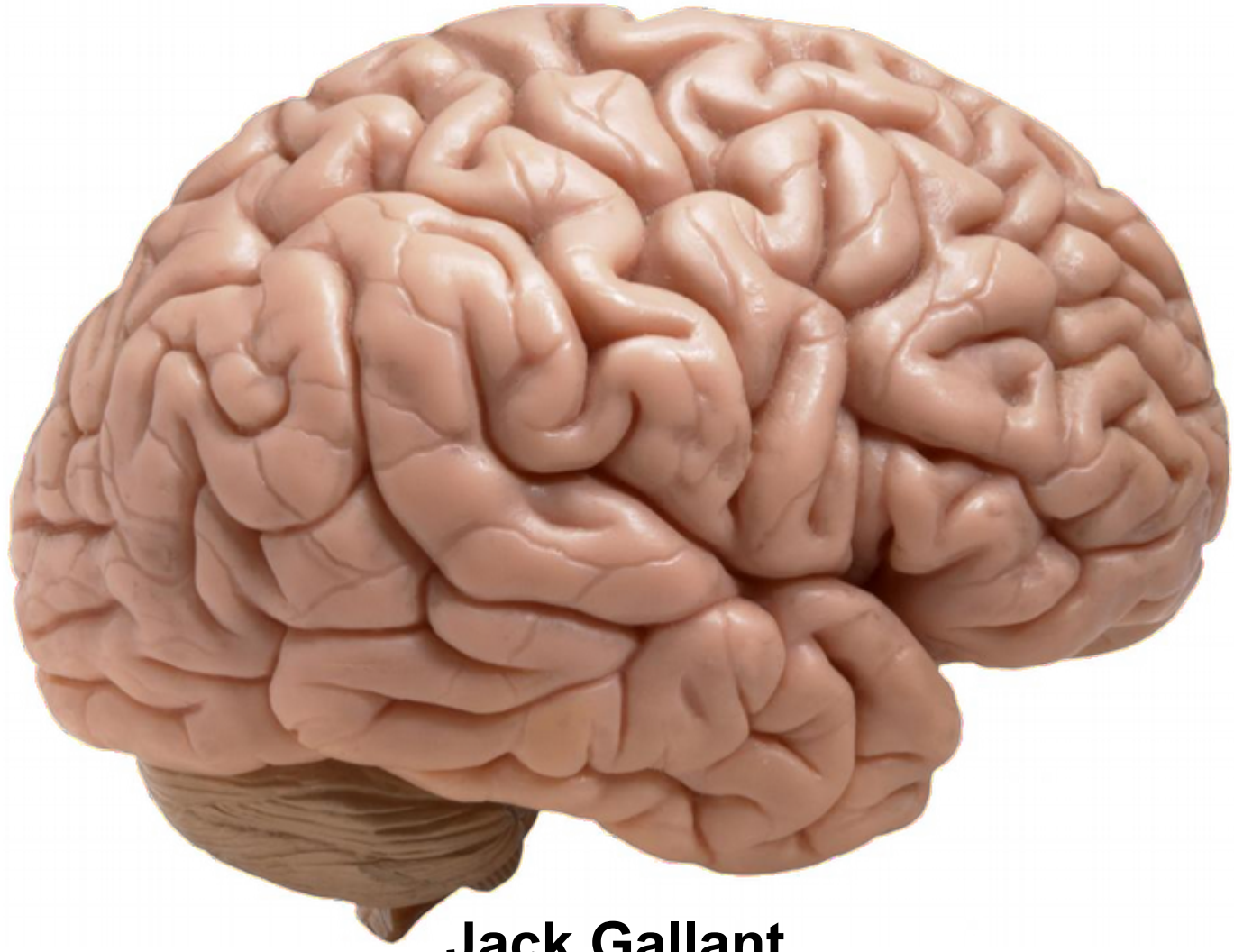
Present capability and future prospects for non-invasive measurement of the human brain



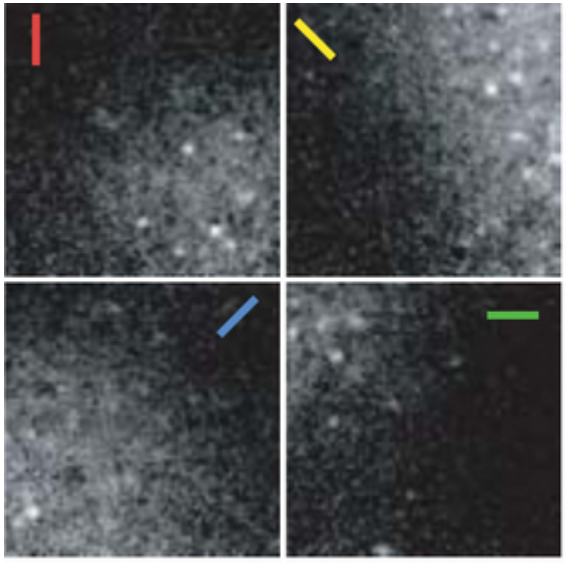
Jack Gallant
University of California at Berkeley

Potential uses of brain decoding

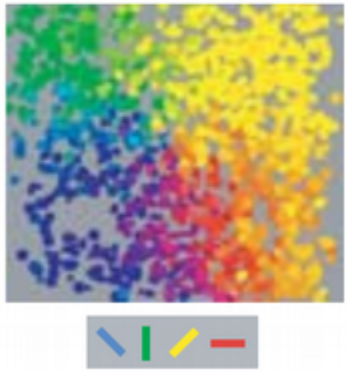
- To assess guilty knowledge, as a form of lie detection.
- To recover imagery related to an event, as an adjunct to eyewitness testimony.
- To recover other non-verbal information (e.g. emotion) that is not accessible to verbal report.

