Mentioning atypical properties of objects is communicatively efficient

Judith Degen, Elisa Kreiss, Robert X.D. Hawkins, Noah Goodman
03/31/2017
CUNY 2017
Typicality effects in overinformative color mention

“Hand me the apple.”
Typicality effects in overinformative color mention

“Hand me the apple.”
Typicality effects in overinformative color mention

“Hand me the apple.”
Typicality effects in overinformative color mention

“Hand me the apple.”

“Hand me the blue apple.”
Typicality effects in overinformative color mention

“Hand me the apple.”

“Hand me the blue apple.”

Sedivy 2003; Westerbeek et al. 2015;
Rubio-Fernandez 2016; Mitchell et al. 2013
Typicality effects in overinformative color mention

“Hand me the apple.”

“Hand me the blue apple.”

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“Hand me the apple.”

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Sedivy 2003; Westerbeek et al. 2015; Rubio-Fernandez 2016; Mitchell et al. 2013

WHY?
Typicality effects in overinformative color mention

“Hand me the apple.”
“Hand me the blue apple.”

Sedivy 2003; Westerbeek et al. 2015; Rubio-Fernandez 2016; Mitchell et al. 2013

Why?

Sonnenschein & Whitehurst 1982; Paarboni et al. 2007; Arts et al. 2011; Rubio-Fernandez 2016
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“Hand me the apple.”

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WHY?

Sonnenschein & Whitehurst 1982; Paarboni et al. 2007; Arts et al. 2011; Rubio-Fernandez 2016
Goal

Rational model of production of “overinformative” referring expressions that can explain typicality effects

No straightforward extension of previous computational models of “overinformative” referring expressions
Dale 1989; Dale & Reiter 1995; Gatt et al. 2013

General idea: utility of a referring expression depends on how good it is (compared to other referring expressions) for a listener to identify a target object
The RSA framework
Frank & Goodman 2012

\[ O = \{\text{green apple, blue banana, red apple}\} \]

\[ U = \{\text{banana, tomato, apple, blue, green, red, blue banana, green tomato, red apple}\} \]
The RSA framework
Frank & Goodman 2012

\[ O = \{\text{green tomato, blue banana, red apple}\} \]

\[ U = \{\text{banana, tomato, apple, blue, green, red, blue banana, green tomato, red apple}\} \]

Pragmatic speaker

\[ P_{S_1}(u|o) \propto e^{\lambda \ln P_{L_0}(o|u) - \text{cost}(u)} \]
The RSA framework

Frank & Goodman 2012

\[ O = \{ \text{tomato, banana, apple} \} \]

\[ U = \{ \text{banana, tomato, apple, blue, green, red, blue banana, green tomato, red apple} \} \]

**Literal listener**

\[ P_{L_0}(o|u) = U(o|\{u \text{ is true of } o\}) \]

\[ [[u]] : O \rightarrow \{ \text{true, false} \} \]

**Pragmatic speaker**

\[ P_{S_1}(u|o) \propto e^{\lambda \ln P_{L_0}(o|u) - \text{cost}(u)} \]
The RSA framework
Frank & Goodman 2012

\[ O = \{ \text{apple, banana, blue banana, green tomato, red apple} \} \]

**Literal listener**

\[ P_{L_0}(o|u) = U(o|\{u \text{ is true of } o\}) \]

\[ [[u]] : O \rightarrow \{ \text{true, false} \} \]

**Pragmatic speaker**

\[ P_{S_1}(u|o) \propto e^{\lambda \ln P_{L_0}(o|u) - \text{cost}(u)} \]
The RSA framework
Frank & Goodman 2012

$O = \{ \text{object images} \}$

$U = \{ \text{banana, tomato, apple, blue, green, red, blue banana, green tomato, red apple} \}$

