A Game-Theoretic Approach to Generating Spatial Descriptions

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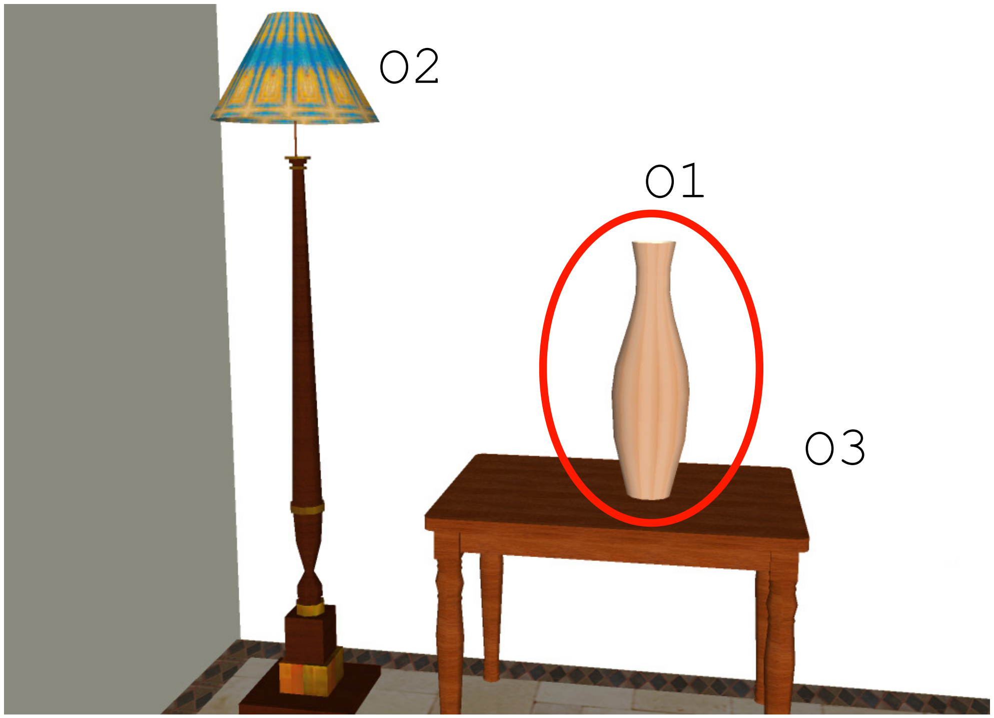
Berkeley

N L P

Language is about Communication

Goal: refer to O1



[Grice, 1975]

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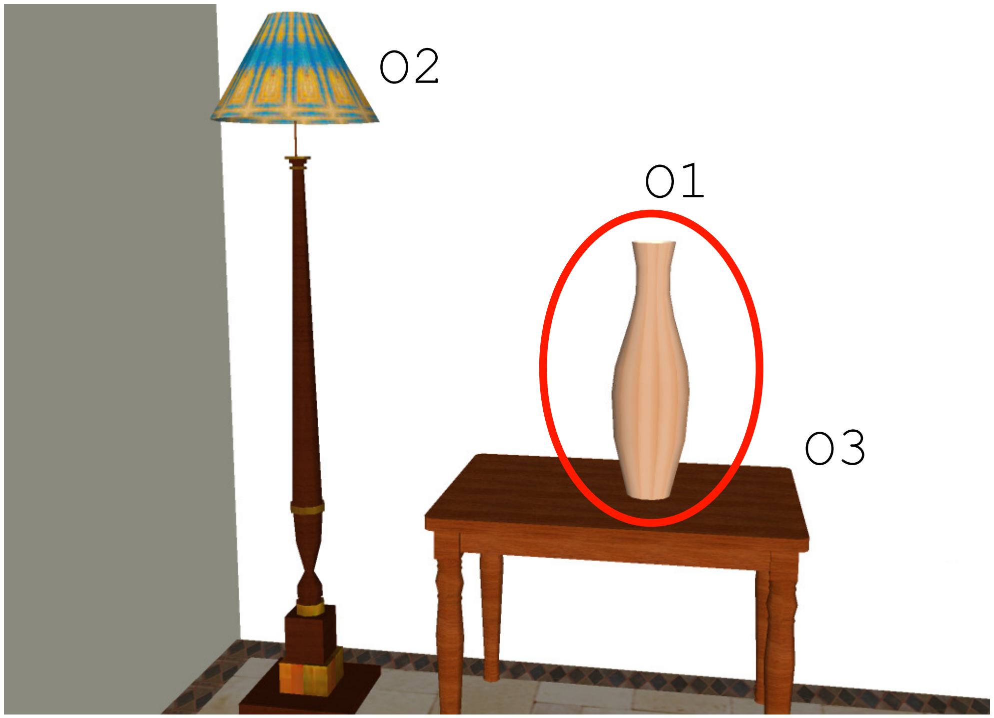

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Language is about Communication

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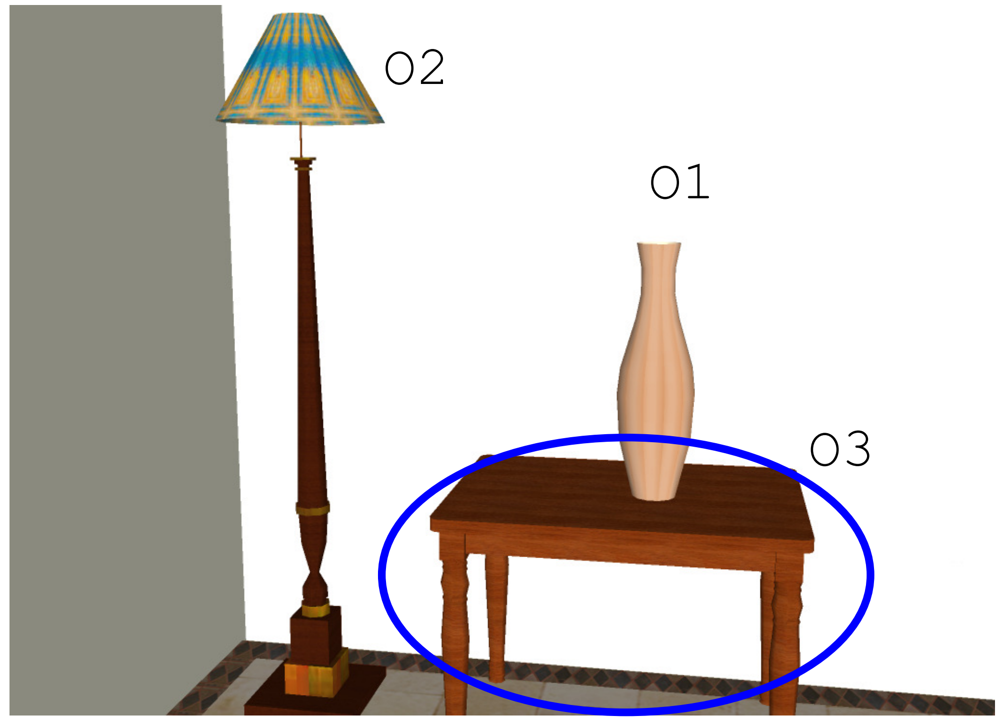
on 03



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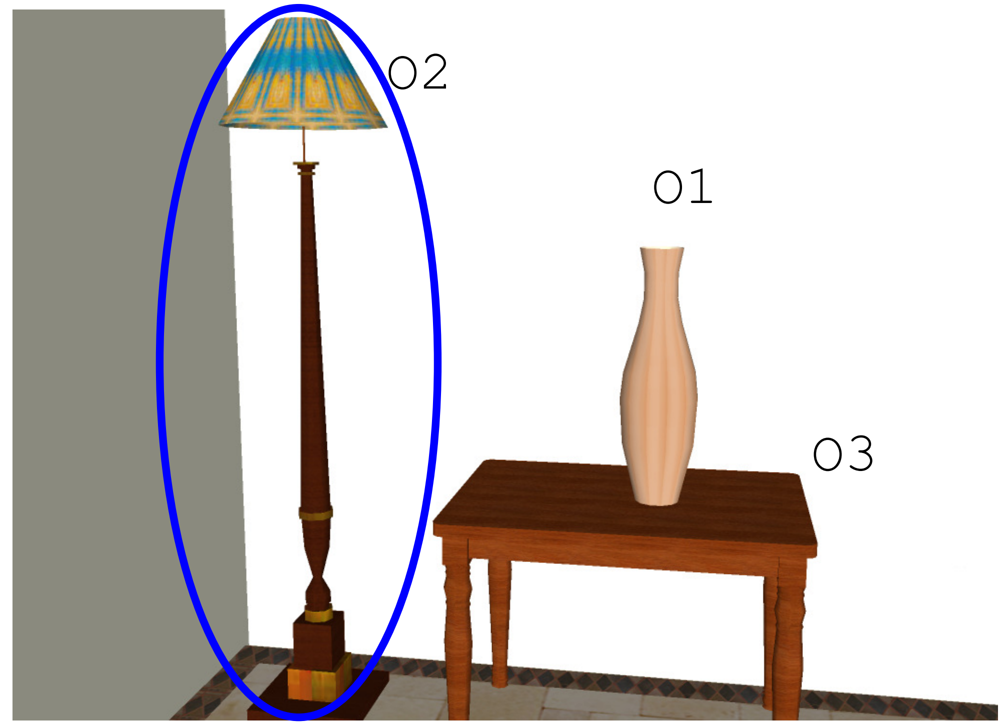
on O3 *right of* O2



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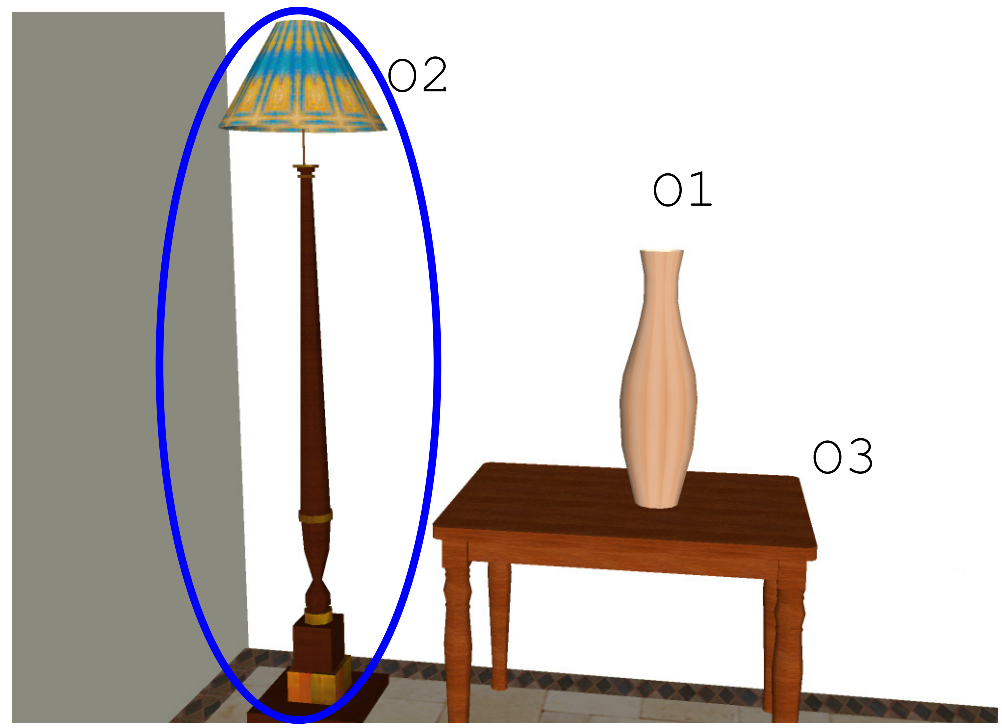

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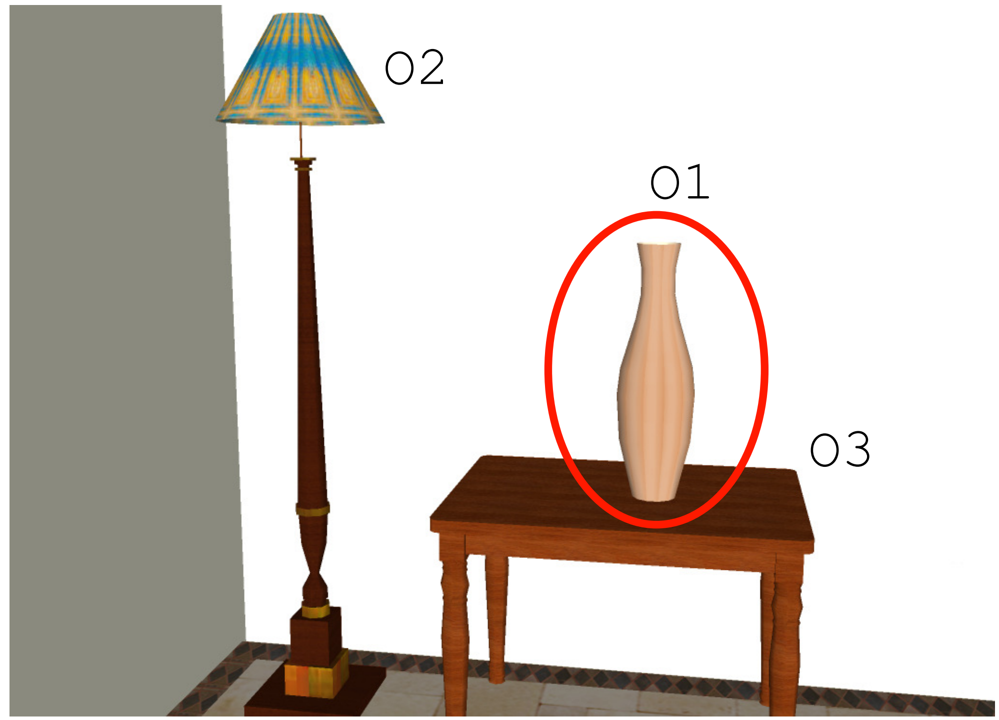

