

Introduction

Episodic memory is the stepchild of cognitive systems. It is an accepted fact that humans retain autobiographical information - controversies only surround the fact whether this involves a separate memory system or not. Implementing episodic memory in a cognitive architecture is not particularly difficult. The problem appears to be more whether it buys us anything.

In this paper we propose to take a second look at the usefulness of episodic memory in the context of the Xapagy cognitive architecture. In contrast to other cognitive architectures, in Xapagy episodic memory is the *primary* means of acquiring and using knowledge. The importance of episodic memory in Xapagy is partially due to its focus on *narrative reasoning*, that is, the mimicking of some of the mental processes which humans perform with respect to stories:

- ▶ Witnessing a series of ongoing events (a story), keeping track of the participants, their identity, properties and activities.
- ▶ Following a fixed story narrated in a language (for instance, by reading a text or listening to another agent's narration).
- ▶ Predicting future events in the story, expressing surprise when unexpected events occur.
- ▶ Inferring events which (for some reason) were not witnessed; understanding narrations where some events have been not explicitly said ("reading between the lines").
- ▶ Recalling a story, summarizing or elaborating on the remembered story, chaining together remembrances.
- ▶ Daydreaming, confabulating new stories.
- ▶ Self-narrate the story by verbalizing the recalled or confabulated story, for the narrating agent's own use.
- ▶ Narrate the story to an audience, adapt the narration based on feedback from an audience, elaborate on aspects of the story or selectively narrate.
- ▶ Act as an audience for a narration, express surprise or puzzlement, request clarification or elaboration for parts of the story and ask questions.
- ▶ Perform collaborative story-telling, develop a story by alternating narrations from multiple agents.

Key ideas in Xapagy

- ▶ **Xapi:** interaction with the outside world takes place using the Xapi *pidgin language*
 - ▷ vocabulary of English
 - ▷ simplified syntax
 - ▷ only compound sentence is the *route*
 - ▷ see example in the right column
- ▶ **Verb instances (VIs):** are the internal representation of the sentences
 - ▷ Verb overlay + parts which can be instances, concept overlays, verb overlay or VIs
- ▶ **Instances:** represent an entity of the *story* over the time span limited by the additivity of their attributes. They are not an entity of the real world.
 - ▷ The colloquial meaning of an "instance", in Xapagy is frequently represented by a number of instances, connected by *identity relations*: view, somatic and succession identity.
- ▶ **Concepts:** represent attributes of instances
 - ▷ Have: *area* (representing specificity), *overlap* and *impact*
 - ▷ Usually found in form of *concept overlays*
- ▶ **Verbs:** similar to concepts
 - ▷ Have: *area* (representing specificity), *overlap* and *impact*
 - ▷ In the form of *verb overlays*, represent the core of a VI.
 - ▷ Some verbs have *side-effects*, triggered when the VI is inserted into the focus
- ▶ **Focus:** the collection of currently active instances and VIs
 - ▷ Once instances and VIs leave the focus they *never return*
- ▶ **Scenes:** a way to organize the focus, each instance is part of a single scene, which can not be changed
 - ▷ Only instances which are in the same scene can interact
 - ▷ Instances in different scenes can be connected by identity relations.
- ▶ **Episodic memory:** during their stay in focus, instances and VIs are recorded into episodic memory, gradually increasing their *salience*
 - ▷ After leaving the focus, salience gradually decays
 - ▷ Salience *never* increases after the instance or VI left the focus, there is no concept of reinforcement.
 - ▷ Episodic memory is the **only** memory used in Xapagy
 - ▷ Instances and VIs can never return to the focus. There is no "recall" in the strict sense of the word.
 - ▷ Episodic memory influences the current state of the agent only through the shadows
- ▶ **Shadows:** instances / VIs in focus are shadowed by collections of instances / VIs from the episodic memory which "match" the focus.
 - ▷ Maintained by dynamic processes which include decay, similarity matching, structural matching, story line consistency, instance identity sharpening and others.
 - ▷ Influenced but not determined by identity relations.
 - ▷ The size of the shadow is controlled by resource constraints.
- ▶ **Headless shadows (HLSs):** shadows which are not connected to instances or VIs in the focus. They can represent:
 - ▷ Continuations: actions planned or expected in the future
 - ▷ Missing actions: actions which the agent feels they should have happened yet they were not witnessed (e.g. "reading between the lines")
 - ▷ Other aspects of narrative reasoning: summarizations, inferred relations etc.
 - ▷ HLSs can be converted to shadows if they were instantiated internally or successfully predicted an externally occurring event.
- ▶ **Activities:** maintain the internal structures of the Xapagy agent:
 - ▷ **Spike activities (SAs)** instantaneous changes, not parallel. Examples: inserting an instance in a focus, enacting the side effects of a VI
 - ▷ **Diffusion activities (DAs)** gradual changes, happen in parallel and in time. Examples: the maintenance of the participations in the shadows and HLSs, the decay of episodic memory.

