Workshop on Applied Deep Learning in Intracranial Neurophysiology

Part 8 – Integrating Neuroscience and Deep Learning

June 21, 2019

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Sachs Lab

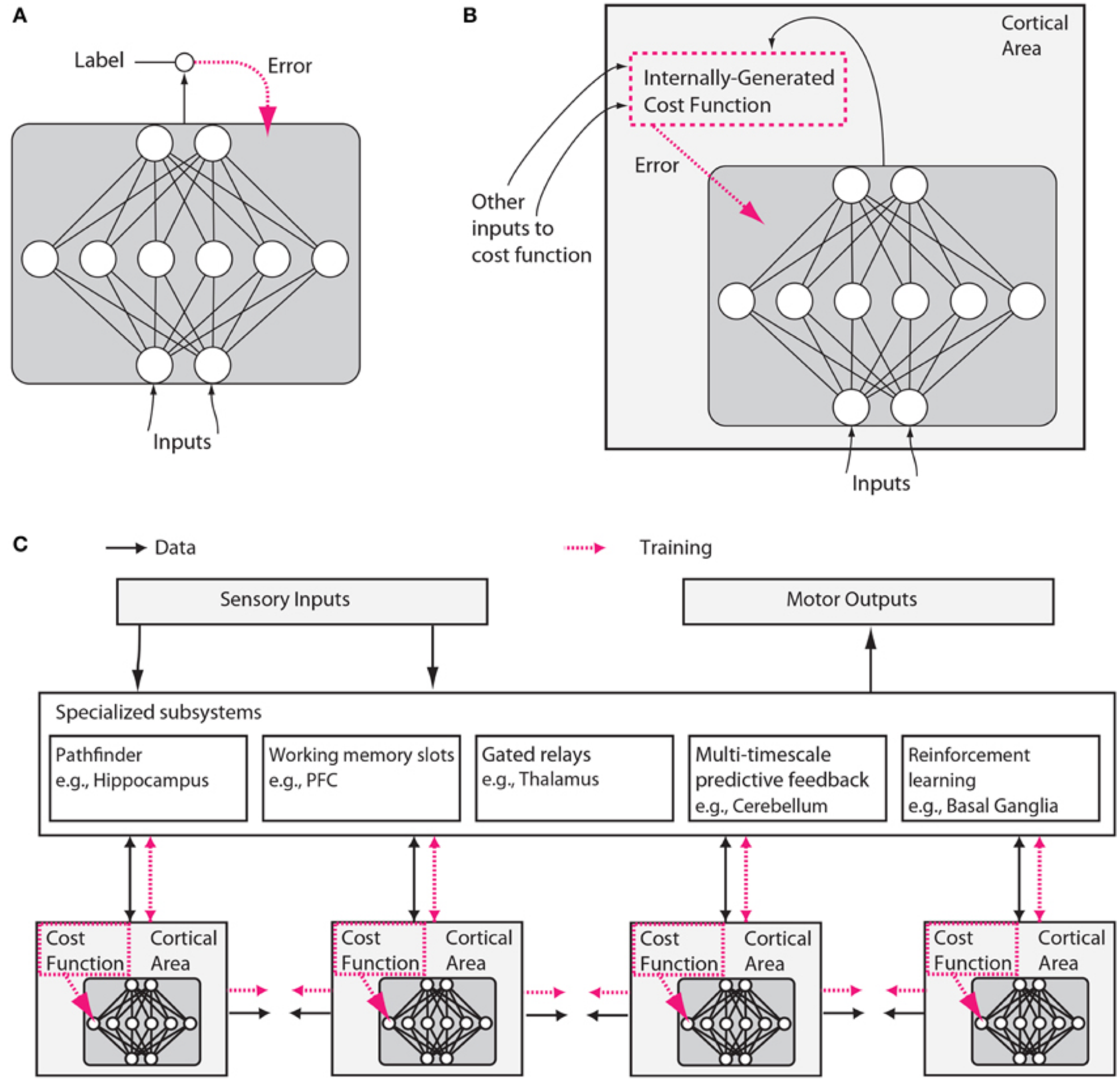
Sources

- Background
  - Marblestone et al. “Toward an Integration of Deep Learning and Neuroscience”. Front. Comput. Neurosci. 2016. Link
  - Hassabit et al., “Neuroscience-Inspired Artificial Intelligence”. Neuron. 2017. Link
  - Cichy and Kaiser. “Deep Neural Networks as Scientific Models”. TICS 2019. Link
  - Barret et al. “Analyzing biological and artificial neural networks: challenges with opportunities for synergy?”. Current Opinion in Neurobiology 2019. Link
- Studies
  - Bashivan, Kar, DiCarlo. “Neural population control via deep image synthesis”. Science 2019. Link
  - Pinotsis, Siegel, Miller. “Sensory Processing and Categorization in Cortical and Deep Neural Networks”. bioarXiv 2019. Link

