Simulating Language
12: Iterated Learning

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How good is our model at learning?

- What does it mean for something to be ‘good’ at learning?

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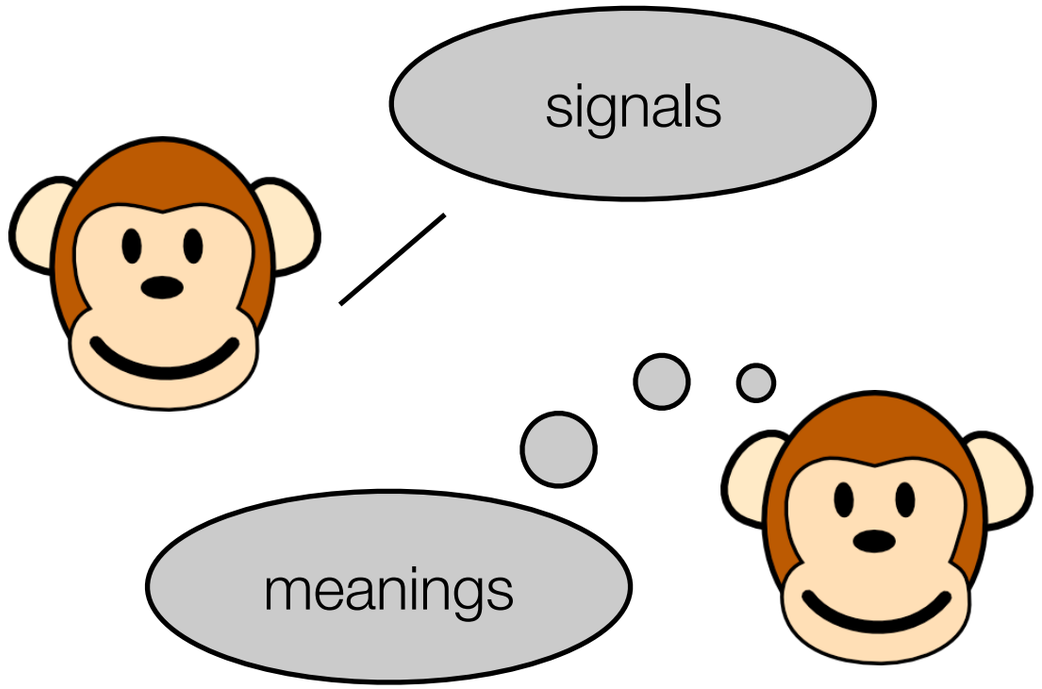
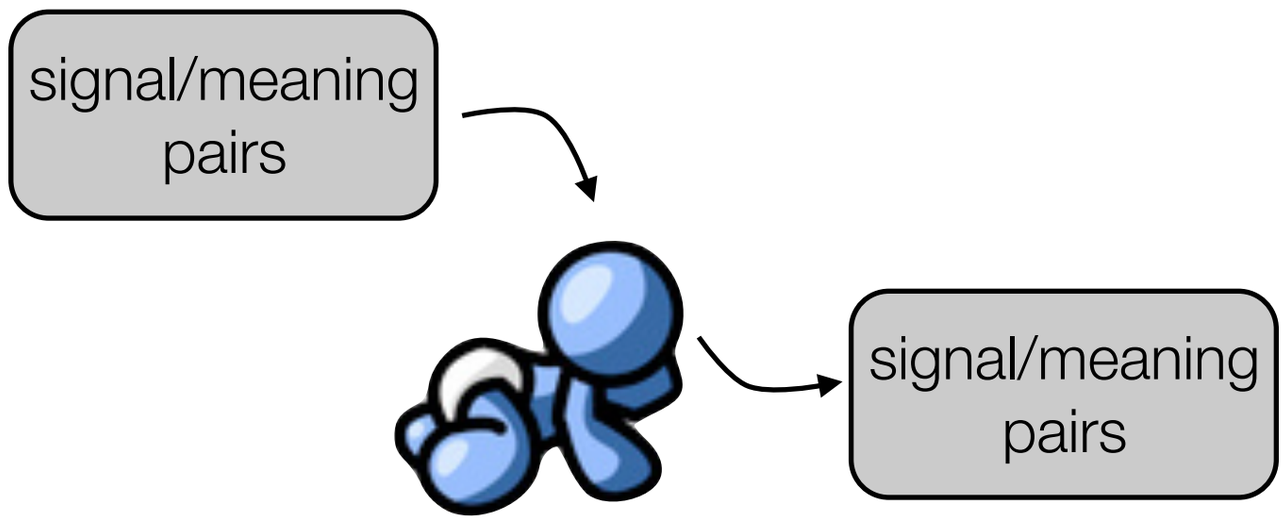
- What does it mean for something to be ‘good’ at learning?
  - One answer: will two agents given the same data be able to **communicate**? Will a learner be able to communicate with its teacher?
  - Another answer: given some training data, can it **recall** that data?
  - A third answer: given some training data, can it **generalise** correctly to unseen data?
- Our training data is meaning-signal pairs, so an obvious test is simply whether meanings correctly map to signals (and vice versa) after learning
- So, some kinds of learner will be good at learning, and others will be bad, right?
- Not as simple as that... **it will depend on what is being learned**

A new kind of question

- Previously, we were interested in how good two innate signalling systems were for communication



- Now, we want to know what kinds of errors a particular learner makes with a particular language



What about our learner?

- How well does it learn?

- Given an optimal language, it learns well:

TRAINING

m1→s1

m2→s2

m3→s3

	s1	s2	s3
m1	1	0	0
m2	0	1	0
m3	0	0	1

RESULT

m1→s1

m2→s2

m3→s3

What about our learner?

- How well does it learn?
- Given a language with synonymy?

TRAINING

m1→s1

m1→s2

m1→s2

	s1	s2	s3
m1	0	0	0
m2	0	0	0
m3	0	0	0

What about our learner?

- How well does it learn?

- Given a language with synonymy, production behaviour depends on frequency of items in training:

TRAINING

m1→s1

m1→s2

m1→s2

	s1	s2	s3
m1	1	2	0
m2	0	0	0
m3	0	0	0

RESULT

m1→s2 only

What about our learner?

- How well does it **generalise**?

- Unable to correctly generalise an optimal language:

TRAINING

m1→s1

m2→s2

~~m3→s3~~

	s1	s2	s3
m1	1	0	0
m2	0	1	0
m3	0	0	0

RESULT

What about our learner?

- How well does it **generalise**?

- Unable to correctly generalise an optimal language:

TRAINING

m1→s1

m2→s2

~~m3→s3~~

	s1	s2	s3
m1	1	0	0
m2	0	1	0
m3	0	0	0

RESULT

m1→s1

m2→s2

m3→s1, s2, s3

What about our learner?

- How well does it **generalise**?

