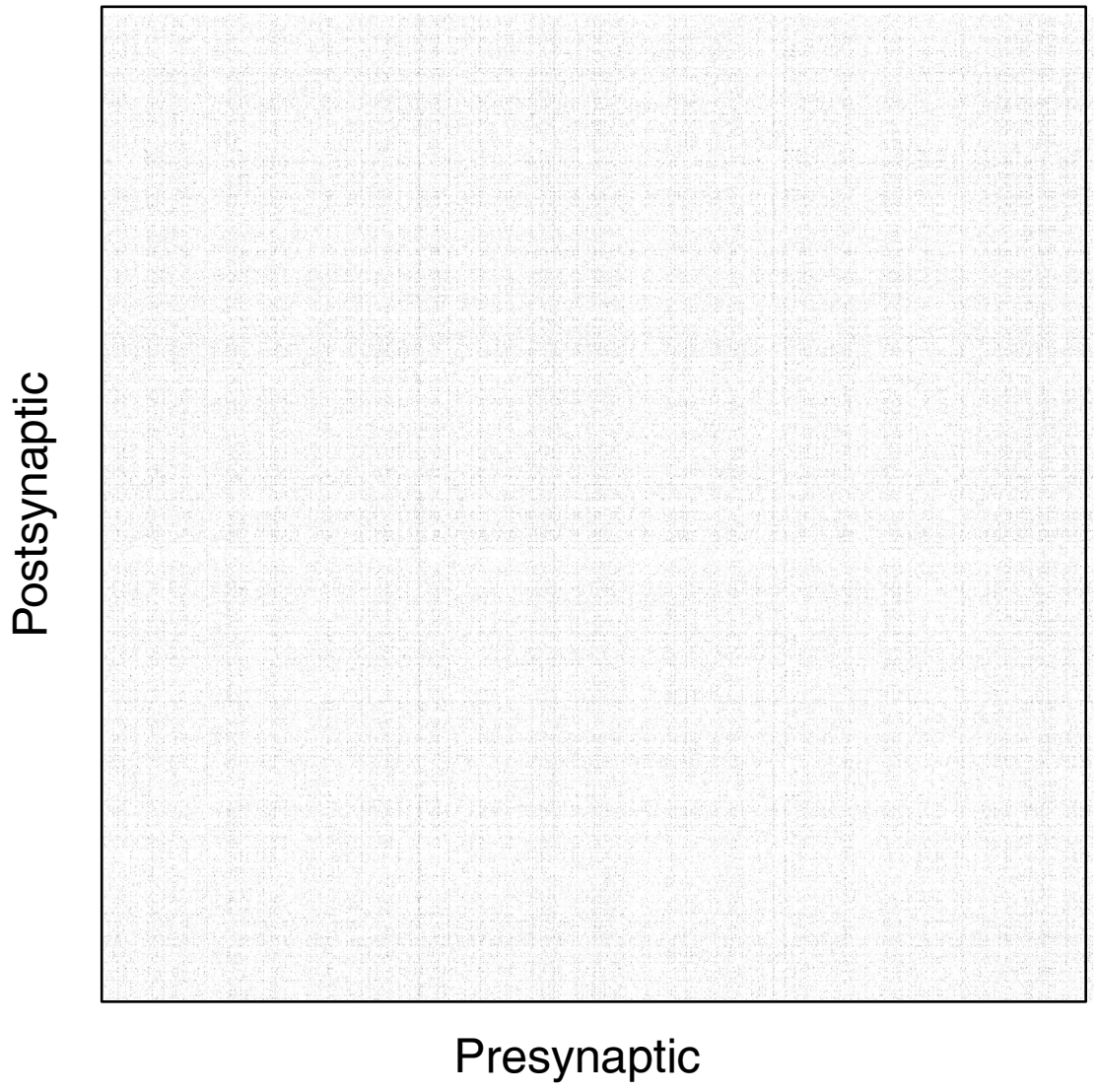
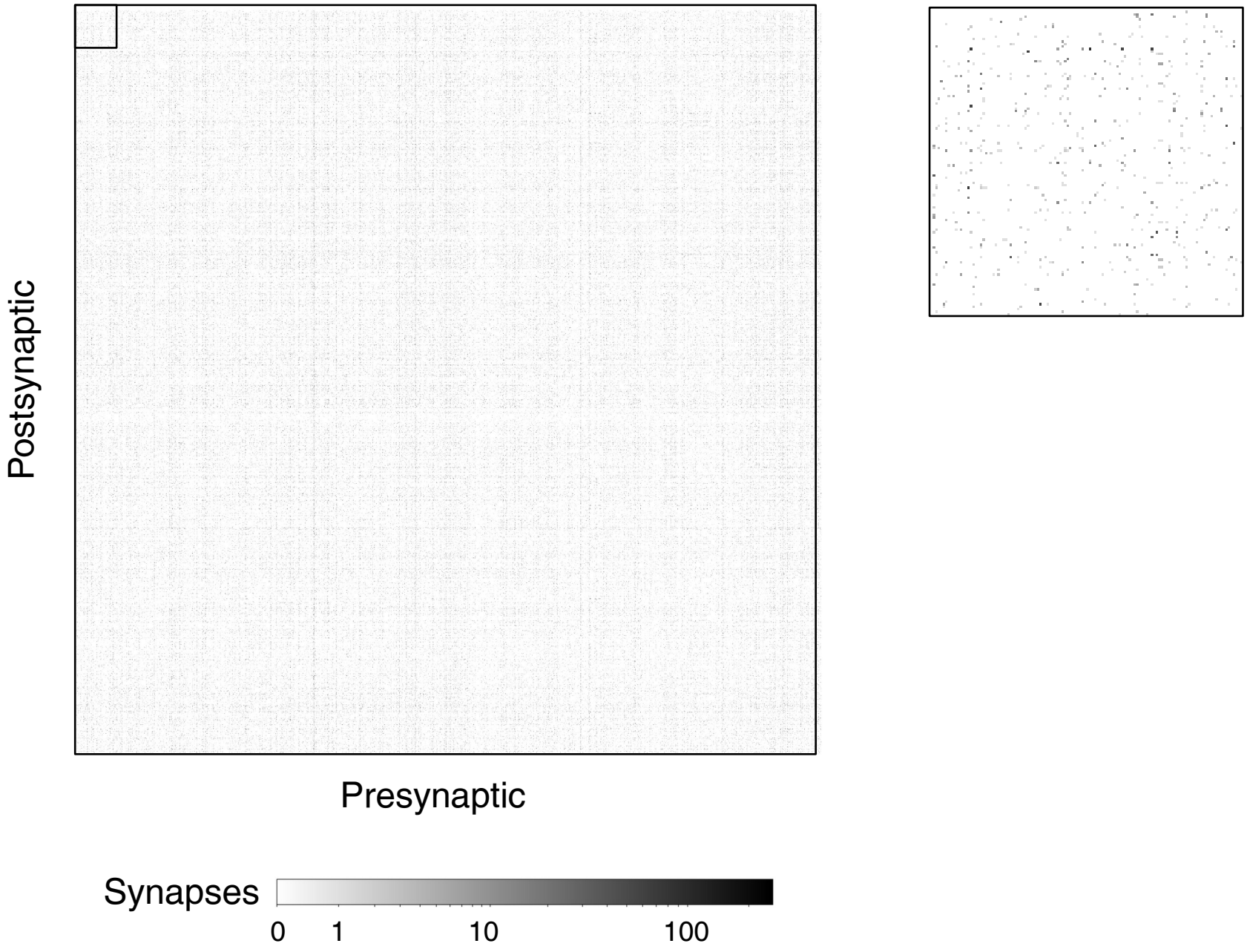
Haozhe Shan


Postsynaptic
Presynaptic
Synapses
0
1
10
100


Postsynaptic
Presynaptic
Synapses
0
1
10
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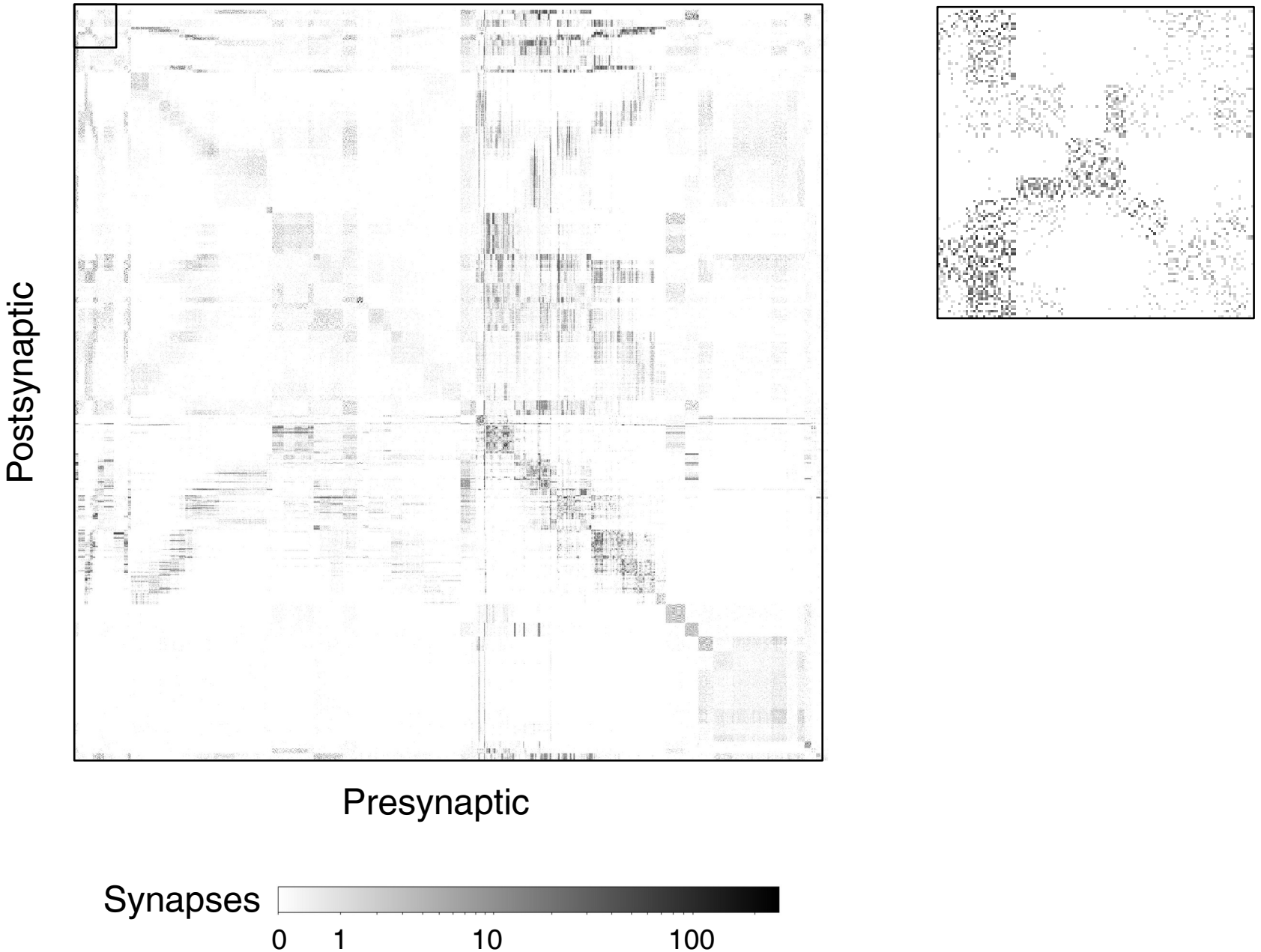
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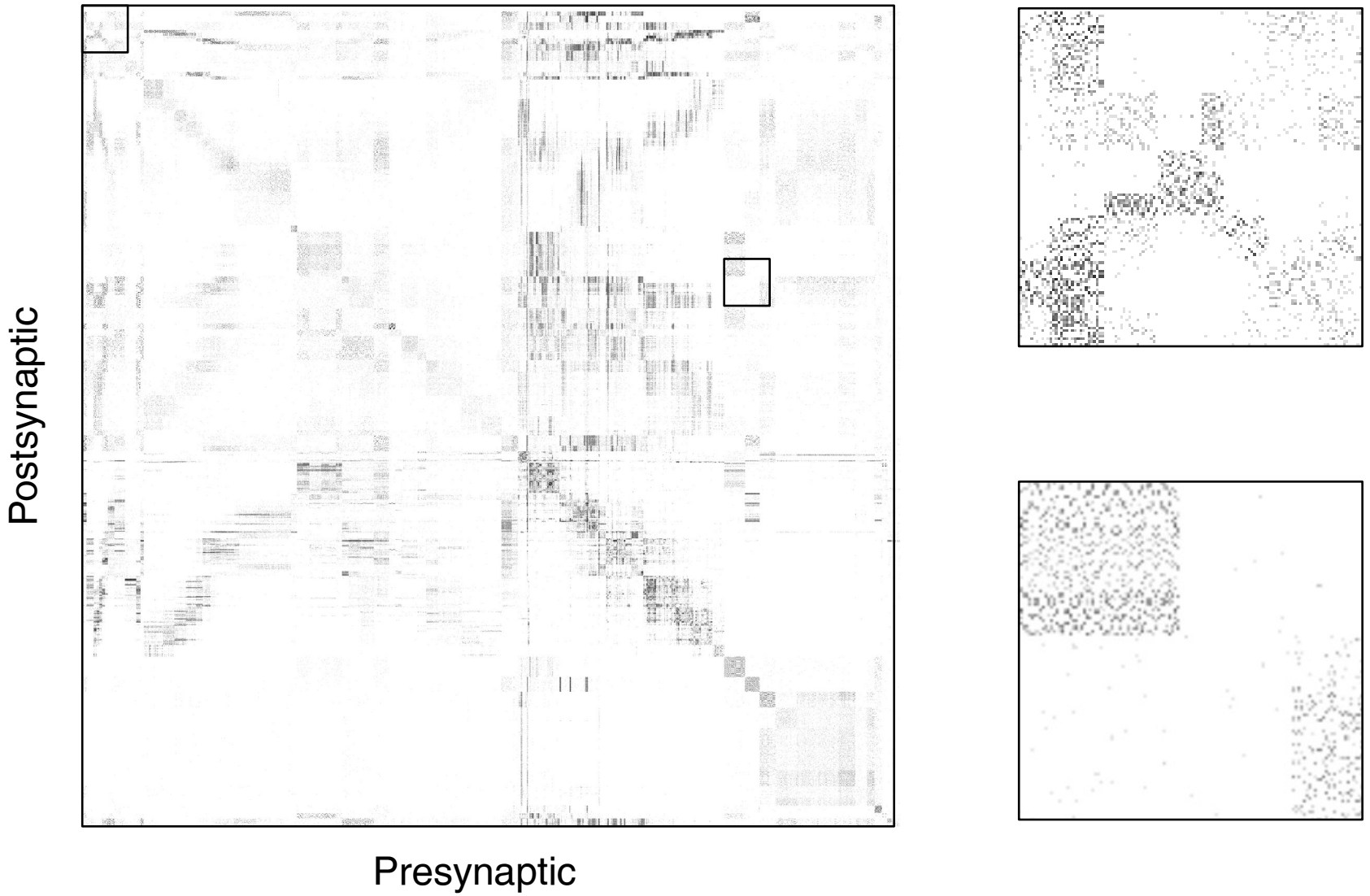
Postsynaptic
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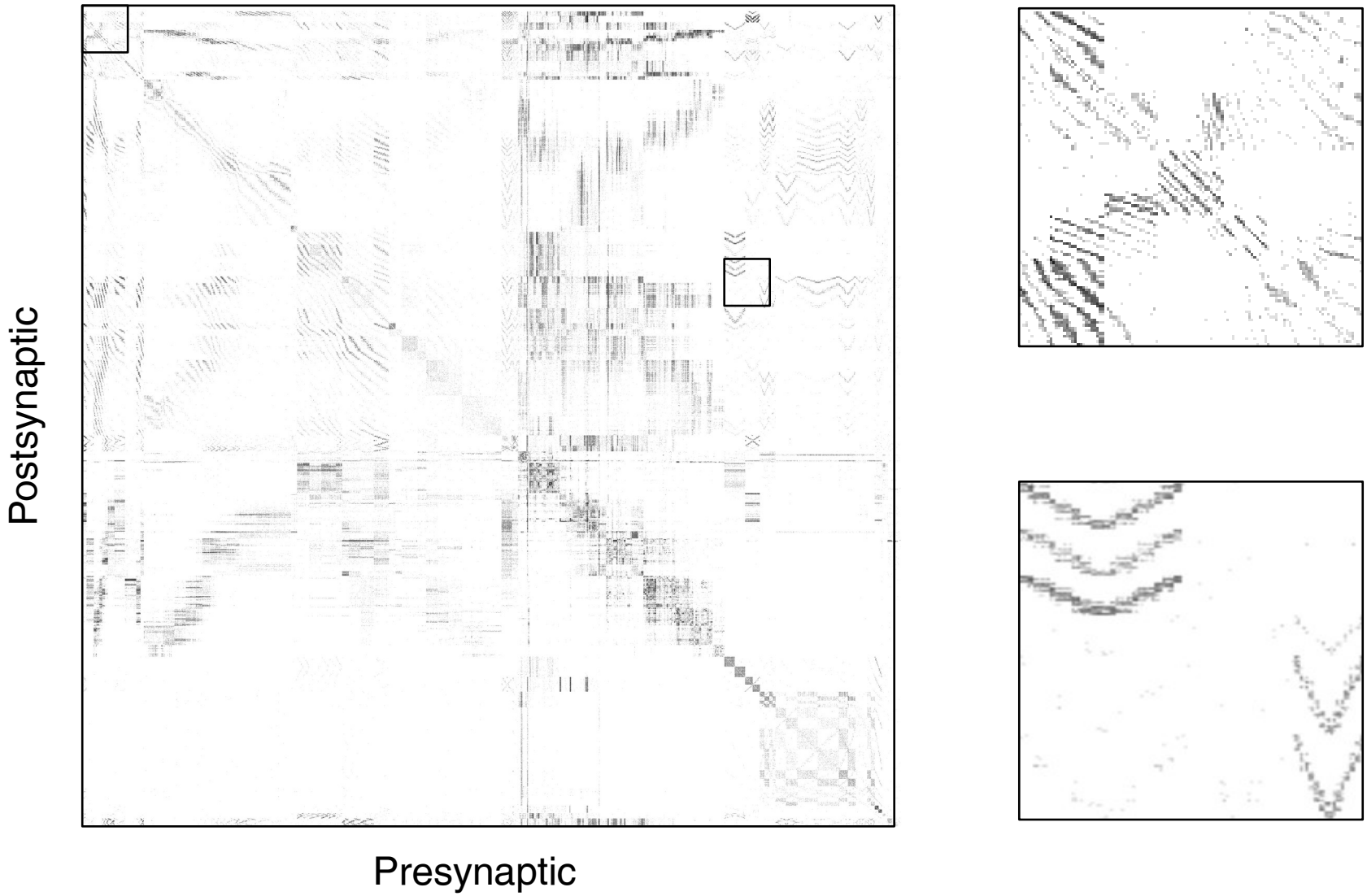
Postsynaptic
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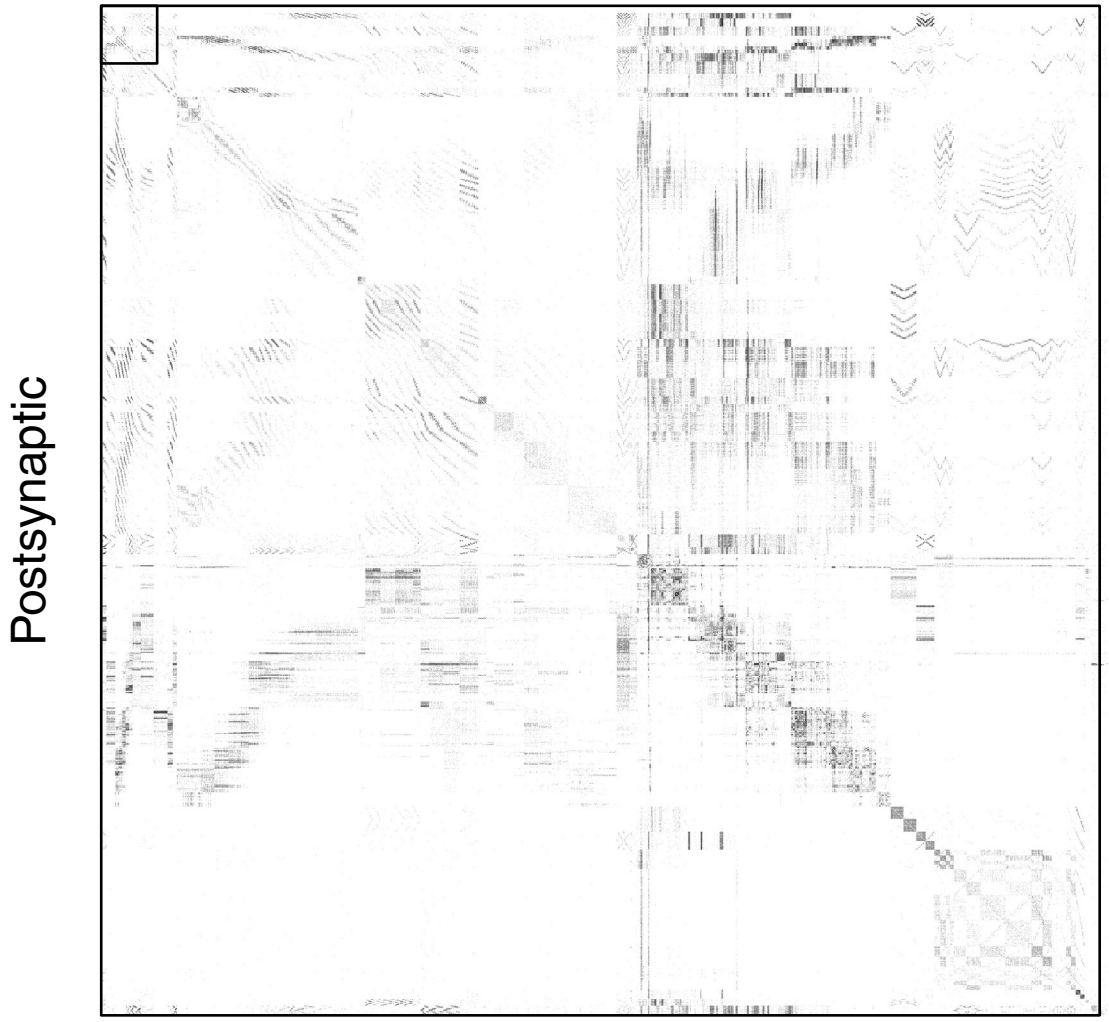
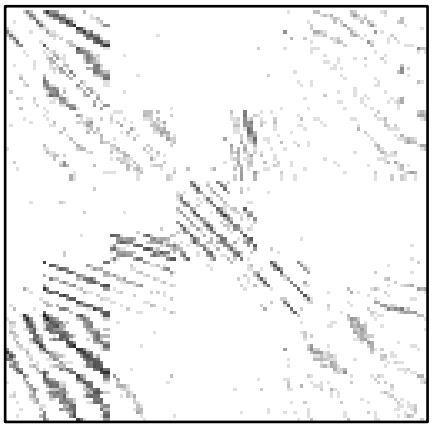
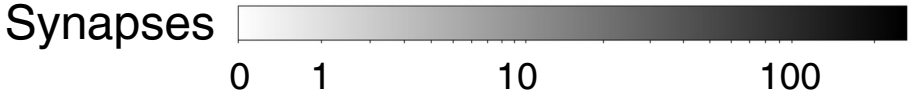
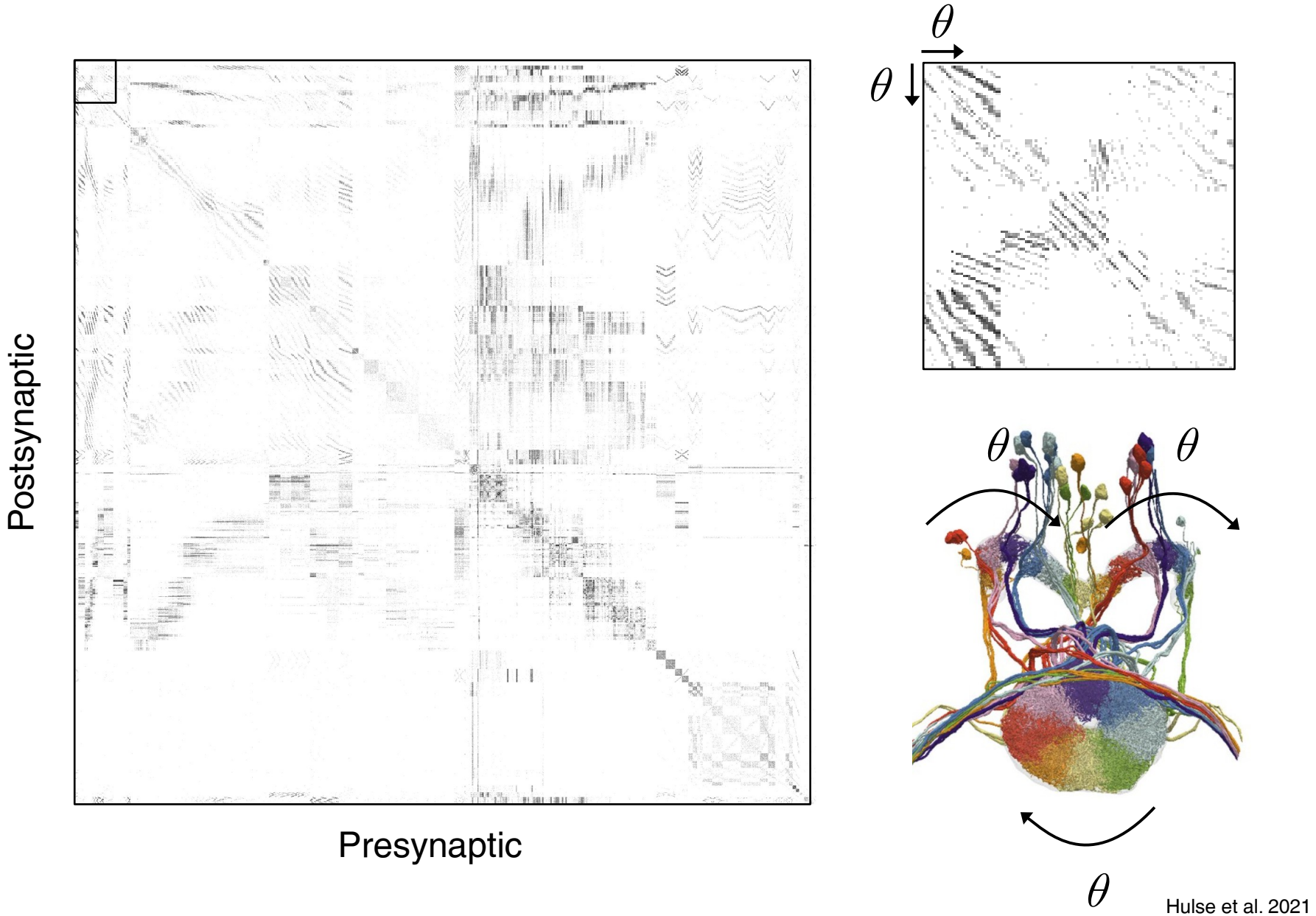


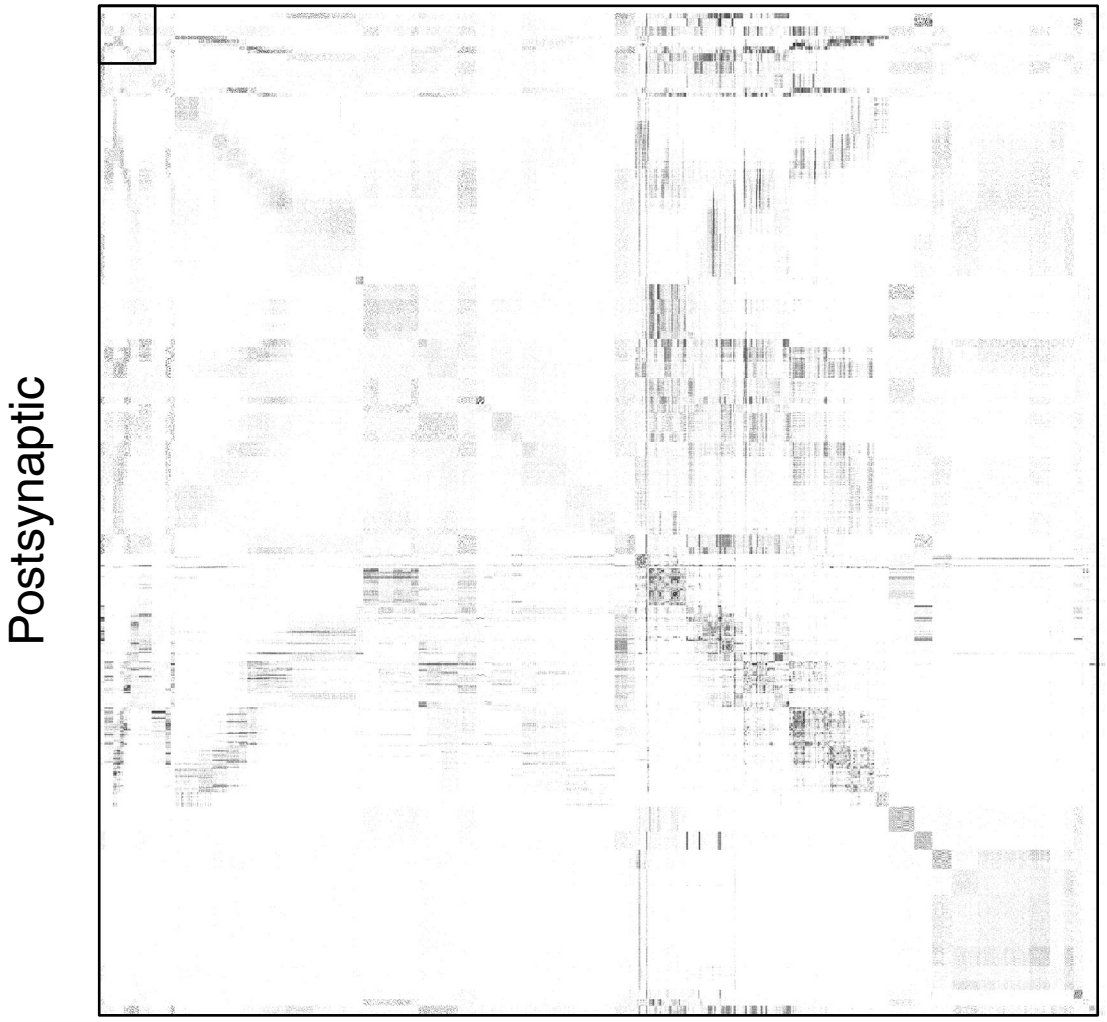


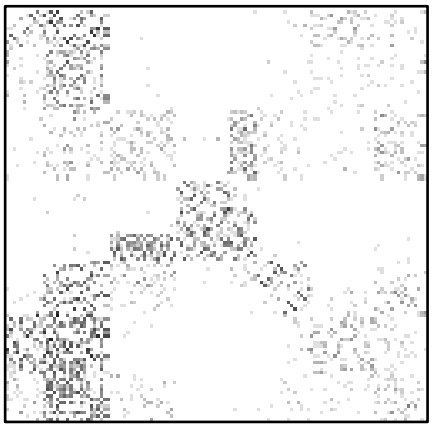


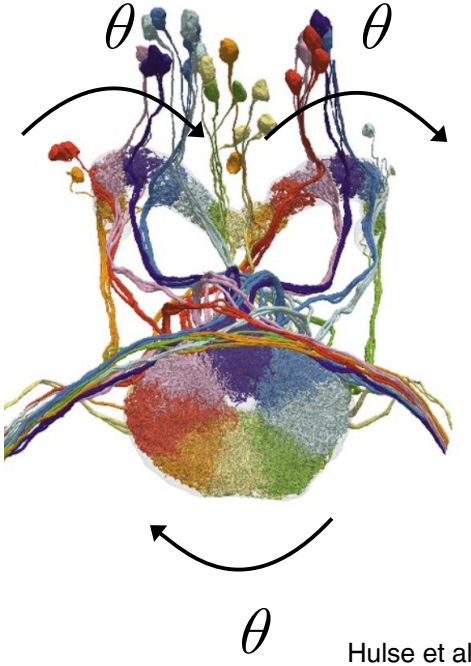
Hulse et al. 2021

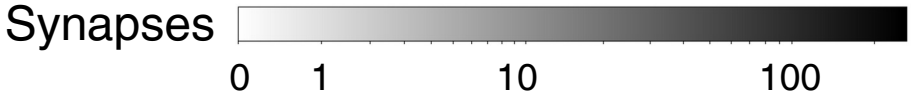


Hulse et al. 2021









Hulse et al. 2021

C. elegans

~300 neurons

1986

`wormwiring.org`

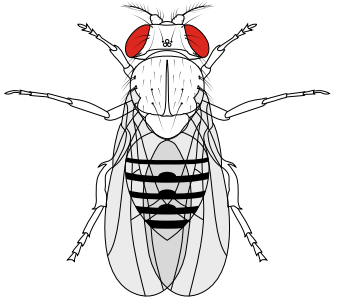
Drosophila larva

~2,000 neurons

2023

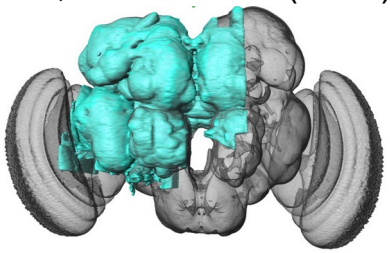
`l1em.catmaid.`
`virtualflybrain.org`

Drosophila adult



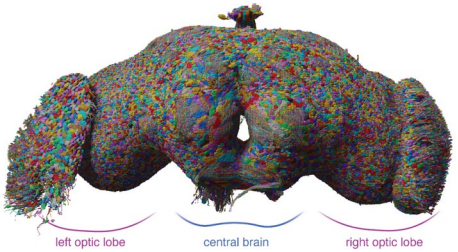
~140,000 neurons

~20,000 neurons (2020)



`neuprint.janelia.org`

~140,000 neurons (2023)



