Simulating Language
9: Gene-culture co-evolution

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Note to self: remember to start the recording!

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 learning device and an evolving socially-transmitted language?

Time for a model!

A co-evolutionary model
(Thompson, Kirby & Smith, 2016)

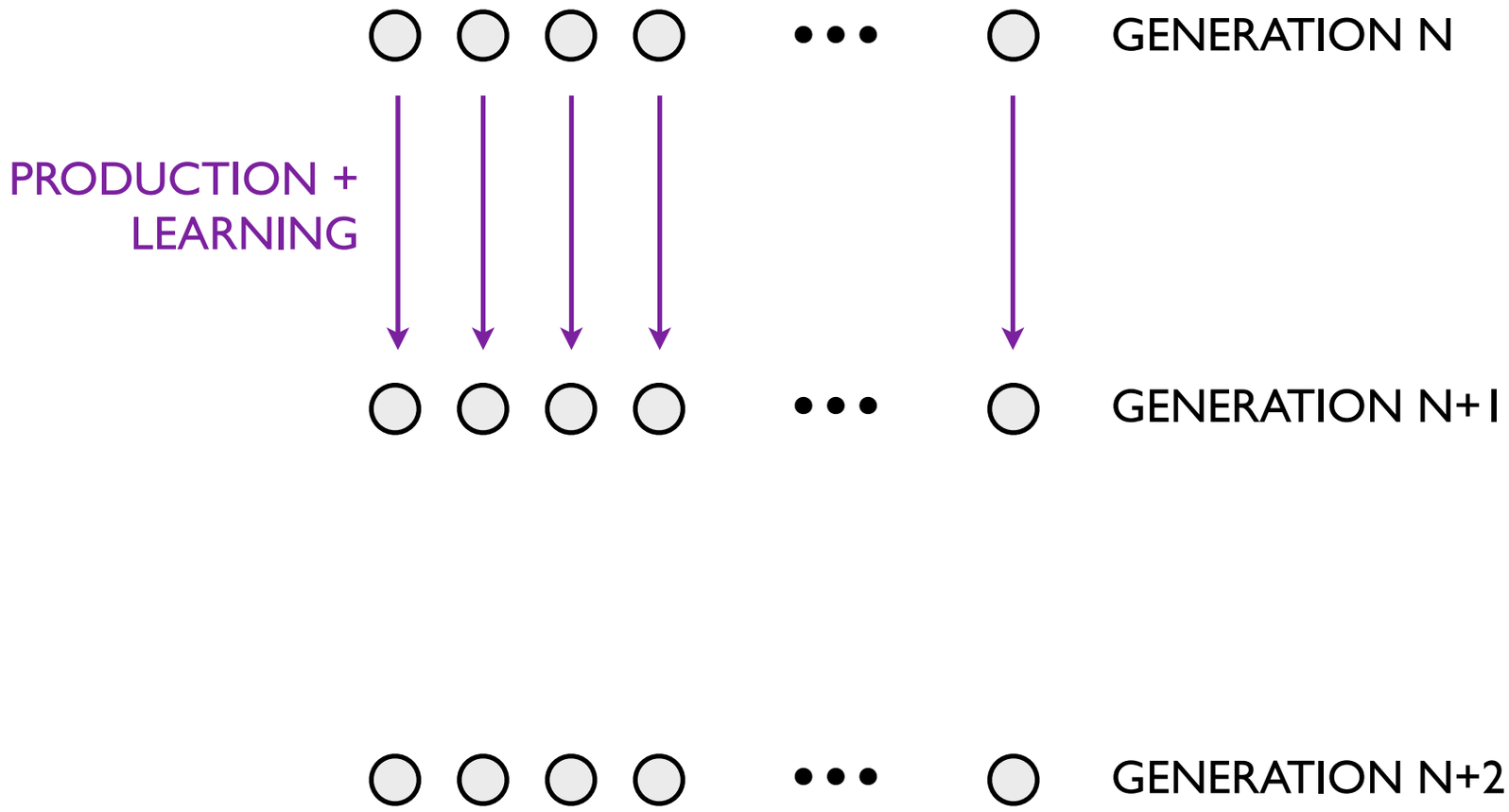
- A population is a series of generations, multiple individuals per generation
- Each agent learns a language from data produced by the previous generation
- Prior encoded as a set of genes that each learner has
    - Initially: uninformative (neutral) prior
- Biological *fitness* determined by how closely your language matches the rest of the population
- Fittest individuals pass on their genes to next generation, with some small probability of mutation (i.e. changes in their genes)
    - Evolving domain-specific priors, since they're really **for** language

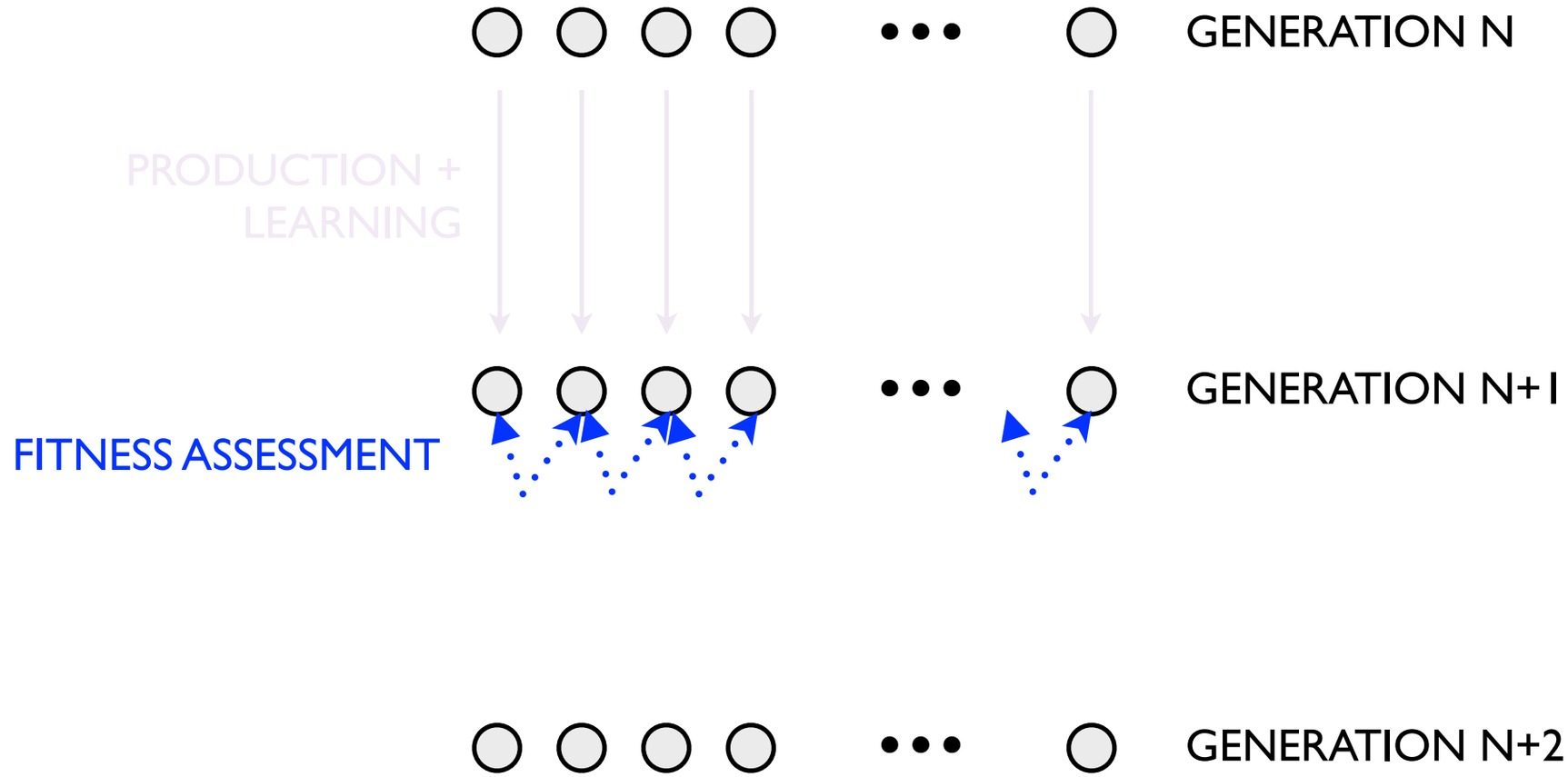
Details

- 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 bias as a set of genes?
- One solution:
    - 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 +
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GENERATION N+1
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GENERATION N+2

