An Analysis and Comparison of ACT-R and Soar

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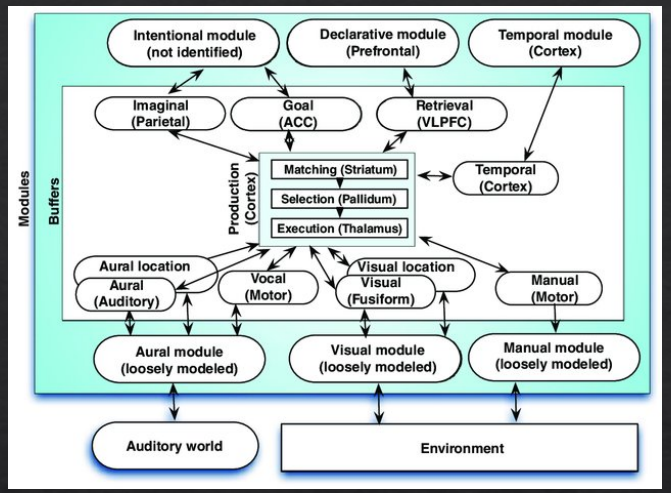
Comparing Cognitive Architectures

- ACT-R: Model human behavior + agents
- Soar: Complex cognitive agents + modeling

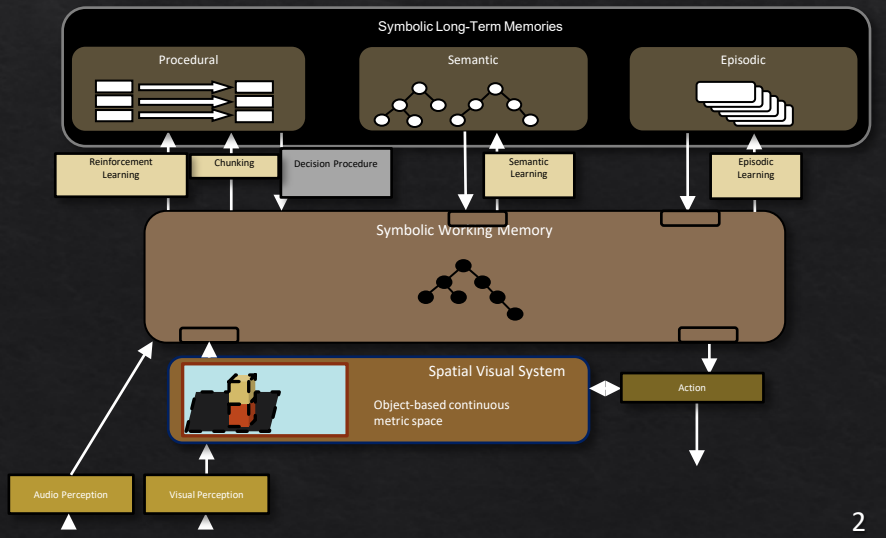
- Mature and general common model architectures
  - Freely available
  - Applied to 100's of tasks
  - Real-time performance
  - On-line incremental learning

- Deeper analysis than the Common Model.

ACT-R



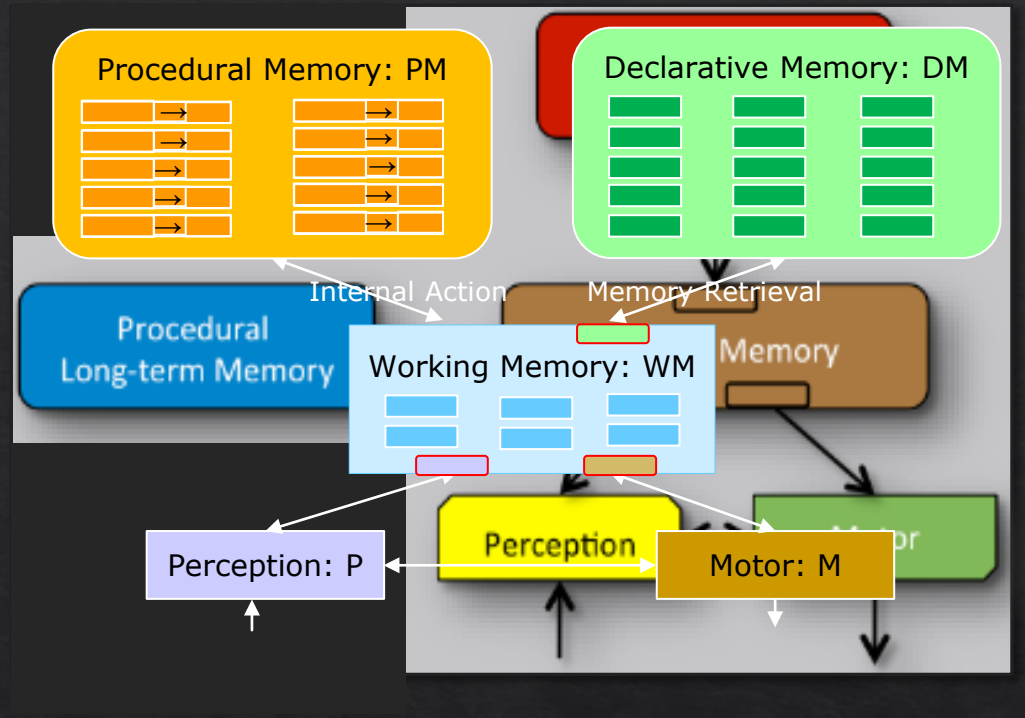
Soar



Common Model of Cognition

- Community consensus: an abstract specification of human-like cognitive architecture
  - Baseline for development and cumulative progress
  - Guide research on individual components
  - Testable theory for cognitive structures and functions
- *Not a prescription for all cognitive architectures*

