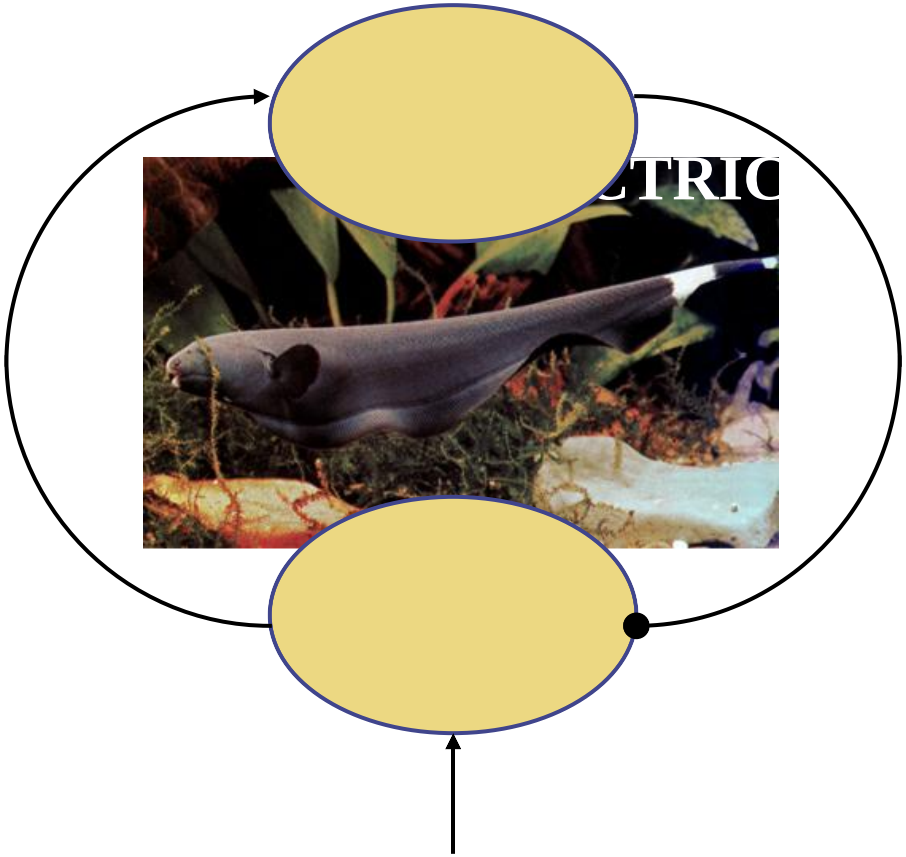
ACTIVE SENSING

Lecture 8 :
Electric fish control loops

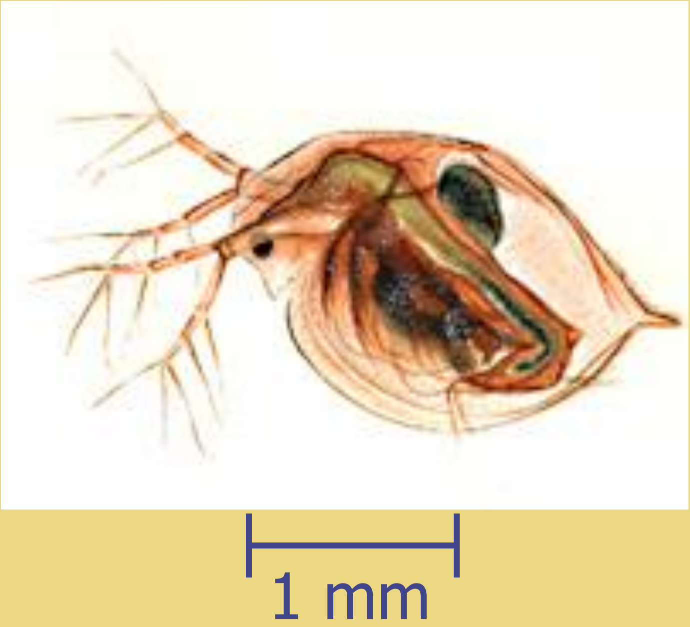


The prey:

Signals available to predators

- Mechanosensory stimuli
- Low-frequency bioelectric fields
- Perturbations to the fish's high-frequency electric field

Prey: Daphnia



Electric Field Generation

Power Considerations

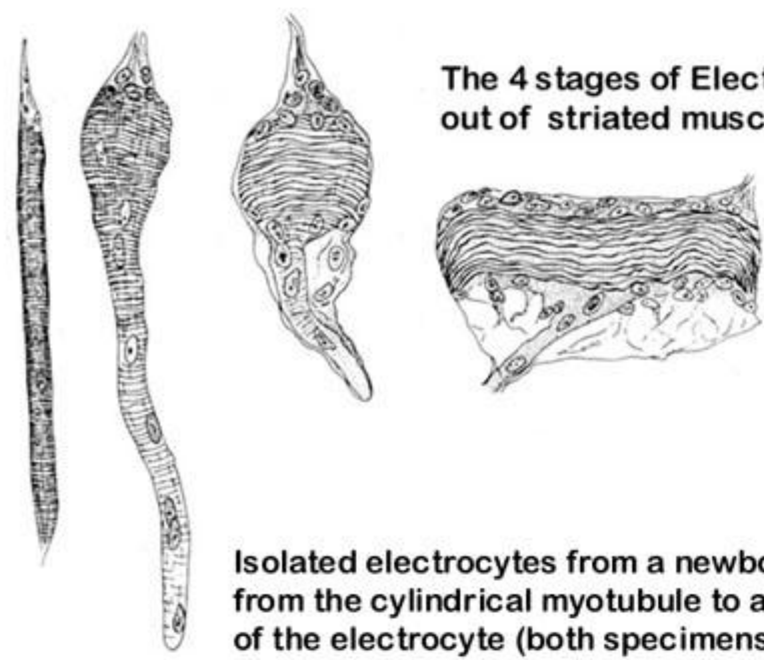
- Weakly electric fish devote about 1% of basal metabolic rate to EOD production

M. E. Nelson

Electric Field Generation

Electric Organ Design

- an electrocyte is a **modified muscle** cell, that lacks the ability to contract and is specialized for the generation of electric current.



