Cognitive Architecture: Model Human Processor

Learning Objective

- In the previous lecture, we learned about the basics of CA and its applications in HCI
- In this lecture, we shall learn more about CAs with the help of the MHP (Model Human Processor)

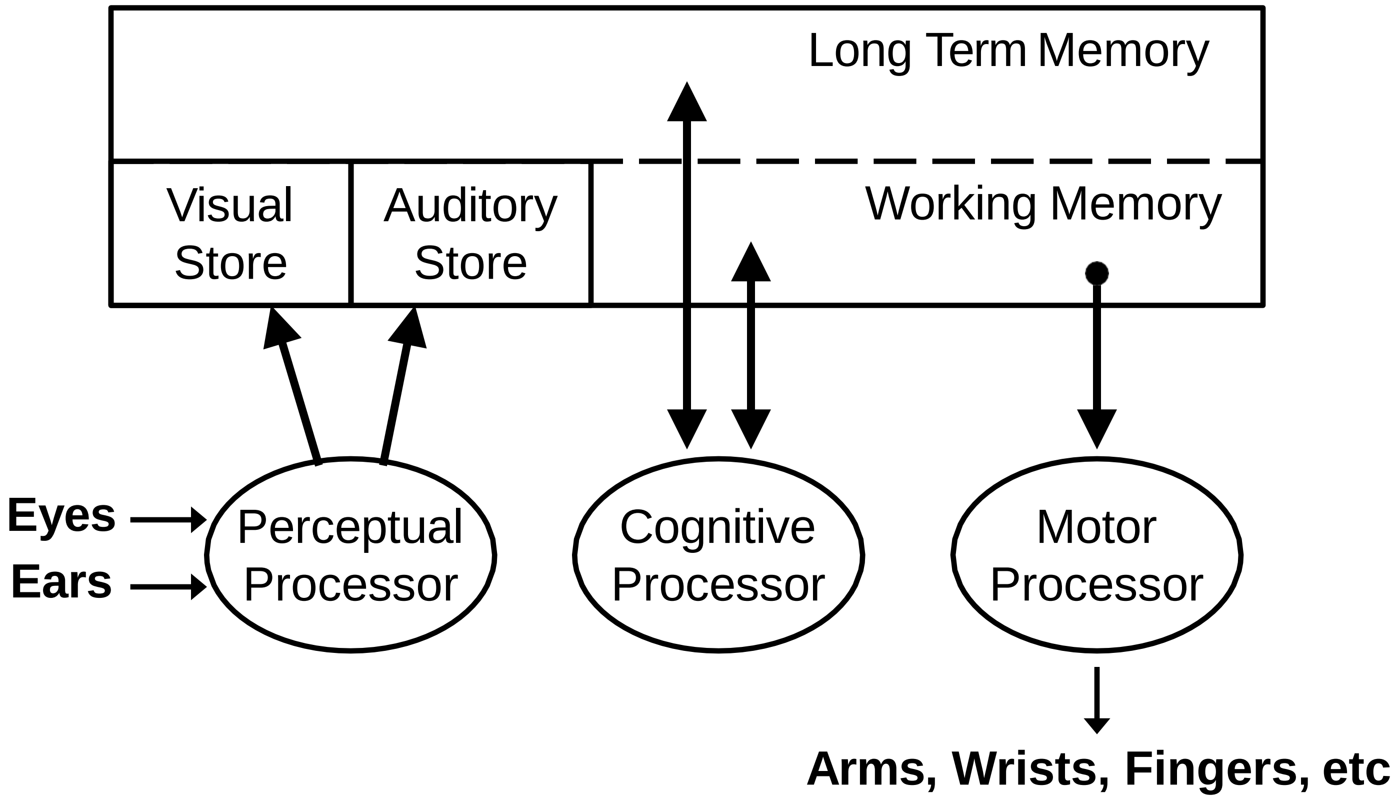
Model Human Processor (MHP)

- Contains THREE Interacting Systems: Perceptual, Cognitive, and Motor Systems
  - For some tasks, systems operate in serial (pressing a key in response to a stimulus)
  - For other tasks, systems operate in parallel (driving, talking to passenger, listening to radio)

MHP

- Each system has its own Memory and Processor with characteristics
  - Memory: Storage Capacity and Decay Time
  - Processor: Cycle Time (incl. The Access Time)
- Each system guided by principles of operation
  - 10 such principles in total

MHP – Schematic Diagram



MHP

- The systems in the MHP are guided by the *Principles of Operation*
  - 10 such principles in total
- Two of these principles are very important
  - The Rationality Principle (RP)
  - The Problem Space Principle (PSP)

