Learning to Order Objects using Haptic and Proprioceptive Exploratory Behaviors

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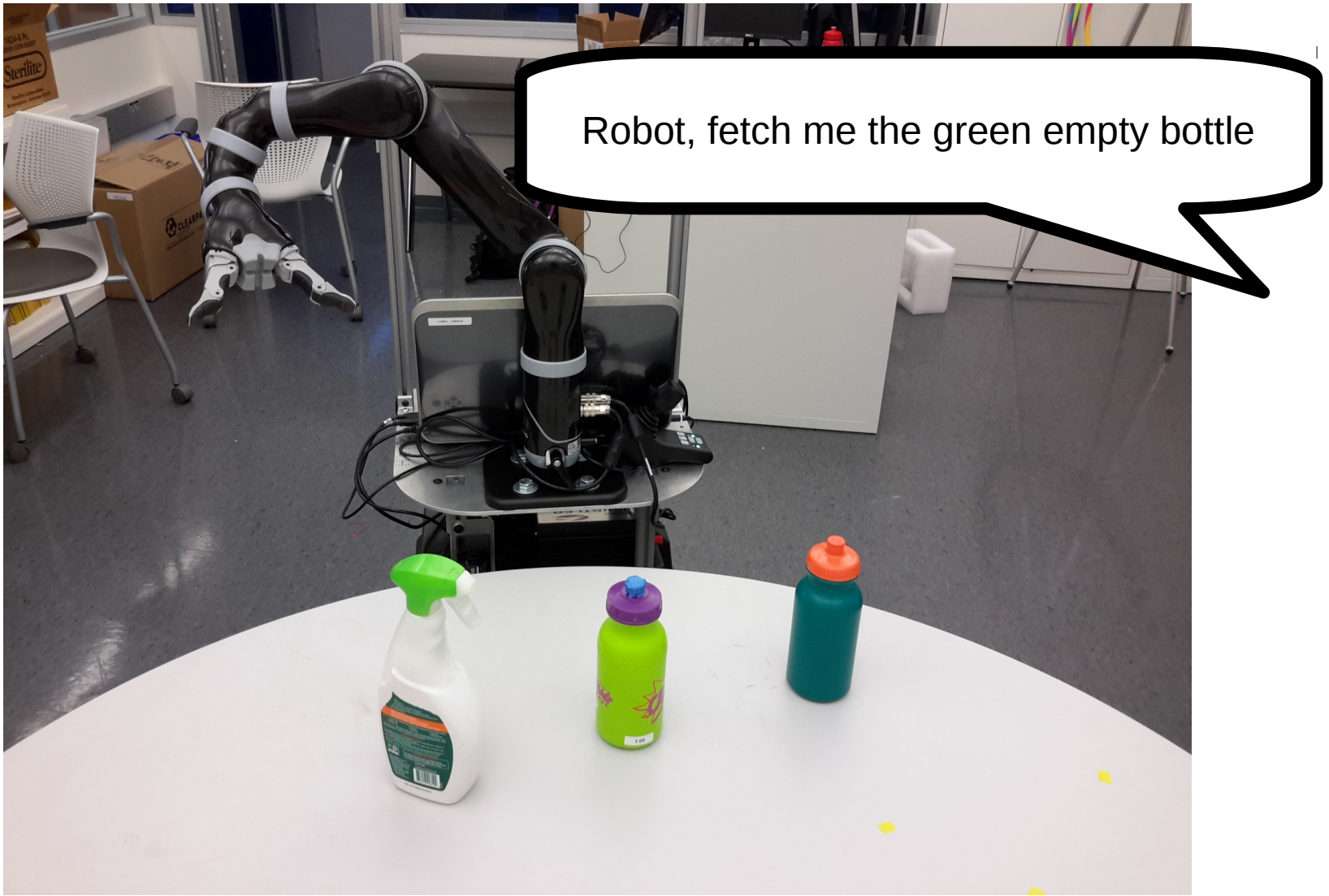
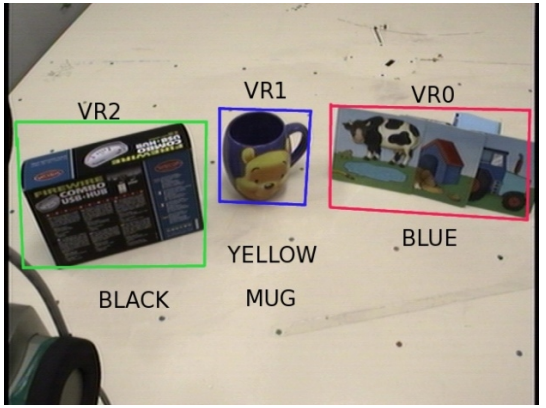
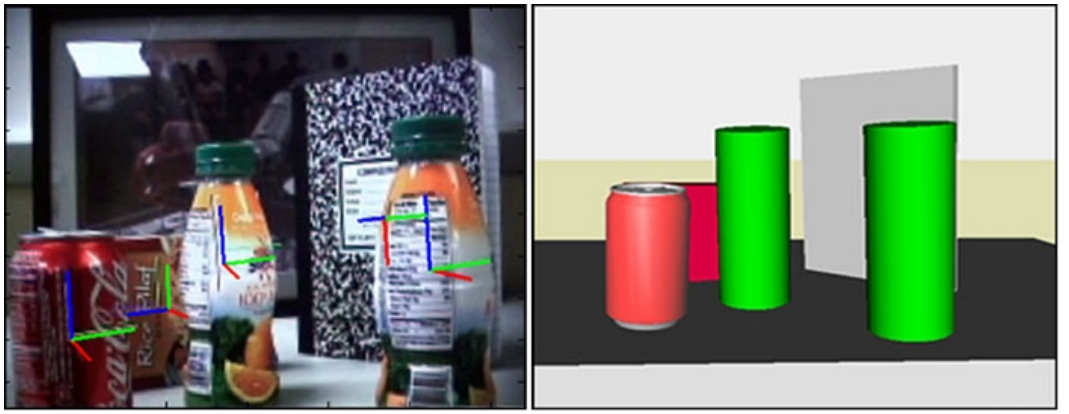
Motivation: Grounded Language Learning



