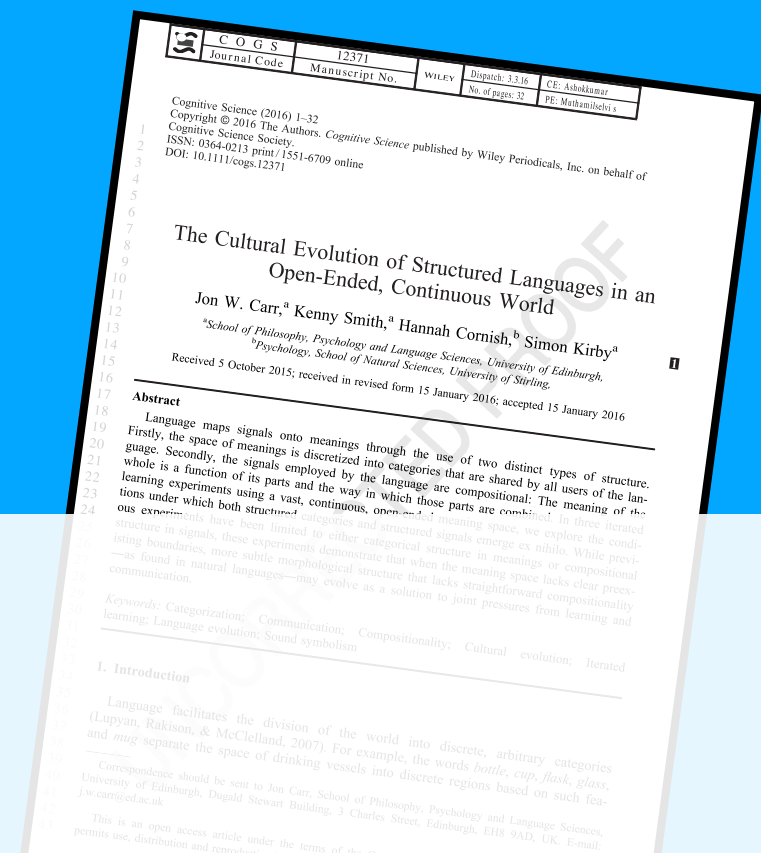


Cultural evolution and communication yield structured languages in an open-ended world

Jon W. Carr, Kenny Smith, Hannah Cornish, Simon Kirby

Carr, J. W., Smith, K., Cornish, H., & Kirby, S. (2016). The cultural evolution of structured languages in an open-ended, continuous world. *Cognitive Science*. doi:10.1111/cogs.12371

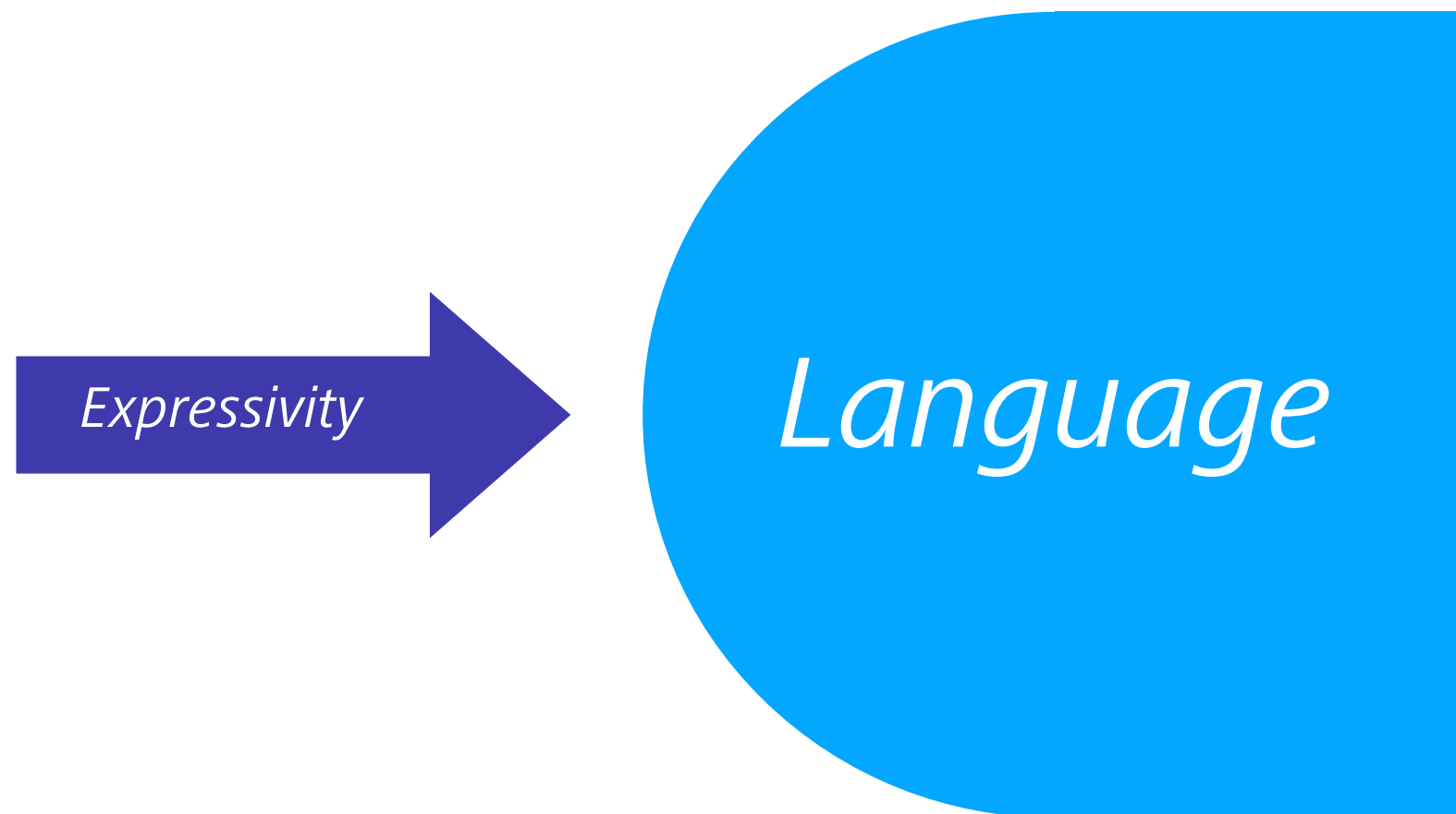


What shapes language?



Language

What shapes language?



What shapes language?



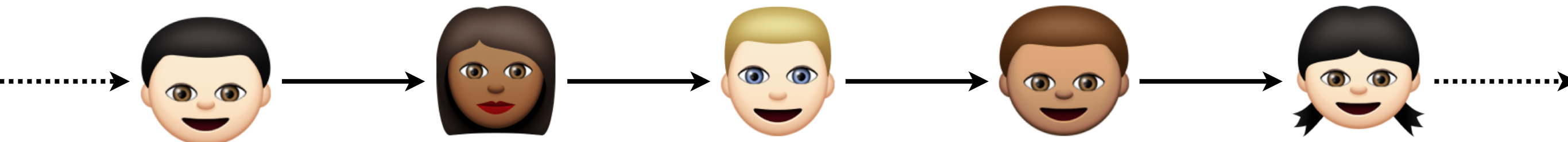
What shapes language?



What shapes language?



Iterated learning

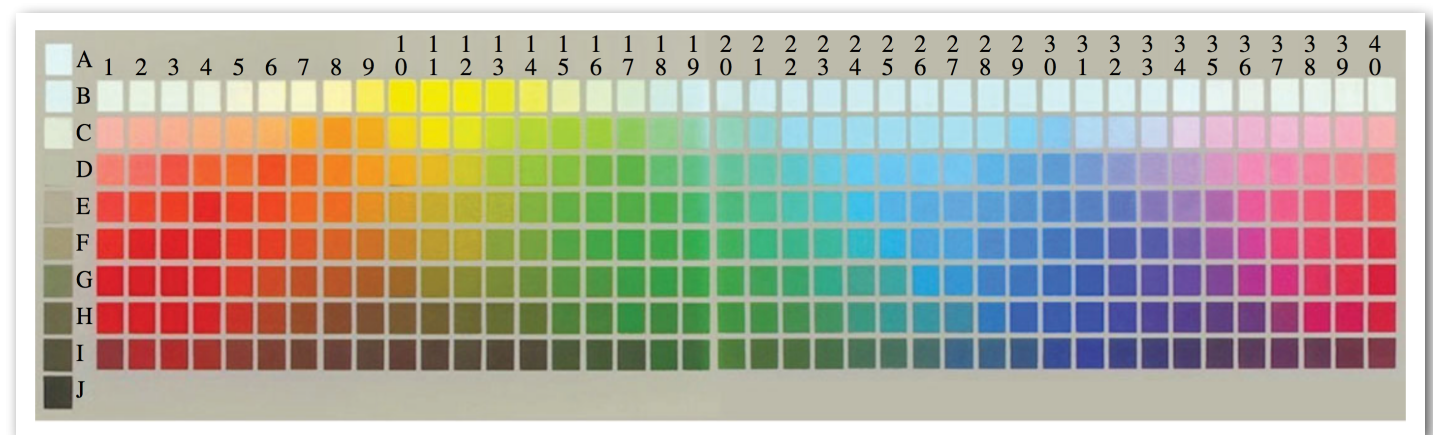


Emergence of compositional structure in the signals

----->	n-ere-ki	l-ere-ki	renana	□
	n-ehe-ki	l-aho-ki	r-ene-ki	○
	n-eke-ki	l-ake-ki	r-ahe-ki	△
~ ~ ~ ~ ~	n-ere-plo	l-ane-plo	r-e-plo	□
	n-eho-plo	l-aho-plo	r-eho-plo	○
	n-eki-plo	l-aki-plo	r-aho-plo	△
⤿	n-e-pilu	l-ane-pilu	r-e-pilu	□
	n-eho-pilu	l-aho-pilu	r-eho-pilu	○
	n-eki-pilu	l-aki-pilu	r-aho-pilu	△

Kirby, Cornish, & Smith, 2008, *PNAS*

Emergence of categorical structure in the meanings



Xu, Dowman, & Griffiths, 2013, *Proc R Soc B*

*Can we see the emergence
of compositional structure
under a continuous, open-
ended meaning space?*

Experiments

Experiment 1

Pressure to be learnable from cultural transmission

No pressure to be expressive

Result: Categories emerge in the meaning space

Experiment 2

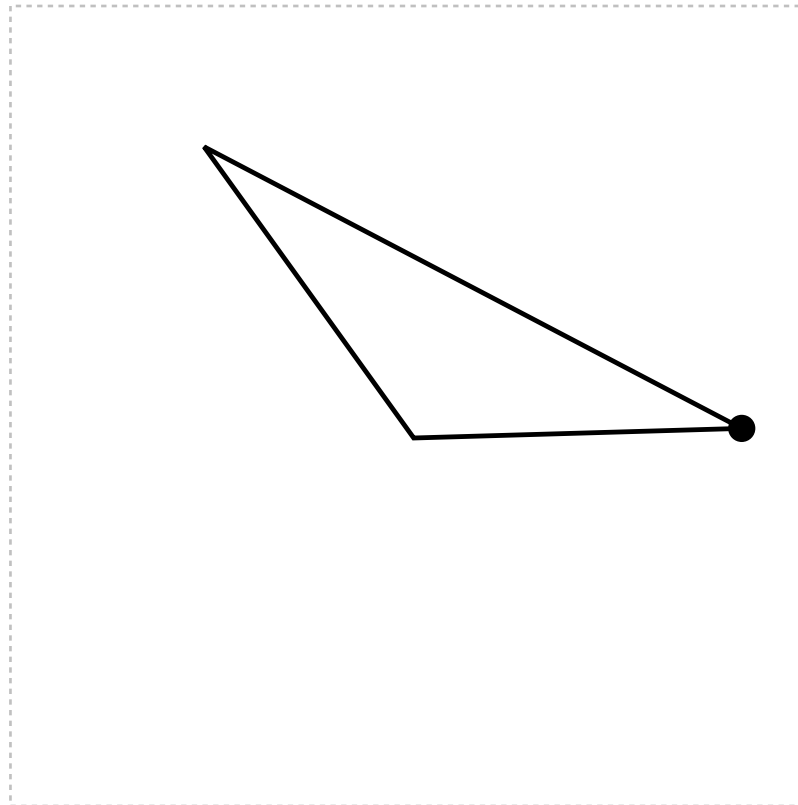
Pressure to be learnable from cultural transmission

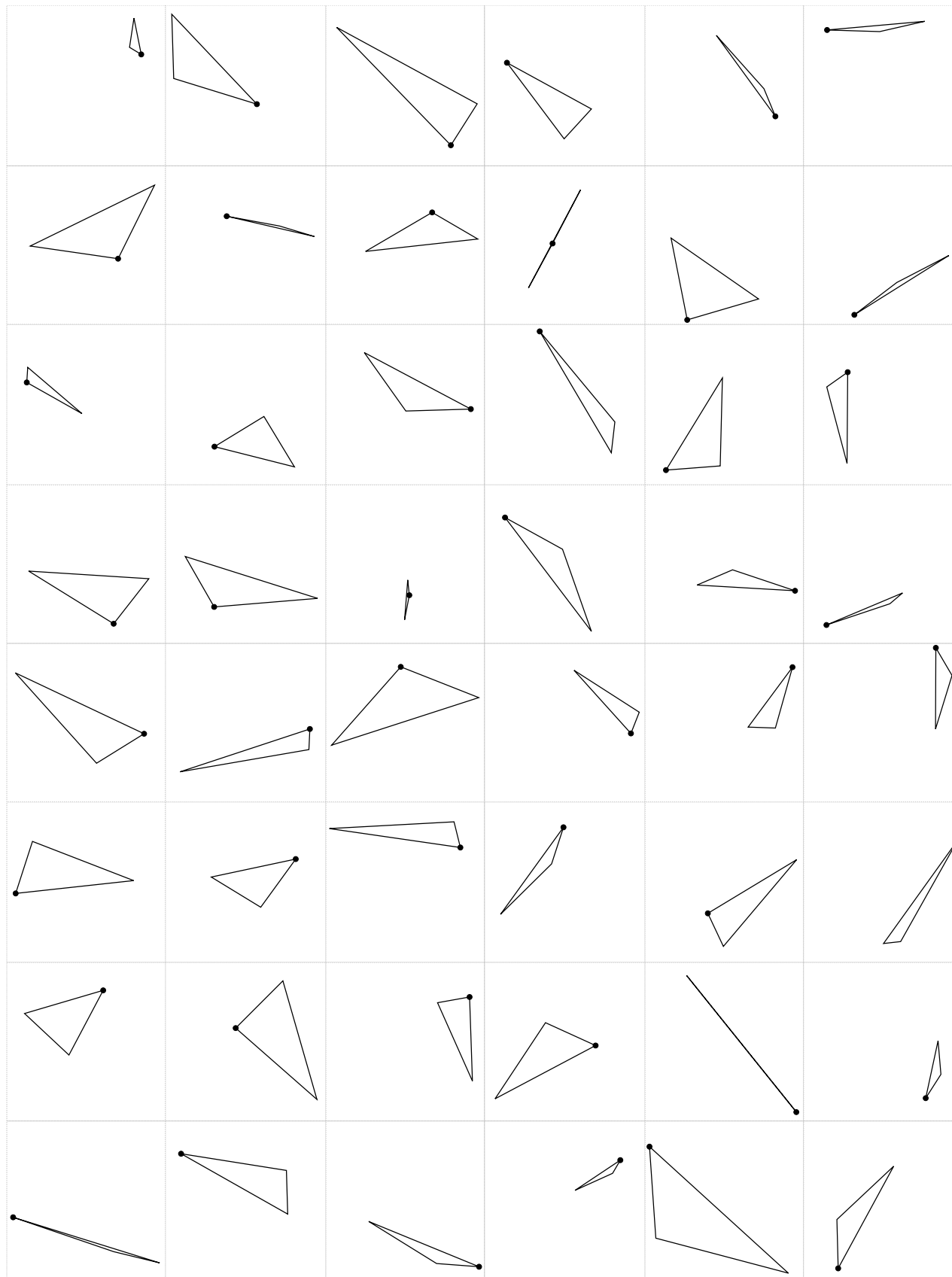
Pressure to be expressive from communication

Result: “Compositional” structure emerges in the signals

Experiment I

Stimuli





Vast in magnitude

6×10^{15} possible triangle stimuli

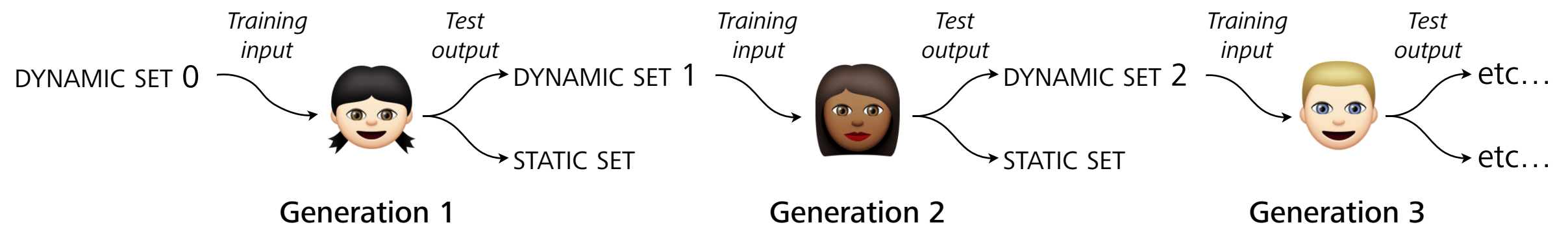
Complex dimensions

Many possible dimensions to the space

Continuous

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

Experimental design



Training phase

Stage 1: Training

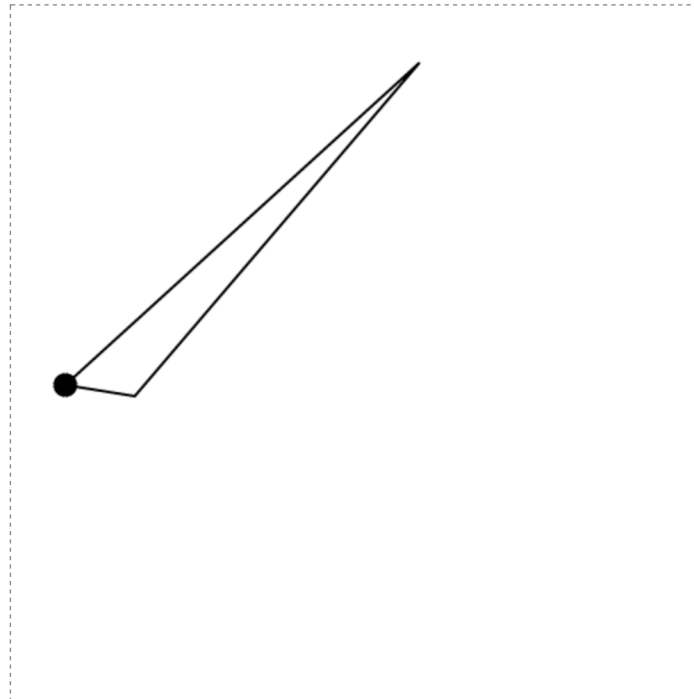
You will see a series of triangles along with the words used to describe them. After every third triangle, you will see one of those three triangles again, and you must type in the word you just learned for it. You will be told whether or not you got it right.

Try to learn the words for the triangles as best as you can, as you will use them to communicate with your partner later on.

