

Learning Prepositions for Spatial Relationships in BOLT

Soar Workshop 2012

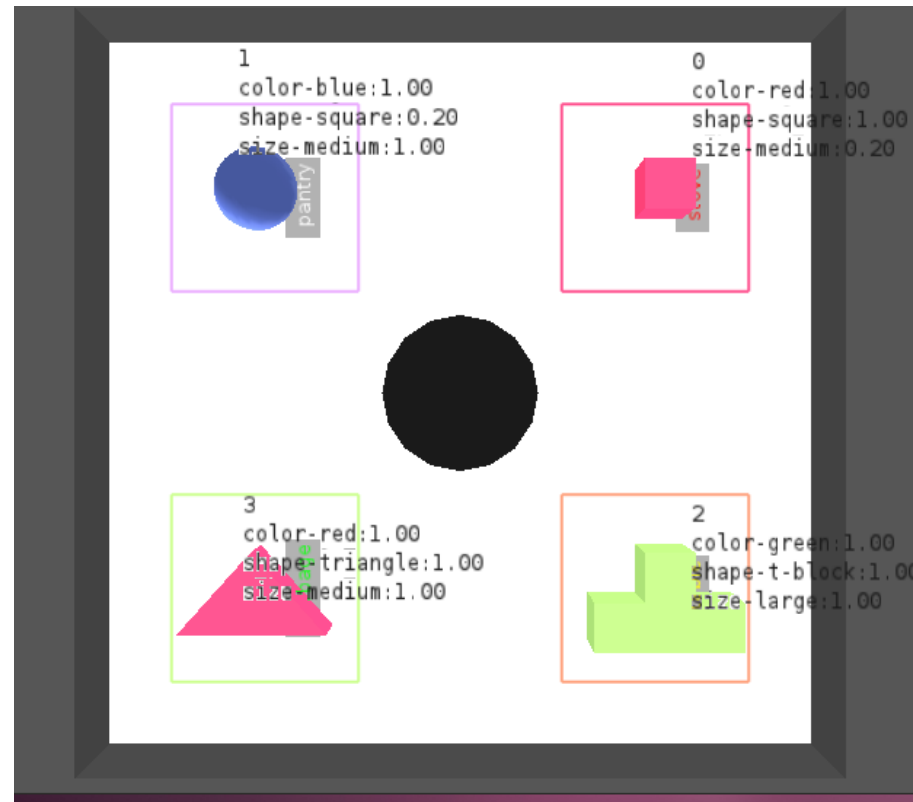
James Kirk, John Laird

6/21/2012

Outline

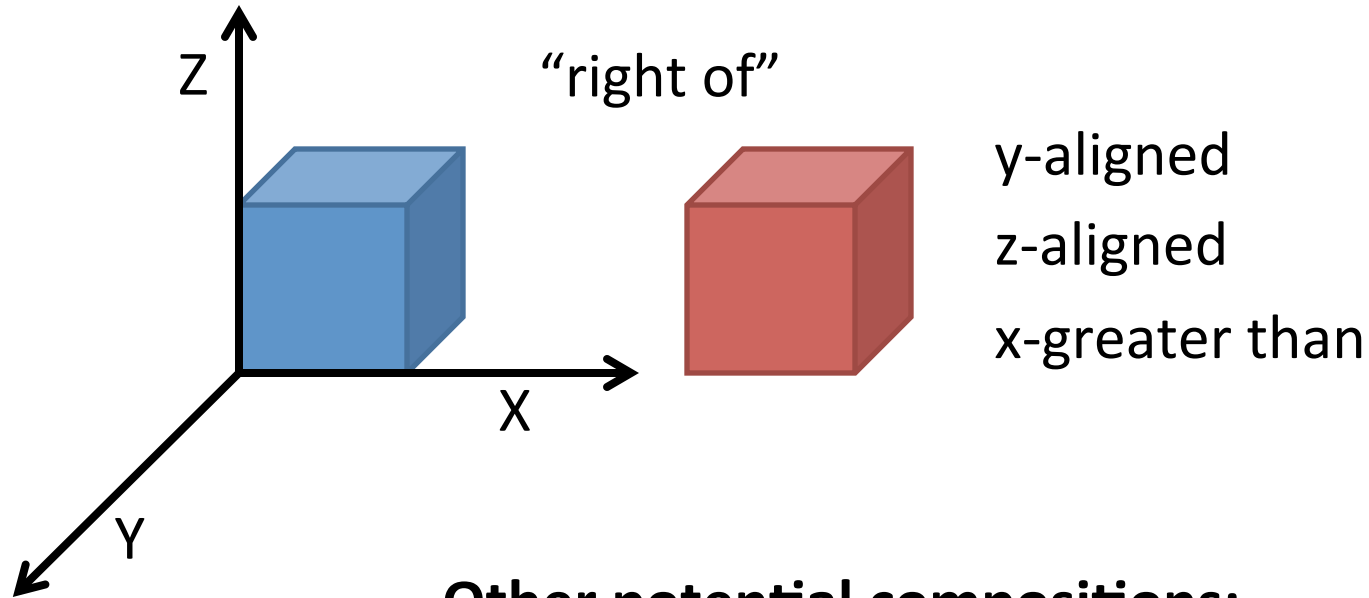
- Prepositions in BOLT
- Compositional Spatial Relationships
- Learning Process in Architecture with SVS
- Projection
- Conclusions

Prepositions/Spatial Relationships in BOLT



- “What is to the right of the pantry?”
- “Put the triangle in the stove.”
- “Pick up the red object to the right of the pantry.”

Spatial Relationships as Compositions



Other potential compositions:

“In front of”
y-less than
z-aligned
x-aligned

“Above”
z-greater than

“Intersecting”
y-aligned
z-aligned
x-aligned

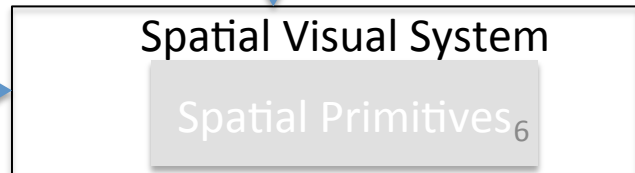
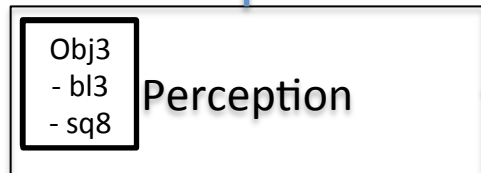
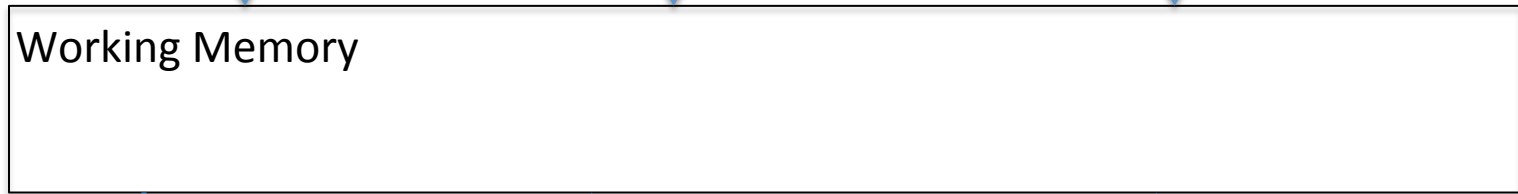
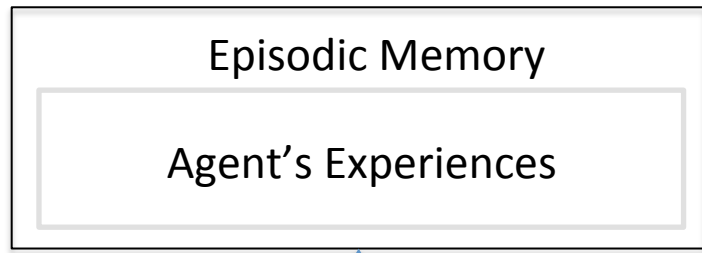
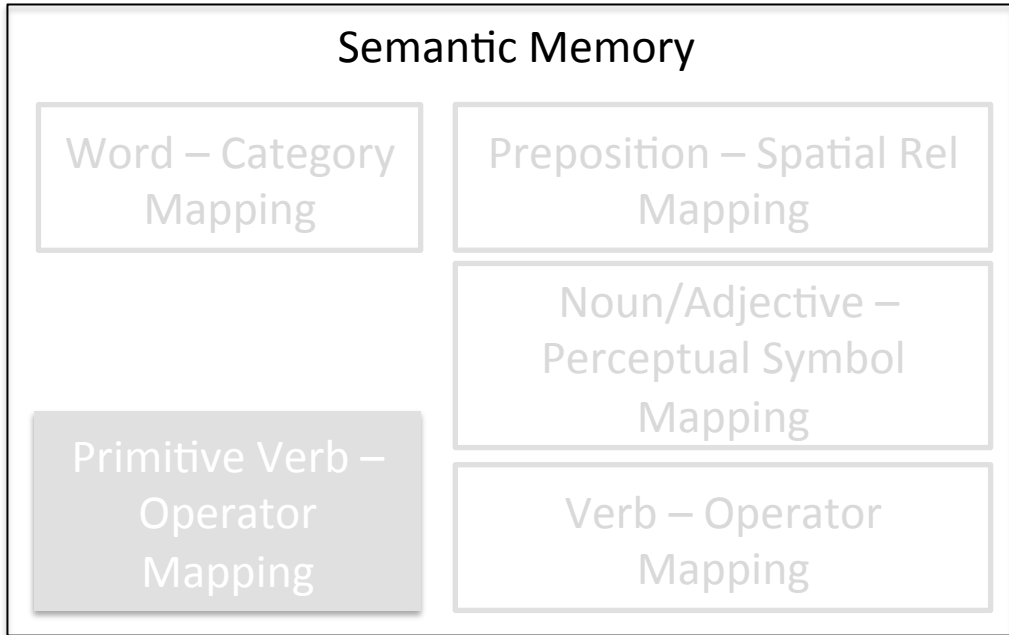
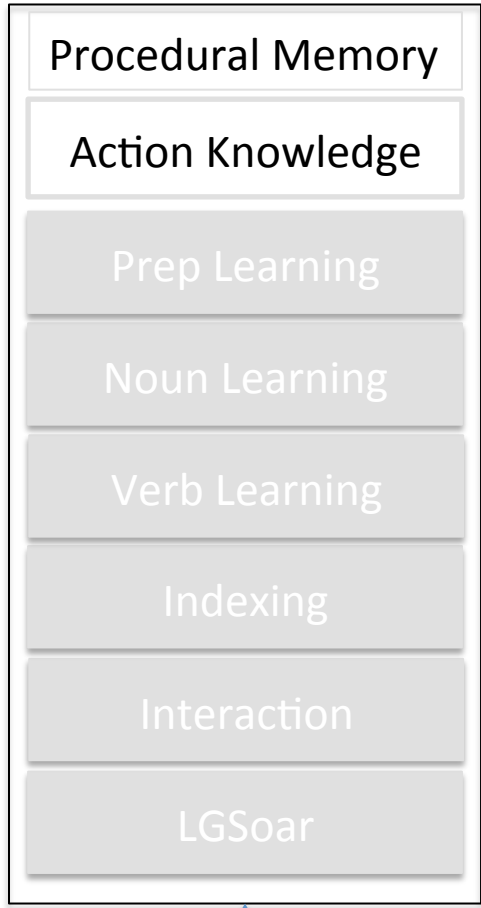
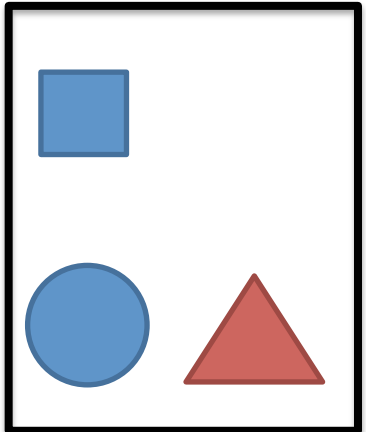
Learn new prepositions that map to spatial relations

“The red triangle is *right of* the blue sphere”

Human:
"The red triangle is
right-of the blue
sphere"