A. Conventional deep learning

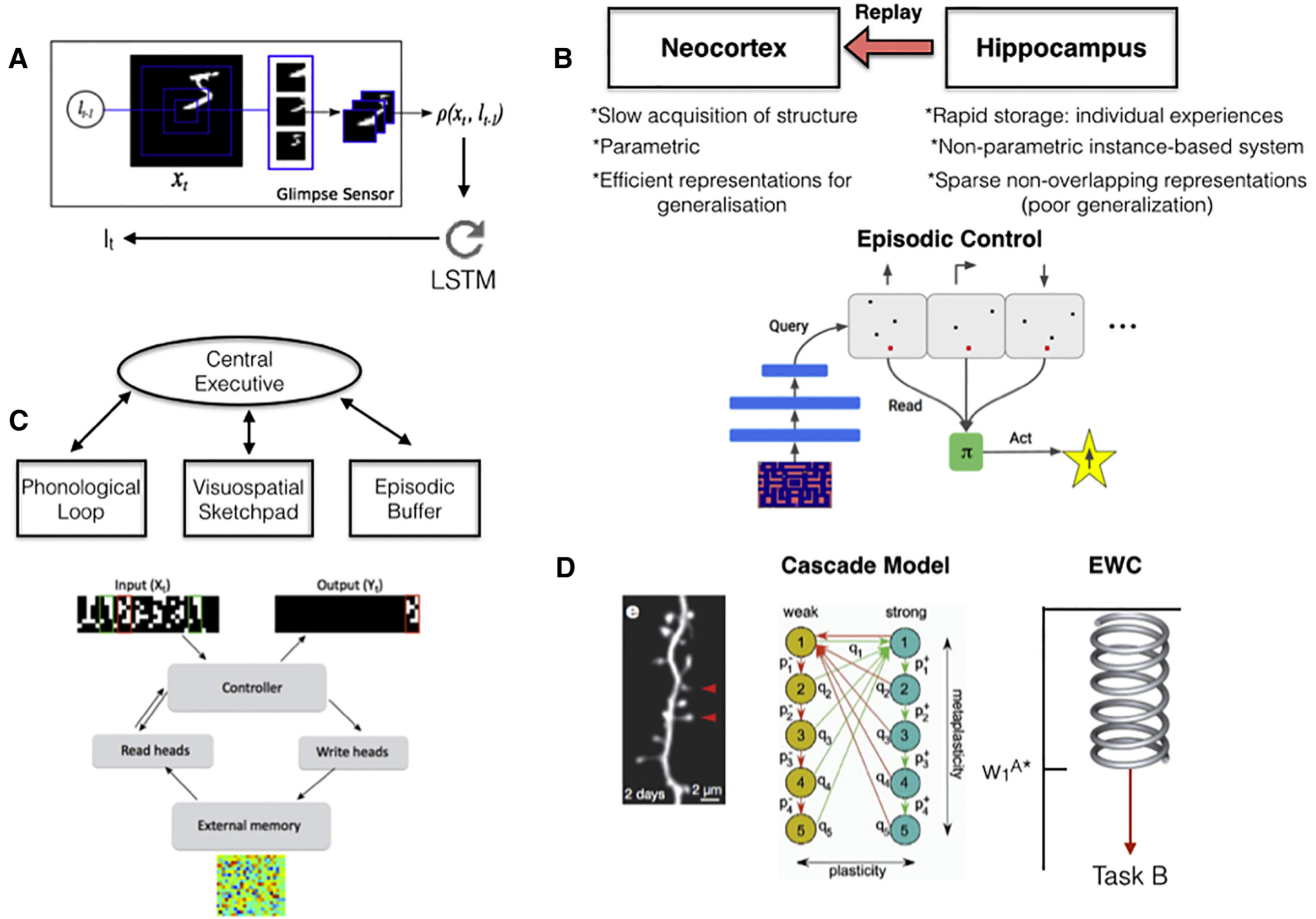
B. Supervised training in the brain.

C. Architecture comprising several specialized systems.



Some neuroscience-inspired developments in AI

- Neuron/Unit/Cell (e.g., non-linear)
- Learning mechanism
- Multiple layers, converging and diverging.
- Parallel distributed processing
- Dropout
- CNN architecture
- Max-pooling
- **Attention mechanism**
- “One shot” – episodic memory in hippocampus
- **Experience replay – memory consolidation**
- RNN – Working memory
- **Elastic weight consolidation to avoid catastrophic forgetting**
- Activity maximization – receptive field mapping



A. Attention mechanism
B. Complementary learning and episodic memory
C. Working memory and DNC with external memory
D. Synaptic weight strengthening and elastic weight consolidation

AI-inspired developments in neuroscience

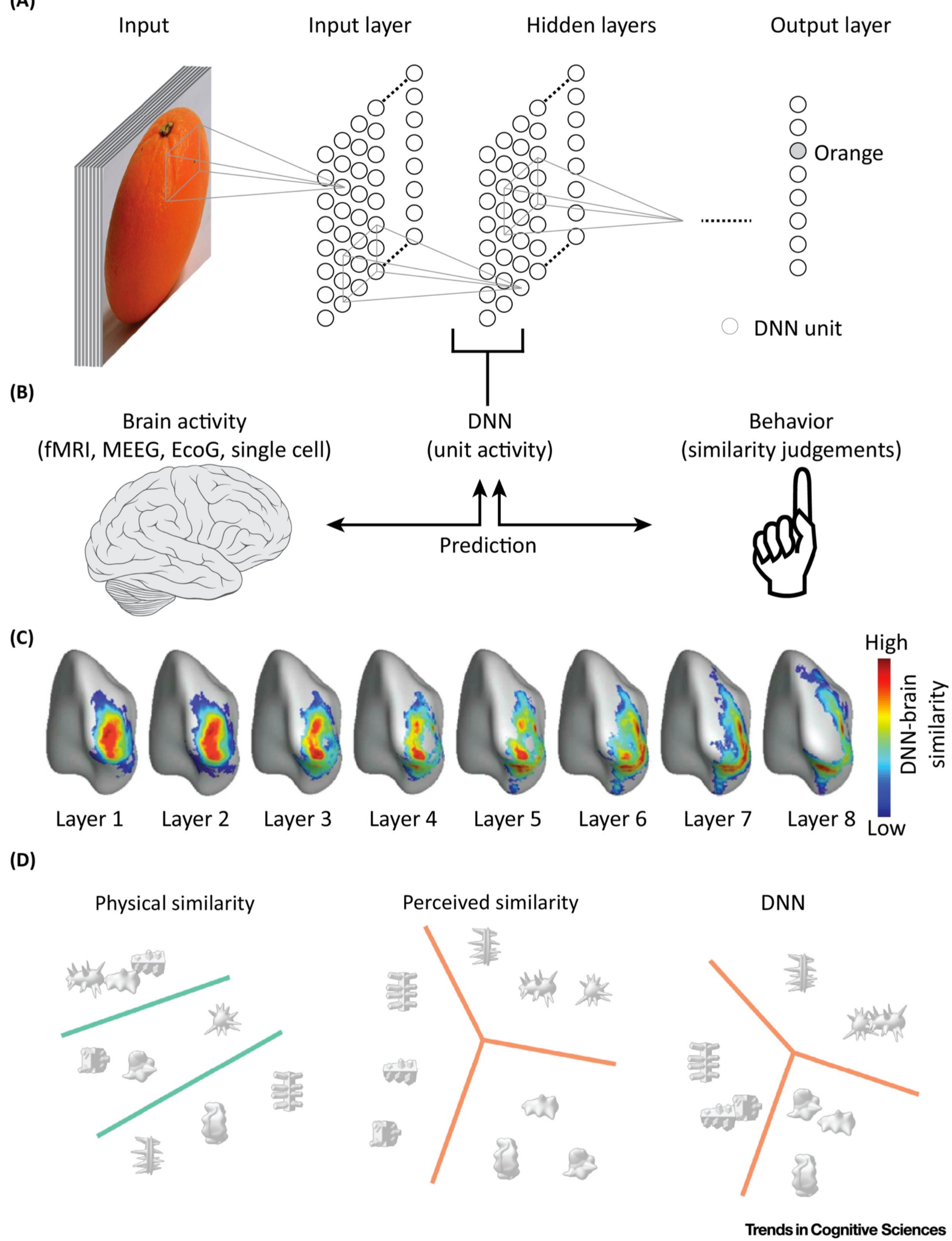
- Psych → RL → TD prediction errors → RPE in midbrain
- LSTM → Gating-based maintenance of WM in PFC
- Backpropagation & credit assignment
- Enhanced CNNs → high-level vision

