

# **Soar Workshop**

# **Episodic Memory Tutorial**

Nate Derbinsky

# Agenda

- Big picture
- Basic usage
- Demo task
- Additional resources

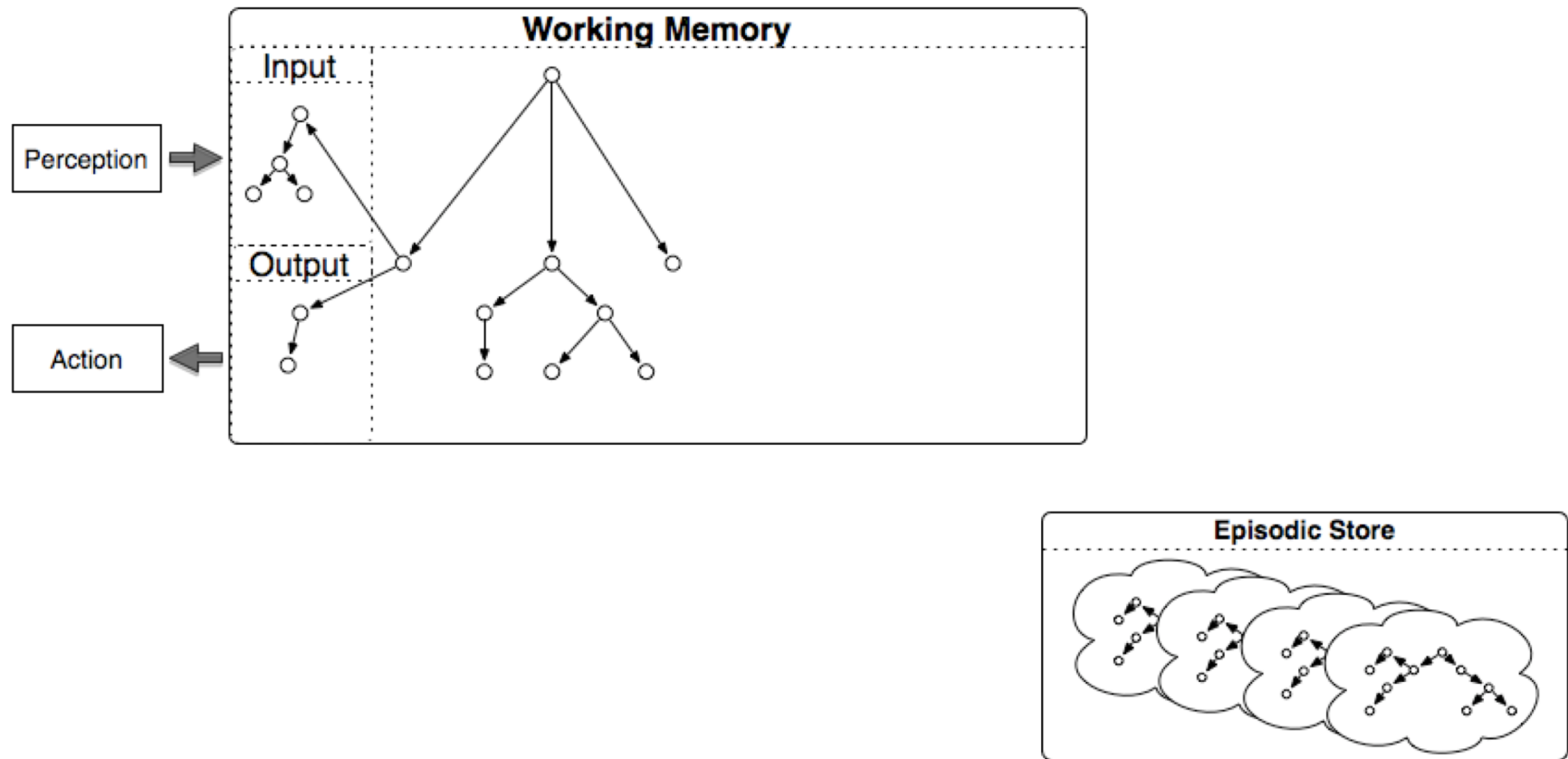
# Episodic Memory: Big Picture

Episodic memory is a weak learning mechanism

