The Computational Problem of Prospective Memory

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A Survey

- Take 10 seconds to think of the last time you forgot something

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- Raise your hand if you forgot to *do* something

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- Raise your hand if you forgot to *do* something
- A significant portion of forgetting is of *intentions*[1]
- This is *prospective memory* (aka. *delayed intentions*)

[1] Crovitz and Daniel (1984),Terry (1988)

Overview

- Goal: define the computational requirements of prospective memory
  - in the context of ACT-R and Soar

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- Introduction
- Defining Prospective Memory
- Prospective Memory Stages
  - Encoding
  - Retention
  - Initiation
  - Execution
  - Completion
- Summary

Defining Prospective Memory

A concrete example:

- Finish milk during cereal breakfast
- Make goal to buy milk after work
- Think about research, give presentations, etc.
- On the way home from work, how does the agent remember to buy milk?

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Forgetting plays a key role in prospective memory

Forgetting and Prospective Memory

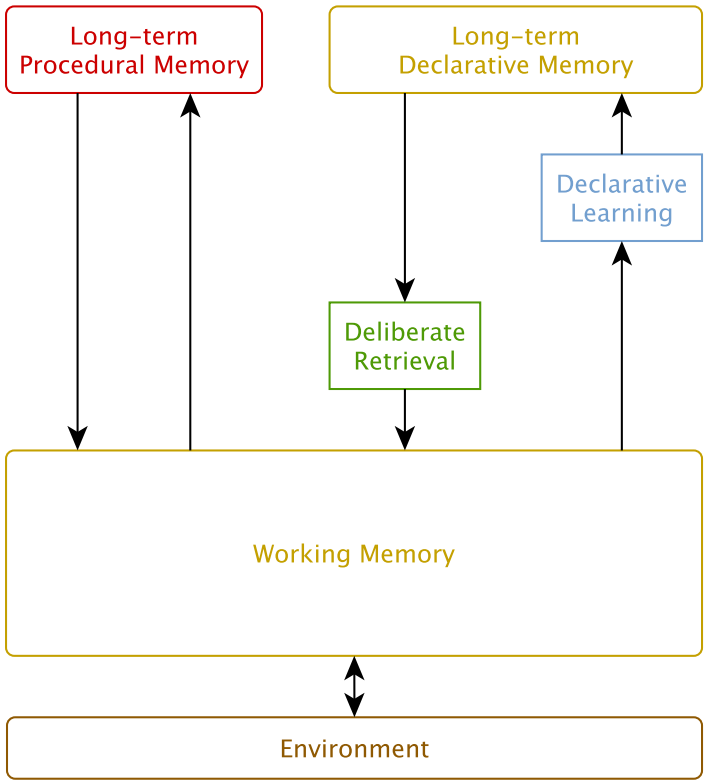
- But why do agents forget?

- ACT-R: fixed buffers of fixed size, to model human memory
- Soar: activation decay of long-term memory elements, to reduce rule-matching cost

- Forgotten items can be recovered from long-term memory (LTM)
  - Although LTM elements may also be forgotten

