Episodic & Semantic
Soar's Long-Term Declarative Memory Systems

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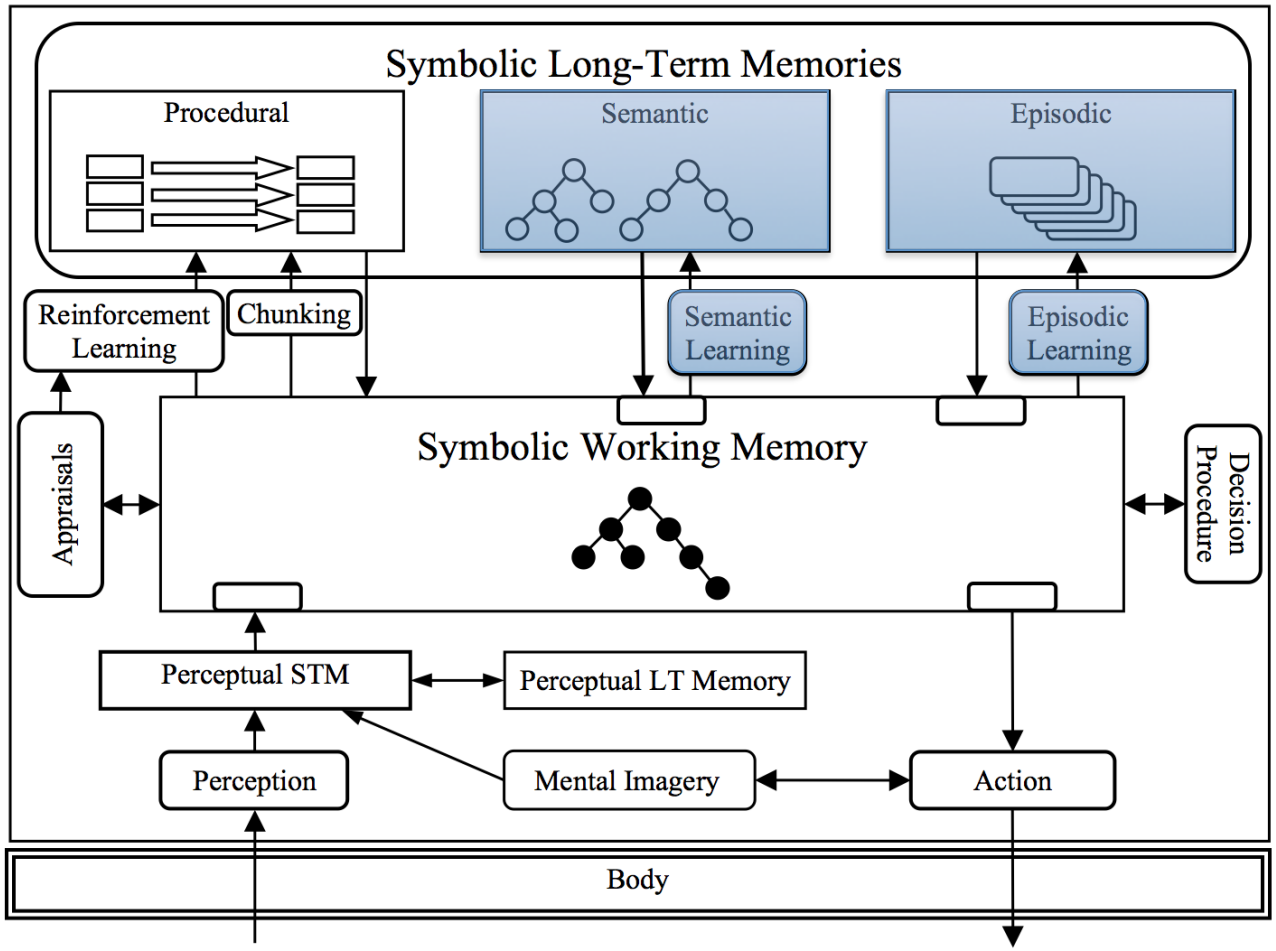
Why Declarative Long-Term Memory Systems?

Guiding Principle. Explore and evaluate new architectural mechanisms *if*…

- agents are missing important functionality *and*
- existing mechanisms cannot effectively and efficiently support this functionality

Soar 9


Symbolic Long-Term Memories
Procedural
Semantic
Episodic
Reinforcement Learning
Chunking
Semantic Learning
Episodic Learning
Symbolic Working Memory
Appraisals
Decision Procedure
Perceptual STM
Perceptual LT Memory
Perception
Mental Imagery
Action
Body

Autobiographic Agent History

What

The ability to remember, in context, experience that wasn't necessarily known to be important

Why

- Virtual Sensing [Nuxoll & Laird 2007]
- Action Modeling [Xu & Laird 2010]

…

Arguments for a distinct mechanism

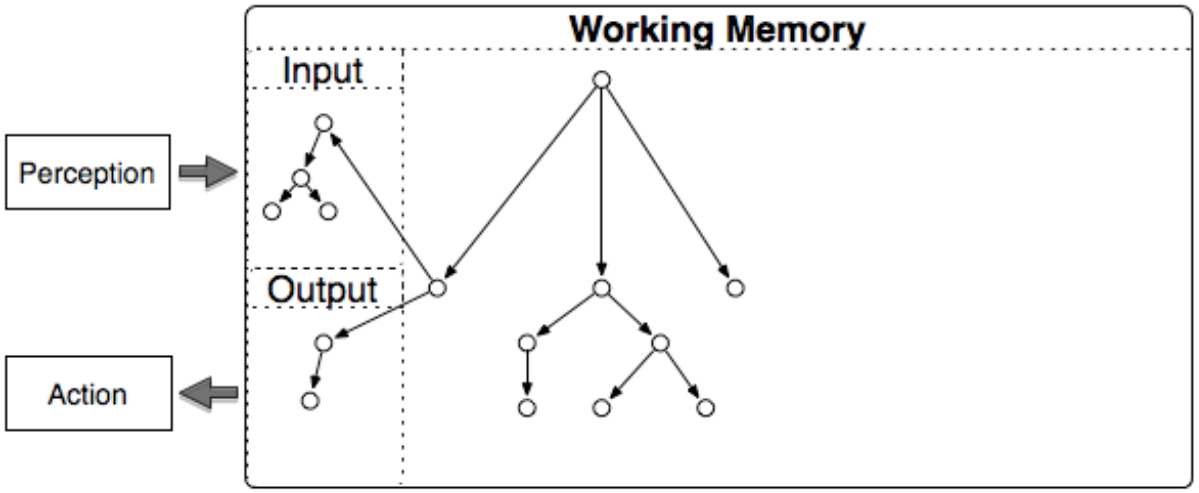
- Rule matching scales with working memory size
- Rule-based episodes would be problematic to encode and retrieve

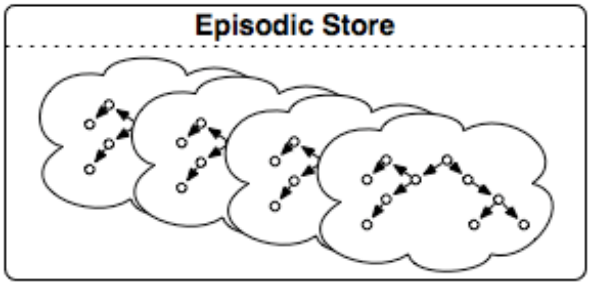
Episodic Memory: Big Picture

Episodic memory is a weak learning mechanism

- Automatically captures, stores, and temporally indexes agent state
- Supports content-addressable agent interface to autobiographical prior experience

