Episodic Memory for Soar

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Outline

- **Review**
  - Definitions and previous work
  - Improving agent behavior
- **Improving Performance**
  - Two algorithms for memory retrieval
  - Memory usage
  - Processing time

What is Episodic Memory?

- Memories of specific events in our past
  - Example: Your last vacation

Previous Work

- **Psychology**
  - Observations of Humans - Endel Tulving
- **Cognitive Modeling**
  - Soar Model (non-architectural) - Erik Altmann
- **Artificial Intelligence**
  - Continuous CBR - Ram and Santamaría
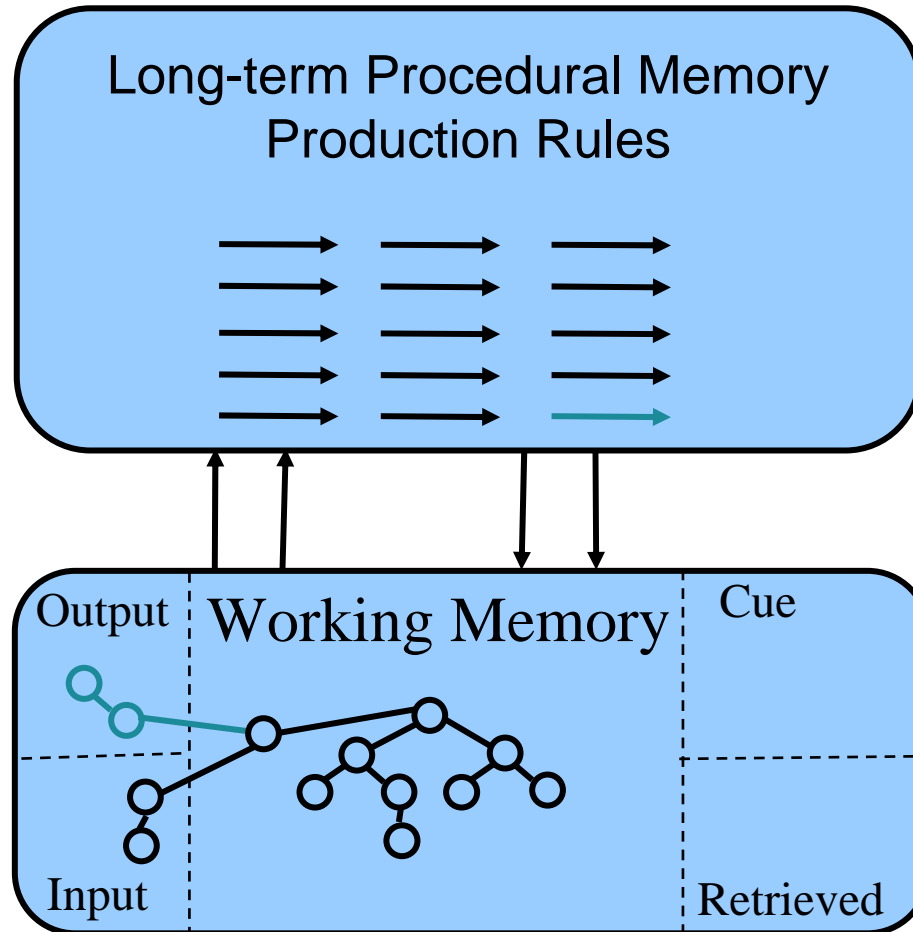 - Comprehensive Agents - Vere and Bickmore

Current Implementation

Encoding
  Initiation?

Storage

Retrieval

Long-term Procedural Memory
Production Rules

Output | Working Memory | Cue

Input | | Retrieved

When the agent takes an action.

Current Implementation

Encoding
   Initiation
   Content?
Storage

Retrieval

Long-term Procedural Memory
Production Rules

Output   Working Memory   Cue

Input   Retrieved
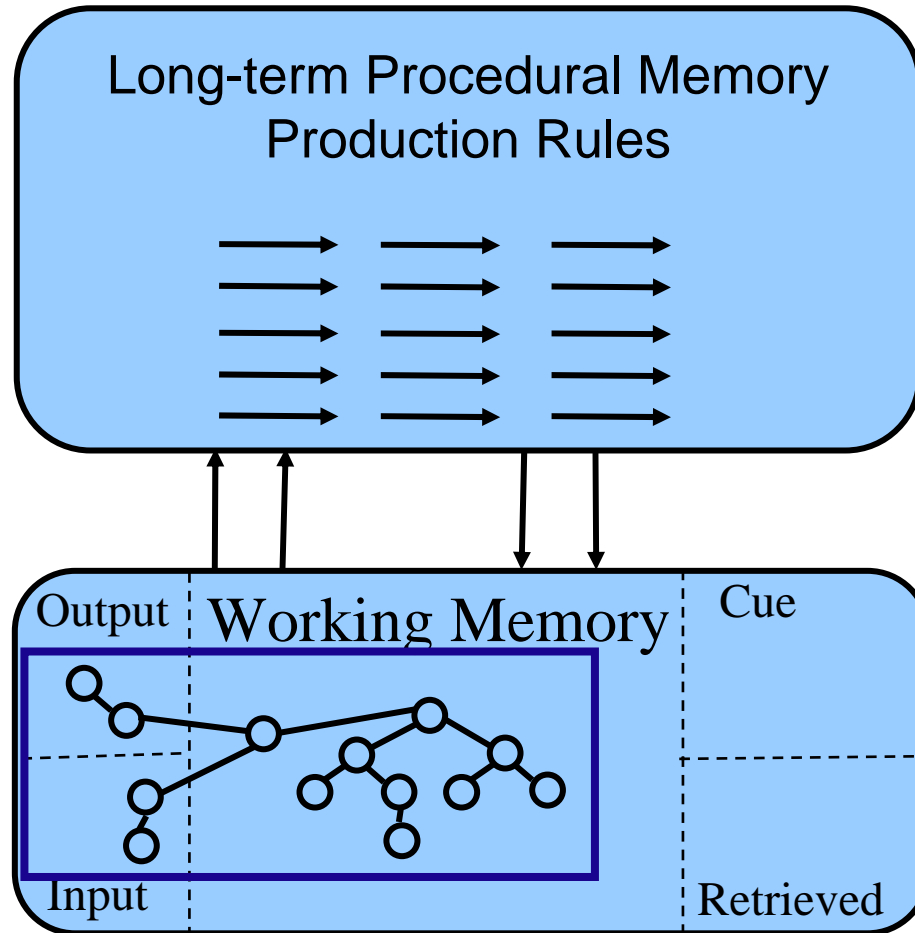
A portion of working memory is stored in the episode