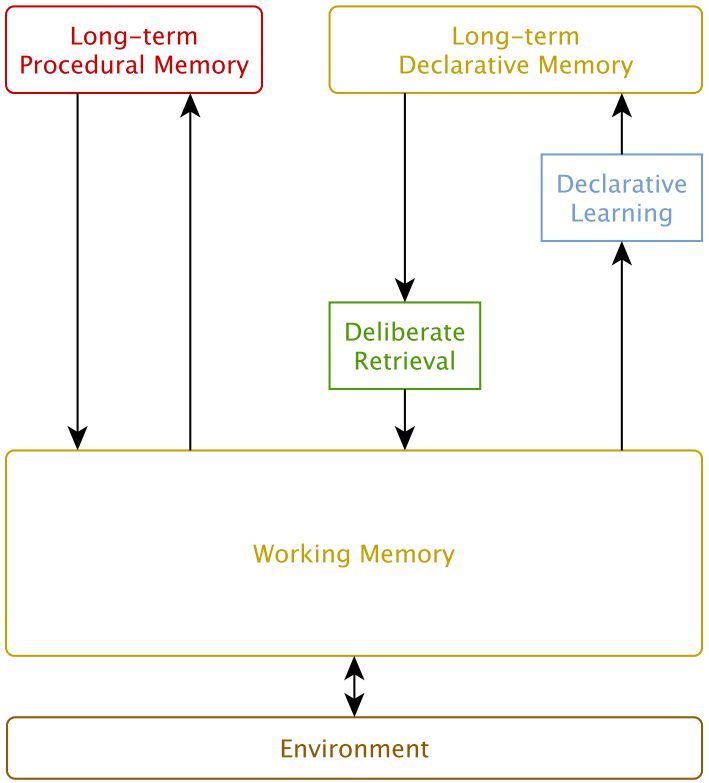
Interactions between Memory and Intentions

- Characteristics of long-term memories differ:
  - representation
  - storage
  - dynamics
  - retrieval



Interactions between Memory and Intentions

- Characteristics of long-term memories differ:
  - representation
  - storage
  - dynamics
  - retrieval
- Examine effects on stages of prospective memory
- Emphasis on initiation



Encoding

The target and action are stored into the long-term memory of the agent.

Necessary agent and architectural processes:

representation	Intention must be translated into LTM representation — possibly across multiple LTMs
storage	Automatic, or agent initiated — agent must recognize that an intention has been formed
dynamics	Agent may need to initiate rehearsal — agent must estimate amount necessary
retrieval	N/A

Example: Deciding to buy milk after work

Retention

The agent pursues other goals while waiting for the perception of the target. The intention may be relegated to long-term memory

Necessary agent and architectural processes:

representation	N/A
storage	N/A
dynamics	Agent may need to initiate rehearsal — agent must estimate amount necessary
retrieval	N/A

Example: Performing other tasks during the day

Initiation

The agent perceives the target, and a window of opportunity arises. The agent must recognize it as the target of an intention.

Necessary agent and architectural processes:

representation N/A

storage N/A

dynamics May cause retrieval failure

retrieval Agent must create a retrieval cue

- When should the cue be created?

Initiation

The agent perceives the target, and a window of opportunity arises. The agent must recognize it as the target of an intention.

Necessary agent and architectural processes:

representation N/A

storage N/A

dynamics May cause retrieval failure

retrieval Agent must create a retrieval cue

- When should the cue be created?
- Naïve solution: when the target is perceived.

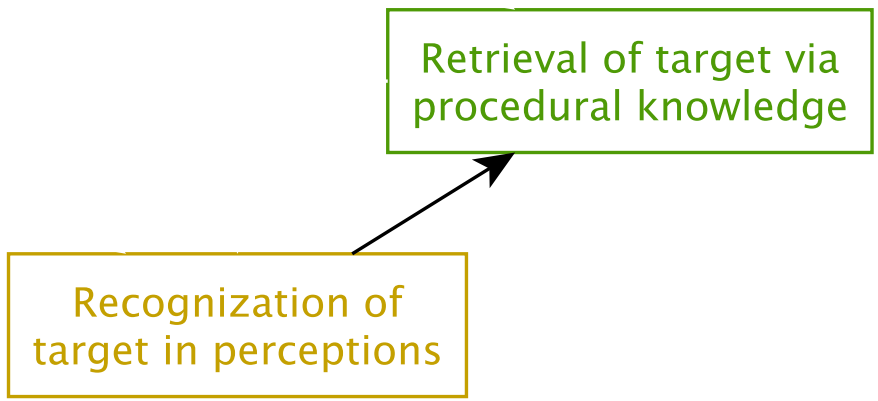
Knowledge Dependencies

- Agent must retrieve the target into WM

Retrieval of target via procedural knowledge

Knowledge Dependencies

- Agent must retrieve the target into WM
- Which requires recognizing the target in perception