`codex.flywire.ai`

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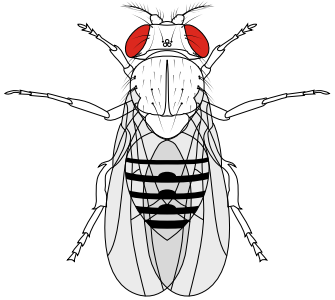

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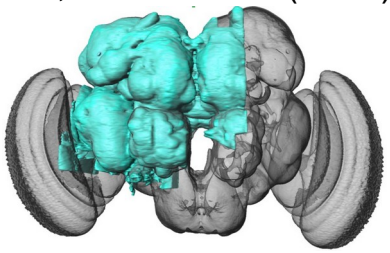
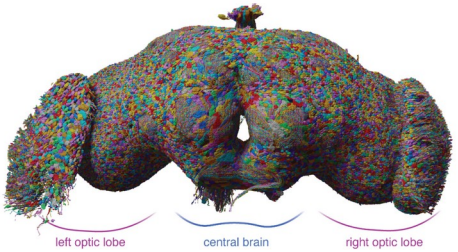


neuprint.janelia.org

~140,000 neurons (2023)

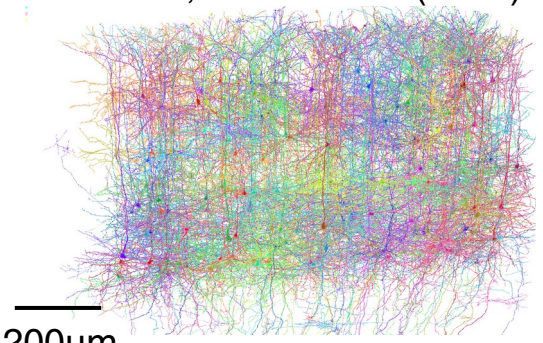


codex.flywire.ai

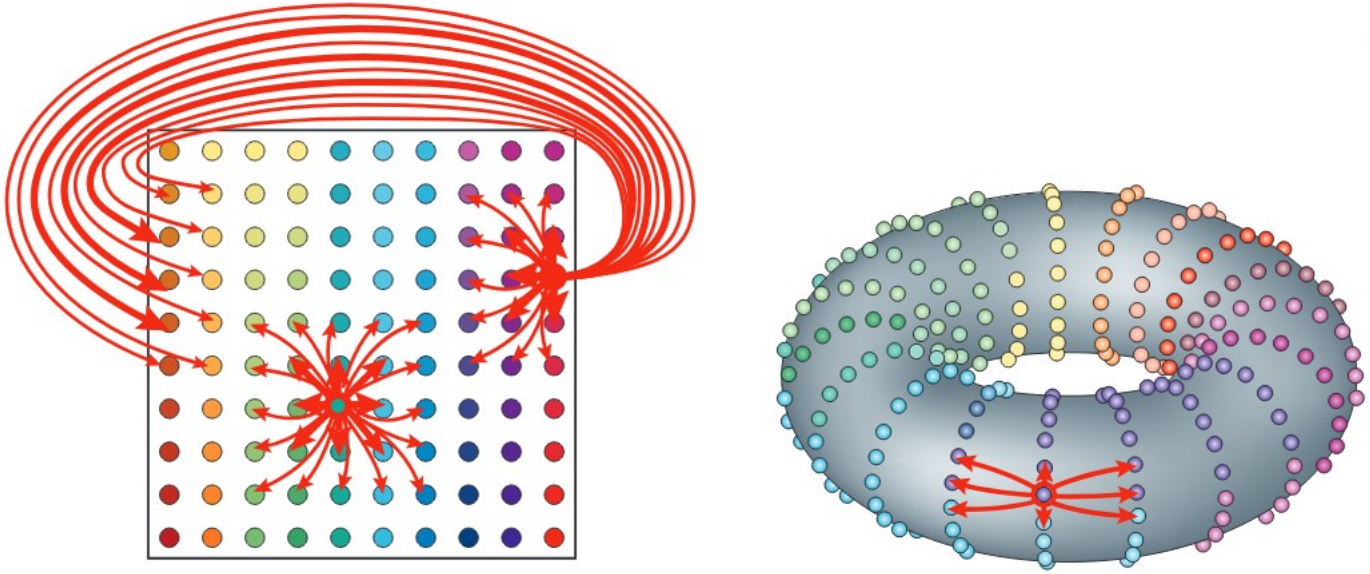
Mouse

~75,000,000 neurons

~200,000 neurons (2021)

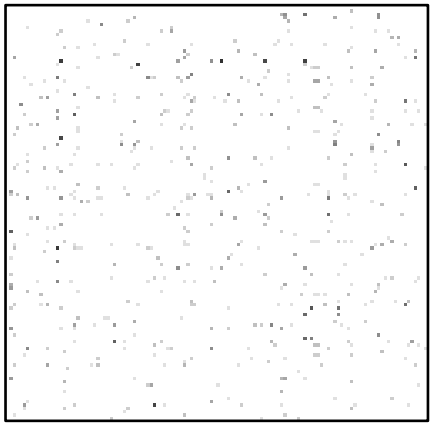


microns-explorer.org

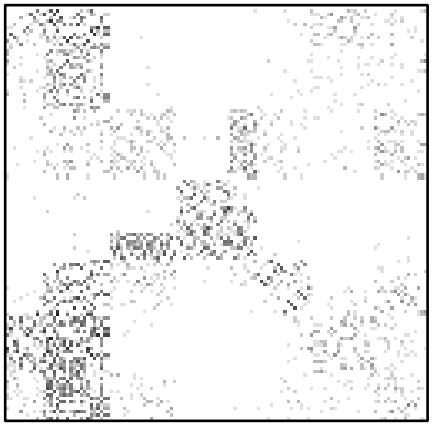


McNaughton et al. 2006

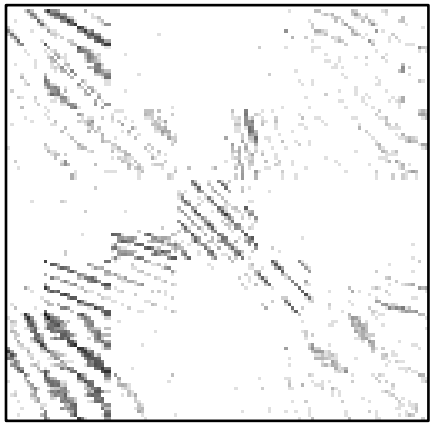
Unsorted



Cell types



Cell types + tuning



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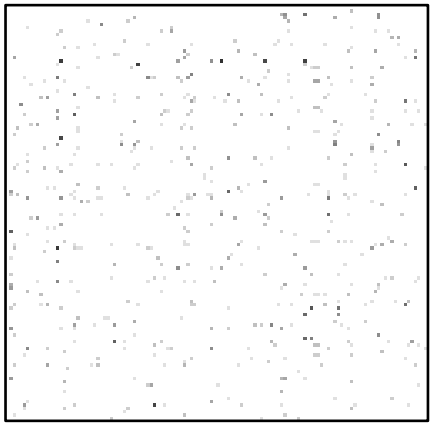
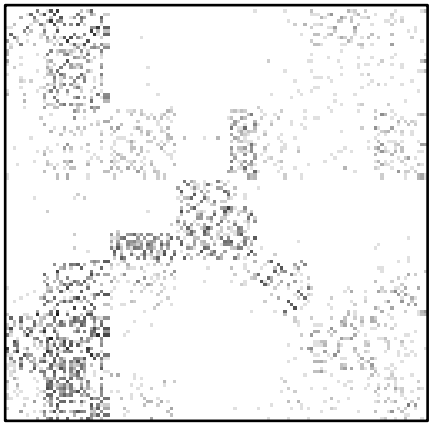
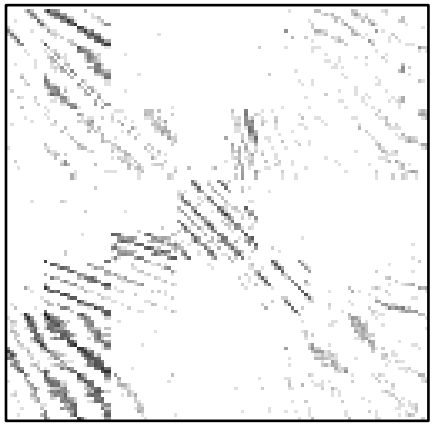
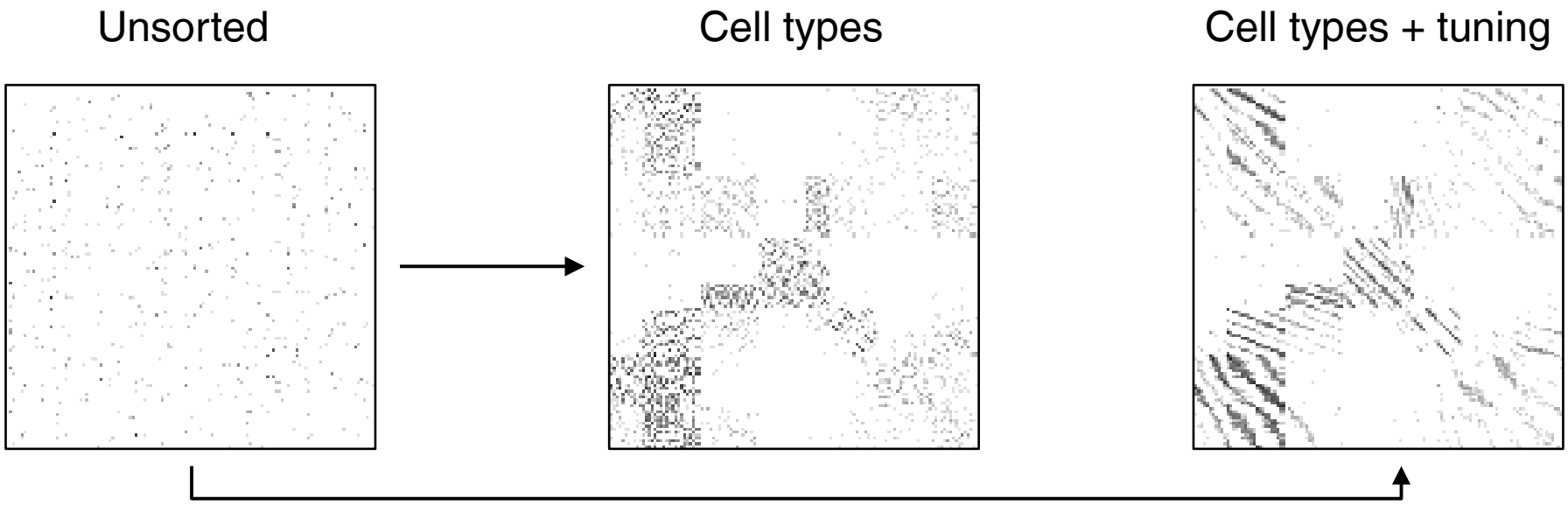


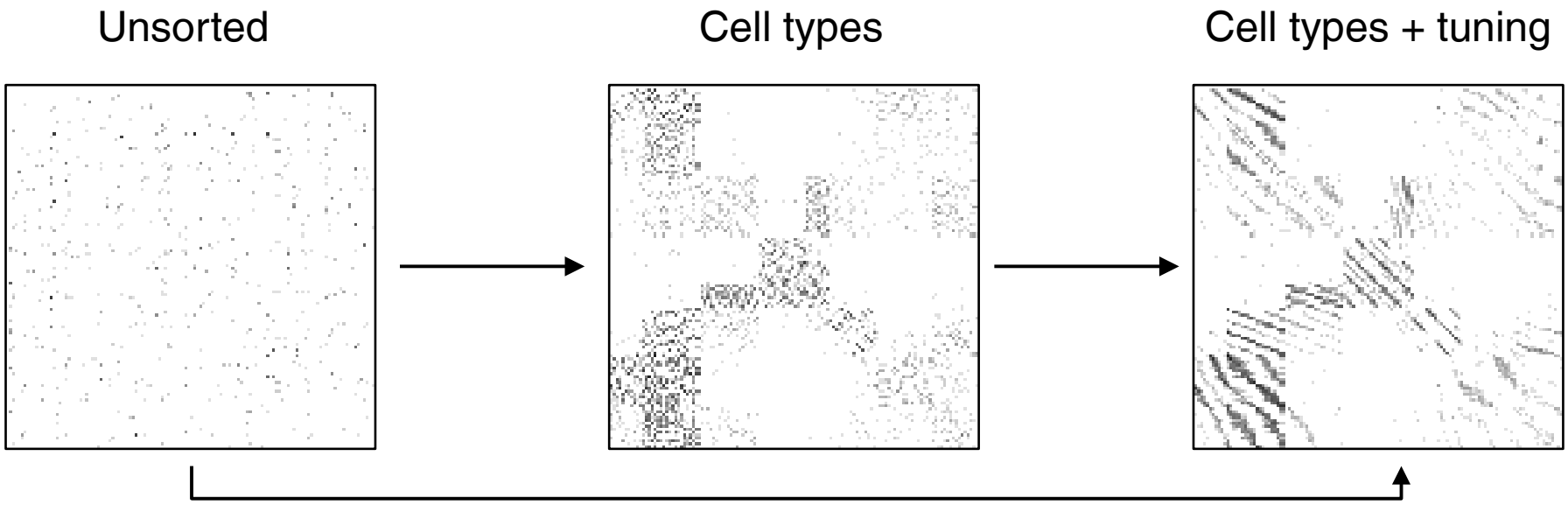
Cell types



Cell types + tuning




Unsorted
Cell types
Cell types + tuning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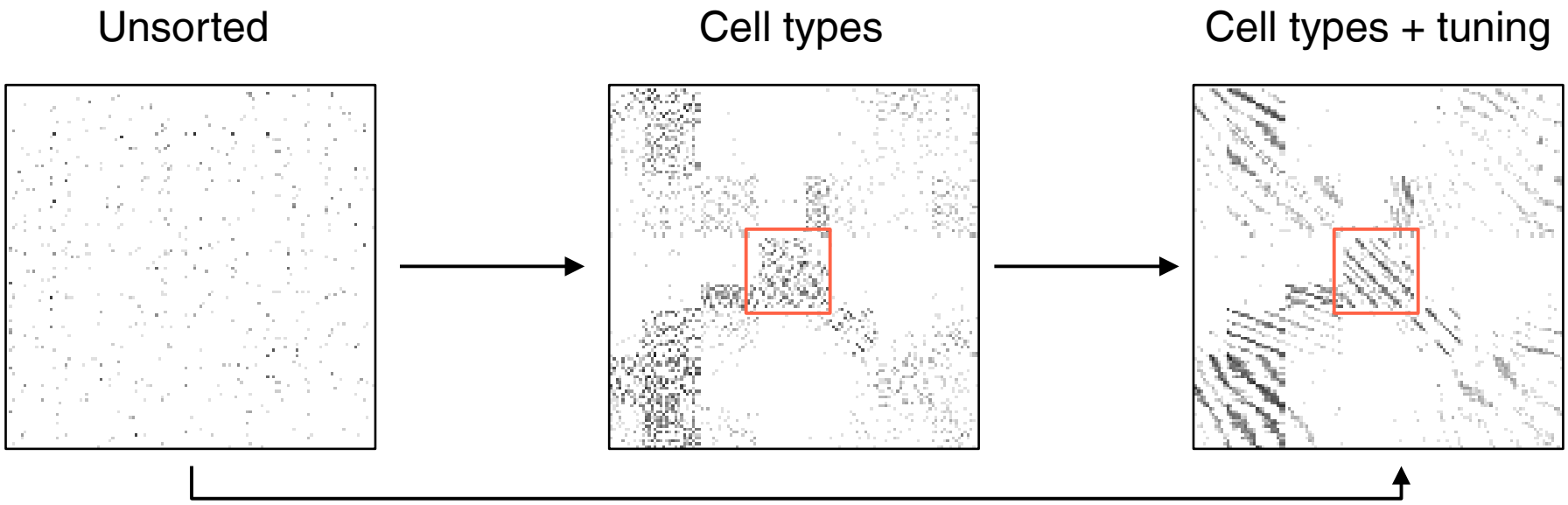
Cell types
Cell types + tuning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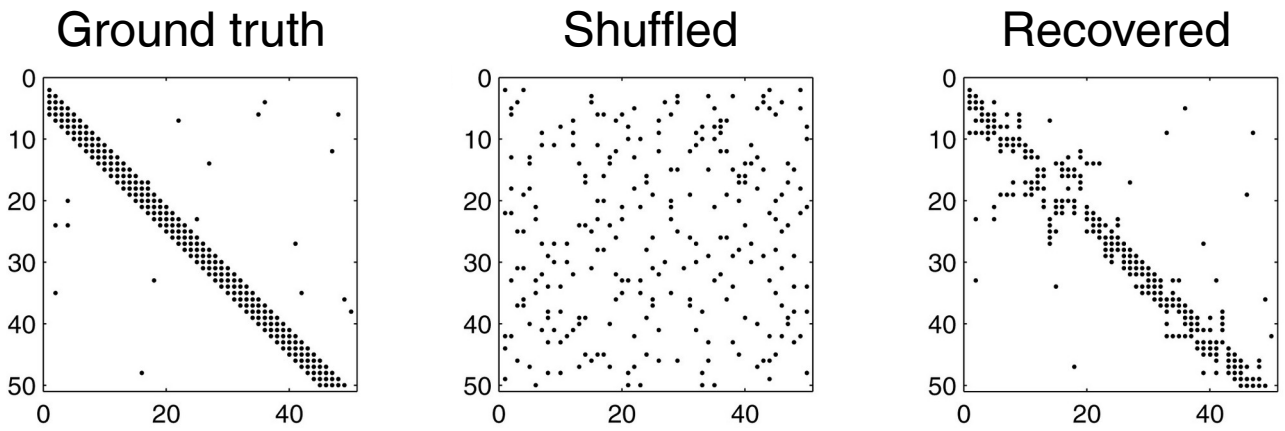
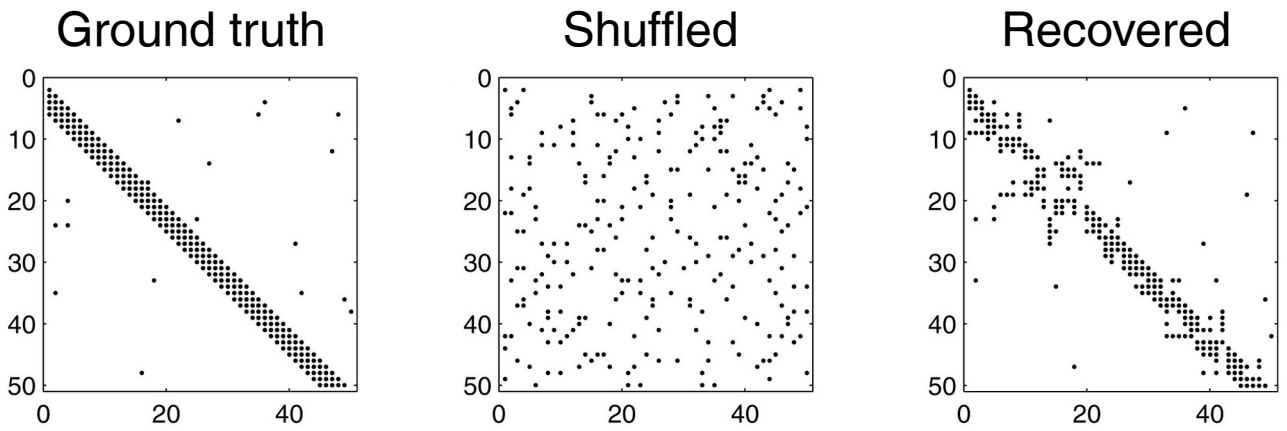
Cell types
Cell types + tuning



Graph layout (Seung 2009)



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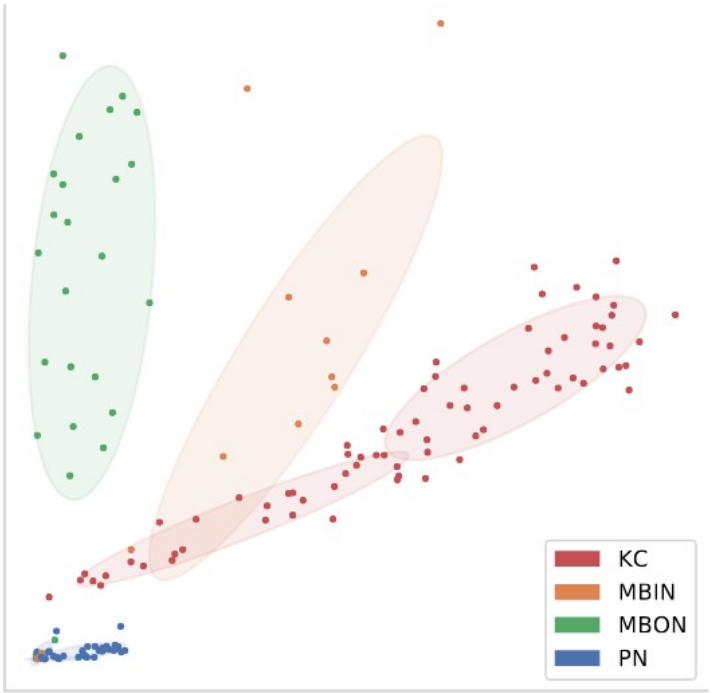
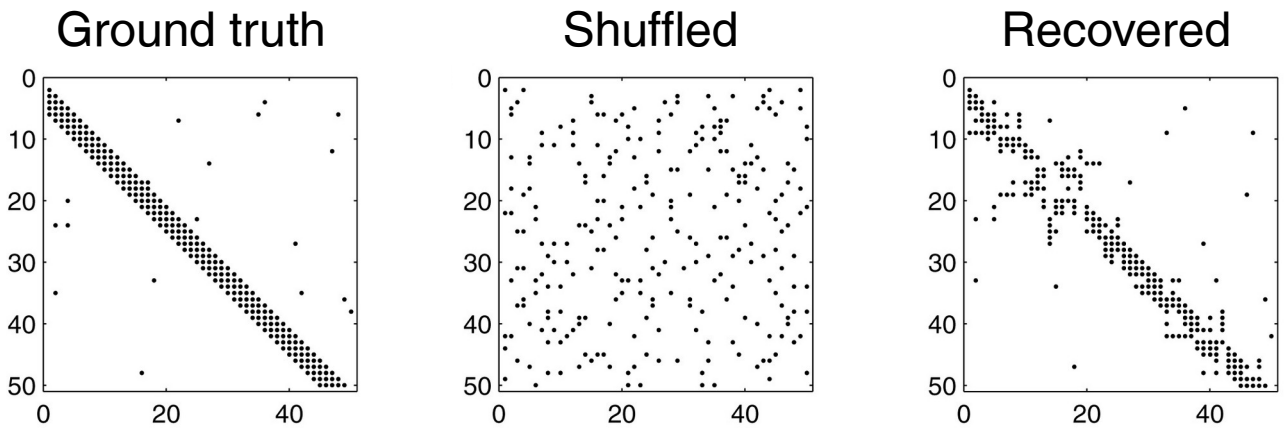


Random dot product graphs (Priebe, Vogelstein, et al.)



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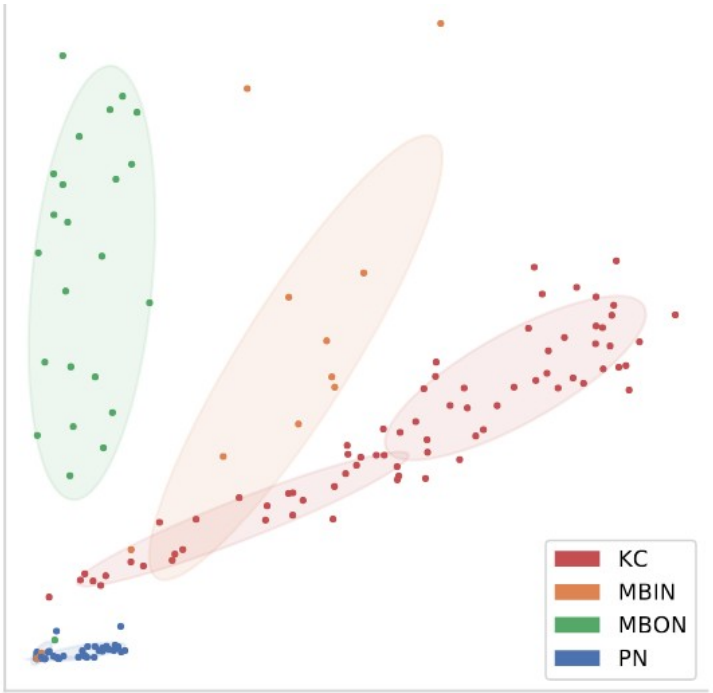

Richter, Schneidman
Poster 3-007

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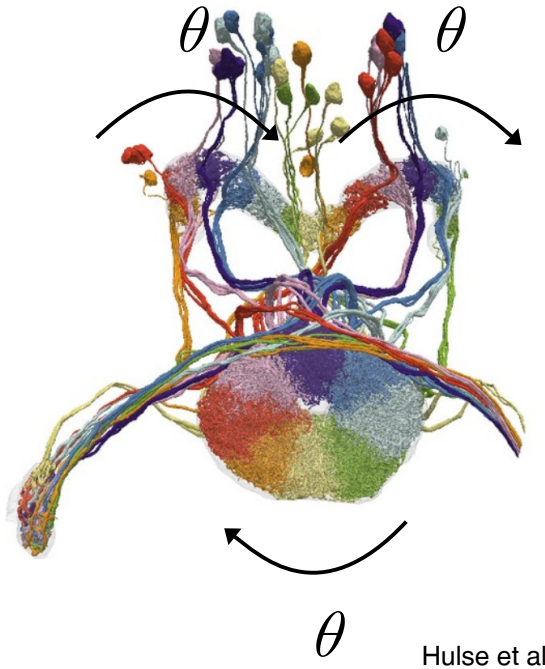
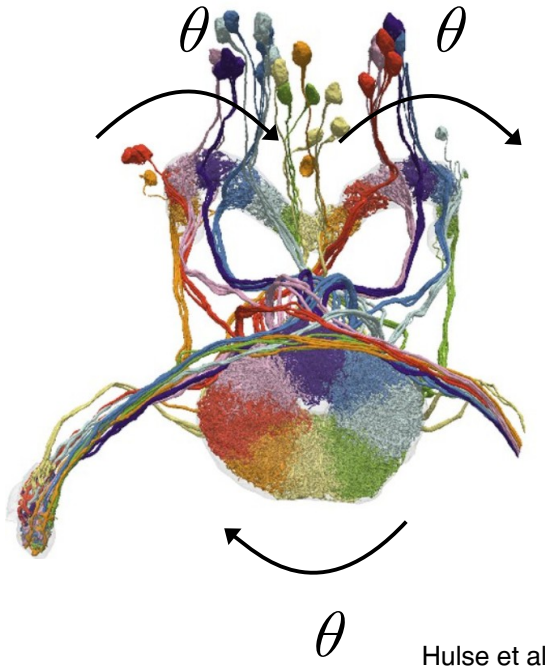


Hulse et al. 2021



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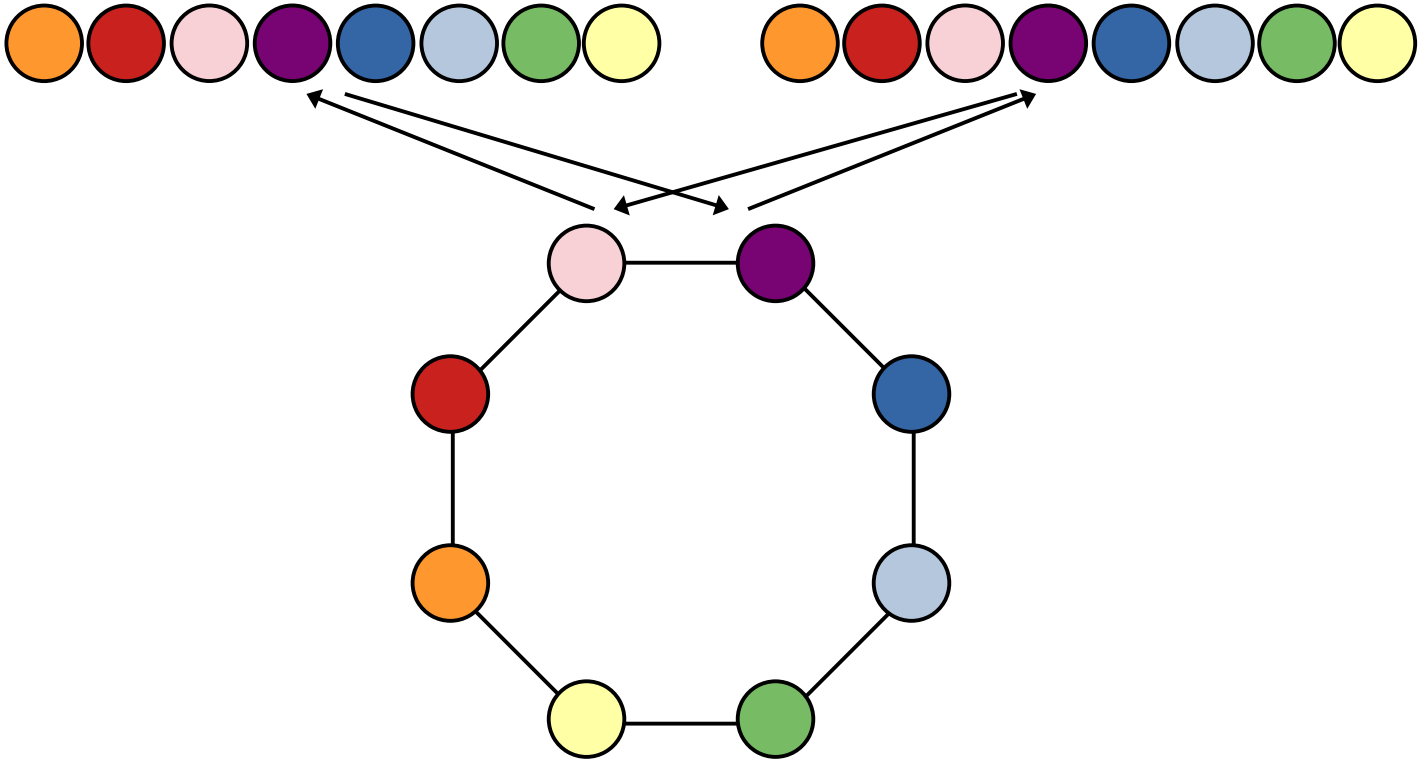