Current Implementation

Encoding
  Initiation
  Content
Storage
  Episode Structure?
Retrieval

Long-term Procedural Memory
Production Rules

Episodic Memory

Output   Working Memory   Cue

Input   Retrieved

Episodic Learning
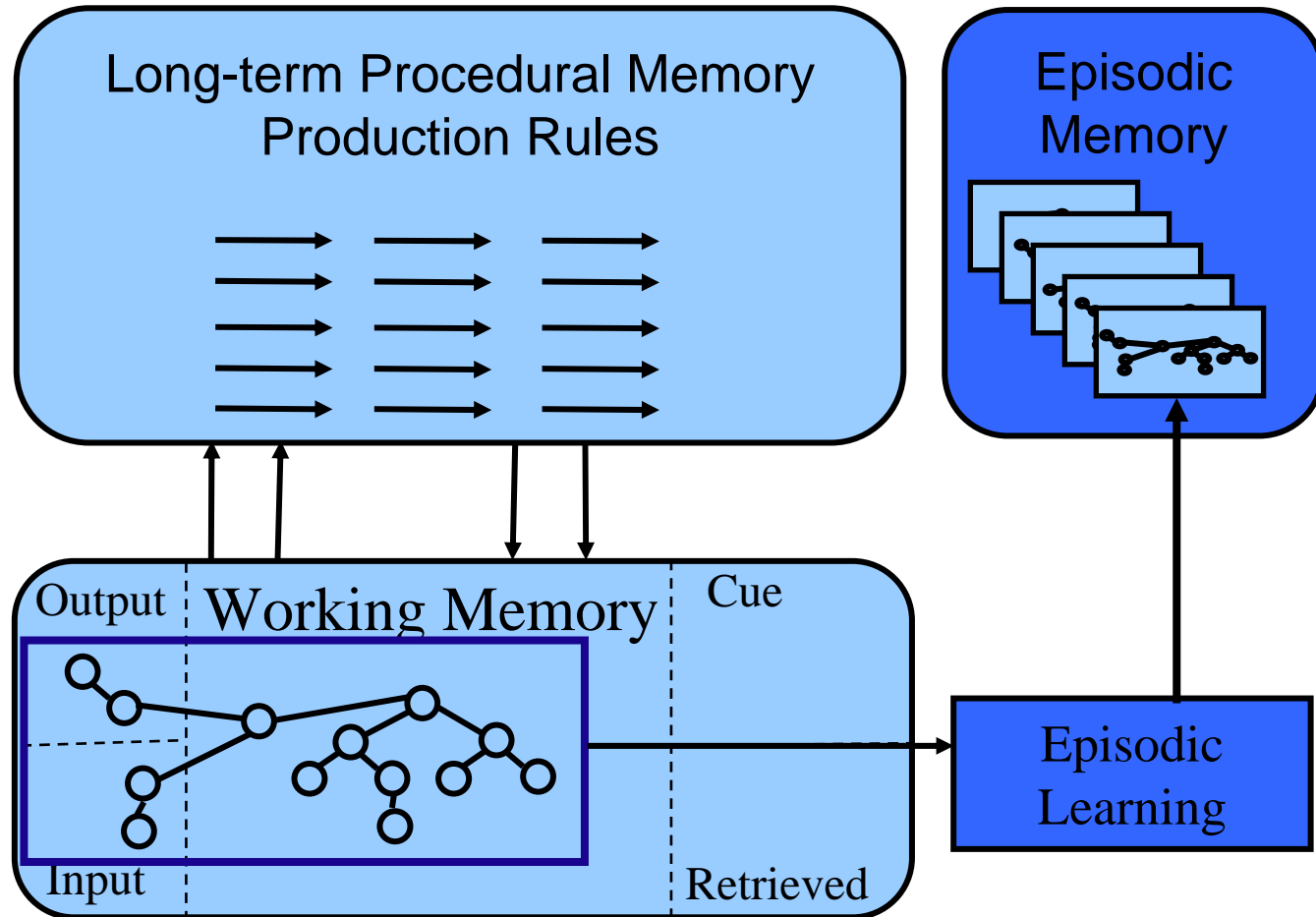
Episodes are stored in a separate memory

Current Implementation

Encoding
  Initiation
  Content
Storage
  Episode Structure
Retrieval
  Initiation/Cue?

Long-term Procedural Memory Production Rules

Episodic Memory

Output Working Memory Cue

Input Retrieved

Episodic Learning
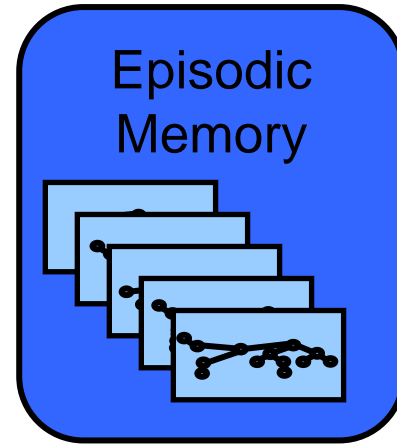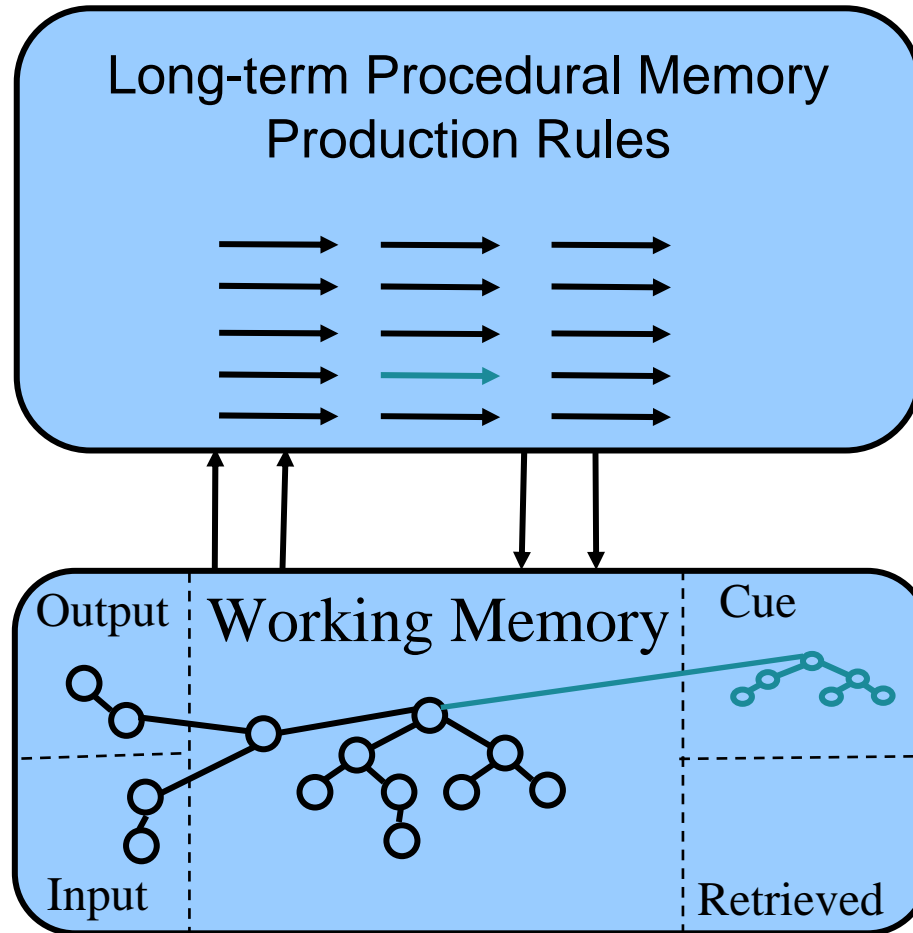
Cue is placed in an architecture specific buffer.