The Rationality Principle

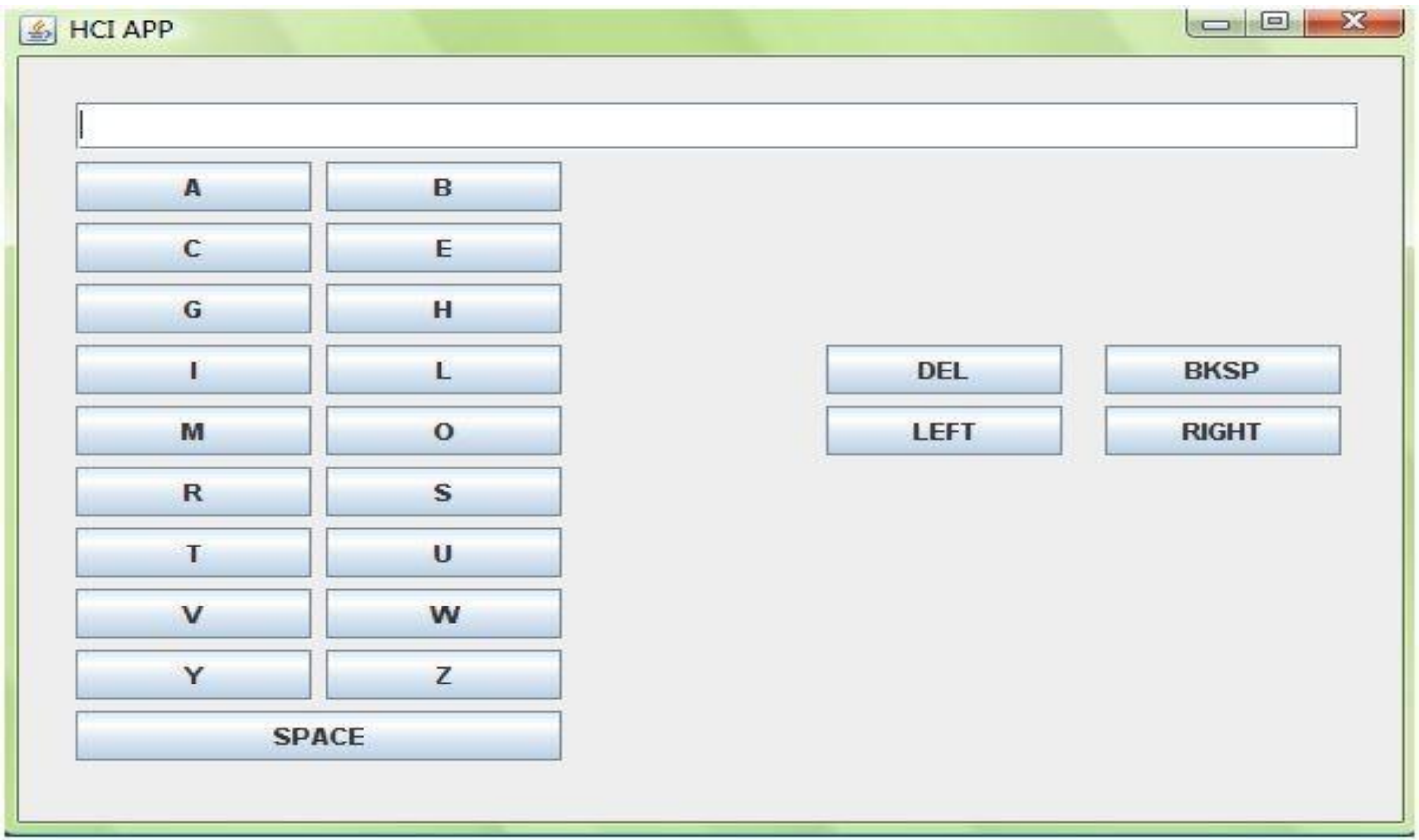
- The RP is one of the guiding principles of MHP
- The principle is based on the assumption that we behave rationally, rather than driven by emotion
- The human behavior is determined by a set of factors that include goals, task, inputs and the knowledge

The Problem Space Principle (PSP)

- The PSP is the other guiding principle of the MHP
- It states that any goal directed activity can be described in terms of the following:
  - A set of states of knowledge
  - Operators for changing one state into another
  - Constraints on applying operators
  - Control knowledge for deciding which operator to apply next

A Little on PSP

Let’s understand PSP with an example. Suppose a user "John" wants to write a correct sentence with only available letters on the following interface.



A Little on PSP

- Human cognitive behaviors assumed to have some of the following common properties:
  - **Behaves in a Goal-Oriented Manner**

    - “John" ultimately wants to write a Grammatically and Semantically Correct Sentence

  - **Operates in a Rich, Complex, detailed Environment**

    -There are many other things that "John" has to keep in his mind. – Key Positions, Keystrokes

  - **Uses a Large Amount of Knowledge**

    - Grammar Rules, Spellings

A Little on PSP

- Human cognitive behaviors assumed to have some of the following common properties:
  - **Behaves flexibly as a function of the environment**

    - may complete any sentence left behind
  - **Uses Symbols and Abstractions**

    - “John" will start thinking from a greater level of abstraction
  - **Learns from the environment and experience**