Knowledge Dependencies

- Agent must retrieve the target into WM
- Which requires recognizing the target in perception
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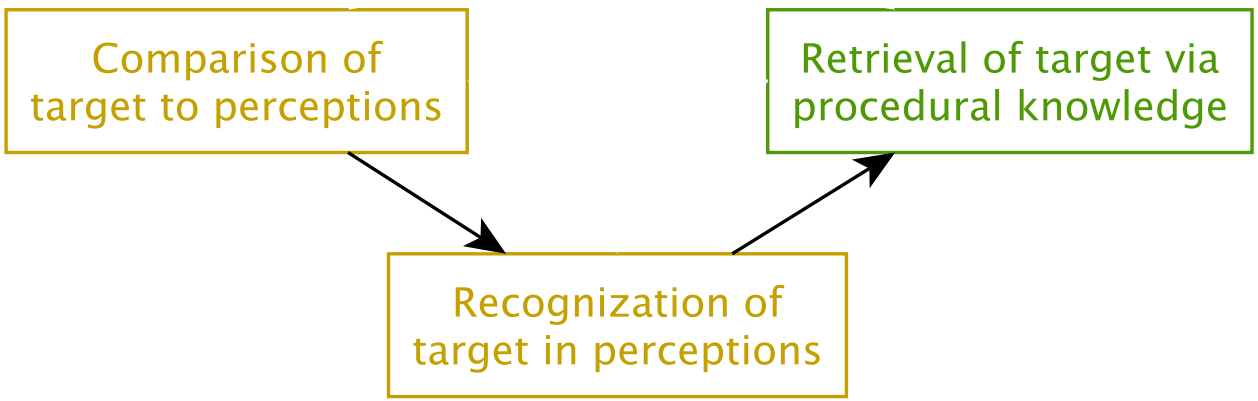

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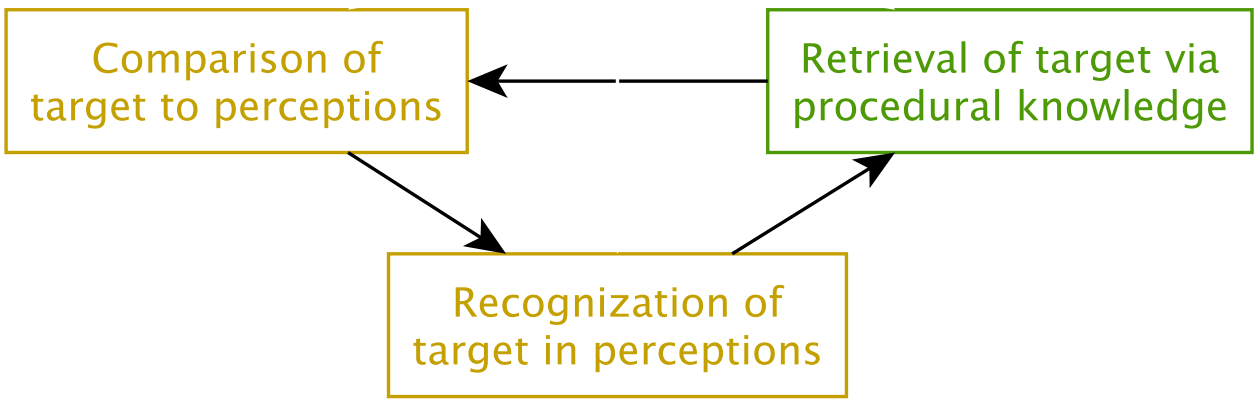