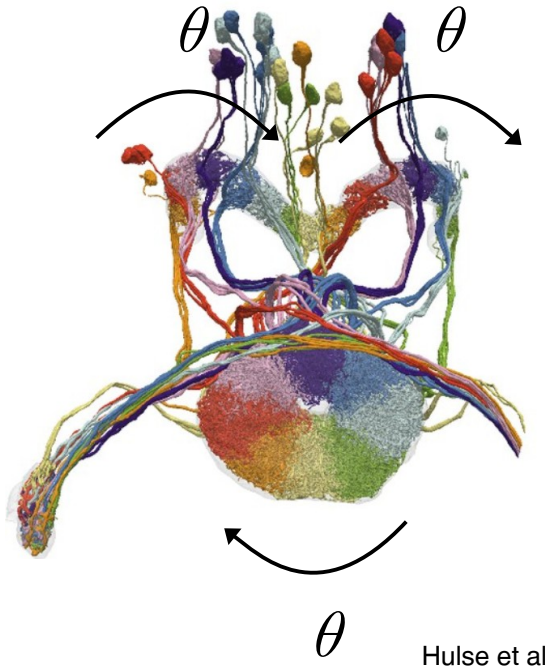

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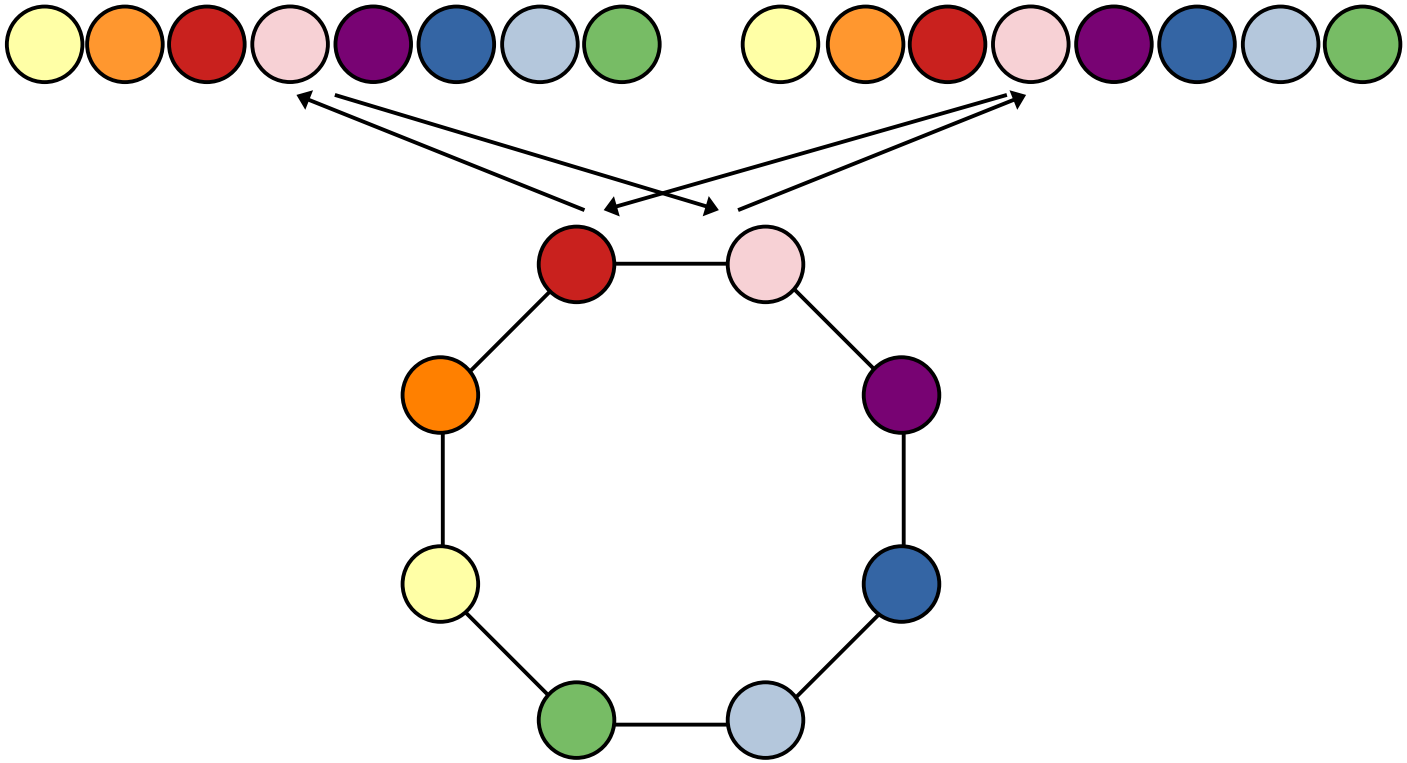
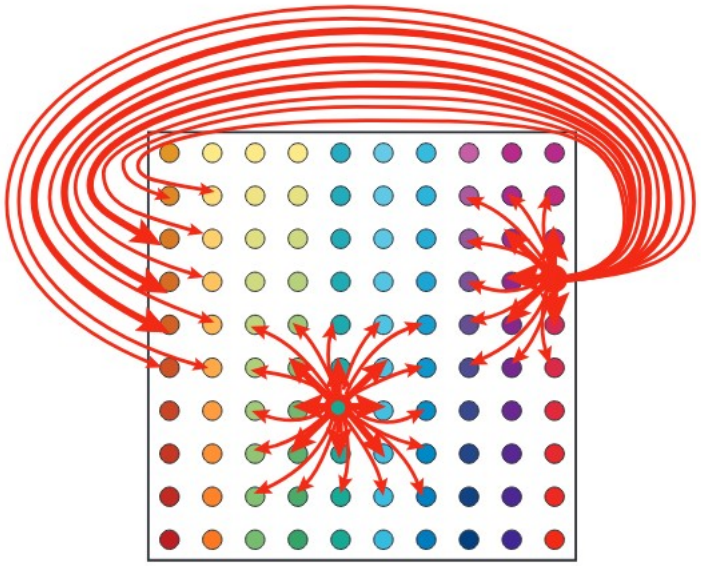
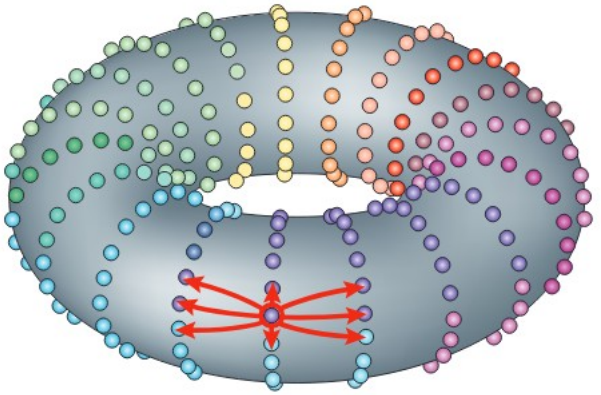
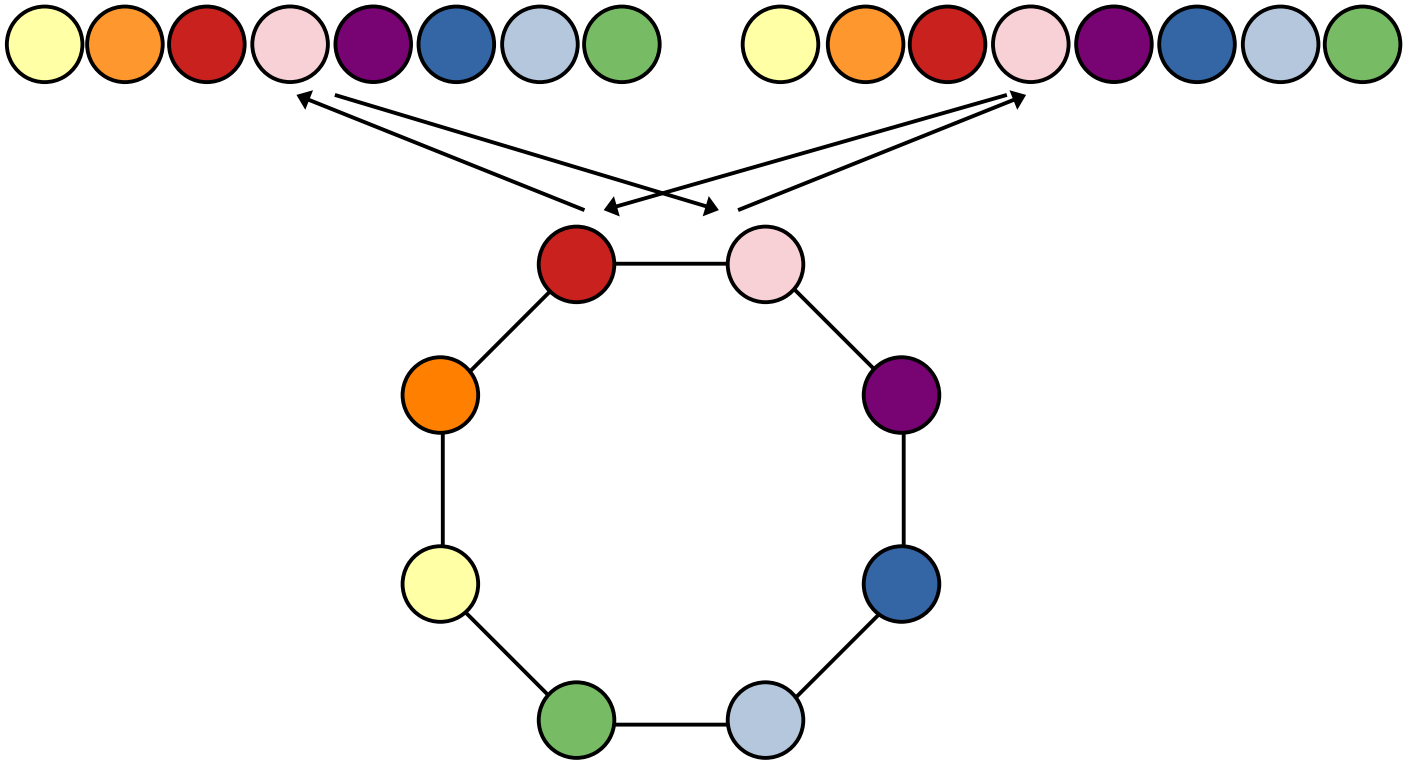
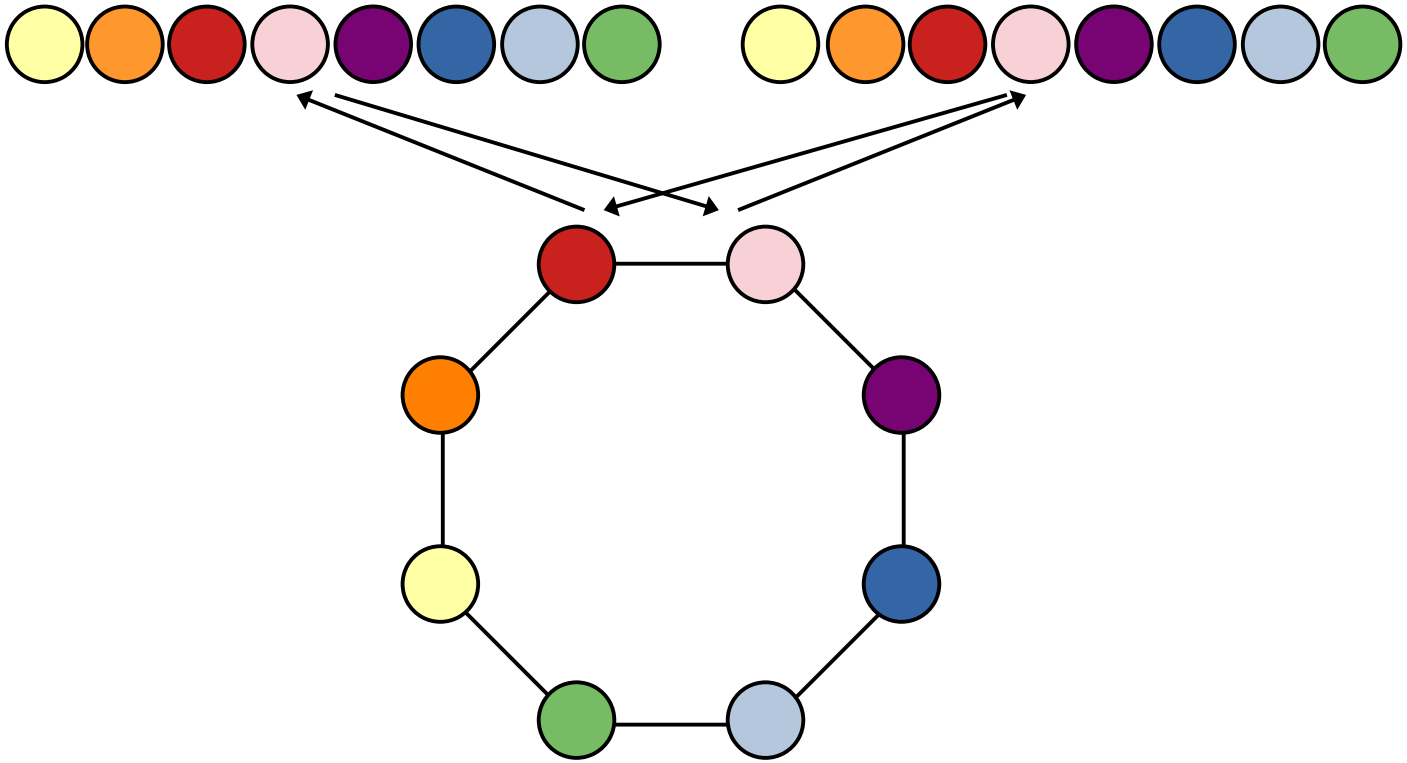




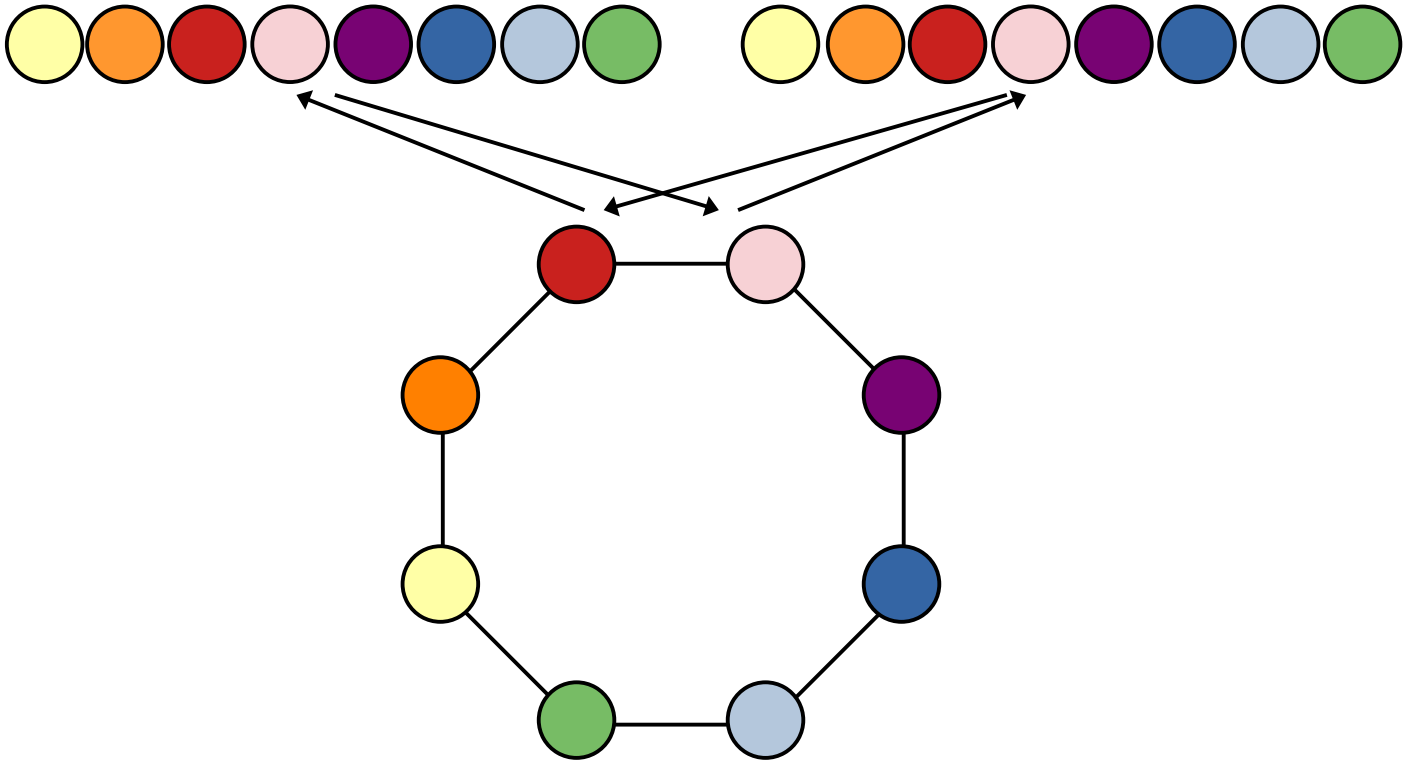


McNaughton et al. 2006



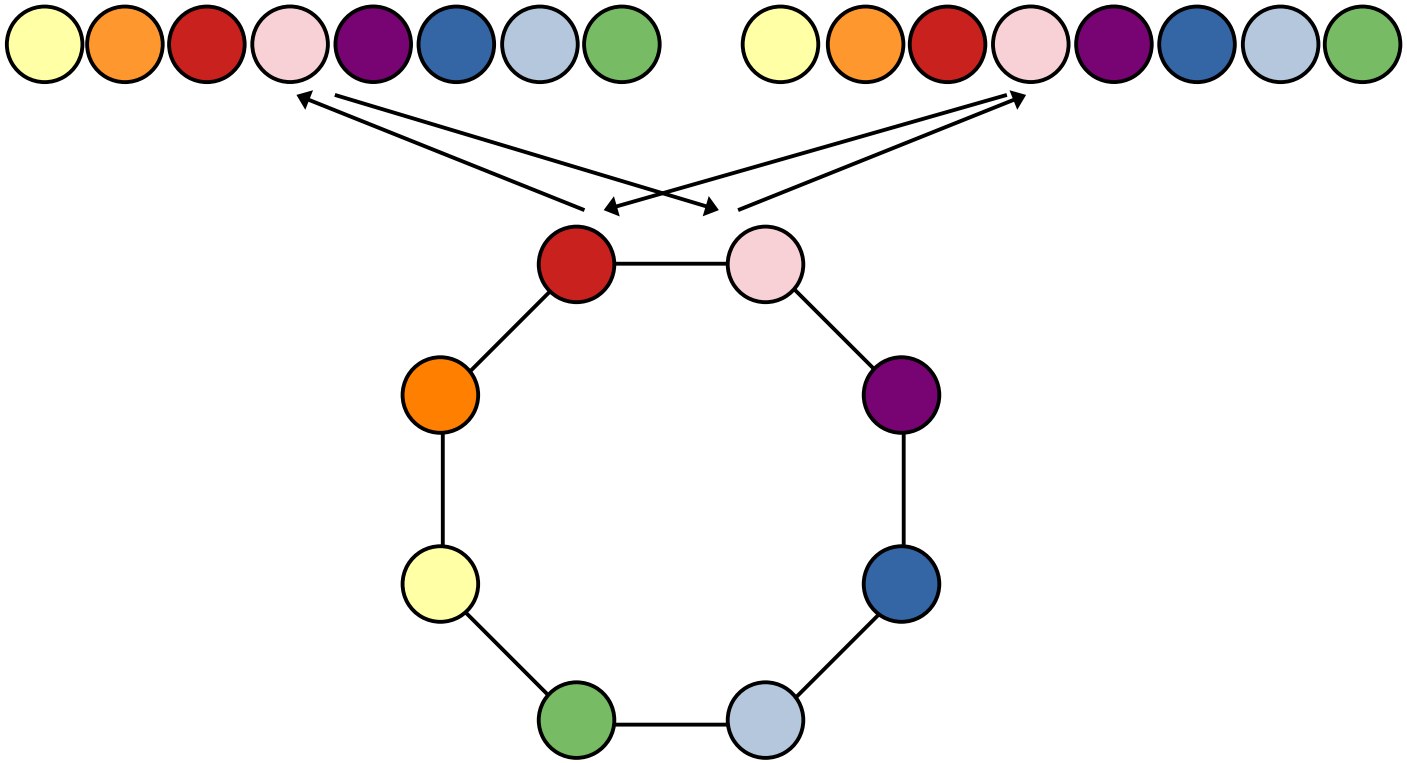


Graph automorphism:



Graph automorphism:

NP-intermediate?



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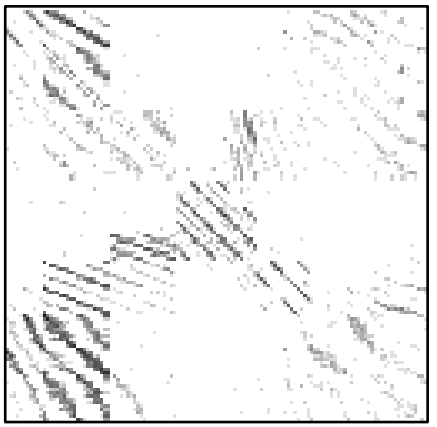
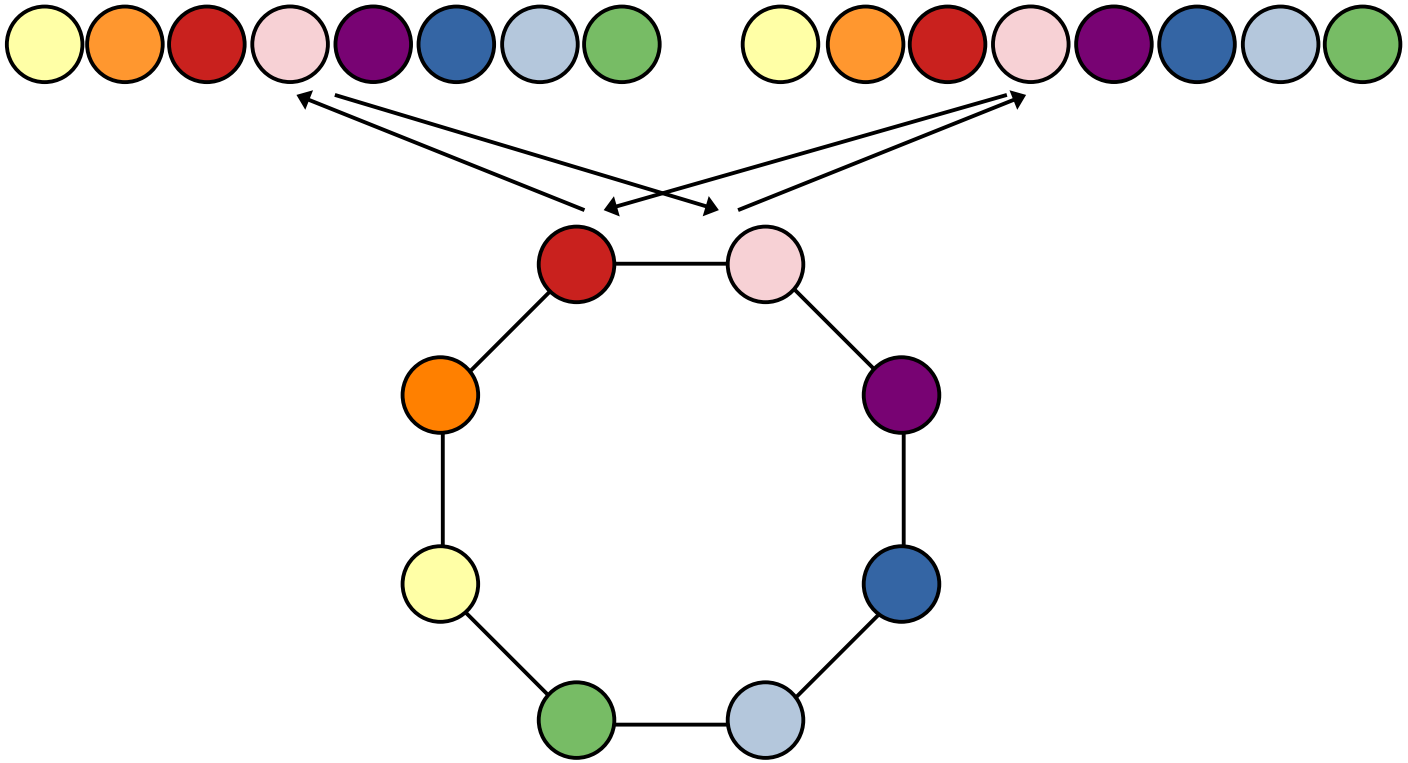
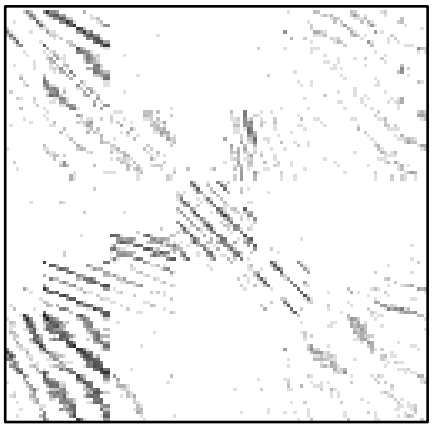


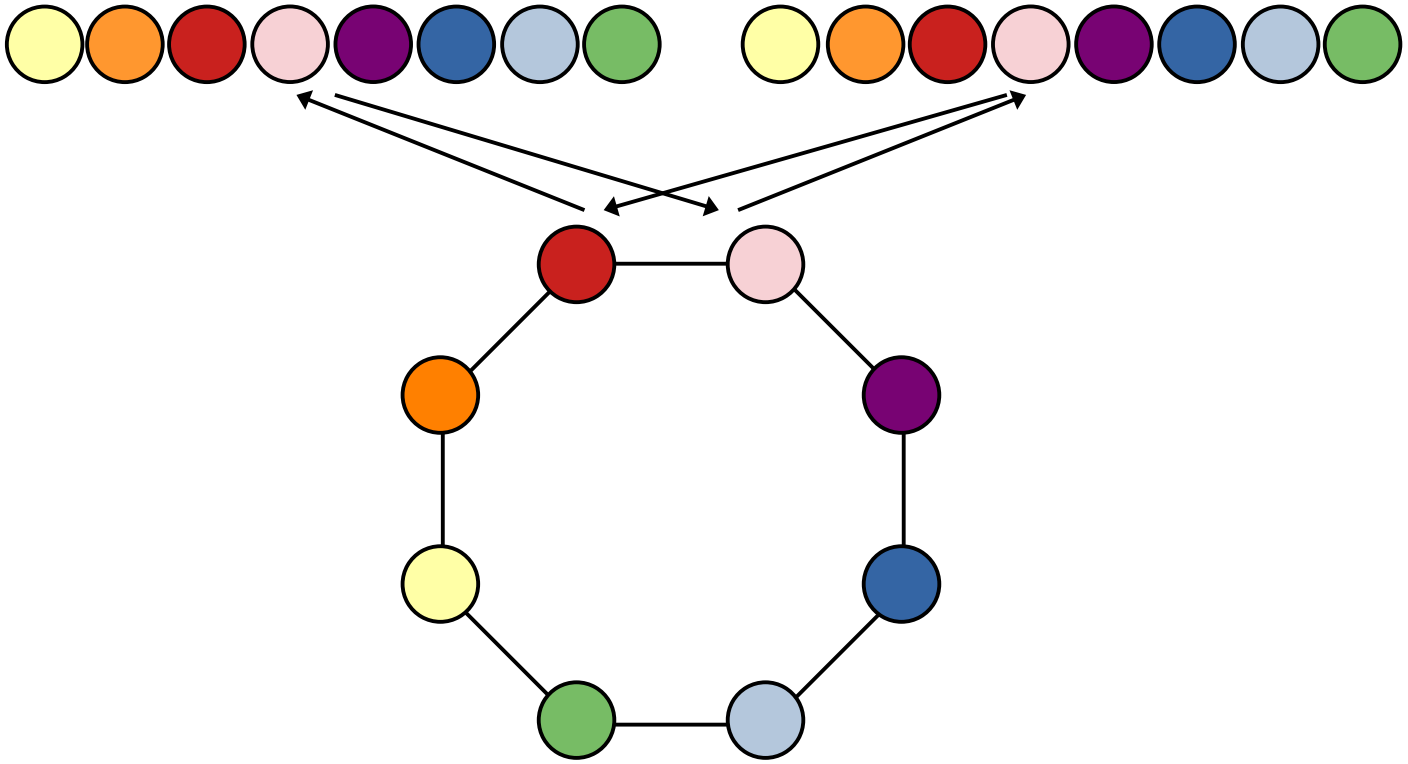


Graph automorphism:

NP-intermediate?

“Approximate automorphism?”





$$W_{ij} \approx \mathbf{z}_i \cdot \mathbf{z}_j$$

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$$\mathbf{z} \in \mathbb{R}^D$$

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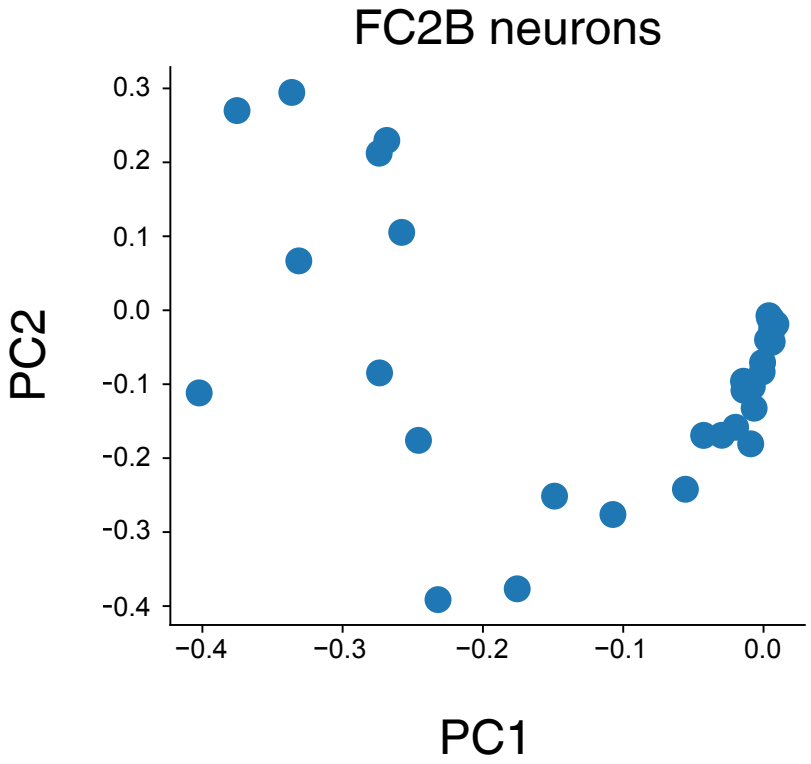

