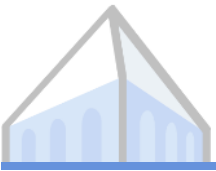


Language Grounding



slides from: Greg Durrett, Daniel Fried, Chris Potts, Nick Tomlin

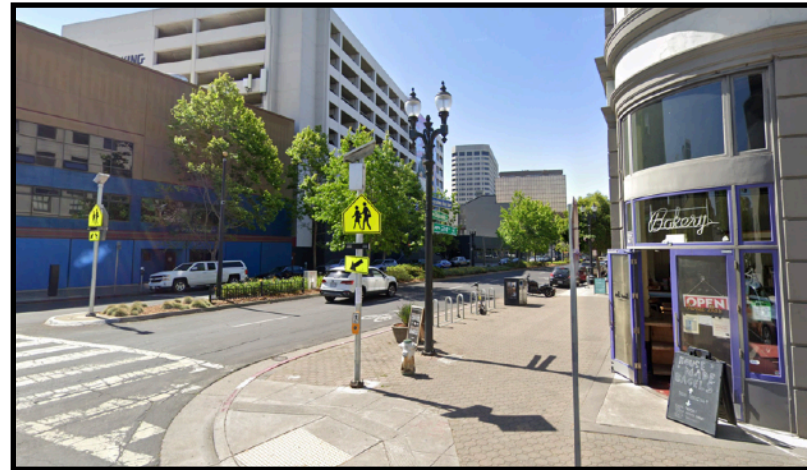


What is Language Grounding?

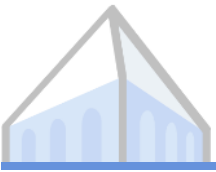
- ▶ Tying language to non-linguistic things (e.g. a database in semantic parsing)
- ▶ The world only looks like a database some of the time!
- ▶ Some settings depend on grounding into perceptual or physical environments:



“Add the tomatoes and mix”



*“To get to BART,
cross the street and
keep going south
toward the tall
buildings...”*



Grounded Semantics

What things, actions, etc. in the world does language refer to?

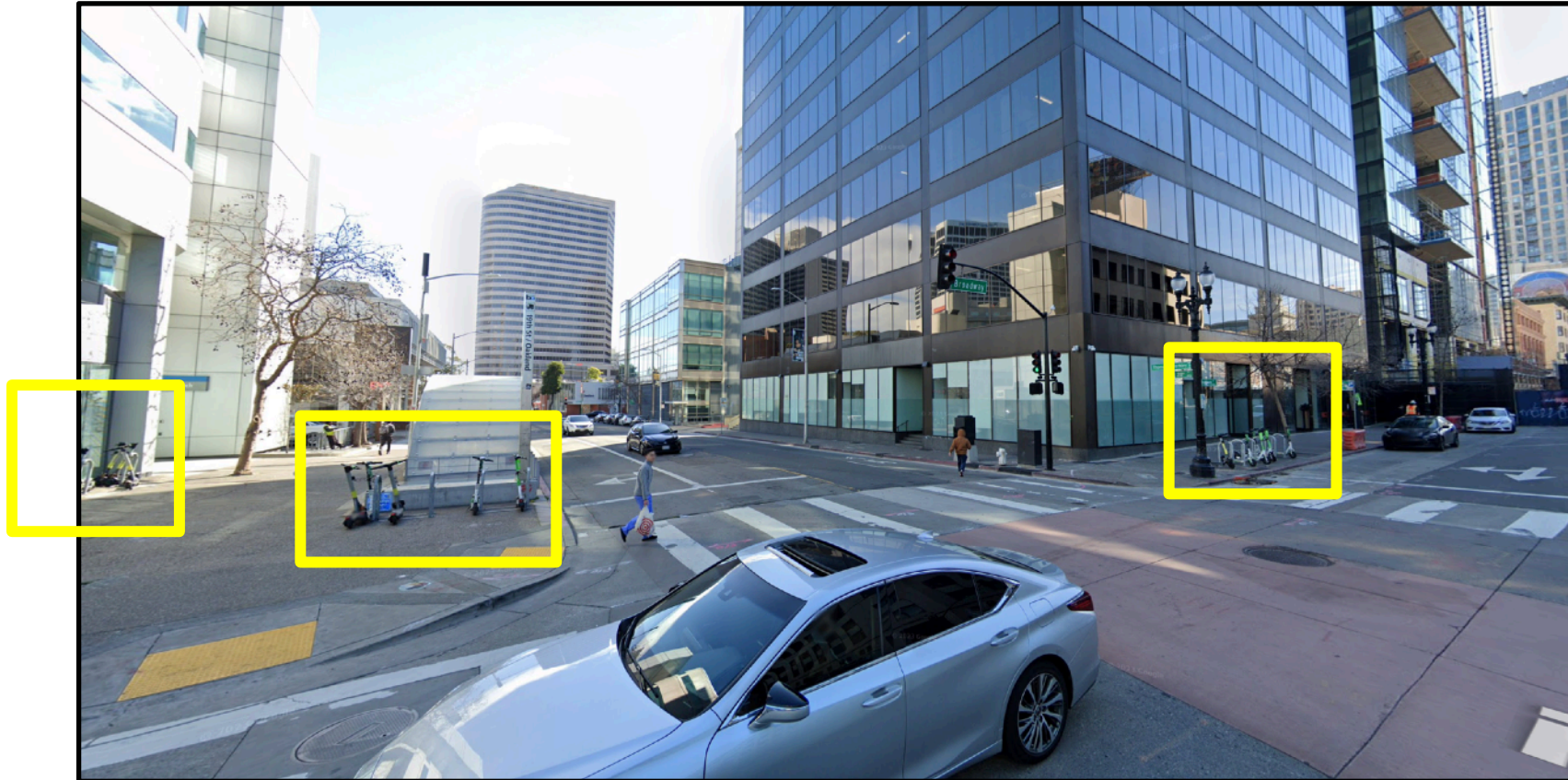


*“The entrance is to the right of
the bare tree in the sun”*



Pragmatics

How does context shape the interpretation of language?



*"The entrance is behind
the scooters"*



Using Language

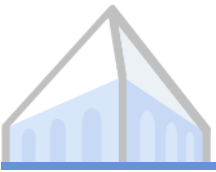
Saying something will often... produce certain consequential effects upon the feelings, thoughts, or actions of the audience.

[How to Do Things with Words. Austin, 1962]

Our talk exchanges ... are cooperative efforts... One of my avowed aims is to see talking as purposive, indeed rational, behavior.

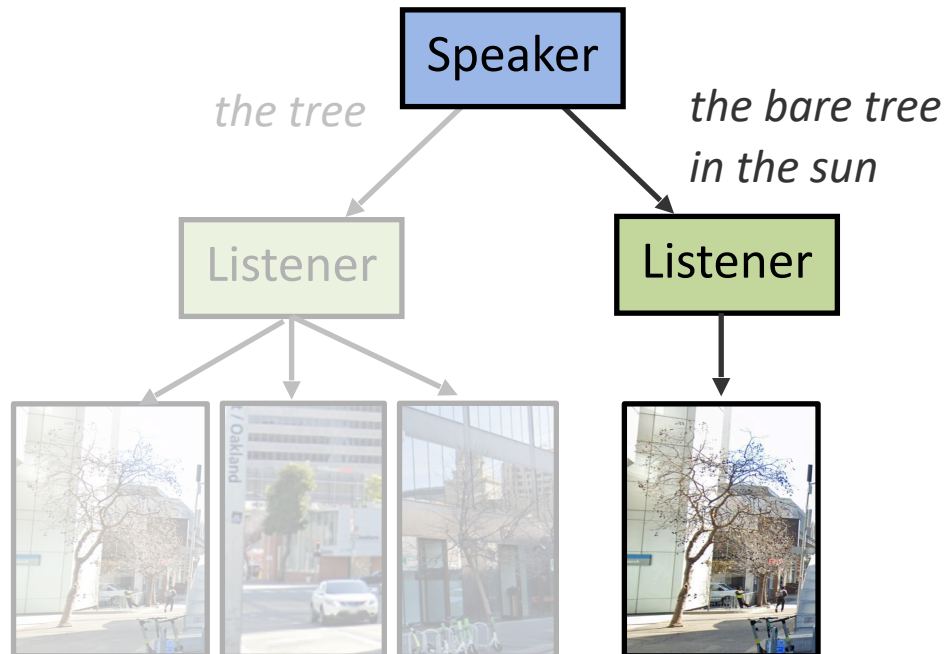
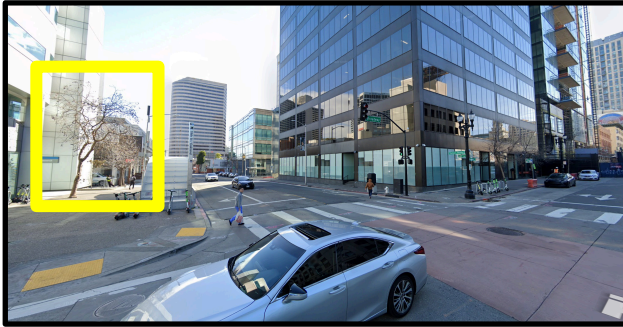
[Logic and Conversation. Grice, 1975]

Language is an act people take to produce effects on others and the world!

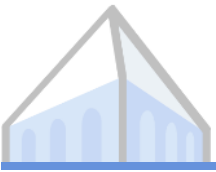


Using Language

Generation

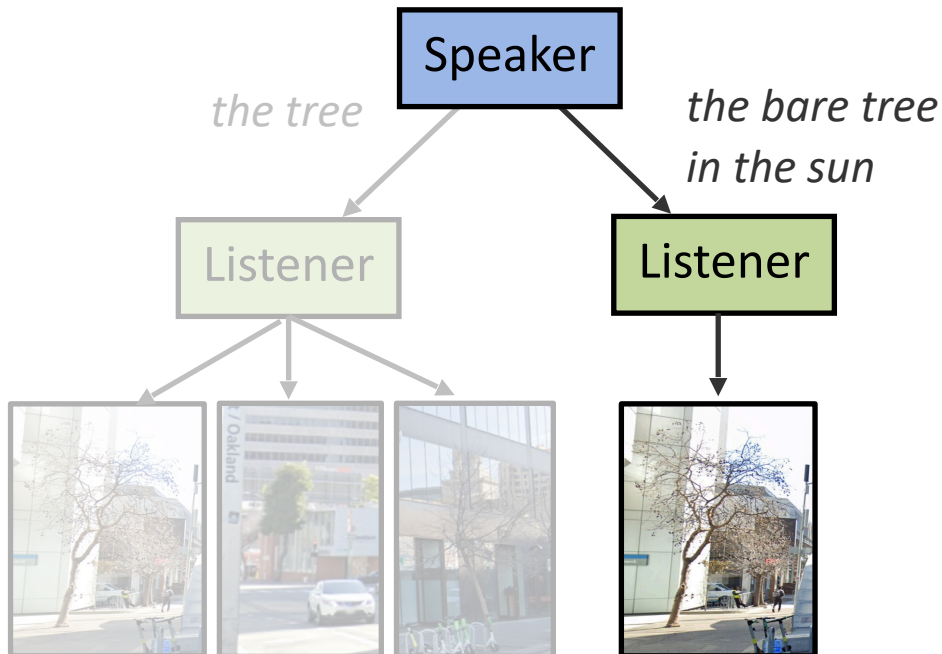
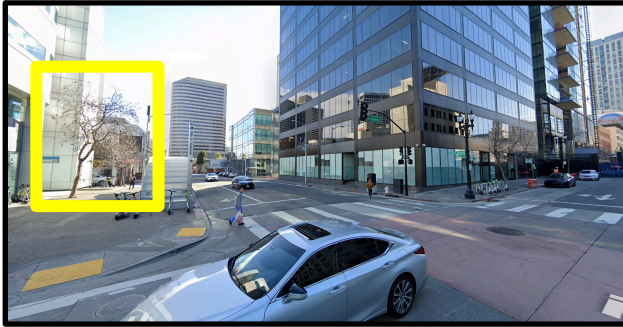


[e.g. Lewis 1969; Golland et al. 2010;
Frank and Goodman 2012; Degen et al. 2013]



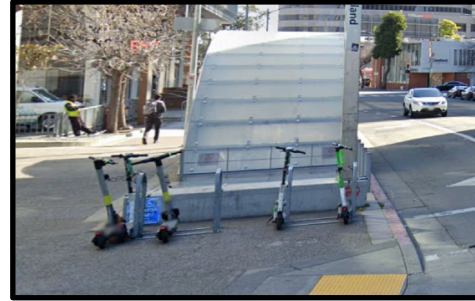
Using Language

Generation

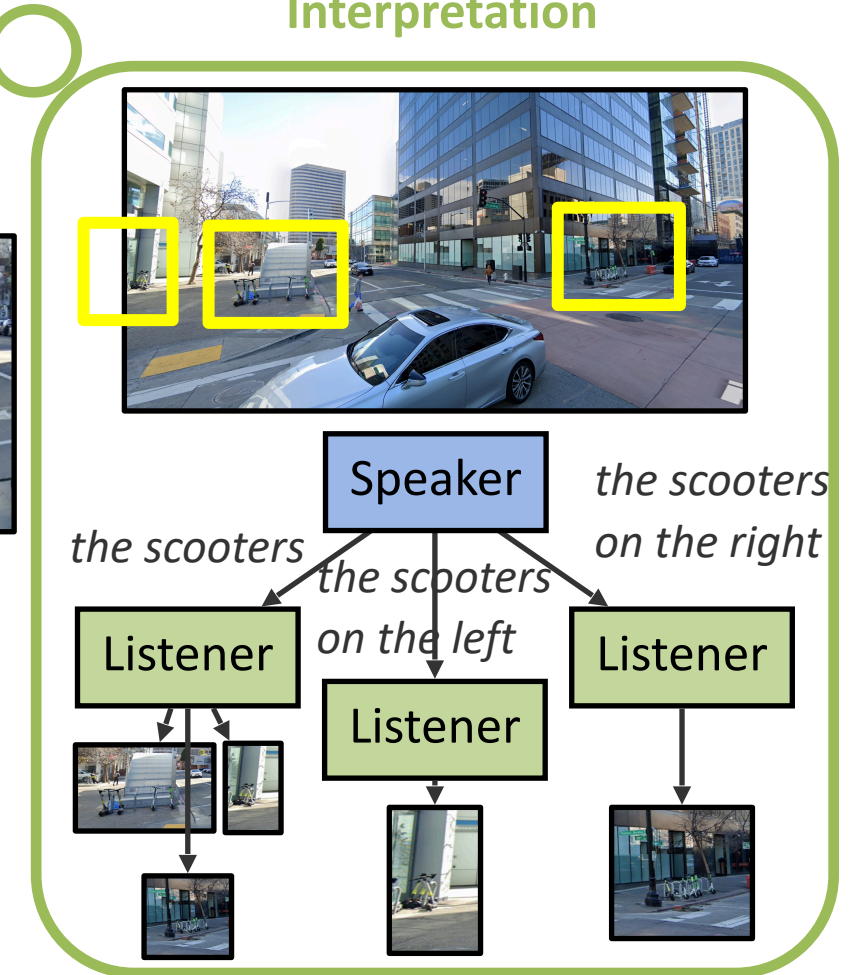


the scooters

Listener



Interpretation



[e.g. Lewis 1969; Golland et al. 2010;
Frank and Goodman 2012; Degen et al. 2013]



Reasoning About Alternatives

Core Idea:

Large chunks of linguistic understanding can be attributed to reasoning about alternatives. E.g., if a speaker says X but not Y, then perhaps Y isn't true, or the speaker doesn't want to talk about Y.



