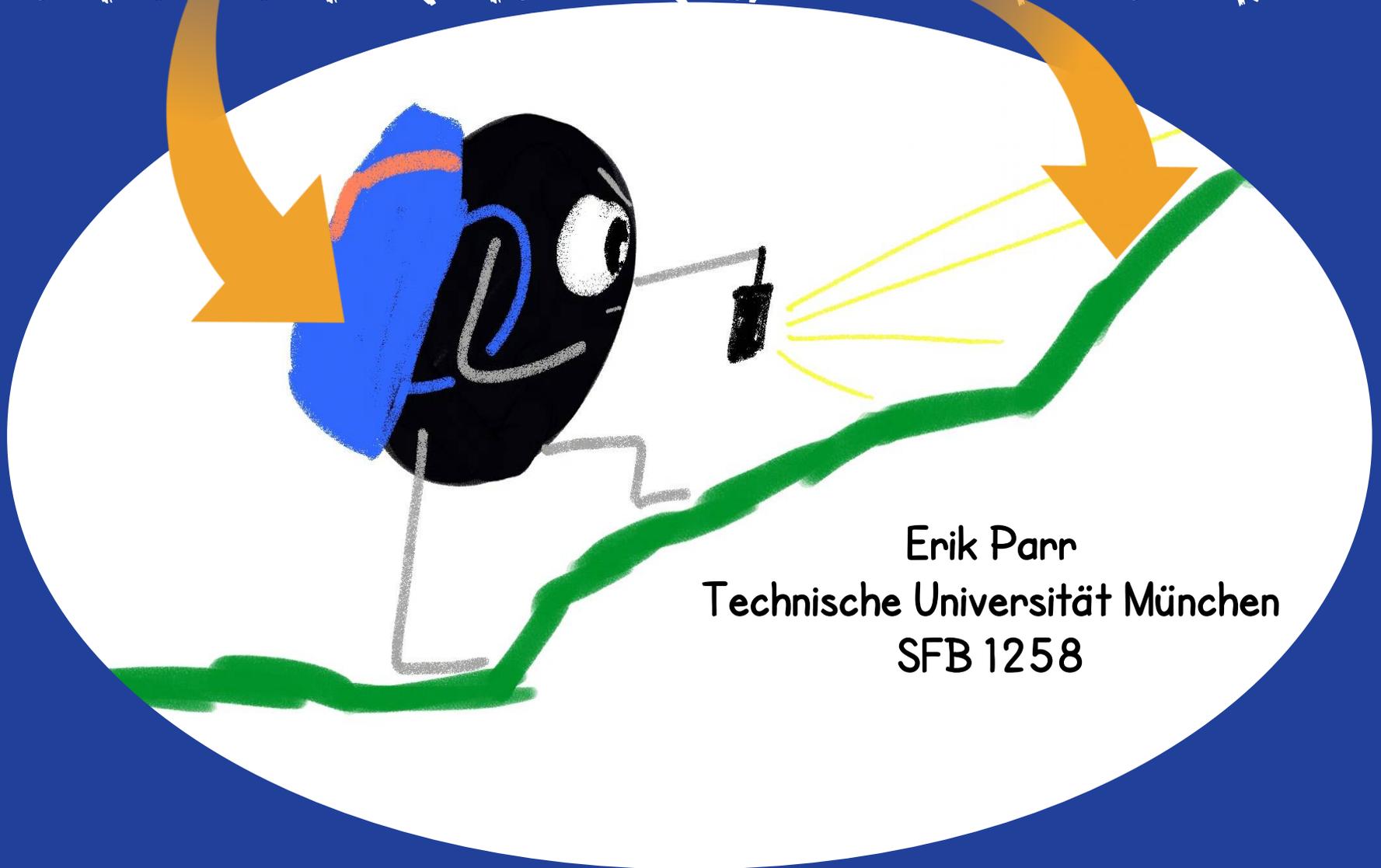


HOW AN UNSUPERVISED NEURAL NETWORK SEES THE HETEROTIC ORBIFOLD LANDSCAPE

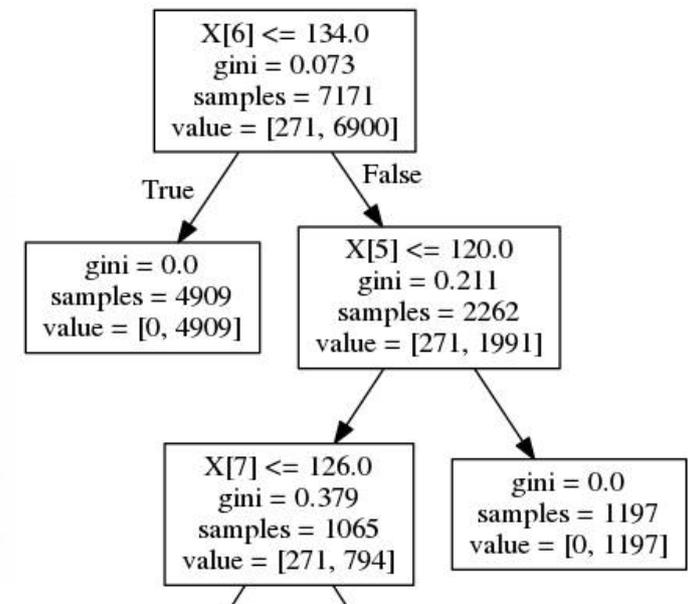
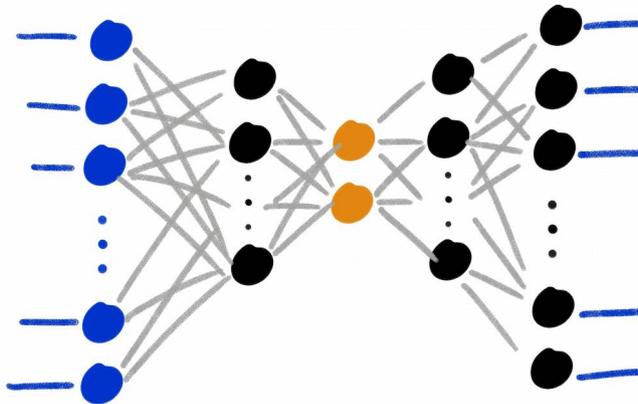
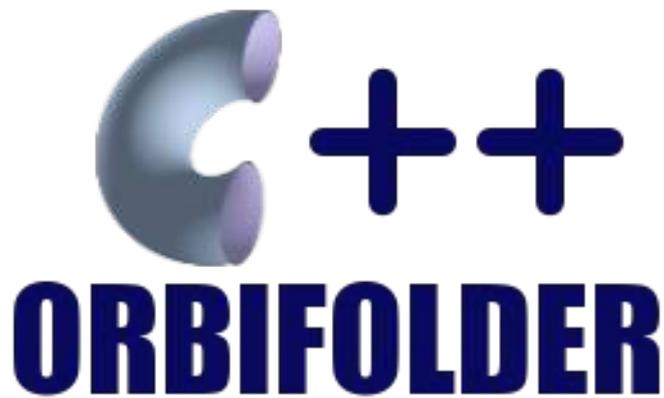


Erik Parr
Technische Universität München
SFB 1258

Based on collaboration with:
Andreas Mütter & Patrick K.S. Vaudrevange

OVERVIEW

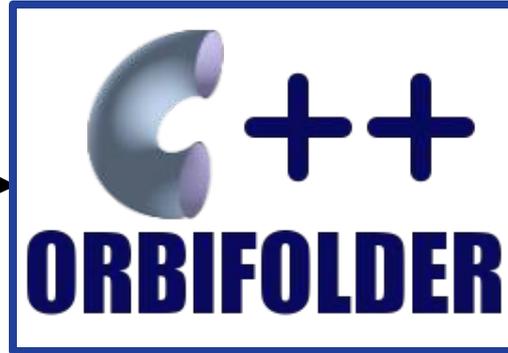
- Data preprocessing
- Search for hidden patterns
- Knowledge extraction



ORBIFOLDER SOFTWARE

Geometry: $\mathbb{Z}_6 - II$

heterotic $E_8 \times E_8$



*H. P. Nilles, S. Ramos-Sanchez,
P. Vaudrevange, A. Wingerter 2011*

ORBIFOLDER SOFTWARE

Geometry: $\mathbb{Z}_6 - II$

heterotic $E_8 \times E_8$



*H. P. Nilles, S. Ramos-Sanchez,
P. Vaudrevange, A. Wingerter 2011*

Shifts & Wilson lines
 E_8

E'_8

V_1 (5/12, -1/4, -1/4, -1/4, -1/4, -1/4, -1/12, -1/12)

(-1/2, 1/2, -1/2, 1/3, 1/3, 1/3, 1/3, -1/6)

W_4 (1/2, -1/2, -1/2, -1/6, -1/6, -1/6, 1/2, 1/2)

(1/2, -1/2, 1/2, -1/2, -1/6, -1/6, -1/6, 1/2)

W_5 (0, -1/2, 0, -1, -1, 1/2, -1, -1)

(-1, -1/2, -1, -1, -1, -1, -1, 1/2)

W_6 (-1/2, -1/2, 1/2, -1/2, -1/2, -1, -1/2, 0)

(-1/2, -1, -1, -1, -1, -1, 1, -1/2)

ORBIFOLDER SOFTWARE

Geometry: $\mathbb{Z}_6 - II$

heterotic $E_8 \times E_8$

Shifts & Wilson lines
 E_8



*H. P. Nilles, S. Ramos-Sanchez,
P. Vaudrevange, A. Wingarter 2011*

4d spectrum

```
Orbifold model "Random5" from "Z6-II_1_1" created
SU(2) + SU(2) and SU(2)
140 ( 1, 1, 1)_L
22 ( 1, 1, 2)_L
18 ( 2, 1, 1)_L
12 ( 1, 2, 1)_L
4 ( 2, 2, 1)_L
4 ( 1, 1, 1)_E

Orbifold model "Random6" from "Z6-II_1_1" created
SU(2) + SU(2) and SU(2)
160 ( 1, 1, 1)_L
20 ( 2, 1, 1)_L
```

E'_8

V_1 (5/12, -1/4, -1/4, -1/4, -1/4, -1/4, -1/12, -1/12)

(-1/2, 1/2, -1/2, 1/3, 1/3, 1/3, 1/3, -1/6)

W_4 (1/2, -1/2, -1/2, -1/6, -1/6, -1/6, 1/2, 1/2)

(1/2, -1/2, 1/2, -1/2, -1/6, -1/6, -1/6, 1/2)

W_5 (0, -1/2, 0, -1, -1, 1/2, -1, -1)

(-1, -1/2, -1, -1, -1, -1, -1, 1/2)

W_6 (-1/2, -1/2, 1/2, -1/2, -1/2, -1, -1/2, 0)

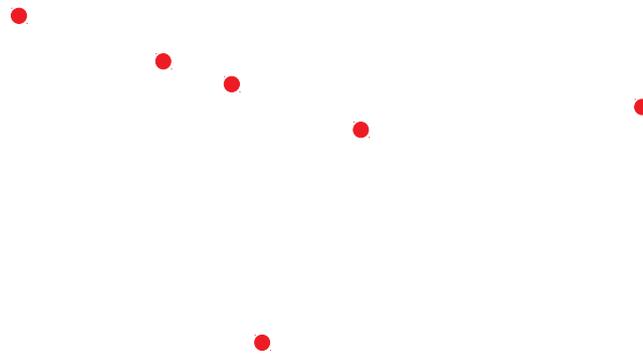
(-1/2, -1, -1, -1, -1, -1, 1, -1/2)

AMBIGUITIES OF SHIFT & WILSON LINE REPRESENTATION

AMBIGUITIES OF SHIFT & WILSON LINE REPRESENTATION

$$T^8 : \quad V \sim V + \lambda \quad \lambda \in \Gamma_8$$

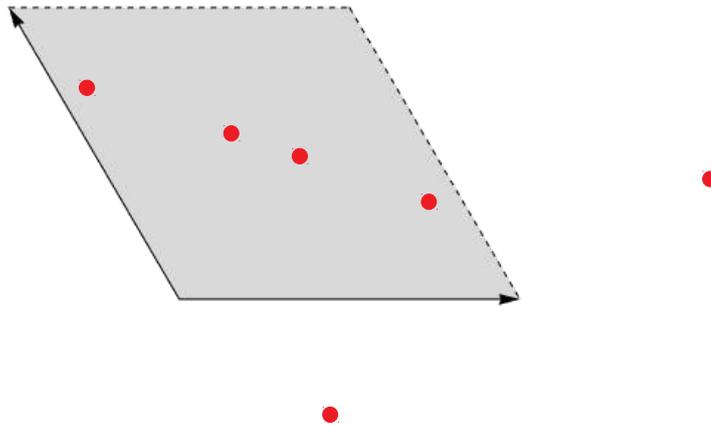
$$W_{E_8} : \quad \mathbf{E}_8 \sim w_\lambda(\mathbf{E}_8) \quad w_\lambda(V) = V - \frac{2(V \cdot \lambda)}{\lambda \cdot \lambda} \lambda$$



