Simulating Language
Lecture 8: What is the constructor bias?

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Smith's (2002) approach to language evolution

- Previous approaches:

  Build learners with particular biases
  Test them with particular hand-built language
  (this is the **acquisition** test)

- But where do the languages come from?

- Cultural evolution through iterated learning
  Learners learn from other learners in a population

- Two new tests of learning bias in a population:

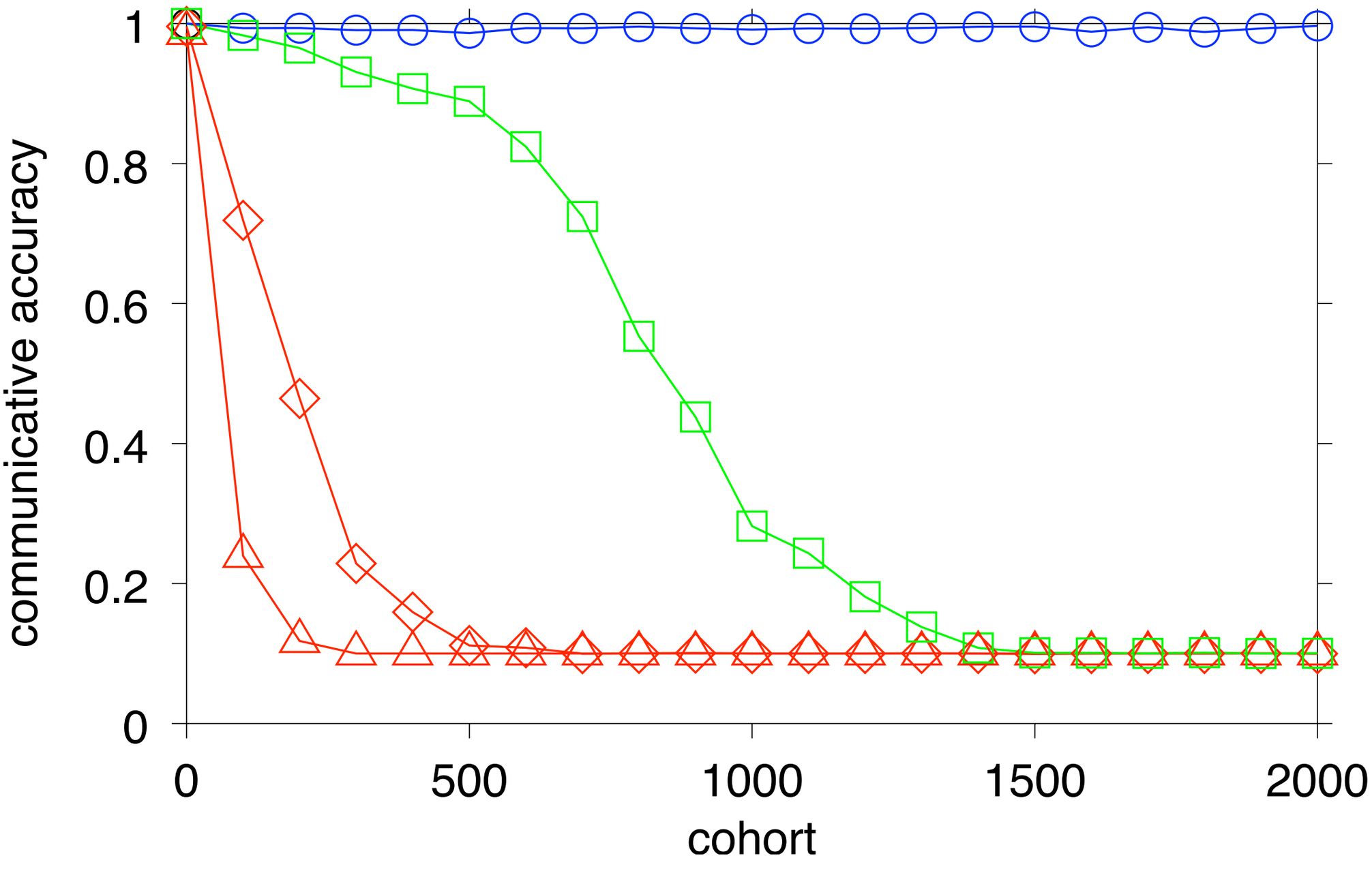
  Maintenance test
  Construction test

The acquisition test results

- If we look at -1, 0, or 1 for α, β, γ and δ, then there are 81 learning rules
- 50 of these fail the **acquisition** test. We will call these **non-learners**
- 31 pass the test: call these **learners**

For all learners: $\alpha + \delta > \beta + \gamma$
For all non-learners: $\alpha + \delta \leq \beta + \gamma$

Maintenance test results



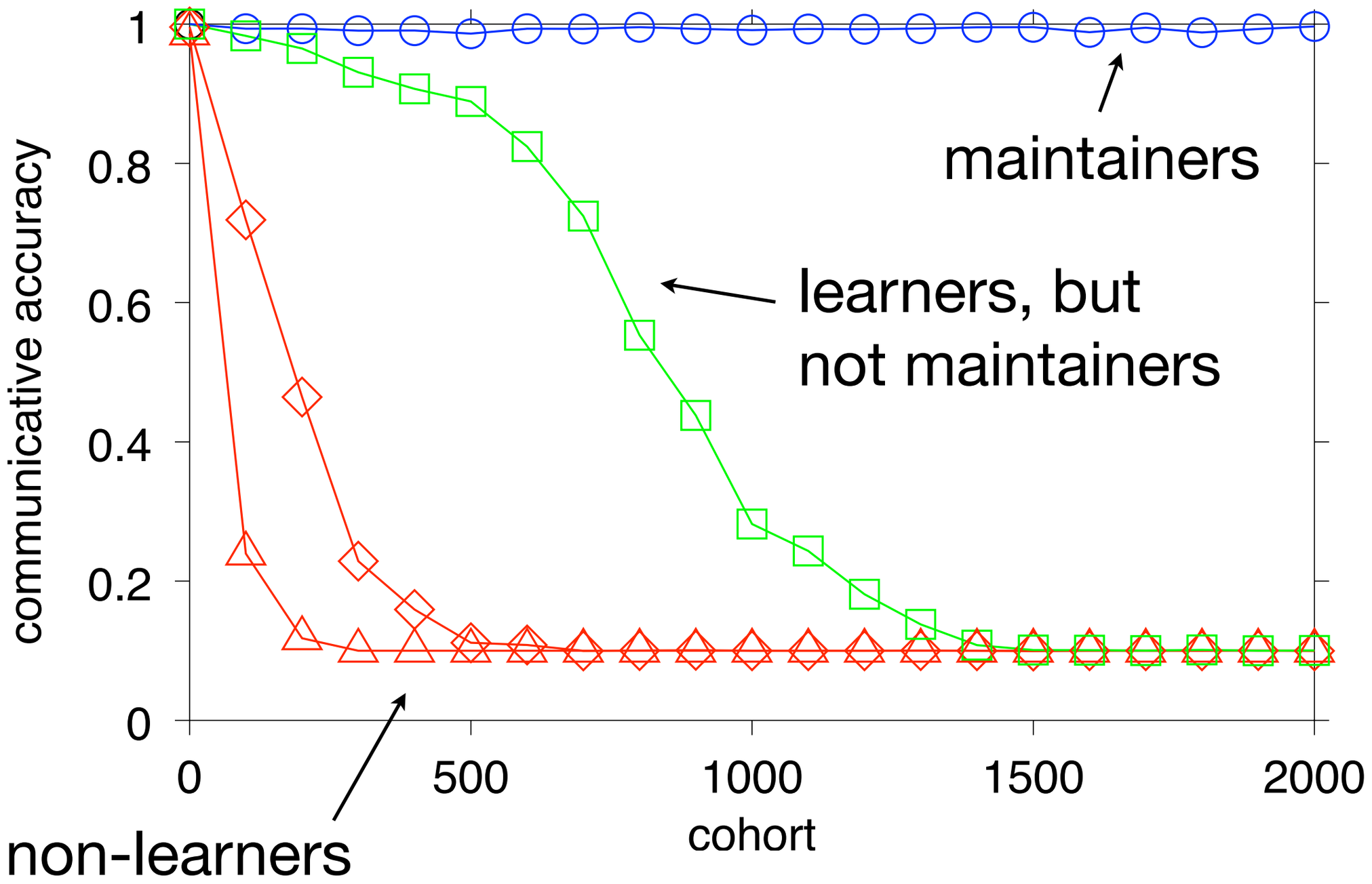
Maintenance test results

- Out of the 81 rules:
    - 63 fail the **maintenance** test
    - 18 pass: call them **maintainers**