    - As "John" starts typing, he learns more about available keys

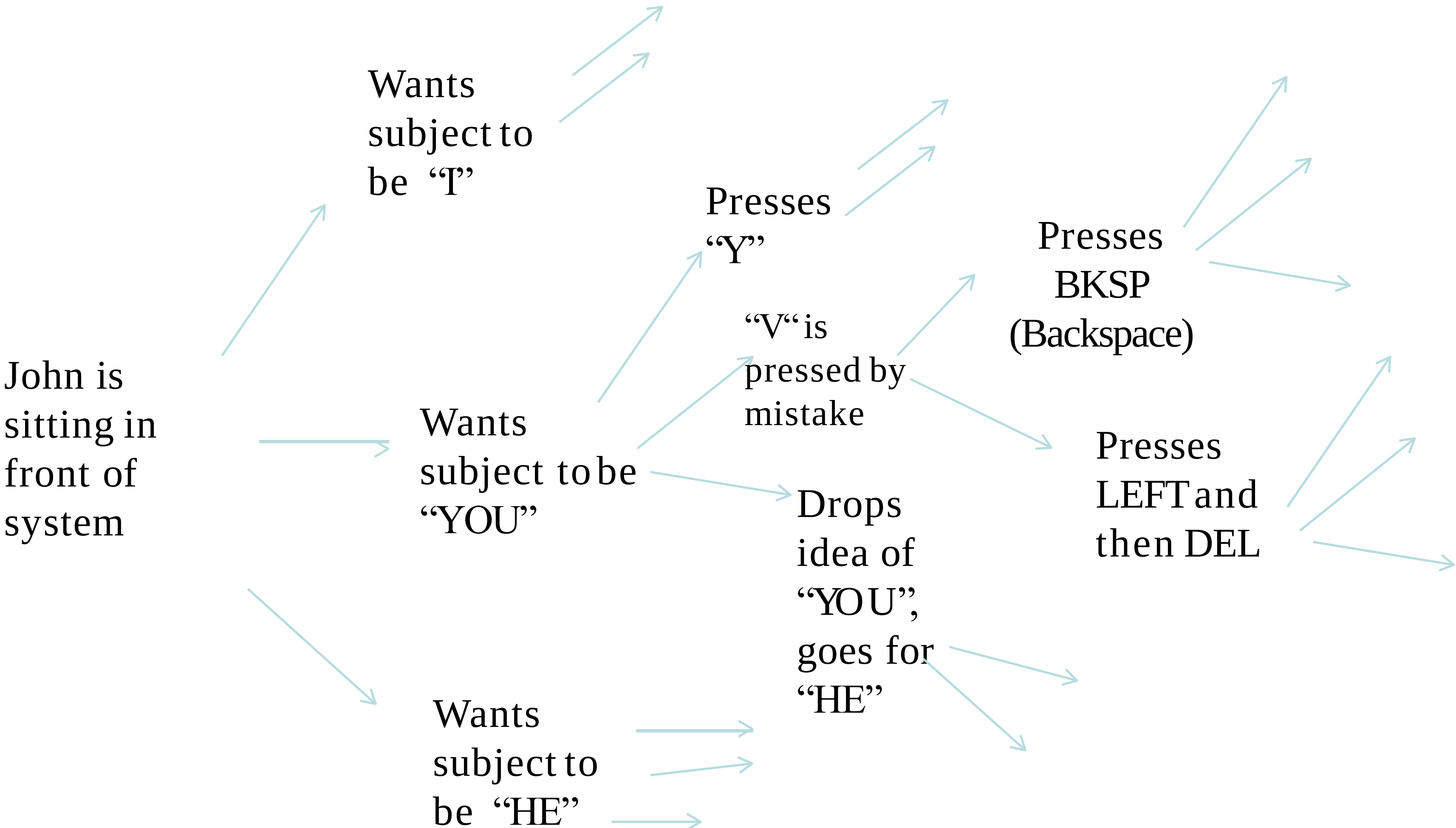
A Little on PSP

- John’s behavior can be described as movement through problem space

- In problem space, there are various states and by taking an appropriate action (goal directed), "John" reaches a new state and this process repeats until the goal is achieved