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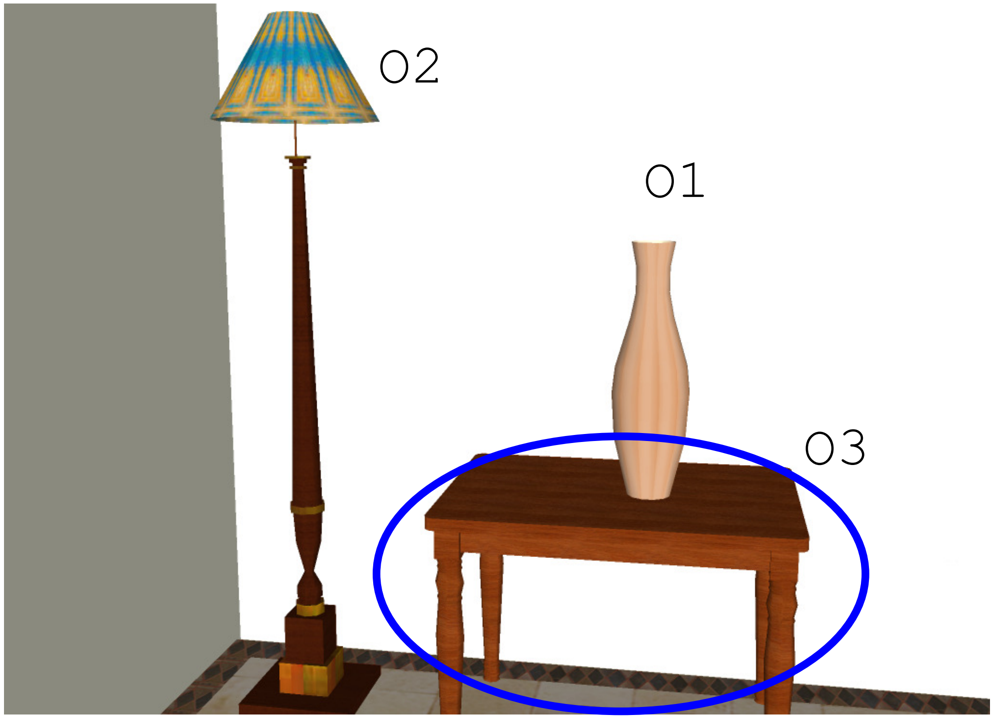

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on O3

[Grice, 1975]

Actual Example

Language Game

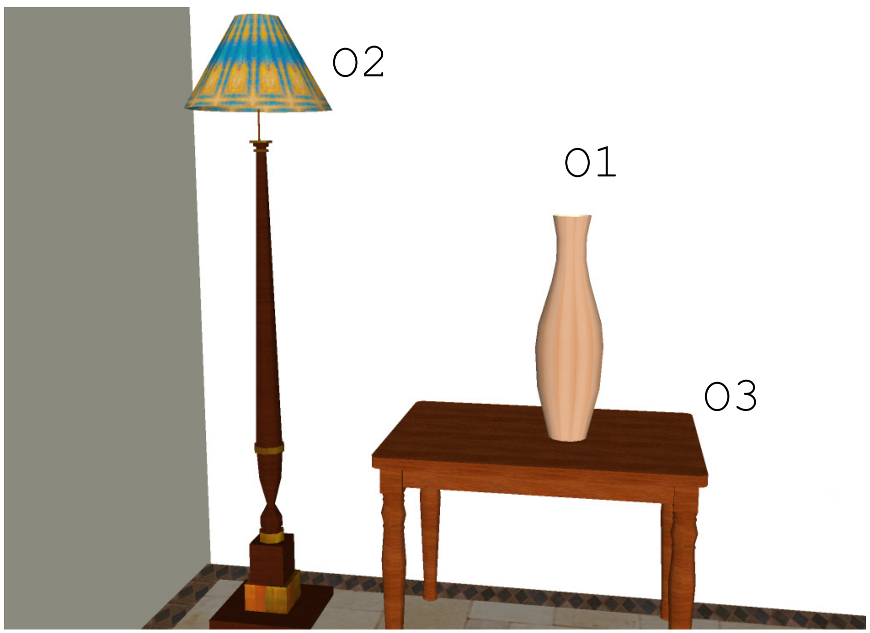
speaker

Language Game

speaker listener

Language Game

speaker listener



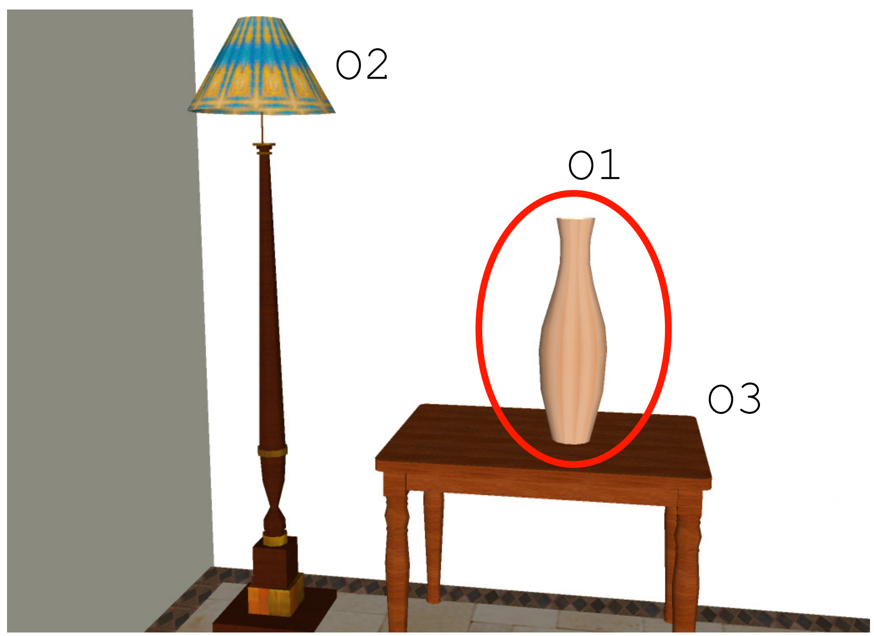
Language Game

target

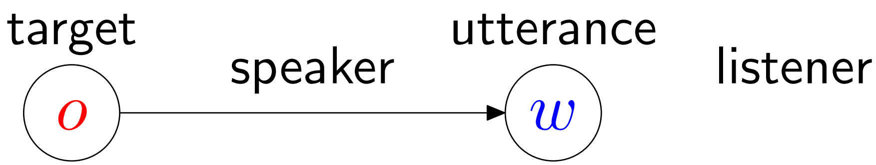
o

speaker

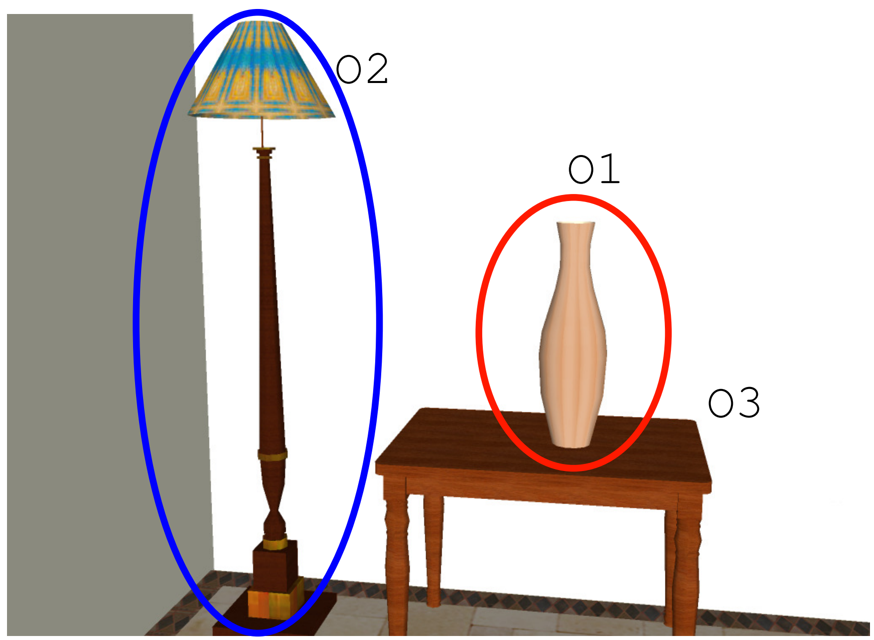
listener



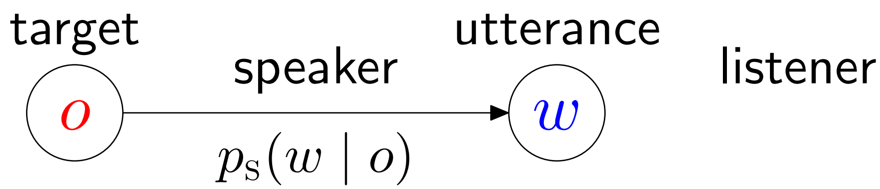
Language Game



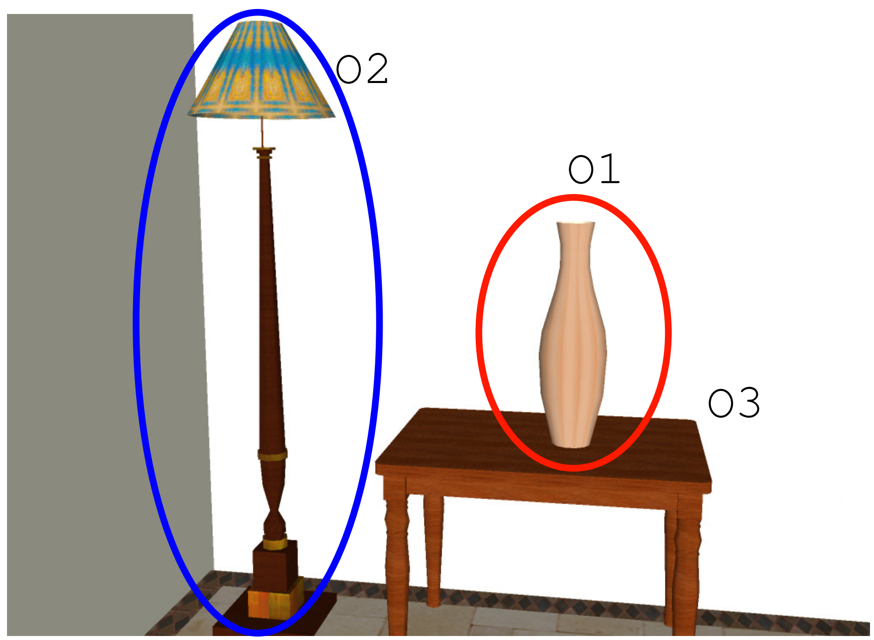
right of 02



Language Game



right of O2

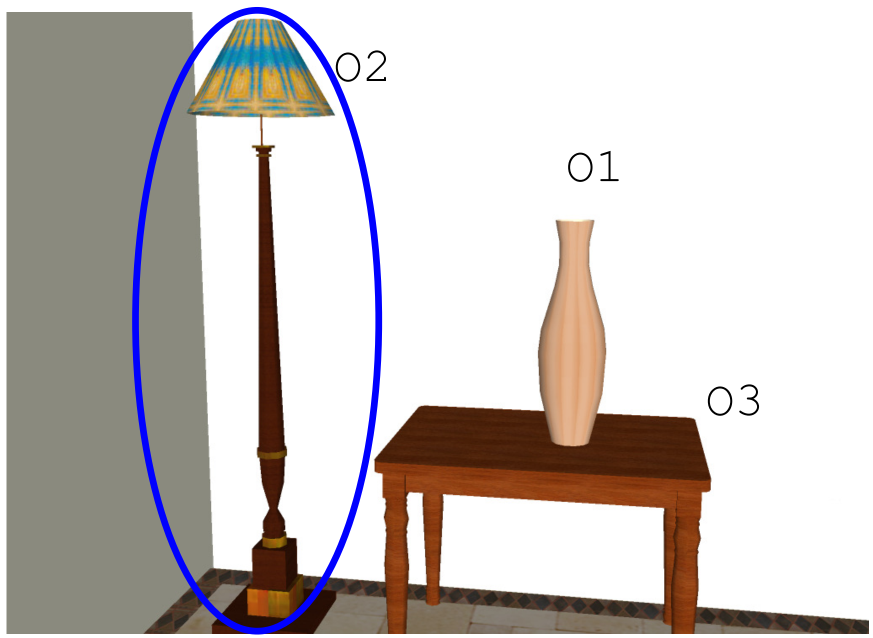


Language Game

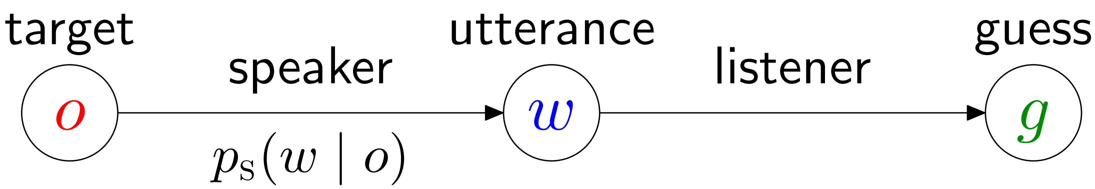
target $\qquad$ utterance $\qquad$ listener

