The Language Organism
Lecture 9: What about syntax?

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What have we looked at so far?

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- Innate signalling
    - Animal communication as a pre-wired mapping between meanings and signals

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- Innate signalling
    - Animal communication as a pre-wired mapping between meanings and signals
- Learned signalling
    - Humans may be unique in *learning* the mapping between meanings and signals
    - Our model builds on the animal signalling model
    - Adds: learning bias and cultural evolution

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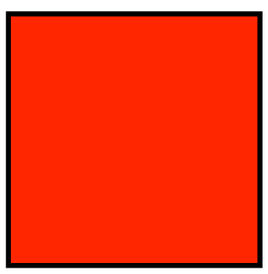
- In reality (for all communicating species) both meanings and signals have internal structure
  - Aside: what does structure mean?
  - One answer: having internal parts that can be recombined
- Does this matter at all?

How we leverage structure...

- What's the missing word?



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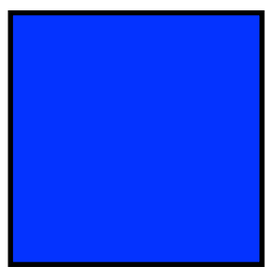

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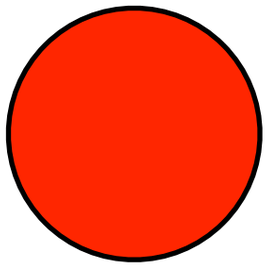

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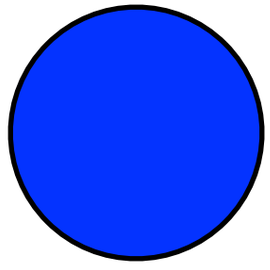

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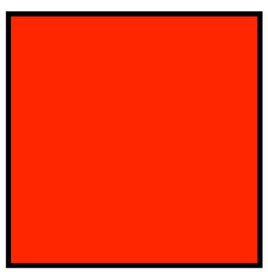

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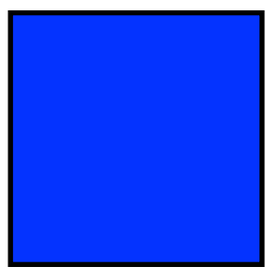

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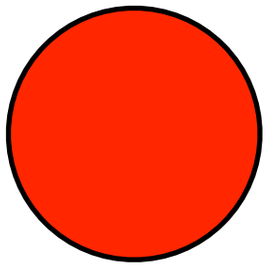

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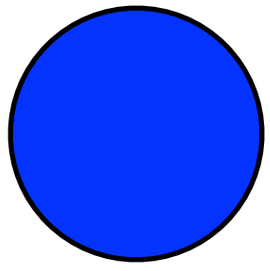

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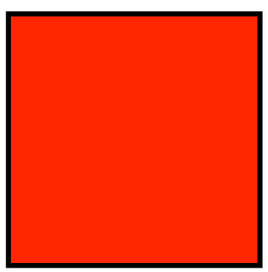

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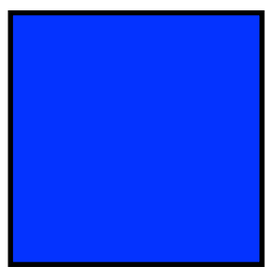

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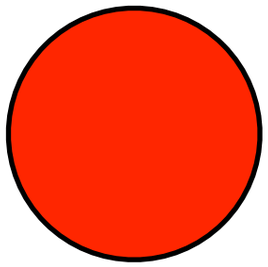

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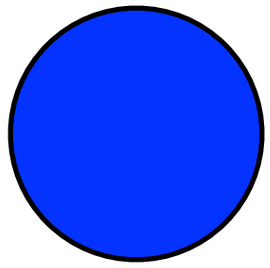

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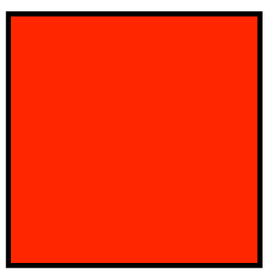

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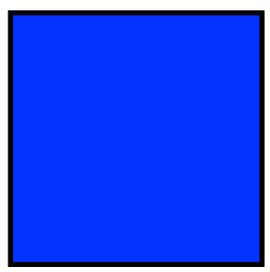

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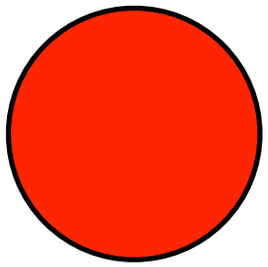

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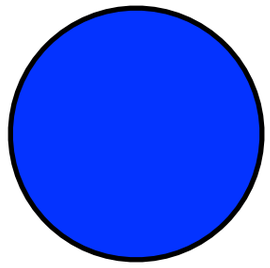

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    - the meanings had internal structure (e.g. color and shape),
    - and the signals had internal structure (e.g. subsequences of syllables)
    - and the mapping utilises the structure in a way that allows us to generalise

Compositionality

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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 (almost) unique to humans, despite being a hugely beneficial trait!

