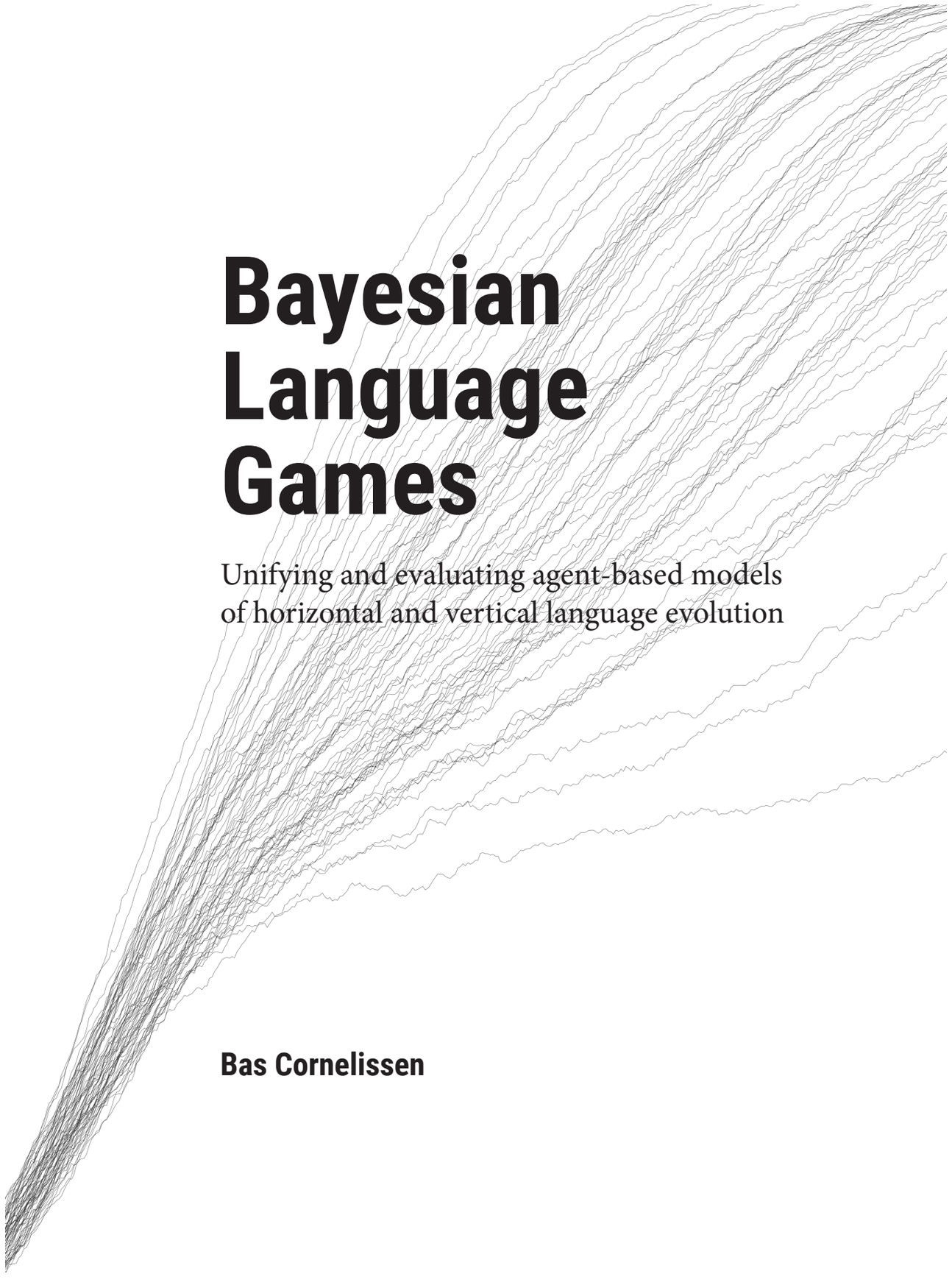
Bayesian Language Games

Unifying and evaluating agent-based models
of horizontal and vertical language evolution

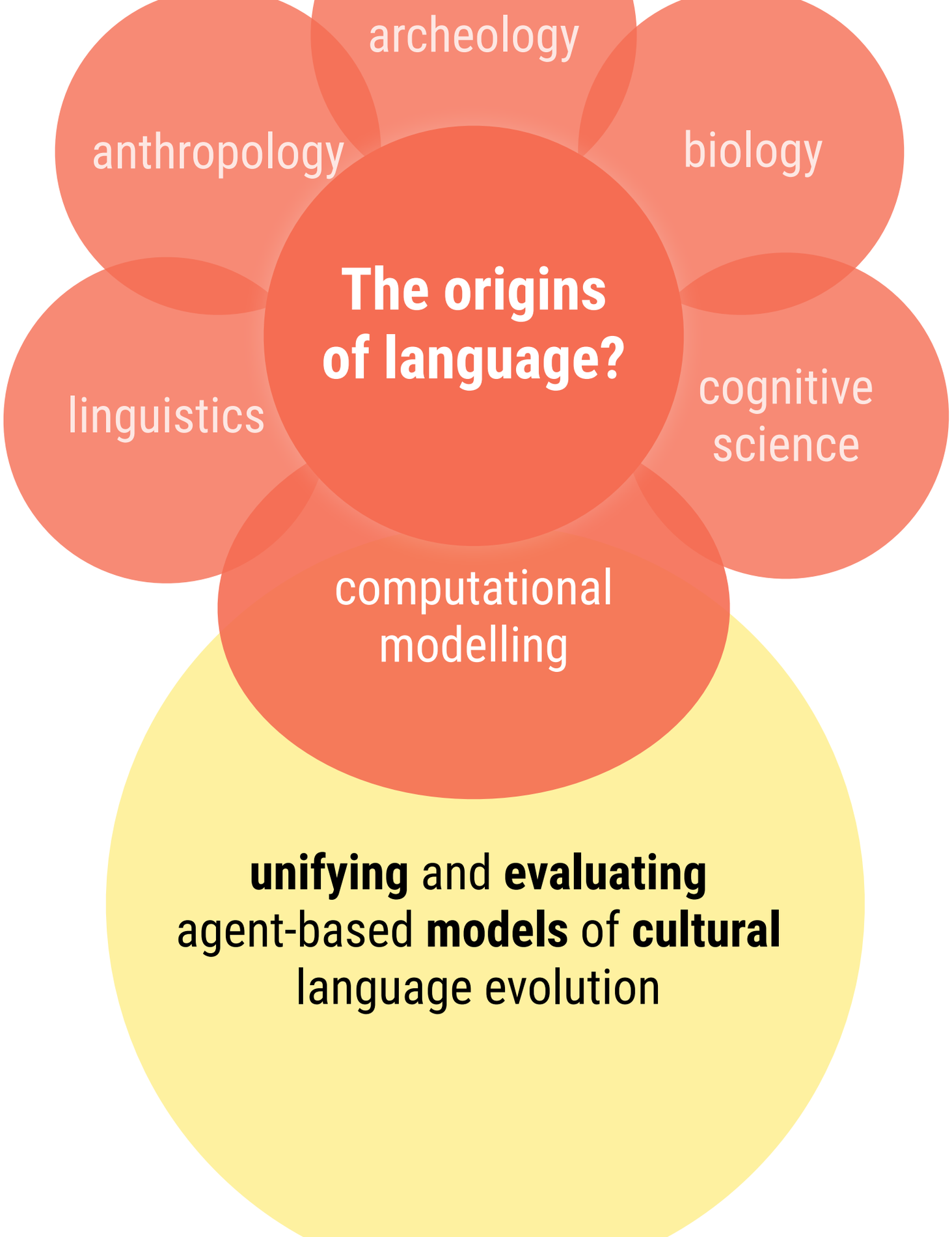


Bas Cornelissen

The (Little) Tower of Babel by **Pieter Bruegel the Elder** (c. 1563) oil on panel; 60 cm × 74.5 cm; Museum Boijmans Van Beuningen, Rotterdam

THE CENTRAL PROBLEM

Sound does not fossilise.


archeology
anthropology
biology
The origins of language?
linguistics
cognitive science
computational modelling
unifying and evaluating agent-based models of cultural language evolution

