Soar Workshop
Episodic Memory Tutorial

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Agenda

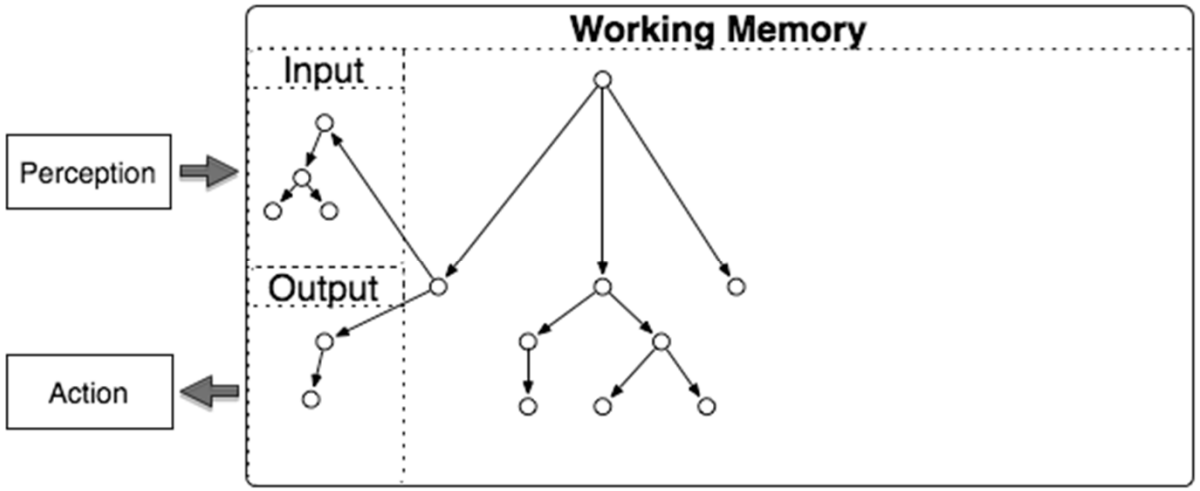
- Big picture
- Basic usage
- Demo task
- Additional resources

