WHAT THE SUCCESS OF BRAIN IMAGING IMPLIES ABOUT THE NEURAL CODE

Preprint: http://dx.doi.org/10.1101/071076

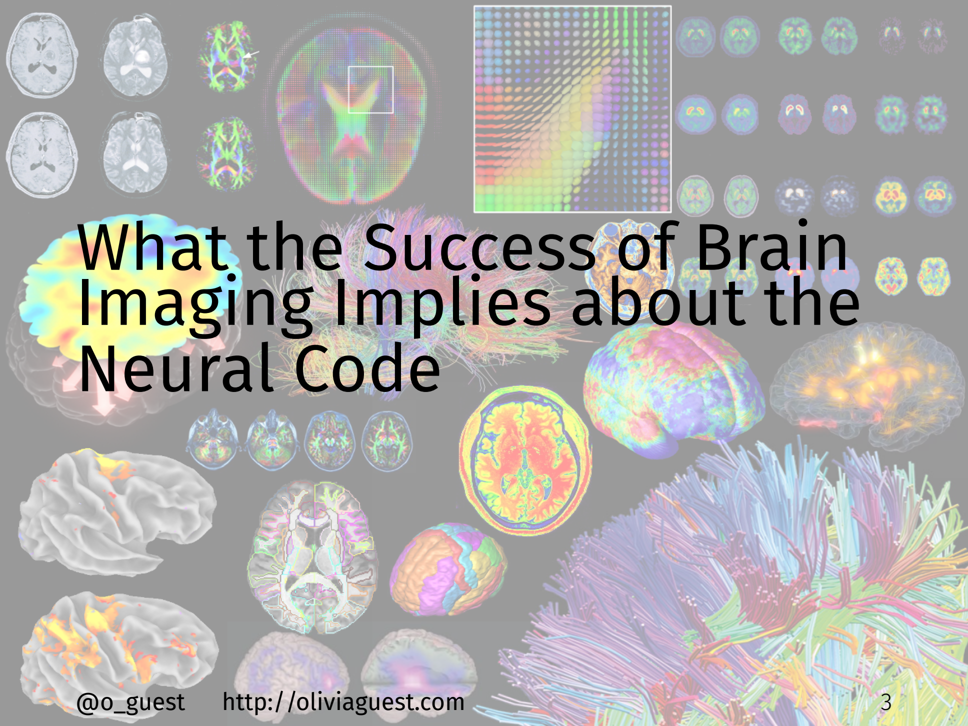
Olivia Guest

November 24, 2016

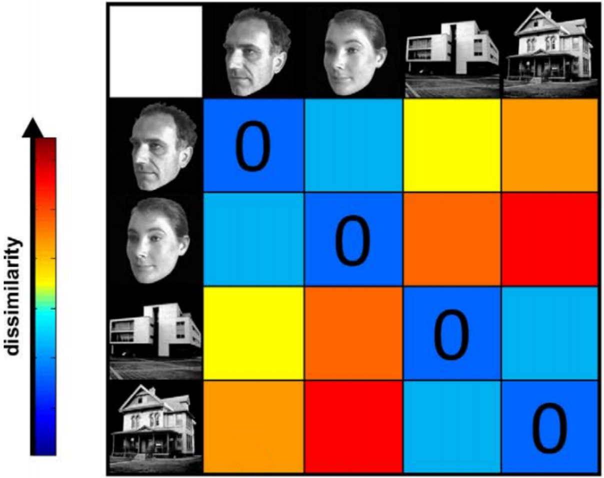
University College London

Bradley C. Love