Phase 1
Perception

- Receive object information from input link
- Create internal representations

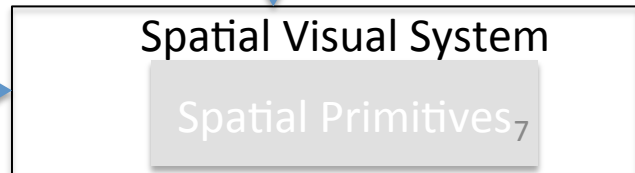
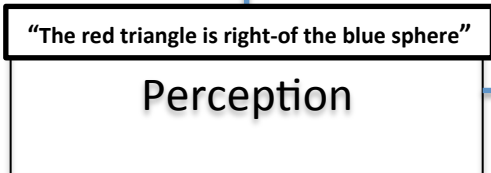
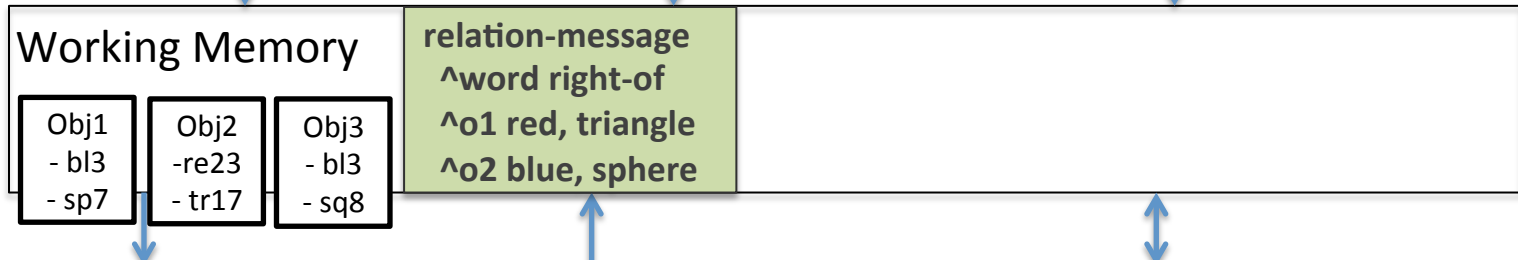
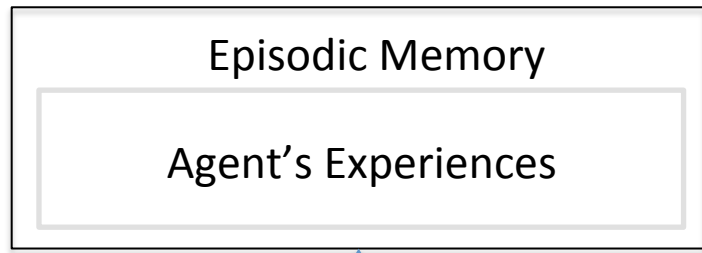
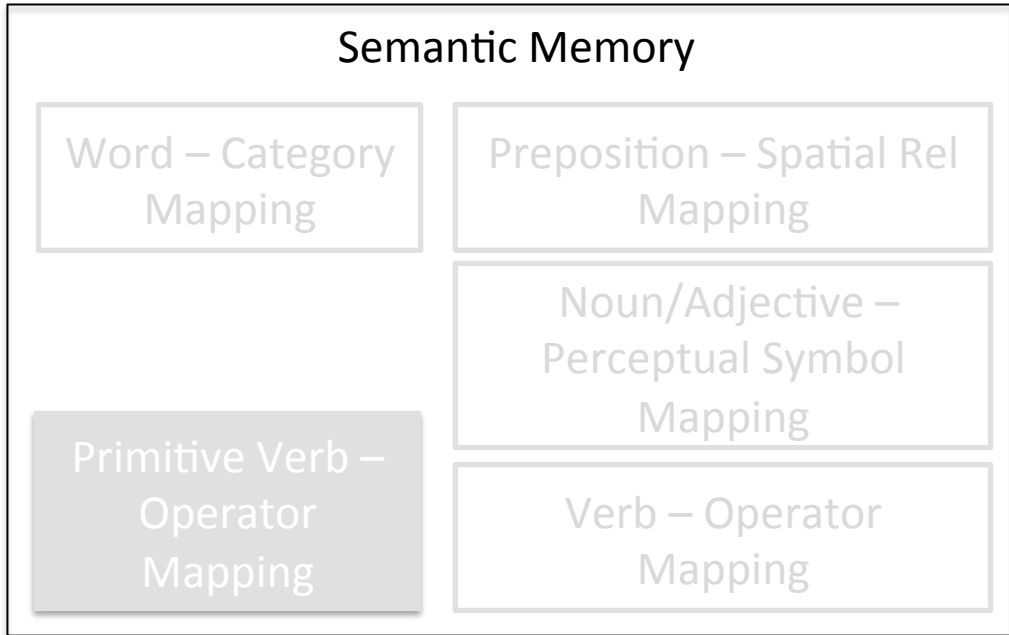
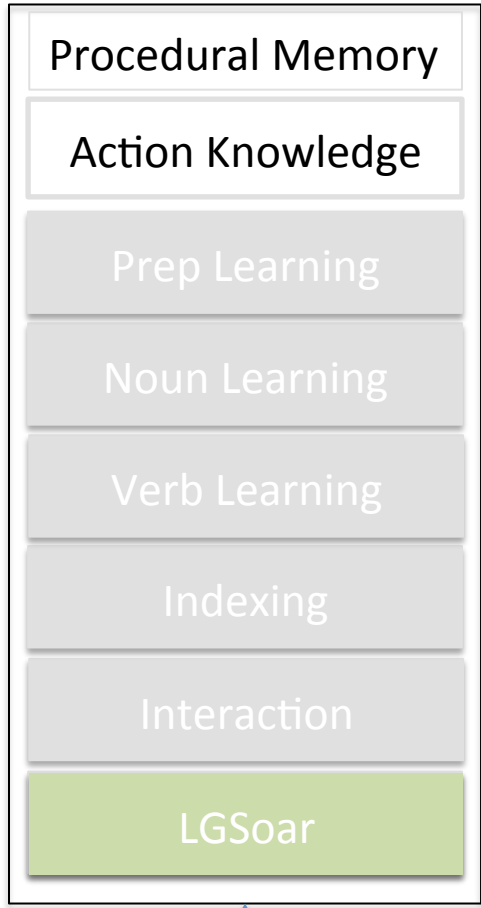
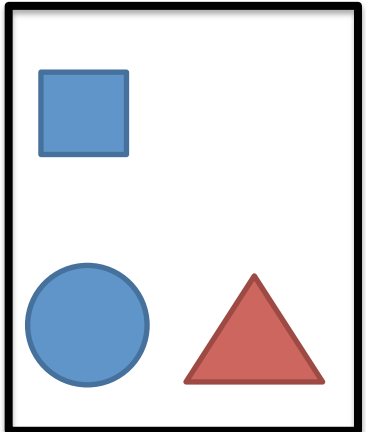


Human:
"The red triangle is right-of the blue sphere"

Phase 2

Message Parsing

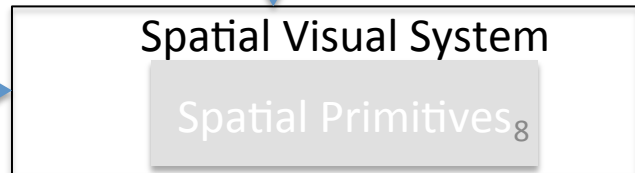
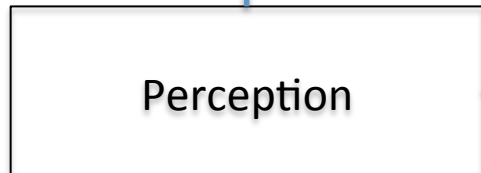
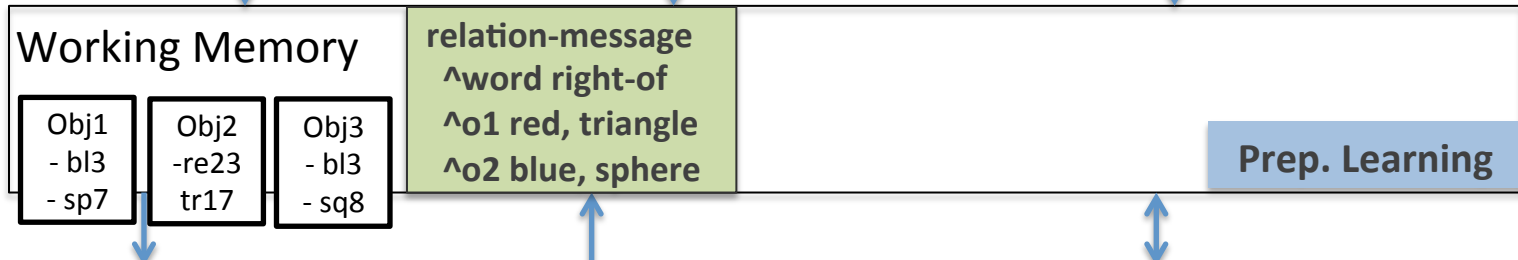
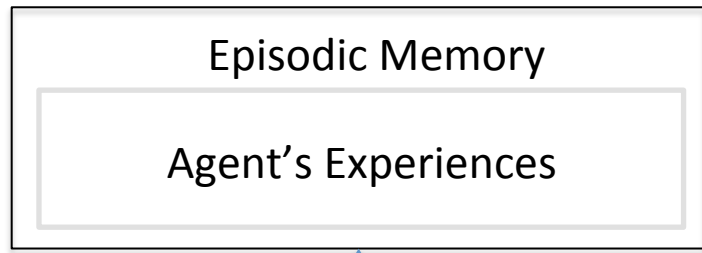
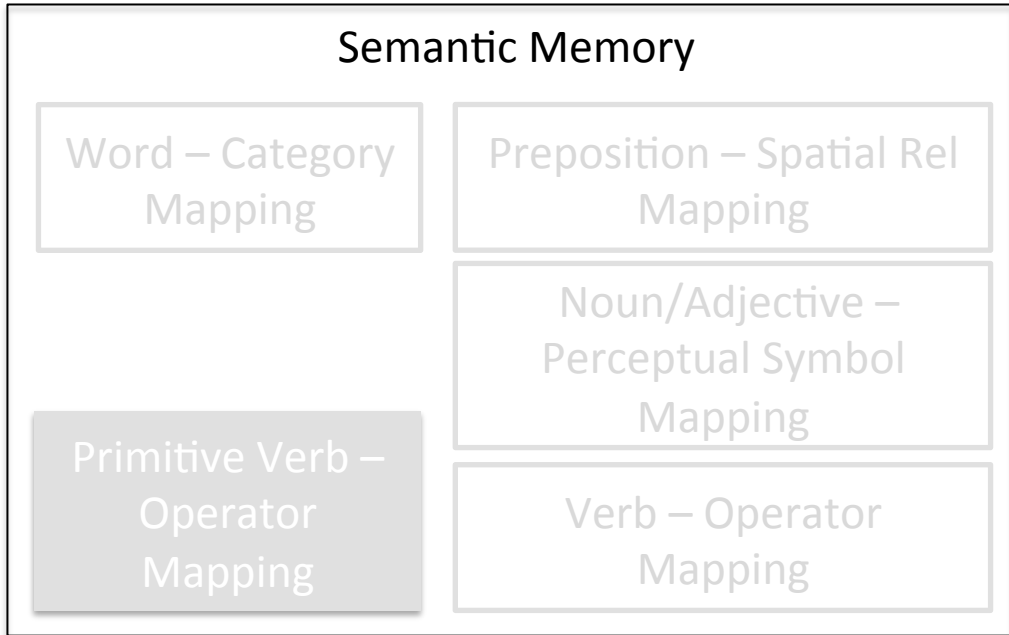
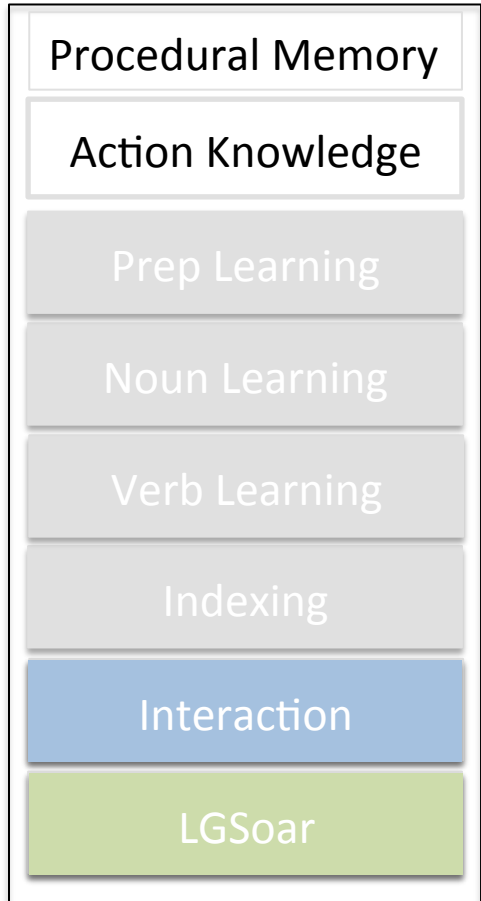
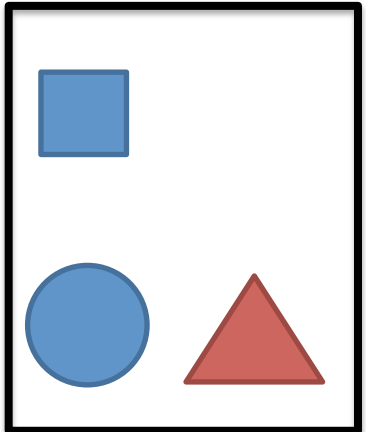
- Parse the given sentence
- Create usable message structures



Human:
"The red triangle is
right-of the blue
sphere"

