Decoding visual perception from human brain activity

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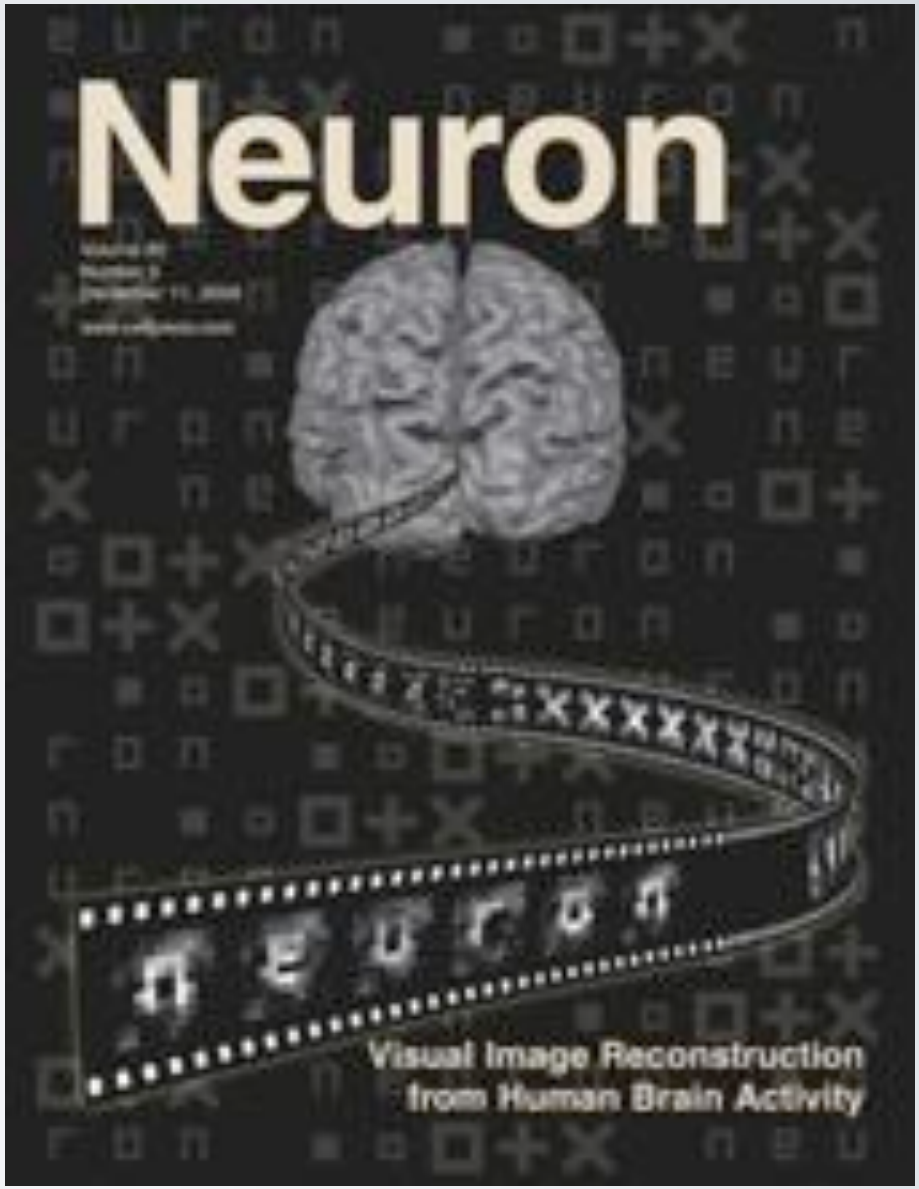
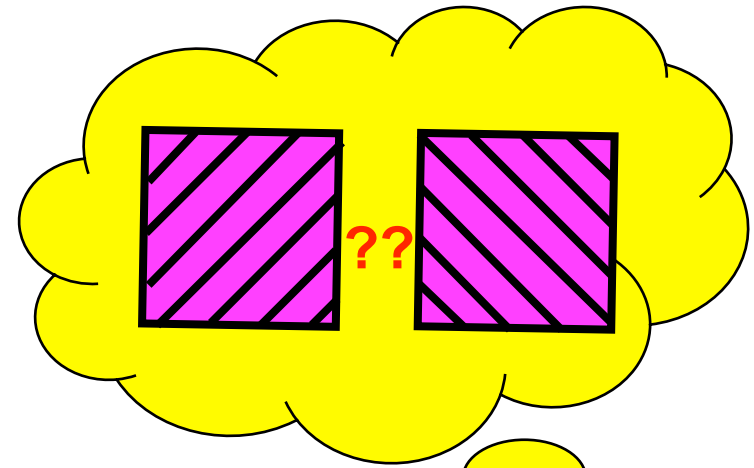


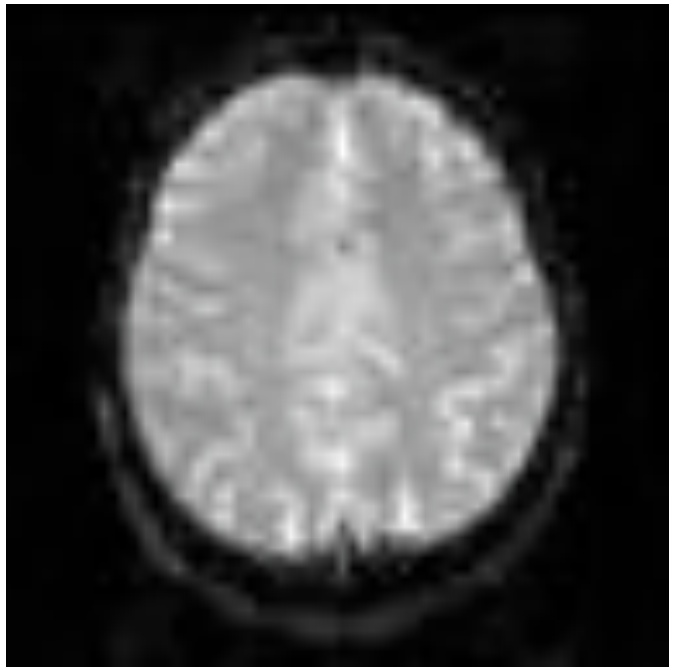
The question

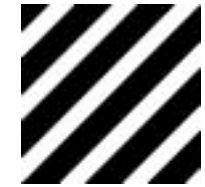
(modified from http://whatisthematrix.warnerbros.com/)

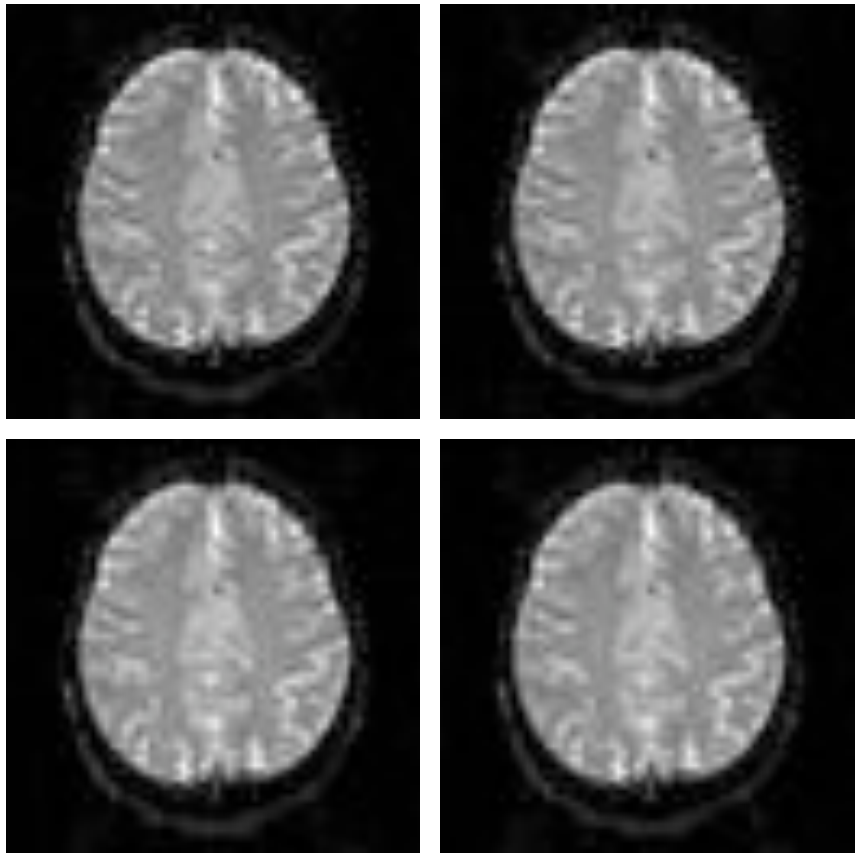


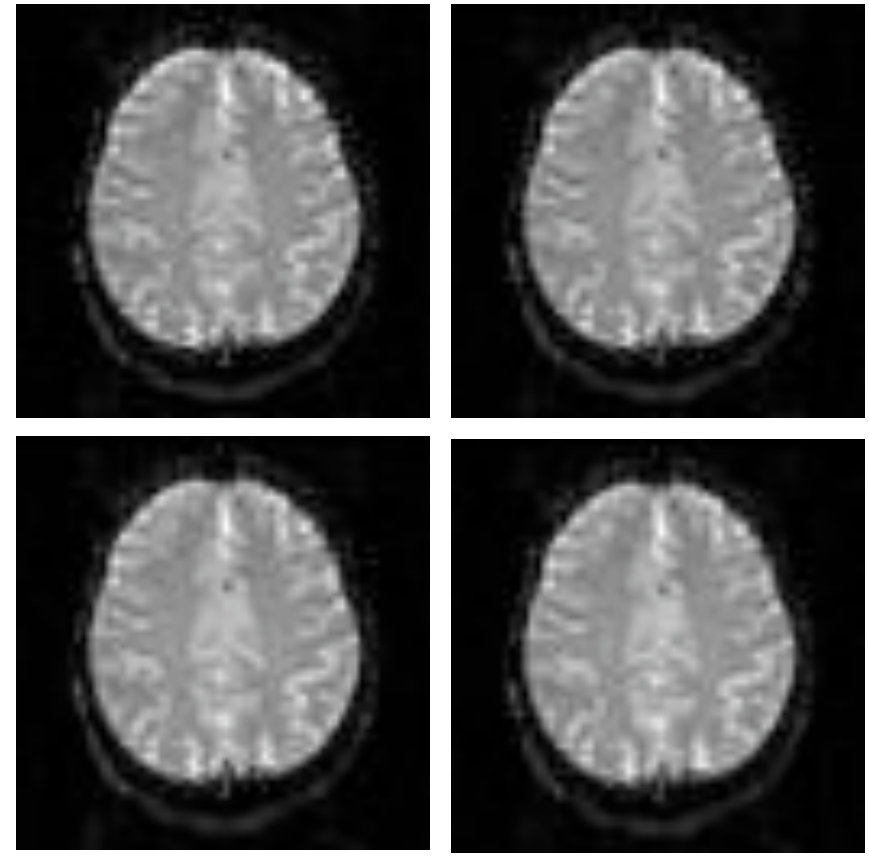
Signals from Neo's brain

What is he seeing?