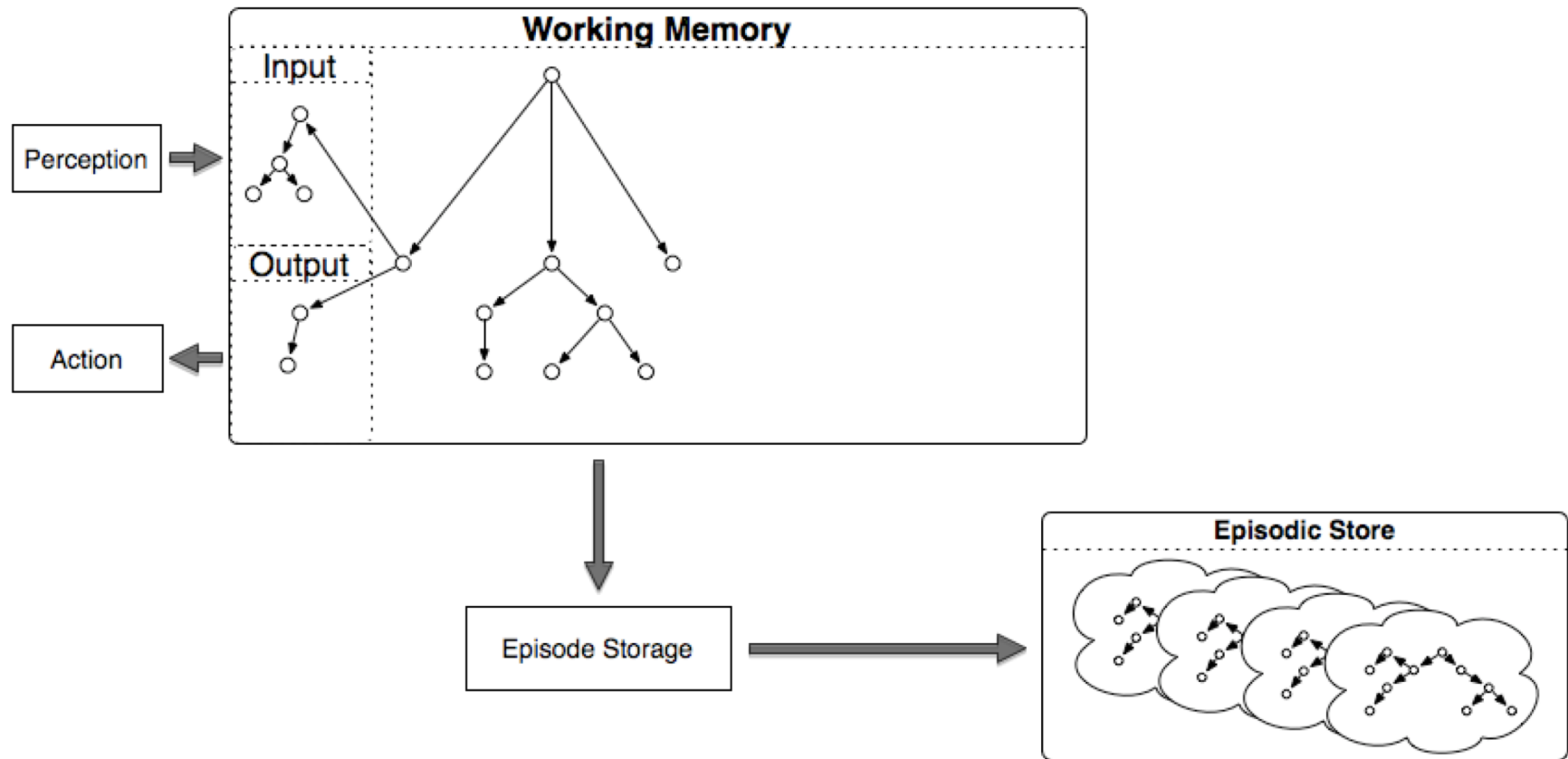
- Automatically captures, stores, and temporally indexes agent state
- Supports content-addressable agent interface to autobiographical prior experience

Used in combination with reasoning/other mechanisms to support a variety of cognitive capabilities