AMBIGUITIES OF SHIFT & WILSON LINE REPRESENTATION

$$T^8 : \quad V \sim V + \lambda \quad \lambda \in \Gamma_8$$

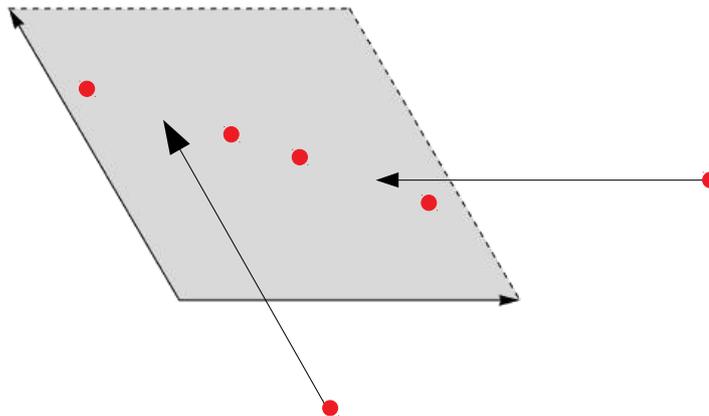
$$W_{E_8} : \quad \mathbf{E}_8 \sim w_\lambda(\mathbf{E}_8) \quad w_\lambda(V) = V - \frac{2(V \cdot \lambda)}{\lambda \cdot \lambda} \lambda$$



AMBIGUITIES OF SHIFT & WILSON LINE REPRESENTATION

$$T^8 : \quad V \sim V + \lambda \quad \lambda \in \Gamma_8$$

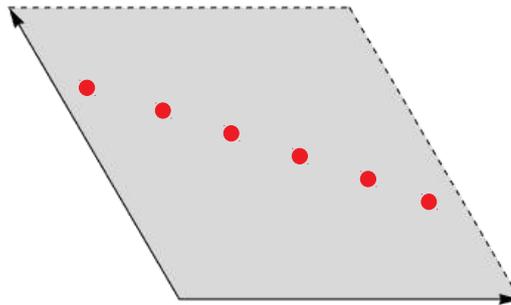
$$W_{E_8} : \quad \mathbf{E}_8 \sim w_\lambda(\mathbf{E}_8) \quad w_\lambda(V) = V - \frac{2(V \cdot \lambda)}{\lambda \cdot \lambda} \lambda$$



AMBIGUITIES OF SHIFT & WILSON LINE REPRESENTATION

$$T^8 : \quad V \sim V + \lambda \quad \lambda \in \Gamma_8$$

$$W_{E_8} : \quad \mathbf{E}_8 \sim w_\lambda(\mathbf{E}_8) \quad w_\lambda(V) = V - \frac{2(V \cdot \lambda)}{\lambda \cdot \lambda} \lambda$$



AMBIGUITIES OF SHIFT & WILSON LINE REPRESENTATION

$$T^8 : \quad V \sim V + \lambda \quad \lambda \in \Gamma_8$$

$$W_{E_8} : \quad \mathbf{E}_8 \sim w_\lambda(\mathbf{E}_8) \quad w_\lambda(V) = V - \frac{2(V \cdot \lambda)}{\lambda \cdot \lambda} \lambda$$

- Number of elements $W_{E_8} : \quad 6,967,296 \cdot 10^8$

AMBIGUITIES OF SHIFT & WILSON LINE REPRESENTATION

$$T^8 : \quad V \sim V + \lambda \quad \lambda \in \Gamma_8$$

$$W_{E_8} : \quad \mathbf{E}_8 \sim w_\lambda(\mathbf{E}_8) \quad w_\lambda(V) = V - \frac{2(V \cdot \lambda)}{\lambda \cdot \lambda} \lambda$$

- Number of elements $W_{E_8} : \quad 6,967,296 \cdot 10^8$

- Fundamental domain of $\frac{T^8}{W_{E_8}}$

➤ Brute-force is not feasible !

BREAKING PATTERNS OF E_8

BREAKING PATTERNS OF E_8

- Compute surviving roots $V \cdot \lambda \stackrel{!}{=} 0 \pmod{1} \quad \lambda \in \Phi(E_8)$

BREAKING PATTERNS OF E_8

- Compute surviving roots $V \cdot \lambda \stackrel{!}{=} 0 \pmod{1} \quad \lambda \in \Phi(E_8)$

V_1	$(5/12, -1/4, -1/4, -1/4, -1/4, -1/4, -1/12, -1/12)$	$(-1/2, 1/2, -1/2, 1/3, 1/3, 1/3, 1/3, -1/6)$
W_4	$(1/2, -1/2, -1/2, -1/6, -1/6, -1/6, 1/2, 1/2)$	$(1/2, -1/2, 1/2, -1/2, -1/6, -1/6, -1/6, 1/2)$
W_5	$(0, -1/2, 0, -1, -1, 1/2, -1, -1)$	$(-1, -1/2, -1, -1, -1, -1, -1, 1/2)$
W_6	$(-1/2, -1/2, 1/2, -1/2, -1/2, -1, -1/2, 0)$	$(-1/2, -1, -1, -1, -1, -1, 1, -1/2)$

BREAKING PATTERNS OF E_8

- Compute surviving roots $V \cdot \lambda \stackrel{!}{=} 0 \pmod{1} \quad \lambda \in \Phi(E_8)$

$$V_1 \quad (5/12, -1/4, -1/4, -1/4, -1/4, -1/4, -1/12, -1/12) \quad (-1/2, 1/2, -1/2, 1/3, 1/3, 1/3, 1/3, -1/6)$$

$$W_4 \quad (1/2, -1/2, -1/2, -1/6, -1/6, -1/6, 1/2, 1/2) \quad (1/2, -1/2, 1/2, -1/2, -1/6, -1/6, -1/6, 1/2)$$

$$W_5 \quad (0, -1/2, 0, -1, -1, 1/2, -1, -1) \quad (-1, -1/2, -1, -1, -1, -1, -1, 1/2)$$

$$W_6 \quad (-1/2, -1/2, 1/2, -1/2, -1/2, -1, -1/2, 0) \quad (-1/2, -1, -1, -1, -1, -1, 1, -1/2)$$

$$\begin{pmatrix} 60 & 36 \\ 126 & 84 \\ 128 & 128 \\ 112 & 112 \end{pmatrix}$$


BREAKING PATTERNS OF E_8

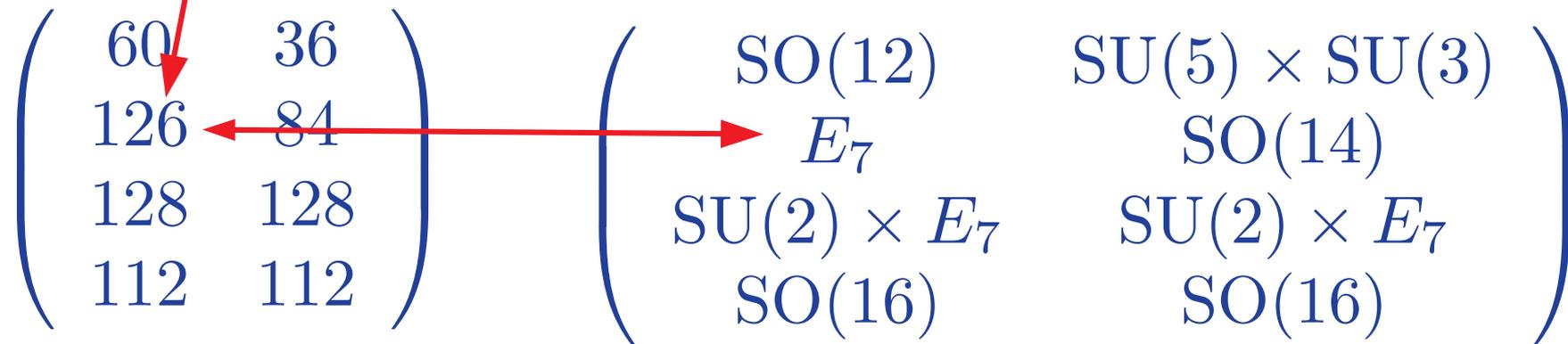
- Compute surviving roots $V \cdot \lambda \stackrel{!}{=} 0 \pmod{1} \quad \lambda \in \Phi(E_8)$

$$V_1 \quad (5/12, -1/4, -1/4, -1/4, -1/4, -1/4, -1/12, -1/12) \quad (-1/2, 1/2, -1/2, 1/3, 1/3, 1/3, 1/3, -1/6)$$

$$W_4 \quad (1/2, -1/2, -1/2, -1/6, -1/6, -1/6, 1/2, 1/2) \quad (1/2, -1/2, 1/2, -1/2, -1/6, -1/6, -1/6, 1/2)$$

$$W_5 \quad (0, -1/2, 0, -1, -1, 1/2, -1, -1) \quad (-1, -1/2, -1, -1, -1, -1, -1, 1/2)$$

$$W_6 \quad (-1/2, -1/2, 1/2, -1/2, -1/2, -1, -1/2, 0) \quad (-1/2, -1, -1, -1, -1, -1, 1, -1/2)$$



BREAKING PATTERNS OF E_8

- Compute surviving roots $V \cdot \lambda \stackrel{!}{=} 0 \pmod{1} \quad \lambda \in \Phi(E_8)$

$$\begin{pmatrix} 60 & 36 \\ 126 & 84 \\ 128 & 128 \\ 112 & 112 \end{pmatrix}$$

BREAKING PATTERNS OF E_8

- Compute surviving roots $V \cdot \lambda \stackrel{!}{=} 0 \pmod{1} \quad \lambda \in \Phi(E_8)$
- ✓ Invariant under addition of lattice vectors
& Weyl reflections

$$\begin{pmatrix} 60 & 36 \\ 126 & 84 \\ 128 & 128 \\ 112 & 112 \end{pmatrix}$$

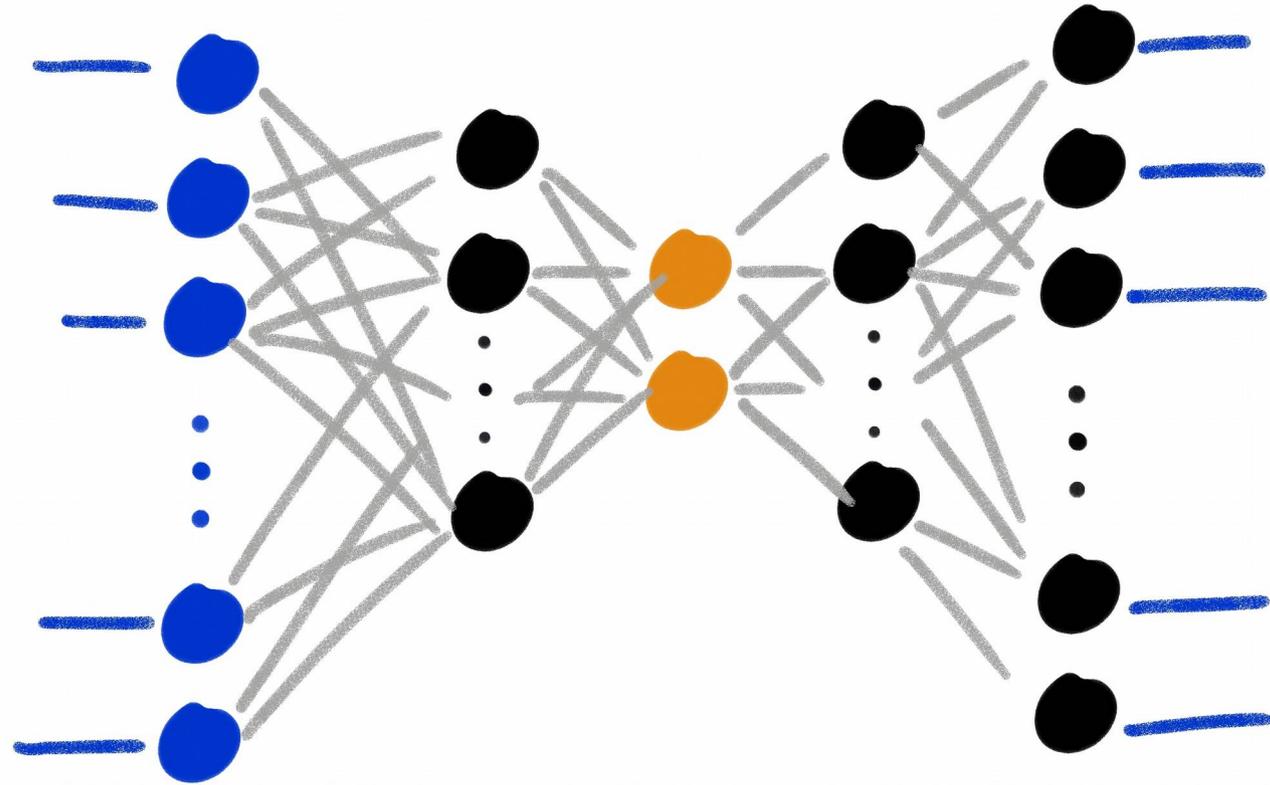
BREAKING PATTERNS OF E_8

- Compute surviving roots $V \cdot \lambda \stackrel{!}{=} 0 \pmod{1} \quad \lambda \in \Phi(E_8)$
- ✓ Invariant under addition of lattice vectors
& Weyl reflections
- ✗ Loss of information & data points: 64 \rightarrow 8