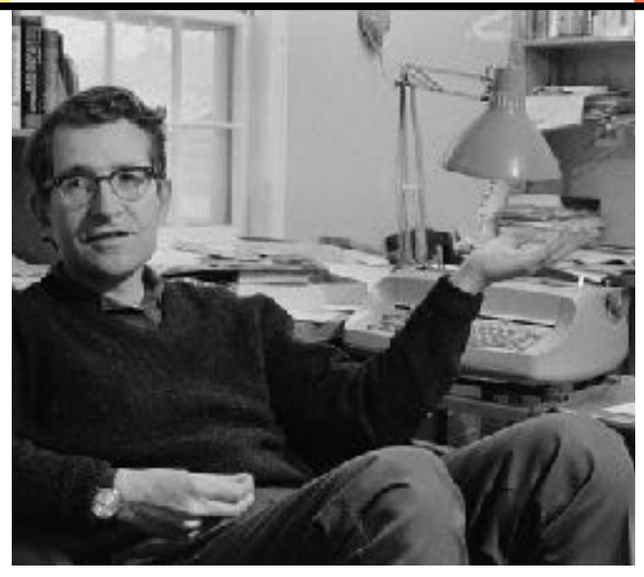
NO LANGUAGE

LANGUAGE

cultural evolution

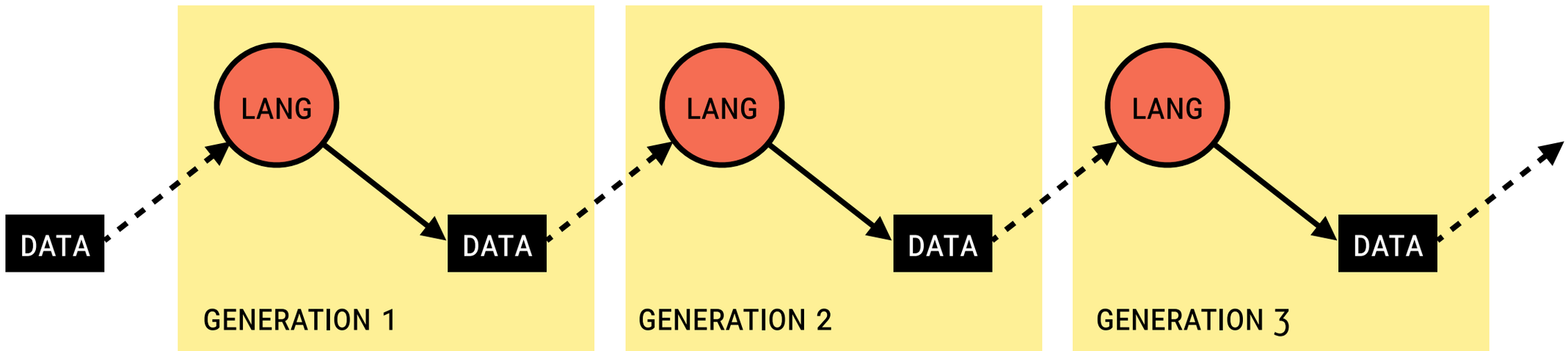
cultural evolution

biological evolution



time

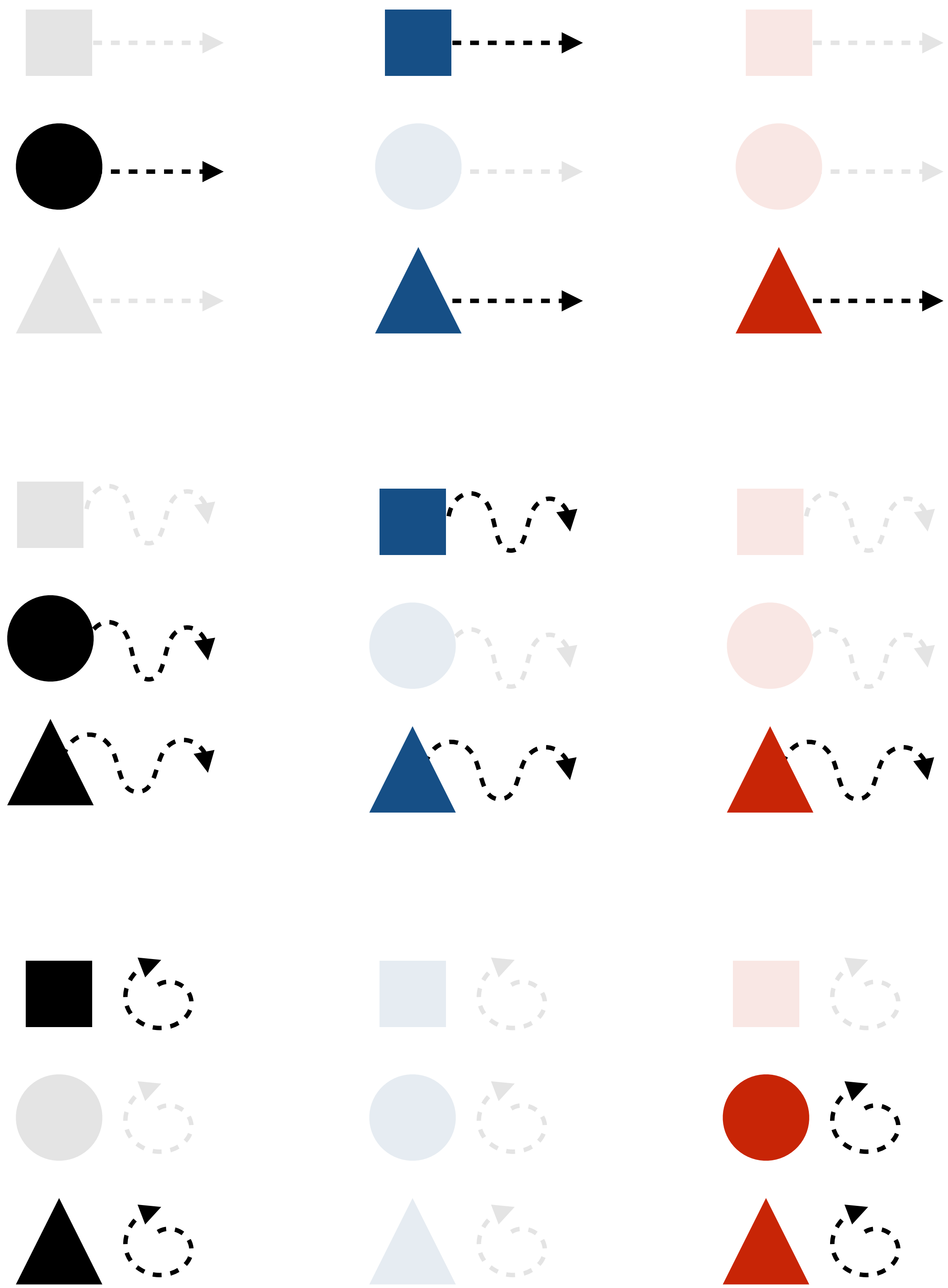
adapted from Tamariz & Kirby (2016)
DOI 10.1016/j.copsyc.2015.09.003



Iterated learning

Every generation learns the language spoken by the previous generation.

Vertical transmission across generations

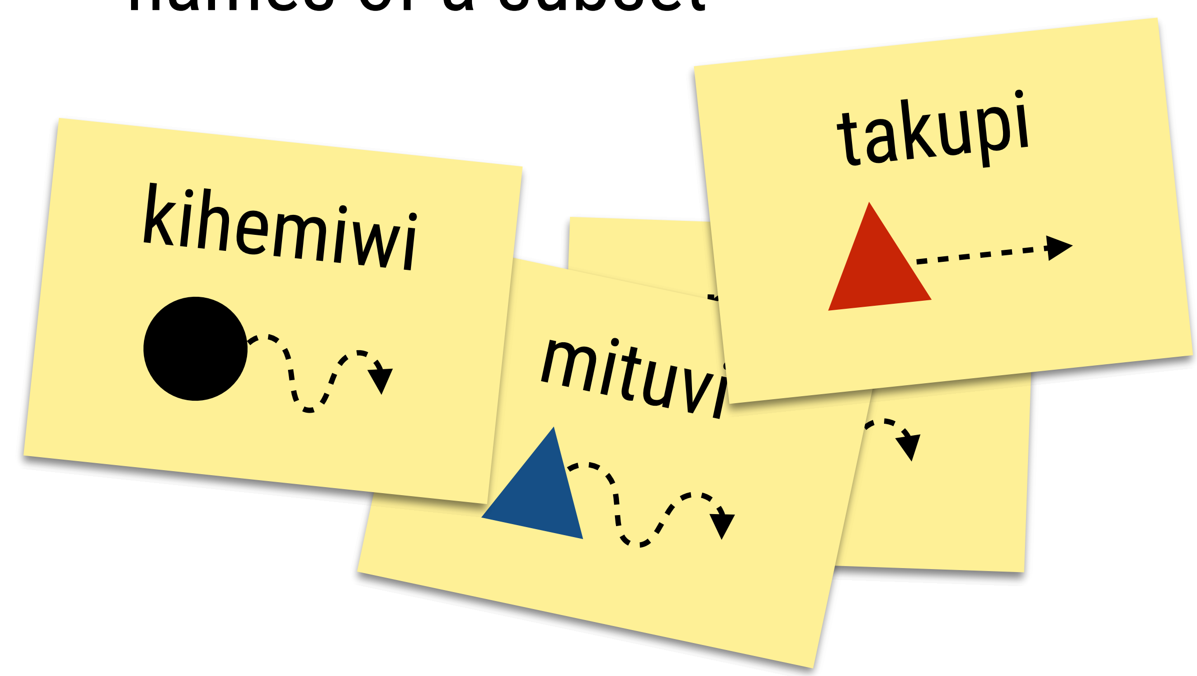


Emerging compositionality

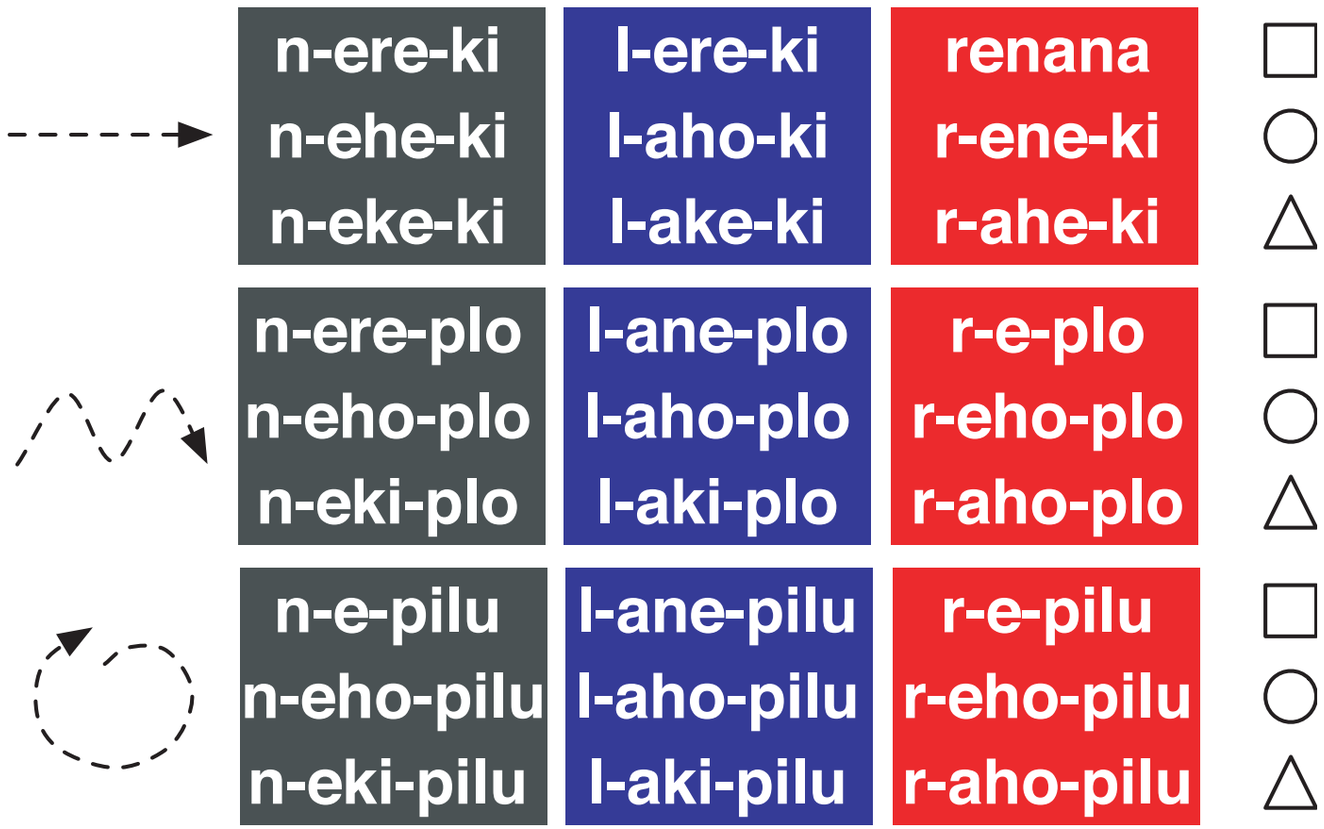
27 objects, different colour, shape and movement, with random names

Use the output, **including errors**, to train the next subject.

1. Train subject to learn the names of a subset



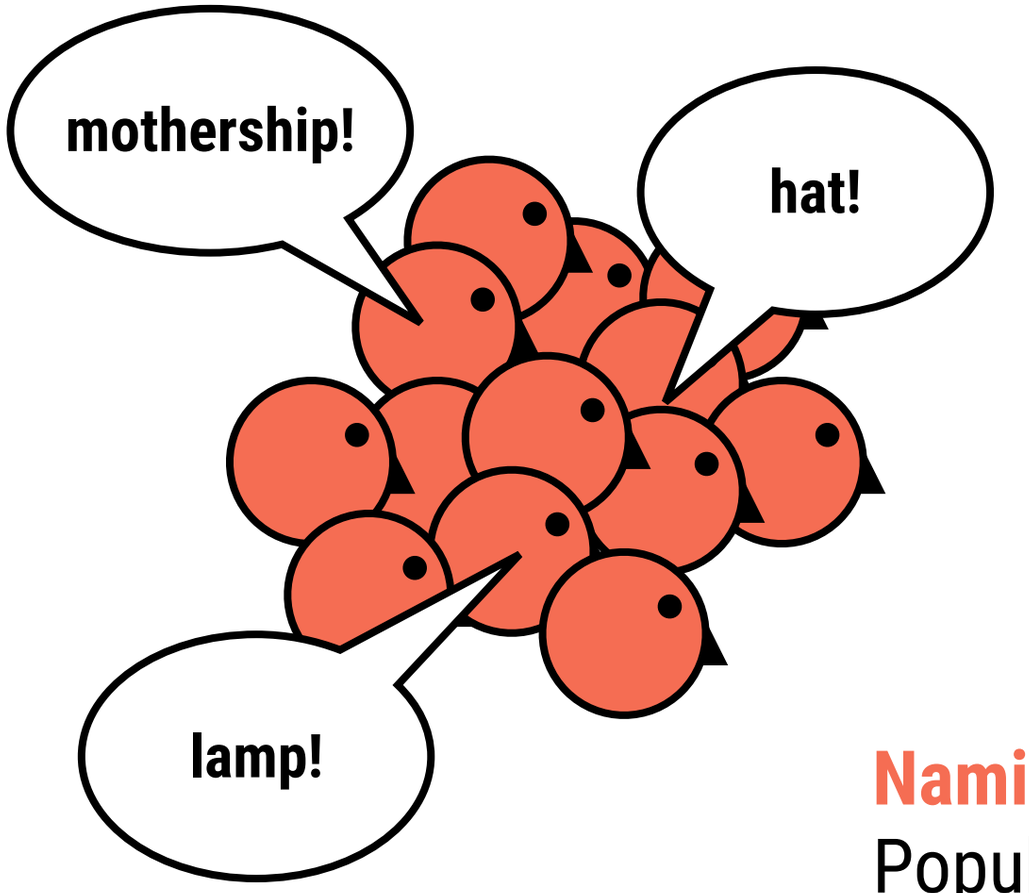
2. Test the subject on the full set of of objects