University College London



What the Success of Brain Imaging Implies about the Neural Code


dissimilarity
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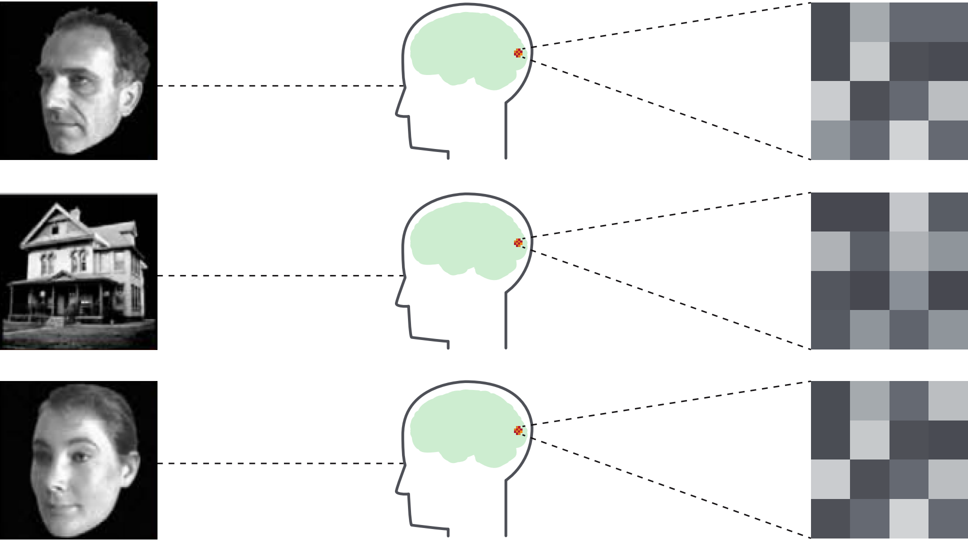
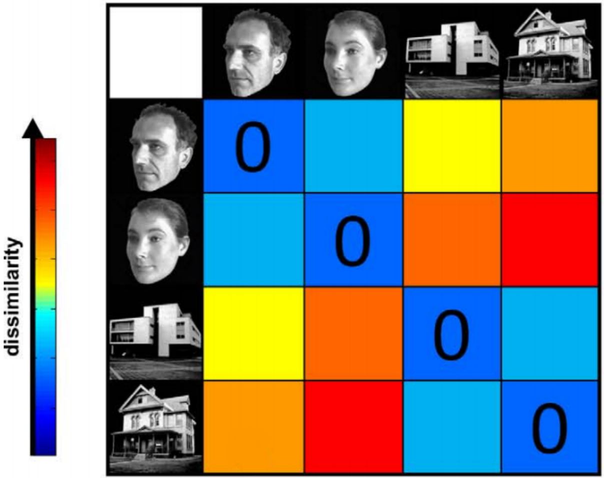
MULTIVARIATE PATTERN ANALYSIS (MVPA)




