

Simulating Language

5: Rational Speech Act model

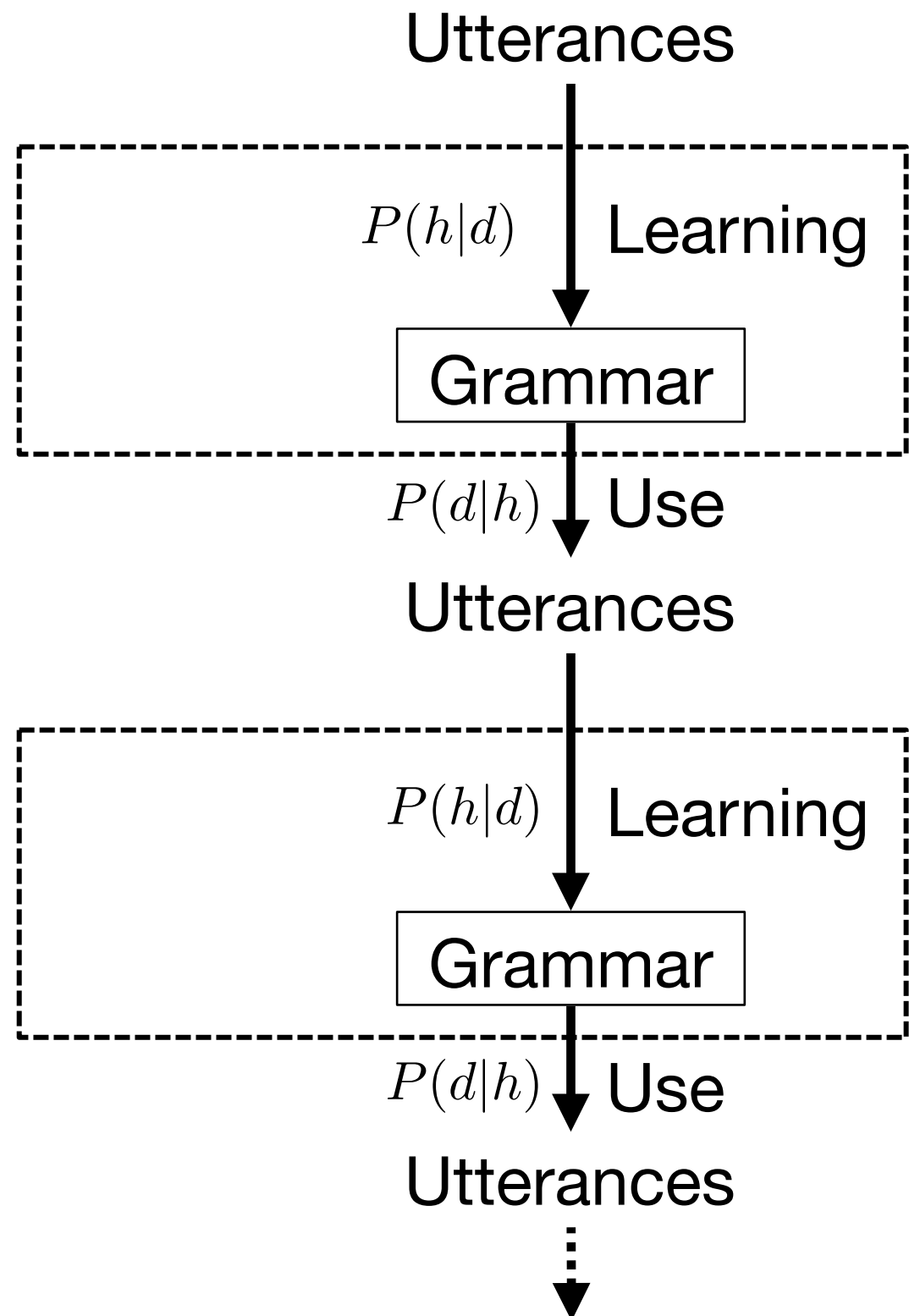
Kenny Smith
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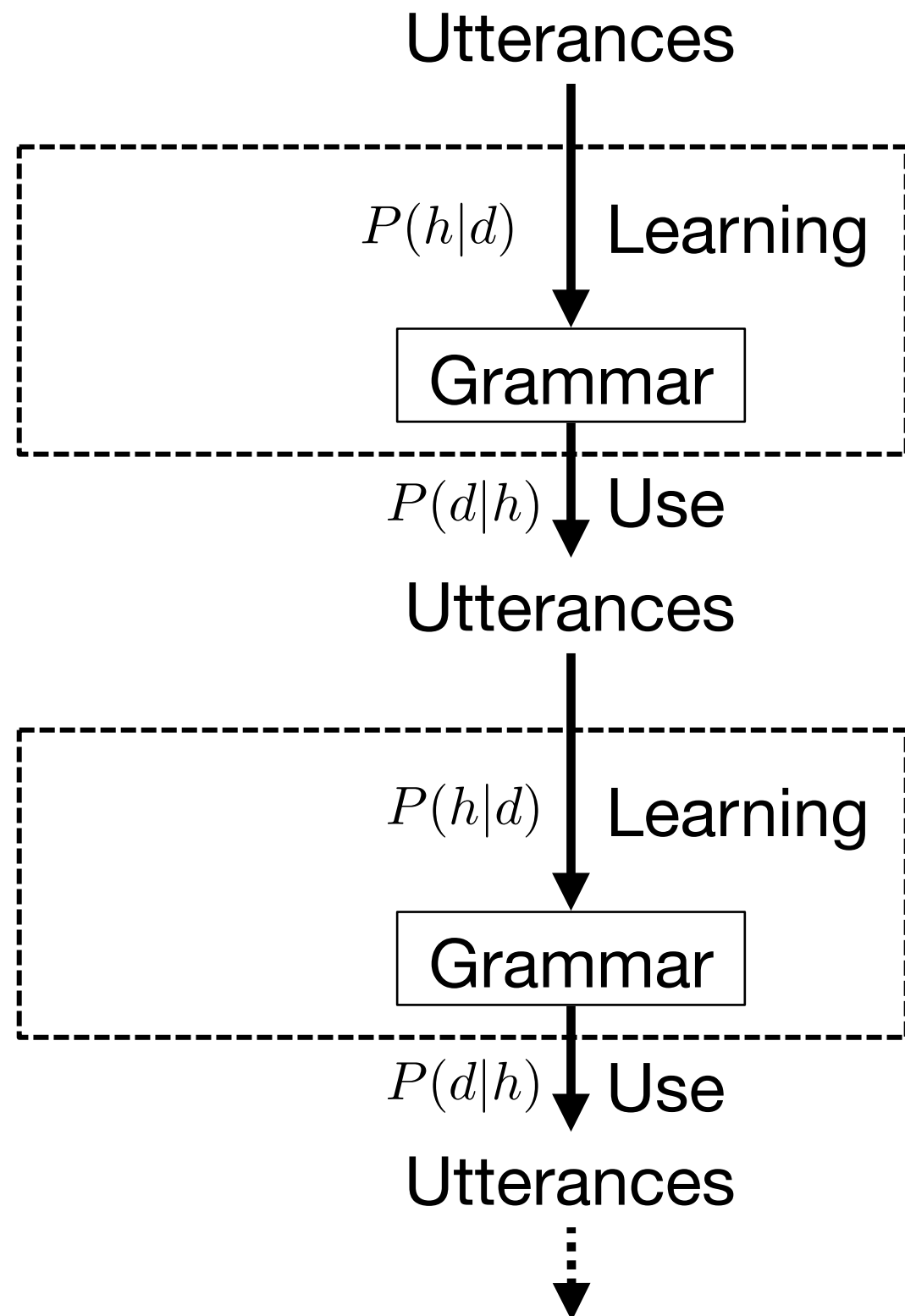
Iterated learning

Simulate language transmission from learner to learner.