Phase 3
Interaction
Stack

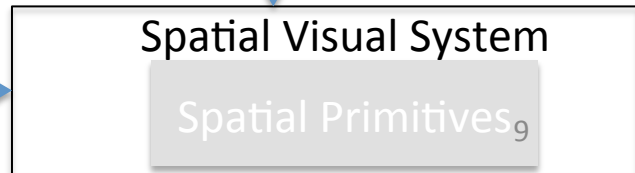
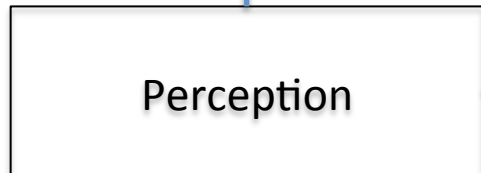
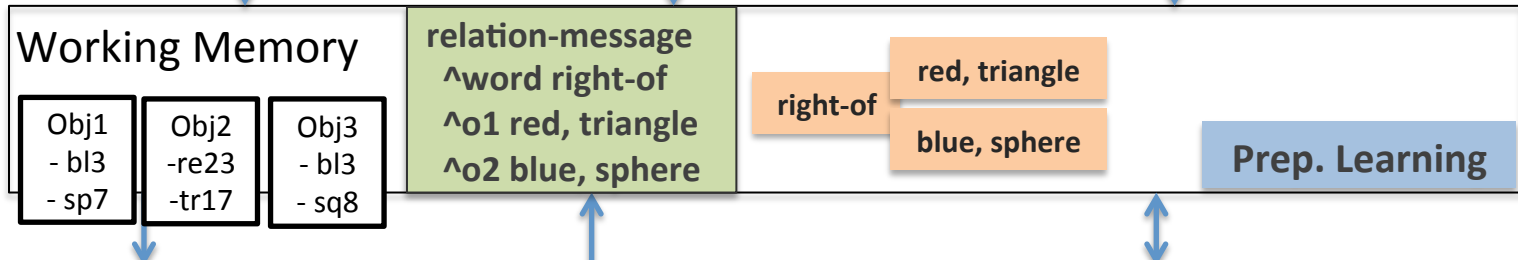
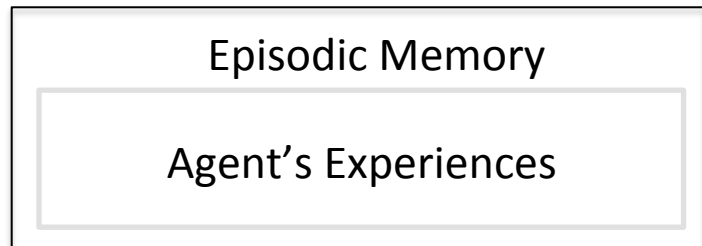
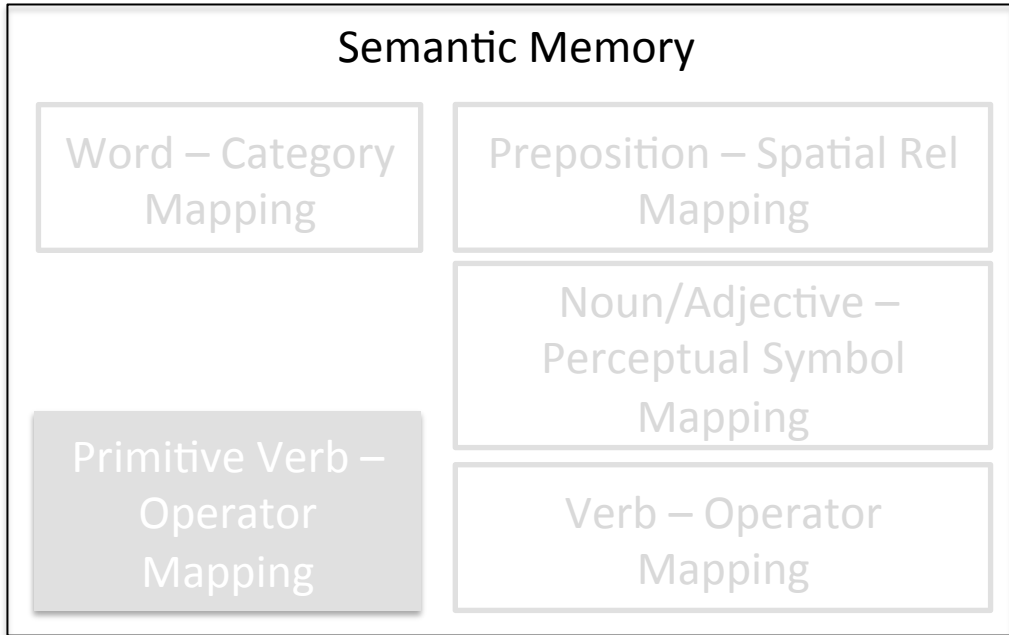
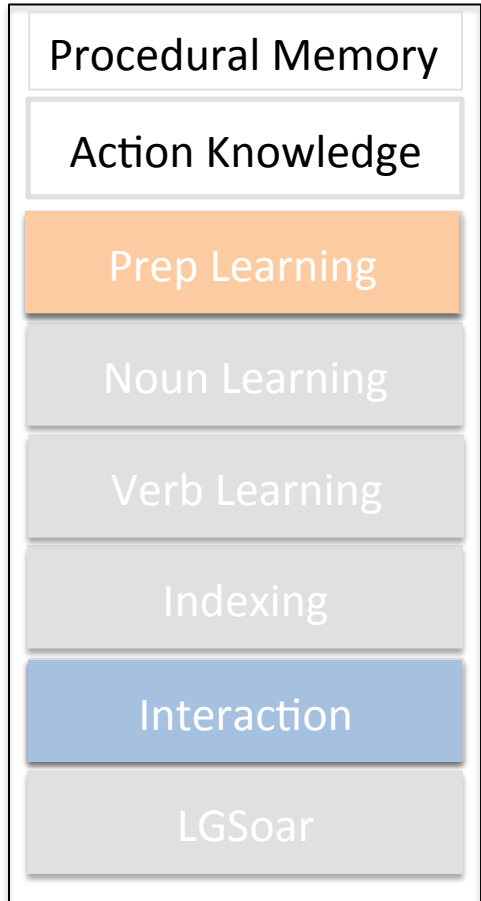
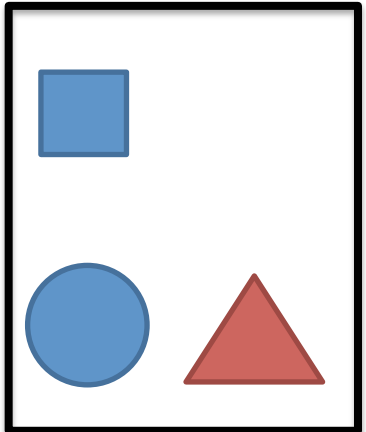
- Designate
message purpose
as preposition
learning



Human:
"The red triangle is
right-of the blue
sphere"

Phase 4

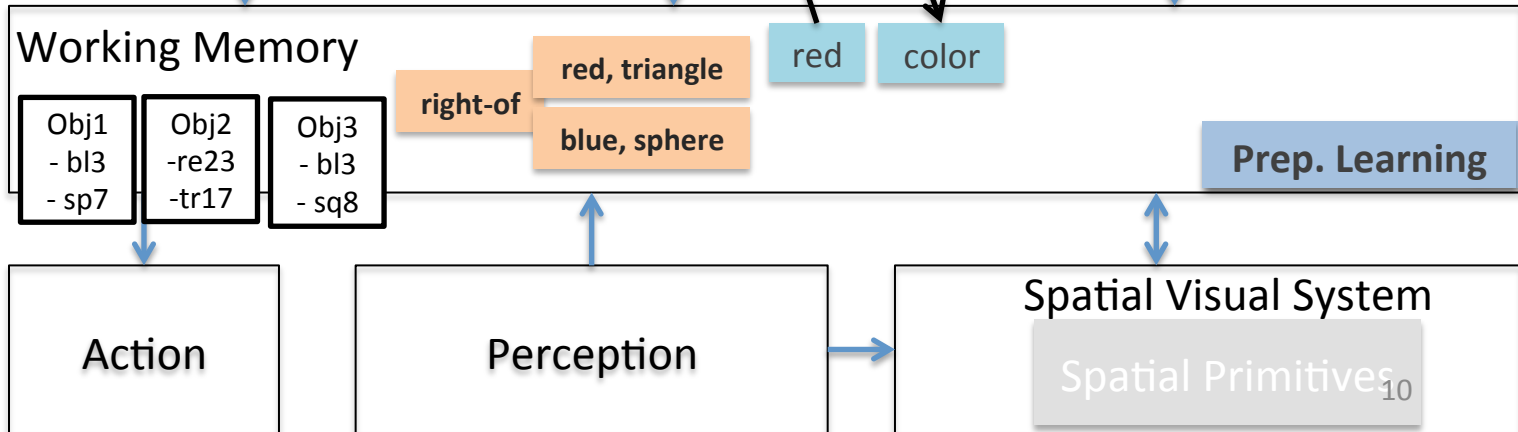
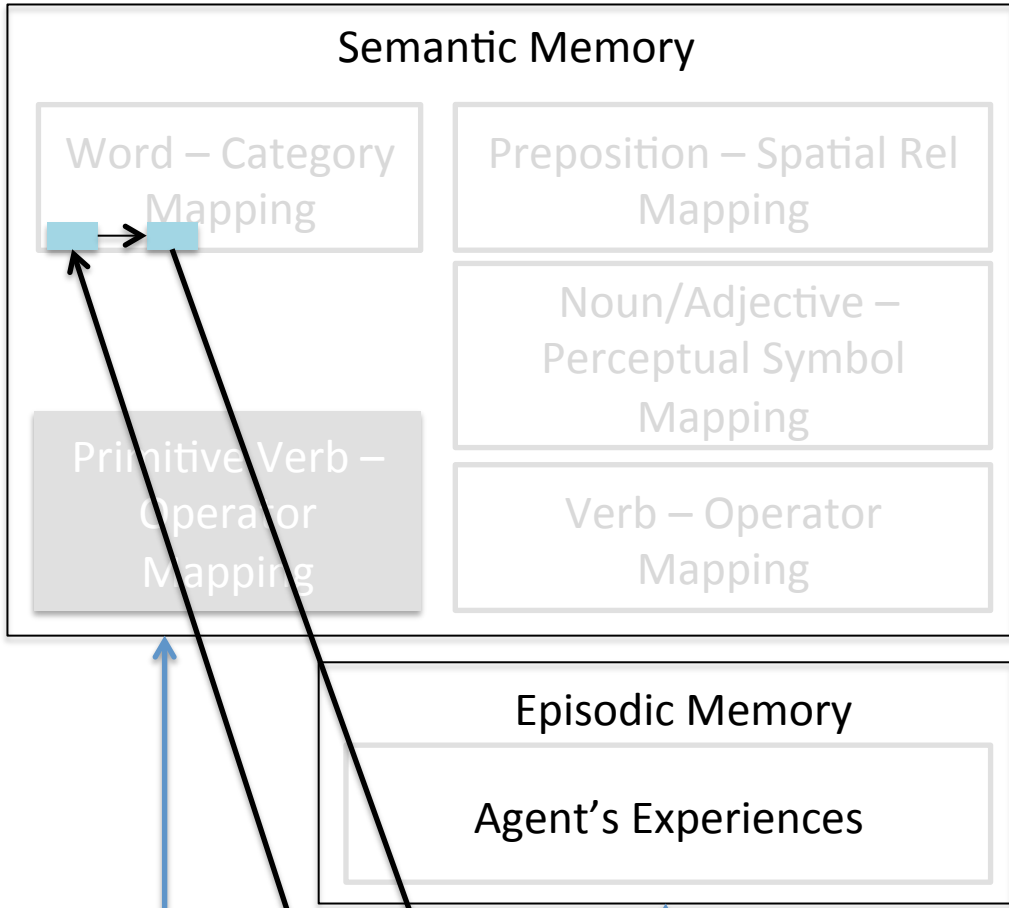
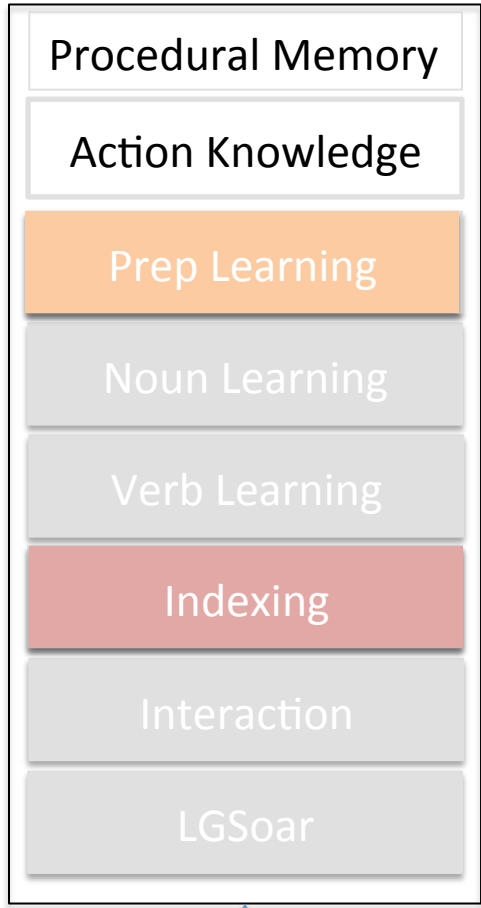
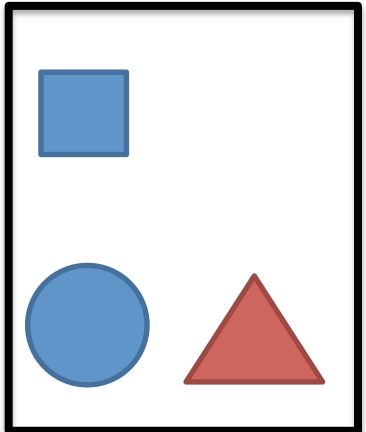
Preposition Learning