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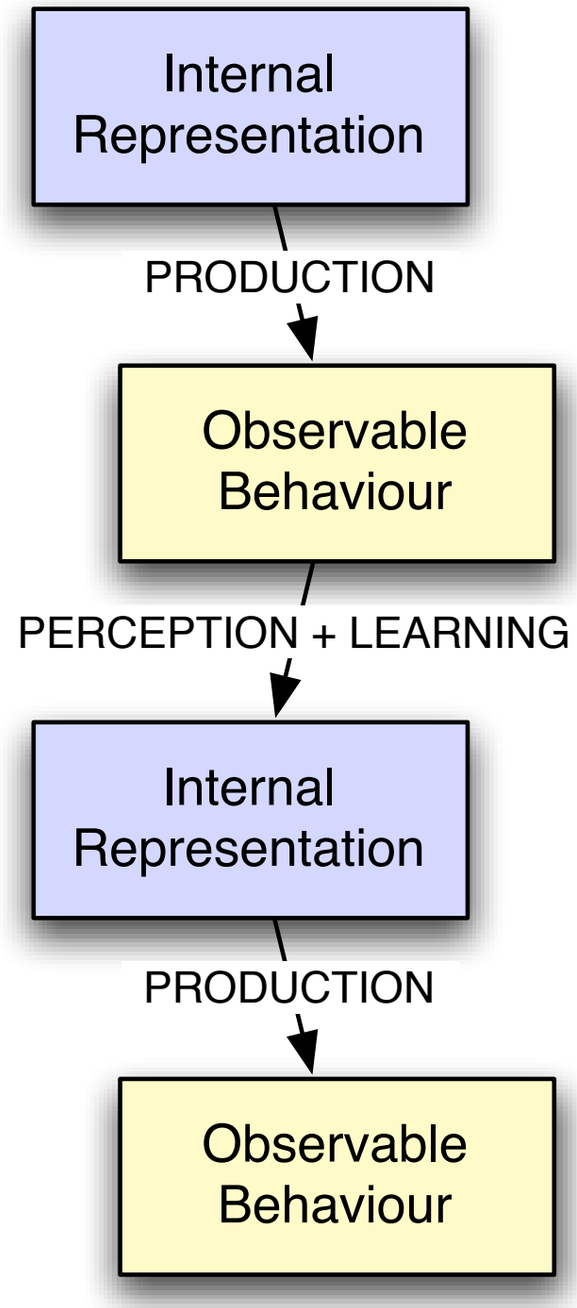
- But are there *alternative process*?

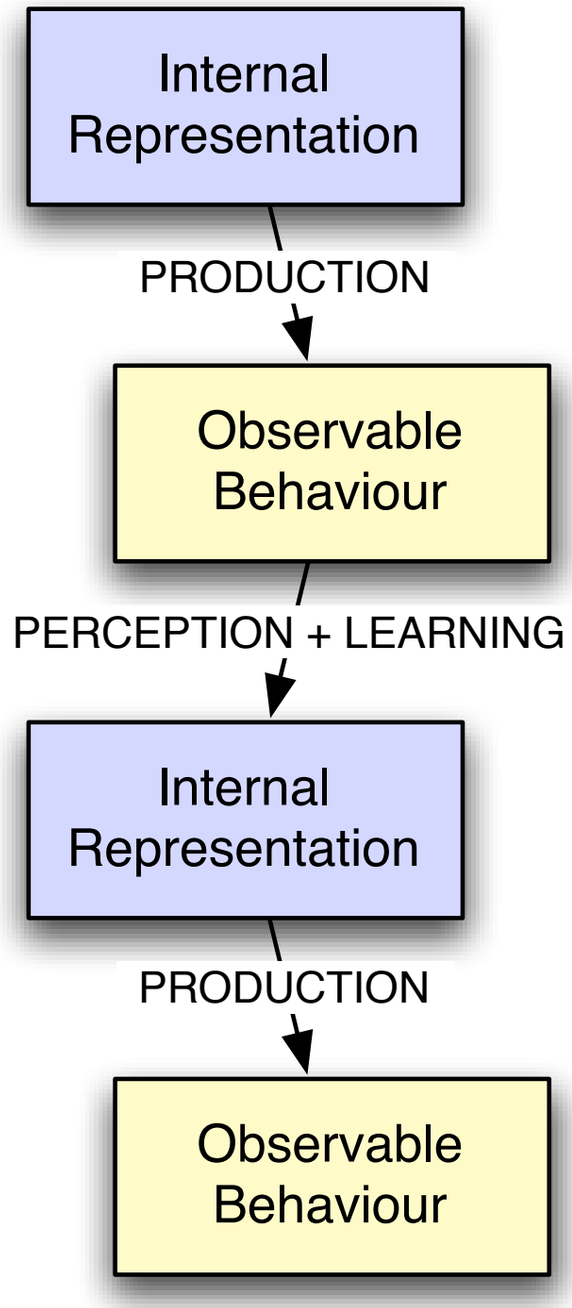
  And anyway, how exactly do properties of our innate endowment lead to observable properties of language (the adaptations they purport to explain)? This is **problem of linkage** again...

Iterated learning again



Iterated learning again

- To solve the problem of linkage, we need to turn again to the iterated learning model



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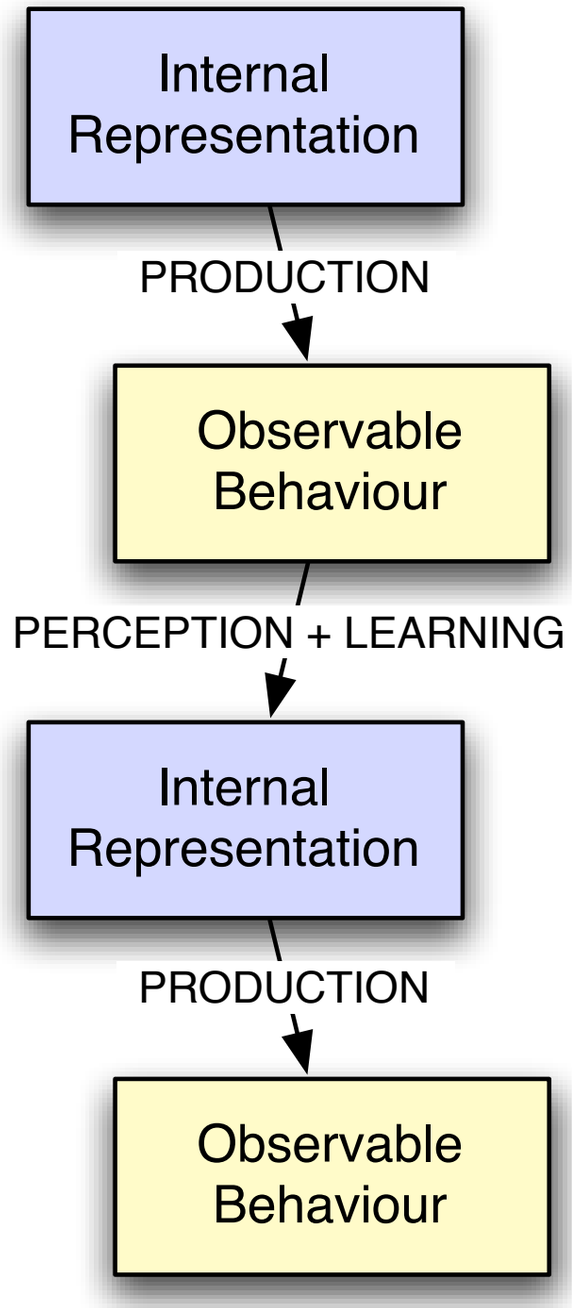
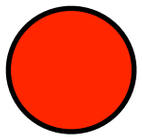
- What happens if, instead of mappings between atomic meanings and signals, we allowed for meanings and signals with structure?

