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

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The evolutionary approach to language

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- 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

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- 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

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(a whistle-stop tour)

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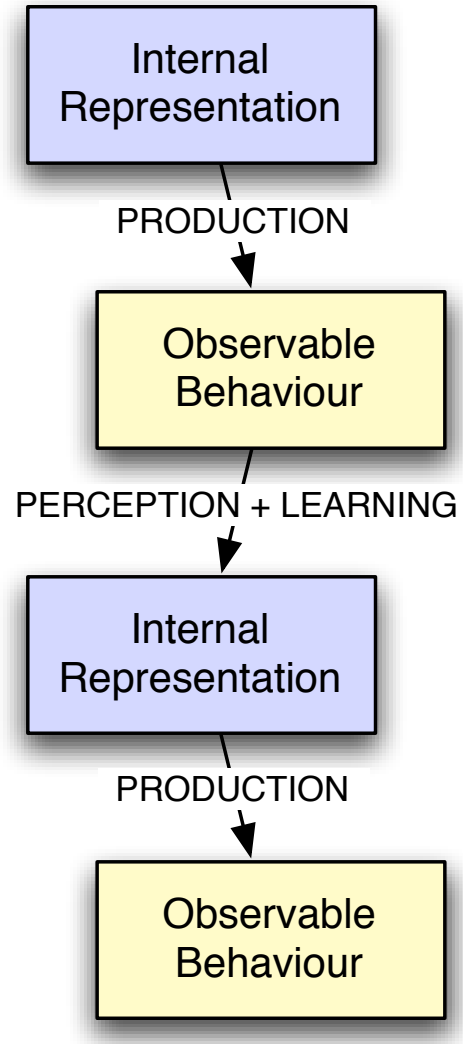
- The Iterated Learning Model (mid 90s onwards)
  - Multi-agent modelling techniques applied to cultural evolution
  - Embed simple models of learners in a dynamic population and an "environment" about which they try to communicate
  - Agents learn to communicate by observing others, who themselves learned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



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  - 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*)
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  - ... 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)

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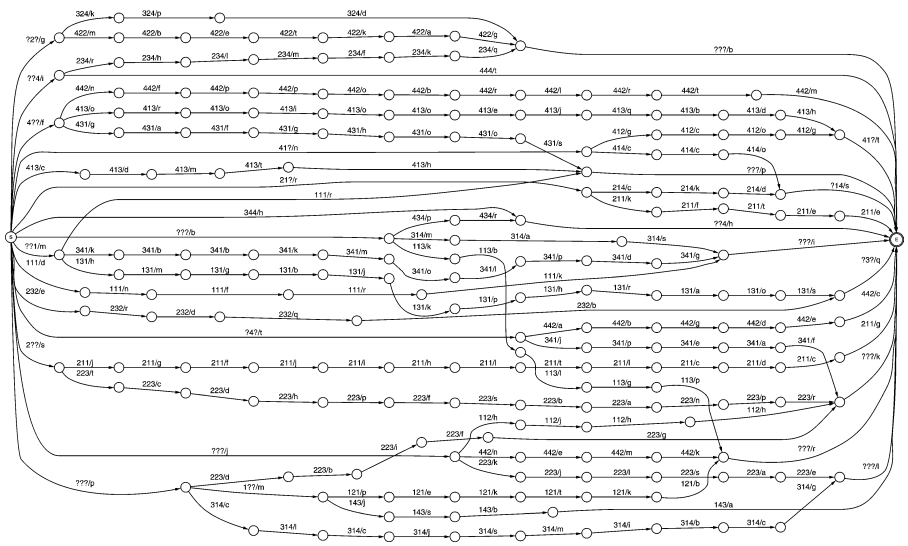

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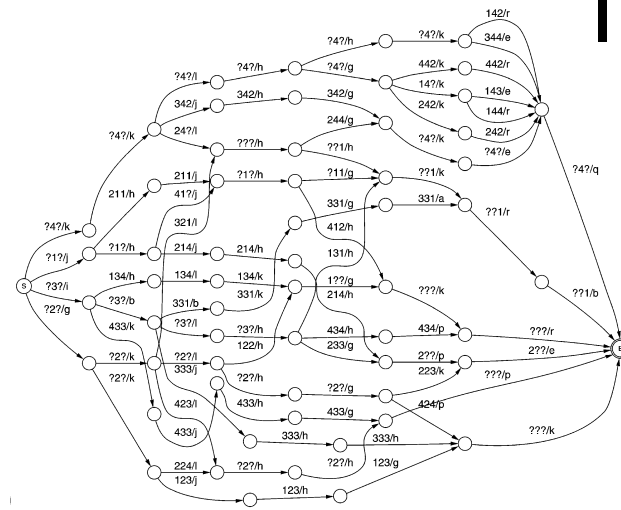

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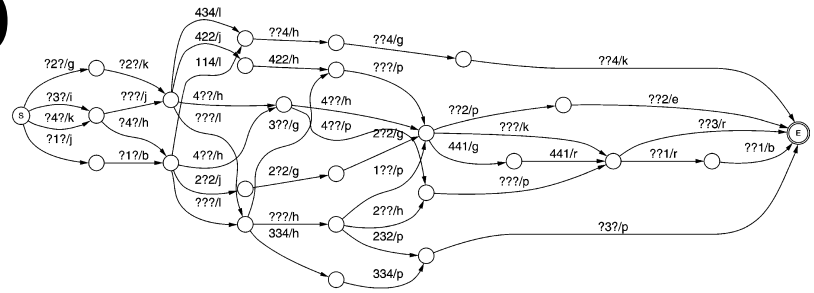

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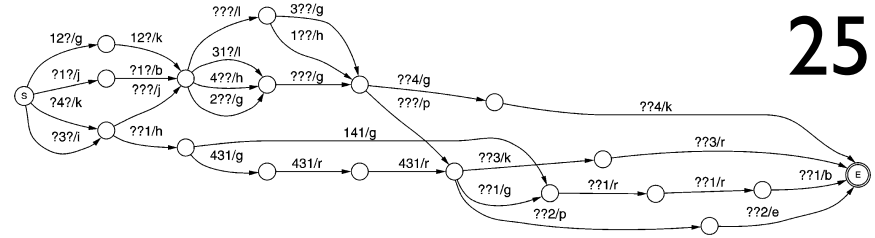

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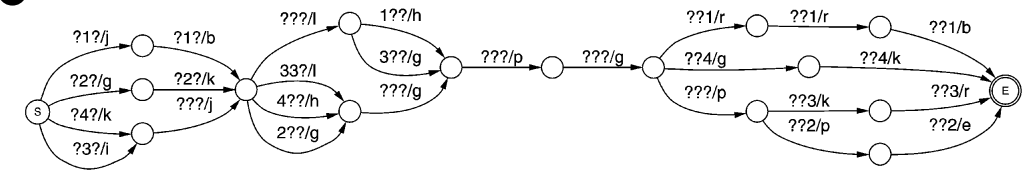

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- Computational models show a third alternative
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  - Consistent with idea of the "invisible hand" (Keller 1990)
- But can we demonstrate this in real human agents?

An experimental approach

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

Kirby, Cornish & Smith (forthcoming) *PNAS*

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An experimental approach

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  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)

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Hypothesis

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

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- Two ways of verifying this:
  - The language should become easier to learn
  - The language should become structured

The Language

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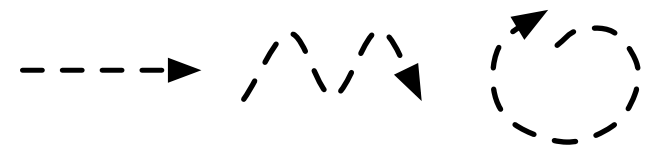
    - Three motions 

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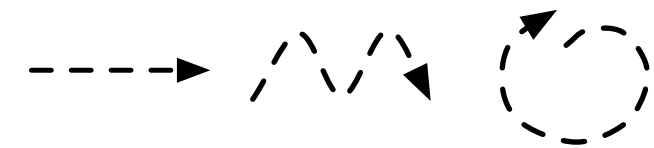
    - Three motions 
- A large set of possible "signals"
  - Random sequences of between two and four syllables chosen from a set of nine
  - No spaces

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  - SEEN set: 14 string-picture pairs
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- 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

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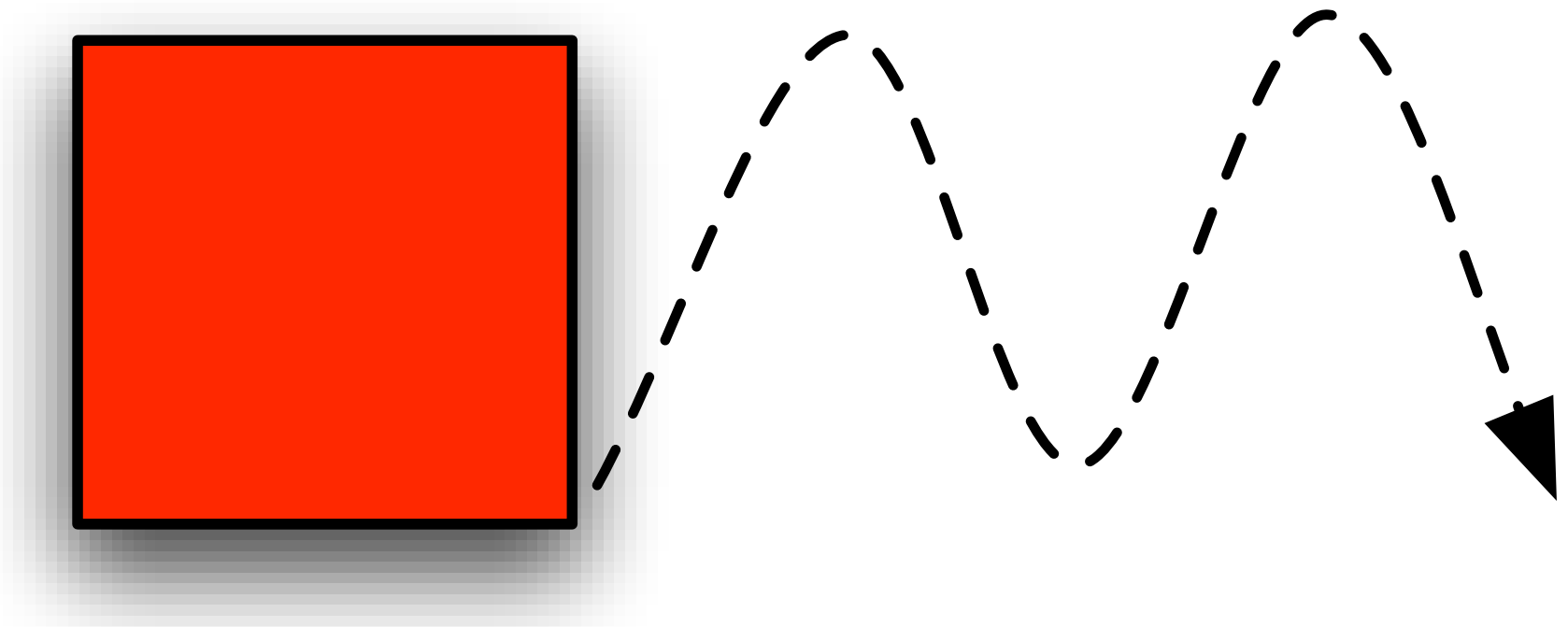

