Activations of deep convolutional neural networks are **aligned** with gamma band activity of human visual cortex

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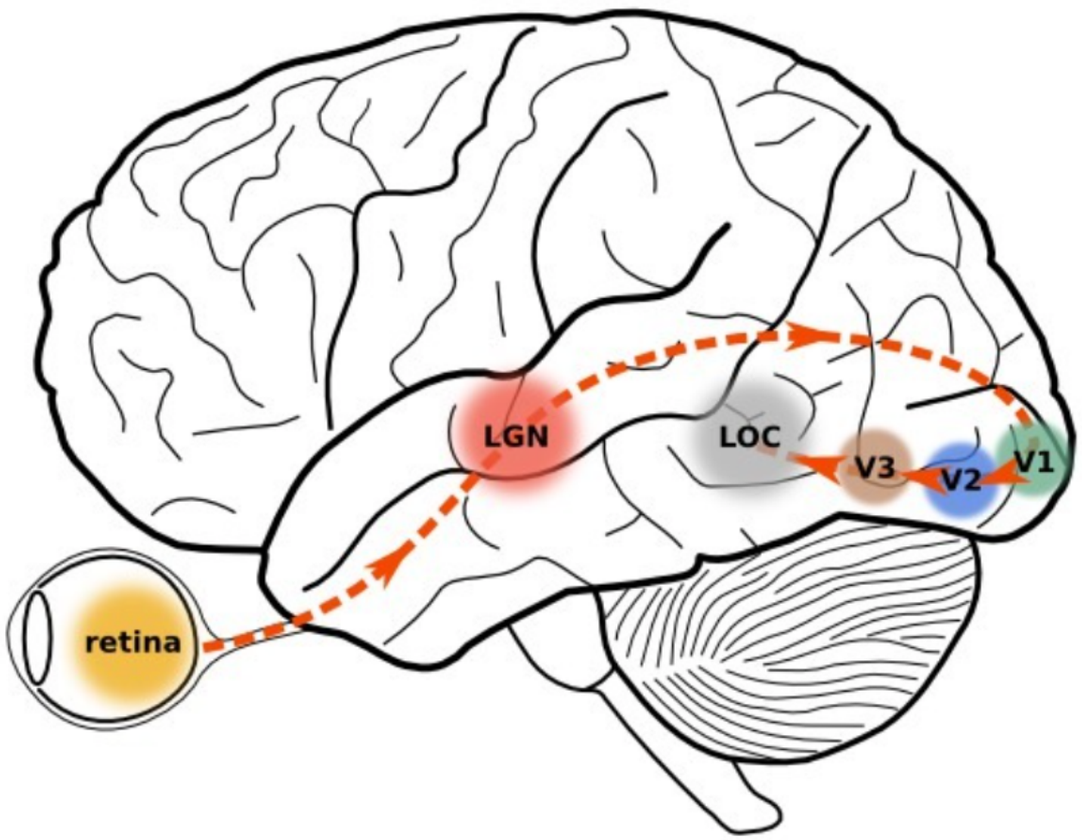
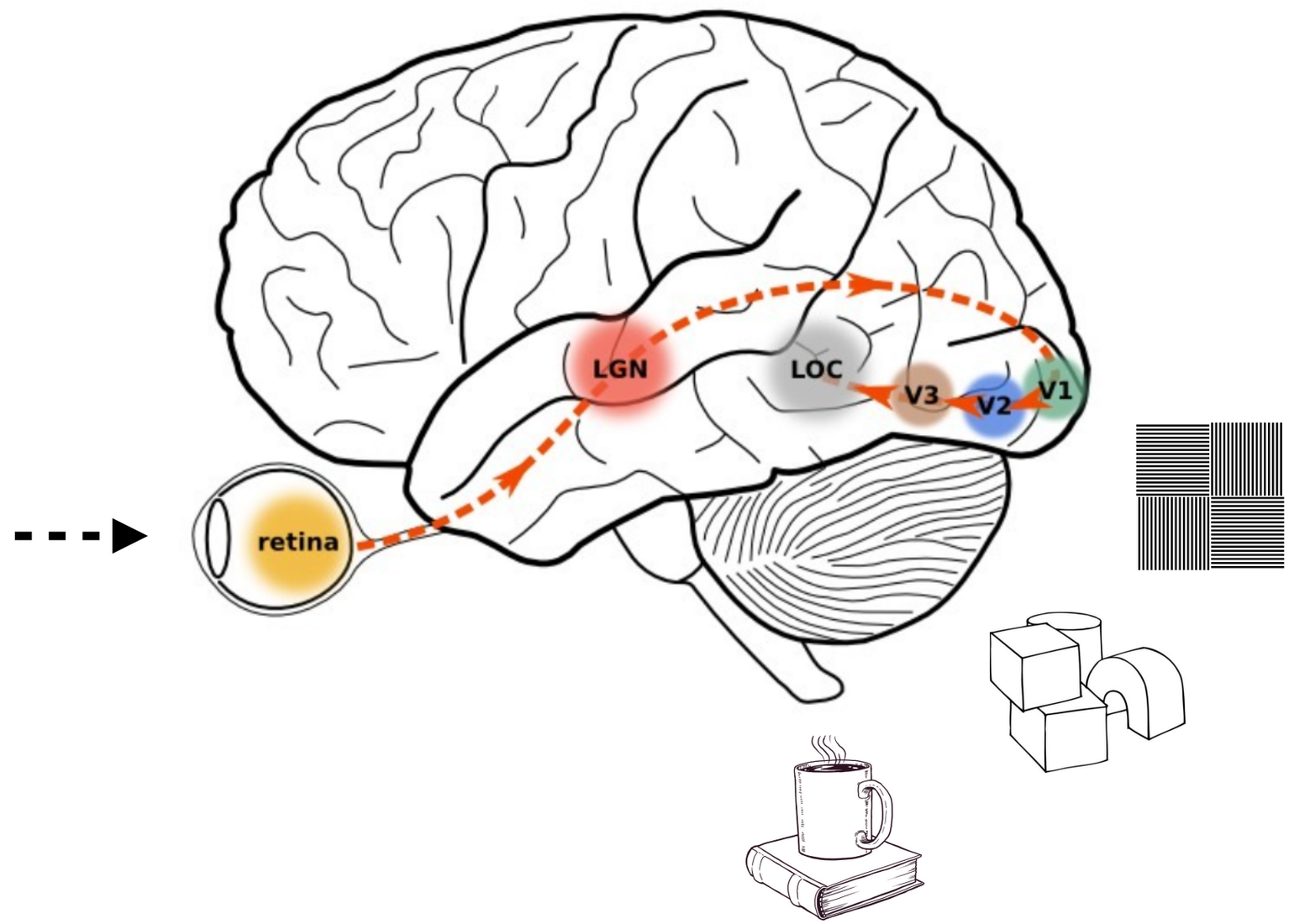
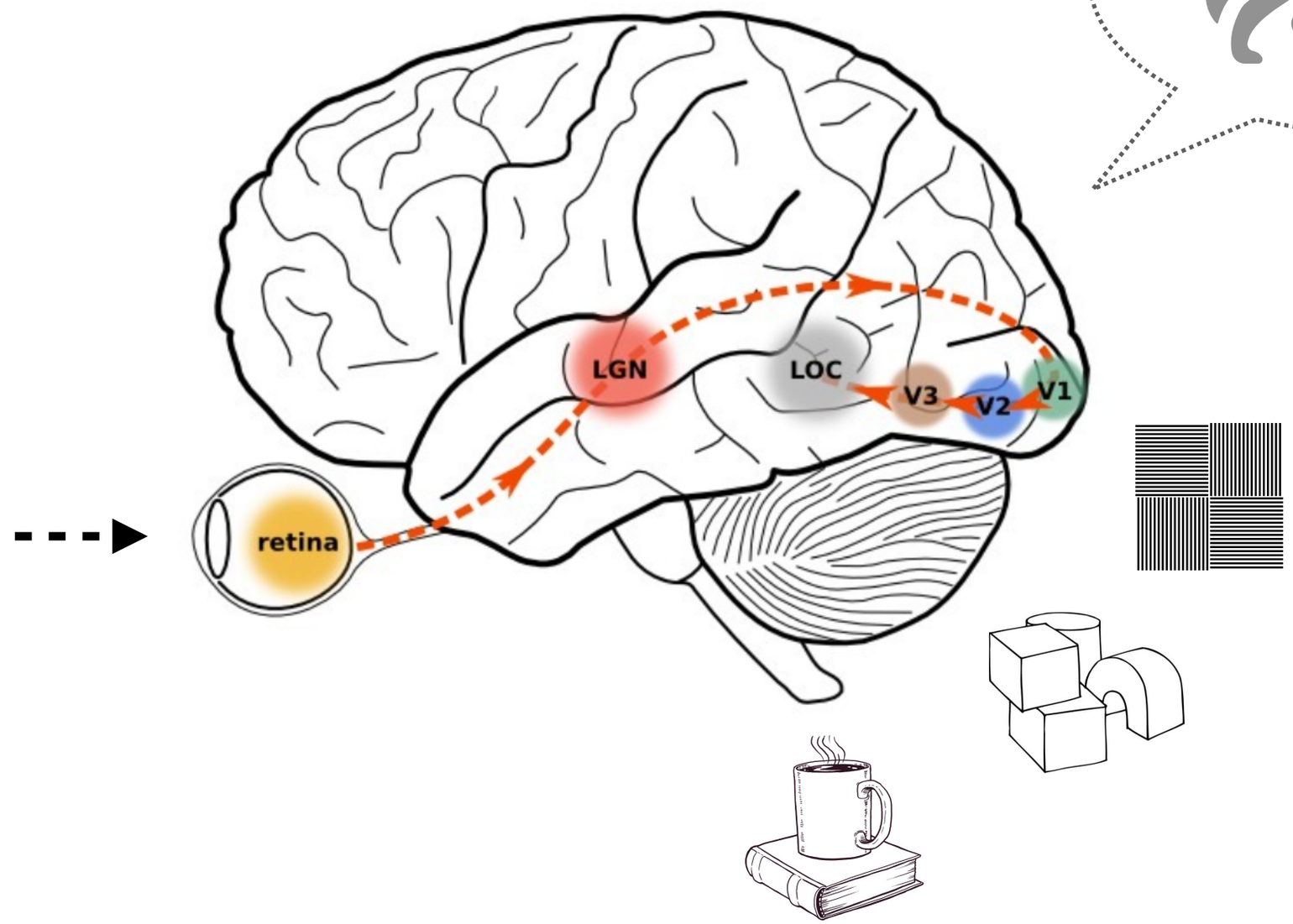
Centre de Recherche Neurosciences Lyon

