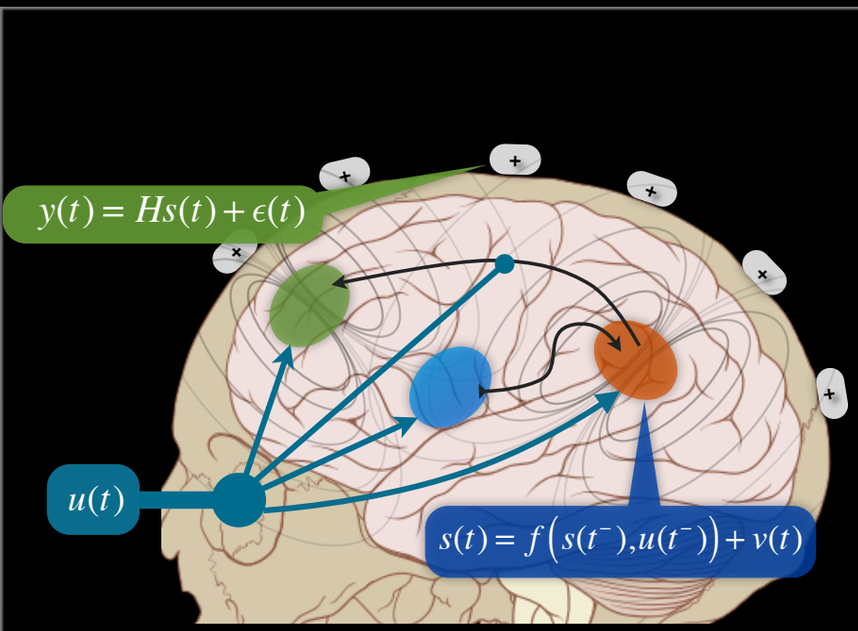
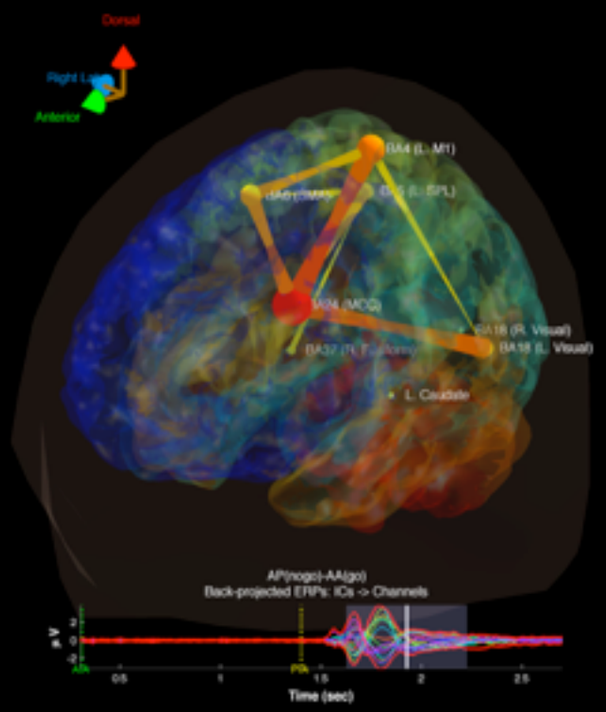
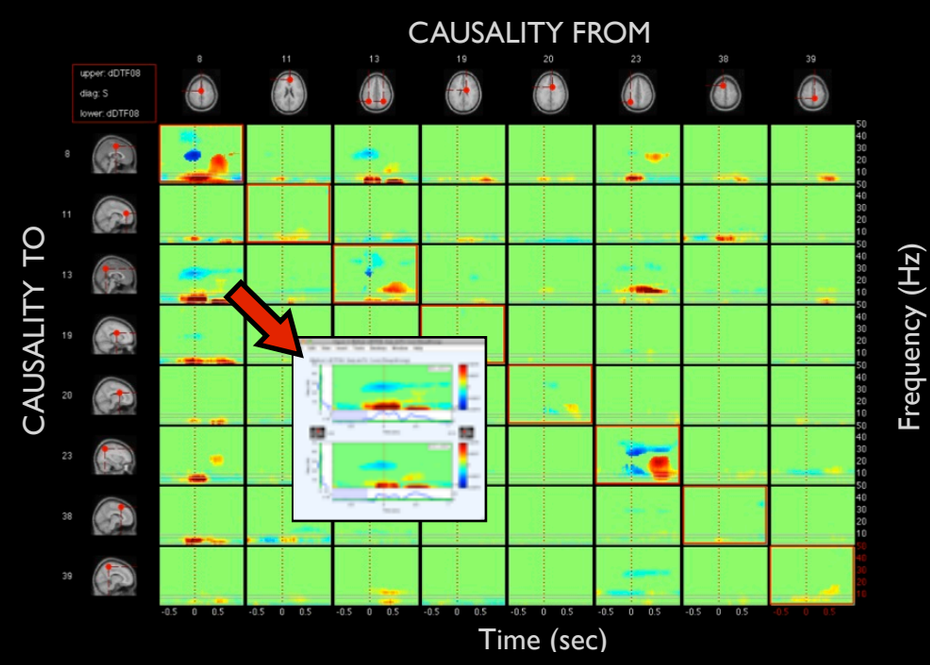
# The Source Information Flow Toolbox