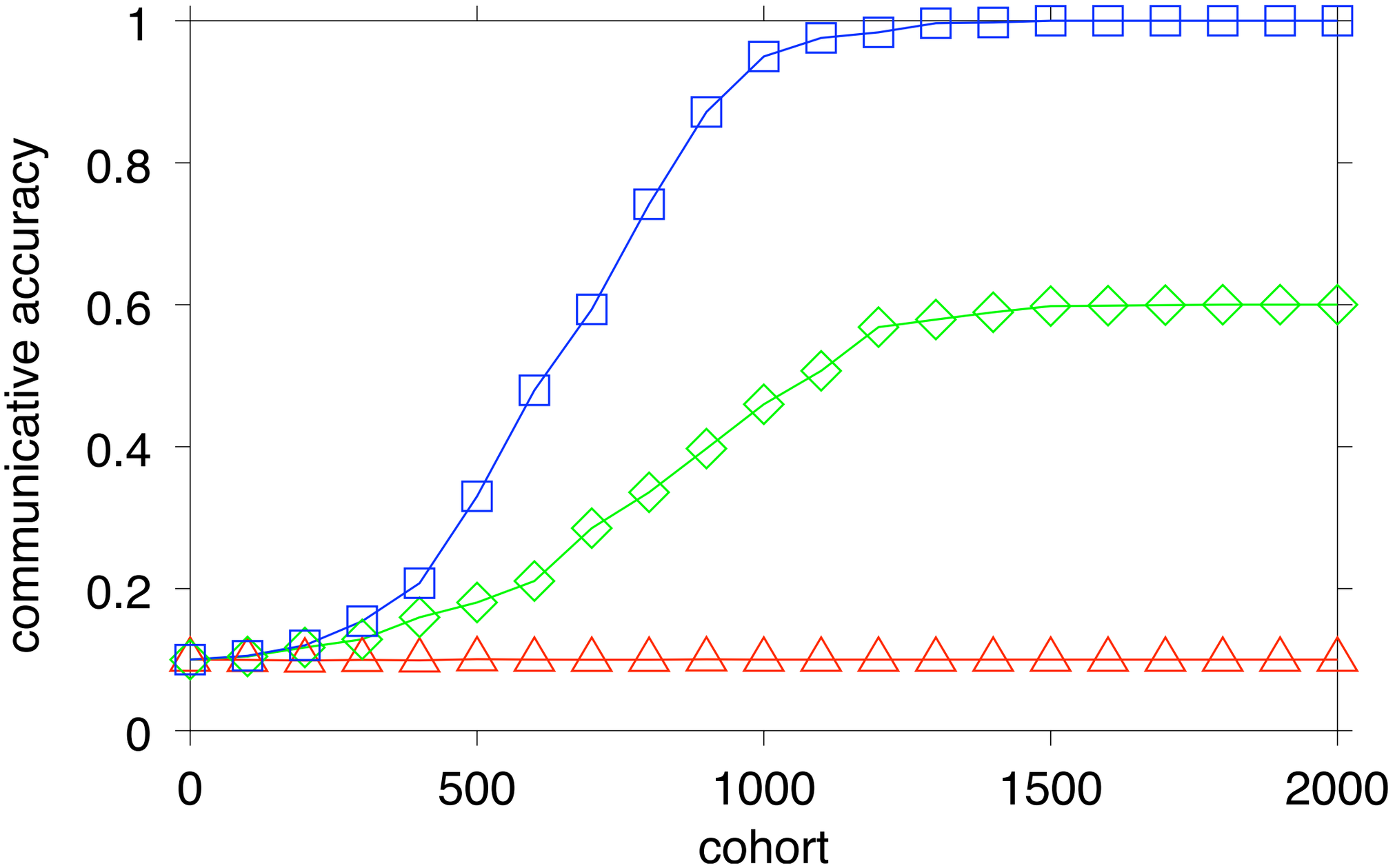
Note, these are a subset of learners

For all maintainers: $\alpha > \beta$ & $\delta \geq \gamma$

Maintenance test results



Construction test results



Construction test results

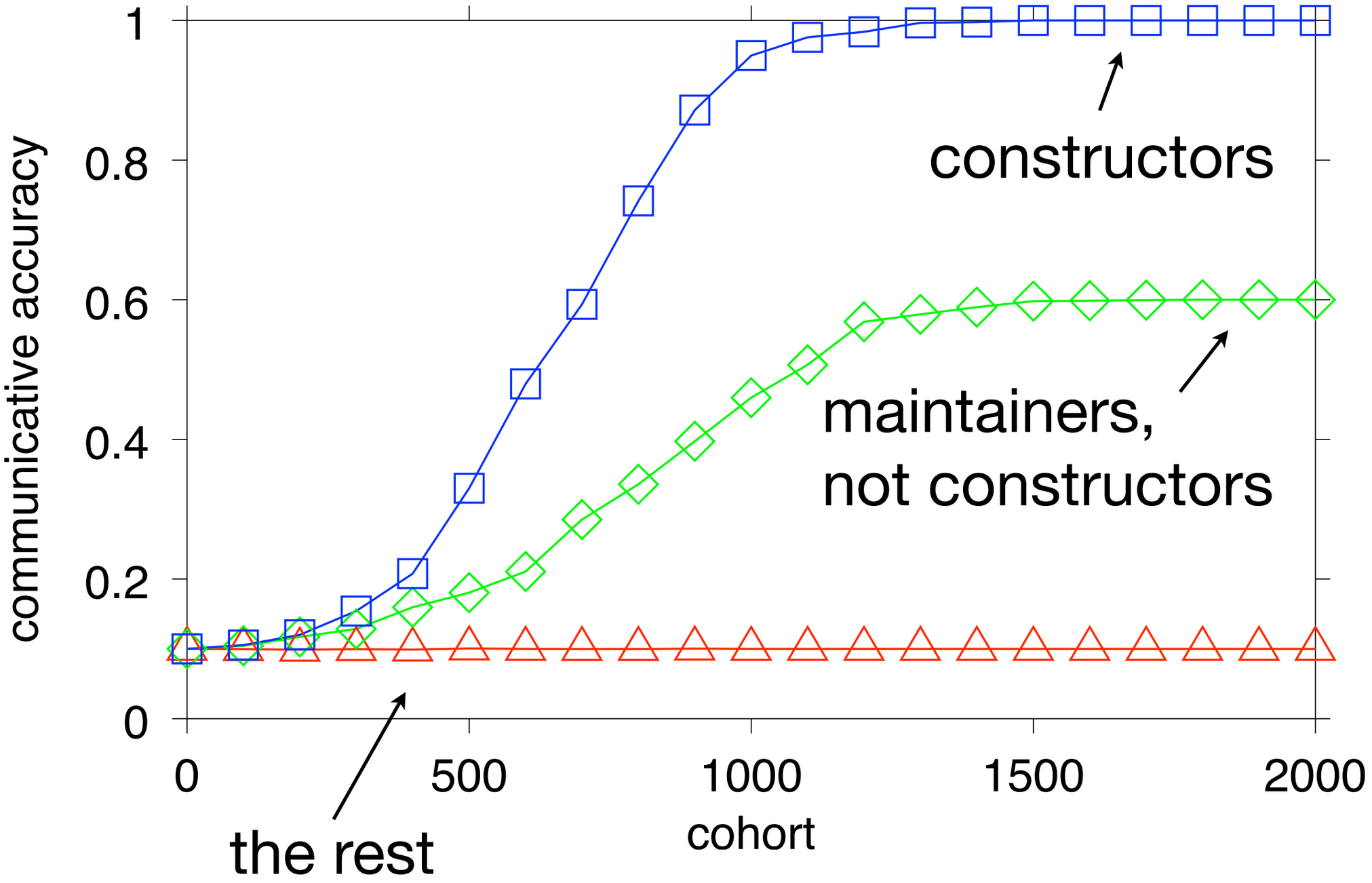
- Out of the 81 rules:
    - 72 fail the construction test
    - 9 pass: call these **constructors**

These are a subset of the maintainers

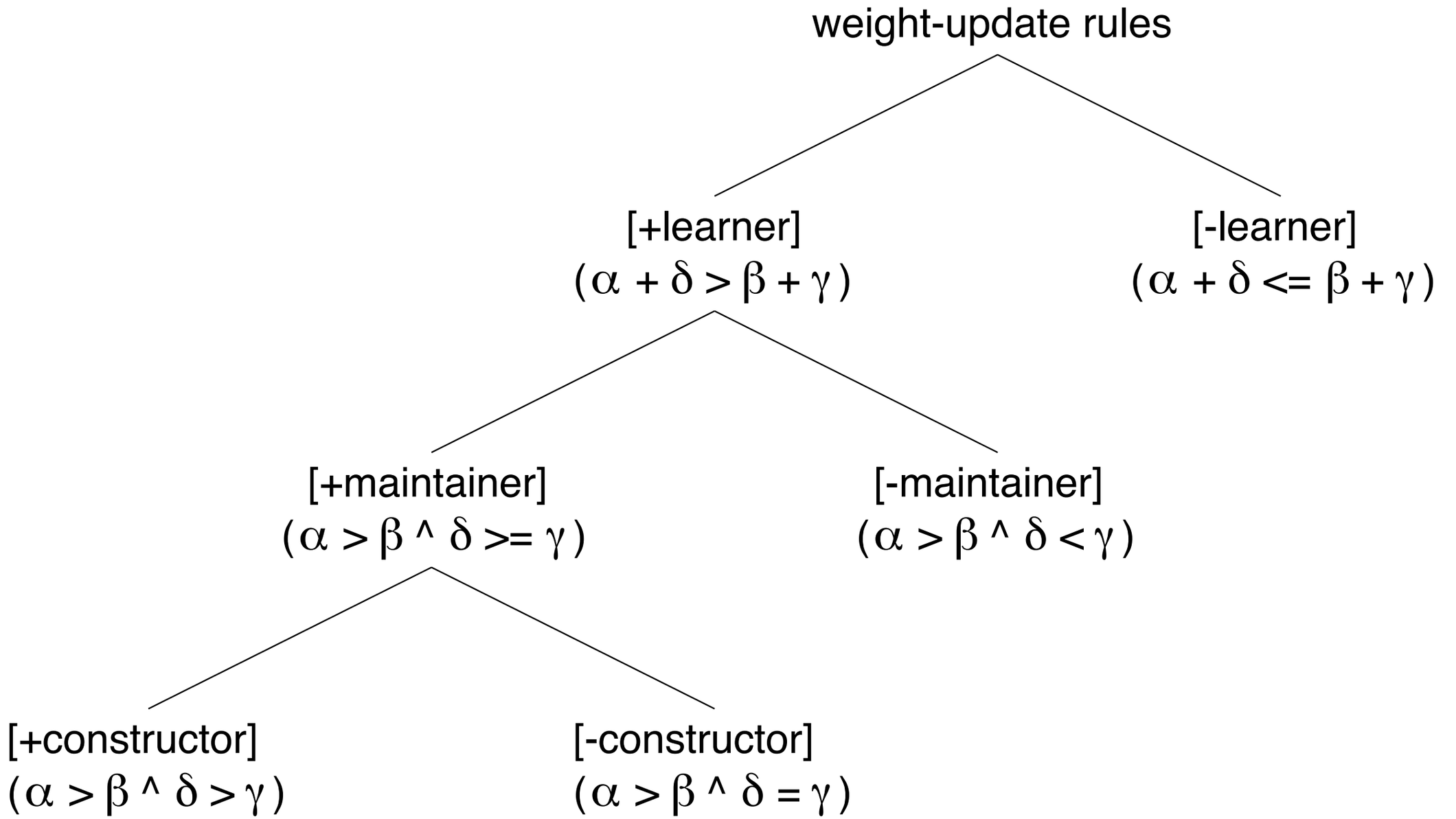
For all constructors: $\alpha > \beta$ & $\delta > \gamma$

(sometimes this is called “lateral inhibition”)

Construction test results



A hierarchy


weight-update rules
[+learner]
(α + δ > β + γ)
[-learner]
(α + δ <= β + γ)
[+maintainer]
(α > β ^ δ >= γ)
[-maintainer]
(α > β ^ δ < γ)
[+constructor]
(α > β ^ δ > γ)
[-constructor]
(α > β ^ δ = γ)

Bias

- Different weight update rules correspond to different ways of learning
- They come with different *biases*
- Population's language (in this case, just a vocabulary really) evolves to fit these biases
- Biases are a consequence of α, β, γ and δ
- But what exactly are these different biases?
- How do they relate to the *human* vocabulary learning strategy?

Three patterns

learning: $\alpha + \delta > \beta + \gamma$

maintenance: $\alpha > \beta \ \& \ \delta \geq \gamma$

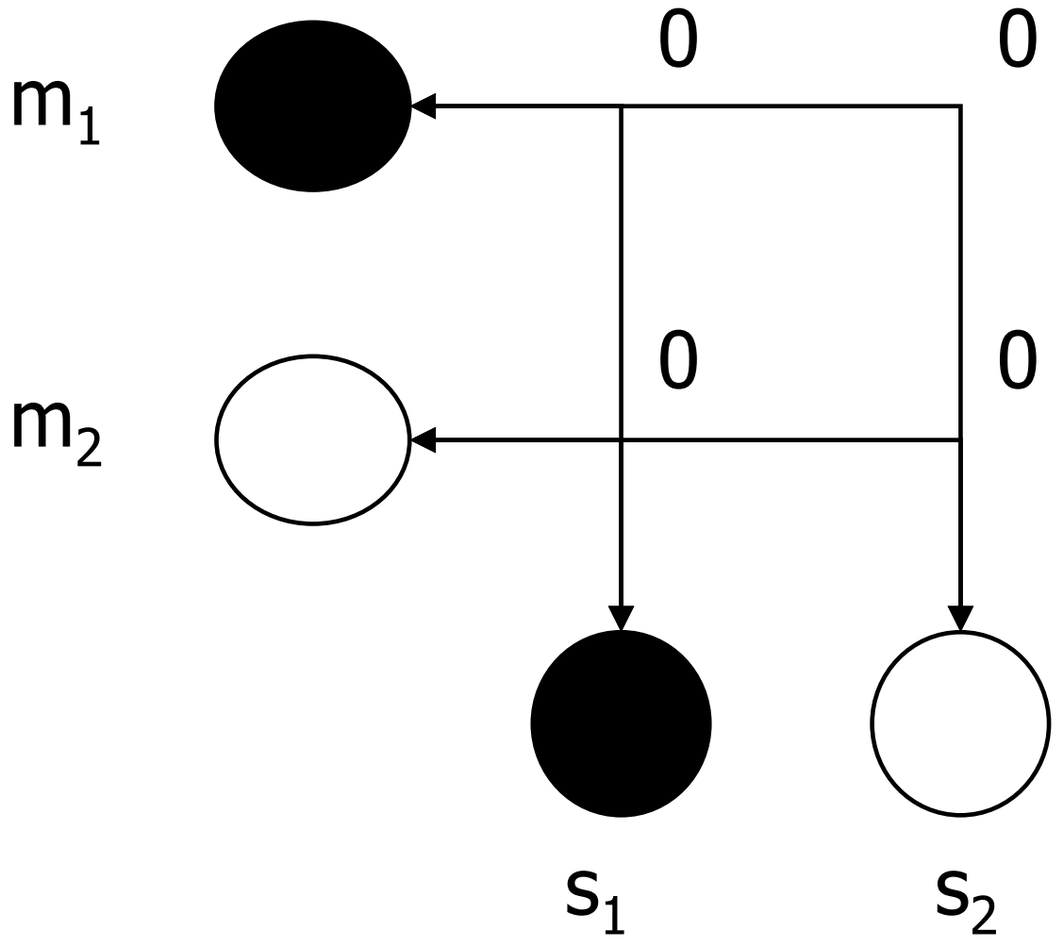
construction: $\alpha > \beta \ \& \ \delta > \gamma$

- What do these patterns mean?

