# Modeling Episodic Memory in Cognitive Architectures

## A Comparative Study of Soar and Xapagy

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**Abstract**

Episodic memory (EM) – the capacity to recall past experiences situated in time and context – is a critical component of intelligent behavior. Although several cognitive architectures (CAs) have incorporated mechanisms inspired by episodic memory, implementations vary widely in structure, mechanisms, and integration with other cognitive functions. While prior work has reviewed episodic memory across a range of architectures in a high-level manner, detailed, structured comparisons among specific systems remain lacking. This study presents a focused comparative analysis of modeling episodic memory in two contrasting cognitive architectures: Soar, a symbolic, rule-based, general-purpose system, and Xapagy, a system designed specifically for narrative reasoning, relying on direct, unprocessed recordings of autobiographical events. By analyzing the representations, structures, and mechanisms of episodic memory in these two systems, this study highlights important design trade-offs and distinct assumptions about the role of episodic memory in cognition and its modeling approaches in CAs.

# 1 Introduction

Cognitive architectures (CA) aim to model the underlying infrastructure of intelligent systems by replicating core functions such as perception, memory, decision-making, and learning [1]. Among these, the ability to store and utilize knowledge of specific past experiences – commonly referred to as episodic memory (EM) – is crucial for adaptive and intelligent behavior. Episodic memory enables agents to recall what happened, when it occurred, and under what circumstances, which is essential for reasoning in dynamic environments and learning from experience over time [2].

In the human cognitive system, episodic memory plays a foundational role in contextualizing decisions, anticipating future events, and adjusting behavior. As Tulving described it, "episodic memory receives and stores information about temporally dated episodes or events and temporal-spatial relations between these events" [3]. Inspired by this, several cognitive architectures have incorporated episodic memory mechanisms to varying extents, modeling how intelligent agents might recall and apply past experiences. However, these implementations differ significantly in structure, function, and integration with other cognitive subsystems. While prior work [2] 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. It can also highlight underexplored aspects and inform future improvements or integrations in artificial cognitive systems.

To address this gap, this research [1] began with a broader systematic review of cognitive architectures that incorporate episodic memory mechanisms, identifying several candidates for detailed, structured comparative study. From this broader survey, a focused, in-depth comparative analysis was undertaken on two representative and contrasting architectures: Soar and Xapagy. These two systems represent two fundamentally different paradigms: Soar exemplifies a symbolic, problem-solving tradition in cognitive modeling, while Xapagy represents a more experience-driven, narrative-based paradigm, closer to how humans recall

[1]Parts of this paper were drafted or refined using NotebookLM and ChatGPT for content extraction, language clarity and summarization. See details in section 7 Responsible Research.

and reason about personal stories. Specifically, Soar is a rule-based, symbolic architecture that integrates episodic memory in addition to procedural reasoning [4], whereas Xapagy is a narrative-based, symbolic system in which episodic memory serves as the core mechanism for behavior and reasoning [5]. This contrast reflects drastically different assumptions about the role of episodic memory in cognition. This focused comparison provides a detailed examination of their respective approaches to episodic memory modeling and highlights how different assumptions about memory representation, mechanisms, and integration affect the design of cognitive systems. The study also serves as a demonstration of how structured, detailed comparisons on subsystems among cognitive architectures can contribute to the field, complementing broader surveys with deeper insights into architectural trade-offs.

### 1.1 Research questions

This research paper aims to answer the 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?* To guide this comparative investigation, the following sub-questions are addressed:

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?

While both Soar and Xapagy are documented in official publications, no prior work has provided a systematic, side-by-side comparison of their episodic memory models. The available sources present details specific to each architecture in isolation, often emphasizing internal goals rather than enabling comparative analysis. This research addresses that gap by offering a structured and critical comparison that highlights not only implementation details but also the different conceptualization about the role of episodic memory in cognition. By synthesizing and organizing this material through a comparative framework, the study helps clarify the design trade-offs and theoretical implications that are otherwise scattered or implicit in primary sources.

### 1.2 Scope and Limitations

This study began with a broad review of cognitive architectures (CAs) that incorporate episodic memory mechanisms, aiming to build a comprehensive understanding of how episodic memory is modeled across the field. The initial scope identified approximately four architectures with detailed, documented episodic memory models suitable for analysis. However, in order to provide an in-depth, comprehensive comparison with given time constraint, the analysis was refined to focus on two representative and contrasting systems: Soar and Xapagy.

The analysis is based on secondary sources – published papers, technical reports, and official documentation – and does not involve new experimental implementations or empirical testing. While some observations about decision-making will emerge, the core focus remains on the modeling of episodic memory itself.

