

# Resolving Referring Expressions with Situated Contexts

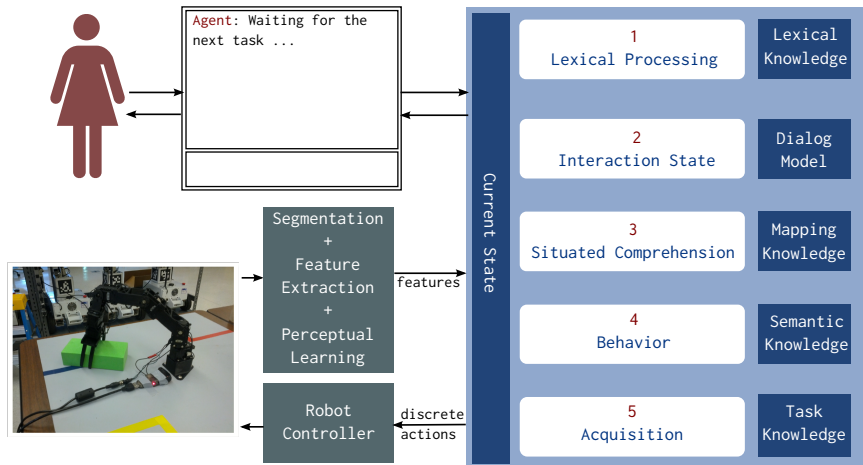
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University of Michigan

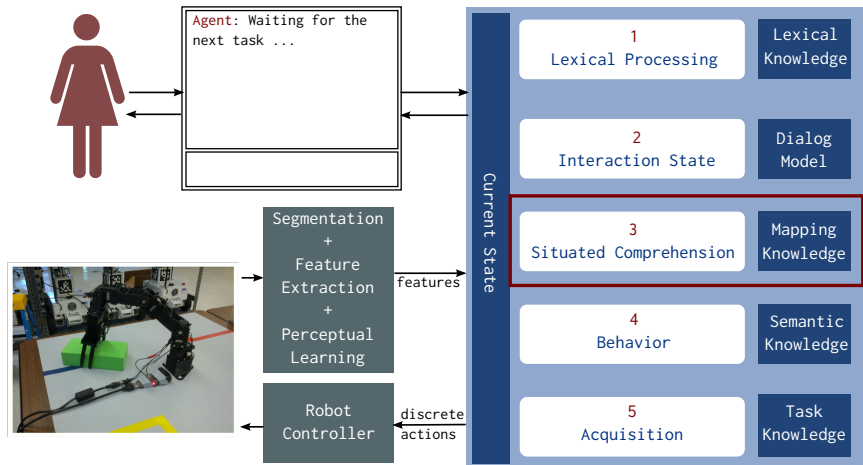
# Learning with Human-Robot/Agent Interaction

- Situated Interactive Instruction
  - agents embodied in real-world like domains
  - natural language interactions
  - exploit the common ground: shared perceptions, domain knowledge, experience
  - mixed-initiative learning
- Learn new tasks/actions (and verbs)
  - situated comprehension (this talk)
  - active learning (next talk)

## Process Overview



## Process Overview



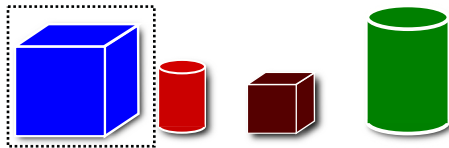
## Referring Expressions

- Phrases used to refer to objects
- Several surface forms: *it, this cube, that, the large cube*
- May be ambiguous with linguistic context alone
- Situational use

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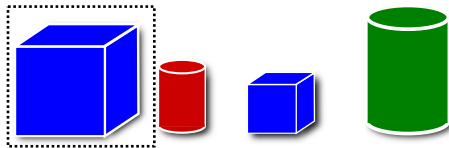
*Pick up the blue cube.*



## Referring Expressions

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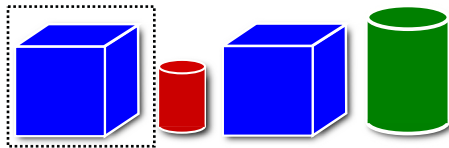
*Pick up the large, blue cube.*