Press the Enter key when you're ready to begin training

×144

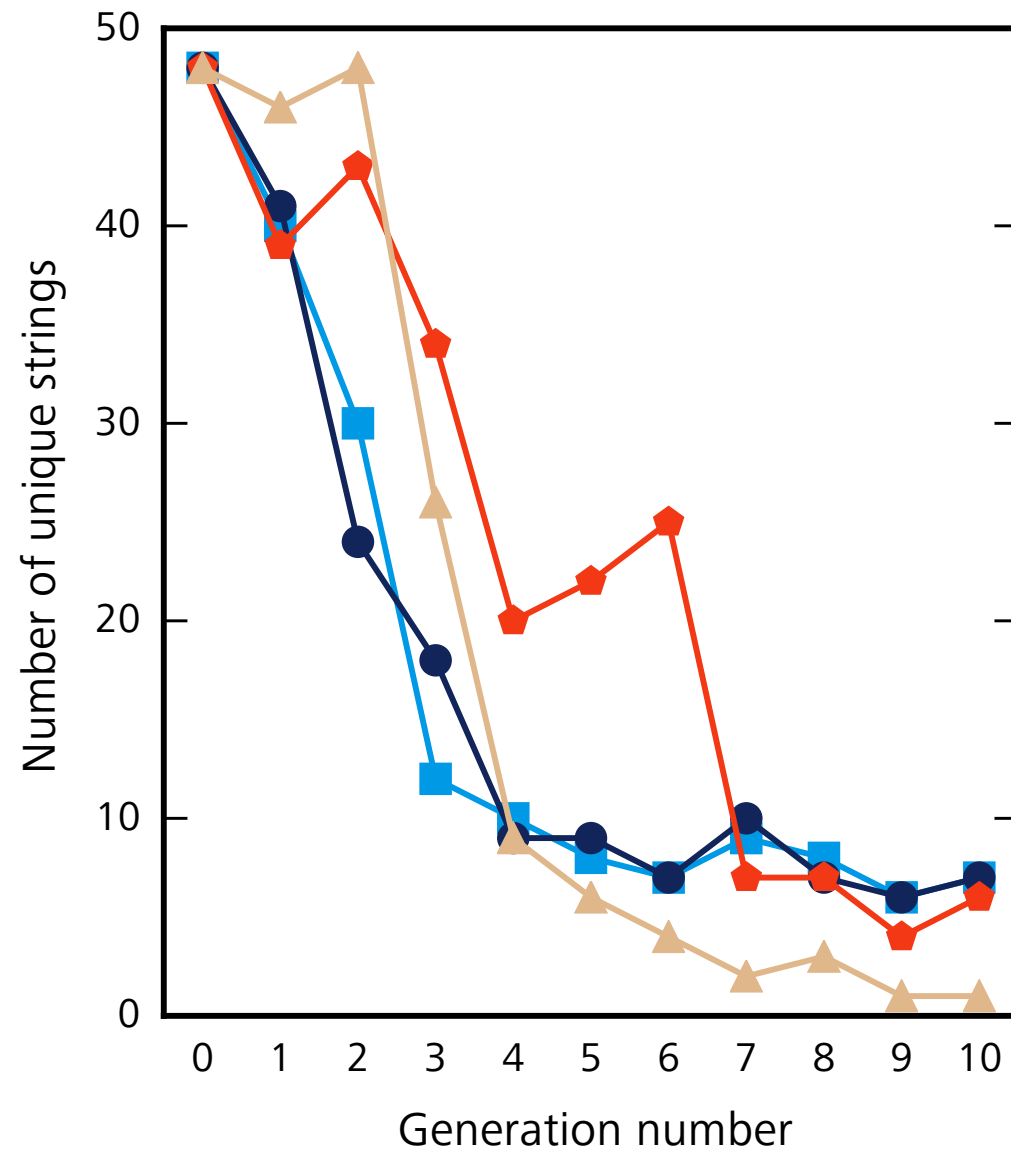
Test phase



Type in the word for this triangle and press Enter

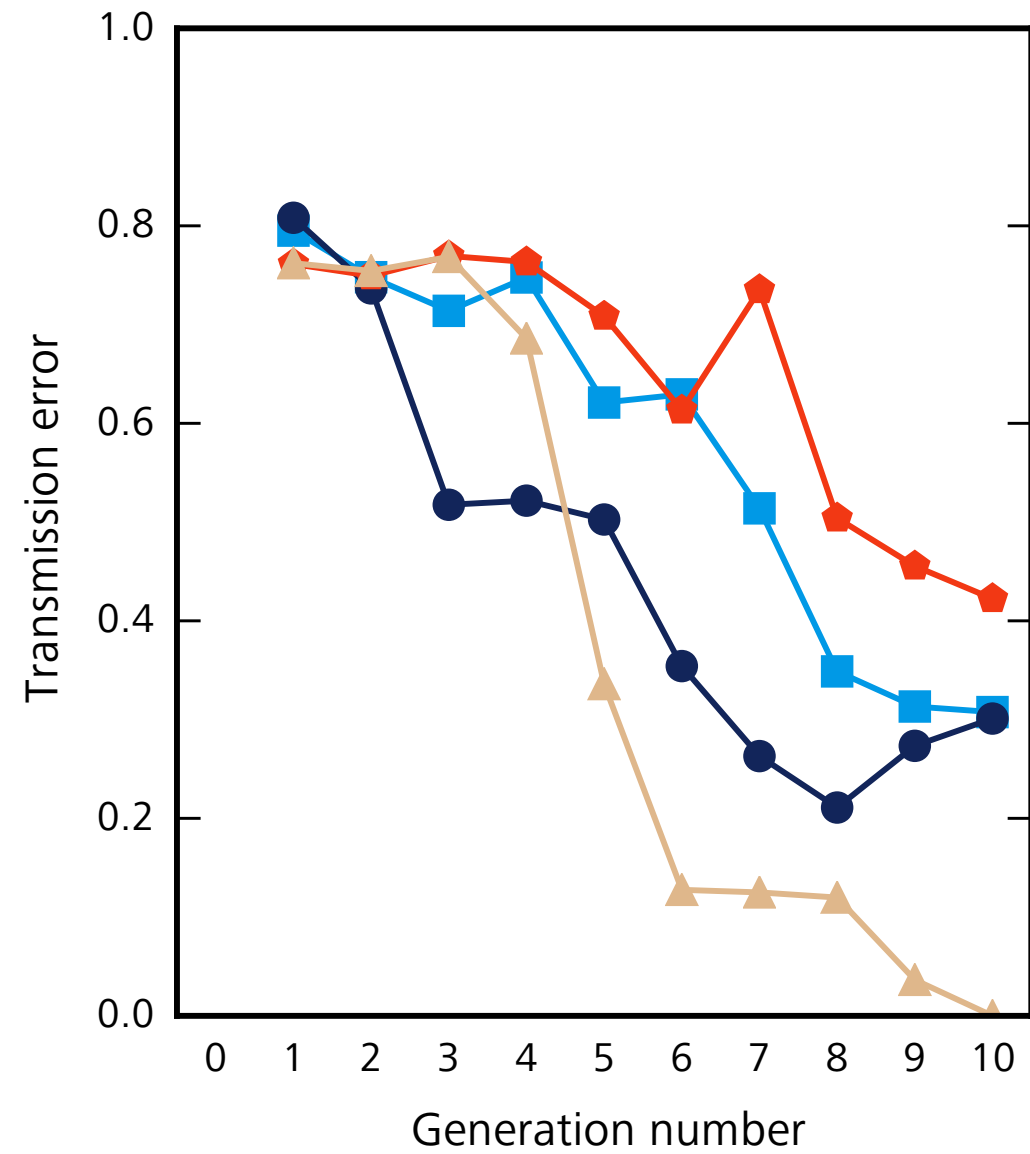
x96

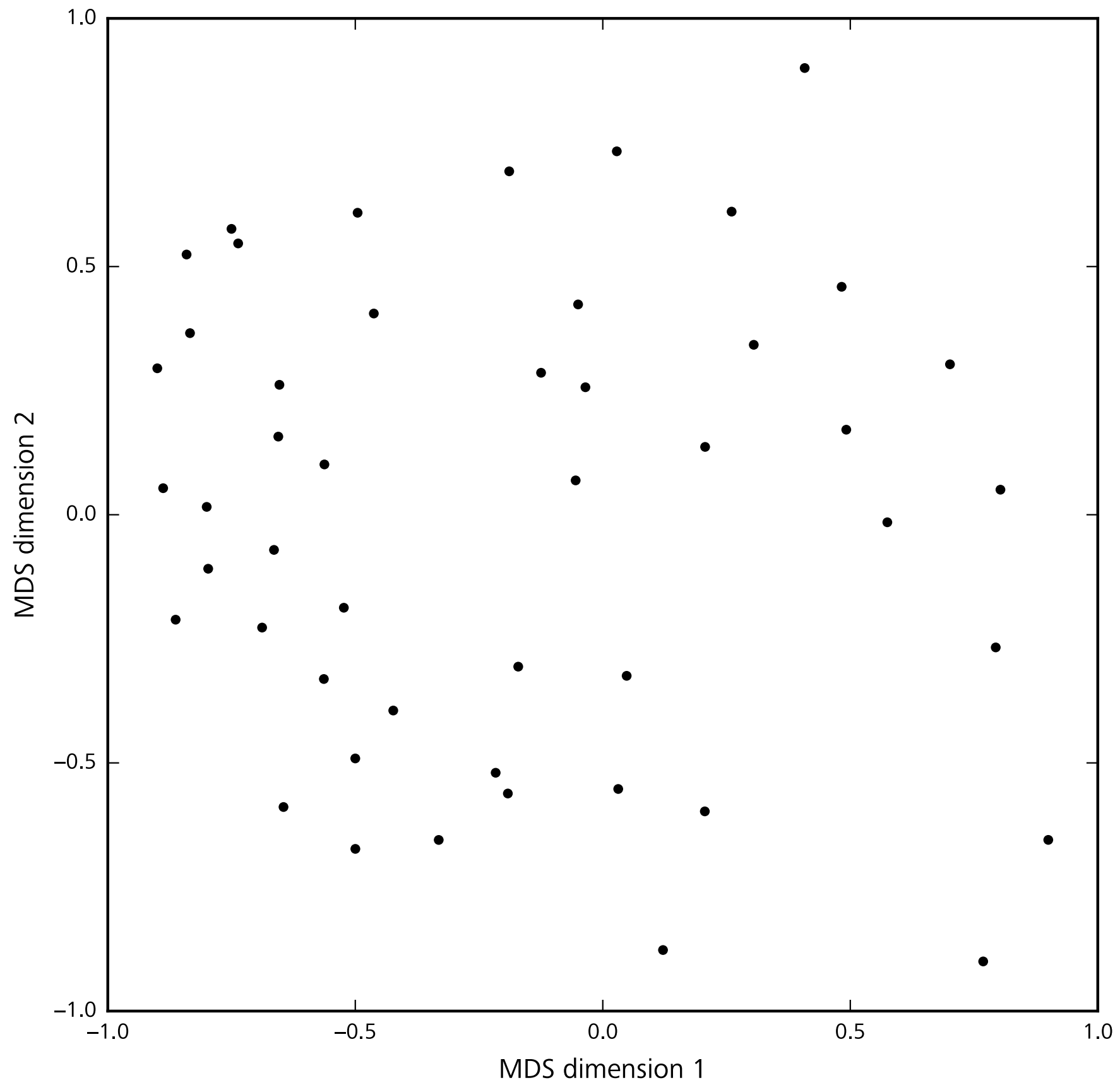
Expressivity

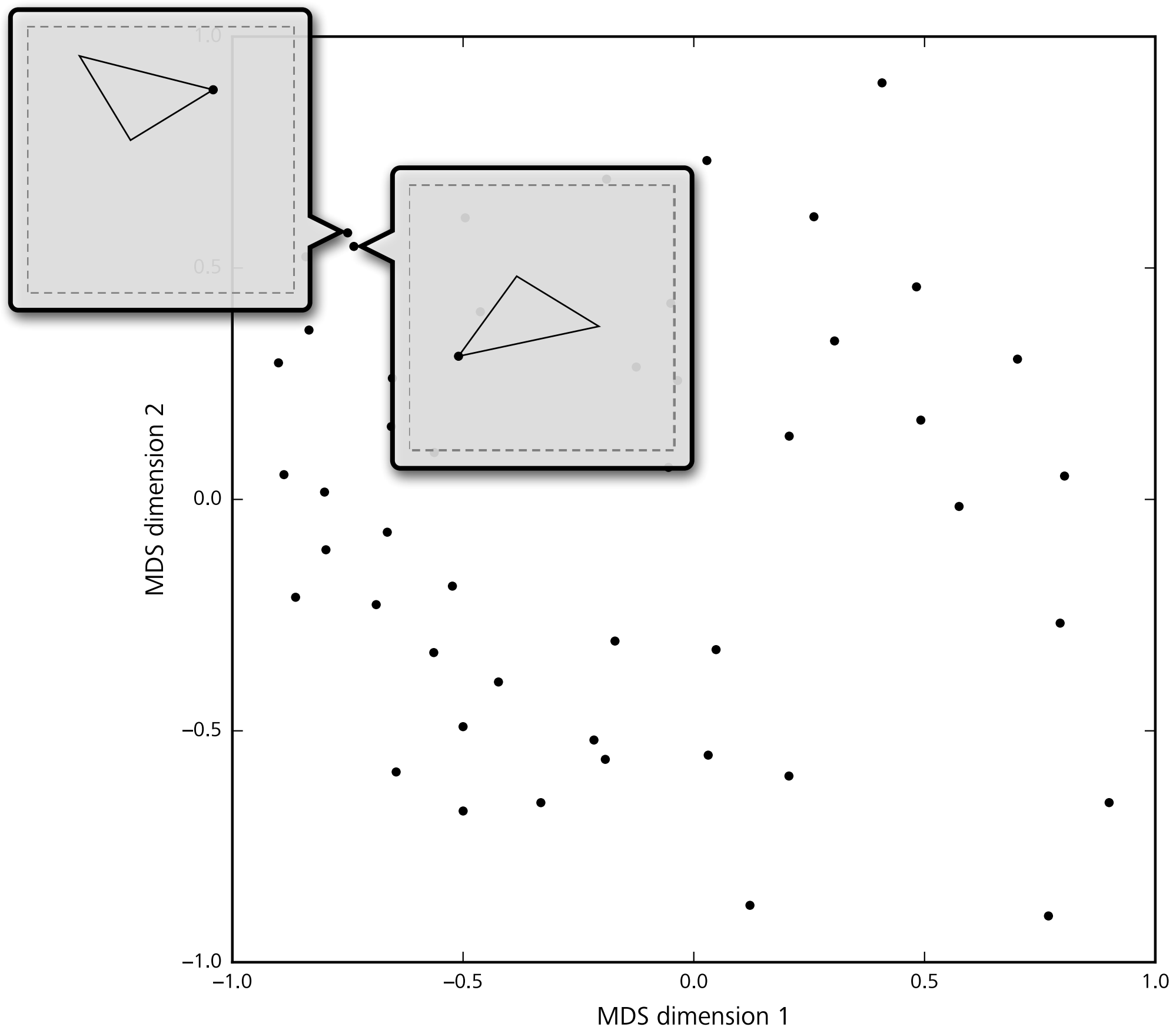


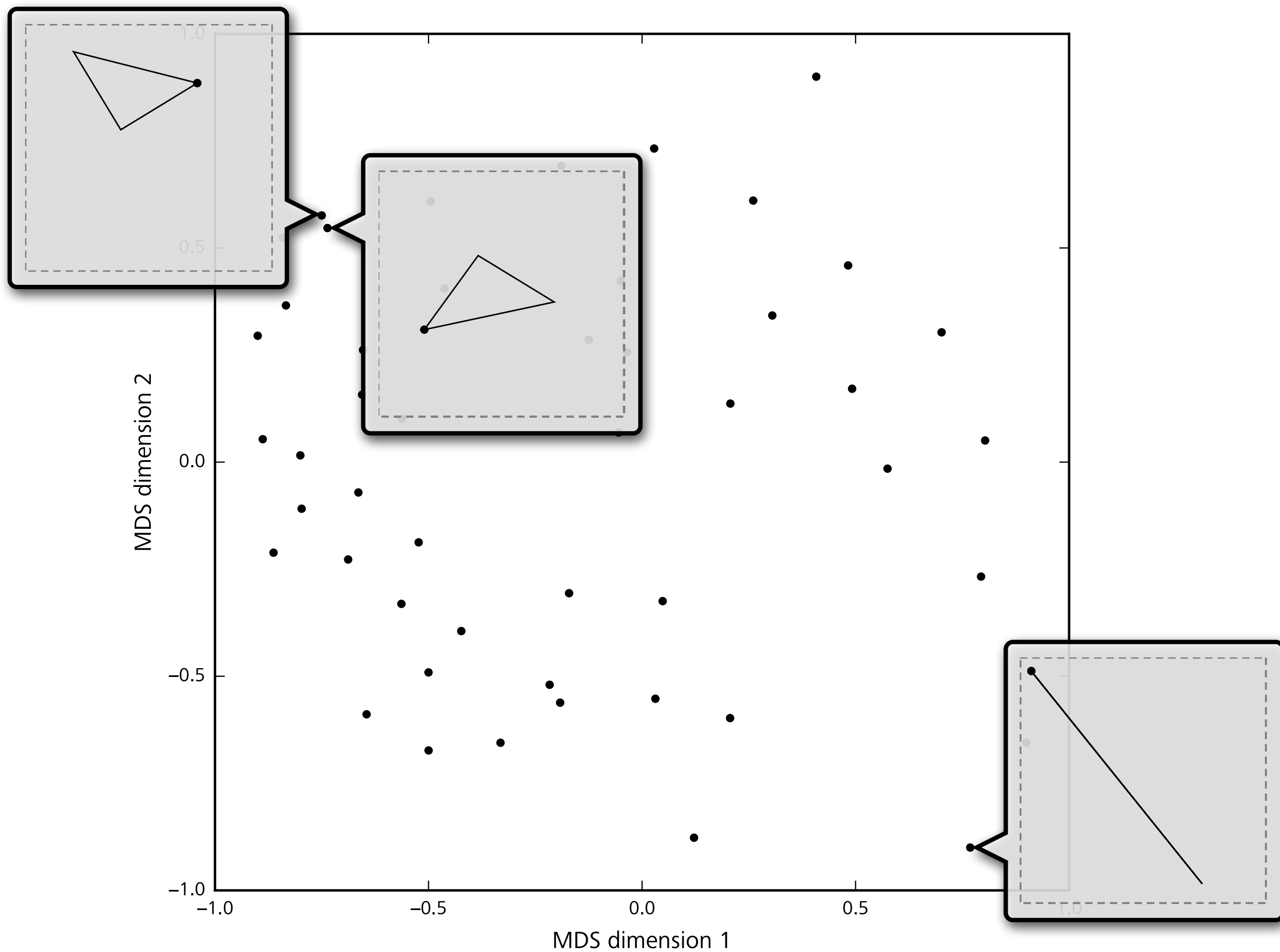
Chain A Chain B Chain C Chain D

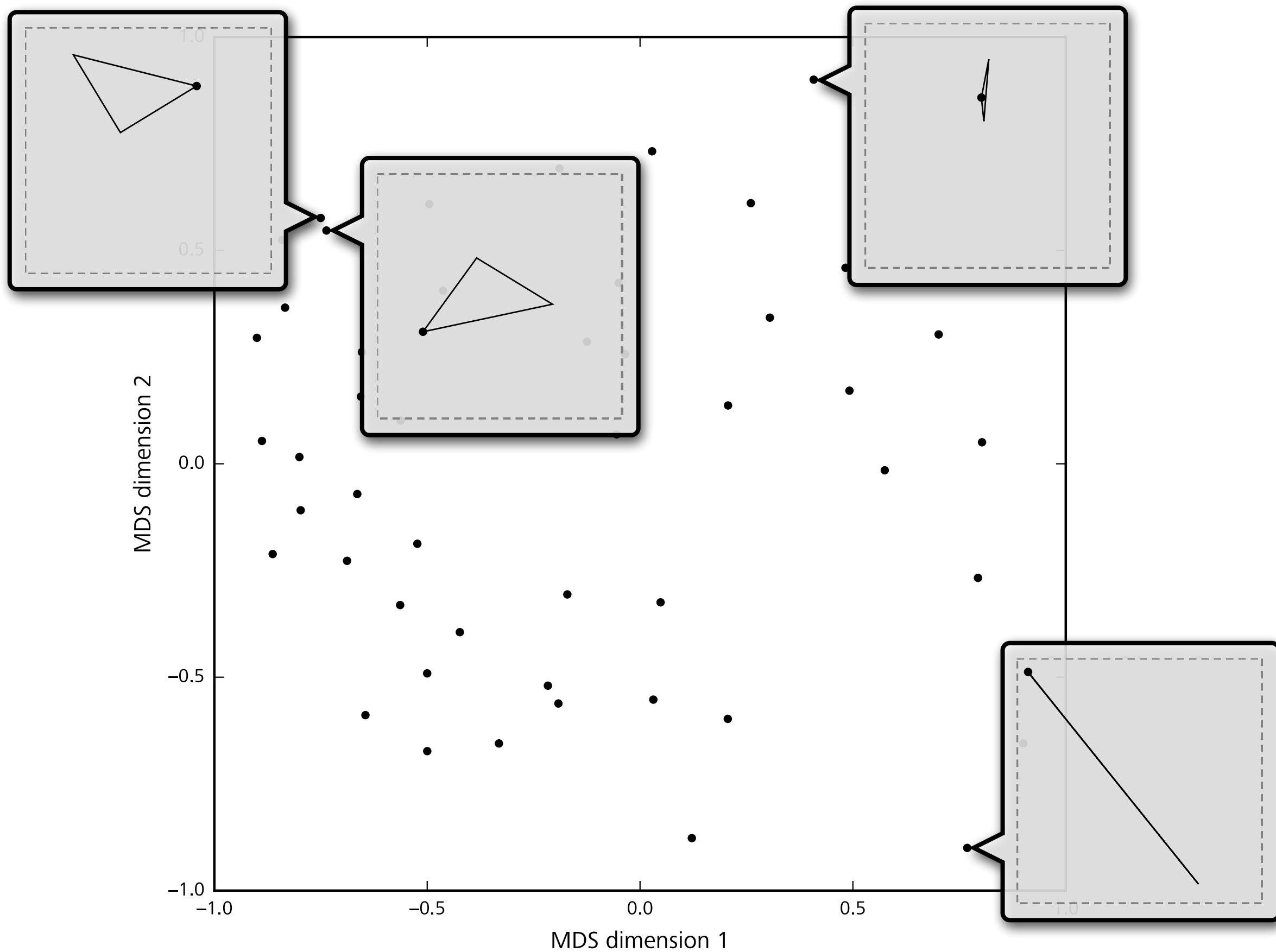
Learnability

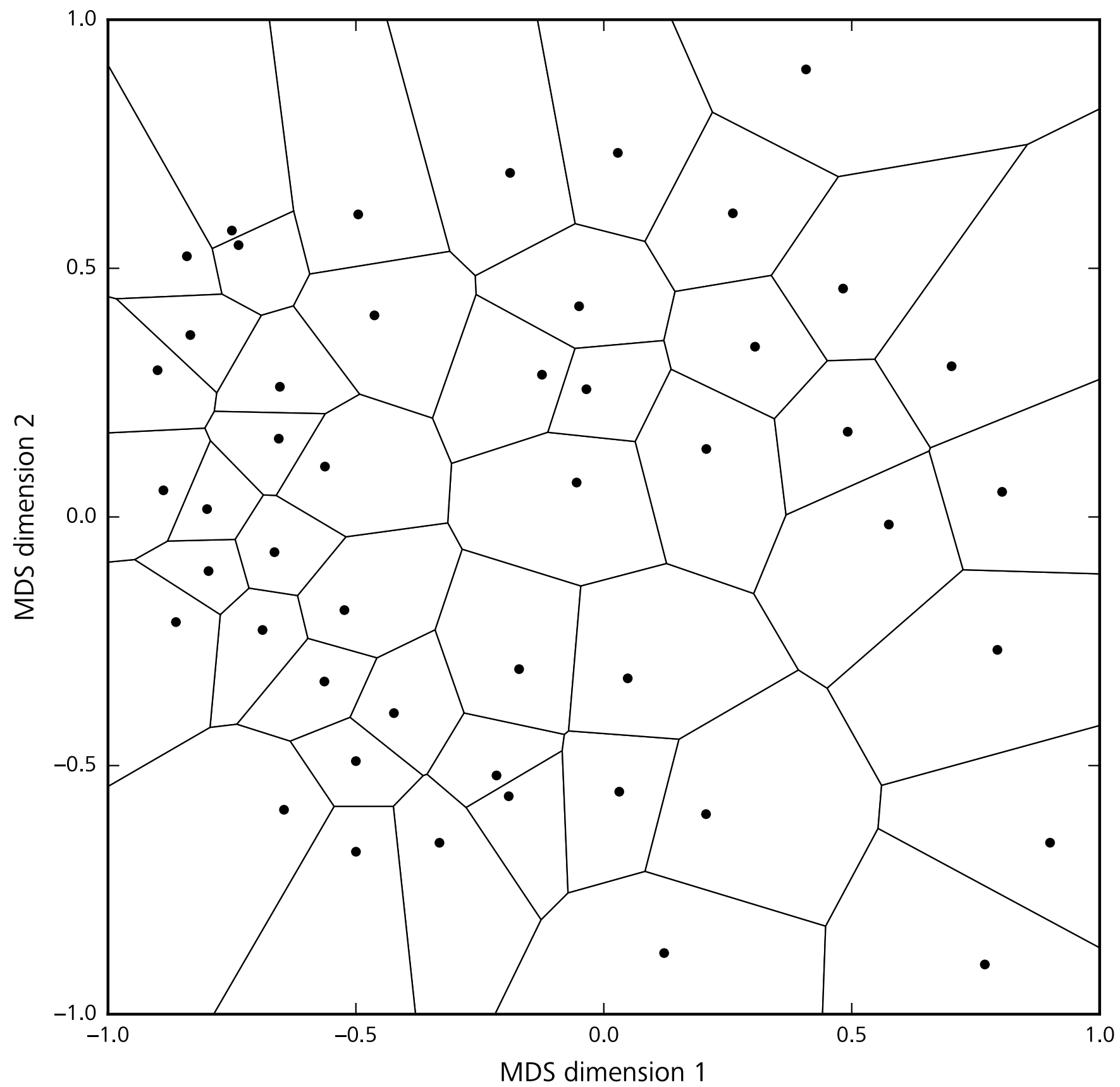


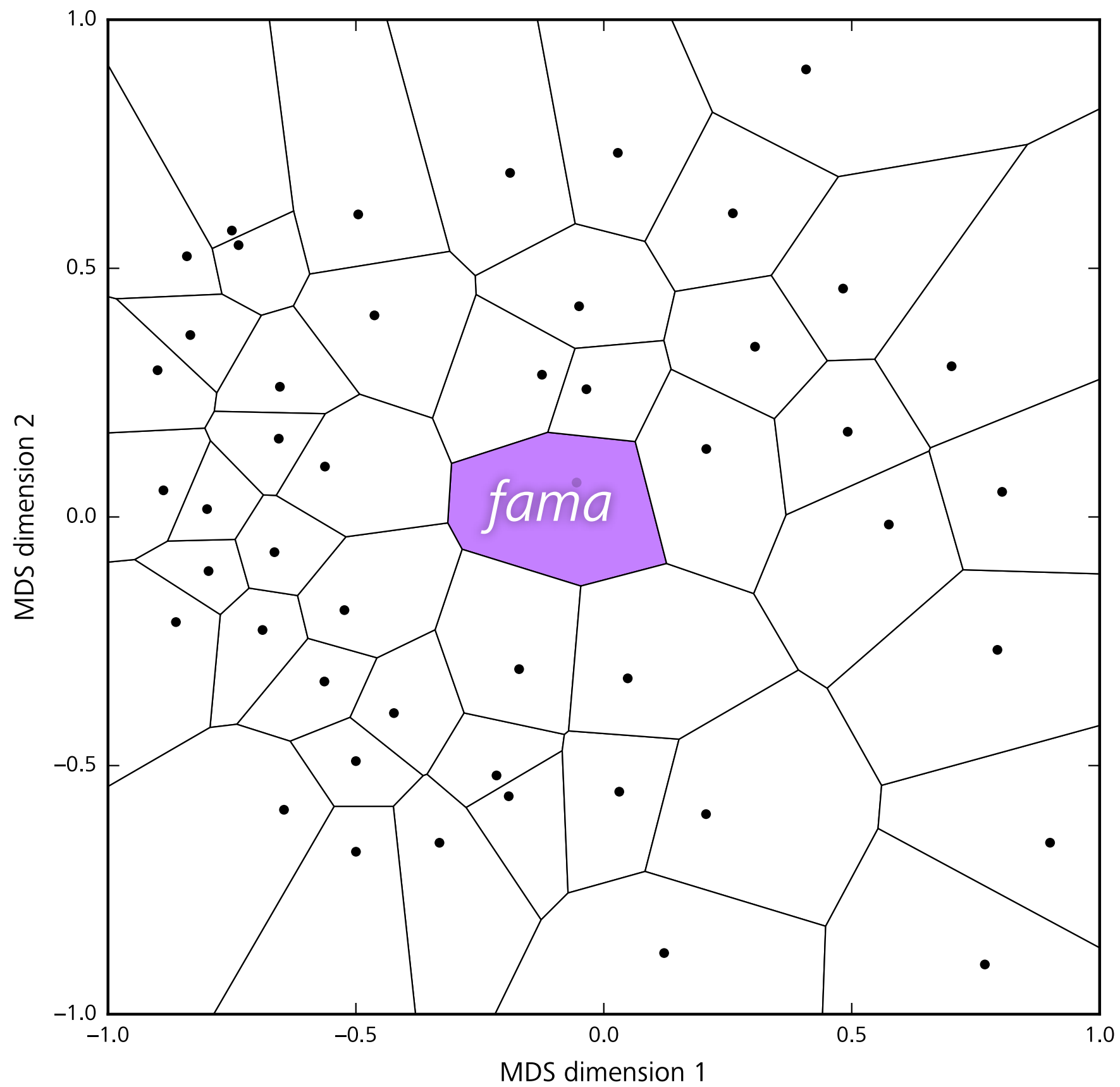


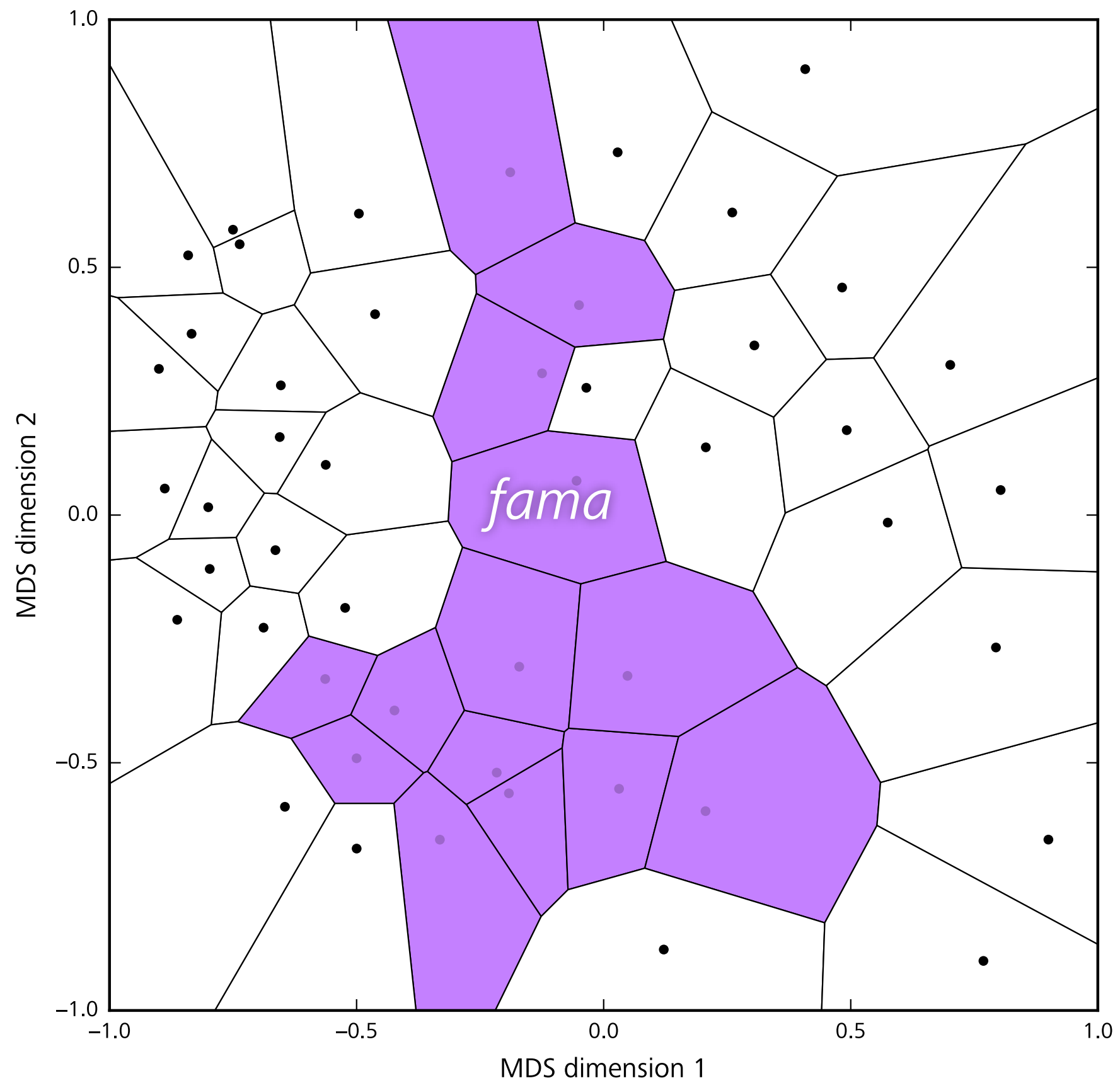


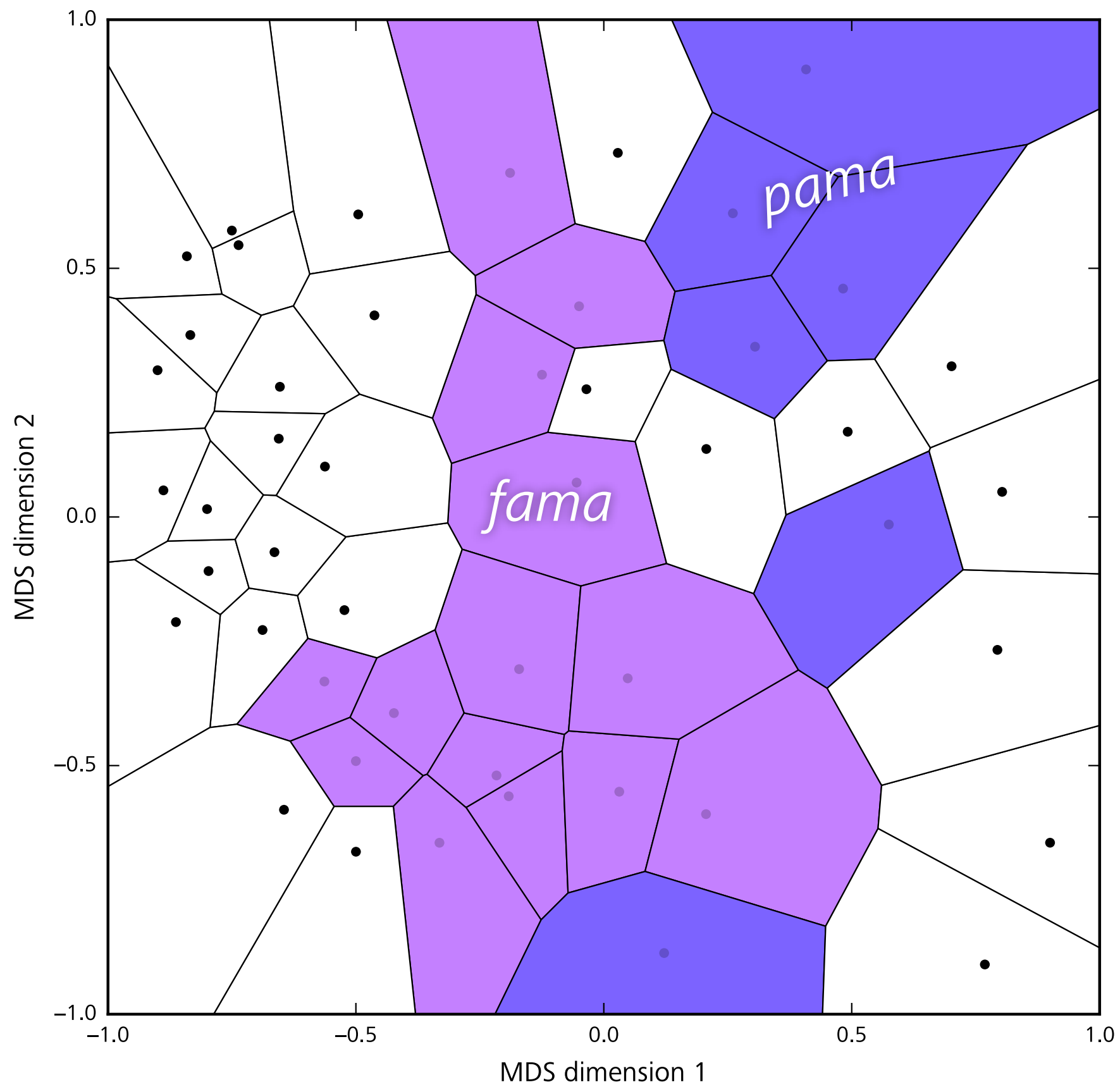


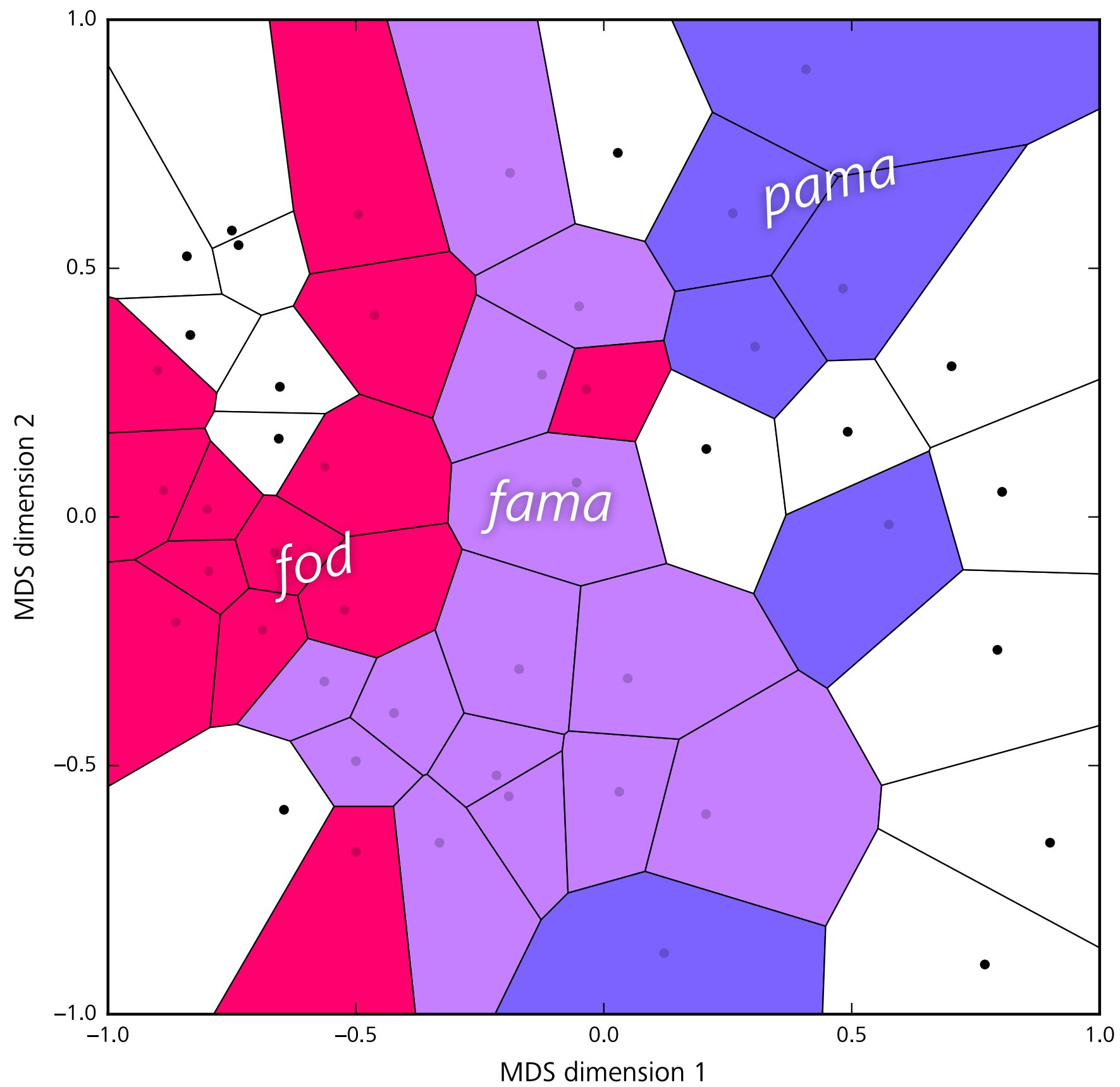


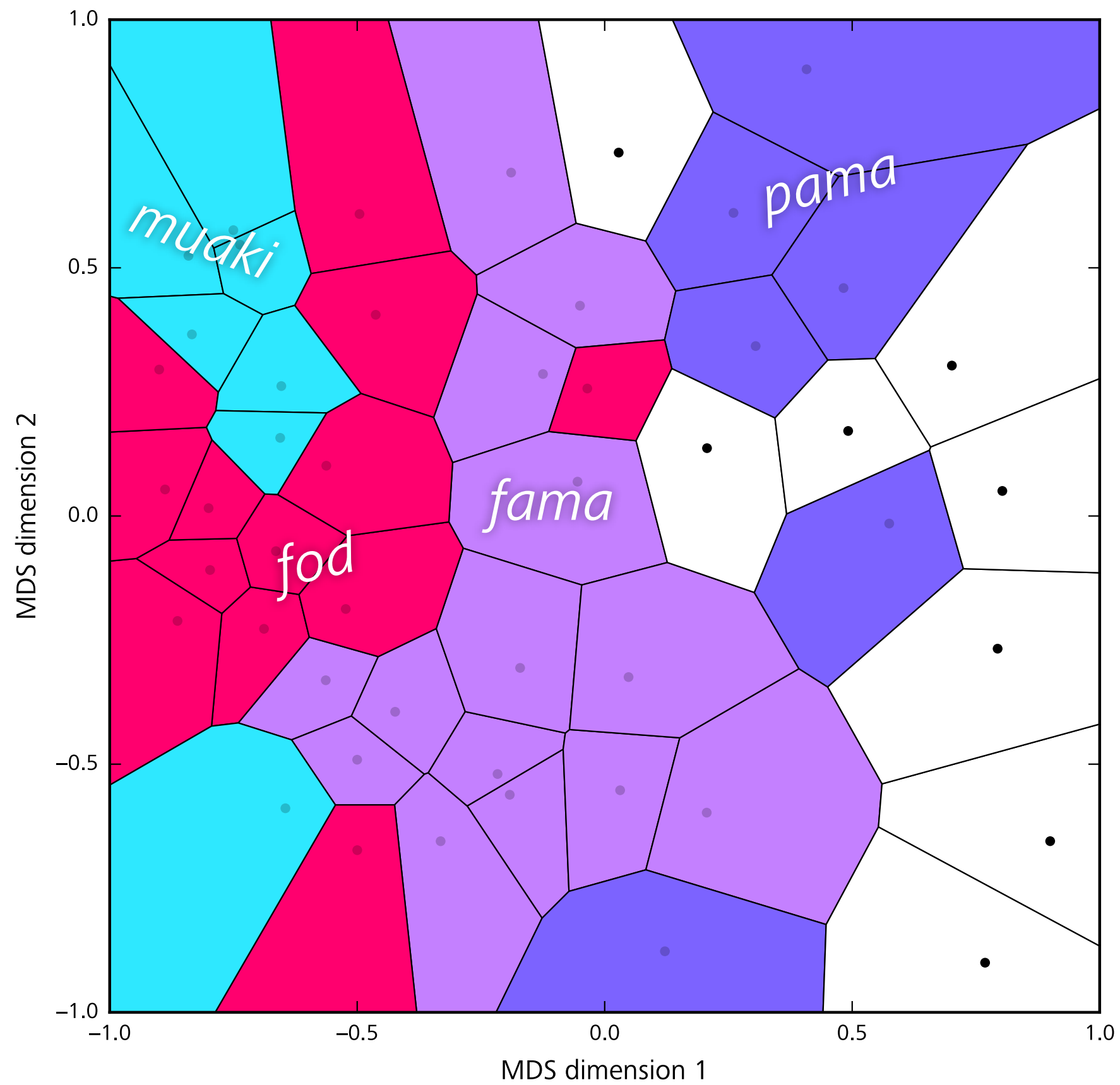


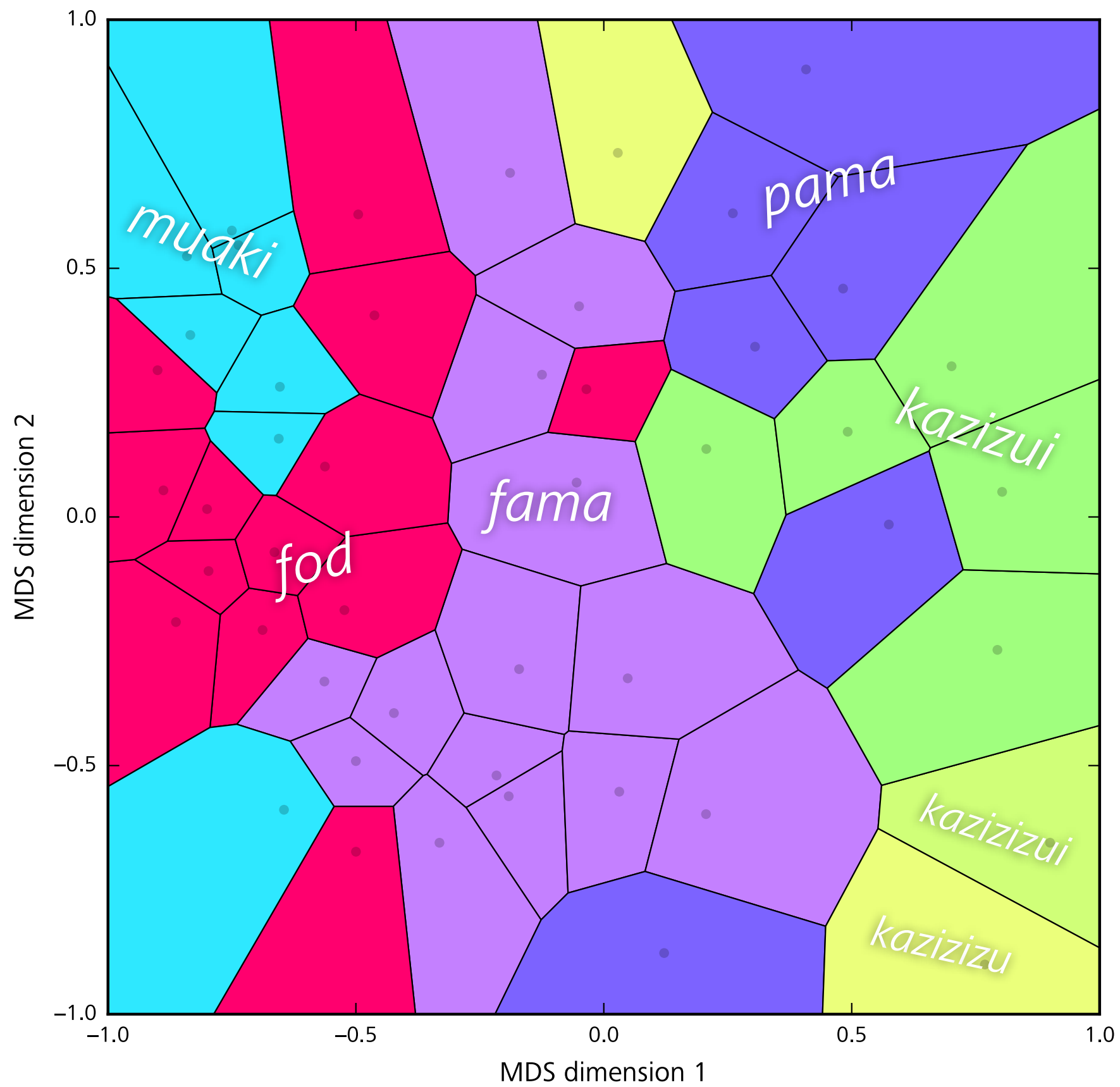