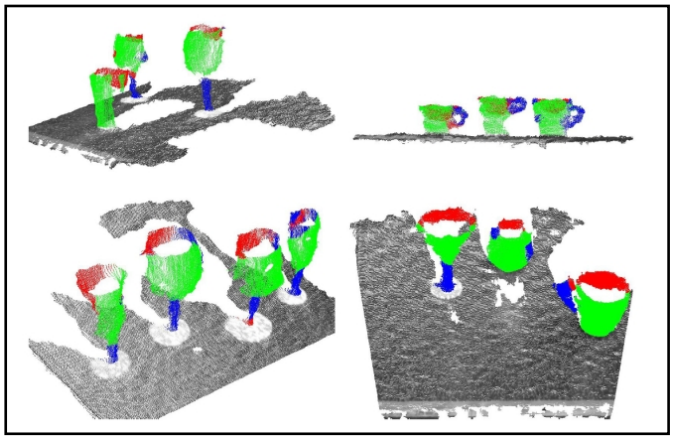
Object Category Recognition in Robotics



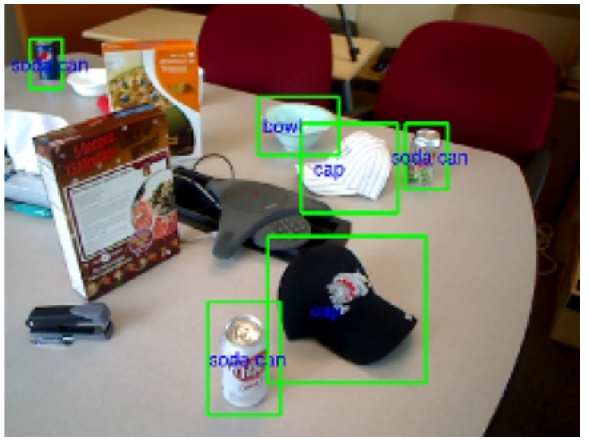
Sridharan *et al*. 2008



Collet *et al*. 2009

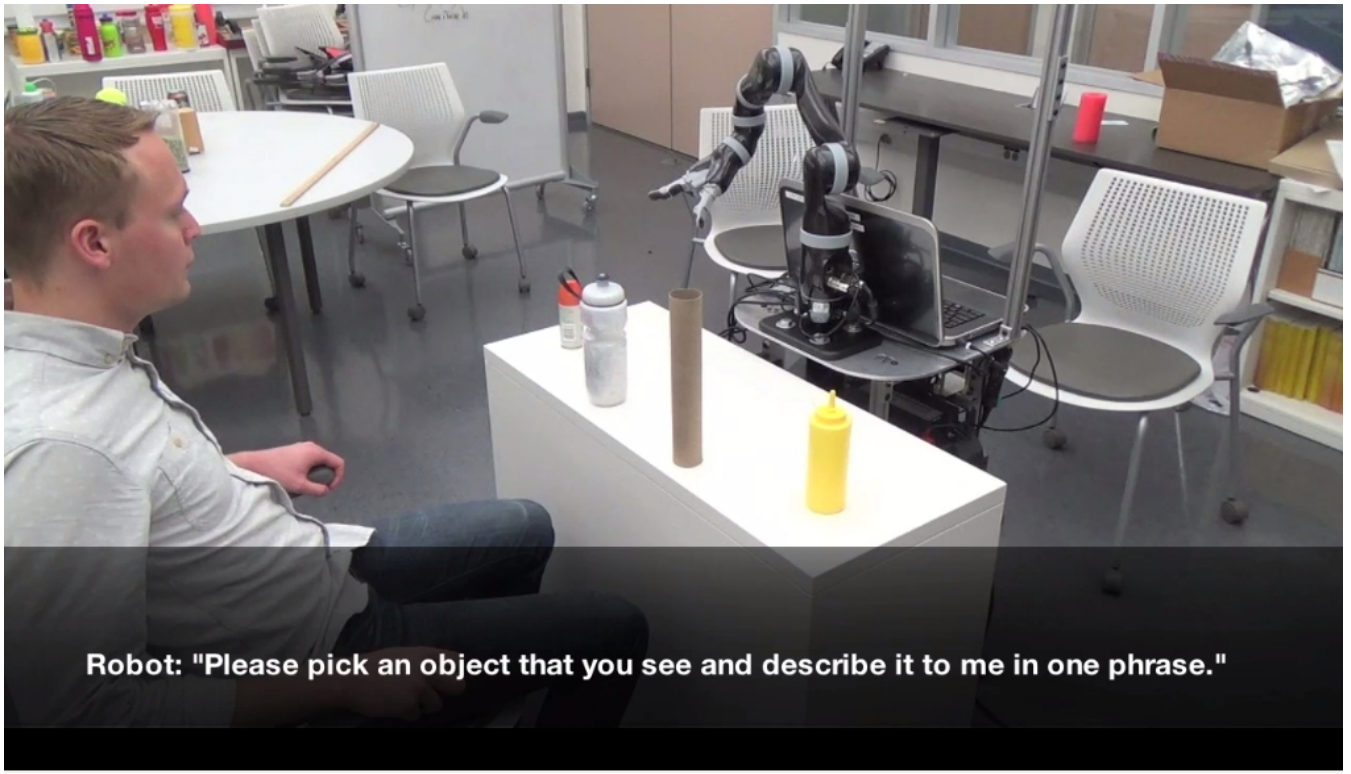


Rusu *et al*. 2009



Lai *et al*. 2011

Object Category Learning in Robotics



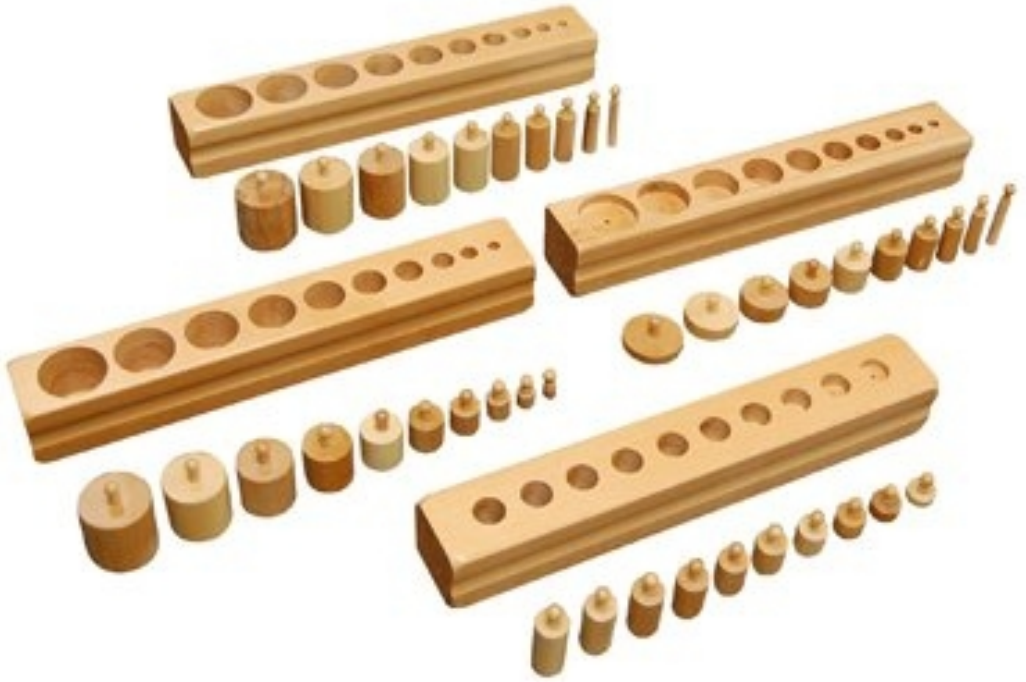
Thomason, J., Sinapov, J., Svetlik, M., Stone, P., and Mooney, R. (2016). Learning Multi-Modal Grounded Linguistic Semantics by Playing I, Spy

Robotics and Vision 3 Session

Now, when and where does this fail...

Consider the word, “weight” - how should it be grounded?

How do humans ground such words?



Sample Montessori toys designed to teach children about the ordinal properties of object weight, height, and size

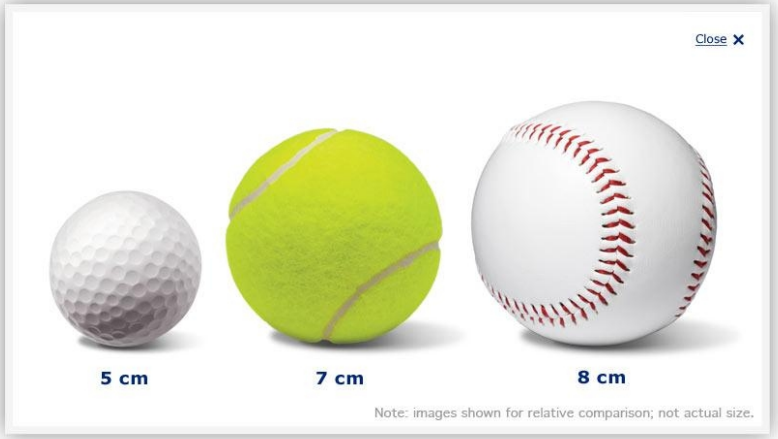
Object Ordering in Psychology

stage IV or III series

stage II series

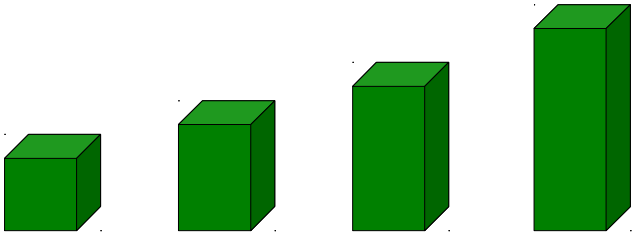
stage I series

Object Orderings in Human Environments

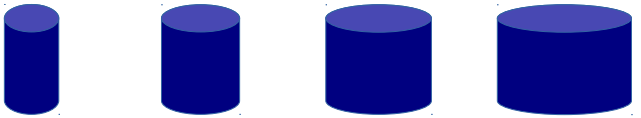


Problem Formulation

- **Order Recognition:** what property is a given series of objects ordered by?



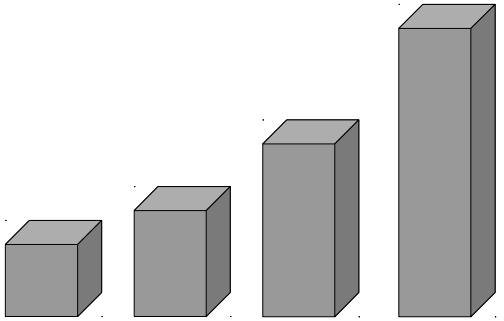
“height”



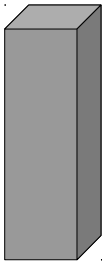
“width”

Problem Formulation (2)

- **Order Insertion**: given an object series, insert a new object into the correct position



series

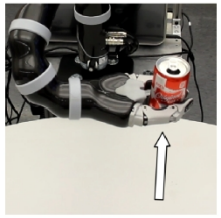


test object

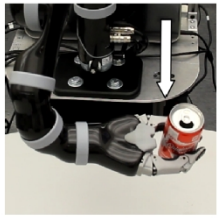
Three-Stage Approach

Stage 1: Object Exploration

grasp



lift



lower

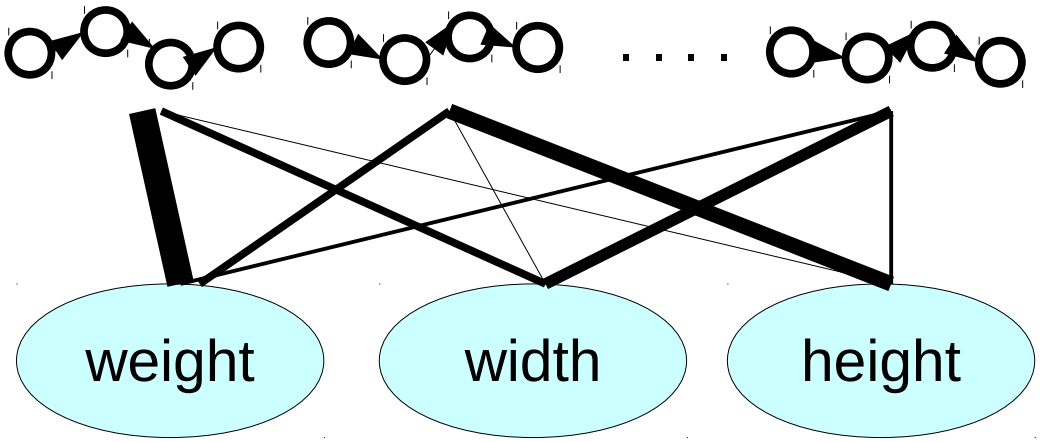
drop

press

push

Stage 2: Unsupervised Order Discovery

Stage 3: Semantic Grounding



Stage 1: Object Exploration

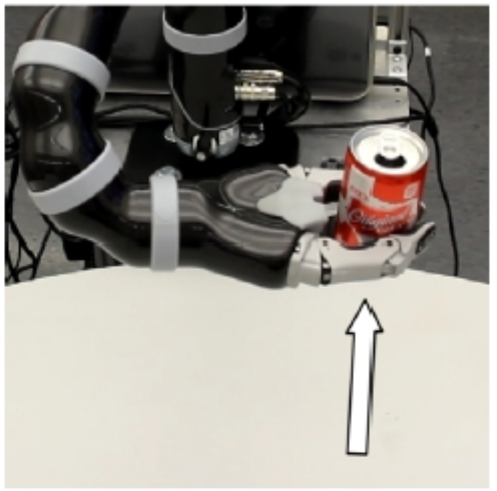
32 common household and office items

The objects vary along three ordinal properties:

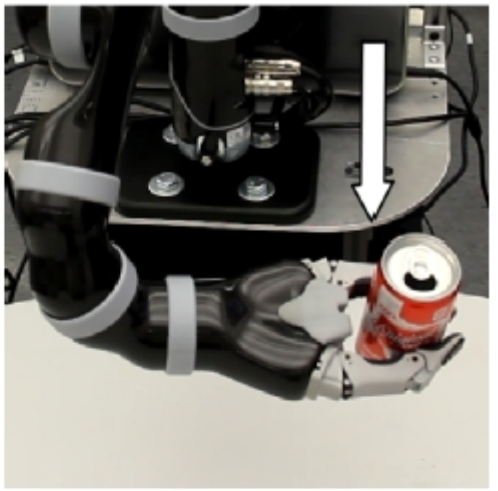
1) Weight
2) Width
3) Height

Exploratory Behaviors

grasp



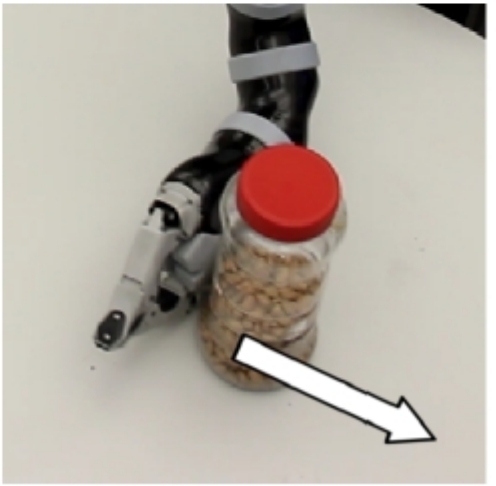
lift



lower

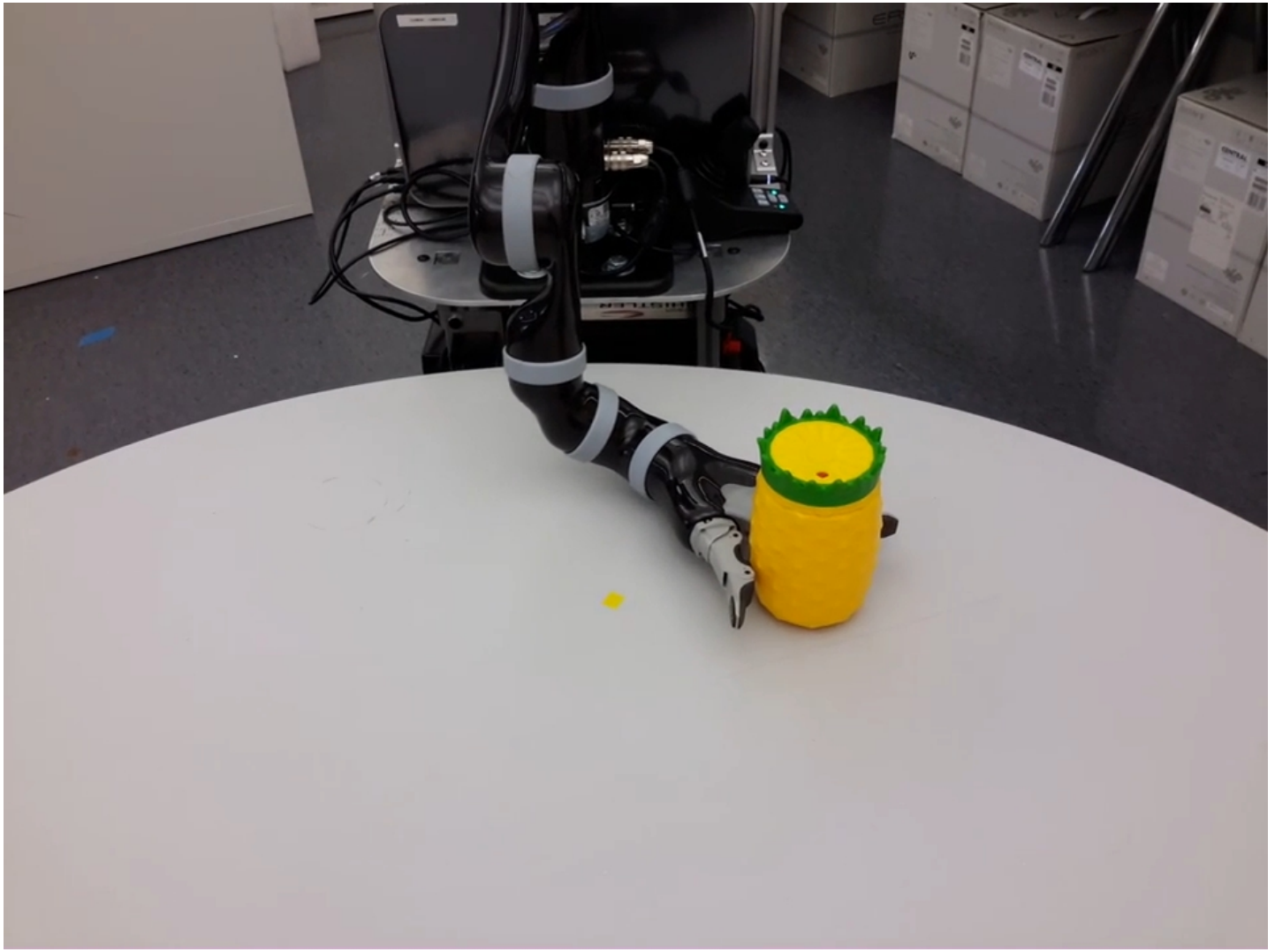
drop

press



push

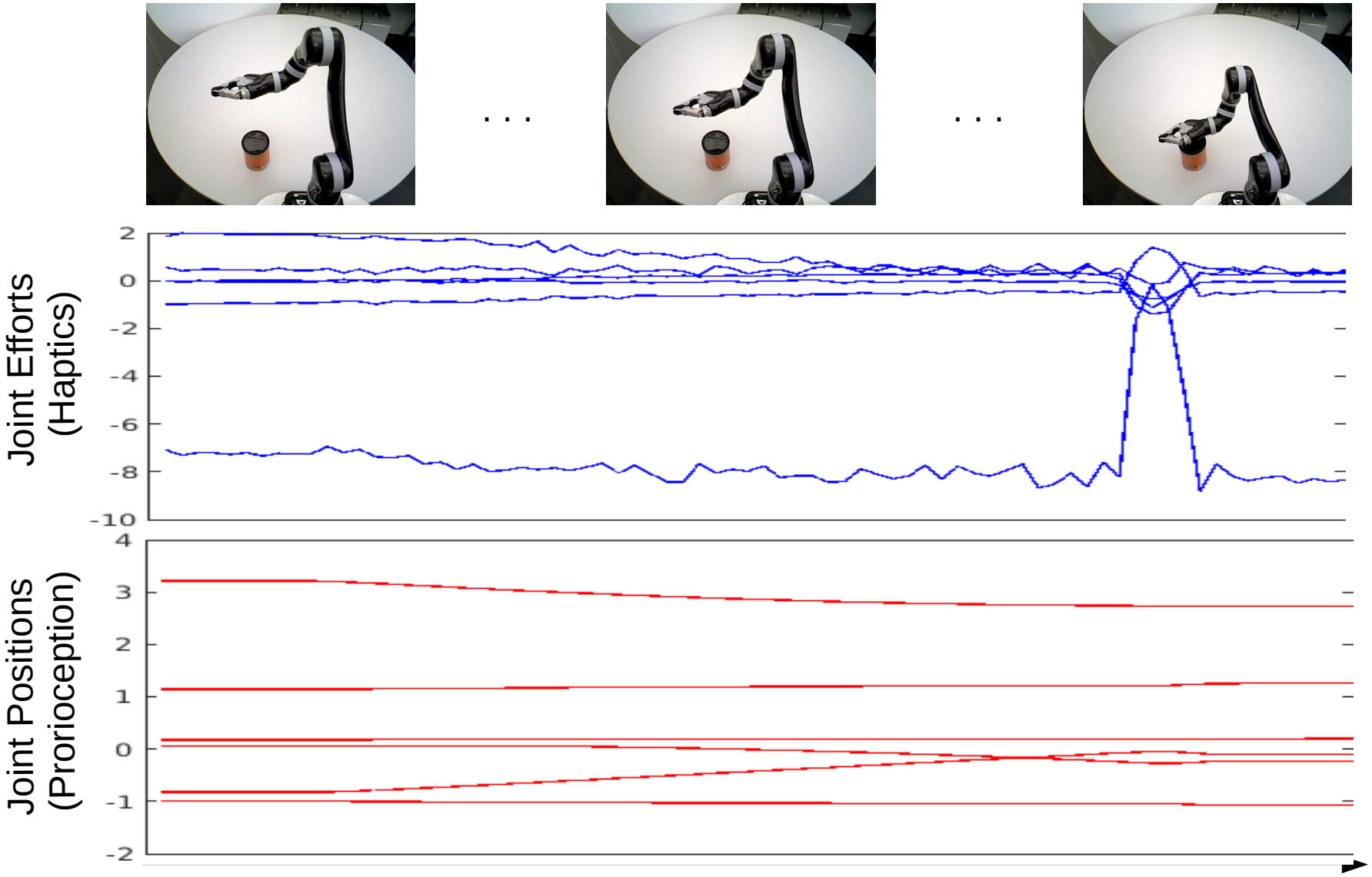
Video



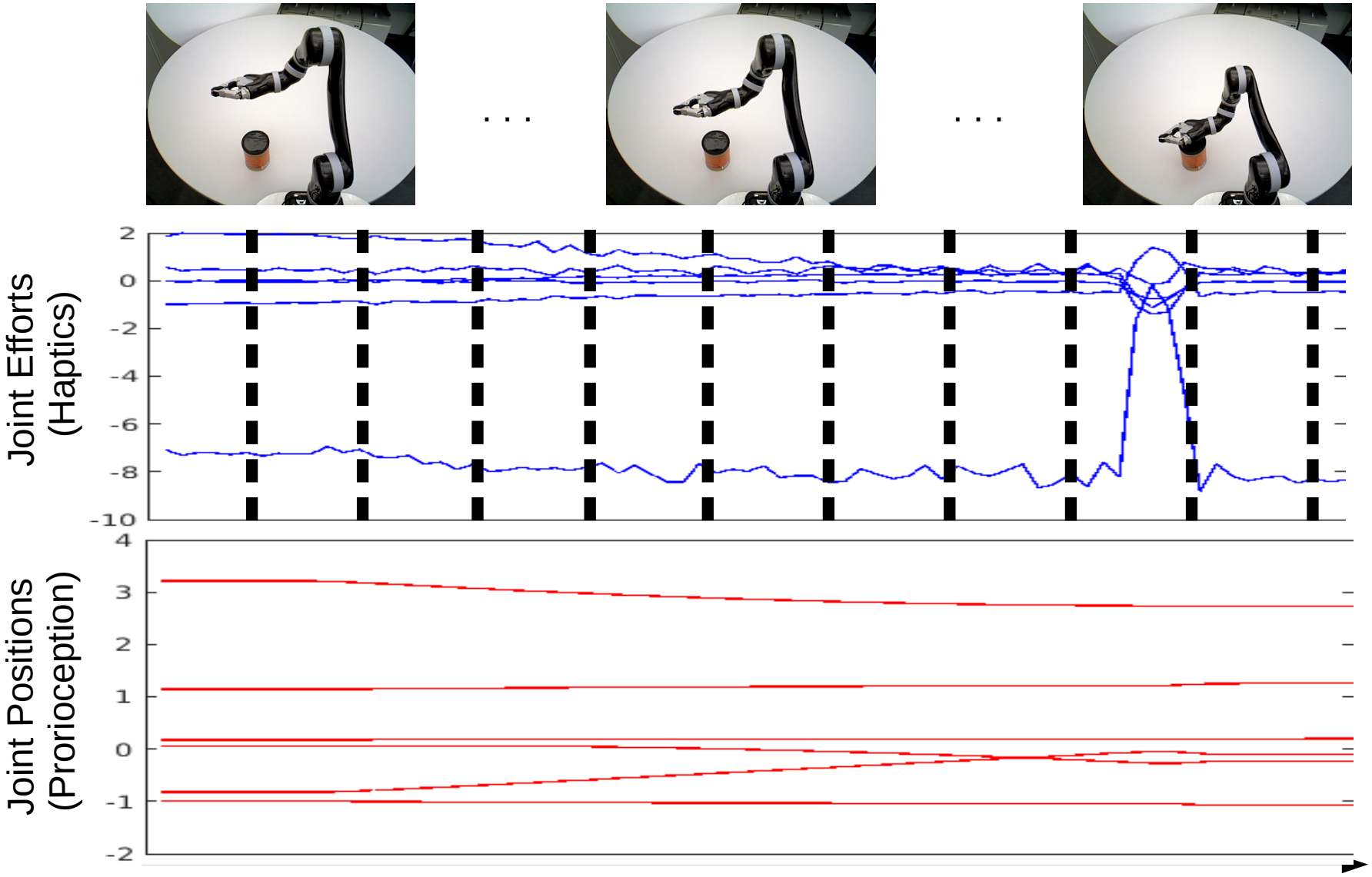
