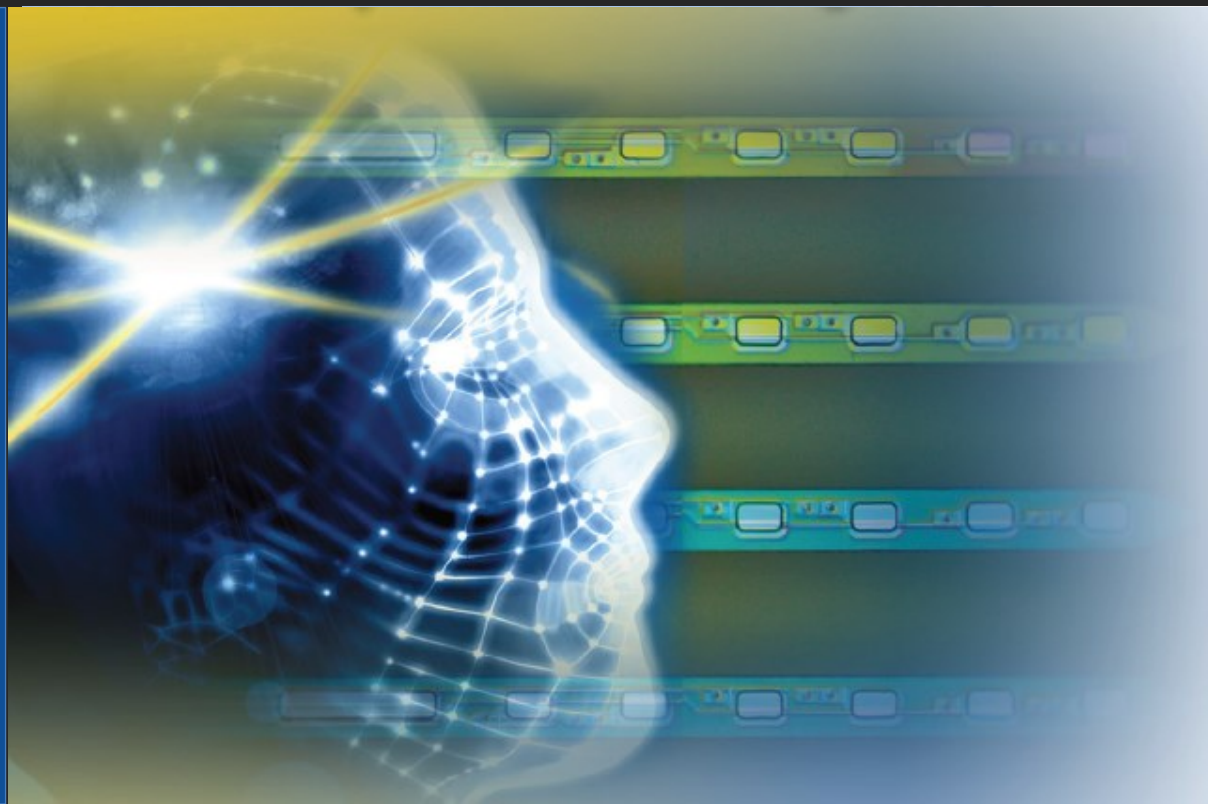
Signal processing in neurotechnology

LLNL CASIS Workshop
May 13, 2015

Sarah Felix

Lawrence Livermore National Laboratory



LLNL-PRES-670531

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

Neurotechnology is a pivotal area of science for the nation

- Increased funding
- Partnerships between government, academia, and industry

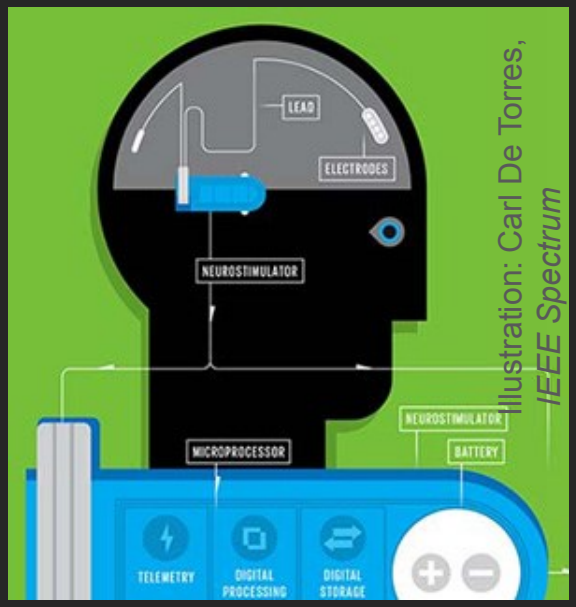
Signal processing is a key element of neurotechnology…

…in clinical treatments and therapies

- Brain-machine interfaces
- Prosthetics

BrainGate System

- Closed-loop control for bioelectric medicine
- Bioinstrumentation for health monitoring



NeuroPace – for epilepsy

"BrainGate amazes again: Paralyzed women moves thought-controlled robotic arm," *neurogadget.com,* May 2012.
"Smart neural stimulators listen to the body," Tim Dennison, Milton Morris, Felice Sun, *IEEE Spectrum,* Jan. 2015.

