While you are waiting...

- **socrative.com,** room number **SIMLANG2016**

Simulating Language
Lecture 14: Evolution of learning bias

Simon Kirby

simon@ling.ed.ac.uk

Linguistic nativism

- Is language innate?
  - Not really a useful question...
  - Language is a product of biology and environment, like everything else
- A better question: does our biology provide a **domain-specific** learning device which imposes **strong constraints** on the form that language can take?

What is domain-specificity?

- A general definition
    - A learning device that only applies to a specific domain (e.g. language, causal relationships, social relationships, ...)
    - Domain-general: I use the same mechanism to learn language, causal relationships, social relationships, ...
- An evolutionary definition
    - Evolved under selection for a specific function (e.g. language learning mechanism evolved for language learning)
    - Domain-general: mechanism did not evolve under selection solely for the function it is currently used for (e.g. general-purpose learning mechanism evolved for learning language, causal relationships, ...)

A classic nativist argument

- Pinker & Bloom (1990): **Yes**, our biology provides a domain-specific learning device which imposes strong constraints on the form that language can take

- Domain-specific:
  - "*we have argued ... that human language, like other specialized biological systems, evolved by natural selection. Our conclusion is based on two facts ...: language shows signs of complex design for the communication of propositional structures, and the only explanation for the origin of organs with complex design is the process of natural selection*"

A classic nativist argument

- Pinker & Bloom (1990): **Yes**, our biology provides a domain-specific learning device which imposes strong constraints on the form that language can take

- Strong constraints:

  - “*Children are fluent speakers of complex grammatical sentences by the age of three, without benefit of formal instruction. They are capable of inventing languages that are more systematic than those they hear, showing resemblances to languages that they have never heard, and they obey subtle grammatical principles for which there is no evidence in their environments.*”

Wait a minute...

- *“language shows signs of complex design for the communication of propositional structures”*

- *“the only explanation for the origin of **organs** with complex design is the process of natural selection”*

- Language isn’t an organ, it’s a socially-learnt behaviour

  - The language organ / faculty is a device for learning a language from data

  - What’s the relationship between an evolving learning device and an evolving socially-transmitted language? What kind of language faculties evolve?

What's the relationship between an evolving bias and an evolving socially-transmitted language?

- Damned if I know - let's model it and find out
- We already have a lovely model of cultural evolution
    - Iterated Bayesian Learning
- We already have a lovely model of biological evolution
    - Genetic algorithms
- Let's just evolve the prior biases of Bayesian learners
- What happens to the priors?

A co-evolutionary model

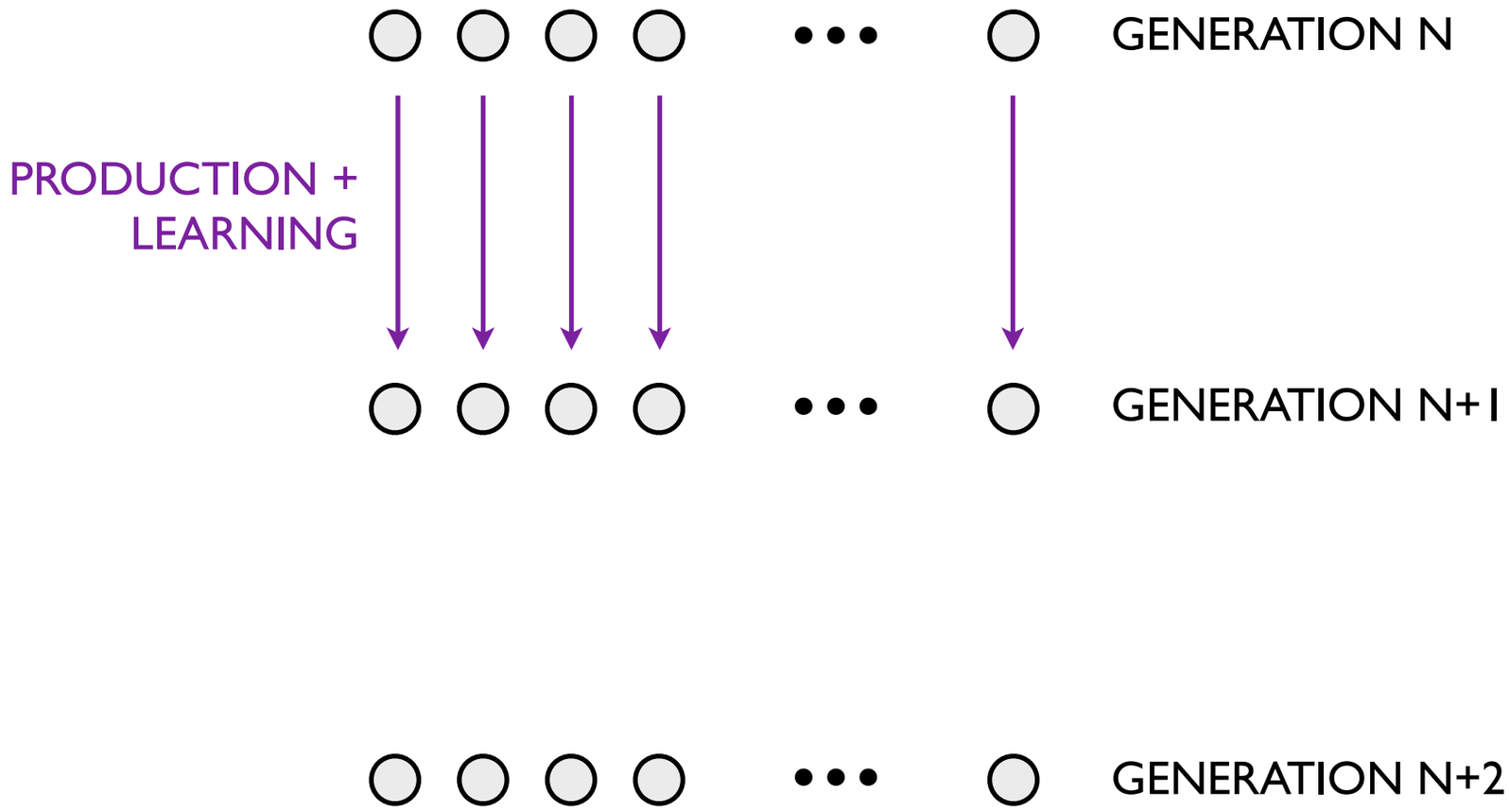
- A population is a series of generations, multiple individuals per generation
- Each agent learns a language from data produced by the previous generation
  - Single teacher
- Prior encoded genetically
  - Initially: uninformative (neutral) prior
- Fitness determined by how closely your language matches the rest of the population
- Fittest individuals pass on their genes to next generation, with some small probability of mutation
  - Evolving domain-specific priors, since they're really **for** language