- Unable to correctly generalise to a maximally ambiguous language:

TRAINING

m1→s1

m2→s1

~~m3→s1~~

	s1	s2	s3
m1	1	0	0
m2	1	0	0
m3	0	0	0

RESULT

m1→s1

m2→s1

m3→s1, s2, s3

Bias

- Our learner, though really simple, is not a completely “blank slate”. It responds differently to different training sets
    - In this case: it struggles with synonyms, but is otherwise faithful to its data (to the extent that it misses ‘obvious’ generalisations)
- Where does this behaviour come from?
- Features of the architecture of the model create an inherent *learning bias* which may favour some languages over others
- What features could we modify to manipulate bias?
- One possibility: the way we update the weights...

Lateral inhibition

- Our current weight update rule: **If signal node and meaning node are active, increase connection weight by one**

- A reasonable addition: **also *reduce* activation between competing meanings and signals (i.e. the meanings that don't match the signal, and the signals that don't match the meaning)**

m1→s1

	s1	s2	s3
m1	1	-1	-1
m2	-1	0	0
m3	-1	0	0

What about lateral inhibition?

- How well does it **generalise**?
- Able to correctly generalise an optimal language!

TRAINING

m1→s1

m2→s2

~~m3→s3~~

	s1	s2	s3
m1	1	-2	-1
m2	-2	1	-1
m3	-1	-1	0

RESULT

m1→s1

m2→s2

m3→s3

What about lateral inhibition?

- How well does it **generalise**?
- Seems positively **unwilling** to correctly generalise to a maximally ambiguous language!

TRAINING

m1→s1

m2→s1

~~m3→s1~~

	s1	s2	s3
m1	0	-1	-1
m2	0	-1	-1
m3	-2	0	0

RESULT

m1→s1

m2→s1

m3→s2, s3

Other routes to optimal communication?

- Learning bias might (or might not) favour communicatively optimal languages through generalisation.

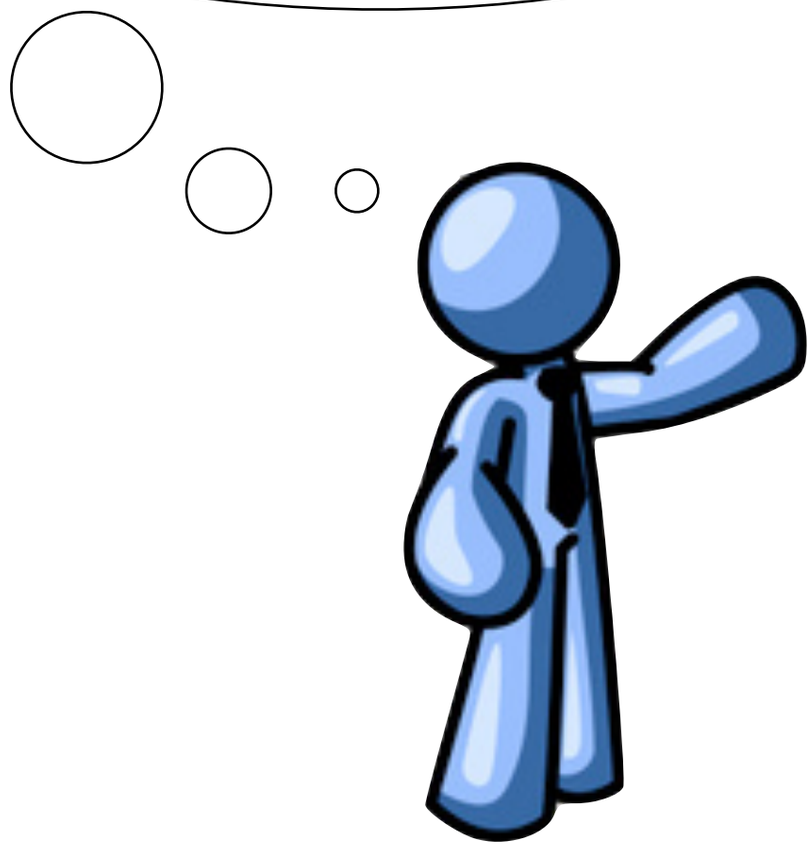
- Differences in learning not the only possible route to optimal signalling

- What if speakers actively tried to behave rationally while communicating?

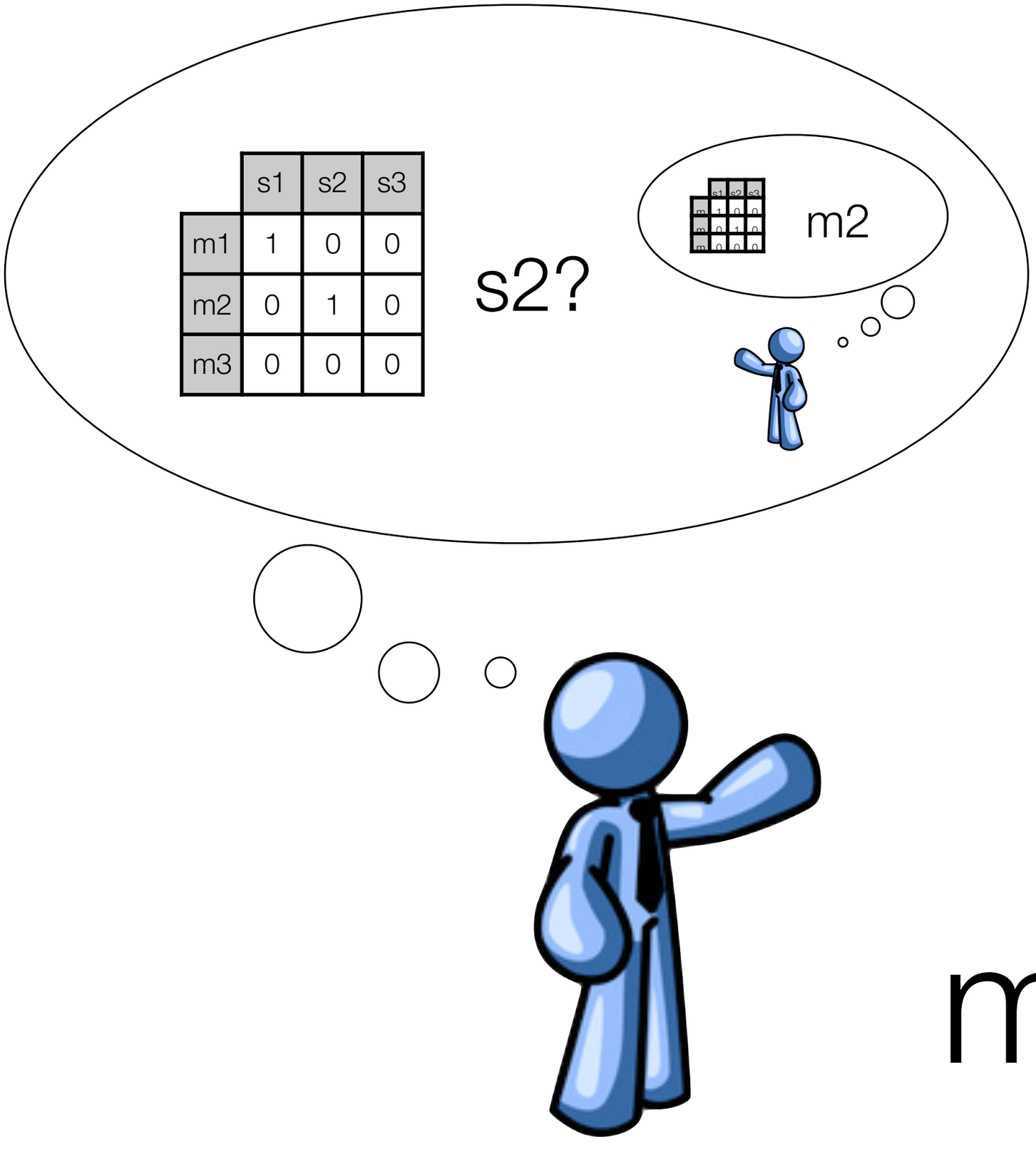
  - Instead of simply producing what they learn, what if speakers avoided producing signals that were ambiguous in interaction?