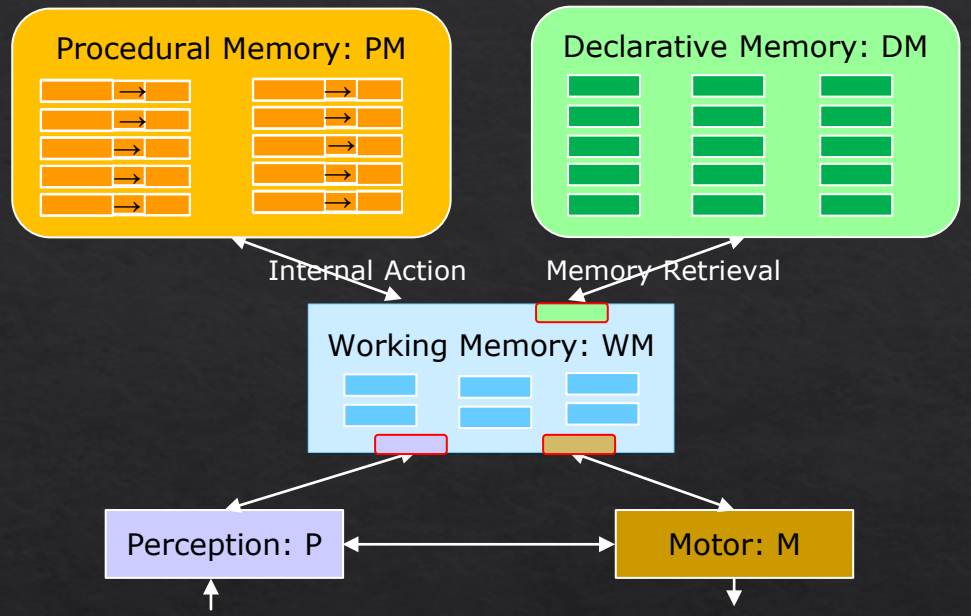
- A fixed set of communicating modules
  - Memories, perception, motor
  - Architectural learning



Laird, J. E., Lebiere, C. & Rosenbloom, P. S. (2017). A Standard Model for the Mind: Toward a Common Computational Framework across Artificial Intelligence, Cognitive Science, Neuroscience, and Robotics , *AI Magazine 38(4).*

Only Task-Independent Memory Modules

- No NL, planning, navigation, … modules
- No task-specific learning modules
- No executive control / metacognition / attentional modules

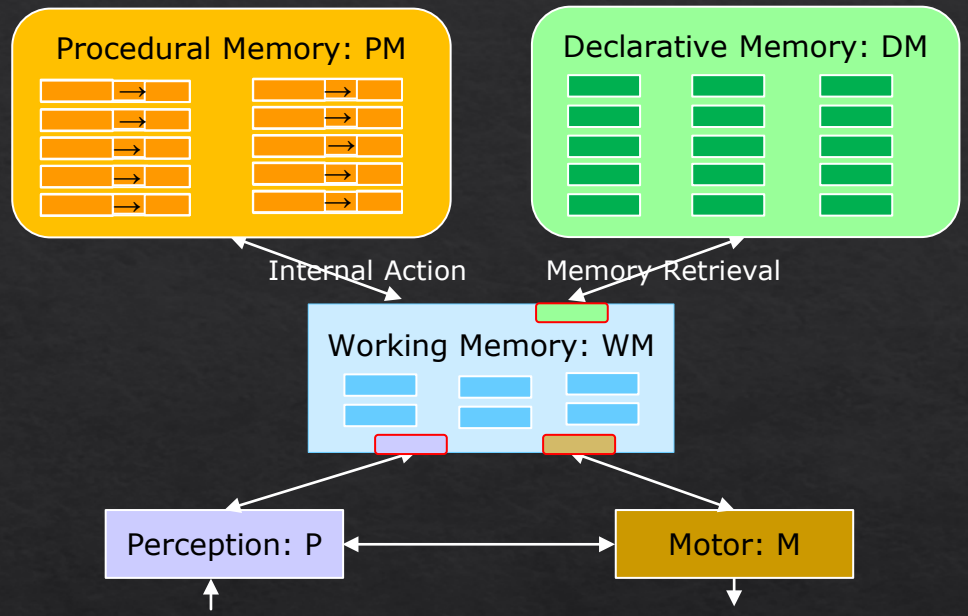


Outline: Commonalities and Differences

- Architecture Overview
  - Processing, Data, Metadata

- Working Memory (WM)
- Procedural Memory (PM)
- Declarative Memory (DM)

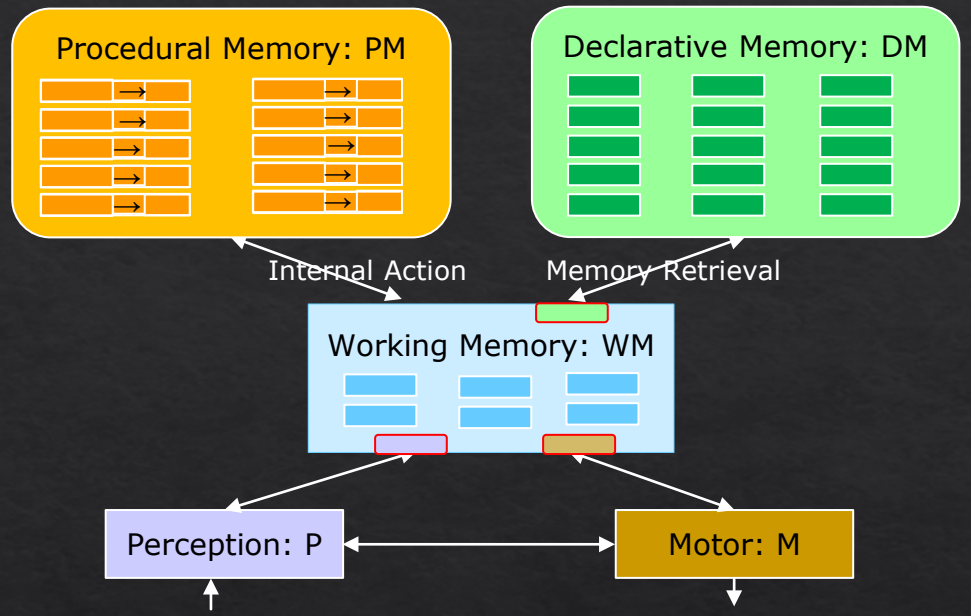
- Discussion: What did I learn?