Human:
"The red triangle is
right-of the blue
sphere"

Phase 4
Preposition
Learning

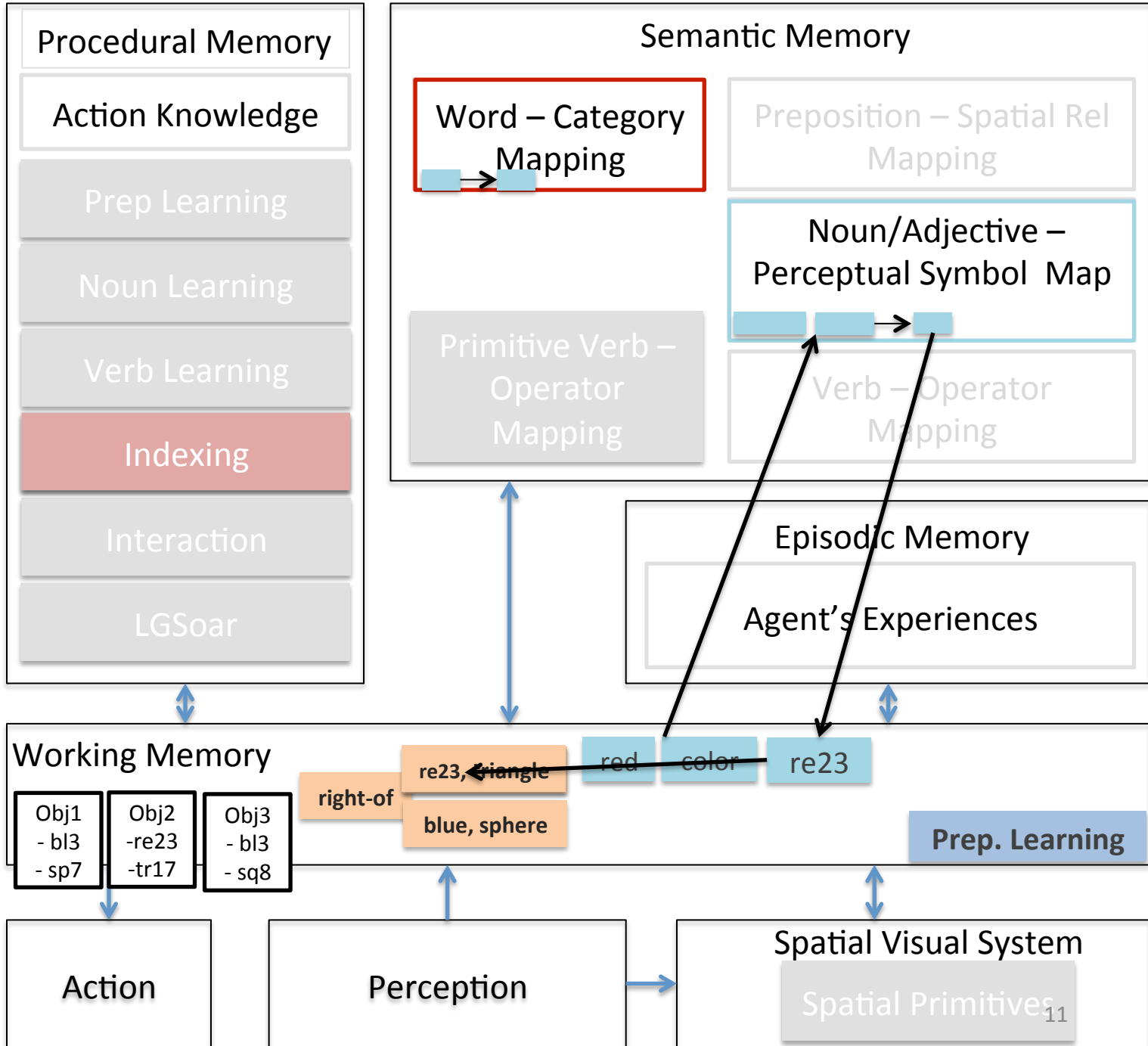
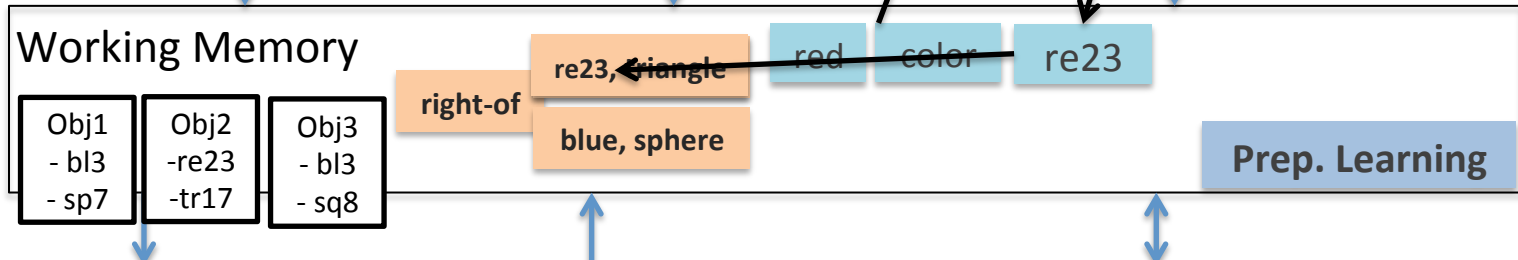
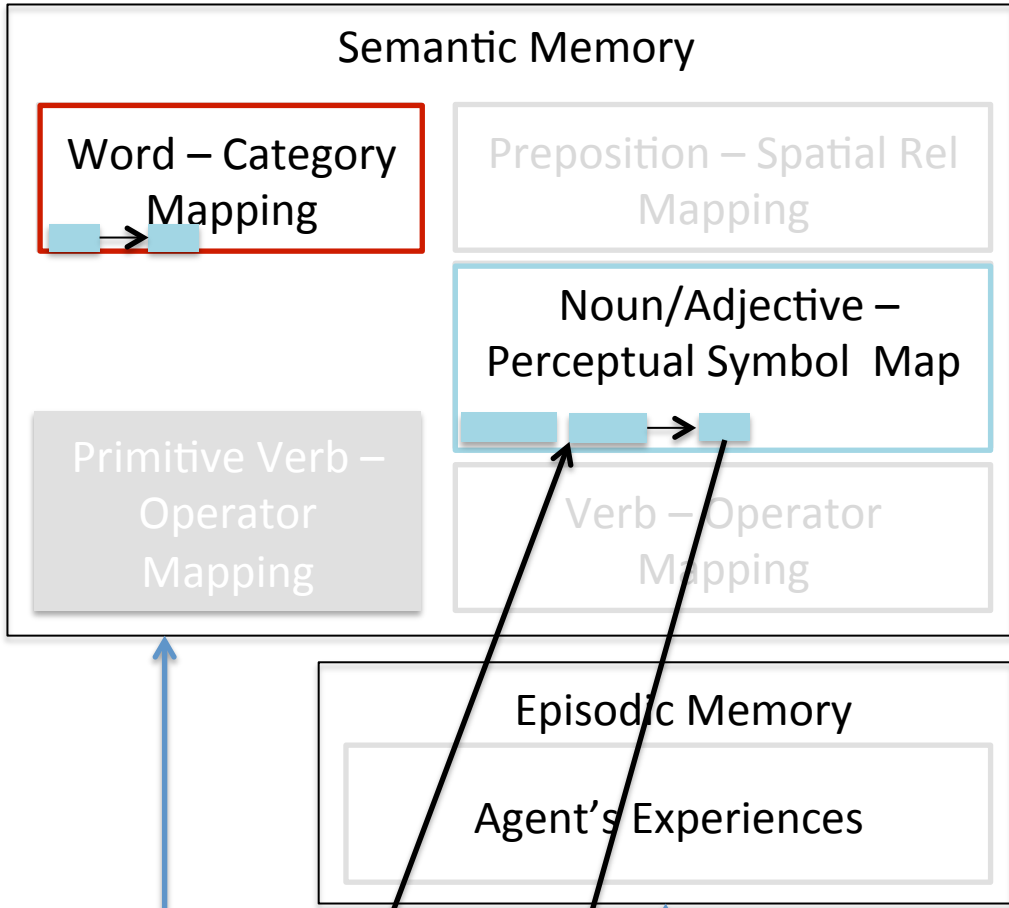
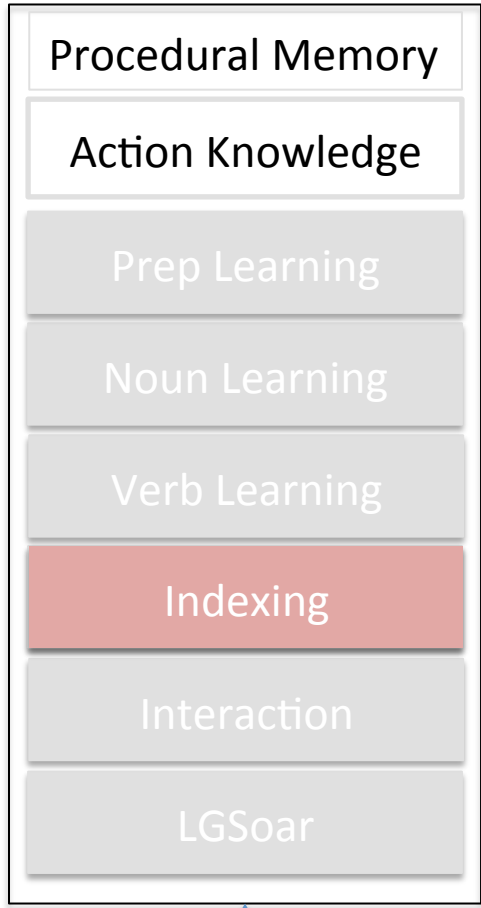
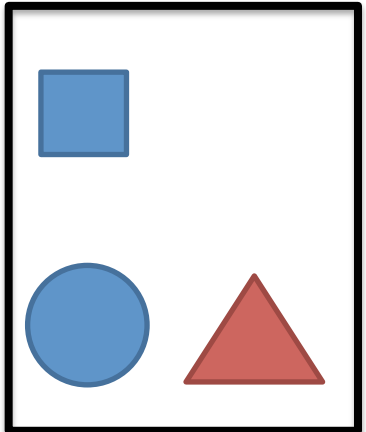
- Lookup the
category of red
from smem



Human:
"The red triangle is
right-of the blue
sphere"

