A Model of Informant Evaluation in Early Word Learning

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A word learning problem

Suppose an infant wants to learn the name of this object
The expression of word forms is variable

- **Speaker-specific variables**
  - Physical characteristics
  - **Dialect, speech accent**

- **Speech conditions**
  - Carefulness/Sloppiness
  - Emotional state
  - Speed

- **Context**
  - Coarticulation/Phonetic context
  - Lexical and semantic context
A word learning problem
dɑ:g
A word learning problem

da:g

da:g
A word learning problem
Standard models of word learning

infants expect all speakers to be equally useful linguistic informants.

(Pinker, 1979; Fried and Holyoak, 1984; De Boer and Kuhl, 2003; Chater and Manning, 2006; Xu and Tenenbaum, 2007; Norris and McQueen, 2008; Frank, Goodman, and Tenenbaum, 2009; McMurray, Aslin, and Toscano, 2009; Rasanen, 2012; Pajak, Bicknell, and Levy, 2013)
A word learning problem

60% daːɡ
20% dʌɡ
20% dɔːɡ
Standard models of word learning

infants expect all speakers to be equally useful linguistic informants.

(Pinker, 1979; Fried and Holyoak, 1984; De Boer and Kuhl, 2003; Chater and Manning, 2006; Xu and Tenenbaum, 2007; Norris and McQueen, 2008; Frank, Goodman, and Tenenbaum, 2009; McMurray, Aslin, and Toscano, 2009; Rasanen, 2012; Pajak, Bicknell, and Levy, 2013)

Our model of word learning

infants know that some speakers of their language are better models than others.
A word learning problem

60% daːɡ (correct)
20% dʌɡ (incorrect)
20% dɔːɡ (incorrect)
Outline

> a word learning problem
> how do learners evaluate sources?
> modeling word learning with source evaluation
> an infant word learning experiment
> ...reinterpreted
> future directions
Child selection of language informants

4 and 5 yo children

● Prefer labels from familiar informants, but will switch to an unfamiliar informant given evidence that they are more reliable
  ○ (Corriveau and Harris 2009)
● Use consensus as evidence, trusting informants who label objects in the same way as the majority of others
  ○ (Corriveau, Meints and Harris 2009)
● Can be modeled as using rational Bayesian inference to jointly determine the label and the knowledgeability of the informant providing it
  ○ (Shafto, Eaves, Navarro and Perfors 2012)
Do 14-month-old infants also infer informant quality?
Overimitation

Faithful copying of unnecessary or causally irrelevant actions in addition to functionally fulfilling the goal of those actions
Infant selection of informants

14-month old infants are more likely to overimitate a model in a non-linguistic task after observing the model

- give reliable affective cues
  - (Poulin Dubois, Brooker and Polonia 2011)
- perform non-linguistic tasks competently
  - (Zmyc, Buttelmann, Carpenter and Daum 2010)
- speak their native language
  - (Buttelman, Zmyc, Daum and Carpenter 2013)
Outline

> a word learning problem
> how do learners evaluate sources?
> **modeling word learning with source evaluation**
> an infant word learning experiment
> ...reinterpreted
> future directions
Modeling the word learning inference

P(C=1)=1/3 /daːɡ/
P(C=2)=1/3 /dʌɡ/
P(C=3)=1/3 /dɔːɡ/

(Shafto, Eaves, Navarro and Perfors 2012)
Modeling the word learning inference

<table>
<thead>
<tr>
<th>Knowledgeability (K)</th>
<th>Category (C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P(K=1) = 0.5</td>
<td>P(C=1) = 1/3</td>
</tr>
<tr>
<td>P(K=0) = 0.5</td>
<td>P(C=2) = 1/3</td>
</tr>
<tr>
<td></td>
<td>P(C=3) = 1/3</td>
</tr>
</tbody>
</table>

(Shafto, Eaves, Navarro and Perfors 2012)
Modeling the word learning inference

knowledgeability

K

P(K=1)=0.5
P(K=0)=0.5

category

C

P(C=1)=1/3 /dɑːɡ/
P(C=2)=1/3 /dʌɡ/
P(C=3)=1/3 /dɔːɡ/

I

intention

(Shafto, Eaves, Navarro and Perfors 2012)
Modeling the word learning inference

(Shafto, Eaves, Navarro and Perfors 2012)
Modeling the word learning inference

knowledgeability

K=1

category

C=1

P(I=da:g)=1

intention

data

D

(da:g)