- This movement in the problem space is illustrated in the next slide

A Little on PSP



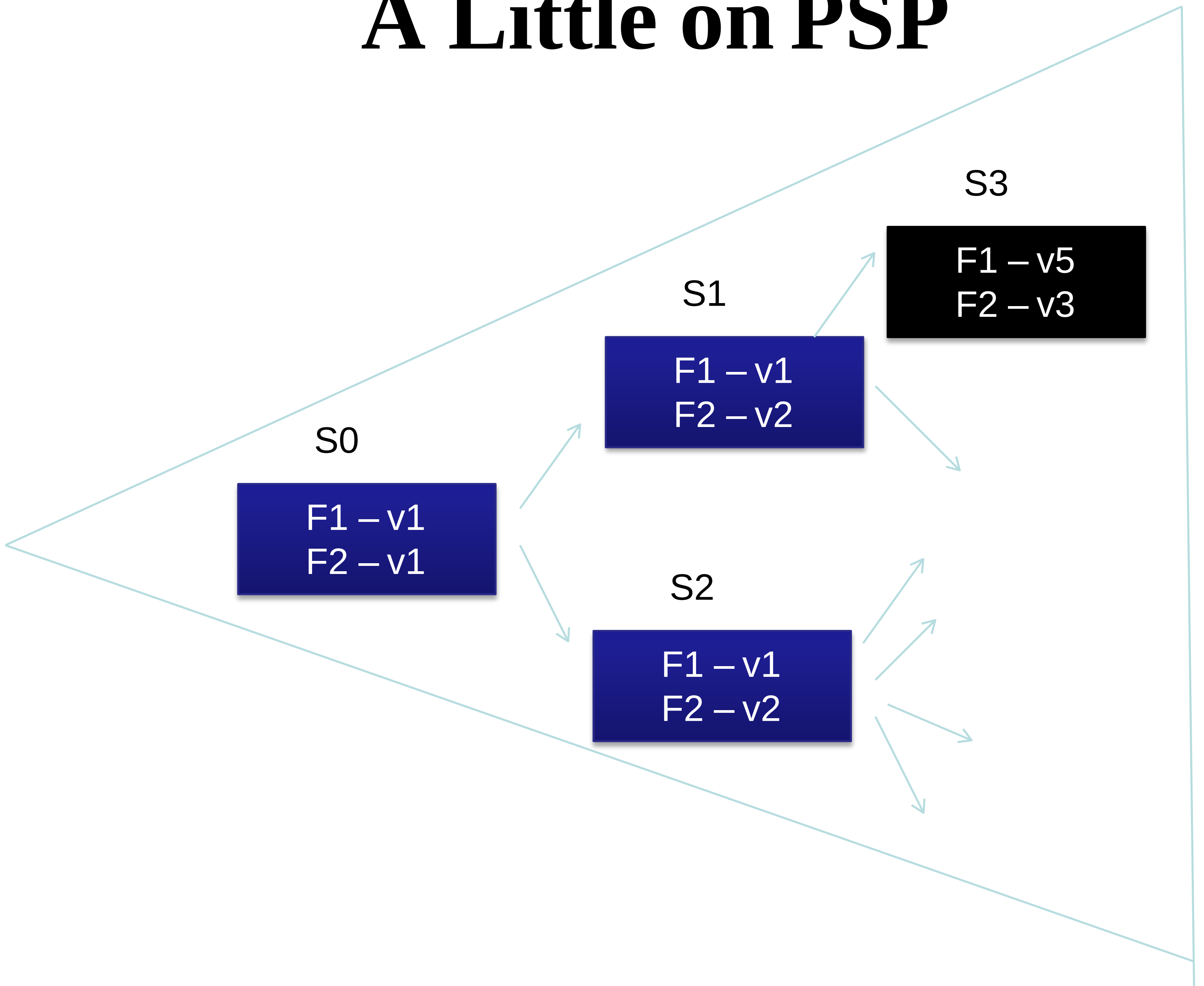
A Little on PSP

- Previous figure was only a portion of the whole problem space for "John"
  - Problem space is almost a finite automata with states, and actions taken by "John" to change states are called *operators*
- A more sophisticated representation will have features and their values attached to each state
  - These features and their values will define whether the system has reached the *final state* or not

A Little on PSP

- In our example, each state can have two features
  - f1- sentence status
  - f2 - word etc. features
- When the feature corresponding to the sentence status (i.e., f1) has value equals to “COMPLETE”, then we say that the goal is achieved

A Little on PSP

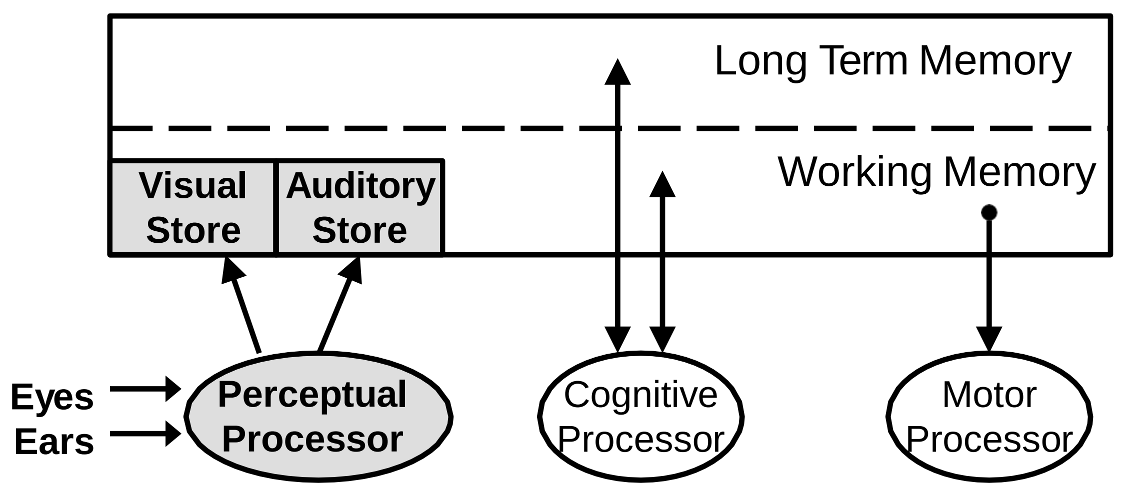


A Little on PSP

- In essence, a problem space is defined by a particular set of states and operators, relative to a goal
- "John" moves randomly in problem space and once the feature f1 gets the final desired value (e.g., complete), then the goal is achieved

MHP Subsystems: Perceptual System

- Responsible for transforming external environment into a form that cognitive system can process
- Composed of *Perceptual Memory* and *Processor*



Perceptual Memory

- Shortly after the onset of stimulus, representation of stimulus appears in perceptual memory
  - Representation is physical (non-symbolic). For example, “7” is just the pattern, not the recognized digit
- As contents of perceptual memory are symbolically coded, they are passed to working/short term memory

Perceptual Memory

- The contents of the perceptual memory gets decayed over time
- Typical decay times are as follows:
  - 200ms for visual store
  - 1500ms for auditory store