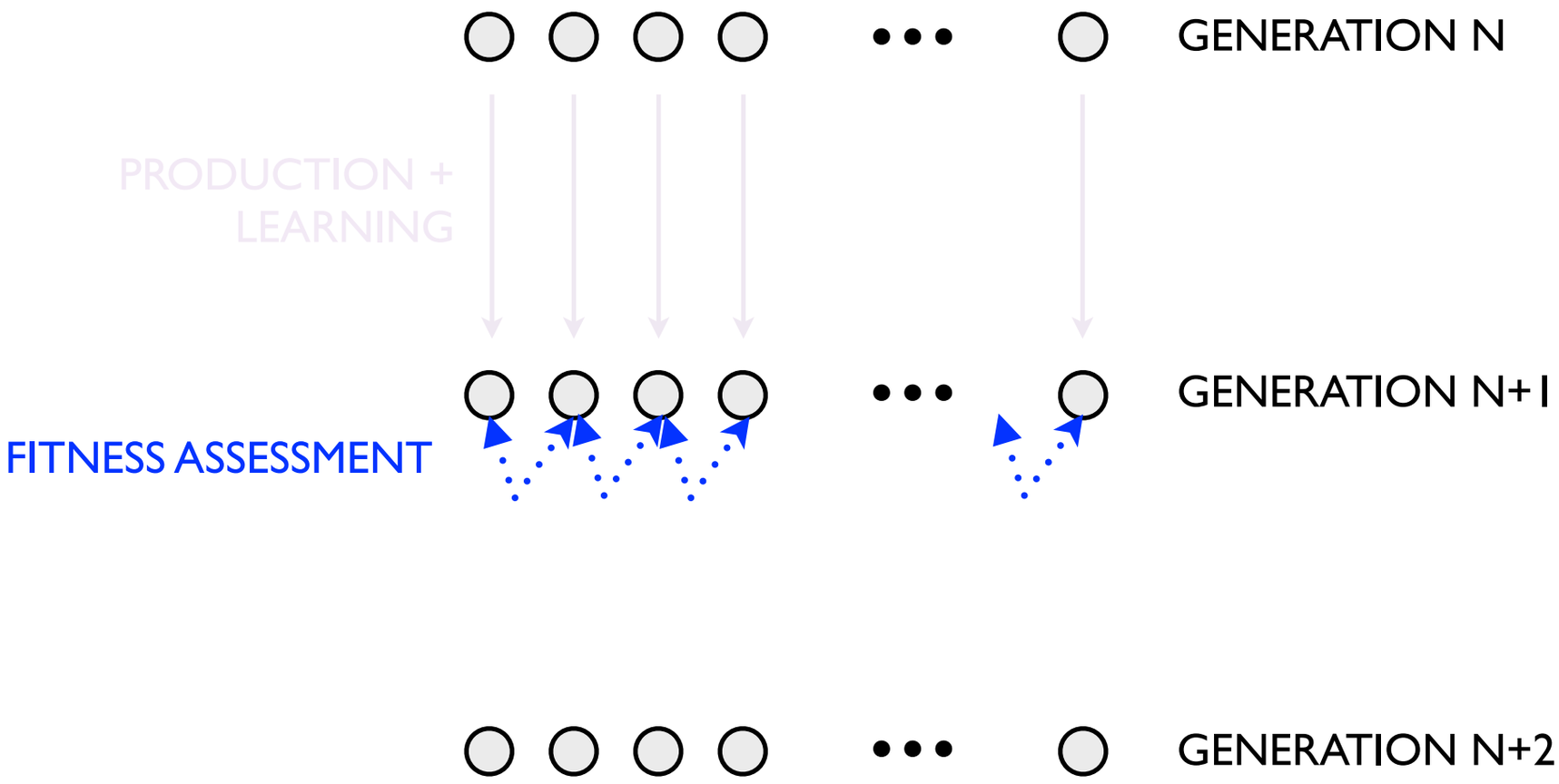
Details

- The language model
    - Two possible languages, 0 and 1
- The bias: P(Language 1)
    - > 0.5, biased in favour of language 1
- Learning
    - MAP or sampling

Genes for prior bias

- How can we represent a genome that encodes a bias?
- One solution: polygenic coding of bias
  - Multiple genes
    - Each contribute a small amount to bias
    - [0,0,0,0,0,0,0,0,0,0] : bias = 0
    - [1,1,1,1,1,1,1,1,1,1]: bias = 1
    - [1,1,1,0,0,1,0,0,1,0]: bias = 0.5
- Any bias possible, but maintaining a strong bias against mutation requires selection for that bias