Working out bias

- A constructor rule: [+1, -1, -1, +1]

Observation:
m1→s1



Working out bias

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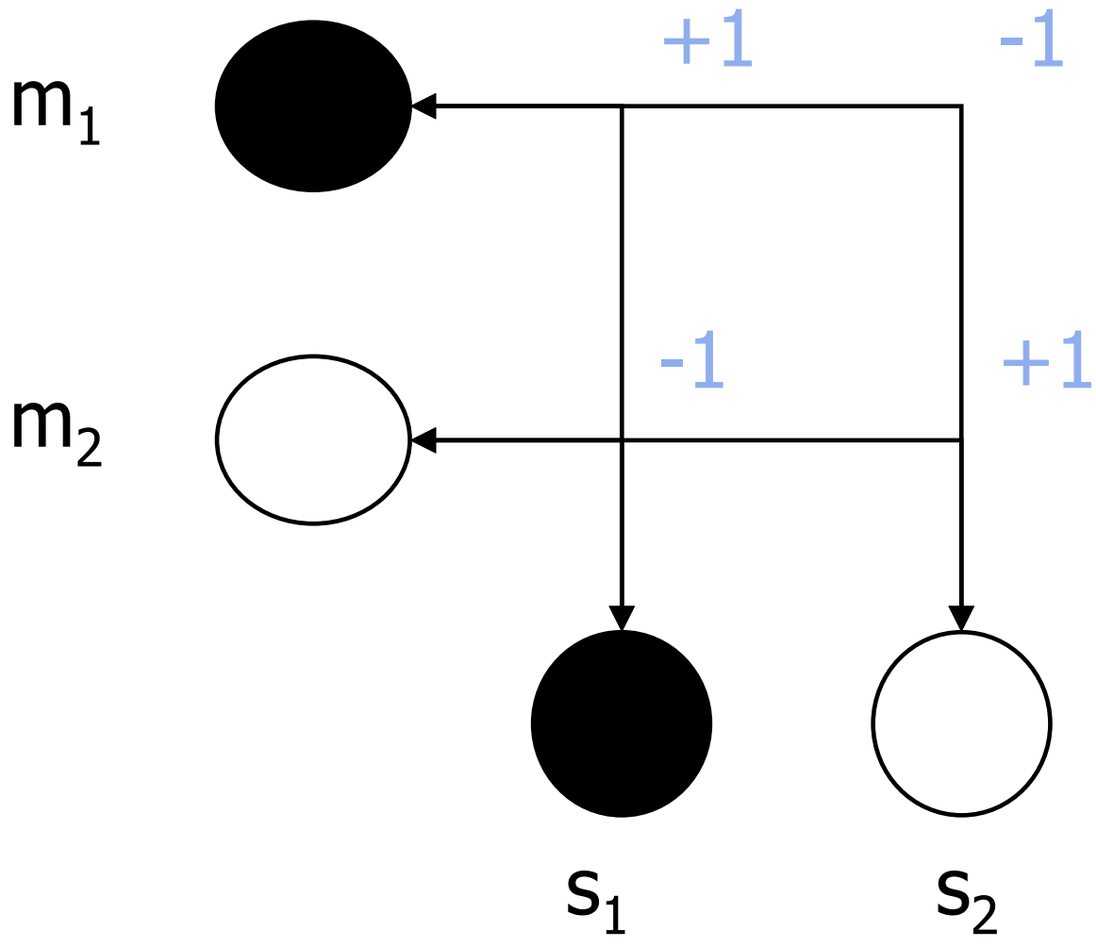

Working out bias

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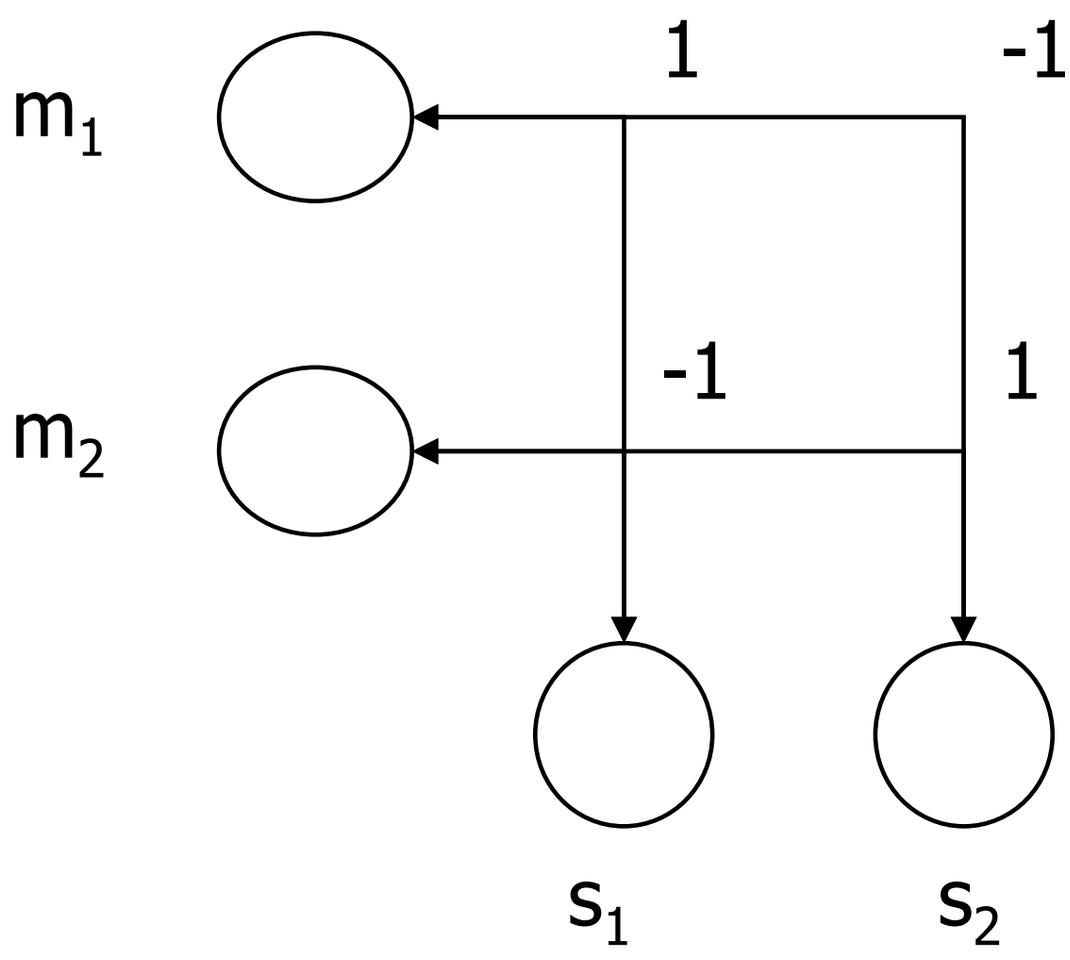
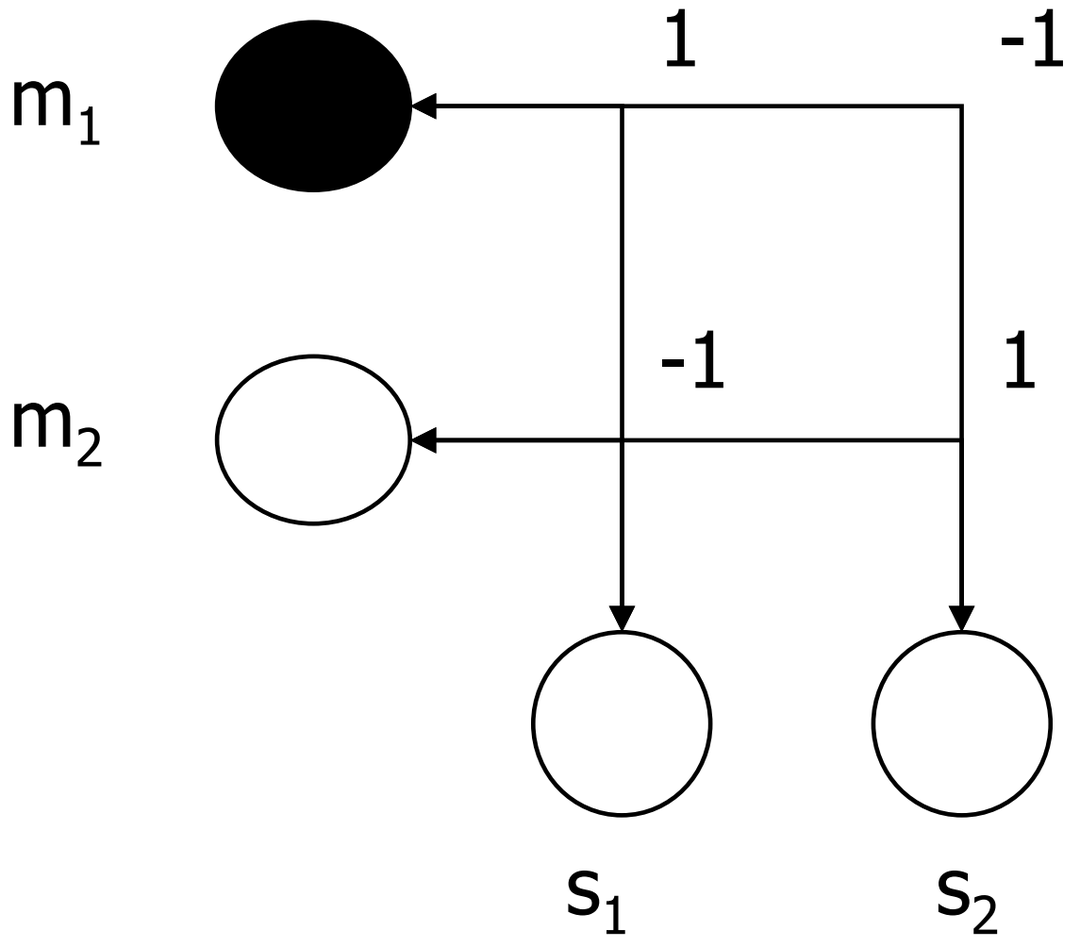


Working out bias

- A constructor rule: [+1, -1, -1, +1]

Production:

m1→?