Architecture Processing

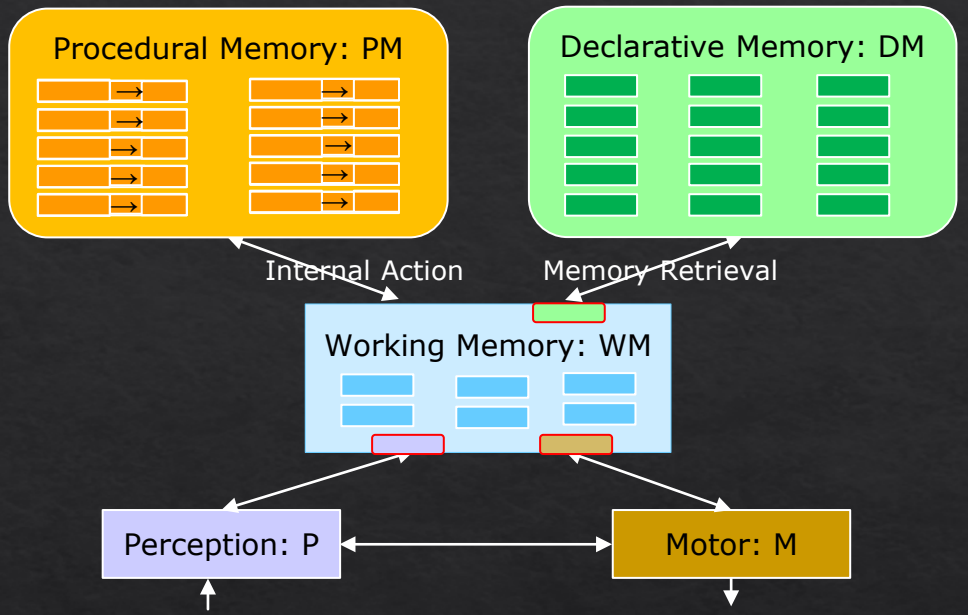
Basic Cycle: Selection and execution of an internal action from Procedural Memory to change Working Memory.

- Internal reasoning
- Declarative memory retrieval
- Motor action execution
- Perception modulation



Agent Data

- Encodes agent/task knowledge.
- Contents of working memory, declarative memory, procedural memory.
- Consist of *memory elements (symbolic).*
  - Independently created, modified, deleted, tested by other *agent data* and learning mechanisms.
- Architecture understands only the *form* of knowledge (some exceptions).

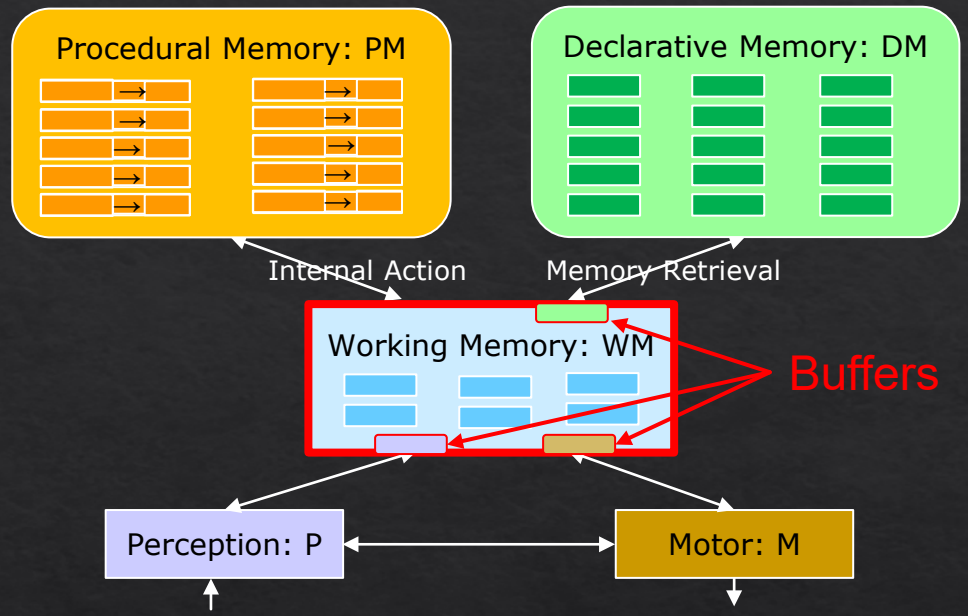


Types of Agent Data

1. **Internal agent data.**
   - Working memory, procedural memory, declarative memory.
   - *Unconstrained content.*