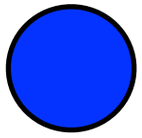
- Could we see a *cultural* rather than biological evolution of compositionality?



Holistic vs. Compositional

- It’s not the structure in meanings/signals that matters, but whether that structure is utilised by the mapping





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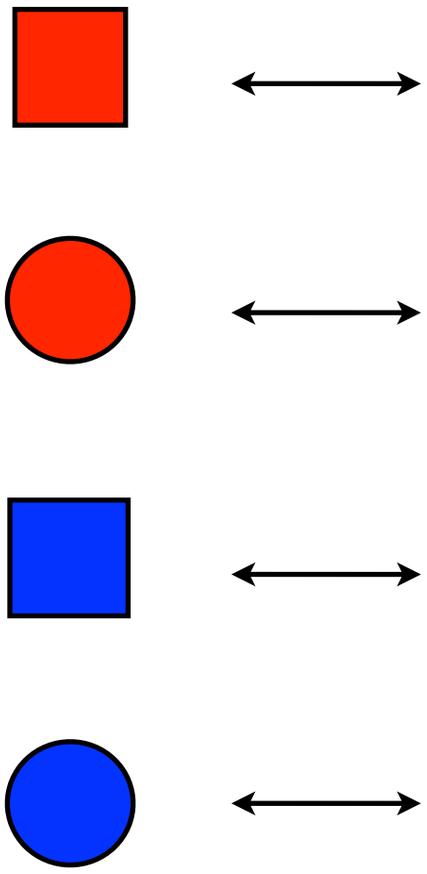

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This mapping between meanings and signals does not preserve structure from one domain to the other. We call this a **holistic** language, and it’s equivalent to what we’ve been looking at in the course so far. It’s basically just a vocabulary.

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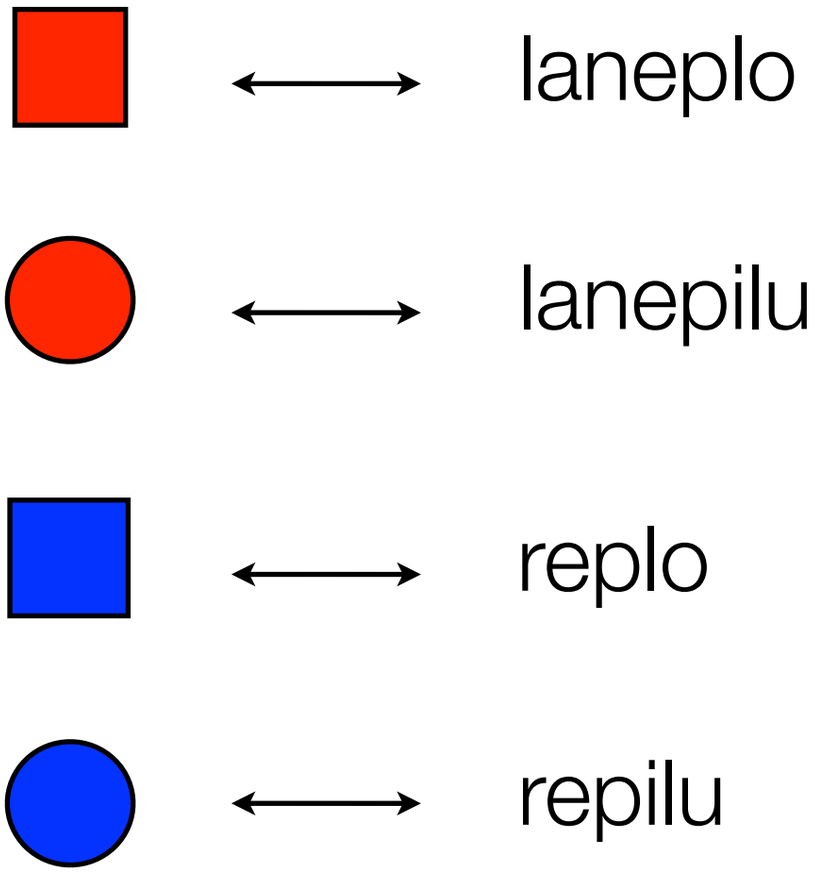

This mapping between meanings and signals *does* preserve structure from one domain to the other. We call this a **compositional** language. On a rudimentary level, it exhibits morphosyntactic properties. It enables generalisation to new meanings.

Simulating the transition to syntax

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  - but we don’t want to simply impose syntactic structure from the outset.