## Referring Expressions

- Phrases used to refer to objects
- Several surface forms: *it, this cube, that, the large cube*
- May be ambiguous with linguistic context alone
- Situational use

*Pick up the cube on the left of the red cylinder.*





## Use of Referring Expressions

- Language is a co-operative joint activity.
- Communicative goal of *referring expression* (RE) is identification of *object of interest* by the hearer.
- Surface form, intonation, word order is influenced by saliency.
  - functionality and usefulness for a task, gestures, changes in appearance, surprise, discourse
- More informative RE for less salient objects and vice-versa.
  - *the red large block* for a new object
  - *it* for an object in context

## The Givenness Hierarchy

(Gundel et al., 1993)

- How are REs resolved in a cognitive system?
- Salience → cognitive accessibility (or status)
  - activated objects in short-term memory have a higher cognitive status than in long-term memory
- RE surface forms signal different cognitive statuses

in focus > activated > familiar > uniquely identifiable > referential > type identifiable

<i>it</i>	<i>this, that</i>	<i>that</i> N	<i>the</i> N	indefinite	<i>a</i> N
				<i>this</i> N	

- Two-dimensions of context (Knoeferle and Crocker, 2006)
  - *informational* and *temporal*

## Indexical Model for Language Comprehension

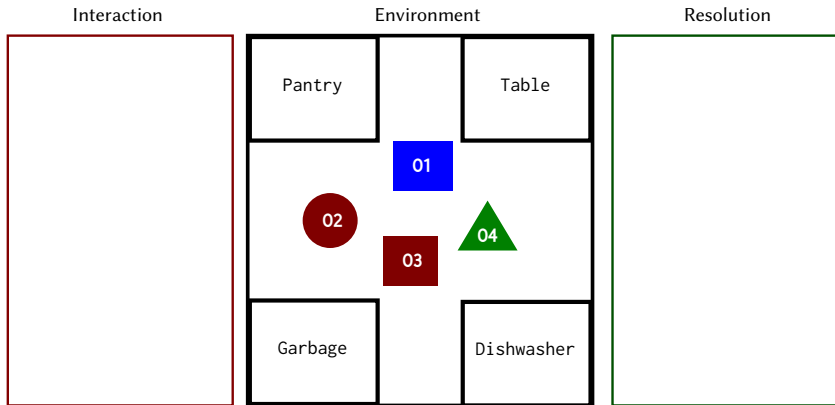
- Language features are cues to search perceptions, task knowledge, past experiences
  - language features → referents
  - *Referring expressions* → objects (perception)
  - *Verb + syntactical structure* → action-concept-network (semantic + procedural memory)
  - *Prepositions* → spatial-relationships (semantic memory + SVS)
- Domain knowledge is associated with referents
- Compose referents to generate a grounded representation.
  - constraints: syntactic, domain knowledge, current state.
  - removes ambiguity, augments underspecific information.

## Reference Resolution Model

A computational model of reference resolution that

- incorporated in the Indexical Model of Comprehension
  - referring expression → objects in perception
- sensitive to RE surface forms
  - exploits the Givenness hierarchy to create a hypothesis space
- incorporates various contexts
  - perceptual semantics, action knowledge, dialog state, attentional state
  - constrain the hypothesis space, guide search
- scales with learning new words (BOLT)
- implemented within the architectural constraints of Soar