Current Implementation

Encoding
  Initiation
  Content
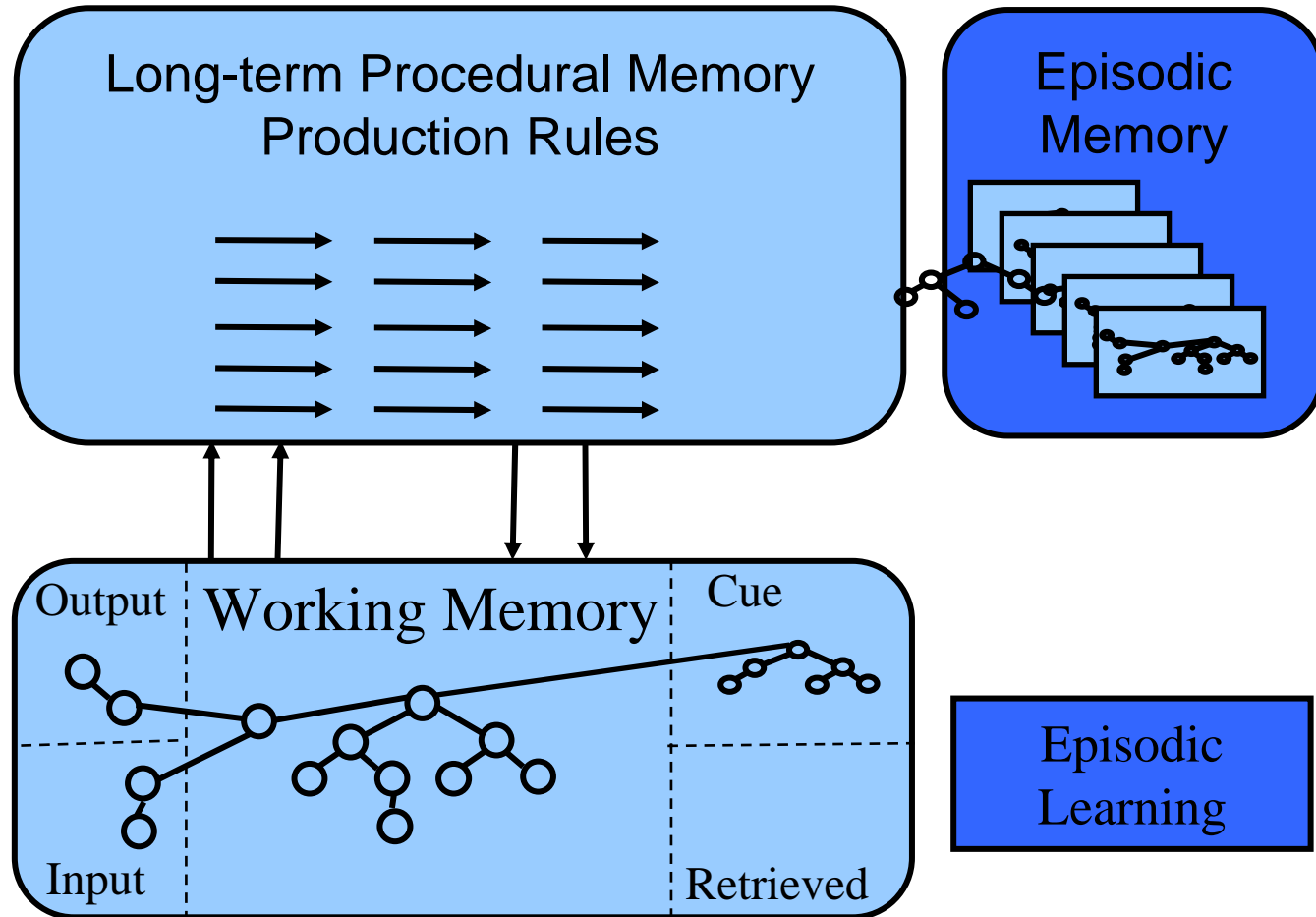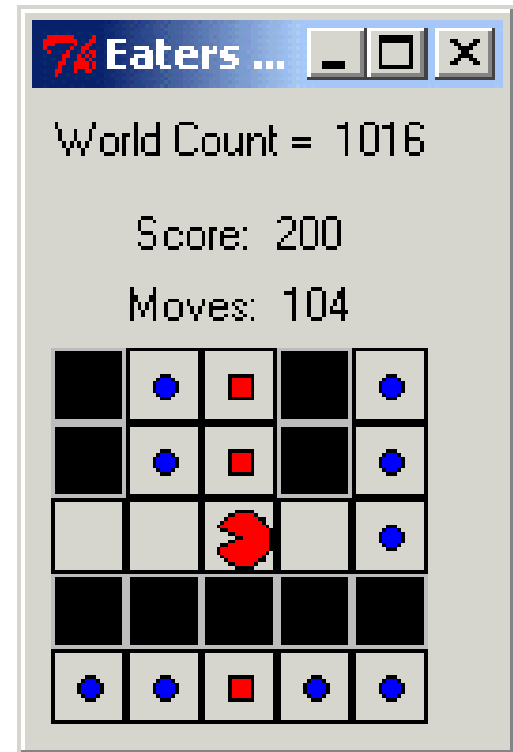Storage
  Episode Structure
Retrieval
  Initiation/Cue
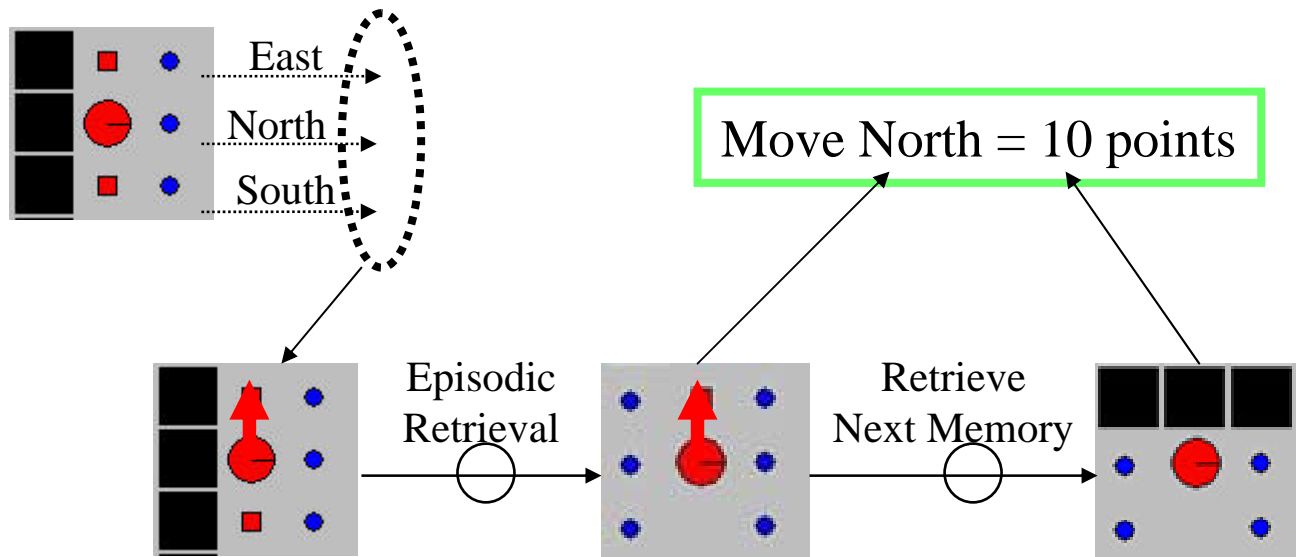 Retrieval

The closest partial match is retrieved.

Evaluation using Eaters

- **Pac-Man-like**
- **Two types of food**
  - Bonus food (10 pts)
  - Normal food (5 pts)

An Episodic Memory Eater

- Evaluate moving in each available direction
- Create a memory cue (input-link + proposed direction)
- Retrieve the best matching memory
- Retrieve the *next* memory (in temporal order)
- Use the change in score to evaluate the proposed action

East

North

South

Episodic
Retrieval

Retrieve
Next Memory

Move North = 10 points

Working Memory Activation

- Used to bias the match at retrieval time
  - Nuxoll, A., Laird, J., James, M. (2004). Comprehensive Working Memory Activation in Soar. International Conference on Cognitive Modeling.