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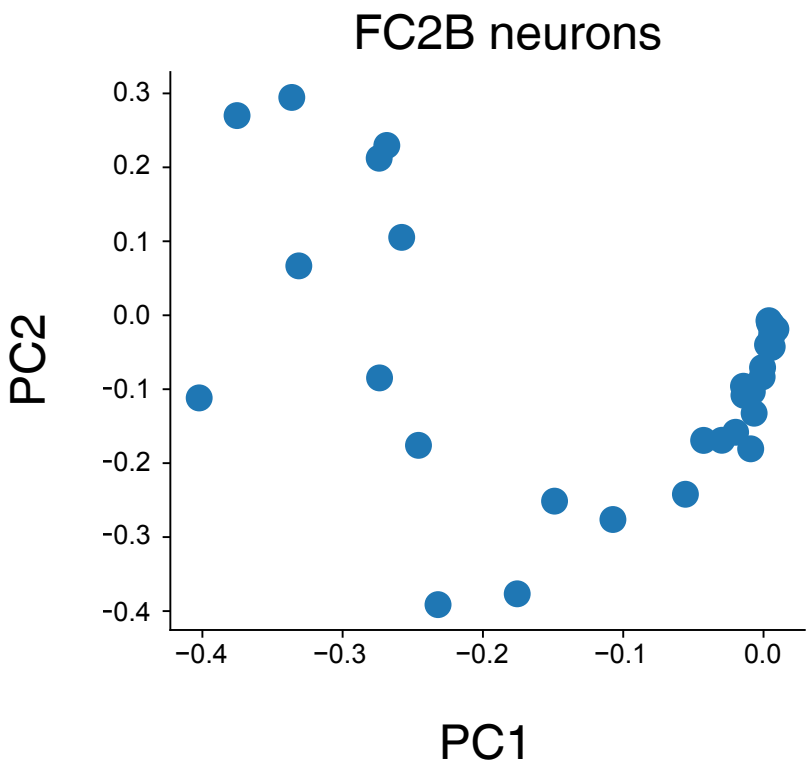
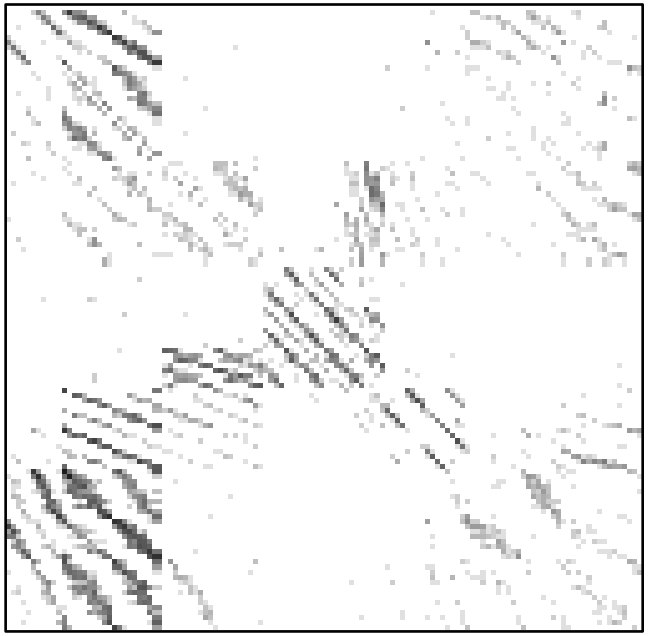
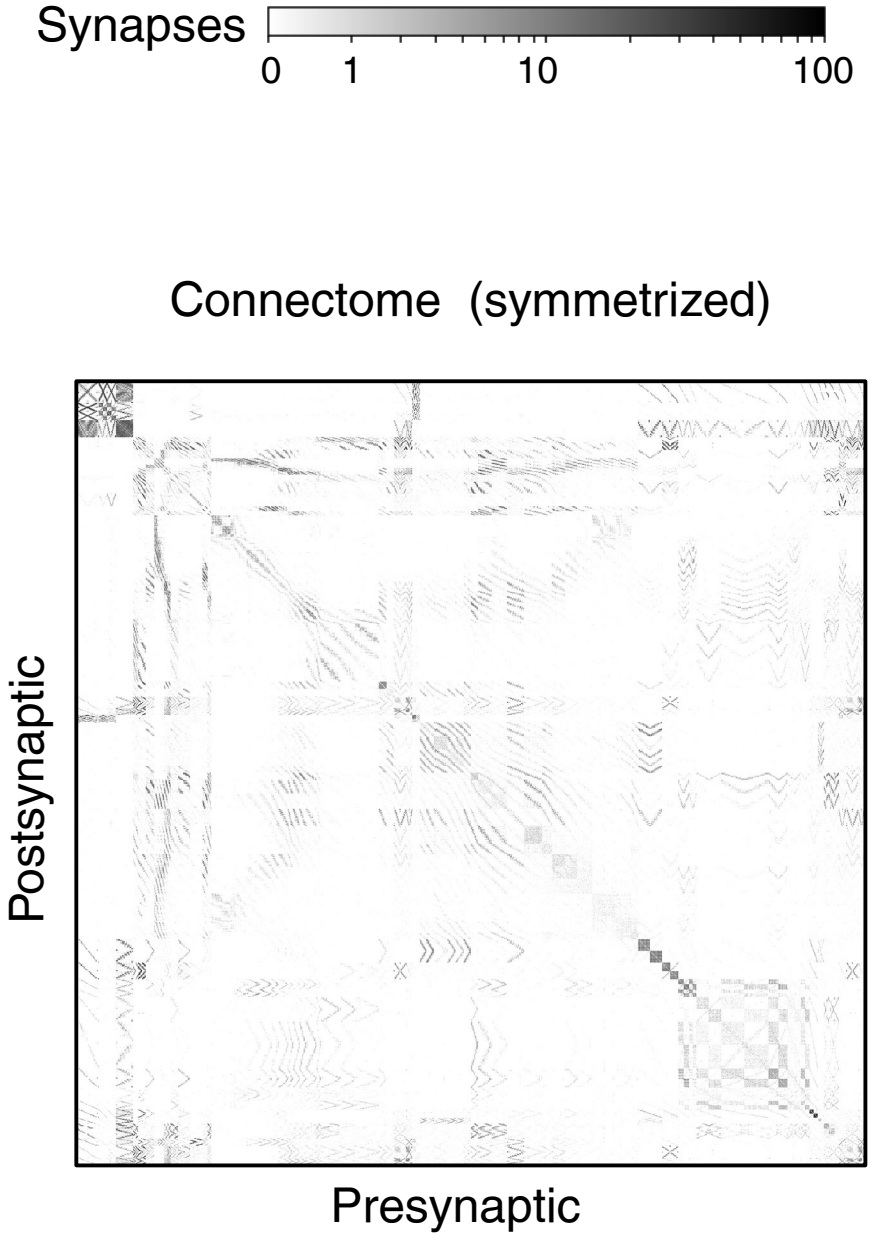
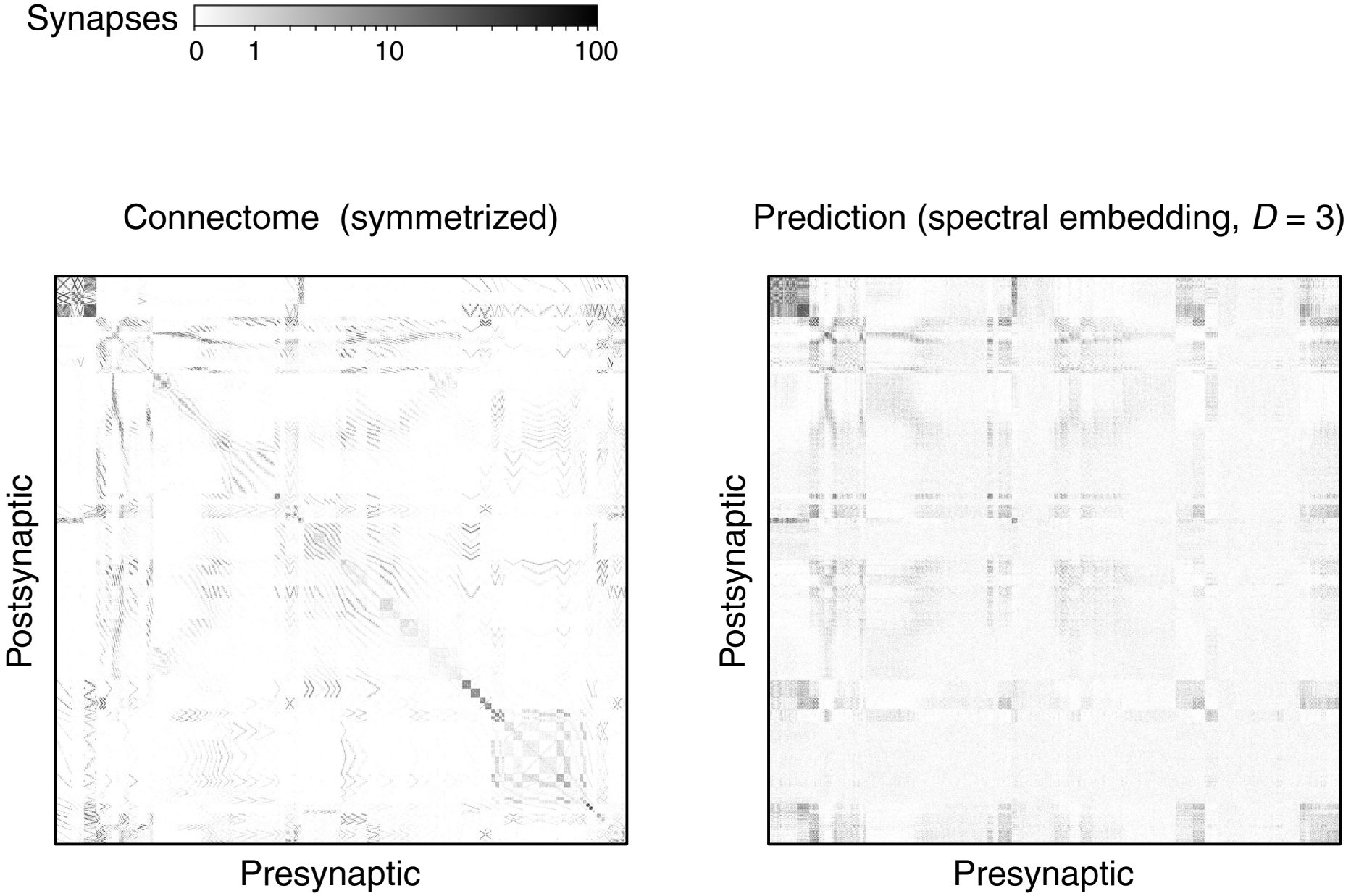
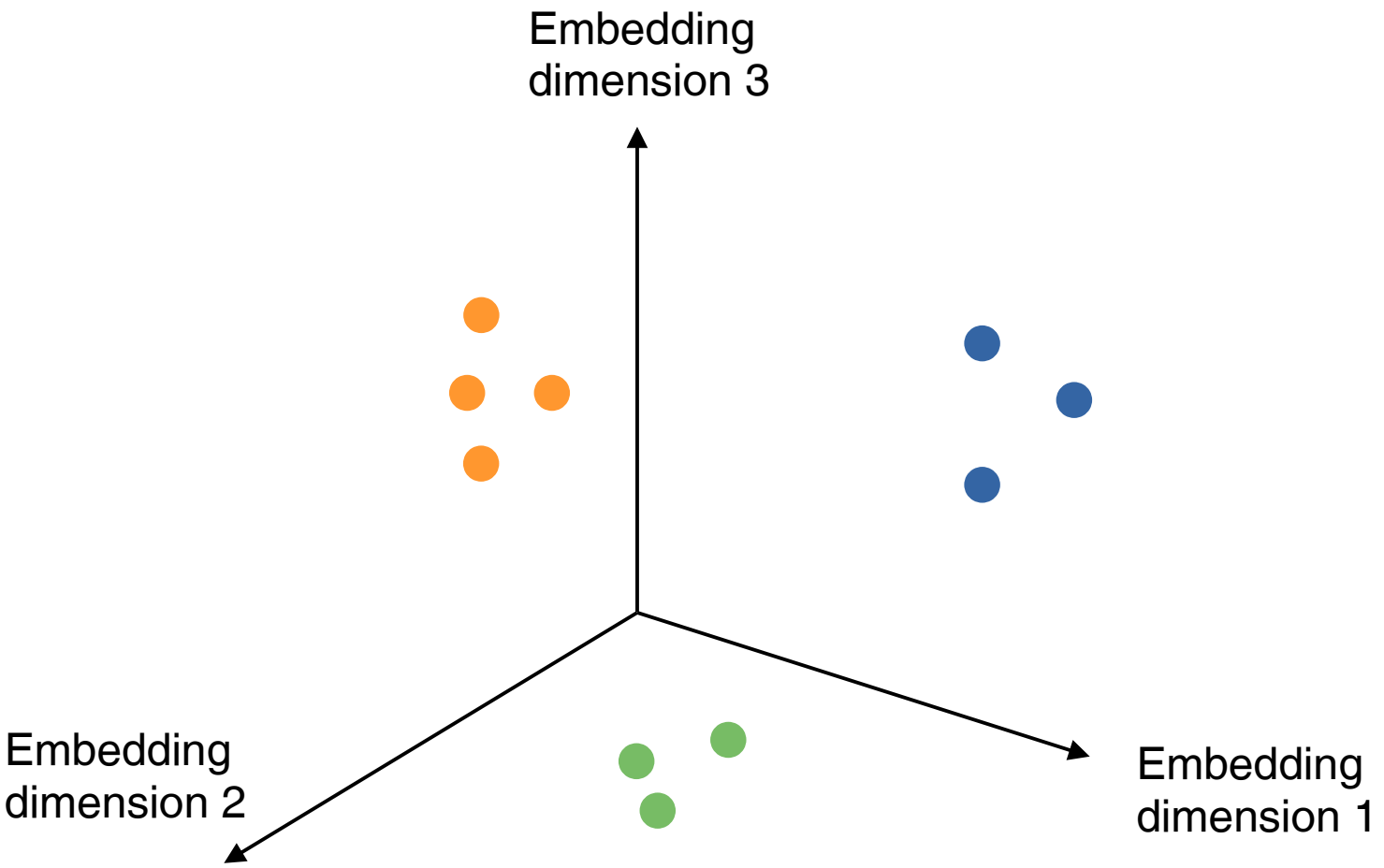
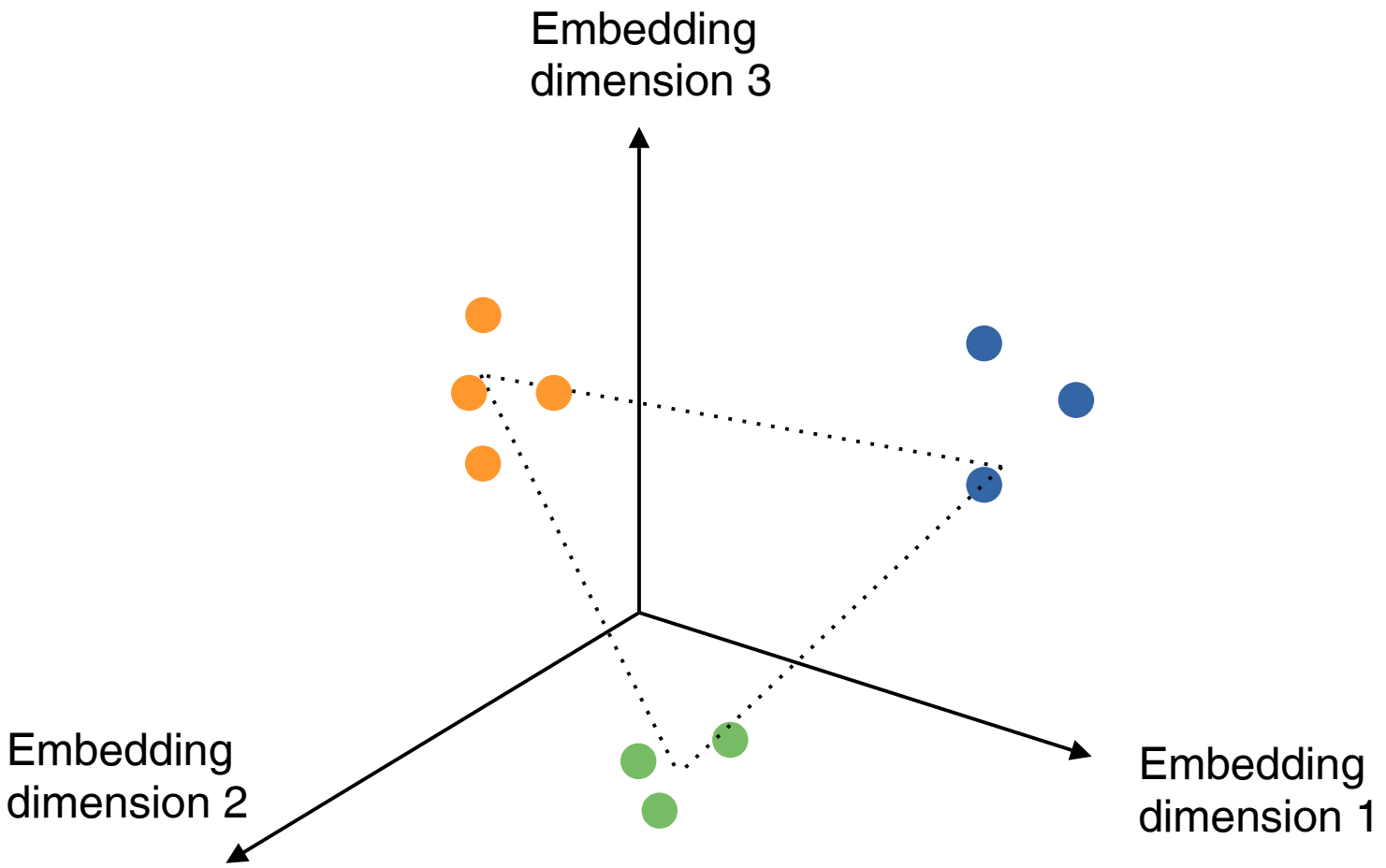


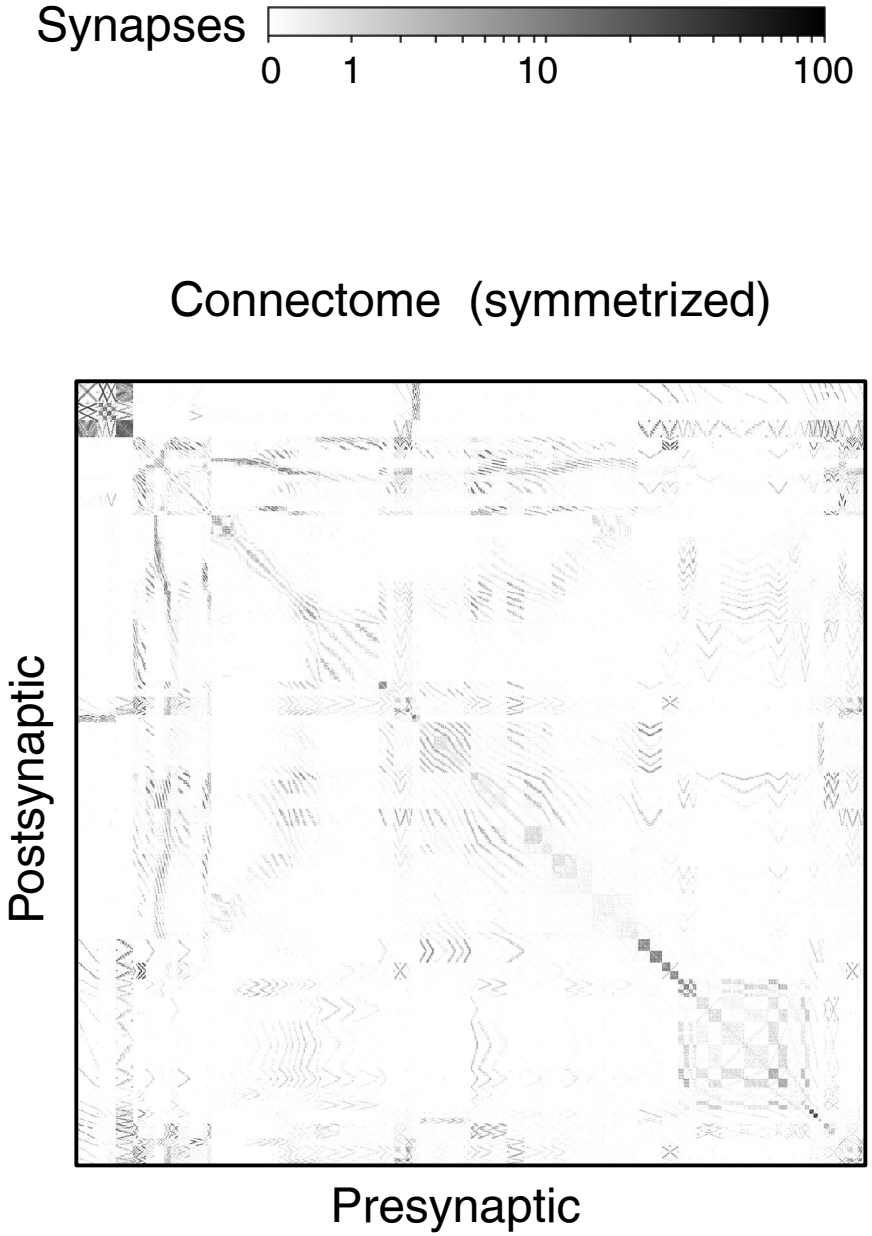


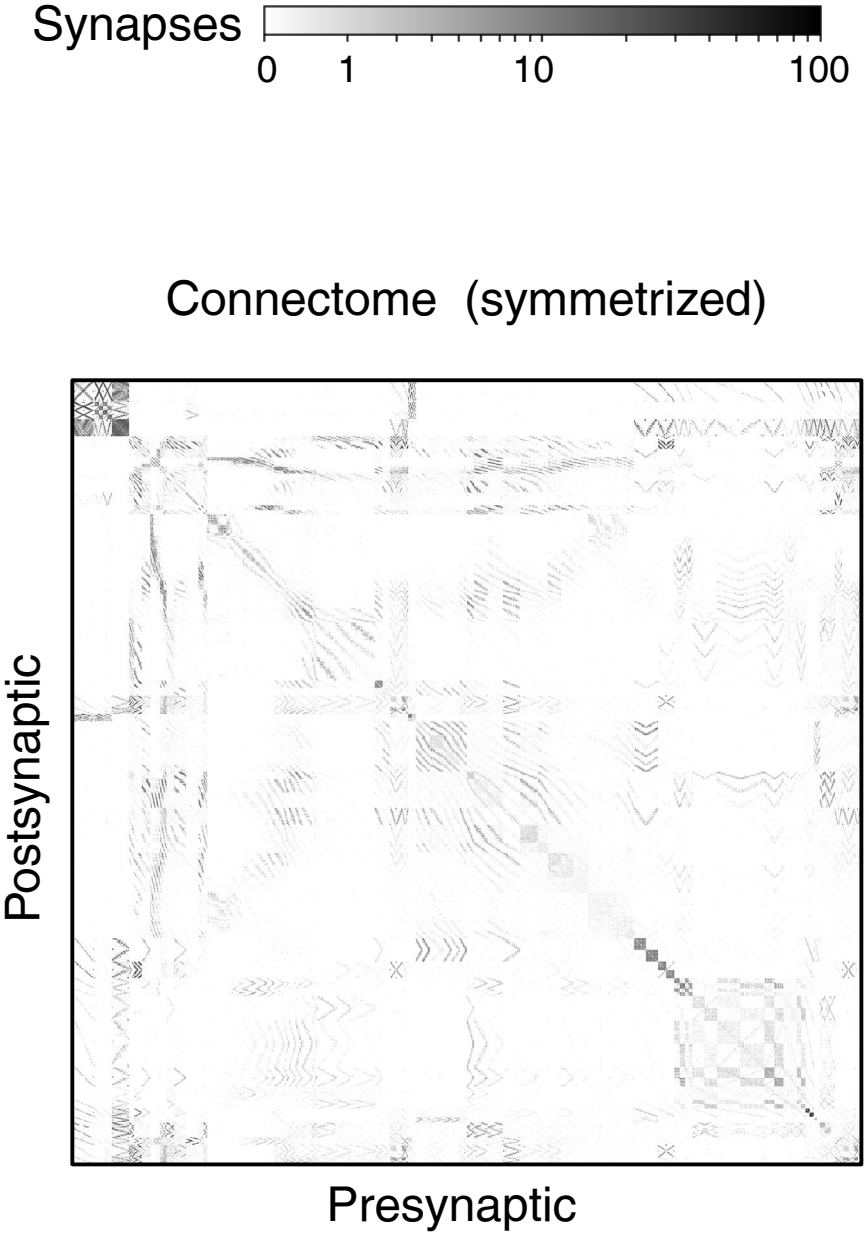

Synapses
0
1
10
100
Connectome (symmetrized)
Postsynaptic
Presynaptic


Synapses
0
1
10
100
Connectome (symmetrized)
Postsynaptic
Presynaptic
Prediction (spectral embedding, D = 3)
Postsynaptic
Presynaptic

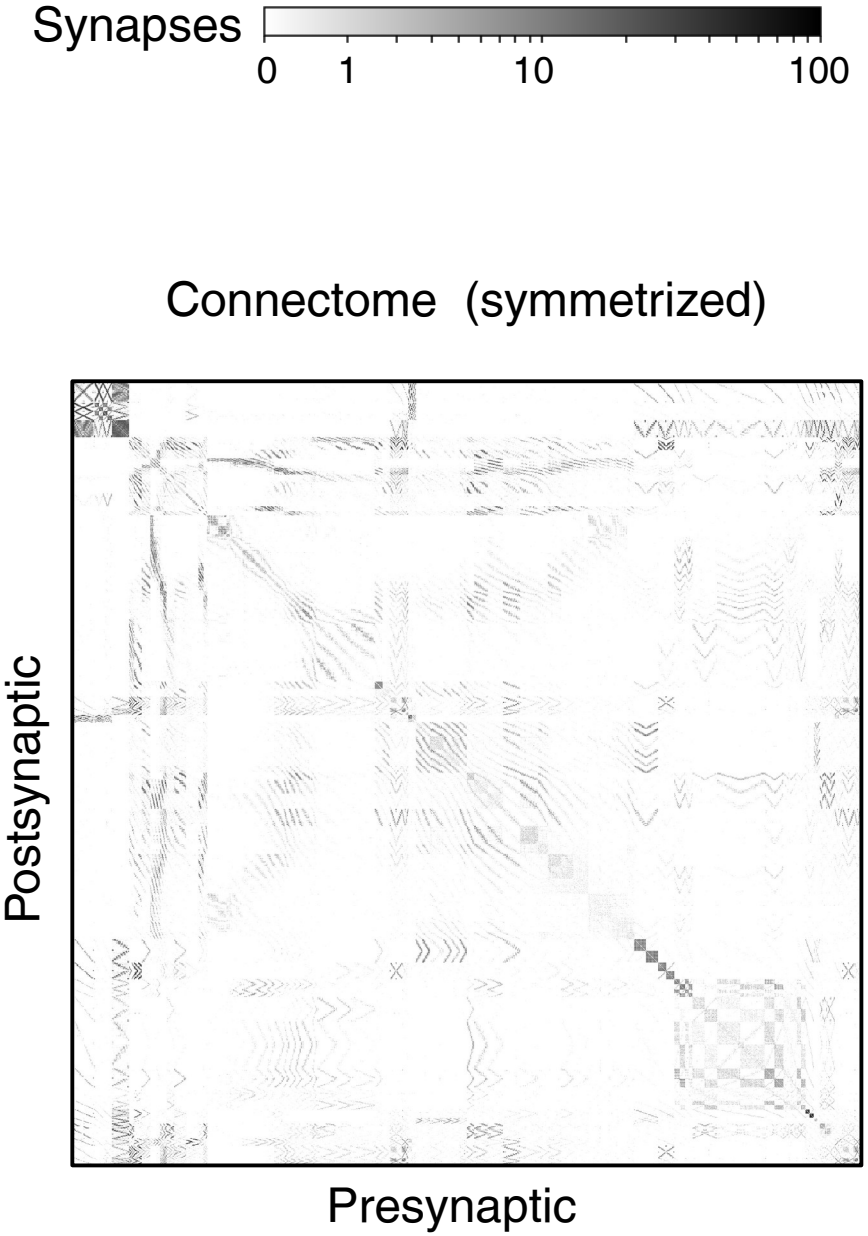

Embedding
dimension 3
Embedding
dimension 2
Embedding
dimension 1


Embedding
dimension 3
Embedding
dimension 2
Embedding
dimension 1


Synapses
0
1
10
100
Connectome (symmetrized)
Postsynaptic
Presynaptic

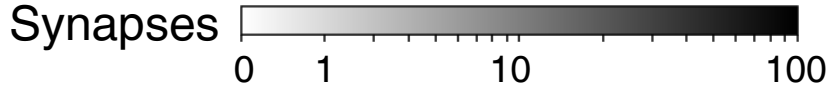


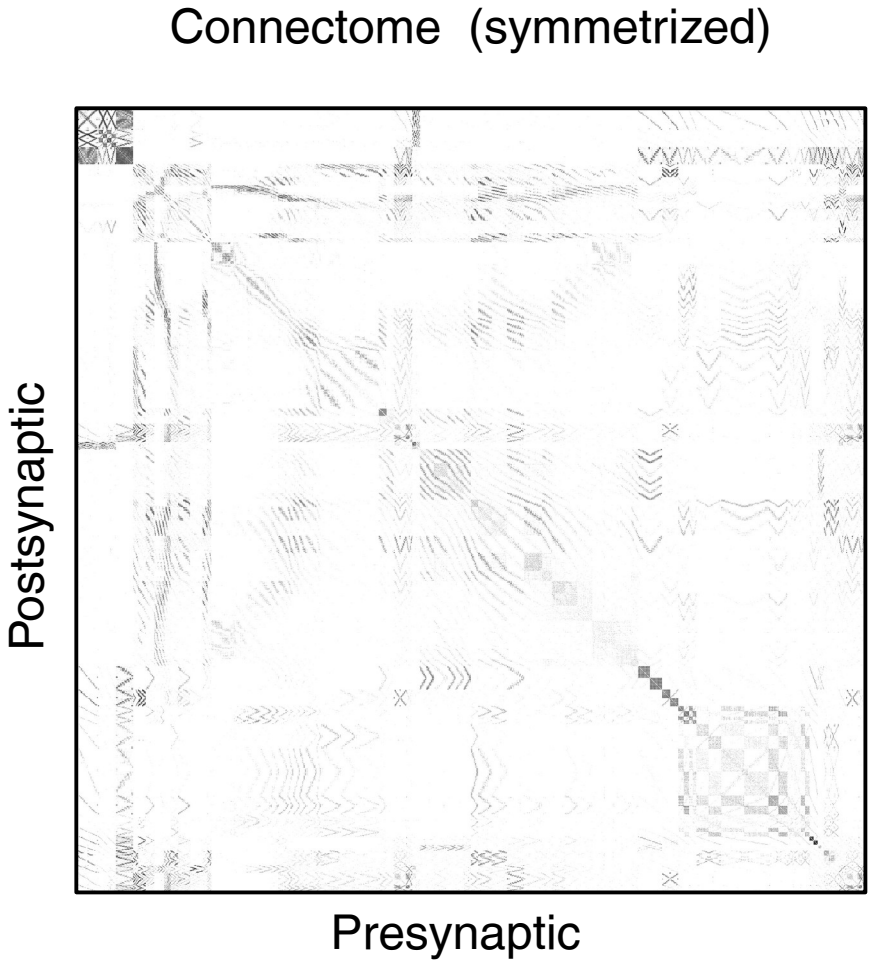
$$W_{ij} \sim \text{Pois}\left(f_{c_i,c_j}(\mathbf{z}_i, \mathbf{z}_j)\right)$$



$$W_{ij} \sim \text{Pois}\left(f_{c_i,c_j}(\mathbf{z}_i, \mathbf{z}_j)\right)$$

c_i : cell type of neuron *i*

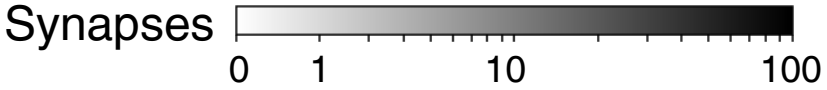




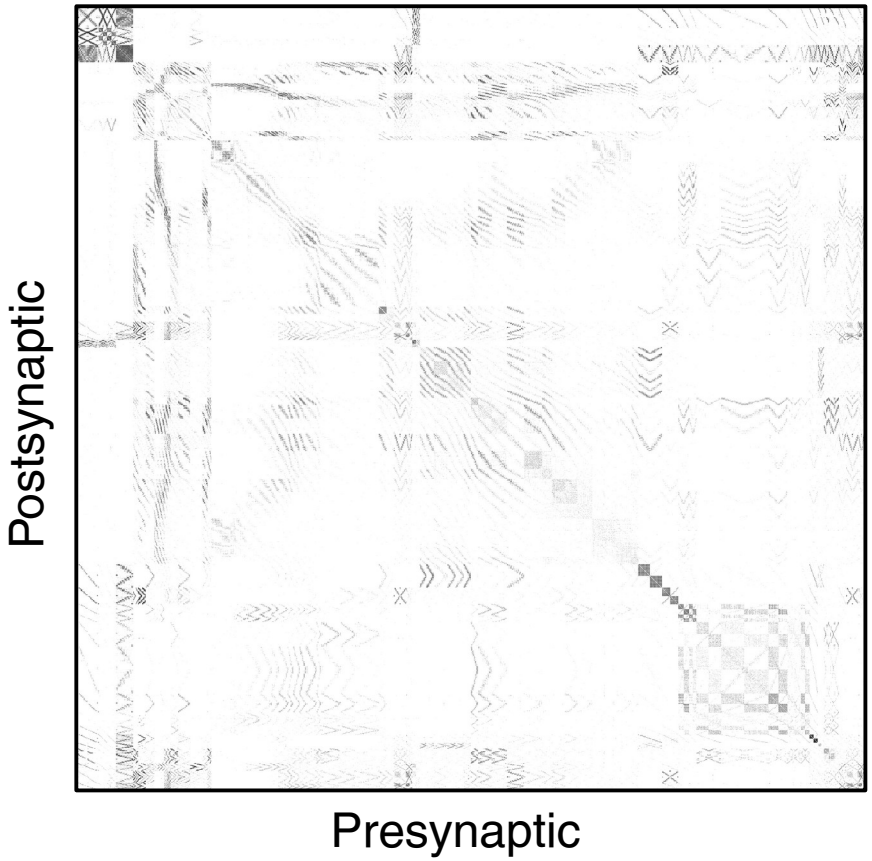
$$W_{ij} \sim \mathrm{Pois}\left(f_{c_i,c_j}(\mathbf{z}_i, \mathbf{z}_j)\right)$$

c_i : cell type of neuron *i*

$$f = A_{c_i,c_j} \exp(\|\mathbf{z}_i - \mathbf{z}_j\|^2 / \sigma^2_{c_i,c_j}) + B_{c_i,c_j}$$



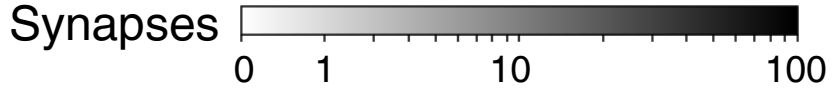
Connectome (symmetrized)

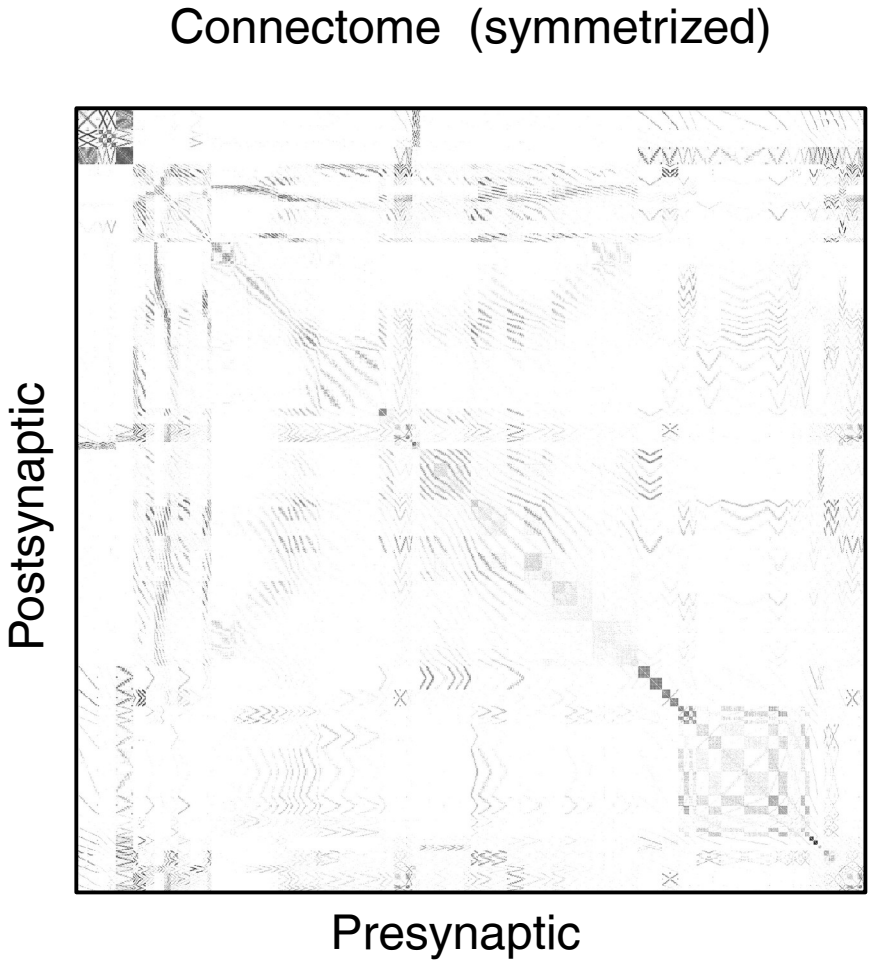


$$W_{ij} \sim \text{Pois}\left(f_{c_i,c_j}(\mathbf{z}_i, \mathbf{z}_j)\right)$$

c_i : cell type of neuron *i*

$$f = A_{c_i,c_j} \exp(\|\mathbf{z}_i - \mathbf{z}_j\|^2 / \sigma^2_{c_i,c_j}) + B_{c_i,c_j}$$

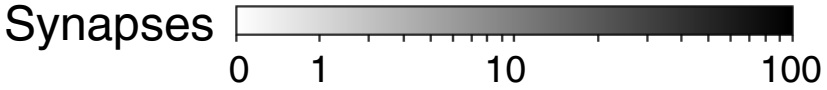




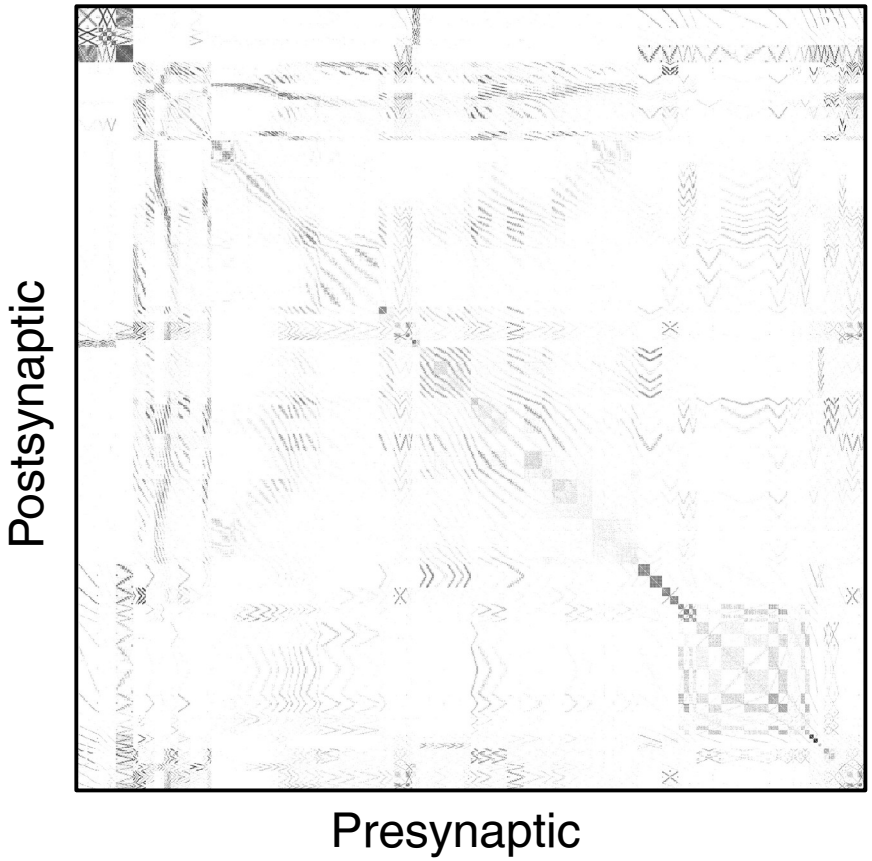
$$W_{ij} \sim \mathrm{Pois}\left(f_{c_i,c_j}(\mathbf{z}_i, \mathbf{z}_j)\right)$$

c_i : cell type of neuron *i*

$$f = A_{c_i,c_j} \exp(\|\mathbf{z}_i - \mathbf{z}_j\|^2 / \sigma^2_{c_i,c_j}) + B_{c_i,c_j}$$



