# Simulating Language
# 14: From individual to population

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# What are the right questions about learning?

- We’ve looked at two types of learning: Hebbian, and Lateral Inhibition

- Smith (2002) looks at a huge range of different weight update rules and their influence on the way language evolves.

  *Smith, K. 2002. The cultural evolution of communication in a population of neural networks, Connection Science, 14:1, 65-84*

- Most obvious question about learning: **can a learner acquire an optimal language**

- But this isn’t the only relevant question...

# The “acquisition test”

- Do the Hebbian and Lateral Inhibition learners pass the test? Can they learn an optimal language?

- **Hebbian:**

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

# The “acquisition test”

- Do the Hebbian and Lateral Inhibition learners pass the test? Can they learn an optimal language?

- **Lateral Inhibition:**

TRAINING

m1→s1

m2→s2

m3→s3

| | s1 | s2 | s3 |
|---|---|---|---|
| m1 | 1 | -3 | -3 |
| m2 | -3 | 1 | -3 |
| m3 | -3 | -3 | 1 |

RESULT

m1→s1

m2→s2

m3→s3

# The “construction test”

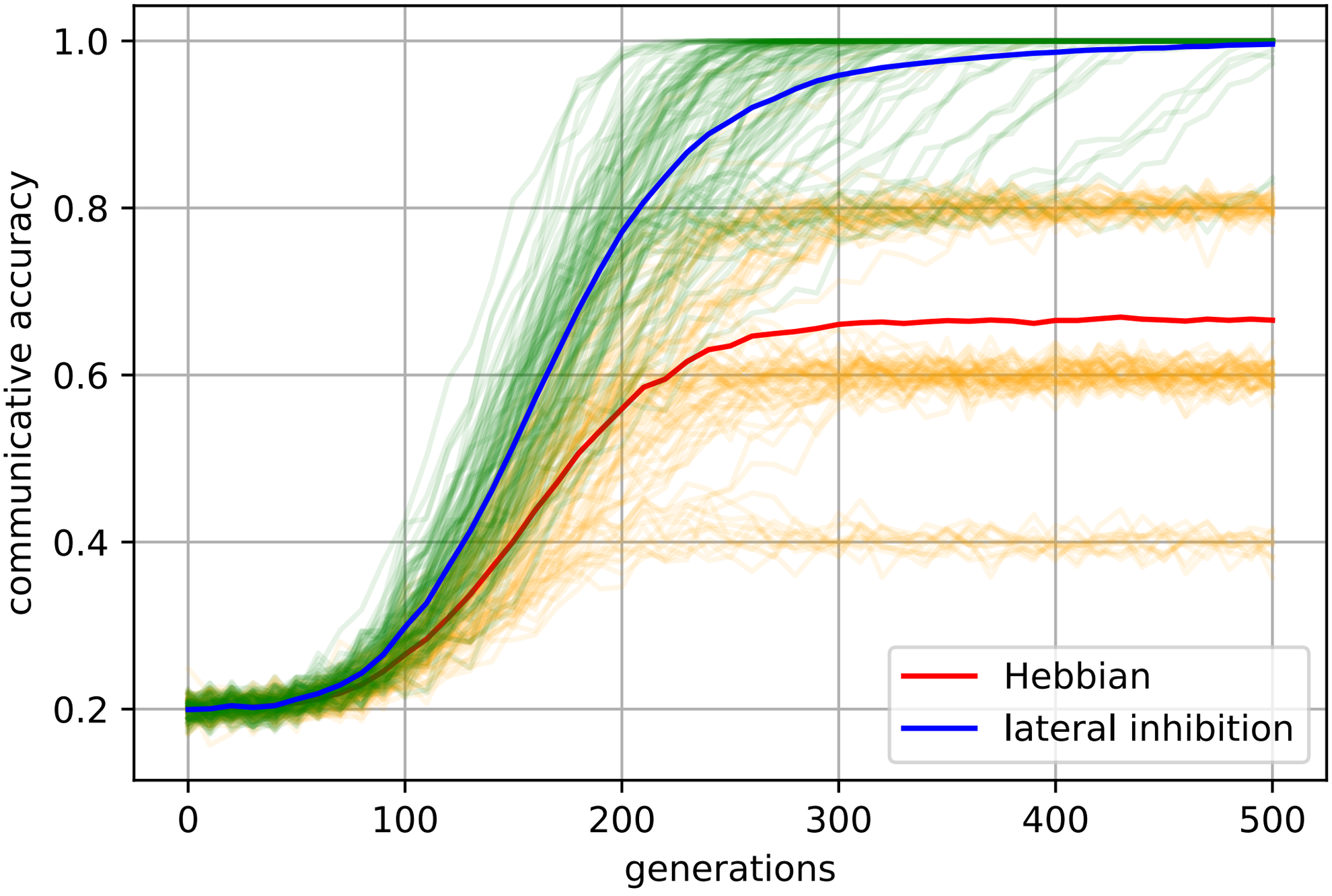
- Both pass the acquisition test just fine...