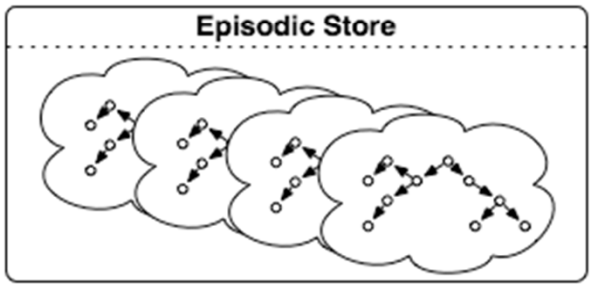
Episodic Memory: Big Picture

Episodic memory is a weak learning mechanism

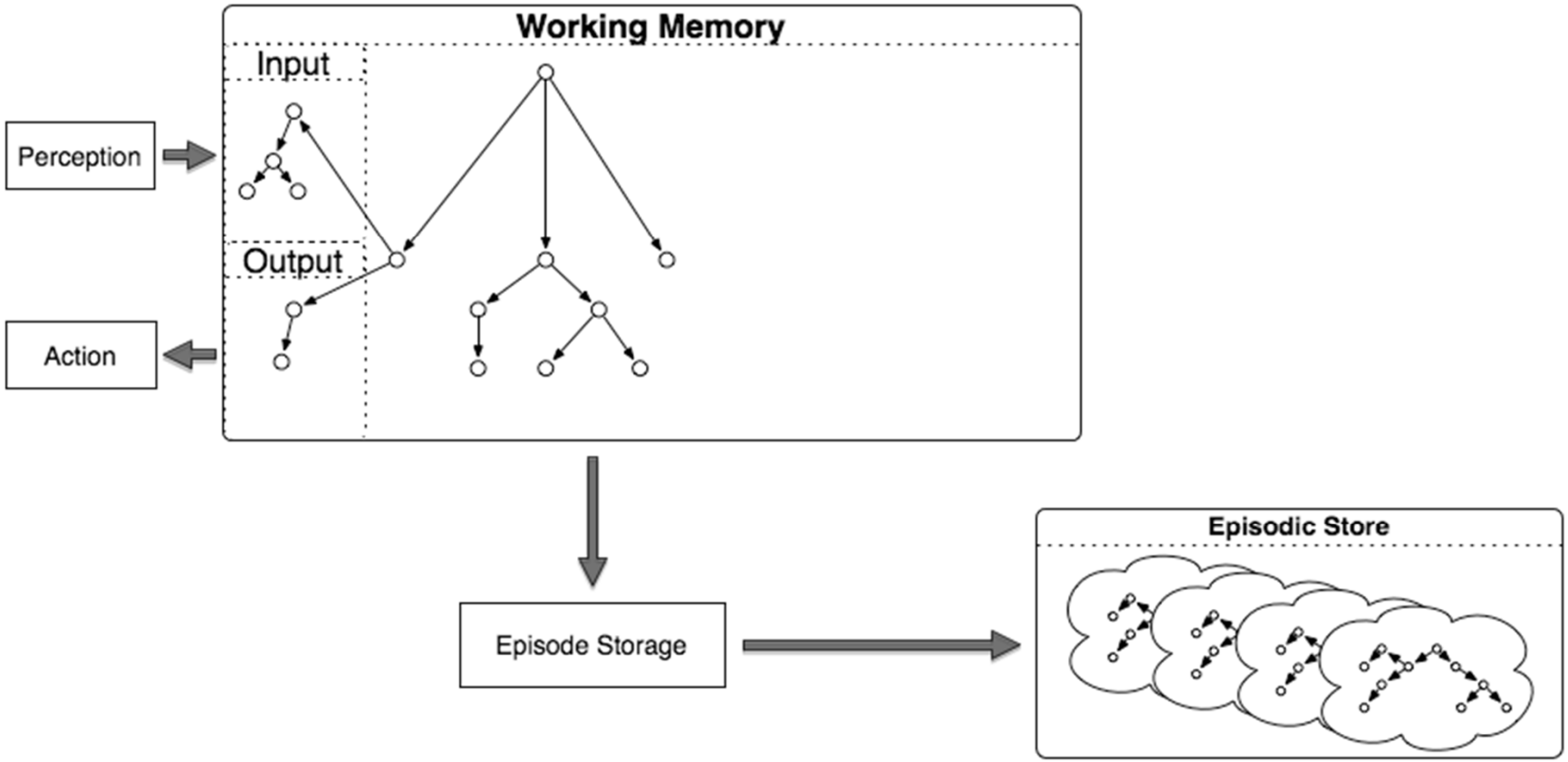
- Automatically captures, stores, and temporally indexes agent state
- Supports content-addressable agent interface to autobiographical prior experience