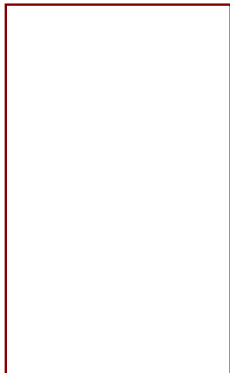
## Resolution Process



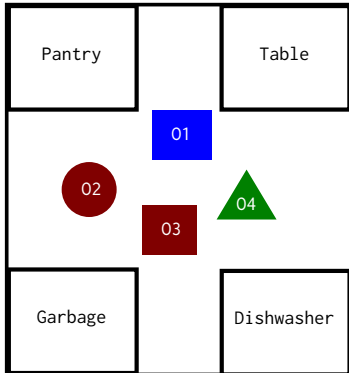
# Resolution Process

maintain cognitive status

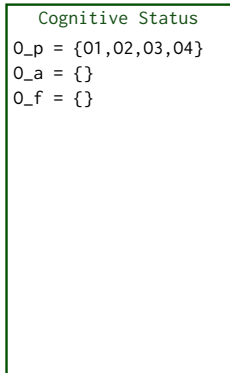
Interaction



Environment



Resolution



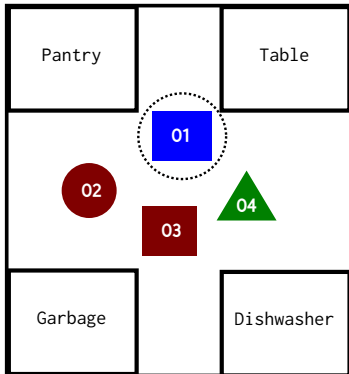
## Resolution Process

maintain cognitive status

Interaction

Instructor: This is a blue rectangle.

Environment



Resolution (*this*)

Cognitive Status

O\_p = {01,02,03,04}  
O\_a = {}  
O\_f = {}

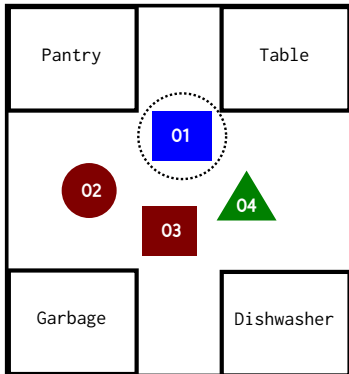
## Resolution Process

maintain cognitive status

Interaction

Instructor: This is a blue rectangle.

Environment



Resolution ('this')

Cognitive Status

O\_p = {01,02,03,04}  
O\_a = {01}  
O\_f = {}



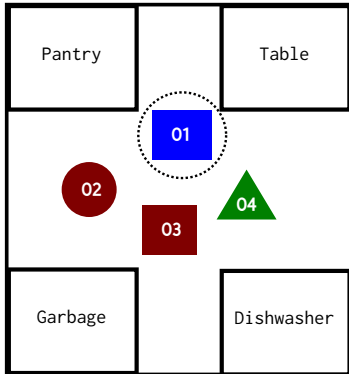
## Resolution Process

use GH heuristics to identify the candidates

Interaction

Instructor: This is a blue rectangle.

Environment



Resolution ('this')

Cognitive Status

$O_p = \{01, 02, 03, 04\}$

$O_a = \{01\}$

$O_f = \{\}$

GH Heuristic

this/that N  $\rightarrow$  active

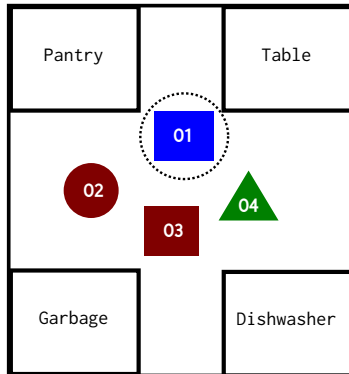
## Resolution Process

use GH heuristics to identify the candidates

Interaction

Instructor: This is a blue rectangle.

Environment



Resolution

Cognitive Status

$O_p = \{01, 02, 03, 04\}$

$O_a = \{01\}$

$O_f = \{\}$

GH Heuristic

this/that  $N \rightarrow active$

$O_c = O_a$

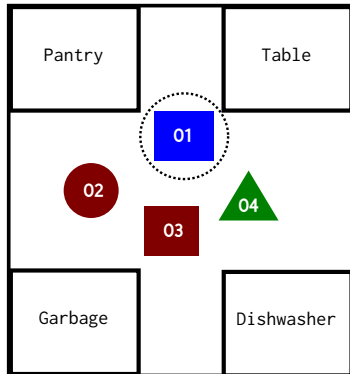
## Resolution Process

resolve

Interaction

Instructor: This is a blue rectangle.