Effects of Memory Activation Bias

Accuracy of Action Evaluation
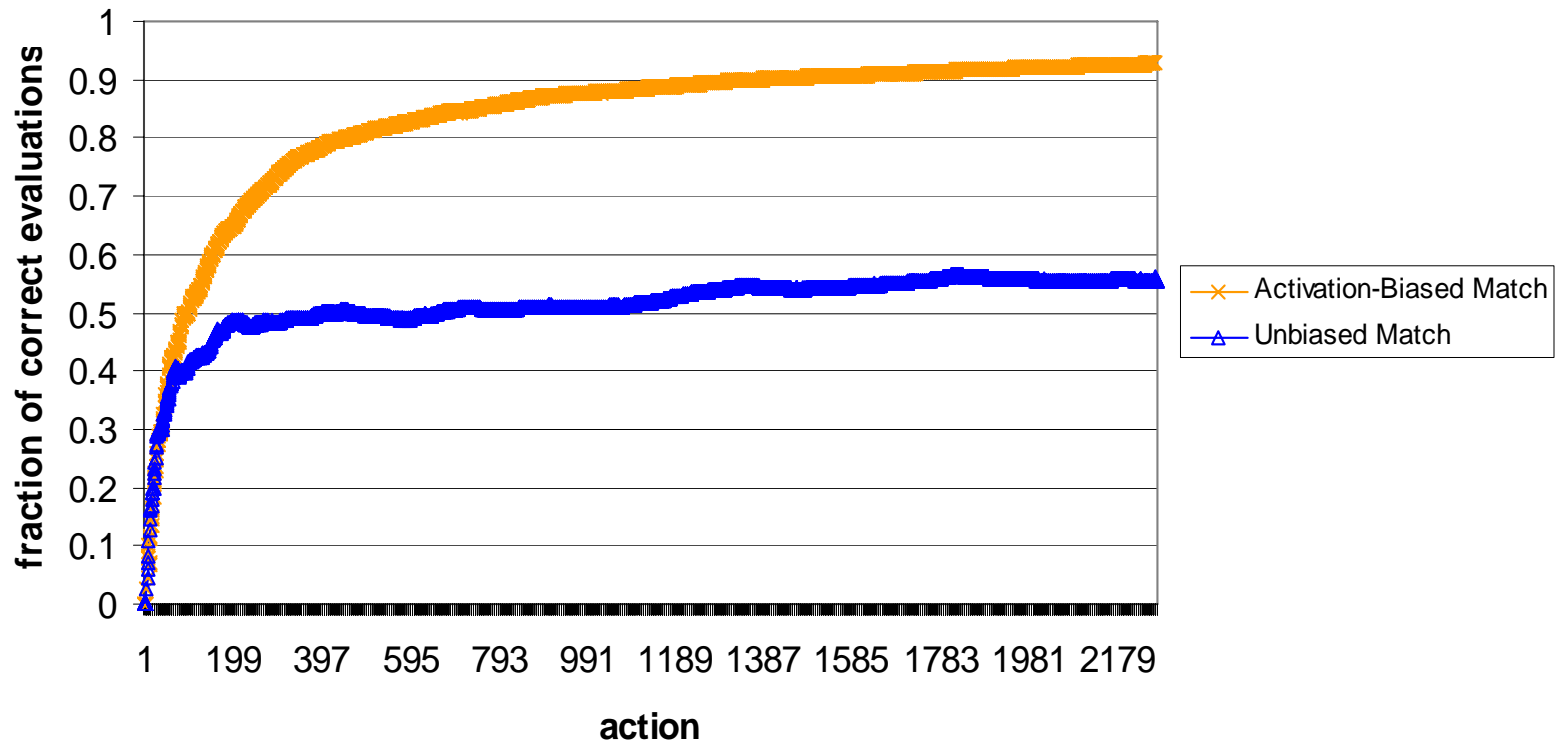
New Business: <u>Improving Performance</u>
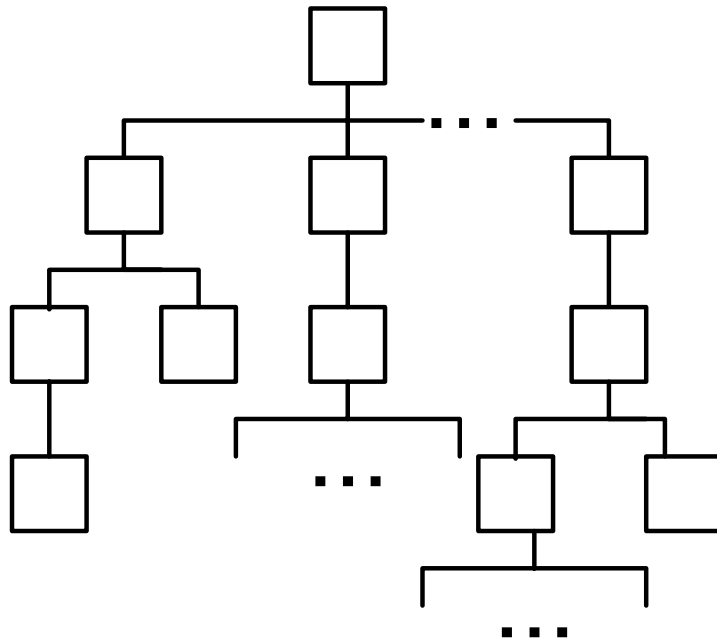
- Memory Usage

- Processing Time

Two Algorithms for Retrieval

- ## Instance-Based
  - Store a complete list of each WME in each memory

- ## Interval-Based
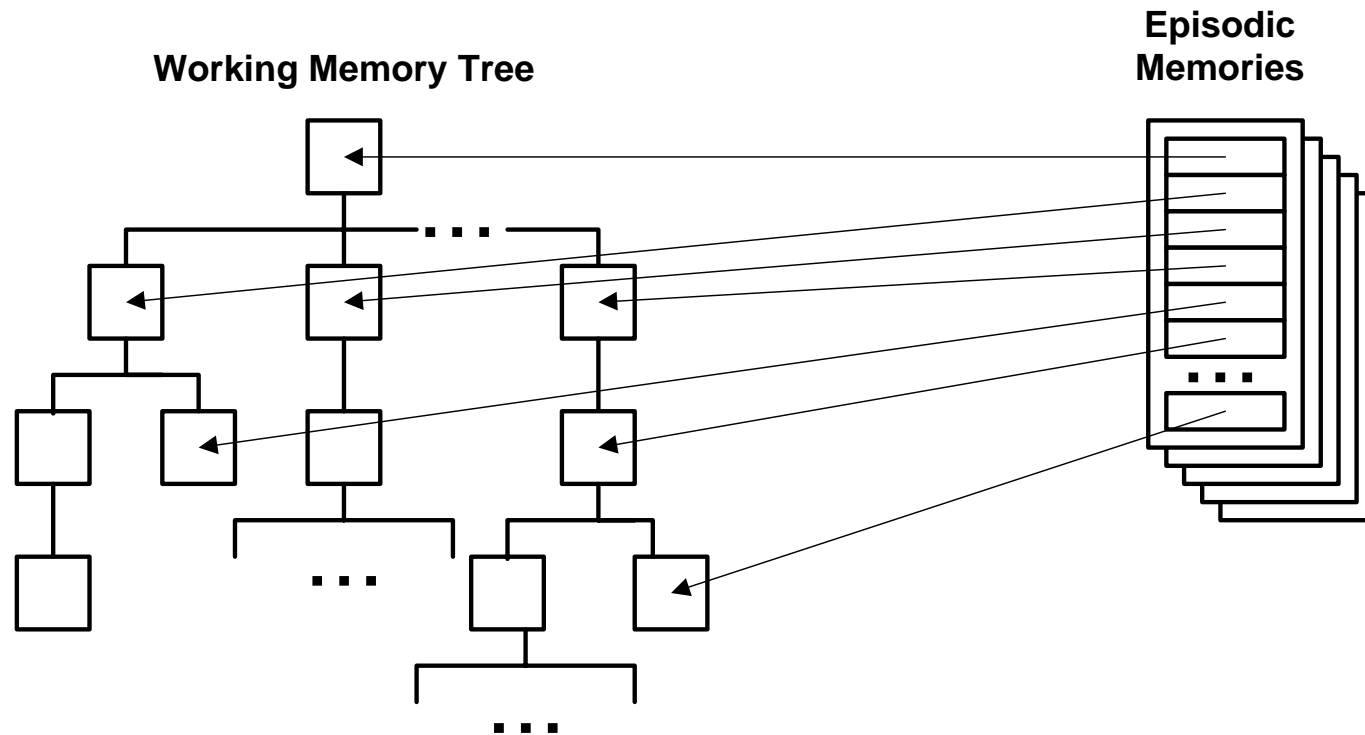 - Store the duration of each WME (i.e., what cycles during which it existed)

