Modeling Episodic Memory in Cognitive Architectures

A Comparative Study of Soar and Xapagy

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Background

Definition

Most cognitive architectures include memory systems for storing intermediate results, supporting learning and adaptation in dynamic environments [1].

Among the various types of memory discussed in cognitive architecture literature, **episodic memory (EM)** has received attention due to its role in enabling agents to recall and learn from past experiences.

EM refers to **memory for events** (episodes), often expressed as the what, the where, and the when [2].

Research Gap

While prior work [3] has reviewed episodic memory across a range of cognitive architectures in a broad and high-level manner, a **detailed, structured comparison** among architectures remains lacking.

This gap is significant, as **understanding how different cognitive models conceptualize and implement episodic memory** can offer insights into their design principles, cognitive plausibility, and practical utility.

Primary Question

How do **different approaches to episodic memory modeling** in CAs reflect **assumptions about the role of episodic memory inn cognition**, and what **design trade-offs** do they reveal ?

Soar vs Xapagy

Purpose

general-purposed VS narrative reasoning only

Memory System

multiple long-term memory models VS EM as the only model

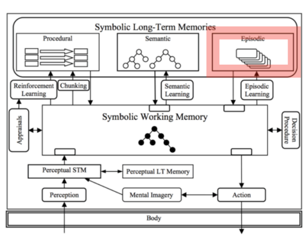

Fig.1 EM (in SOAR) and its subsystems [4]

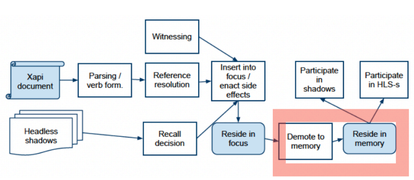

Fig.2 EM as the only memory model in Xapagy [5]

Research Question

Main Question

How do different approaches to episodic memory modeling **in Soar and Xapagy** reflect assumptions about the role of episodic memory in cognition, and what design trade-offs do they reveal for cognitive architectures?

Sub Questions

1) How is episodic memory **represented and structured** in Soar and Xapagy?
2) What mechanisms are employed by each architecture for **encoding**, **storing**, **retrieving**, and **updates** of episodic memories?
3) What are the **key differences** and **limitations** in the implementation of episodic memory between the two architectures?
4) What **implications** do these differences have for the development of future cognitive architectures involving episodic memory?

Methodology

Literature Search

Systematic literature collection to **identify and select** CAs with EM mechanisms documented in detail, for in-depth analysis.

Comparison Study

Analysis based on **comparison framework**

Dimension	Description
Representation & Structure	How are episodes represented within the system? What elements does an episode contain?
Encoding	How are episodes formed or encoded during system operation?
Storage	How are episodic memories stored within the architecture?
Retrieval	How are episodes retrieved and what triggers retrieval?
Memory Updates	Are there mechanisms for forgetting, updating, or managing memory?
Biological Plausibility	How does the architecture resemble human episodic memory?
Limitations	Are there any known issues, limitations, or missing components in the EM model?

Synthesis

Identify **patterns, design trade-offs, and implications.**

Identification of studies via databases

Identification

Records identified from: (n=347)
- Scopus (n = 92)
- IEEExplore (n = 108)
- Web Of Science (n = 60)
- ACM Digital Library (n = 37)
- Science Direct(n=50)

Records removed before screening:
- Records from other fields removed (n = 266)
- Duplicate records removed (n = 184)

Screening

Records screened by abstract with inclusion criteria (n=61)

Records screened by abstract with exclusion criteria (n = 37)

Included

Records screened by full text (n = 26)

Soar, Xapagy, ICARUS, LIDA

Records for chosen models (n = 10)

Soar vs Xapagy

References

[1] Iuliia Kotseruba and John K. Tsotsos. A review of 40 years of cognitive architecture research: Core cognitive abilities and practical applications. *arXiv preprint arXiv:1610.08602*, 2016.

[2] Endel Tulving. Episodic and semantic memory. In Endel Tulving and Wayne Donaldson, editors, *Organization of Memory*, pages 381–403. Academic Press, New York, 1972.

[3] Luis Martin, Karina Jaime, Felix Ramos, and Francisco Robles. Bio-inspired cognitive architecture of episodic memory. *Cognitive Systems Research*, 76:26–45, 2022.

[4] John E. Laird. *The Soar Cognitive Architecture*, chapter Introduction, pages 1–25. MIT Press, 2012.

[5] Ladislau Bölöni. An investigation into the utility of episodic memory for cognitive architectures. *AAAI Fall Symposium* - Technical Report, 01 2011.

Results

Dimension	Soar	Xapagy
Representation & Structure	Symbolic snapshots of working memory; Graph-structured with identifiers and attributes; Temporally ordered episodes	Raw episodic recording; Conceptual overlays; Verb-instance graphs; Each episode is made of atomic VIs connected temporally and contextually
Encoding	Automatic at intervals; Captures changes only in top level of working memory	Instances and VIs are encoded by staying in the focus, gaining salience over time, influenced by marking rate and activity type
Storage	Indexed by temporal order; Stores only changes; Does not store substates or retrievals	Weighted sets; Non-indexed; Passive memory;
Retrieval	Cue-based; Explicit queries with features; Returns best-matching episode by recency or similarity	Shadowing; Retrieval occurs via automatic matching between current focus (working memory) and episodic memories; forming predictions or inferences
Memory Updates	Static after encoding; No automatic forgetting or generalization	Exponential decay; Self-shadowing and drift; Memories lose salience over time; repeated recalls can distort memory content through drift
Biological Plausibility	Inspired by human episodic memory concepts but structurally tied to symbolic reasoning;	Emergent memory dynamics; Models forgetting, interference, and recall bias similar to human episodic memory
Limitations	Retrieval depends on explicit cues; Recency bias; No automatic integration with procedural knowledge; Computational cost increases with memory size	No abstraction; No procedural memory; Episodic-only reasoning; Lacks generalization; Memory cannot be queried directly

Key Insights

1) Distinctive cognitive **goals lead to fundamentally different design choices**.
2) Contrasting assumptions about **the role of episodic memory in cognition**:
   1) Soar: supportive to rule-based problem-solving
   2) Xapagy: cognitive behavior emerging solely from accumulative experience
3) High level **conceptualization guides implementation** of EM in sub-systems
   1) Soar: structural organization, efficiency, accuracy
   2) Xapagy: flexibility, association, dynamic
4) Different **development dynamics**:
   1) Soar: extension to an existing system, constrained by legacy systems
   2) Xapagy: design from ground-up, memory-centric, simple

Conclusion

Conclusion

Different approaches to EM modeling in Soar and Xapagy reflect distinctive **assumptions about role of EM in cognition**, and various **design trade-offs,** between generality and specialization, between symbolic precision and experiential flexibility, **aligned with respective design goals.**

Future Work

1) Apply similar comparison framework to additional architectures, to generalize findings and identify broader design trends and patterns.
2) Empirical evaluation through task-based benchmarks
3) Explore hybrid approaches to model EM in CA
4) Other forms of episodic memory – such as imagery – can be incorporated into existing architectures