

# Simulating Language

## 6: The evolution of compositionality

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Note to self: remember to start the recording!

# What's missing from our models so far?

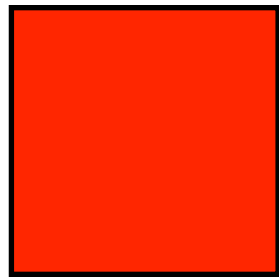
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- In all our models, both meanings and signals are *atomic*
- In reality (for all communicating species) both meanings and signals have internal structure
  - They have internal parts that can be recombined
- Does this matter at all?

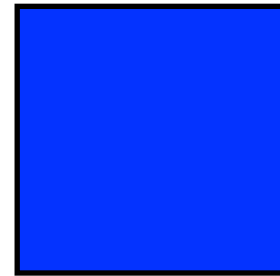
# How we leverage structure...

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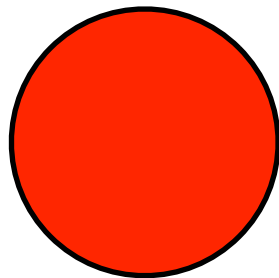
- What's the missing word?



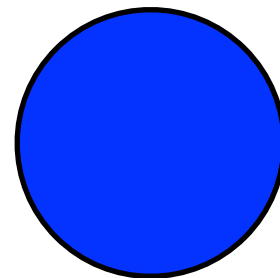
lapalu



kanepi



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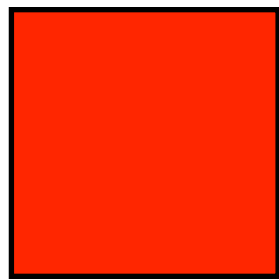


**??????**

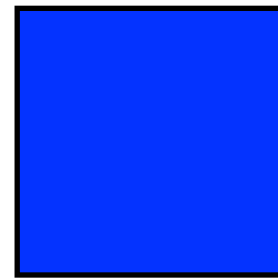
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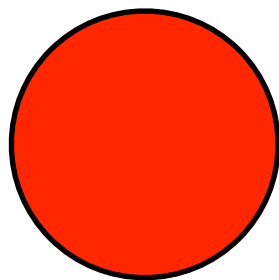
- What's the missing word?



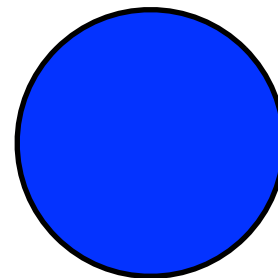
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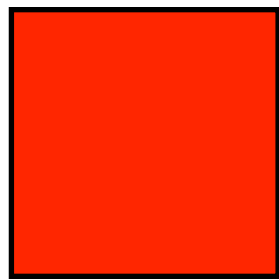


**neluka**

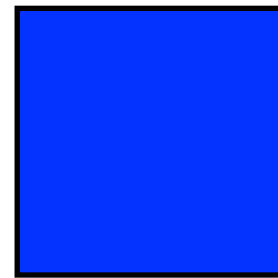
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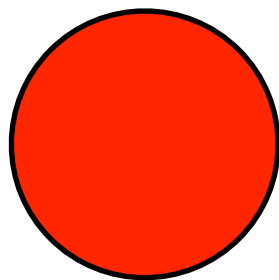
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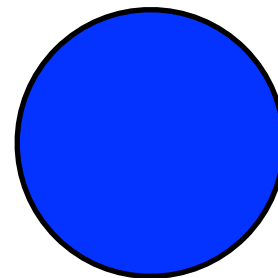
laneplo



replo



lanepilu

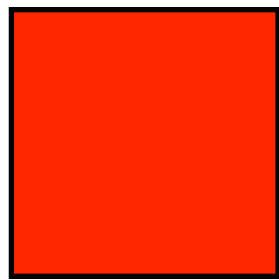


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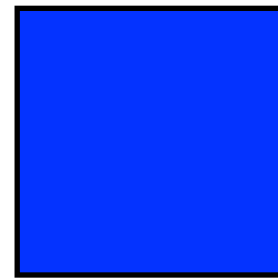
# How we leverage structure...