Architectural Integration





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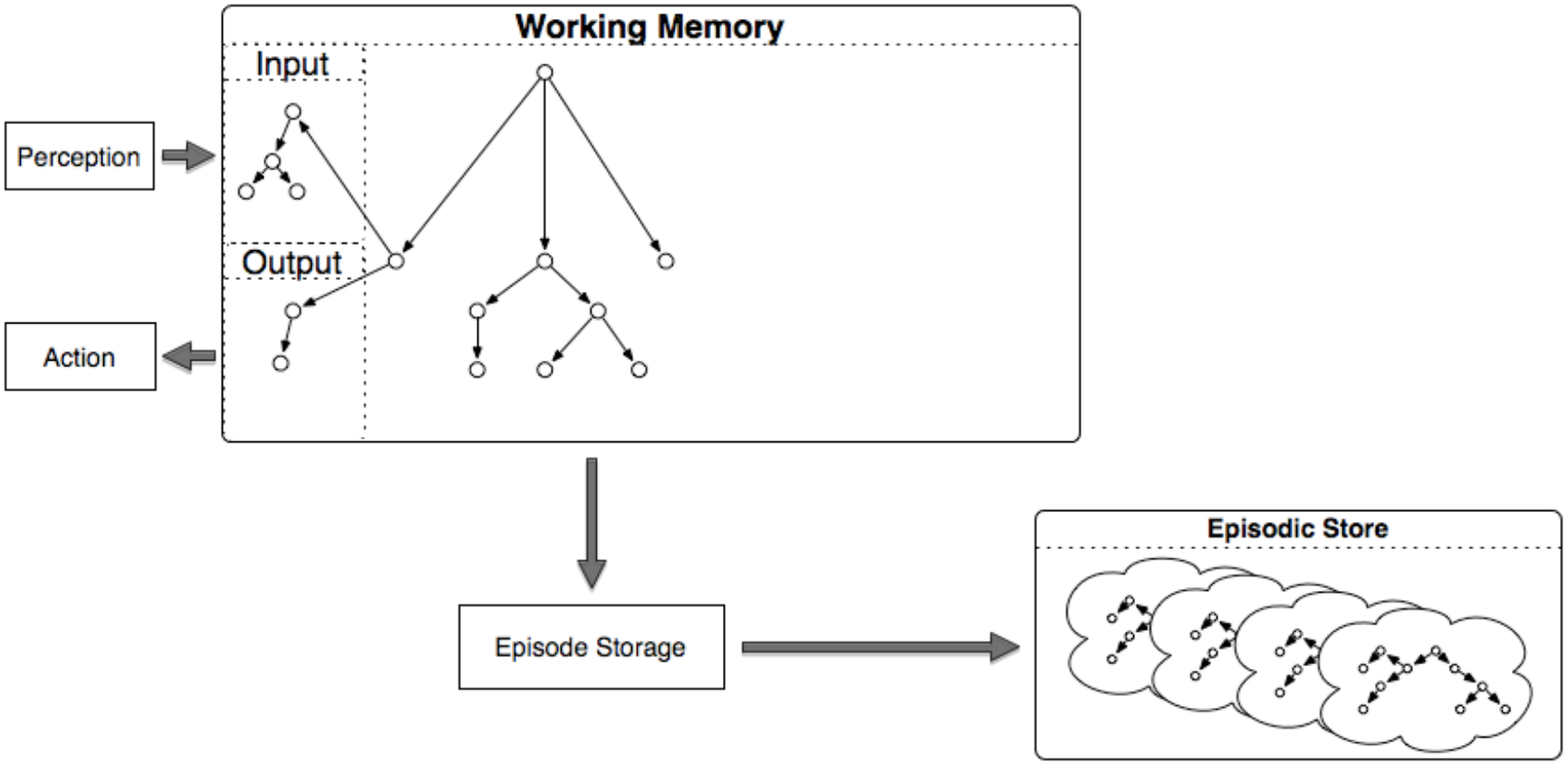

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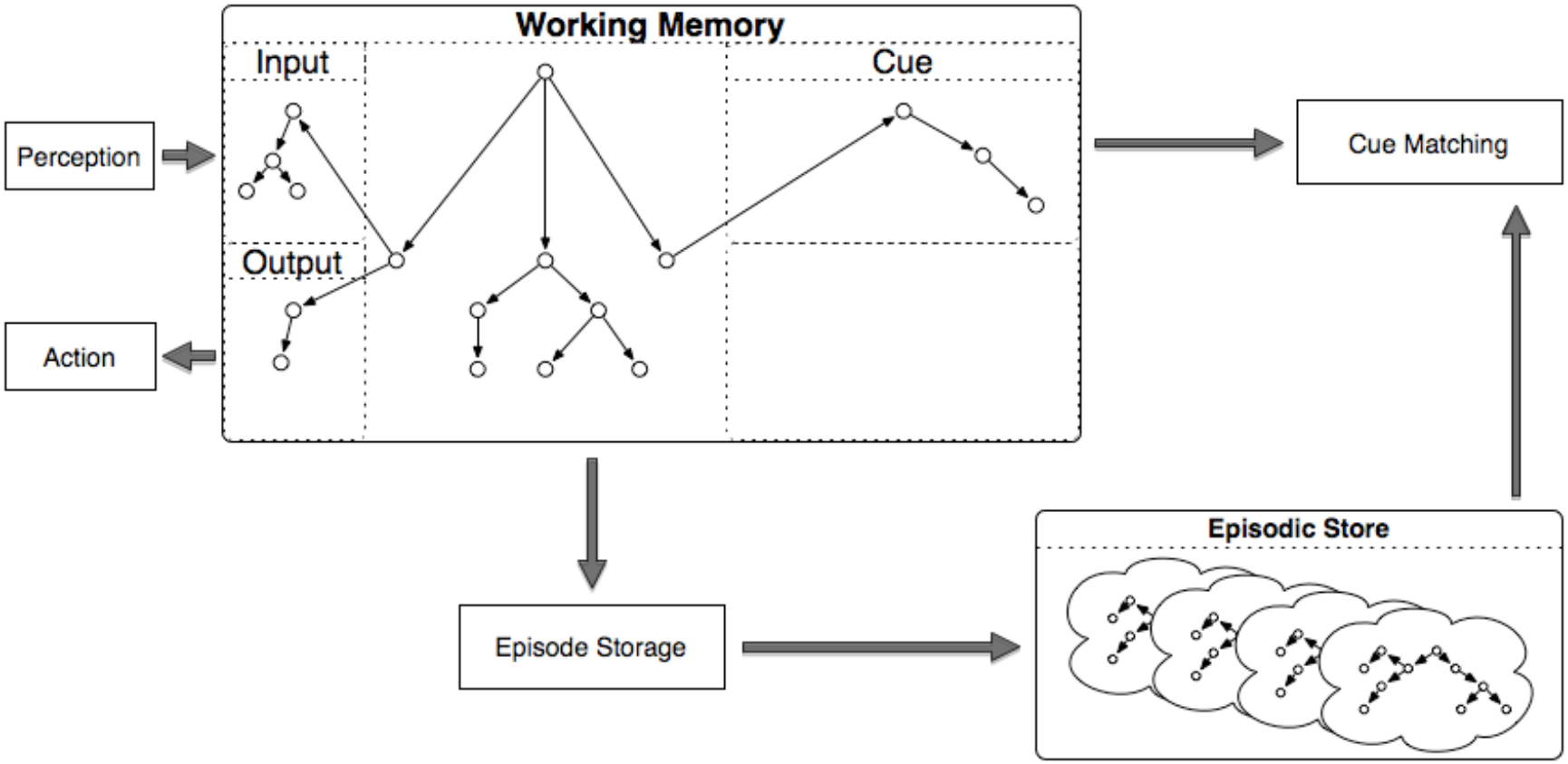

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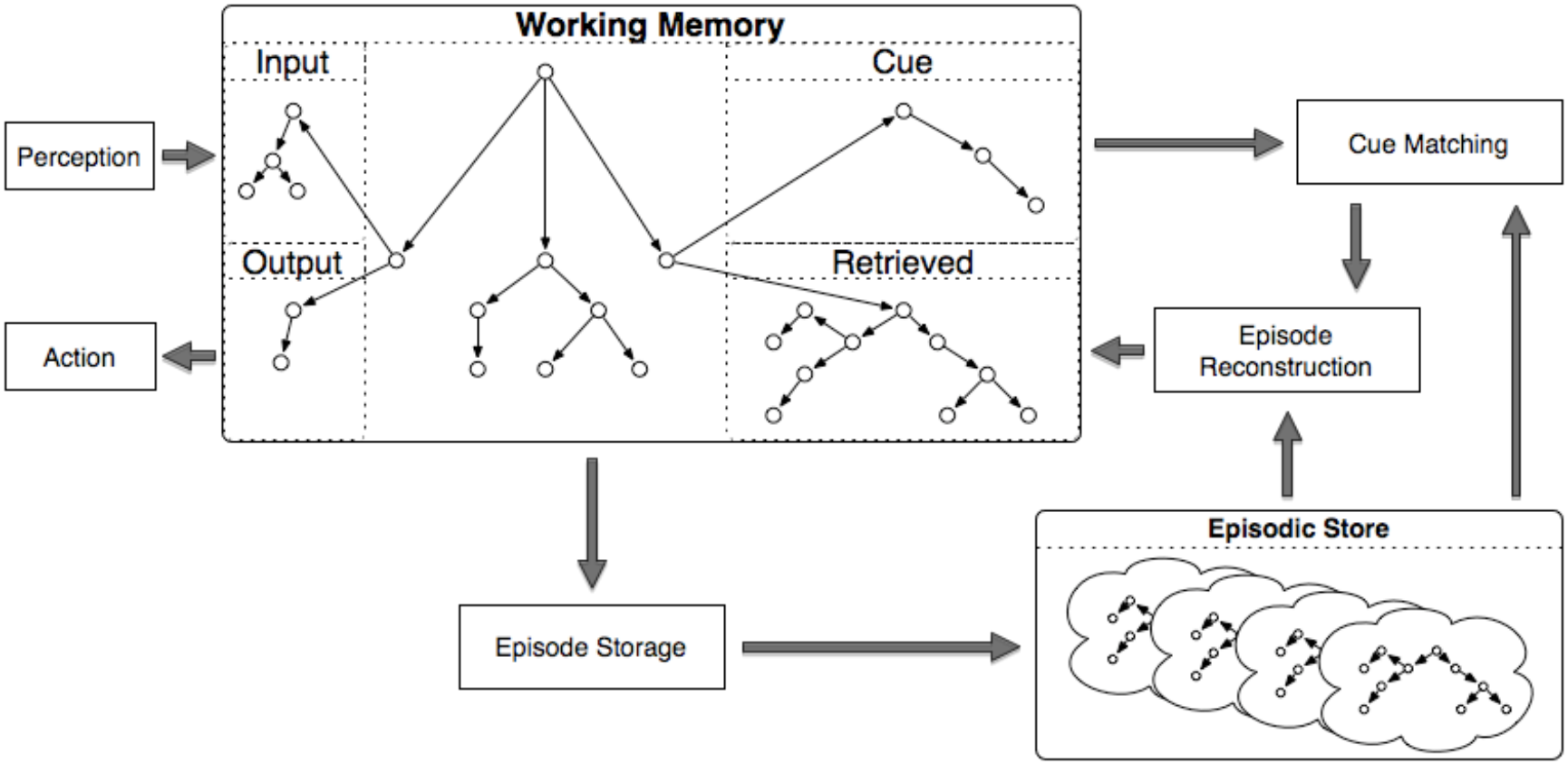

