Language Evolution in the Lab: from models to experiments in evolutionary linguistics

Simon Kirby

Hannah Cornish, Thom Scott-Phillips, Kenny Smith

Language Evolution & Computation Research Unit

University of Edinburgh

www.lel.ed.ac.uk/lec

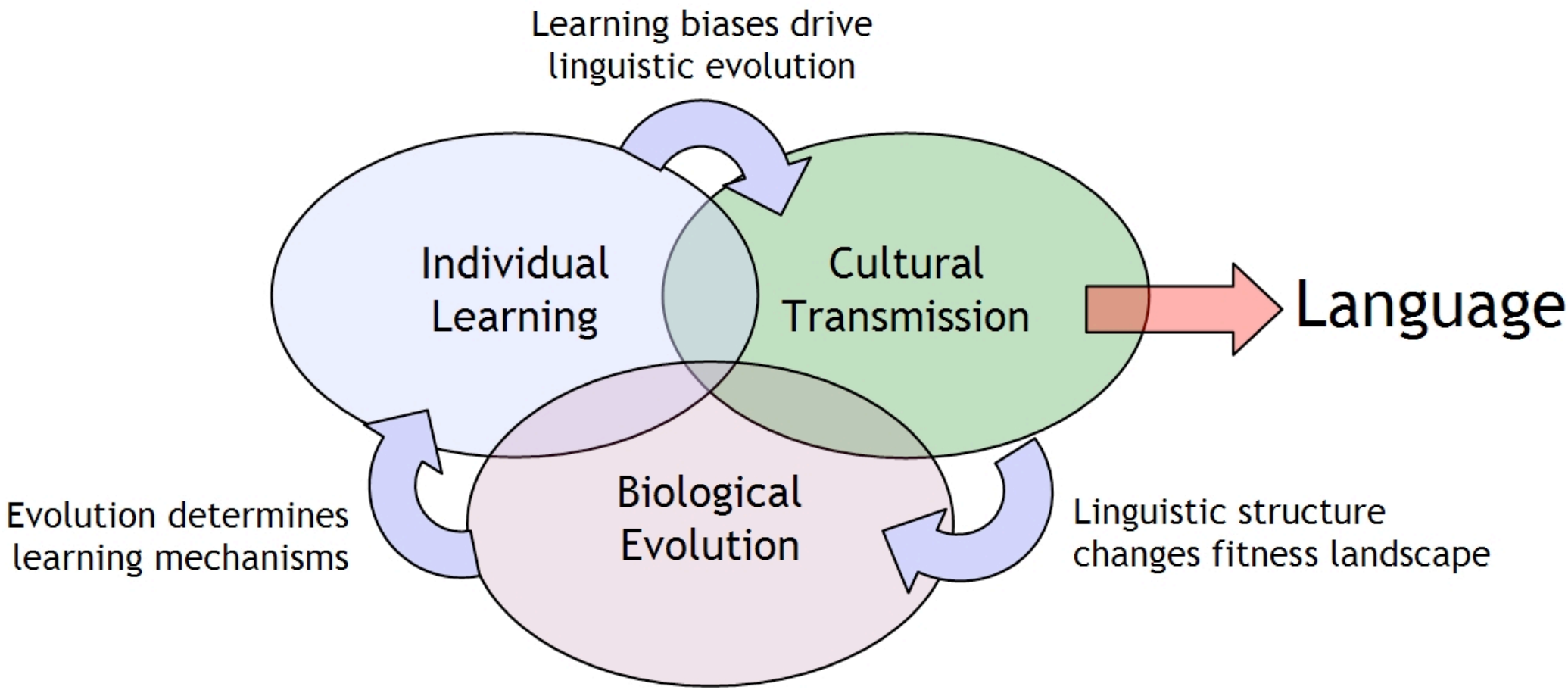
The evolutionary approach to language

The evolutionary approach to language

- Language is (almost) unique in nature

The evolutionary approach to language

- Language is (almost) unique in nature
- It involves three complex adaptive systems:
  - Biological evolution
  - Individual learning
  - Cultural transmission
- Language arises from the interaction of these three


Learning biases drive
linguistic evolution
Individual
Learning
Cultural
Transmission
Language
Biological
Evolution
Evolution determines
learning mechanisms
Linguistic structure
changes fitness landscape

The challenge...

The challenge...

- Evolutionary linguistics rests on the premise:
  - to understand why language is the way it is, we need to understand these adaptive processes and their interaction

The challenge...

- Evolutionary linguistics rests on the premise:
  - to understand why language is the way it is, we need to understand these adaptive processes and their interaction
- But how do we do this?
- One approach: build models
  - explore the adaptive processes in miniature, and then apply what we learn to the real thing

This talk

- I'm going to focus on cultural transmission
  - mainly because its importance has been underemphasised in traditional evolutionary approaches
- I want to show that you can study this in the lab
  - New experimental methodologies inspired by earlier computational models
- Ultimately this gives us a new perspective on the biological prerequisites for human language

Previous computational models
(a whistle-stop tour)

Previous computational models (a whistle-stop tour)

- The Iterated Learning Model (mid 90s onwards)

Previous computational models (a whistle-stop tour)

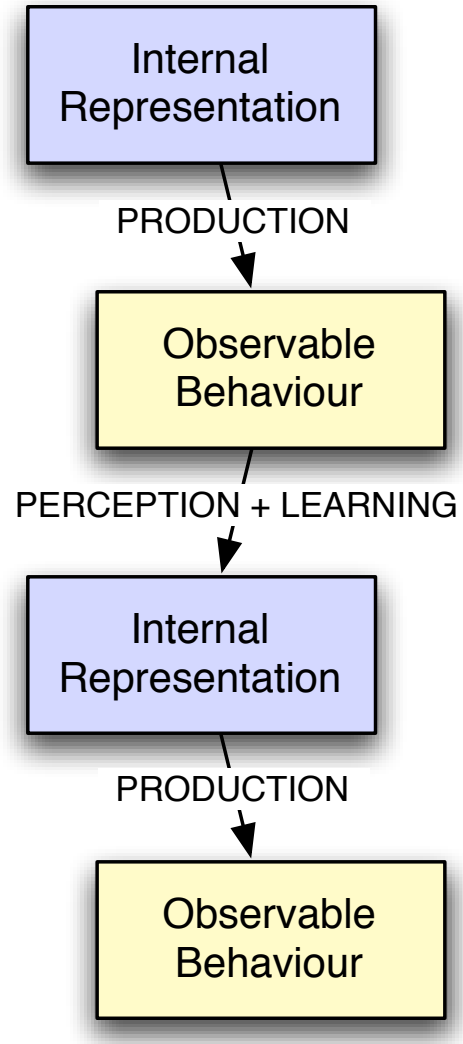
- The Iterated Learning Model (mid 90s onwards)
  - Multi-agent modelling techniques applied to cultural evolution

Previous computational models (a whistle-stop tour)

- The Iterated Learning Model (mid 90s onwards)
  - Multi-agent modelling techniques applied to cultural evolution
  - Embed simple models of learners in a dynamic population and an "environment" about which they try to communicate

Previous computational models (a whistle-stop tour)

- The Iterated Learning Model (mid 90s onwards)
  - Multi-agent modelling techniques applied to cultural evolution
  - Embed simple models of learners in a dynamic population and an "environment" about which they try to communicate
  - Agents learn to communicate by observing others, who themselves learned the same way (cf. broken telephone)



Previous modelling work
(a whistle-stop tour)

Previous modelling work
(a whistle-stop tour)

- Key insight: *transmission bottlenecks*

Previous modelling work
(a whistle-stop tour)

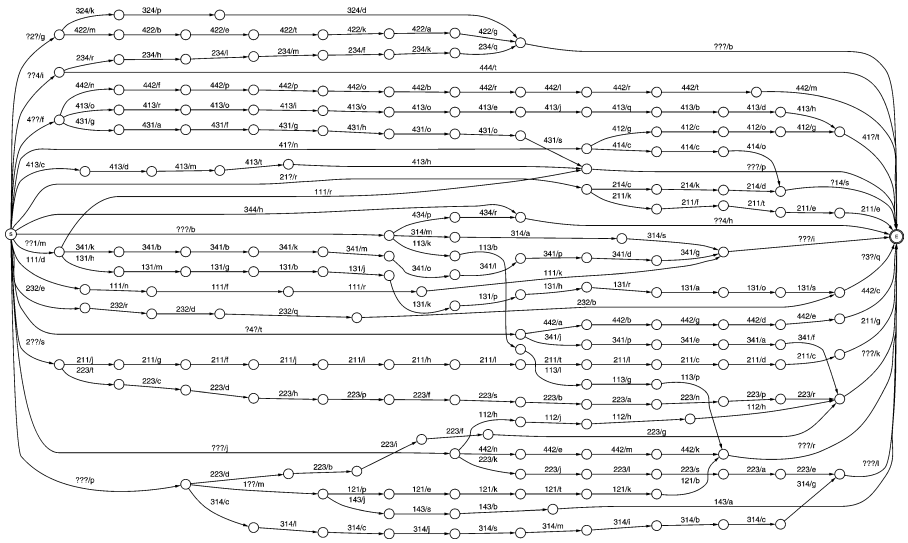
- Key insight: *transmission bottlenecks*
  - If a learner is given imperfect information about the language, e.g. noise, processing constraints, or simply not hearing all the data (cf. *stimulus poverty*)
  - ... cultural transmission becomes an adaptive system.
  - Language will adapt so that it appears to be designed to "fit" the bottleneck

Previous modelling work (a whistle-stop tour)

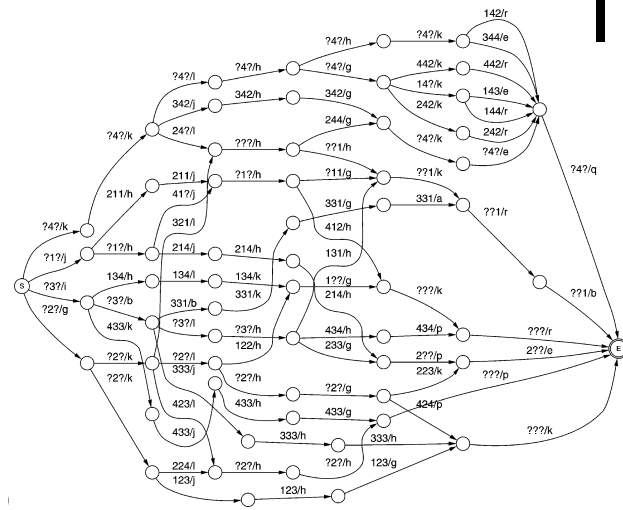
- Key insight: *transmission bottlenecks*
  - If a learner is given imperfect information about the language, e.g. noise, processing constraints, or simply not hearing all the data (cf. *stimulus poverty*)
  - ... cultural transmission becomes an adaptive system.
  - Language will adapt so that it appears to be designed to "fit" the bottleneck
  - Features like compositional syntax emerge spontaneously in these models

Brighton et al (2005)

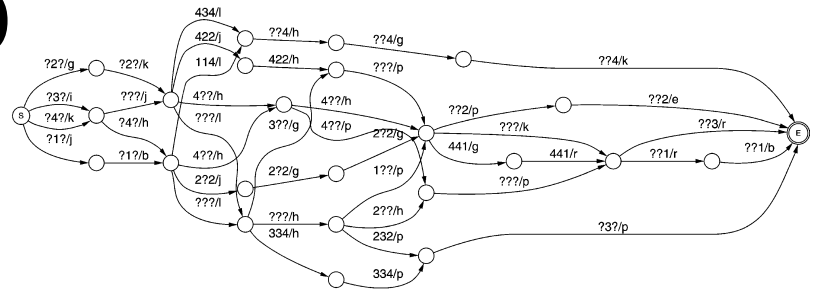
1



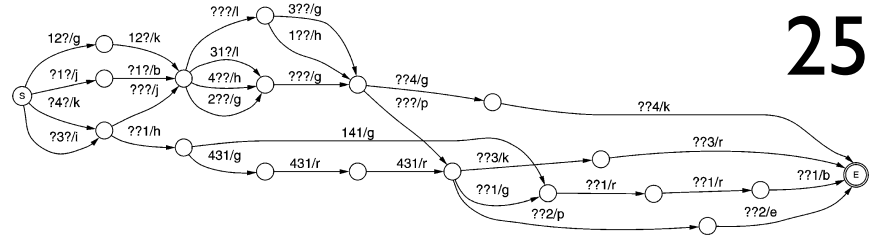
10



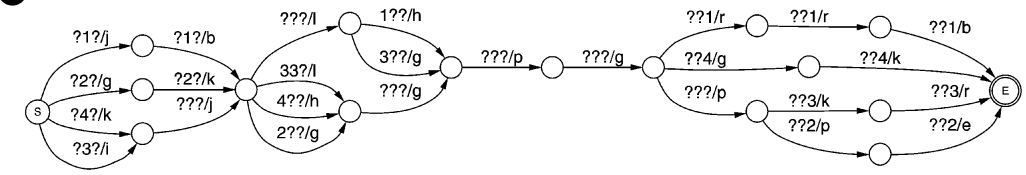
20



25



50



Design without a designer

Design without a designer

- Languages (arguably) have the "appearance of design"

Design without a designer

- Languages (arguably) have the "appearance of design"
- Two obvious mechanisms to explain this:
  - Biological evolution (cf. Pinker & Bloom 1990)
  - Intentional design by individuals

Design without a designer

- Languages (arguably) have the "appearance of design"
- Two obvious mechanisms to explain this:
  - Biological evolution (cf. Pinker & Bloom 1990)
  - Intentional design by individuals
- Computational models show a third alternative
  - Cultural evolution
  - Consistent with idea of the "invisible hand" (Keller 1990)

Design without a designer

- Languages (arguably) have the "appearance of design"
- Two obvious mechanisms to explain this:
  - Biological evolution (cf. Pinker & Bloom 1990)
  - Intentional design by individuals
- Computational models show a third alternative
  - Cultural evolution
  - Consistent with idea of the "invisible hand" (Keller 1990)
- But can we demonstrate this in real human agents?

