavabats.htm

# Broadband Bats (FM bats)

- Calls that span many frequencies are called broadband
- Typical of the many bats that hunt in uncluttered open spaces.
- Echoes from broadband signals provide an echolocator with the most detailed information about its target.
- short in duration
- Pulse starts high frequency, sweeps down

# Narrowband Bats (CF bats)

- Focusing a lot of energy within a small range of frequencies.
- Low frequency, narrowband calls increase a bat's detection range,
- Because lower frequencies have longer wavelengths, they provide less detail about a target.
- Fewer harmonics
- Typically greater than 5 ms
- Some bats switch between broad and narrowband calls to get more detailed information

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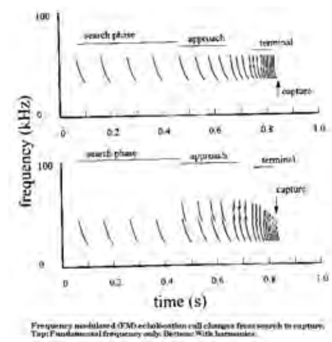


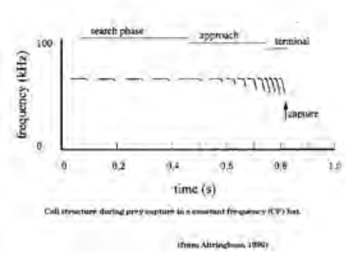


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Specific parameters that bats extract from echoes about objects

- **Distance**
  -
- **Angular size**
- **Absolute object size**
  -
- **Azimuth:** the horizontal position (angle)
  -
- **Elevation**: vertical angle
  -
  -
- **Texture of object**
  -
- **Velocity/relative velocity**
  -

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# What can bats "see"?

- **Distance**
  - based on echo delay
- **Angular size**
  - based on echo loudness;
- **Absolute object size**
  - based on Delay + loudness
- **Azimuth:** the horizontal position (angle)
  - based on aural delay
- **Elevation**: vertical angle
  - differential loudness based on changing ear position
  - pinna shape
- **Texture of object**
  - based on FM and/or Doppler shift
- **Velocity/relative velocity**
  - Doppler shift

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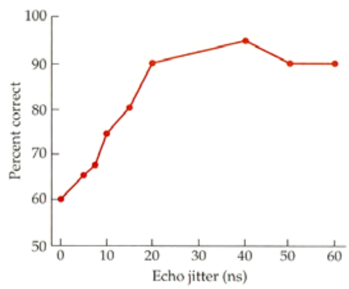
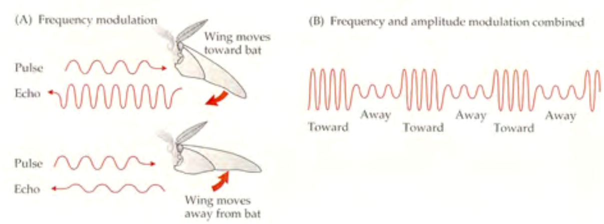
# What can bats “see”?

Bats are able to discern echo delay differences of **10 nano-seconds**
•Equates to a distance of **2μm**



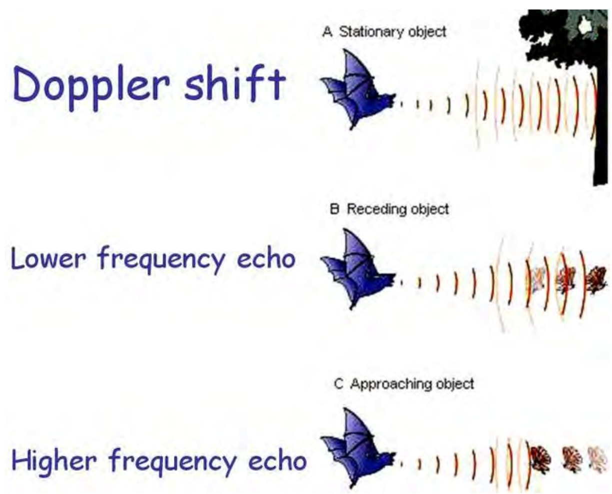



# What can bats “see”?




•Each moth species has a characteristic wing beat frequency and amplitude.
•Bats are able to discriminate insects based on the different Frequency-amplitude profiles.

