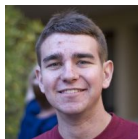


# Learning in extended and approximate Rational Speech Acts models

Christopher Potts

Stanford Linguistics

EMNLP 2016



Will Monroe



## Gricean pragmatics

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- **Quality:** Contribute only what you know to be true. Do not say false things. Do not say things for which you lack evidence.
- **Quantity:** Make your contribution as informative as is required. Do not say more than is required.
- **Relation (Relevance):** Make your contribution relevant.
- **Manner:** (i) Avoid obscurity; (ii) avoid ambiguity; (iii) be brief; (iv) be orderly.
- **Politeness:** Be polite, so be tactful, respectful, generous, praising, modest, deferential, and sympathetic. (Leech)

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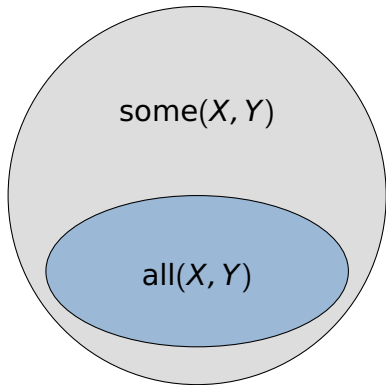
# Overview

1. Meaning from a communicative tension
2. The Rational Speech Acts (RSA) model
3. Learning in the Rational Speech Acts Model
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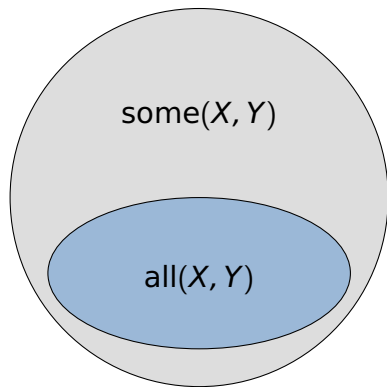
# Scalar implicature

John Stuart Mill: *I saw some of your children to-day* invites the inference that I didn't see all of them



## Scalar implicature

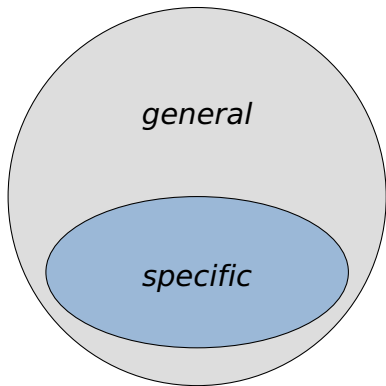
**John Stuart Mill:** *I saw **some** of your children to-day* invites the inference that I didn't see **all** of them “not because the words mean it, but because, if I had seen them all, it is most likely that I should have said so.”





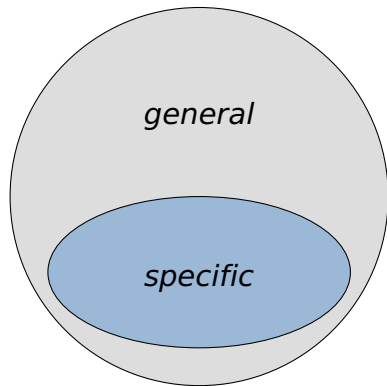
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**Generalization:** Using a general term invites the inference that its more specific, salient alternatives are inappropriate.



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**Generalization:** Using a general term invites the inference that its **more specific, salient** alternatives are inappropriate.



# Scalar implicature

**George Bush:** “As I understand it, the current form asks the question ‘Did somebody use drugs within the last seven years?’, and I will be glad to answer that question, and the answer is ‘No’.”

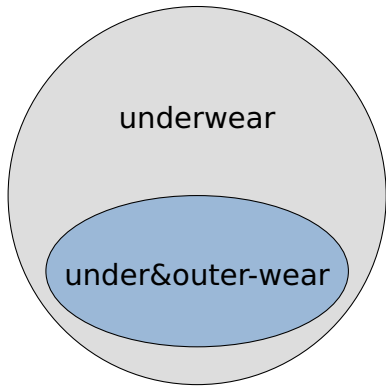


# Scalar implicature

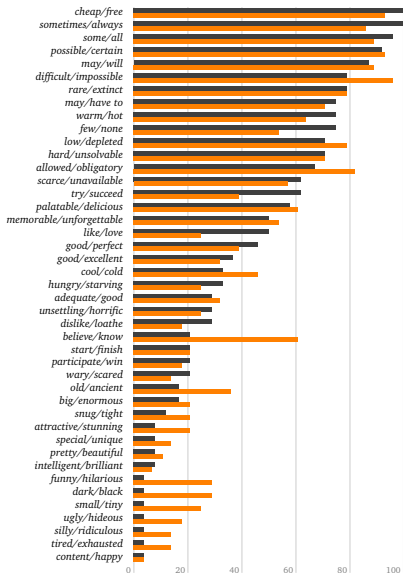
**Chris Potts:** Watching TV in your underwear – that's a scalar implicature!

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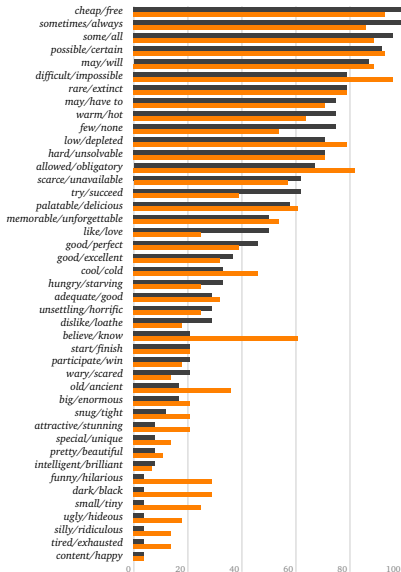


# Scalar diversity



van Tiel, van Miltenburg,  
Zevakhina, and Geurts,  
'Scalar diversity'

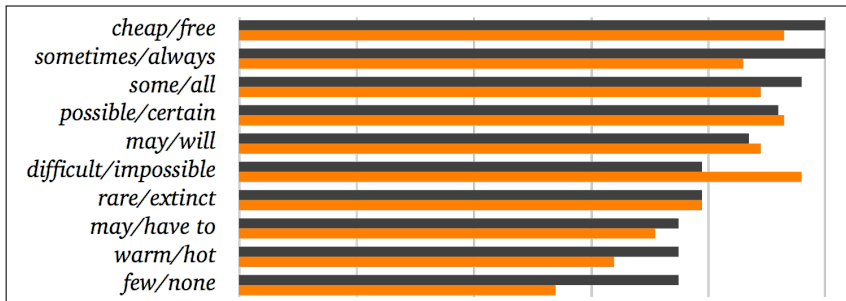
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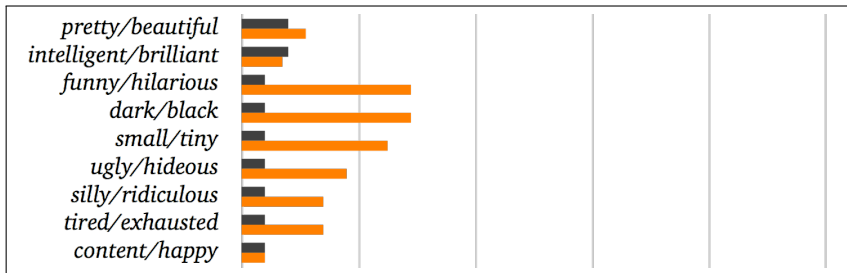
Also: Judith Degen,  
'Investigating the distribution  
of some (but not all)  
implicatures using corpora  
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# Scalar diversity





# Scalar diversity



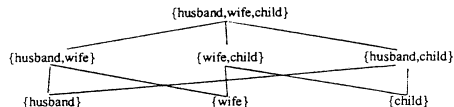
# Partial-order implicature

Hirschberg 1985, *A Theory of Scalar Implicature*

# Partial-order implicature

A: Do you speak  
German?

