

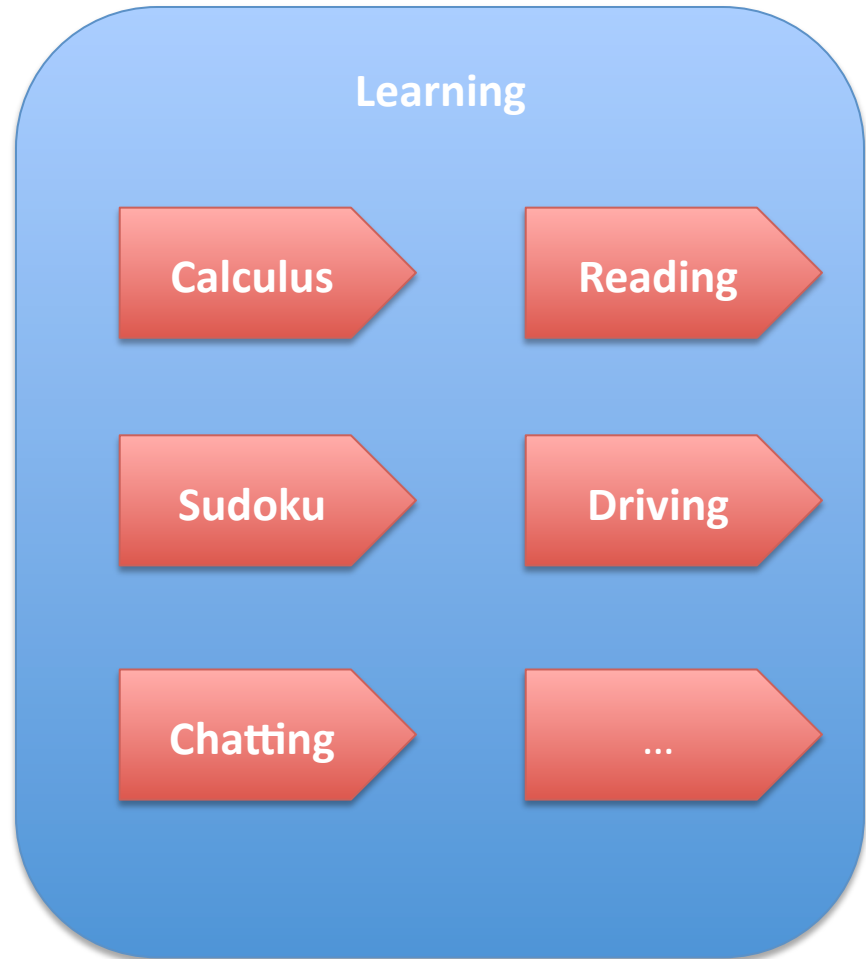
Long-Term Symbolic Memories for Long-Living Learning Agents

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Goal: Human-Level AI

- Autonomous
- Long-Living
 - Months, Years
- Multiple, complex tasks



Challenge: Lots of Knowledge

Over long lifetimes, learning agents accumulate large stores of knowledge

- Lexical (WordNet)
- Common sense (Cyc)
- Personal history
- etc.

Given limited computation, they must remain reactive to a complex, dynamic environment

Memory Systems

Data structures and algorithms to *encode, store,* and *retrieve* agent experience

Design decisions

- Which experience to encode?
- Which knowledge to keep? For how long?
- How does the agent gain access? In what form?
- ...