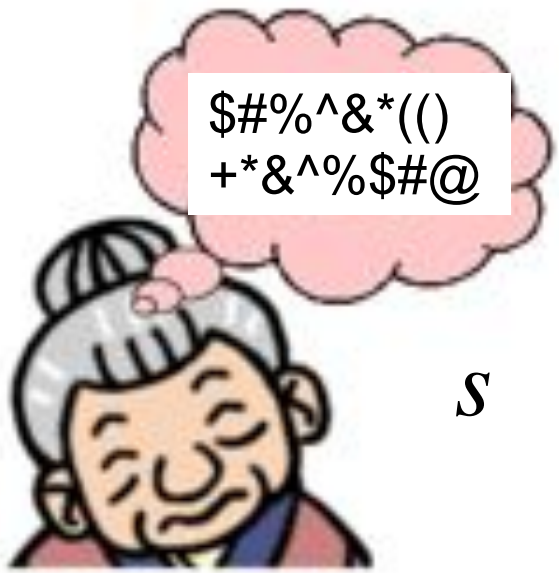








Let the computer learn!: Machine learning-based decoding



$P[\mathbf{r} \mid s]$

Coding

s

$\mathbf{r}$

Decoding

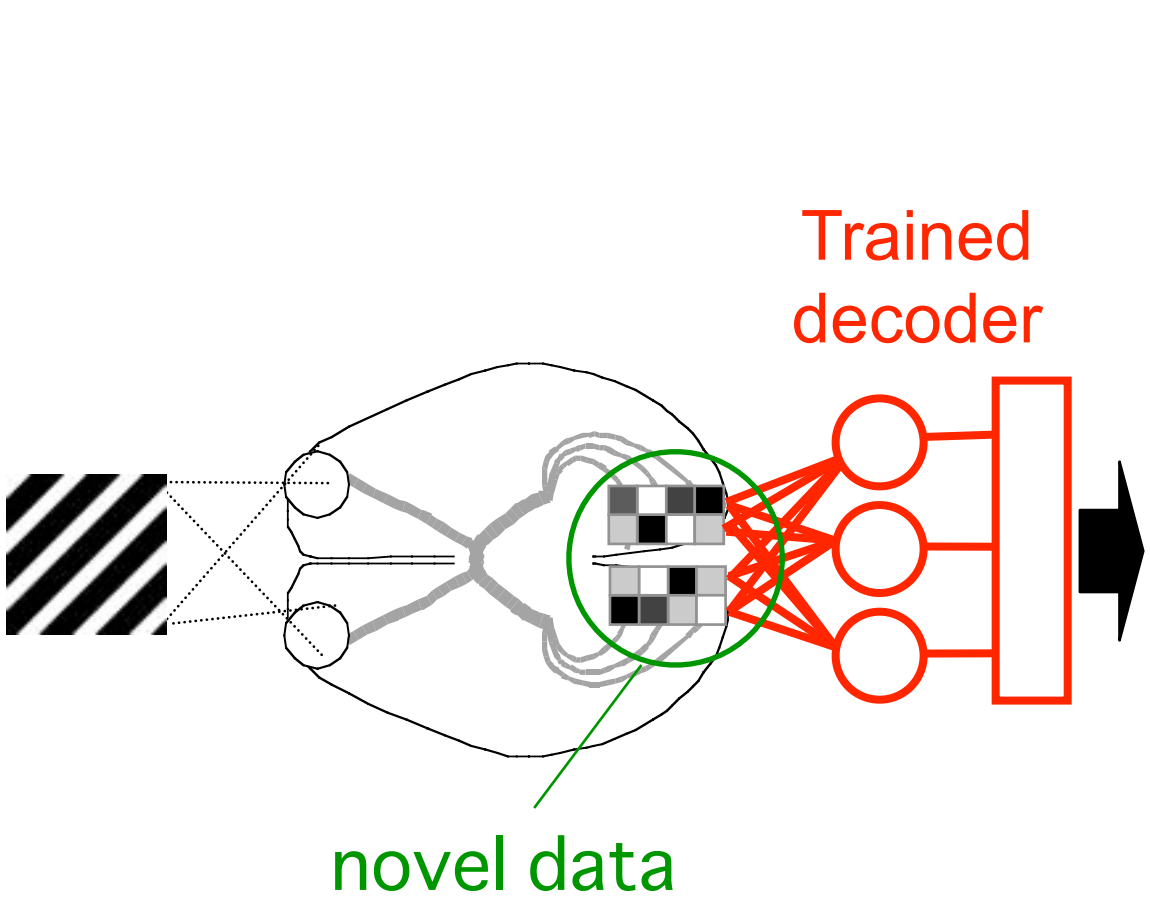
Mind/behavior

Brain

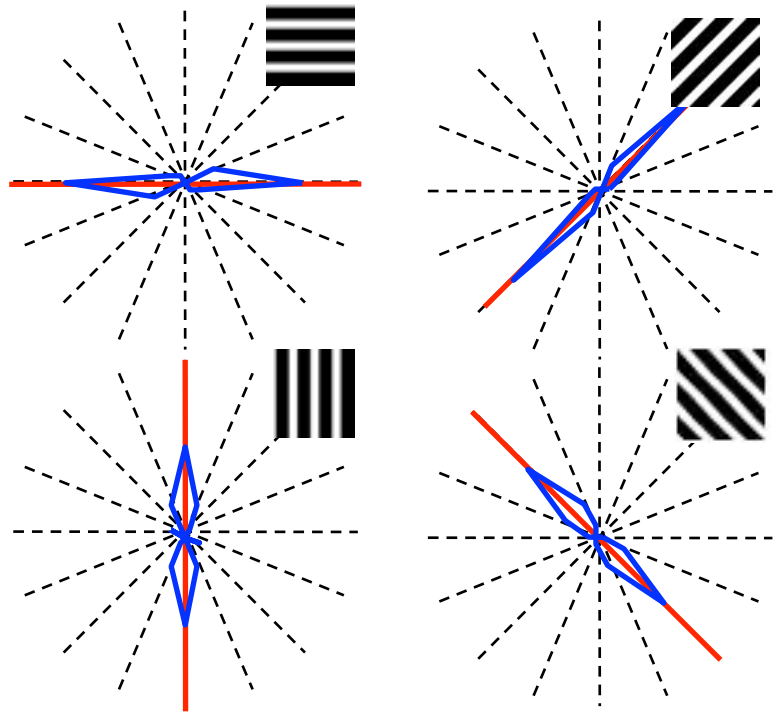
$$P[s \mid \mathbf{r}] = \frac{P[\mathbf{r} \mid s]P[s]}{\sum_{s} P[\mathbf{r} \mid s]P[s]}$$

fMRI decoding of visual orientation

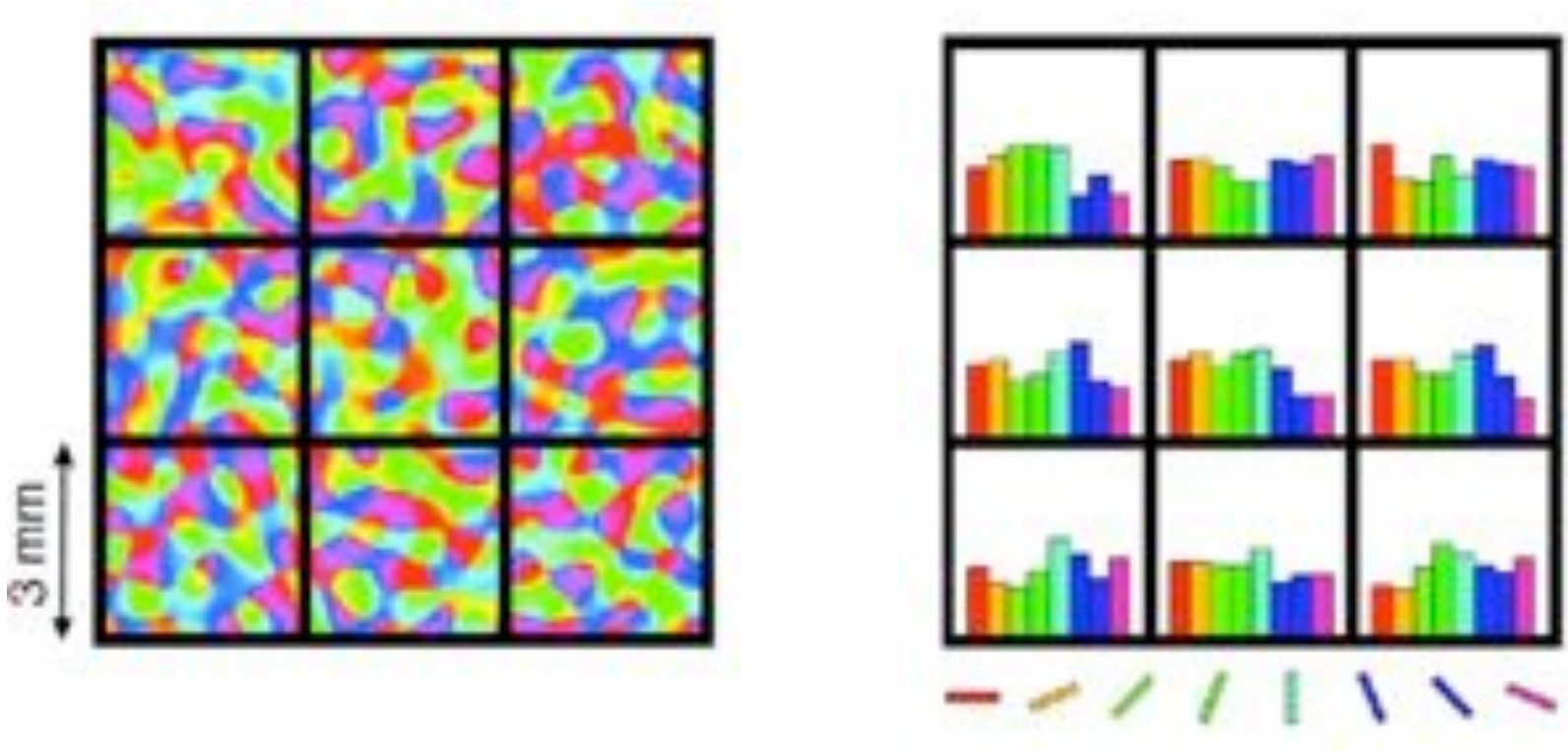
(Kamitani & Tong, *Nat. Neurosci.* 2005)



Decoded orientation



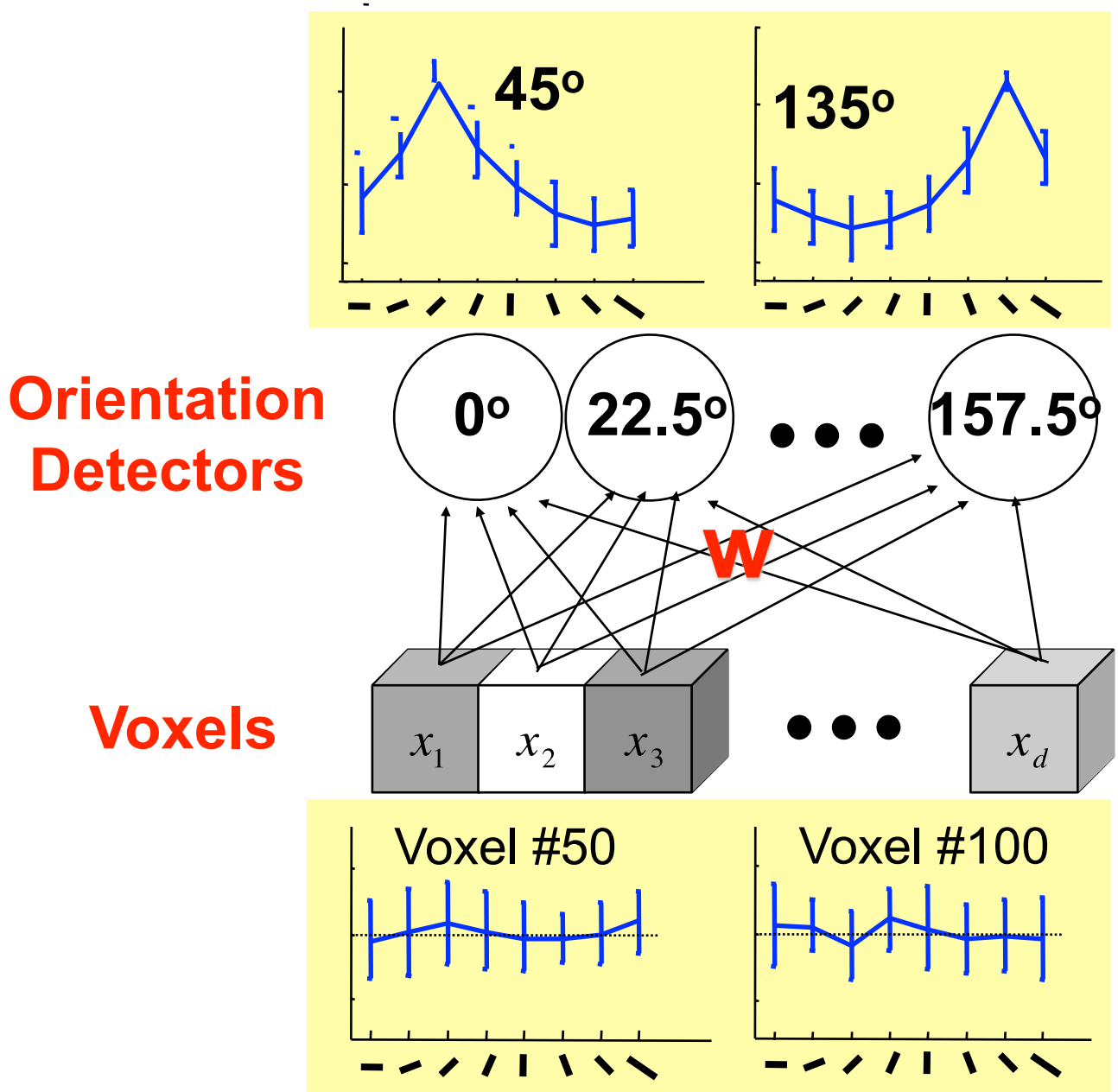
Columns and voxels



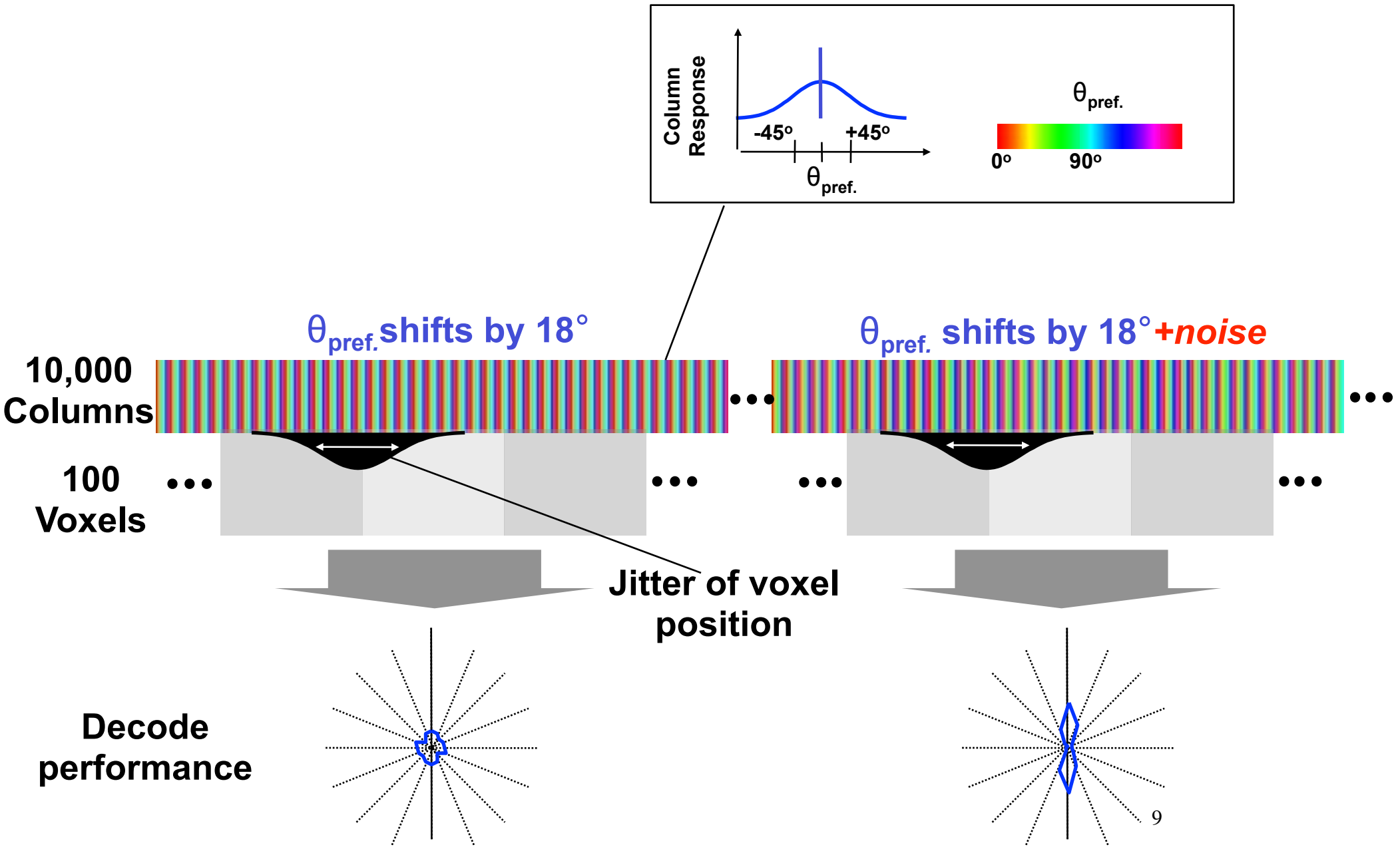
(cf., Boynton, 2005; Rojer and Schwartz, 1990)