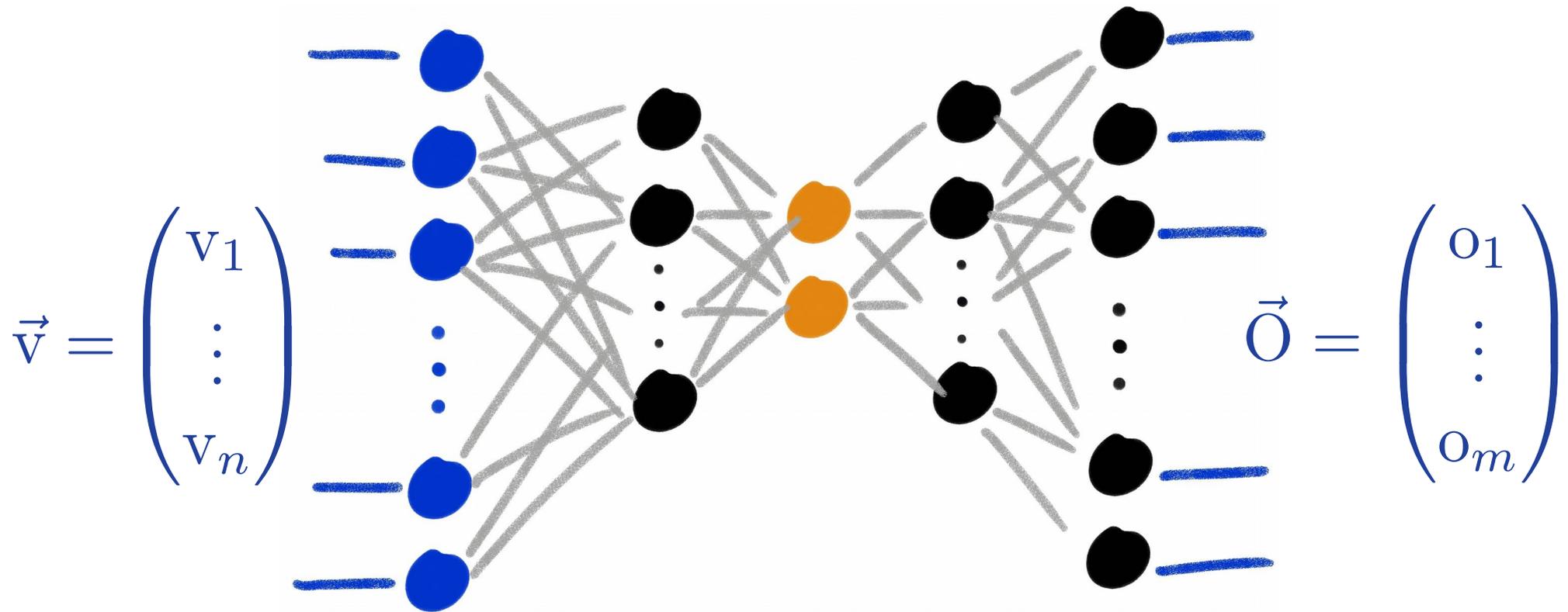
$$\begin{pmatrix} 60 & 36 \\ 126 & 84 \\ 128 & 128 \\ 112 & 112 \end{pmatrix}$$

NEURAL NETWORKS

NEURAL NETWORK



NEURAL NETWORK



AUTOENCODER

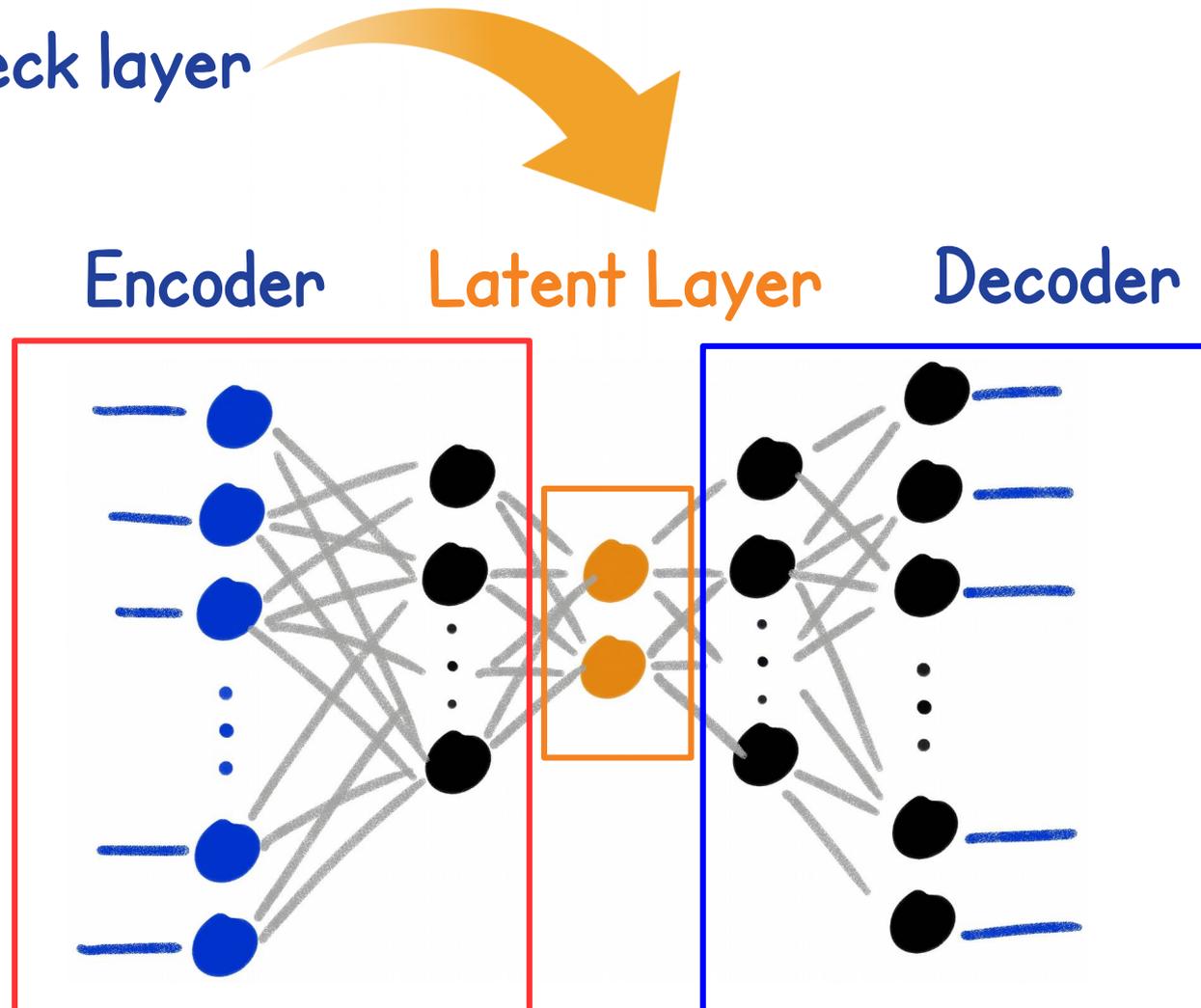
1. Unsupervised learning: $\vec{o} \stackrel{!}{=} \vec{v}$

AUTOENCODER

1. Unsupervised learning: $\vec{o} \stackrel{!}{=} \vec{v}$
2. Bottleneck layer

AUTOENCODER

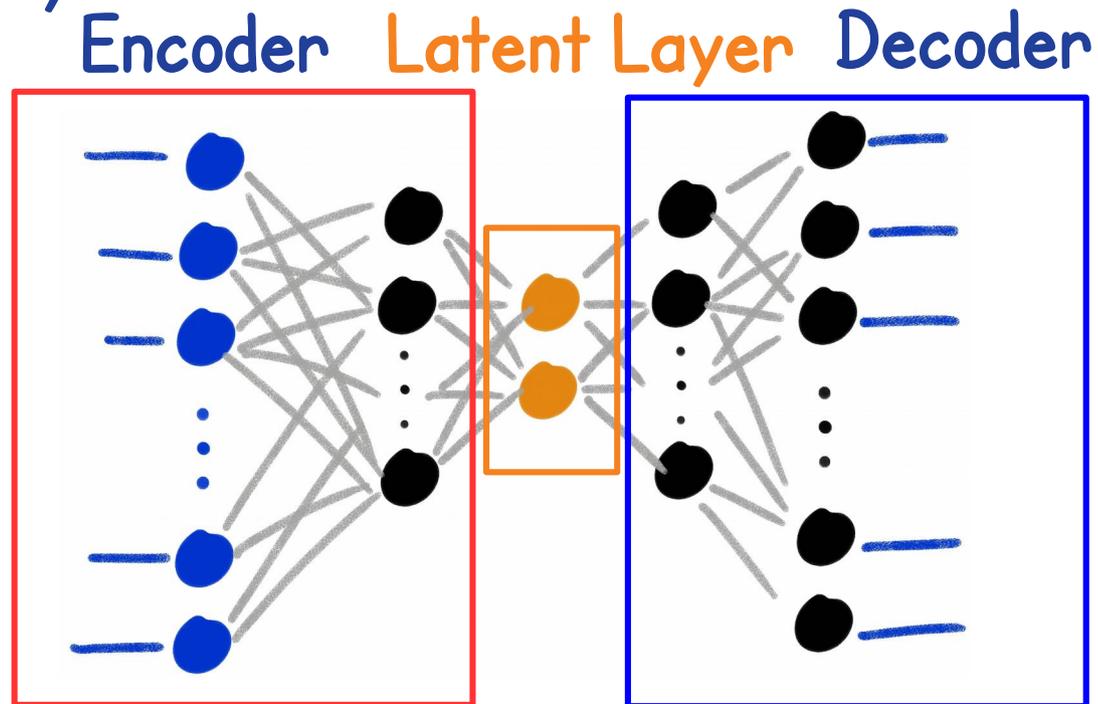
1. Unsupervised learning: $\vec{O} \stackrel{!}{=} \vec{V}$
2. Bottleneck layer



AUTOENCODER

1. Unsupervised learning: $\vec{O} \stackrel{!}{=} \vec{V}$

2. Bottleneck layer

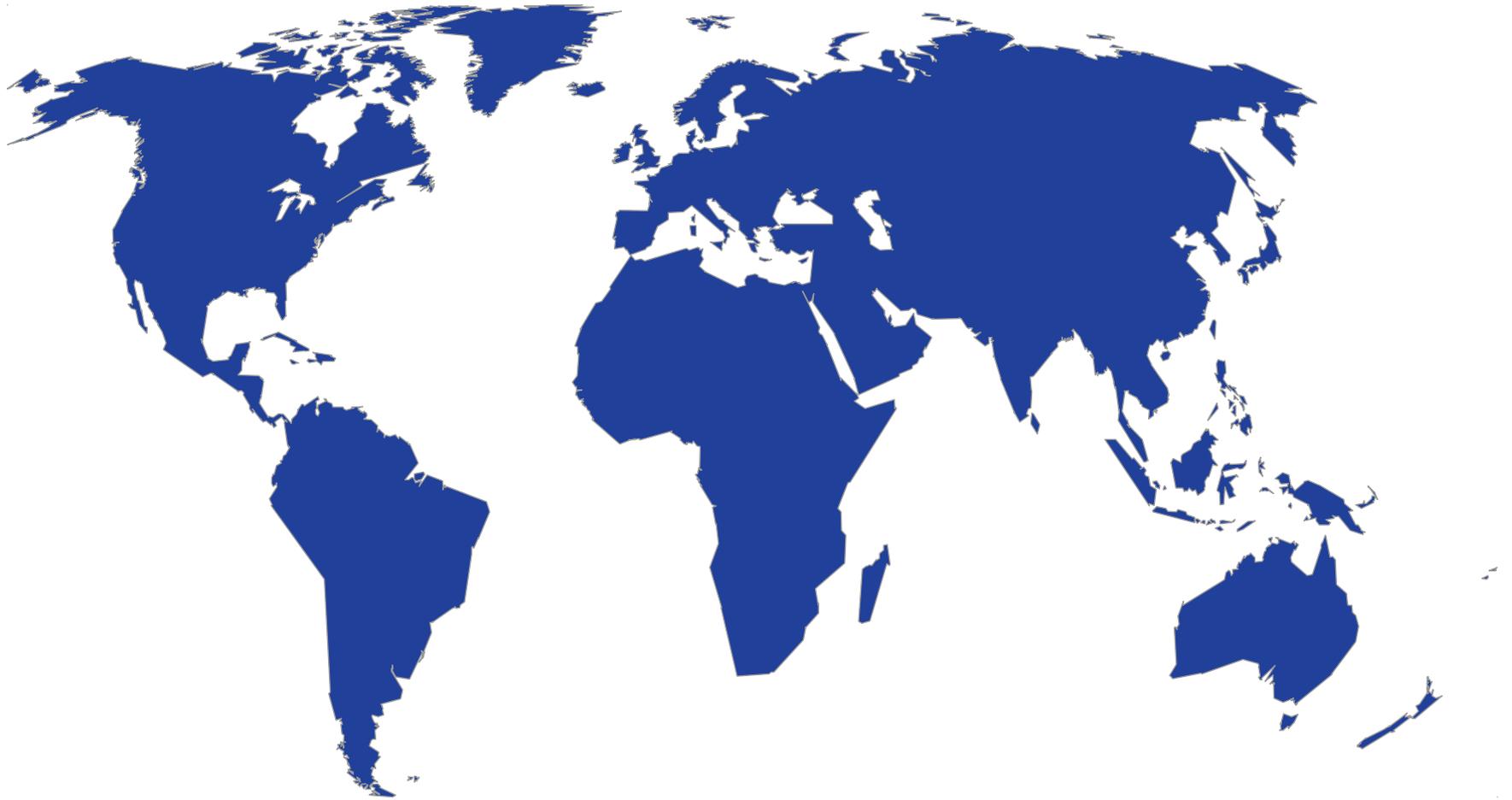


• Dimension of layers:

8 --- 24 --- 4 --- 2 --- 24 --- 8

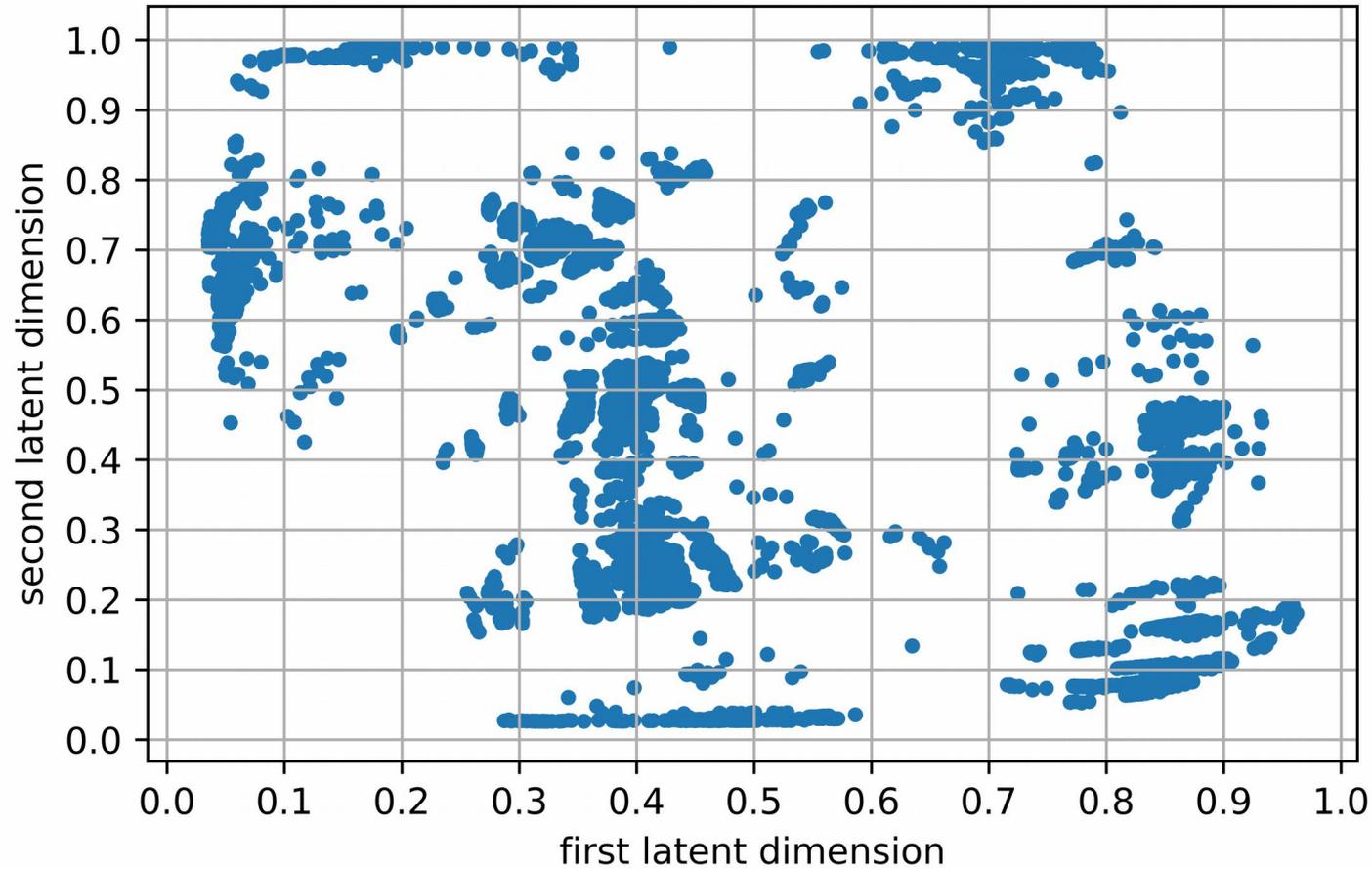
PERFORMANCE ON HETEROTIC ORBIFOLD

Let's draw a map of the string landscape ...