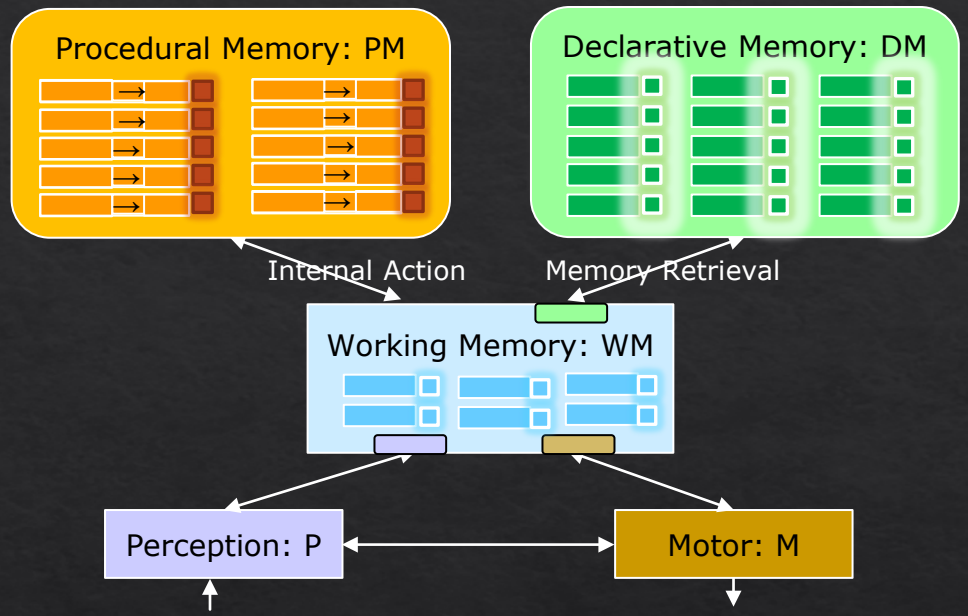
2. **Module commands.**
   - WM elements created by PM actions in WM *buffers*.
   - Sent to a module (P, DM, M) to initiate its processes.
   - *Innate/fixed set of symbols that define module commands.*

3. **Module status data.**
   - WM elements created by a module in its WM buffer.
   - Provide feedback on the module's processes: success/failure.
   - Meta-process data: data about architectural processing.
     - Signal to initiate metareasoning
   - *Innate/fixed set of symbols.*



Agent Metadata

- Data *about* agent data elements
  - Associated with agent data
  - Not defined as data used in metareasoning
  - Numeric and relational
  - *Fixed semantics – architecturally defined*
- Examples:
  - Activation of long-term memory elements
  - Utility of procedural memory elements
  - Derivational data for working memory elements
- Created, updated, and tested by the architecture
  - *Not accessible or modifiable by agent data*
- Influences architectural processing of agent data
  - *Retrievals from PM and DM memory*
  - *Learning*
  - *Forgetting*



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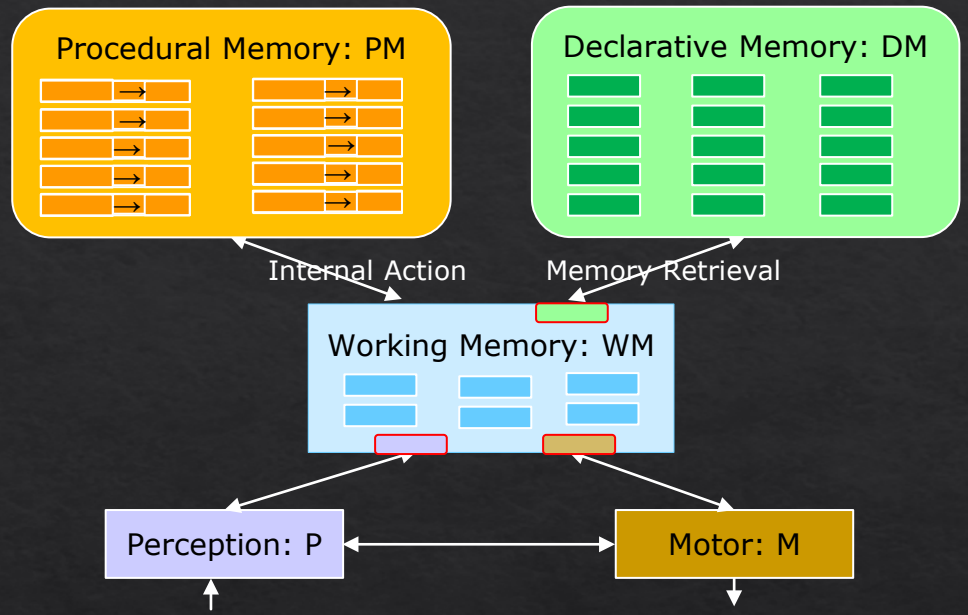
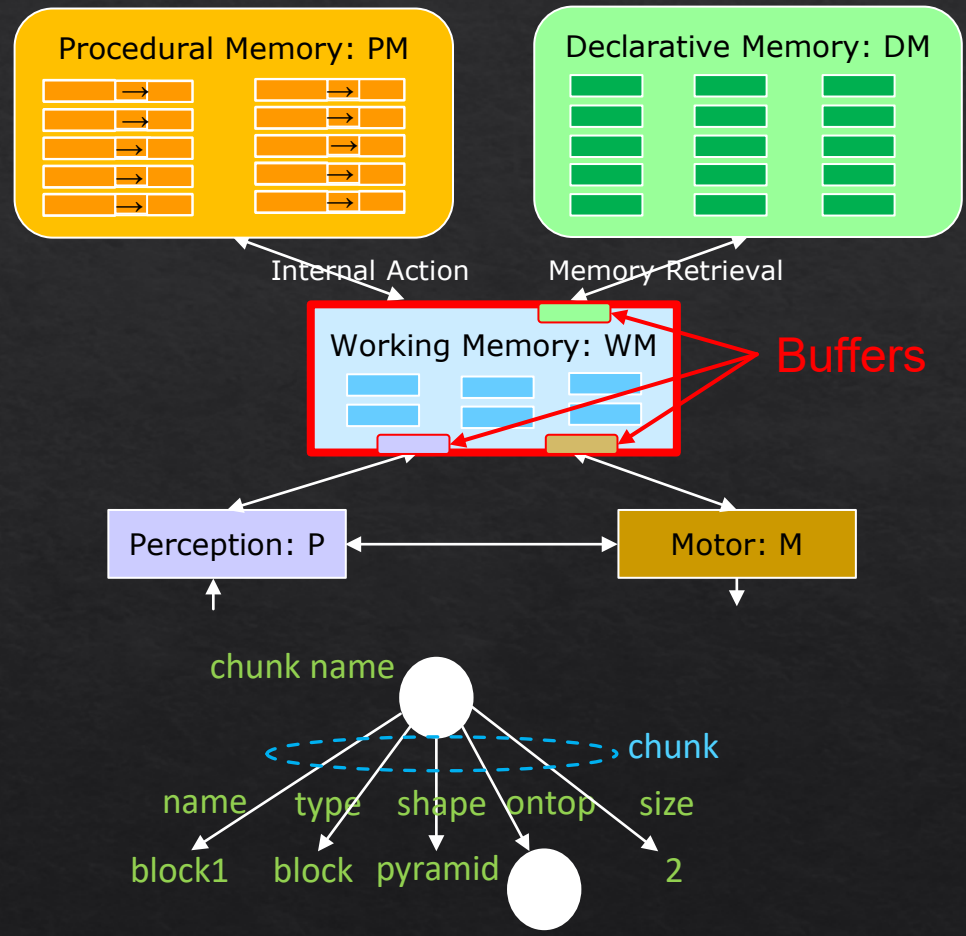