Perceptual Processor

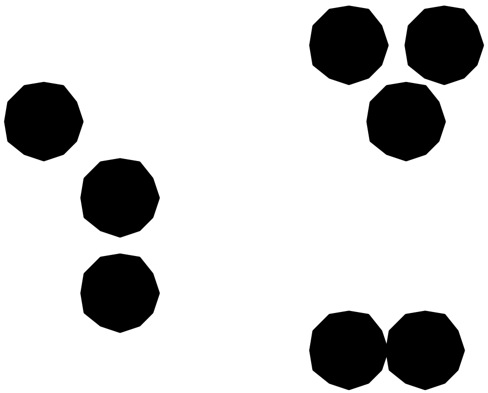
- The perceptual processor encodes information in the perceptual memory for about 100ms and then retrieves the next stimulus
  - Cycle time = ~100ms
- Processor cannot code all information before the next stimulus arrives
  - Type and order of coding are governed by the Gestalt principles (perceive shape from atomic parts) and Attention (directs processing or filters information)

Gestalt Laws of Perception

- The organizing principles, which enables us to perceive the patterns of stimuli as meaningful wholes, are defined as
  - Proximity
  - Similarity
  - Closure
  - Continuity
  - Symmetry

Proximity

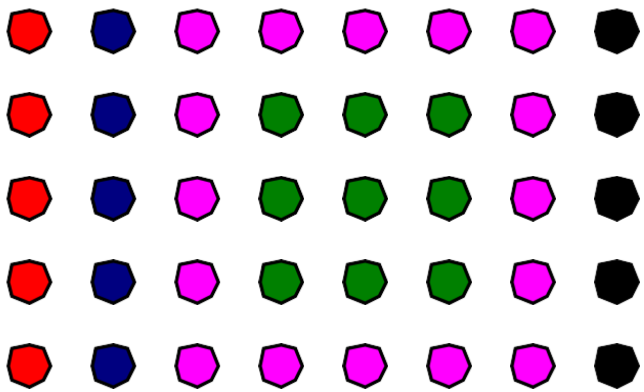
- Elements close together tend to organize into units



Here, the dots appear as groups rather than a random cluster of elements

Similarity

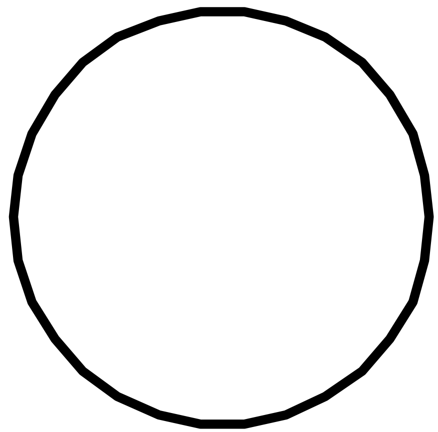
- Objects that are look-alike tend to be grouped together



There is a tendency for elements of the same shape or color to be seen as belonging together

Closure

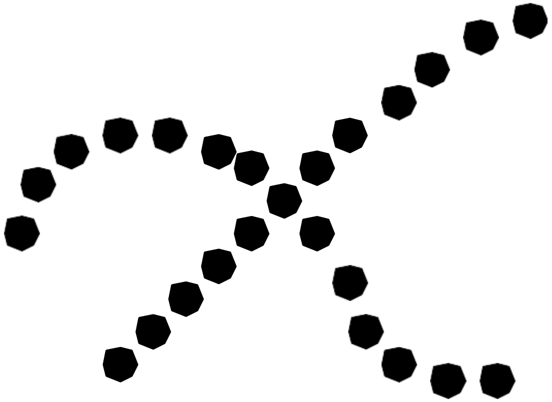
- We prefer to see regular shapes, inferring occlusion to do so



Missing parts of the figure are filled in to complete it,
so that it appear as a whole circle

Continuity

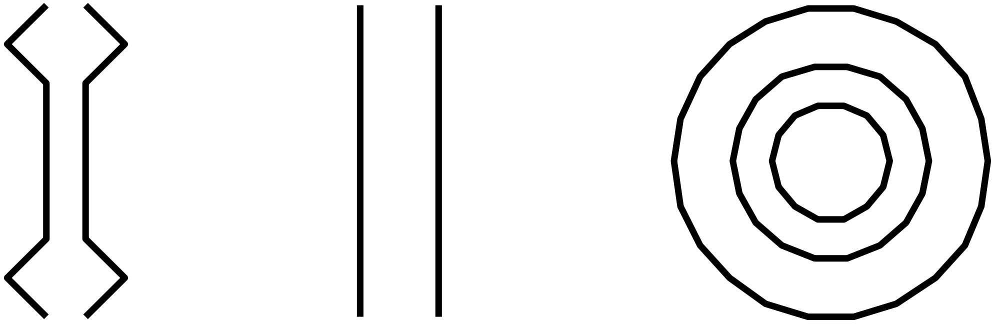
- Human sees lines as being continuous



The stimulus appears to be made of two lines of dots, traversing each other, rather than a random set of dots