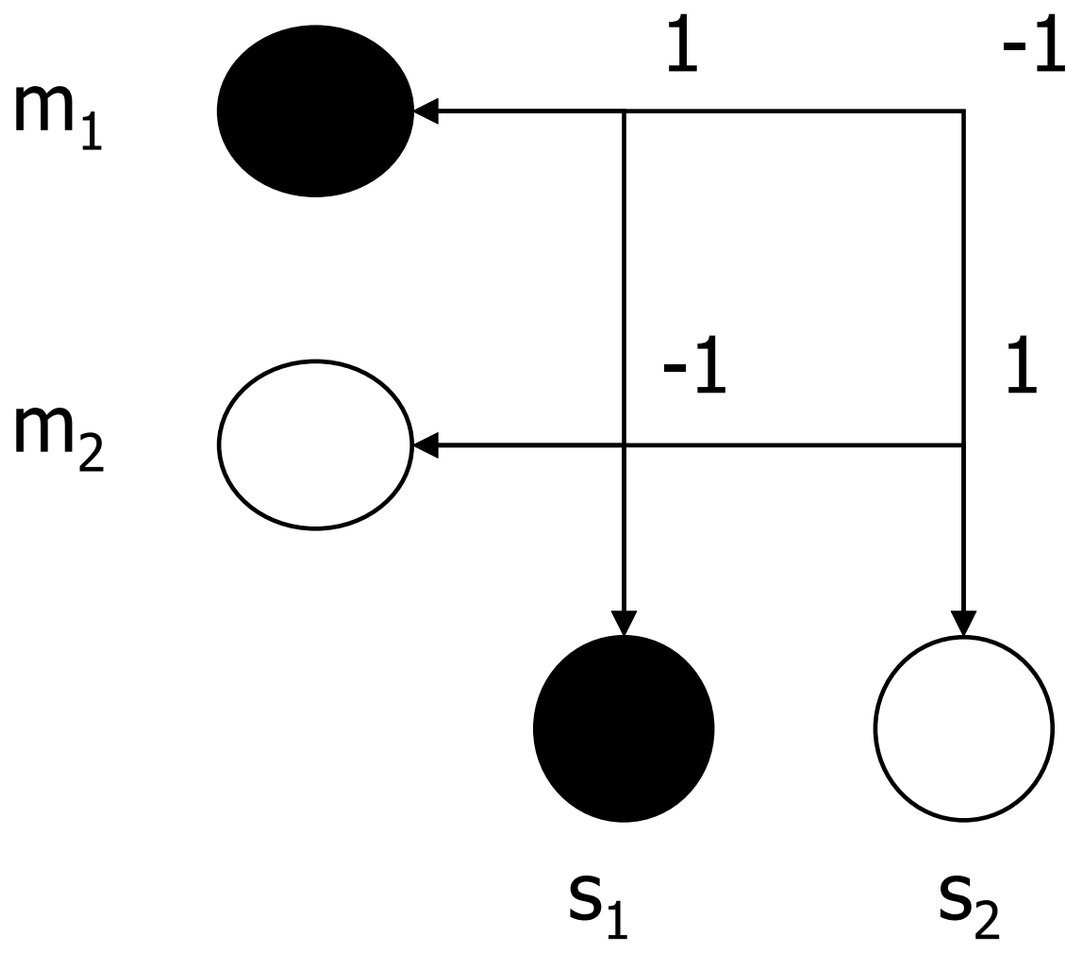
Working out bias

- A constructor rule: [+1, -1, -1, +1]

Production:

m1→s1

(*not* s2)

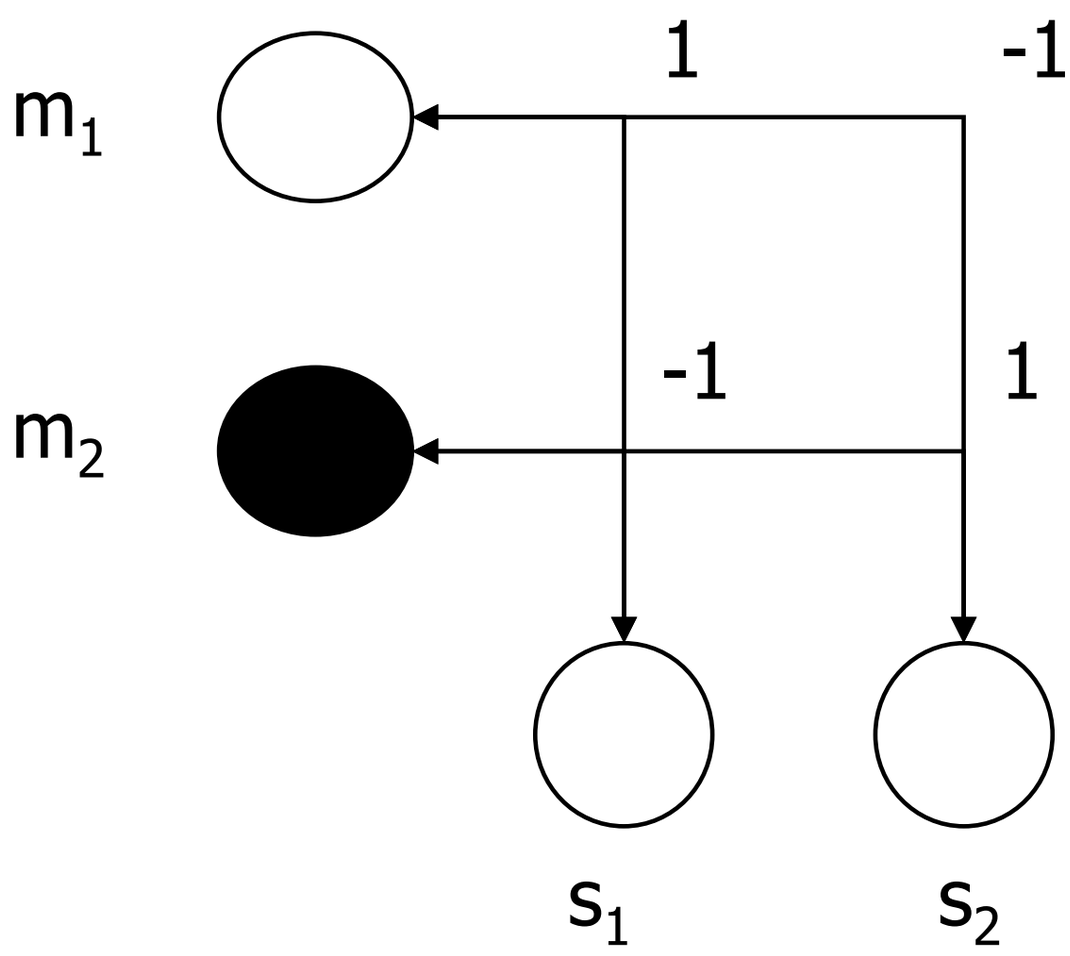


Working out bias

- A constructor rule: [+1, -1, -1, +1]

Production:

m2→?



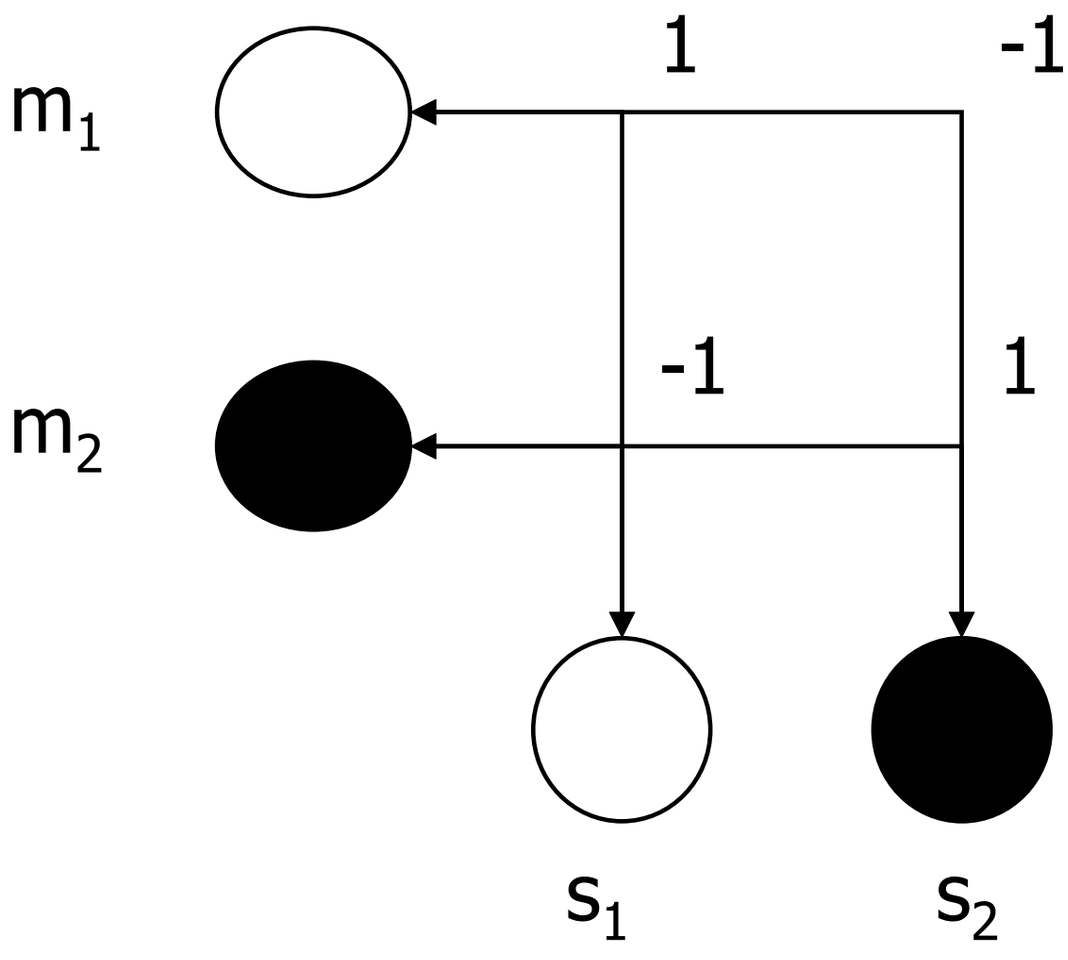
Working out bias

- A constructor rule: [+1, -1, -1, +1]

Production:

m2→s2

(*not* s1)