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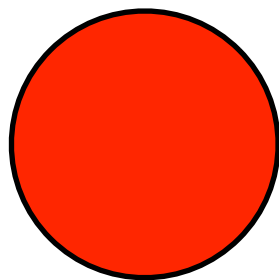
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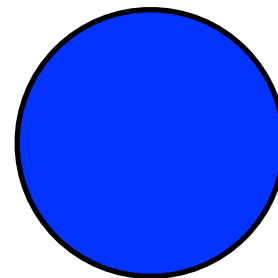
laneplo



replo



lanepilu



**repilu**

# What's the difference?

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- In the first example, the meanings and signals might as well have been unstructured/atomic
  - We were essentially seeing a vocabulary.
- In the second example, we relied on the fact that:
  - the meanings had internal structure (e.g. color and shape),
  - and the signals had internal structure (e.g. subsequences of syllables)
  - and the mapping utilises the structure in a way that allows us to **generalise**

# Compositionality

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- The crucial structure of the mapping is *compositionality*

**Compositionality:** the meaning of the whole is a function of the meaning of the parts and how they are put together.

- Arguably the most important feature of the syntax of human language
- Enables open-ended communication (more fundamentally than recursion)
- Strangely, it is rare and quite restricted in non-human animals, despite being a hugely beneficial trait!



# Where does compositionality come from?

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- Compositionally-structured meaning-signal mappings are adaptive, since they enable open-ended communication
- So... might suggest an explanation in terms of natural selection:

“Evolutionary theory offers clear criteria for when a trait should be attributed to natural selection: complex design for some function, and *the absence of alternative processes capable of explaining such complexity*. Human language meets these criteria.” Pinker & Bloom (1990)

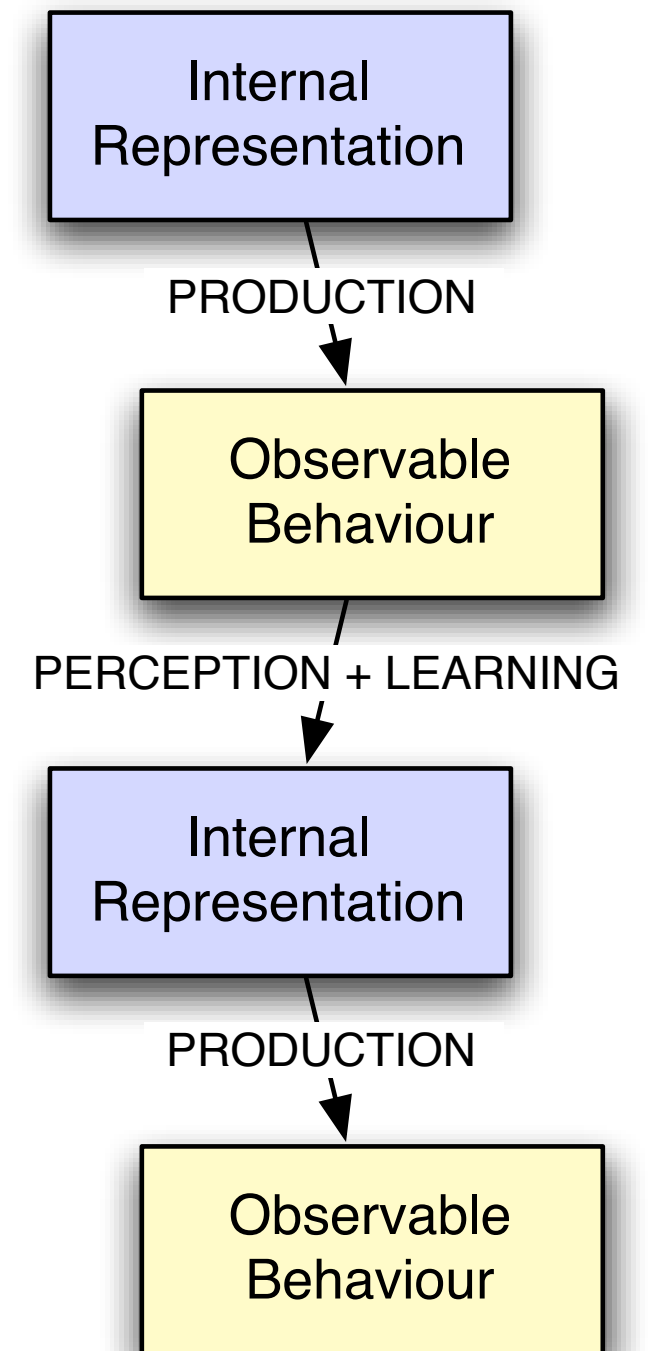
- But are there *alternative process*?