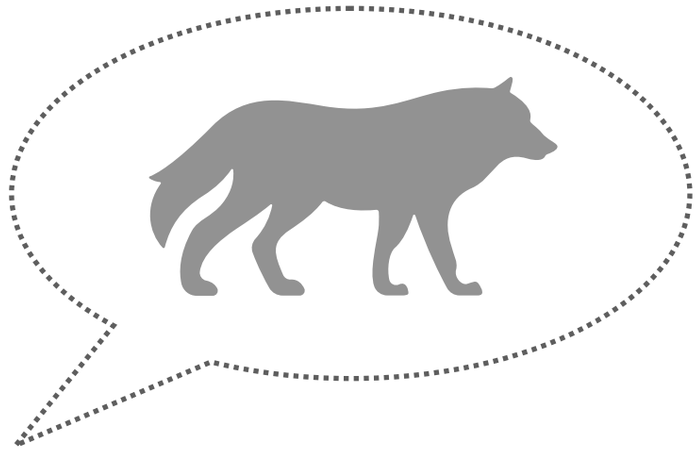


Biological system of vision

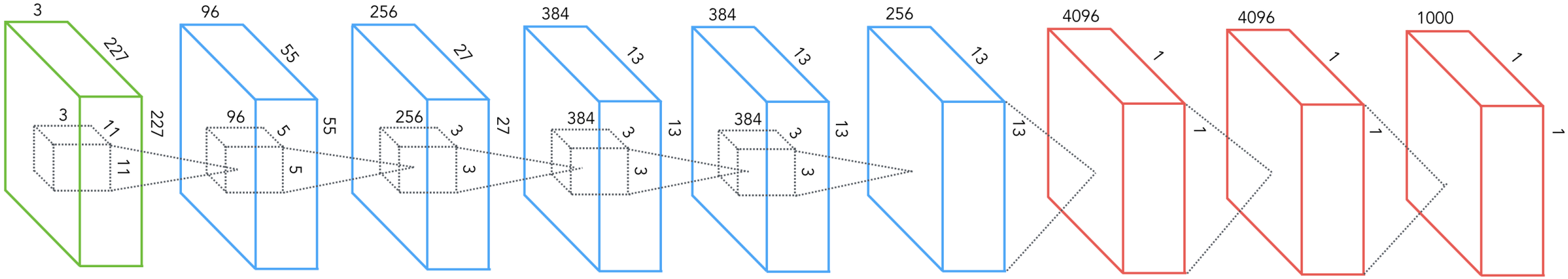


Biological system of vision

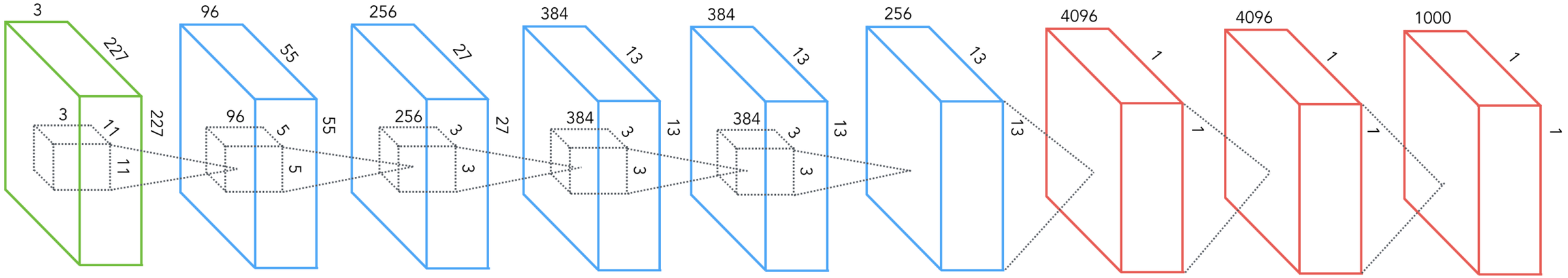




Biological system of vision



Artificial system of vision



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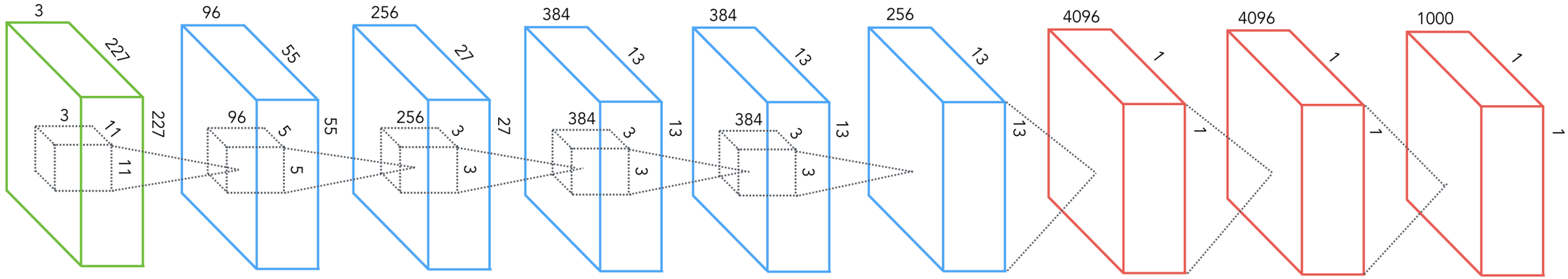

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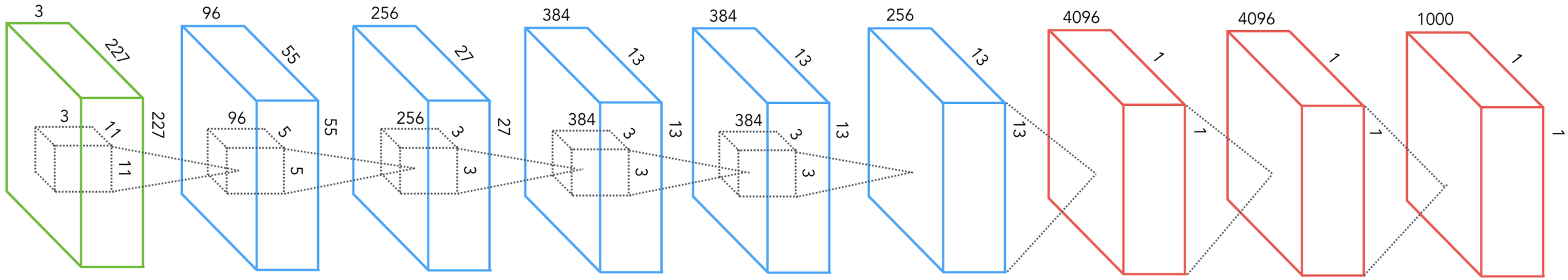