A. CNN analogous to hierarchical visual processing

B. DNNs to predict behaviour

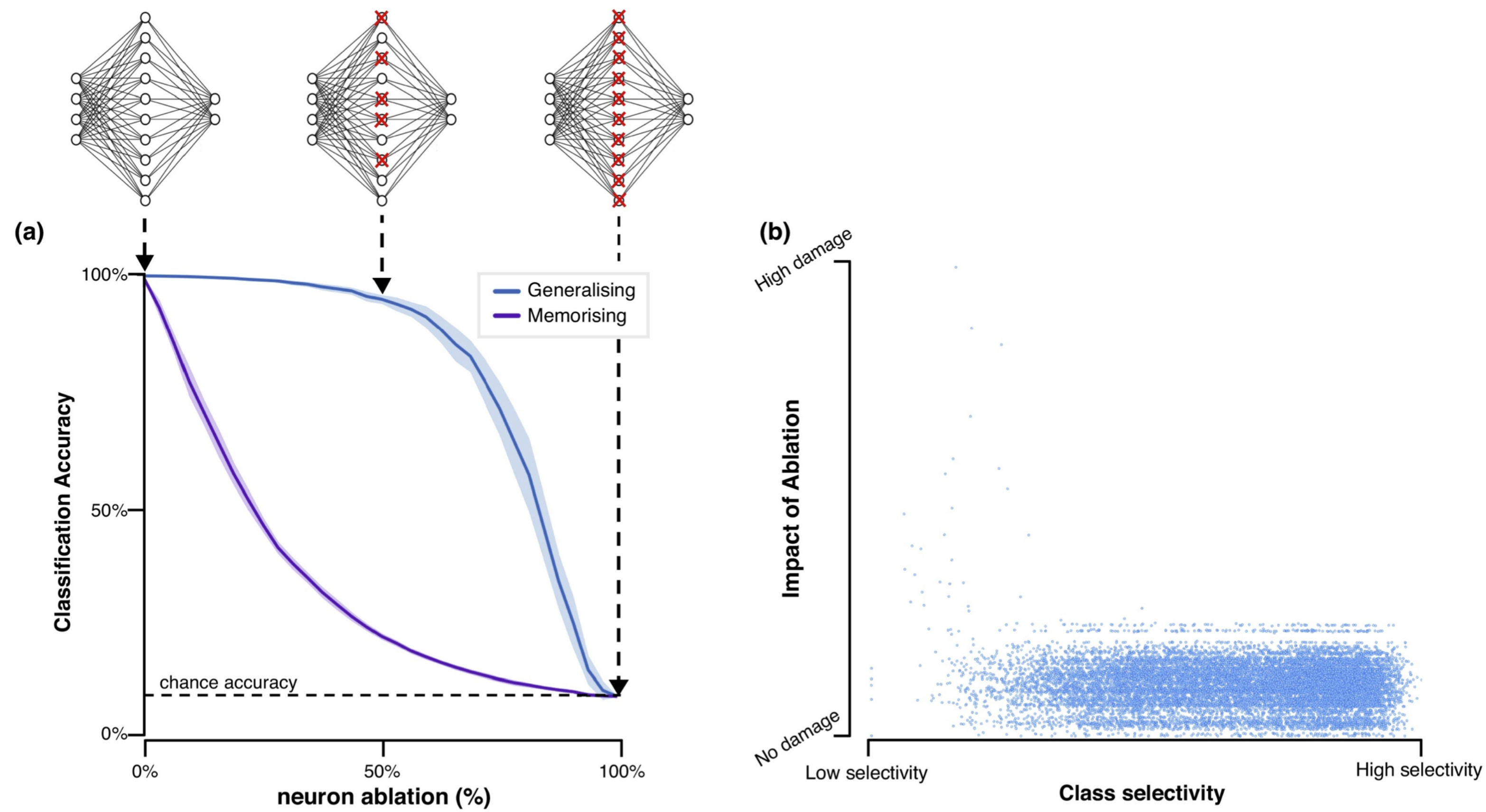
C. Low-level CNN predicts low-level fMRI activation

D. DNN trained for object-categorization more similar to (human) perceived similarity than physical similarity



Sharing analyses between DL and Neuroscience

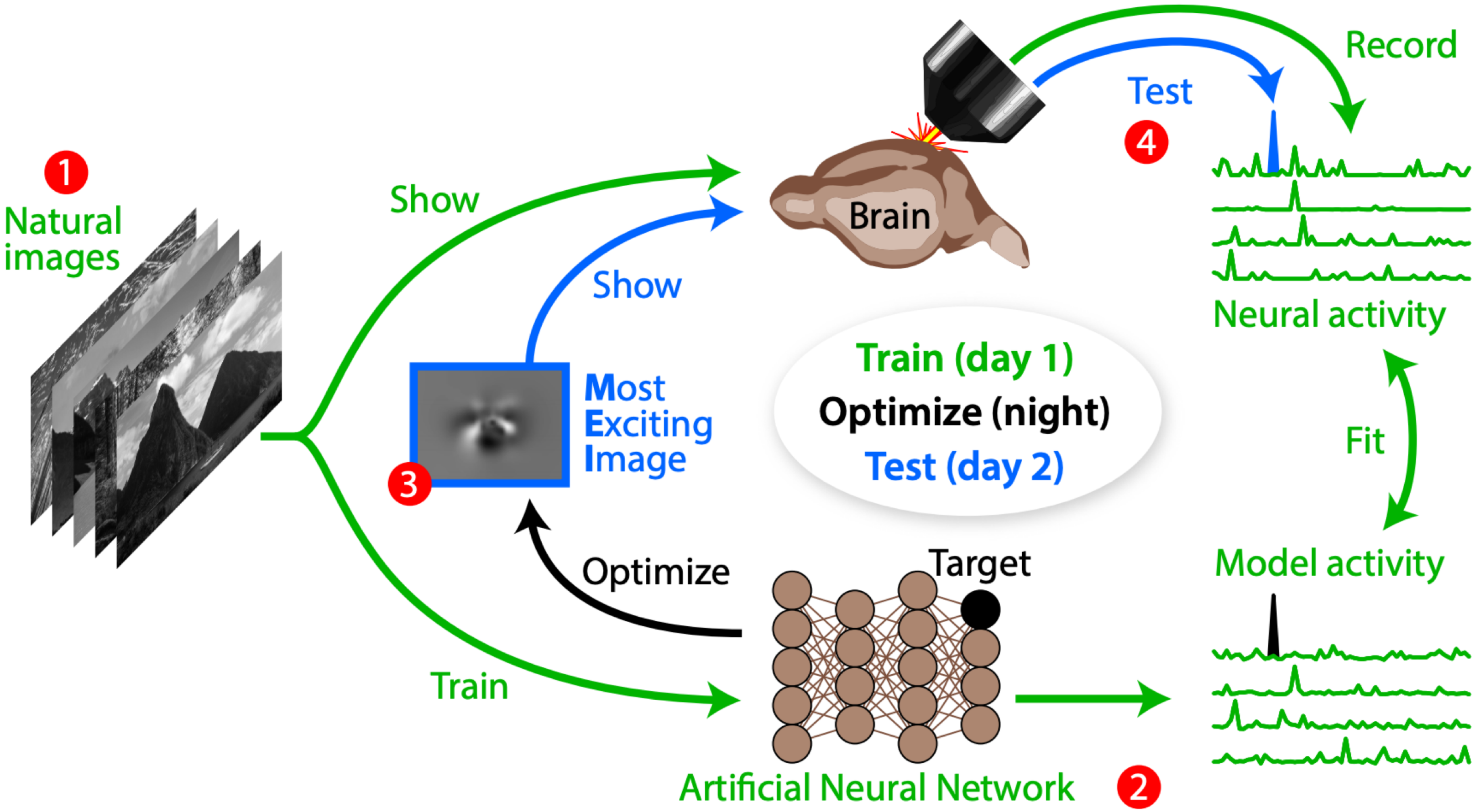
- Neuron-ablation
- Dimensionality reduction
- Canonical correlation analysis
- Representational similarity analysis