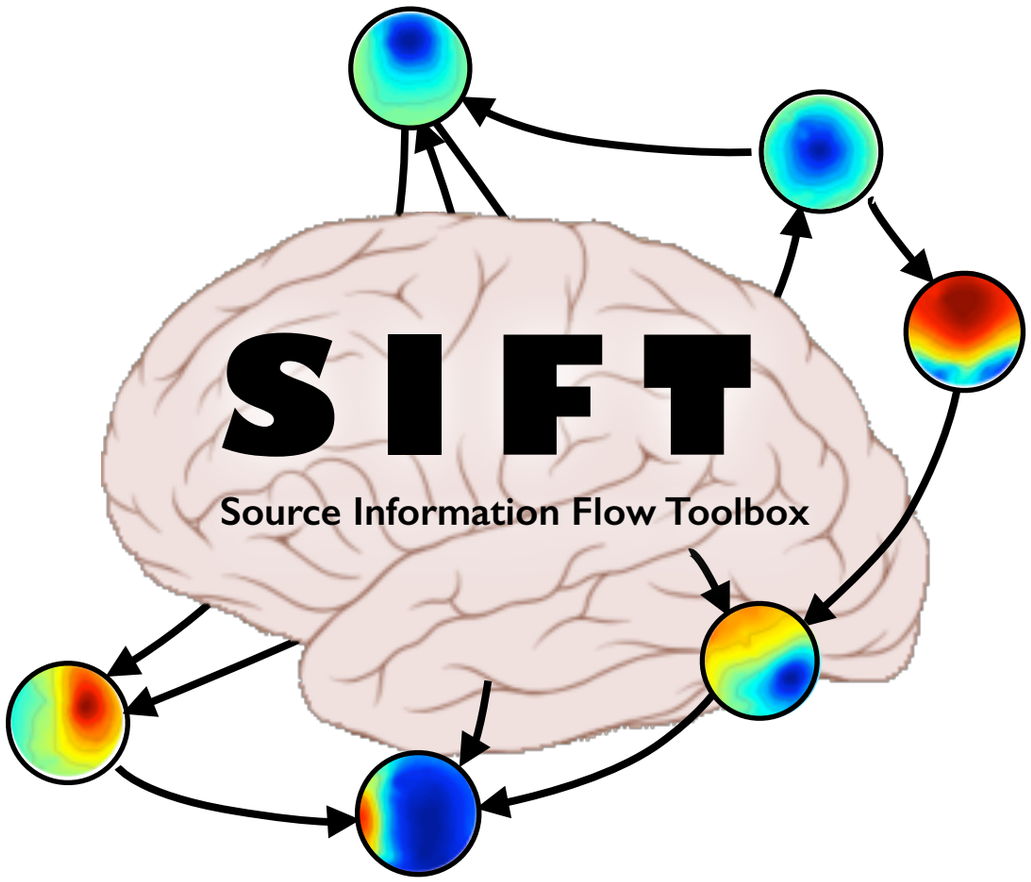





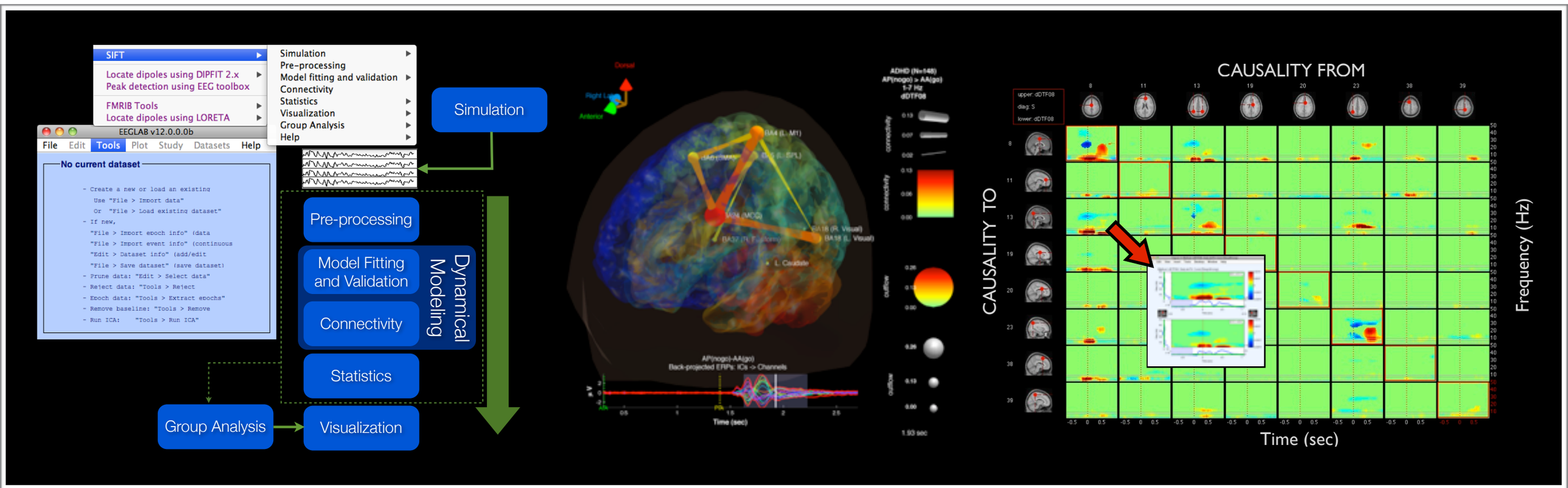
## Tim Mullen, PhD

Swartz Center for Computational Neuroscience
Institute for Neural Computation
UC San Diego
and Qusp Labs

Mullen, T & Makeig, S., "The Source Information Flow Toolbox: An Electrophysiological Dynamical Modeling Toolbox for EEGLAB", *in prep*
Delorme, A., Mullen, T., et al, "EEGLAB, SIFT, NFT, BCILAB, and ERICA: New tools for advanced EEG/MEG processing." *Comp. Intel. and Neuro.*, vol 12, 2011




- A toolbox for (source-space) electrophysiological information flow and causality analysis (single- or multi-subject) integrated into the EEGLAB software environment.
- Modular architecture intended to support multiple modeling approaches
- Emphasis on vector autoregression and SSMs and time-frequency domain approaches
- Standard and novel interactive visualization methods for exploratory analysis of connectivity across time, frequency, and spatial location



# SIFT Workshop Sessions

| Theoretical Foundations I |
| --- |
| Functional Connectivity Measures (PLV, PAC, Coherence) |
| Linear Dynamical Systems and the VAR model |
| Granger Causality and Effective Connectivity Measures |
| Scalp versus Source |
| Adapting to Time-Varying Dynamics |
| Practicum: Hands-On Walkthrough of SIFT |

Friday, 18th
2:00-5:00pm
Session D1
Track C (VizLab)

| Theoretical Foundations II |
| --- |
| Model Validation |
| Multivariate vs. Bivariate |
| Imposing Constraints |
| Single-trial Estimation and State-Space Models |
| Statistical Testing |
| Practicum: Hands-On Simulation-based training |

Saturday, 19th
2:00-5:00pm
Session D2
Track C (INC Open Space)

The Source Information Flow Toolbox

# Source Information Flow Toolbox (SIFT)

Tim Mullen

- **Requirements**: EEGLAB, MATLAB 2008a - 2013b
- Some functions leverage: Signal Processing Toolbox, Statistics Toolbox

