Lecture 6. Perceptual and Motor Schemas

Reading Assignments:

TMB2:*

Sections 2.1, 2.2, 5.1 and 5.2.

HBTNN:

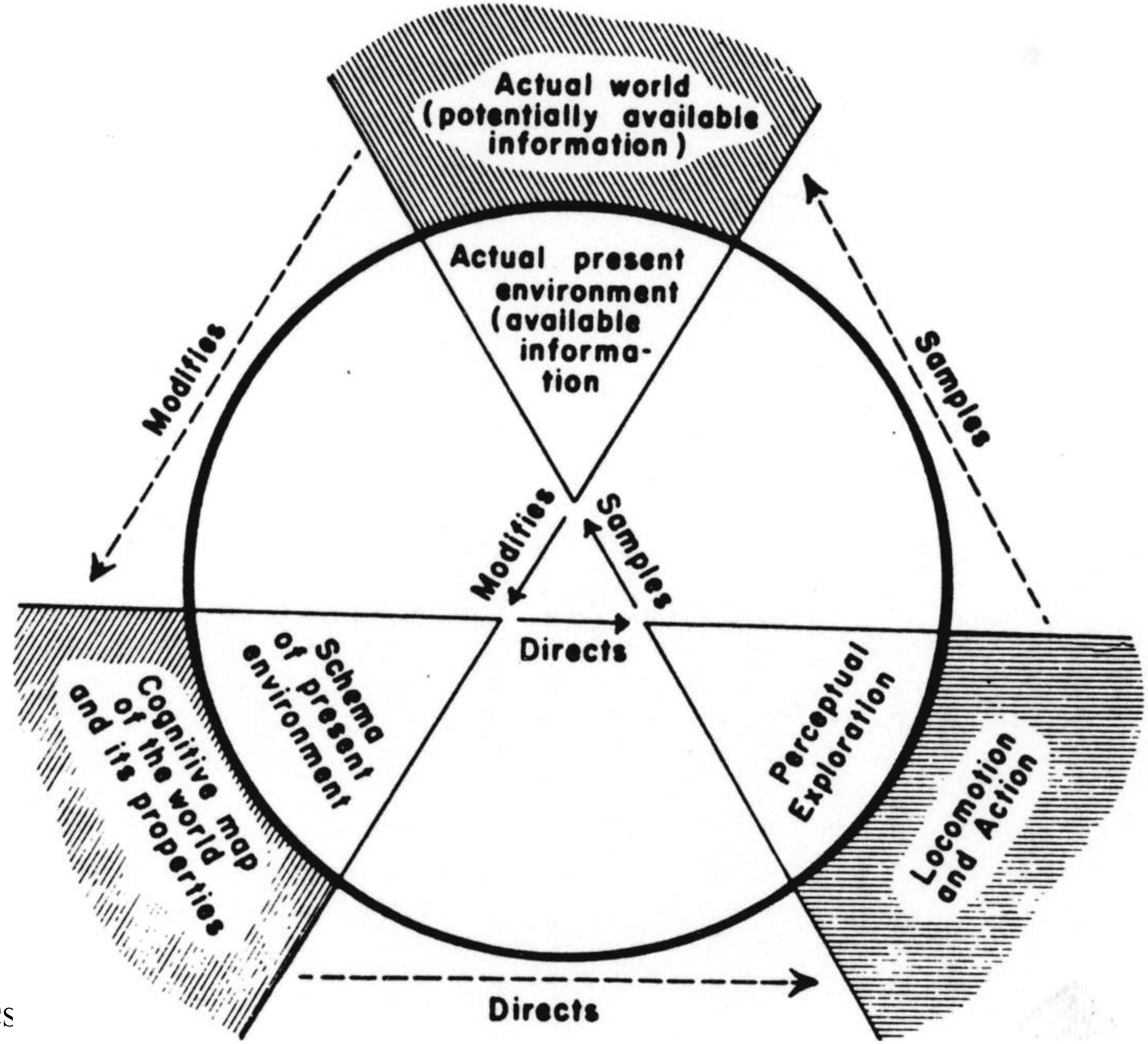
Schema Theory (Arbib) [Also required]

Distributed Artificial Intelligence (Durfee)

* Unless indicated otherwise, the TMB2 material is the required reading, and the other readings supplementary.