Ensemble feature selectivity

(Kamitani & Tong, 2005, 2006)

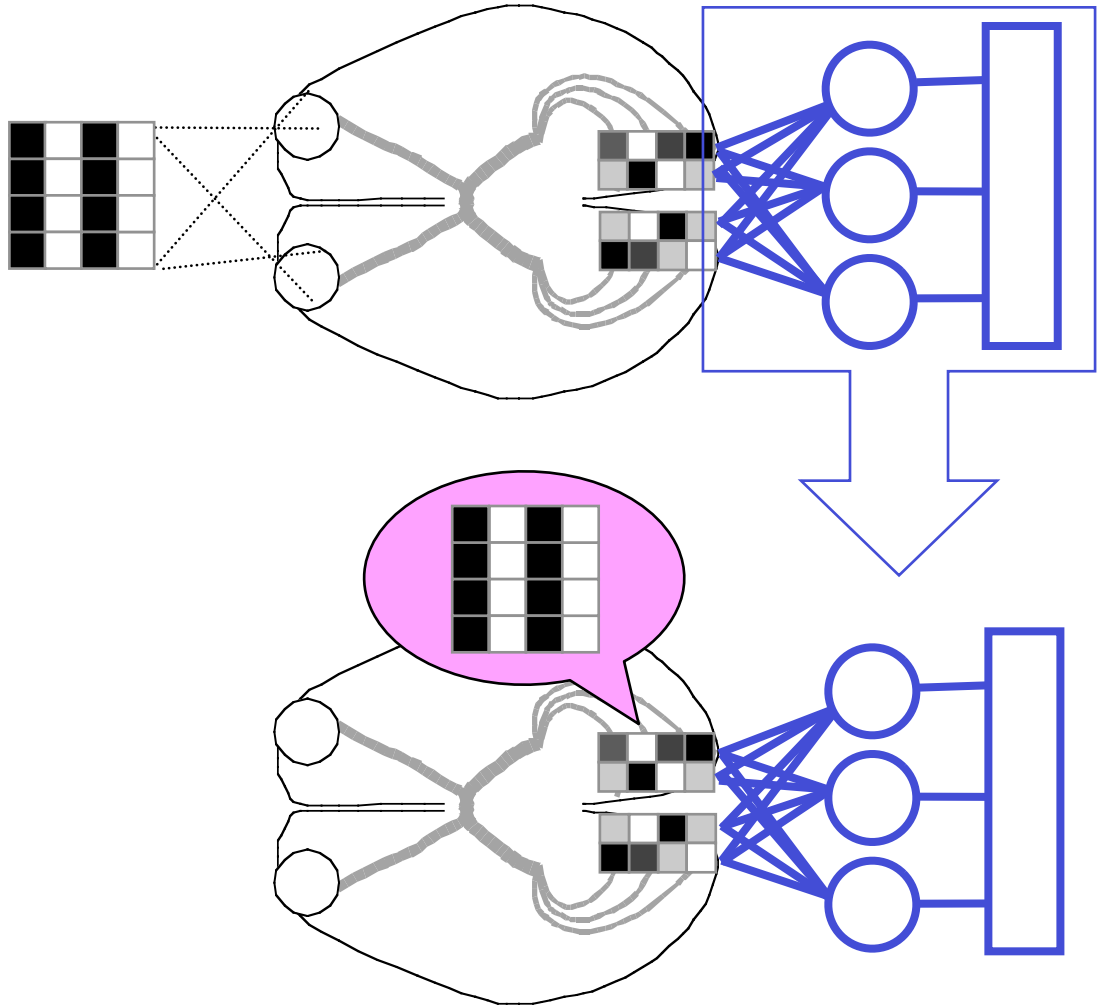


1-D simulation of columns and voxels



Method of "neural mind-reading"

(Kamitani & Tong, 2005, 2006)



Training with unambiguous stimuli (relatively objective)

Prediction of subjective states

Assumption: Stimulus-induced perception and subjective mentation share some neural representation.

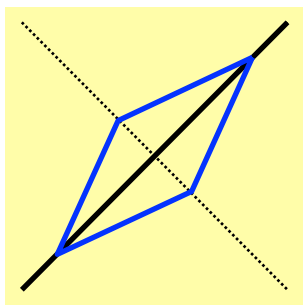
Neural mind-reading of attention

(Kamitani & Tong, 2005, 2006)

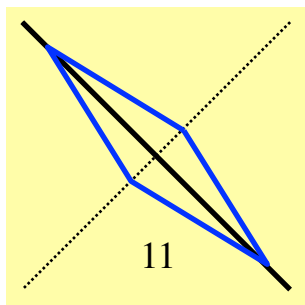
What's on your mind, Neo?

Trained with unambiguous single gratings

Attend to 

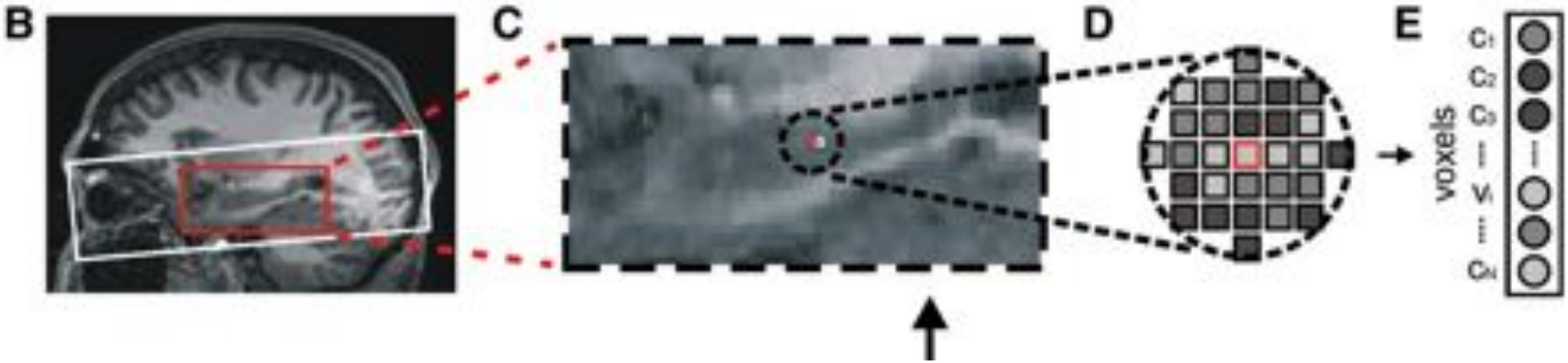


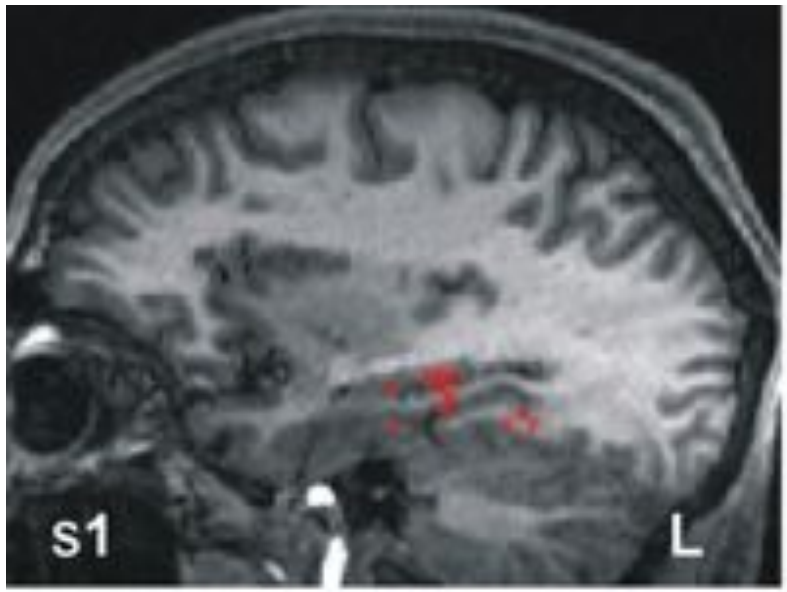
Attend to 

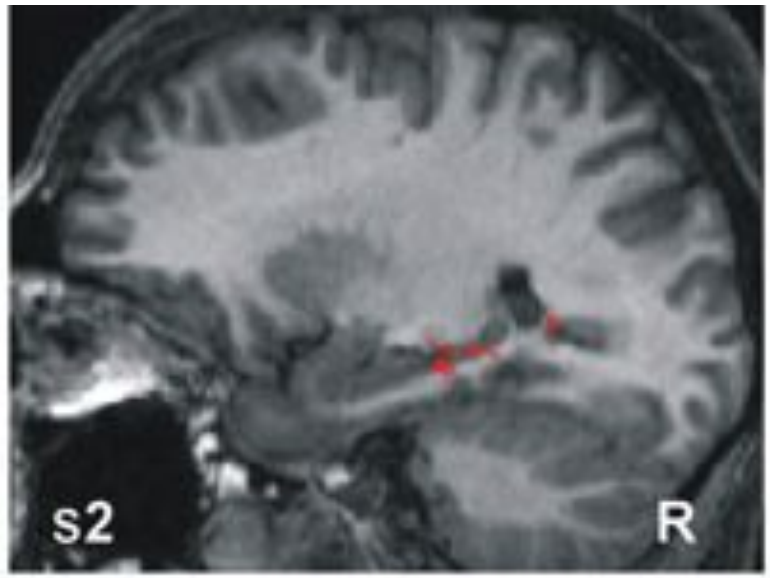


(c.f., Mind-reading of mental imagery: Stokes et al.,2009; Harrison et al., 2009)

Decoding from human hippocampus

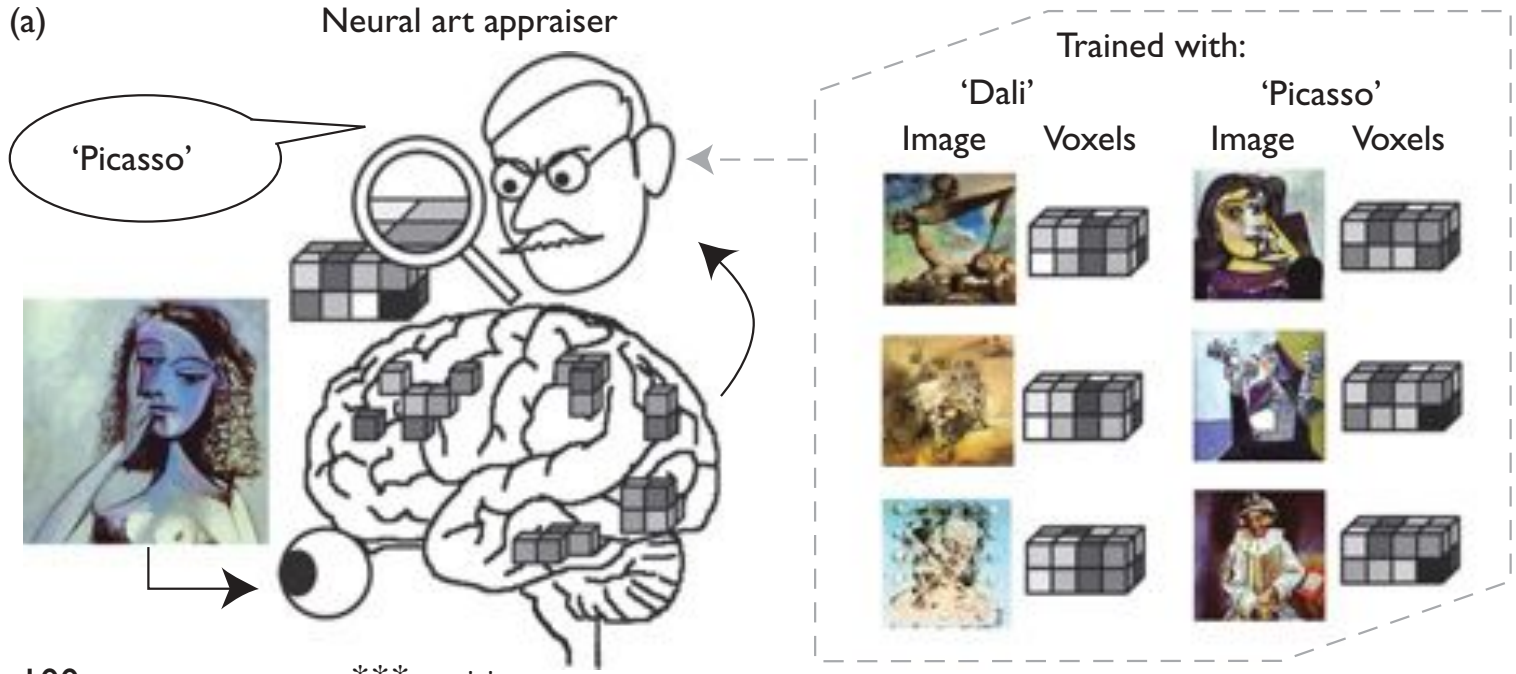


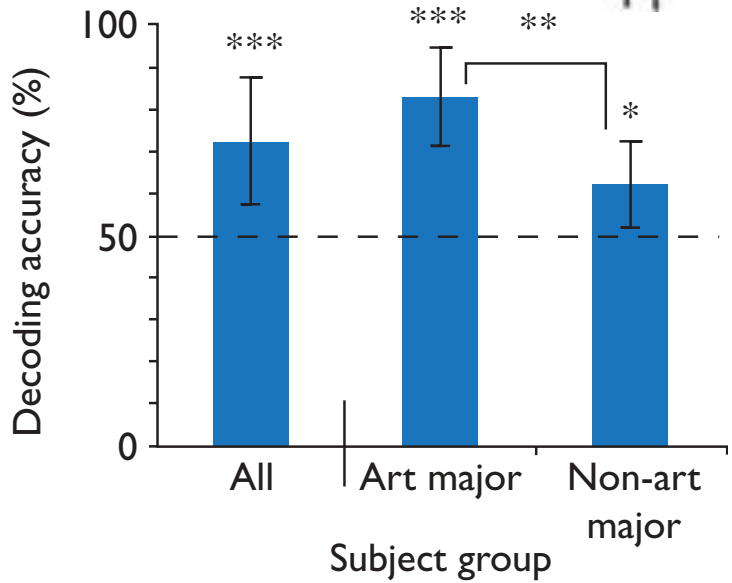




(Hassabis et al. Curr Biol 2009)