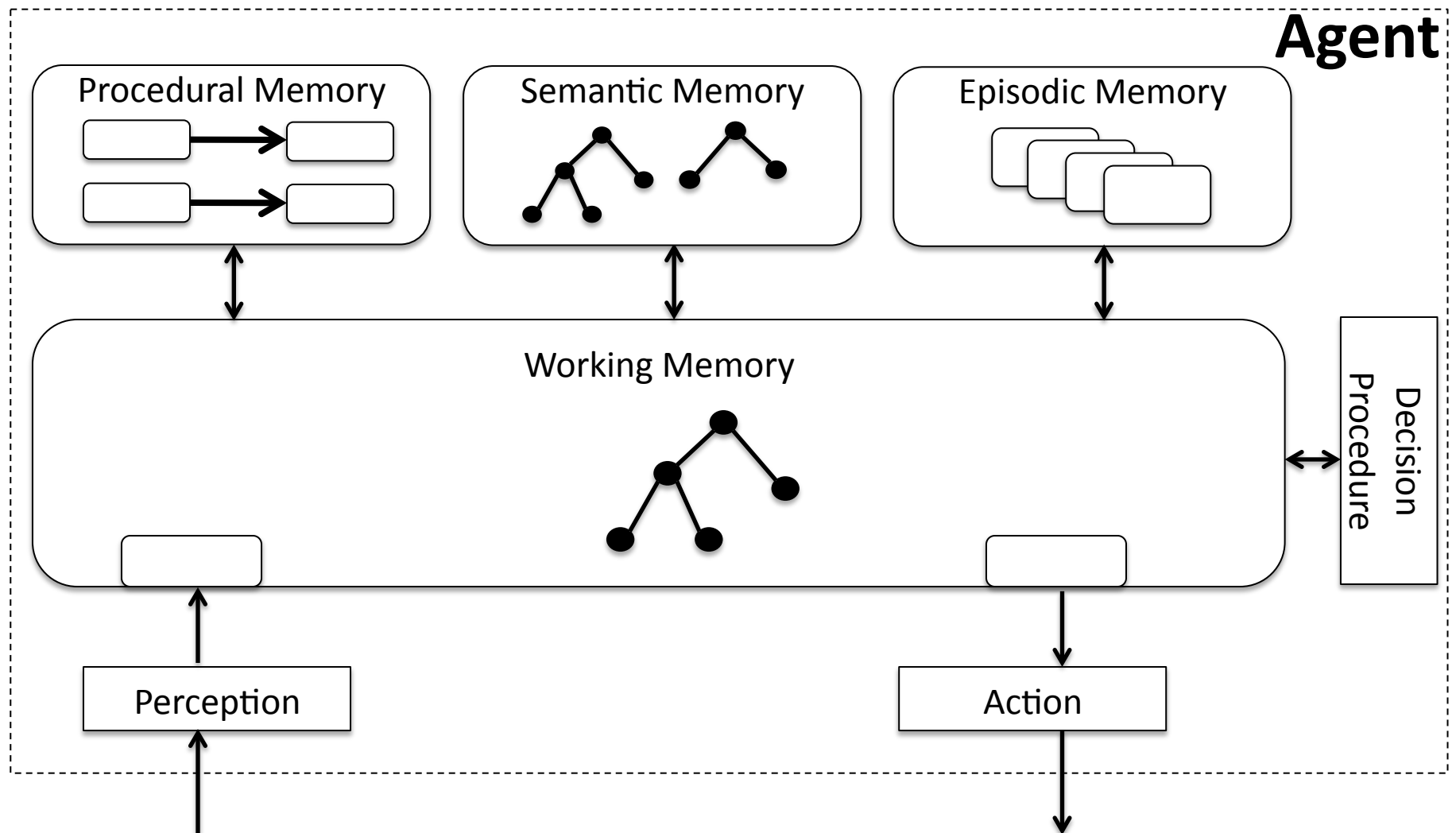
This Talk

Analysis of memory systems in Soar

Focus: function & efficiency

Future directions

Soar Memory Systems Overview

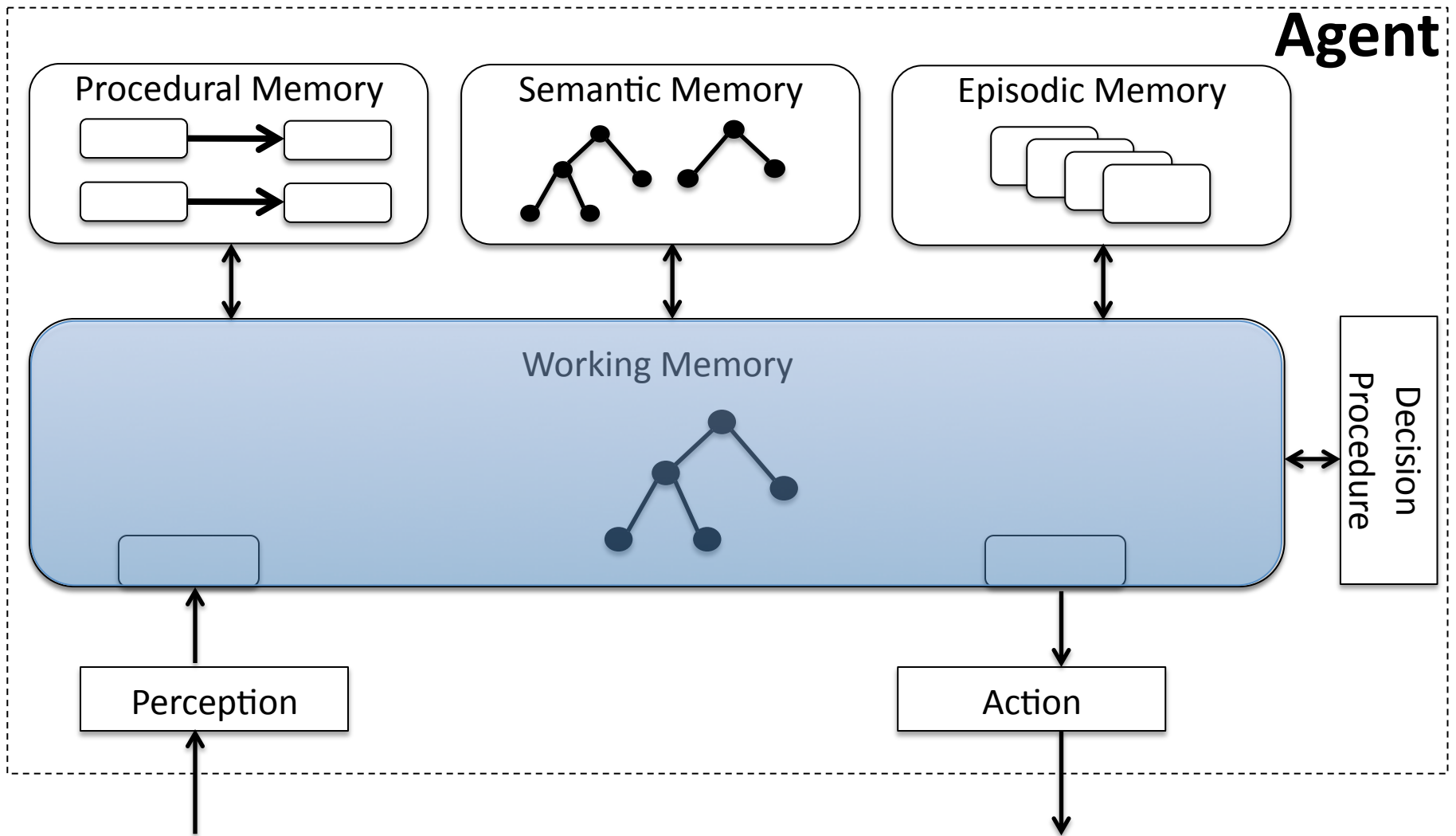


Search Dichotomy

To remain reactive, while bringing to bear large amounts of knowledge to reason in complex tasks, Soar divides search

Problem Search	Knowledge Search
Deliberate reasoning via operators	Long-term memory retrievals
Combinatorial	Bounded
Generative	Limited [to directly available information]

Working Memory



Working Memory Function

Capture current agent state

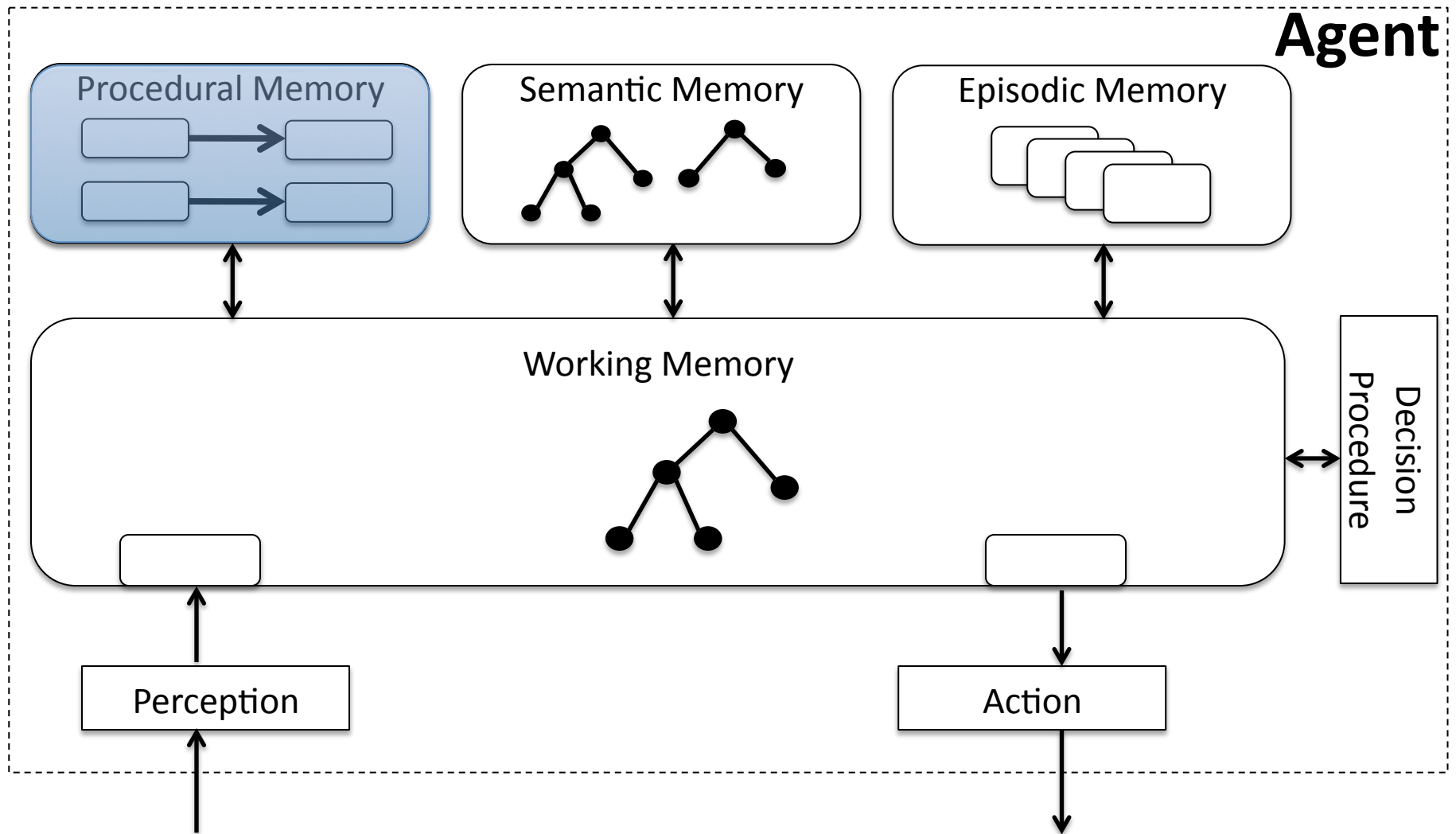
Represent arbitrary and novel combinations and compositions of symbols

- Separate store (vs. activated long-term)

Provide common representation substrate

- Initiate external action
- Cue long-term memories (and hold retrievals)

Procedural Memory



Procedural Memory Function

Knowledge of when and how to perform internal and external actions

- Initiate actions in the external environment
- Cue internal memory systems
- Deliberate reasoning

Procedural Storage

Chunking

Compiles sub-task processing to convert deliberation to reaction

Reinforcement Learning

Incrementally tunes production actions to reflect an expectation of action performance