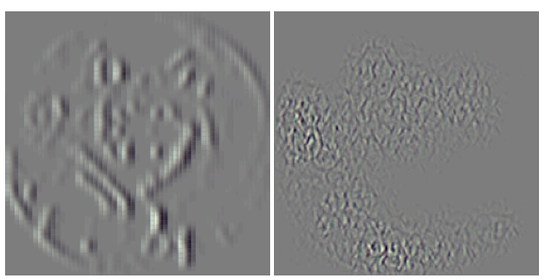

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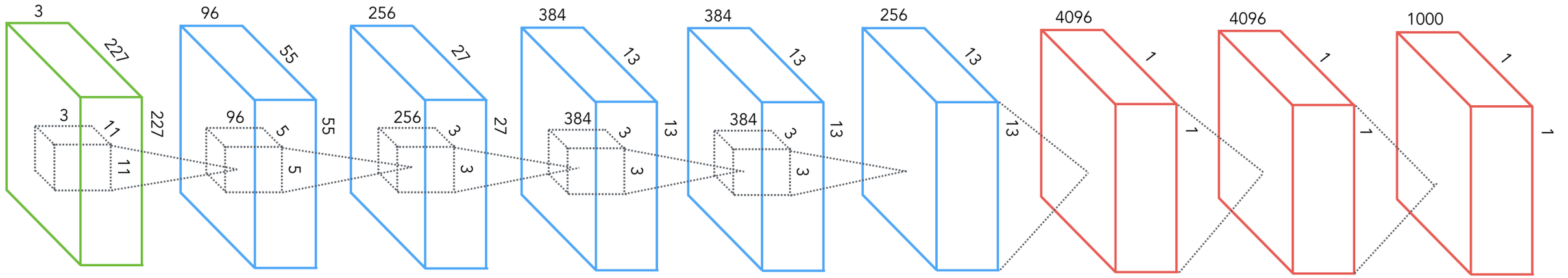
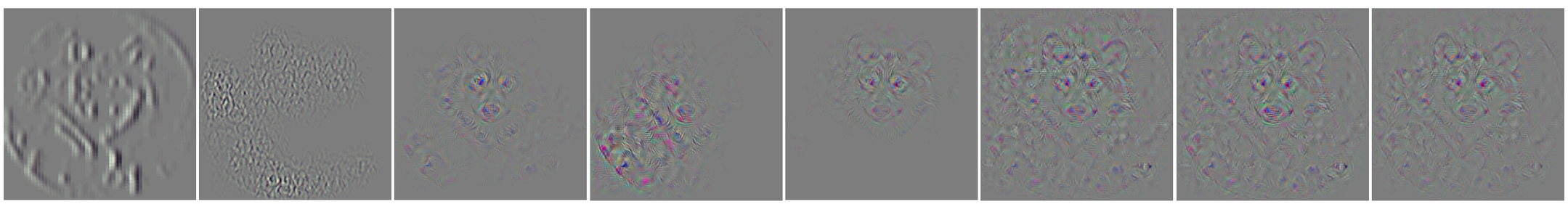
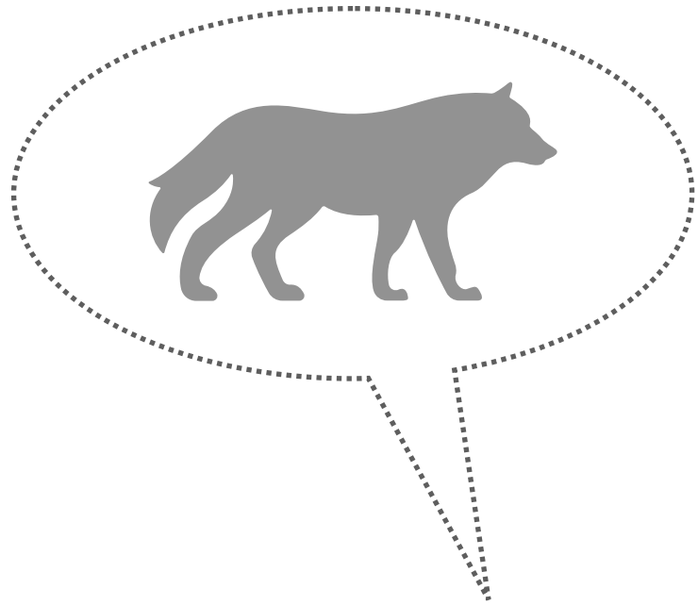
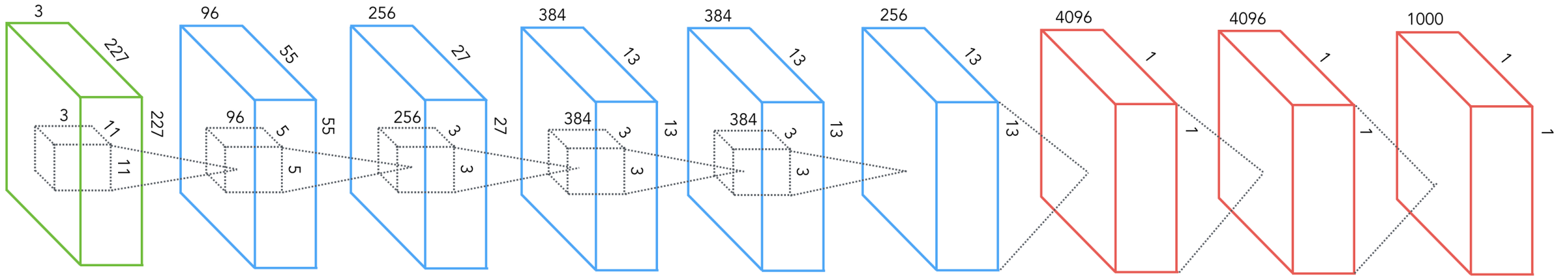
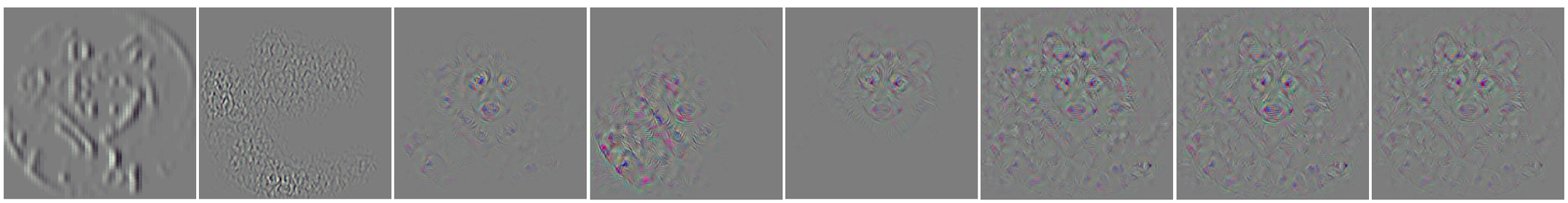




Artificial system of vision



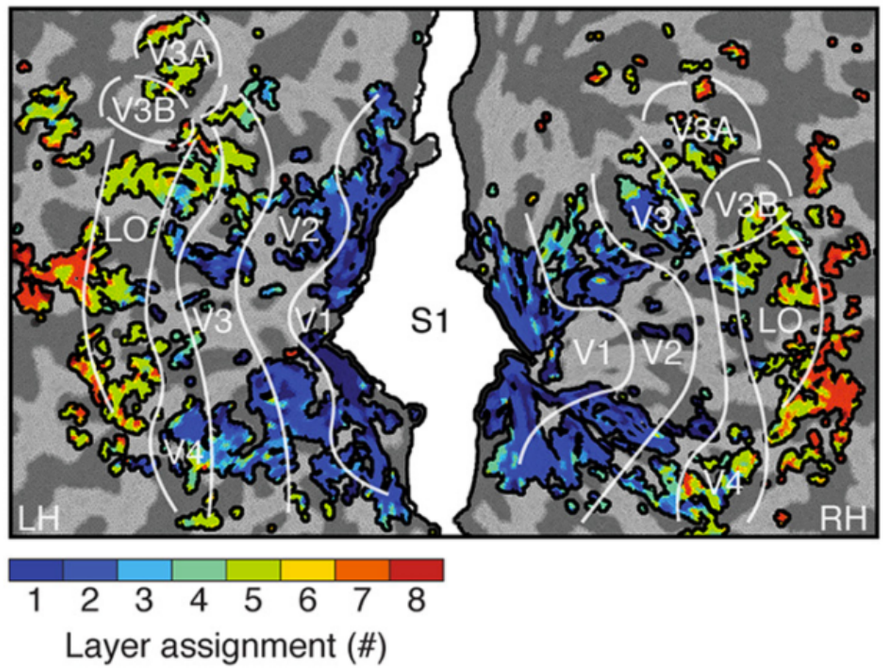




Artificial system of vision

Is there a correspondence between the hierarchies of features of artificial and biological systems of vision?

Güçlü, U. & van Gerven, M. A.
Deep neural networks reveal a gradient in the complexity of neural representations across the ventral stream.
J. Neurosci. 35, 10005–10014 (2015).



