Learning in extended and approximate Rational Speech Acts models

Christopher Potts

Stanford Linguistics

EMNLP 2016
Gricean pragmatics

- **The cooperative principle**: Make your contribution as is required, when it is required, by the conversation in which you are engaged.
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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
4. Neural RSA
5. Language and action
1. Meaning from a communicative tension
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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.”
Scalar implicature

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

**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!
Scalar implicature

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Scalar diversity

van Tiel, van Miltenburg, Zevakhina, and Geurts, ‘Scalar diversity’
Scalar diversity

van Tiel, van Miltenburg, Zevakhina, and Geurts, ‘Scalar diversity’

Also: Judith Degen, ‘Investigating the distribution of some (but not all) implicatures using corpora and web-based methods’
Scalar diversity

- cheap/free
- sometimes/always
- some/all
- possible/certain
- may/will
- difficult/impossible
- rare/extinct
- may/have to
- warm/hot
- few/none
Scalar diversity

- pretty/beautiful
- intelligent/brilliant
- funny/hilarious
- dark/black
- small/tiny
- ugly/hIDEOUS
- silly/ridiculous
- tired/exhausted
- content/happy
Partial-order implicature

Hirschberg 1985, *A Theory of Scalar Implicature*
Partial-order implicature

A: Do you speak German?

B: My husband does.

Hirschberg 1985, *A Theory of Scalar Implicature*
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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Levinson: “what is simply described is stereotypically exemplified”.
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1. At a busy marina in water-skiing country: “boat” interpreted as *motorboat*

2. “boat or canoe”
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2. “boat or canoe”
3. Kim is in France. (in Paris)
4. “The nuptials will take place in either France or Paris.”
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.
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- **Community**: Community members adopt a speech style that is easily distinguished from the mainstream, enhancing solidarity.
Sociolinguistic variables

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.
1. Meaning from a communicative tension
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5. Language and action
Origin story
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- Rosenberg and Cohen 1964: early Bayesian model of production and comprehension
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- Lewis 1969: signaling systems
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- **Michael Franke and Gerhard Jäger**: iterated best response
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- Golland, Liang, and Klein 2010 (*EMNLP*): pragmatic listeners and probabilistic compositionality
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- Michael Franke and Gerhard Jäger: iterated best response
- 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

\[ l_0(w \mid msg, \text{Lex}) \propto \text{Lex}(msg, w)P(w) \]
Pragmatic listeners

Pragmatic speaker

\[ s_1(msg \mid w, \text{Lex}) \propto \exp \lambda \left( \log l_0(w \mid msg, \text{Lex}) - C(msg) \right) \]

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Literal listener

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Pragmatic listeners

Pragmatic listener

\[ l_1(w \mid msg, Lex) = \text{pragmatic speaker} \times \text{state prior} \]

Pragmatic speaker

\[ s_1(msg \mid w, Lex) = \text{literal listener} - \text{message costs} \]

Literal listener

\[ l_0(w \mid msg, Lex) = \text{lexicon} \times \text{state prior} \]
RSA listener example

<table>
<thead>
<tr>
<th>Object</th>
<th>RSA</th>
<th>Learned RSA</th>
<th>Neural RSA</th>
</tr>
</thead>
<tbody>
<tr>
<td>beard</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>glasses</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>tie</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

\[ I_1 \quad s_1 \quad l_0 \quad \text{Lex} \]
RSA listener example

<table>
<thead>
<tr>
<th></th>
<th>beard</th>
<th>glasses</th>
<th>tie</th>
</tr>
</thead>
<tbody>
<tr>
<td>$l_0$</td>
<td>0</td>
<td>.5</td>
<td>0</td>
</tr>
<tr>
<td>$s_1$</td>
<td>0</td>
<td>0</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Lex
**RSA listener example**

<table>
<thead>
<tr>
<th>beard</th>
<th>glasses</th>
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</tr>
</thead>
<tbody>
<tr>
<td>0.67</td>
<td>0.33</td>
<td>0</td>
</tr>
</tbody>
</table>