- We need a learner that is happy with either **holistic** or **compositional** languages

Example model (Kirby, 2002)

- Meanings are simple predicate logic expressions. e.g.:
  loves(mary, john)
  thinks(mary, likes(john, heather)

- There are 5 different individuals, 5 simple predicates, and 5 predicates of propositional attitude in the agents' world

- Signals are simply strings of random characters from the alphabet. e.g.:
  agjds
  gfhiyjilkq
  marylovesjohn

Learning

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- Fundamental principle: Learning is compression

  - Learners try and fit the data heard, but also generalise by compressing their grammar (cf. Occam's Razor)

  - Learning is a trade-off between fit to data and generalisation

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- Generalisation (whenever possible, within certain heuristic constraints)

S/**loves(peter, mary)** → peterlovesmary
S/**loves(john, mary)** → johnlovesmary

↯

S/**loves(*x*, mary)** → C/*x* lovesmary
C/**john** → john
C/**peter** → peter

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9. Repeat 2-8 thousands of times.

Results 1: initial stages

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- A *protolanguage* emerges for some meanings, but no structure. These are *holistic* expressions:

`ldg`	“Mary admires John”
`xkq`	“Mary loves John”
`gj`	“Mary admires Gavin”
`axk`	“John admires Gavin”
`gb`	“John knows that Mary knows that John admires Gavin”

Big complex grammar
but low expressivity

S/loves(john,mary) → sdx

S/admires(mary,gavin) → gj

S/admires(john,gavin) → axk

S/admires(gavin,heather) → nui

S/loves(john,heather) → my

S/loves(mary,john) → xkq

S/admires(mary,john) → ldg

S/thinks(john,loves(mary,gavin)) → fi

S/thinks(heather,loves(heather,gavin)) → ad

S/thinks(john,admires(heather,gavin)) → xuy

S/knows(gavin,loves(gavin,mary)) → k

S/knows(gavin,loves(john,mary)) → ysw

S/thinks(mary,knows(gavin,loves(heather,john))) → pq

S/thinks(mary,knows(heather,loves(heather,john))) → rr

S/knows(john,knows(mary,admires(mary,john))) → lr

... (plus another 101 rules)

Results 2: many generations later...

gjhftejm	“Mary admires John”
gjhftejwp	“Mary loves John”
gjqpftejm	“Mary admires Gavin”
gjqpfhm	“John admires Gavin”
ihuitejugjqpfhm	“John knows that Mary knows that John admires Gavin”

Results 2: many generations later...

gj h f tej m
John Mary admires
“Mary admires John”

gj h f tej wp
John Mary loves
“Mary loves John”

gj qp f tej m
Gavin Mary admires
“Mary admires Gavin”

gj qp f h m
Gavin John admires
“John admires Gavin”

i h u i tej u gj qp f h m
John knows Mary knows Gavin John admires
“John knows that Mary knows that John admires Gavin”

$$S/p(x,y) \rightarrow \texttt{gj}\ A/y\ \texttt{f}\ A/x\ \ B/p$$
$$S/p(x,q) \rightarrow \texttt{i}\ A/x\ \ D/p\ \ S/q$$
$$A/\text{heather} \rightarrow \texttt{dl}$$
$$A/\text{mary} \rightarrow \texttt{tej}$$
$$A/\text{pete} \rightarrow \texttt{n}$$
$$A/\text{gavin} \rightarrow \texttt{qp}$$
$$A/\text{john} \rightarrow \texttt{h}$$
$$B/\text{detests} \rightarrow \texttt{b}$$
$$B/\text{loves} \rightarrow \texttt{wp}$$
$$B/\text{hates} \rightarrow \texttt{c}$$
$$B/\text{likes} \rightarrow \texttt{e}$$
$$B/\text{admires} \rightarrow \texttt{m}$$
$$D/\text{believes} \rightarrow \texttt{g}$$
$$D/\text{knows} \rightarrow \texttt{u}$$
$$D/\text{decides} \rightarrow \texttt{ipr}$$
$$D/\text{says} \rightarrow \texttt{p}$$
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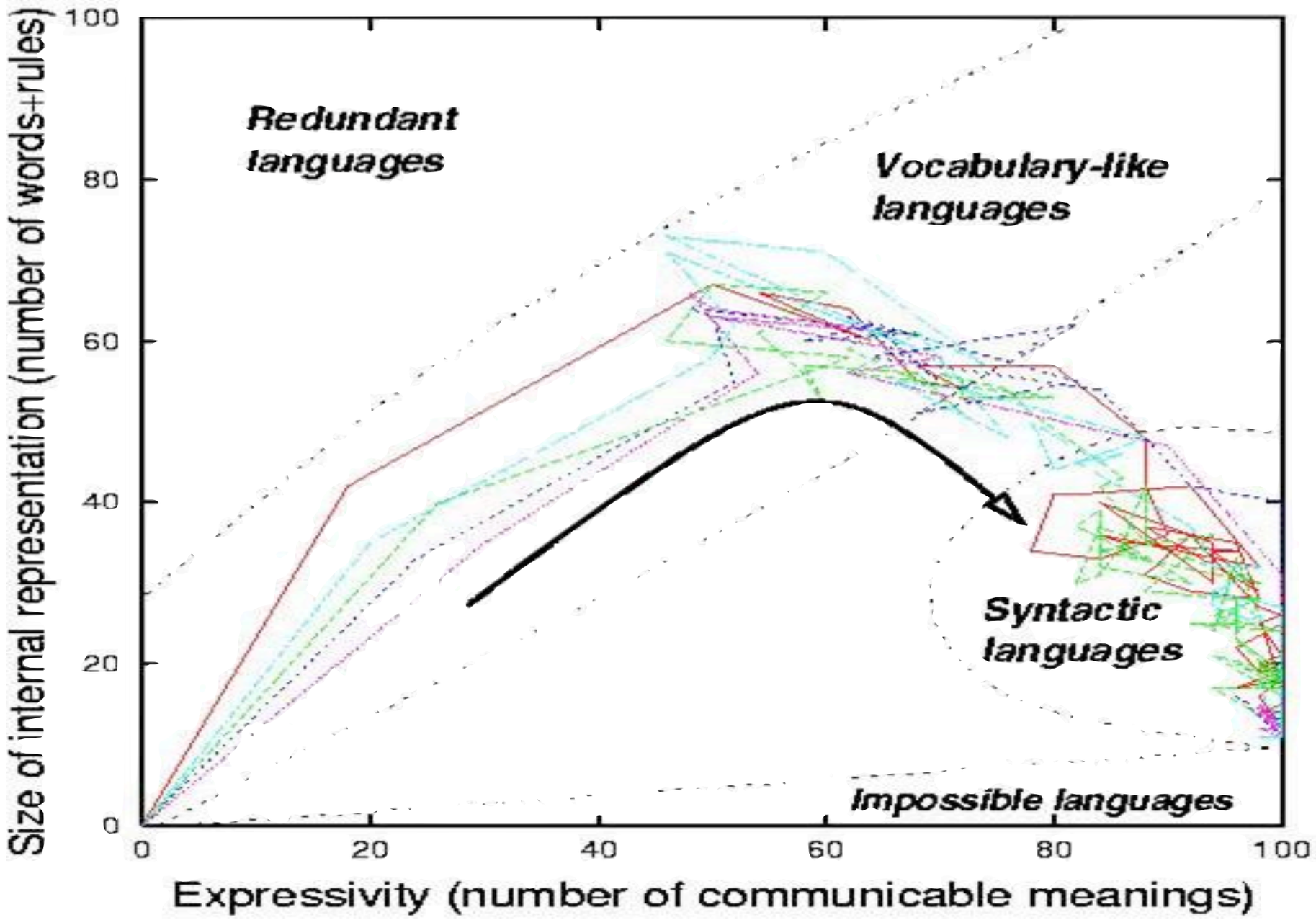
Small, simple grammar
infinite expressivity

