Simulating Language
5: Rational Speech Act model

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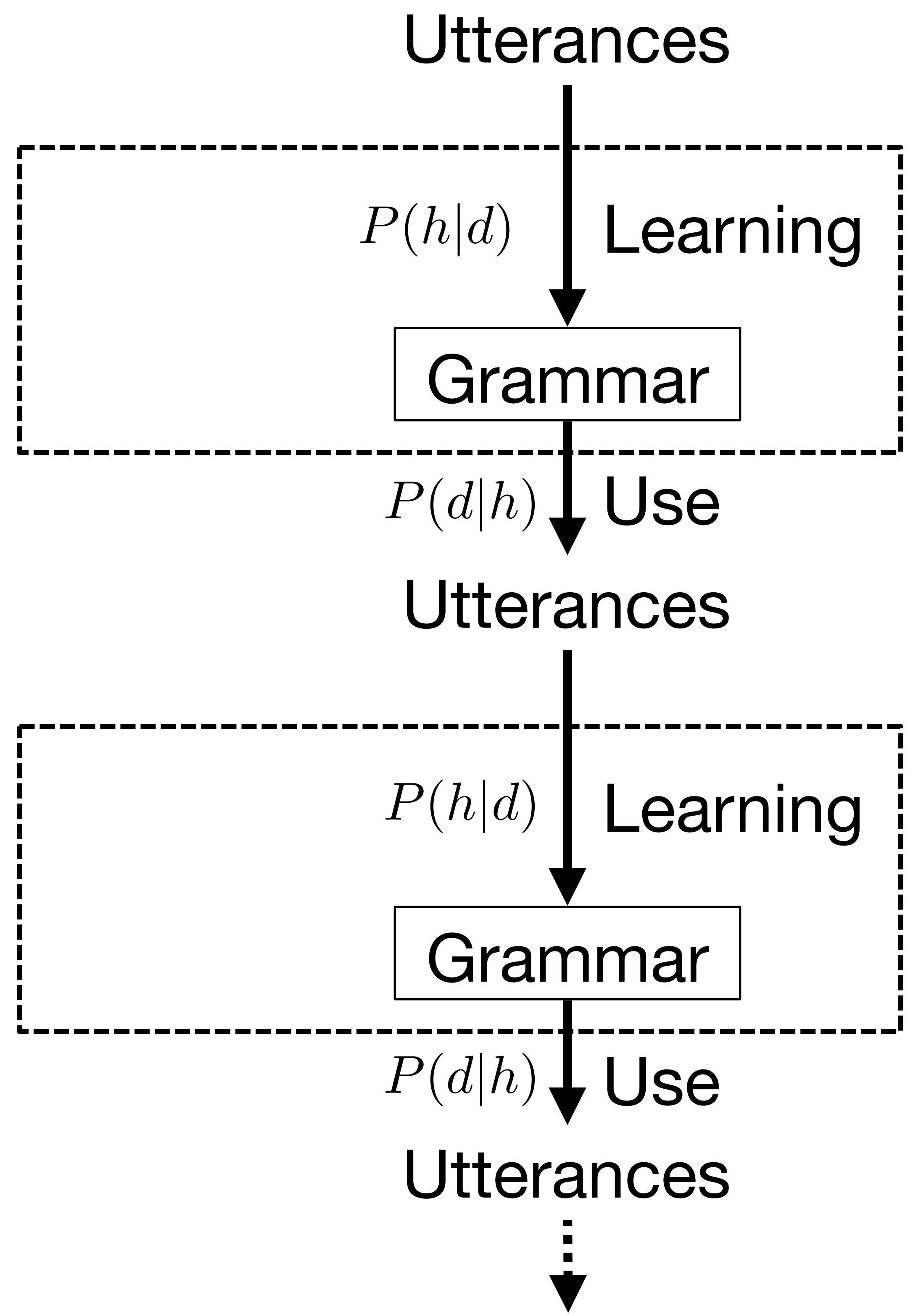
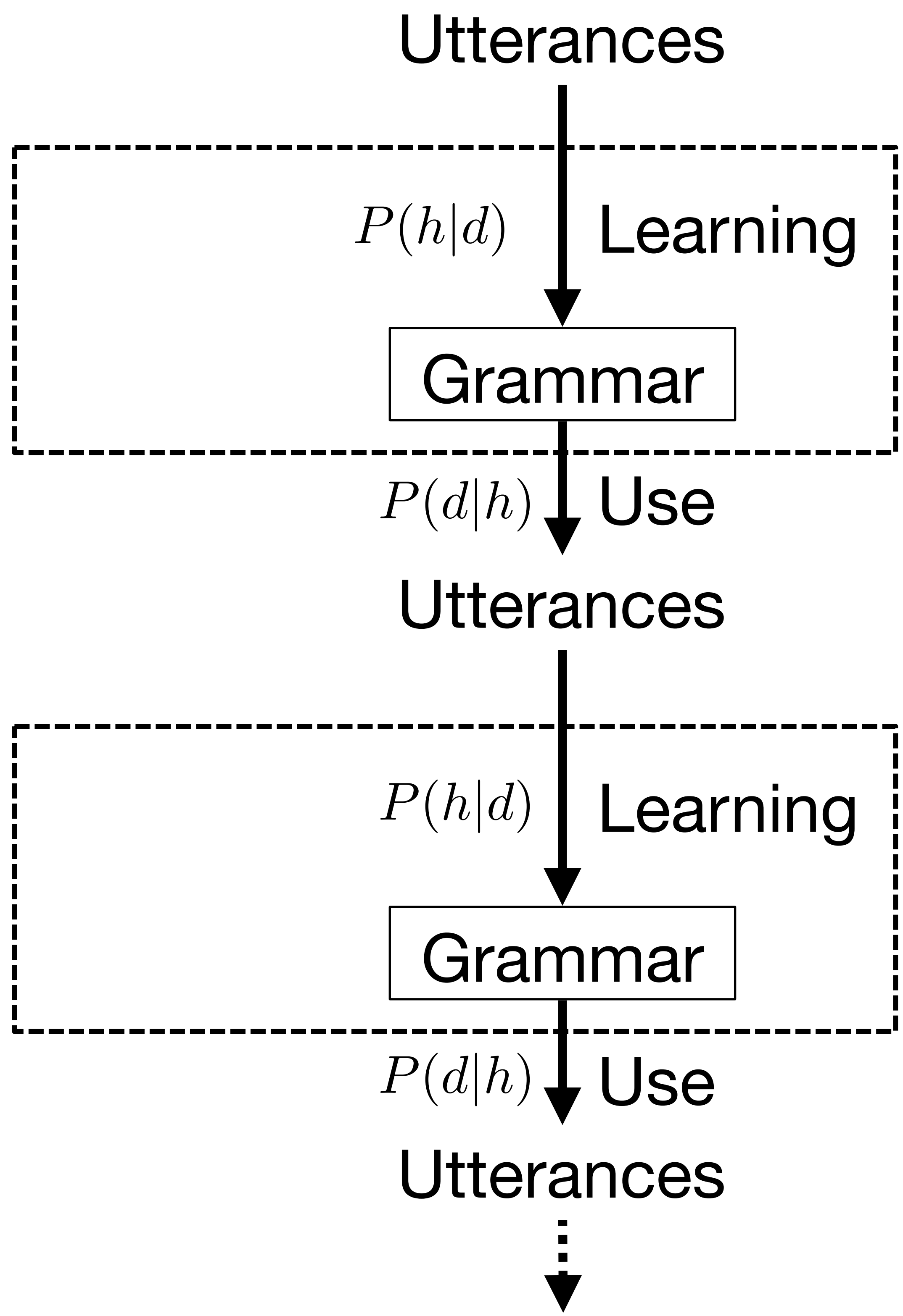
Iterated learning

Simulate language transmission from learner to learner.