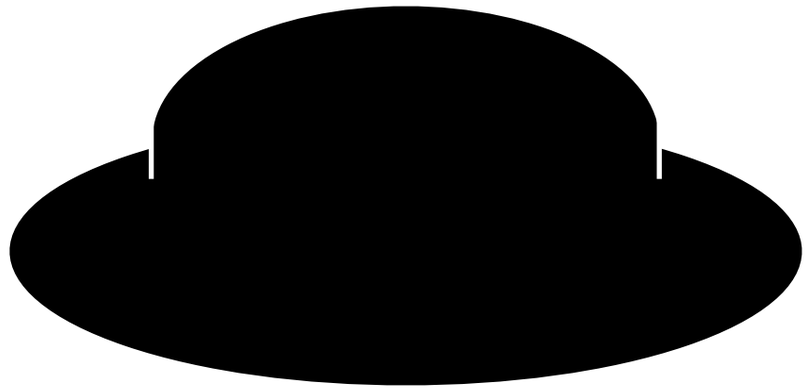


Compositional language

Meaning of a signal determined by meaning of parts

Cultural processes (transmission & communication) pressure for compositional languages

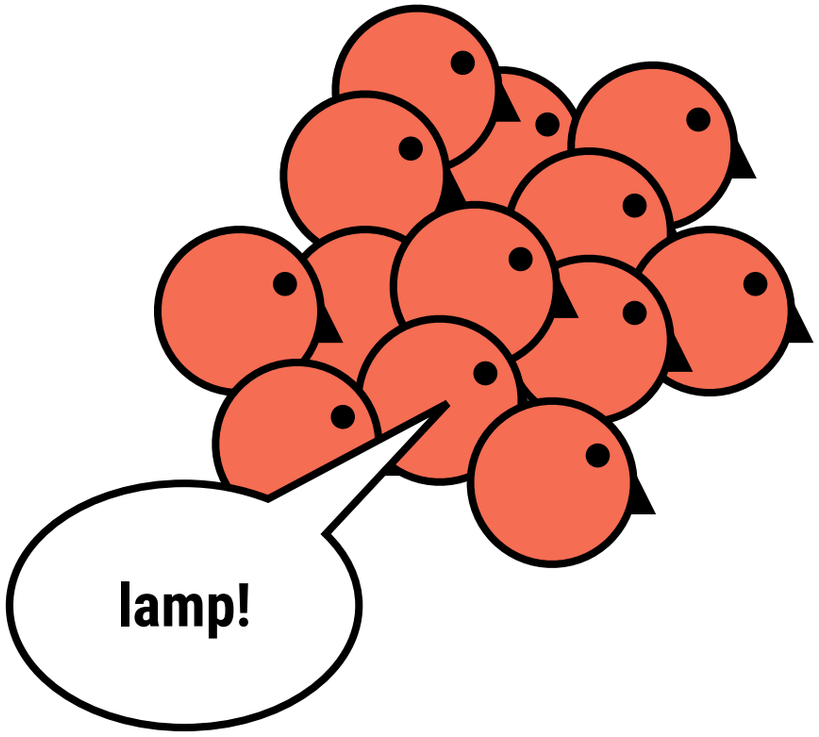


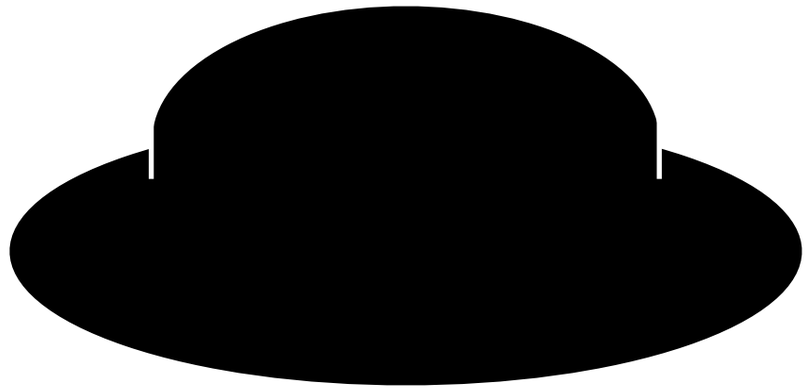


Naming game

Population negotiates a shared convention via local interactions:

1. Select random speaker & hearer
2. The hearer utters a word.
3. Both agents ‘align’ languages





Minimal NG
Every agent can **invent, add** and **remove** words to its vocabulary

Success

SPEAKER	HEARER
hat	**lamp**
ship	hat
lamp	

→

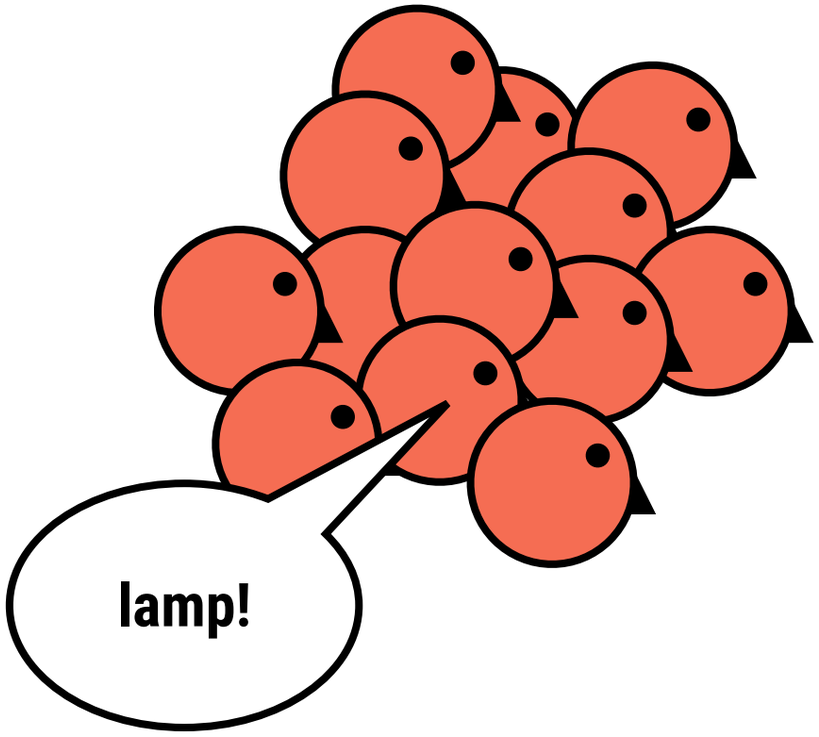
SPEAKER	HEARER
lamp	**lamp**

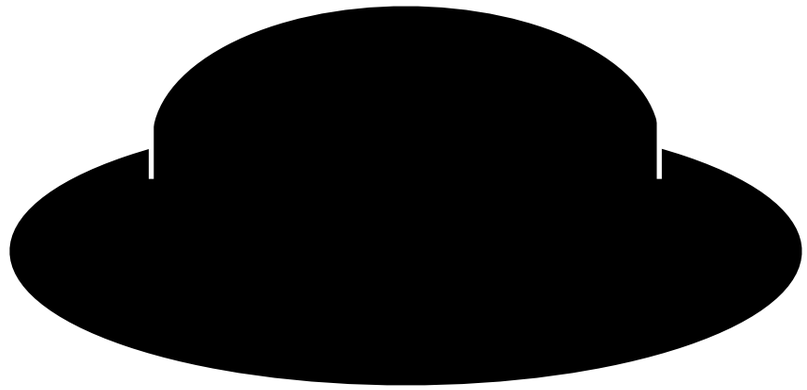
Failure

SPEAKER	HEARER
hat	hat
ship	
lamp	

→

SPEAKER	HEARER
hat	hat
ship	**lamp**
lamp	





Success

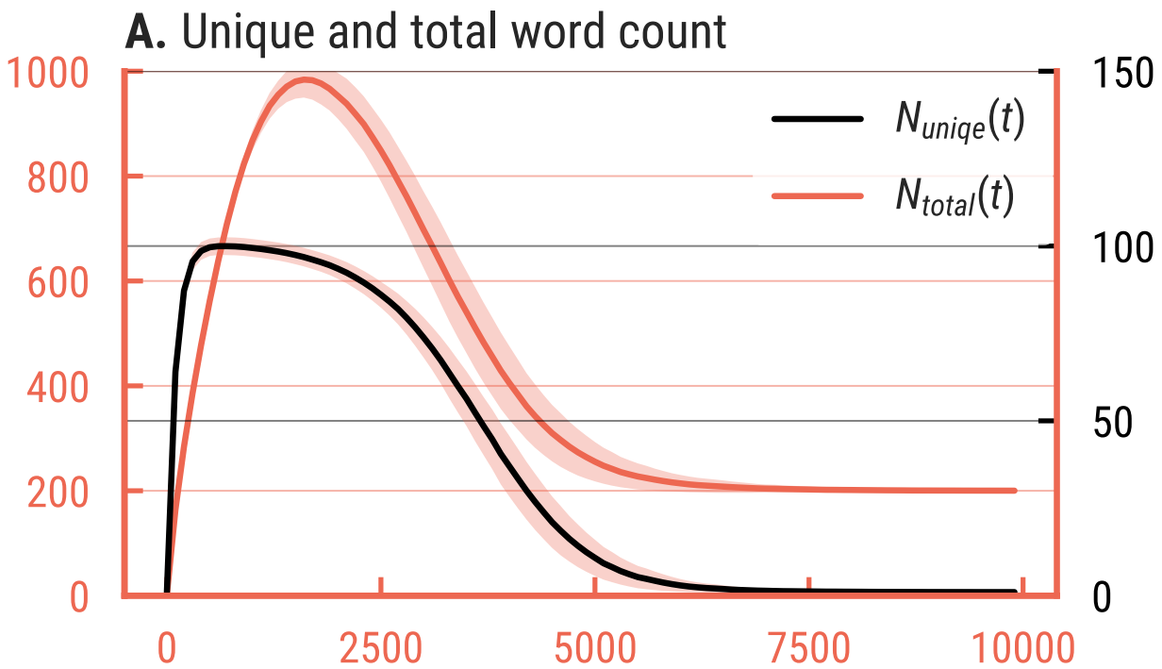
SPEAKER	HEARER
hat 0.4	**lamp** 0.1
ship 0.3	hat 0.2
lamp 0.2	