(a)
100%
50%
0%
Classification Accuracy
Generalising
Memorising
chance accuracy
0%
50%
100%
neuron ablation (%)
(b)
High damage
No damage
Impact of Ablation
Low selectivity
High selectivity
Class selectivity

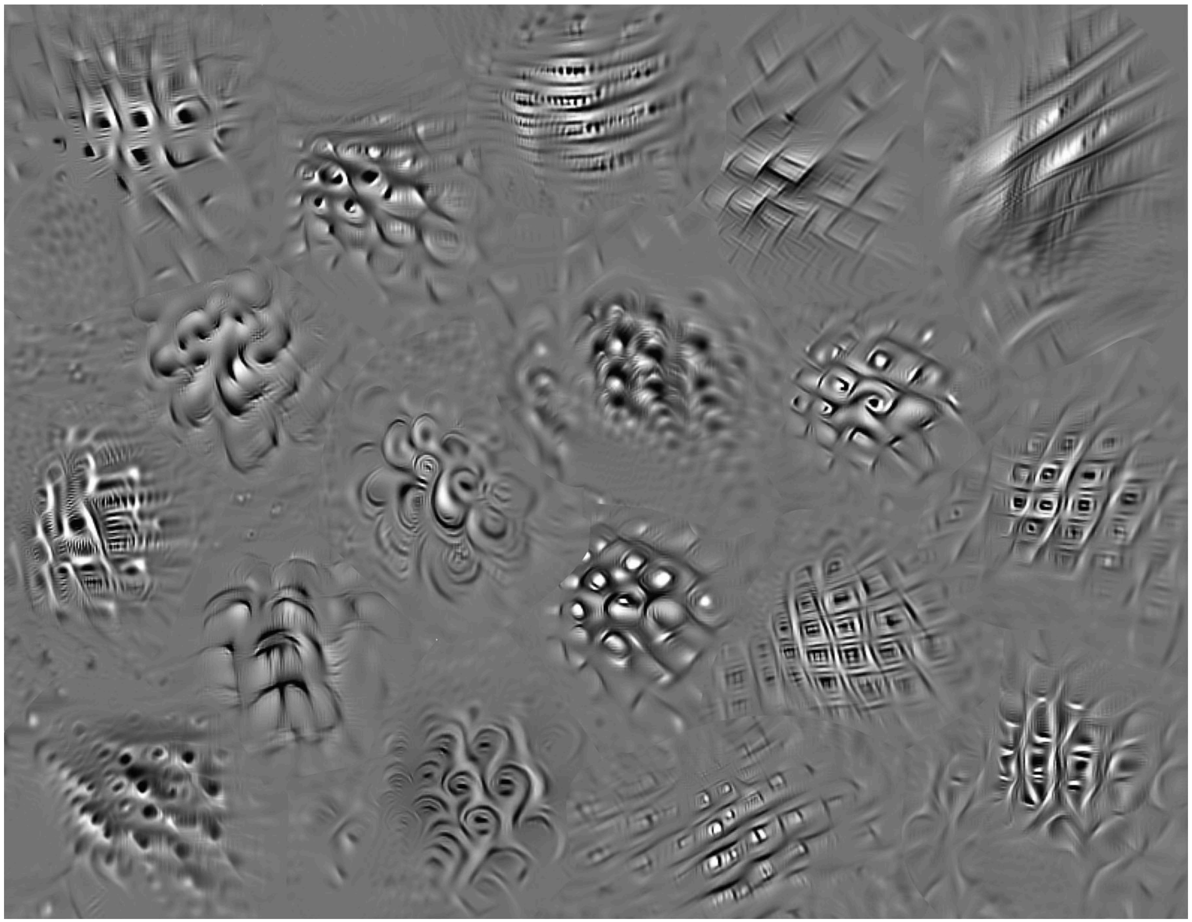
Inception in visual cortex: *in vivo-silico* loops reveal most exciting images