Mechanism Detail

Encoding

Faithful “snapshot” of top-state

Storage

No dynamics (such as forgetting)

Retrieval

Nearest-neighbor using structural cue matching

- Biased by recency
- Partial match

Select Prior Work

Architectural Integration & Agent Capabilities

Extending Cognitive Architecture with Episodic Memory
Andrew Nuxoll & John Laird. AAAI (2007)

Efficiency

Efficiently Implementing Episodic Memory
Nate Derbinsky & John Laird. ICCBR (2009)

Integrating Learning Mechanisms

Learning to Use Episodic Memory
Nicholas Gorski & John Laird. Cognitive Systems Research (2011)

Using Diverse Cognitive Mechanisms for Action Modeling
John Laird, Joseph Xu, & Sam Wintermute. ICCM (2010)

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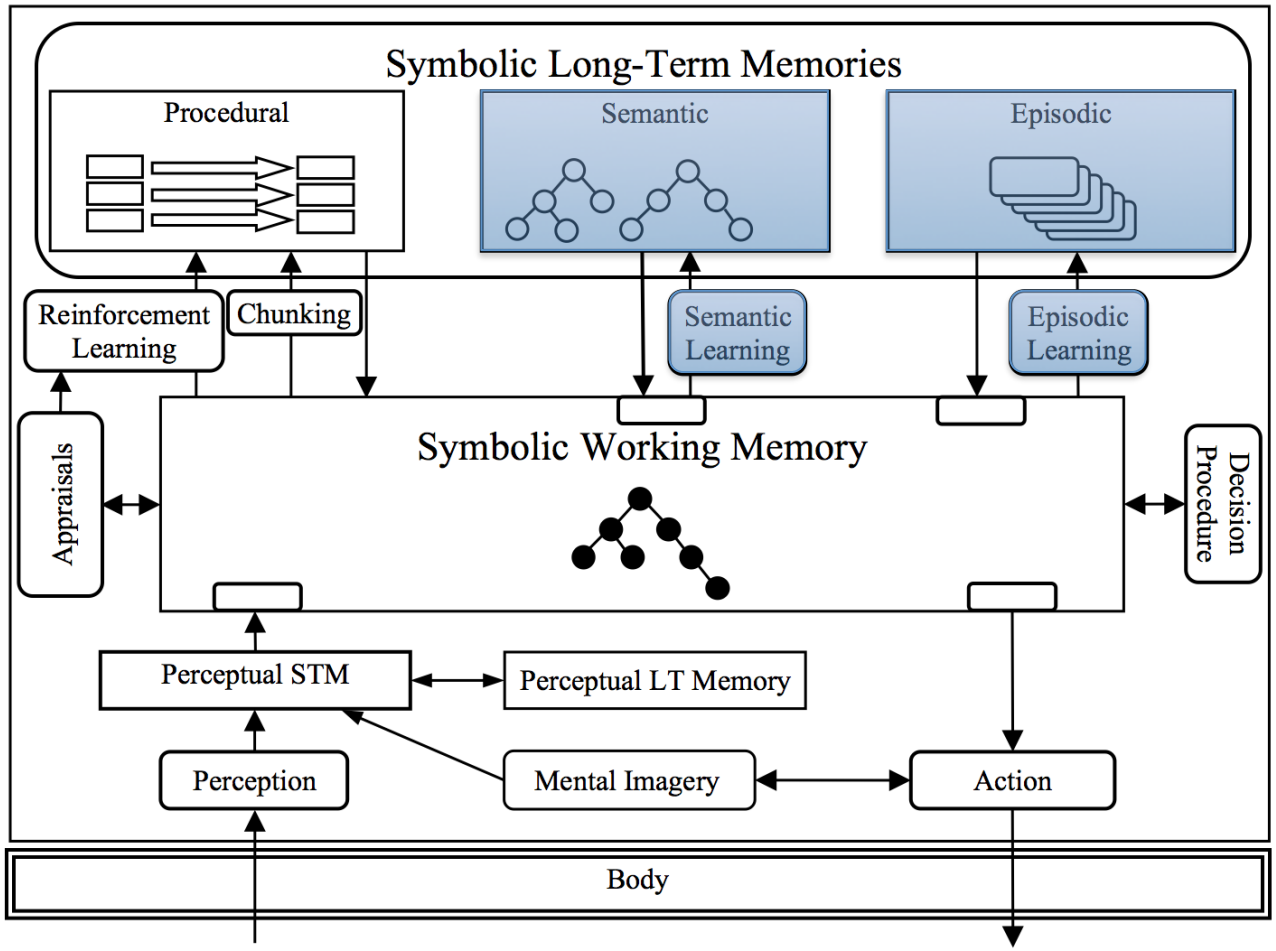
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Declarative Knowledge Store

What

The ability to store and flexibly retrieve large amounts of knowledge about the world, independent of the context in which it was originally learned

Why

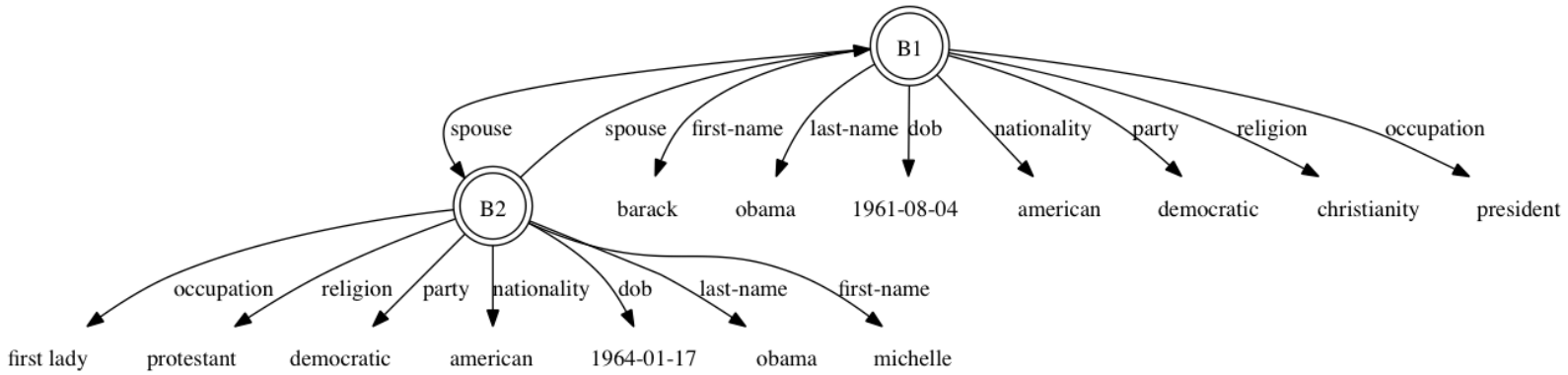
- Large, diverse KBs
  - Lexical (WordNet)
  - Ontological (Cyc)
  - …

Arguments for a distinct mechanism

- Data chunking: exponential rules, difficult to encode/change
- Working memory: rule matching grows with number of objects

Semantic Memory: Big Picture

Supports deliberate storage and retrieval of long-term objects, features, and relations



