Organisms, Simulated & Real

Lecture 11 I400/I590

Artificial Life as an approach to Artificial Intelligence

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Simulacra

- Historically, there have been many legends of living statues, magical pictures, dolls, icons, robots, and automata that represent or embody the living
- Not until the electronic age have people attempted to emulate the nervous system
- While neural activations *may* be effectively binary, alternative, analog simulations may also have much to contribute to the understanding of living systems

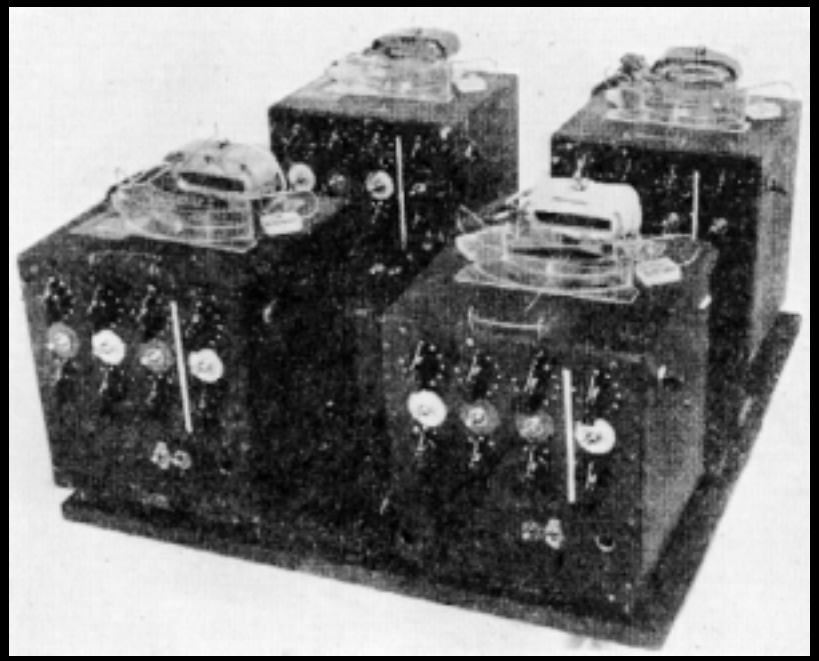
Ross Ashby

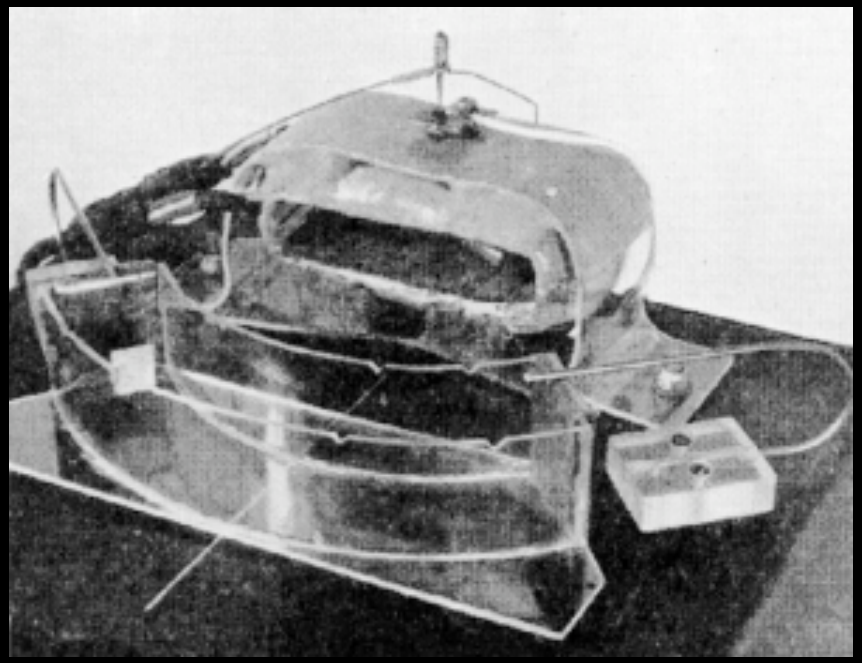
- Ross Ashby, author of *Design for a Brain* (1952) and *Introduction to Cybernetics* (1956), declared a system's ability to maintain stability and adapt, in the face of novel stimuli, as a defining attribute of life
- He described the stability of living systems, then, in terms of self-regulatory feedback, and related complex adaptive behavior to complex self-regulation
  - Variety absorbs variety
  - "Only variety in R can force down variety due to D; only variety can destroy variety."
    - Where R is a regulator and D a disturbance in Ashby's parlance

Homeostat

- Ashby designed a "Homeostat" device, consisting of four pivoting magnets, motion constraints, and various electrical connections and switches, to demonstrate what he called an "ultrastable" system—one that would return to homeostasis regardless of the magnitude of its perturbations

Homeostat





http://www.hrat.btinternet.co.uk/Homeostat.html

Early Cyberneticians

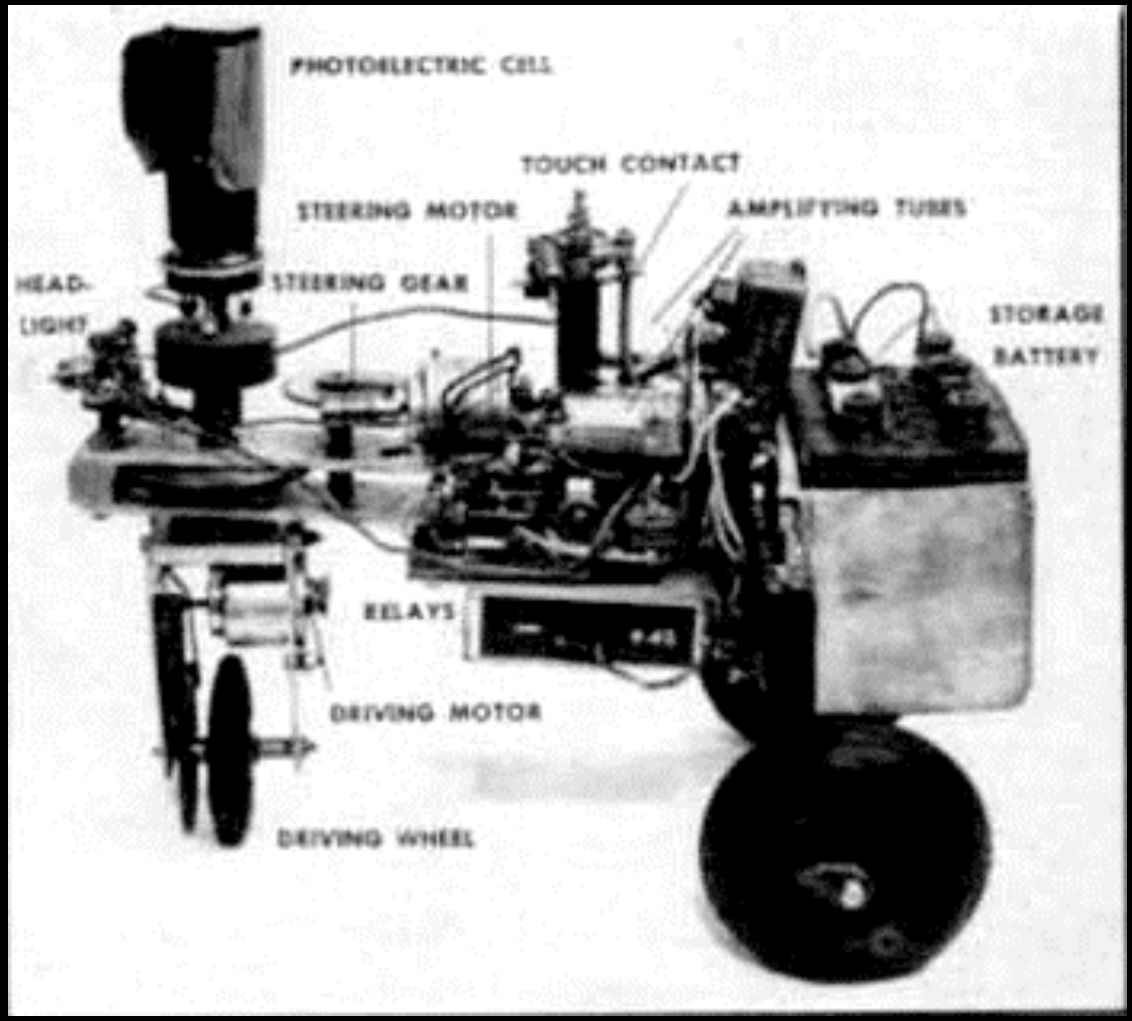
Ross Ashby, Warren McCulloch, W. Grey Walter, Norbert Weiner

W. Grey Walter

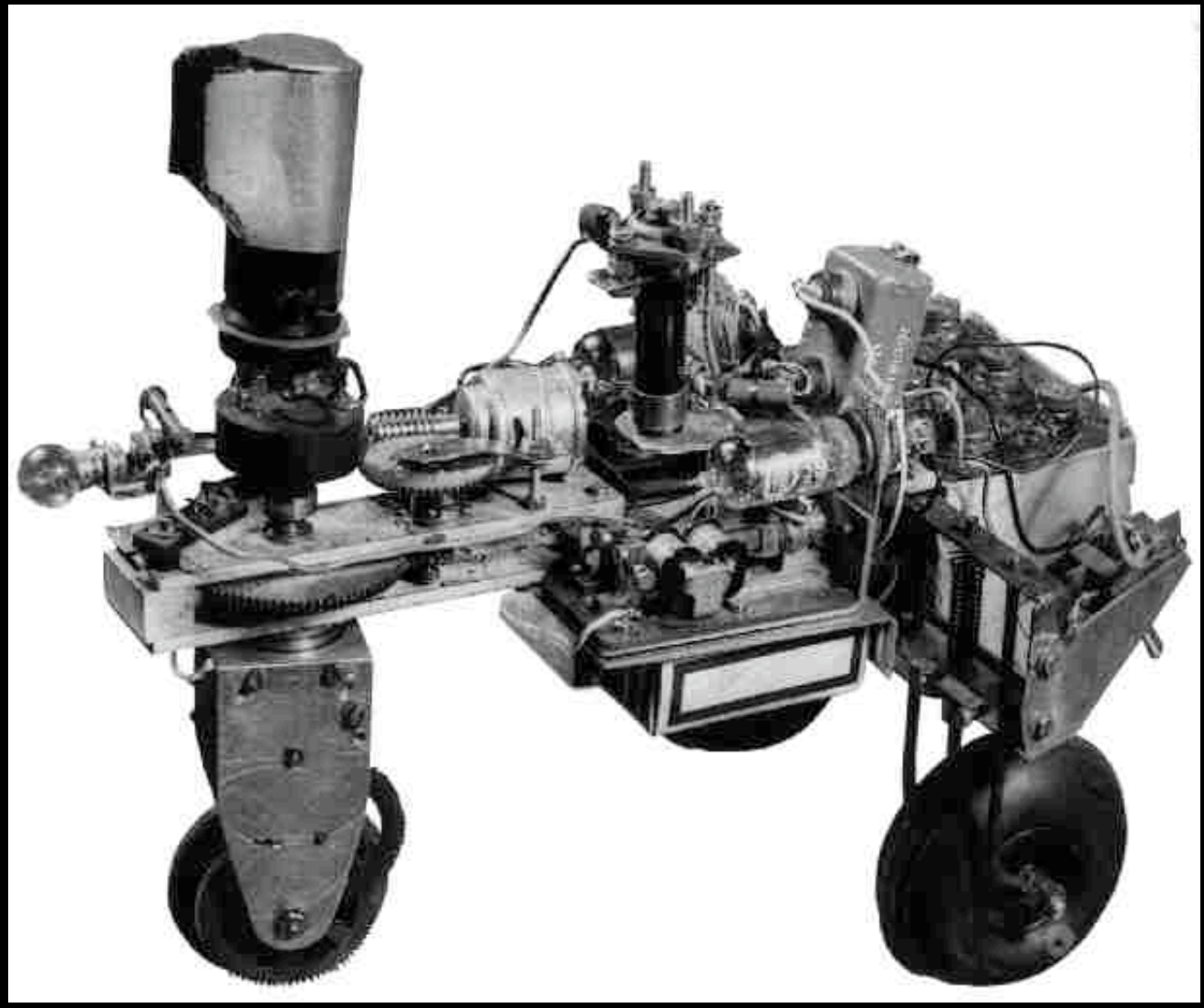
- Walter Grey Walter, author of *The Living Brain* (1953), experimented with electro-mechanical "turtles"
  - Family "Machina Speculatrix"
  - Genus "Testudo" (tortoise)
- Built between Easter 1948 and Christmas 1949, the first two of these turtles were Elmer and Elsie, after ELectro MEchanical Robots, Light-Sensitive, with Internal and External stability
  - "Stability" may have been related to Ashby's homeostasis
  - "External" might be intended to distinguish Testudo from Homeostat

