Using Top-Down Knowledge in Soar to Maintain Object Identity

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Motivation

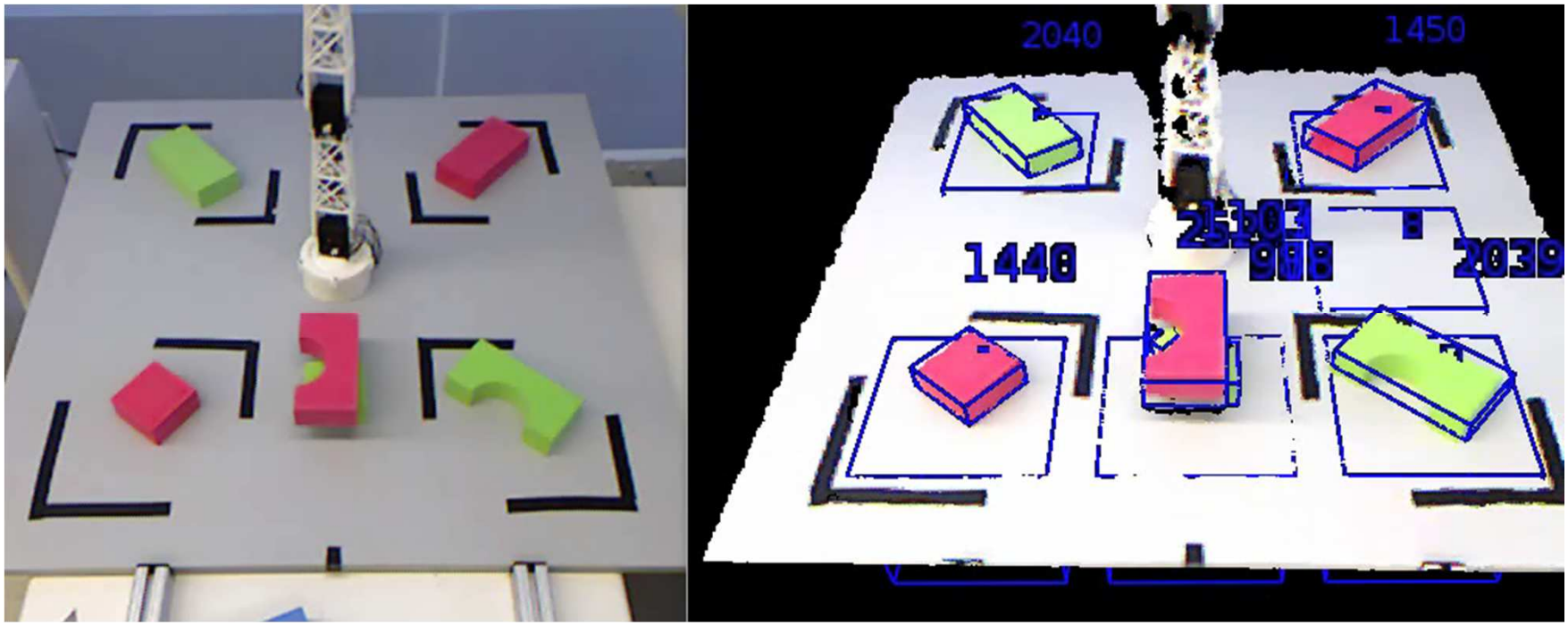
A robotic agent must have an accurate understanding of its environment in order to act, plan, reason, and learn.

Object tracking is vital for tasks which require maintaining information about the objects over time

Object Tracking Challenges

- Partial/Total Occlusions
- Bad Segmentations
- Displacement during occlusions
- Non-rigid deformations and appearance changes
- Object Movement

Addressed in this work

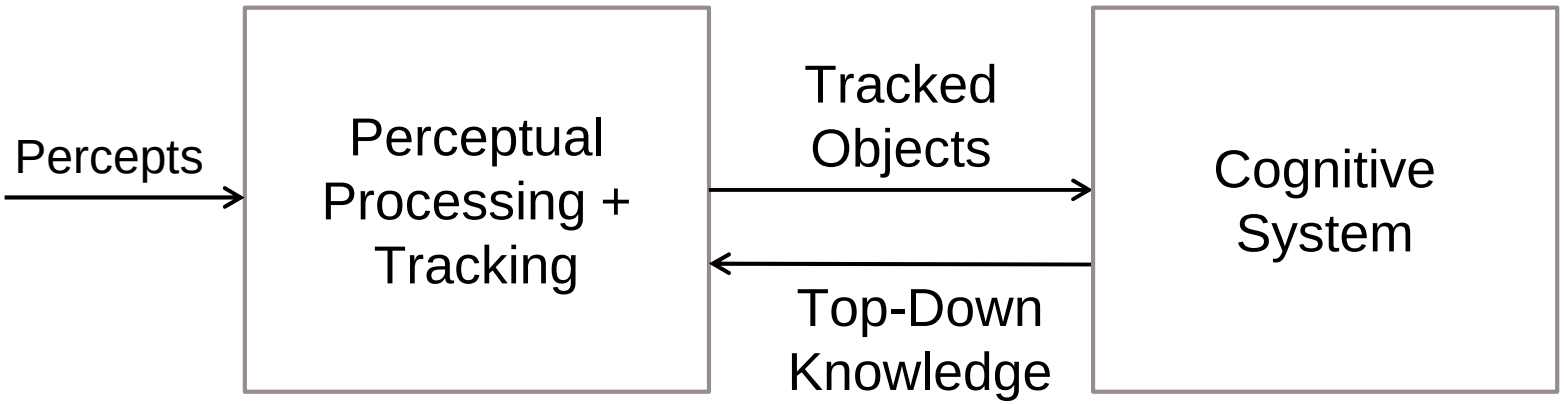


Research Claim

A Cognitive System can be a good source of top-down knowledge for object tracking in a robotic system:

- Beliefs about the world
- Knowledge about actions it takes
- Reasoning about the current situation
- Information from human interaction