### 1.3 Structure of the paper

The remainder of this paper is organized as follows:

- **Section 2 Background and Related Work:** This section provides an overview of cognitive architectures and their approaches to memory systems, with a focus on episodic memory. It also highlights current research gaps and provides an overview of the two selected cognitive architectures.
- **Section 3 Methodology:** This section outlines the methodological approach used in this study. It details the search and screening process for relevant literature, and introduces the comparison framework used to analyze episodic memory mechanisms.
- **Section 4 Results:** This section applies the comparison framework to Soar and Xapagy. Each architecture is examined in terms of how it represents and models episodic memory, their similarities, differences and implications.
- **Section 5 Discussion:** This section interprets the findings from the comparative analysis. It discusses theoretical and practical insights, reflects on the ideas and design dynamics of existing models.
- **Section 6 Conclusion and Future Work:** This section summarizes the key insights of the study and identifies directions for future work in episodic memory modeling in cognitive systems.
- **Section 7 Responsible Research:** The final section reflects on the ethical considerations and responsible conduct of this research. It discusses the theoretical nature of the work, the use of publicly accessible sources, and the measures taken to ensure transparency, reproducibility, and academic integrity.

## 2 Background and Related Work

### 2.1 Cognitive Architectures and Memory Systems

Cognitive architectures are theoretical frameworks designed to model the structure and processes of human cognition [6]. Memory is a fundamental component of any systems–level cognitive architecture. Accordingly, most cognitive architectures include mechanisms for storing intermediate results, supporting learning and adaptation in dynamic environments. Although these memory systems serve similar purposes, their specific implementations vary considerably depending on each architecture's conceptual orientation, biological plausibility, and engineering constraints. In various literature, memory is often categorized by duration (e.g., short-term vs. long-term) and type (e.g., procedural, declarative, semantic, episodic), though these distinctions are not always realized as separate modules within the system.

## 2.2 Episodic Memory

Among the various types of memory discussed in cognitive architecture literature, *episodic memory* has received attention due to its role in enabling agents to recall and learn from past experiences. Episodic memory was first extensively described by Tulving [3], who distinguished it from semantic memory based on its phenomenological properties. Whereas semantic memory involves general knowledge detached from context, episodic memory is concerned with the recollection of specific events situated in time and space. This capability underpins functions such as planning, learning from experience, and anticipating future events, making it a key aspect of human-like cognition. Despite its significance, EM has historically been underrepresented in computational models of cognition. As noted by Kotseruba and Tsotsos [6], "The existence of this memory structure has been known for decades [3] and its importance for learning, communication, and self-reflection is widely recognized; however, episodic memory remains relatively neglected in computational models of cognition." In recent years, several cognitive architectures have incorporated mechanisms inspired by episodic memory, although in different ways.

## 2.3 Related Work

Prior work by Martin et al. [2] provided a broad, high-level survey of episodic memory mechanisms across several cognitive architectures. Their review highlighted the diversity of implementation strategies and identified areas where episodic memory remains underdeveloped. However, their work does not examine narrative-based systems such as Xapagy, nor does it offer a detailed comparative framework for analyzing design trade-offs between architectures. Other researchers, including Menager et al. [7] and Subagdja and Tan [8], have proposed alternative models of episodic memory, including biologically inspired and neural-network-based approaches not discussed in Martin et al.'s work [2].

## 2.4 Research Gap

While prior work [2] has surveyed episodic memory implementations across a range of architectures, few studies have offered an in-depth, structured comparison between episodic memory systems with divergent design principles. This study addresses that gap by comparing Soar and Xapagy – two architectures that treat episodic memory as a functional component, but differ fundamentally in representation, structure and mechanisms. By applying a consistent analytical framework to these systems, this study aims to reveal how differing assumptions about episodic memory shape cognitive system's behavior, limitations, and cognitive plausibility.

## 2.5 Overview of Two Cognitive Architectures

### 2.5.1 Soar

Soar is a general-purpose cognitive architecture developed to enable human-level intelligence system by integrating various cognitive processes such as reasoning, planning, execution, and learning [9]. Central to Soar is the Problem-Space Computational Model (PSCM), which frames behavior as the result of moving through problem spaces using states, operators, and knowledge-driven operator selection mechanisms.

As illustrated in the Soar 9 block diagram (Fig.1), input comes in through the perception module and is held in the perceptual short-term memory [9]. Symbolic representations are derived from this memory and placed into Soar's working memory, which acts as a global short-term storage that cues the retrieval of knowledge from symbolic long-term memories, as well as being the basis for initiating action. Soar incorporates three types of symbolic long-term memory: procedural, semantic, and episodic, each supporting different learning methods. The episodic memory system captures time-stamped snapshots of working memory and bases its learning entirely on these contents [10], as shown in Fig.2. Once new data is learned, it is immediately stored in long-term memory, typically without extensive generalization or further processing.