Over time, the bias reveals itself

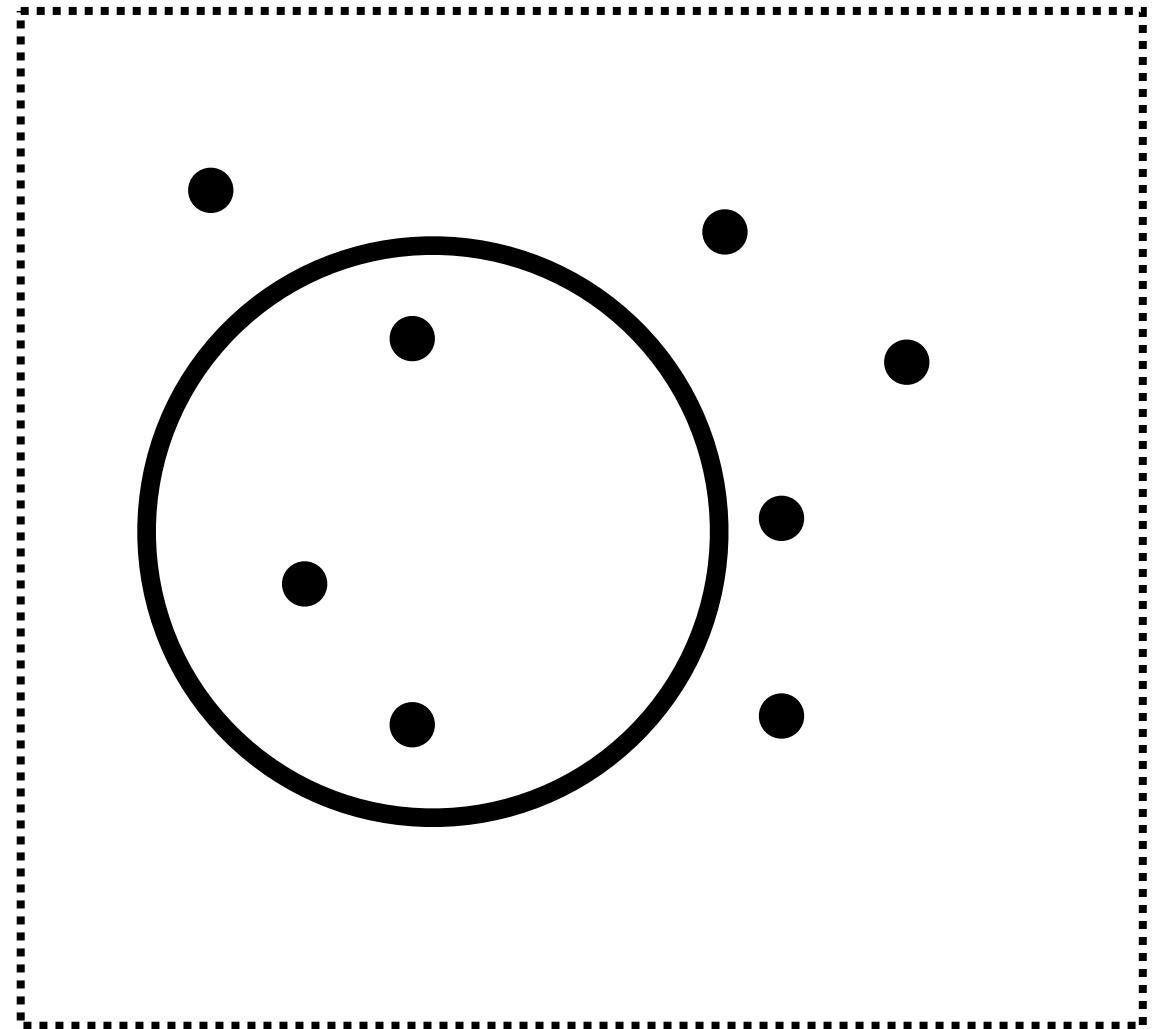
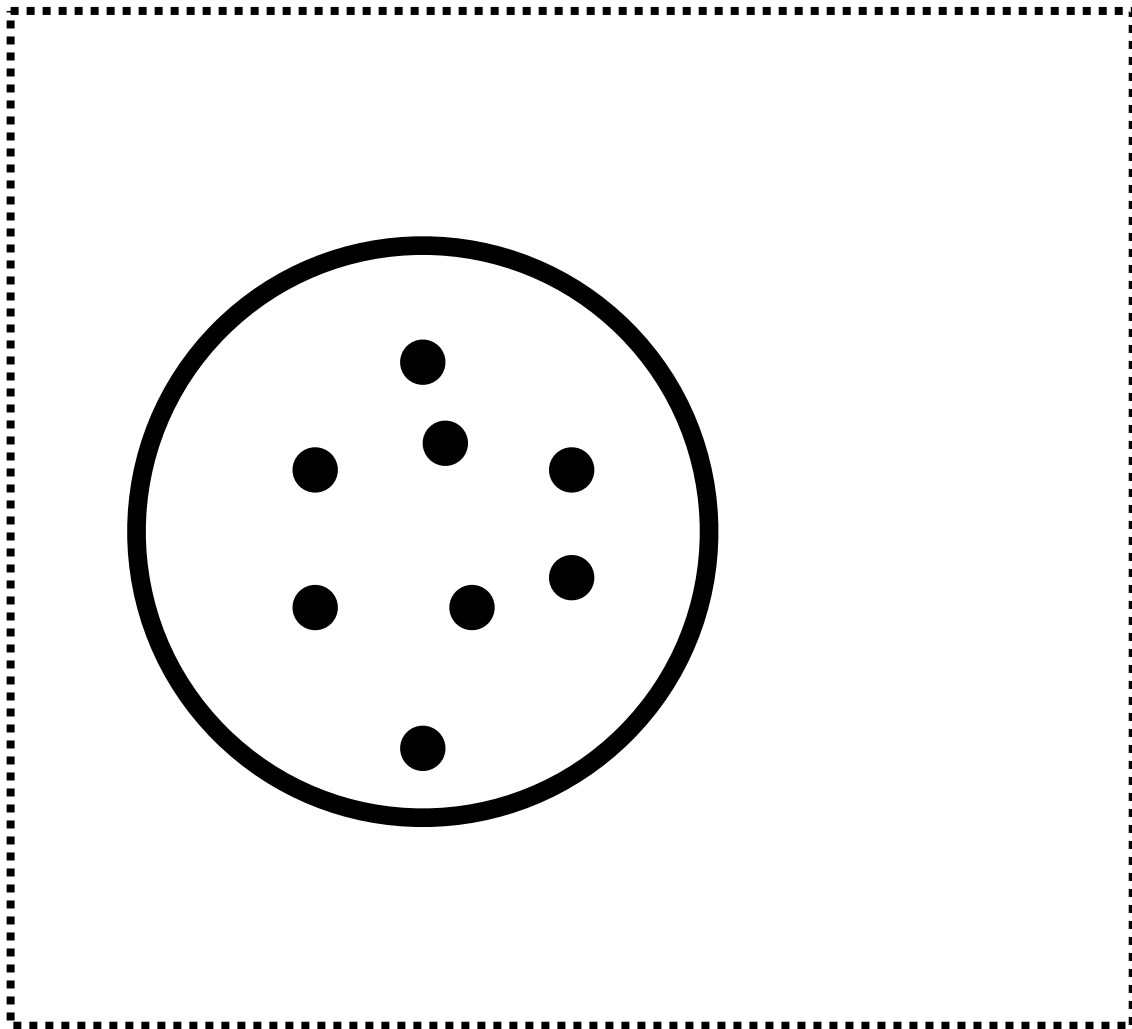


Iterated learning



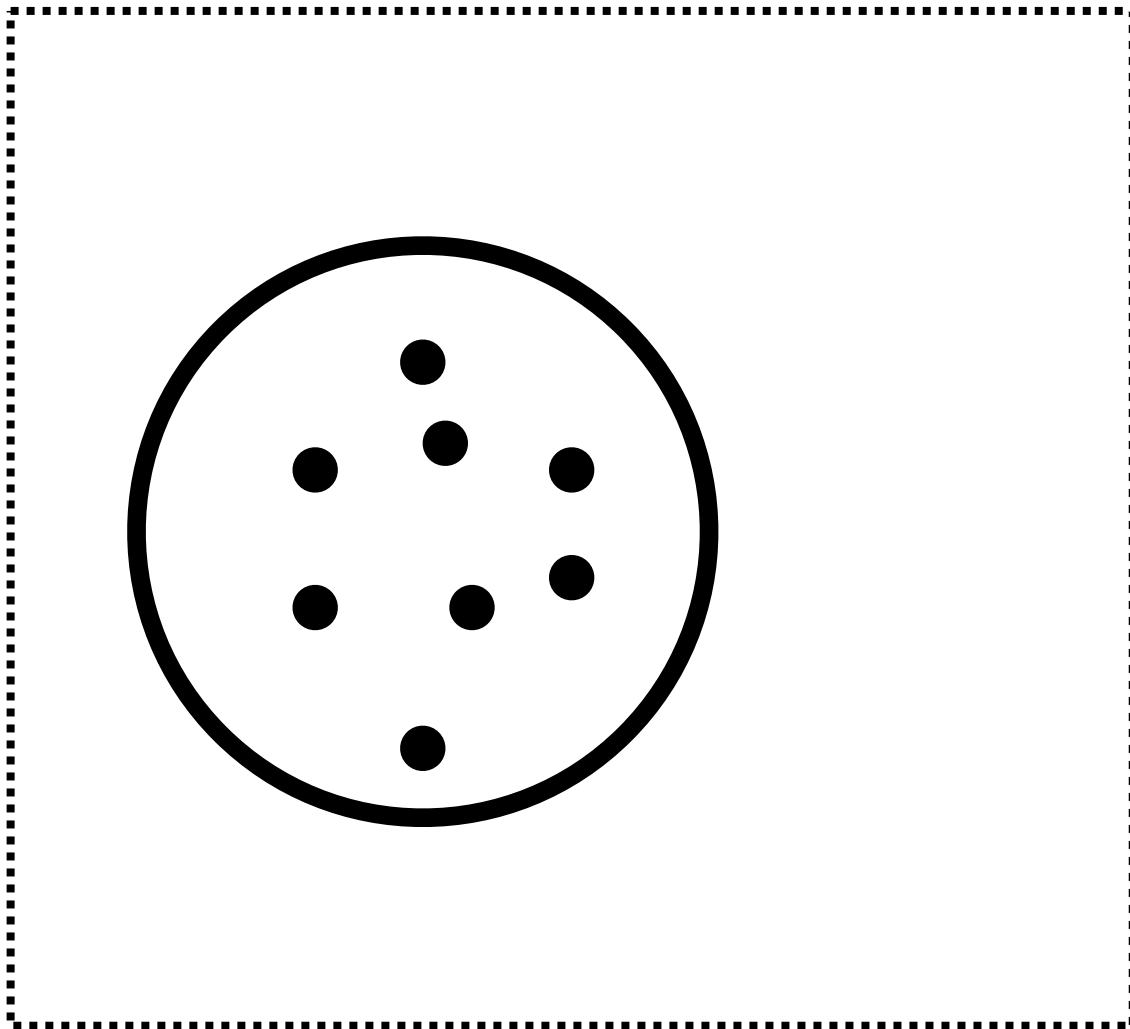


Language is for communication

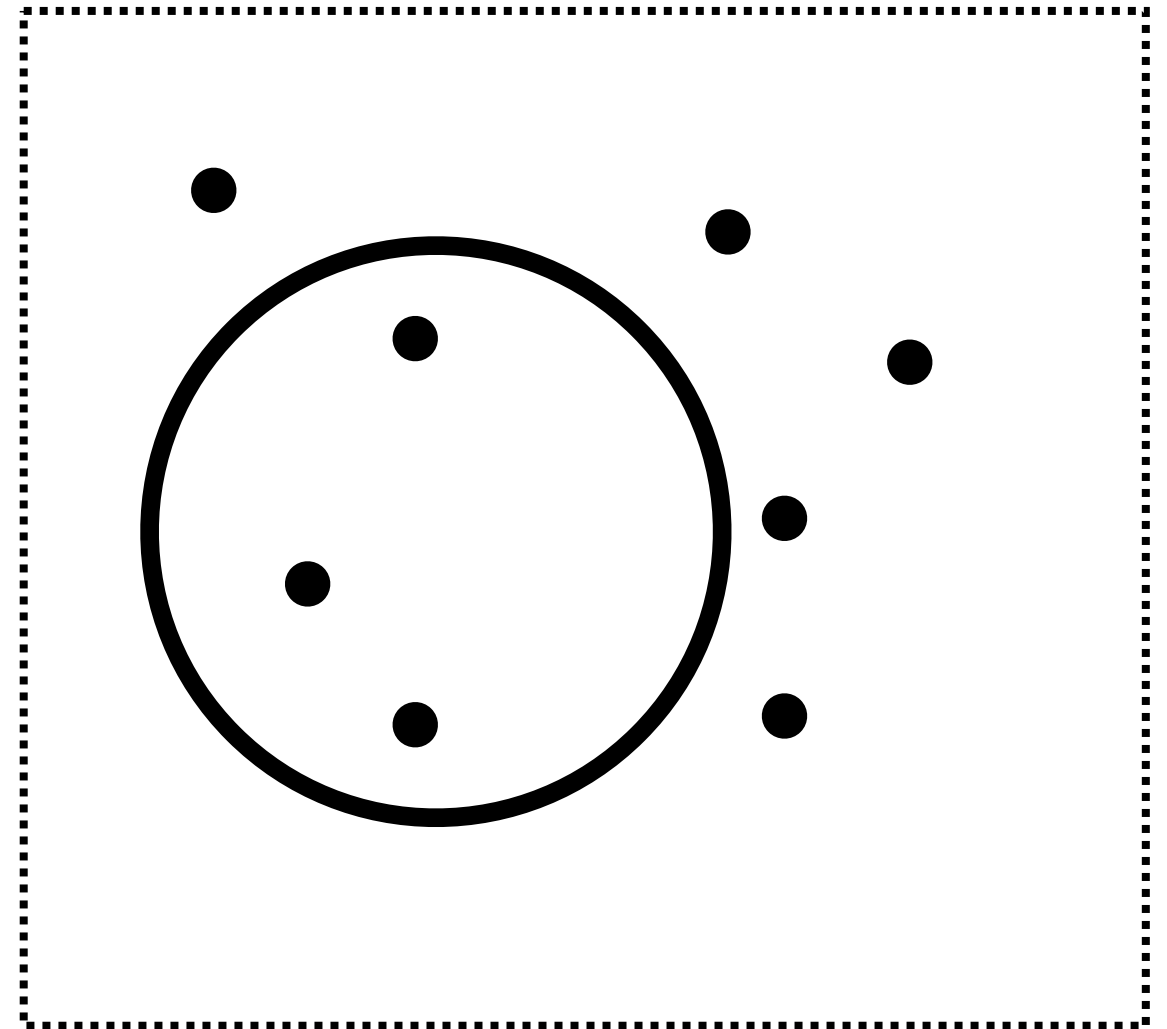


“Some of the dots are in the circle”