dissimilarity
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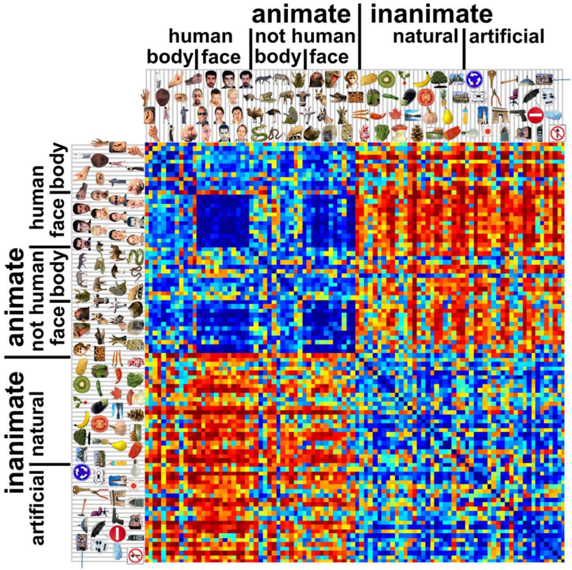
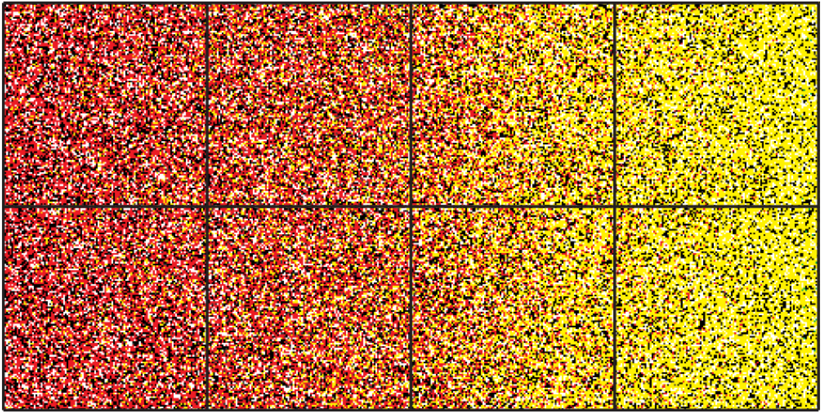
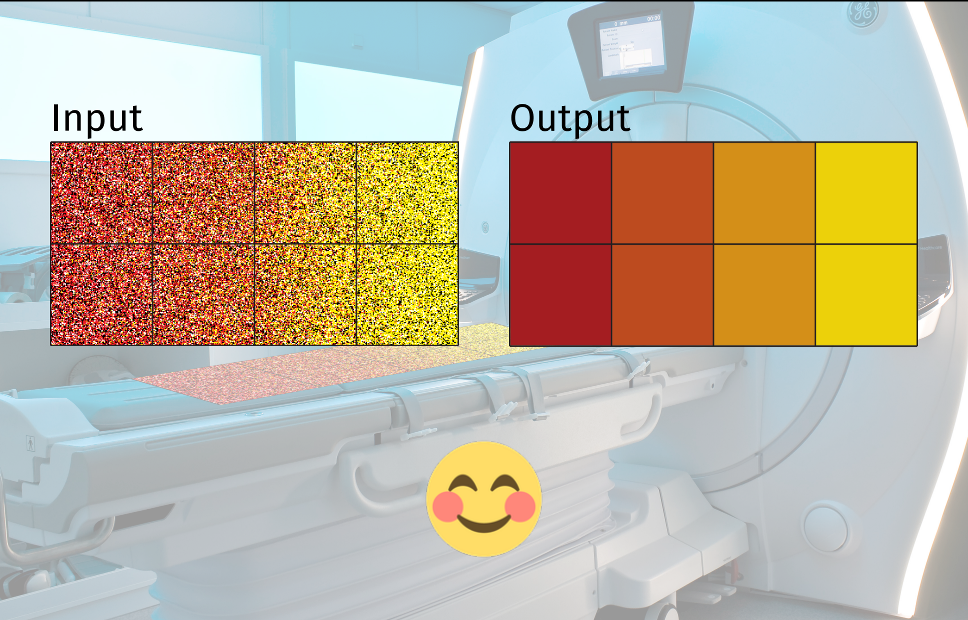


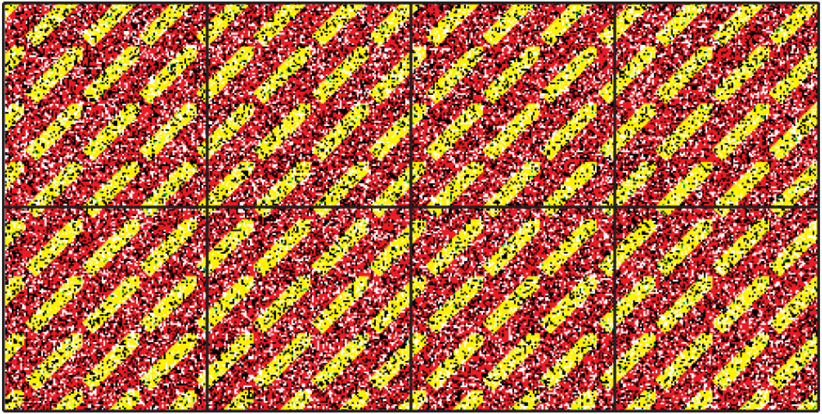
Kriegeskorte, N. et al. (2008). Matching categorical object representations in inferior temporal cortex of man and monkey. Neuron.



