

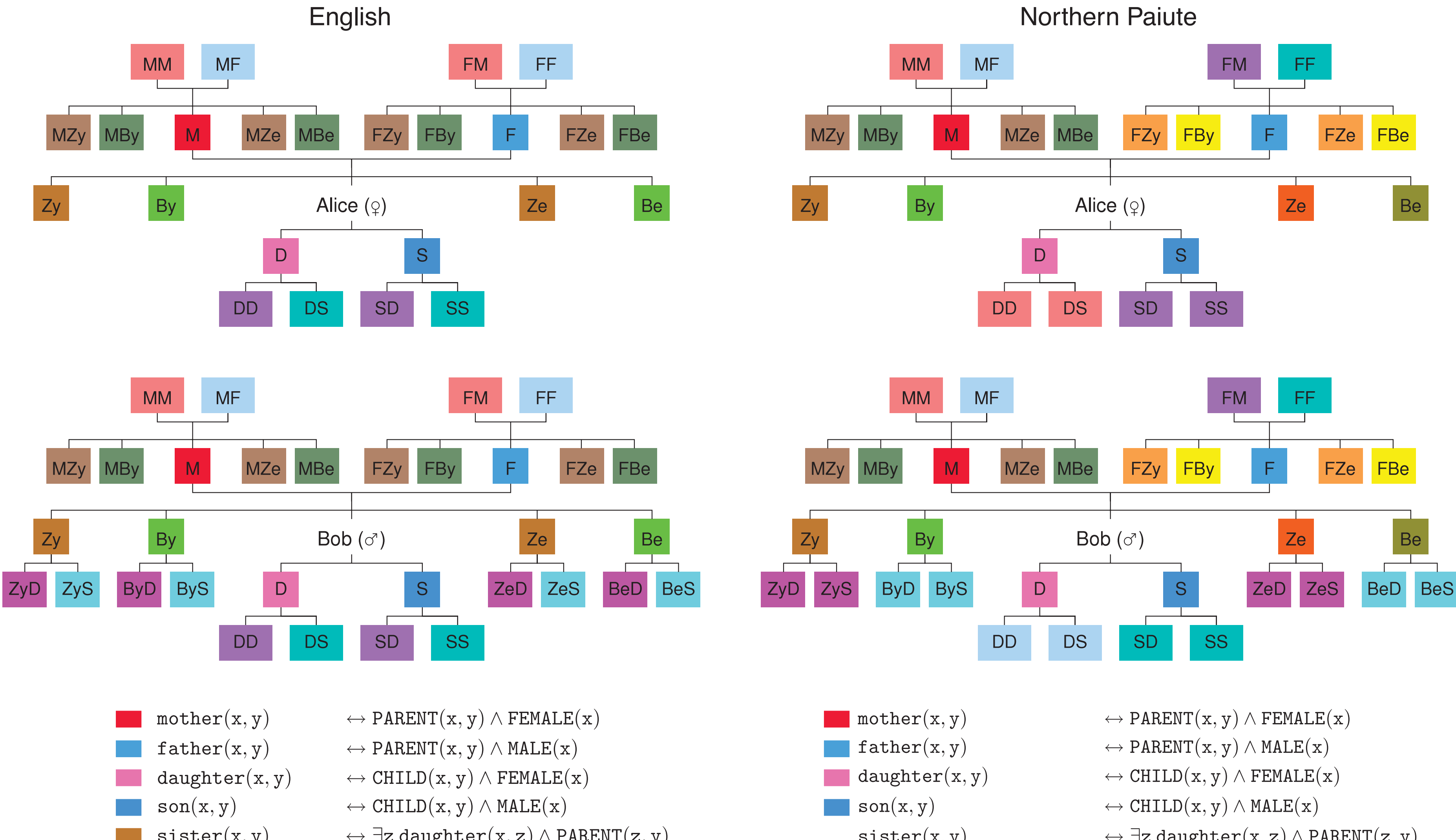
Induction and interaction in the evolution of language and conceptual structure

Jon W. Carr



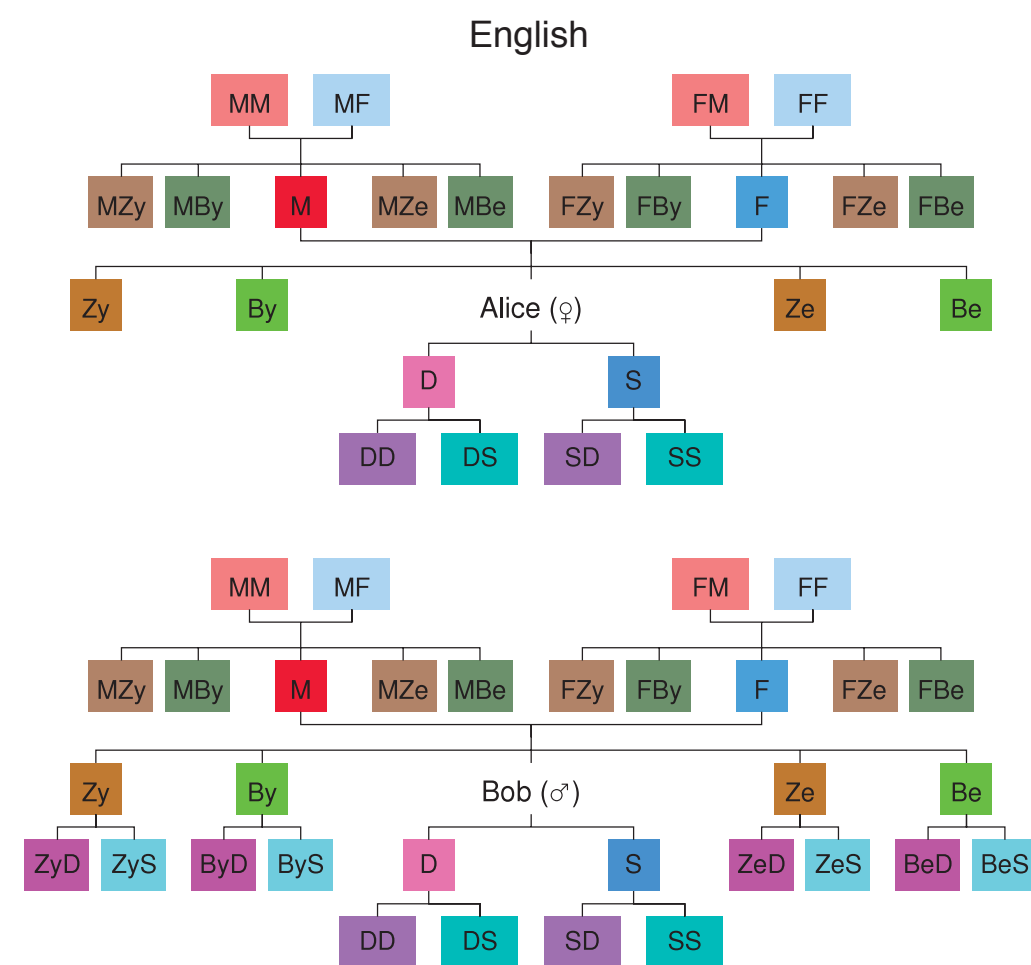
Kinship terms are simple and informative

Kemp & Regier (2012)

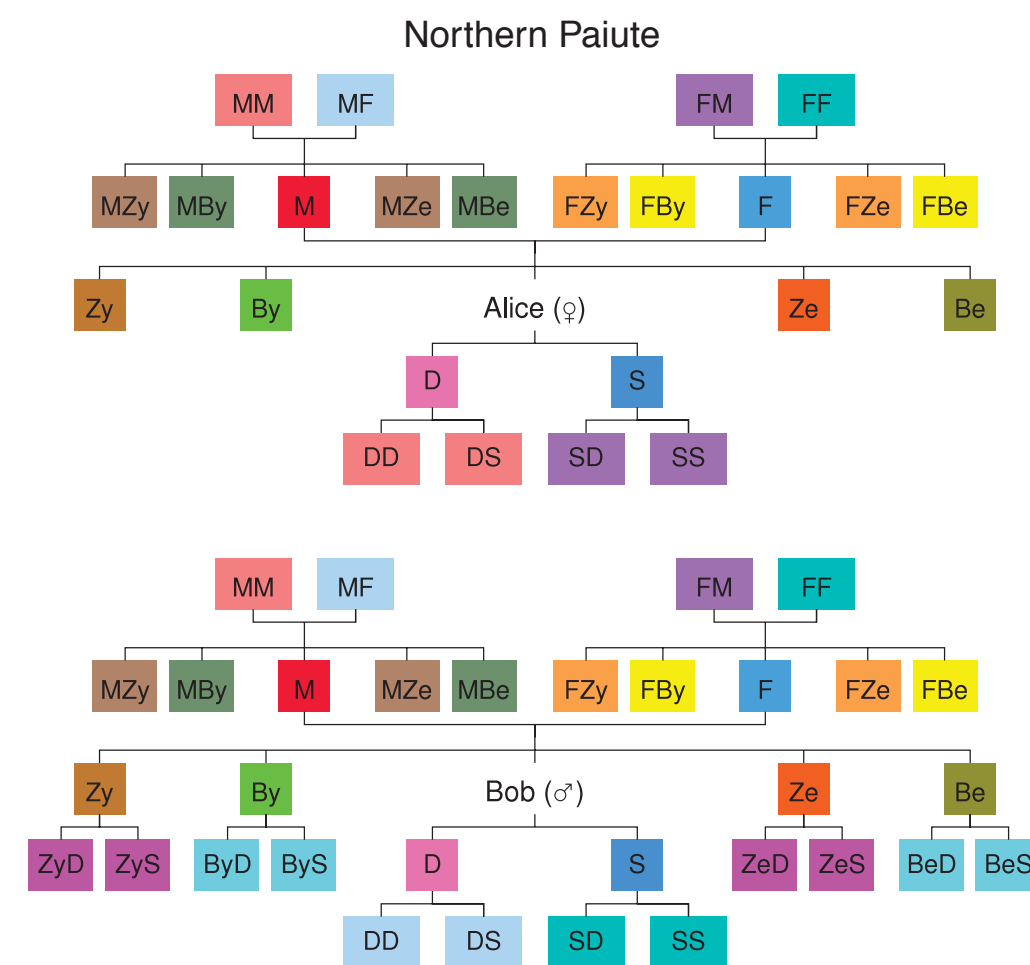


Kinship terms are simple and informative

Kemp & Regier (2012)

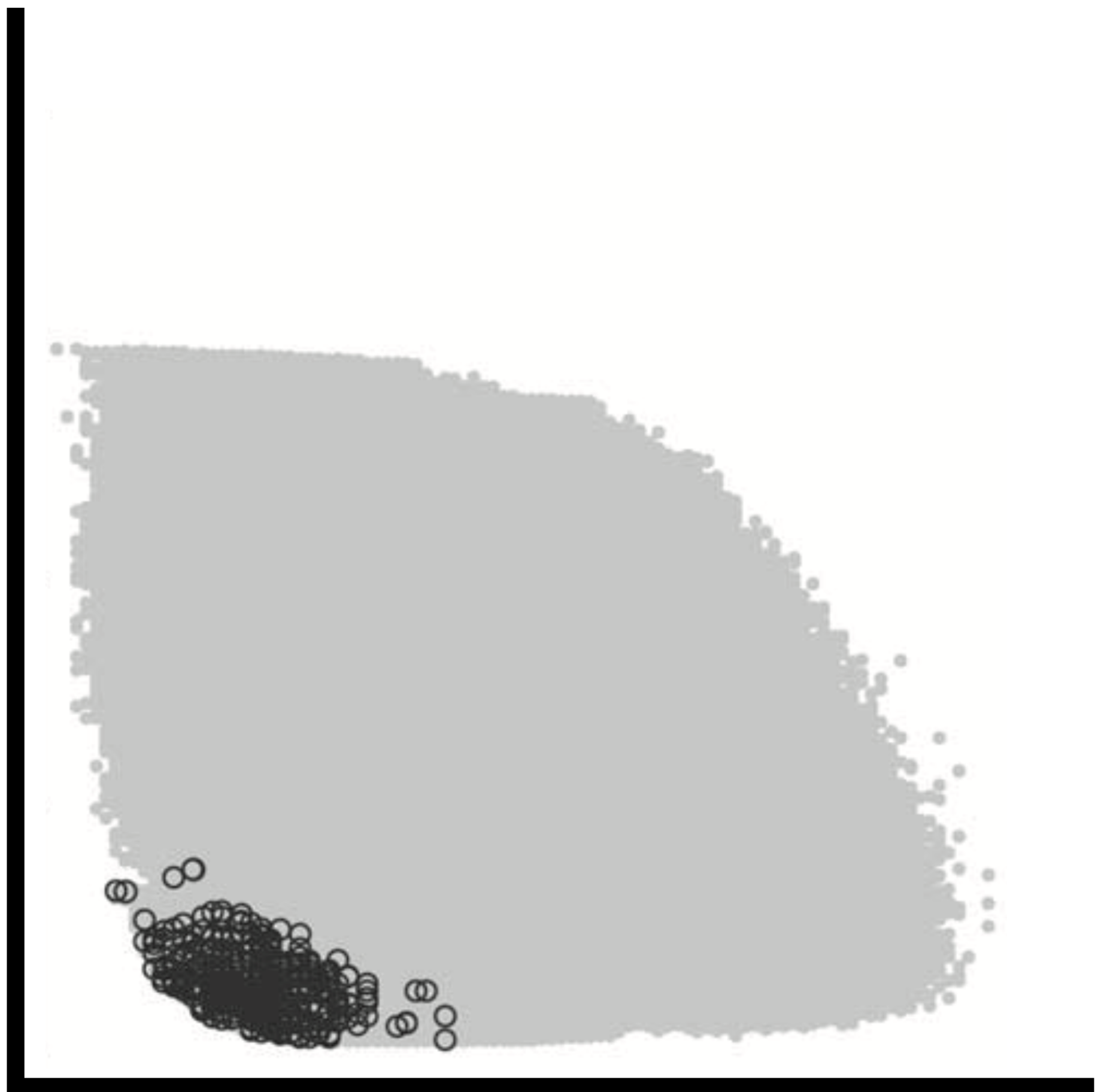


mother(x, y)	$\leftrightarrow \text{PARENT}(x, y) \wedge \text{FEMALE}(x)$
father(x, y)	$\leftrightarrow \text{PARENT}(x, y) \wedge \text{MALE}(x)$
daughter(x, y)	$\leftrightarrow \text{CHILD}(x, y) \wedge \text{FEMALE}(x)$
son(x, y)	$\leftrightarrow \text{CHILD}(x, y) \wedge \text{MALE}(x)$
sister(x, y)	$\leftrightarrow \exists z \text{ daughter}(x, z) \wedge \text{PARENT}(z, y)$
brother(x, y)	$\leftrightarrow \exists z \text{ son}(x, z) \wedge \text{PARENT}(z, y)$
sibling(x, y)	$\leftrightarrow \exists z \text{ CHILD}(x, z) \wedge \text{PARENT}(z, y)$
aunt(x, y)	$\leftrightarrow \exists z \text{ sister}(x, z) \wedge \text{PARENT}(z, y)$
uncle(x, y)	$\leftrightarrow \exists z \text{ brother}(x, z) \wedge \text{PARENT}(z, y)$
niece(x, y)	$\leftrightarrow \exists z \text{ daughter}(x, z) \wedge \text{sibling}(z, y)$
nephew(x, y)	$\leftrightarrow \exists z \text{ son}(x, z) \wedge \text{sibling}(z, y)$
grandmother(x, y)	$\leftrightarrow \exists z \text{ mother}(x, z) \wedge \text{PARENT}(z, y)$
grandfather(x, y)	$\leftrightarrow \exists z \text{ father}(x, z) \wedge \text{PARENT}(z, y)$
granddaughter(x, y)	$\leftrightarrow \exists z \text{ daughter}(x, z) \wedge \text{CHILD}(z, y)$
grandson(x, y)	$\leftrightarrow \exists z \text{ son}(x, z) \wedge \text{CHILD}(z, y)$



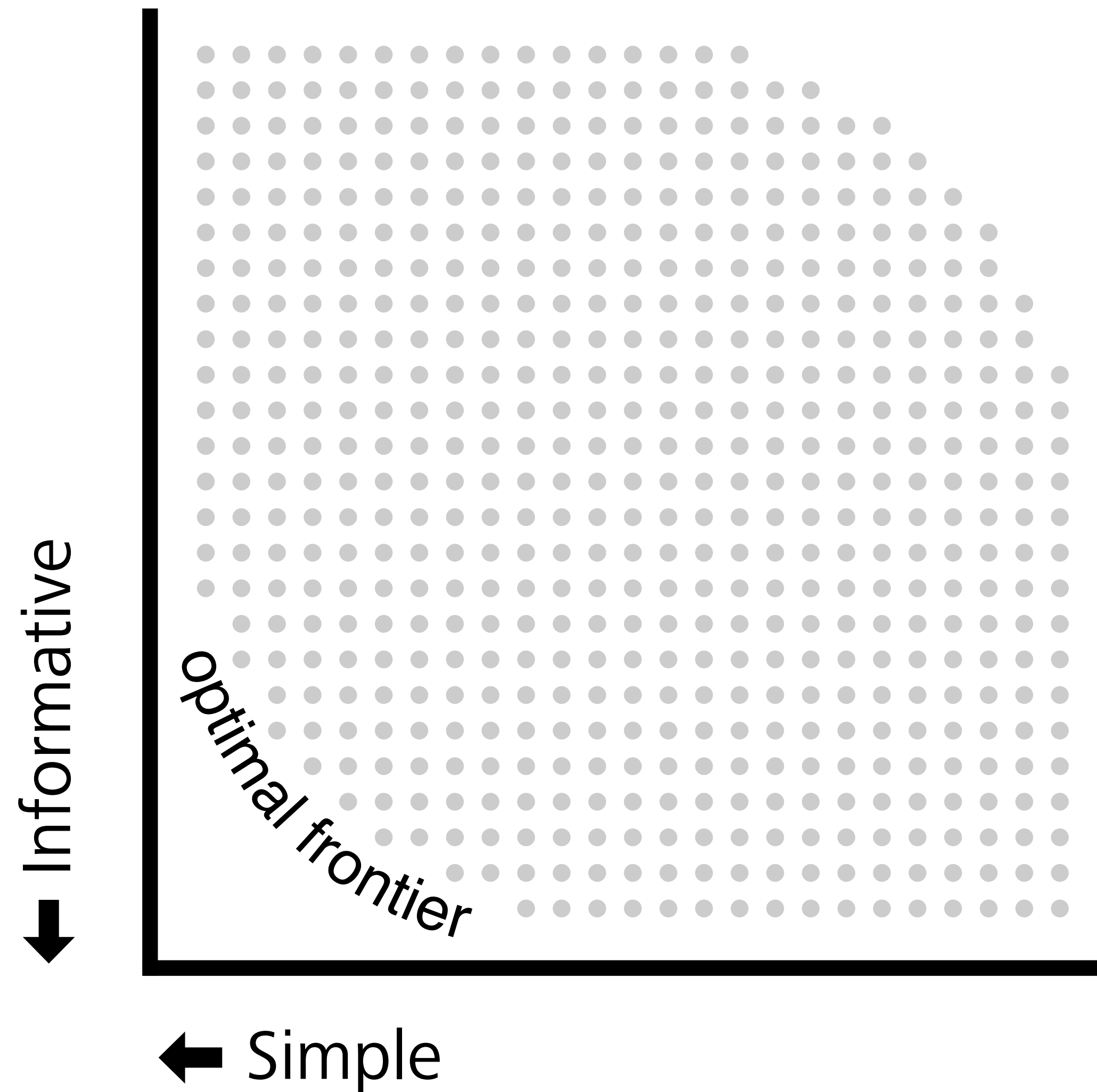
mother(x, y)	$\leftrightarrow \text{PARENT}(x, y) \wedge \text{FEMALE}(x)$
father(x, y)	$\leftrightarrow \text{PARENT}(x, y) \wedge \text{MALE}(x)$
daughter(x, y)	$\leftrightarrow \text{CHILD}(x, y) \wedge \text{FEMALE}(x)$
son(x, y)	$\leftrightarrow \text{CHILD}(x, y) \wedge \text{MALE}(x)$
sister(x, y)	$\leftrightarrow \exists z \text{ daughter}(x, z) \wedge \text{PARENT}(z, y)$
brother(x, y)	$\leftrightarrow \exists z \text{ son}(x, z) \wedge \text{PARENT}(z, y)$
youngersister(x, y)	$\leftrightarrow \text{sister}(x, y) \wedge \text{YOUNGER}(x, y)$
oldersister(x, y)	$\leftrightarrow \text{sister}(x, y) \wedge \text{OLDER}(x, y)$
youngerbrother(x, y)	$\leftrightarrow \text{brother}(x, y) \wedge \text{YOUNGER}(x, y)$
olderbrother(x, y)	$\leftrightarrow \text{brother}(x, y) \wedge \text{OLDER}(x, y)$
maternalaunt(x, y)	$\leftrightarrow \exists z \text{ sister}(x, z) \wedge \text{mother}(z, y)$
maternaluncle(x, y)	$\leftrightarrow \exists z \text{ brother}(x, z) \wedge \text{mother}(z, y)$
paternalaunt(x, y)	$\leftrightarrow \exists z \text{ sister}(x, z) \wedge \text{father}(z, y)$
paternaluncle(x, y)	$\leftrightarrow \exists z \text{ brother}(x, z) \wedge \text{father}(z, y)$
mansisterchild(x, y)	$\leftrightarrow \text{maternaluncle}(y, x)$
manbrotherchild(x, y)	$\leftrightarrow \text{paternaluncle}(y, x)$
maternalgrandmother(x, y)	$\leftrightarrow \exists z \text{ mother}(x, z) \wedge \text{mother}(z, y)$
maternalgrandfather(x, y)	$\leftrightarrow \exists z \text{ father}(x, z) \wedge \text{mother}(z, y)$
paternalgrandmother(x, y)	$\leftrightarrow \exists z \text{ mother}(x, z) \wedge \text{father}(z, y)$
paternalgrandfather(x, y)	$\leftrightarrow \exists z \text{ father}(x, z) \wedge \text{father}(z, y)$
selfreciprocal1(x, y)	$\leftrightarrow \text{maternalgrandmother}^{\neg}(x, y)$
selfreciprocal2(x, y)	$\leftrightarrow \text{maternalgrandfather}^{\neg}(x, y)$
selfreciprocal3(x, y)	$\leftrightarrow \text{paternalgrandmother}^{\neg}(x, y)$
selfreciprocal4(x, y)	$\leftrightarrow \text{paternalgrandfather}^{\neg}(x, y)$

Informative

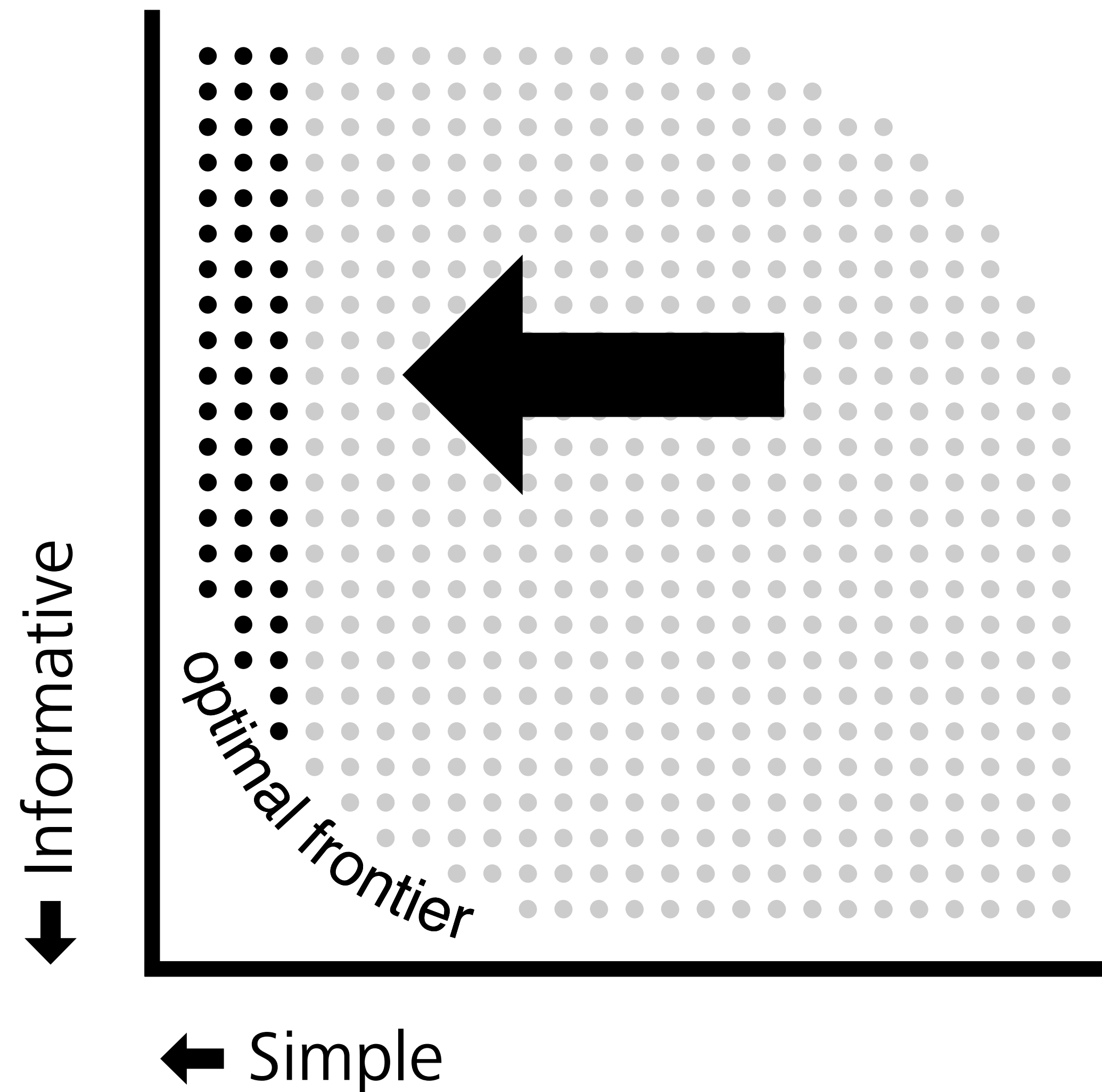


Simple

Pressures operating in simplicity–informativeness space



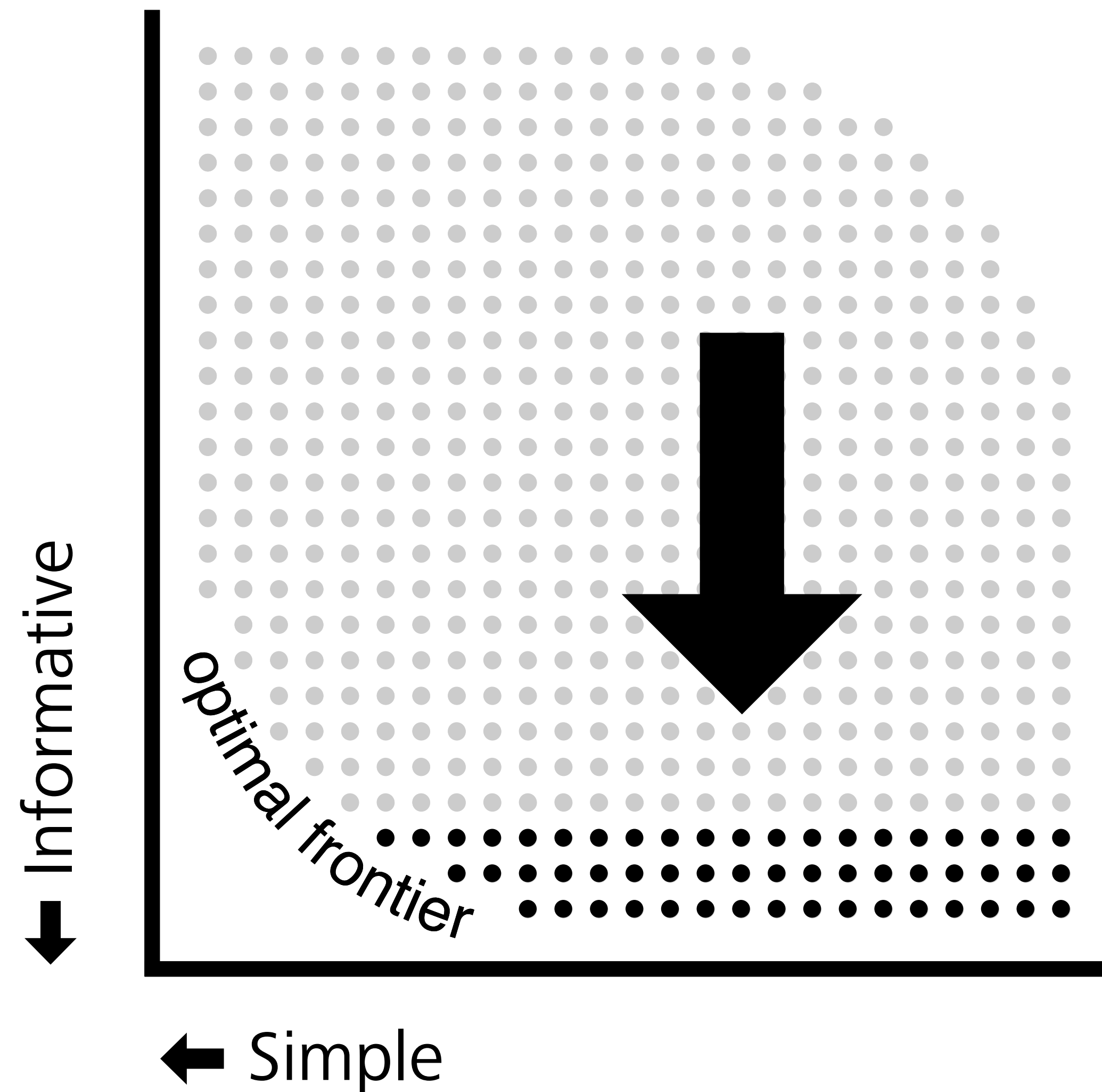
Pressures operating in simplicity–informativeness space



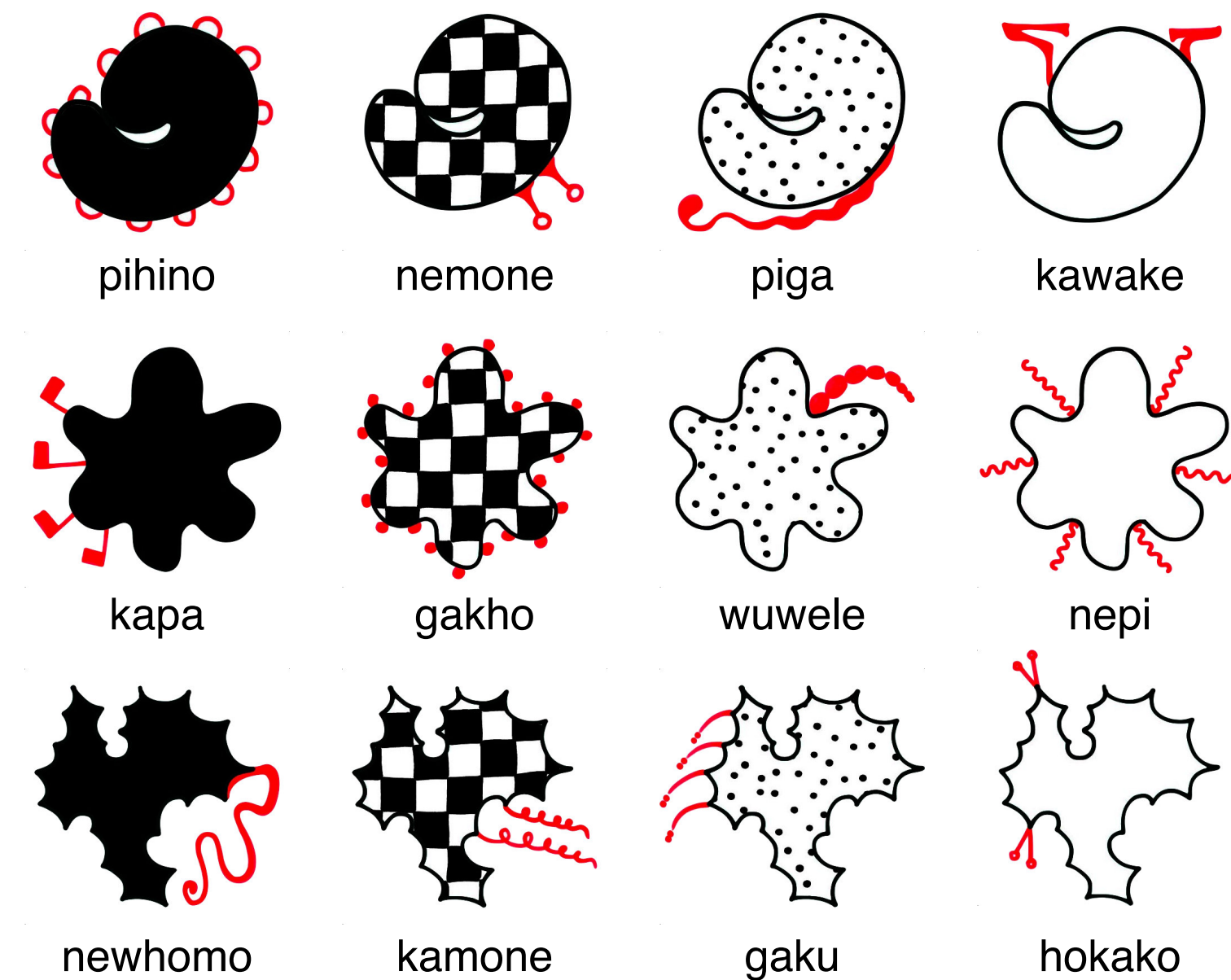
Learning exerts pressure for simplicity



Pressures operating in simplicity–informativeness space

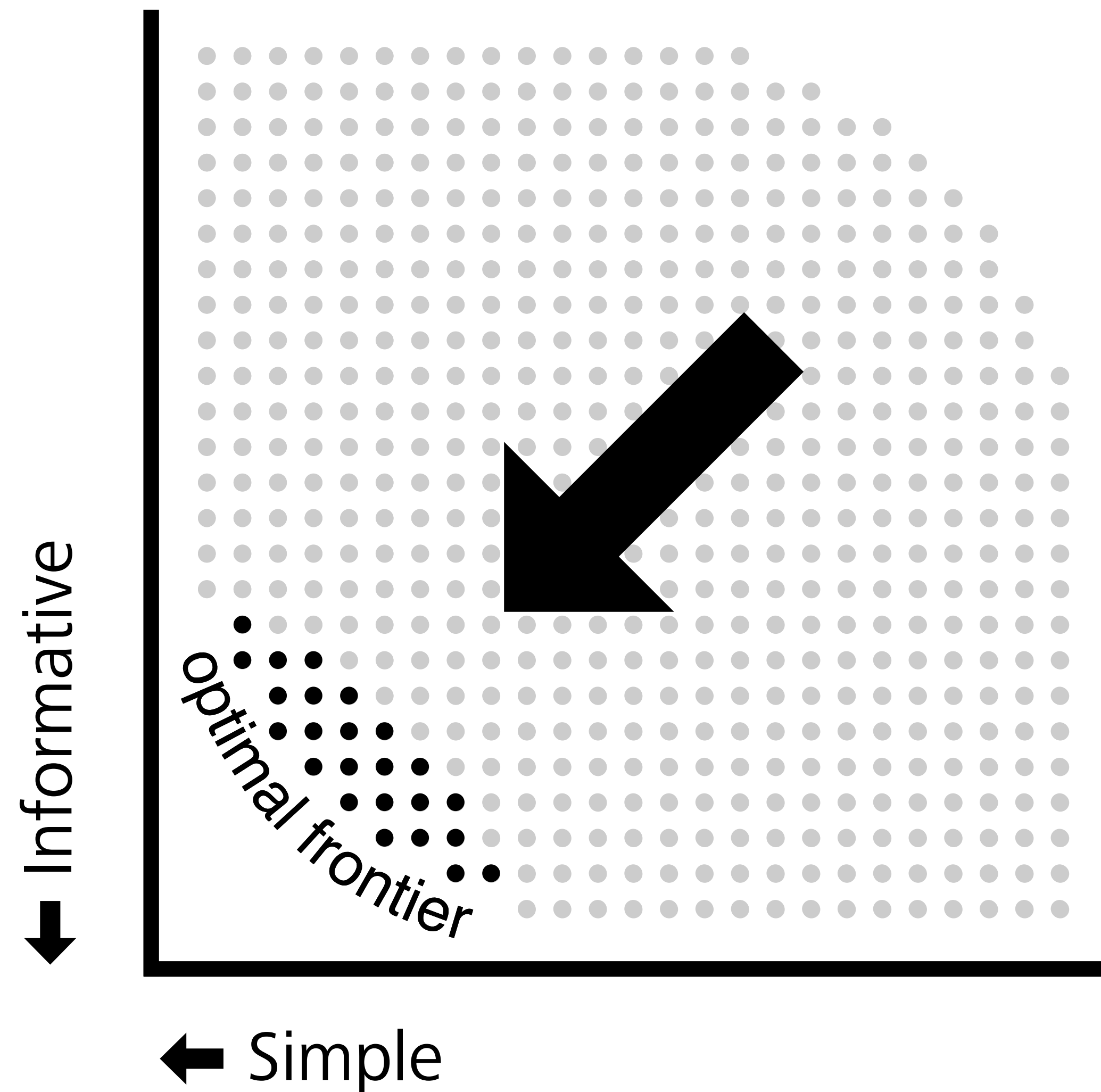


Communication exerts pressure
for informativeness

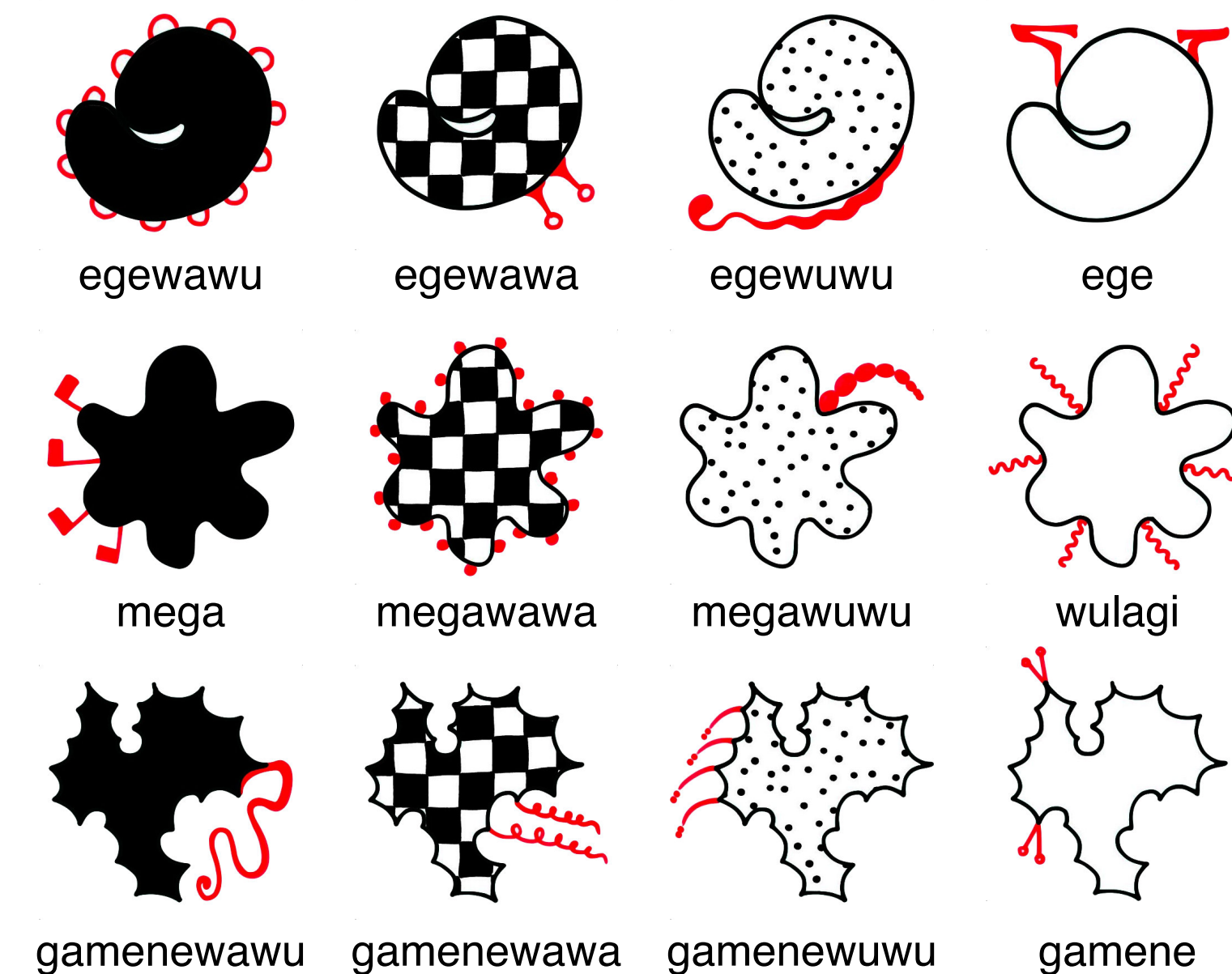


Kirby, Tamariz, Cornish, & Smith (2015)