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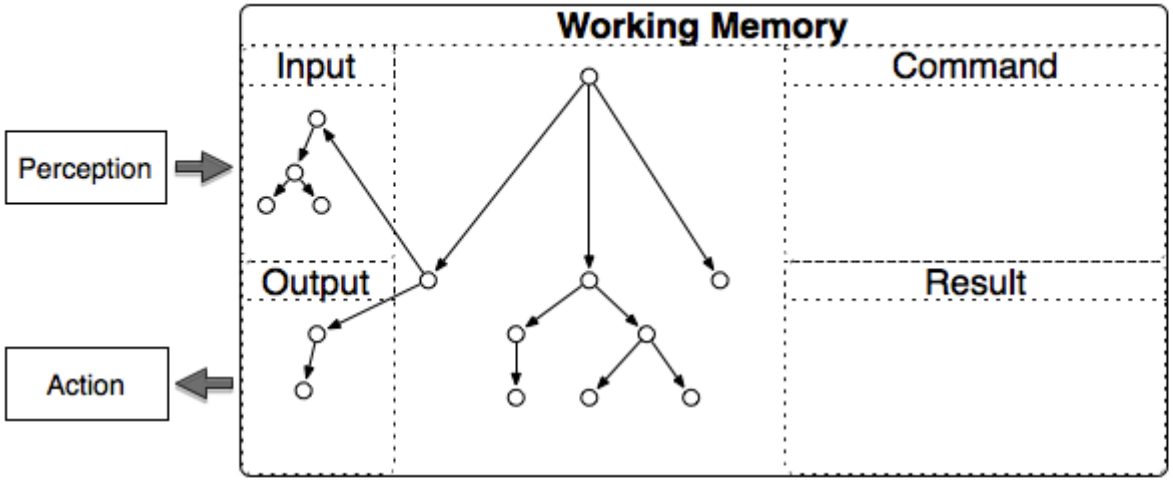
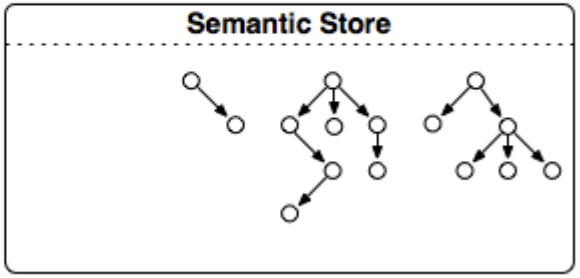
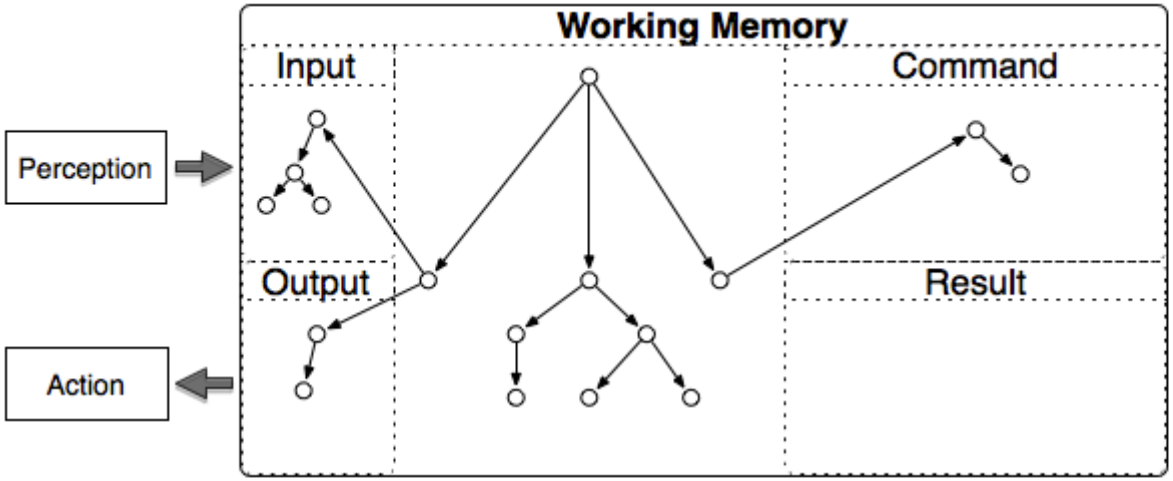
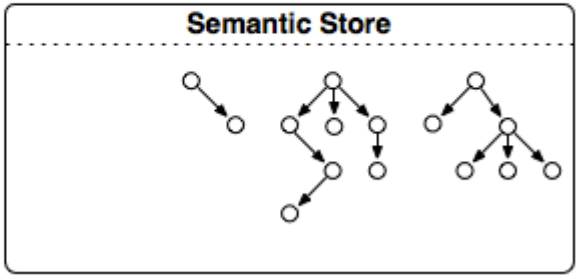




Architectural Integration

Storage





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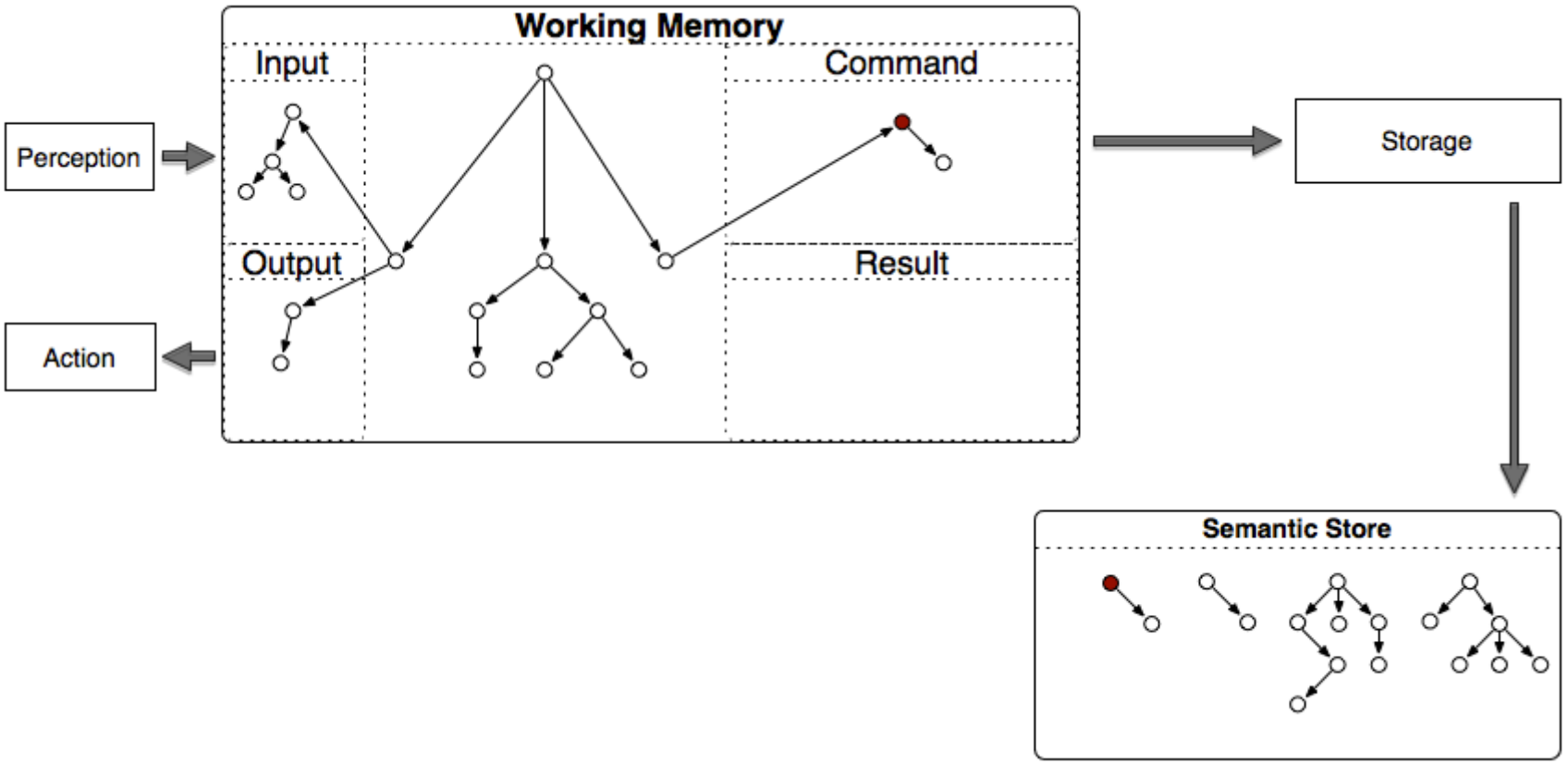

