Non-invasive human brain measurement for AR /VR applications

Jack Gallant
Helen Wills Neuroscience Institute
University of California at Berkeley
gallant@berkeley.edu
A brain-based AR/VR controller would be much more flexible and powerful than current methods.
Brain decoding is limited by both brain measurements and brain models.

$$I(X;Y) = \sum_{y \in Y} \sum_{x \in X} p(x, y) \log \left( \frac{p(x, y)}{p(x)p(y)} \right)$$
No current portable, non-invasive brain imaging method is broadly useful for brain decoding.
Non-invasive measurement devices are limited in space or time.
The best current method for recovering functional brain information is magnetic resonance imaging (MRI)
Modeling these data is essentially a multiple-regression problem that can be solved using many different methods.
Individuals share a common conceptual space

Huth, de Heer, Griffiths, Theunissen & Gallant, *Nature*, 2016
Conceptual information is represented in complex gradients across much of cortex.
You can inspect these data yourself using our online, interactive brain viewer

Huth, de Heer, Griffiths, Theunissen & Gallant, *Nature*, 2016

http://gallantlab.org/huth2016
Each concept is represented at multiple locations and each location represents a group of related concepts

Map for the concept, “dog”.

http://boldpredictions.gallantlab.org
Attention changes the flow of information through the brain and so changes conceptual maps.

Cukur, Nishimoto, Huth & Gallant, *Nat. Neuro.*, 2013
Conceptual maps from different individuals are similar but not identical.
(Preliminary data slide redacted)
Any encoding model can be converted into a decoding model

\[ P(f(S)|R) \propto P(R|f(S))P(f(S)) \]
Decoding structural information from early visual areas

Naselaris, Kay, Prenger, Oliver and Gallant, *Neuron*, 2009
Decoding scene categories and contents from higher-order visual areas

<table>
<thead>
<tr>
<th>Image</th>
<th>Likely Scene</th>
<th>Likely Objects</th>
<th>Image</th>
<th>Likely Scene</th>
<th>Likely Objects</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Image" /></td>
<td>land animals, few people, food, fields, water animals</td>
<td>man, woman, person, head, animal</td>
<td><img src="image2" alt="Image" /></td>
<td>urban areas, large crowds, building, road, people</td>
<td>sky, car, ground</td>
</tr>
<tr>
<td><img src="image3" alt="Image" /></td>
<td>sporting event, large crowds, few people, lecture hall, horses</td>
<td>athlete, people, man, woman, person</td>
<td><img src="image4" alt="Image" /></td>
<td>fields, fenced areas, large crowds, birds, field, fence</td>
<td>grass, trees, field, ground</td>
</tr>
<tr>
<td><img src="image5" alt="Image" /></td>
<td>signs/text</td>
<td>text, sign, washbowl, beverage, background</td>
<td><img src="image6" alt="Image" /></td>
<td>food</td>
<td>fruit, vegetables, container</td>
</tr>
</tbody>
</table>

Stansbury, Naselaris and Gallant, *Neuron*, 2013
Decoding structural information from early visual areas

Nishimoto, Vu, Naselaris et al, *Current Biology*, 2011; Bilenko, Savage & Gallant, *unpublished*
Decoding semantic categories from higher-order visual areas

Presented movie

Decoded concepts

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.
The resolution of current non-invasive neuroimaging is still fairly low, relative to invasive methods.
Many groups are developing new methods for improving non-invasive functional brain imaging.

- High-resolution fMRI
- Acoustic-optical approaches
- Picopulse imaging

Berkeley high resolution MRI project

- Develop f/MRI to achieve 100-500 micron resolution for imaging of the cerebral cortex.
- Design new radiofrequency coil arrays that maximize SNR in the cerebral cortex.
- Design new pulse sequences and image reconstruction methods optimized for cortical imaging.
- Develop susceptibility tensor imaging for cortical tractography.
- In collaboration with Siemens, Miki Lustig (Berkeley), Chunli Liu (Berkeley), Larry Wald (Martinos), Kaiwin Setsompop (Martinos) and others.
(Preliminary data slide redacted)
Current Lab Members

Tom Dupre  Storm Slivkoff
Fatma Deniz  Christine Tseng
James Gao  Tianjiao Zhang
Anwar Nunez  Matteo Visconti
Sara Popham

Past Lab Members

Natalia Bilenko (Bay Labs)  Thomas Naselaris (MUSC)
Tolga Cukur (Bilkent U)  Shinji Nishimoto (NIST Japan)
Stephen David (OHSU)  Mike Oliver (Allen Institute)
Kate Gustavsen (BronxZoo)  Ryan Prenger (Baidu)
Robert Gibboni (Driven Data)  Dustin Stansbury (Quizlet)
Kathleen Hansen (OHSU)  Ben Willmore (Cambridge U)
Ben Hayden (U Minnesota)  Bill Vinje (Programmer)
Alex Huth (UT Austin)  An Vu (UCSF)
Kendrick Kay (U Minn)  Leila Wehbe (Carnegie Mellon)
Mark Lescroart (U Nevada)  Michael Wu (PROS)
James Mazer (Montana U)

This work was supported by NEI, NIMH, NSF, ONR and IARPA