An experimental approach

- Combine *diffusion chain* and *artificial language learning* studies

Kirby, Cornish & Smith (forthcoming) *PNAS*

An experimental approach

- Combine *diffusion chain* and *artificial language learning* studies
- Cultural transmission of an "alien language"

Kirby, Cornish & Smith (forthcoming) *PNAS*

An experimental approach

- Combine *diffusion chain* and *artificial language learning* studies
- Cultural transmission of an "alien language"

1. Start off with a random artificial language

Kirby, Cornish & Smith (forthcoming) *PNAS*

An experimental approach

- Combine *diffusion chain* and *artificial language learning* studies
- Cultural transmission of an "alien language"
  1. Start off with a random artificial language
  2. Ask an experimental subject to try and learn this language and test them

Kirby, Cornish & Smith (forthcoming) *PNAS*

An experimental approach

- Combine *diffusion chain* and *artificial language learning* studies
- Cultural transmission of an "alien language"
  1. Start off with a random artificial language
  2. Ask an experimental subject to try and learn this language and test them
  3. Use their output on test as the language to teach the next subject in the experiment (and repeat)

Kirby, Cornish & Smith (forthcoming) *PNAS*

Hypothesis

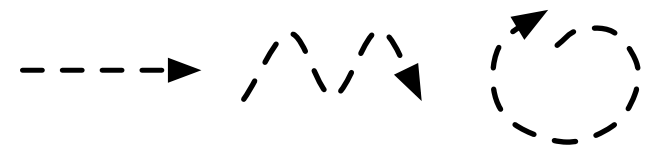
- There will be cumulative cultural adaptation of the language without intentional design by participants

Hypothesis

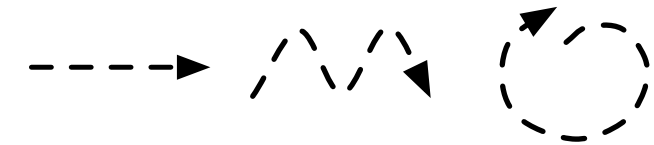
- There will be cumulative cultural adaptation of the language without intentional design by participants
- Two ways of verifying this:
  - The language should become easier to learn
  - The language should become structured

The Language

The Language

- A set of 27 possible "meanings"
  - Pictures with coloured objects in motion:
    - Three shapes 
    - Three colours 
    - Three motions 

The Language

- A set of 27 possible "meanings"
  - Pictures with coloured objects in motion:
    - Three shapes □ ○ △
    - Three colours 
    - Three motions 
- A large set of possible "signals"
  - Random sequences of between two and four syllables chosen from a set of nine
  - No spaces

Procedure

Procedure

- Language divided randomly into two sets:
  - SEEN set: 14 string-picture pairs
  - UNSEEN set: remaining 13 string-picture pairs

Procedure

- Language divided randomly into two sets:
  - SEEN set: 14 string-picture pairs
  - UNSEEN set: remaining 13 string-picture pairs
- Subjects trained on SEEN set

Procedure

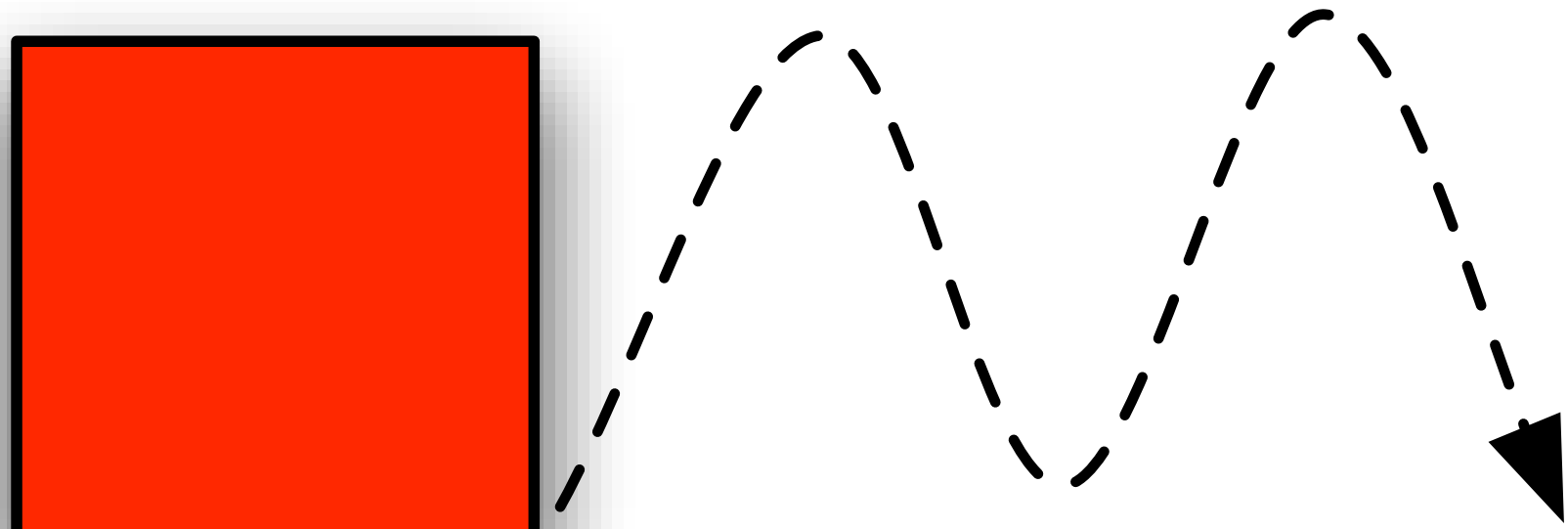
- Language divided randomly into two sets:
  - SEEN set: 14 string-picture pairs
  - UNSEEN set: remaining 13 string-picture pairs
- Subjects trained on SEEN set
- String displayed for 1 second, then string and picture for a further 5 seconds

Procedure

- Language divided randomly into two sets:
  - SEEN set: 14 string-picture pairs
  - UNSEEN set: remaining 13 string-picture pairs
- Subjects trained on SEEN set
- String displayed for 1 second, then string and picture for a further 5 seconds
- Tested on complete set,
  - randomly redivided into new SEEN and UNSEEN sets for next generation