Phase 4
Preposition
Learning

- Lookup the
symbol for red +
color from smem

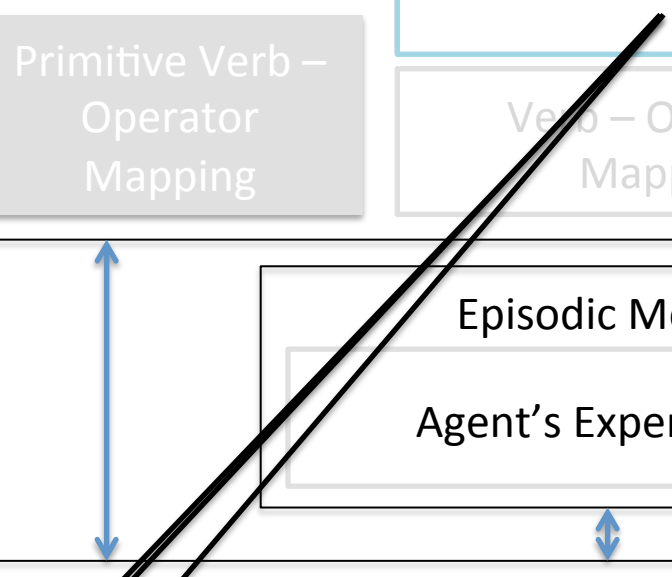
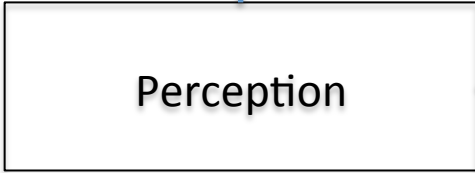
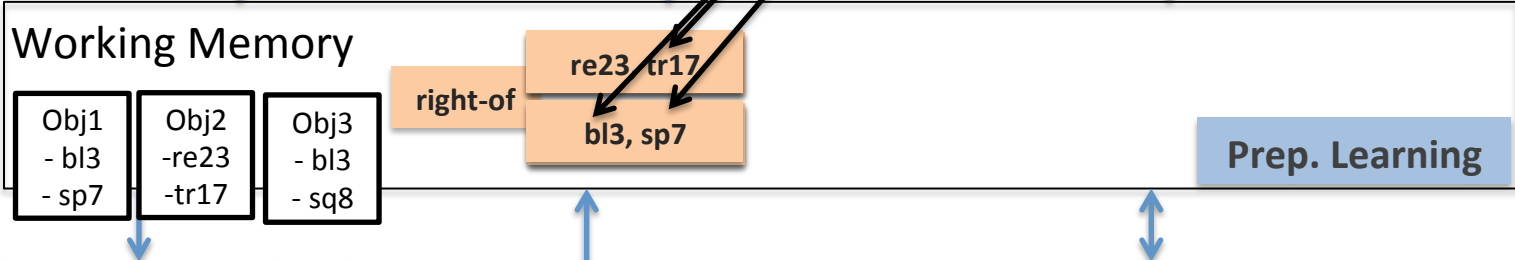
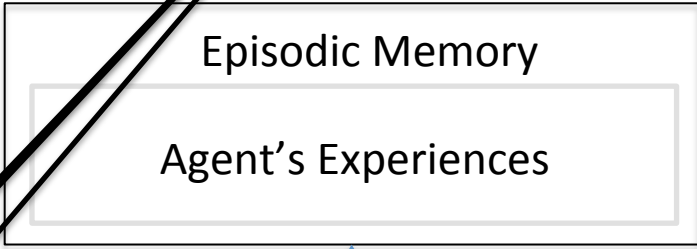
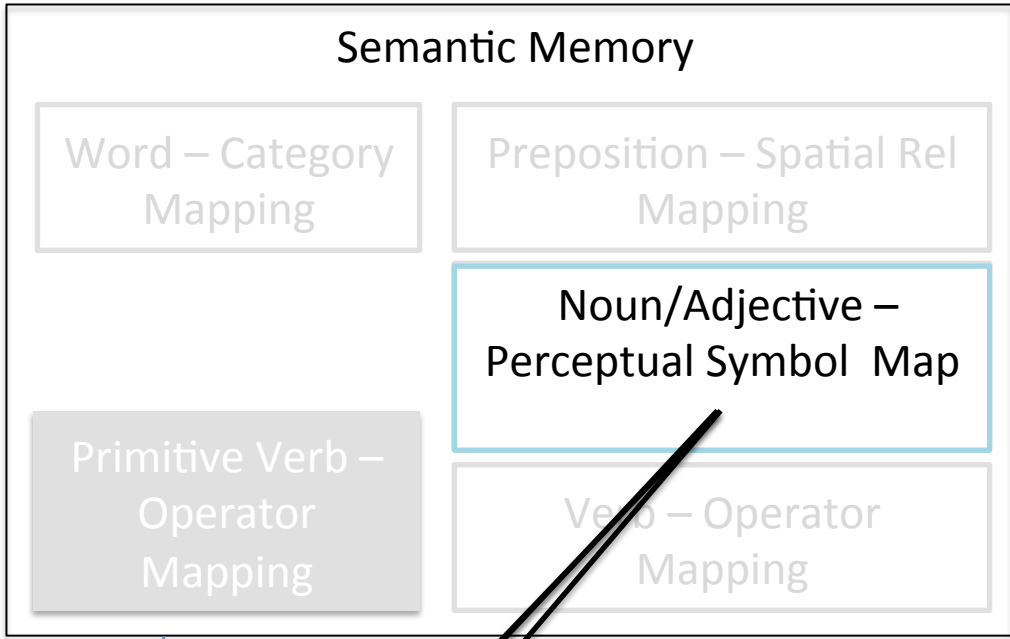
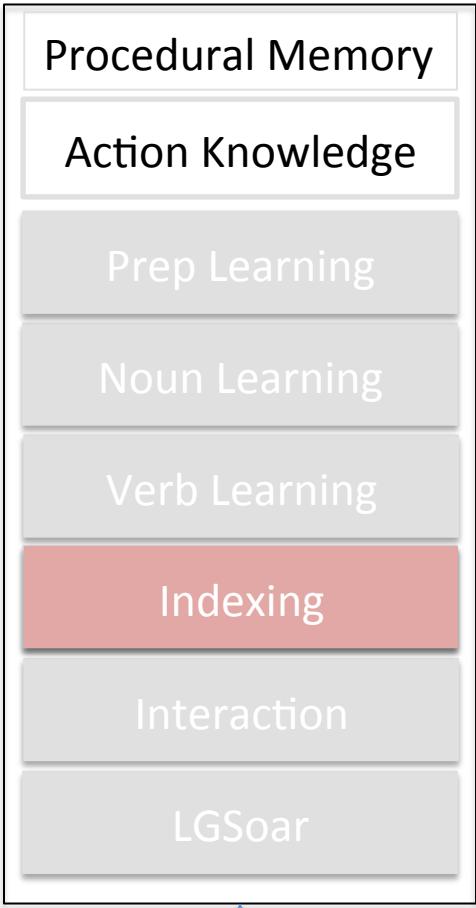
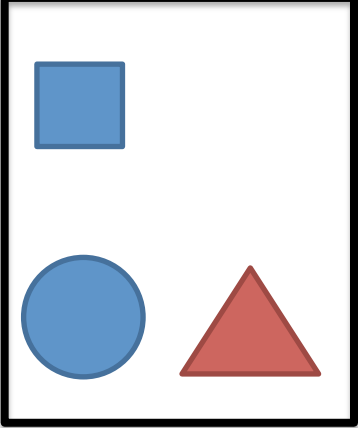


Human:
"The red triangle is
right-of the blue
sphere"

Phase 4

Preposition Learning

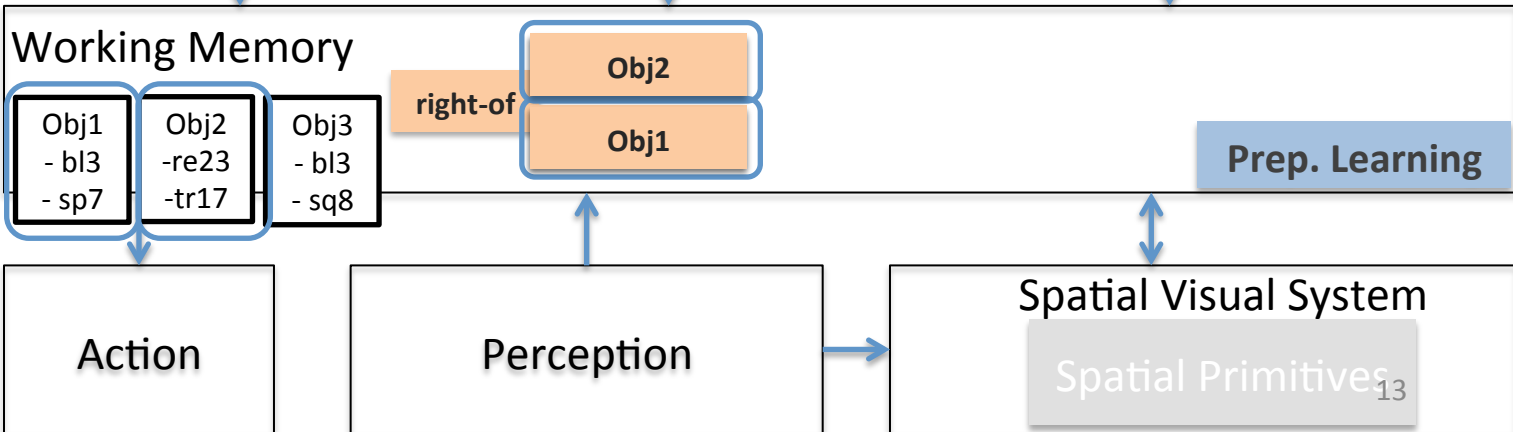
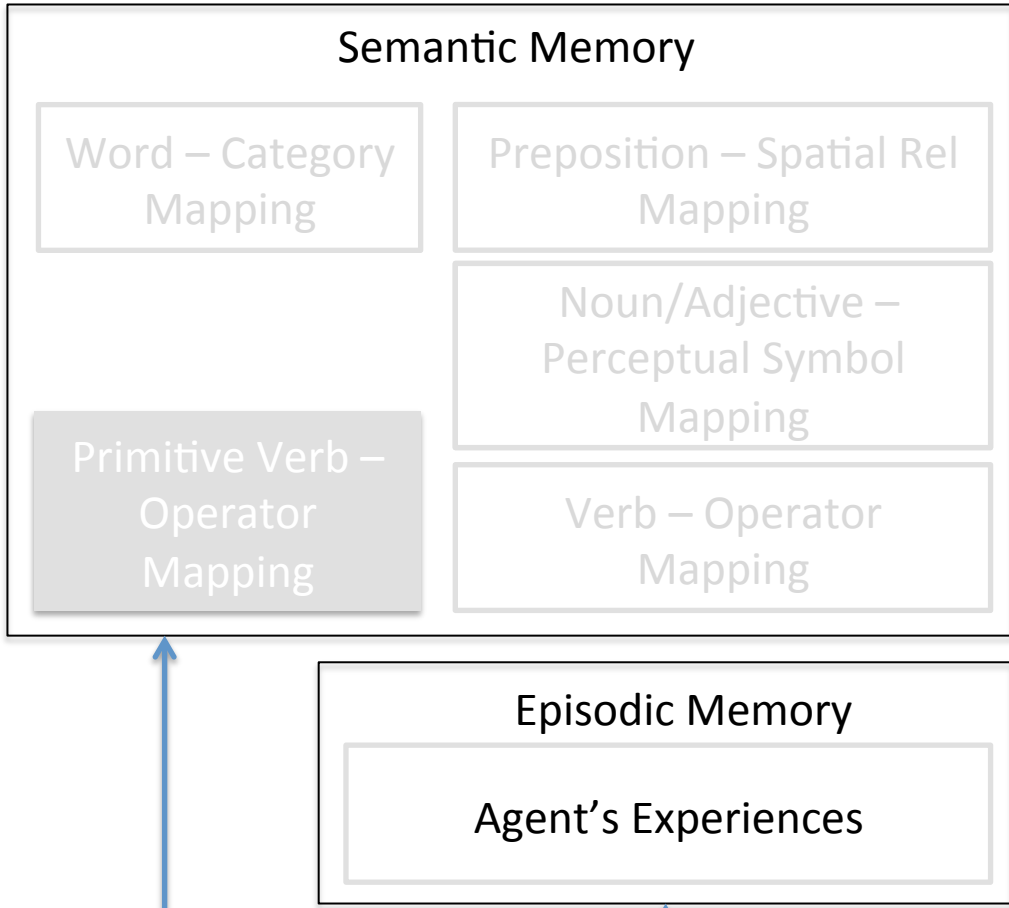
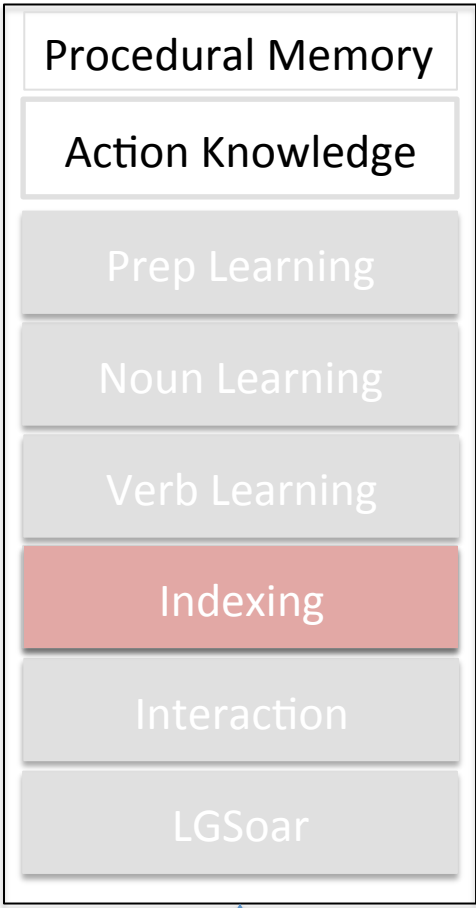
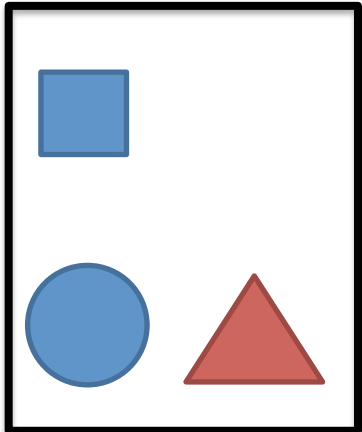
- Update the descriptions with perceptual symbols



Human:
"The red triangle is
right-of the blue
sphere"

