Iterated learning in an open-ended meaning space

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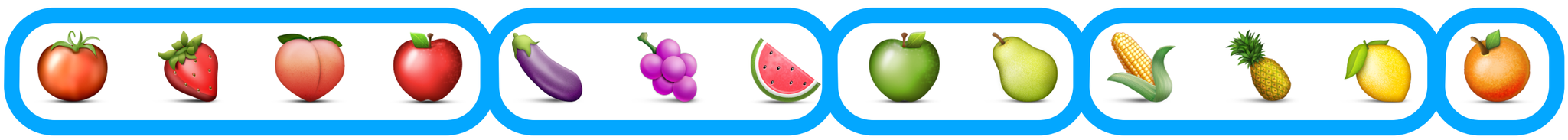
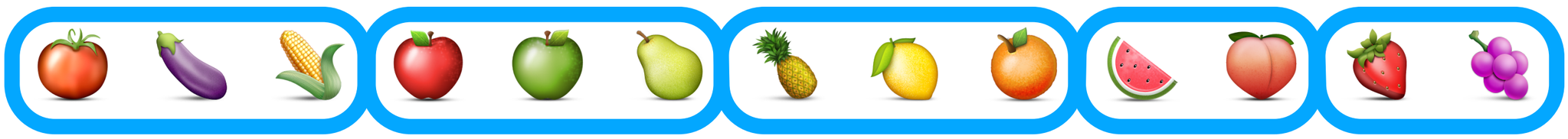
Categorical structure





Compositional structure

Meaning of the whole = Meaning of the parts + The way in which the parts are combined

	Blue	Green
🍎	1	2
🍌	3	4

Compositional structure

Meaning of the whole = Meaning of the parts + The way in which the parts are combined

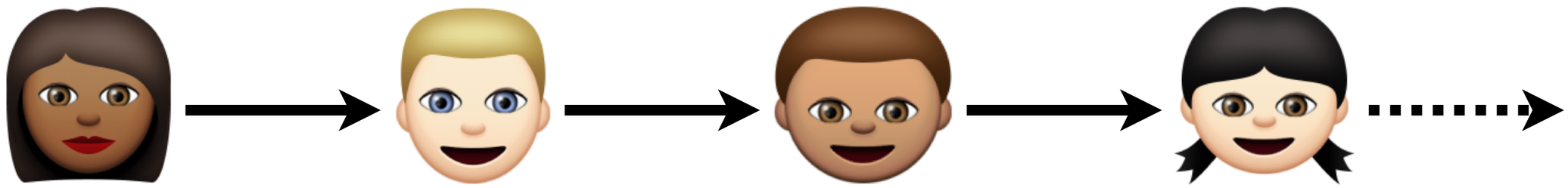
	Blue	Green
	poi	gugi
	meshin	tikolu

Compositional structure

Meaning of the whole = Meaning of the parts + The way in which the parts are combined

	Blue	Green
🍎	blueapple	greenapple
🍌	bluebanana	greenbanana

Iterated learning

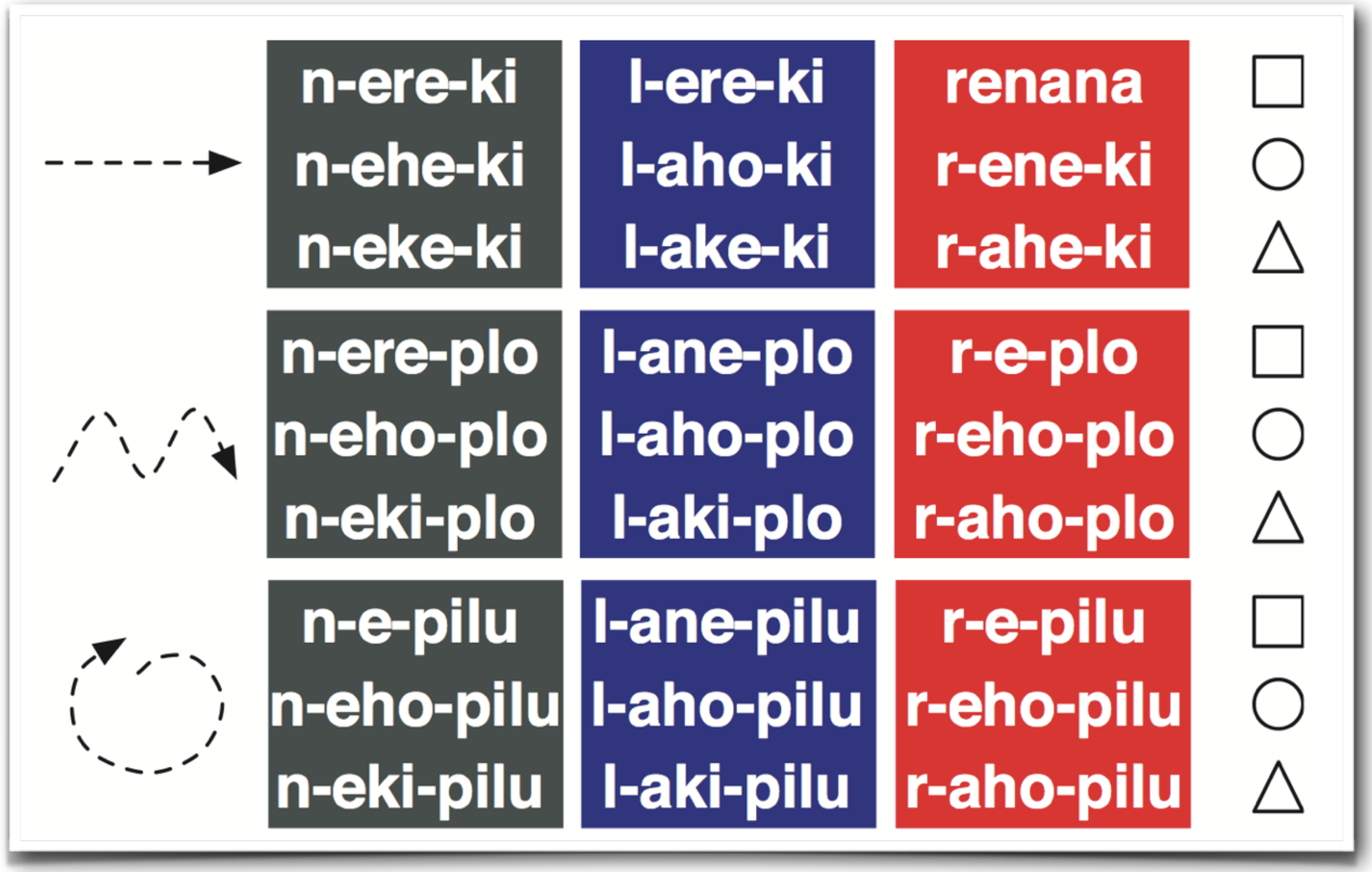


Languages get more learnable as they adapt to this process of iteration

Languages get more systematic in terms of:

- categorical structure in the meaning space
- compositional structure in the signal space