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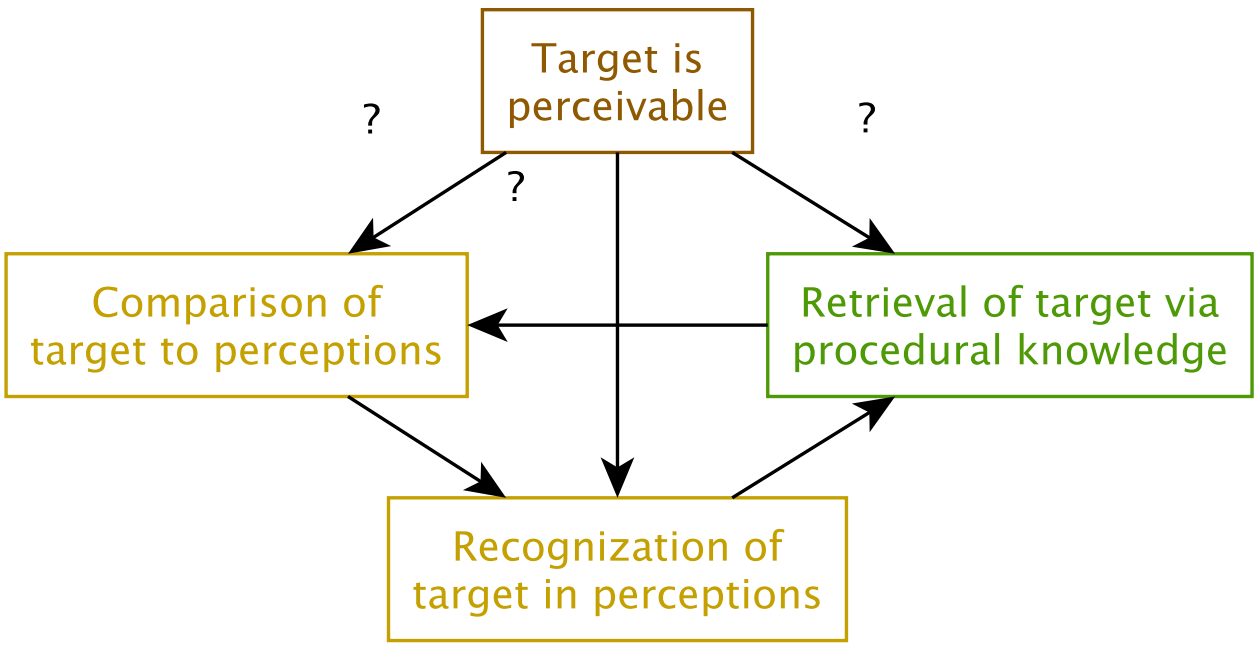

Circular Knowledge Dependencies

It is *impossible* in the current framework to retrieve the intention only when it is needed

- Either the intention is already in memory
- Or procedural rules never fire

Claim: this is the fundamental problem of prospective memory

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Three classes of strategies used by humans:

- Preemptive Strategies
- Spontaneous Retrieval Strategies
- Noticing-Plus-Search Strategies

Preemptive Strategies

The agent retrieves the target and compares it to perception periodically or at context switches

Necessary agent and architectural processes:

representation	N/A
storage	N/A
dynamics	Agent may need to rehearse intentions to prevent forgetting
retrieval	Agent needs to iterate through potentially relevant intentions

Example: Repeating the need to buy milk every 15 minutes

Spontaneous Retrieval Strategies

The architecture automatically retrieves memory elements based on context

Necessary agent and architectural processes:

representation	Stored target must directly match working memory
storage	N/A
dynamics	Dynamics in retrieval bias may effect intention returned
retrieval	Done automatically by the architecture