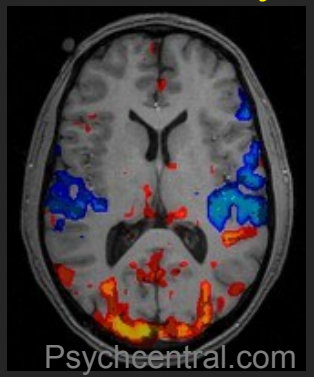
…in basic neuroscience

- Imaging
- Analyzing connectivity

Structural Connectivity

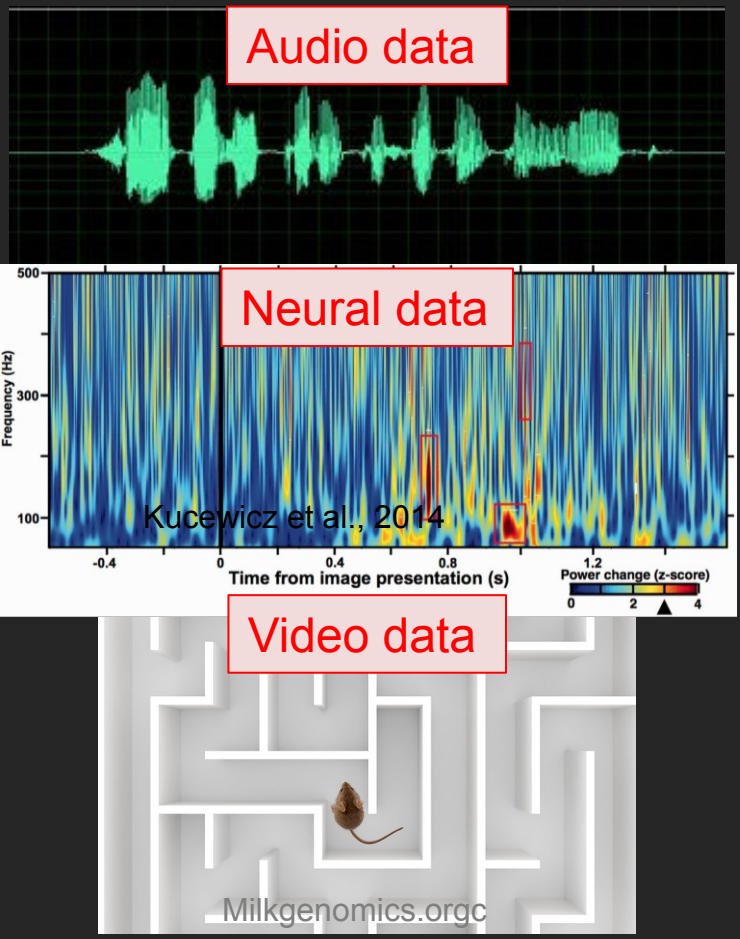
Diffusion tensor imaging

Functional Connectivity



Functional MRI

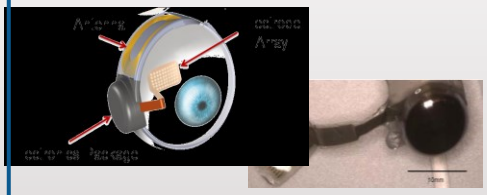
- Multi-modal data fusion



LLNL's Neurotechnology Projects

www.neurotech.llnl.gov

Artificial Retina

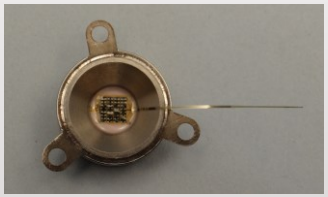


Second Sight

First FDA-approved retinal prosthesis

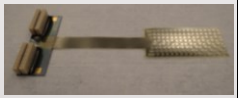
USC, UCSC, UU, SNI, ORNL, ANL, LANL

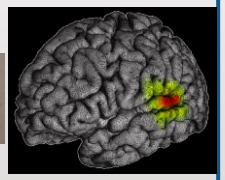
NIH Advanced Neural Interfaces



UCSF, HRMI, JHU, UCI, BI

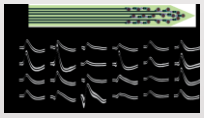
Human ElectroCorticography





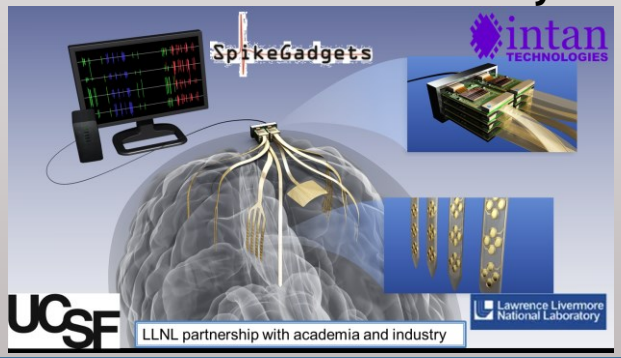
UCSF, UCLA

Understanding the Brain



UCSF

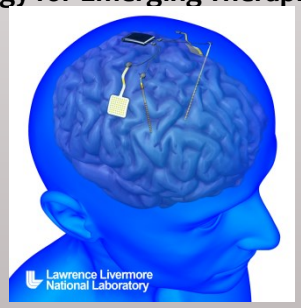
NIH 1000+ Channel Modular System



DARPA RAM & SUBNETS

Restoring Active Memory

Systems-Based Neurotechnology for Emerging Therapies

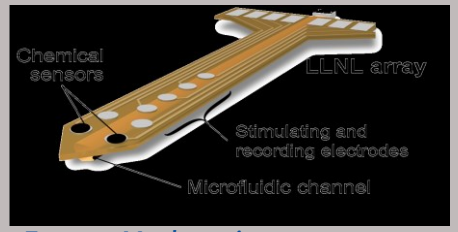


A closed-loop DBS approach for therapy and cure of brain disorders.