Accurate and robust while remaining efficient



Our Approach

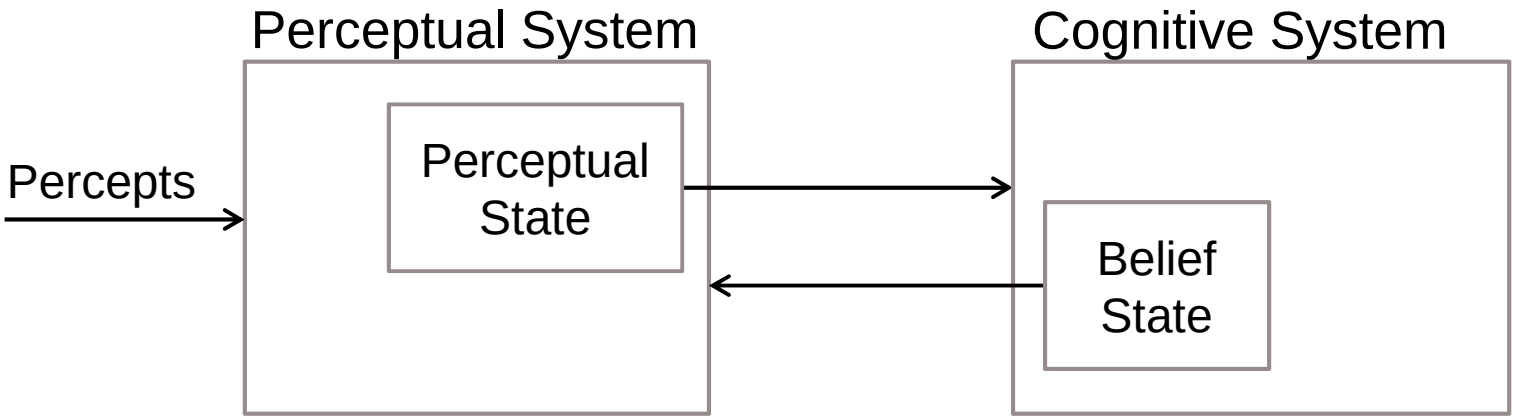
Two representations of the state of the world

Perceptual State

- Maintained by perception
- What the agent currently perceives

Belief State

- Maintained by the cognitive system
- What the agent believes to be true about the world



Belief Maintenance

Belief State

- Independent representation of the world maintained by the cognitive system
- Provides a stable and accurate view
- Used for reasoning and planning in other tasks

Belief Maintenance

The cognitive system brings many different sources of knowledge to bear when maintaining its belief

- What issues can arise and how to detect/resolve them
- How the actions it performs impact the world
- What regularities exist in the environment

Belief Maintenance

Three Steps for Maintenance

- *Detect* when belief is no longer consistent
- *Evaluate* the situation to determine the cause
- *Reconcile* belief and perception

Detection

The agent compares belief and perception

- SVS: monitor volume and position
- WM: monitor properties and number of objects

Detectors

- new-object
- stale-object
- moved-object
- shrunken-object
- grown-object
- changed-property

Discrepancy Evaluation

Evaluate why a detector was triggered

- Use SVS to find out more information

Causes:

- Added Object/Removed Object
- Noise/Tracking Errors
- Over-Segmentation/Under-Segmentation
- Occlusion
- Property Changes
- Position and Size Changes

Discrepancy Evaluation

Occlusion

Cause

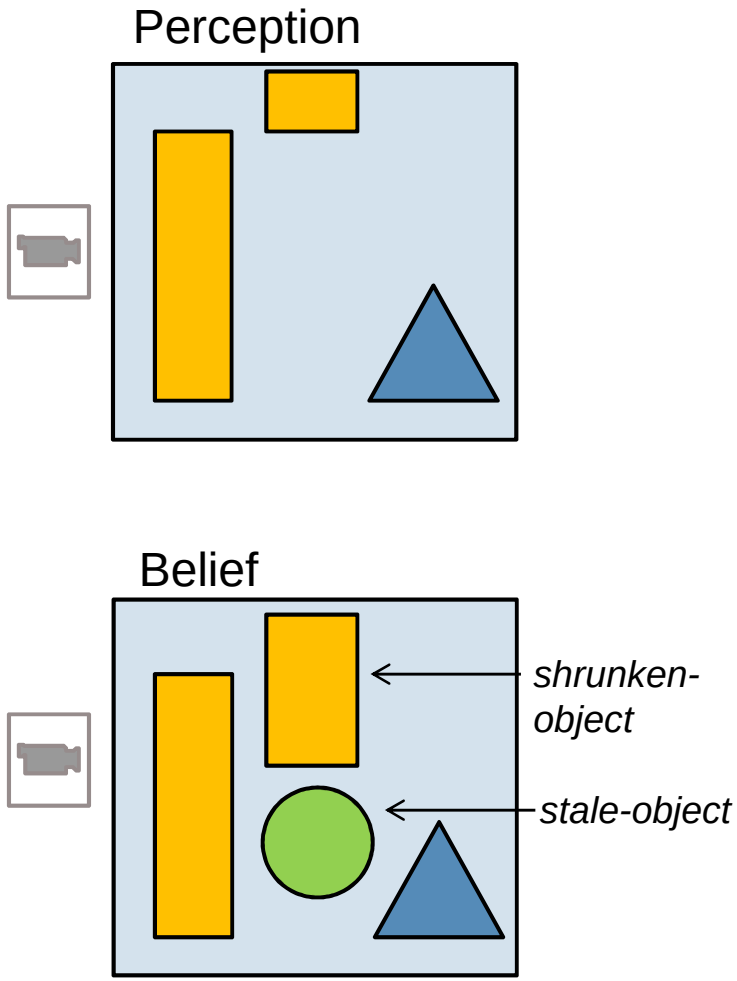
- One object is placed in front of another, obscuring it

Detectors

- *shrunken-object* for partial occlusion
- *stale-object* for total occlusion

Evaluation

- Check to see if the shrunken object is being occluded
- SVS filter *occlusion*



Reconciliation

Once the cause has been identified, it is usually straight-forward to resolve it

- Update the belief state
- Ignore the detector

Moving Objects

- When moving an object, Soar projects the object to where it expects to put it down
- Perception will match the projected object
- If the object doesn’t appear, the agent tries to match it to all new object

Evaluation - Task

Demonstrate end-to-end performance in a task that requires reliable object tracking