Architectural Integration

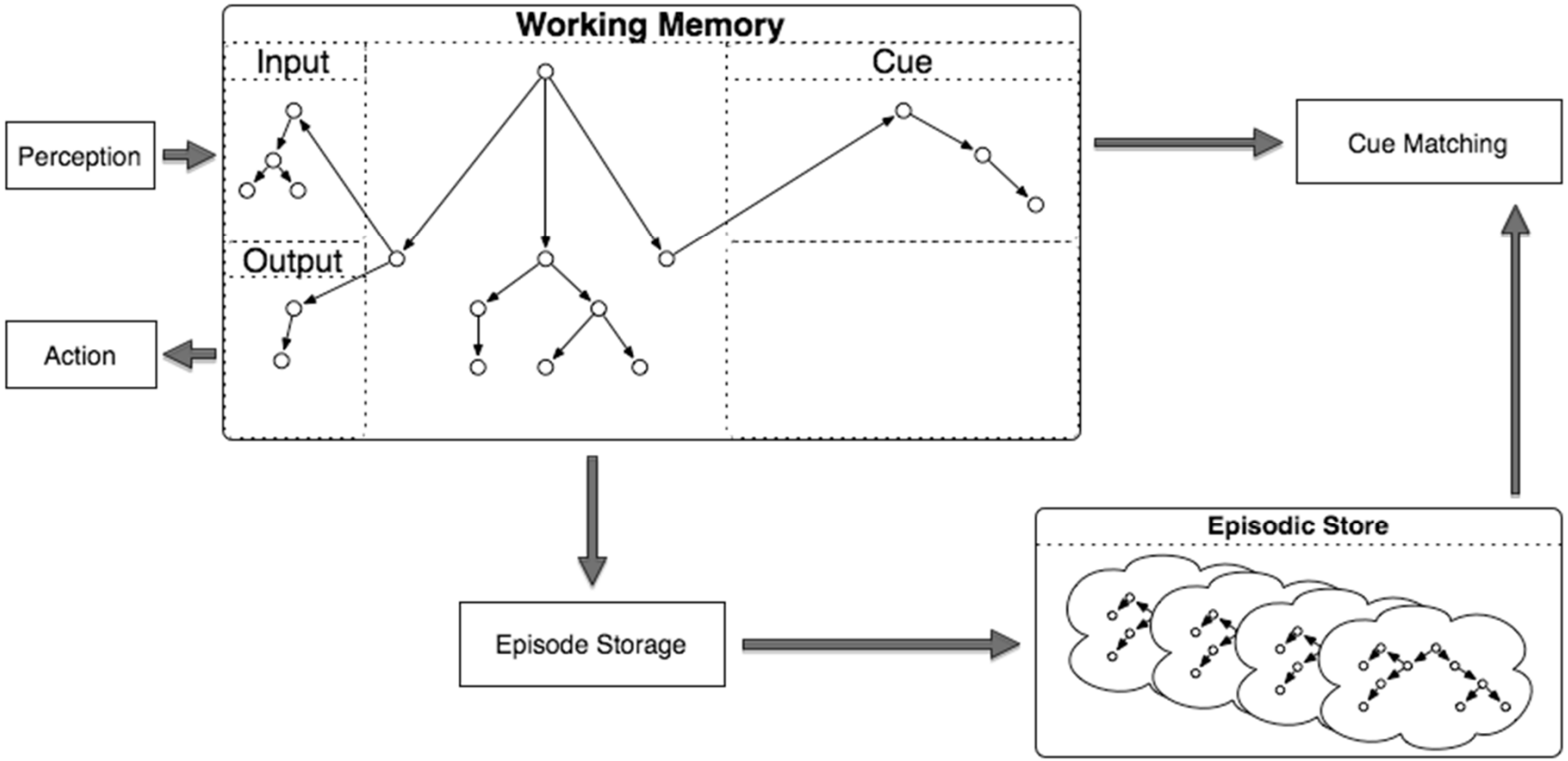




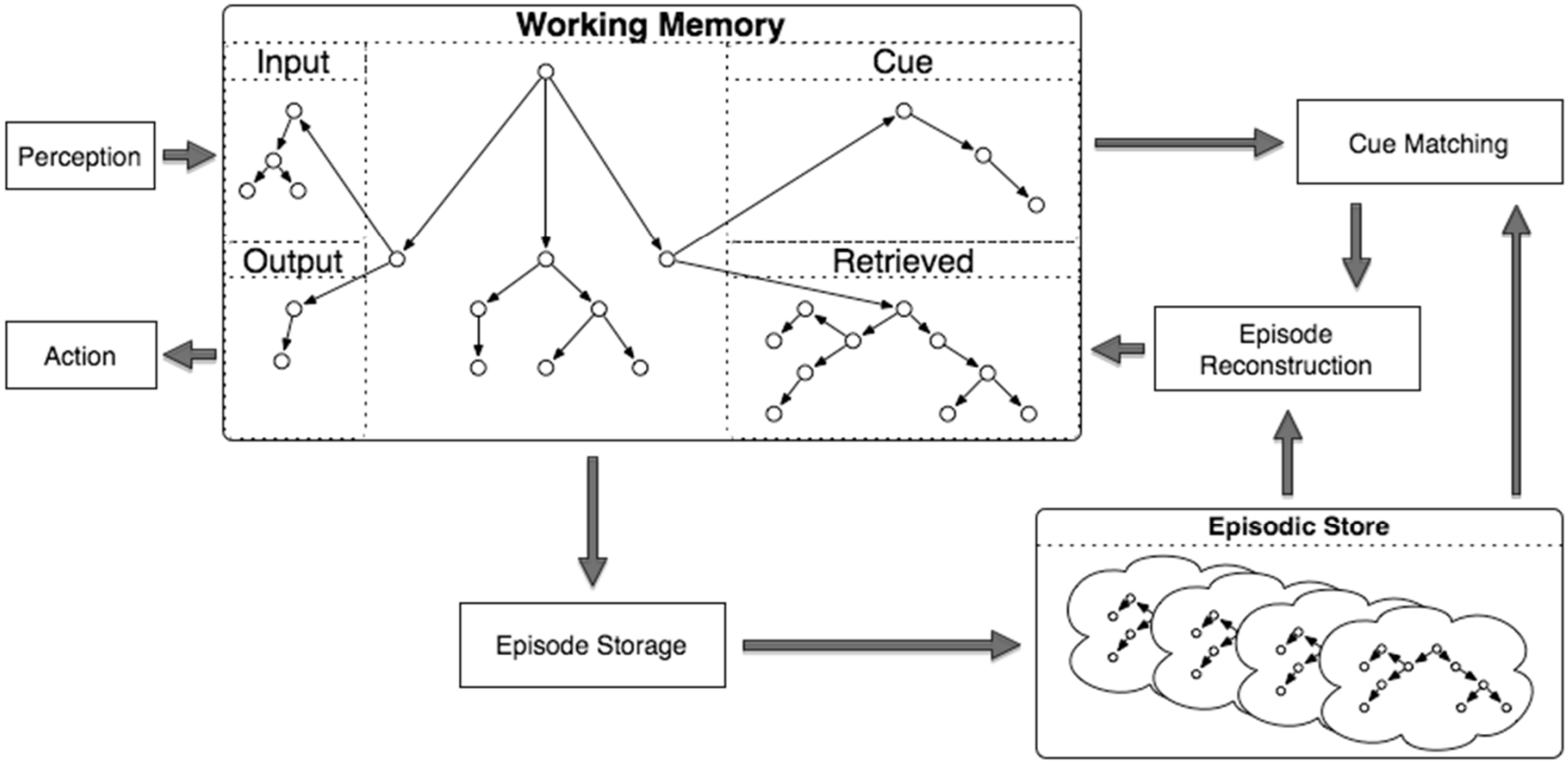
Architectural Integration



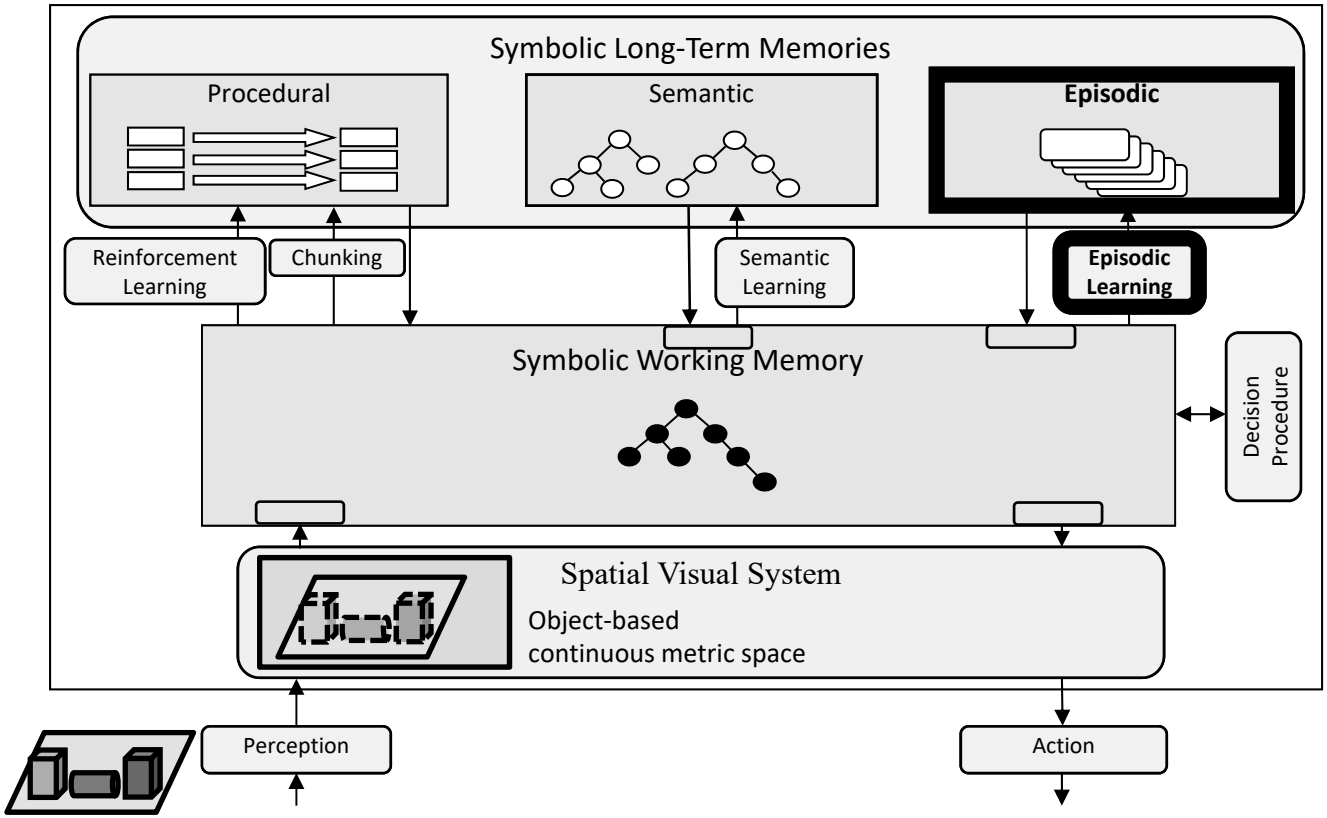