Status

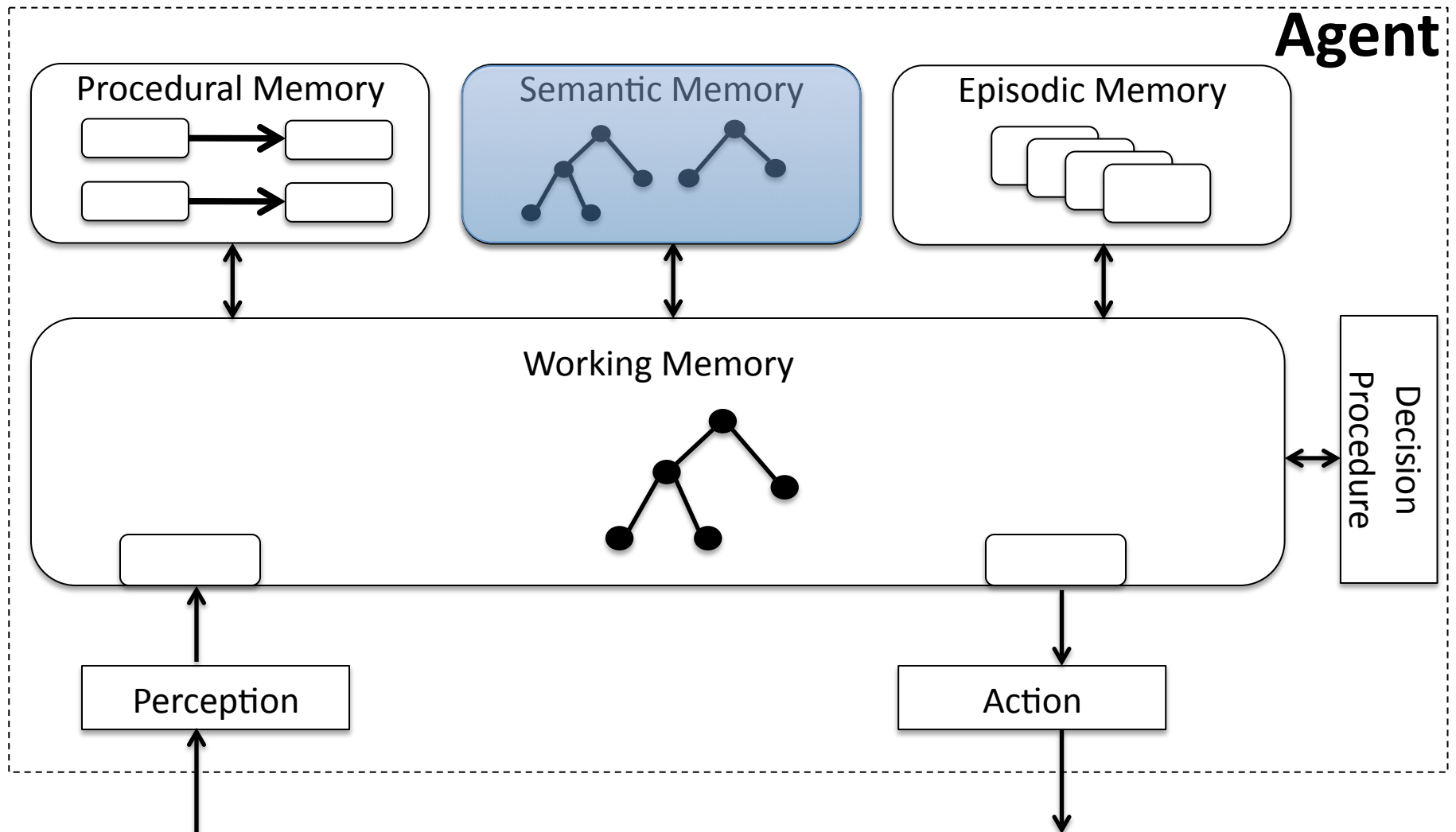
At this point, Soar functionally...

- represents state
- has long-term knowledge of when and how to perform internal and external action

Is there missing functionality?

If so, can an existing memory system efficiently provide this functionality?

Semantic Memory



Semantic Motivation

Who was the first President of the United States?

When/where/how did you first learn this fact?

Is context always necessary/advantageous?



Semantic Memory Function

Efficiently retrieve facts independent of original context

Assumes some experience is useful in differing situations (vocabulary, arithmetic, etc.)

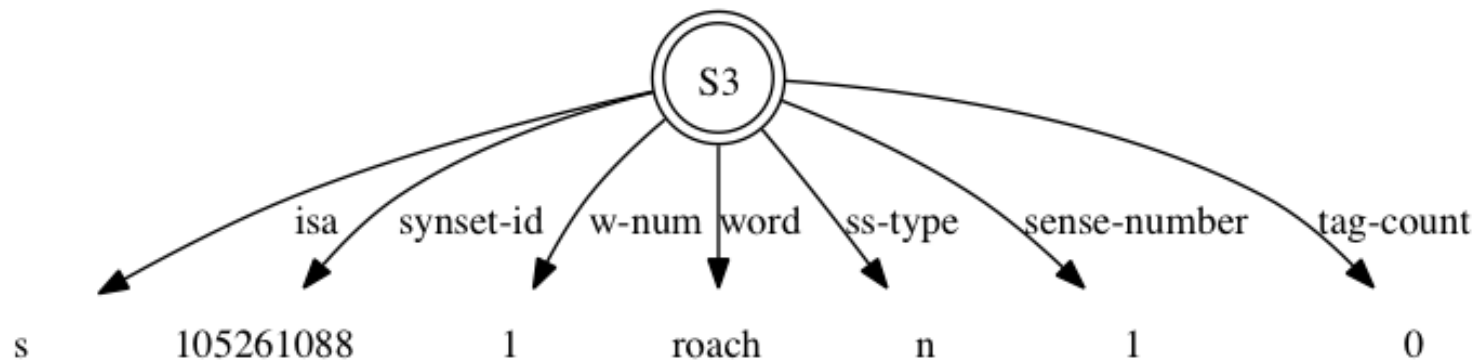
Semantic Knowledge

Long-term identifier and augmentations

- Same representation as working memory

Similar to ACT-R declarative chunks

- No pre-defined chunk types
- Supports multi-valued attributes



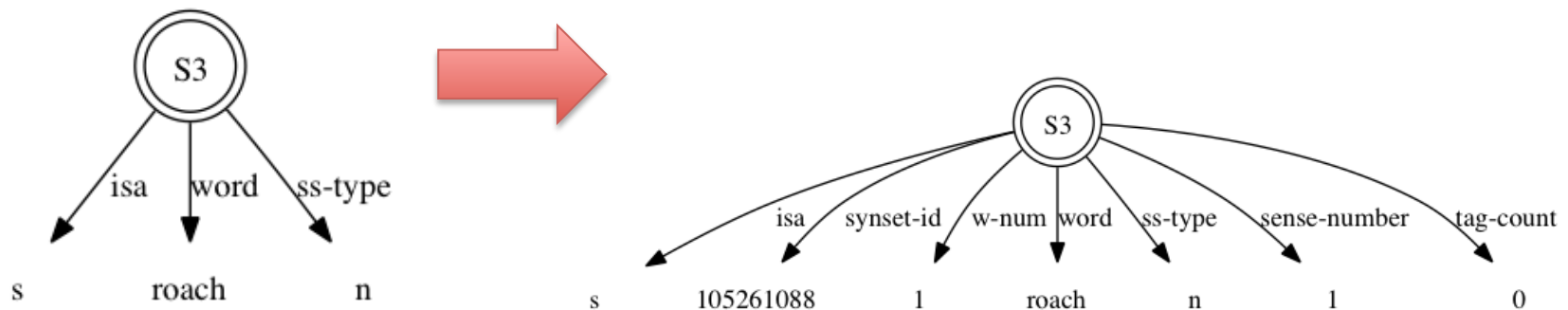
Semantic Retrievals

Given

- Conjunctive set of attribute[/value pairs]
- Semantic store

Find

- Most recently accessed identifier that contains cue structures



Semantic Scaling

(stay tuned for the next talk)