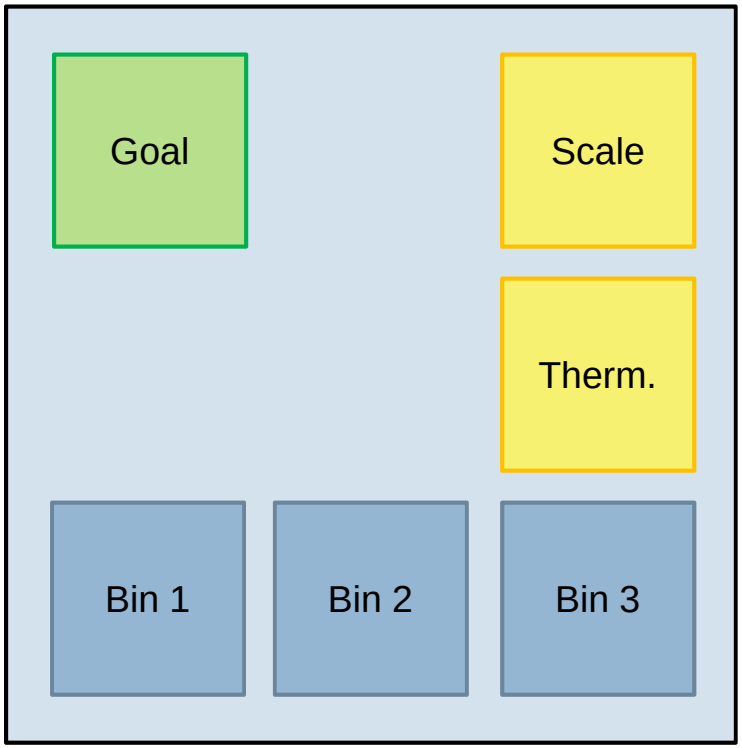
Find-object task:
The system is asked to find an object with a specified property

Find a red object
Find a hot object
Find the heaviest object

Evaluation - Environment

Locations

- Bins
  - Used for storing objects
- Goal
  - Where the found obj is placed
- Scale
  - Used to measure weight
- Thermometer
  - Used to measure temperature



Evaluation - Agents

- **A1**: **Perception Only**
  Belief state is an exact copy of perception
- **A2**: **+ Action Knowledge**
  Agent assists in tracking moved objects
- **A3**: **+ Object Permanence**
  Agent maintains independent belief for all objects
- **A4**: **+ Segmentation Reasoning**
  The agent will reason about segmentation errors

Evaluation - Setup

Same script with 18 commands in each test

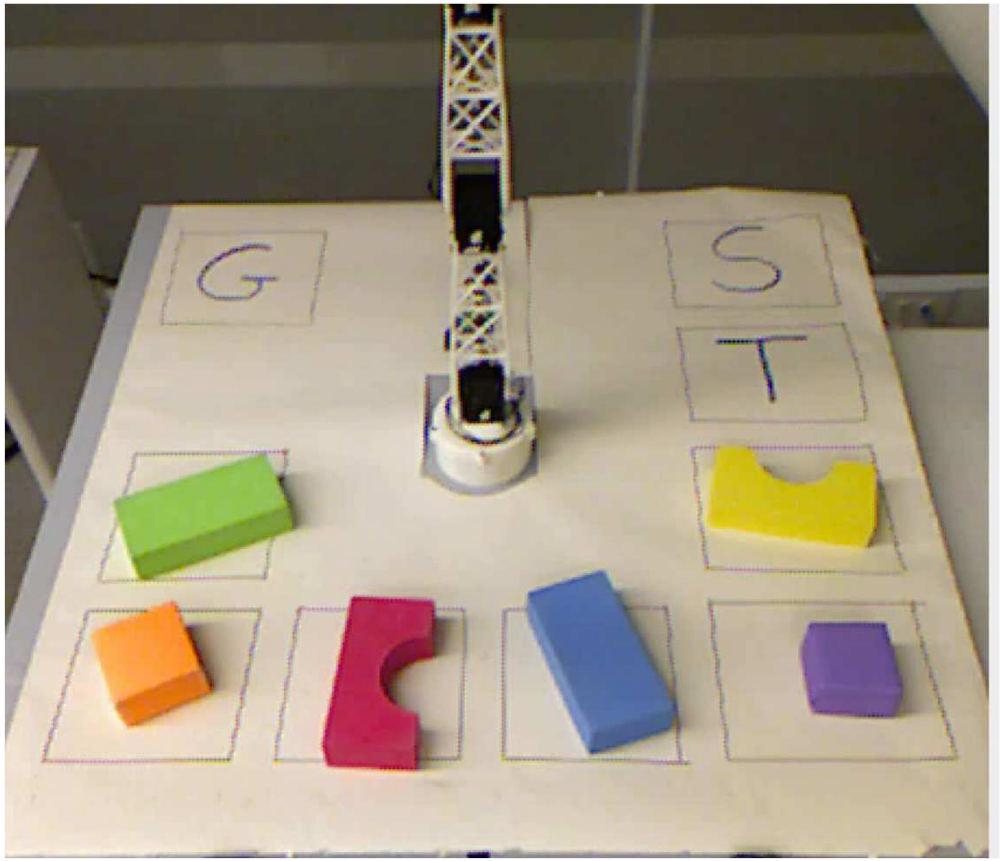
	Weight Superlative	Color Perceptual	Weight Measurable	**Temperature Superlative**	Shape Perceptual	Temperature Measureable
1	**Heaviest**	Red	Light	**Hottest**	Rectangle	Cool
2	**Lightest**	Green	Heavy	**Coldest**	Arch	Hot
3	**Heaviest**	Blue	Light	**Hottest**	Square	Cold

Measure the number of movements per command
Failure: Give up after 16 measurements
Failure: Incorrect block is found