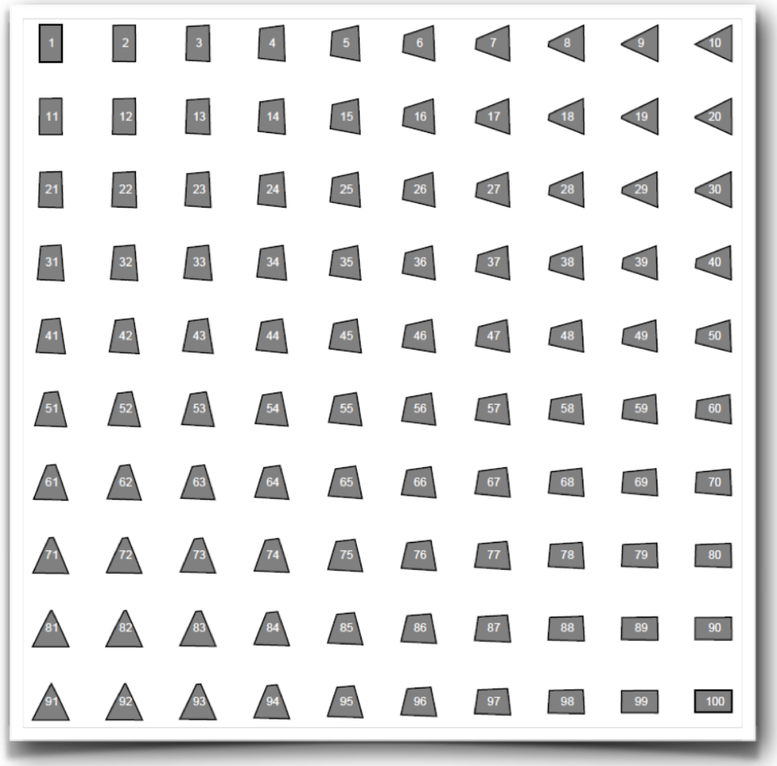
Discrete meaning spaces



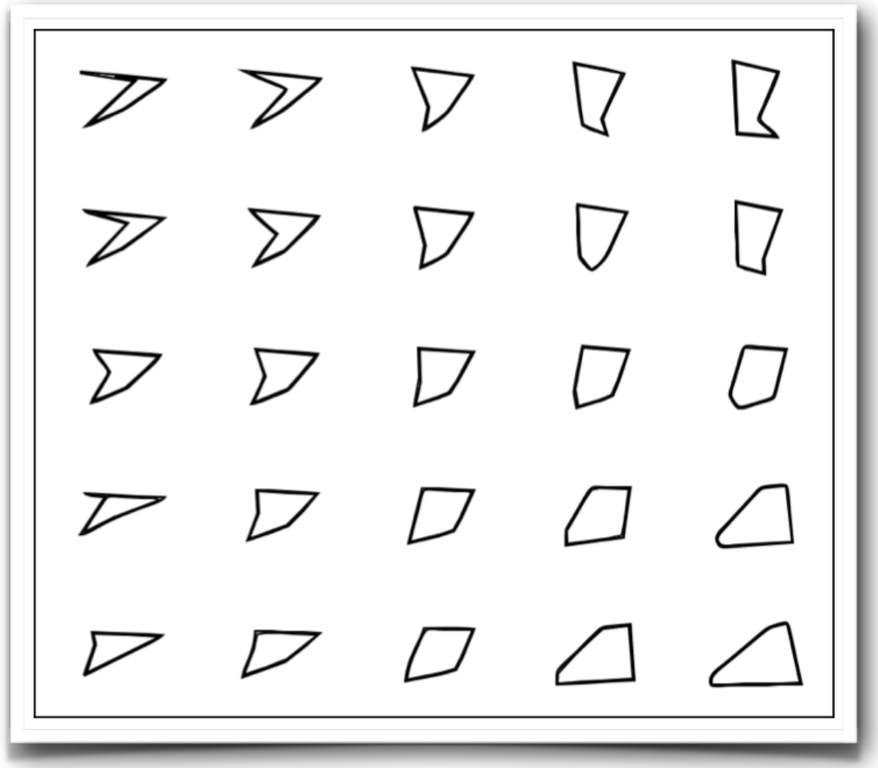
Kirby, Cornish, & Smith (2008)

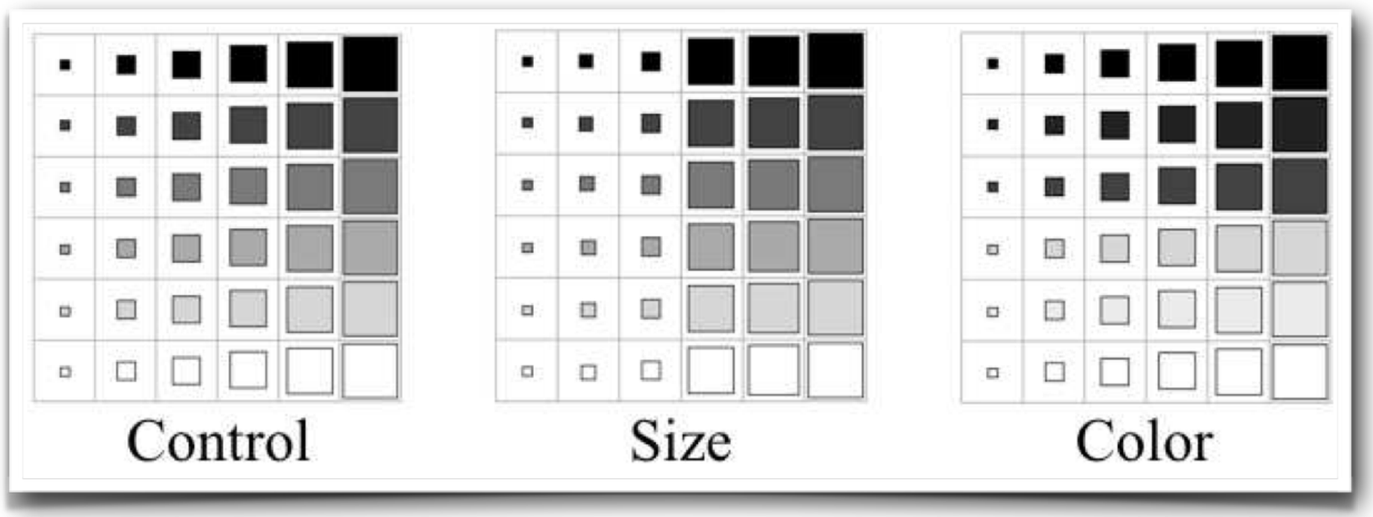
Continuous meaning spaces

Matthews (2009)



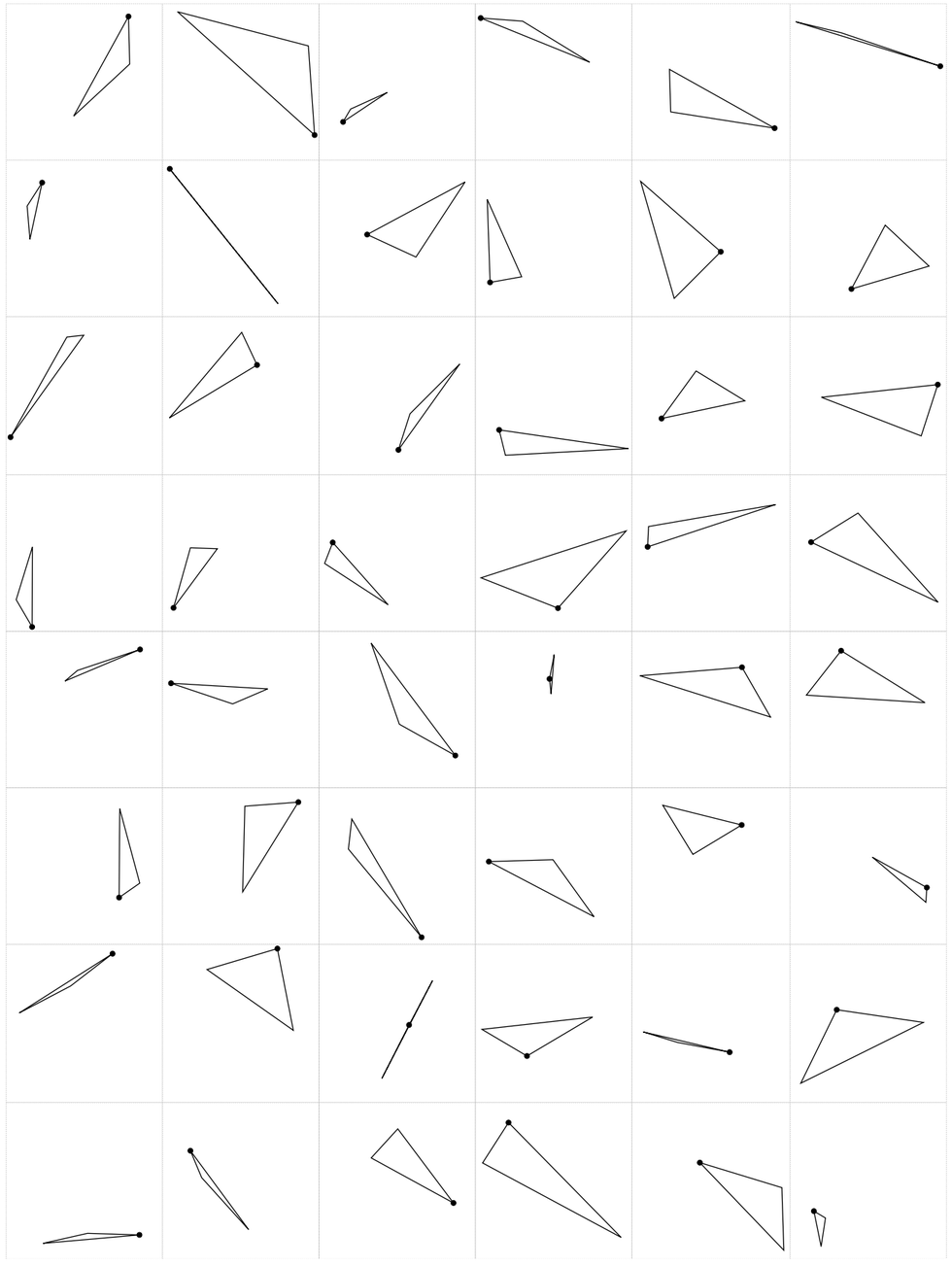
Silvey, Kirby, & Smith (2013)





Perfors & Navarro (2014)

An open-ended meaning space



Complex dimensions: Many possible dimensions to the space

Continuous: On each dimension, the triangle stimuli vary over a continuous scale

Vast in magnitude: 6×10^{15} possible triangle stimuli

Not pre-specified by the experimenter: no particular hypothesis about which features participants would find salient

Hypotheses

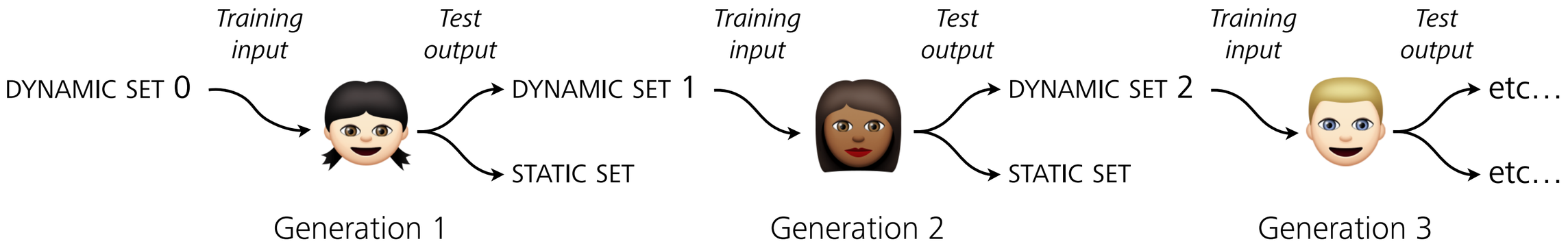
Hypothesis 1: the languages will become easier to learn