Action-Oriented Perception: The Action-Perception Cycle

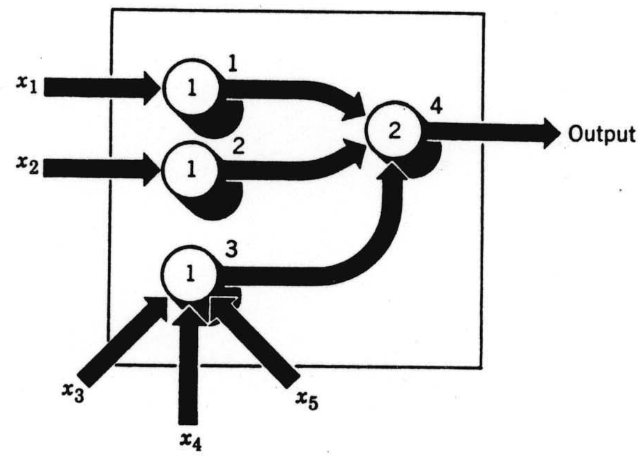
Neisser
1976

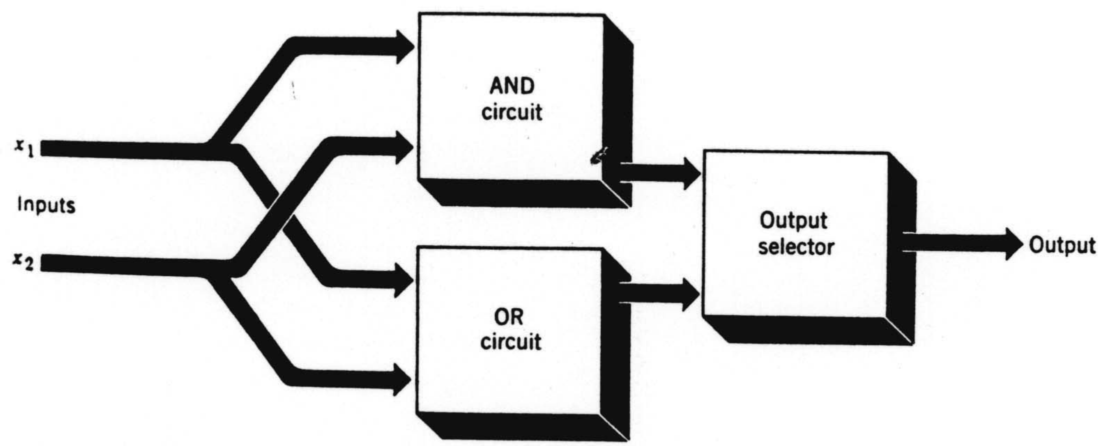


Structure Versus Function

Two systems with the same function but with different structure:

Their external behavior is identical: they can only be told apart by "lesions" or by monitoring internal variables





What are Schemas?

Schemas are

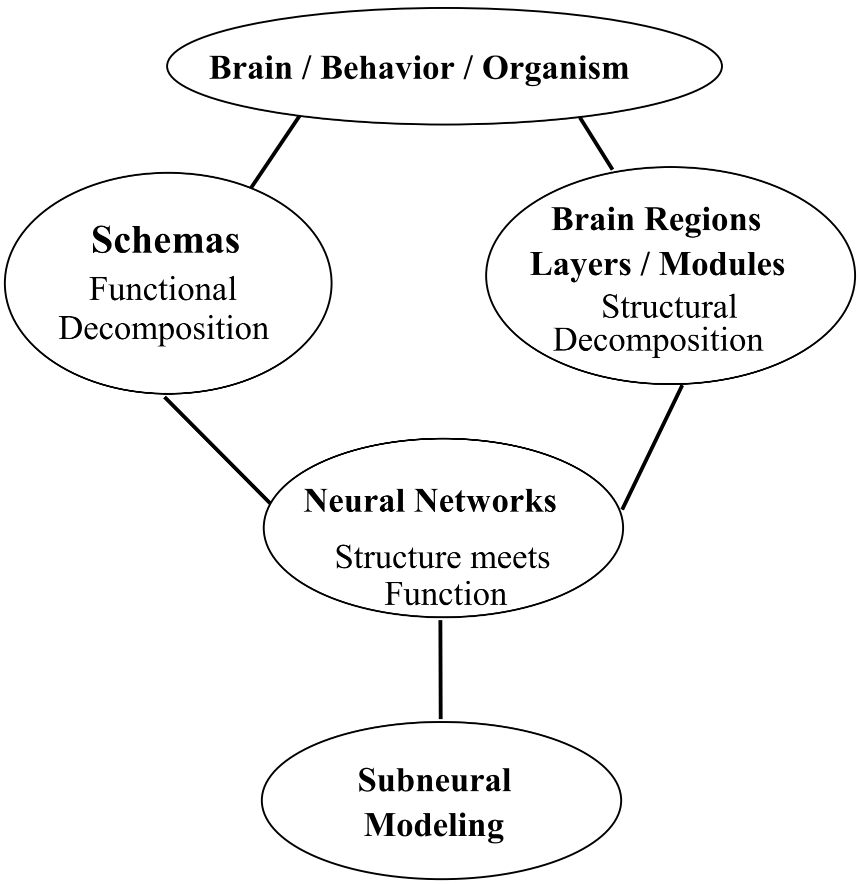
- functional units (intermediate between overall behavior and neural function) for analysis of cooperative competition in the brain