Cichy, R. M., Khosla, A., Pantazis, D., Torralba, A. & Oliva, A.
Comparison of deep neural networks to spatio-temporal cortical dynamics of human visual object recognition reveals hierarchical correspondence.
Sci. Rep. 6, (2016).

Yamins, D. L. & DiCarlo, J. J.
Using goal-driven deep learning models to understand sensory cortex.
Nat. Neurosci. 19, 356–365 (2016).

Eickenberg, M., Gramfort, A., Varoquaux, G. & Thirion, B.
Seeing it all: convolutional network layers map the function of the human visual system.
Neuroimage 152, 184–194 (2016)

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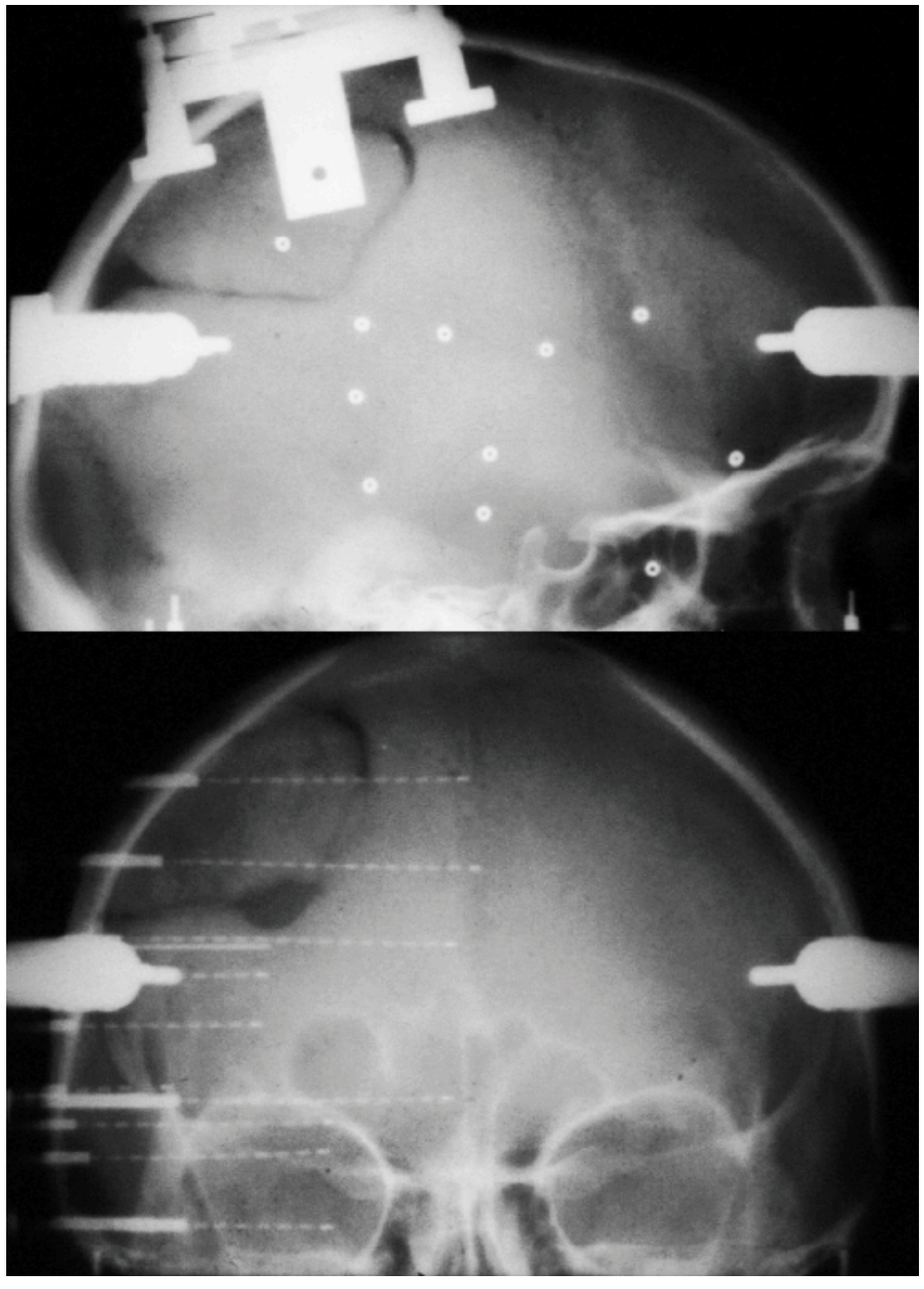
x100



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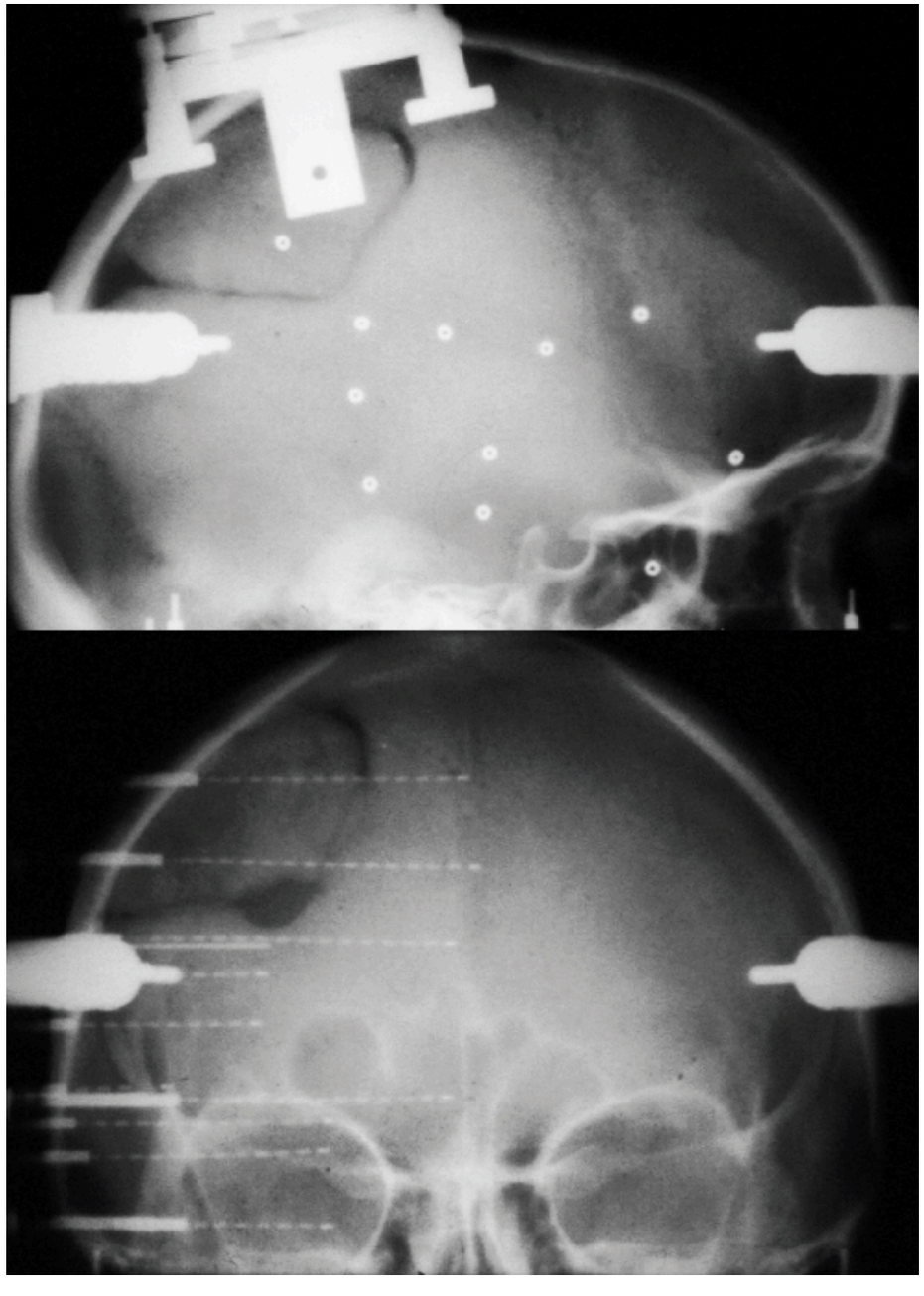
x100