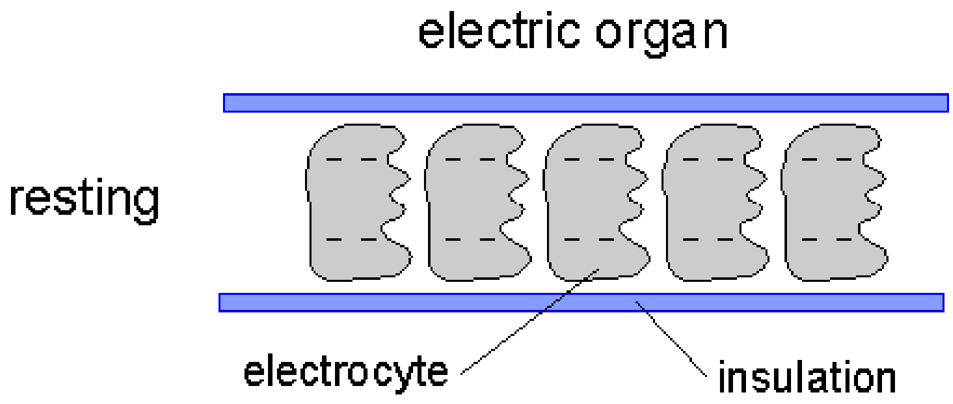
The 4 stages of Electrocyte development in *Raja clavata* out of striated muscle tissue.

Isolated electrocytes from a newborn *R.erinacea* showing the transition from the cylindrical myotubule to a cup-shaped cell during differentiation of the electrocyte (both specimens are innervated - arrows).

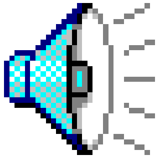
Electric Field Generation

Electric Organ Design

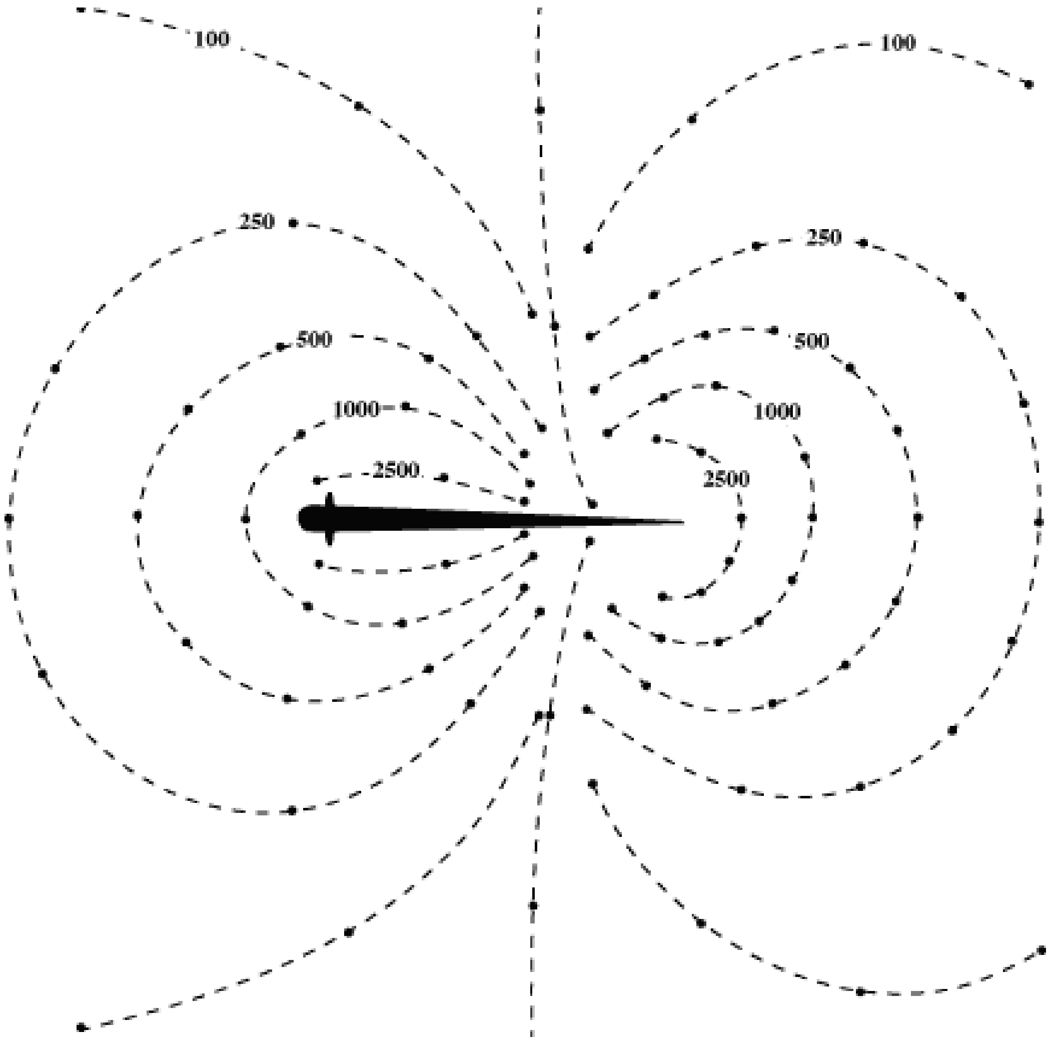
- The electric organ contains **columns of stacked *electrocytes***
- To generate a signal, the brain sends an **electric signal to the first electrocyte** in the column, which depolarizes the innervated electroplate surface. This creates a a **depolarization wave along the electroplate column**.
- Essentially, the stacked electroplates act as a **series of batteries.** The charge generated from these connected "batteries" is released into the surrounding water.