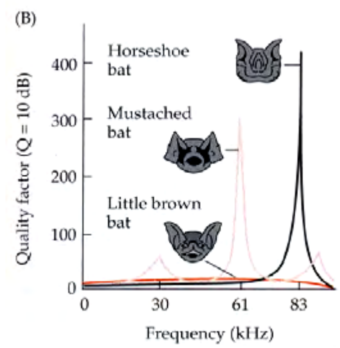





# Acoustic fovea

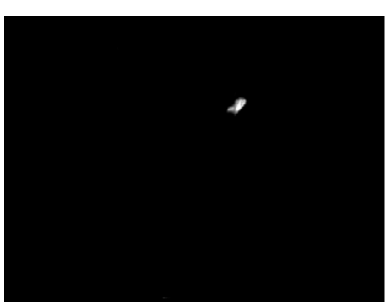
•Bats have a very narrow frequency band that they are particularly sensitive to.

•Doppler shift causes problems. Why?






### Bio-sonar: Bat echolocation



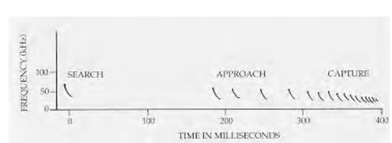
x25

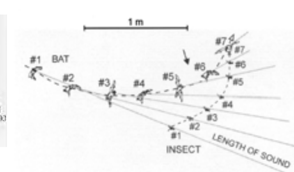


(*In these examples of bat sonar, sounds have been shifted to frequencies audible to the human ear*)

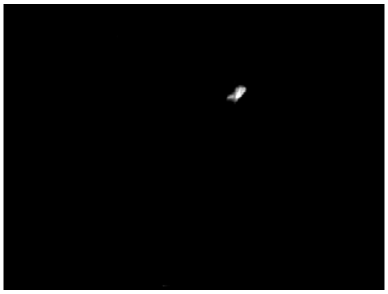
### Bio-sonar: Bat echolocation

- **How does a bat catch a moth**
  - **Search**
    - 10 cries/sec, until a moth is detected
  - **Approach**
    - 20-40 cries/sec - to get more information about prey
  - **Terminal buzz**
    - 100-200 cries/sec - to get all information needed to catch a moth
    - As the behavior progress to terminal buzz pulse rate increases, FM range decreases
  - **Capture**
    - A moth is captured (like a baseball)



**Bio-sonar: Bat echolocation**



x25

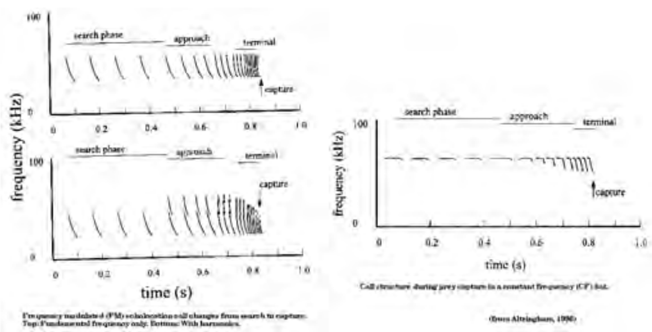


*(In these examples of bat sonar, sounds have been shifted to frequencies audible to the human ear)*