Status

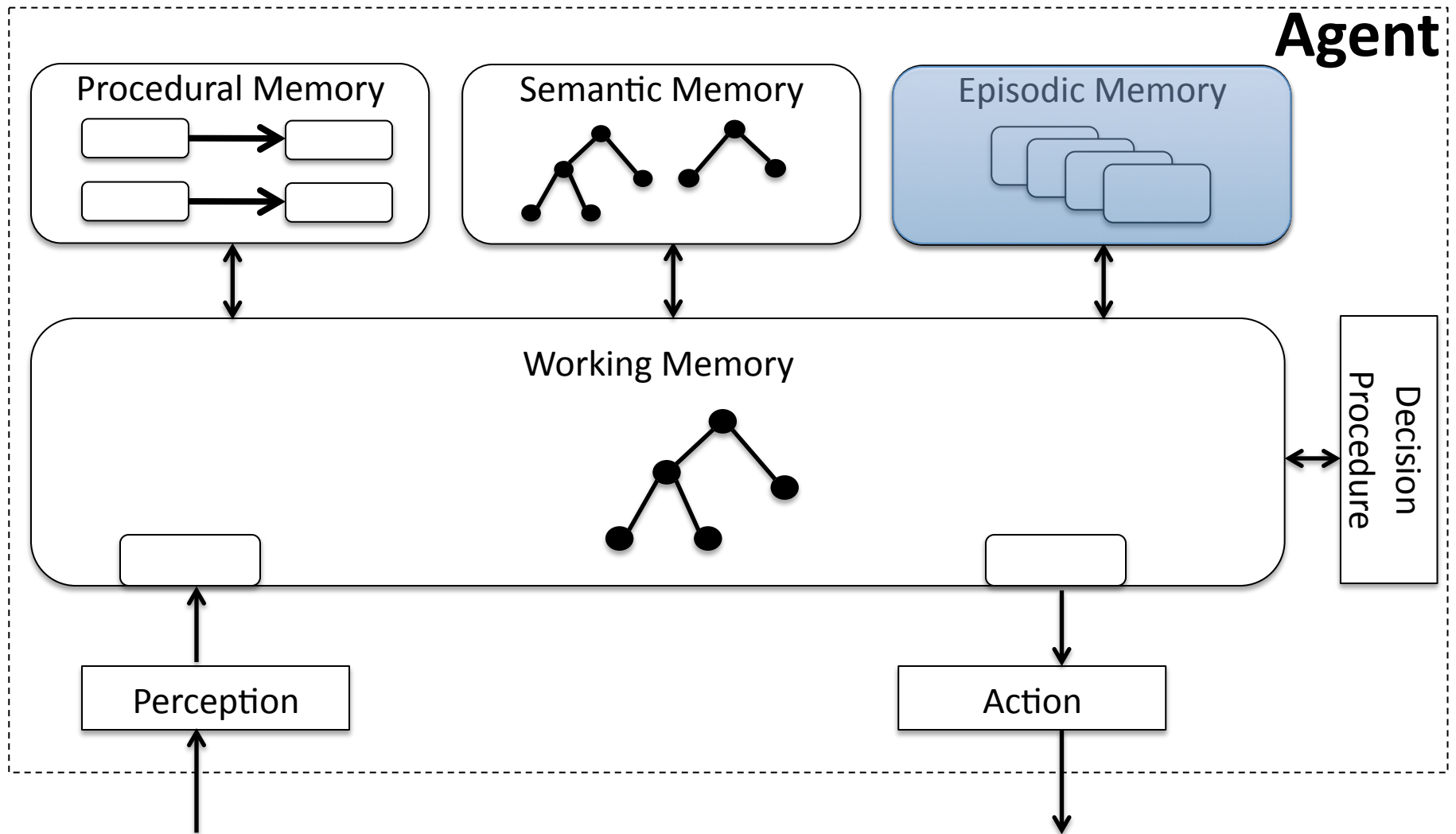
At this point, Soar functionally...

- represents state
- has long-term knowledge of when and how to perform internal and external action
- stores and retrieves context-less facts

Is there missing functionality?

If so, can an existing memory system efficiently provide this functionality?

Episodic Memory



Episodic Motivation



Recall the first time you failed a school assignment...

- What was the subject?
- How did you feel?
- How did your parents react?
 - Lessons learned?

Is personal history advantageous?

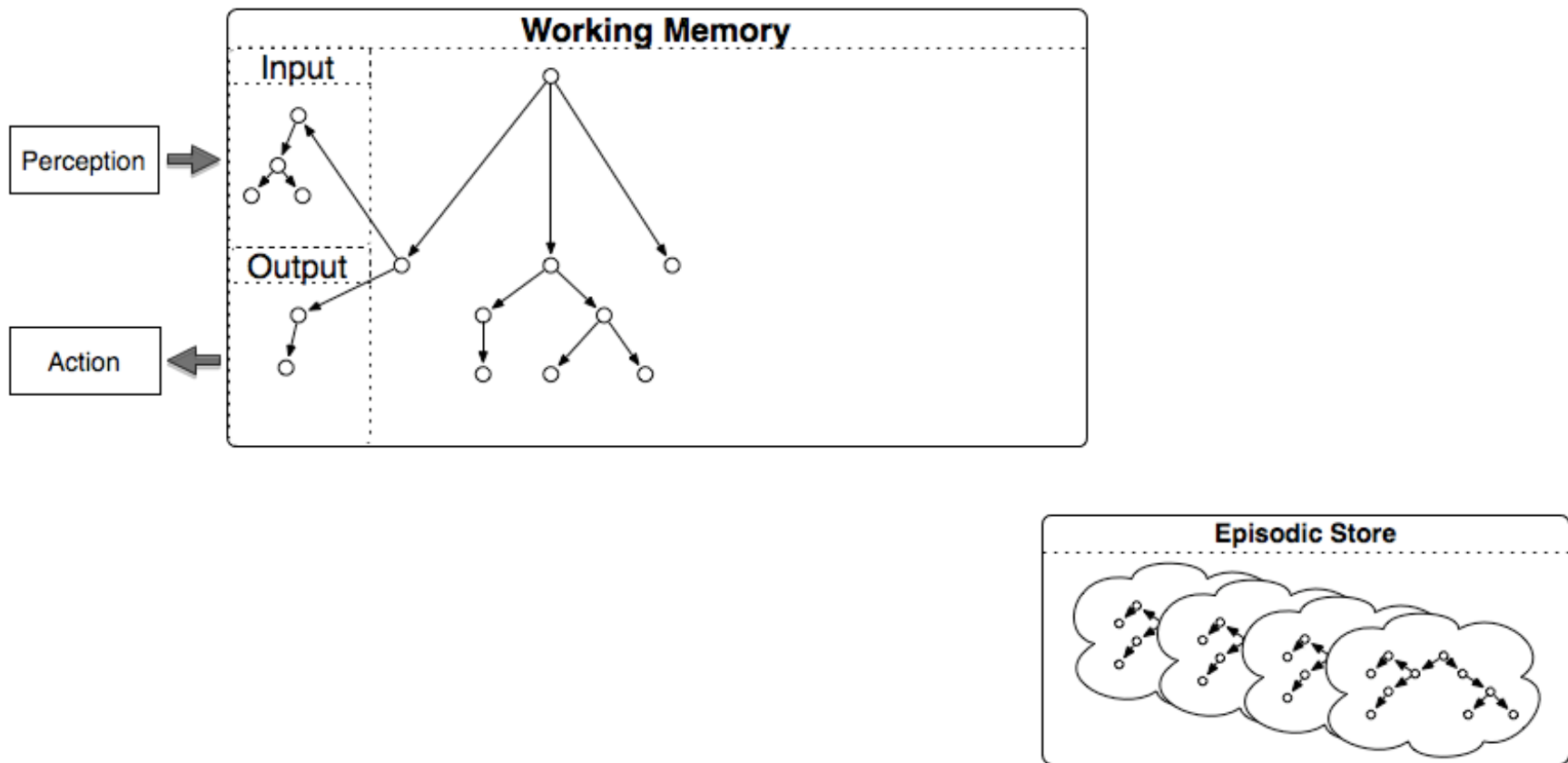
Episodic Memory Function

Efficiently capture and retrieve what an agent “remembers”