Using episodic memory: headless shadows

- ▶ All the narrative reasoning models can be understood in terms of a single procedural pattern:
 - ▷ **maintain** a collection of HLSs reflecting the current state of the narration
 - ▷ **choose** an HLS for instantiation based on a specific criteria
 - ▷ **instantiate** the HLS by creating a new VI
 - ▷ **insert** the new VI to the focus and **transform** the HLS into its regular shadow
 - ▷ **verbalize** the VI

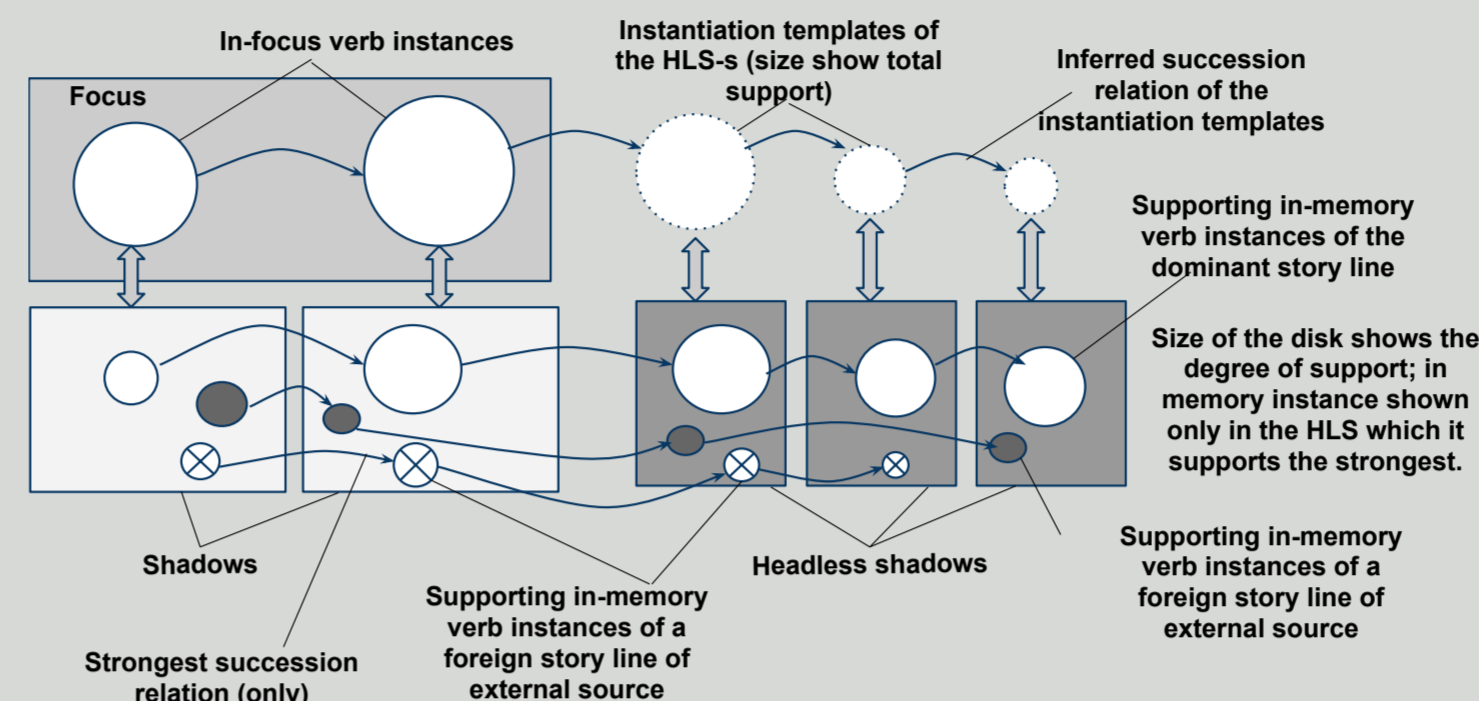


Figure: General pattern of the use of shadows and headless shadows

- ▶ **Expectation fulfillment** is the support of the HLS matched to the incoming VI (or zero is no such HLS has been found).
 - ▷ An event was **expected** if there was a HLS with a strong support matching it.
 - ▷ **unexpected** otherwise.
- ▶ **Surprise** is defined as the magnitude of change in the continuation pool, triggered by the event
 - ▷ Even the least surprising event will have a non-zero value, as the continuation HLSs will adjust, extending themselves into the future
- ▶ Expectation fulfillment and surprise are related metrics
 - ▷ but they can not be trivially transformed into each other
 - ▷ often the most expected event will generate the least surprise
 - ▷ we can have unexpected events, which do not create a surprise (*Hector, in the heat of the battle, stops to wipe his brow*)
 - ▷ expected events, can have a large surprise value (*the death of Hector is not unexpected in the context of a duel, but affects a radical change in the continuations*)
- ▶ **Recall:** internally instantiating VIs which closely resemble a previously experienced story - the **dominant story line**
 - ▷ other story lines might be in the shadows: **foreign story lines**
 - ▷ Perfect recall can be only obtained under a **purity condition**
 - ▶ all the HLSs are supported by **only** by the dominant story line
 - ▶ shadows can contain foreign story lines
 - ▶ purity condition is possible only what either the agent is completely clueless or the story does not resemble anything