Instance-Based Retrieval Algorithm
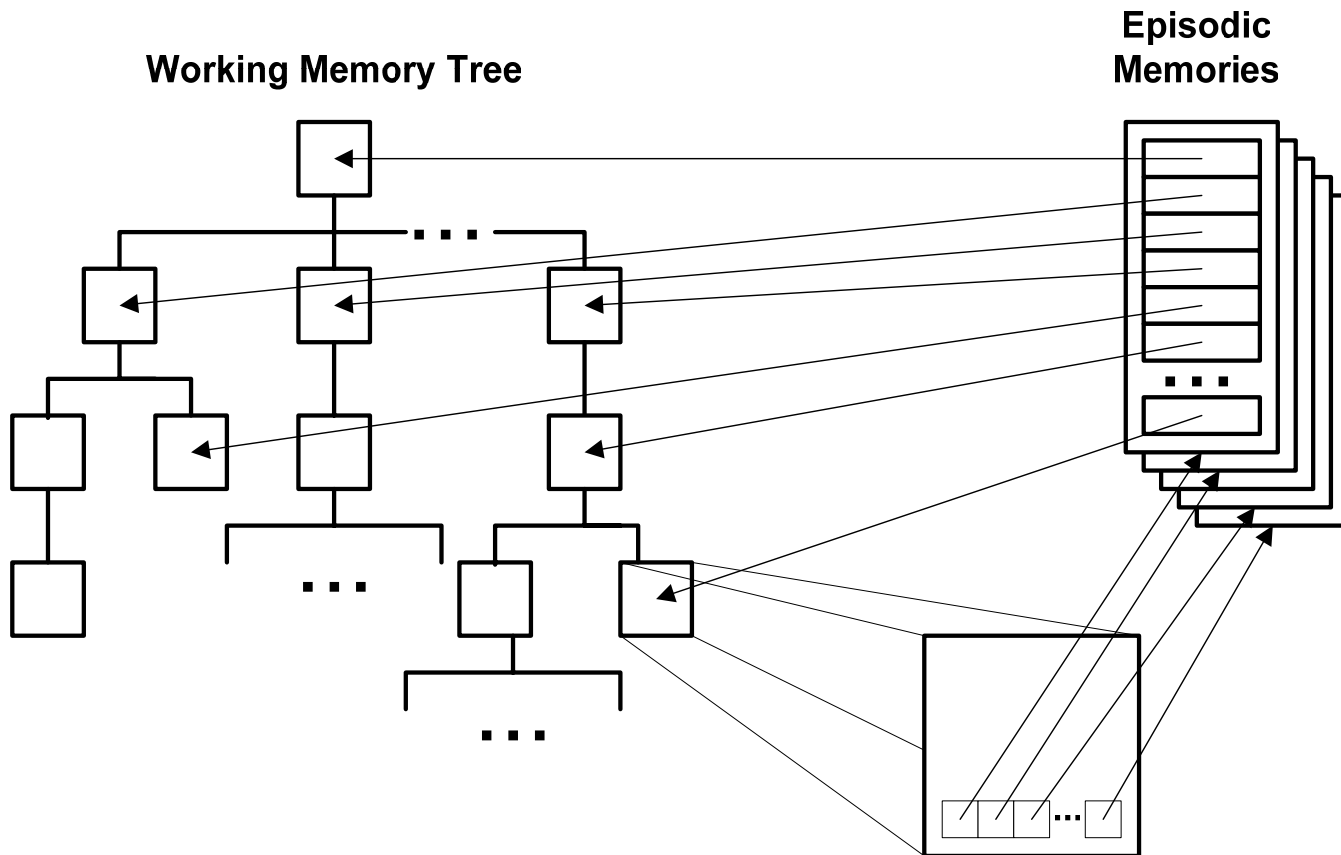
Working Memory Tree
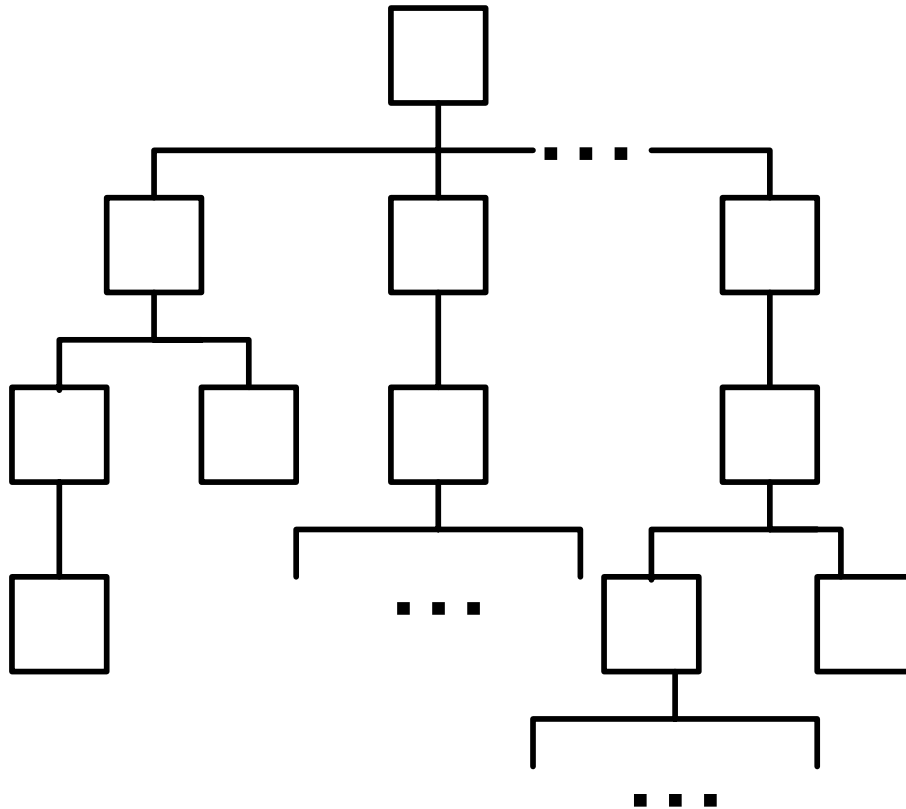
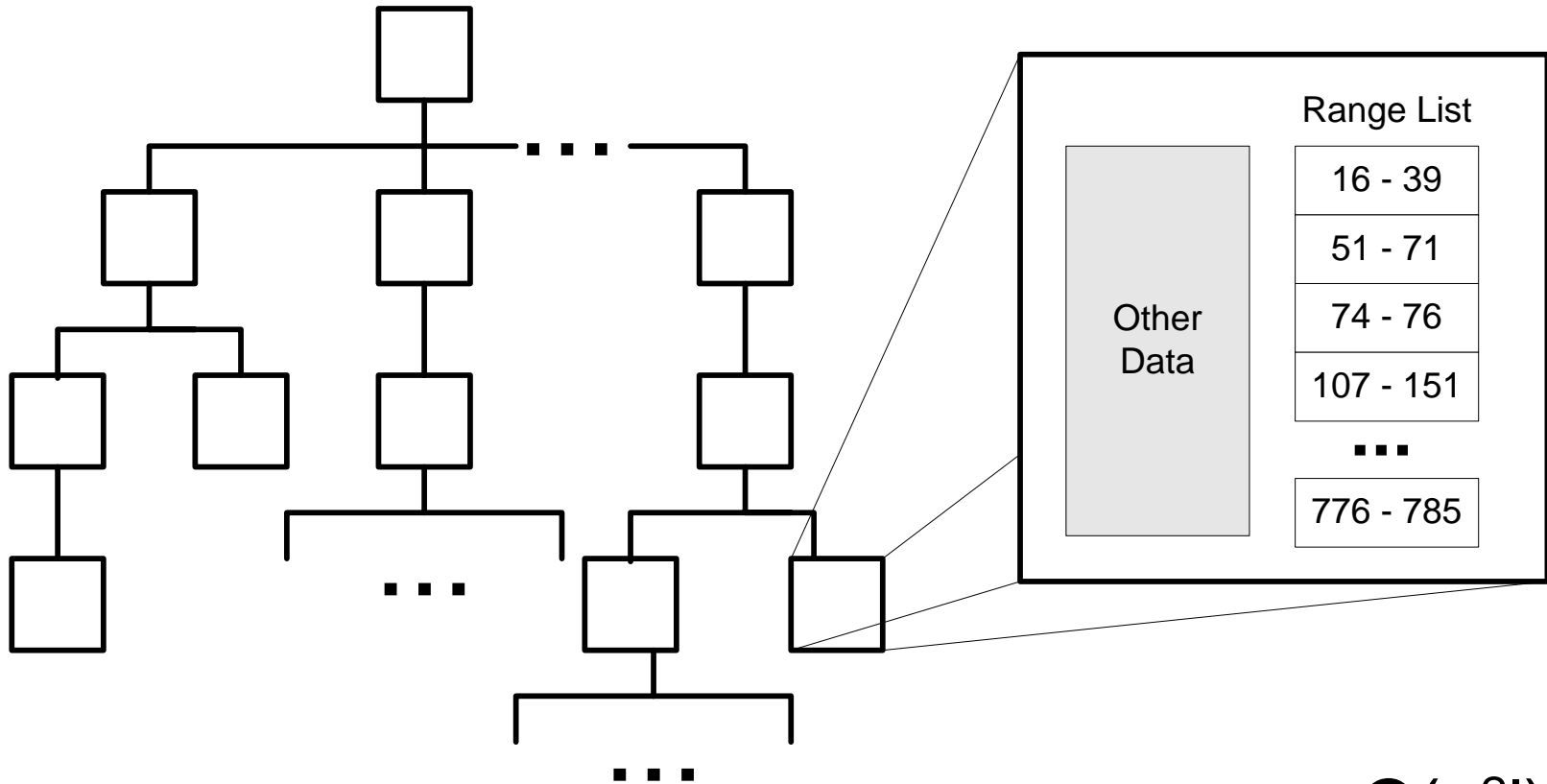# Instance-Based Retrieval Algorithm