Symmetry

- Region bounded by symmetrical borders tend to be perceived as coherent figures



Principles of Perceptual System

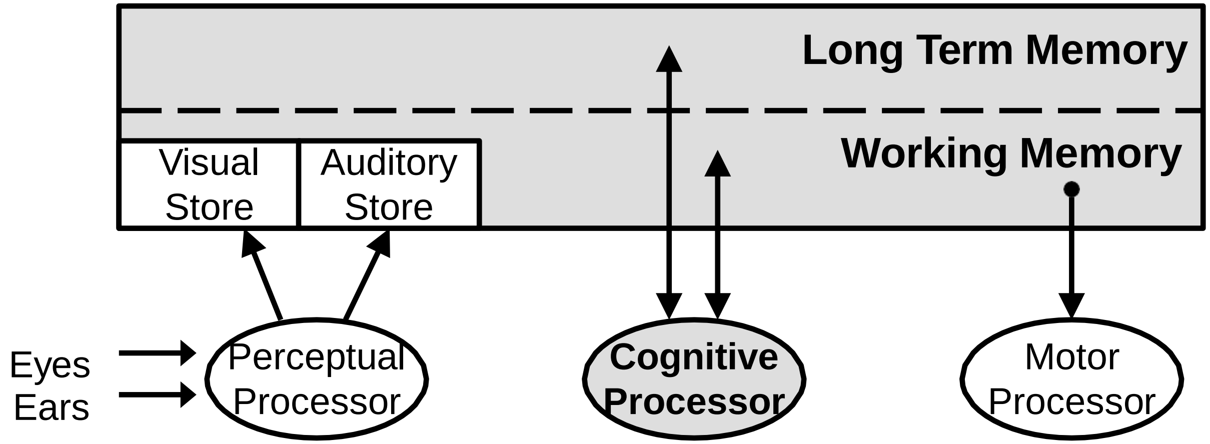
- There are two principles governing the working of the perceptual system
  - Variable processor rate principle - processor cycle time varies inversely with stimulus intensity (brighter screens need faster refresh rates)
  - Encoding specificity principle - encoding at the time of perception impacts (a) what and how information is stored and (b) what retrieval cues are effective at retrieving the stored information

Cognitive System

- The cognitive system in MHP is responsible for decision making
- It is a production system comprising of
  - A set of production (IF-THEN) rules (Stored in the Memory; Working Memory (WM) + Long Term Memory (LTM))
  - A rule interpretation engine (Cognitive Processor)

Cognitive System

- It uses the contents of WM and LTM to make decisions and schedule actions with motor system
- Composed of a processor and the two memories (WM and LTM)



Working Memory (WM)

- Holds intermediate products of thinking and representations produced by perceptual system
- Comprised of activated sections of LTM called "chunks"
  - A chunk is a hierarchical symbol structure
  - 7 ± 2 chunks active at any given time (7 ± 2 principle)

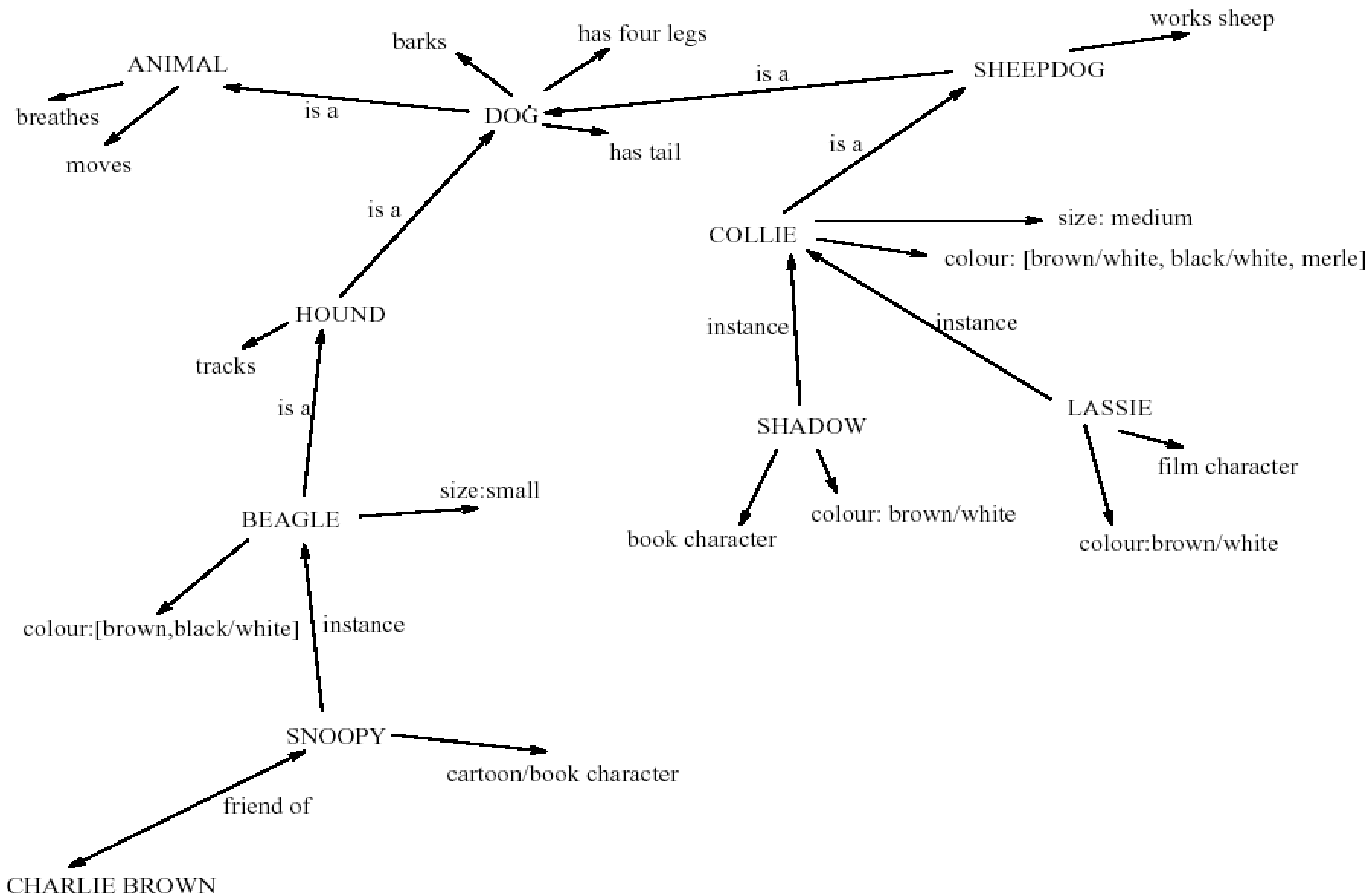
Working Memory (WM)