Environment



Resolution ('this')

Cognitive Status  
 $O_p = \{01, 02, 03, 04\}$   
 $O_a = \{01\}$   
 $O_f = \{\}$   
GH Heuristic  
this/that N  $\rightarrow$  active  
  
 $O_c = O_a$   
Resolution  
*this = 01*

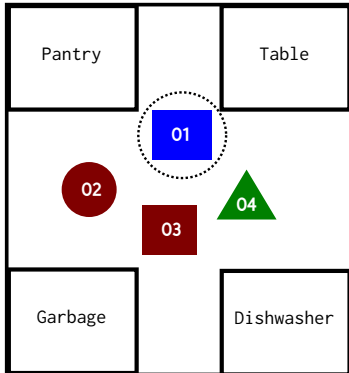
## Resolution Process

resolve

Interaction

Instructor: This is a blue rectangle.

Environment



Resolution ('this')

Cognitive Status

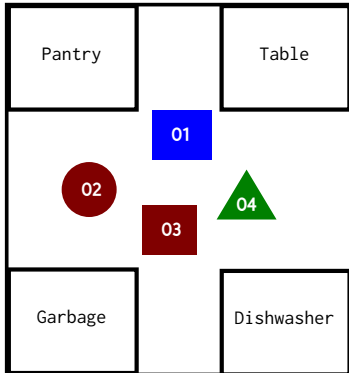
O\_p = {01,02,03,04}  
O\_a = {01}  
O\_f = {01}

## Resolution Process

### Interaction

**Instructor:** This is a blue rectangle.  
**Instructor:** This is to the right of the red cylinder.

### Environment



### Resolution ('this')

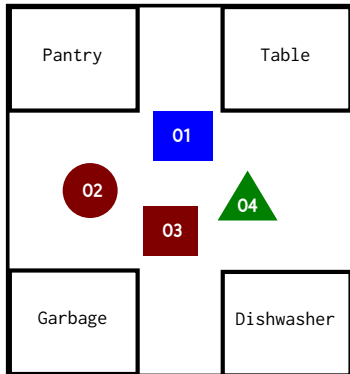
**Cognitive Status**  
O\_p = {01,02,03,04}  
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O\_f = {}

## Resolution Process

### Interaction

Instructor: This is a blue rectangle.  
Instructor: This is to the right of the red cylinder.

### Environment



### Resolution ('this')

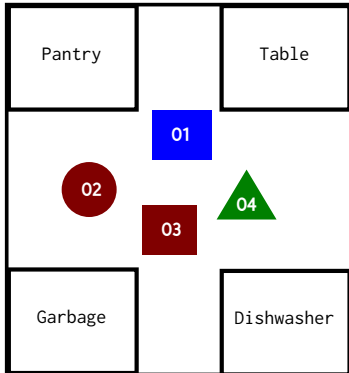
Cognitive Status  
O\_p = {01,02,03,04}  
O\_a = {01}  
O\_f = {}  
GH Heuristic  
this/that N → active

## Resolution Process

### Interaction

Instructor: This is a blue rectangle.  
Instructor: This is to the right of the red cylinder.

### Environment



### Resolution ('this')

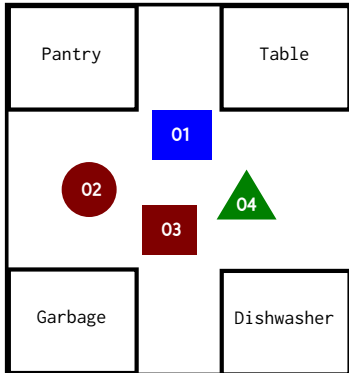
Cognitive Status  
 $O_p = \{01, 02, 03, 04\}$   
 $O_a = \{01\}$   
 $O_f = \{\}$   
GH Heuristic  
this/that  $N \rightarrow active$   
 $O_c = O_a$

## Resolution Process

## Interaction

Instructor: This is a blue rectangle.  
Instructor: This is to the right of the red cylinder.