Evaluation – Domain 1

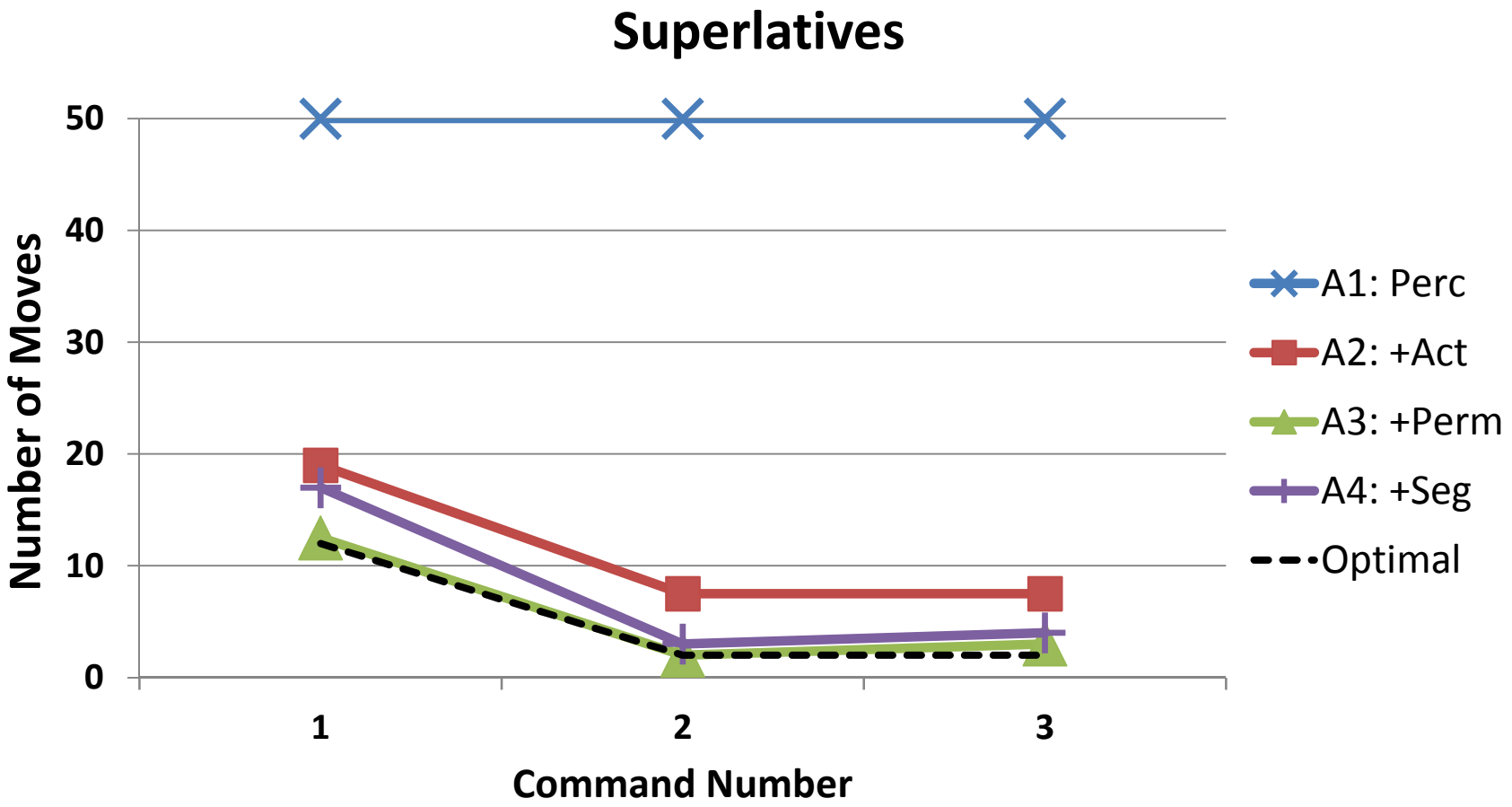
D1: No Occlusion

6 bins and 6 objects (different colors)