PERFORMANCE ON HETEROTIC ORBIFOLD

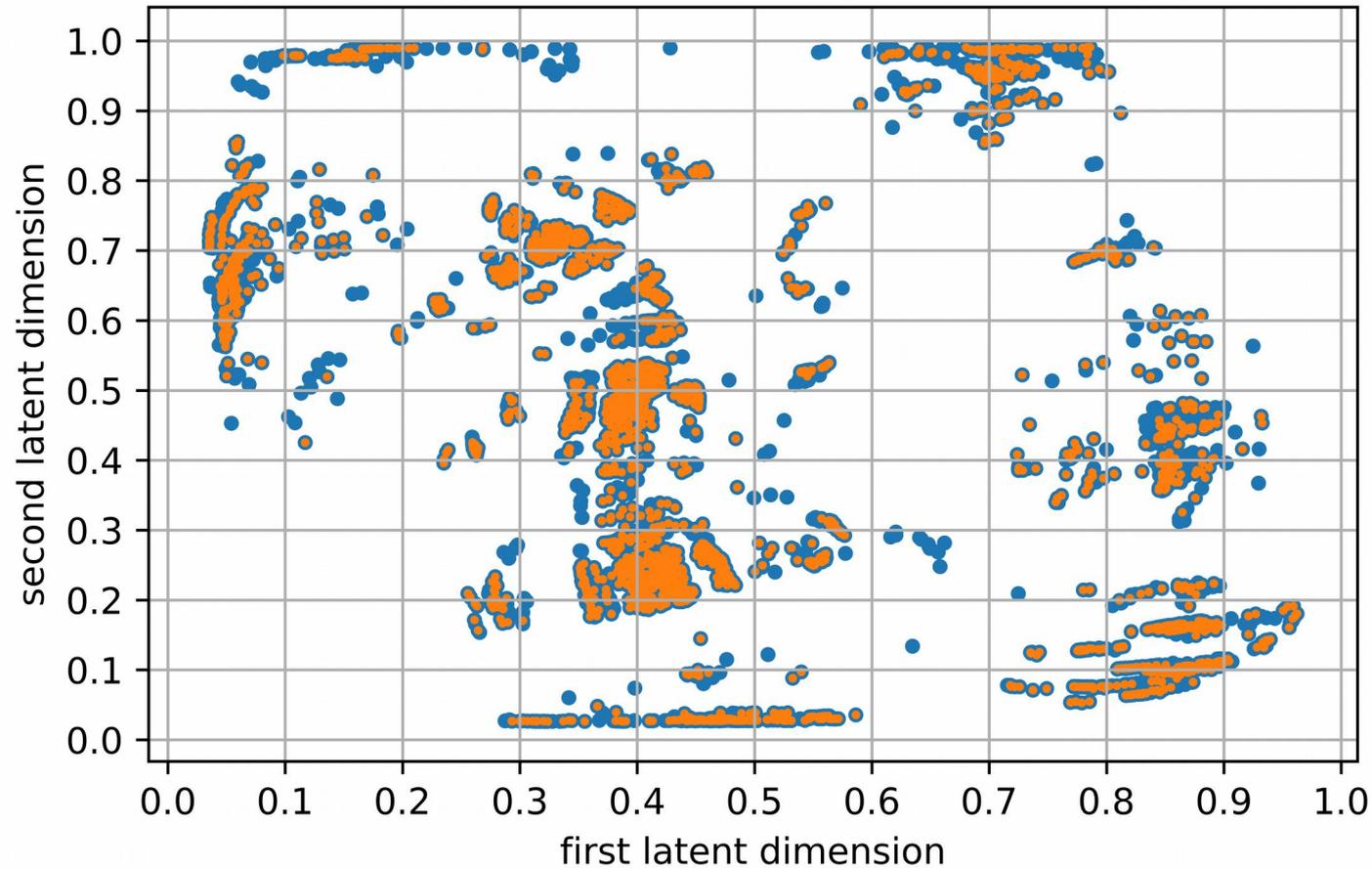
● Random



PERFORMANCE ON HETEROTIC ORBIFOLD

● Random

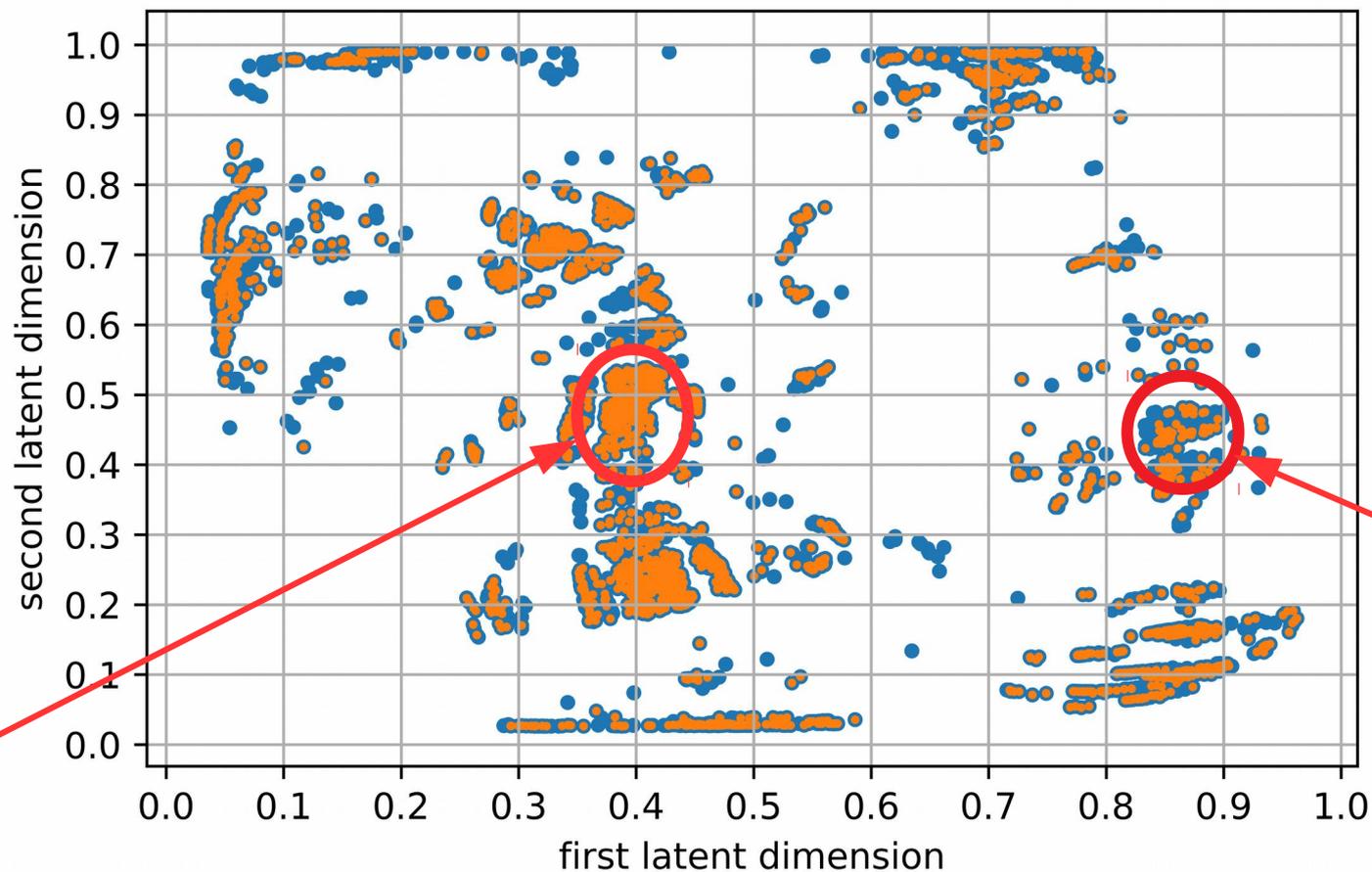
● N gen. MSSM-like



PERFORMANCE ON HETEROTIC ORBIFOLD

● Random

● N gen. MSSM-like

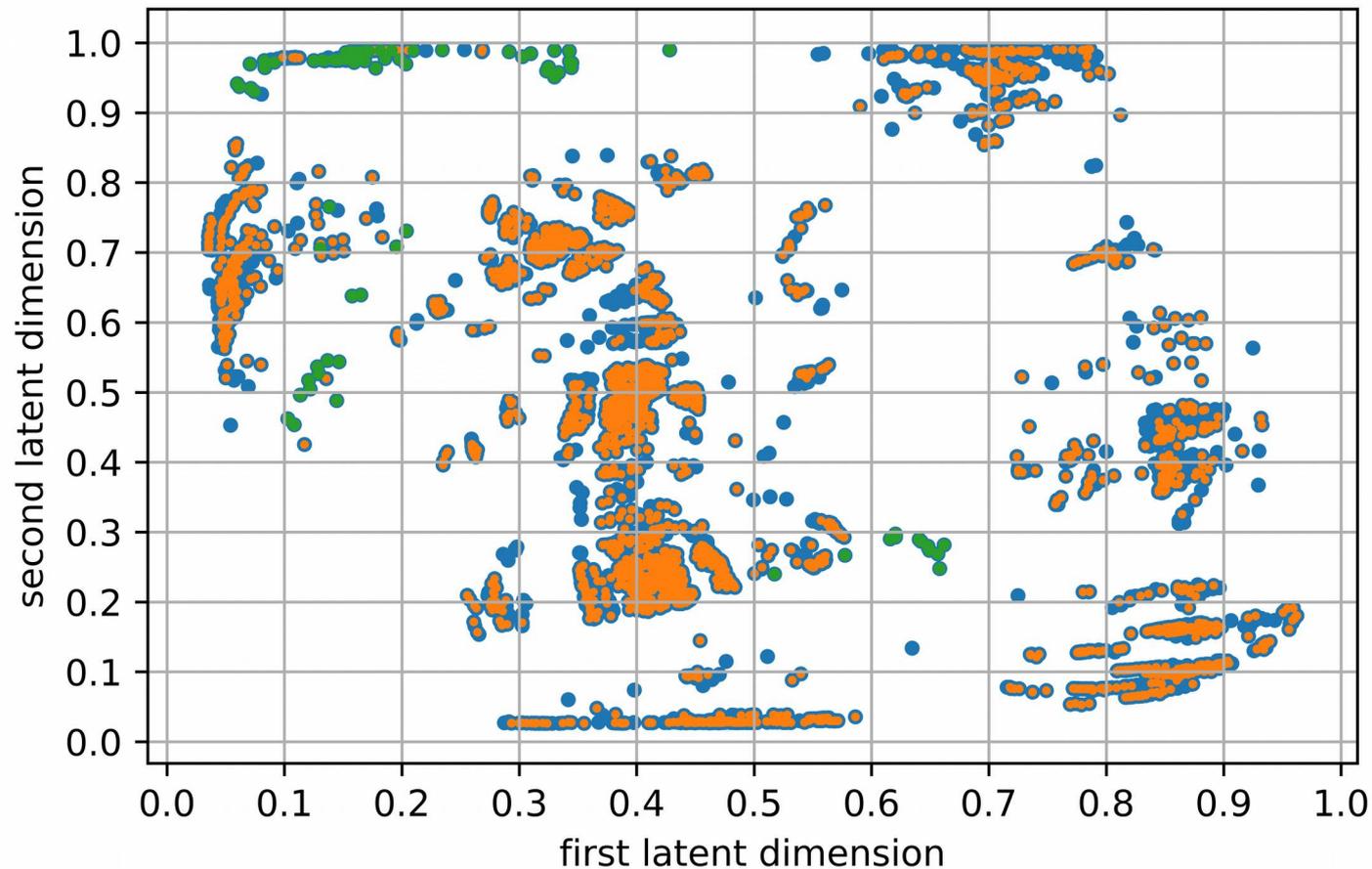


PERFORMANCE ON HETEROTIC ORBIFOLD

● Random

● N gen. MSSM-like

● Mini-Landscape



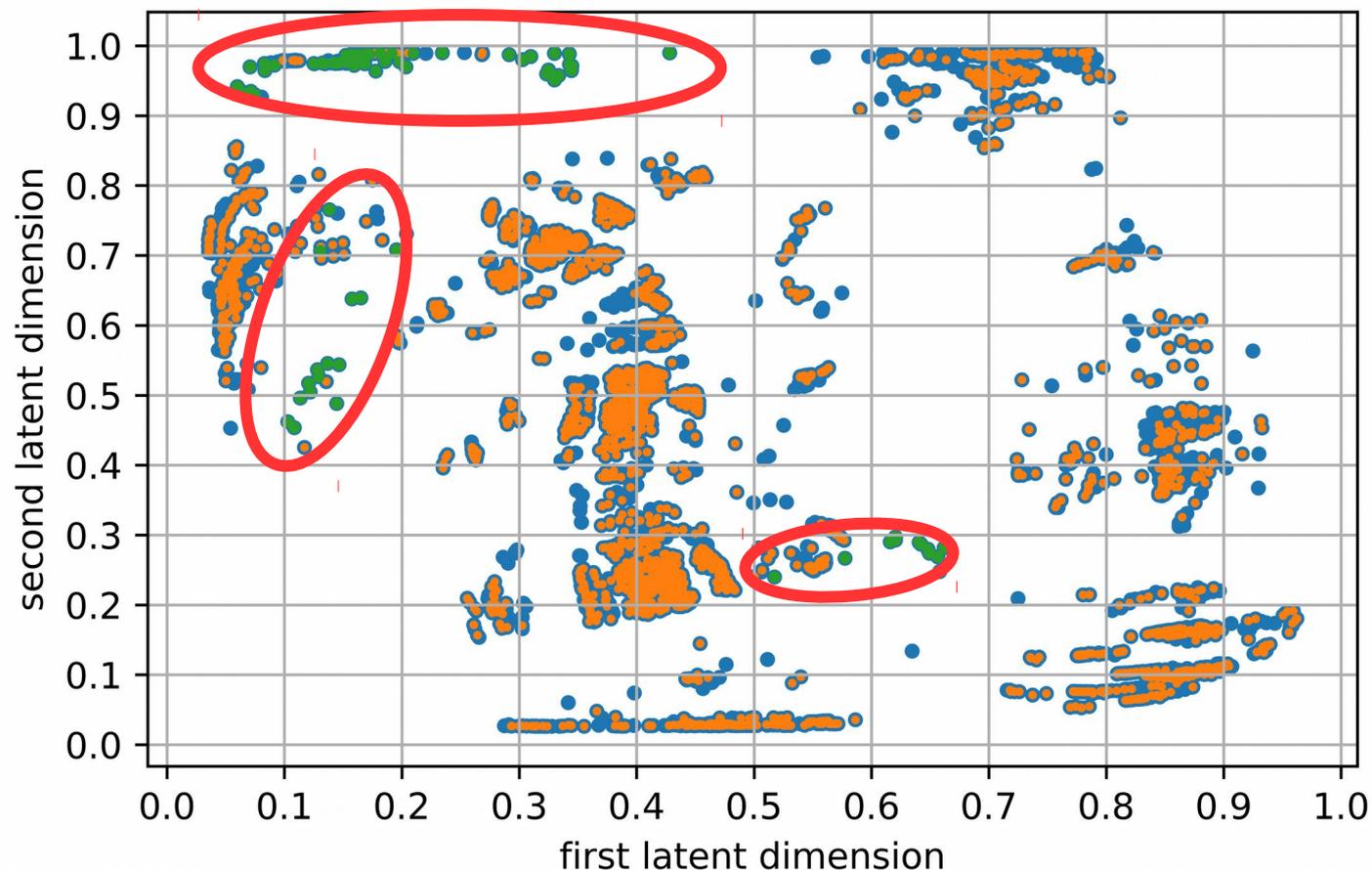
O. Lebedev, H. P. Nilles, S. Raby, S. Ramos-Sanchez, M. Ratz, P. Vaudrevange, A. Wingerter 2006