Pressures operating in simplicity–informativeness space

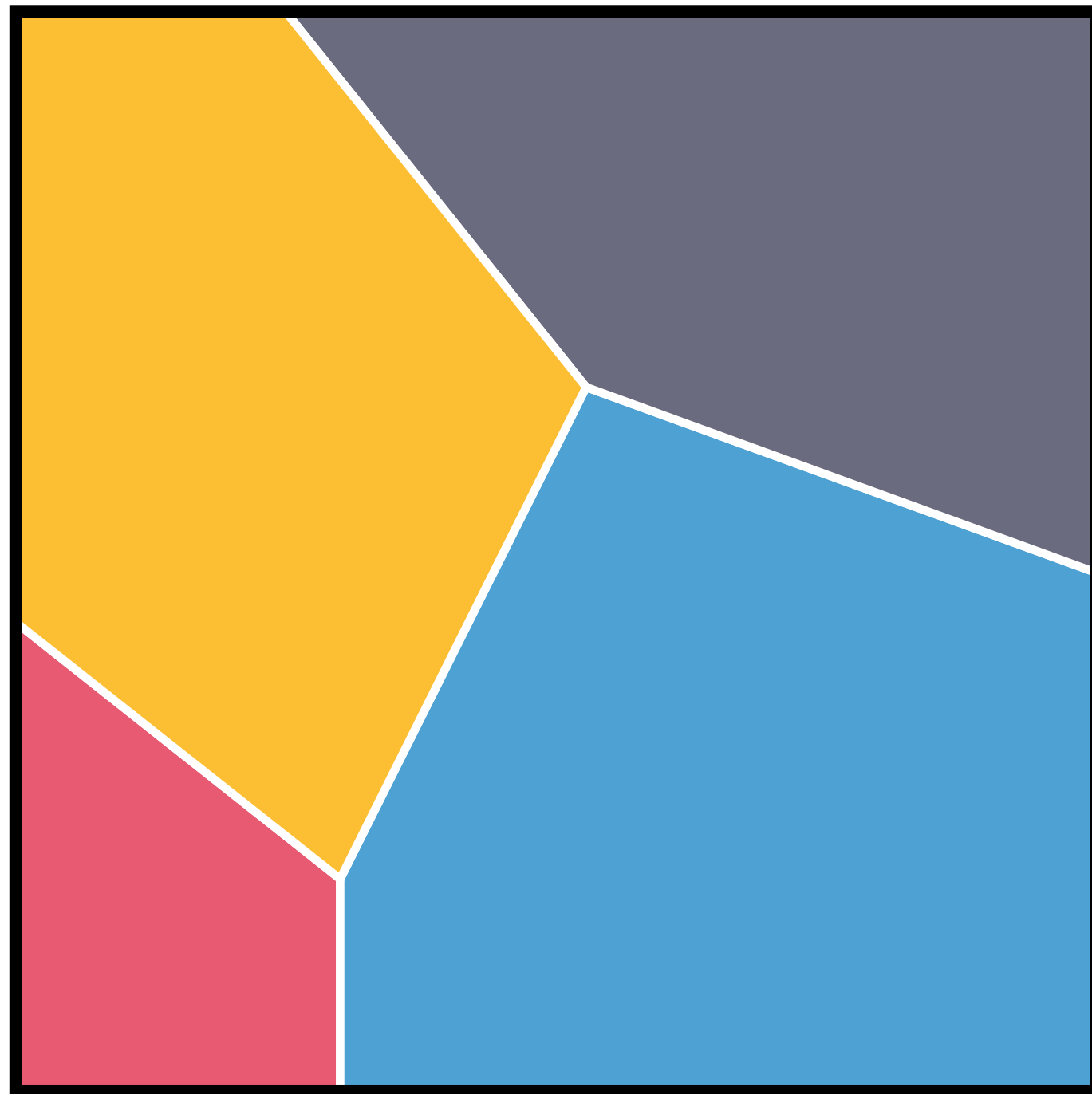


Learning + Communication
exerts pressure for simplicity
and informativeness

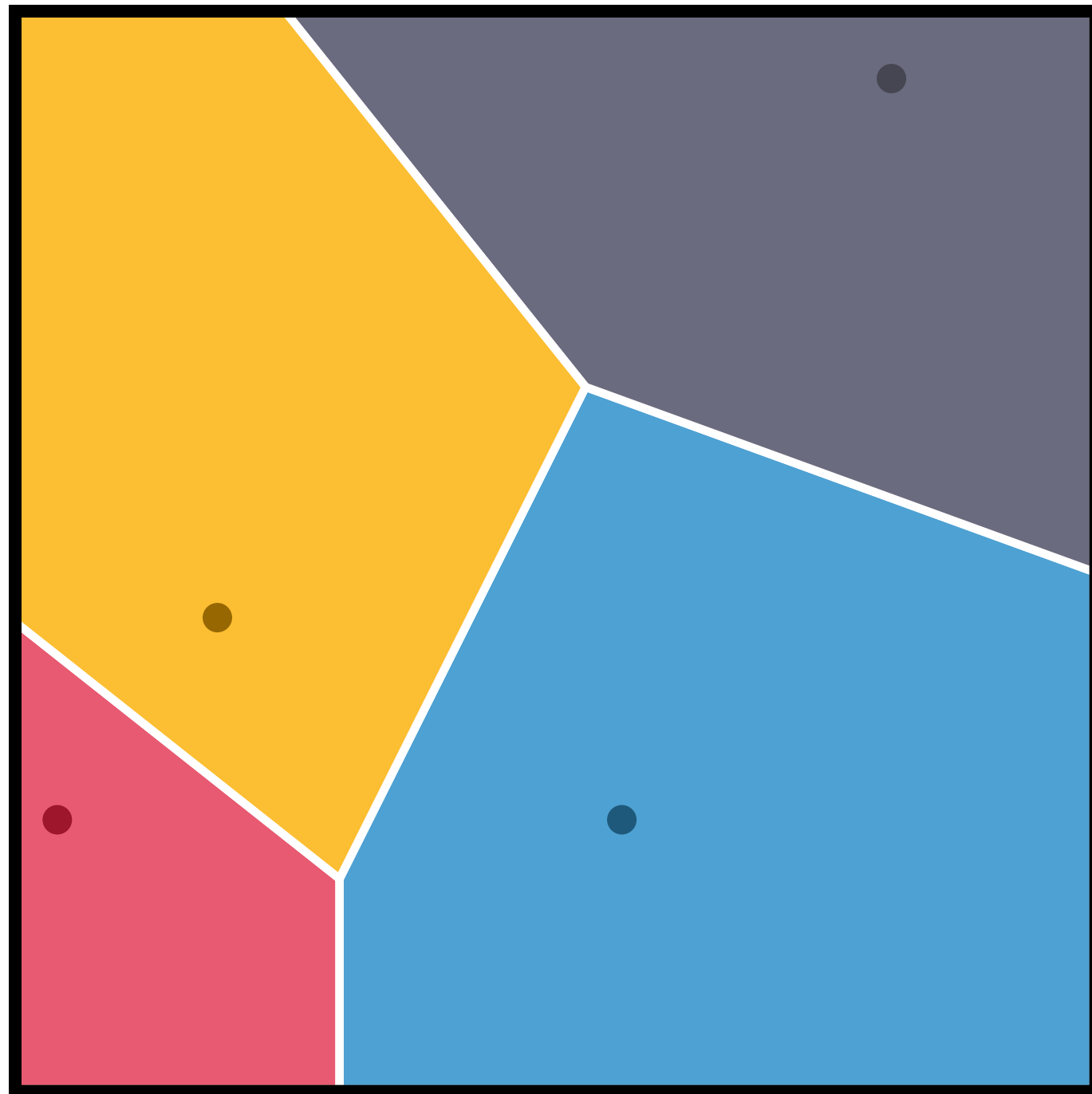


Kirby, Tamariz, Cornish, & Smith (2015)

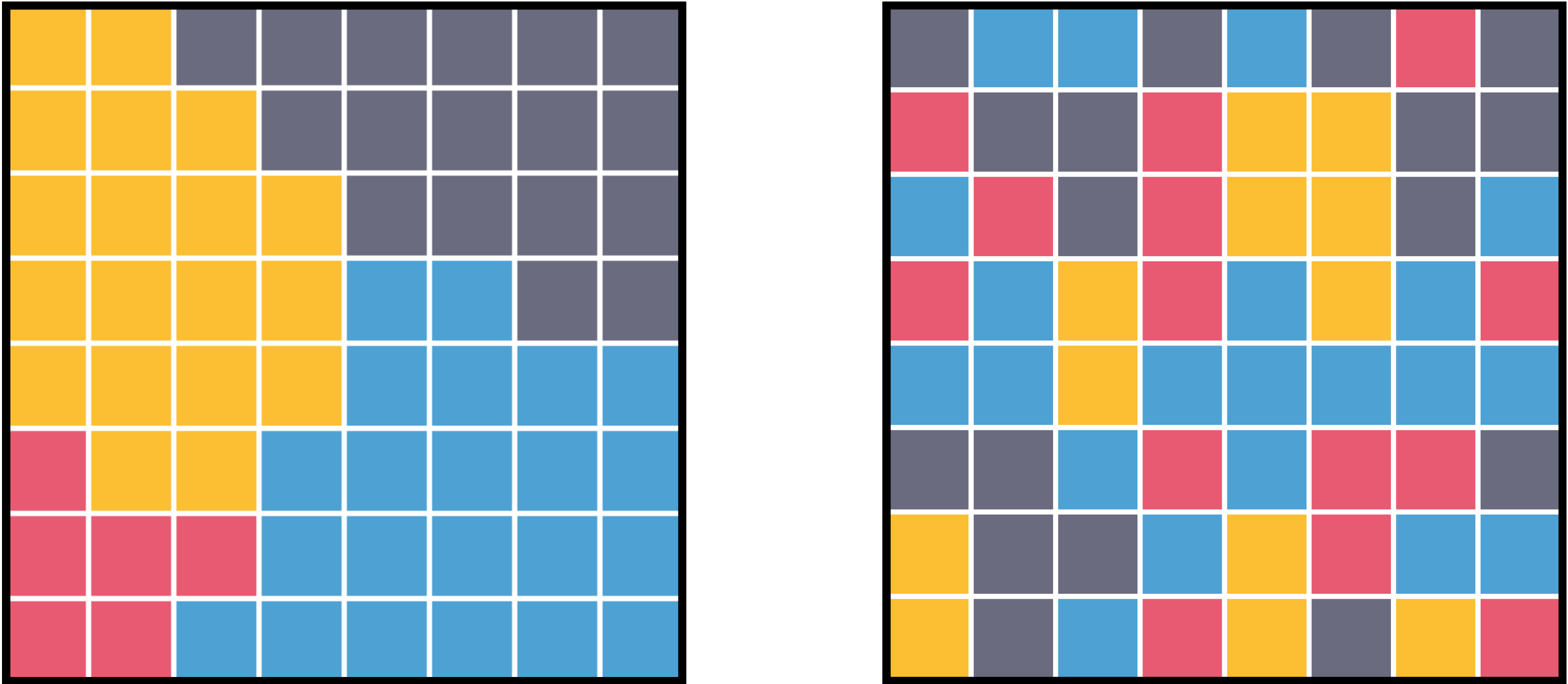
Semantic category systems



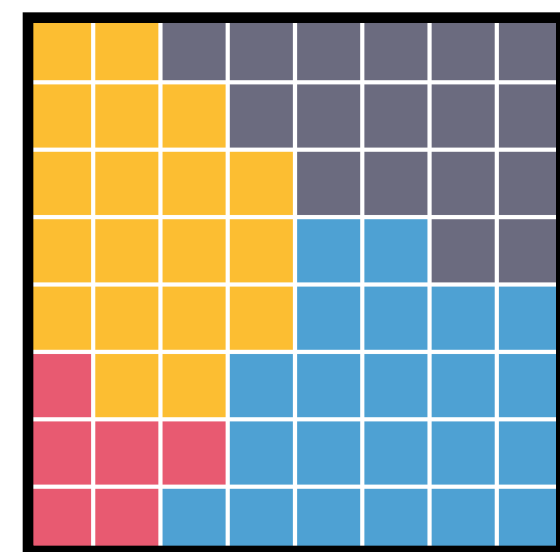
Semantic category systems



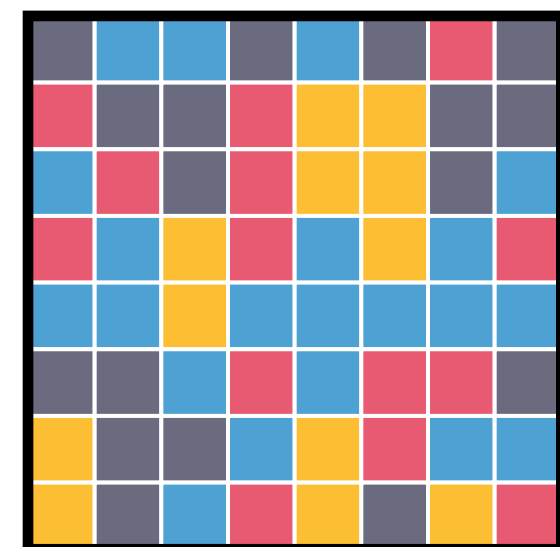
Semantic category systems



Simplicity and informativeness of semantic category systems

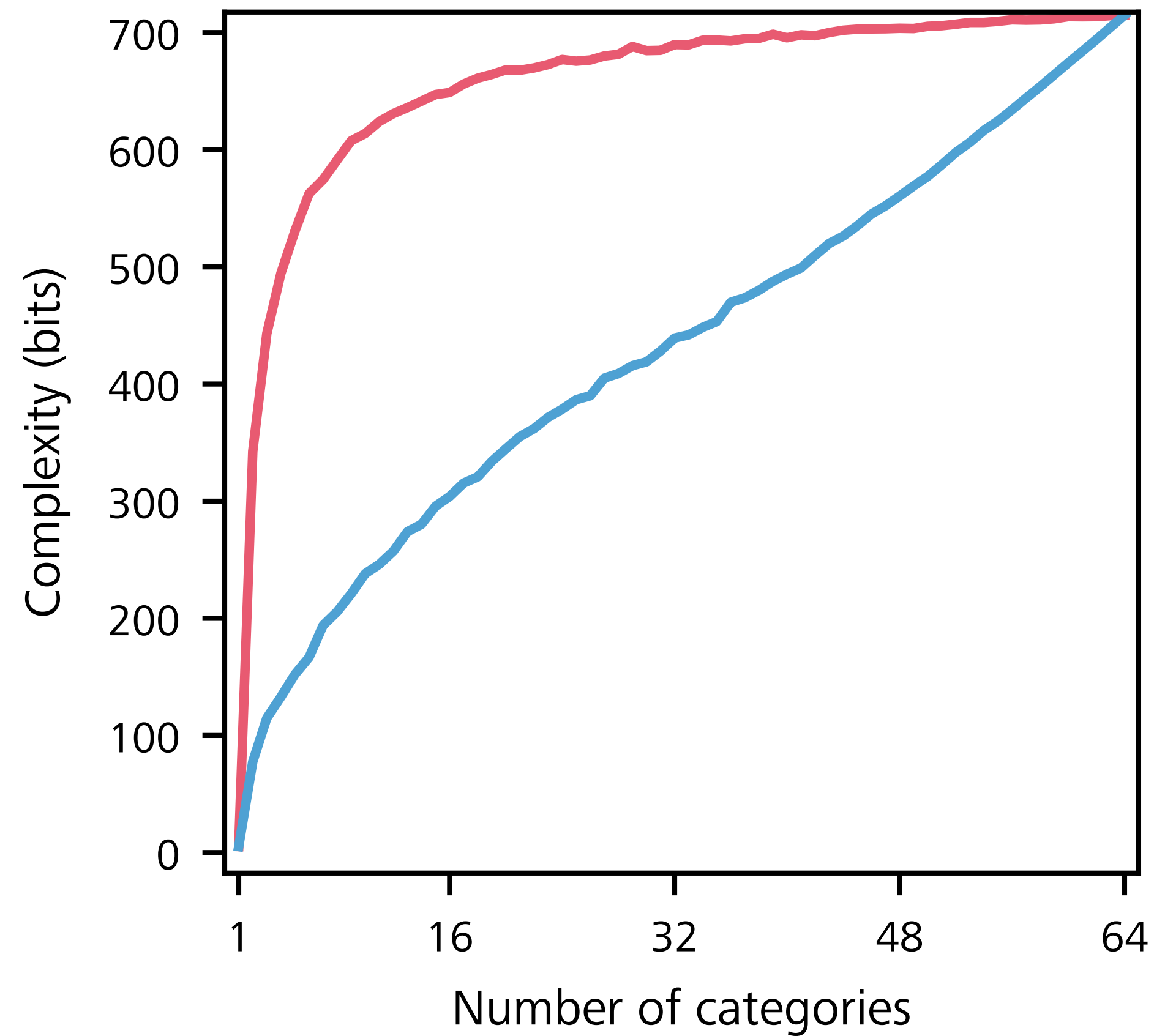


— Compact

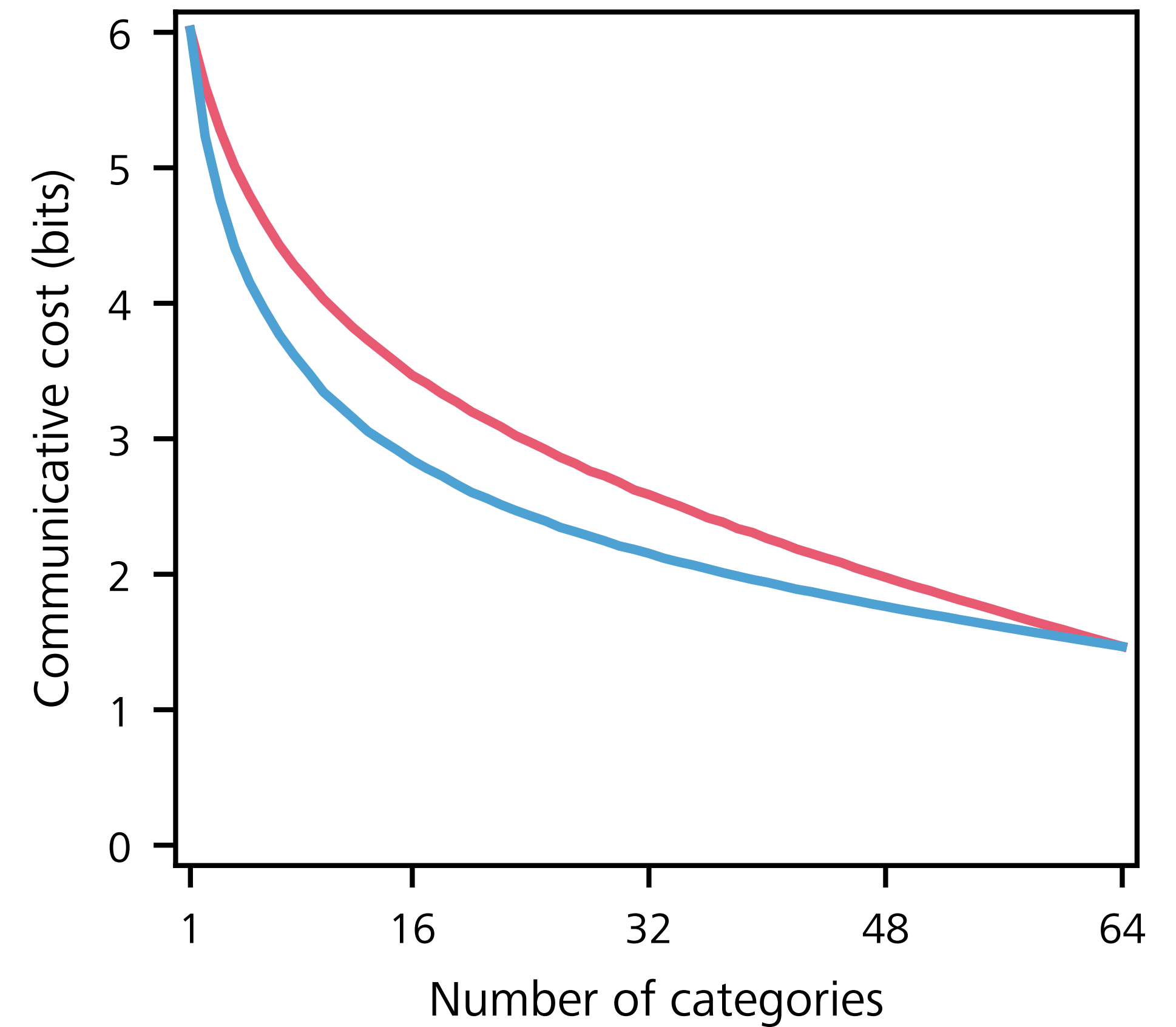


— Random

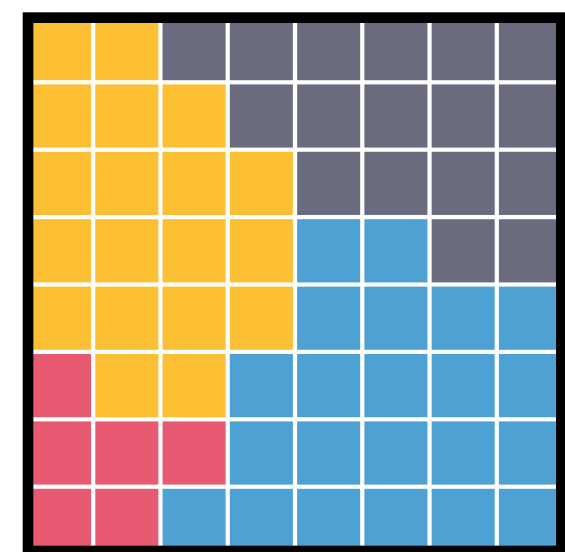
Simplicity



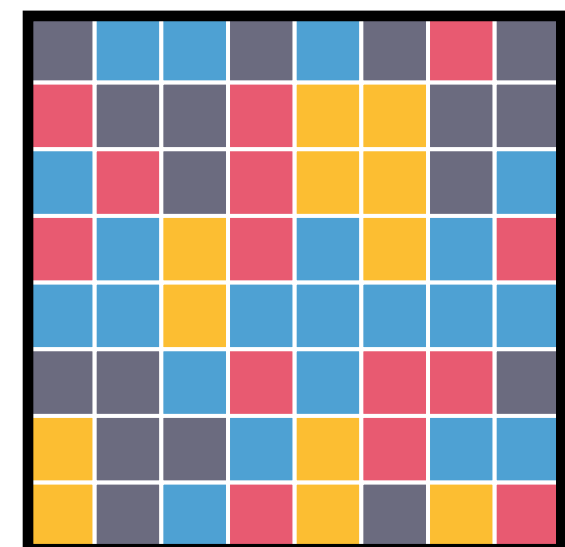
Informativeness



Simplicity and informativeness of semantic category systems

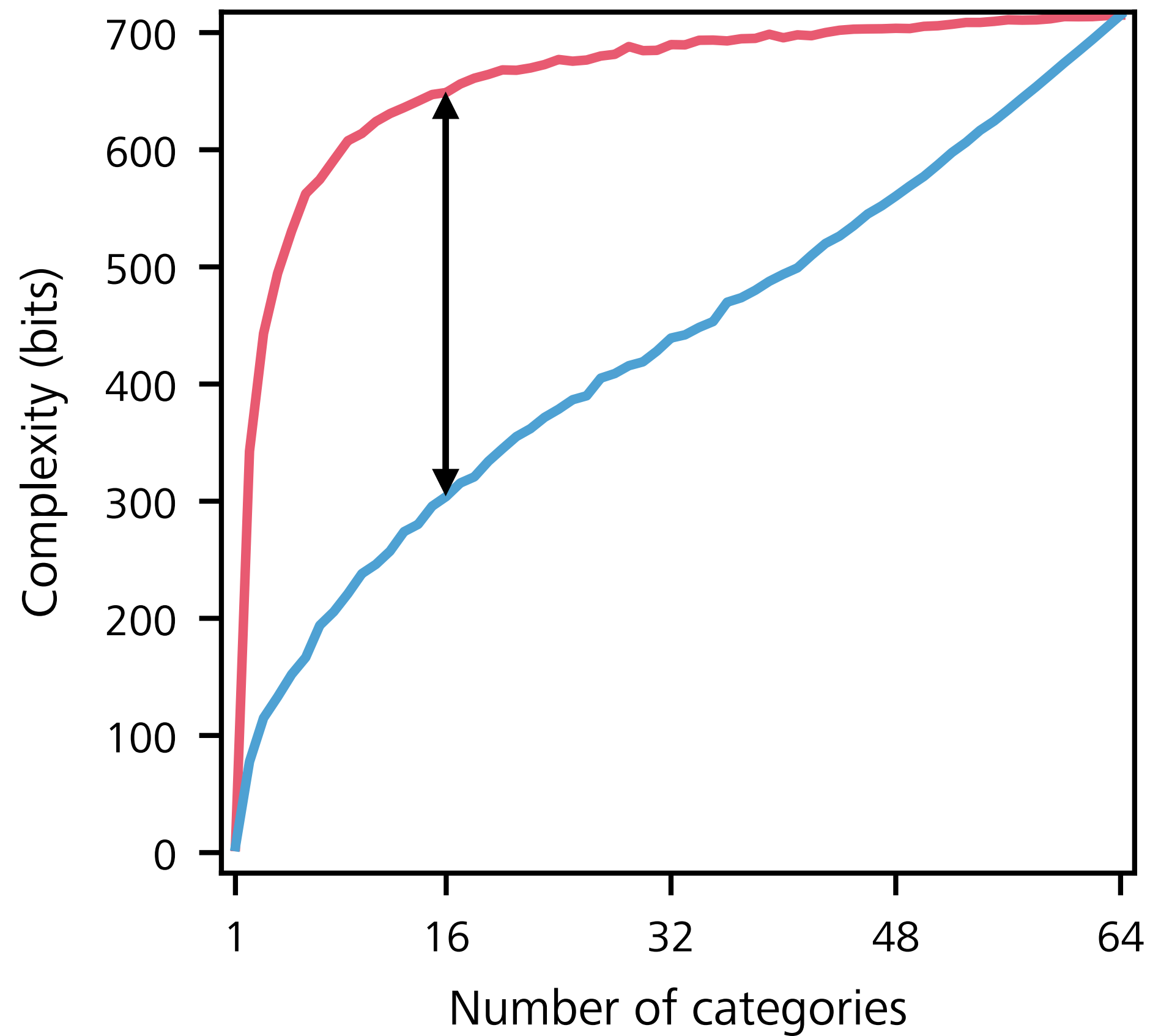


— Compact

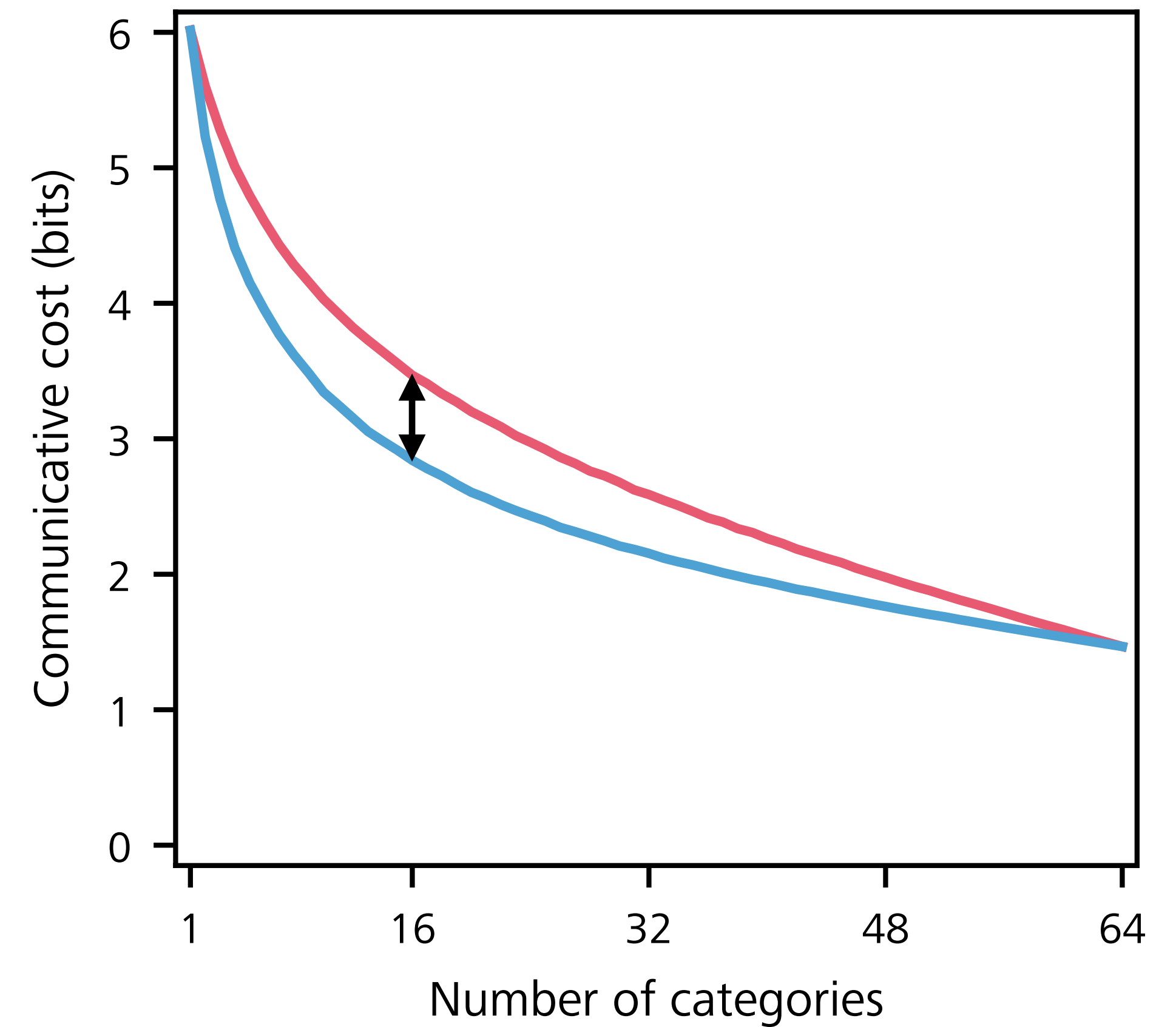


— Random

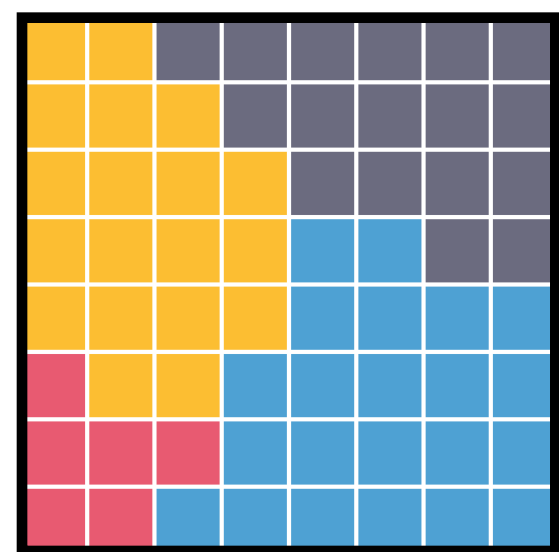
Simplicity



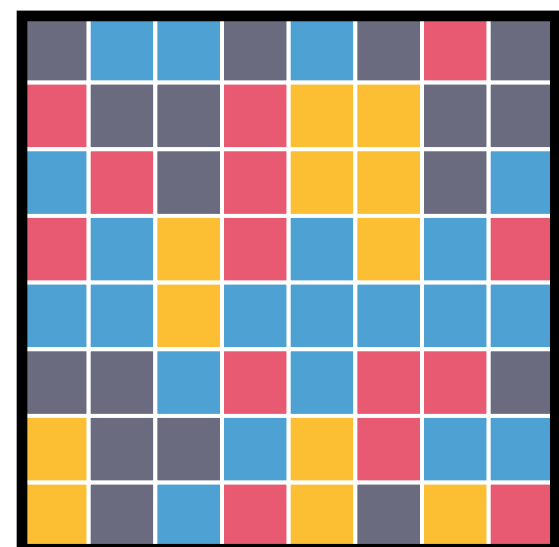
Informativeness



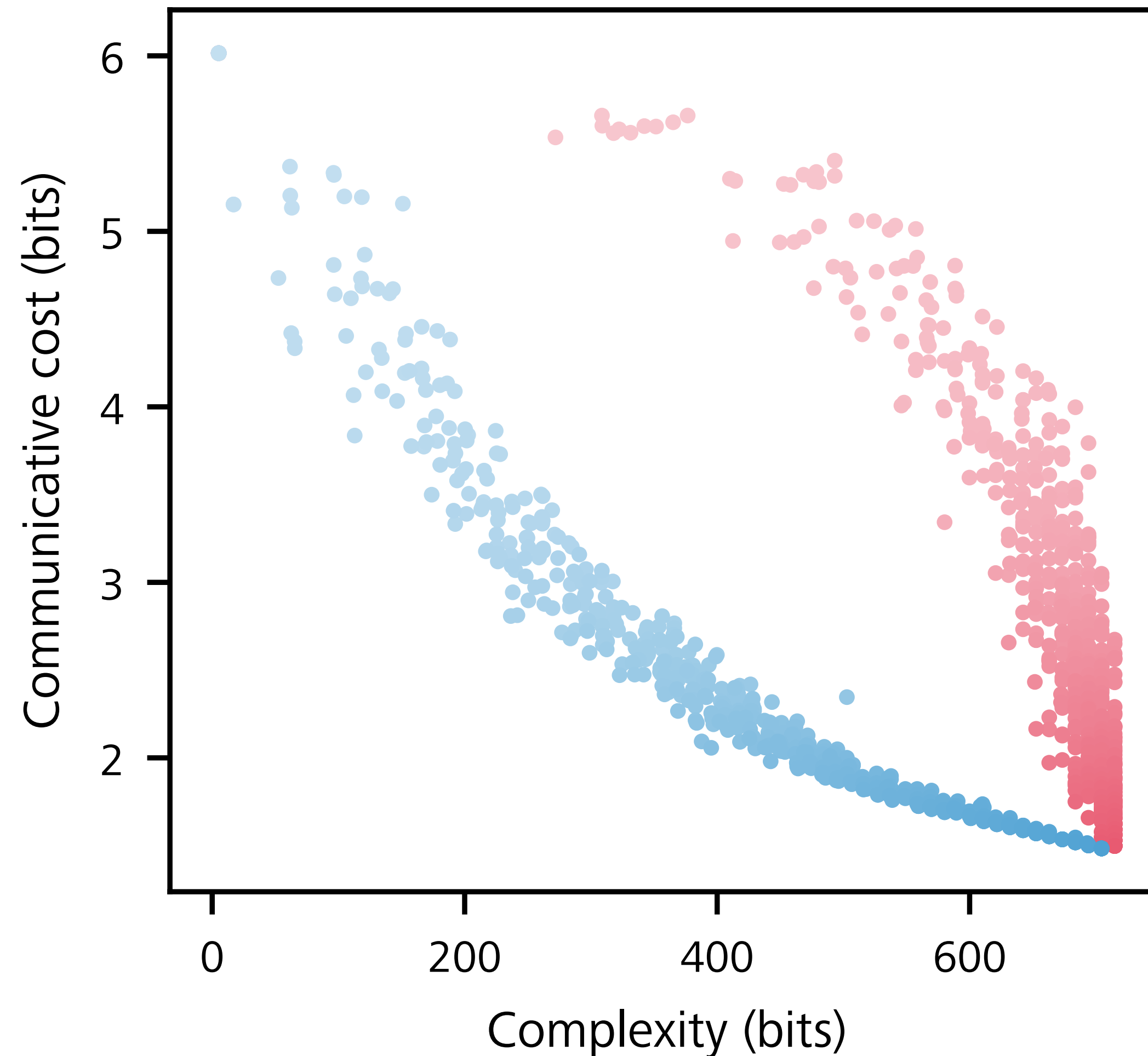
Hallmark features of simple and informative category systems



● Compact



● Random



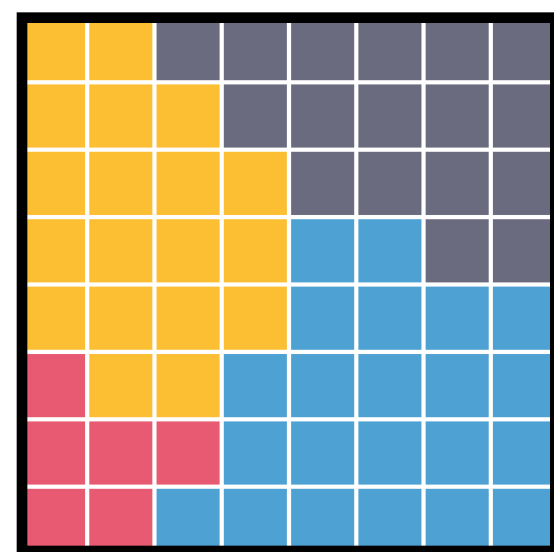
Simplicity pressure from induction favours

Few categories
Compactness

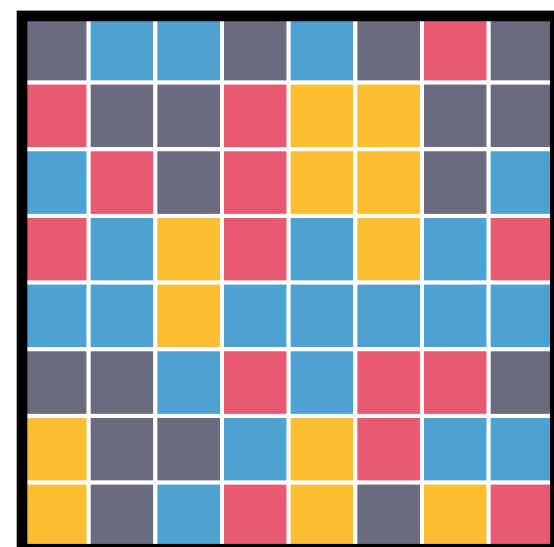
Informativeness pressure from interaction favours

Many categories
Compactness

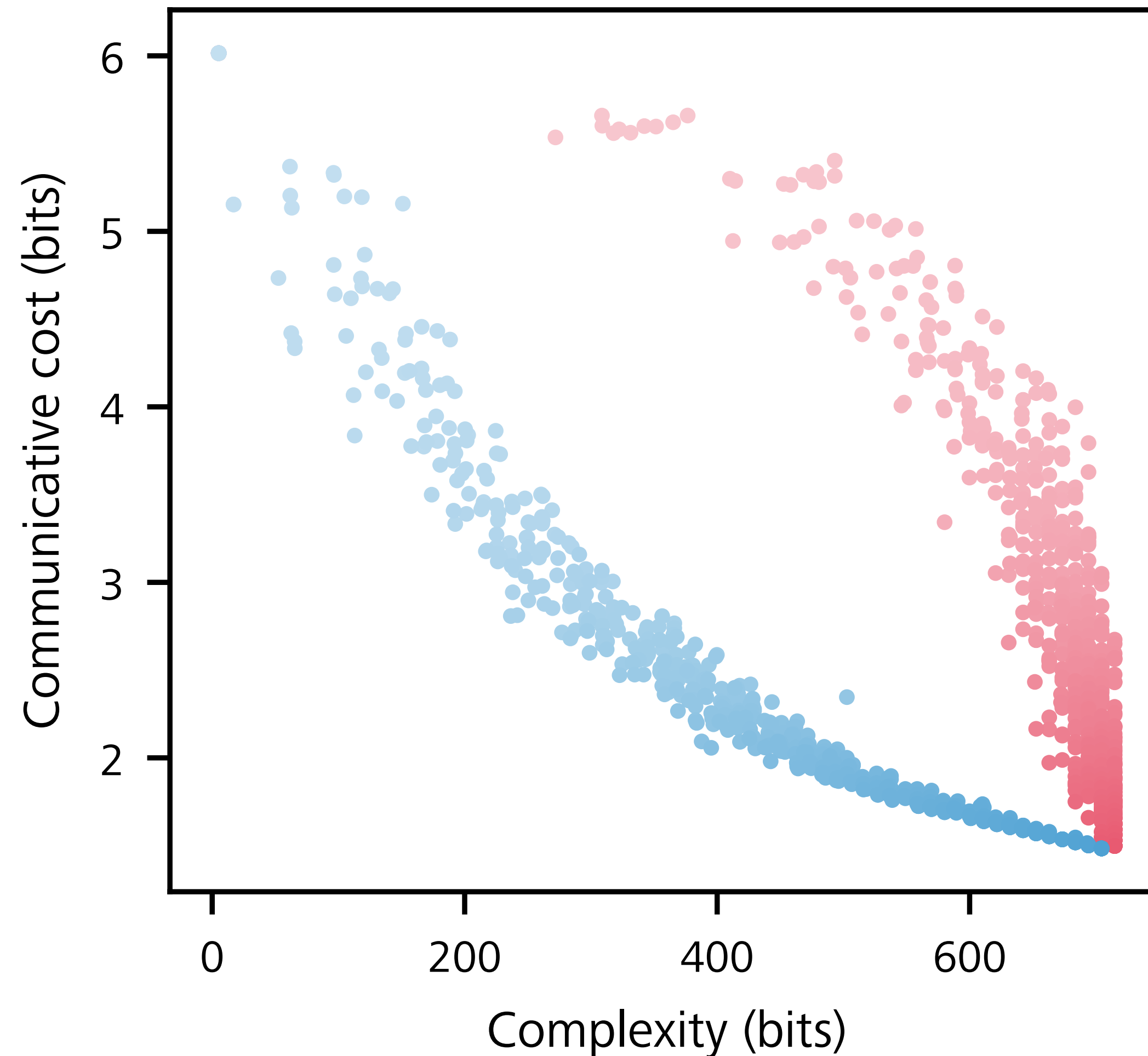
Hallmark features of simple and informative category systems



● Compact



● Random



Simplicity pressure from induction favours

Few categories
Compactness

Informativeness pressure from interaction favours

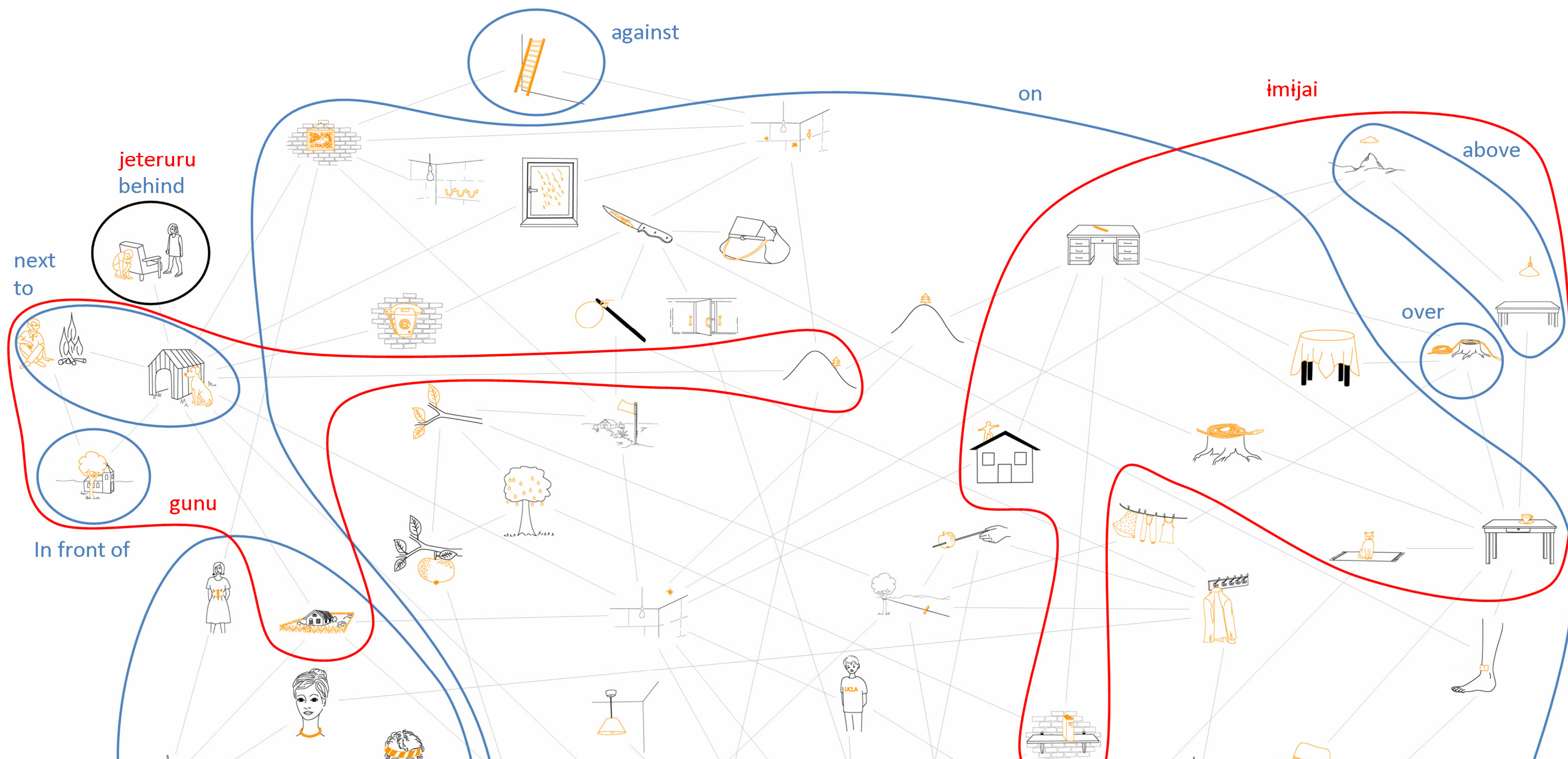
Many categories
Compactness

Are semantic categories compact because of simplicity or informativeness?