Video

Video

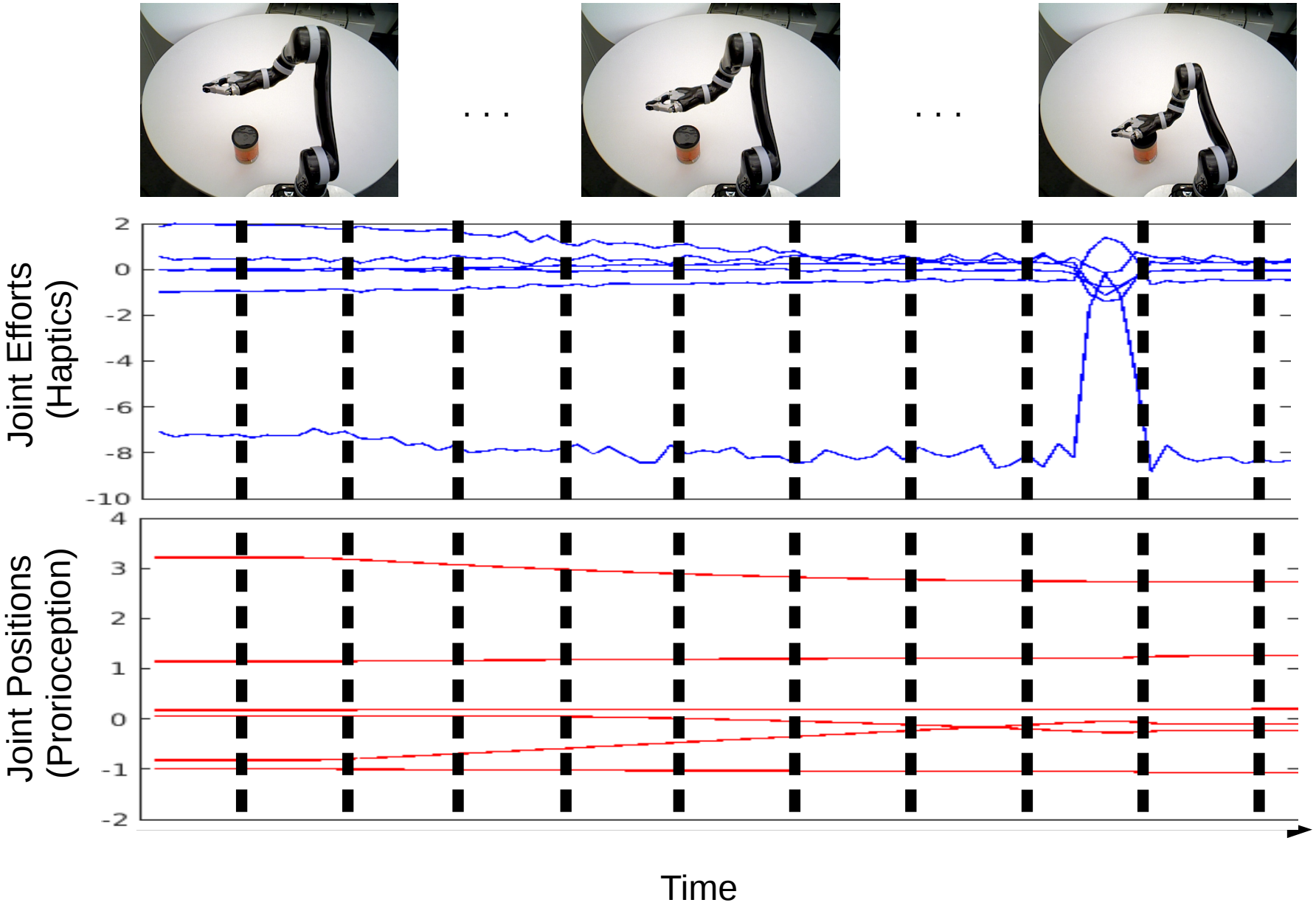
Haptic and Proprioceptive Feature Extraction



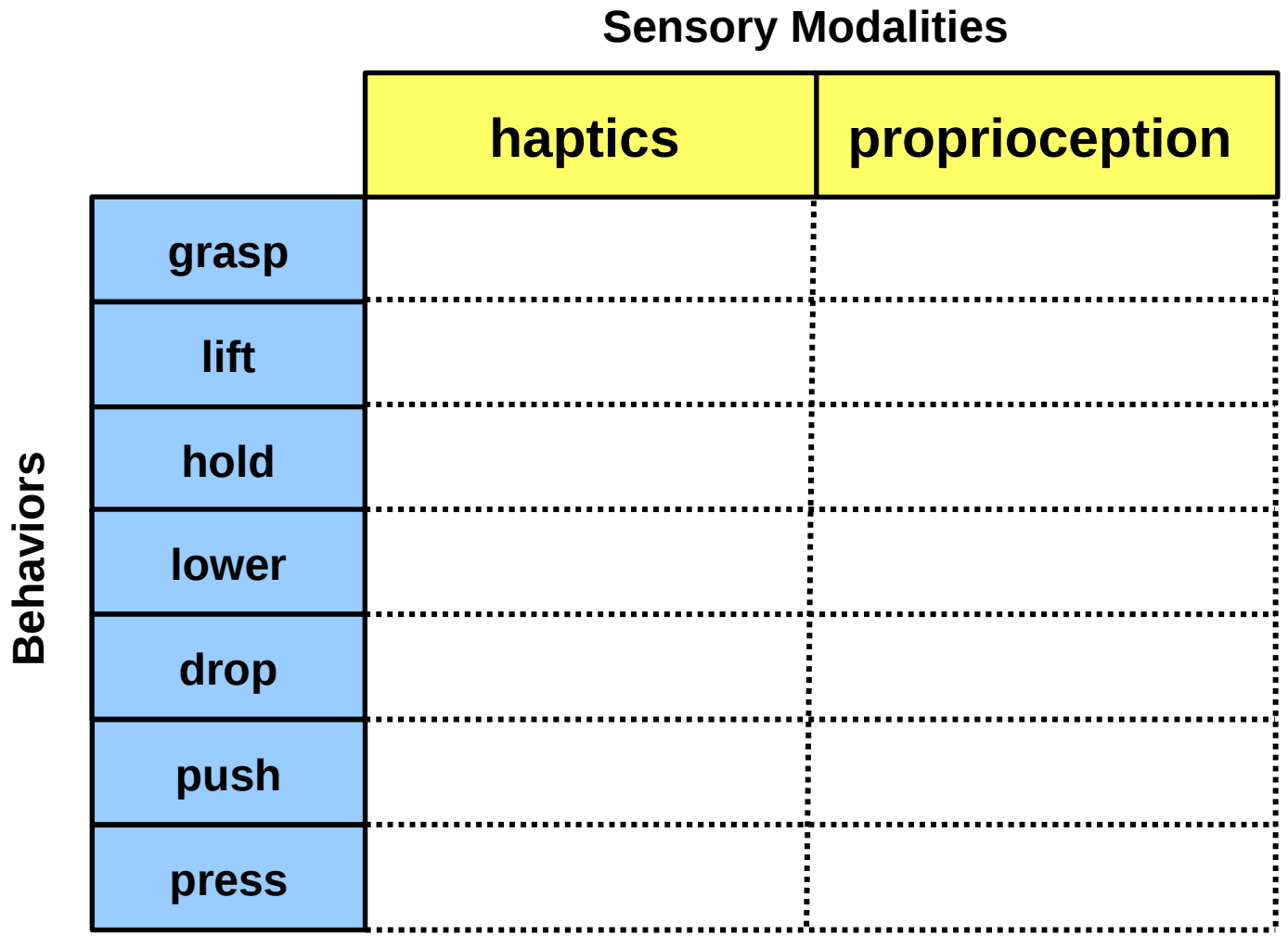
Haptic and Proprioceptive Feature Extraction



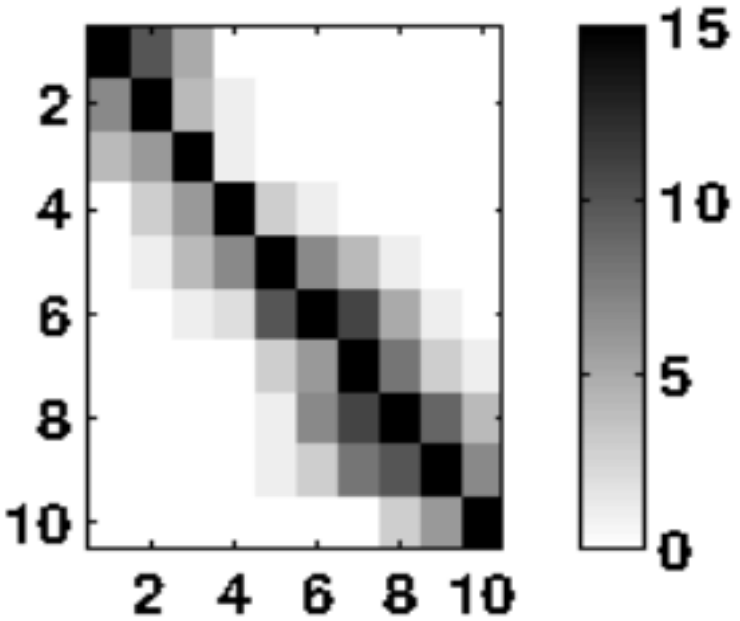
Haptic and Proprioceptive Feature Extraction