B: My husband does.

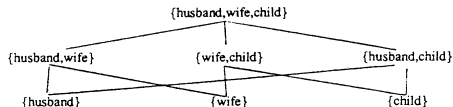


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## Partial-order implicature

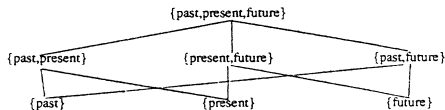
A: Do you speak German?

B: My husband does.



A: Are you on your honeymoon?

B: Well, I was.



Hirschberg 1985, *A Theory of Scalar Implicature*

# Highly particularized implicature



R1



R2

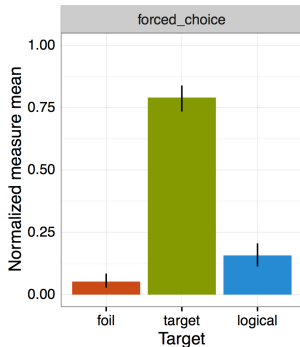


R3

“glasses”

## Reference games

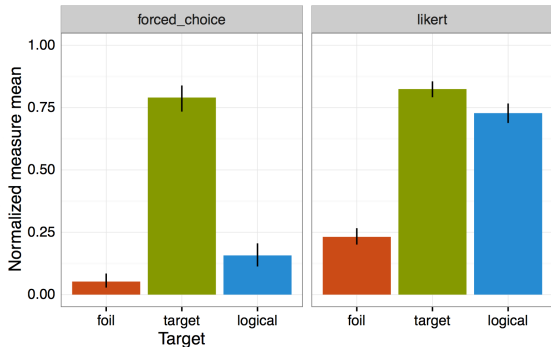
Frank, Gómez, Peloquin, Goodman, and Potts 2016, 10 experiments, each  $N \approx 600$  (4,651 participants). The summary picture:



<https://github.com/langcog/pragmods>

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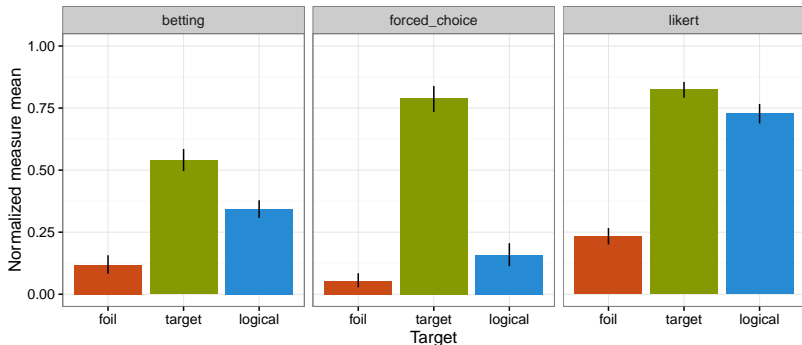
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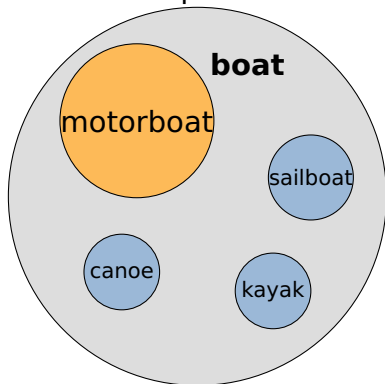
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5. I hit the button and it started. (causation)
6. Sandy finished the book. (reading)



# M-implicature

Levinson: “What’s said in an abnormal way isn’t normal.”

1. a. Turn on the car.  
b. Get the car to turn on.
2. a. Stop the car.  
b. Cause the car to stop.

# Sociolinguistic variables

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## Generalization

Where two forms are in salient contrast, the choice of one will lead to inferences about the other.

- **Community**: Community members adopt a speech style that is easily distinguished from the mainstream, enhancing solidarity.
- **Individual**: An individual systematically varies their speech style by context to construct different personae.

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# Origin story

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- **Golland, Liang, and Klein 2010 (*EMNLP*)**: pragmatic listeners and probabilistic compositionality
- **Frank and Goodman 2012 (*Science*)**: very sophisticated pragmatic agents and a new Bayesian foundation

# Pragmatic listeners

# Pragmatic listeners

Literal listener

$$I_0(w \mid msg, Lex) \propto Lex(msg, w)P(w)$$



# Pragmatic listeners

## Pragmatic speaker

$$s_1(msg | w, Lex) \propto \exp \lambda (\log I_0(w | msg, Lex) - C(msg))$$

## Literal listener

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# Pragmatic listeners

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$$l_1(w | msg, Lex) \propto s_1(msg | w, Lex)P(w)$$

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# Pragmatic listeners

## Pragmatic listener

$$l_1(w | msg, Lex) = \text{pragmatic speaker} \times \text{state prior}$$

## Pragmatic speaker

$$s_1(msg | w, Lex) = \text{literal listener} - \text{message costs}$$

## Literal listener

$$l_0(w | msg, Lex) = \text{lexicon} \times \text{state prior}$$

# RSA listener example



<i>beard</i>	1	0	0
<i>glasses</i>	1	1	0
<i>tie</i>	0	1	1

 $I_1$  $S_1$  $I_0$ 

Lex

# RSA listener example




<i>beard</i>	<b>1</b>	0	0
<i>glasses</i>	.5	.5	0
<i>tie</i>	0	.5	.5

 $I_1$  $S_1$  $I_0$ 

Lex

# RSA listener example

	<i>beard</i>	<i>glasses</i>	<i>tie</i>
	<b>.67</b>	.33	0
	0	<b>1</b>	0
	0	0	<b>1</b>

 $I_1$  $S_1$  $I_0$ 

Lex

# RSA listener example



<i>beard</i>	<b>1</b>	0	0
<i>glasses</i>	.25	<b>.75</b>	0
<i>tie</i>	0	0	<b>1</b>

 $I_1$  $S_1$  $I_0$ 

Lex

# Pragmatic speakers



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$$s_0(msg | w, Lex) \propto \exp \lambda (\log Lex(msg, w) - C(msg))$$

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	<i>beard</i>	<i>glasses</i>	<i>tie</i>
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	0	1	1
	0	0	1

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Lex

# RSA speaker example

	<i>beard</i>	<i>glasses</i>	<i>tie</i>
	.5	.5	0
	0	.5	.5
	0	0	<b>1</b>

 $S_1$  $I_1$  $S_0$ 

Lex



# RSA speaker example



<i>beard</i>	<b>1</b>	0	0
<i>glasses</i>	.5	.5	0
<i>tie</i>	0	.33	<b>.67</b>

 $S_1$ 
 $I_1$ 
 $S_0$ 
 $Lex$

# RSA speaker example

	<i>beard</i>	<i>glasses</i>	<i>tie</i>
	<b>.67</b>	.33	0
	0	<b>.6</b>	.4
	0	0	<b>1</b>

$S_1$

$I_1$

$S_0$

Lex



# Joint reasoning

$$L(w, Context | msg) \propto P(w)P_C(Context)s_1(msg | w, Context)$$

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$$L(w, Context | msg) \propto P(w)P_{\mathbf{C}}(Context)s_1(msg | w, Context)$$

$$L(w | msg) \propto P(w) \sum_{Context \in \mathbf{C}} P_{\mathbf{C}}(Context)s_1(msg | w, Context)$$