UCSF, UC Berkeley, Cortera, NYU, UCLA, Medtronic

Deep Brain Stimulation

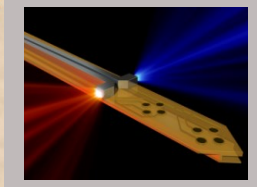
Multi-functional arrays



Emory, Medtronic

NIH Auditory Implant

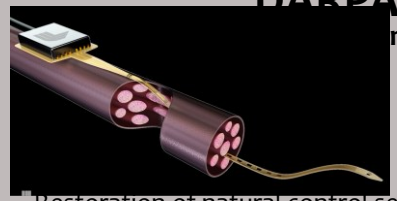
Intraneural Interfaces

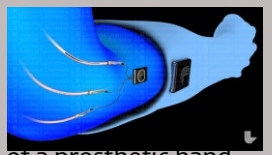


JHU, HMRI, UCSF, UW, UCI, BI

DARPA HAPTIX

n and Touch Interfaces

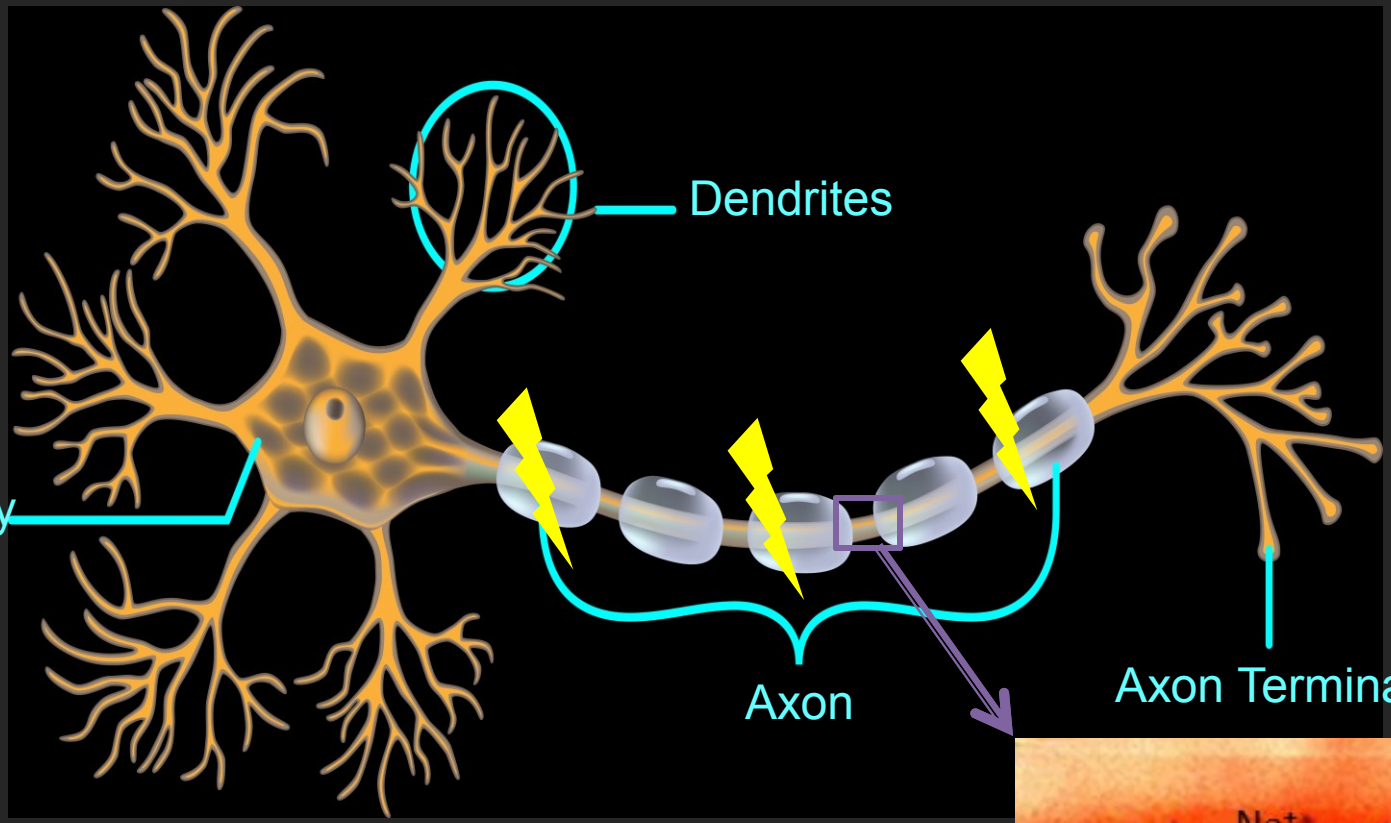


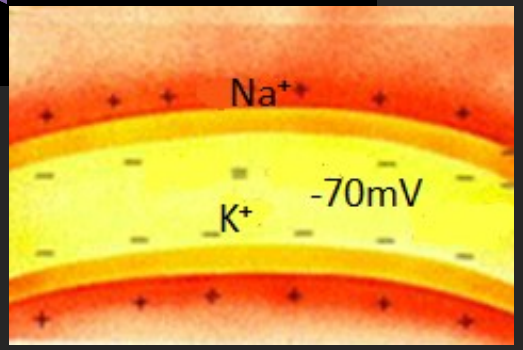


Restoration of natural control sensation of a prosthetic hand.

CASE, Medtronic, Ardiem

Basics of neuron bioelectricity



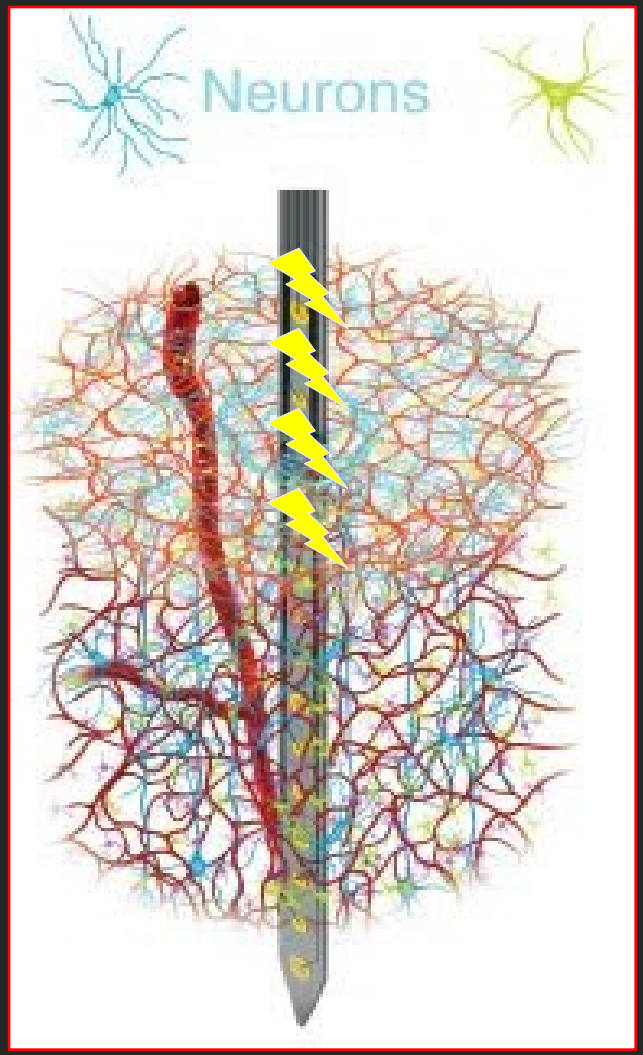


- Electrical charge travels because of changing "potential" across the cell membrane