Machina Speculatrix / Testudo

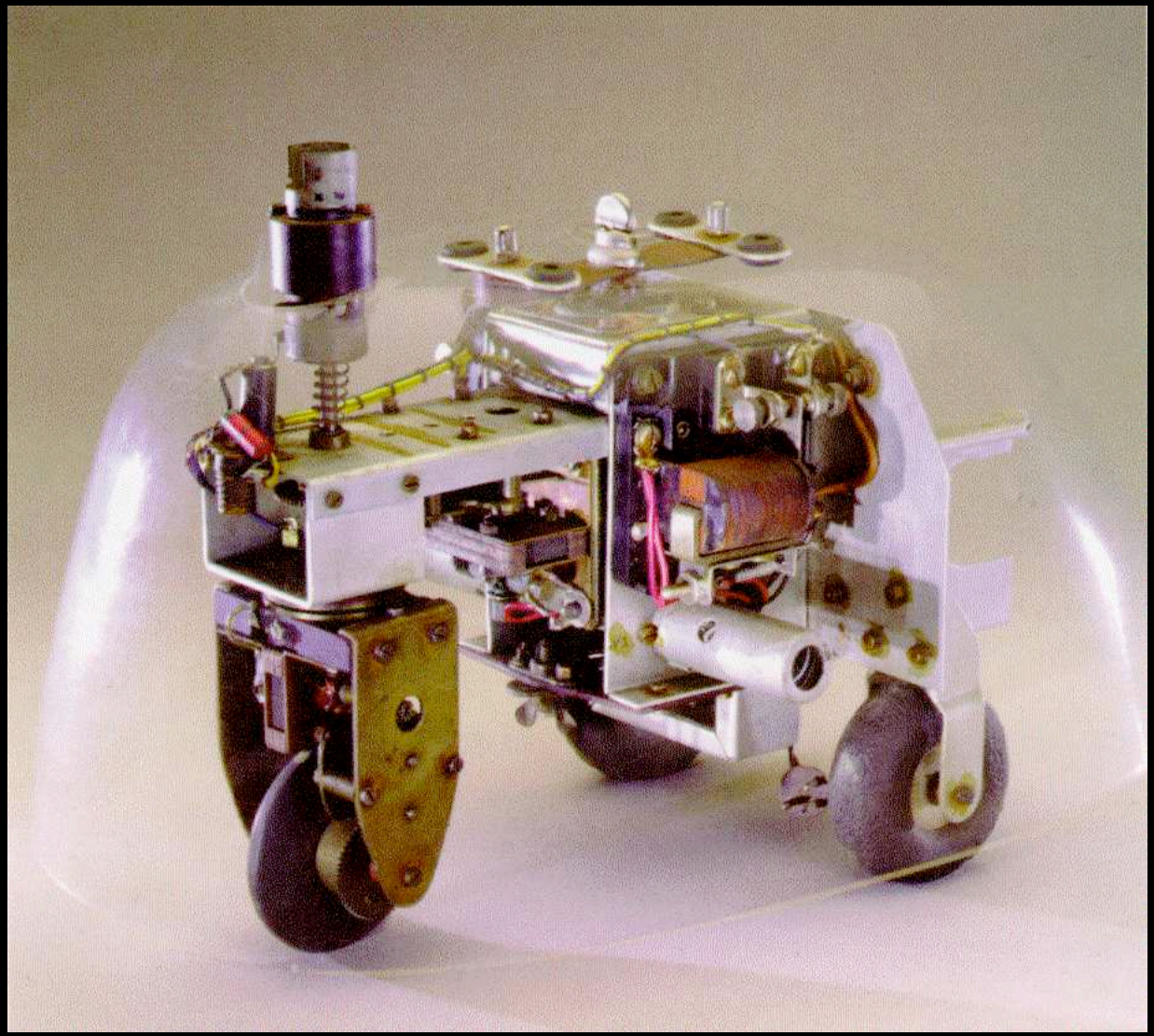
Testudo annotatus



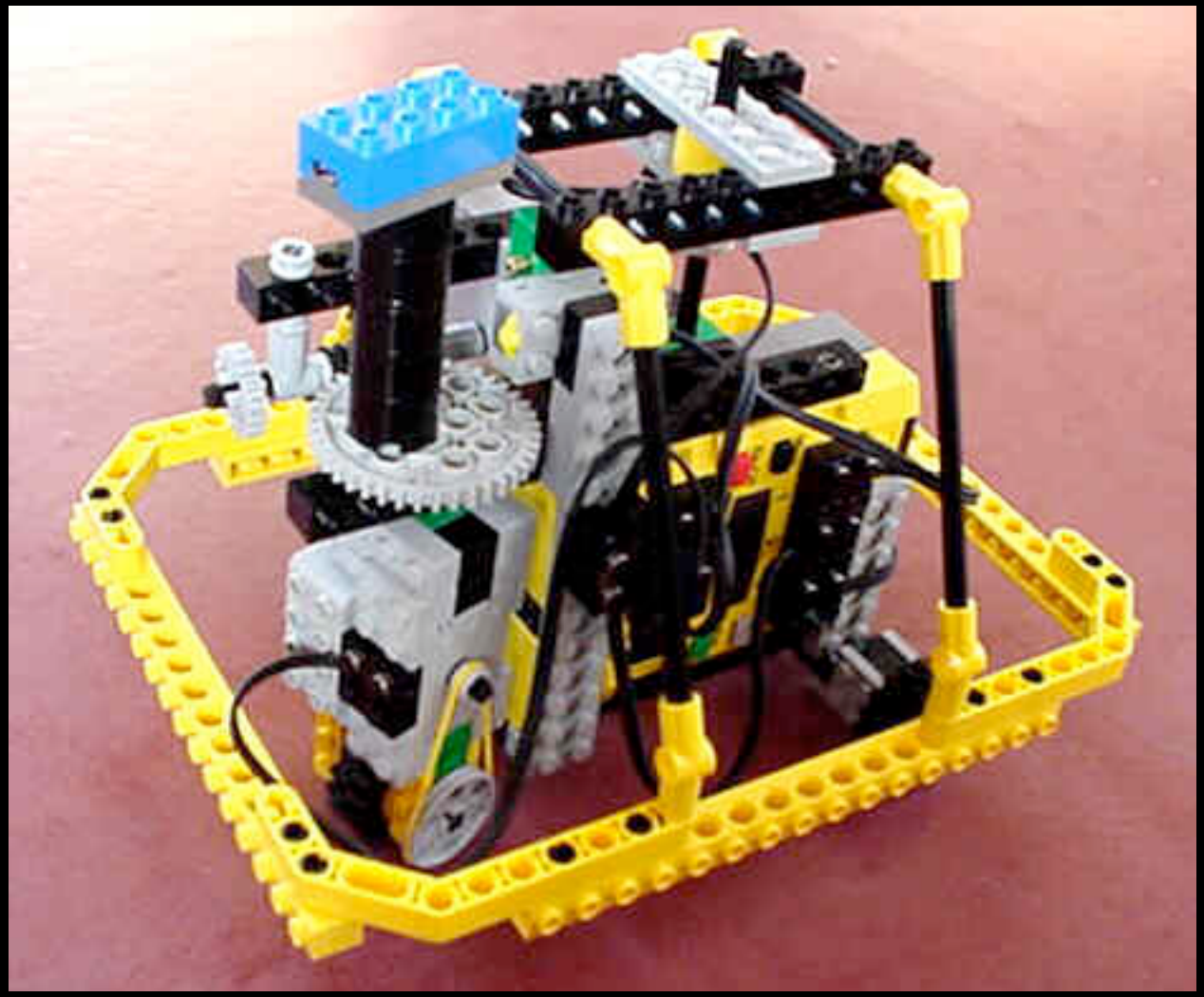
Elsie



Testudo bristol (Smithsonian)