Hypothesis 2: categorical structure will emerge in the meaning space

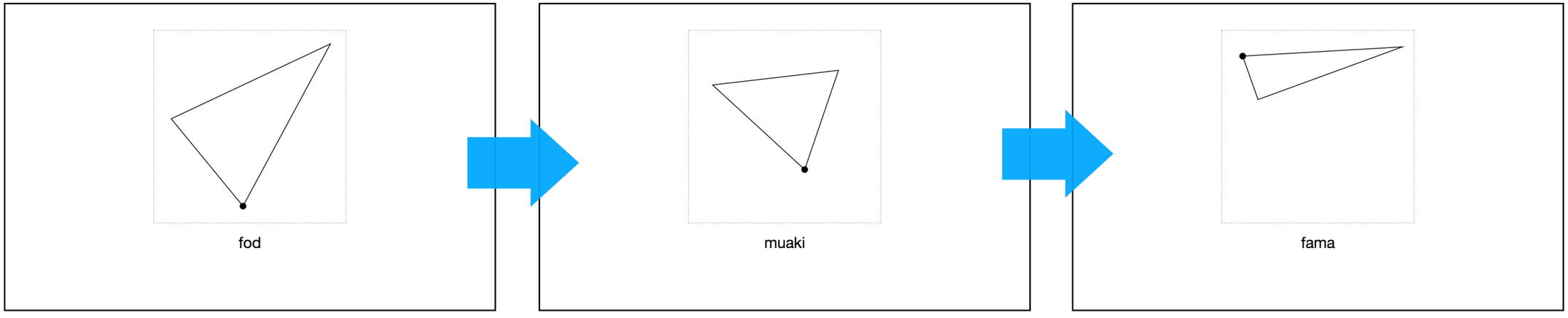
Hypothesis 3: compositional structure will emerge in the signal space