Self-generated Electric Field



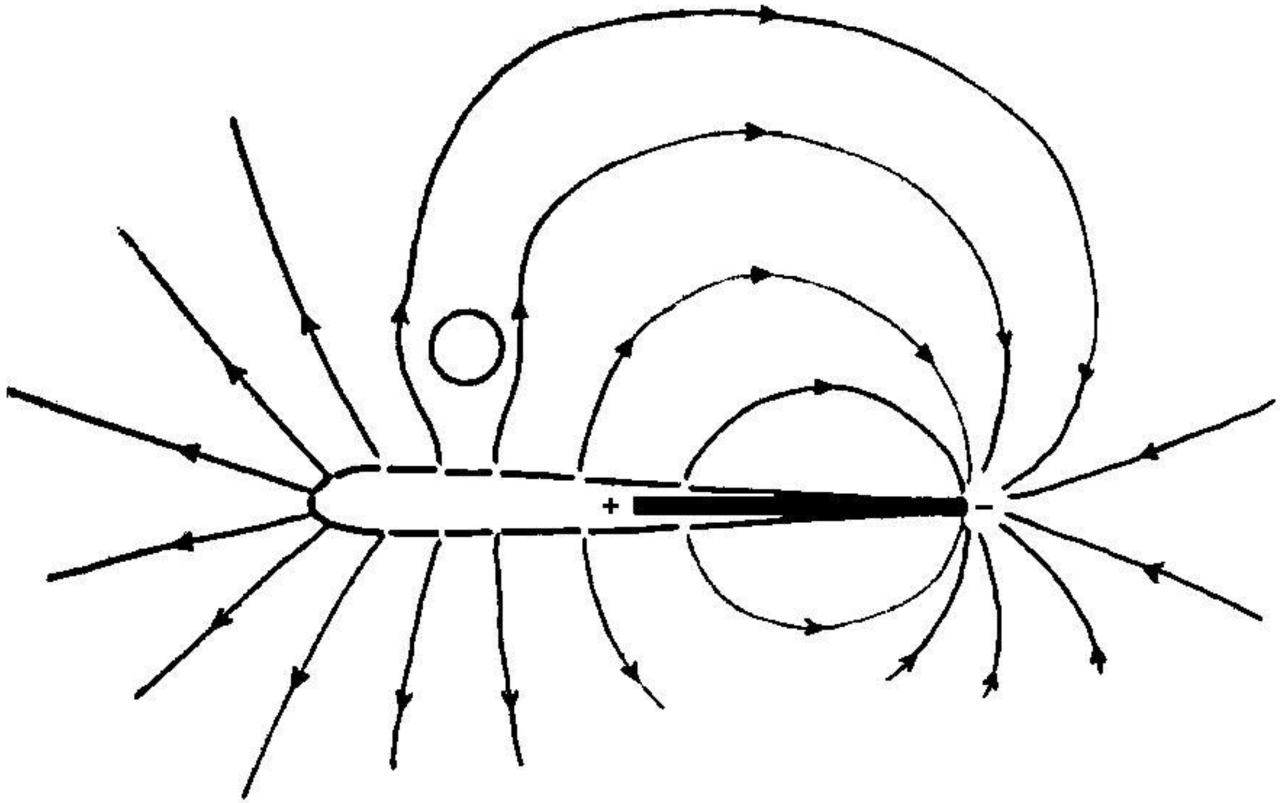
isopotential lines (peak, in microvolts)