### 2.5.2 Xapagy

The Xapagy architecture describes an autonomous agent designed for narrative reasoning, which mimics human mental processes related to stories. This includes witnessing and tracking ongoing events, following narrated stories, narrating stories, acting as an audience, and collaborative story-telling [5]. Unlike many cognitive architectures that minimize episodic memory, Xapagy considers it the primary mechanism for learning and using knowledge, employing a process called shadowing based on past experiences [11]. Xapagy interacts with the external world, including humans, using the Xapi pidgin language, which has a simplified syntax but uses regular English words mapped to internal concepts and verb concepts. The architecture includes a simple model of conceptual and dictionary knowledge but lacks a model of procedural knowledge.

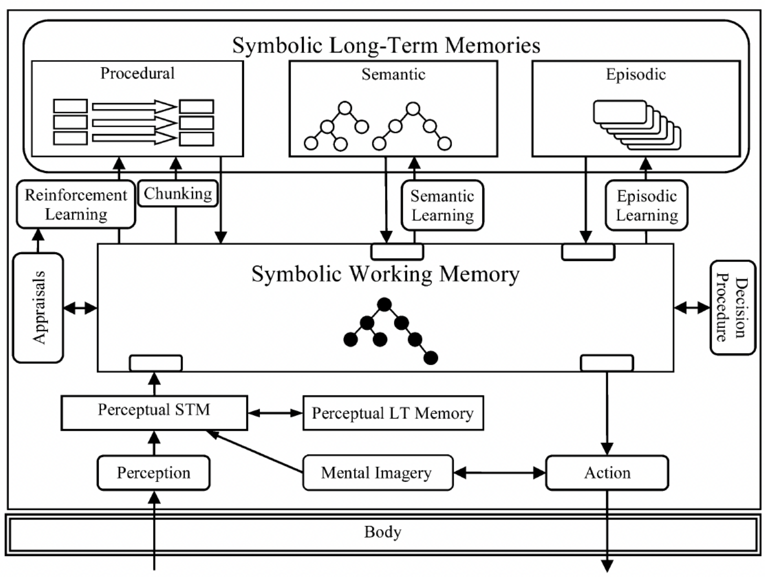


Figure 1: Block diagram of Soar 9. [9]

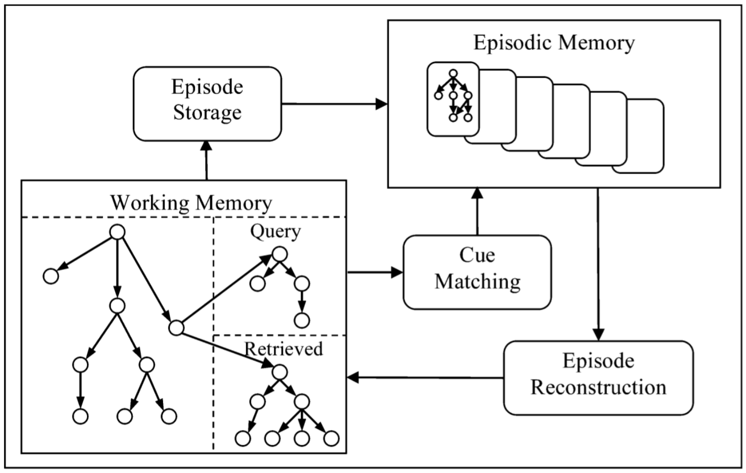


Figure 2: Processing and memories modules supporting episodic memory. [12]

# 3 Methodology

This study consists of three stages: (1) systematic literature collection to identify suitable CAs, (2) comparative analysis based on a predefined evaluation framework and (3) synthesis on findings. Firstly, a systematic literature review was conducted, with the aim of capturing a range of architectures with sufficiently detailed descriptions of their episodic memory mechanisms for comparison. This process resulted in an initial list of primarily four candidate architectures. Based on practical considerations and the need for detailed analysis – the scope of this research was refined to focus on two representative systems: Soar and Xapagy. The second stage – comparative analysis – is conducted following a comparison framework. Lastly, synthesis is made on findings from comparison study to connect the detailed technical differences to identify patterns, design trade-offs, and theoretical implications.

## 3.1 Literature Collection

The literature collection process is designed to identify relevant academic publications that discuss the implementation and role of episodic memory within cognitive architectures. To guide the selection, specific eligibility criteria were established to filter studies based on their relevance to the research questions, particularly those focusing on memory modeling.

### 3.1.1 Eligibility Criteria

Key publications were selected based on their relevance, citations, and direct discussion of episodic memory mechanisms. In this review, the following criteria were formulated:
**Exclusion Criteria:**

- The paper discusses memory in general but does not explicitly discusses episodic memory.