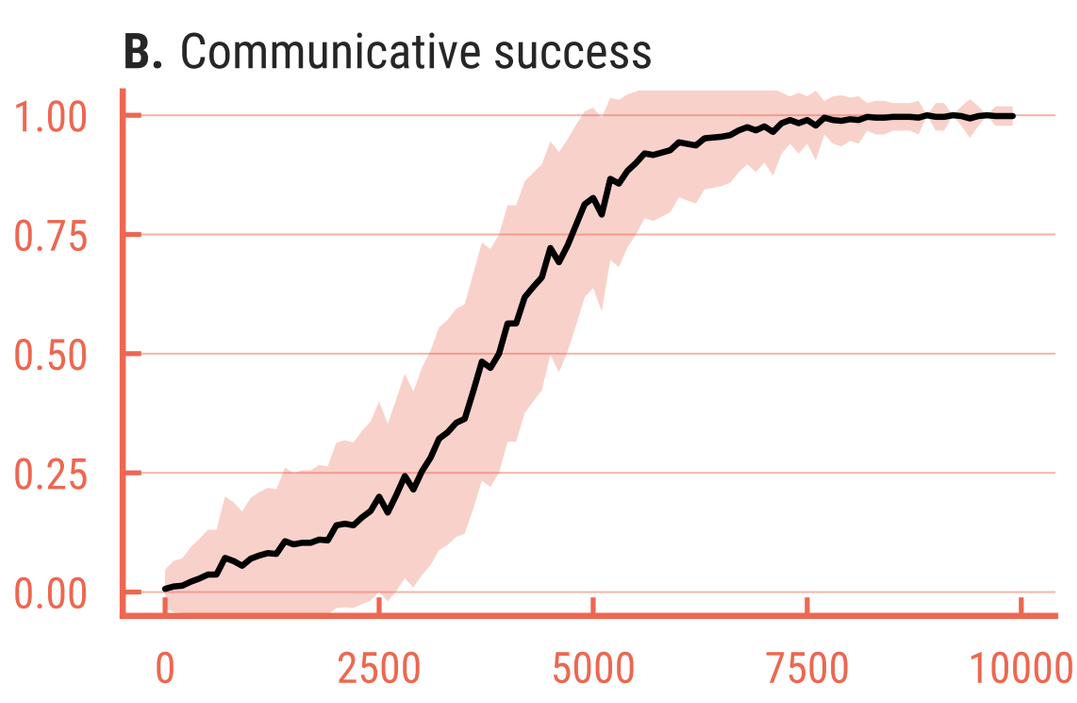
→

SPEAKER	HEARER
hat 0.3	**lamp** 0.3
ship 0.2	hat 0.1
lamp 0.4	

Lateral inhibition

After success, decrease the scores of competing words





Dynamics of the minimal NG

Three stages lead to the convergence to a single word:

1. Invention of words
2. Spread through population
3. Elimination of words

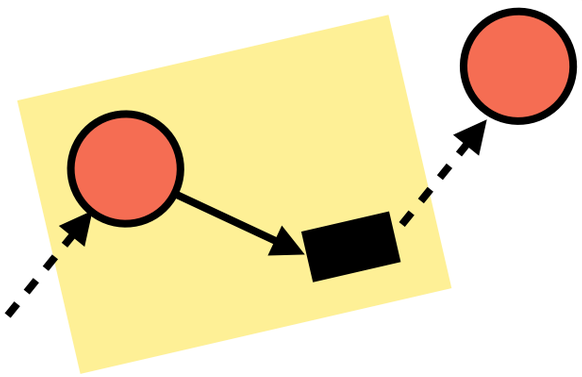
Cultural process of social negotiation leads to shared emergence of a convention

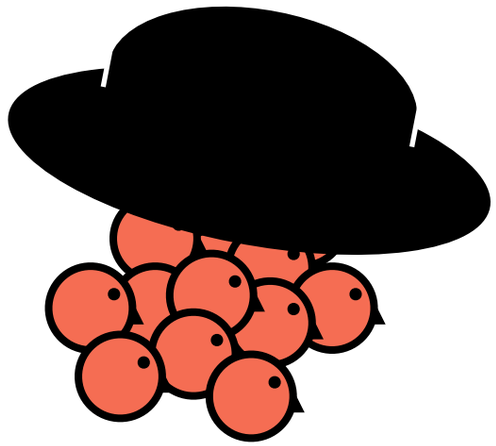
linguistics

The origins of language?

cognitive science

computational modelling

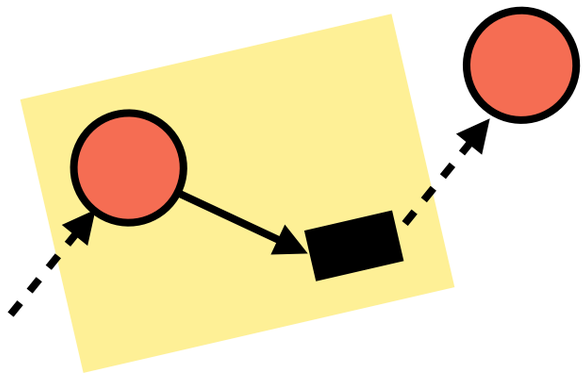




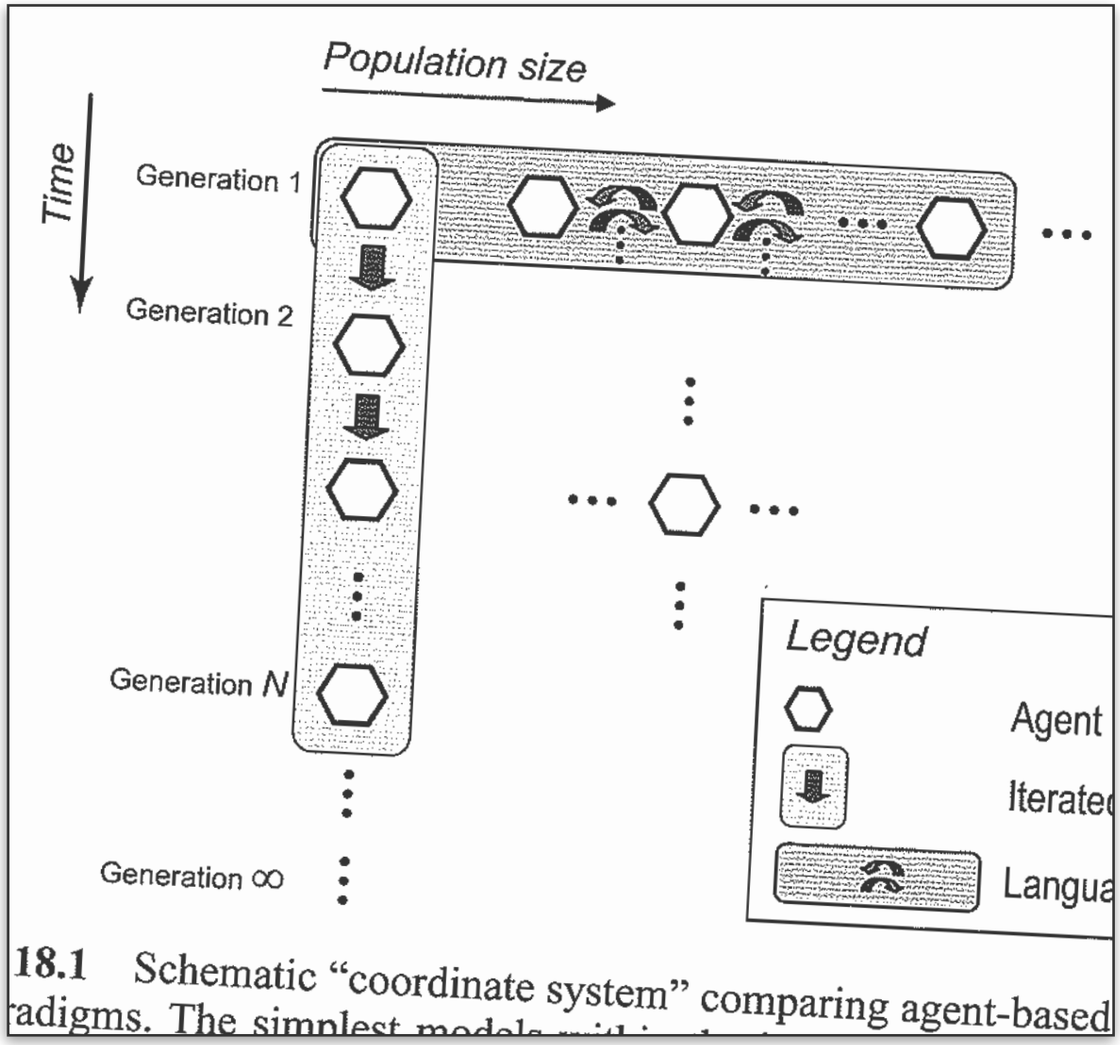
unifying and evaluating agent-based models of cultural language evolution

VERTICAL
iterated learning

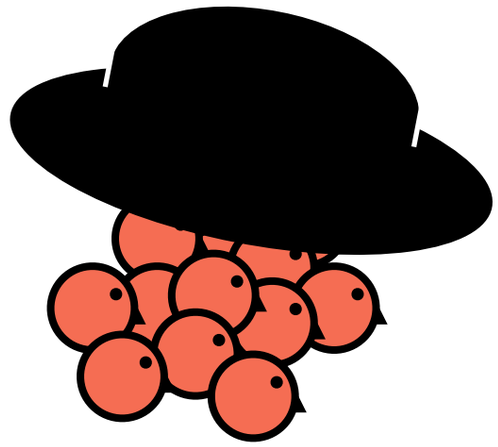
HORIZONTAL
naming game



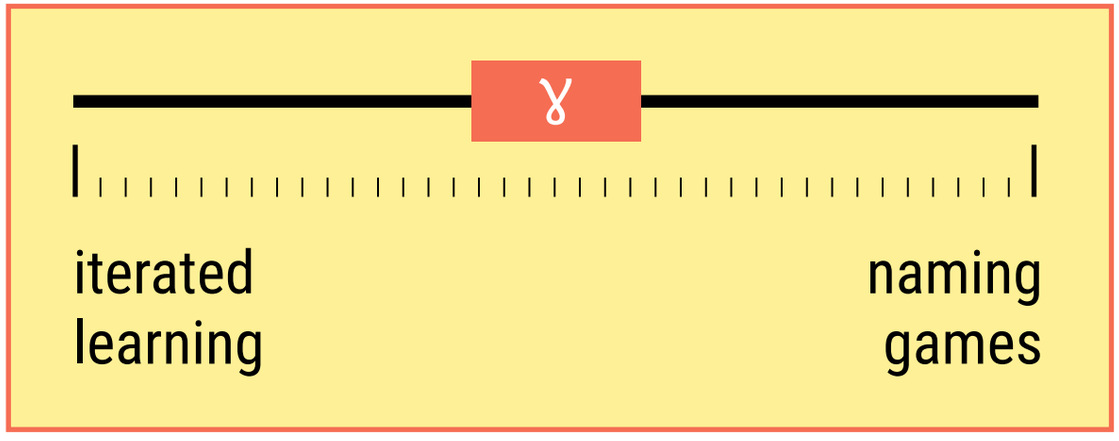
VERTICAL
iterated learning



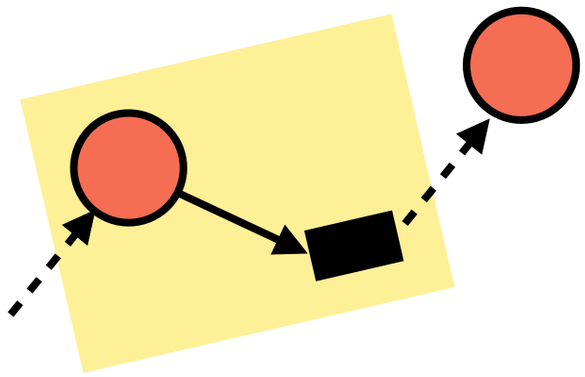
18.1 Schematic "coordinate system" comparing agent-based
radigms. The simplest models