Part 2

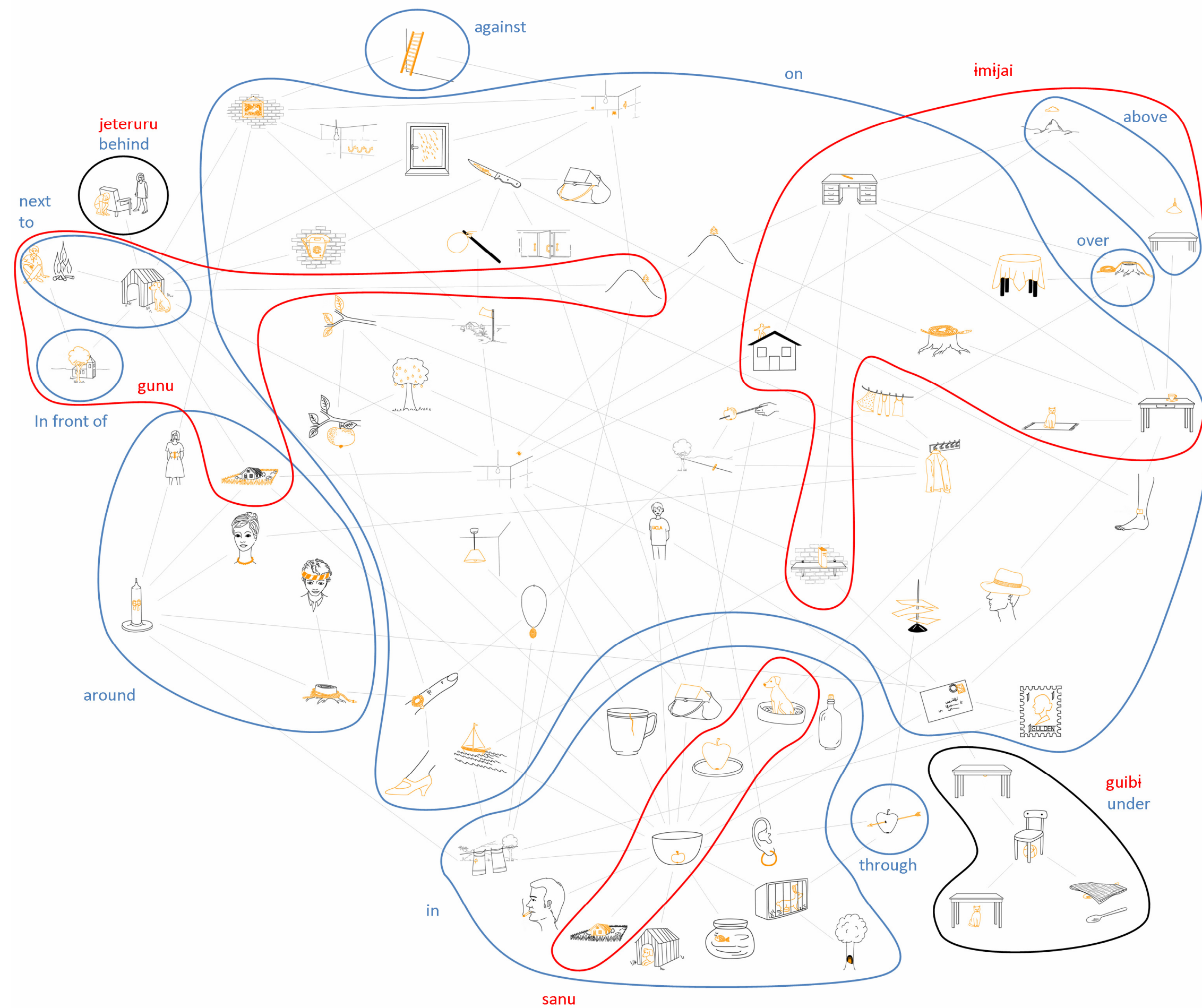
Can iterated learning give rise to informative languages?

Carstensen, Xu, Smith, & Regier (2015)

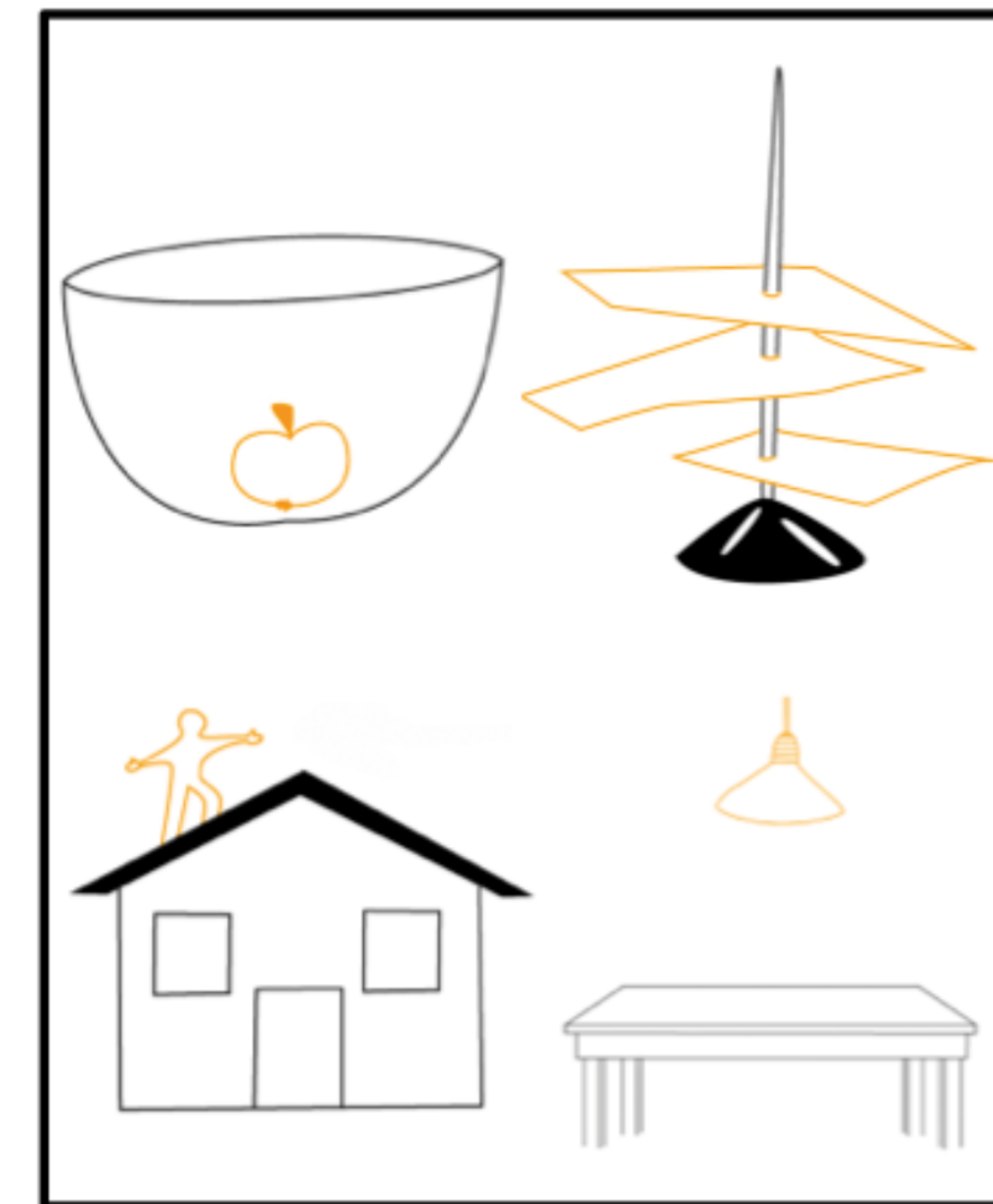


Can iterated learning give rise to informative languages?

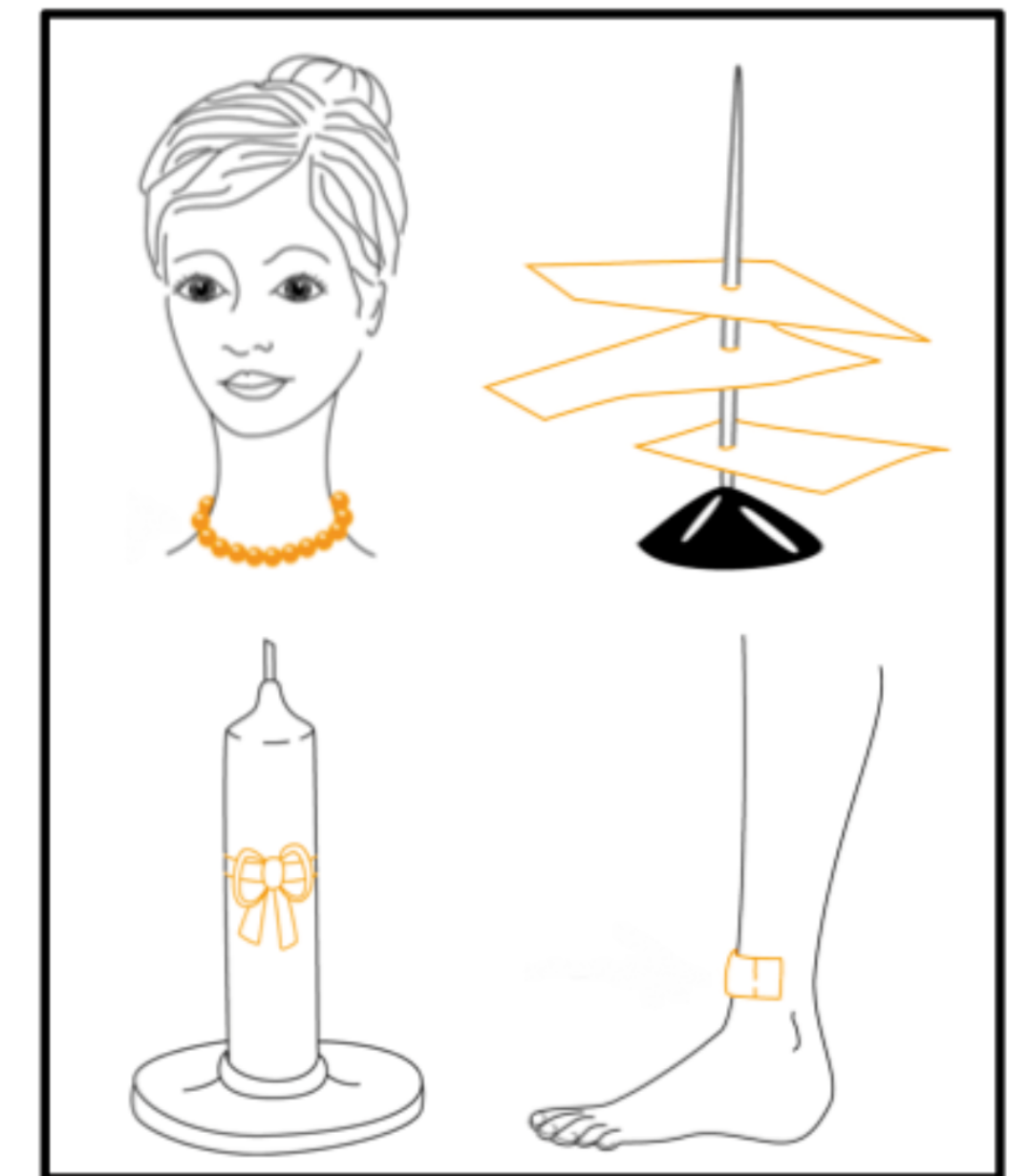
Carstensen, Xu, Smith, & Regier (2015)



Generation 0

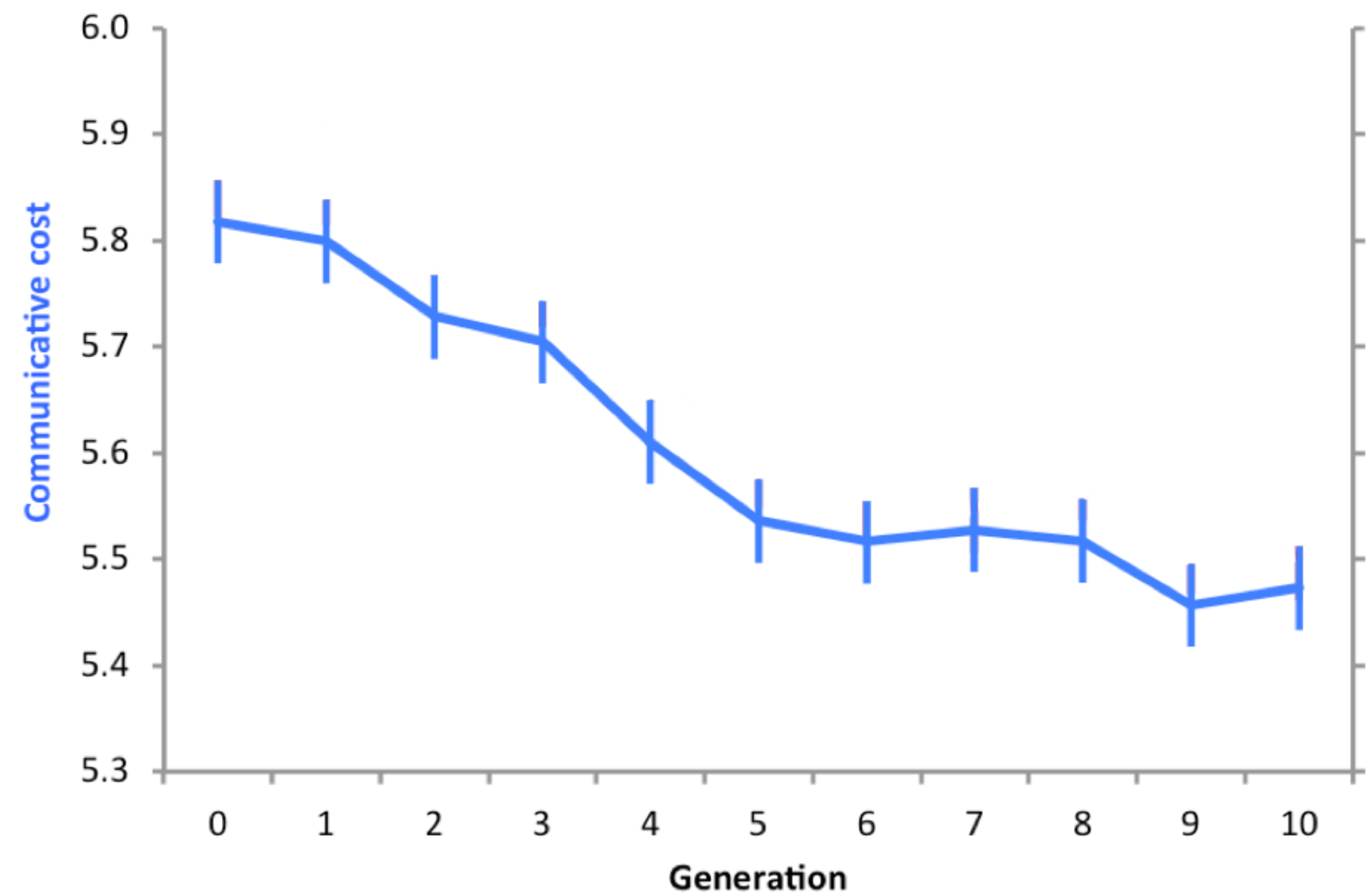
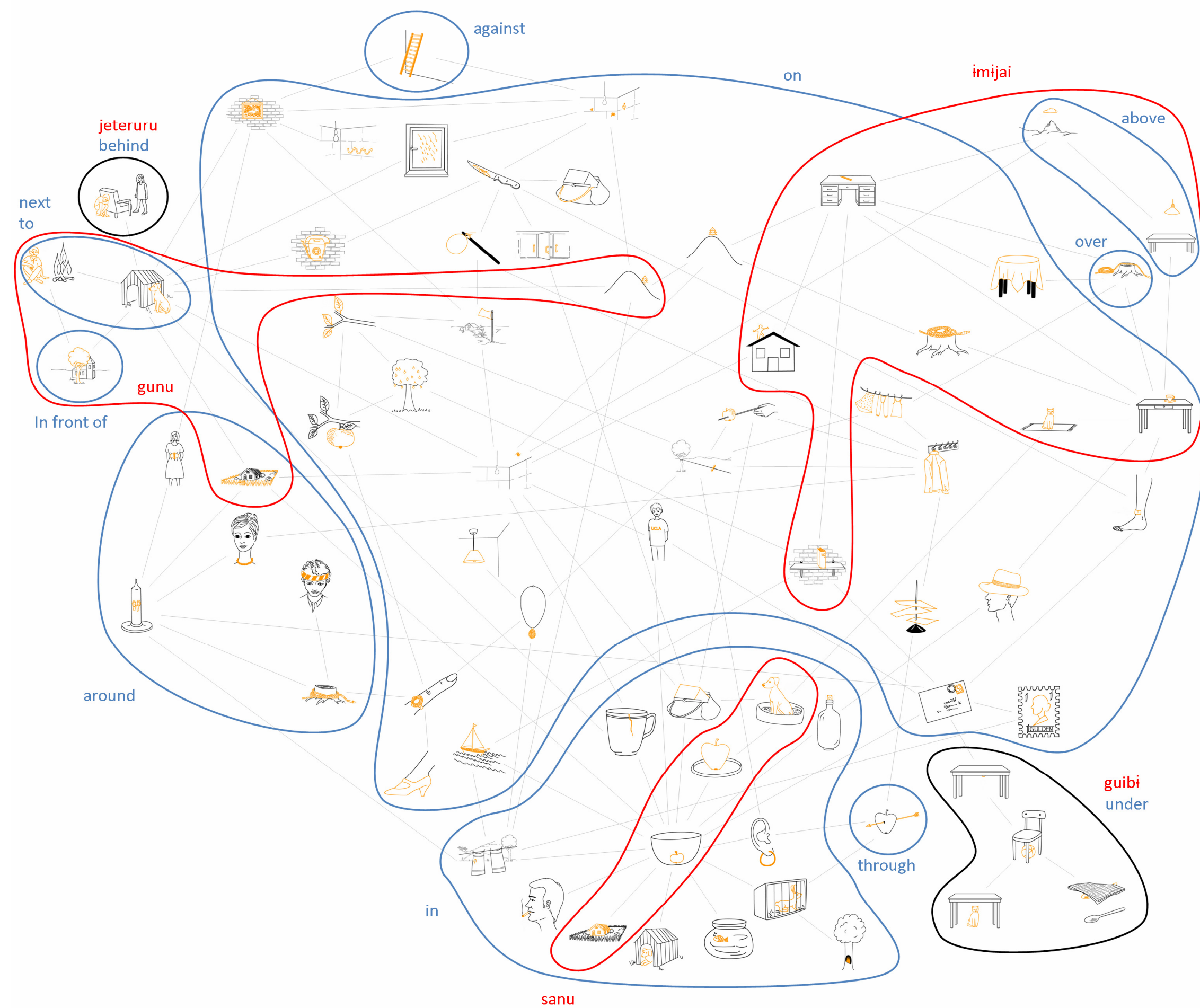


Generation 10

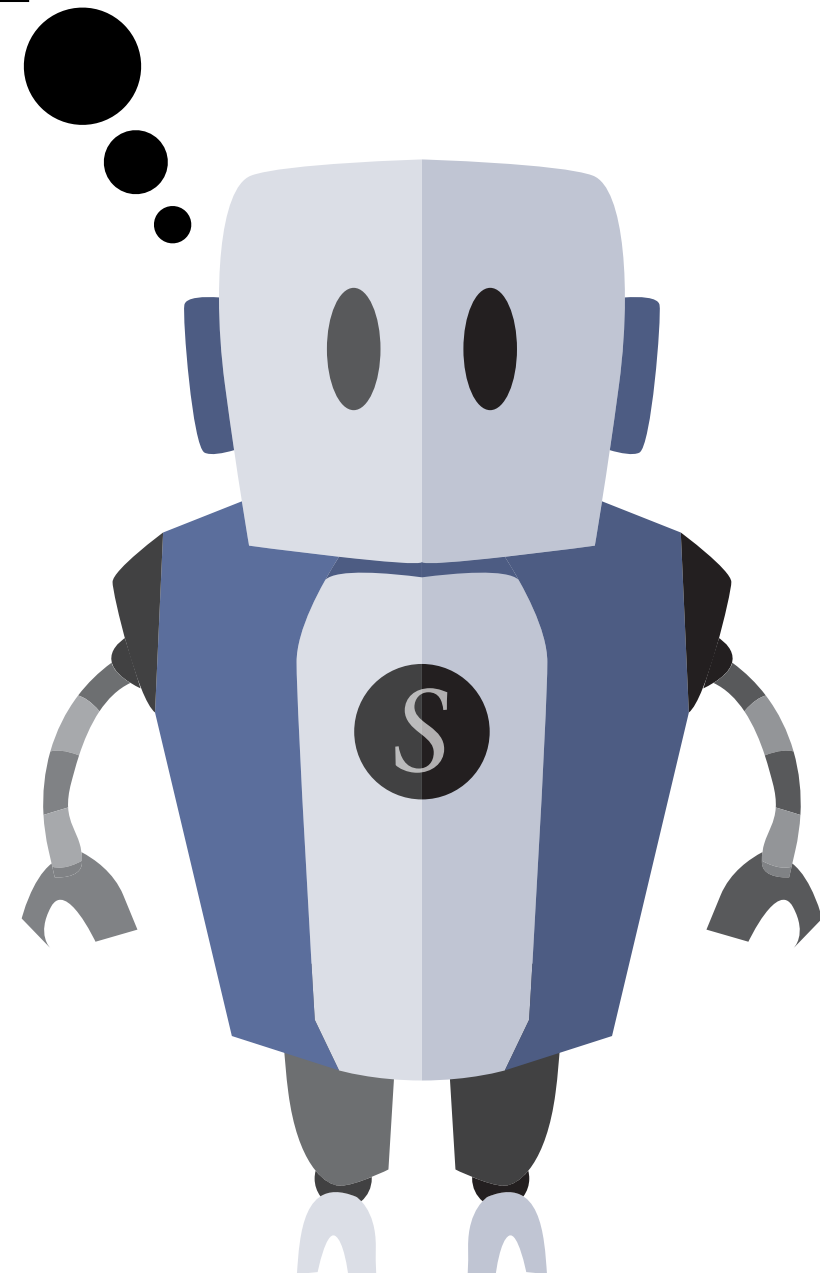
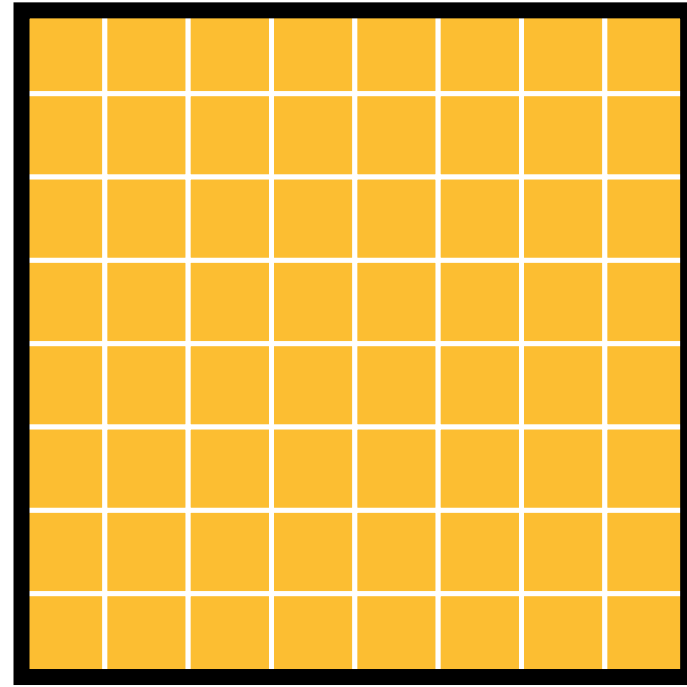


Can iterated learning give rise to informative languages?

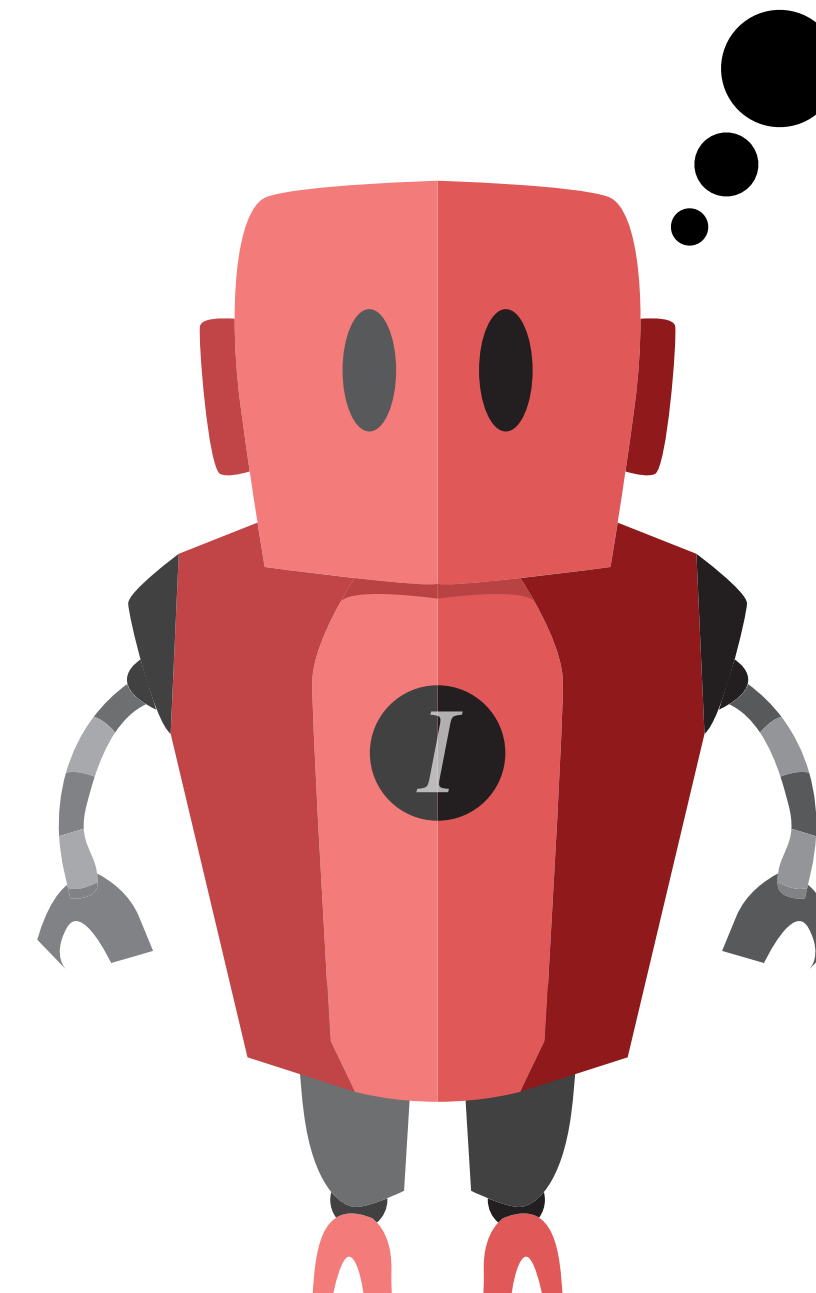
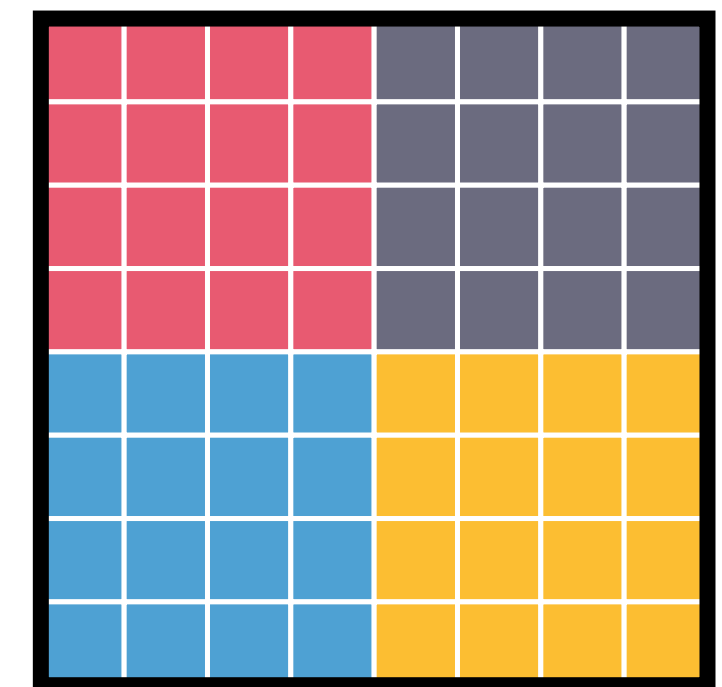
Carstensen, Xu, Smith, & Regier (2015)



Modelling a Bayesian learner



Simplicity bias



Informativeness bias

Bayesian inference

$$\mathcal{L} = \left\{ \begin{array}{c} \begin{array}{|c|c|c|c|} \hline \text{yellow} & \text{grey} & \text{grey} & \text{grey} \\ \hline \text{yellow} & \text{yellow} & \text{grey} & \text{grey} \\ \hline \text{yellow} & \text{yellow} & \text{blue} & \text{blue} \\ \hline \text{pink} & \text{blue} & \text{blue} & \text{blue} \\ \hline \end{array} \\ \begin{array}{|c|c|c|c|} \hline \text{pink} & \text{grey} & \text{grey} & \text{yellow} \\ \hline \text{pink} & \text{grey} & \text{pink} & \text{blue} \\ \hline \text{blue} & \text{grey} & \text{yellow} & \text{pink} \\ \hline \text{blue} & \text{blue} & \text{pink} & \text{yellow} \\ \hline \end{array} \\ \begin{array}{|c|c|c|c|} \hline \text{pink} & \text{pink} & \text{pink} & \text{pink} \\ \hline \text{blue} & \text{blue} & \text{blue} & \text{blue} \\ \hline \text{grey} & \text{grey} & \text{grey} & \text{grey} \\ \hline \text{yellow} & \text{yellow} & \text{yellow} & \text{yellow} \\ \hline \end{array} \\ \begin{array}{|c|c|c|c|} \hline \text{grey} & \text{grey} & \text{grey} & \text{pink} \\ \hline \text{grey} & \text{blue} & \text{blue} & \text{grey} \\ \hline \text{grey} & \text{blue} & \text{blue} & \text{pink} \\ \hline \text{blue} & \text{blue} & \text{pink} & \text{pink} \\ \hline \end{array} \\ \begin{array}{|c|c|c|c|} \hline \text{pink} & \text{pink} & \text{pink} & \text{blue} \\ \hline \text{blue} & \text{pink} & \text{pink} & \text{blue} \\ \hline \text{blue} & \text{pink} & \text{pink} & \text{blue} \\ \hline \text{pink} & \text{blue} & \text{pink} & \text{blue} \\ \hline \end{array} \\ \begin{array}{|c|c|c|c|} \hline \text{grey} & \text{grey} & \text{grey} & \text{grey} \\ \hline \text{grey} & \text{grey} & \text{grey} & \text{grey} \\ \hline \text{grey} & \text{grey} & \text{grey} & \text{grey} \\ \hline \text{grey} & \text{grey} & \text{grey} & \text{grey} \\ \hline \end{array} \\ \begin{array}{|c|c|c|c|} \hline \text{pink} & \text{pink} & \text{pink} & \text{pink} \\ \hline \text{blue} & \text{blue} & \text{blue} & \text{blue} \\ \hline \text{grey} & \text{grey} & \text{grey} & \text{grey} \\ \hline \text{grey} & \text{grey} & \text{grey} & \text{grey} \\ \hline \end{array} \\ \begin{array}{|c|c|c|c|} \hline \text{pink} & \text{pink} & \text{yellow} & \text{yellow} \\ \hline \text{grey} & \text{blue} & \text{yellow} & \text{pink} \\ \hline \text{pink} & \text{yellow} & \text{yellow} & \text{grey} \\ \hline \text{blue} & \text{blue} & \text{blue} & \text{grey} \\ \hline \end{array} \\ \begin{array}{|c|c|c|c|} \hline \text{blue} & \text{blue} & \text{pink} & \text{grey} \\ \hline \text{pink} & \text{grey} & \text{blue} & \text{grey} \\ \hline \text{yellow} & \text{yellow} & \text{yellow} & \text{yellow} \\ \hline \text{yellow} & \text{blue} & \text{grey} & \text{grey} \\ \hline \end{array} \end{array} \dots \right\}$$

Bayesian inference

$\mathcal{L} = \{$

Yellow	Grey	Grey	Grey
Yellow	Yellow	Grey	Grey
Yellow	Yellow	Blue	Blue
Pink	Blue	Blue	Blue

Pink	Grey	Grey	Yellow
Pink	Grey	Pink	Blue
Blue	Grey	Yellow	Pink
Blue	Blue	Pink	Yellow

Pink	Pink	Pink	Pink
Blue	Blue	Blue	Blue
Grey	Grey	Grey	Grey
Yellow	Yellow	Yellow	Yellow

Grey	Grey	Grey	Pink
Grey	Blue	Blue	Grey
Grey	Blue	Blue	Pink
Blue	Blue	Pink	Pink

Pink	Pink	Pink	Blue
Blue	Pink	Pink	Blue
Pink	Blue	Pink	Blue
Pink	Blue	Pink	Blue

Grey	Grey	Grey	Grey
Grey	Grey	Grey	Grey
Grey	Grey	Grey	Grey
Grey	Grey	Grey	Grey

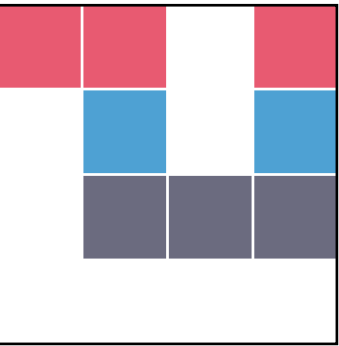
Pink	Pink	Pink	Pink
Blue	Blue	Blue	Blue
Grey	Grey	Grey	Grey
Grey	Grey	Grey	Grey

Pink	Pink	Yellow	Yellow
Grey	Blue	Yellow	Pink
Pink	Yellow	Yellow	Grey
Blue	Blue	Blue	Grey

Blue	Blue	Pink	Grey
Pink	Grey	Blue	Grey
Yellow	Yellow	Yellow	Yellow
Yellow	Blue	Grey	Grey

$\dots \}$

$D = [\langle m_1, s_1 \rangle, \langle m_2, s_2 \rangle, \langle m_3, s_3 \rangle, \dots, \langle m_n, s_n \rangle]$