The brain is organized at multiple scales

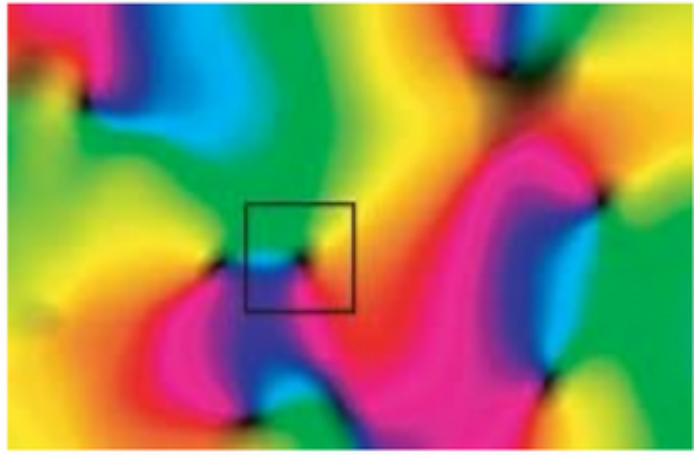
Tuned neurons



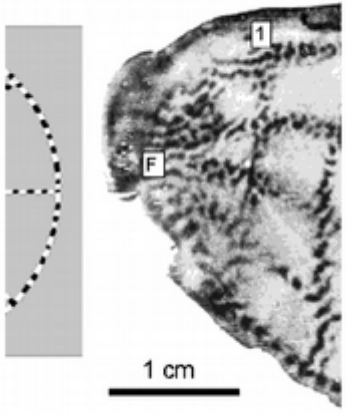
Functional columns



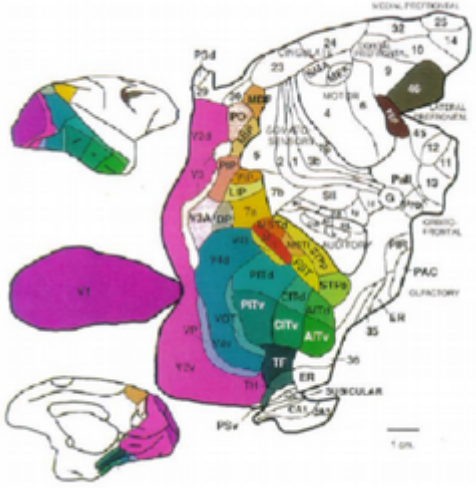
Functional maps



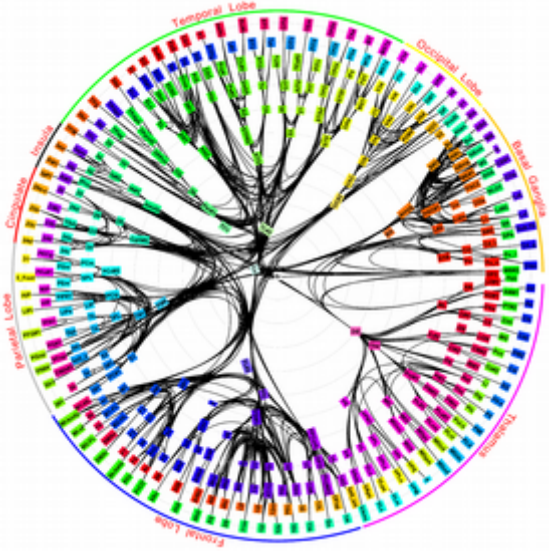
Functional areas



Functional systems

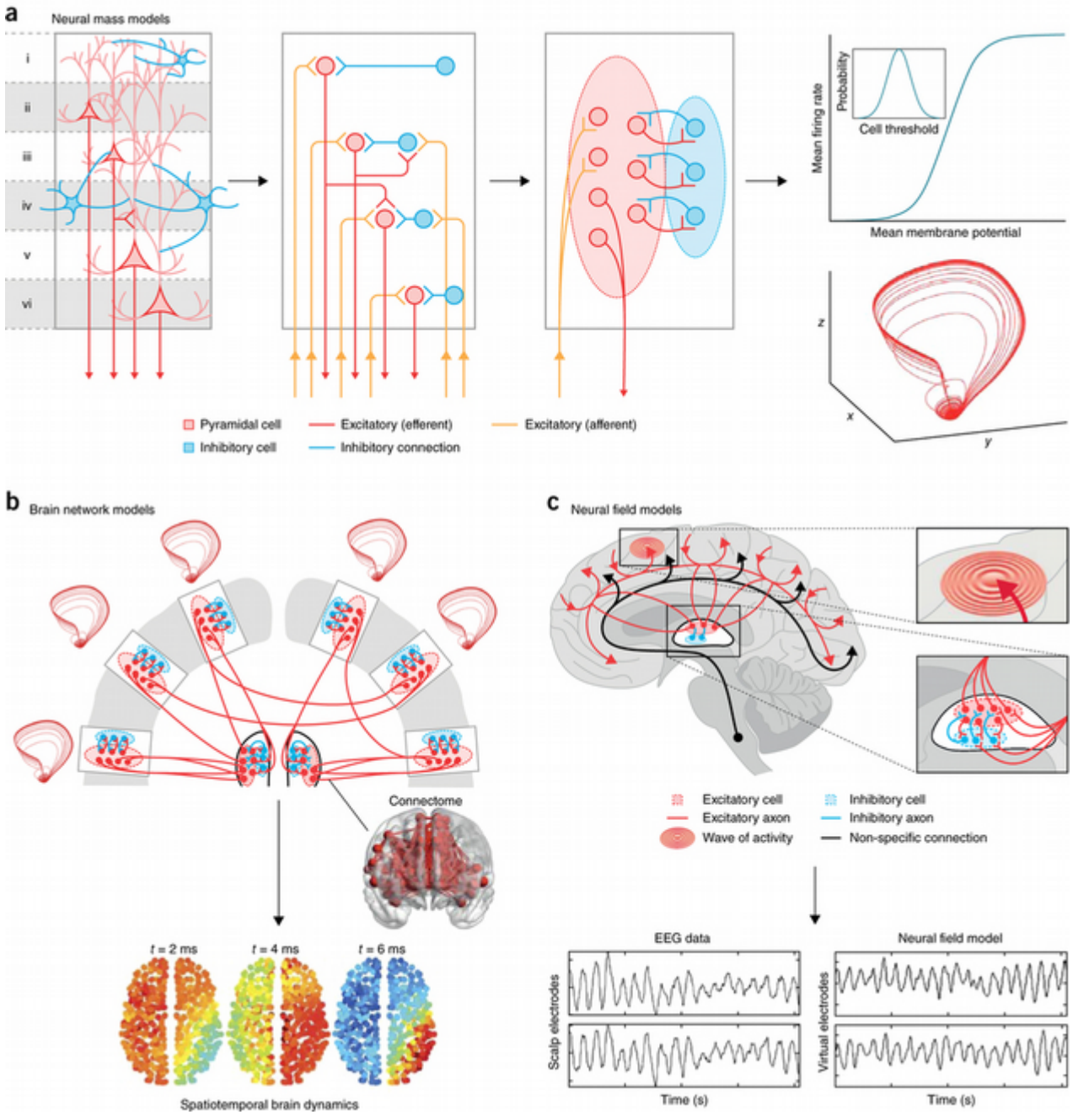


Interconnected networks



Adapted from Ohki et al. 2006; Tootel et al. 1998; Felleman & Van Essen 1992; Modha & Singh 2010