Option 1



Option 2



“Some of the dots are in the circle”

Option 1



Option 2

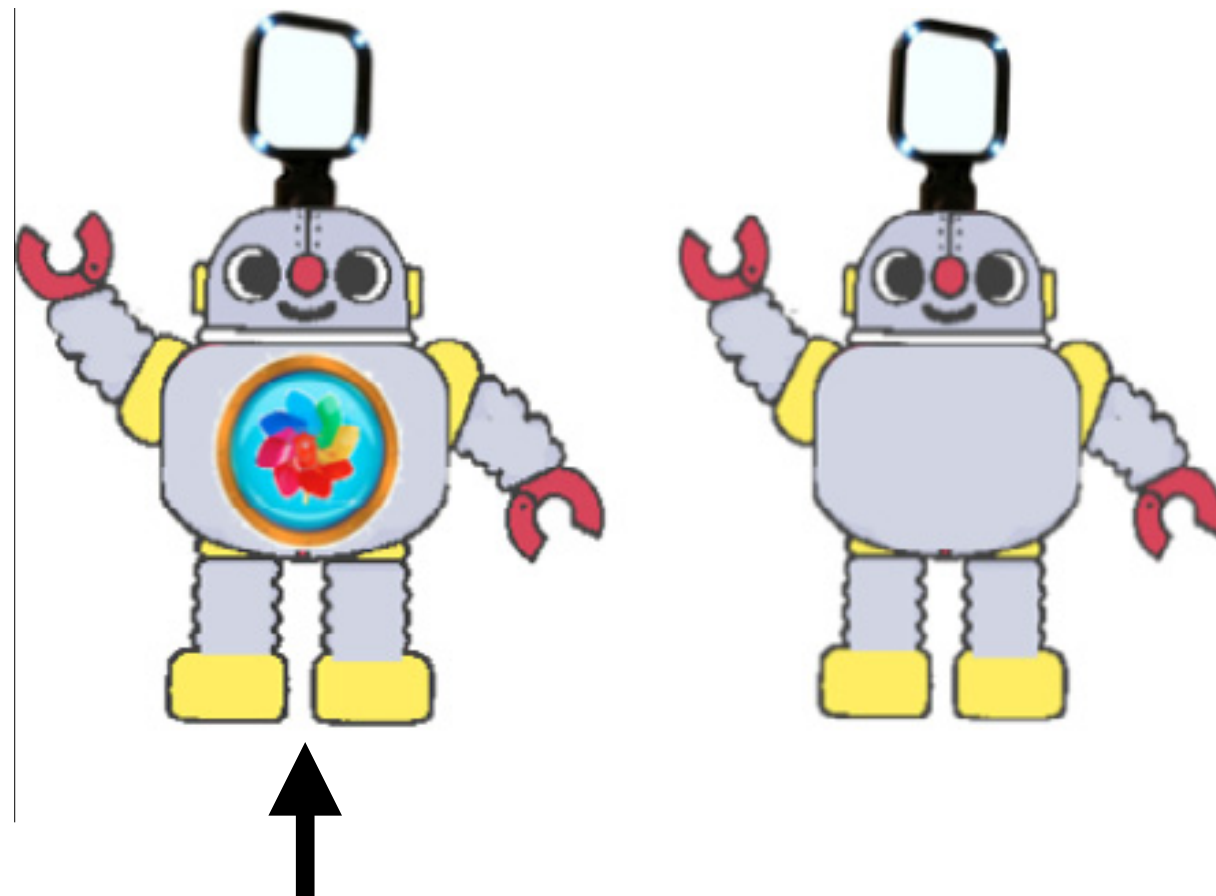
“I like the one with the headband”

Option 1



Option 2

“I like the one with the bandana”



“This is a robot with a **fep**”

Option 1: “fep” means antenna

Option 2: “fep” means swirly chest thing

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

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

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

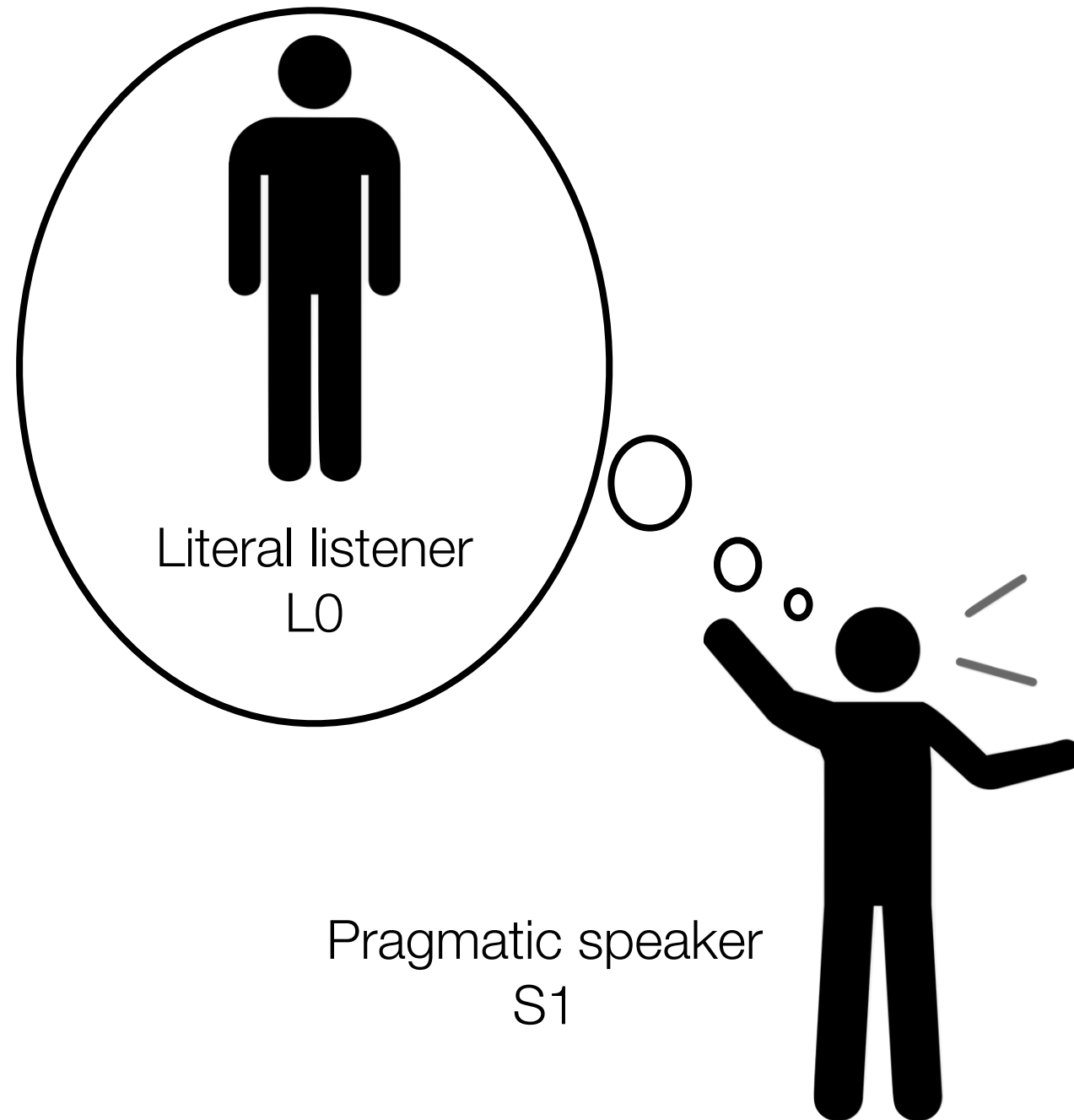
$P_{\text{Speaker}}(\text{utterance} \mid \text{intended meaning})$

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

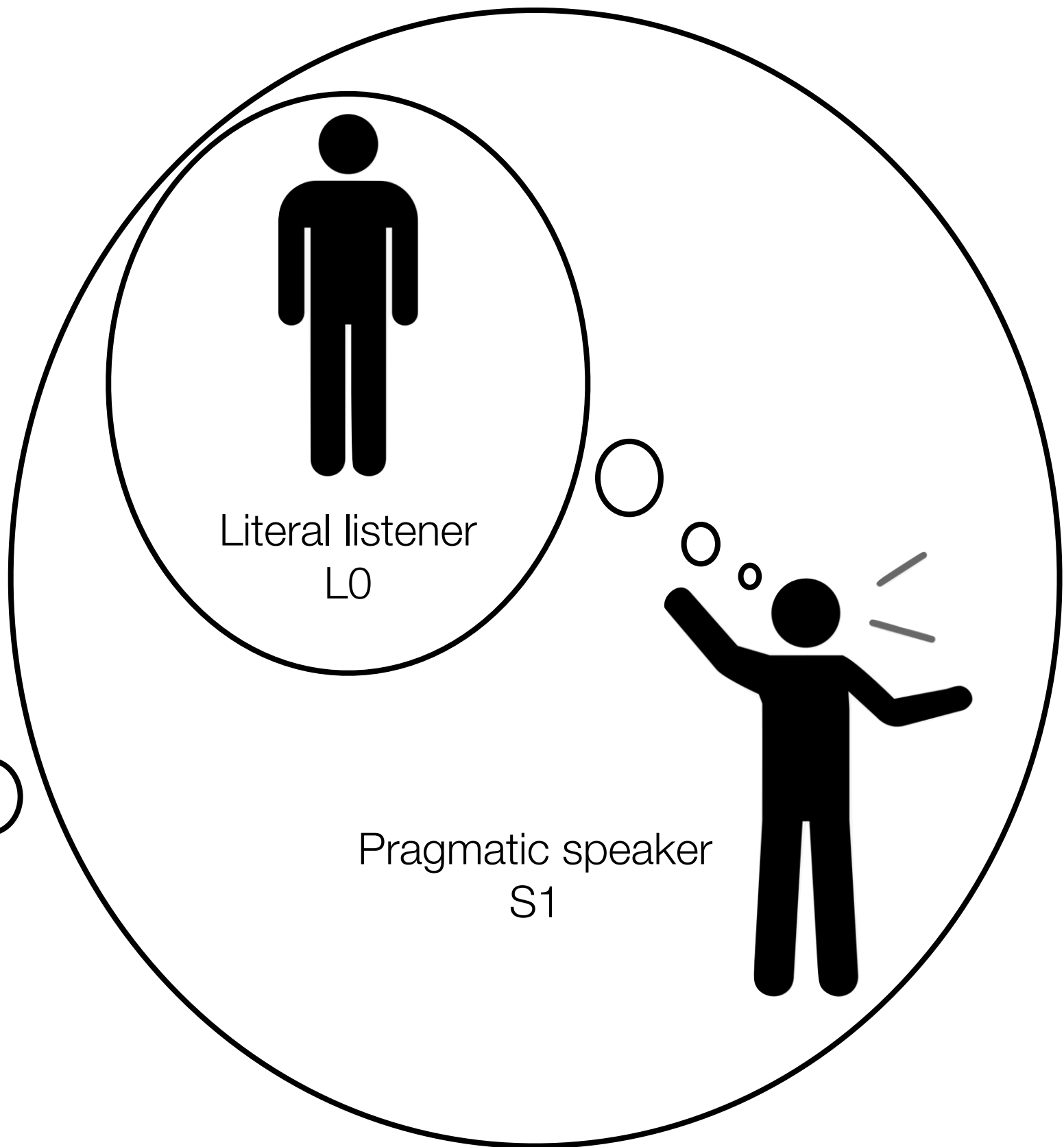
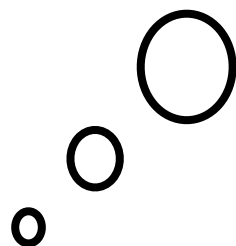
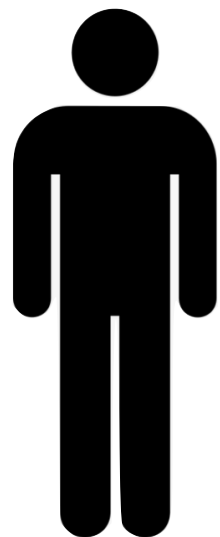
Is there any way out of this loop of listeners and speakers reasoning endlessly about one another reasoning about one another reasoning about one another...?