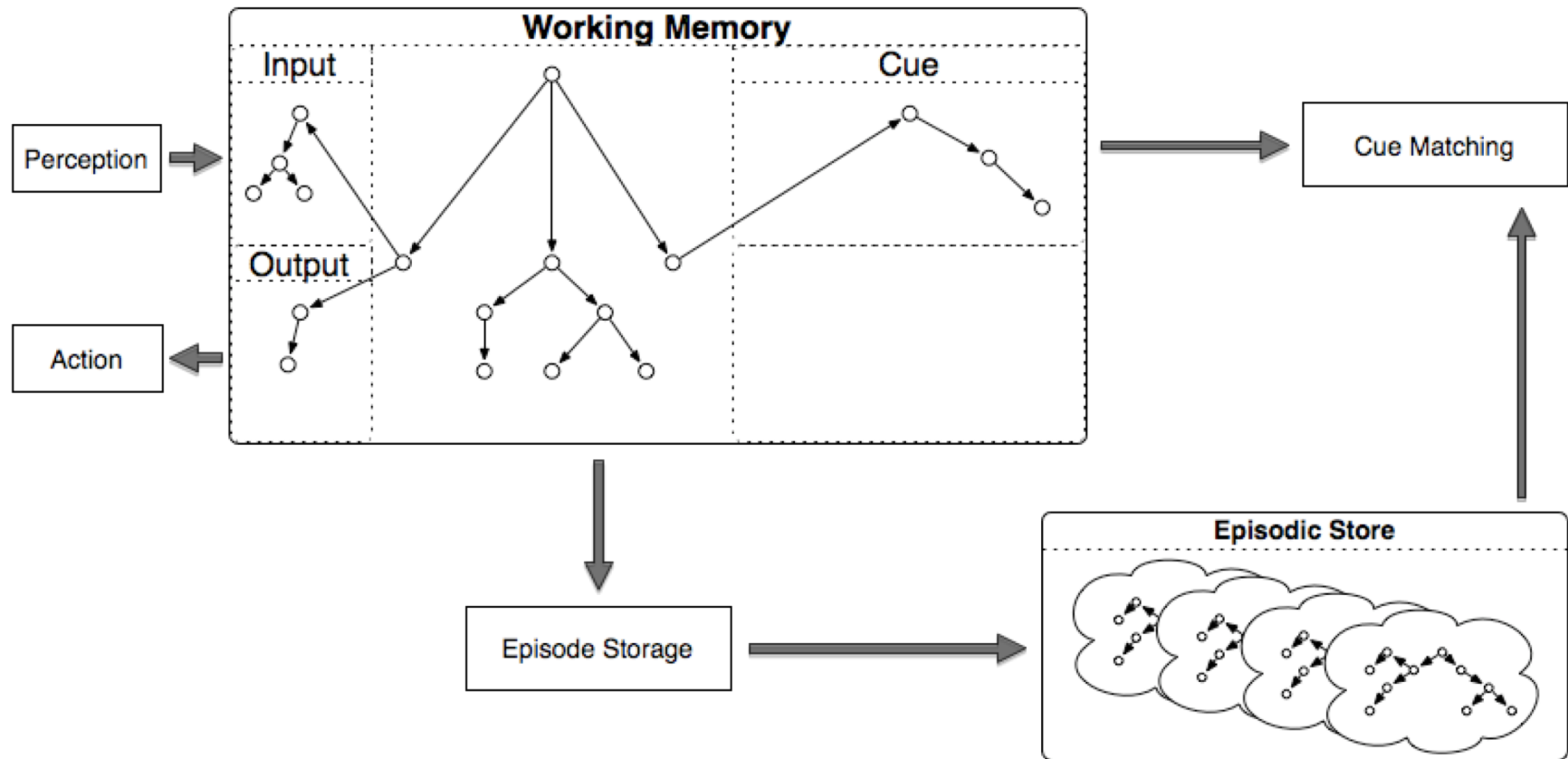
# Architectural Integration



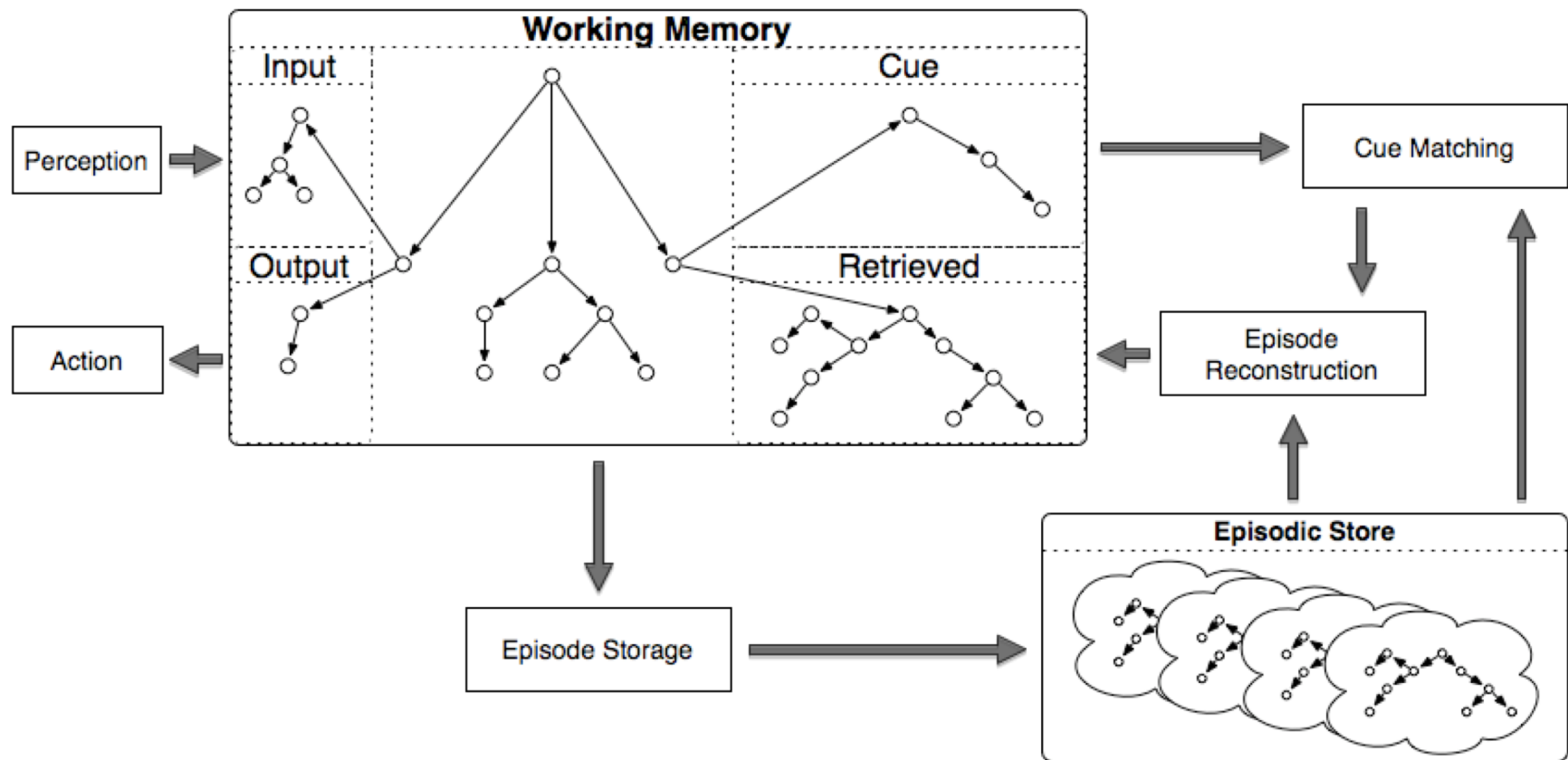
# Architectural Integration



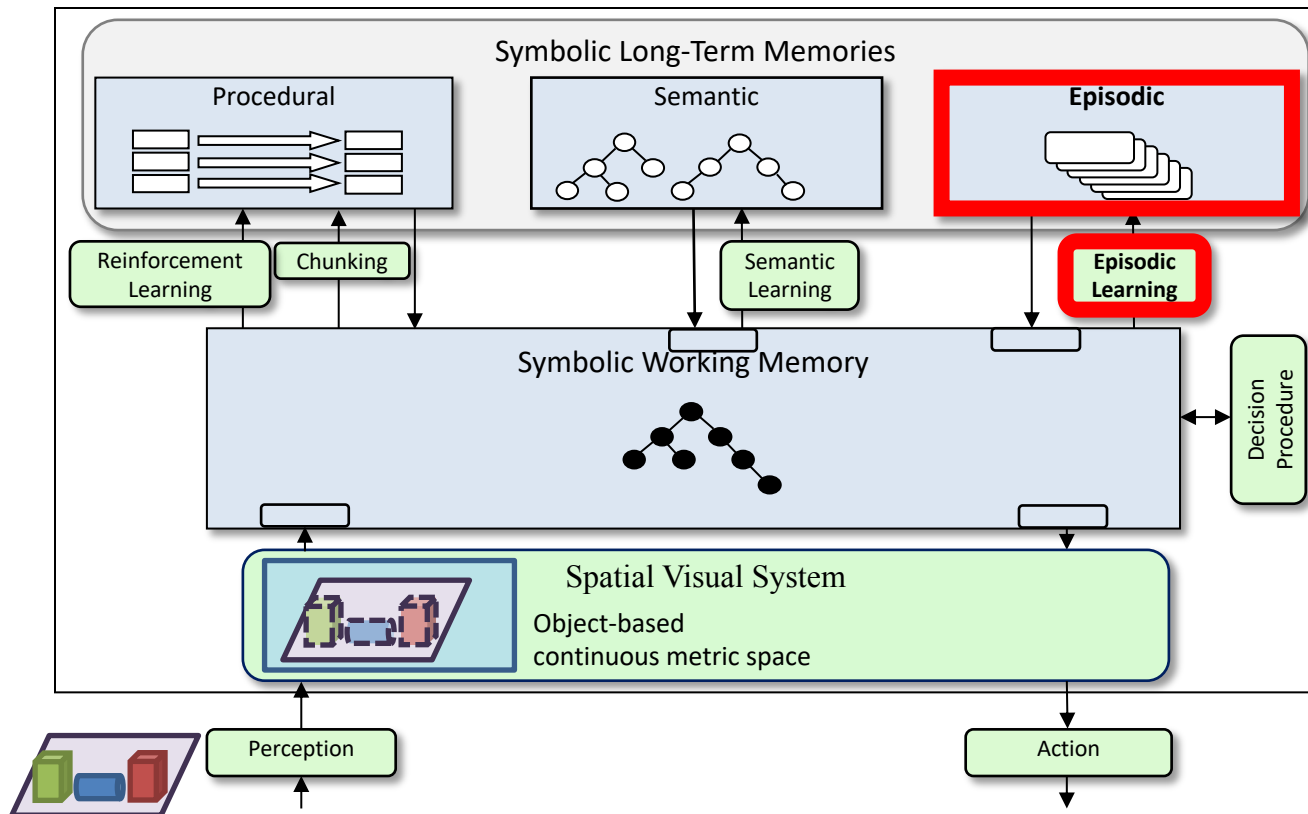
# Architectural Integration



# Architectural Integration



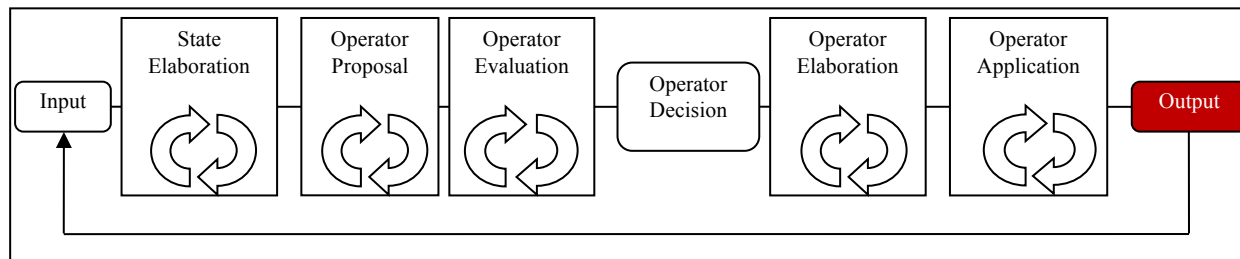
# Soar 9





# Soar Basic Functions

- 1. Input from environment
2. Elaborate current situation: *parallel rules*