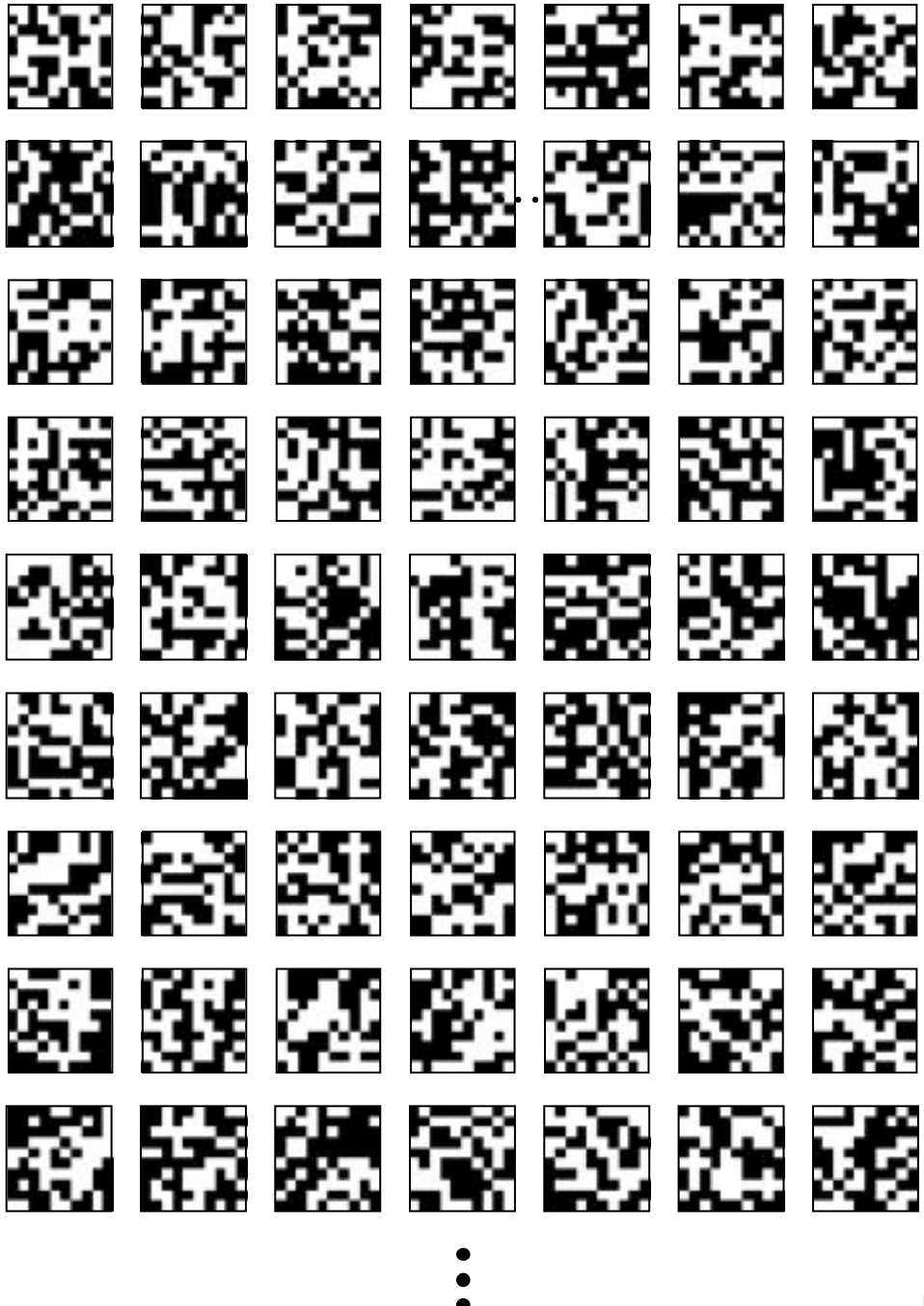
Neural art appraisal of painter: Dali or Picasso?





(Yamamura, Sawahata, Yamamoto, Kamitani, 2009)

Decoding into an image: Visual image reconstruction



In the case of 10 x 10 binary pixels

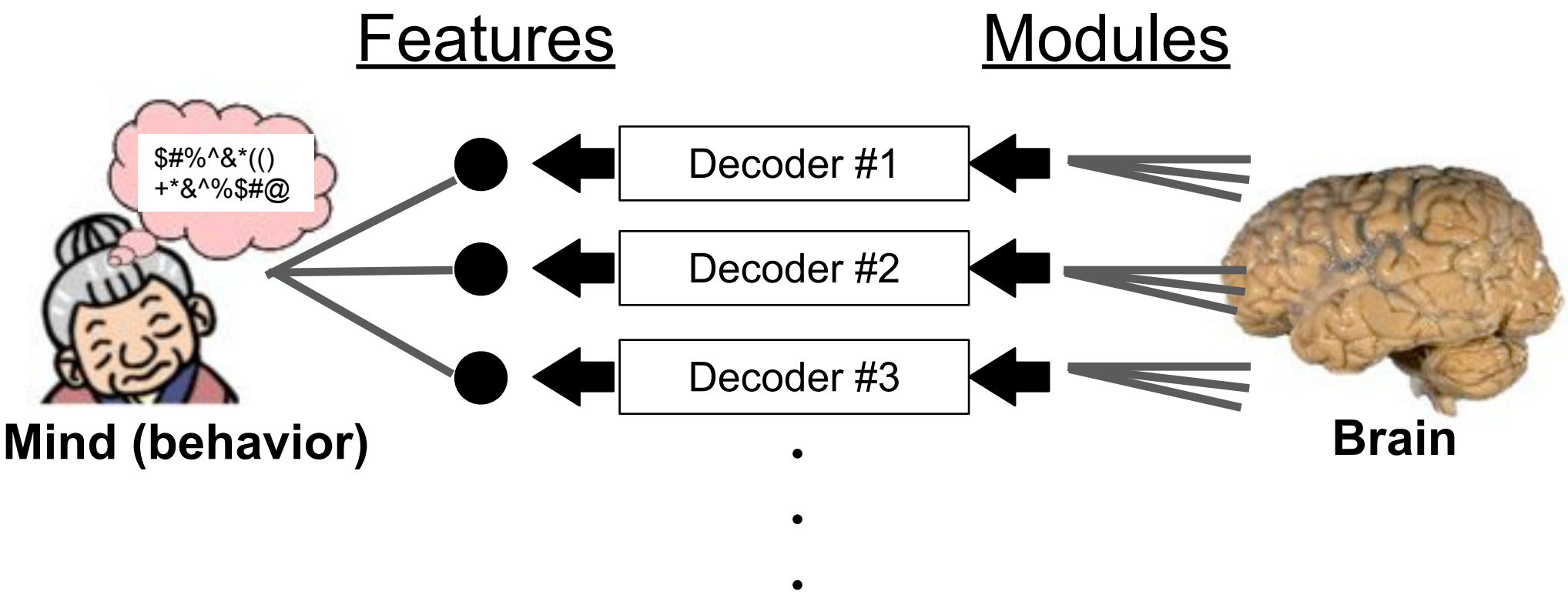
$$2^{100} = 10000000 \cdot \cdot \cdot \text{ possible images}$$

~30 zeros

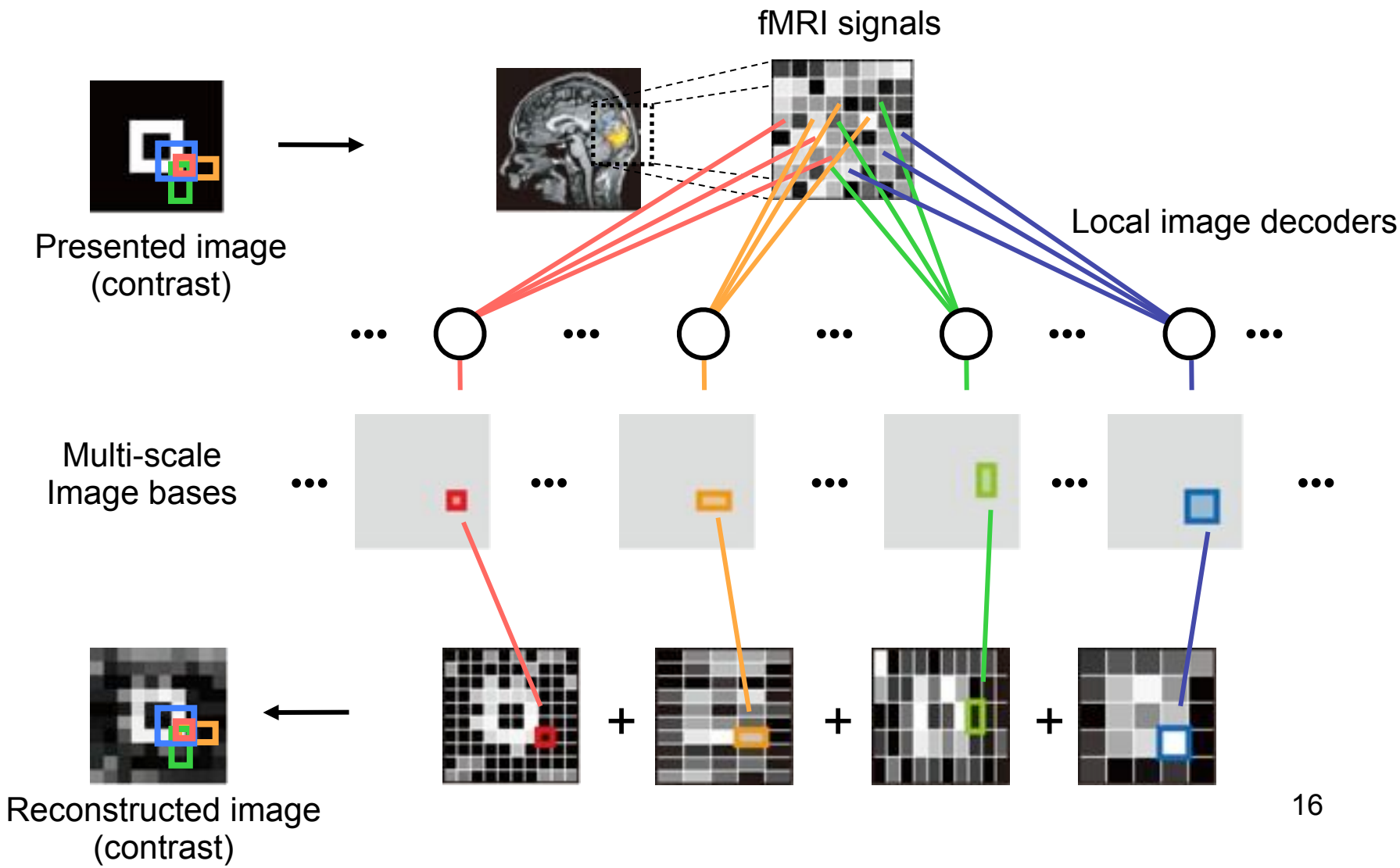
Impossible to measure brain activity for all possible images!