TOY FMRI

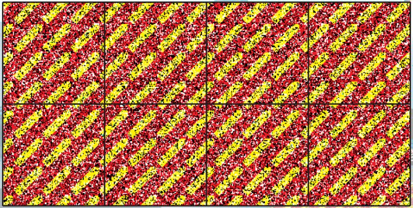
TOY FMRI



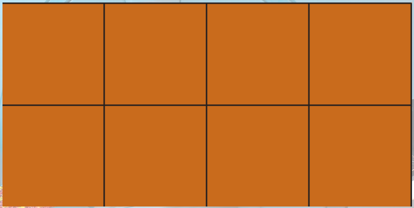


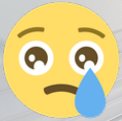
TOY FMRI

Input



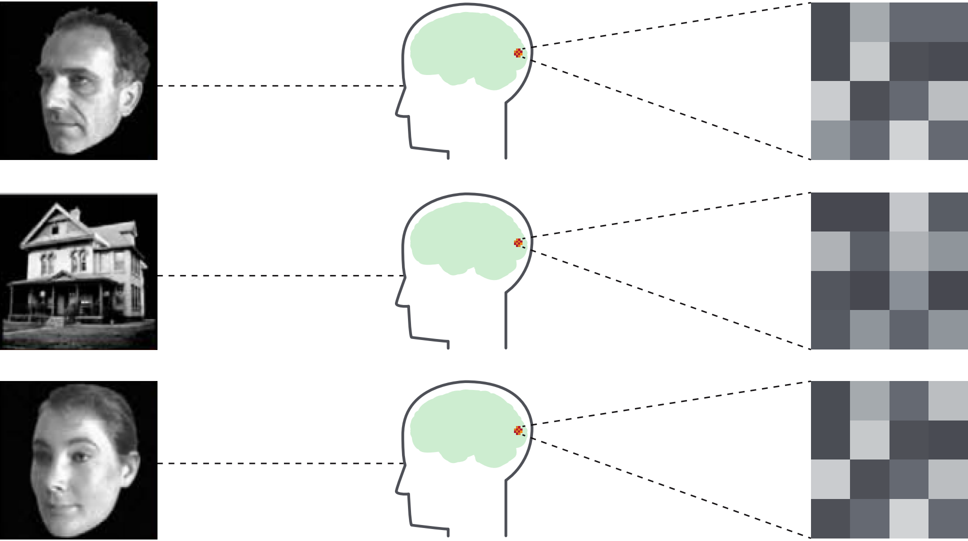
Output





- sub-voxel smoothness
- super-voxel smoothness
- functional smoothness

MULTIVARIATE PATTERN ANALYSIS (MVPA)



CODES THAT DO NOT WORK

- hash function coding
- burstiness coding
- factorial design coding

Factorial design:

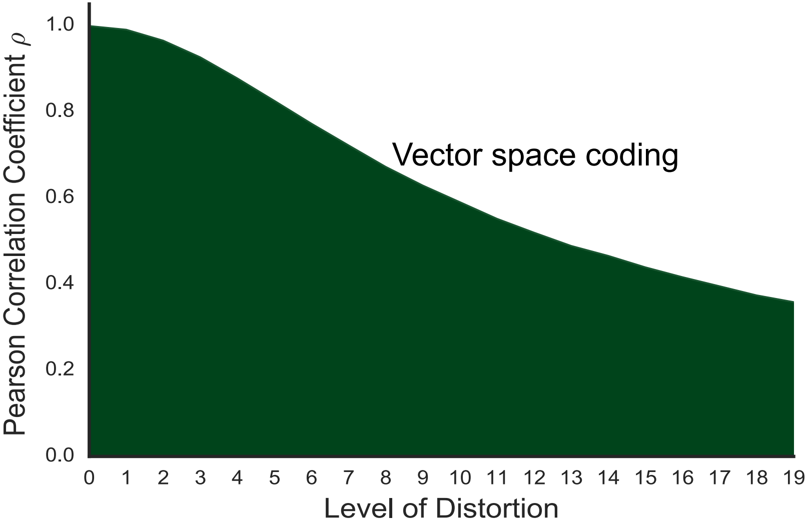
- columns = features
- orthogonal representations