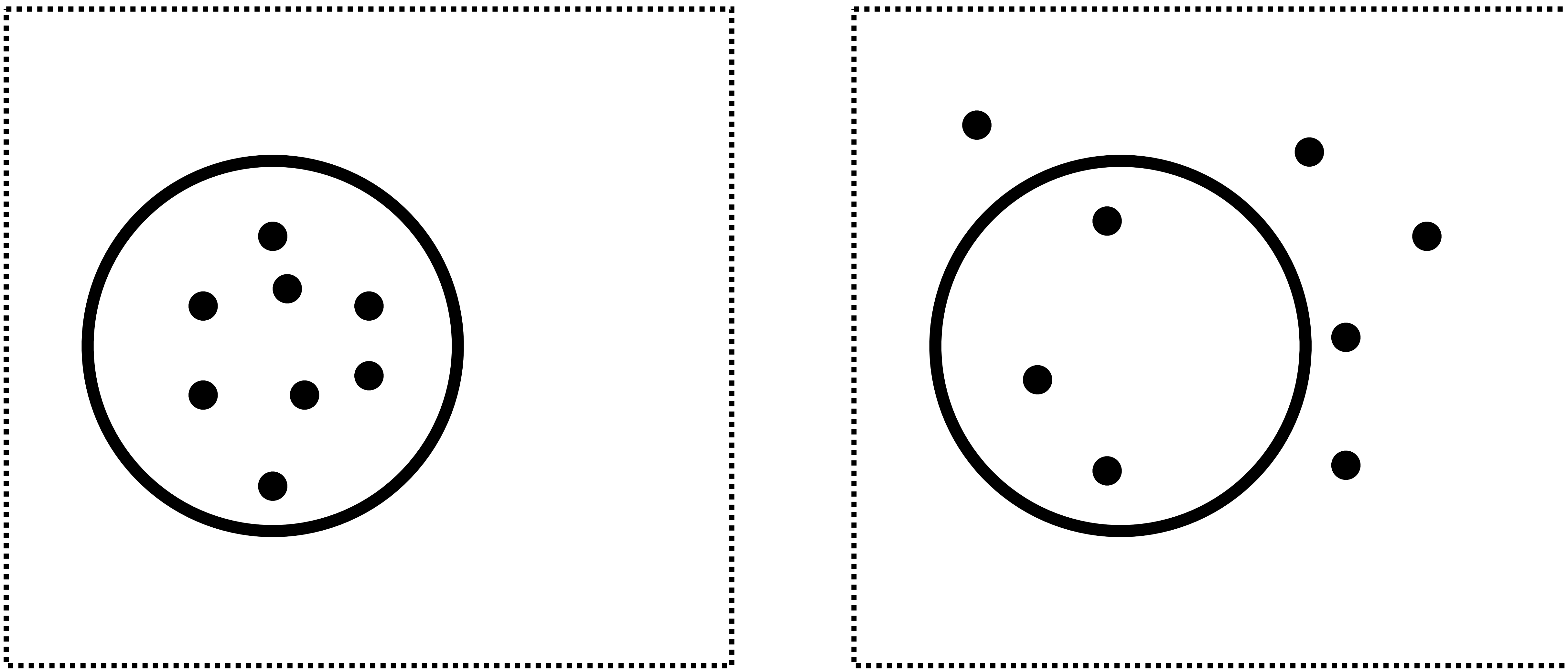
Over time, the bias reveals itself



Iterated learning

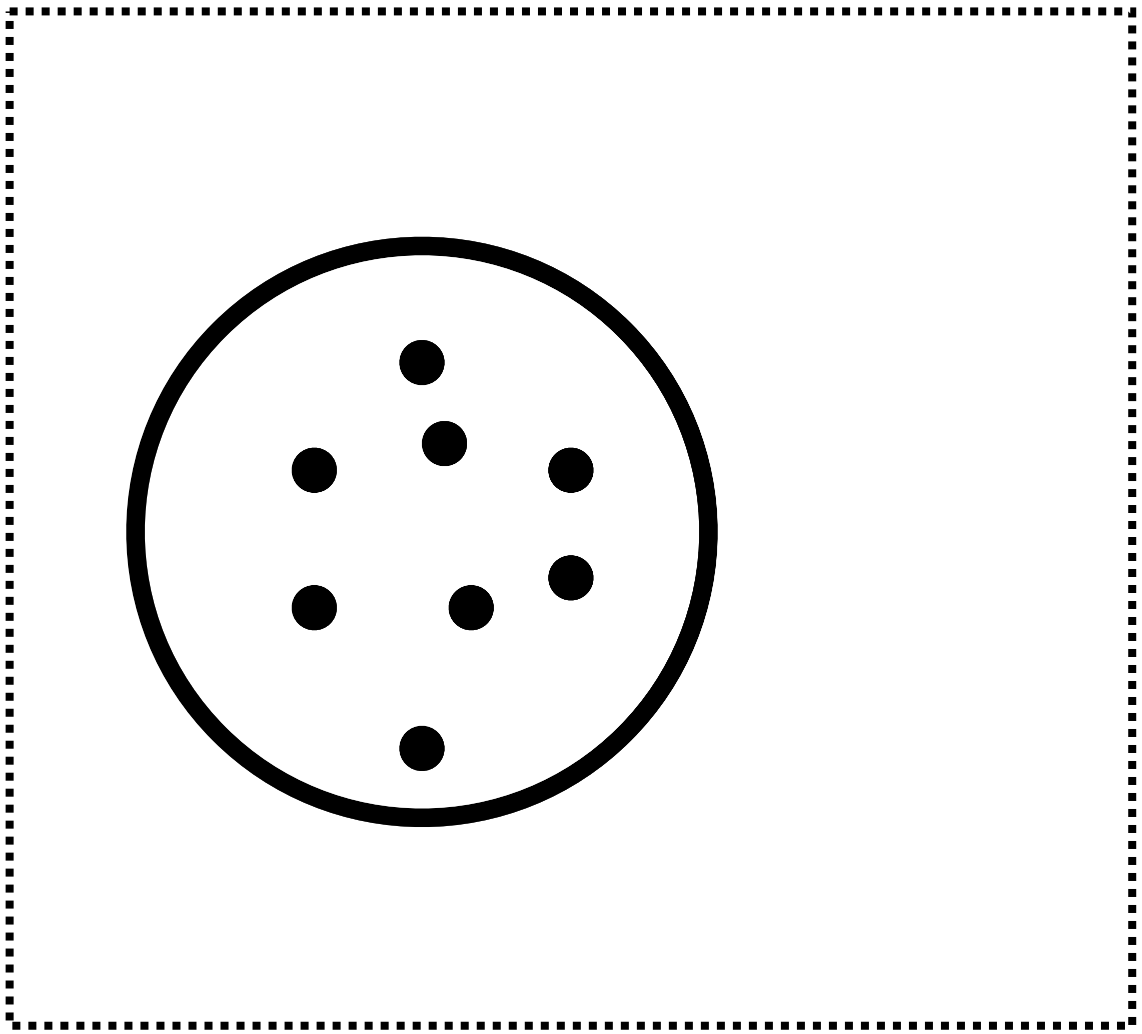



Language is for communication

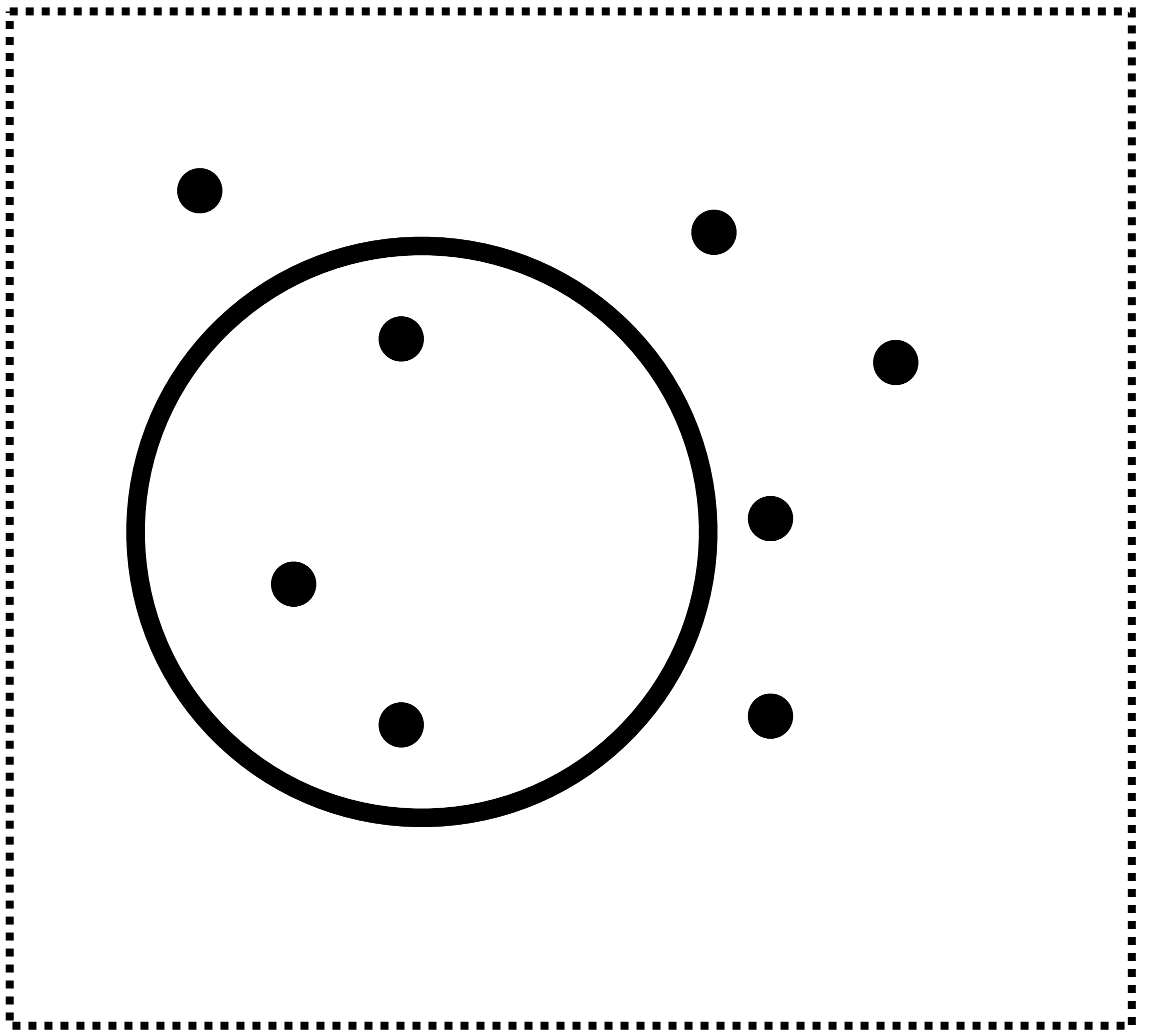


“Some of the dots are in the circle”

Option 1



Option 2



“Some of the dots are in the circle”

Option 1

Option 2

“I like the one with the headband”

Option 1

Option 2

“I like the one with the bandana”

Gricean pragmatics (e.g. Grice, 1975)

- Speakers are cooperative and choose their utterances to convey certain meanings
- Listeners should assume this when interpreting the speaker's utterances

The maxim of relation: says things that are relevant

Person A: What time is it?

Person B: My phone is out of battery

The maxim of manner: try to be clear and brief, avoid obscurity and ambiguity

A: Where do they live?