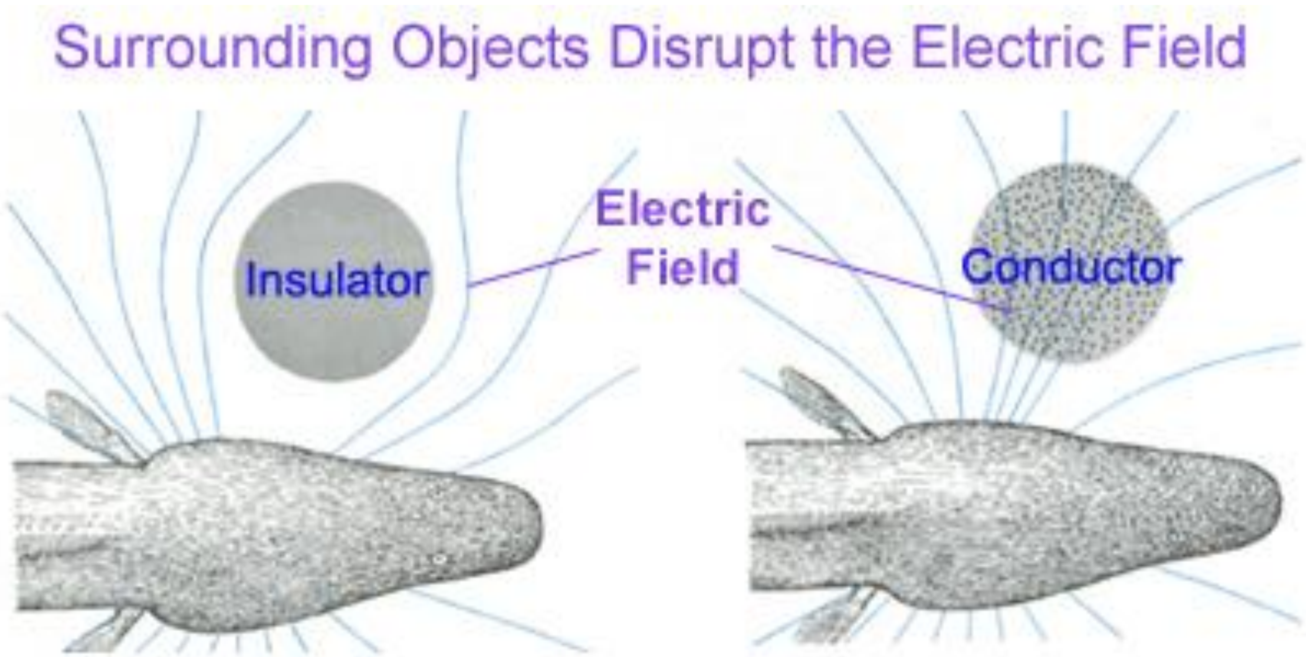
M. E. Nelson

Self-generated Electric Field

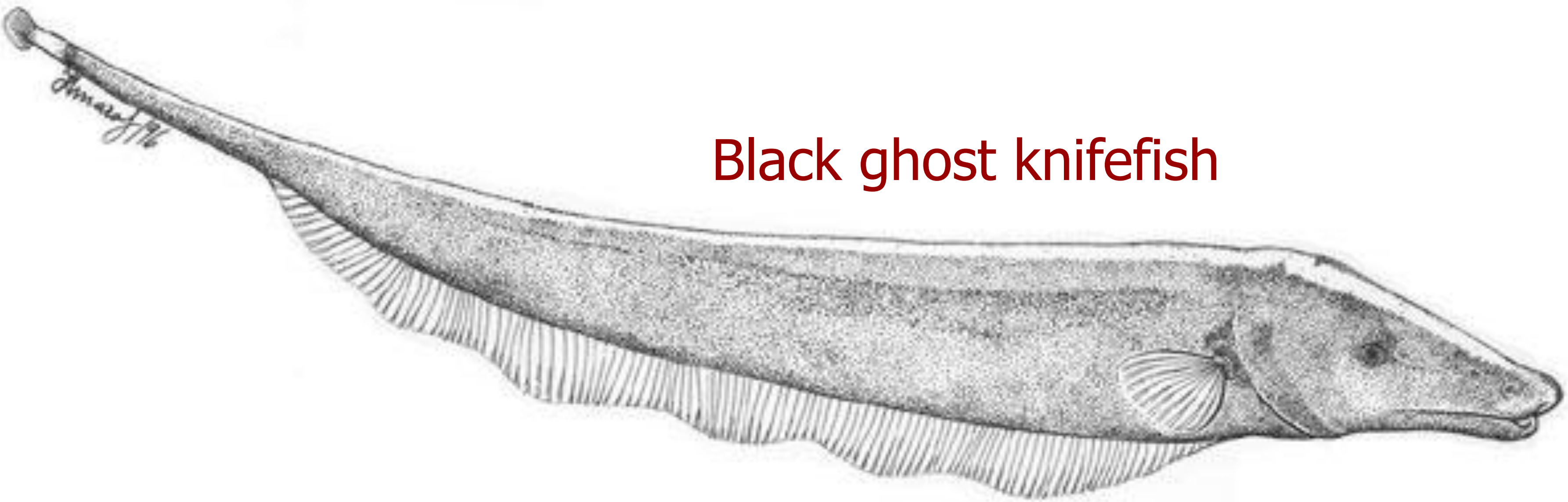
current flows perpendicular to the isopotential lines



Principles of active electrolocation



Black ghost knifefish



Fabrizio Gabbiani, Nat Neurosci 2003

Electroreceptors

~15,000 tube**rous electroreceptor organs**
1 nerve fiber per electroreceptor organ

at least two types of electroreceptors:

P-type – respond to the intensity of electrical current

T-type - respond to the phase of electrical current

Complications with emitted-energy active sensing

- conspicuousness
  - Detection of energy by prey and other predators
- confusion with peers

Adaptations specific to emitted-energy active sensing

- conspicuousness
  - Detection of energy by prey and predators
- confusion with peers

- technology war
- Ciphering
- jamming avoidance

Technology war

make the probe less conspicuous to the prey/predator.

Example:

echolocating killer whales **A** → dolphins
echolocating killer whales **B** → fish

Dolphins can detect the ecolocating signals
Fish cannot

echolocating killer whales **A** use irregular short clicks
echolocating killer whales **B** use continuous emission

Technology war

make the probe less conspicuous to the prey/predator.

Example 2:

The prevalence of passive vision systems make it difficult for **bioluminescence-based active photoreception** to be a viable strategy in most ecological niches.

Solution 1: Flashlight fish **open and close a "lid"** to expose their light organ briefly

Solution 2: **In deep sea**, vision is usually based on the **blue-green** portion of the spectrum. deep-sea dragonfish have two bioluminescent organs, one of which produces a near **infrared wavelength** of light that only they can see.

Ciphering

keep a private signal that allows decoding the echo

Example: CF-FM echolocating bats

1st harmonic is weak and does not reach the peers
2nd harmonic is loud and also echoed well

pairing of 2nd harmonic (source) & delayed 2nd harmonic (echo) would include peer calls

These bats have evolved cells that respond to
1st harmonic & delayed 2nd harmonic

other ciphering tricks?

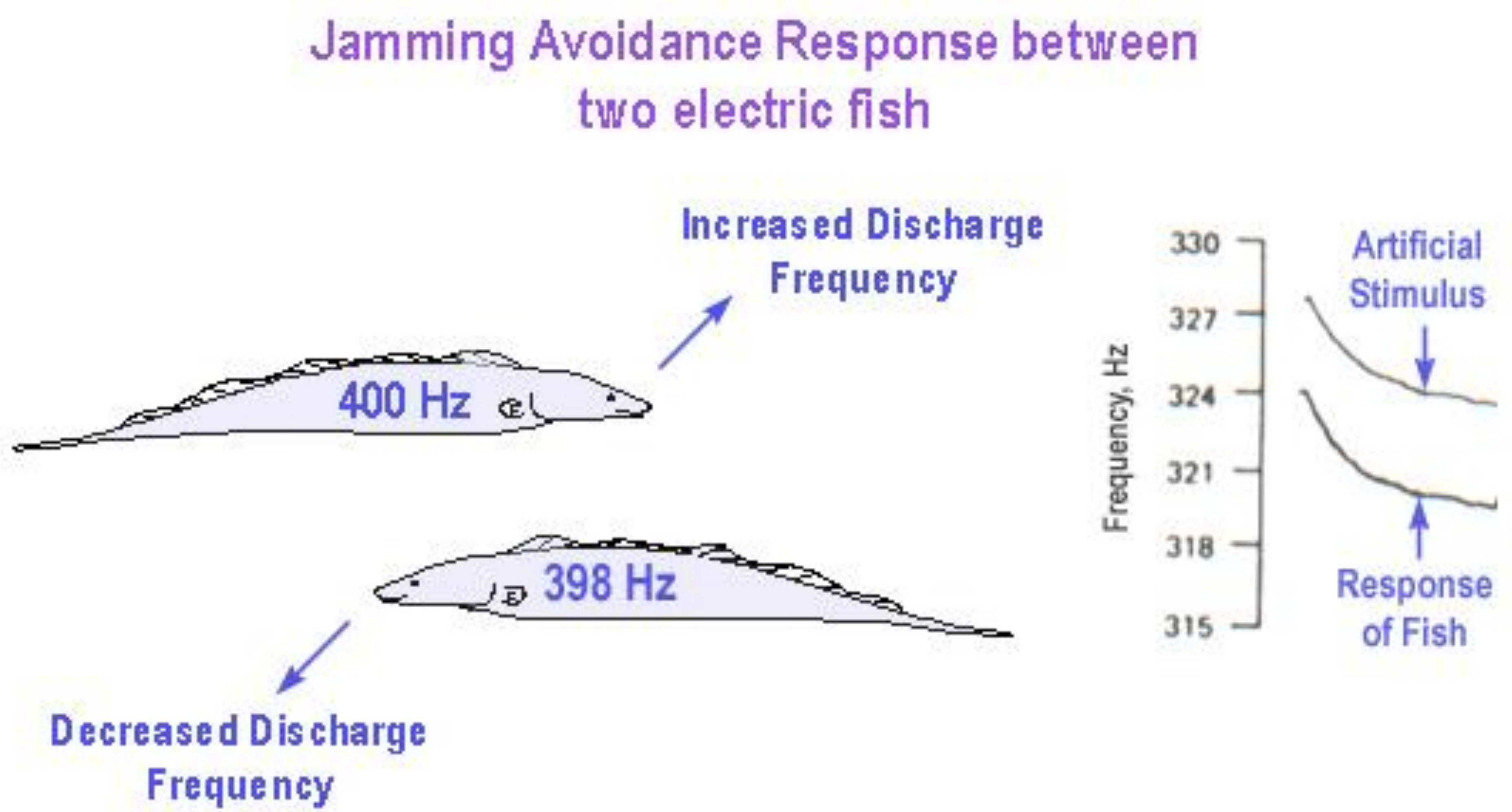
Adaptations specific to emitted-energy active sensing

