# Retracing the Rational Analysis of Memory

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# What is this talk about?

Goal:

- (re)examine and formalize the goal of memory mechanisms
- unify mechanisms such as cued and spontaneous retrieval, working and semantic memory activation, etc.

# The Rational Analysis of Memory

Anderson (1990) performed a *rational analysis* of memory:

Goal

Environment

Constraints

Optimization

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**Goal** provide the agent with knowledge it is most likely to need

**Environment**

**Constraints**

**Optimization**

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| Goal | provide the agent with knowledge it is most likely to need |
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# The Rational Analysis of Memory

Anderson (1990) performed a *rational analysis* of memory:

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|---|---|
| Goal | provide the agent with knowledge it is most likely to need |
| Environment | one where probability of need is a function of recency and frequency |
| Constraints | memories are accessed sequentially at fixed cost |
| Optimization | stop retrieval when |

$$\text{cost} > \text{probability of need} * \text{gain}$$

# Bayesian Memory

Goal: return element $m \in M$ with the highest probability of need $P(m)$

Given: set of context elements $C \subset M$

Find:

$$\begin{aligned} \arg\max_{m \in M} \; P(m|C) &= \arg\max_{m \in M} \; \frac{P(m)P(C|m)}{P(C)} \\ &= \arg\max_{m \in M} \; P(m)P(C|m) \end{aligned}$$

# Bayesian Memory

$$\arg\max_{m \in M} P(m)P(C|m)$$

What does this mean?

- $P(m)$ probability of need of element $m$ (ie. the *prior*)
- $P(C|m)$ probability of need of the context $C$ given that $m$ is needed (ie. the *likelihood*)

# ACT-R's Memory Mechanisms

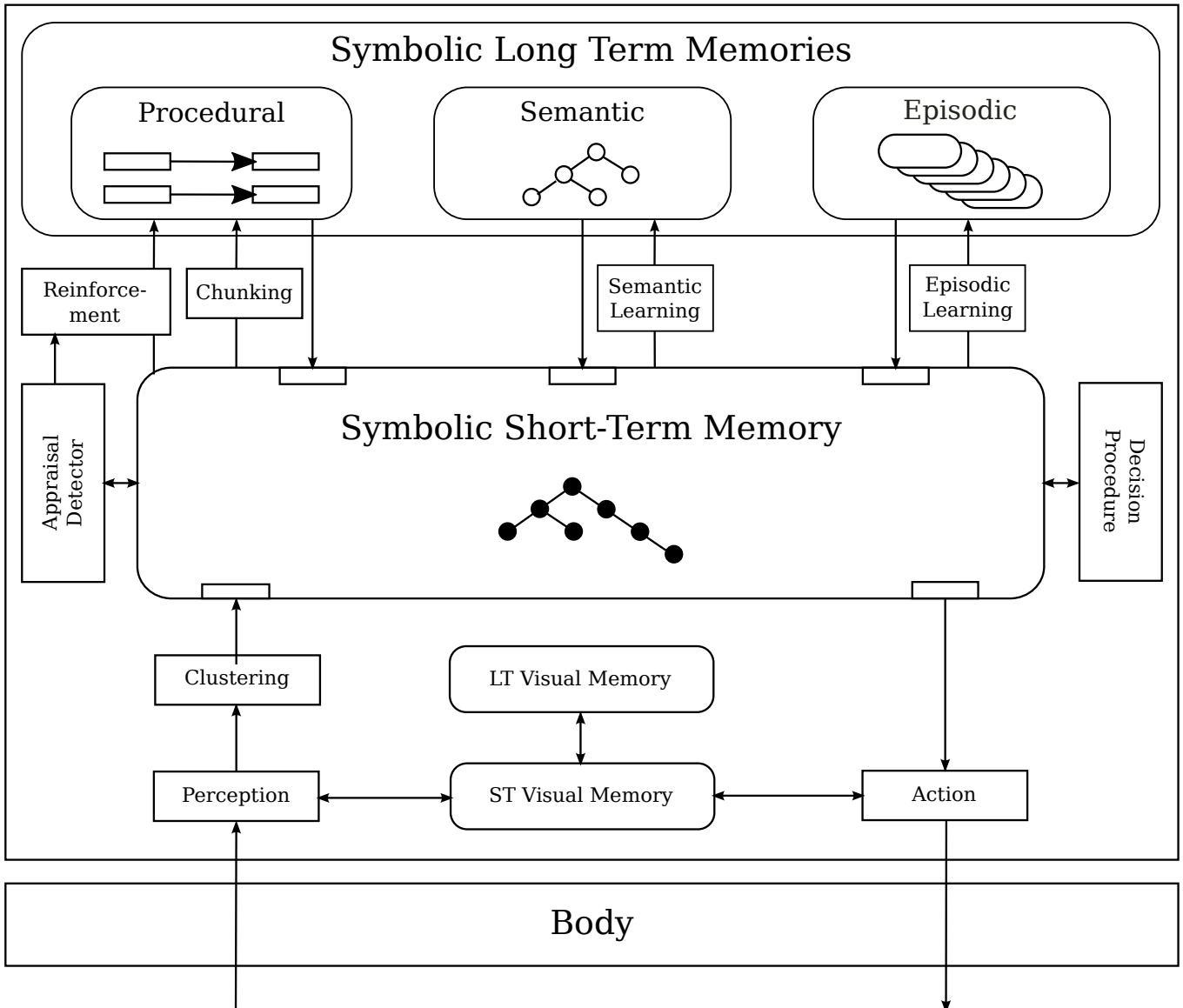
- Cued Retrieval
- Partial Match
- Spreading Activation