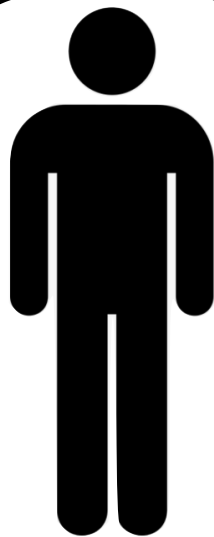
Literal listener
L0



Pragmatic listener
L1



Literal listener
L0



Pragmatic speaker
S1



Core features of the RSA model

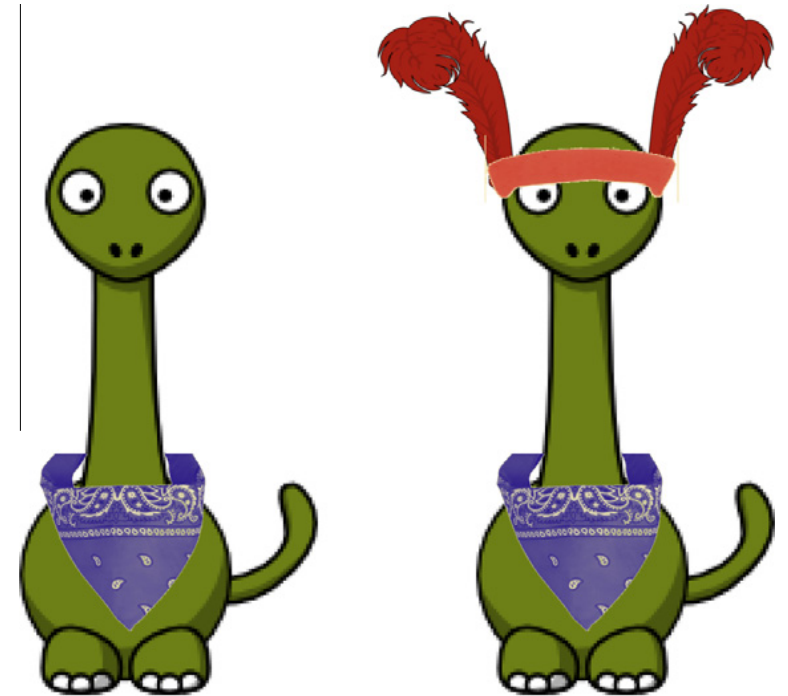
- Communication involves inferring hidden causes of observable behaviours
 - It's an inference problem
- Speakers design utterances for their listeners in order to convey an intended meaning
- Hearers assume that speakers are doing this



Literal listener
L0

Starting with the literal listener, L0

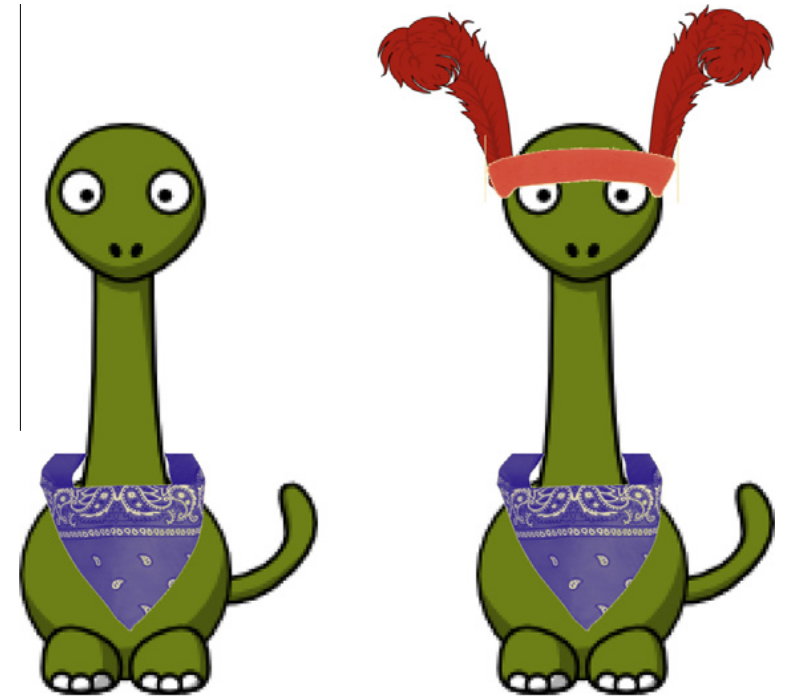
- “I like the dinosaur wearing the **headband**”



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

Starting with the literal listener, L0

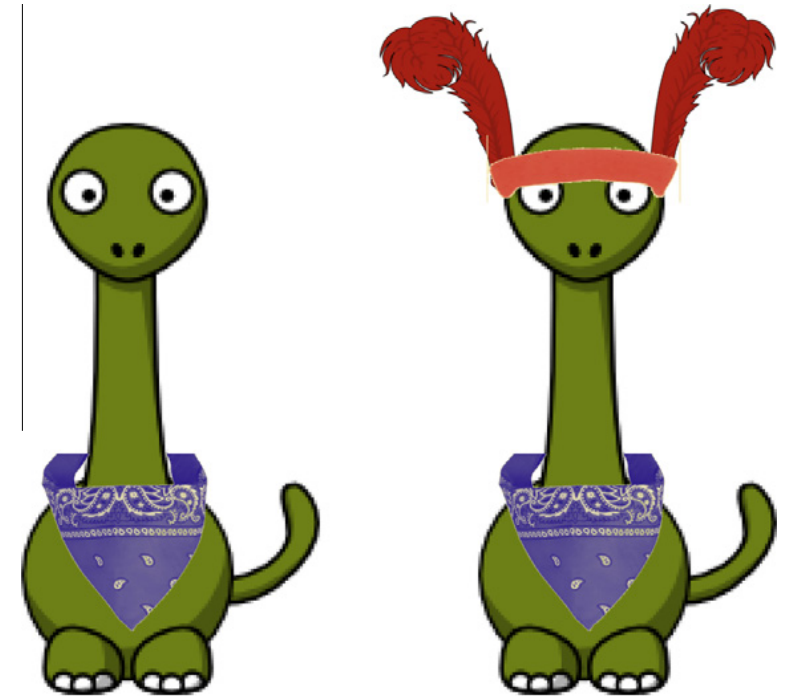
- “I like the dinosaur wearing the **headband**”



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

Starting with the literal listener, L0

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

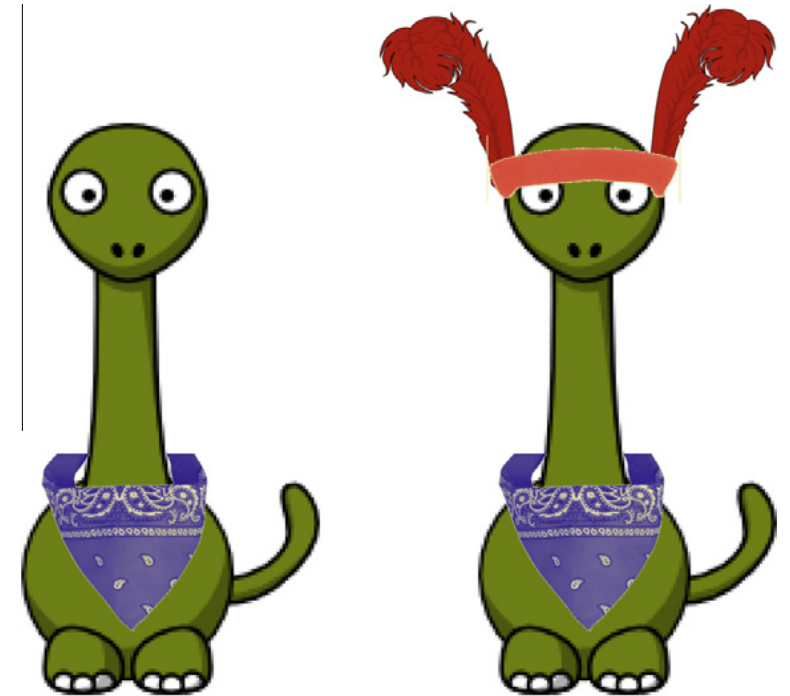


$$P_{L0}(\text{dinosaur without headband} \mid \text{“headband”}) = 0 \quad P_{L0}(\text{dinosaur with headband} \mid \text{“headband”}) = 1$$

$$P_{L0}(\text{dinosaur without headband} \mid \text{“bandana”}) = ? \quad P_{L0}(\text{dinosaur with headband} \mid \text{“bandana”}) = ?$$