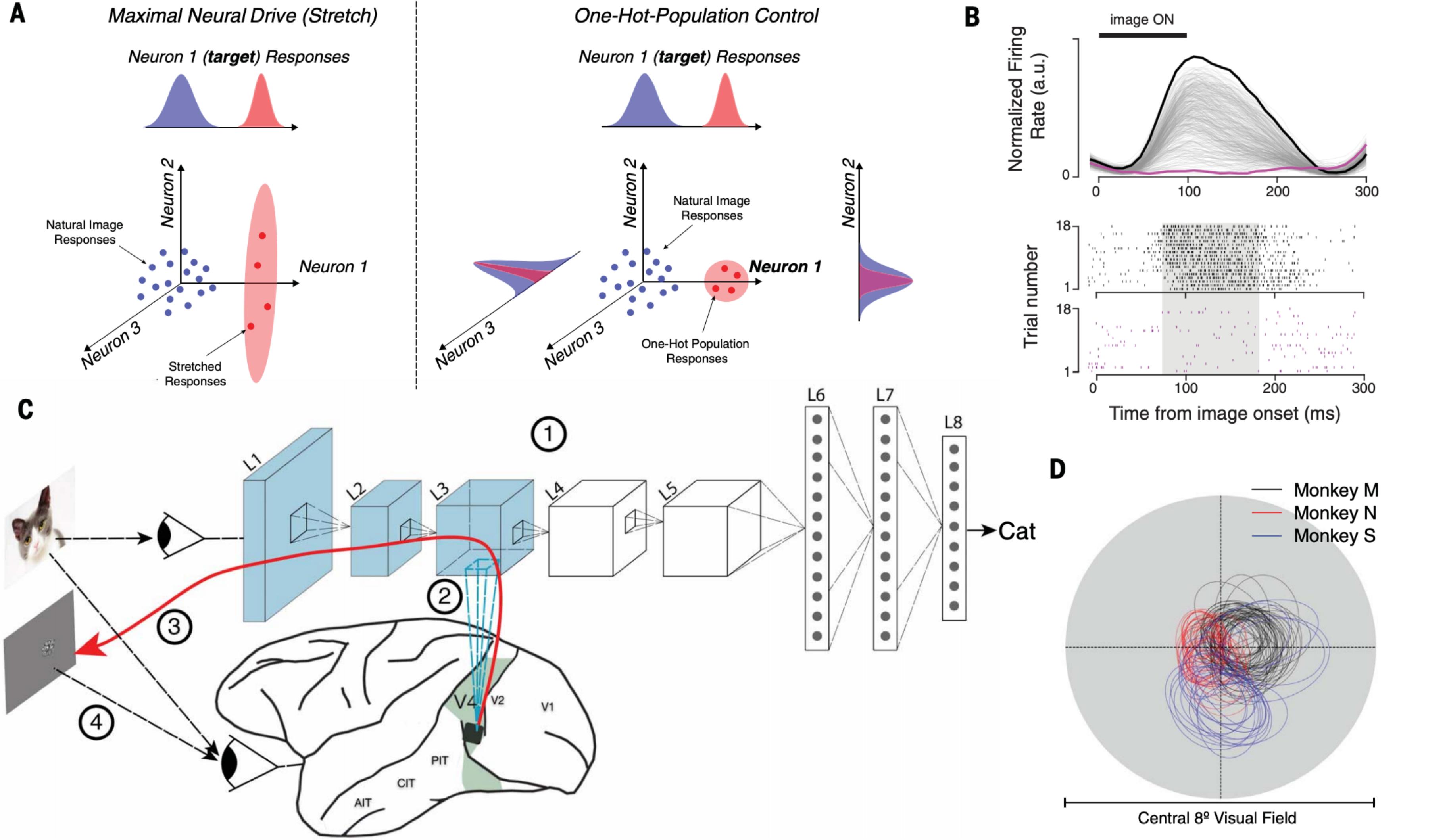
Edgar Y. Walker,[1,2†*] Fabian H. Sinz,[1,2,5,7†*] Emmanouil Froudarakis,[1,2]
Paul G. Fahey,[1,2] Taliah Muhammad,[1,2] Alexander S. Ecker,[2,4–6] Erick Cobos,[1,2]
Jacob Reimer,[1,2] Xaq Pitkow,[1–3] Andreas S. Tolias[1–3*]



Neural population control via deep image synthesis

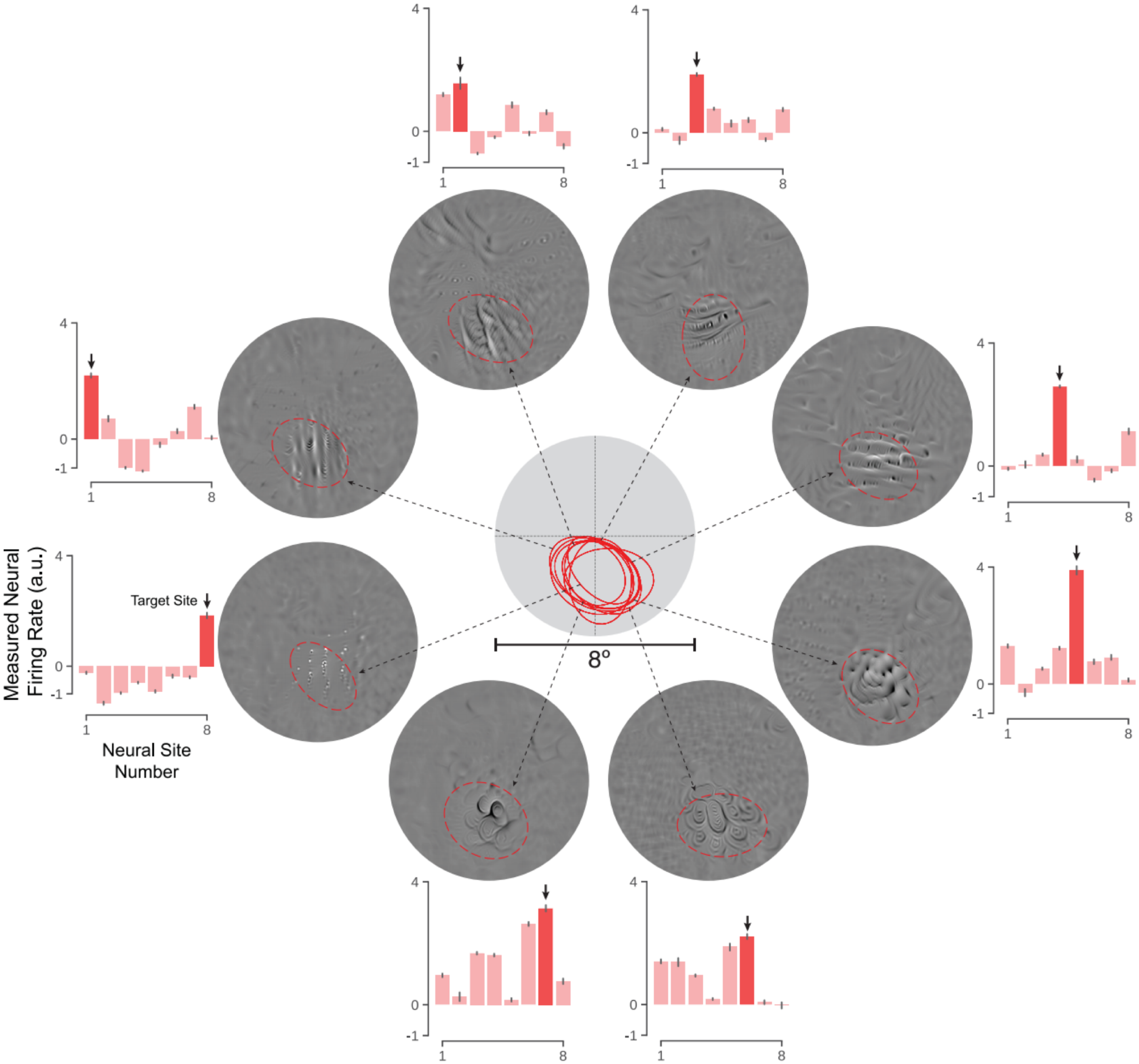
Pouya Bashivan*, Kohitij Kar*, James J. DiCarlo†