And anyway, how exactly do properties of our innate endowment lead to observable properties of language (the adaptations they purport to explain)? This is **problem of linkage** again...

# Iterated learning again

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- To solve the problem of linkage, we need to turn again to the iterated learning model
- What happens if, instead of mappings between atomic meanings and signals, we allowed for meanings and signals with structure?
- Could we see a *cultural* rather than biological evolution of compositionality?



Kirby, S., Tamariz, M., Cornish, H., & Smith, K. (2015).  
Compression and communication in the cultural evolution of  
linguistic structure. *Cognition*, 141, 87-102.

# The simplest possible model?

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- What's the simplest setup that would still allow us to compare **compositional** and non-compositional (**holistic**) languages?

- Signals: two syllable words, with two possible syllables

*baba, baki, kiba, kiki*

['aa', 'ab', 'ba', 'bb']

- Meanings: two features, with two possible “values” on each feature

square+red, circle+red, square+blue, circle+blue

['02', '12', '03', '13']

# Some grammars

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$S : 02 \rightarrow aa$

$S : 03 \rightarrow ab$

$S : 12 \rightarrow bb$

$S : 13 \rightarrow ba$

**Holistic**

$S \rightarrow AB$

$A : 0 \rightarrow a$

$A : 1 \rightarrow b$

$B : 2 \rightarrow a$

$B : 3 \rightarrow b$

**Compositional**

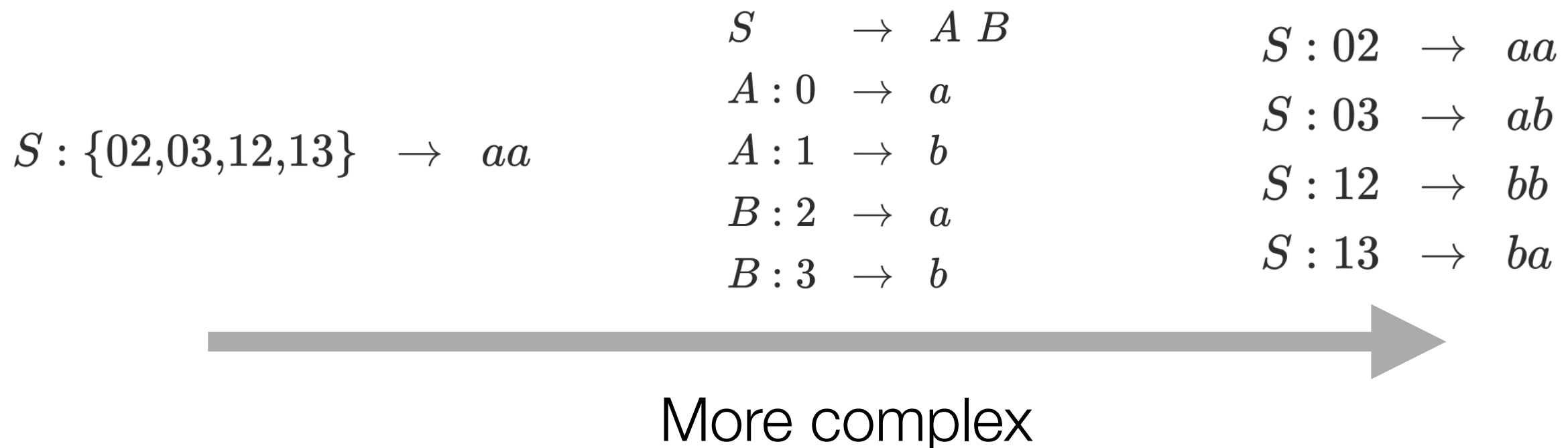
$S : \{02, 03, 12, 13\} \rightarrow aa$

**Degenerate**

# A very general prior

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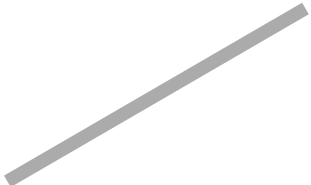
- Occam's razor: **simpler solutions are more likely than complex ones**
- Faced with different theories of the world (or data), we should prefer the simpler ones
- We can actually measure simplicity by looking at how much it takes to encode (roughly, write down) our grammars:



# Learning

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$$P(h|d) \propto P(d|h)P(h)$$