**Literal listener**

$P_{L_0}(o|u) = U(o|\{u \text{ is true of } o\})$

$[[u]] : O \rightarrow \{ \text{true, false} \}$

**Pragmatic speaker**

$P_{S_1}(u|o) \propto e^{\lambda \ln P_{L_0}(o|u) - \text{cost}(u)}$
The RSA framework
Frank & Goodman 2012

\[ O = \{ \text{object images} \} \]

**Literal listener**

\[ P_{L_0}(o|u) = \mathcal{U}(o|\{u \text{ is true of } o\}) \]
\[ [[u]] : O \rightarrow \{\text{true, false}\} \]

**Pragmatic speaker**

\[ P_{S_1}(u|o) \propto e^{\lambda \ln P_{L_0}(o|u) - \text{cost}(u)} \]

**Object Probability**

- banana: 0.00
- blue: 0.50
- blue banana: 0.00
- green: 0.00
- green tomato: 0.00
- red: 0.00
- red apple: 0.00

**Utterance Probability**

- banana
- blue
- blue banana
The RSA framework
Frank & Goodman 2012

\[
O = \{ \text{green apple, blue banana, red apple} \}
\]

Literal listener

\[
P_{L_0}(o|u) = U(o|\{u \text{ is true of } o\})
\]

\[
[[u]] : O \rightarrow \{\text{true, false}\}
\]

Pragmatic speaker

\[
P_{S_1}(u|o) \propto e^{\lambda \ln P_{L_0}(o|u) - \text{cost}(u)}
\]

\[
U = \{\text{banana, tomato, apple, blue, green, red, blue banana, green tomato, red apple}\}
\]
The RSA framework
Frank & Goodman 2012

\[ O = \{ \text{object} \} \]

**Literal listener**

\[ P_{L_0}(o | u) = U(o | \{ u \text{ is true of } o \}) \]

\[ [[u]] : O \rightarrow \{ \text{true, false} \} \]

**Pragmatic speaker**

\[ P_{S_1}(u | o) \propto e^\lambda \ln P_{L_0}(o | u) - \text{cost}(u) \]

\[ U = \{ \text{banana, tomato, apple, blue, green, red, blue banana, green tomato, red apple} \} \]
The RSA framework
Frank & Goodman 2012

\[ O = \{ \text{green apple, banana, red apple} \} \]

\[ U = \{ \text{banana, tomato, apple, blue, green, red, blue banana, green tomato, red apple} \} \]

**Literal listener**

\[ P_{L_0}(o|u) = U(o|\{u \text{ is true of } o\}) \]

\[ [[u]] : O \rightarrow \{ \text{true, false} \} \]

**Pragmatic speaker**

\[ P_{S_1}(u|o) \propto e^{\lambda \ln P_{L_0}(o|u) - \text{cost}(u)} \]

Basic RSA can’t account for typicality effects
The RSA framework
The RSA framework

Pragmatic speaker

\[ P_{S_1}(u|o) \propto e^{\lambda \ln P_{L_0}(o|u) - \text{cost}(u)} \]
The RSA framework

Pragmatic speaker

\[ P_{S_1}(u|o) \propto e^{\lambda \ln P_{L_0}(o|u) - \text{cost}(u)} \]

\[ \text{cost}(u) = \begin{cases} 
  c_{\text{type}} & \text{“banana”} \\
  c_{\text{type}} + c_{\text{color}} & \text{“yellow banana”} \\
  c_{\text{color}} + c_{\text{color-only}} & \text{“yellow”} 
\end{cases} \]
The RSA framework


**Literal listener**

\[ P_{L_0}(o|u) \propto [[u]](o) \]

\[ [[u]](o) = \text{typicality}(u, o) \]

**Pragmatic speaker**

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The RSA framework

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P_{L_0}(o|u) \propto [[u]](o)
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\[
[[u]](o) = \text{typicality}(u, o)
\]

**Pragmatic speaker**

\[
P_{S_1}(u|o) \propto e^{\lambda \ln P_{L_0}(o|u) - \text{cost}(u)}
\]

\[
\text{cost}(u) = \begin{cases} 
  c_{\text{type}} & \text{if } u \text{ is a noun} \\
  c_{\text{type}} + c_{\text{color}} & \text{if } u \text{ is modified noun} \\
  c_{\text{color}} + c_{\text{color-only}} & \text{if } u \text{ is a color}
\end{cases}
\]

How typical is \( o \) for \( u \)?