Brain activity is distributed over space and evolves over time

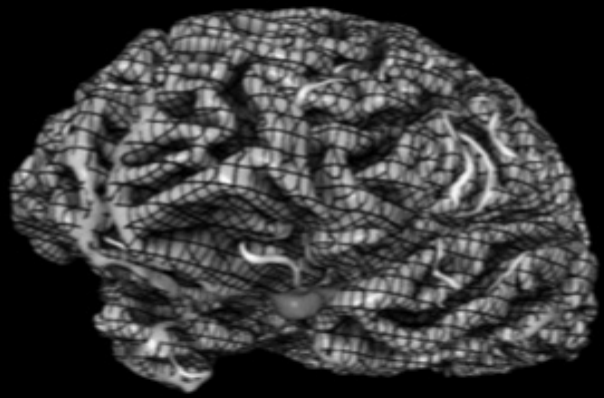


Breakspear, *Nature Neuroscience*, 2017

Non-invasive measurement devices are limited in space or time

Anything in current working circuits is potentially decodable

REST



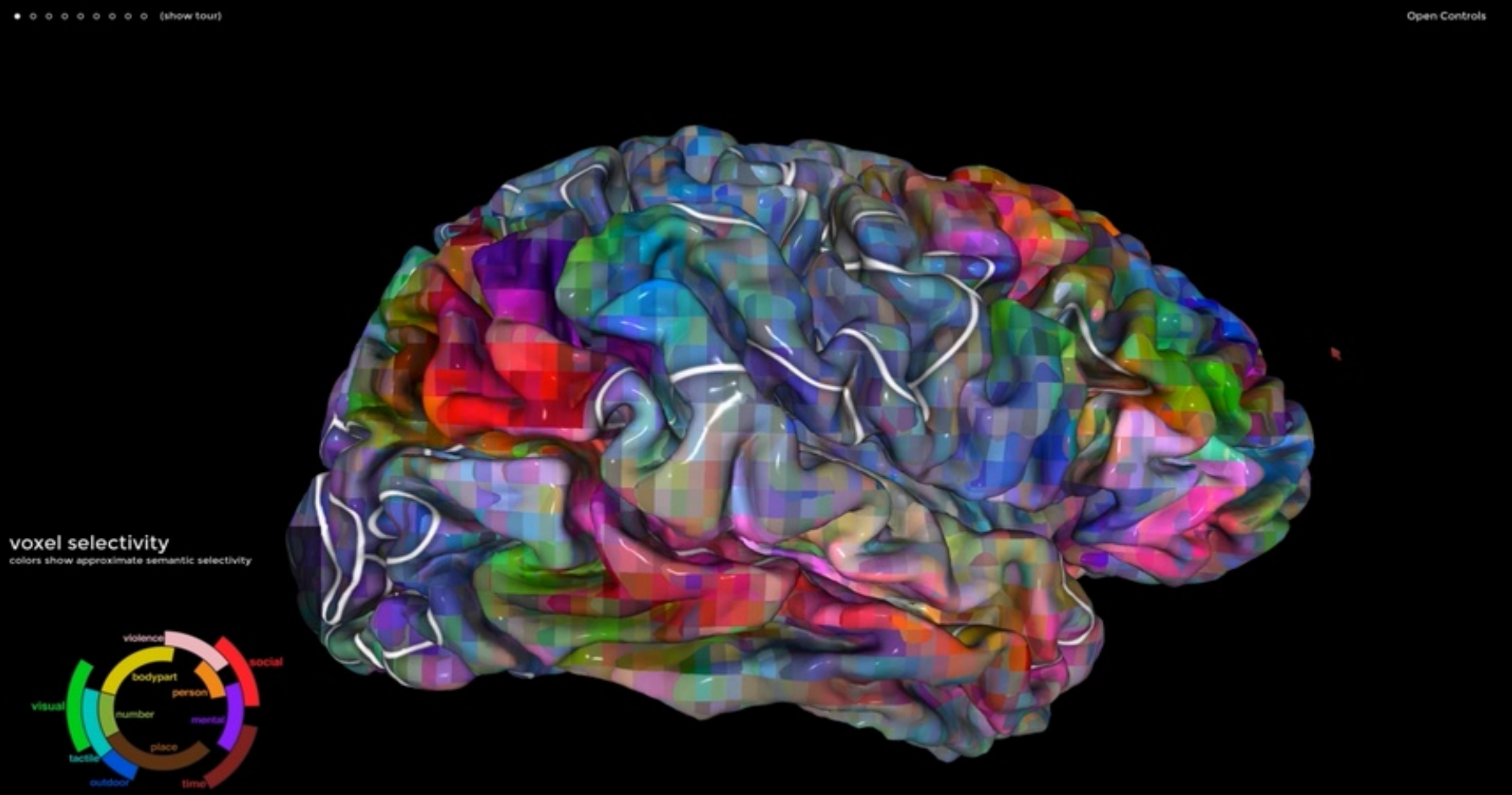
Less activity

Average activity

More activity

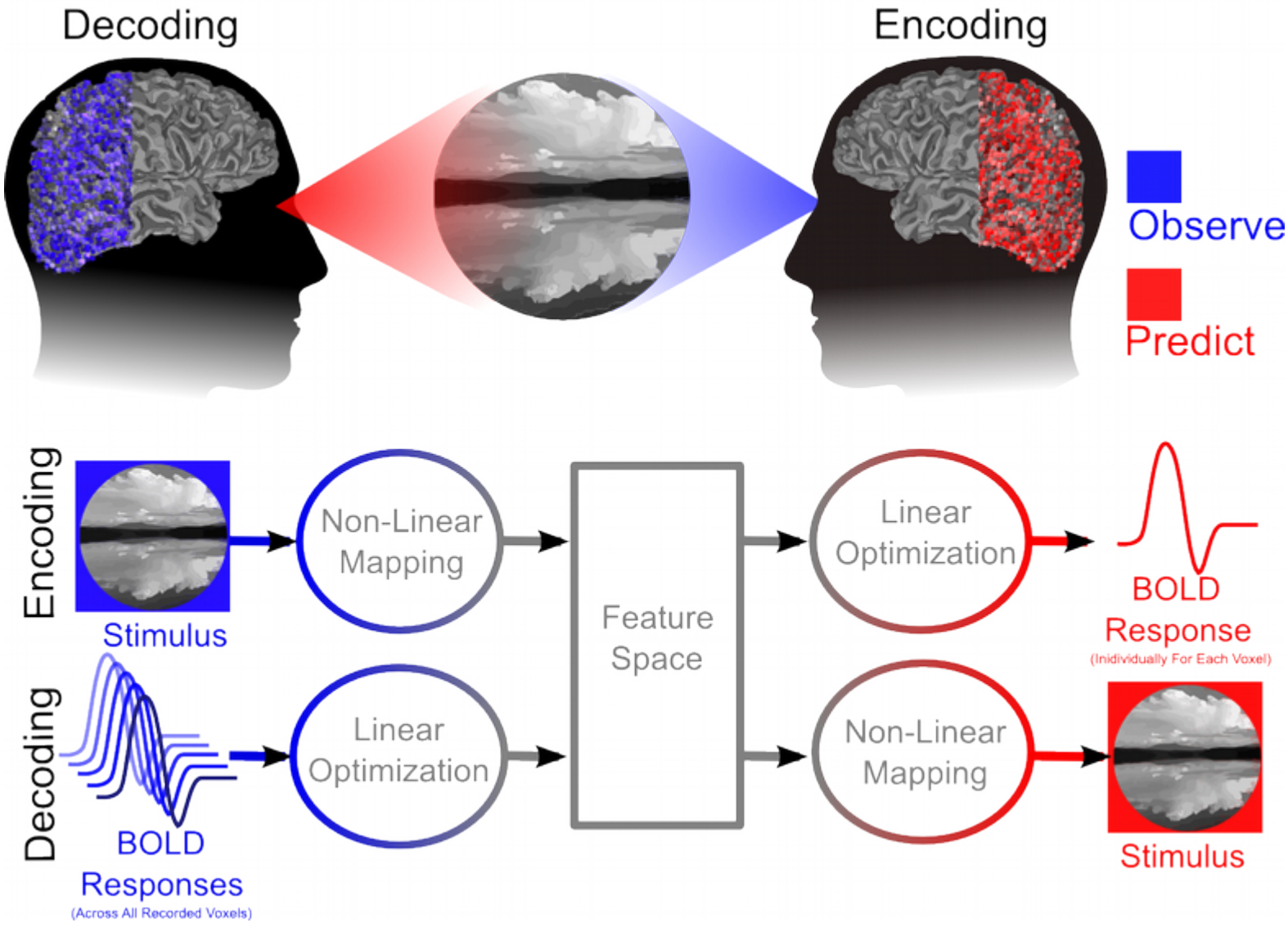
Nunez-Elizalde & Gallant, *unpublished*