$$o \xrightarrow[p_{\mathrm{S}}(w \mid o)]{\text{speaker}} w$$

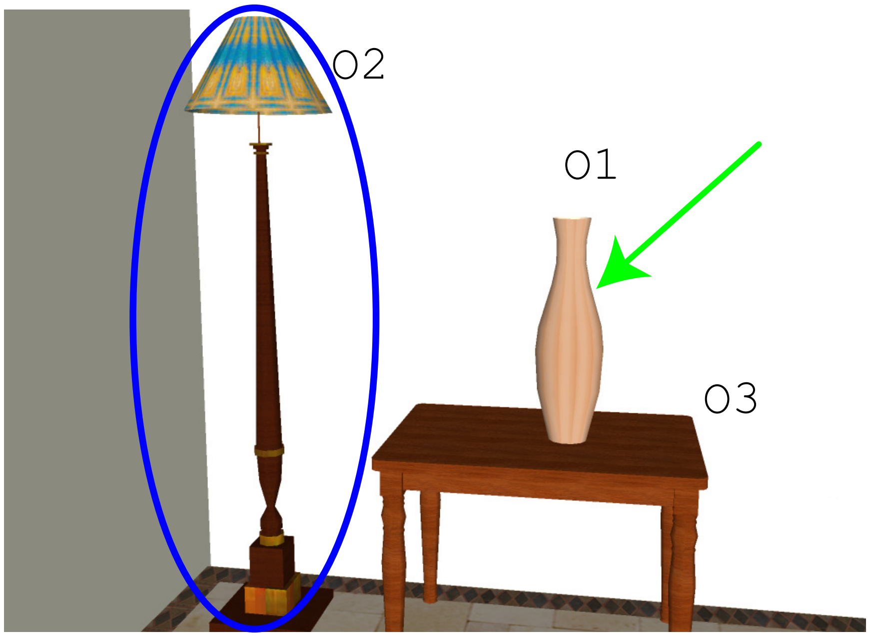
right of O2



Language Game



right of O2

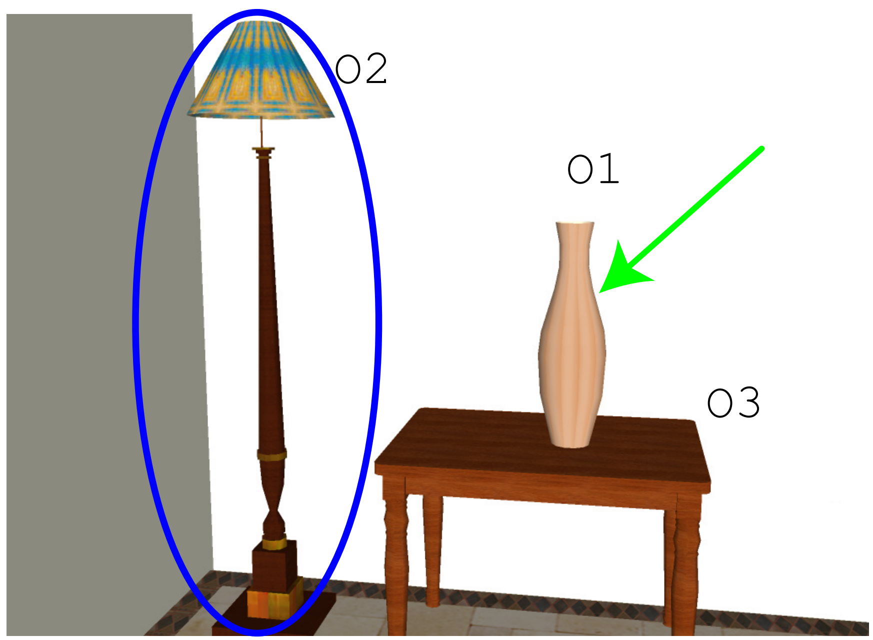


Language Game

target | utterance | guess

$$\underset{\text{target}}{o} \xrightarrow[p_{\mathrm{S}}(w \mid o)]{\text{speaker}} \underset{\text{utterance}}{w} \xrightarrow[p_{\mathrm{L}}(g \mid w)]{\text{listener}} \underset{\text{guess}}{g}$$

right of O2



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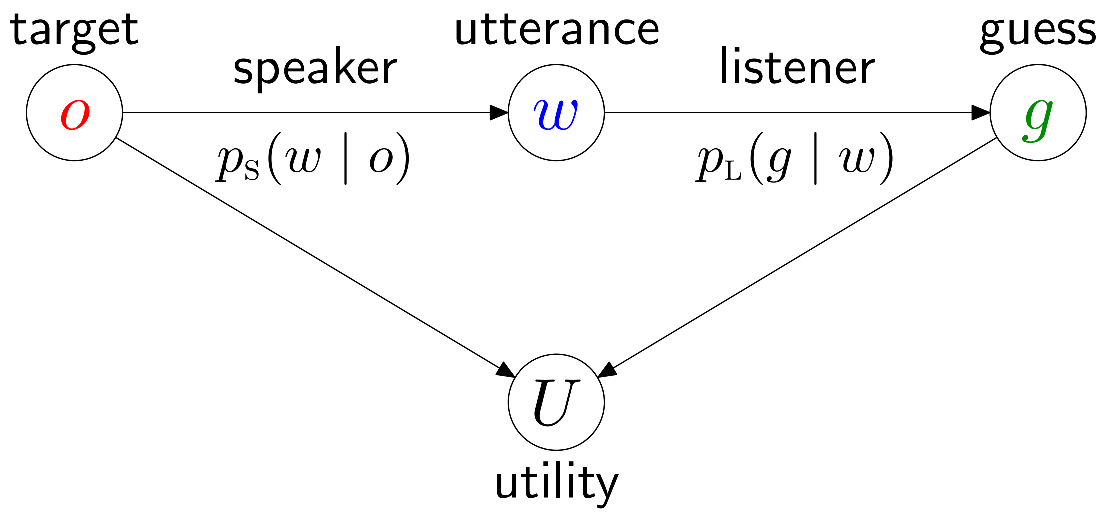
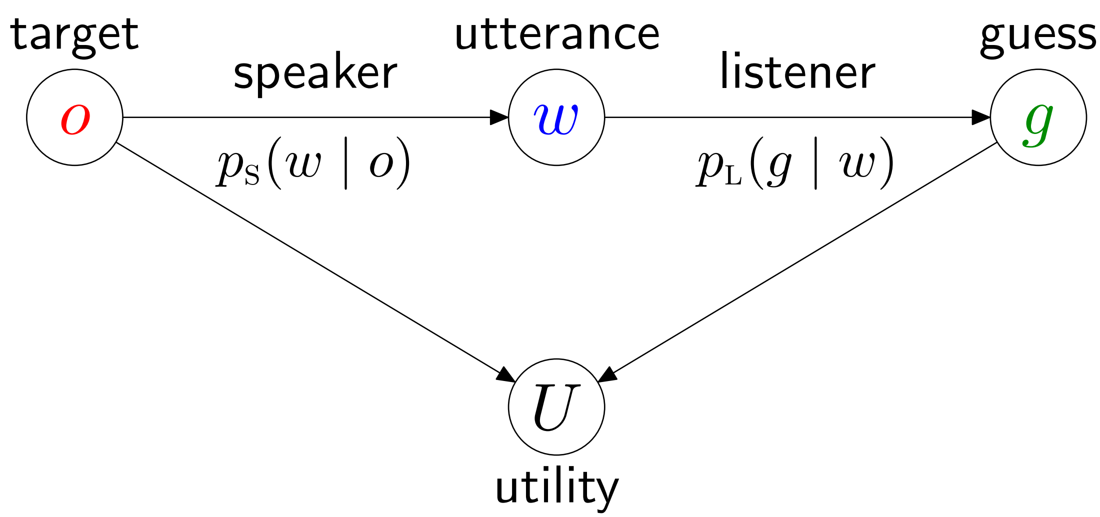


$$\mathsf{U}(o, g) = \mathbb{I}[o = g] = \begin{cases} 1 & \text{if } o = g \\ 0 & \text{otherwise} \end{cases}$$

Language Game



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$$\mathsf{EU}(\text{S}, \text{L}) = \mathbb{E}_{\text{S},\text{L}}[U(o, g)]$$

Speaker Strategies

Assign scores to utterances via:

$$p_{\mathrm{S}}(w|o)$$

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1. semantics only (Maxim of Quality)

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1. semantics only (Maxim of Quality)
2. semantics + pragmatics (Maxims of Quality + Manner)

Semantics Only

Game tree:

01
- *right of* 02
- *on* 03

Semantics Only

Game tree:

$$\begin{tikzcd}[column sep=small] & \textit{right of } \mathsf{O2} \\ \mathsf{O1} \arrow[ur, dash] \arrow[dr, dash] & \\ & \textit{on } \mathsf{O3} \end{tikzcd}$$

$p_{\mathrm{S}}(w|o)$ depends only on truth of utterance, does not need to take listener into account

Semantics Only

Game tree:

O1 — *right of* O2

O1 — *on* O3

$p_{\mathrm{S}}(w|o)$ depends only on truth of utterance, does not need to take listener into account

Reflex speaker because it does not consider consequence of actions.

Semantics + Pragmatics

Maximize wrt. $p_{\text{S}}(w|o)$:

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$$\begin{array}{ll} & \textit{right of } 02 \\ 01 & \\ & \textit{on } 03 \end{array}$$

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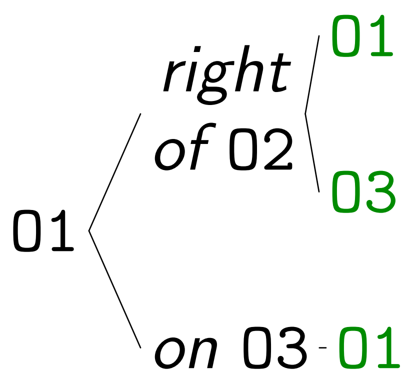

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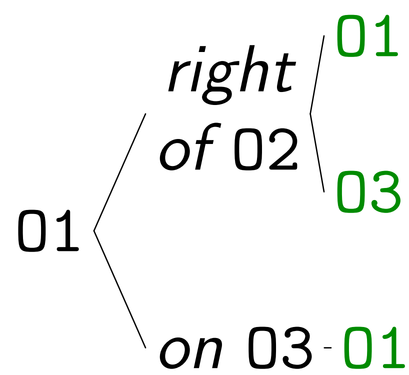
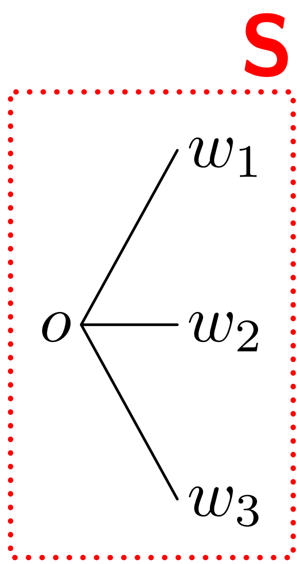
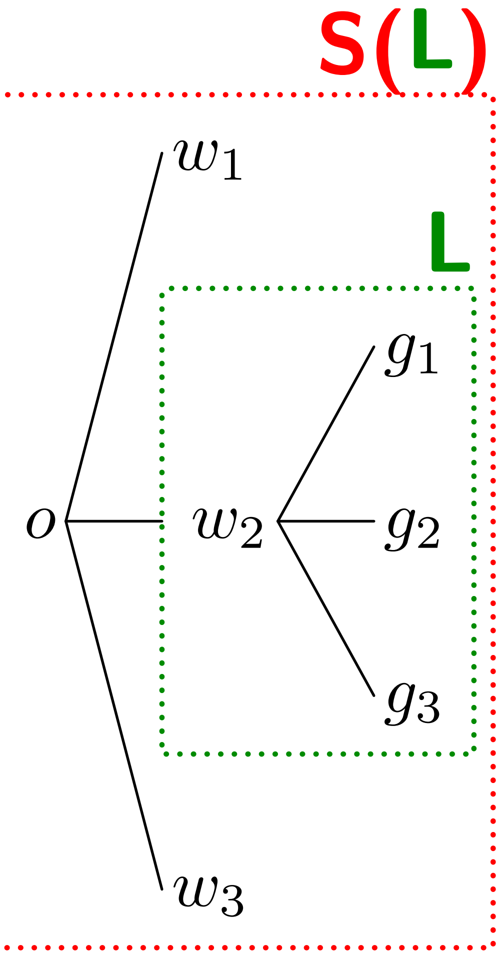


<u>Rational speaker</u> because it is optimal with respect to given listener.