## Environment



## Resolution ('this')

Cognitive Status  
 $O_p = \{01, 02, 03, 04\}$   
 $O_a = \{01\}$   
 $O_f = \{\}$   
GH Heuristic  
this/that  $N \rightarrow active$   
 $O_c = O_a$   
Resolution  
 $this = 01$

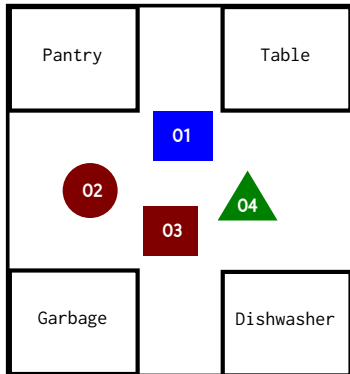


## Resolution Process

## Interaction

Instructor: This is a blue rectangle.  
Instructor: This is to the right of the red cylinder.

## Environment



## Resolution ('the red cylinder')

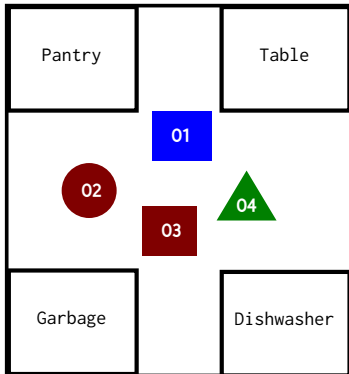
Cognitive Status  
 $O_p = \{01, 02, 03, 04\}$   
 $O_a = \{01\}$   
 $O_f = \{\}$   
GH Heuristic  
the N  $\rightarrow$  *percept*  
 $O_c = O_p$

## Resolution Process

## Interaction

Instructor: This is a blue rectangle.  
Instructor: This is to the right of the red cylinder.

## Environment



## Resolution ('the red cylinder')

## Cognitive Status

$O_p = \{01, 02, 03, 04\}$   
 $O_a = \{01\}$   
 $O_f = \{\}$

## GH Heuristic

the N  $\rightarrow$  *percept*

$O_c = O_p$

Filter(red)

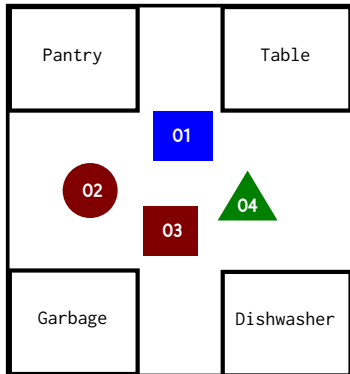
$O_c = \{02, 03\}$

## Resolution Process

## Interaction

Instructor: This is a blue rectangle.  
Instructor: This is to the right of the red cylinder.

## Environment



## Resolution ('the red cylinder')

## Cognitive Status

 $O_p = \{01, 02, 03, 04\}$  $O_a = \{01\}$  $O_f = \{\}$ 

## GH Heuristic

the N  $\rightarrow$  *percept* $O_c = O_p$ 

Filter(red)

 $O_c = \{02, 03\}$ 

Filter(cylinder)

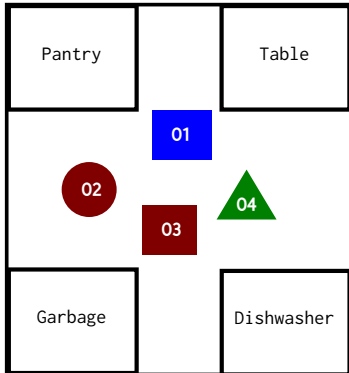
 $O_c = \{02\}$

## Resolution Process

## Interaction

Instructor: This is a blue rectangle.  
Instructor: This is to the right of the red cylinder.

## Environment



## Resolution ('the red cylinder')

## Cognitive Status

$O_p = \{01, 02, 03, 04\}$   
 $O_a = \{01\}$   
 $O_f = \{\}$

## GH Heuristic

the N  $\rightarrow$  *percept*

$O_c = O_p$

Filter(red)

$O_c = \{02, 03\}$

Filter(cylinder)

$O_c = \{02\}$

Resolution

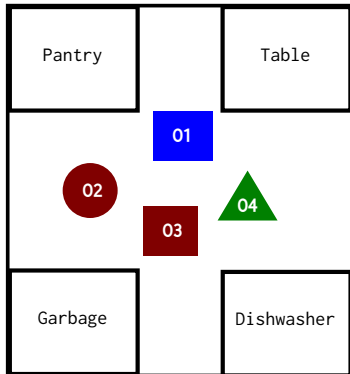
'the red cylinder' = 02

## Resolution Process

## Interaction

Instructor: This is a blue rectangle.  
Instructor: This is to the right of the red cylinder.