- Charged ions move in and out of cell

Types of neural recordings

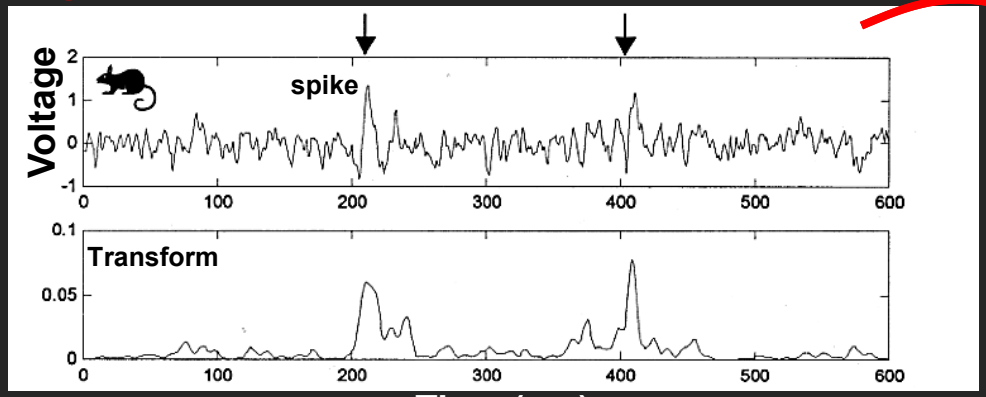
- Single spikes vs. field potential
- Trade off between invasiveness and resolution
- Depends on scientific question or application
  - Understanding cell-level circuitry?
  - Classifying signals based on inputs or stimuli?
  - Controlling a prosthetic?