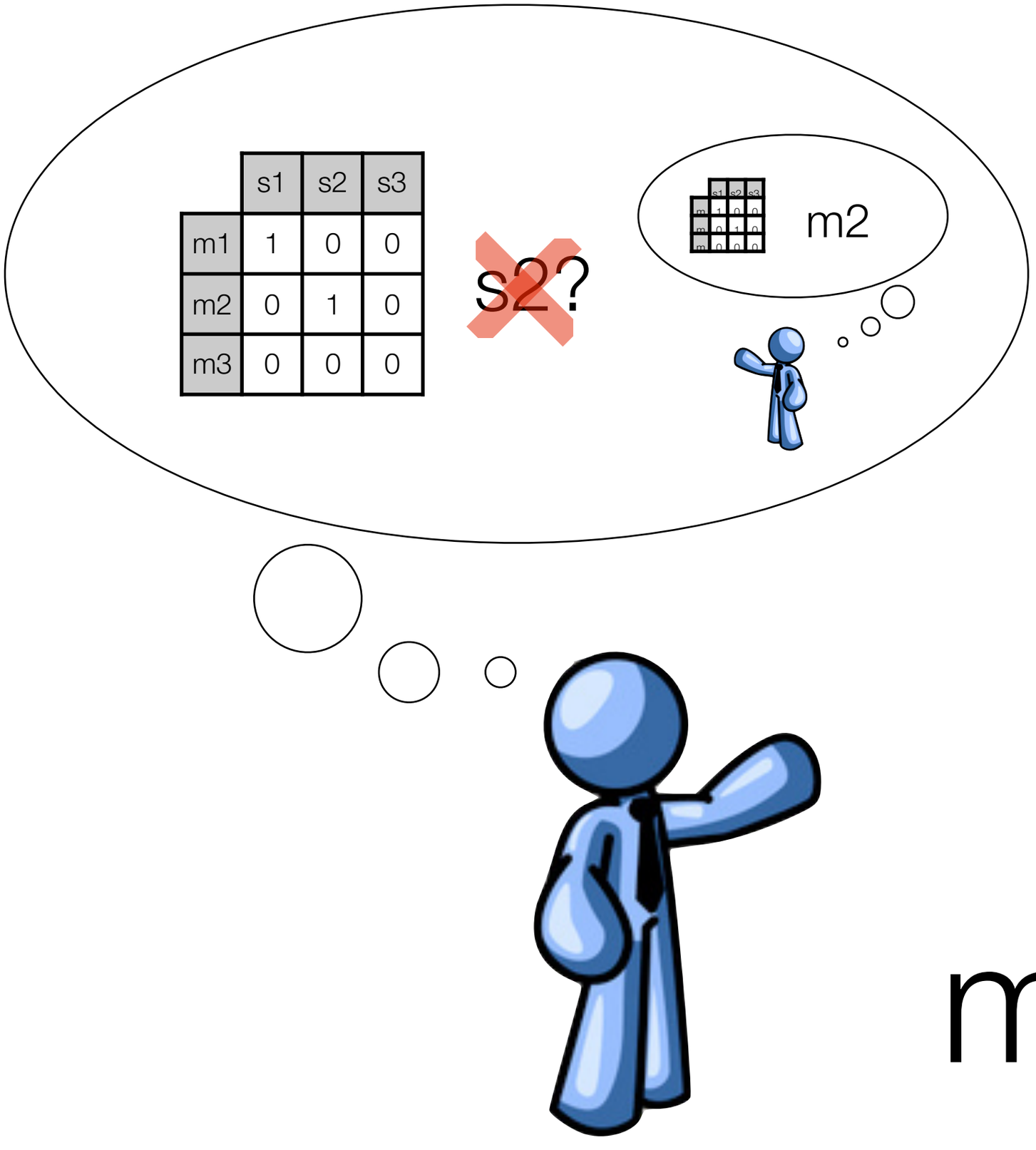
	s1	s2	s3
m1	1	0	0
m2	0	1	0
m3	0	0	0

s2?