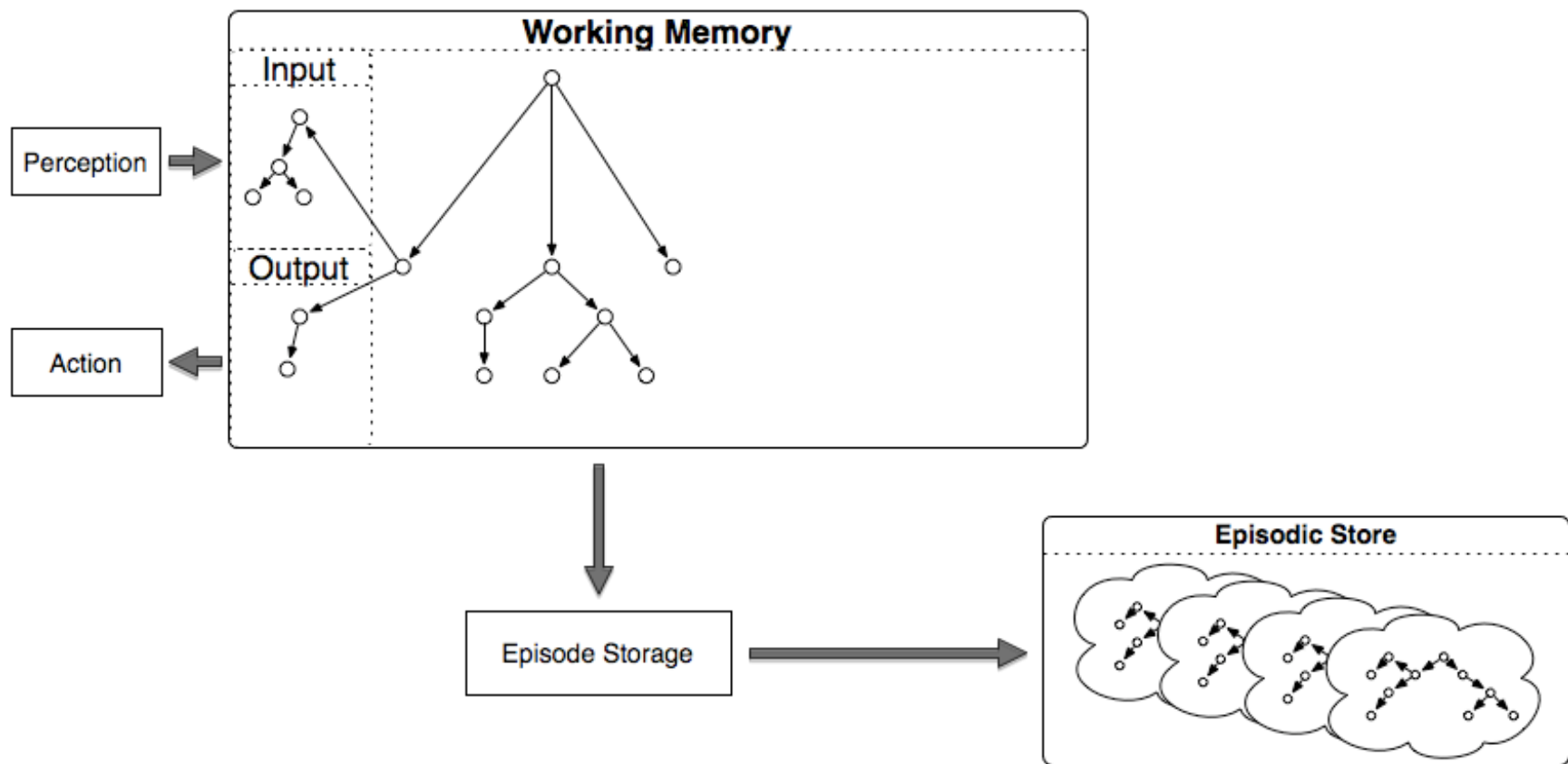
Many possible functional roles

Virtual sensing, action modeling, retroactive learning, ...