# Achievements

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Bergen, Levy, Goodman, 'Pragmatic reasoning through semantic inference'

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- **Metaphor**

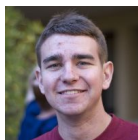
Kao, Bergen, Goodman, 'Formalizing the pragmatics of metaphor understanding'



# Limitations

- Hand-specified lexicon
- High-bias model; few chances to learn from data
- Cognitive demands limit speaker rationality
- Speaker preferences
- Scalability

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Will Monroe

# TUNA furniture example



# TUNA furniture example



Utterance: “blue fan small”

# TUNA furniture example



colour:green  
orientation:left  
size:small  
type:fan  
x-dimension:1  
y-dimension:1



colour:green  
orientation:left  
size:small  
type:sofa  
x-dimension:1  
y-dimension:2



colour:red  
orientation:back  
size:large  
type:fan  
x-dimension:1  
y-dimension:3



colour:red  
orientation:back  
size:large  
type:sofa  
x-dimension:2  
y-dimension:1



colour:blue  
orientation:left  
size:large  
type:fan  
x-dimension:2  
y-dimension:2



colour:blue  
orientation:left  
size:large  
type:sofa  
x-dimension:3  
y-dimension:1

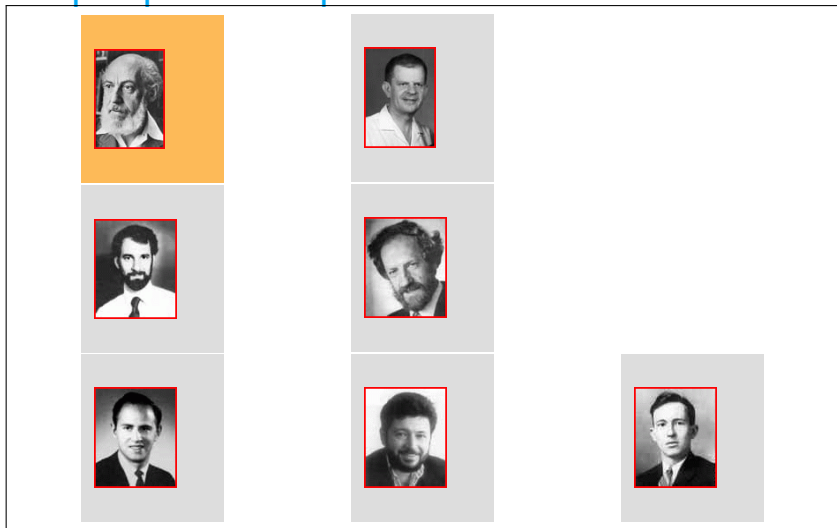


colour:blue  
orientation:left  
size:small  
type:fan  
x-dimension:3  
y-dimension:3

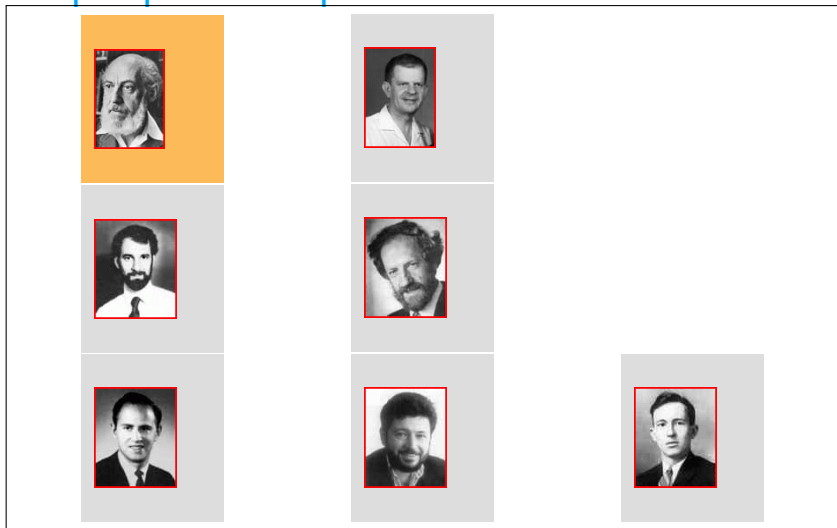
Utterance: “blue fan small”

Utterance attributes: [colour:blue]; [size:small]; [type:fan]

# TUNA people example

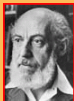


# TUNA people example



Utterance: "The bald man with a beard"

# TUNA people example



age:old  
hairColour:light  
hasBeard:1  
hasGlasses:0  
hasHair:0  
hasShirt:1  
hasSuit:0  
hasTie:0  
type:person



age:young  
hairColour:dark  
hasBeard:0  
hasGlasses:0  
hasHair:1  
hasShirt:1  
hasSuit:0  
hasTie:0  
type:person



age:young  
hairColour:dark  
hasBeard:1  
hasGlasses:0  
hasHair:1  
hasShirt:1  
hasSuit:0  
hasTie:1  
type:person



age:young  
hairColour:dark  
hasBeard:1  
hasGlasses:0  
hasHair:1  
hasShirt:0  
hasSuit:1  
hasTie:1  
type:person



age:young  
hairColour:dark  
hasBeard:0  
hasGlasses:0  
hasHair:1  
hasShirt:0  
hasSuit:1  
hasTie:1  
type:person



age:young  
hairColour:dark  
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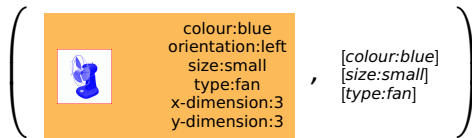


age:young  
hairColour:dark  
hasBeard:0  
hasGlasses:0  
hasHair:1  
hasShirt:0  
hasSuit:1  
hasTie:1  
type:person

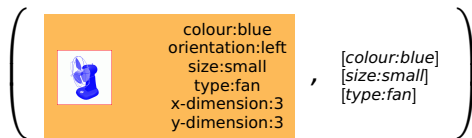
Utterance: "The bald man with a beard"  
Utterance attributes:  $[hasBeard:1]$ ;  $[hasHair:0]$ ;  $[type:person]$



# Feature representations



# Feature representations




---

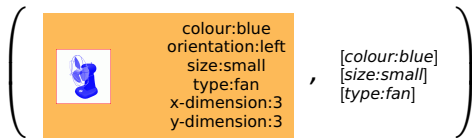
## Cross-product features

---

colour:blue  $\wedge$  [colour:blue]  
 colour:blue  $\wedge$  [size:small]  
 colour:blue  $\wedge$  [type:fan]  
 orientation:left  $\wedge$  [colour:blue]  
 orientation:left  $\wedge$  [size:small]  
 ⋮

---

# Feature representations




---

## Cross-product features

---

colour:blue  $\wedge$  [colour:blue]  
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 colour:blue  $\wedge$  [type:fan]  
 orientation:left  $\wedge$  [colour:blue]  
 orientation:left  $\wedge$  [size:small]  
 ⋮

---



---

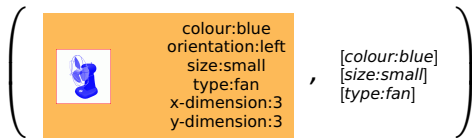
## Generation features

---

**color**  
**type + color**  
**color +  $\neg$ size**  
**attribute-count = 3**  
 ⋮

---

# Feature representations




---

## Cross-product features

---

colour:blue  $\wedge$  [colour:blue]  
 colour:blue  $\wedge$  [size:small]  
 colour:blue  $\wedge$  [type:fan]  
 orientation:left  $\wedge$  [colour:blue]  
 orientation:left  $\wedge$  [size:small]  
 ⋮