Instance-Based Retrieval Algorithm

Interval-Based Retrieval Algorithm

Working Memory Tree

Interval-Based Retrieval Algorithm
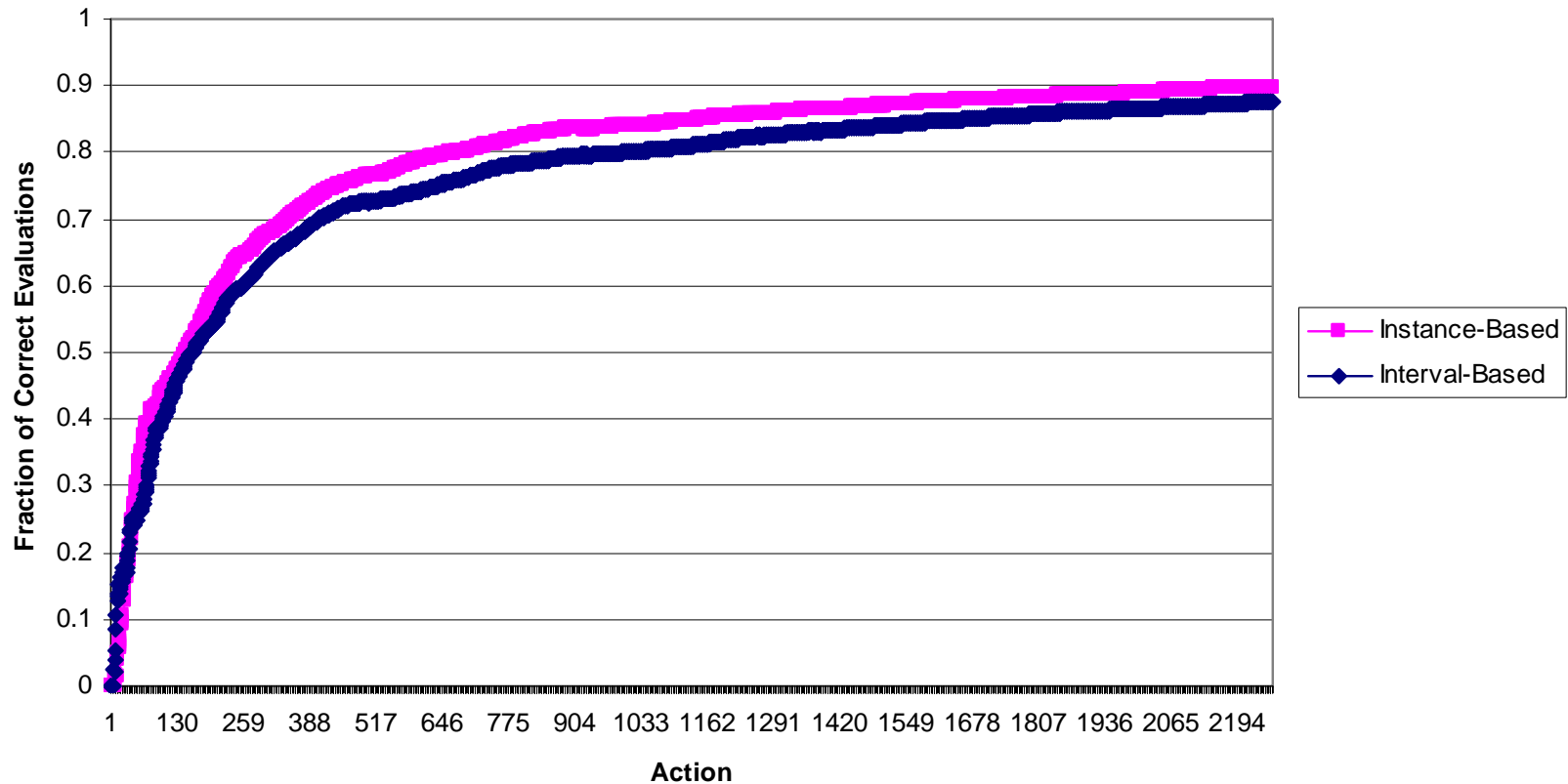
Working Memory Tree

Range List

16 - 39
51 - 71
74 - 76
107 - 151
...
776 - 785

Other Data

$O(n^2l)$

Interval-Based: Merging Ranges

Memory-Bias vs. Cue-Bias

Episodic Memory Eaters Performance

Memory Usage

Memory Usage Comparison

(y-axis: Memory allocated (kilobytes), 0 to 8000; x-axis: decision cycles, 0 to 60000)