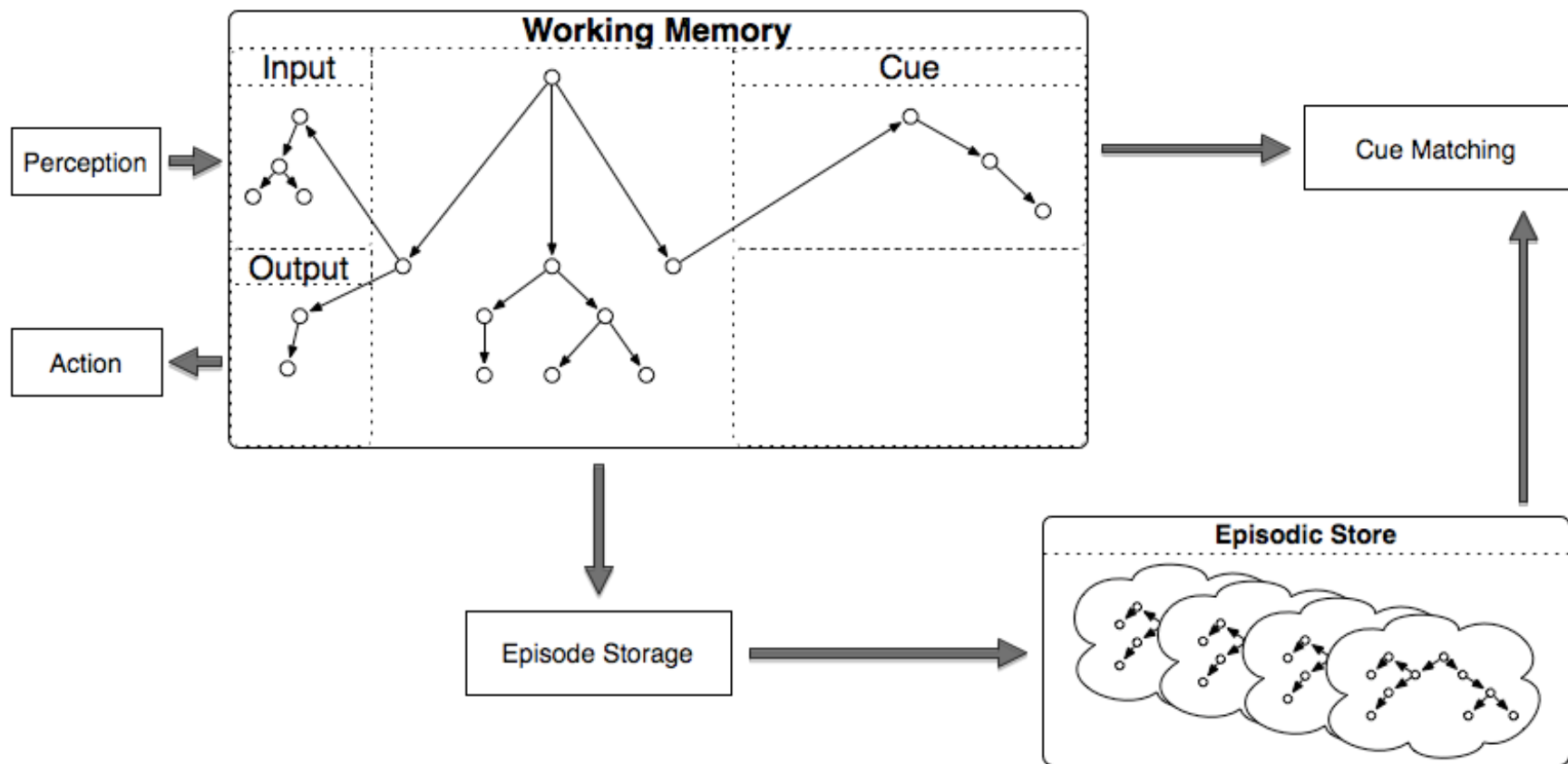
Episodic Integration in Soar



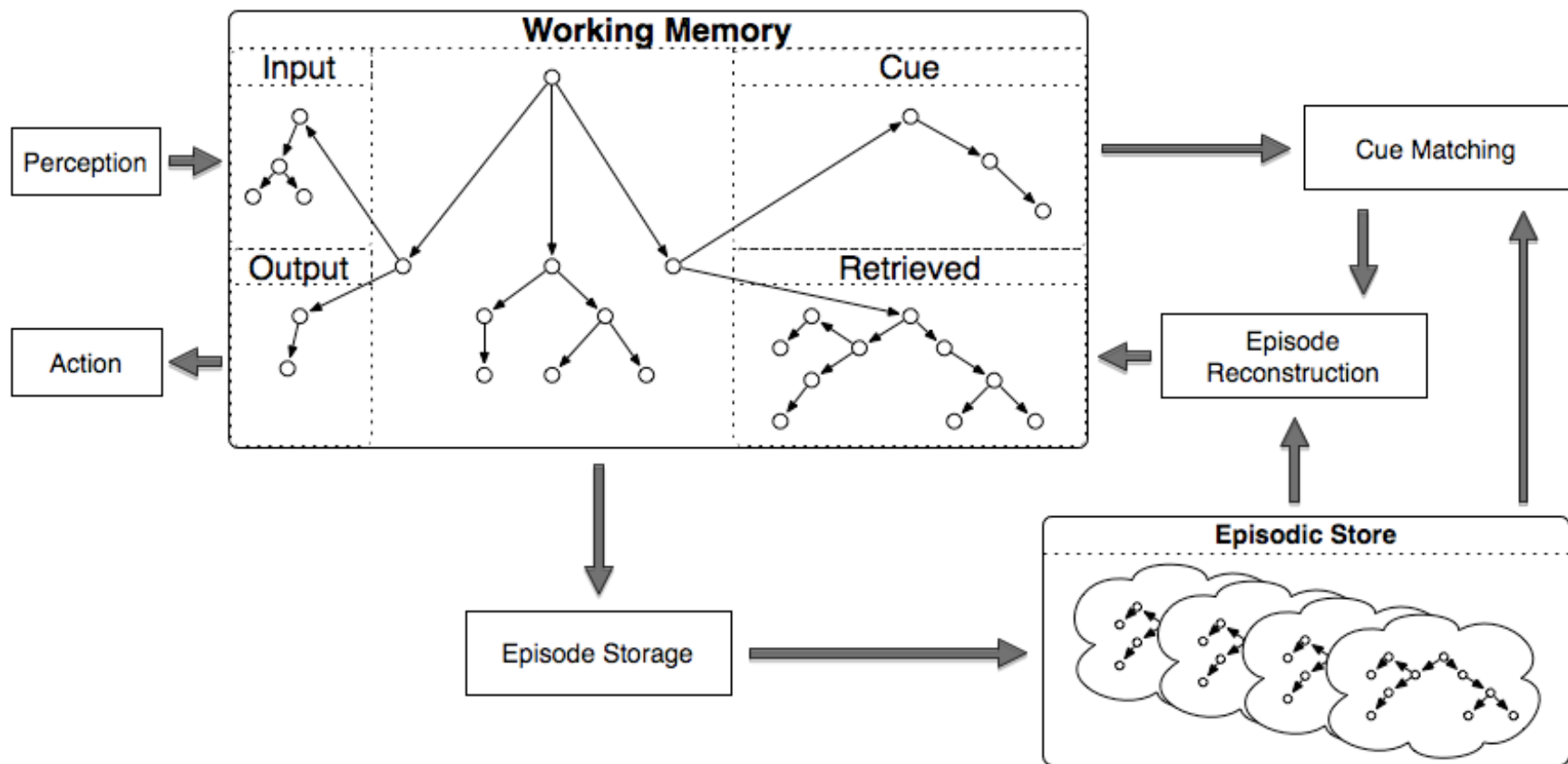
Episodic Integration in Soar



Episodic Integration in Soar



Episodic Integration in Soar



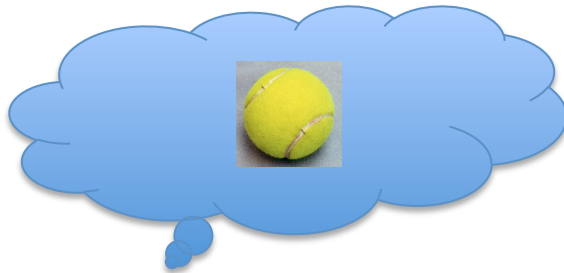
Episodic Retrievals

Given

- Contextualized cue of working memory structures
- Episodic store

Retrieve

- Single, best episode



Episodic Scaling

Very challenging in general, but usable results on commodity hardware for many tasks

TankSoar (MappingBot)

~ 2500 features

~ 70-90% inputs change



Episodic Scaling: TankSoar

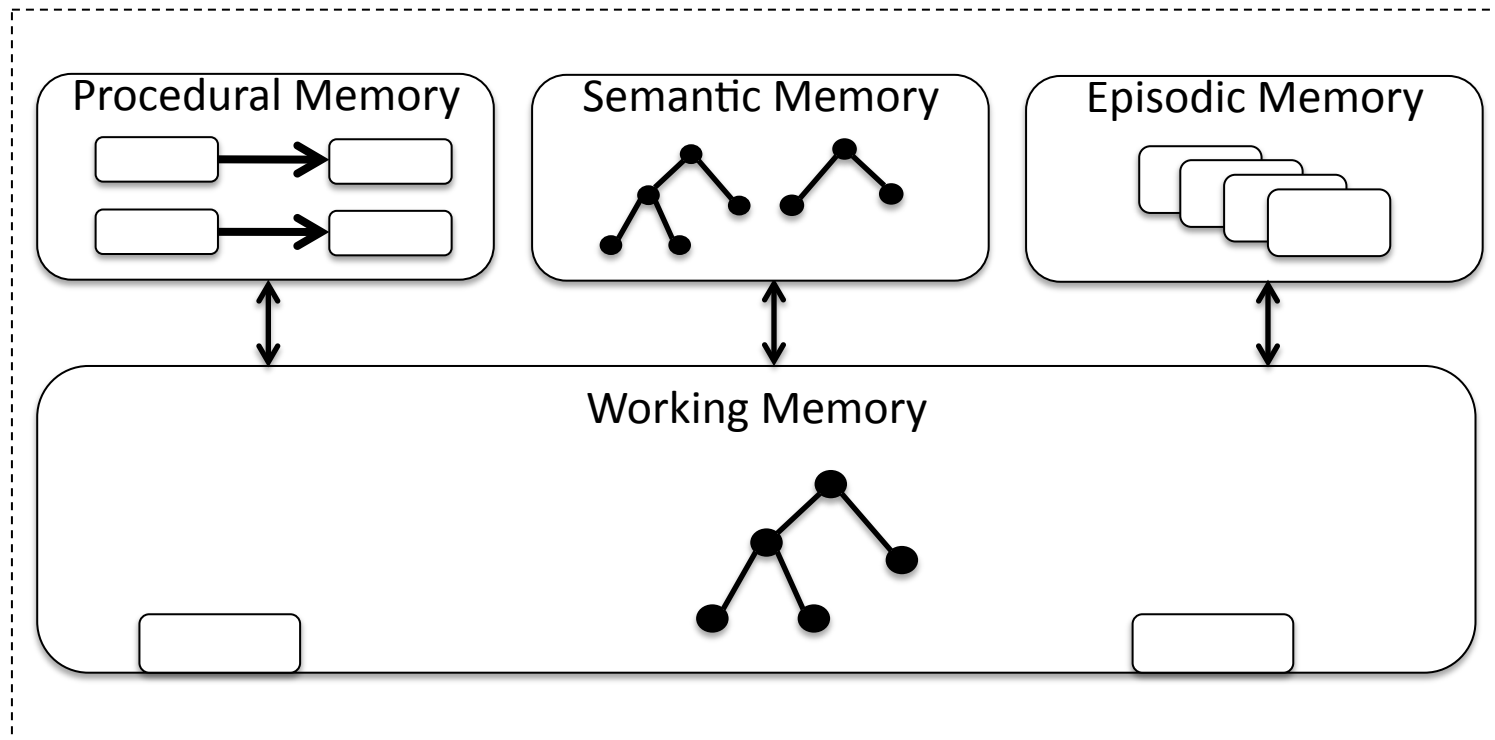
1 million episodes (~hours-days of real-time), 10 trials