- The memory content gets decayed
- The decay is caused by the following:
  - Time: about 7s for three chunks, but high variance
  - Interference: more difficult to recall an item if there are other similar items (activated chunks) in memory
- Discrimination Principle
  - Difficulty of retrieval determined by candidates that exist in memory relative to retrieval cues

Long-Term Memory

- Holds mass of knowledge; facts, procedures, history
- Two types
  - Procedural – IF-THEN rules
  - Declarative – facts
- Declarative memory consists of a network of related chunks where edge in the network is an association (semantic network)

LTM - Semantic Network



Long-Term Memory

- Fast read, slow write
- Infinite storage capacity, but you may forget because:
  - Cannot find effective retrieval cues
  - Similar associations to other chunks interfere with retrieval of the target chunk (**discrimination principle**)

Cognitive Processor

- Implements “cognition”
- Operation called cognitive/production/decision cycles - A pattern matching process
  - IF side tests for a particular pattern in declarative memory
  - When IF side matches, THEN side is executed (i.e. *rule firing*)

Cognitive Processor

- A cycle completes when no more firing is possible
- A firing can
  - Activate motor component (ACT)
  - Fire another rule
  - Change WM/declarative memory (thus helping in other cycles)

Cognitive Processor Principle

- Principle of recognize-act cycle
  - Recognize: activate associatively-linked chunks in LTM
  - Act: modify contents of WM
- Cycle time = ~70ms

Cognitive System Principles

- Uncertainty Principle

  Decision time increases with the uncertainty about the judgment to be made, requires more cognitive cycles

- Variable Rate Principle

  Cycle time is shorter when greater effort is induced by increased task demands or information loads; it also diminishes with practice

Cognitive System Principles

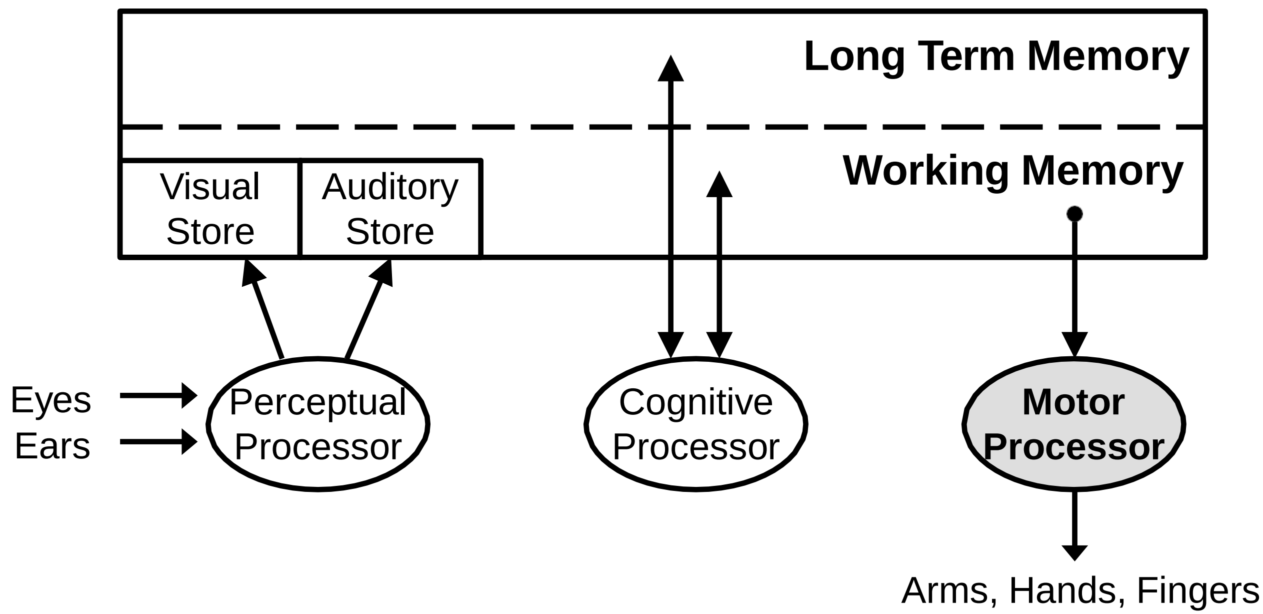
- Power Law of Practice

$$T_n = T_1 * n^{-\alpha}$$

Here, T_n is the task completion time at the n-th trial, T_1 is the task completion time in the first attempt and α is *learning constant* (usually taken as 0.4)