Evaluation – Domain 1

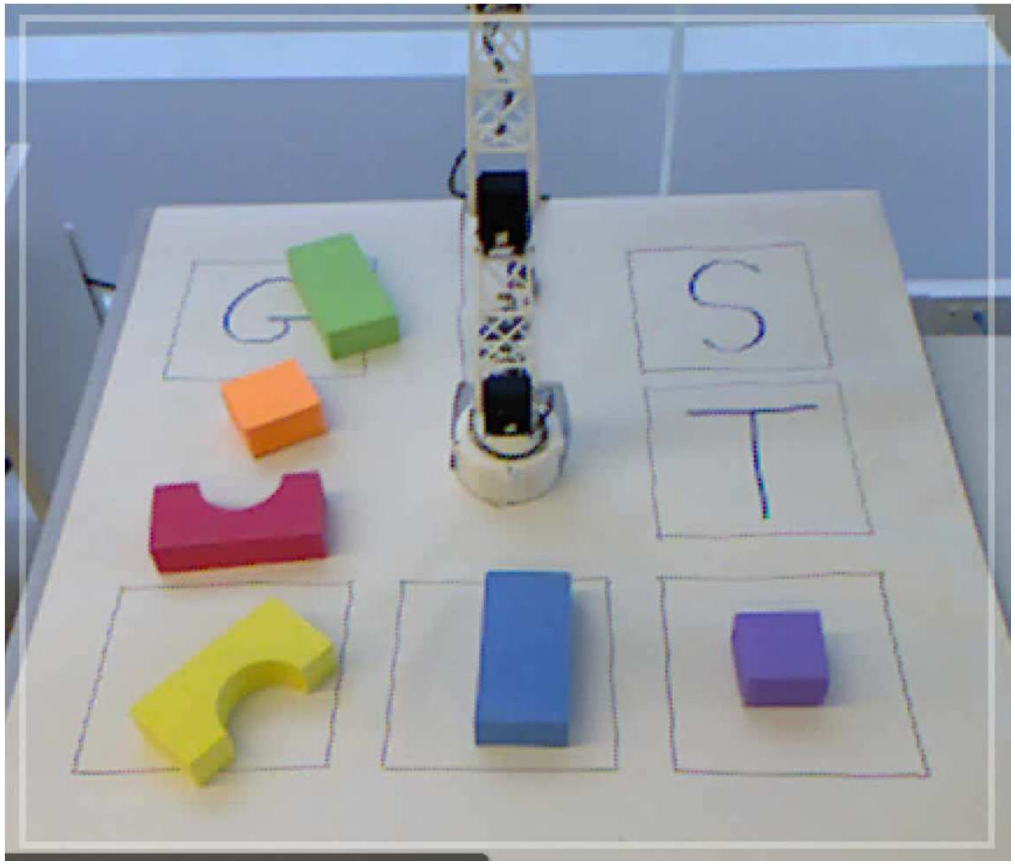
D1: No Occlusion



Evaluation – Domain 2

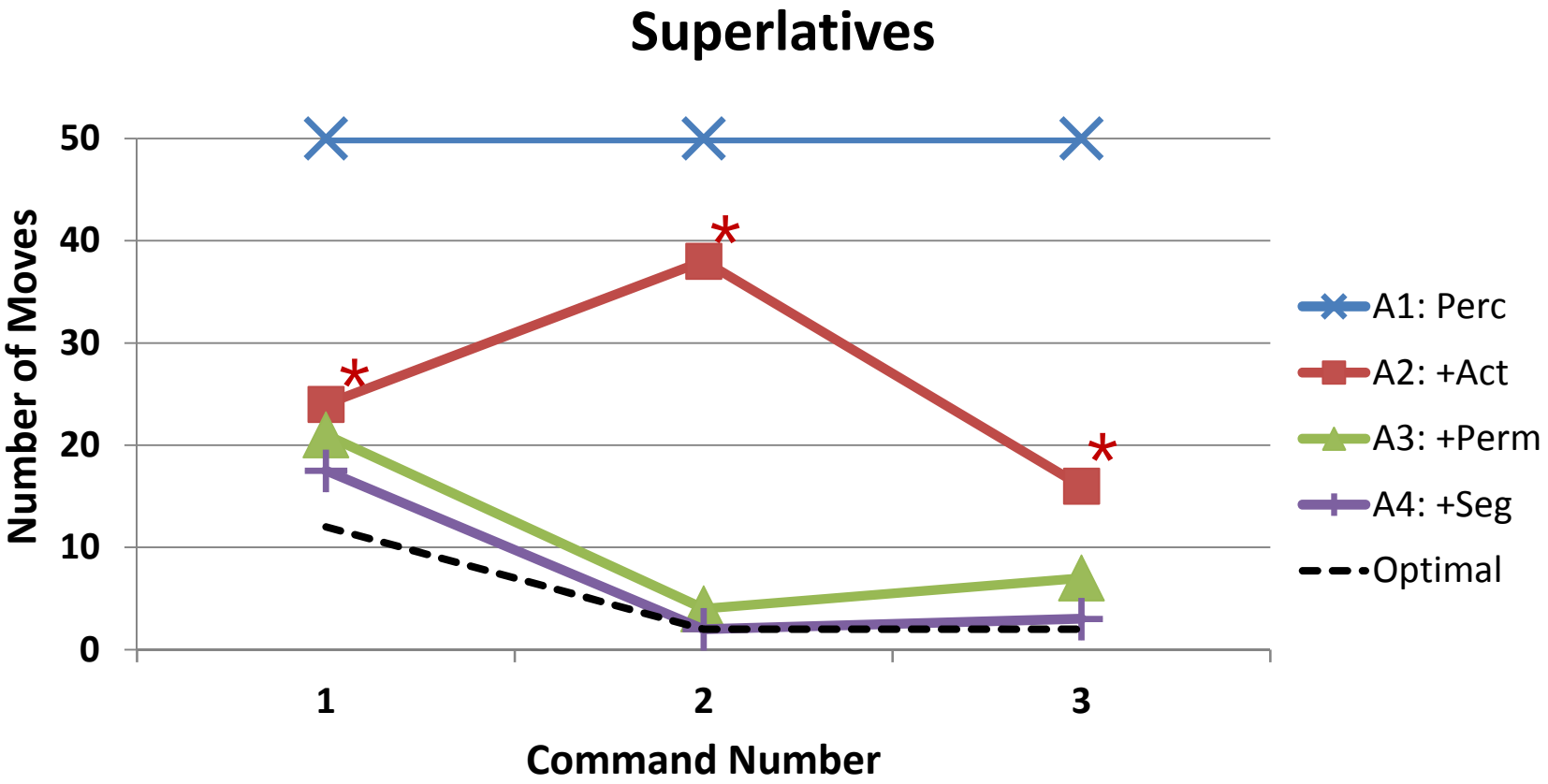
D2: Partial Occlusion

3 bins and 6 objects (different colors)



Evaluation – Domain 2

D2: Partial Occlusion



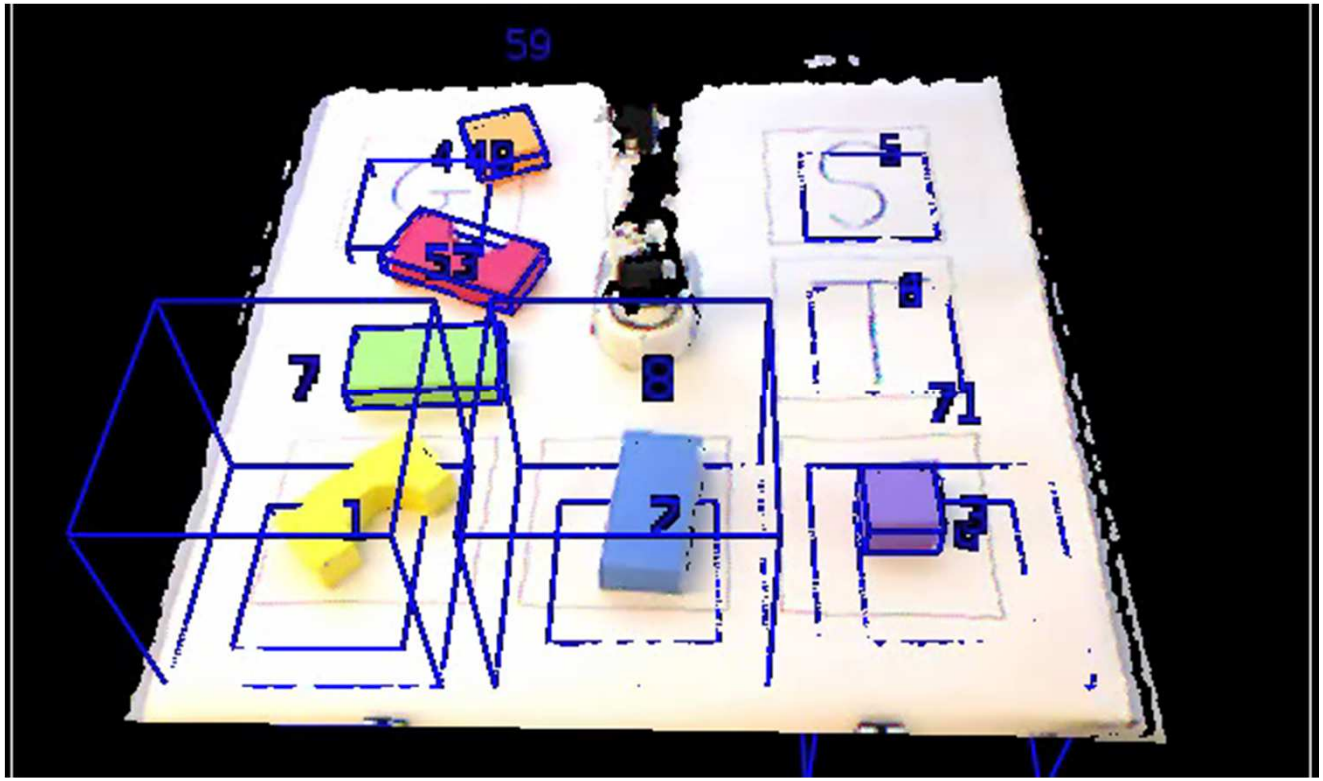
* Each point with an asterisk represents 1 success and 1 failure