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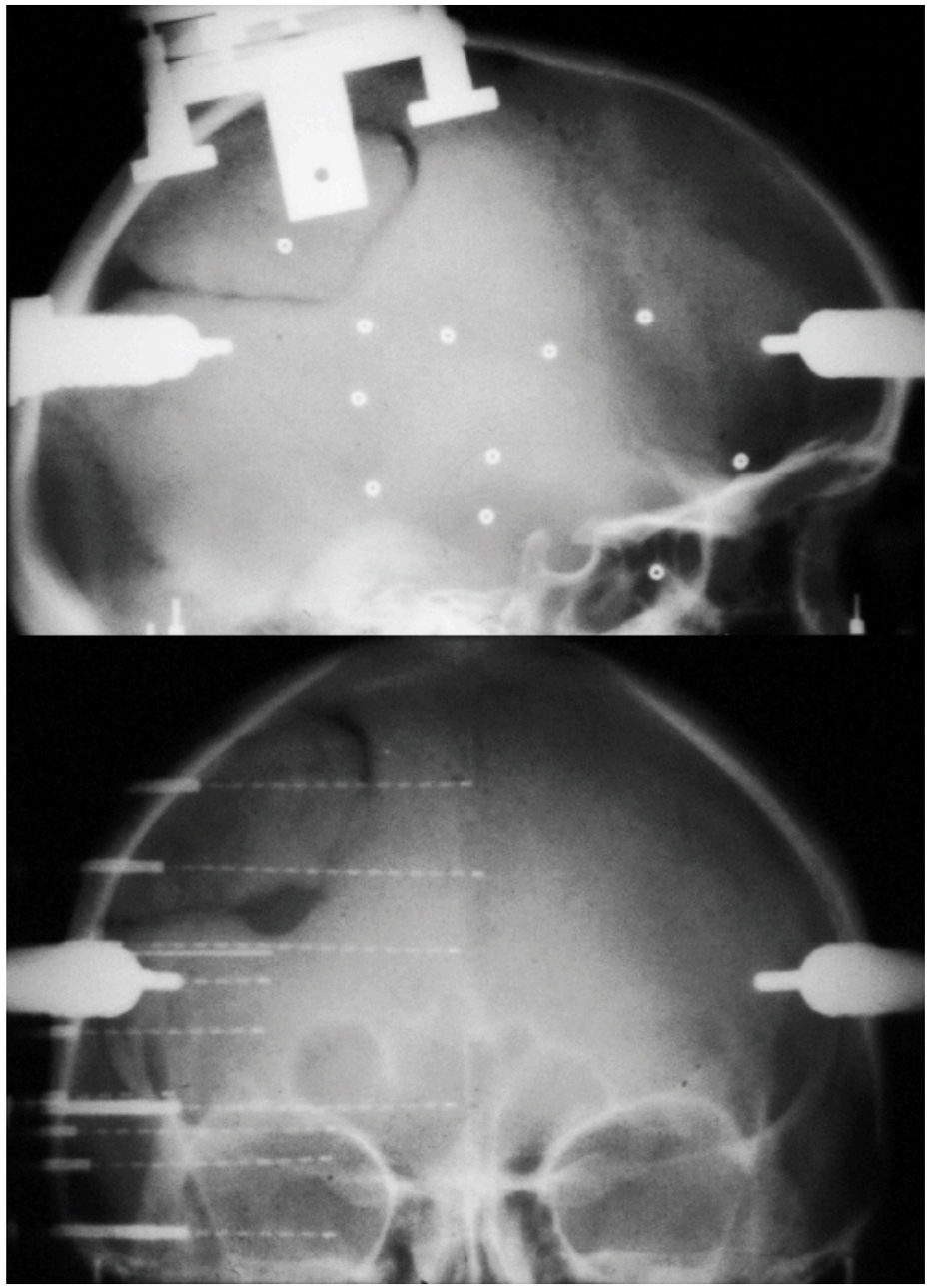
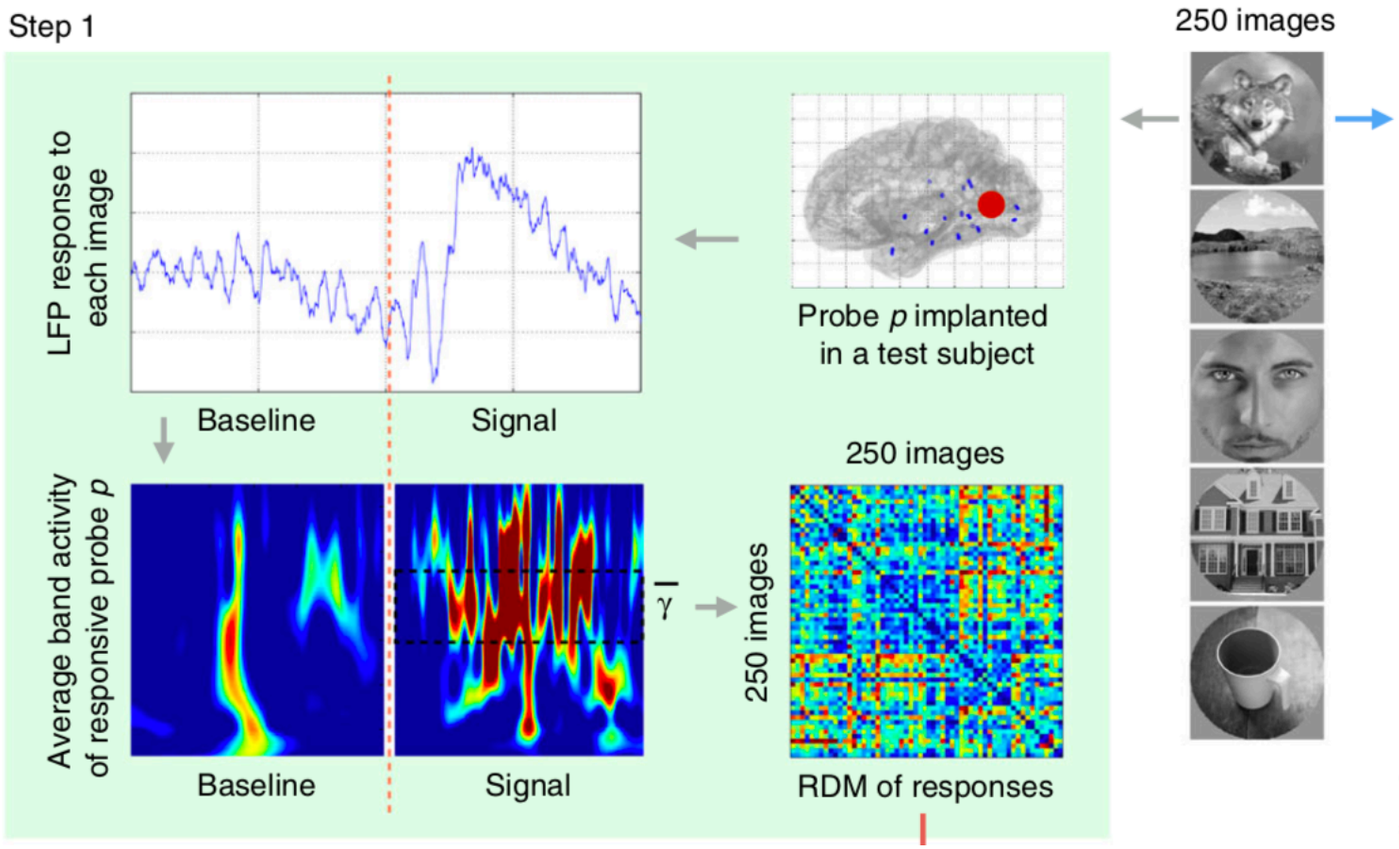
x100