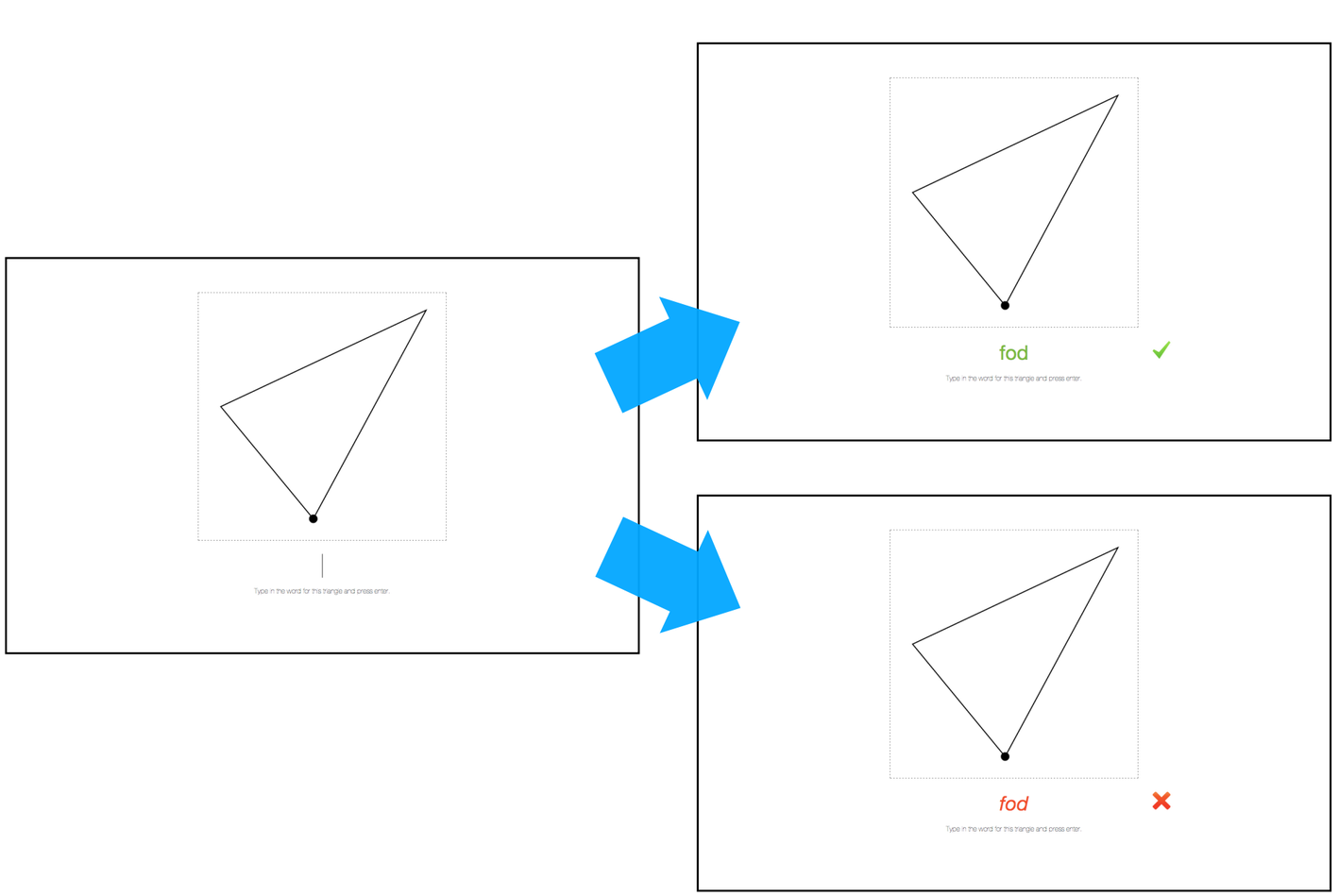
Experiment I

Transmission paradigm



Training phase

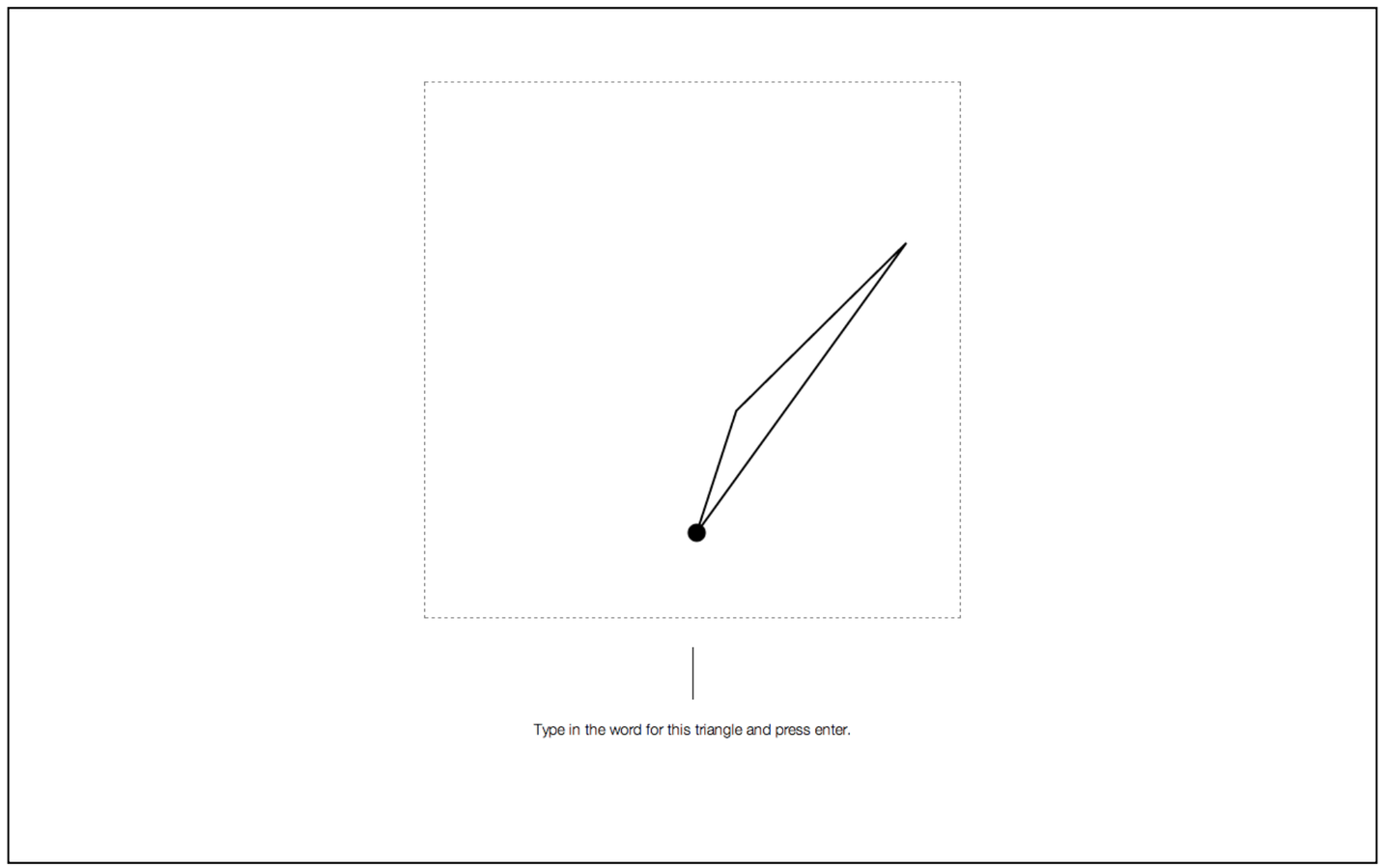




× 48

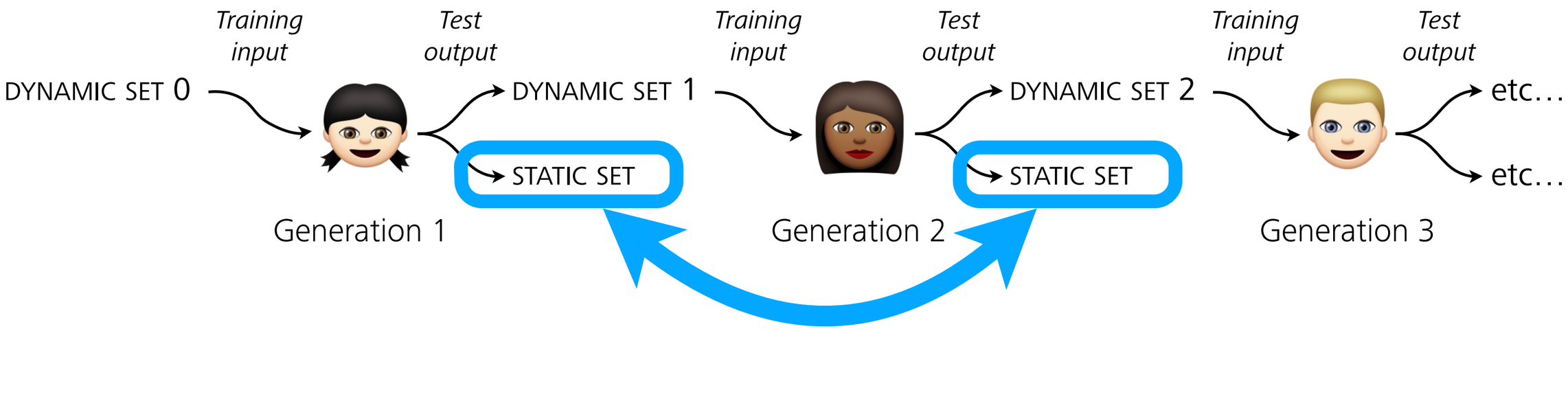
- each item mini-tested once
- each item presented three times
- 144 total presentations

Test phase



× 96

Measure of learnability



Transmission error is the mean normalized Levenshtein distance:

$$e(i) = \frac{1}{|M|} \sum_{m \in M} \frac{\mathrm{LD}(s_i^m, s_{i-1}^m)}{\max(\mathrm{len}(s_i^m), \mathrm{len}(s_{i-1}^m))}$$

Learnability is transmission error adjusted for chance using a Monte Carlo method

Measure of structure

The languages are essentially mappings between signals and meanings

To measure structure, we correlate the dissimilarity between pairs of strings with the dissimilarity between pairs of triangles for all $n(n-1)/2$ pairs

We then perform a Mantel test (Mantel, 1967) which compares this correlation against a distribution of correlations for Monte-Carlo permutations of the signal-meaning pairs

This yields a standard score (z-score) quantifying the significance of the observed correlation

Normalized Levenshtein distance used to measure the dissimilarity between pairs of strings