# The Source Information Flow Toolbox

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SIFT

Locate dipoles using DIPFIT 2.x

Peak detection using EEG toolbox

FMRIB Tools

Locate dipoles using LORETA

Simulation

Pre-processing

Model fitting and validation

Connectivity

Statistics

Visualization

Group Analysis

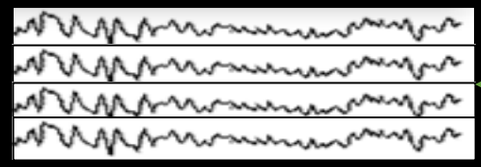
Help

EEGLAB v12.0.0.0b

File Edit Tools Plot Study Datasets Help

**No current dataset**

```
- Create a new or load an existing
   Use "File > Import data"
   Or  "File > Load existing dataset"
- If new,
  "File > Import epoch info" (data
  "File > Import event info" (continuous
  "Edit > Dataset info" (add/edit
  "File > Save dataset" (save dataset)
- Prune data: "Edit > Select data"
- Reject data: "Tools > Reject
- Epoch data: "Tools > Extract epochs"
- Remove baseline: "Tools > Remove
- Run ICA:    "Tools > Run ICA"
```



Simulation

Pre-processing

Model Fitting and Validation

Connectivity

Statistics

Group Analysis

Visualization

Dynamical Modeling

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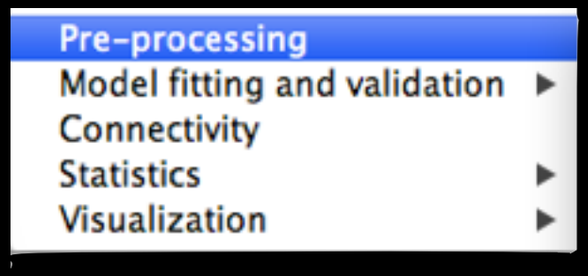
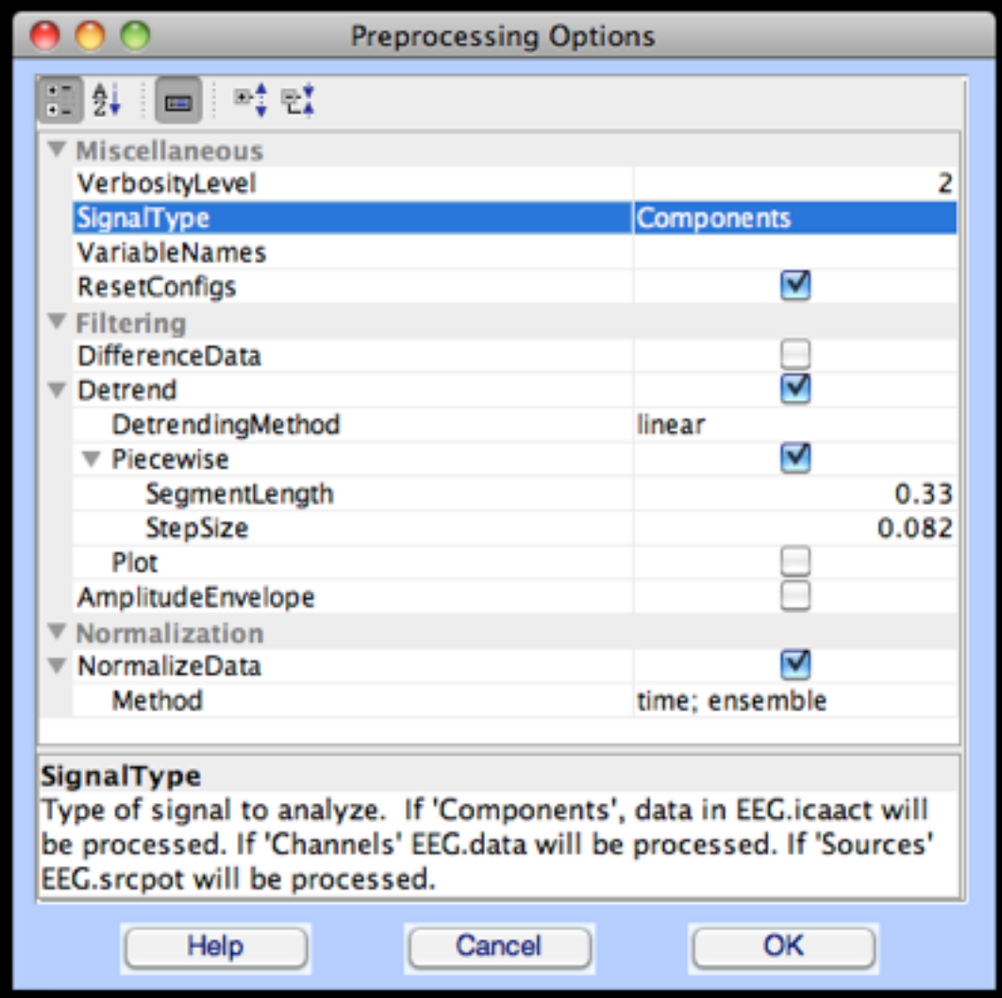
# Preprocessing