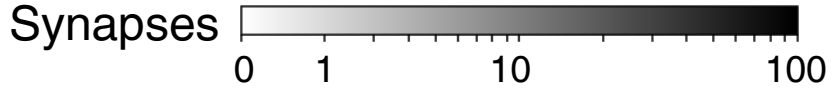
Connectome (symmetrized)

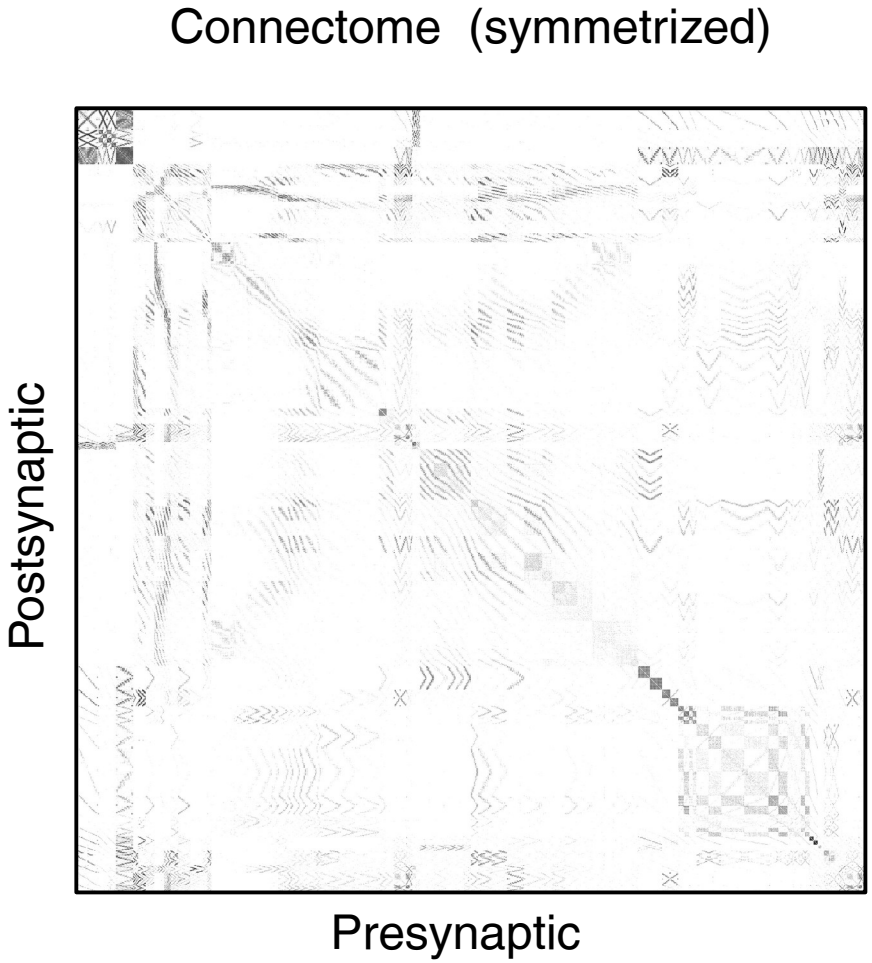


$$W_{ij} \sim \text{Pois}\left(f_{c_i,c_j}(\mathbf{z}_i, \mathbf{z}_j)\right)$$

c_i : cell type of neuron *i*

$$f = A_{c_i,c_j} \exp(\|\mathbf{z}_i - \mathbf{z}_j\|^2 / \sigma^2_{c_i,c_j}) + B_{c_i,c_j}$$

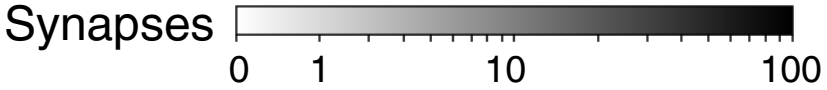




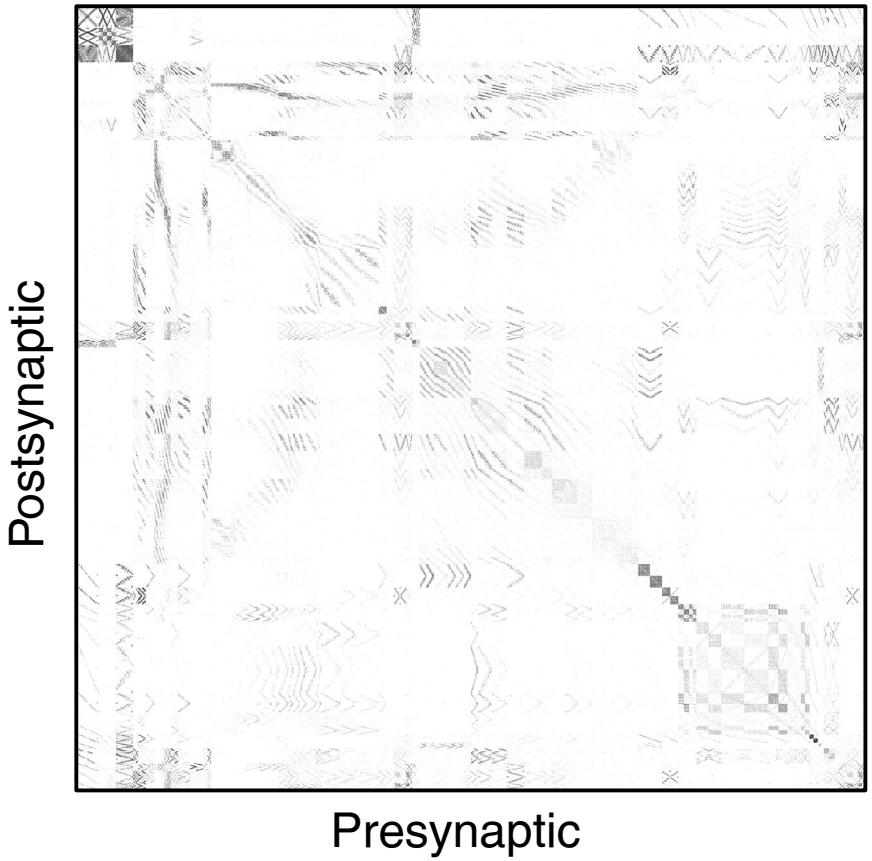
$$W_{ij} \sim \mathrm{Pois}\left(f_{c_i,c_j}(\mathbf{z}_i, \mathbf{z}_j)\right)$$

c_i : cell type of neuron *i*

$$f = A_{c_i,c_j} \exp(\|\mathbf{z}_i - \mathbf{z}_j\|^2 / \sigma^2_{c_i,c_j}) + B_{c_i,c_j}$$



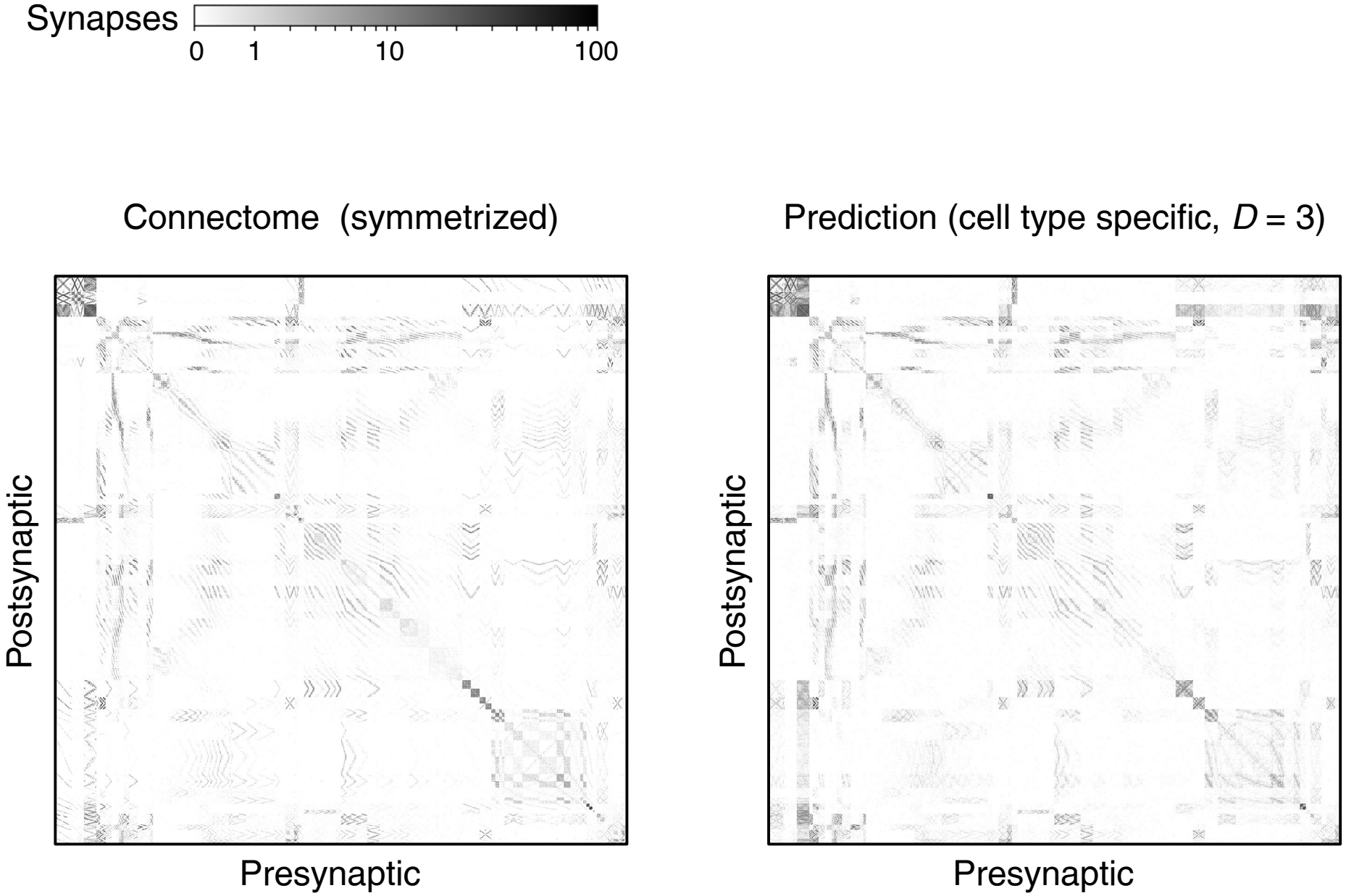
Connectome (symmetrized)



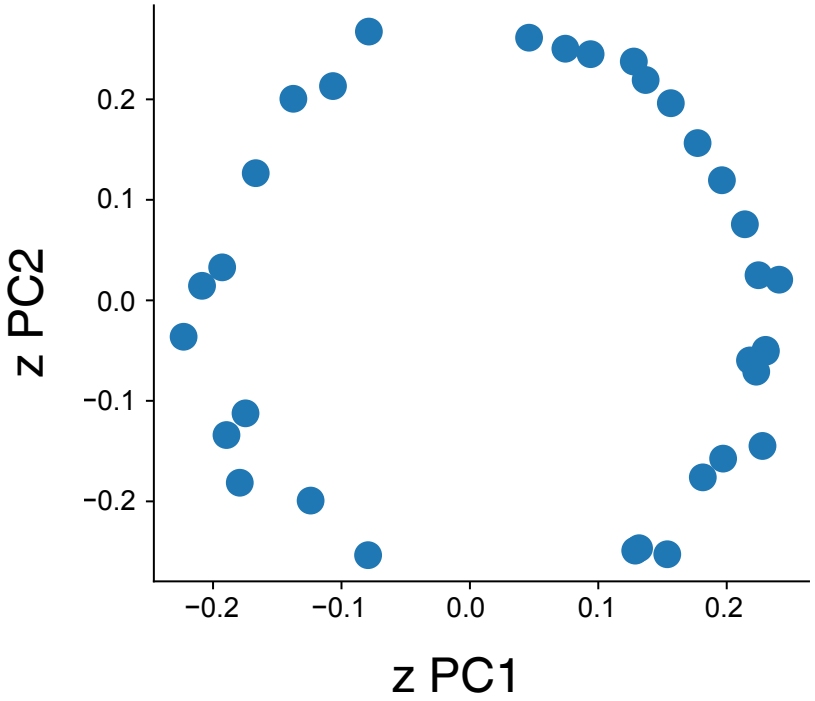
$$W_{ij} \sim \text{Pois}\left(f_{c_i,c_j}(\mathbf{z}_i, \mathbf{z}_j)\right)$$

c_i : cell type of neuron *i*

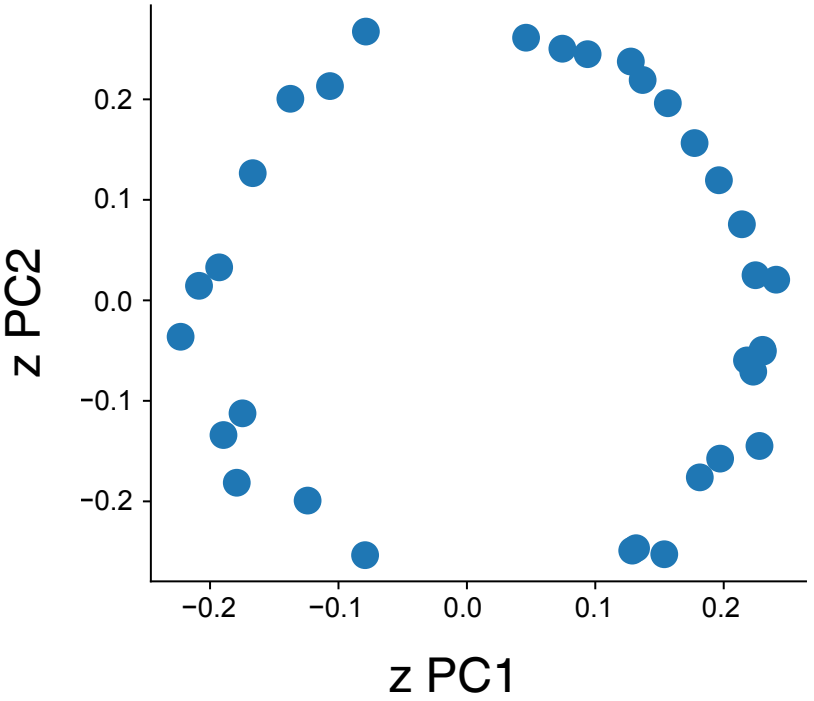
$$f = A_{c_i,c_j} \exp(\|\mathbf{z}_i - \mathbf{z}_j\|^2 / \sigma^2_{c_i,c_j}) + B_{c_i,c_j}$$


Synapses
0
1
10
100
Connectome (symmetrized)
Postsynaptic
Presynaptic
Prediction (cell type specific, D = 3)
Postsynaptic
Presynaptic

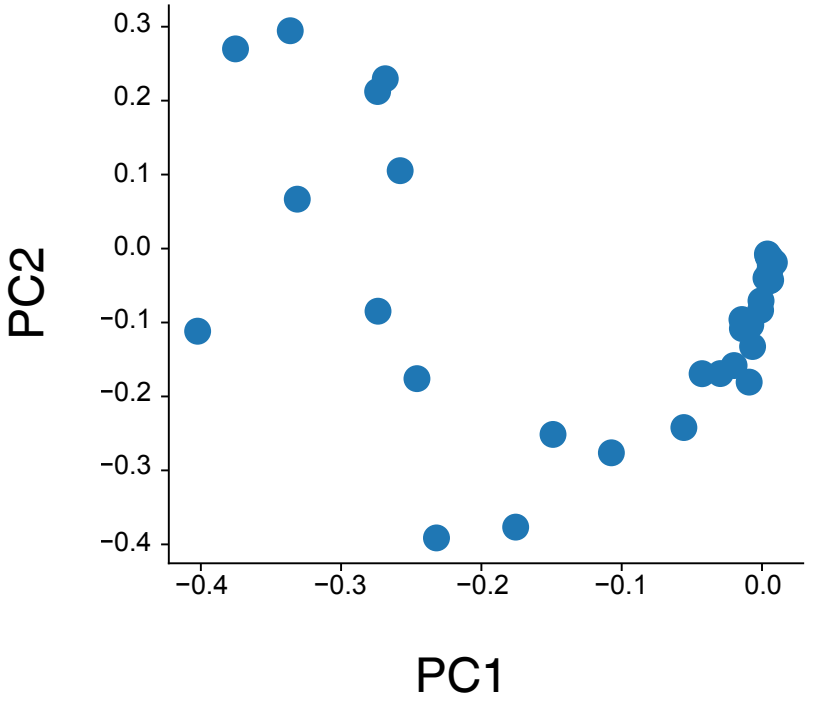
FC2B neurons

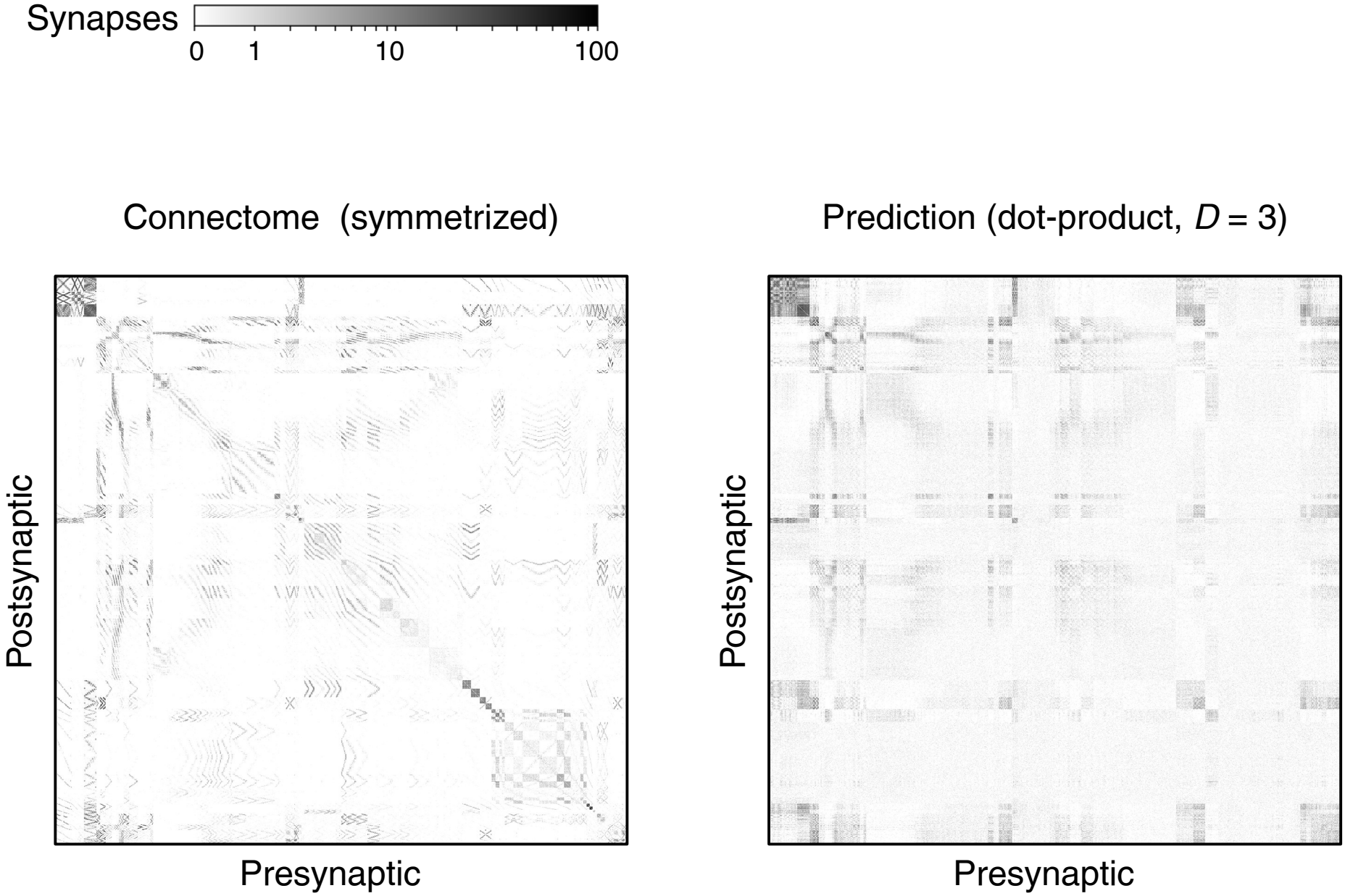


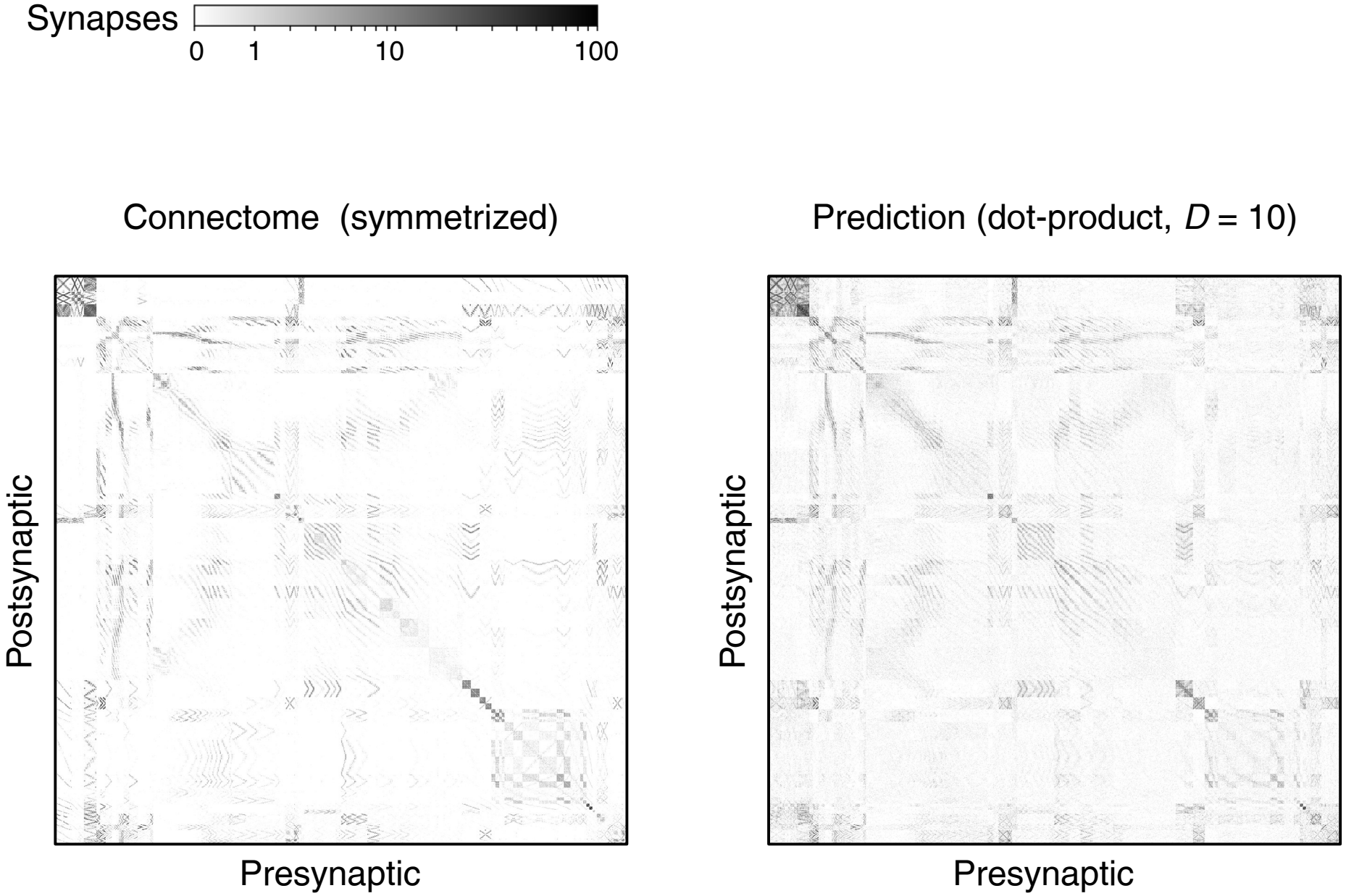
FC2B neurons

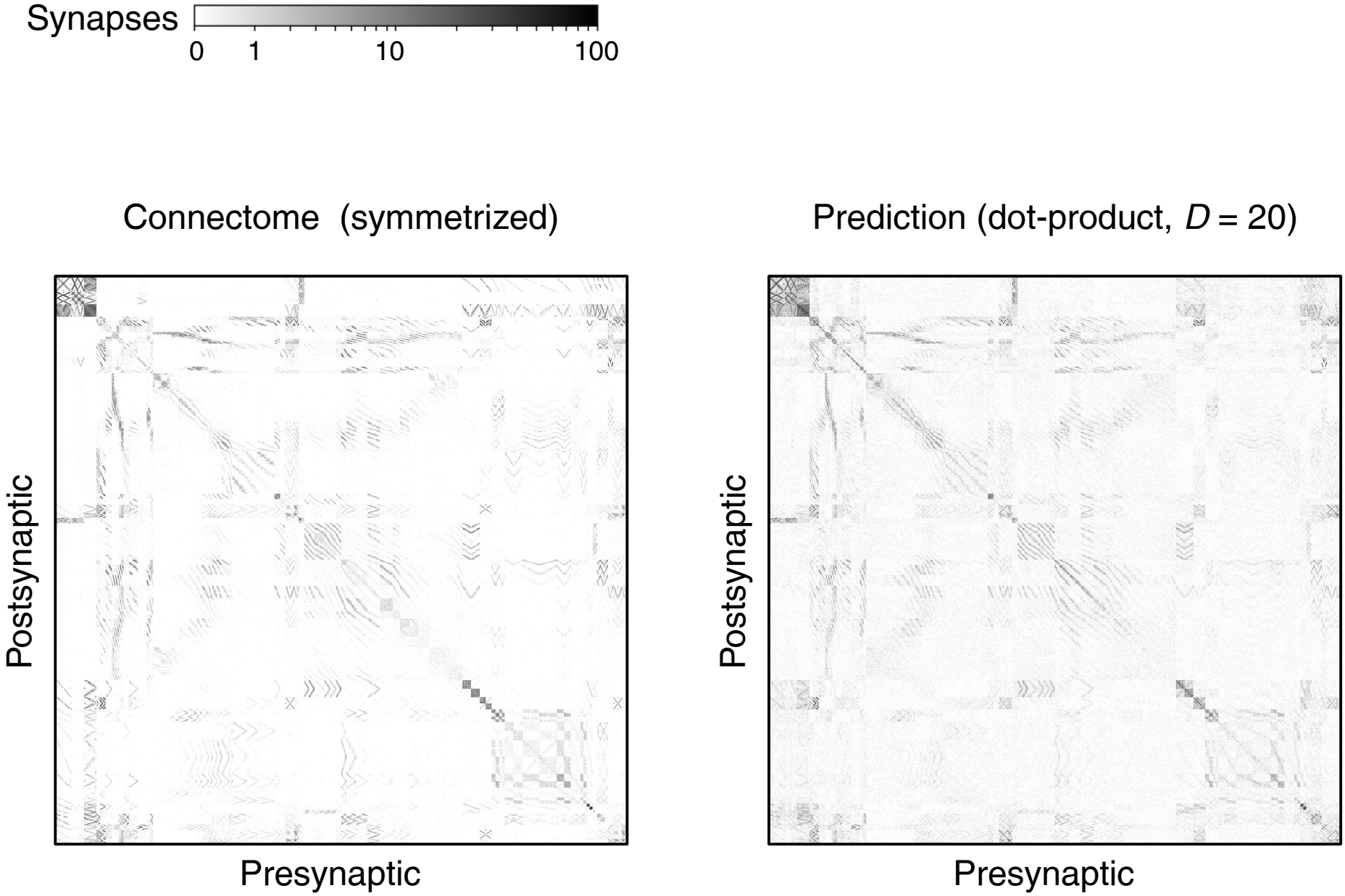


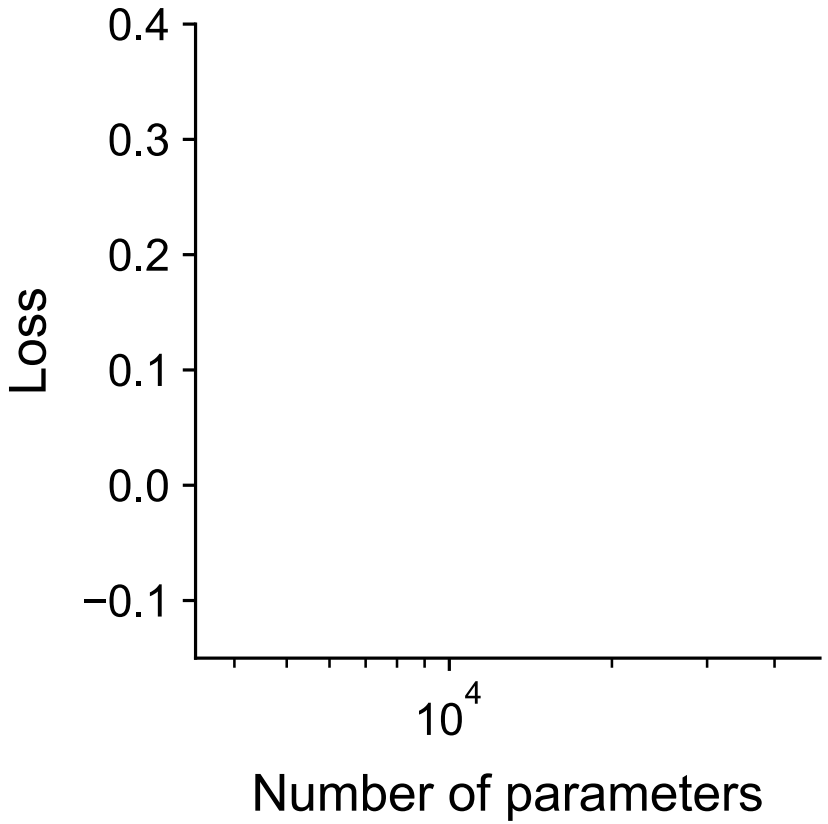
Spectral embedding

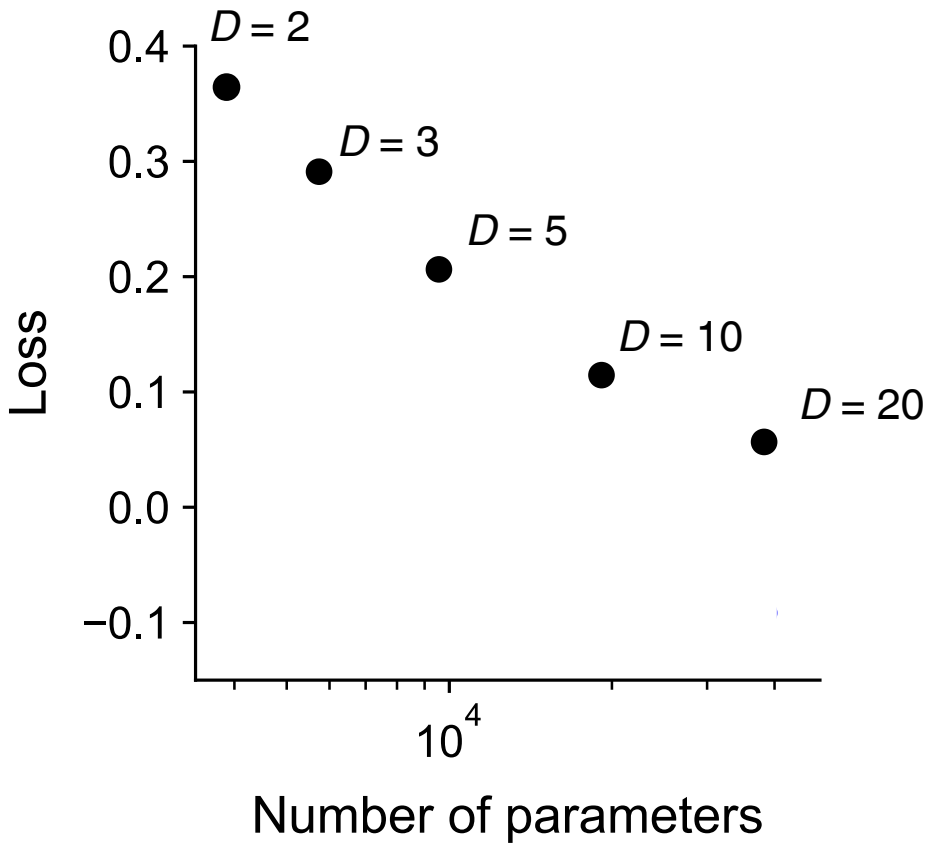


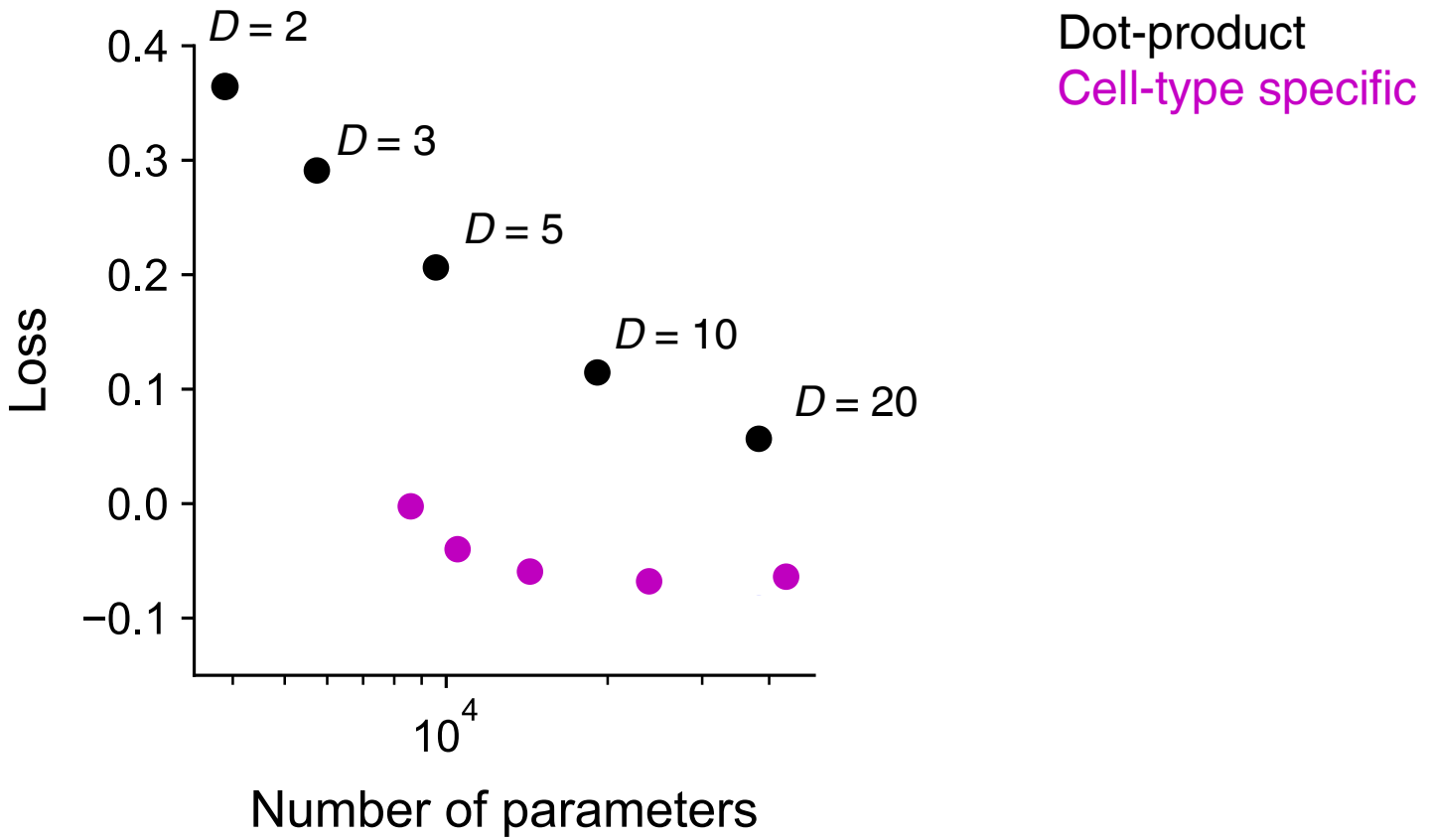

Synapses
0
1
10
100
Connectome (symmetrized)
Postsynaptic
Presynaptic
Prediction (dot-product, D = 3)
Postsynaptic
Presynaptic