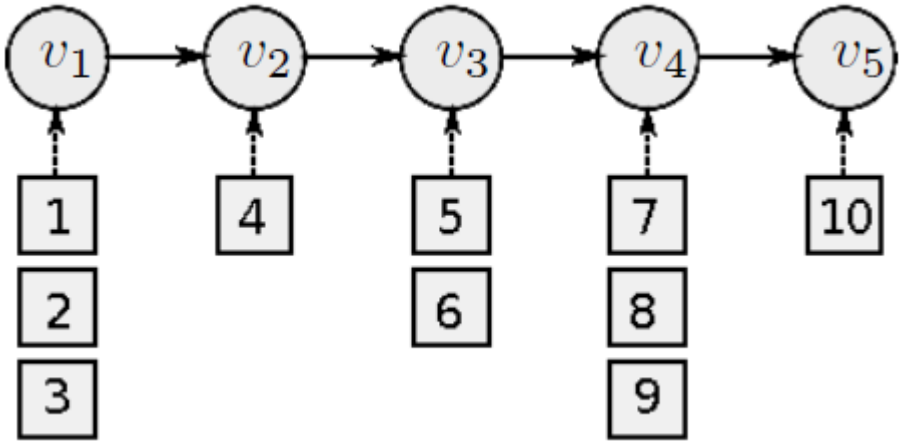
Stage 2: Unsupervised Order Discovery



Unsupervised Order Discovery Example with Synthetic Data

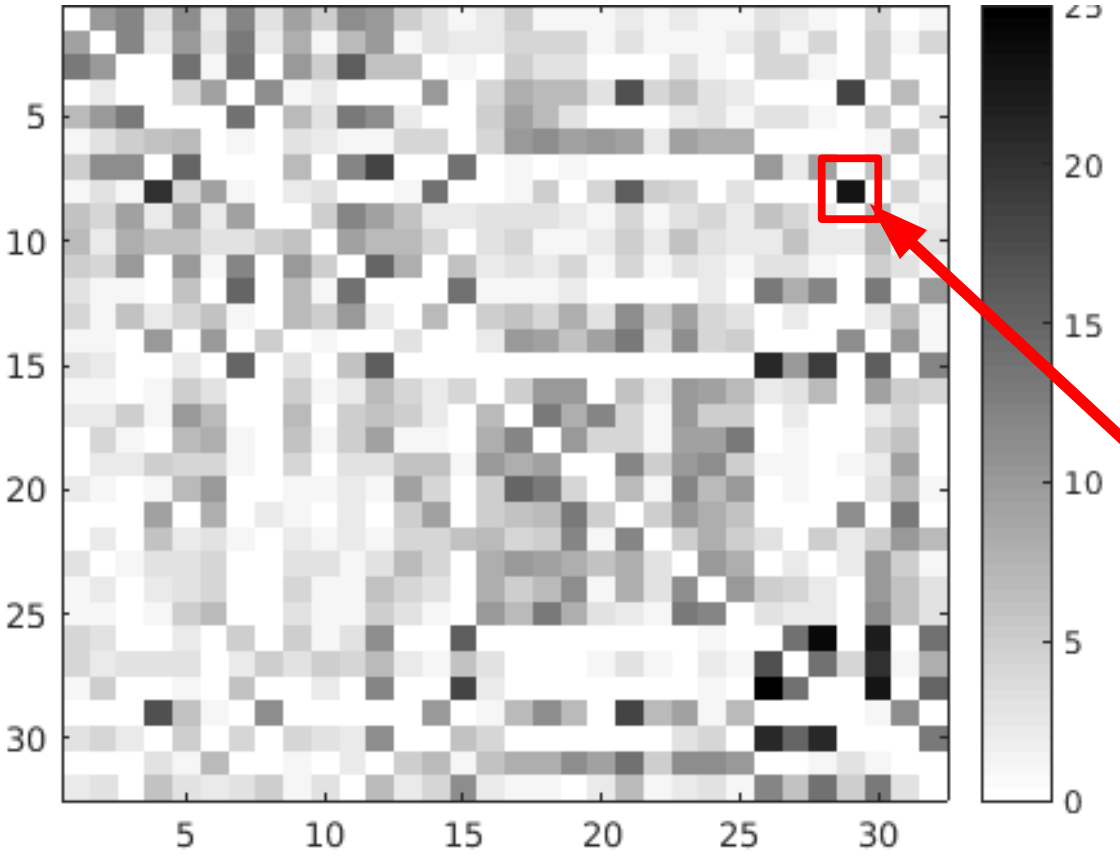


Input Relational Count Matrix



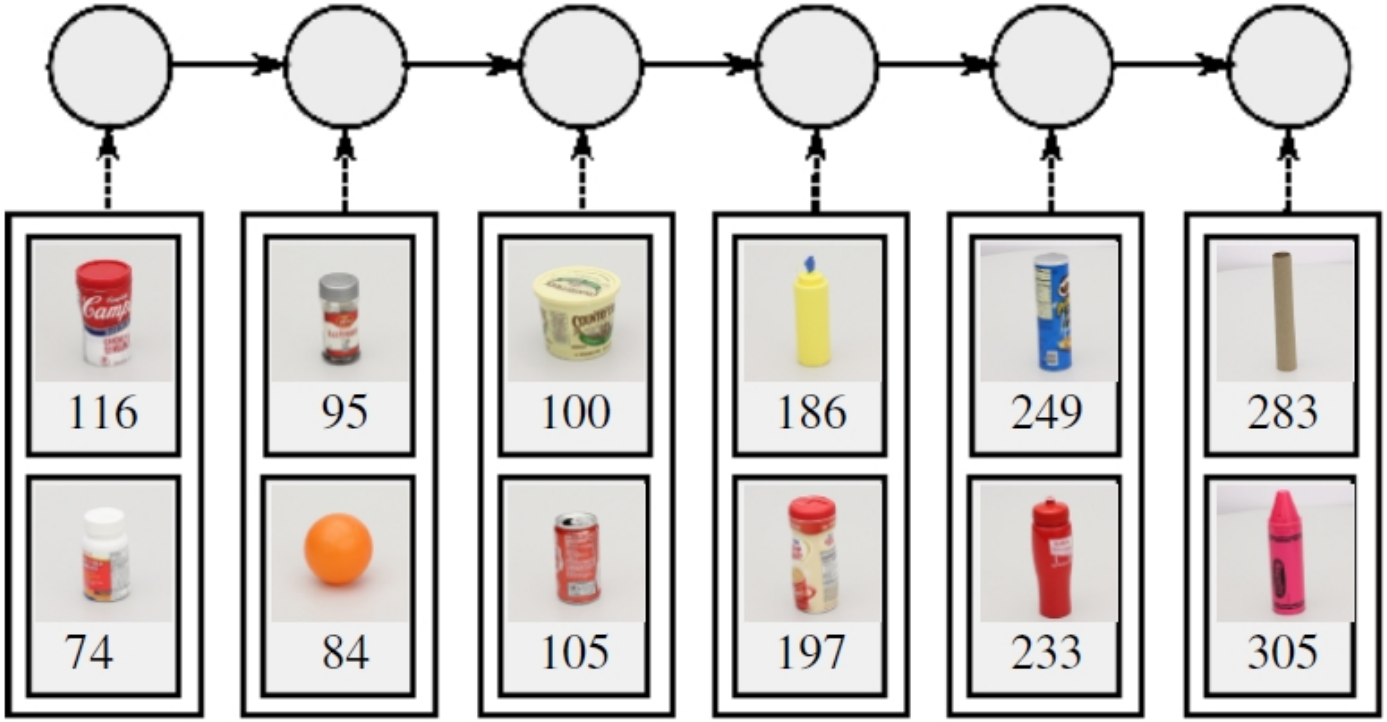
Object order with highest likelihood using the method of [Kemp and Tennenbam, 2008]

Example Relational Count Matrix with the *Press* action and *Haptic* features



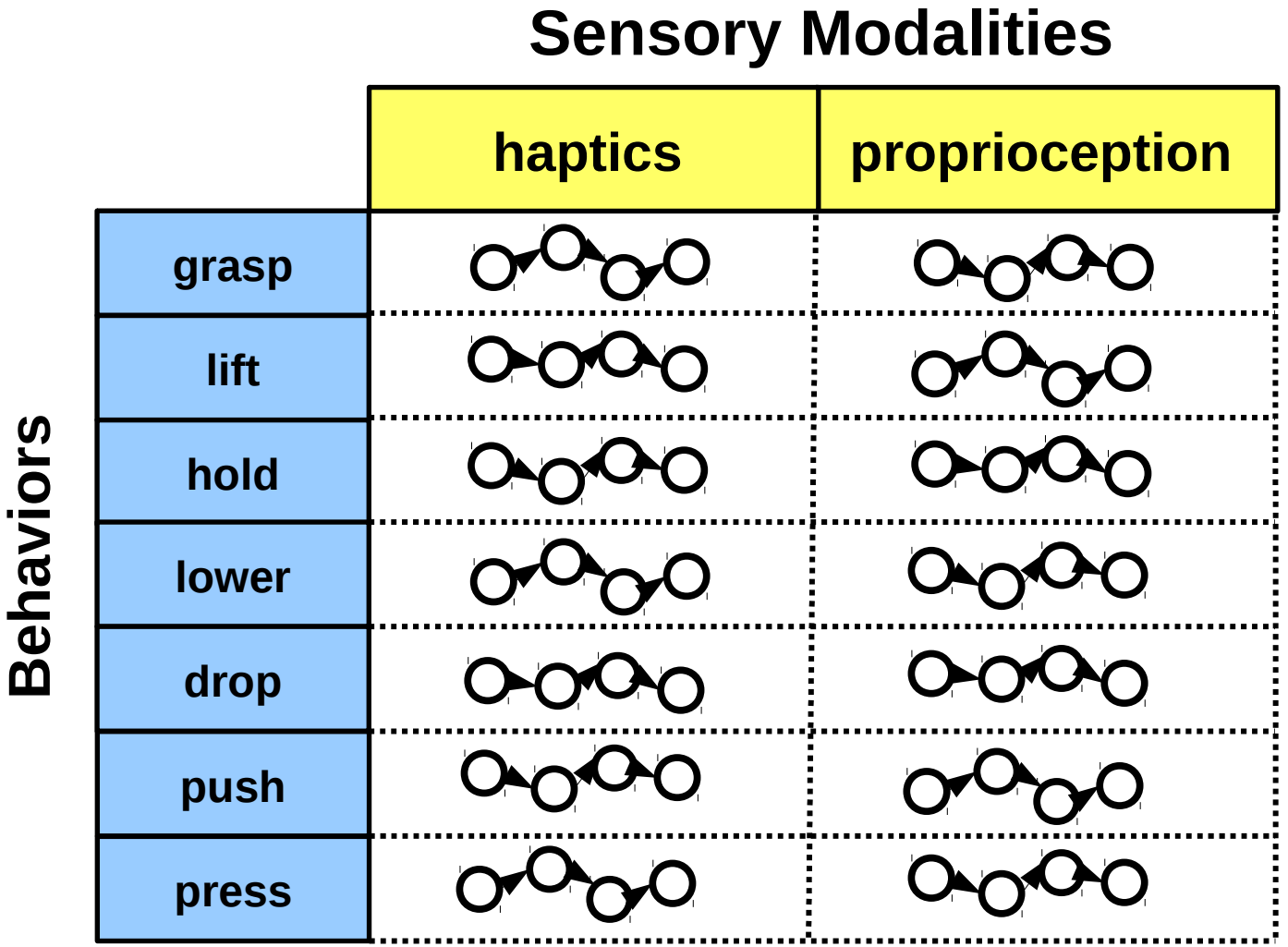
Similarity between objects *i* and *j* in the *press-haptic* sensorimotor context

Resulting Order
(*Press* behavior and *Haptic* modality)