- “banana”
- “yellow banana”
- “brown banana”
- “brown”

…
RSA predictions with continuous semantics

typicality("banana", ) = .4

typicality("blue banana", ) = .98

typicality("banana", ) = .01

typicality("banana", ) = .98

typicality("yellow banana", ) = .98
RSA predictions with continuous semantics

typicality("banana", 🍌) = .4

typicality("blue banana", 🍌) = .98

typicality("yellow banana", 🍌) = .98

typicality("banana", 🍎) = .01
Predictions

Literal listener

<table>
<thead>
<tr>
<th>Probability</th>
<th>'banana'</th>
<th>'blue banana'</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td><img src="image1" alt="Graph" /></td>
<td><img src="image2" alt="Graph" /></td>
</tr>
</tbody>
</table>

Pragmatic speaker

<table>
<thead>
<tr>
<th>Probability</th>
<th>'banana'</th>
<th>'yellow banana'</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td><img src="image3" alt="Graph" /></td>
<td><img src="image4" alt="Graph" /></td>
</tr>
</tbody>
</table>
Predictions

**Literal listener**

- ‘banana’:
  - Probability: 0.00, 0.25, 0.50, 0.75
- ‘blue banana’:
  - Probability: 0.00, 0.25, 0.50, 0.75

**Pragmatic speaker**

- Utterance:
  - Probabilities: banana, blue, blue banana
  - Probability: 1.00, 0.75, 0.50, 0.25, 0.00

**Object**

- ‘banana’:
  - Probability: 0.00, 0.25, 0.50, 0.75
- ‘yellow banana’:
  - Probability: 0.00, 0.25, 0.50, 0.75
Predictions

Literal listener

<table>
<thead>
<tr>
<th>Object</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>'banana'</td>
<td>0.00</td>
</tr>
<tr>
<td>'blue banana'</td>
<td>0.25</td>
</tr>
<tr>
<td>'red banana'</td>
<td>0.50</td>
</tr>
<tr>
<td>'yellow banana'</td>
<td>0.75</td>
</tr>
</tbody>
</table>

Pragmatic speaker

<table>
<thead>
<tr>
<th>Utterance</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>banana</td>
<td>0.00</td>
</tr>
<tr>
<td>blue</td>
<td>0.25</td>
</tr>
<tr>
<td>blue banana</td>
<td>0.50</td>
</tr>
<tr>
<td>blue blue banana</td>
<td>0.75</td>
</tr>
</tbody>
</table>

with cost
Predictions

Literal listener

- 'banana'
- 'blue banana'

Pragmatic speaker

- with cost
- banana, blue, blue banana

Object

- Probability
- 0.00, 0.25, 0.50, 0.75

Utterance

- Probability
- 0.00, 0.25, 0.50, 0.75, 1.00

Utterance

- Probability
- 0.00, 0.25, 0.50, 0.75, 1.00

Utterance

- Probability
- 0.00, 0.25, 0.50, 0.75, 1.00

Utterance

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- 0.00, 0.25, 0.50, 0.75, 1.00

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Utterance
Predictions

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<tr>
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<th>Object</th>
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<tbody>
<tr>
<td>0.00</td>
<td>'banana'</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>0.25</td>
<td>'blue banana'</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>0.50</td>
<td>'banana'</td>
<td>0.75</td>
<td>0.75</td>
</tr>
<tr>
<td>0.75</td>
<td>'blue banana'</td>
<td>1.00</td>
<td>1.00</td>
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</tbody>
</table>