Reflex vs. Rational



Reflex
(semantics only)



Rational
(semantics + pragmatics)

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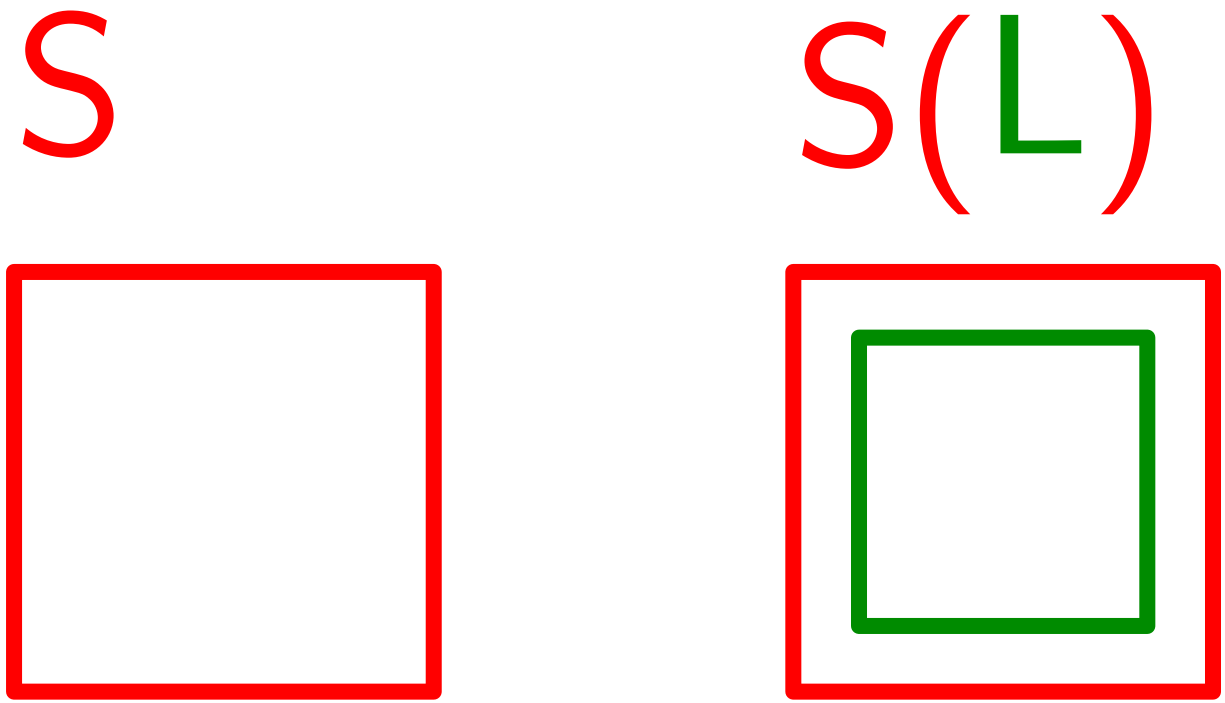


Reflex
(semantics only)

Rational
(semantics + pragmatics)

Experimental Setup

Google sketchup: 43 rooms, average of 22 objects per room

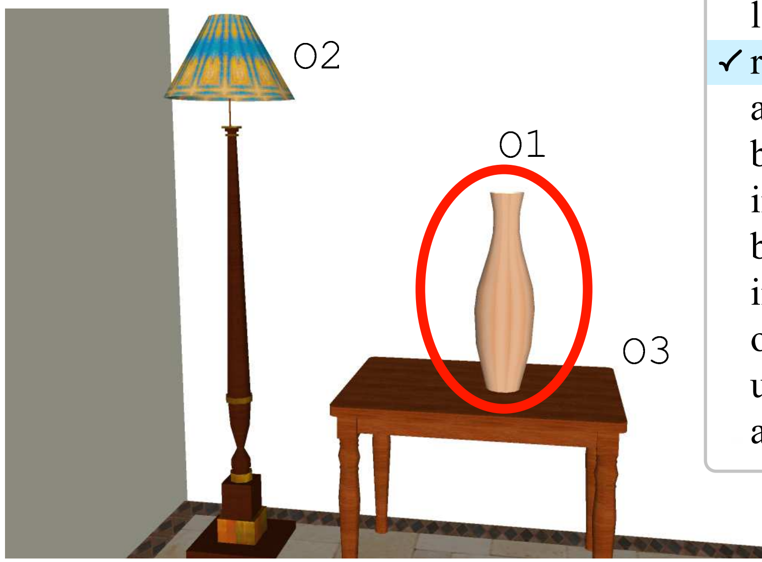
Data Collection with Mechanical Turk

Question: Where is the object outlined in red?

Answer: The object outlined in red is

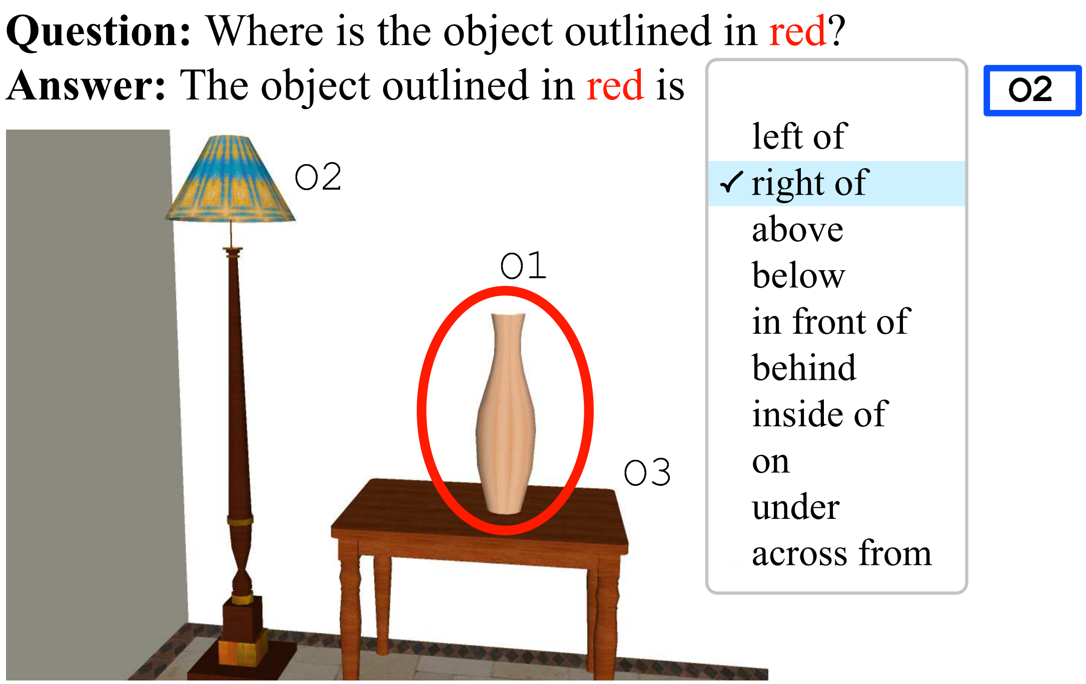
- left of
- ✓ right of
- above
- below
- in front of
- behind
- inside of
- on
- under
- across from

O2



Speaker: $o \to w$

Data Collection with Mechanical Turk



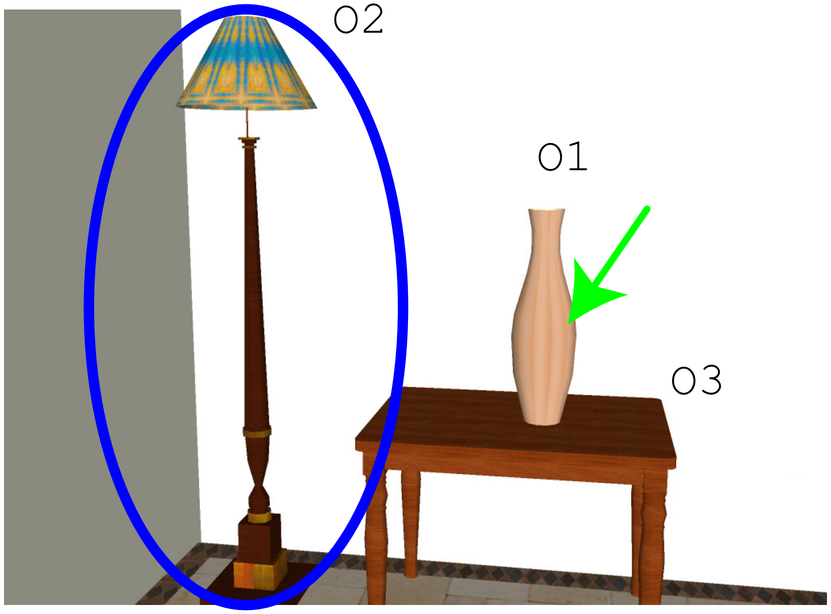
Speaker: $o \rightarrow w$

Yields annotated data:

$$\{(o_1, w_1), \cdots, (o_n, w_n)\}$$

Evaluation with Mechanical Turk

Question: What object is **right of** $\boxed{\text{O2}}$?



Listener: $w \rightarrow g$

Evaluation with Mechanical Turk

Given $p_{\mathrm{S}}(w|o)$, and $(o_1, \ldots, o_n)$,

Evaluation with Mechanical Turk

Given $p_{\mathrm{S}}(w|o)$, and $(o_1, \ldots, o_n)$,

S generates:

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Given $p_{\mathrm{S}}(w|o)$, and $(o_1, \ldots, o_n)$,

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where:

$$w_i = \mathsf{argmax}_w \, p_{\mathrm{S}}(w|o_i)$$

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turkers generate:

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turkers generate:

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compute success metric:

$$\textsc{Success}(\text{S}) = \frac{1}{n} \sum_i \mathbb{I}[o_i = g_i]$$

Evaluation with Mechanical Turk

Given $p_{\textsc{s}}(w|o)$, and $(o_1, \ldots, o_n)$,

$\textsc{s}$ generates:

$$(w_1, \ldots, w_n)$$

where:

$$w_i = \text{argmax}_w \, p_{\textsc{s}}(w|o_i)$$

turkers generate:

$$(g_1, \ldots, g_n)$$

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Note: only collecting data and evaluating are done by humans.

Results

LITERAL agents put mass uniformly on true outputs

	Speaker	Success
Reflex	S LITERAL	4.6%
Rational	S(L) LITERAL	33.7%

Rational speaker outperforms reflex speaker.

Key Points

Rational speaker S(L) outperforms reflex speaker S

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Up next: extensions for improving the listener model.

Listener Extensions

- Training a Listener
- Generating Complex Utterances
- Modeling Listener Confusion

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Learned Listener Model

Before: listener was LITERAL

Learned Listener Model

Before: listener was $\textsc{Literal}$

Now: learn from mturk data:

$$\{(o_1, w_1), \ldots, (o_n, w_n)\}$$

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Train a log-linear model:

$$p_{\textsc{Learned}}(g|w; \theta_{\textsc{l}}) \propto \exp\{{\theta_{\textsc{l}}}^\top \phi(g, w)\}$$

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Use it to define the rational $\overset{\text{S(L)}}{\boxed{\square}}$ Learned speaker

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Use it to define the rational S(L) Learned speaker

We also train $p_{\textsc{s}}(w|o; \theta_{\textsc{s}})$ using the same data and features

to get the reflex S Learned speaker

Features

The features $\phi(g, w)$ are defined between:

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- guess object g

Features inspired by [Regier, 2001; Tellex, 2009; Landau, 1993]

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Features

The features $\phi(g, w)$ are defined between:

- guess object g
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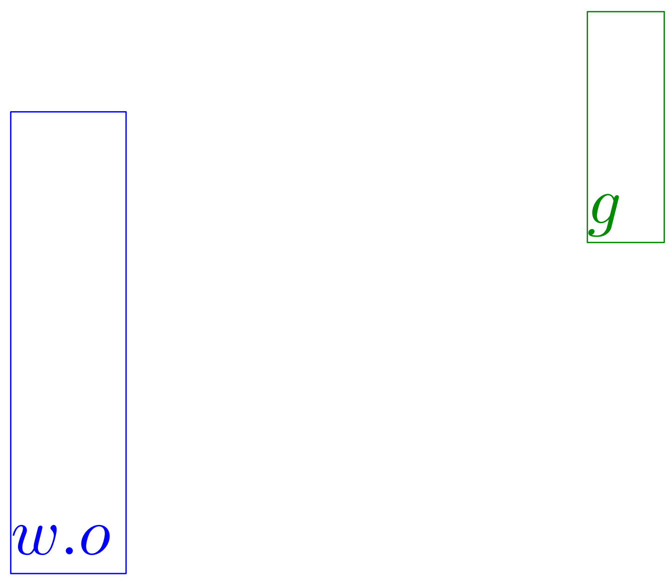
Features inspired by [Regier, 2001; Tellex, 2009; Landau, 1993]

Features

The features $\phi(g, w)$ are defined between:

- guess object g
- w $= \underbrace{\textit{right of}}_{w.r}\,\underbrace{\text{02}}_{w.o}$
- g and $w.o$ are bounding boxes



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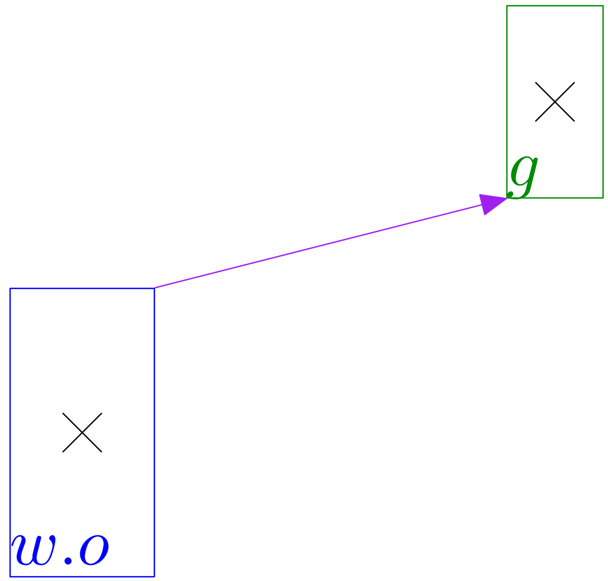
Distance Features



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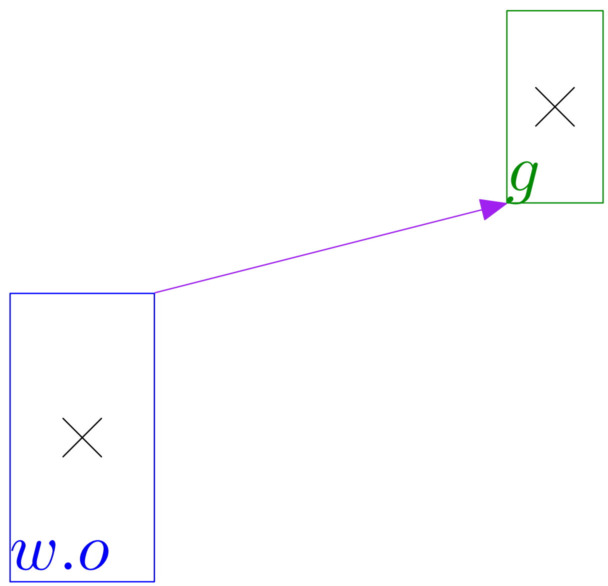
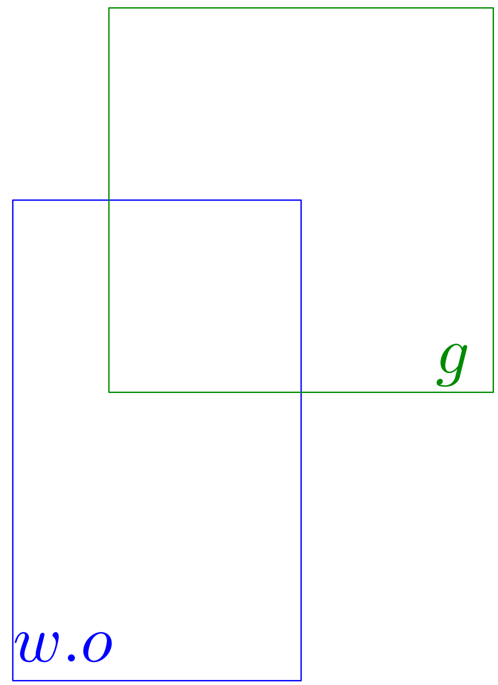