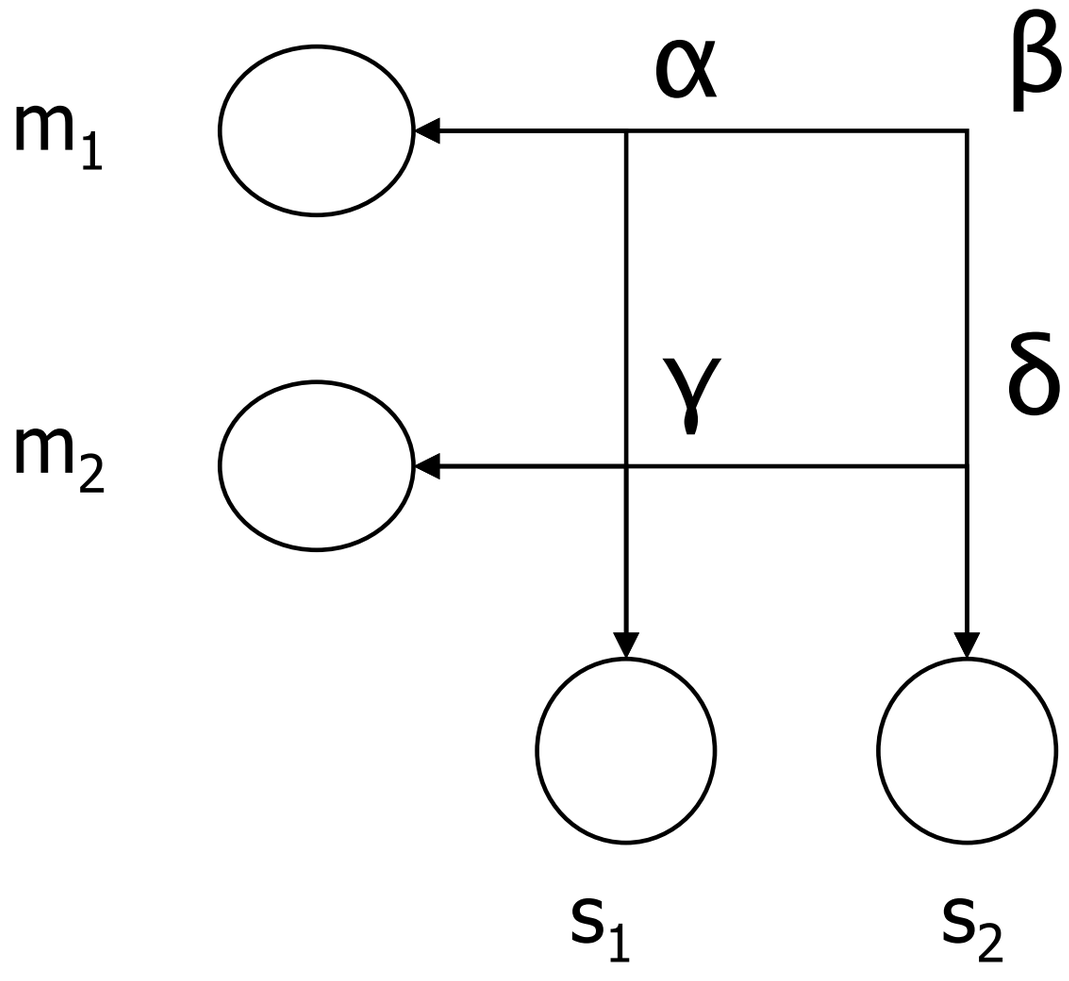
Working out bias

- Constructors in general: α > β & δ > γ
  After one exposure to m1→s1

Production:

m1→s1

m2→s2

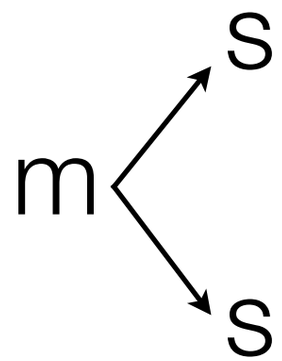


The constructor bias

- Constructors don't like:

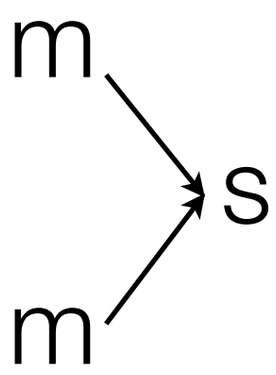
- One meaning to multiple signals

  because α > β
  bias against synonymy



- Multiple meanings to one signal

  because δ > γ
  bias against homonymy



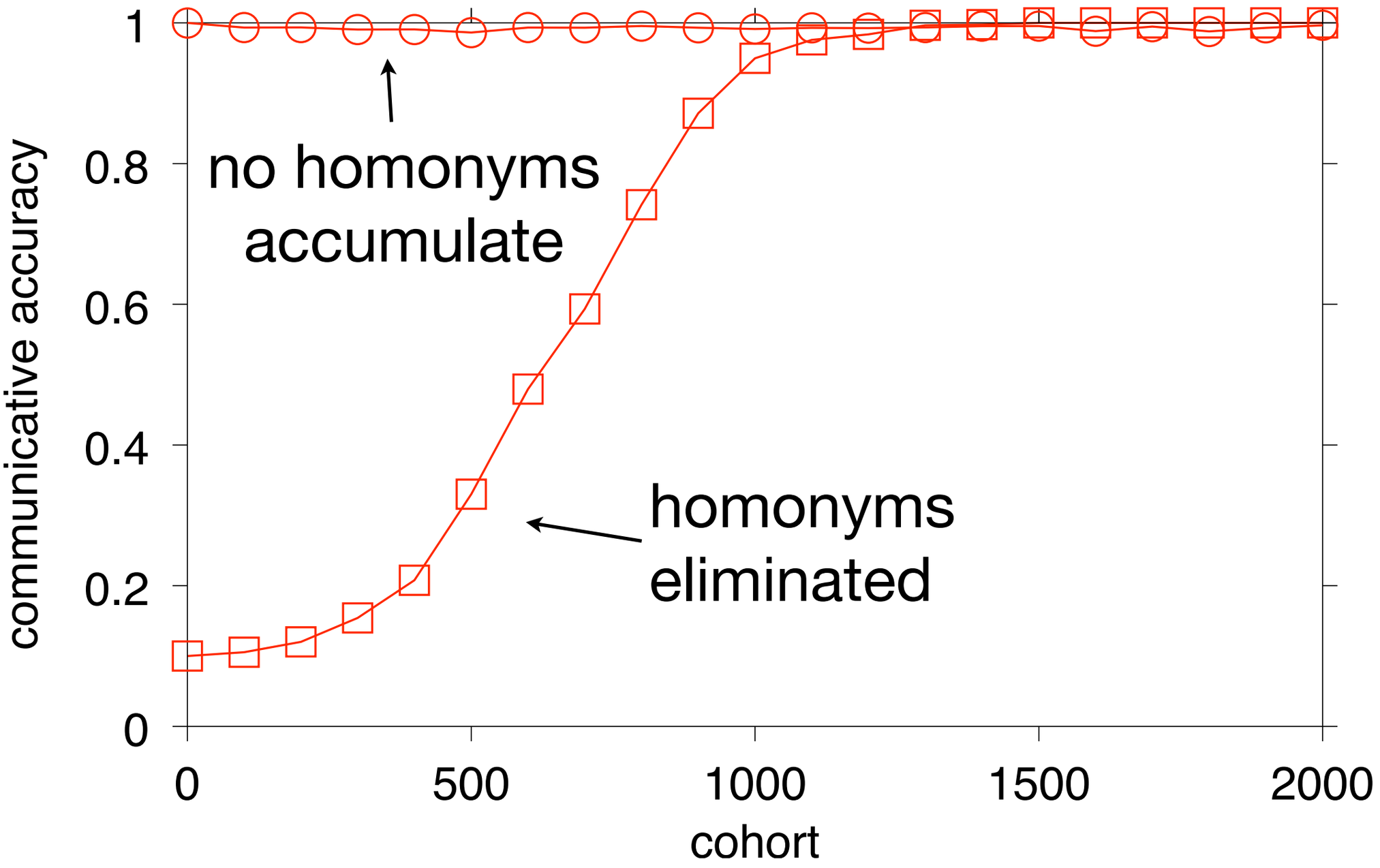
The constructor bias

- Constructors biased in favour of **one-to-one** mappings between meanings and signals

- Population's vocabulary changes over time to match this bias

- One-to-one systems happen to be optimal for communication

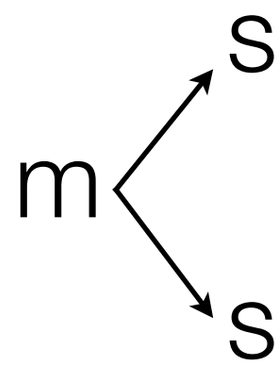
Constructor behaviour



The maintainer bias

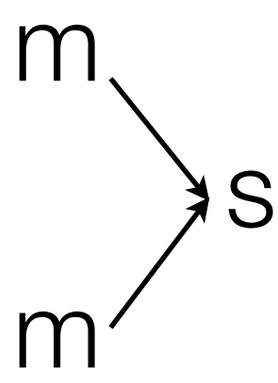
- Biased against synonymy

  because α > β

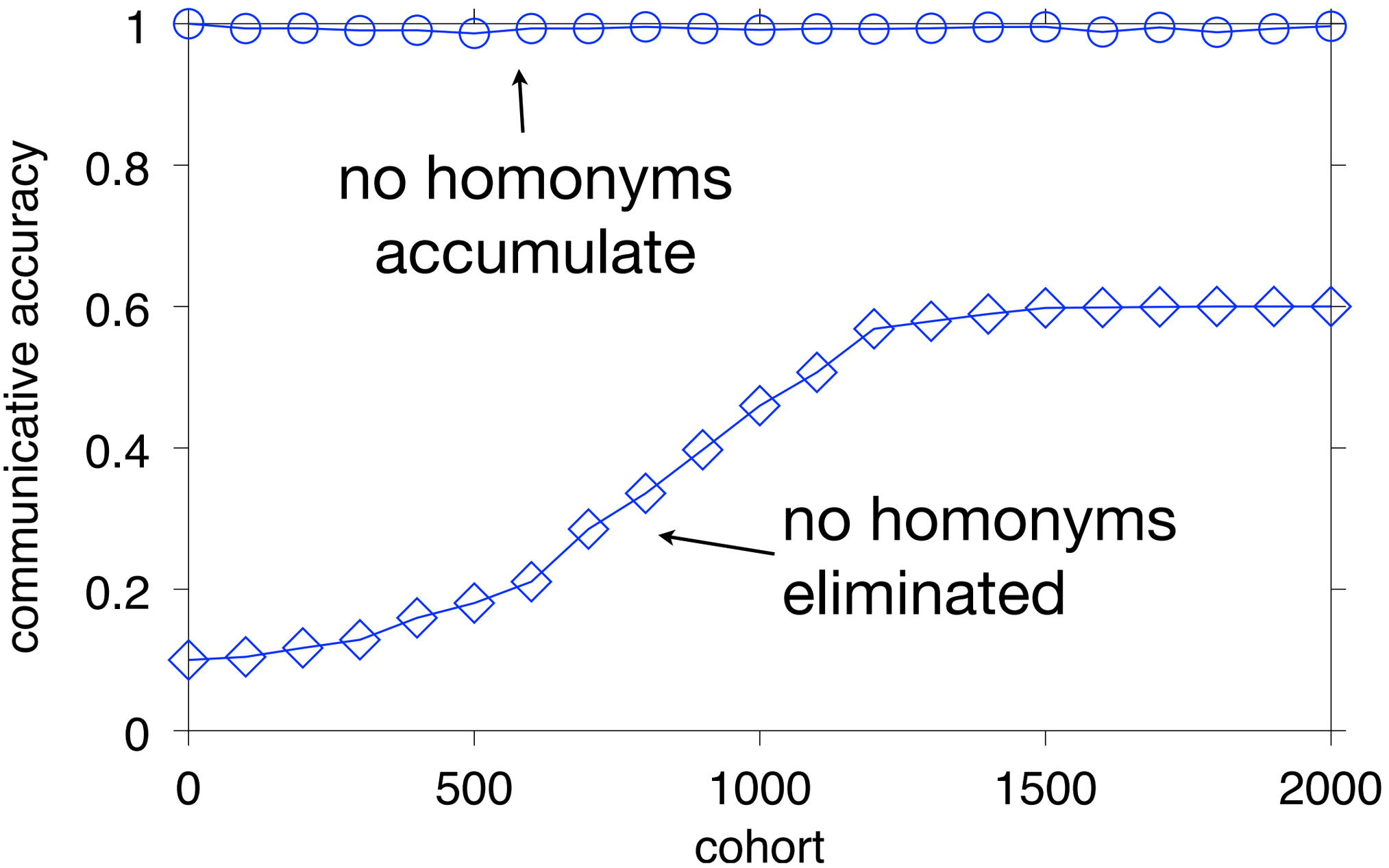


- Neutral with respect to homonymy

  because δ = γ



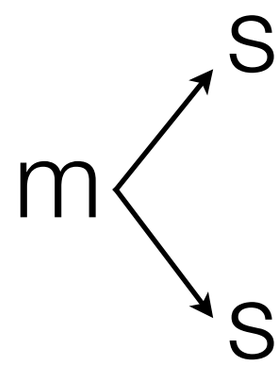
Maintainer behaviour



The learner bias (in most cases)