Example: The need to buy milk “popping” up while leaving work

Noticing-Plus-Search Strategies

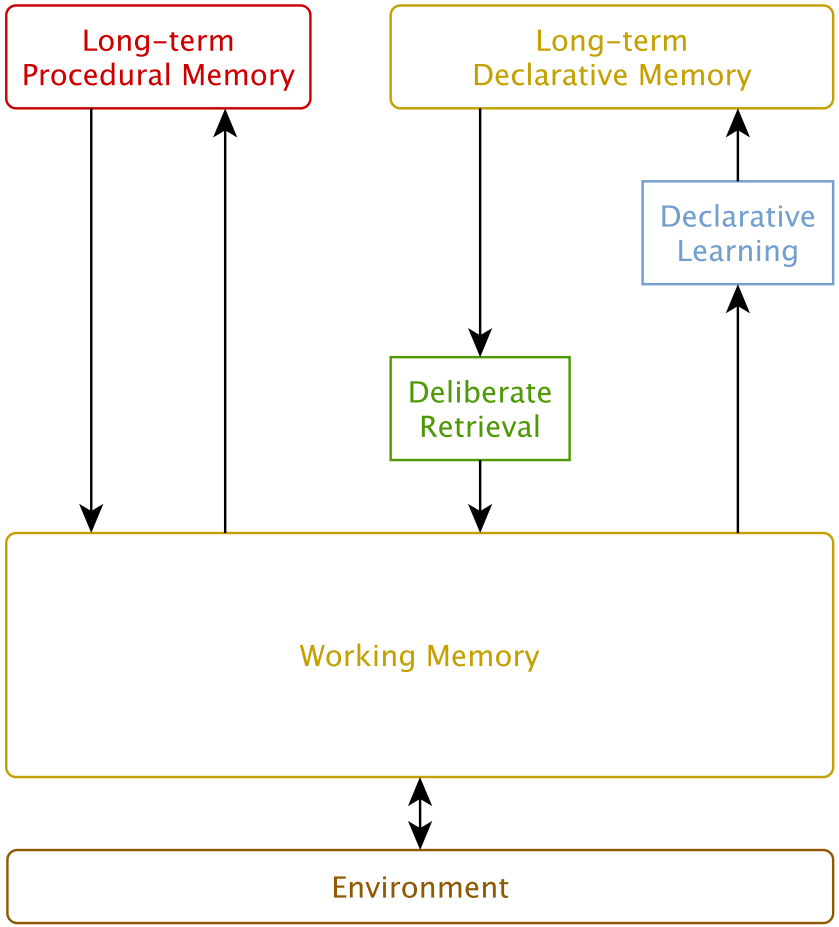
The architecture automatically provides metadata on working memory elements, prompting deliberate retrieval

Necessary agent and architectural processes:

representation	Stored target must directly match working memory (for now)
storage	N/A
dynamics	N/A
retrieval	Metadata may suggest cues for deliberate retrieval