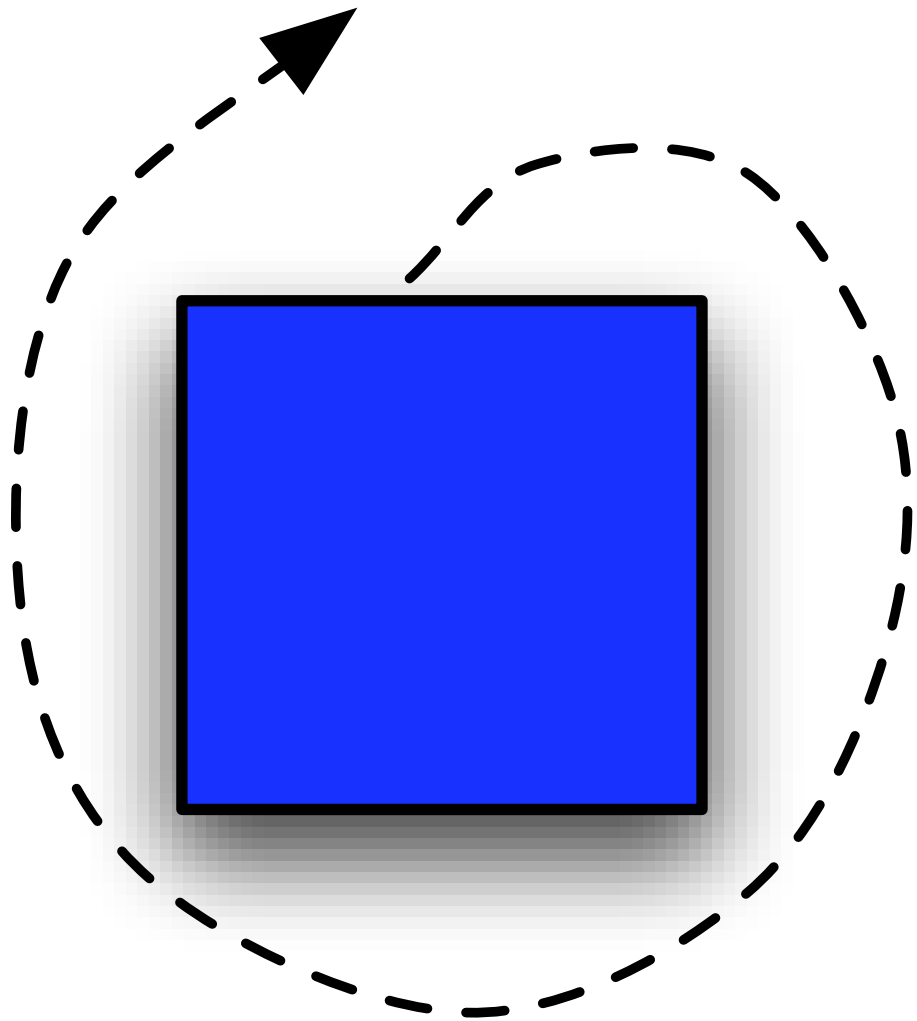
kihemiwi

kihemiwi

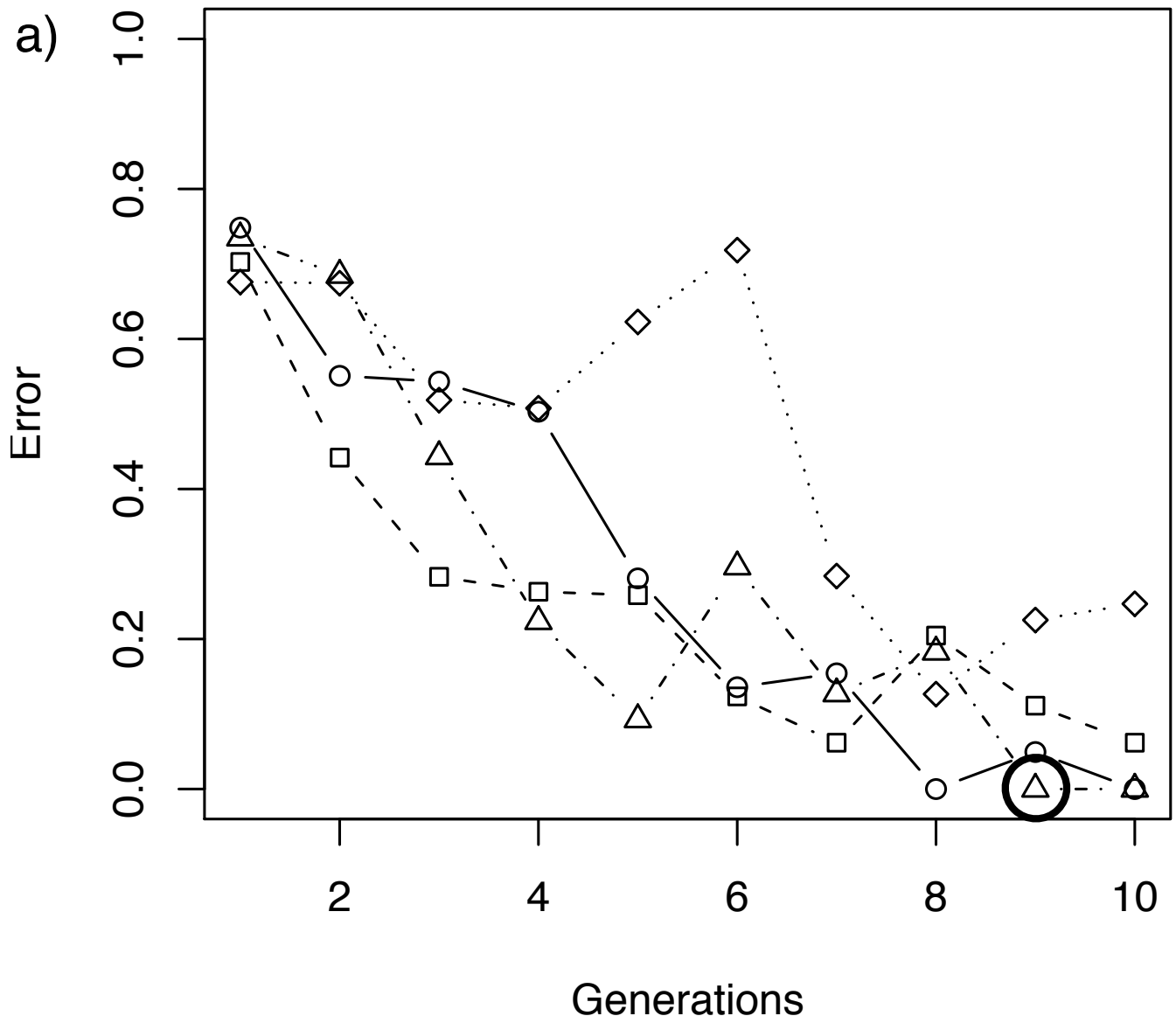


kunige

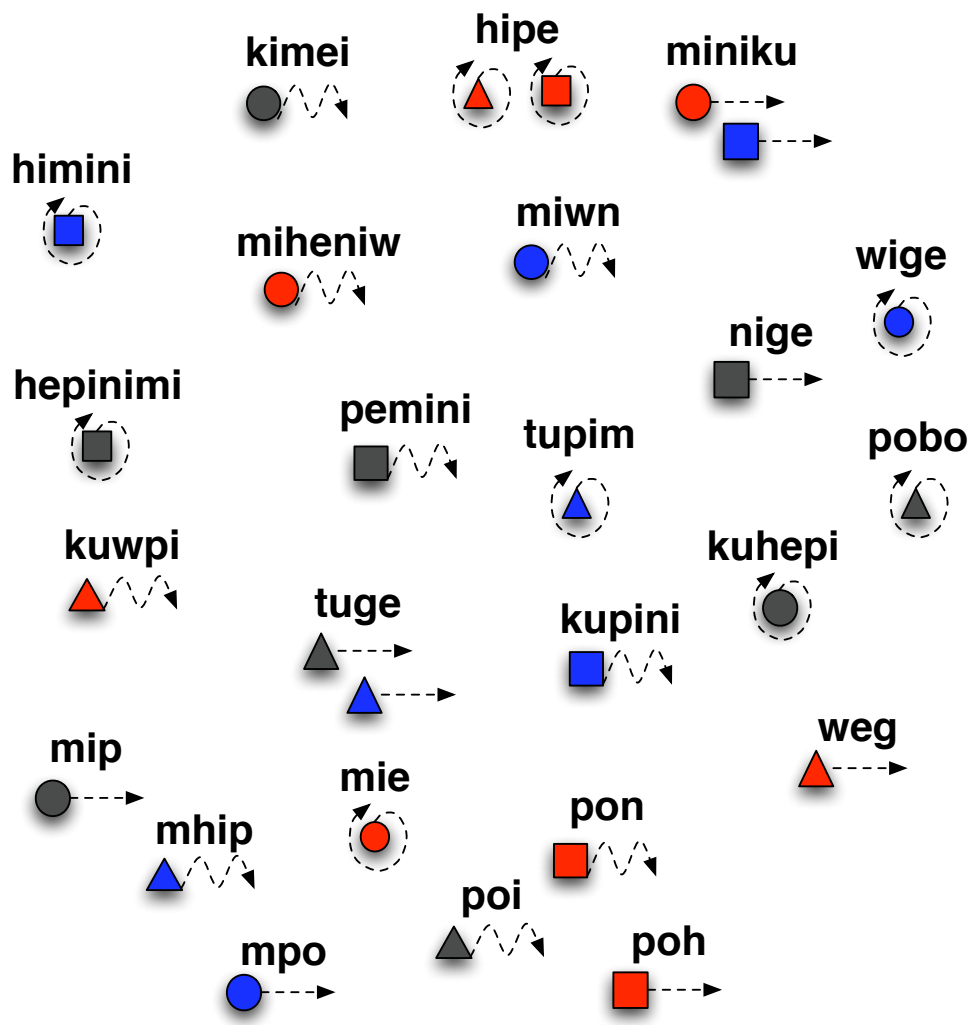
kunige



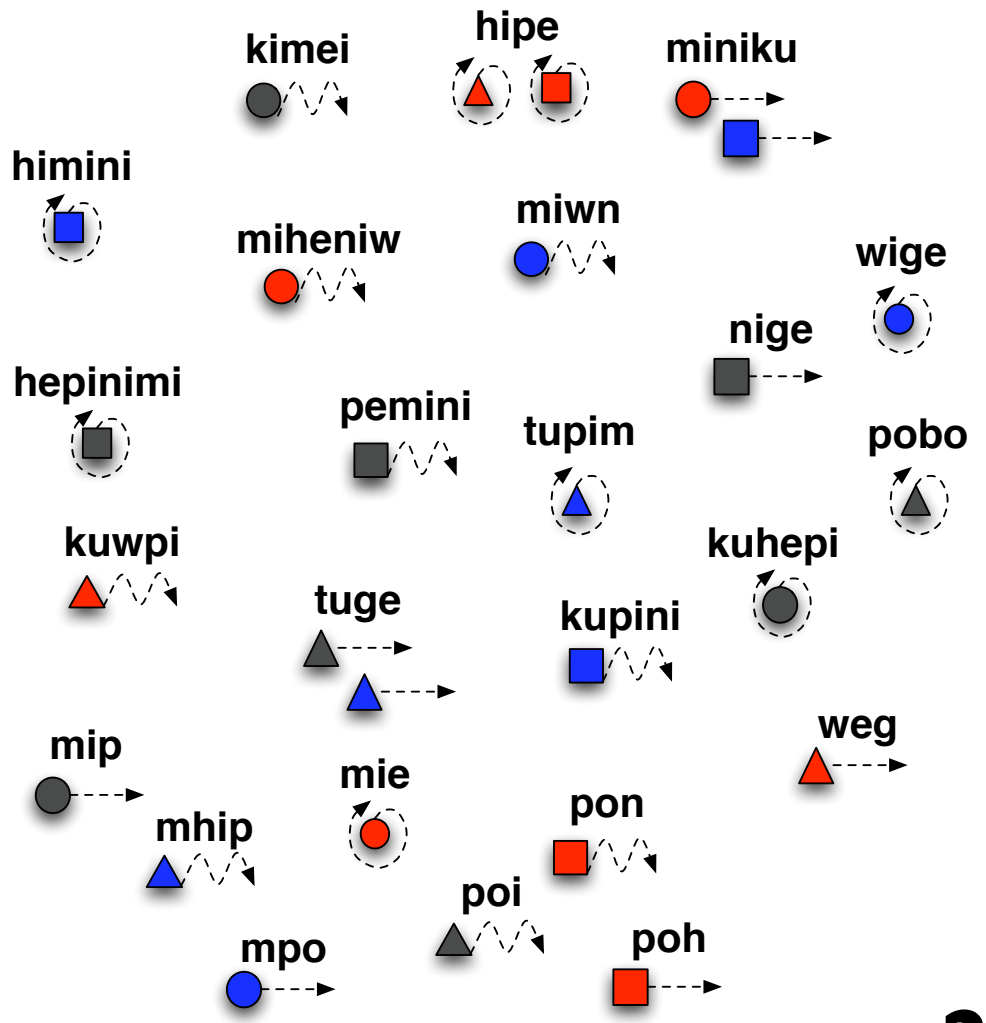
Language becomes easier to learn



After Generation 1:

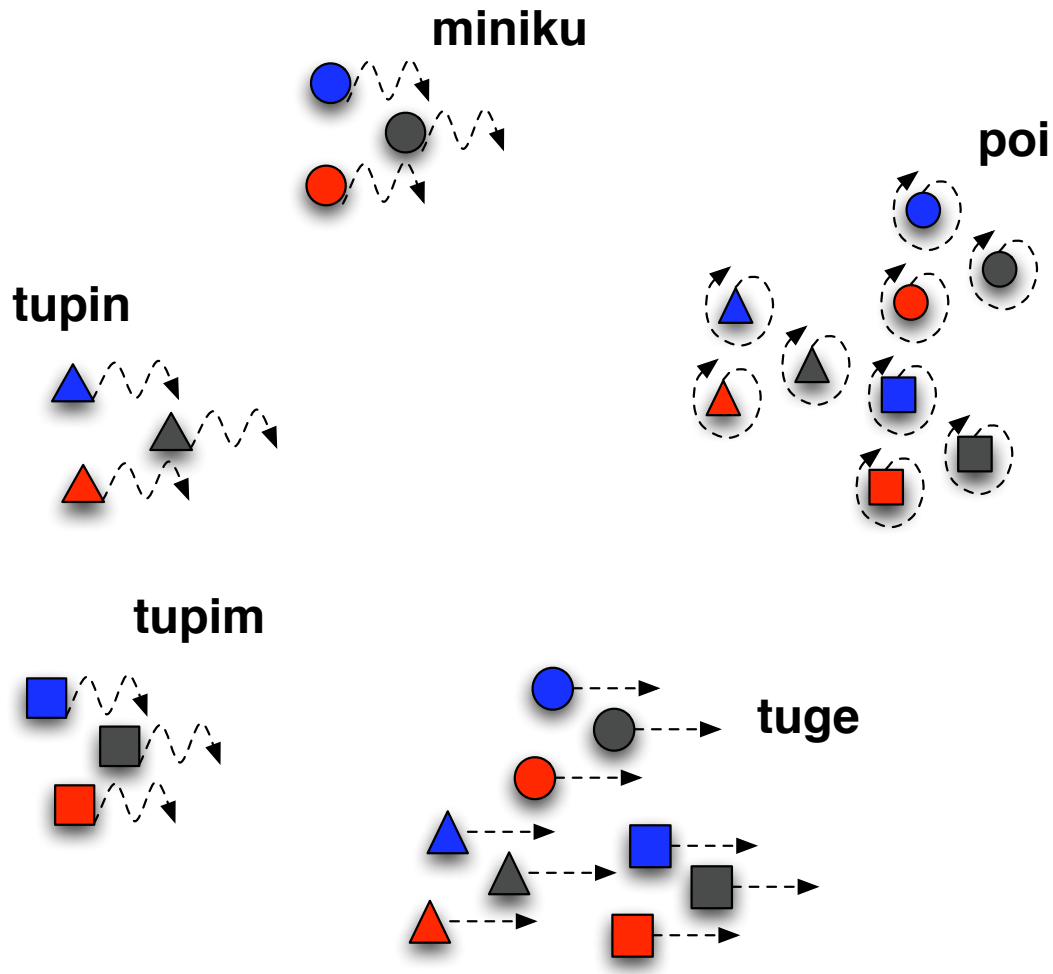


After Generation 1:

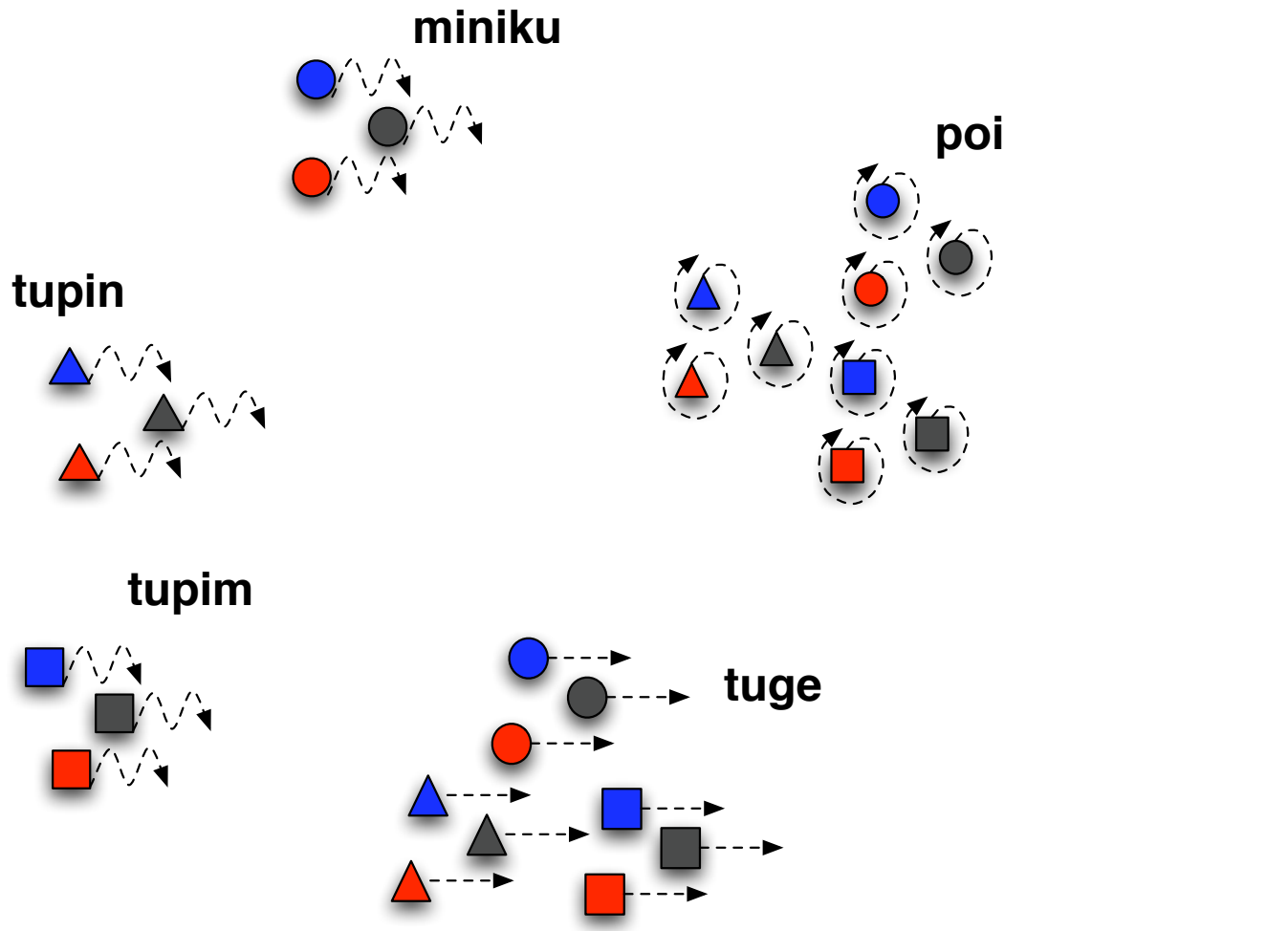


24 words

After Generation 10:



After Generation 10:



5 words

How has language become easier?

How has language become easier?

- Looks like it might be just that there are fewer words.

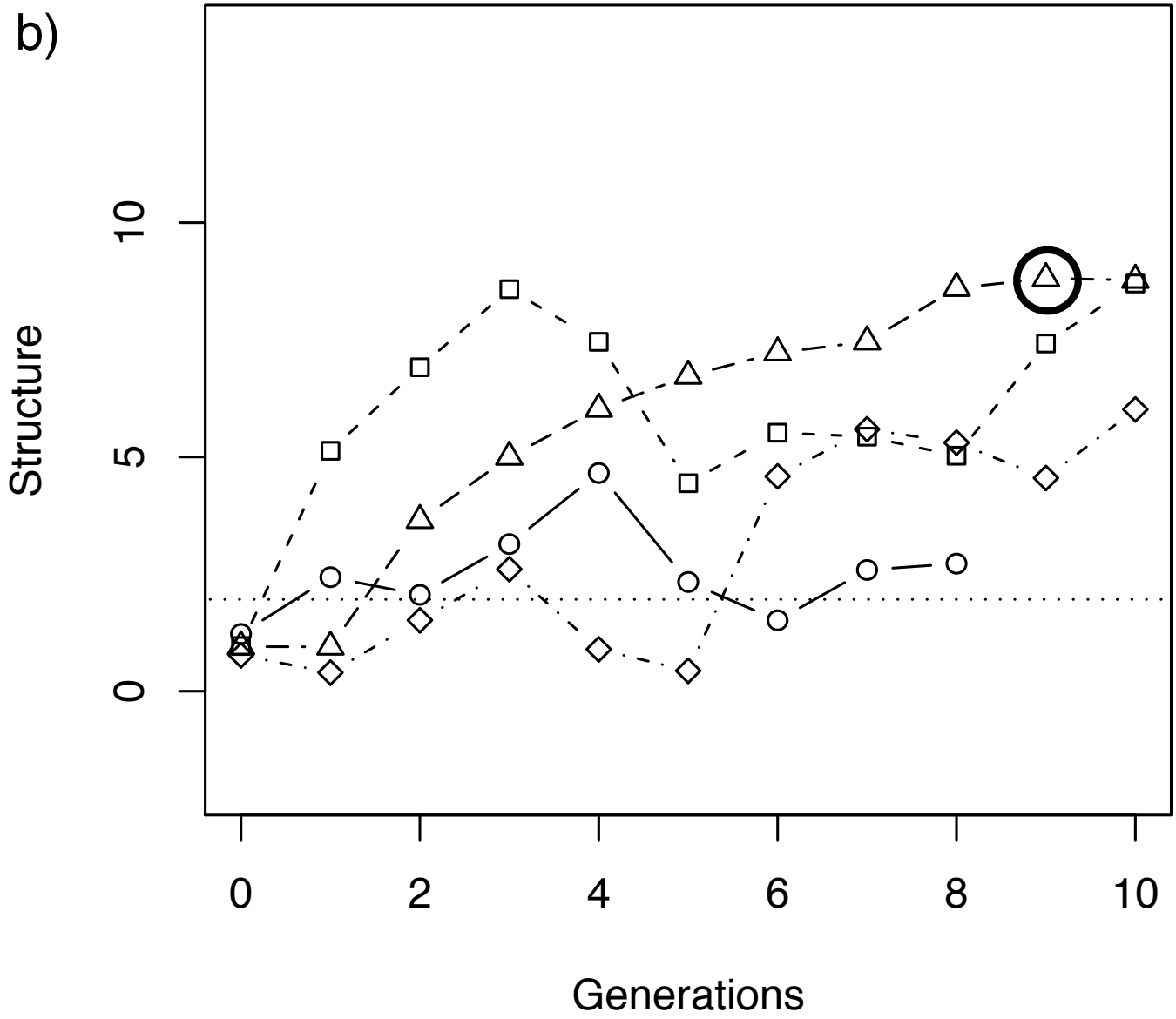
How has language become easier?

- Looks like it might be just that there are fewer words.
- If this were all that was going on, then subjects' performance on unseen items should be random

How has language become easier?