Triangle dissimilarity metric

Size features

Area

Perimeter

Centroid size

Positional features

Location of dot on *x*-axis

Location of dot on *y*-axis

Location of centroid on *x*-axis

Location of centroid on *y*-axis

Orientational features

Radial distance from North by dot

Radial distance from North by thinnest angle

Shape feattures

Angle of thinnest vertex

Angle of widest vertex

Standard deviation of angles

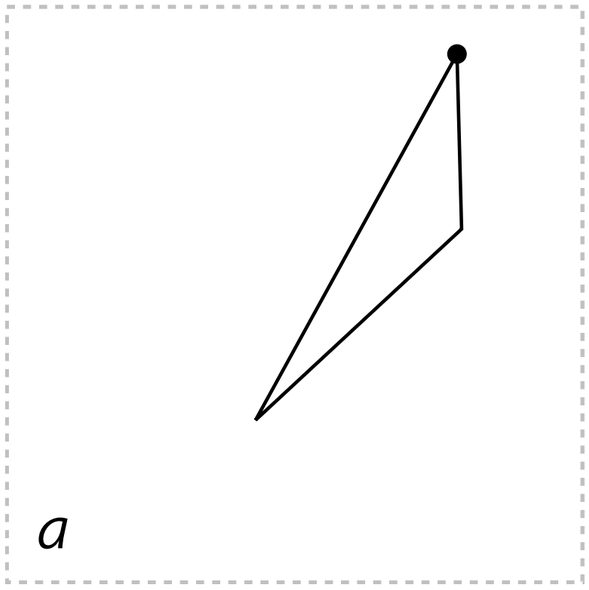
Bounding box features

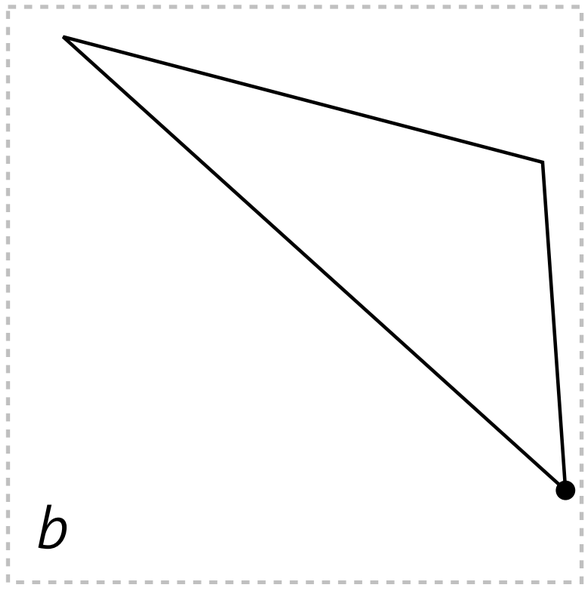
Distance from dot to nearest corner

Distance from dot to nearest edge

Mean distance from vertices to nearest

Mean distance from vertices to nearest edge

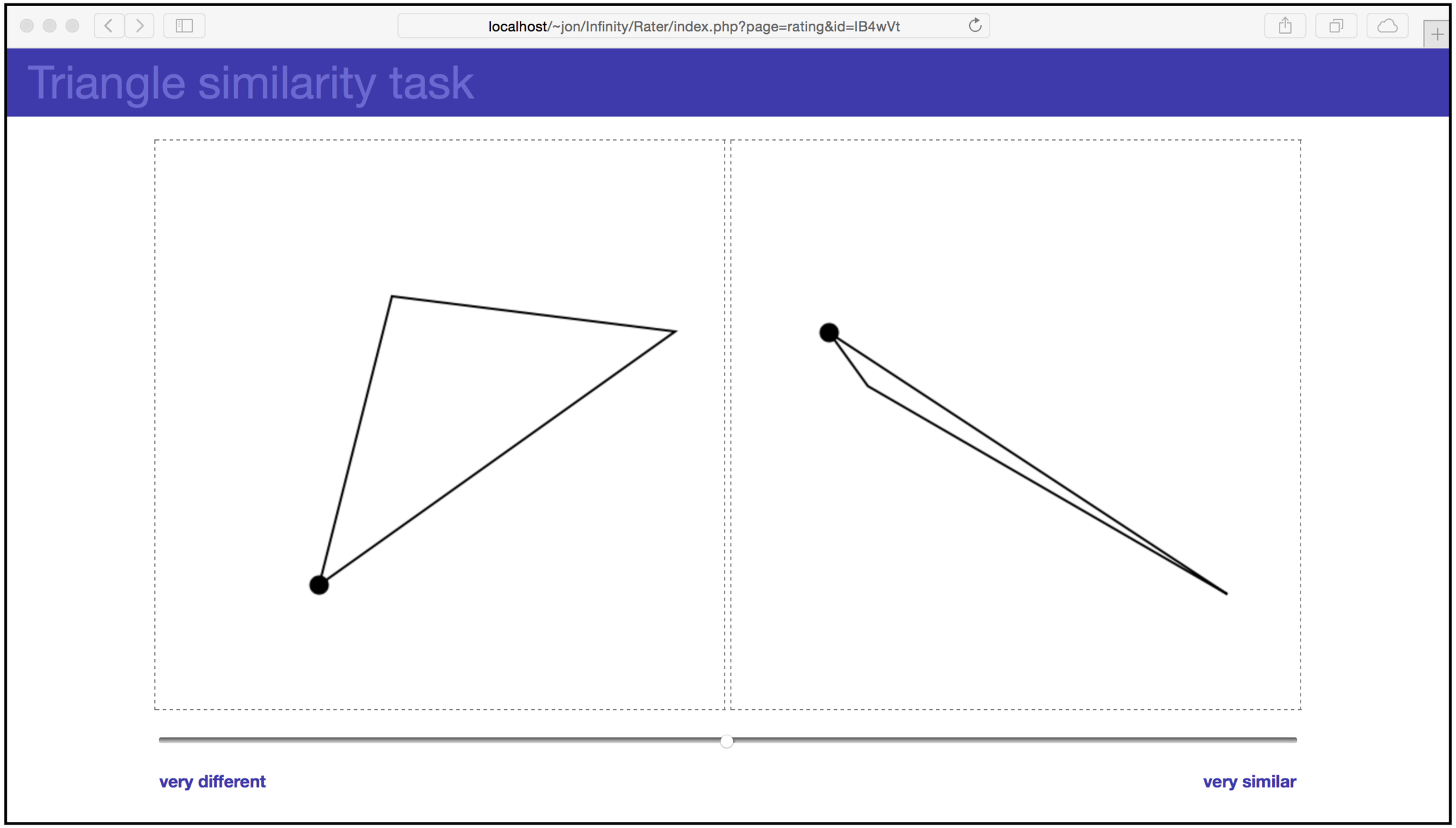




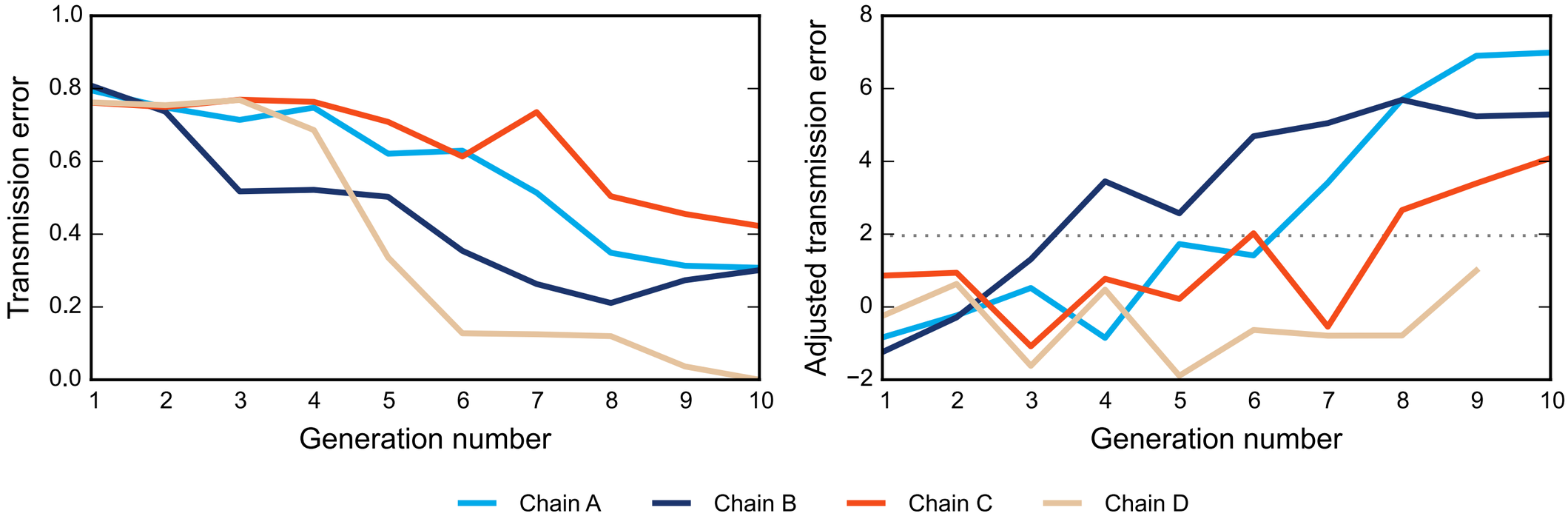
Euclidean distance through the feature space:

$$d(a,b) = \sqrt{\sum_{f \in F} (a_f - b_f)^2}$$

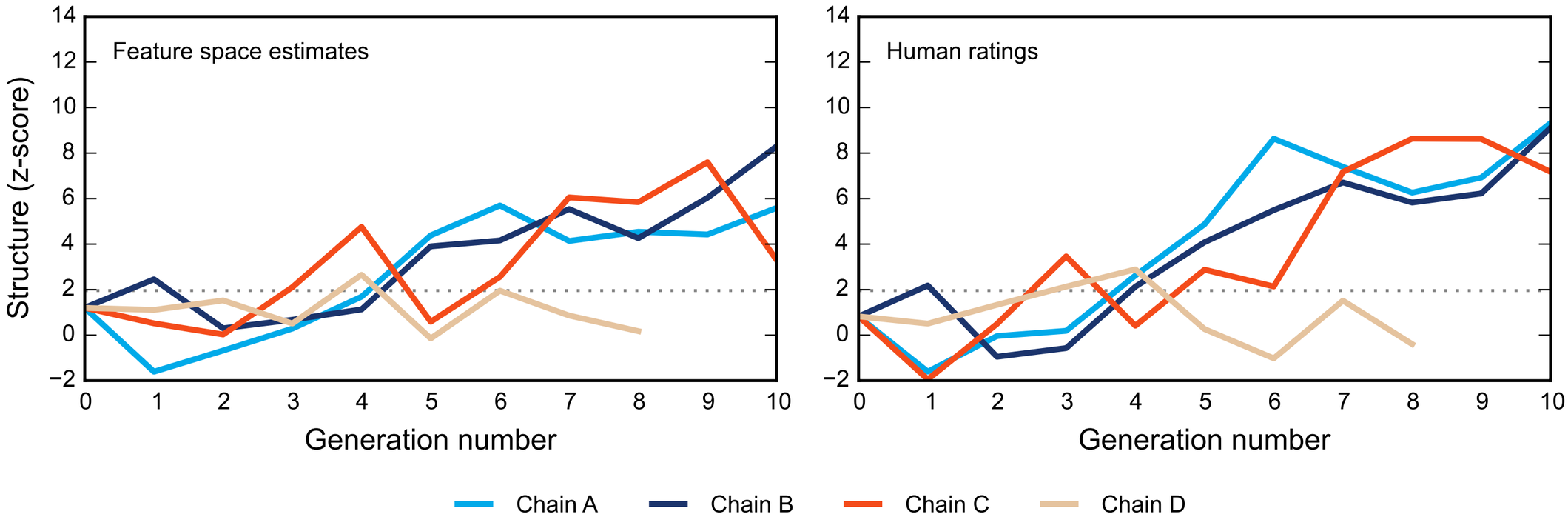
Online dissimilarity experiment



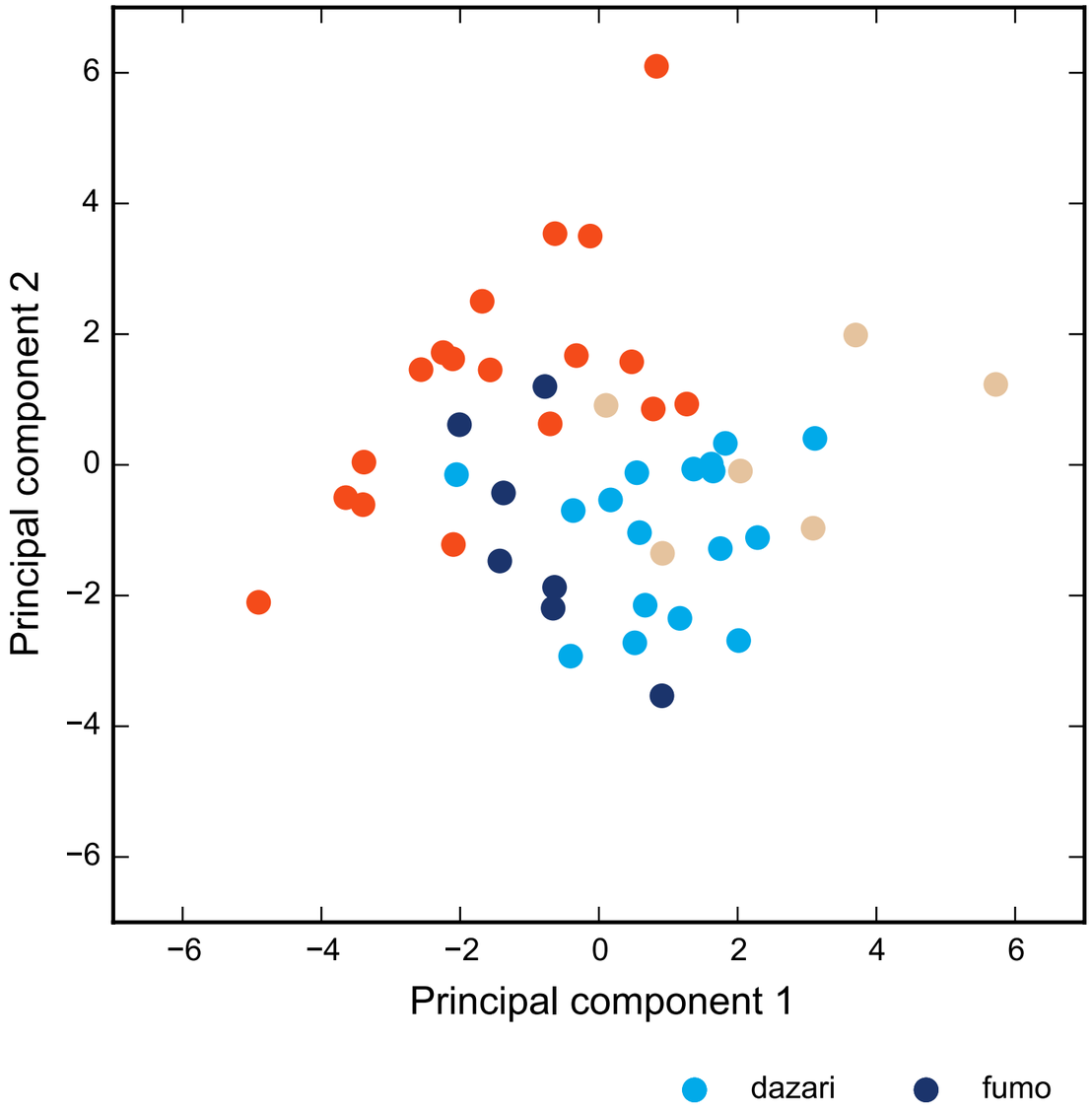
Increase in learnability

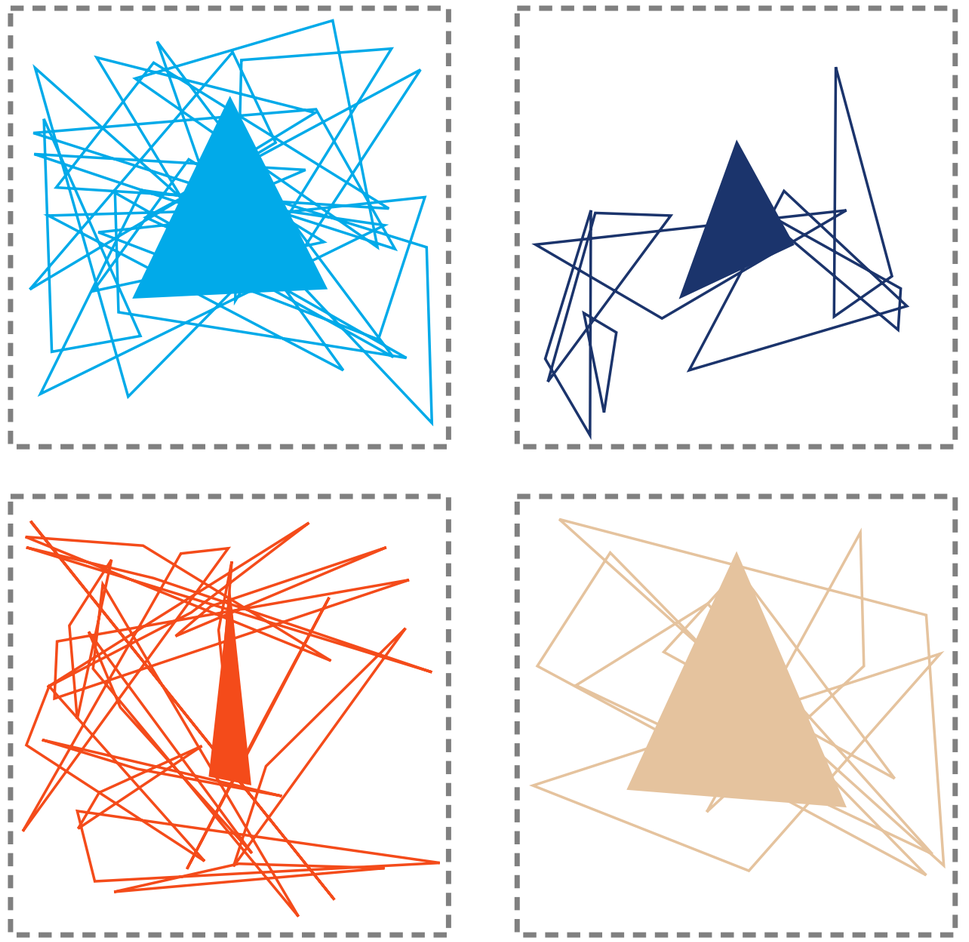


Emergence of structure

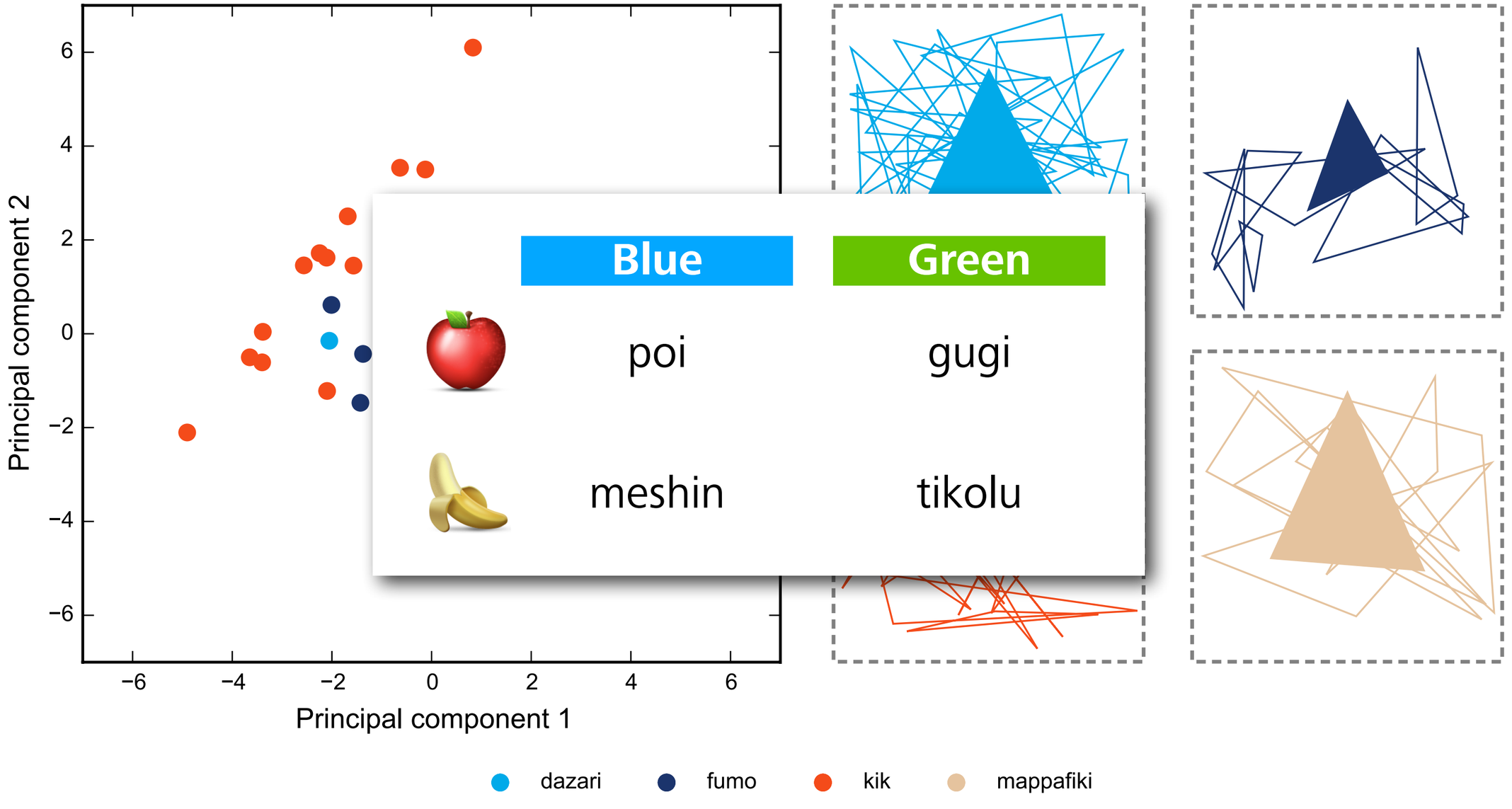


Categorical structure



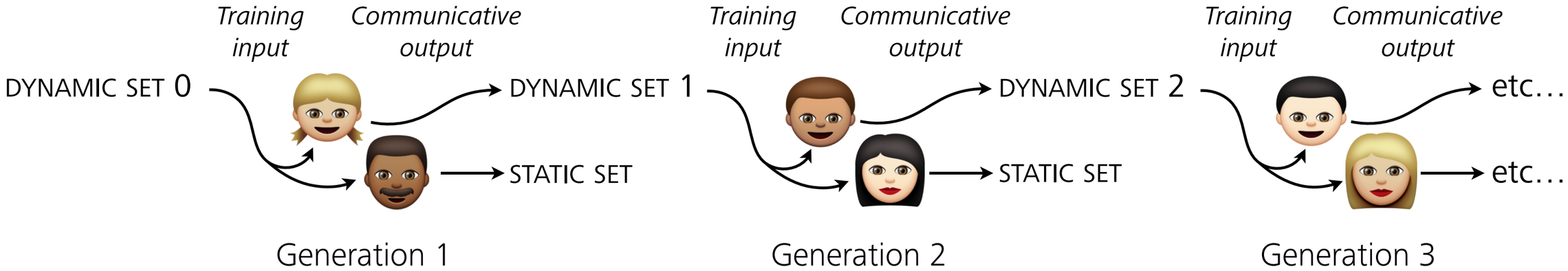


Categorical structure



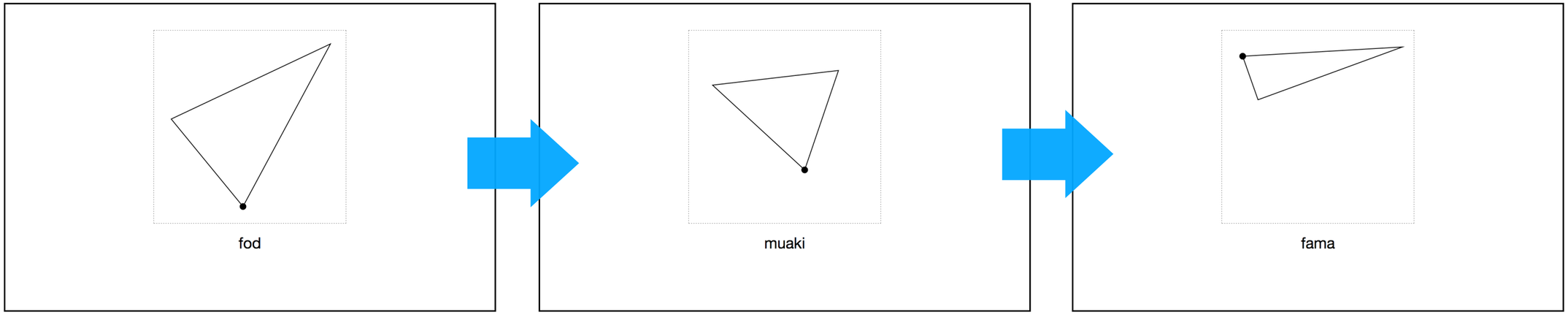
Experiment 2

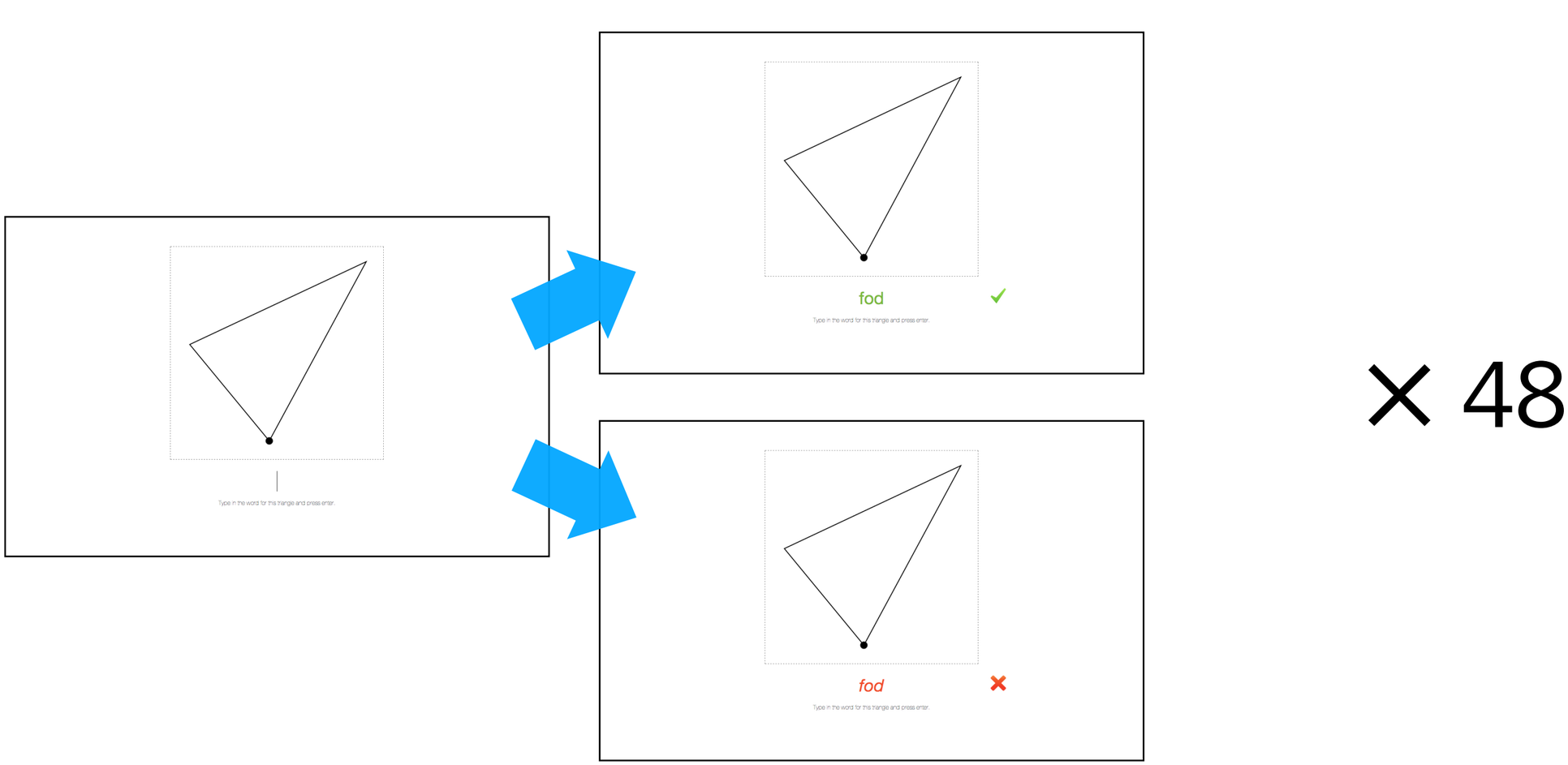
Transmission paradigm



Generation 1 Generation 2 Generation 3

Training phase





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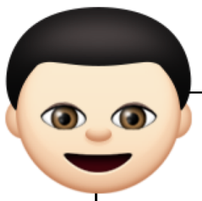
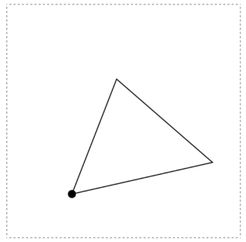
Communication phase