B: Somewhere just outside of Edinburgh

The Rational Speech Act model

- **Communication is another inference problem**: inferring hidden causes of observable behaviour
- Medicine: hidden cause = illness, observable = symptoms
- Word learning: hidden cause = word meaning, observable = labelling
- Frequency learning: hidden cause = word frequency, observable = word use
- **Communication:** hidden cause = intended meaning, observable = utterances

$$P(\text{intended meaning} \mid \text{what you said})$$

The Rational Speech Act model

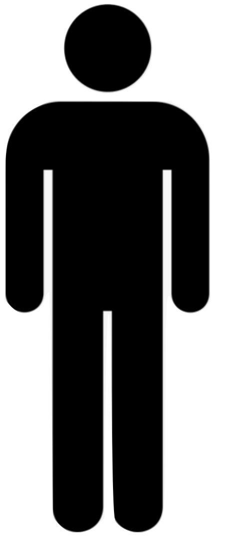
$$P_{\text{Listener}}(\text{intended meaning} \mid \text{utterance})$$

$$\propto P_{\text{Speaker}}(\text{utterance} \mid \text{intended meaning})\, P(\text{intended meaning})$$

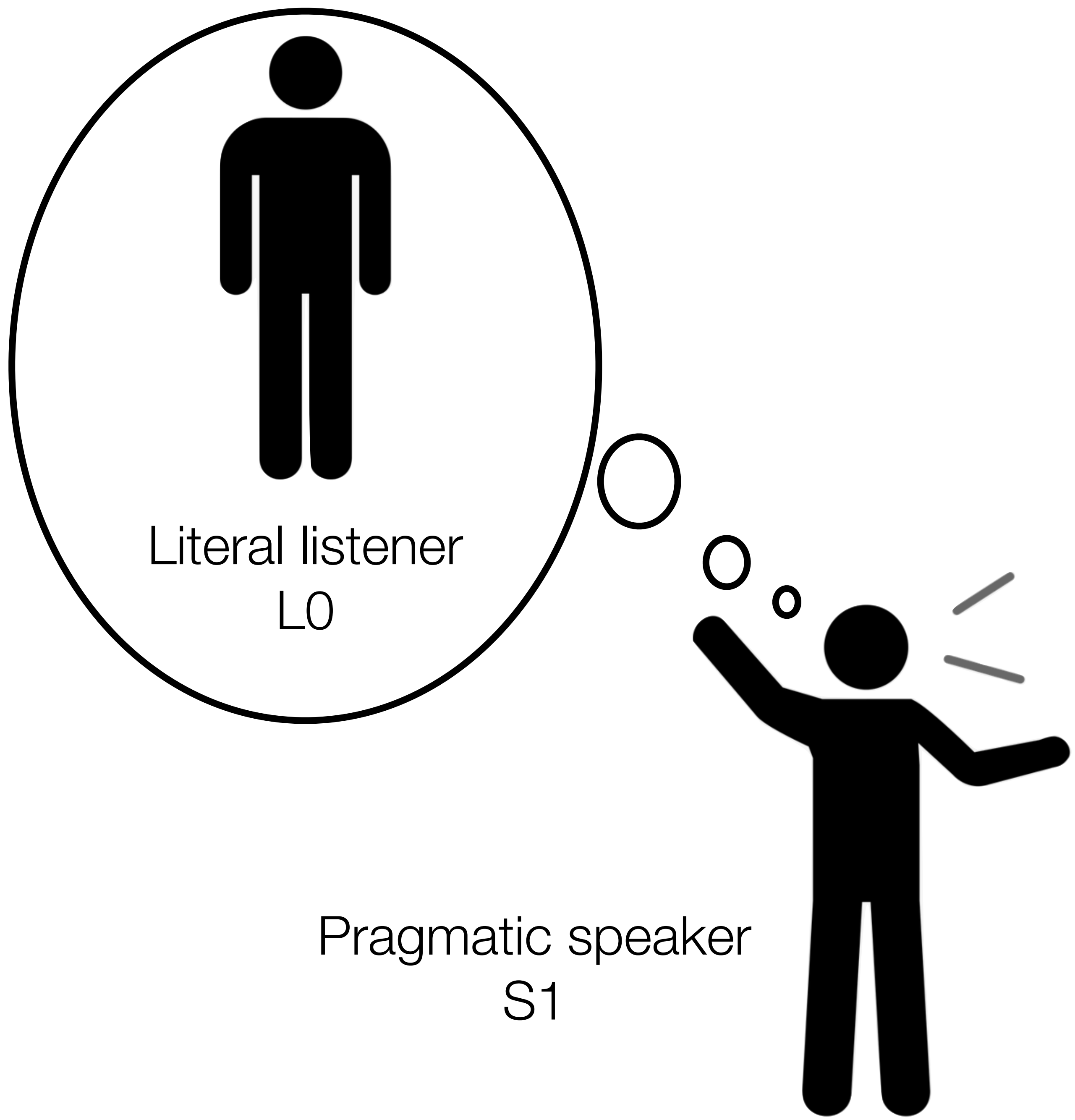
$$P_{\text{Speaker}}(\text{utterance} \mid \text{intended meaning})$$

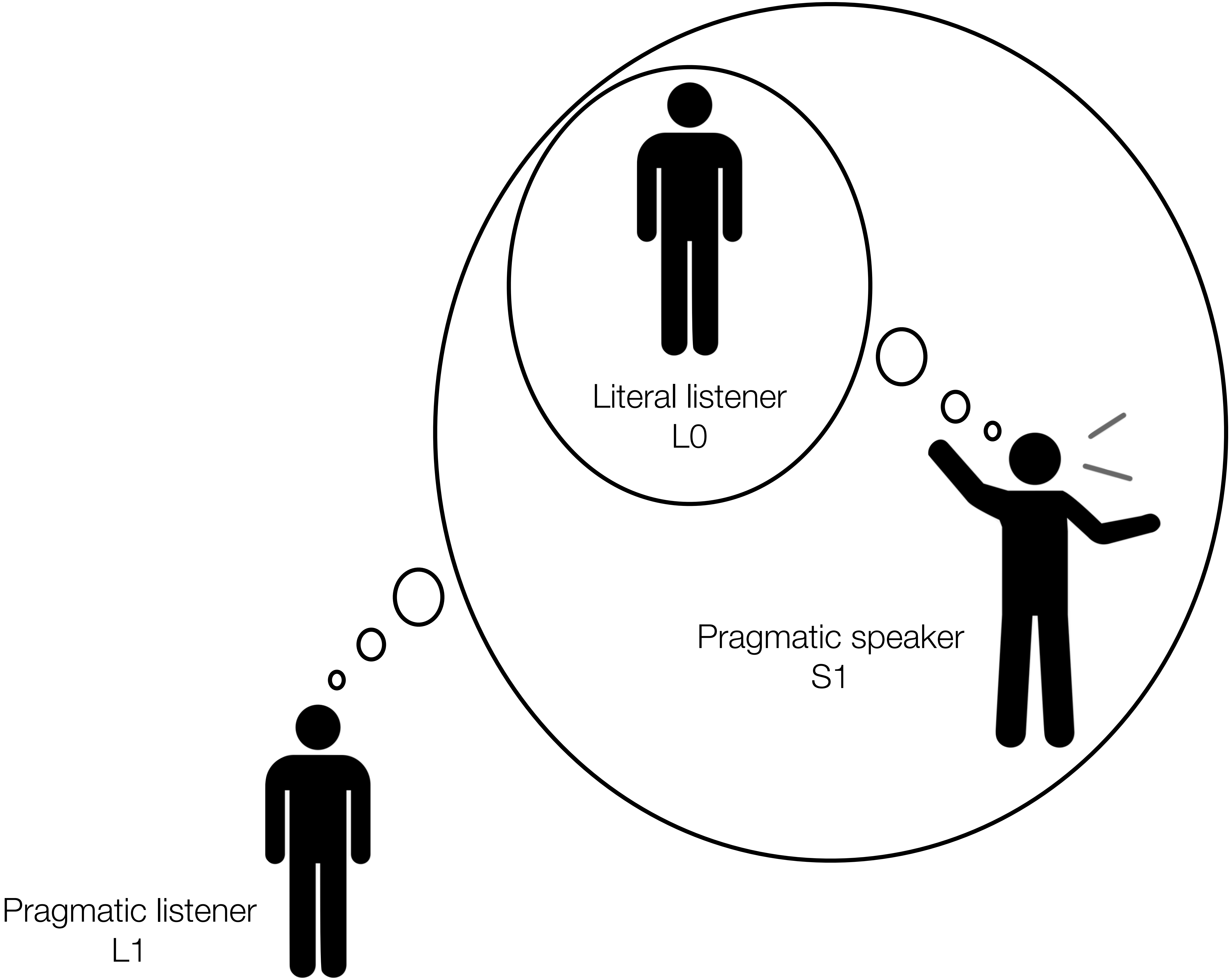
$$\propto P_{\text{Listener}}(\text{intended meaning} \mid \text{utterance})\, P(\text{utterance})$$

Is there any way out of this loop of listeners and speakers reasoning endlessly about one another reasoning about one another reasoning about one another…?



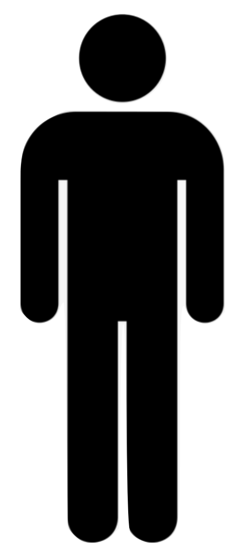
Literal listener
L0


Literal listener
L0
Pragmatic speaker
S1


Literal listener
L0
Pragmatic speaker
S1
Pragmatic listener
L1

Core features of the RSA model

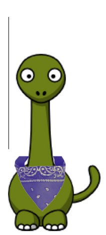
- Communication involves inferring hidden causes of observable behaviours
    - It’s an inference problem
- Speakers design utterances for their listeners in order to convey an intended meaning
- Hearers assume that speakers are doing this



Literal listener
L0

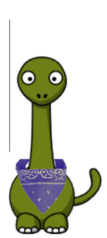
Starting with the literal listener, L0

- “I like the dinosaur wearing the **headband**”

$P_{L0}($  $|$ “headband”$) = ?$ $P_{L0}($  $|$ “headband”$) = ?$

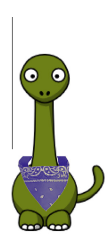
Starting with the literal listener, L0

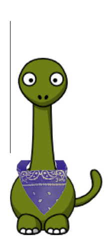
- “I like the dinosaur wearing the **bandana**”

$P_{L0}($  $|$ “headband”$) = 0$ $P_{L0}($  $|$ “headband”$) = 1$

Starting with the literal listener, L0

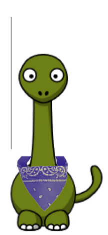
- "I like the dinosaur wearing the **bandana**"
- "I like the one with the **headband**"

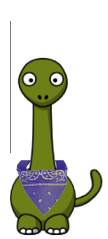
$P_{L0}($  $\mid$ "headband") = 0 $\quad$ $P_{L0}($  $\mid$ "headband") = 1