Quantitative results: languages evolve



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Languages themselves are evolving to the conditions of the iterated learning process in order that they are learnable.

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- So, why are structured languages evolving?
- The "language-as-organism" hypothesis:

  Languages themselves are evolving to the conditions of the iterated learning process in order that they are learnable.

- The agents never see all the meanings…
- Only languages that are *generalisable* from limited exposure are stable.

Language has to fit through a narrow *bottleneck*

Linguistic competence

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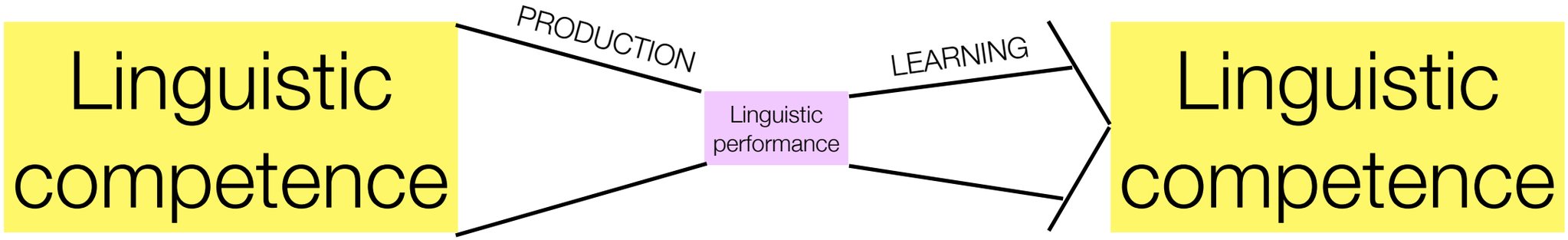

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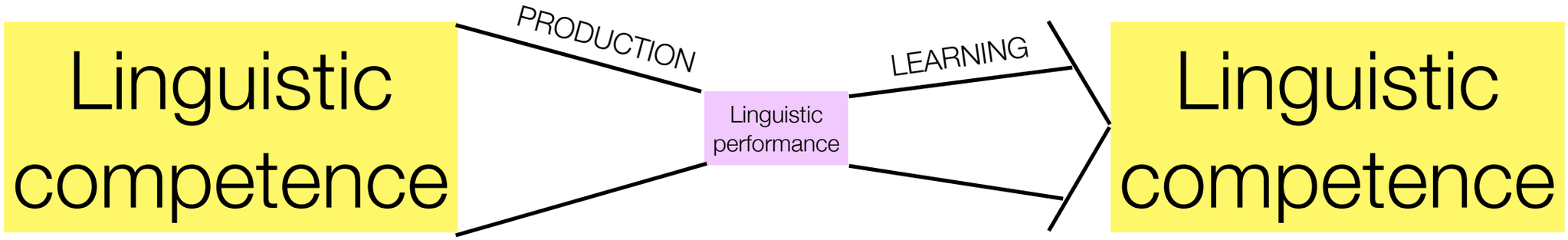

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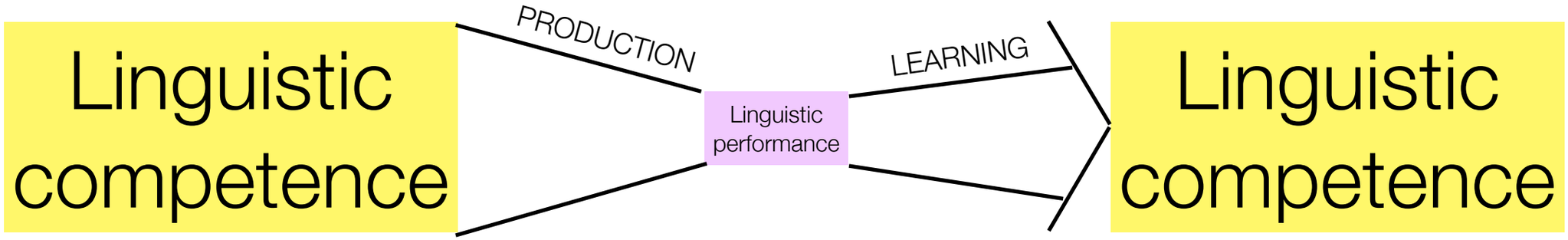