---



---

## Generation features

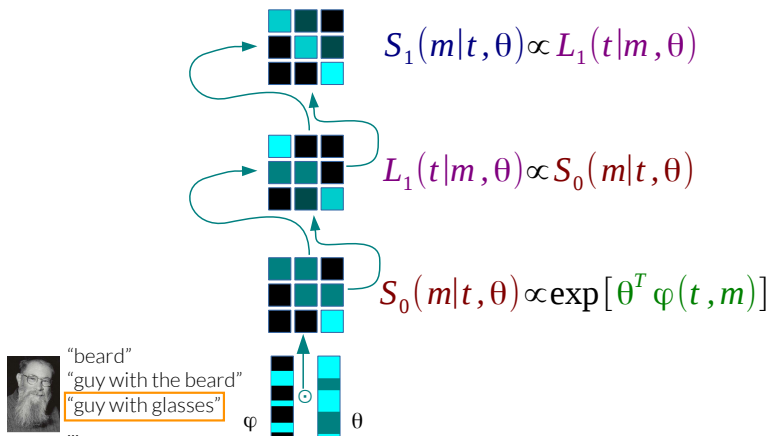
---

**color**  
**type + color**  
**color +  $\neg$ size**  
**attribute-count = 3**  
 ⋮

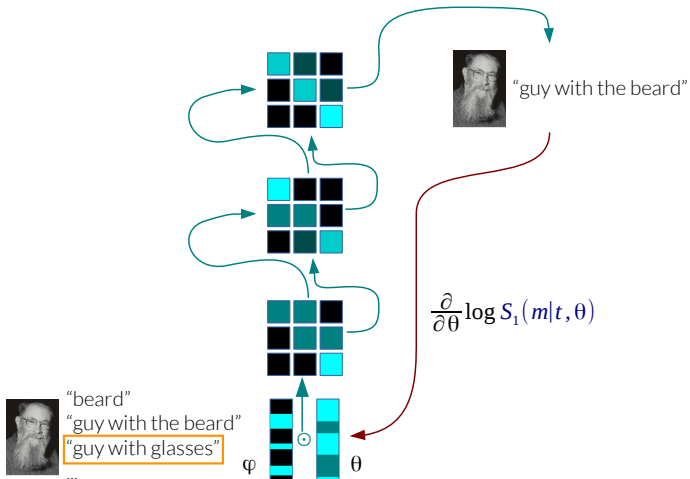
---

**type  $\gg$  orientation  $\gg$  color  $\gg$  size**

# Model definition



# Optimization



# Addressing the drawbacks of RSA

---

**Goal**

**Features**

---

---

# Addressing the drawbacks of RSA

---

## Goal

## Features

---

Avoid hand-built lexicon

---



## Addressing the drawbacks of RSA

---

<b>Goal</b>	<b>Features</b>
Avoid hand-built lexicon	Cross-product features

---

# Addressing the drawbacks of RSA

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## Goal

Avoid hand-built lexicon  
Learn quirks of production

## Features

Cross-product features

---

# Addressing the drawbacks of RSA

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<b>Goal</b>	<b>Features</b>
Avoid hand-built lexicon	Cross-product features
Learn quirks of production	Features like <b>color</b>

---

# Addressing the drawbacks of RSA

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## Goal

Avoid hand-built lexicon  
Learn quirks of production  
Learn attribute hierarchies

---

## Features

Cross-product features  
Features like **color**

---

## Addressing the drawbacks of RSA

Goal	Features
Avoid hand-built lexicon	Cross-product features
Learn quirks of production	Features like <b>color</b>
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Avoid hand-built lexicon	Cross-product features
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# Addressing the drawbacks of RSA

Goal	Features
Avoid hand-built lexicon	Cross-product features
Learn quirks of production	Features like <b>color</b>
Learn attribute hierarchies	Features like <b>color</b> + $\neg$ <b>size</b>
Learn message costs	Length features and others

# Addressing the drawbacks of RSA

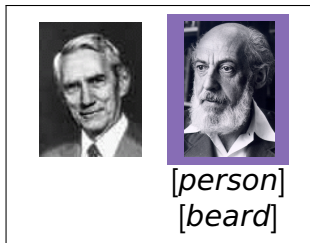
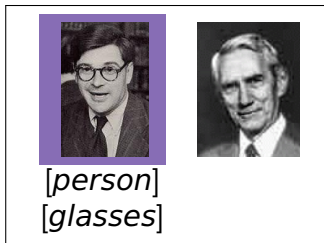
Goal	Features
Avoid hand-built lexicon	Cross-product features
Learn quirks of production	Features like <b>color</b>
Learn attribute hierarchies	Features like <b>color</b> + $\neg$ <b>size</b>
Learn message costs	Length features and others

**Cognitive and linguistic insights  
combined with learning**

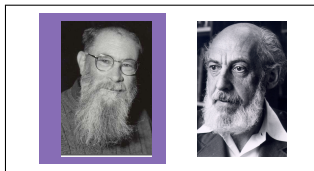


# Example

Train



Test





∅

[*person*]

[*glasses*]

[*beard*]

[*person*]; [*glasses*]

[*person*]; [*beard*]





[*glasses*]; [*beard*]

[*all*]



∅	.08	.25
[ <i>person</i> ]	.08	.25
[ <i>glasses</i> ]	<b>.17</b>	.00
[ <i>beard</i> ]	.08	.25
[ <i>person</i> ];[ <i>glasses</i> ]	<b>.17</b>	.00
[ <i>person</i> ];[ <i>beard</i> ]	.08	.25
[ <i>glasses</i> ];[ <i>beard</i> ]	<b>.17</b>	.00
[ <i>all</i> ]	<b>.17</b>	.00

**RSA**

				
∅	.08	.25	.03	.00
[ <i>person</i> ]	.08	.25	<b>.22</b>	.10
[ <i>glasses</i> ]	<b>.17</b>	.00	.03	.00
[ <i>beard</i> ]	.08	.25	.03	.04
[ <i>person</i> ]; [ <i>glasses</i> ]	<b>.17</b>	.00	<b>.22</b>	.01
[ <i>person</i> ]; [ <i>beard</i> ]	.08	.25	<b>.22</b>	.74
[ <i>glasses</i> ]; [ <i>beard</i> ]	<b>.17</b>	.00	.03	.00
[ <i>all</i> ]	<b>.17</b>	.00	<b>.22</b>	.10
	<b>RSA</b>		<b>Learned <math>S_0</math></b>	