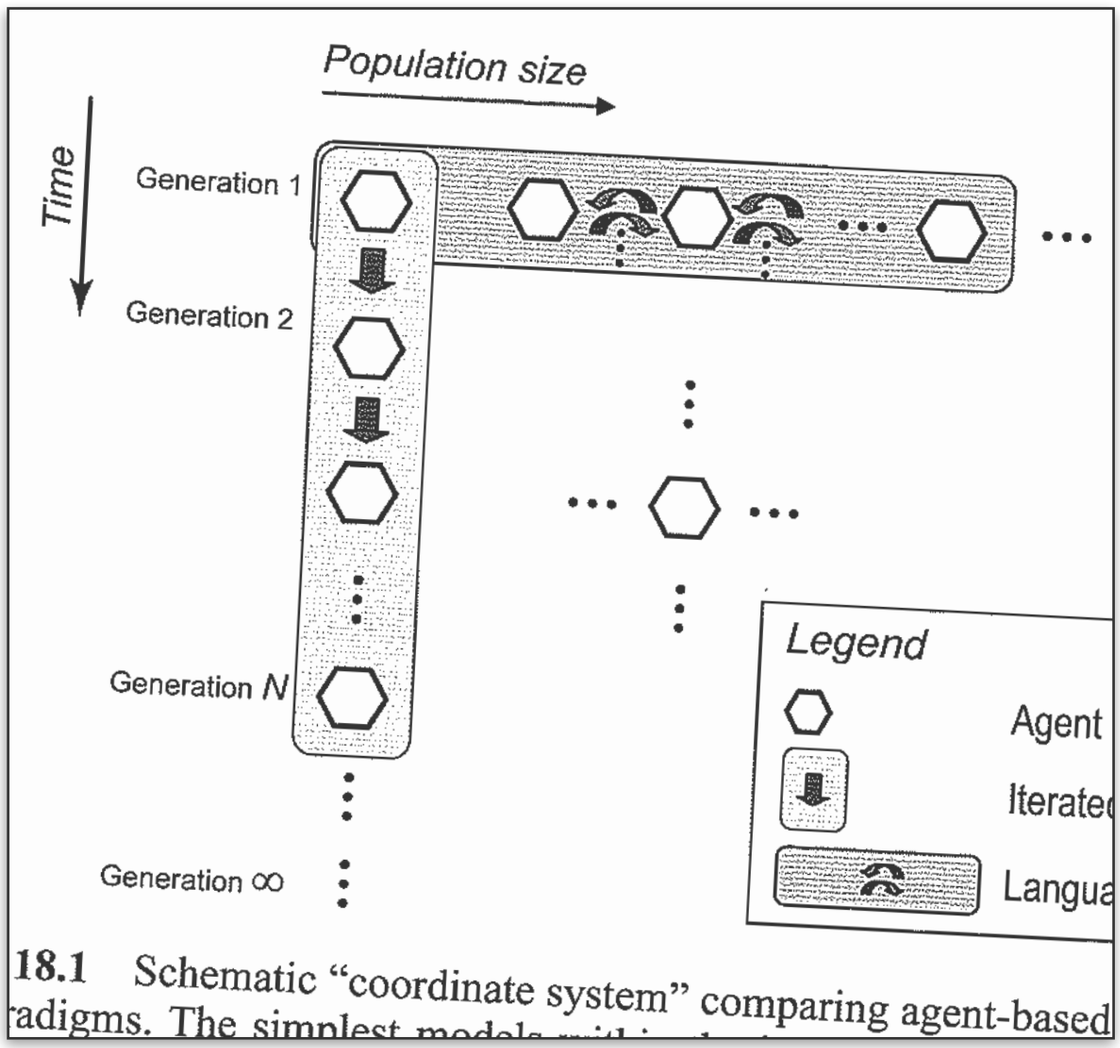
HORIZONTAL
naming game



1. shared formalism **2.** population model



VERTICAL
iterated learning



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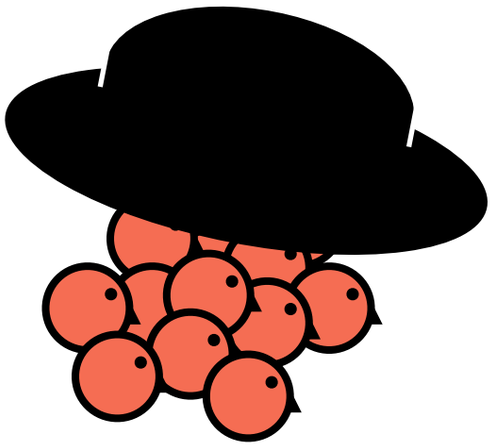
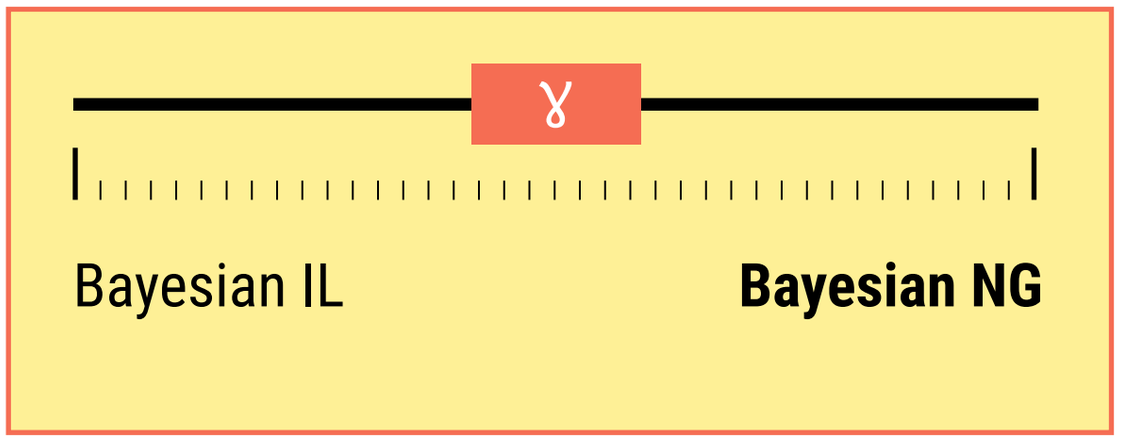
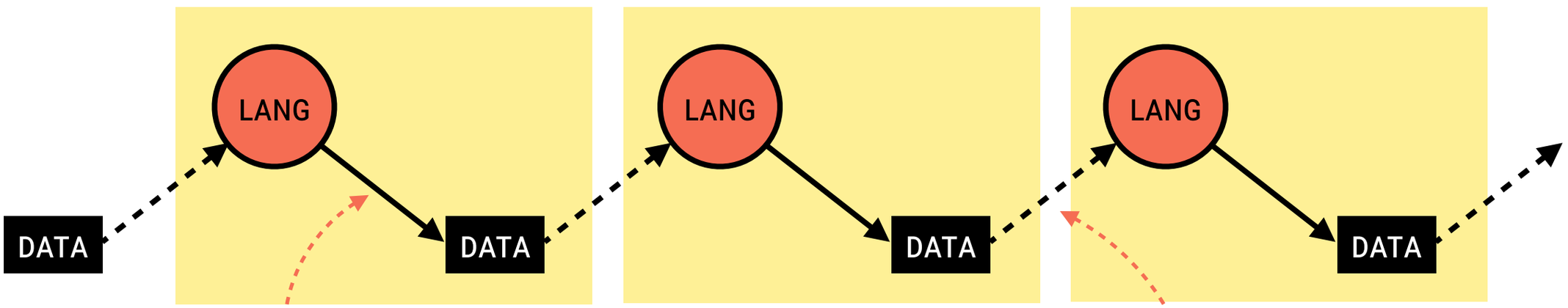


HORIZONTAL
naming game



BAYESIAN
LANGUAGE
GAME

1. shared formalism **2.** population model



production algorithm

$p(\text{data} \mid \text{lang})$

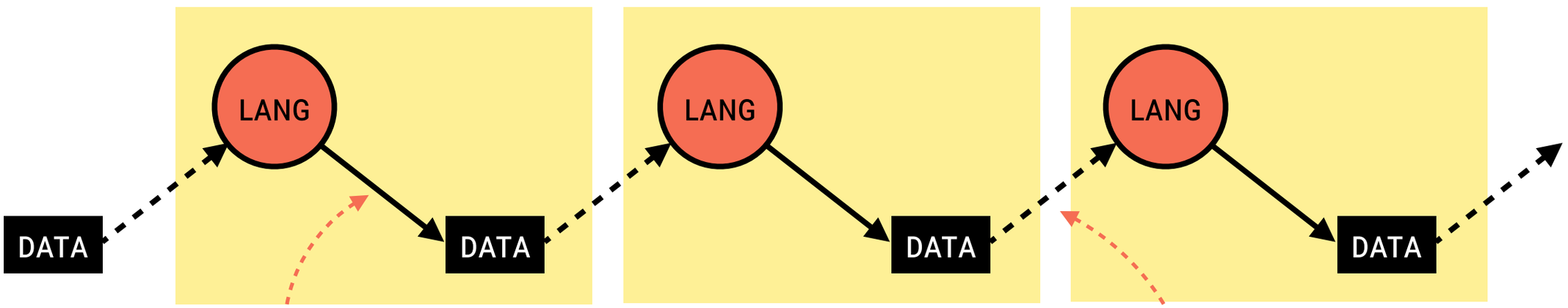
learning algorithm

$p(\text{lang} \mid \text{data})$

$$p(\text{lang} \mid \text{data}) \propto p(\text{data} \mid \text{lang}) \cdot p(\text{lang})$$

probability of adopting a language

biases of the learners



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learning algorithm

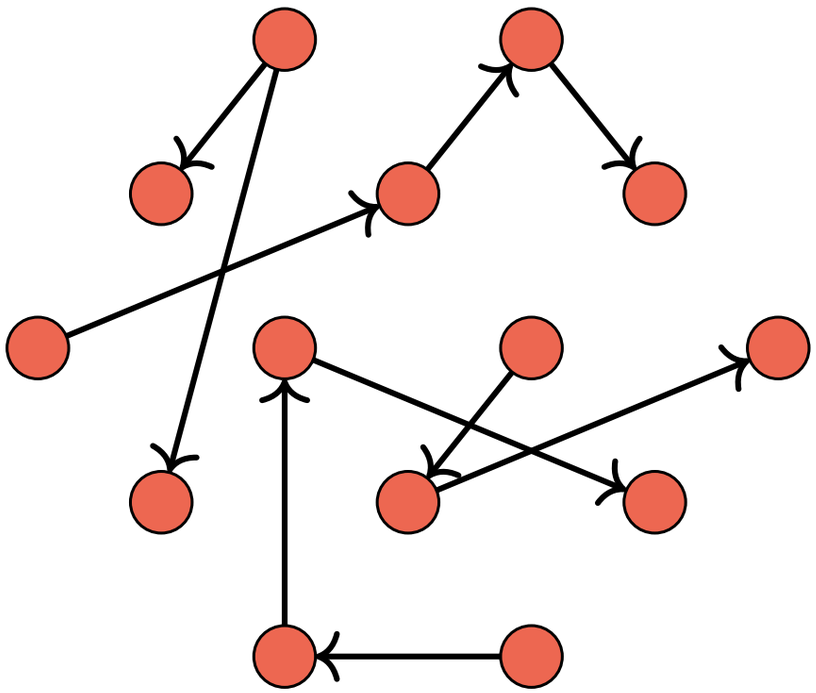
$p(\text{lang} \mid \text{data})$

$$p(\text{lang} \mid \text{data}) \propto p(\text{data} \mid \text{lang}) \cdot p(\text{lang})$$