## Environment



## Resolution ('the red cylinder')

## Cognitive Status

$O_p = \{01, 02, 03, 04\}$   
 $O_a = \{02, 01\}$   
 $O_f = \{\}$

## GH Heuristic

the  $N \rightarrow$  *percept*

$O_c = O_p$

Filter(red)

$O_c = \{02, 03\}$

Filter(cylinder)

$O_c = \{02\}$

Resolution

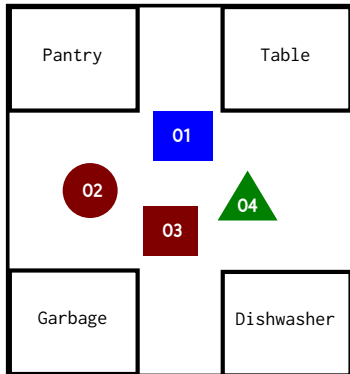
'the red cylinder' = 02

## Resolution Process

### Interaction

**Instructor:** This is a blue rectangle.  
**Instructor:** This is to the right of the red cylinder.

### Environment



### Resolution ('this')

**Cognitive Status**  
O\_p = {01,02,03,04}  
O\_a = {02,01}  
O\_f = {01,02}

## Resolution Process

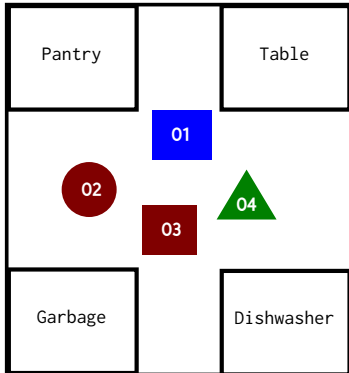
## Interaction

Instructor: This is a blue rectangle.

Instructor: This is to the right of the red cylinder.

Instructor: Move the rectangle to the pantry.

## Environment

Resolution (*the rectangle*)

## Cognitive Status

 $O_p = \{01, 02, 03, 04\}$  $O_a = \{02, 01\}$  $O_f = \{\}$ 

## GH Heuristic

the  $N \rightarrow$  *percept* $O_c = O_p$ 

Filter(rectangle)

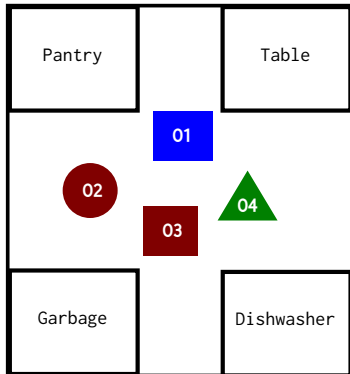
 $O_c = \{01, 03\}$

## Resolution Process

## Interaction

Instructor: This is a blue rectangle.  
Instructor: This is to the right of the red cylinder.  
Instructor: Move the rectangle to the pantry.

## Environment



## Resolution ('the rectangle')

Cognitive Status  
 $O_p = \{01, 02, 03, 04\}$   
 $O_a = \{02, 01\}$   
 $O_f = \{\}$   
GH Heuristic  
the  $N \rightarrow percept$   
 $O_c = O_p$   
Filter(rectangle)  
 $O_c = \{01, 03\}$   
Resolution  
'the rectangle' = 01

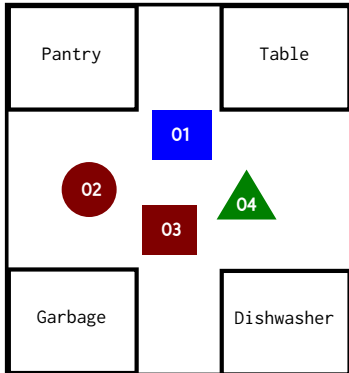


## Resolution Process

### Interaction

**Instructor:** This is a blue rectangle.  
**Instructor:** This is to the right of the red cylinder.  
**Instructor:** Move the rectangle to the pantry.