The number corresponds to the object's height in millimeters

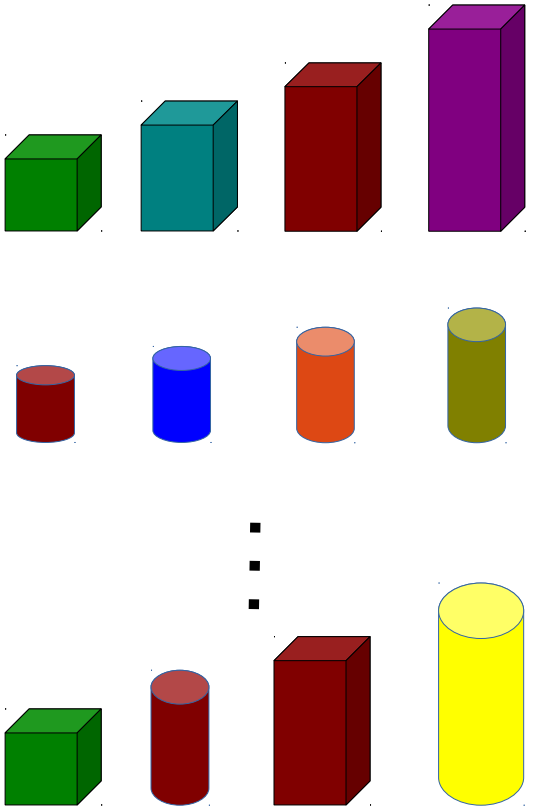
Stage 2: Unsupervised Order Discovery



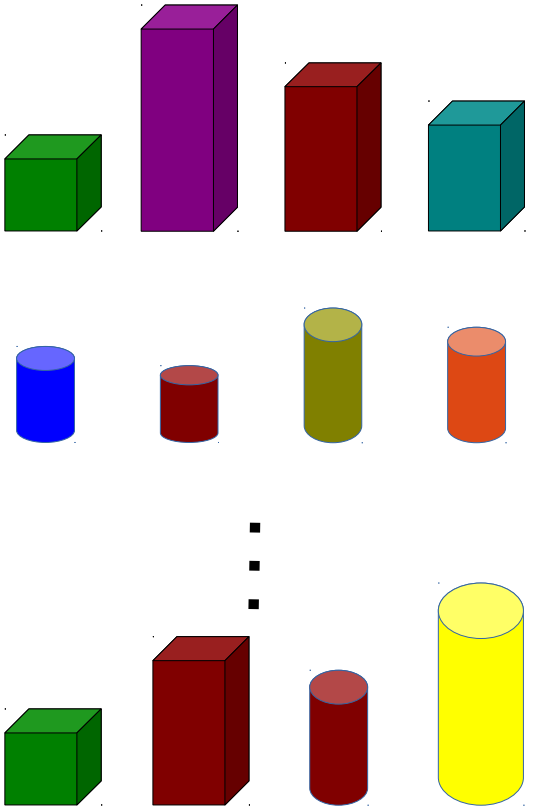
Stage 3: Order Grounding Stage

Order Grounding Example: “height”

Positive Examples:

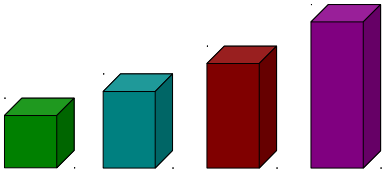


Negative Examples:



Object Order Representation

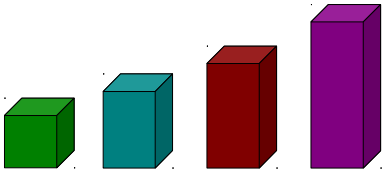
Training Example:

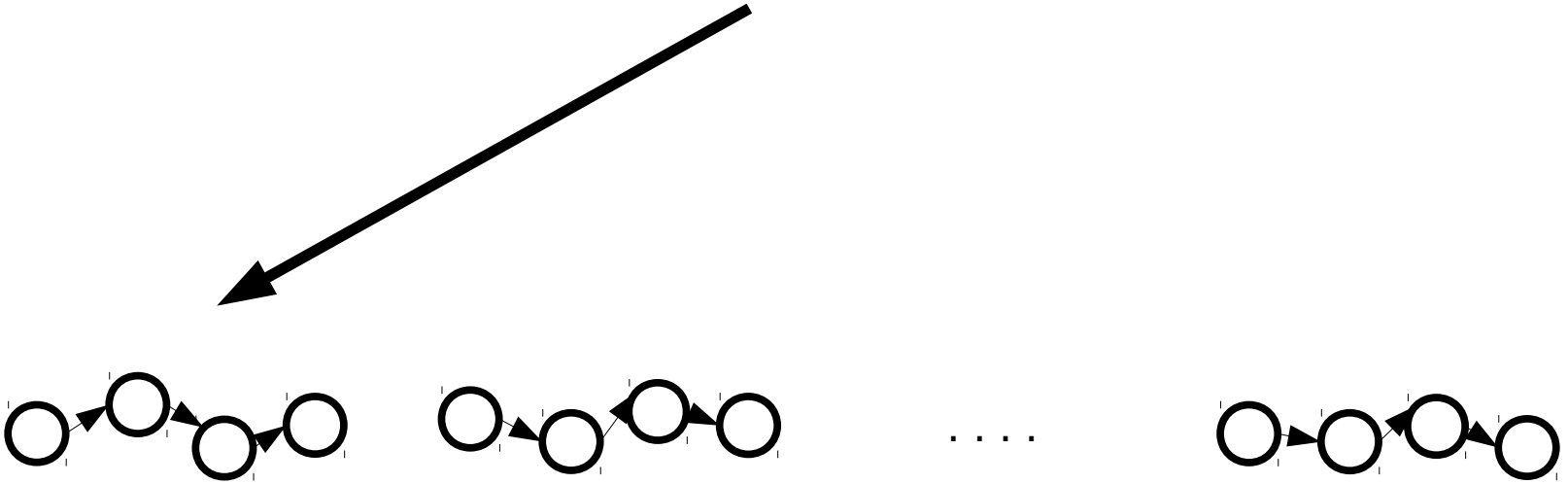


Object Orders Discovered During Stage 2

Object Order Representation

Training Example:

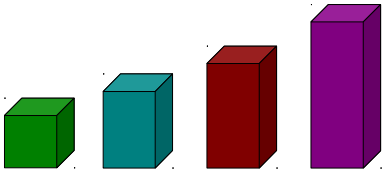




Object Orders Discovered During Stage 2

Object Order Representation

Training Example:

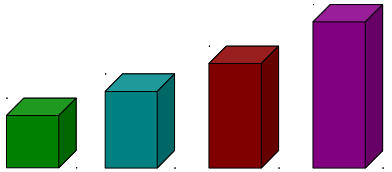


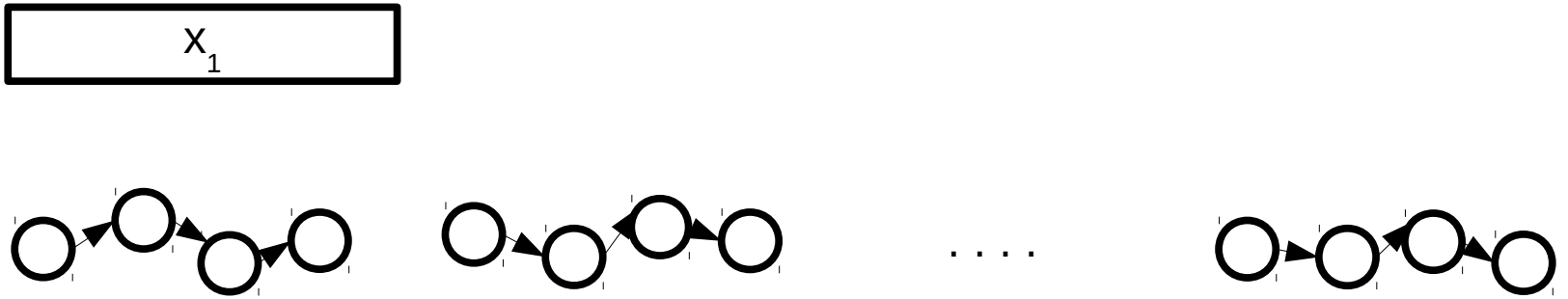
$$d(S_n, S_n^c) = \sum_{i \in \mathcal{O}_S} \sum_{j \in \mathcal{O}_S} \left| \frac{h_{S_n}(i,j)}{length(S_n)} - \frac{h_{S_n^c}(i,j)}{length(S_n^c)} \right|$$

Object Orders Discovered During Stage 2

Object Order Representation

Training Example:





Object Orders Discovered During Stage 2

Object Order Representation

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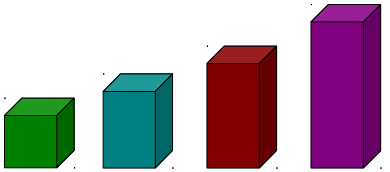

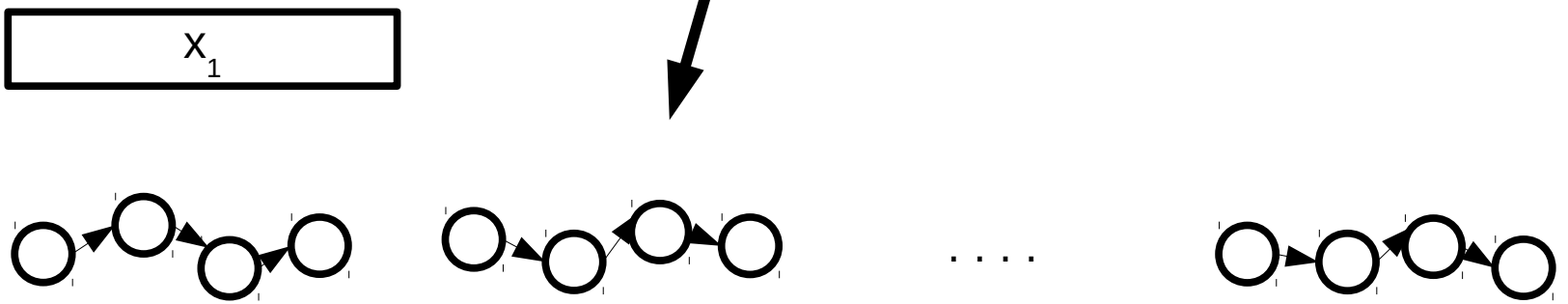

Object Orders Discovered During Stage 2

Object Order Representation

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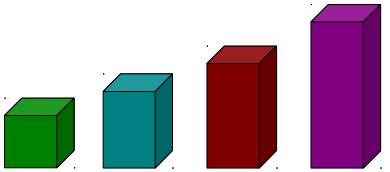