Evaluation – Domain 3

D3: Total Occlusion

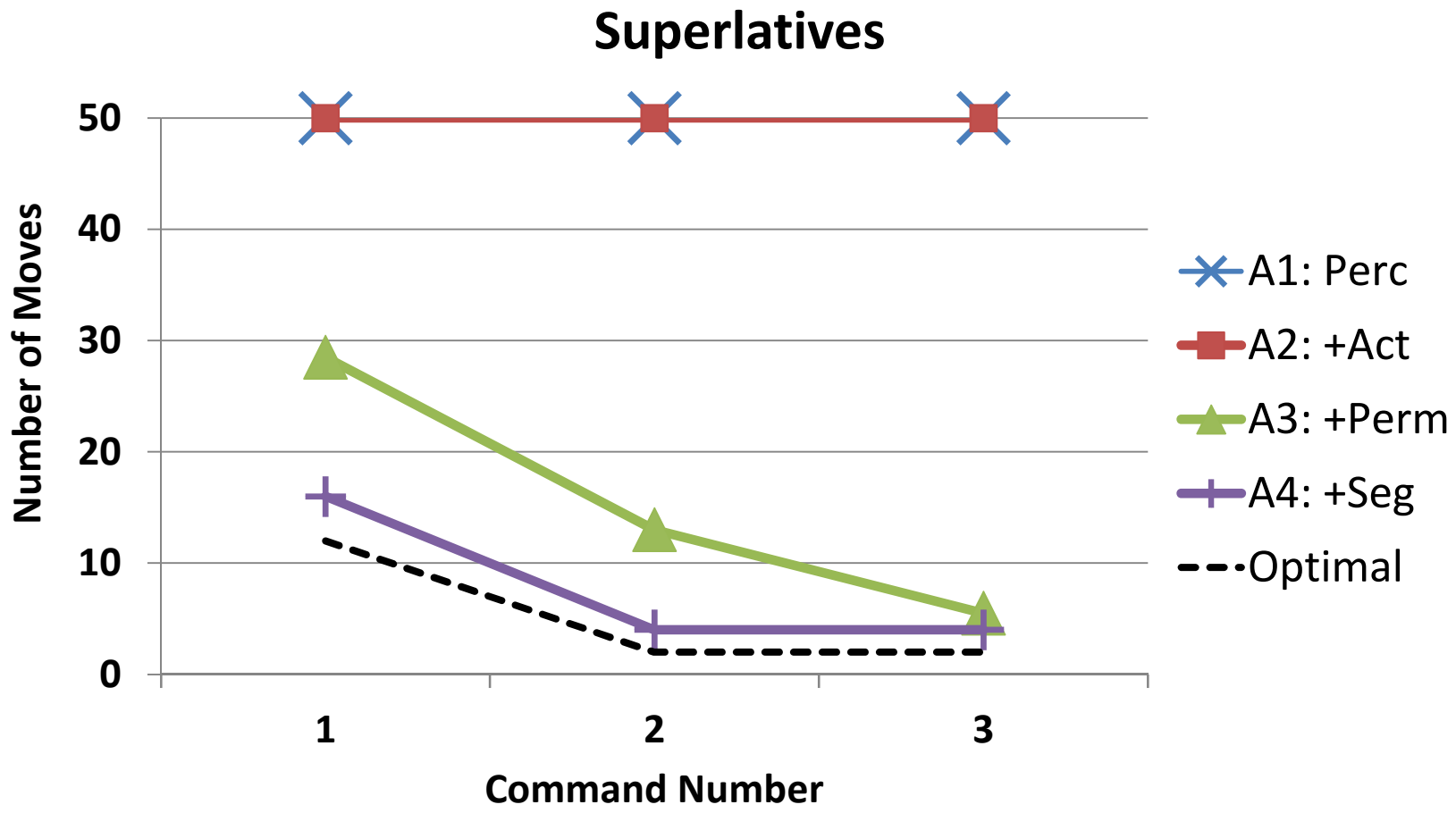
3 bins and 6 objects (different colors)