m3


s1 s2 s3
m1 1 0 0
m2 0 1 0
m3 0 0 0
s2?
m2
m3


s1
s2
s3
m1
1
0
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m2
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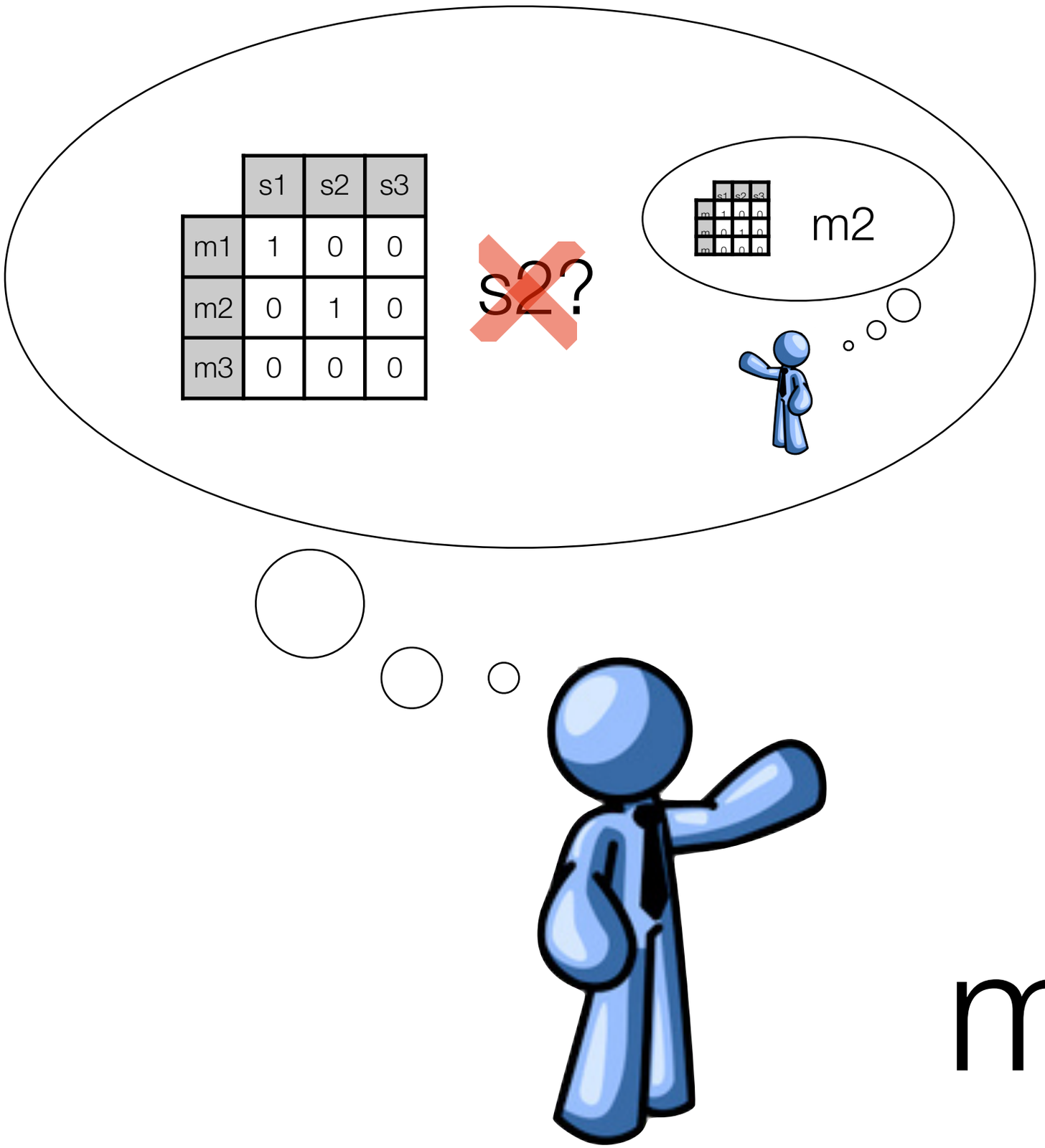
1
0
m3
0
0
0
s2?
m2
m3



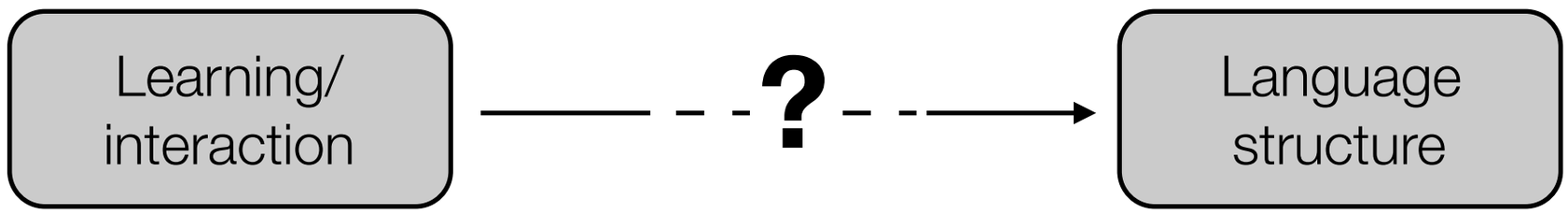
“Rational” speaker model

1. Use matrix to choose signal.
2. Use matrix to see what meaning you’d understand if you heard that signal.
3. If it meanings don’t match, change the signal to a random one.

Possible routes to favouring optimal languages

- Differences in **learning** or **interaction** could possibly change the type of languages being preferred

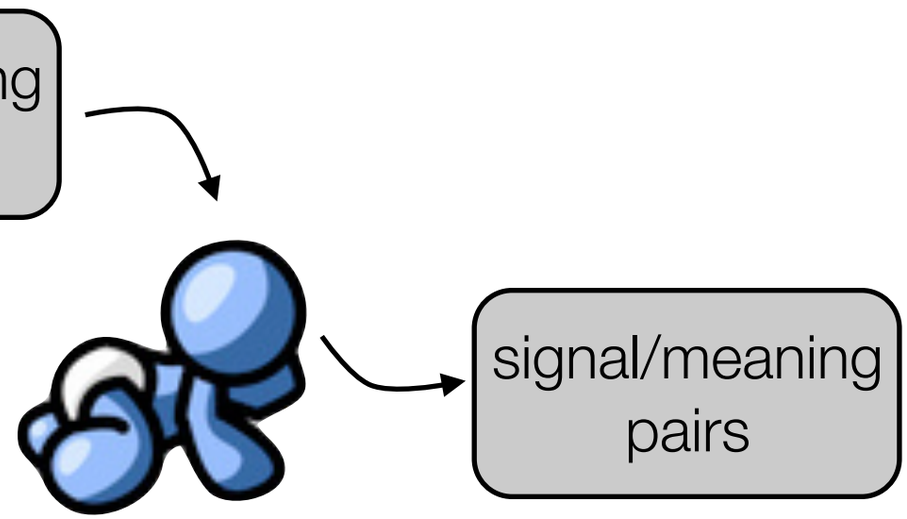
- Two issues:
  - Where do these languages come come from in the first place?
  - How do we bridge the gap between learning bias/communicative strategies and universal properties of language structure?