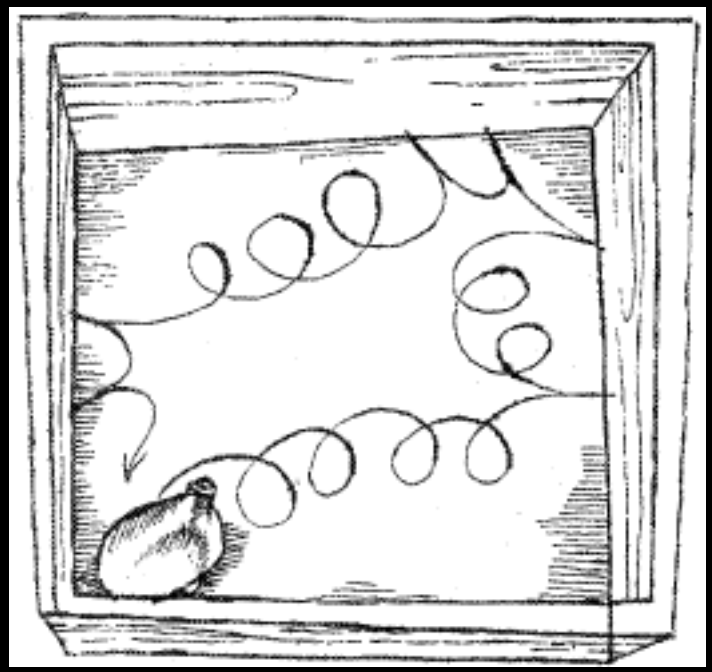


Testudo legos

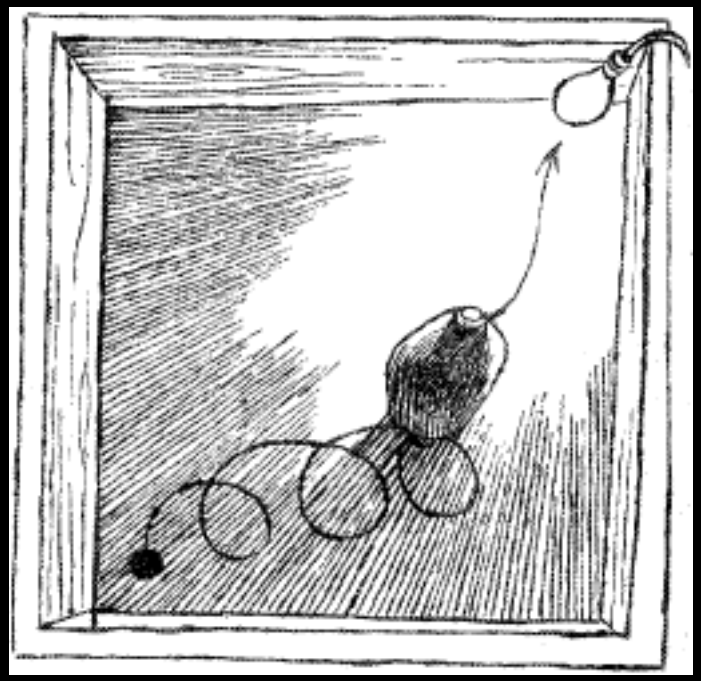


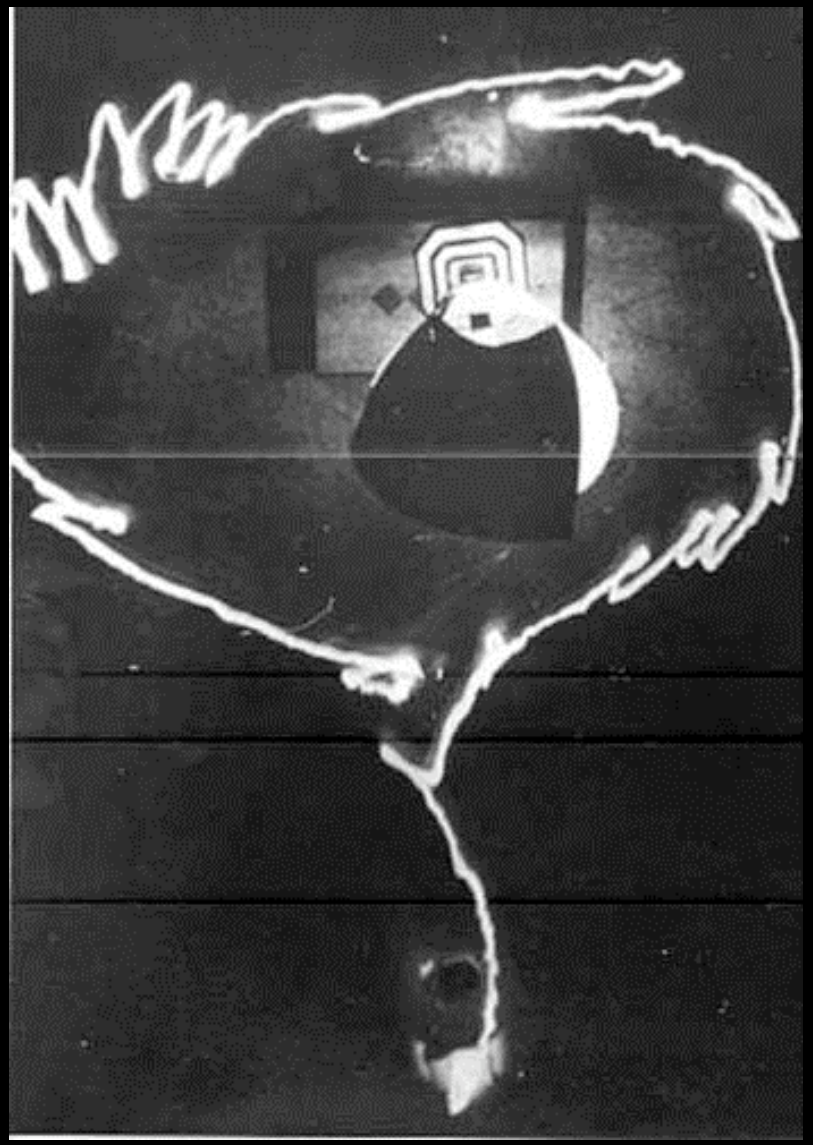
Testudo bristol with Hutch

Basic Exploratory Behavior

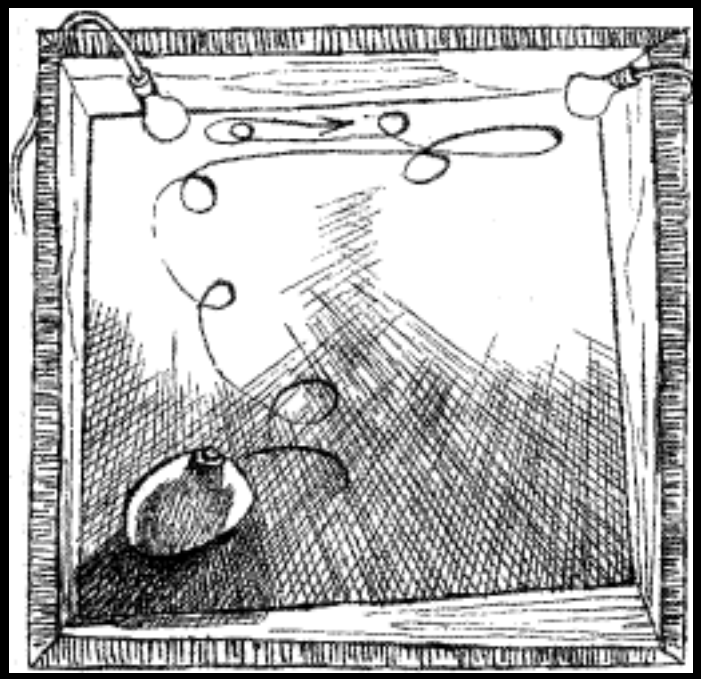


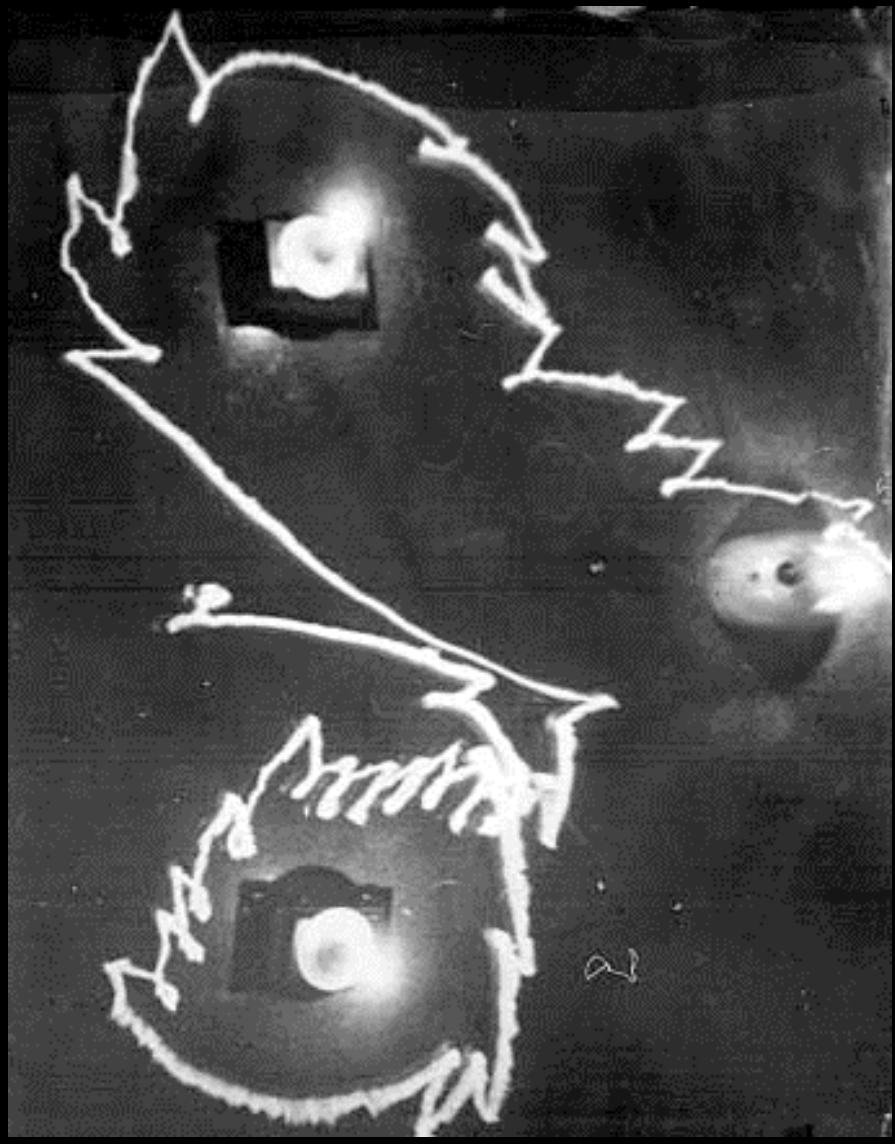
Attraction to Light



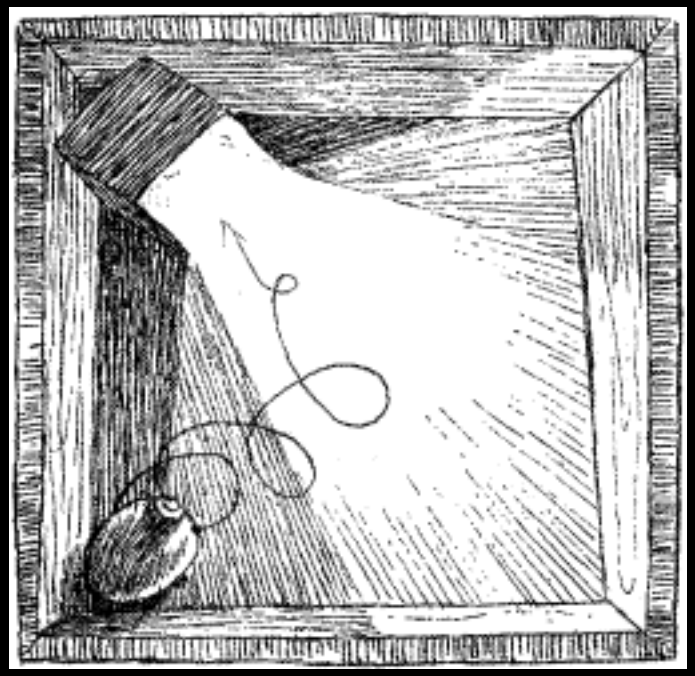


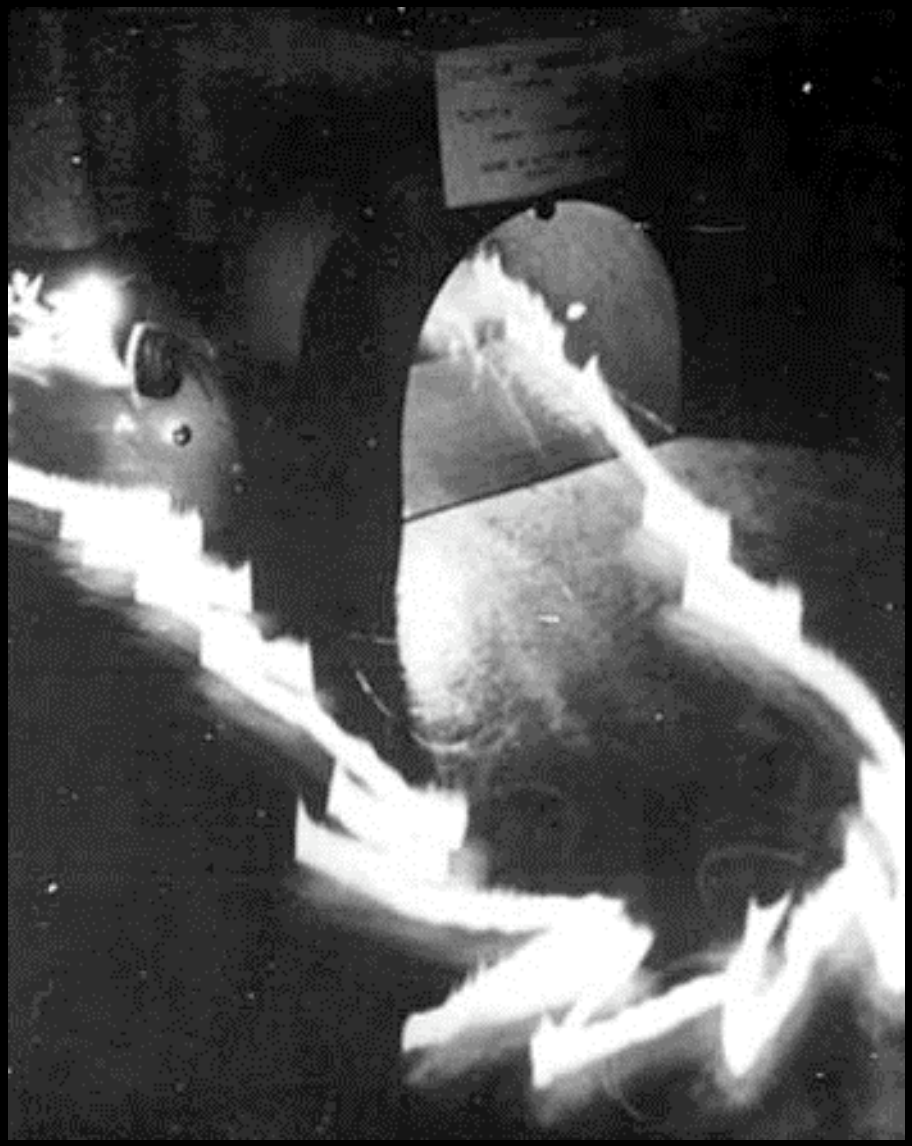
Multiple Lights



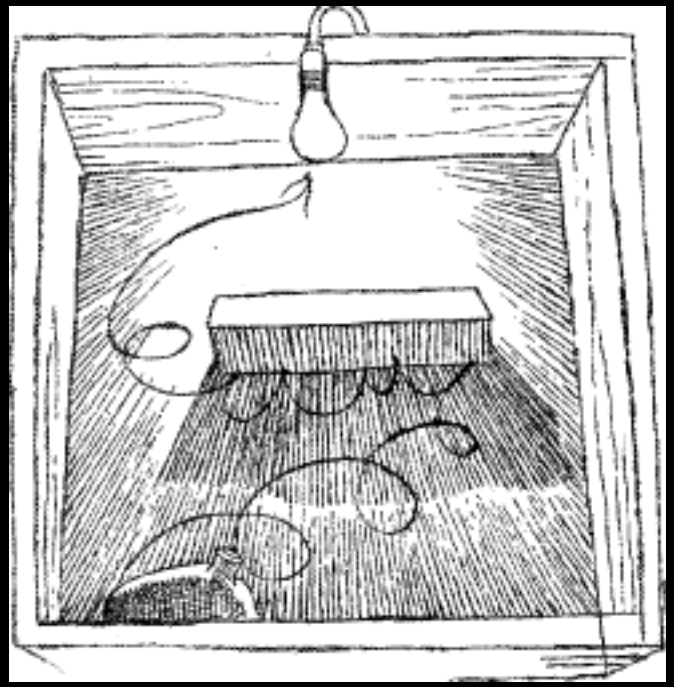


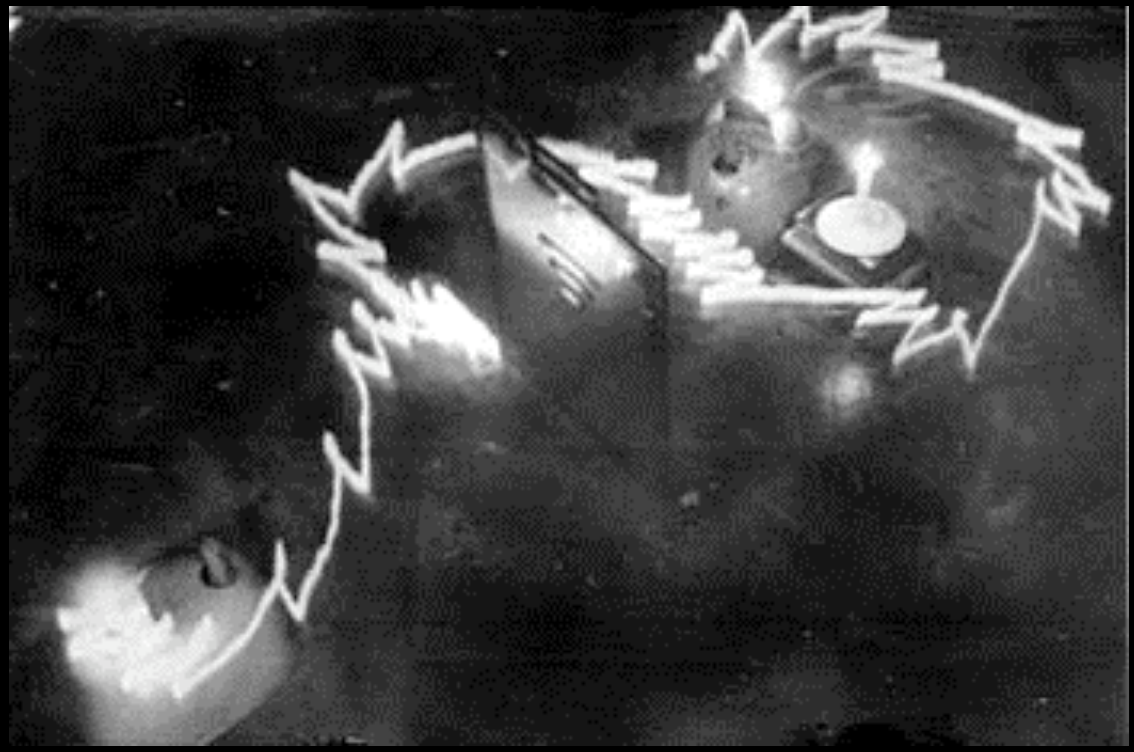
Charging Home



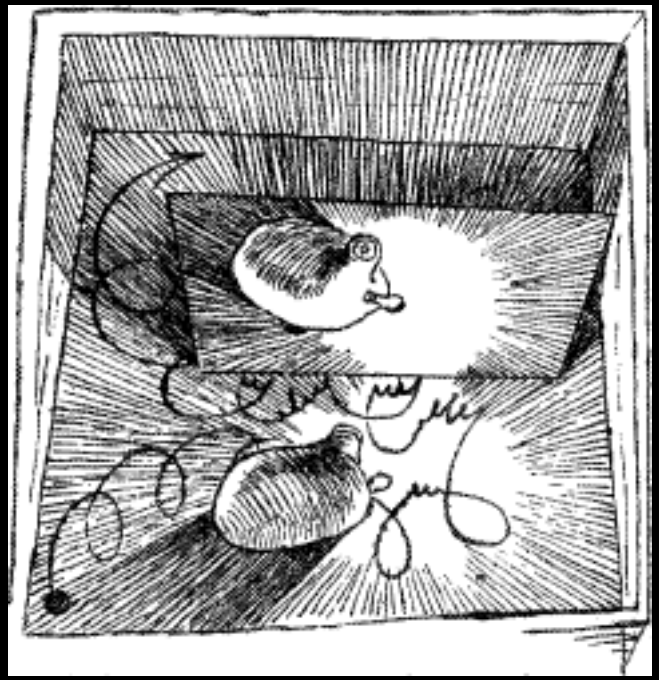


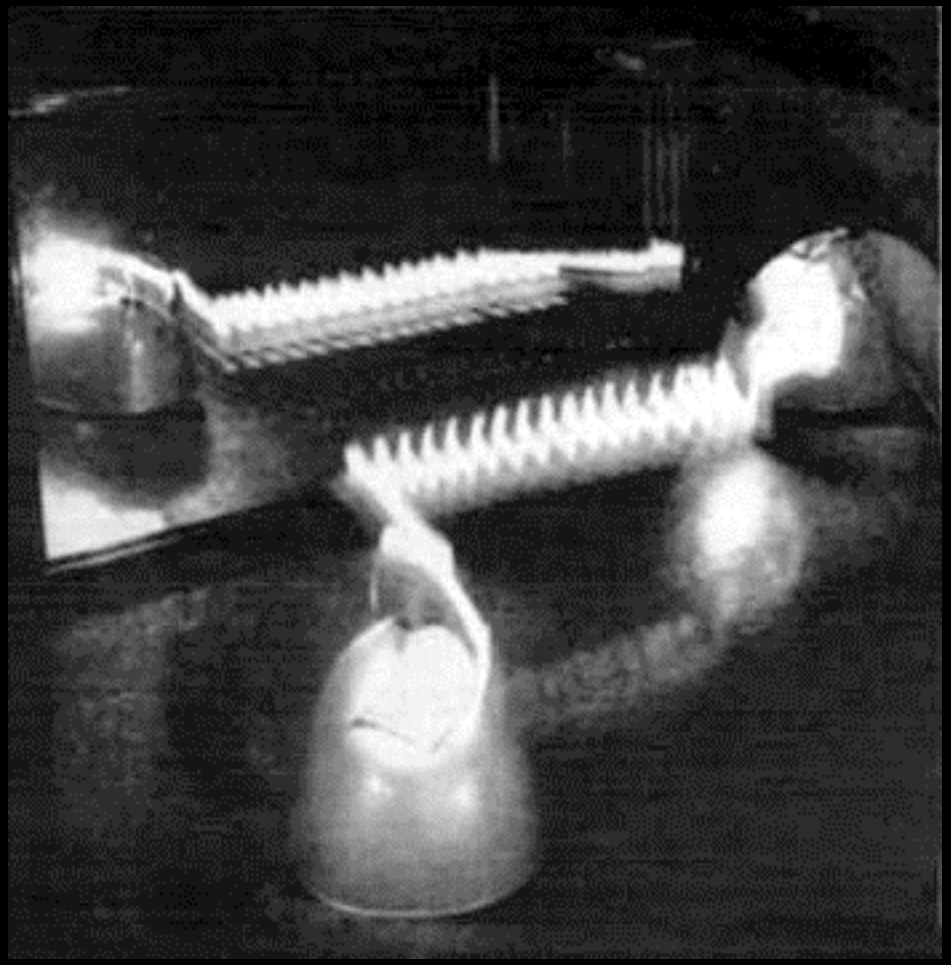
Obstacle Avoidance



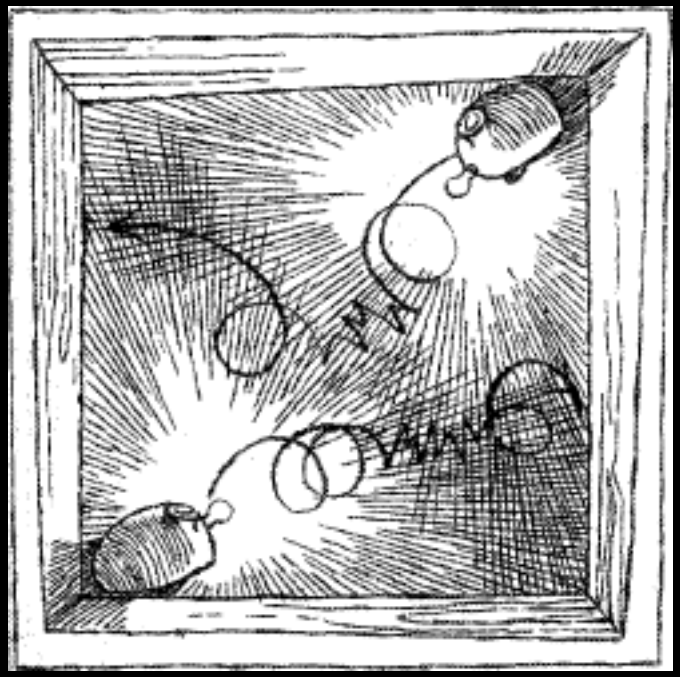


The Mirror Dance

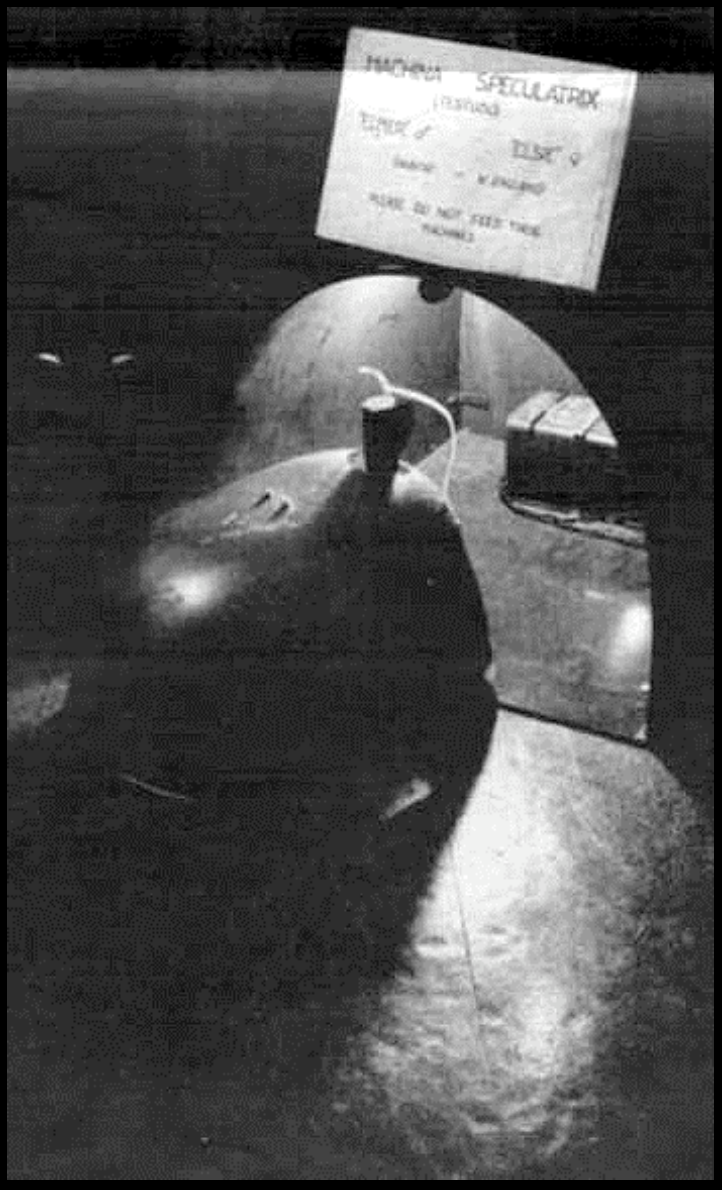




Elmer and Elsie Dance



Home Sweet Home



Non-Human Intelligence

- Animal cognition and intelligence is a tricky subject
- Even human cognition may not be anything more than adaptive, associative behavior
- Animal intelligence and cognition studies often place onerous and contentious constraints on their experiments and the interpretation of those experiments
  - "parsimonious" often means any explanation that avoids the phenomenon under investigation