GENERATION N
PRODUCTION +
LEARNING
GENERATION N+1
GENERATION N+2


GENERATION N
PRODUCTION +
LEARNING
GENERATION N+1
FITNESS ASSESSMENT
GENERATION N+2

GENERATION N

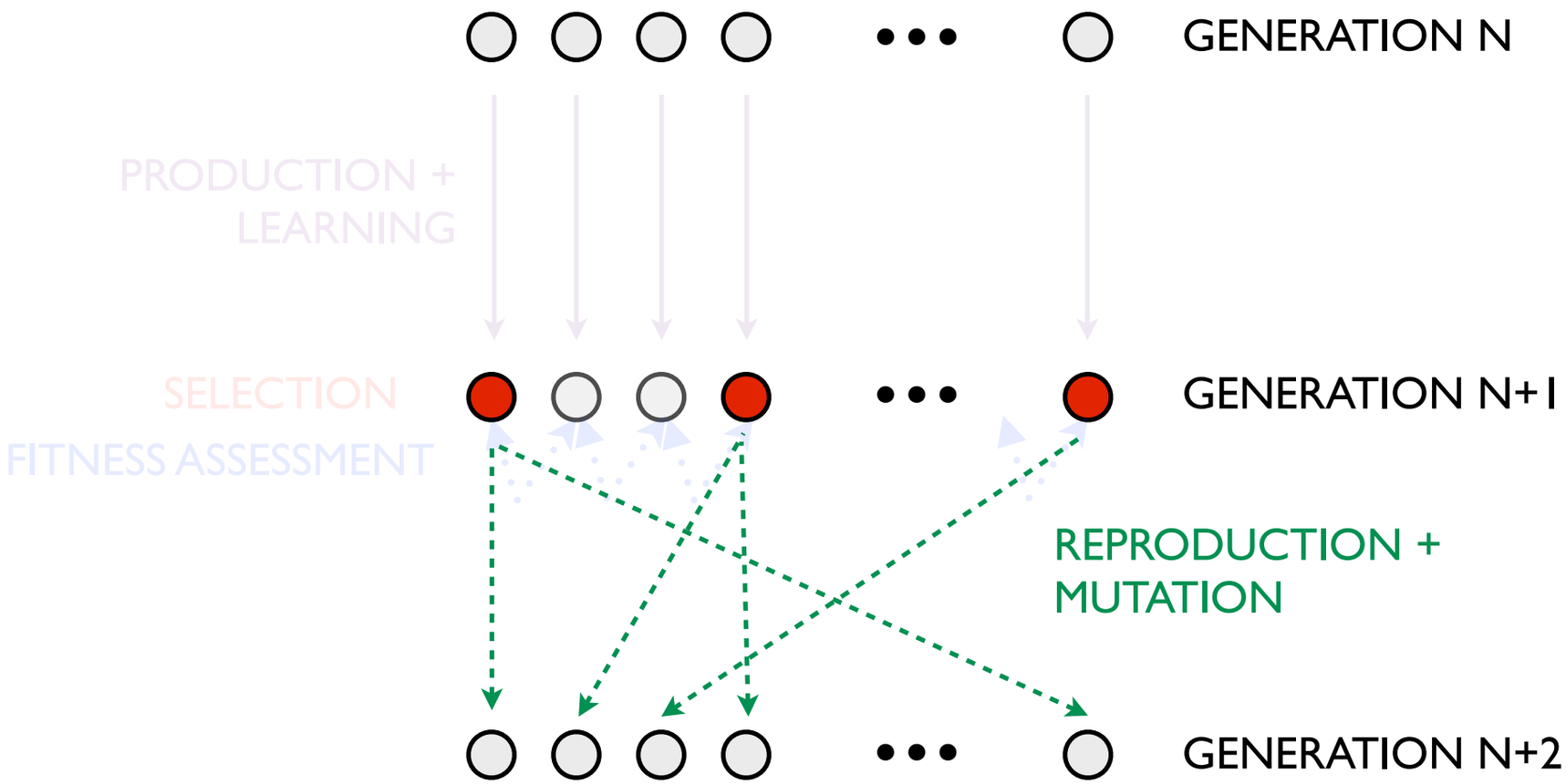
PRODUCTION +
LEARNING

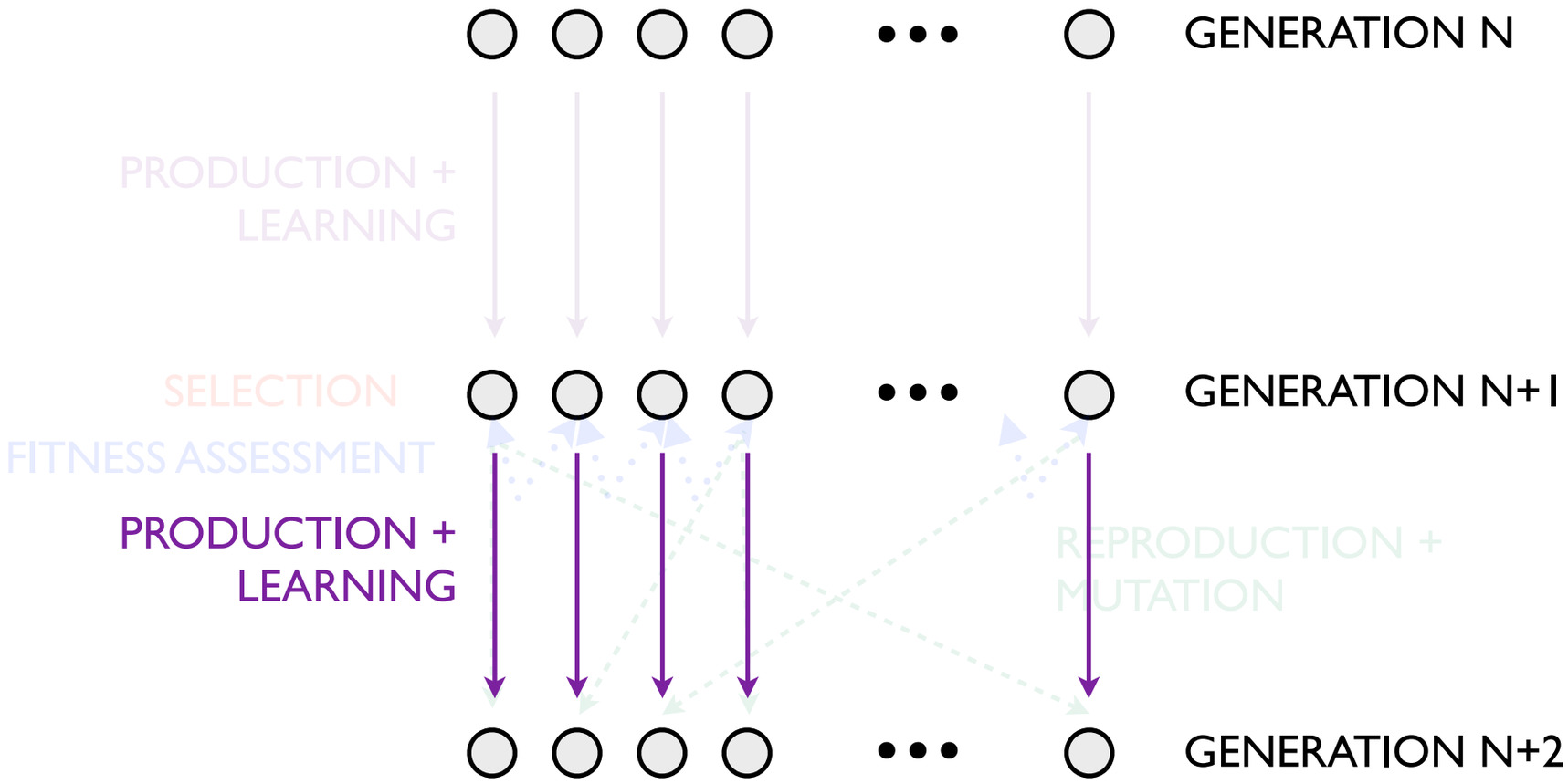
SELECTION

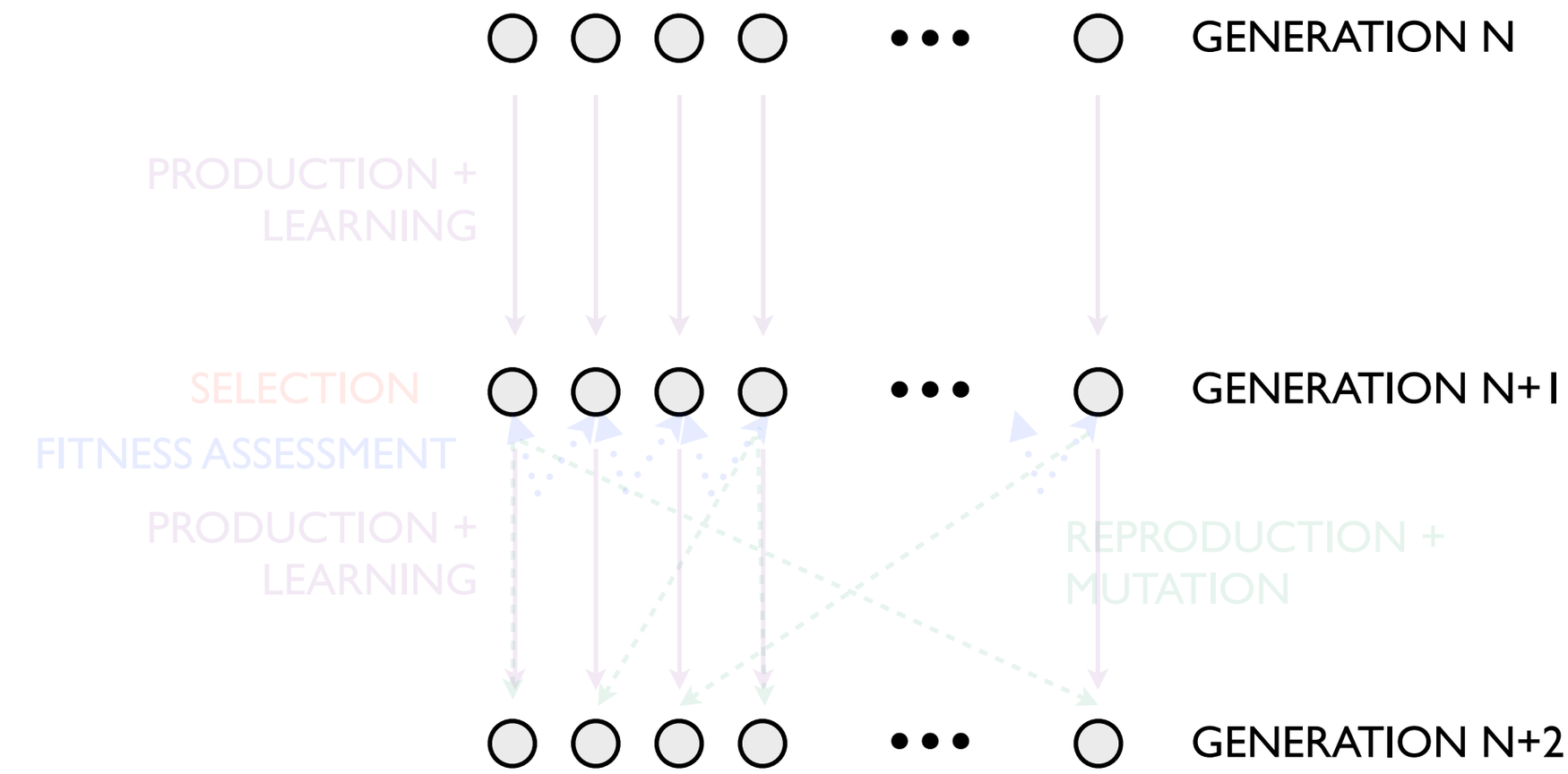
GENERATION N+1

FITNESS ASSESSMENT

GENERATION N+2


GENERATION N
PRODUCTION +
LEARNING
SELECTION
FITNESS ASSESSMENT
GENERATION N+1
REPRODUCTION +
MUTATION
GENERATION N+2


GENERATION N
PRODUCTION +
LEARNING
SELECTION
FITNESS ASSESSMENT
GENERATION N+1
PRODUCTION +
LEARNING
REPRODUCTION +
MUTATION
GENERATION N+2