Modular decoding approach

(Miyawaki, Uchida, Yamashita, Sato, Morito,Tanabe, Sadato, Kamitani, *Neuron* 2008)



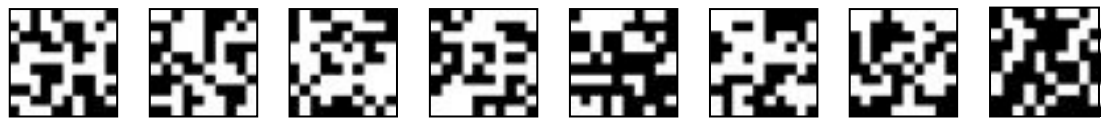
Reconstruction using multi-scale local image decoders

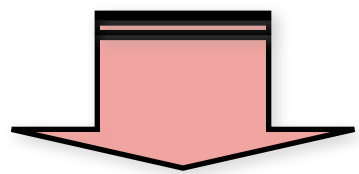


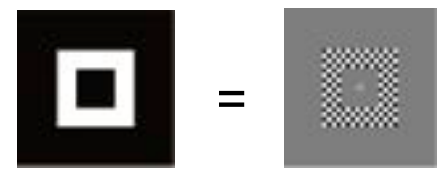
Procedure

Training

~400 random images (~ 1 hour)







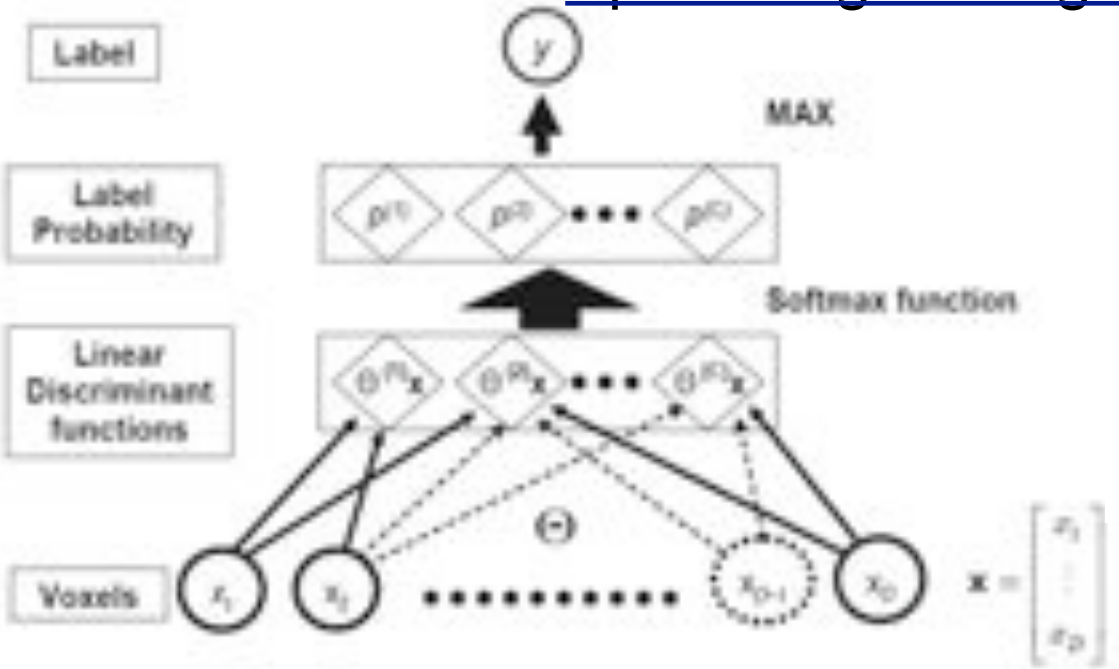
Test

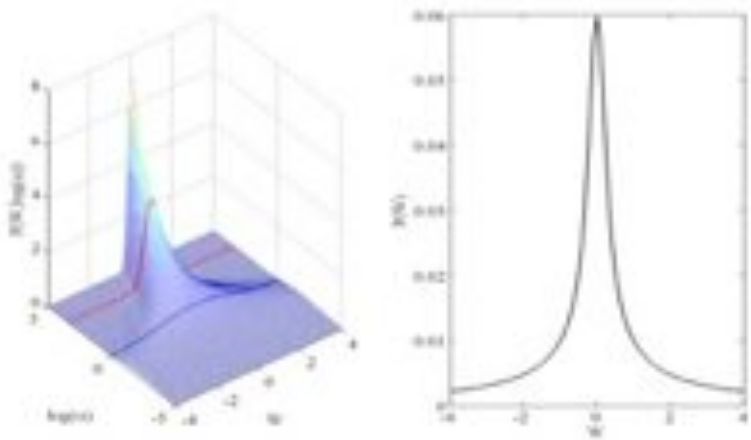
Geometric shapes, alphabets, random images (not used in training)

Automatic voxel selection by local decoder

(Yamashita, Sato, Yoshioka, Tong, Kamitani, *Neuroimage* 2008)

Sparse logistic regression





- Finds an optimal set of voxels for each image basis from the whole visual cortex.
- Selected voxels form a complex pattern, outperforming retinotopy-based prediction.

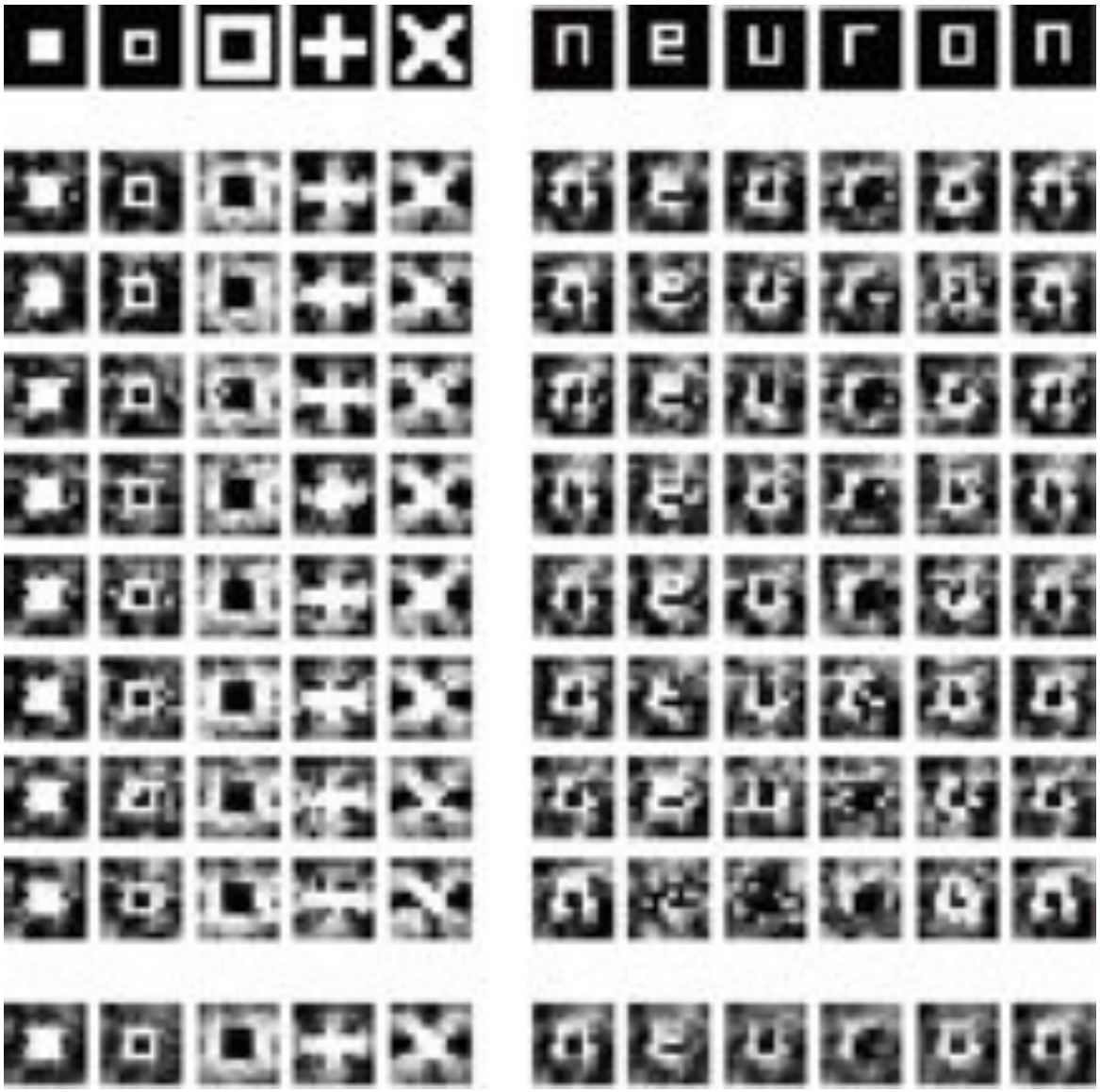
Reconstruction results:

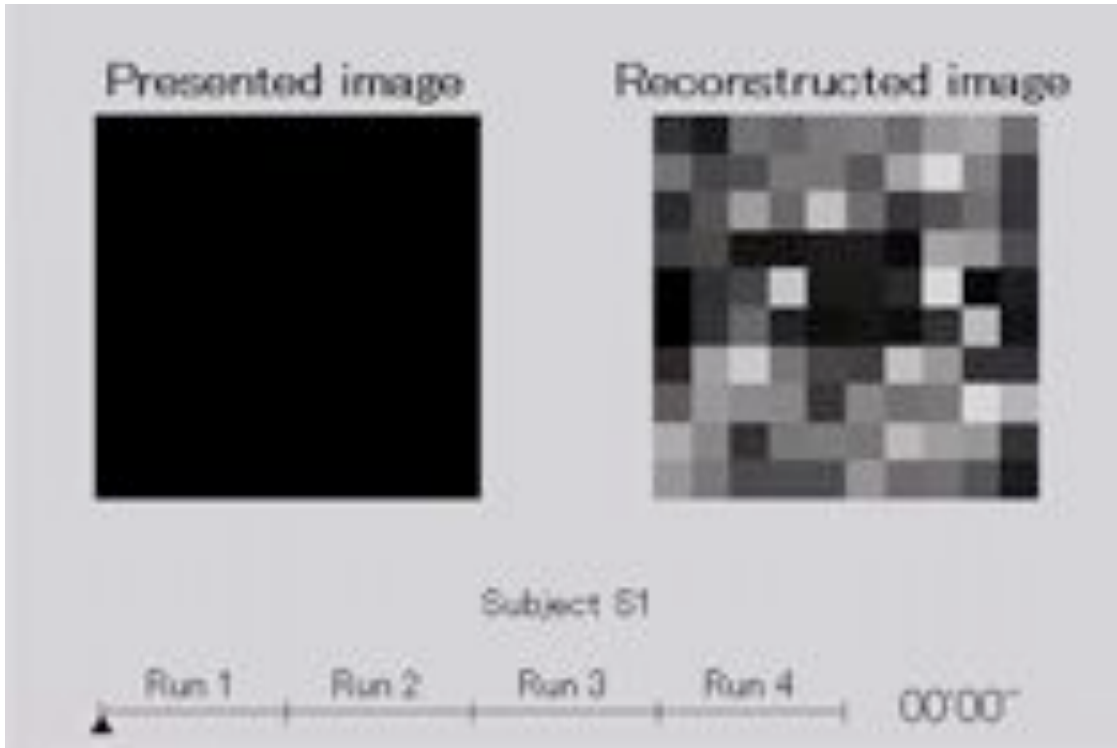
Block averaged fMRI signals (6 volumes = 12 s)

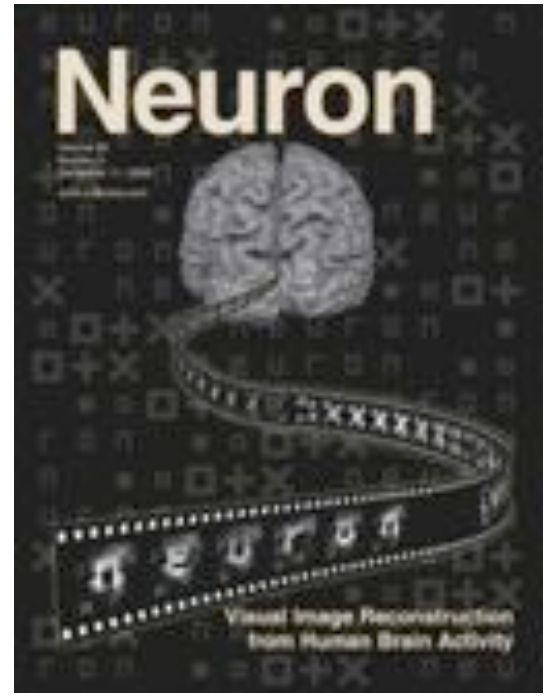
Presented images (contract)