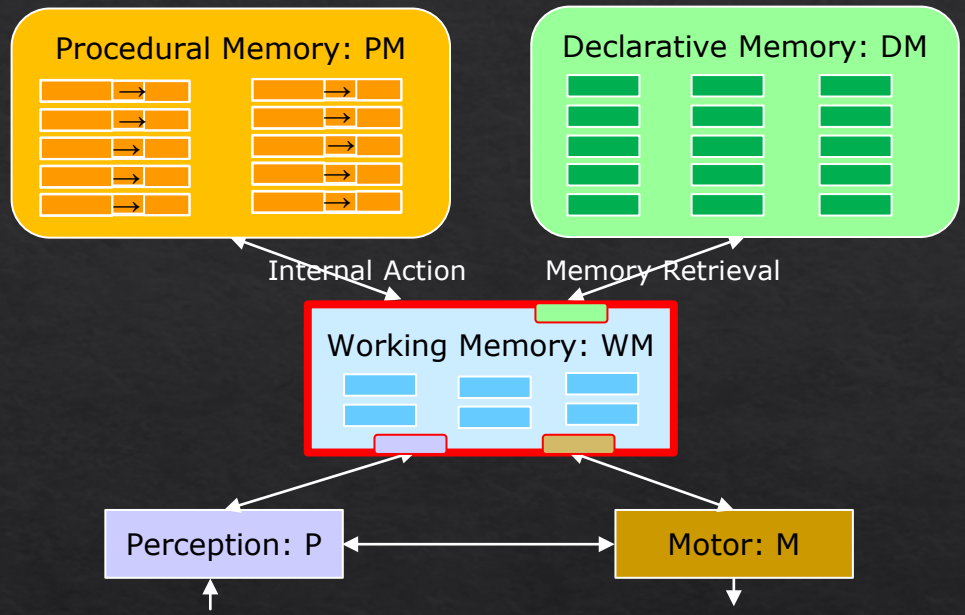
Working Memory Data Commonalities

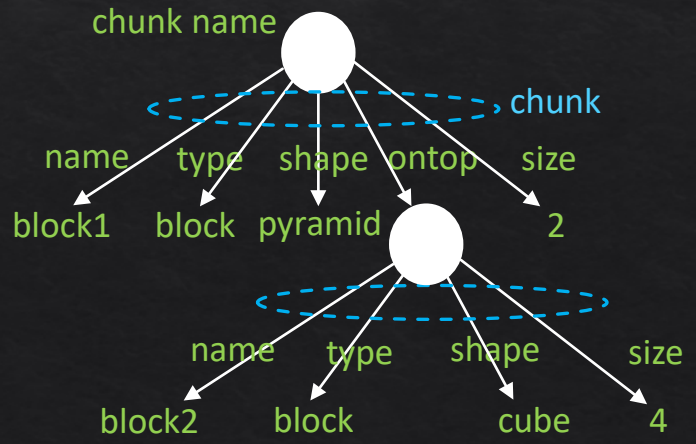
- Relational graph structures
  - *Element* is a triple: symbolic node, labeled edge, value.
  - *Declarative chunk*: Elements that share node
- Buffers to other modules: DM, PM, P, M
  - Chunks – data transfer to module
  - Module commands (read only – fixed semantics)
  - Module status (read only – fixed semantics)
    - Meta-process data



Working Memory Data Differences

- ACT-R
  - Fixed number of buffers – no other WM elements.
  - Exact number varies by agent/model
  - Single level chunks in buffers – no substructure.
- Soar
  - Unlimited graph in breadth and depth.
  - Rooted in *state* node.
  - Substates are created at impasse
    - Meta-process data for procedural memory.
    - Allows recursive “universal” subgoaling = metagoals.