A Gricean ideal  
oo

Implicatures  
ooooo







RSA  
oooooooo

Learned RSA  
ooooooooo●ooo

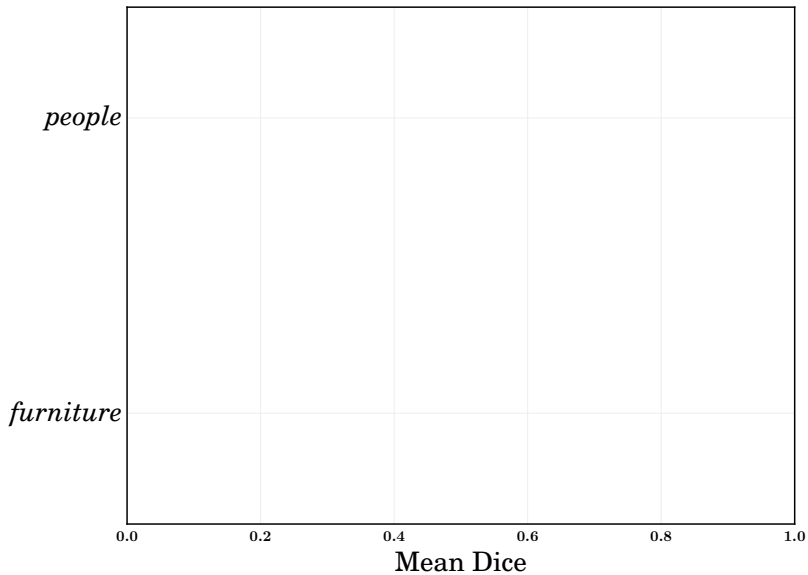
Neural RSA  
oooo

Language and action  
oooooooooooo

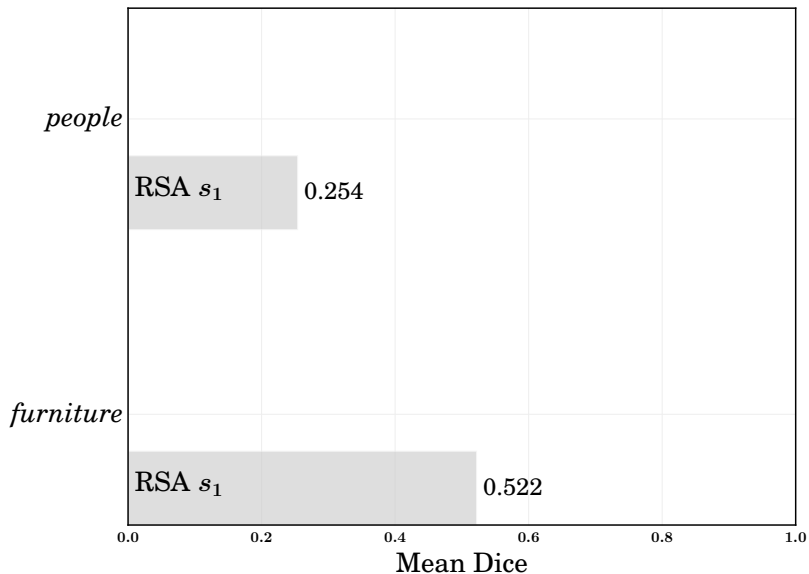
Prospects

						
$\emptyset$	.08	.25	.03	.00	.10	.11
[ <i>person</i> ]	.08	.25	.22	.10	.16	.13
[ <i>glasses</i> ]	.17	.00	.03	.00	.11	.07
[ <i>beard</i> ]	.08	.25	.03	.04	.08	.17
[ <i>person</i> ]; [ <i>glasses</i> ]	.17	.00	.22	.01	.18	.08
[ <i>person</i> ]; [ <i>beard</i> ]	.08	.25	.22	.74	.12	.19
[ <i>glasses</i> ]; [ <i>beard</i> ]	.17	.00	.03	.00	.10	.11
[ <i>all</i> ]	.17	.00	.22	.10	.16	.11
	<b>RSA</b>		<b>Learned <math>S_0</math></b>		<b>Learned <math>S_1</math></b>	

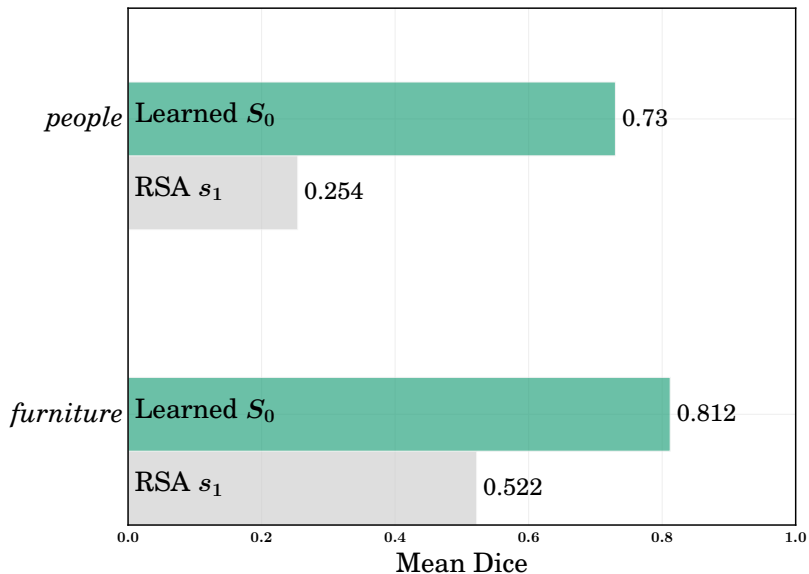
# TUNA Results



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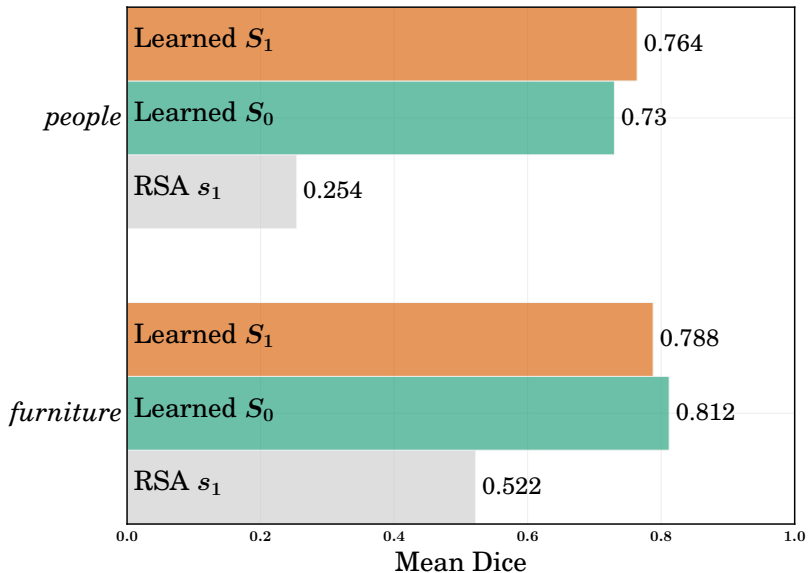