- conspicuousness
  - Detection of energy by prey and predators

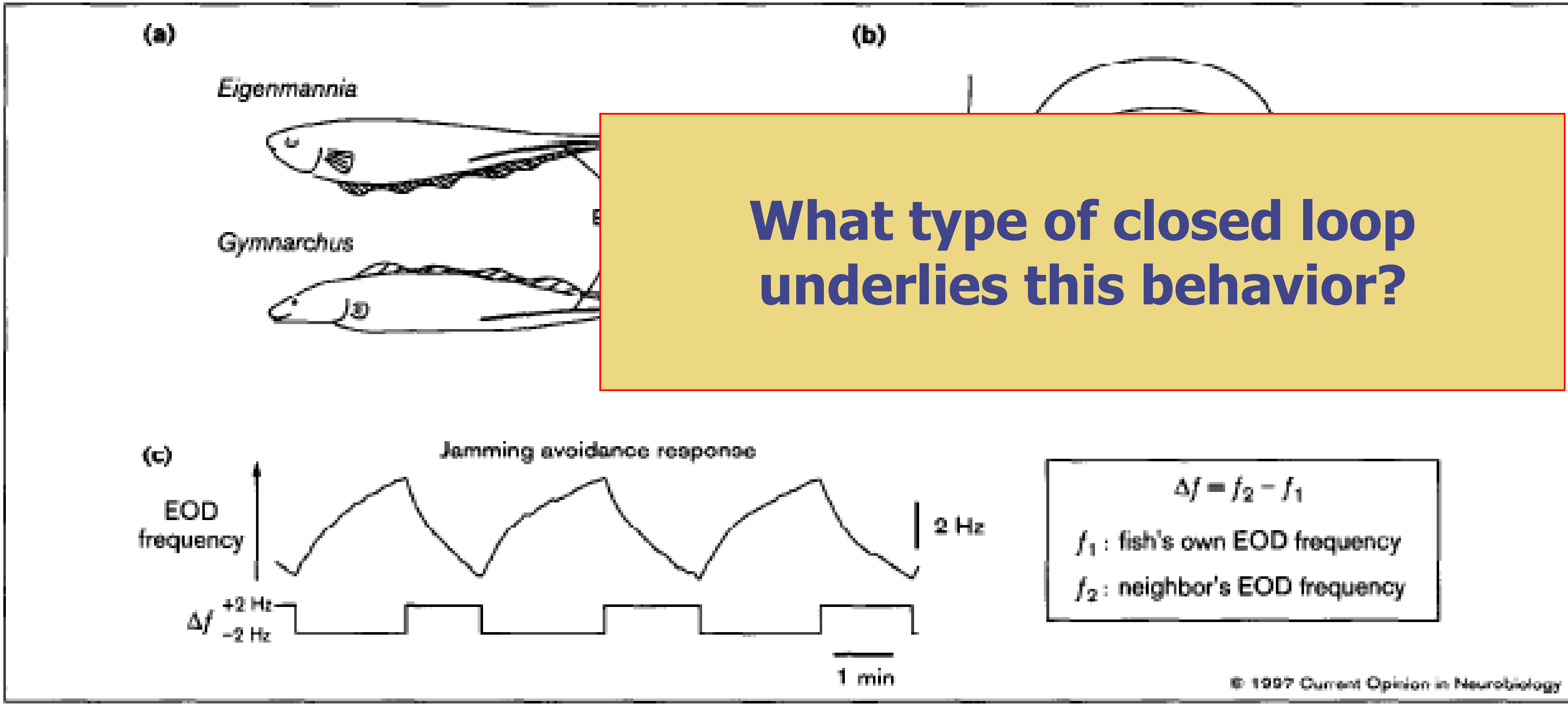
  - technology war
  - Ciphering

- confusion with peers
  - jamming avoidance

Jamming avoidance



Jamming avoidance



Electrolocation and jamming avoidance response. **(a)** *Eigenmannia* and *Gymnarchus* emit EODs from the electric organ in their tail. **(b)** Distortion of the fish's electric field in response to an object (dark gray circle) is detected by electroreceptors on the body surface. **(c)** The top trace depicts a fish's EOD frequency, displaying a jamming avoidance response, in response to Δf (bottom trace), which represents the difference between the fish's own (f_1) and its neighbor's (f_2) EOD frequency.