- If learning a language was all we cared about, we’d have nothing more to say. Either learner is fine.

- But what about evolving a language in the first place?

- This is why we implemented cultural evolution!

- The construction test: **can a population of learners construct an optimal language starting from sub-optimal ones?**


communicative accuracy
1.0
0.8
0.6
0.4
0.2
0
100
200
300
400
500
generations
Hebbian
lateral inhibition

Hebbian: passes acquisition test but does not construct

Lateral inhibition: passes acquisition test and does construct

**Difference only visible at the population level (and after cultural evolution)**

# Bias

- Different weight update rules correspond to different ways of learning
- They come with different *biases*
    - Although that's not immediately obvious just from looking at acquisition
- Population's language (in this case, just a vocabulary really) evolves to fit these biases
- But what exactly are these different biases?
- How do they relate to the *human* vocabulary learning strategy?

# Constructor bias

TRAINING

m1→s1

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

RESULT

m1→s1 (not s2, s3)

m2→s2, s3 (not s1)

This learning rule is biased against synonyms (because inhibition is spread along the row)

It’s also biased against homonyms (because inhibition is spread down the column)

# Hebbian bias?

TRAINING

m1→s1

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

RESULT

m1→s1 (not s2, s3)

m2→s1, s2, s3

This learning rule is biased against synonyms (because only activation on the row is for the signal seen)

It is neutral with respect to homonyms (because other weights are unchanged)

# Languages adapt to the bias

- Population's vocabulary changes over time to match the bias of learners

- Constructors (like the lateral inhibition learner) are biased in favour of **one-to-one** mappings between meanings and signals

- One-to-one systems happen to be optimal for communication, so this is what emerges through the process of iterated learning

- This is adaptation without biological evolution

# What about real humans?

- Experiment on children's learning bias
  Markman & Wachtel (1988) on synonymy

"Show me the fendle."

- Children pick the unfamiliar object given an unfamiliar word

# Anti-synonymy bias (Mutual Exclusivity)

## Before

banana

???

## After (two possibilities)


banana

fendle

# Homonymy bias (Doherty 2004)

- “... at the zoo, they saw a strange tapir from Brazil. Hamish thought the tapir’s long nose looked funny”


“Which one is the tapir in this story?”

# Homonymy bias (Doherty 2004)

- "... at the zoo, they saw a strange **cake** from Brazil. Hamish thought the **cake's** long nose looked funny"


"Which one is the **cake** in this story?"

# Anti-homonymy bias

## Before

cake

???

## After (two possibilities)

cak

c e

cake

???

# Children's learning biases

- Children don't like:
    - synonymy
    - homonymy

- They have the same biases as the lateral inhibition learners in our simple model and populations of such learners evolve optimal communication systems

- Our model would predict that human vocabularies would be pushed in this direction **simply through iterated learning**

But but but... wait...

# Where do these biases come from?

- A tempting answer: They evolved, just like the innate signalling systems supporting optimal communication did.

- Instead of evolving the signalling systems directly, biases that lead to the *cultural* evolution of optimal signalling could have evolved biologically.

- Easy enough to test! Just treat the learning algorithm as being genetically inherited whilst also transmitting languages culturally via iterated learning. Select on the basis of good communication.

- Smith (2004) tried just this.

  *Smith, K. (2004). The evolution of vocabulary. Journal of theoretical biology, 228(1), 127-142.*

# Invasion of the mutants

- Smith (2004) plays **lateral inhibition** and **Hebbian** learners off against each other

- Create a population mainly made up of one type, but with a small number of another type (the mutant)

- Agents inherit both the communication system (by cultural transmission), and their learning strategy (by genetic transmission)

- Both culture and biology evolve

- If selection is based on mutual communicative success, which mutants will invade?