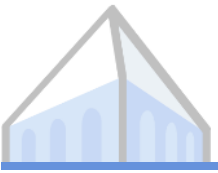
Reasoning About Alternatives

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Example:

“I didn't steal your scooter.”



Reasoning About Alternatives

Core Idea:

Large chunks of linguistic understanding can be attributed to reasoning about alternatives. E.g., if a speaker says X but not Y, then perhaps Y isn't true, or the speaker doesn't want to talk about Y.

Example:

“I didn't steal your scooter.”

Conveyed meaning:

Someone stole your scooter, but it wasn't me.



Reasoning About Alternatives

Core Idea:

Large chunks of linguistic understanding can be attributed to reasoning about alternatives. E.g., if a speaker says X but not Y, then perhaps Y isn't true, or the speaker doesn't want to talk about Y.

Example:

“I didn't steal your scooter.”

Conveyed meaning:

Contrary to what you think, I did not steal your scooter.



Reasoning About Alternatives

Core Idea:

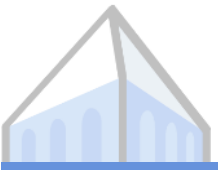
Large chunks of linguistic understanding can be attributed to reasoning about alternatives. E.g., if a speaker says X but not Y, then perhaps Y isn't true, or the speaker doesn't want to talk about Y.

Example:

“I didn't steal your scooter.”

Conveyed meaning:

I did something to your scooter, but didn't steal it. E.g. just borrowed it.



Reasoning About Alternatives

Core Idea:

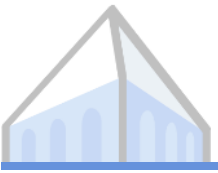
Large chunks of linguistic understanding can be attributed to reasoning about alternatives. E.g., if a speaker says X but not Y, then perhaps Y isn't true, or the speaker doesn't want to talk about Y.

Example:

“I didn't steal your scooter.”

Conveyed meaning:

I stole somebody else's scooter.



Reasoning About Alternatives

Core Idea:

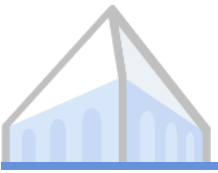
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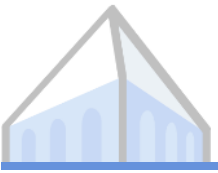
Conveyed meaning:

I stole something you own, but not your scooter.



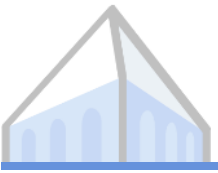
Language is Contextual

- ▶ Some problems depend on grounding references to context
- ▶ Indexicals and *Deixis*: “pointing or indicating” (e.g. pronouns, “this”, “that”, “here”, “now”)
 - ▶ *I am speaking*
 - ▶ *We lost* (a team I’m on, OR a team I support)
 - ▶ *I am here* (in Berkeley; in Wurster Hall)
 - ▶ *We are here* (pointing to a map)
 - ▶ *I’m in a class now*
 - ▶ *I’m in a graduate program now*
 - ▶ *I’m not here right now* (voicemail greeting)



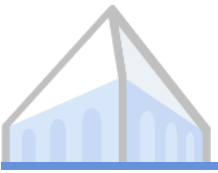
Language is Contextual

- ▶ Some problems depend on grounding into speaker intents or goals:
 - ▶ “Can you pass me the salt”
 - > please pass me the salt
 - ▶ “Do you have any kombucha?” // “I have tea”
 - > I don’t have any kombucha
 - ▶ “I now pronounce you...” (at a wedding)
 - > *performative*, that changes the state of the world



Language is Contextual

- Scope or type of answers: *Where are you from?*
 - Athens, Ohio (issue: hometown)
 - The U.S. (issue: nationality)
 - Berkeley (issue: affiliation)
 - Planet Earth (issue: intergalactic meetings)



Language is Contextual

how big is the contextually restricted domain of students?

what's the additional contextual restriction?

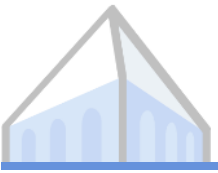
[false for *most students*?]

— who's the speaker?

→ *Many students met with me yesterday.*

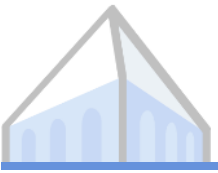
what's the time of utterance?

[but perhaps many met with the speaker at other times?]



Language is Contextual

- ▶ Children learn word meanings incredibly fast, from incredibly little data
 - Regularity and contrast in the input signal
 - Social cues
 - Inferring speaker intent
 - Regularities in the physical environment



The Cooperative Principle

The Cooperative Principle (Grice 1975):

“Make your contribution such as is required, at the stage at which it occurs, by the accepted purpose or direction of the talk exchange in which you are engaged.”

Language is a rational action in a cooperative game.



Gricean Maxims

Grice (1975) claims that many of these phenomena are explained by the tensions between the following ***maxims***:

1. **Quantity** – be as informative as possible, give as much information as needed, but no more. (*“The cyclist was hit.”*)
2. **Quality** - be truthful, and don’t give information that is false or unsupported by evidence. (*“how are you doing?” // (sarcastically) “fantastic”*)
3. **Relation** – be relevant, and say things that are pertinent to the discussion. (*“I’m out of gas” // “There’s a station round the corner.”*)
4. **Manner** – be clear, brief, and orderly as possible; avoid unnecessary prolixity. (*“the singer produced a series of sounds corresponding closely to the score of an aria from “Rigoletto”.*” (from Levinson 1983))



Implicature



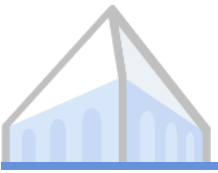
The New York Times 
@nytimes



We've deleted an earlier tweet and updated a sentence in our article that implied that only "some experts" view the ingestion of household disinfectants as dangerous. To be clear, there is no debate on the danger.

9:17 AM · Apr 24, 2020 · [Twitter Web App](#)

4.7K Retweets **22K** Likes



Scalar Implicature

Q: Does *some* mean *not all*?

A: Not always:

- “Some of the students were late for class; in fact, they all were.”
- “I’d be much happier if some grocery stores had eggs in stock.”

We call this *implicature*. The implicature occurs because a rational listener might assume that the speaker would have said *all* if they meant to, since *all* is the more informative choice.



Conversational Implicature

“The cyclist was hit.”

- *The speaker doesn't know, or doesn't want to tell, how the cyclist was hit.*

“Did you invite Alice and Bob?” // “I invited Alice.”

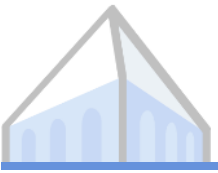
- *The speaker didn't invite Bob.*

“I'm out of gas.” // “There's a station round the corner.”

- *You can get gas there (e.g. it's open).*

“He overslept and failed the test.”

- *Those events happened in that order.*



Implicature \neq Entailment

Implicatures are cancellable:

“Some of the students were late for class; in fact, they all were.”

But presuppositions and entailments aren't:

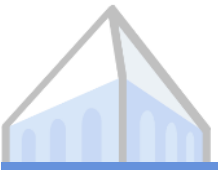
“I stopped going into the office; in fact, I've never been there before.”

“I stopped going into the office; in fact, I didn't stop going in.”



Conversational Implicature

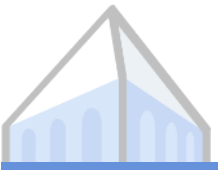
Speaker S saying utterance U to listener L conversationally implicates q if, and only if,



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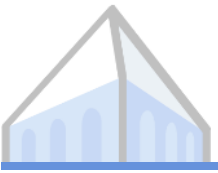
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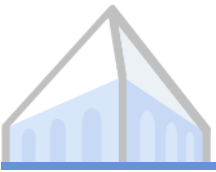
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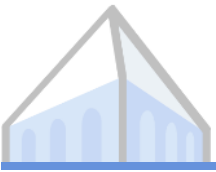
- ① S and L mutually, publicly presume that S is obeying the cooperative principle.
- ② To maintain ① given U, it must be supposed that S thinks that q.
- ③ S thinks that both S and L mutually, publicly presume that L is willing and able to work out that ② holds.



Conversational Implicature

Ann: What city does Paul live in?

Bob: Hmm ... he lives in California.



Conversational Implicature

Ann: What city does Paul live in?

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Conversational implicature: Bob does not know which city Paul lives in.



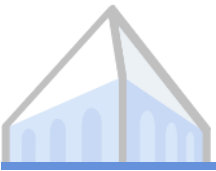
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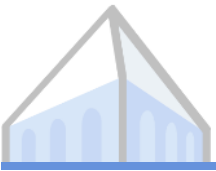
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- ③ Bob supplied less information than was required, seemingly contradicting ②.
- ④ Assume Bob does not know which city Paul lives in.
- ⑤ Then Bob's answer is optimal given his evidence.



Reference Games

- Simple form of *using language*
- Set of candidate referents R
- Encoding meaning
 - A speaker has an intent, which is a target referent $r \in R$
 - Speaker maps this intent r and context R to an utterance u
- Decoding meaning
 - A listener observes R and u
 - Listener *resolves* the reference u to $r' \in R$
- Success: $r = r'$



Reference Games



R1

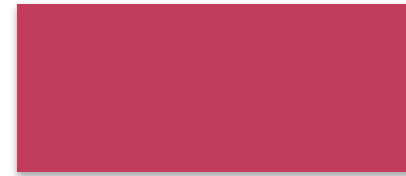


R2

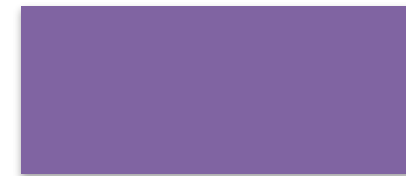
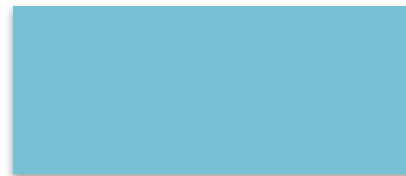


R3

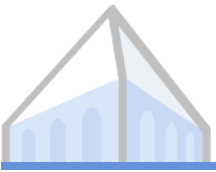
“Hat”



?



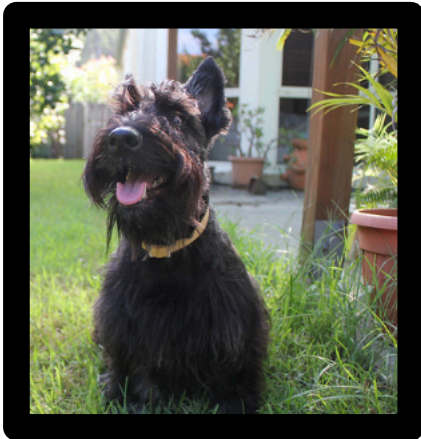
?



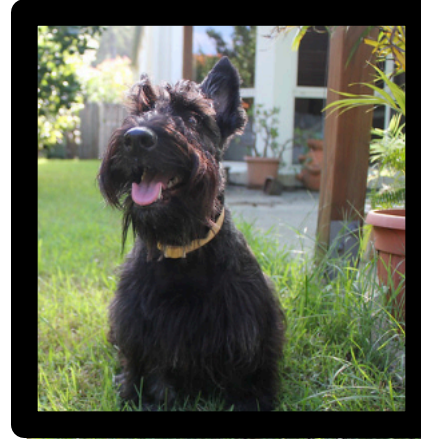
Reference Games



“Ice skater”



?



?





Demo!

PollEv.com/alanesuhr930



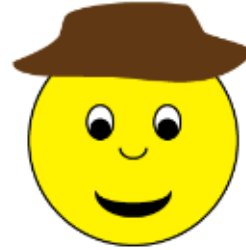
Speakers and Listeners



R1

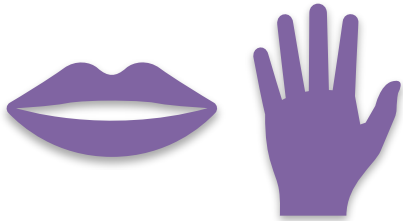


R2



R3

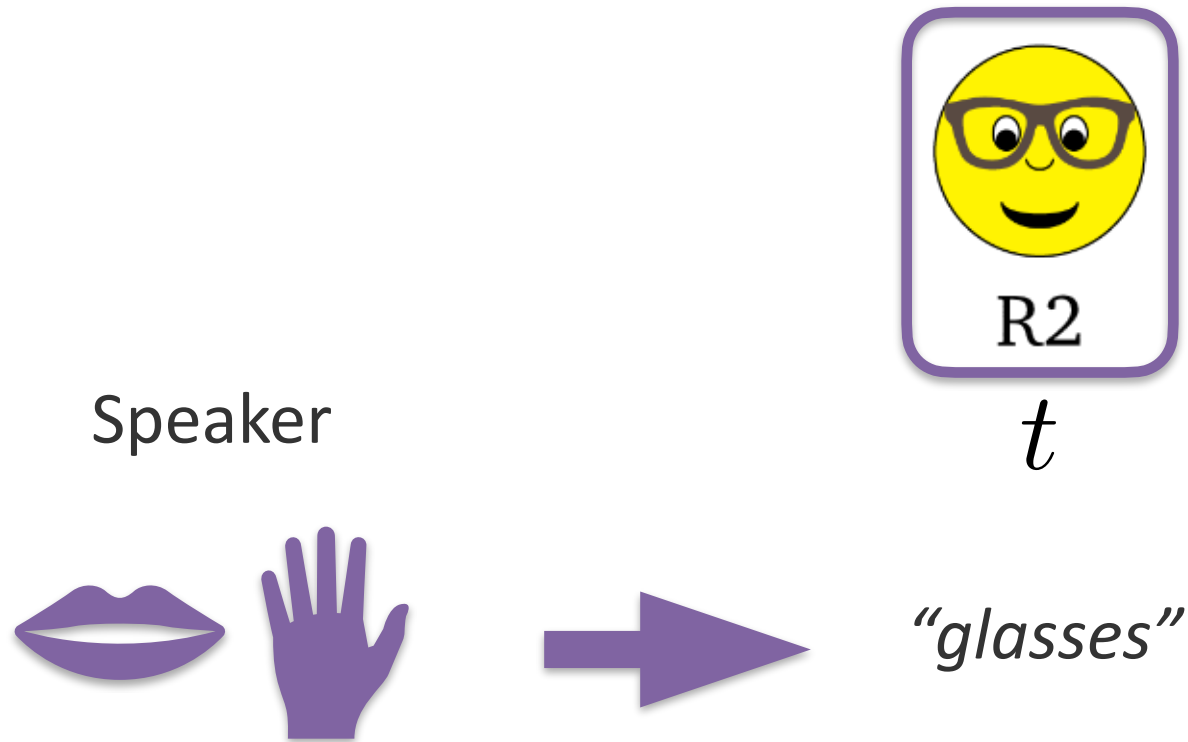
Speaker



t

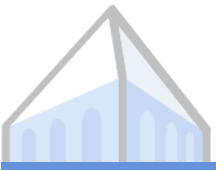


Speakers and Listeners



$$p_{\text{Literal}}^{\text{Speaker}}(\cdot | t)$$

	R1	R2	R3
<i>hat</i>		0	
<i>glasses</i>		1	
<i>mustache</i>		0	



Speakers and Listeners

[[*"glasses"*]]