(Shafto, Eaves, Navarro and Perfors 2012)
Modeling the word learning inference

Knowledgeability

Category

K=0

C=1

Intention

P(I=da:g)=1/3

Data

D

(Shafto, Eaves, Navarro and Perfors 2012)
Infants infer $P(C|D)$

$K=1$

$P(C=1)=1/3$  /daːg/
$P(C=2)=1/3$  /dʌg/
$P(C=3)=1/3$  /dɔːɡ/

(Shafto, Eaves, Navarro and Perfors 2012)
Inferring the category without source evaluation

\[ P(C,|D=\text{“daːg”}) \propto P(D=\text{“daːg”}|C) \ P(C) \]

- \( P(C=\text{daːg}) \)
- \( P(C=\text{dɔːg}) \)
- \( P(C=\text{dʌg}) \)
Inferring the category without source evaluation

P(C_{\text{da:g}} \mid D=\text{“da:g”}) \propto P(D=\text{“da:g”} \mid C) P(C)

<table>
<thead>
<tr>
<th>P(C)</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>P(C=\text{da:g})</td>
<td></td>
</tr>
<tr>
<td>P(C=\text{do:g})</td>
<td>0</td>
</tr>
<tr>
<td>P(C=d\text{ag})</td>
<td>0</td>
</tr>
</tbody>
</table>
Inferring the category without source evaluation

\[
P(C|D_1=\text{“daːɡ”}, D_2=\text{“daːɡ”}) \propto P(D_1=\text{“daːɡ”}, D_2=\text{“daːɡ”}|C) \ P(C)
\]

<table>
<thead>
<tr>
<th></th>
<th>(P(C=\text{daːɡ}))</th>
<th>(P(C=\text{dɔːɡ}))</th>
<th>(P(C=\text{dʌɡ}))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Infants infer $P(K, C|D)$

knowledgeability  category

$K$  $C$

$P(K=1) = 0.5$
$P(K=0) = 0.5$

$P(C=1) = 1/3$ /daːɡ/
$P(C=2) = 1/3$ /dəg/
$P(C=3) = 1/3$ /dɔːɡ/

intention

data

(Shafto, Eaves, Navarro and Perfors 2012)
Jointly inferring category and informant quality

\[ P(C,K|D_1=\text{da:g}) \propto P(D_1=\text{da:g}|C,K) P(C,K) \]

<table>
<thead>
<tr>
<th></th>
<th>K=1</th>
<th>K=0</th>
</tr>
</thead>
<tbody>
<tr>
<td>C=da:g</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C=do:g</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C=d^g</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Jointly inferring category and informant quality

\[ P(C,K|D_1=\text{"da:ɡ"}) \propto P(D_1=\text{"da:ɡ"}|C,K) P(C,K) \]

<table>
<thead>
<tr>
<th>C</th>
<th>K=1</th>
<th>K=0</th>
</tr>
</thead>
<tbody>
<tr>
<td>da:ɡ</td>
<td>1/2</td>
<td>1/6</td>
</tr>
<tr>
<td>do:ɡ</td>
<td>0</td>
<td>1/6</td>
</tr>
<tr>
<td>dʌ:ɡ</td>
<td>0</td>
<td>1/6</td>
</tr>
</tbody>
</table>
Jointly inferring category and informant quality

\[ P(C, K_1, K_2 | D_1 = "dɑ:g", D_2 = "dɑ:g") \propto P(D_1 = "dɑ:g", D_2 = "dɑ:g" | C, K_1, K_2) P(C, K_1, K_2) \]

<table>
<thead>
<tr>
<th>(K_1=1, K_2=1)</th>
<th>(K_1=1, K_2=0)</th>
<th>(K_1=0, K_2=1)</th>
<th>(K_1=0, K_2=0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C=da:g</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C=da:g</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C=dɔ:g</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C=dʌɡ</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Jointly inferring category and informant quality

\[ P(C, K_1, K_2 | D_1 = \text{“da:ɡ”}, D_2 = \text{“da:ɡ”}) \propto P(D_1 = \text{“da:ɡ”}, D_2 = \text{“da:ɡ”} | C, K_1, K_2) P(C, K_1, K_2) \]

<table>
<thead>
<tr>
<th>C=da:ɡ</th>
<th>K_1=1,K_2=1</th>
<th>K_1=1,K_2=0</th>
<th>K_1=0,K_2=1</th>
<th>K_1=0,K_2=0</th>
</tr>
</thead>
<tbody>
<tr>
<td>9/18</td>
<td>3/18</td>
<td>3/18</td>
<td>1/18</td>
<td></td>
</tr>
<tr>
<td>C=dɔ:ɡ</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1/18</td>
</tr>
<tr>
<td>C=dʌ:ɡ</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1/18</td>
</tr>
</tbody>
</table>
Outline

> a word learning problem

> how do learners evaluate sources?