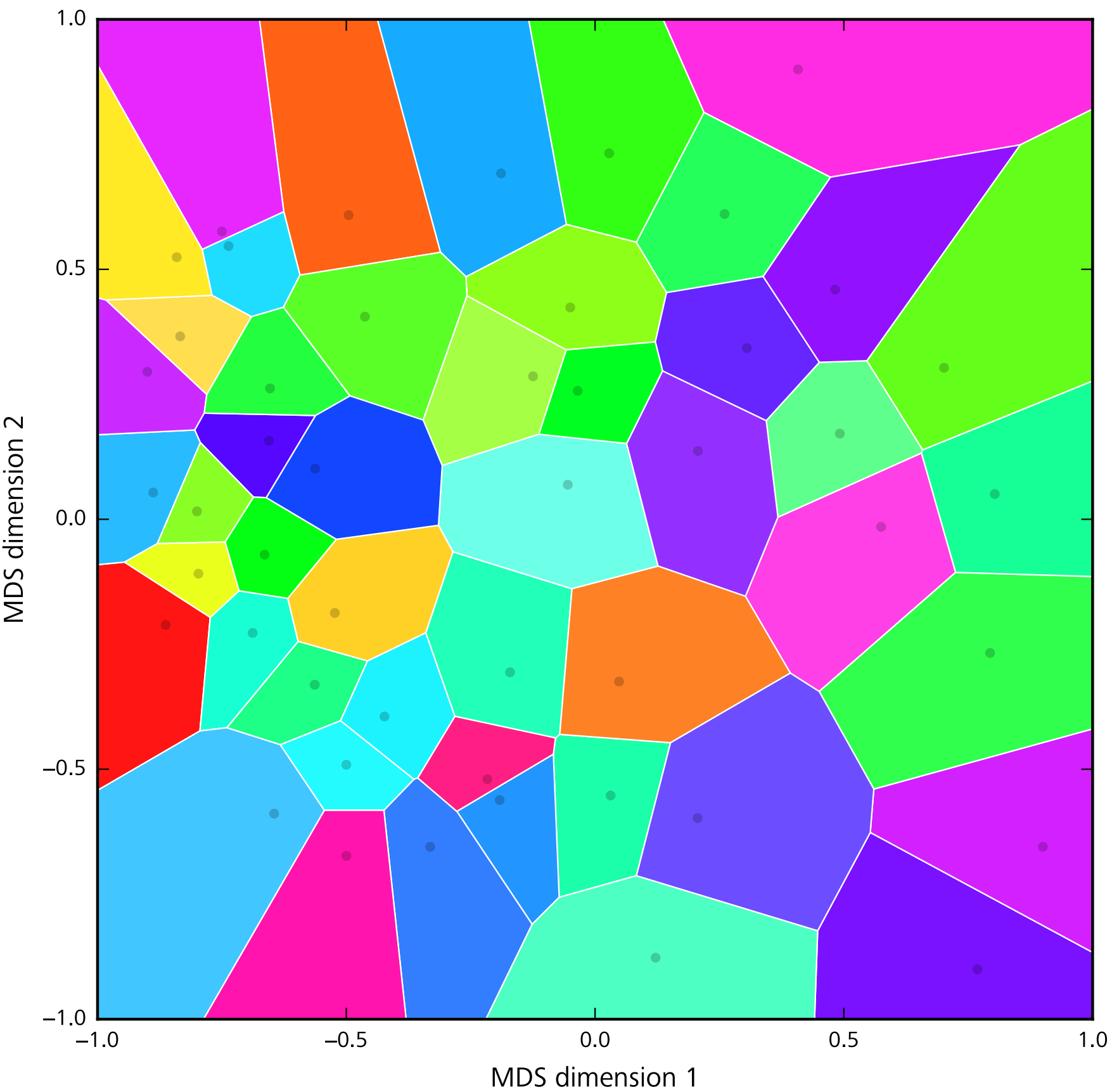






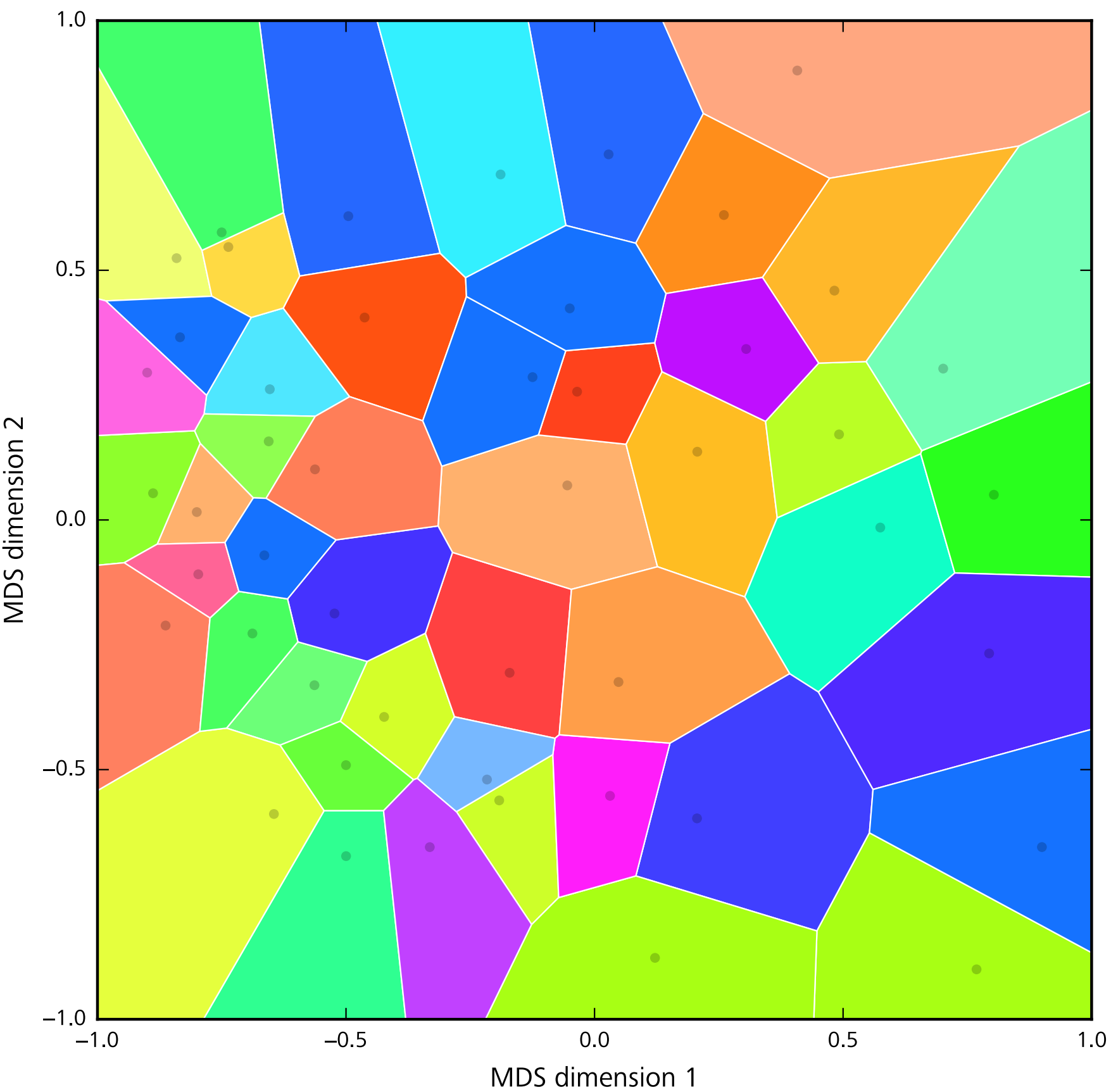






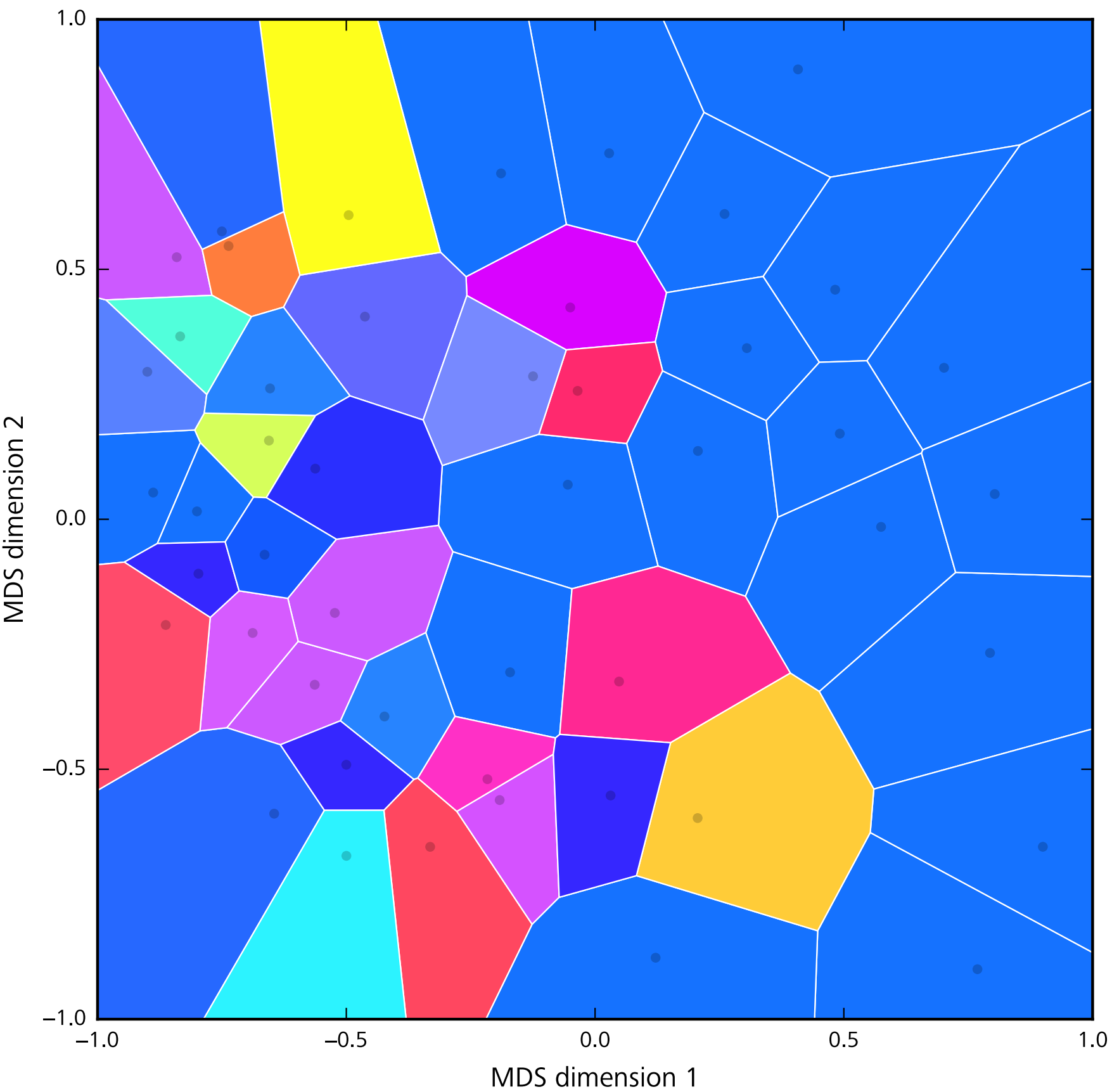
Generation

0



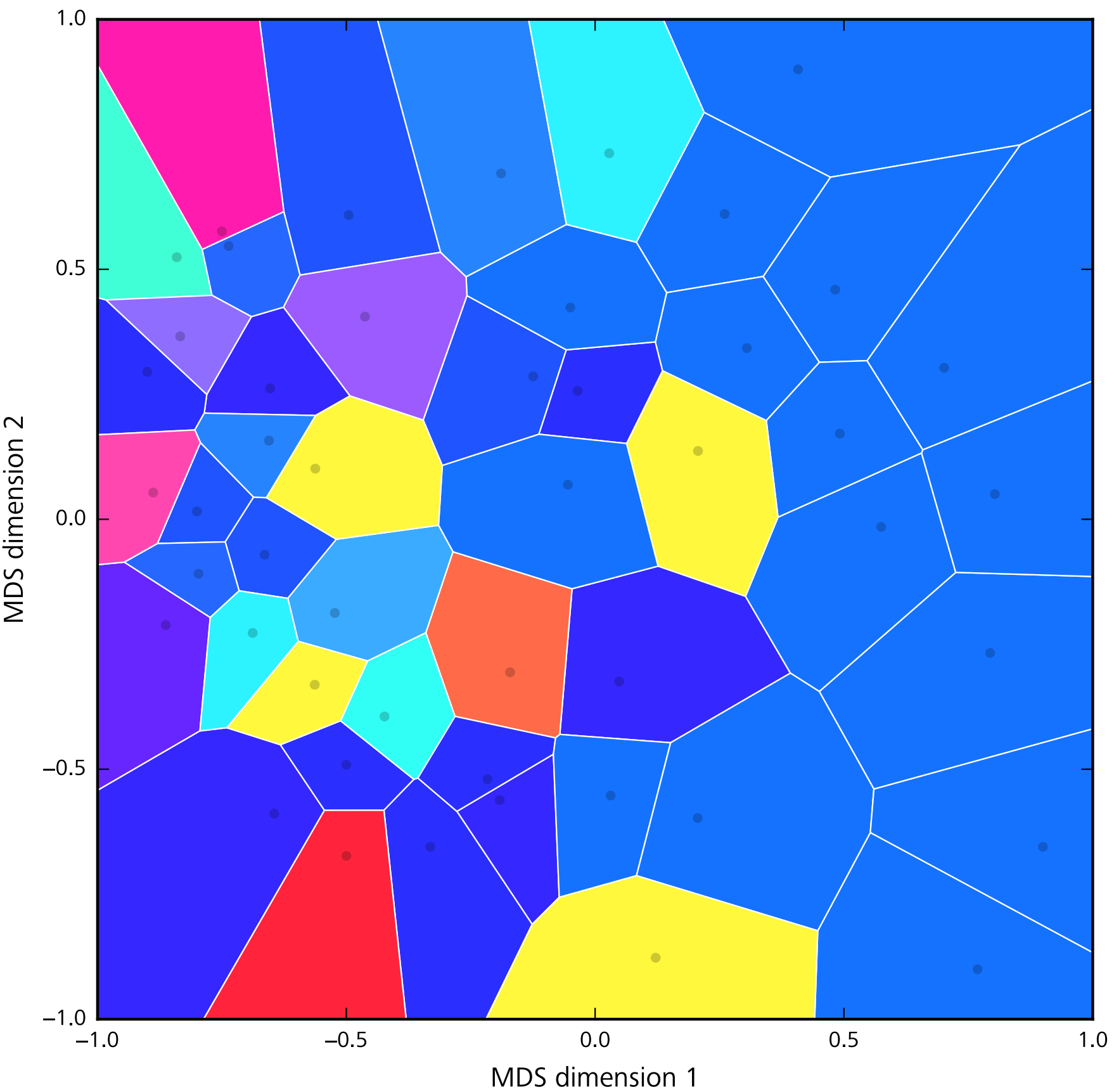
Generation

1



Generation

2

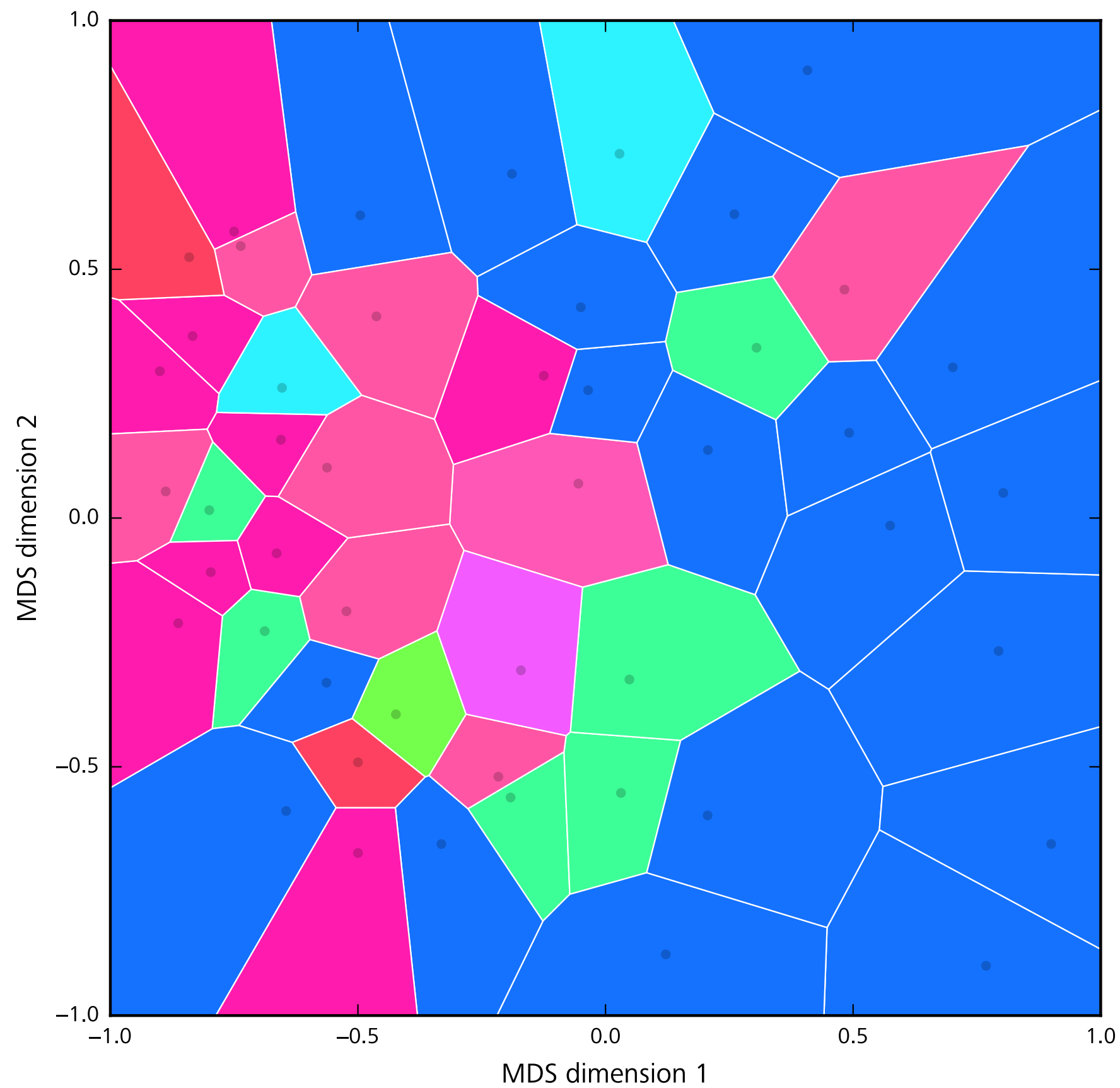


Generation

3

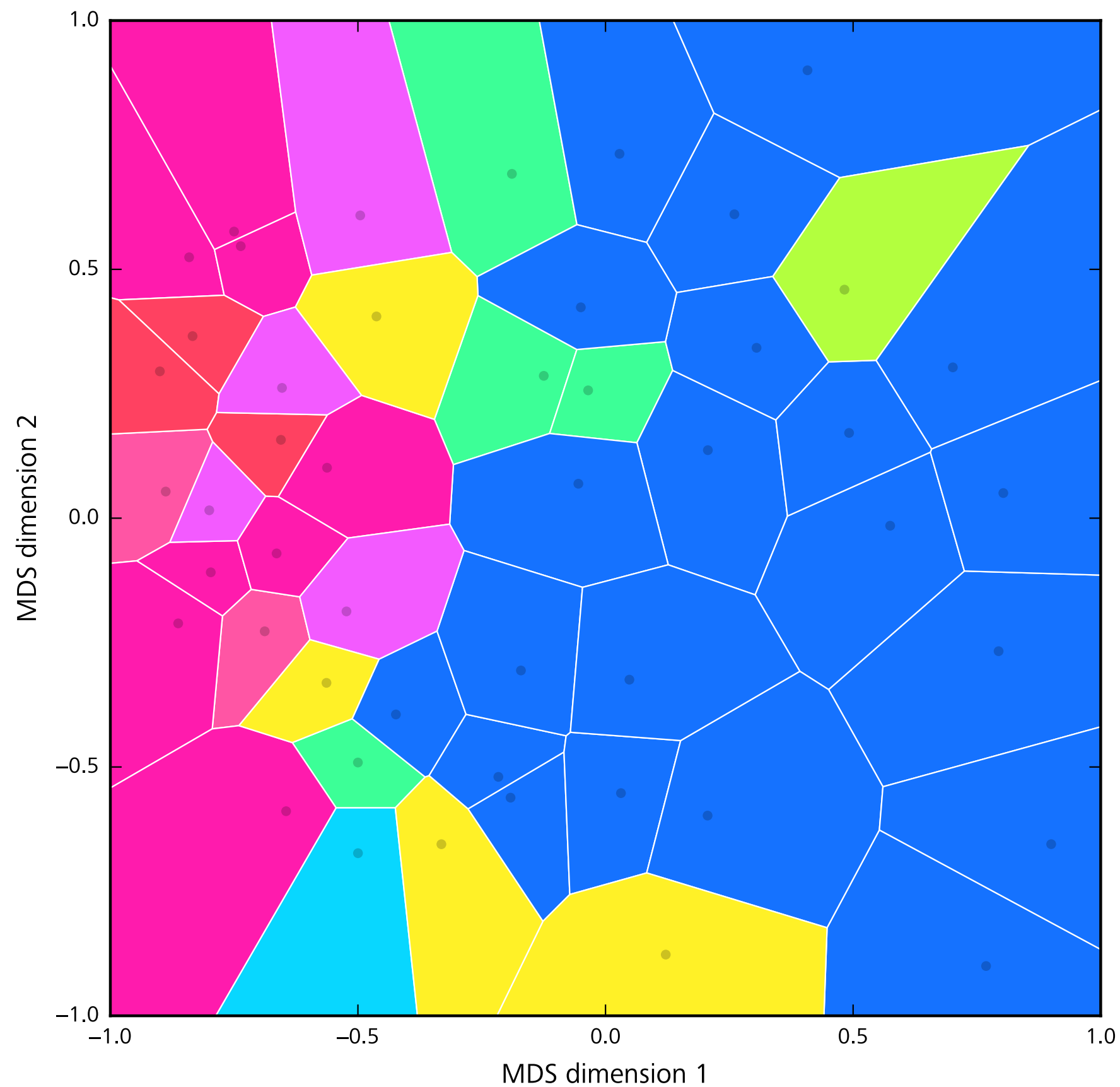
Generation

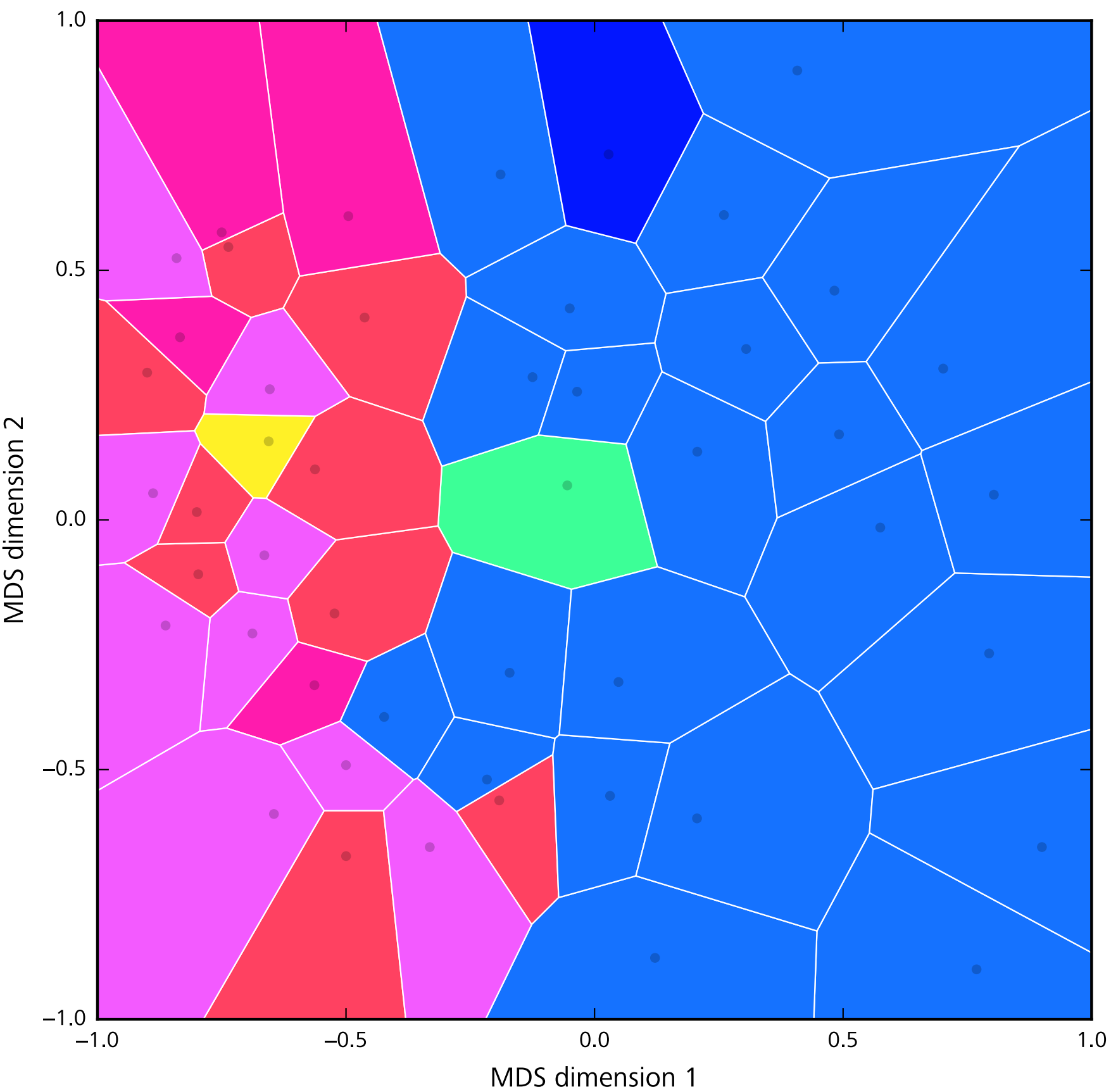
4



Generation

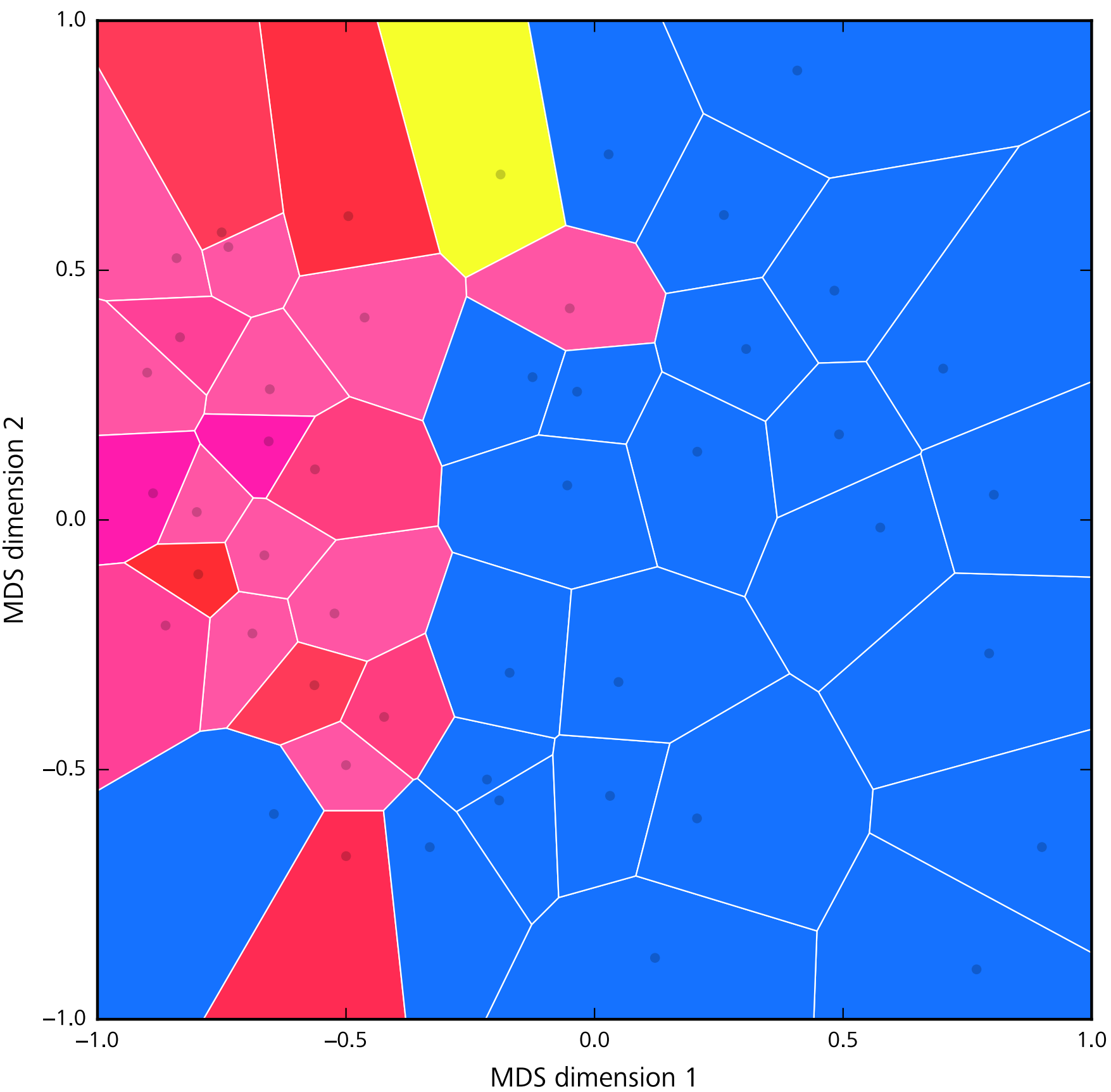
5





Generation

6

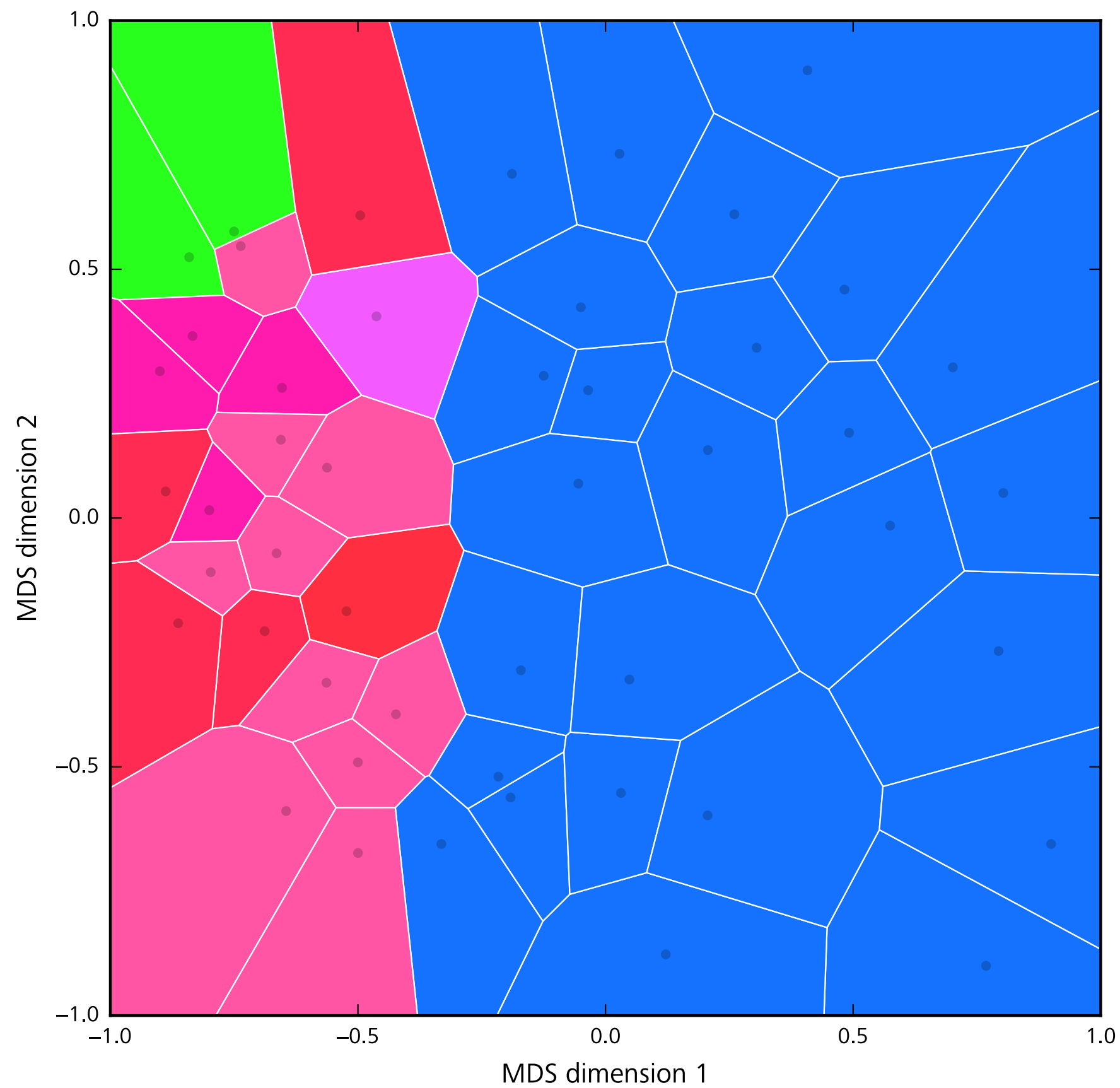


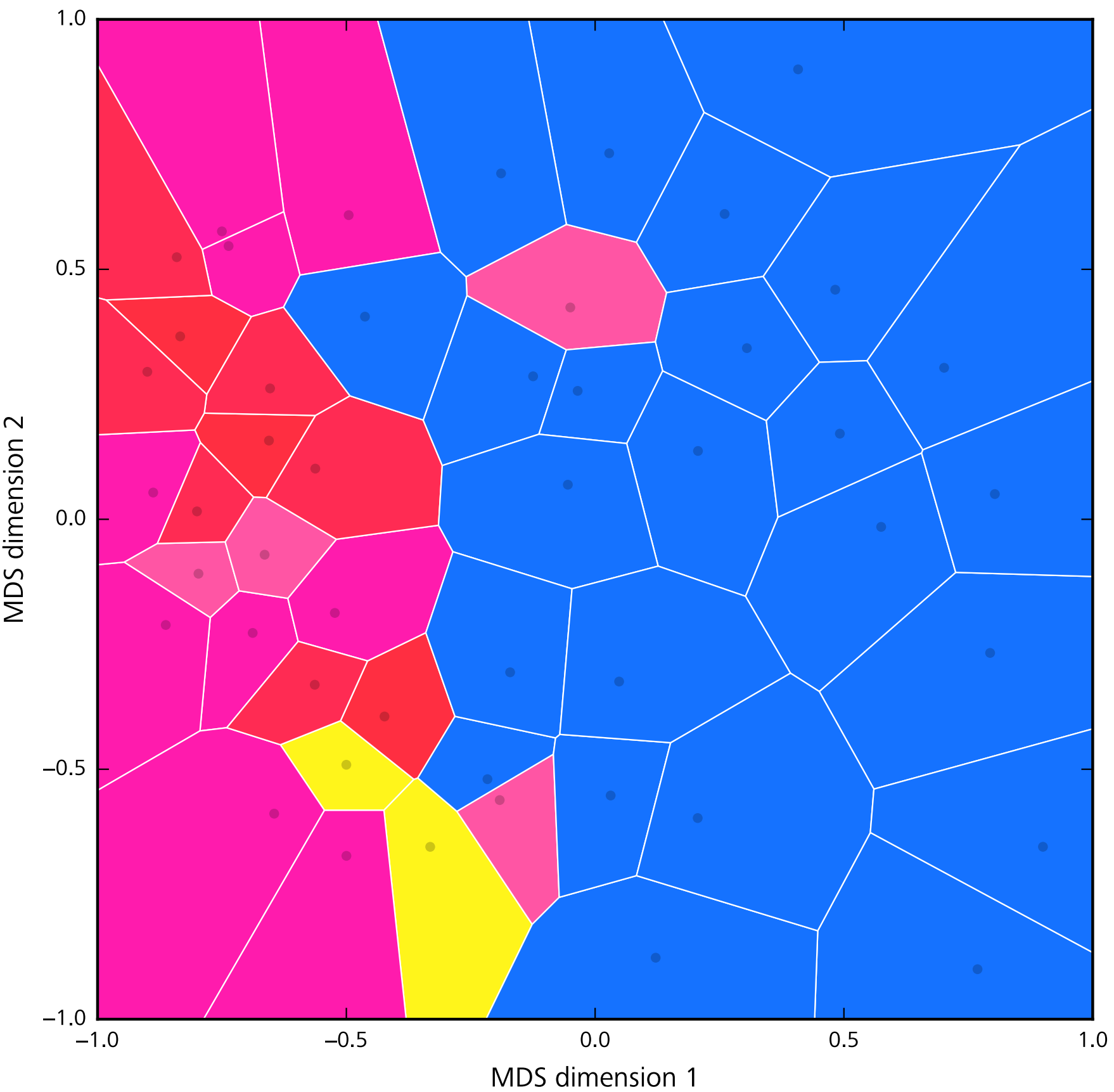
Generation

7

Generation

8

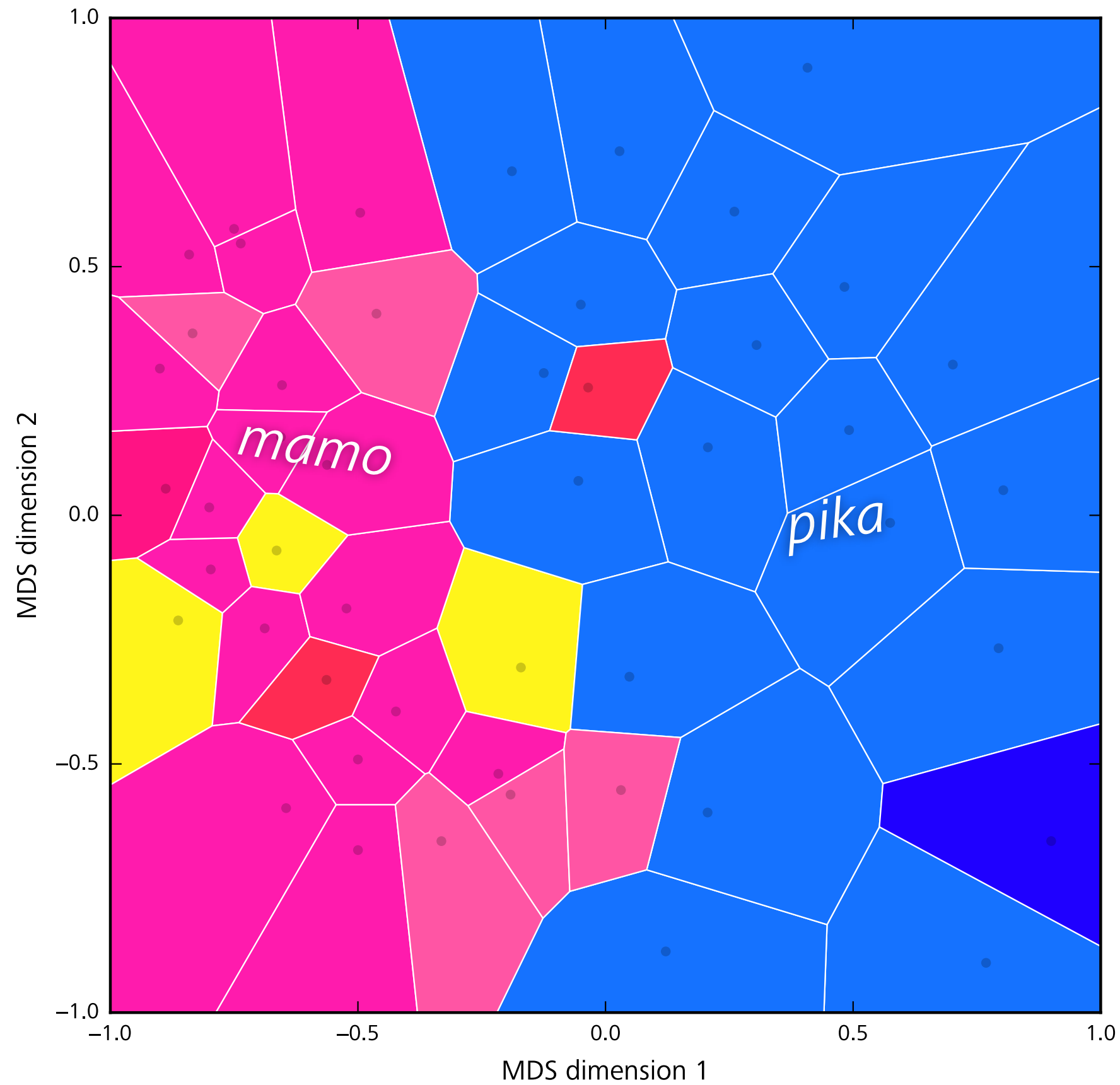




Generation

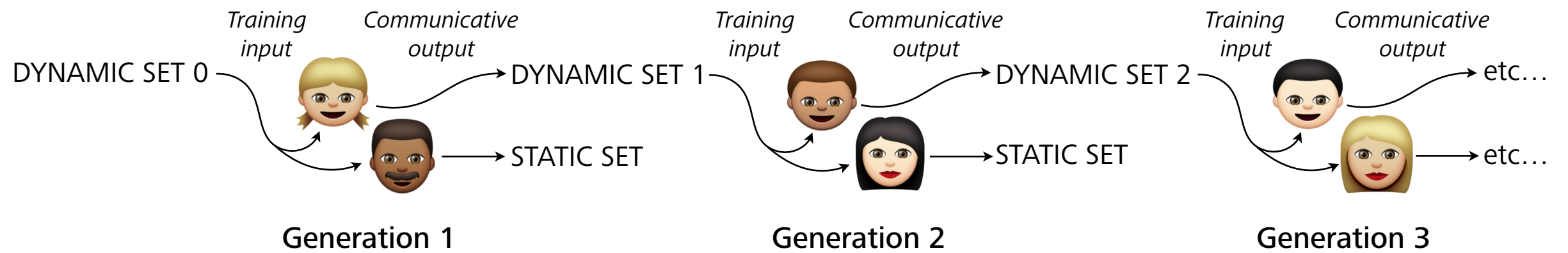
9

Generation
10



Experiment 2

Experimental design





Stage 2: Communication