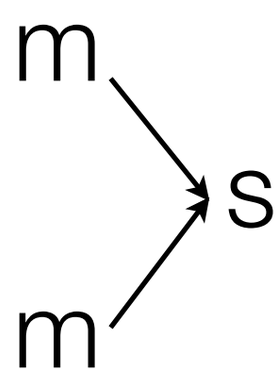
- Biased against synonymy

  because $\alpha > \beta$

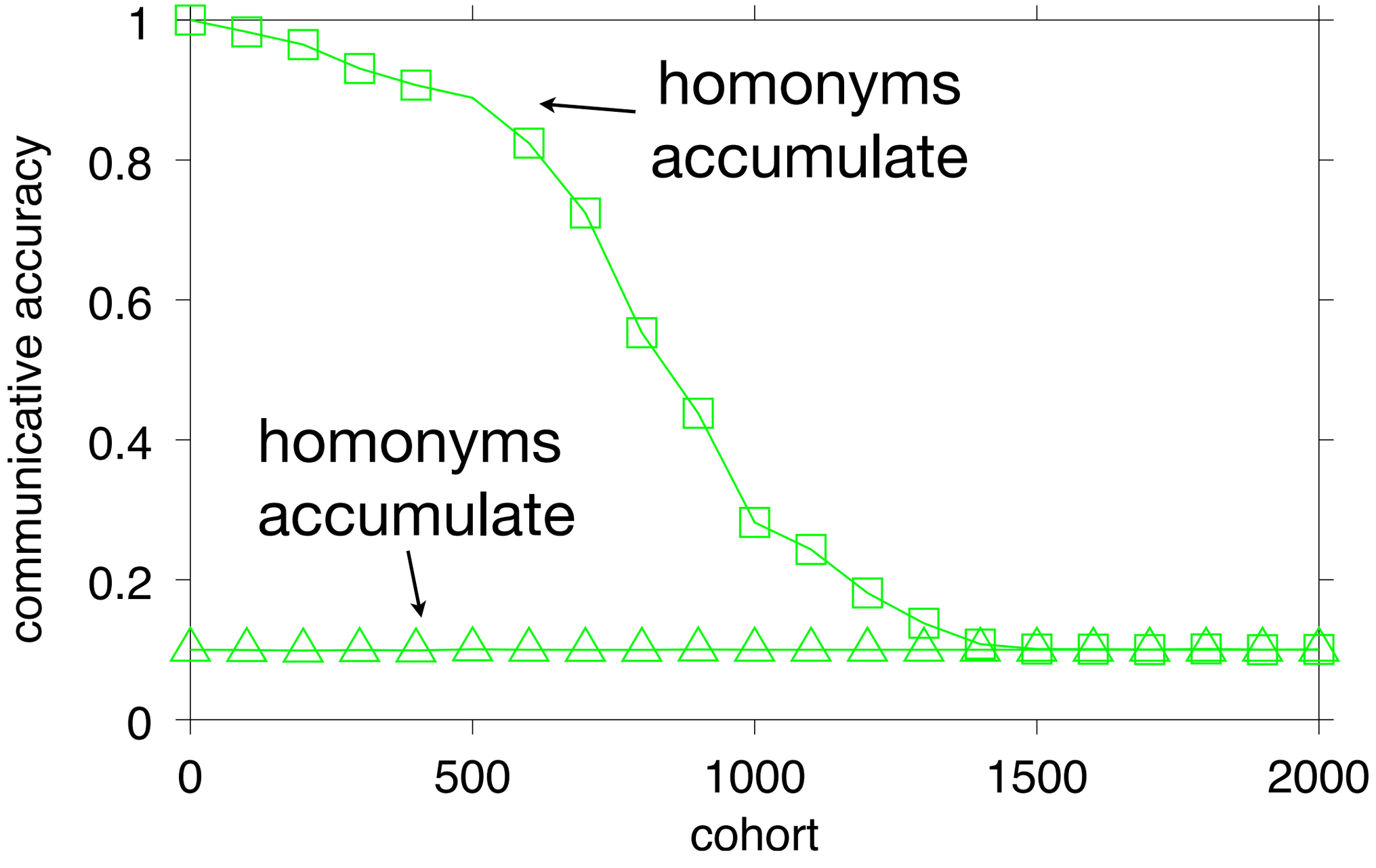


- Biased *in favour* of homonymy

  because $\delta < \gamma$

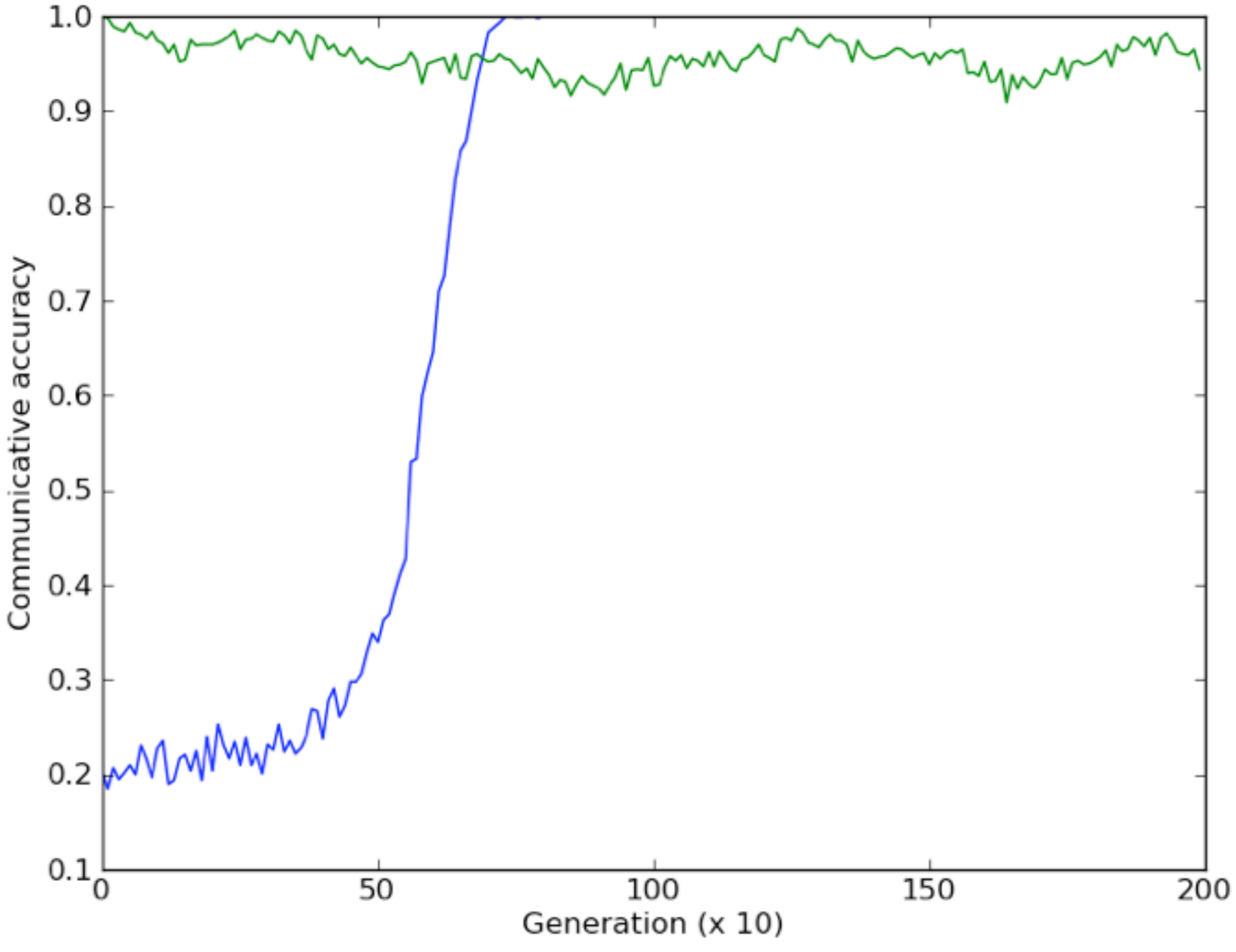


Learner behaviour



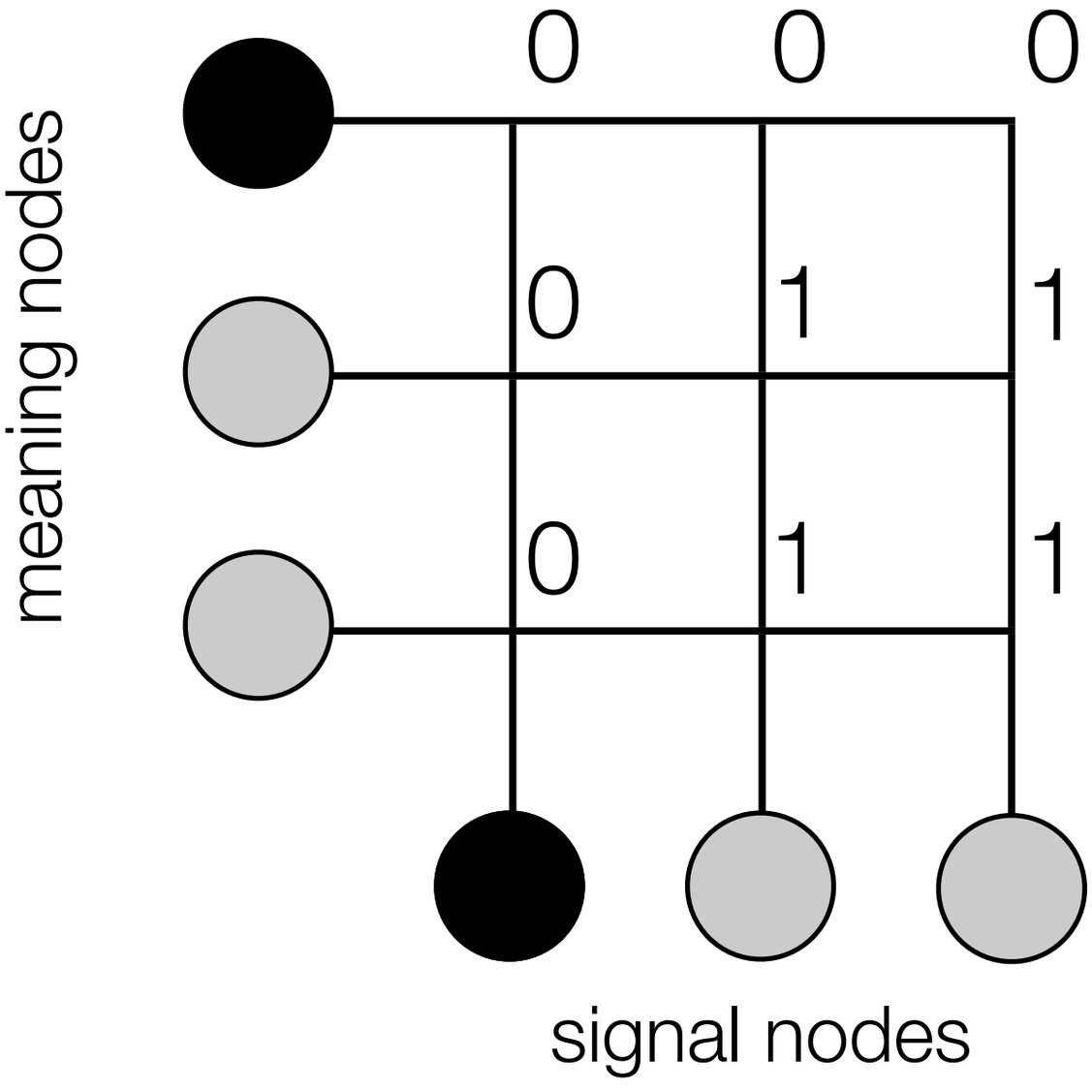
A problem (thanks to Hanna and Alan)