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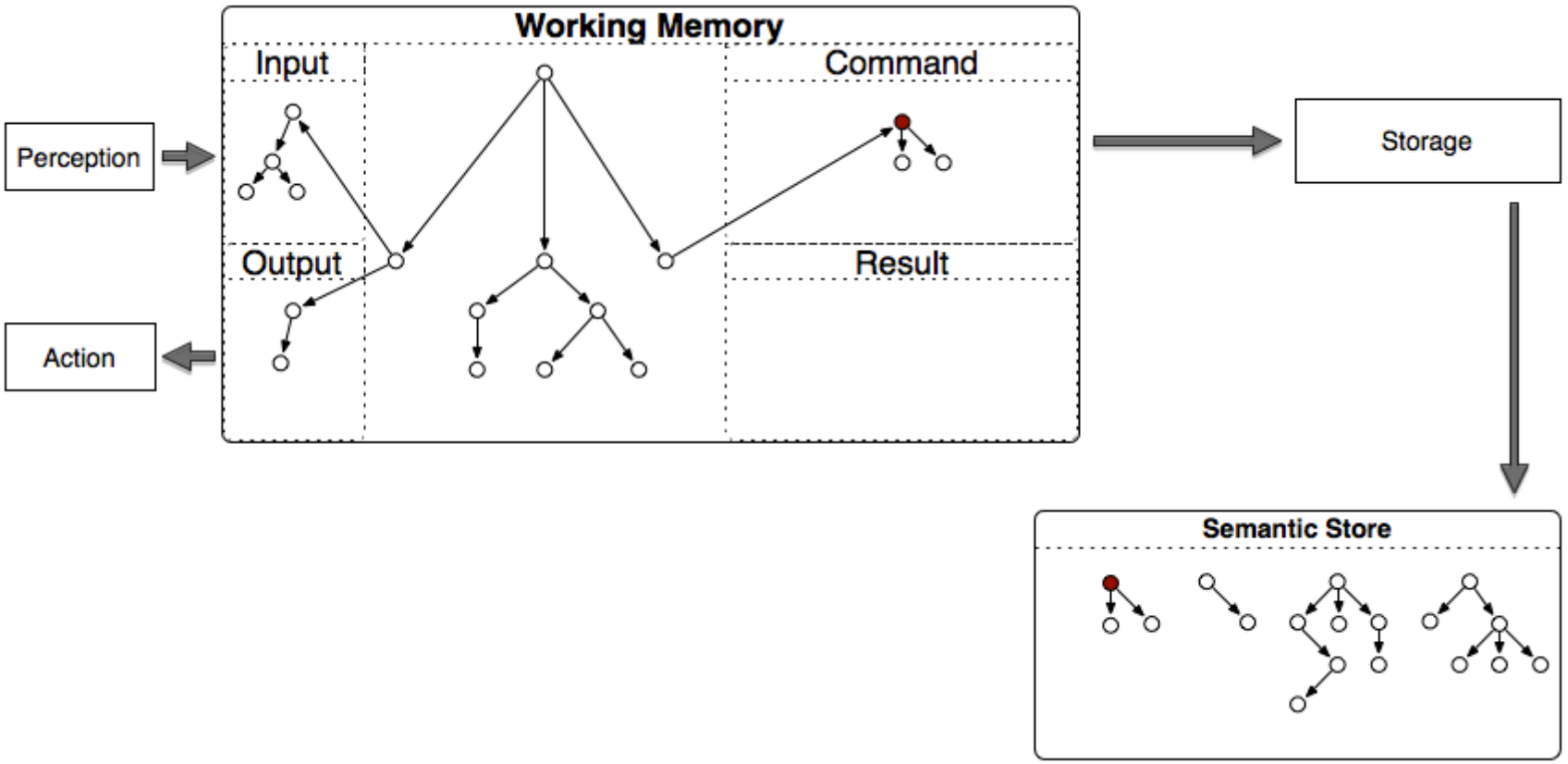
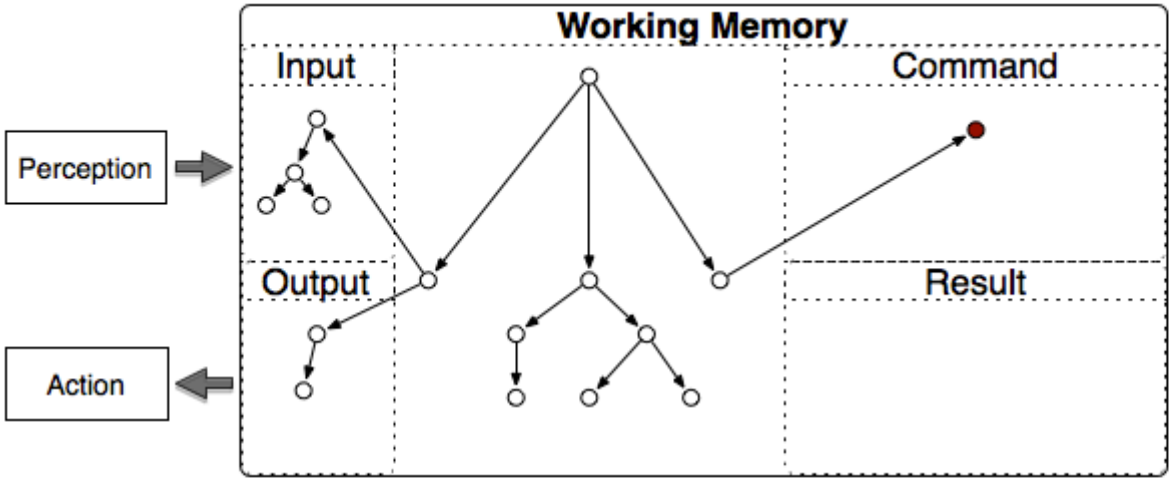
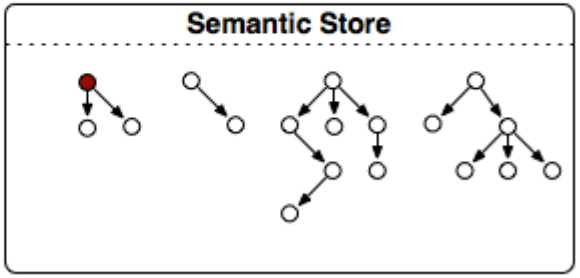


Architectural Integration

Non-Cue-Based Retrieval





Architectural Integration

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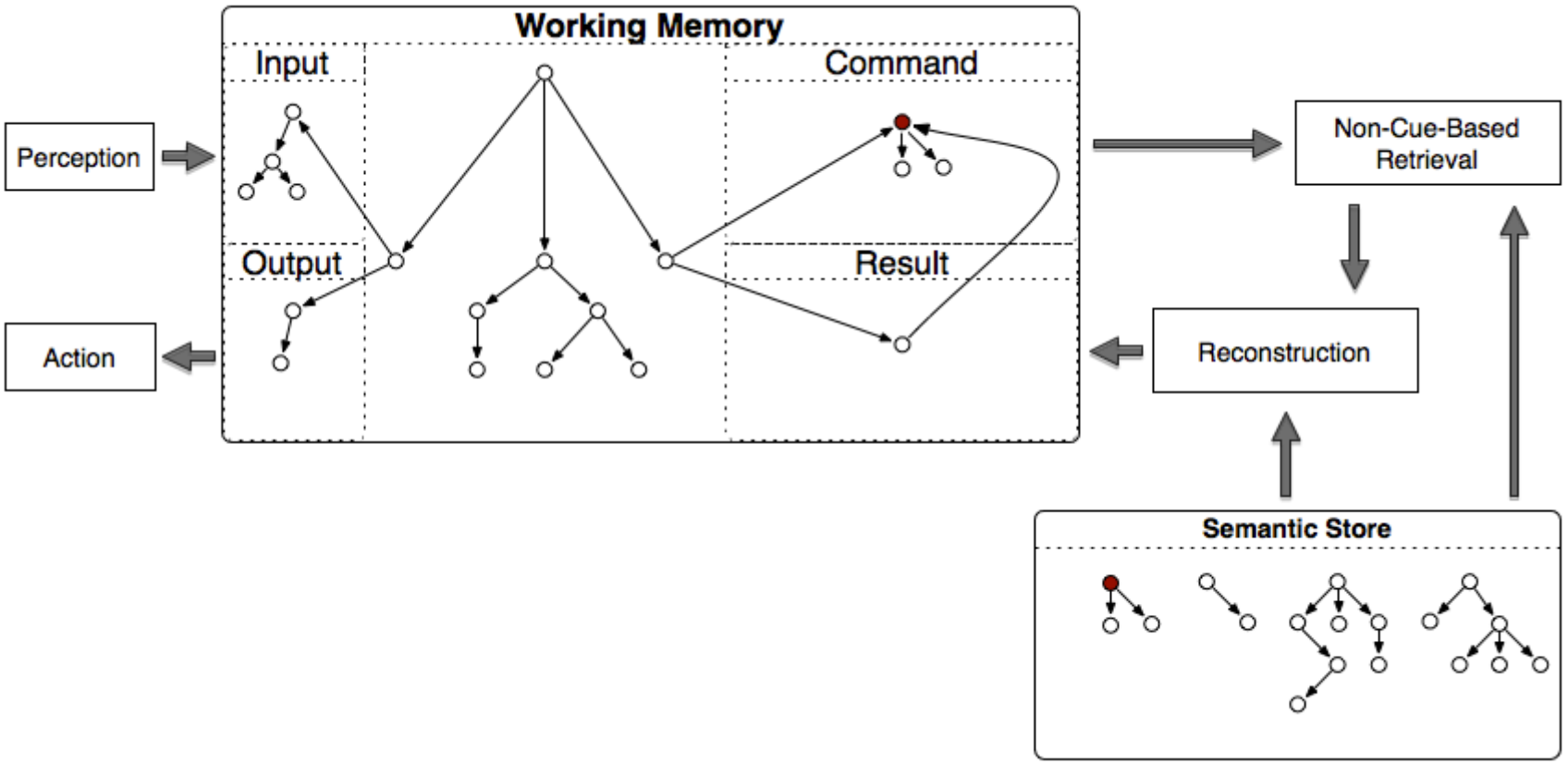
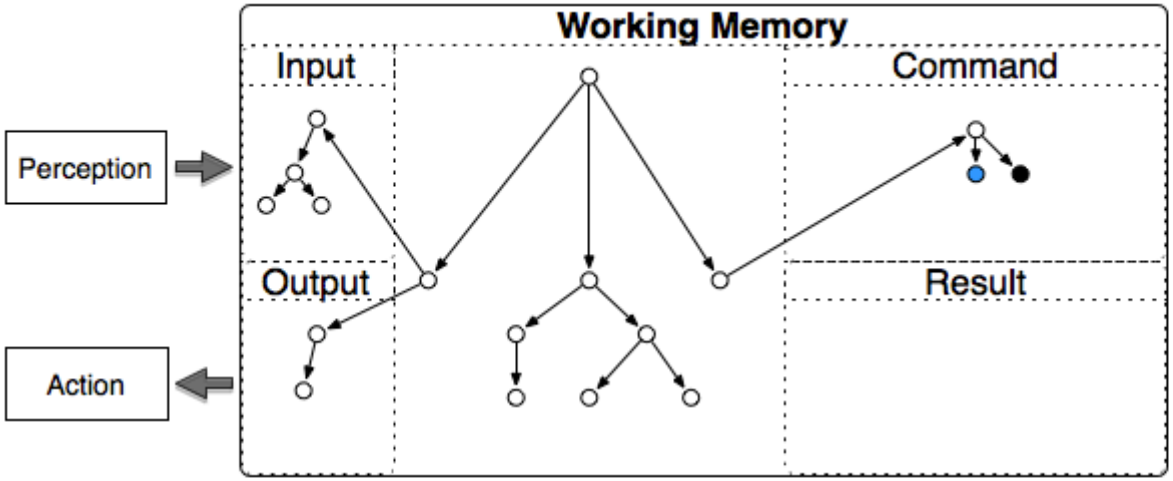
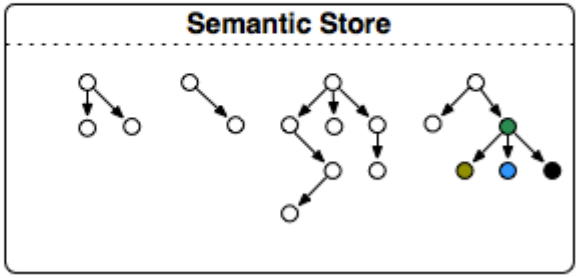