![RSA listener example](image-url)
### RSA listener example

<table>
<thead>
<tr>
<th>Word</th>
<th>RSA</th>
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<th>Language and action</th>
<th>Prospects</th>
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</thead>
<tbody>
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<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>glasses</td>
<td>.25</td>
<td>.75</td>
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- $l_1$  
- $s_1$  
- $l_0$  
- Lex
Pragmatic speakers
Pragmatic speakers

Literal speaker

\[ s_0(msg \mid w, \text{Lex}) \propto \exp \lambda (\log \text{Lex}(msg, w) - C(msg)) \]
Pragmatic speakers

Pragmatic listener

\[ l_1(w \mid msg, Lex) \propto s_0(msg \mid w, Lex) P(w) \]

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$s_0$

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$s_1$

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$s_1$

$l_1$

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S1

\[ l_1 \]

s0

Lex
Joint reasoning

\[ L(w, Context \mid msg) \propto P(w)P_C(Context)s_1(msg \mid w, Context) \]
Joint reasoning

\[ L(w, \text{Context} \mid \text{msg}) \propto P(w)P_C(\text{Context})s_1(\text{msg} \mid w, \text{Context}) \]

\[ L(w \mid \text{msg}) \propto P(w) \sum_{\text{Context} \in \mathcal{C}} P_C(\text{Context})s_1(\text{msg} \mid w, \text{Context}) \]
Achievements
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- **M-implicatures**
  Bergen, Levy, Goodman, ‘Pragmatic reasoning through semantic inference’
Achievements

- **M-implicatures**
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- **I-implicatures and implicature blocking**
  Potts and Levy, ‘Negotiating lexical uncertainty and speaker expertise with disjunction’
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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
1. Meaning from a communicative tension
2. The Rational Speech Acts (RSA) model
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TUNA furniture example
### TUNA furniture example

<table>
<thead>
<tr>
<th>Utterance: “blue fan small”</th>
<th>![blue fan small] left</th>
<th>![blue sofa] center</th>
<th>![blue couch] right</th>
</tr>
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**A Gricean ideal**

**Implicatures**

**RSA**

**Learned RSA**

**Neural RSA**

**Language and action**

**Prospects**
TUNA furniture example

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

Utterance: “The bald man with a beard”
Utterance attributes: [hasBeard:1]; [hasHair:0]; [type:person]
Feature representations

\[
\left( \text{colour:blue, orientation:left, size:small, type:fan, x-dimension:3, y-dimension:3} \right) \cup \left( \text{[colour:blue], [size:small], [type:fan]} \right)
\]
Feature representations

Cross-product features

- colour:blue ∧ [colour:blue]
- colour:blue ∧ [size:small]
- colour:blue ∧ [type:fan]
- orientation:left ∧ [colour:blue]
- orientation:left ∧ [size:small]
  
  ...
Feature representations

Cross-product features

- colour:blue \land [colour:blue]
- colour:blue \land [size:small]
- colour:blue \land [type:fan]
- orientation:left \land [colour:blue]
- orientation:left \land [size:small]

Generation features

- color
- type + color
- color + \neg size

attribute-count = 3

::
Feature representations

Cross-product features

- colour:blue \land [colour:blue]
- colour:blue \land [size:small]
- colour:blue \land [type:fan]
- orientation:left \land [colour:blue]
- orientation:left \land [size:small]
- : 

Generation features

- color
type + color
- color + \neg size
- attribute-count = 3

\textbf{type} \gg \textbf{orientation} \gg \textbf{color} \gg \textbf{size}
Model definition

\[ S_1(m|t, \theta) \propto L_1(t|m, \theta) \]

\[ L_1(t|m, \theta) \propto S_0(m|t, \theta) \]

\[ S_0(m|t, \theta) \propto \exp[\theta^T \varphi(t, m)] \]
Optimization
Addressing the drawbacks of RSA