Bayesian inference

$$\mathcal{L} = \left\{ \begin{array}{c} \begin{array}{|c|c|c|c|} \hline \text{yellow} & \text{grey} & \text{grey} & \text{grey} \\ \hline \text{yellow} & \text{yellow} & \text{grey} & \text{grey} \\ \hline \text{yellow} & \text{yellow} & \text{blue} & \text{blue} \\ \hline \text{pink} & \text{blue} & \text{blue} & \text{blue} \\ \hline \end{array} & \begin{array}{|c|c|c|c|} \hline \text{pink} & \text{grey} & \text{grey} & \text{yellow} \\ \hline \text{pink} & \text{grey} & \text{pink} & \text{blue} \\ \hline \text{blue} & \text{grey} & \text{yellow} & \text{pink} \\ \hline \text{blue} & \text{blue} & \text{pink} & \text{yellow} \\ \hline \end{array} & \begin{array}{|c|c|c|c|} \hline \text{pink} & \text{pink} & \text{pink} & \text{pink} \\ \hline \text{blue} & \text{blue} & \text{blue} & \text{blue} \\ \hline \text{grey} & \text{grey} & \text{grey} & \text{grey} \\ \hline \text{yellow} & \text{yellow} & \text{yellow} & \text{yellow} \\ \hline \end{array} & \begin{array}{|c|c|c|c|} \hline \text{grey} & \text{grey} & \text{grey} & \text{pink} \\ \hline \text{grey} & \text{blue} & \text{blue} & \text{grey} \\ \hline \text{grey} & \text{blue} & \text{blue} & \text{pink} \\ \hline \text{blue} & \text{blue} & \text{pink} & \text{pink} \\ \hline \end{array} & \begin{array}{|c|c|c|c|} \hline \text{pink} & \text{pink} & \text{pink} & \text{pink} \\ \hline \text{blue} & \text{pink} & \text{pink} & \text{blue} \\ \hline \text{blue} & \text{pink} & \text{pink} & \text{blue} \\ \hline \text{pink} & \text{blue} & \text{pink} & \text{blue} \\ \hline \end{array} & \begin{array}{|c|c|c|c|} \hline \text{grey} & \text{grey} & \text{grey} & \text{grey} \\ \hline \text{grey} & \text{grey} & \text{grey} & \text{grey} \\ \hline \text{grey} & \text{grey} & \text{grey} & \text{grey} \\ \hline \text{grey} & \text{grey} & \text{grey} & \text{grey} \\ \hline \end{array} & \begin{array}{|c|c|c|c|} \hline \text{pink} & \text{pink} & \text{pink} & \text{pink} \\ \hline \text{blue} & \text{blue} & \text{blue} & \text{blue} \\ \hline \text{grey} & \text{grey} & \text{grey} & \text{grey} \\ \hline \text{grey} & \text{grey} & \text{grey} & \text{grey} \\ \hline \end{array} & \begin{array}{|c|c|c|c|} \hline \text{pink} & \text{pink} & \text{yellow} & \text{yellow} \\ \hline \text{grey} & \text{blue} & \text{yellow} & \text{pink} \\ \hline \text{pink} & \text{yellow} & \text{yellow} & \text{grey} \\ \hline \text{blue} & \text{blue} & \text{blue} & \text{grey} \\ \hline \end{array} & \begin{array}{|c|c|c|c|} \hline \text{blue} & \text{blue} & \text{pink} & \text{grey} \\ \hline \text{pink} & \text{grey} & \text{blue} & \text{grey} \\ \hline \text{yellow} & \text{yellow} & \text{yellow} & \text{yellow} \\ \hline \text{yellow} & \text{blue} & \text{grey} & \text{grey} \\ \hline \end{array} \dots \end{array} \right\}$$

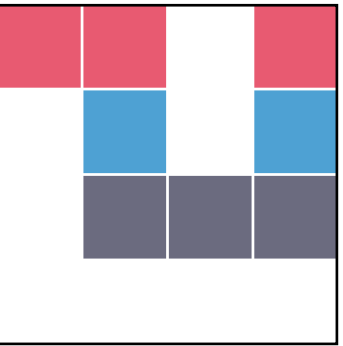
$$D = [\langle m_1, s_1 \rangle, \langle m_2, s_2 \rangle, \langle m_3, s_3 \rangle, \dots, \langle m_n, s_n \rangle]$$

$$\text{likelihood}(D|L) = \prod_{\langle m, s \rangle} P(s|L, m)$$

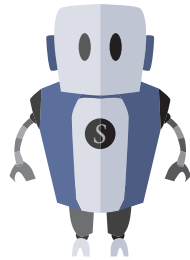
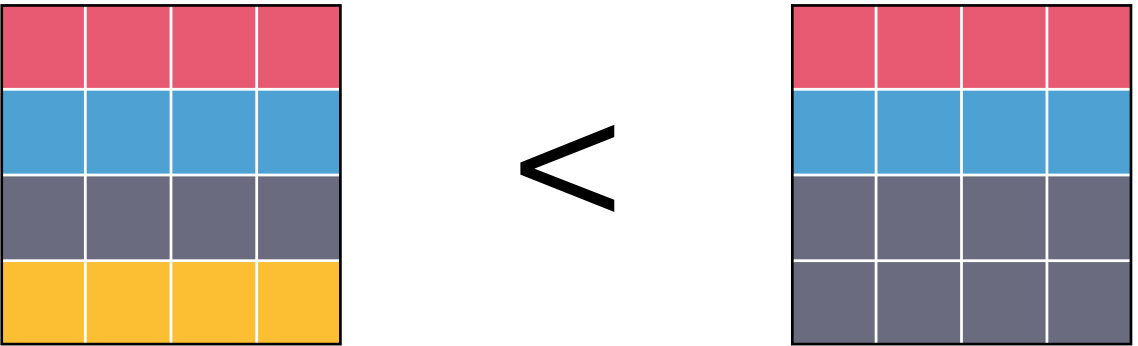
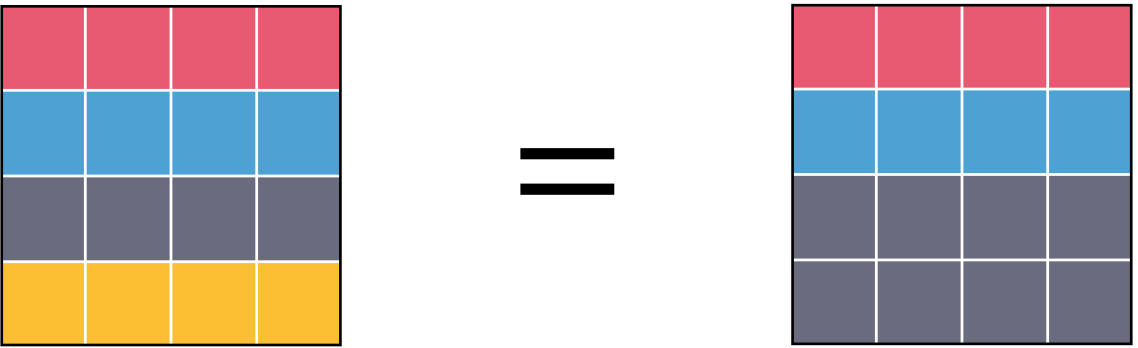
Bayesian inference

$$\mathcal{L} = \left\{ \begin{array}{c} \begin{array}{|c|c|c|c|} \hline \text{yellow} & \text{grey} & \text{grey} & \text{grey} \\ \hline \text{yellow} & \text{yellow} & \text{grey} & \text{grey} \\ \hline \text{yellow} & \text{yellow} & \text{blue} & \text{blue} \\ \hline \text{pink} & \text{blue} & \text{blue} & \text{blue} \\ \hline \end{array} \\ \begin{array}{|c|c|c|c|} \hline \text{pink} & \text{grey} & \text{grey} & \text{yellow} \\ \hline \text{pink} & \text{grey} & \text{pink} & \text{blue} \\ \hline \text{blue} & \text{grey} & \text{yellow} & \text{pink} \\ \hline \text{blue} & \text{blue} & \text{pink} & \text{yellow} \\ \hline \end{array} \\ \begin{array}{|c|c|c|c|} \hline \text{pink} & \text{pink} & \text{pink} & \text{pink} \\ \hline \text{blue} & \text{blue} & \text{blue} & \text{blue} \\ \hline \text{grey} & \text{grey} & \text{grey} & \text{grey} \\ \hline \text{yellow} & \text{yellow} & \text{yellow} & \text{yellow} \\ \hline \end{array} \\ \begin{array}{|c|c|c|c|} \hline \text{grey} & \text{grey} & \text{grey} & \text{pink} \\ \hline \text{grey} & \text{blue} & \text{blue} & \text{grey} \\ \hline \text{grey} & \text{blue} & \text{blue} & \text{pink} \\ \hline \text{blue} & \text{blue} & \text{pink} & \text{pink} \\ \hline \end{array} \\ \begin{array}{|c|c|c|c|} \hline \text{pink} & \text{pink} & \text{pink} & \text{blue} \\ \hline \text{blue} & \text{pink} & \text{pink} & \text{blue} \\ \hline \text{blue} & \text{pink} & \text{pink} & \text{blue} \\ \hline \text{pink} & \text{blue} & \text{pink} & \text{blue} \\ \hline \end{array} \\ \begin{array}{|c|c|c|c|} \hline \text{grey} & \text{grey} & \text{grey} & \text{grey} \\ \hline \text{grey} & \text{grey} & \text{grey} & \text{grey} \\ \hline \text{grey} & \text{grey} & \text{grey} & \text{grey} \\ \hline \text{grey} & \text{grey} & \text{grey} & \text{grey} \\ \hline \end{array} \\ \begin{array}{|c|c|c|c|} \hline \text{pink} & \text{pink} & \text{pink} & \text{pink} \\ \hline \text{blue} & \text{blue} & \text{blue} & \text{blue} \\ \hline \text{grey} & \text{grey} & \text{grey} & \text{grey} \\ \hline \text{grey} & \text{grey} & \text{grey} & \text{grey} \\ \hline \end{array} \\ \begin{array}{|c|c|c|c|} \hline \text{pink} & \text{pink} & \text{yellow} & \text{yellow} \\ \hline \text{grey} & \text{blue} & \text{yellow} & \text{pink} \\ \hline \text{pink} & \text{yellow} & \text{yellow} & \text{grey} \\ \hline \text{blue} & \text{blue} & \text{blue} & \text{grey} \\ \hline \end{array} \\ \begin{array}{|c|c|c|c|} \hline \text{blue} & \text{blue} & \text{pink} & \text{grey} \\ \hline \text{pink} & \text{grey} & \text{blue} & \text{grey} \\ \hline \text{yellow} & \text{yellow} & \text{yellow} & \text{yellow} \\ \hline \text{yellow} & \text{blue} & \text{grey} & \text{grey} \\ \hline \end{array} \end{array} \dots \right\}$$

$$D = [\langle m_1, s_1 \rangle, \langle m_2, s_2 \rangle, \langle m_3, s_3 \rangle, \dots, \langle m_n, s_n \rangle]$$



$$\text{likelihood}(D|L) = \prod_{\langle m, s \rangle} P(s|L, m)$$

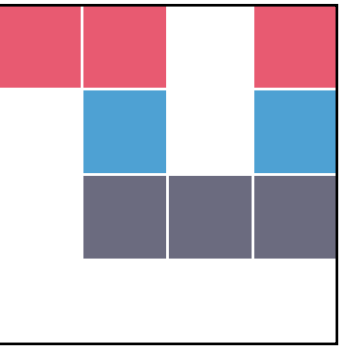


$$\text{prior}(L) \propto 2^{-\text{complexity}(L)}$$

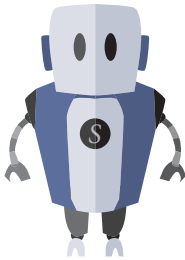
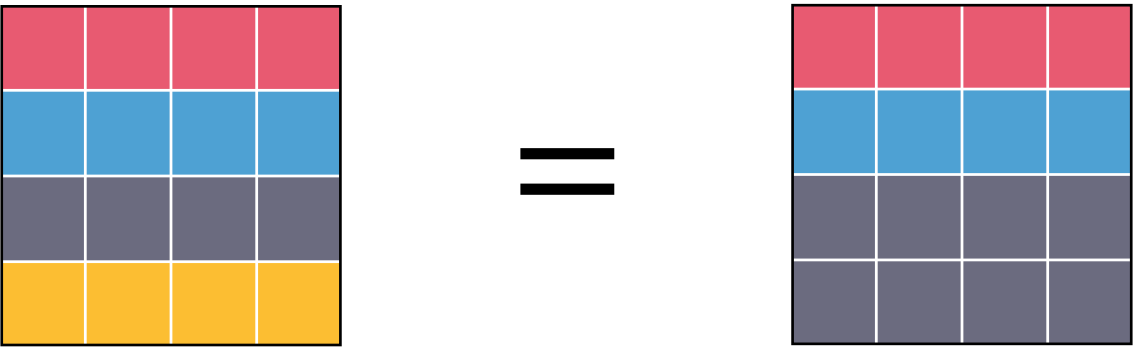
Bayesian inference

$$\mathcal{L} = \left\{ \begin{array}{c} \begin{array}{|c|c|c|c|} \hline \text{yellow} & \text{grey} & \text{grey} & \text{grey} \\ \hline \text{yellow} & \text{yellow} & \text{grey} & \text{grey} \\ \hline \text{yellow} & \text{yellow} & \text{blue} & \text{blue} \\ \hline \text{pink} & \text{blue} & \text{blue} & \text{blue} \\ \hline \end{array} & \begin{array}{|c|c|c|c|} \hline \text{pink} & \text{grey} & \text{grey} & \text{yellow} \\ \hline \text{pink} & \text{grey} & \text{pink} & \text{blue} \\ \hline \text{blue} & \text{grey} & \text{yellow} & \text{pink} \\ \hline \text{blue} & \text{blue} & \text{pink} & \text{yellow} \\ \hline \end{array} & \begin{array}{|c|c|c|c|} \hline \text{pink} & \text{pink} & \text{pink} & \text{pink} \\ \hline \text{blue} & \text{blue} & \text{blue} & \text{blue} \\ \hline \text{grey} & \text{grey} & \text{grey} & \text{grey} \\ \hline \text{yellow} & \text{yellow} & \text{yellow} & \text{yellow} \\ \hline \end{array} & \begin{array}{|c|c|c|c|} \hline \text{grey} & \text{grey} & \text{grey} & \text{pink} \\ \hline \text{grey} & \text{blue} & \text{blue} & \text{grey} \\ \hline \text{grey} & \text{blue} & \text{blue} & \text{pink} \\ \hline \text{blue} & \text{blue} & \text{pink} & \text{pink} \\ \hline \end{array} & \begin{array}{|c|c|c|c|} \hline \text{pink} & \text{pink} & \text{pink} & \text{blue} \\ \hline \text{blue} & \text{pink} & \text{pink} & \text{blue} \\ \hline \text{blue} & \text{pink} & \text{pink} & \text{blue} \\ \hline \text{pink} & \text{blue} & \text{pink} & \text{blue} \\ \hline \end{array} & \begin{array}{|c|c|c|c|} \hline \text{grey} & \text{grey} & \text{grey} & \text{grey} \\ \hline \text{grey} & \text{grey} & \text{grey} & \text{grey} \\ \hline \text{grey} & \text{grey} & \text{grey} & \text{grey} \\ \hline \text{grey} & \text{grey} & \text{grey} & \text{grey} \\ \hline \end{array} & \begin{array}{|c|c|c|c|} \hline \text{pink} & \text{pink} & \text{pink} & \text{pink} \\ \hline \text{blue} & \text{blue} & \text{blue} & \text{blue} \\ \hline \text{grey} & \text{grey} & \text{grey} & \text{grey} \\ \hline \text{grey} & \text{grey} & \text{grey} & \text{grey} \\ \hline \end{array} & \begin{array}{|c|c|c|c|} \hline \text{pink} & \text{pink} & \text{yellow} & \text{yellow} \\ \hline \text{grey} & \text{blue} & \text{yellow} & \text{pink} \\ \hline \text{pink} & \text{yellow} & \text{yellow} & \text{grey} \\ \hline \text{blue} & \text{blue} & \text{blue} & \text{grey} \\ \hline \end{array} & \begin{array}{|c|c|c|c|} \hline \text{blue} & \text{blue} & \text{pink} & \text{grey} \\ \hline \text{pink} & \text{grey} & \text{blue} & \text{grey} \\ \hline \text{yellow} & \text{yellow} & \text{yellow} & \text{yellow} \\ \hline \text{yellow} & \text{blue} & \text{grey} & \text{grey} \\ \hline \end{array} \dots \end{array} \right\}$$

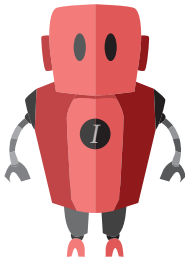
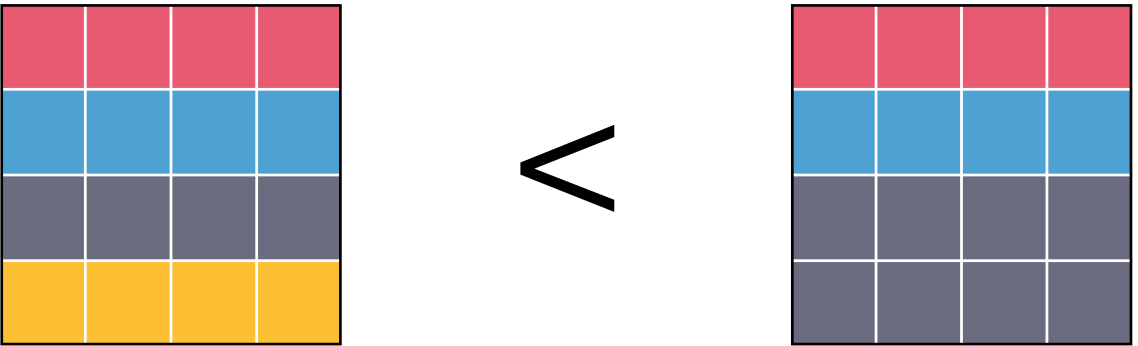
$$D = [\langle m_1, s_1 \rangle, \langle m_2, s_2 \rangle, \langle m_3, s_3 \rangle, \dots, \langle m_n, s_n \rangle]$$



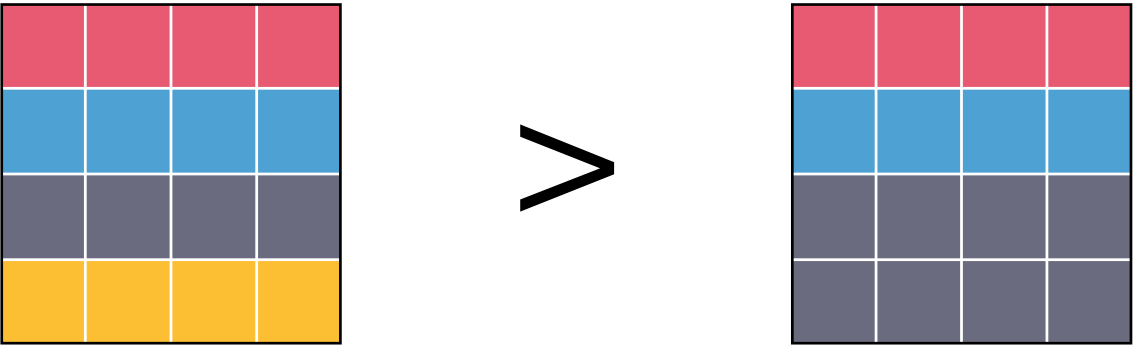
$$\text{likelihood}(D|L) = \prod_{\langle m, s \rangle} P(s|L, m)$$



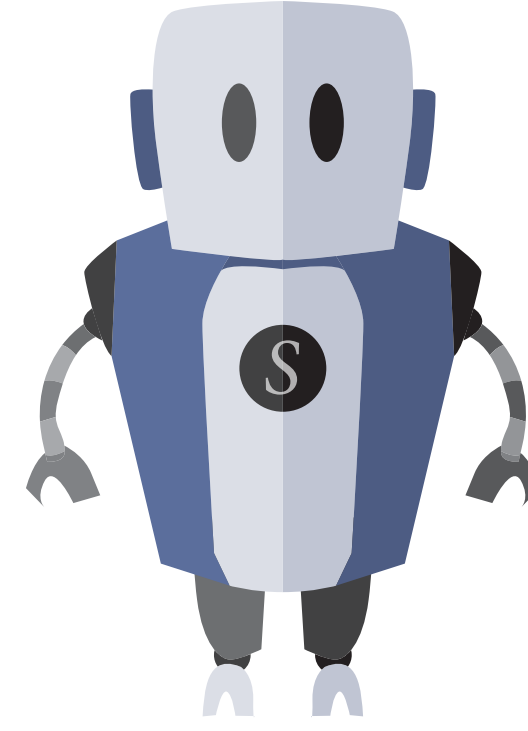
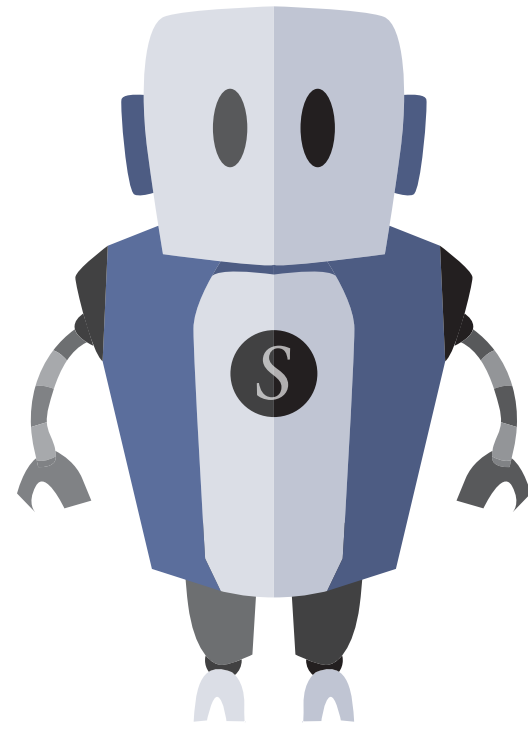
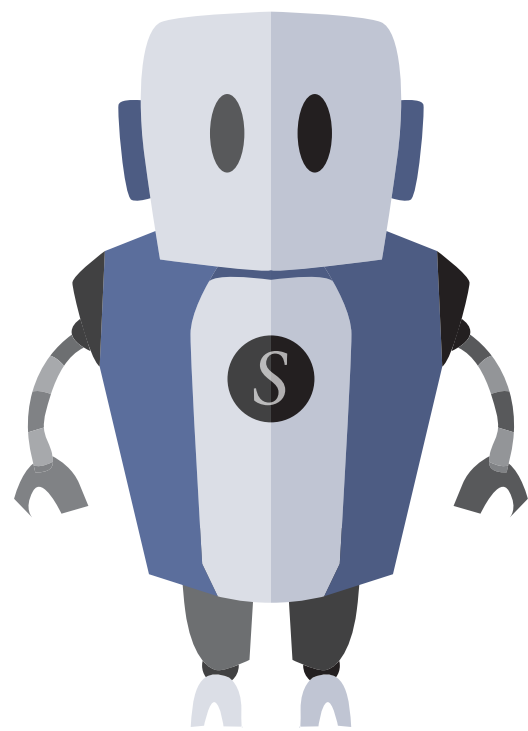
$$\text{prior}(L) \propto 2^{-\text{complexity}(L)}$$



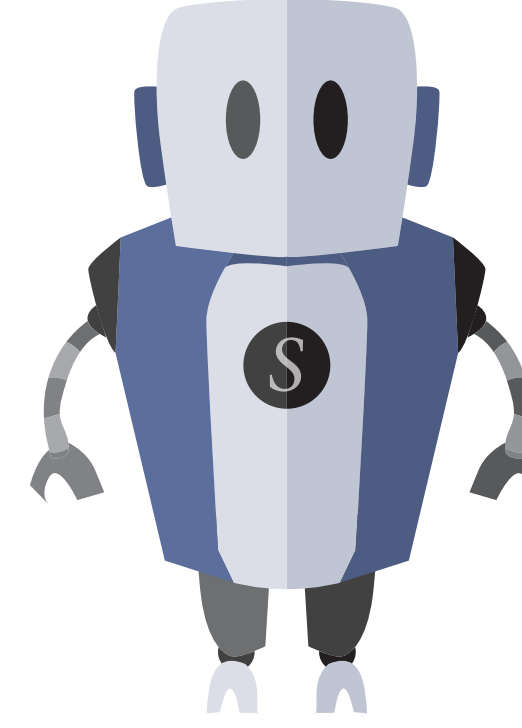
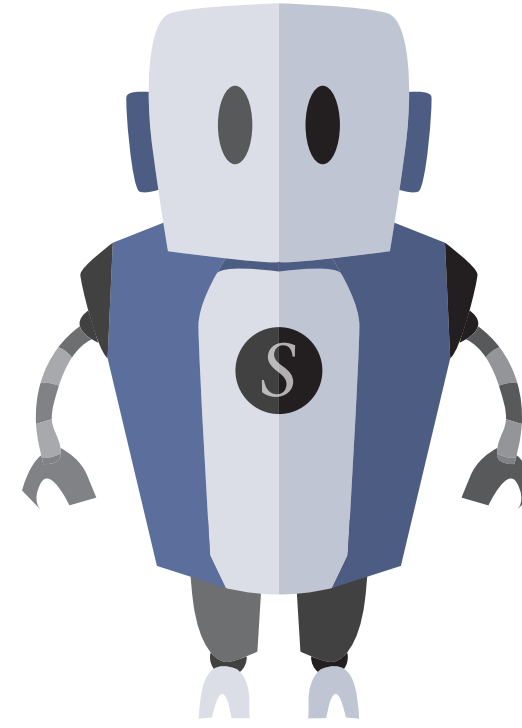
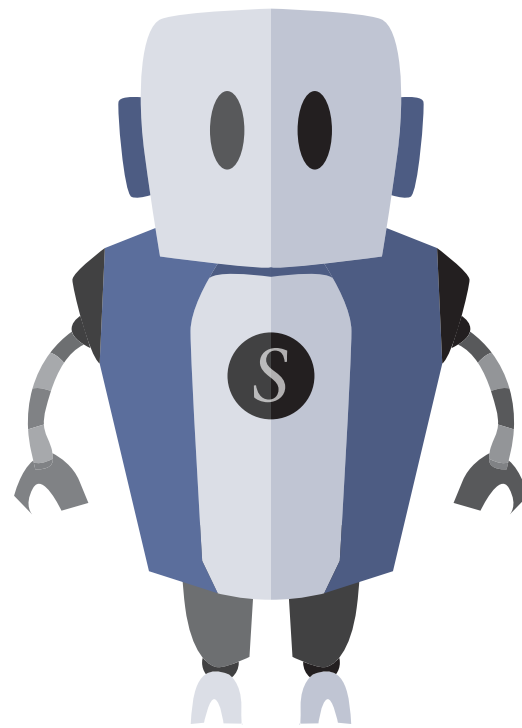
$$\text{prior}(L) \propto 2^{-\text{cost}(L)}$$



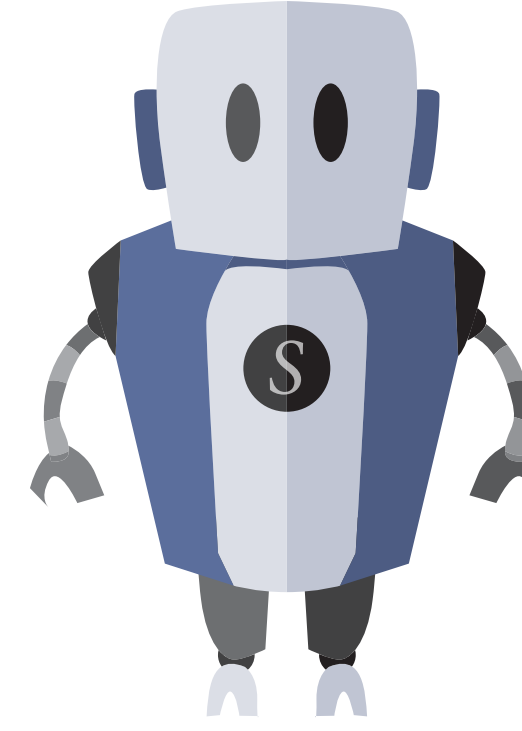
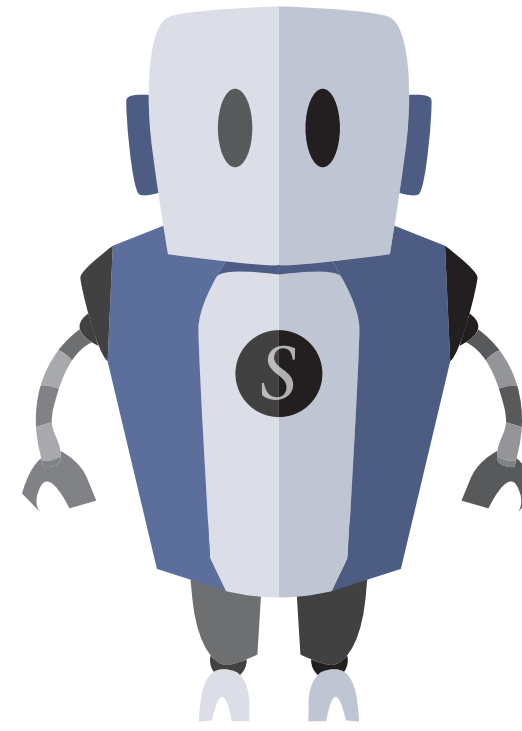
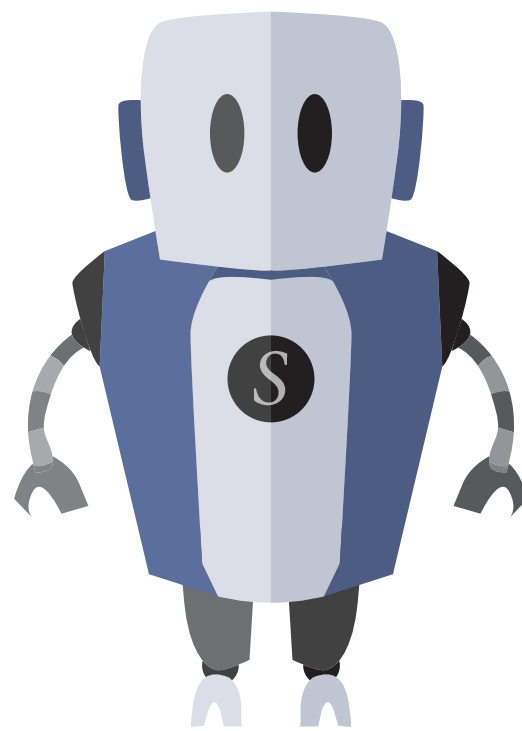
Bayesian iterated learning under a **simplicity** prior



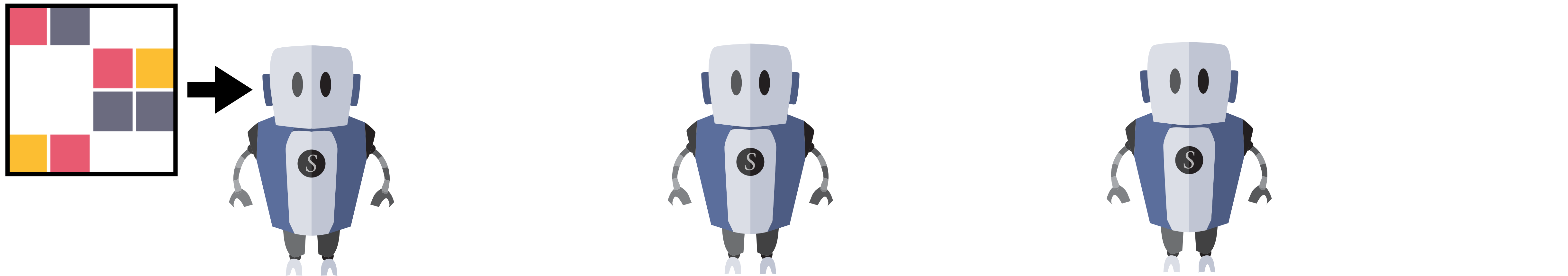
Bayesian iterated learning under a **simplicity** prior



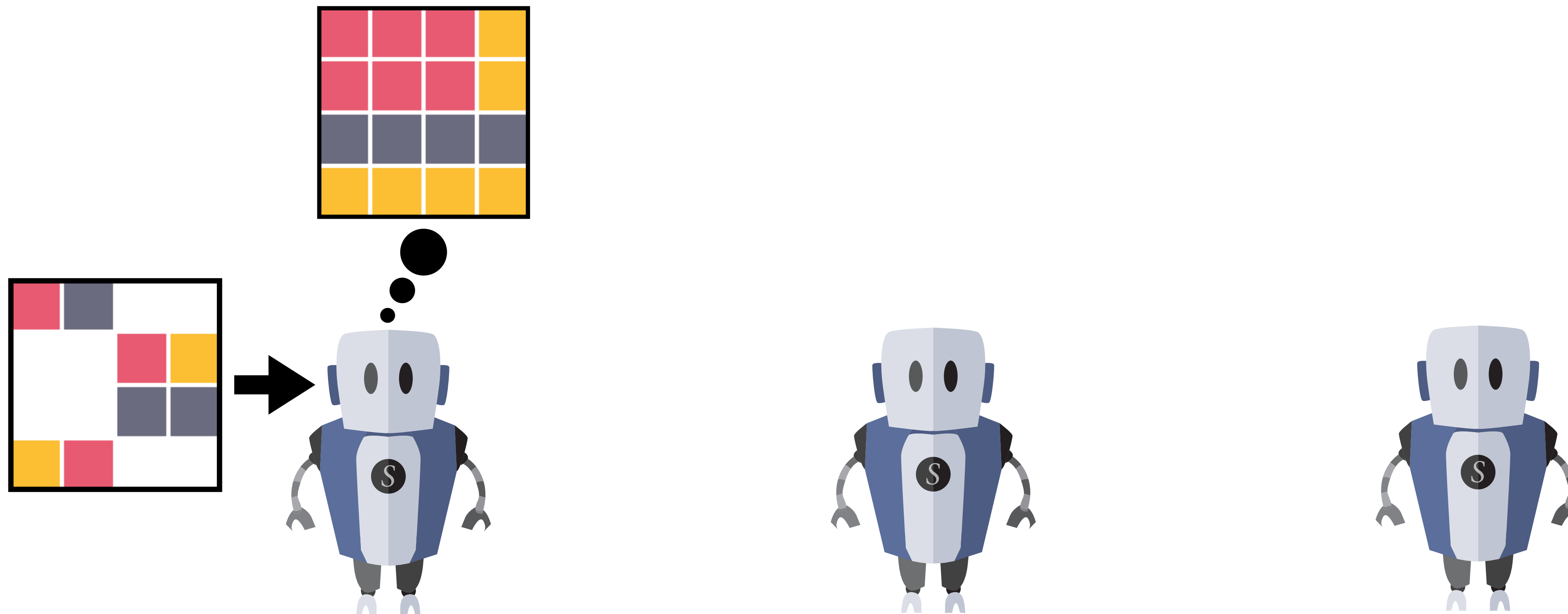
Bayesian iterated learning under a **simplicity** prior



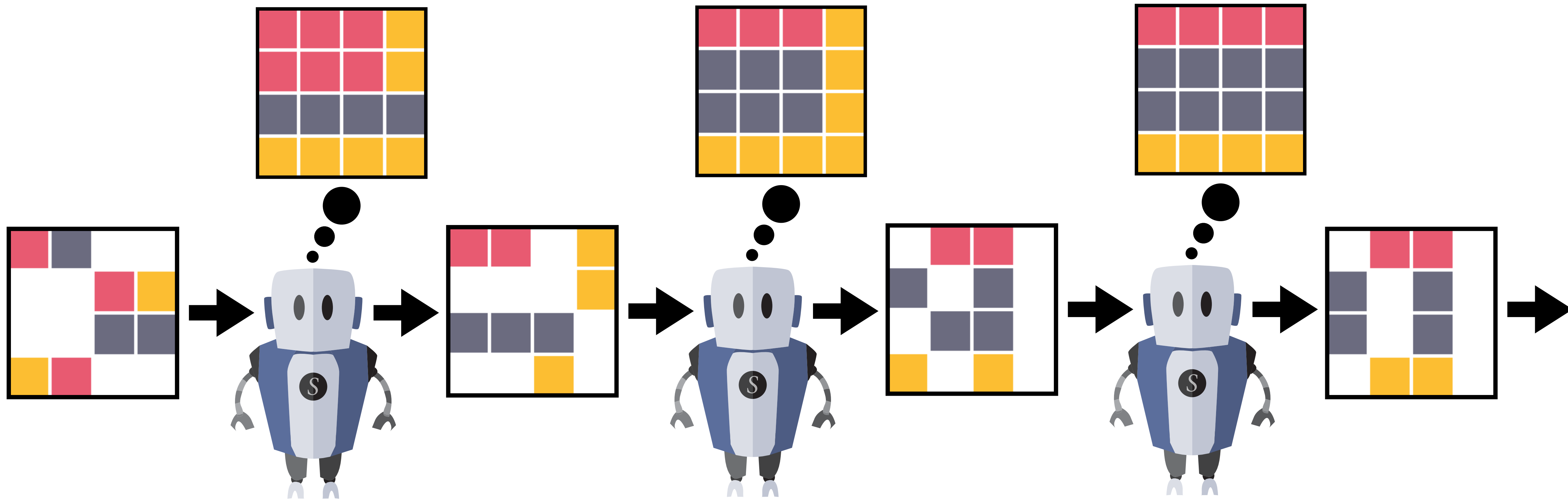
Bayesian iterated learning under a **simplicity** prior



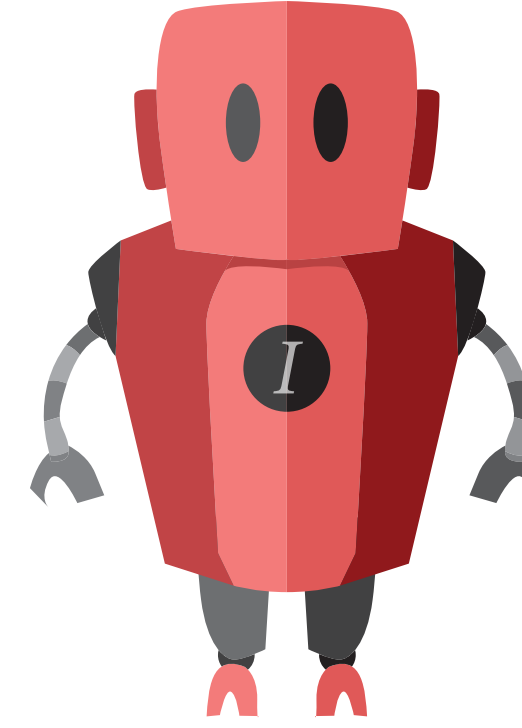
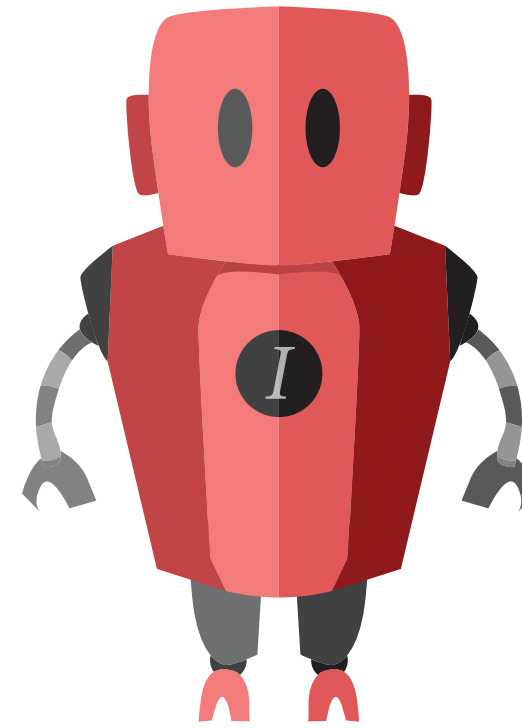
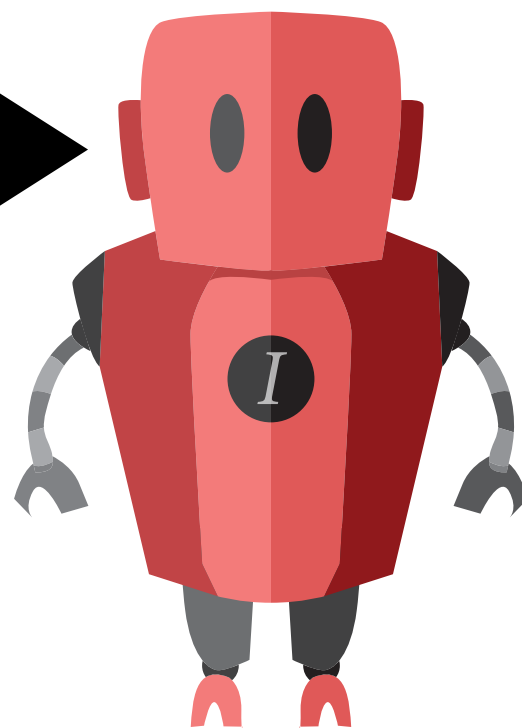
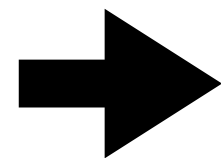
Bayesian iterated learning under a **simplicity** prior