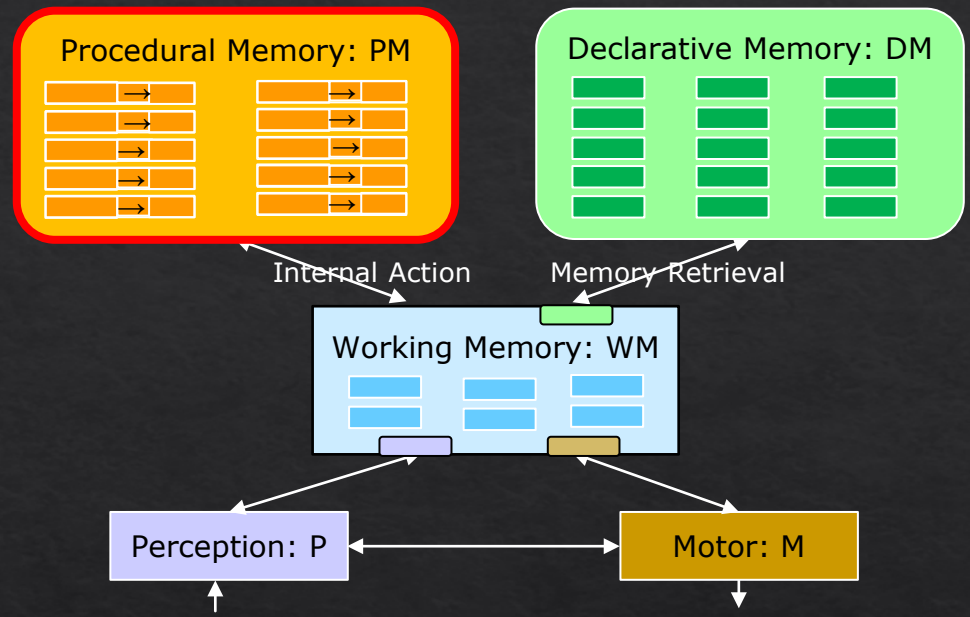
Working Memory Metadata

- Common
  - Source (relational):
    - Connection from WM chunk in DM chunk
    - Used for updating DM chunks and DM metadata
  - Derivation (relational):
    - Instantiation of procedural memory element used to create WM *elements*
    - Used in procedural learning

- ACT-R: above
- Soar: above +
  - Activation (numeric):
    - Base-level activation of element - recency and frequency of creation and access
    - Used in forgetting and for biasing DM retrievals
  - Highest substate (relational):
    - Used in returning results from substates and procedural learning

Procedural Memory Data

- Common:
  - A single PM element is selected on cognitive cycle
  - Rule-like elements with conditions and actions
    - Conditions test WM elements (not metadata)
    - Actions modify WM elements:
    - Updates metadata (PM utility, WM derivation, ...)
- ACT-R: above +
  - PM element = individual rule.
- Soar: above +
  - PM element = *operator* = collection of rules.
  - *Elaboration, proposal, selection, and application rules.*
  - Impasse if failed selection.

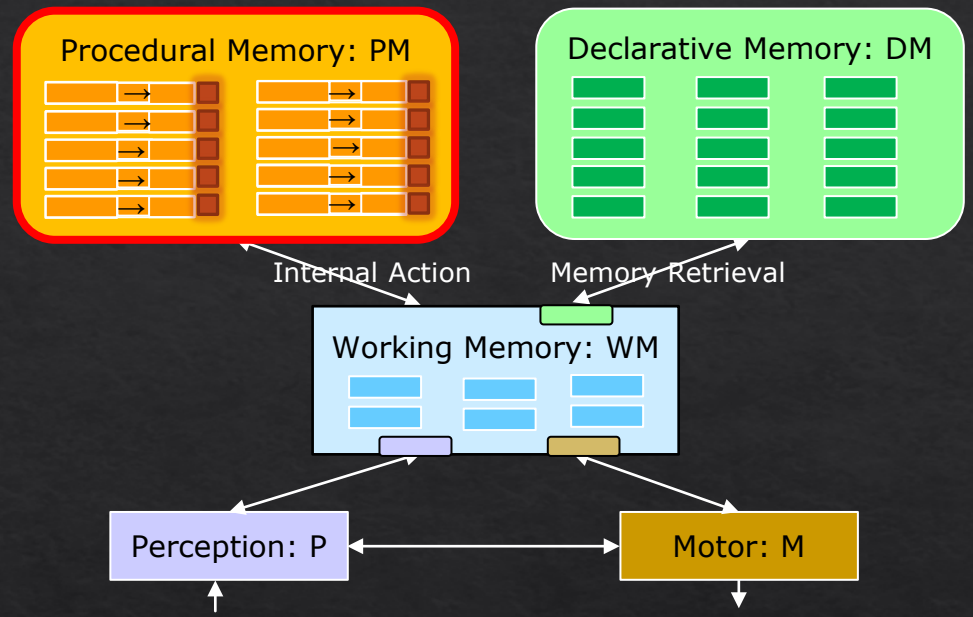


Procedural Memory Element: Rule vs. Operator

- ACT-R: Individual rule
  - Conditions match chunks in buffers
  - *Select rule based on utility and degree of match*
  - Selected rule actions change contents of buffers
- Soar: Operator
  - Elaboration rules: create WM structures tested in proposal and selection
  - Proposal rules: create proposed operator structures
  - Selection rules: create preferences with ratings of proposed operators
  - *Select operator based on preferences*
  - Selected operator apply rules change working memory data

Procedural Memory Metadata

- Common:
  - Utility associated with PM elements
  - Computed via temporal difference learning
- ACT-R: above
- Soar: above +
  - Utility associated with selection rules for an operator
  - Activation:
    - Recency and frequency of creation and access
    - Used in forgetting