Example: Feeling that something was forgotten while passing the grocery store

Circular Knowledge Dependencies



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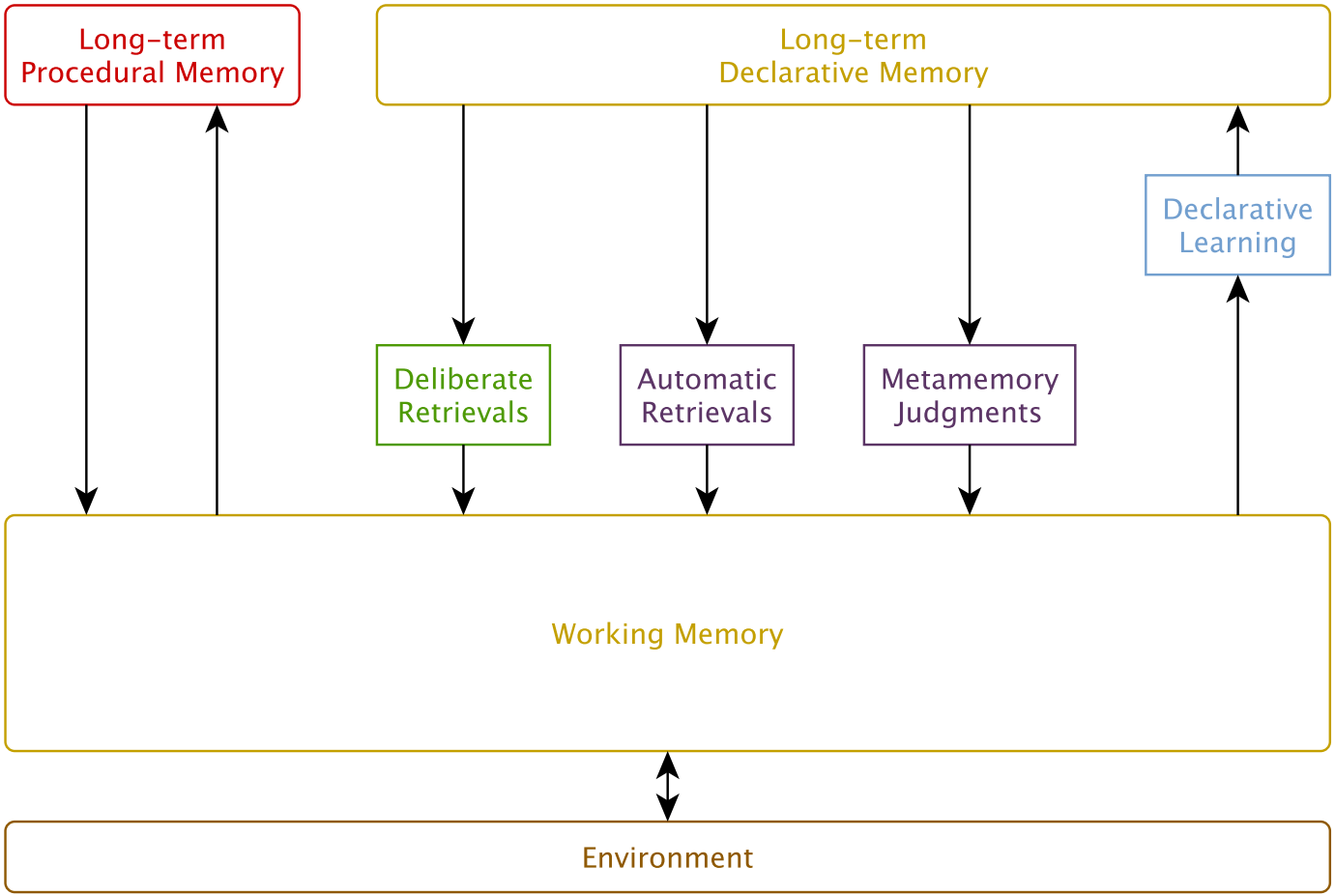