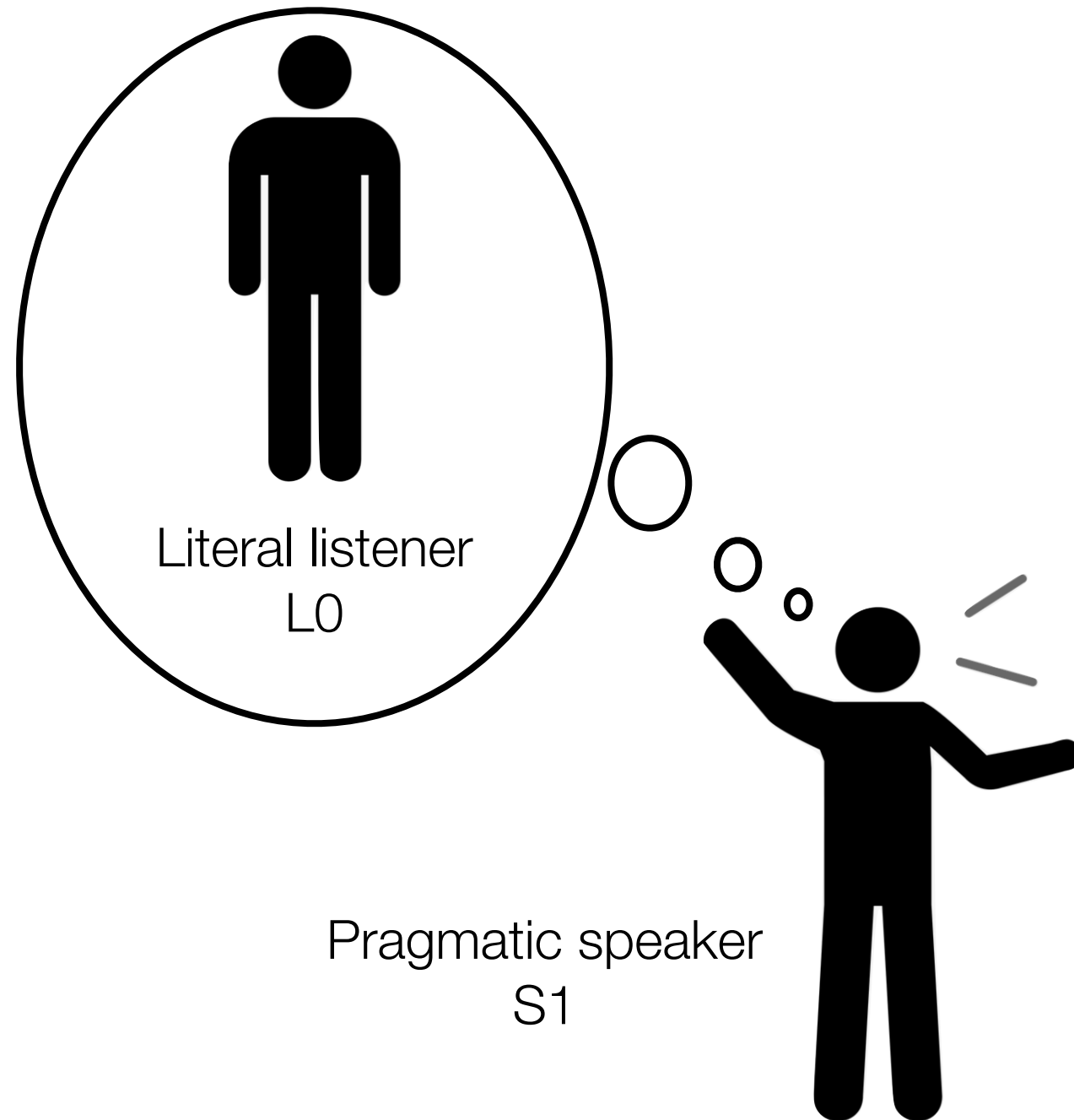
Starting with the literal listener, L0

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

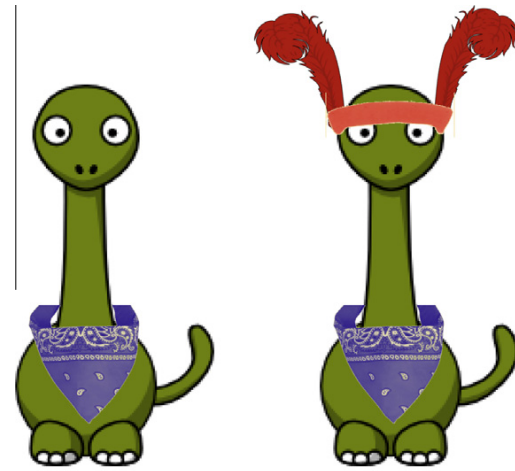


$$P_{L0}(\text{dinosaur without headband} \mid \text{“headband”}) = 0 \quad P_{L0}(\text{dinosaur with headband} \mid \text{“headband”}) = 1$$

$$P_{L0}(\text{dinosaur without headband} \mid \text{“bandana”}) = \frac{1}{2} \quad P_{L0}(\text{dinosaur with headband} \mid \text{“bandana”}) = \frac{1}{2}$$



The pragmatic speaker, S1



$$P_{Lo}(\text{ } | \text{ "headband" }) = 0 \quad P_{Lo}(\text{ } | \text{ "headband" }) = 1$$

$$P_{Lo}(\text{ } | \text{ "bandana" }) = \frac{1}{2} \quad P_{Lo}(\text{ } | \text{ "bandana" }) = \frac{1}{2}$$

$$P_{S1}(\text{ "bandana" } | \text{ }) \propto P_{Lo}(\text{ } | \text{ "bandana" })$$

The pragmatic speaker, S1



$$P_{Lo}(\text{no headband} \mid \text{"headband"}) = 0 \quad P_{Lo}(\text{headband} \mid \text{"headband"}) = 1$$

$$P_{Lo}(\text{no headband} \mid \text{"bandana"}) = \frac{1}{2} \quad P_{Lo}(\text{headband} \mid \text{"bandana"}) = \frac{1}{2}$$

$$P_{S1}(\text{"bandana"} \mid \text{no headband}) = \frac{P_{Lo}(\text{no headband} \mid \text{"bandana"})}{P_{Lo}(\text{no headband} \mid \text{"bandana"}) + P_{Lo}(\text{no headband} \mid \text{"headband"})}$$

The pragmatic speaker, S1

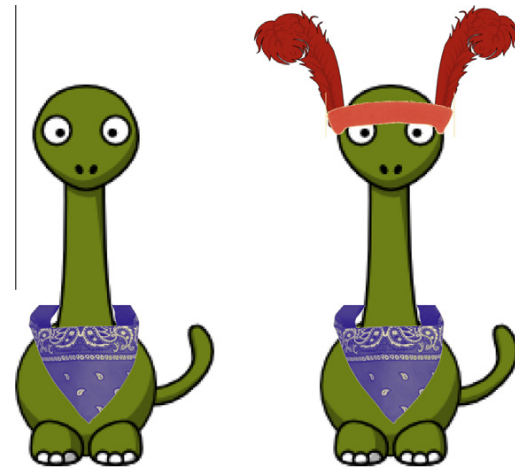


$$P_{Lo}(\text{no headband} \mid \text{"headband"}) = 0 \quad P_{Lo}(\text{headband} \mid \text{"headband"}) = 1$$

$$P_{Lo}(\text{no headband} \mid \text{"bandana"}) = \frac{1}{2} \quad P_{Lo}(\text{headband} \mid \text{"bandana"}) = \frac{1}{2}$$

$$P_{S1}(\text{"bandana"} \mid \text{no headband}) = \frac{\frac{1}{2}}{\frac{1}{2} + 0} = 1$$

The pragmatic speaker, S1



$$P_{Lo}(\text{ dinosaur without headband } | \text{ "headband" }) = 0 \quad P_{Lo}(\text{ dinosaur with headband } | \text{ "headband" }) = 1$$

$$P_{Lo}(\text{ dinosaur without headband } | \text{ "bandana" }) = \frac{1}{2} \quad P_{Lo}(\text{ dinosaur with headband } | \text{ "bandana" }) = \frac{1}{2}$$

$$P_{S1}(\text{ "headband" } | \text{ dinosaur without headband }) \propto P_{Lo}(\text{ dinosaur without headband } | \text{ "headband" })$$

The pragmatic speaker, S1



$$P_{Lo}(\text{no headband} \mid \text{"headband"}) = 0 \quad P_{Lo}(\text{red headband} \mid \text{"headband"}) = 1$$

$$P_{Lo}(\text{no headband} \mid \text{"bandana"}) = \frac{1}{2} \quad P_{Lo}(\text{red headband} \mid \text{"bandana"}) = \frac{1}{2}$$

$$P_{S1}(\text{"headband"} \mid \text{no headband}) = \frac{P_{Lo}(\text{no headband} \mid \text{"headband"})}{P_{Lo}(\text{no headband} \mid \text{"bandana"}) + P_{Lo}(\text{no headband} \mid \text{"headband"})}$$

The pragmatic speaker, S1

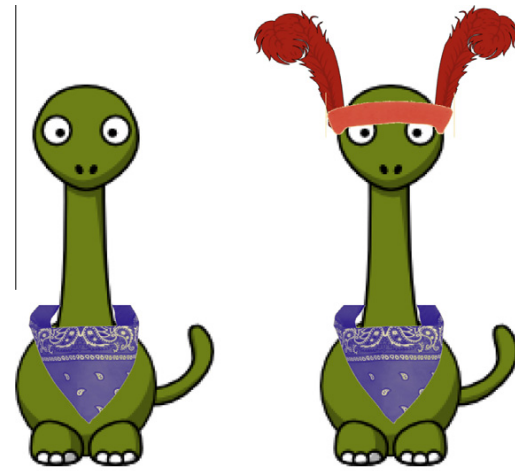


$$P_{Lo}(\text{no headband} \mid \text{"headband"}) = 0 \quad P_{Lo}(\text{headband} \mid \text{"headband"}) = 1$$

$$P_{Lo}(\text{no headband} \mid \text{"bandana"}) = \frac{1}{2} \quad P_{Lo}(\text{headband} \mid \text{"bandana"}) = \frac{1}{2}$$

$$P_{S1}(\text{"bandana"} \mid \text{no headband}) = \frac{0}{\frac{1}{2} + 0} = 0$$

The pragmatic speaker, S1



$$P_{Lo}(\text{no headband} \mid \text{"headband"}) = 0 \quad P_{Lo}(\text{red headband} \mid \text{"headband"}) = 1$$

$$P_{Lo}(\text{no headband} \mid \text{"bandana"}) = \frac{1}{2} \quad P_{Lo}(\text{red headband} \mid \text{"bandana"}) = \frac{1}{2}$$

$$P_{S1}(\text{"bandana"} \mid \text{red headband}) \propto P_{Lo}(\text{red headband} \mid \text{"bandana"})$$

The pragmatic speaker, S1



$$P_{Lo}(\text{no headband} \mid \text{"headband"}) = 0 \quad P_{Lo}(\text{headband} \mid \text{"headband"}) = 1$$

$$P_{Lo}(\text{no headband} \mid \text{"bandana"}) = \frac{1}{2} \quad P_{Lo}(\text{headband} \mid \text{"bandana"}) = \frac{1}{2}$$

$$P_{S1}(\text{"bandana"} \mid \text{headband}) = \frac{P_{Lo}(\text{headband} \mid \text{"bandana"})}{P_{Lo}(\text{headband} \mid \text{"bandana"}) + P_{Lo}(\text{no headband} \mid \text{"bandana"})}$$

The pragmatic speaker, S1



$$P_{Lo}(\text{no headband} \mid \text{"headband"}) = 0 \quad P_{Lo}(\text{red headband} \mid \text{"headband"}) = 1$$

$$P_{Lo}(\text{no headband} \mid \text{"bandana"}) = \frac{1}{2} \quad P_{Lo}(\text{red headband} \mid \text{"bandana"}) = \frac{1}{2}$$

$$P_{S1}(\text{"bandana"} \mid \text{red headband}) = \frac{\frac{1}{2}}{\frac{1}{2} + 1} = \frac{1}{3}$$