3. Propose operators via acceptable preferences
4. Evaluate operators via *preferences: Numeric indifferent preference*
5. Select operator
6. Apply operator: Modify internal data structures: *parallel rules*
7. Output to motor system [and access to long-term memories]



# Basic Usage

- Working-memory structure
- Episodic-memory representation
- Controlling episodic memory
- Storing knowledge
- Retrieving knowledge

# Working-Memory Structure

Soar creates an `epmem` structure on each state

- Soar Java Debugger
  - `step`
  - `print <s> -d 2`
  - `print e1`

Each `epmem` structure has specialized substructure

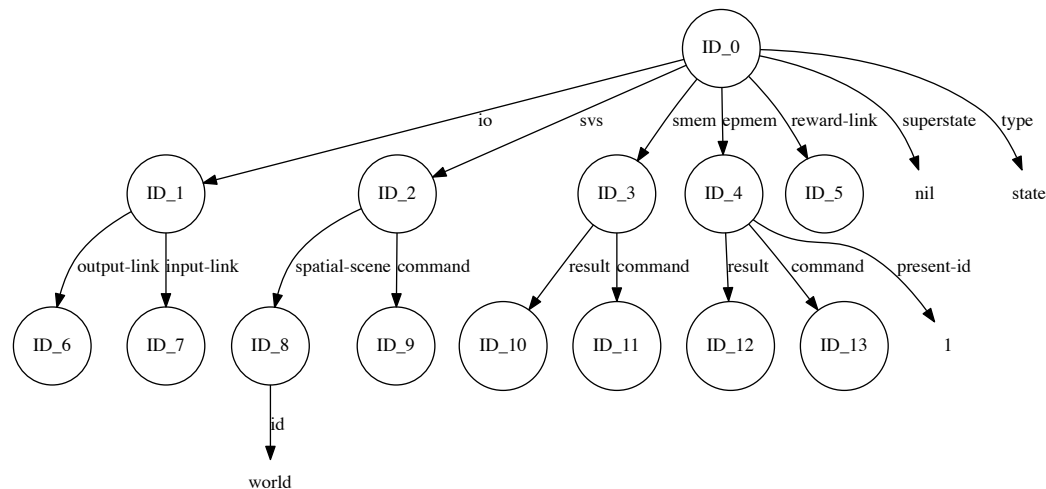
- `command`: agent-initiated actions
- `result`: architectural feedback
- `present-id`: current episode number (more later)