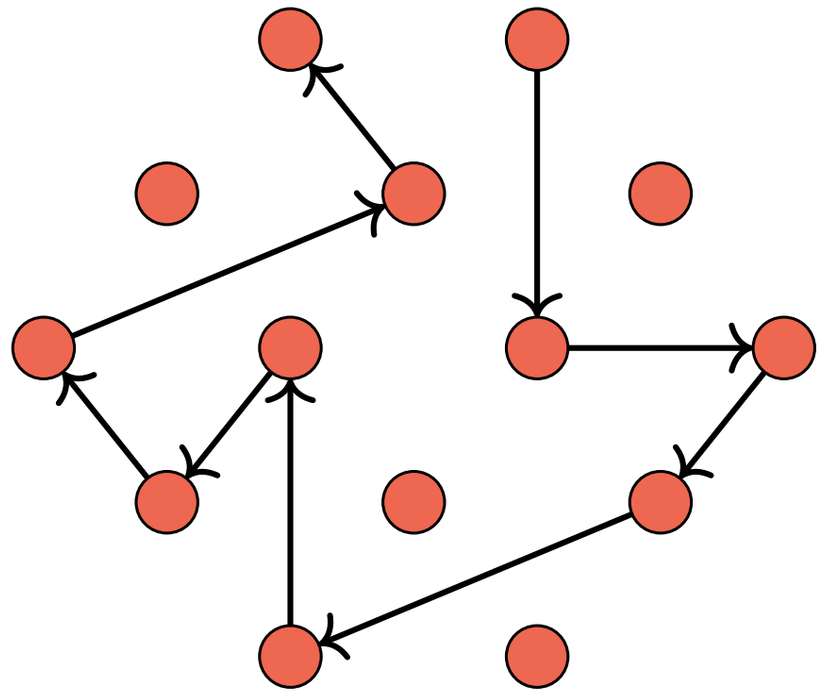
probability of language
after previous interaction

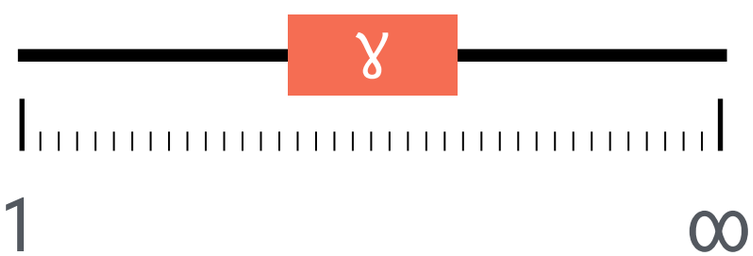
VERTICAL
transmission chain

HORIZONTAL
homogeneous mixing



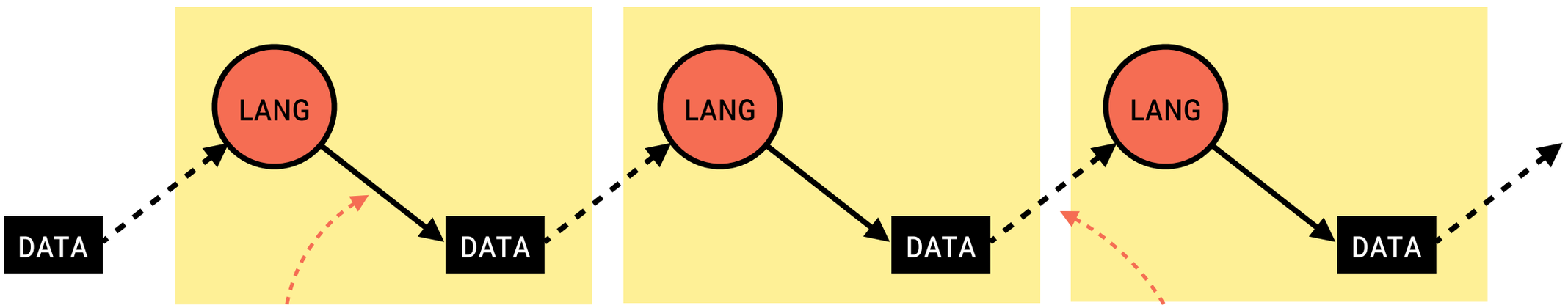
BOTH
random walk





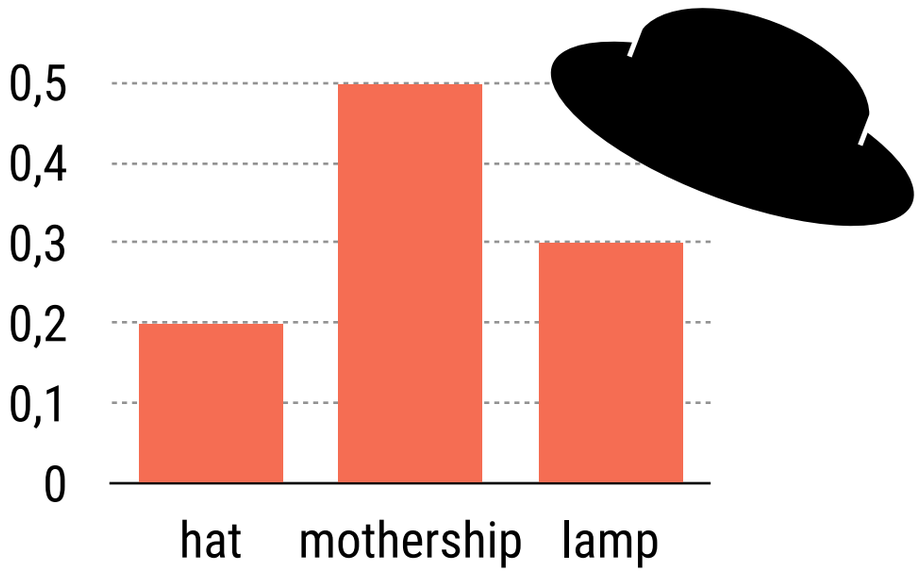
LIFE EXPECTANCY ɣ
The age at which a speaker dies

The Bayesian Naming Game



production algorithm

$p(\text{data} \mid \text{lang})$



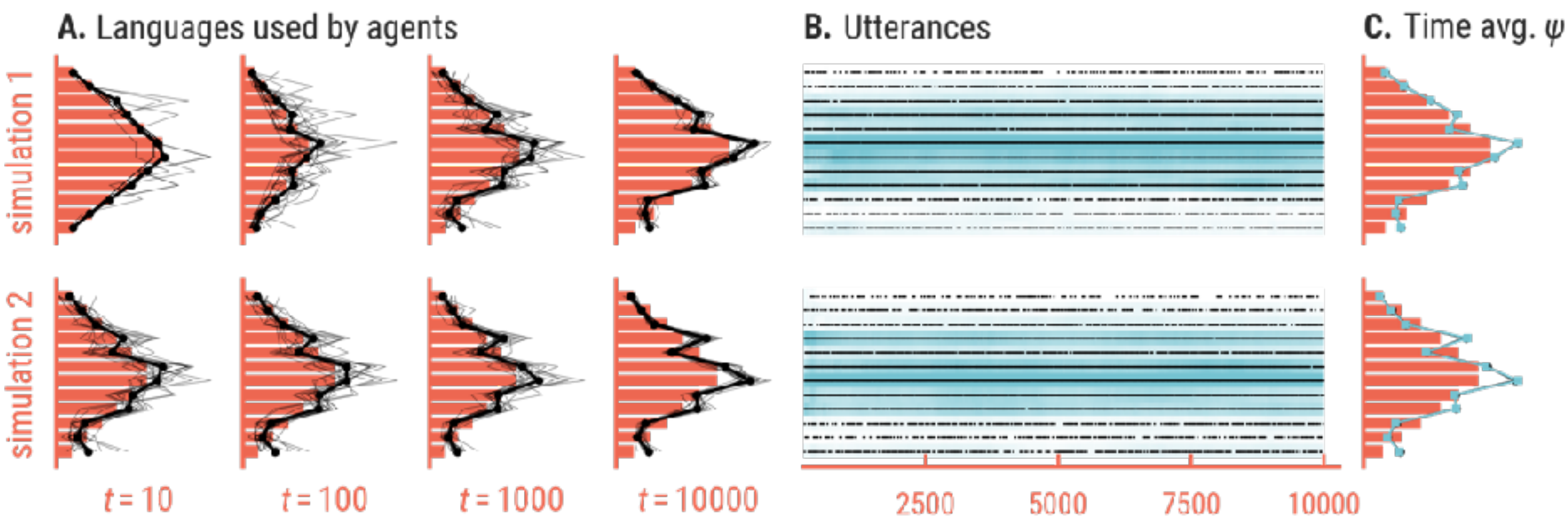
learning algorithm

$p(\text{lang} \mid \text{data})$

A language is a distribution over words

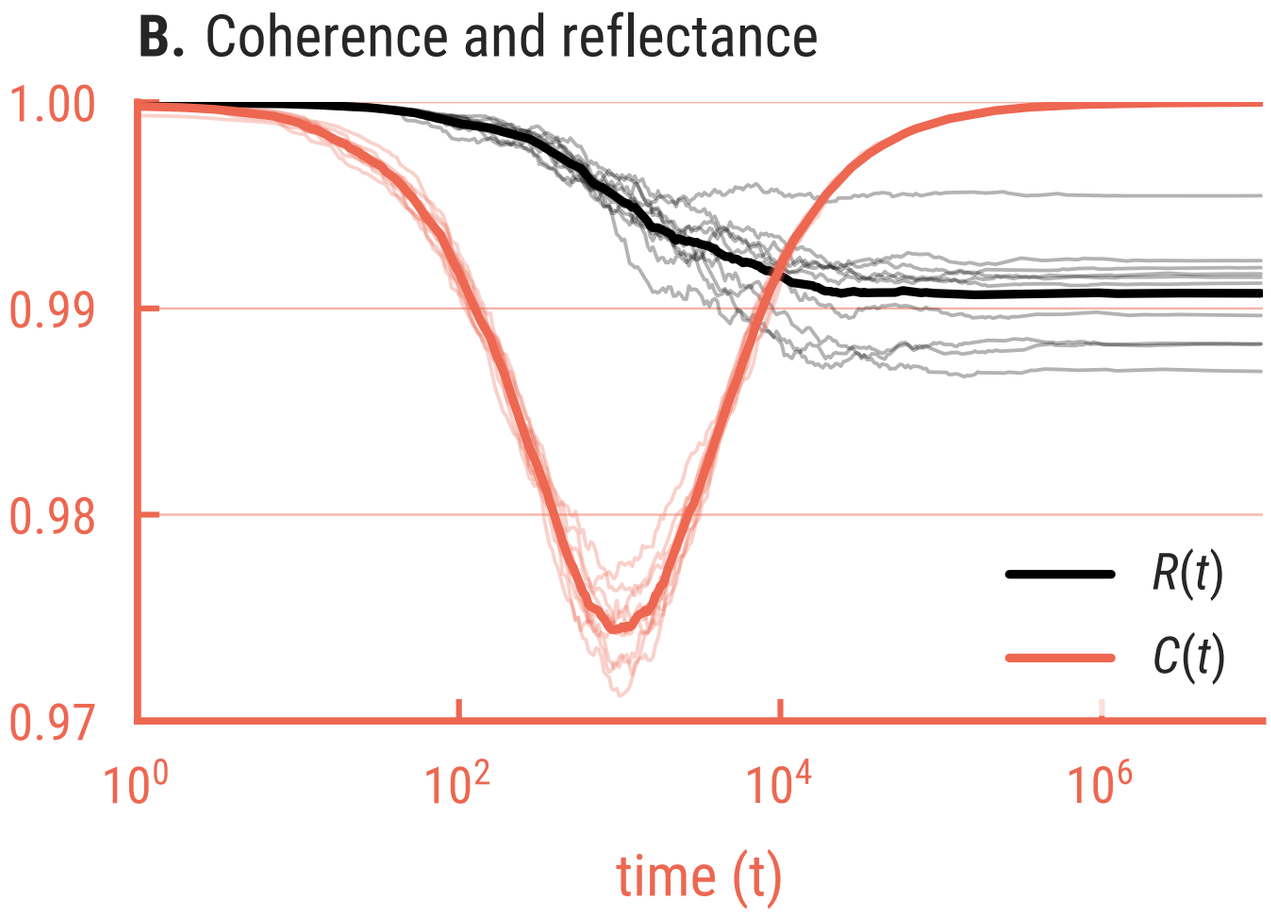
(or e.g. linguistic features)