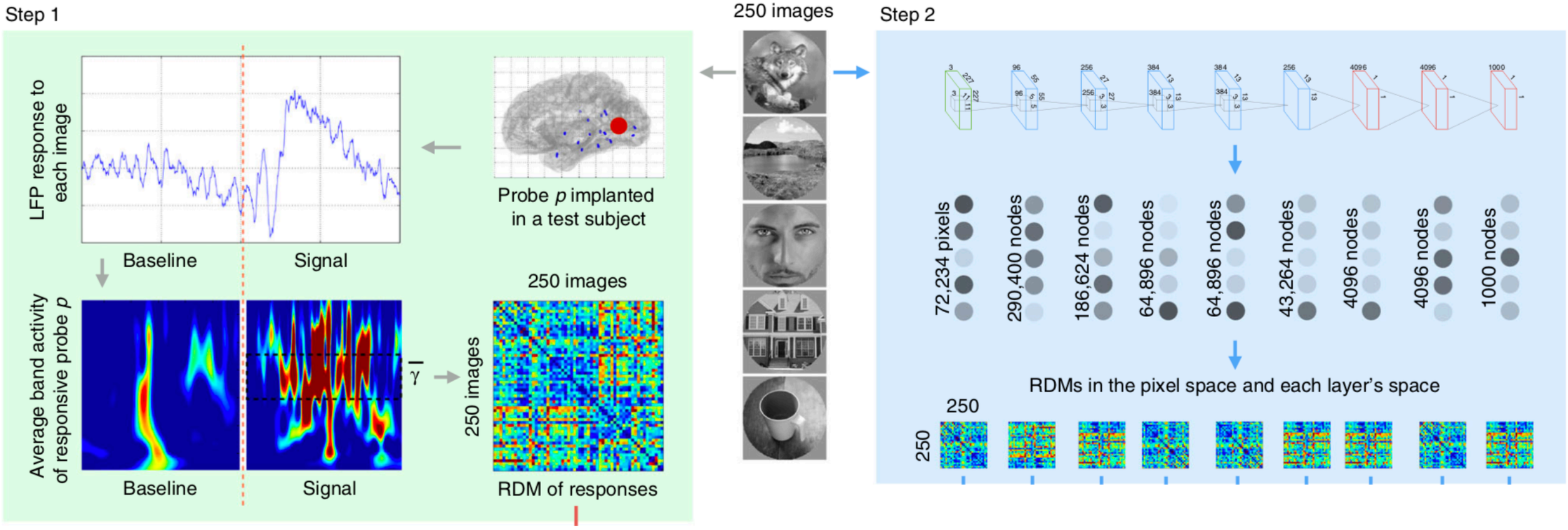


~100
probes per
subject

9073
probes total

250 images


Step 1
LFP response to each image
Baseline
Signal
Probe p implanted in a test subject
250 images
Average band activity of responsive probe p
Baseline
Signal
γ
250 images
250 images
RDM of responses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LFP response to each image
Baseline
Signal
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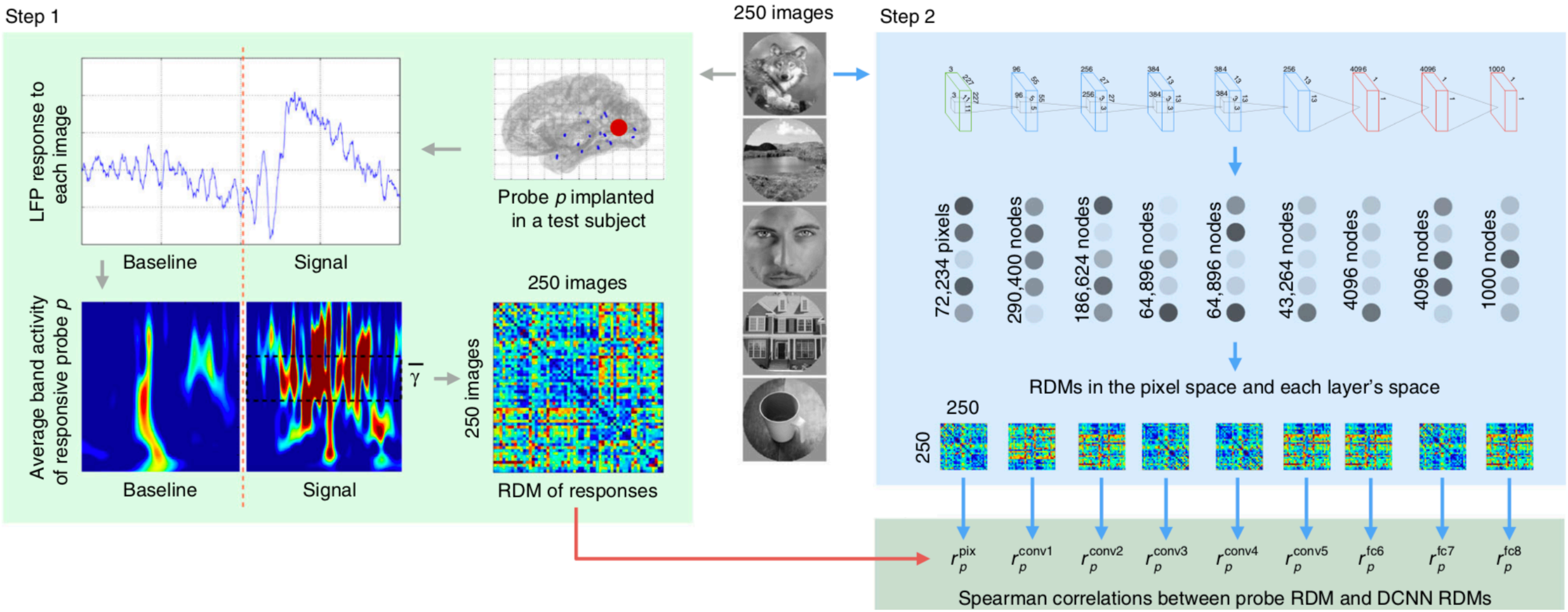
250 images
Average band activity of responsive probe p
Baseline
Signal
γ
250 images
250 images
RDM of responses
Step 2
72,234 pixels
290,400 nodes
186,624 nodes
64,896 nodes
64,896 nodes
43,264 nodes
4096 nodes
4096 nodes
1000 nodes
RDMs in the pixel space and each layer's space
250
250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4096 nodes
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RDMs in the pixel space and each layer's space
250
250
r_p^{pix} r_p^{conv1} r_p^{conv2} r_p^{conv3} r_p^{conv4} r_p^{conv5} r_p^{fc6} r_p^{fc7} r_p^{fc8}
Spearman correlations between probe RDM and DCNN RDMs

Step 1

LFP response to each image

Baseline

Signal

Average band activity of responsive probe *p*

Baseline

Signal

$\overline{\gamma}$

Probe *p* implanted in a test subject

250 images

250 images

RDM of responses

250 images

Step 2

72,234 pixels

290,400 nodes

186,624 nodes

64,896 nodes

64,896 nodes

43,264 nodes

4096 nodes

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1000 nodes

RDMs in the pixel space and each layer's space

250

250

r_p^{pix} r_p^{conv1} r_p^{conv2} r_p^{conv3} r_p^{conv4} r_p^{conv5} r_p^{fc6} r_p^{fc7} r_p^{fc8}

Spearman correlations between probe RDM and DCNN RDMs

Step 3

10,000 permutations to assess the significance of correlation between RDMs

Step 1

LFP response to each image

Baseline

Signal

Average band activity of responsive probe *p*

Baseline

Signal

$\overline{\gamma}$

Probe *p* implanted in a test subject

250 images

250 images

RDM of responses

250 images

Step 2

72,234 pixels

290,400 nodes

186,624 nodes

64,896 nodes

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4096 nodes

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1000 nodes

RDMs in the pixel space and each layer's space

250

250

r_p^{pix} r_p^{conv1} r_p^{conv2} r_p^{conv3} r_p^{conv4} r_p^{conv5} r_p^{fc6} r_p^{fc7} r_p^{fc8}