THE PROBLEM OF LINKAGE

Solving the problem of linkage

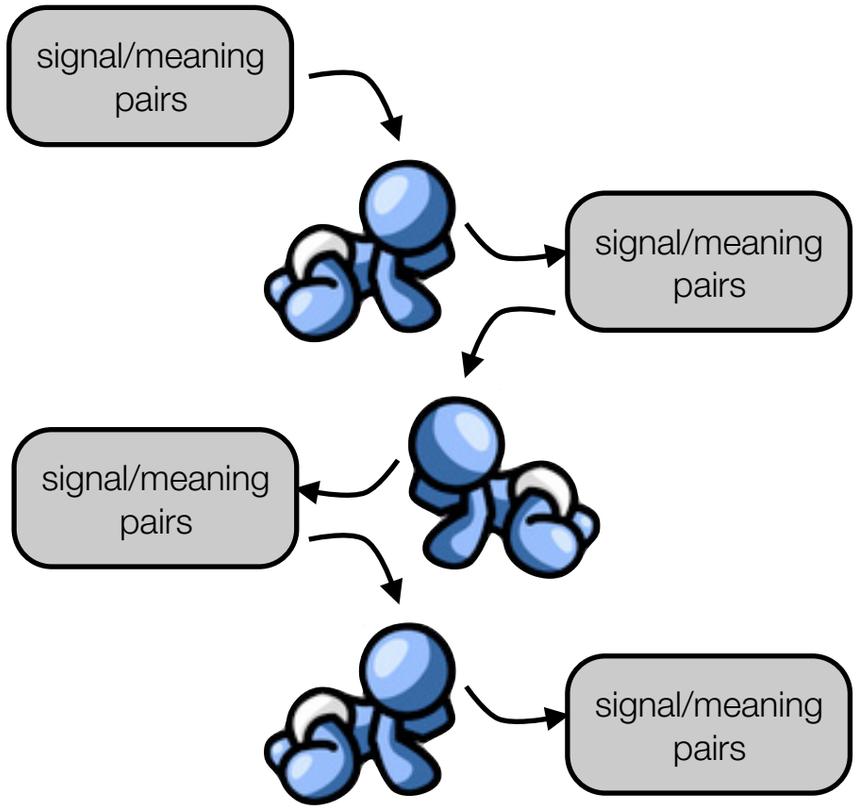
- Where does the language data come from that our learners have to acquire?



Solving the problem of linkage

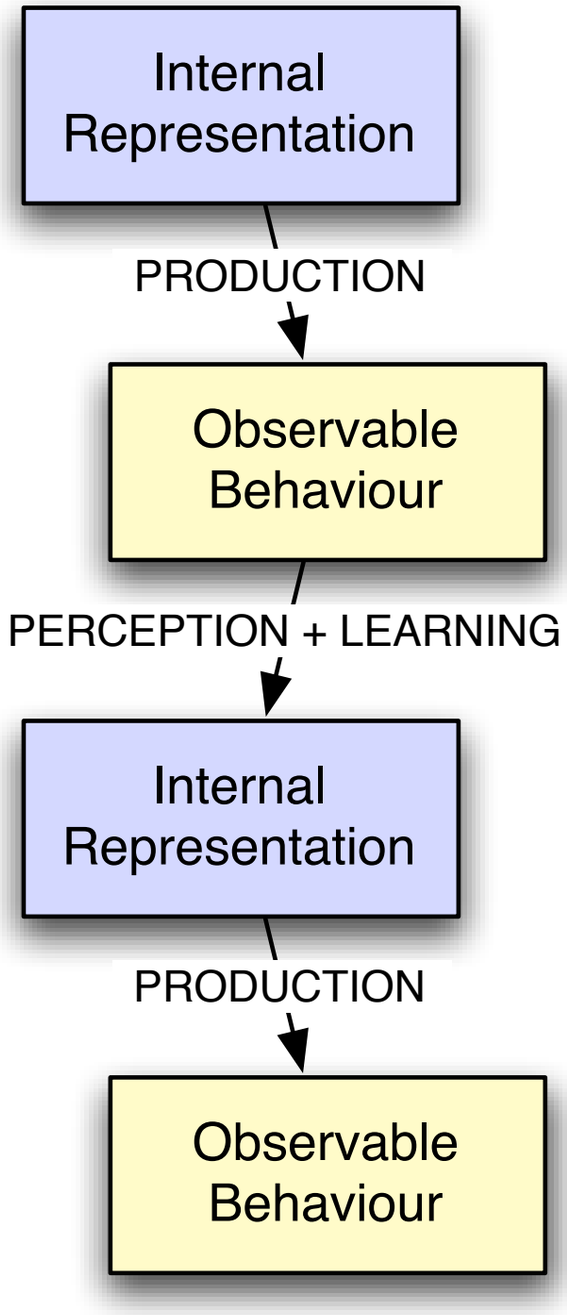
- Where does the language data come from that our learners have to acquire?

- From other learners!



Solving the problem of linkage

- Where does the language data come from that our learners have to acquire?
- From other learners!
- Language persists over time by repeatedly being learned and used by multiple individuals in a population
- It is out of this continual process of *iterated learning* that the structure of language emerges
- Note, this is *cultural* rather than biological evolution

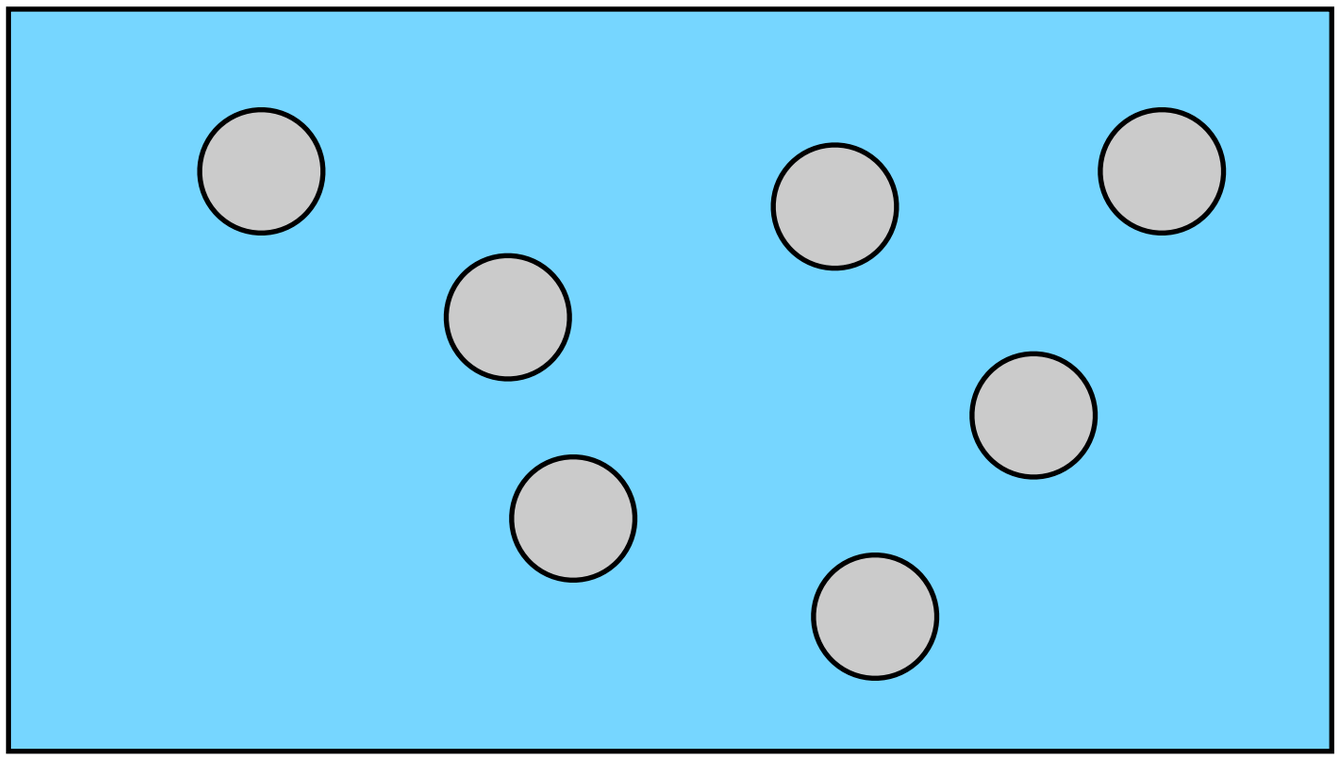


Key research question for iterated learning

What is the relationship between properties of individual learners and emergent universal properties of language structure?