The Bayesian Naming Game

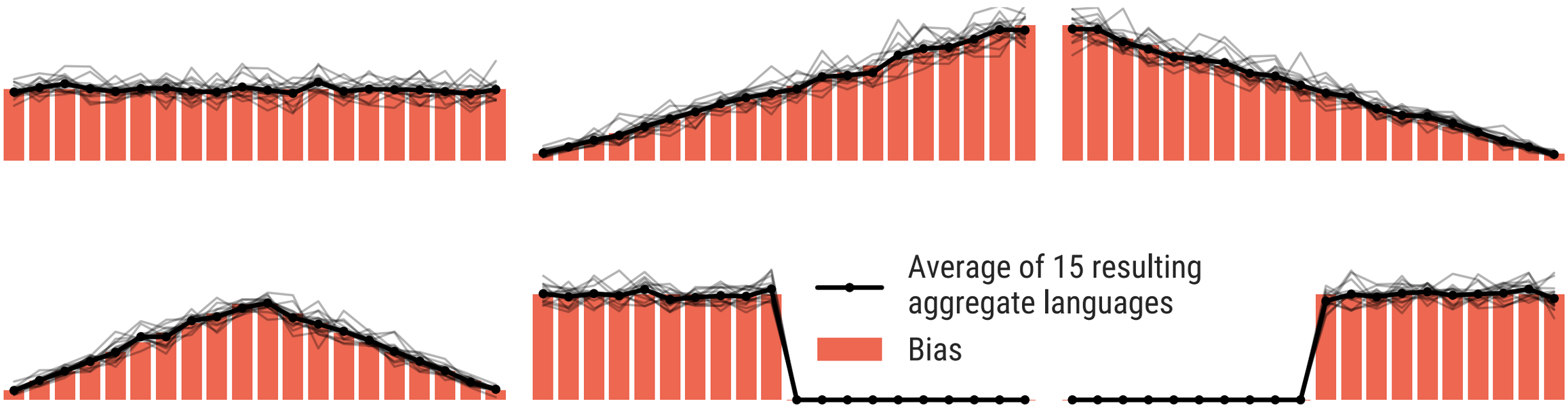


- Lineage specificity
- Reflection of the bias
  (rather than convergence to the prior)
- Language stability

The Bayesian Naming Game



The Bayesian Naming Game



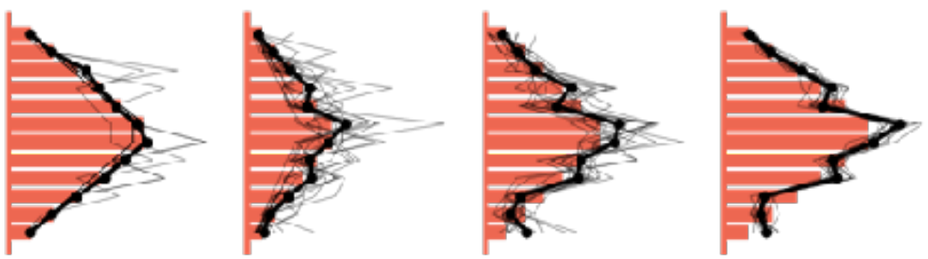
On average, the Bayesian Naming Game reproduces the innate biases.

Reminiscent of “wide but constrained variation” (e.g. colour terms)

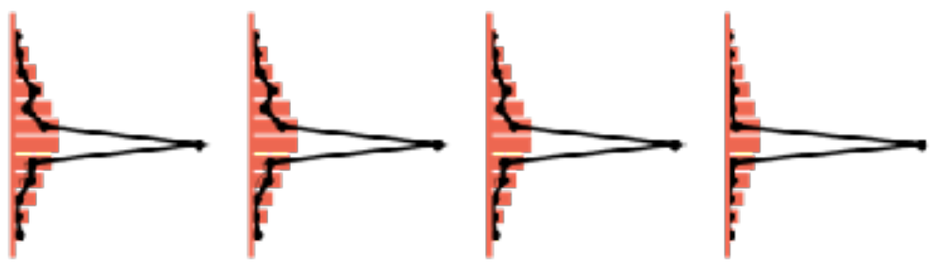
Regier et al. (2015). DOI 10.1002/9781118346136.ch11

Different strategies

But why this?

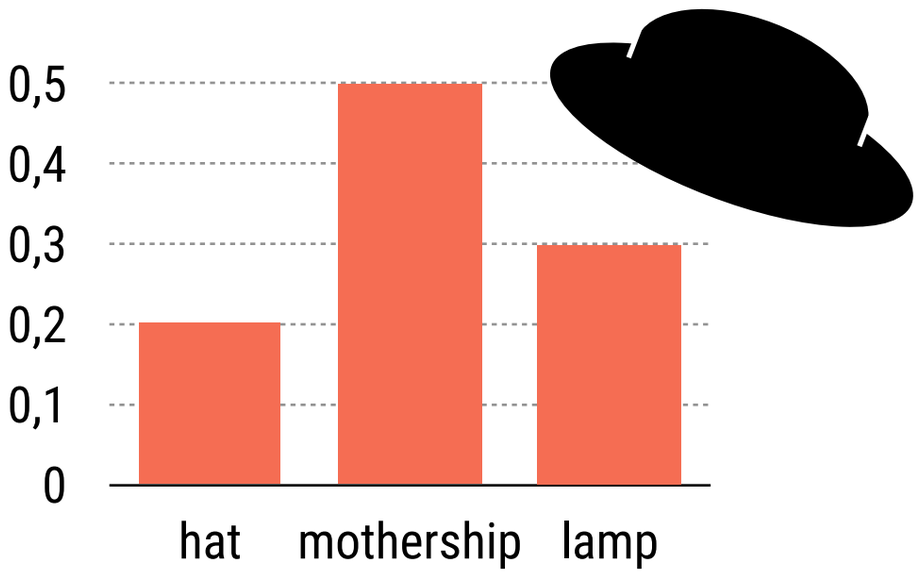


Shouldn’t we expect this?



production algorithm

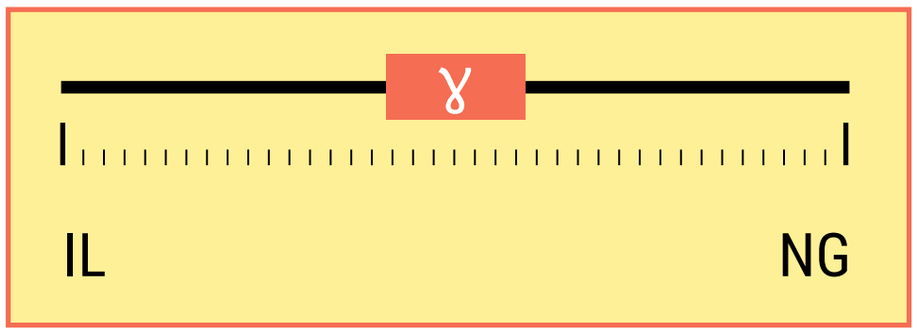
$$p(\text{data} \mid \text{lang})$$

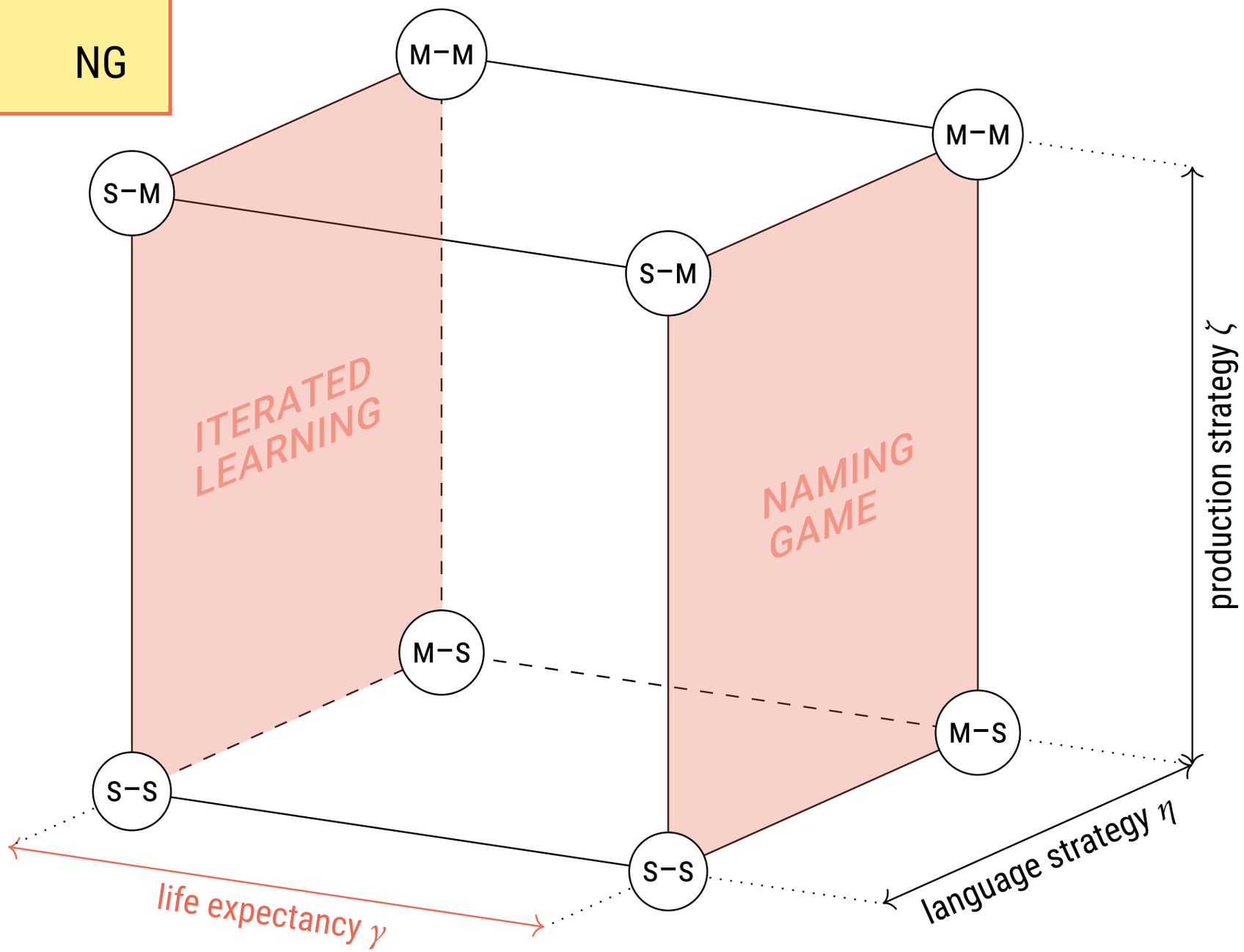


Strategies

One can vary the ‘production strategy’ and ‘language strategy’ **sample** or **maximise**