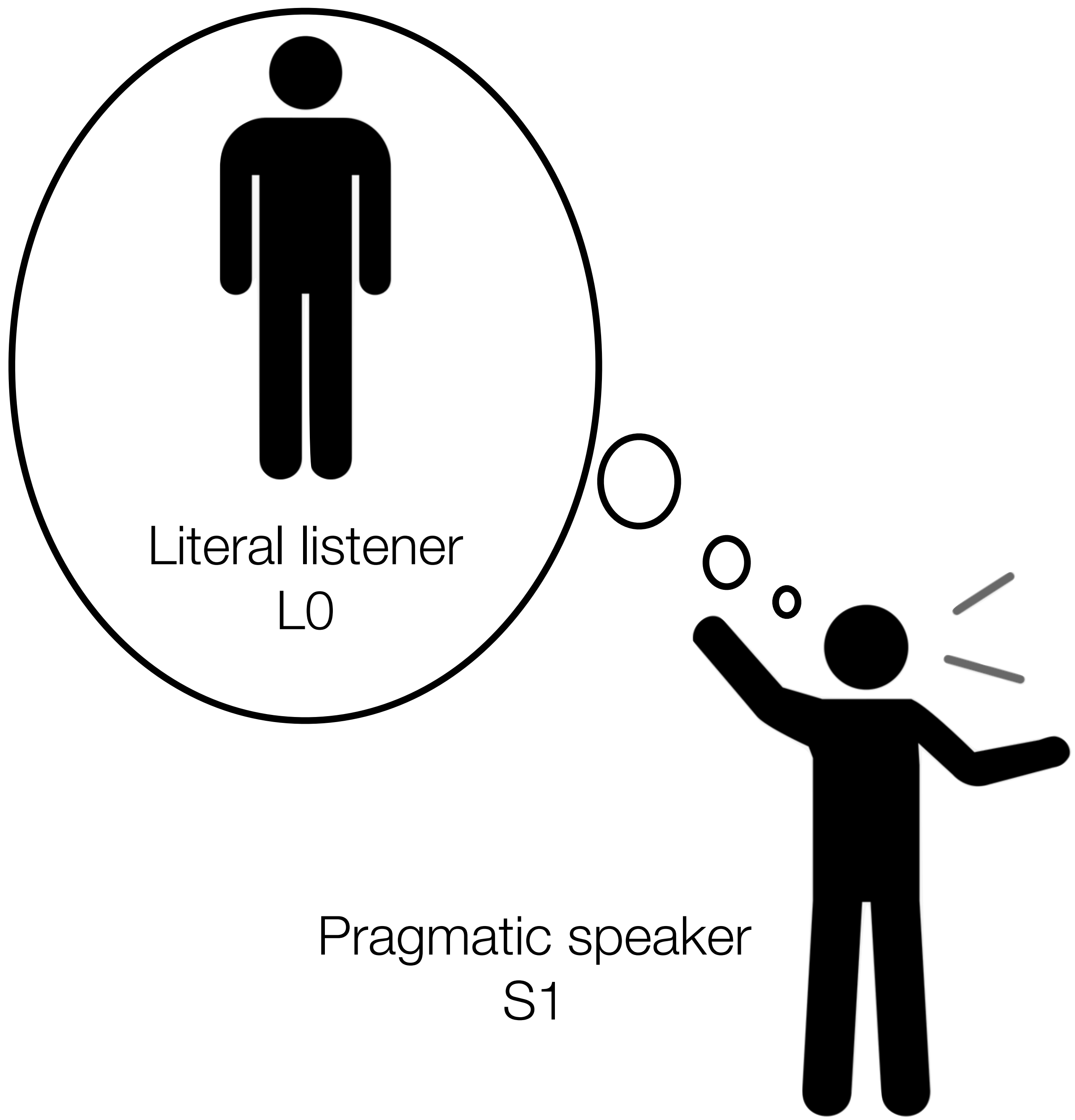
$P_{L0}($  $\mid$ "bandana") = ? $\quad$ $P_{L0}($  $\mid$ "bandana") = ?

Starting with the literal listener, L0

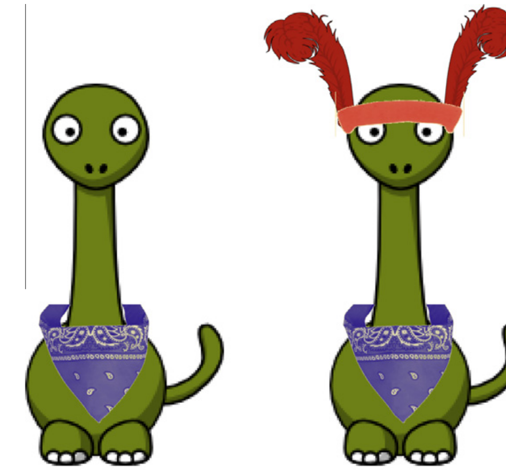
- “I like the dinosaur wearing the **bandana**”
- “I like the one with the **headband**”

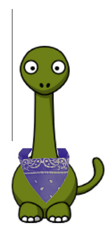
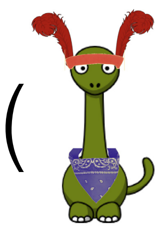
$P_{L0}($  $\mid \text{“headband”}) = 0$ $P_{L0}($  $\mid \text{“headband”}) = 1$

$P_{L0}($  $\mid \text{“bandana”}) = \frac{1}{2}$ $P_{L0}($  $\mid \text{“bandana”}) = \frac{1}{2}$

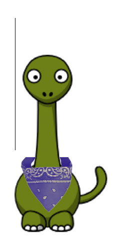

Literal listener
L0
Pragmatic speaker
S1

The pragmatic speaker, S1



$P_{L0}($  | “headband”$) = 0$ $P_{L0}($  | “headband”$) = 1$

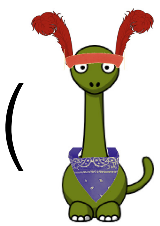
$P_{L0}($  | “bandana”$) = \frac{1}{2}$ $P_{L0}($  | “bandana”$) = \frac{1}{2}$

$P_{S1}($“bandana” |  $) \propto$ $P_{L0}($  | “bandana”$)$

The pragmatic speaker, S1

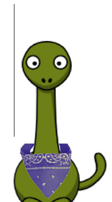
P_{L0}( | “headband”) = 0 P_{L0}( | “headband”) = 1

P_{L0}( | “bandana”) = $\frac{1}{2}$ P_{L0}( | “bandana”) = $\frac{1}{2}$

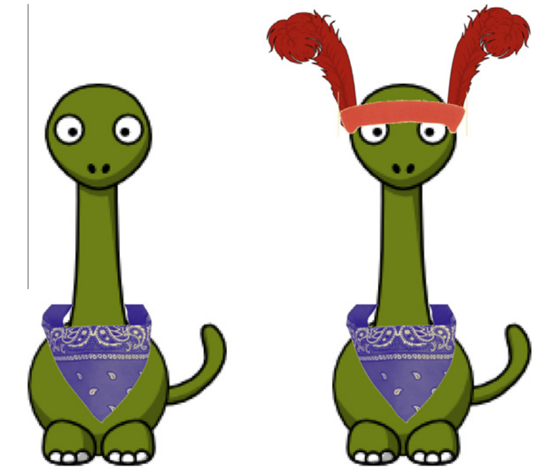
P_{S1}(“bandana” | ) =

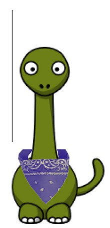
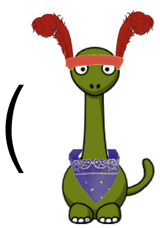
P_{L0}( | “bandana”)

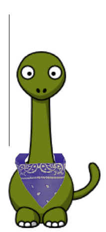
over

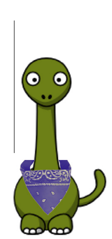
P_{L0}( | “bandana”) + P_{L0}( | “headband”)

The pragmatic speaker, S1

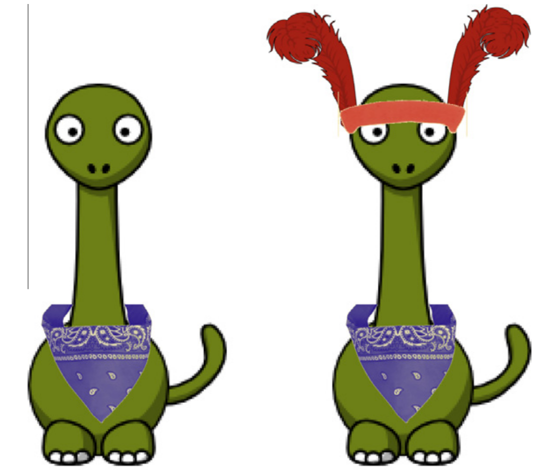


$P_{L0}($  $\mid$ “headband”$) = 0$ $P_{L0}($  $\mid$ “headband”$) = 1$

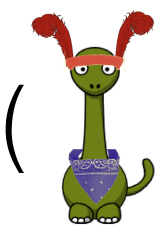
$P_{L0}($  $\mid$ “bandana”$) = \frac{1}{2}$ $P_{L0}($  $\mid$ “bandana”$) = \frac{1}{2}$

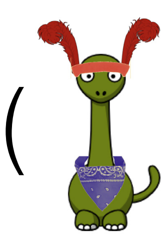
$P_{S1}($“bandana” $\mid$  $) = \dfrac{\frac{1}{2}}{\frac{1}{2} + 0} = 1$

The pragmatic speaker, S1

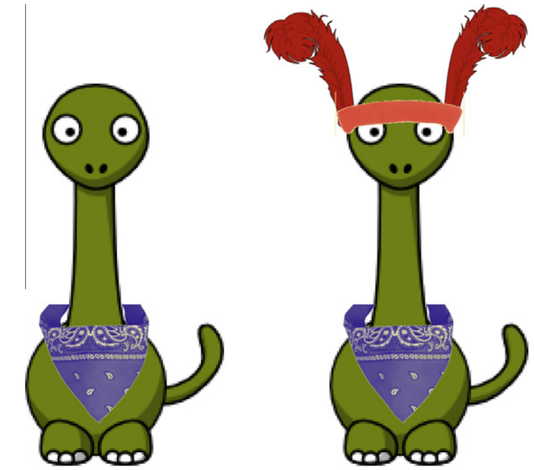


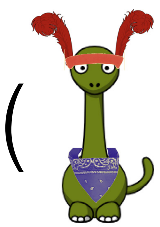
$P_{L0}($  $|$ “headband”$) = 0$ $P_{L0}($  $|$ “headband”$) = 1$