You can now take off the headphones.

In stage two, you and your partner will take turns to communicate about triangles. When it's your turn to communicate, you'll be presented with a triangle. You must type in the word for this triangle and press Enter to send it to your partner. You must only communicate using the Flatlander language that you and your partner just learned.

The word you use will show up on your partner's screen. He or she will see a selection of six triangles (including the one that you're trying to convey). Your partner will have to figure out which triangle you're talking about by clicking on it with the mouse.

You may find it difficult to remember the words for the different triangles. Go with your instinct and type in a word that feels right. Your partner may still be able to identify it even if it's only partially correct.

As a team, you'll score 10 points for every successful communication.

When you're ready to start, click the button below. After clicking the button, you may need to wait a minute or so for your partner to be ready too.

I'm ready



Stage 2: Communication

You can now take off the headphones.

In stage two, you and your partner will take turns to communicate about triangles. When it's your turn to communicate, you'll be presented with a triangle. You must type in the word for this triangle and press Enter to send it to your partner. You must only communicate using the Flatlander language that you and your partner just learned.

The word you use will show up on your partner's screen. He or she will see a selection of six triangles (including the one that you're trying to convey). Your partner will have to figure out which triangle you're talking about by clicking on it with the mouse.

You may find it difficult to remember the words for the different triangles. Go with your instinct and type in a word that feels right. Your partner may still be able to identify it even if it's only partially correct.

As a team, you'll score 10 points for every successful communication.

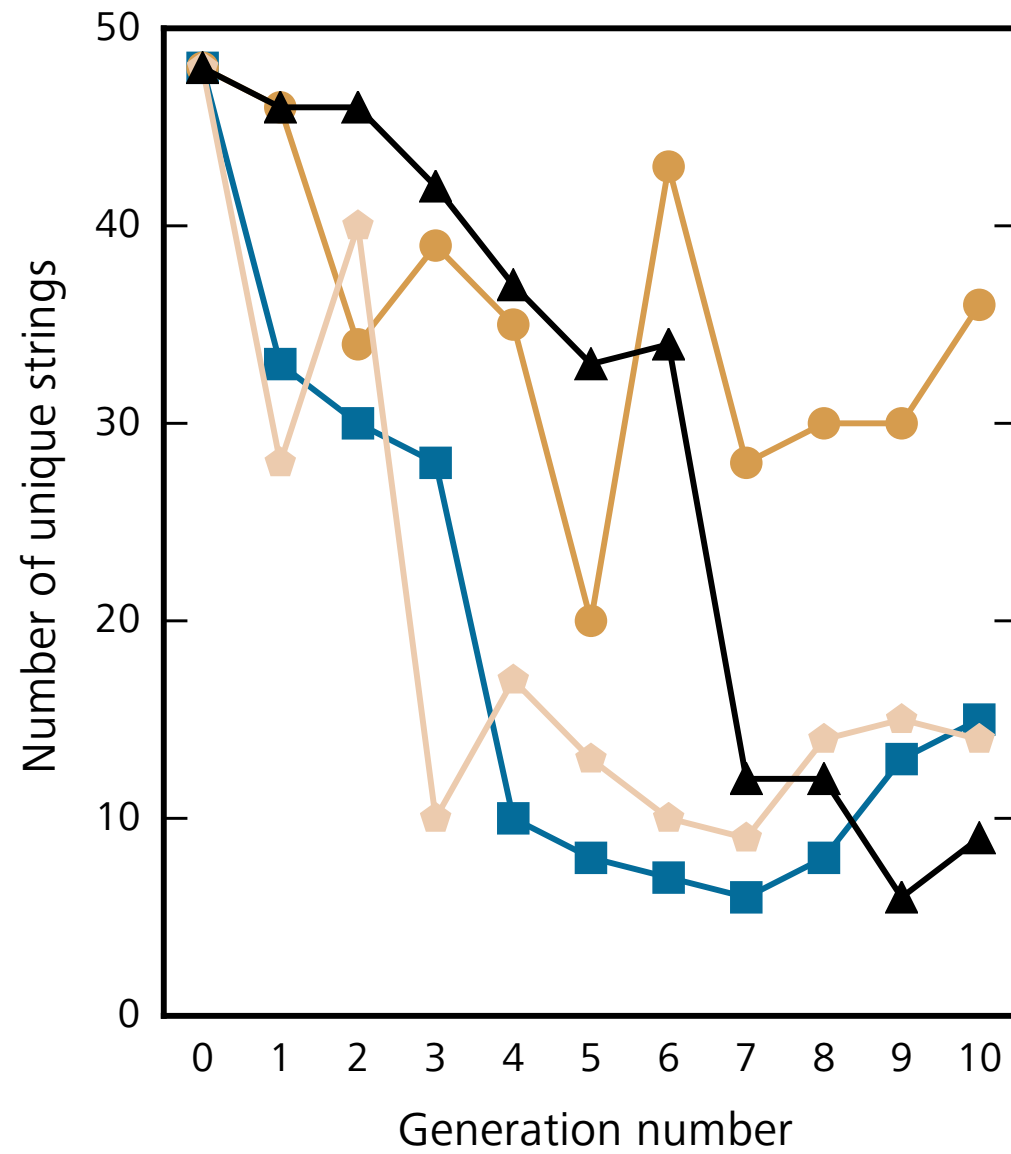
When you're ready to start, click the button below. After clicking the button, you may need to wait a minute or so for your partner to be ready too.