Functional maps reveal cortical representations



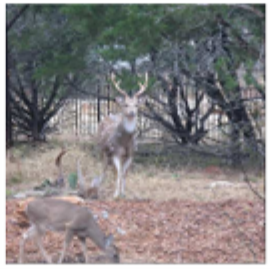
http://gallantlab.org/huth2016/

Brain measurement, modeling and decoding are linked



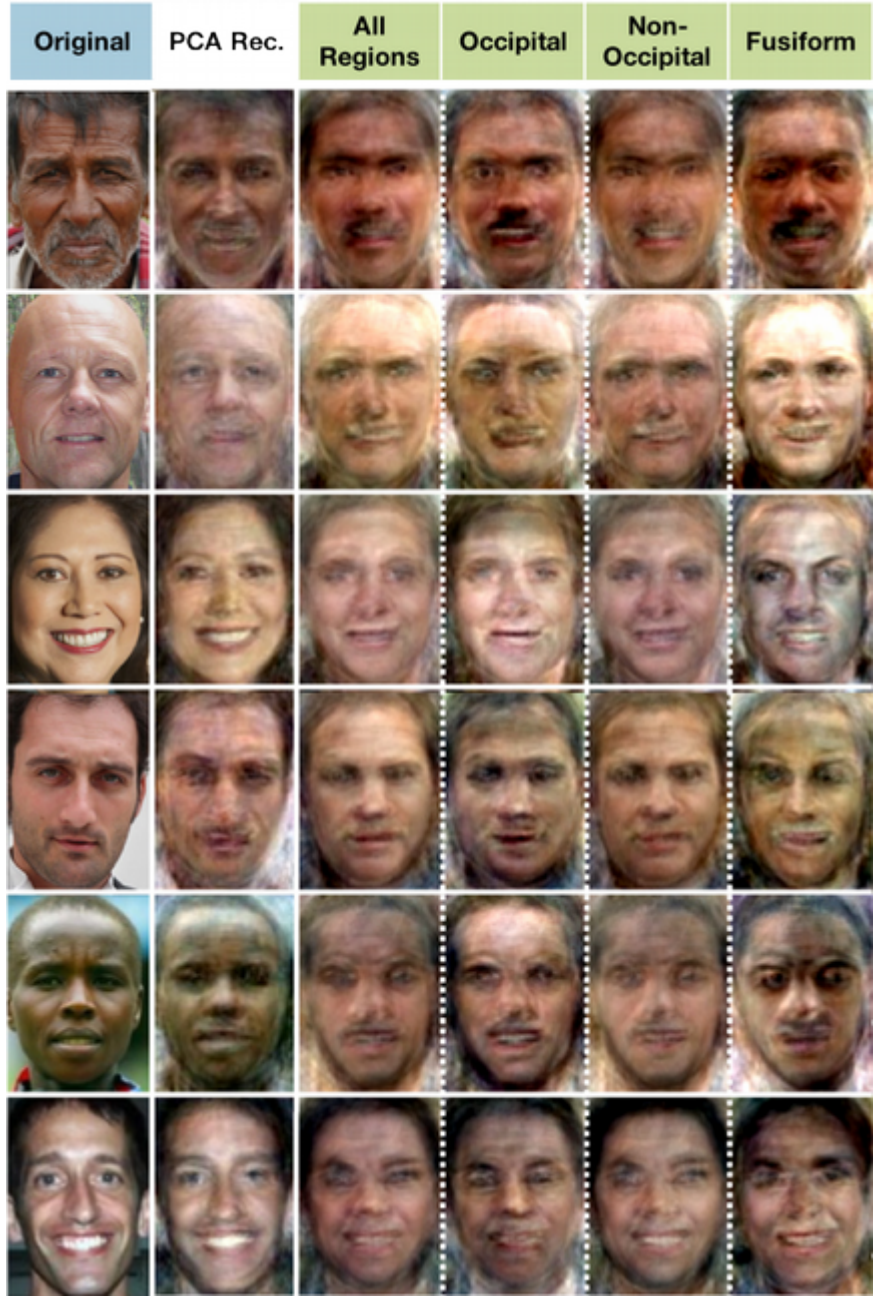
$$P(f(S)|R) \propto P(R|f(S))\,P(f(S))$$

Decoding scene category and scene content from fMRI

Image	Likely Scene	Likely Objects	Image	Likely Scene	Likely Objects
	land animals few people food fields water animals	man woman person head animal		urban areas large crowds lecture hall fields living area	sky car building road people