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- Language becomes generalisable from a limited subset of utterances:
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  - *Generalisable* equates to *compositional* in this case
- Syntax is an adaptive response **by language** (arising from cultural evolution) to the problem of getting through this bottleneck

From simulations to experiments

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- Since running these simulations (and many more like them) there have been criticisms that this process is implausible

- Is it really likely that random mistakes could lead us from a holistic protolanguage to a compositional syntax? Do these learning algorithms really reflect the human language learning biases?

From simulations to experiments

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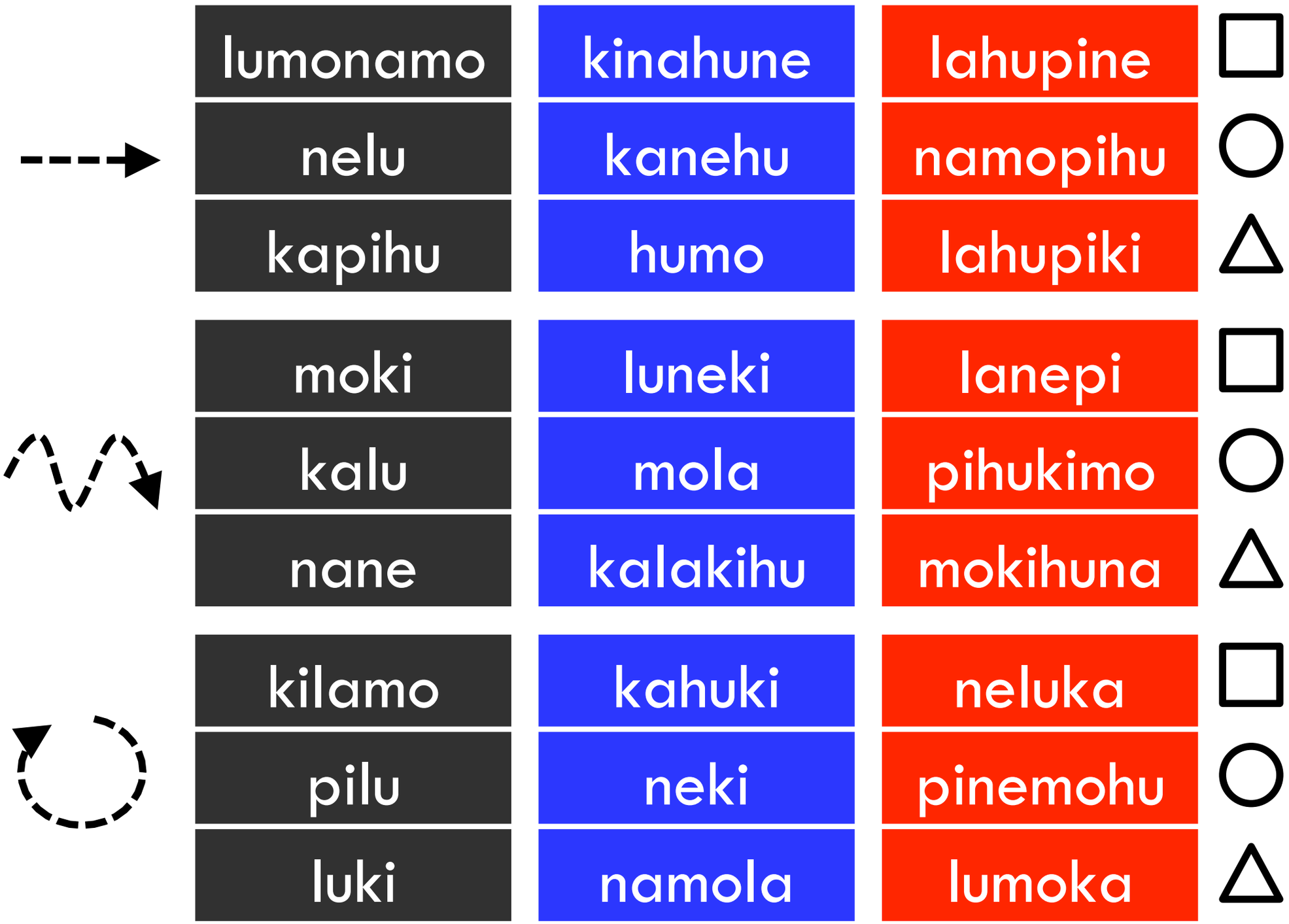
- Is it really likely that random mistakes could lead us from a holistic protolanguage to a compositional syntax? Do these learning algorithms really reflect the human language learning biases?

- Kirby, Cornish & Smith (2008) replicate the simulations using real human subjects to test this.