Architectural Integration

Cue-Based Retrieval





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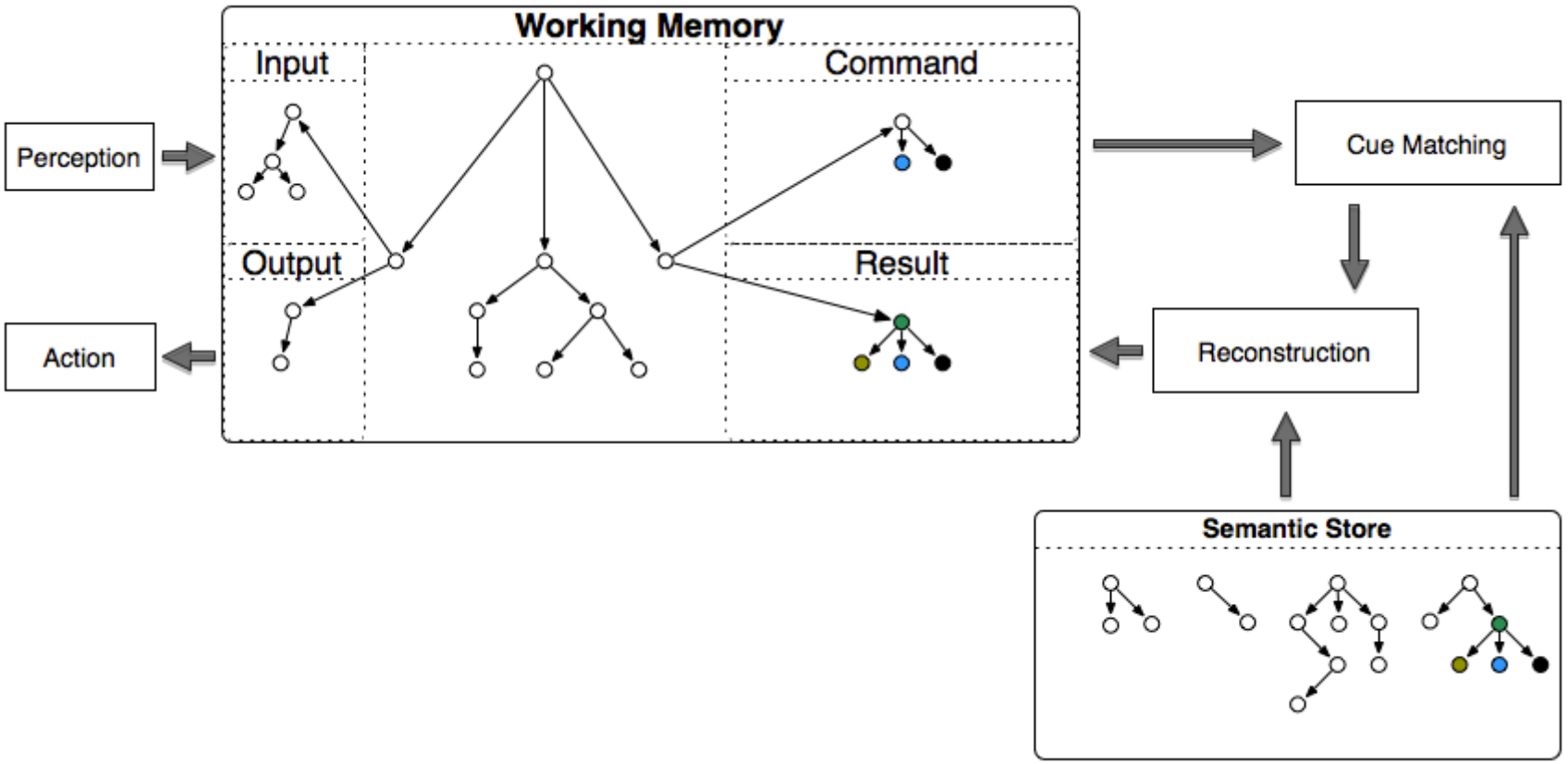
Cue-Based Retrieval



Mechanism Detail

Encoding

- Deliberate (via rules)
- Representation: (<*long-term identifier*> ^attribute value)

Storage

- Agent-modifiable over time

Retrieval

- Associative cue: given feature subset, retrieve node (parameterized biases)
- Expansion: given node, retrieve augmentations

Memory Comparison

	Episodic	Semantic
Encoding	Automatic Top-State	Deliberate Object+Features/Relations
Storage	No dynamics	Agent modifiable
Retrieval	Disjunctive Structural	Conjunctive Features/Relations

Select Prior Work

Efficiency

Towards Efficiently Supporting Large Symbolic Declarative Memories

Nate Derbinsky, John Laird, & Bryan Smith. ICCM (2010)

Integrating Learning Mechanisms

Using Diverse Cognitive Mechanisms for Action Modeling

John Laird, Joseph Xu, & Sam Wintermute. ICCM (2010)

Today's Talks

EpMem	SMem	Talk
	x	*Effective and Efficient Historical Memory Retrieval Bias in Soar's Semantic Memory* Nate Derbinsky
	x	*Playing with Semantic Memory* Bob Marinier
x	x	*Performance Evaluation of Soar's Declarative Memories* John Laird
x		*Do's and Don't's of Episodic Memory* Justin Li
x	x	*Supporting Delayed Intentions with Long-Term Memories* Justin Li

DISCUSSION

Open Research Issues

Architecture

- Functionality
  - Encoding
  - Storage
  - Retrieval
- Efficiency
- Integration