- The focus of the paper is mainly on semantic, working, or procedural memory with little to no mention of episodic memory.
- It does not address cognitive architectures.
- It does not include content on modeling, representation, encoding, or retrieval of episodic memory.
- The paper discusses episodic memory in neuroscience, education, or clinical psychology exclusively with no reference to computational modeling or cognitive architectures.
- It is not published in a peer-reviewed journal or reputable conference proceedings.
- The paper is not a research article, review, or conceptual framework.
- The paper is not available in full text.

#### 3.1.2 Search Engines

A systematic literature search was conducted across the following academic databases: Scopus, ACM Digital Library, IEEE Xplore, ScienceDirect, and Web of Science. These sources were chosen for their broad coverage of peer-reviewed literature in cognitive science, artificial intelligence, and computational modeling.

#### 3.1.3 Search Process and Results

The search strategy combined key terms *"episodic memory"* and *"cognitive architecture"* using Boolean operators to refine results. The queries were adapted to the syntax of each database and targeted article titles, abstracts, and keywords. The complete list of search queries is provided in Appendix A.

A total of 347 records [2] were initially retrieved from five databases. Before screening, records were removed for being unrelated to the research domain or identified as duplicates, leaving 184 potentially relevant records. Although there is significant work on episodic memory in the fields of neuroscience and cognitive psychology, a review of representative articles from this area (e.g., [13, 14, 15]) showed that most of this work focuses on conceptual or theoretical accounts of episodic memory, often without detailed computational modeling or integration into specific cognitive architectures. These articles were selected for citation because they exemplify this broader conceptual trend and contrast with the computational focus of this study.

Then records were screened based on abstracts using predefined exclusion criteria. Finally, the 37 papers that passed the exclusion filter were reviewed at the full-text level, resulting in 26 articles.

#### 3.1.4 Selected models

Based on a review of the literature found, four cognitive architectures – Soar, LIDA, ICARUS, and Xapagy were identified as having descriptions of episodic memory mechanisms. Among these candidates identified, Soar and Xapagy were chosen for detailed comparison, based on the contrast in their cognitive modeling approaches.

[2] Database search conducted on May 11, 2025.

ICARUS, while offering a modular approach to symbolic cognition, shares many of the same foundational assumptions and representational structures as Soar, as both architectures assume that episodic memory is a long-term, cue-based system that maintains cues in the agent's working memory, and the agent deliberately encodes experiences as episodes and is able to retrieve them [16]. Because ICARUS would largely reinforce the same symbolic, rule-based perspective as Soar, it was excluded to avoid redundancy and to maintain a sharper contrast in the comparative analysis. LIDA, on the other hand, adopts a hybrid and biologically inspired approach to episodic memory, but its episodic module remains less mature and formally specified in the literature, making detailed comparison more difficult [2].

Finally, ten articles on the two chosen architectures are included for detailed analysis. This complete process is summarized in Figure 3.

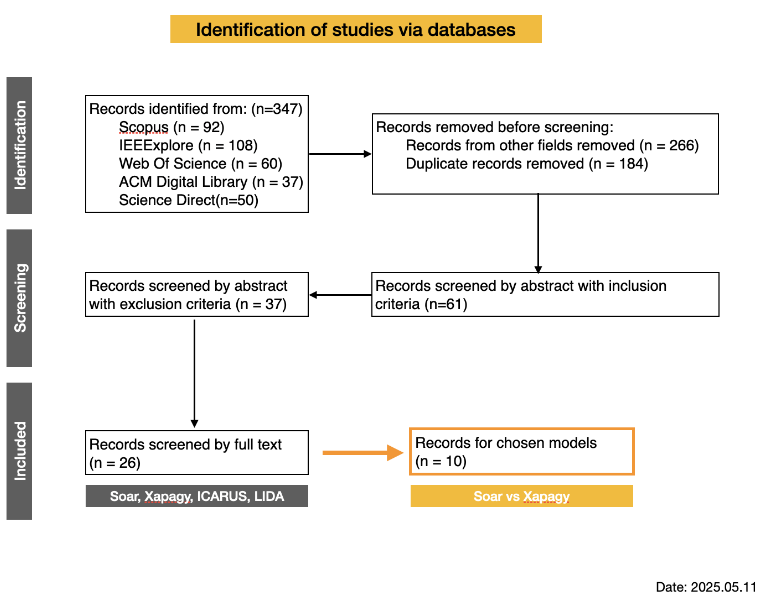


Figure 3: Identification of studies via databases

## 3.2 Comparison Framework

To ensure a consistent and structured comparison, a comparison framework was developed, as shown in Table 1. It outlines seven dimensions – covering key subsystems and mechanisms within the episodic memory module, as well as overall biological plausibility and limitations – along which the episodic memory systems of the two selected cognitive architectures are evaluated.