GENERATION N

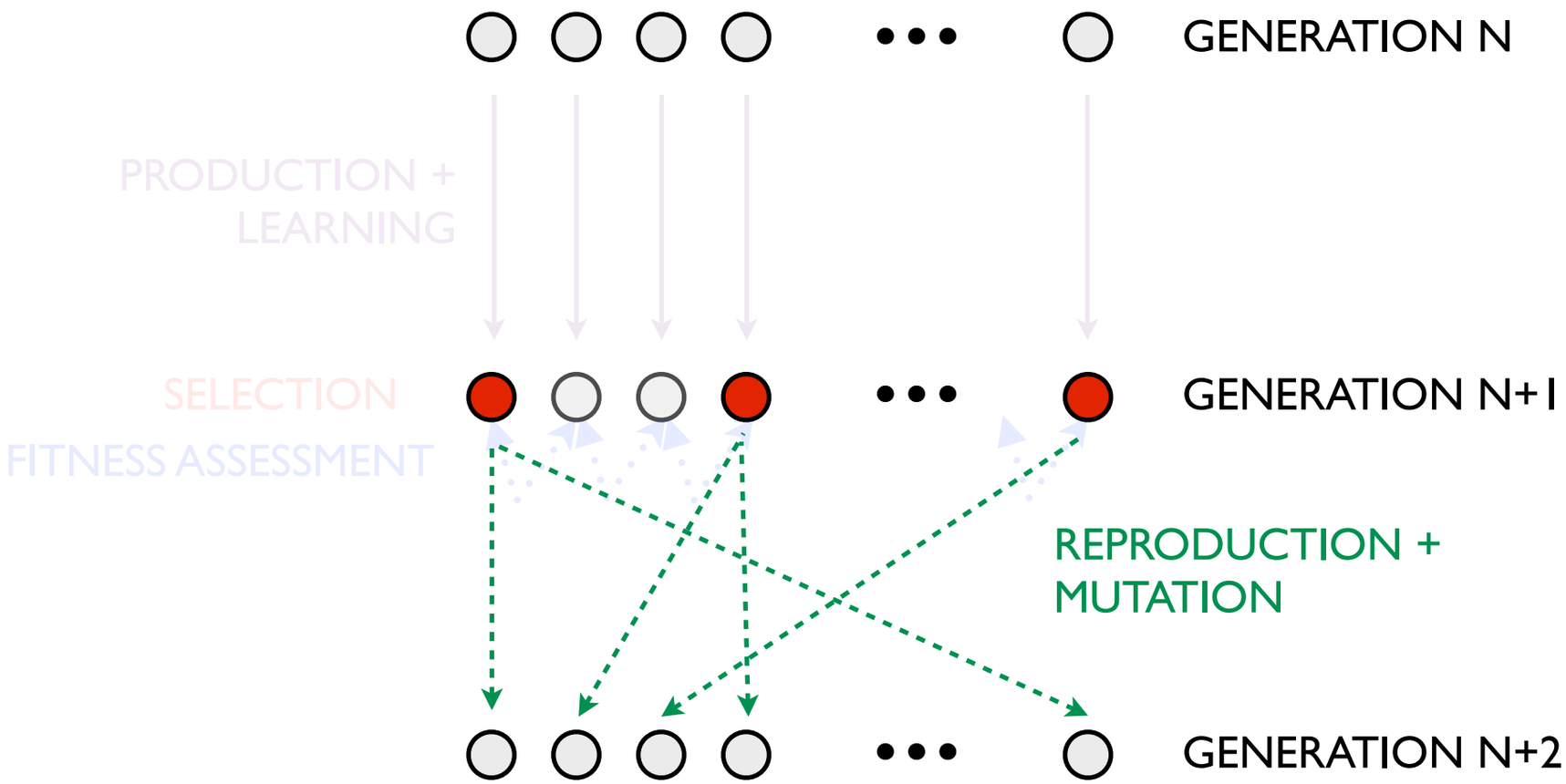
PRODUCTION +
LEARNING

SELECTION

GENERATION N+1

FITNESS ASSESSMENT

GENERATION N+2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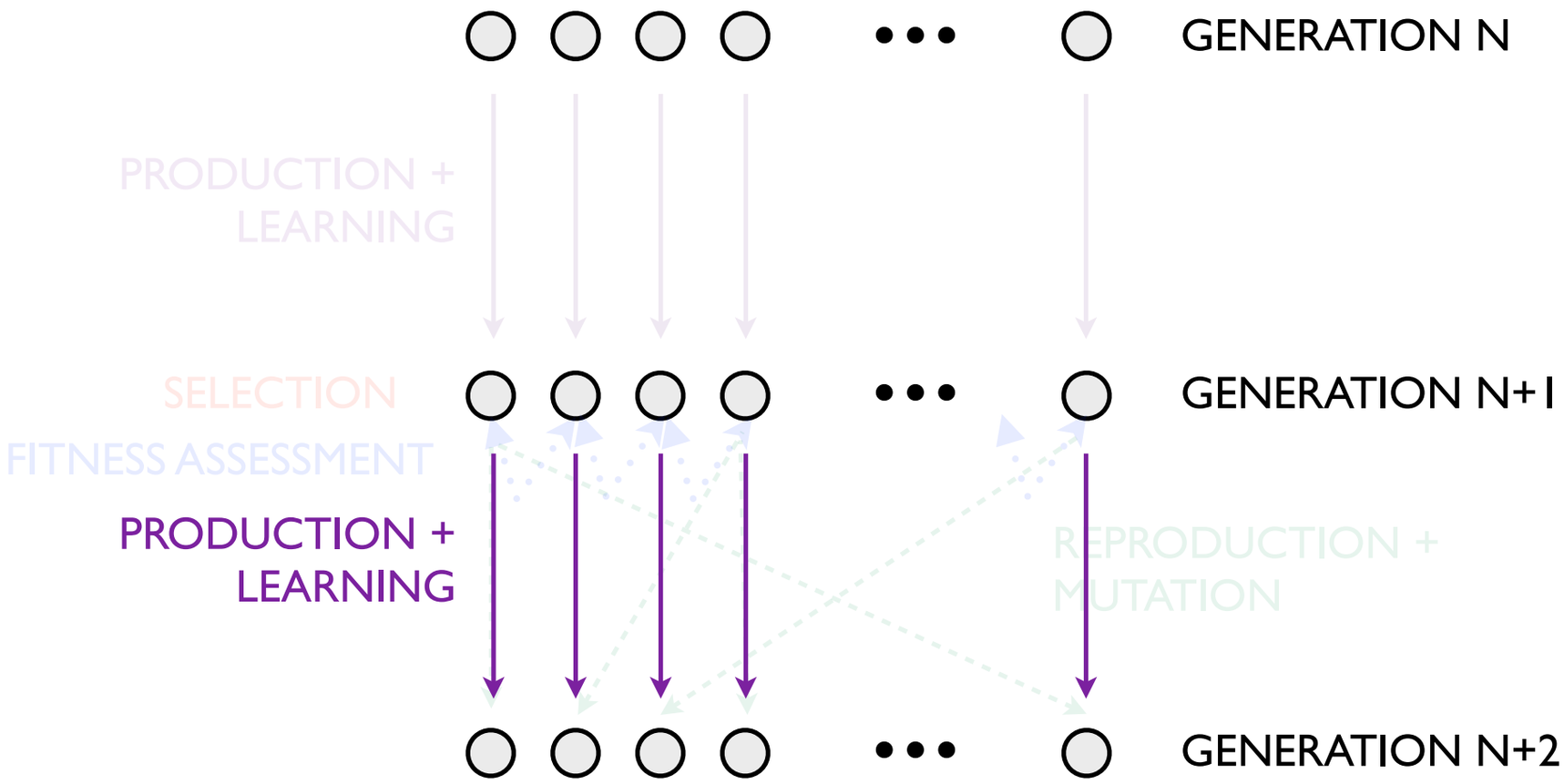
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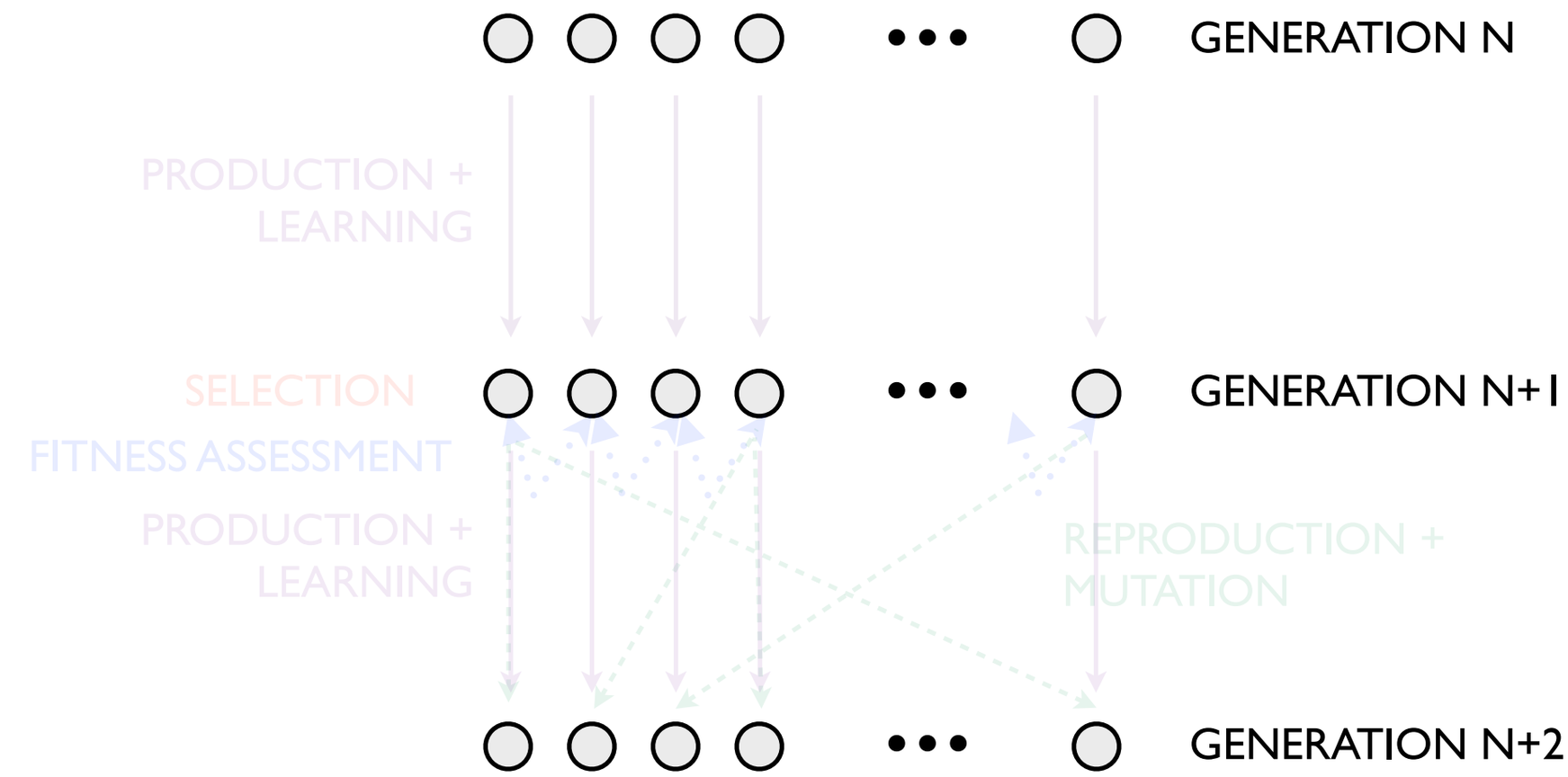