The pragmatic speaker, S1

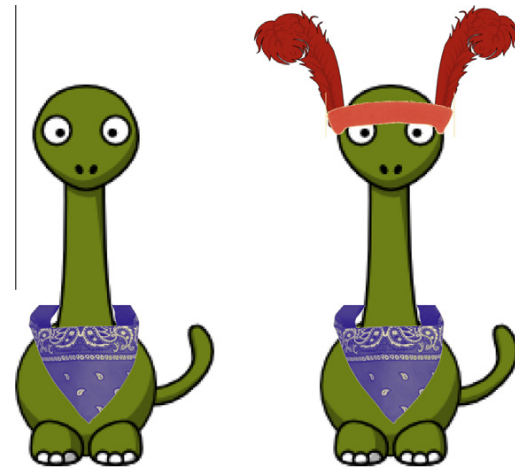


$$P_{Lo}(\text{no headband} \mid \text{"headband"}) = 0 \quad P_{Lo}(\text{headband} \mid \text{"headband"}) = 1$$

$$P_{Lo}(\text{no headband} \mid \text{"bandana"}) = \frac{1}{2} \quad P_{Lo}(\text{headband} \mid \text{"bandana"}) = \frac{1}{2}$$

$$P_{S1}(\text{"headband"} \mid \text{headband}) \propto P_{Lo}(\text{headband} \mid \text{"headband"})$$

The pragmatic speaker, S1



$$P_{Lo}(\text{no headband} \mid \text{"headband"}) = 0 \quad P_{Lo}(\text{red headband} \mid \text{"headband"}) = 1$$

$$P_{Lo}(\text{no headband} \mid \text{"bandana"}) = \frac{1}{2} \quad P_{Lo}(\text{red headband} \mid \text{"bandana"}) = \frac{1}{2}$$

$$P_{S1}(\text{"headband"} \mid \text{red headband}) = \frac{P_{Lo}(\text{red headband} \mid \text{"headband"})}{P_{Lo}(\text{red headband} \mid \text{"bandana"}) + P_{Lo}(\text{red headband} \mid \text{"headband"})}$$

The pragmatic speaker, S1



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

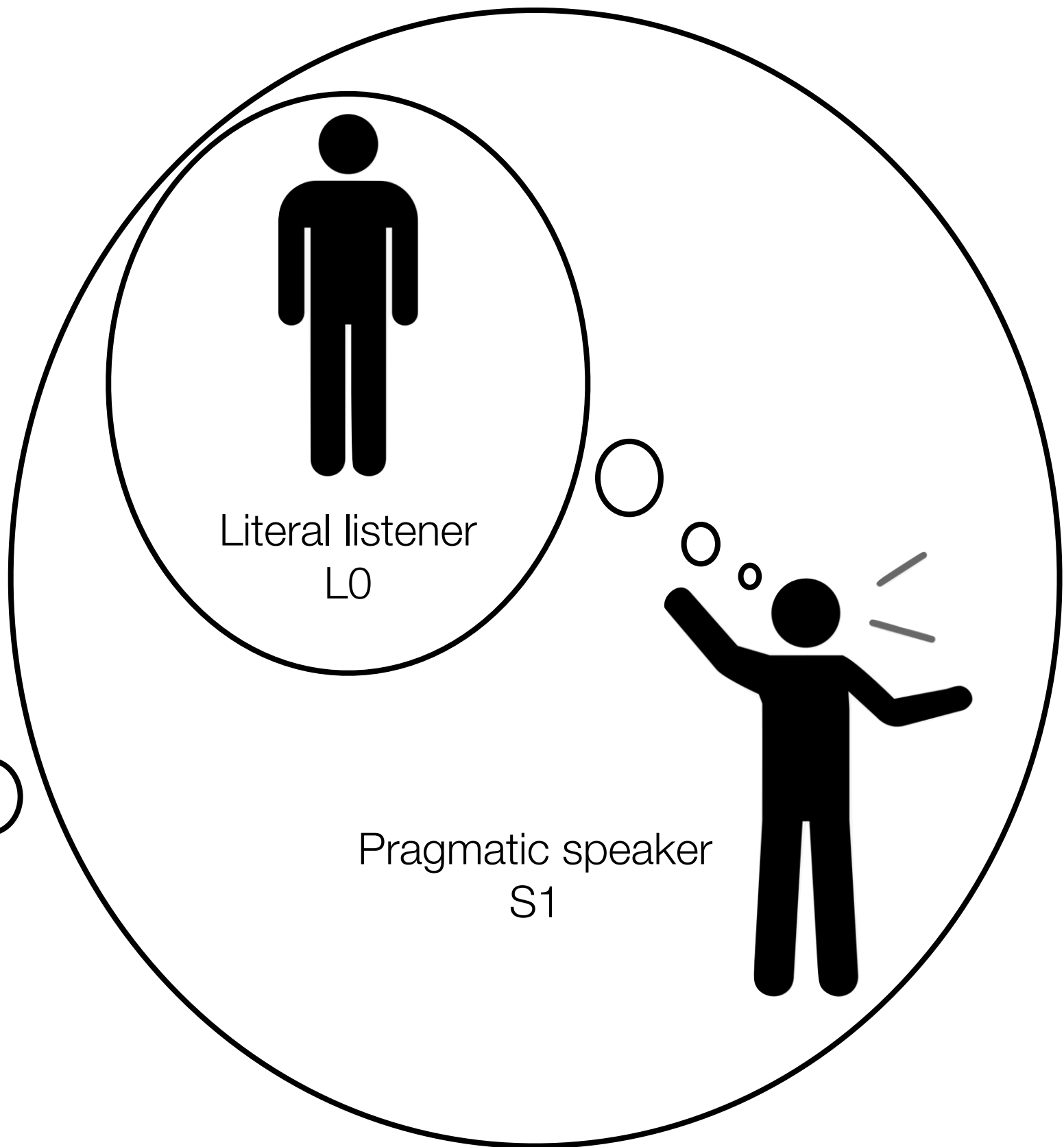
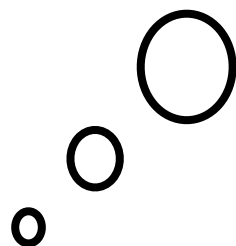
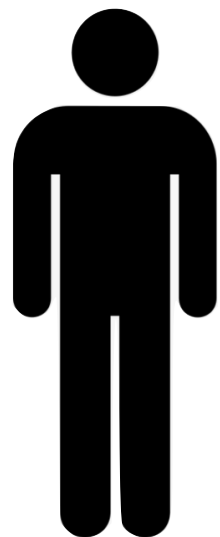
$$P_{Lo}(\text{ } \mid \text{“bandana”}) = \frac{1}{2} \quad P_{Lo}(\text{ } \mid \text{“bandana”}) = \frac{1}{2}$$

$$P_{S1}(\text{“headband”} \mid \text{ }) = \frac{1}{\frac{1}{2} + 1} = \frac{2}{3}$$

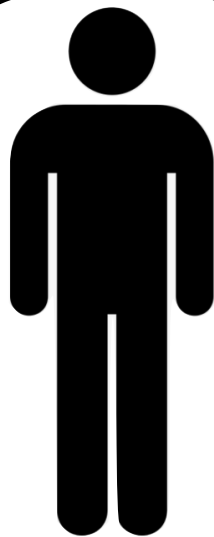
$$P_{S1}(\text{"bandana"} \mid \text{🦎}) = 1 \quad P_{S1}(\text{"headband"} \mid \text{🦎}) = 0$$

$$P_{S1}(\text{"bandana"} \mid \text{🦎👑}) = \frac{1}{3} \quad P_{S1}(\text{"headband"} \mid \text{🦎👑}) = \frac{2}{3}$$

Pragmatic listener
L1



Literal listener
L0



Pragmatic speaker
S1



The pragmatic listener, L1

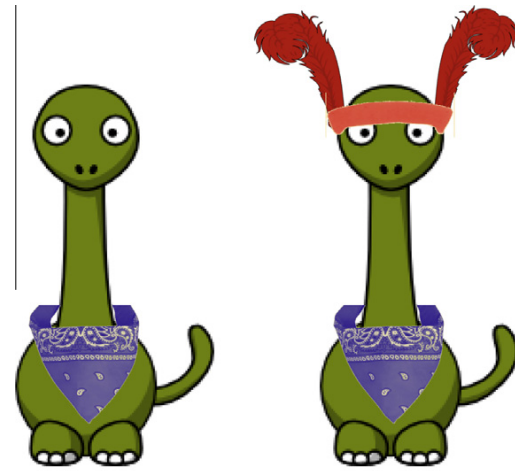


$$P_{S1}(\text{"bandana"} \mid \text{bandana dinosaur}) = 1 \quad P_{S1}(\text{"headband"} \mid \text{bandana dinosaur}) = 0$$

$$P_{S1}(\text{"bandana"} \mid \text{headband dinosaur}) = \frac{1}{3} \quad P_{S1}(\text{"headband"} \mid \text{headband dinosaur}) = \frac{2}{3}$$

$$P_{L1}(\text{bandana dinosaur} \mid \text{"bandana"}) \propto P_{S1}(\text{"bandana"} \mid \text{bandana dinosaur}) P(\text{bandana dinosaur})$$

The pragmatic listener, L1

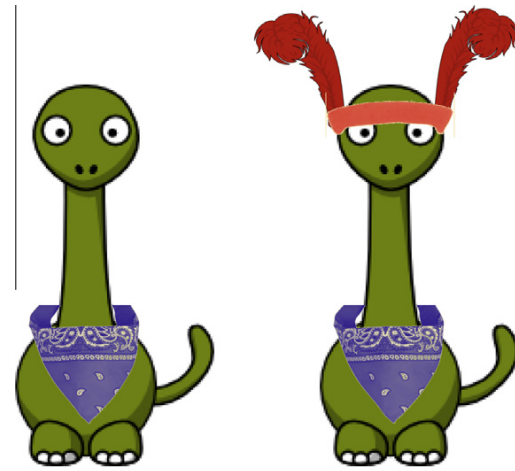


$$P_{S1}(\text{"bandana"} \mid \text{img1}) = 1 \quad P_{S1}(\text{"headband"} \mid \text{img1}) = 0$$

$$P_{S1}(\text{"bandana"} \mid \text{img2}) = \frac{1}{3} \quad P_{S1}(\text{"headband"} \mid \text{img2}) = \frac{2}{3}$$

$$P_{L1}(\text{img1} \mid \text{"bandana"}) \propto P_{S1}(\text{"bandana"} \mid \text{img1})$$

The pragmatic listener, L1

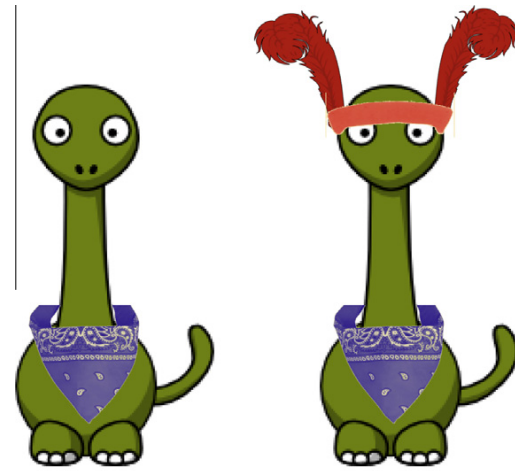


$$P_{S1}(\text{"bandana"} \mid \text{bandana dinosaur}) = 1 \quad P_{S1}(\text{"headband"} \mid \text{bandana dinosaur}) = 0$$

$$P_{S1}(\text{"bandana"} \mid \text{headband dinosaur}) = \frac{1}{3} \quad P_{S1}(\text{"headband"} \mid \text{headband dinosaur}) = \frac{2}{3}$$

$$P_{L1}(\text{bandana dinosaur} \mid \text{"bandana"}) = \frac{P_{S1}(\text{"bandana"} \mid \text{bandana dinosaur})}{P_{S1}(\text{"bandana"} \mid \text{bandana dinosaur}) + P_{S1}(\text{"bandana"} \mid \text{headband dinosaur})}$$

