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This presentation was to review our yearly progress.

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decision making, cortical network, neural decoding, brain-machine interface, neurally-informed model

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This presentation was to review our yearly progress.
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ARO/ARL Site Visit

Paul Sajda

Laboratory for Intelligent Imaging and Neural Computing
Department of Biomedical Engineering
Columbia University
### Agenda

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<td>Overview of ARO Decision &amp; Neuro-Sciences</td>
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<td>Overview of ARO/ARL Projects at Columbia</td>
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Laboratory for Intelligent Imaging and Neural Computing
LIINC

…using principles of reverse engineering to characterize the cortical networks underlying rapid decision making…

**Measuring:** Simultaneous EEG/fMRI

**Perturbing:** High Resolution Informed TMS

**Modeling:** Large Scale Neural Simulations

**Building:** Cortically Coupled Computer Vision
ARO/ARL Projects

• Cortical Networks Underlying Rapid Decision Making (ARO)

• Cortically-Coupled Computing: A Paradigm for Mutually-Derived Situational Awareness (Seedling under ARL CTA)

• Image Database and Neuroimaging Data Collection for Rapid Visual Decision Making (ARL Technology Transition Project)
Cortical Networks Underlying Rapid Decision Making

**micro**
- single neurons

**macro**
- functional imaging

From Britten et al., 1992

From Philiastides & Sajda, 2006

Heekeren et al., 2004
Cortical Networks Underlying Rapid Decision Making

- **micro**: single neurons
- **meso**: large populations
- **macro**: functional imaging
Cortical Networks Underlying Rapid Decision Making

Statement of Work

• Year 1:
  • Systematically design RSVP stimulus presentation paradigms and experiments for simultaneous EEG/fMRI.
  • Run 5 subjects while simultaneously recording EEG and fMRI.
  • Analyze results in terms of spatial networks localized by integrating EEG and fMRI. Compare to dipole fits and rLoreta maps using EEG.

• Year 2:
  • Begin design of spatio-temporal (e.g. video) stimulus experiments which investigate integration of evidence across time
  • Manipulate difficulty of decision
  • Run 5 subjects while simultaneously recording EEG and fMRI.
  • Begin relating trial-to-trial variability to decision making models such as the drift diffusion models (of Ratcliff, 1978, 2009) and the bayesian decision models (of Beck, Ma et al, 2008.)

• Year 3:
  • Begin design of experiments for free-viewing search (eye-tracking).
  • Run 5 subjects while simultaneously recording EEG and fMRI.
  • Create a publicly available database of neural signatures of trial-to-trial variability, code for analyzing EEG/fMRI and code for neurally-informing decision models
Single-trial Analysis of Simultaneously Acquired fMRI and EEG

...a window into latent brain states...
Why Acquire EEG and fMRI Simultaneously?

• Electrical activity of the brain can be correlated with hemodynamic changes
  • Understanding neurovascular coupling

• High temporal resolution of EEG complements high spatial resolution of fMRI
  • fMRI seeding of EEG source localization
  • Correlating ERPs (trial-averages) with BOLD

• Single-trial variations in EEG, related to latent brain states (attentional shifting, cognitive load, decision evidence, memory encoding, etc.) can be correlated with hemodynamic activity.
Challenges

- complicated equipment
- auditory noise
- gradient artifact
- BCG artifact
- bias field

How to combine the data?
Our Solutions

\[ M_p u = \begin{bmatrix} 1_p & M_p \end{bmatrix} \begin{bmatrix} e_p \\ n \end{bmatrix} \leftarrow \text{EEG}^+_{BCG} \]

\[ \text{BCG} \]

Using EEG Single-Trial Variability to Construct fMRI Regressors

- Channel 1
- Channel 2
- Channel N

EEG Data

Single-Trial Analysis of EEG

\[ y = w^T x \]

Magnet-Compatible 64 Channel Amplifier

Twisted Pair Multi-Lead Electrodes with 10kΩ Series Resistors

7/11/2012
Observing latent trial-to-trial fluctuations of attention/alertness/perceived-stimulus-salience

(Goldman et al., *Neuroimage* 2009)
Observing latent trial-to-trial fluctuations of attention/alertness/perceived-stimulus-salience

Modulation of attention/alertness via the locus coeruleus (LC)?