$P_{L0}($  $|$ “bandana”$) = \frac{1}{2}$ $P_{L0}($  $|$ “bandana”$) = \frac{1}{2}$

$P_{S1}($“bandana” $|$  $) \propto$ $P_{L0}($  $|$ “bandana”$)$

The pragmatic speaker, S1



P_{L0}( | “headband”) = 0 P_{L0}( | “headband”) = 1

P_{L0}( | “bandana”) = $\frac{1}{2}$ P_{L0}( | “bandana”) = $\frac{1}{2}$

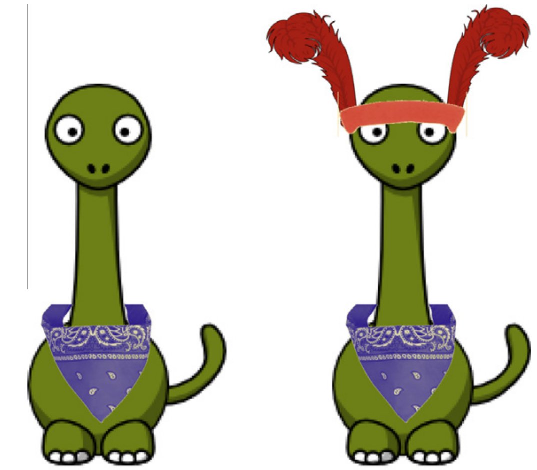
P_{S1}(“bandana” | ) =

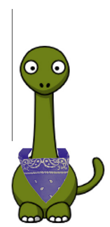
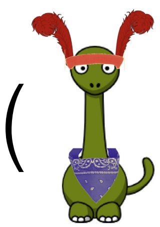
P_{L0}( | “bandana”)

divided by

P_{L0}( | “bandana”) + P_{L0}( | “headband”)

The pragmatic speaker, S1

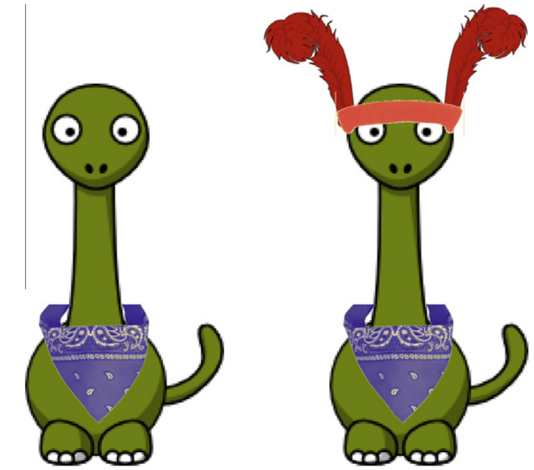


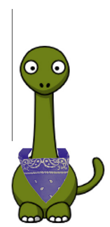
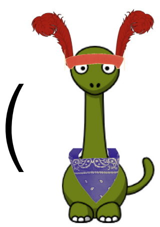
$P_{L0}($  $|$ "headband"$) = 0$ $P_{L0}($  $|$ "headband"$) = 1$

$P_{L0}($  $|$ "bandana"$) = \frac{1}{2}$ $P_{L0}($  $|$ "bandana"$) = \frac{1}{2}$

$P_{S1}($"bandana" $|$  $) = \dfrac{\frac{1}{2}}{\frac{1}{2} + 1} = \dfrac{1}{3}$

The pragmatic speaker, S1

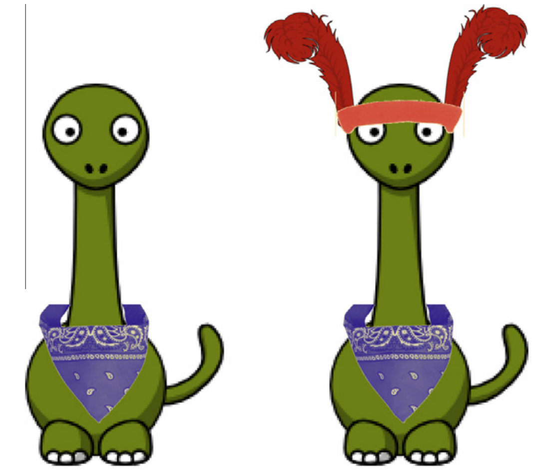


$P_{L0}($  $\mid$ “headband”$) = 0$ $P_{L0}($  $\mid$ “headband”$) = 1$

$P_{L0}($  $\mid$ “bandana”$) = \frac{1}{2}$ $P_{L0}($  $\mid$ “bandana”$) = \frac{1}{2}$

$P_{S1}($“headband” $\mid$  $) \propto$ $P_{L0}($  $\mid$ “headband”$)$

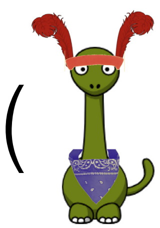
The pragmatic speaker, S1



$P_{L0}($  $|$ "headband"$) = 0$

$P_{L0}($  $|$ "headband"$) = 1$

$P_{L0}($  $|$ "bandana"$) = \frac{1}{2}$

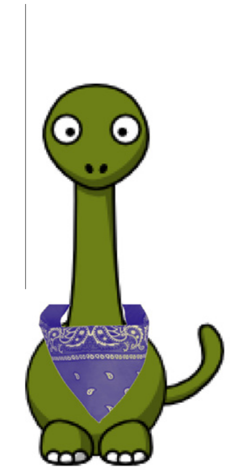
$P_{L0}($  $|$ "bandana"$) = \frac{1}{2}$

$P_{S1}($"headband" $|$  $) =$

Numerator: $P_{L0}($  $|$ "headband"$)$

Denominator: $P_{L0}($  $|$ "bandana"$) + P_{L0}($  $|$ "headband"$)$

The pragmatic speaker, S1

$P_{L0}($  $|$ "headband"$) = 0$

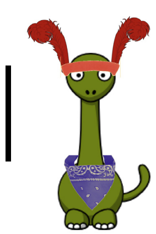
$P_{L0}($  $|$ "headband"$) = 1$

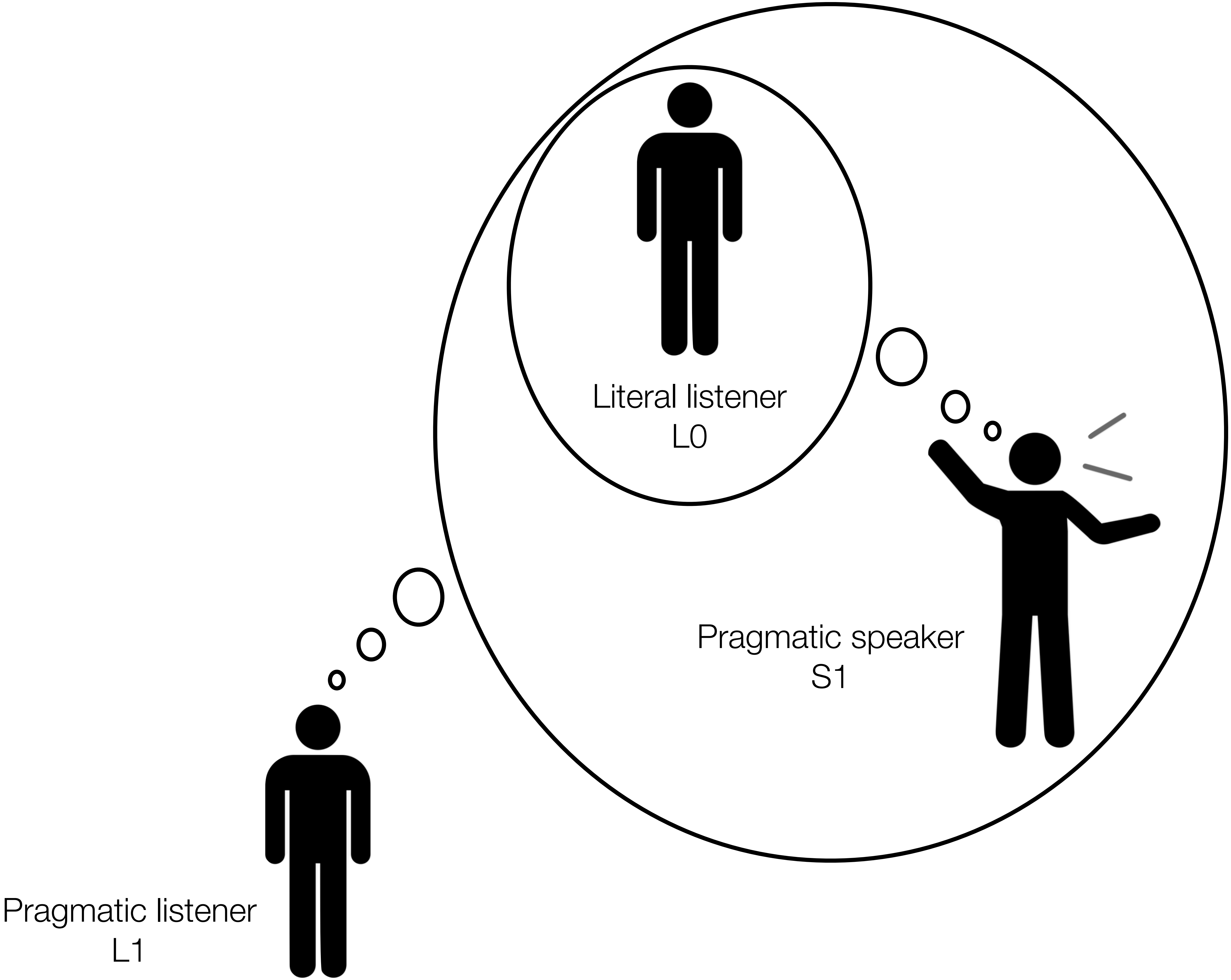
$P_{L0}($  $|$ "bandana"$) = \frac{1}{2}$