Only able to view 1 bin at a time



Evaluation – Domain 3

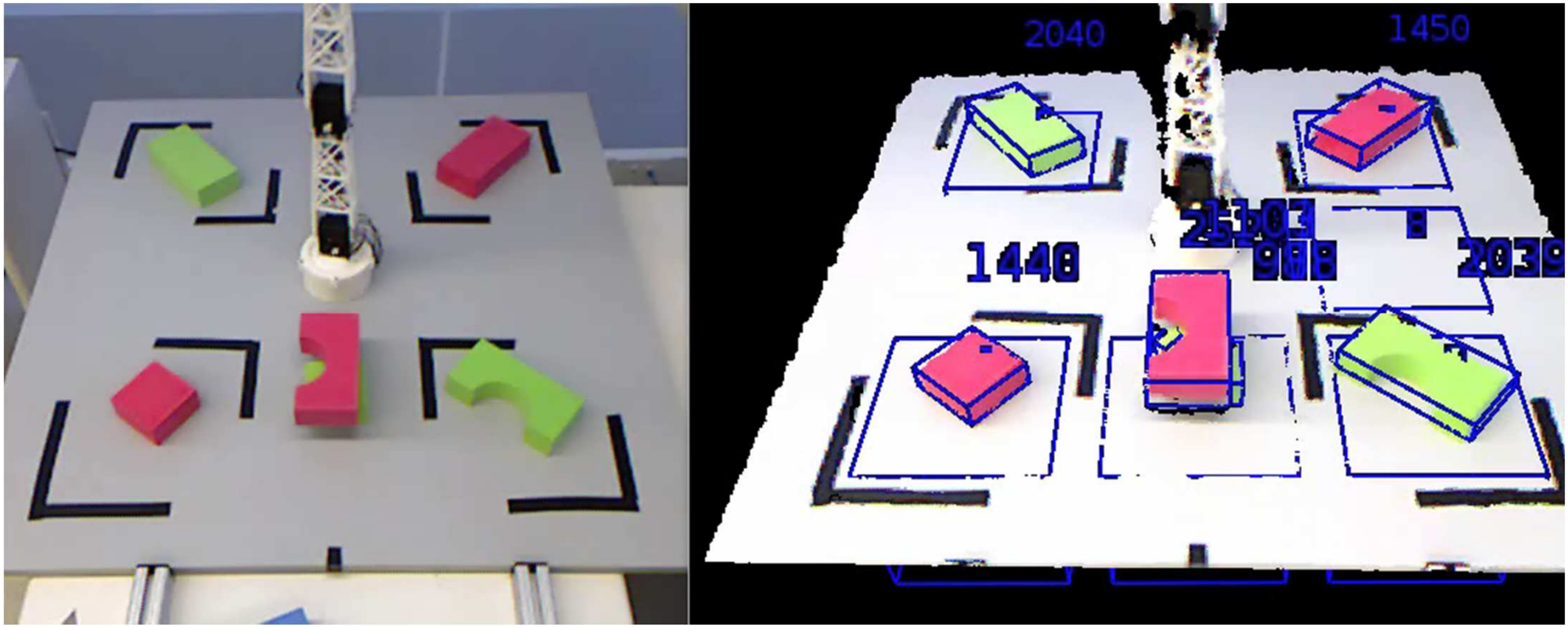
D3: Total Occlusion



Evaluation – Domain 4

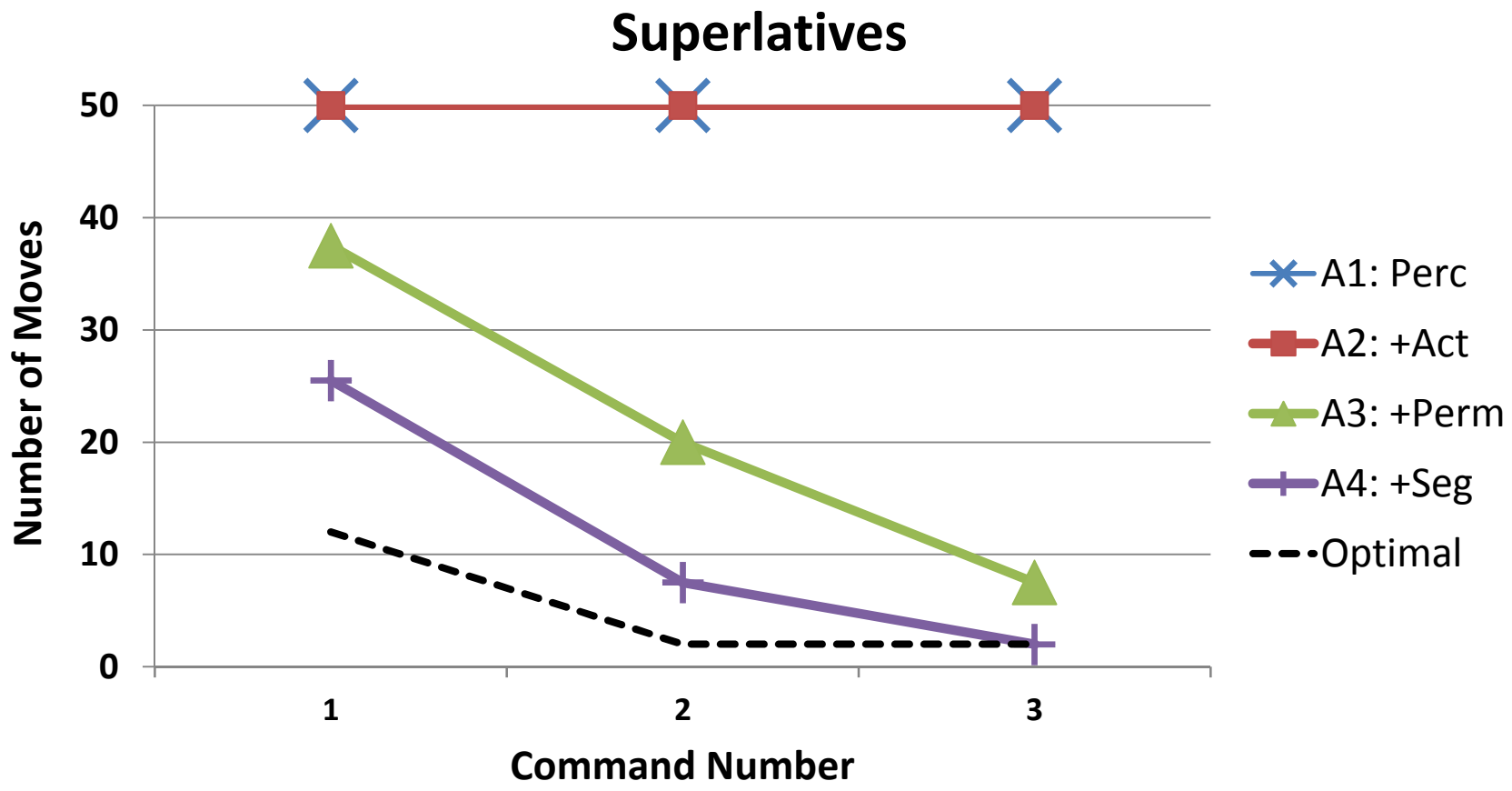
D4: Under-segmentation

3 bins and 6 objects (2 colors)