Reconstructed images （8 trials / image）

Mean reconstructed images

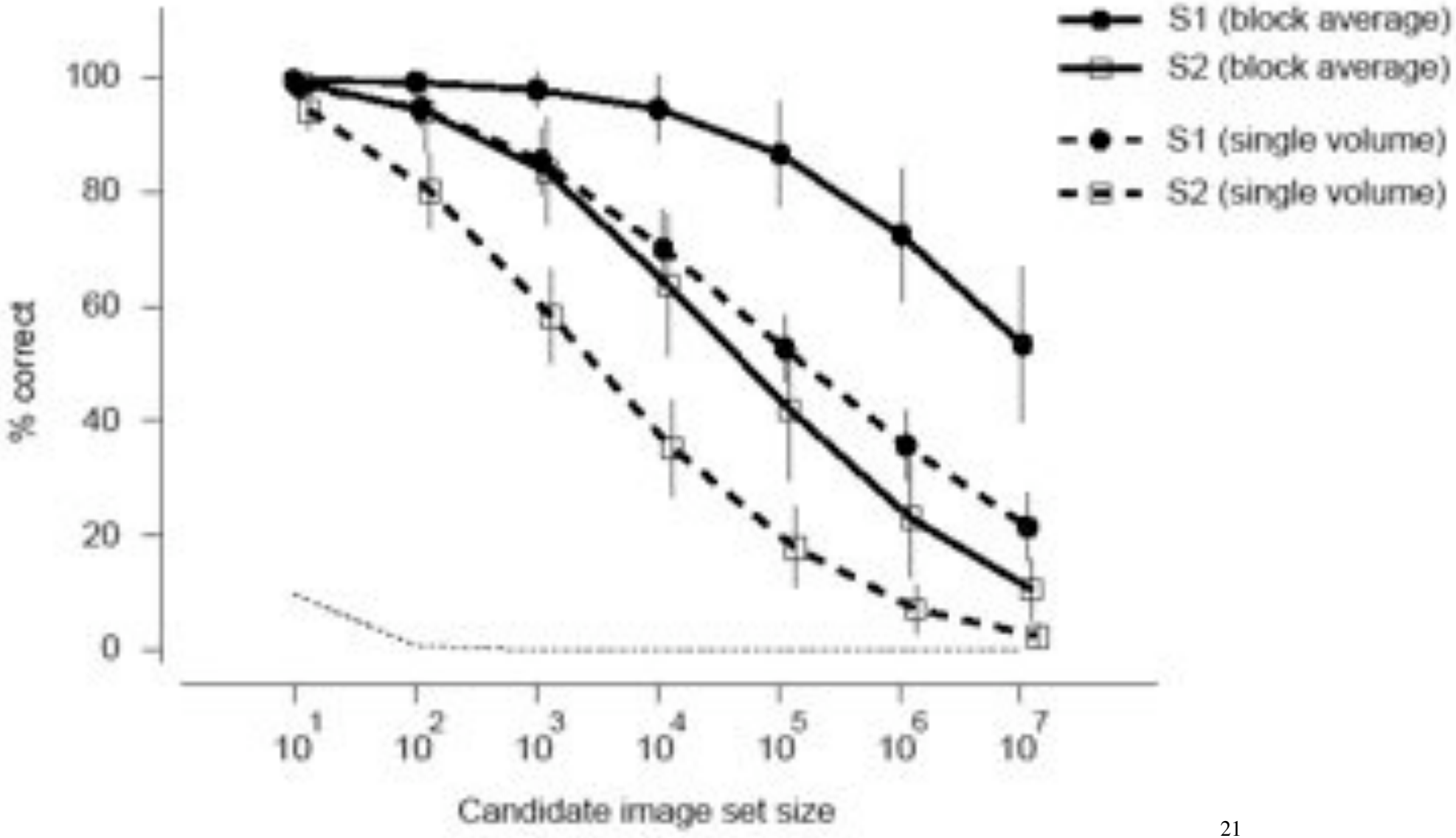




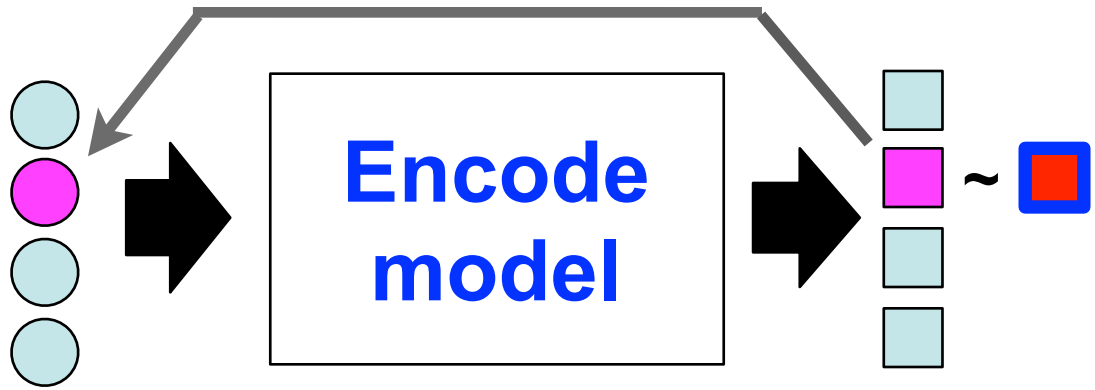


(Miyawaki, Uchida, Yamashita, Sato, Morito,Tanabe, Sadato, Kamitani, *Neuron* 2008)

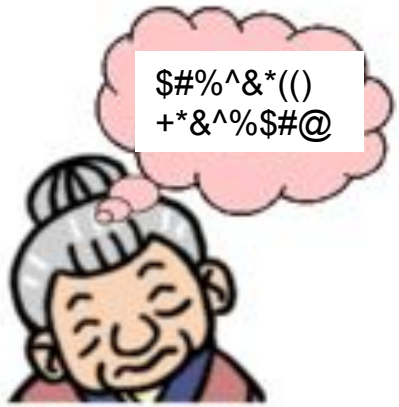
Image identification via reconstruction



Encode vs. decode models

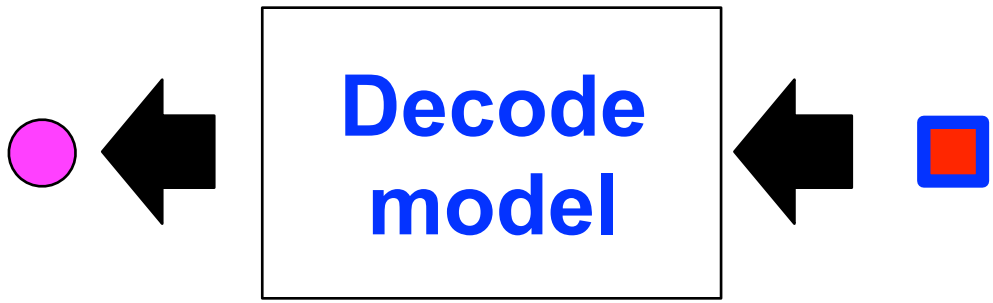


(Kay et al. Nature 2008;
Mitchell et al. Science 2008)



Mind

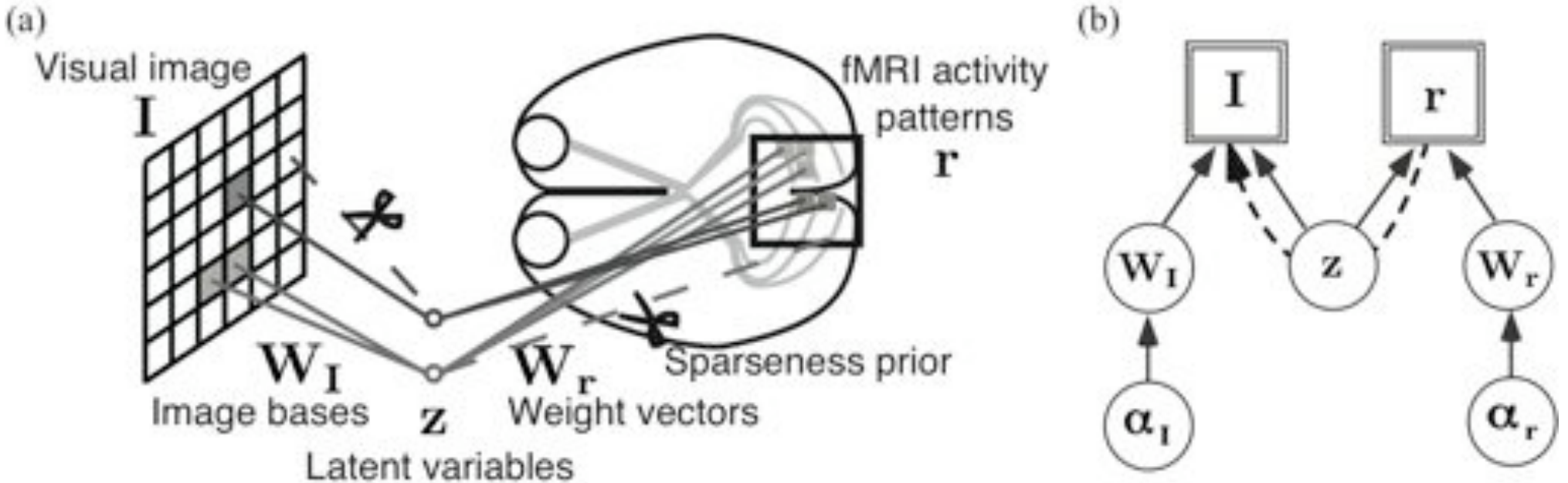
Brain



(Miyawaki et al. Neuron 2008)

Bidirectional model?

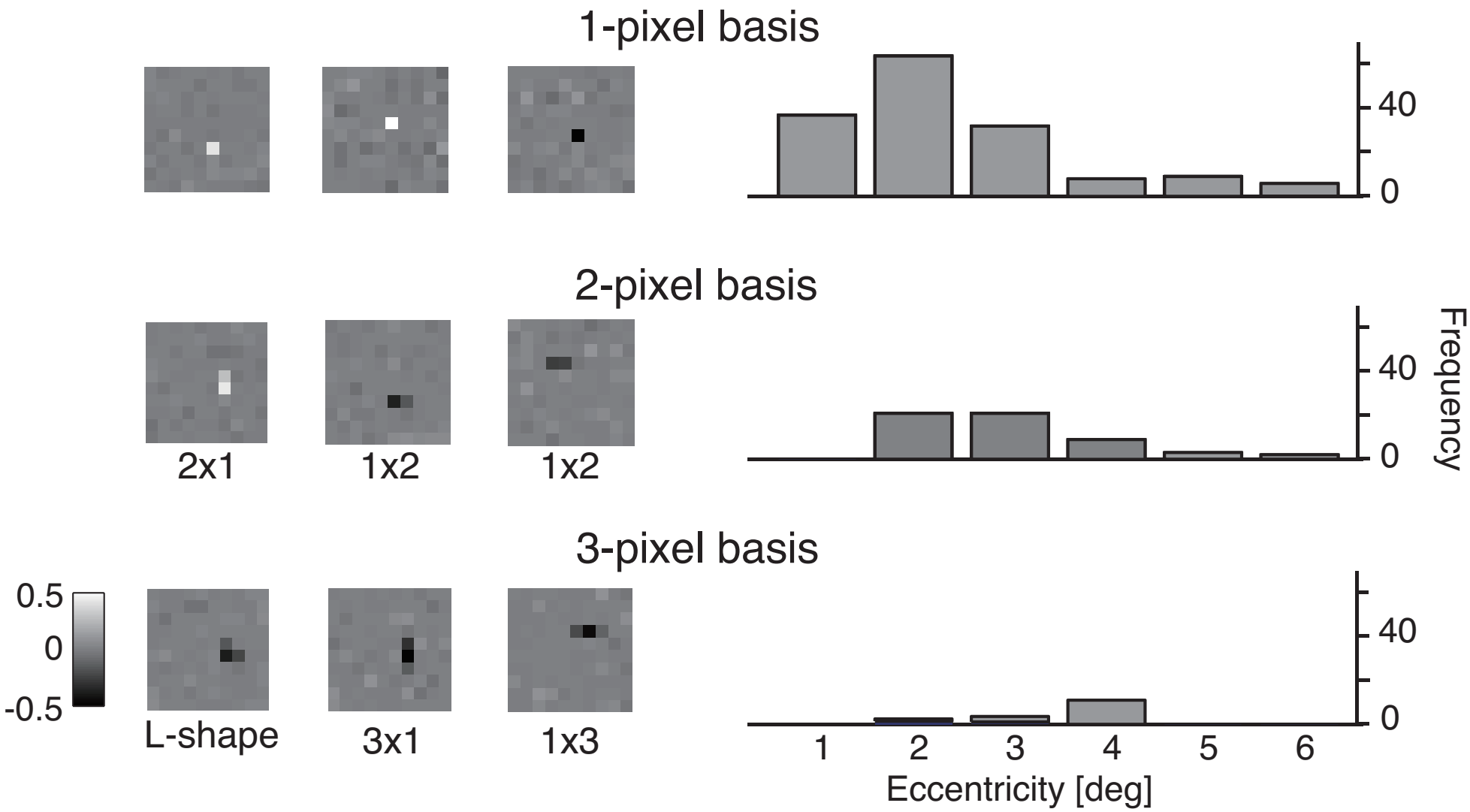
Automatic extraction of image bases: A Bayesian CCA model



(Fujiwara, Miyawaki, Kamitani, *NIPS* 2009)

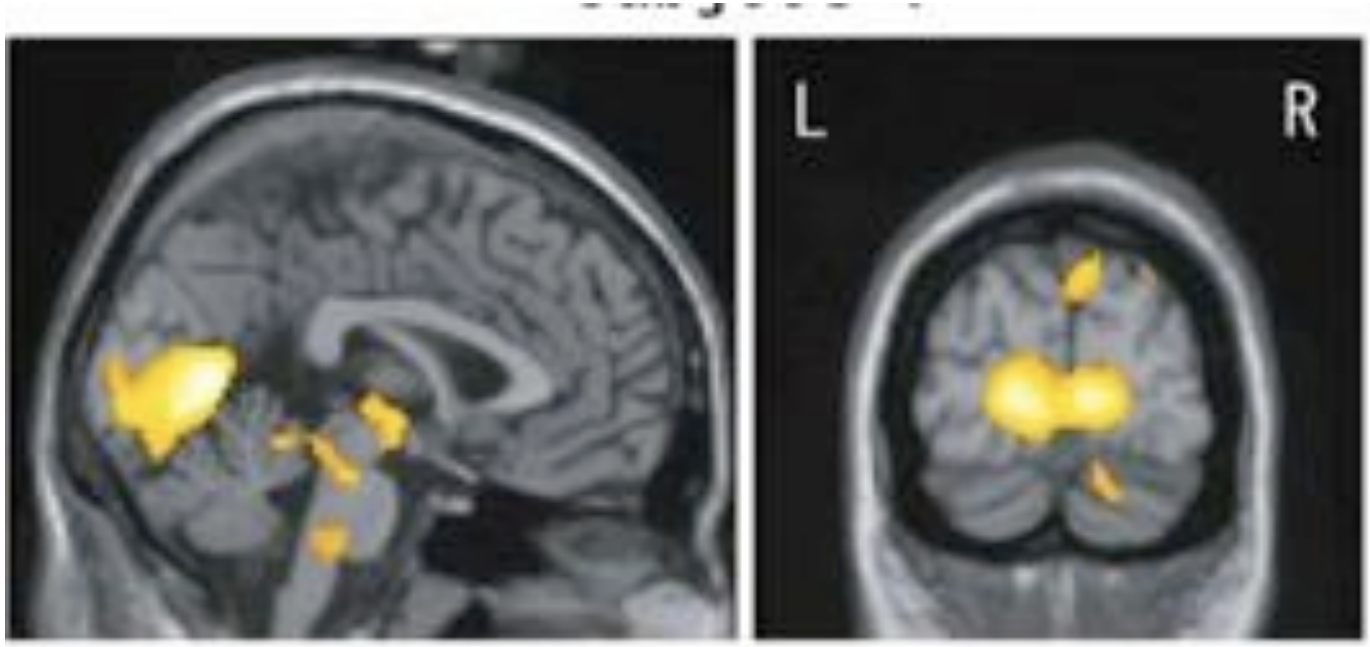
Image bases estimated from data

(a) Estimated image bases by Bayesian CCA



DREAMY scientists say they will come up with new technology which shows what is on our minds when we're ASLEEP.
(The Sun, 11 Dec, 2008)