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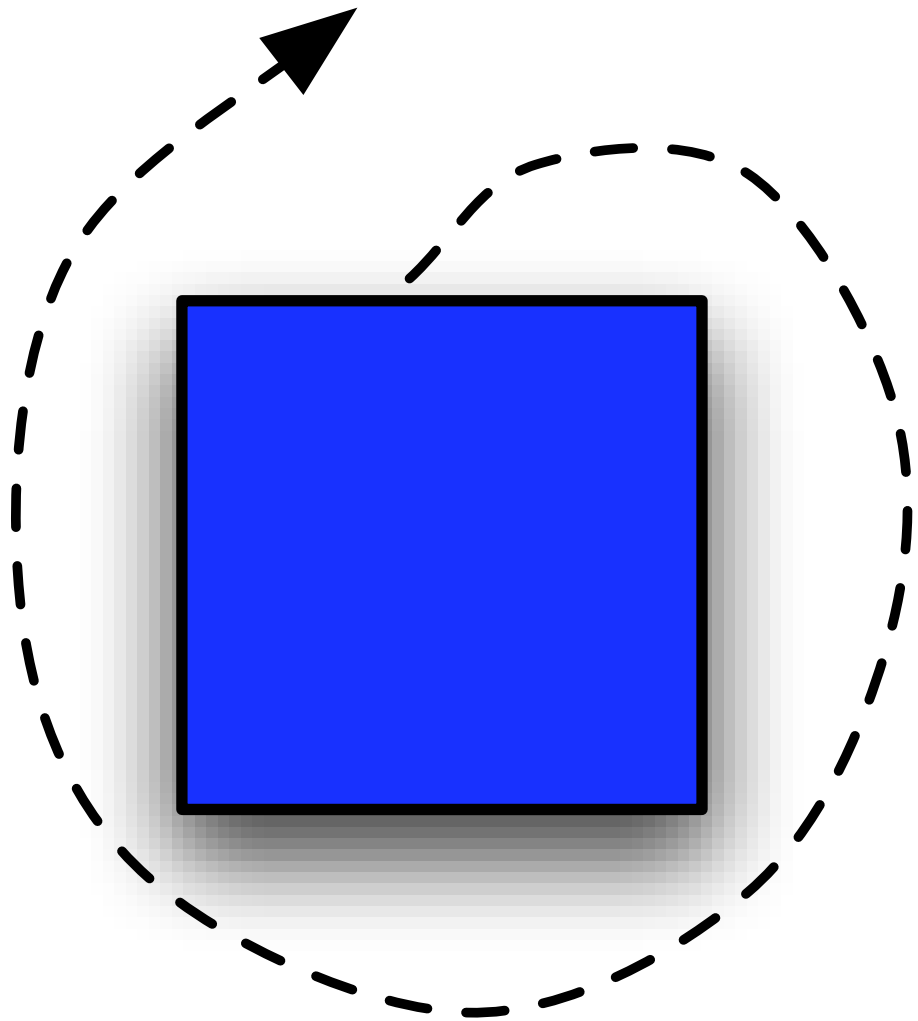
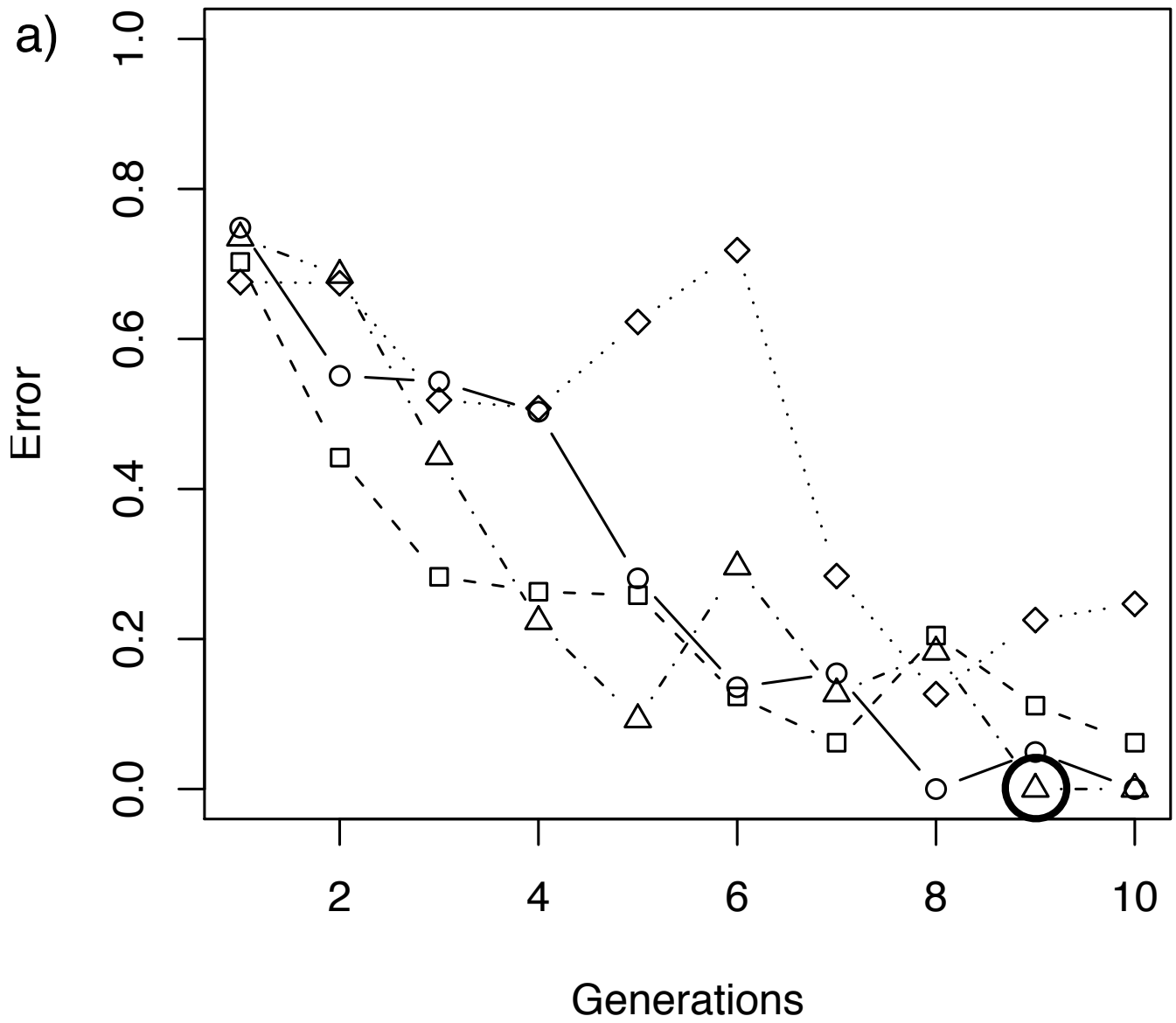


Language becomes easier to learn



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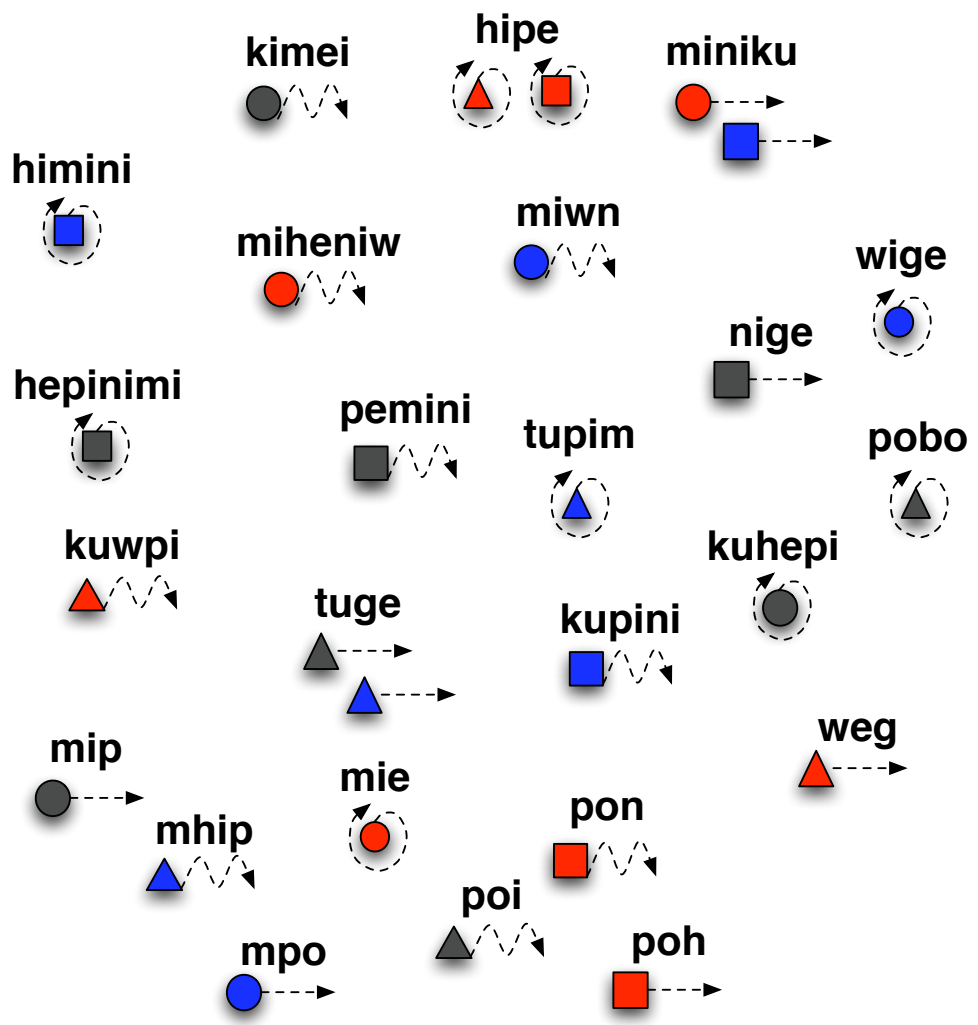

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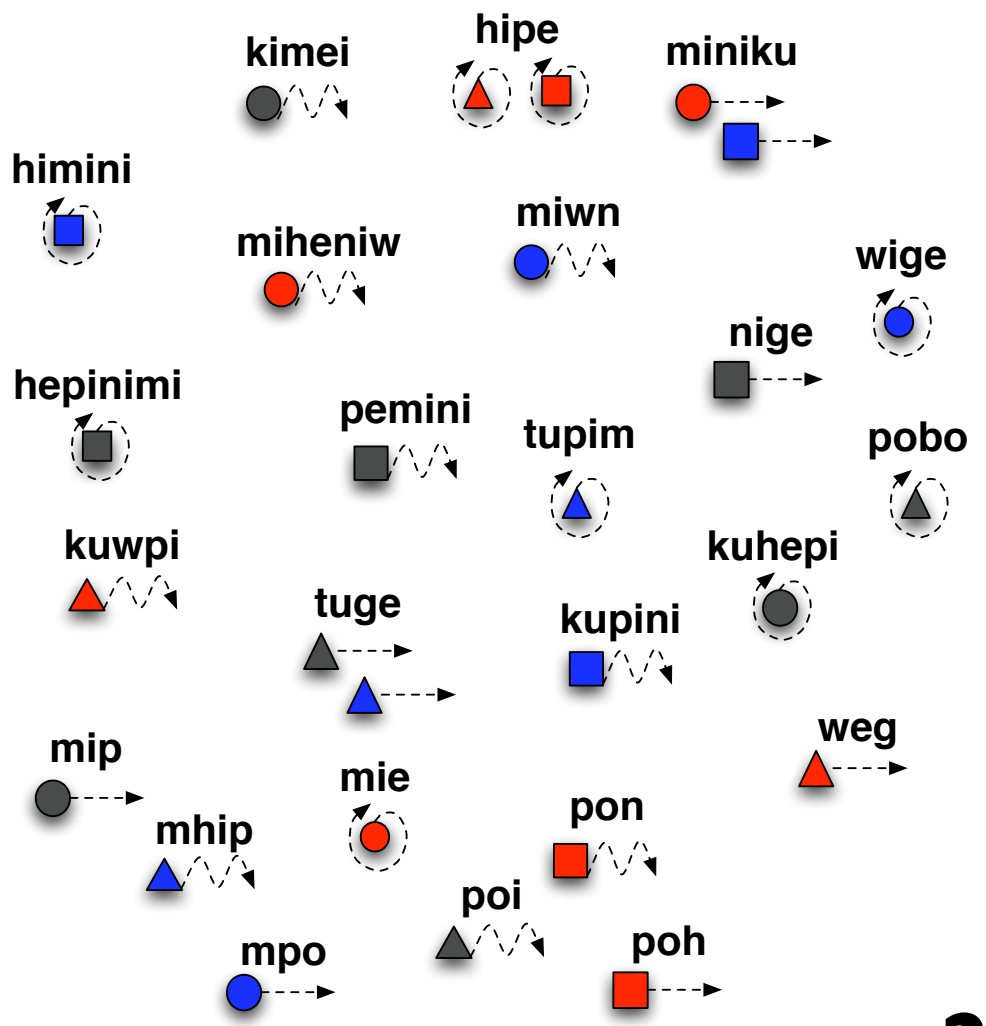
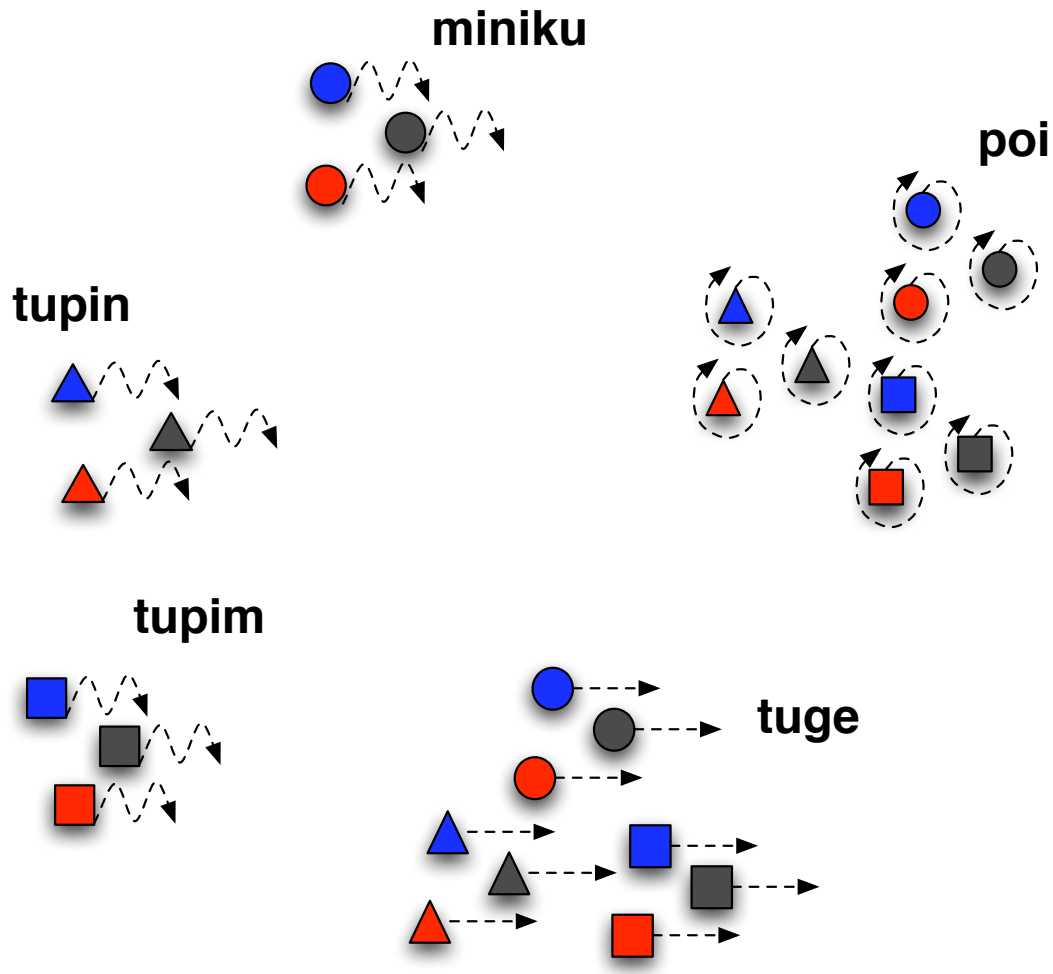


24 words

After Generation 10:



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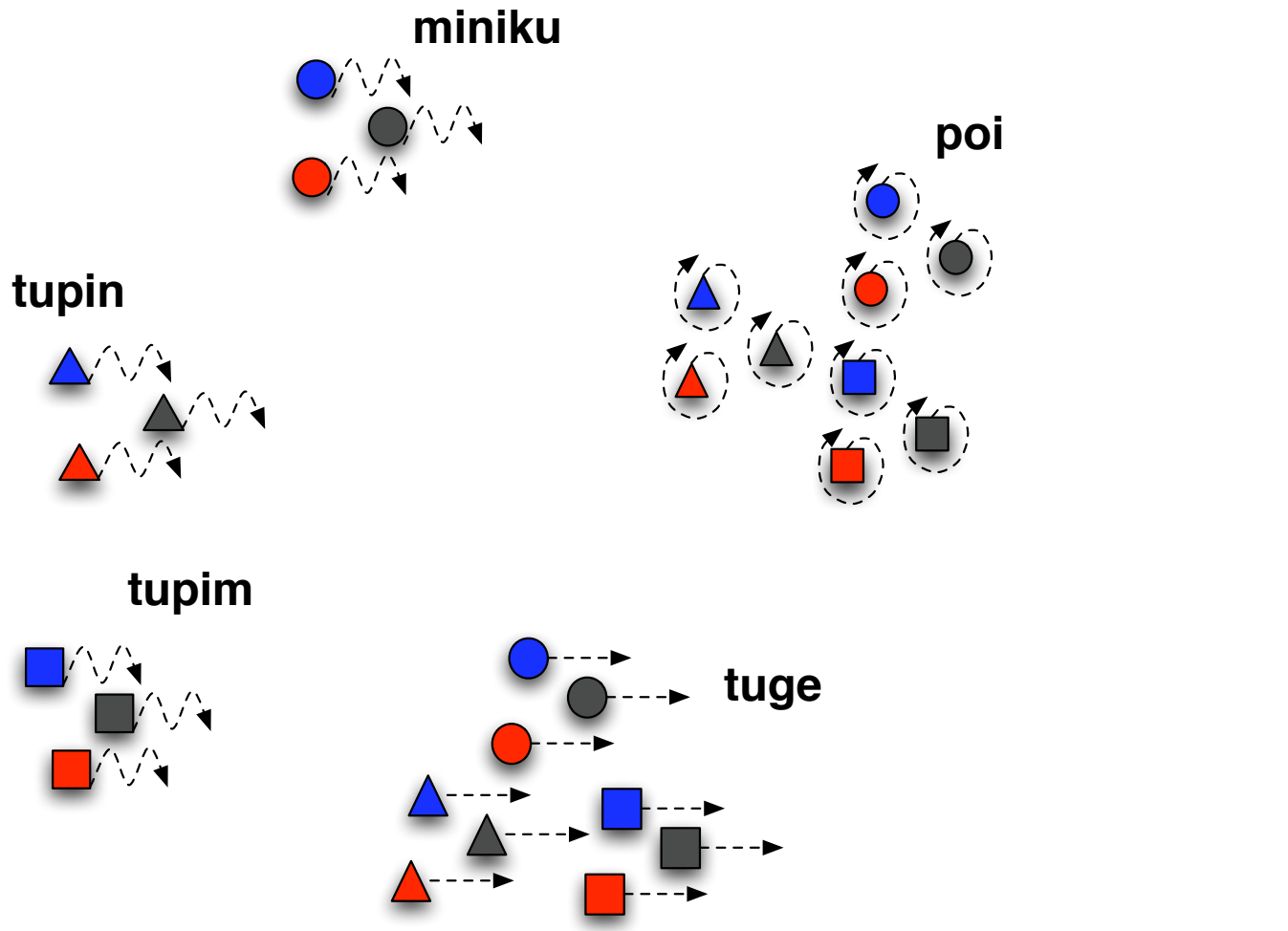

5 words

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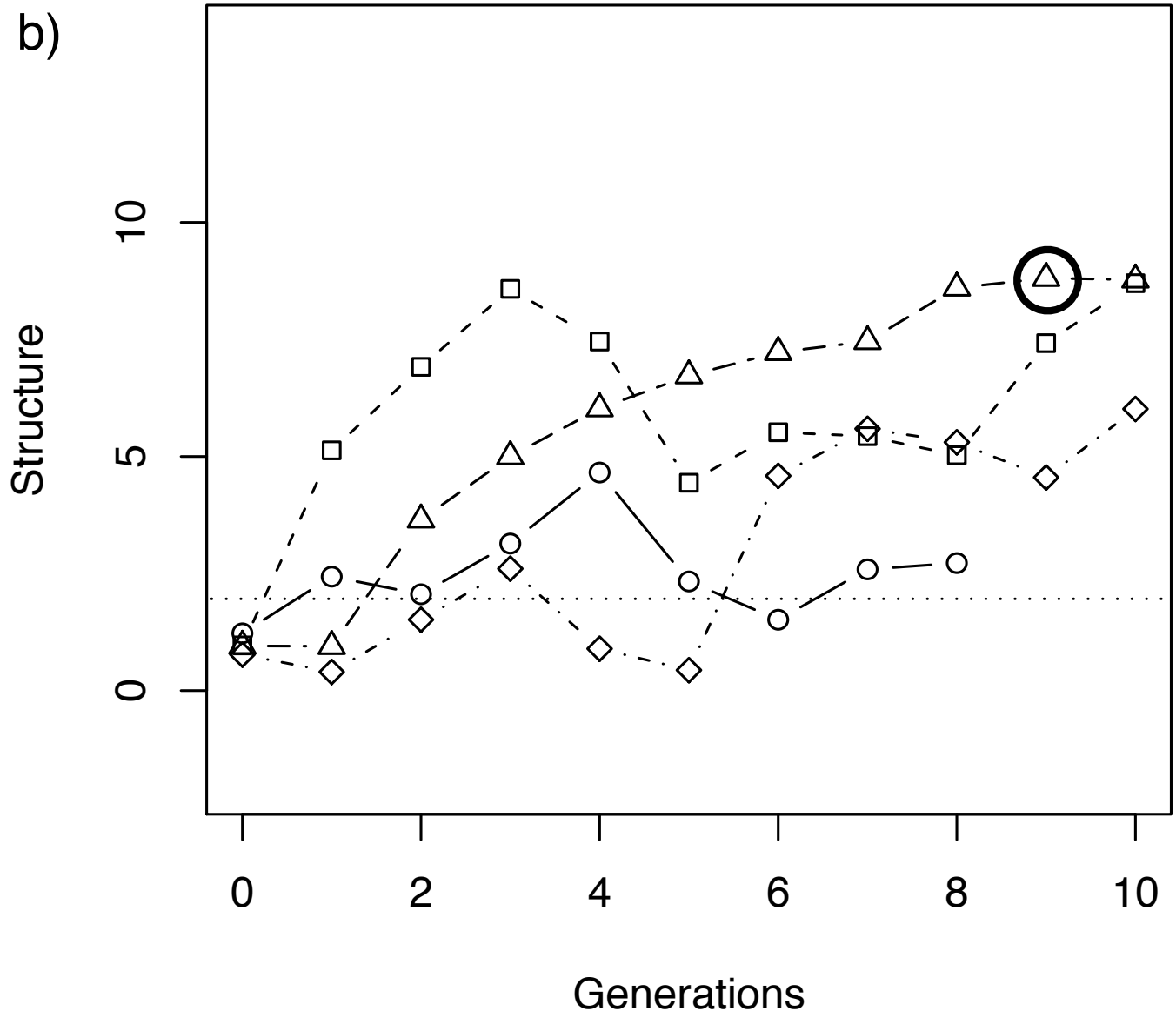
- Looks like it might be just that there are fewer words.
- If this were all that was going on, then subjects' performance on unseen items should be random
- This doesn't appear to be the case...

Language becomes systematic



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

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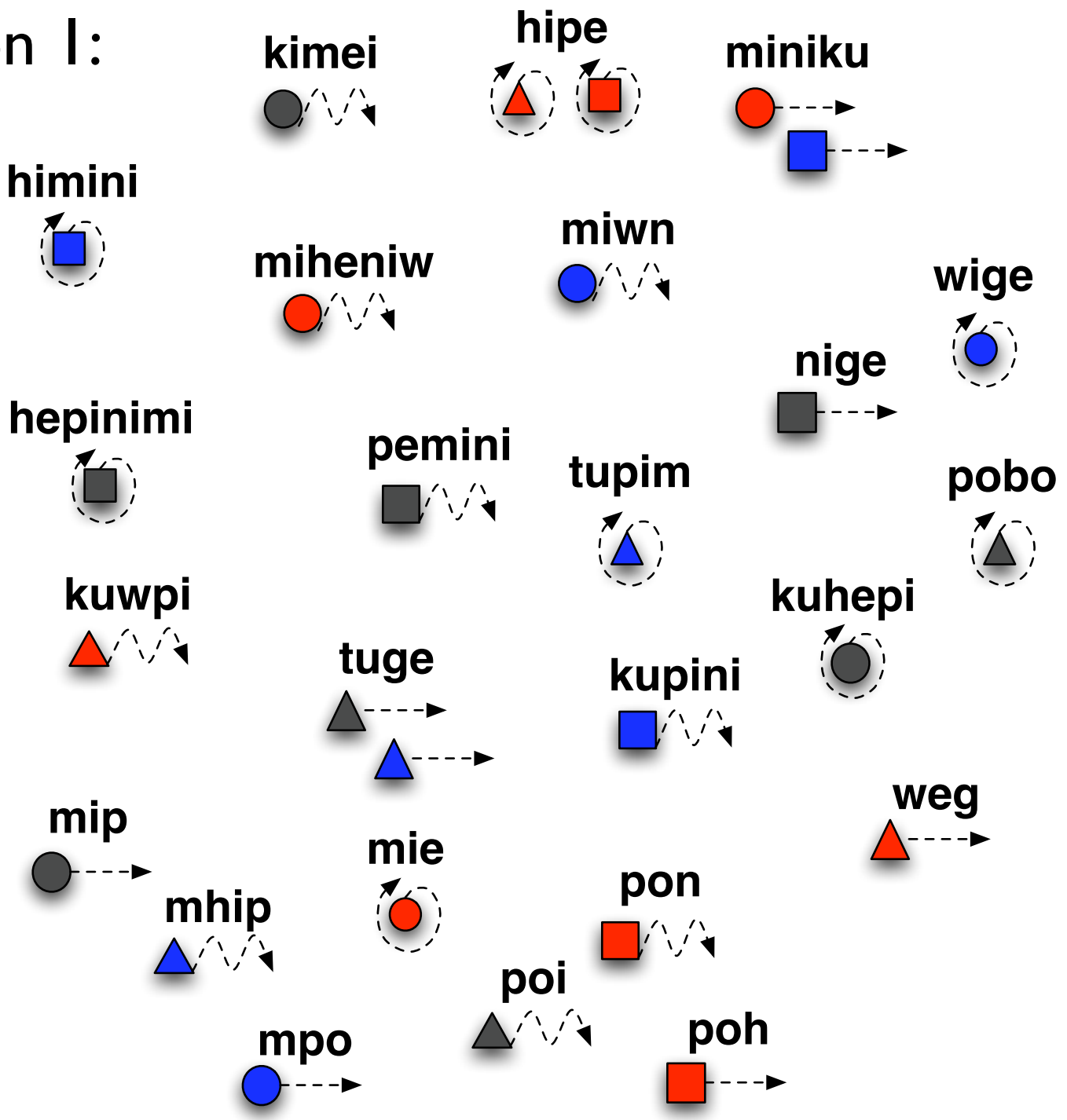
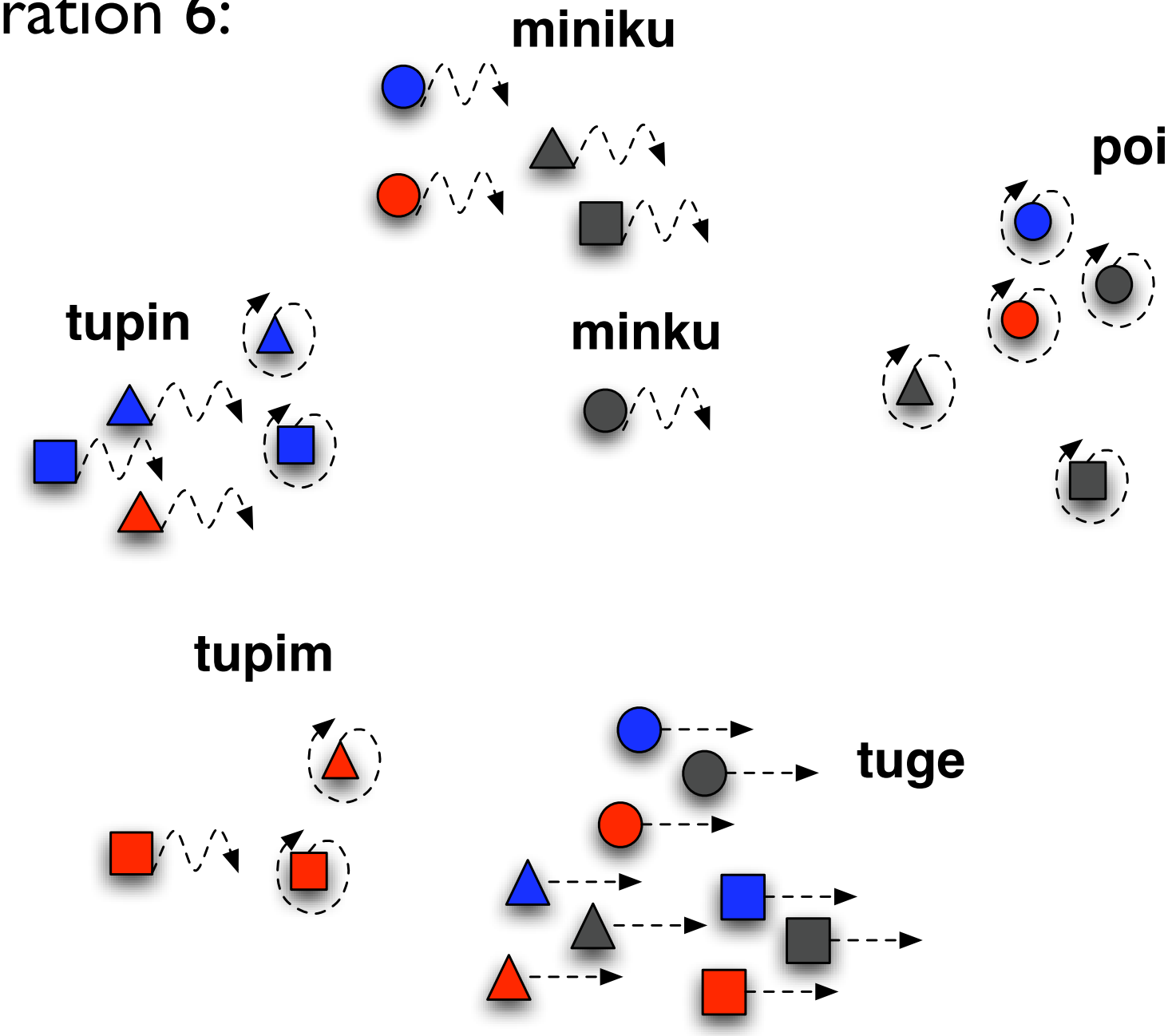
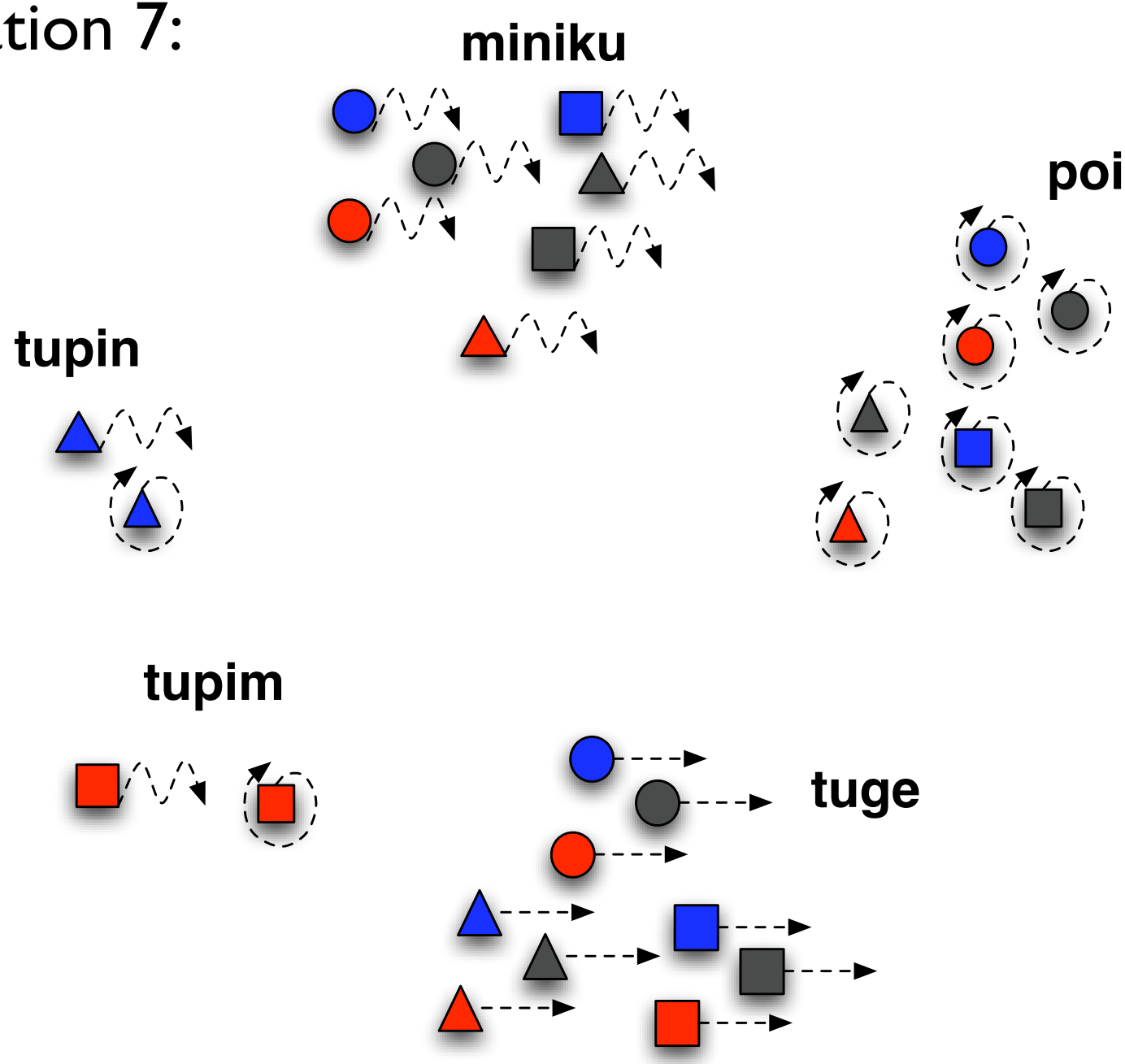