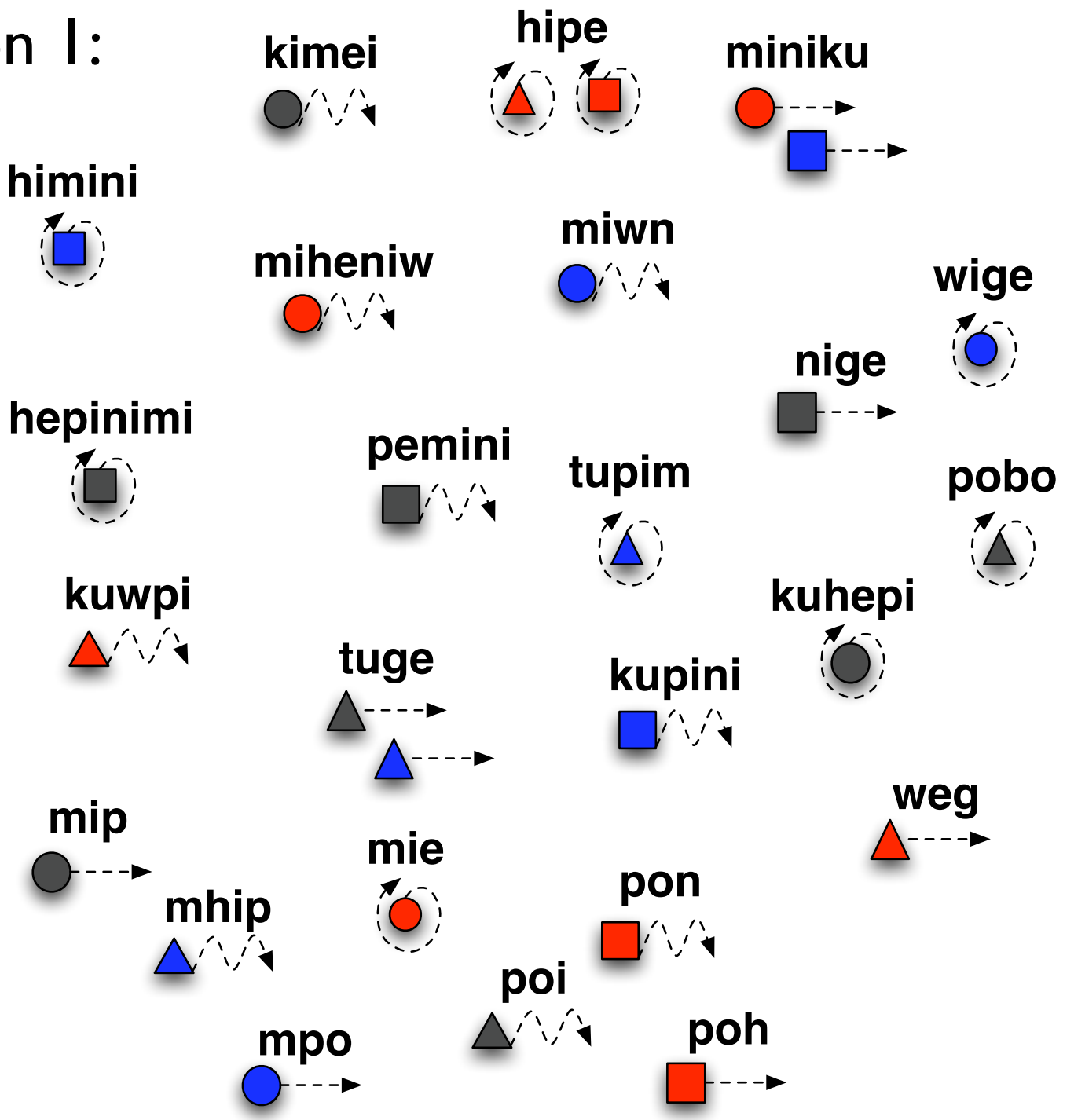
- Looks like it might be just that there are fewer words.
- If this were all that was going on, then subjects' performance on unseen items should be random
- This doesn't appear to be the case...

Language becomes systematic

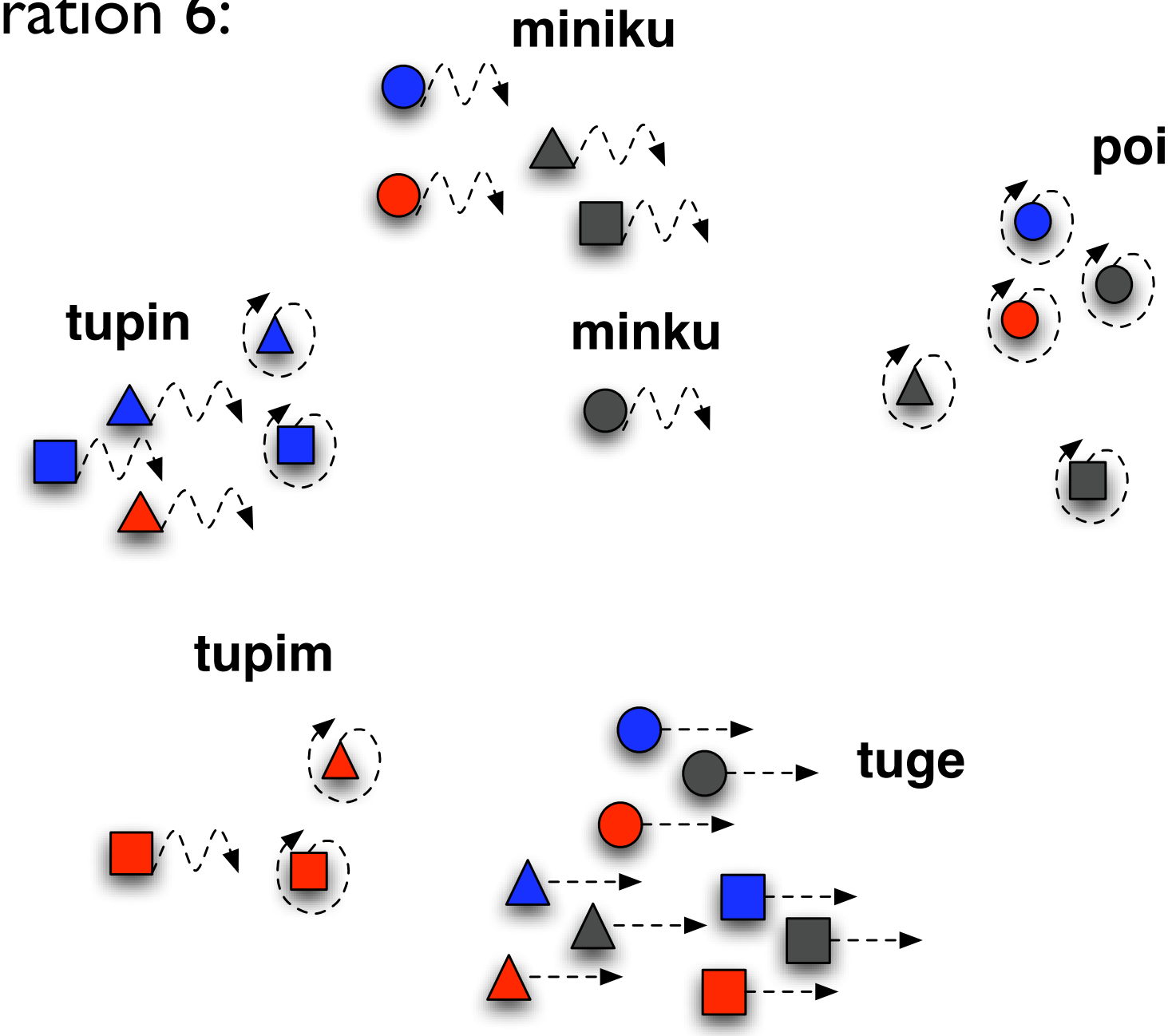


Measure shows the degree to which meaning and form are systematically related.

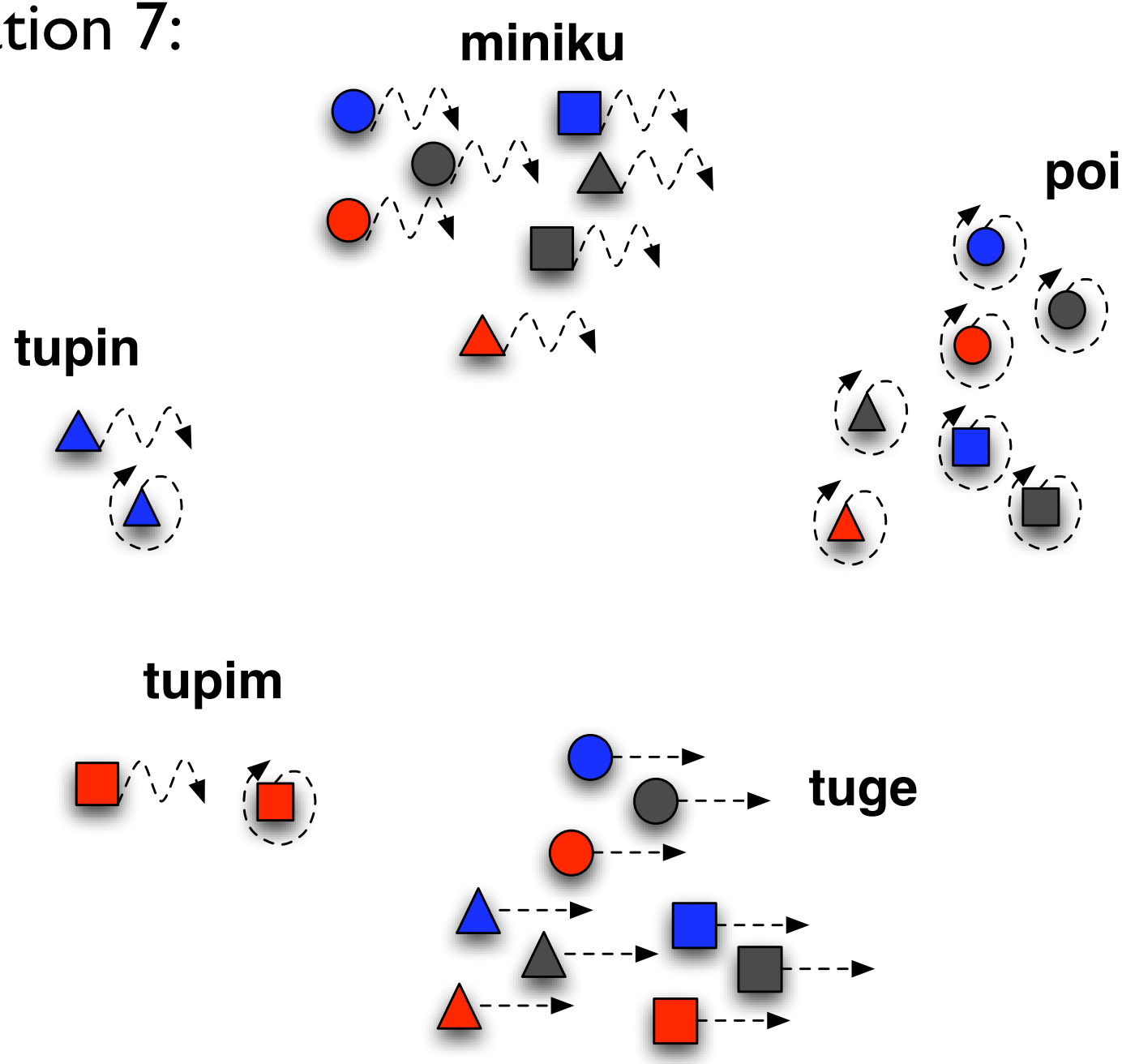
After Generation 1:



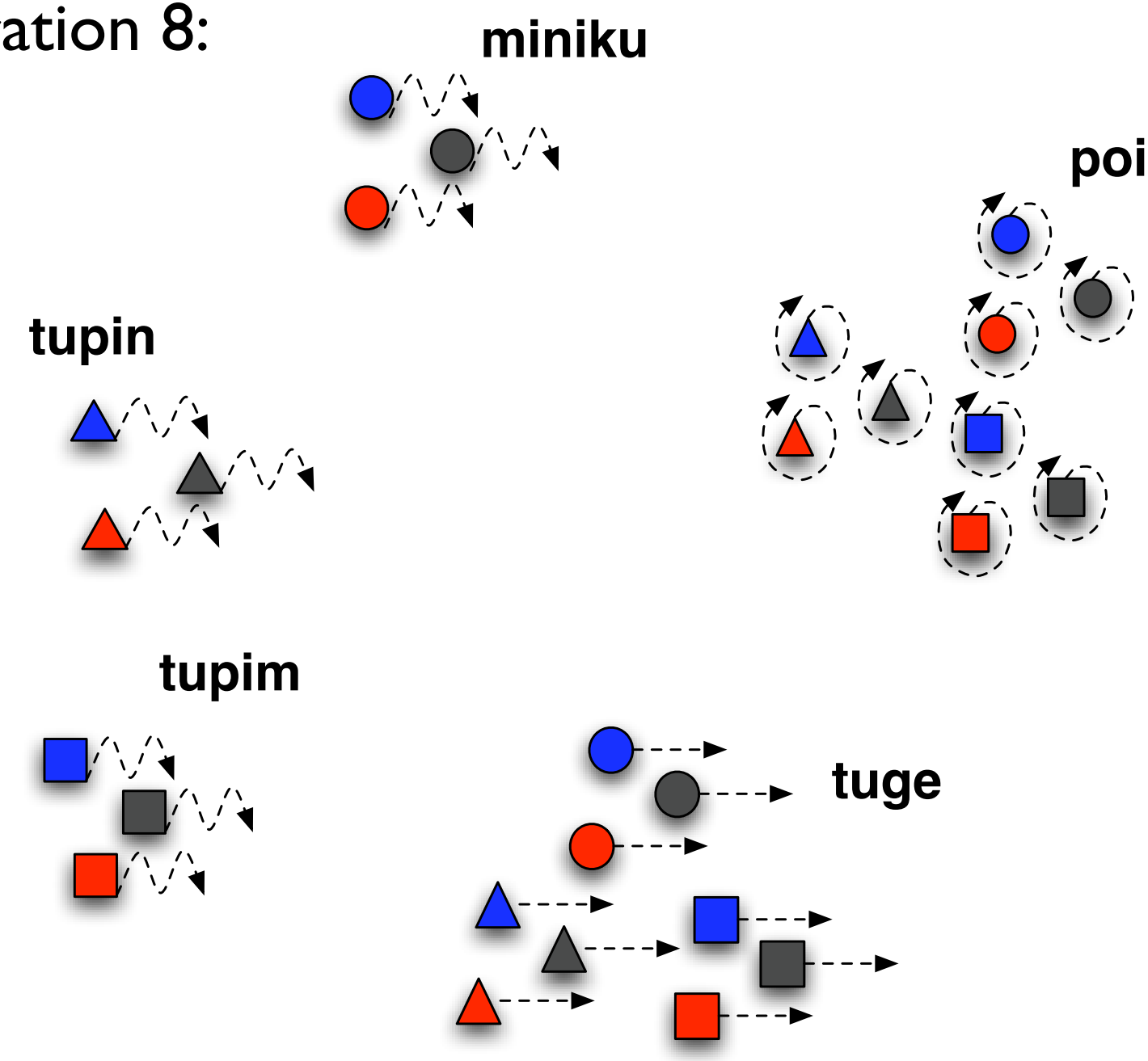
After Generation 6:



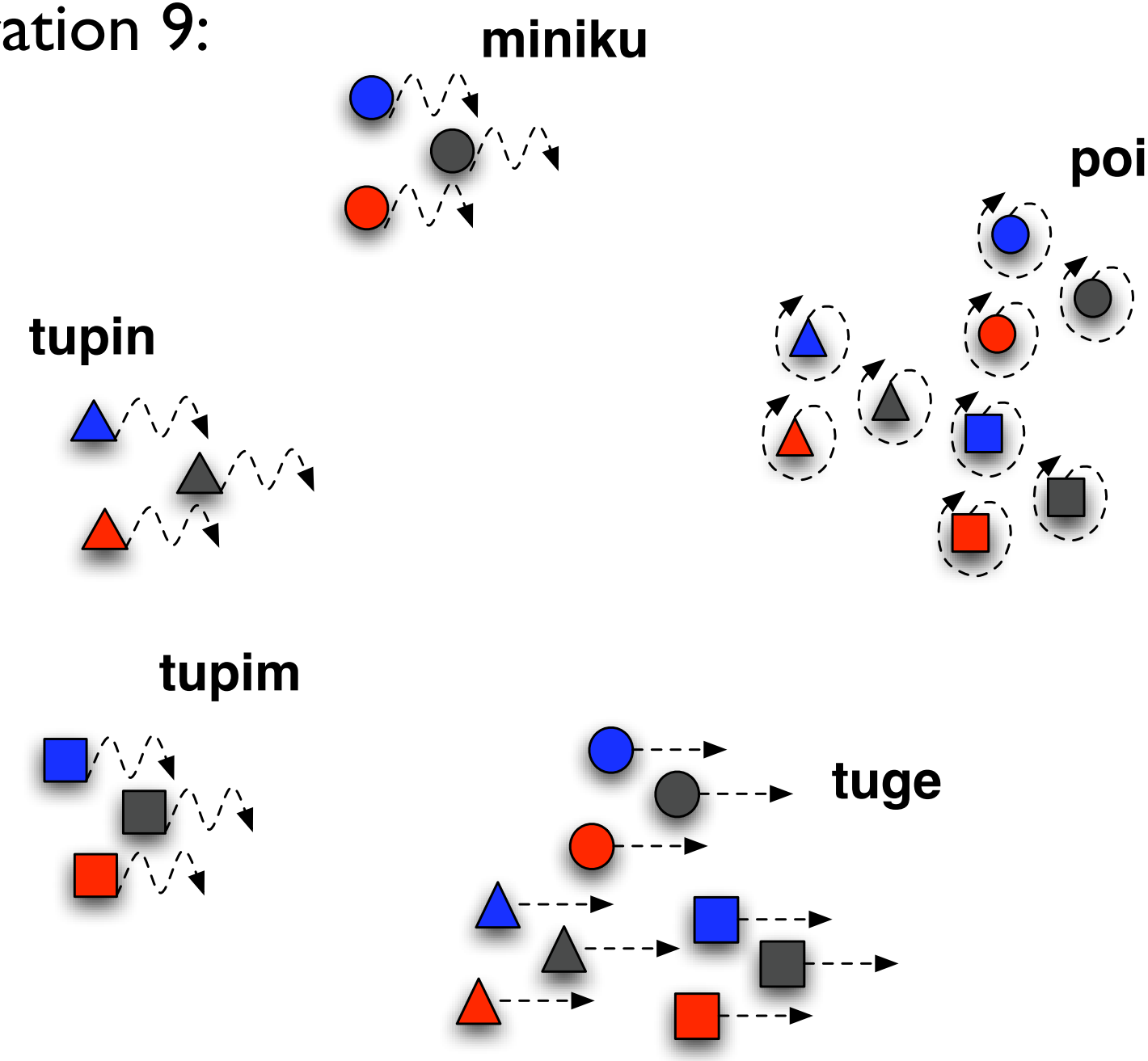
After Generation 7:



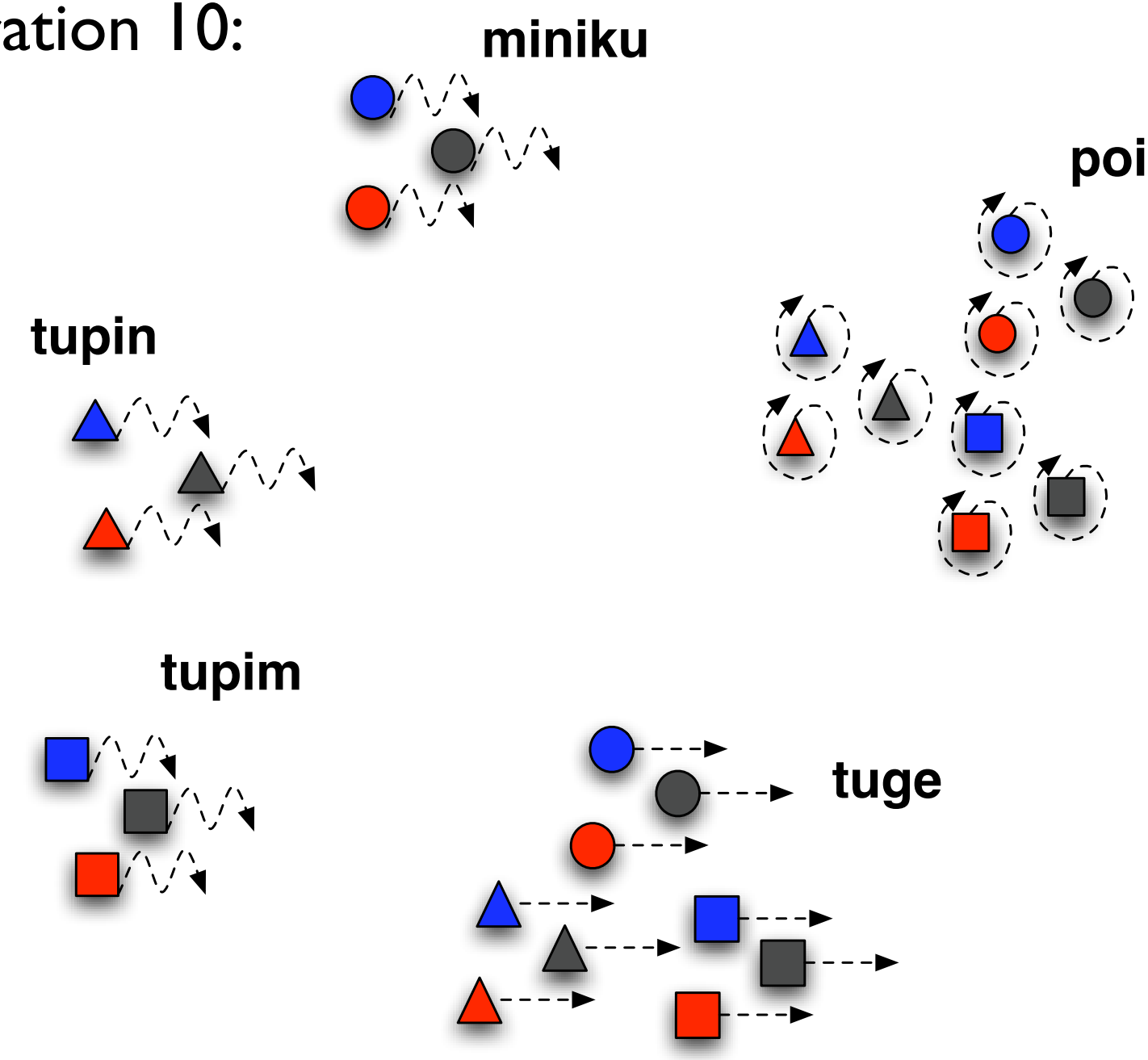
After Generation 8:



After Generation 9:



After Generation 10:



Language adapts to be structured

- Language adapts
  - **Subjects are not aware of this** (they aren't even aware they are being shown unseen items!)
  - Systematic underspecification is an *adaptation by language to aid its own survival*
- Cumulative cultural adaptation without intention

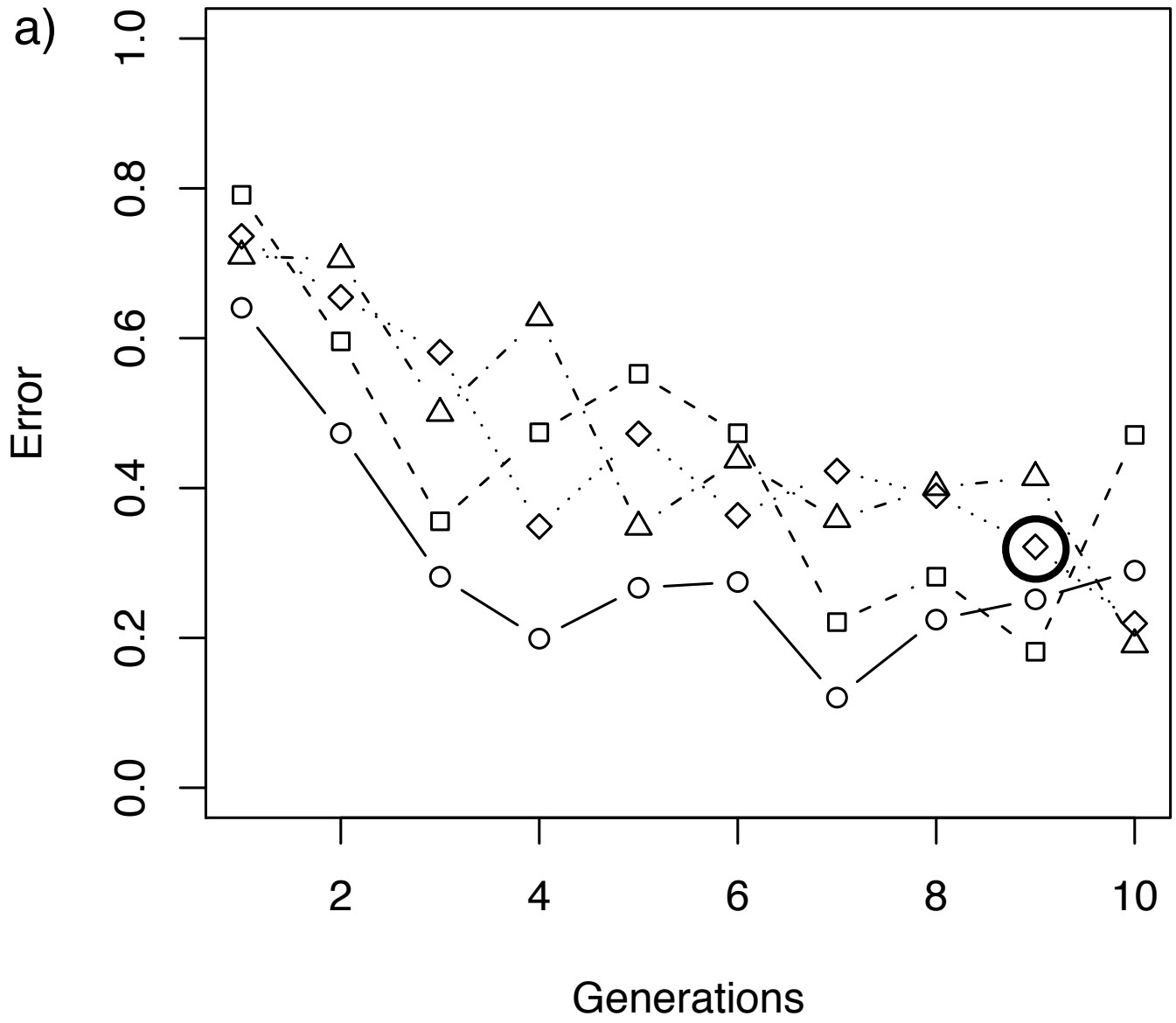
More interesting structure?

- In reality language exhibits structure (e.g. morphology, syntax) that makes it learnable *and* expressive
- There's no pressure for expressivity in the experiment

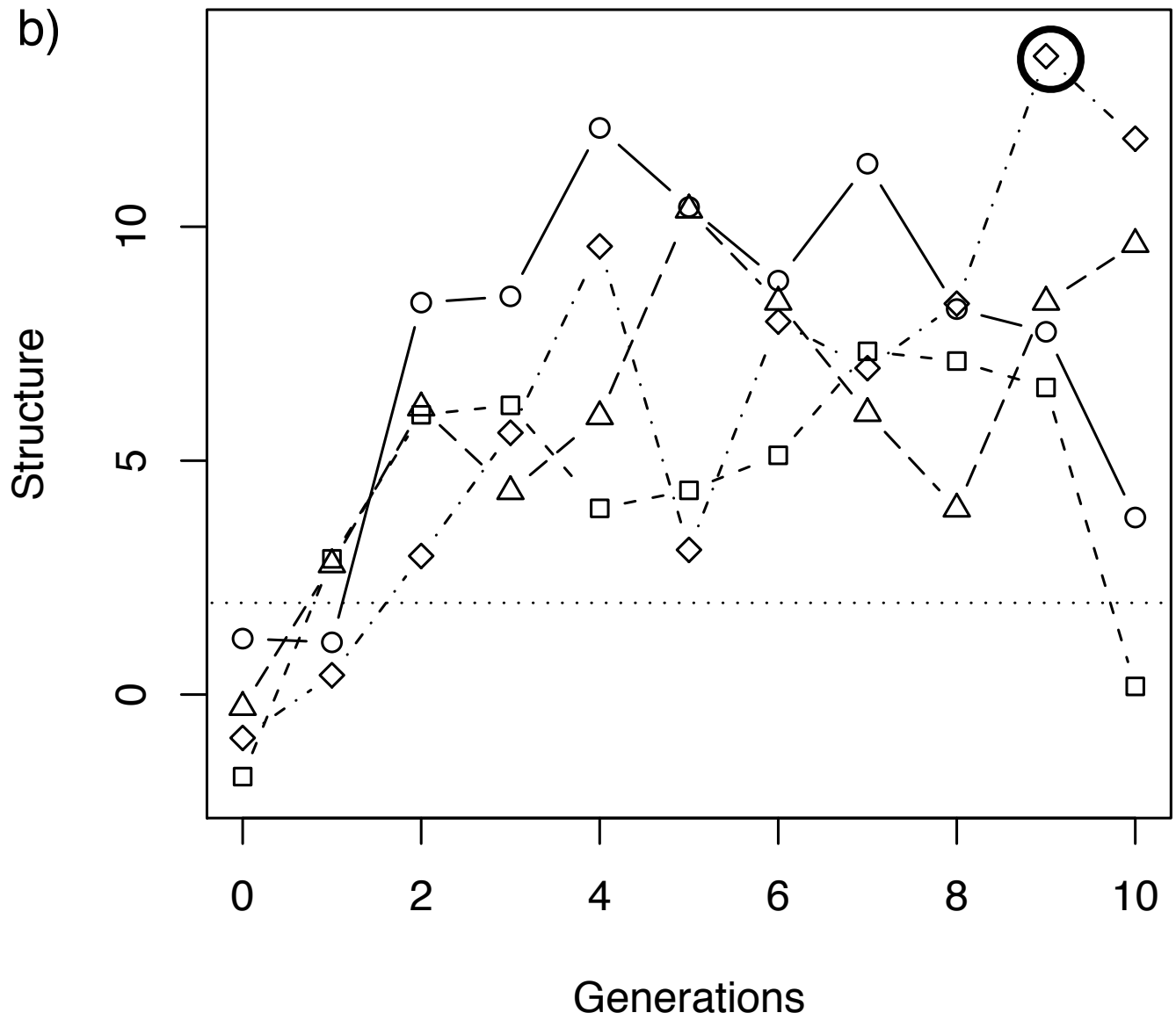
More interesting structure?

