Supporting Delayed Intentions with Long-Term Memories

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A Concrete Example

A day in the life of Alex Agent:

- ran out of milk in the morning
- decided to buy milk after work
- wrote code, gave talks, attended Soar workshops

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At the end of the day, how does it remember to buy milk?

Motivation: Why Delayed Intentions?

- **Delayed Intention**: a goal with a delay between intent formation and execution
- Important component of long-term goal management

- Known as *prospective memory* in psychology [McDaniel and Einstein, 2007]
  - have intentions with cues and actions
    - **cue**: a set of features, the context of the intention
    - **action**: what the agent must do to fulfill the intention
  - are embedded in cognitively-demanding background tasks

Functional Requirements of Prospective Memory

The agent must:

1. represent and store the intention in long-term memory
2. recognize the cue to an intention while engaged
3. retrieve the intention from memory
4. modify memory to stop its pursuit

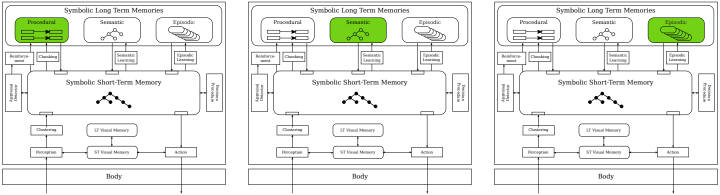
How do long-term memories support prospective memory?

Long-term memories differ in:

- How and when knowledge is stored
- What encoding the knowledge takes
- How knowledge can be retrieved
- Whether knowledge can be changed

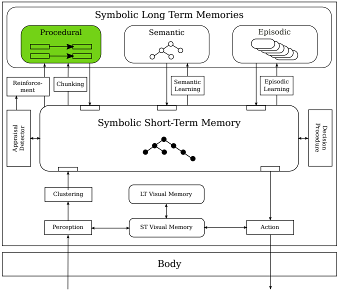
Memories of other architectures share similar profiles

A Framework for All Memories



1. Create intention in working memory
2. Store intention and remove from working memory
3. Perceive cue and propose operator
4. Apply operator to fulfill intention
5. Change memory to prevent continued pursuit of intention

Using Procedural Memory for Delayed Intentions



Properties:

- Automatic storage through chunking
- No declarative representation or retrieval
- Rules are unmodifiable once learned

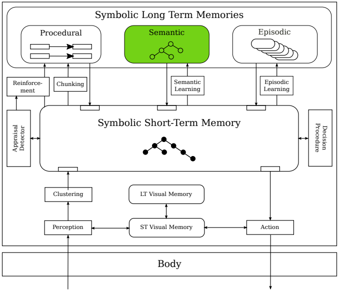
Using Procedural Memory for Delayed Intentions

- Creates intention in working memory
- Stores intention in a *data chunk*, conditioned on cue
- Learns second chunk to reject operator, to prevent repeated selections

Costs of Procedural Memory

- Rules incur lifetime cost to the agent
- Rules lack declarative representation

Using Semantic Memory for Delayed Intentions



Properties:

- Deliberate storage
- Retrieval: by identifier, by full cue match
- Modifiable on re-storage

Using Semantic Memory for Delayed Intentions

- Creates intention in working memory
- Stores intention in semantic memory
- Stores intention in data chunk, conditioned on cue *and LTI*
- Predicts features and retrieves LTI for matching intentions
- Retrieves action on operator selection
- Removes LTI from working memory

Costs and Benefits of Semantic Memory

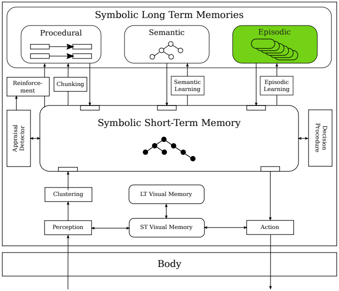
Benefits:

- Avoids lifetime cost
- Allows reasoning over intentions

Costs:

- Minor use of working memory
- Requires feature prediction

Using Episodic Memory for Delayed Intentions



Properties:

- Automatic storage
- Retrieval: by episode, by partial cue match
- Episodes are unmodifiable once stored

Using Episodic Memory for Delayed Intentions

- Creates intention in working memory
- Automatically stores intention in episodic memory
- Searches episodic memory with all features in proposal phase
- Automatically stores updated status into memory

Episodic Memory: A Modification

Problem:

- Knowledge is correct at the time of *storage*, but not necessarily at *retrieval*
- Agent may retrieve episodes before it fulfilled an intention

Solution: modify the architecture to...

- ...maintain pointer to the most recent version of objects
- ...allow agent to restrict retrievals to the most recent versions

Costs and Benefits of Episodic Memory

Benefits:

- Avoids lifetime cost
- Allows reasoning over intentions

Costs:

- Modifies architecture
- Could interrupt episodic queries

Evaluation

Dimensions:

- **Accuracy**: Whether intentions are fulfilled under increased task load
- **Scalability**: Whether Soar remains reactive as the number of intentions grow

Working memory agent as baseline

Evaluation Domain for Accuracy

For a fixed number of cycles, the environment presents a combination of

- a new intention to be encoded
- a cue for a previous intention, to be acted upon
- a background even the agent must respond to

Agent always prefers background events over intention encoding/retrieval

Accuracy: Results

Question: how many intentions can the agent complete in a given time frame?

- Note: semantic memory agent assumes perfect feature prediction

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Agent	Intentions Fulfilled
working memory	82.66%
episodic memory	81.10%
procedural memory	40.42%
semantic memory	9.33%

Low accuracy is due to the chunking process being interrupted

Evaluation Domain for Scalability

Goal: Assess how methods degrade with large numbers of intentions

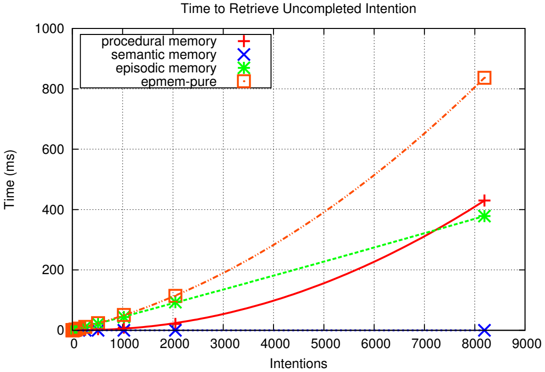
- Environment presents n intentions and $n - 1$ cues
- Agent completes $n - 1$ intentions
- Agent must now retrieve the remaining uncompleted intention

For procedural memory, agent must reject the $n - 1$ operators

Scalability: Results

Question: how quickly can the agent retrieve the uncompleted intention?

- Note: working memory agent would be along bottom axis



Modified Epmem has lower complexity for prospective memory

Evaluation Summary

- Episodic memory recalls intentions, but slows down over time
- Semantic memory performs poorly, but scales well

Nuggets and Coal

Nuggets

- Understand functional requirements of prospective memory
- Soar can fulfill delayed intentions to a limited extent

Coal

- Long-term memories trade-off in accuracy and scalability
- Cannot rule out the need for a separate memory
- Work to be done on more extensive evaluations

Thank You

Further Reading

- Altmann, E. M. and Trafton, J. G.. Memory for goals: An architectural perspective. In *Proceedings of the 21st Annual Meeting of the Cognitive Science Society*, 1999.
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