- In particular, animal experimenters often fail to account for differences between lab and field, or design tasks bearing little or no relation to animals' evolved behavioral repertoire
- Some studies deny various aspects of animal intelligence (by those studies' definitions), others clearly confirm those and other aspects

Animal Intelligence

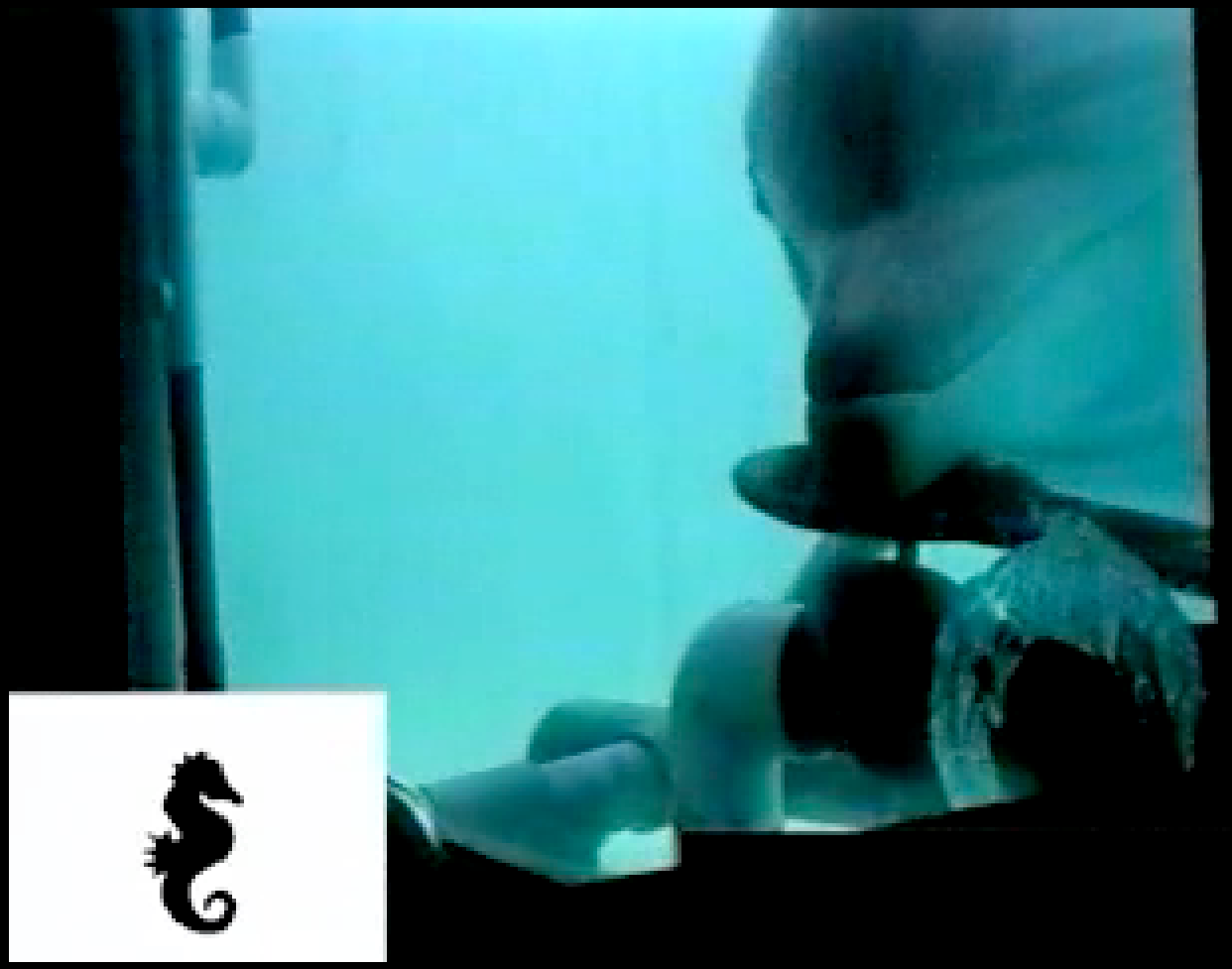
- Laboratory evidence exists for self-awareness in humans, chimpanzees, orangutans, and more recently elephants, based on the classic red-dot and mirror test (or white cross and very large mirror)
- Behaviorist accounts of associative learning in animals are extensive
- Mice with larger (genetically enhanced) brains solve more complicated behavioral tasks
- Scrub jays and ravens exhibit caching behaviors that take into account their own experience and the experience of conspecifics, and have demonstrated future planning
- Washoe the chimp and Koko the gorilla have learned American Sign Language, and invent new combinations of words for novel situations
- Kanzi the bonobo ape has learned hundreds of lexigrams and correlates them with an apparent understanding of several thousand English words

Animal Intelligence

- Anecdotal evidence abounds
  - Yet everyone is aware of the "Clever Hans" effect
  - And anthropomorphism is difficult to eliminate