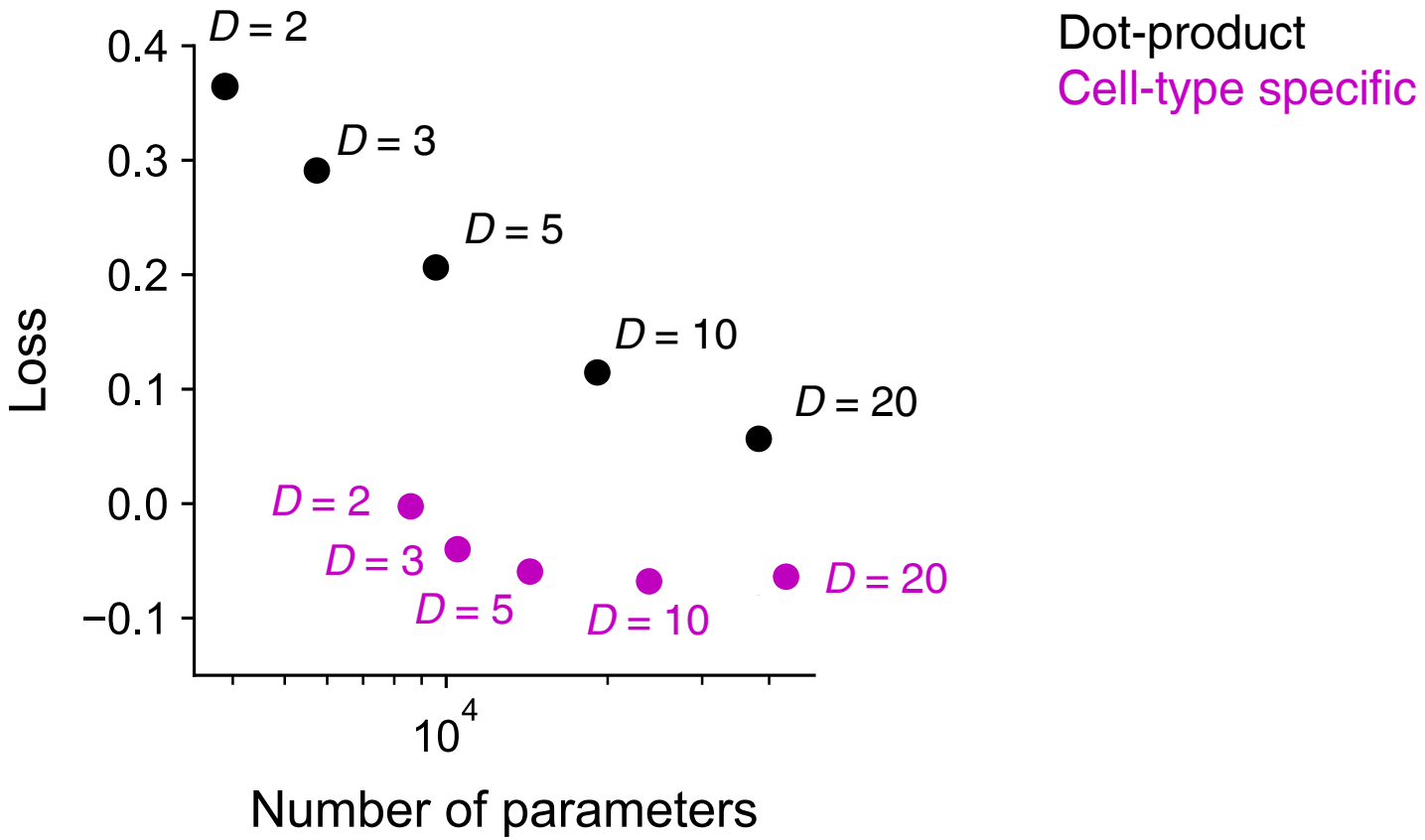

Synapses
0
1
10
100
Connectome (symmetrized)
Postsynaptic
Presynaptic
Prediction (dot-product, D = 10)
Postsynaptic
Presynaptic

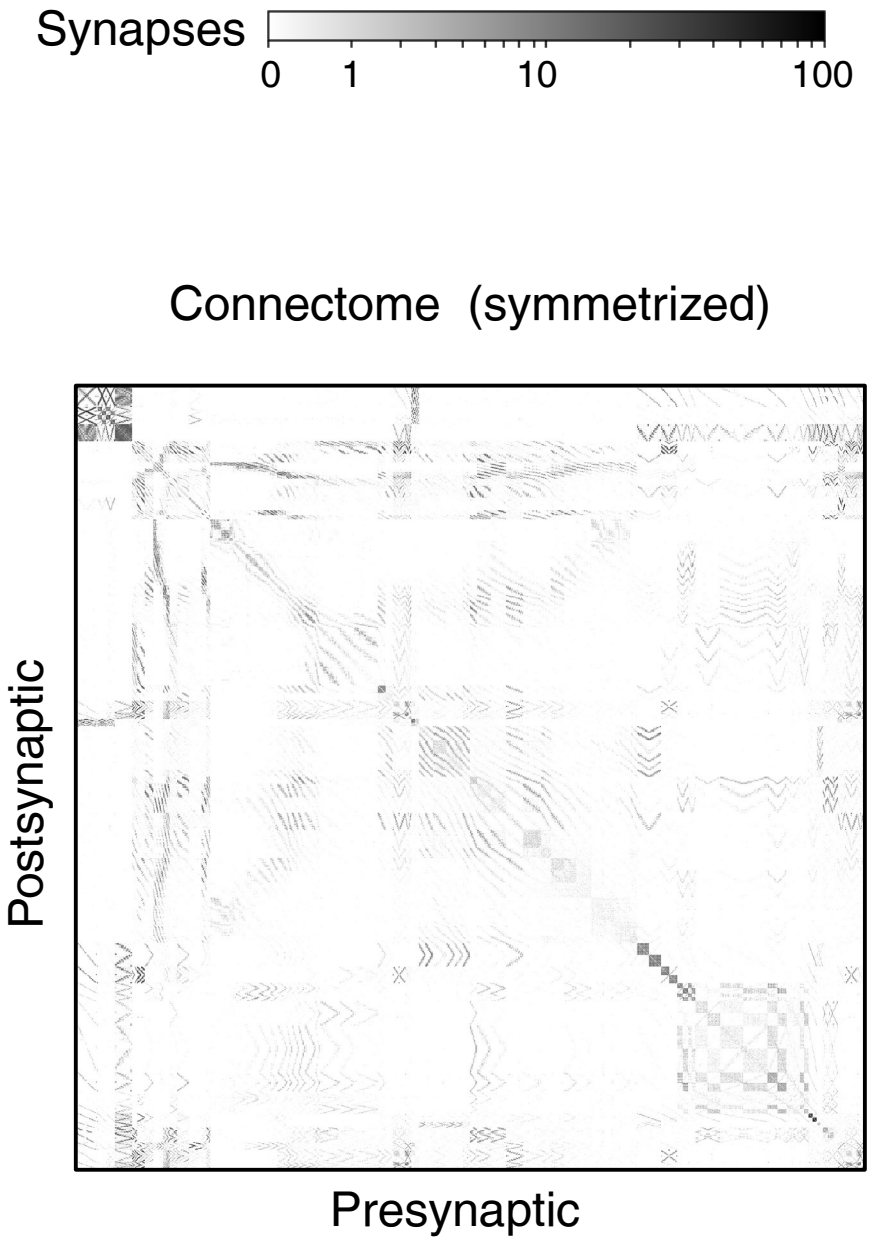

Synapses
0
1
10
100
Connectome (symmetrized)
Postsynaptic
Presynaptic
Prediction (dot-product, D = 20)
Postsynaptic
Presynaptic

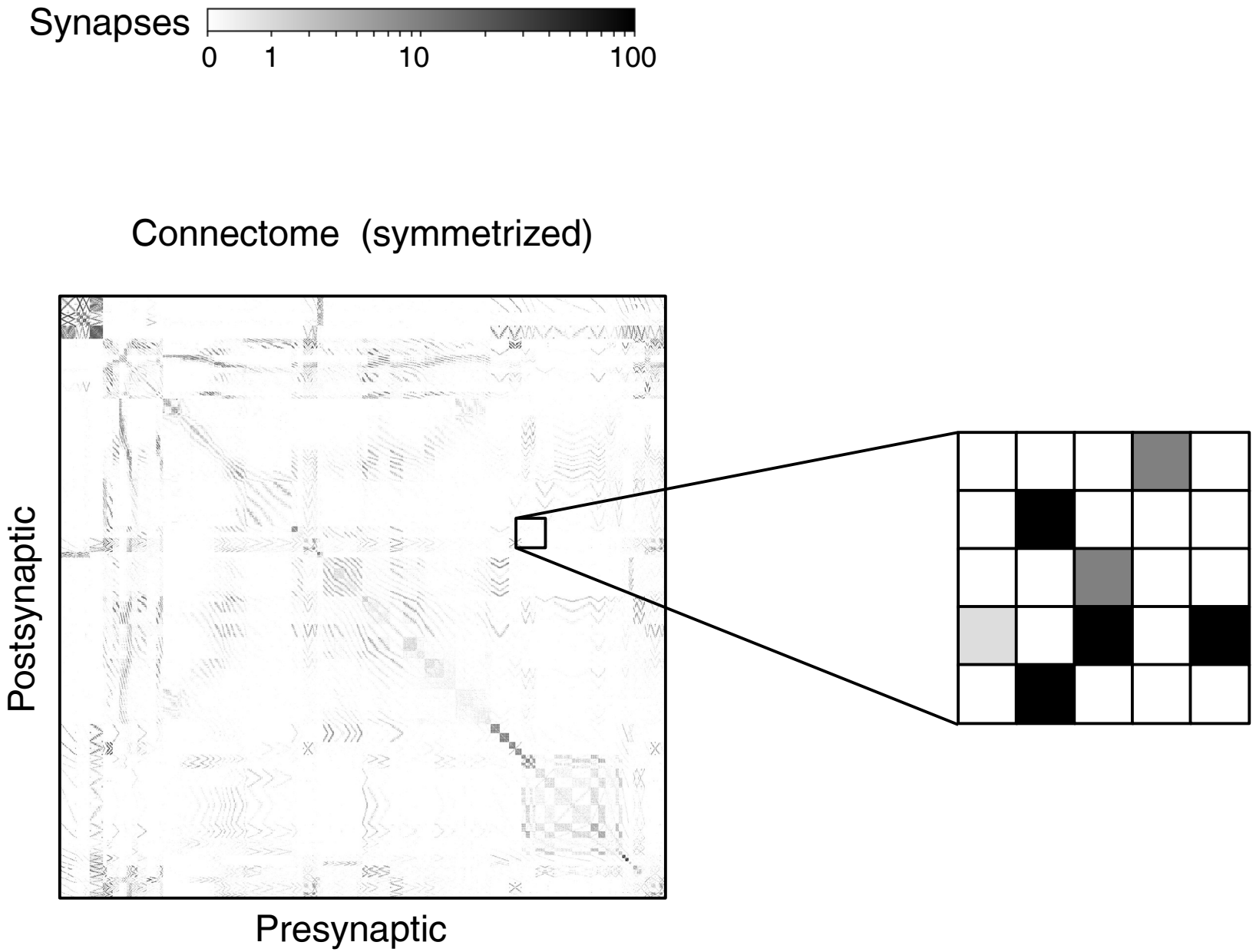

0.4
0.3
0.2
0.1
0.0
−0.1
Loss
10^4
Number of parameters

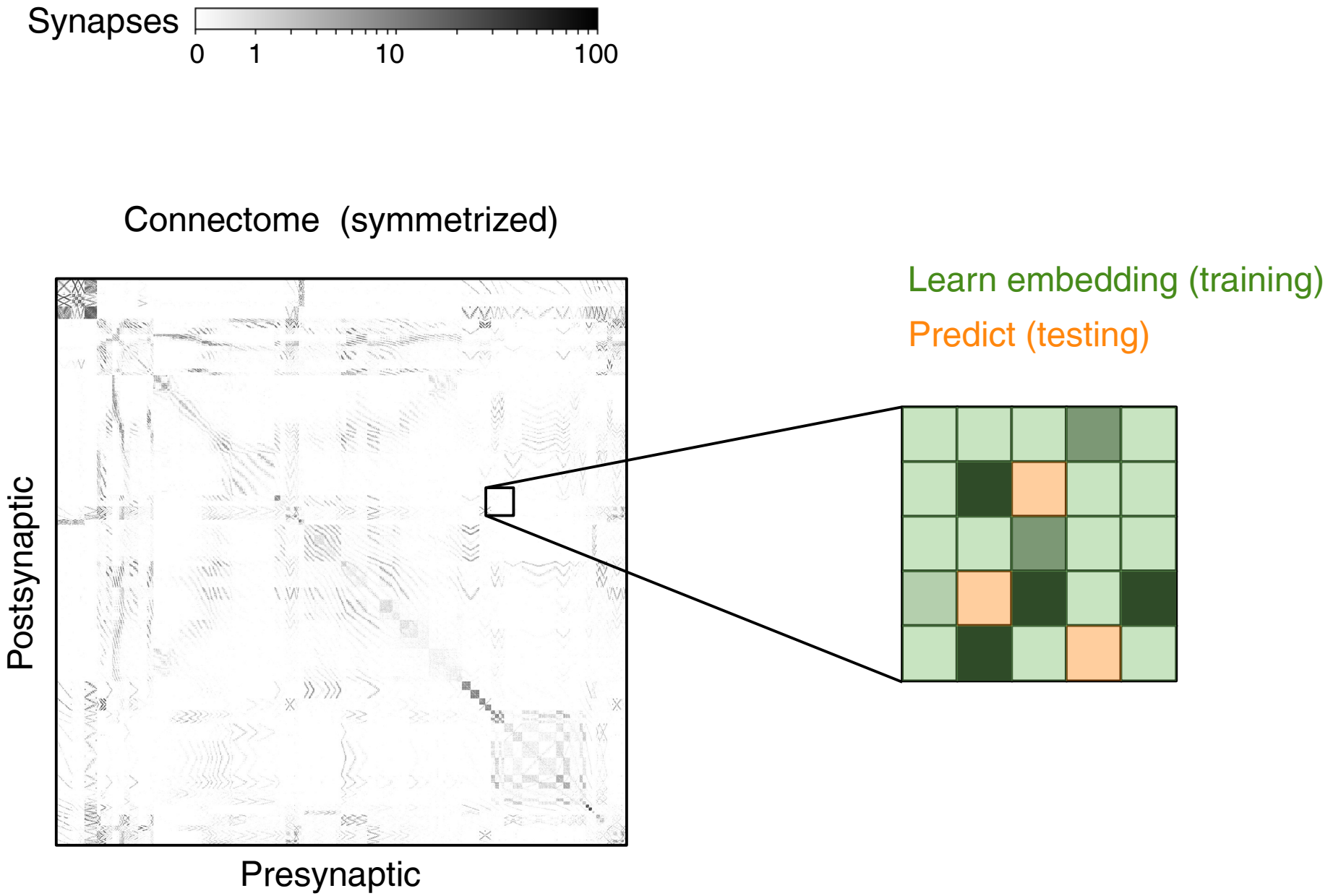

Dot-product
D = 2
D = 3
D = 5
D = 10
D = 20
0.4
0.3
0.2
0.1
0.0
−0.1
Loss
10^4
Number of parameters

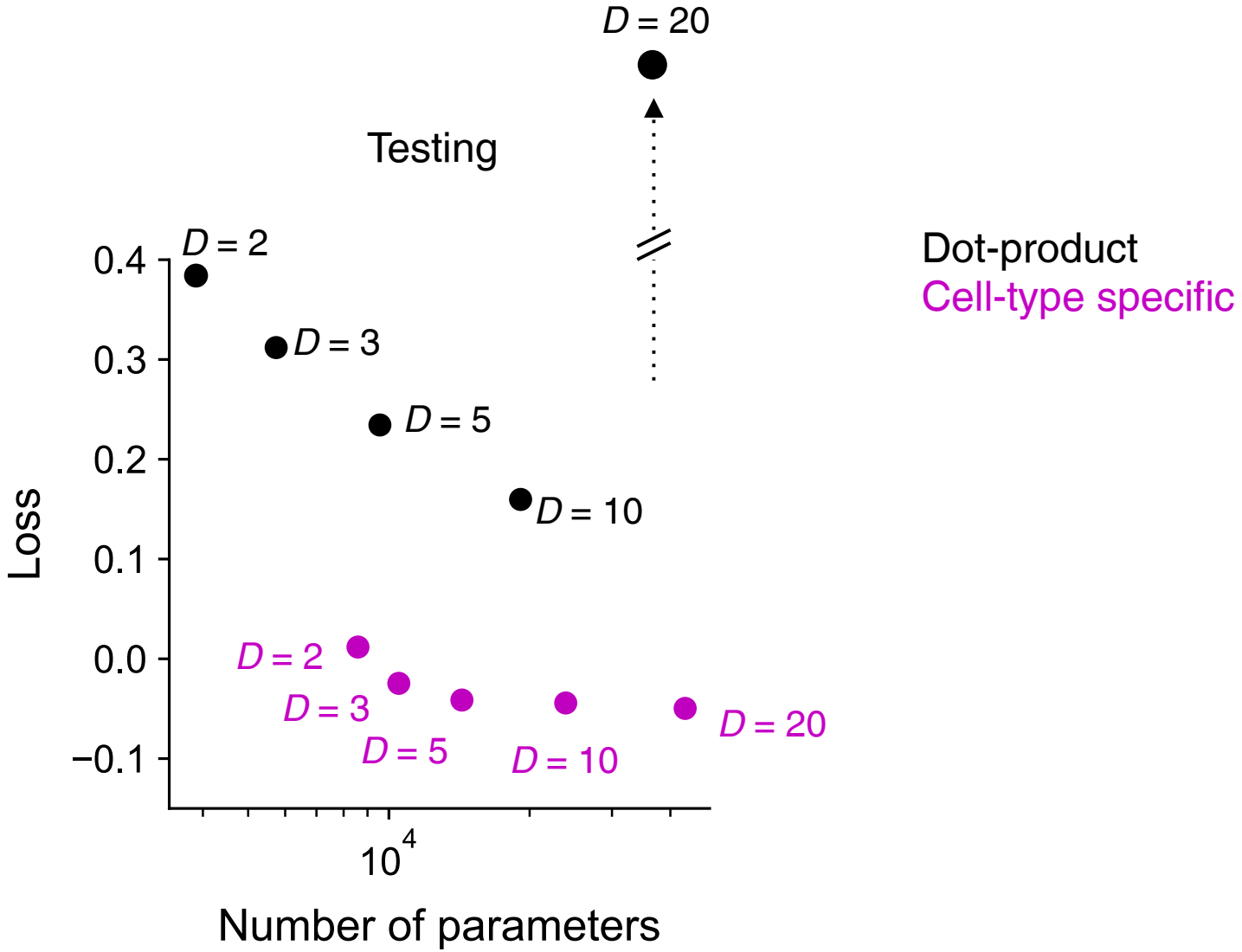

D = 2
D = 3
D = 5
D = 10
D = 20
0.4
0.3
0.2
0.1
0.0
−0.1
Loss
10^4
Number of parameters
Dot-product
Cell-type specific

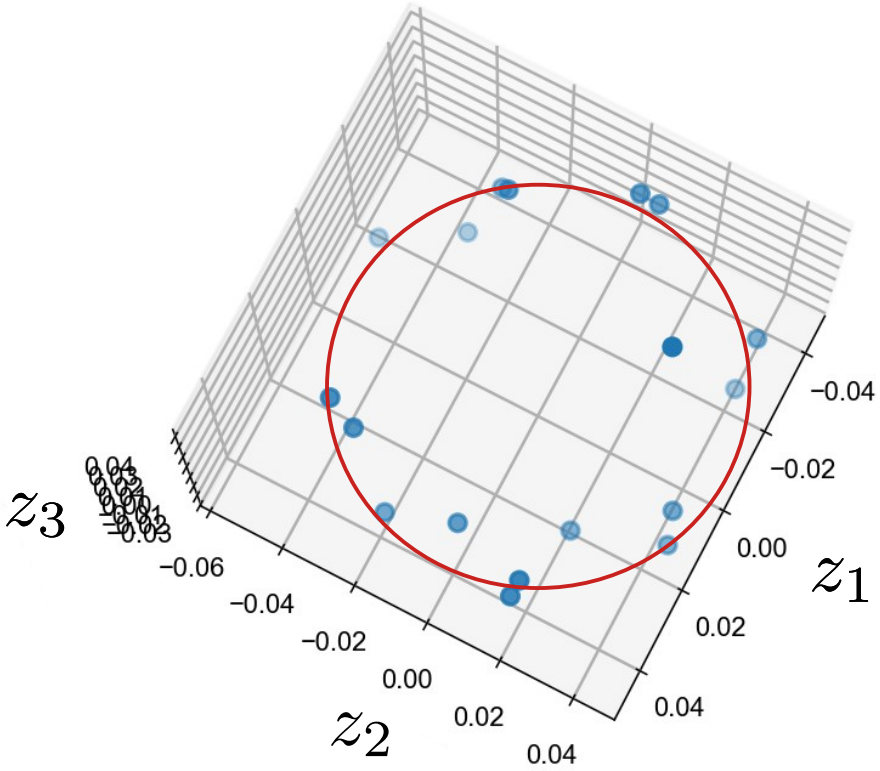

Dot-product
Cell-type specific
0.4
0.3
0.2
0.1
0.0
−0.1
Loss
D = 2
D = 3
D = 5
D = 10
D = 20
D = 2
D = 3
D = 5
D = 10
D = 20
10^4
Number of parameters

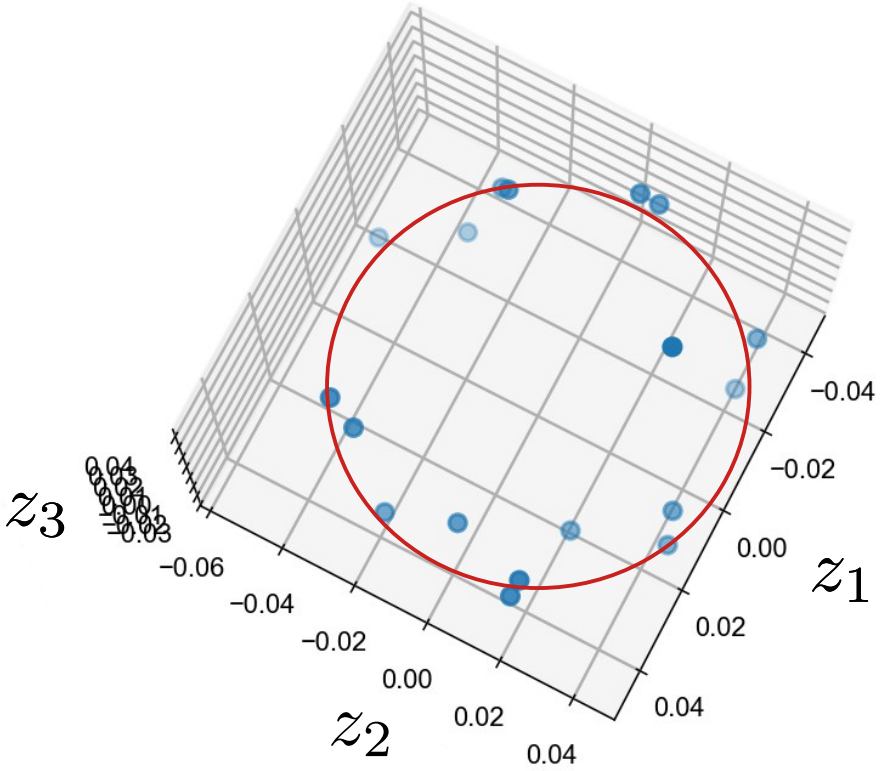

Synapses
0
1
10
100
Connectome (symmetrized)
Postsynaptic
Presynaptic

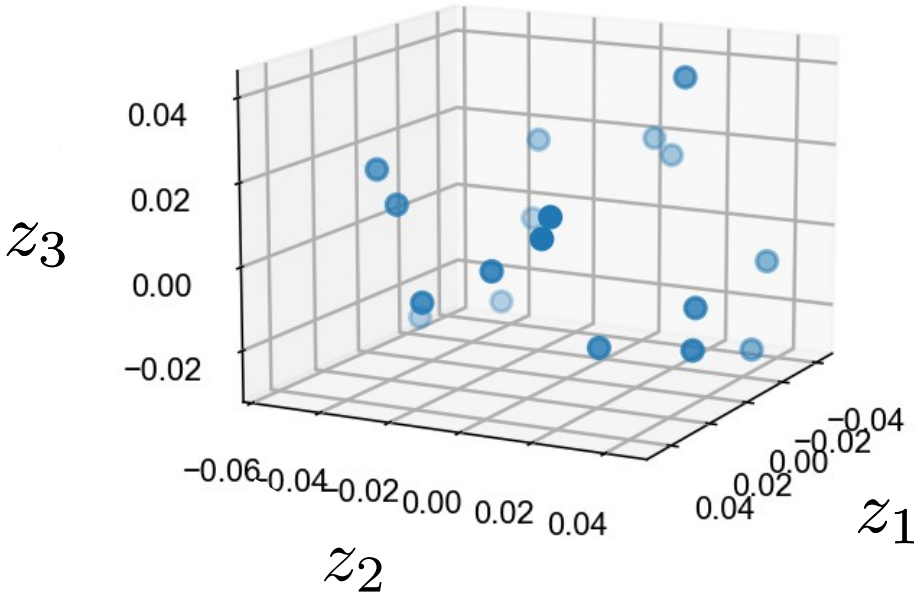

Synapses
0
1
10
100
Connectome (symmetrized)
Postsynaptic
Presynaptic

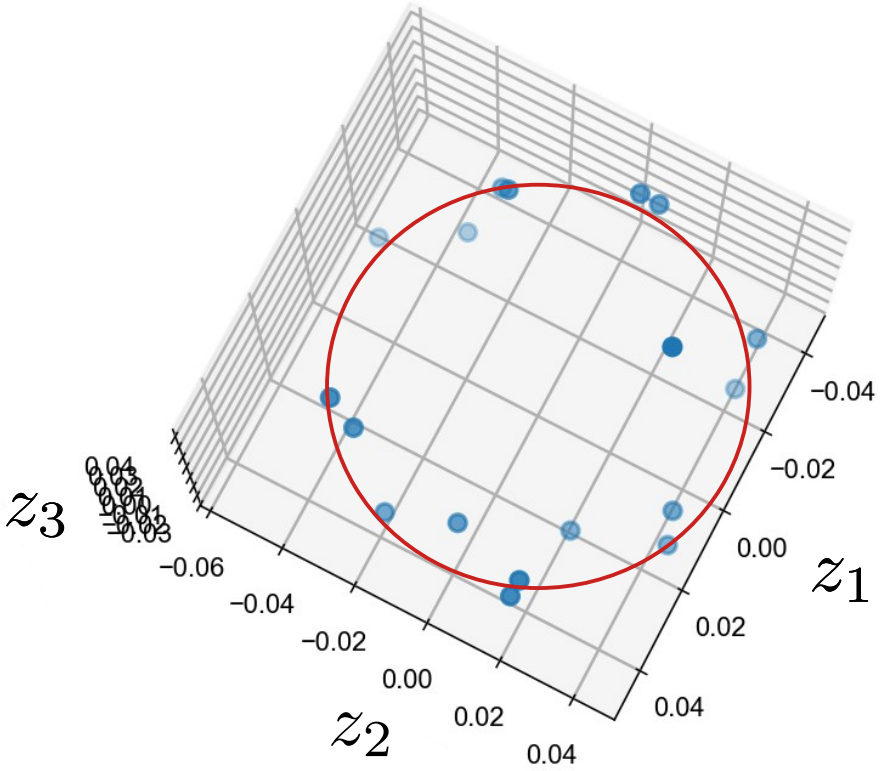

Synapses
0
1
10
100
Connectome (symmetrized)
Postsynaptic
Presynaptic
Learn embedding (training)
Predict (testing)

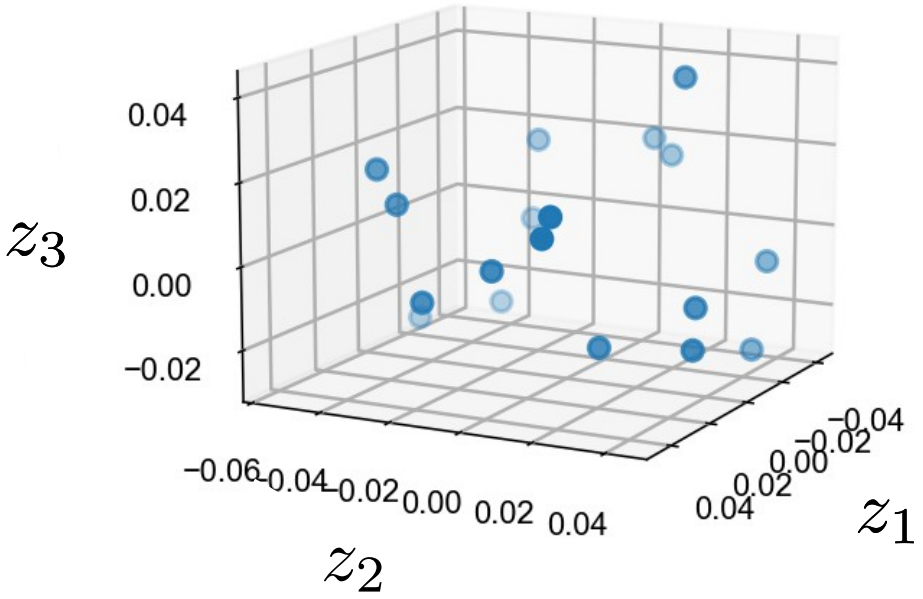

D = 20
Testing
D = 2
0.4
D = 3
0.3
D = 5
0.2
D = 10
Loss
0.1
D = 2
0.0
D = 3
D = 5
D = 10
D = 20
−0.1
10^4
Number of parameters
Dot-product
Cell-type specific


z_3
−0.06
−0.04
−0.02
0.00
0.02
0.04
z_2
−0.04
−0.02
0.00
0.02
0.04
z_1

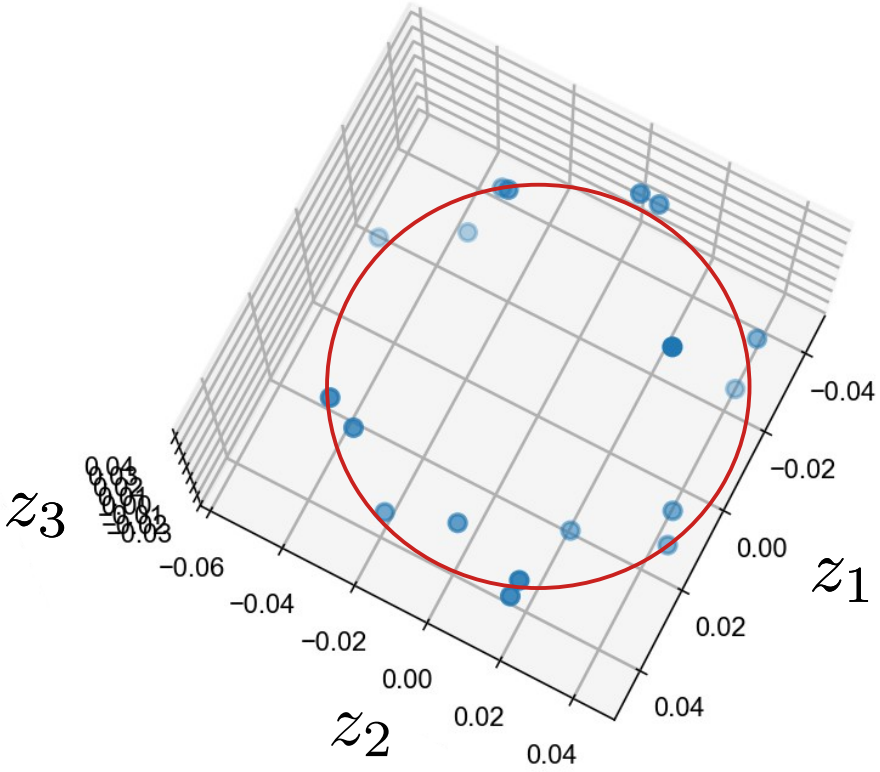

z_3
z_2
z_1
−0.06
−0.04
−0.02
0.00
0.02
0.04
−0.04
−0.02
0.00
0.02
0.04

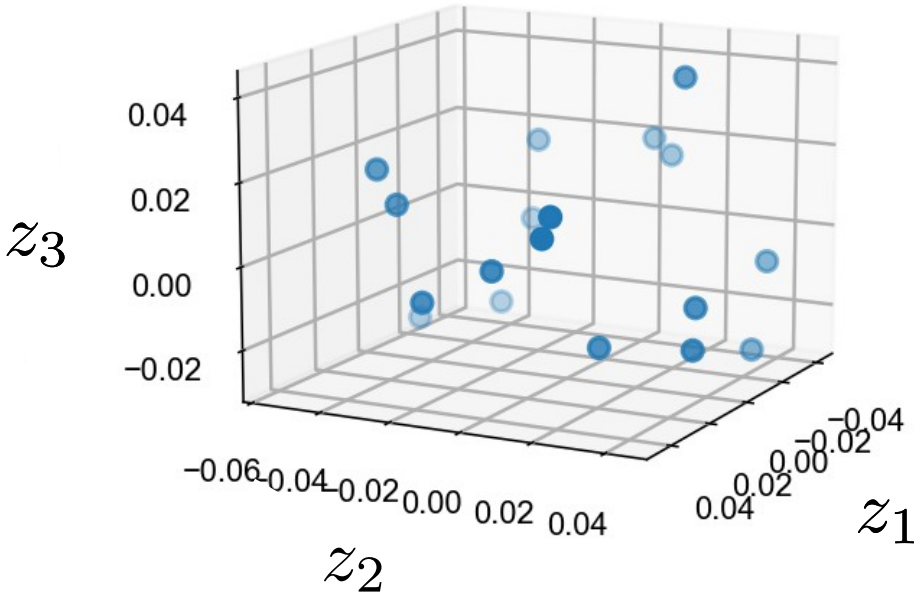

z_3
z_2
z_1
0.04
0.02
0.00
−0.02
−0.06
−0.04
−0.02
0.00
0.02
0.04
0.04
0.02
0.00
−0.02
−0.04