Table 1: Comparison Framework for Episodic Memory in Cognitive Architectures

| **Dimension** | **Description** |
|---|---|
| Representation and 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 Updating | 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 episodic memory model? |

# 4 Results

Before diving into the details of how Soar and Xapagy model episodic memory, it is worth mentioning again that the design goals for these two architectures are drastically different. For Soar, episodic memory is an extension to existing long-term memory modules, and it is to be an automatic, architectural symbolic memory that supports cue-based retrieval and autobiographical representation of the agent's moment-to-moment experiences [12]. In contrast, Xapagy was designed specifically to support narrative reasoning – the ability to process, generate, and participate in stories [5]. Episodic memory in Xapagy is not just an architectural feature but the central mechanism through which the system reasons and behaves, relying entirely on raw autobiographical experiences to interpret ongoing events, make predictions, and engage in narrative construction.

## 4.1 Representation and Structure of Episodes

Episodic memory in Soar is represented as snapshots of working-memory elements and can be cued using multi-level graph structures from working memory [9]. Episodic memory provides access to past experiences, including the properties of states that have been visited, operators that have been applied, and possibly results that have been produced.

Episodic knowledge within the Xapagy cognitive architecture is represented in a fundamentally different way, in the most raw format of unprocessed recording of past events [5]. Episodes in Xapagy are Verb Instances (VIs), see Fig. 4. Episodic memory is a repository containing all VIs and Instances that have, at some point, been part of the agent's focus – a temporary, modifiable working set [11]. These VIs can have succession links, particularly when supporting hypotheses about a story.

These contrasting representations reflect different cognitive priorities. Soar's symbolic structure is designed for tasks requiring traceable reasoning and structured learning, while Xapagy's raw representation supports narrative flexibility but sacrifices precision. This shows that episodic memory can serve different roles: either as structured knowledge for problem-solving or as experience for creative narrative understanding.

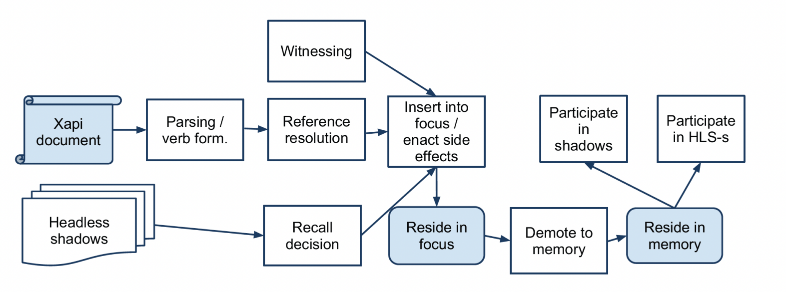


Figure 4: The life cycle of a verb instance. [11]

### 4.2 Encoding

In Soar, episodes are created and stored incrementally and automatically as experiences occur [12]. Instead of saving the full contents of working memory every time, Soar only records the changes – what was added or removed – at temporal intervals. This way, it keeps track of when certain working-memory elements were present without needing to store everything at once. Two different approaches of transition from one episode to another are supported. In the first approach, each episode corresponds to a single processing cycle, so changes are recorded at the end of each processing cycle. The second approach is to only record when the agent executes an external action. This captures agents' interactions with its environment, but does not record changes that occur in between agent actions.

The encoding mechanism in Xapagy involves the creation of Instances and VIs, which occurs when the agent observes external events, processes narrated stories, or through internal processes like recall or confabulation [5]. Newly created Instances and VIs are initially placed in the focus, a dynamically evolving graph where they are mutable for a limited duration [11]. During its time in focus, the salience of each component increases, determining how strongly it is remembered. Encoding is continuous and modulated by spike activities (instantaneous events) and diffusion activities (gradual processes), with additional influence from attention-like processes. After a certain time or due to other events, Instances and VIs leave the focus and are demoted to the memory.

The contrast in encoding methods highlights a trade-off between efficiency and expressiveness. Soar's change-based encoding reduces storage demands, favoring systems with limited memory or predictable tasks. Xapagy's salience-driven encoding aligns better with dynamic, story-rich environments but may lead to storage of redundant or noisy data.

### 4.3 Storage

In Soar, episodes are temporally ordered, each of which includes the symbolic structures from the top level of working memory, as well as some limited meta-data related to the time of storage [12]. It does not yet support storing images or other sensory formats. Substates are not saved because the top state holds all the necessary information about what the agent is sensing and aware of, which is the basis for most uses of episodic memory. This approach also reduces the amount of stored data and the complexity of storing and retrieving process. Soar also avoids saving the results of past memory retrievals, as this could make the episodes too large.

The storage method for episodic memory in Xapagy is described as a repository containing all the VIs and instances that have been demoted from the focus [11]. Internally, this is implemented using two weighted sets based on their salience at the time of demotion, one for instances and one for VIs.

Soar's structured, indexed storage emphasizes efficiency and retrieval reliability, supporting structured tasks, while Xapagy's passive, salience-weighted storage suggests that for systems designed around narrative improvisation, strict organization may not be necessary. This indicates that future cognitive architectures could benefit from flexible storage models tailored to the system's core reasoning strategy.