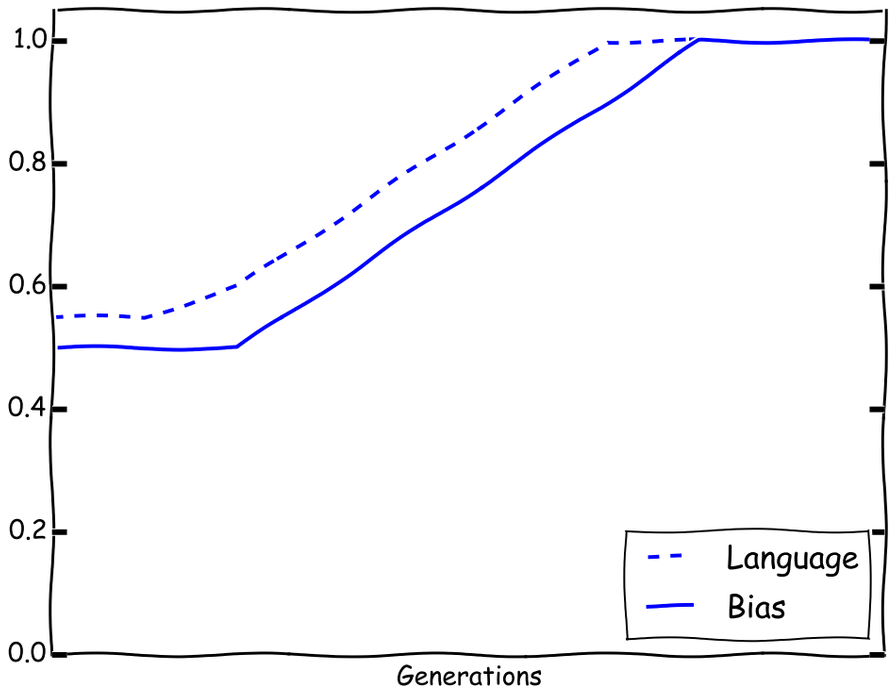


Note two kinds of inheritance - iterated learning and genetic transmission. Evolution due to all of: misconvergence in learning, natural selection, and mutation.

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

A



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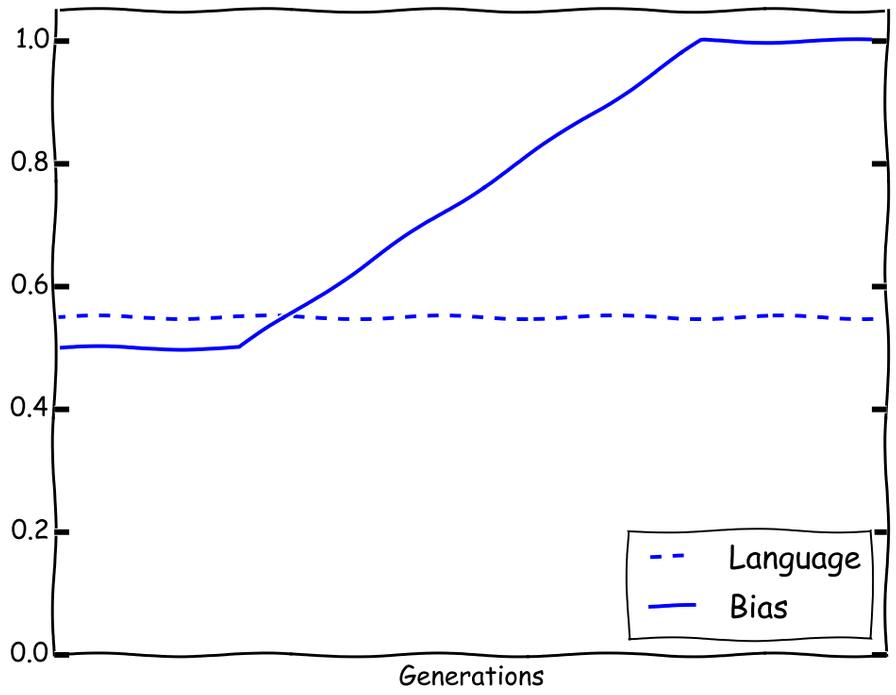