Koko the Gorilla

Dolphins



Alex the Parrot

Betty the Crow

Insect Intelligence

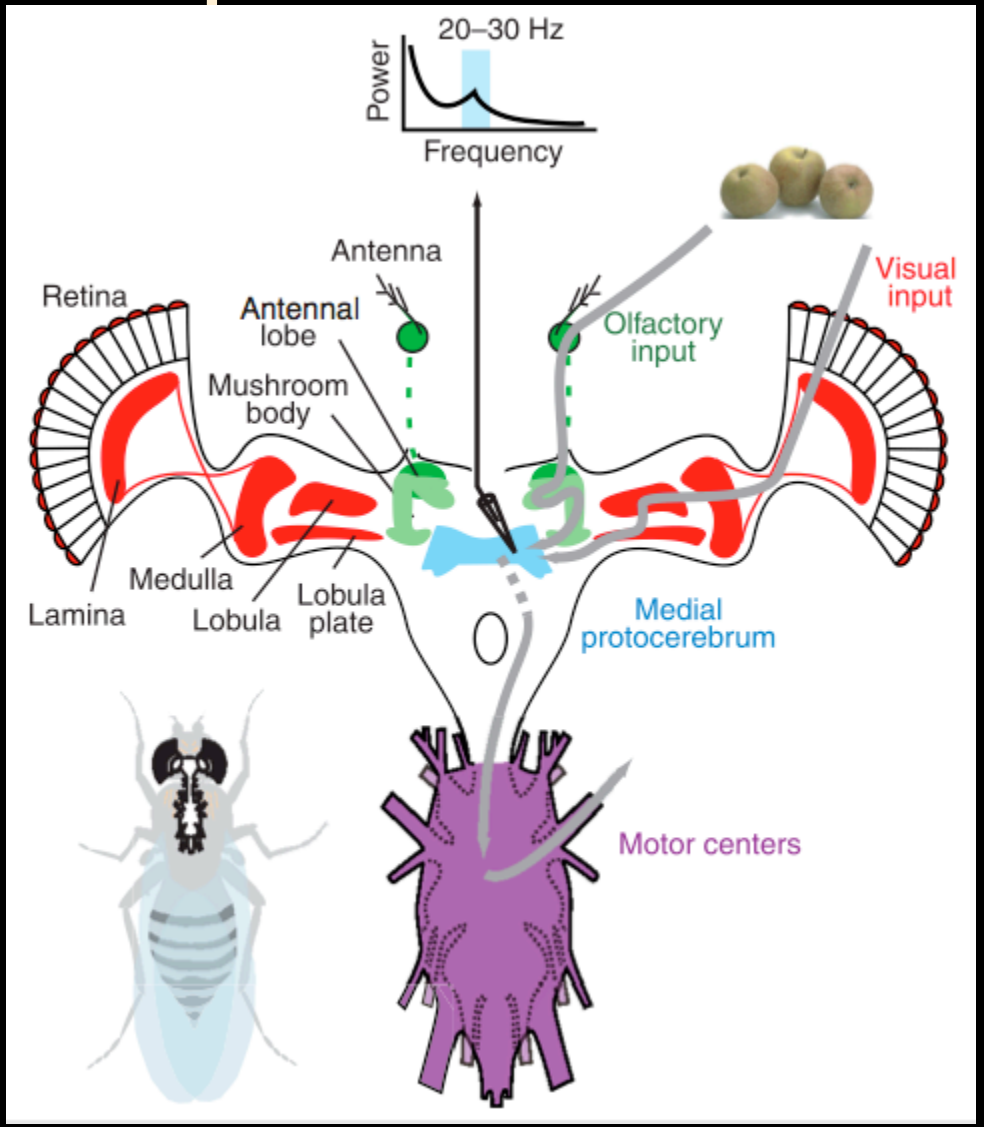
- Despite "swarm intelligence" of ants and "hive intelligence" of bees, awareness of bee dances, etc., insects have largely been regarded as too primitive to exhibit anything resembling individual intelligence
- However, recently, fruit flies (*Drosophila melanogaster*), have been shown to have a 20-30 Hz "salience" response akin to the 40-60 Hz attention response in humans
- And honeybees (*Apis mellifera*) have been shown to be capable of learning the abstract concepts of ***same*** and ***different***

Drosophila

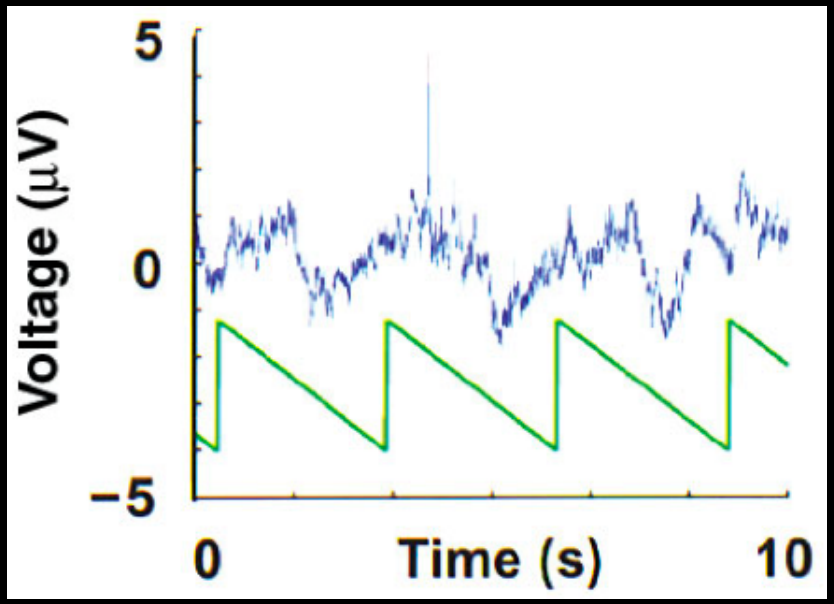
- Has a brain sized somewhere between a poppy seed and a sesame seed
- Contains about 250,000 neurons
- Appears to sleep nightly
- Learns by association
  - Apply peach odor and a shock, and it will avoid peaches
- Possesses short, medium, and long-term memories
- Reacts to general anesthetics with the same progression of brain function loss as in humans, at equivalent doses

Experimental Setup

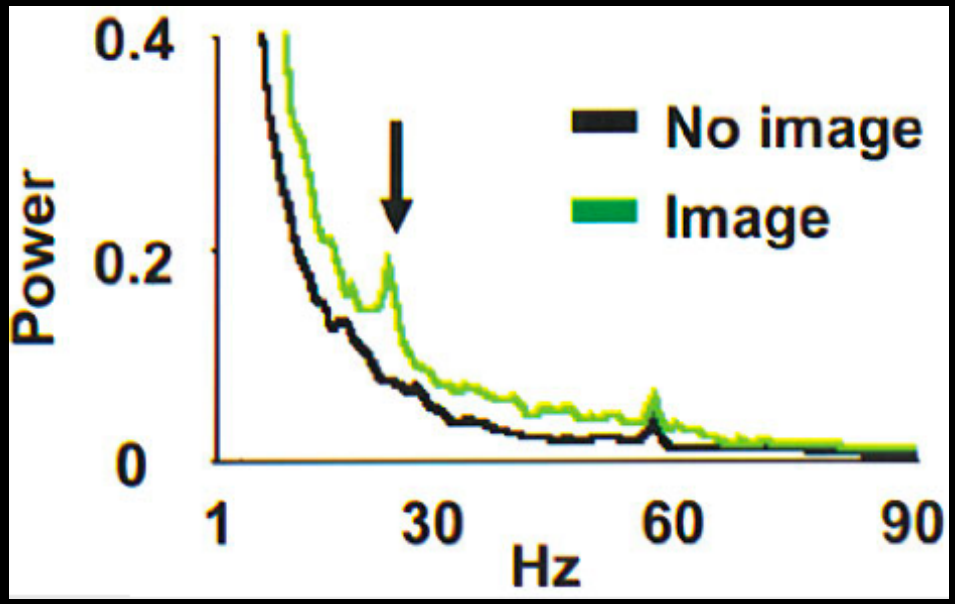
Mushroom bodies receive input from multiple senses and are involved in memory recall



Response to Visual Stimuli

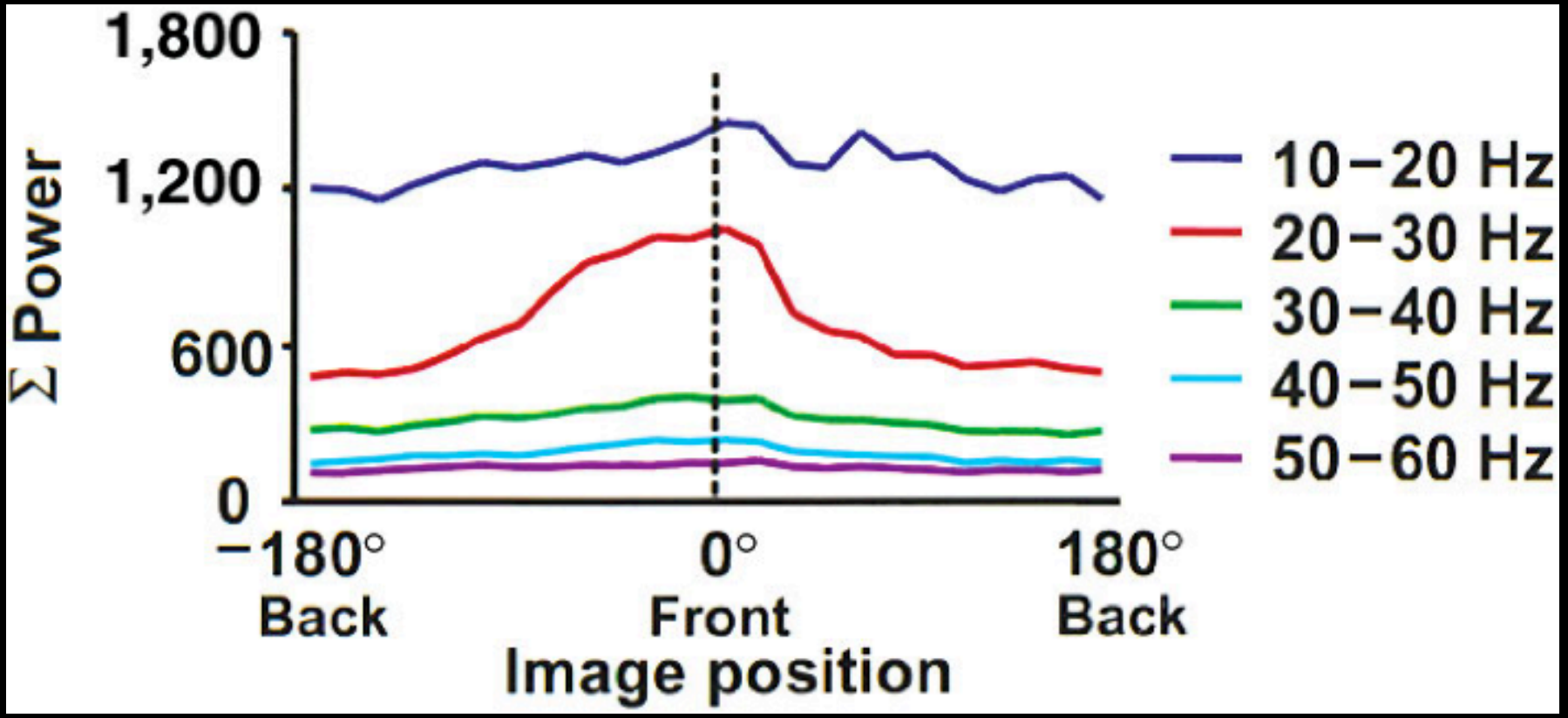


10 sec of raw brain trace (blue) with image rotation sequence (green)



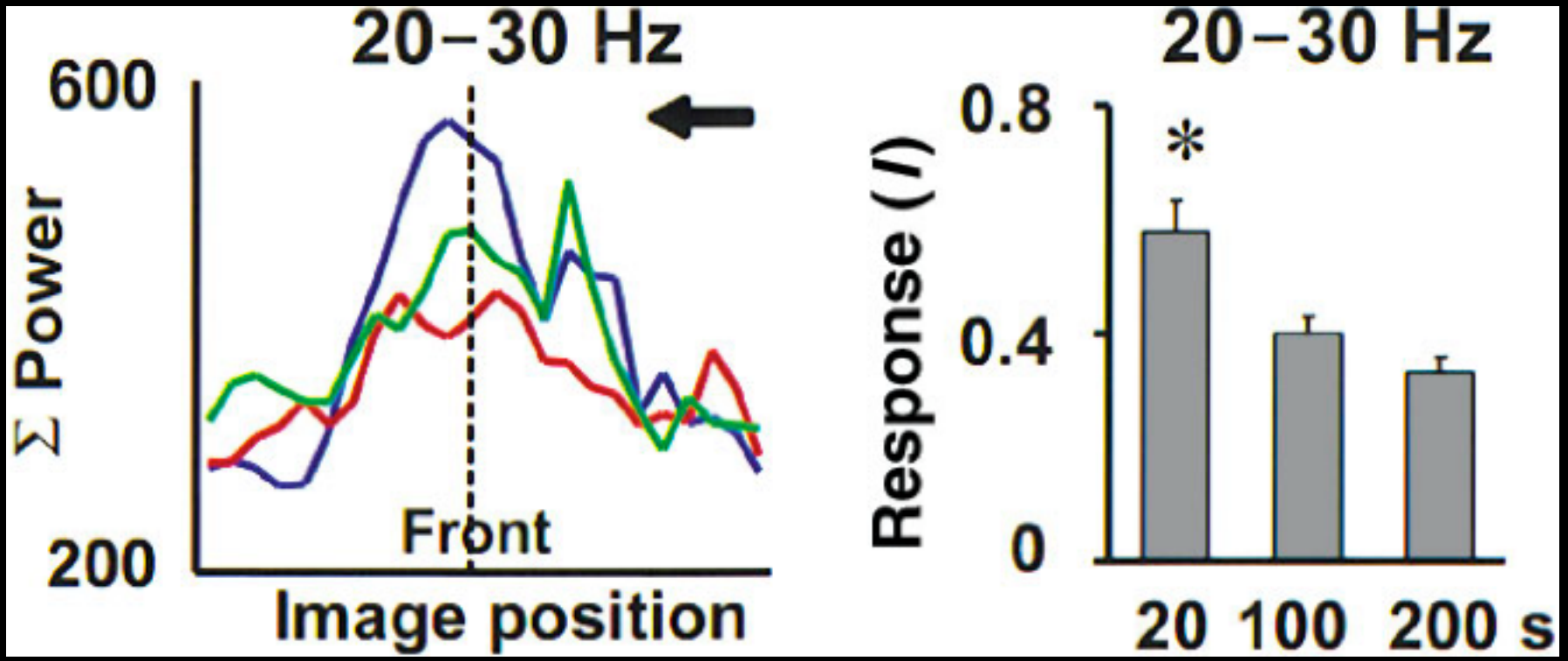
Sample power spectrum of brain frequencies (1-100Hz) for a lit but featureless rotating panorama (no image) compared to a spectrum for a lit rotating panorama featuring a 10°-wide unlit vertical bar (image)

Salience at 20-30 Hz



Summed power over 200 sec, in multiple frequency brackets, as a function of angular stimulus position (relative to the fly's oriented visual field)