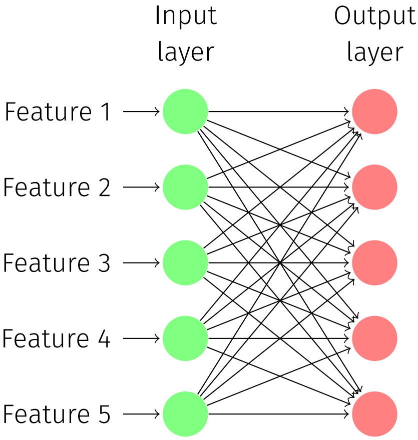
I	A	B	C	AB	AC	BC	ABC
1	−1	−1	−1	1	1	1	−1
1	1	−1	−1	−1	−1	1	1
1	−1	1	−1	−1	1	−1	1
1	1	1	−1	1	−1	−1	−1
1	−1	−1	1	1	−1	−1	1
1	1	−1	1	−1	1	−1	−1
1	−1	1	1	−1	−1	1	−1
1	1	1	1	1	1	1	1

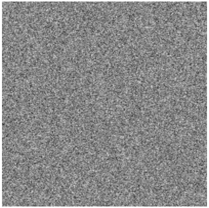
INPUT

- vector space coding
- matrix multiplication coding
- perceptron coding
- multiple layer network coding

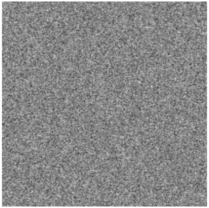
$235 \times 200 = 47000$


Pearson Correlation Coefficient ρ
1.0
0.8
0.6
0.4
0.2
0.0
Vector space coding
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
Level of Distortion


Input layer
Output layer
Feature 1
Feature 2
Feature 3
Feature 4
Feature 5

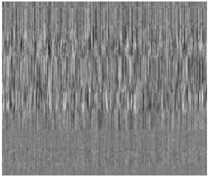


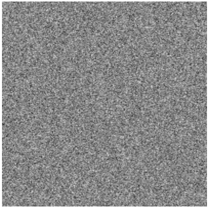
$\times$



$\times$

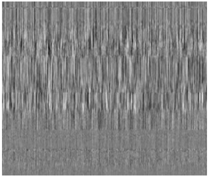
$=$





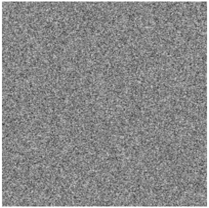
×

tanh (



)