**Posterior:** learners pick grammars based on their probability given the sentences they see

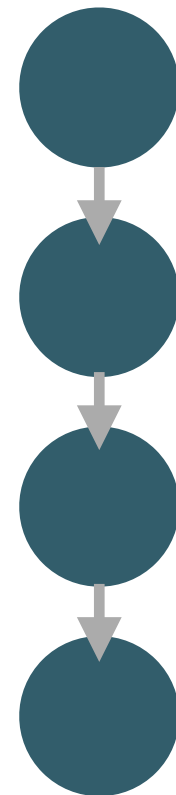
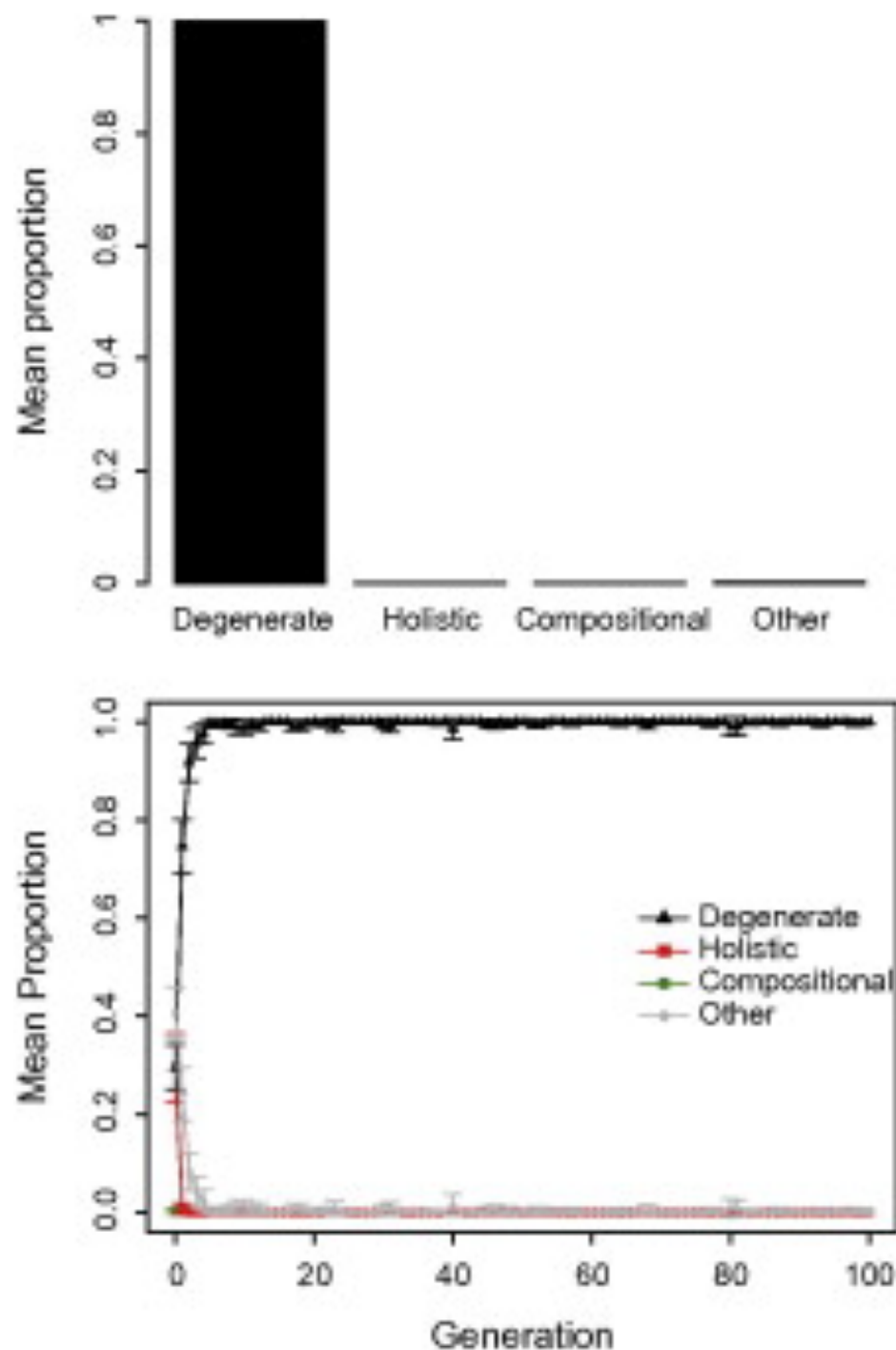