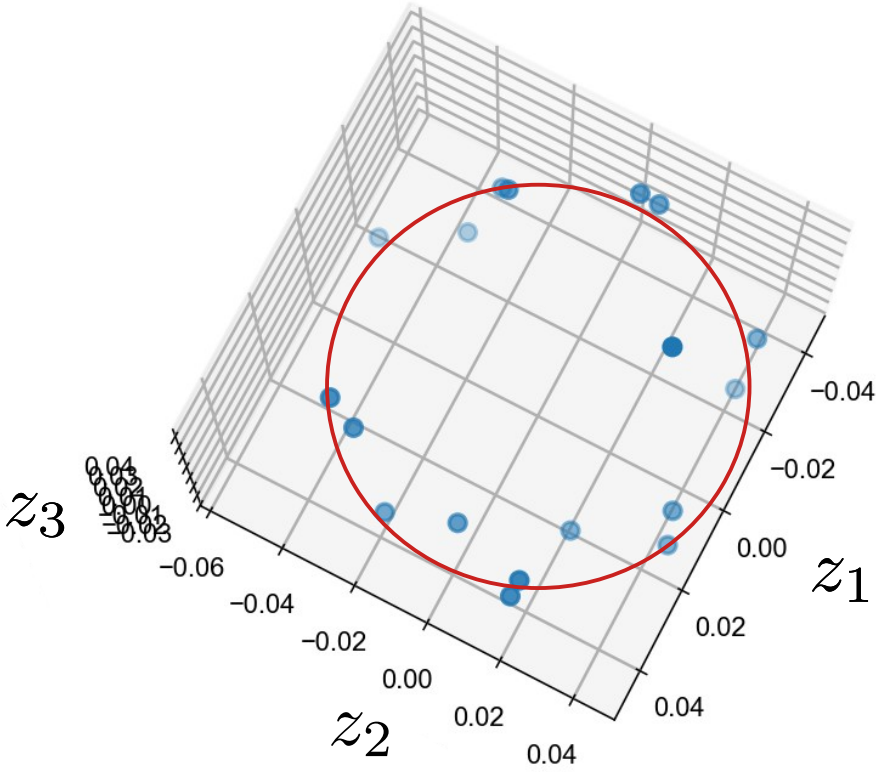
$\mathbf{C}$: target “shape”

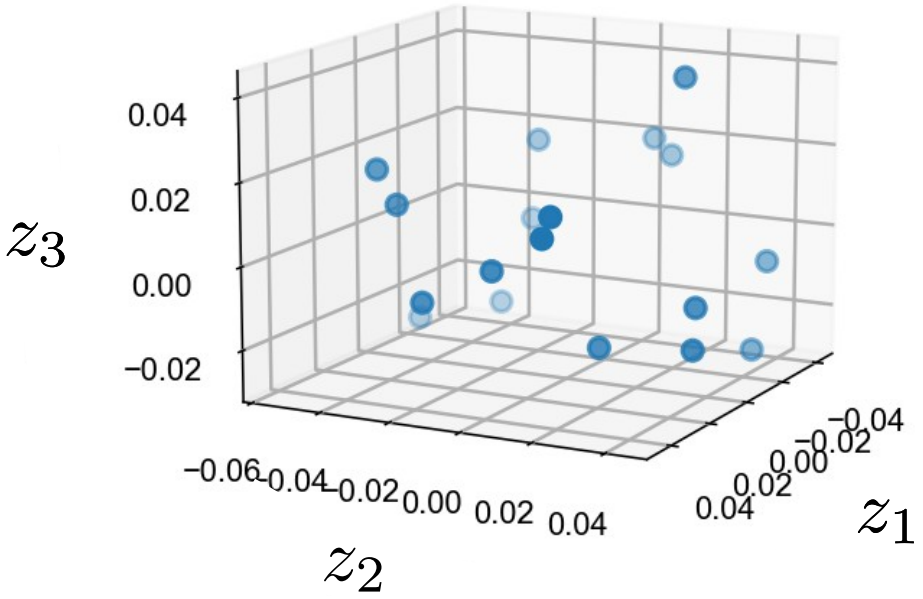




$$\mathbf{\Pi}^*, \mathbf{T}^* = \arg\min_{\mathbf{\Pi}, \mathbf{T}} \|\mathbf{C} - \mathbf{\Pi Z T}\|^2$$

$\mathbf{C}$: target “shape”

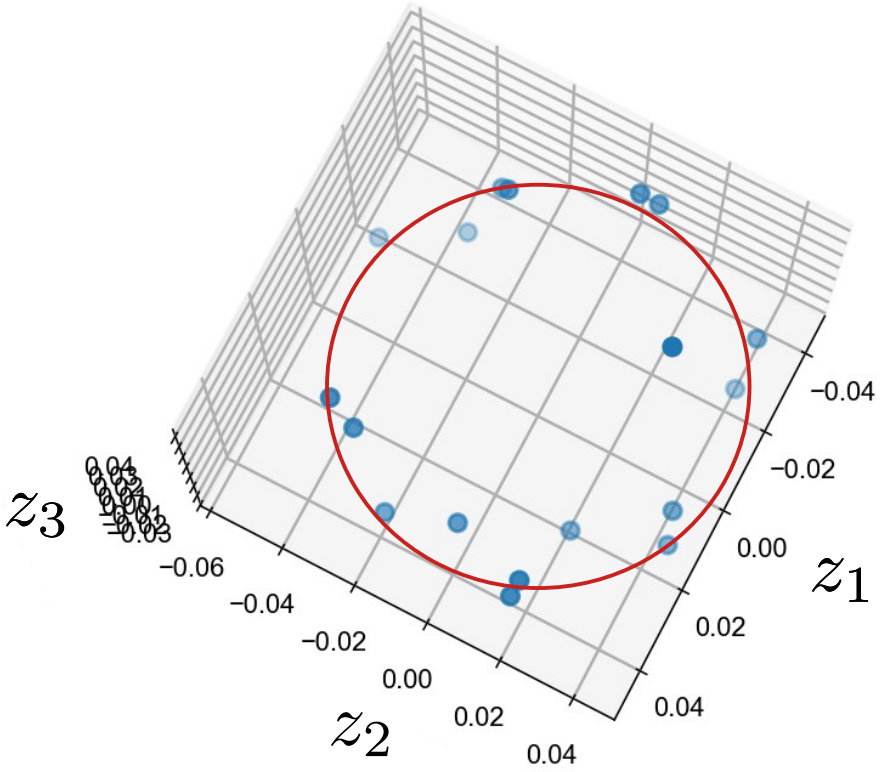


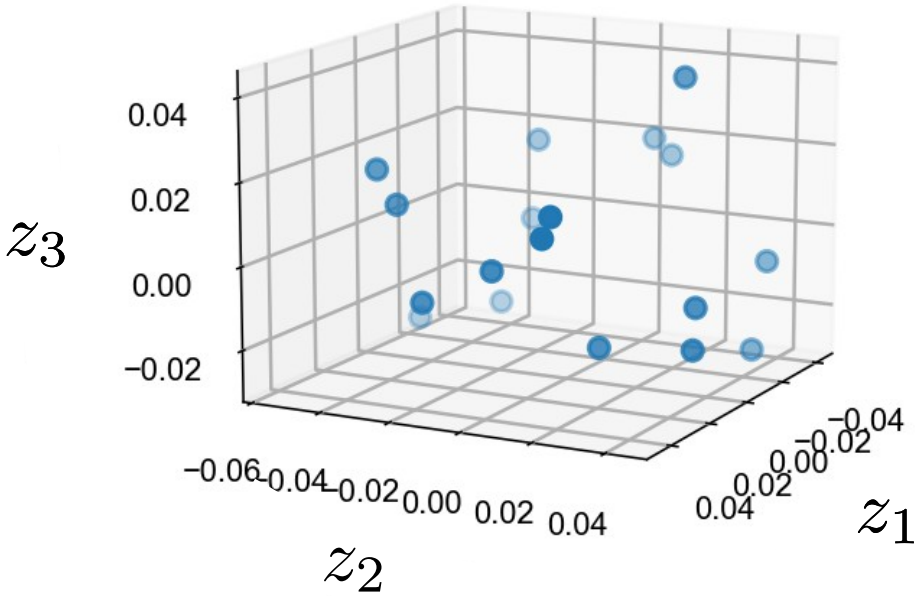


$$\mathbf{\Pi}^*, \mathbf{T}^* = \arg\min_{\mathbf{\Pi}, \mathbf{T}} \|\mathbf{C} - \mathbf{\Pi Z T}\|^2$$

$\mathbf{C}$: target “shape”

$\mathbf{\Pi}$: permutation matrix



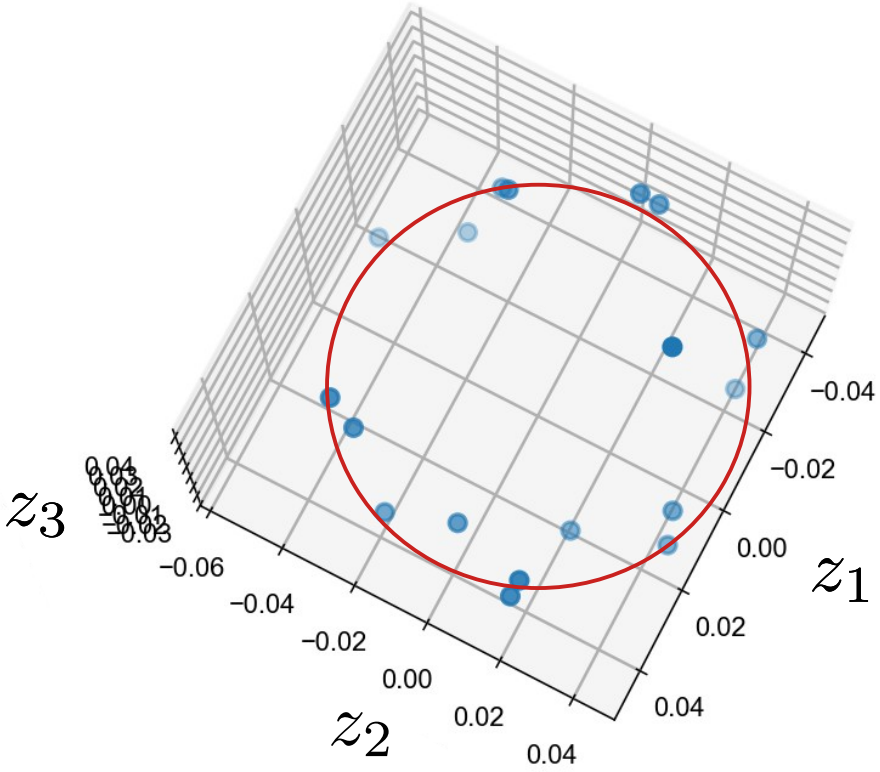


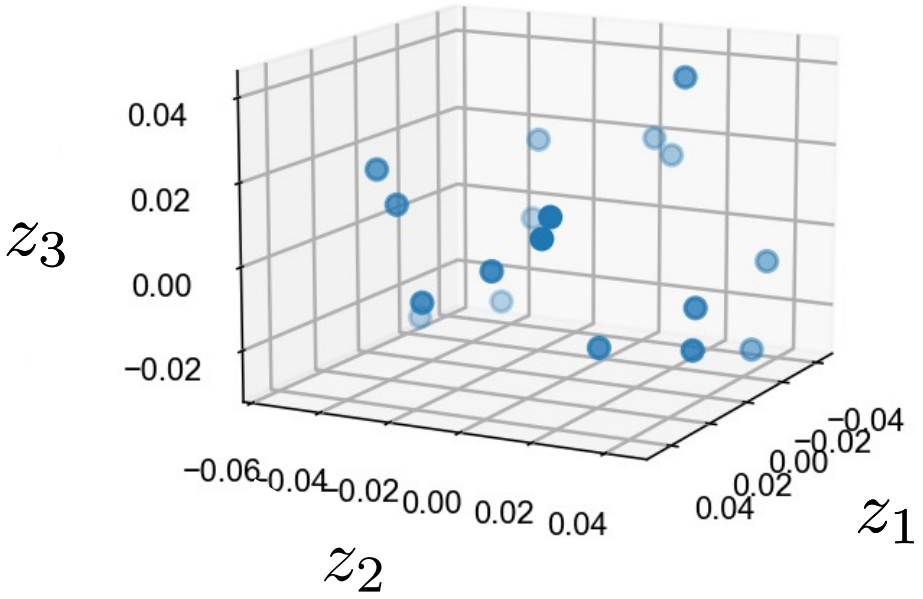
$$\mathbf{\Pi}^*, \mathbf{T}^* = \arg\min_{\mathbf{\Pi}, \mathbf{T}} \|\mathbf{C} - \mathbf{\Pi Z T}\|^2$$

$\mathbf{C}$: target “shape”

$\mathbf{\Pi}$: permutation matrix

$\mathbf{T} : \mathbb{R}^D \rightarrow \mathbb{R}^2$: linear projection



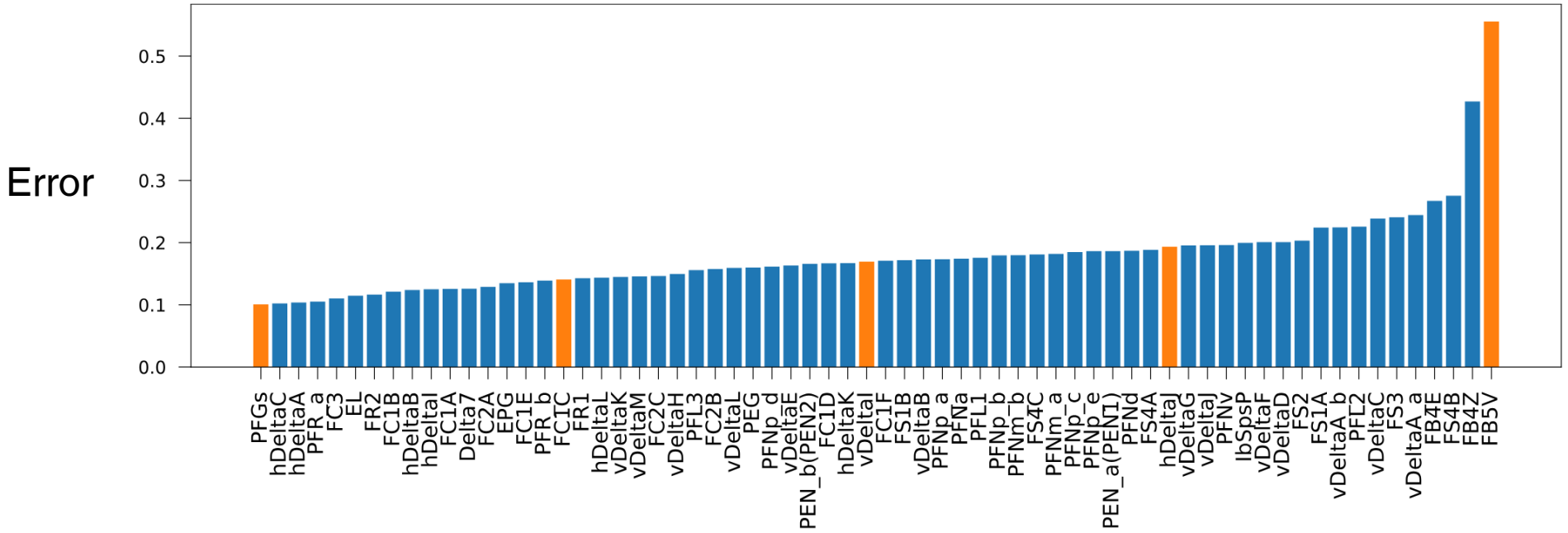


$$\mathbf{\Pi}^*, \mathbf{T}^* = \arg\min_{\mathbf{\Pi}, \mathbf{T}} \|\mathbf{C} - \mathbf{\Pi Z T}\|^2$$

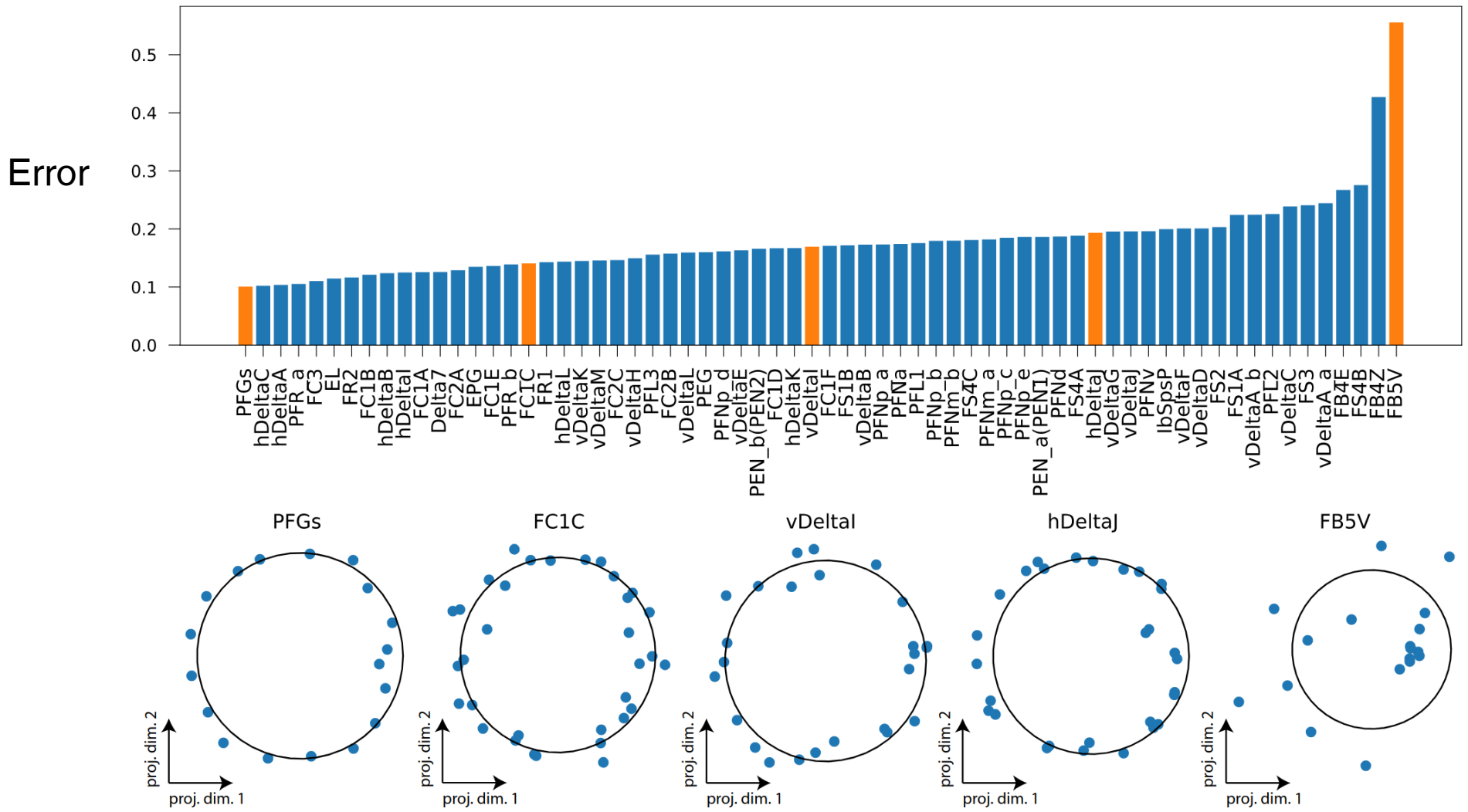
Alternating minimization wrt $\mathbf{\Pi}$ (linear assignment problem) and $\mathbf{T}$ (least squares regression)

Application 1: Finding circles

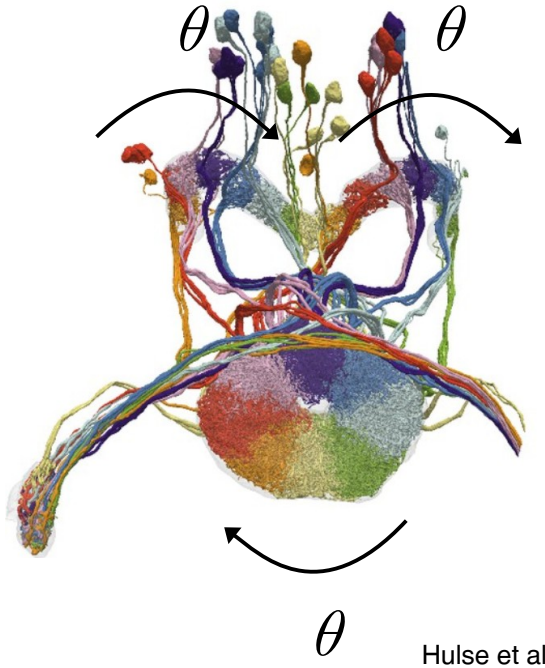
Application 1: Finding circles



Application 1: Finding circles

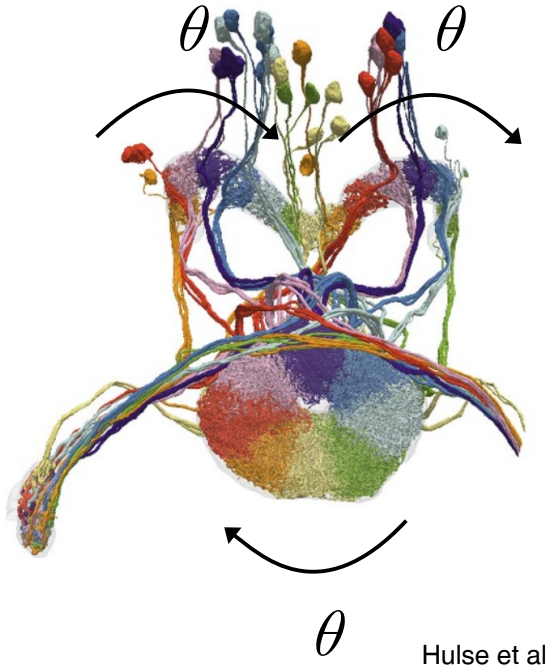


Application 2: Shifts

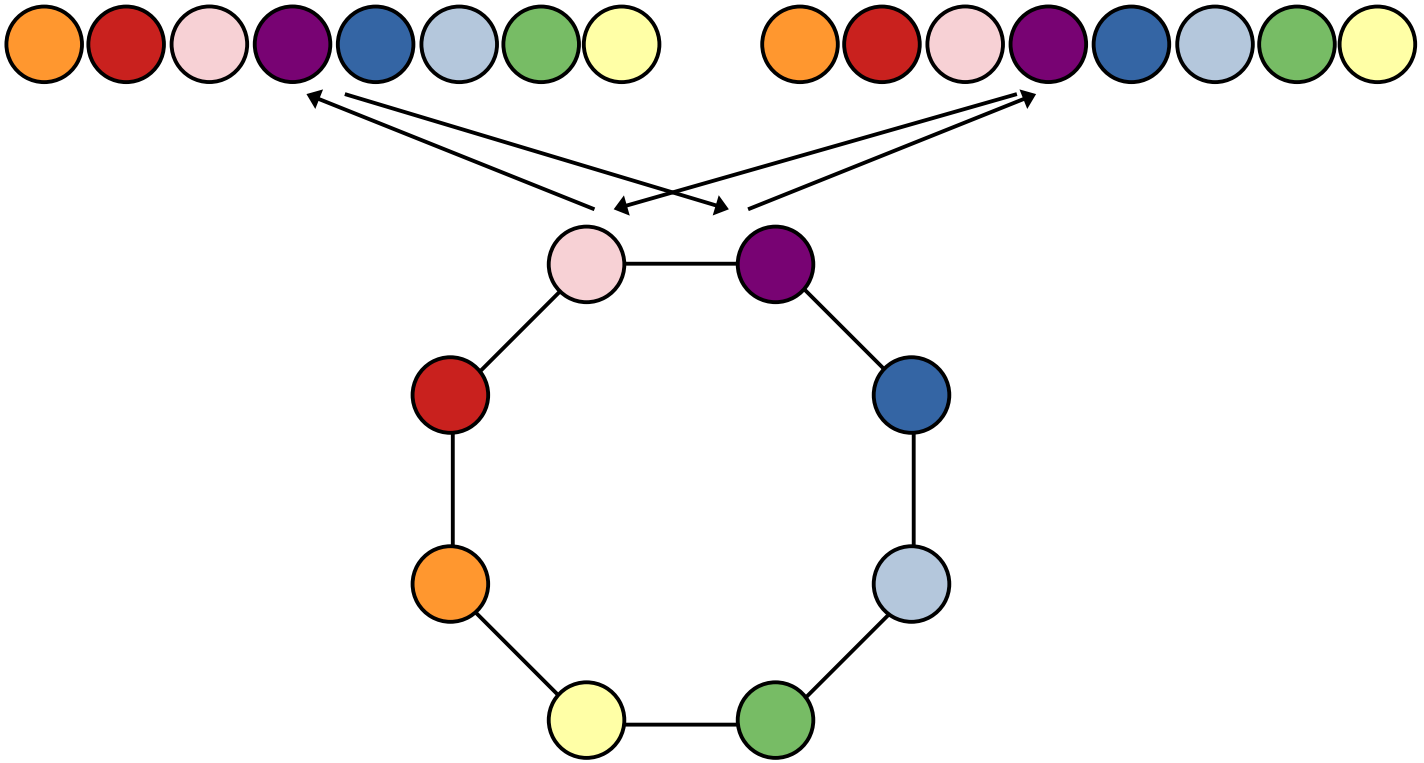


Hulse et al. 2021

Application 2: Shifts

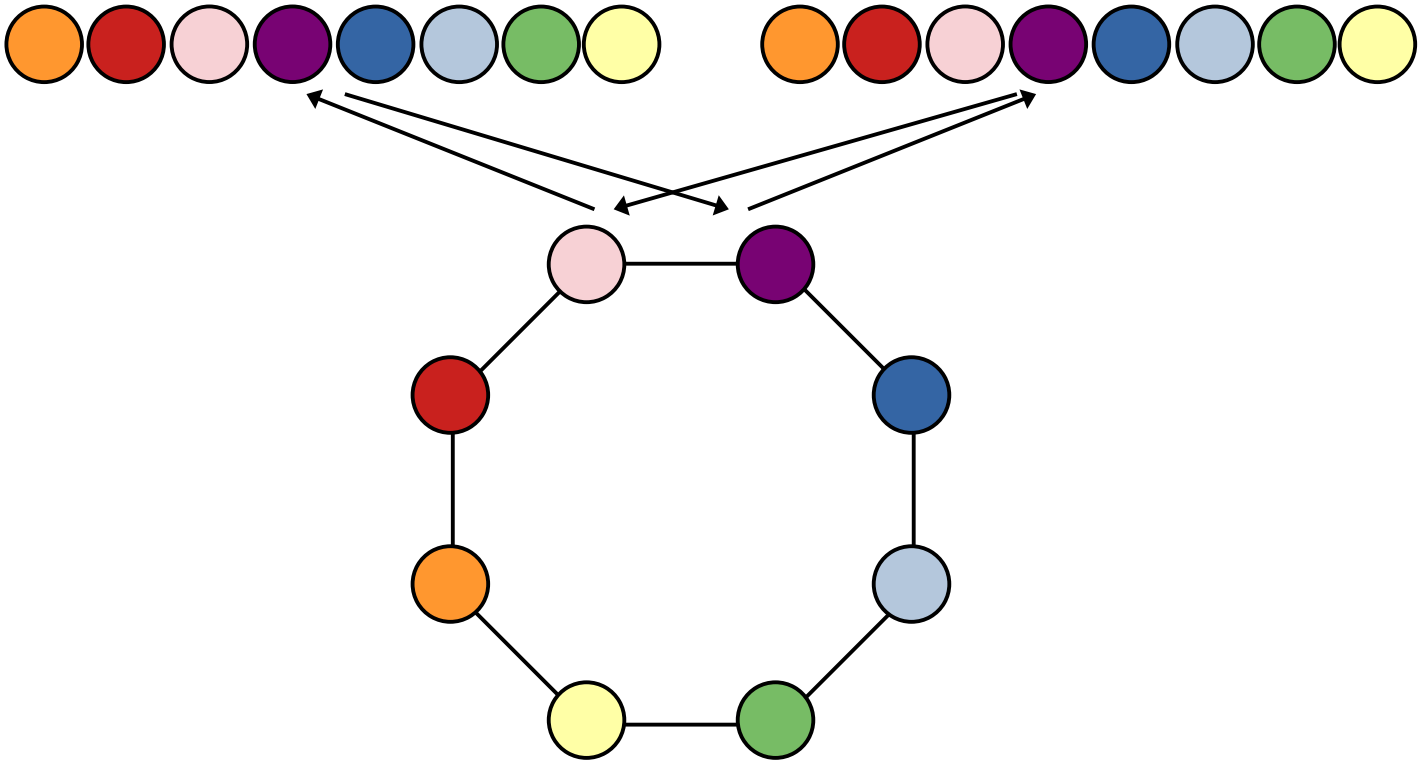


Hulse et al. 2021



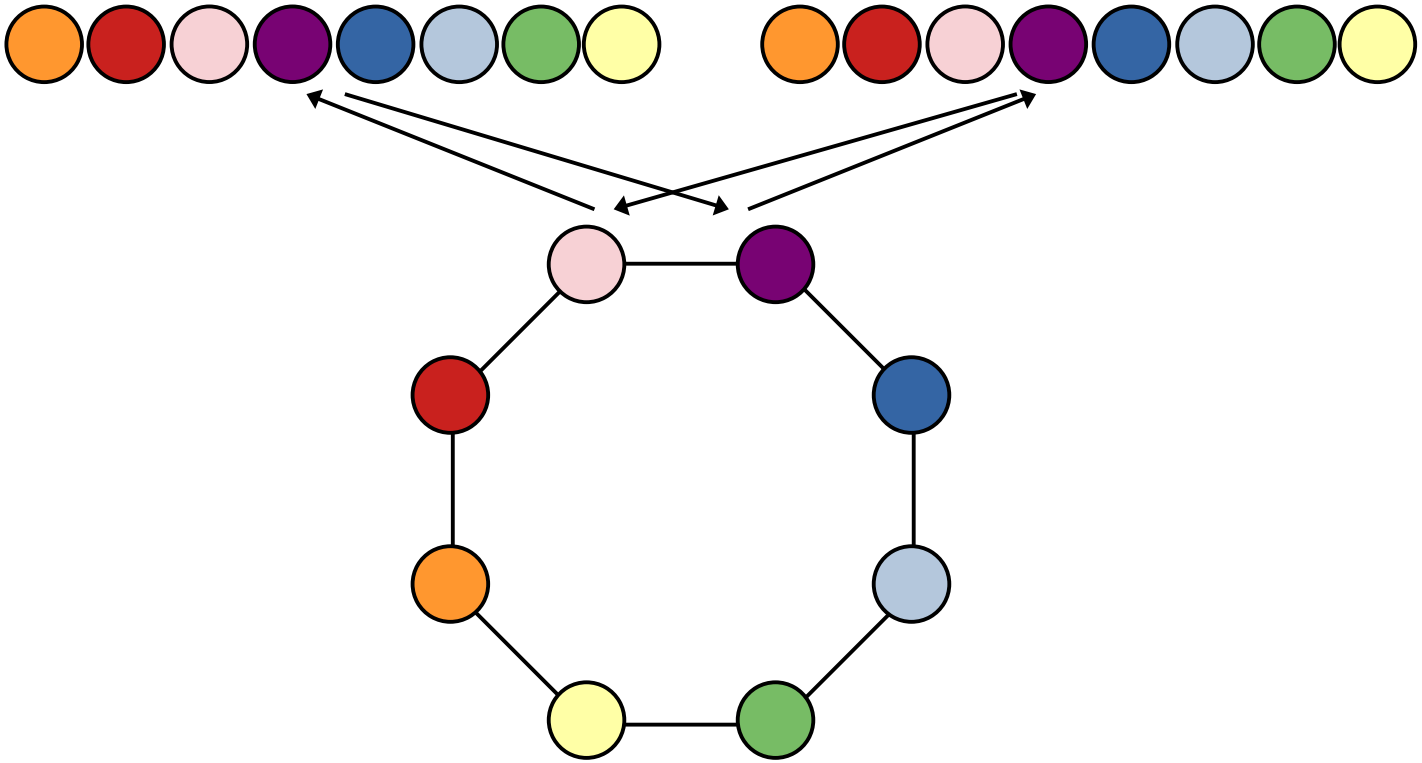
Application 2: Shifts

$$f = A_{c_i,c_j} \exp(\|\mathbf{z}_i - \mathbf{z}_j\|^2 / \sigma^2_{c_i,c_j}) + B_{c_i,c_j}$$