$P_{L0}($  $|$ "bandana"$) = \frac{1}{2}$

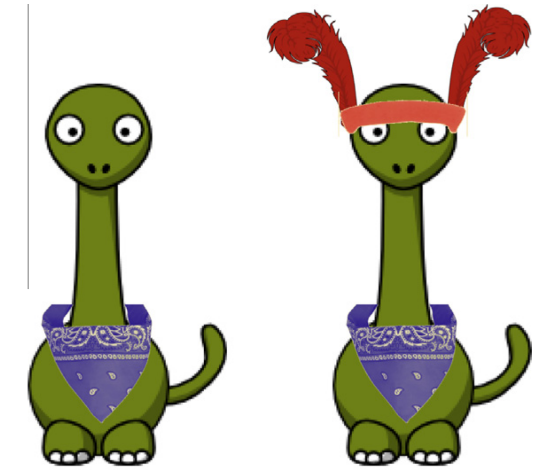
$P_{S1}($"headband" $|$  $) = \dfrac{1}{\frac{1}{2} + 1} = \dfrac{2}{3}$

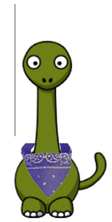
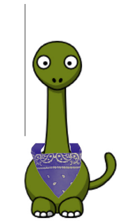
$P_{S1}($“bandana” $|$  $) = 1$ $P_{S1}($“headband” $|$  $) = 0$

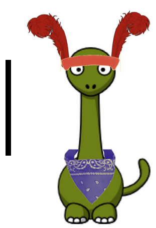
$P_{S1}($“bandana” $|$  $) = \frac{1}{3}$ $P_{S1}($“headband” $|$  $) = \frac{2}{3}$

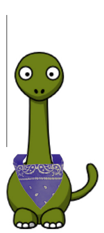
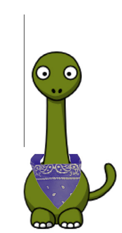
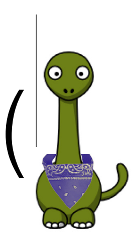

Literal listener
L0
Pragmatic speaker
S1
Pragmatic listener
L1

The pragmatic listener, L1

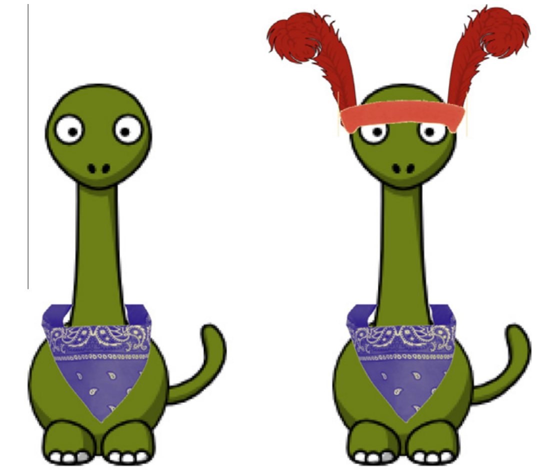


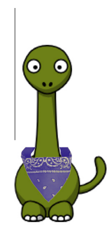
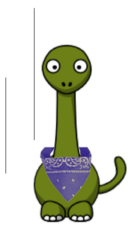
P_{S1}(“bandana” | ) = 1 P_{S1}(“headband” | ) = 0

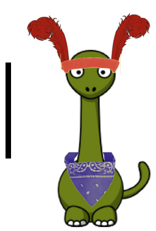
P_{S1}(“bandana” | ) = $\frac{1}{3}$ P_{S1}(“headband” | ) = $\frac{2}{3}$

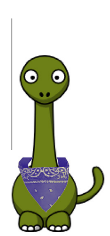
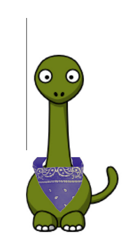
P_{L1}( | “bandana”) $\propto$ P_{S1}(“bandana” | ) P()

The pragmatic listener, L1

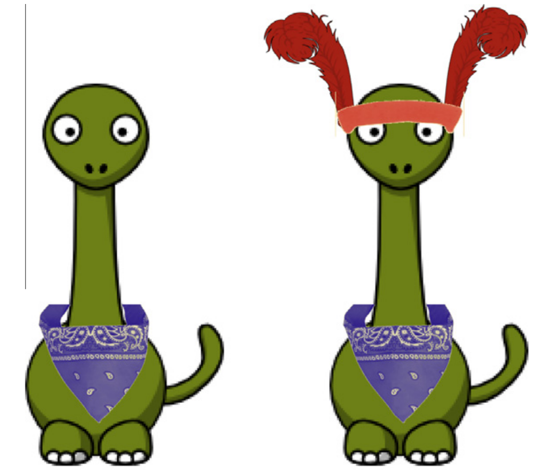


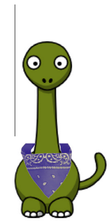
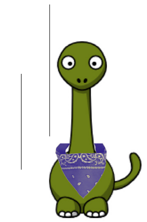
P_{S1}(“bandana” | ) = 1 P_{S1}(“headband” | ) = 0

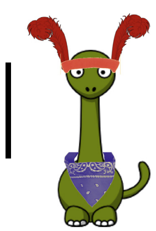
P_{S1}(“bandana” | ) $= \frac{1}{3}$ P_{S1}(“headband” | ) $= \frac{2}{3}$

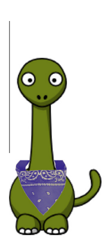
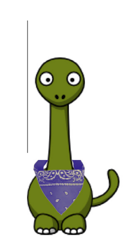
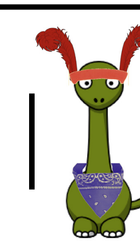
P_{L1}( | “bandana”) $\propto$ P_{S1}(“bandana” | )

The pragmatic listener, L1

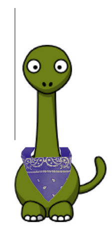
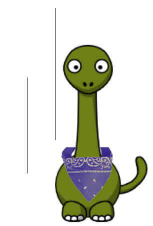


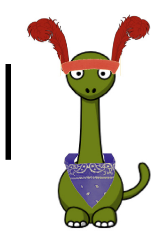
P_{S1}(“bandana” | ) = 1 P_{S1}(“headband” | ) = 0

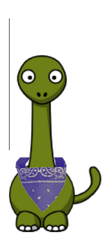
P_{S1}(“bandana” | ) $= \frac{1}{3}$ P_{S1}(“headband” | ) $= \frac{2}{3}$

P_{L1}( | “bandana”) = [P_{S1}(“bandana” | )] / [P_{S1}(“bandana” | ) + P_{S1}(“bandana” | )]

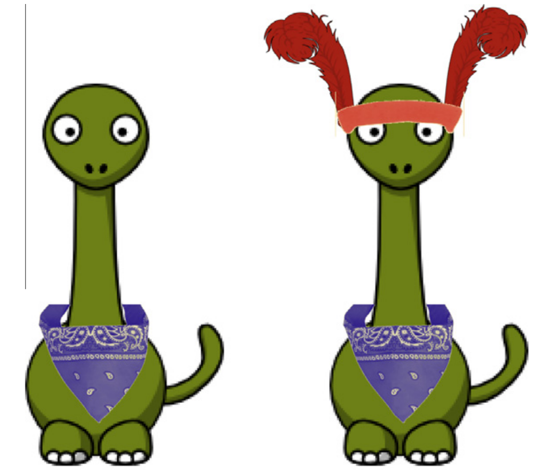
The pragmatic listener, L1

P_{S1}(“bandana” | ) = 1 P_{S1}(“headband” | ) = 0

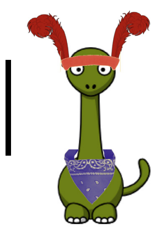
P_{S1}(“bandana” | ) = $\frac{1}{3}$ P_{S1}(“headband” | ) = $\frac{2}{3}$

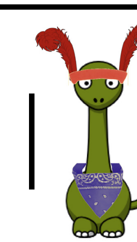
P_{L1}( | “bandana”) $= \dfrac{1}{1+\frac{1}{3}} = \dfrac{3}{4}$

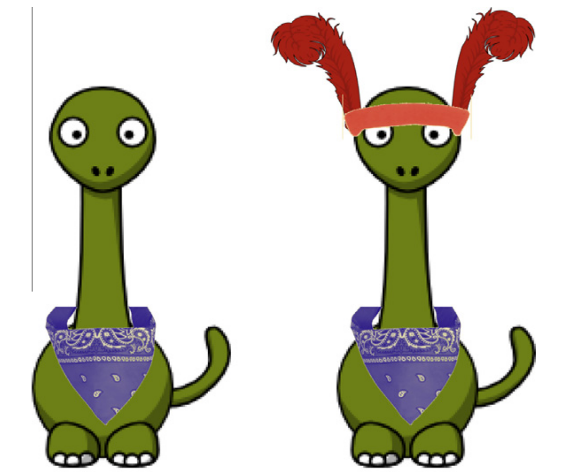
The pragmatic listener, L1



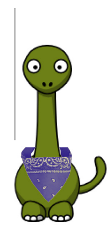
P_{S1}(“bandana” | ) = 1 P_{S1}(“headband” | ) = 0

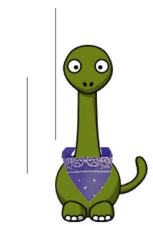
P_{S1}(“bandana” | ) = $\frac{1}{3}$ P_{S1}(“headband” | ) = $\frac{2}{3}$

P_{L1}( | “bandana”) = [P_{S1}(“bandana” | )] / [P_{S1}(“bandana” | ) + P_{S1}(“bandana” | )]