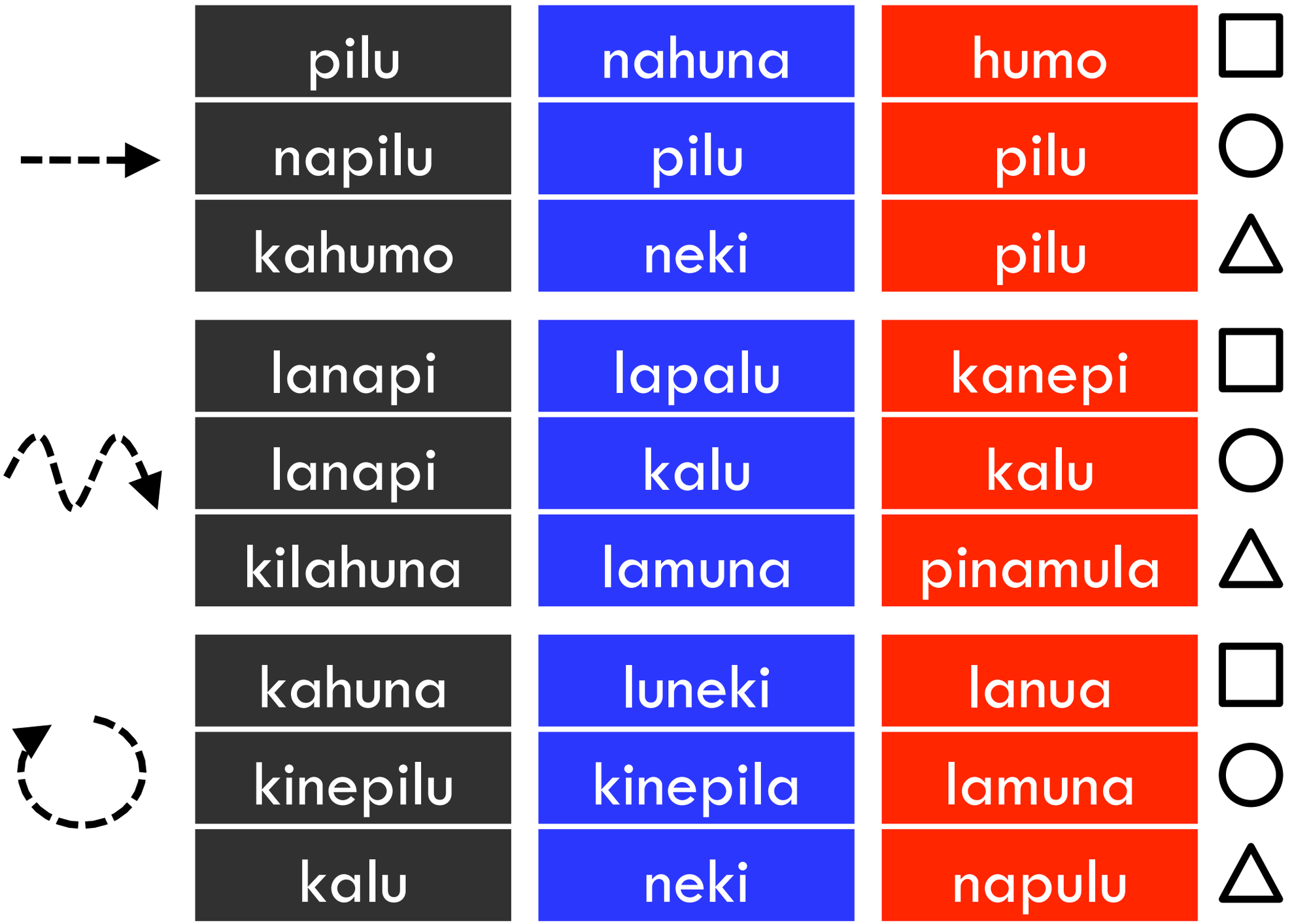
- Participants learn an initially random artificial “alien” language by seeing part of that language and then are tested on meanings from the whole language.