ϕ_{dist} = value of shortest distance between g and $w.o$
$\phi_{top1} = \mathbb{I}[g \text{ is closest to } w.o]$
$\phi_{top5} = \mathbb{I}[g \text{ is among top 5 closest to } w.o]$
$\phi_{top10} = \mathbb{I}[g \text{ is among top 10 closest to } w.o]$

Containment Features



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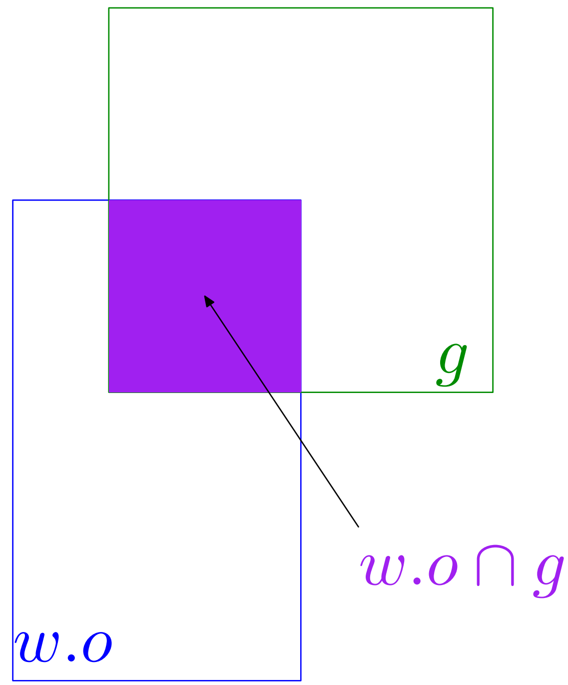
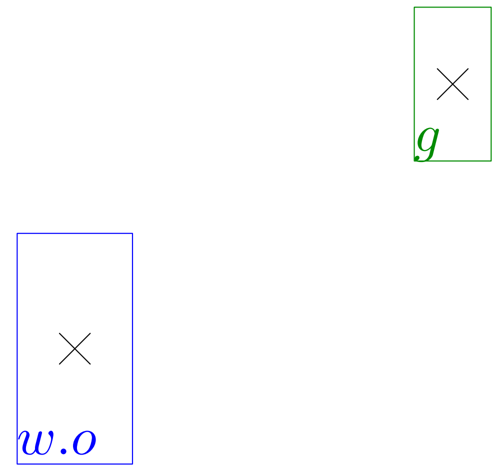


$$\phi_{cont2} = \mathsf{vol}(w.o \cap g)\ /\ \mathsf{vol}(g)$$

$$\phi_{cont1} = \mathsf{vol}(w.o \cap g)\ /\ \mathsf{vol}(w.o)$$

Projection Features



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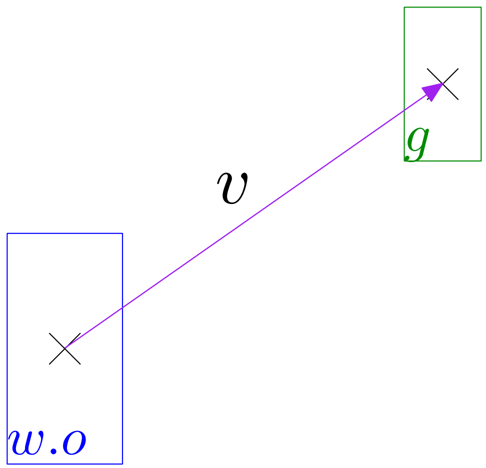

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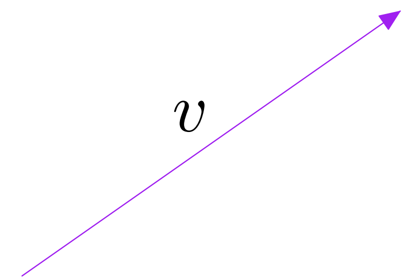

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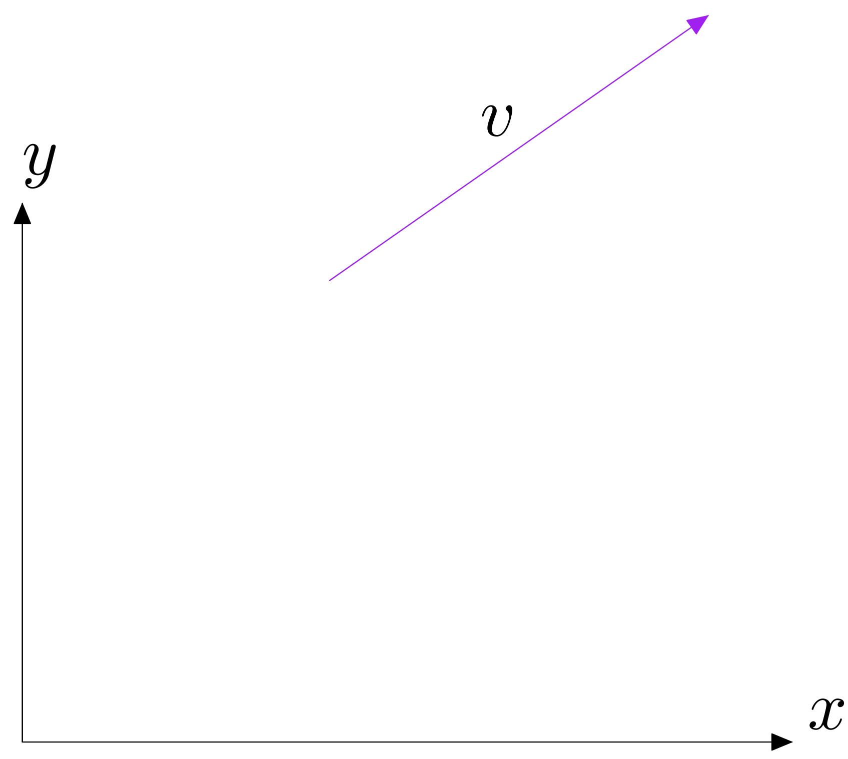

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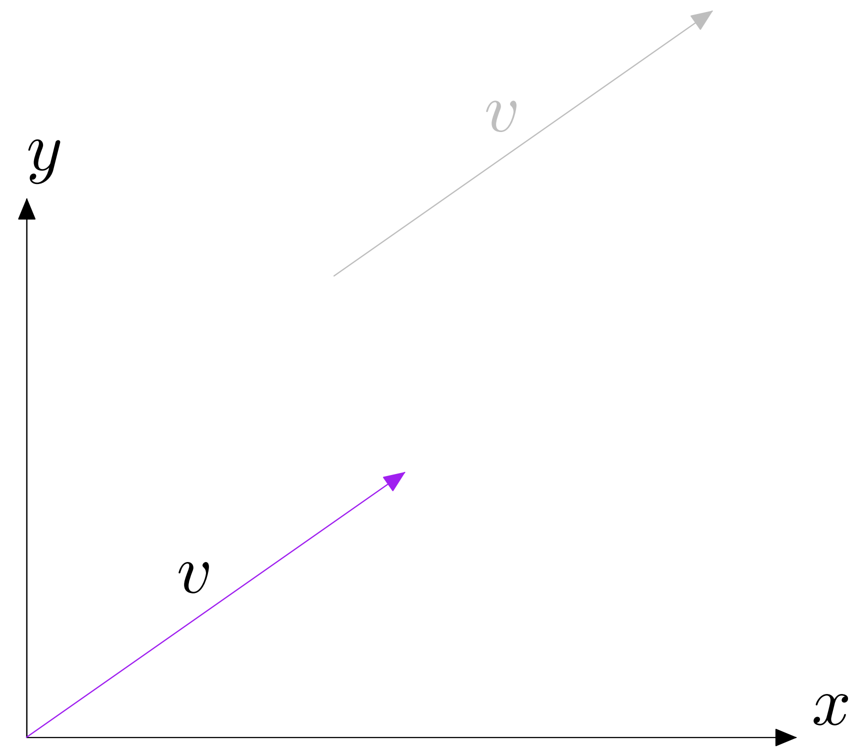

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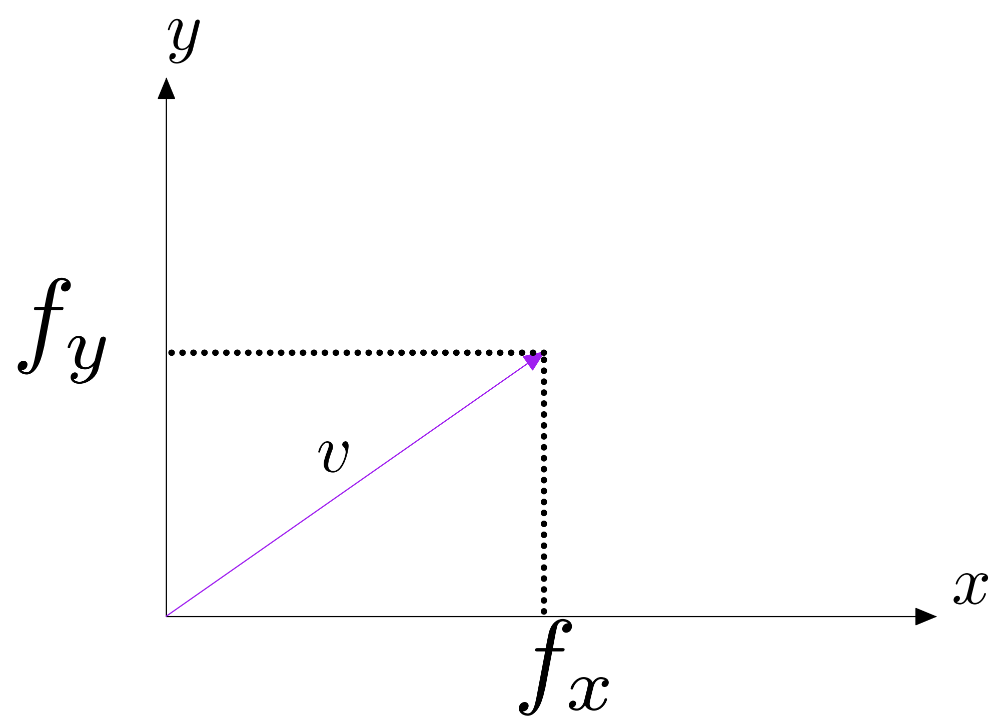
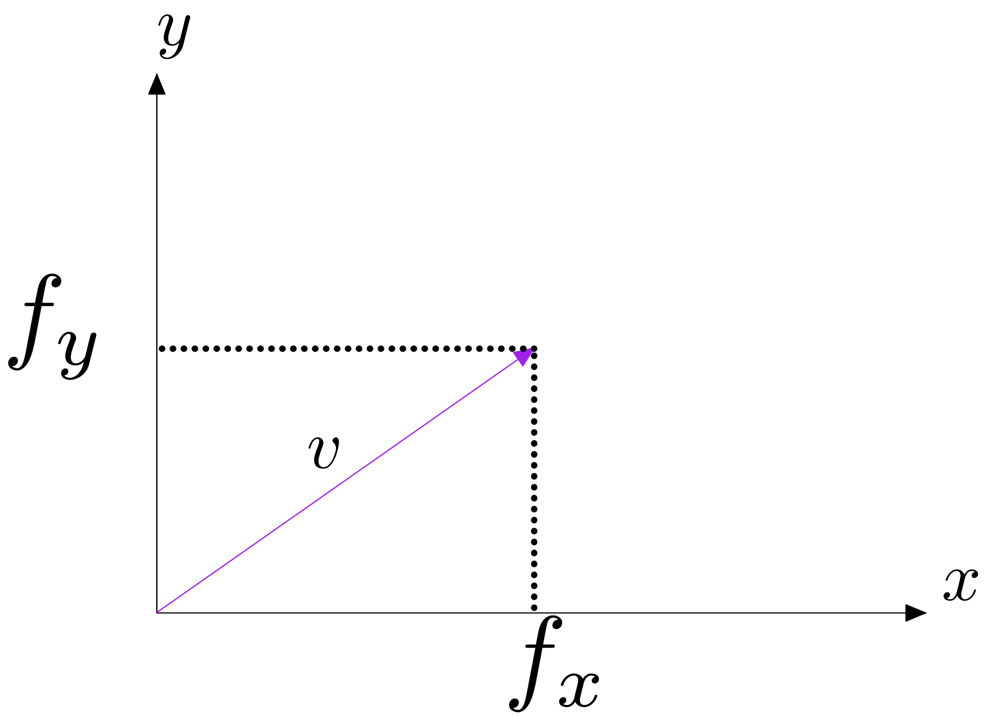


Projection Features

$$\phi_{projx} = f_x$$
$$\phi_{projy} = f_y$$
$$\phi_{projz} = f_z$$
$$\phi_{proj1} = \mathbb{I}[f_x = \max\{f_x, f_y, f_z\}]$$
$$\phi_{proj2} = \mathbb{I}[f_y = \max\{f_x, f_y, f_z\}]$$
$$\phi_{proj3} = \mathbb{I}[f_z = \max\{f_x, f_y, f_z\}]$$



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Results

	Speaker	Success
Reflex	S LITERAL	4.6%
Rational	S(L) LITERAL	33.7%
Reflex	S LEARNED	38.4%
Rational	S(L) LEARNED	52.6%

What's missing?