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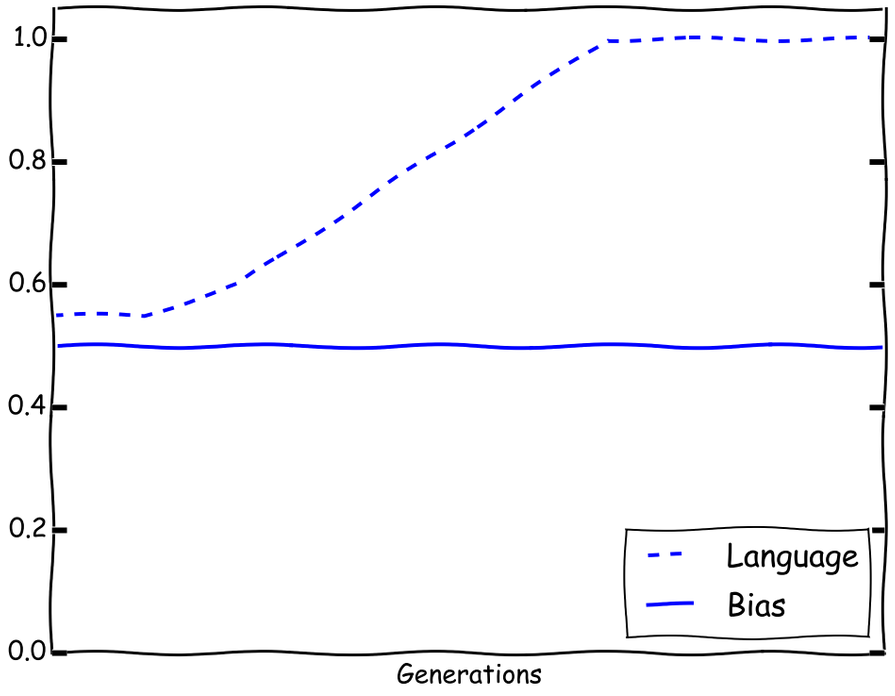

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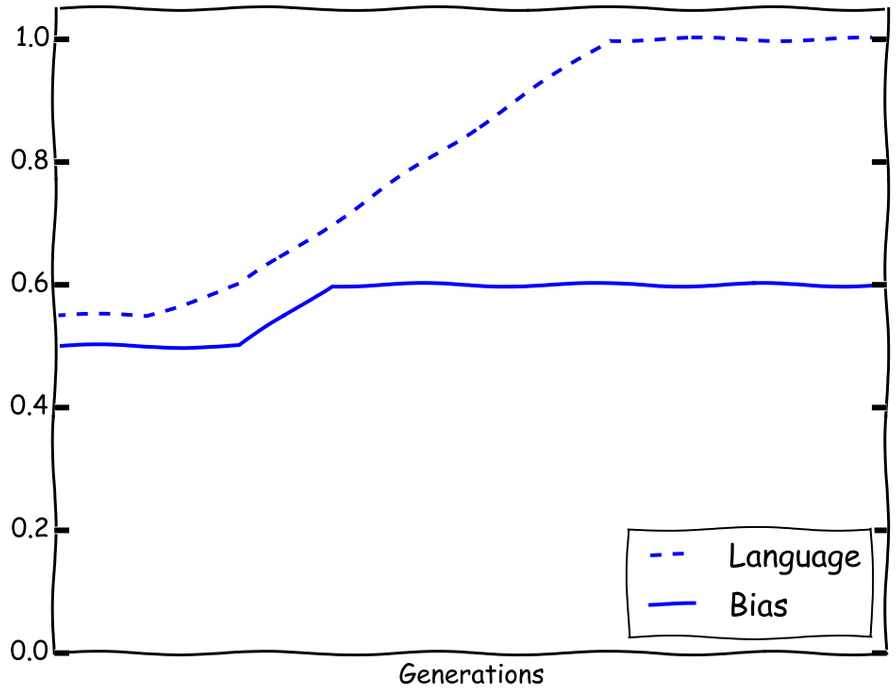


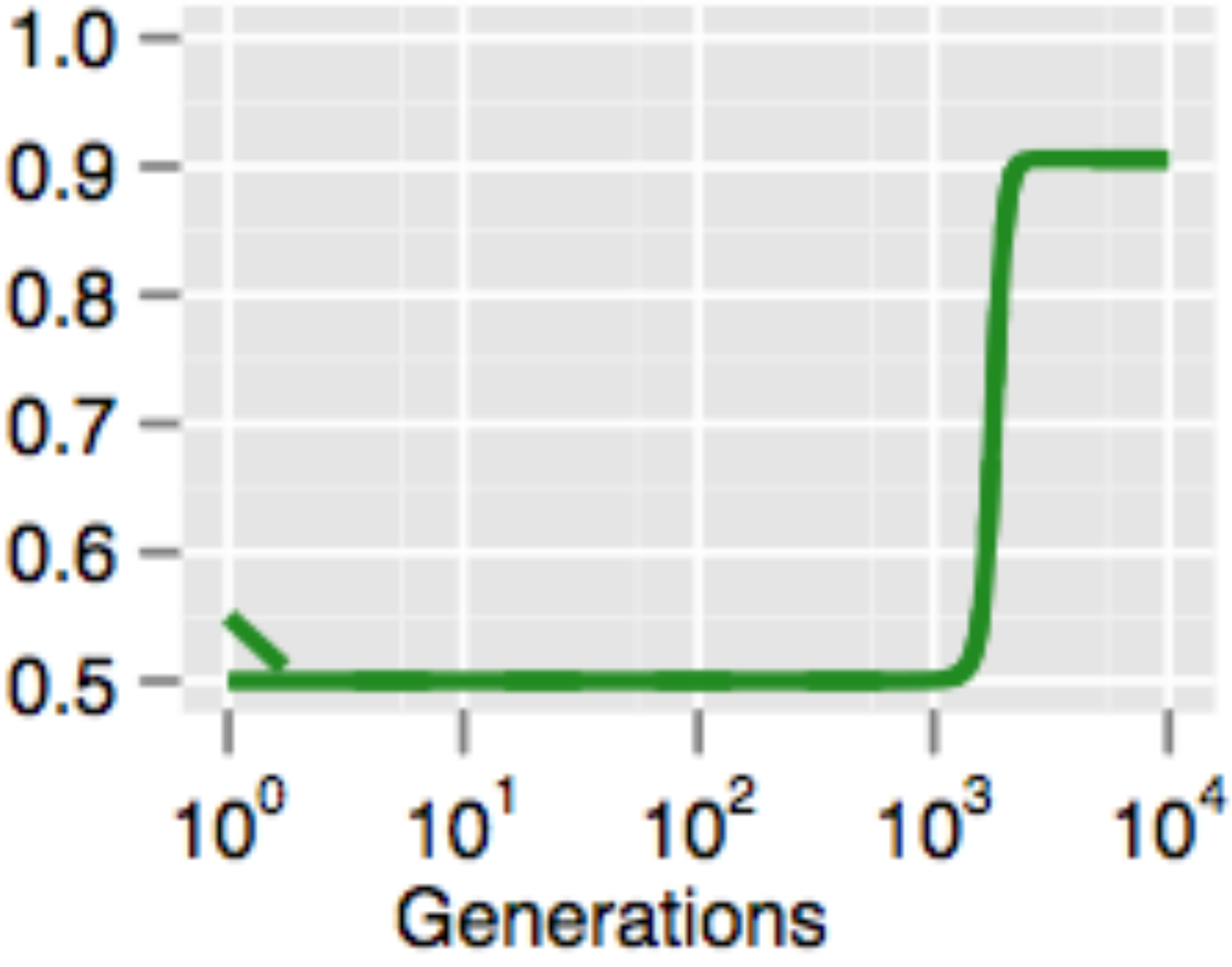
Before we run the model, can we work out what to expect from our experience in the last lab?