# TUNA Results

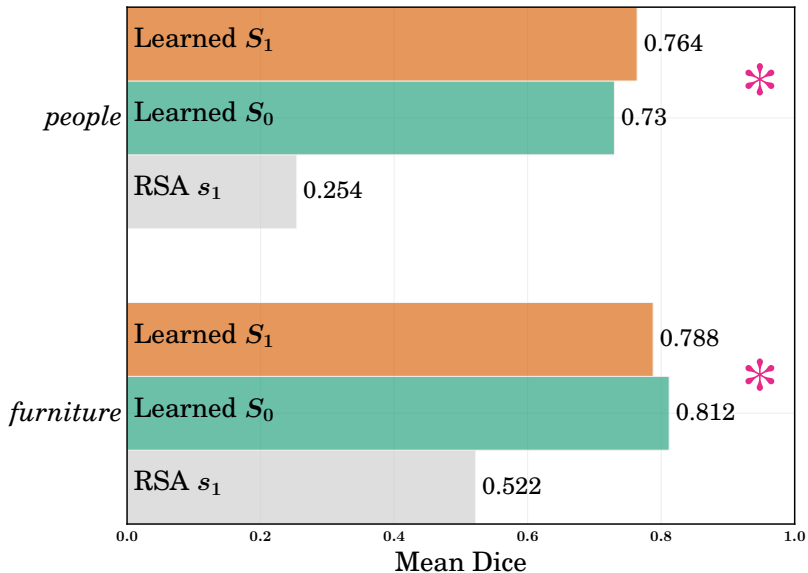




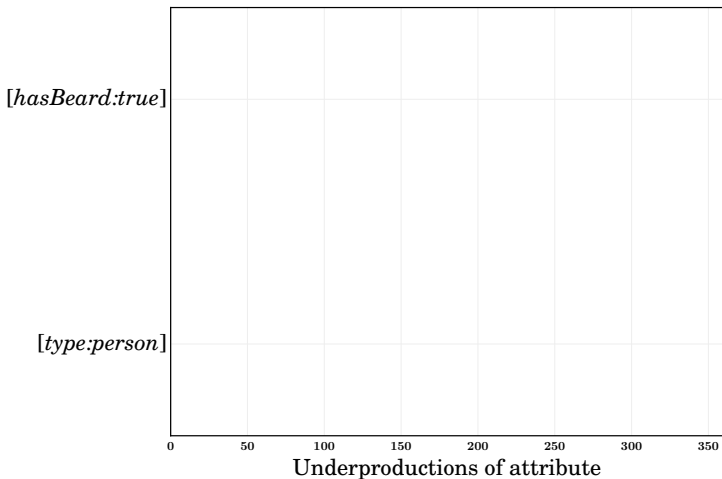
# TUNA Results



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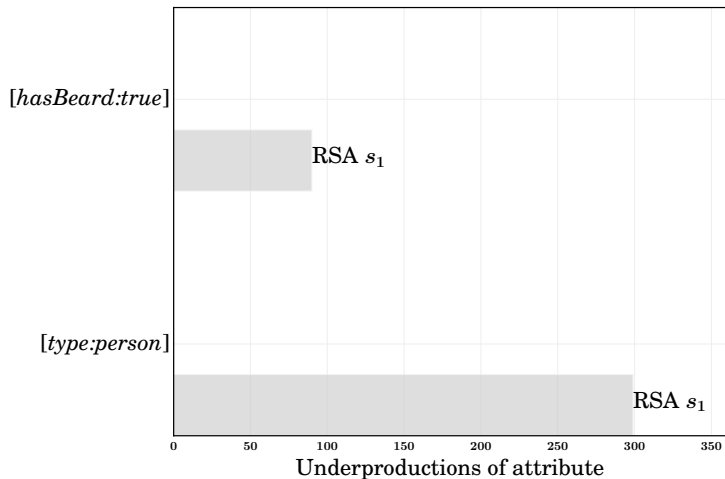


# Error analysis



(Lower is better!)

# Error analysis



(Lower is better!)

# Error analysis



(Lower is better!)

# Error analysis



(Lower is better!)

# Limitations

- Hand-specified lexicon
- High-bias model; few chances to learn from data
- Cognitive demands limit speaker rationality
- Speaker preferences
- Scalability

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1. Meaning from a communicative tension
2. The Rational Speech Acts (RSA) model
3. Learning in the Rational Speech Acts Model
4. Neural RSA
5. Language and action



Robert Hawkins







Will Monroe



Noah Goodman

## Color reference

---

Color	Utterance
	violet
	blue
	dark green
	the best color in the freakin' world!!!

---



[Table](#): Examples from the xkcd color survey

Color papers at this conference, Friday: Monroe et al. (Session 8A) and Kawakami et al. (Session P8)

# Colors in context

## Colors in context

---


Context			Utterance
			blue

---

**Table:** Example from the Colors in Context corpus from the Stanford Computation & Cognition Lab

## Colors in context

---







	Context		Utterance
			blue
			The darker blue one

---

**Table:** Example from the Colors in Context corpus from the Stanford Computation & Cognition Lab

## Colors in context

---













	Context		Utterance
			blue
			The darker blue one
			dull pink not the super bright one

---

**Table:** Example from the Colors in Context corpus from the Stanford Computation & Cognition Lab

## Colors in context
















---

	Context		Utterance
			blue
			The darker blue one
			dull pink not the super bright one
			Purple

---

**Table:** Example from the Colors in Context corpus from the Stanford Computation & Cognition Lab

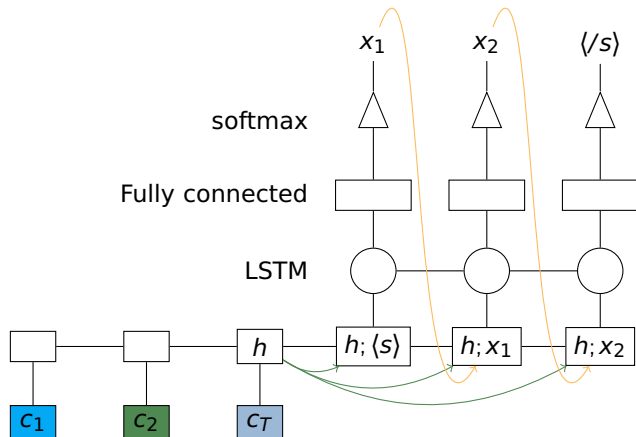
## Colors in context

	Context		Utterance
			blue
			The darker blue one
			dull pink not the super bright one
			Purple
			blue

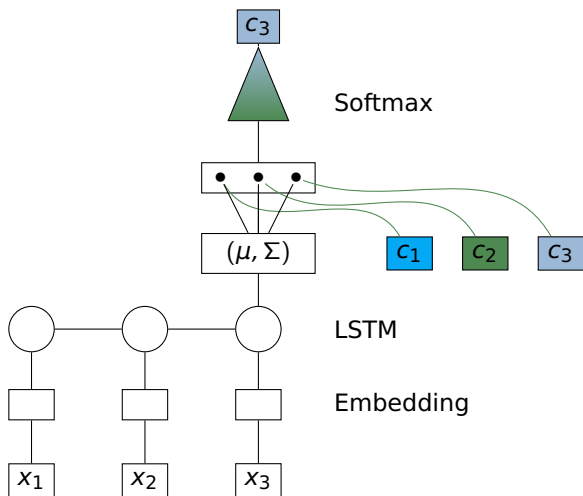
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# Literal neural speaker $\mathcal{S}_0$



# Neural literal listener $\mathcal{L}_0$



# Neural pragmatic agents

# Neural pragmatic agents

Neural pragmatic speaker (Andreas & Klein, here!)

$$S_1(msg | c, C; \theta) = \frac{\mathcal{L}_0(c | msg, C; \theta)}{\sum_{msg' \in X} \mathcal{L}_0(c | msg', C; \theta)}$$

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## Neural pragmatic listener

$$\mathcal{L}_1(c | msg, C; \theta) \propto \mathcal{S}_1(msg | c, C; \theta)$$

## Blended neural pragmatic listener

Weighted combination of  $\mathcal{L}_0$  and  $\mathcal{L}_1$ .

# Language and action

1. Meaning from a communicative tension
2. The Rational Speech Acts (RSA) model
3. Learning in the Rational Speech Acts Model
4. Neural RSA
5. Language and action



Adam Vogel Dan Jurafsky



# The Cards task

TYPE HERE

Yellow boxes mark cards in your line of sight.

You are on 2D

Task description: Six consecutive cards of the same suit (decide which suit together). Each of you can hold only three cards at a time, so you'll have to coordinate your efforts. You can talk all you

I'm on 2D, which isn't too useful. There are cards to my right and below, though. I'll check them out.

Disable Sound

P1 turns remaining: 546  
P2 turns remaining: 599

Indicate Task Complete

up

Click a card to pick it up:

2D

left right

Click a card to drop it from your hand:

JH

down

The cards you are holding

Move with the arrow keys or these buttons.

## The Cards task

*Gather six consecutive cards of the same suit (decide which suit together) or determine that this is impossible. Each of you can hold only three cards at a time, so you'll have to coordinate your efforts. You can talk all you want, but you can make only a limited number of moves.*

## The Cards task

*Gather six consecutive cards of the same suit (decide which suit together) or determine that this is impossible. Each of you can hold only three cards at a time, so you'll have to coordinate your efforts. You can talk all you want, but you can make only a limited number of moves.*

What's going on?