Pragmatic speaker

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<th>Probability</th>
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<th>with cost</th>
</tr>
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<tbody>
<tr>
<td>0.00</td>
<td>'banana'</td>
<td>0.25</td>
</tr>
<tr>
<td>0.25</td>
<td>'blue'</td>
<td>0.50</td>
</tr>
<tr>
<td>0.50</td>
<td>'blue banana'</td>
<td>0.75</td>
</tr>
<tr>
<td>0.75</td>
<td>'banana'</td>
<td>1.00</td>
</tr>
</tbody>
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<table>
<thead>
<tr>
<th>Probability</th>
<th>Utterance</th>
<th>with cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>'yellow banana'</td>
<td>0.25</td>
</tr>
<tr>
<td>0.25</td>
<td>'yellow'</td>
<td>0.50</td>
</tr>
<tr>
<td>0.50</td>
<td>'yellow banana'</td>
<td>0.75</td>
</tr>
<tr>
<td>0.75</td>
<td>'banana'</td>
<td>1.00</td>
</tr>
</tbody>
</table>
Non-redundant utterances more likely when probability of confusion is low.
Independent empirical evidence for RSA with continuous semantics?

**Literal listener**

\[ P_{L_0}(o|u) \propto [[u]](o) \]

\[ [[u]](o) = \text{typicality}(u, o) \]

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1. Typicality norming
2. Production study
3. Model evaluation
Typicality norming studies

How typical is this object for a banana?

very atypical

very typical
Typicality norming studies

How typical is this object for a banana?

very atypical

very typical
Typicality norming studies

Exp. 1a: type nouns

How typical is this object for a banana?

very atypical  very typical
Typicality norming studies

Exp. 1a: type nouns

How typical is this object for a brown banana?

very atypical

very atypical

very typical
Typicality norming studies

Exp. 1a: type nouns

Exp. 1b: color-type

How typical is this color for the color blue?

very atypical

very typical
Typicality norming studies

Exp. 1a: type nouns
How typical is this object for a banana?
very atypical  very typical
75 participants 90 trials

Exp. 1b: color-type
How typical is this object for a brown banana?
very atypical  very typical
100 participants 110 trials

Exp. 1c: color
How typical is this color for the color blue?
very atypical  very typical
75 participants 90 trials
Typicality norming studies

Exp. 1a: type nouns
How typical is this object for a banana?
very atypical
very typical
75 participants
90 trials
7 fruit/vegetable categories in 3 colors each

Exp. 1b: color-type
How typical is this object for a brown banana?
very atypical
very typical
100 participants
110 trials

Exp. 1c: color
How typical is this color for the color blue?
very atypical
very typical
75 participants
90 trials
Typicality norming results

| banana | .98 | .66 | .42 | .05 |
Typicality norming results

<table>
<thead>
<tr>
<th></th>
<th>banana</th>
<th>yellow banana</th>
<th>brown banana</th>
<th>blue banana</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>.98</td>
<td>.98</td>
<td>.28</td>
<td>.20</td>
</tr>
<tr>
<td></td>
<td>.66</td>
<td>.33</td>
<td>.90</td>
<td>.18</td>
</tr>
<tr>
<td></td>
<td>.42</td>
<td>.17</td>
<td>.18</td>
<td>.91</td>
</tr>
<tr>
<td></td>
<td>.05</td>
<td>.05</td>
<td>.04</td>
<td>.06</td>
</tr>
</tbody>
</table>
Typicality norming results