Agent/Task

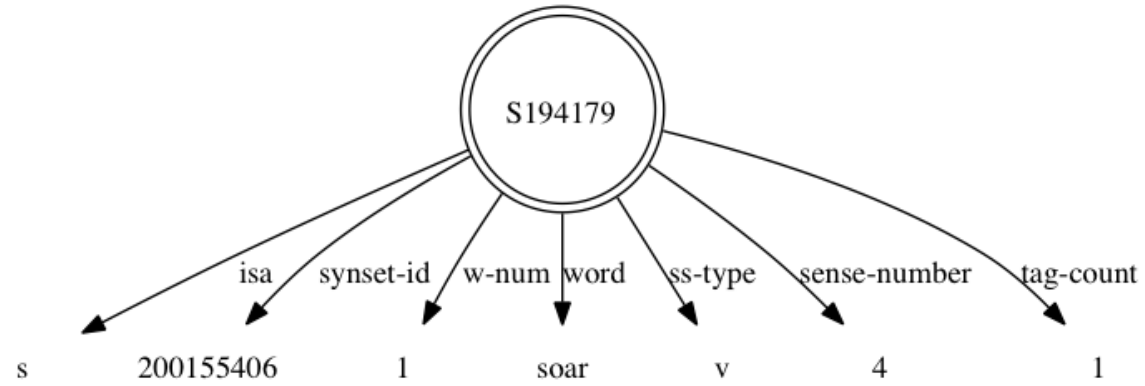
- Knowledge
  - Representation
  - Consistency
  - Sharing
  - Capabilities
- Evaluation
  - Tasks
  - Metrics
- Tools

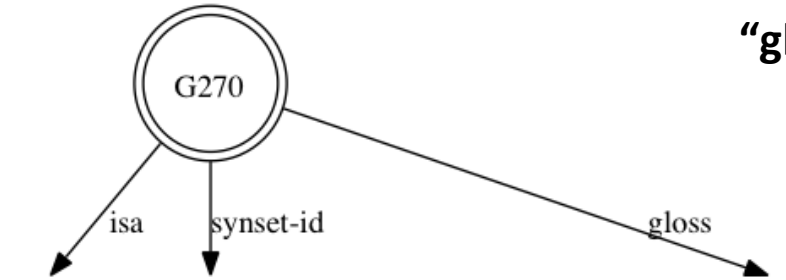
Encoding: Episodic

- Should EpMem capture sub-goal processing?
  - Space and retrieval time multiplier
- Explore space saver tradeoff: stop at LTIs
  - Sacrifice of fidelity ("changing" episodes)
  - Added deliberation required to "reconstruct" episode contents
  - Can't search substructure

Example Semantic Knowledge: “soar”

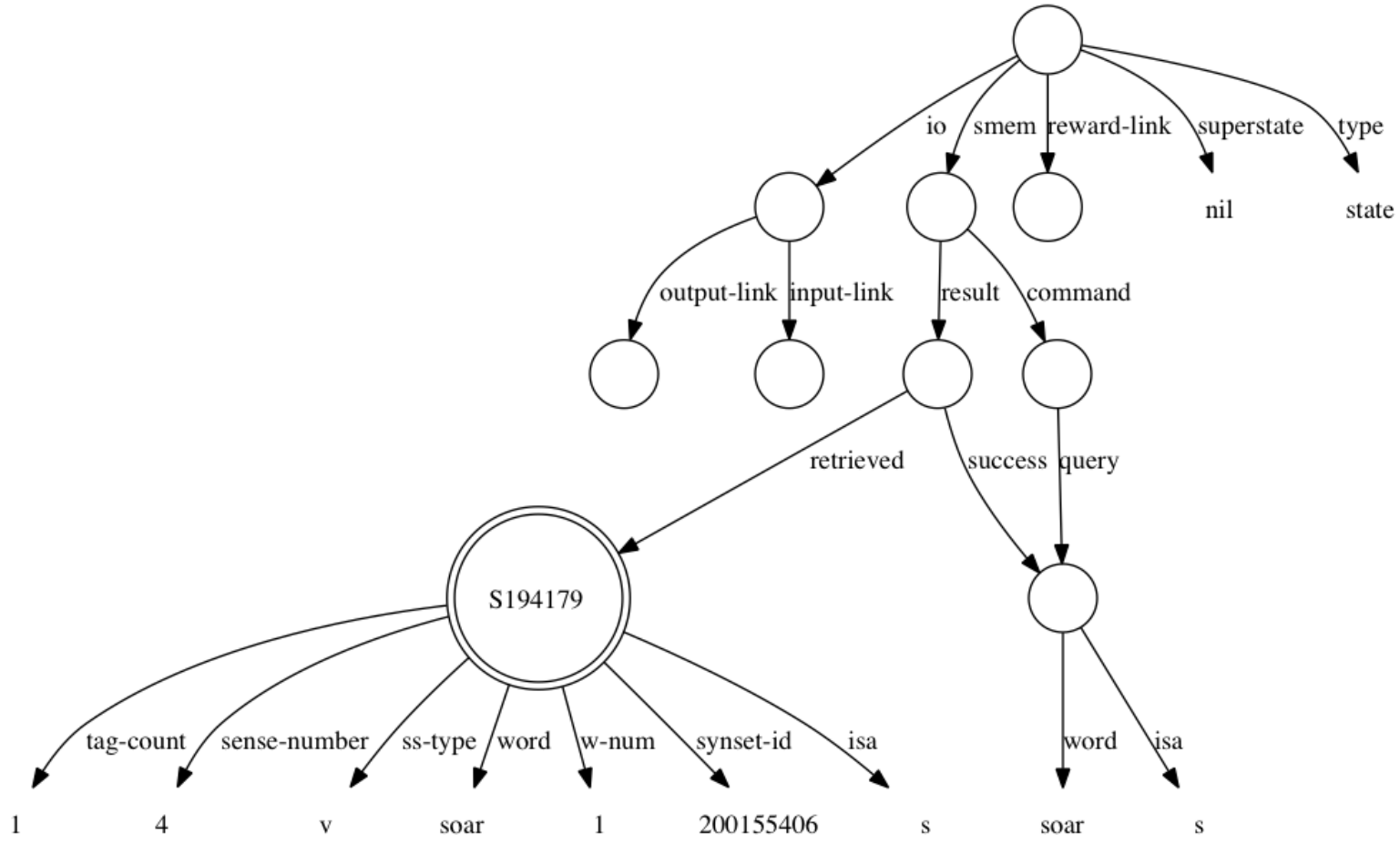
“sense” of the word “soar”





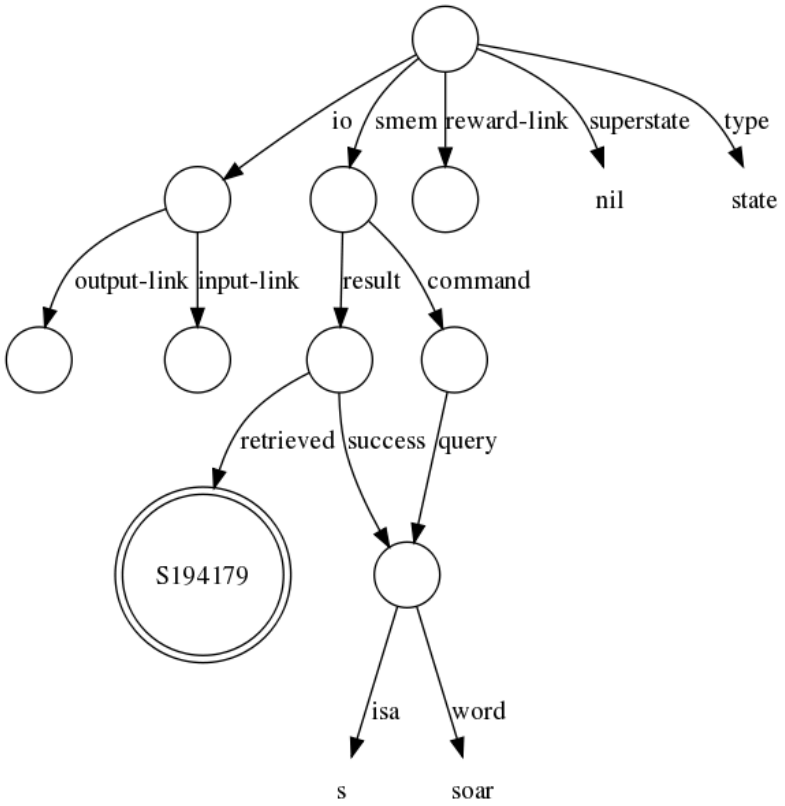
“gloss” with the synset-id “200155406”