Which suit should we pursue?



Which sequence should we pursue?



Where is card X?

## Task-oriented dialogue corpora

Corpus	Task type	Domain	Task-orient.	Docs.	Format
Switchboard	discussion	open	very loose	2,400	aud/txt
SCARE	search	3d world	tight	15	aud/vid/txt
TRAINS	routes	map	tight	120	aud/txt
Map Task	routes	map	tight	128	aud/vid/txt
Columbia Games	games	maps	tight	12	aud/txt
Settlers	strategy	board	tight	40	txt
Cards	search	2d grid	tight	1,266	txt

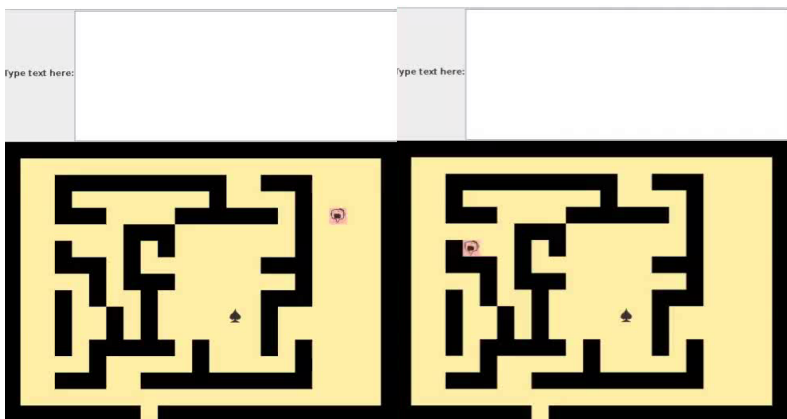
Chief selling points for Cards:

- Pretty large
- Controlled enough that similar things happen often
- Very highly structured

# Simplified cards scenario



Both agents must find the ace of spades.



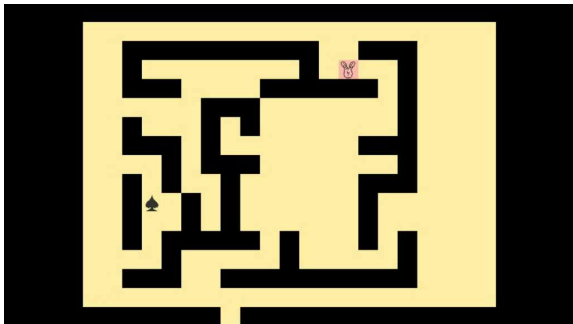
# ListenerBot

- A POMDP agent that learns to navigate its world and interpret language.
- Driven by its small negative reward for not having the card and its large positive reward for finding it.
- No sensitivity to the other player.
- Literal listeners: each message  $msg$  denotes  $P(w | msg)$  estimated from the Cards corpus.
- Bayes rule to incorporate these as observations.

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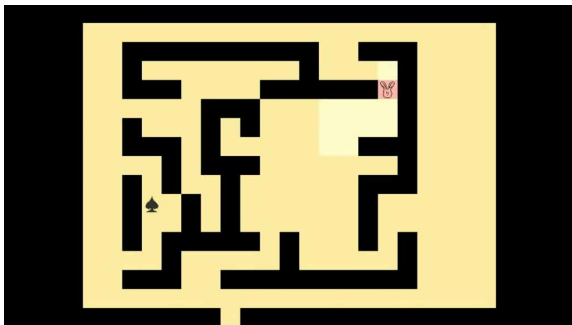
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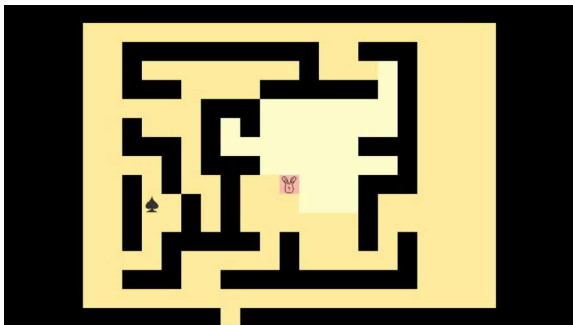




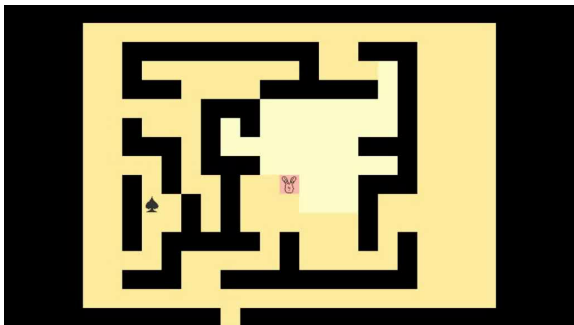
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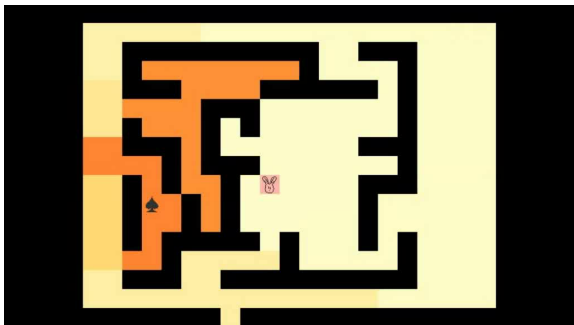


“it’s on the left side”

⇒ **board(left)** ⇒



# ListenerBot



“it’s on the left side”

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# DialogBot

A strict extension of Listener Bot:

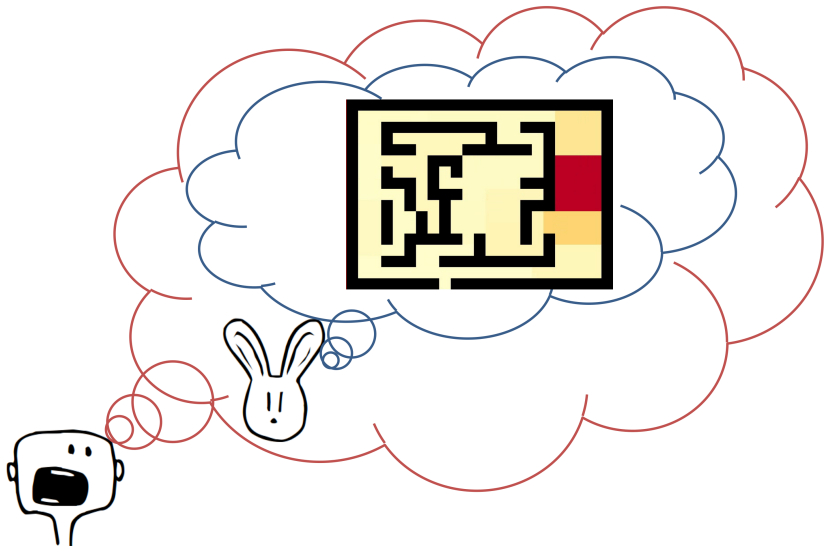
- The set of states is now all combinations of
  - ▶ both players' positions
  - ▶ the card's region
  - ▶ the region the other player believes the card to be in
- The set of actions now includes dialogue actions.
- Same basic reward structure as for Listenerbot, except now also sensitive to whether the other player has found the card.
- Speech actions are modeled in terms of how they affect the agent's estimation of the belief state of the other agent.