Examples: Analyzing spike data

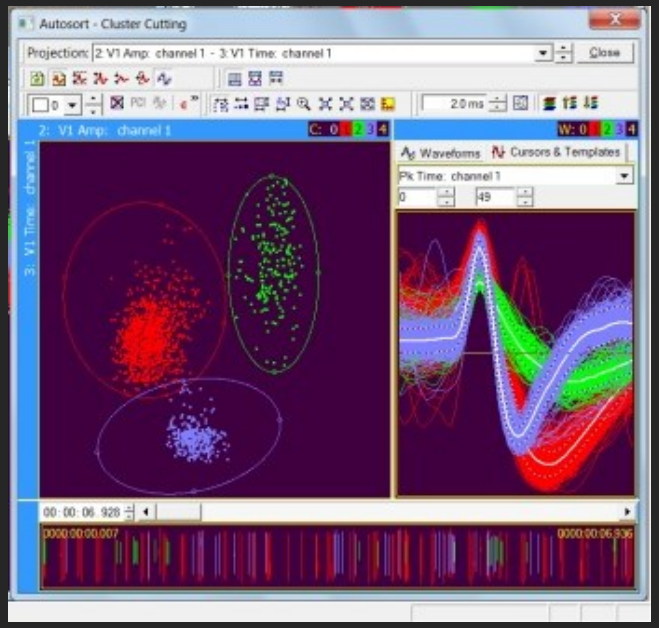
1. Spike detection

e.g. Wavelet Transform

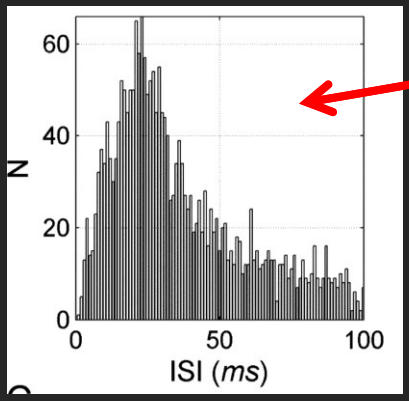


2. Spike classification

e.g. Principle component analysis



Software from DataWave Technologies



Histogram of inter-spike intervals

3. Spike train analysis

e.g. Point Process Models

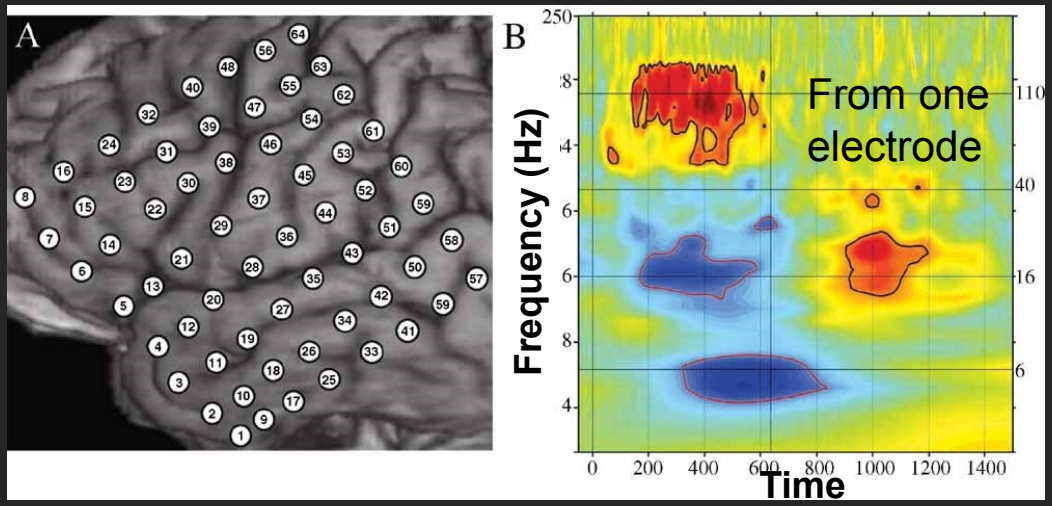
References on last slide

Examples: Analyzing field potential data

- Time frequency analysis

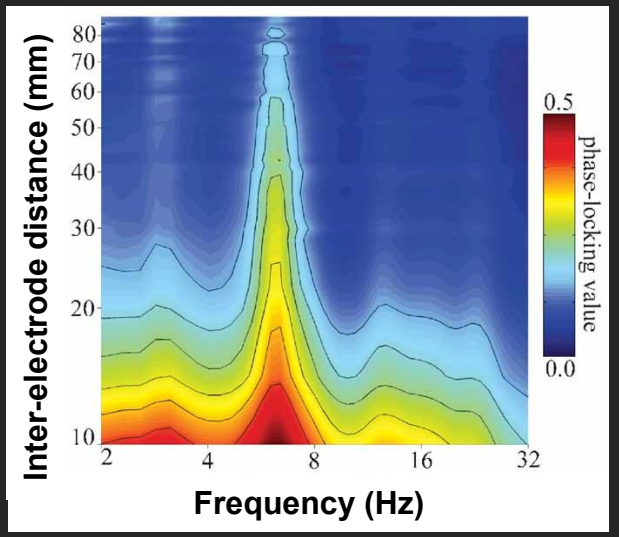
ECoG electrodes on the brain

Power in frequency bands over time



e.g. Analytic Gabor basis function

- Coherence and spatial correlation



e.g. Mean Phase Locking Value

"Spatiotemporal dynamics of word processing in the human brain," Conolty et al., *Frontiers in Neuroscience*, 2003

Resources

- BRAIN Initiative areas of interest: braininitiative.nih.gov
- Neurotechnology group @ LLNL: *neurotech.llnl.gov*, Sat Pannu
- Analyzing spike data (slide 9)
  - Kim, K. H. and Kim, S. J., “A wavelet-based method for action potential detection from extracellular neural signal recording with low signal-to-noise ratio,"*Biomedical Engineering, IEEE Transactions,* 2003.
  - Brown, Emery N., et al. "Likelihood methods for neural spike train data analysis." *Computational neuroscience: A comprehensive approach* (2003): 253-286.
  - Gibson, Sarah, Jack W. Judy, and Dejan Markovic. "Spike Sorting." *IEEE Signal processing magazine* 29.1 (2012): 124.
- Other useful texts
  - *Statistical Signal Processing for Neuroscience and Neurotechnology*, Karim Oweiss
  - *Signal Processing for Neuroscientists,* Wim van Drongelen
  - *Analyzing Neural Time Series Data*, Mike X Cohen