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<td>Features like color</td>
<td></td>
</tr>
<tr>
<td>Learn attribute hierarchies</td>
<td></td>
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<tr>
<td>Features like color + ¬ size</td>
<td></td>
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<tr>
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<td>Length features and others</td>
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<td>Features like <strong>color + ¬size</strong></td>
</tr>
<tr>
<td>Learn message costs</td>
<td>Length features and others</td>
</tr>
</tbody>
</table>
Addressing the drawbacks of RSA

<table>
<thead>
<tr>
<th>Goal</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avoid hand-built lexicon</td>
<td>Cross-product features</td>
</tr>
<tr>
<td>Learn quirks of production</td>
<td>Features like <code>color</code></td>
</tr>
<tr>
<td>Learn attribute hierarchies</td>
<td>Features like <code>color + ¬size</code></td>
</tr>
<tr>
<td>Learn message costs</td>
<td>Length features and others</td>
</tr>
</tbody>
</table>

Cognitive and linguistic insights combined with learning
Example

Train

[Test]

[person]
[beard]

Test

[Test]

[person]
[glasses]
A Gricean ideal

Implicatures

RSA

Learned RSA

Neural RSA

Language and action

Prospects

∅

[person]

[glasses]

[beard]

[person];[glasses]

[person];[beard]

[glasses];[beard]

[all]
<table>
<thead>
<tr>
<th></th>
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<th>Learned RSA</th>
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<tr>
<td>Ø</td>
<td>.08</td>
<td>.25</td>
</tr>
<tr>
<td>[person]</td>
<td>.08</td>
<td>.25</td>
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<tr>
<td>[glasses]</td>
<td>.17</td>
<td>.00</td>
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<tr>
<td>[beard]</td>
<td>.08</td>
<td>.25</td>
</tr>
<tr>
<td>[person];[glasses]</td>
<td>.17</td>
<td>.00</td>
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<tr>
<td>[person];[beard]</td>
<td>.08</td>
<td>.25</td>
</tr>
<tr>
<td>[glasses];[beard]</td>
<td>.17</td>
<td>.00</td>
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<tr>
<td>[all]</td>
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<td>.00</td>
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</table>

RSA
<table>
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<tr>
<th></th>
<th>RSA</th>
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<th>Neural RSA</th>
<th>Language and action</th>
<th>Prospects</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\emptyset$</td>
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<td>.25</td>
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<td>.00</td>
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<tr>
<td>[person]</td>
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<tr>
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<td>.00</td>
<td>.03</td>
<td>.00</td>
<td></td>
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<td>.00</td>
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<td>.01</td>
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<td>.00</td>
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<td>.00</td>
<td>.22</td>
<td>.10</td>
<td></td>
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</tbody>
</table>

RSA

Learned $S_0$
<table>
<thead>
<tr>
<th></th>
<th>RSA</th>
<th>Learned $S_0$</th>
<th>Learned $S_1$</th>
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</thead>
<tbody>
<tr>
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<td>.25</td>
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</tr>
<tr>
<td>[all]</td>
<td>.17</td>
<td>.00</td>
<td>.22</td>
</tr>
</tbody>
</table>
TUNA Results

Mean Dice

people

furniture

0.0 0.2 0.4 0.6 0.8 1.0
TUNA Results

- **Mean Dice**
  - **furniture**
    - RSA $s_1$: 0.522
  - **people**
    - RSA $s_1$: 0.254
TUNA Results