Spearman correlations between probe RDM and DCNN RDMs

Step 3

10,000 permutations to assess the significance of correlation between RDMs

Step 4

MNI coordinates of probe *p*

19

Probe *p* is mapped to a Brodmann area

Step 1

LFP response to each image

Baseline

Signal

Average band activity of responsive probe *p*

Baseline

Signal

$\overline{\gamma}$

Probe *p* implanted in a test subject

250 images

250 images

RDM of responses

250 images

Step 2

72,234 pixels

290,400 nodes

186,624 nodes

64,896 nodes

64,896 nodes

43,264 nodes

4096 nodes

4096 nodes

1000 nodes

RDMs in the pixel space and each layer's space

250

250

Step 3

10,000 permutations to assess the significance of correlation between RDMs

Step 4

MNI coordinates of probe *p*

19

Probe *p* is mapped to a Brodmann area

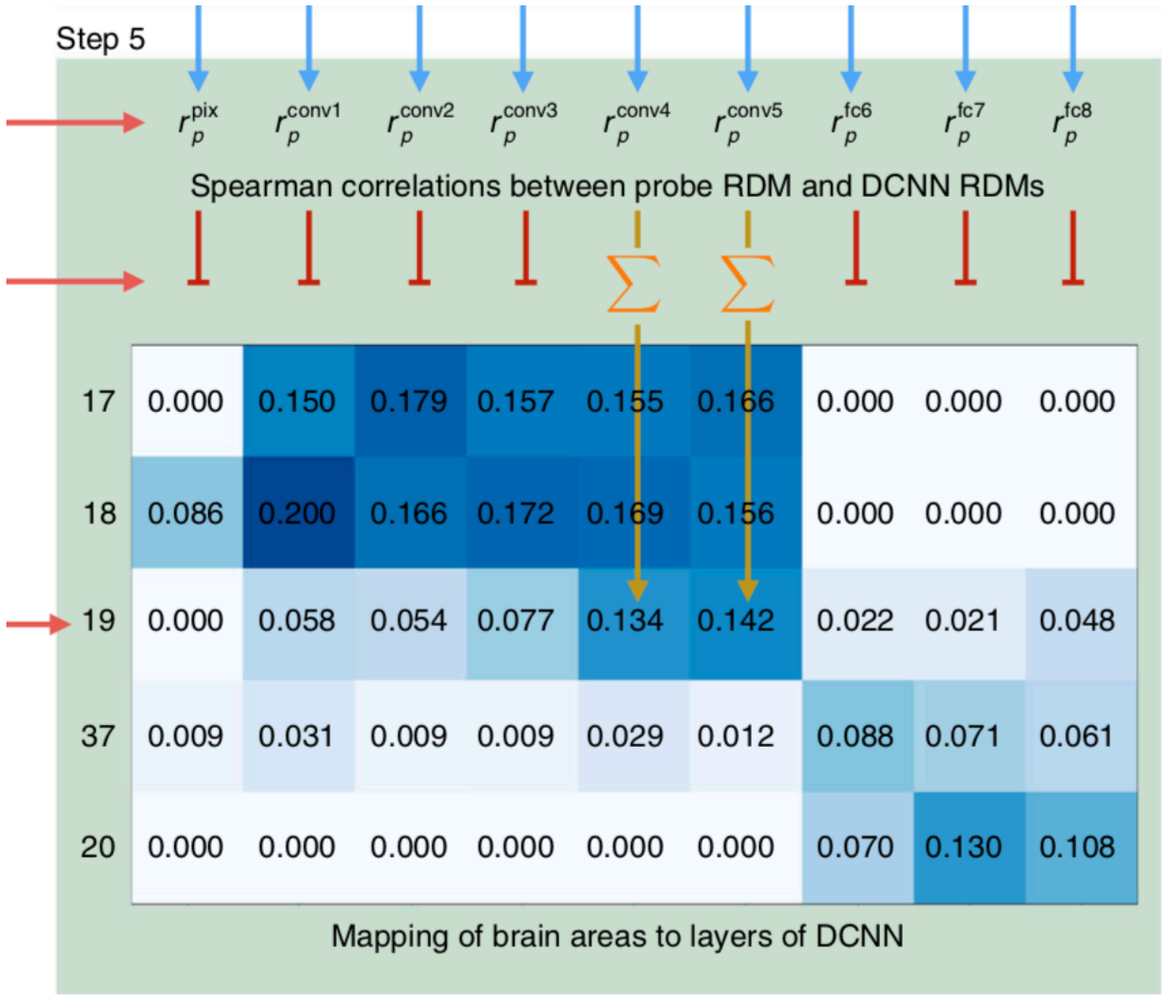
Step 5

r_p^{pix} r_p^{conv1} r_p^{conv2} r_p^{conv3} r_p^{conv4} r_p^{conv5} r_p^{fc6} r_p^{fc7} r_p^{fc8}

Spearman correlations between probe RDM and DCNN RDMs

17	0.000	0.150	0.179	0.157	0.155	0.166	0.000	0.000	0.000
18	0.086	0.200	0.166	0.172	0.169	0.156	0.000	0.000	0.000
19	0.000	0.058	0.054	0.077	0.134	0.142	0.022	0.021	0.048
37	0.009	0.031	0.009	0.009	0.029	0.012	0.088	0.071	0.061
20	0.000	0.000	0.000	0.000	0.000	0.000	0.070	0.130	0.108

Mapping of brain areas to layers of DCNN


Step 5
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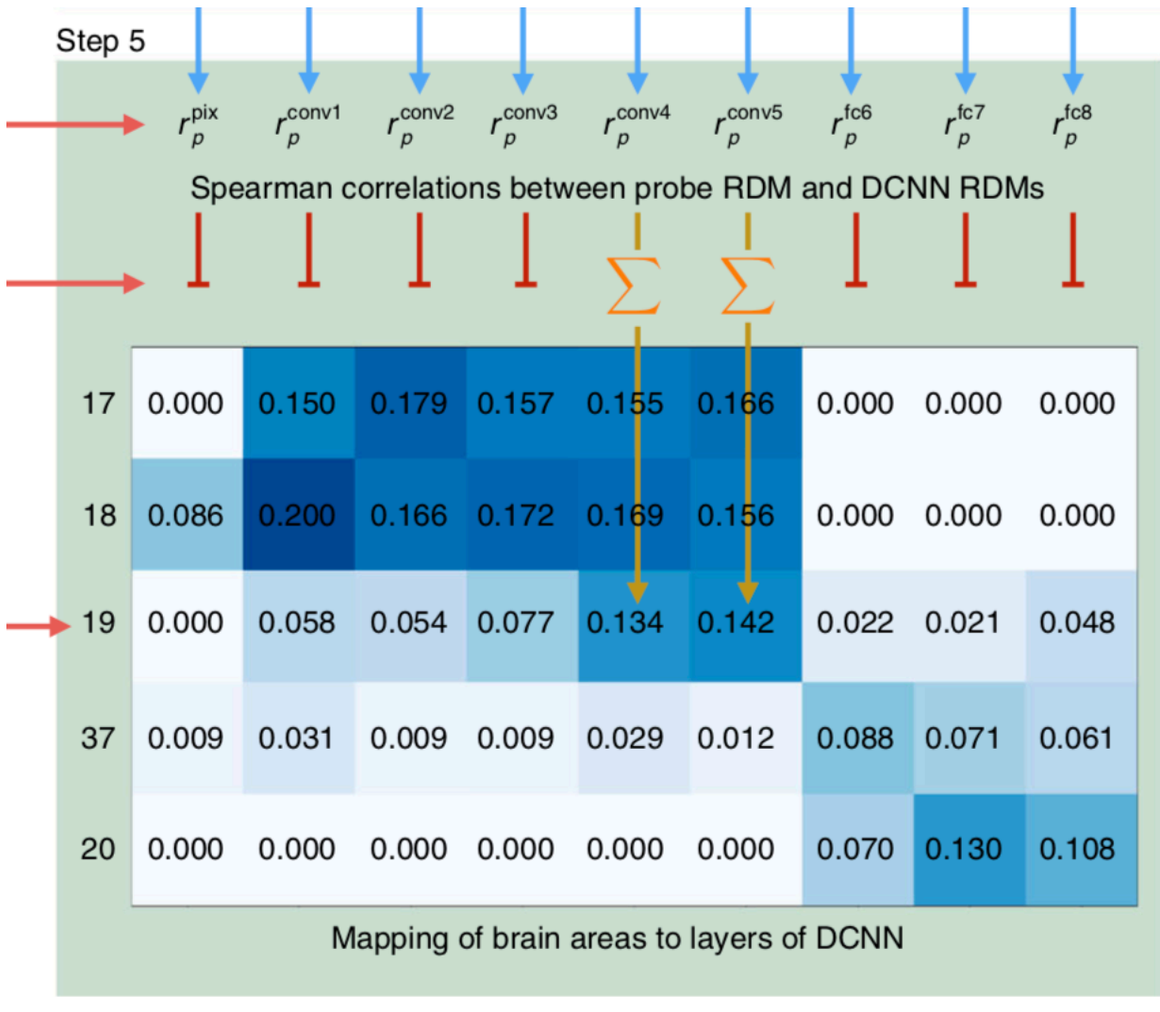
Spearman correlations between probe RDM and DCNN RDMs
17 0.000 0.150 0.179 0.157 0.155 0.166 0.000 0.000 0.000
18 0.086 0.200 0.166 0.172 0.169 0.156 0.000 0.000 0.000
19 0.000 0.058 0.054 0.077 0.134 0.142 0.022 0.021 0.048
37 0.009 0.031 0.009 0.009 0.029 0.012 0.088 0.071 0.061
20 0.000 0.000 0.000 0.000 0.000 0.000 0.070 0.130 0.108
Mapping of brain areas to layers of DCNN