Modeling

Statistics

Visualization




**Source reconstruction**
(performed externally using EEGLAB or other toolboxes)

Local Detrending or Filtering

Downsampling (EEGLAB)

Differencing

Normalization (temporal or ensemble)

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Preprocessing

Modeling

Model Fitting

Validation

Connectivity

Statistics

Visualization

Tim Mullen

Preprocessing | **Modeling** | Statistics | Visualization

Model Fitting | Validation | Connectivity

| Modeling Algorithm (1) | Linear | Nonlinear |
|---|---|---|
| Segmentation VAR (Sliding Window) | | |
| Unconstrained | | |
| Vieira-Morf | ☑ | |
| ARfit | ☑ | |
| Regularized | | |
| Ridge Regression ($L_2$) | ☑ | |
| Group Lasso ($L_{1,2}$) ADMM, DAL | ☑ | |
| Sparse Bayesian Learning ($L_p$) TMSBL, BSBL | ☑ | |

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Preprocessing | **Modeling** | Statistics | Visualization

Model Fitting | Validation | Connectivity

| Modeling Algorithm (2) | Linear | Nonlinear |
|---|---|---|
| State-Space Modeling | | |
| Linear Kalman Filtering | ☑ | |
| Dual Extended Kalman Filtering | | ☑ |
| Cubature Kalman Filtering | | ☑ |
| Sparsely Connected Components Analysis (SCSA) | ☑ | |