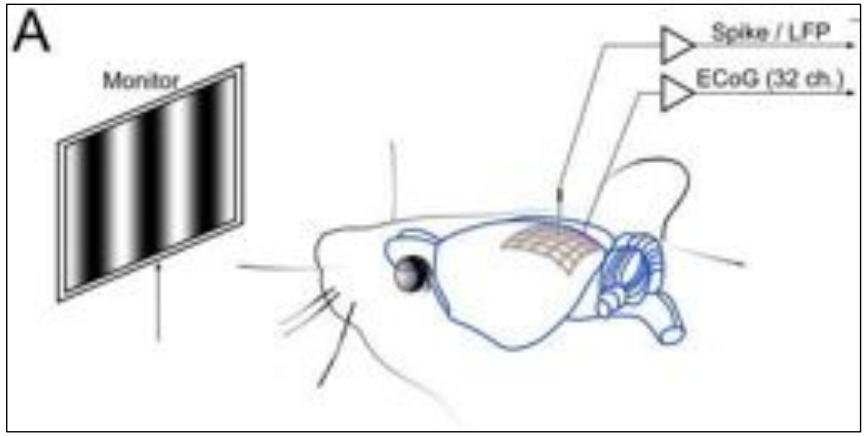
Visual cortical activation during REM sleep

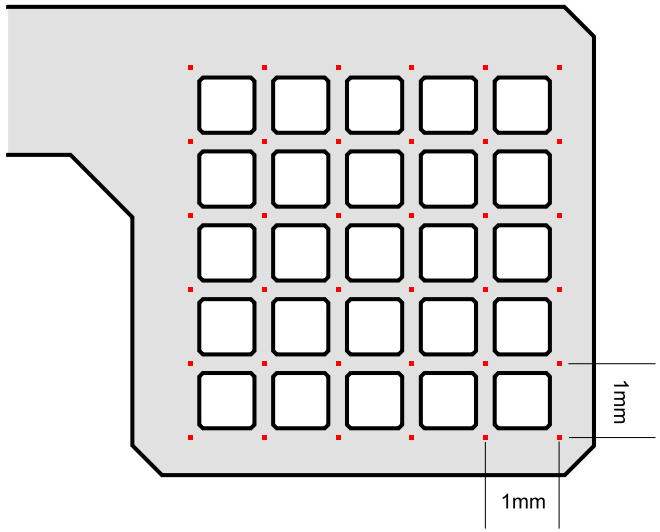


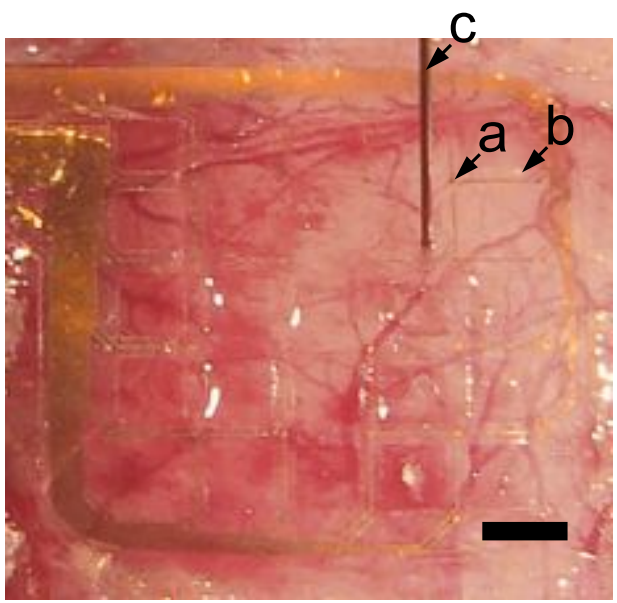
fMRI activity during REM (triggered by eye movements)
(Miyauchi et al., 2008)

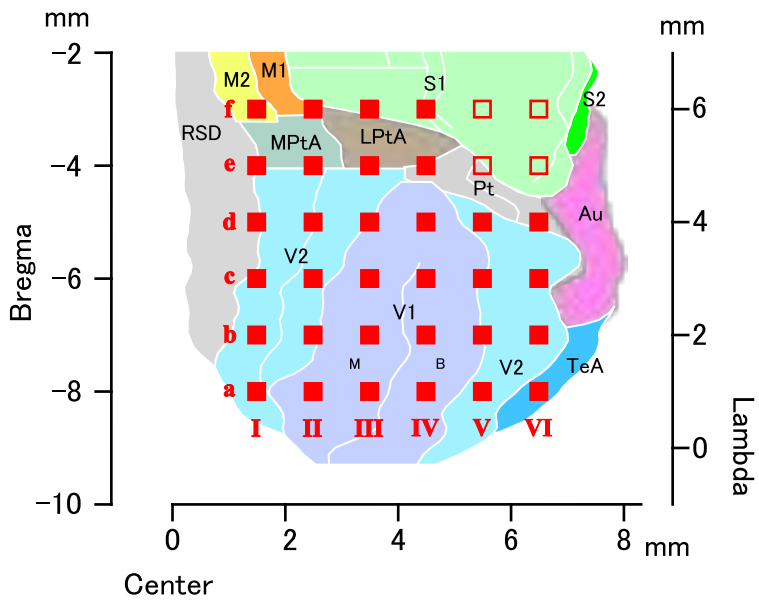
Flexible mesh ECoG array

(Collaboration with Niigata U. and U. Tokyo)



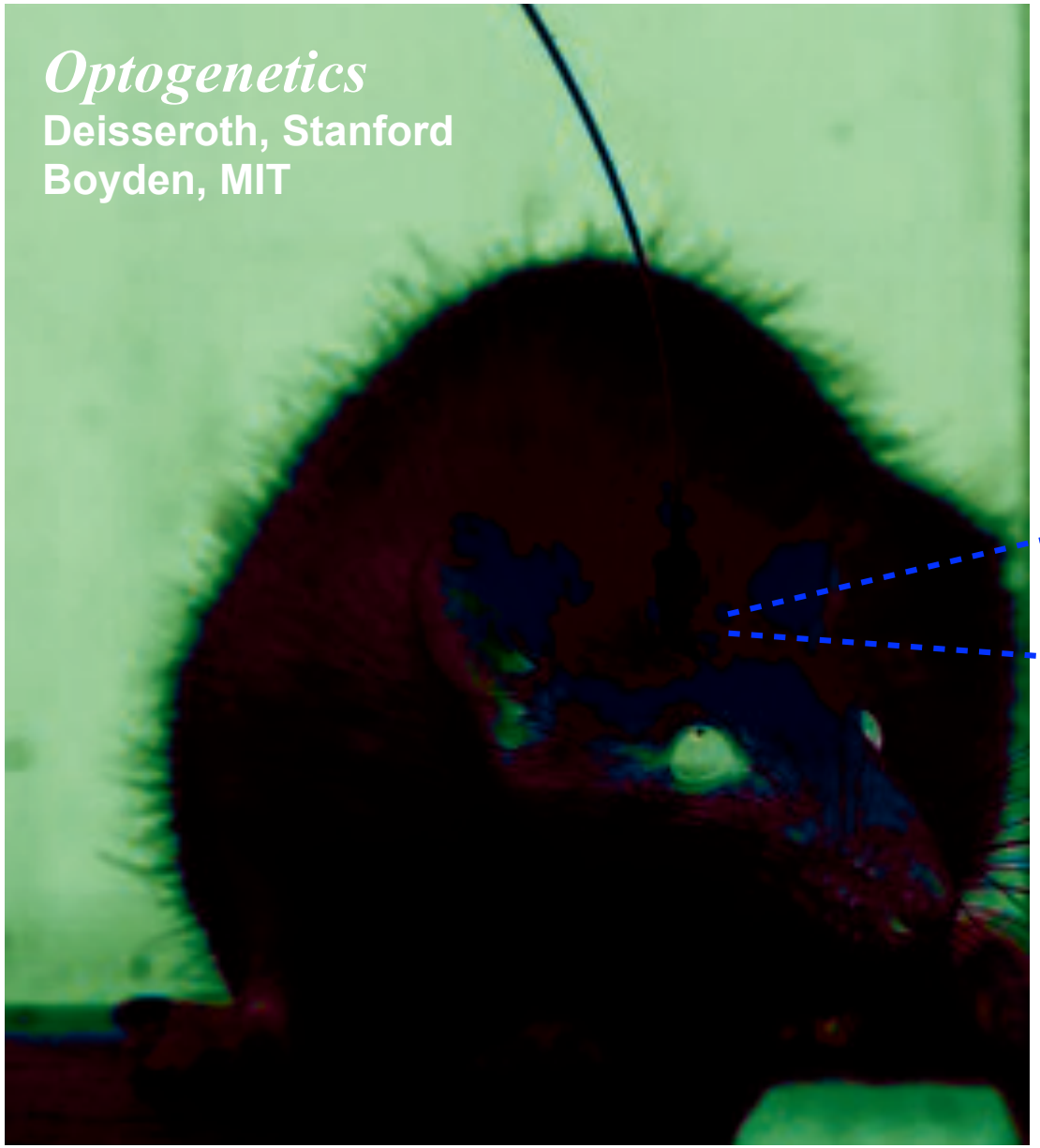


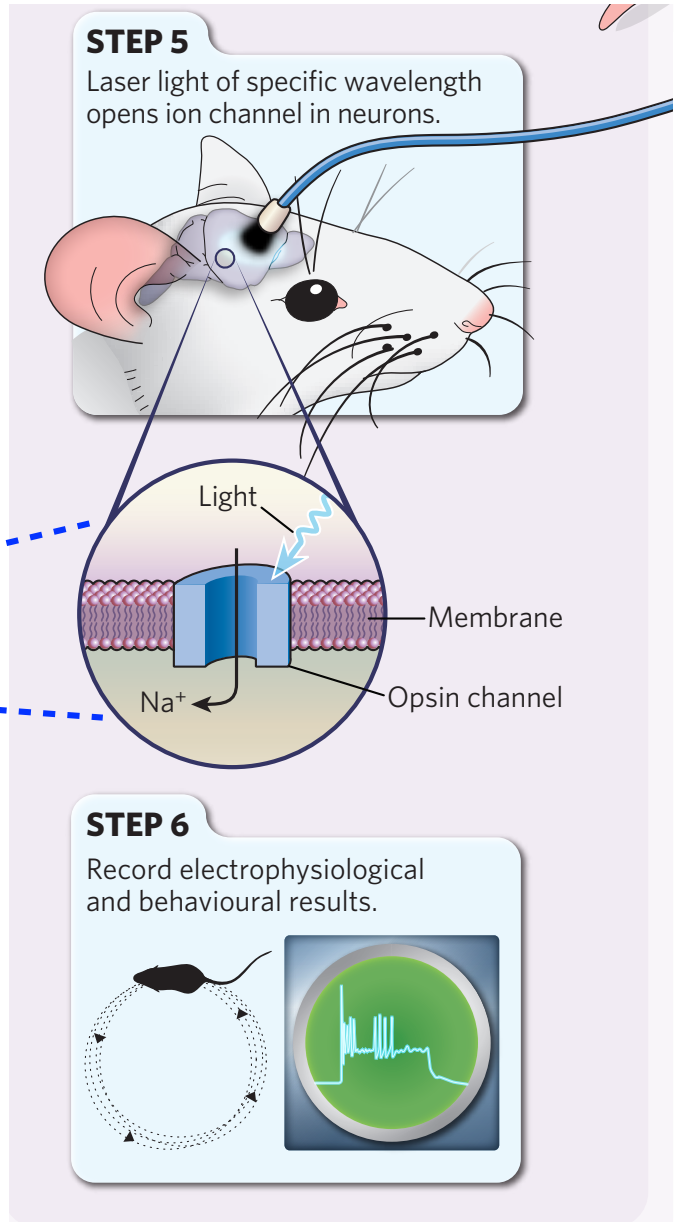




(Toda, Sawahata, Suzuki, Majima, Kamitani, Hasegawa, 2011)