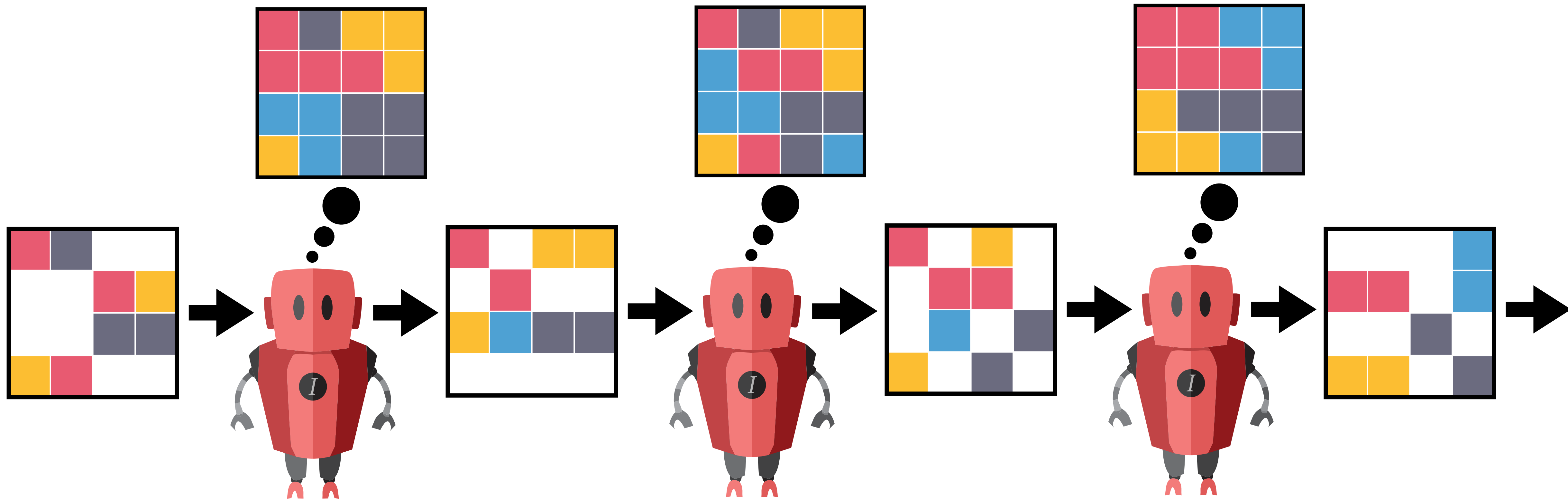
Bayesian iterated learning under a **simplicity** prior



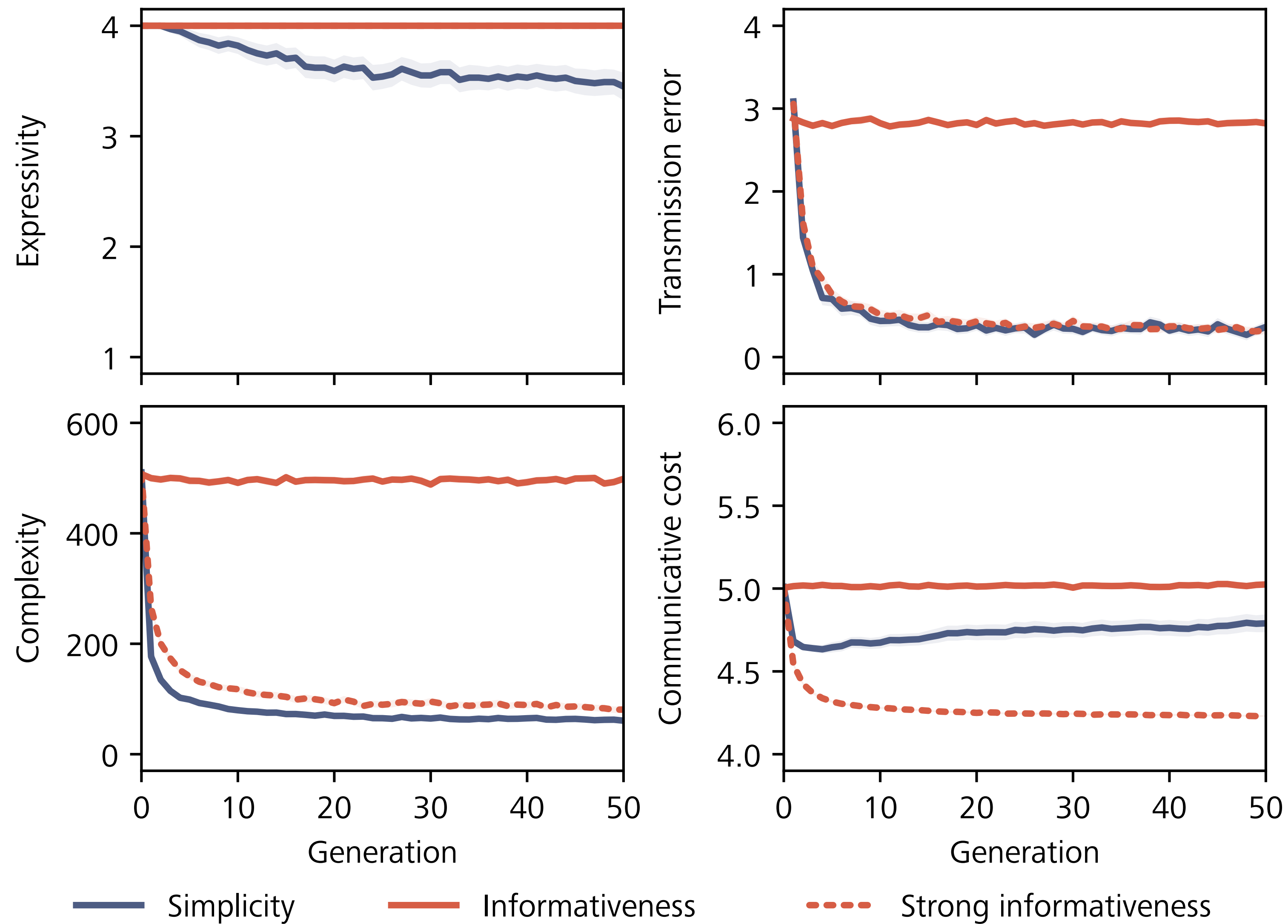
Bayesian iterated learning under an **informativeness prior**



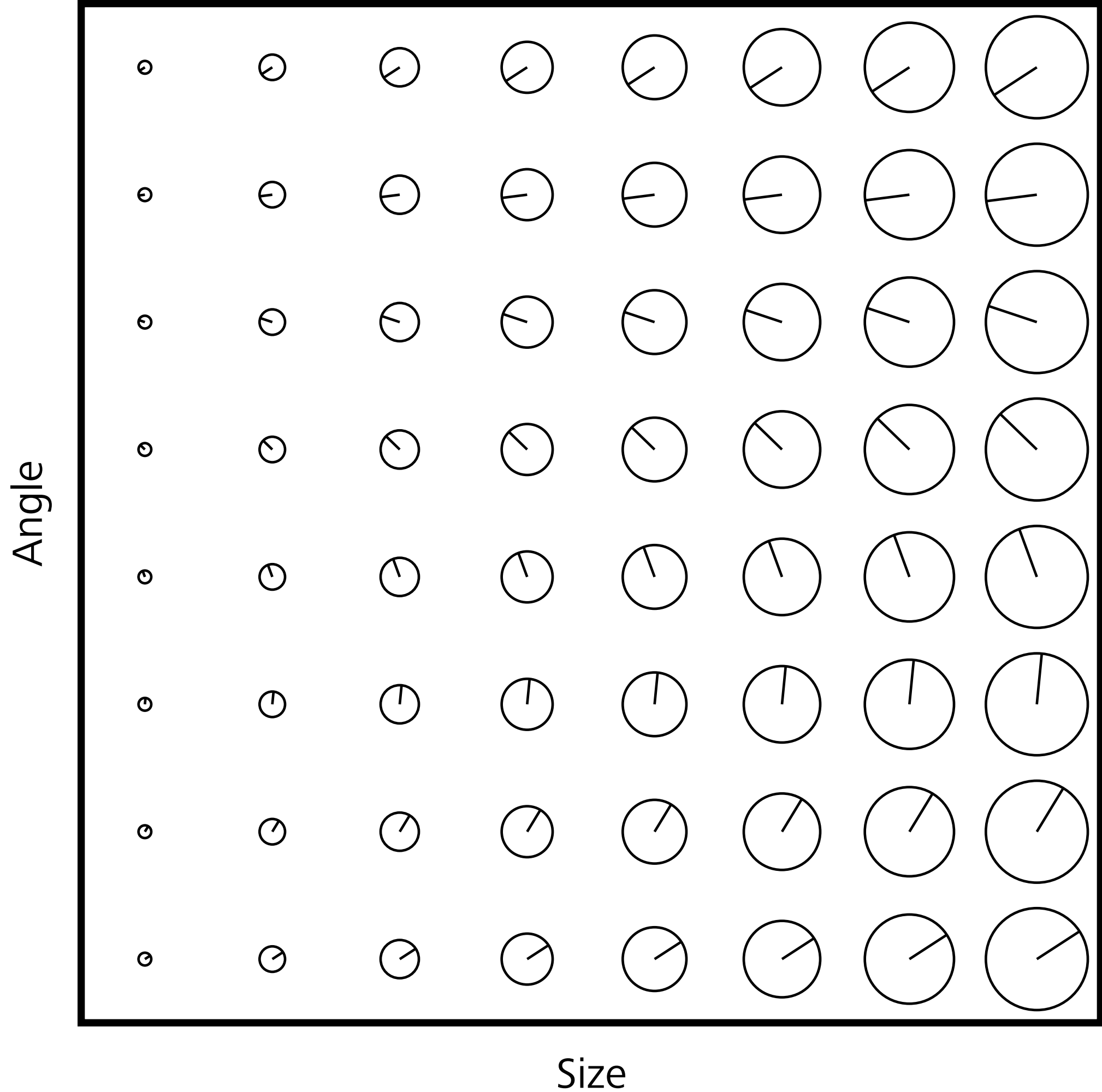
Bayesian iterated learning under an **informativeness** prior



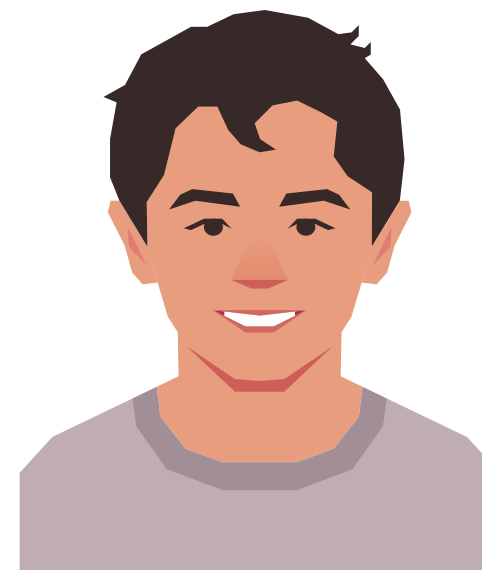
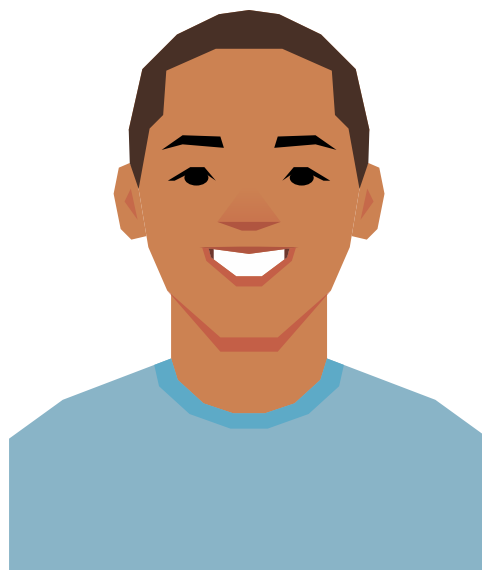
Model results



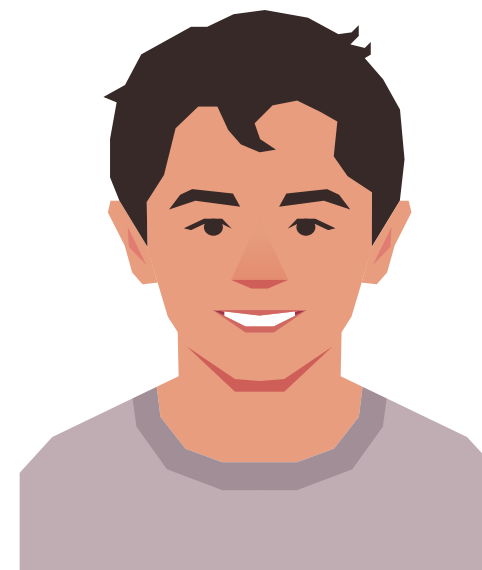
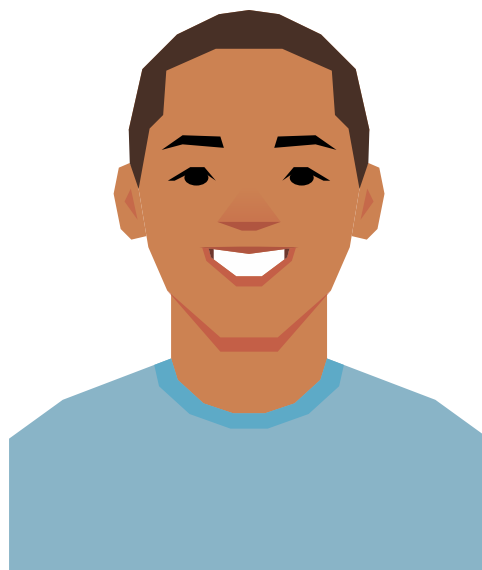
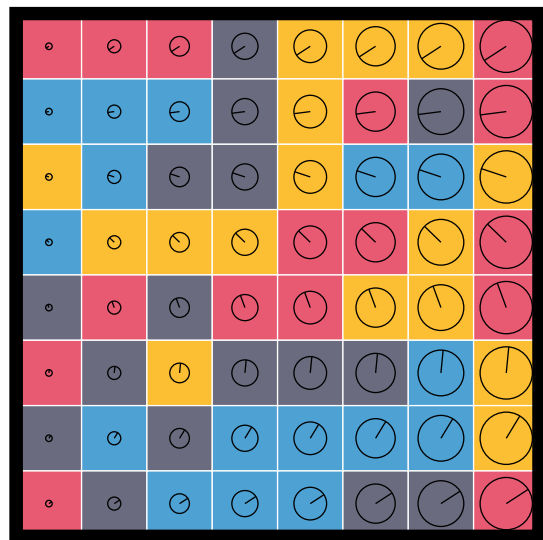
Experimental stimuli



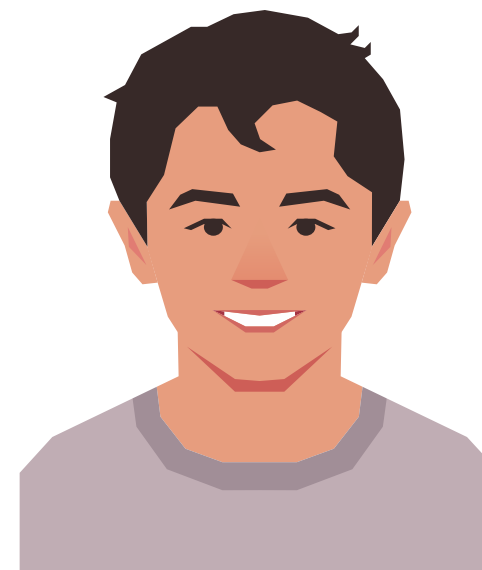
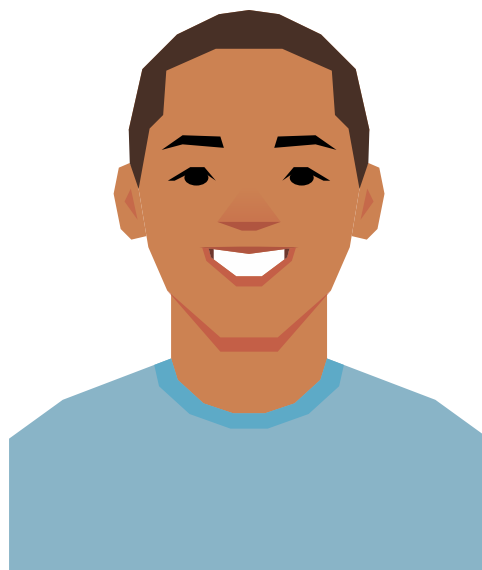
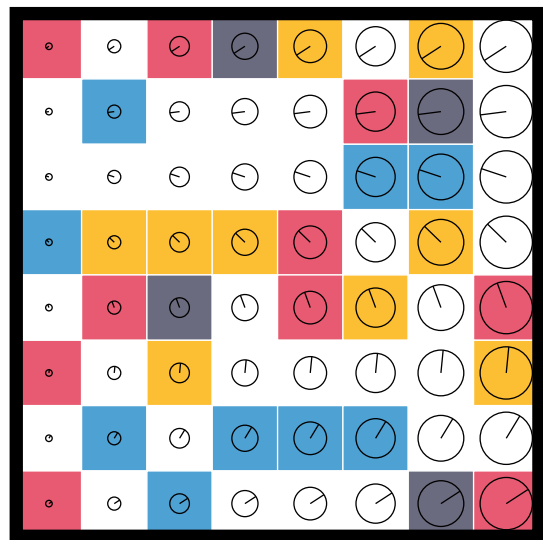
Iterated learning with humans



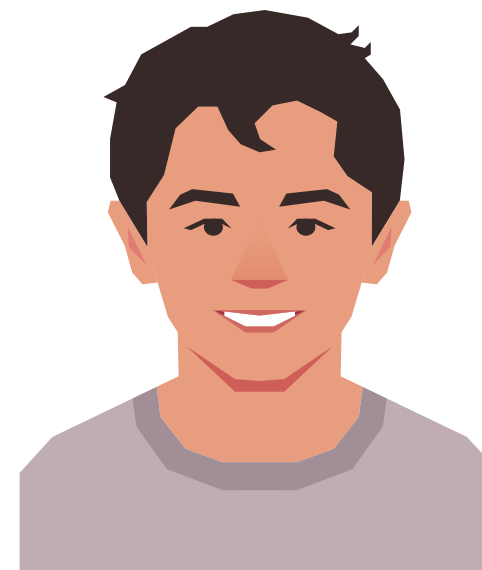
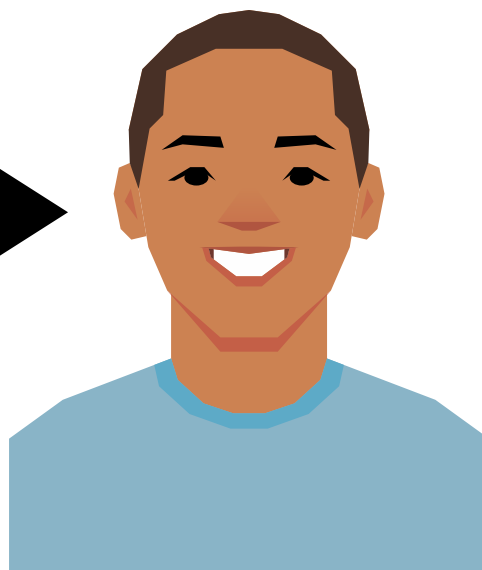
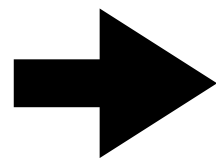
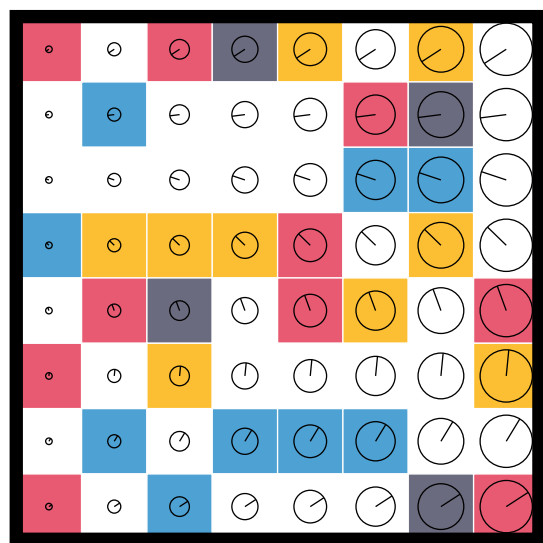
Iterated learning with humans



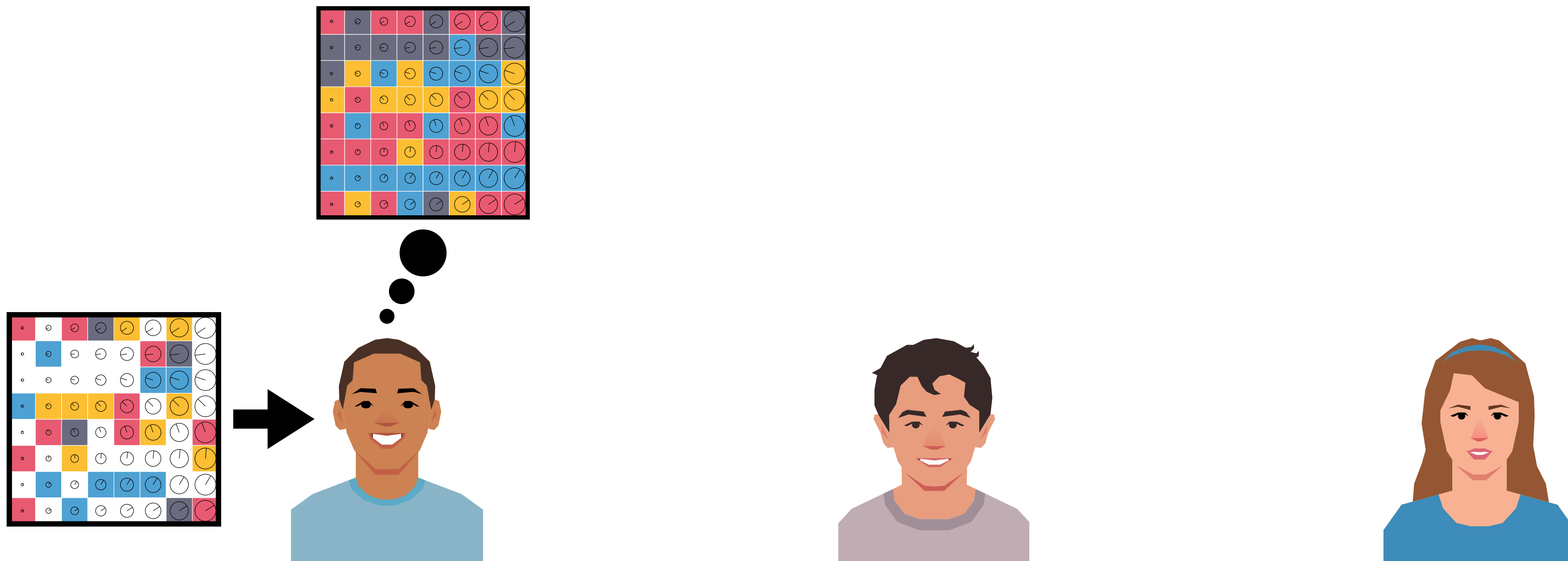
Iterated learning with humans



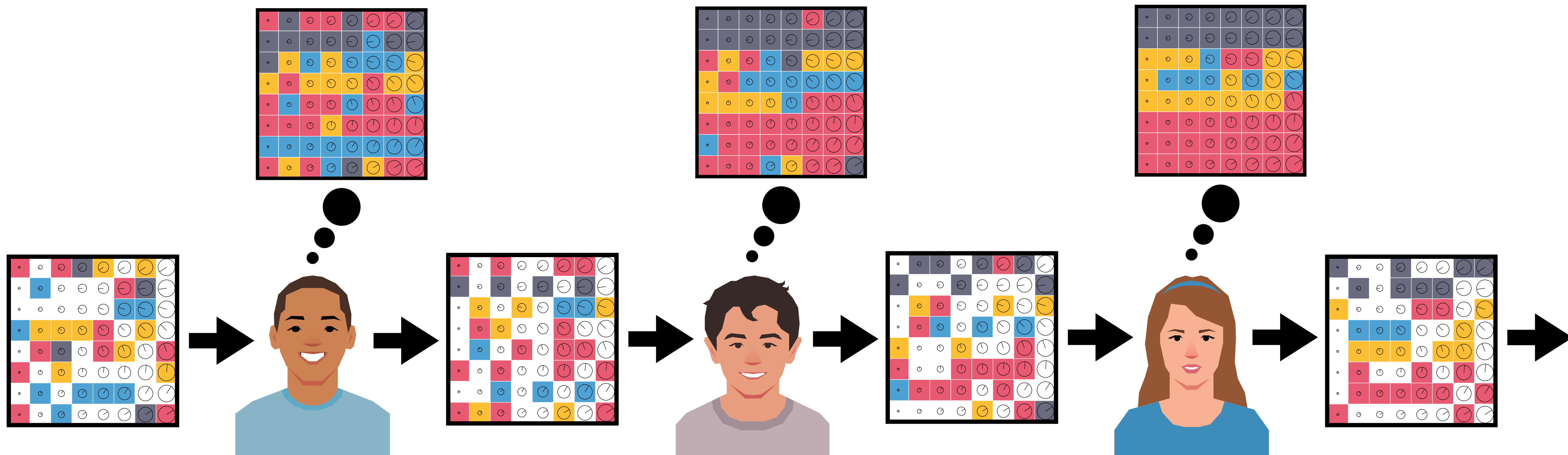
Iterated learning with humans

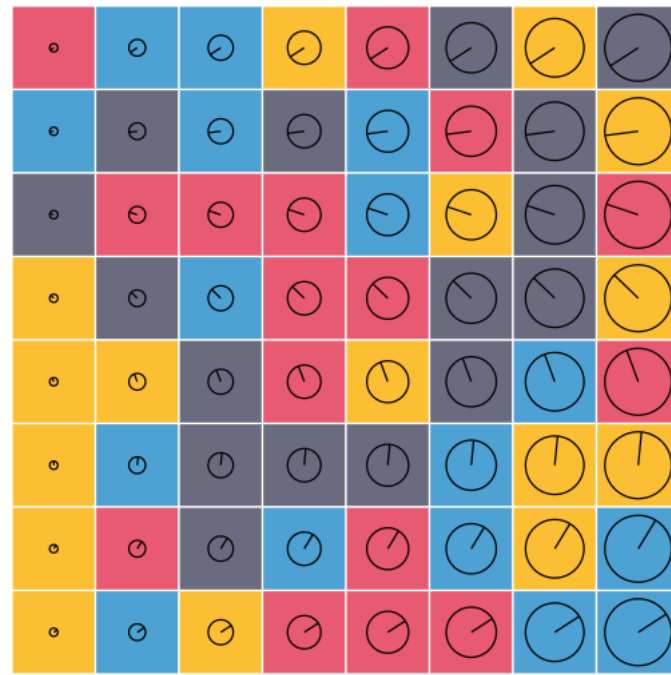
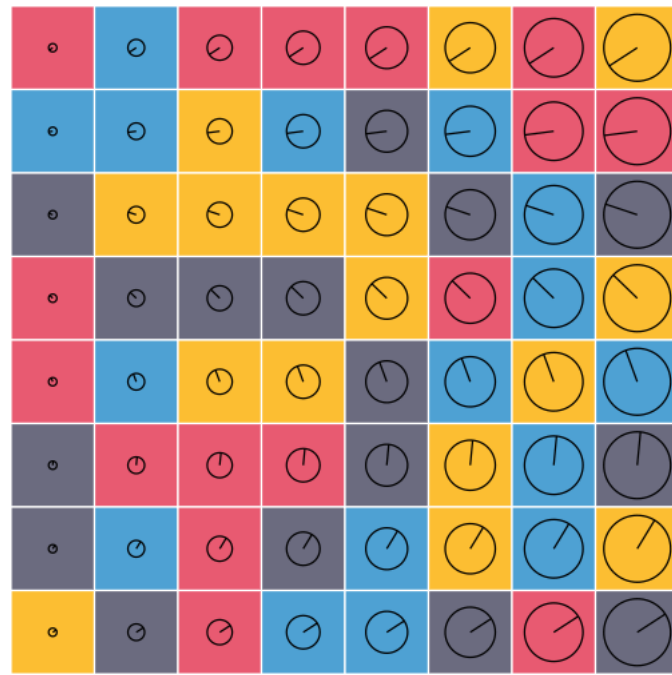
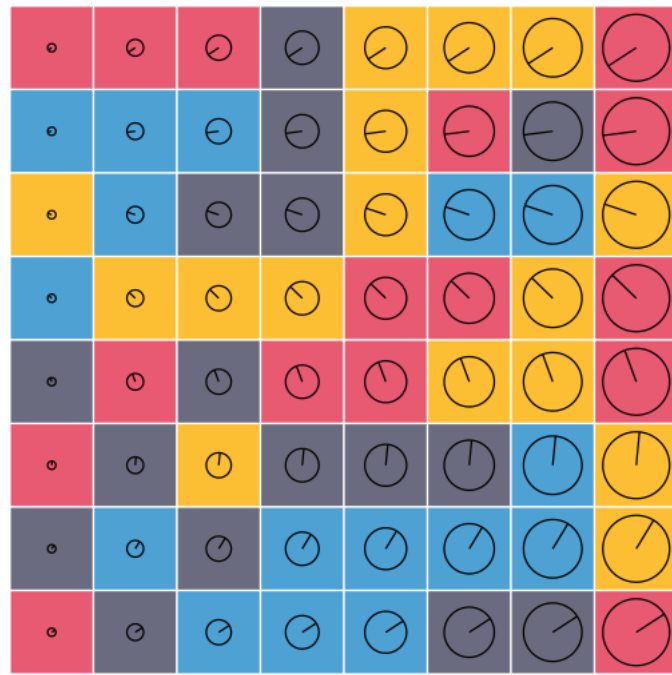
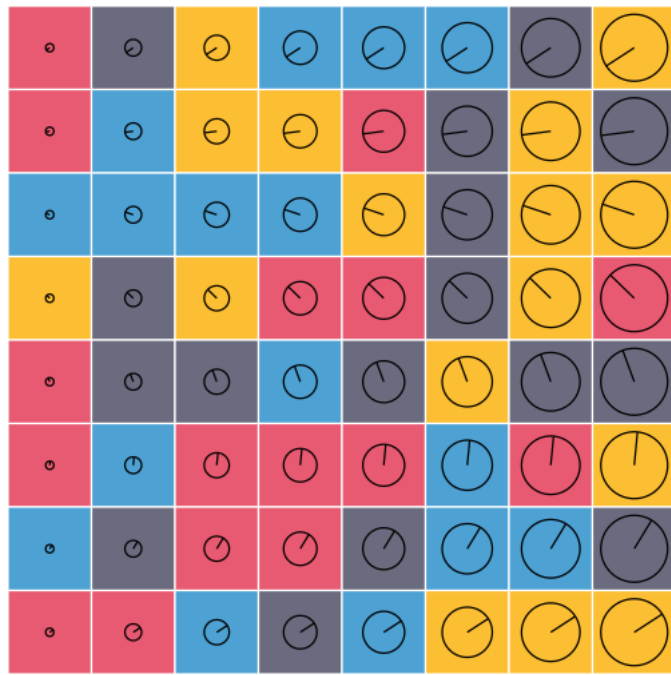
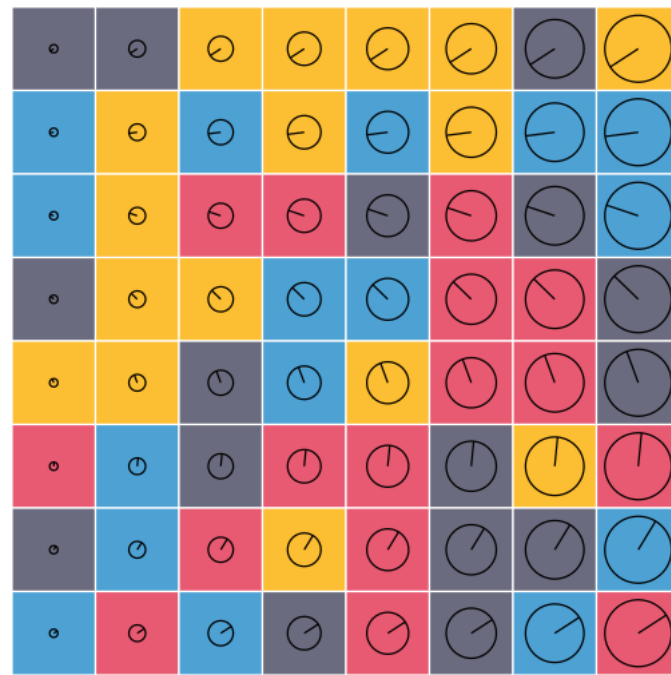
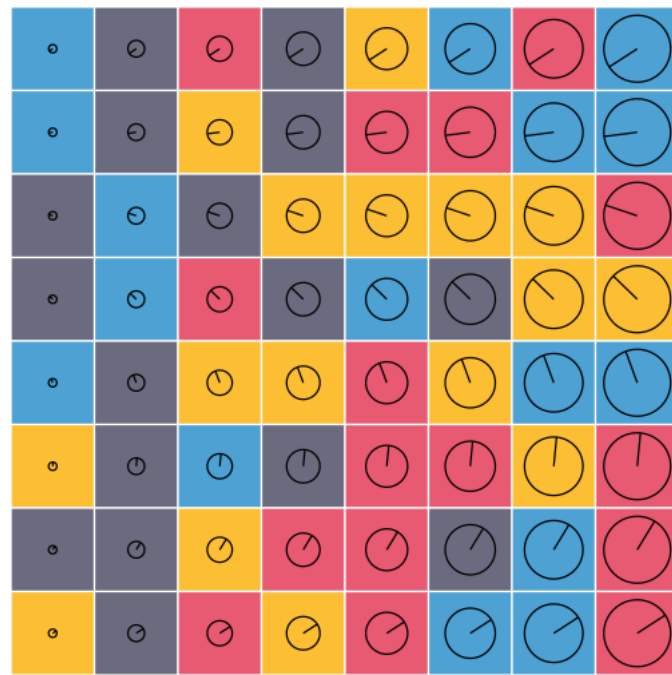
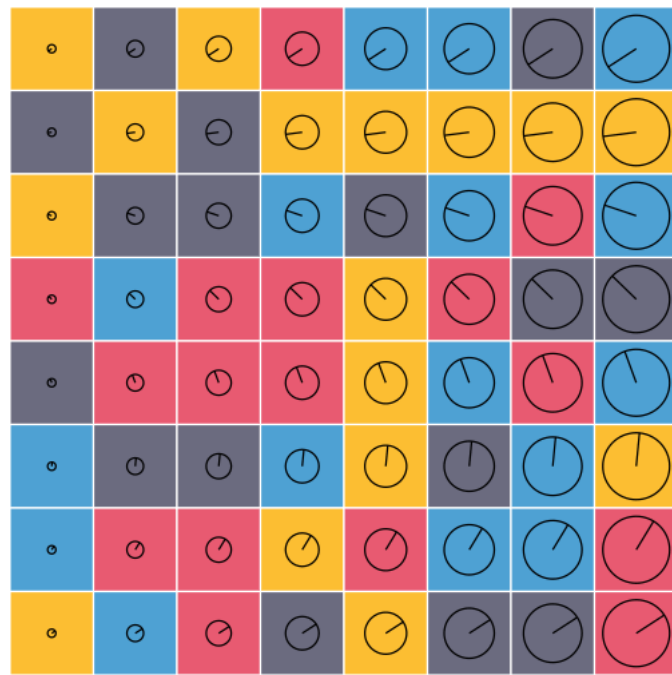
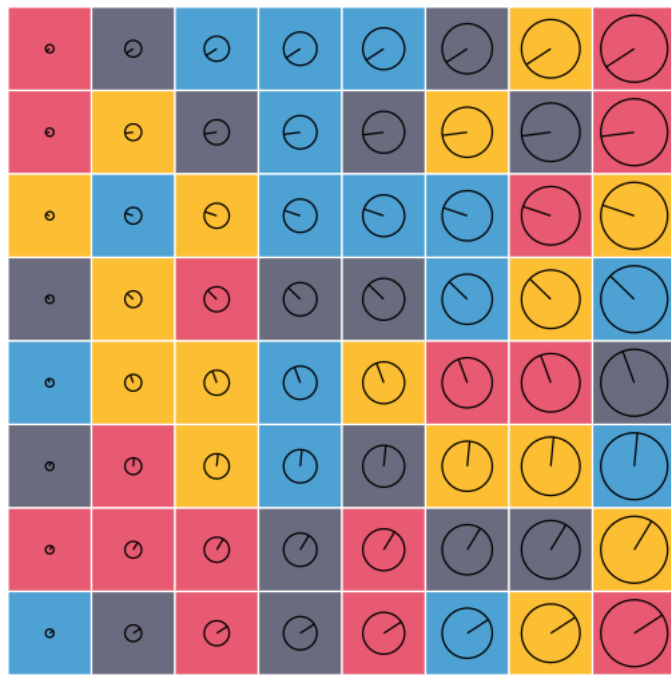
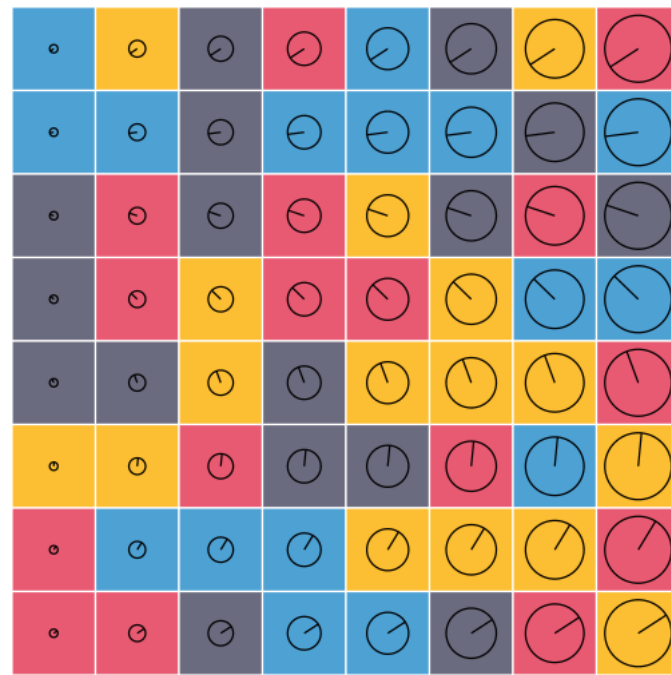
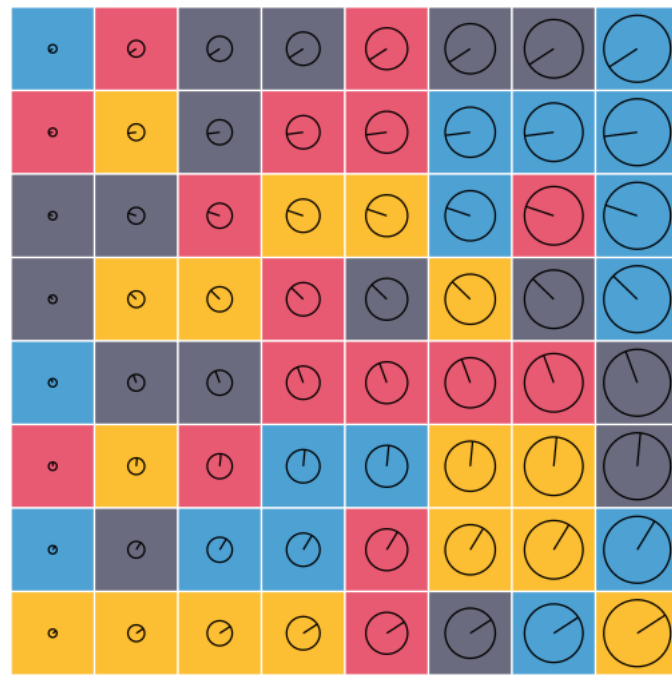
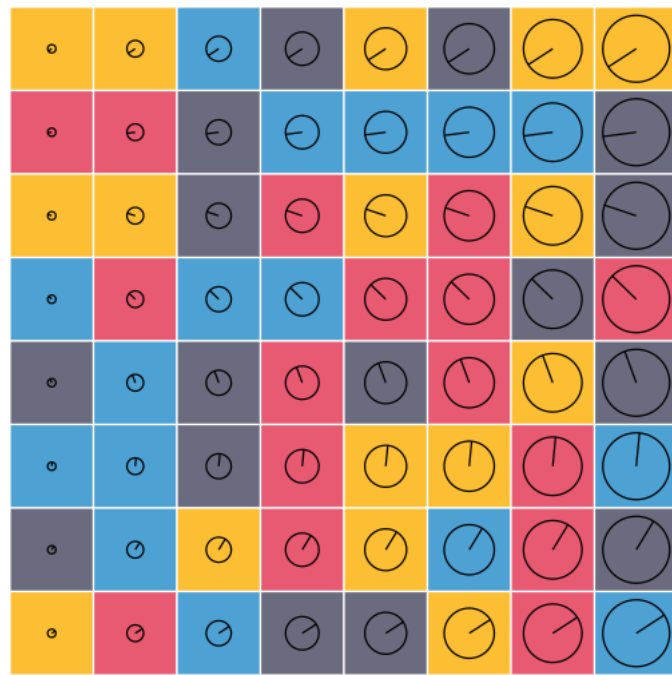
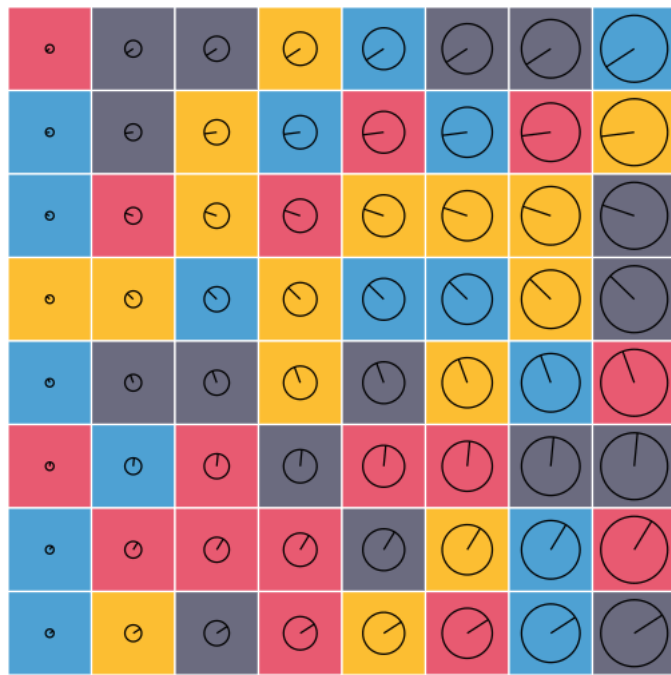