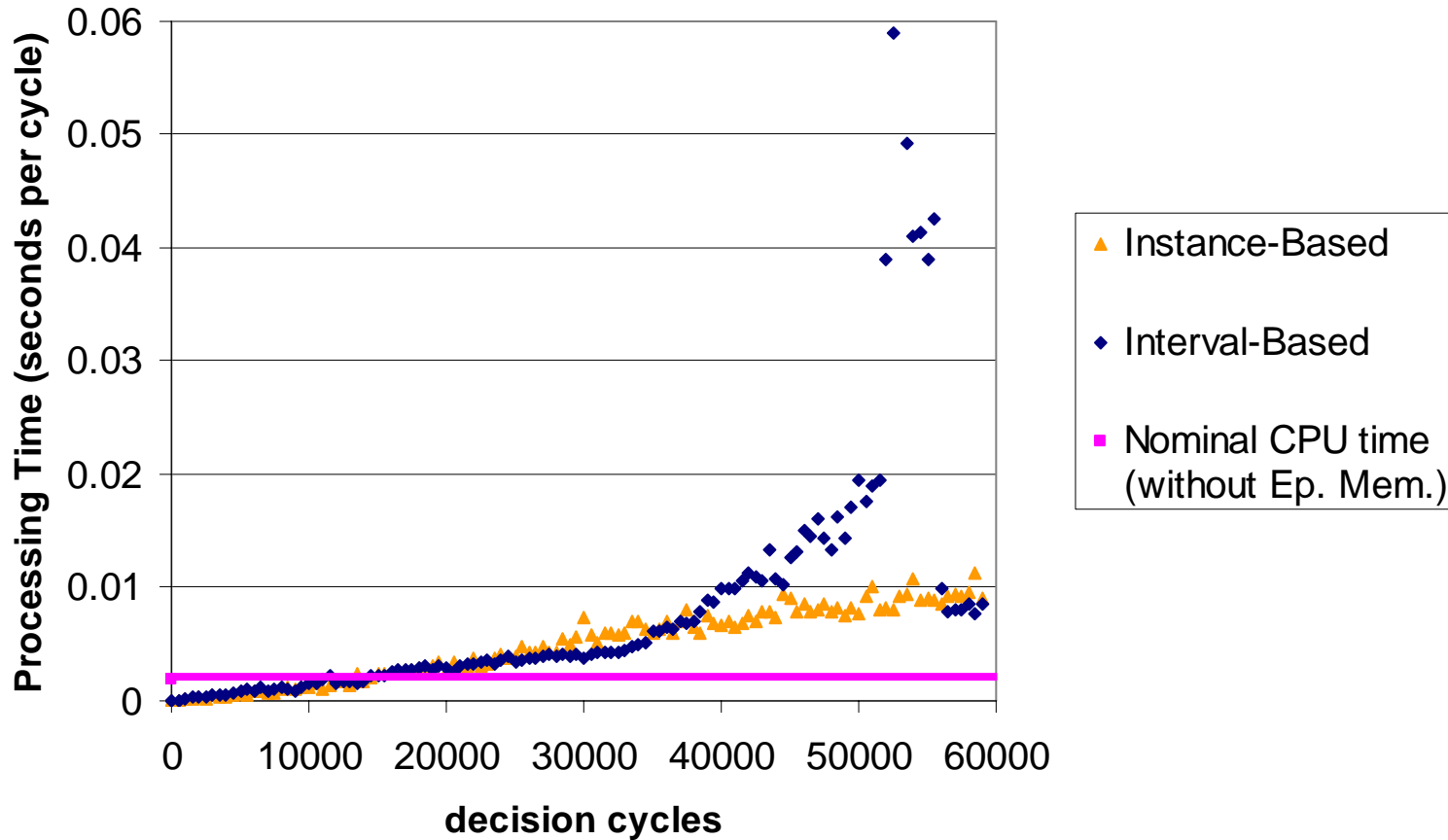Legend: ◆ Instance-Based, ■ Interval-Based
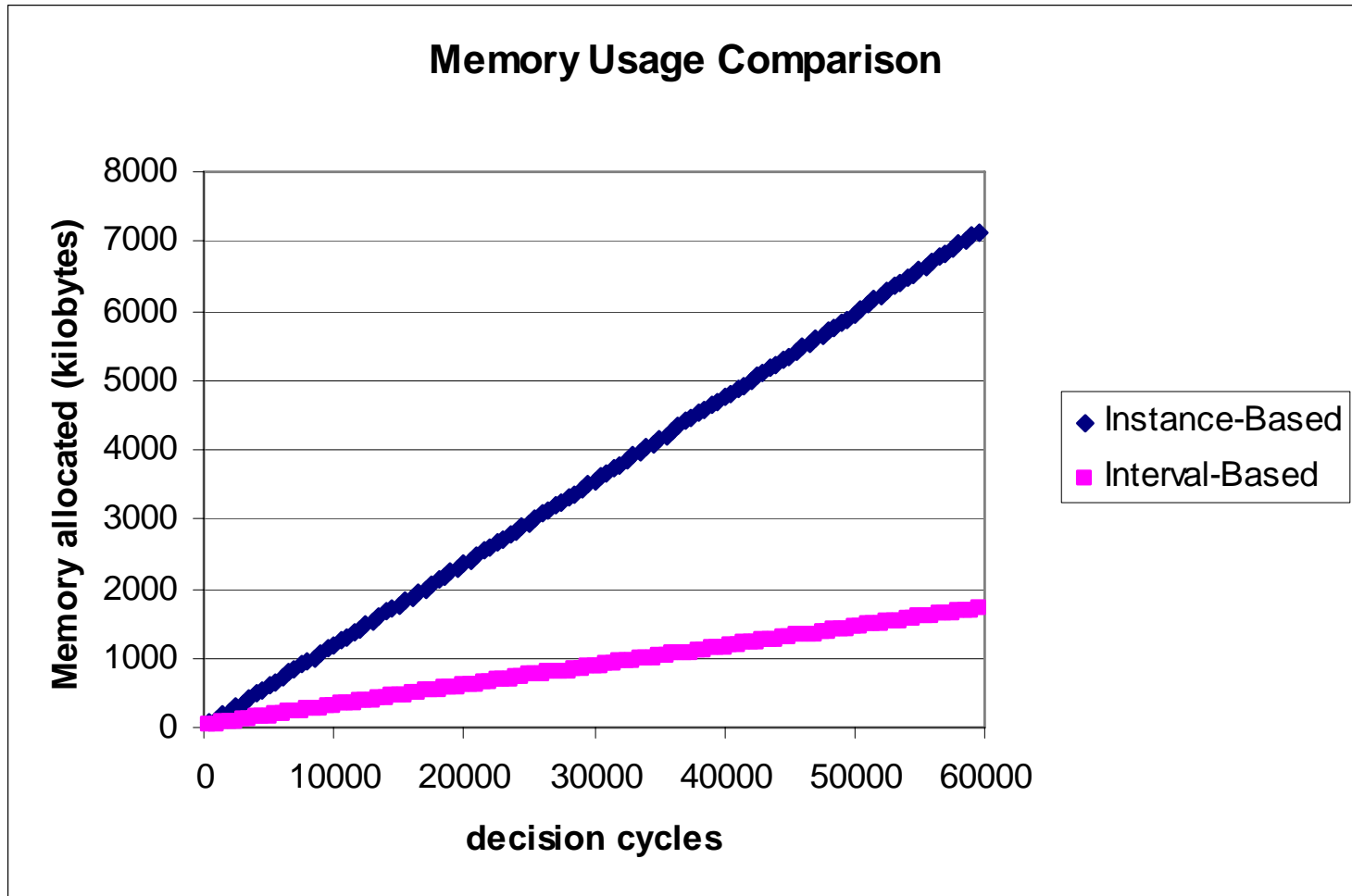
Evaluating Memory Usage