- ▶ **Confabulation:** internally instantiating stories which do not resemble any previously seen story.
- ▶ **Recall-confabulation continuum:** the Xapagy system can exhibit features of a range of behaviors, ranging from pure recall... various levels of distortion... to freely associative confabulation.

An example: self shadowing and story drift

- ▶ An agent which witnessed a story only once, but recalled it many times.
- ▶ The story lines in shadows and the HLSs contain all types of VIs both externally and internally generated, directly witnessed, read or heard.
 - ▷ Necessary and useful: allows an agent to make correct predictions when witnessing real world situations about which previously it had only book knowledge
 - ▷ It includes the recalls of the story, which are necessarily very close to the original story: **self-shadowing**

Positive consequences of self-shadowing

- ▶ Accurate recalls reinforce the HLSs of the dominant story, and make it less likely that foreign stories can compete with the recall
- ▶ With this mechanism, the Xapagy system automatically exhibits *learning through repetition* (see the Eberhardt learning curve or Paul Pimsleur's spaced repetition technique)

Negative consequences of self-shadowing: story drift

- ▶ If the recalls differ from the dominant story line in a consistent way (for instance, by regularly skipping some events) there will be a strong likelihood that a specific recall will follow not the original story line but the "usual way of recalling it".
 - ▷ ...mimics suppressed memories and self-deception in humans
- ▶ Closely related situation: the shadowing stories are not coming from internal recalls, but from external retelling of the same story in modified form
 - ▷ ...mimics human behavior where excessive external praise might modify the person's own recollection of the past.

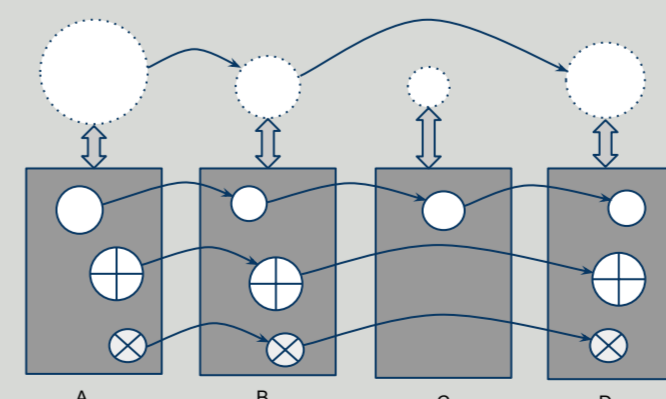


Figure: Self shadowing and drifting: the frequent omission of the VI C from the retelling (for instance by constraints) drifts the story line, such that the retelling will proceed on the story line A → B → D even when no constraints are present.