Waiting for your partner...

x96

Expressivity



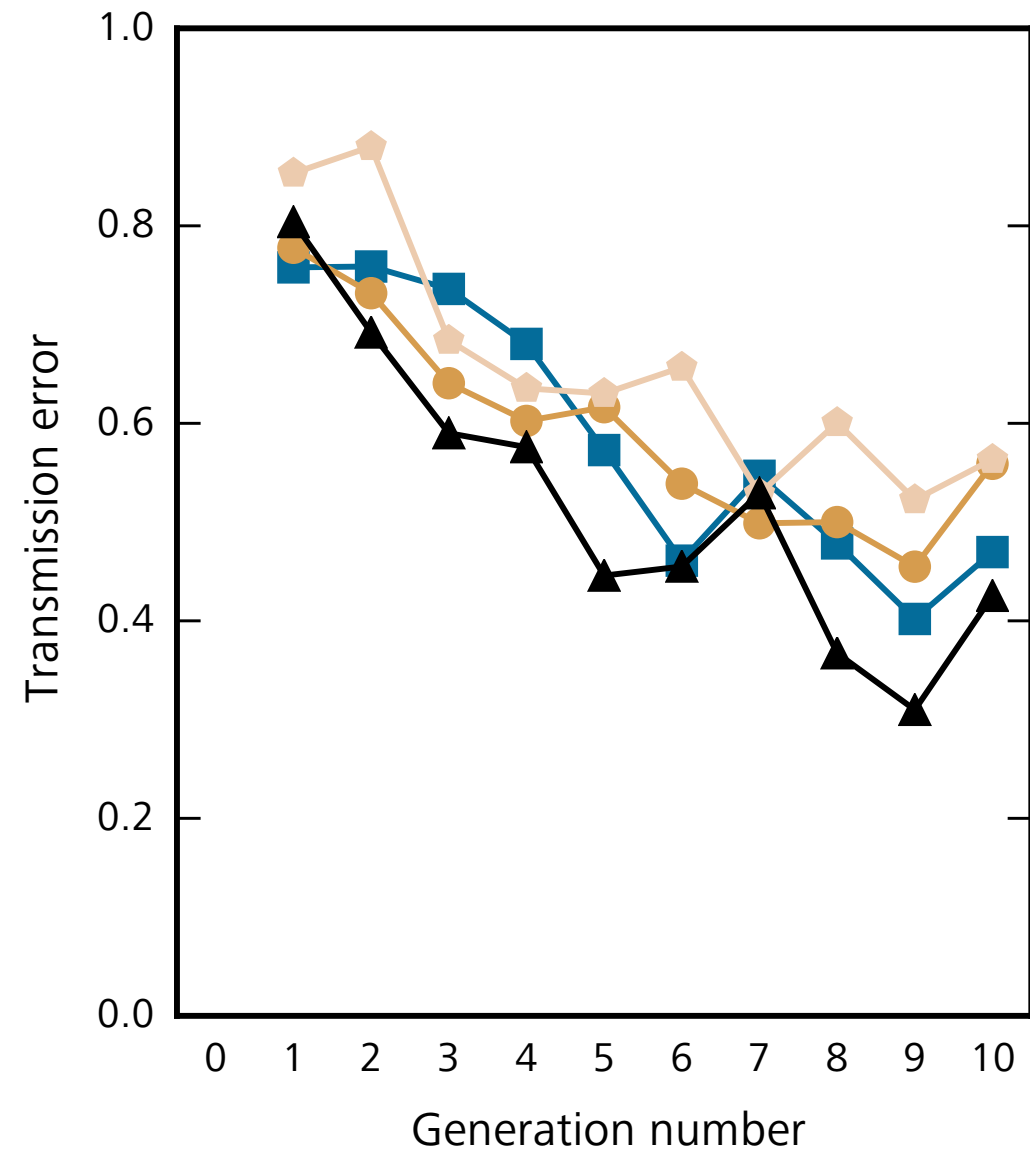
Chain I

Chain J

Chain K

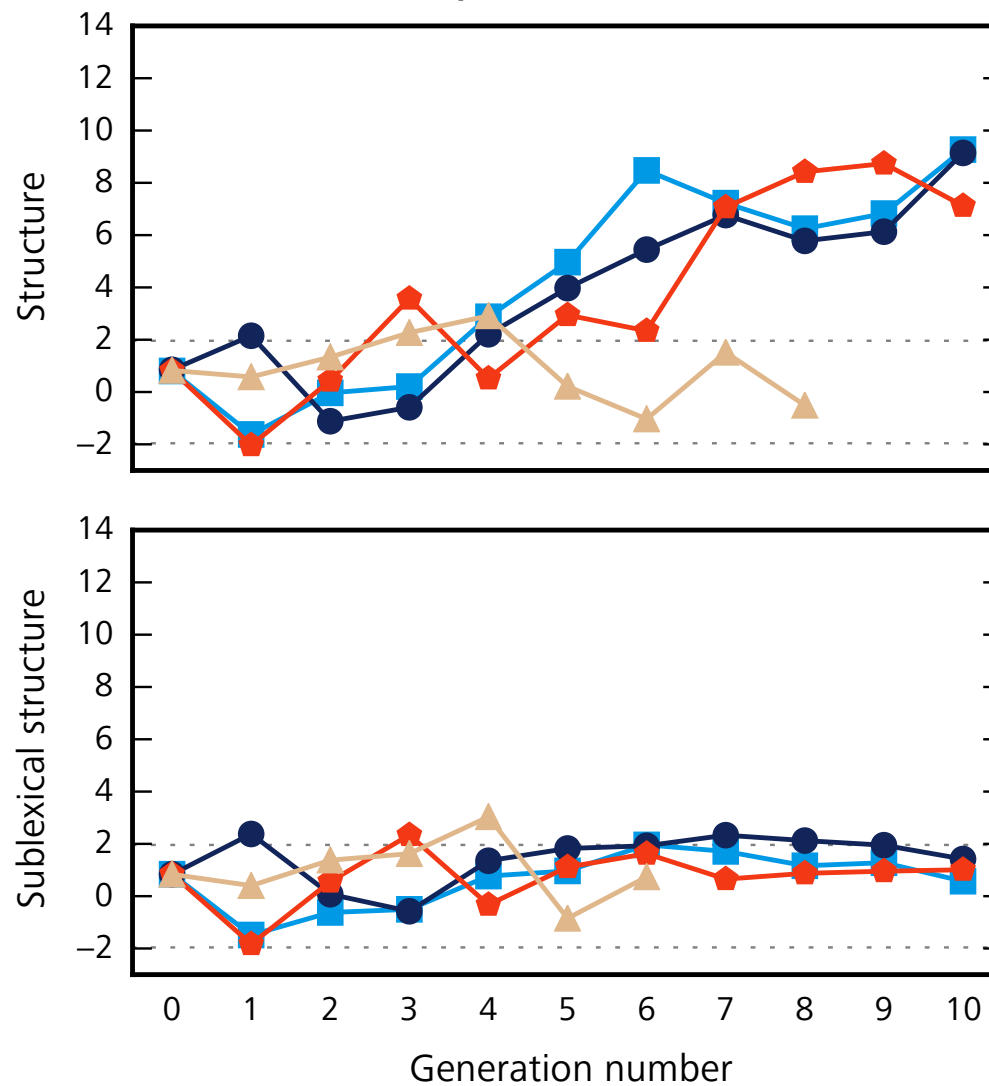
Chain L

Learnability

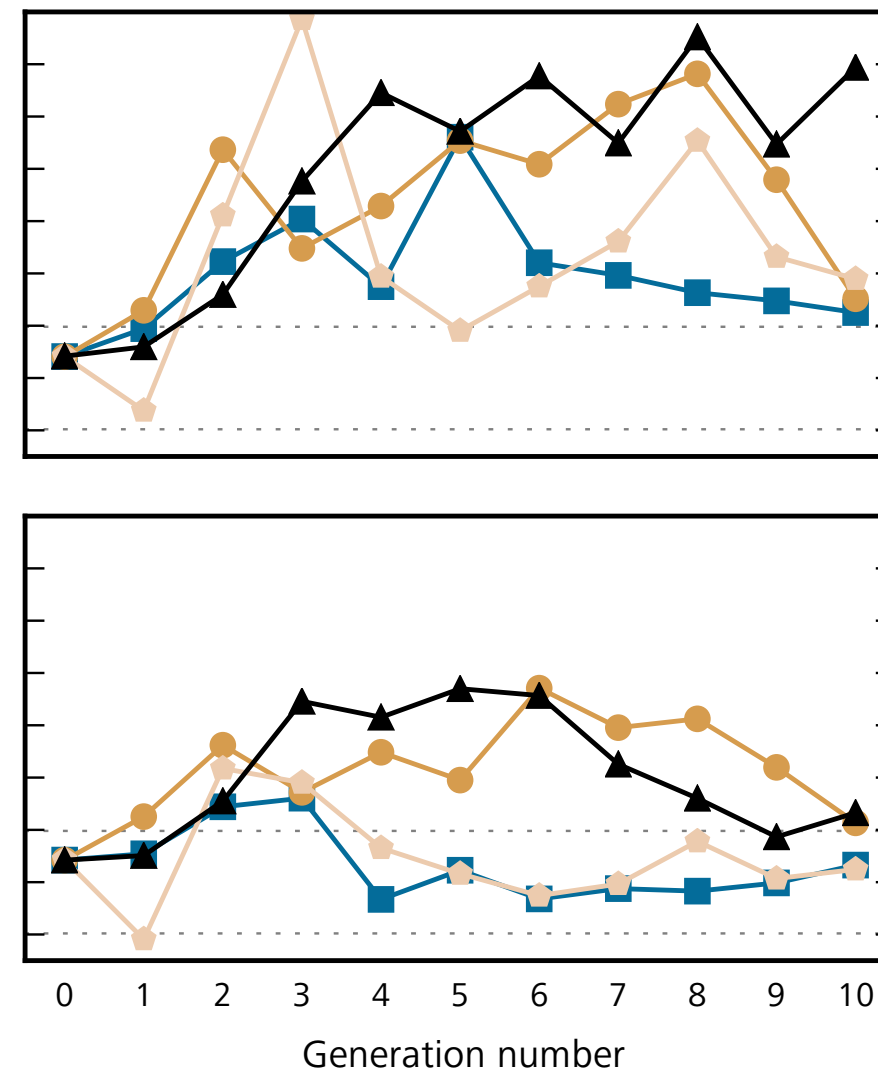


Structure in the languages

Experiment 1

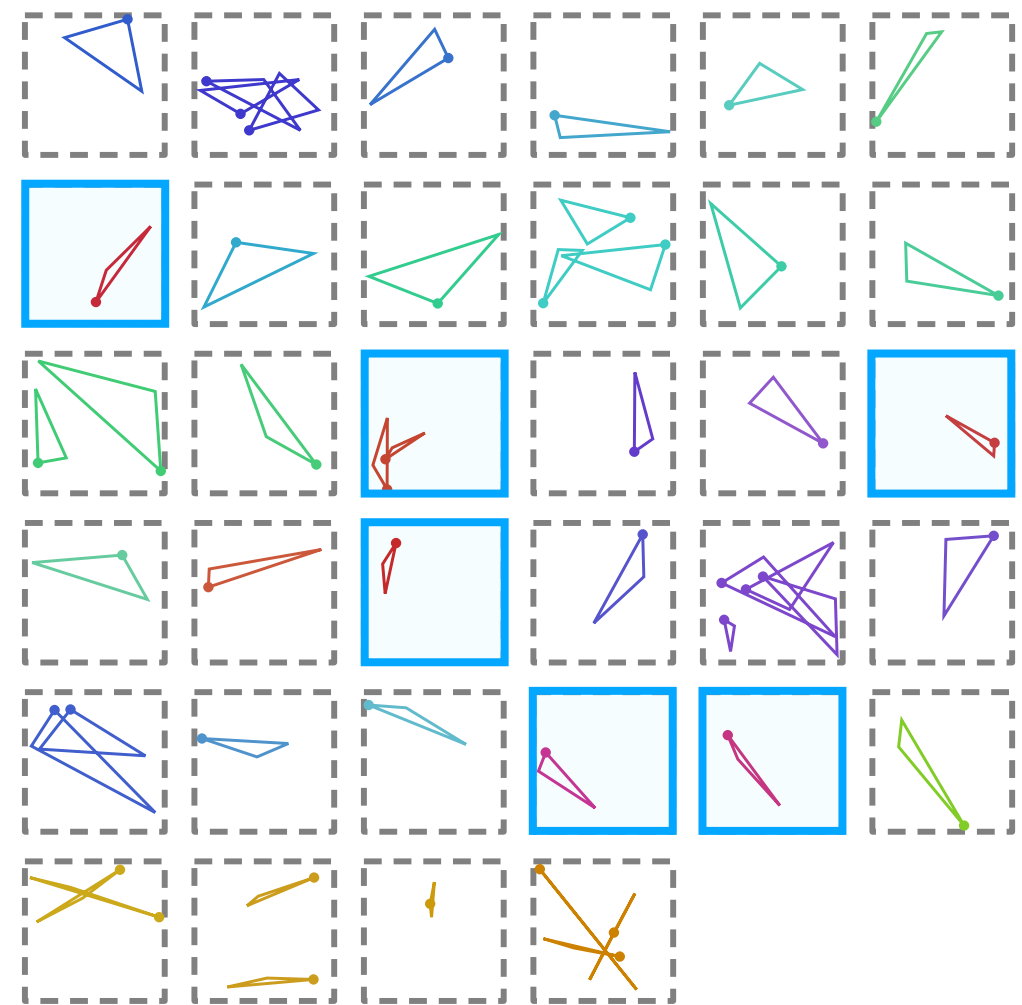
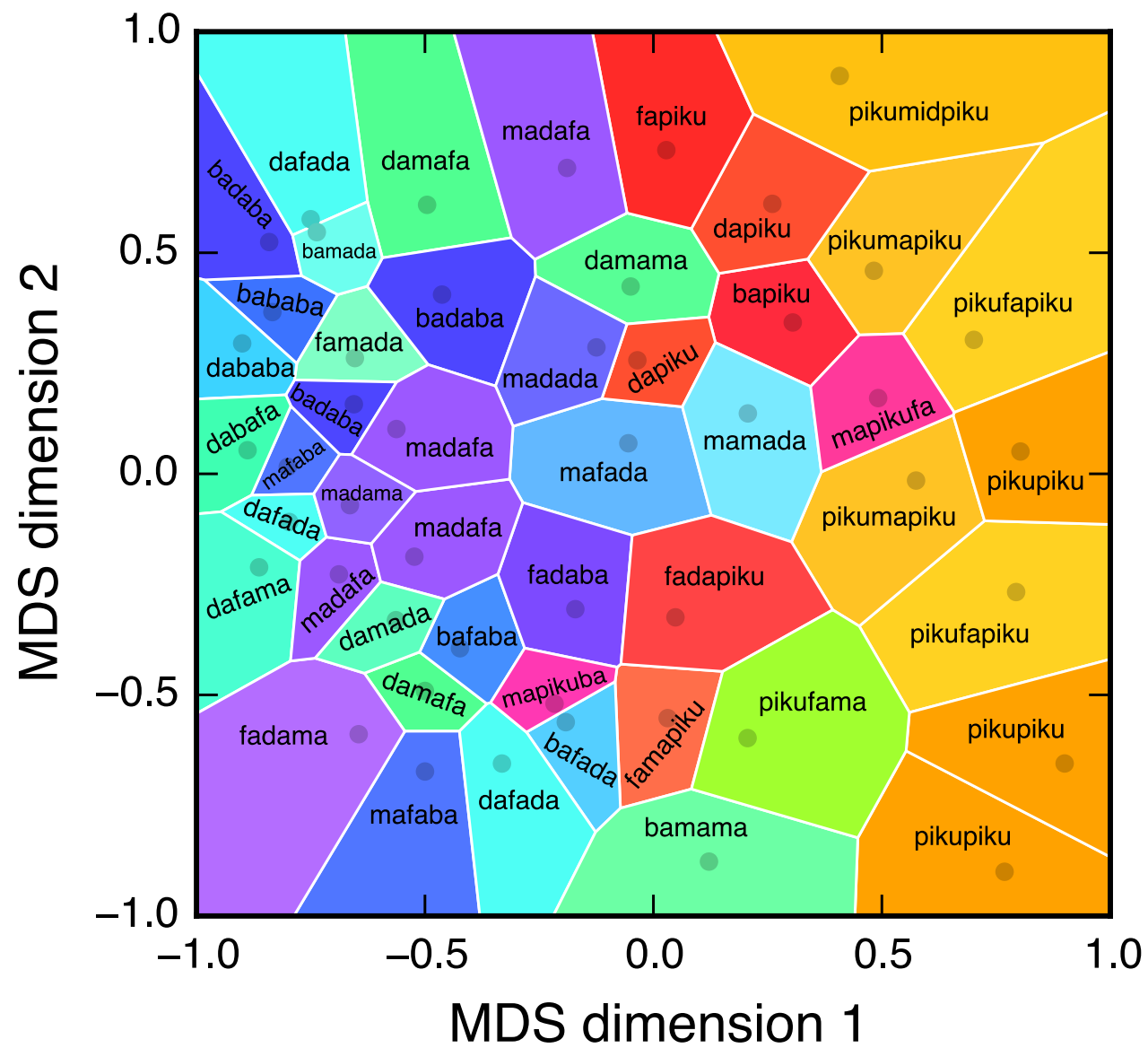


Experiment 2

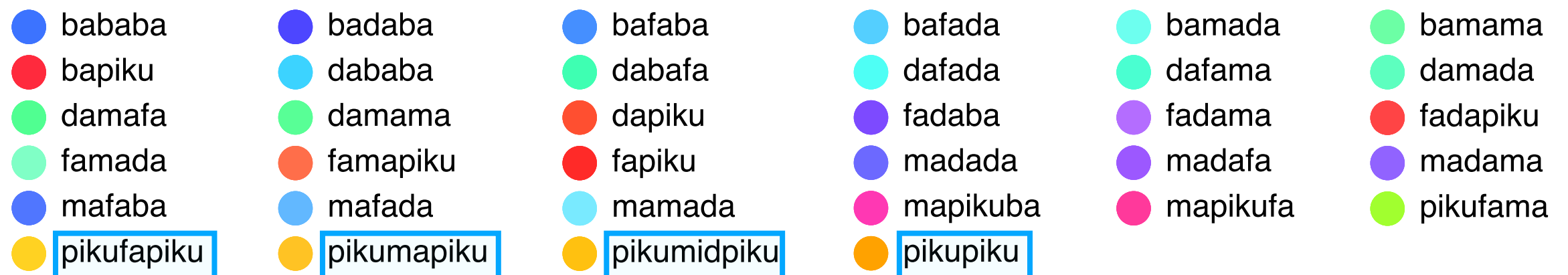
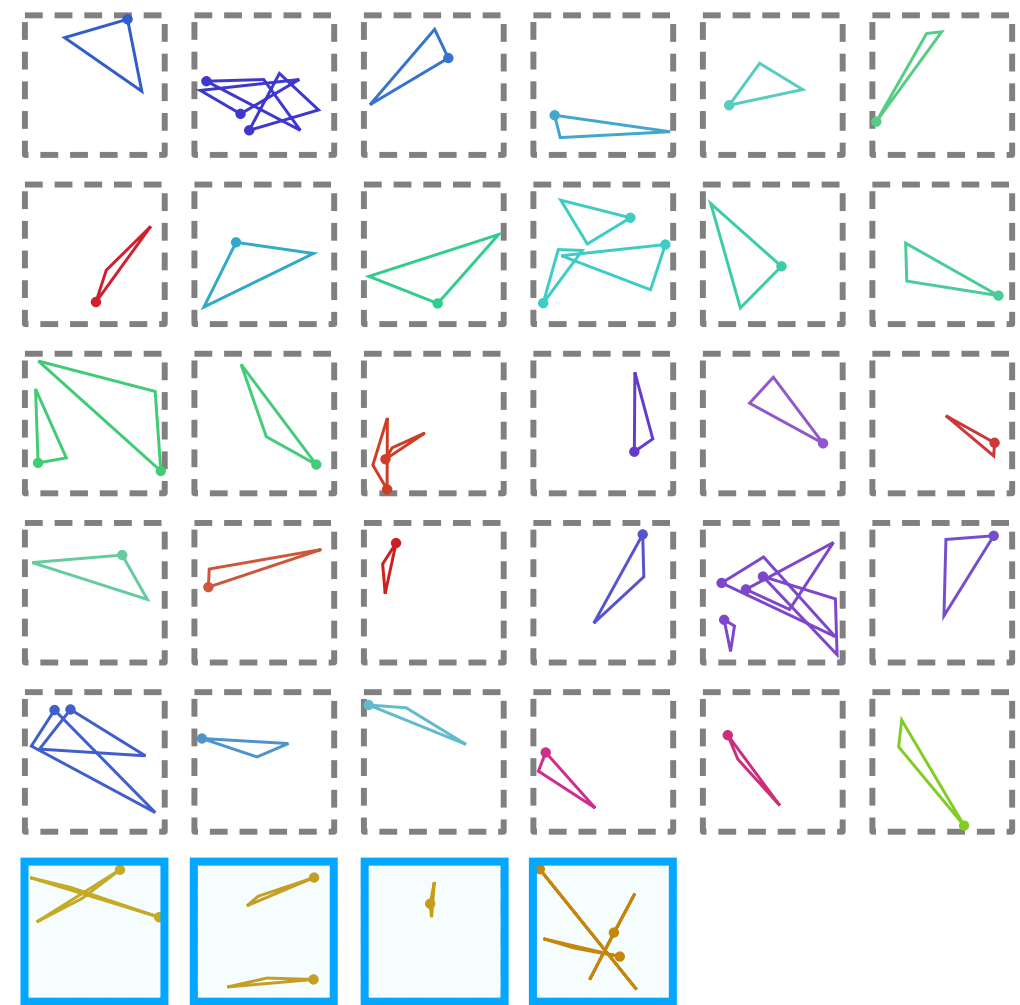
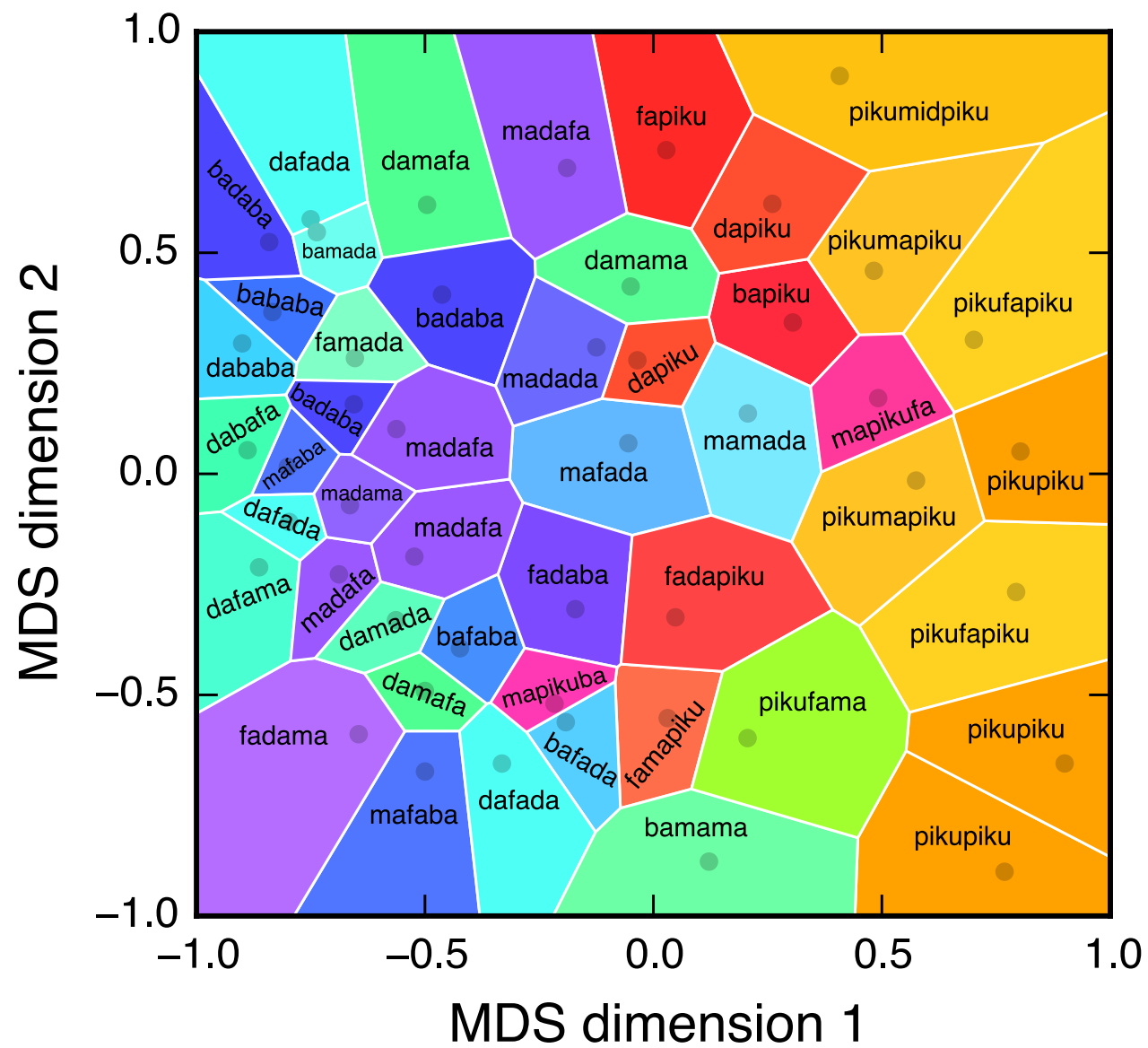