- In reality language exhibits structure (e.g. morphology, syntax) that makes it learnable *and* expressive
- There's no pressure for expressivity in the experiment
- Simple modification: filter out all ambiguous items from SEEN set before subjects see them

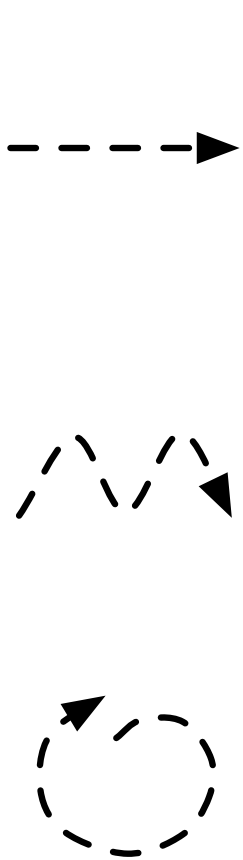
Language becomes easier to learn



Language becomes systematic

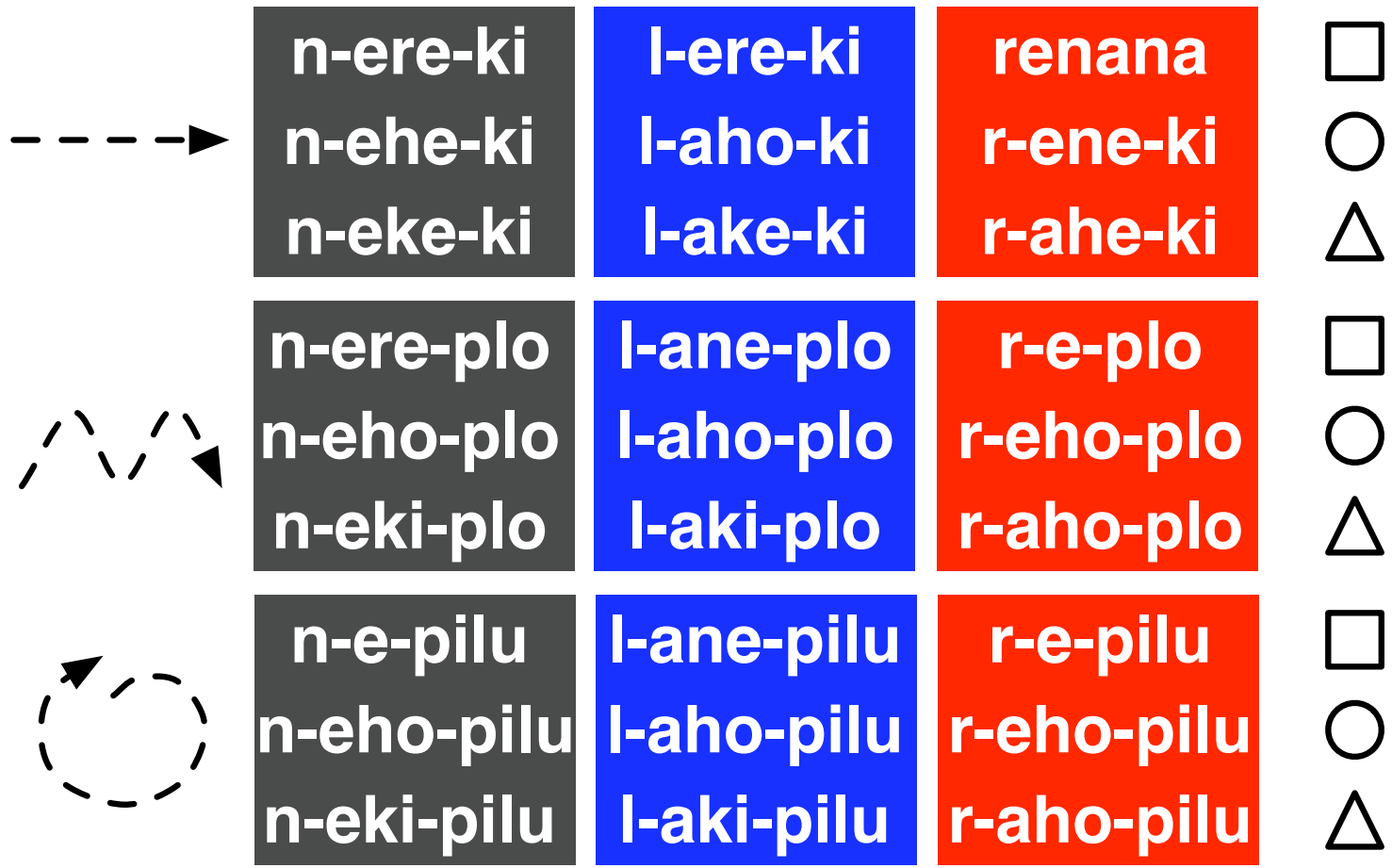


Example initial language



lumonamo	kinahune	lahupine	□
nelu	kanehu	namopihu	○
kapihu	humo	lahupiki	△
moki	luneki	lanepi	□
kalu	mola	pihukimo	○
nane	kalakihu	mokihuna	△
kilamo	kahuki	neluka	□
pilu	neki	pinemohu	○
luki	namola	lumoka	△

Example final language
(10 "generations" later)



Adaptation again

Adaptation again

- Language adapts to the transmission "bottleneck"

Adaptation again

- Language adapts to the transmission "bottleneck"
- It must be learned even though:
  - only a sub-sample is seen by learners
  - ambiguous signals are filtered out

Adaptation again

- Language adapts to the transmission "bottleneck"
- It must be learned even though:
  - only a sub-sample is seen by learners
  - ambiguous signals are filtered out
- Morphological/syntactic structure is a solution to this problem

Adaptation again

- Language adapts to the transmission "bottleneck"
- It must be learned even though:
  - only a sub-sample is seen by learners
  - ambiguous signals are filtered out
- Morphological/syntactic structure is a solution to this problem
- Note: subjects cannot be aware of the filtering, but language structure is very different
  - Demonstrates that adaptation is *non-intentional*
  - Culture gives us *design without a designer*

The emergence of culturally transmitted communication

The emergence of culturally transmitted communication

- The previous paradigm assumed that individuals:
  - want to communicate
  - know what to communicate about
  - have a dedicated "channel" for communication
  - want to share their communication system.

The emergence of culturally transmitted communication

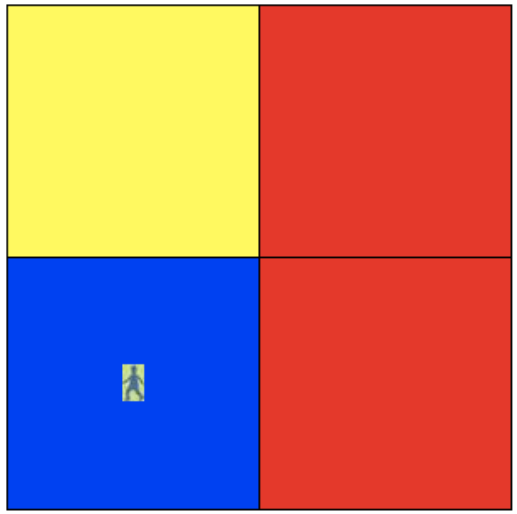
- The previous paradigm assumed that individuals:
  - want to communicate
  - know what to communicate about
  - have a dedicated "channel" for communication
  - want to share their communication system.
- In other words, they are already *symbolic learners*
  - Can we explore the genuine emergence of symbols in the lab?
  - New experiment inspired by study in evolutionary robotics (Quinn 2001)

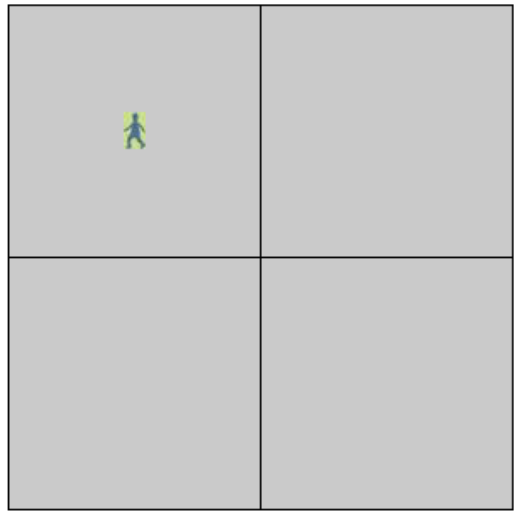
The Embodied Communication Game: A test-bed for the emergence of symbolic communication

- Participants play a two-player cooperative computer game where the other player is in another room
- Steer a character round a room with different coloured floor tiles and try to finish up on the same colour as the other player
- Similar to study by Galantucci (2005) but *without a communication channel*

Scott-Phillips, Kirby & Ritchie (forthcoming)

Player 1 sees:

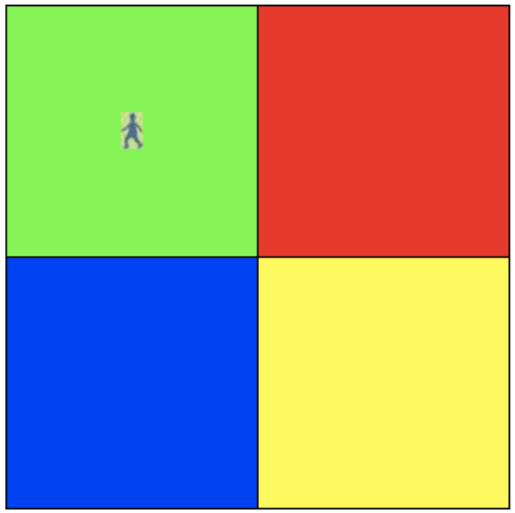


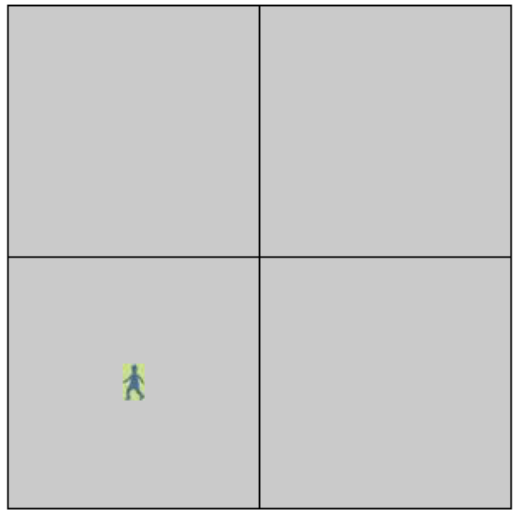


Points in succession: 0 Highest: 3

Press space when you're finished

Player 2 sees:

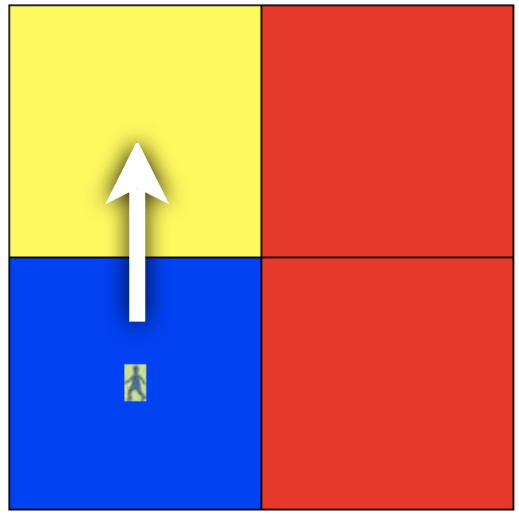


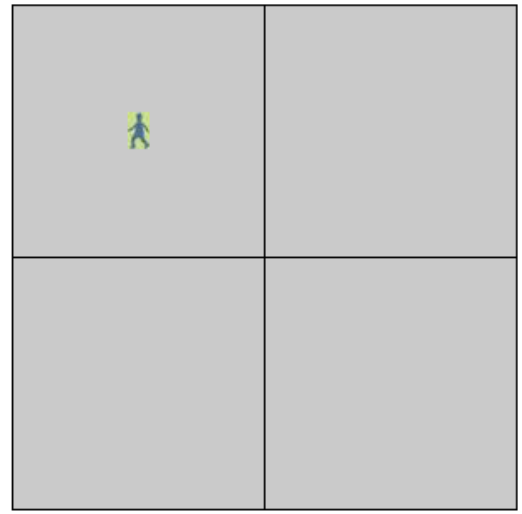


Points in succession: 0 Highest: 3

Press space when you're finished

Player 1 sees:

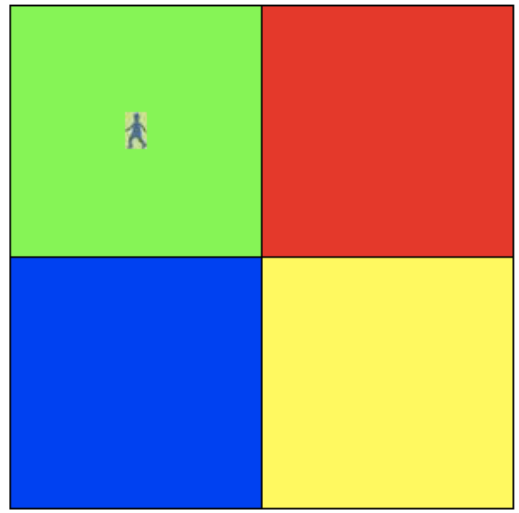


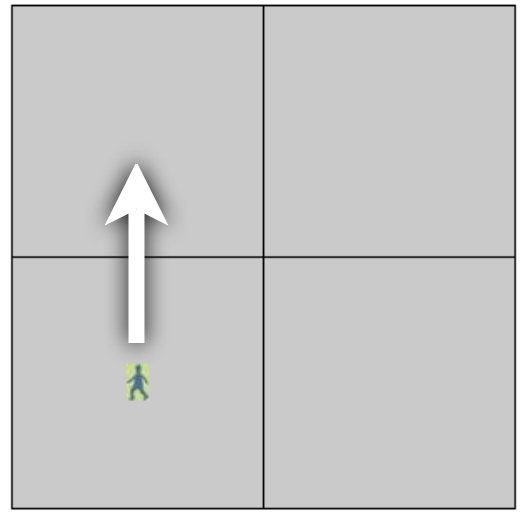


Points in succession: 0 Highest: 3

Press space when you're finished

Player 2 sees:

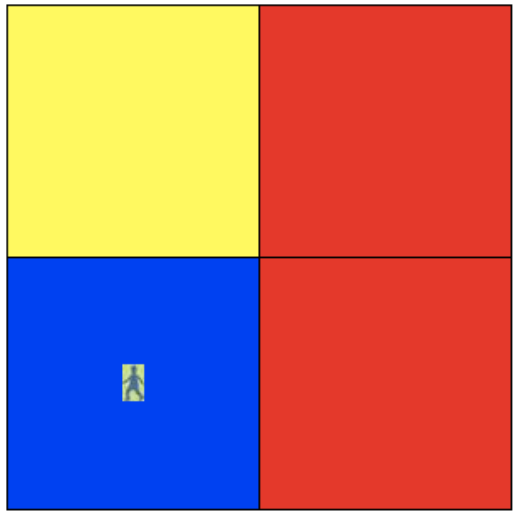


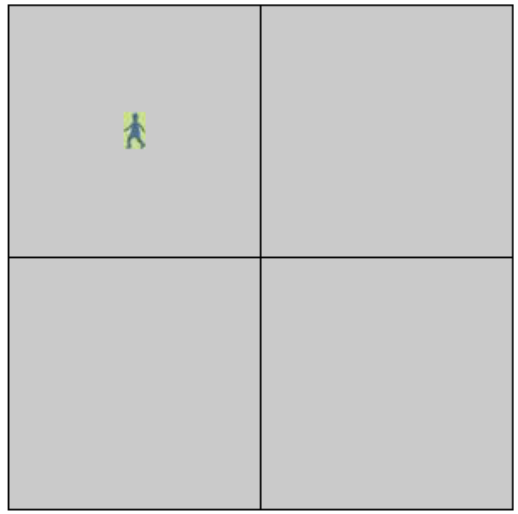


Points in succession: 0 Highest: 3

Press space when you're finished

Player 1 sees:

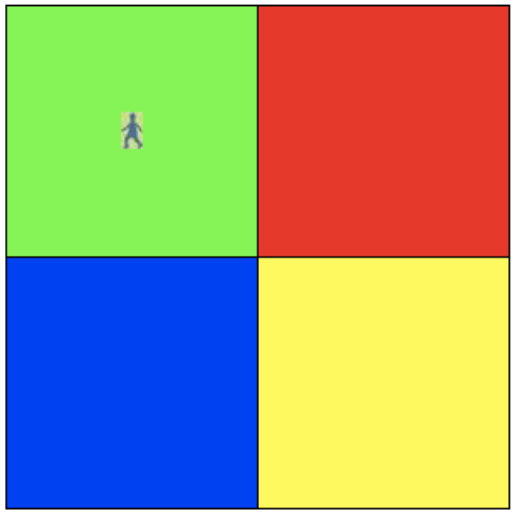


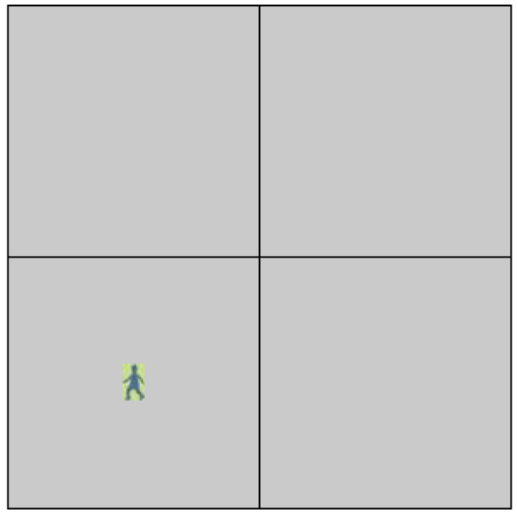


Points in succession: 0 Highest: 3

Press space when you're finished

Player 2 sees:

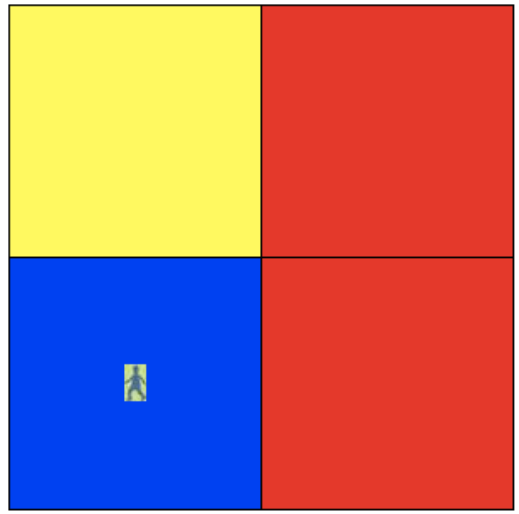


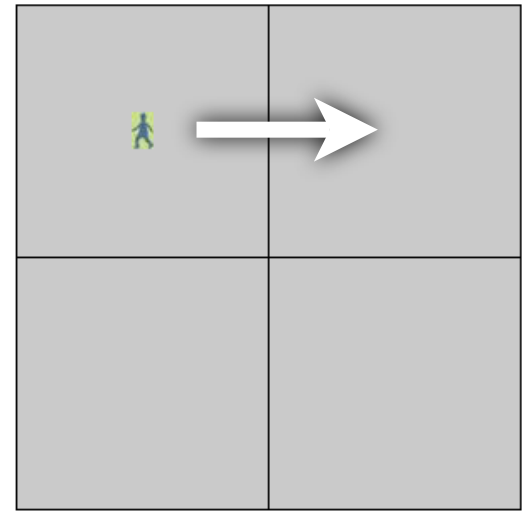


Points in succession: 0 Highest: 3

Press space when you're finished

Player 1 sees:

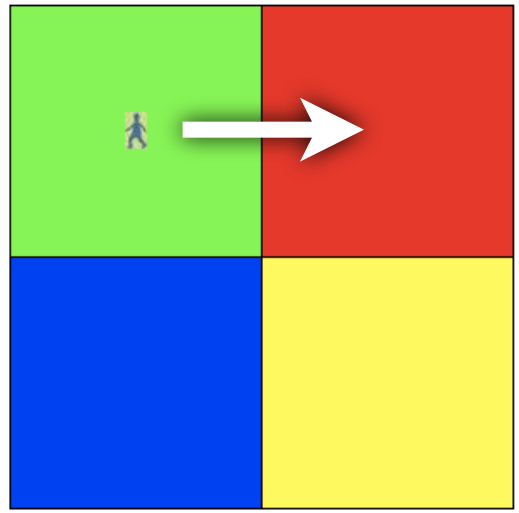


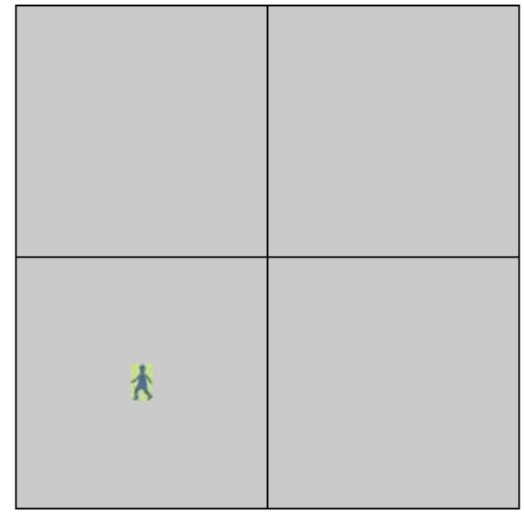


Points in succession: 0 Highest: 3

Press space when you're finished

Player 2 sees:

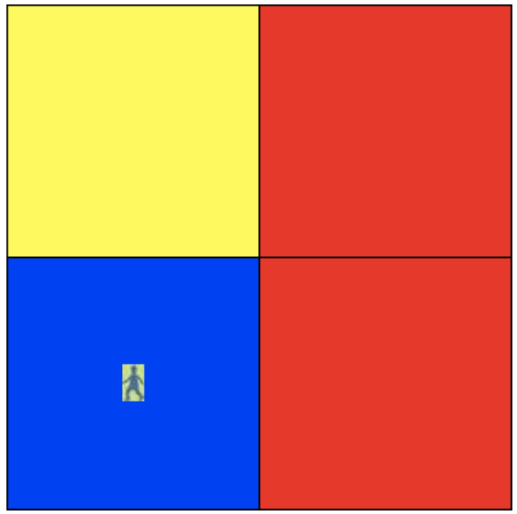


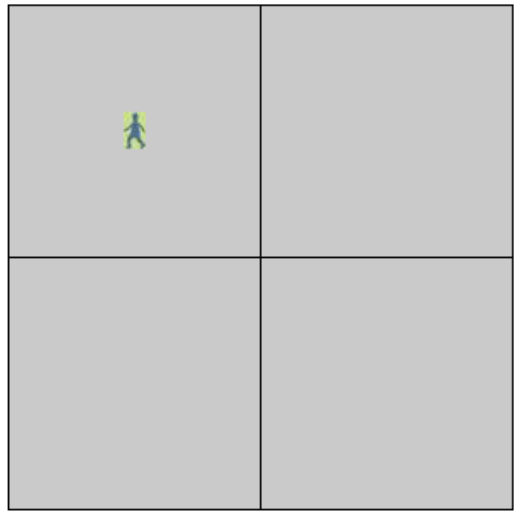


Points in succession: 0 Highest: 3

Press space when you're finished

Player 1 sees:

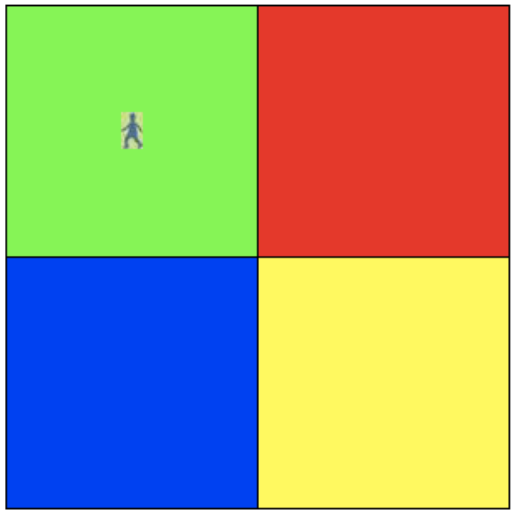


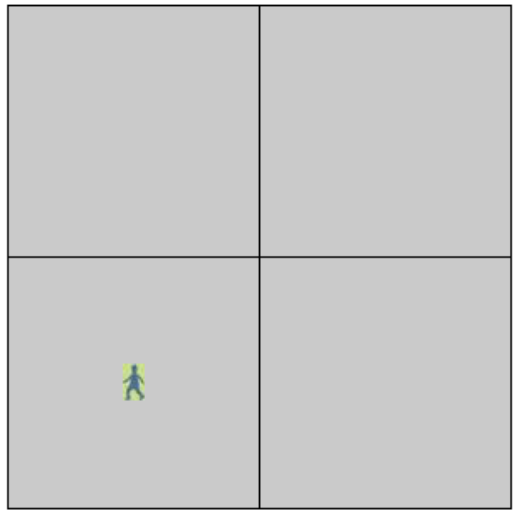


Points in succession: 0 Highest: 3

Press space when you're finished

Player 2 sees:





Points in succession: 0 Highest: 3

Press space when you're finished

Rules

Rules

- Score if on same colour after both press finish

Rules

- Score if on same colour after both press finish
- Always at least one colour that's in both rooms (but equally there may be colours that are unique to room)

Rules

- Score if on same colour after both press finish
- Always at least one colour that's in both rooms (but equally there may be colours that are unique to room)
- Colour assignment is completely random after each turn

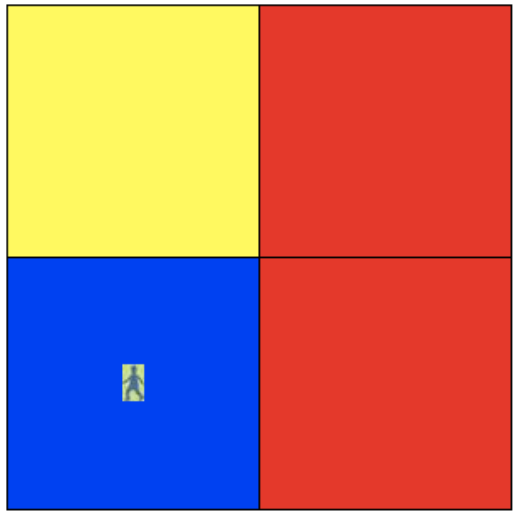
Rules

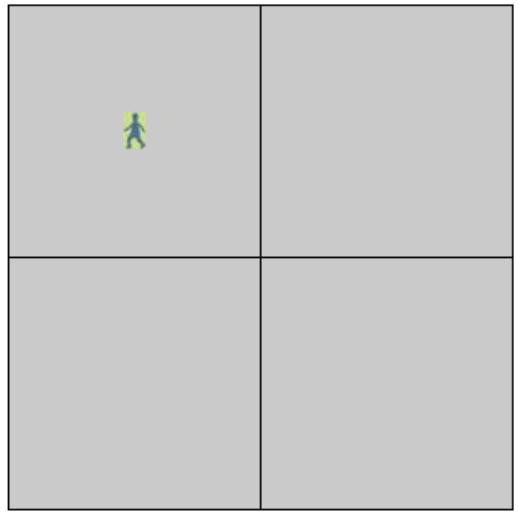
- Score if on same colour after both press finish
- Always at least one colour that's in both rooms (but equally there may be colours that are unique to room)
- Colour assignment is completely random after each turn
- After turn, other player's colours are revealed

Rules

- Score if on same colour after both press finish
- Always at least one colour that's in both rooms (but equally there may be colours that are unique to room)
- Colour assignment is completely random after each turn
- After turn, other player's colours are revealed
- It *is* possible to find a strategy for winning on every turn

Player 1 sees:

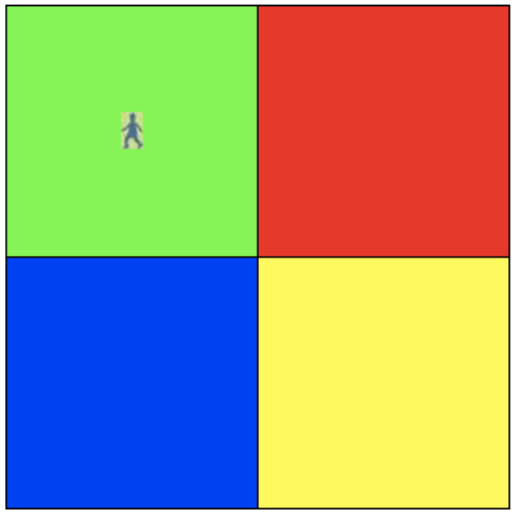


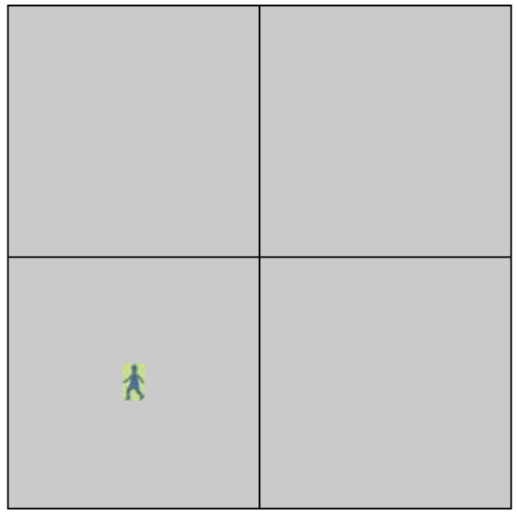


Points in succession: 0 Highest: 3

Press space when you're finished

Player 2 sees:

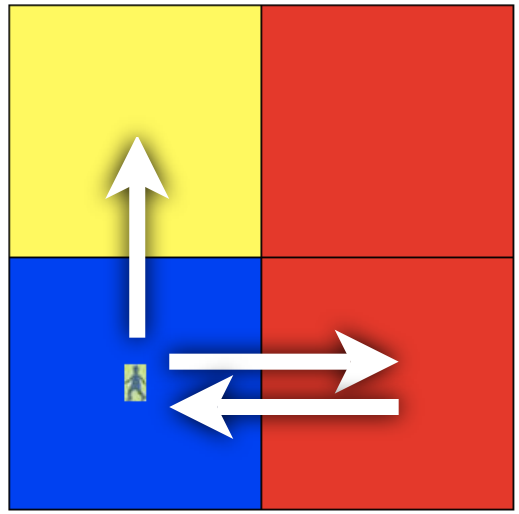


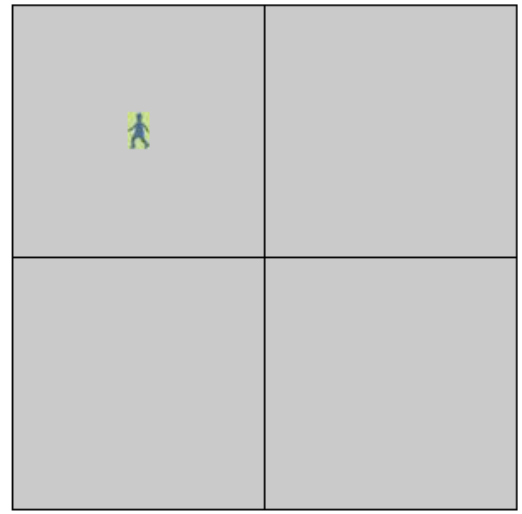


Points in succession: 0 Highest: 3

Press space when you're finished

Player 1 sees:

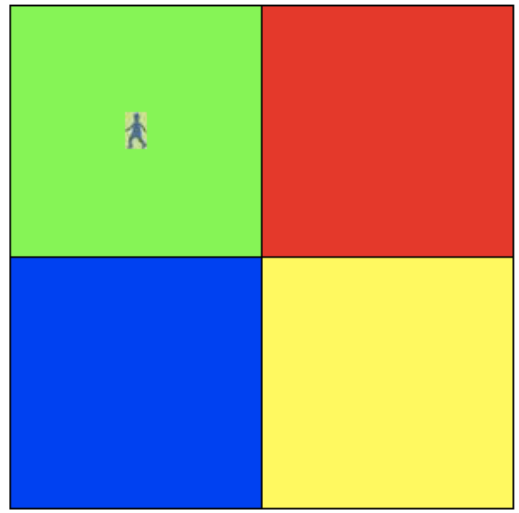


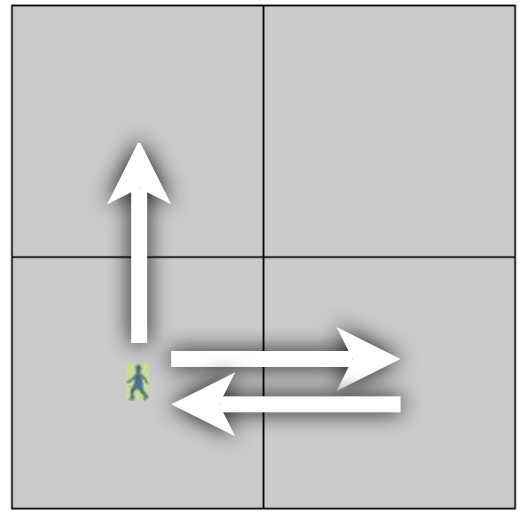


Points in succession: 0 Highest: 3

Press space when you're finished

Player 2 sees:

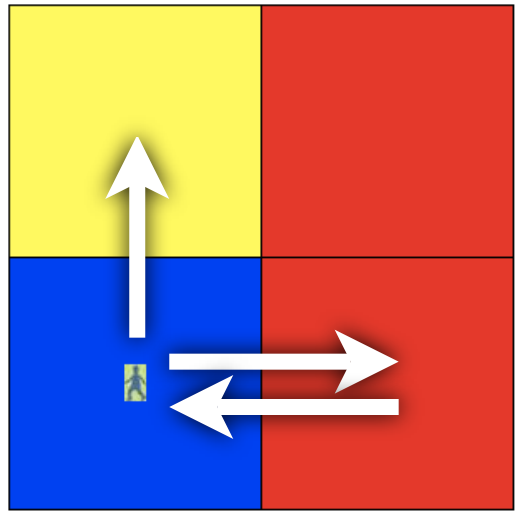




Points in succession: 0 Highest: 3

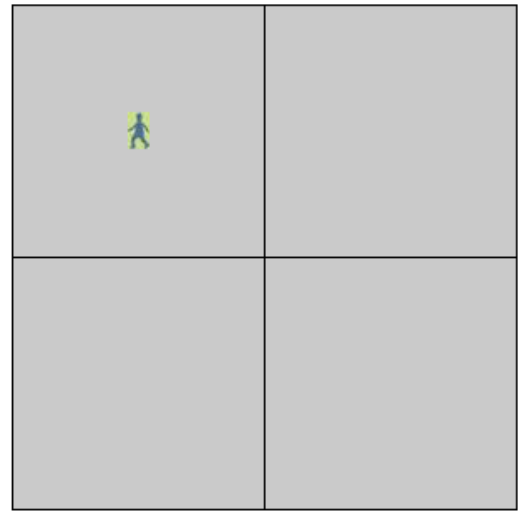
Press space when you're finished

Player 1 sees:

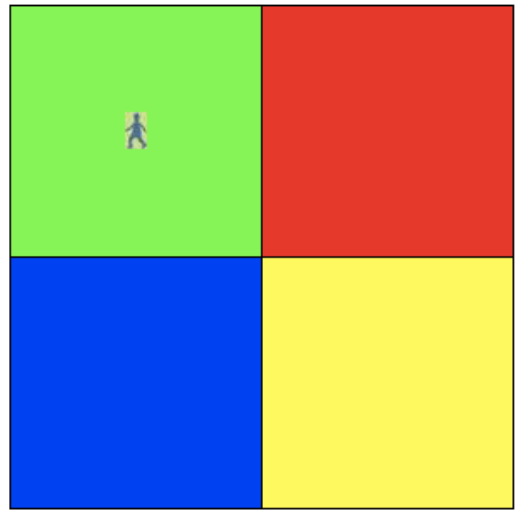


Points in succession: 0 Highest: 3

Press space when you're finished

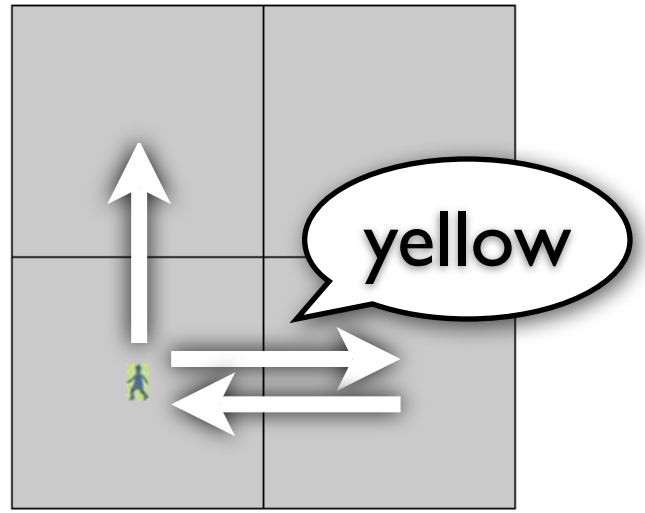


Player 2 sees:

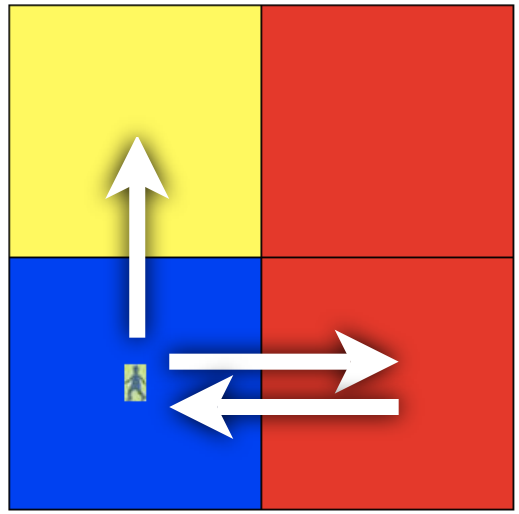


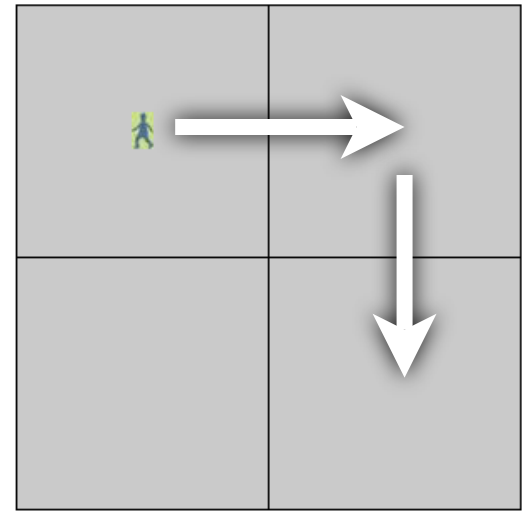
Points in succession: 0 Highest: 3

Press space when you're finished



Player 1 sees:

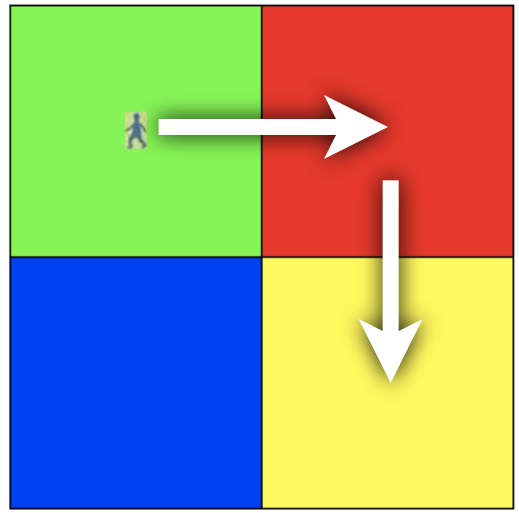


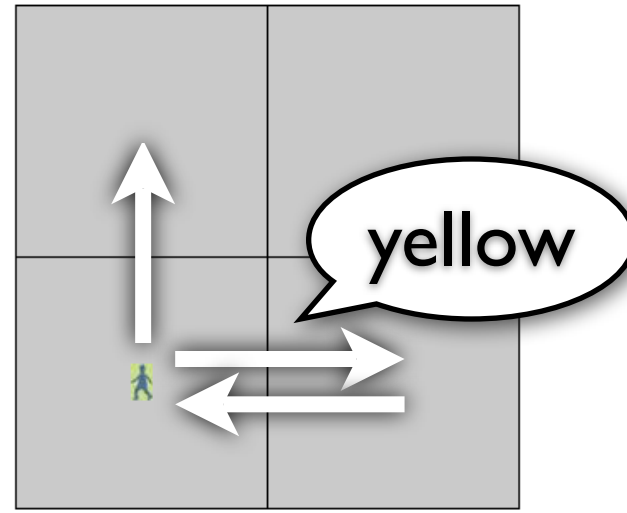


Points in succession: 0 Highest: 3

Press space when you're finished

Player 2 sees:





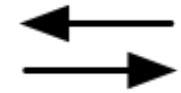
Points in succession: 0 Highest: 3

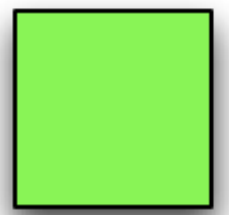
Press space when you're finished

Move & stop (default strategy)

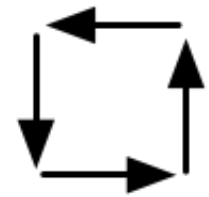
Oscillations

or

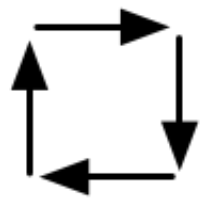


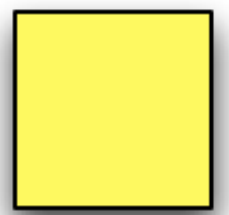


Loop

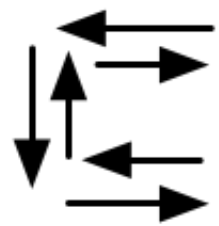


or





C-shape



A typical pattern of emergence

A typical pattern of emergence

1. First a “default” strategy emerges

A typical pattern of emergence

1. First a "default" strategy emerges
2. Then a signal to mean "something's wrong!"

A typical pattern of emergence

1. First a "default" strategy emerges
2. Then a signal to mean "something's wrong!"
3. Ritualised to mean a particular colour

A typical pattern of emergence

1. First a "default" strategy emerges
2. Then a signal to mean "something's wrong!"
3. Ritualised to mean a particular colour
4. Extended to the other colours

A typical pattern of emergence

1. First a "default" strategy emerges
2. Then a signal to mean "something's wrong!"
3. Ritualised to mean a particular colour
4. Extended to the other colours

- Demonstrates again the fundamental importance of the socio/cultural process

Conclusions

Conclusions

- Cultural evolution a crucial part of an explanatory account of language structure
- We can study it in the lab
  - The Embodied Communication Game shows how sequential behaviours can become meaningful
  - The iterated learning experiments show how this can lead to systematic structure

Conclusions

- Cultural evolution a crucial part of an explanatory account of language structure
- We can study it in the lab
  - The Embodied Communication Game shows how sequential behaviours can become meaningful
  - The iterated learning experiments show how this can lead to systematic structure
- What's left for biological evolution?
  - Preadaptations enabling learning of complex sequential signals (we're the only primate that can do this)