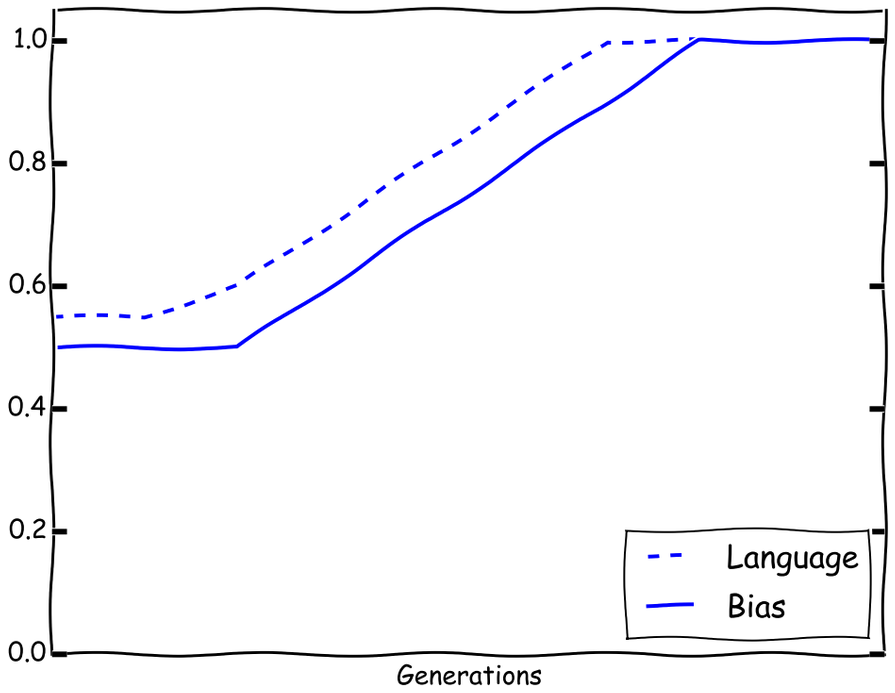


Note two kinds of inheritance - iterated learning and genetic transmission. Evolution due to all of: misconvergence in learning, natural selection, and mutation.

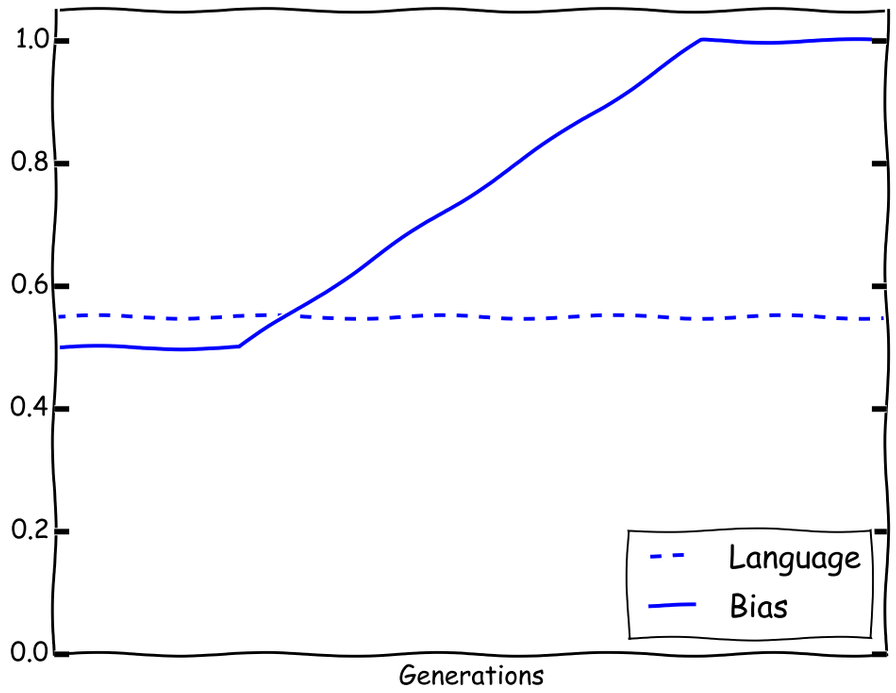
What would the evolution of strong constraints on learning look like?