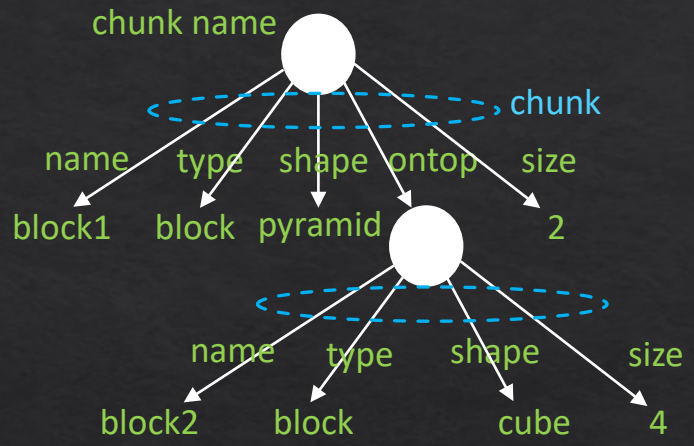


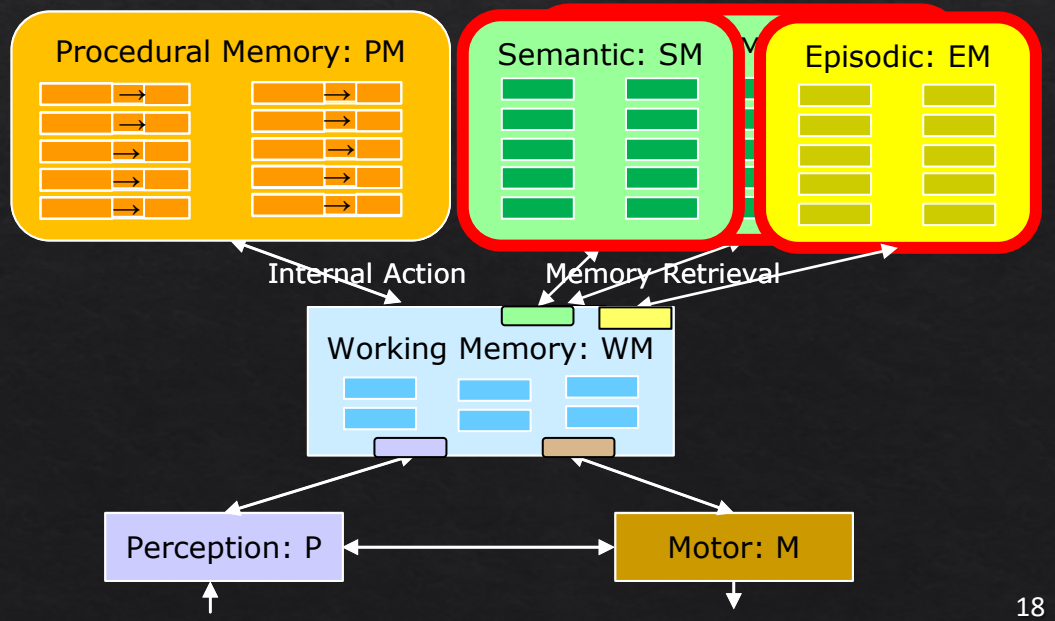
Procedural Memory Learning

- Common
  - RL is updated using PM elements utility metadata.
  - Procedural composition:
    - Use derivation metadata to create new PM elements that summarize processing
- ACT-R/Soar
  - Differences in details, but same functionality.

Declarative Memory Data

- Common:
  - Same relational graph structures as WM
- ACT-R: above
- Soar: above +
  - Semantic Memory = ACT-R Declarative Memory
  - Episodic Memory = Record of changes to WM





Declarative Memory Metadata

- Common
  - Base-level activation associated with every *chunk*
    - Computed from recency and frequency of access
    - Influences future retrievals from DM
- ACT-R: above +
  - Association strength between *pairs* of elements based on co-occurrence
    - Used in spreading activation
- Soar: above +
  - Base-level activation associated with every *element*
    - Used in spreading activation
  - Episodic memory has temporal and sequencing metadata for elements.

Declarative Memory Retrieval Differences

ACT-R: above +

- Select: Spontaneous Retrieval

Soar: above +

- Select: Direct Retrieval

Declarative Memory Learning

ACT-R

- Add chunk to DM when any buffer is cleared.
- Update DM chunk activation on chunk use and access.

Soar

- Direct storage of WM chunk to Semantic Memory ☹
- Update DM chunk activation on chunk use and access.
- All changes to WM recorded in Episodic Memory.

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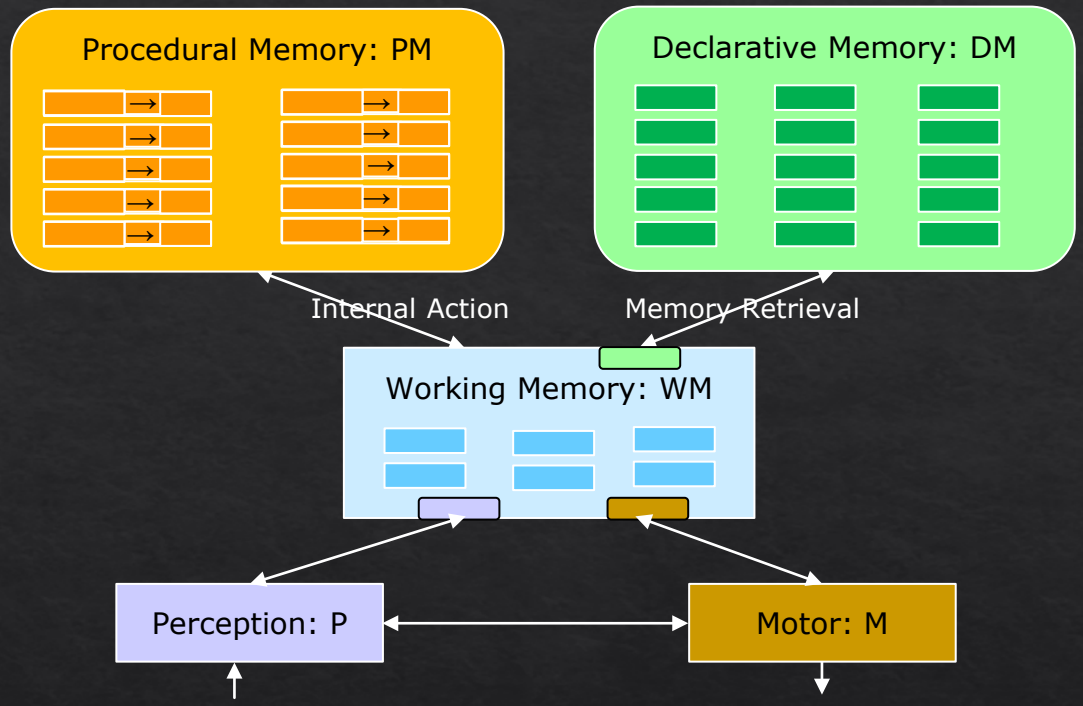