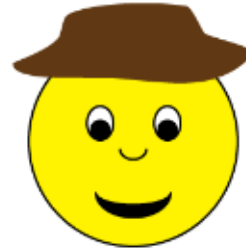
	R1	R2	R3
<i>hat</i>			
<i>glasses</i>	0	1	0
<i>mustache</i>			



R1

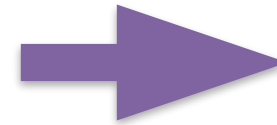


R2

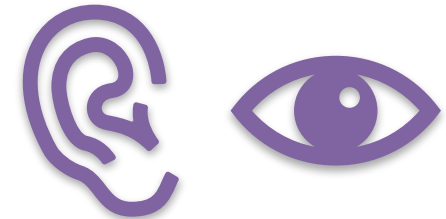


R3

$x = \text{"glasses"}$



Listener





Speakers and Listeners

$$p_{\text{Literal}}^{\text{Listener}}(\cdot \mid x)$$

	R1	R2	R3
<i>hat</i>			
<i>glasses</i>	0	1	0
<i>mustache</i>			



R1

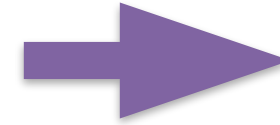


R2

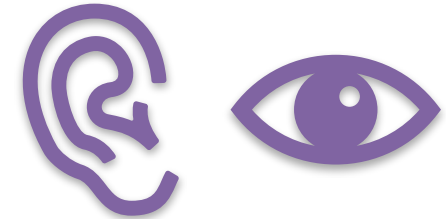


R3

$x = \text{"glasses"}$

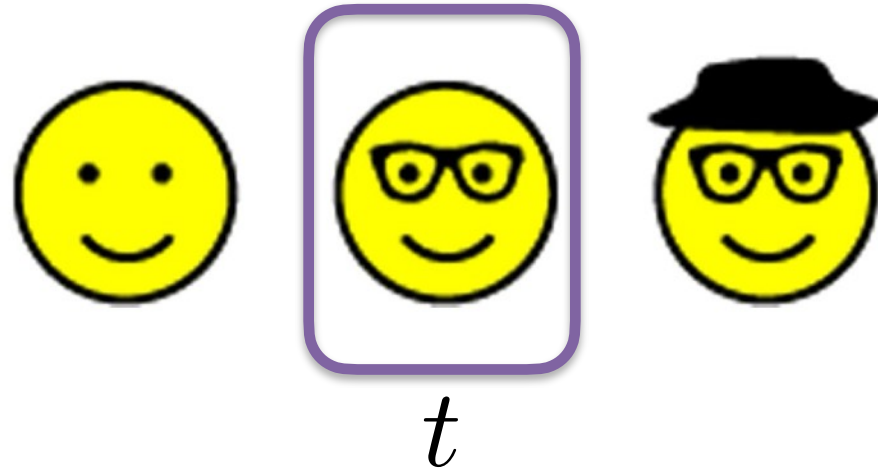


Listener

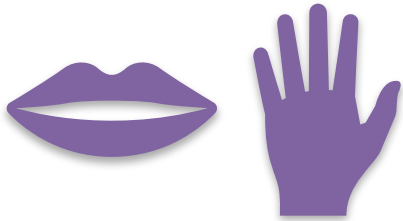


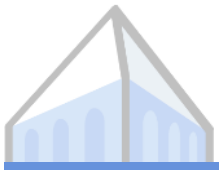


Context-Dependence

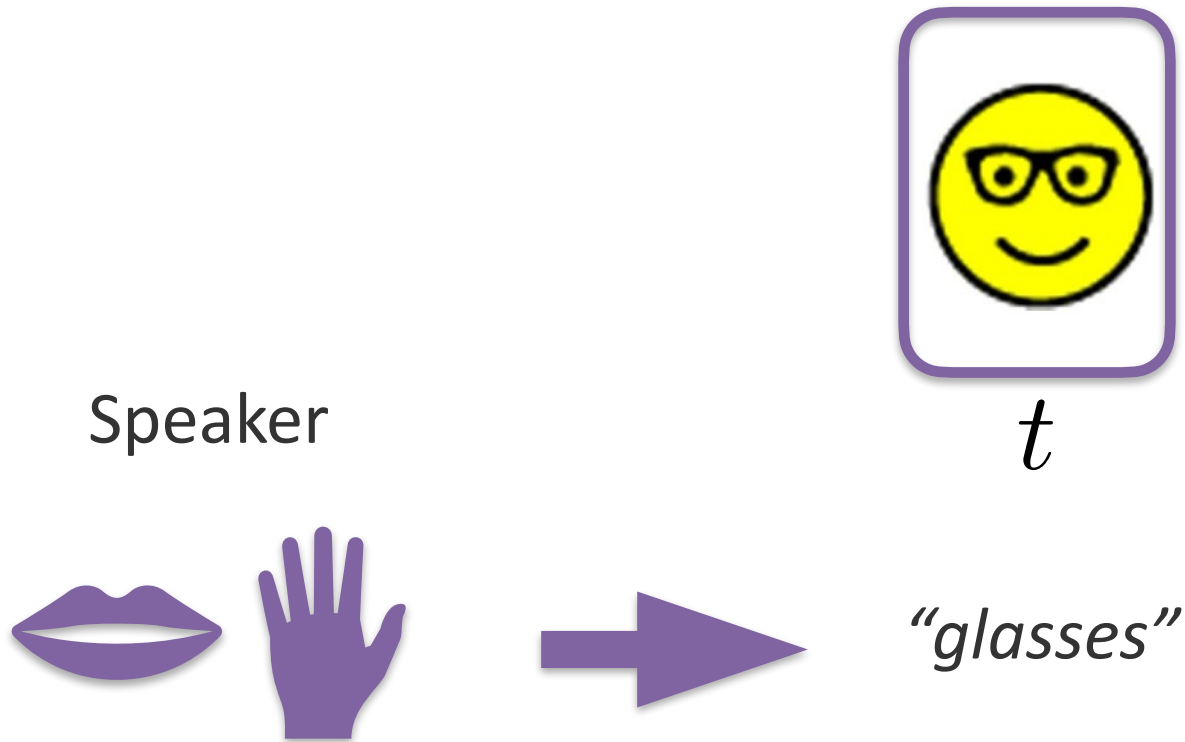


Speaker





Context-Dependence



$$p_{\text{Literal}}^{\text{Speaker}}(\cdot \mid t)$$

	R1	R2	R3
<i>hat</i>		0	
<i>glasses</i>		1	
<i>mustache</i>		0	



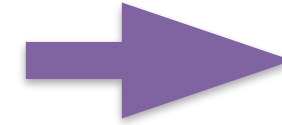
Context-Dependence

[[*"glasses"*]]

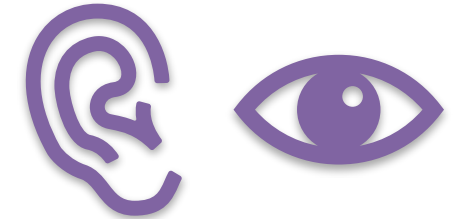
	R1	R2	R3
<i>hat</i>			
<i>glasses</i>	0	1	1
<i>mustache</i>			



$x = \text{"glasses"}$



Listener

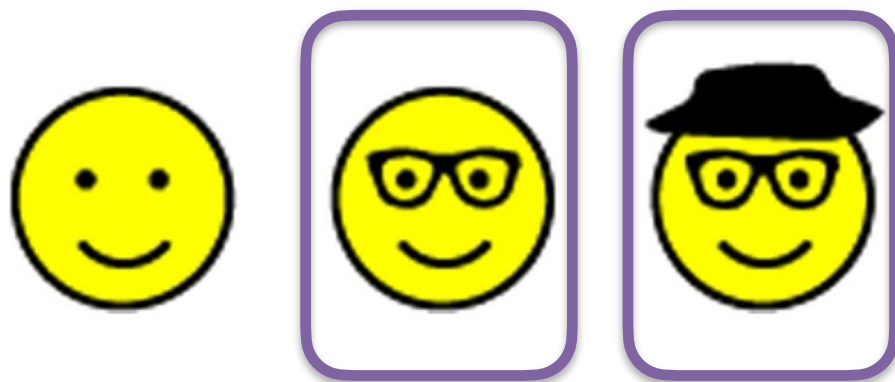




Context-Dependence

$$p_{\text{Literal}}^{\text{Listener}}(\cdot \mid x)$$

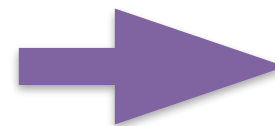
	R1	R2	R3
<i>hat</i>			
<i>glasses</i>	0	0.5	0.5
<i>mustache</i>			



???