	sporting event large crowds few people lecture hall fields	athlete people man woman person		fields fenced areas large crowds birds living area	grass trees fence field ground
	signs/text living area food manmade objects	text sign washbowl beverage background		food few people human indoors	food fruit vegetables vegetable container

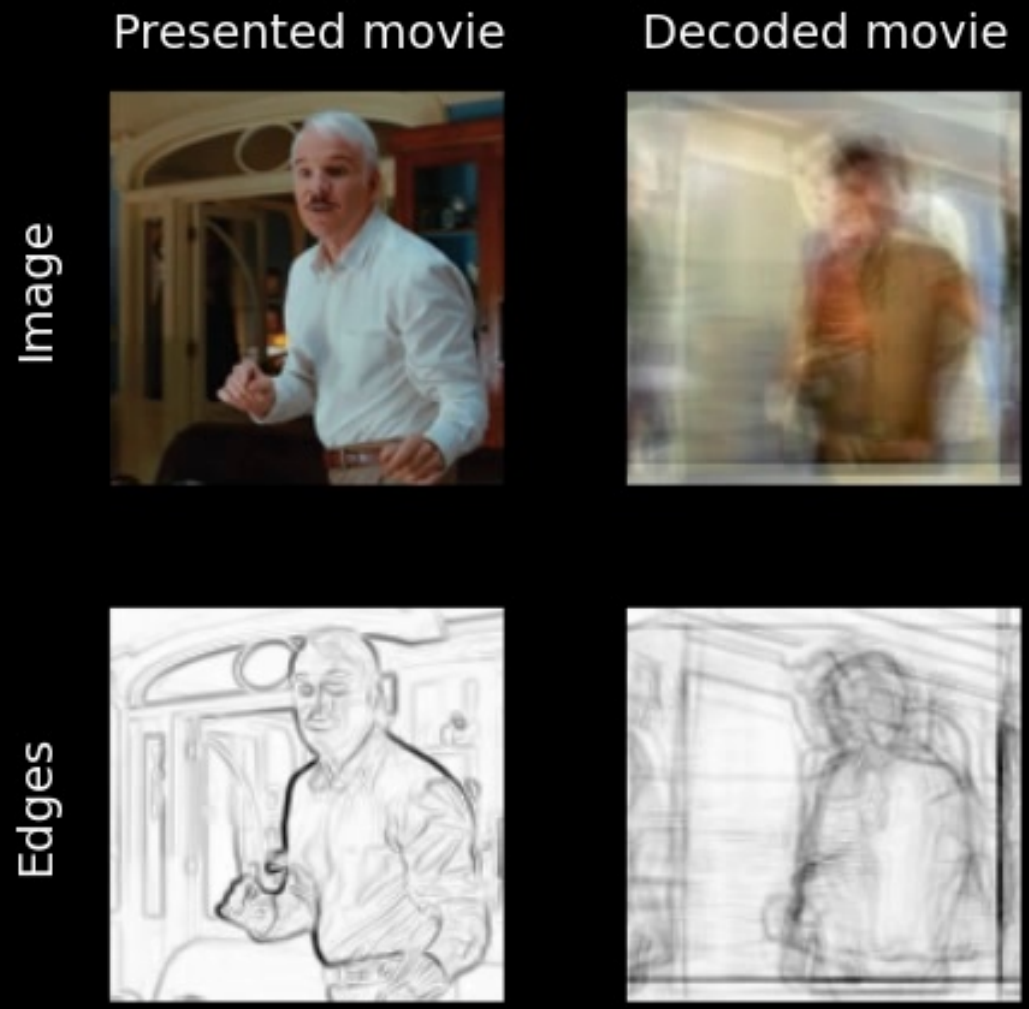
Stansbury, Naselaris and Gallant, *Neuron*, 2013