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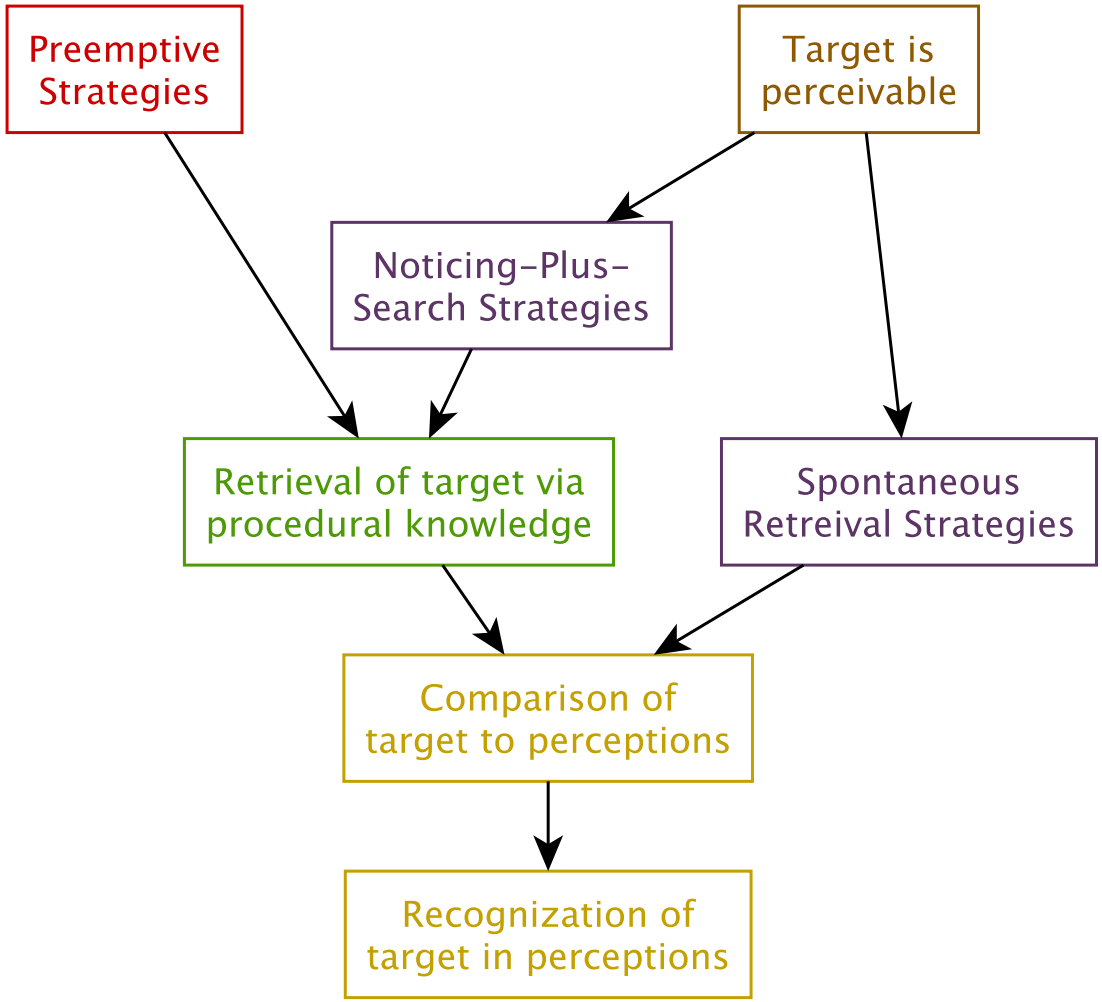


Execution

The agent performs the stored action.

Necessary agent and architectural processes:

representation	N/A
storage	N/A
dynamics	N/A
retrieval	N/A

Example: Buying milk

Completion

The agent must modify its memory such that the next perception of the target does not lead to action.

Necessary agent and architectural processes:

representation	N/A
storage	N/A
dynamics	Architecture may not support modification or forgetting
retrieval	N/A

Example: Not buying milk again the next day

Existing Agents

Claim: Circular knowledge dependencies is the fundamental problem of prospective memory

- Only a property of the agent in few models
- Altmann and Trafton (2002) implements a restricted preemptive strategy
- Li and Laird (2011) uses procedural memory, but is unscalable
- Li and Laird (2013) implements preemptive strategies more fully (next talk!)