Phase 4
Preposition
Learning

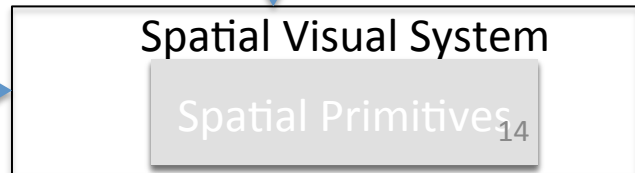
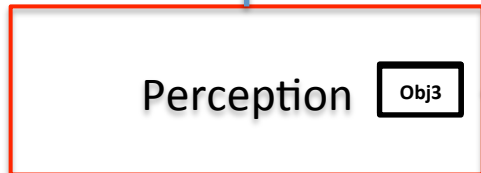
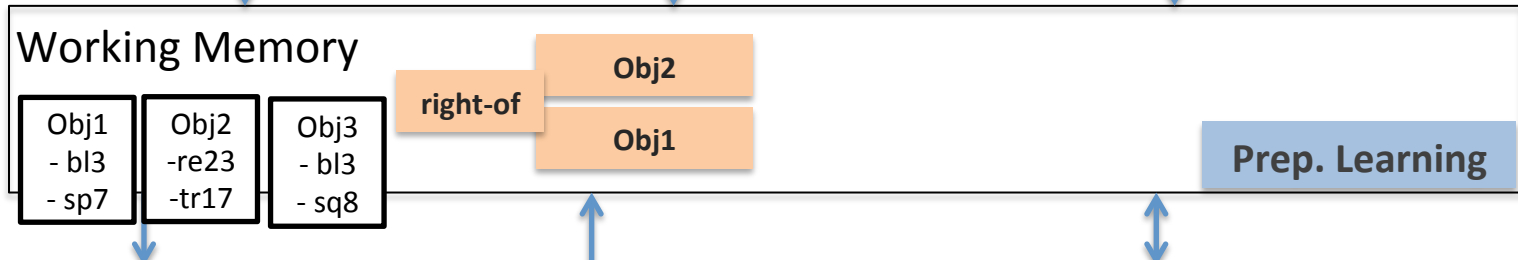
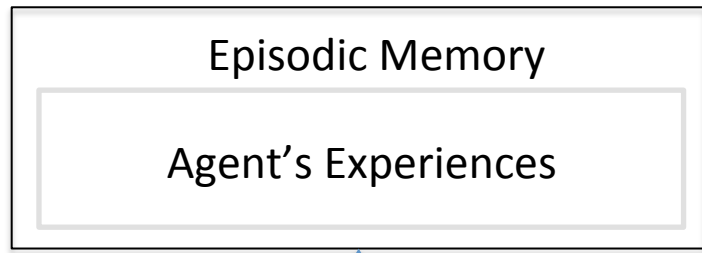
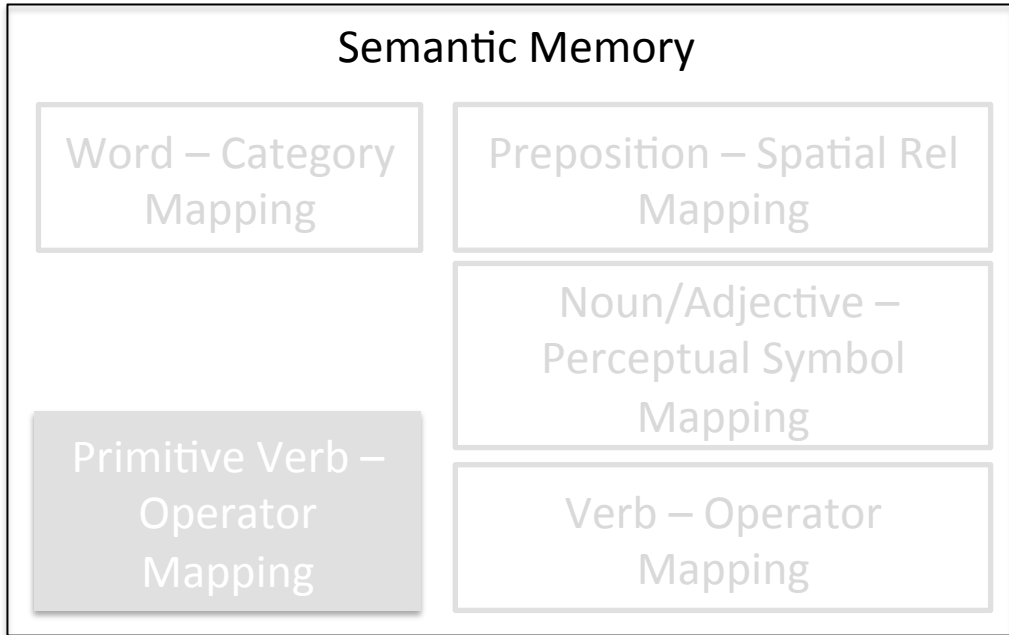
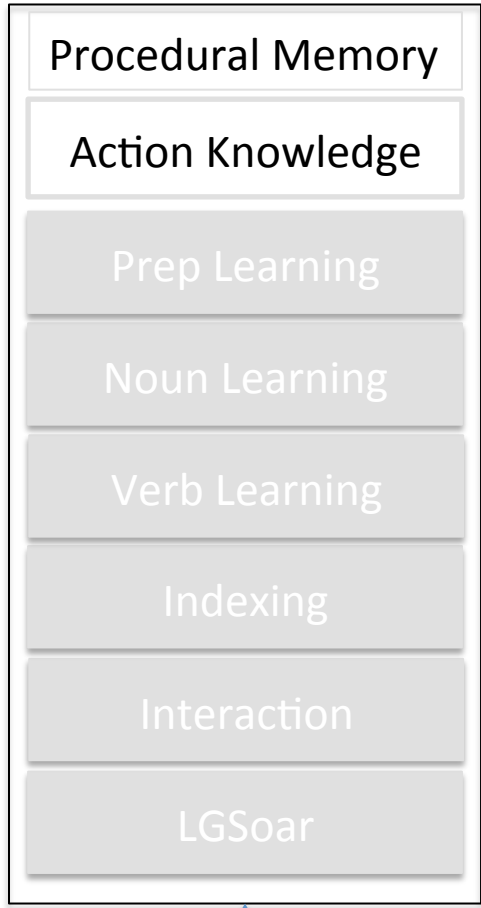
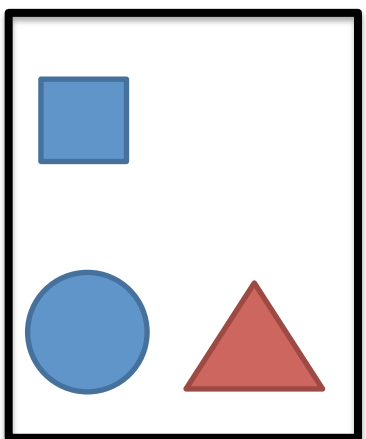
- Look for the
objects matching
the description



Human:
"The red triangle is
right-of the blue
sphere"

Phase 4
Preposition
Learning

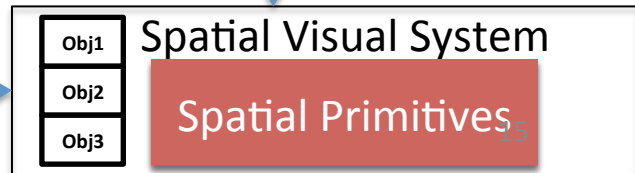
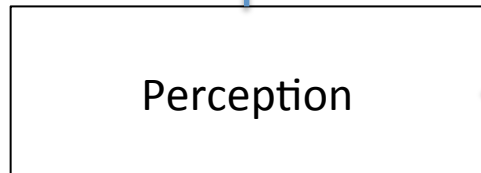
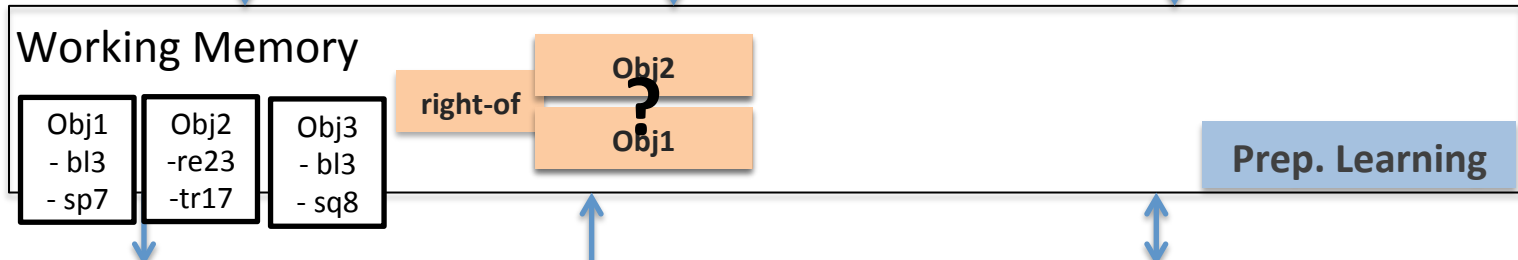
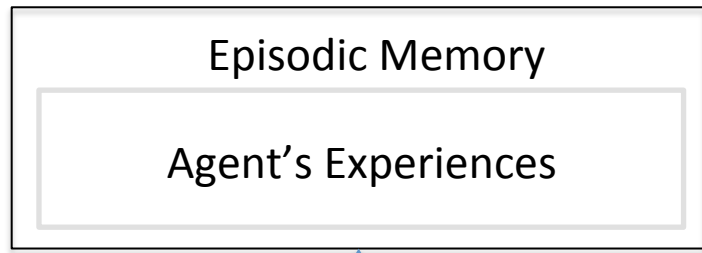
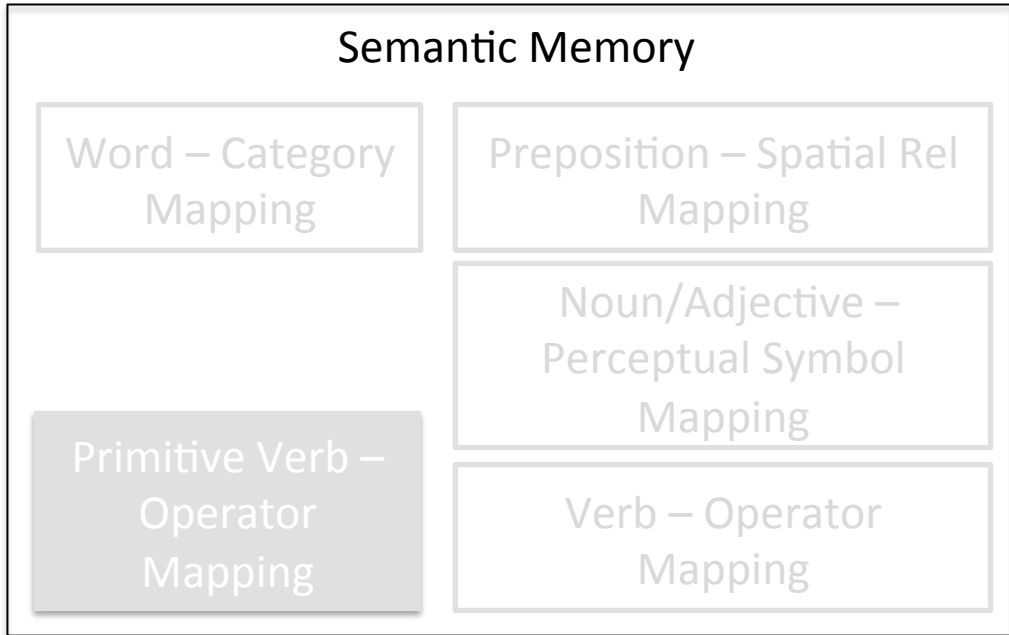
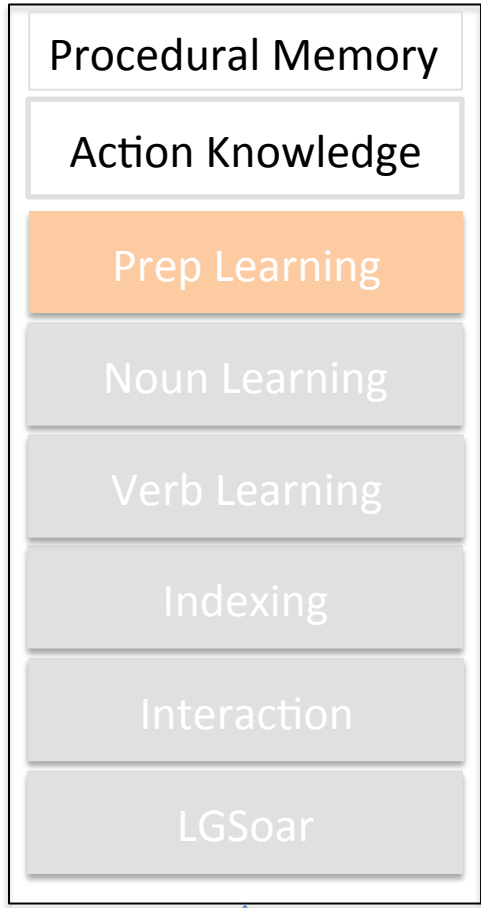
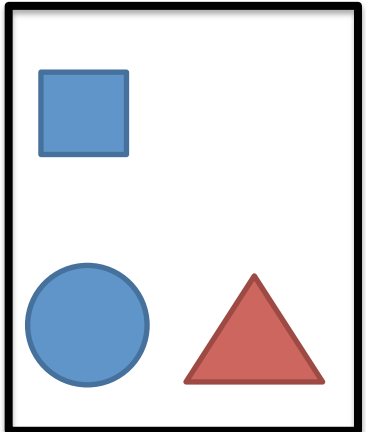
- SVS updates
model of objects
in the world from
the perception
input.