PERFORMANCE ON HETEROTIC ORBIFOLD

● Random

● N gen. MSSM-like

● Mini-Landscape

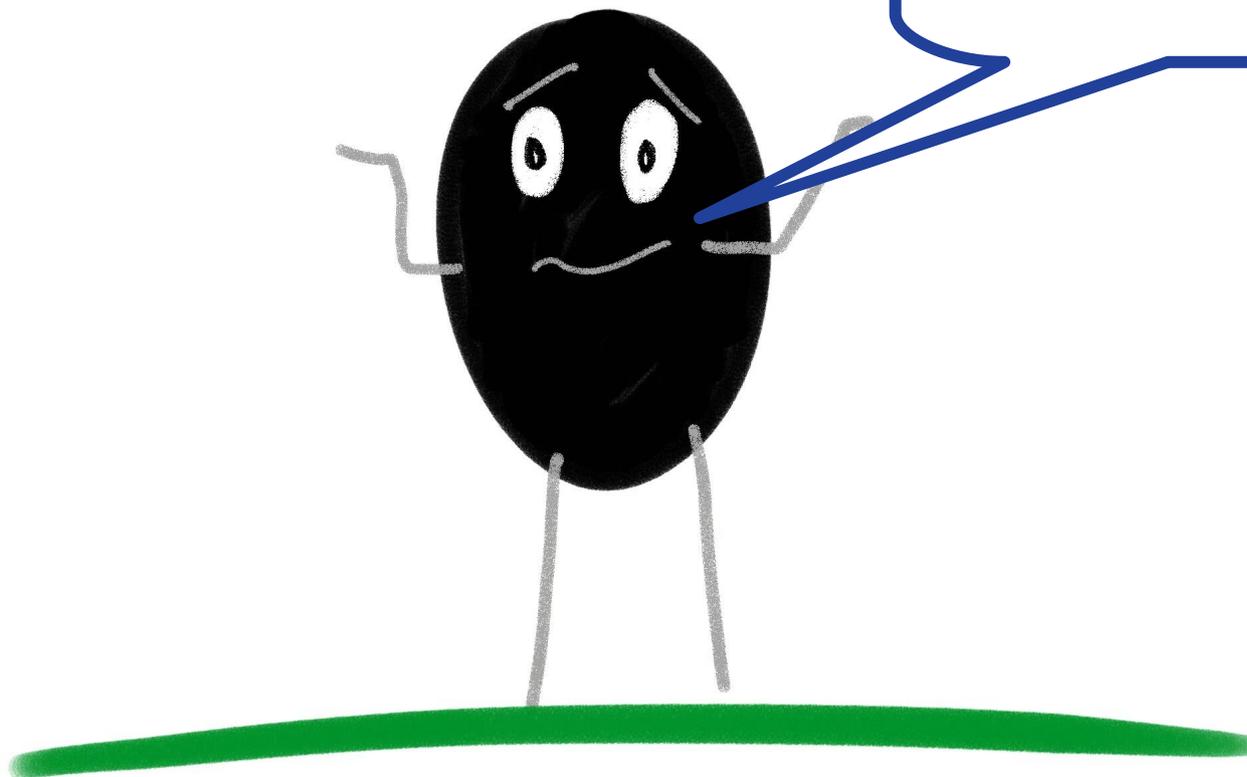


O. Lebedev, H. P. Nilles, S. Raby, S. Ramos-Sanchez, M. Ratz, P. Vaudrevange, A. Wingerter 2006

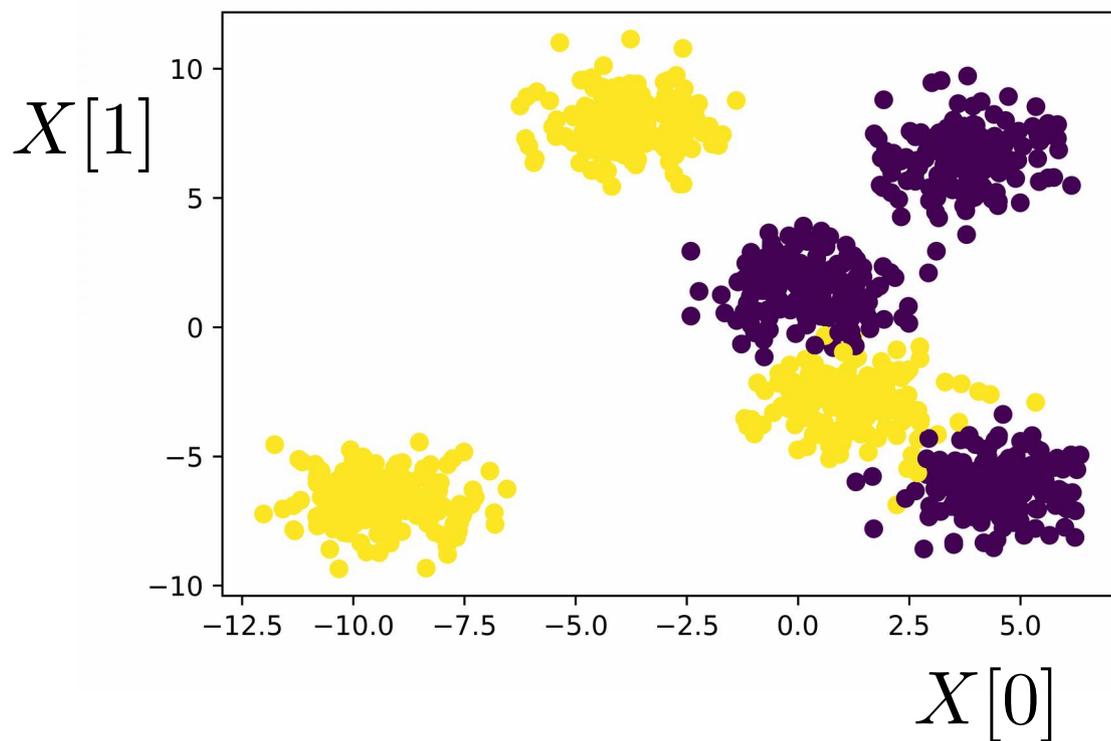
KNOWLEDGE EXTRACTION

$$8 \times 24 + 24 \times 4 + 4 \times 2 = 296$$

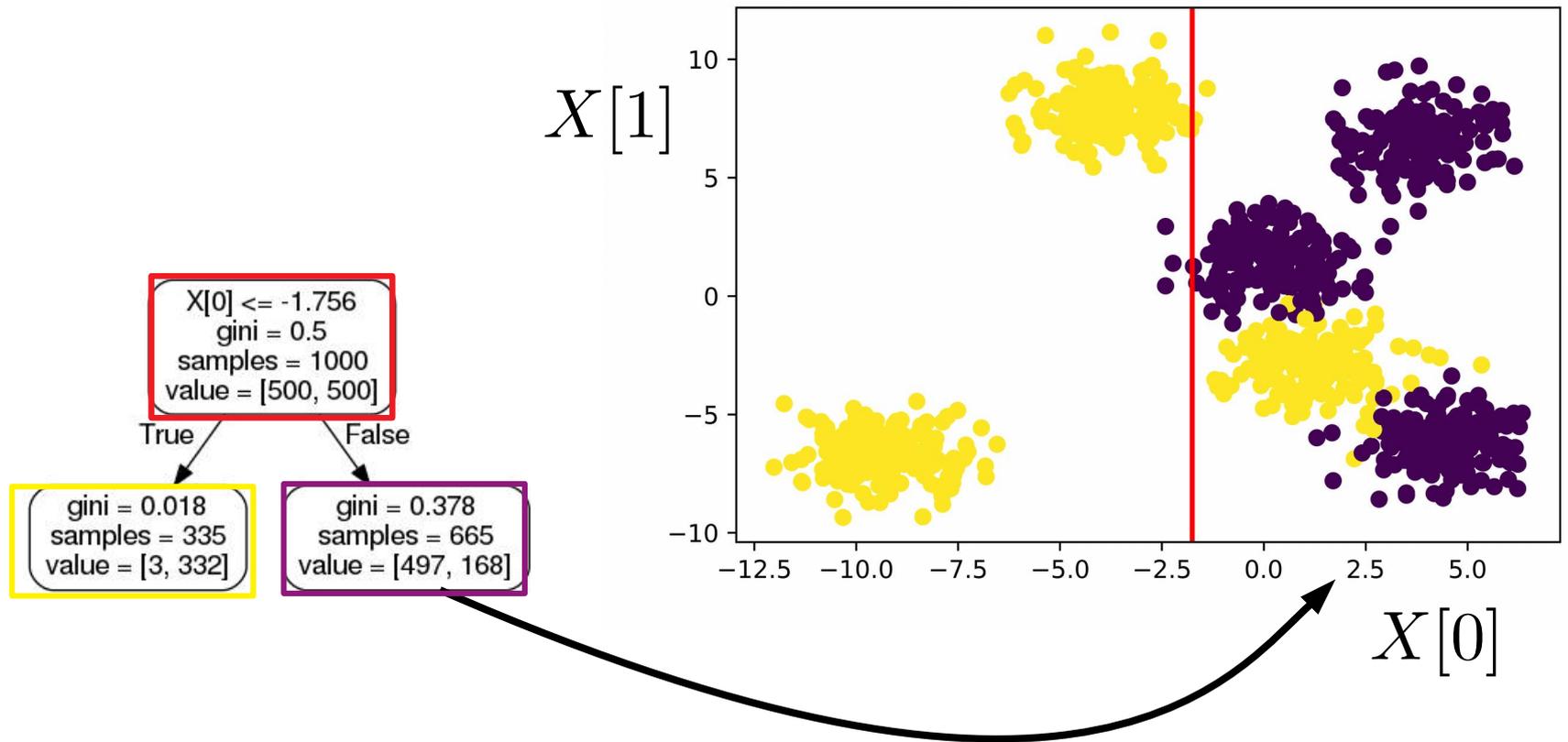
What have we learned?!?



DECISION TREE - EXAMPLE

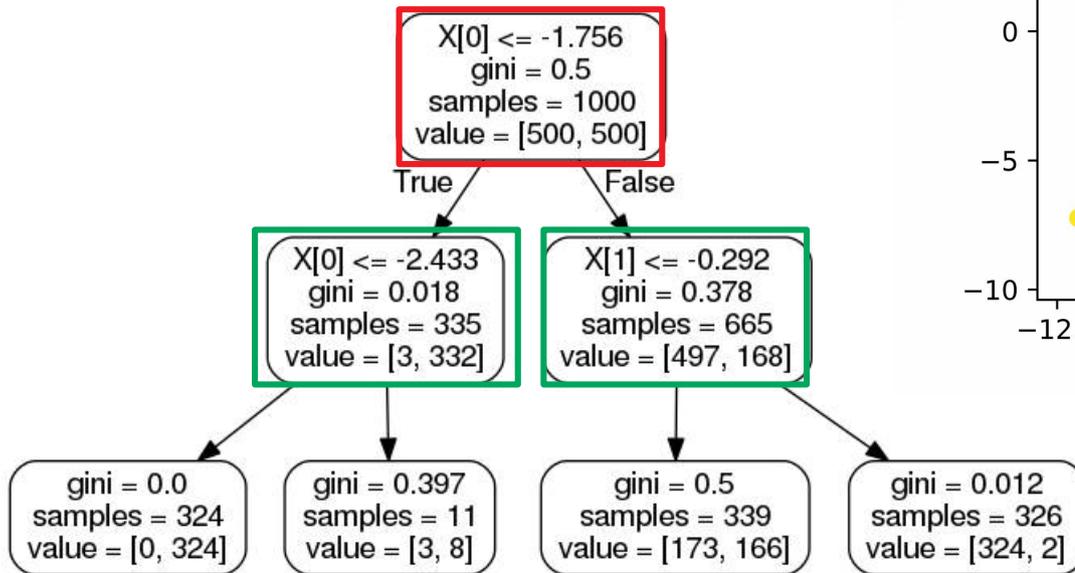
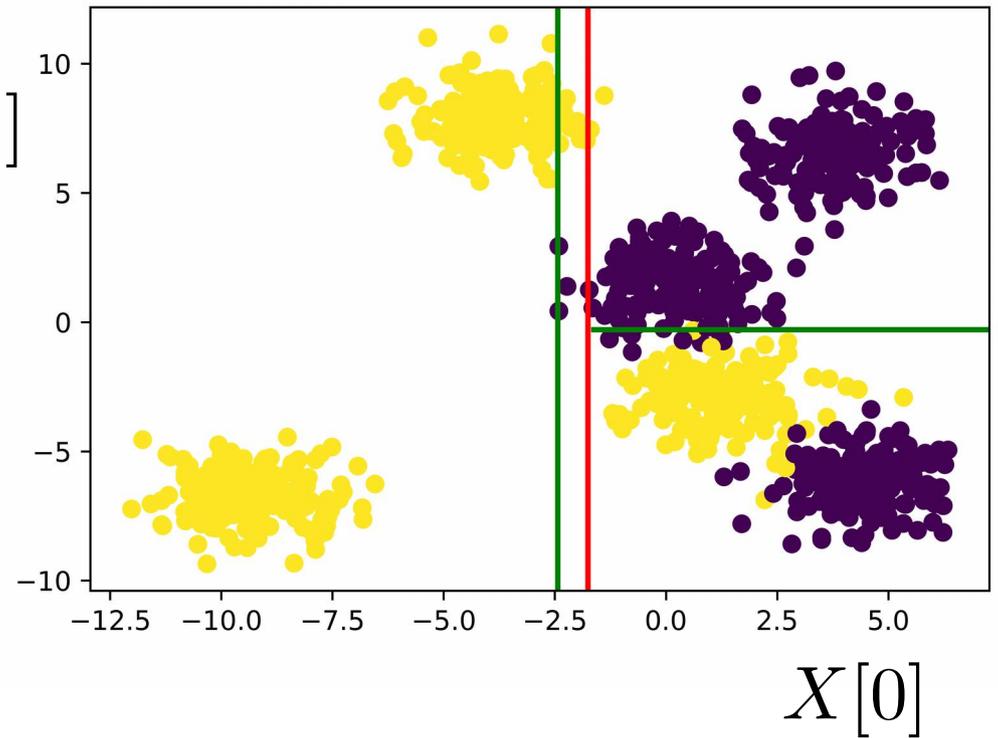