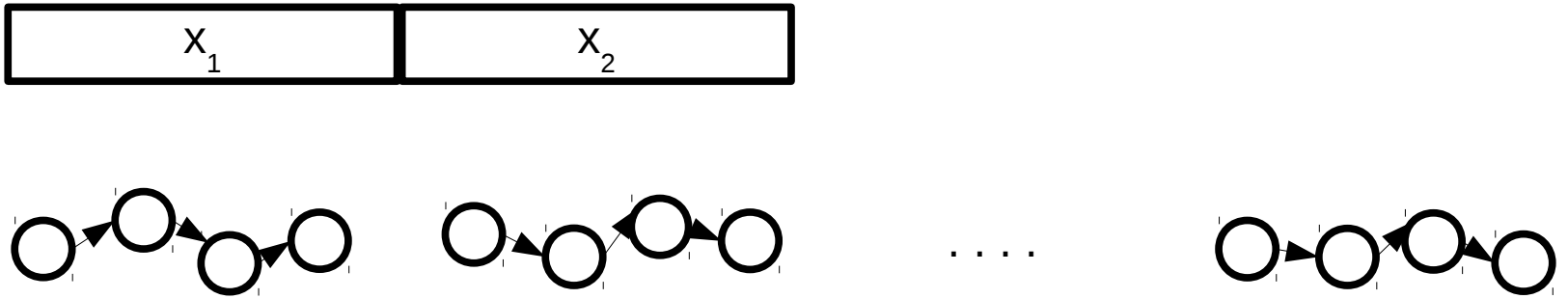

Object Orders Discovered During Stage 2

Object Order Representation

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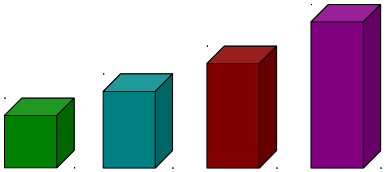
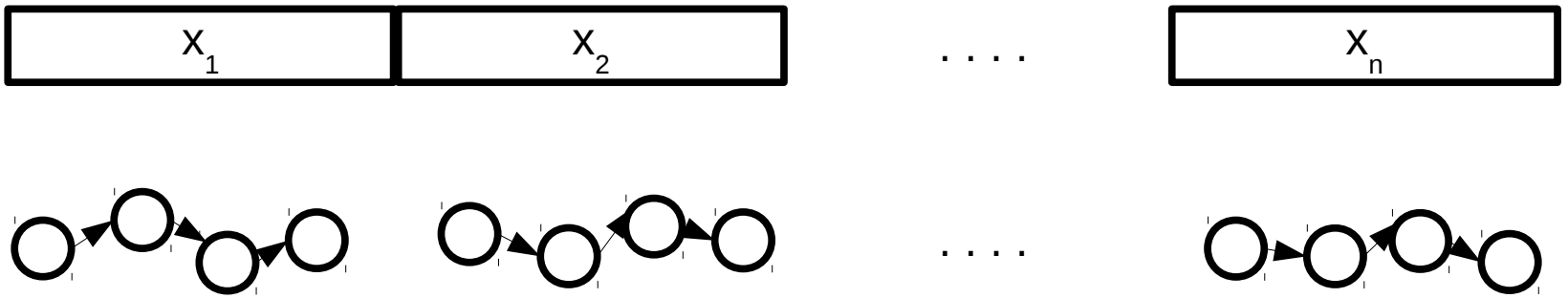




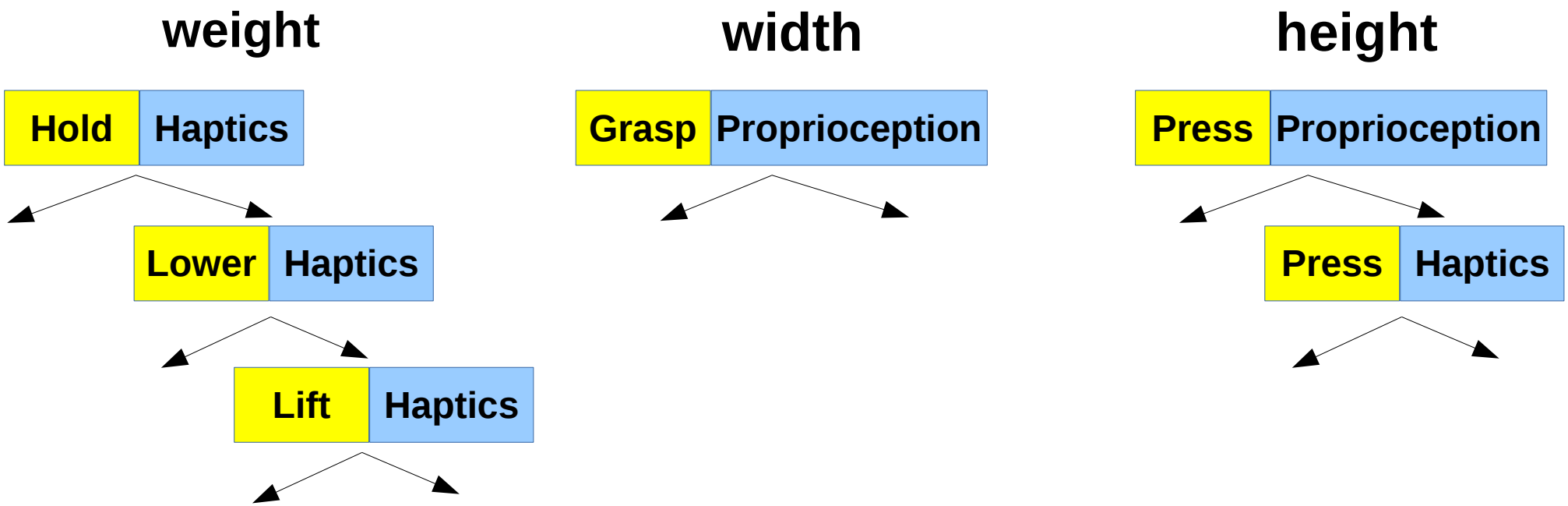
Object Orders Discovered During Stage 2

Results: Order Recognition

Table 1: Order Recognition Rates (% Accuracy)

concept	k-NN	SVM	Decision Tree
weight	89.48	92.42	96.67
width	78.82	82.49	91.70
height	86.44	90.18	98.42

Sample Learned Decision Trees

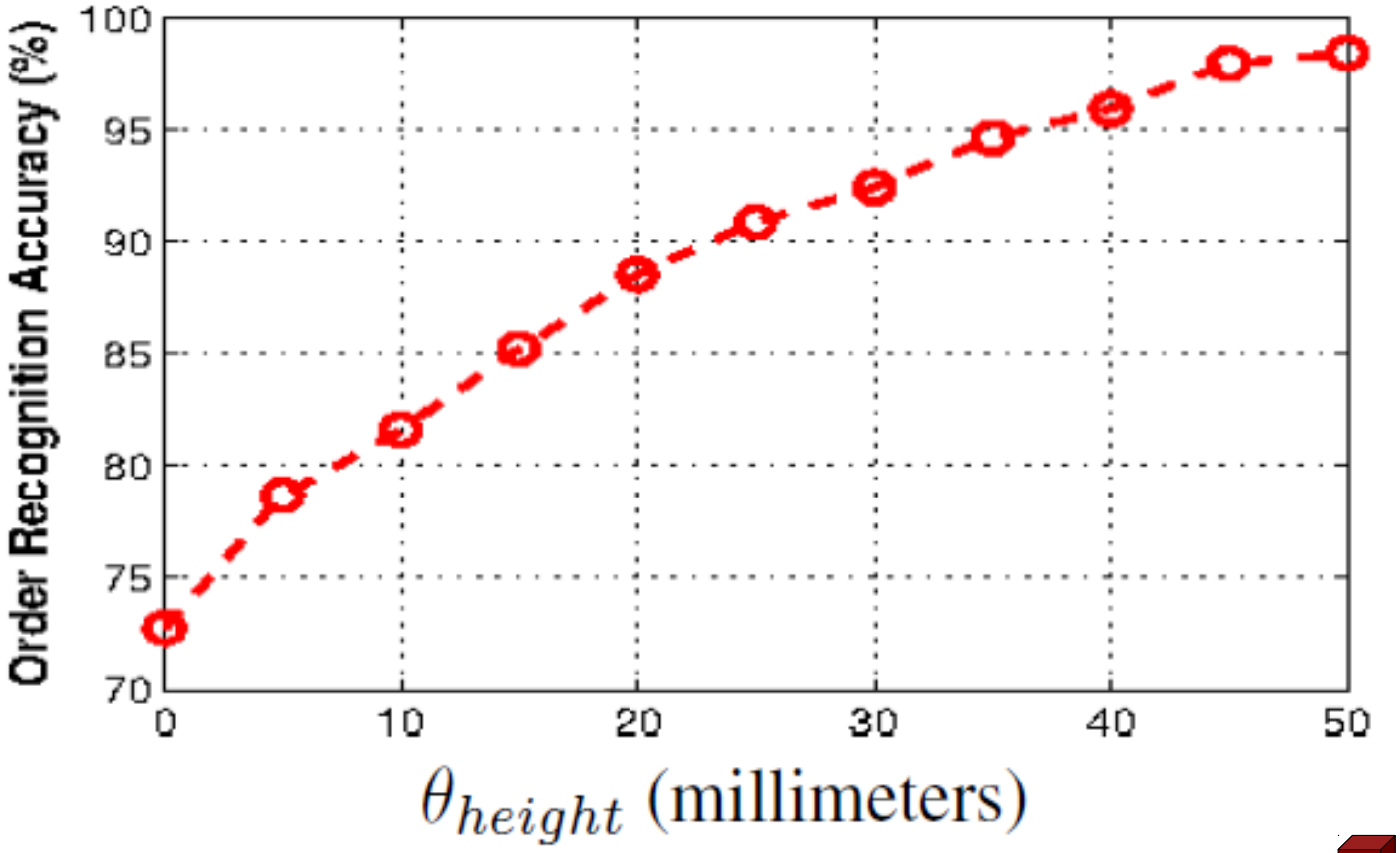


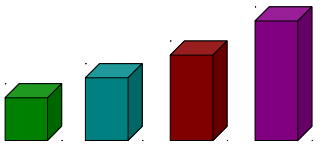
When does the robot make mistakes?