- Each participant’s output at testing is used to train the next participant

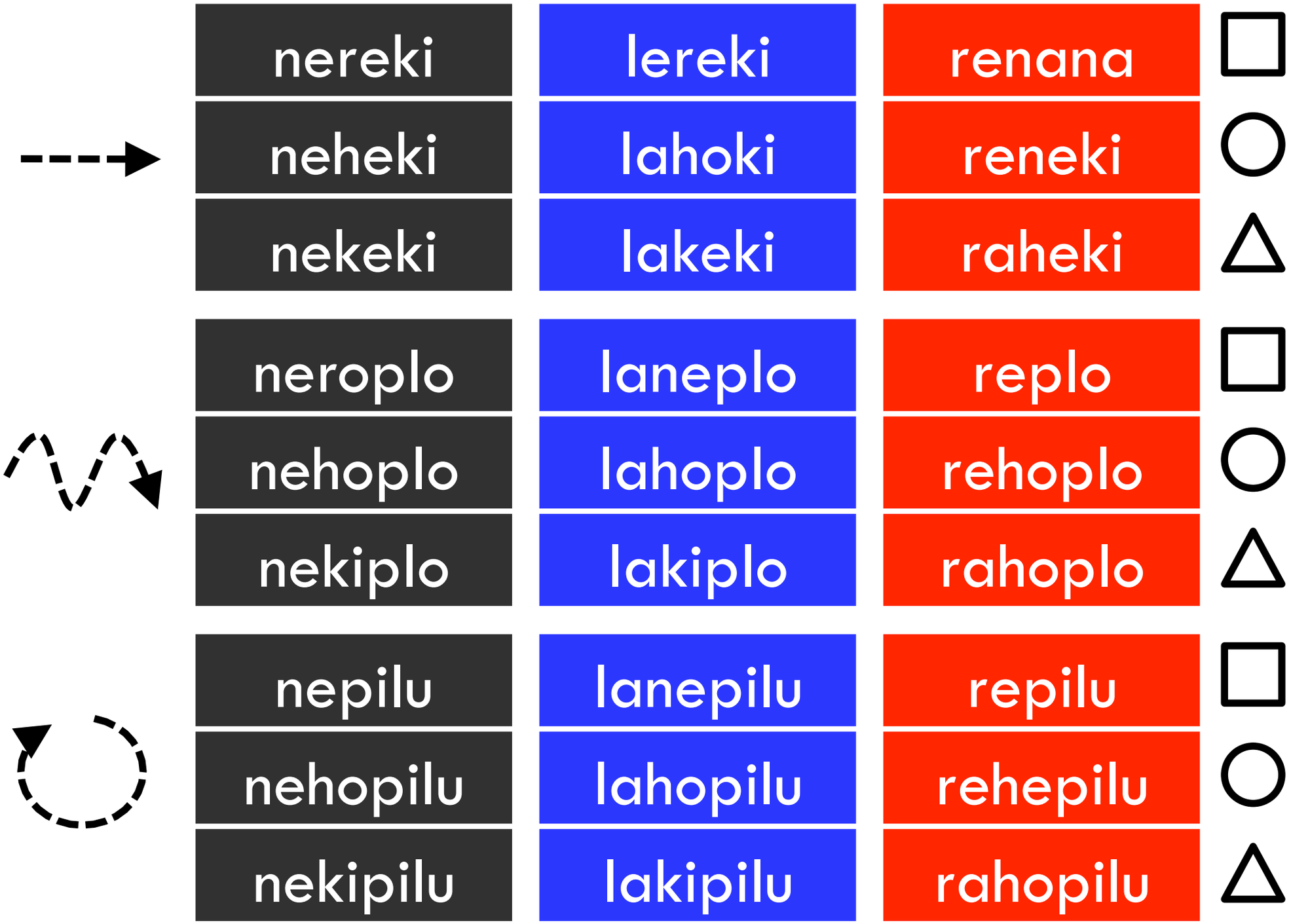
Generation: 0



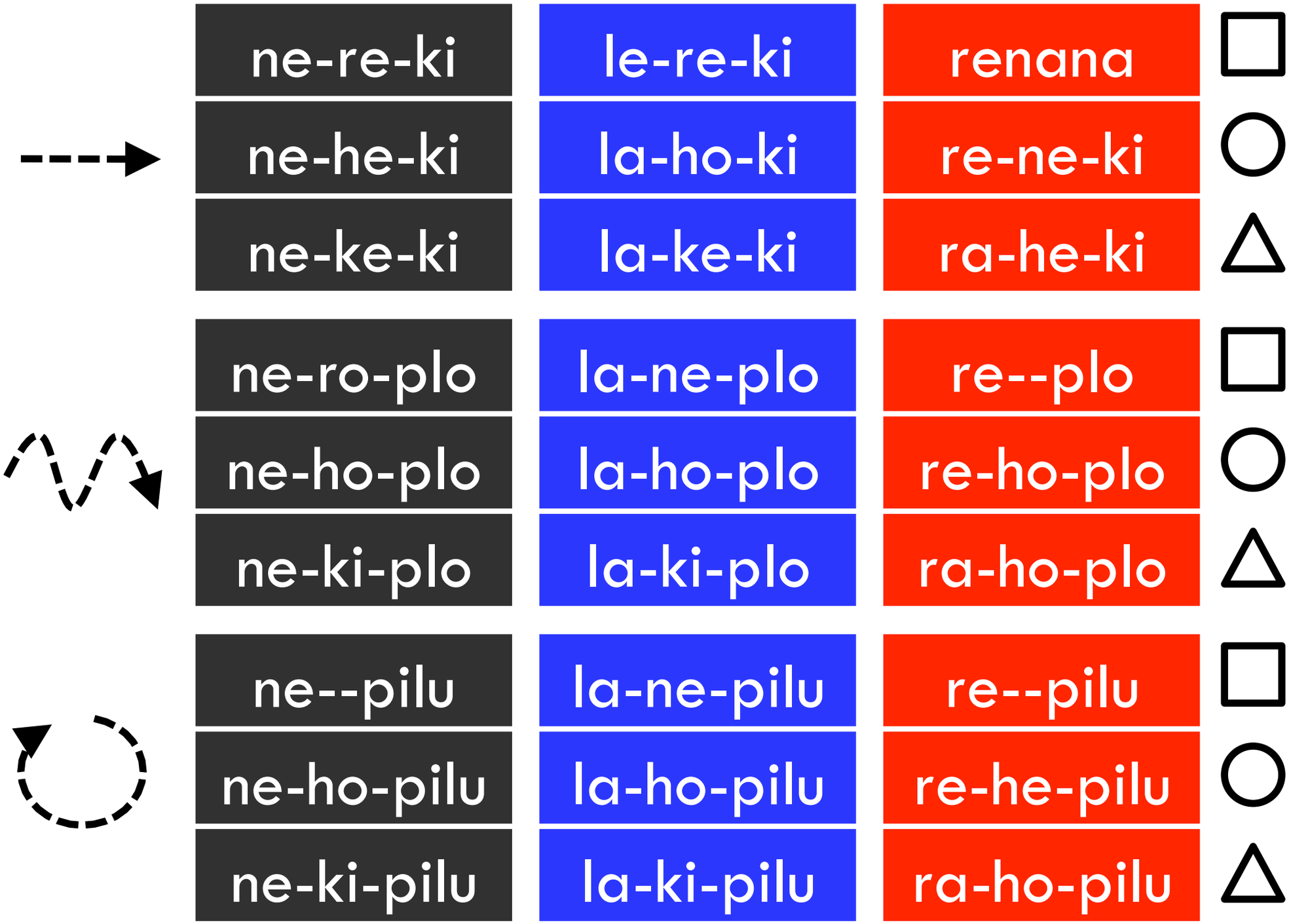
Generation: 1



Generation: 9



Generation: 9



Readings for this lecture

- Kirby, S. & Hurford, J. (2002) The emergence of linguistic structure: An overview of the iterated learning model. In Cangelosi, A. and Parisi, D., editors, *Simulating the Evolution of Language*, chapter 6, pages 121-148. Springer Verlag, London.

- Kirby, S., Cornish, H., and Smith, K. (2008). Cumulative Cultural Evolution in the Laboratory: an experimental approach to the origins of structure in human language. *Proceedings of the National Academy of Sciences*, 105(31): 10681-10686.