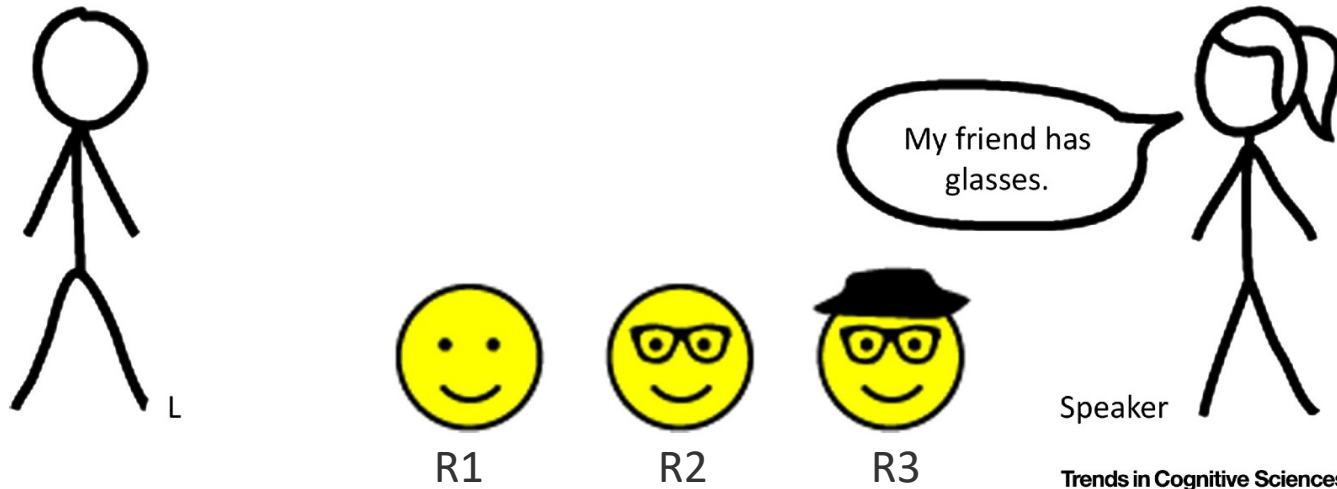
Listener

$x = \text{"glasses"}$



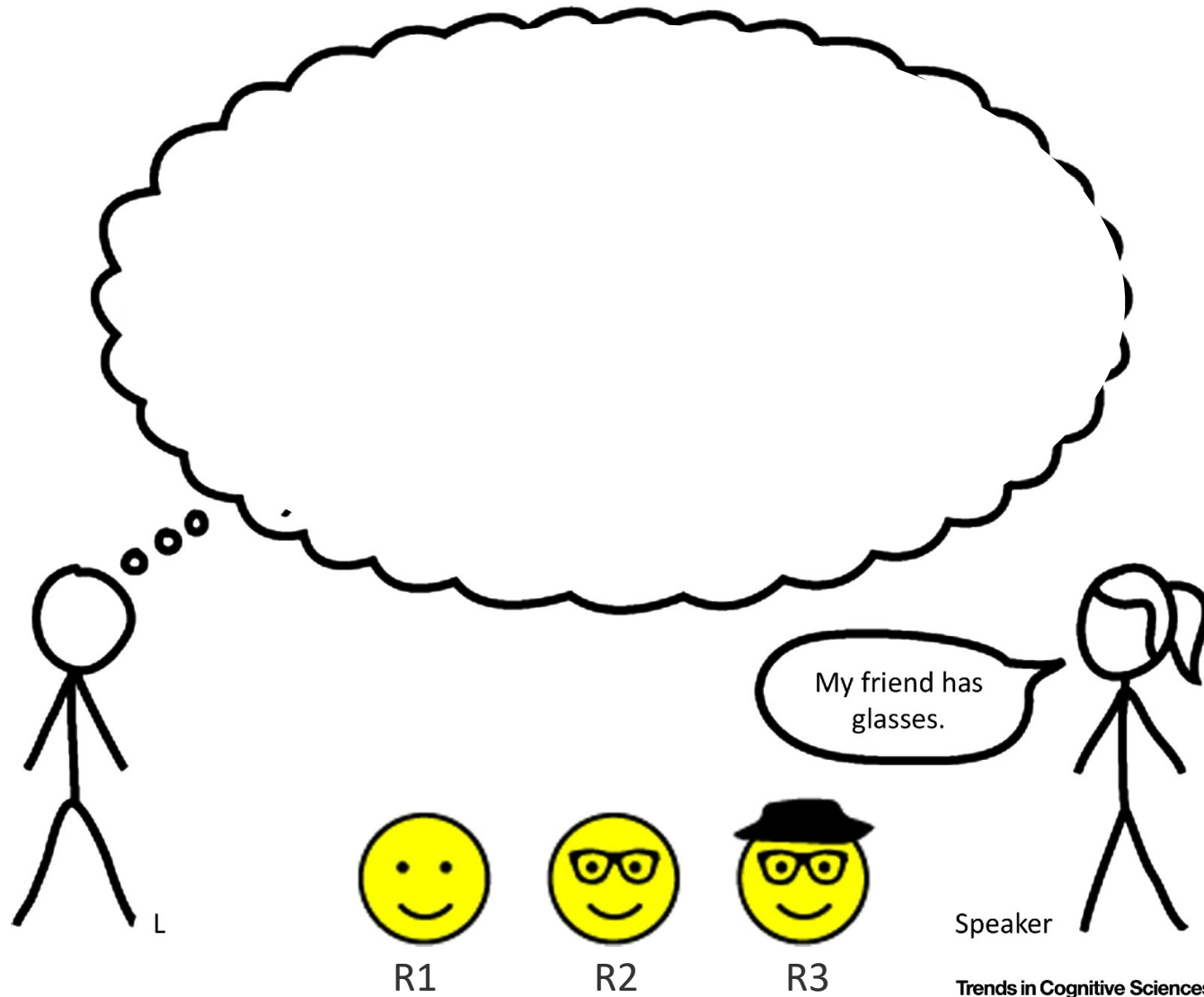


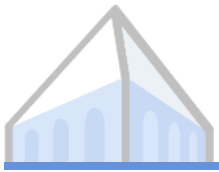
Pragmatic Speakers and Listeners



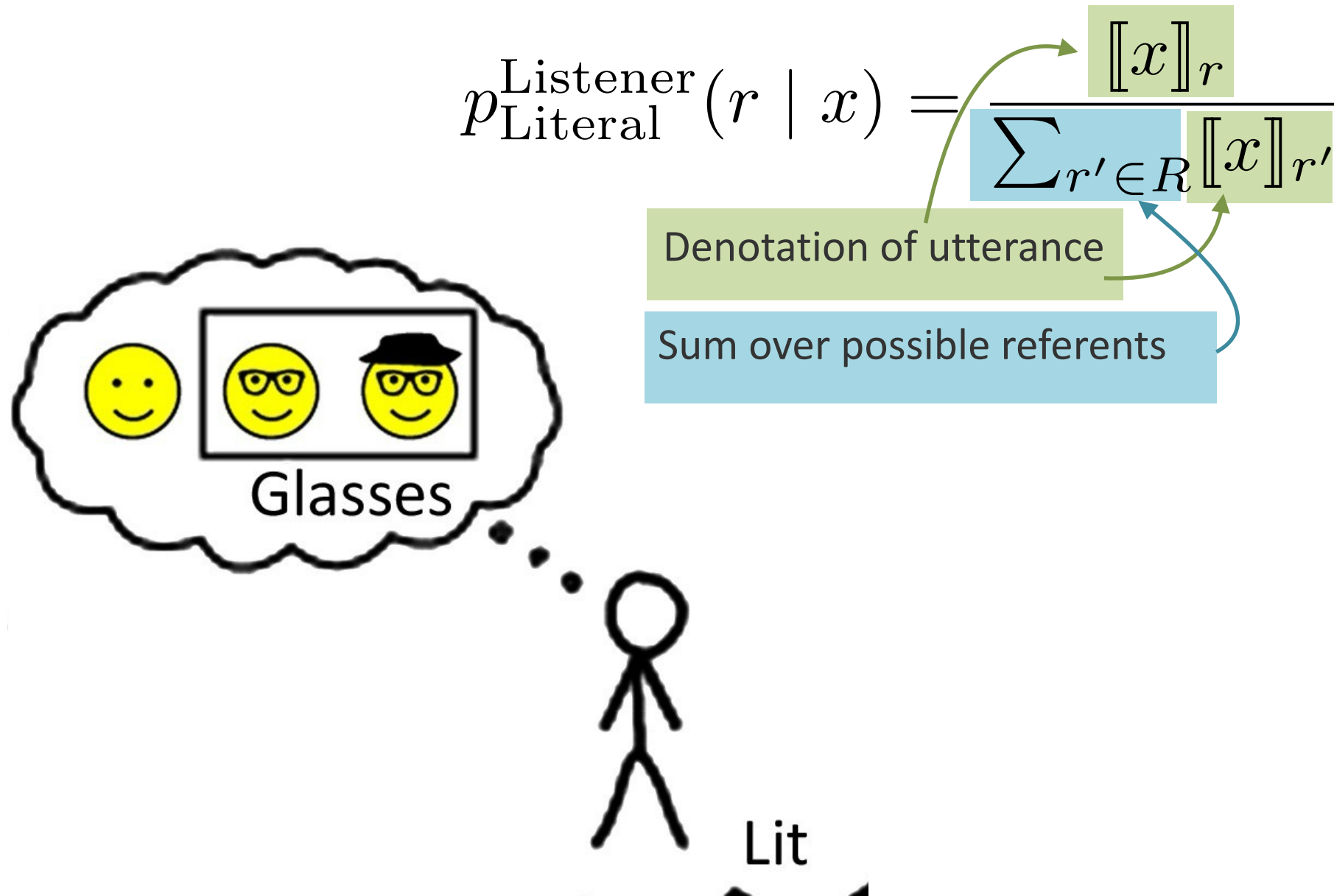


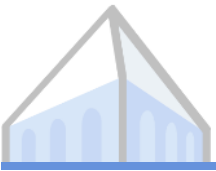
Rational Speech Acts Model





Rational Speech Acts Model





Rational Speech Acts Model

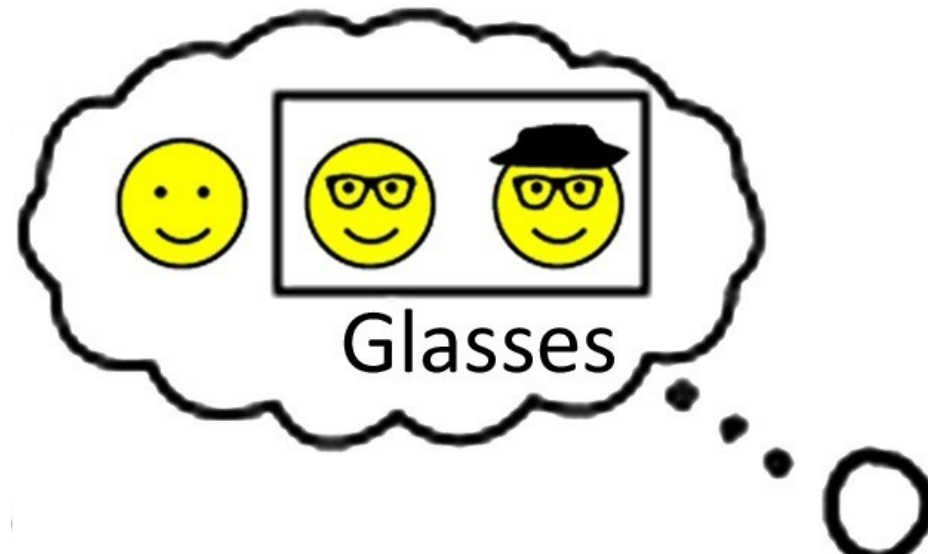
[[*"glasses"*]]

	R1	R2	R3
<i>hat</i>			
<i>glasses</i>			
<i>mustache</i>			

$$p_{\text{Literal}}^{\text{Listener}}(r \mid x) = \frac{[[x]]_r}{\sum_{r' \in R} [[x]]_{r'}}$$

Denotation of utterance

Sum over possible referents





Rational Speech Acts Model

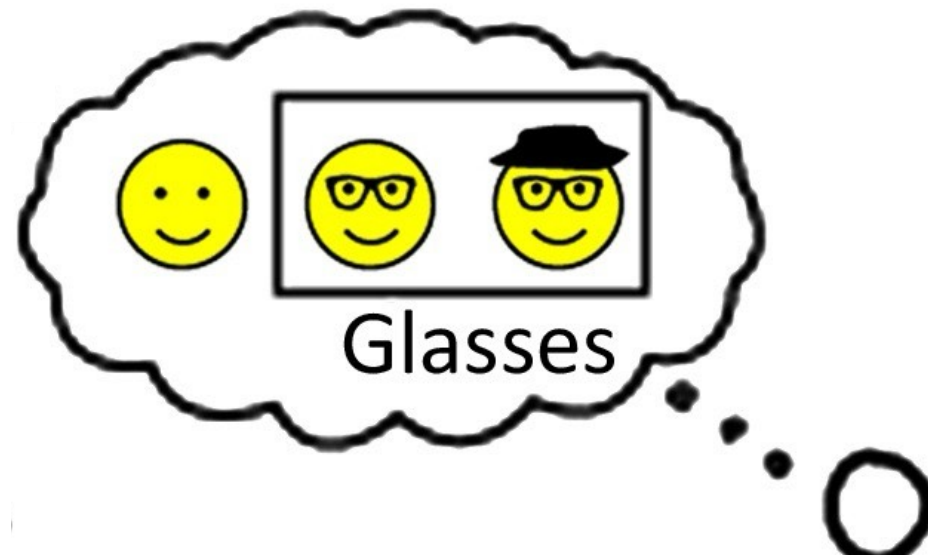
$\llbracket \text{"glasses"} \rrbracket$

	R1	R2	R3
<i>hat</i>			
<i>glasses</i>	0	1	1
<i>mustache</i>			

$$p_{\text{Literal}}^{\text{Listener}}(r \mid x) = \frac{\llbracket x \rrbracket_r}{\sum_{r' \in R} \llbracket x \rrbracket_{r'}}$$

Denotation of utterance

Sum over possible referents





Rational Speech Acts Model

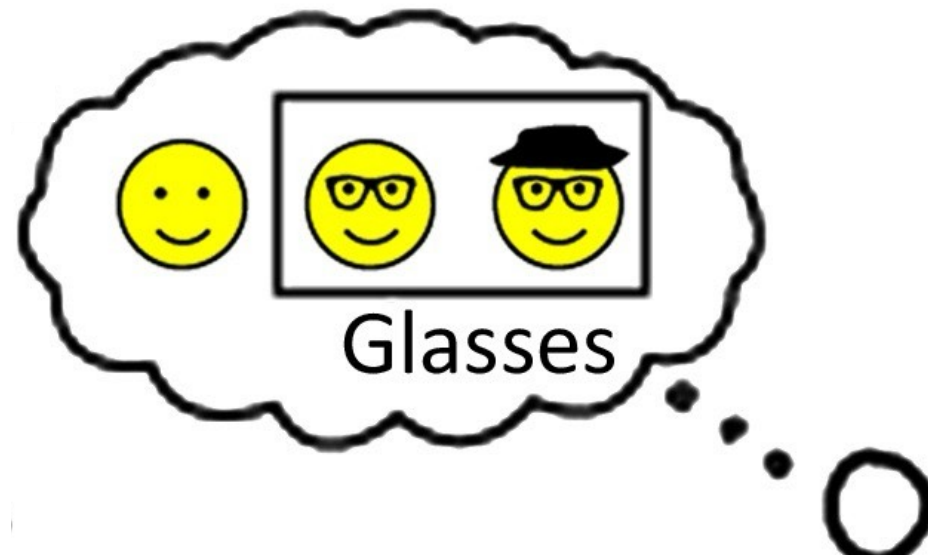
$$p_{\text{Literal}}^{\text{Listener}}(\cdot \mid x)$$

	R1	R2	R3
<i>hat</i>			
<i>glasses</i>	0	1/2	1/2
<i>mustache</i>			

$$p_{\text{Literal}}^{\text{Listener}}(r \mid x) = \frac{[[x]]_r}{\sum_{r' \in R} [[x]]_{r'}}$$

Denotation of utterance

Sum over possible referents

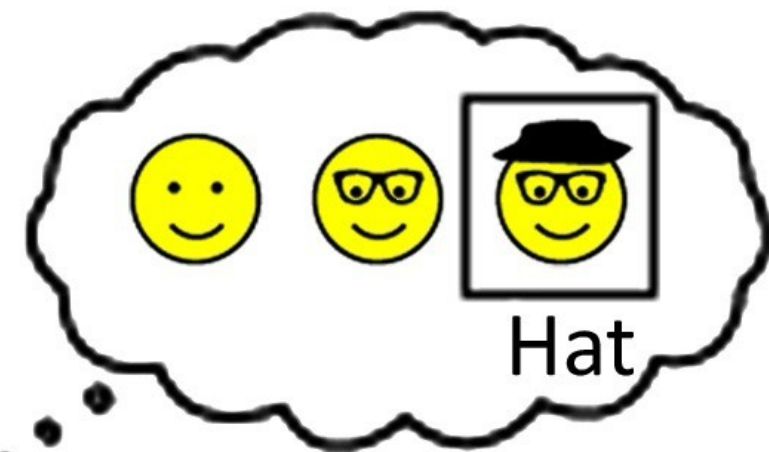
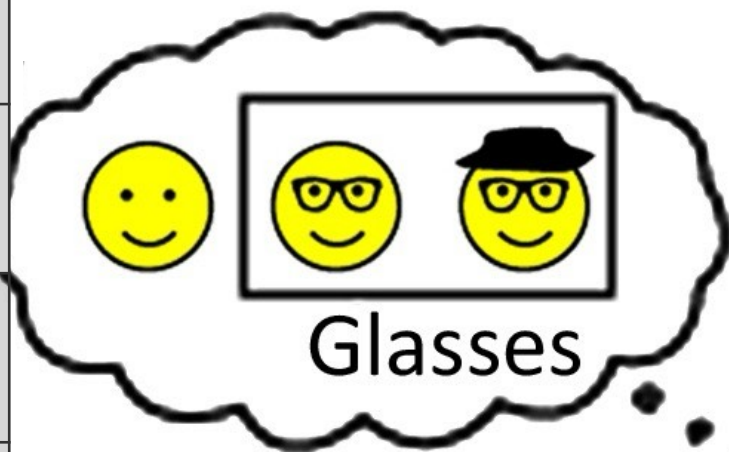




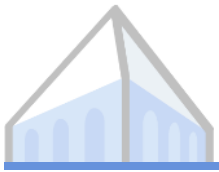
Rational Speech Acts Model

$$p_{\text{Literal}}^{\text{Listener}}(\cdot \mid x) \quad p_{\text{Literal}}^{\text{Listener}}(r \mid x) = \frac{\llbracket x \rrbracket_r}{\sum_{r' \in R} \llbracket x \rrbracket_{r'}}$$