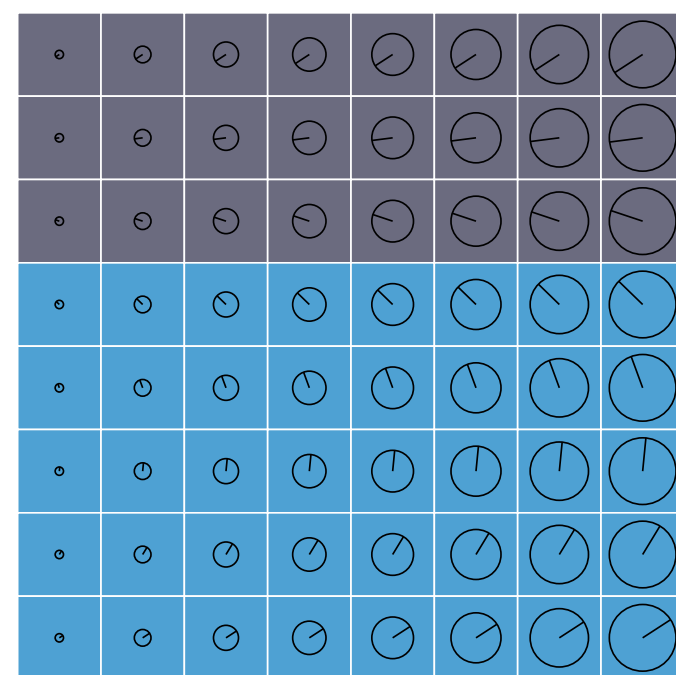
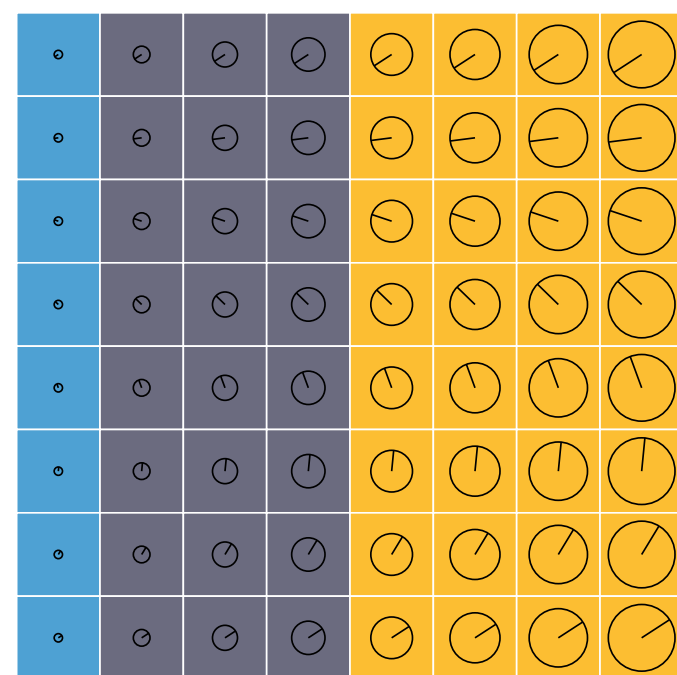
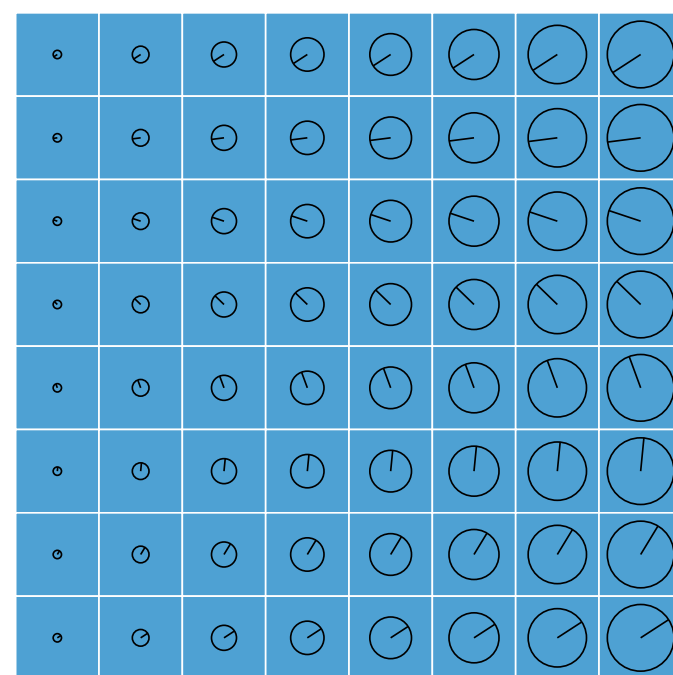
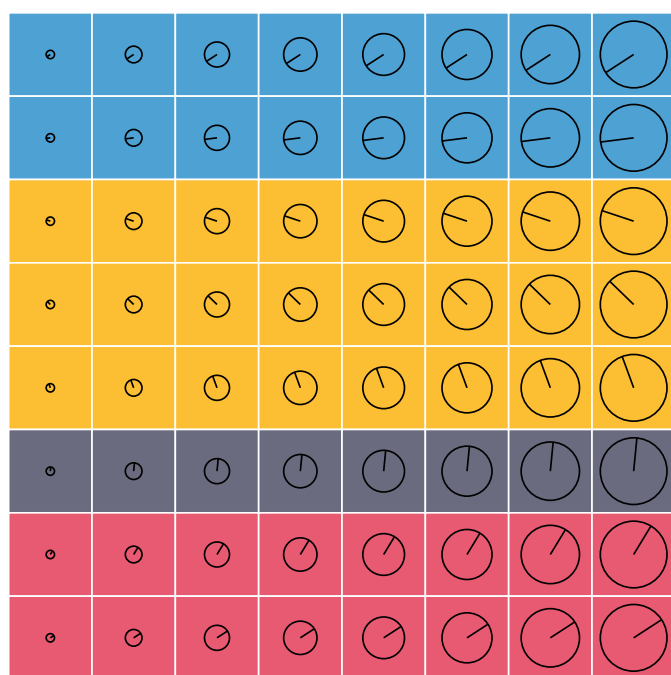
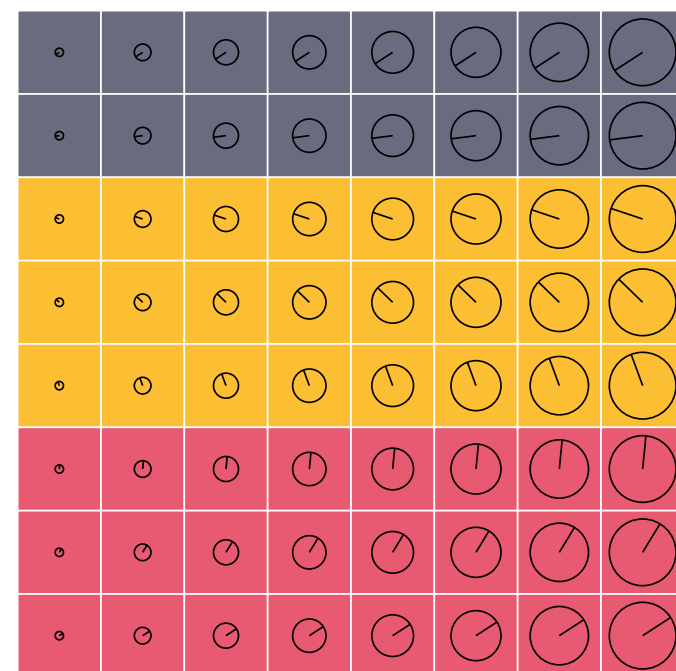
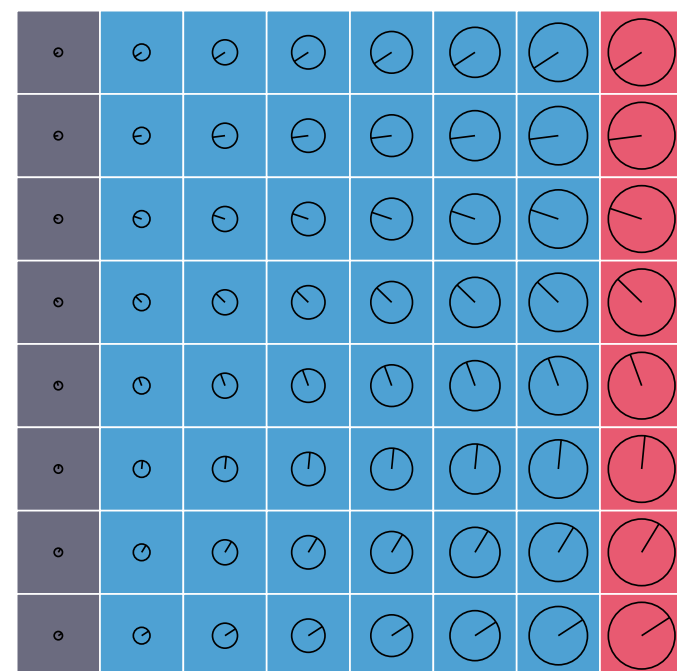
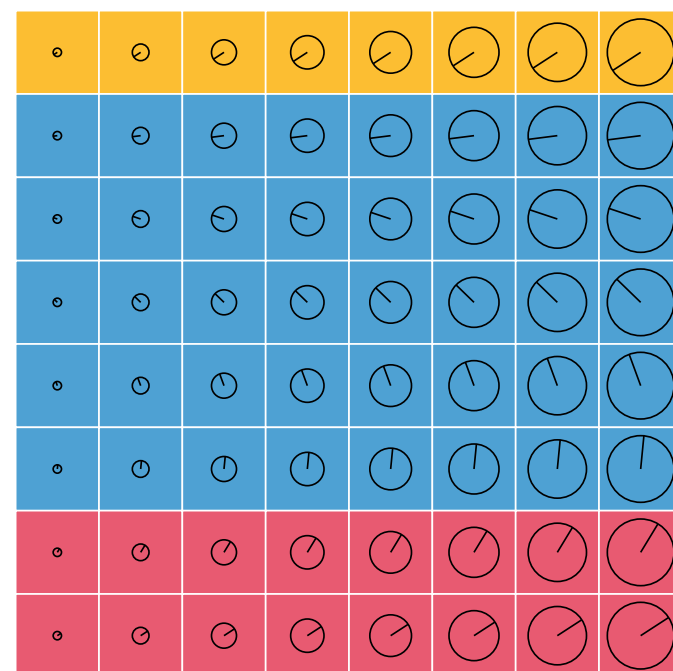
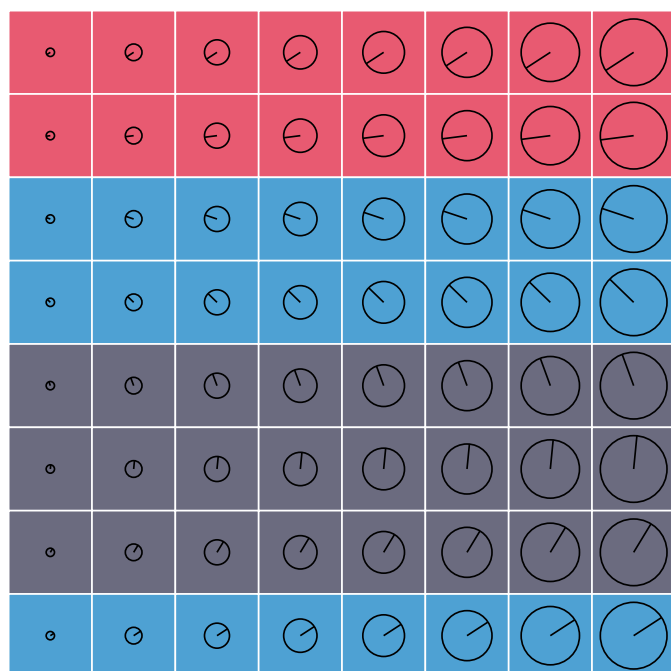
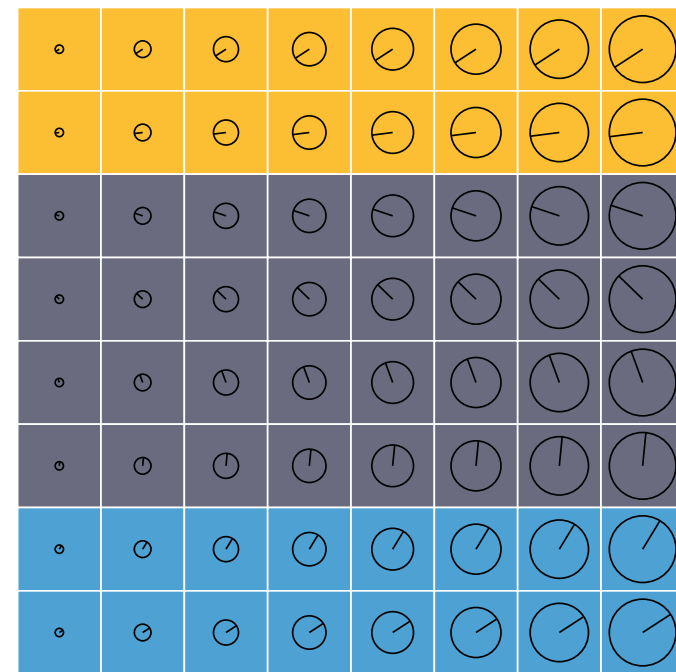
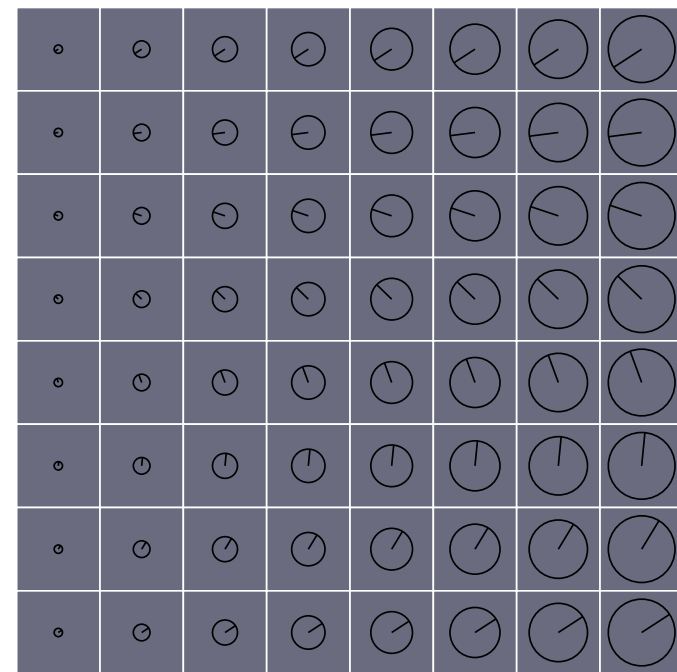
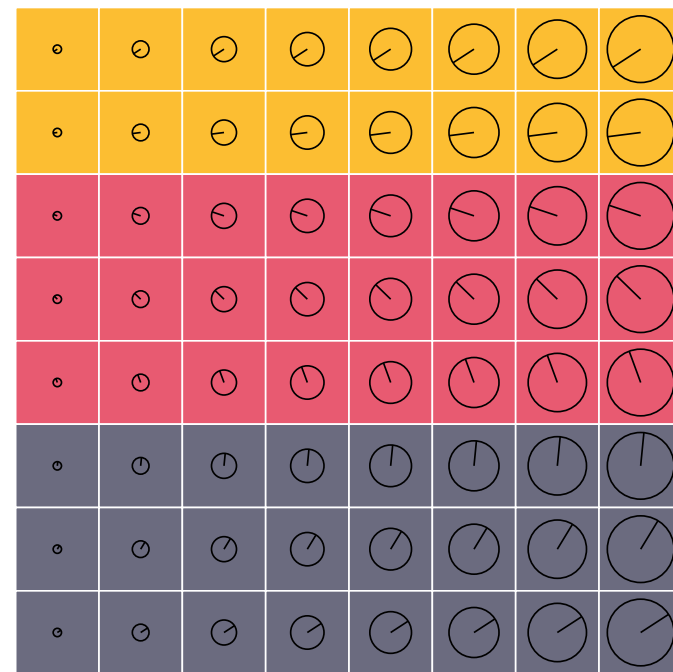
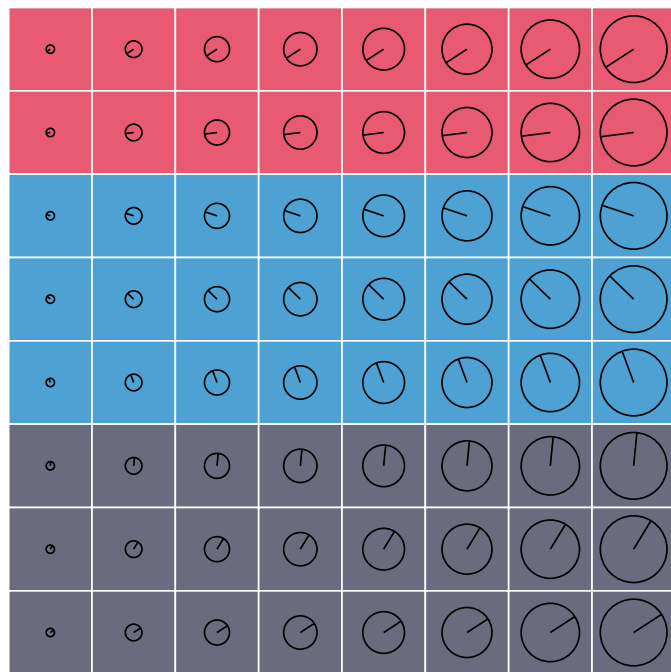
Iterated learning with humans



Iterated learning with humans

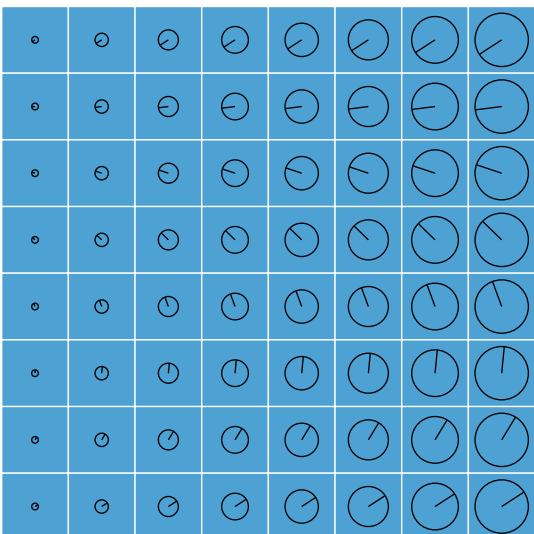
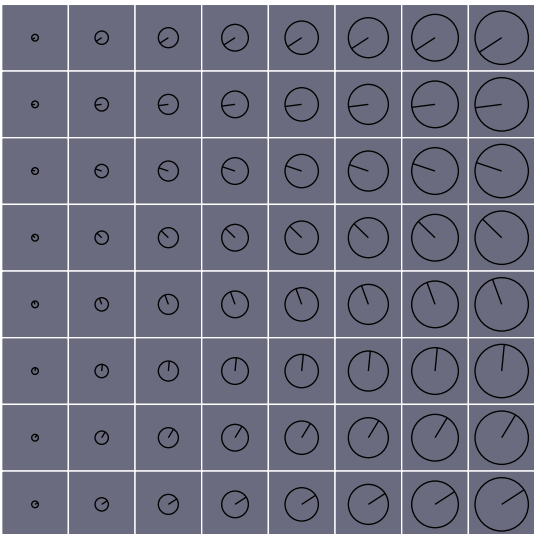




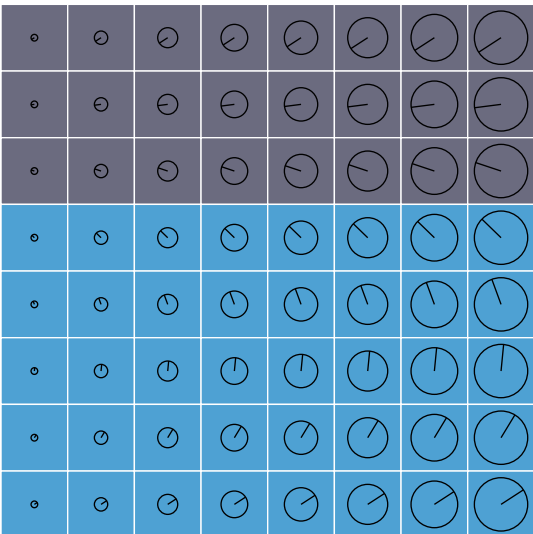


Converged-on category systems

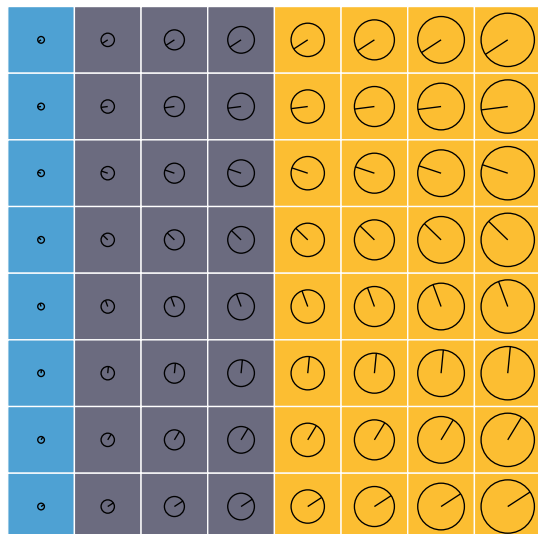
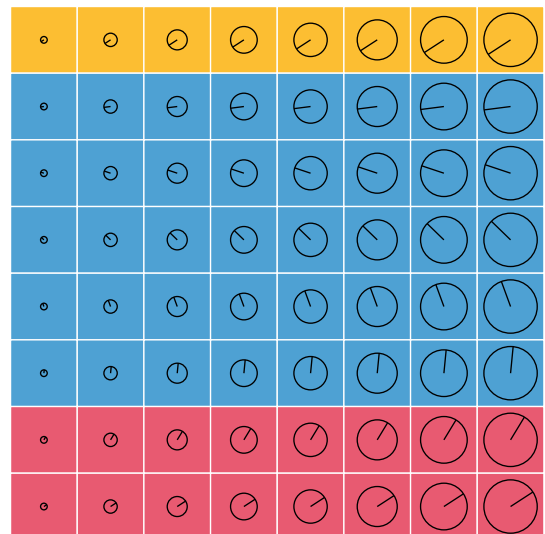
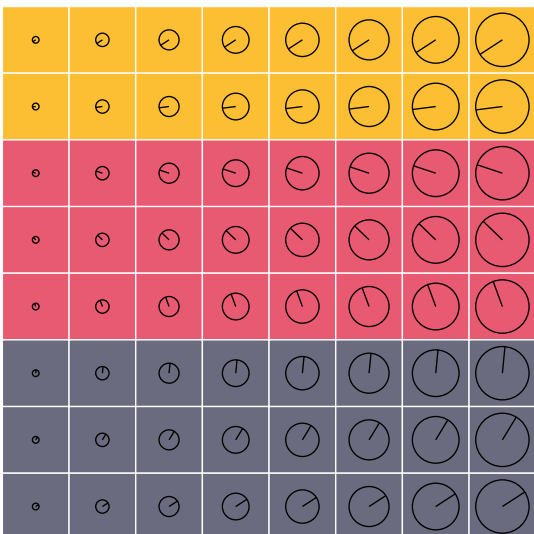
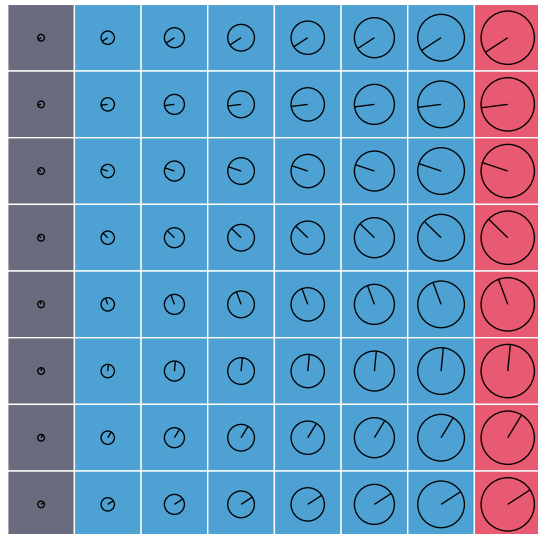
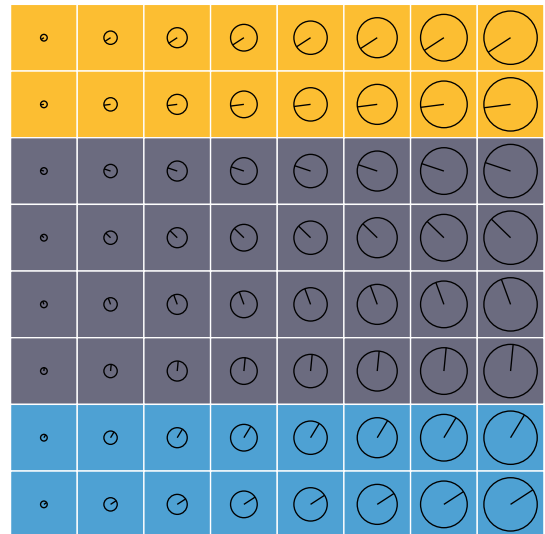
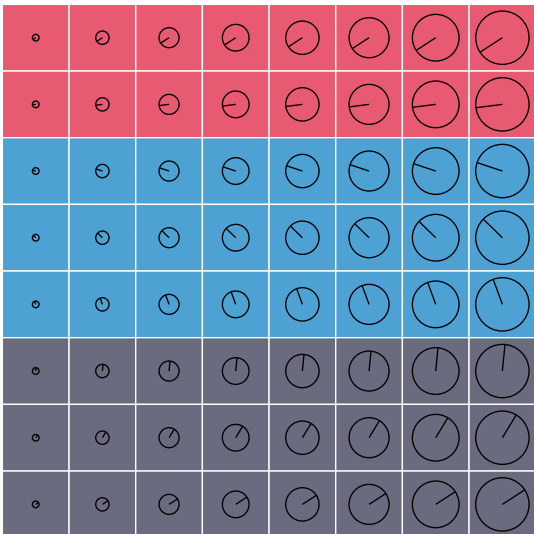
1 category (2/12)



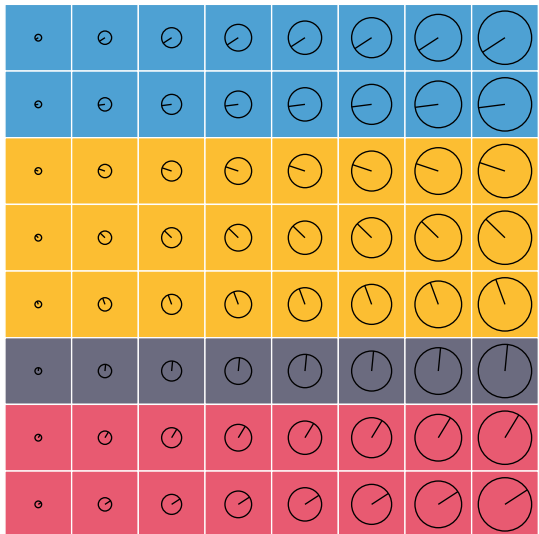
2 categories (1/12)



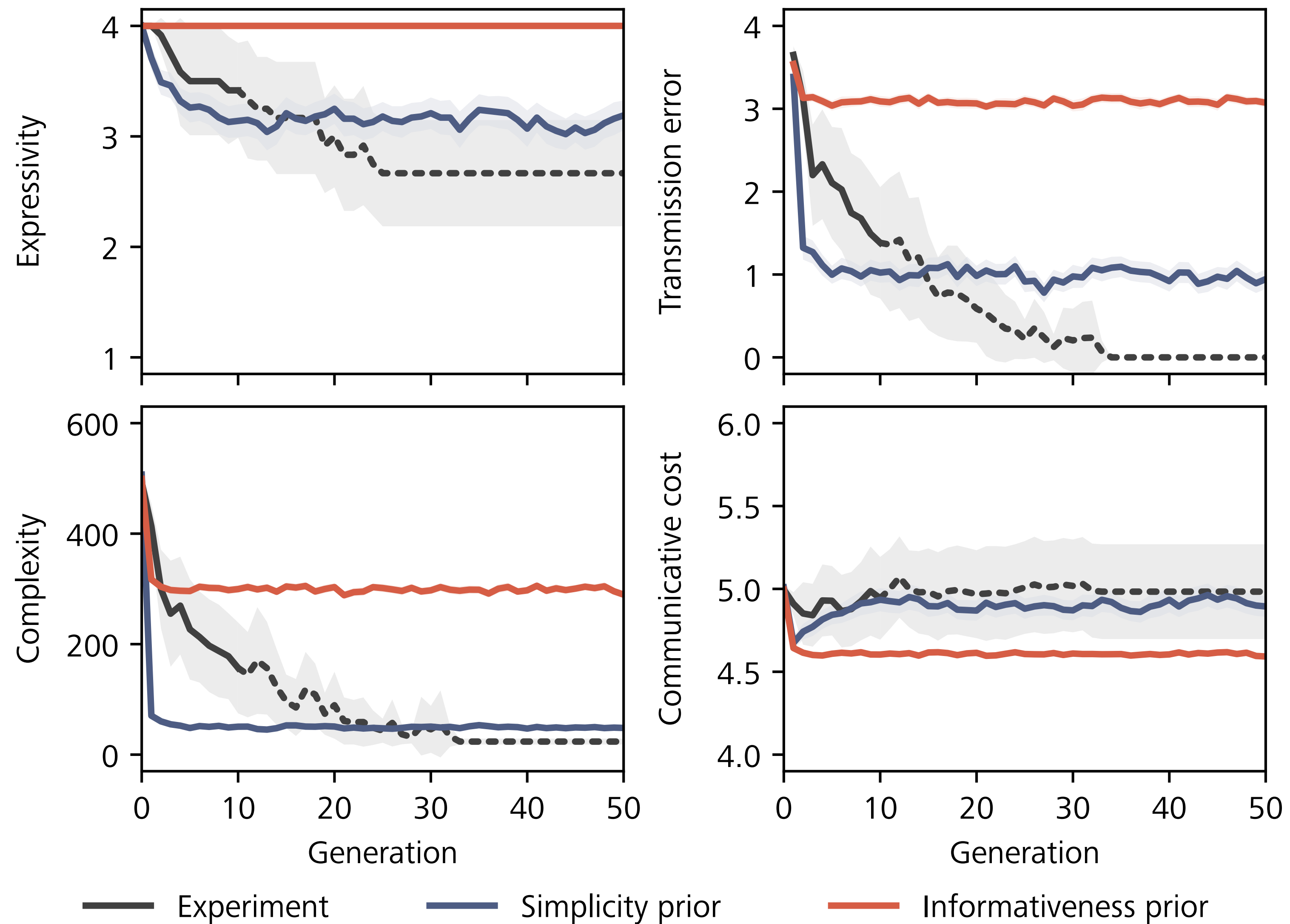
3 categories (8/12)



4 categories (1/12)

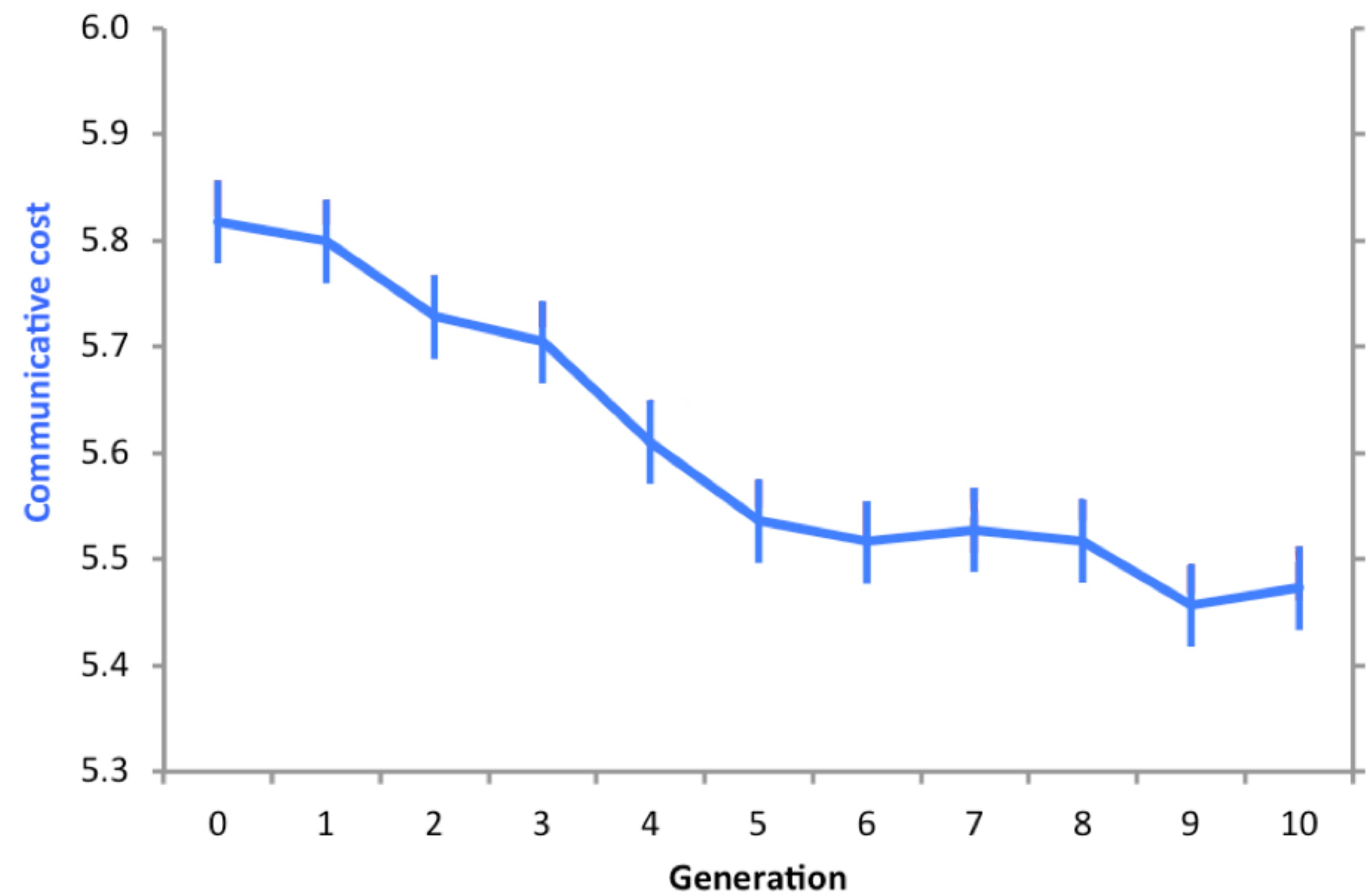
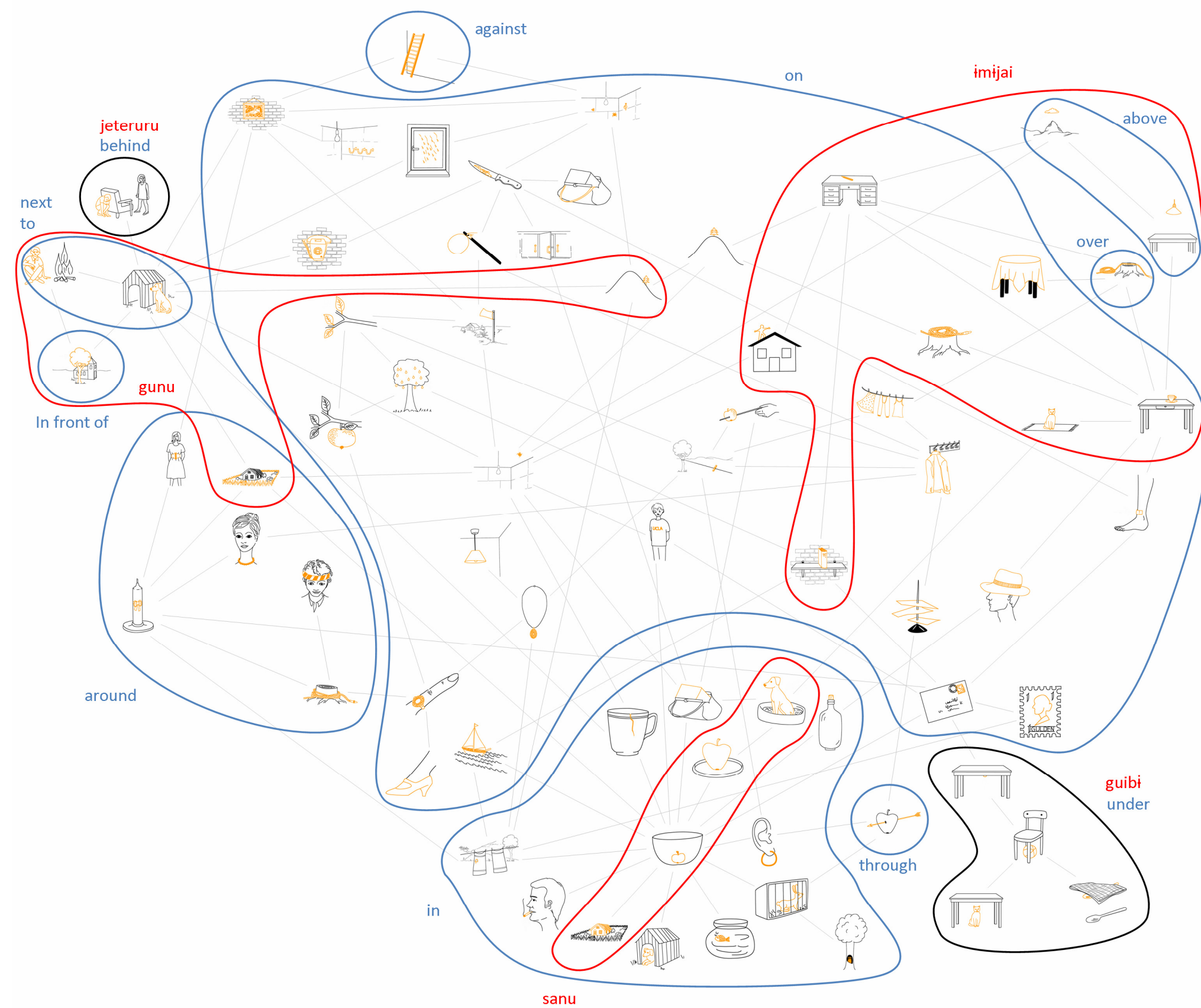


Model results under best-fit parameters

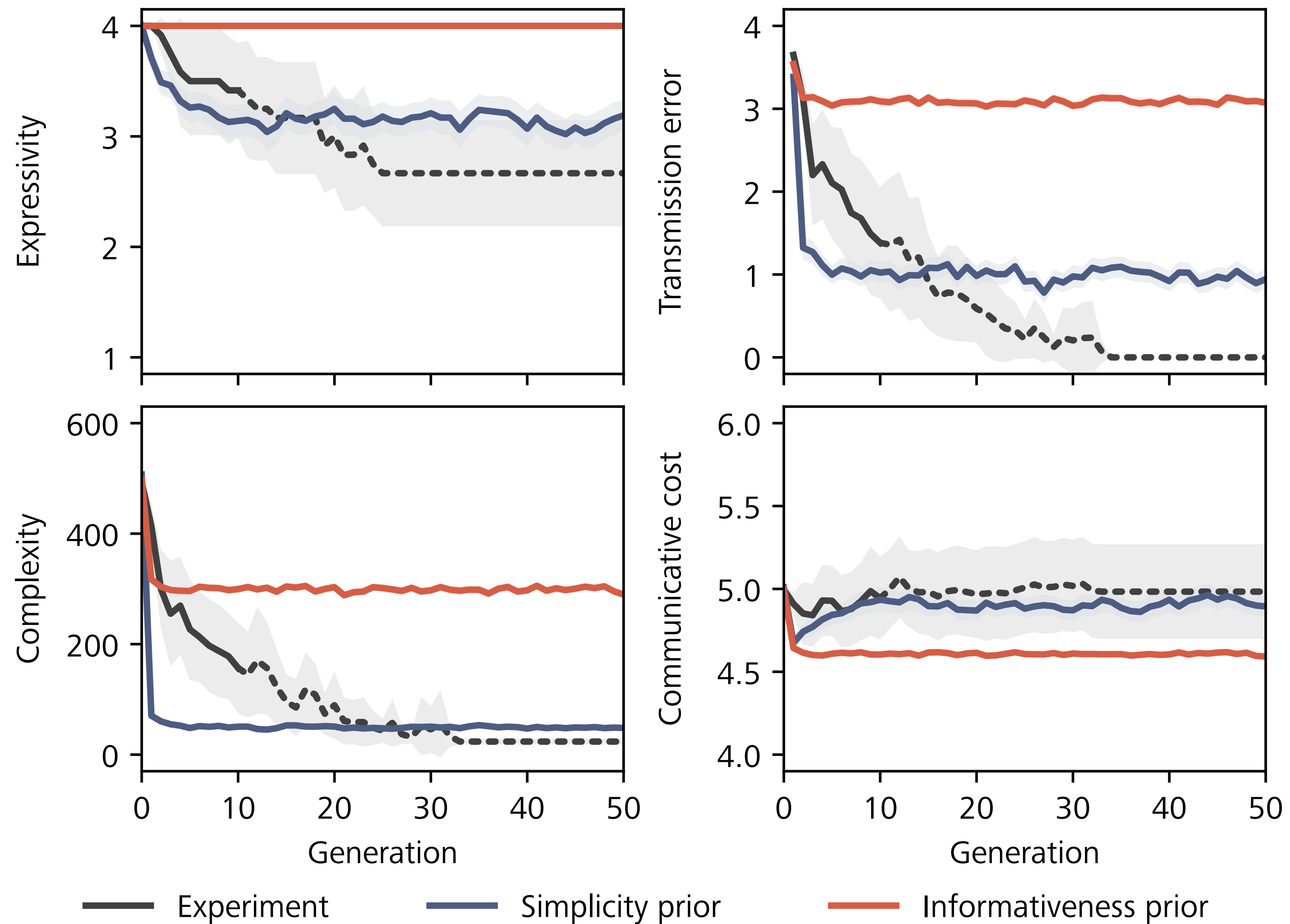


Can iterated learning give rise to informative languages?