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# Relationship to RSA



## Pursuing the ideal of Gricean pragmatics

- **The cooperative principle:** Make your contribution as is required, when it is required, by the conversation in which you are engaged.
- **Quality:** Contribute only what you know to be true. Do not say false things. Do not say things for which you lack evidence.
- **Quantity:** Make your contribution as informative as is required. Do not say more than is required.
- **Relation (Relevance):** Make your contribution relevant.
- **Manner:** (i) Avoid obscurity; (ii) avoid ambiguity; (iii) be brief; (iv) be orderly.
- **Politeness:** Be polite, so be tactful, respectful, generous, praising, modest, deferential, and sympathetic. (Leech)



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## Quality

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- For DialogBot, this emerges from the decision problem: false information is (typically) more costly.
- DialogBot would lie if he thought it would move them toward the objective.

# Emergent pragmatics

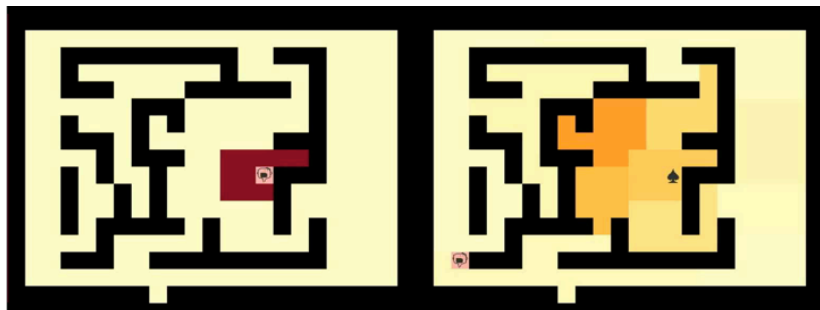
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## Quantity and Relevance

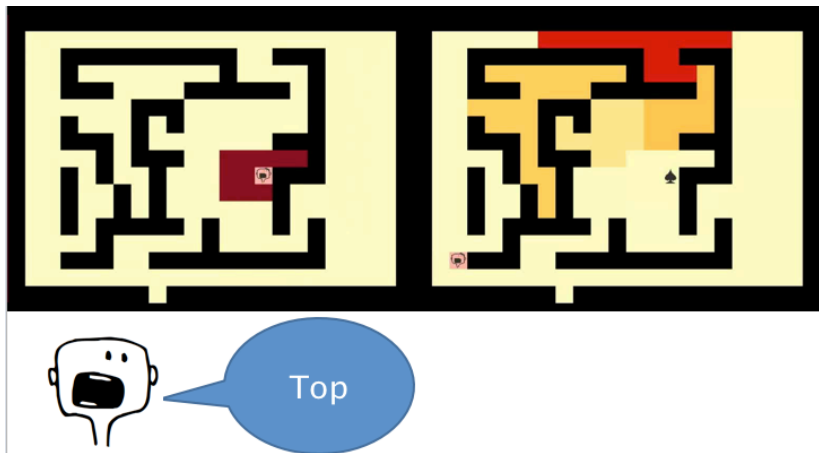
- Favor informative, timely contributions.
- When DialogBot finds the card, it communicates its location, not because it is hard-coded to do so, but rather because it will help the other agent.

# Grown-up DialogBots



Middle  
of the  
board

# Baby DialogBots

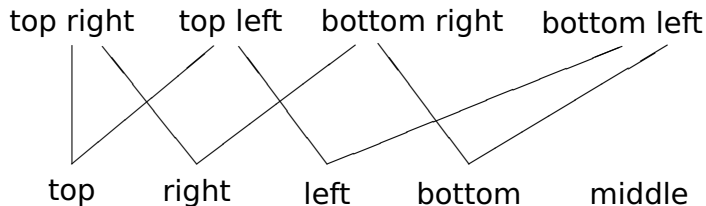


## Experimental results

Agents	% Success	Average Moves
ListenerBot & ListenerBot	84.4%	19.8
ListenerBot & DialogBot	87.2%	17.5
DialogBot & DialogBot	90.6%	16.6

**Table:** The evaluation for each combination of agents. 500 random initial states per agent combination.

# Scalar implicature





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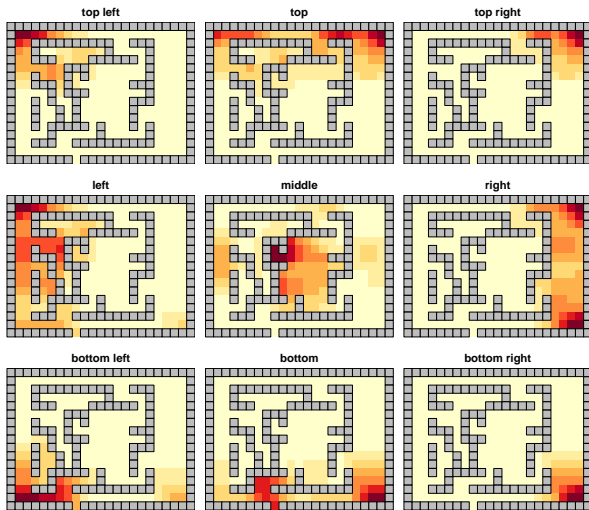


Figure: Human literal interpretations

# Scalar implicature

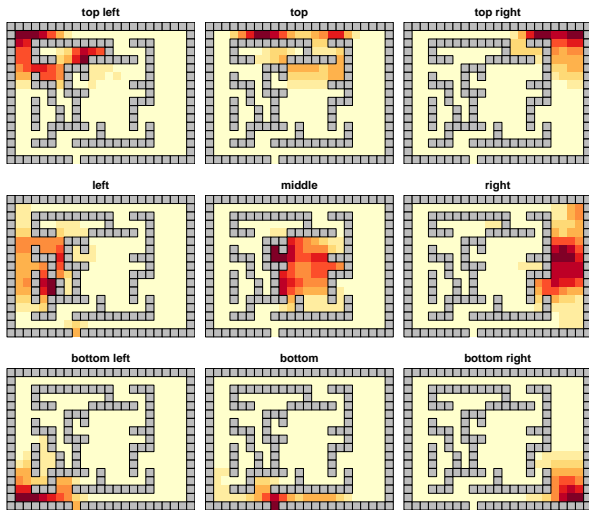


Figure: Human pragmatic interpretations

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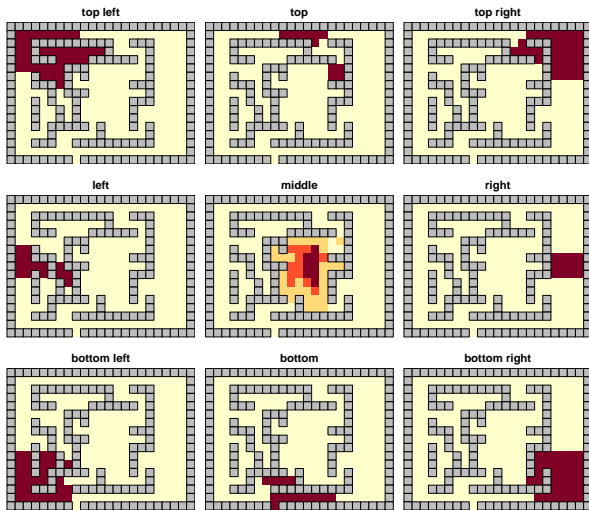


Figure: DialogBot interpretations

## Limitations

	States
Card location	231
	x
Agent location	231
	x
Partner location	231
	x
Partner's card beliefs	231
<b>Total</b>	<b>≈3 billion</b>

- Exact solutions are out of the question.
- State-of-the-art approximate POMDP solutions can solve problems with around 20K states.

# Conclusion and prospects

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Thanks!