- When does it pay to have a bias in favour of a particular language?
  - When that language is common in the population

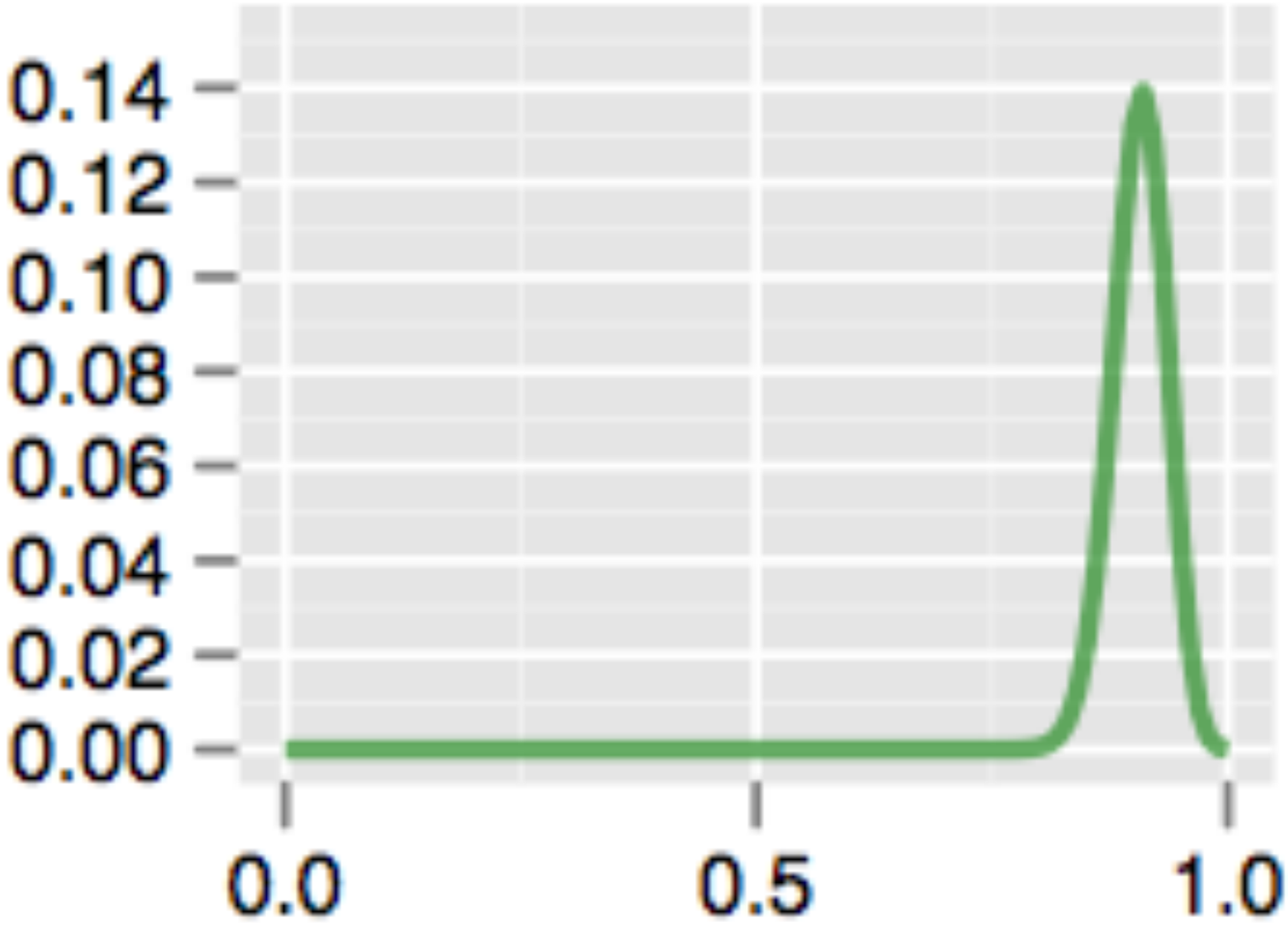
- For samplers, when does one language become very common?
  - When there is a strong bias in favour of that language

- For MAP learners, when does one language become very common?
  - When there is any bias in favour of that language (weak or strong)