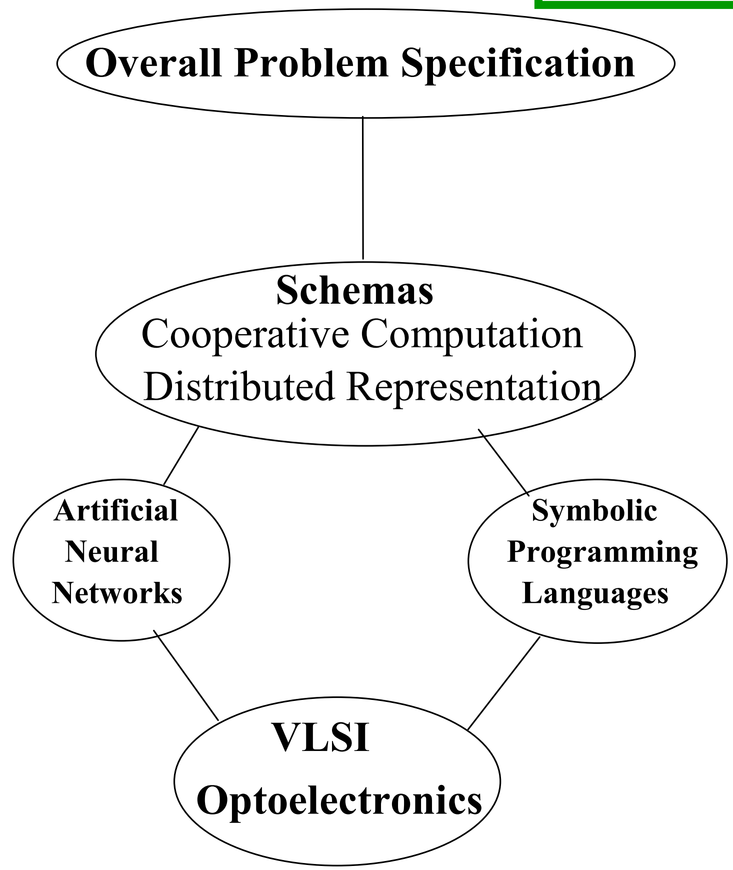
- program units especially suited for a system which has continuing perception of, and interaction with, its environment

- a programming language for new systems in computer vision, robotics and expert systems

- a bridging language between Distributed AI and neural networks for specific subsystems