MATRIX MULTIPLICATION CODING



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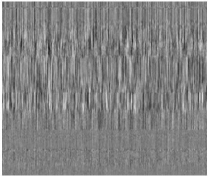
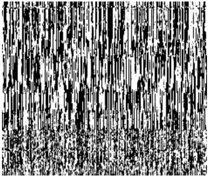
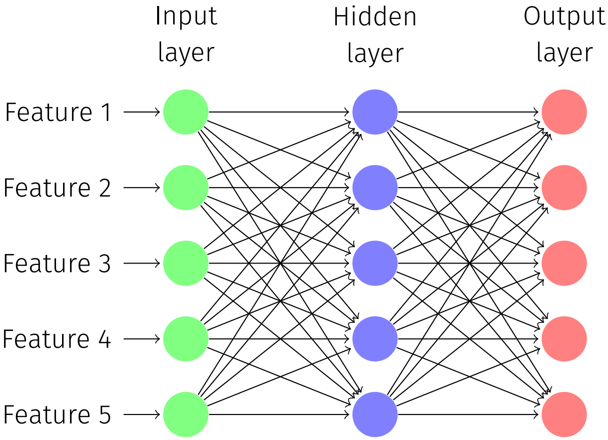
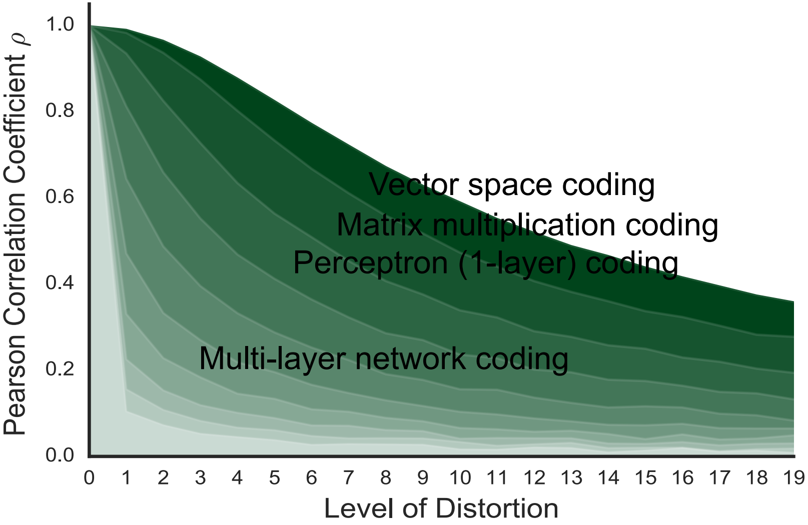
tanh (

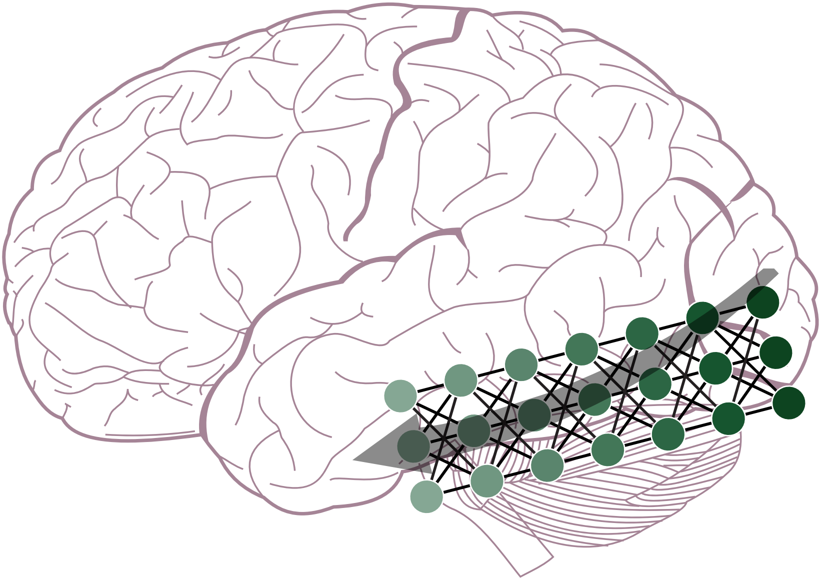


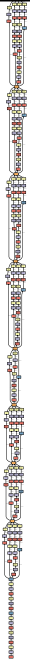
) =



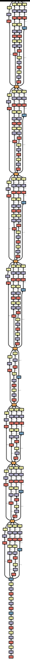

Input
layer
Hidden
layer
Output
layer
Feature 1
Feature 2
Feature 3
Feature 4
Feature 5


Pearson Correlation Coefficient ρ
1.0
0.8
0.6
0.4
0.2
0.0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
Level of Distortion
Vector space coding
Matrix multiplication coding
Perceptron (1-layer) coding
Multi-layer network coding



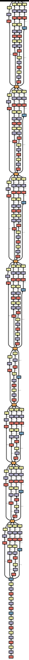


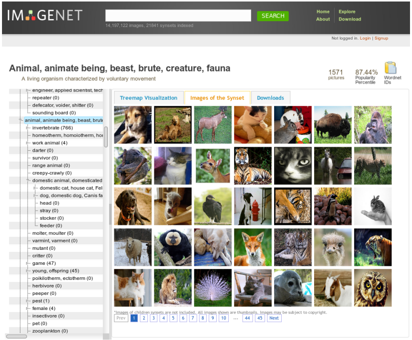
- Inception v3
  of GoogleNet
- 25 million parameters
- 3.5% top-5 error