# Cued Retrieval

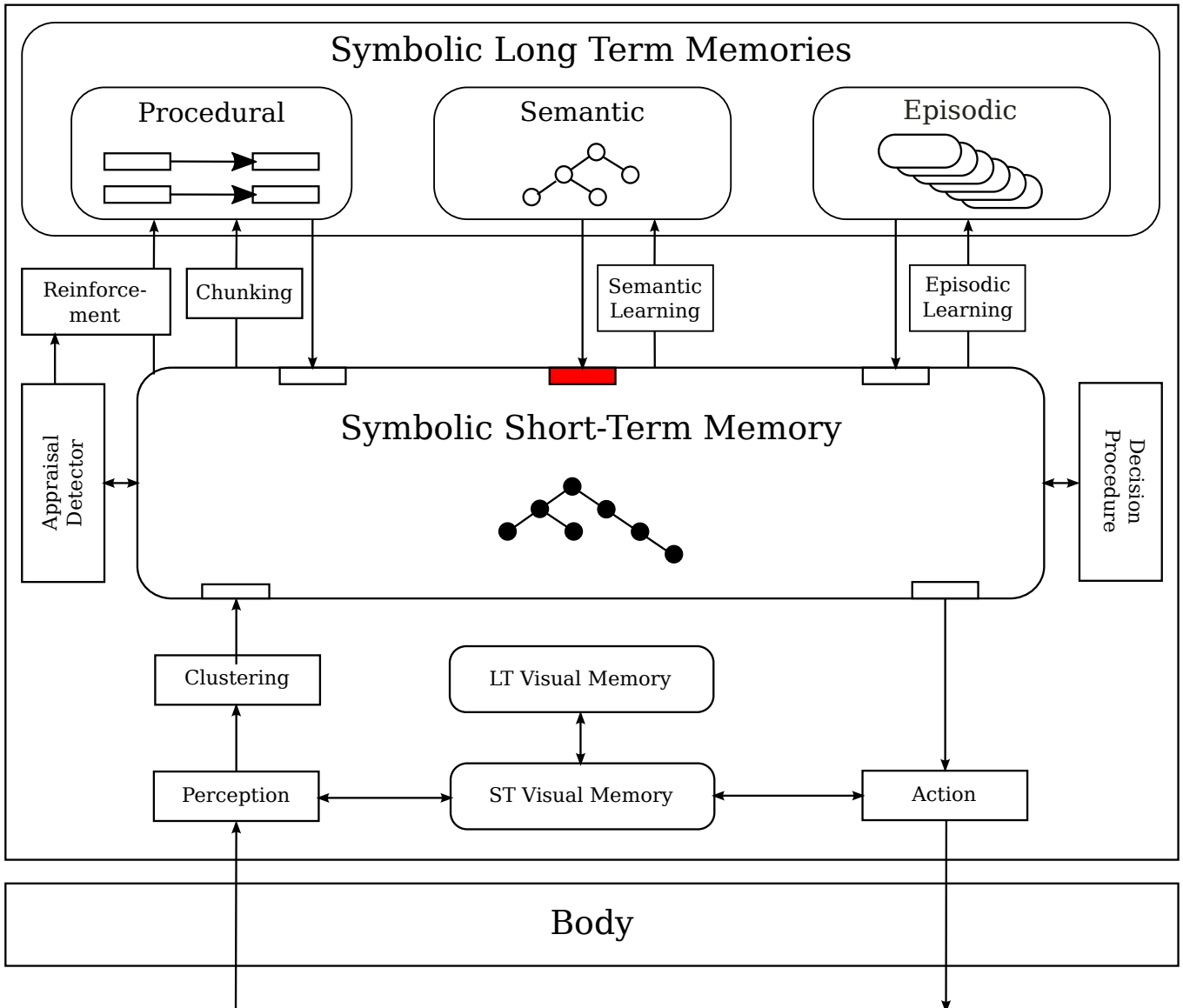
Assuming the context C is the set of cues:

$$\arg\max_{m \in M} \; P(C|m)P(m)$$

# Cued Retrieval



# Cued Retrieval



# Cued Retrieval

Assuming the context C is the set of cues:

$$\arg\max_{m \in M} \; P(C|m)P(m)$$

We want $\forall m, P(C|m_1) = P(C|m_2)$
Take

$$P(c|m) = \begin{cases} 1, & \text{if } \forall c \in C \text{ is a child of } m \\ 0, & \text{otherwise} \end{cases}$$

# Partial Match

Assuming the context C is the set of cues:

$$\arg\max_{m \in M} \; P(C|m)P(m)$$

We want $P(C|m)$ to be:

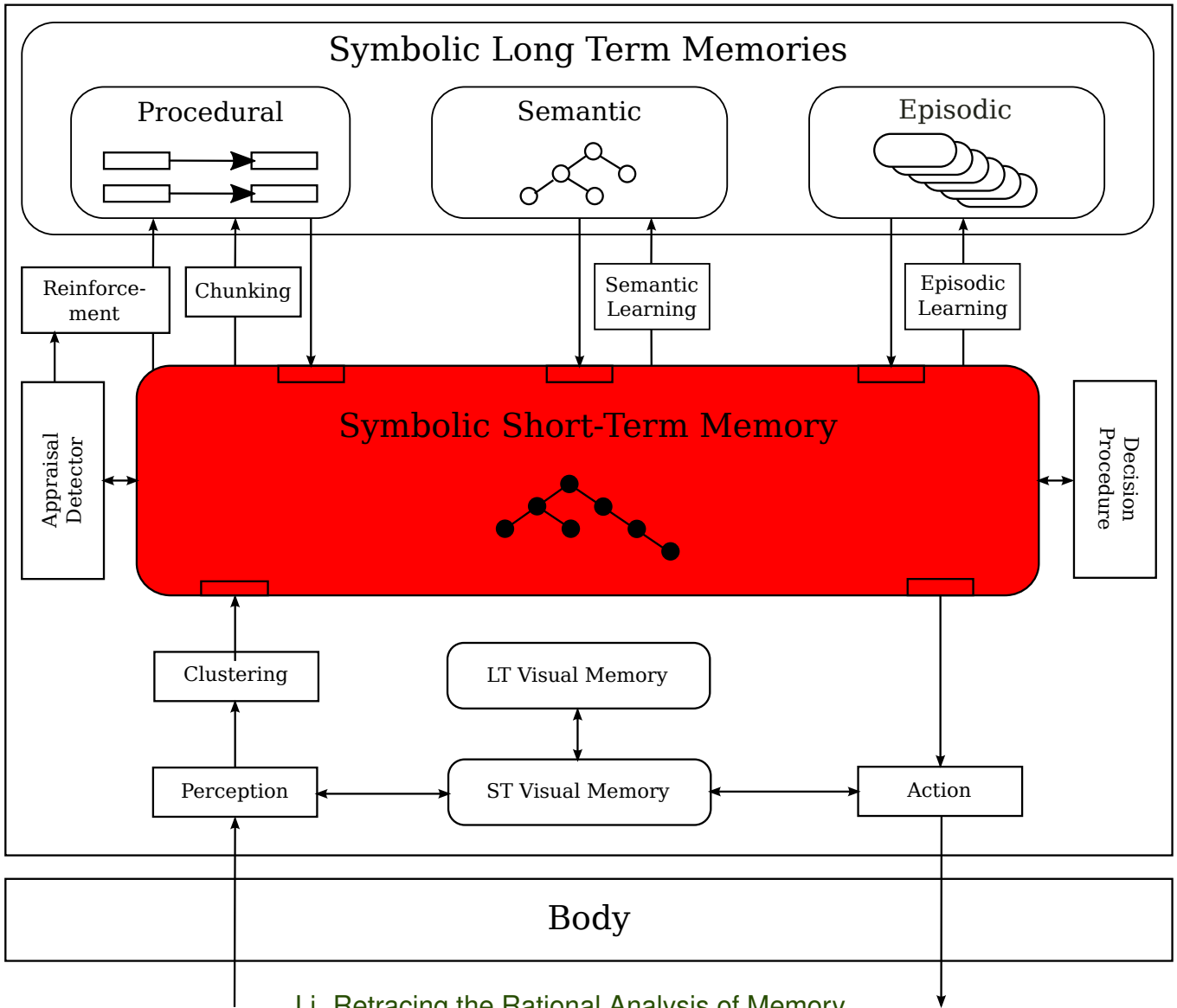
- proportional to the number of $c \in C$ that is a child of $m$
- inversely proportional the number of children that $m$ has

# Spreading Activation

Assuming the context C is the working memory:

$$\arg\max_{m \in M} \; P(C|m)P(m)$$

# Spreading Activation



# Spreading Activation

Assuming the context C is the working memory:

$$\arg\max_{m \in M} \; P(C|m)P(m)$$

Note there is *no cue* – this model could also *spontaneous*

# Bayesian Networks

Problems:

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  - other options?
  - working memory activation or semantic memory activation?

# Bayesian Networks

Problems:

- What is $P(m)$?
  - in ACT-R, base-level activation is $ln(P(m))$
  - other options?
  - working memory activation or semantic memory activation?
- What is $P(C|m)$?
  - in a Bayes net, all external factors
  - inference is NP-hard
  - semantic networks are not Bayesian networks (ie. acyclic)