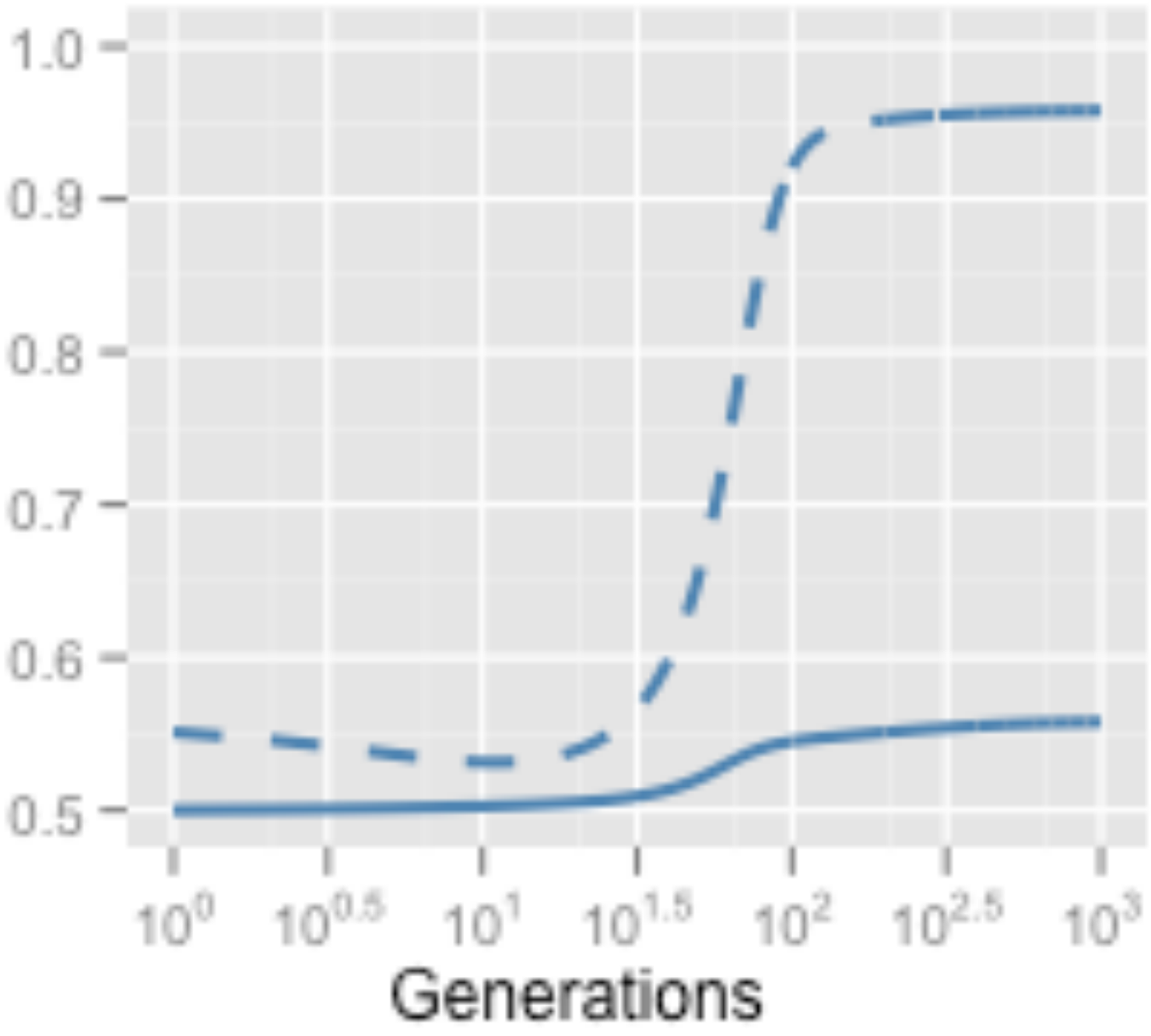
Genetic evolution **only**



Genetic evolution **only**



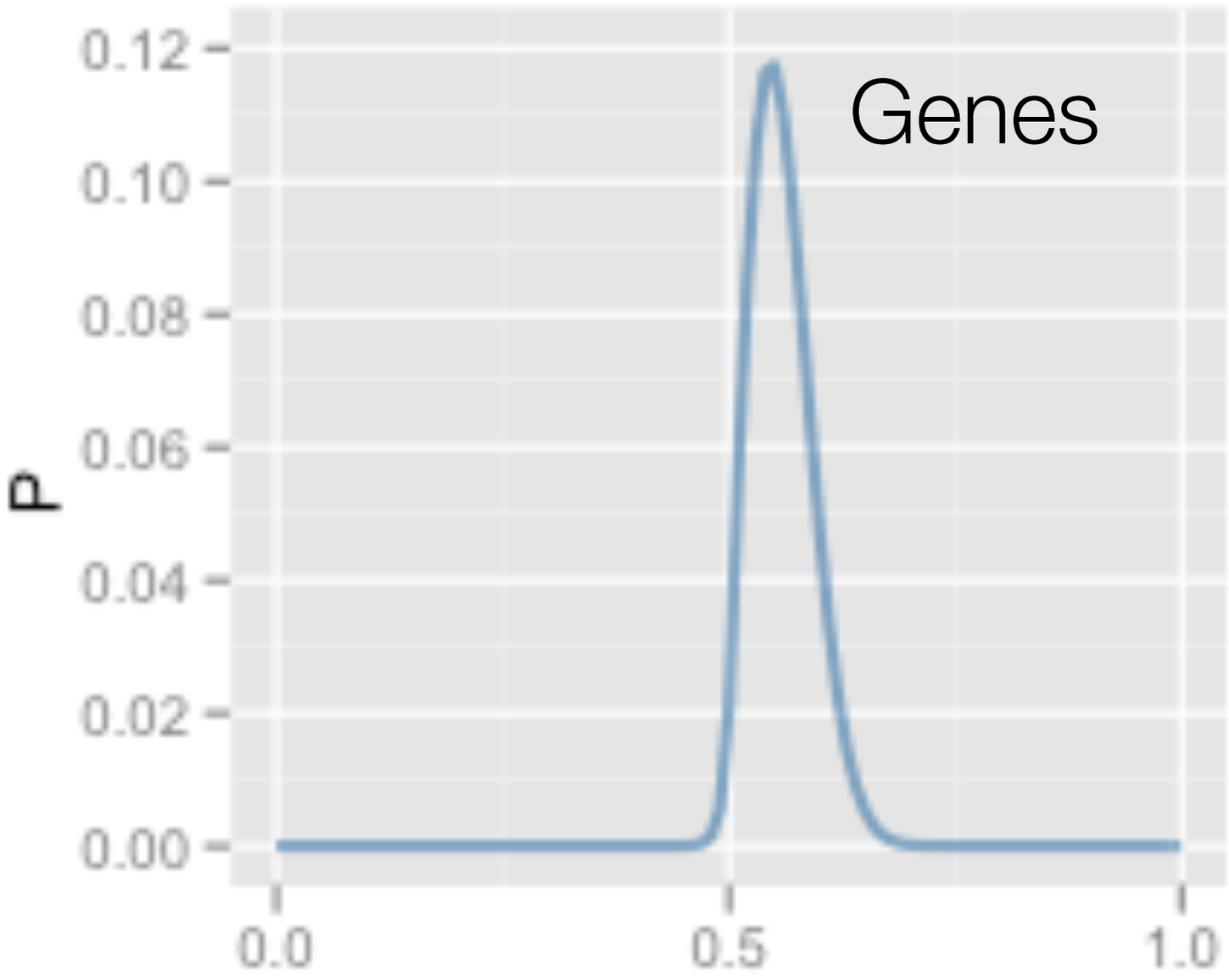
MAP coevolution



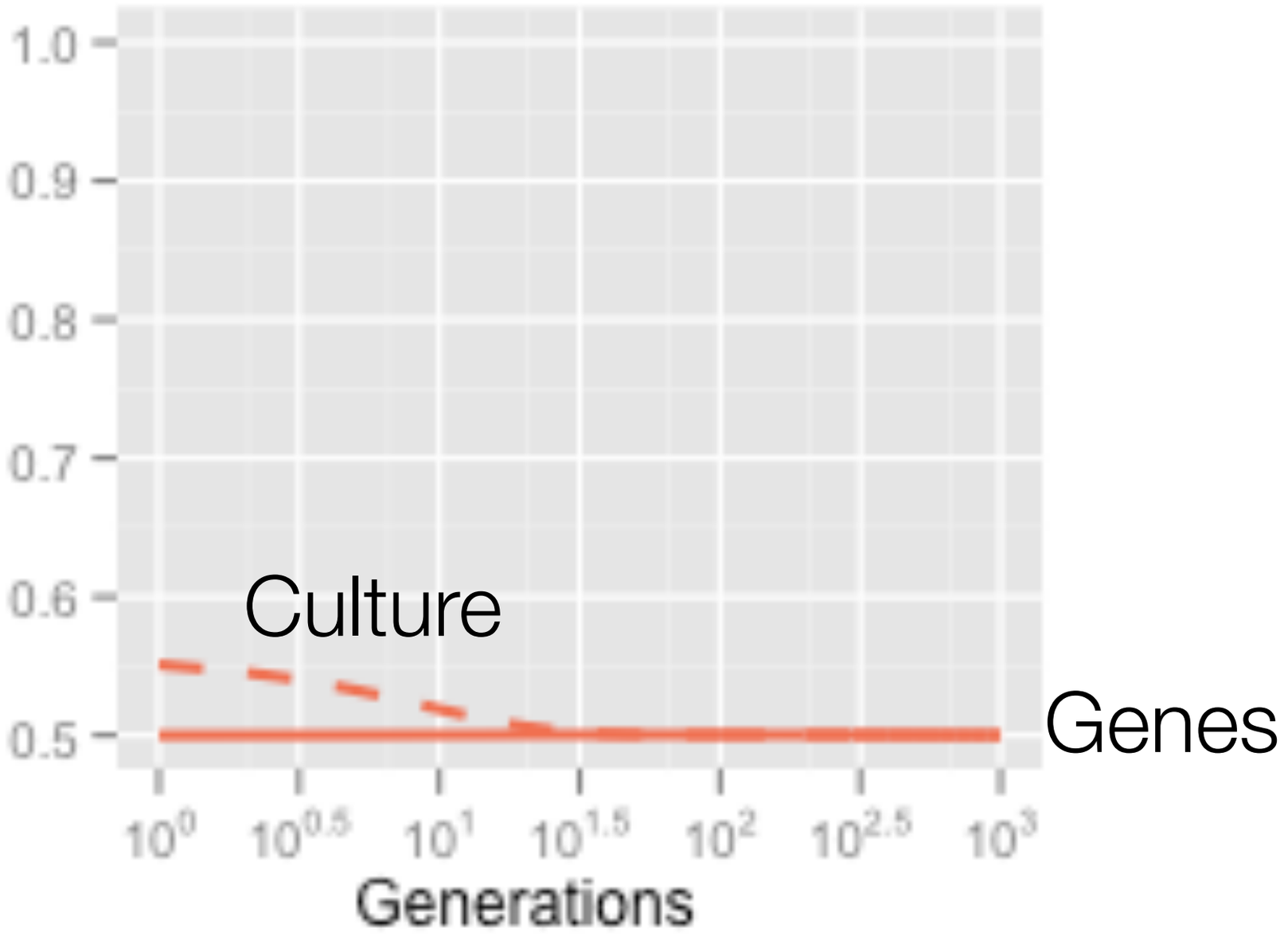
Culture

Genes

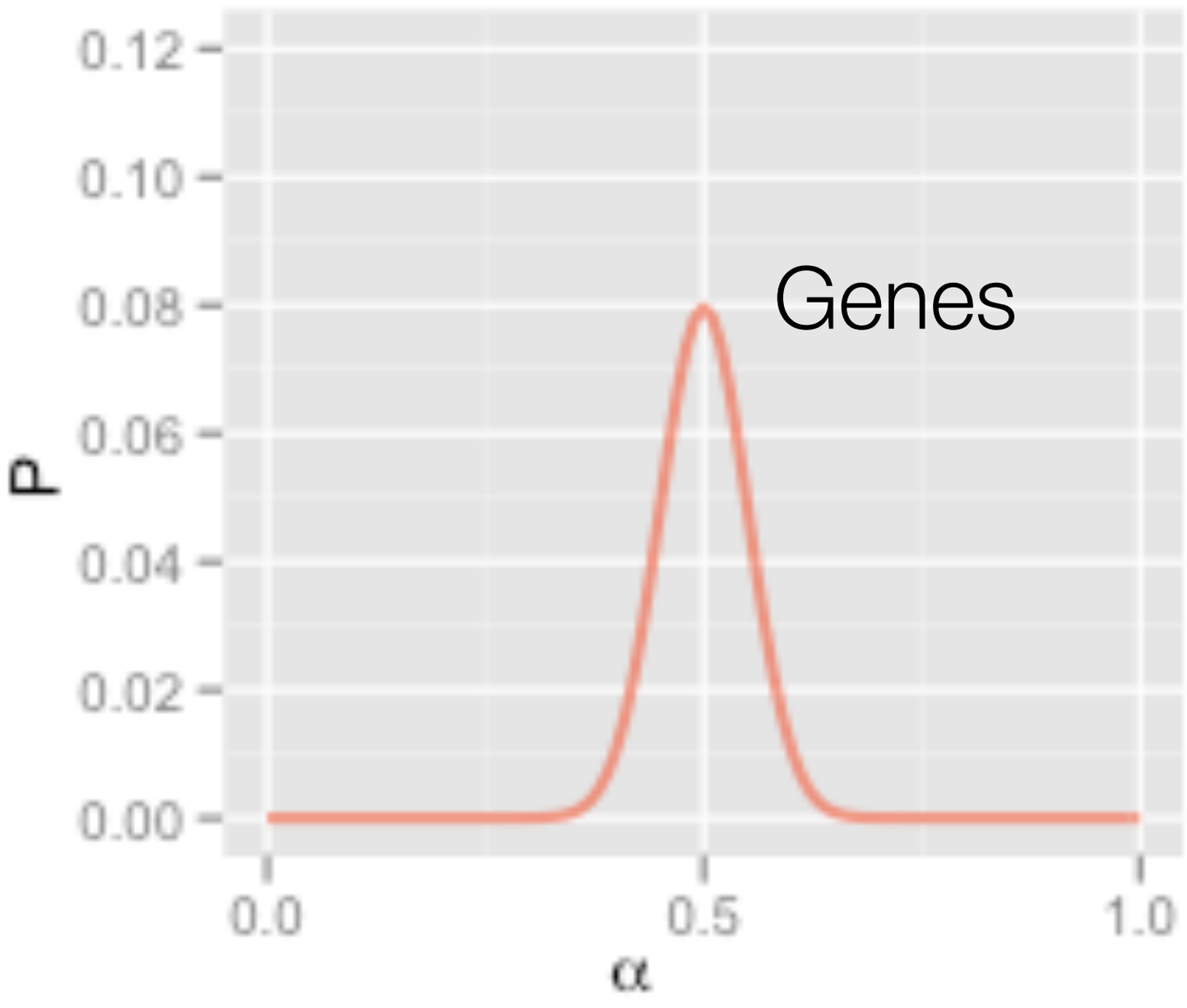
MAP coevolution

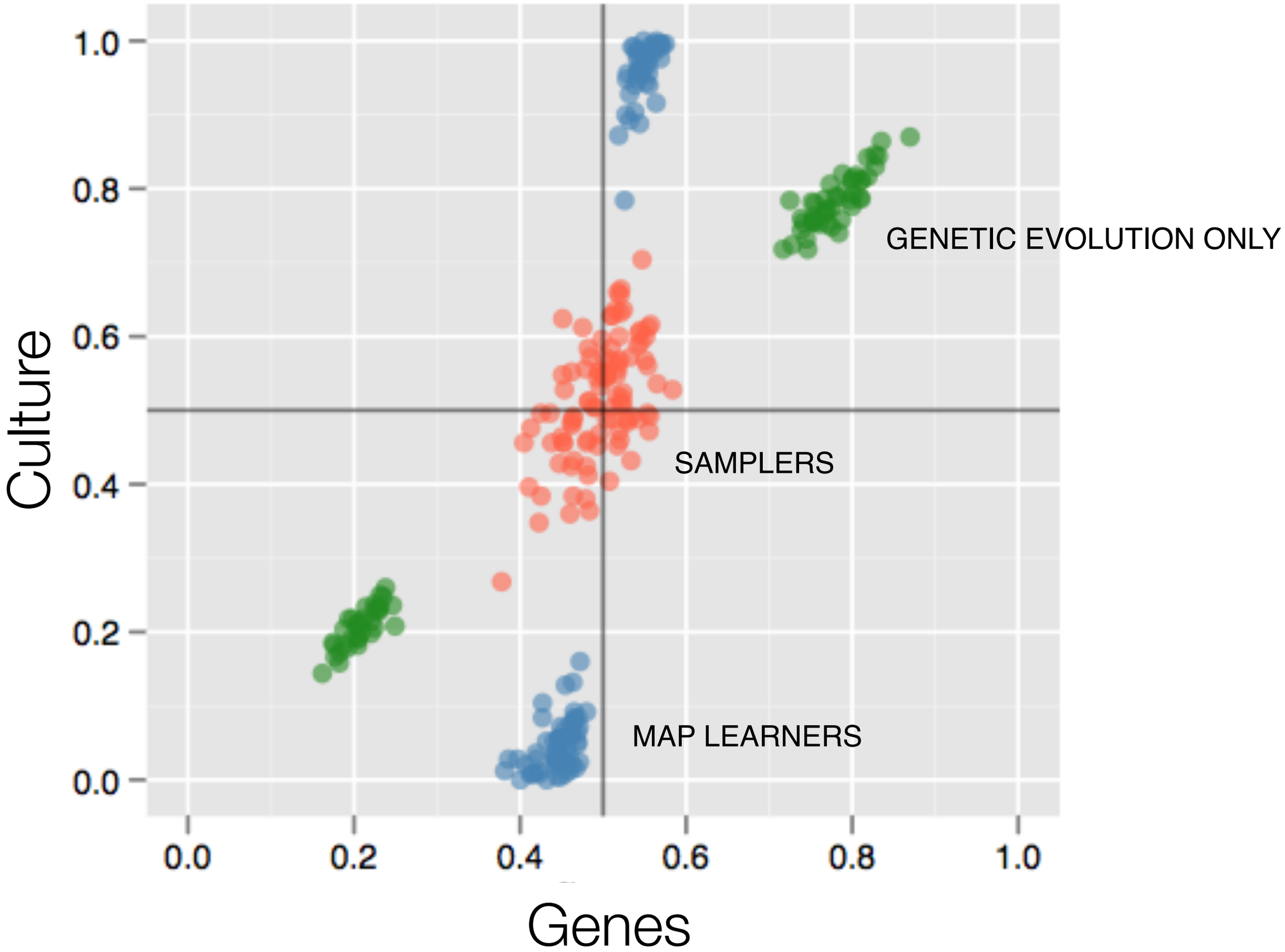


Sampler co-evolution



Sampler co-evolution




1.0
0.8
0.6
0.4
0.2
0.0
Culture
0.0
0.2
0.4
0.6
0.8
1.0
Genes
GENETIC EVOLUTION ONLY
SAMPLERS
MAP LEARNERS

Sampling vs. MAP