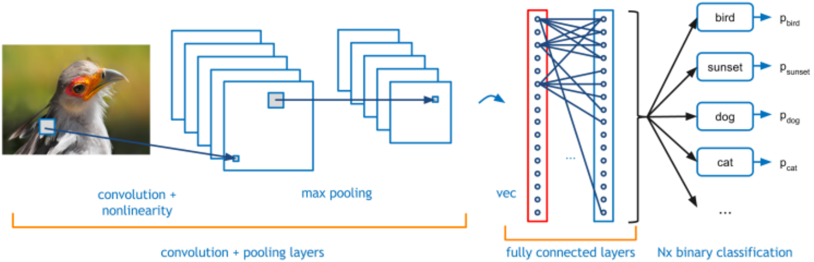


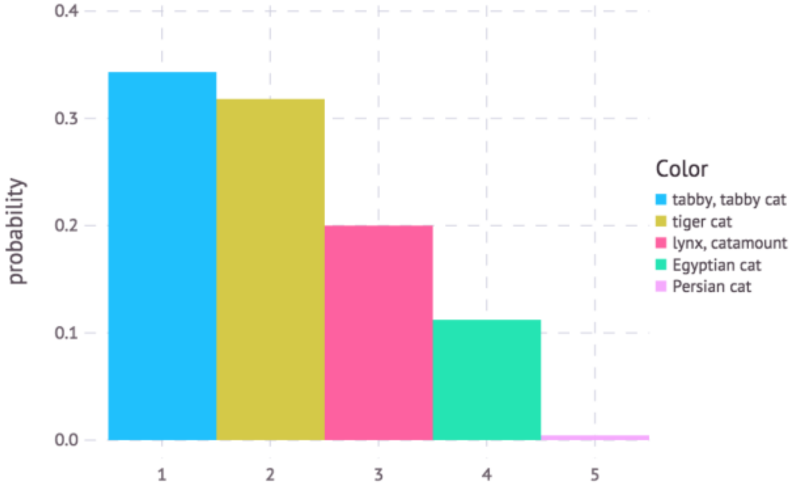
DEEP NETWORK CODING

- trained on millions of photos
- 1000 categories

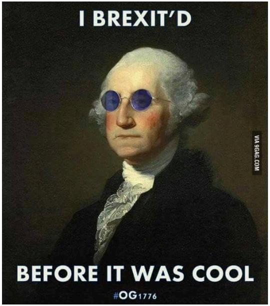





convolution +
nonlinearity
max pooling
convolution + pooling layers
vec
...
fully connected layers
bird
sunset
dog
cat
...
p_{bird}
p_{sunset}
p_{dog}
p_{cat}
Nx binary classification


0.4
0.3
0.2
0.1
0.0
probability
1
2
3
4
5
Color
tabby, tabby cat
tiger cat
lynx, catamount
Egyptian cat
Persian cat

- dust cover: 44.9%
- comic book: 14.7%
- throne: 7.8%
- pyjama: 4.4%
- suit: 3.6%