### Environment



### Resolution ('this')

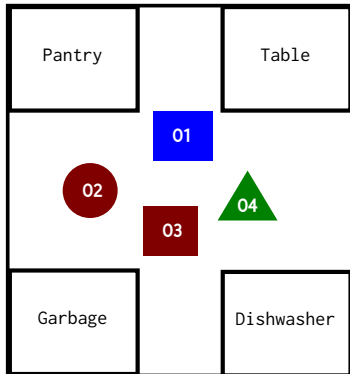
**Cognitive Status**  
O\_p = {01,02,03,04}  
O\_a = {02,01}  
O\_f = {01,pantry}

## Resolution Process

## Interaction

Instructor: This is a blue rectangle.  
Instructor: This is to the right of the red cylinder.  
Instructor: Move the rectangle to the pantry.  
Instructor: Pick it up.

## Environment



## Resolution ('it')

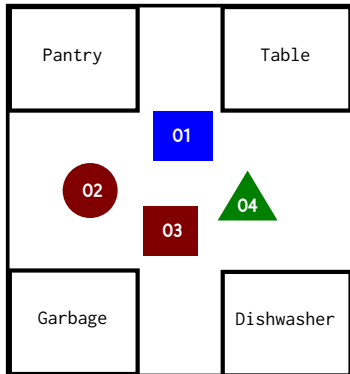
Cognitive Status  
O\_p = {01,02,03,04}  
O\_a = {02,01}  
O\_f = {01,pantry}  
GH Heuristic  
it → *focus*  
O\_c = O\_f

## Resolution Process

## Interaction

Instructor: This is a blue rectangle.  
Instructor: This is to the right of the red cylinder.  
Instructor: Move the rectangle to the pantry.  
Instructor: Pick it up.

## Environment



## Resolution ('it')

## Cognitive Status

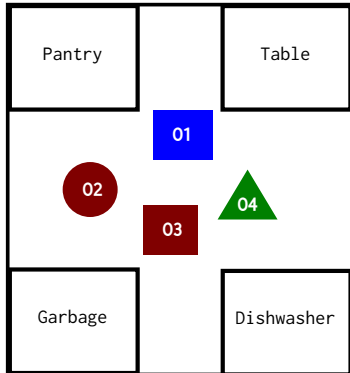
```
O_p = {01,02,03,04}
O_a = {02,01}
O_f = {01,pantry}
  GH Heuristic
  it → focus
  O_c = O_f
  Filter(pick-up)
  O_c = {01}
```

## Resolution Process

## Interaction

Instructor: This is a blue rectangle.  
Instructor: This is to the right of the red cylinder.  
Instructor: Move the rectangle to the pantry.  
Instructor: Pick it up.

## Environment



## Resolution ('it')

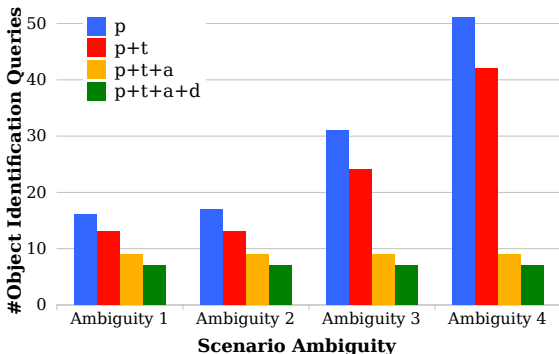
Cognitive Status  
O\_p = {01,02,03,04}  
O\_a = {02,01}  
O\_f = {01,pantry}  
GH Heuristic  
it → *focus*  
O\_c = O\_f  
Filter(pick-up)  
O\_c = {01}  
Resolution  
'it' = 01

## Results

**scenarios:** number of distractors

**models:**  $p$ ,  $p+t$ ,  $p+t+a$ ,  $p+t+a+d$

**corpus:** instructional dialogs, 12 personal pronouns (*it*), 4 demonstrative pronouns (*this*), 3 demonstrative phrases (*that cylinder*), and 14 noun phrases (*the red cylinder*)



## Nuggets and Coal

- Nuggets
  - `integrative theory' of situated contexts
  - integrates with interaction
  - non-linguistic knowledge for linguistic comprehension
- Coal
  - not complete
  - not rigorously evaluated