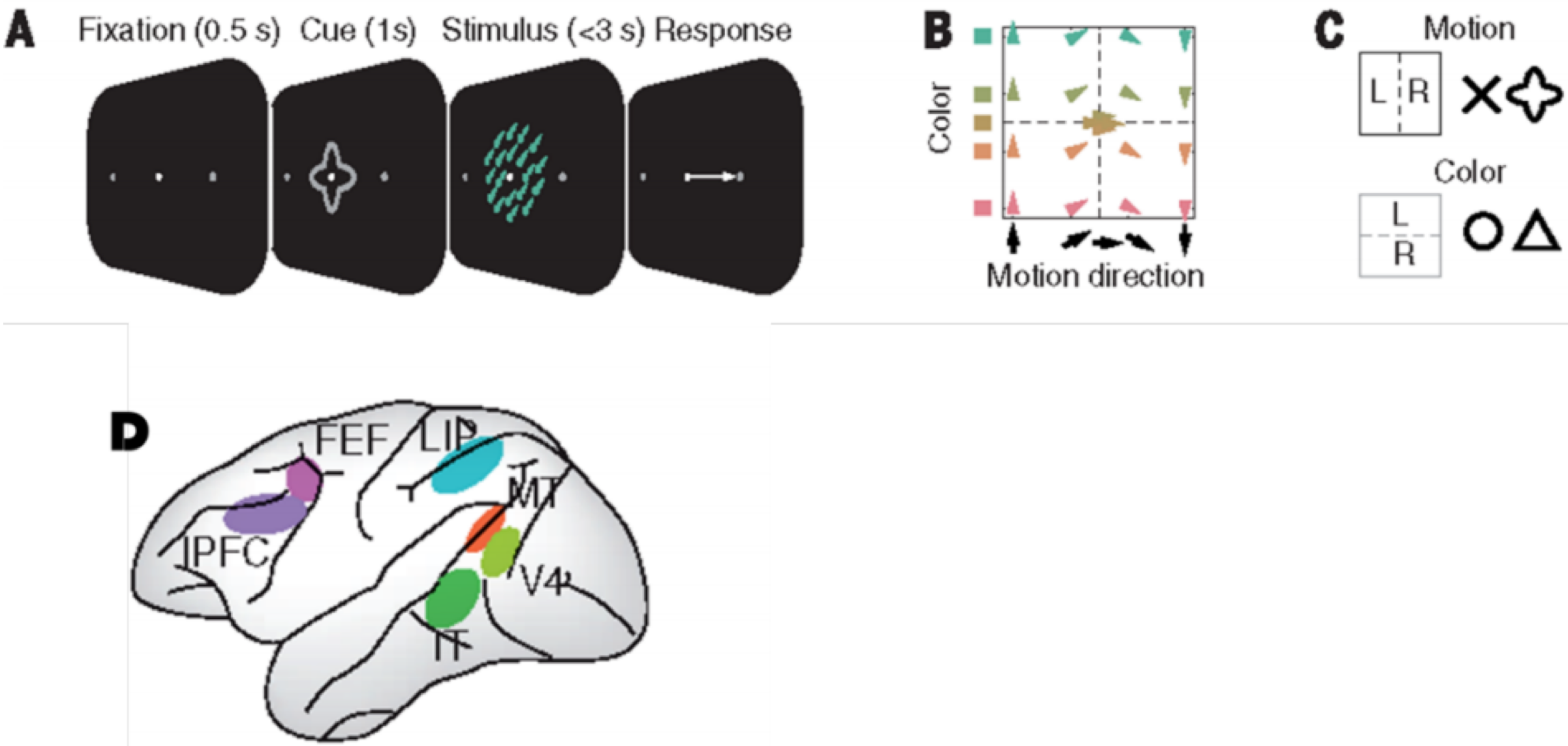
A. Firing rates of 3 neurons to natural image and image designed to enhance firing in neuron 1; Responses to natural image and image designed to enhance firing in neuron 1 while suppressing firing in neurons 2 and 3.