Architectural Integration



Architectural Integration

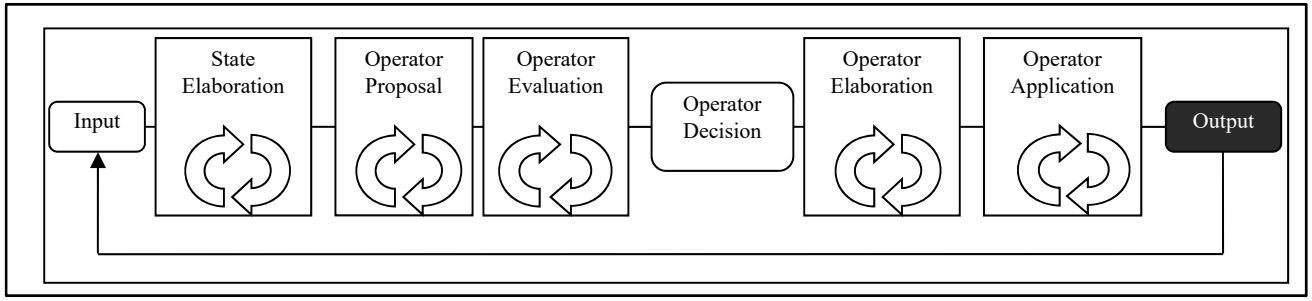


Soar 9


Symbolic Long-Term Memories
Procedural
Semantic
Episodic
Reinforcement Learning
Chunking
Semantic Learning
Episodic Learning
Symbolic Working Memory
Decision Procedure
Spatial Visual System
Object-based
continuous metric space
Perception
Action