> modeling word learning with source evaluation

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> ...reinterpreted

> future directions
The Switch Task

Violation of expectation paradigm (Stager and Werker 1997)

Habituation

buk  buk  buk  buk

Same Trial

buk

Switch Trial

puk
The Switch Task

Violation of expectation paradigm (Stager and Werker 1997)

Habituation

Same Trial

buk

Switch Trial

puk
Stager and Werker 1997

[Graph showing mean looking time (s) for different conditions: 8 months, 14 months (object: 'Bih'-'Dih'), 14 months (checkerboard: 'Bih'-'Dih'). Error bars indicate variability. Stars denote statistical significance (* p<0.05).]
Rost and McMurray 2009

Single speaker condition

Habituation

Same Trial

Switch Trial
Rost and McMurray 2009

![Graph showing mean looking time](image)
Rost and McMurray 2009

Multiple speaker condition

Habituation

buk buk buk buk

Same Trial

buk

Switch Trial

puk
Rost and McMurray 2009

The figure shows a bar graph comparing mean looking times between two conditions: "same" and "switch". The error bars indicate the variability in looking times. The "switch" condition shows a significantly higher mean looking time compared to the "same" condition, as indicated by the asterisk (*) above the "switch" bar.
Apfelbaum and McMurray 2011

Associative learning model
Outline

> a word learning problem

> how do learners evaluate sources?

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> ...reinterpreted

> future directions
Standard models of word learning

(Pinker, 1979; Fried and Holyoak, 1984; De Boer and Kuhl, 2003; Chater and Manning, 2006; Xu and Tenenbaum, 2007; Norris and McQueen, 2008; Frank, Goodman, and Tenenbaum, 2009; McMurray, Aslin, and Toscano, 2009; Rasanen, 2012; Pajak, Bicknell, and Levy, 2013)

infants expect all speakers of their language to be equally useful linguistic informants.

infants know that some speakers of their language are better models than others.
Standard models of word learning

(Shafto, Eaves, Navarro and Perfors 2012)
Inferring the category without source evaluation

\[ P(C|D=\text{“da:g”}) \propto P(D=\text{“da:g”}|C) P(C) \]

<table>
<thead>
<tr>
<th>C</th>
<th>P(C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>buk</td>
<td>1</td>
</tr>
<tr>
<td>puk</td>
<td>0</td>
</tr>
<tr>
<td>duk</td>
<td>0</td>
</tr>
</tbody>
</table>
Inferring the category without source evaluation

\[ P(C|D_1=\text{"da:g"}, D_2=\text{"da:g"}) \propto P(D_1=\text{"da:g"}, D_2=\text{"da:g"}|C) P(C) \]

<table>
<thead>
<tr>
<th>C</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>buk</td>
<td></td>
</tr>
<tr>
<td>puk</td>
<td>0</td>
</tr>
<tr>
<td>duk</td>
<td>0</td>
</tr>
</tbody>
</table>
Inferring the category without source evaluation

\[ P(C|D_1=D_2=D_3=D_4=D_5=D_6=D_7=\text{“buk”}) \propto P(D_1=D_2=D_3=D_4=D_5=D_6=D_7=\text{“buk”}|C) \, P(C) \]

<table>
<thead>
<tr>
<th>C</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>C=buk</td>
<td>1</td>
</tr>
<tr>
<td>C=puk</td>
<td>0</td>
</tr>
<tr>
<td>C=duk</td>
<td>0</td>
</tr>
</tbody>
</table>
Inferring the category without source evaluation

\[ P(C|D_1=D_2=D_3=D_4=D_5=D_6=D_7=\text{"buk")} \propto P(D_1=D_2=D_3=D_4=D_5=D_6=D_7=\text{"buk"}|C) \ P(C) \]

<table>
<thead>
<tr>
<th>C</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>C=buk</td>
<td>1</td>
</tr>
<tr>
<td>C=puk</td>
<td>0</td>
</tr>
<tr>
<td>C=duk</td>
<td>0</td>
</tr>
</tbody>
</table>
Stager and Werker 1997

The figure shows a bar graph with error bars, comparing mean looking times in seconds between different conditions. The x-axis represents age in months (8 months, 14 months) and type of stimulus (object 'Bih'-'Dih', checkerboard 'Bih'-'Dih'). The y-axis represents mean looking time in seconds. The data indicate significant differences marked with an asterisk (*), where * represents p<0.05.
Standard models of word learning

infants expect all speakers of their language to be equally useful linguistic informants.