# Nuggets and Coal

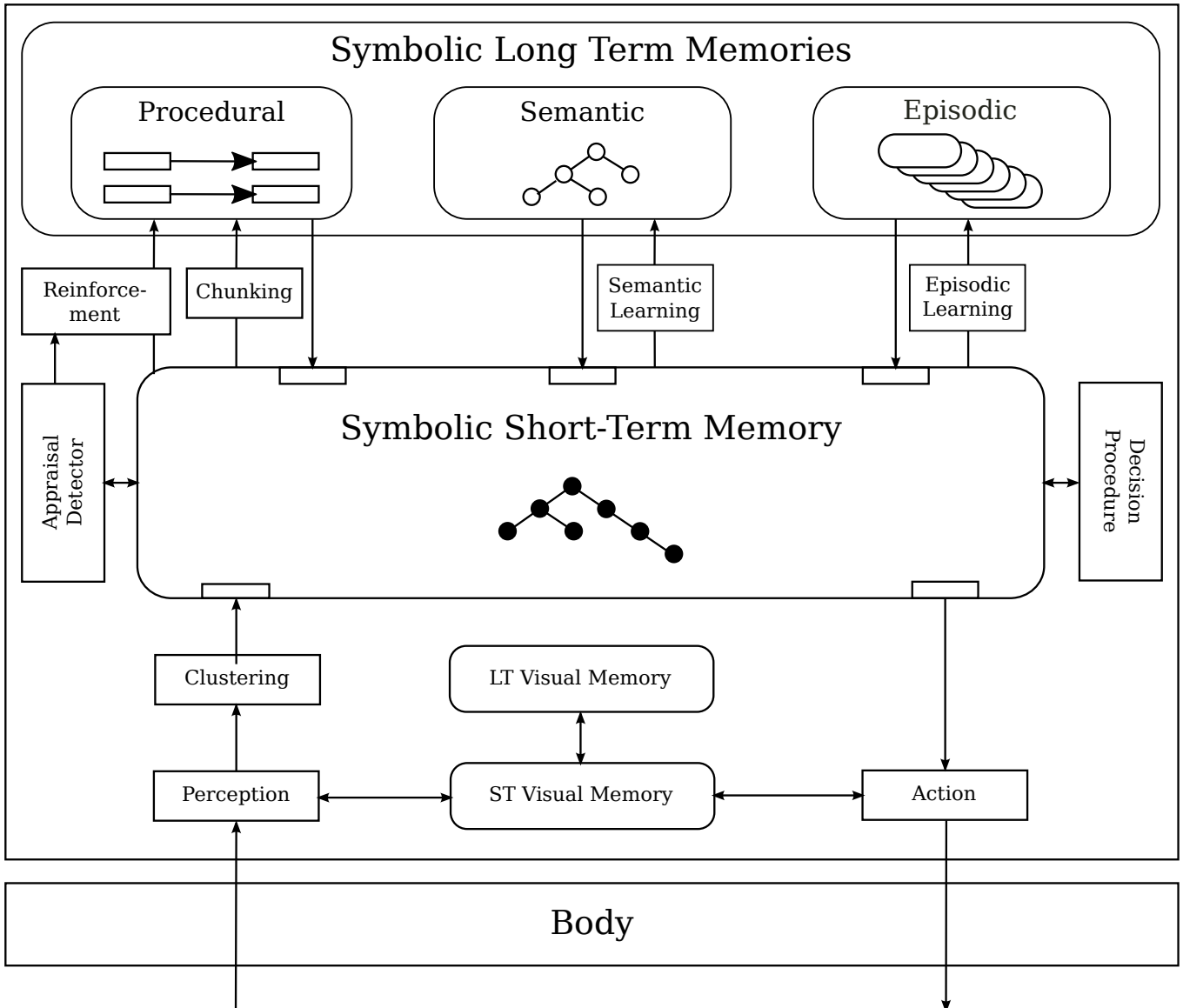
## Nuggets

- Memory retrieval can be cast in a Bayesian framework
- This framework provides explanations for multiple memory mechanisms

## Coal

- Bayesian inference fails on semantic networks
- Additional assumptions needed to make inference tractable and correct

# Questions?


Symbolic Long Term Memories
Procedural
Semantic
Episodic
Reinforce-ment
Chunking
Semantic Learning
Episodic Learning
Symbolic Short-Term Memory
Appraisal Detector
Decision Procedure
Clustering
LT Visual Memory
Perception
ST Visual Memory
Action
Body