Decoding face identity from fMRI



Cowen, Chun & Kuhl, *NeuroImage*, 2014

Decoding low-level structural features of movies from fMRI



Bilenko, Savage & Gallant, *unpublished*

Nishimoto, Vu, Naselaris, Bejamini, Yu & Gallant, *Current Biology*, 2011

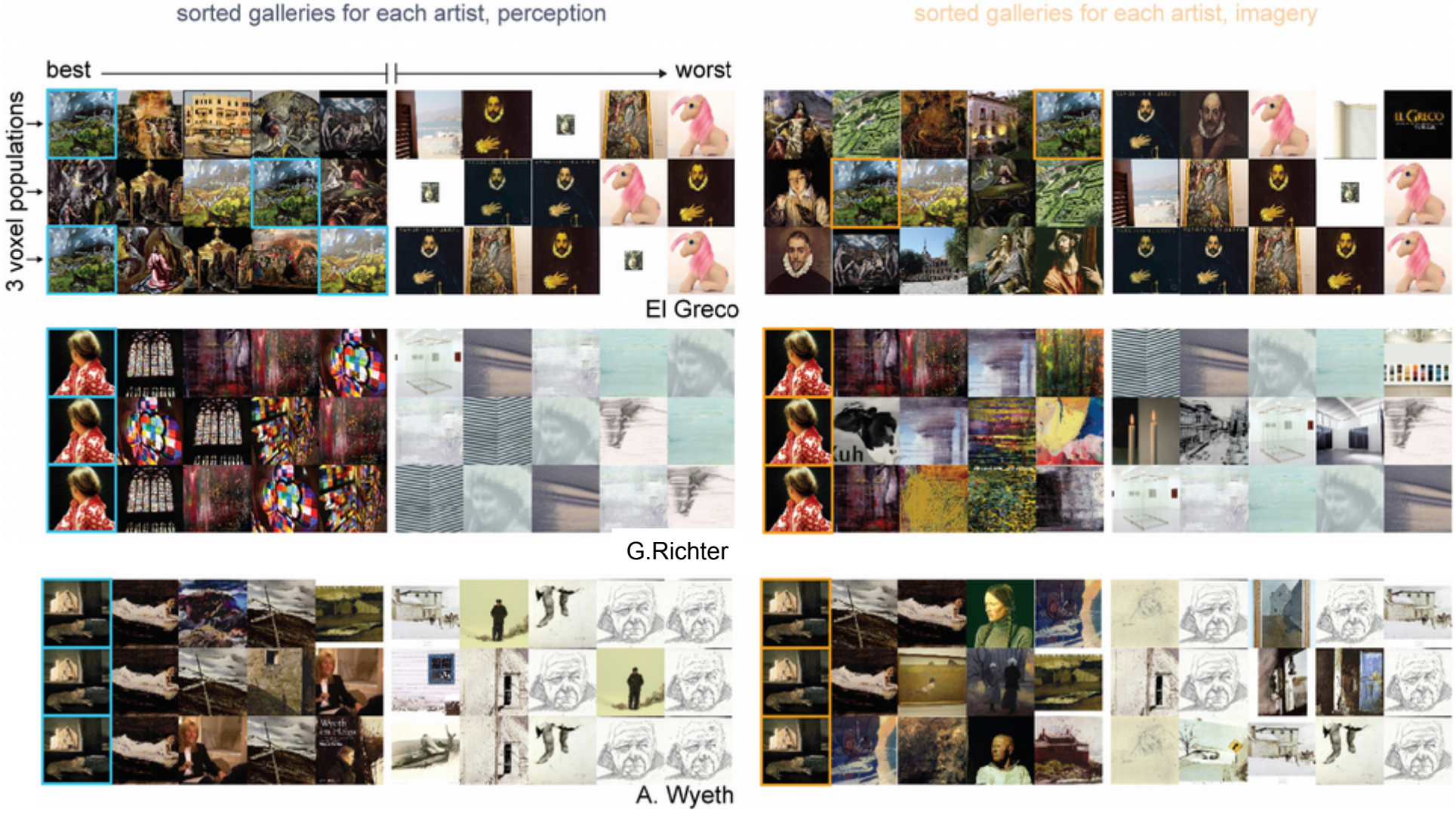
Decoding high-level semantic content of movies from fMRI