- **Rough Order of Magnitude Calculation**
  - Varies based upon agent and task
- **One new episode per 150ms (3 cycles)**
  - 55MB or 210MB per 24 hours
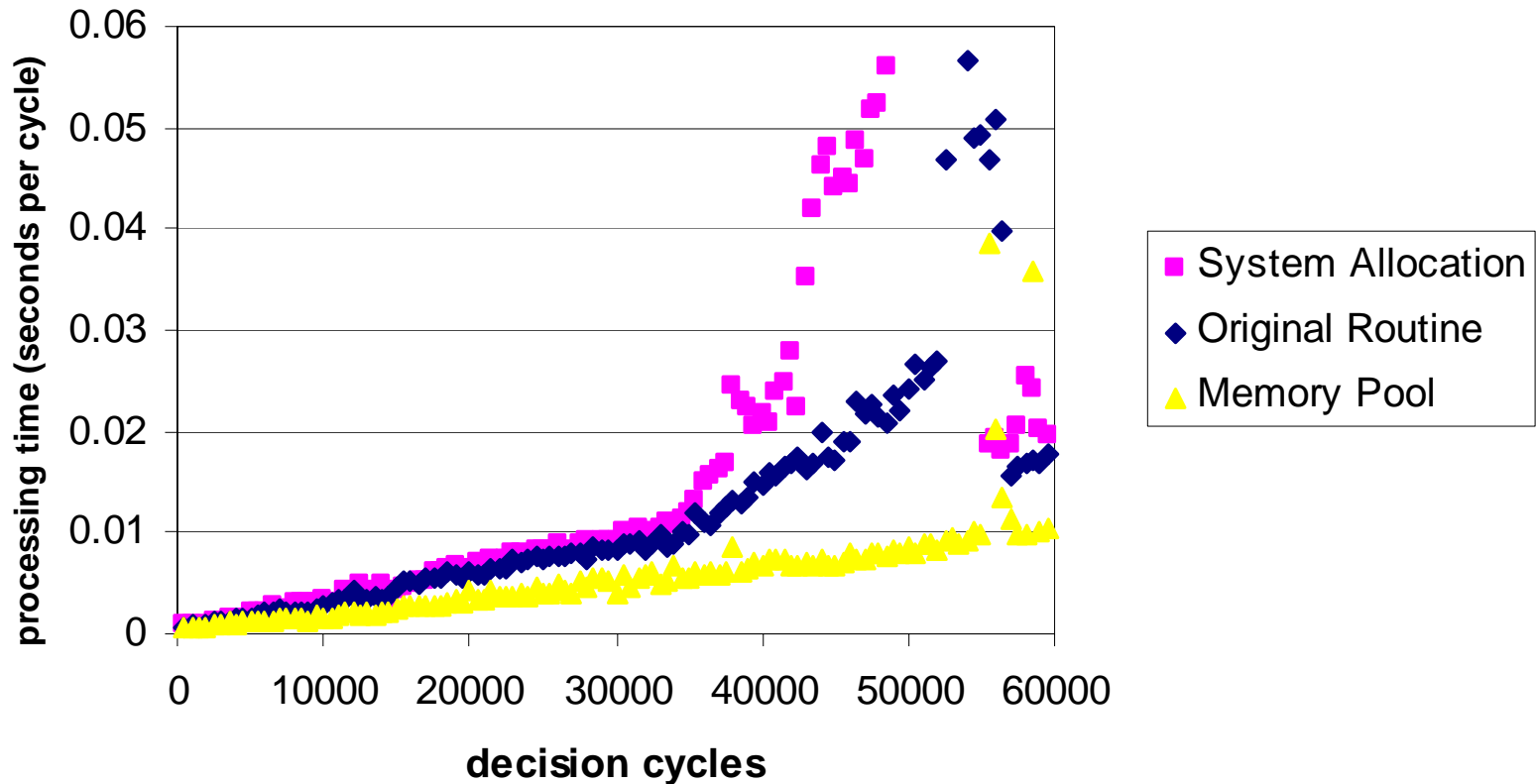- **One new episode per 5-10 seconds**
  - <10 MB per 24 hours

Processing Time
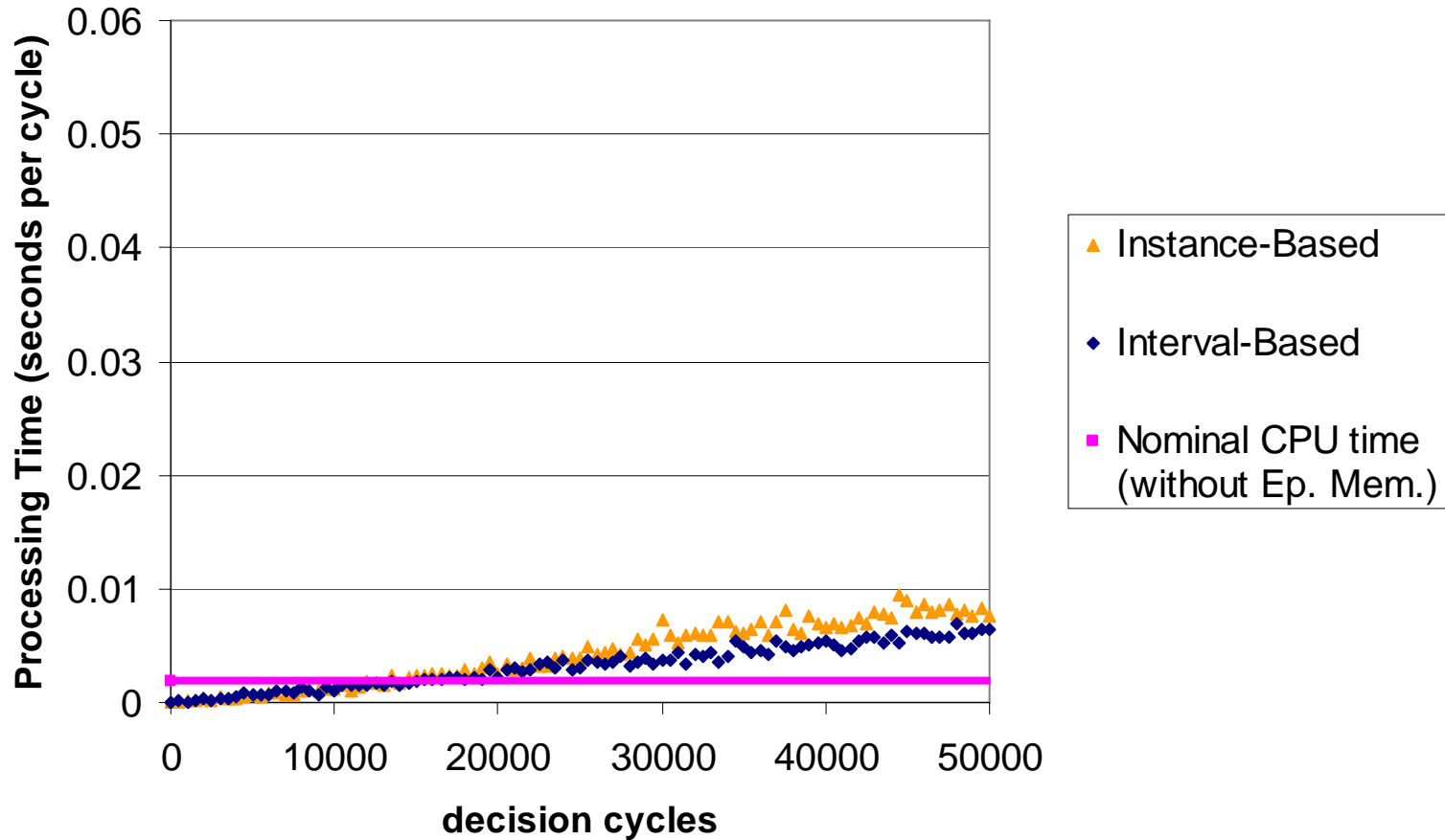

Episodic Memory Processing Time

Diagnosing "The Spike"

Diagnosing the Processing Time Spike

Processing Time Potential

Episodic Memory Processing Time (w/o Allocation)

Evaluating Processing Time

- **Rough Order of Magnitude Calculation**
  - Varies based upon agent and task
- **Worst Case (primitive action level):**
  - One new episode per 150ms (3 cycles)
  - Maximum of 50ms allowed for retrieval
  - **Result:** Limit exceed after four hours (115,000 cycles)
- **Best Case (human level):**
  - One new episode every 5-10 seconds
  - Maximum of 0.1 to 5 seconds allowed for retrieval
  - **Result:** Limited exceeded in ~1 year

Nuggets   Coal

- Domain independent, architectural implementation
- Potential for effective performance

- Performance glitches
- Needs to be tested in multiple domains