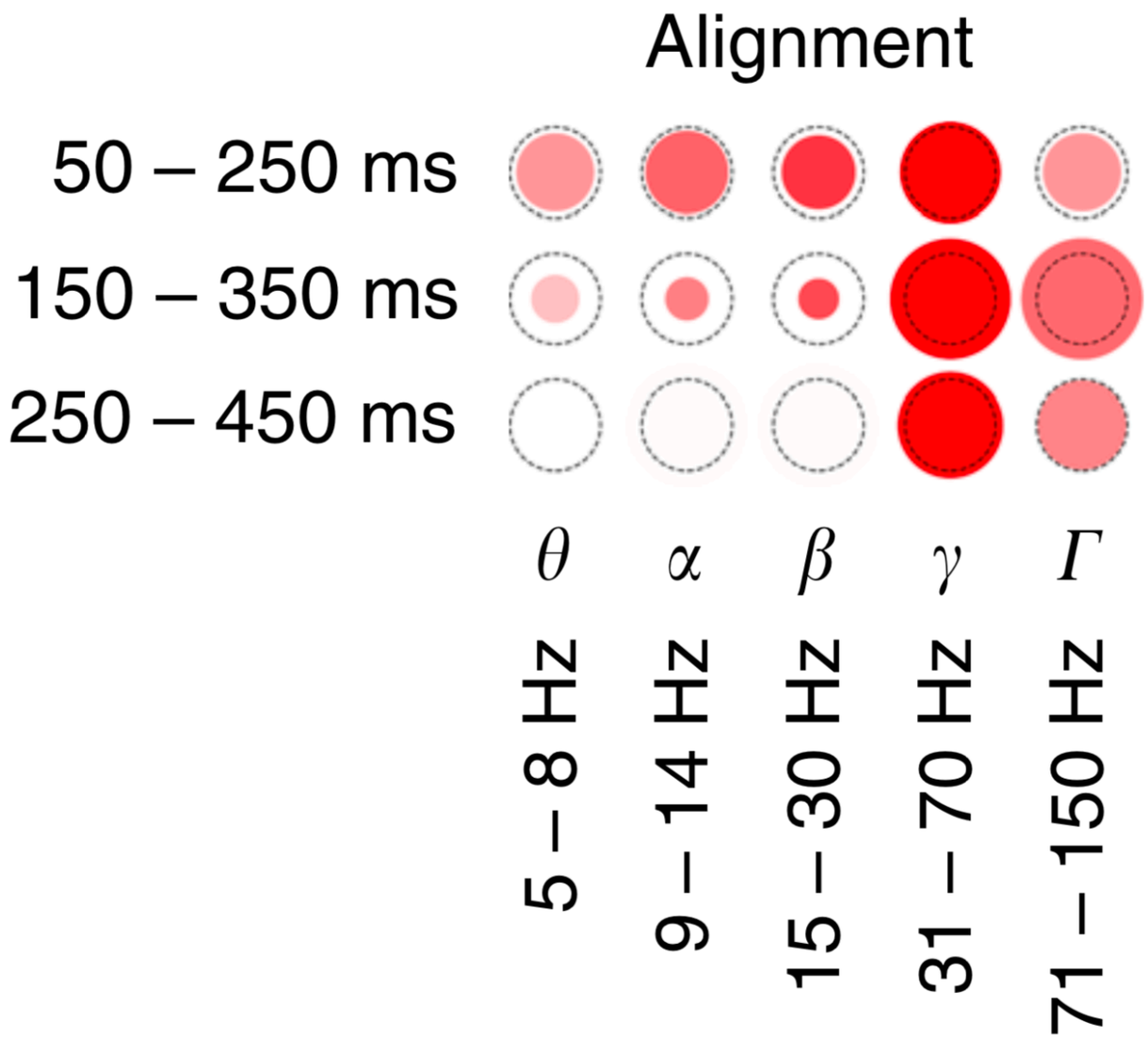
Quantify the diagonal trend

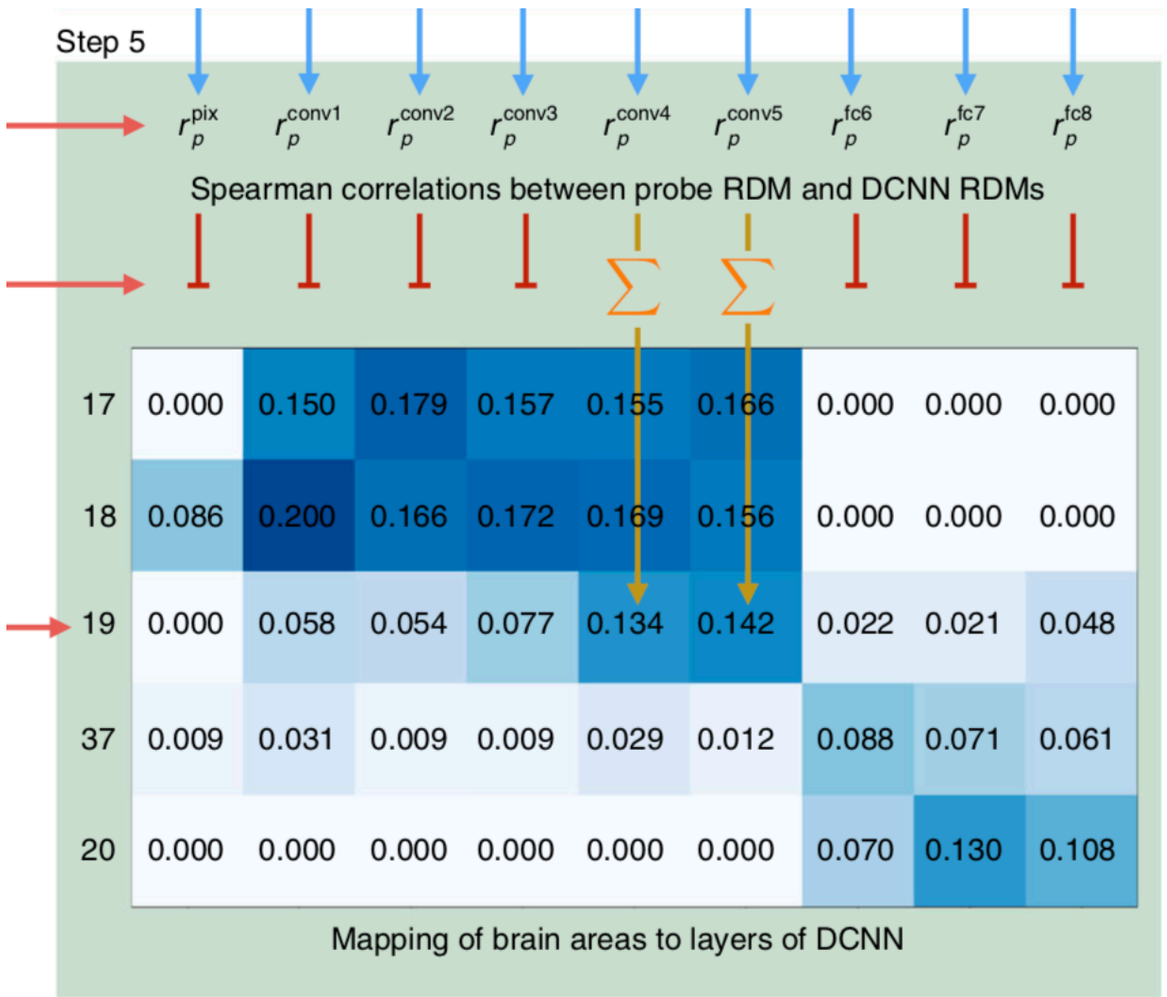
ρ_{align} = *Spearman(*
Assignment to DNN layers,
Assignment to Brodmann areas)

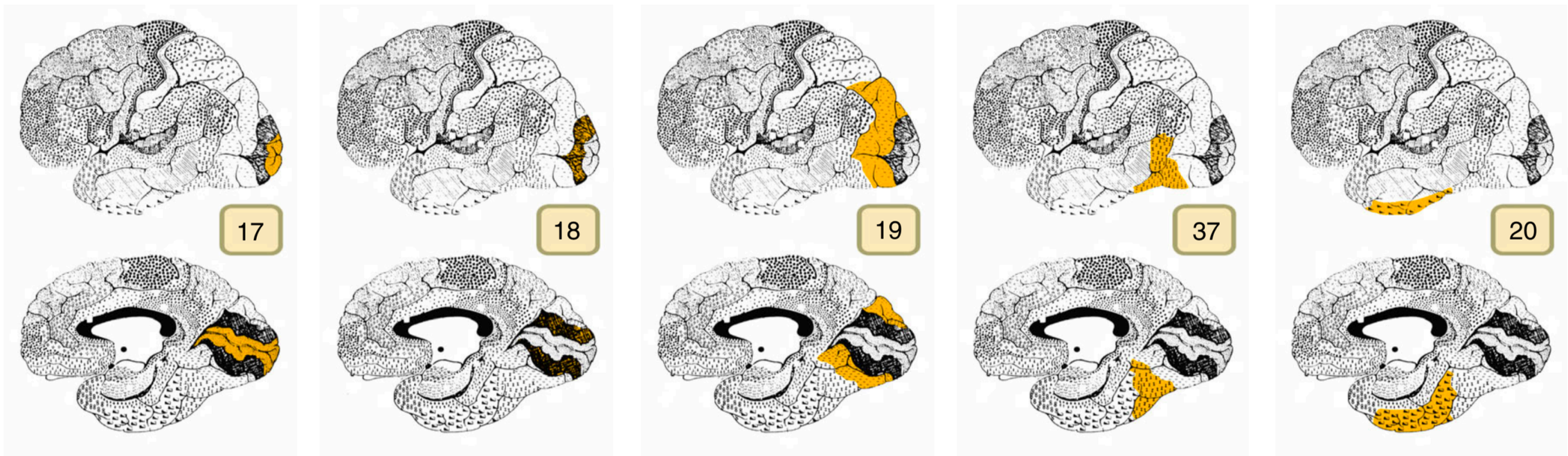


Quantify the diagonal trend

ρ_{align} = *Spearman(*
Assignment to DNN layers,
Assignment to Brodmann areas)







- simple features (mapped to lower layers of DCNN)
- complex features (higher layers)

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https://www.nature.com/articles/s42003-018-0110-y

https://github.com/kuz/Human-Intracranial-Recordings-and-DCNN-to-Compare-Biological-and-Artificial-Mechanisms-of-Vision