socrative.com, room number **SIMLANG2016**

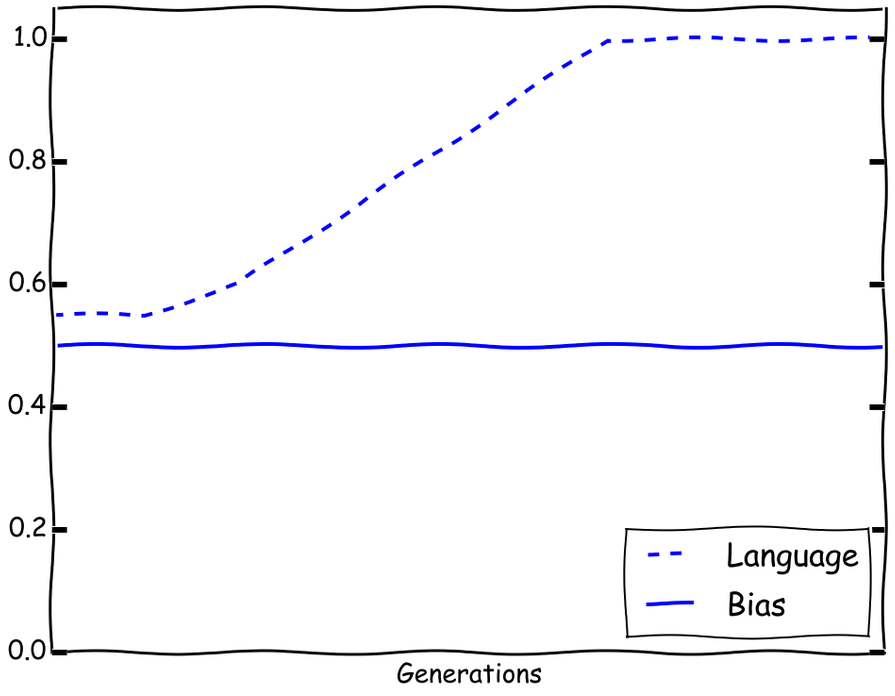
A



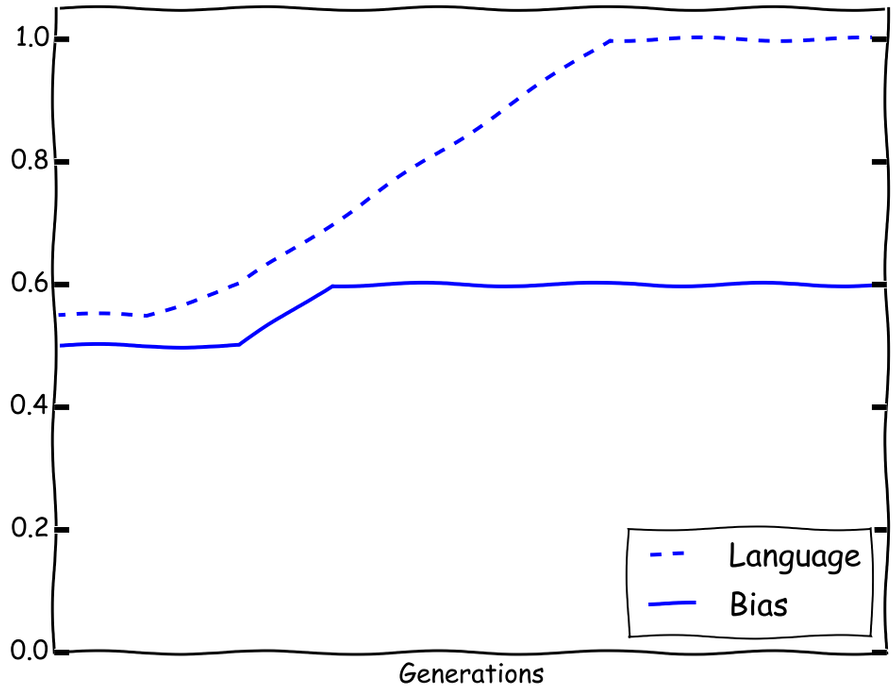
B



C



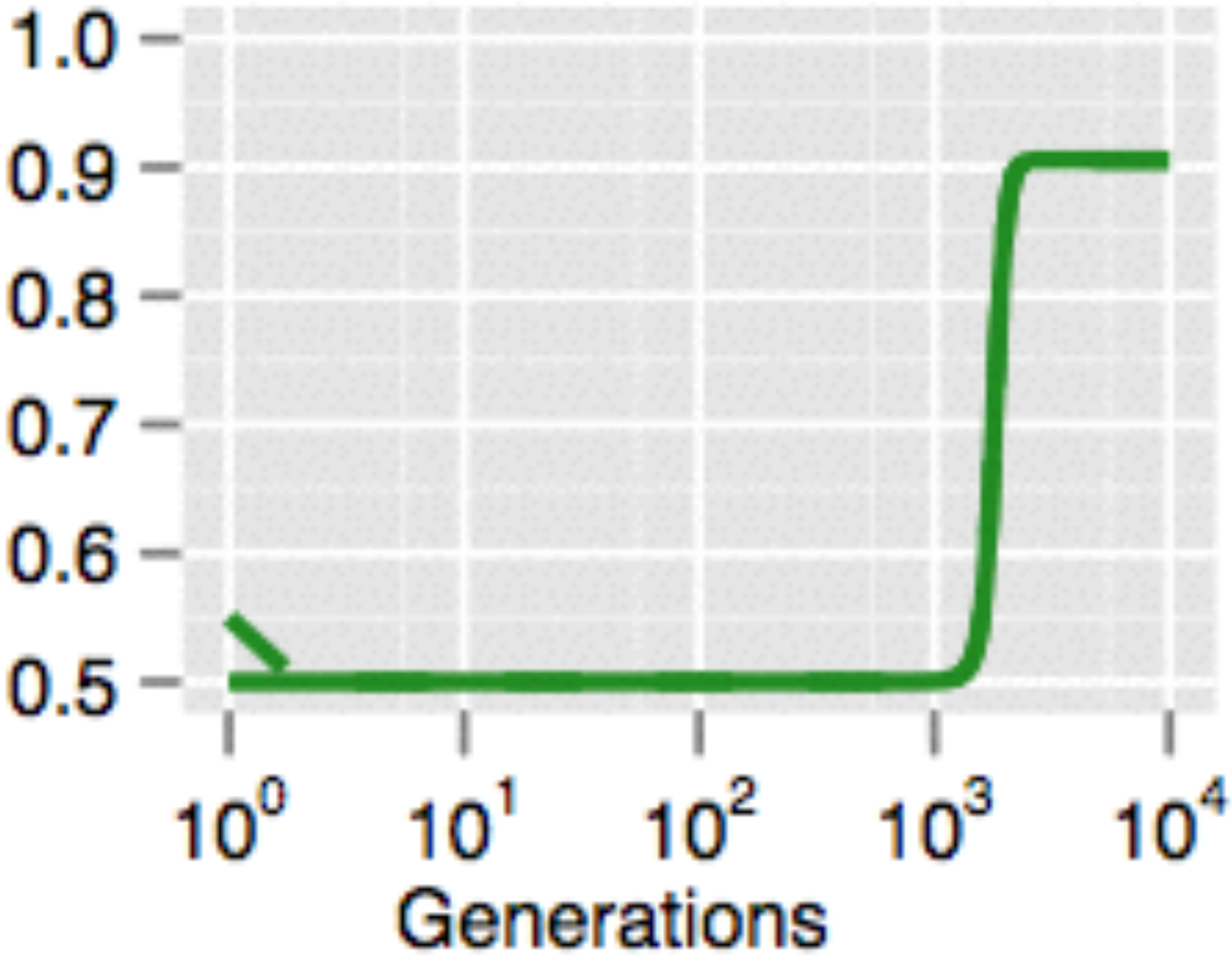
D



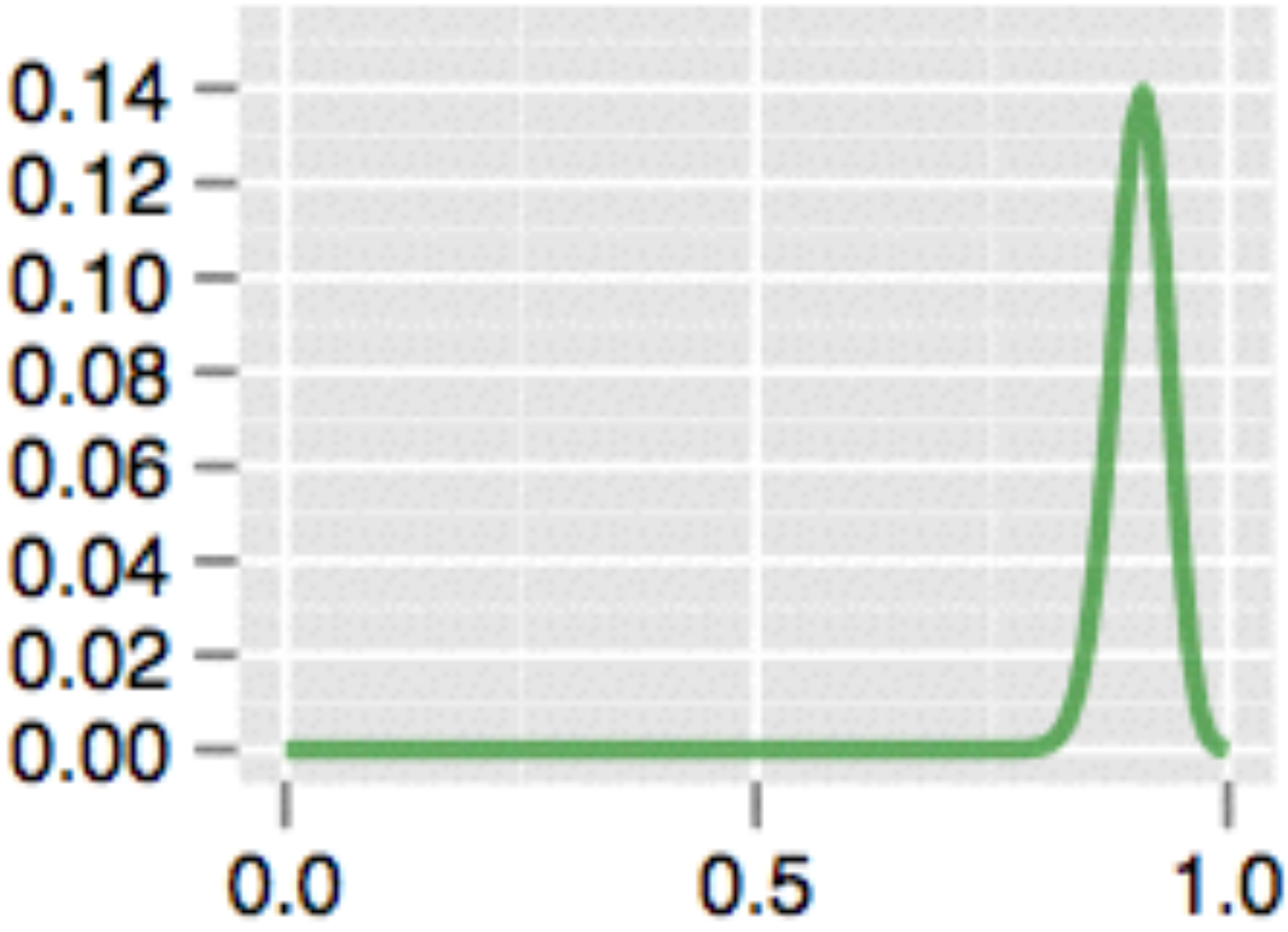
Before we run the model, can we work out what to expect?

- When does it pay to have a bias in favour of a particular language?
- For samplers, when does one language become very common?
- For MAP learners, when does one language become very common?
- What’s going to happen from our starting point of neutral priors?