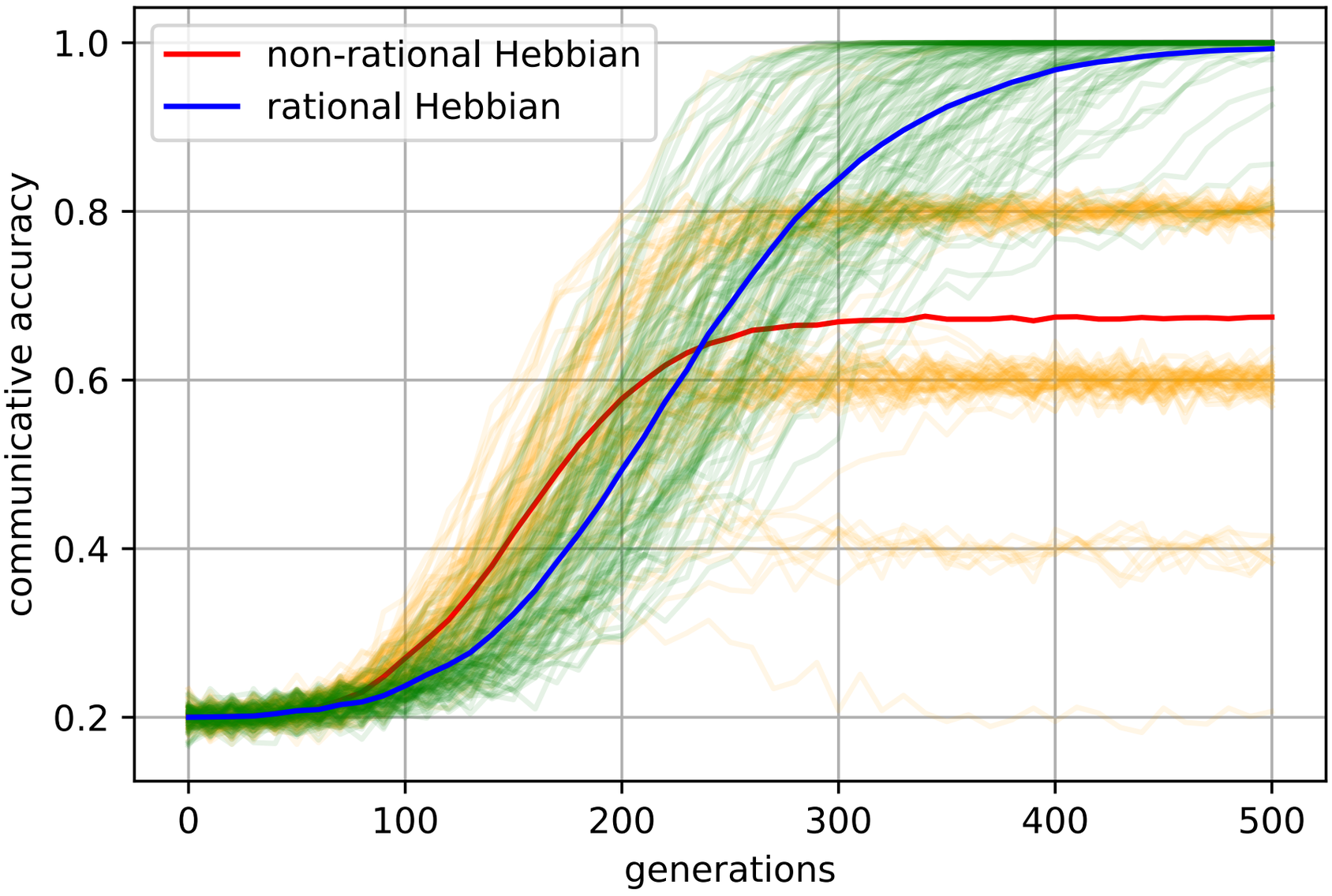
# Surprising result: evolution is hard

- Lateral inhibition learners don't often invade, *even though it would increase the fitness of the population if they did*

- Two problems:
  - Need a lot of mutants before they start to have a good effect on the population's language...
  - ...and even then, there's a time-delay before the good language evolves culturally.

- Speculative conclusion: human learning biases *haven't* evolved only for communication.

# An alternative solution: communicative rationality



# Routes to communication

- We’ve now seen three ways of getting optimal signalling off the ground
    - 1. Biological evolution of innate signalling (under certain circumstances)
    - 2. Cultural evolution of signalling in a population of learners with the right kind of learning bias
    - 3. Cultural evolution of signalling in a population of learners who do some rational inference about communication
- Which is it for language?
  It can’t be 1, but we don’t actually know between 2 and 3.

# The story so far, and what comes next

- Signalling systems (and languages) can evolve as a result of their transmission
    - We can model this
- The **biases** of learners shapes what evolves
- This potentially allows us to link findings about biases in learning at the individual level to predictions / observations about language at the population level
    - But caution (or better, a model) is required - the acquisition test here was misleading, there is more than one route to optimal systems

- **Next up:** a class of models that allow us to be very clear and very precise about bias