- Evidence that low freq LFPs (< 30Hz) have neg. corr. with BOLD (Mukamel et al, 2005)
- LC associated with P300 (Aston-Jones & Cohn, 2005)
- LC fires phasically close to response and appears to modulate decision/response and not sensory inputs (Clayton, et al. 2004)
Neurally-Informed Models of Decision Making

level of abstraction
Model Summary

- Macaque V1, input layer (4Cα/β)
- 4 ocular dominance columns
- 64 orientation hypercolumns
- 16 mm² cortical area, 0-10° eccentricity
- Approx. 65,000 neurons (integrate-and-fire) per configuration (α, β, 0°-10°) = 260,000 neurons.
- Cell populations:
  - 75% excitatory cells
  - 25% inhibitory cells
  - 30% receive LGN input
  - 70% do not receive LGN input
- Anatomically realistic LGN input and retinotopic map
- Anatomically “correct” cortical length scales:
  - $r_E^{\text{axon}} = 200 \mu\text{m}$, $r_I^{\text{axon}} = 100 \mu\text{m}$
  - $r_E^{\text{dend}} = 50 \mu\text{m}$, $r_I^{\text{dend}} = 50 \mu\text{m}$
- First-order LGN temporal kernel
- Cortical time scales:
  - AMPA (5 msec)
  - NMDA (50 msec)
  - GABA (10; 100 msec)
Model Has Realistic Response Properties

receptive fields

Wielaard and Sajda, 2006

orientation pinwheels

Wielaard and Sajda, 2003

characteristics of S & C cells
Realistic Nonclassical Response Properties

...suppression and RF shifts at high and low contrasts...

**Experimental Data**

(a) 

Model

(b)

from Sceniak et. al., 1999

Experimental Data

(b) 

Model

(c)

Experimental Data

(c)

Model

(d)

(Wieland and Sajda, 2006)
The Perceptual Decision Making Task
Mapping A Rapidly Flashed Static Scene into Spikes

Face or Car?
Using Population LFPs for Discrimination

(a) Face

(b) Car

(c) Face–Car

(d) Discrimination

Firing Rate (Hz)

Firing Rate (Hz)

Firing Rate (Hz)

Discrimination Accuracy

% Phase Coherence
Sparness of V1 Model Activity in Space and Time

(a)  

(b)  

(c)  

(d)  
kurtosis = 1.65

(kurtosis = 10.26)
The Spike-based Feature Space
or “Neural Word”
Decoding High-dimensional Spatio-temporal Dynamics

$$\arg \min_{w,v} l_{avg}(w, v) + \lambda \|w\|_1$$
Training and Testing Procedure

- Used 12 face images and 12 car images
- Divided into training and testing
  - 6 completely different faces and cars used to train and test
- Manipulated phase coherence of images at each of 7 different coherence levels.
- Images repeated 30 times resulting in a total of 5040 trials (2520 for training and 2520 for testing).
- Images covered approximately 4 degrees of visual angle for simulations.
Discrimination Results

Neurometric curve NOT optimized to match psychometric curve!

Average across 6 models and 10 subjects

Matrix word is better match to psychometric results. High temporal precision (temporal code) is superior to rate code.
Analysis of Informative Dimensions

(a) # Informative Dimensions    (b) # Informative Neurons    (c) Difference

More neurons are recruited at lower coherences
Few neurons are utilized at more than one time bin
Selected Neurons

(a)

Coherence 25%

Coherence 35%

Coherence 45%

(b)

Cortex Y

Cortex X

(c)

Neuron

Time
Uniqueness of Informative Dimensions
Where We Are:
Task: 3-Choice Perceptual Decision

(a)