- **people**
  - Learned $S_0$: 0.73
  - RSA $s_1$: 0.254

- **furniture**
  - Learned $S_0$: 0.812
  - RSA $s_1$: 0.522
TUNA Results

<table>
<thead>
<tr>
<th>Category</th>
<th>Learned $S_0$</th>
<th>Learned $S_1$</th>
<th>RSA $s_1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>furniture</td>
<td>Learned $S_0$</td>
<td>0.812</td>
<td>0.522</td>
</tr>
<tr>
<td>furniture</td>
<td>Learned $S_1$</td>
<td></td>
<td>0.764</td>
</tr>
<tr>
<td>people</td>
<td>Learned $S_0$</td>
<td>0.73</td>
<td>0.254</td>
</tr>
<tr>
<td>people</td>
<td>Learned $S_1$</td>
<td></td>
<td>0.788</td>
</tr>
</tbody>
</table>
TUNA Results

- **Learned $S_1$**
  - **People**: 0.764
  - **Furniture**: 0.788

- **Learned $S_0$**
  - **People**: 0.73
  - **Furniture**: 0.812

- **RSA $s_1$**
  - **People**: 0.254
  - **Furniture**: 0.522

*Note: The asterisks indicate statistical significance.*
Error analysis

![Diagram showing underproductions of attribute](Lower is better!)
Error analysis

![Graph showing underproductions of attribute with labels RSA $s_1$.](image)

(Lower is better!)
Error analysis

(Lower is better!)
Error analysis

![Graph showing underproductions of attribute](image)

(Lower is better!)
Limitations

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

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

<table>
<thead>
<tr>
<th>Color</th>
<th>Utterance</th>
</tr>
</thead>
<tbody>
<tr>
<td>violet</td>
<td></td>
</tr>
<tr>
<td>blue</td>
<td></td>
</tr>
<tr>
<td>dark green</td>
<td></td>
</tr>
<tr>
<td>the best color in the freakin’ world!!!</td>
<td></td>
</tr>
</tbody>
</table>

**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

<table>
<thead>
<tr>
<th>A Gricean ideal</th>
<th>Implicatures</th>
<th>RSA</th>
<th>Learned RSA</th>
<th>Neural RSA</th>
<th>Language and action</th>
<th>Prospects</th>
</tr>
</thead>
</table>

- The darker blue one
- dull pink not the super bright one
- Purple
# Colors in context

<table>
<thead>
<tr>
<th>Context</th>
<th>Utterance</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Darker Blue" /></td>
<td><img src="image2" alt="Blue" /></td>
</tr>
</tbody>
</table>

The darker blue one
dull pink not the super bright one
Blue

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

<table>
<thead>
<tr>
<th>Context</th>
<th>Utterance</th>
</tr>
</thead>
<tbody>
<tr>
<td>[Image of blue shade]</td>
<td><strong>blue</strong></td>
</tr>
<tr>
<td>[Image of blue shade]</td>
<td><strong>The darker blue one</strong></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Context</th>
<th>Utterance</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Blue" /></td>
<td>blue</td>
</tr>
<tr>
<td><img src="image" alt="Darker Blue" /></td>
<td>The darker blue one</td>
</tr>
<tr>
<td><img src="image" alt="Dull Pink" /></td>
<td>dull pink not the super bright one</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Context</th>
<th>Utterance</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Blue" /></td>
<td>blue</td>
</tr>
<tr>
<td><img src="image" alt="Darker Blue" /></td>
<td>The darker blue one</td>
</tr>
<tr>
<td><img src="image" alt="Dull Pink" /></td>
<td>dull pink not the super bright one</td>
</tr>
<tr>
<td><img src="image" alt="Purple" /></td>
<td>Purple</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Context</th>
<th>Utterance</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Blue" /></td>
<td>blue</td>
</tr>
<tr>
<td><img src="image2" alt="Blue" /></td>
<td>The darker blue one</td>
</tr>
<tr>
<td><img src="image3" alt="Dull pink" /></td>
<td>dull pink not the super bright one</td>
</tr>
<tr>
<td><img src="image4" alt="Purple" /></td>
<td>Purple</td>
</tr>
<tr>
<td><img src="image5" alt="Blue" /></td>
<td>blue</td>
</tr>
</tbody>
</table>

*Table: Example from the Colors in Context corpus from the Stanford Computation & Cognition Lab*
Literal neural speaker $S_0$
Neural literal listener $\mathcal{L}_0$
Neural pragmatic agents
Neural pragmatic agents

Neural pragmatic speaker (Andreas & Klein, here!)

\[ S_1(msg \mid c, C; \theta) = \frac{\mathcal{L}_0(c \mid msg, C; \theta)}{\sum_{msg' \in X} \mathcal{L}_0(c \mid msg', C; \theta)} \]
Neural pragmatic agents

Neural pragmatic speaker (Andreas & Klein, here!)