(Pinker, 1979; Fried and Holyoak, 1984; De Boer and Kuhl, 2003; Chater and Manning, 2006; Xu and Tenenbaum, 2007; Norris and McQueen, 2008; Frank, Goodman, and Tenenbaum, 2009; McMurray, Aslin, and Toscano, 2009; Rasanen, 2012; Pajak, Bicknell, and Levy, 2013)

Our model of word learning

infants know that some speakers of their language are better models than others.
Applying the Shafto et al. 2012 model

knowledgeability

category

P(K=1)=0.5
P(K=0)=0.5

P(C=1)=1/3 /buk/
P(C=2)=1/3 /puk/
P(C=3)=1/3 /duk/

intention

data

(Shafto, Eaves, Navarro and Perfors 2012)
Inferring the category using source evaluation

The single speaker case

\[ P(C,K|D_1=D_2=D_3=D_4=D_5=D_6=D_7=\text{“buk”}) \propto P(D_1=D_2=D_3=D_4=D_5=D_6=D_7=\text{“buk”}|C,K) P(C,K) \]

<table>
<thead>
<tr>
<th>K=1</th>
<th>K=0</th>
</tr>
</thead>
<tbody>
<tr>
<td>C=buk</td>
<td>(\frac{3}{4})</td>
</tr>
<tr>
<td>C=puk</td>
<td>0</td>
</tr>
<tr>
<td>C=duk</td>
<td>0</td>
</tr>
</tbody>
</table>
Inferring the category using source evaluation

The multiple speaker case

\[ P(C, K_1, K_2, K_3, K_4, K_5, K_6, K_7 | D_1 = D_2 = D_3 = D_4 = D_5 = D_6 = D_7 = "buk") \propto \prod P(D_i | C, K_i) P(C, K_i) \]

<table>
<thead>
<tr>
<th>Category</th>
<th>K=1&gt;0</th>
<th>K=1=0</th>
</tr>
</thead>
<tbody>
<tr>
<td>C=buk</td>
<td>0.667</td>
<td>0.331</td>
</tr>
<tr>
<td>C=puk</td>
<td>0</td>
<td>0.001</td>
</tr>
<tr>
<td>C=duk</td>
<td>0</td>
<td>0.001</td>
</tr>
</tbody>
</table>
Rost and McMurray 2009

Single speaker condition

Multiple speaker condition

---

**Mean looking time ($)**

- **Same**
- **Switch**

---

*Note: The asterisk (*) indicates a significant difference.*
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Our model of word learning

infants know that some speakers of their language are better models than others.
Discussion

• Assuming that the infant’s phonetic representations are adult-like, and that infants are jointly inferring the object label and the informant’s knowledgeability, our model reproduces the pattern of results from Rost and McMurray 2009.

• This model was previously applied to explain the labeling behavior of 4-5 year old children.

• It also accurately models the behavior of 14 month old infants
Explanations for the Switch Task

• Infants fail at the task because it is too cognitively demanding

What makes this task “cognitively challenging” is inferring informant quality

(Yoshida, Fennel, Swingley and Werker 2009; Fennell and Werker 2003; Fennell et al. 2007)
Explanations for the Switch Task

- Infants fail at the task because they aren’t sure that the speech act is intended to label the object.
- Improved performance with:
  - Familiar objects and labels
  - Use of sentence frames
  - Pretest training demonstrating labeling behavior

Measures that reduce referential ambiguity also suggest the informant will be of high quality

(Fennell and Werker 2003; Fennell and Waxman 2006; Fennell and Waxman 2010)
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Future Directions

What is the impact of infant beliefs about informant reliability on language learning?

- How else might we control for infants inclination to trust and believe the speaker as a linguistic model?
- Switch task using pre-test familiarizations with the speakers.
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> modeling label evaluation with source evaluation

> future directions
Thank you!

Dr. Jeff Lidz
Dr. Jan Edwards
Dr. Yi Ting Huang
Alexander Sushenov
The Probabilistic Modeling Lab

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