Motor System

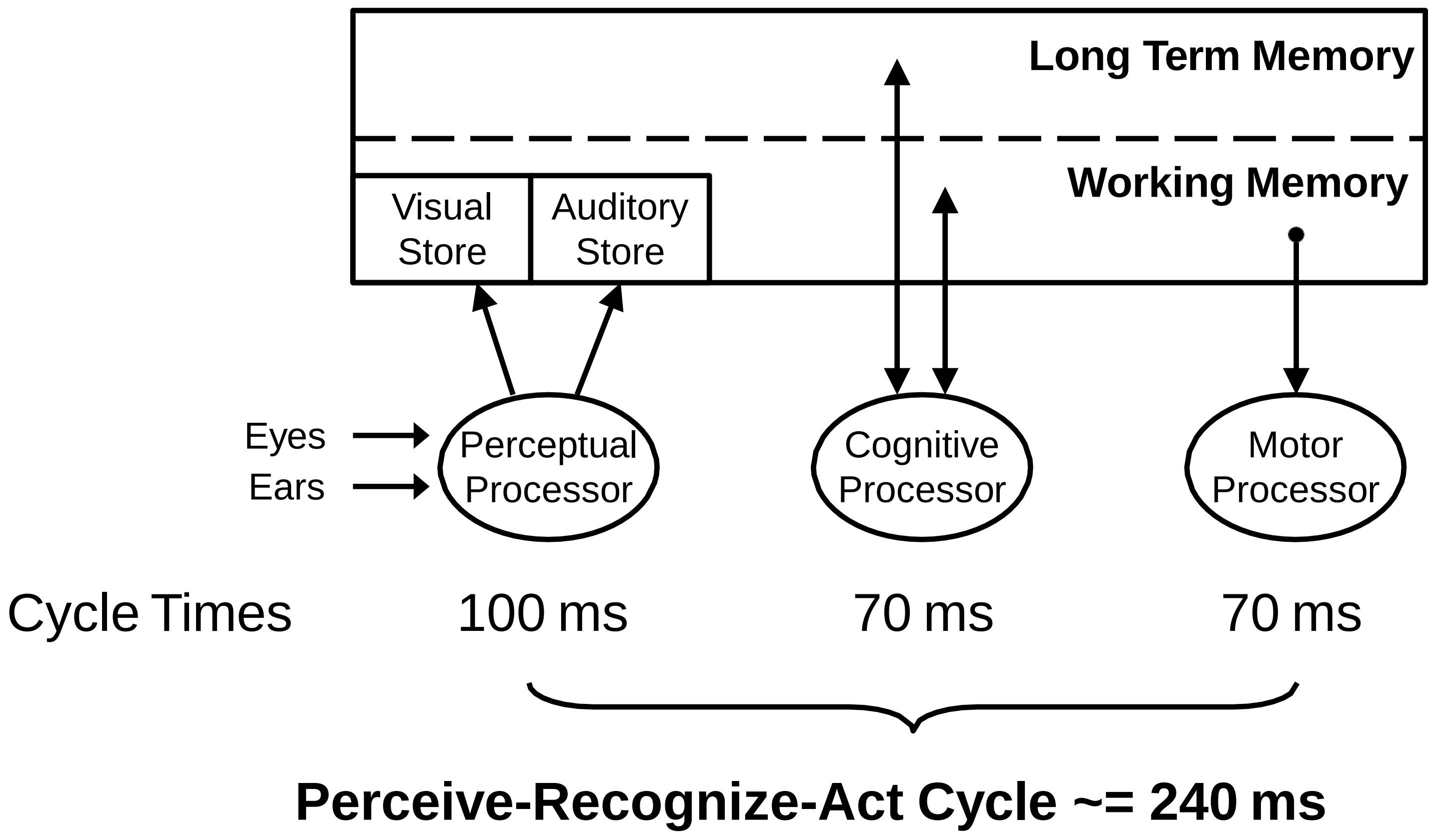
- Translates thoughts into actions
  - Head-neck and arm-hand-finger actions



Motor Processor

- Controls movements of body
  - Movement composed of discrete micro-movements
  - Micro-movement lasts about 70ms
  - Cycle time of motor processor is about 70ms
- Principle: Fitts' law (we already discussed)

Putting All Together



Principles - Summary

- Basis of the Model
  - P0: Recognize-Act Cycle of the Cognitive Processor
  - P8: Rationality Principle
  - P9: Problem Space Principle

Principles - Summary

- Other 7 principles tend to describe ways of estimating the duration of operators:
  - P1 -- Variable Perceptual Processor Rate
  - P2 -- Encoding Specificity Principle
  - P3 -- Discrimination Principle
  - P4 -- Variable Cognitive Processor Rate Principle
  - P5 -- Fitts's Law
  - P6 -- Power Law of Practice
  - P7 -- Uncertainty Principle

Example 1

- A user sits before a computer terminal. Whenever a symbol appears, s/he must press the space bar. What is the time between stimulus and response?

  T_p (perceive the symbol) + T_c (recognize the symbol) + T_m (press key) = 240 ms

  T_p = Perceptual Cycle Time

  T_c = Cognitive Cycle Time

  T_m = Motor Cycle Time

Example 2

- Two symbols appear on the computer terminal. If the second symbol matches the first, then the user presses "Y" and presses "N" otherwise. What is the time between the second signal and response?

Tp + 2Tc (compare + decide) + Tm = 310 ms