- [0,0,0,1]: should be [+learner, -maintainer, -constructor]



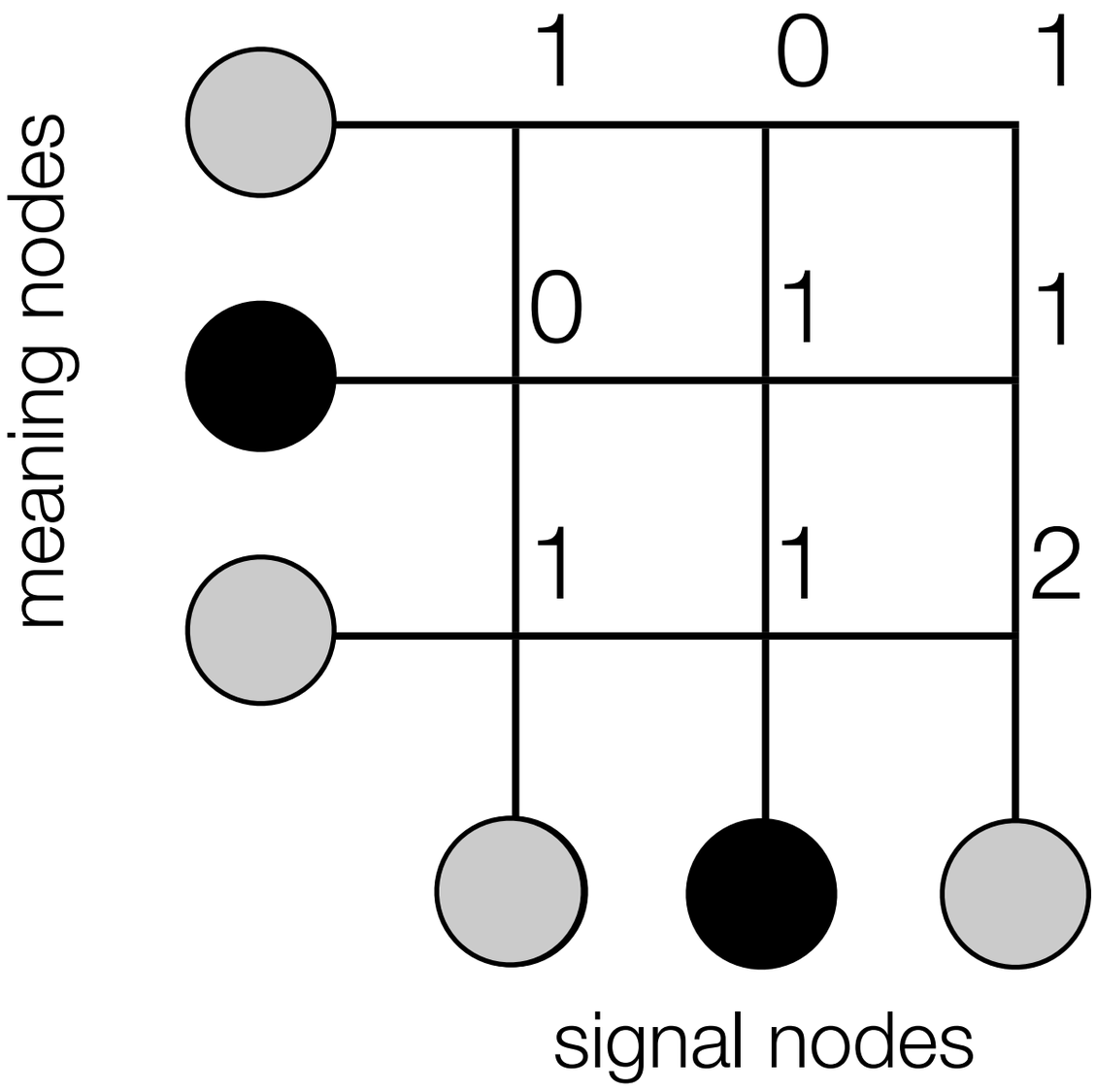
An anomalous rule: learning by co-non-occurence

Observation:
m1↔s1



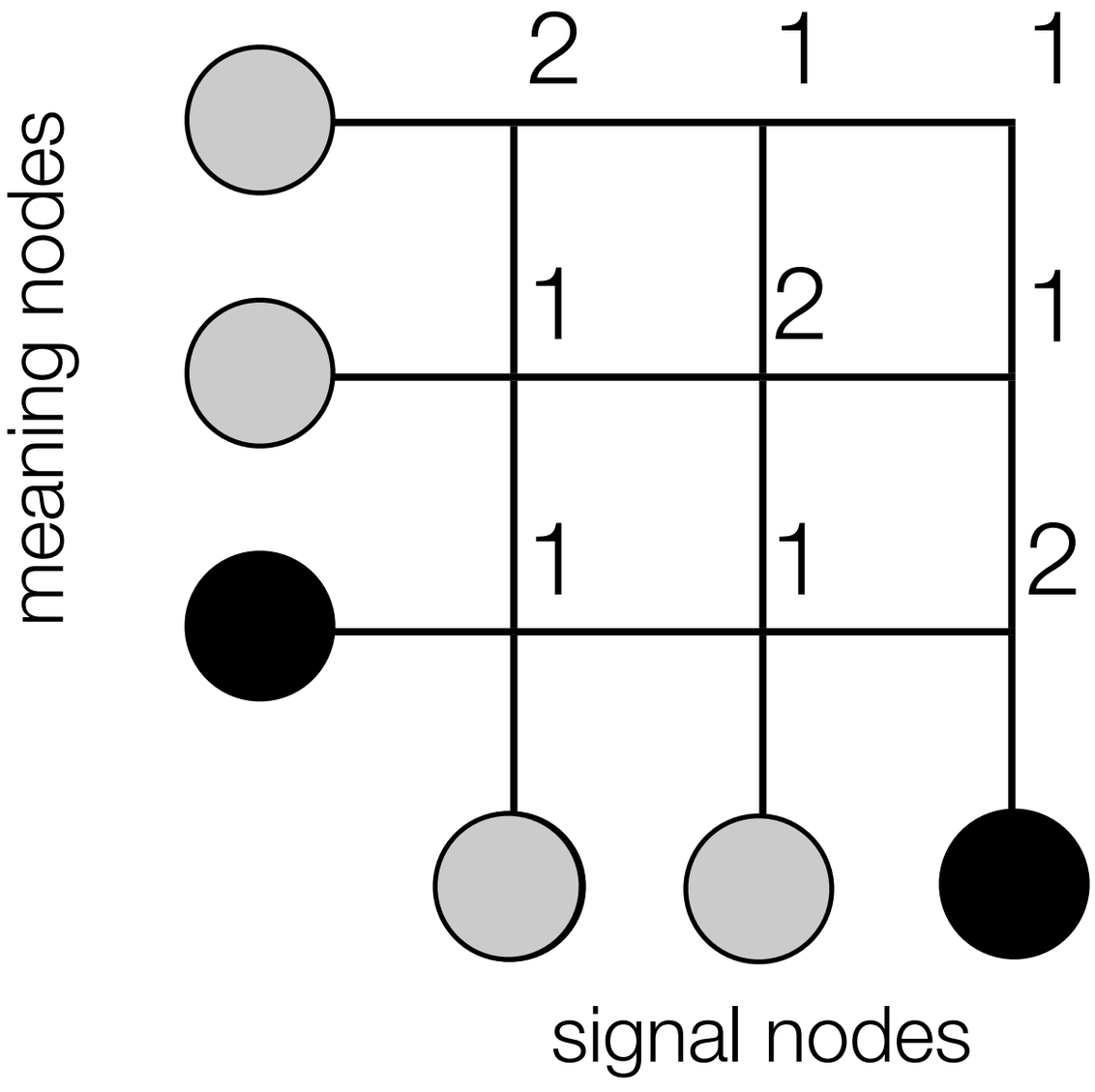
An anomalous rule: learning by co-non-occurence