# Episodic-Memory Representation

Similar to working memory: symbolic triples

- Attributes cannot be identifiers (currently)
- Structures within an episode are connected; separate episodes are disconnected

```
(<id0> ^epmem <id4>
^io <id1>
^reward-link <id5>
^smem <id3>
^superstate nil
^svs <id2>
^type state)
(<id1> ^input-link <id7>
^output-link <id6>)
(<id2> ^command <id9>
^spatial-scene <id8>)
(<id3> ^command <id11> ^result <id10>)
(<id4> ^command <id13> ^present-id 1 ^result <id12>)
(<id8> ^id world)
```



# Controlling Episodic Memory

Get/Set a parameter:

- `epmem [-g|--get] <name>`
- `epmem [-s|--set] <name> <value>`

EpMem is **disabled** by default. To enable it...

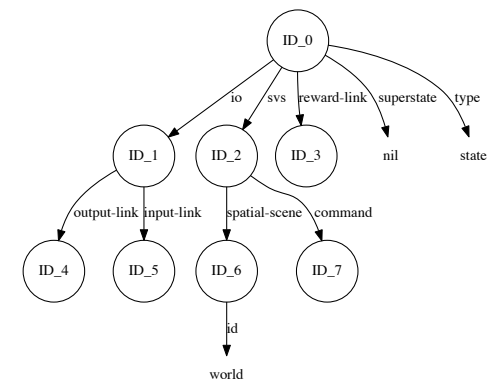
1. `epmem`
2. `epmem --set learning on`
3. `epmem`

# Storing Knowledge

- Automatic storage requires EpMem to be **enabled** (see slide 12)
- Storage captures the top state of working memory
- Events trigger storage of new episodes
  - `epmem --set trigger << dc output >>`
    - `dc`: decision cycle (default)
    - `output`: new augmentation of output-link
- Storage takes place at the end of a phase
  - `epmem --set phase << output selection >>`
    - `output` is default
    - `selection` may be useful for in-the-head agents

# Automatic Storage: Example

- Soar Java Debugger
  1. `epmem --set learning on`
  2. `watch --epmem`
  3. `run 5 -p`
  4. `epmem --print 1`
  5. `print e1`
  6. `epmem --stats`



# Automatic Storage: Debrief

- What wasn't captured?
- Attributes can be excluded from encoding (and subsequent recursion)
  - `epmem --set exclusions <label>`
    - If `<label>` already excluded, now included
- Try previous example, add before #1:
  - `epmem --set exclusions epmem`
  - `epmem --set exclusions smem`



# Retrieving Knowledge

## Cue-Based

Find the episode that best matches a cue and add it to working memory

## Temporal Progression

Replace the currently retrieved episode with the next/previously encoded episode

## Non-Cue-Based (not covered)

Add an episode to working memory from episode #

## Common Constraints:

- Requires that EpMem is enabled (slide 12)
- Only one per state per decision
- Processed during phase (slide 13)
- Only re-processed if WM changes to commands
- Meta-data (status, etc) automatically cleaned by the architecture

# Cue-Based Retrieval: Syntax

( <epmem> ^command <cmd> )

( <cmd> ^query <q>  
          ^neg-query <nq> )

- The neg-query is optional
- Cues must be acyclic
- The <q> and <nq> identifiers form the roots of episode sub-graph cues
  - query represents desired structures
  - neg-query represents undesired structures

# Cue-Based Retrieval: Cue Semantics

Values of cue WMEs are interpreted by type

- Constant: exact match
- Short-Term ID: wildcard (but must be identifier)
- Long-Term ID: exact match\*, stop

\*Depends on the version of Soar. For tutorial, exact match.