	R1	R2	R3
<i>hat</i>	0	0	1
<i>glasses</i>	0	1/2	1/2
<i>mustache</i>	0	0	0



Lit



Rational Speech Acts Model

$$p_{\text{Literal}}^{\text{Listener}}(\cdot \mid x)$$

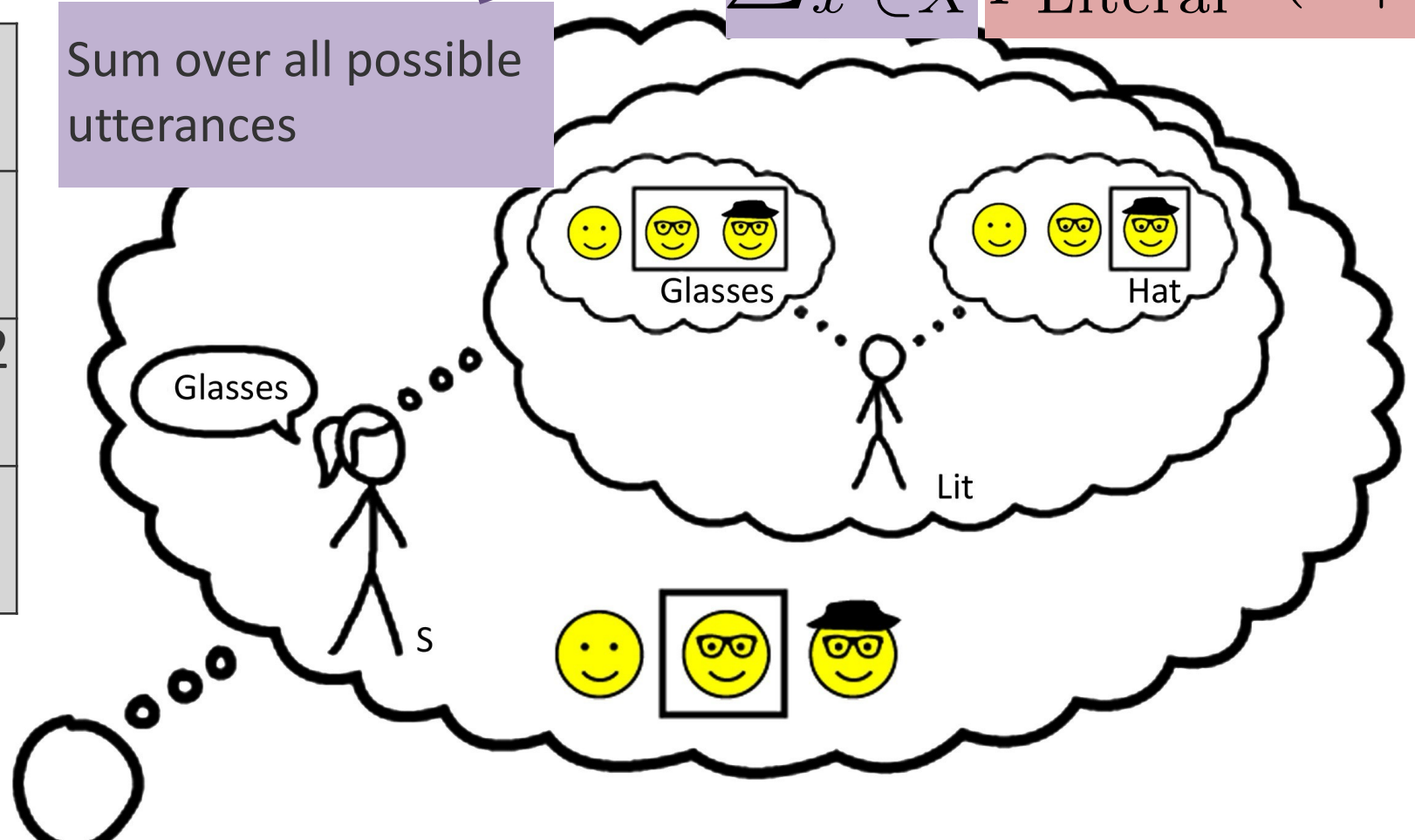
$$p_{\text{Pragmatic}}^{\text{Speaker}}(x \mid r) =$$

$$p_{\text{Literal}}^{\text{Listener}}(r \mid x)$$

$$\sum_{x' \in X} p_{\text{Literal}}^{\text{Listener}}(r \mid x')$$

Sum over all possible utterances

	R1	R2	R3
<i>hat</i>	0	0	1
<i>glasses</i>	0	1/2	1/2
<i>mustache</i>	0	0	0





Rational Speech Acts Model

$$p_{\text{Pragmatic}}^{\text{Speaker}}(\cdot \mid r)$$

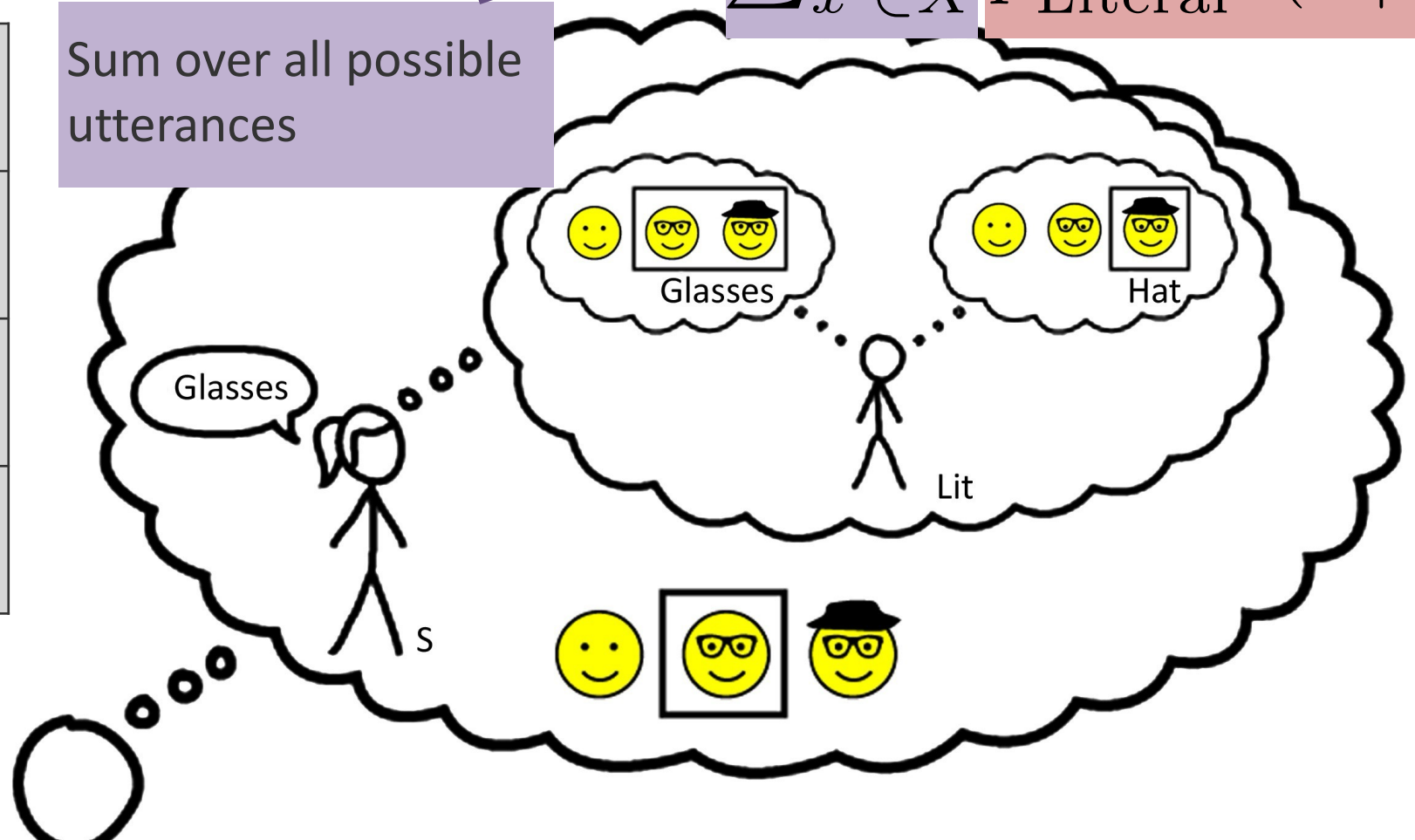
$$p_{\text{Pragmatic}}^{\text{Speaker}}(x \mid r) =$$

$$p_{\text{Literal}}^{\text{Listener}}(r \mid x)$$

$$\sum_{x' \in X} p_{\text{Literal}}^{\text{Listener}}(r \mid x')$$

Sum over all possible utterances

	R1	R2	R3
<i>hat</i>	0	0	2/3
<i>glasses</i>	0	1	1/3
<i>mustache</i>	0	0	0





Rational Speech Acts Model

$$p_{\text{Pragmatic}}^{\text{Speaker}}(\cdot \mid r)$$

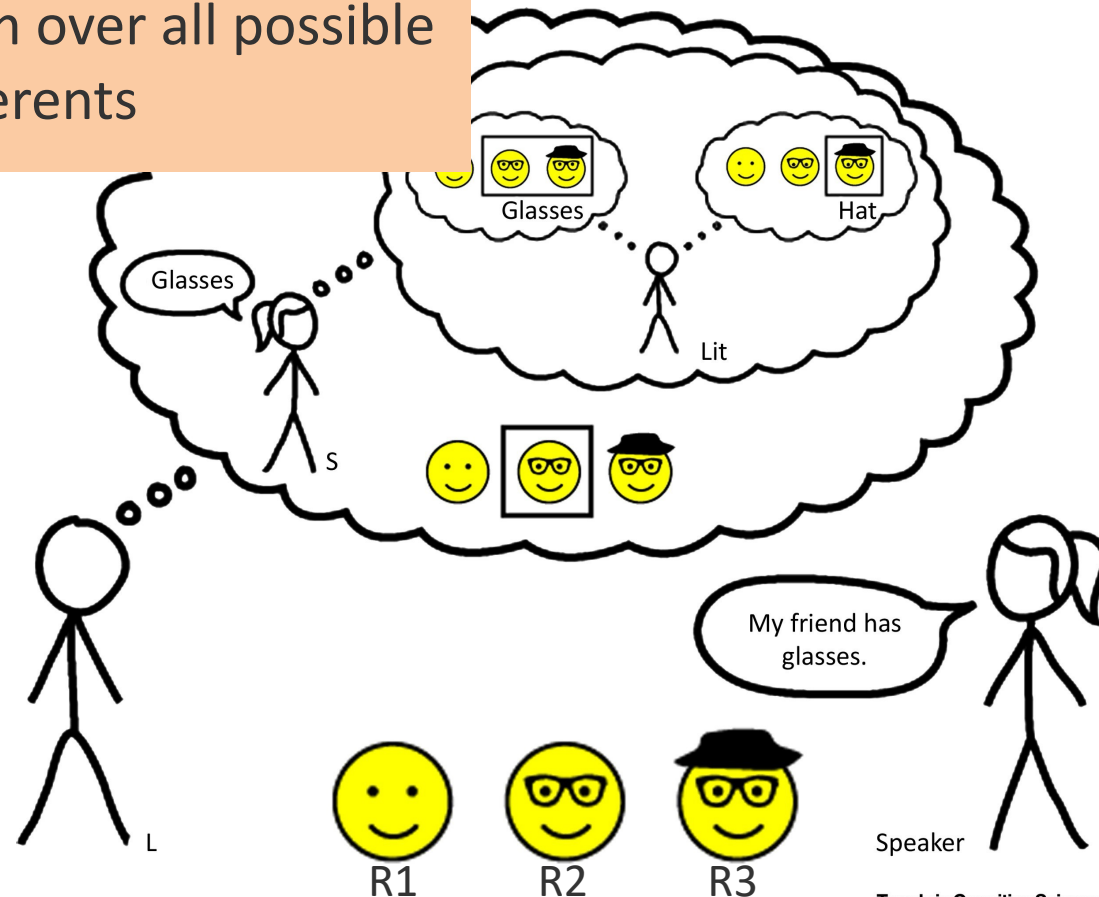
	R1	R2	R3
<i>hat</i>	0	0	2/3
<i>glasses</i>	0	1	1/3
<i>mustache</i>	0	0	0

$$p_{\text{Pragmatic}}^{\text{Listener}}(r \mid x) =$$

$$p_{\text{Pragmatic}}^{\text{Speaker}}(x \mid r)$$

$$\sum_{r' \in R} p_{\text{Pragmatic}}^{\text{Speaker}}(x \mid r')$$

Sum over all possible referents



Speaker



Rational Speech Acts Model

$$p_{\text{Pragmatic}}^{\text{Listener}}(\cdot \mid x)$$

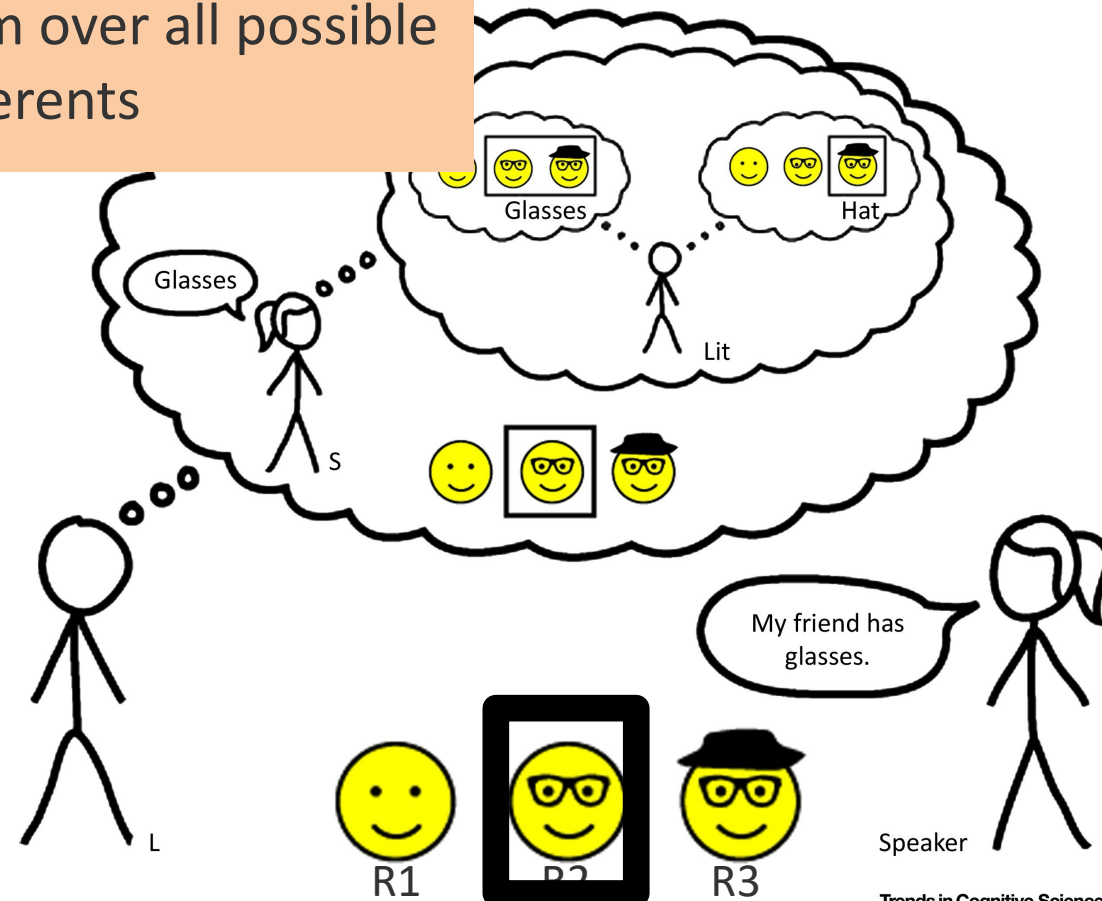
$$p_{\text{Pragmatic}}^{\text{Listener}}(r \mid x) =$$

$$p_{\text{Pragmatic}}^{\text{Speaker}}(x \mid r)$$

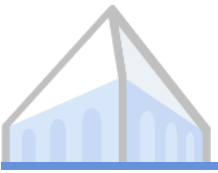
$$\sum_{r' \in R} p_{\text{Pragmatic}}^{\text{Speaker}}(x \mid r')$$

Sum over all possible referents

	R1	R2	R3
<i>hat</i>	0	0	1
<i>glasses</i>	0	3/4	1/4
<i>mustache</i>	0	0	0



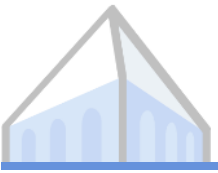
Speaker



RSA: Review

- **Literal listener:** uses denotational semantics to map utterances to probability of referents

$$p_{\text{Literal}}^{\text{Listener}}(r \mid x) = \frac{[[x]]_r}{\sum_{r' \in R} [[x]]_{r'}}$$