Observation:
m2↔s2



An anomalous rule: learning by co-non-occurence

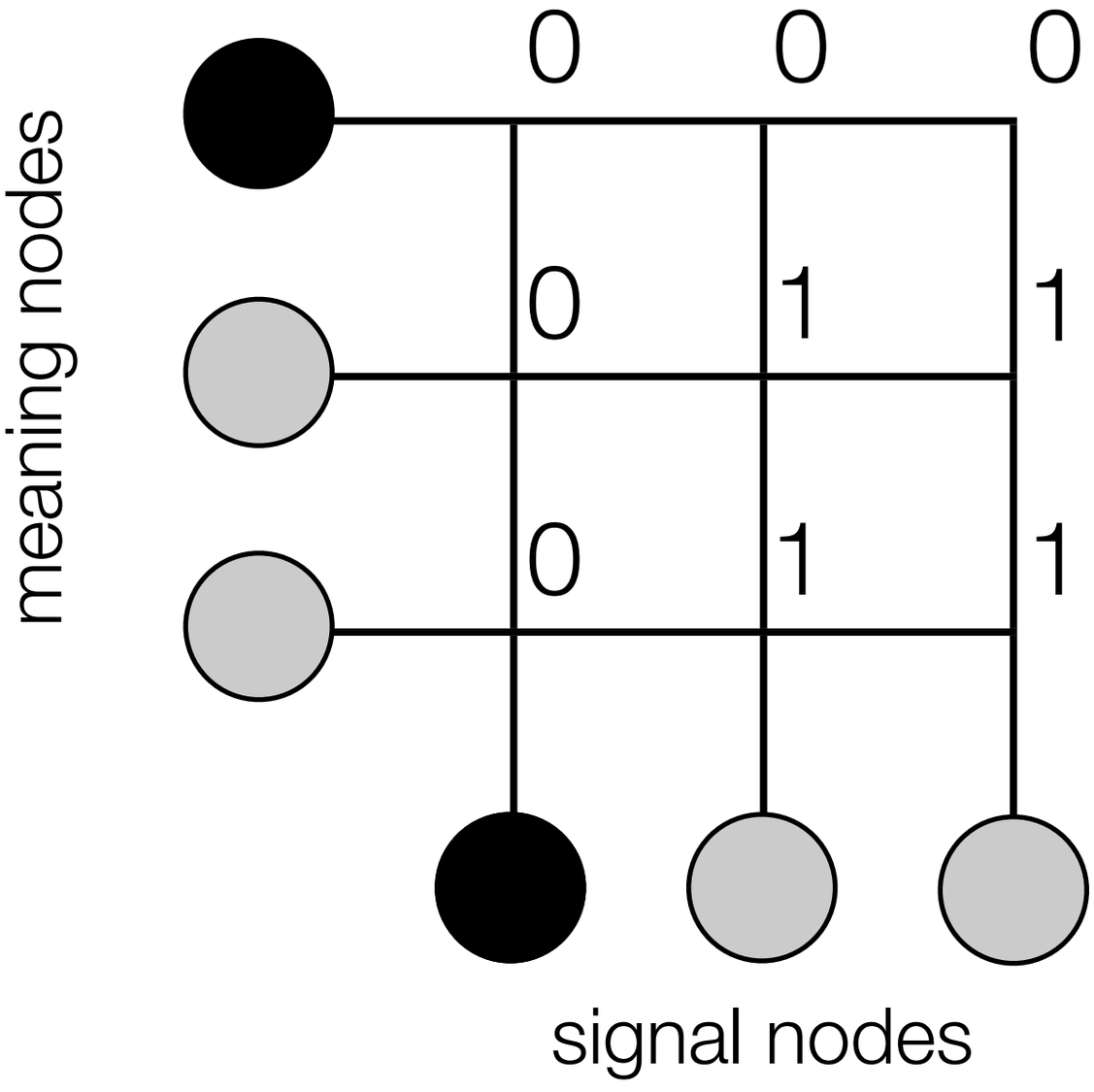
Observation:
m3↔s3



An anomalous rule: learning by co-non-occurence

Observation:
m1↔s1

This looks like a 1-to-1 bias - that's why it constructs and maintains



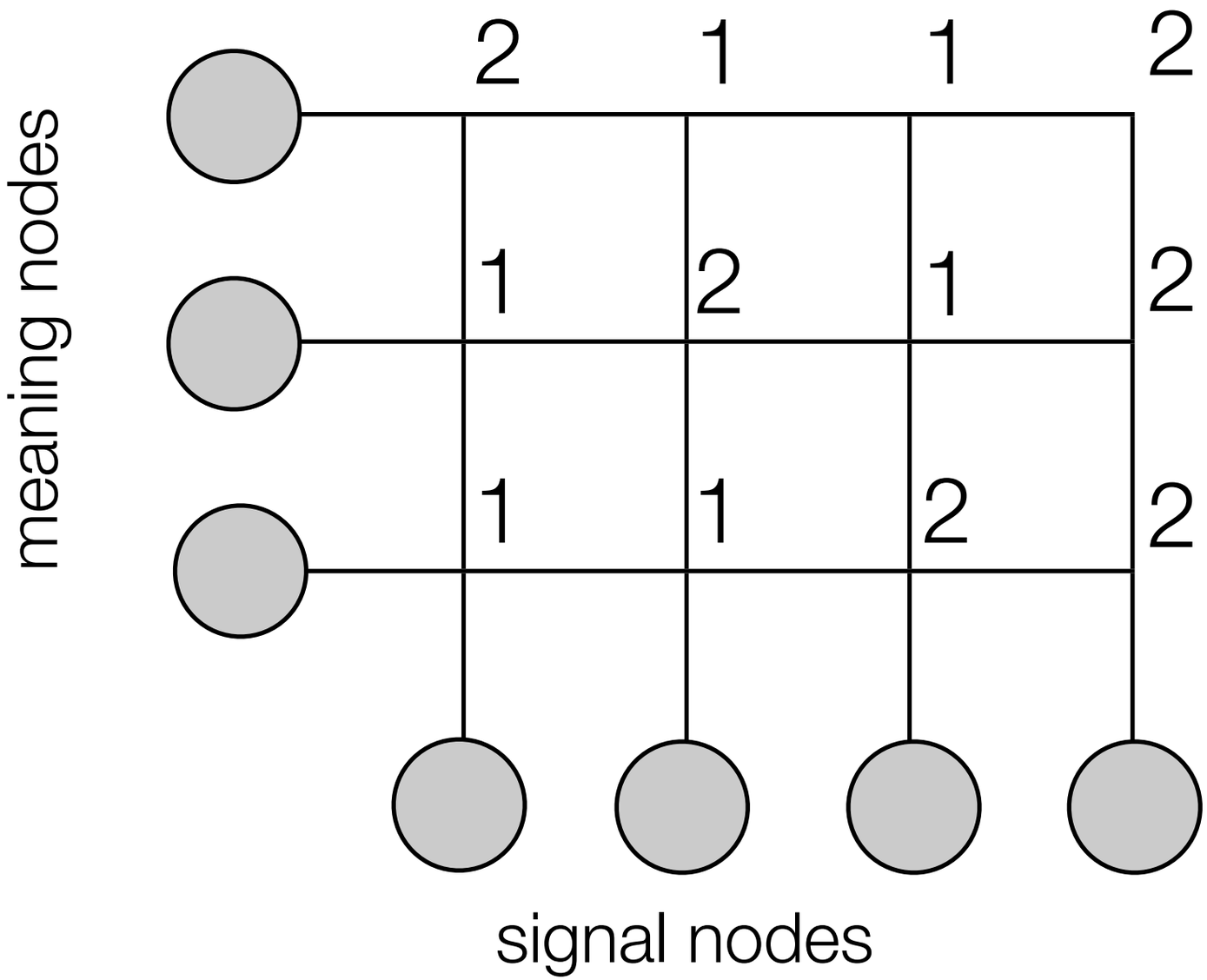
But ... adding more signals breaks it

Observations:

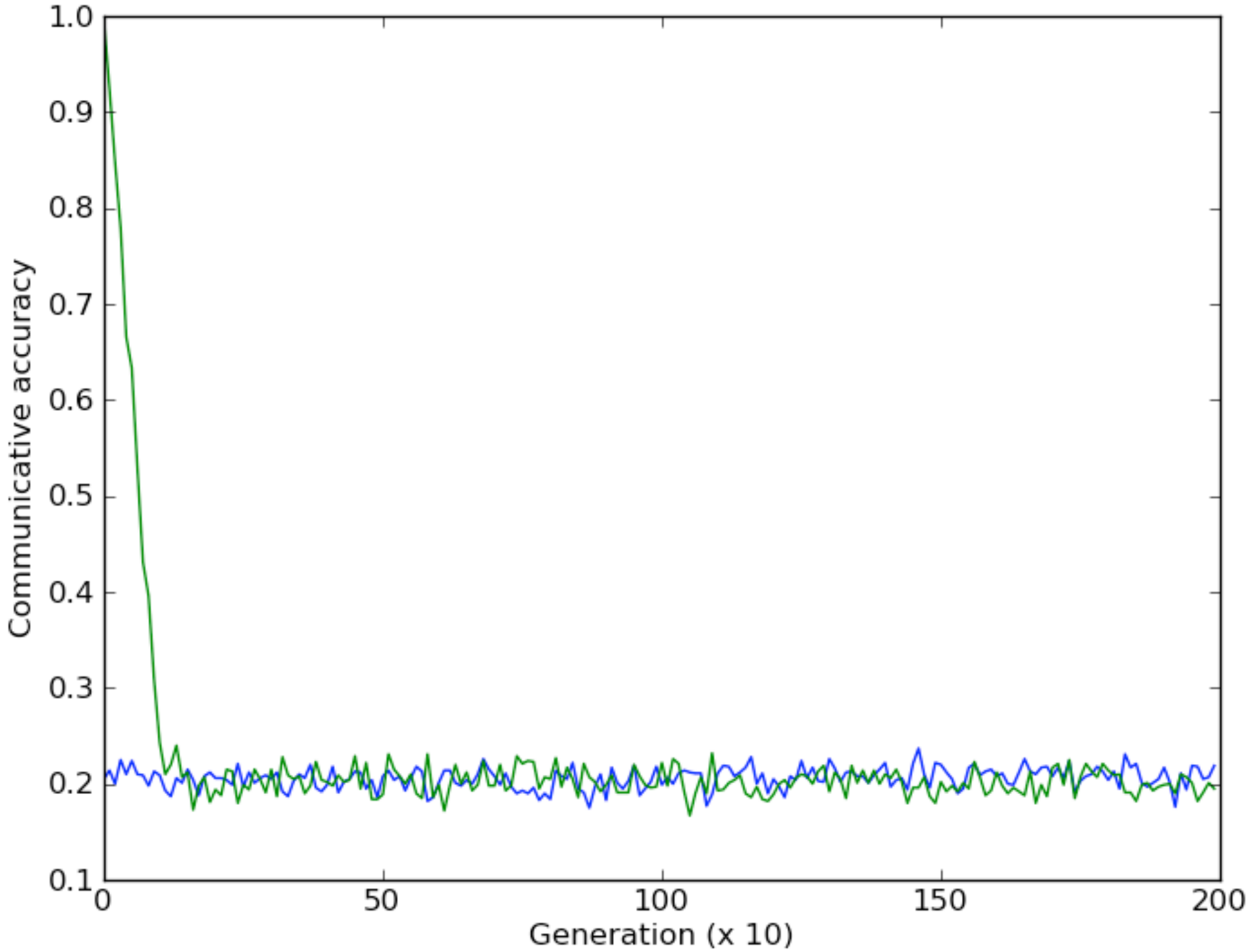
m1↔s1

m2↔s2

m3↔s3



5 meanings, 20 signals



A modified aquisition criterion

For all learners: $\alpha + \delta > \beta + \gamma$
For all non-learners: $\alpha + \delta \leq \beta + \gamma$

Additionally: if $|s| > |m|$, $\alpha > \beta$ required for acquisition

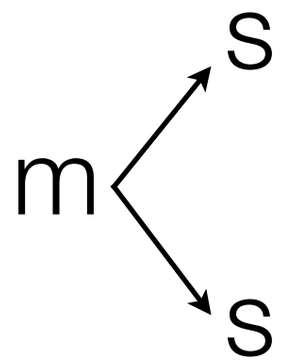
- Missed this in Smith (2002)
    - Slightly different implementation made anomalous behaviour less obvious
- Included in Smith (2004)

The constructor bias

- Constructors don't like:

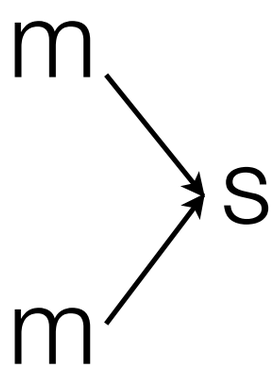
- One meaning to multiple signals

  because α > β
  bias against synonymy



- Multiple meanings to one signal

  because δ > γ
  bias against homonymy



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

Synonymy bias

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?"

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 constructors in our simple model
- Populations of constructors evolve optimal communication systems

A co-evolutionary hypothesis (Smith 2004)

Children's learning biases have evolved through natural selection, because they're good for communication.

- Examine this idea using our model
- Two central assumptions:
  - Weight update rule is given by a genotype
  - Better communicators breed more

Invasion of the mutants

- Smith (2004) plays **constructors**, **maintainers**, and **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 communicative success, which mutants will invade?

Surprising result: evolution is hard

- Constructors 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.

Summary

- Smith (2002, 2004) look in detail at how learning bias can give us (or fail to give us) language

- Brings together 3 complex processes in one model:

  Learning
  Cultural transmission
  Biological evolution

- Highlights the crucial importance of the second of these three

- BUT... language model is extremely simple. Next we'll look at making acquisition of meanings more realistic, and then we'll have a look at models of the evolution of more complex signals (i.e. syntax)

Reading

- Smith, K. (2004) The evolution of vocabulary. *Journal of Theoretical Biology, 228,* 127–142

  Extends the model in the previous paper to look at evolution of bias by examining invasion of mutants.