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

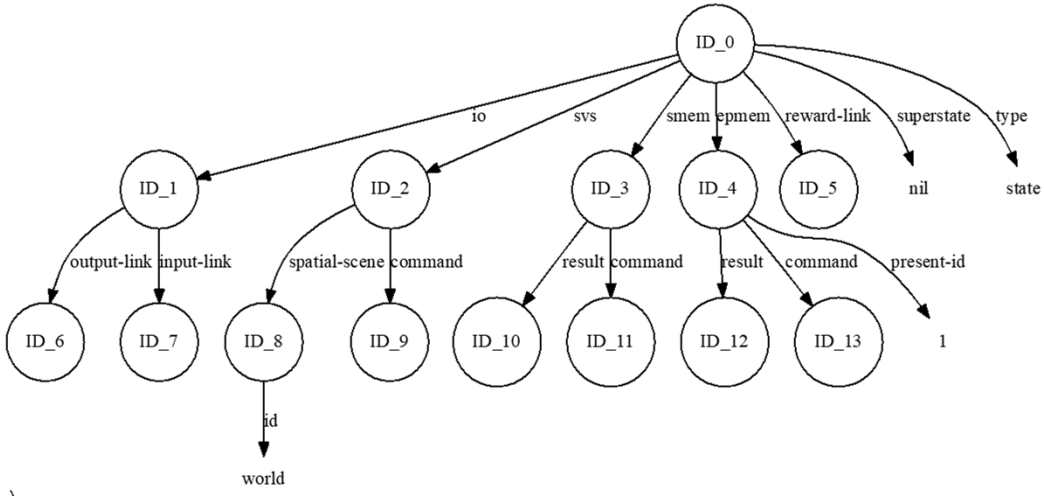
- `command`: agent-initiated actions
- `result`: architectural feedback
- `present-id`: current episode number (more later)

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…

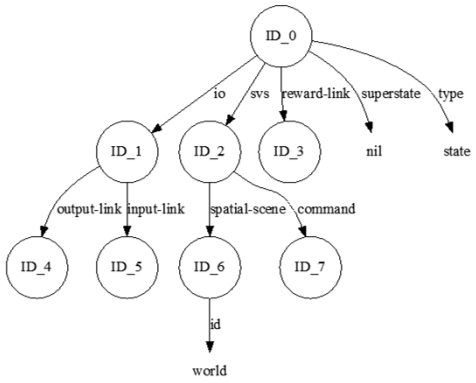
1. `epmem`
2. `epmem --set learning on`
3. `epmem`

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
  - (balance)(cardinality) + (1-balance)(activation)
  - balance: parameter=[0,1], default=1
  - cardinality: # satisfied leaf WMEs
  - activation: Σ 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