Human:
"The red triangle is
right-of the blue
sphere"

Phase 4
Preposition
Learning

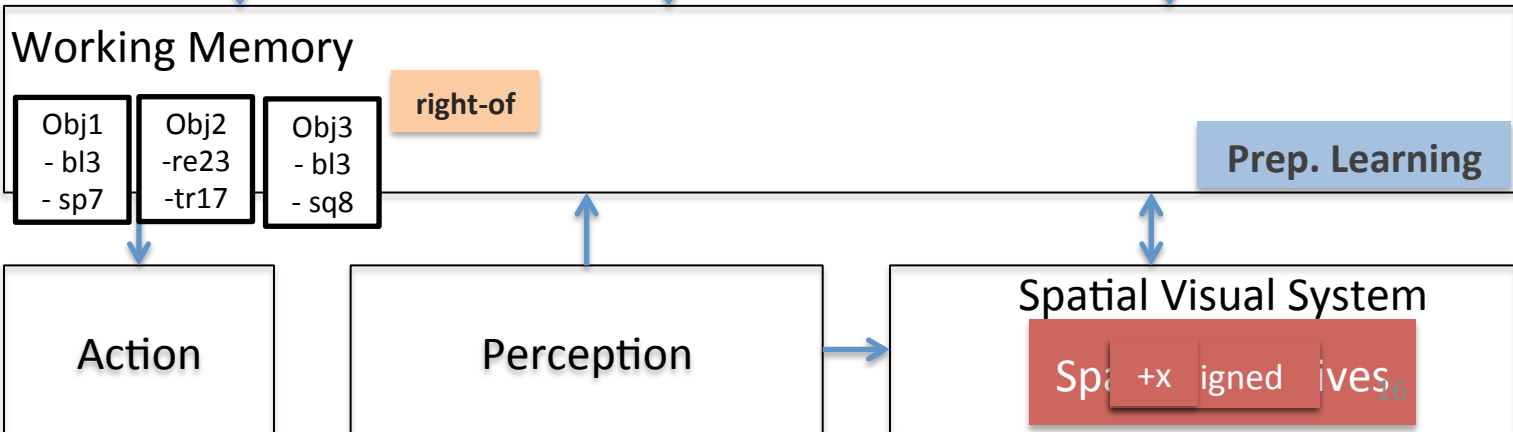
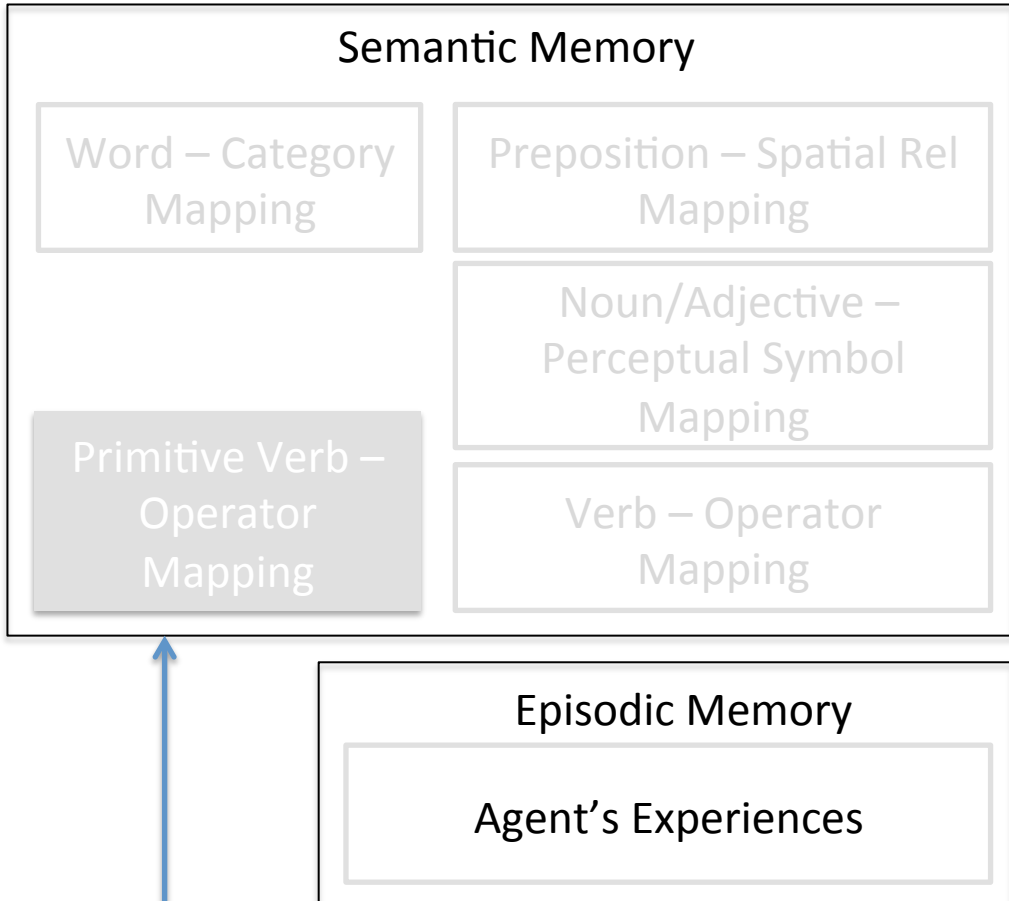
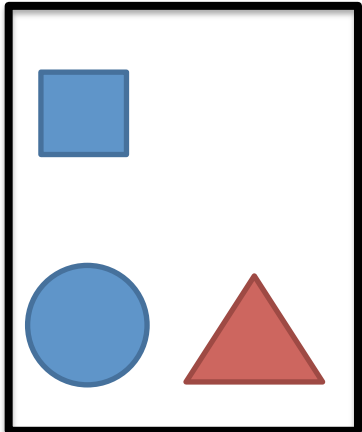
- SVS is queried for primitive spatial relationships between Obj1 and Obj2



Human:
"The red triangle is
right-of the blue
sphere"

Phase 4
Preposition
Learning

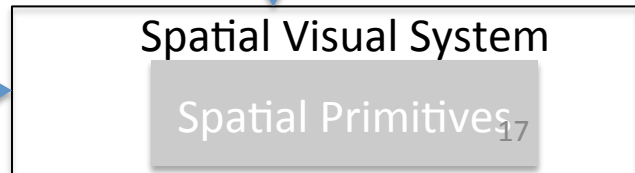
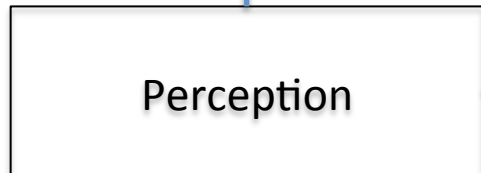
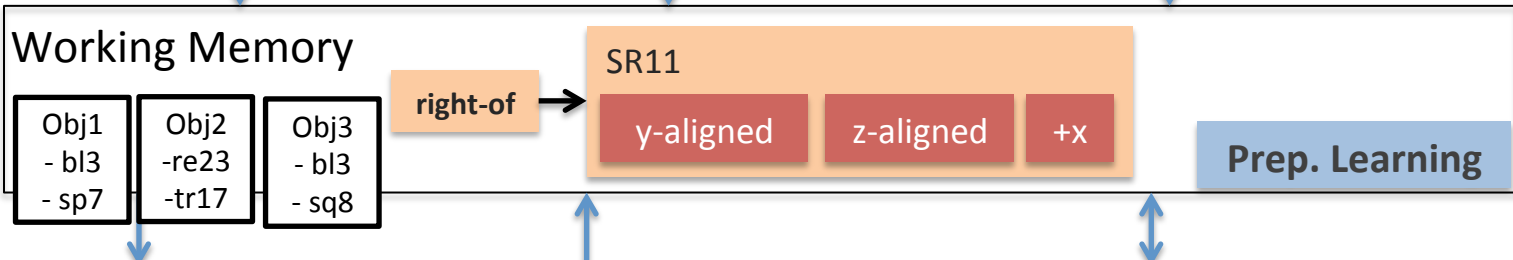
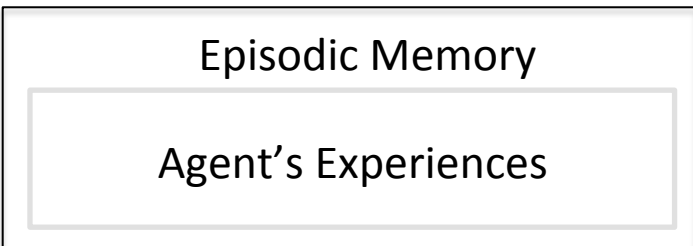
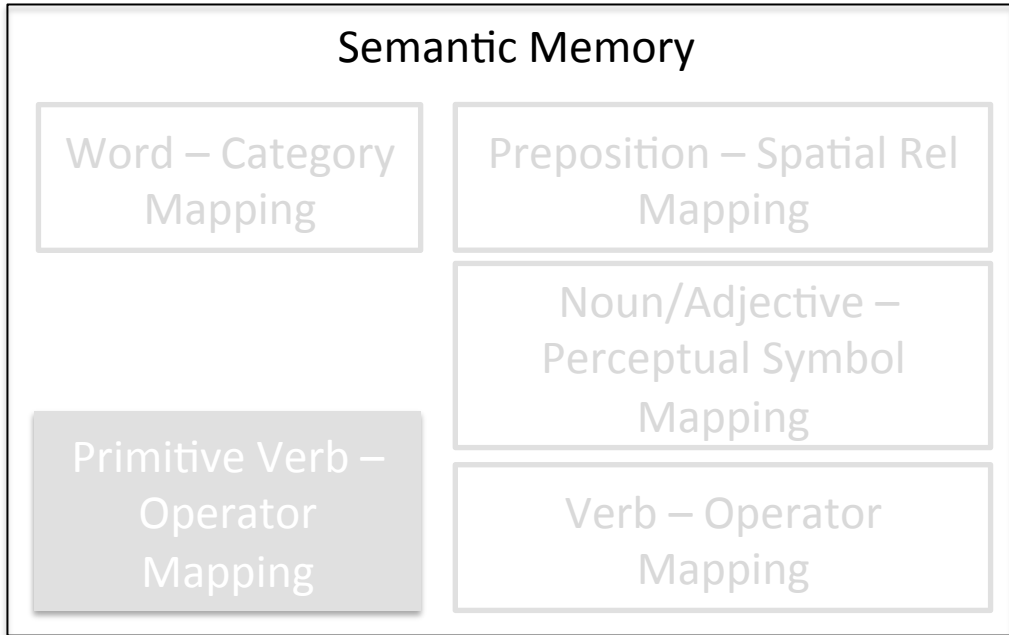
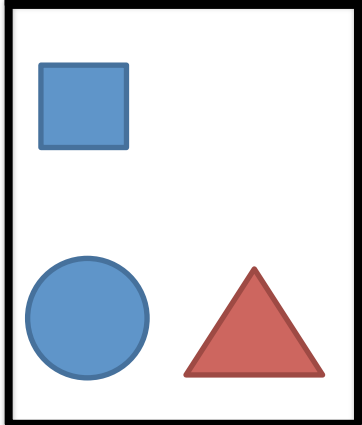
- The results of the query are stored in working memory.