DECISION TREE - EXAMPLE

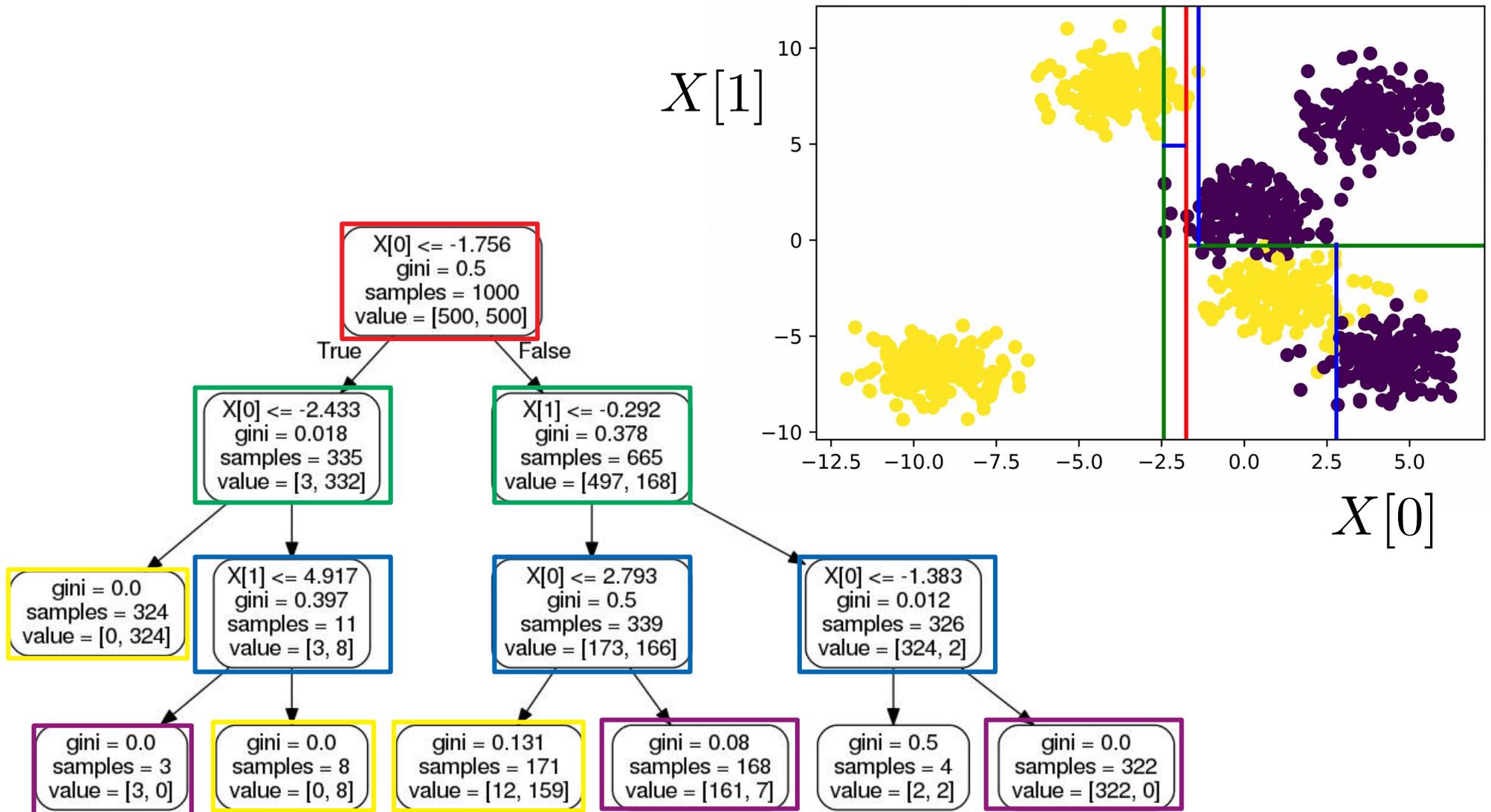


DECISION TREE - EXAMPLE

$X[1]$



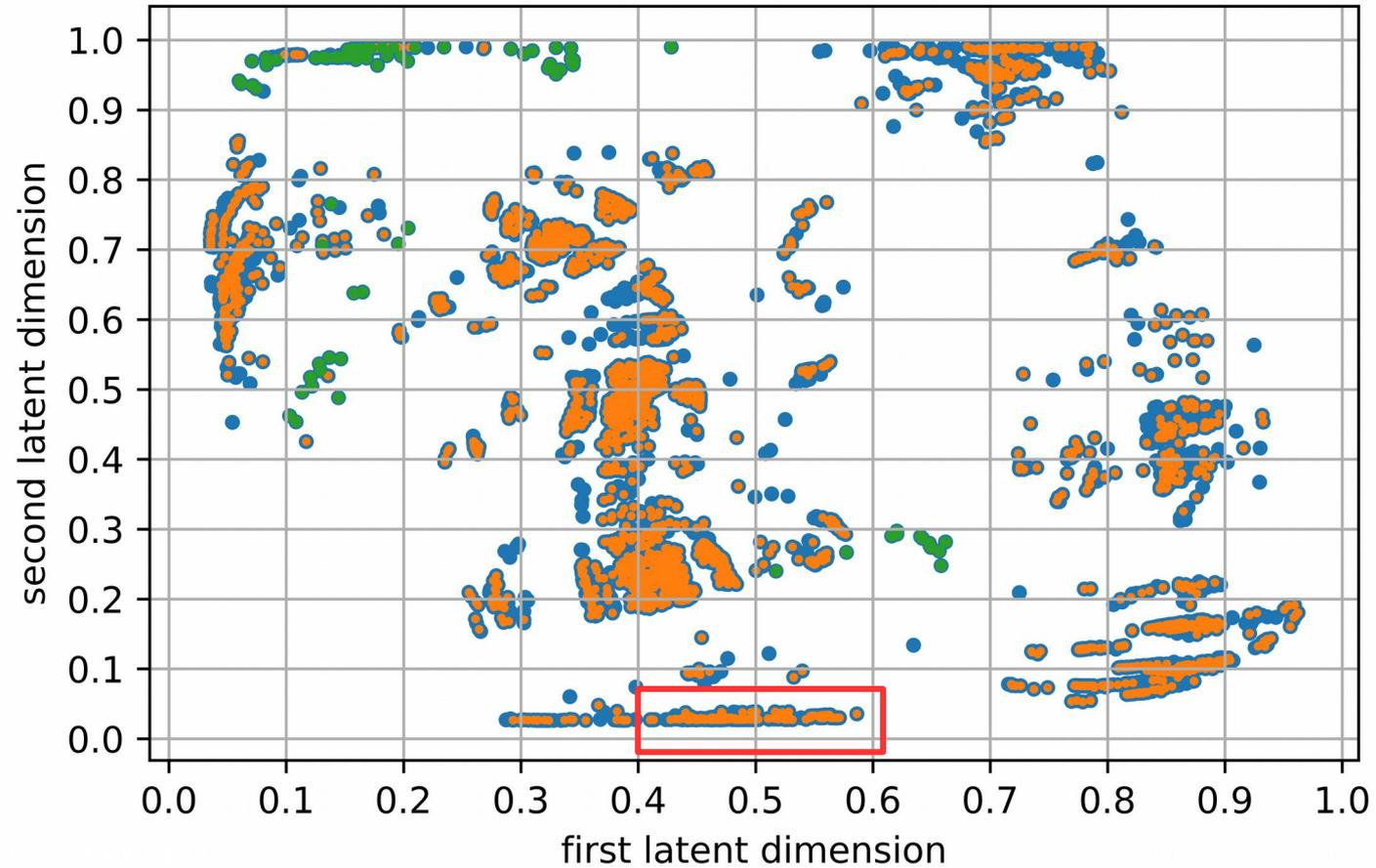
DECISION TREE - EXAMPLE



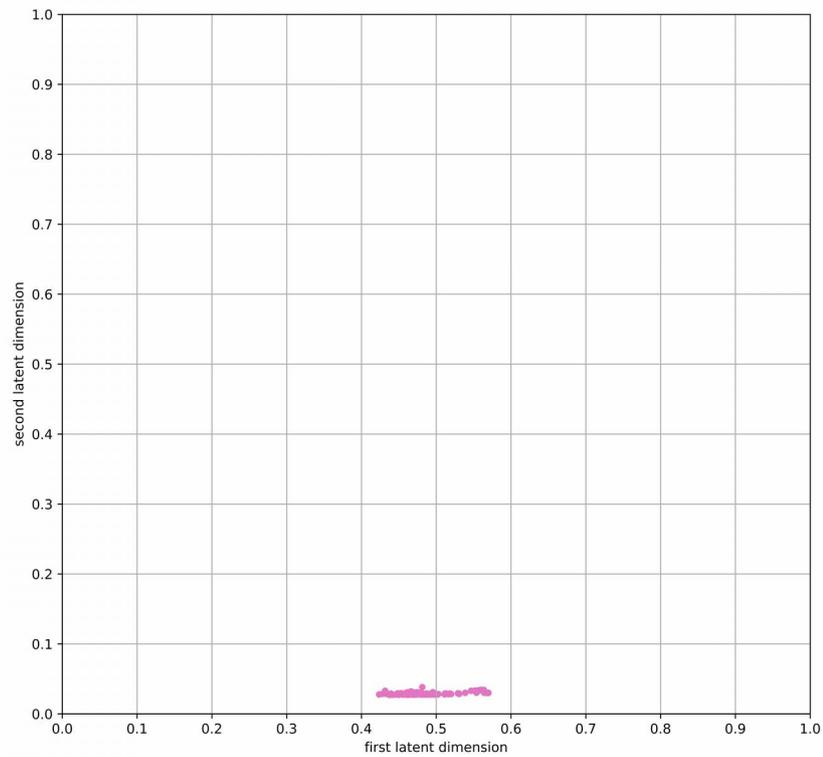
DECISION TREE

- ✓ Highly non-linear
- ✓ Very easy to understand
- ✗ Only splits orthogonal to the axes
- ✗ Weak predictive power

DECISION TREE



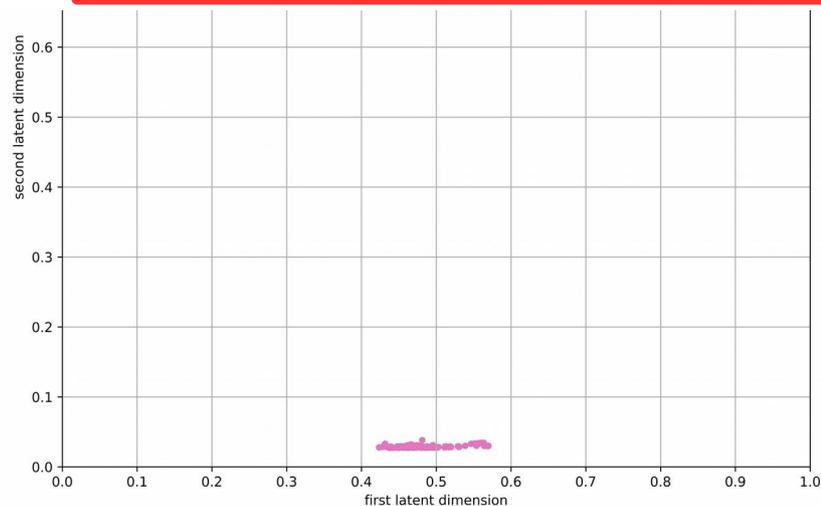
DECISION TREE - 8D



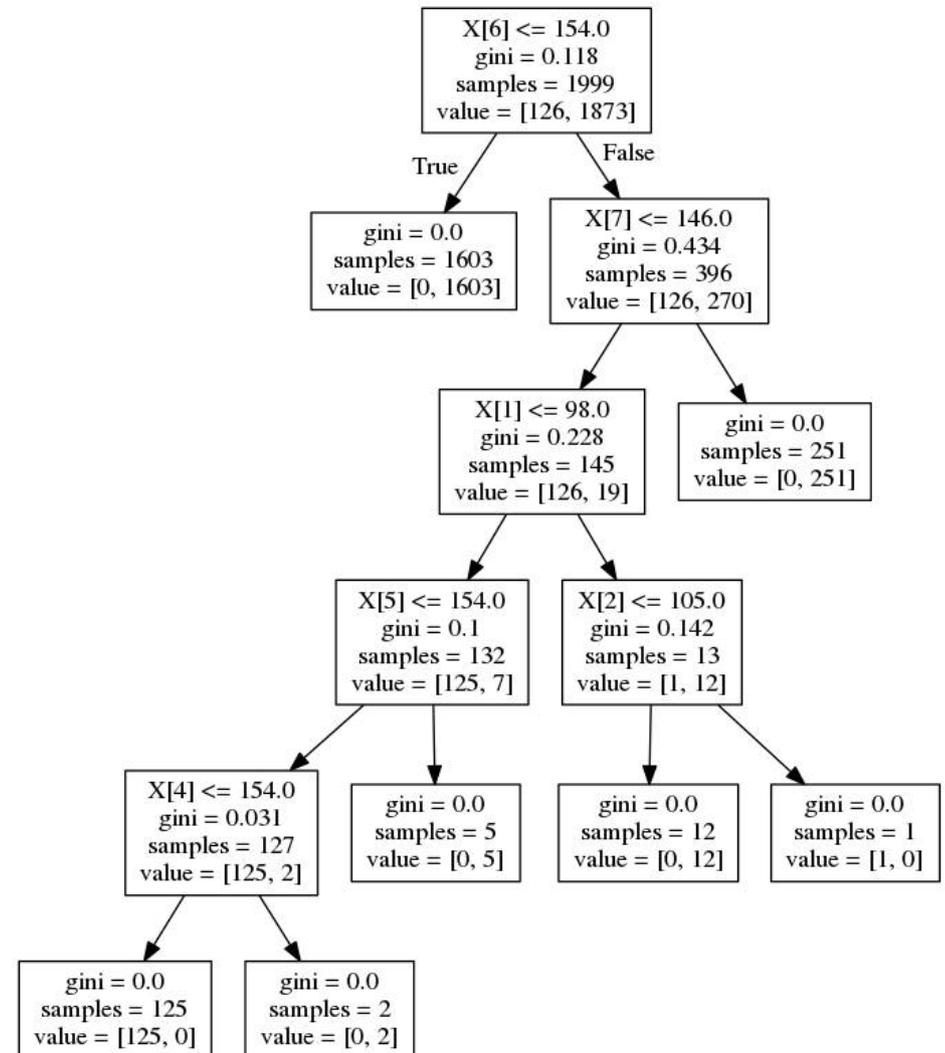
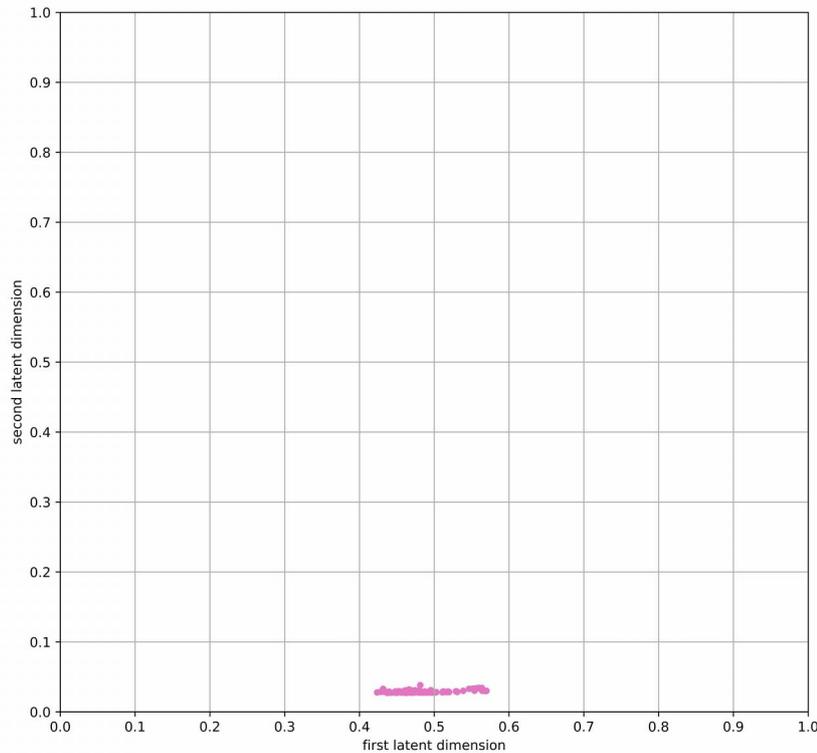
DECISION TREE - 8D