### 4.4 Retrieval

There are two methods of retrieval in Soar: cue-based and sequence-based retrieval. The cue-based retrieval is initiated when the agent constructs a cue from elements in working memory, which is then matched against the stored episodes [12]. A cue is partial description of an object in the memory in a graph-structured set of symbolic elements, it can contain specific attributes and values, and/or attributes with unspecified (variable) values [17]. The sequence-based retrieval happens after retrieving an episode successfully, the agent issues commands to step forward or backward through episodes, as episodes are temporally ordered in storage.

In Xapagy, episodic memory is not directly searchable or symbolically addressed. Instead, it is accessed through shadows and headless shadows, which align past experience with current context [5]. Retrieval of memory is conducted through shadowing: each current focus component (instance or VI) forms a "shadow" composed of similar past experiences from episodic memory. These shadows can give rise to headless shadows (HLS), which represent anticipated, inferred, or missing events, see Fig. 5. HLSs guide reasoning, recall, prediction, and even imagination or confabulation.

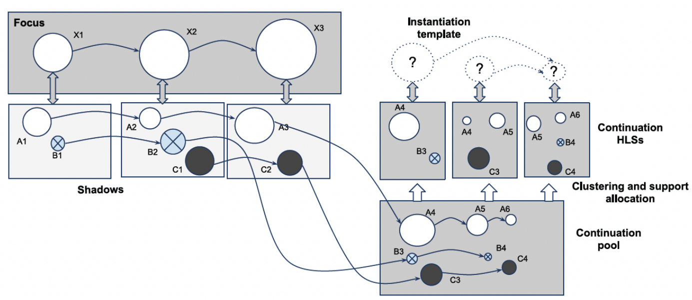


Figure 5: A simplified representation of the continuation HLS formation. [11]

These two contrasting retrieval strategies suggest that systems requiring explainable reasoning should use explicit retrieval mechanisms, while creative systems can opt for emergent, associative retrieval methods.

## 4.5 Memory updates

In Soar 9, episodes do not change after encoding. There is no automatic generalization process that analyzes episodes and looks for regularities, nor is there any forgetting mechanism [12]. However, it is considered as one of the possible future extensions to the model to be able to modify the dynamics of episodic memory so that the number of episodes is bounded. One possible approach is to introduce a forgetting mechanism that automatically removes episodes that have a low probability of being useful.

In Xapagy, forgetting is included and modeled as exponential decay of salience over time [5]. Recalling an event does not boost its salience; instead, it creates a new, similar VI, potentially reinforcing similar patterns. Mechanisms like self-shadowing and story drift also influence how memory evolves through repeated recall or narration. Pauses in events can affect the strength of temporal links between VIs and longer pauses might lead to daydreaming instead of processing.

Soar's lack of forgetting suggests a limitation for long-term, autonomous operation, as its episodic memory can grow indefinitely without mechanisms for managing memory size. In contrast, Xapagy's self-modifying, decaying memory mechanism allows its episodic content to evolve over time, which would be better for supporting narrative improvisation and change, but at the cost of stability and accurate recall.

## 4.6 Biological Plausibility

Soar's episodic memory system is broadly inspired by Tulving's work on human cognition [3], as described in [9]. It aligns with the notion of episodic memory as "what you remember," in contrast to semantic memory as "what you know" [12]. However, its encoding, retrieval, and usage strategies are implemented through structured, symbolic reasoning processes.

Xapagy is designed specifically to model and mimic human activities related to narrative reasoning, such as witnessing, reading, and recalling stories. It aims to replicate human mental processes concerning stories and acknowledges psychological phenomena like the difficulty of pure recall of similar events ("repisodes"), which its recall competition attempts to model [5].

While both systems are inspired by human cognition, Xapagy's emergent experience-driven memory dynamics more closely resemble the fallible, associative nature of human recall, making it possible to imitate rather complex human reasoning behaviors, such as storyline jumping, random wandering, etc. [5]. Soar's structured approach, although biologically inspired, it is simplified and provides more reliable behavior in contexts needing more consistent, precise memory use.

## 4.7 Limitations

While Soar's episodic memory retrieval, which relies on cues and working memory, bears some similarity to Xapagy's continuation HLS mechanism, the two differ significantly in terms of recall accuracy [11]. In Soar, the system can retrieve a previous episode with a complete and accurate snapshot of the working memory. In contrast, Xapagy cannot guarantee even an accurate reconstruction of the general structure of a recalled story .