Toward brain-to-brain communication

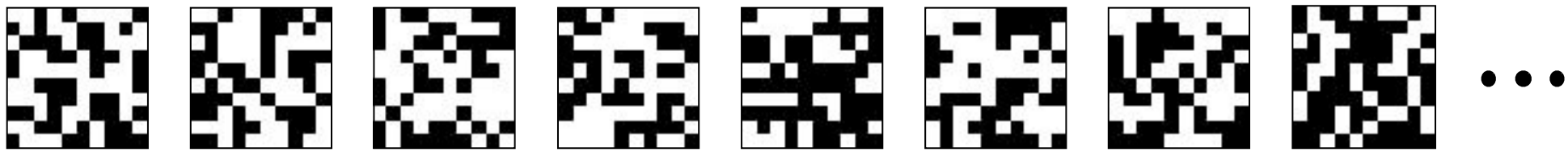


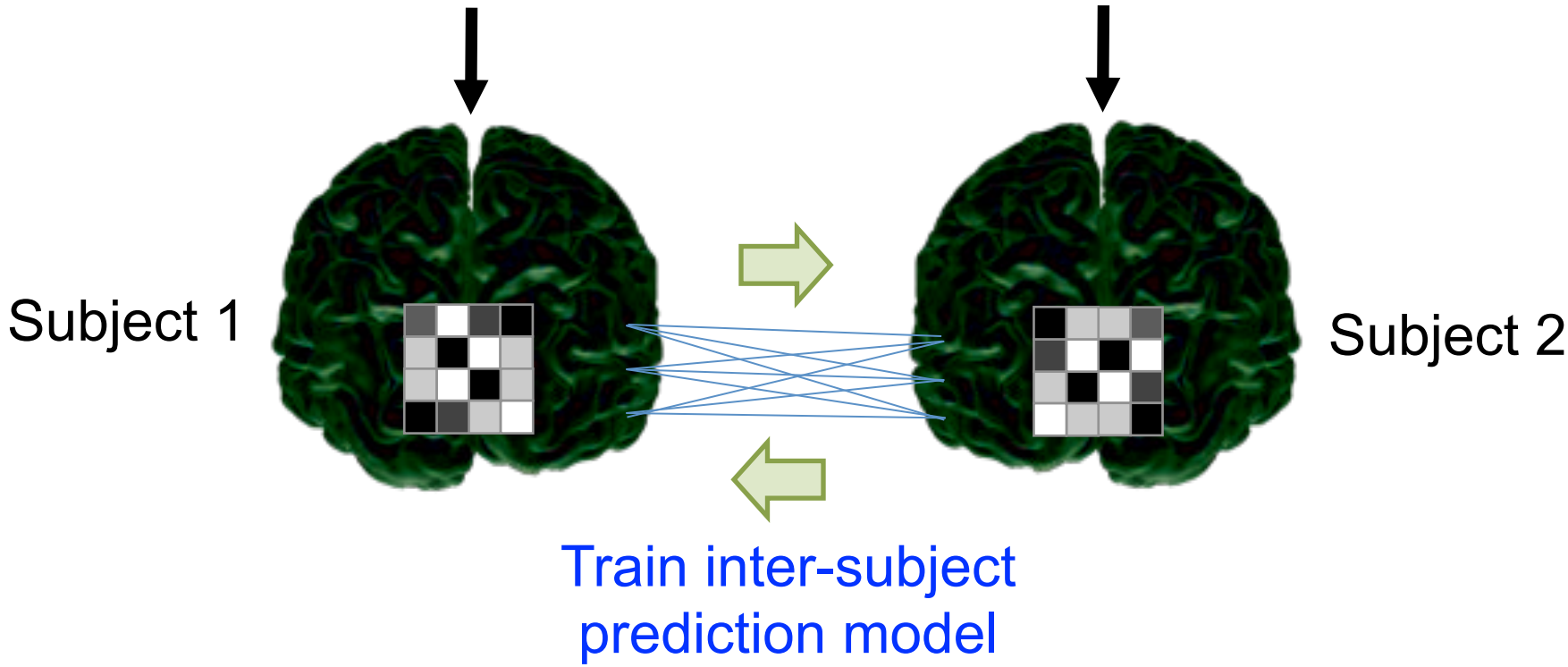


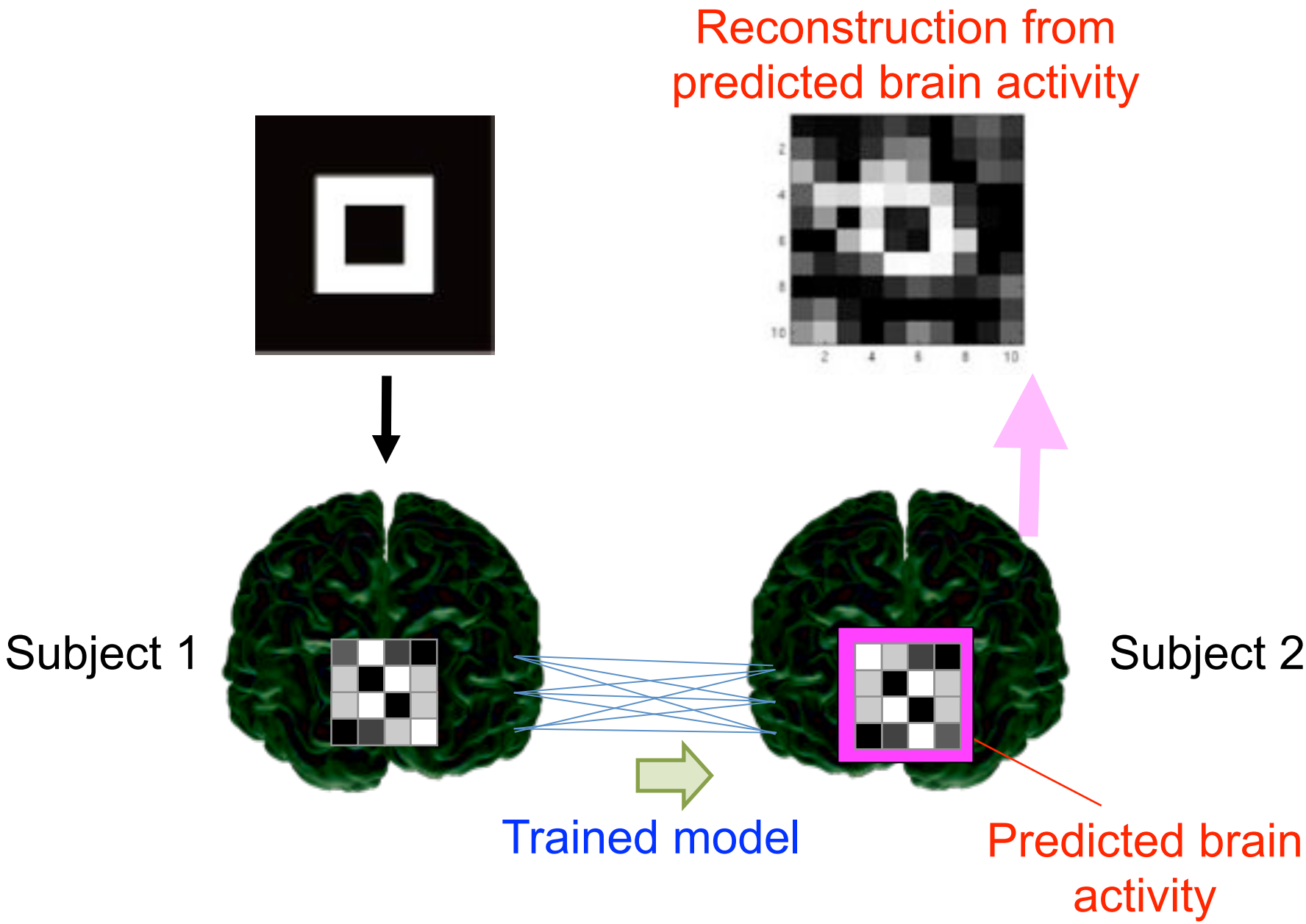
(Buchen, 2010)

“Neural coder converter”

(Kamitani et al., in prep)





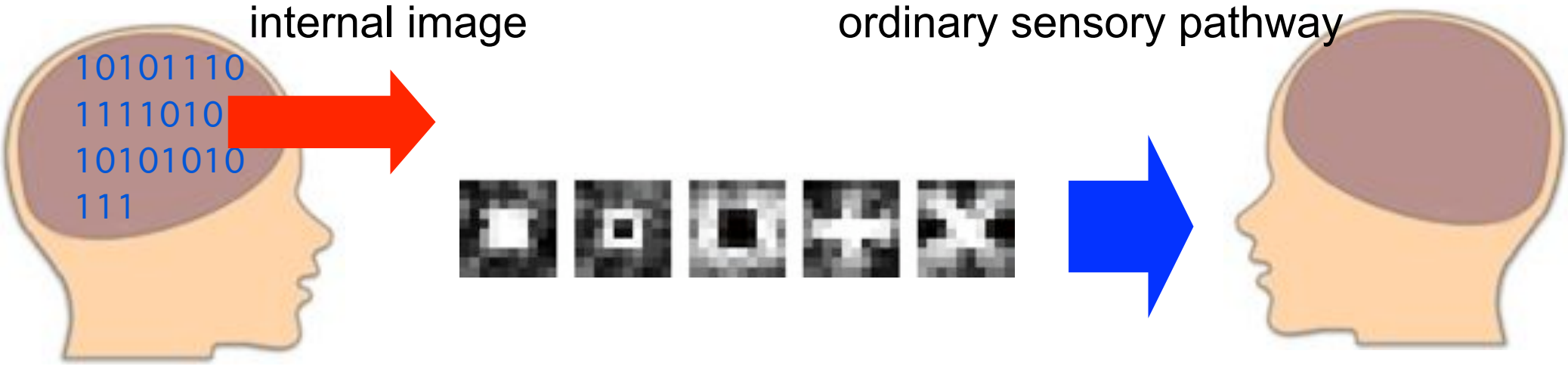


Application to "Image/thought transfer"?

Brain-based visual communication 1.0

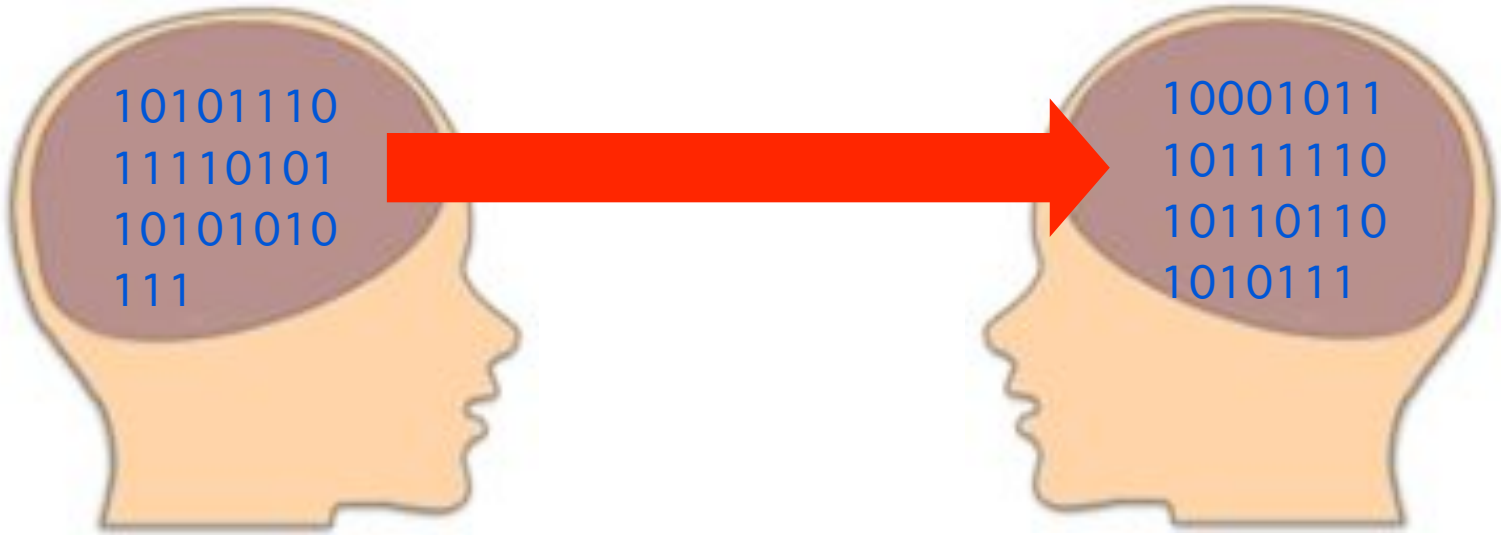
Externalization of internal image

Image understanding via ordinary sensory pathway



Brain-based visual communication 2.0

Brain-to-brain transfer by neural code conversion and stimulation



Summary

1. Machine learning-based approach to the decoding

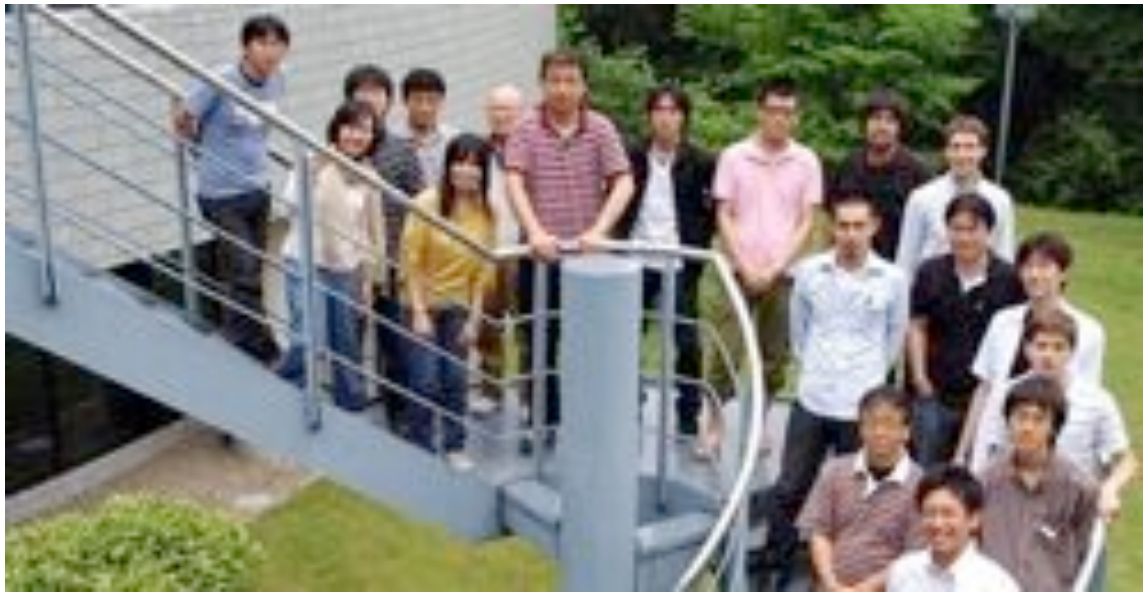
2. Primitive form of neural mind-reading

3. Subvoxel neural representation as a possible information source

4. Modular decoding and its application to visual image reconstruction

5. Neural code converter and its implication for brain-to-brain communication

Acknowledgments



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K. Yamada

Vanderbilt
F. Tong

NIPS
Y. Morito
N.Tanabe
N. Sadato

Codes and data available at:
http://www.cns.atr.jp/dni/

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