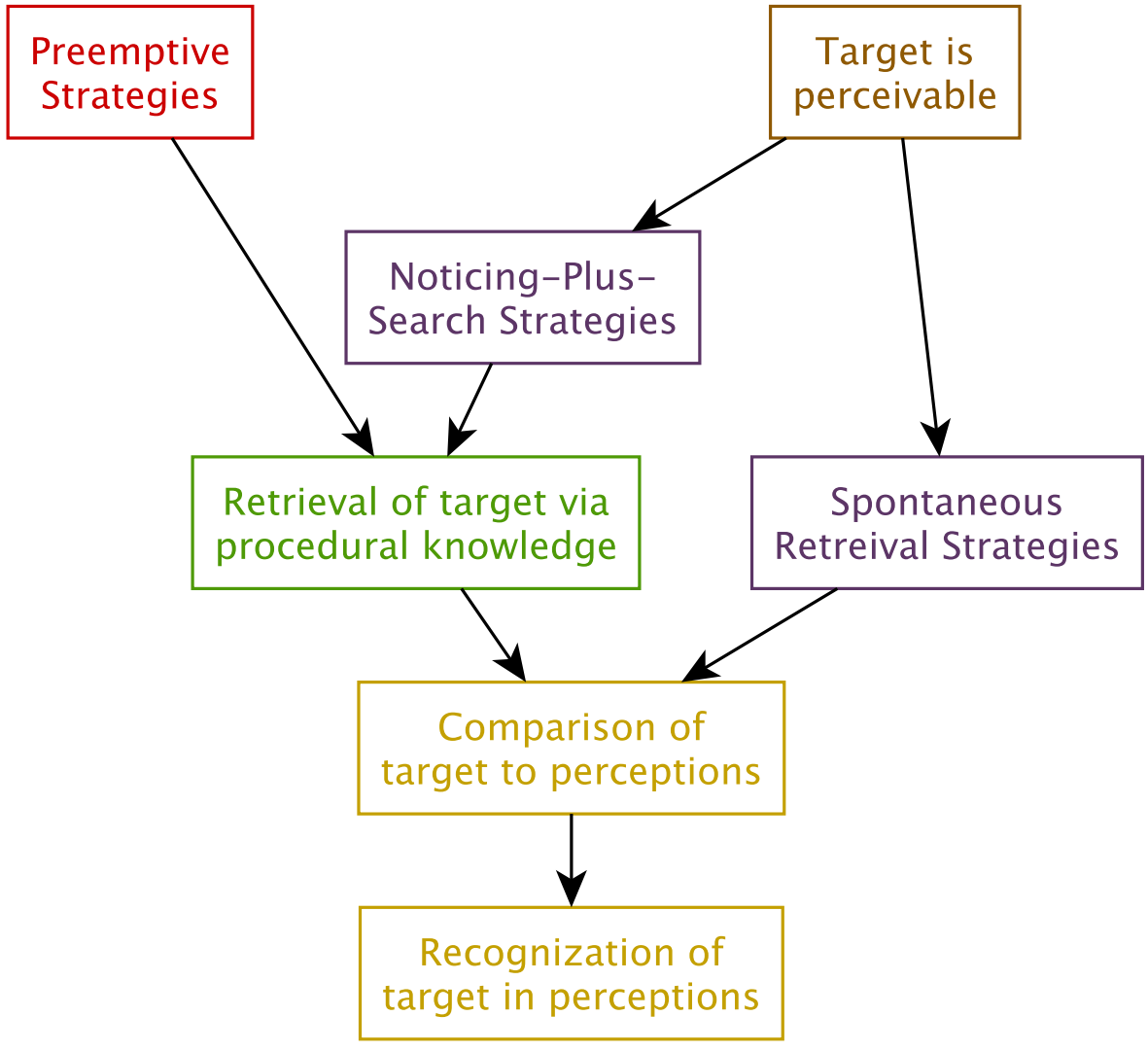
Nuggets and Coal

Nuggets

- Circular knowledge dependency problem of prospective memory
- Map of memory designs and possible effects
- Initial implementations of two strategies
  - Preemptive strategies
  - Meta-memory judgment system

Coal

- Much architectural work to be done
  - Modifying long-term memory
  - Automatic retrievals
  - Meta-memory judgments


Preemptive Strategies
Target is perceivable
Noticing-Plus-Search Strategies
Retrieval of target via procedural knowledge
Spontaneous Retreival Strategies
Comparison of target to perceptions
Recognization of target in perceptions

Circular Dependencies for Perception

- A similar dependency cycle exists for active perception
  - Must recognize opportunity to perceive target
  - Must perceive target to recognize opportunity
- This also applies to *external memory*
- Preemptive strategies continue to work
- Other strategies unexplored