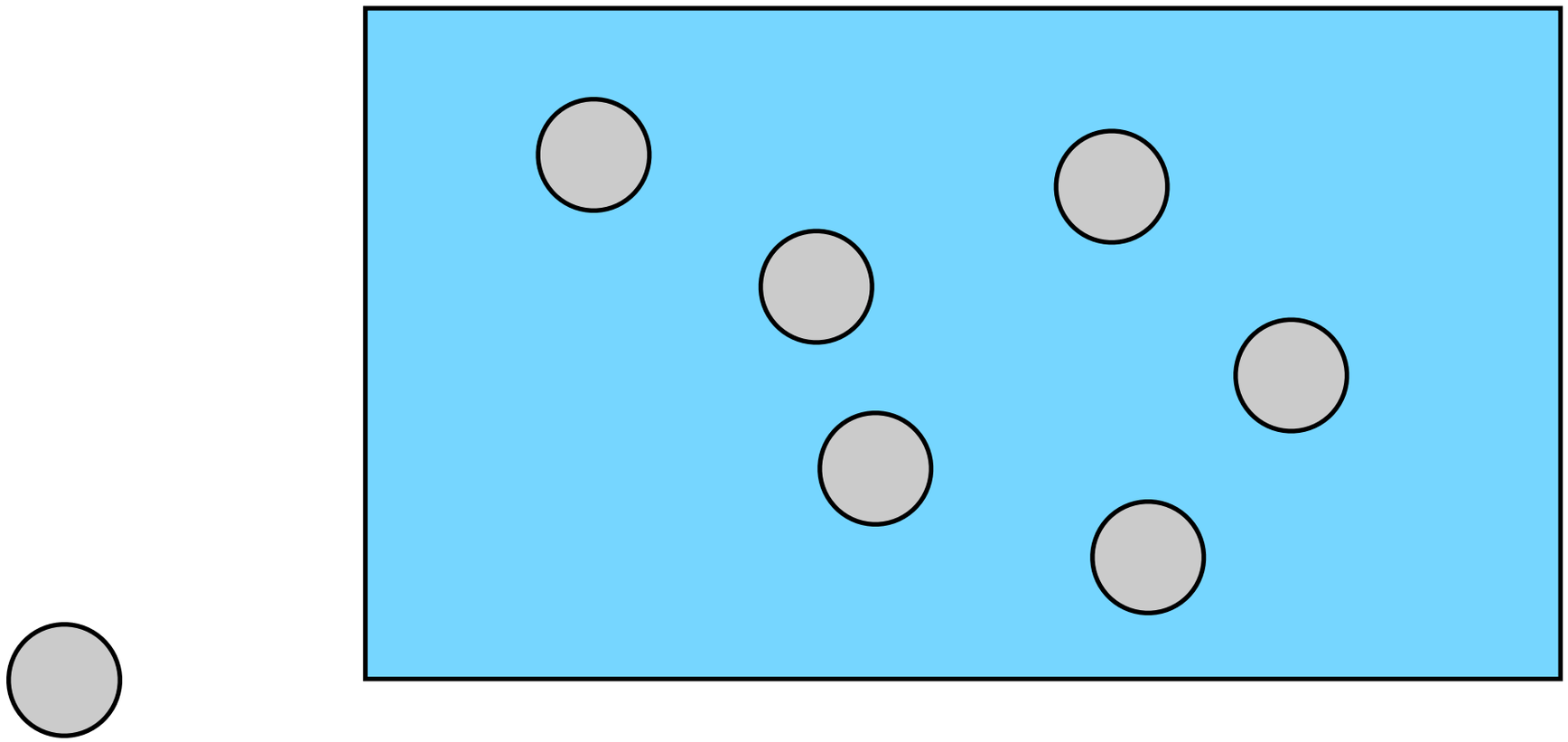
- We can try and tackle this by using our computational model
- Place agents in population in which they learn from each others utterances.
- Start with random language and observe what languages emerge given different possible learning rules and communicative strategies.