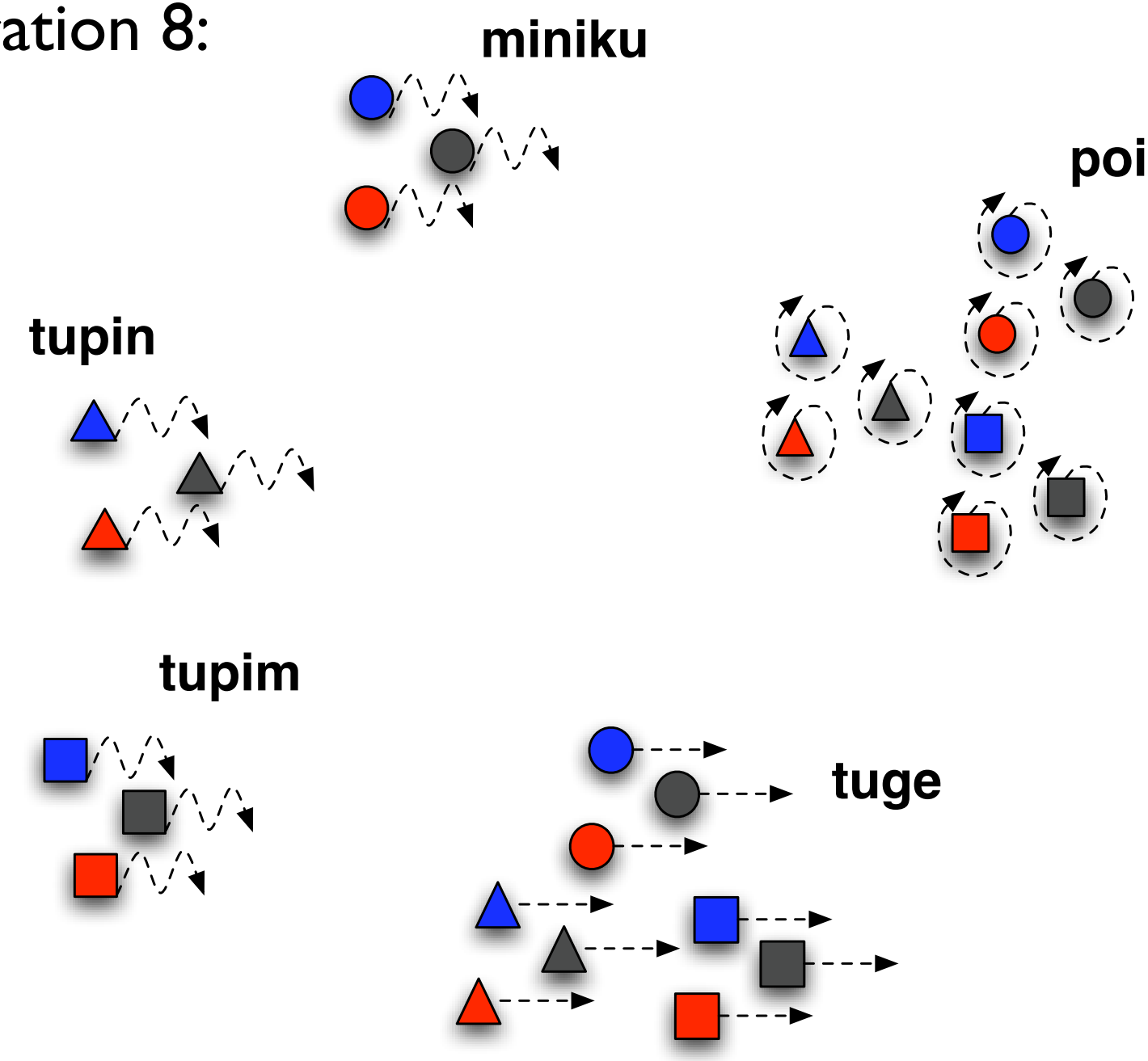
After Generation 6:



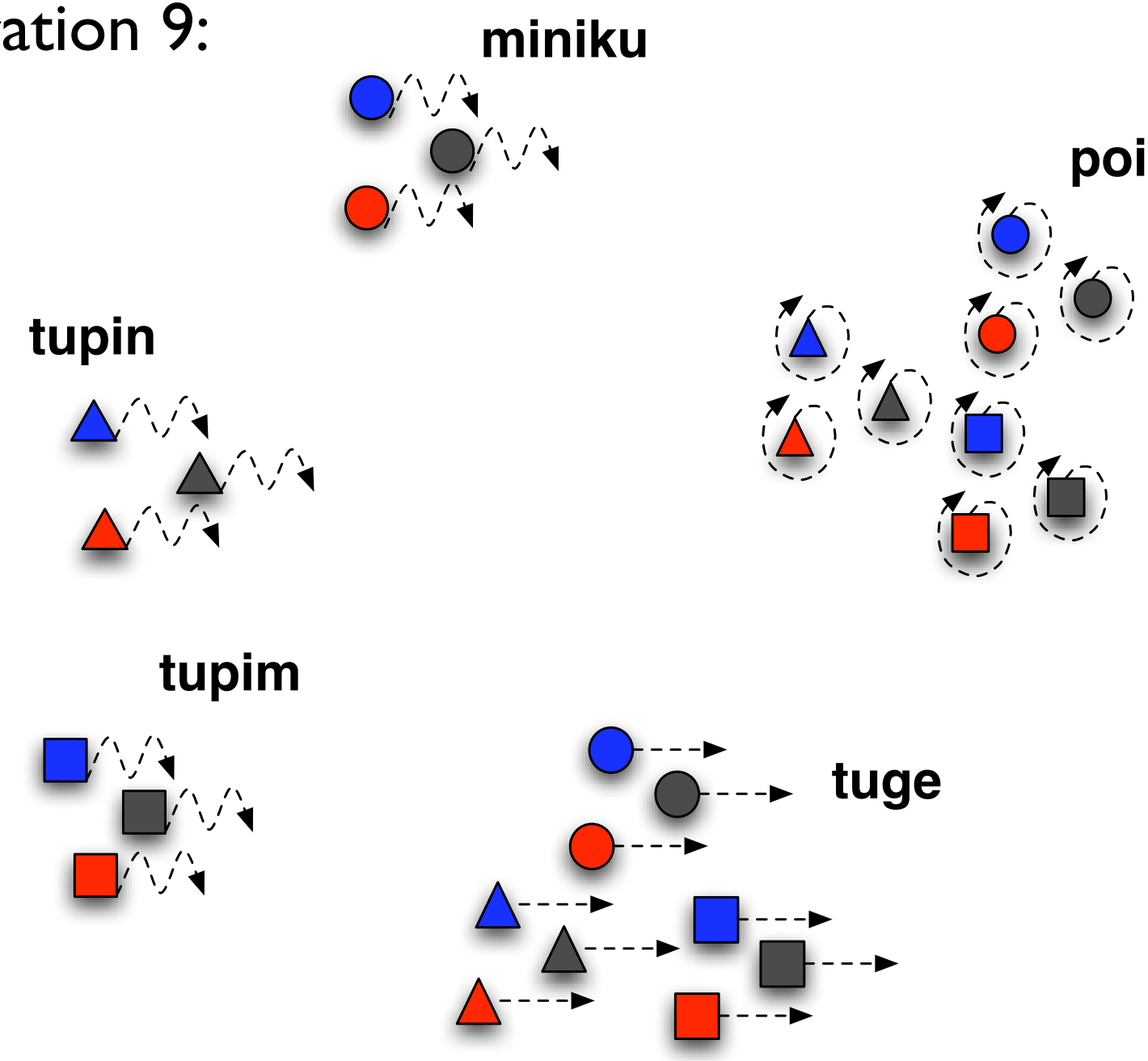
After Generation 7:



After Generation 8:



After Generation 9:



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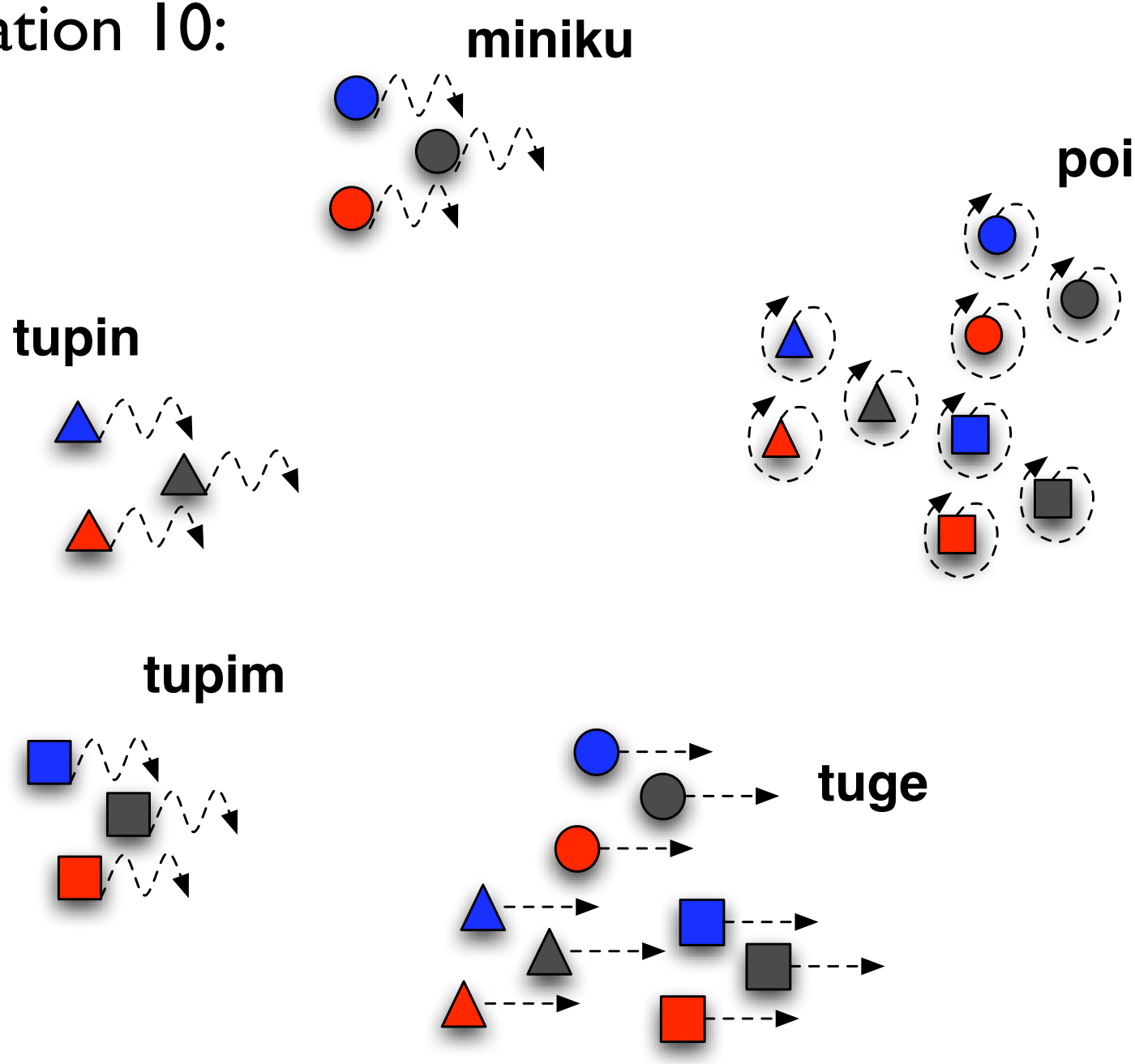