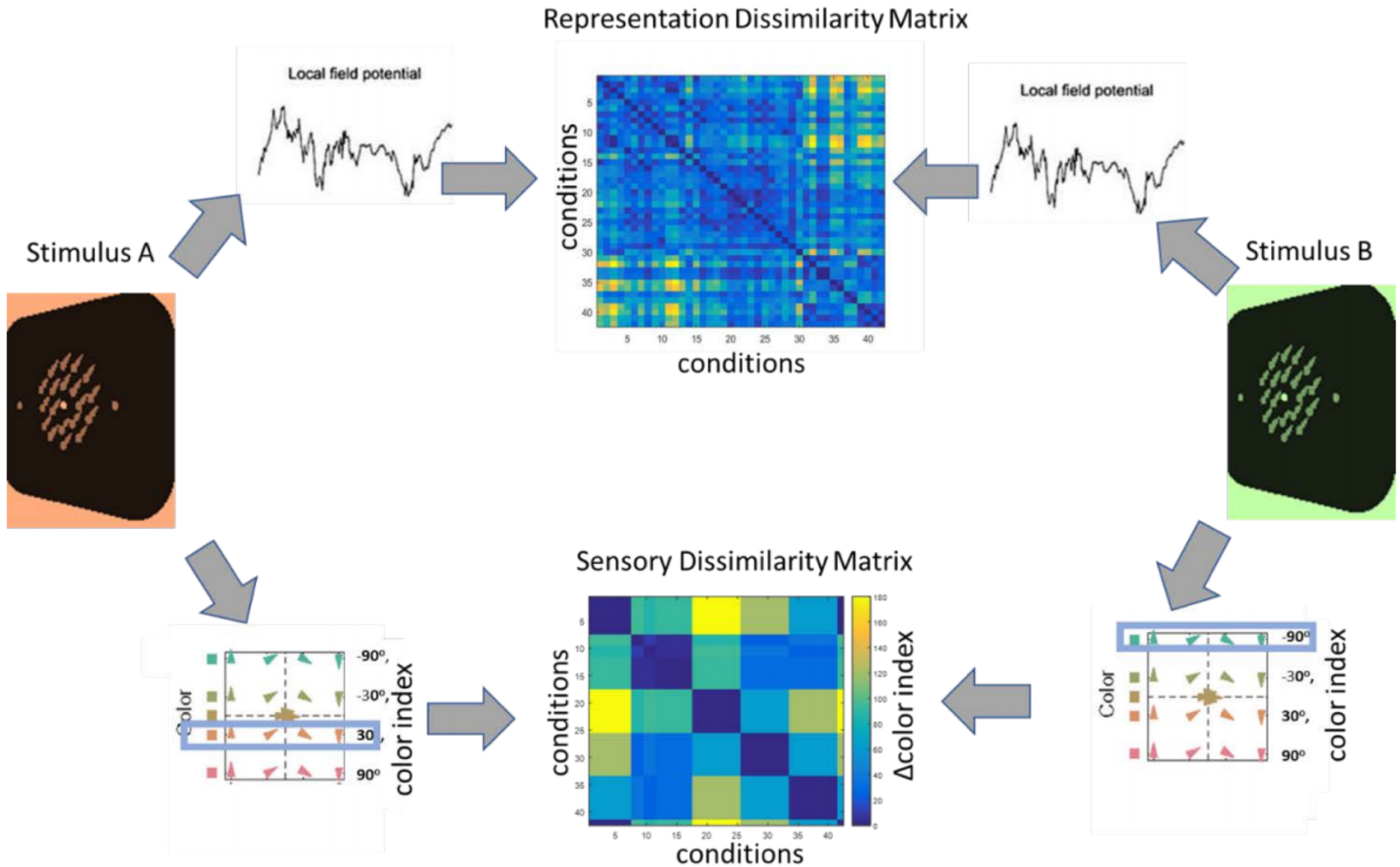
C. (2) mapping VGG layer 3 to NHP V4. Unlike LFADS stitching, not PC-regression. Uses 2-step method; step 1 imposes receptive field similarity and step 2 finds weighted sum of feature maps.


Measured Neural Firing Rate (a.u.)
Neural Site Number
Target Site
8°
4
0
-1
1
8

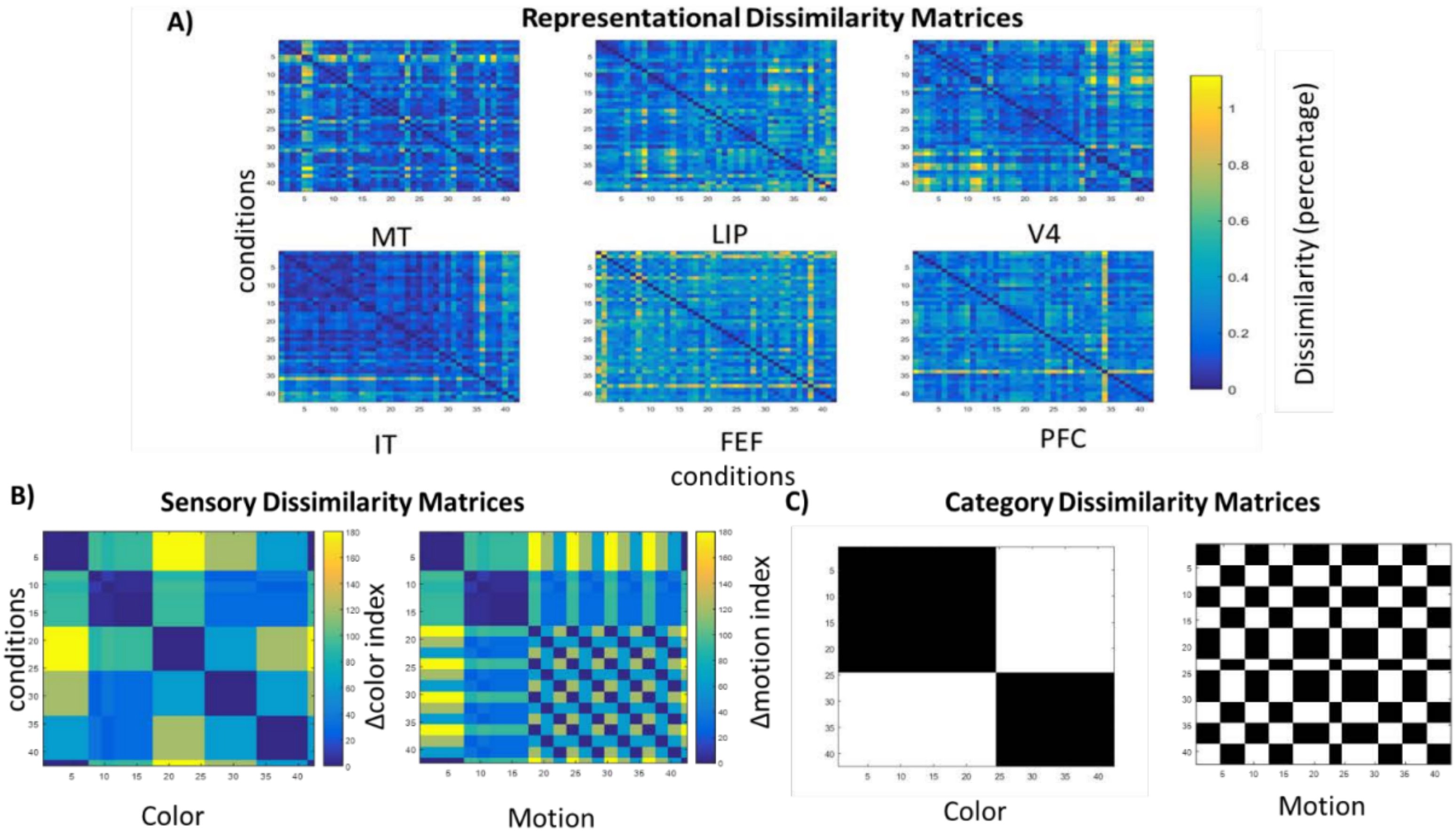
Sensory Processing and Categorization in Cortical and Deep Neural Networks

Dimitris A. Pinotsis[1,2], Markus Siegel[3] and Earl K. Miller[2]