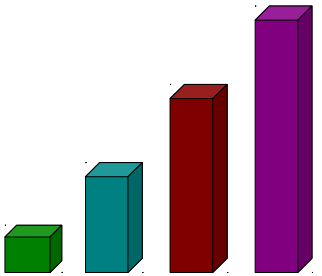
When does the robot make mistakes?

difficult ⟷ easy

When does the robot make mistakes?







difficult ⟷ easy

Object Order Insertion Results

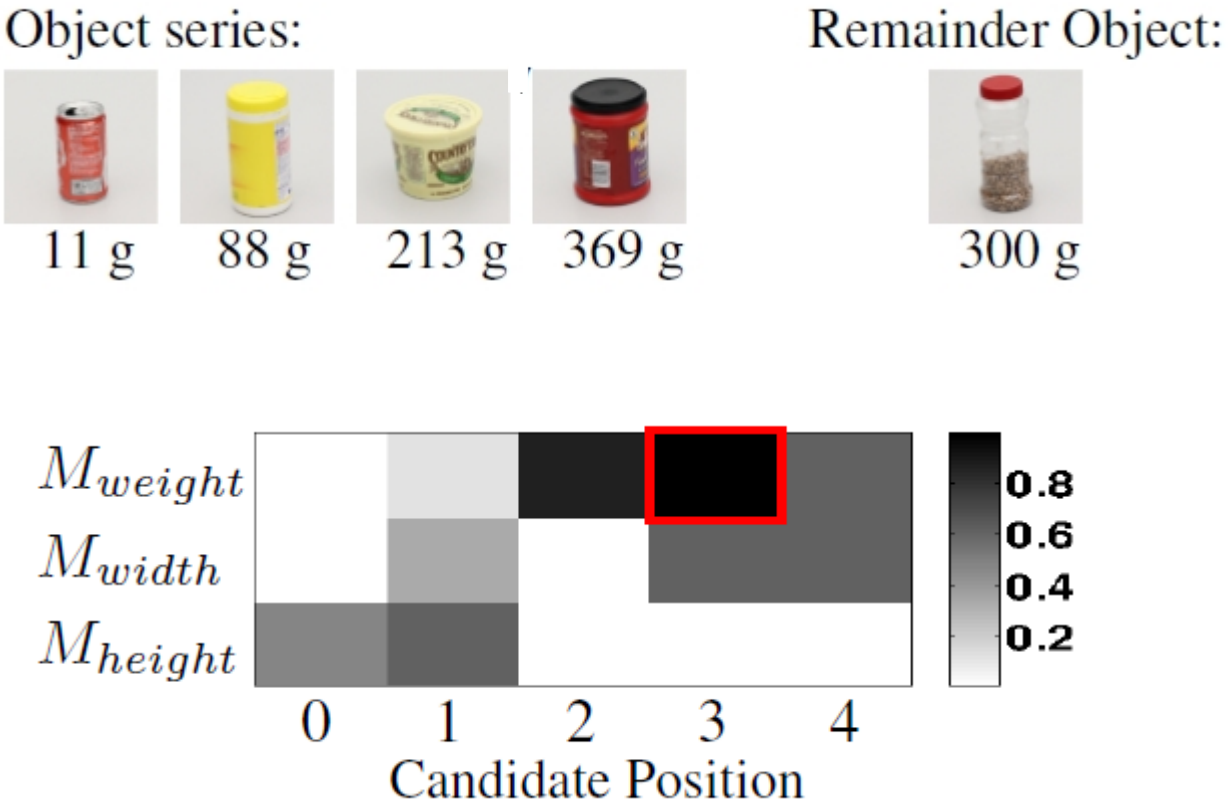
Object series:

11 g 88 g 213 g 369 g

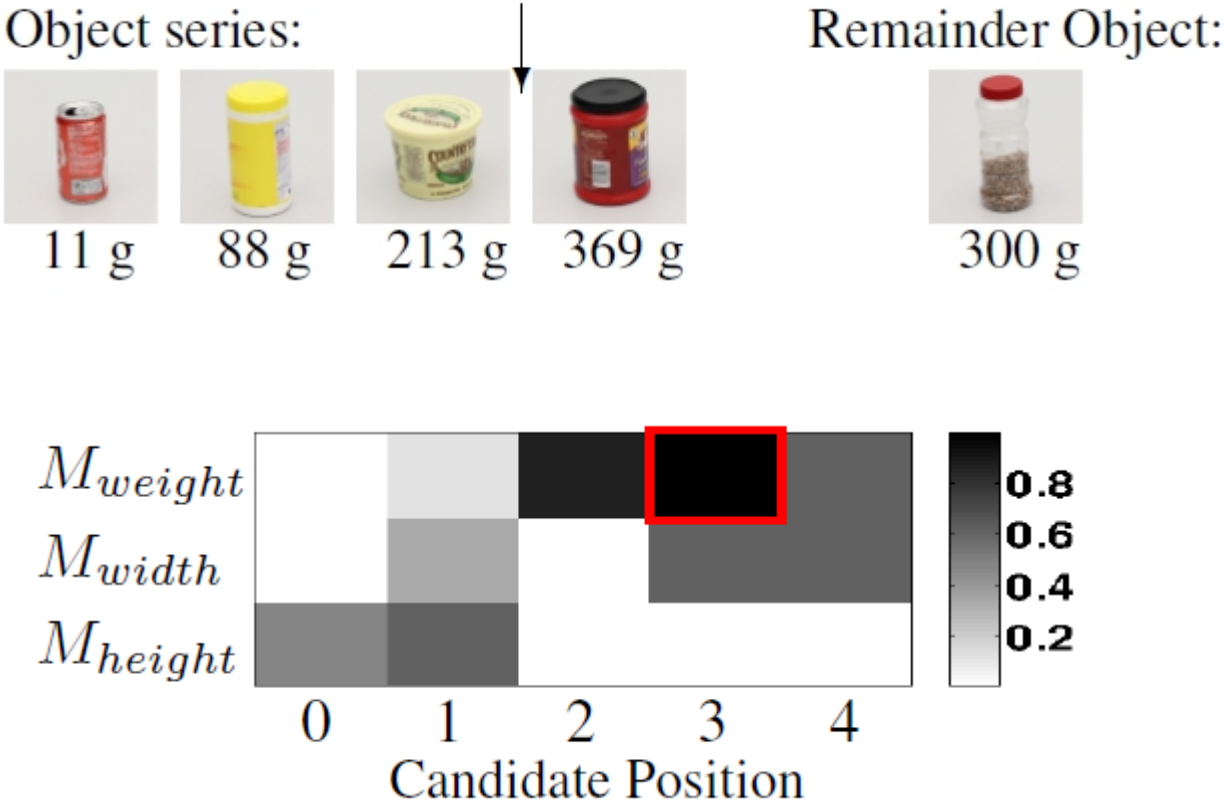
Remainder Object:

300 g

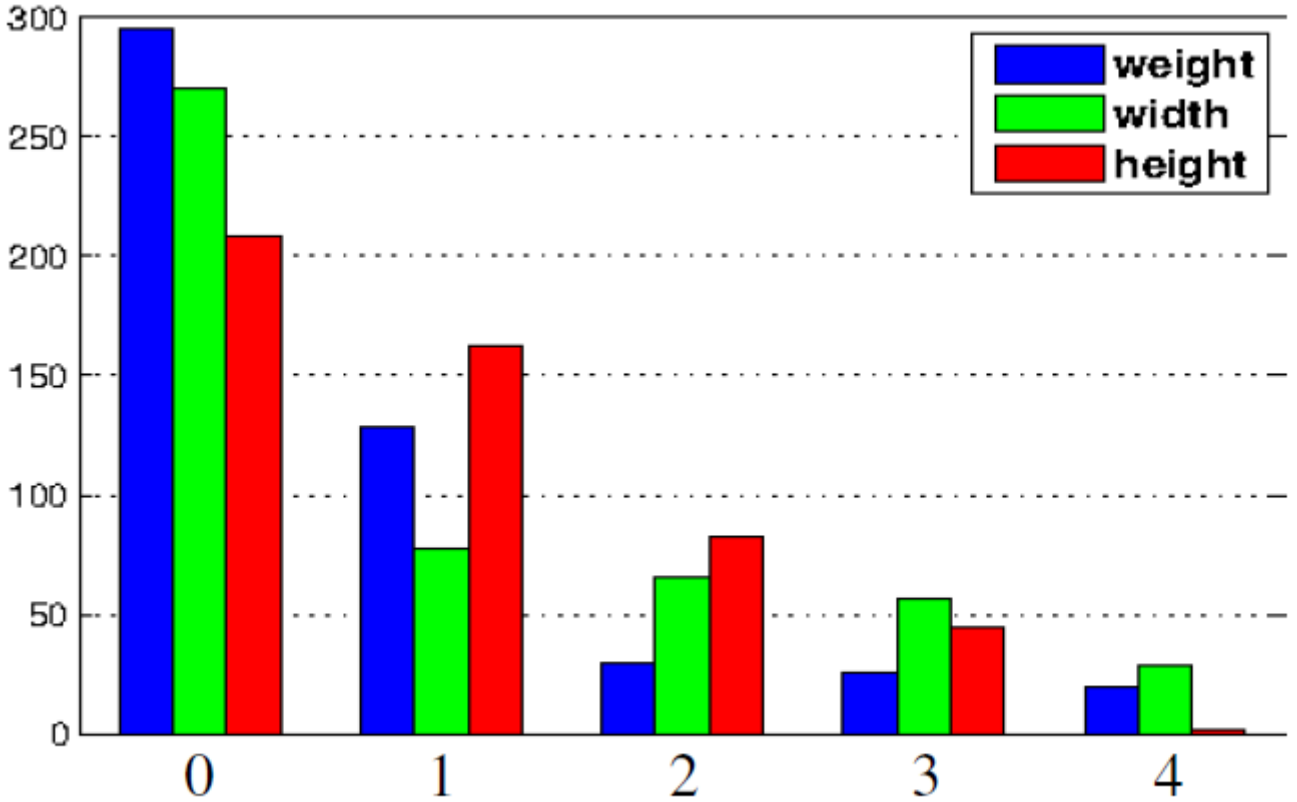
Object Order Insertion Results



Object Order Insertion Results



Object Order Insertion Results

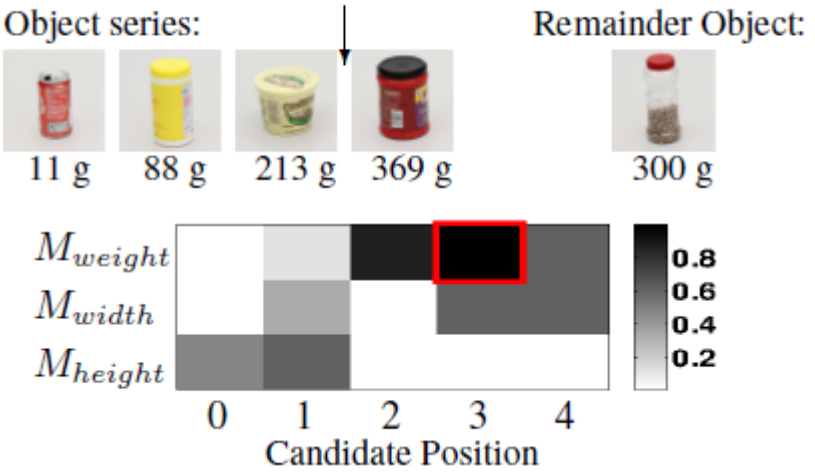


b) Histogram of Object Insertion Errors

Conclusion

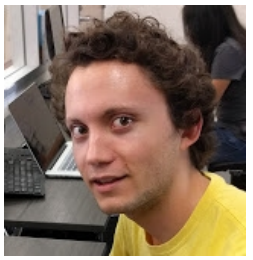
- A behavior-grounded framework for learning object ordering concepts
- The robot grounded three ordering concepts, “weight”, “height”, and “width”
- Future Work:
  - Active action selection
  - Learn object ordering concepts in conjunction with object categories, pairwise object relations, etc.
  - Learn from humans (for a preview, see our next talk at **Robotics and Vision III**)

Thank you!



Jivko Sinapov

Priyanka Khante



Maxwell Svetlik

Peter Stone

http://www.cs.utexas.edu/~larg/bwi_web/