# Cue-Based Retrieval: Episode Scoring

- **Leaf WME**, either...
  - Cue WME whose value is a constant/long-term identifier OR
  - Cue WME whose value is a short-term identifier and that identifier has no augmentations
- A leaf wme is *satisfied* (w.r.t. an episode) if...
  - The episode contains that WME AND
  - The episode contains a path from root to that WME
- Episode scoring
  - $(\text{balance})(\text{cardinality}) + (1 - \text{balance})(\text{activation})$
  - balance: parameter=[0,1], default=1
  - cardinality: # satisfied leaf WMEs
  - activation:  $\sum$  satisfied leaf WME activation (see Manual)
  - cardinality/activation negated for neg-query

# Cue-Based Retrieval: Cue Matching

## Graph matching

`epmem --set graph-match << on off >>`

- on by default

## Candidate episode

Defined as satisfying at least one leaf WME

Cue matching will return the most recent graph-matched episode, or the most recent non-graph-matched candidate episode with the maximal episode score

# Cue-Based Retrieval: Result

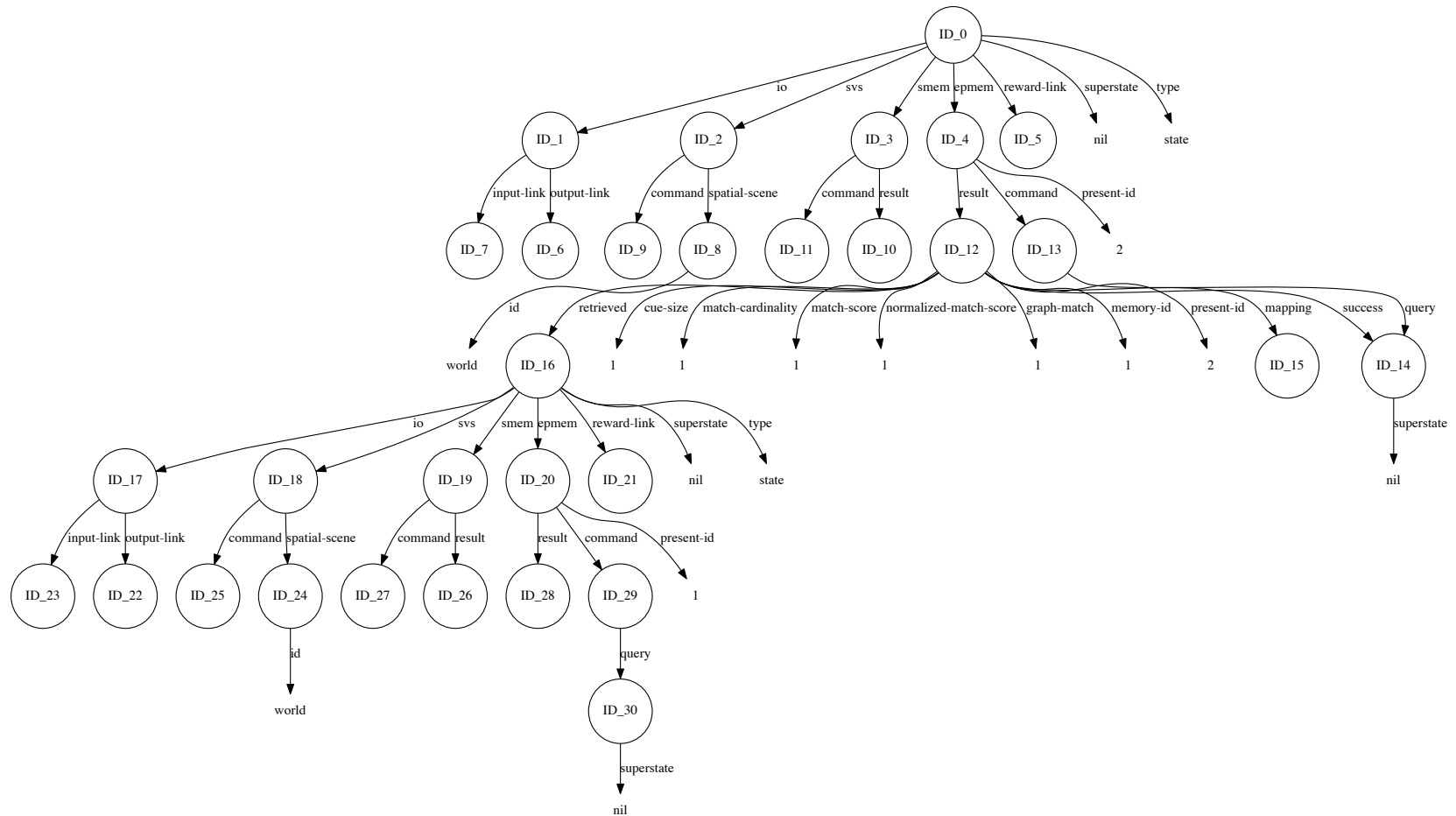
Augmentation	Meaning
<code>^retrieved &lt;retrieval-root&gt;</code>	Root of the retrieved memory
<code>^&lt;&lt; success failure &gt;&gt; &lt;query&gt; &lt;neg-query&gt;</code>	Query status
<code>^match-score #</code>	Float, episode score (slide 19)
<code>^cue-size #</code>	Integer, number of leaf WMEs
<code>^normalized-match-score #</code>	match-score/cue-size
<code>^match-cardinality #</code>	Integer, number of satisfied leaf WMEs ( $ query  -  neg-query $ )
<code>^memory-id #</code>	Integer, episode # retrieved
<code>^present-id #</code>	Integer, current episode #
<code>^graph-match &lt;&lt; 0 1 &gt;&gt;</code>	Integer, 1 if graph match succeeded
<code>^mapping &lt;mapping-root&gt;</code>	A mapping from the cue to episode