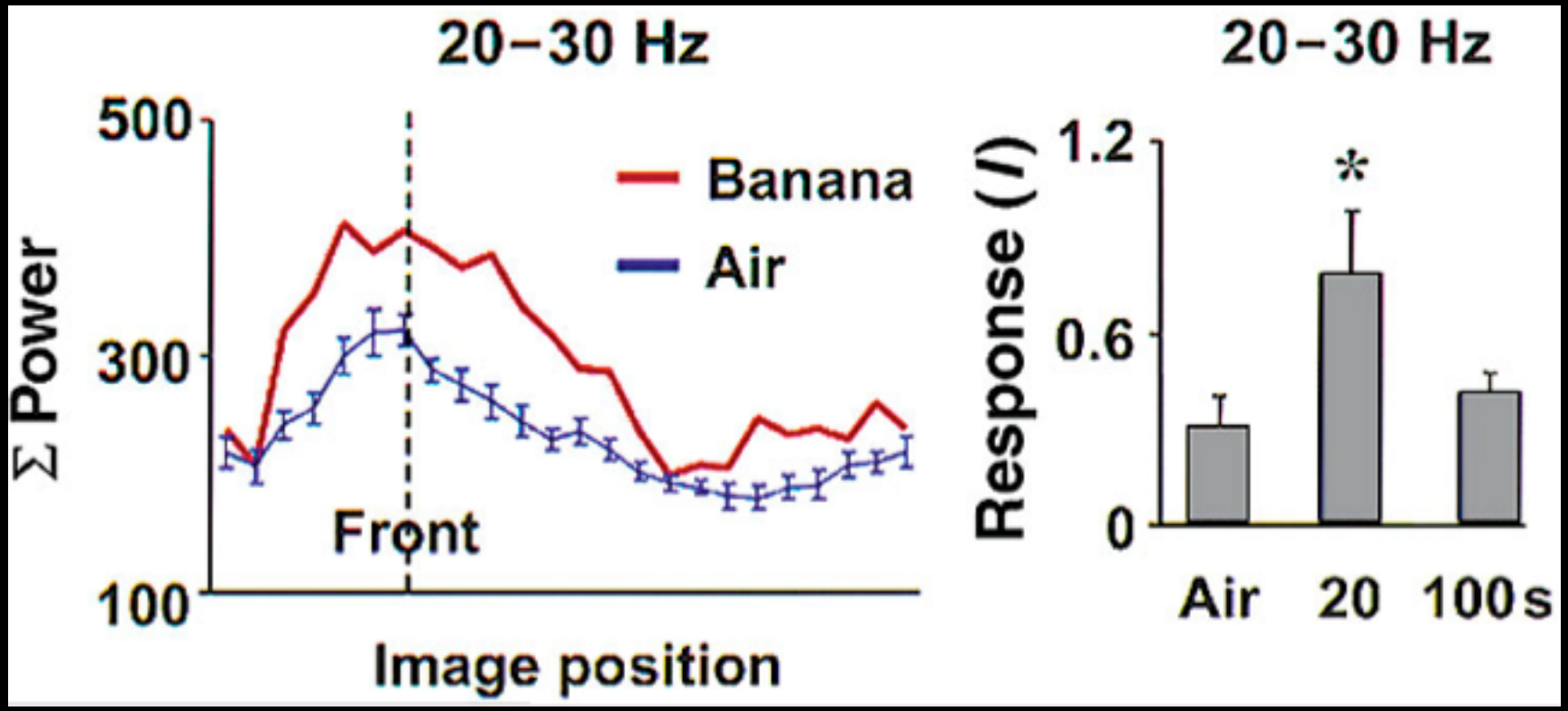
Habituation -> Reduced Salience



Successive 1 min summed power mappings, in the 20-30 Hz band

Successive total power measurements in the 20-30 Hz band

Odor and Increased Salience

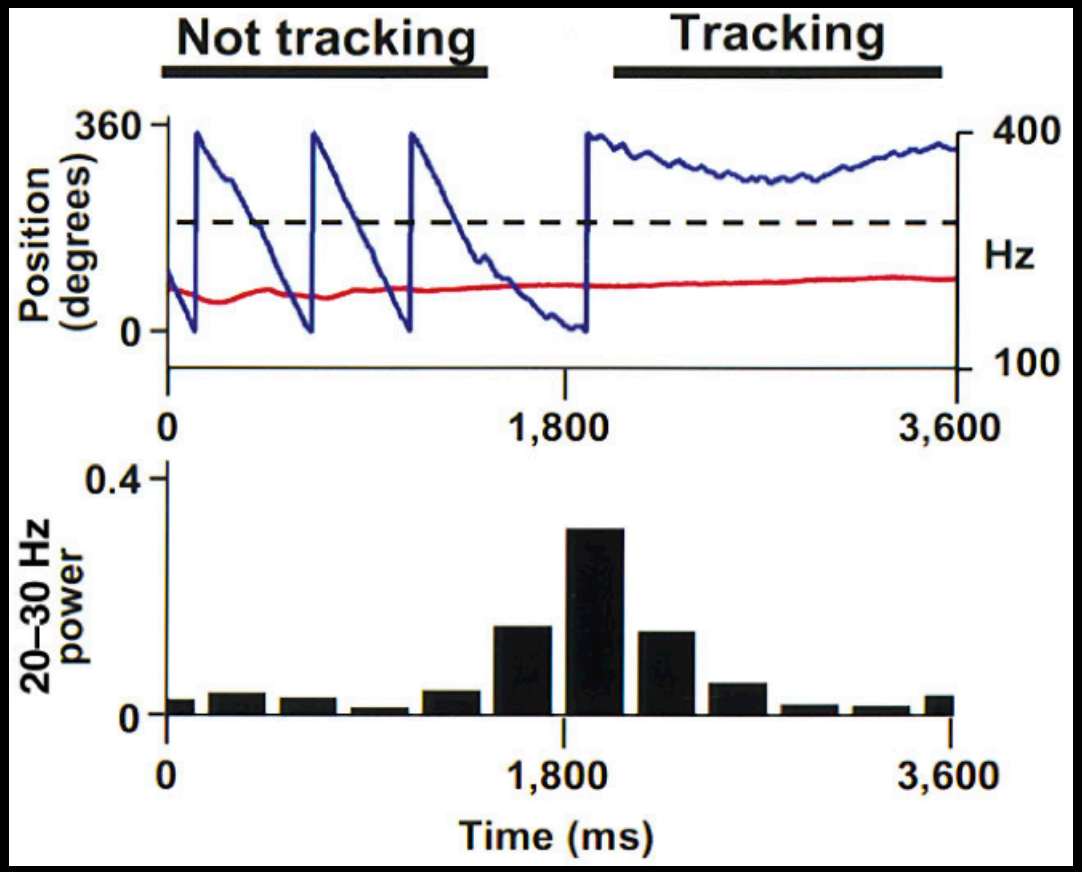


Baseline (blue) and Odor-synchronized (red) salience in first 20 second epoch of banana puffs

Decreased salience in later epochs of banana puffs

(Similar effect observed with heat instead of odor)

Salience Response and Tracking



Blue line indicates stimulus position, 360° per ratchet

Red line indicates (constant) wing beat rate

Image is in front of the fly at position of dashed line

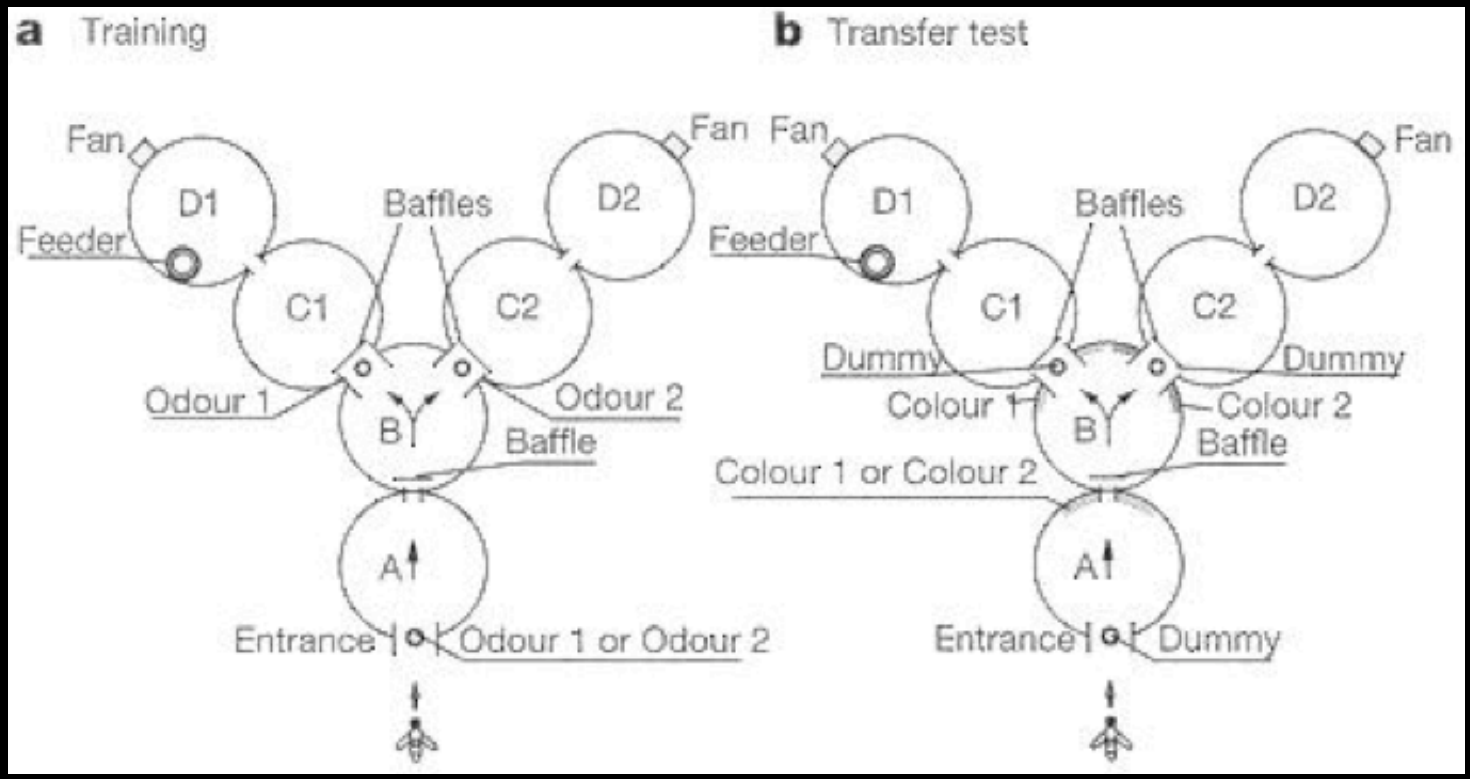
Transition period corresponding to onset of tracking behavior is represented by the gap between the thick black lines

Transition to tracking behavior coincides with strong salience response

Honeybee

- Brainiest of insects
- Has about 1 million neurons
- Learn by association
- Interpolate visual information, exhibit associative recall, categorize visual information, and learn contextual information
- Have now been demonstrated to learn abstract relations between stimuli (***same*** and ***different***)

Experimental Setup



Y-maze used for training and testing "delayed matching to sample" and "delayed matching to non-sample" performance

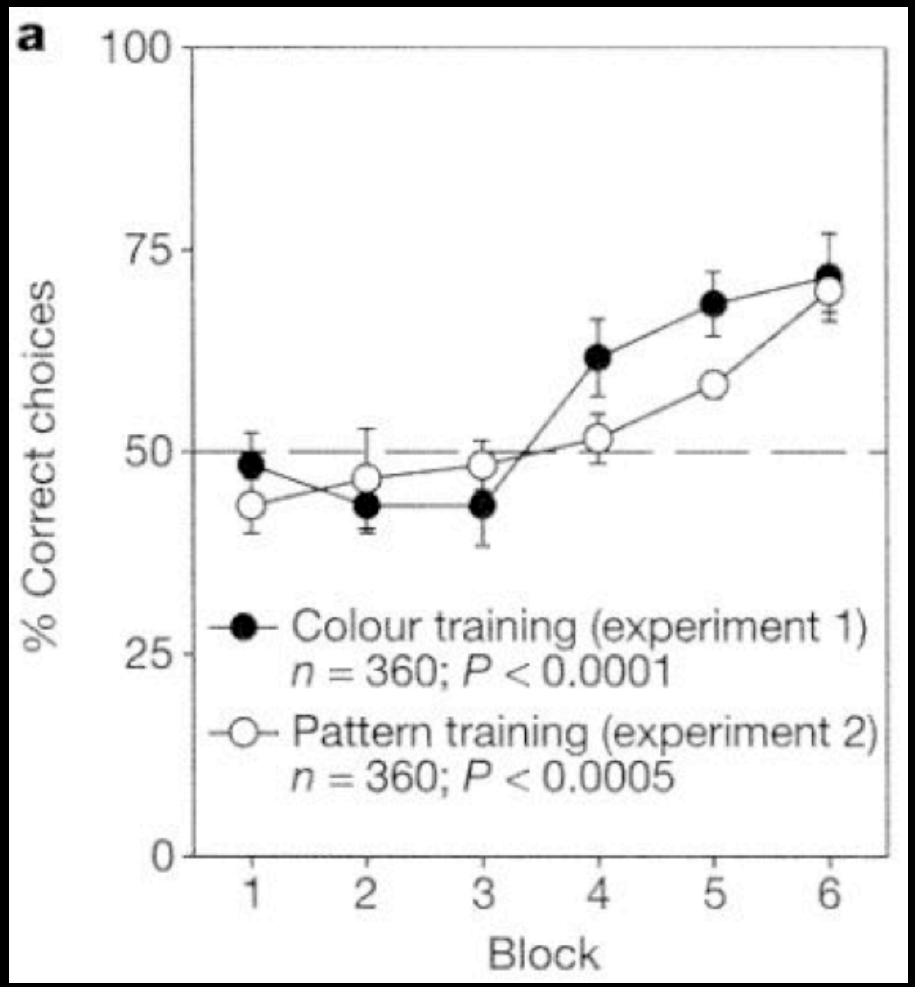
Experimental Procedure

- At the maze entrance, the bee encounters the *sample* stimulus
  - One of two different stimuli, A or B, are alternated in a pseudo-random sequence
- Next comes a decision chamber, where the bee can choose one of two arms
  - Each arm carries either A or B as a *secondary* stimulus
- The bee is rewarded with sucrose solution only if it chooses the correct secondary stimulus (matching or non-matching, depending on the current test procedure)