Another limitation in Xapagy is its lack of abstract schemas or general templates, such as those found in typical event scripts (e.g., restaurant scenarios) [11]. Instead, it depends entirely on concrete past instances, making generalization difficult. Soar, while more structured in its retrieval, is still constrained by its reliance on cues and a strong bias toward recency due to memory's temporal structure [17, 12]. Additionally, retrieval in Soar can become computationally expensive, especially when dealing with complex queries or a large number of stored episodes [12]. Empirical studies have also shown a high rate of retrieval failures in Soar under certain conditions, particularly when no matching episode is found for a given cue. Both systems also have limitations when it comes to mental imagery. While Soar includes some support for imagery, it is not yet fully integrated into its episodic memory system [18]. Xapagy, on the other hand, lacks imagery capabilities altogether.

### 4.8 Summary

This section compared the modeling details of episodic memory in Soar and Xapagy across seven key dimensions. A summary of the comparison is provided in Appendix B.

While both systems aim to capture and utilize past experiences, they differ significantly in conceptualization and implementation. Soar treats episodic memory as a structured, symbolic mechanism tightly integrated with its working memory and problem-space computational model. It supports accurate recall of past working memory states through cue-based retrieval, enabling detailed re-experiencing of prior episodes. However, Soar's reliance on explicit cues, recency bias, and lack of forgetting mechanism can limit its flexibility and long-term operations.

In contrast, Xapagy relies entirely on episodic memory for reasoning, without abstract generalizations or procedural rules. Its narrative-based approach uses raw autobiographical events and a mechanism called shadowing to interpret ongoing situations. While this enables story–like reasoning, it comes at the cost of precision and accurate reconstruction of past narratives. The absence of schema-like representations in Xapagy limits its applicability in tasks that required structure or abstraction, such as logical planning.

## 5 Discussion

The structured comparison of episodic memory modeling in Soar and Xapagy reveals fundamentally different philosophies and design choices, each aligned with the architectures' distinct cognitive goals. Soar is designed to support general intelligent behavior across a wide range of domains, whereas Xapagy is specifically tailored for narrative reasoning. The contrast in their modeling approaches reflects different assumptions about the role of episodic memory in cognition. Soar emphasizes structured, cue-based retrieval to support problem-solving and decision-making in general tasks, while Xapagy assumes that cognitive behavior can emerge entirely from the accumulation and association of raw experiences. These divergent perspectives suggest that a comprehensive understanding of episodic memory in cognition should accommodate both structured, purpose-driven retrieval (as in Soar) and fluid, experience-driven reasoning (as in Xapagy), depending on the context and goals of the cognitive task.

The differences in conceptualizing episodic memory lead to design trade-offs in every component of the memory system, including representation, structure, encoding, storage, retrieval and memory updates. Soar prioritizes structural organization, efficiency, and accuracy of recall to support deliberate reasoning, while Xapagy emphasizes flexibility, association, and emergent behavior from experiential data. This contrast highlights broader implications for the design of cognitive architectures: depending on whether the architecture seeks general-purpose cognitive capabilities or specialized reasoning (e.g., narrative understanding), different trade-offs between structure and flexibility will be necessary.

Furthermore, the development dynamics of these systems reveal an important distinction. Episodic memory in Soar was introduced as an extension to an already mature symbolic problem-solving framework, primarily to enable episodic learning. Consequently, its design is constrained by legacy mechanisms such as the Problem-Space Computational Model (PSCM) and the existing working memory mechanisms. This results in certain limitations, such as the reliance on structured, cue-based retrieval and limited integration with procedural knowledge. In contrast, Xapagy was conceived from the ground up as a memory-centric system. It forgoes abstraction and symbolic generalization in favor of a much simpler, minimally structured model. While this limits its applicability as a general-purpose architecture, it enables a distinctive approach to narrative reasoning that is entirely grounded in episodic accumulation.

Together, these contrasting approaches illustrate the dynamic design space for cognitive architectures involving episodic memory: whether it is treated as a supplementary extension to established mechanisms or as a foundational core determines both the opportunities and constraints of the resulting system.

# 6 Conclusions and Future Work

This study aims to address the gap in the literature regarding detailed, structured comparisons of episodic memory modeling among different cognitive architectures. By examining two fundamentally different systems – Soar, a symbolic, rule-based architecture, and Xapagy, a narrative-based, memory-centric system – this study has highlighted different ideas about episodic memory in cognition and following design choices that shape the capabilities and limitations of cognitive models. These differences reflect trade-offs between generality and specialization, and between symbolic precision and experiential flexibility.

Several directions for future work emerge from this comparative study. First, future research could apply similar comparison framework to additional architectures – such as LIDA, ICARUS, etc. – to better generalize findings and identify broader design trends and patterns. Second, empirical evaluation through task-based benchmarks could help quantify how episodic memory performance affects behavior in real-time environments on different type of tasks, such as storytelling, or problem-solving tasks. Third, there is potential in hybrid approaches: integrating the structured recall of Soar with the narrative flexibility of Xapagy may yield more robust and adaptable cognitive systems. Finally, it is also an opportunity to explore how richer forms of episodic memory – such as imagery – can be incorporated into existing architectures. Such advancements may improve not only the cognitive plausibility of these systems but also their practical utility in complex, human-like tasks.