Hierarchies in Brain Theory and Distributed AI





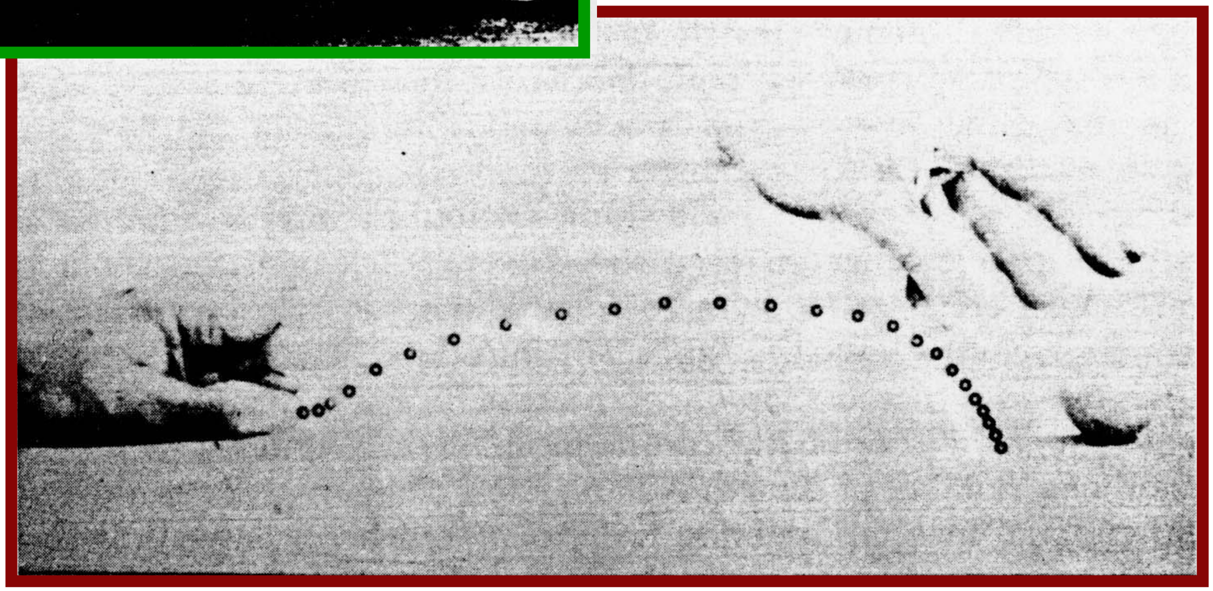
Perceptual And Motor Schemas

A *perceptual schema* embodies the process whereby the system determines whether a given domain of interaction is present in the environment.

A *schema assemblage* combines an estimate of environmental state with a representation of goals and needs

The internal state is also updated by knowledge of the state of execution of current plans made up of *motor schemas*
which are akin to control systems but distinguished by the fact that they can be combined to form *coordinated control programs*