Commonalities

1. Agent data represented as graph structures: elements, chunks, and rules
2. PM and DM retrievals biased by metadata
   - Change WM; update metadata; set module status
3. Modules interact through buffers in WM
   - Provide meta-process data
4. Agent Metadata
   - Numeric and relational
   - Updated in parallel with retrievals from PM and DM.
   - Not readable or modifiable.
   - Activation used to focus on important memory elements for selection and learning.
5. Learning is side-effect of PM and DM activity

Most Important Differences

ACT-R

- WM: Fixed set of buffers
- PM elements: single rules
- PM retrieval is all or none
  - And no indication of failure
- Single declarative memory

Soar

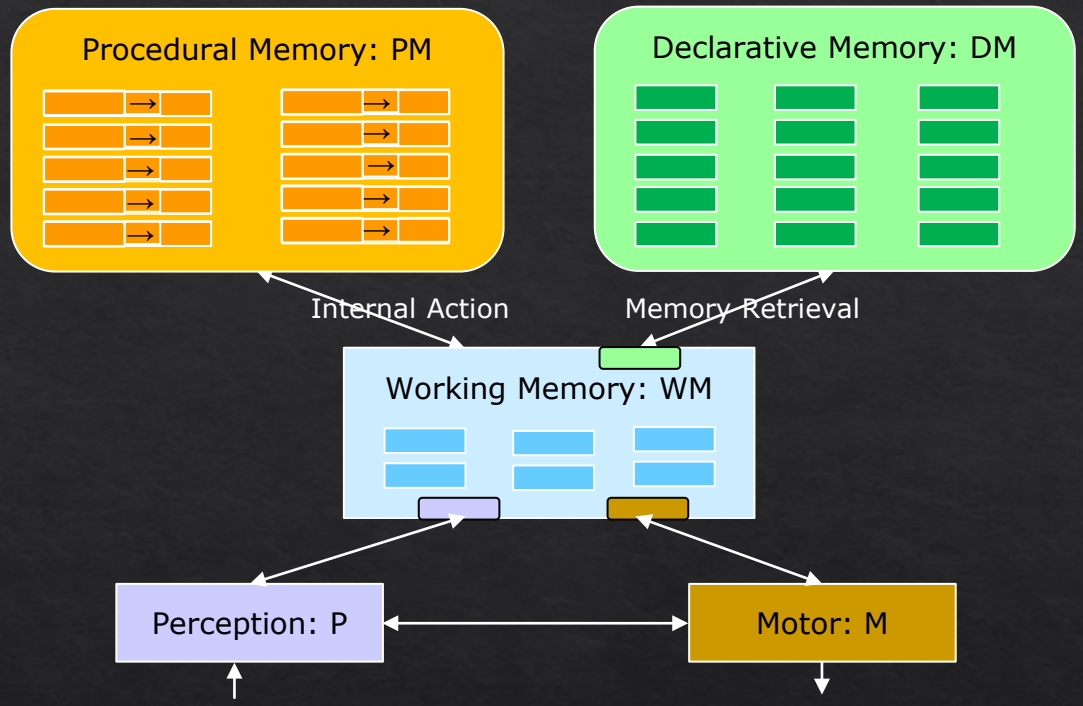
- WM: Unconstrained graph structure
  - Multiple states
- PM elements: operators
  - Multiple rules
- PM retrieval can fail in multiple ways
  - Impasses with substates
- Semantic and episodic memory

3 Types of Information

- Agent Data:
  - Created by perception, retrievals from procedural and declarative memory, and architectural learning mechanisms
  - Tested and modified by PM (except perception)
- Agent Metadata:
  - Associated with Agent Data
  - Created by architectural processing as a side effect of agent reasoning.
  - Influences architectural processing – retrievals and learning.
  - Does not “mix” with agent data – cannot be tested or modified by agent data.
- Module Status Data:
  - Meta-process data: created by module processing
  - Opening for metacognition
  - Tested by PM by cannot be modified

Only Task-Independent Memory Modules

- No NL, planning, navigation, … modules
- No task-specific learning modules
- No executive control / metacognition / attentional modules
  - Use same processing, but with access to meta-process data



Future

1. Analyze more architectures.
2. How represent metacognitive/metamemory appraisals?
   - Familiarity in a belief; feeling of knowing; feelings about ease of processing; judgments of remembering vs. knowing.
   - Status associated with retrievals from semantic and episodic memories?
   - Readable metadata?
3. Incorporate modality specific representations – mental imagery, …
4. Fold back into Common Model of Cognition