Language adapts to be structured

- 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
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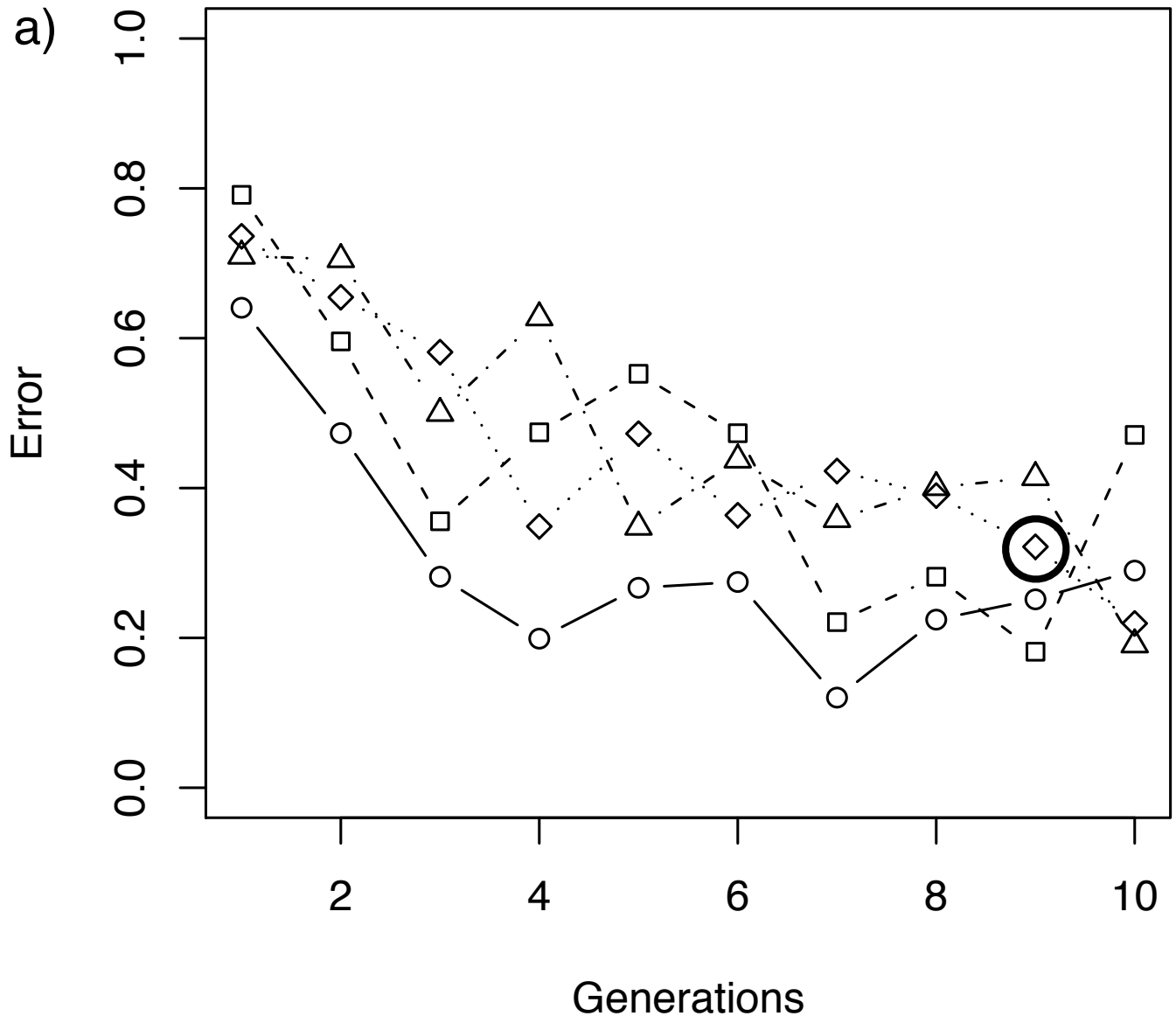
- There's no pressure for expressivity in the experiment
- Simple modification: filter out all ambiguous items from SEEN set before subjects see them

Language becomes easier to learn



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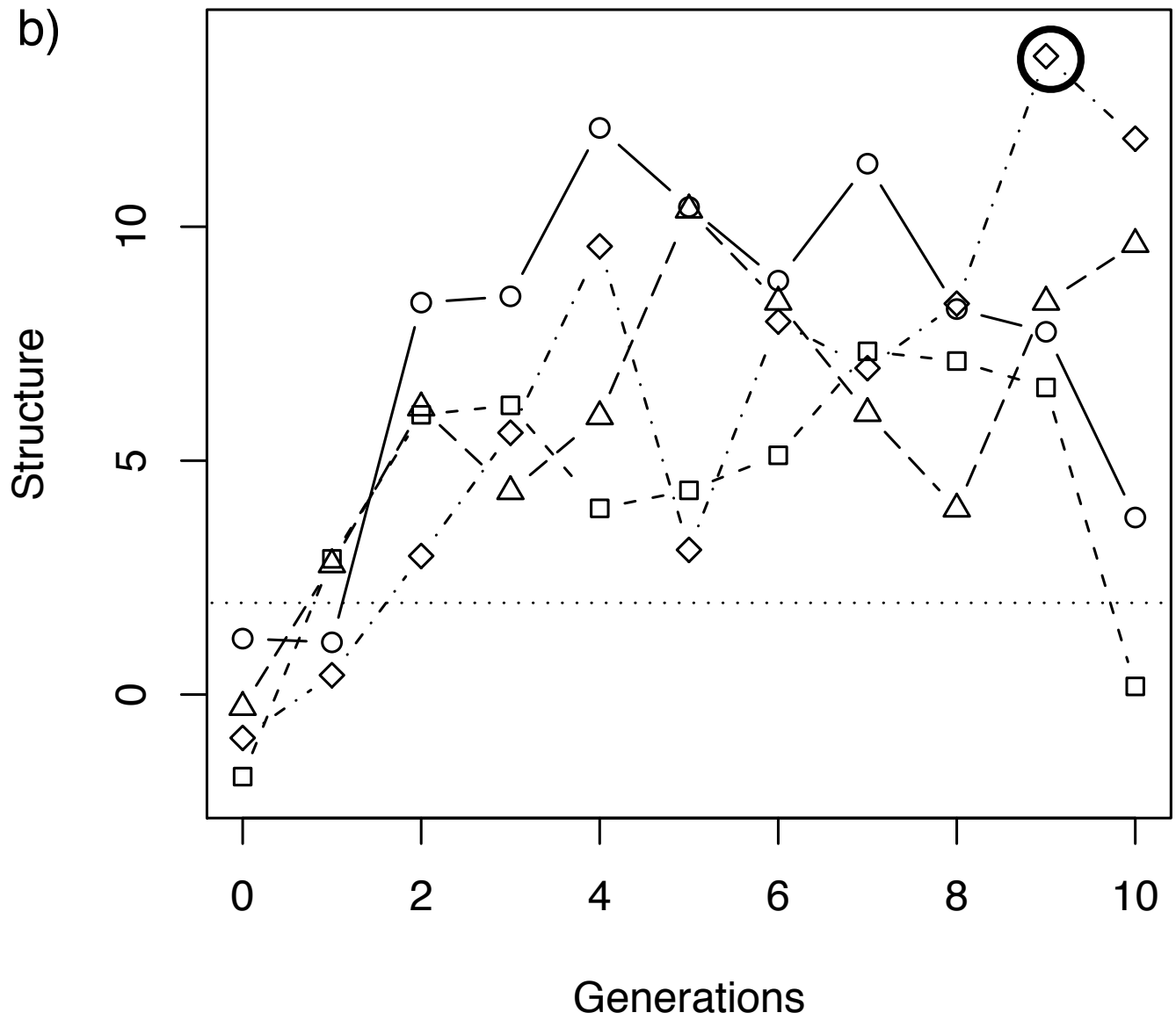
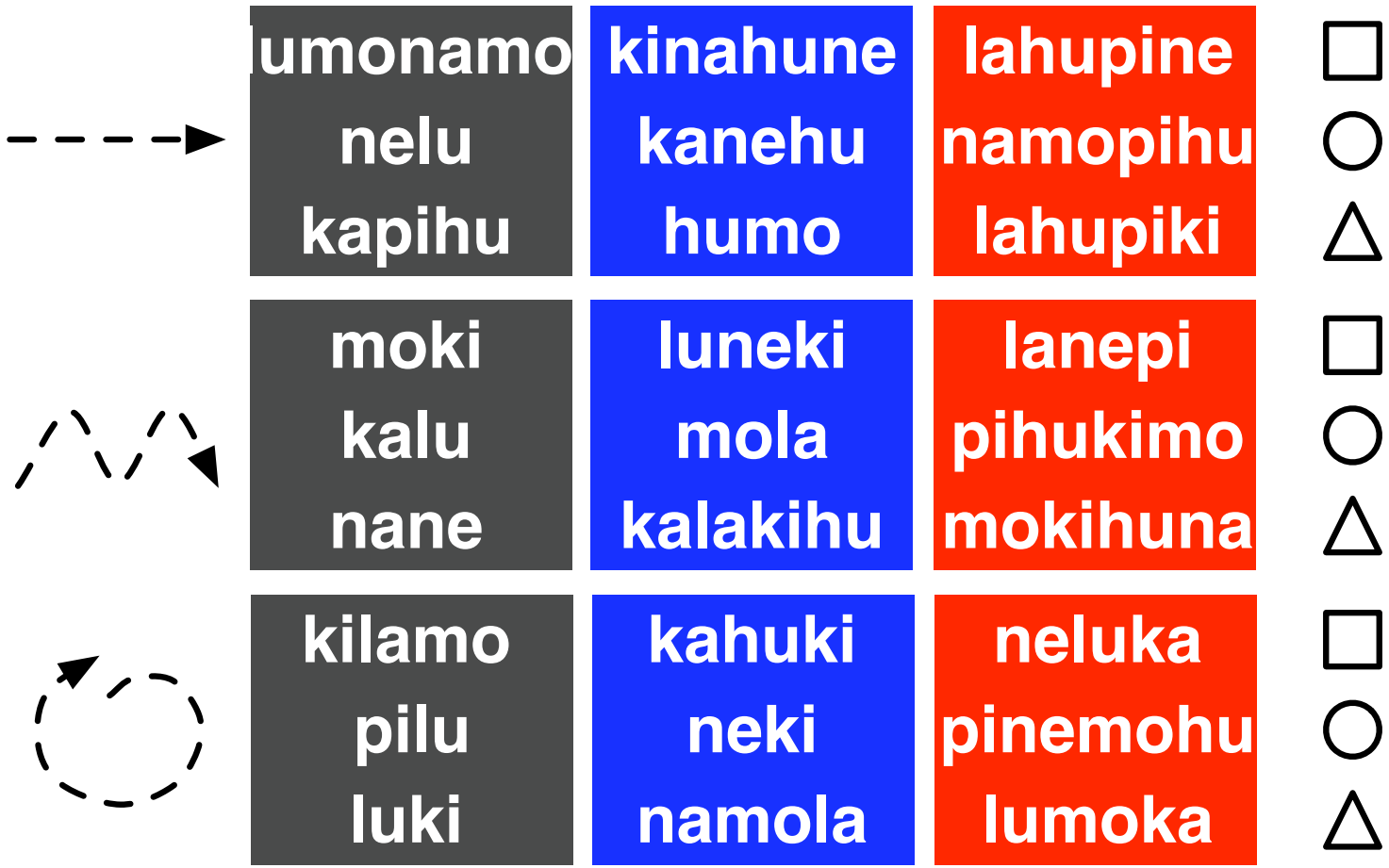
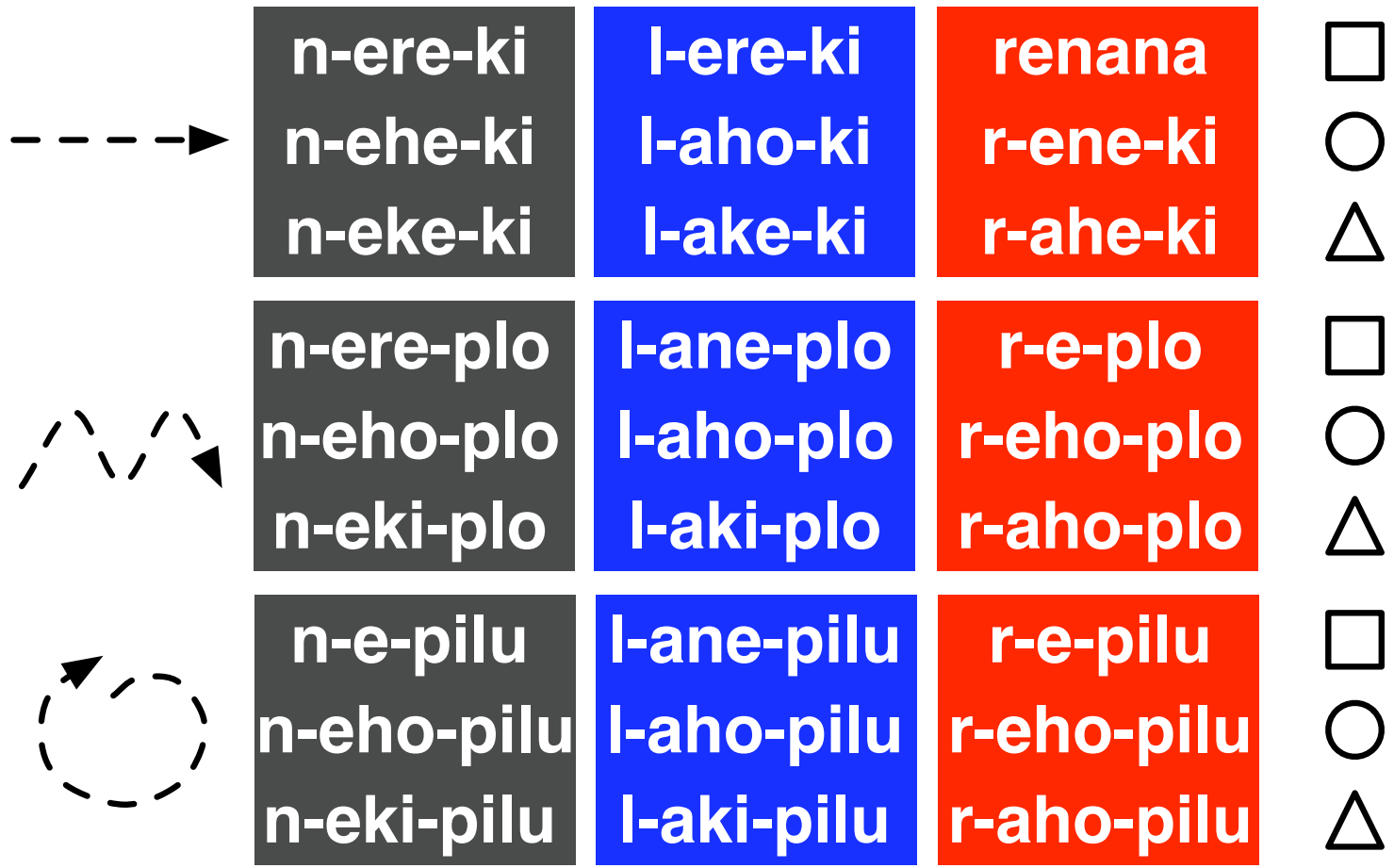