Little Red Riding Hood in Xapi

Narrative voices:

A little girl, Cindy, goes to bed and asks her Daddy to read her a story.
"I am going to read you a story, written by the Brothers Grim. Once upon a time, there was a little girl, who had a red riding hood."
"I have a red hood myself", says Cindy.
"They called her Little Red Riding Hood".

```

1 The scene / is-a / "bedroom".
2 A little girl "Cindy" / is-inside / a bed.
3 A big man / exists.
4 The girl / has-as-parent / the man.
5 A scene "writing" / exists.
6 A scene "fairytale" / exists.
7 The man / says in "writing" //
8 a "BrothersGrimm" / exists.
9 The man --parent-of-- "Cindy" /
10 says in "writing" //
11 a "BrothersGrimm" / exists.
12 The man / says in "writing" //
13 "BrothersGrimm" / says in "fairytale" //
14 a little girl / exists.
15 The man / says in "writing" //
16 "BrothersGrimm" / says in "fairytale" //
17 The girl / is-a / "LittleRedRidingHood".
18 The man / says in "fairytale" //
19 The girl / has / a red hood.
20 "Cindy" / says in "bedroom" //
21 I / has / a red hood.
22 The man / says in "fairytale" //
23 The girl / has / a basket.
24 The man / says in "fairytale" //
25 The girl / is-a / "LittleRedRidingHood".
    
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Orders from Mom:

Little Red Riding Hood's mother told her: "Pick up a basket and fill it with bread, cheese, and a bottle of wine. Take it to Grandma's house in the forest."

```

1 A scene "LRRHs-house" / is-only-scene.
2 A little girl "LRRH" / exists.
3 A woman / exists.
4 The girl / has-as-parent / the woman.
5 The "LRRHs-house"/has-fictional-future/
6 a scene "orders".
7 The little girl "LRRH"
8 -- in -- scene "orders" / exists.
9 The woman / says in "orders" //
10 "LRRH" / picks-up / a basket.
11 The woman / says in "orders" //
12 a house / exists.
13 The woman / says in "orders" //
14 "LRRH" / goes-to / the house.
    
```

Talking / lying to the wolf:

"Where are you going, little girl?", asked the wolf.
"I am going to a picnic with my boyfriend, the hunter. I am carrying a basket of food and wine, and a concealed weapon."

```

1 A scene "forest" / is-current-scene.
2 A little girl "LRRH" / exists.
3 A wolf / exists.
4 The scene "forest" / has-view /
5 a scene "conversation".
6 The little girl "LRRH"
7 -- in -- "conversation" / exists.
8 The wolf -- in -- "conversation" / exists.
9 Wolf / says in "conversation" //
10 girl / goes-to / wh?
11 "LRRH" / says in "conversation" //
12 I / has / a basket.
13 "LRRH" / says in "conversation" //
14 I / has / a weapon.
15 "LRRH" / says in "conversation" //
16 a man hunter / exists.
17 "LRRH" / says in "conversation" //
18 the hunter / is-boyfriend-of / I.
19 // The wolf's plan
20 A scene "wolf-plan" / exists.
21 The scene "wolf-plan" /has-fictional-future
22 / the scene "forest".
23 The little girl --in-- "wolf-plan"/exists.
24 The wolf -- in -- "wolf-plan" / exists.
25 The wolf / thinks in "wolf-plan" //
26 The wolf / attacks / the girl.
27 The wolf / thinks in "wolf-plan" //
28 The girl / shoots / the wolf.
29 The wolf / thinks in "wolf-plan" //
30 The wolf / changes / dead.
    
```

Impersonating Grandma:

"Why are your eyes so big?" asked the girl.
"To see you better," said the wolf.
"But why are your ears so big?" asked the girl.
"To hear you better," answered the wolf.
"But why is your mouth so big?" asked Little Red Riding Hood.
"To swallow you better!" said the wolf, and jumped up and swallowed Little Red Riding Hood whole.

```

1 A scene "GrandmasHouse" / is-only-scene.
2 A wolf / exists.
3 A little girl "LRRH" / exists.
4 A scene "conversation" / exists.
5 The scene "conversation" / is-current-scene.
6 An old woman "Grandma" / exists.
7 "Grandma" / is-identical
8 / the wolf -- in -- "GrandmasHouse".
9 The wolf -- in -- "GrandmasHouse" /
10 is-identical / "Grandma".
11 "Grandma" / has / an eyes.
12 "Grandma" / has / a mouth.
13 A girl "LRRH" / is-identical /
14 "LRRH" -- in -- "GrandmasHouse".
15 The girl / has-as-grandparent / "Grandma".
16 The scene "GrandmasHouse" / is-current-scene.
17 The girl / asks in scene "conversation" //
18 eyes -- of -- "Grandma" / wh is-a / big?
19 The wolf / says in scene "conversation" //
20 eyes -- of -- I / sees good / the girl.
21 The girl / asks in scene "conversation" //
22 mouth -- of -- "Grandma" / wh is-a / big?
23 The wolf / says in scene "conversation" //
24 I / swallows good / the girl.
25 The wolf / swallows / "LRRH".
    
```