Storage	Cue Matching*	Reconstruction**	Total
2.68ms 625-1620MB (0.64-1.66KB/ep)	57.6ms	22.65ms	82.93ms

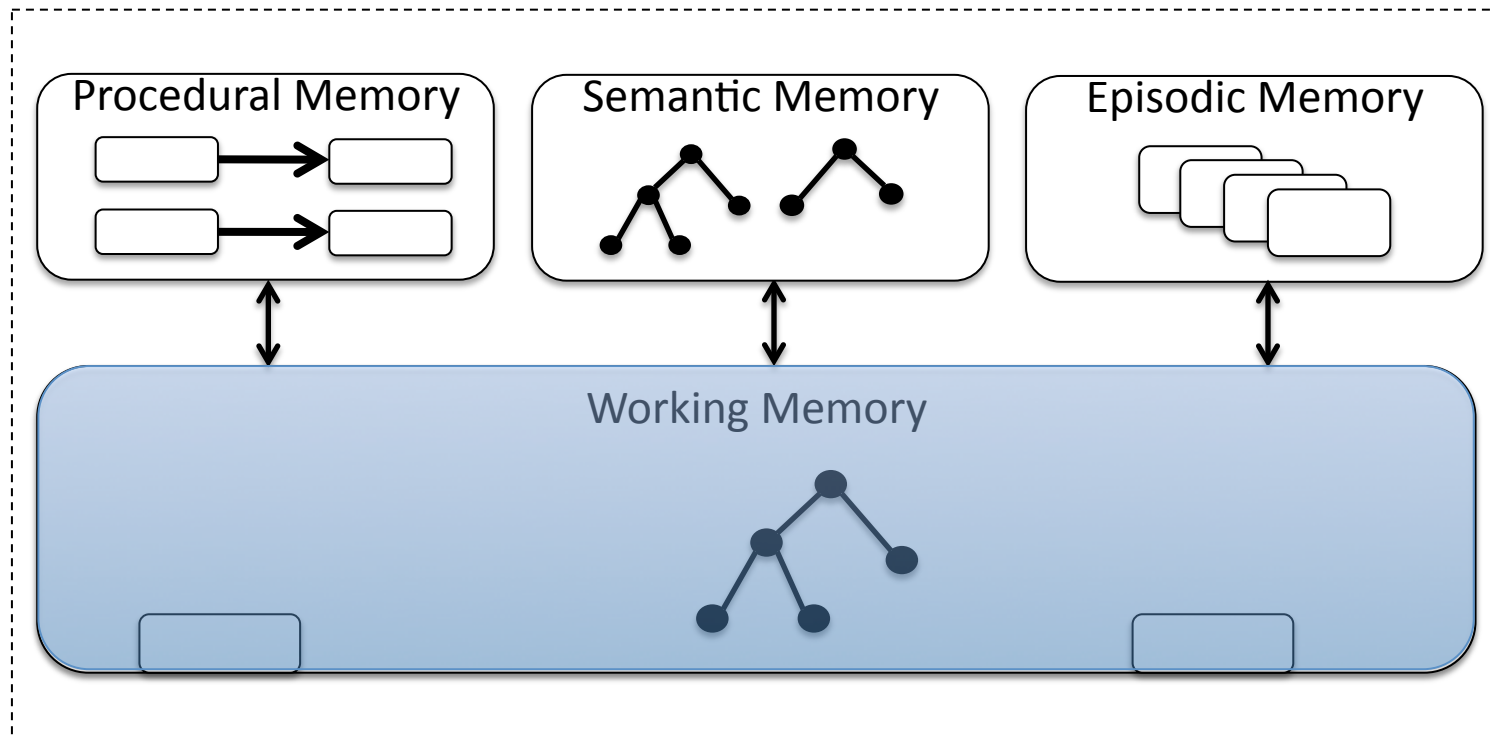
* 15 cues

** 50 random times

Soar Memory Systems

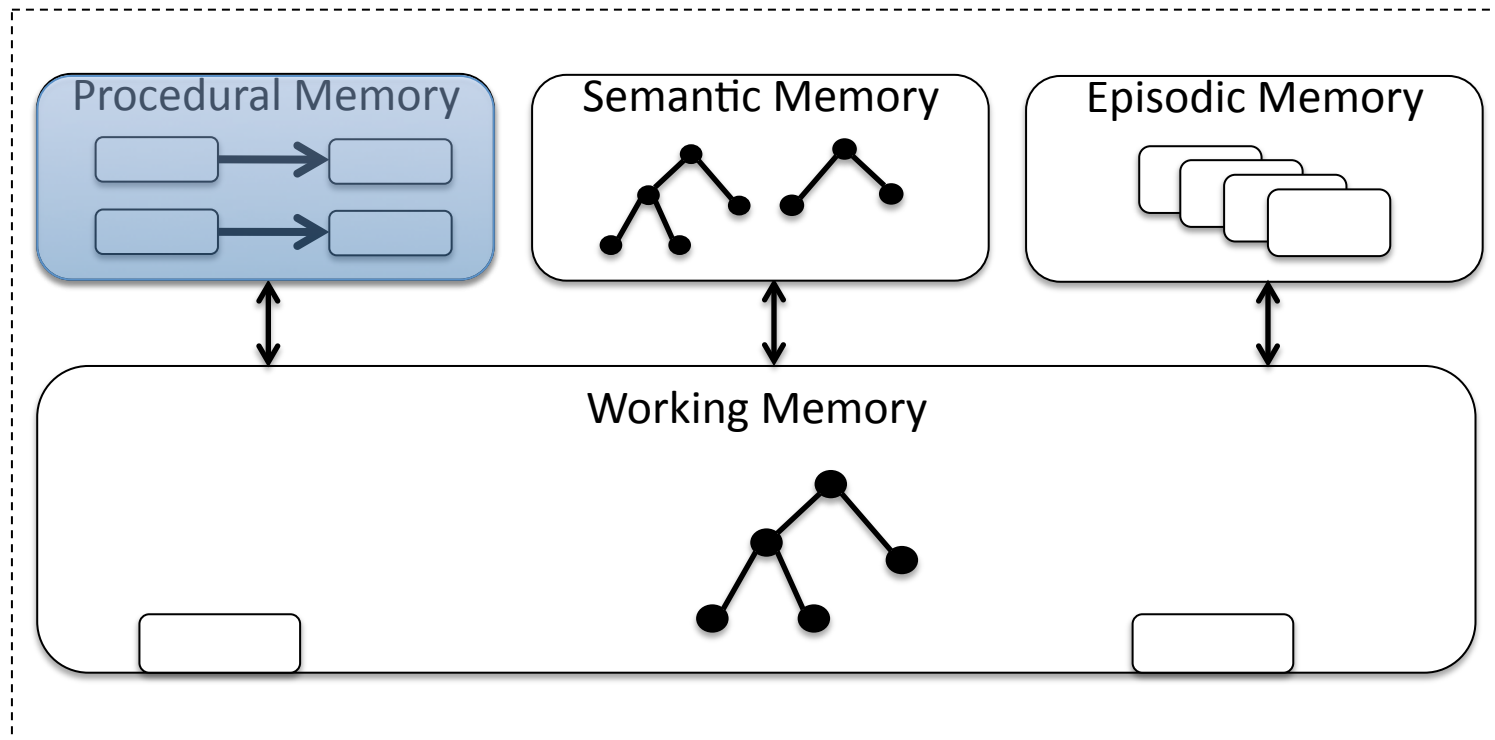


Soar Memory Systems



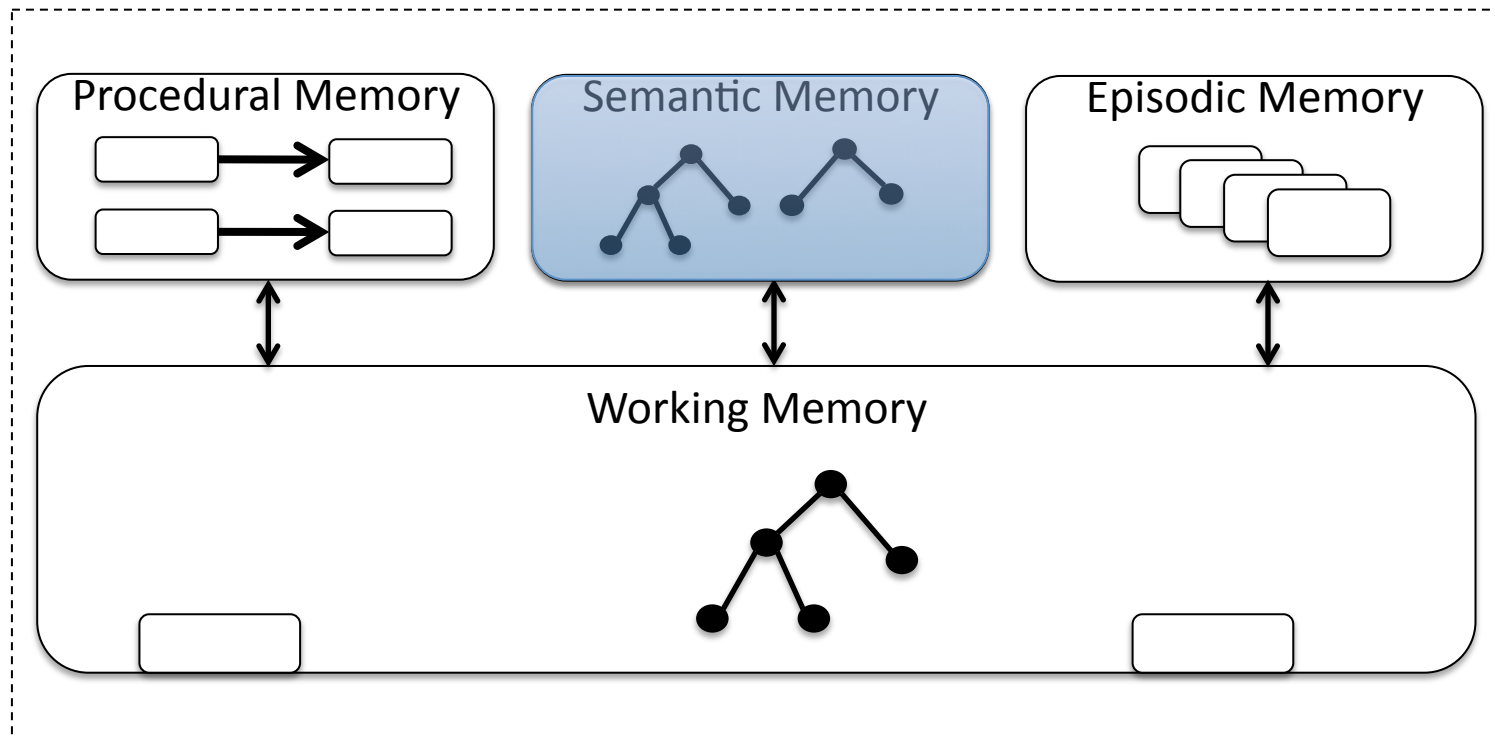
Symbolically represent, reason with, and retrieve long-term knowledge about arbitrary and novel combinations and compositions of symbols

Soar Memory Systems



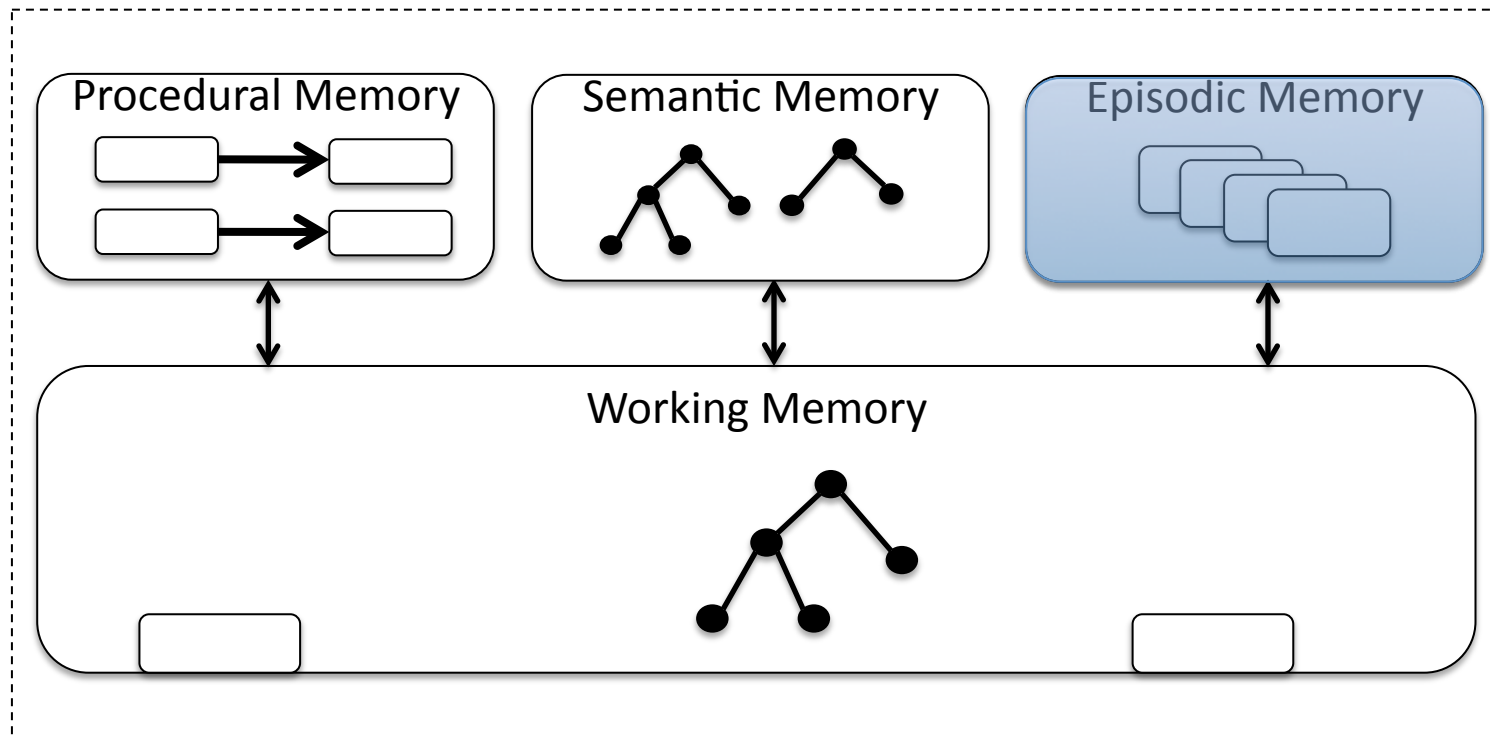
When and how to perform internal and external actions

Soar Memory Systems



Content-addressable access to facts and relations,
independent of original context

Soar Memory Systems



Content-addressable, contextualized access to
auto-biographical agent experience

Future Directions

- Automatic storage of semantic knowledge
- Bounding semantic and episodic retrievals
 - Will likely have to allow for some error
- Understanding the value of past experience
 - Enriching semantic and episodic retrievals with bias of context and history
- Synergies
 - Ex. mining historical trends from episodes

Evaluation

Nuggets

Functional and scalable LT
symbolic memory systems in
Soar 9.3.0

Coal

Developing mechanisms
without theory of use

vs.

Developing model of use
without a mechanism to
incorporate with agents

Evaluation

Nuggets

Functional and scalable LT
symbolic memory systems in
Soar 9.3.0

Coal