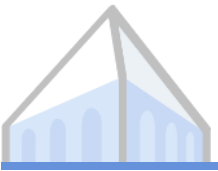
RSA: Review

- **Literal listener:** uses denotational semantics to map utterances to probability of referents

$$p_{\text{Literal}}^{\text{Listener}}(r \mid x) = \frac{\llbracket x \rrbracket_r}{\sum_{r' \in R} \llbracket x \rrbracket_{r'}}$$

- **Pragmatic speaker:** re-normalizes probabilities over utterances given literal listener's interpretations

$$p_{\text{Pragmatic}}^{\text{Speaker}}(x \mid r) = \frac{p_{\text{Literal}}^{\text{Listener}}(r \mid x)}{\sum_{x' \in X} p_{\text{Literal}}^{\text{Listener}}(r \mid x')}$$



RSA: Review

- **Literal listener:** uses denotational semantics to map utterances to probability of referents

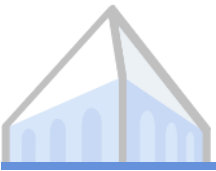
$$p_{\text{Literal}}^{\text{Listener}}(r \mid x) = \frac{\llbracket x \rrbracket_r}{\sum_{r' \in R} \llbracket x \rrbracket_{r'}}$$

- **Pragmatic speaker:** re-normalizes probabilities over utterances given literal listener's interpretations

$$p_{\text{Pragmatic}}^{\text{Speaker}}(x \mid r) = \frac{p_{\text{Literal}}^{\text{Listener}}(r \mid x)}{\sum_{x' \in X} p_{\text{Literal}}^{\text{Listener}}(r \mid x')}$$

- **Pragmatic listener:** takes into account alternative utterances the speaker *could* have used to refer to referents, but didn't

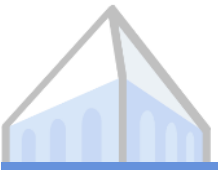
$$p_{\text{Pragmatic}}^{\text{Listener}}(r \mid x) = \frac{p_{\text{Pragmatic}}^{\text{Speaker}}(x \mid r)}{\sum_{r' \in R} p_{\text{Pragmatic}}^{\text{Speaker}}(x \mid r')}$$



RSA Variations

- Priors over referents

$$p_{\text{Literal}}^{\text{Listener}}(r \mid x) = \frac{[[x]]_r \cdot P(r)}{\sum_{r' \in R} [[x]]_{r'} \cdot P(r')}$$



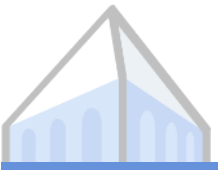
RSA Variations

- Priors over referents

$$p_{\text{Literal}}^{\text{Listener}}(r \mid x) = \frac{\llbracket x \rrbracket_r \cdot P(r)}{\sum_{r' \in R} \llbracket x \rrbracket_{r'} \cdot P(r')}$$

- Utterance costs

$$p_{\text{Pragmatic}}^{\text{Speaker}}(x \mid r) = \frac{\exp(\log p_{\text{Literal}}^{\text{Listener}}(r \mid x) + C(x))}{\sum_{x \in X} \exp(\log p_{\text{Literal}}^{\text{Listener}}(r \mid x) + C(x))}$$



RSA Variations

- Priors over referents

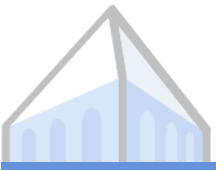
$$p_{\text{Literal}}^{\text{Listener}}(r \mid x) = \frac{\llbracket x \rrbracket_r \cdot P(r)}{\sum_{r' \in R} \llbracket x \rrbracket_{r'} \cdot P(r')}$$

- Utterance costs

$$p_{\text{Pragmatic}}^{\text{Speaker}}(x \mid r) = \frac{\exp(\log p_{\text{Literal}}^{\text{Listener}}(r \mid x) + C(x))}{\sum_{x \in X} \exp(\log p_{\text{Literal}}^{\text{Listener}}(r \mid x) + C(x))}$$

- Adjusting temperature of distributions

$$p_{\text{Pragmatic}}^{\text{Speaker}}(x \mid r) = \frac{\exp(\alpha \cdot (\log p_{\text{Literal}}^{\text{Listener}}(r \mid x) + C(x)))}{\sum_{x \in X} \exp(\alpha \cdot (\log p_{\text{Literal}}^{\text{Listener}}(r \mid x) + C(x)))}$$

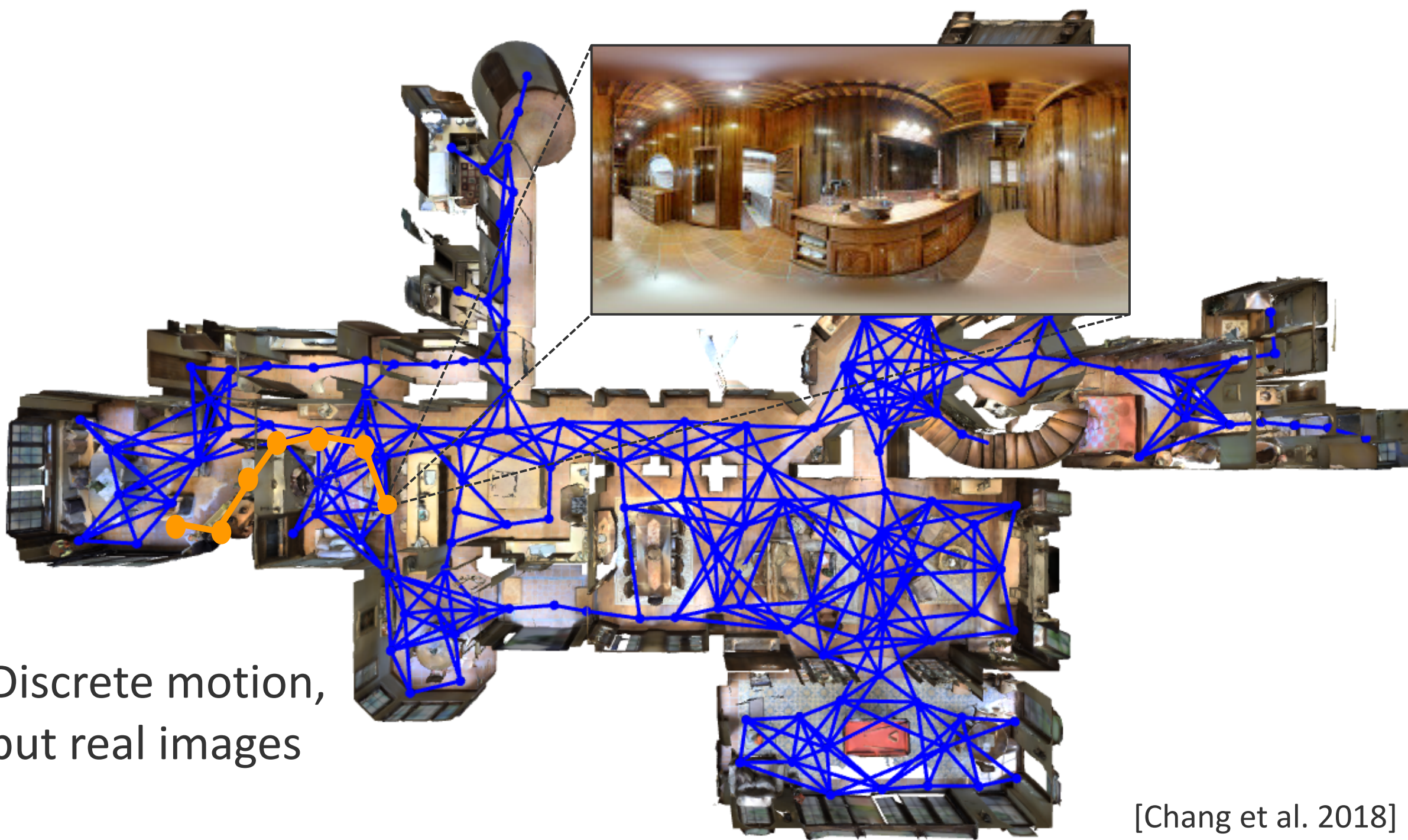


Language Use Beyond Reference

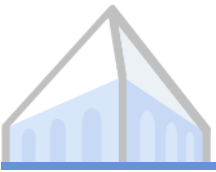


Turn left and take a right at the table. Take a left at the painting and then take your first right. Wait next to the exercise equipment.

[Vision-and-Language Navigation Task. Anderson et al., 2018]



- Discrete motion, but real images



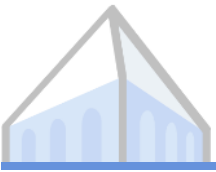
Instruction Following

Input instructions:

Go forward between the kitchen counters and then turn right into the living room. Walk forward onto the rug.

Output a route:





Instruction Generation

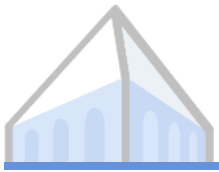
Input a route:



Output instructions:

Go forward between the kitchen counters and then turn right into the living room. Walk forward onto the rug.