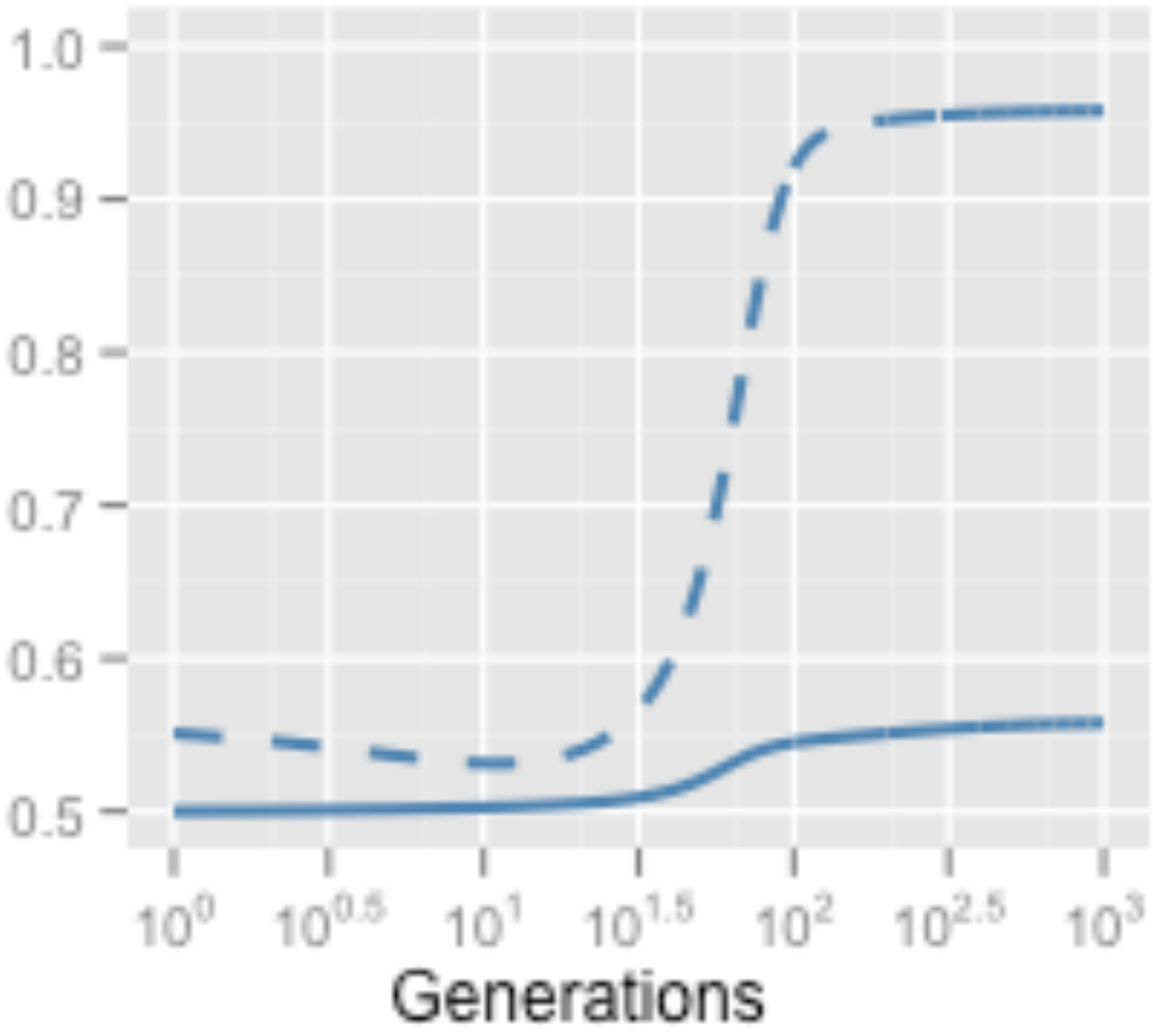
Genetic evolution **only**



Genetic evolution **only**



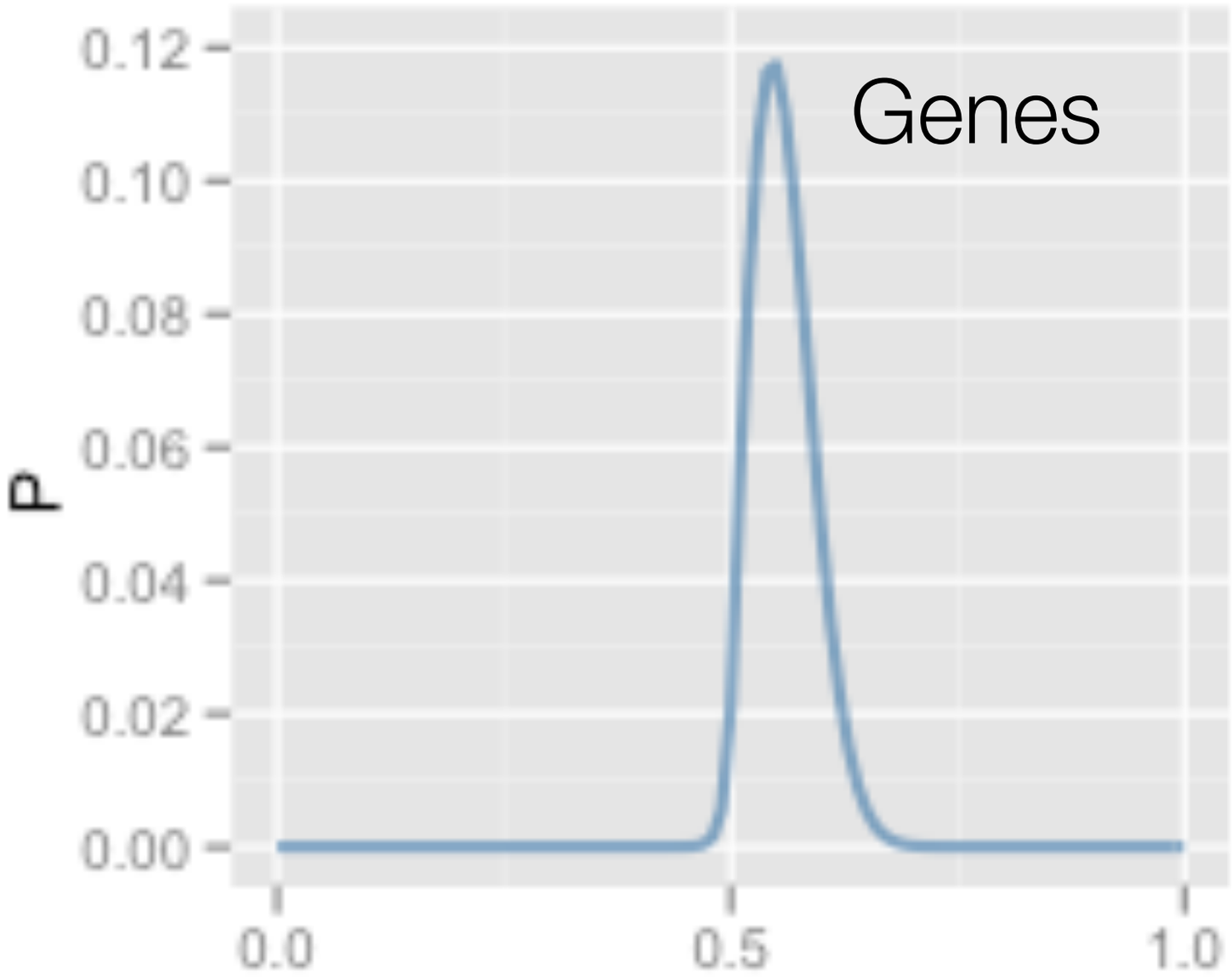
MAP coevolution



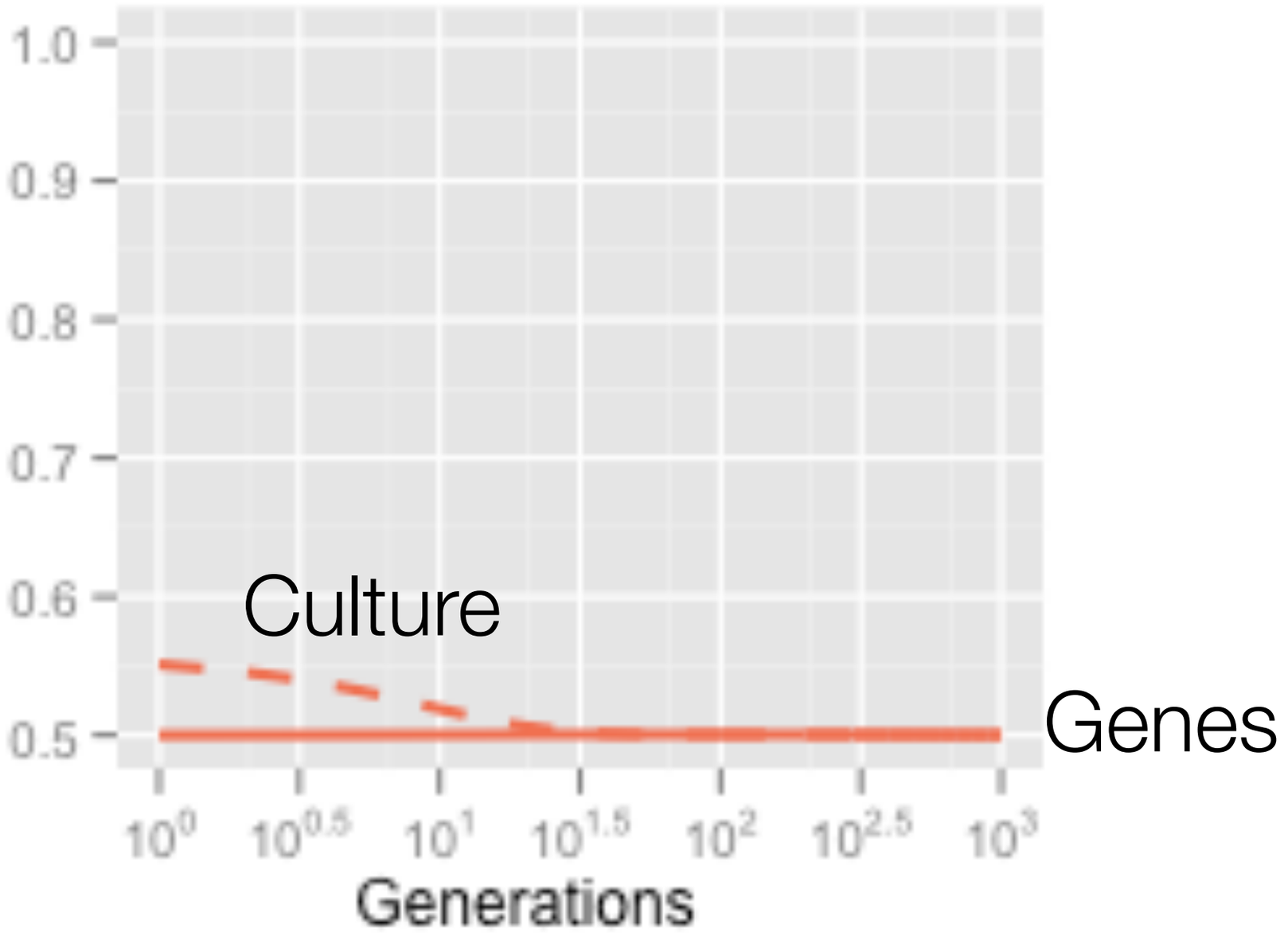
Culture

Genes

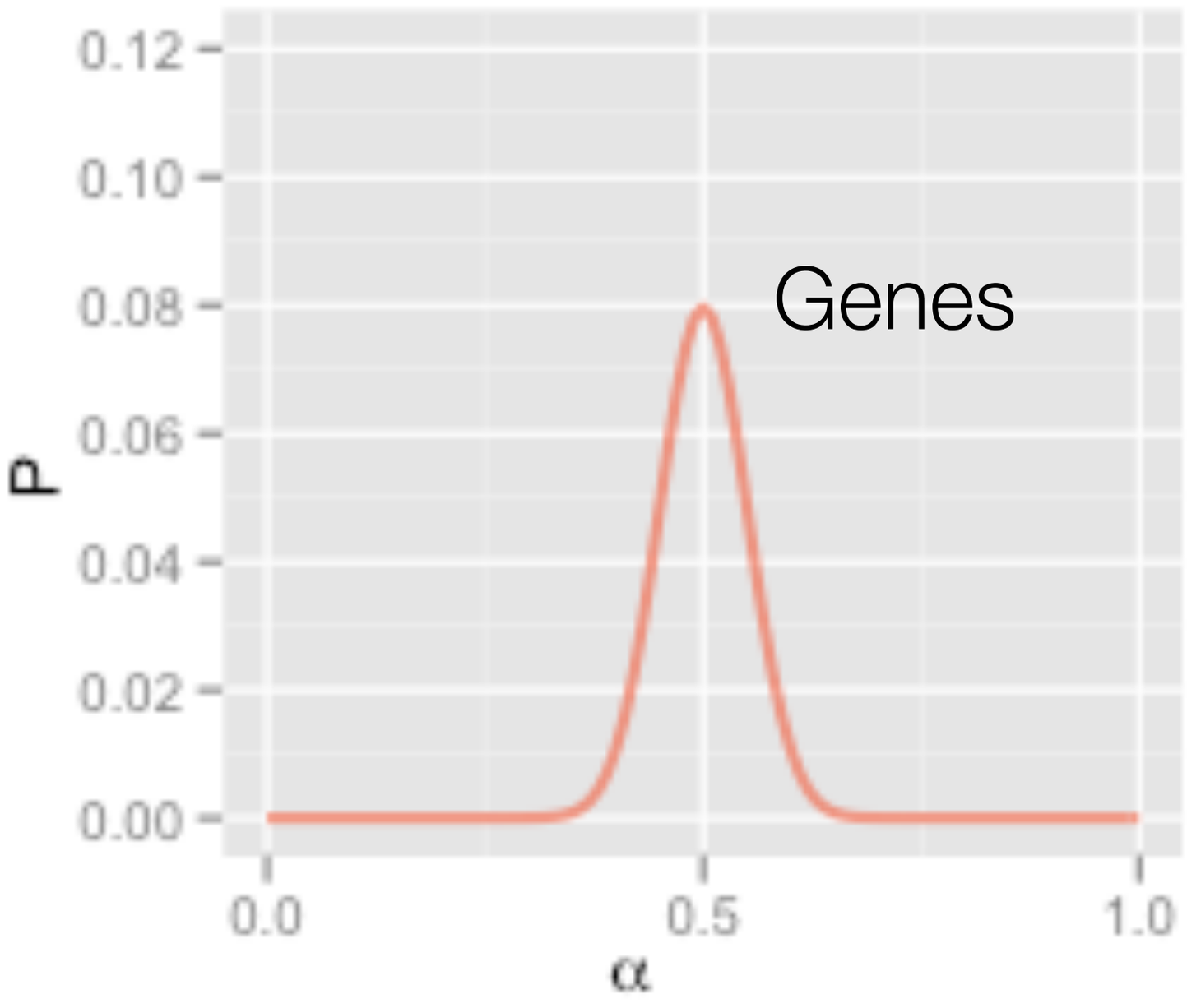
MAP coevolution

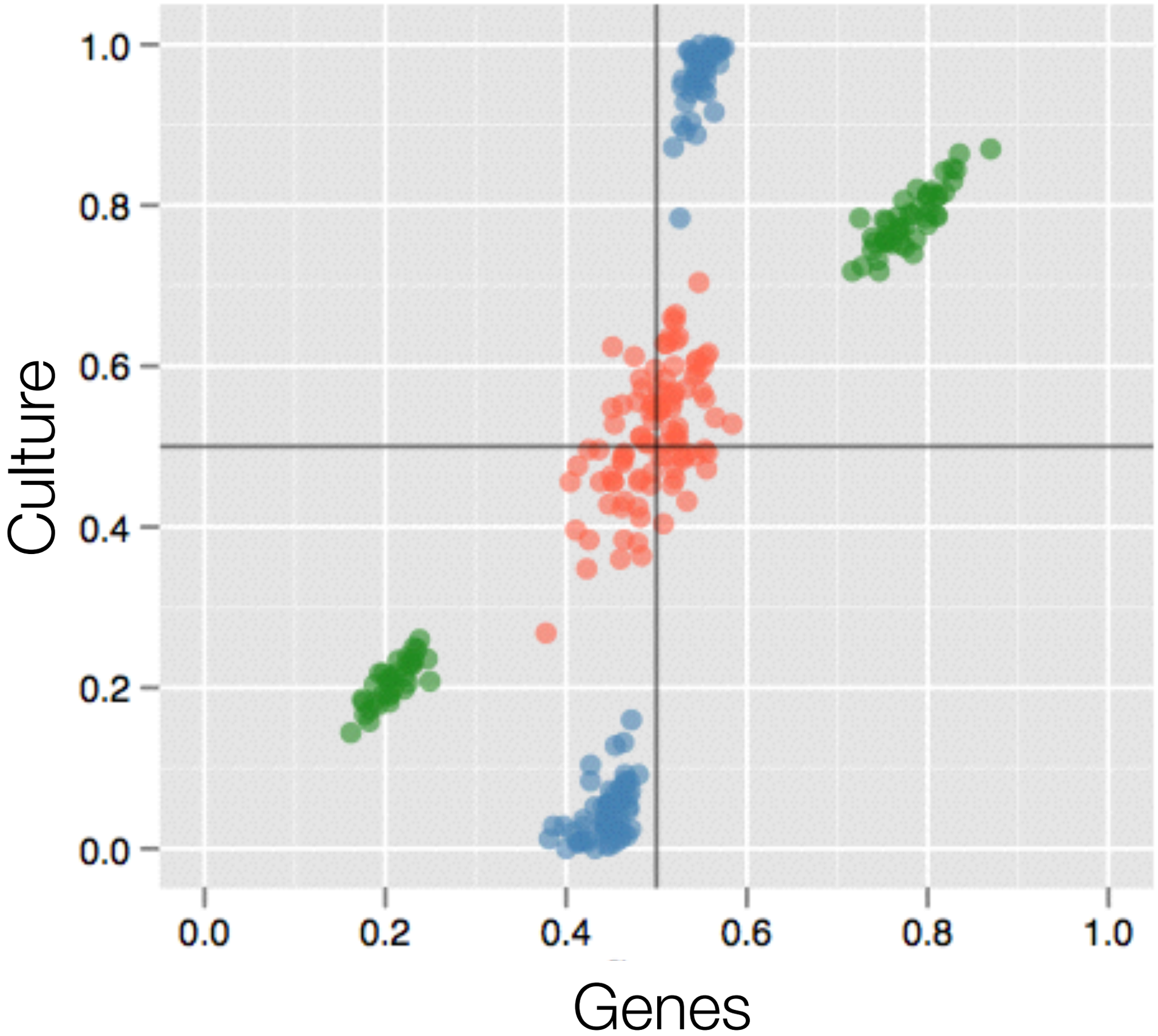


Sampler co-evolution



Sampler co-evolution




Cu
lture
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
Genes

Sampling vs. MAP

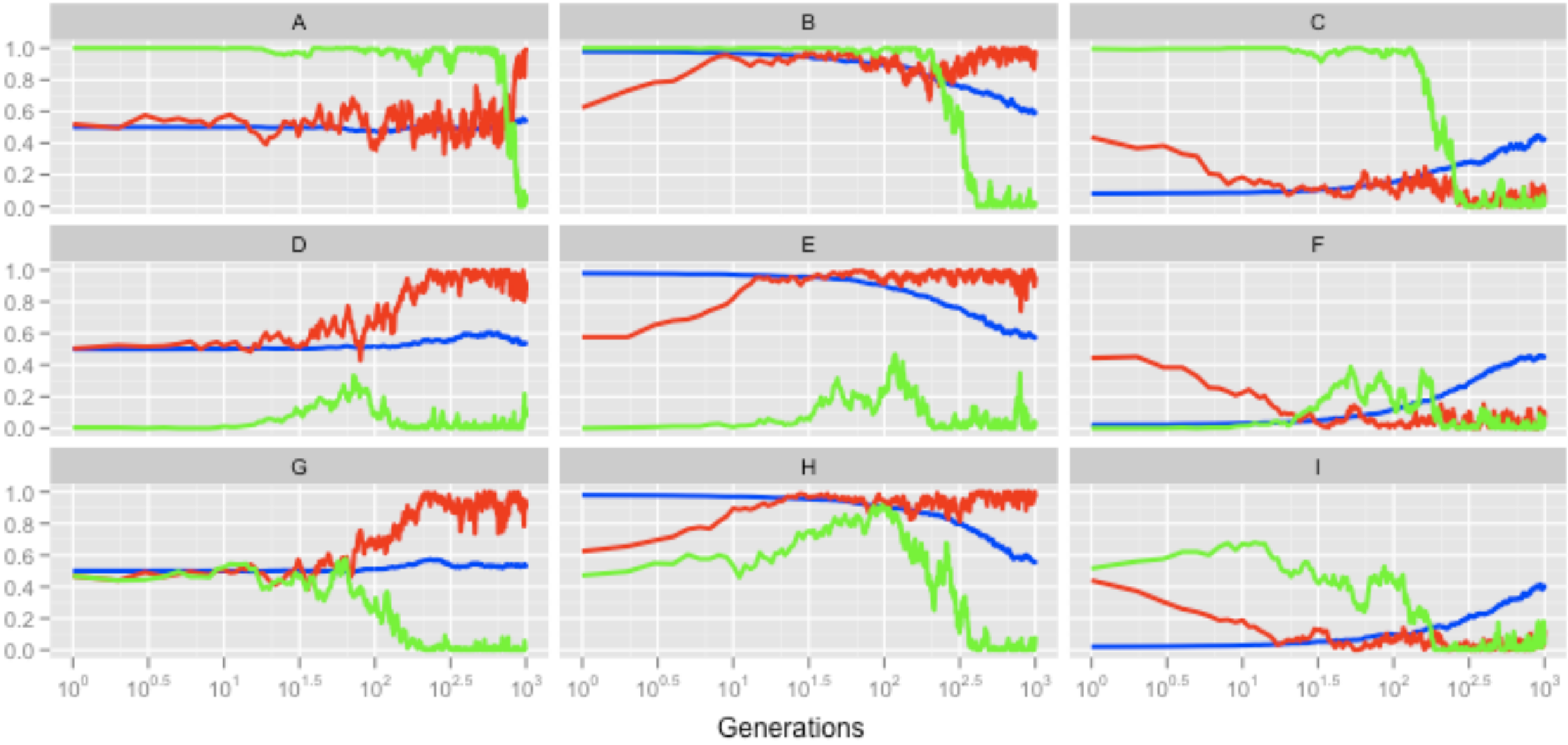
- If you have to pick the same language as someone else trained on similar data to yourself, would you pick the MAP language or sample?

- Smith & Kirby (2008): MAP learning is **always** selected for over sampling, for coordination problems

- Suggests that evolution might have given us a specialised strategy for learning coordinated tasks