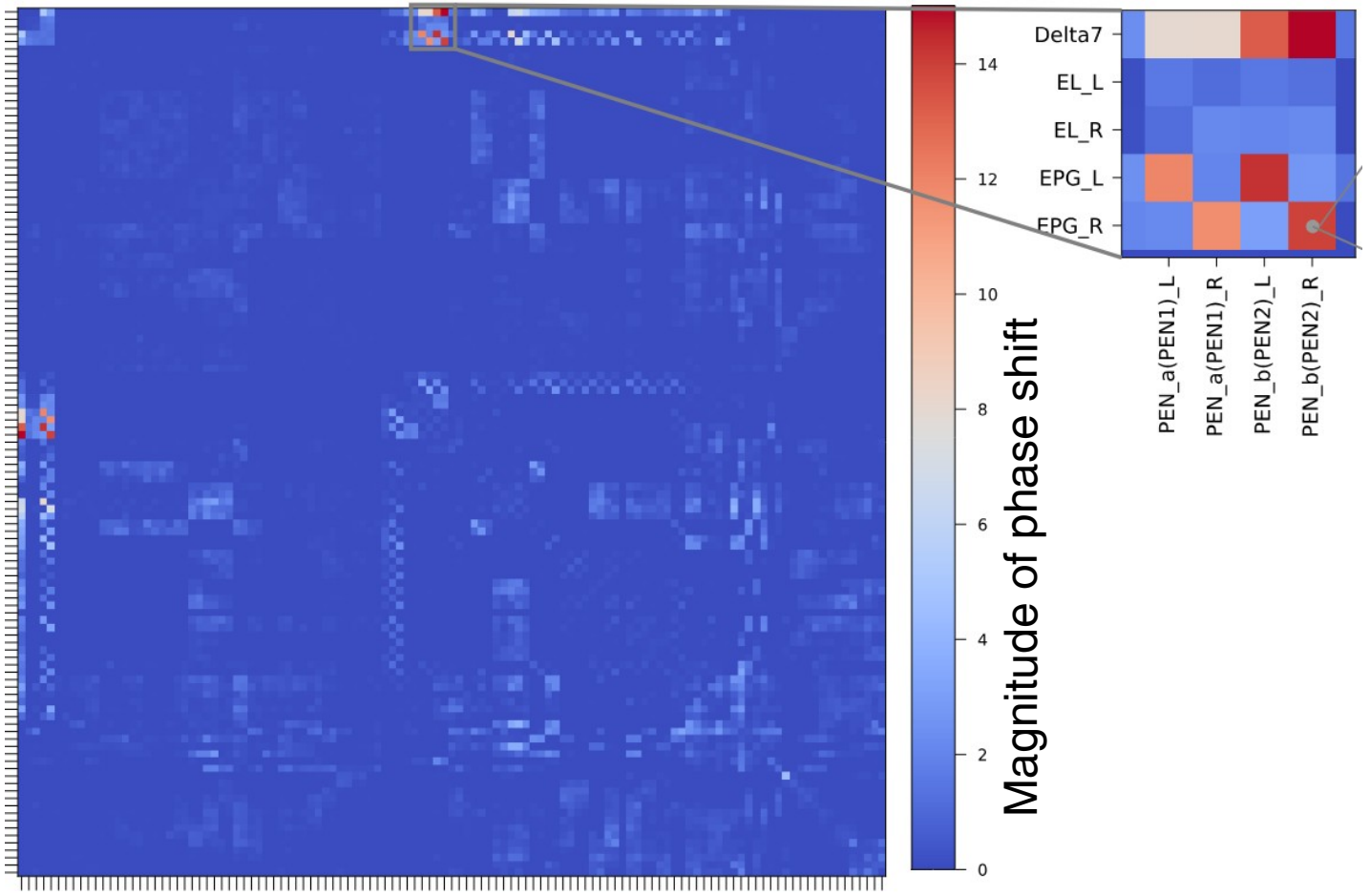
Application 2: Shifts

$$f = A_{c_i,c_j} \exp(\left\| \mathbf{z}_i - R_{c_i,c_j} \mathbf{z}_j \right\|^2 / \sigma^2_{c_i,c_j}) + B_{c_i,c_j}$$

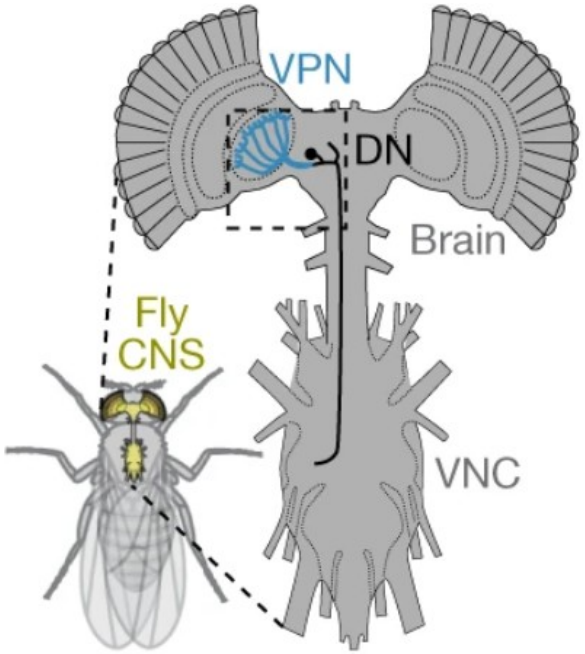


Application 2: Shifts

$$f = A_{c_i,c_j} \exp(\left\| \mathbf{z}_i - R_{c_i,c_j} \mathbf{z}_j \right\|^2 / \sigma^2_{c_i,c_j}) + B_{c_i,c_j}$$

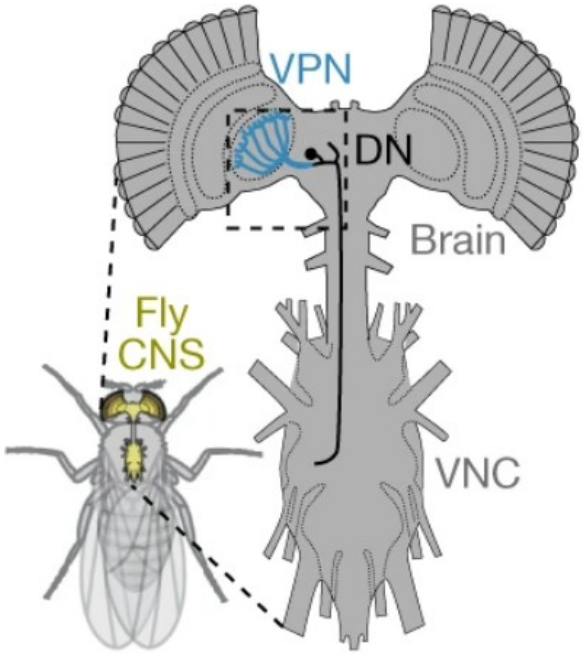


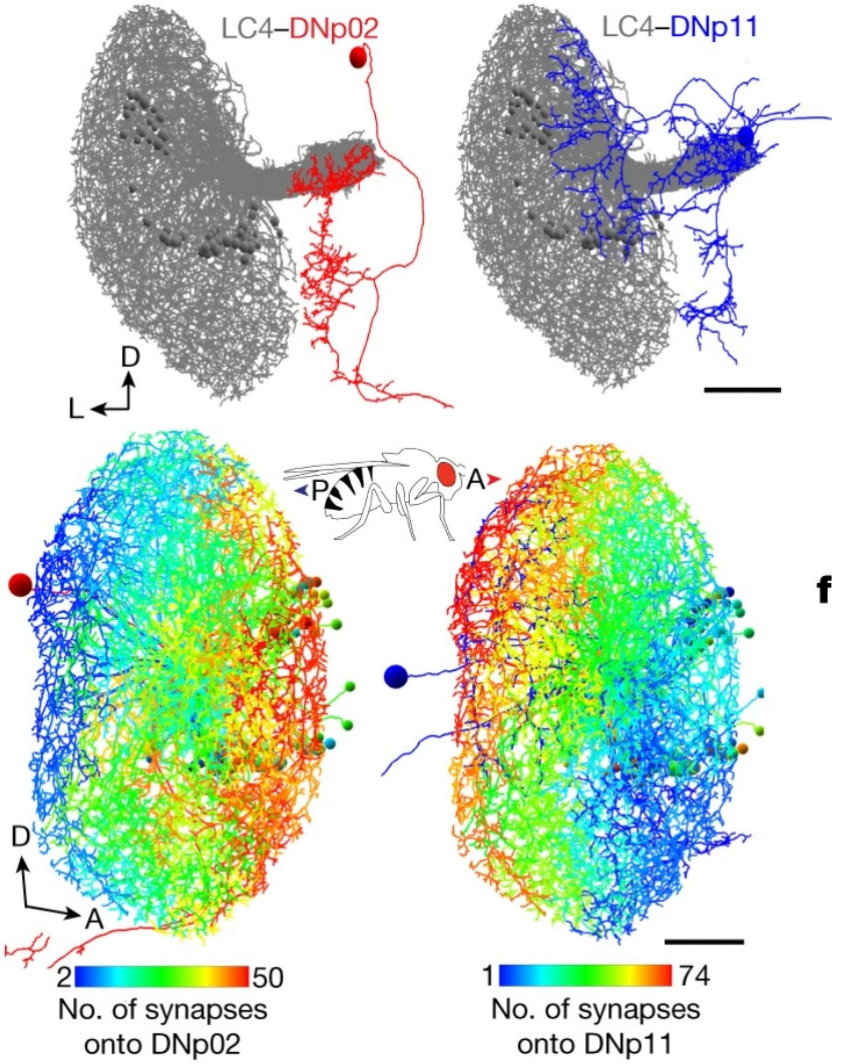
Application 3: Gradients



Dombrovski et al. 2023

Application 3: Gradients

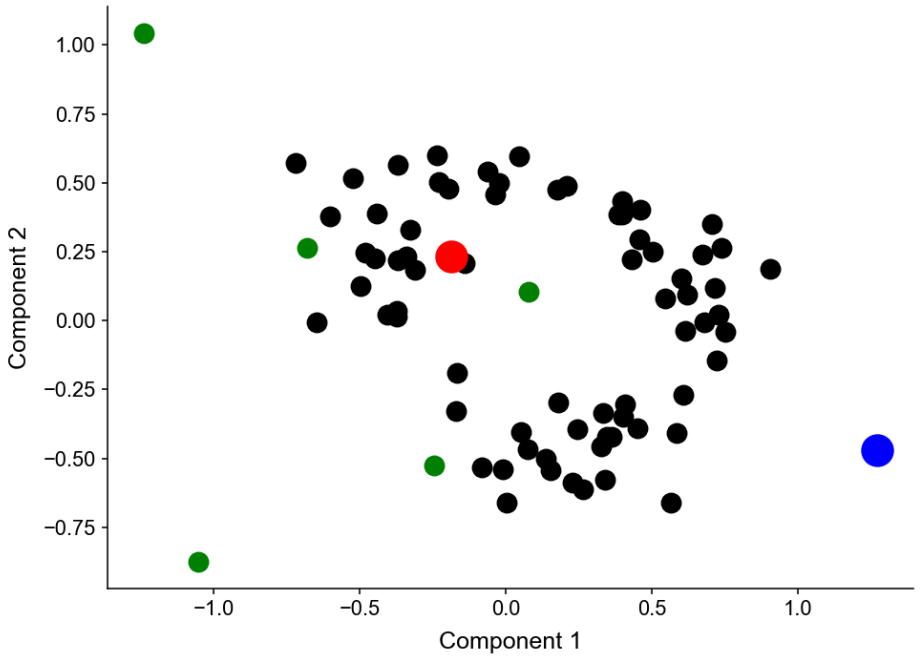


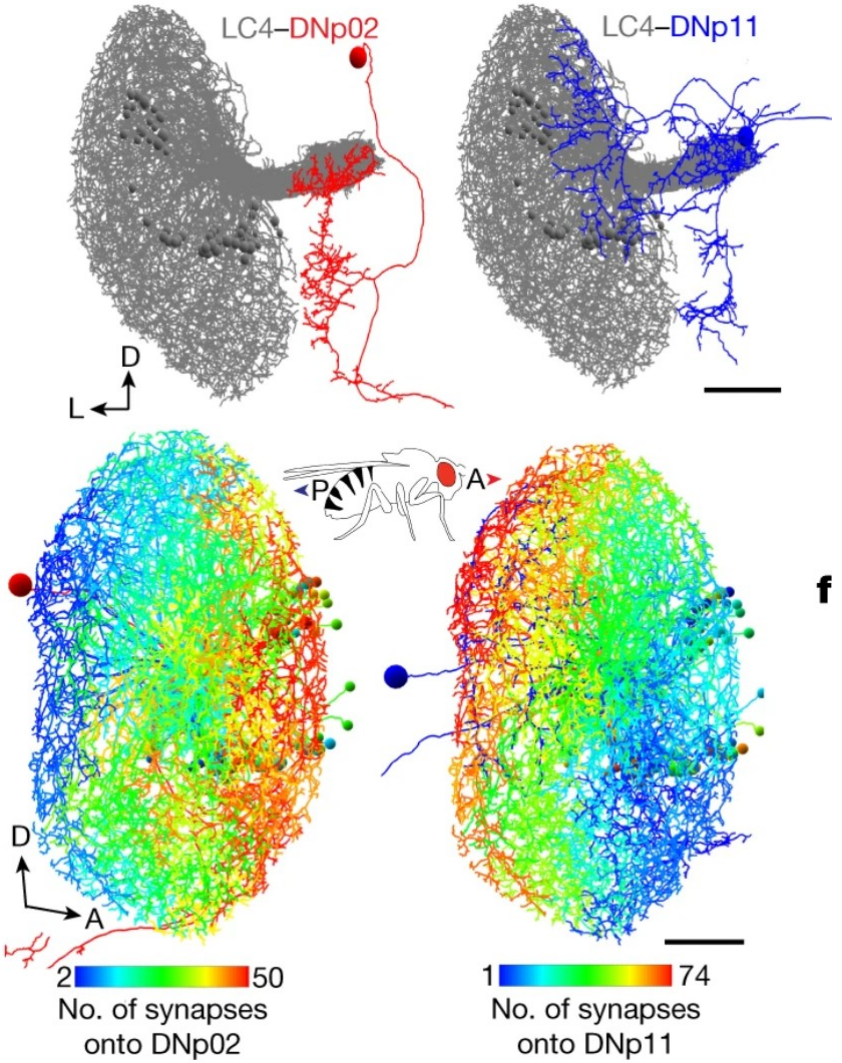


Dombrovski et al. 2023

Application 3: Gradients

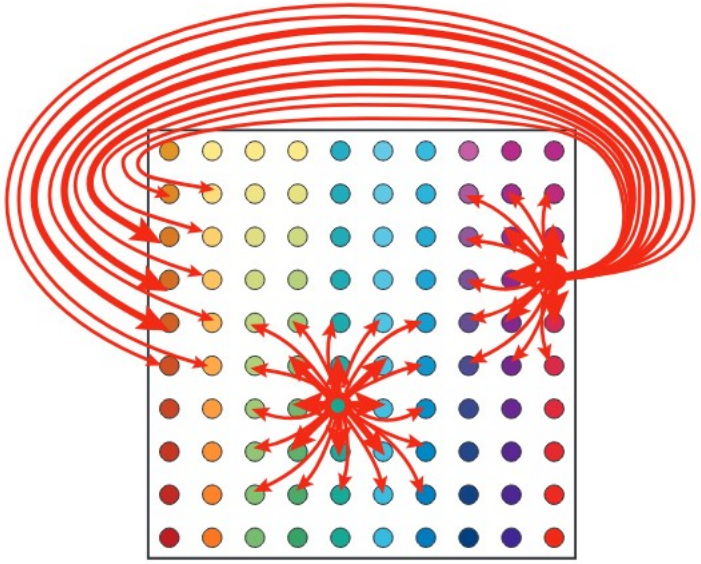
Visual projection neurons (LC4)
Descending neurons (DNp02, DNp11)

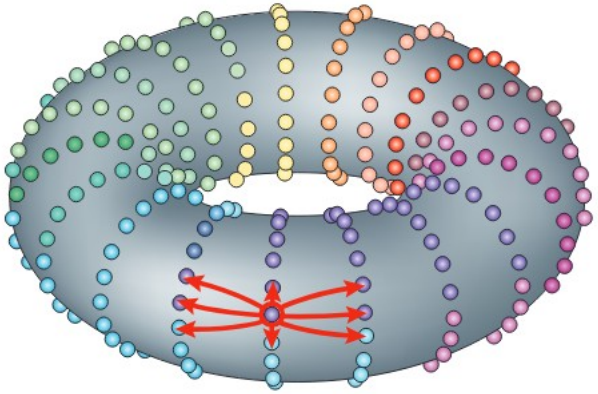




Dombrovski et al. 2023

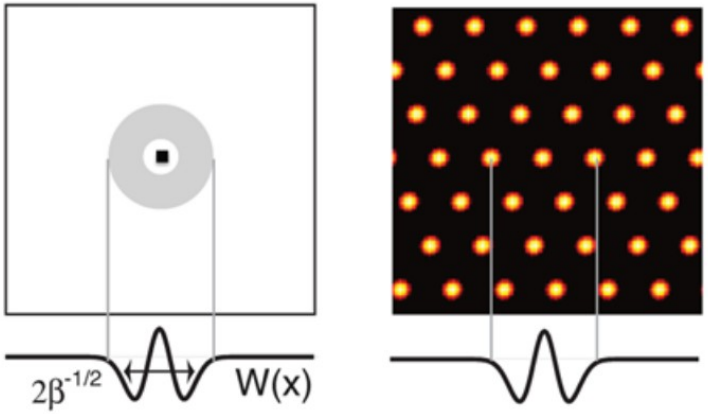
Application 4: Grid cells





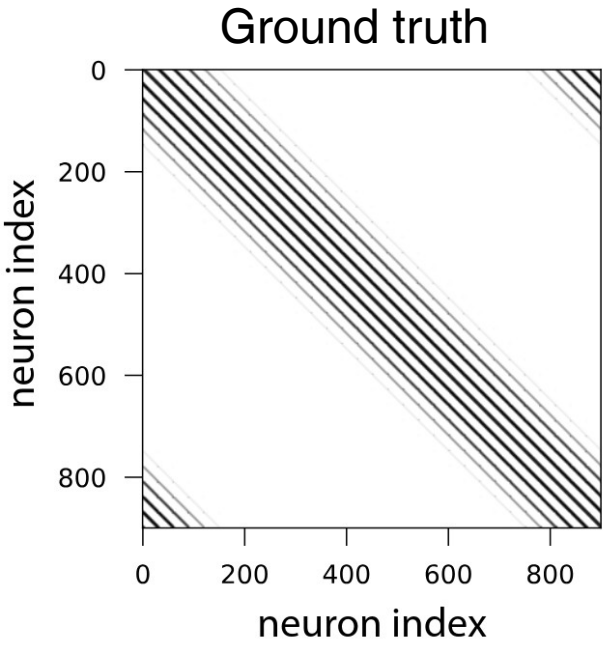
McNaughton et al. 2006

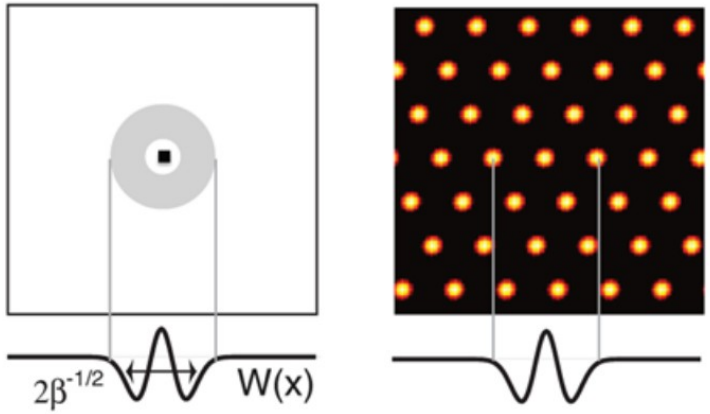
Application 4: Grid cells



Burak & Fiete 2009

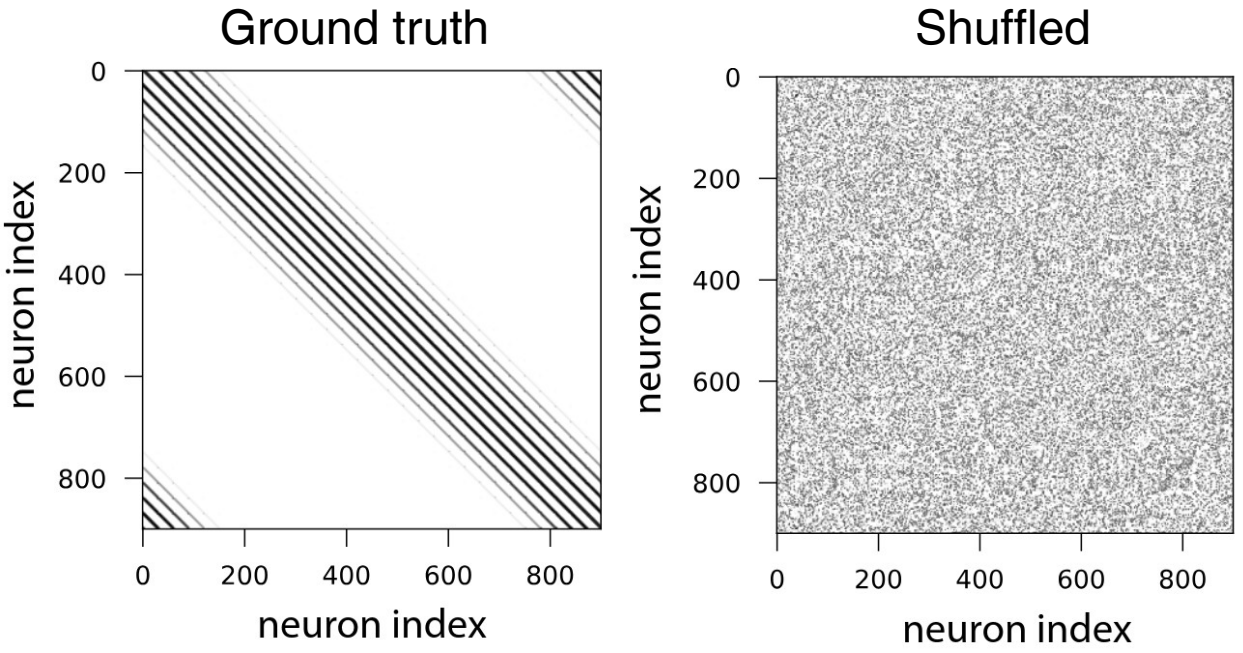
Application 4: Grid cells

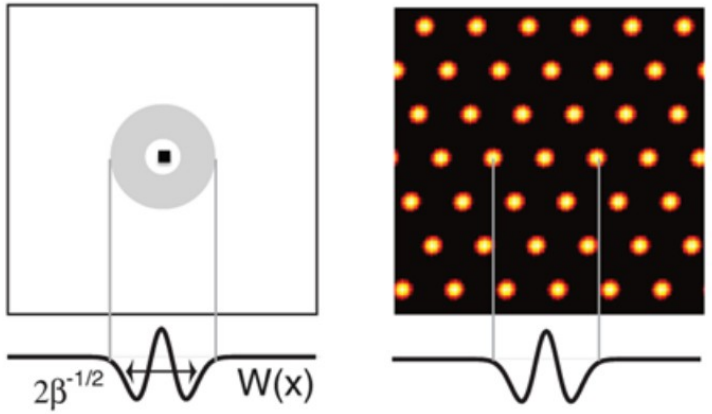




Burak & Fiete 2009

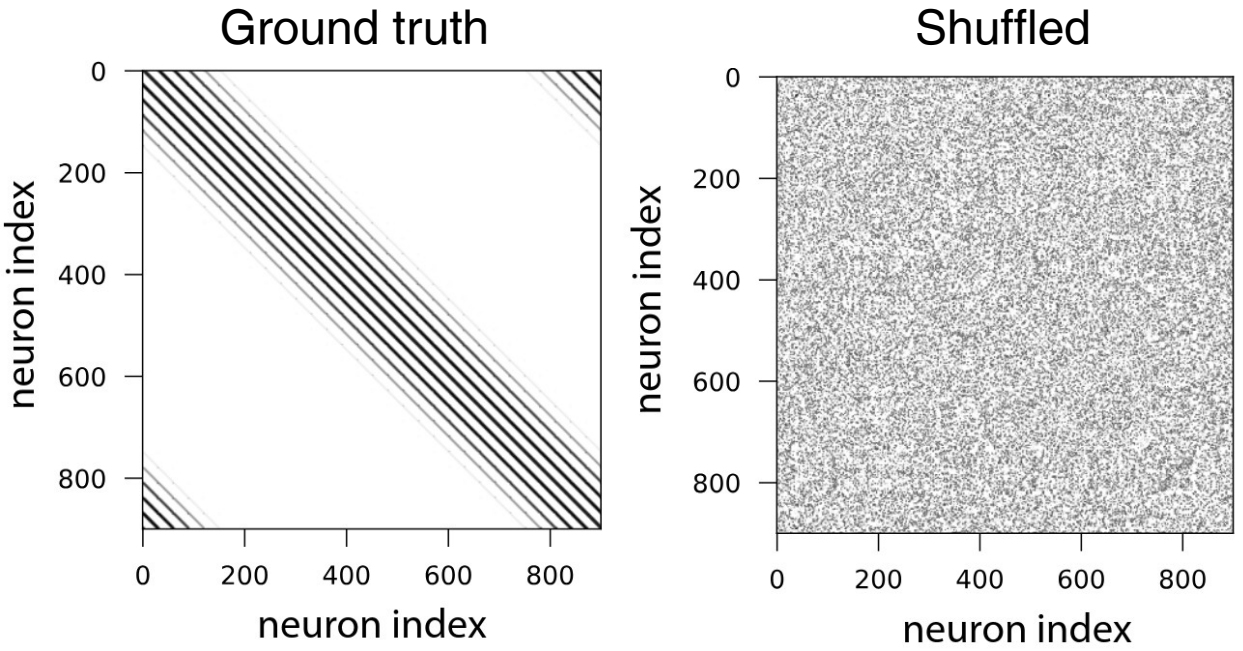
Application 4: Grid cells

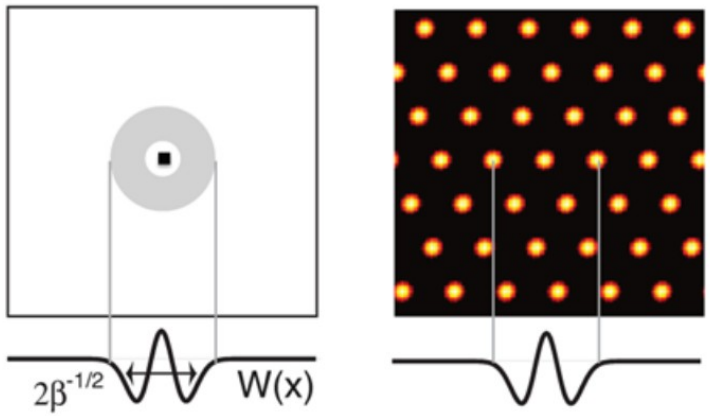




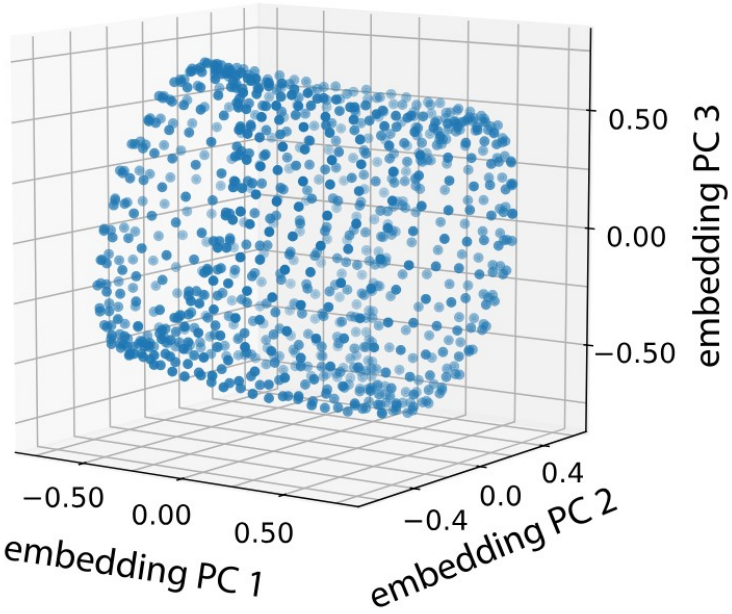
Burak & Fiete 2009

Application 4: Grid cells

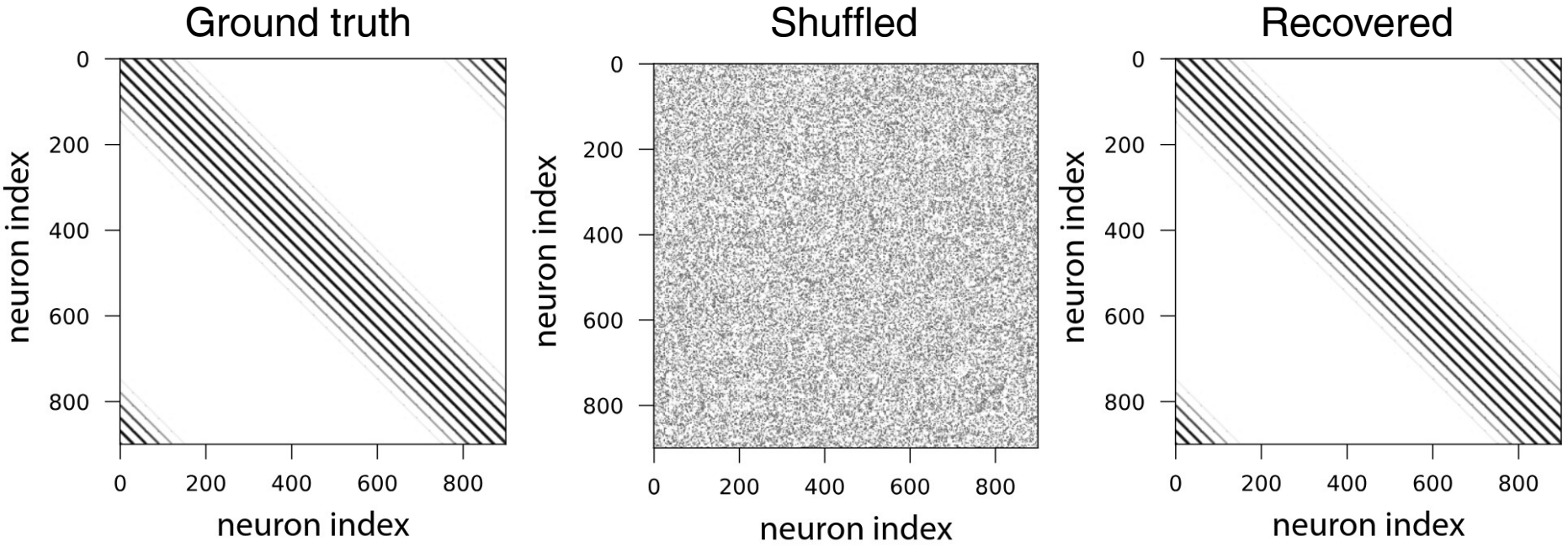


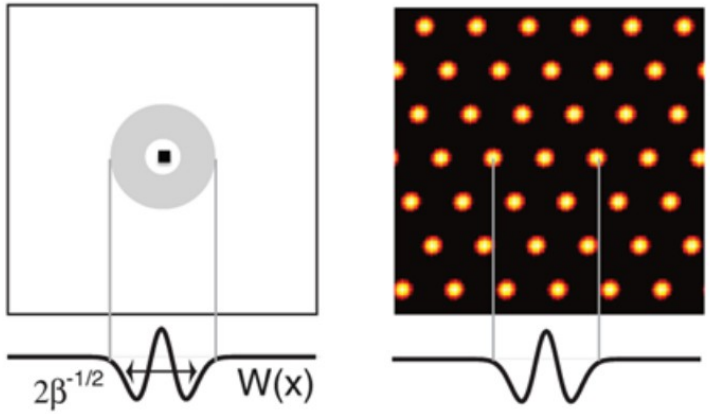


Burak & Fiete 2009

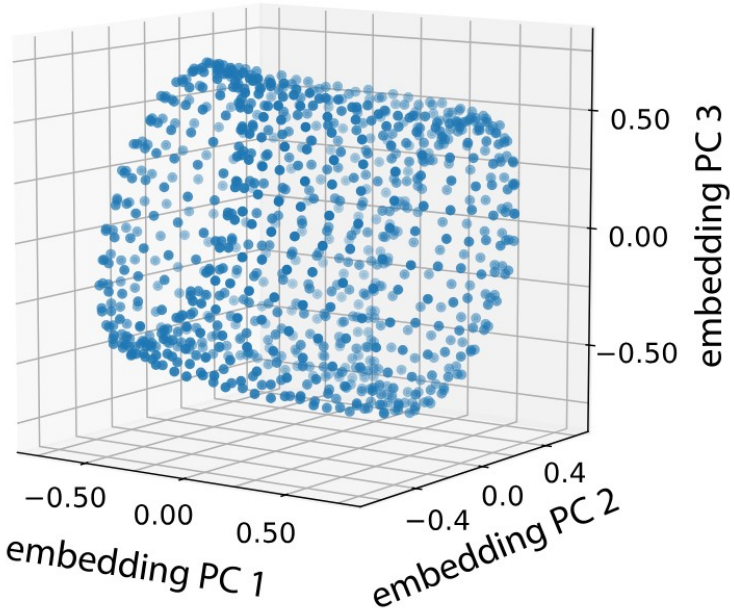


Application 4: Grid cells





Burak & Fiete 2009



Haozhe Shan