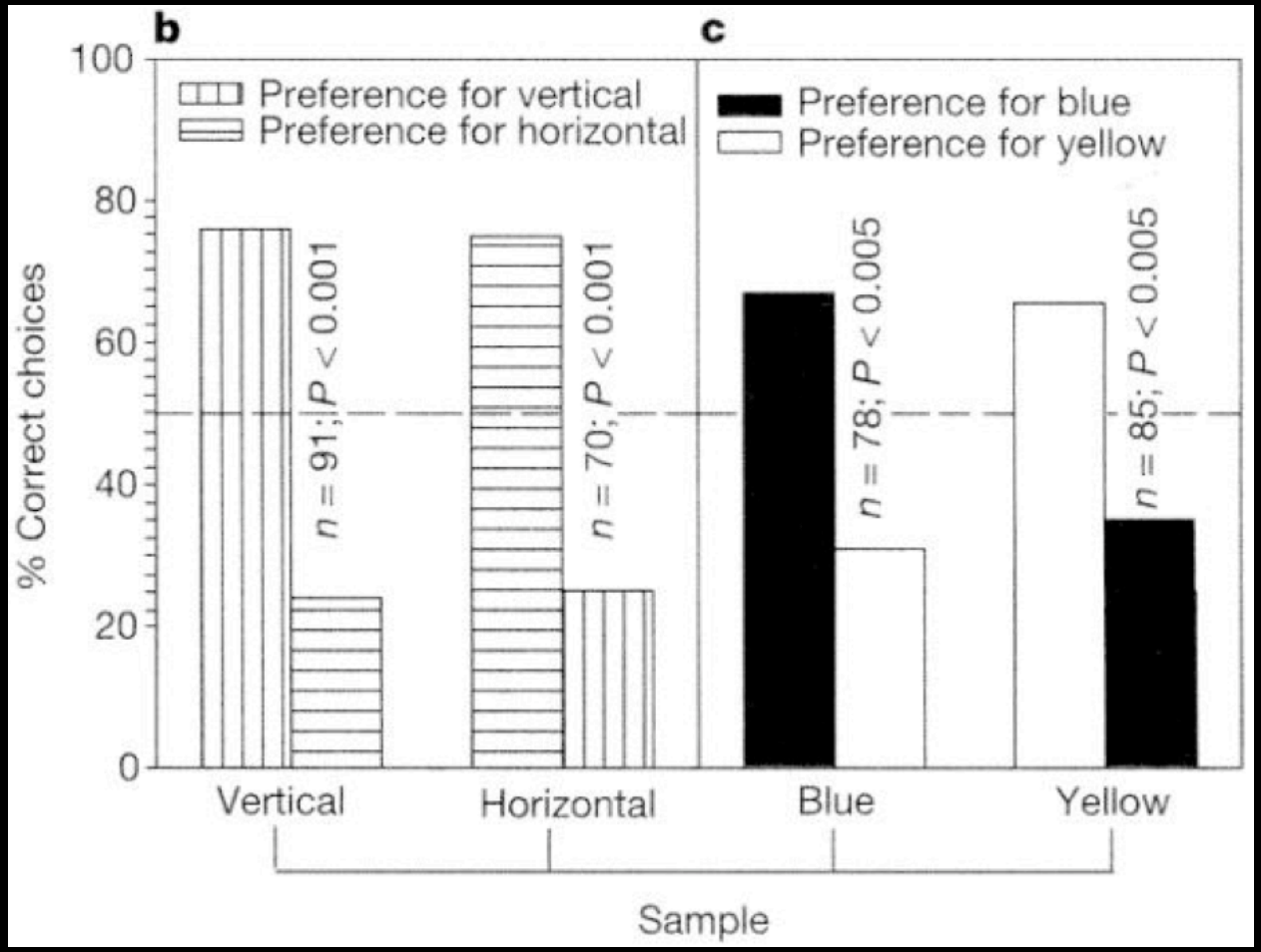
Stimuli

- In some tests, both training and test stimuli were visual, with a transfer of learning tested by substituting different visual stimuli
  - Horizontal and vertical gratings
  - Blue and yellow colors
  - Radial and circular gratings
- In some tests, either the training or test stimuli were olfactory, demonstrating cross-modality transfer
  - Lemon and mango odors

Learning Match-to-Sample (Same)

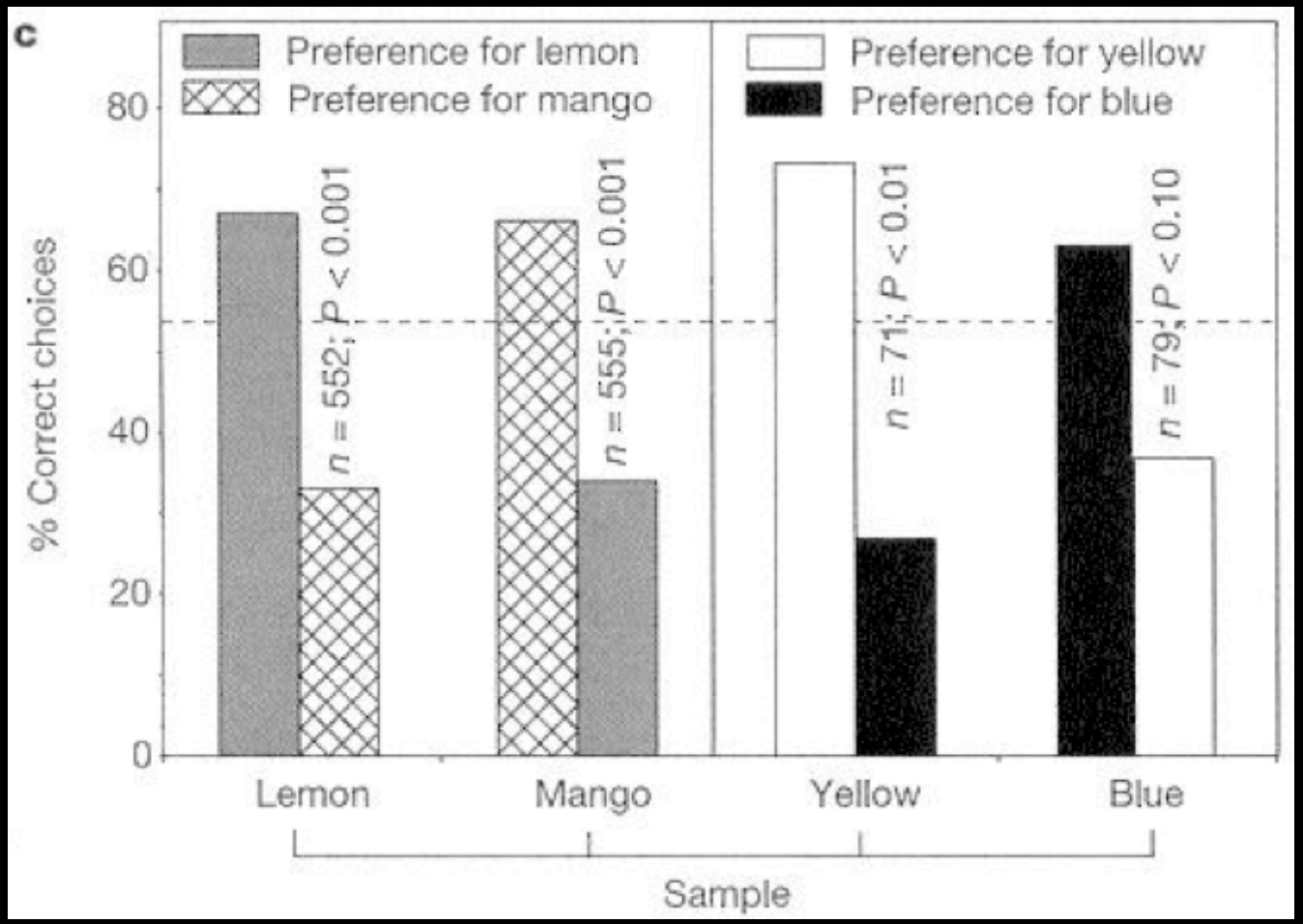


Transfer of Learning (Same)



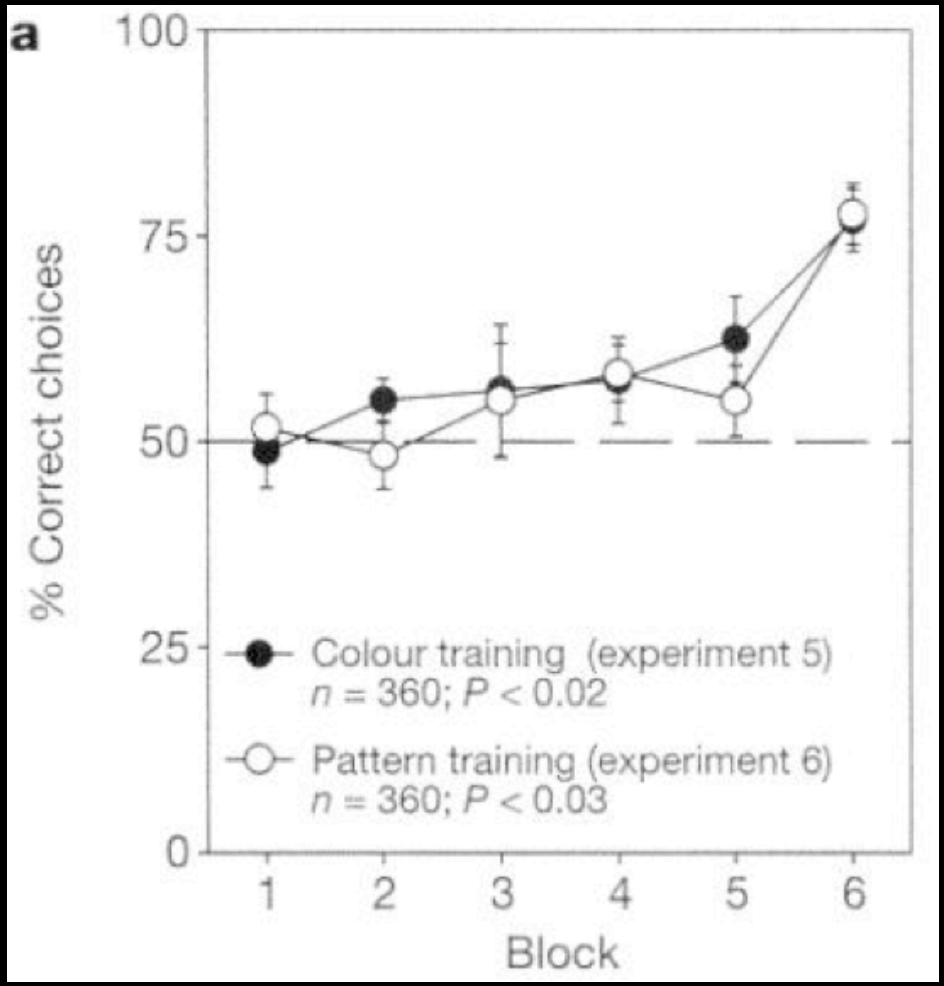
Bees initially trained to select same linear grating, then tested on linear gratings and colors

Cross-Modality Transfer (Same)

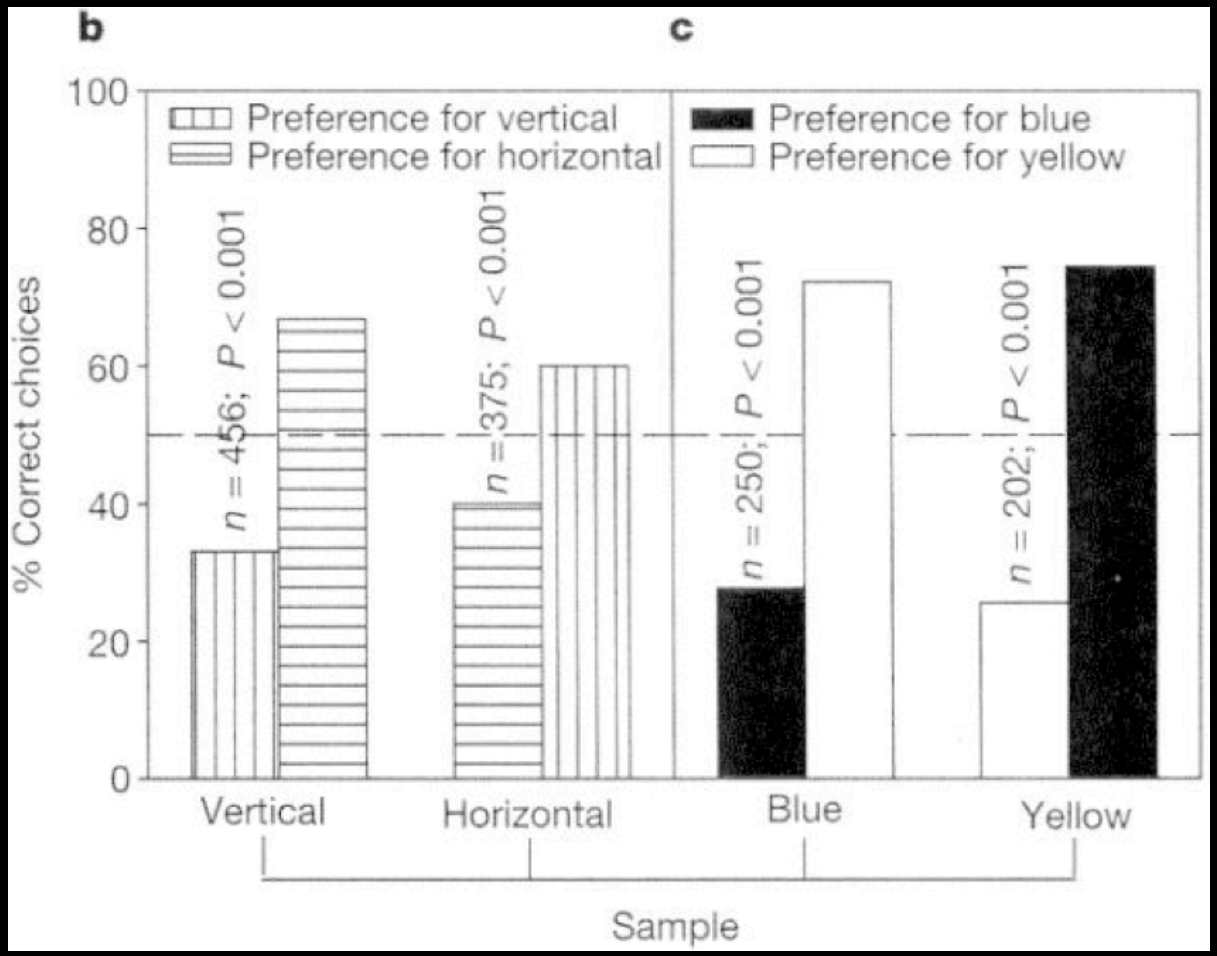


Bees initially trained to select same odor, then tested on odors and colors

Learning Non-Match-to-Sample (Different)