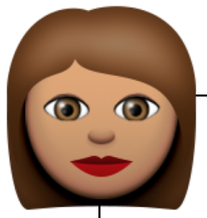




muaki

Type in the word for this triangle and press Enter

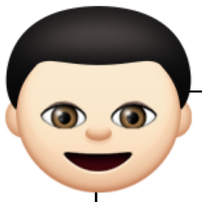
★ 0

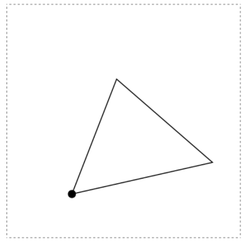


Waiting for your partner...

★ 0

Communication phase

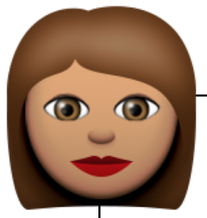


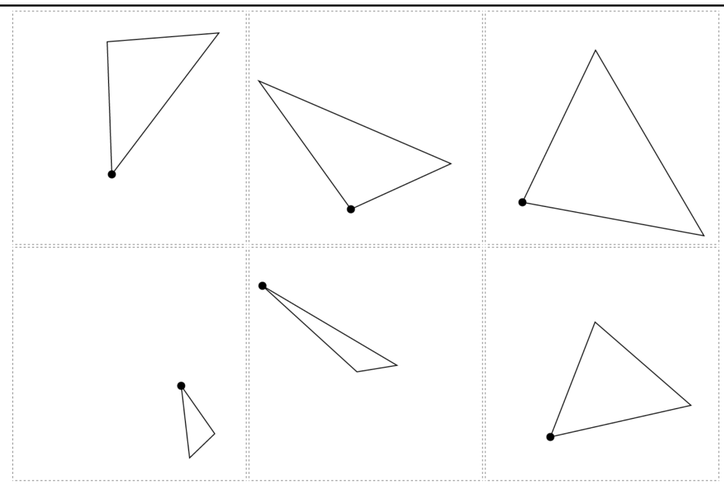


You called it: ***muaki***

Waiting for your partner's response...

★ 0



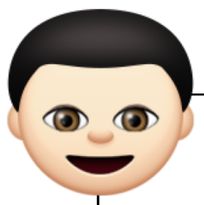


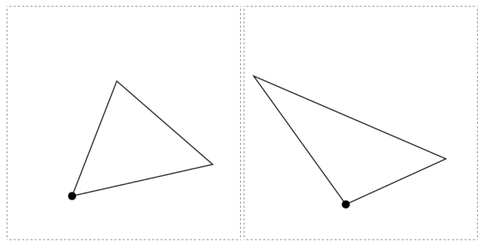
muaki

Which triangle is your partner seeing?

★ 0

Communication phase



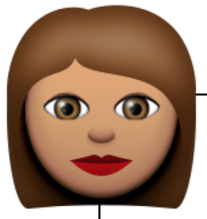


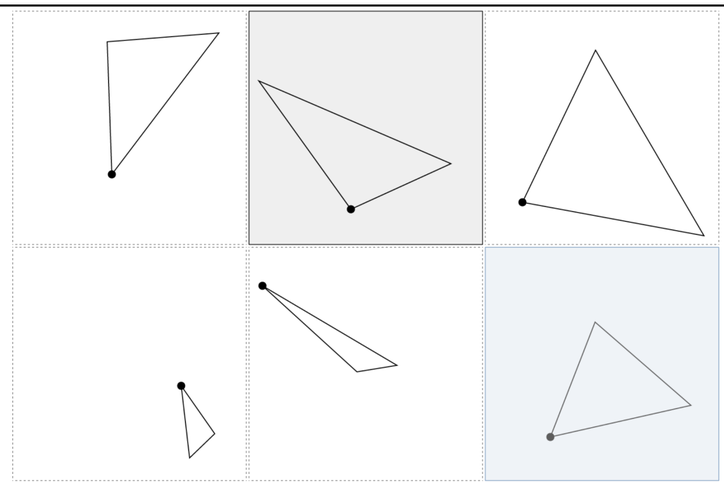
You called it: ***muaki***

Your partner selected

Please wait...