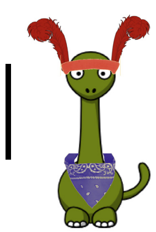


The pragmatic listener, L1

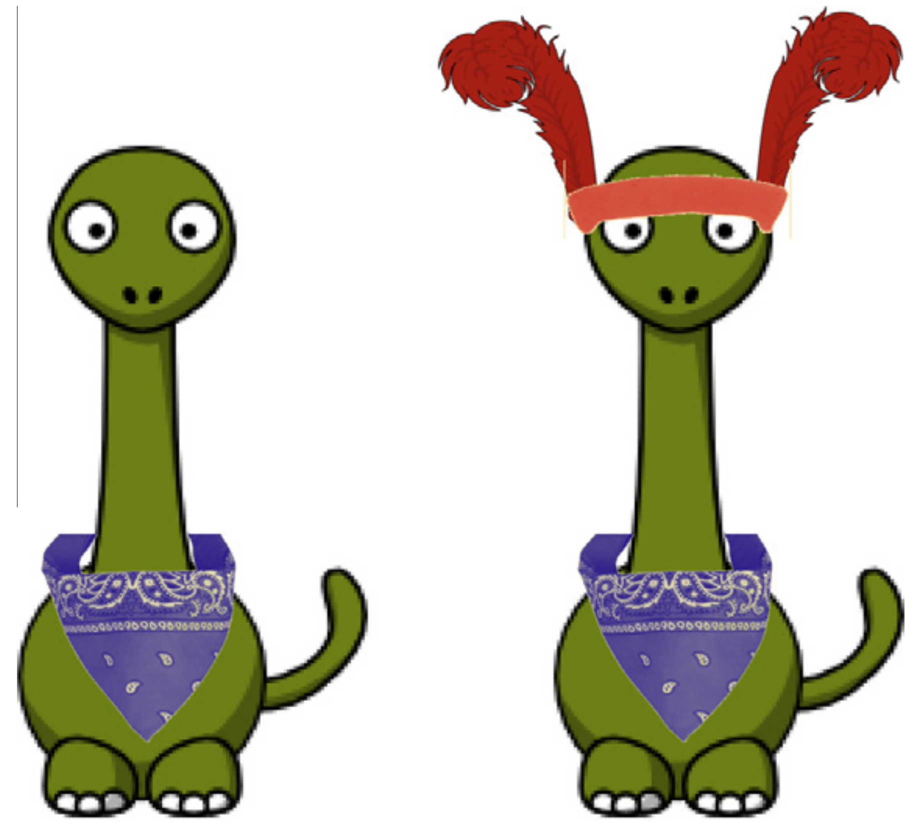
P_{S1}(“bandana” | ) $= 1$

P_{S1}(“headband” | ) $= 0$

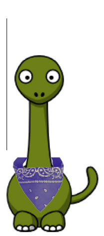
P_{S1}(“bandana” | ) $= \frac{1}{3}$

P_{S1}(“headband” | ) $= \frac{2}{3}$

P_{L1}( | “bandana”) $= \dfrac{\frac{1}{3}}{1 + \frac{1}{3}} = \dfrac{1}{4}$



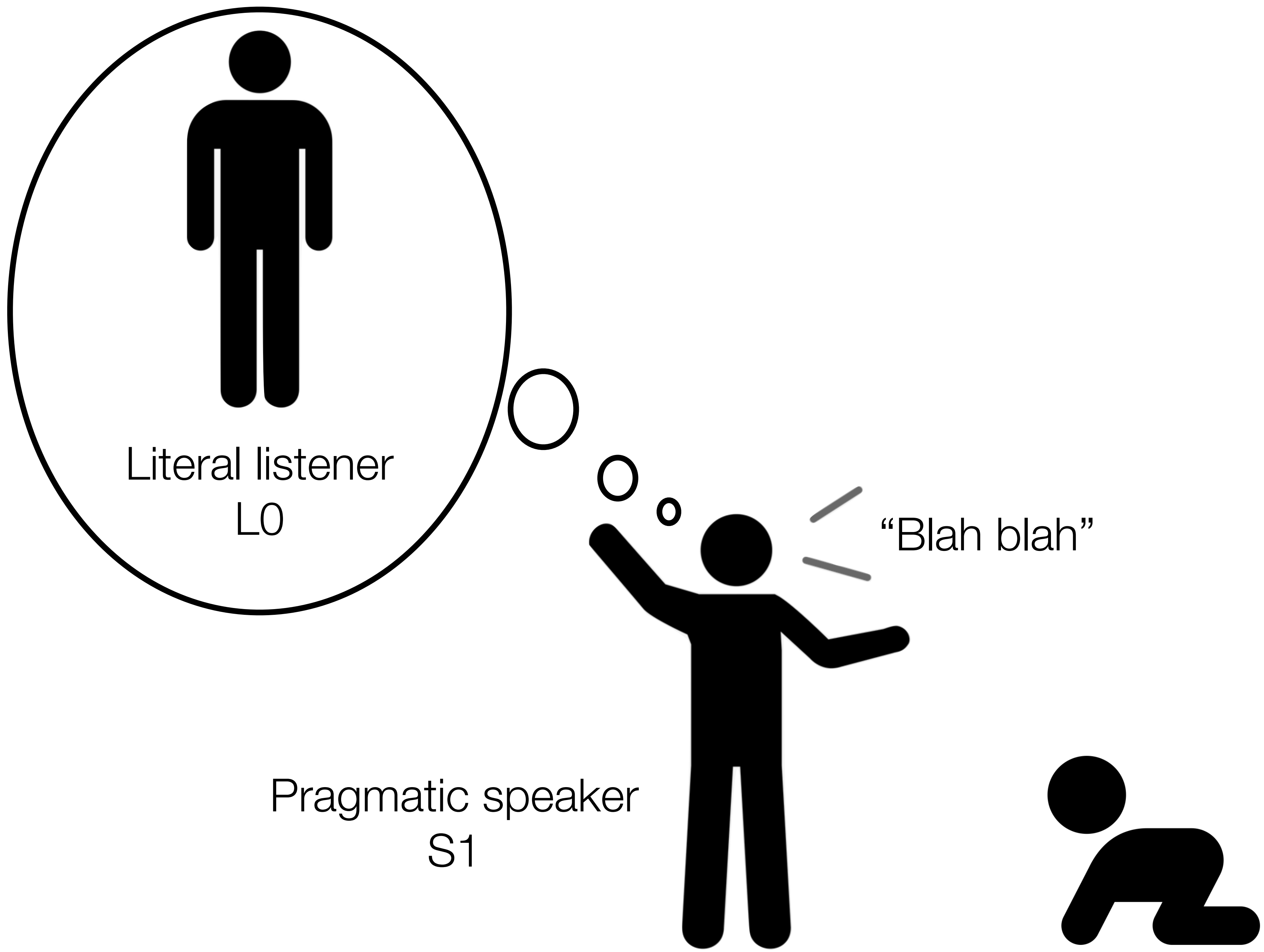
“I like the one with the bandana”

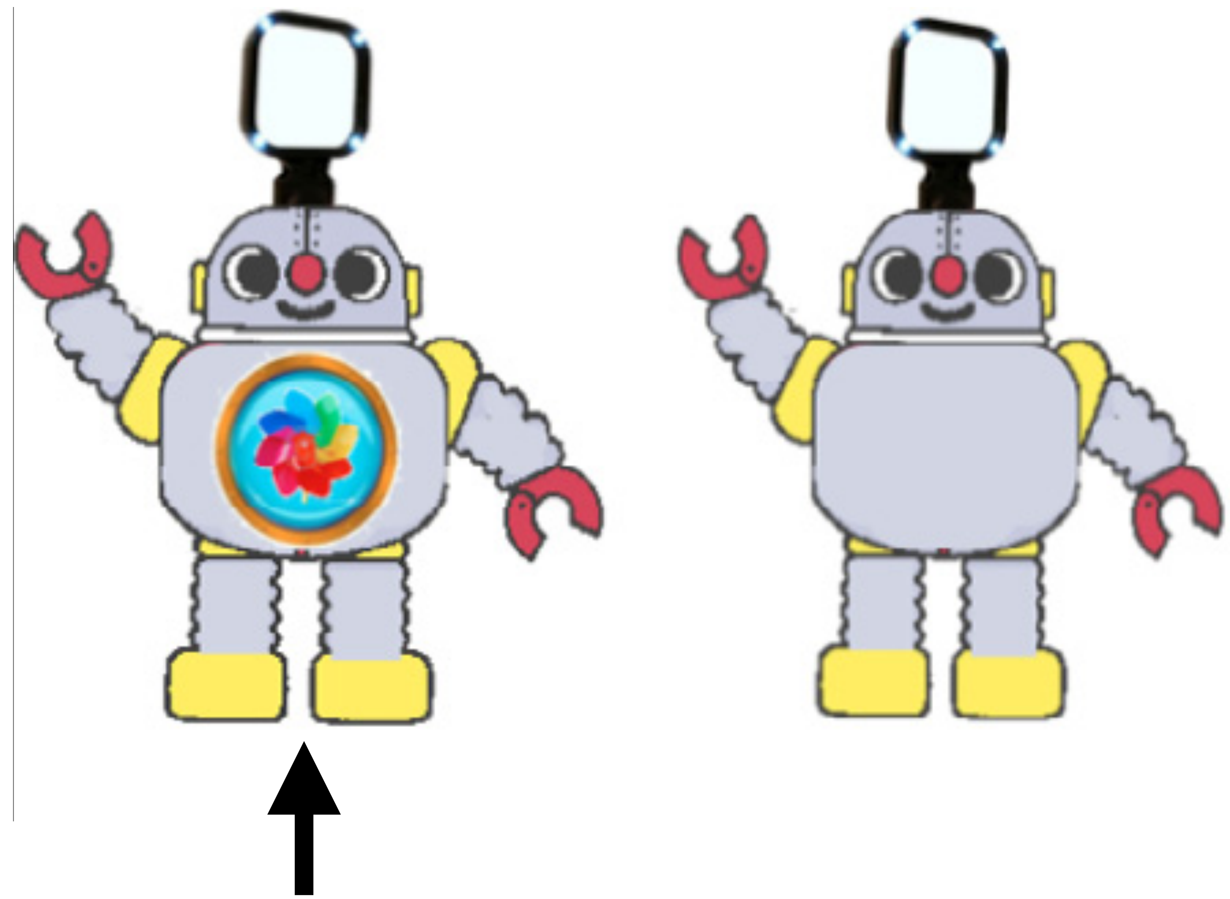
$P_{L1}($  $\mid$ “bandana”$) = \frac{3}{4}$

$P_{L1}($  $\mid$ “bandana”$) = \frac{1}{4}$

Core features of the RSA model

- Communication involves inferring hidden causes of observable behaviours
    - It’s an inference problem
- Speakers design utterances for their listeners in order to convey an intended meaning
- Hearers assume that speakers are doing this