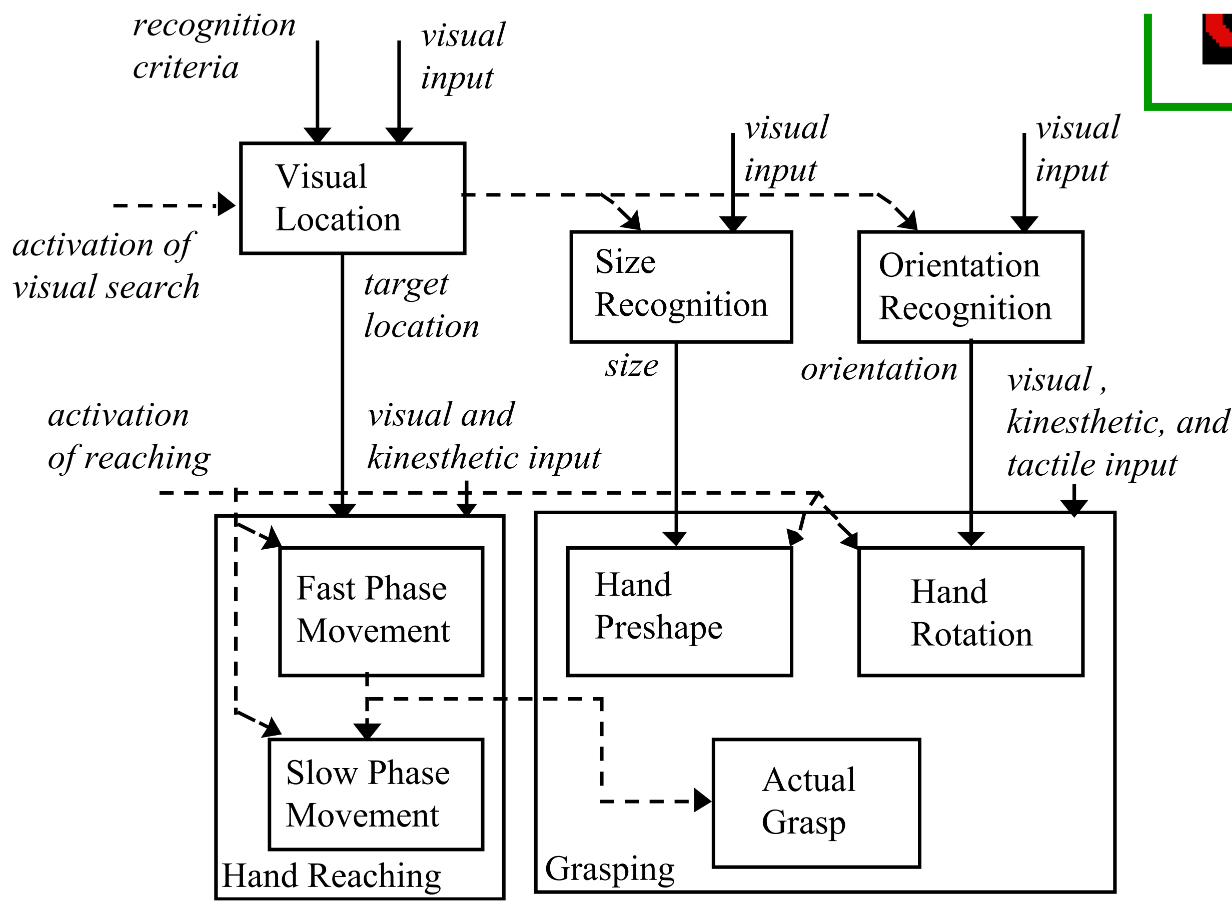
Preshaping While Reaching to Grasp



Hypothetical coordinated control program for reaching and grasping

Perceptual Schemas

Motor Schemas



Dashed lines — activation signals; solid lines — transfer of data.

(Adapted from Arbib 1981)

Conventional Computers vs. Schema-Based Computation

Conventional computers store data passively, to be retrieved and processed by some central processing unit.

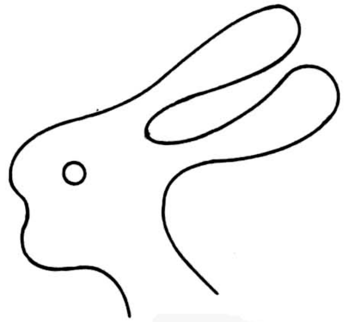
Schema theory explains behavior in terms of the interaction of many concurrent activities:

Cooperative computation: "computation based on the competition and cooperation of concurrently active agents"

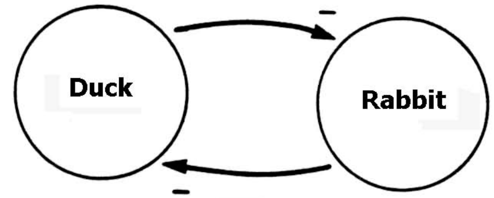
Cooperation: yields a pattern of "strengthened alliances" between mutually consistent schema instances

Competition: instances which do not meet the evolving (data-guided) consensus lose activity, and thus are not part of this solution (though their continuing subthreshold activity may well affect later behavior).

The Famous Duck-Rabbit

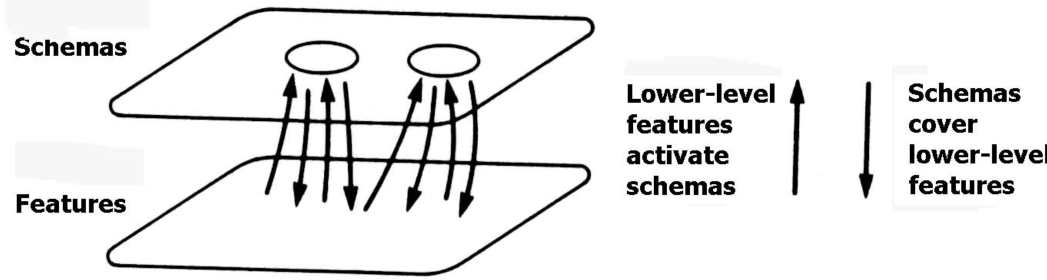


(a)



(b)