**Likelihood:** favour grammars that predict the data well



**Prior:** favour simple grammars

# What happens when we iterate in a chain?



$$S : \{02,03,12,13\} \rightarrow aa$$

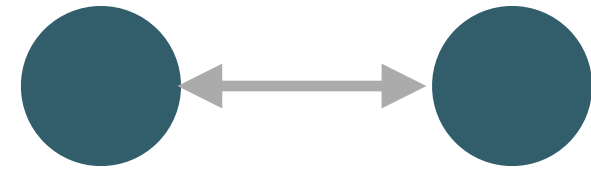
Very **learnable** (i.e. simple),  
but **inexpressive**



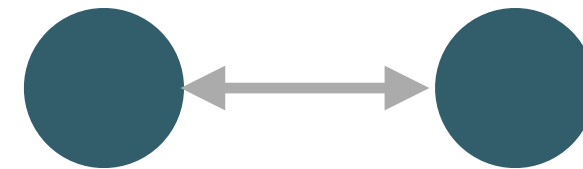
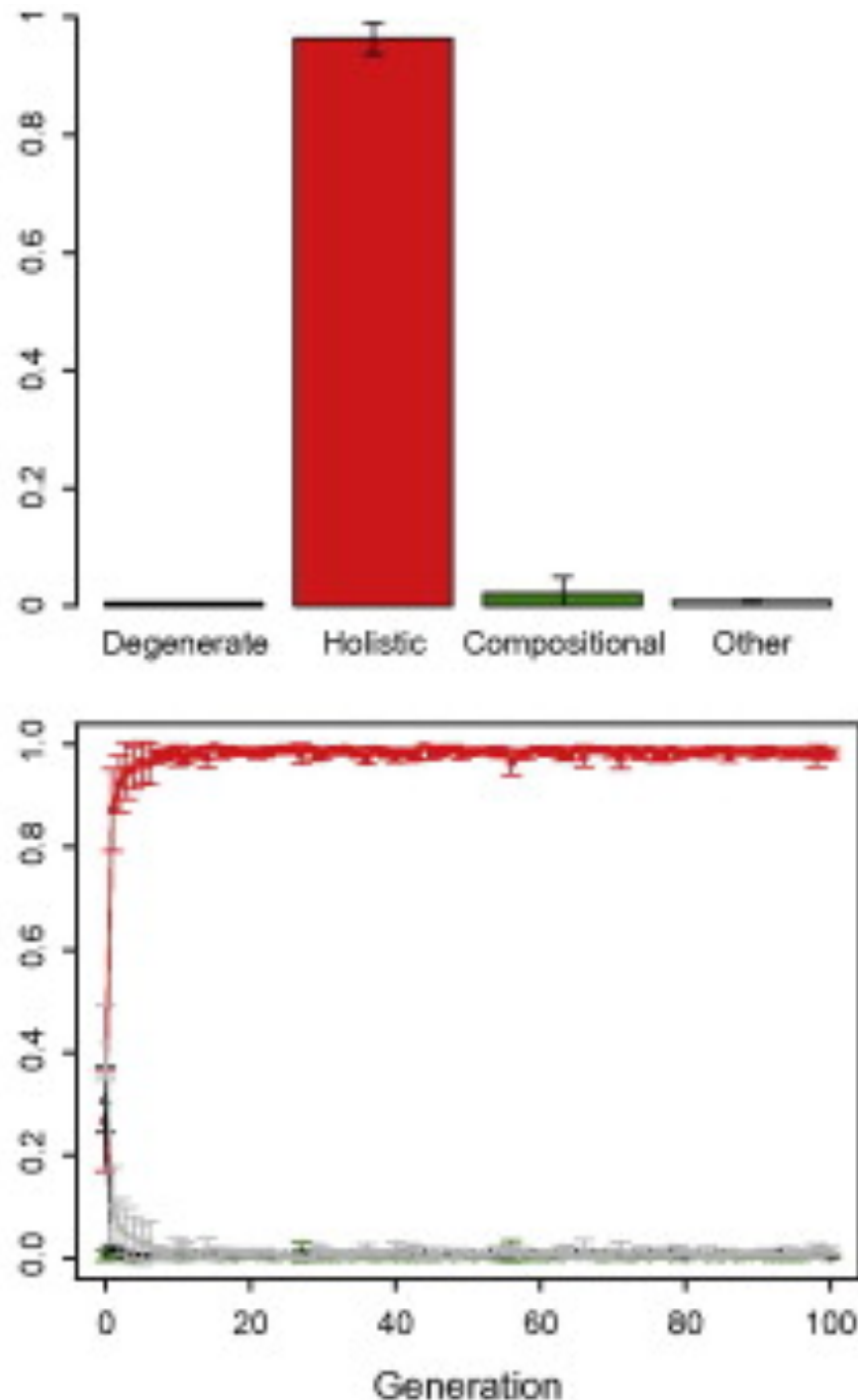
# Communication