Literal listener
L0
"Blah blah"
Pragmatic speaker
S1



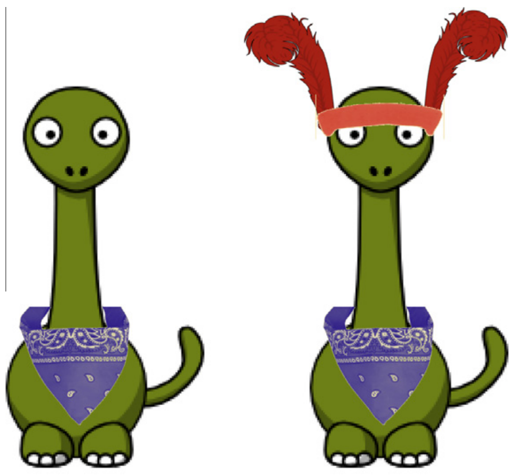
“This is a robot with a **fep**”

Option 1: “fep” means antenna

Option 2: “fep” means swirly chest thing

Frank & Goodman (2014): Learning from a rational speaker

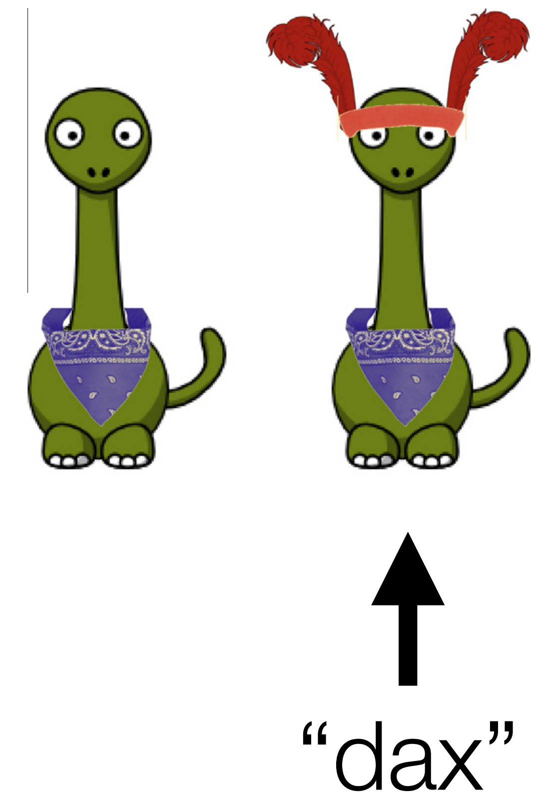
- P_{S1}(utterance|meaning)
- P_{S1}(utterance|meaning, **lexicon**)



"This is a dinosaur with a dax"

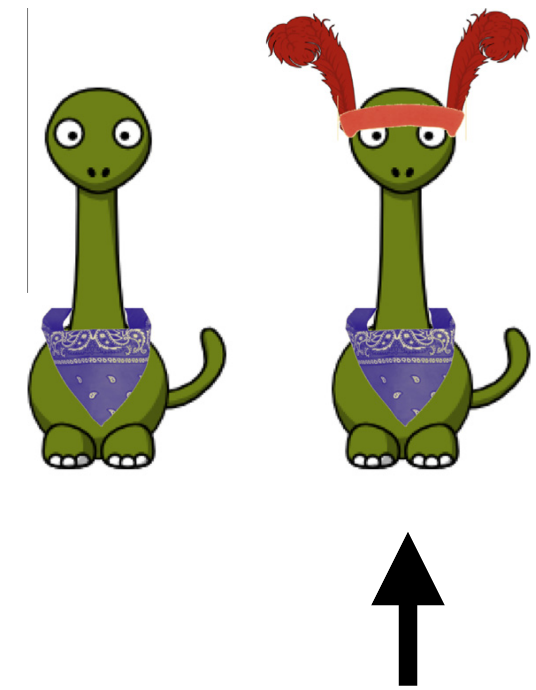
Learning from a rational speaker

- Candidate Lexicon 1: dax = “headband”
- Candidate Lexicon 2: dax = “bandana”



P(lexicon | , “dax”) $\propto$ P_{S1}(“dax” | , lexicon) P(lexicon)

Learning from a rational speaker



"dax"

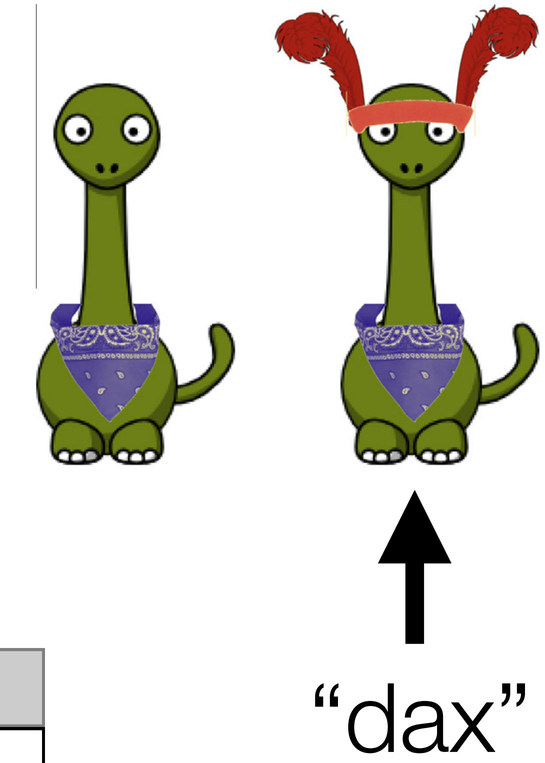
- Candidate Lexicon 1: dax = "headband"
- Candidate Lexicon 2: dax = "bandana"

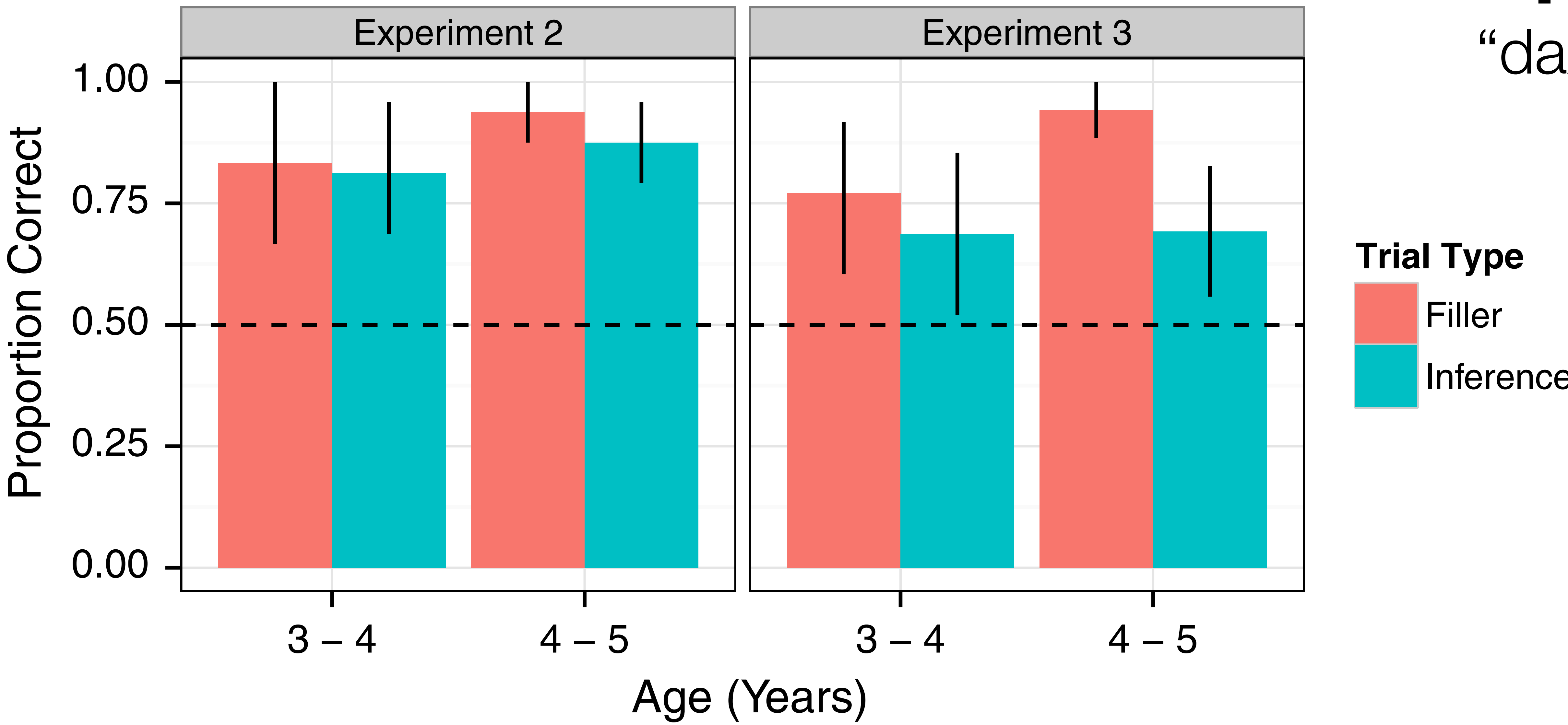
$P(\text{lexicon} \mid$  $, \text{“dax”}) \propto P_{S1}(\text{“dax”} \mid$  $, \text{lexicon}) \; P(\text{lexicon})$

$P_{S1}(\text{“dax”} \mid$  $, \text{dax=bandana}) = \frac{1}{3}$

$P_{S1}(\text{“dax”} \mid$  $, \text{dax=headband}) = \frac{2}{3}$

Frank & Goodman (2014): even quite young children can do this inference





Summary and next up

- Communication as another inference problem
- Rational speakers will avoid in-context ambiguity
- And rational listeners can exploit this during communication and learning
- Read Frank & Goodman (2014) and, optionally, Goodman & Frank (2016)
  - Links from course webpage
- Thursday and Friday: lab on the RSA model

References

Frank, M. C., & Goodman, N. D. (2014). Inferring word meanings by assuming that speakers are informative. *Cognitive Psychology, 75,* 80-96.

Grice, H. P. (1975). Logic and conversation. In Cole, P. and Morgan, J. (Eds.), *Syntax and Semantics* (Vol. 3, pp. 41–58). Academic Press.