- Classification report:

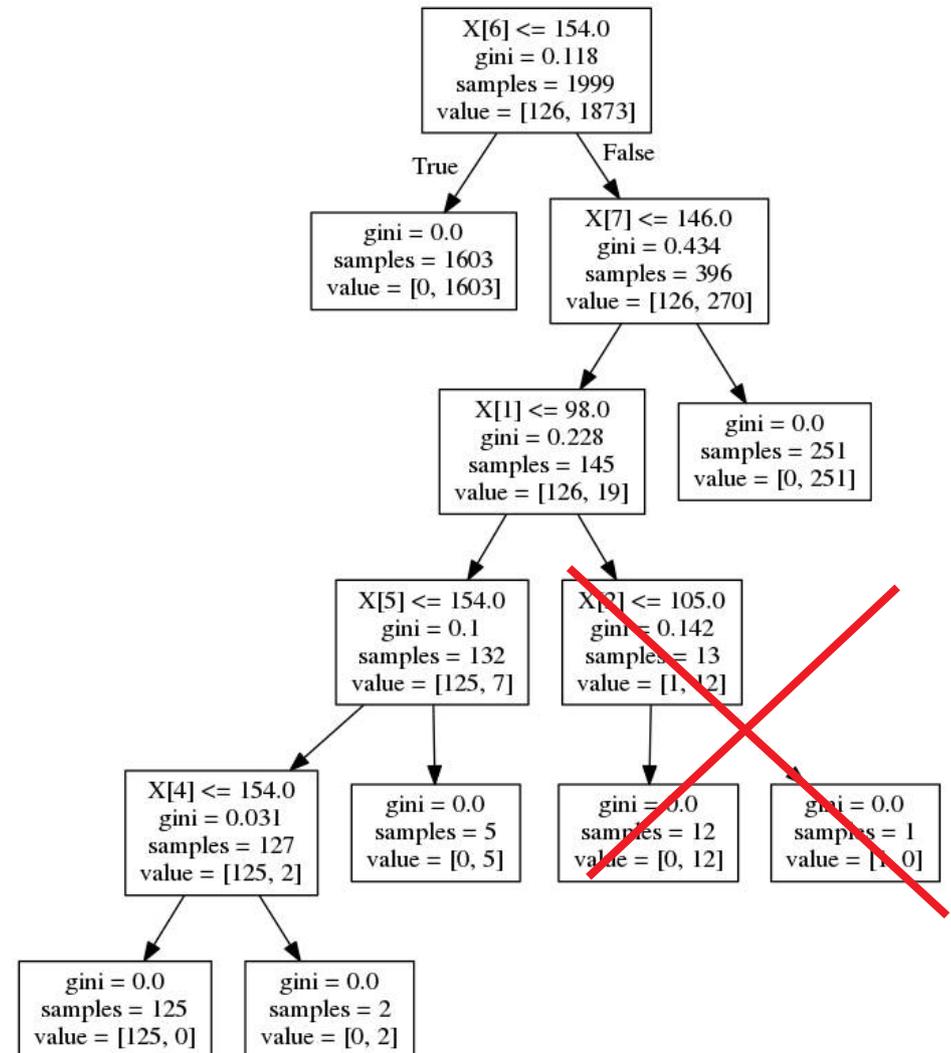
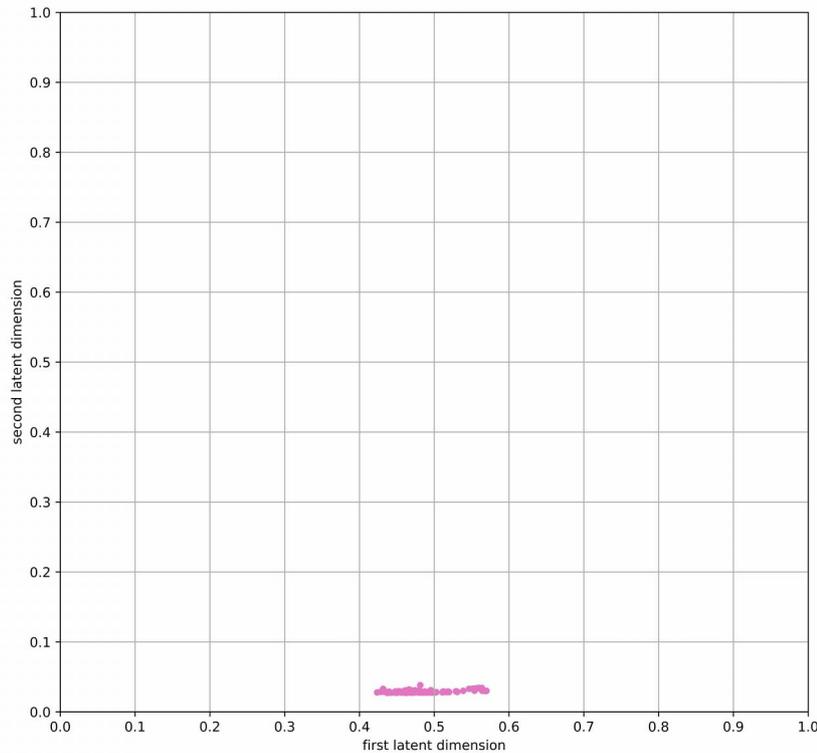
	precision	recall	f1-score
patch	1.00	1.00	1.00
others	1.00	1.00	1.00
avg / total	1.00	1.00	1.00



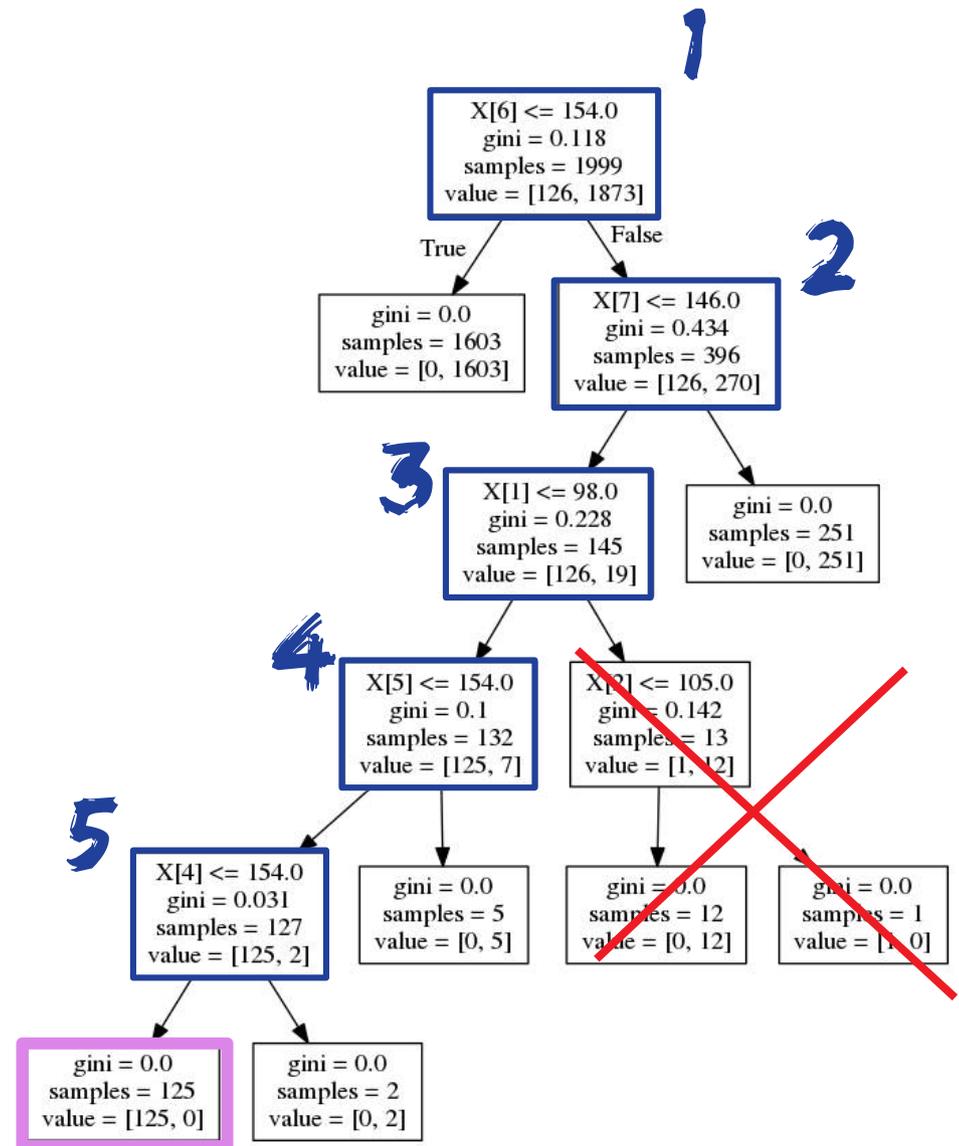
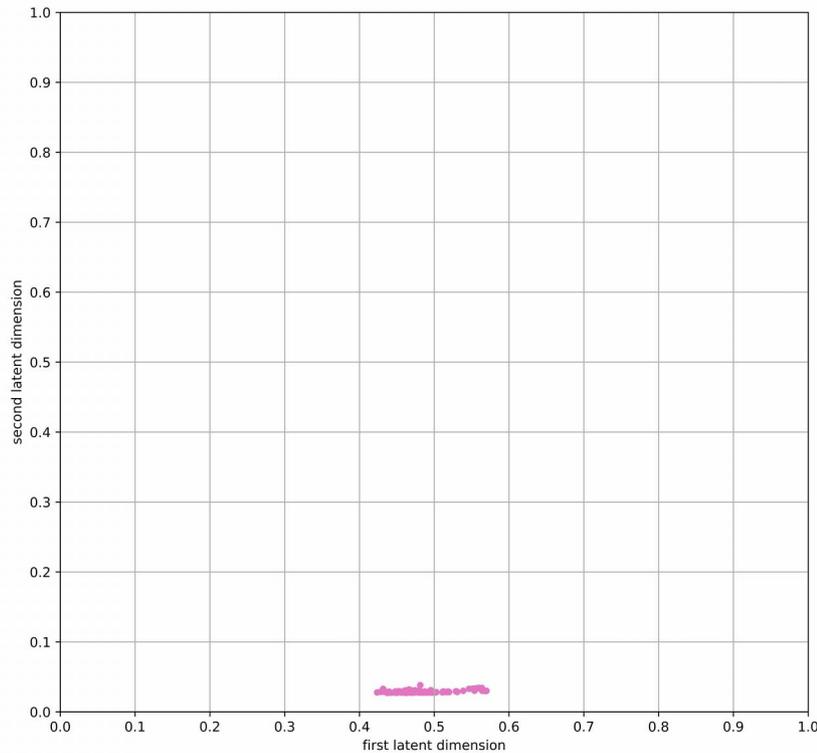
DECISION TREE - 8D



DECISION TREE - 8D

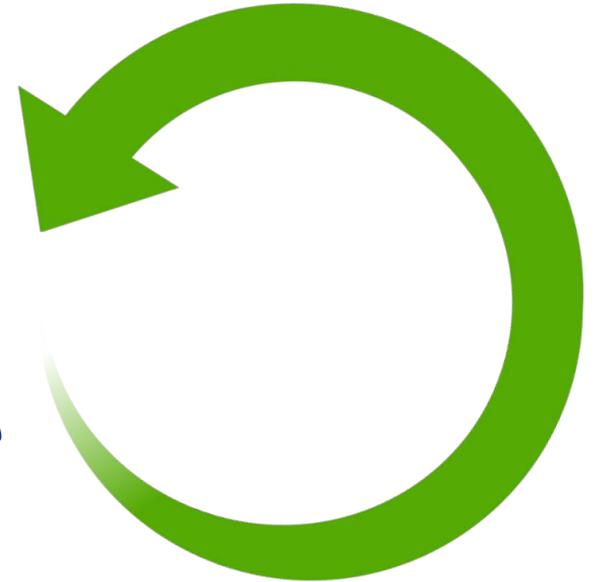


DECISION TREE - 8D



WHY ?

1. Random search
2. Identify fertile patches
3. Find constraints for the Orbifolder



THANK YOU FOR YOUR ATTENTION