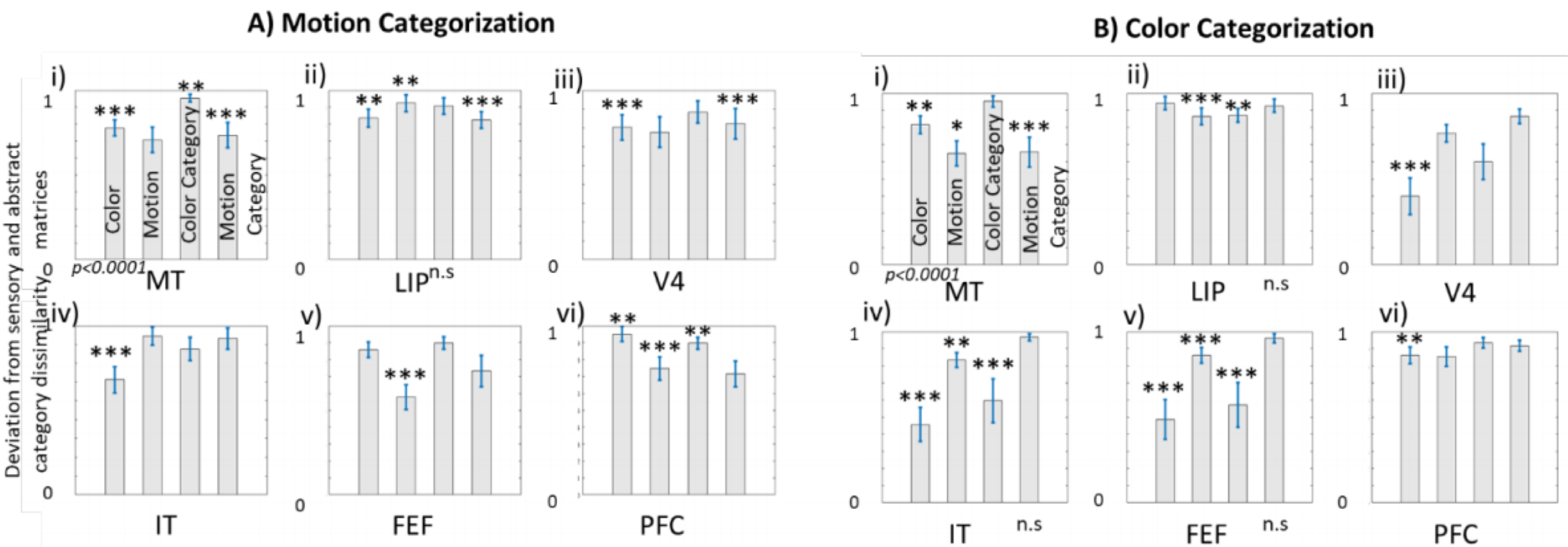




Representation Dissimilarity Matrix
Local field potential
Local field potential
Stimulus A
Stimulus B
conditions
conditions
Sensory Dissimilarity Matrix
conditions
conditions
Δcolor index
Color
color index
-90°,
-30°,
30
90°
Color
color index
-90°
-30°,
30°,
90°

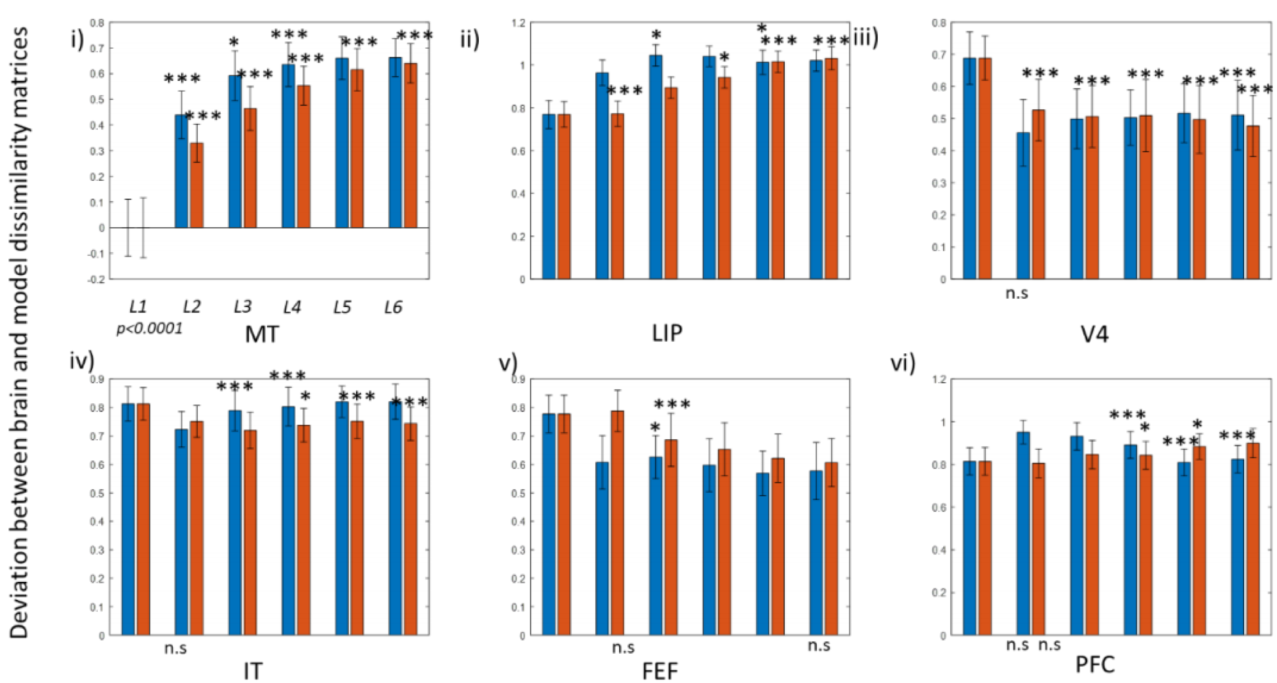


A)
Representational Dissimilarity Matrices
conditions
MT
LIP
V4
IT
FEF
PFC
conditions
Dissimilarity (percentage)
B)
Sensory Dissimilarity Matrices
conditions
Δcolor index
Δmotion index
Color
Motion
C)
Category Dissimilarity Matrices
Color
Motion


A) Motion Categorization
B) Color Categorization
i)
ii)
iii)
iv)
v)
vi)
Deviation from sensory and abstract category dissimilarity matrices
Color
Motion
Color Category
Motion Category
p<0.0001
MT
LIP
n.s
V4
IT
FEF
PFC

- RNN
  - 6 LSTM layers (38, 28, 28, 38, 38, 38)
  - Other common features (Dropout @ 40%, Batchnorm, Dense, Softmax)
  - 2 variants:
    - Sensory RNN (21 motion + 21 colour conditions)
    - Category RNN (2 motion + 2 colour categories)
  - Only used MT or IT to train!
- Calculated RDMs on output of each layer in RNN.
- Compare layer-RDMs to brain region-RDMs.

Motion Task



Color Task