Example initial language



Example final language
(10 "generations" later)



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- It must be learned even though:
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  - 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

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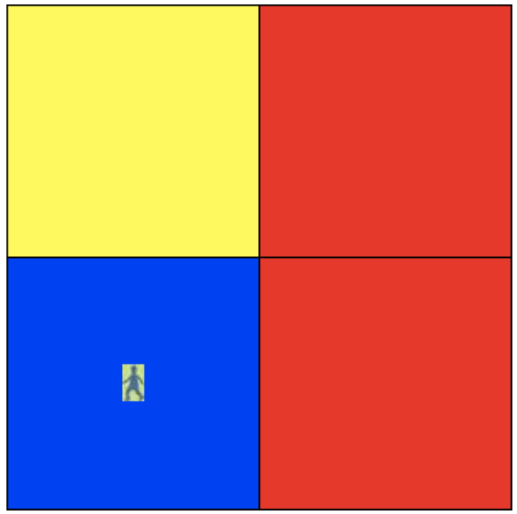
  - want to communicate
  - know what to communicate about
  - have a dedicated "channel" for communication
  - want to share their communication system.
- In other words, they are already *symbolic learners*
  - Can we explore the genuine emergence of symbols in the lab?
  - New experiment inspired by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

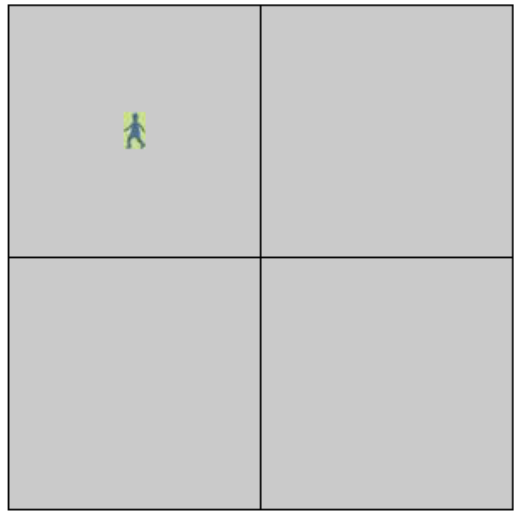
The Embodied Communication Game: A test-bed for the emergence of symbolic communication

- 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:

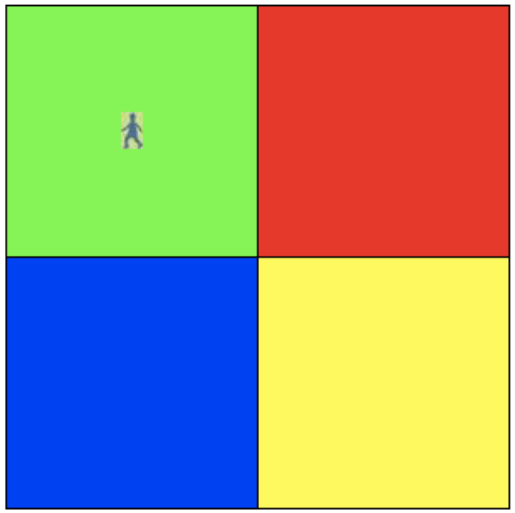


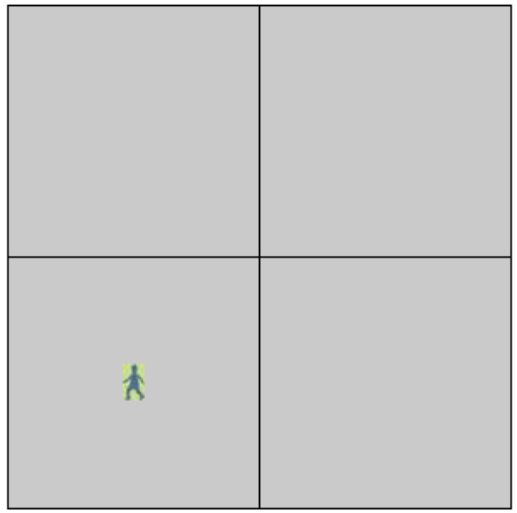


Points in succession: 0 Highest: 3

Press space when you're finished

Player 2 sees:





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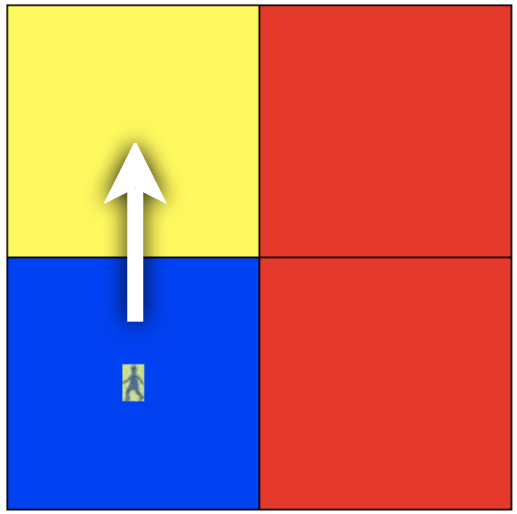

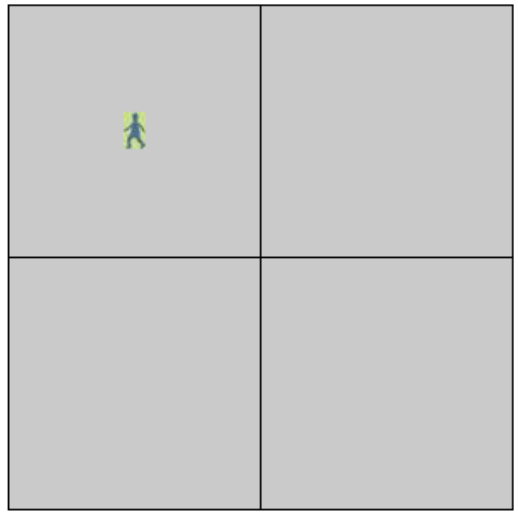

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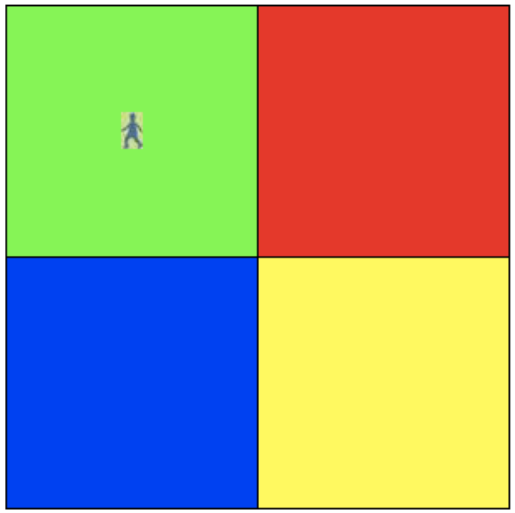

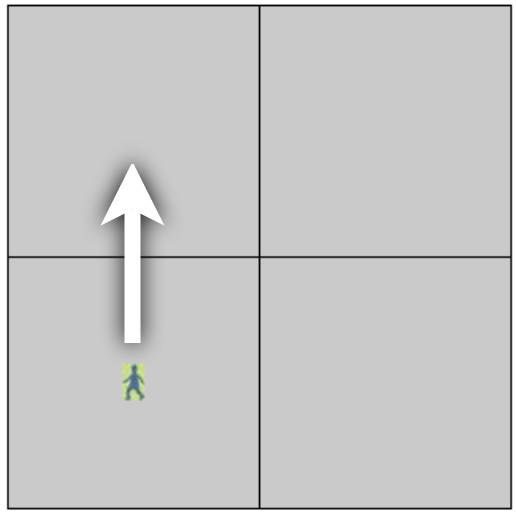

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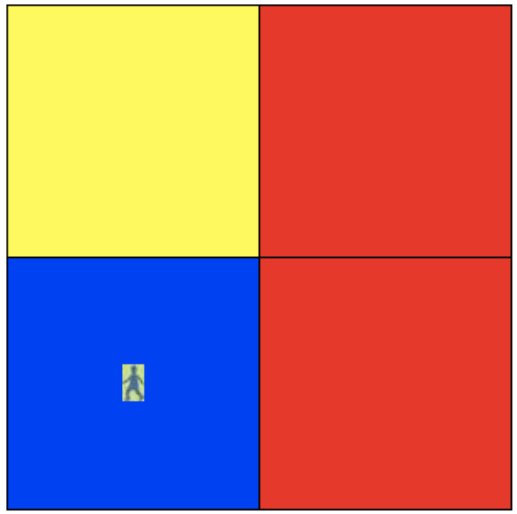

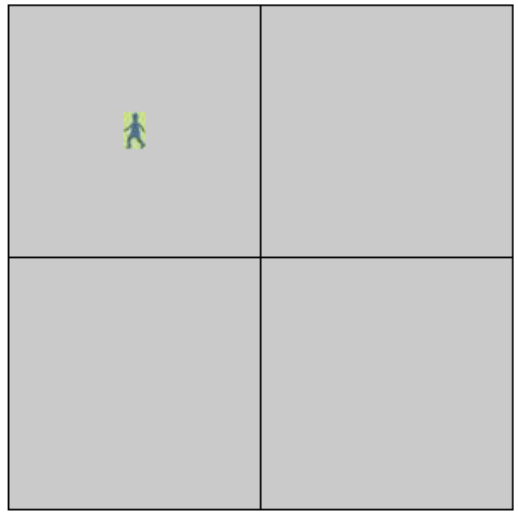

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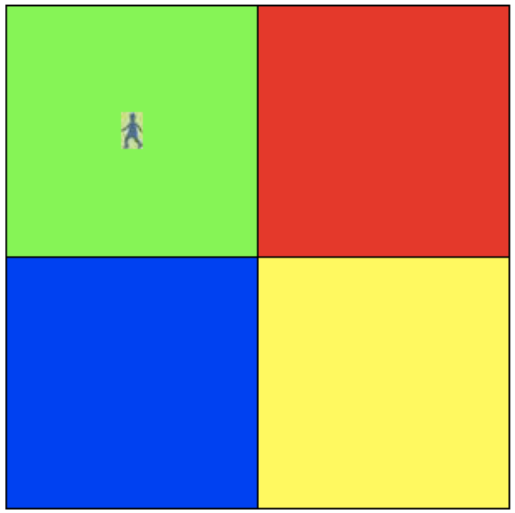