The pragmatic listener, L1

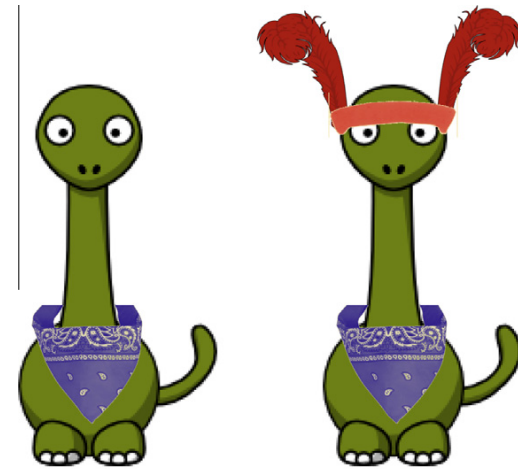


$$P_{S1}(\text{"bandana"} \mid \text{bandana dinosaur}) = 1 \quad P_{S1}(\text{"headband"} \mid \text{bandana dinosaur}) = 0$$

$$P_{S1}(\text{"bandana"} \mid \text{headband dinosaur}) = \frac{1}{3} \quad P_{S1}(\text{"headband"} \mid \text{headband dinosaur}) = \frac{2}{3}$$

$$P_{L1}(\text{bandana dinosaur} \mid \text{"bandana"}) = \frac{1}{1 + \frac{1}{3}} = \frac{3}{4}$$

The pragmatic listener, L1

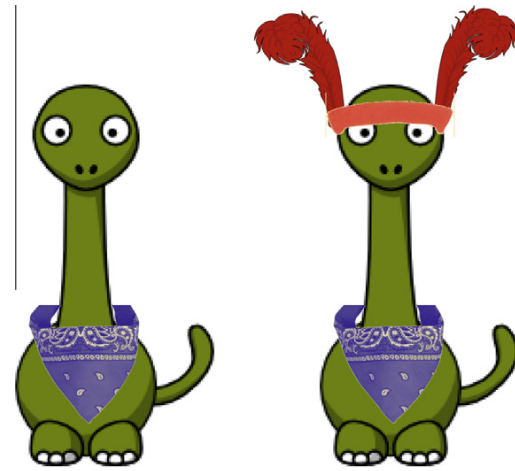


$$P_{S1}(\text{"bandana"} \mid \text{bandana dinosaur}) = 1 \quad P_{S1}(\text{"headband"} \mid \text{bandana dinosaur}) = 0$$

$$P_{S1}(\text{"bandana"} \mid \text{headband dinosaur}) = \frac{1}{3} \quad P_{S1}(\text{"headband"} \mid \text{headband dinosaur}) = \frac{2}{3}$$

$$P_{L1}(\text{headband dinosaur} \mid \text{"bandana"}) = \frac{P_{S1}(\text{"bandana"} \mid \text{headband dinosaur})}{P_{S1}(\text{"bandana"} \mid \text{bandana dinosaur}) + P_{S1}(\text{"bandana"} \mid \text{headband dinosaur})}$$

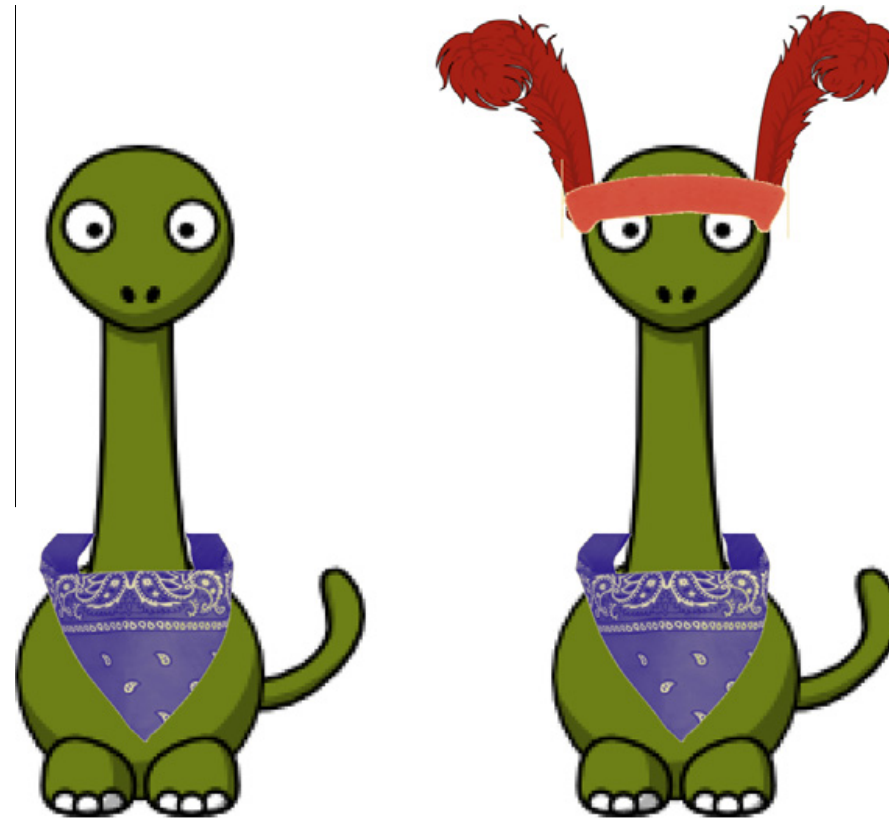
The pragmatic listener, L1



$$P_{S1}(\text{"bandana"} \mid \text{bandana dinosaur}) = 1 \quad P_{S1}(\text{"headband"} \mid \text{bandana dinosaur}) = 0$$

$$P_{S1}(\text{"bandana"} \mid \text{headband dinosaur}) = \frac{1}{3} \quad P_{S1}(\text{"headband"} \mid \text{headband dinosaur}) = \frac{2}{3}$$

$$P_{L1}(\text{headband dinosaur} \mid \text{"bandana"}) = \frac{\frac{1}{3}}{1 + \frac{1}{3}} = \frac{1}{4}$$



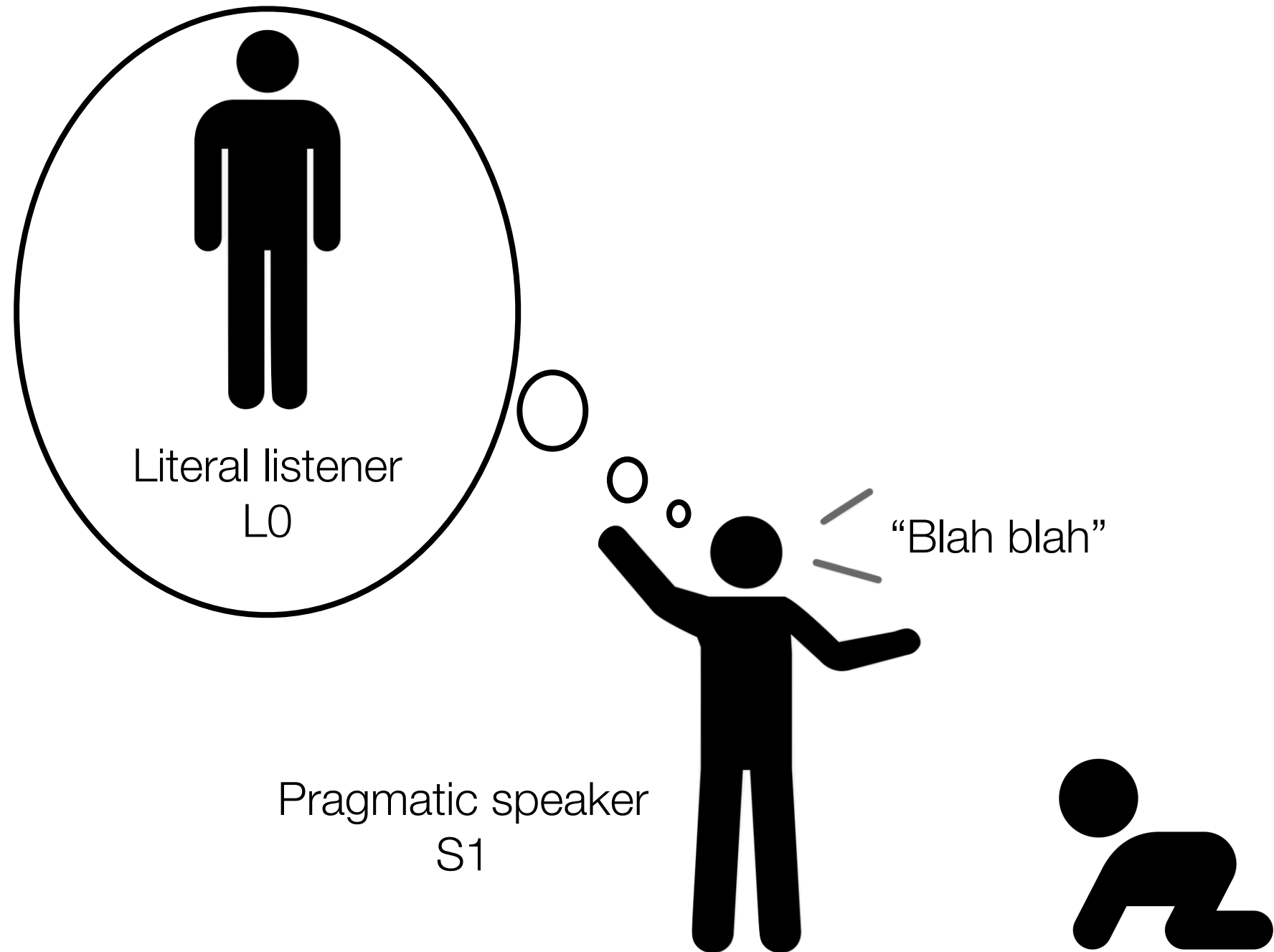
“I like the one with the bandana”