# 7 Responsible Research

This research is theoretical and analytical in nature, focusing on the comparative study of how episodic memory is modeled in existing cognitive architectures. It does not involve empirical experimentation, or the use of sensitive or private data. Therefore, there are no direct ethical concerns related to participant welfare, consent, or data protection. Instead, the study relies entirely on secondary sources, including publicly available peer-reviewed publications and existing implementations of architectures.

In the interest of transparency, it is important to note that this paper includes content drafted and edited with the assistance of NotebookLM (Google) and ChatGPT (OpenAI). The models were used to summarize technical contents, improve language clarity, and refine phrasing. All ideas, analytical structure, and conclusions were generated and validated by the author. No sensitive or proprietary information was provided to the model during this process.

In terms of research integrity and reproducibility, efforts has been taken to document the selection criteria for literature, the analysis framework, and the comparison dimensions used. The methods and frameworks applied in this study are designed to be transparent and repeatable. Other researchers following the same criteria and analytical dimensions should be able to reproduce the findings or adapt the framework for related work.

In general, this work aligns with the principles of responsible research by being transparent, reproducible, respectful of intellectual property, and oriented toward constructive advancement of scientific understanding.

## A Constructed queries for the full survey

- Scopus: TITLE-ABS-KEY ( "cognitive architecture" AND "episodic memory" )
- Science Direct: "episodic memory" AND "cognitive architecture" (in title, abstract or author specified keywords)
- IEEE Xplore: ("All Metadata":episodic memory) AND ("All Metadata":cognitive architecture)
- Web Of Science: TS=("episodic memory" AND "cognitive architecture")
- ACM Digital Library: "cognitive architecture" AND ("episodic memory")

## B Comparison Overview

| Dimension | Soar | Xapagy |
|---|---|---|
| **Representation and Structure** | Symbolic snapshots of working memory; Graph-structured with identifiers and attributes; Temporally ordered episodes | Raw episodic recording; Comceptual overlays; Verb-instance graphs; Each episode is made of atomic VIs connected temporally and contextually |
| **Encoding** | Automatic at intervals; Captures changes in top level 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 (additions/removals); Does not store substates or retrievals | Weighted sets; Passive memory; Stored memories are not symbolically indexed |
| **Retrieval** | Cue-based; Explicit queries with features; Returns best-matching episode by recency or similarity | Shadowing; Headless shadows; Retrieval occurs via automatic matching between current focus (working momery) and past memories (episodes), forming predictions or inferences |
| **Memory Updating** | 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 akin 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 searched directly |

Table 2: Summary of Comparison results on Soar and Xapagy

## References


[1] Pat Langley, John E. Laird, and Seth Rogers. Cognitive architectures: Research issues and challenges. *Cognitive Systems Research*, 10(2):141–160, 2009.

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

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

[4] John E. Laird. *The Soar Cognitive Architecture*. MIT Press, 2012.

[5] Ladislau Bölöni. Xapagy: a cognitive architecture for narrative reasoning. *Computing Research Repository - CORR*, 05 2011.

[6] 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.

[7] David H. Ménager and Dongkyu Choi. A robust implementation of episodic memory for a cognitive architecture. *Cognitive Science*, 2016.

[8] Budhitama Subagdja and Ah-Hwee Tan. Neural modeling of sequential inferences and learning over episodic memory. *Neurocomputing*, 161:229–242, 2015.

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

[10] John E. Laird. *The Soar Cognitive Architecture*, chapter Conclusion, pages 325–346. MIT Press, 2012.

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

[12] John E. Laird. *The Soar Cognitive Architecture*, chapter Episodic Memory, pages 225–246. MIT Press, 2012.

[13] David H. Ménager, Dongkyu Choi, and Sarah Robins. A hybrid theory of event memory. *Minds and Machines*, 32, 06 2022.

[14] Taisuke Akimoto. Narrative structure in the mind: Translating genetteâs narrative discourse theory into a cognitive system. *Cognitive Systems Research*, 58:342–350, 2019.

[15] Taisuke Akimoto. Narrative structure in the mind: Translating genette's narrative discourse theory into a cognitive system. *Cognitive Systems Research*, 58:342–350, DEC 2019.

[16] David H. Ménager. Episodic memory in a cognitive model. In *ICCBR Workshops*, 2016.

[17] John E. Laird. *The Soar Cognitive Architecture*, chapter Semantic Memory, pages 203–224. MIT Press, 2012.

[18] John E. Laird. *The Soar Cognitive Architecture*, chapter Visuospatial Processing with Mental Imagery, pages 247–270. MIT Press, 2012.