Example Episode

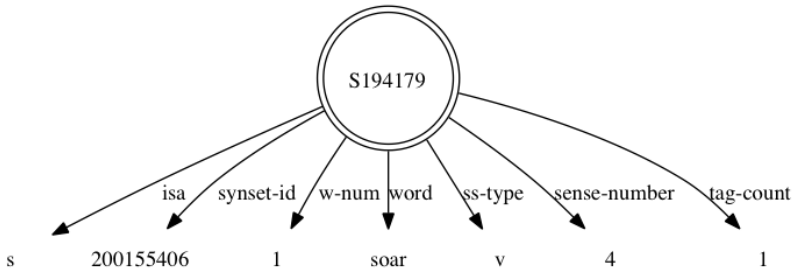


Pruned Episodic Encoding

Episodic



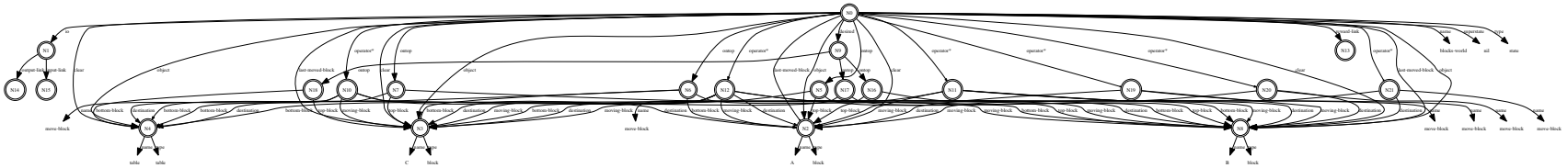
Semantic



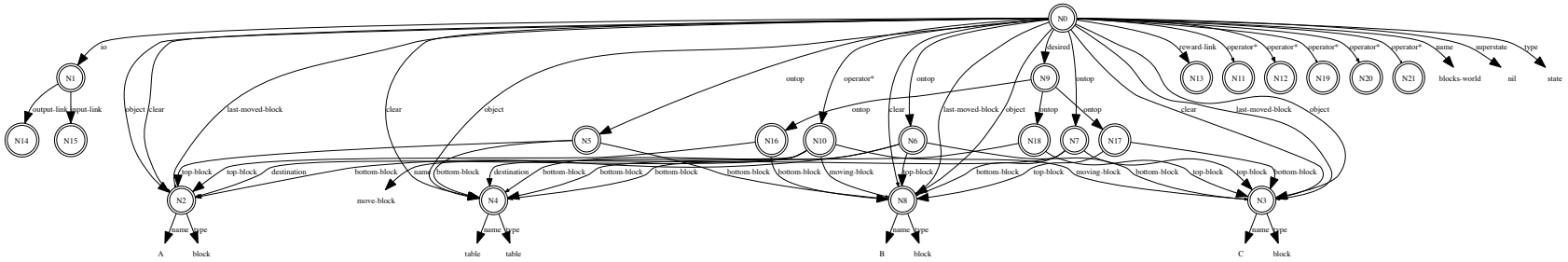
Encoding: Semantic

- Where does knowledge come from?
  - Consolidating from EpMem via stability

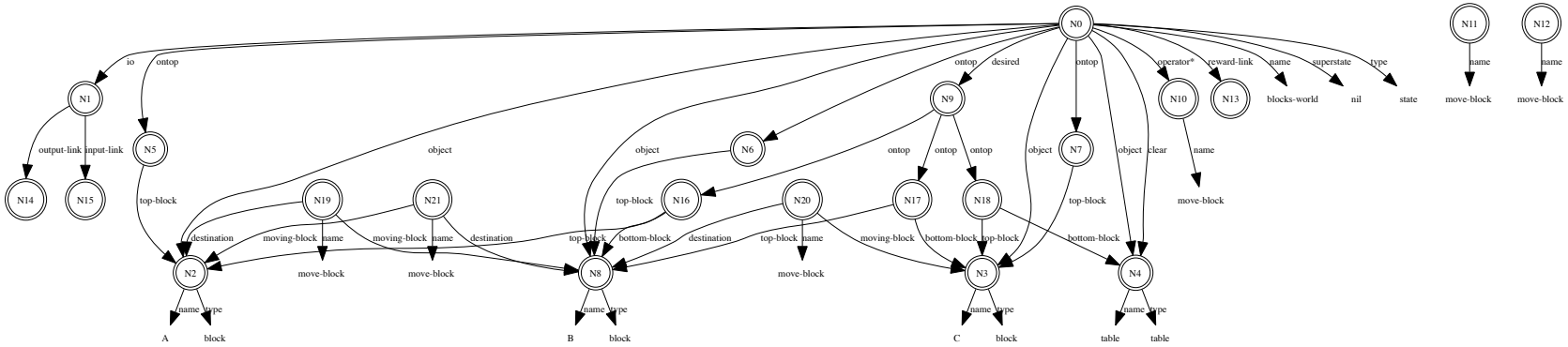
Structural Stability (1)



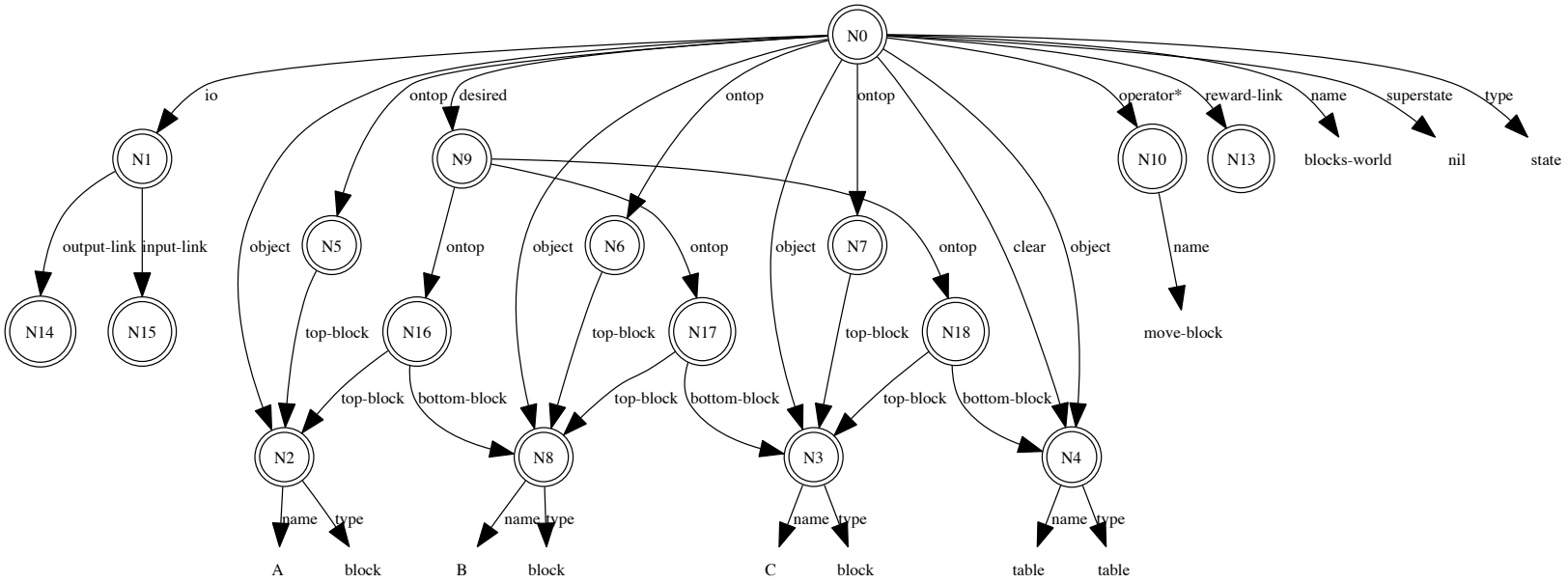
Structural Stability (2)



Structural Stability (3)



Structural Stability (4)



Encoding: Semantic

- Where does knowledge come from?
  - Consolidating from EpMem via stability
  - From WM via situational focus (activation)
  - Mirroring
    - Hypotheticals?

Storage: Episodic

- Memory is cheap, but not unlimited…
  - Forgetting
    - Recency, emotional salience
  - Merging
  - Can such operations occur in an incremental fashion?
  - Is there a functional benefit to forgetting?

Storage: Semantic

- Memory is cheap, but not unlimited…
  - Forgetting via activation (ala ACT-R)
  - Is there a functional benefit to forgetting?

Retrieval: Episodic

- Evaluating retrieval quality
- Biases for ambiguous cues
  - Episode emotional appraisal
  - Element activation
  - How to do this efficiently!!??
- More complex similarity functions
  - Possibly exploit static structure of IO

Retrieval: Semantic

- Effective & efficient biases (ala ACT-R)
  - Base-level
  - Spreading (more than 1-level?)
  - Partial match
  - Noise
  - Other?

Efficiency

- Asynchronous retrievals
  - Pragmatic: max time per cycle
  - Explore multiple approaches to a problem, while LTMs are searching
    - Faster memory -> better task performance?

Integration

- Learning to control LTMs
- Knowledge-level learning/retrieval strategies
- Symbolic vs. Perceptual LTMs
  - How can symbolic LTM inform perceptual processes?

Knowledge

- What types of representations do we need to support and learn large, diverse semantic stores?
- How do we maintain consistency between the long-term memories (or at least remain robust to inconsistencies)?
- To what extent can long-term knowledge be shared between agents?
- How do we capture high-level capabilities as re-usable components (i.e. rule libraries)?

Evaluation

- What is a "comprehensive" set of domains/ tasks by which to measure progress of LTM development?
  - Metrics?

- At what time scale should we evaluate LTMs for generally intelligent agents?
  - Is this feasible in real-time domains?

Tools

As agents persist for long periods of time and build up their own knowledge stores, how do we assess/visualize progress and debug agents?