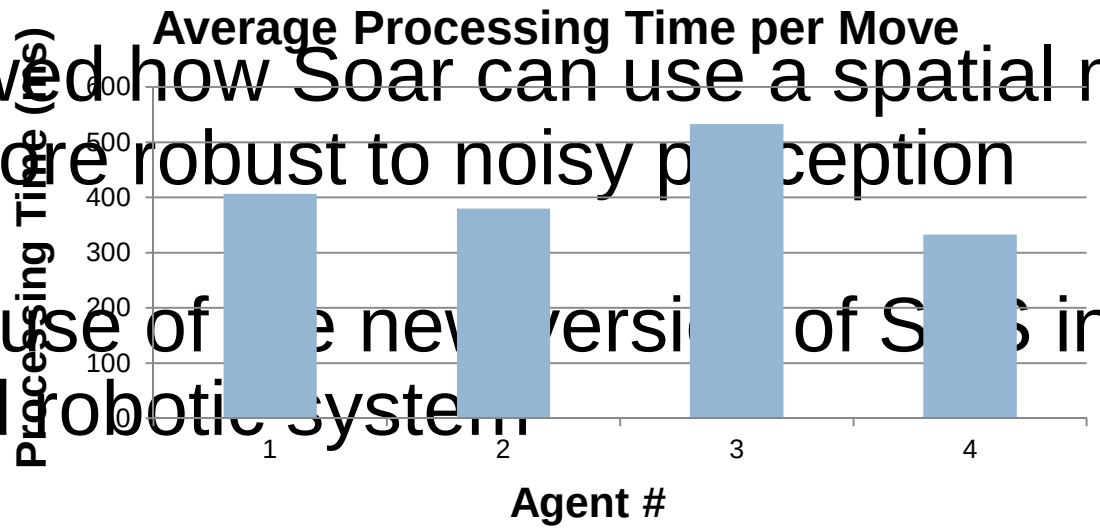
Evaluation – Domain 4

D4: Under-segmentation



Nuggets

- Tracked objects through occlusions, segmentation errors, and noise
- Adding additional knowledge did not increase processing time on average
- Showed how Soar can use a spatial memory to be more robust to noisy perception
- First use of the new version of SVS in a real-world robotic system

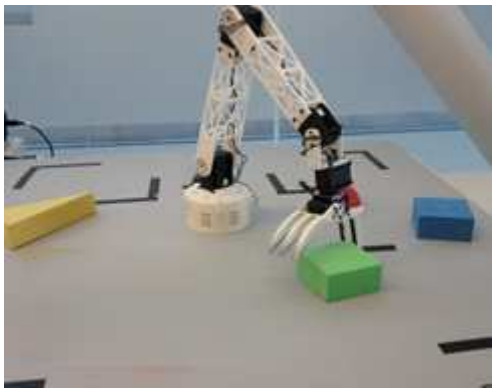


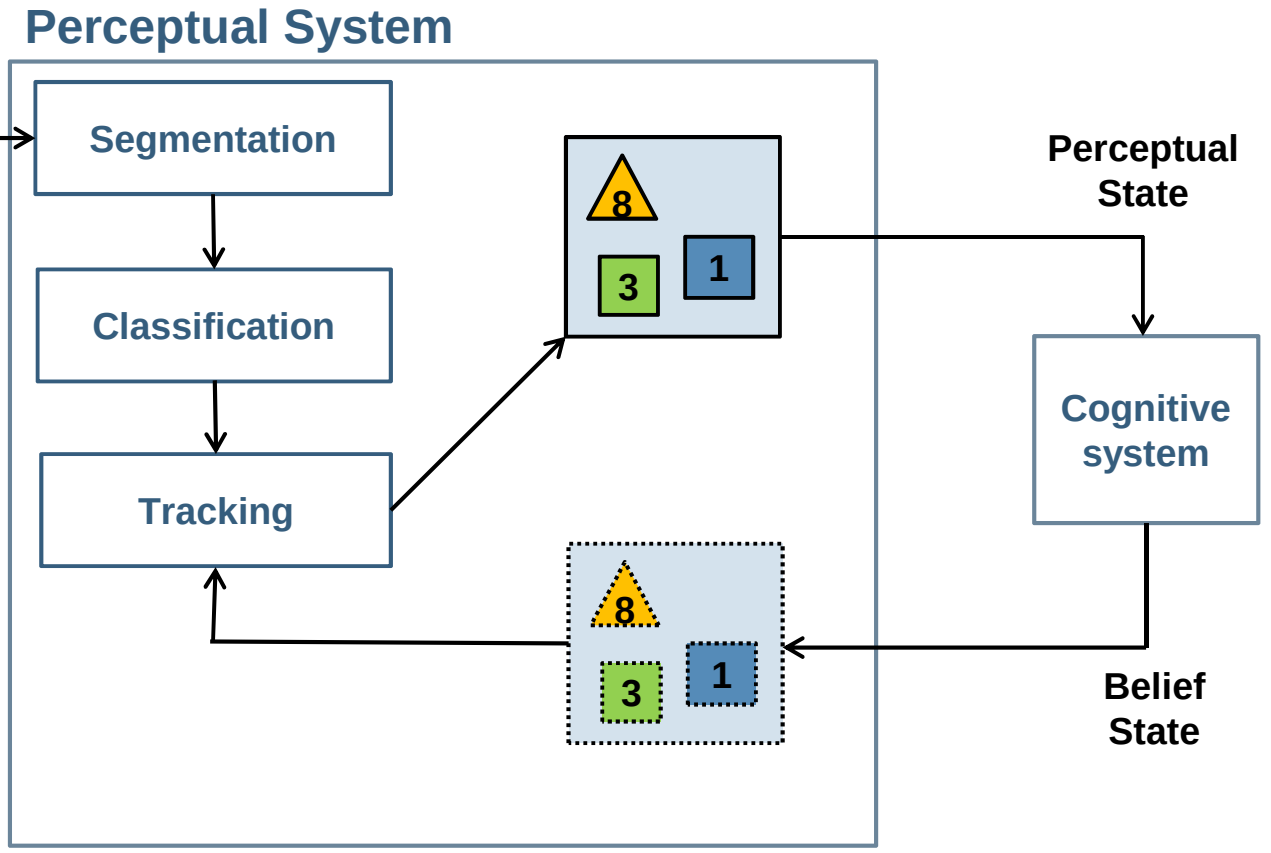
Coal

- Simplified representations of objects
- Too much noise can overwhelm the system
- Perceptual system is fragile, requires a restricted environment
- Cognitive System makes simplifying assumptions about objects

Questions

Perception - Tracking





Cognitive System