Two things are missing from the setup so far.

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1. Arbitrary descriptors

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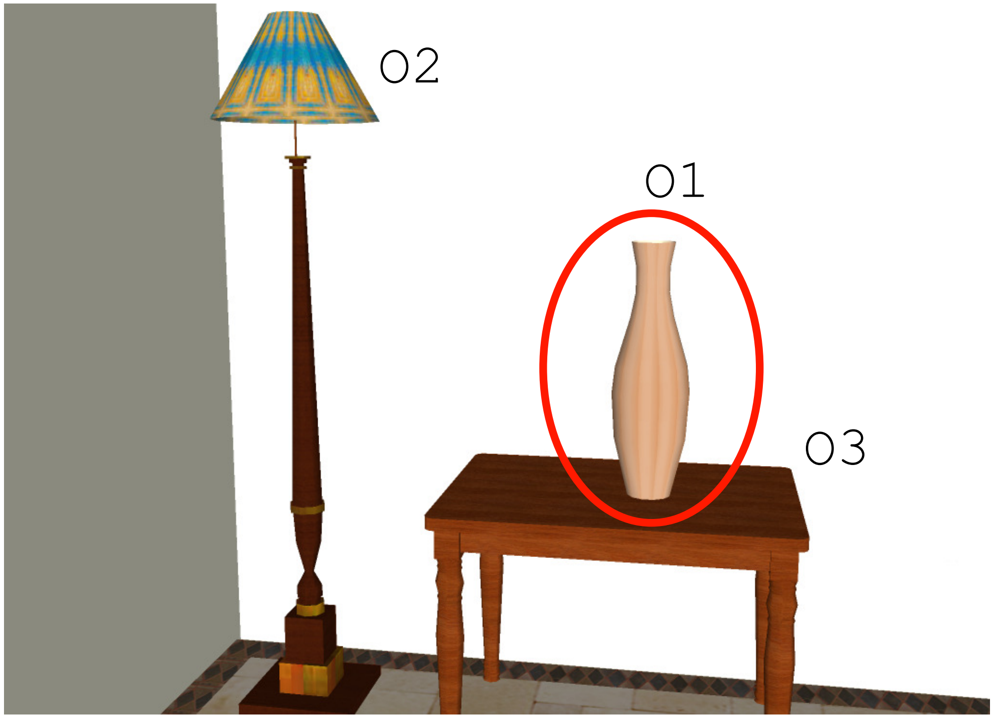

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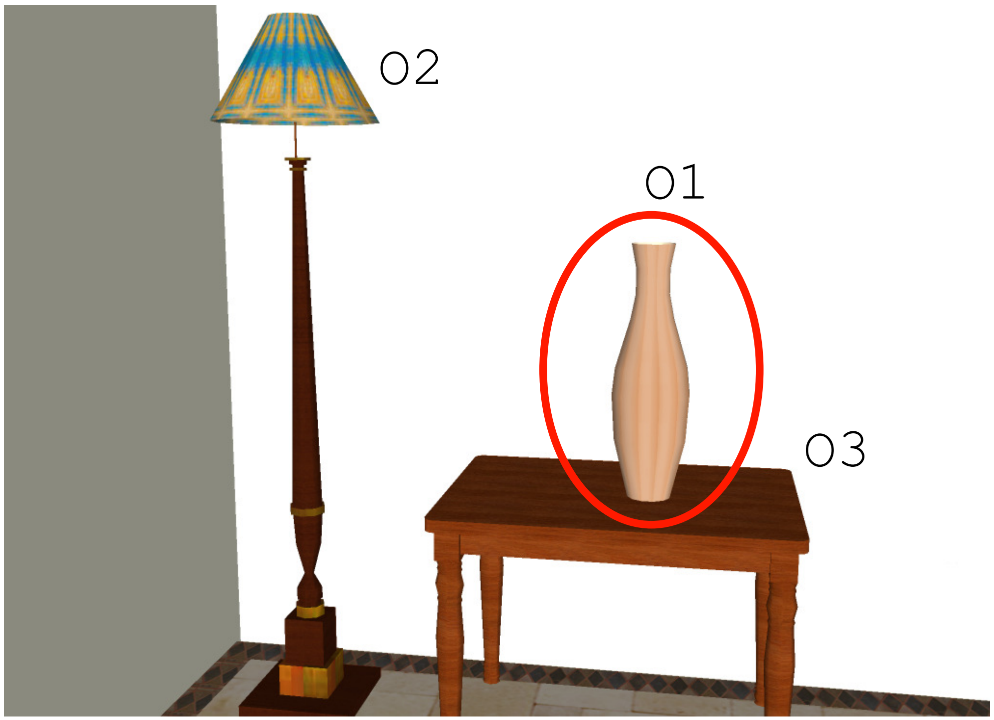

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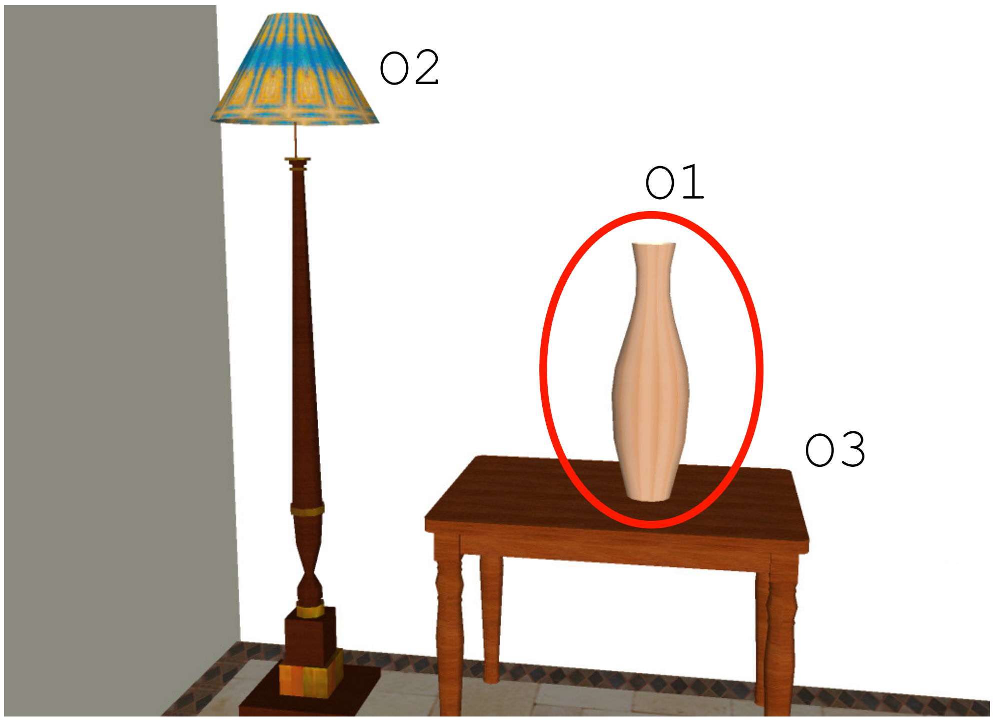

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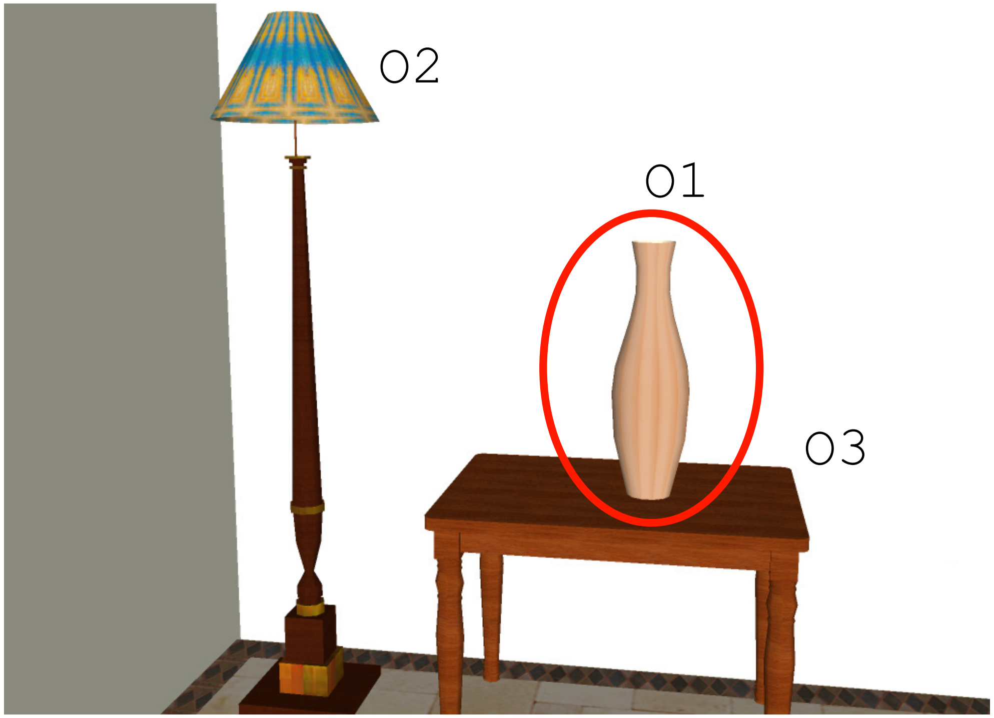

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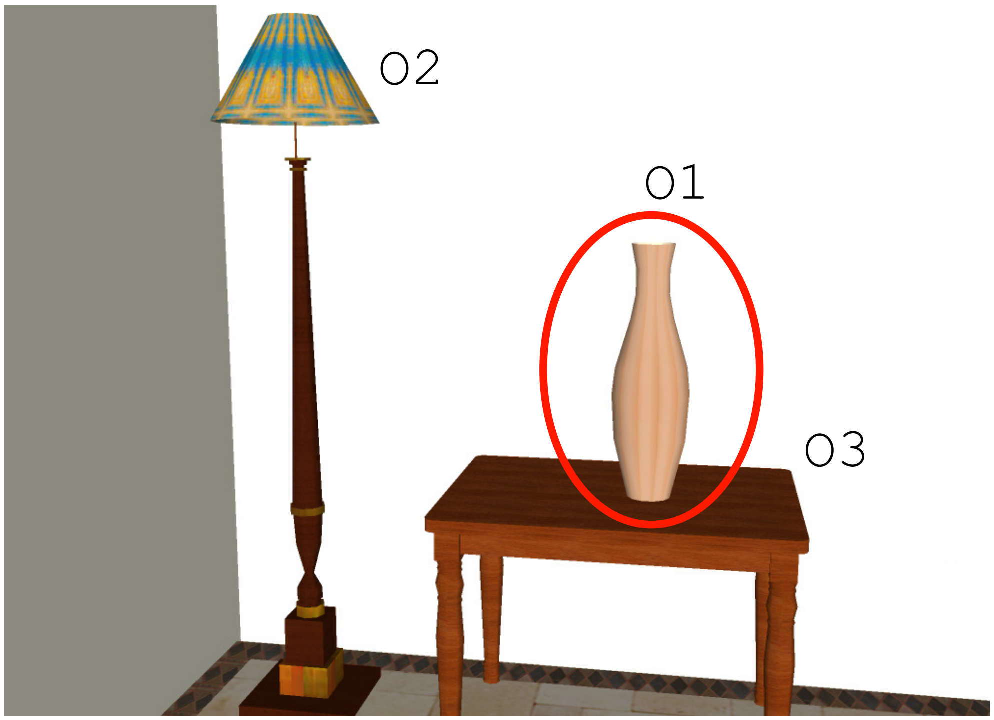

We will not be seeing 100% in this talk.

2. Complex utterances (coming up)

Listener Extensions

- Training a Listener
- Generating Complex Utterances
- Modeling Listener Confusion

Complex Utterances

Before: utterances were simple, such as:

right of O2 *on* O3

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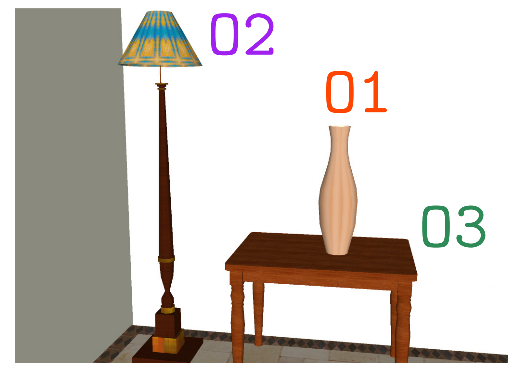
right of 02 *and on* 03

Example Interpretation

Computing: $p(g \mid$ *on something right of* `O2`$)$



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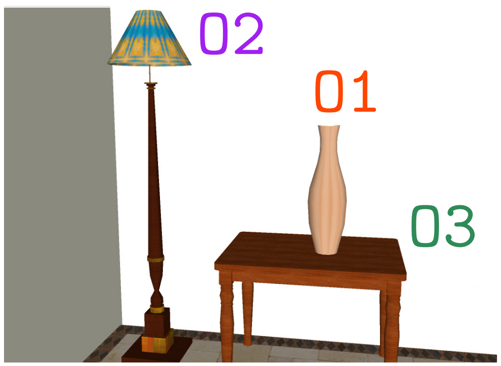
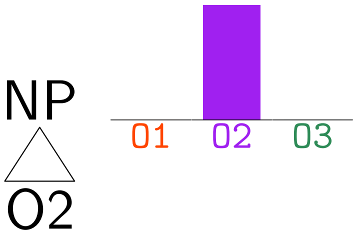
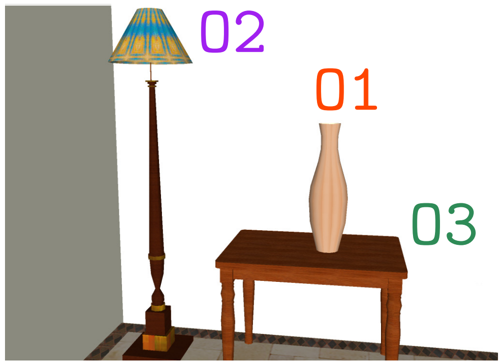


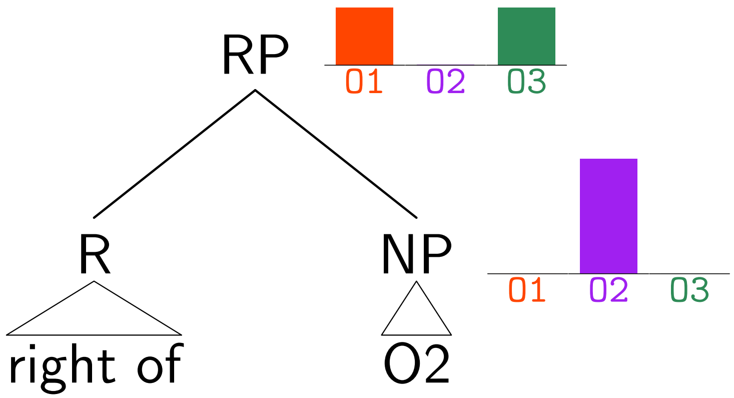


If w is rooted at N, $p_{\mathrm{L}}(g|w) = \mathbb{I}[w = g]$.