From Schemas to Schema Assemblages



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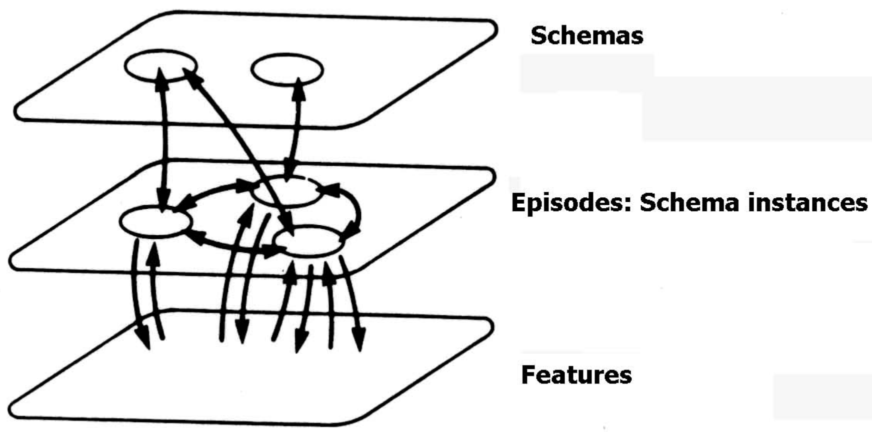
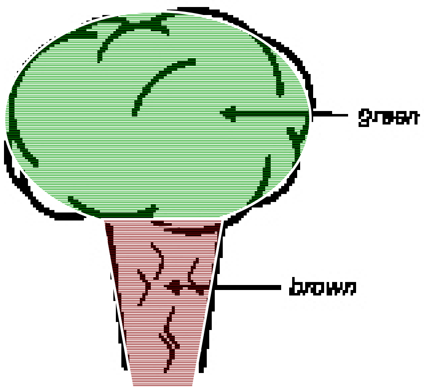


(d)

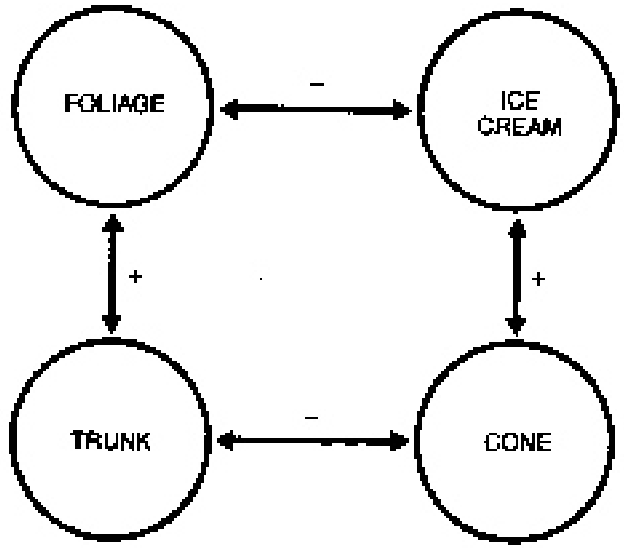
Competition and Cooperation Between Perceptual Schemas

Tree



or Ice Cream Cone?

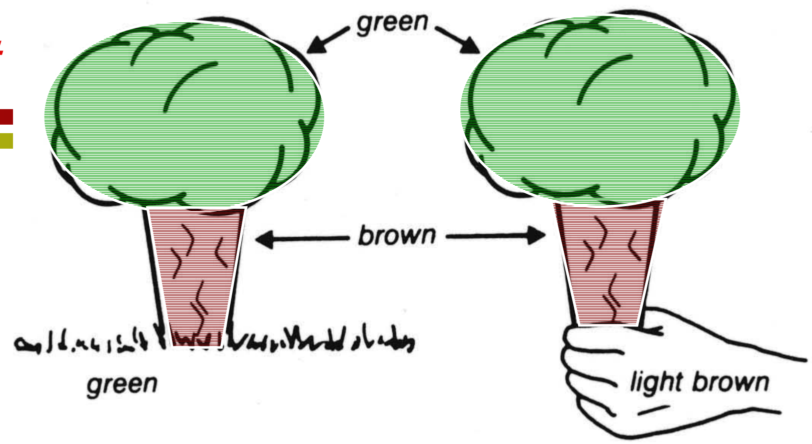
Cooperation: + signs
(specific knowledge)



Competition: - signs
(general constraint)

What are the equilibrium states?