Human:
 "The red triangle is
 right-of the blue
 sphere"

Phase 4
Preposition
Learning

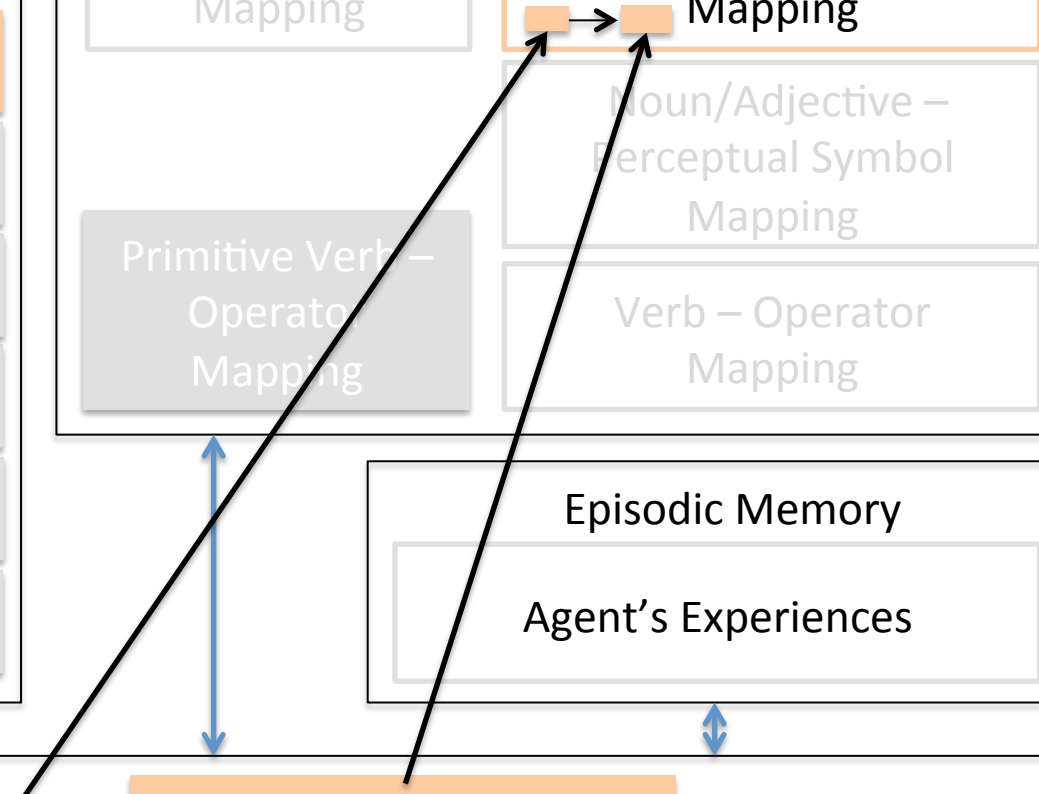
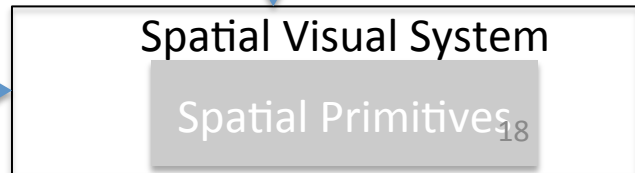
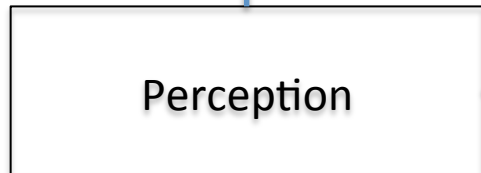
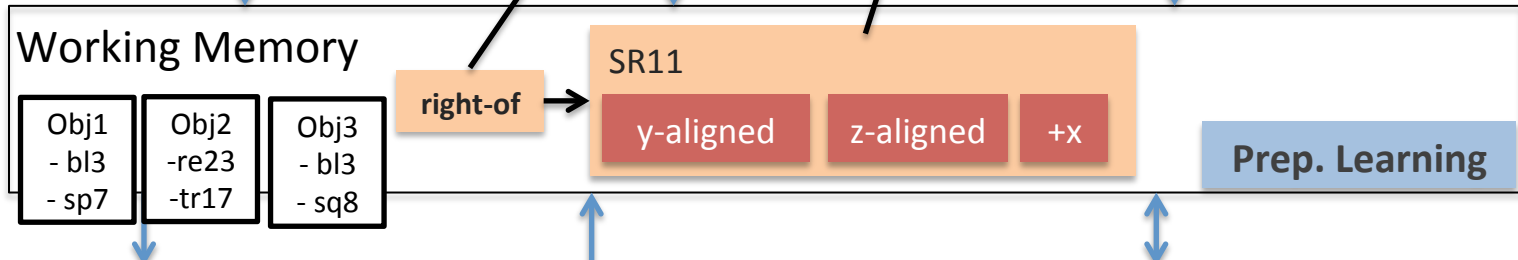
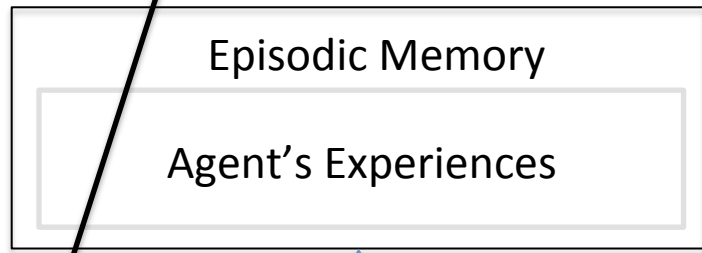
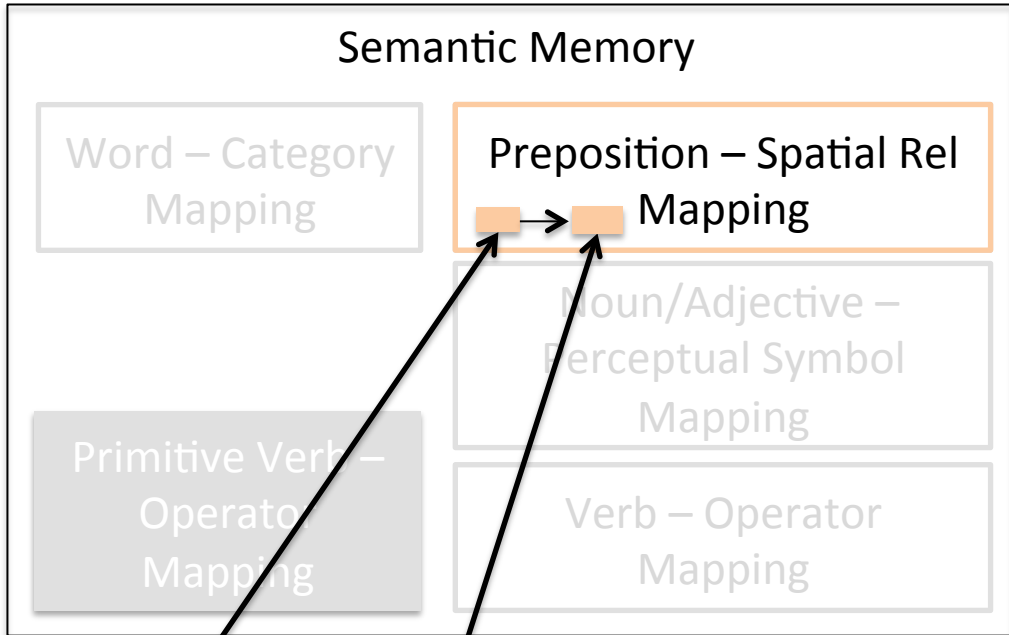
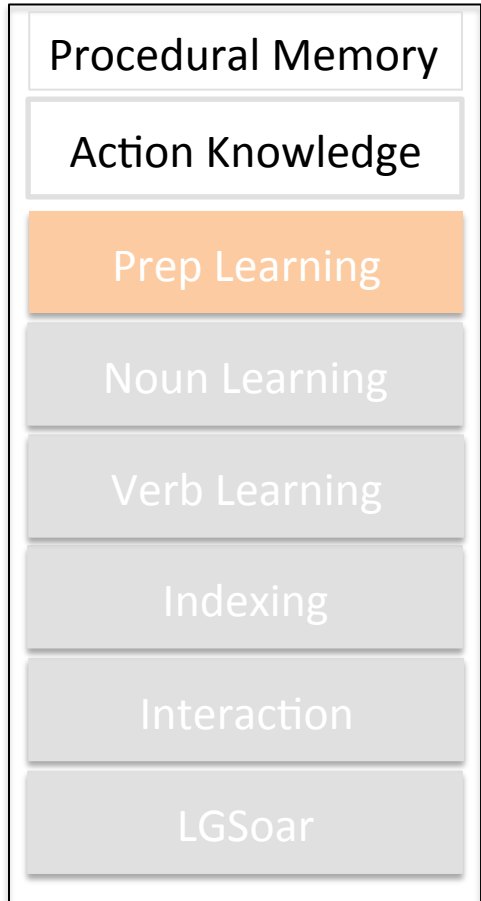
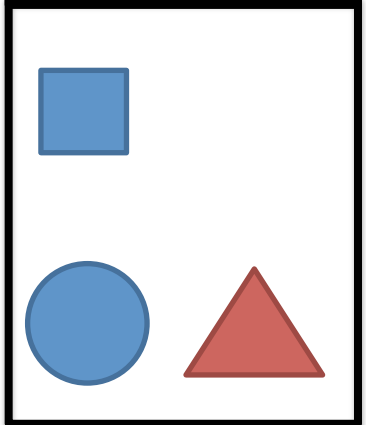
- List of spatial
 primitives are
 abstracted into
 general spatial
 relationship and
 mapped to "right-
 of."



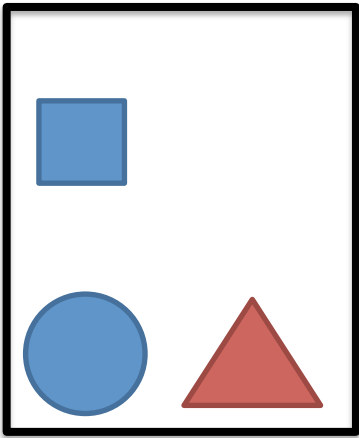
Human:
 "The red triangle is
 right-of the blue
 sphere"

Phase 4
Preposition
Learning

- Learned spatial
 relationship
 mapping to
 "right-of" is
 stored in
 semantic
 memory.



Refining learned knowledge



Is this triangle also to the right of the square?

Disjunctive primitive relationships in training are removed.

Learning is interactive

- Learning can be initiated by instructor or agent

“What is behind the blue sphere?”

- *“I don’t know the preposition behind. Please teach me with examples.”*

“The green square is behind the red triangle.”

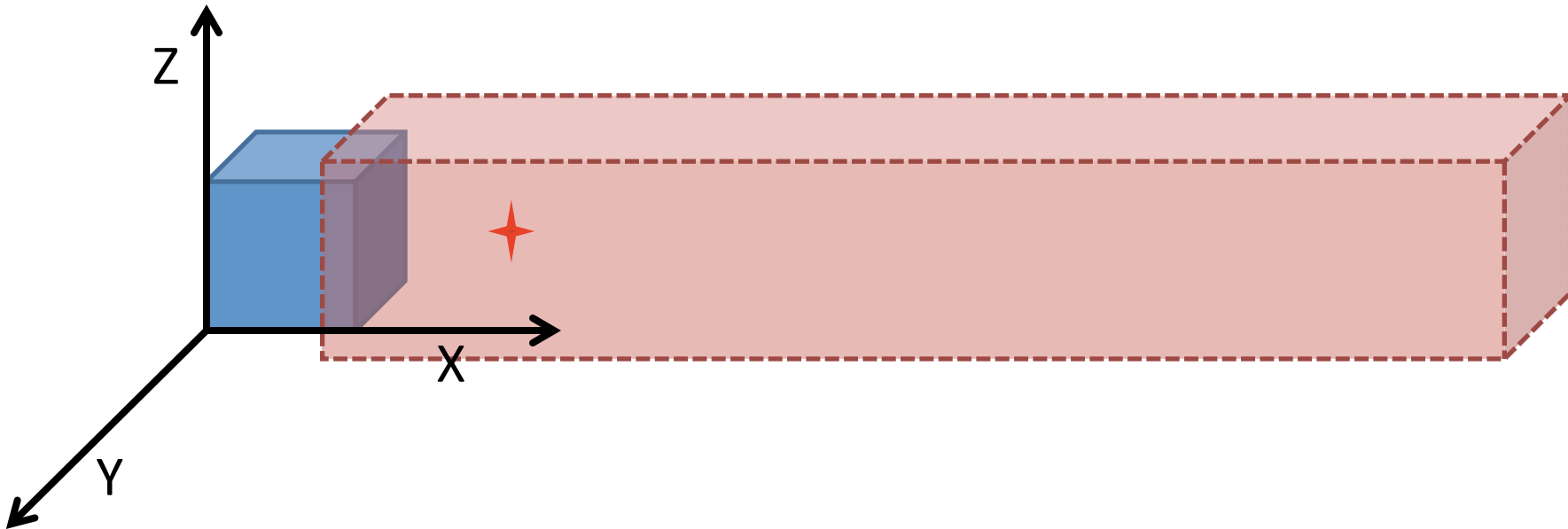
“Finished teaching.”

- *“The blue square is behind the blue sphere.”*

Spatial Projection

“Put the object to the right of the pantry.”

“right of”



Current Uses

- Describing the scene
- Specifying objects in the scene
- Tracking objects and relationships
 - “The goal is that the red triangle is inside the pantry”
- Projecting relationships back to a point in 3D space to perform actions

Evaluation

Nuggets

- Learns very fast
- Works well for simple relationships and projection/tracking

Coals

- Cannot learn complex relationships with many objects
- Cannot learn certain types of relationships such as diagonal
- Not robust to mistakes in training examples

Future Work

- Complex multi-object relationships
 - For example in a line or a circle
- More complex spatial relationships
 - Using distance/contacting etc.
 - Pattern matching (diagonal)
 - Will require more training examples
- Projection with multiple relationships
 - “put this inside the pantry and to the right of the blue object”

Questions?