Population model



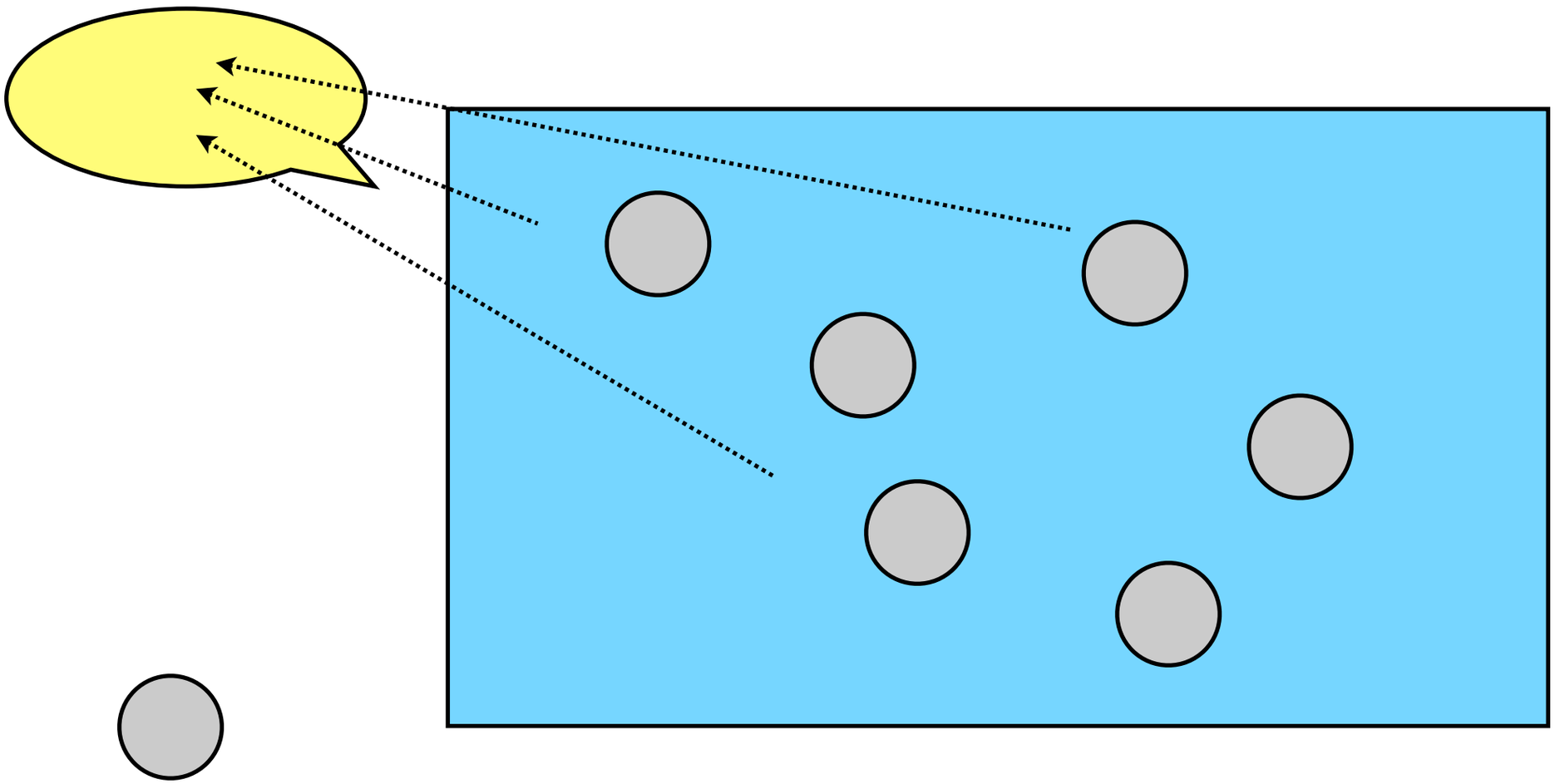
1. Somebody dies

Population model



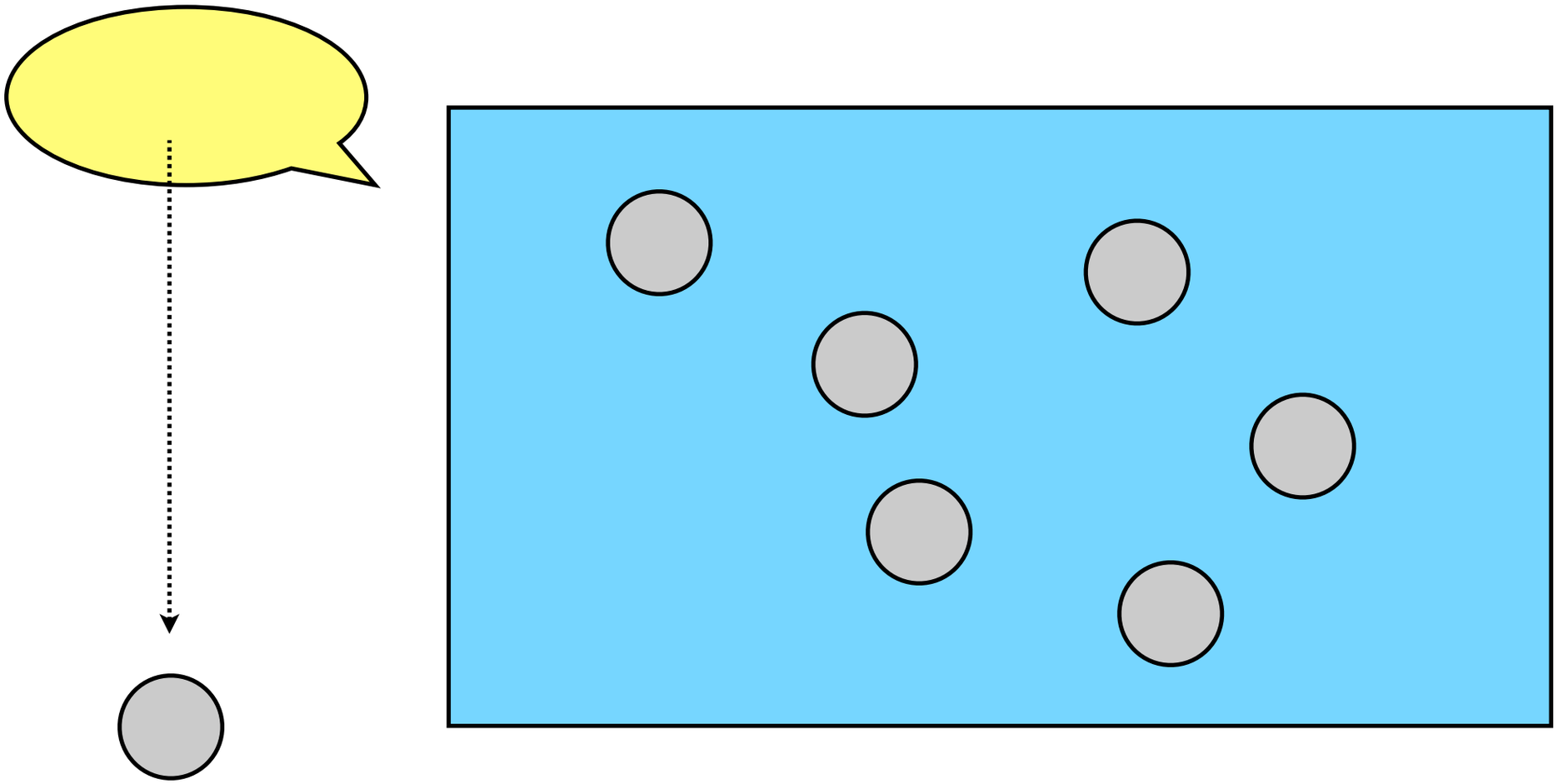
2. A child is born

Population model



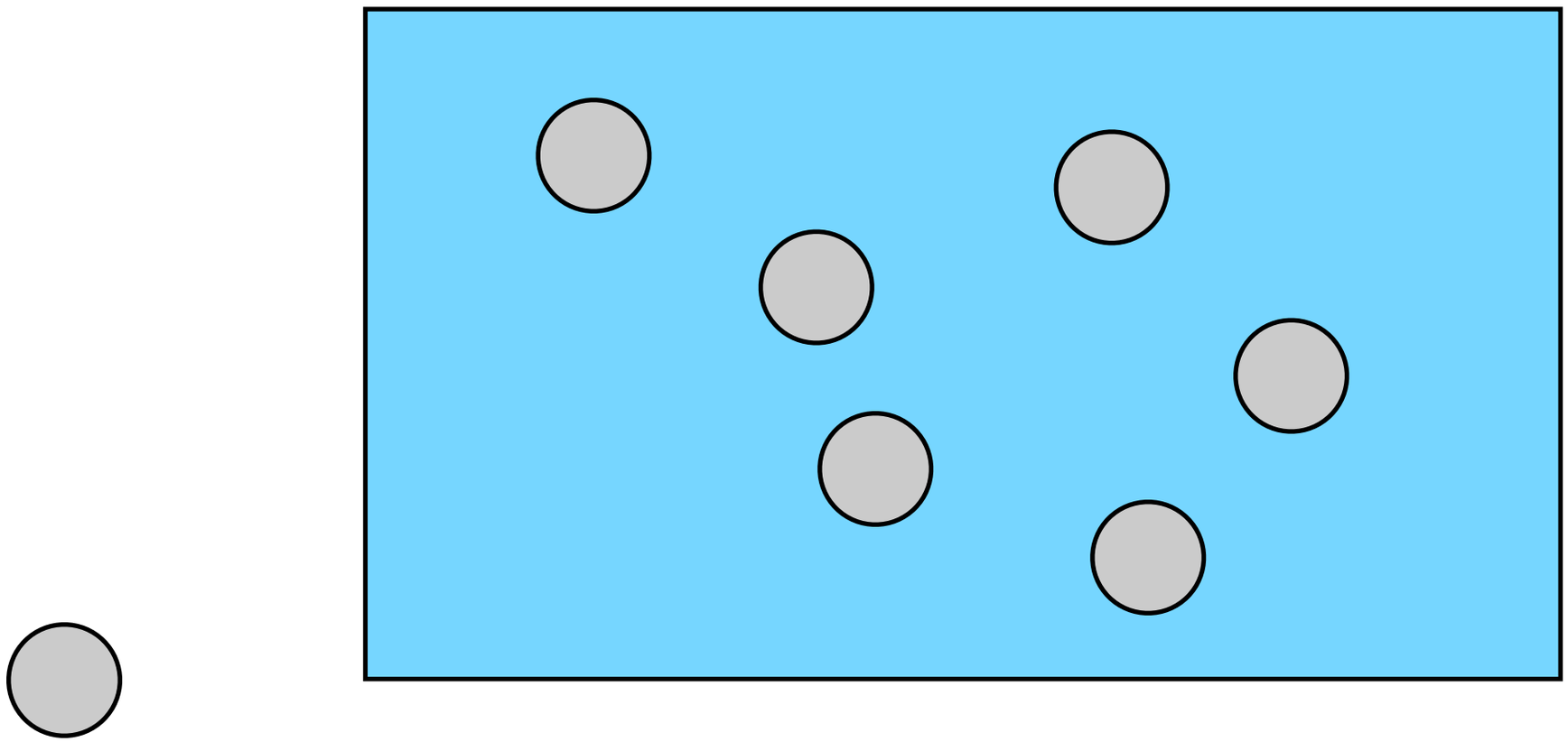
3. Adults speak

Population model



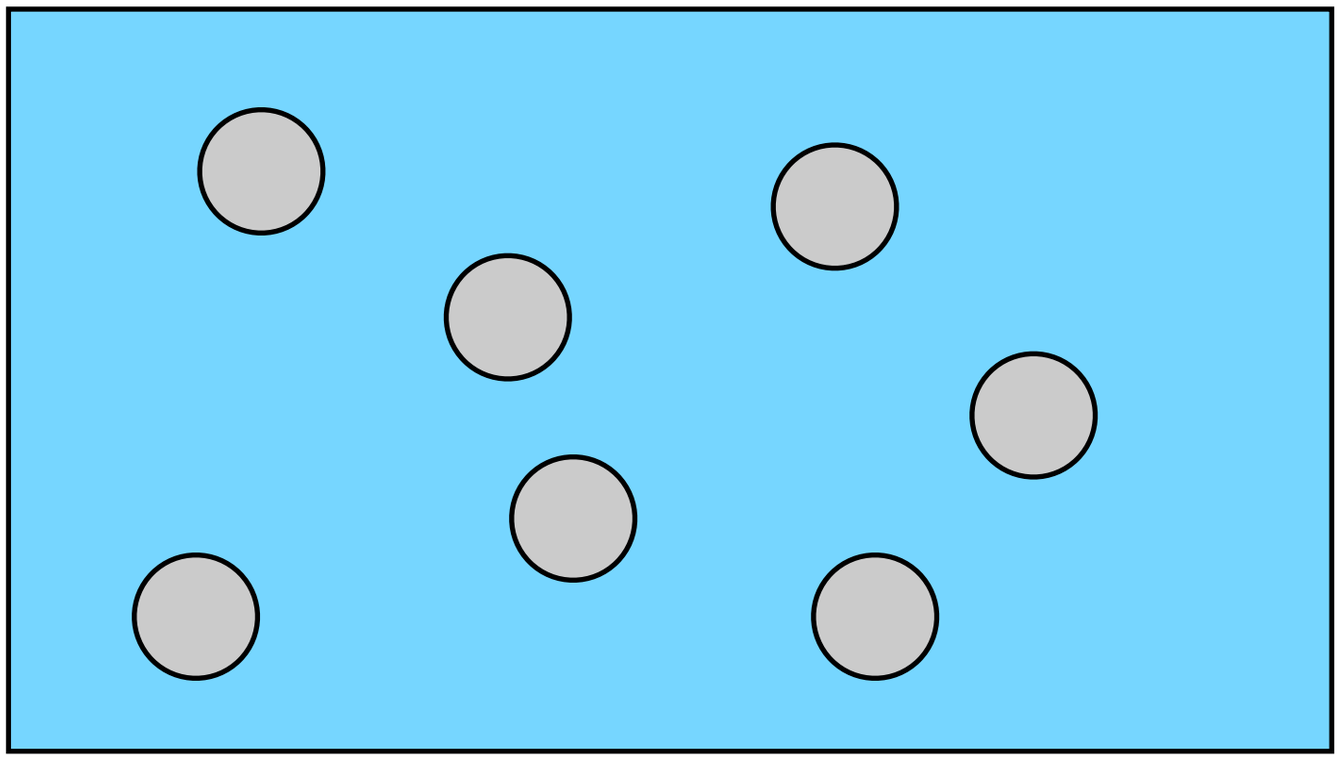
4. Child learns

Population model



5. Child enters population

Population model



6. Repeat

An aside: other possible population models

- Mesoudi & Whiten (2008) review a number of different ways we could model cultural evolution.

  - Replacement method (gradually replace individuals)

  - Transmission chain (whole population learns from previous generation, which is then replaced)

  - Closed group (no turnover at all, individuals constantly learn from each other)

Mesoudi, A., & Whiten, A. (2008). The multiple roles of cultural transmission experiments in understanding human cultural evolution. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *363*(1509), 3489-3501.

So what's going to happen?

- Find out in the lab next week!

- We'll implement cultural evolution by iterated learning.

    - Test to see the effect of lateral inhibition, speaker rationality, population dynamics have on the emerging language.

- After the lab: more background readings will appear on the website on cultural evolution, speaker rationality, learning bias

- Then a bit of a mid-term break for a week and a half.