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- Language adapts to the learner. So simplest possible language emerges, but it's useless for communication!
- An alternative model: two agents interact with each other and learn from their interactions.
- Use the simple “rational” speaker that we implemented before.



# What happens when a pair interact?



$S : 02 \rightarrow aa$

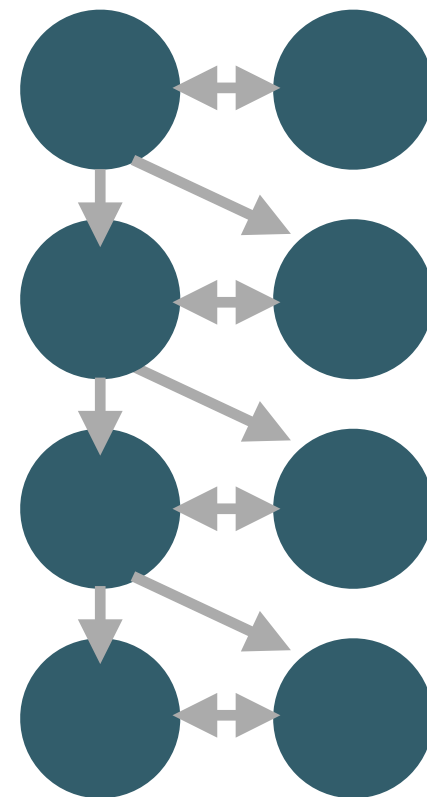
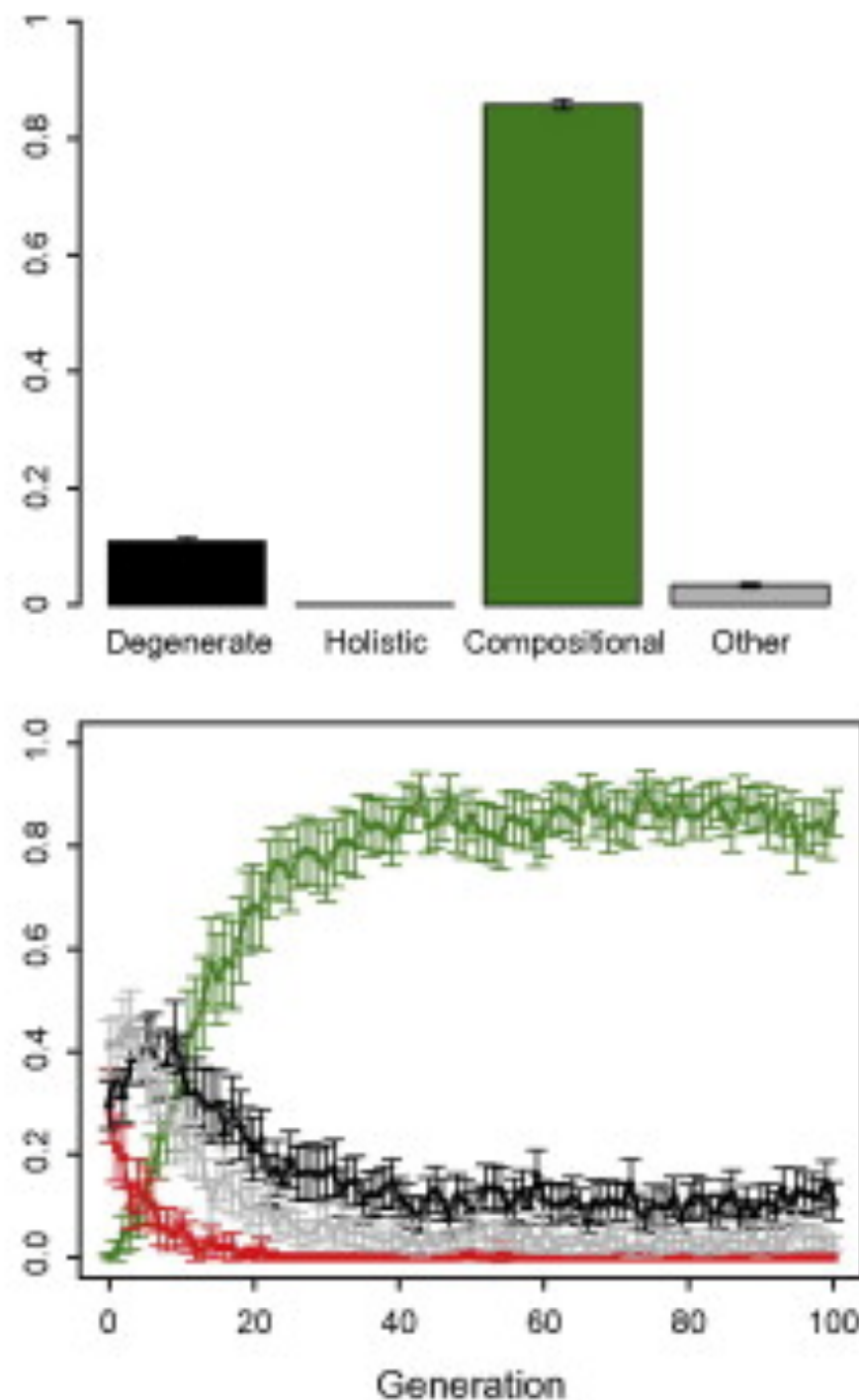
$S : 03 \rightarrow ab$