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where \( X \) is a sample from \( S_0(msg \mid c, C; \theta) \) such that \( msg^* \in X \).
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where \( X \) is a sample from \( S_0(msg \mid c, C; \theta) \) such that \( msg^* \in X \).

Neural pragmatic listener

\[ L_1(c \mid msg, C; \theta) \propto S_1(msg \mid c, C; \theta) \]
Neural pragmatic agents

Neural pragmatic speaker (Andreas & Klein, here!)

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

where \( X \) is a sample from \( S_0(msg \mid c, C; \theta) \) such that \( msg^* \in X \).

Neural pragmatic listener

\[
\mathcal{L}_1(c \mid msg, C; \theta) \propto S_1(msg \mid c, C; \theta)
\]

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

You are on 2D

Yellow boxes mark cards in your line of sight.

The cards you are holding

Move with the arrow keys or these buttons.

Task description: Six consecutive cards of the same suit

Received: hi
Sent: I have the JH
Received: I have the BQ

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

The Cards task

43 / 56
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

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

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.
ListenerBot

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- Bayes rule to incorporate these as observations.
ListenerBot
ListenerBot
ListenerBot
ListenerBot

“it’s on the left side”
ListenerBot

“it’s on the left side”

⇒ board(left) ⇒
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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- Same basic reward structure as for Listenerbot, except now also sensitive to whether the other player has found the card.
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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)
Pursuing the ideal of Gricean pragmatics

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Emergent pragmatics

• Very roughly, "Be truthful".
• 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.

• 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.
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Quantity and Relevance

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• 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
Baby DialogBots
### Experimental results

<table>
<thead>
<tr>
<th>Agents</th>
<th>% Success</th>
<th>Average Moves</th>
</tr>
</thead>
<tbody>
<tr>
<td>ListenerBot &amp; ListenerBot</td>
<td>84.4%</td>
<td>19.8</td>
</tr>
<tr>
<td>ListenerBot &amp; DialogBot</td>
<td>87.2%</td>
<td>17.5</td>
</tr>
<tr>
<td>DialogBot &amp; DialogBot</td>
<td>90.6%</td>
<td>16.6</td>
</tr>
</tbody>
</table>

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

Figure: Human literal interpretations
Scalar implicature

Figure: Human pragmatic interpretations
Scalar implicature

Figure: DialogBot interpretations
## Limitations

<table>
<thead>
<tr>
<th>States</th>
<th>Card location</th>
<th>Agent location</th>
<th>Partner location</th>
<th>Partner’s card beliefs</th>
</tr>
</thead>
<tbody>
<tr>
<td>States</td>
<td>231</td>
<td>231</td>
<td>231</td>
<td>231</td>
</tr>
<tr>
<td>Card location</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>Agent location</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>Partner location</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>Partner’s card beliefs</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>≈3 billion</strong></td>
<td><strong>≈3 billion</strong></td>
<td><strong>≈3 billion</strong></td>
<td><strong>≈3 billion</strong></td>
</tr>
</tbody>
</table>

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

1. The RSA insight $L(S(L))$ is a powerful tool for achieving pragmatic language understanding.
Conclusion and prospects

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3. The intractability of these models traces to the inherent intractability of pragmatic reasoning.
4. Computational and cognitive considerations should lead us to effective approximations.
Conclusion and prospects

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Thanks!