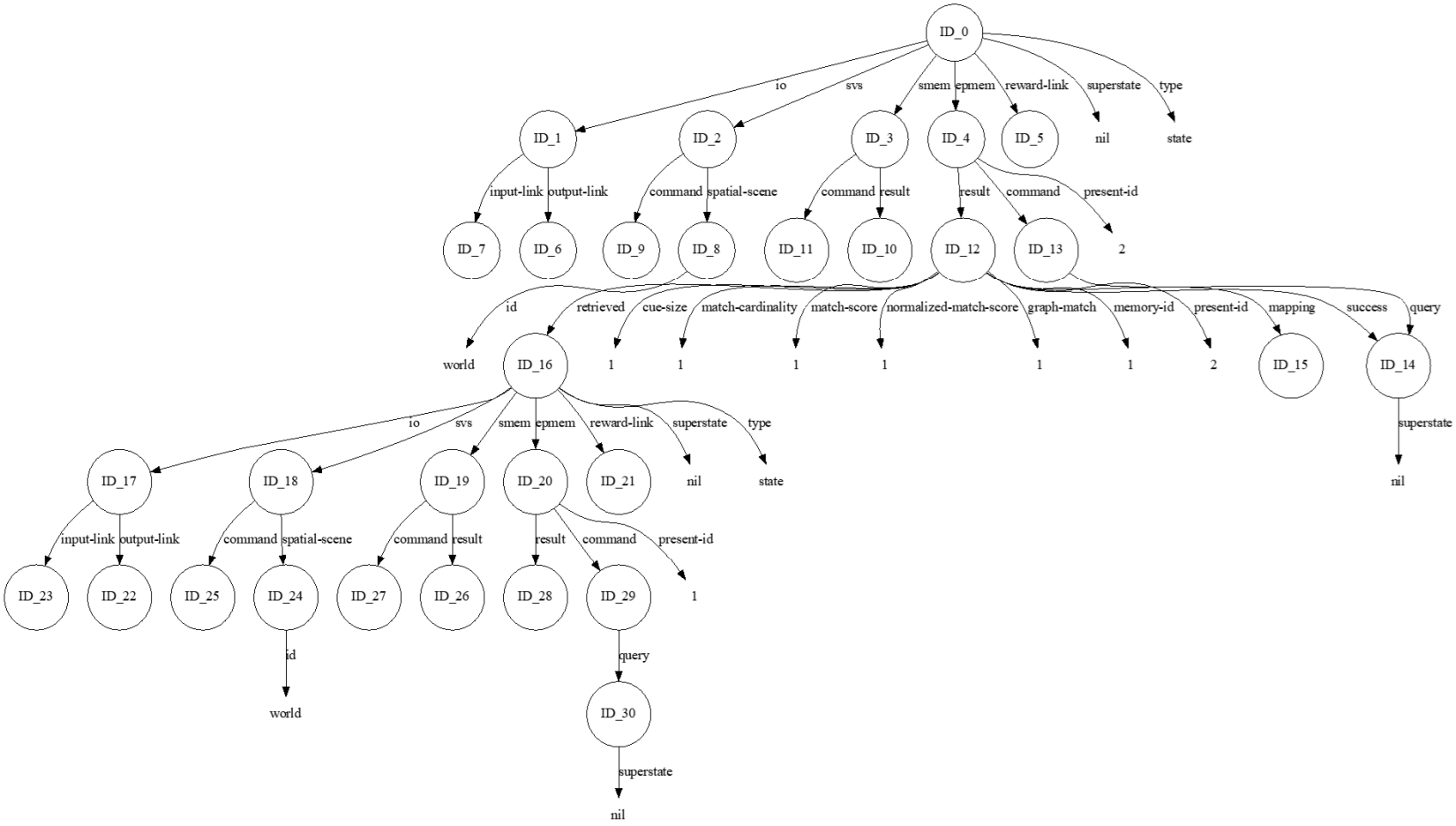
Augmentation	Meaning
^retrieved <retrieval-root>	Root of the retrieved memory
^<< success failure >> <query> <neg-query>	Query status
^match-score #	Float, episode score (slide 19)
^cue-size #	Integer, number of leaf WMEs
^normalized-match-score #	match-score/cue-size
^match-cardinality #	Integer, number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

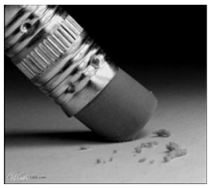
Retrieves the next/previous episode, temporally, with respect to the last that was retrieved

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!

Interactive Task Learning (Rosie)

- Memory of past problem solving
- Useful for retrospective analysis, …

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)