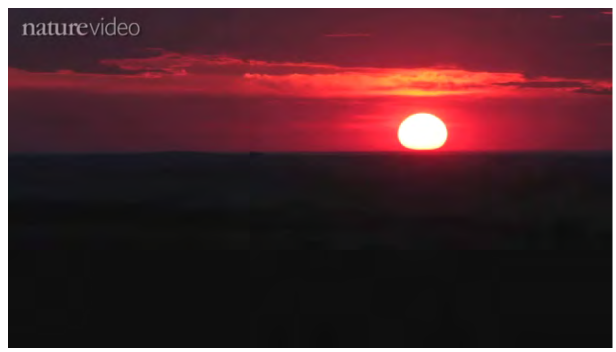
**Bio-sonar: Bat echolocation**




*(In these examples of bat sonar, sounds have been shifted to frequencies audible to the human ear)*






**http://www.youtube.com/watch?v=gZxLUNHEmPw**



**Bio-sonar: Bat echolocation**

Any potential problems with active perception?

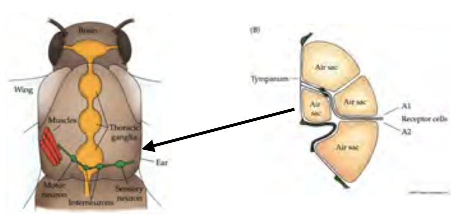
First infra-red nigh vision cameras (“sniperscope”)

WWII: allowed snipers to illuminate their target without their target being aware of it. However, night vision became employed by both sides, and as a result the "active" IR beams began to betray the sniper's position

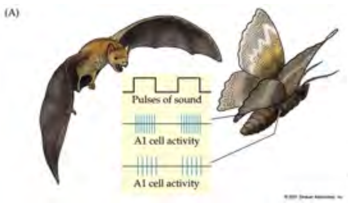


# Sonic detectors

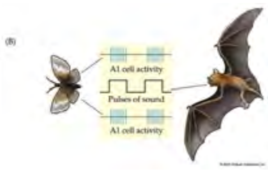
- Many moths have "ears" to detect bat echolocation.
- These "ears" are membranes stretched over sensors.
- Not always found on the moth's head
- Found on the body, wings or even mouth parts



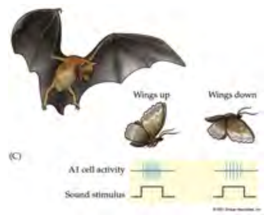
Differential A1 responses allow interneurons to code bat position




Bat to one side causes symmetric A1 response causes counter steering




Bat below or behind Symmetric A1 response no affect of wing beat




Bat above: Both A1 cells produce symmetric responses that are disrupted by wing beating of moth



# Moth Stealth Technology

- Fuzzy wings attenuate sonar reflection



## Ways to go the world beyond human experience…

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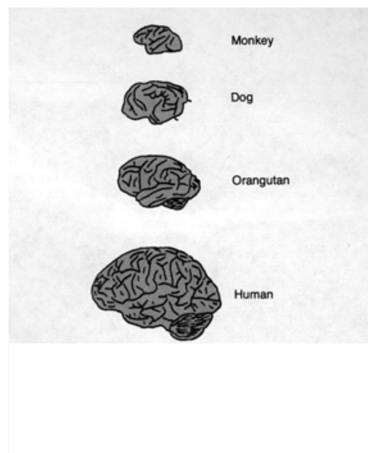
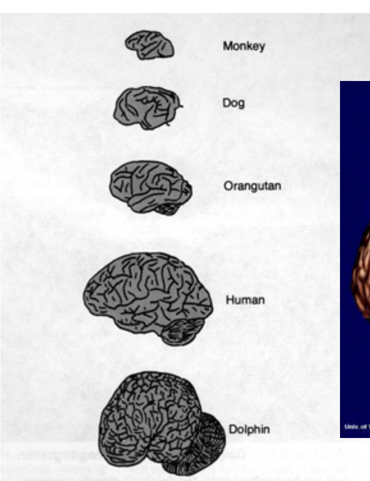



**Comparative sizes of brains of dolphin and other mammals.**






**Comparative sizes of brains of dolphin and other mammals.**