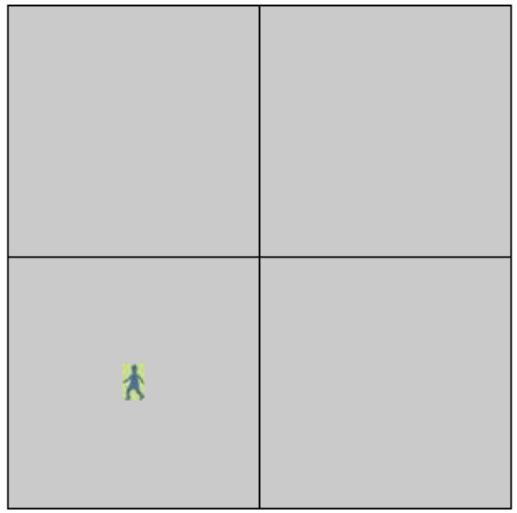

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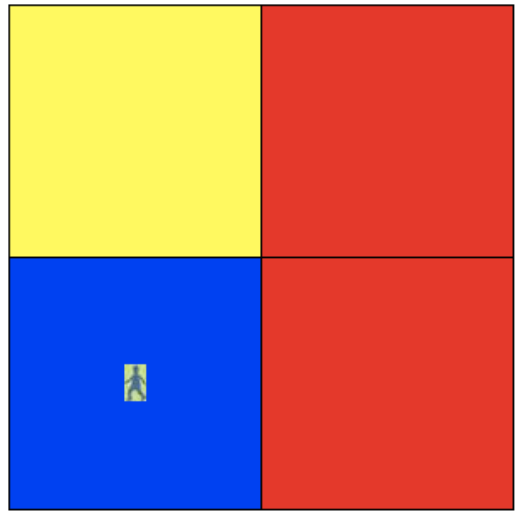
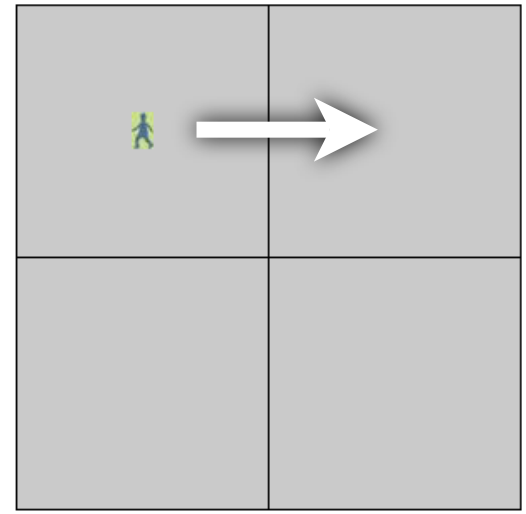
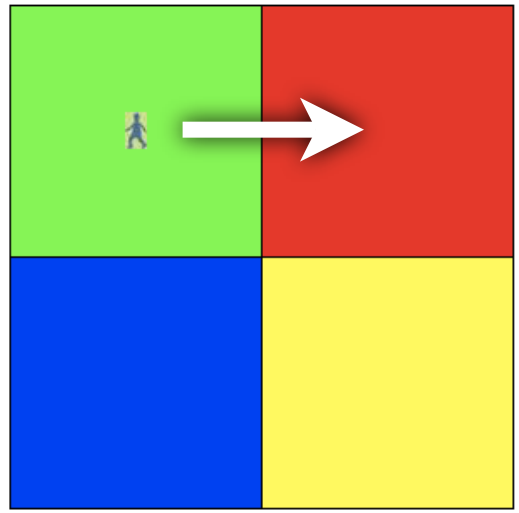


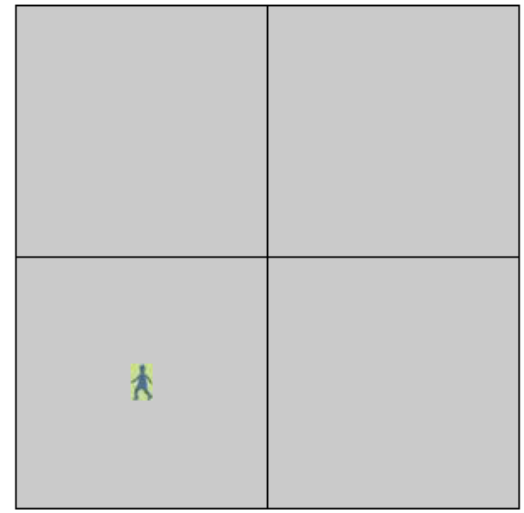


Points in succession: 0 Highest: 3

Press space when you're finished

Player 2 sees:





Points in succession: 0 Highest: 3

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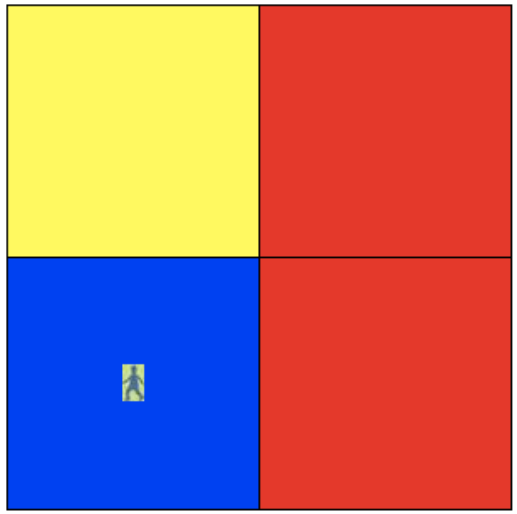
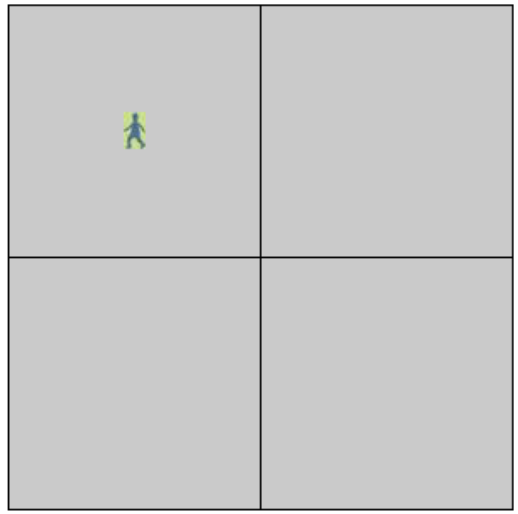
Player 1 sees:

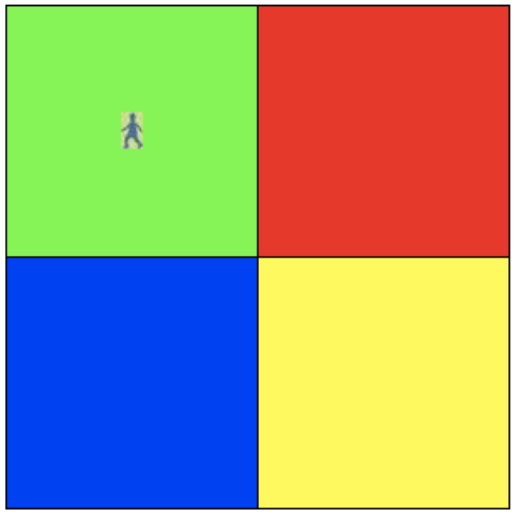


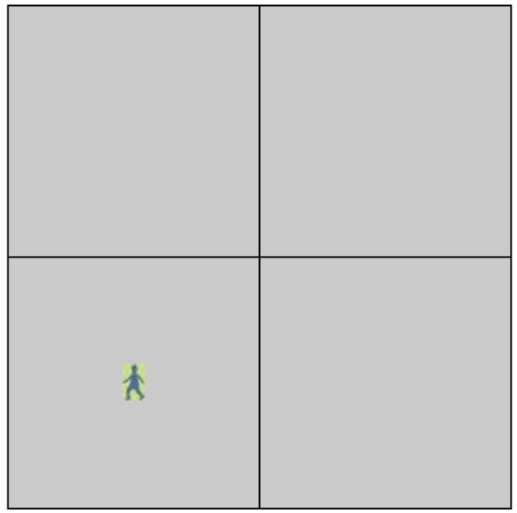


Points in succession: 0 Highest: 3

Press space when you're finished

Player 2 sees:





Points in succession: 0 Highest: 3

Press space when you're finished

Rules

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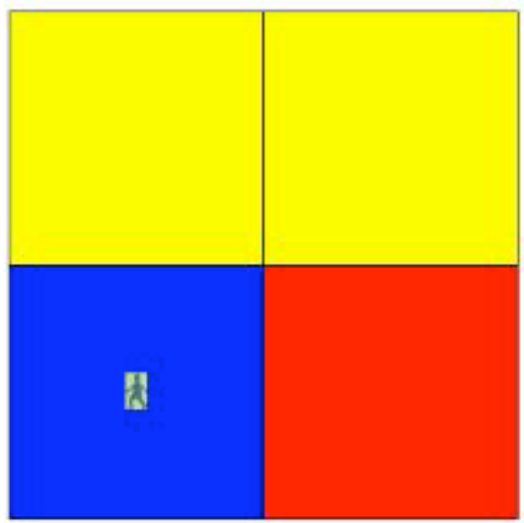
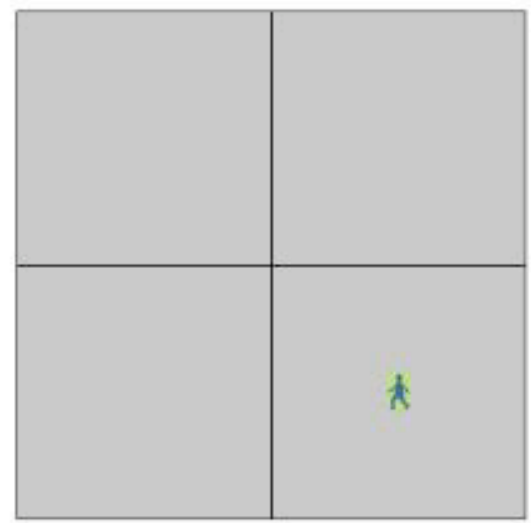
- Always at least one colour that's in both rooms (but equally there may be colours that are unique to room)
- Colour assignment is completely random after each turn
- After turn, other player's colours are revealed
- It *is* possible to find a strategy for winning on every turn

Typical early behaviour

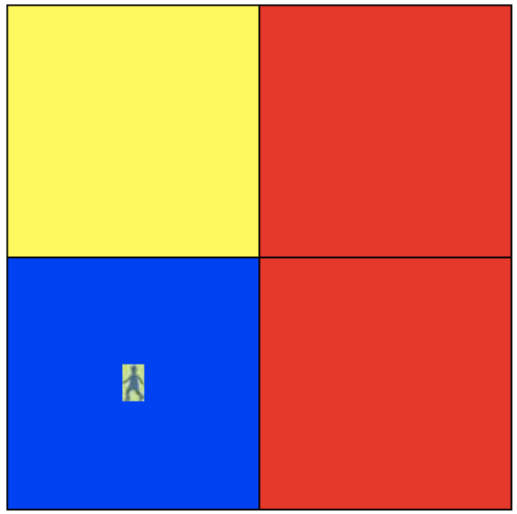


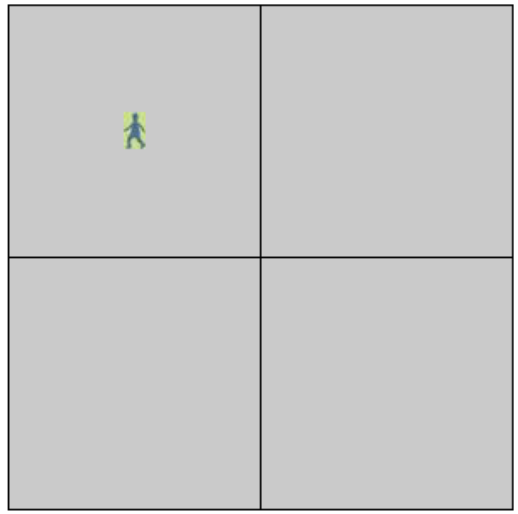
Points in succession: 0 Highest: 0

Press space when you're finished



Player 1 sees:

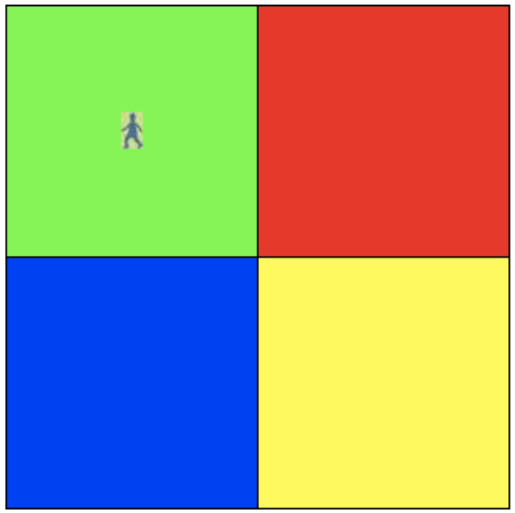


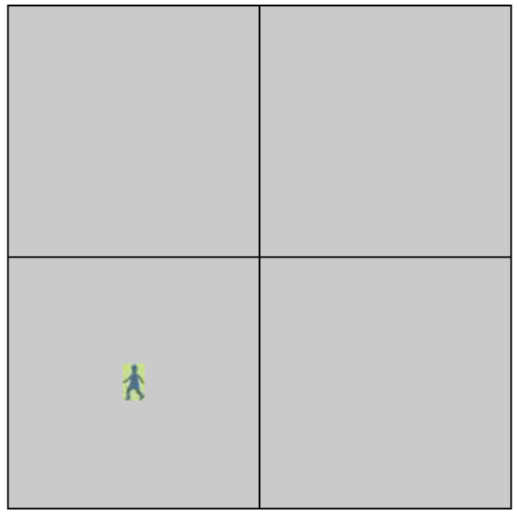


Points in succession: 0 Highest: 3

Press space when you're finished

Player 2 sees:

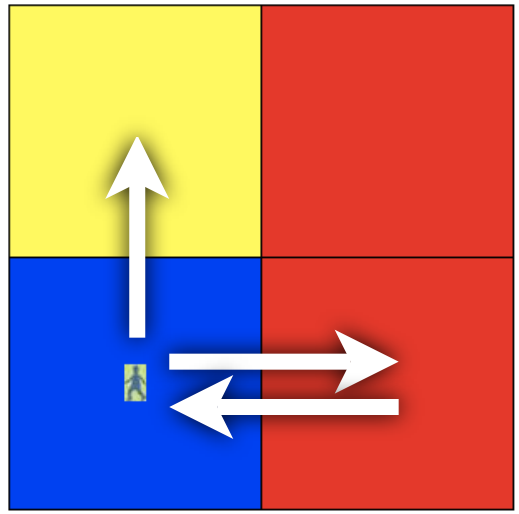


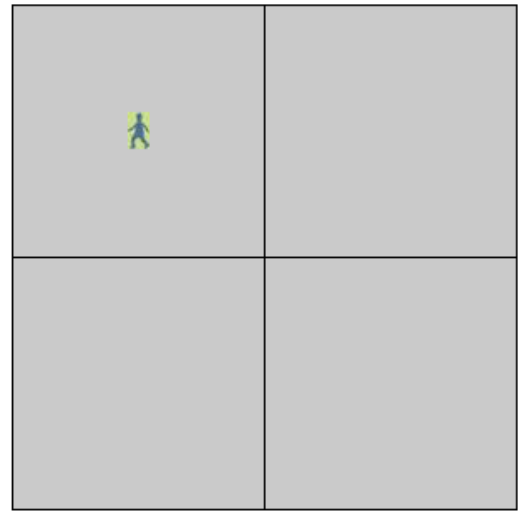


Points in succession: 0 Highest: 3

Press space when you're finished

Player 1 sees:

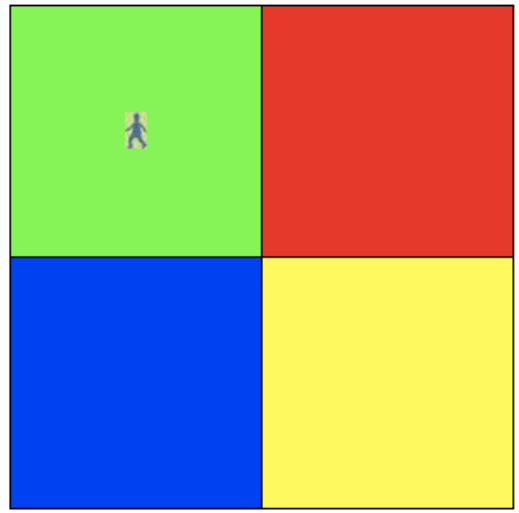


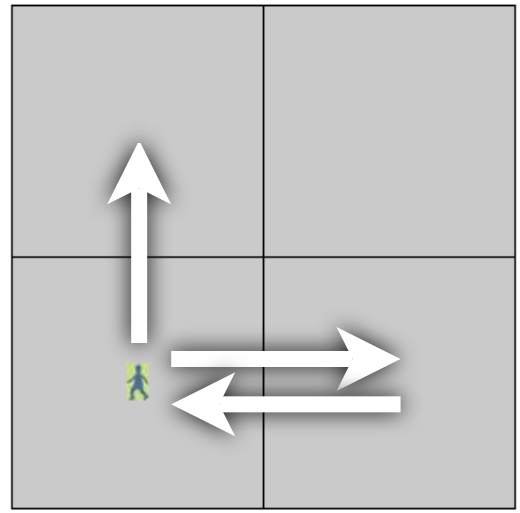


Points in succession: 0 Highest: 3

Press space when you're finished

Player 2 sees:





Points in succession: 0 Highest: 3

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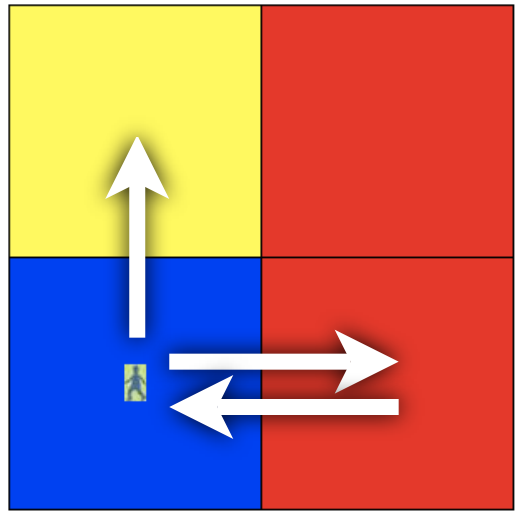
Player 1 sees:



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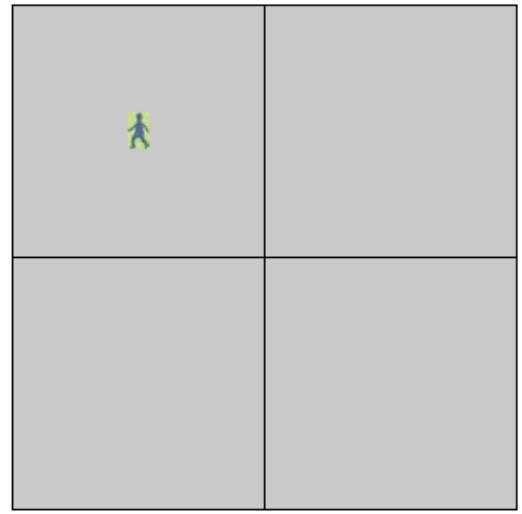
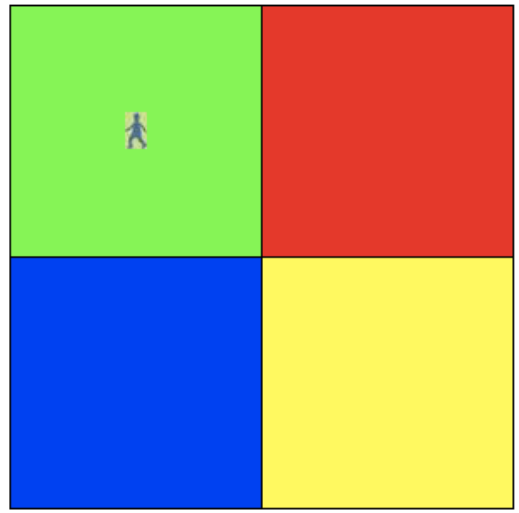
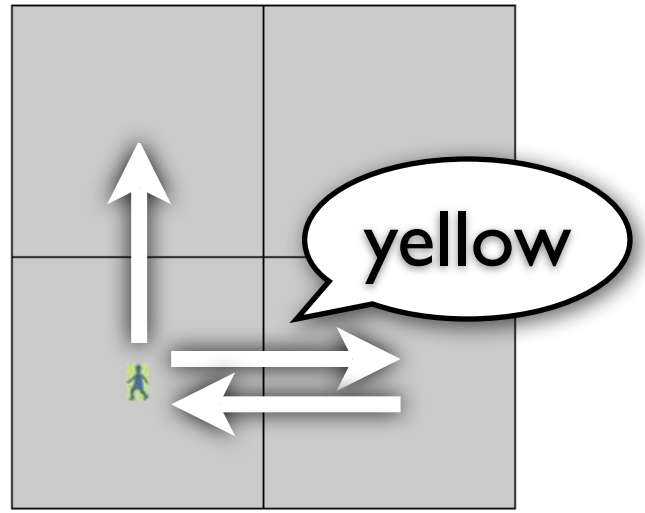


Player 2 sees:

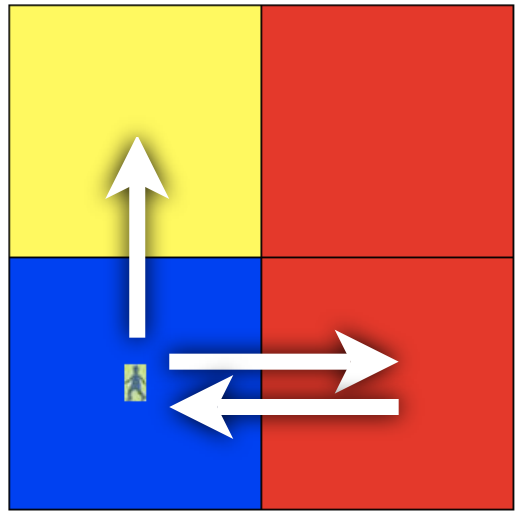


Points in succession: 0 Highest: 3

Press space when you're finished



Player 1 sees:



Points in succession: 0 Highest: 3

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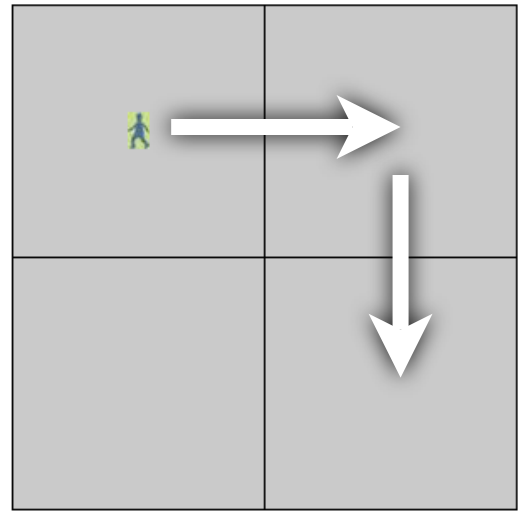
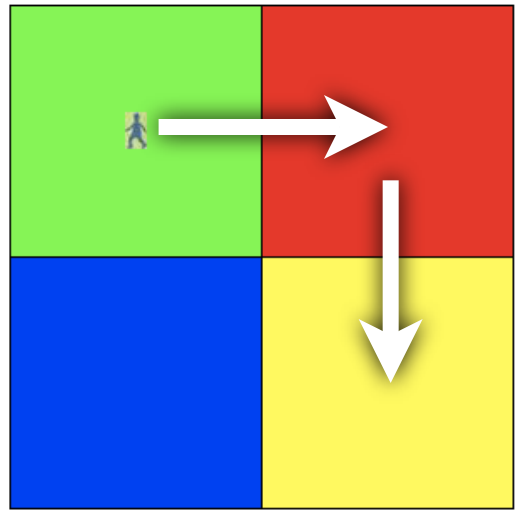


Player 2 sees:



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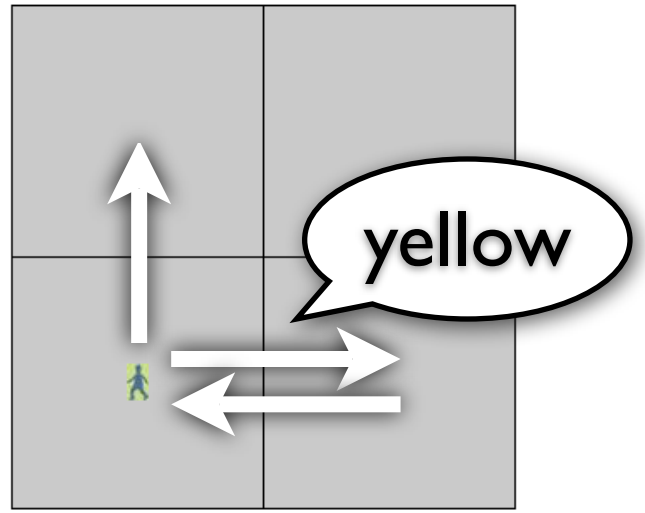
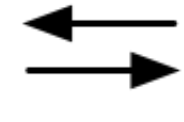
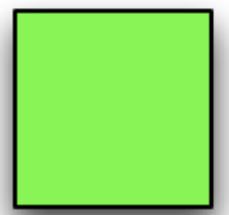


Move & stop (default strategy)

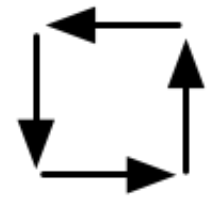
Oscillations

or

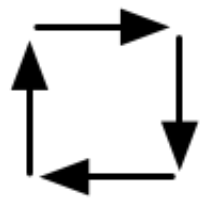


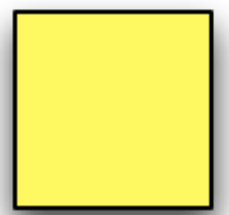


Loop

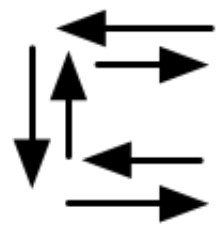


or

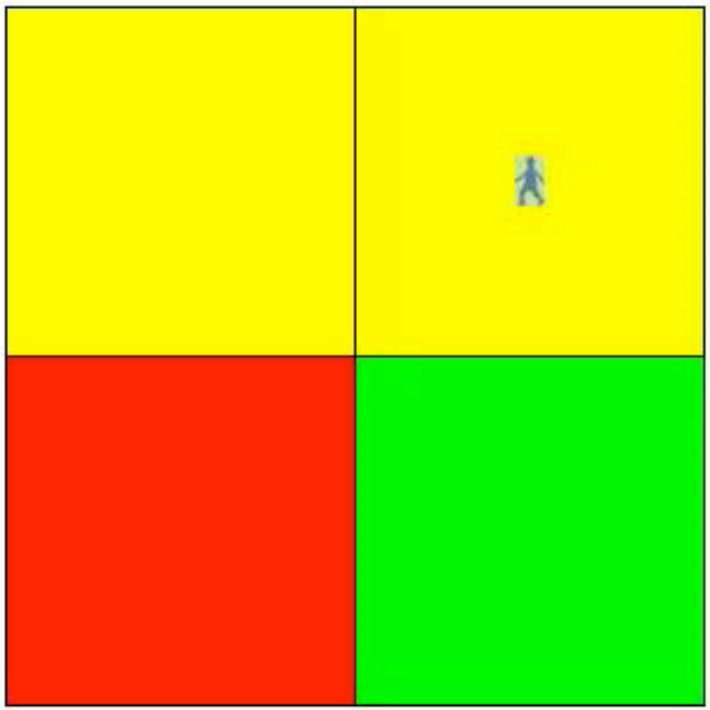




C-shape

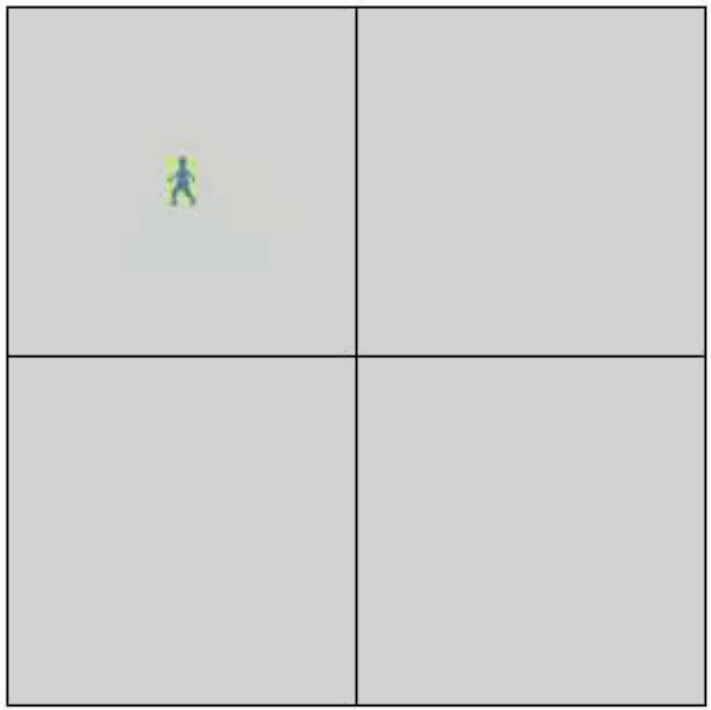


An example of dialogue



Points in succession: 1 Highest: 2

Press space when you're finished



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

Conclusions

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- 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

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- 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)