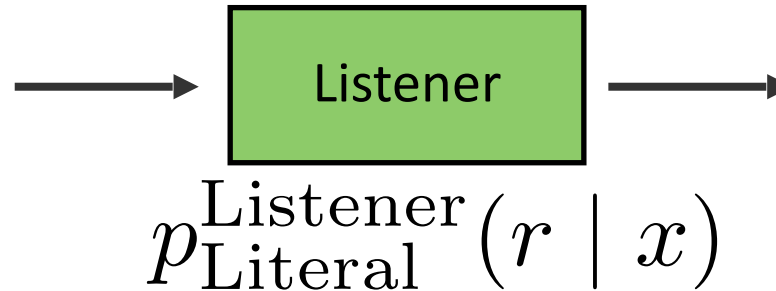


Speakers and Listeners

Inputs

*Go forward between the
kitchen counters...*

Instruction x



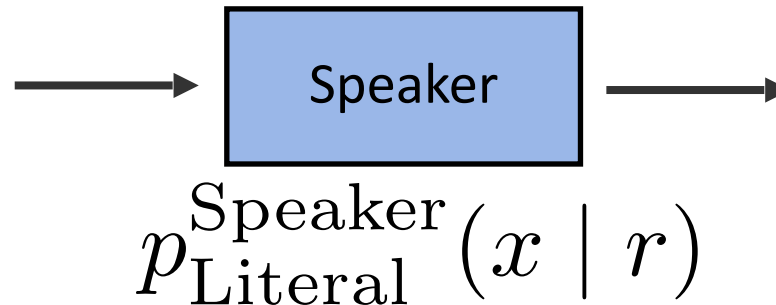
Outputs



Route r

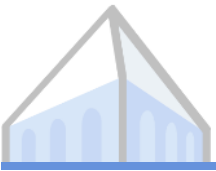


Route r

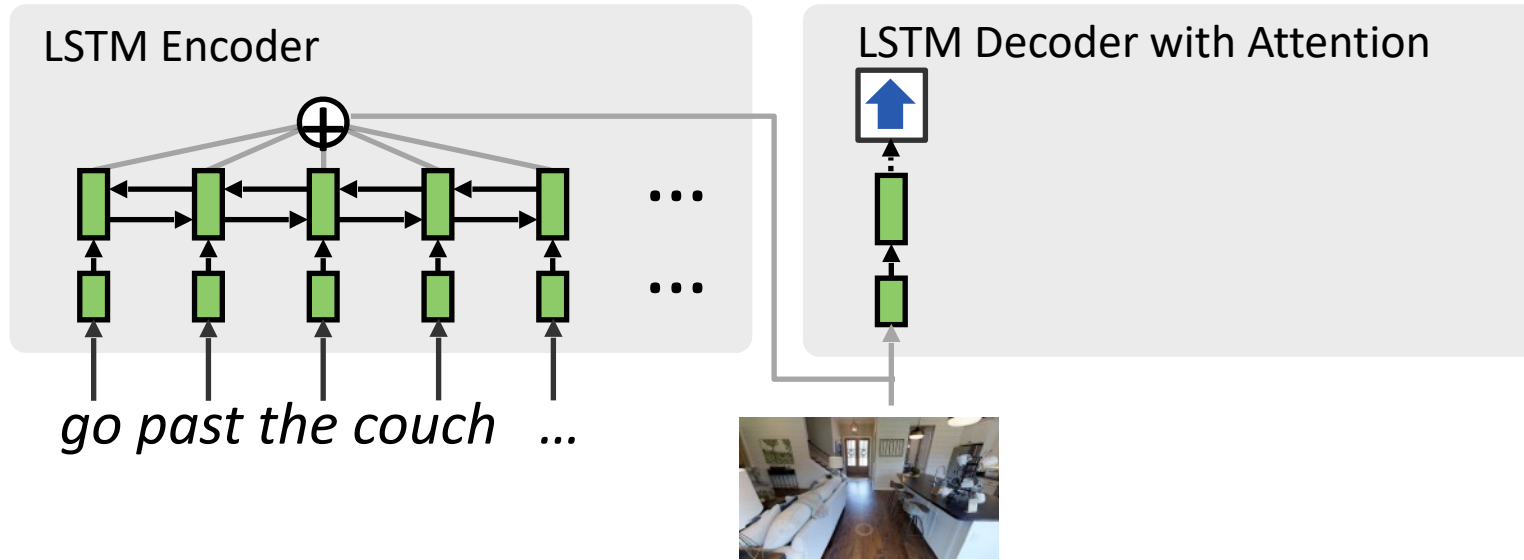


*Go forward between the
kitchen counters...*

Instruction x

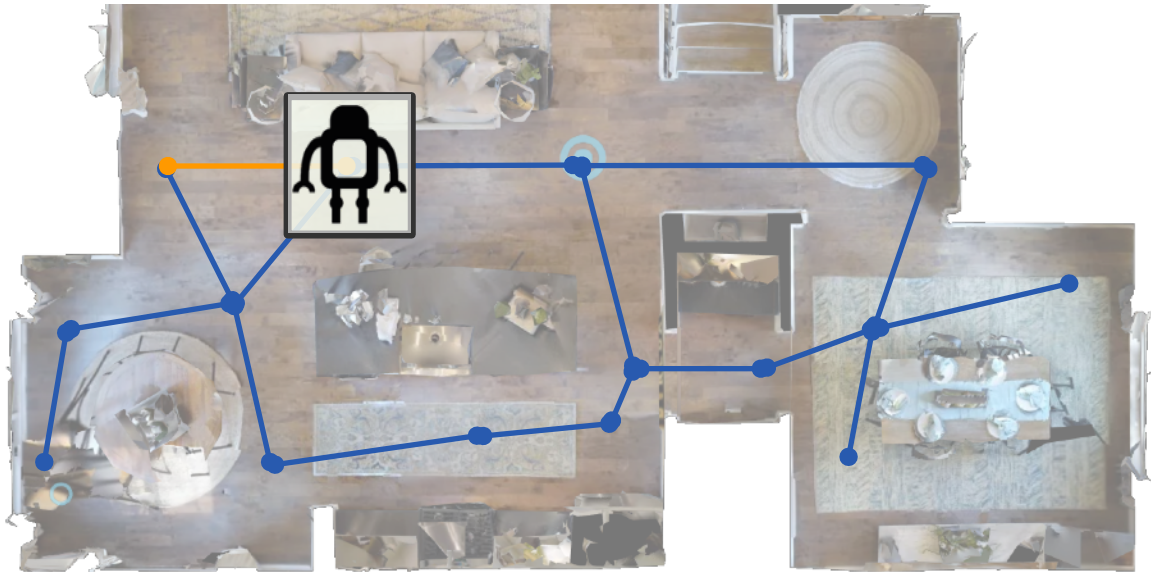
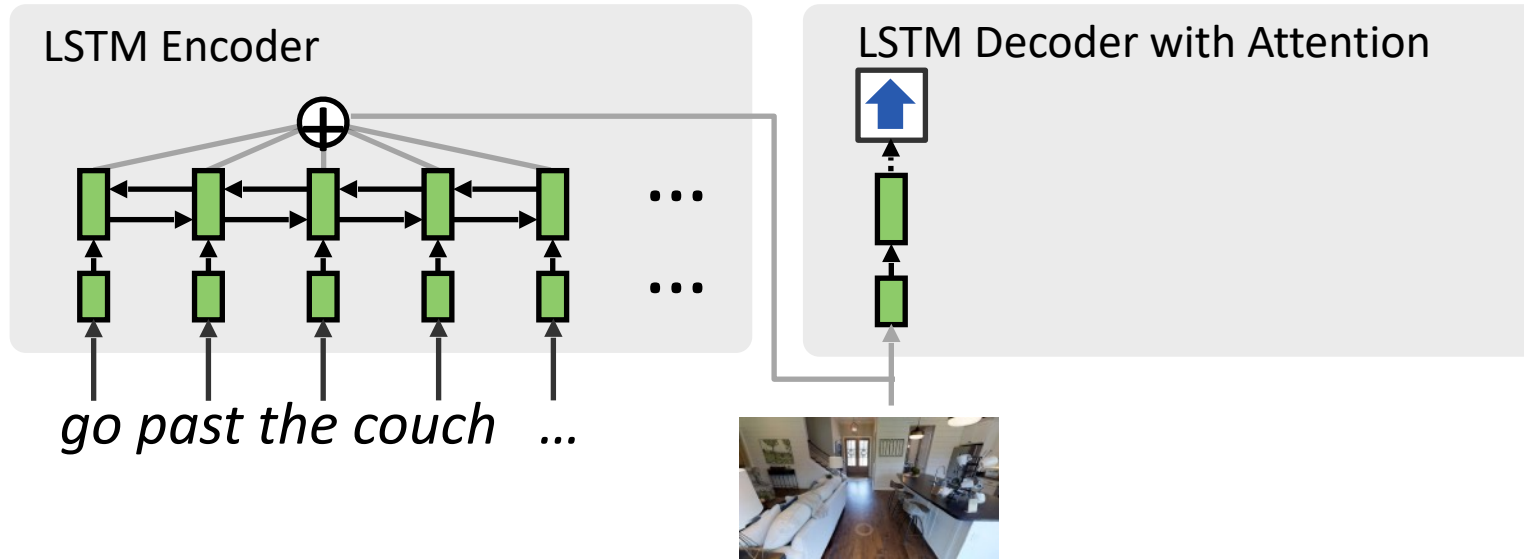


Literal Listener



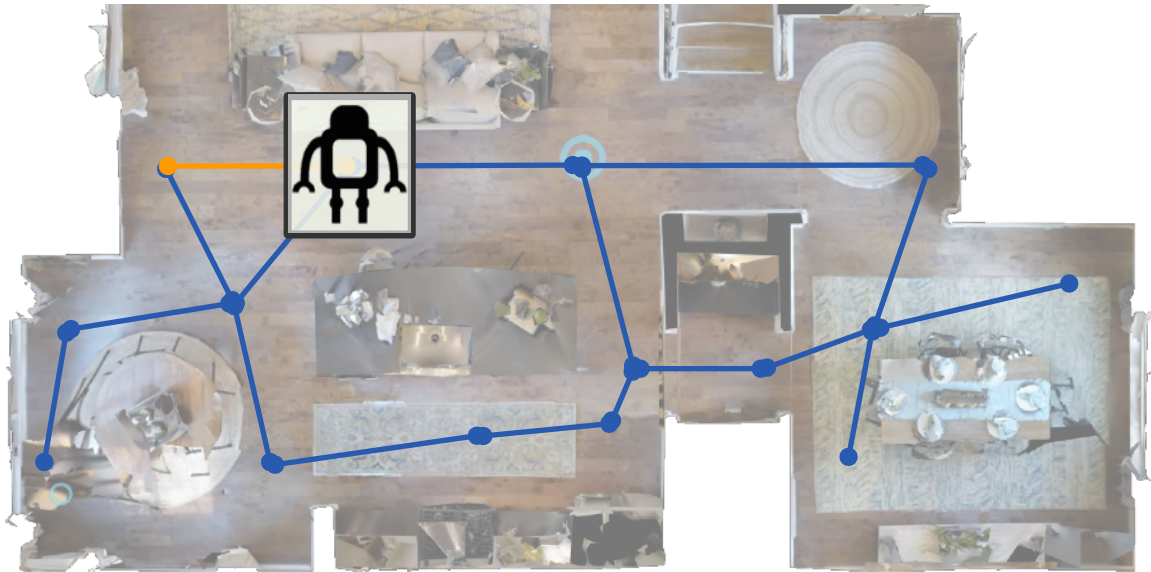
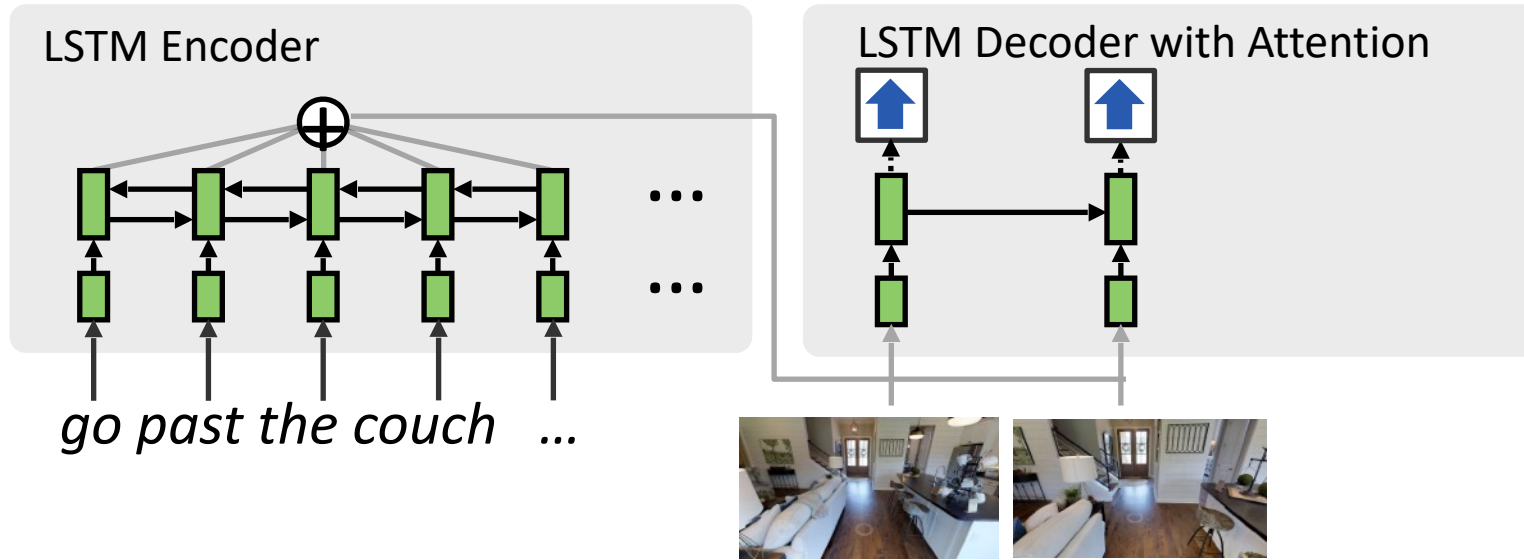


Literal Listener



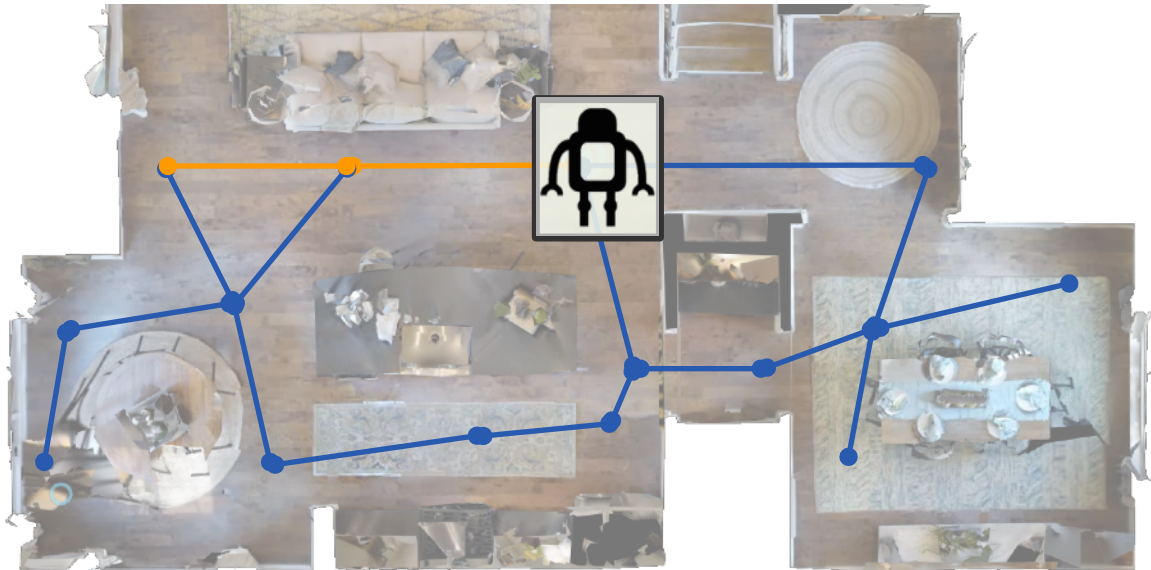
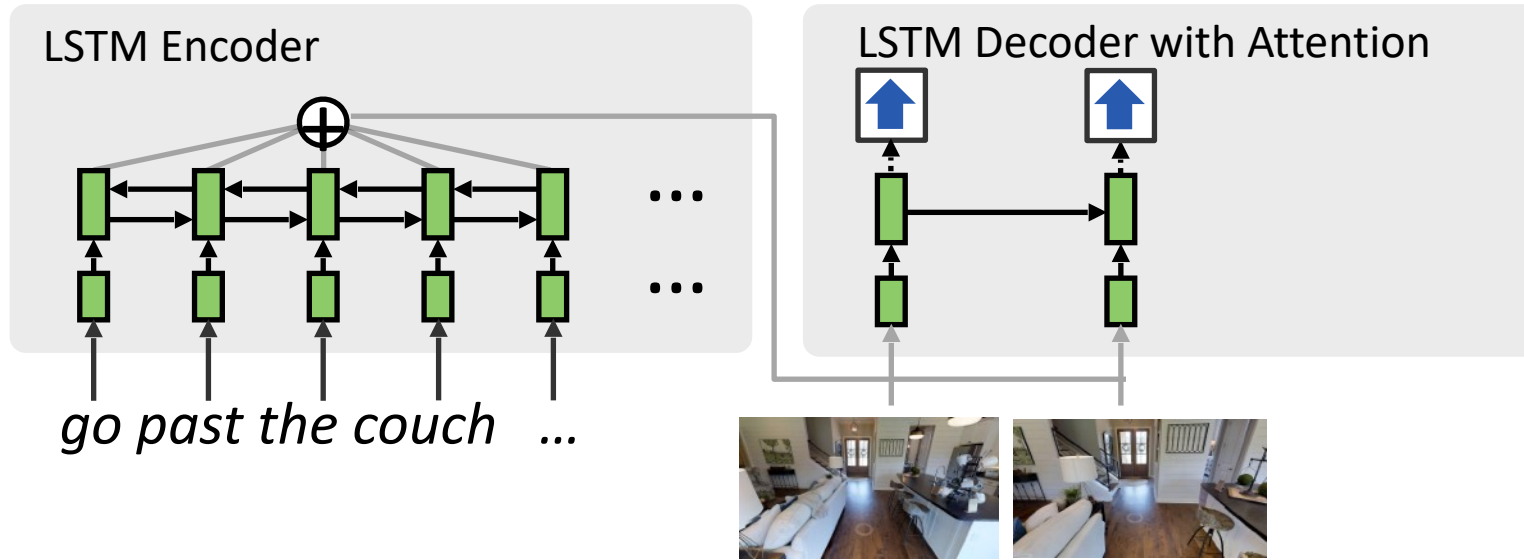