Movie

Likely
Objects and Actions

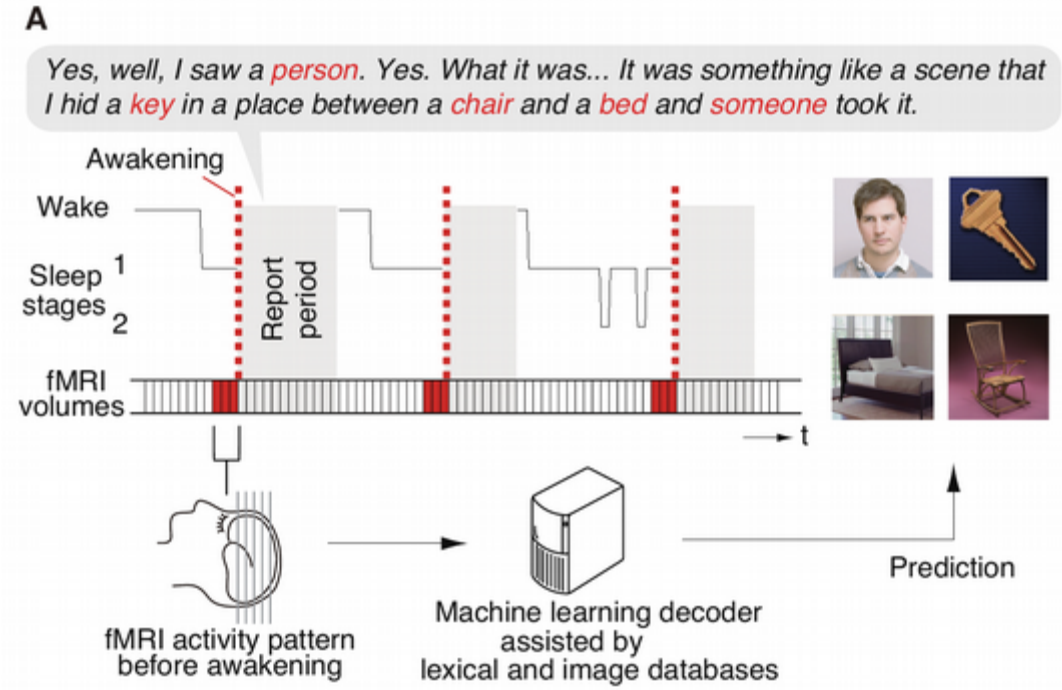
Huth, Lee, Nishimoto & Gallant, Front. Sys. Neurosci., 2016

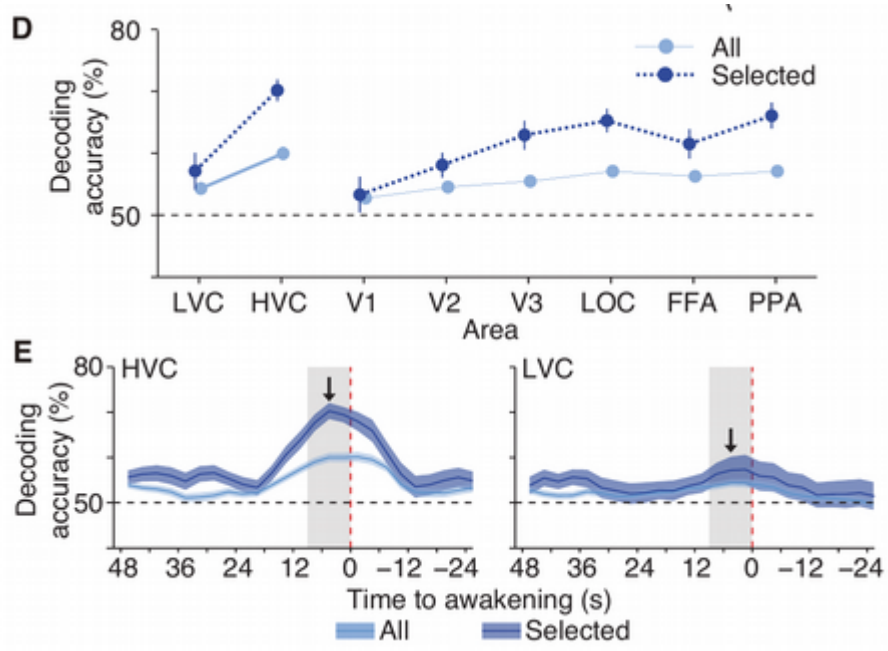
Decoding visual imagery from fMRI



Naselaris et al., NeuroImage, 2014

Decoding hypnogogic dreams from fMRI



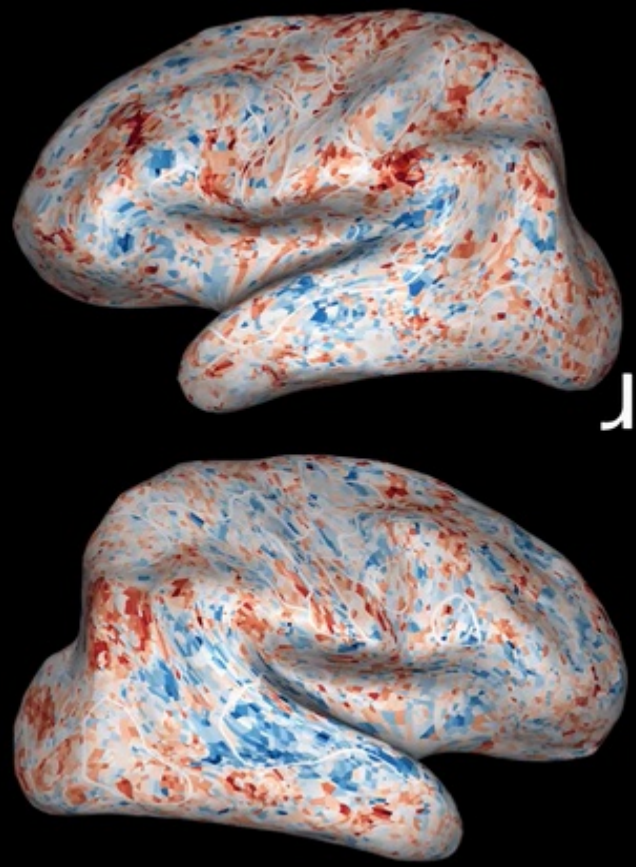


Horikawa, Tamaki, Miyawaki & Kamitani, Science, 2013

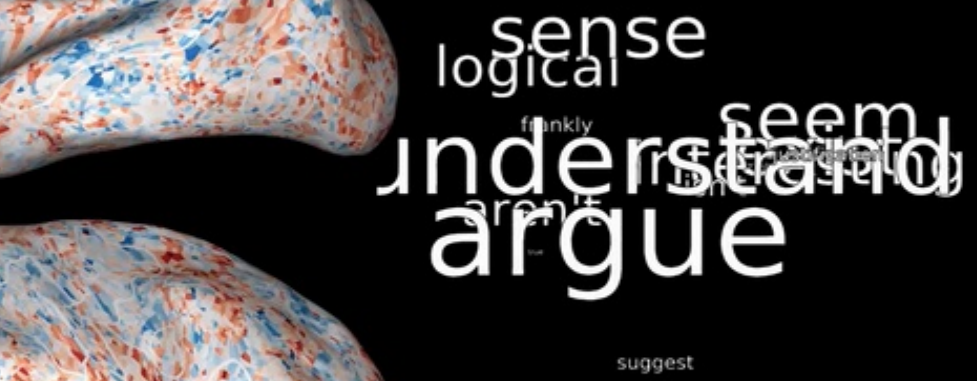
Poor temporal resolution of fMRI limits decodability