Masashi Kawasaki **Current Opinion in Neurobiology 1997, 7:473-479**

Jamming avoidance

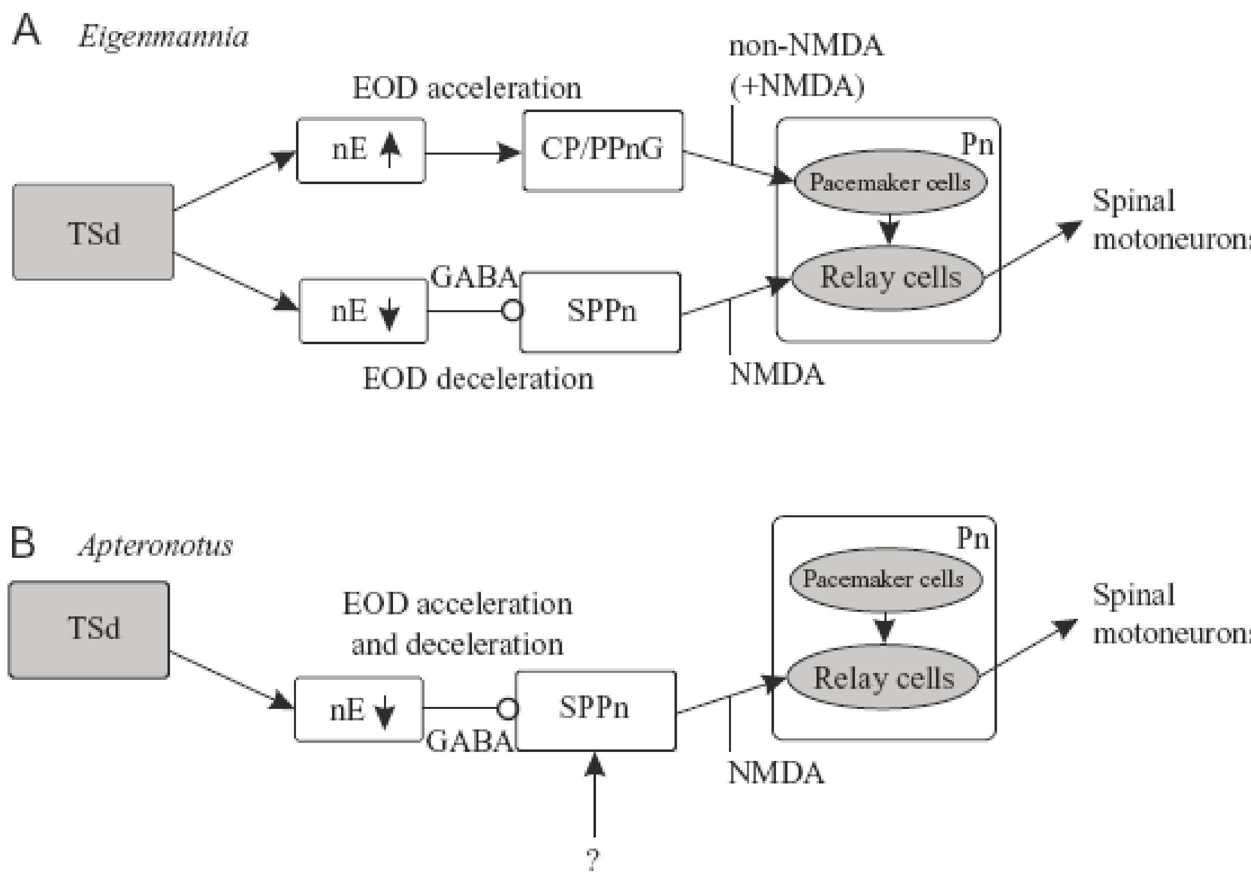


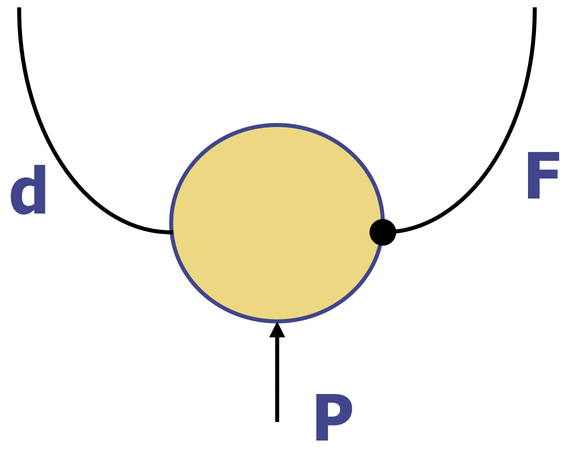
Fig. 1. Flow diagrams of premotor control of the jamming avoidance response (JAR) in *Eigenmannia* (A) and *Apteronotus* (B). Arrowheads indicate excitatory and open circles inhibitory connections. For details, see text. (After Kawasaki et al., 1988; Dye et al., 1989; Keller and Heiligenberg, 1989; Metzner, 1993; Heiligenberg et al., 1996; Juranek and Metzner, 1997, 1998.) CP/PPnG, dorsomedial portion of the diencephalic prepacemaker nucleus complex; nE↑, dorsal portion of the diencephalic nucleus electrosensorius complex whose stimulation causes gradual rises in electric organ discharge (EOD) frequency; nE↓, ventral portion of the diencephalic nucleus electrosensorius complex whose stimulation causes gradual reductions in EOD frequency; Pn, medullary pacemaker nucleus; SPPn, sublemniscal prepacemaker nucleus; TSd, mesencephalic torus semicircularis dorsalis; ?, postulated but unidentified excitatory input; GABA, γ-aminobutyric acid; NMDA, *N*-methyl-D-aspartate.