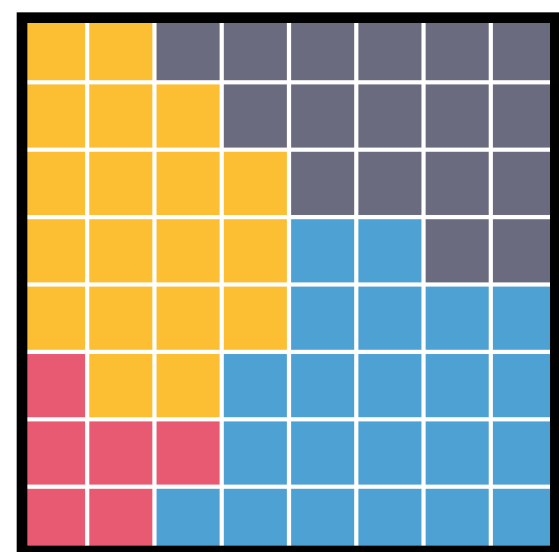
Carstensen, Xu, Smith, & Regier (2015)



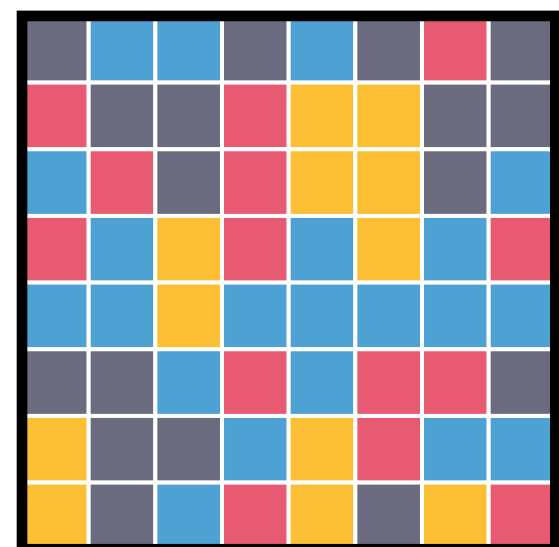
Model results under best-fit parameters



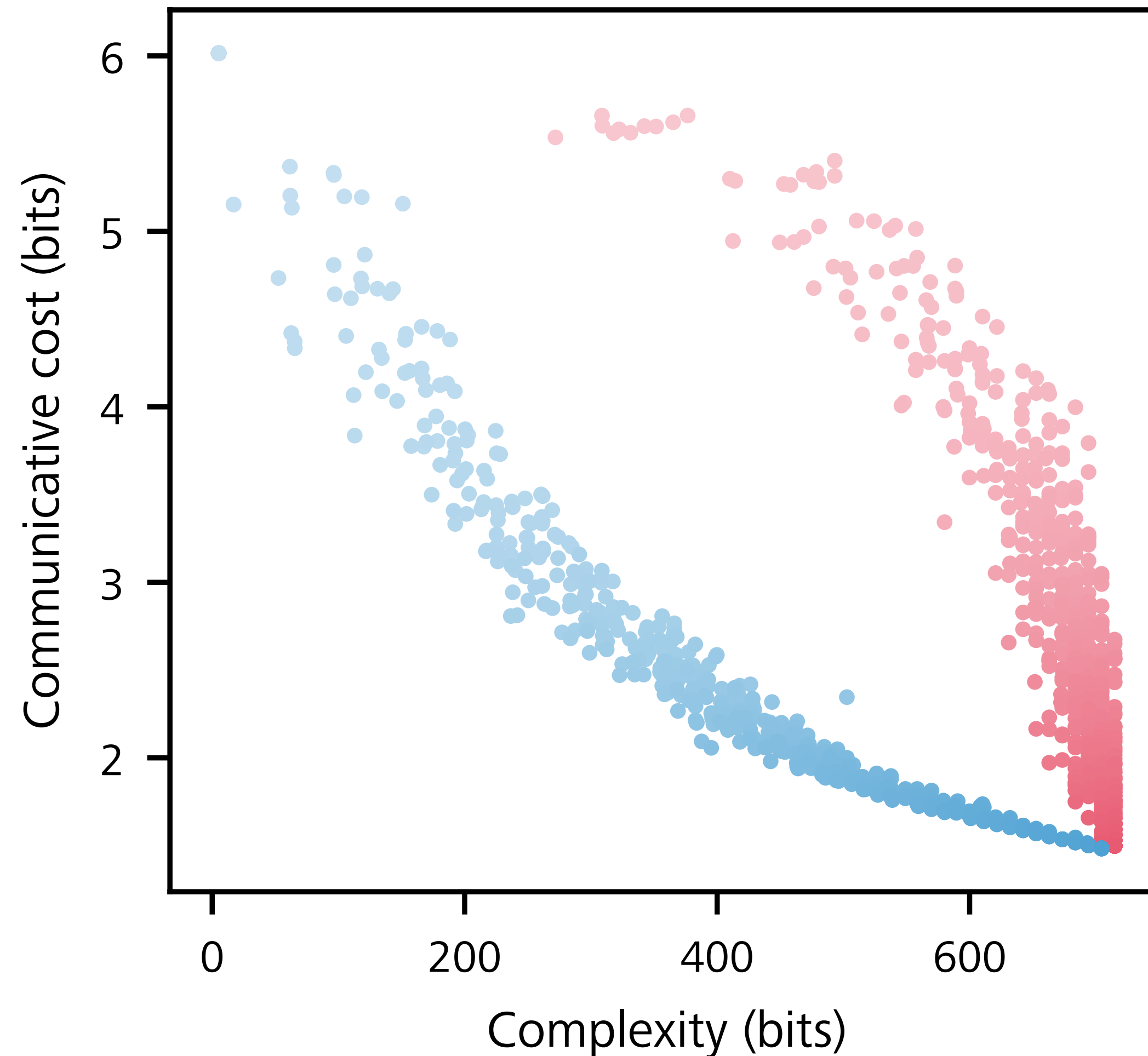
Hallmark features of simple and informative category systems



● Compact



● Random



Simplicity pressure from induction favours

Few categories
Compactness

Informativeness pressure from interaction favours

Many categories
Compactness

Part 3

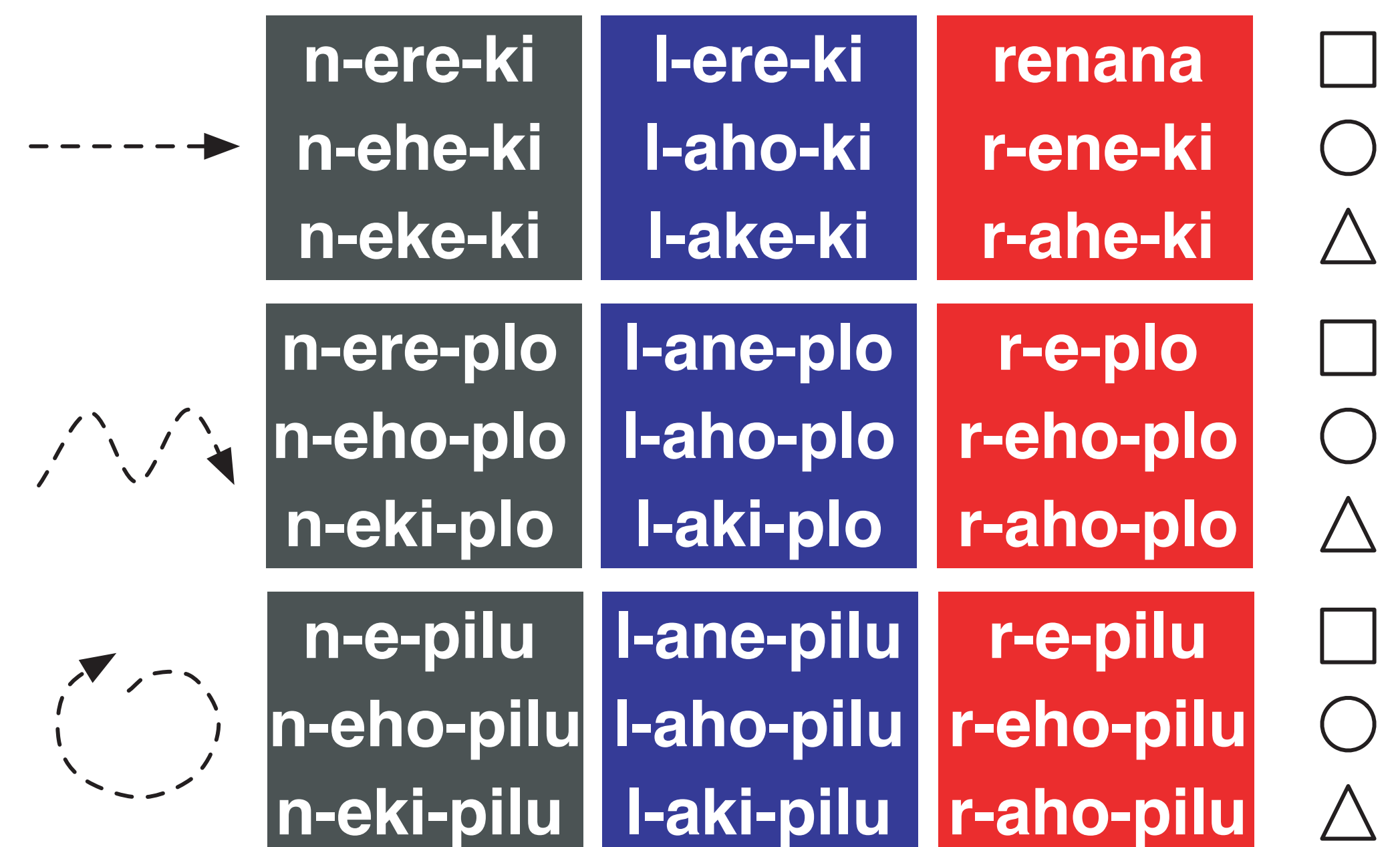
A pressure for informativeness prevents degeneration

Kirby, Cornish, & Smith (2008)

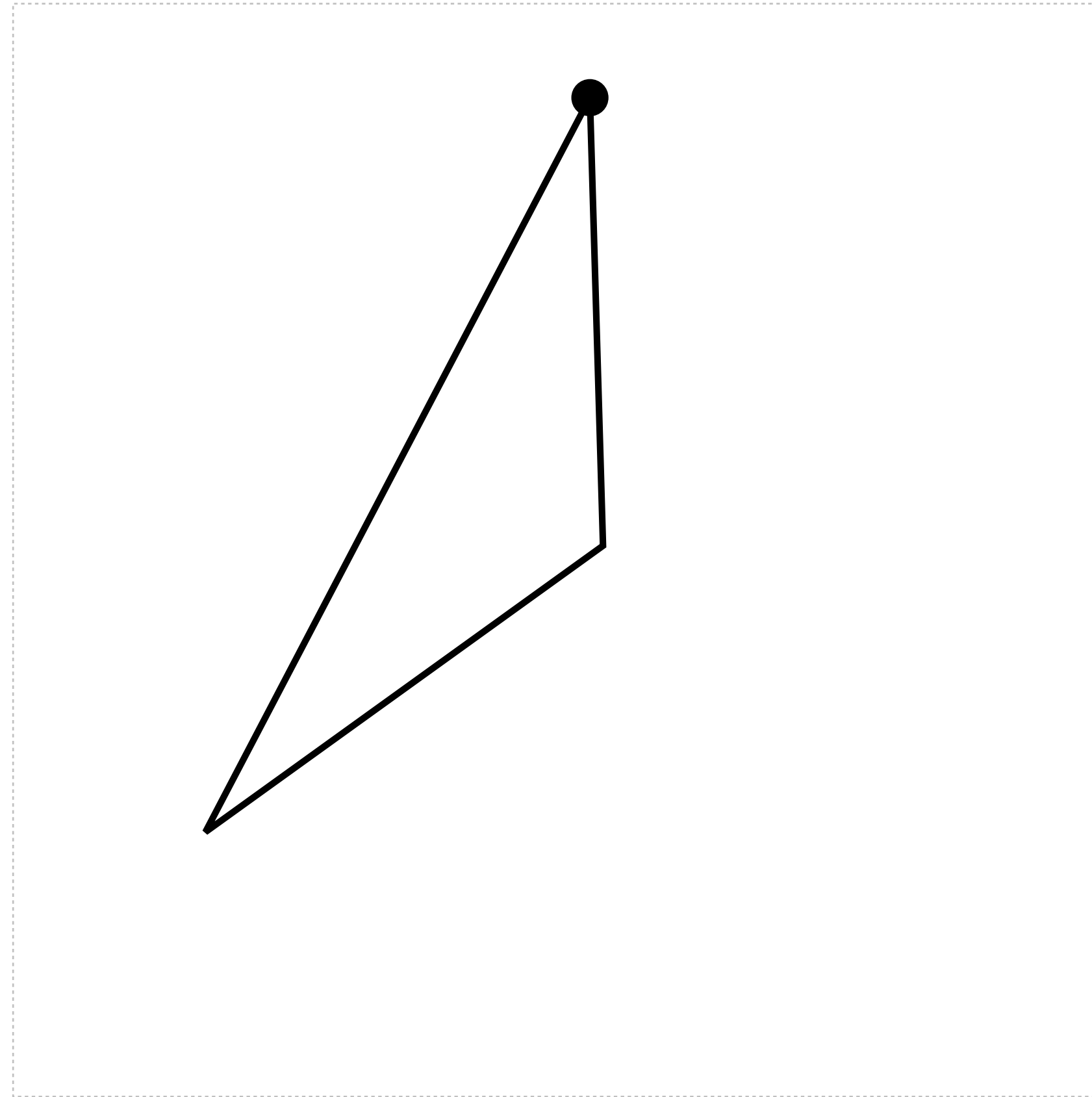
Experiment 1
Iterated learning

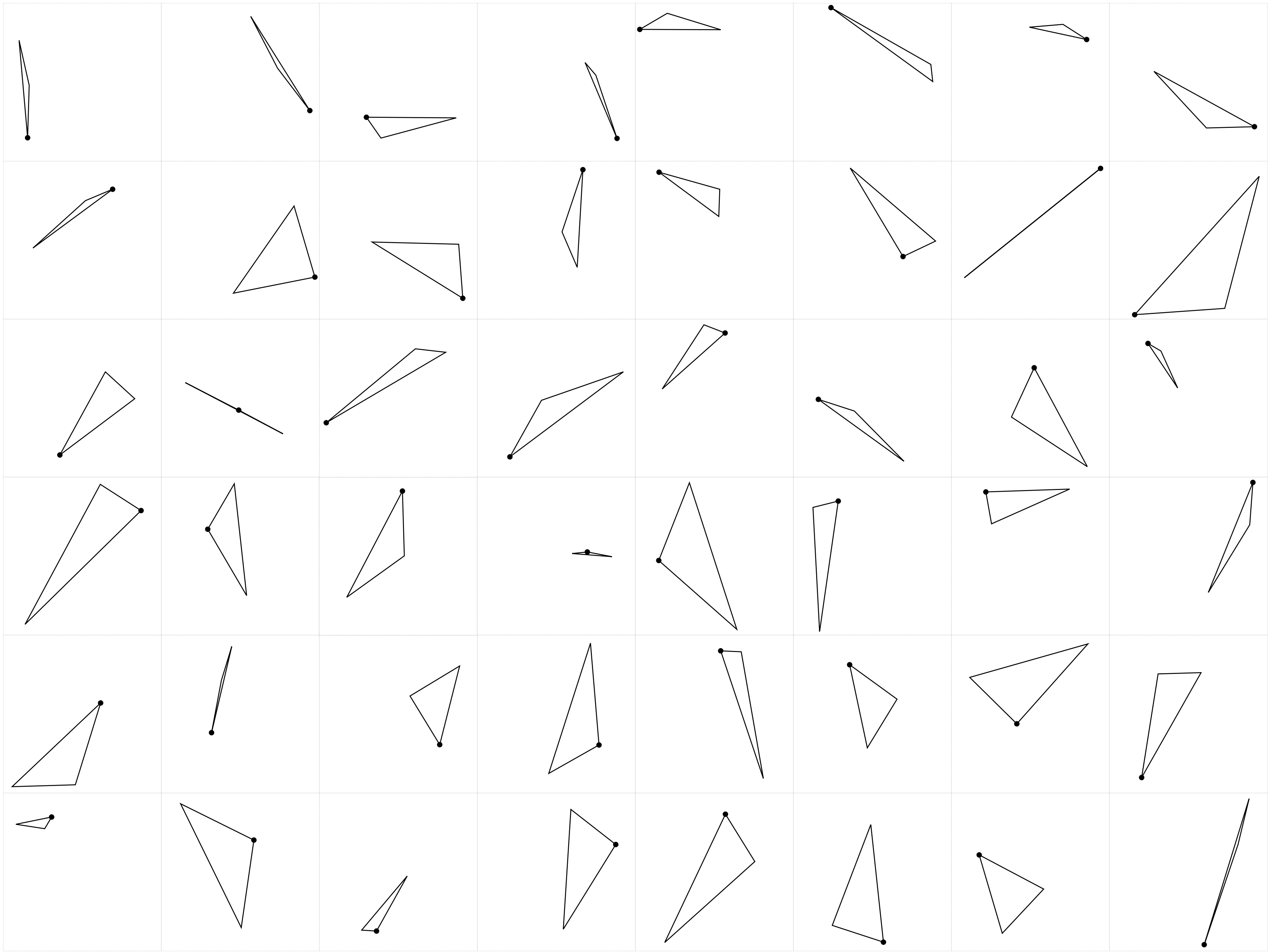


Experiment 2
Iterated learning with an informativeness pressure



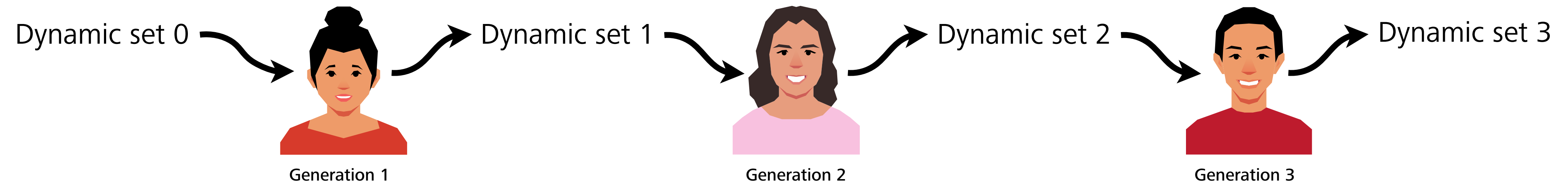
Continuous, open-ended stimulus space





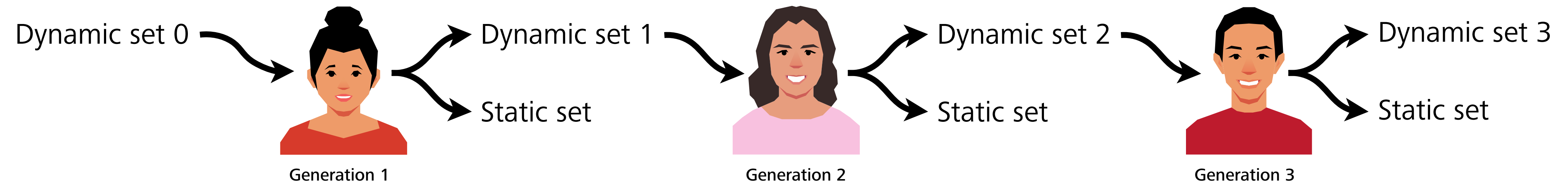
Transmission design

Iterated learning



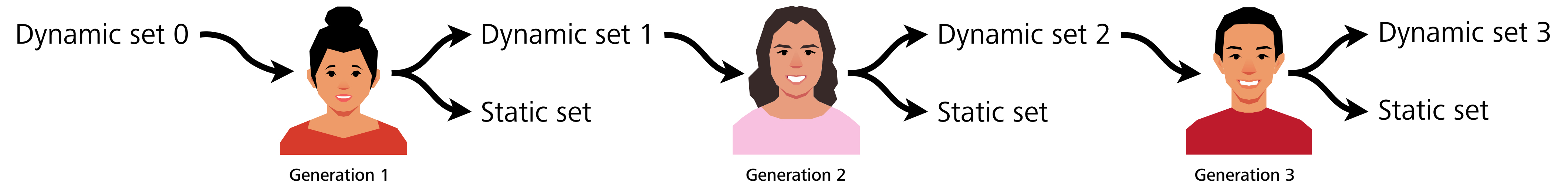
Transmission design

Iterated learning

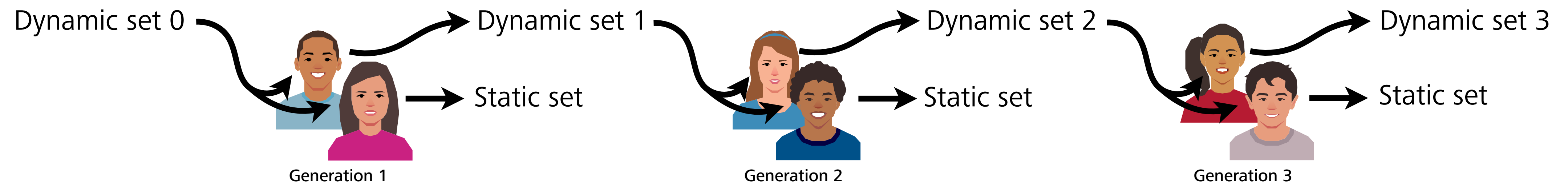


Transmission design

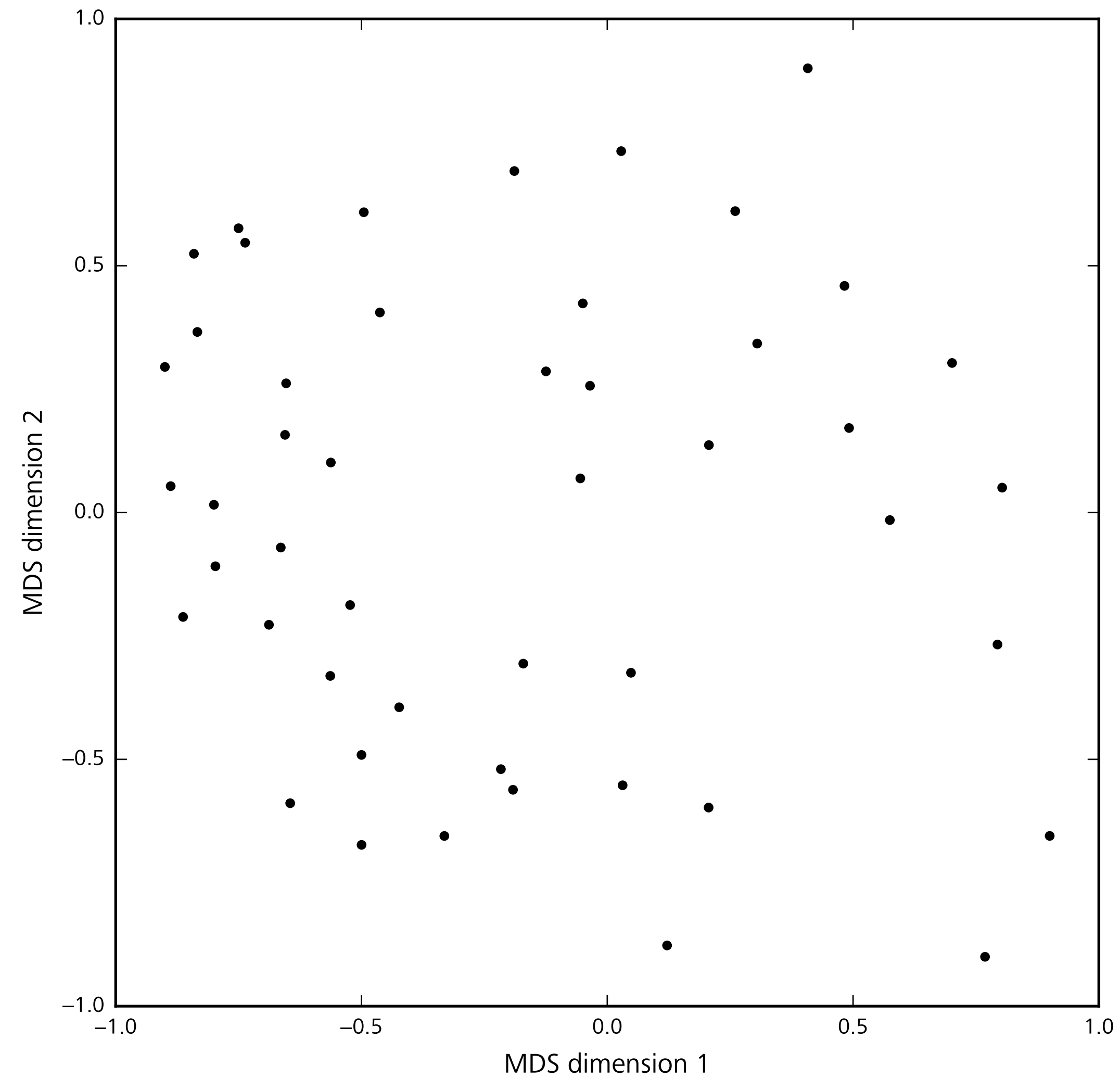
Iterated learning



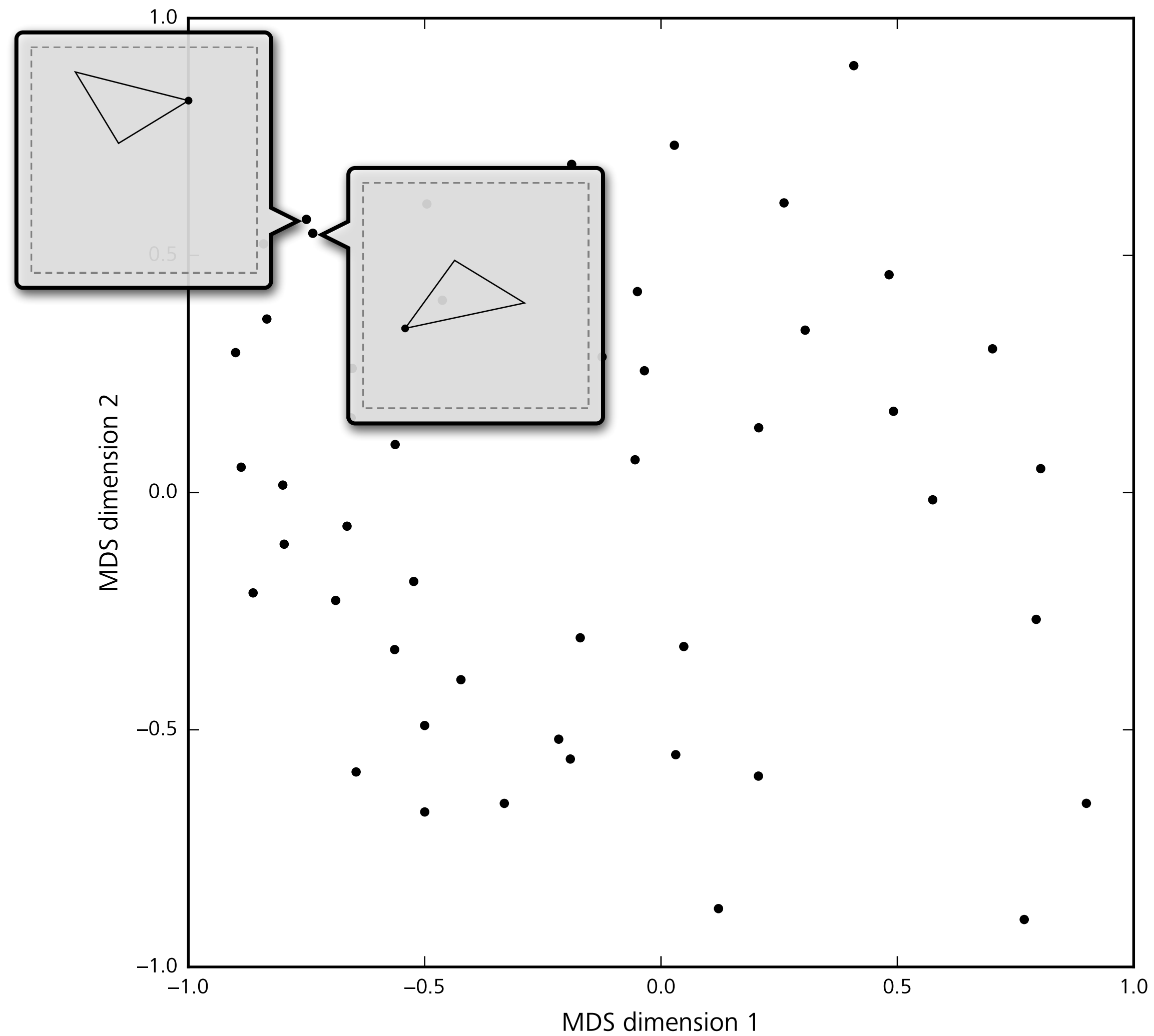
Iterated learning with communicative interaction



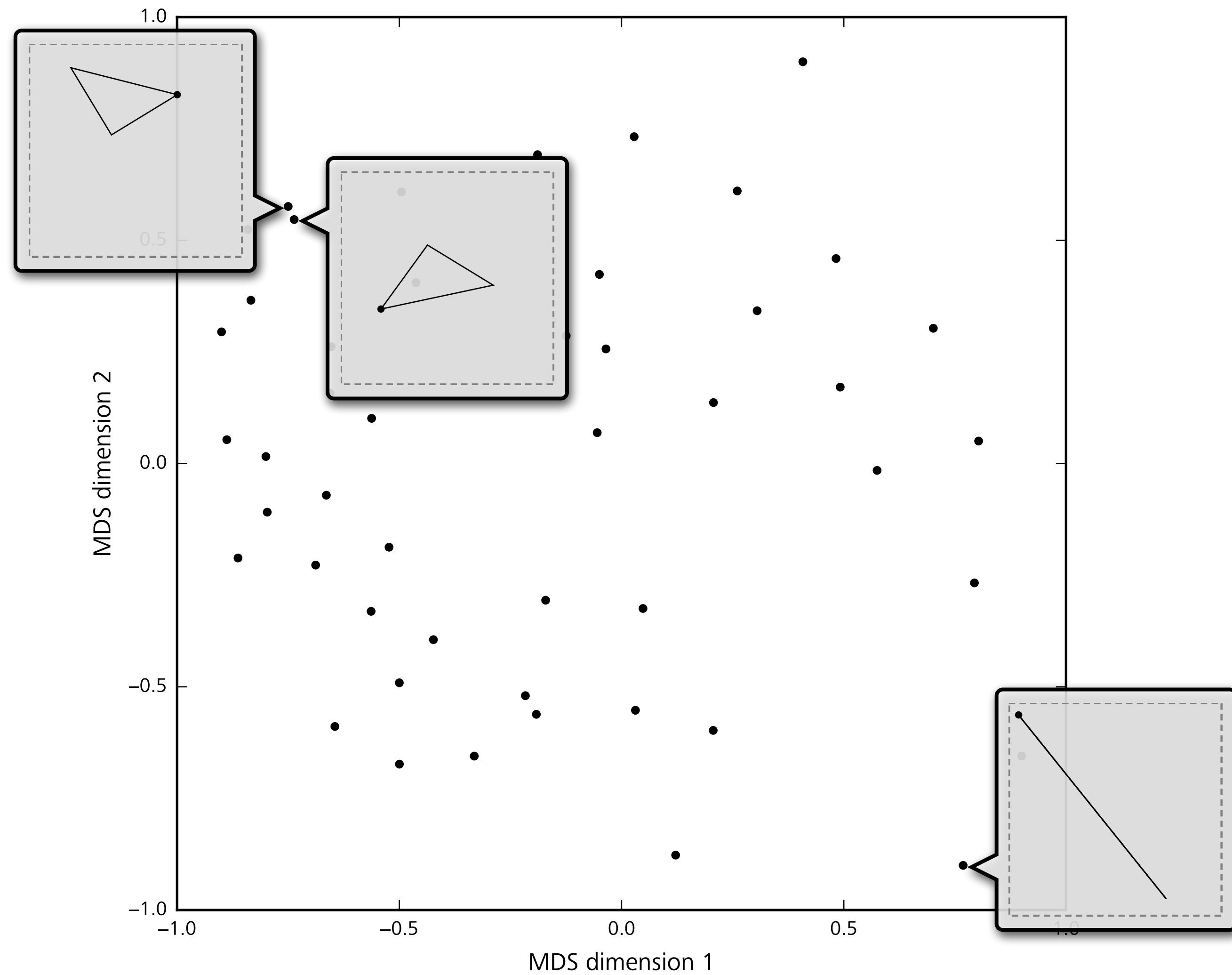
Iterated learning gives rise to discrete categories



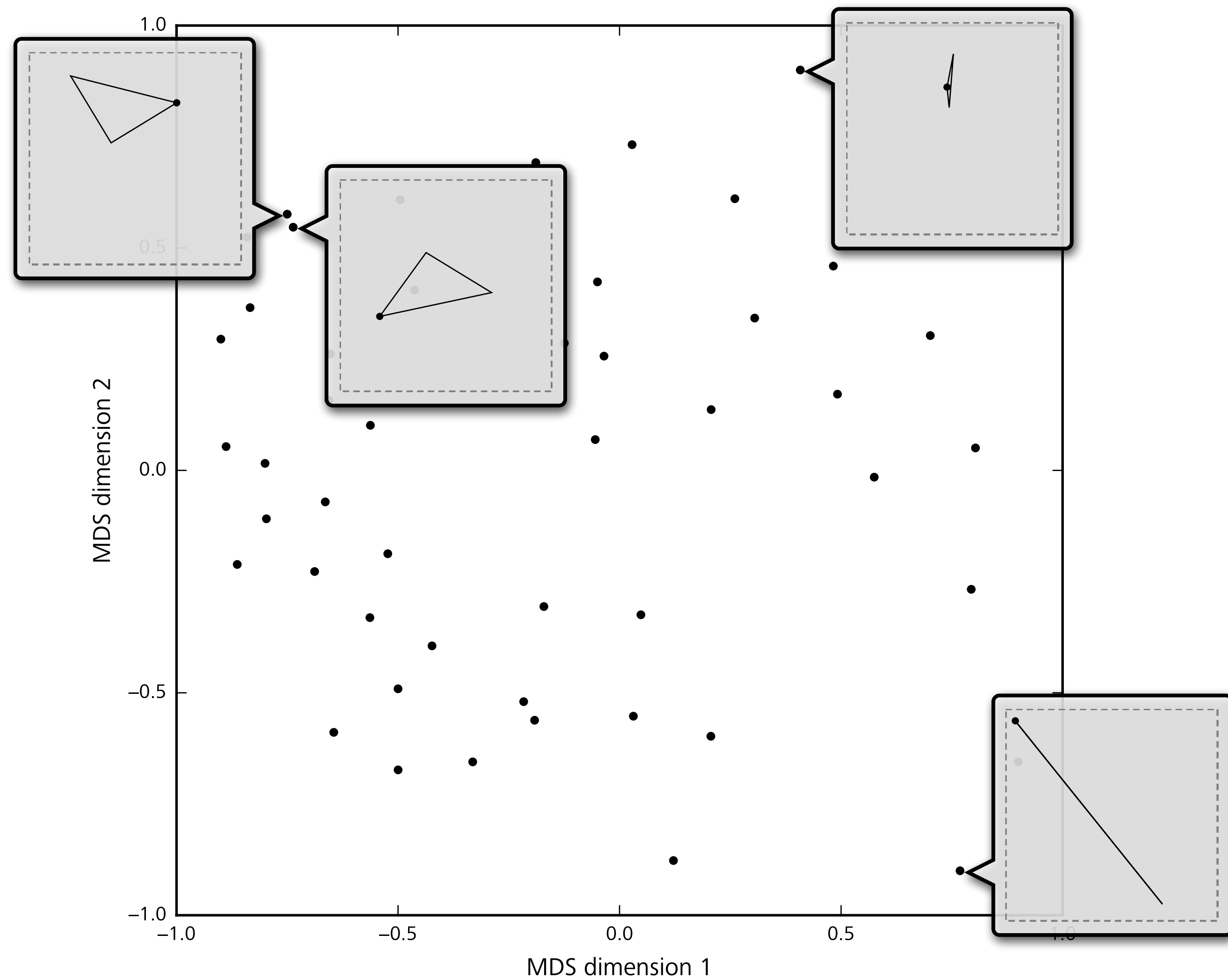
Iterated learning gives rise to discrete categories



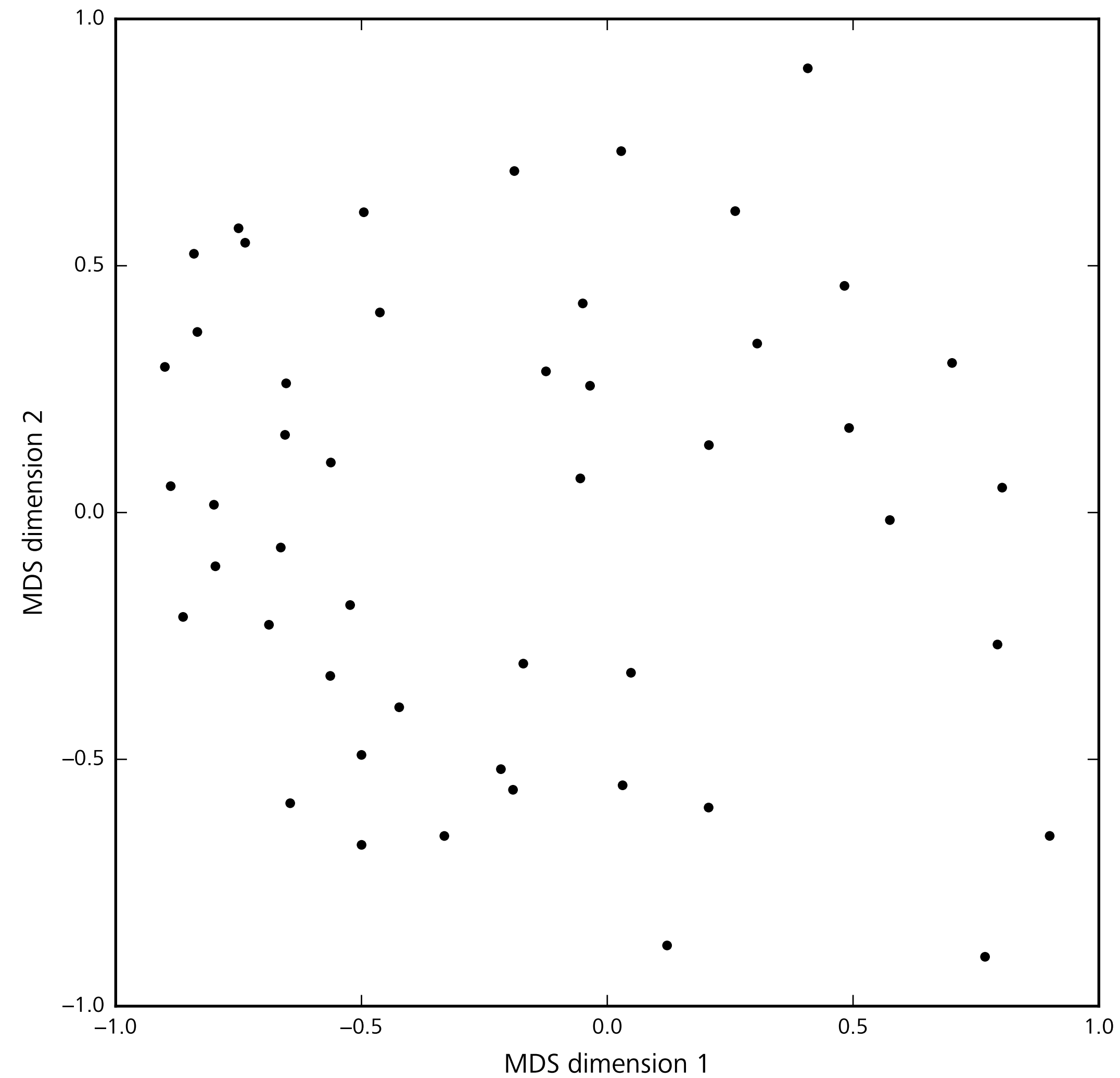
Iterated learning gives rise to discrete categories