Stimulus

pagan festivals of
that season of winter
what a crazy world
we're bringing our
children

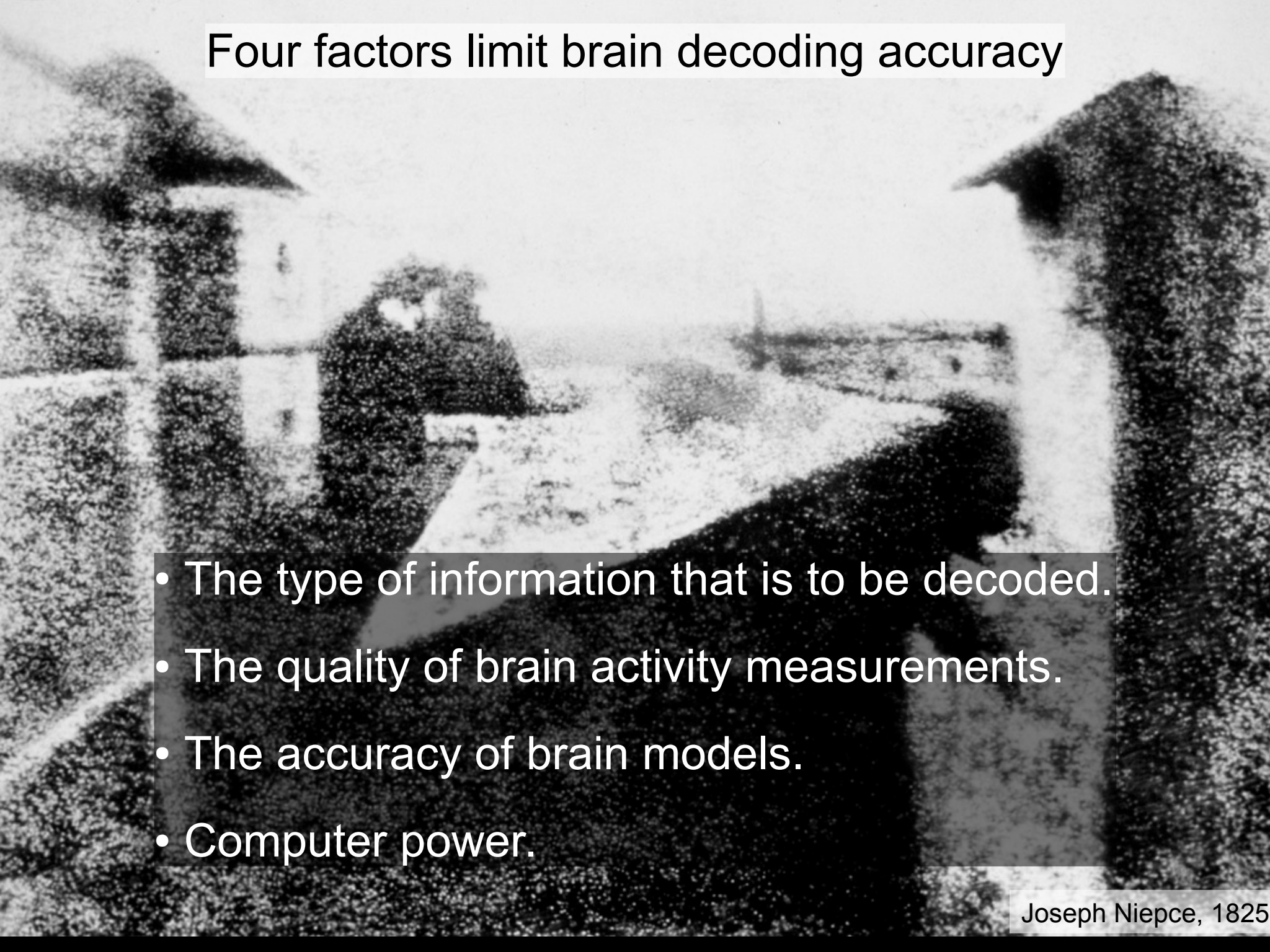


Decoding



Huth, Gibboni & Gallant, *unpublished*

Four factors limit brain decoding accuracy



- The type of information that is to be decoded.
- The quality of brain activity measurements.
- The accuracy of brain models.
- Computer power.

Joseph Niepce, 1825

Non-invasive methods currently under development

- Next-generation fMRI. Expected spatial resolution less than 500 microns but poor temporal resolution.
- Phase-sensitive fNIRS-DOT. Incrementel improvements over current fNIRS, a potential spatial resolution of 6 mm but poor temporal resolution.
- Focused ultrasound. Works well in rodents but is unlikely to work in humans.
- Photo-acoustic approaches. Works well in rodents but is unlikely to work in humans.
- Microwave radar. Well developed technology but spatial resolution in biological tissues is limited by scattering.

Recommendations for use of decoding in a legal context

- Accurate brain decoding depends on obtaining high-resolution measurements in both space and time, but methods used currently have very poor resolution in either space or time. Signal quality is also highly variable across individuals.
- Current methods of non-invasive brain measurement are neither precise nor accurate, especially when used for one-shot decoding of information from one individual in one particular situation.
- There is no known method to decode implicit memories that are not in active use. Information must be reinstantiated in current working memory before it can be decoded.
- With the potential exception of brain decoding for lie detection, information decoded from the brain is not necessarily any more accurate than testimony, and the information so obtained is biased by many of the same factors that bias testimony.