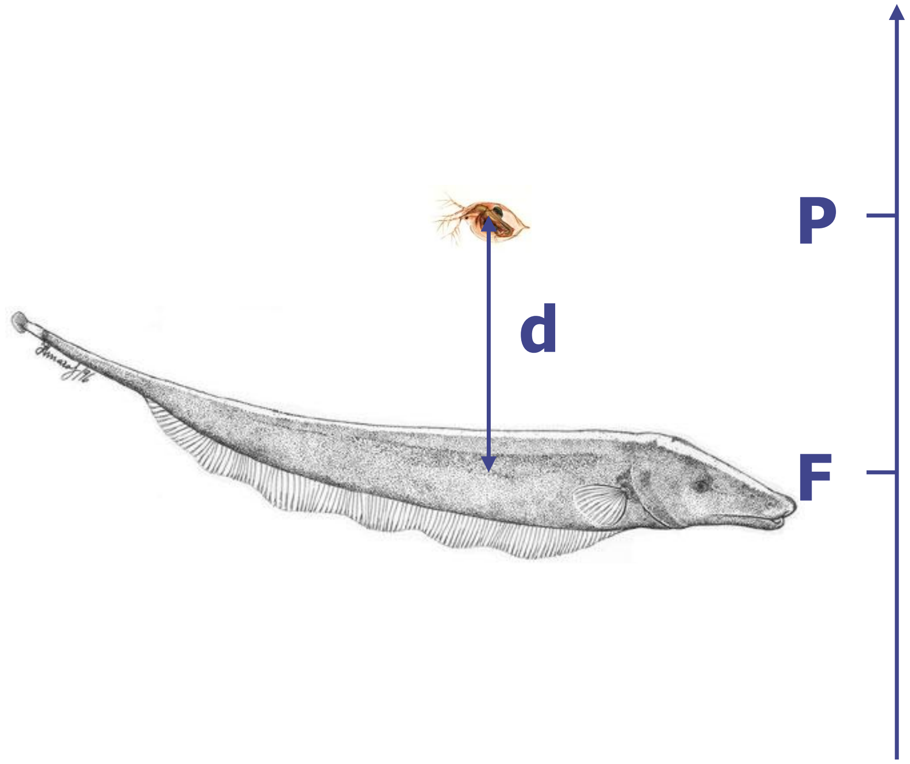
WALTER METZNER, The Journal of Experimental Biology 202, 1365–1375 (1999)

Prey capture behavior

What is the control loop?

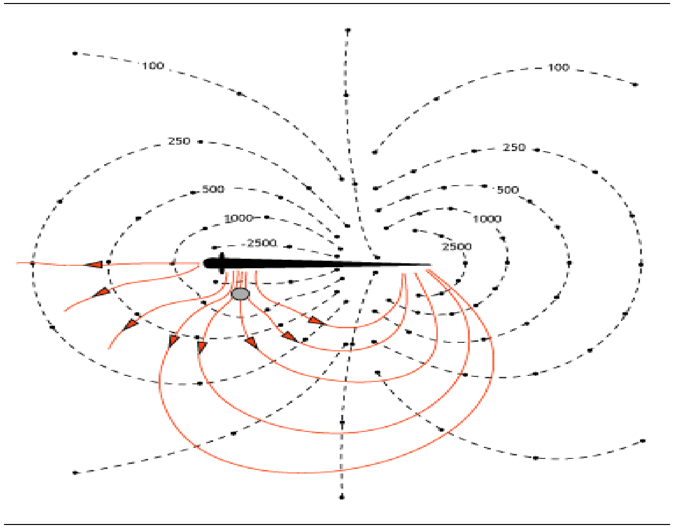
how to design a prey-capture loop

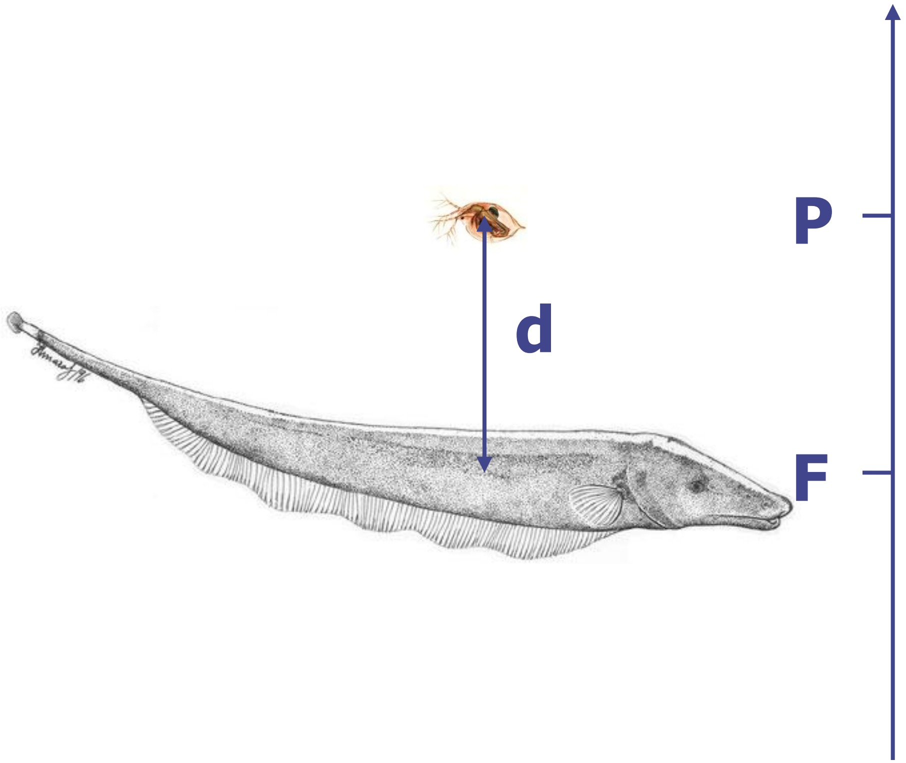




What is the control loop?