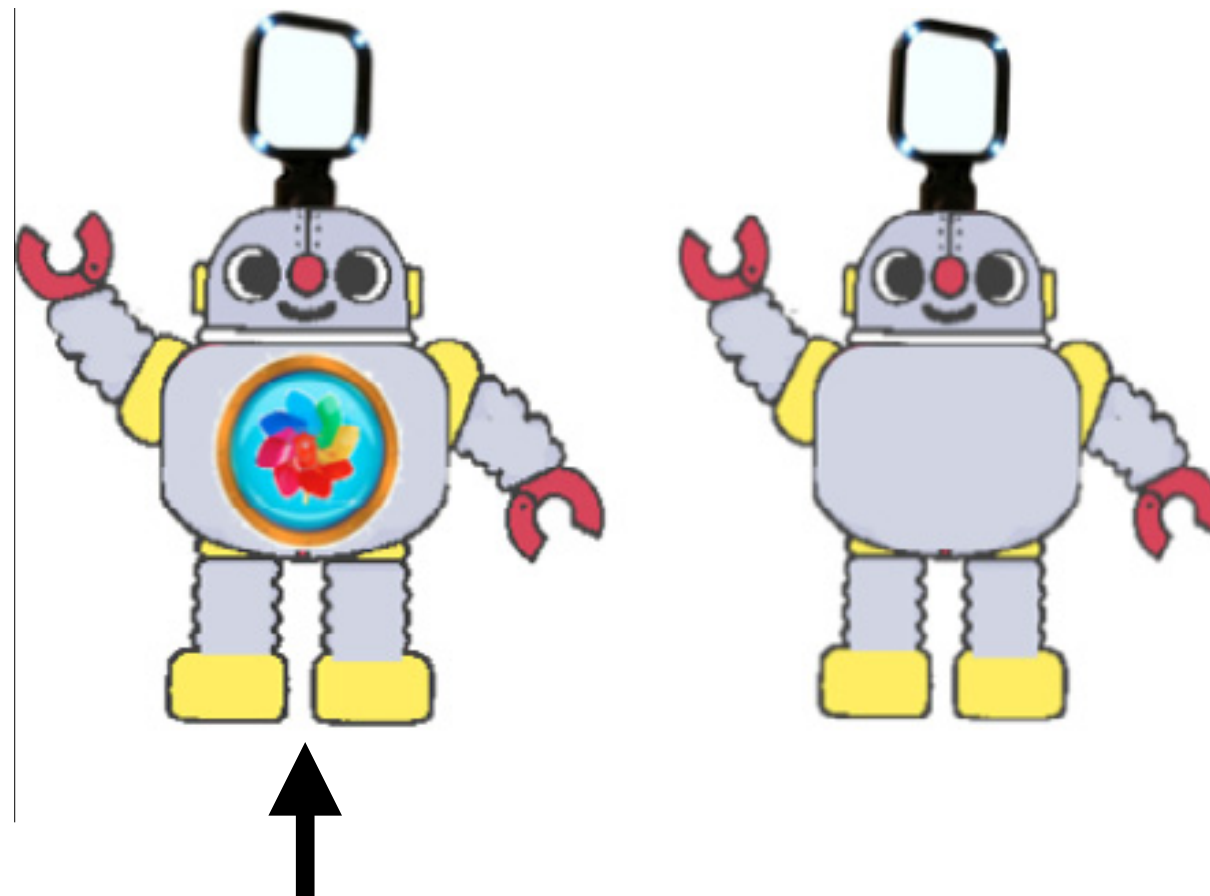
$$P_{L1}(\text{🦖} \mid \text{“bandana”}) = \frac{3}{4}$$

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

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





“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

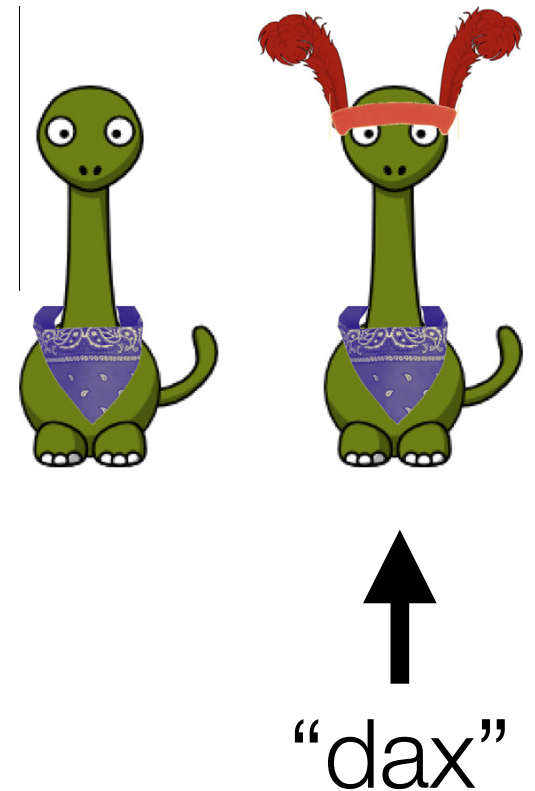
- $P_{S1}(\text{utterance}|\text{meaning})$
- $P_{S1}(\text{utterance}|\text{meaning}, \textbf{lexicon})$



“This is a dinosaur with a dax”

Learning from a rational speaker

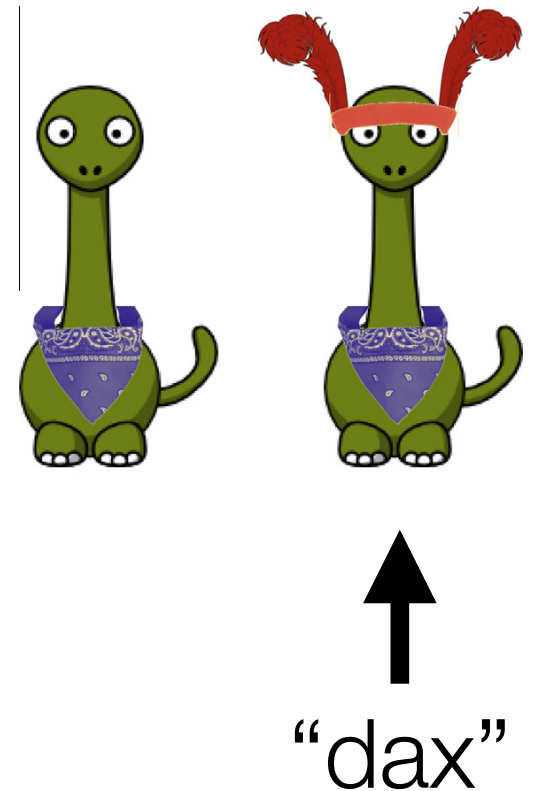
- Candidate Lexicon 1: dax = “headband”
- Candidate Lexicon 2: dax = “bandana”



$$P(\text{lexicon} \mid \text{dinosaur}, \text{"dax"}) \propto P_{S1}(\text{"dax"} \mid \text{dinosaur}, \text{lexicon}) P(\text{lexicon})$$

Learning from a rational speaker

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

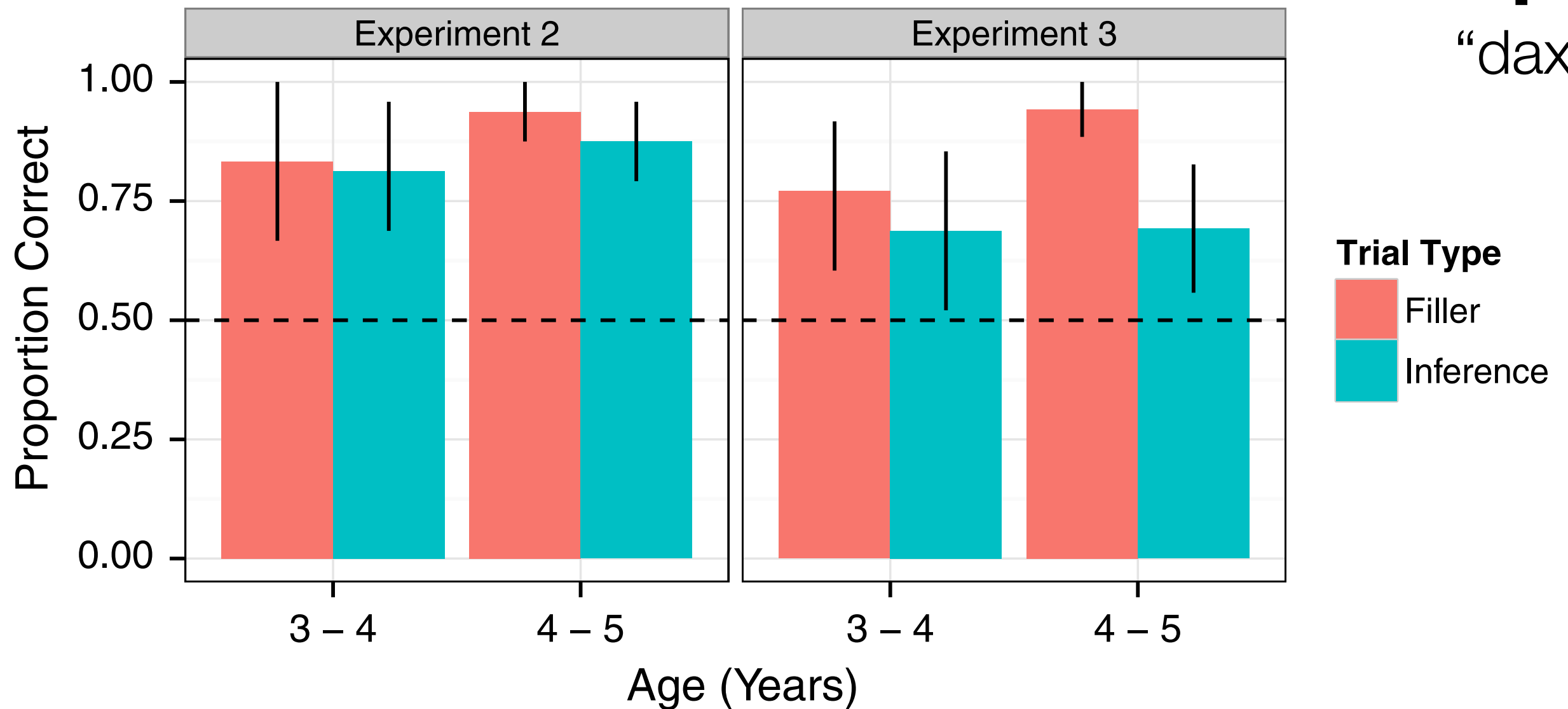
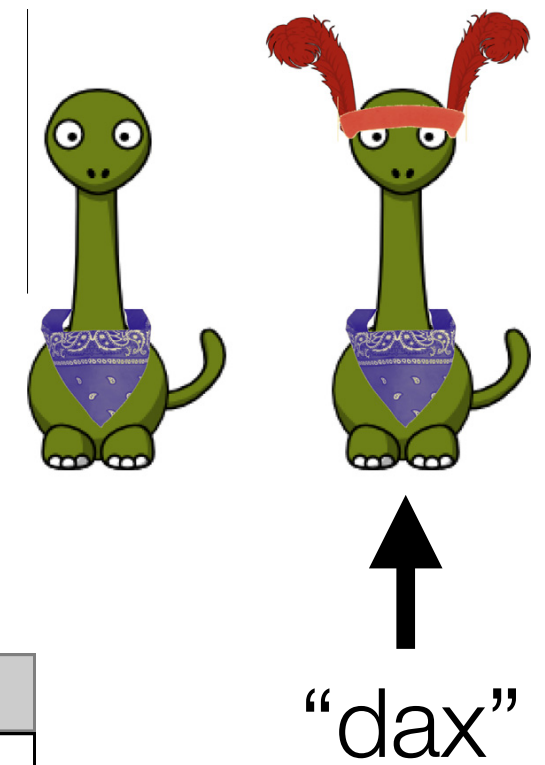


$$P(\text{lexicon} \mid \text{dinosaur}, \text{"dax"}) \propto P_{S1}(\text{"dax"} \mid \text{dinosaur}, \text{lexicon}) P(\text{lexicon})$$

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

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

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.