Bringing in Context



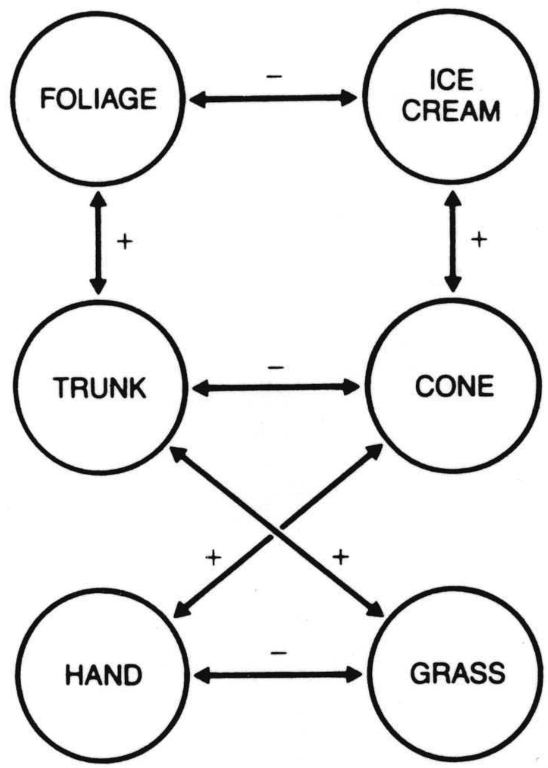
For Further Reading:

TMB2:

Section 5.2 for the VISIONS system for schema-based interpretation of visual scenes.

HBTNN:

Visual Schemas in Object Recognition and Scene Analysis



Decentralized Control/Emergent Behavior

The Activity Level of an instance of a perceptual schema represents a confidence level that the object represented by the schema is indeed present.

The Activity Level of an instance of a motor schema may signal its degree of readiness to control some course of action.

A schema network does not, in general, need a top-level executor since schema instances can combine their effects by distributed processes of competition and cooperation. This may lead to apparently emergent behavior, due to the absence of global control. Activity may involve

- passing of messages
- changes of state (including activity level)
- instantiation to add new schema instances
- deinstantiation to remove instances
- self-modification and self-organization.

Schema theory is a Learning Theory, Too

Jean Piaget (Swiss "Genetic Epistemology" --
The Construction of Reality in the Child, etc.):

Assimilation: understanding the current situation in terms of existing schemas

Accommodation: creating new schemas when assimilation fails.

In our coordinated control program/schema assemblage framework:

New schemas may be formed as assemblages of old schemas

Tunability of schema-assemblages allows them to start as composite but emerge as primitive

Neural Schema Theory

In most of the preceding discussion, the words "brain" and "neural" do not appear.

Neural schema theory is a specialized branch of schema theory, just as neuropsychology is a specialized branch of psychology.

A given schema, defined functionally, may be distributed across more than one brain region;

A given brain region may be involved in many schemas.

Hypotheses about the localization of (sub)schemas in the brain may be tested by lesion experiments.

Schemas for Pattern-Recognition in the Toad

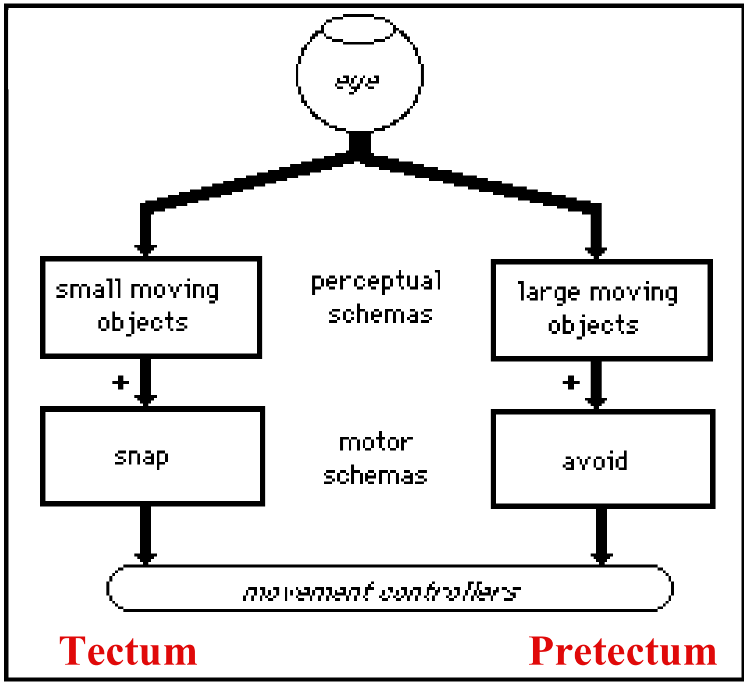
One task of the tectum: directing the snapping of the animal at small moving objects

Also: the frog jumps away from large moving objects and does not respond when there are only stationary objects.