    - We can imagine an evolutionary transition from sampling to MAP for language

Evolution of MAP



PROPORTION OF SAMPLERS (GENES)

BIAS (GENES)

LANGUAGE (CULTURE)

Why do we get these results?

- Think about evolution in terms of *masking* and *unmasking*
- MAP learning rapidly selected for.
- Subsequently:
    - Non-neutrality is *unmasked*
    - Bias strength is *masked*
- Weak learning biases have big effects on culture
    - But there is no pressure to make these into strong constraints

Conclusions

- Recall: linguistic nativism proposes domain-specific strong constraints
- Model's predictions:
    - Samplers drift randomly leading to no strong constraints or universals (and sampling is selected against anyway)
    - MAP learners lead to domain specific biases that are *as weak as possible*
- If we do find a strong innate constraints in language learning, they are likely to have come from selection for something else (i.e. be domain-general)
- You can get *either* domain-specific weak biases, *or* domain-general strong biases

References

- Pinker, S., & Bloom, P. (1990). Natural language and natural selection. *Behavioral and Brain Sciences, 13,* 707-784.

- Smith, K., & Kirby, S. (2008). Cultural evolution: implications for understanding the human language faculty and its evolution. *Philosophical Transactions of the Royal Society B, 363,* 3591-360.

- Thompson, B., Kirby, S., & Smith, K. (2016). Culture shapes the evolution of cognition. *Proceedings of the National Academy of Science.* In press.