Example Interpretation

Computing: $p(g \mid$ *on something right of* O2$)$

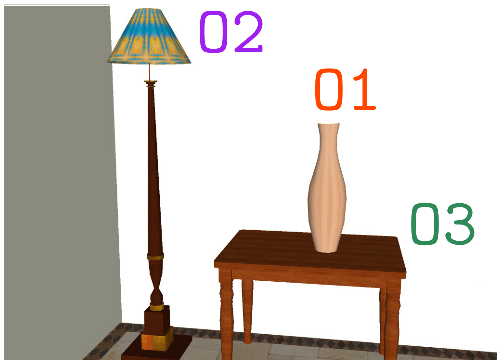


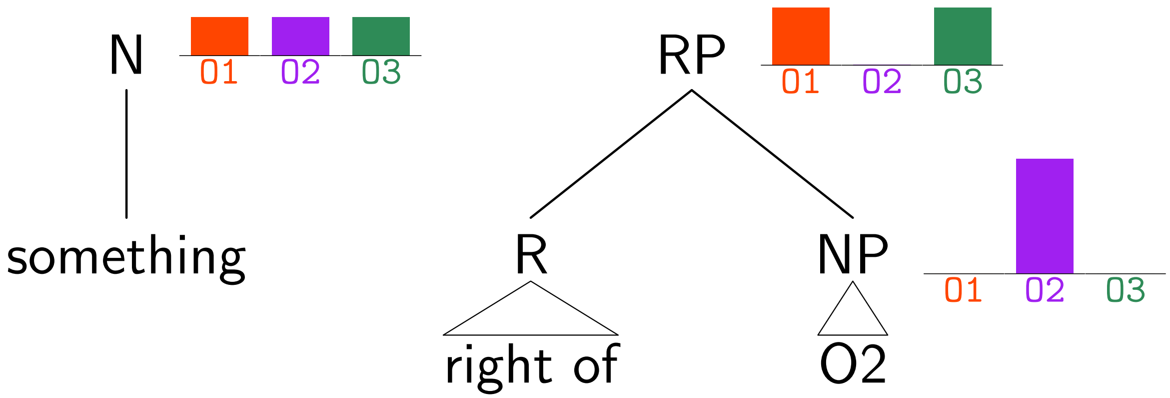


If w is rooted at RP, recurse on NP subtree, use base listener.

Example Interpretation

Computing: $p(g \mid \textit{on something right of}\ \mathrm{O2})$

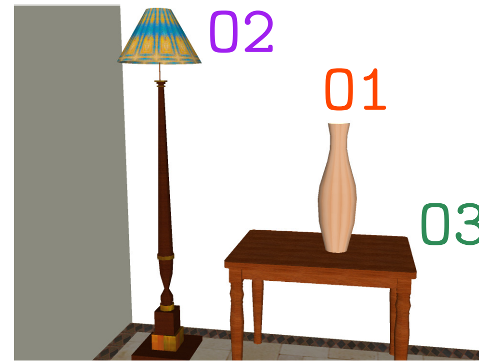


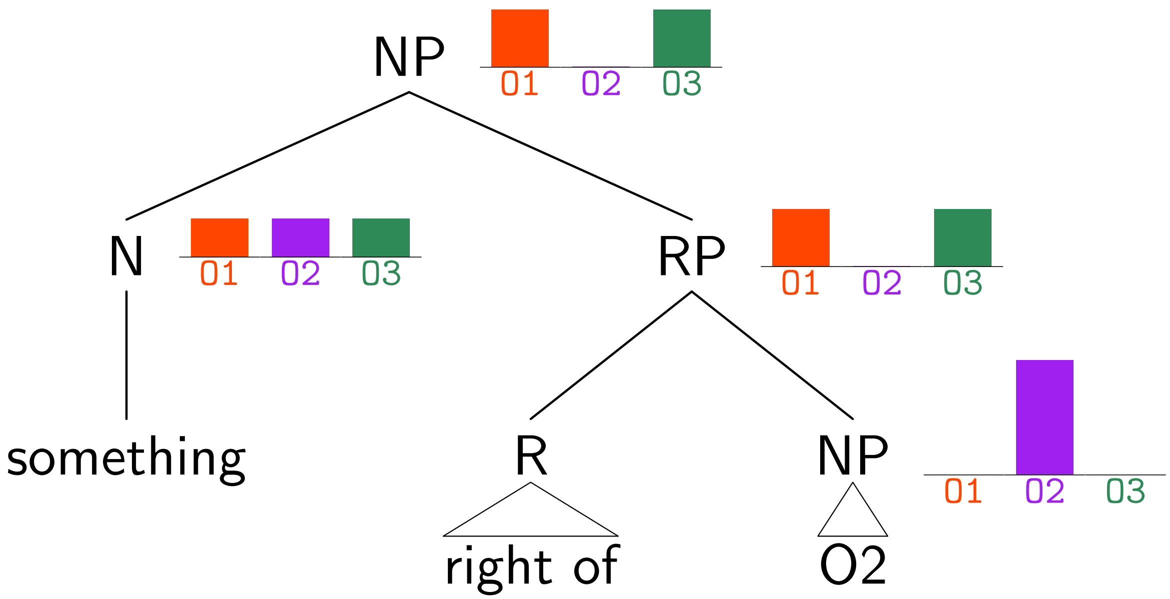


If w is rooted at N and $w = \textit{something}$, $p_{\mathrm{L}}(g|w)$ is uniform.

Example Interpretation

Computing: $p(g \mid$ *on something right of* O2$)$

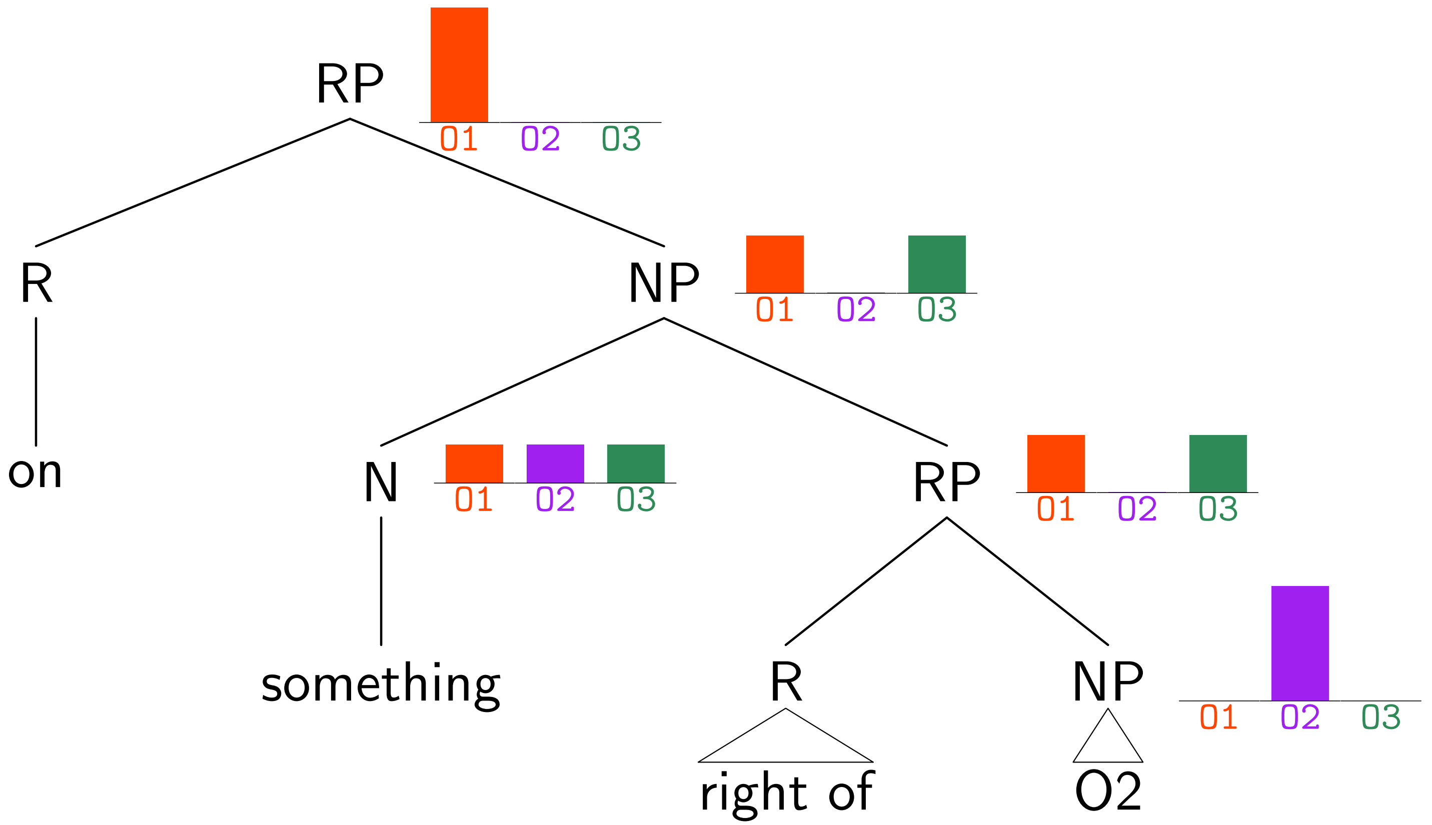


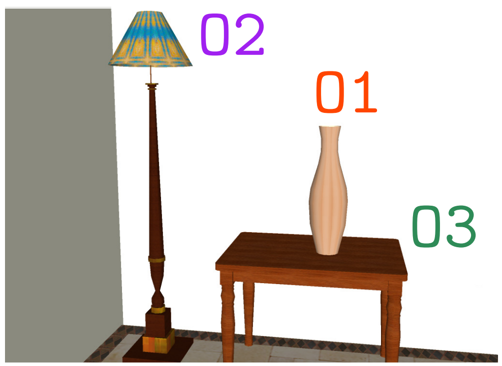


If w is rooted at NP, recurse on children, multiply and renormalize.

Example Interpretation

Computing: $p(g \mid \textit{on something right of } \texttt{O2})$





If w is rooted at RP, recurse on NP subtree, use base listener.

Results

Speaker		Success
Reflex	S $\boxed{}$ Learned	38.4%
Rational	S(L) $\boxed{\boxed{}}$ Learned	52.6%

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Problem: introducing complex utterances hurts success

Listener Confusion

Observations: success is lower

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Observations: success is lower & all uterances are longer

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Is longer always better?

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Right of the lamp

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Is longer always better?

Right of the lamp and on the table

Listener Confusion

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Right of the lamp and on the table and below the ceiling

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Right of the lamp and on the table and below the ceiling and in the room

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Maxim of manner: also be brief

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Right of the lamp and on the table and below the ceiling and in the room and etc.

Maxim of manner: also be brief

- saves time

Listener Confusion

Observations: success is lower & all uterances are longer

Is longer always better?

Right of the lamp and on the table and below the ceiling and in the room and etc.

Maxim of manner: also be brief

- saves time
- prevents confusion

Listener Extensions

- Training a Listener
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Modeling Listener Confusion

Problem: our model does not match turkers

$|w|$ $|w|$

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Confused turkers guess randomly.