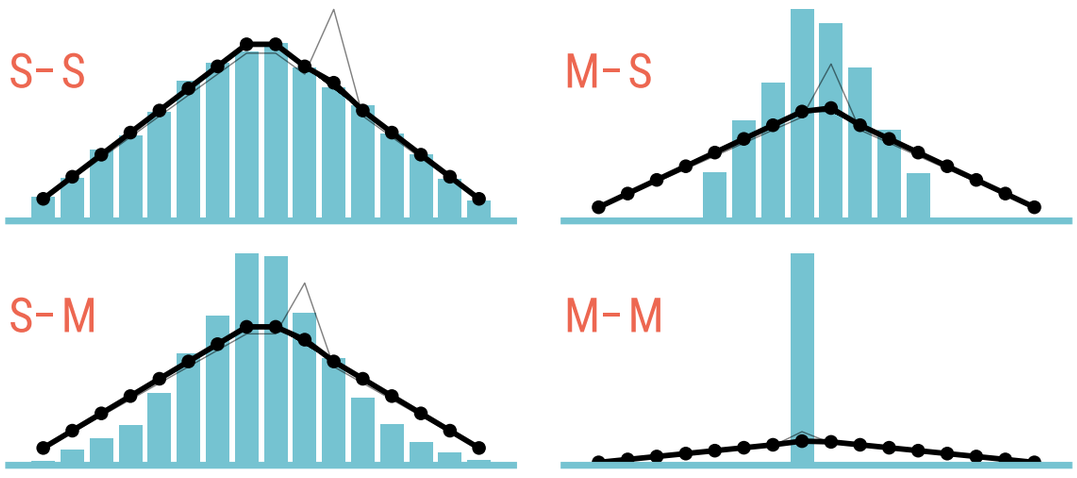
Different strategies



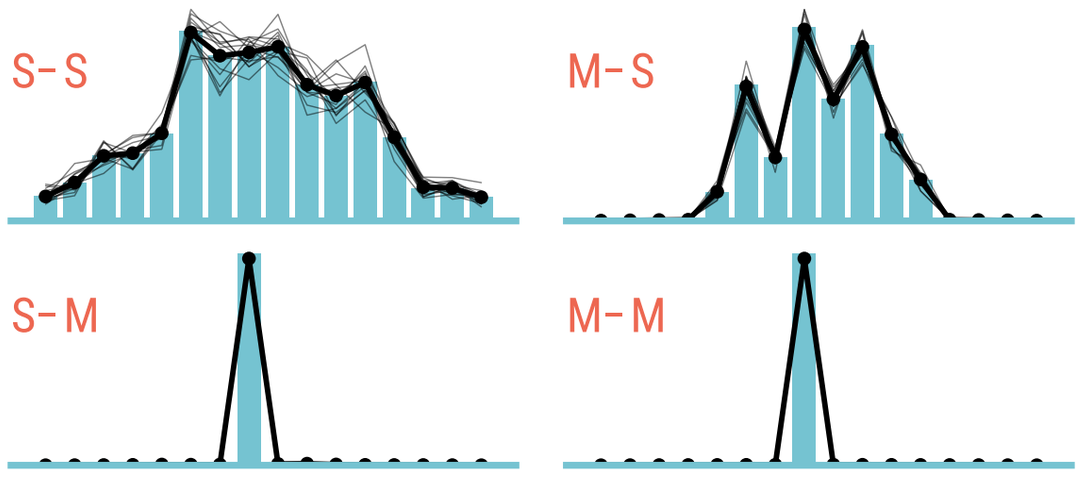


Different strategies

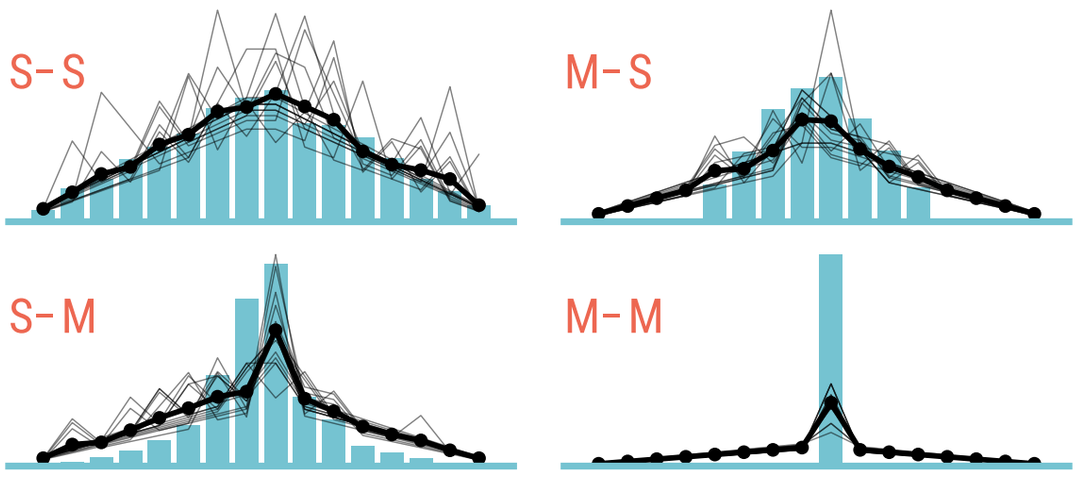
A. Iterated learning ($\gamma = 1$)



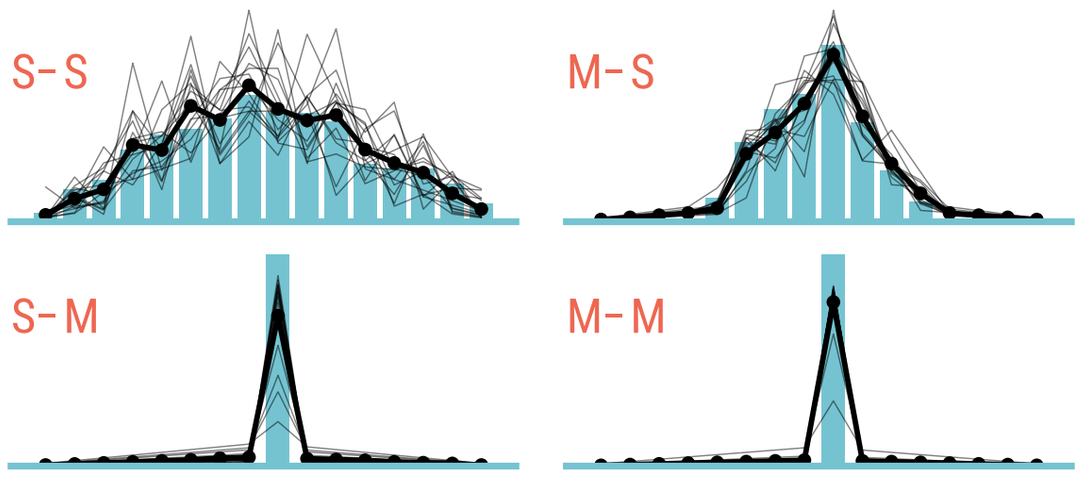
B. Naming Game ($\gamma = \infty$)



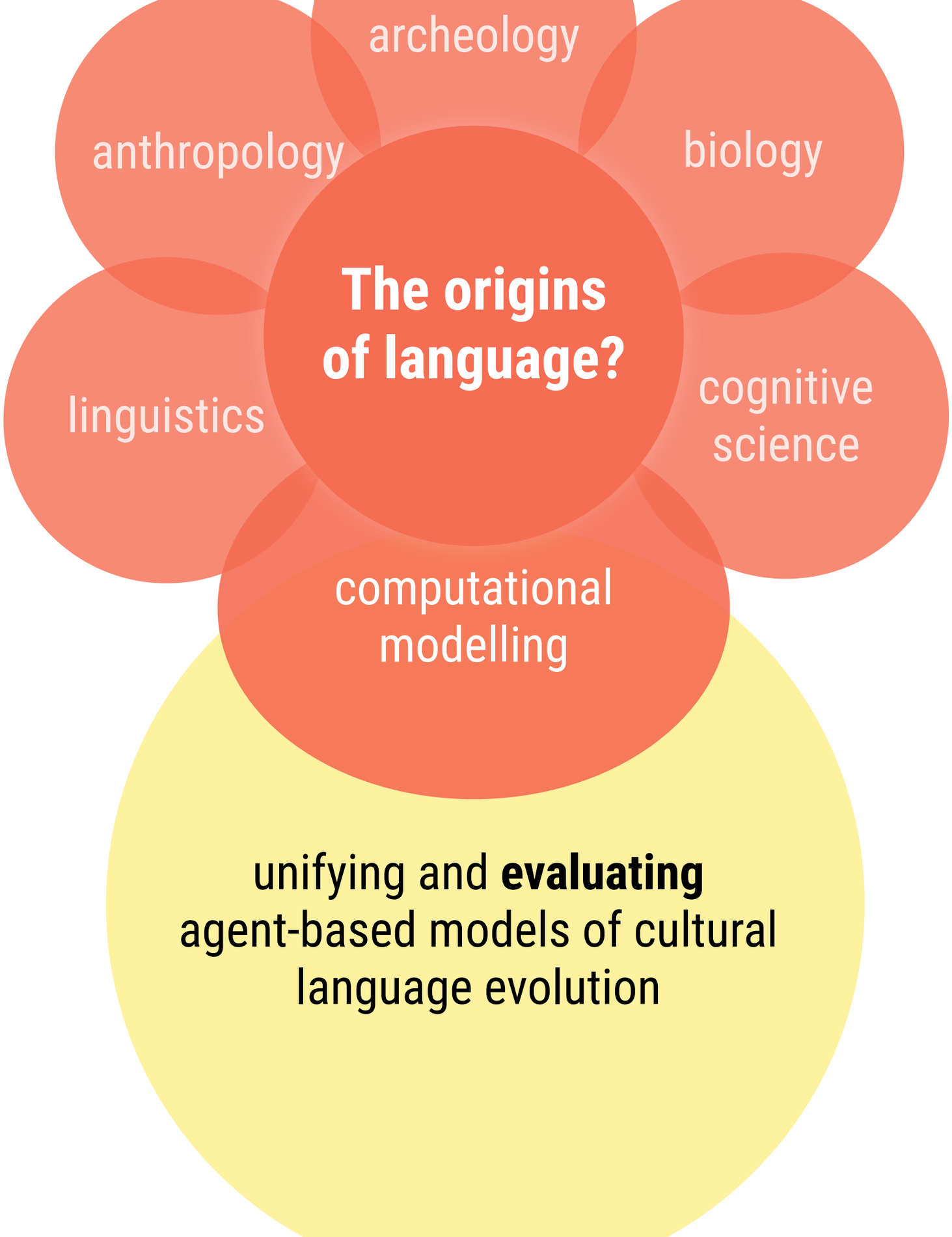
C. Quick turnover ($\gamma = 10$)



D. Medium turnover ($\gamma = 100$)



Aggregate language $\bar{\pi}$ — Expected language π — External language ψ


archeology
anthropology
biology
The origins of language?
linguistics
cognitive science
computational modelling
unifying and **evaluating** agent-based models of cultural language evolution

Take home messages

Iterated learning and the naming game closely related:

language evolution through frequency tracking and innate biases.

Realistic?

Lineage-specific languages reflecting innate biases in the Bayesian naming game.

unifying and **evaluating** agent-based models of cultural language evolution

The (Little) Tower of Babel by **Pieter Bruegel the Elder** (c. 1563) oil on panel; 60 cm × 74.5 cm; Museum Boijmans Van Beuningen, Rotterdam