★ 0





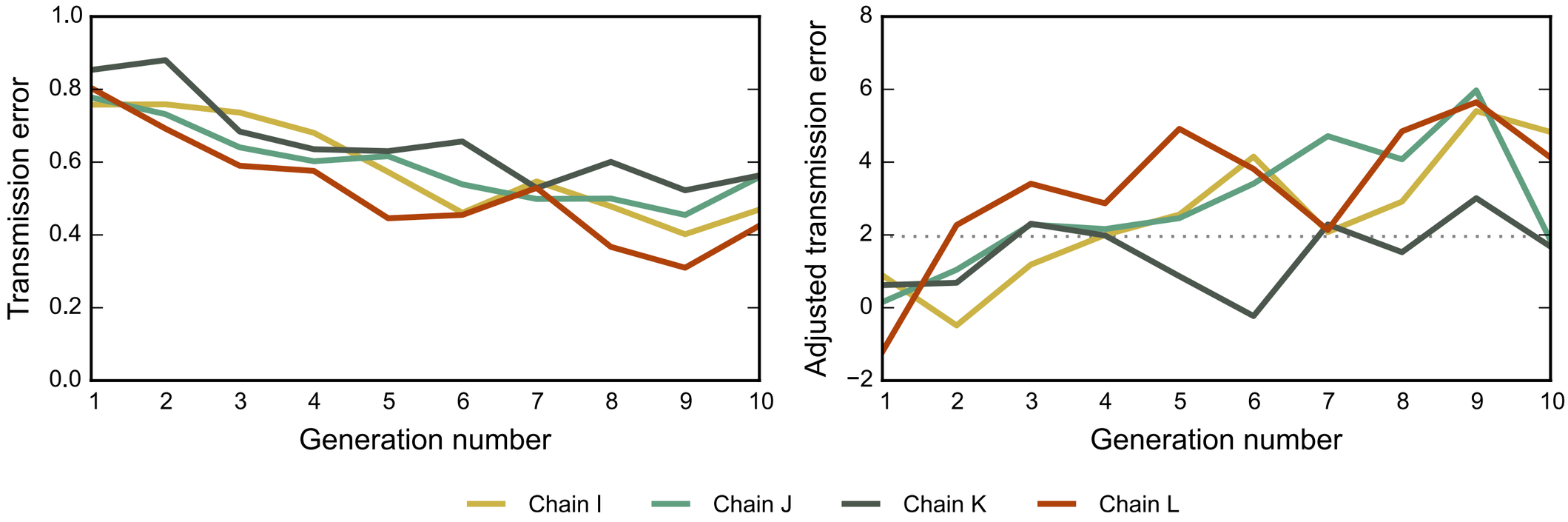
muaki

Please wait...

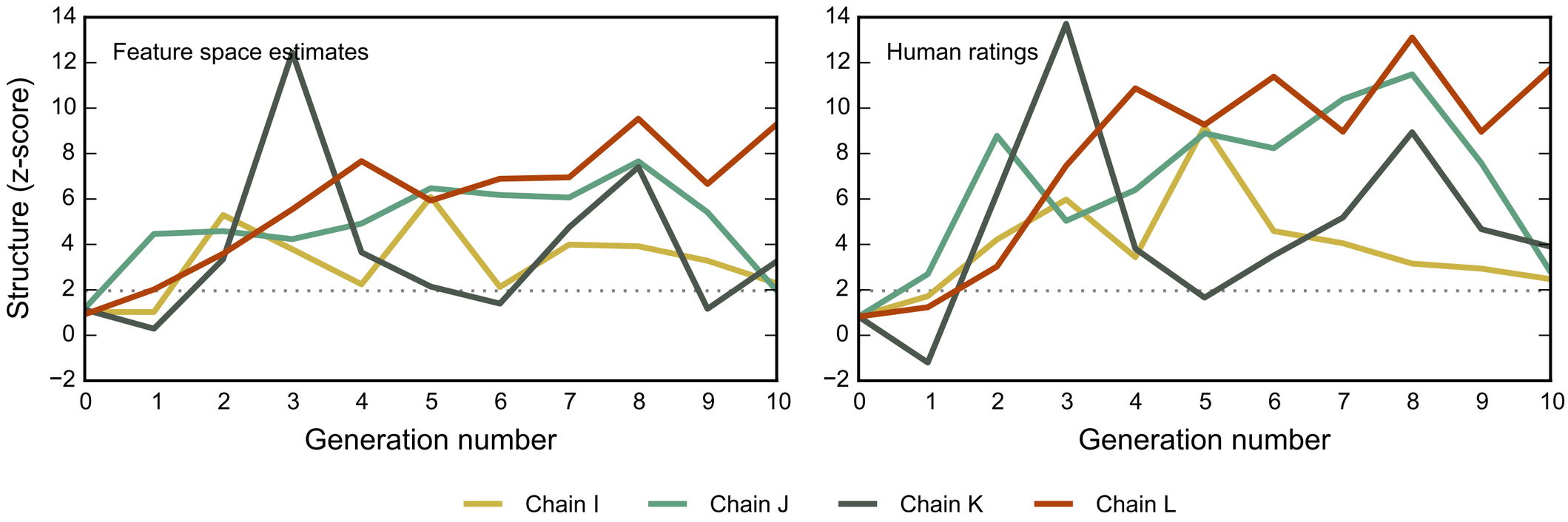
★ 0

× 96

Increase in learnability



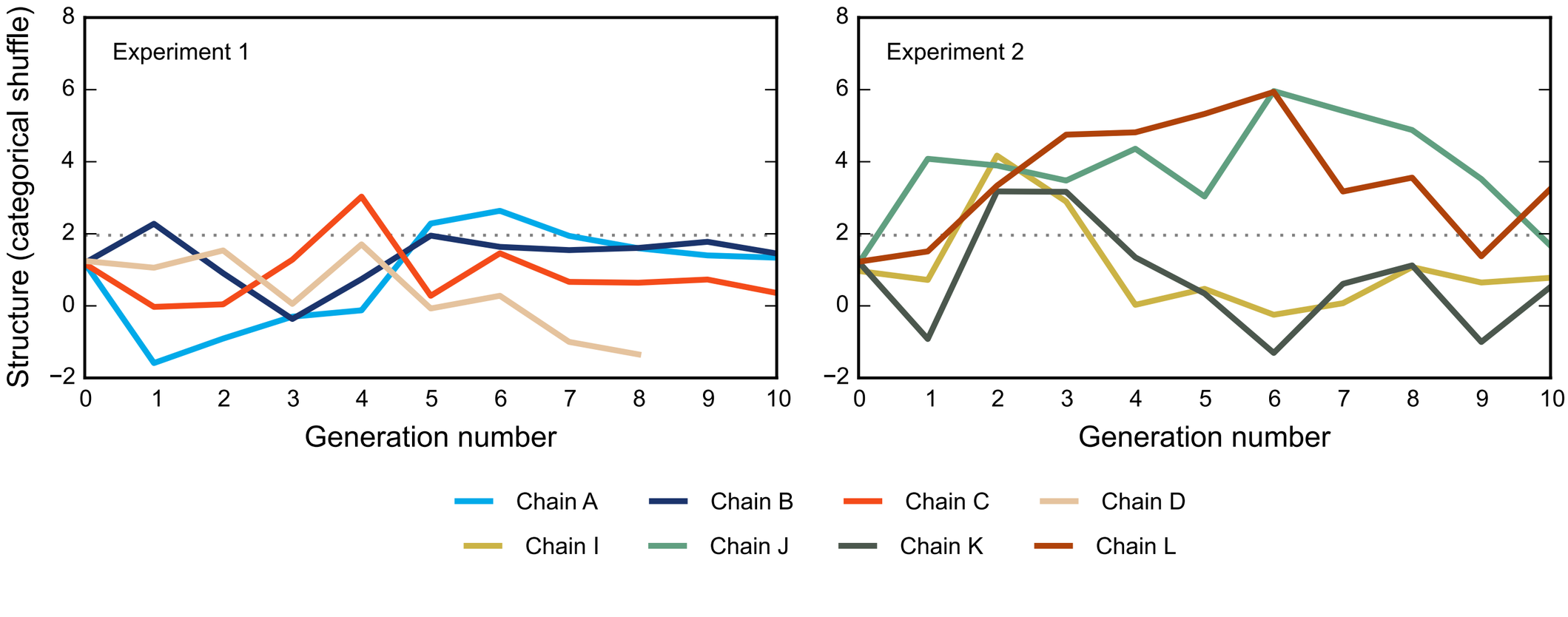
Emergence of structure



Emergence of ***compositional*** structure

Normal shuffle		Category shuffle	
kik	1	kik	1
mappafiki	2	kik	2
kik	3	dazari	3
dazari	4	dazari	4
kik	5	fumo	5
mappafiki	6	dazari	6
dazari	7	dazari	7
fumo	8	dazari	8
kik	9	fumo	9
dazari	10	fumo	10
kik	11	fumo	11
dazari	12	mappafiki	12
dazari	13	dazari	13
fumo	14	fumo	14
fumo	15	dazari	15
kik	16	dazari	16
mappafiki	17	fumo	17
kik	18	fumo	18
dazari	19	mappafiki	19
mappafiki	20	mappafiki	20
kik	21	dazari	21
dazari	22	kik	22
kik	23	dazari	23
kik	24	kik	24
…	…	…	…

Emergence of ***compositional*** structure



Conclusions

Hannah Cornish

Simon Kirby

Kenny Smith

Thanks!

References

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