Hypothesis: the animal is controlled by two schemas:

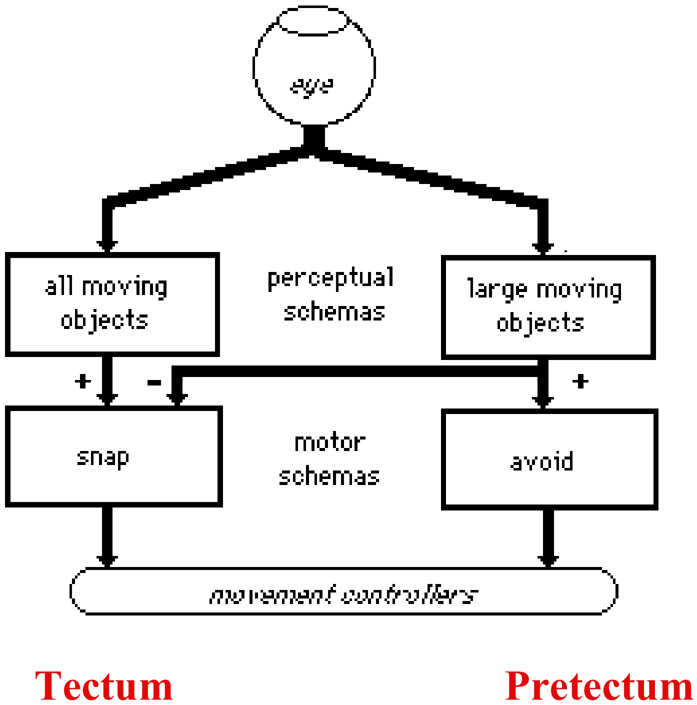
one for prey catching which is triggered by the recognition of small moving objects, and

one for predator avoidance which is triggered by large moving objects.



But … lesioning pretectum does not yield the predicted effect on behavior.

Schemas for Pattern-Recognition in the Toad



Moral:

Even gross lesion studies can distinguish between alternative top-down analyses of a given behavior.

[Such an analysis can be refined by more detailed behavioral and neurophysiological studies (cf. TMB2, Section 7.3).]

Bringing in World Knowledge

The distinction between

retinotopic representations in certain parts of the brain and abstract representations associated with object recognition

is reflected in the distinction used in machine vision:

Low-level vision:

general physics of light and surfaces: the processing done to recode information using parallel array processing

High-level vision:

knowledge of specific classes of objects comprises "knowledge intensive processes".

The general scheme is bottom-up processing through several levels of representation until "world knowledge" can be invoked to generate hypotheses; but “hypothesis-driven/top-down” processing may at times be dominant.

LTM versus STM

Specialized perceptual schemas
(Long-Term Memory: LTM)
for recognizing different objects
or controlling various tasks
form a representation of the current scene
(Short-Term Memory: STM) by a combination of:

Data-Driven (Bottom-Up) Processing

Looking at characteristics of different portions of the image as represented in the low level data; and

Hypothesis-Driven (Top-Down) Processing

Passing messages to each other to settle on a coherent interpretation.

A working hypothesis: future machine vision systems will have their low-level components tailored to the particular application domain, while the communication pathway from high-level processes to low-level processes will be in terms of a "low-level vocabulary."

VISIONS: Schema-Based High-Level Vision

The VISIONS image understanding system
(Hanson and Riseman):
A knowledge-based system influenced by HEARSAY and schema theory. Its use of schemas for high-level vision exemplifies a "brain-like" style of cooperative computation.
The VISIONS system uses the pattern of segmentation of a 2D image for its intermediate representation.
The logic is inherently distributed:
Interpretation integrates many procedures:
using pattern identification techniques to identify classes of objects associated with regions; using a network of object-part relations to guide the process.
The system uses parallel distributed control, taking advantage of redundancies to recover object identity from noisy errorful data
The lecture will conclude with a "Picture Show" illustrating the integration of bottom-up and top-down processing in VISIONS.
See TMB2 Section 5.2 for figures and details.