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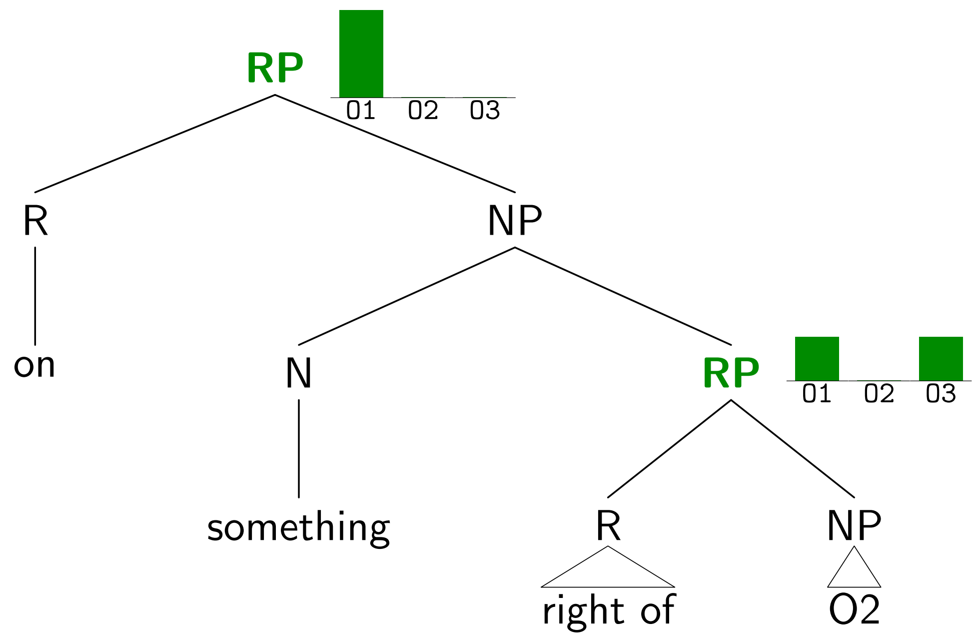

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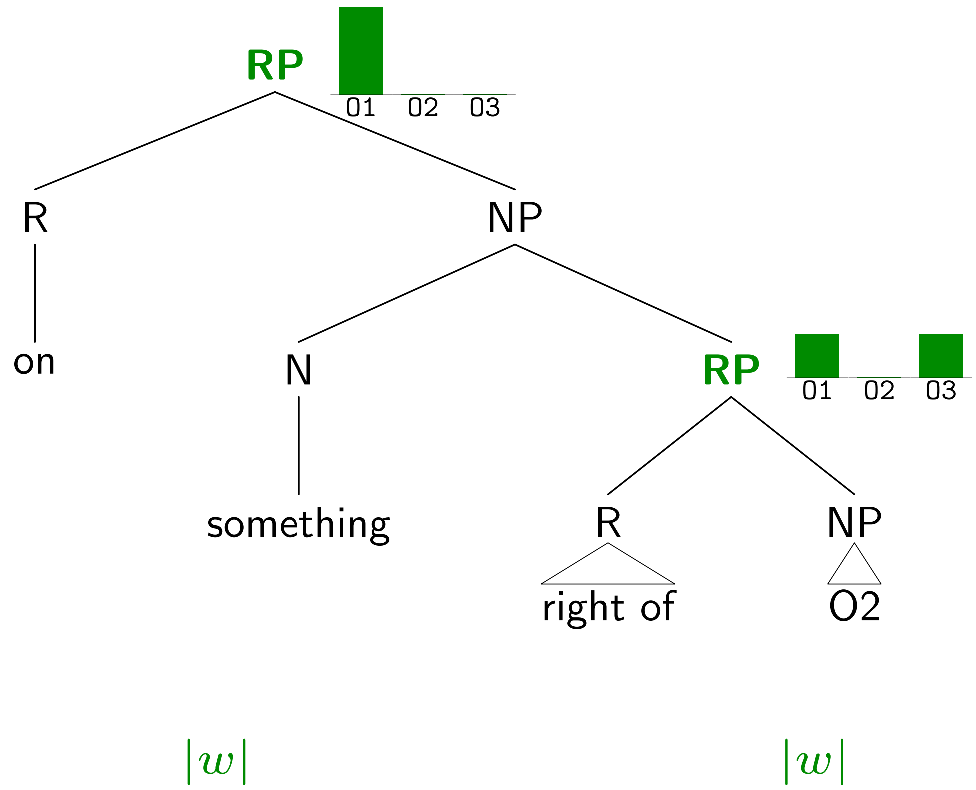

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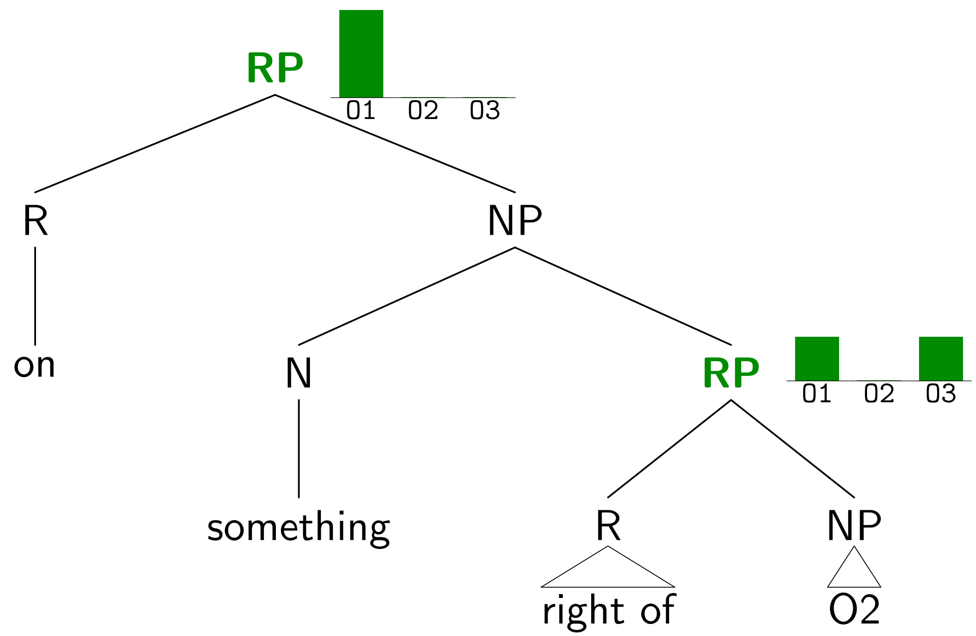

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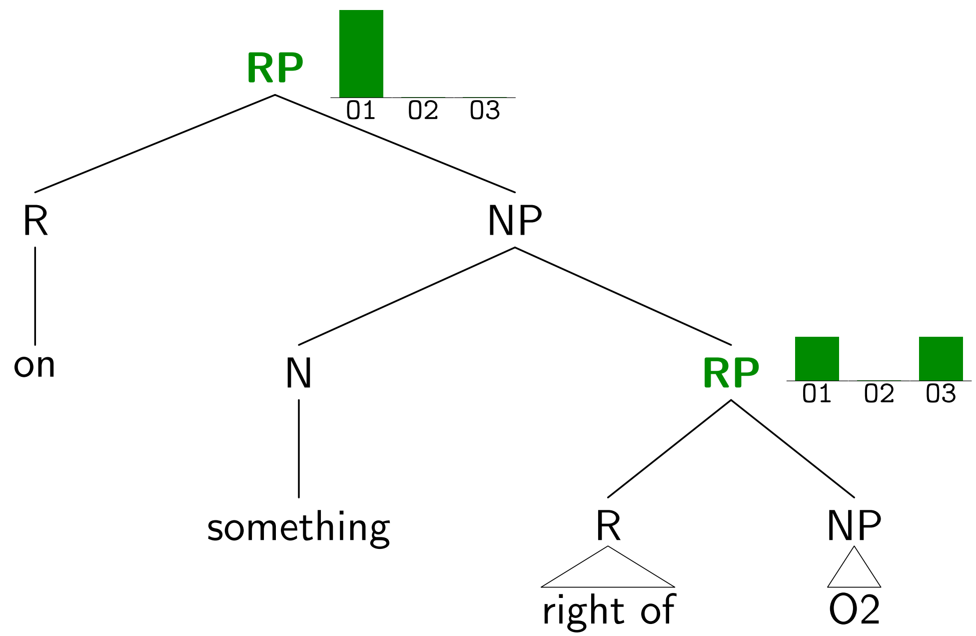

$$\alpha^{|w|} \underbrace{p_{\mathrm{L}}(g \mid w)}_{\text{understand}} \qquad |w|$$

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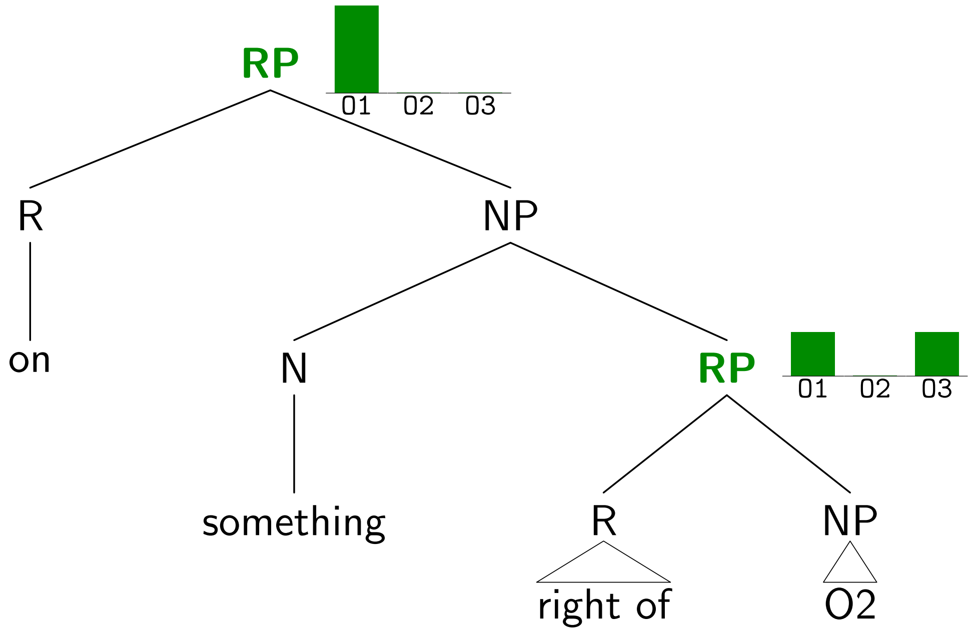

$$\alpha^{|w|}\underbrace{p_{\mathrm{L}}(g \mid w)}_{\text{understand}} + (1-\alpha^{|w|})$$

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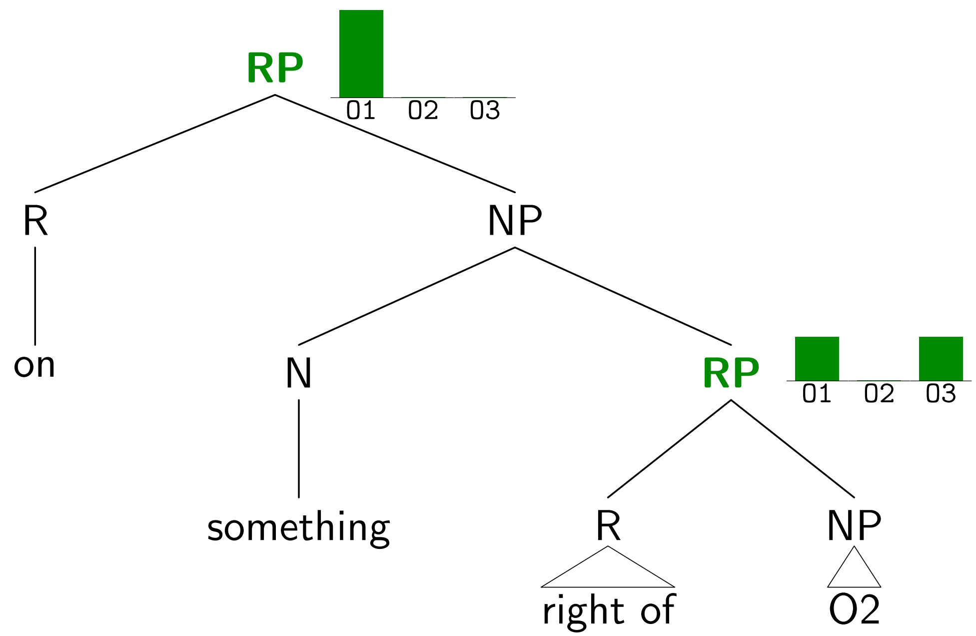

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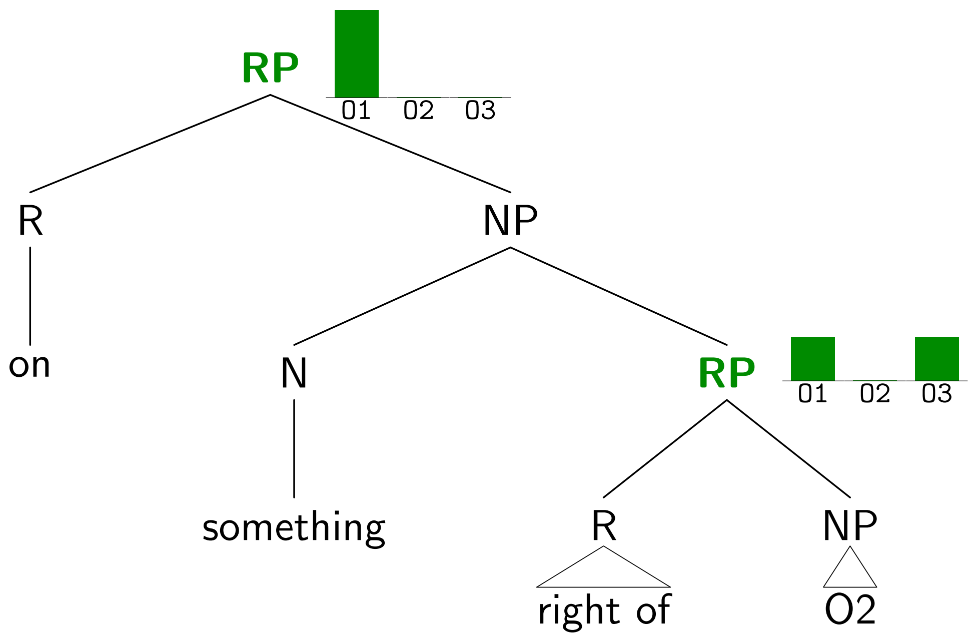

$$\tilde{p}_{\mathrm{L}}(g \mid w) = \alpha^{|w|} \underbrace{p_{\mathrm{L}}(g \mid w)}_{\text{understand}} + (1 - \alpha^{|w|}) \underbrace{p_{\mathsf{rnd}}(g \mid w)}_{\text{confused}}$$

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Rational $\boxed{\boxed{\ }}$ S(L) Learned	+confusion model	54.5%

Final Remarks

Observation: people avoid saying ambiguous utterances

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Our contribution: we show how a game theoretic pragmatics model can be used to successfully generate spatial descriptions

Thank you!

Berkeley NLP

slides compiled with rfig