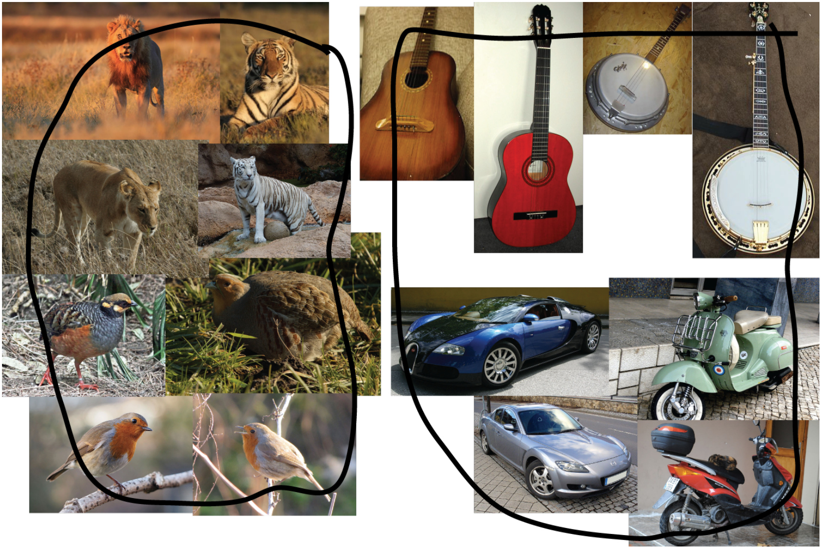


- dust cover: 44.9%
- comic book: 14.7%
- throne: 7.8%
- pyjama: 4.4%
- suit: 3.6%

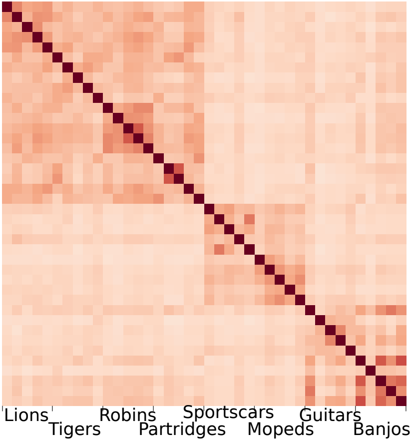
- sunglasses: 40.7%
- wig: 8.4%
- sunglass: 7.9%
- dust cover: 5.6%
- suit: 2.8%

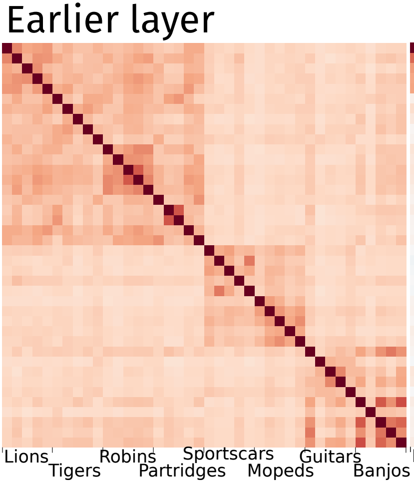
DEEP NETWORK CODING

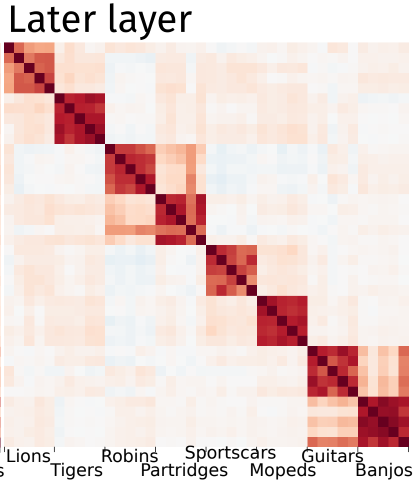
DEEP NETWORK CODING



Earlier layer




Earlier layer
Lions
Tigers
Robins
Partridges
Sportscars
Mopeds
Guitars
Banjos


Later layer
Lions
Tigers
Robins
Partridges
Sportscars
Mopeds
Guitars
Banjos

- Success of fMRI constrains the nature of the neural code
- Connectionist models are consistent with the success of fMRI
- Deep belief networks behave similarly

- Subvoxel and functional smoothness are required for fMRI
- Functional smoothness breaks down at advanced network layers
- Ergo might be harder to uncover similarity in “advanaced” brain regions

Thanks for listening!

- wig: 99.0%
- sunglasses: << 0.01%
- wool: << 0.01%
- sunglass: << 0.01%
- hair spray: << 0.01%

- hoopskirt: 13.3%
- lab coat: 10.3%
- groom: 8.6%
- vestment: 2.8%
- toilet paper: 2.7%