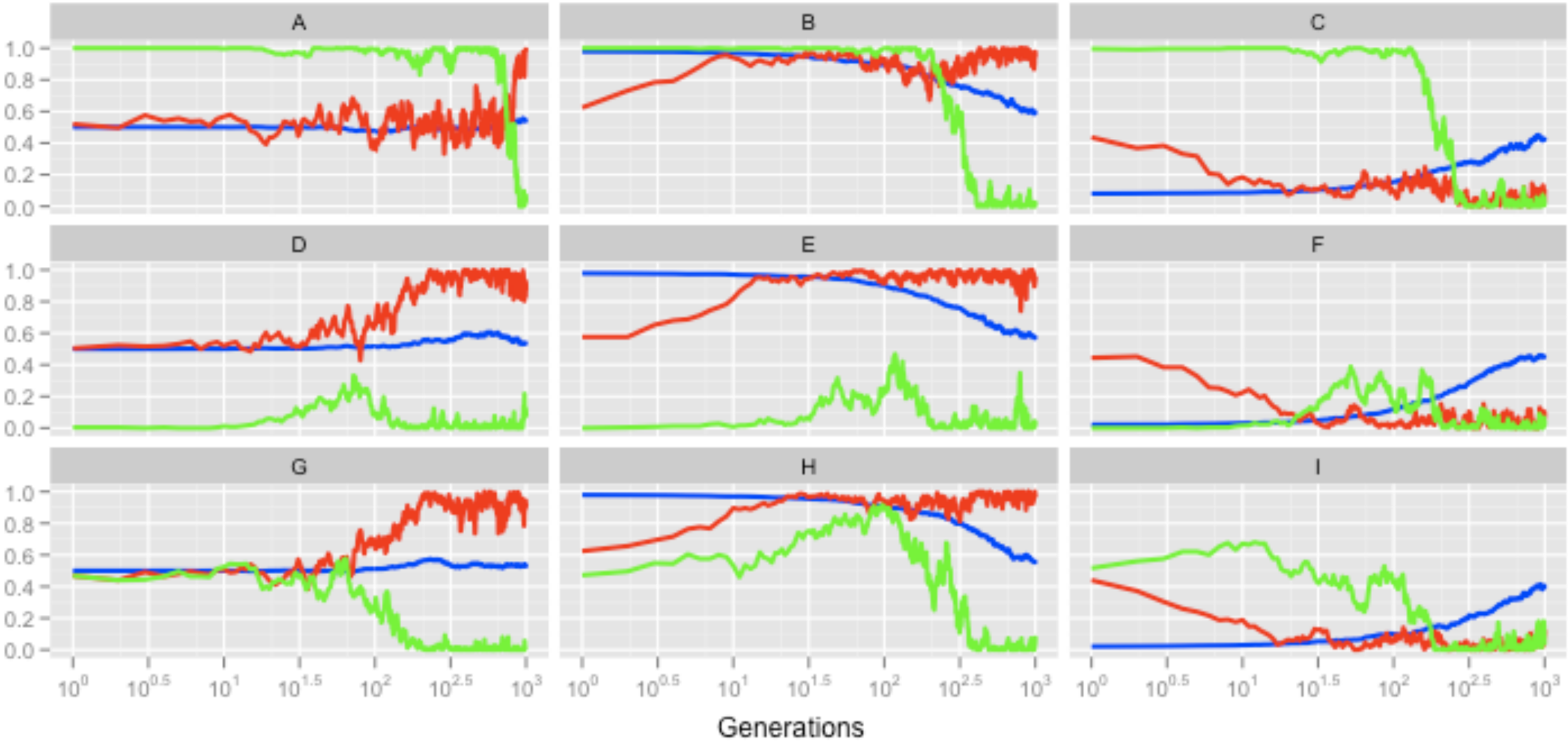
- If you have to pick the same language as someone else trained on similar data to yourself, would you pick the MAP language or sample?

- 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)

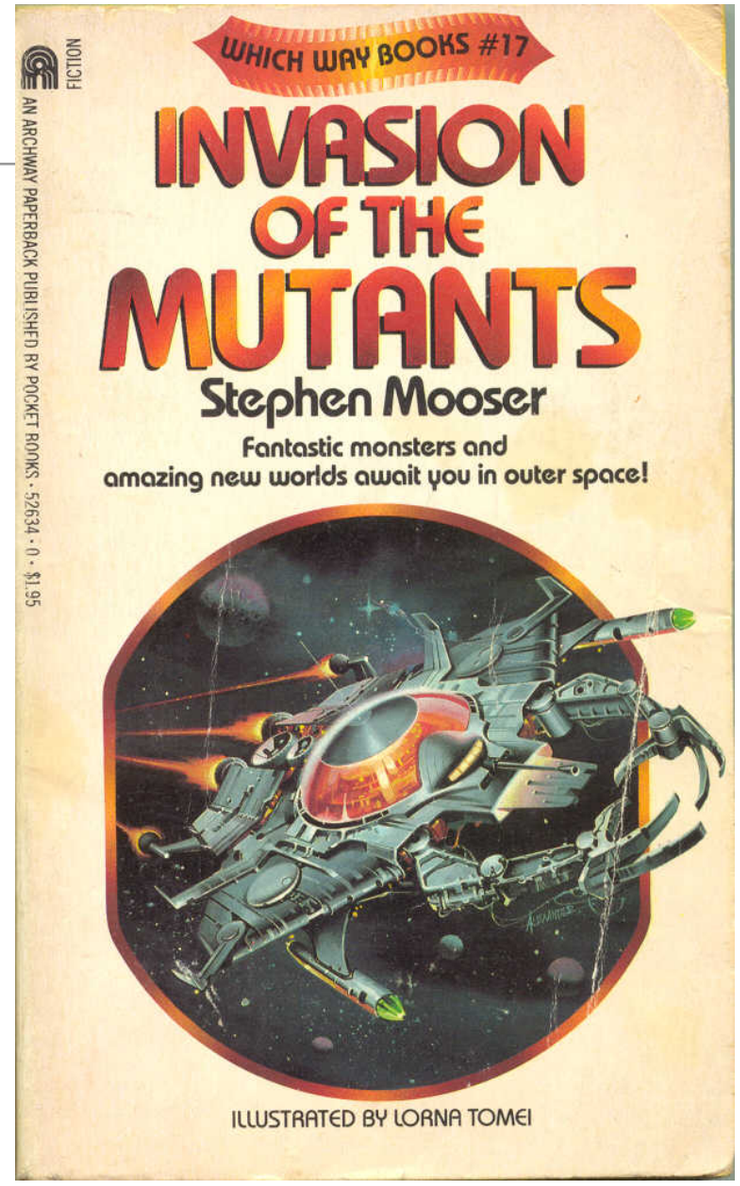
LANGUAGE (CULTURE)

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

The lab this week

- Instead of modelling the whole process of evolution, we're going to look at **when mutants invade**
    - Imagine you have a homogeneous population of some type of learner, and iterated learning has given you the stationary distribution.
    - What happens if a mutant arises in that population that has a different bias, or a different hypothesis selection strategy?



- Answer depends on whether they are better at learning the languages in the stationary distribution than the majority learners are.

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... **But not linguistic nativism**

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, 113:16, 4530–4535.