# Cue-Based Retrieval: Example

- Soar Java Debugger
  1. `epmem --set learning on`
  2. `watch --epmem`
  3. `sp {query1`  
    `(state <s> ^superstate nil`  
        `^epmem.command <cmd>)`  
    `-->`  
    `(<cmd> ^query.superstate nil)}`
  5. `run 5 -p`
  6. `print -d 10 e1`

# Cue-Based Retrieval: Example

## *Result*





# Cue-Based Retrieval: Example

## *Trace*

```
CONSIDERING EPISODE (time, cardinality, score): (1, 1, 1.000000)  
NEW KING (perfect, graph-match): (true, true)
```

# Cue-Based Retrieval

## *Optional Modifiers*

(<cmd> ^before time-id)

(<cmd> ^after time-id)

(<cmd> ^prohibit time-id1 time-id2 ...)

Hard constraints on the episodes that can be retrieved.

# Temporal Progression

(<cmd> ^next <new-id>)

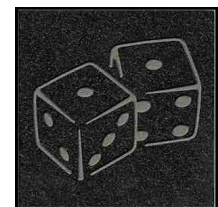
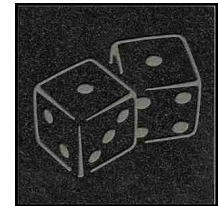
(<cmd> ^previous <new-id>)

Retrieves the next/previous episode, temporally,  
with respect to the last that was retrieved

# EpMem Task: Virtual Sensing

*epmem-virtual-sensing.soar*

1. Produce a random number in WM  
EpMem automatically records this episode
2. Remove the number from WM  
Write to the trace (for later verification)
3. Query episodic memory  
When did I last see a random number?
4. Reason about the retrieved episode  
Extract and print the number



# Eaters!

# Additional Resources

- Documentation
- Readings

# Documentation

## Soar Manual and Tutorial

### Additional Topics

- Absolute non-cue-based retrievals
- Disk-based databases
- Performance
- Usage: commands, parameters, statistics, etc.
- ...

# Select Readings

*<http://soar.eecs.umich.edu/Soar-RelatedResearch>*

2004

- A Cognitive Model of Episodic Memory Integrated with a General Cognitive Architecture  
Andrew M. Nuxoll, John E. Laird (ICCM)

2007

- Extending Cognitive Architecture with Episodic Memory  
Andrew M. Nuxoll, John E. Laird (AAAI)

2009

- Efficiently Implementing Episodic Memory  
Nate Derbinsky, John E. Laird (ICCBR)
- A Year of Episodic Memory  
John E. Laird, Nate Derbinsky (IJCAI Workshop)

2010

- Extending Soar with Dissociated Symbolic Memories  
Nate Derbinsky, John E. Laird (AISB)
- Instance-Based Online Learning of Deterministic Relational Action Models  
Joseph Xu, John E. Laird (AAAI)

2011

- Learning to Use Episodic Memory  
Nicholas A. Gorski, John E. Laird (Cognitive Systems Research)

2012

- Enhancing Intelligent Agents with Episodic Memory  
Andrew M. Nuxoll, John E. Laird (Cognitive Systems Research)
- A Multi-Domain Evaluation of Scaling in a General Episodic Memory  
Nate Derbinsky, Justin Li, John E. Laird (AAAI)

2014

- A Case Study of Knowledge Integration Across Multiple Memories in Soar
  - John E. Laird, Shiwali Mohan (BICA)