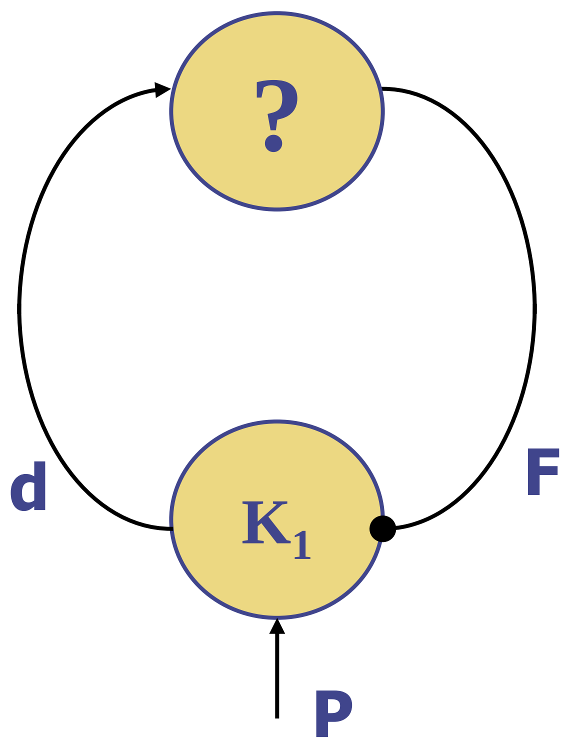
how to design a prey-capture loop

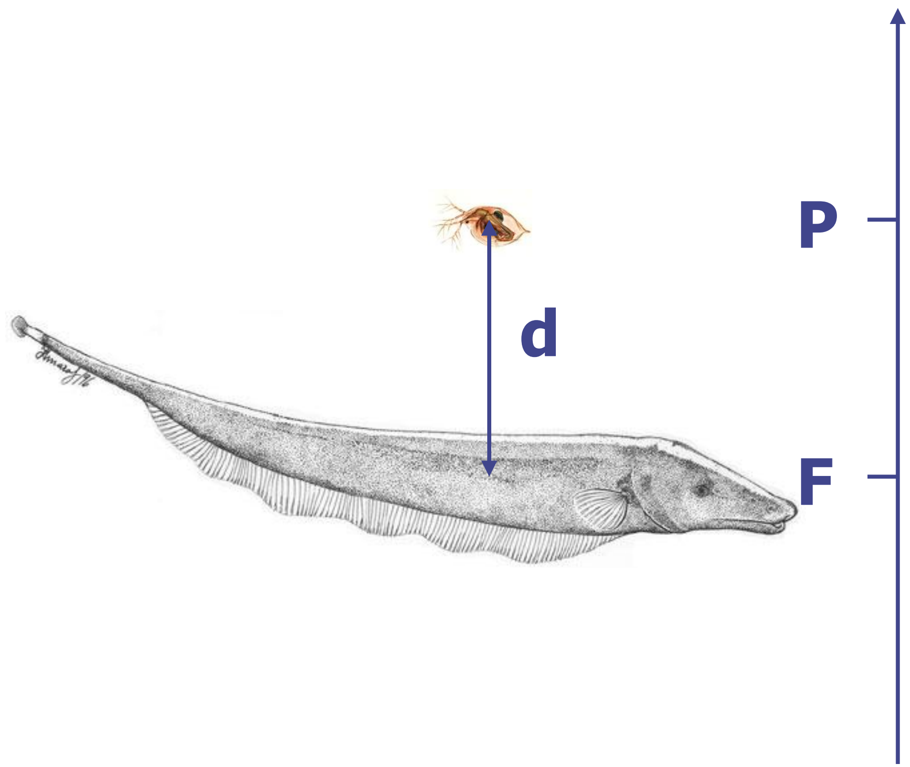




What is the control loop?

how to design a prey-capture loop

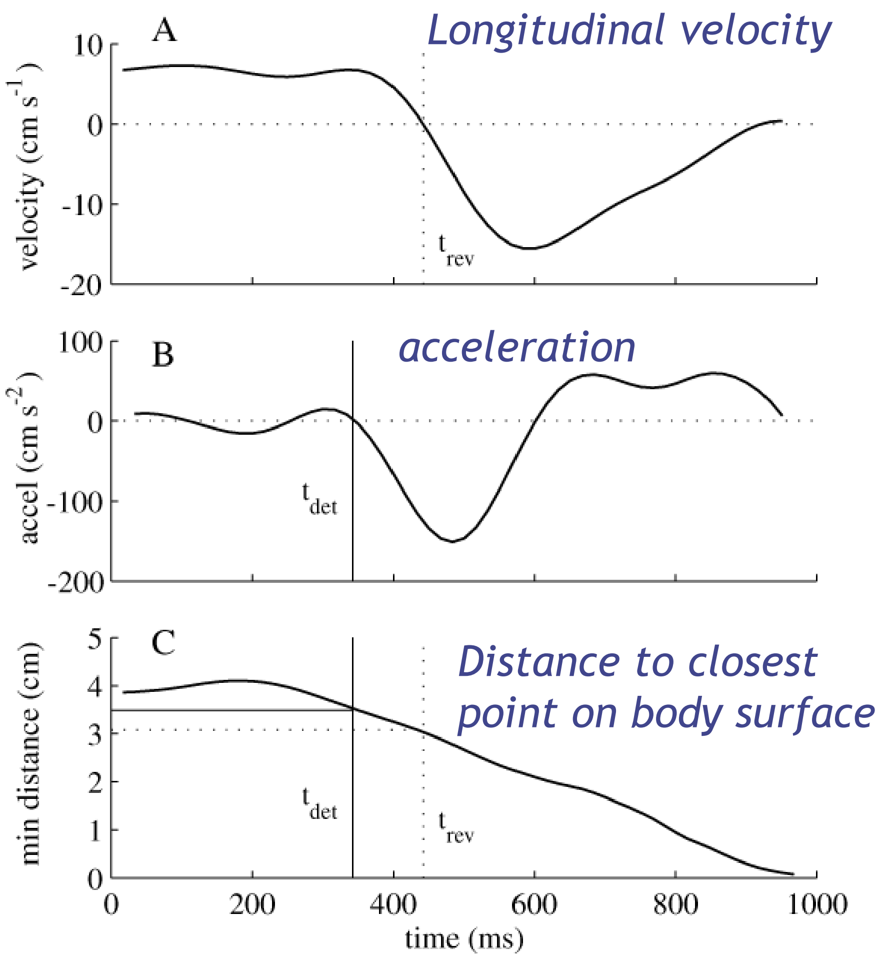




Prey-capture loop design

- Phase plane
- Convergence regimes
- Convergence dynamics

Prey capture kinematics



Localization loops in other systems

Echo-location
Electro-location

Olfacto-location
Audio-location
Tacto-location
Visuo-location ***Exercise 2***

ACTIVE SENSING

Lecture 9 :

Electric fish control loops