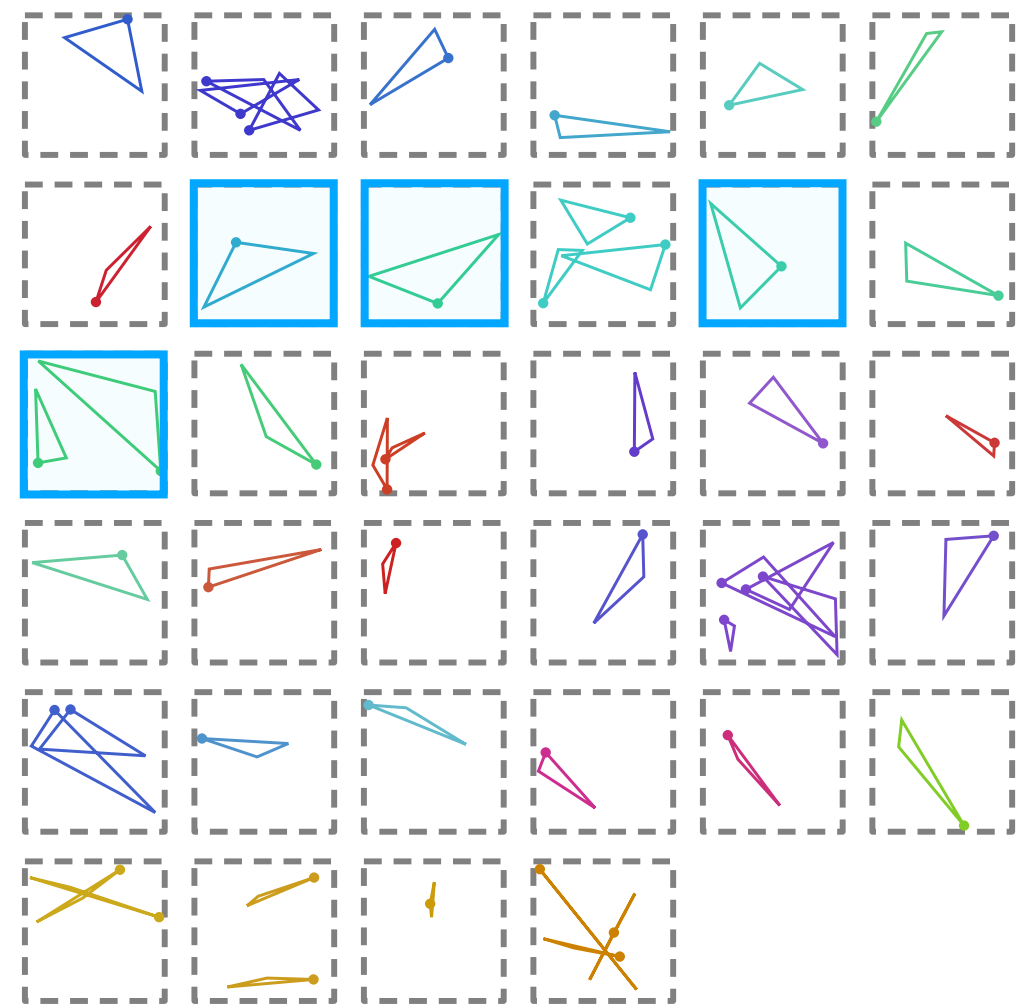
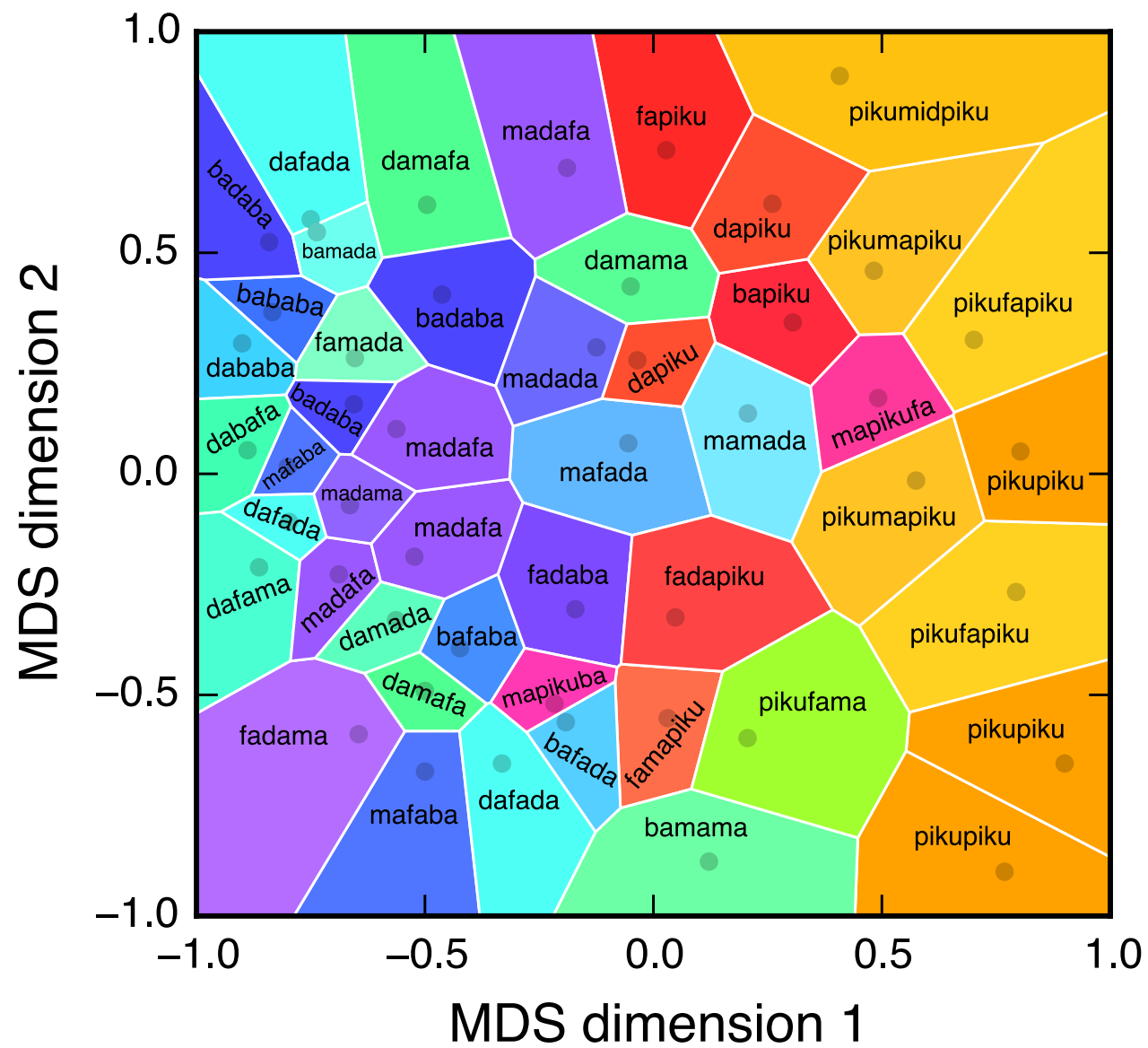
Chain A Chain B
Chain C Chain D

Chain I Chain J
Chain K Chain L

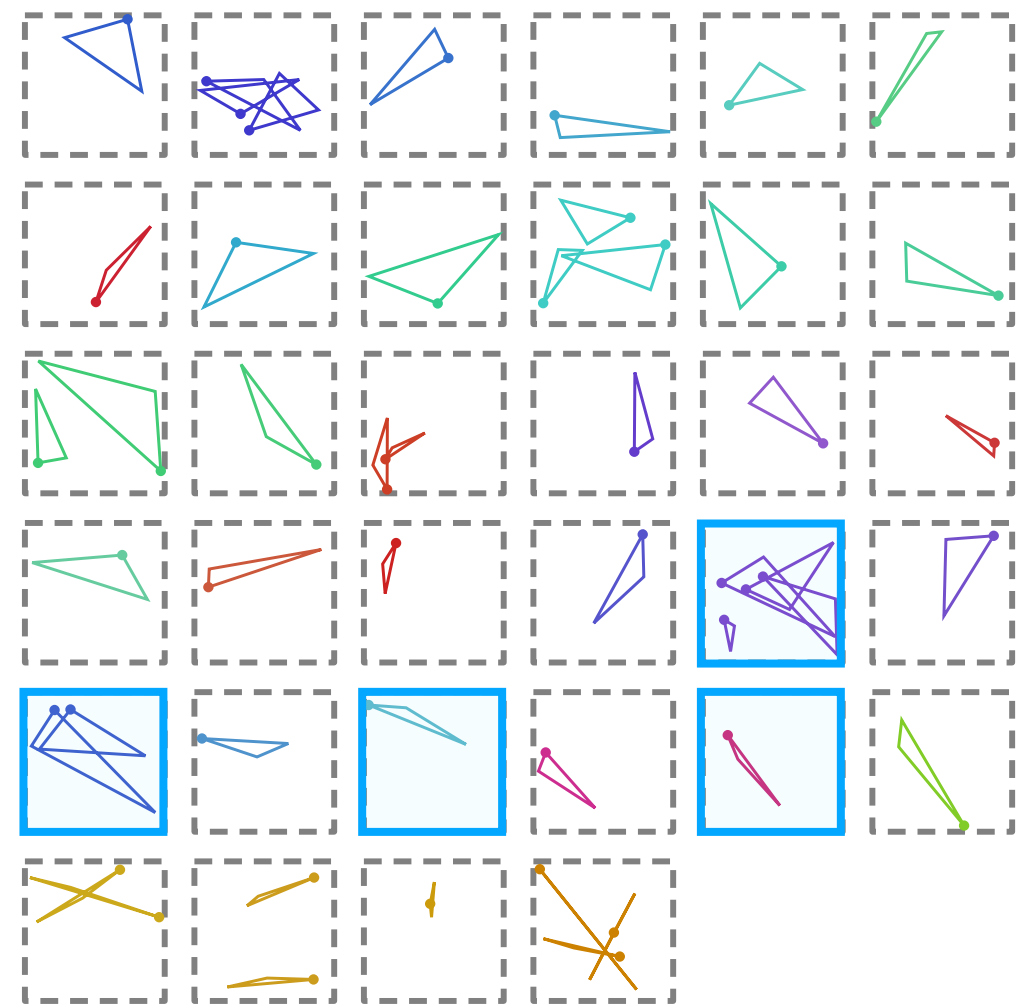
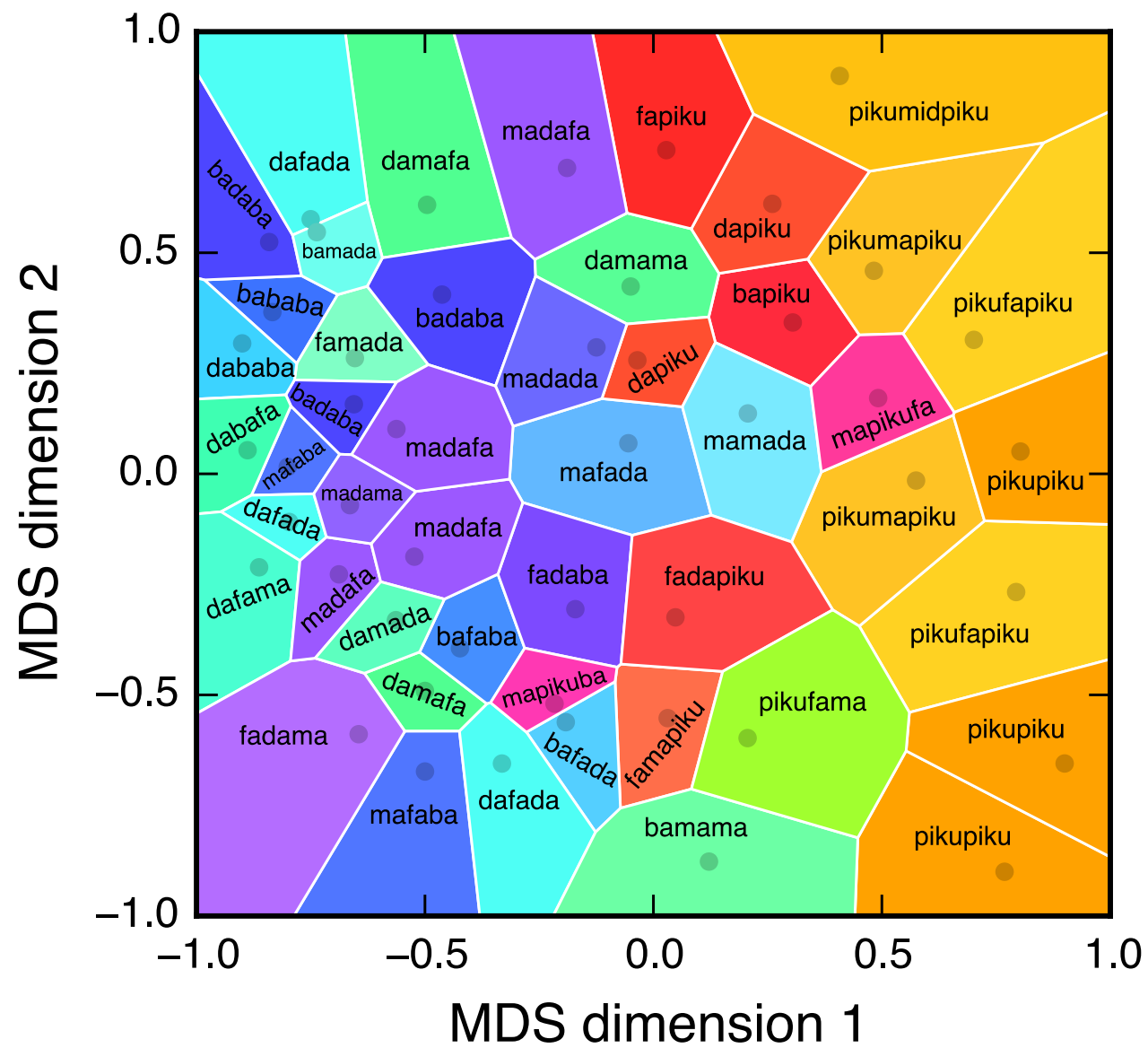


- | | | | | | |
|---|--------------|---|---|---|---|
| ● bababa | ● badaba | ● bafaba | ● bafada | ● bamada | ● bamama |
| ● bapiku | ● dababa | ● dabafa | ● dapiku | ● dapiku | ● damada |
| ● damafa | ● damama | ● dapiku | ● dapiku | ● dapiku | ● fadamapiku |
| ● famada | ● famapiku | ● dapiku | ● dapiku | ● dapiku | ● fadamapiku |
| ● mafaba | ● mafada | ● mamada | ● mapikuba | ● mapikufa | ● madama |
| ● pikufapiku | ● pikumapiku | ● pikumidpiku | ● pikupiku | ● pikupiku | ● pikufama |





- | | | | | | |
|--------------|--------------|---------------|-------------|------------|------------|
| ● bababa | ● badaba | ● bafaba | ● bafada | ● bamada | ● bamama |
| ● bapiku | ● dababa | ● dabafa | ● dafada | ● dafama | ● damada |
| ● damafa | ● damama | ● dapiku | ● fadaba | ● fadama | ● fadapiku |
| ● famada | ● famapiku | ● fapiku | ● madada | ● madafa | ● madama |
| ● mafaba | ● mafada | ● mamada | ● mapikuba | ● mapikufa | ● pikufama |
| ● pikufapiku | ● pikumapiku | ● pikumidpiku | ● pickupiku | | |



- | | | | | | |
|--------------|--------------|---------------|------------|------------|------------|
| ● bababa | ● badaba | ● bafaba | ● bafada | ● bamada | ● bamama |
| ● bapiku | ● dababa | ● dabafa | ● dafada | ● dafama | ● damada |
| ● damafa | ● damama | ● dapiku | ● fadaba | ● fadama | ● fadapiku |
| ● famada | ● famapiku | ● fapiku | ● madada | ● madafa | ● madama |
| ● mafaba | ● mafada | ● mamada | ● mapikuba | ● mapikufa | ● pikufama |
| ● pikufapiku | ● pikumapiku | ● pikumidpiku | ● pikupiku | | |

Conclusions

The experimental design avoids several of the simplifications of previous experiments:

- Continuous
- Unstructured by the experimenter
- Vast in magnitude
- Different stimuli across generations

Experiment 1 showed that cultural evolution can deliver languages that categorize the meaning space under pressure from learnability.

Experiment 2 combined a pressure for learnability with a pressure for expressivity derived from a genuine communicative task.

This gave rise to languages that use both categorization and string-internal structure to be both learnable and expressive.

However, unlike previous work, this emergent structure was sublexical rather than morphosyntactic, and as such bears similarities to certain aspects of natural lexicons.