Transfer of Learning (Different)



Bees initially trained to select different linear grating, then tested on linear gratings and colors

Abstract Concepts

- The ability to learn ***same*** versus ***different*** has been demonstrated widely in vertebrates
  - Rhesus monkeys, cats, raccoons, chimpanzees, dolphins, pigeons, corvids (crows), and others
- These results demonstrate that the ability to make this conceptualization exists in at least one invertebrate

Kinds of Minds

- In Daniel Dennett's *Kinds of Minds*, he defines a "Tower of Generate-and-Test", that discriminates amongst a number of different levels of intelligence
  - He uses "Generate-and-Test" because his thesis is that the ability to "produce" the future is the fitness function that serves as the driving evolutionary force

Ground Floor: Darwinian Creatures

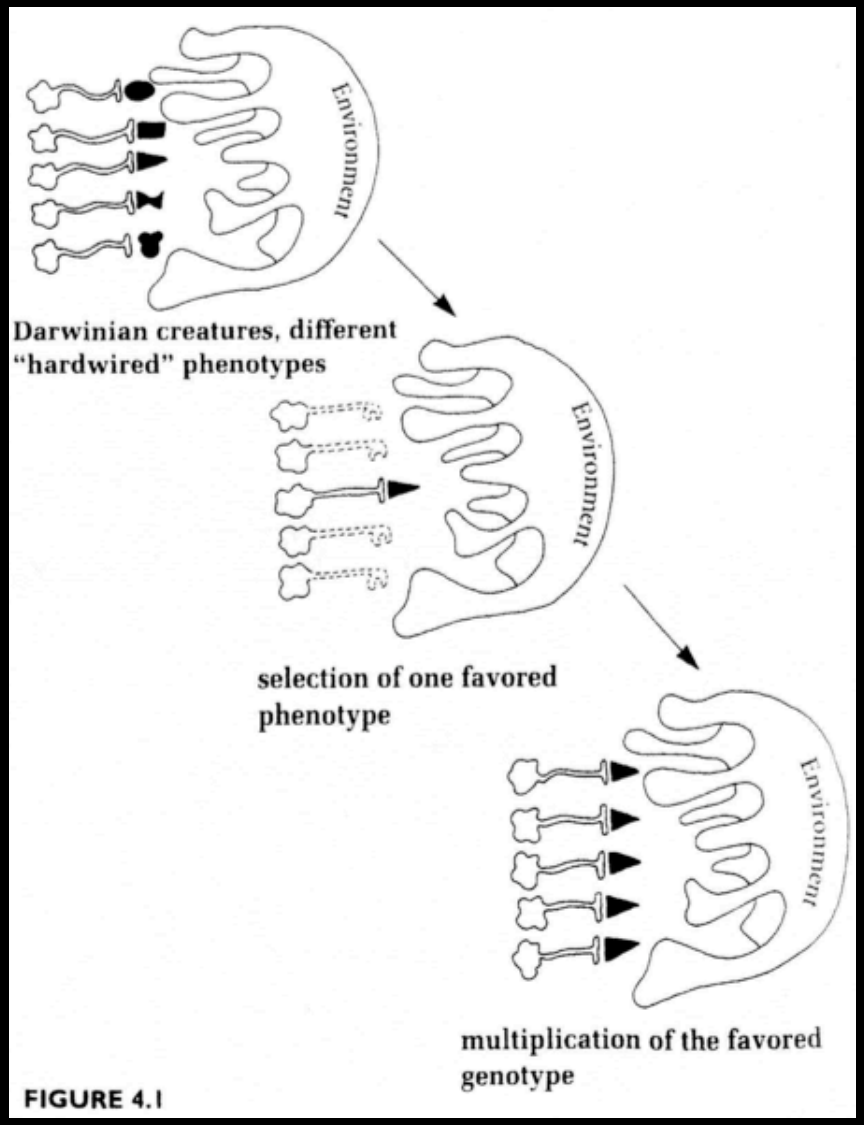
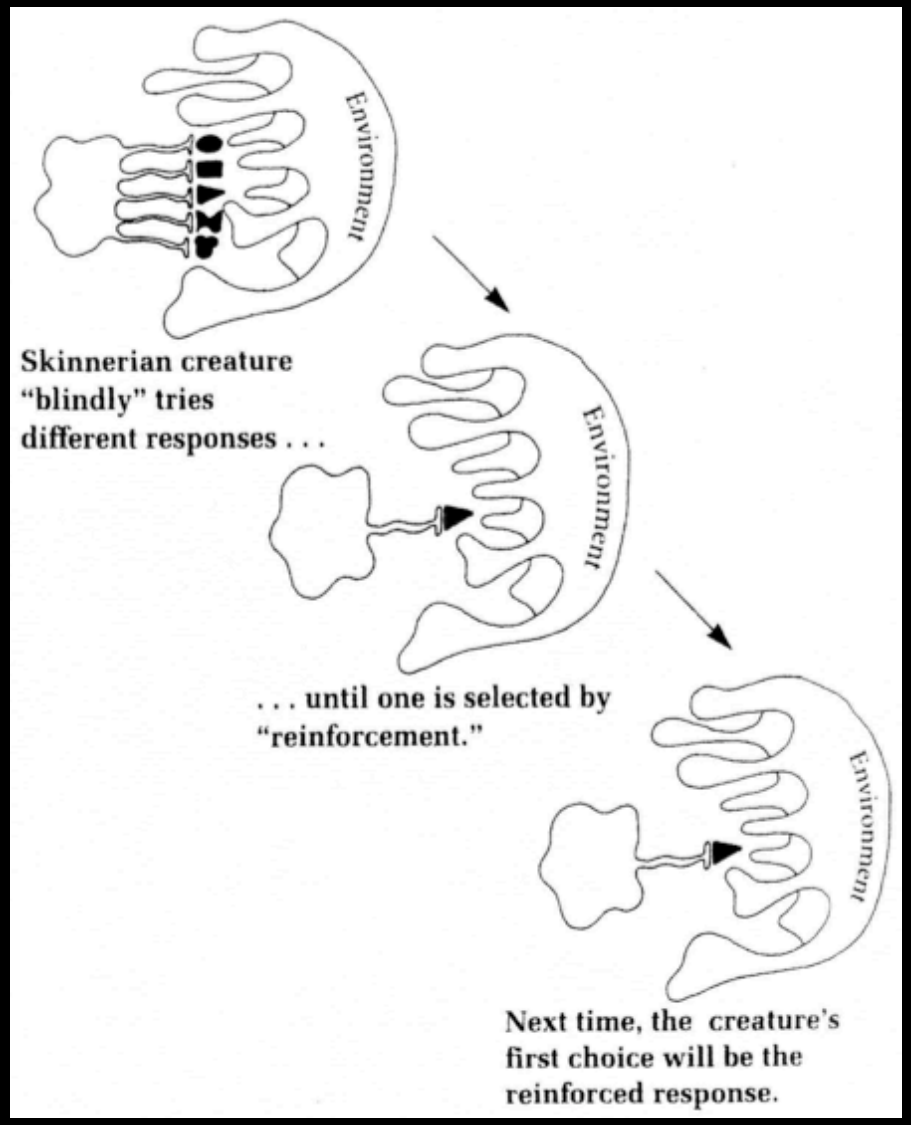


FIGURE 4.1

Evolution initially produced organisms well suited to their individual niches

Eventually evolution produced designs with the property of *phenotypic plasticity…*

Second Floor: Skinnerian Creatures



Associationism, Behaviorism, and Connectionism sample the space of possible behaviors more rapidly and more efficiently

But a better system involves prediction and *preselection*…

Third Floor: Popperian Creatures

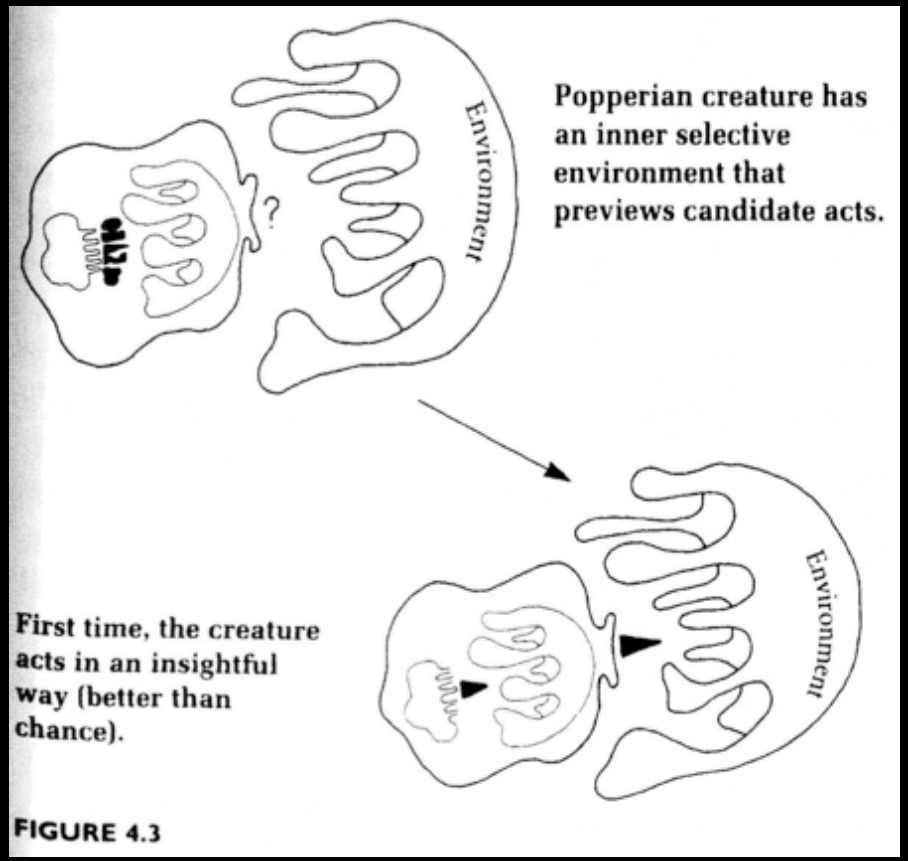
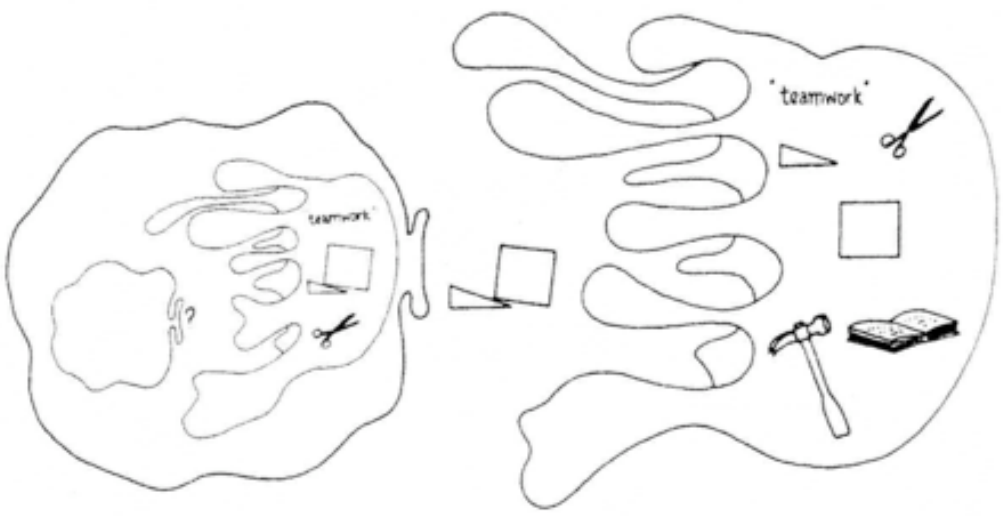


FIGURE 4.3

Preselection, based on the accumulation of accurate information about the world, "permits our hypotheses to die in our stead" (Popper)

But reasoning about the world may include reasoning about our own artifacts…

Fourth Floor: Gregorian Creatures



Gregorian creature imports mind tools from the (cultural) environment; these improve both the generators and the testers.

FIGURE 4.4

Informed by the *designed* elements of the environment, culture and tools enable both creator and consumer

(*Mamataxis* leads to categorization leads to symbolic thought)

Credits

- Images of Ross Ashby's Homeostat and early Cyberneticians from http://www.culture.com.au/brain_proj/
- Image of Grey Walter kneeling with early turtle from http://en.wikipedia.org/wiki/Grey_Walter
- Image of Grey Walter working on Elsie from http://www.frc.ri.cmu.edu/~hpm/book98/fig.ch2/p018.html
- Images of Elsie, *Testudo bristol*, and *Testudo legos* from http://www.plazaearth.com/usr/gasperi/walter.htm
- Images of Elmer and Elsie in action from Grey Walter online archive http://www.ias.uwe.ac.uk/Robots/gwonline/gwonline.html
- Other images from the reading assignments plus extra paper: van Swinderen, B. and Greenspan, R.J. (2003) "Salience Modulates 20-30 Hz Brain Activity in Drosophila." Nature Neuroscience 6: 579-586
- Dennett's "Tower of Generate-and-Test" images from his book, *Kinds of Minds*

References

- Ross Ashby Homeostat Java simulator http://www.hrat.btinternet.co.uk/Homeostat.html
- Ross Ashby aphorisms http://www.cybsoc.org/ross.htm
- Grey Walter online archive http://www.ias.uwe.ac.uk/Robots/gwonline/gwonline.html
- Grey Walter turtles in Legos http://www.plazaearth.com/usr/gasperi/walter.htm
- Grey Walter turtle Java simulator http://zoo.cs.yale.edu/classes/cs490/01-02b/stuart.james.jws27/
- Some Grey Walter images from Hans Moravec's site http://www.frc.ri.cmu.edu/~hpm/
- About *Drosophila melanogaster* http://www.ceolas.org/fly/intro.html
- Koko and the Gorilla Foundation http://www.koko.org/