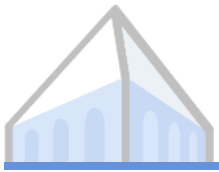
Literal Listener



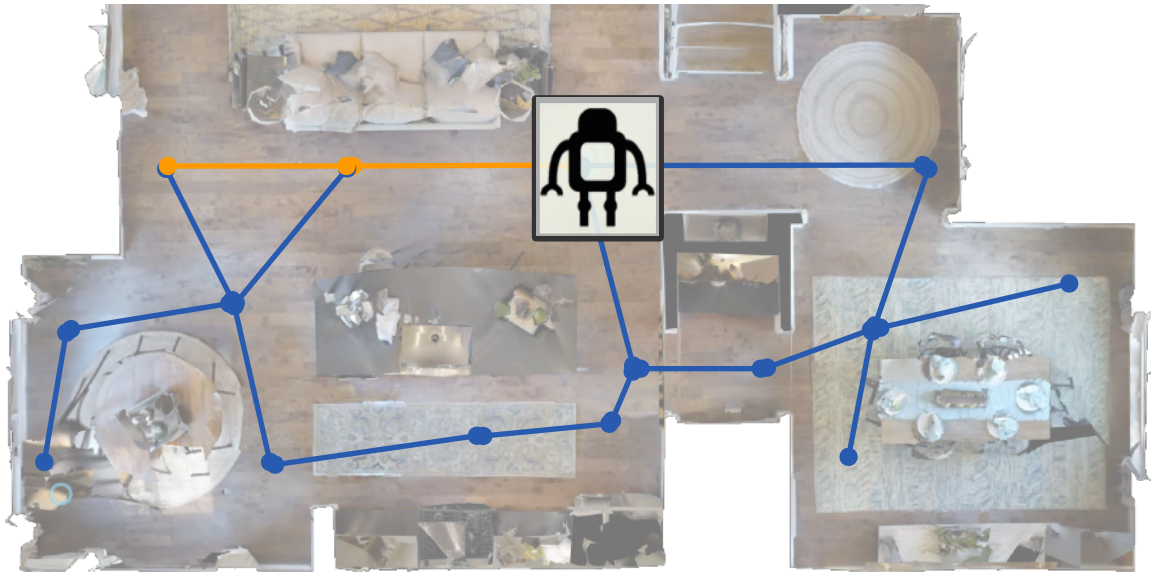
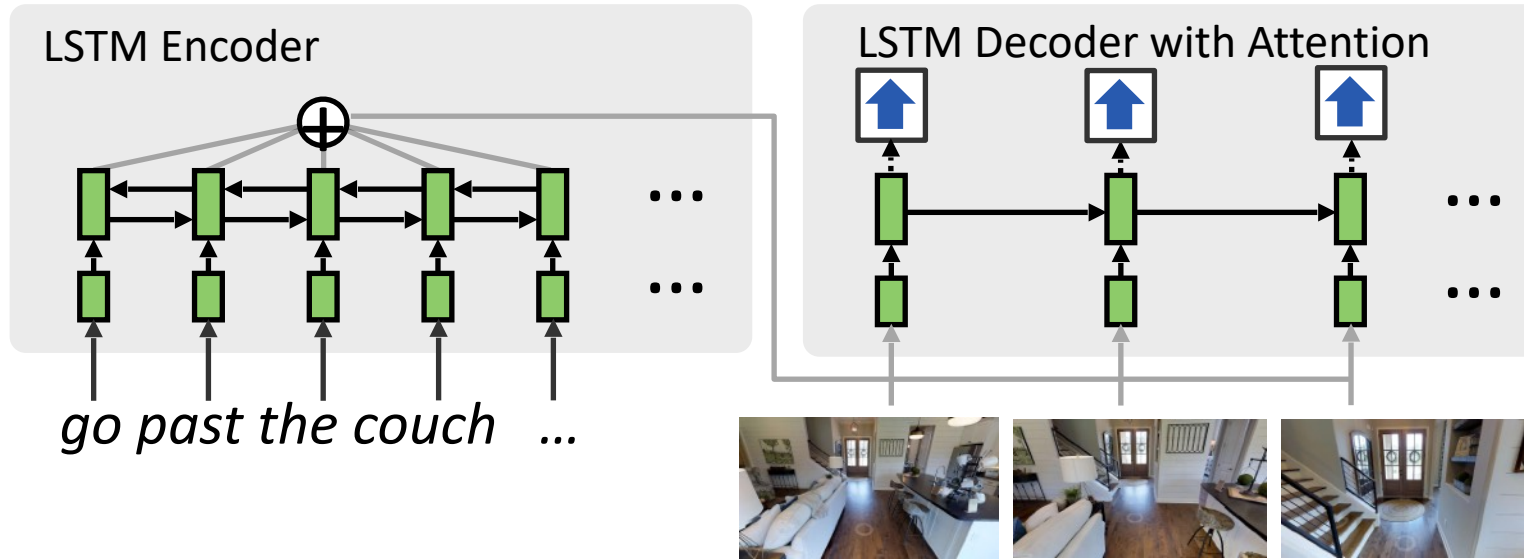


Literal Listener





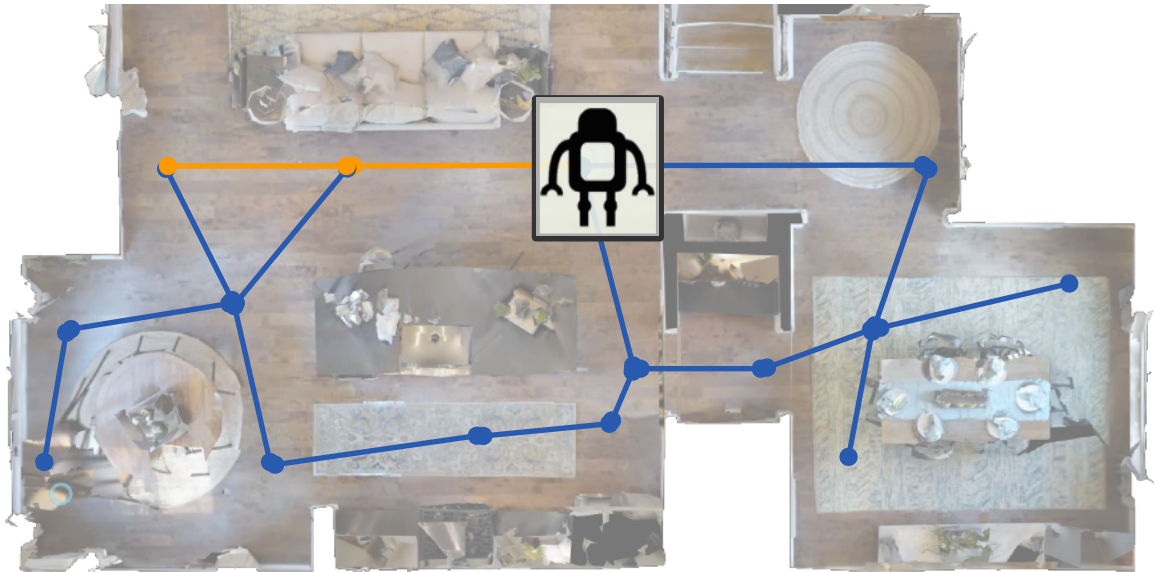
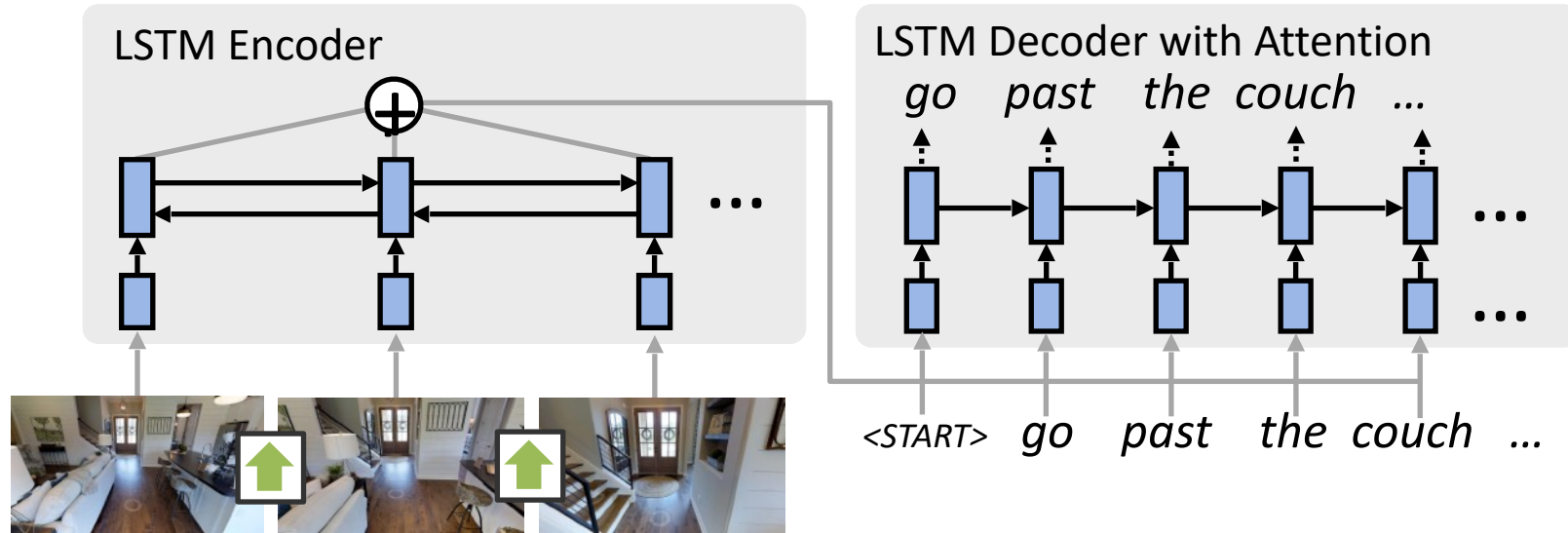
Literal Listener

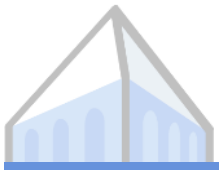


[Anderson et al., 2018]

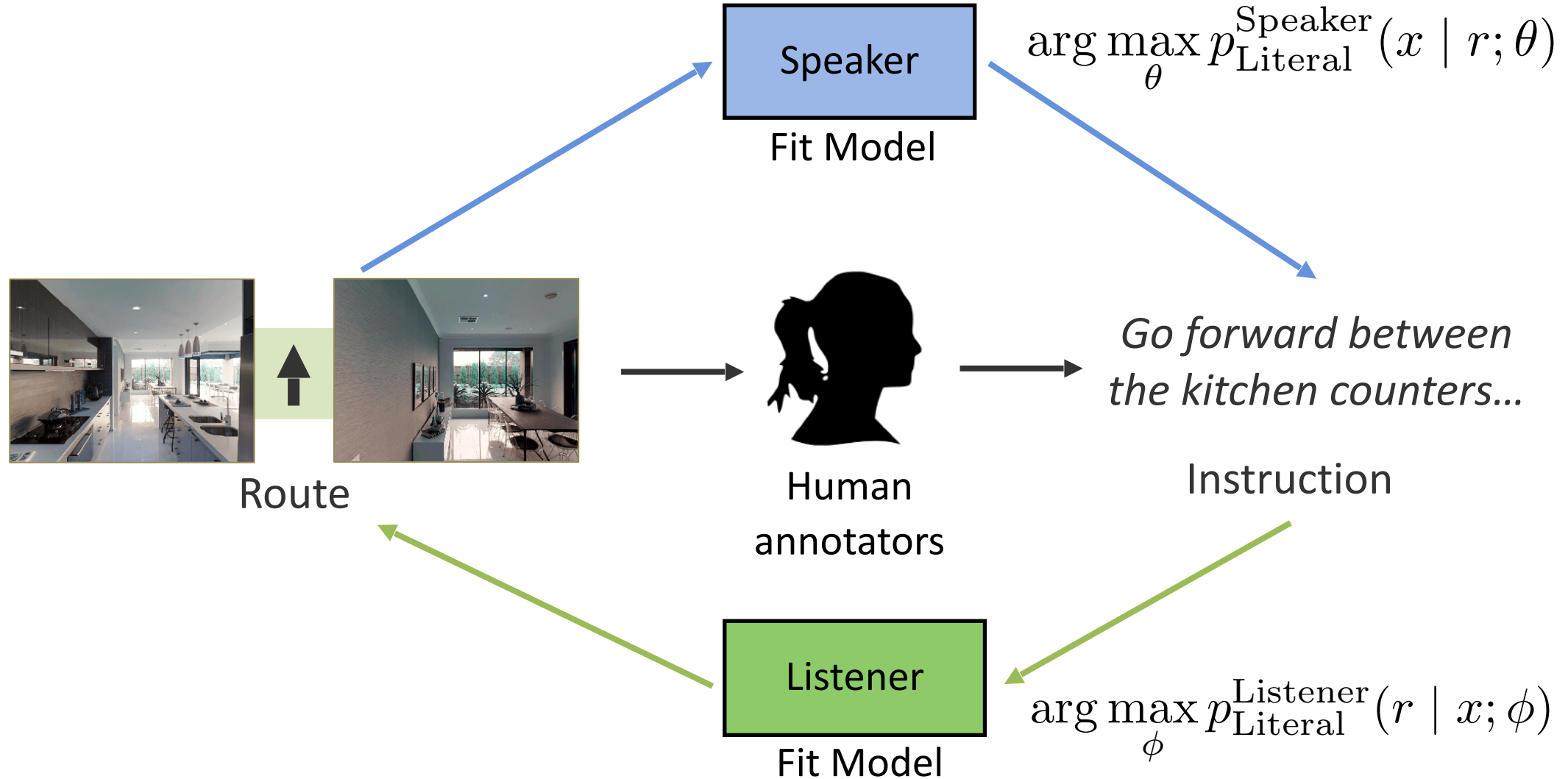


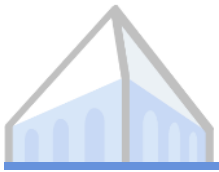
Literal Speaker



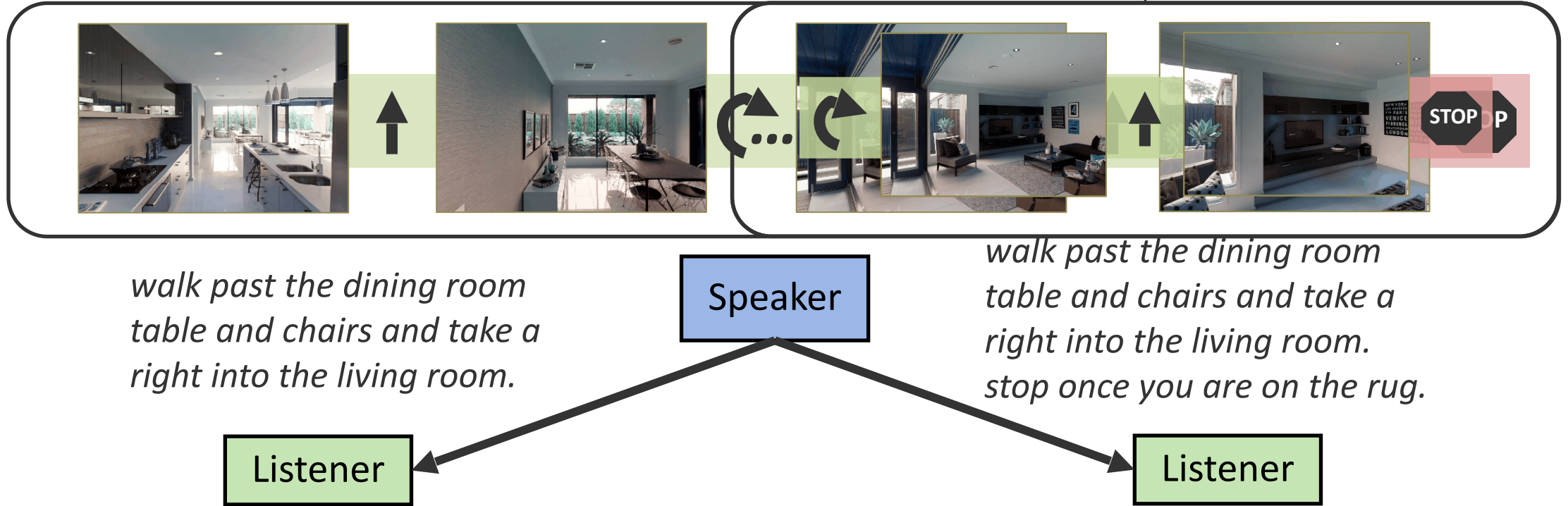


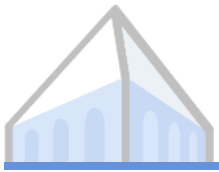
Training Literal Listener and Speaker





Pragmatic Instruction Generation





Pragmatic Instruction Generation



*walk past the dining room
table and chairs and take a
right into the living room.*

Speaker

*walk past the dining room
table and chairs and take a
right into the living room.
stop once you are on the rug.*

Listener

Listener

...



...





Pragmatic Instruction Generation



*walk past the dining room
table and chairs and take a
right into the living room.*

Speaker

*walk past the dining room
table and chairs and take a
right into the living room.
stop once you are on the rug.*

Listener

0.4

$$p_{\text{Literal}}^{\text{Listener}}(r^* \mid x; \phi)$$

Listener

0.8

...



...