$S : 12 \rightarrow bb$

$S : 13 \rightarrow ba$

**Expressive**, but not very  
**learnable** (i.e. complex)

OK, what about both iteration *and* interaction?



$S \rightarrow A B$   
 $A : 0 \rightarrow a$   
 $A : 1 \rightarrow b$   
 $B : 2 \rightarrow a$   
 $B : 3 \rightarrow b$

**Expressive**, and fairly  
**learnable** (i.e. reasonably  
simple)

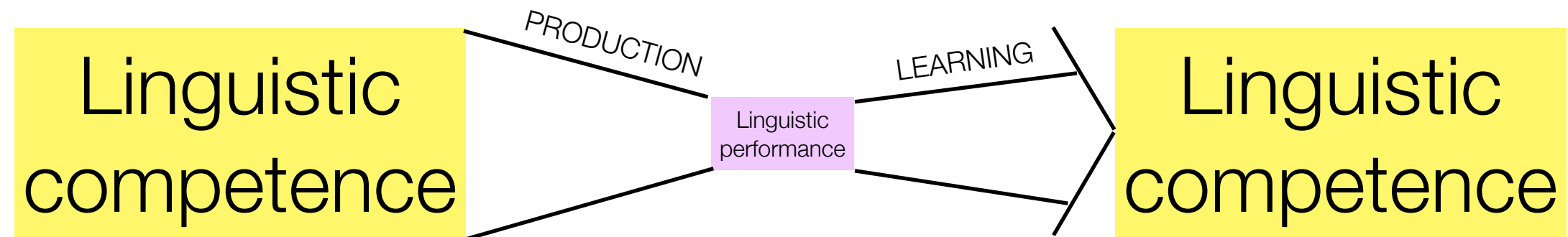
# How confident can we be in this result?

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- This is an interesting result, but how realistic is it?
- Kirby et al (2015) recreate the simulation in the experiment lab
- Participants come into the lab and learn a miniature holistic language, then use it to communicate with another participant
- New pairs of participants learn from the behaviour of the previous pair
- New learners + communication -> compositional languages  
New learners + no communication -> degenerate languages  
No new learners + communication -> holistic languages

# Language has to fit through a narrow *bottleneck*

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- This has profound implications for the structure of language
- Only languages that are *generalisable* from limited exposure are stable if they are transmitted to new learners
- Only languages that are unambiguous are stable if they are used by speakers who avoid ambiguity
- Compositional syntax is an adaptive response **by language** (arising from cultural evolution) to the problem of getting through this bottleneck

# Up next

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- Labs this week: a replication of the model in Kirby et al (2015)
- Coming next... we've been assuming particular prior biases throughout this course, but where do they come from?
  - Next week: learning how to learn
  - Final weeks of the course: how **biological evolution** can shape learning and culture, and how this finally answers some fundamental questions about whether language is innate