<table>
<thead>
<tr>
<th>Fruit</th>
<th>Typicality</th>
<th>Yellow</th>
<th>Brown</th>
<th>Blue</th>
<th>Typicality</th>
</tr>
</thead>
<tbody>
<tr>
<td>banana</td>
<td>.98</td>
<td>.66</td>
<td>.42</td>
<td>.05</td>
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<td>yellow banana</td>
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<td>blue banana</td>
<td>.20</td>
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<td>.91</td>
<td>.06</td>
<td></td>
</tr>
<tr>
<td>yellow</td>
<td>.77</td>
<td>.05</td>
<td>.06</td>
<td>.09</td>
<td></td>
</tr>
<tr>
<td>brown</td>
<td>.11</td>
<td>.87</td>
<td>.01</td>
<td>.12</td>
<td></td>
</tr>
<tr>
<td>blue</td>
<td>.06</td>
<td>.06</td>
<td>.92</td>
<td>.07</td>
<td></td>
</tr>
</tbody>
</table>
Production study: interactive reference game experiment
You are the speaker.
Send messages to tell the listener which object is the target.
You are the listener.
Click on the target object which the speaker is telling you about.

speaker: blue banana
Experimental details

• 60 pairs of participants on Mechanical Turk
• random assignment to speaker/listener role
• 42 trials
• varied contextual informativeness of utterances:

presence of same type  x  presence of color competitor
## Data processing

<table>
<thead>
<tr>
<th>Item</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>“blue”</td>
<td>color</td>
</tr>
<tr>
<td>“yellow banana”</td>
<td>color-and-type</td>
</tr>
<tr>
<td>“the banana”</td>
<td>type</td>
</tr>
<tr>
<td>“banan”</td>
<td></td>
</tr>
<tr>
<td>“funky carrot”</td>
<td>other</td>
</tr>
</tbody>
</table>
“blue banana”
“brown banana”
“yellow banana”

1. replication of Westerbeek et al 2015
“blue banana”
“brown banana”
“yellow banana”

1. replication of Westerbeek et al 2015
2. novel demonstration of typicality effects even when color is ‘informative’

1. replication of Westerbeek et al 2015

“blue banana”
“brown banana”
“yellow banana”
Model evaluation

- Model predictions
- Typicality of noun

$R^2 = .77$
Model evaluation

$R^2 = .77$
Model evaluation

$$R^2 = .77$$

- Typicality of noun
- Model predictions
- Utterance Type
  - informative
    - $$R^2 = .77$$
  - overinformative
  - overinformative–cc

$$\text{color}$$
$$\text{color\_and\_type}$$
$$\text{type}$$
Model evaluation

\[ R^2 = .77 \]

Typicality of noun

<table>
<thead>
<tr>
<th>UtteranceType</th>
<th>color</th>
<th>color_and_type</th>
<th>type</th>
</tr>
</thead>
<tbody>
<tr>
<td>informative</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>informative–cc</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>overinformative</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>overinformative</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Model evaluation

\[ R^2 = .77 \]
Model evaluation

1. Model captures qualitative patterns

2. Mostly captures quantitative patterns but overpredicts type mention

$R^2 = .77$
Summary & Conclusion

Speakers redundantly mention color when confusability of intention otherwise high

RSA with continuous semantics captures this

level of reference

Graf et al 2016

modifier choice

Degen et al 2016
Summary & Conclusion

Speakers redundantly mention color when confusability of intention otherwise high.

RSA with continuous semantics captures this overinformative referring expressions.

level of reference

[Images of a pug, a dalmatian, and an eagle]

Graf et al 2016

modifier choice

[Images of red and blue pushpins]

Degen et al 2016
Summary & Conclusion

Speakers redundantly mention color when confusability of intention otherwise high

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level of reference

Graf et al. 2016

modifier choice

Degen et al. 2016
Summary & Conclusion

Speakers redundantly mention color when confusability of intention otherwise high.

RSA with continuous semantics captures this overinformative referring expressions rationally redundant referring expressions.

level of reference

Graf et al 2016

modifier choice

Degen et al 2016
Thank you

Collaborators
• Caroline Graf
• Robert Hawkins
• Elisa Kreiss
• Noah Goodman

Funding
• James S. McDonnell grant to NG
• ONR grant N00014-13-1-0788 to NG