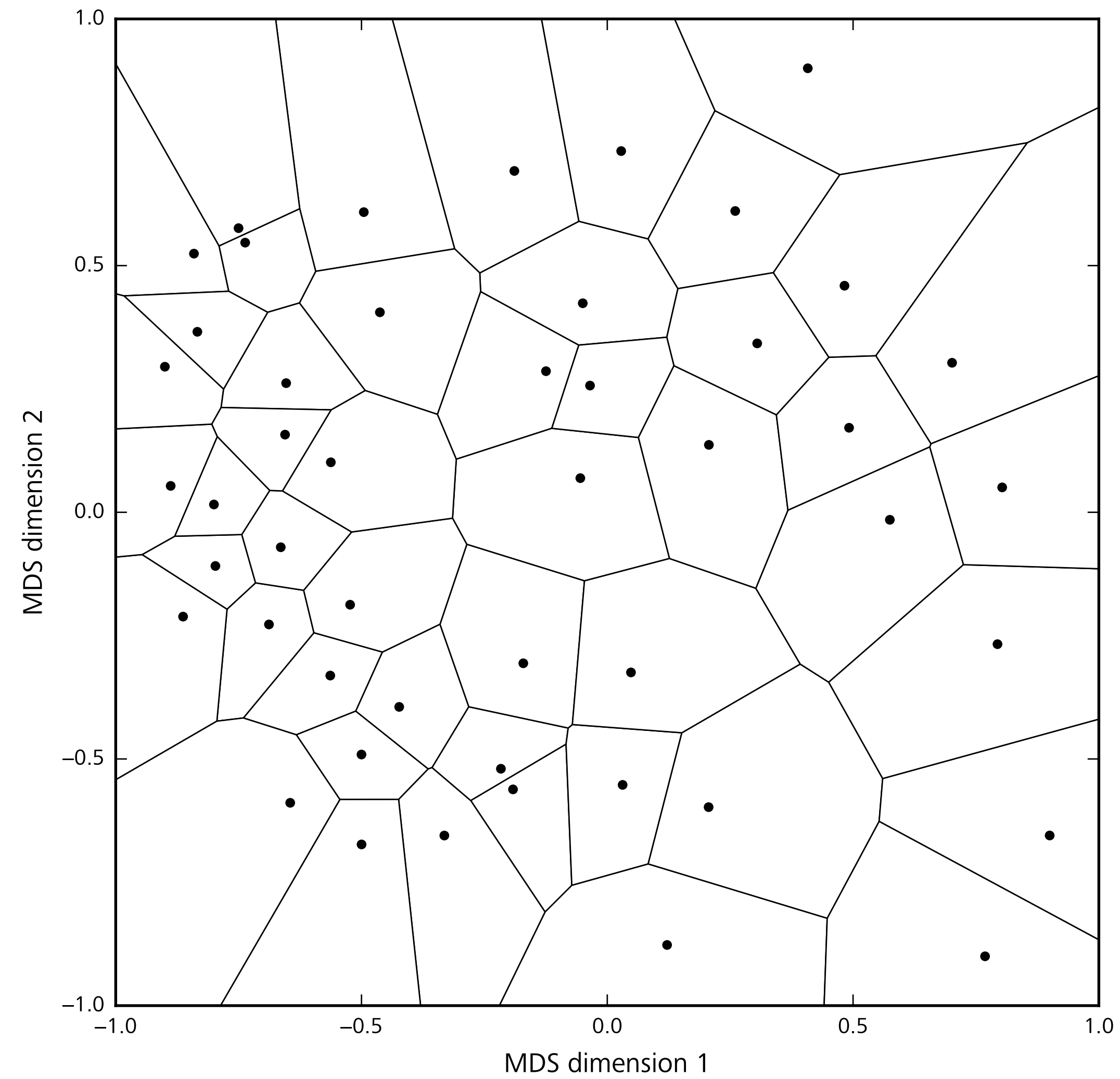
Iterated learning gives rise to discrete categories



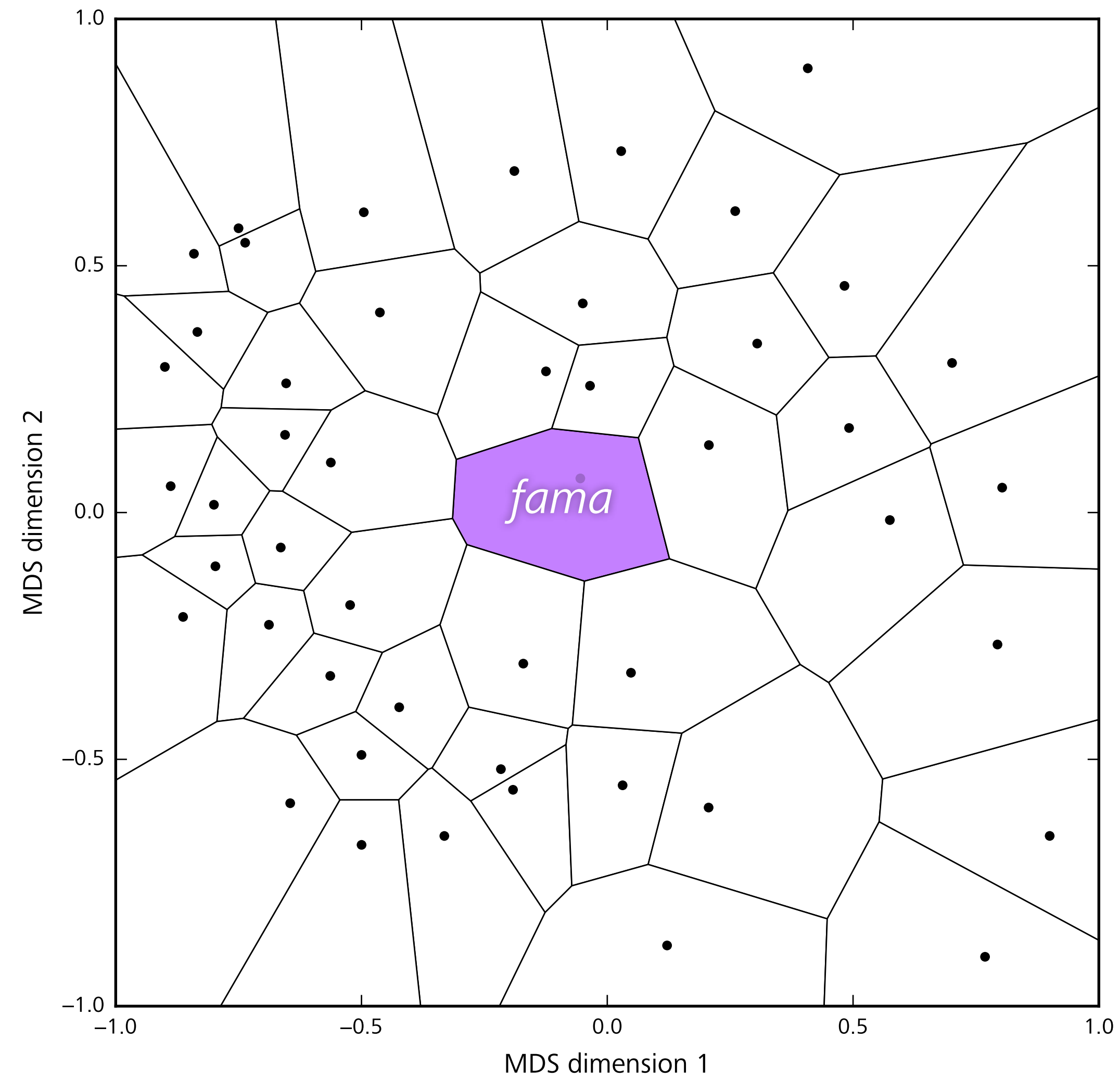
Iterated learning gives rise to discrete categories



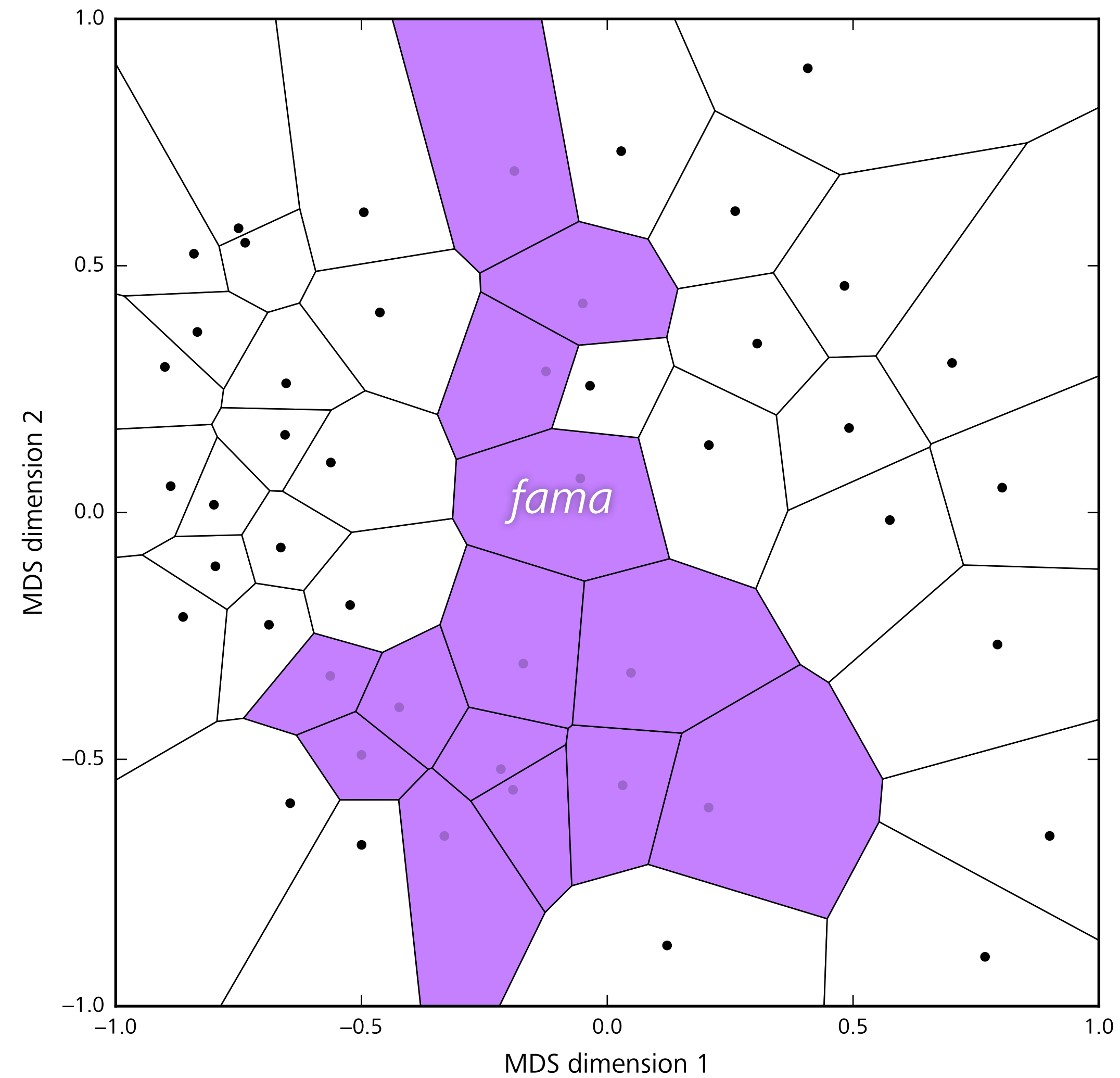
Iterated learning gives rise to discrete categories



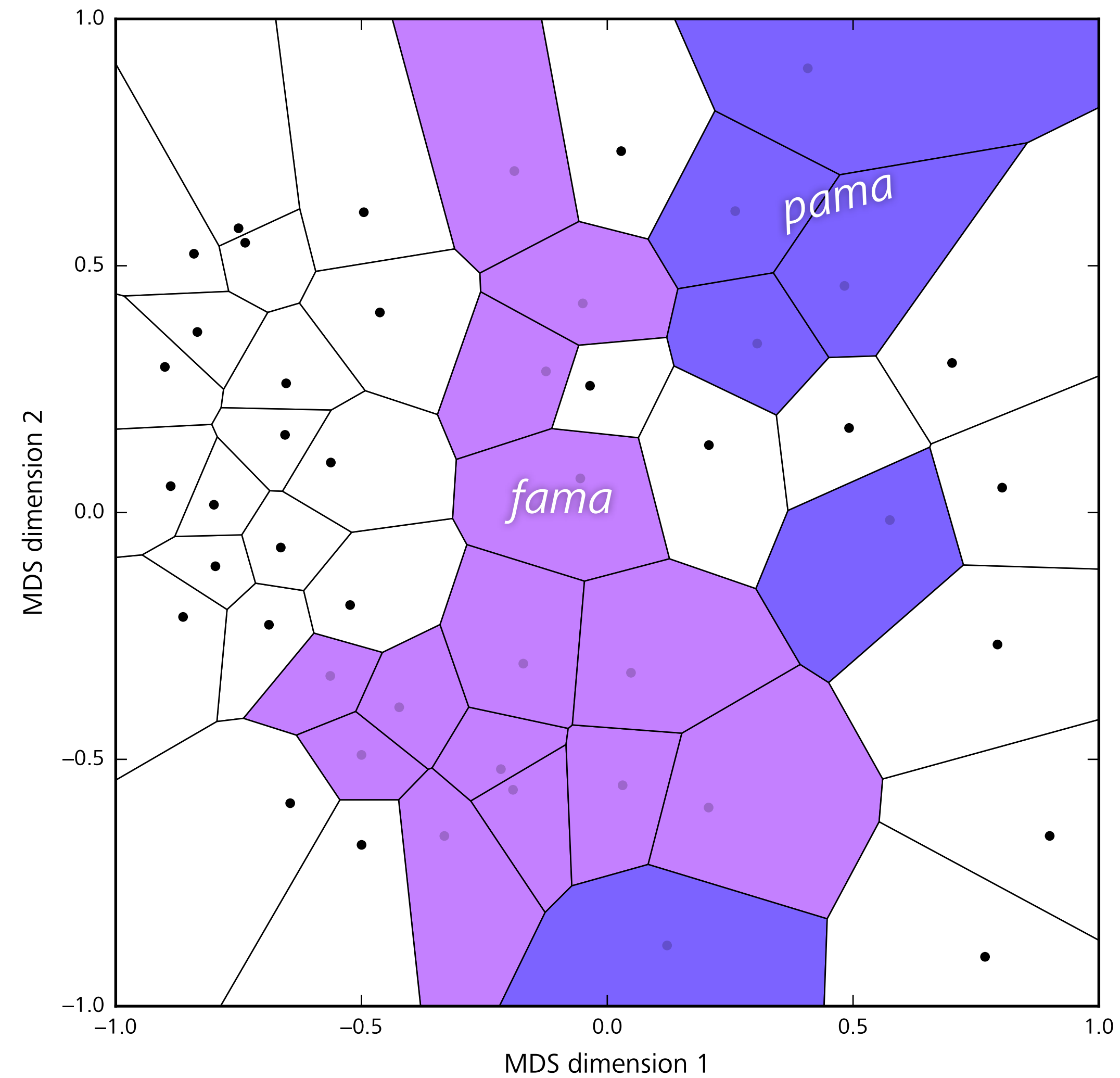
Iterated learning gives rise to discrete categories



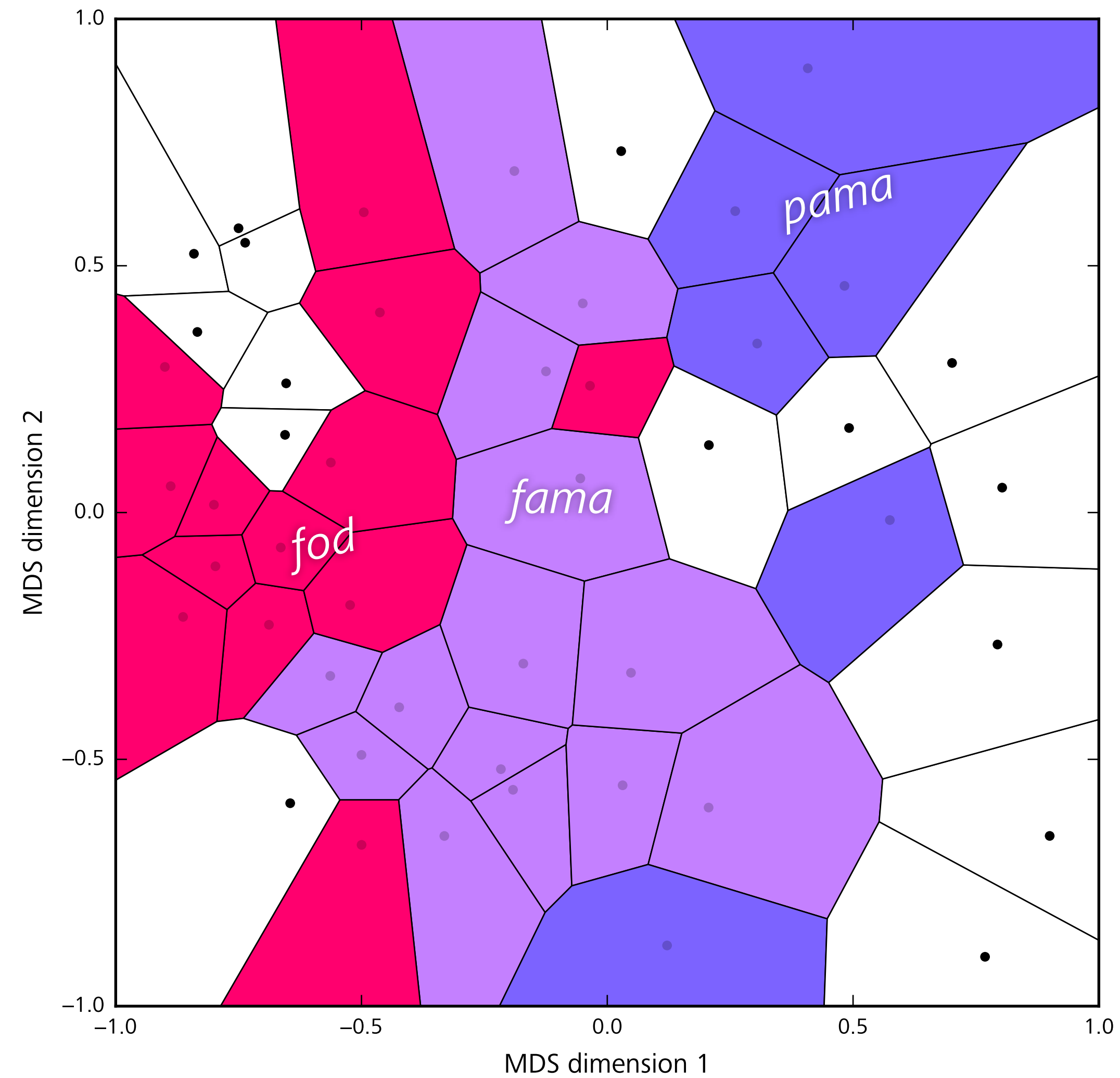
Iterated learning gives rise to discrete categories



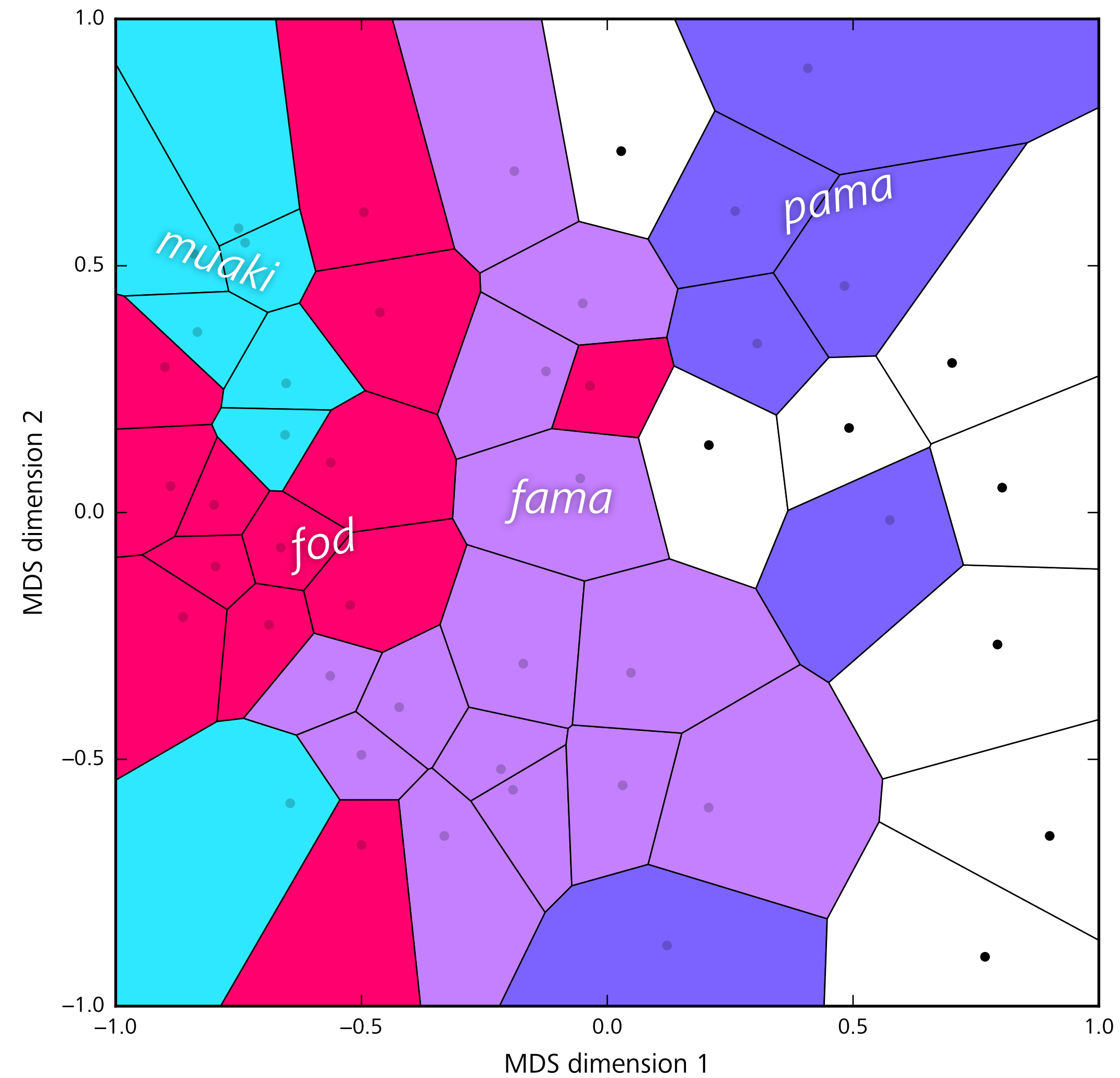
Iterated learning gives rise to discrete categories



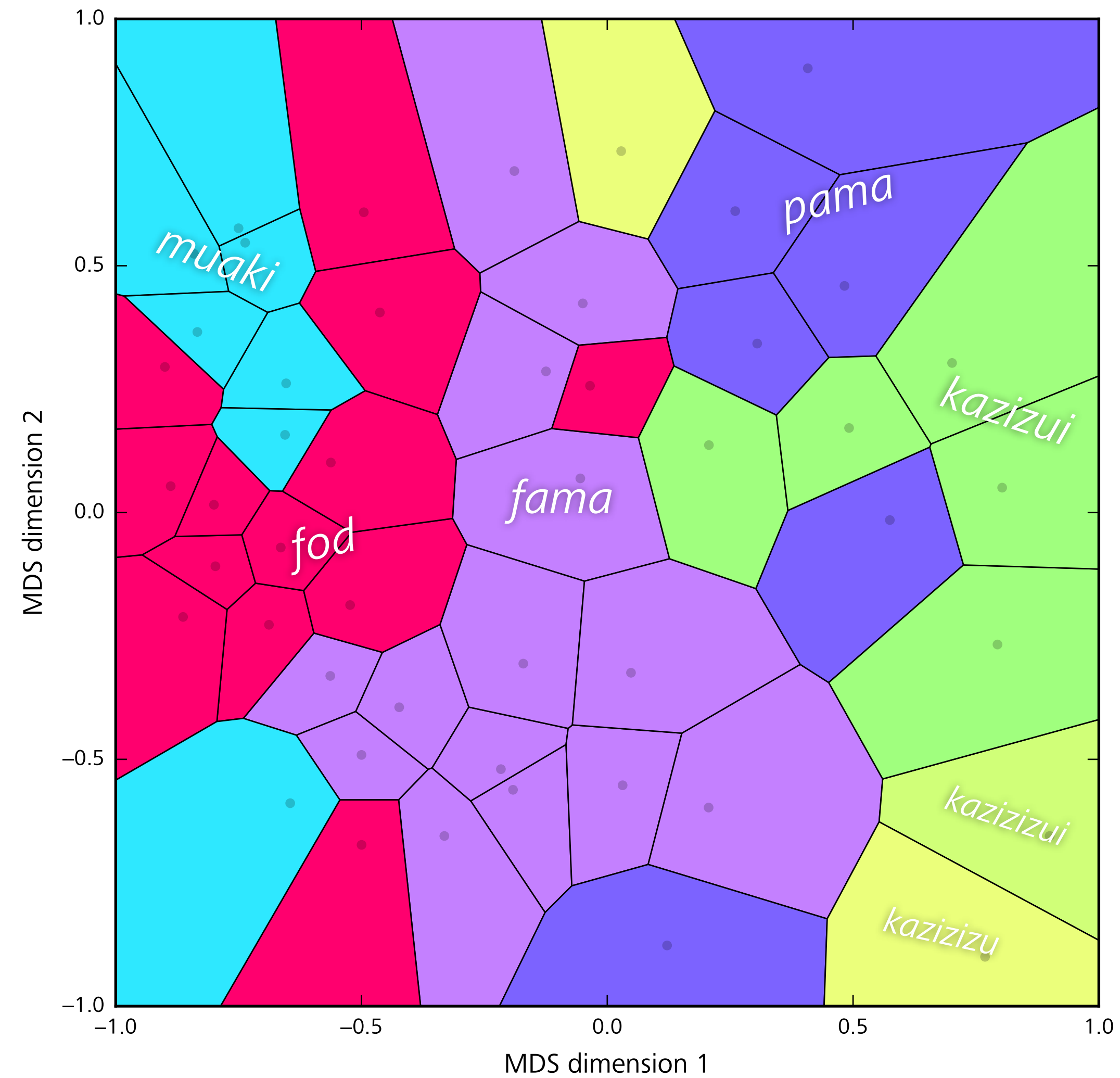
Iterated learning gives rise to discrete categories



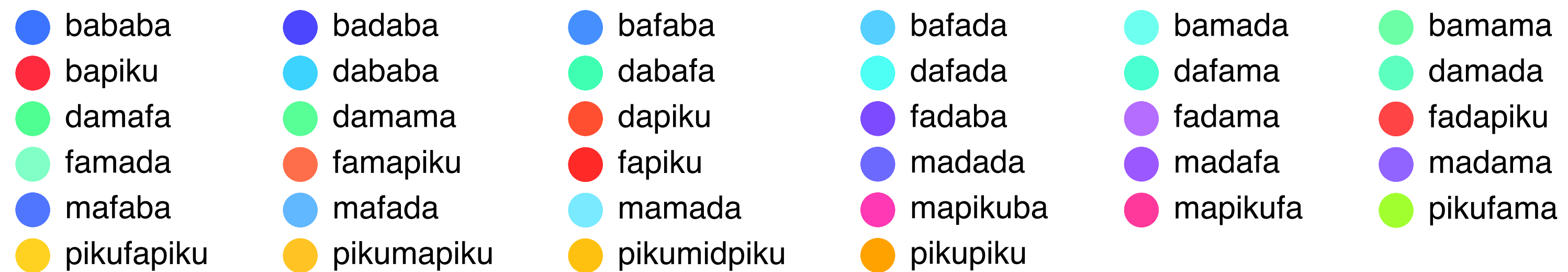
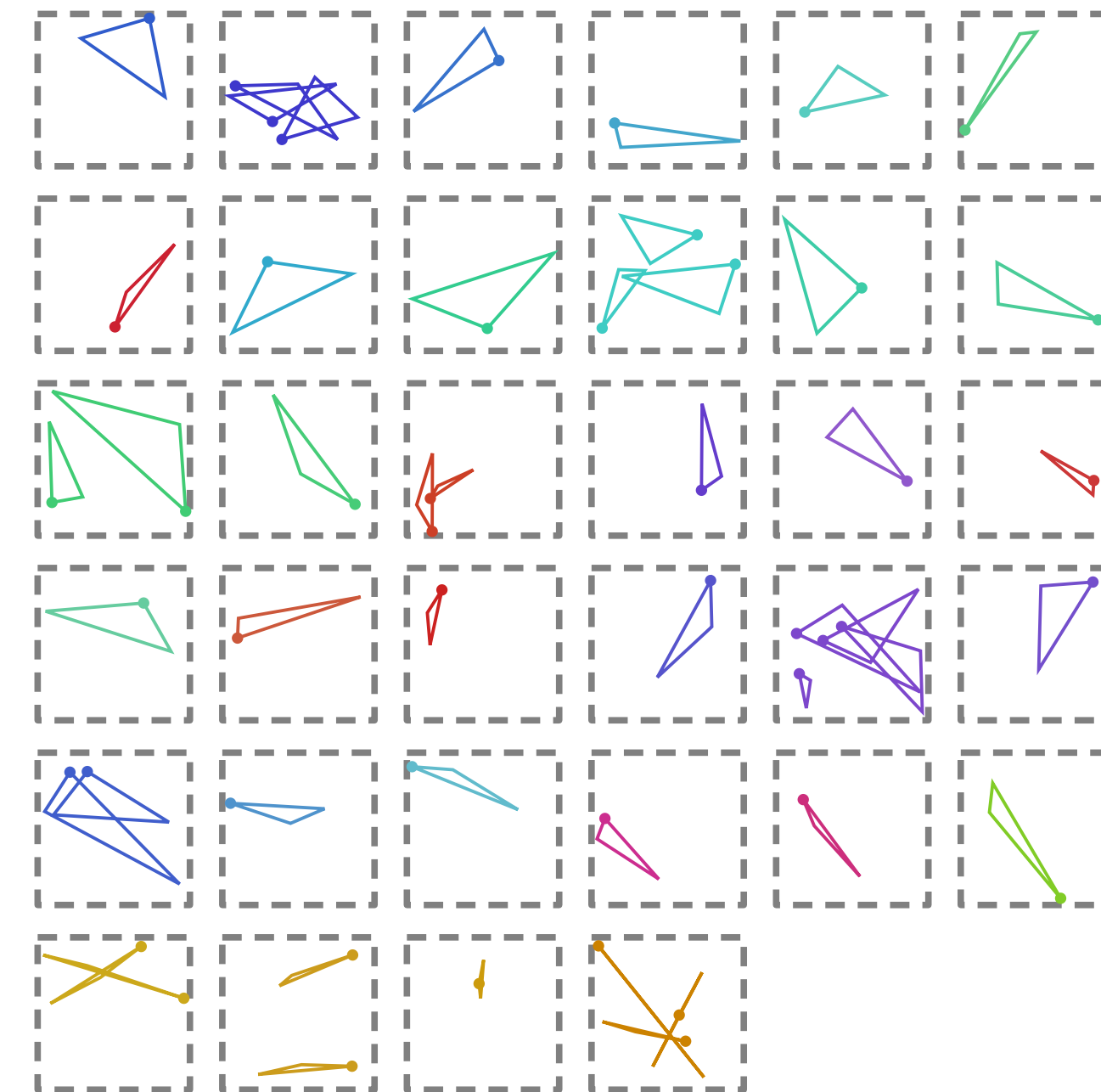
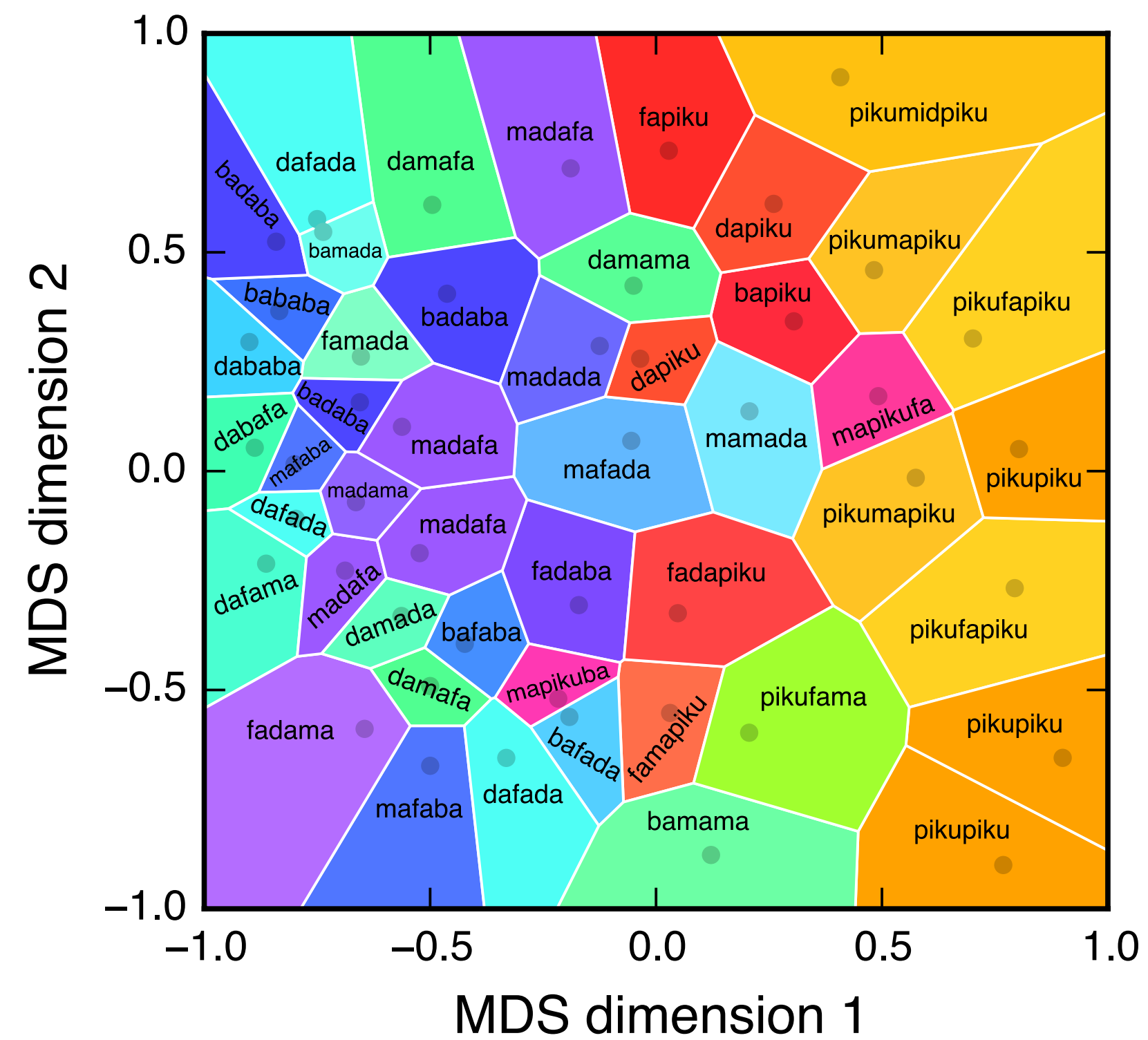
Iterated learning gives rise to discrete categories



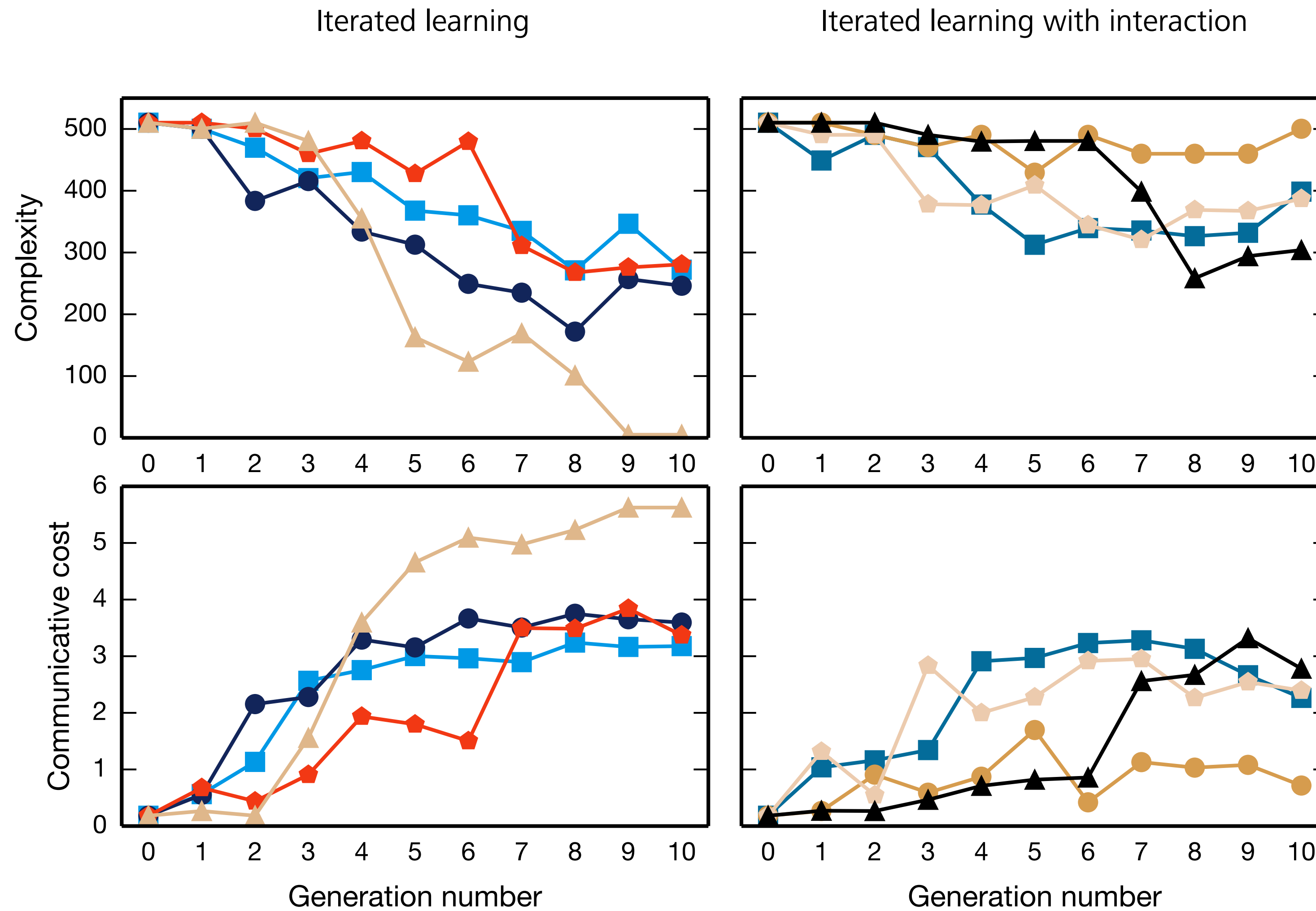
Iterated learning gives rise to discrete categories



Communicative interaction gives rise to sublexical structure



Communicative interaction gives rise to sublexical structure



Conclusions

Conclusions

- Languages are shaped by competing pressures from induction and interaction
- The human inductive bias is best characterized by a preference for simplicity
- Therefore, iterated learning gives rise to simple, inexpressive category systems with simple, compact structure
Side-note: Compact structure also happens to be a feature of informativeness, obscuring the mechanism
- But! The presence of communicative interaction prevents this process getting out of hand by permitting the emergence of higher-level forms of linguistic structure
- The framework developed in the CLE (which, by the way, has many parallels with a body of work from Regier and colleagues) is resilient to more realistic assumptions about meaning

Thanks!