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Preprocessing

Modeling

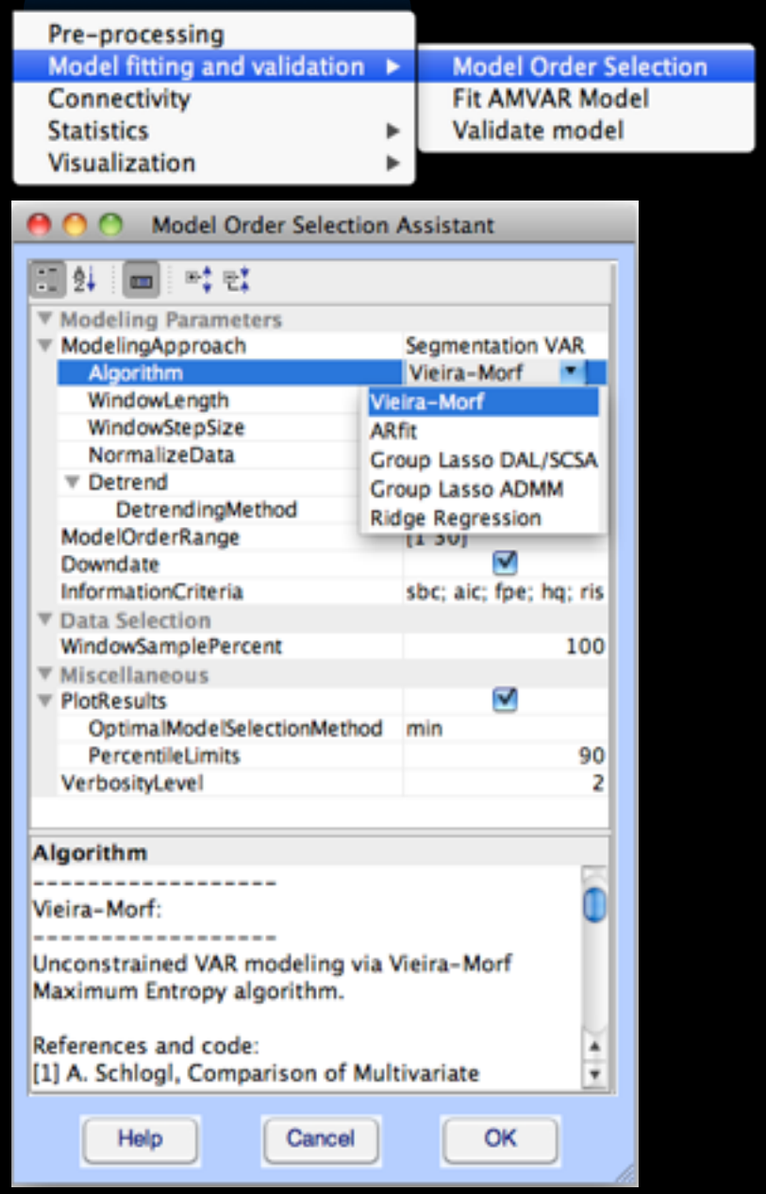
Statistics

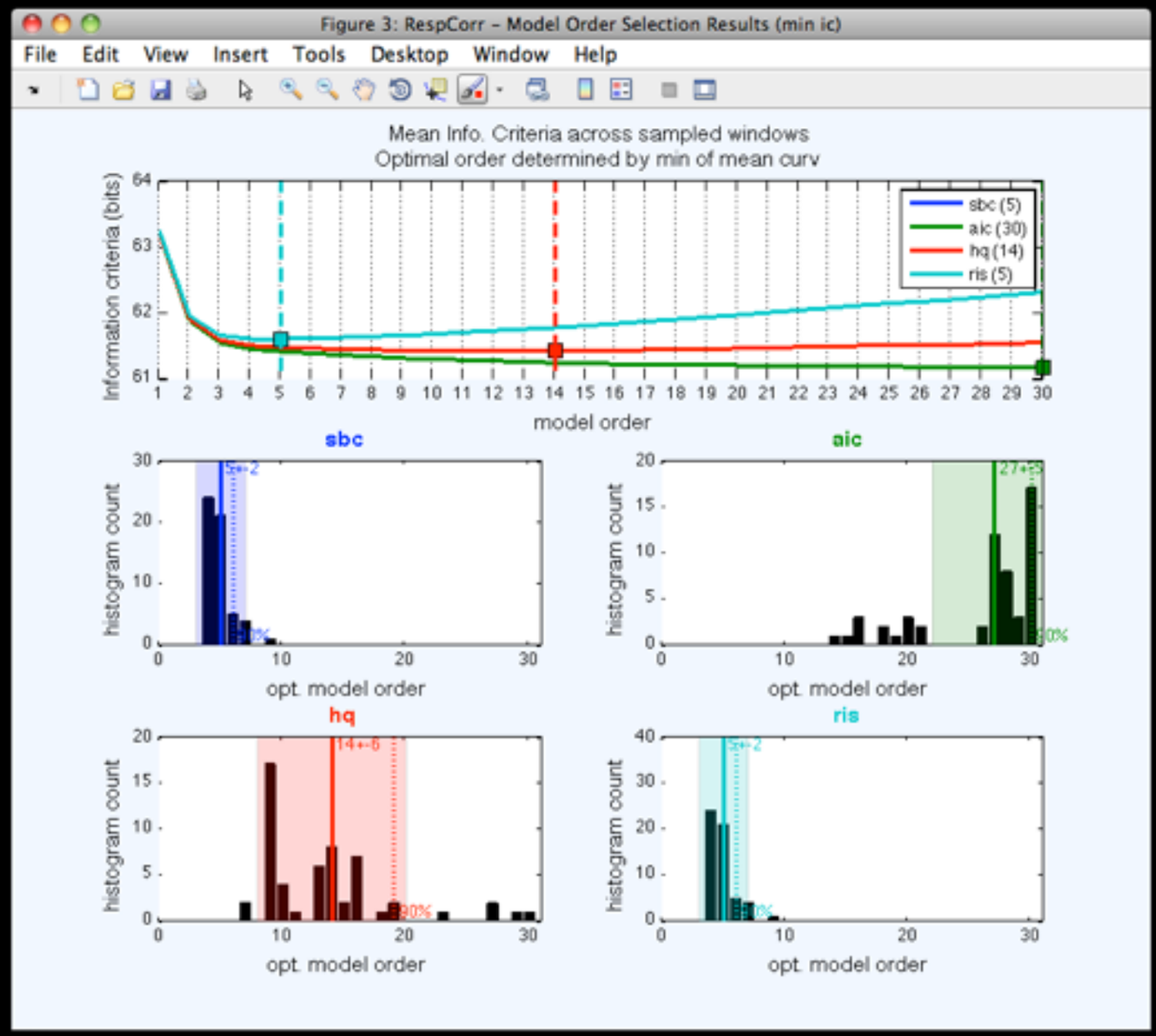
Visualization

Model Fitting

Validation

Connectivity



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Preprocessing | Modeling | Statistics | Visualization

Model Fitting | Validation | Connectivity

## VAR Model Validation

Residual ‘Whiteness’ Tests

- Multivariate portmanteau tests
- Residual autocorrelation probability test

Model Consistency

Model Stability

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Preprocessing

Modeling

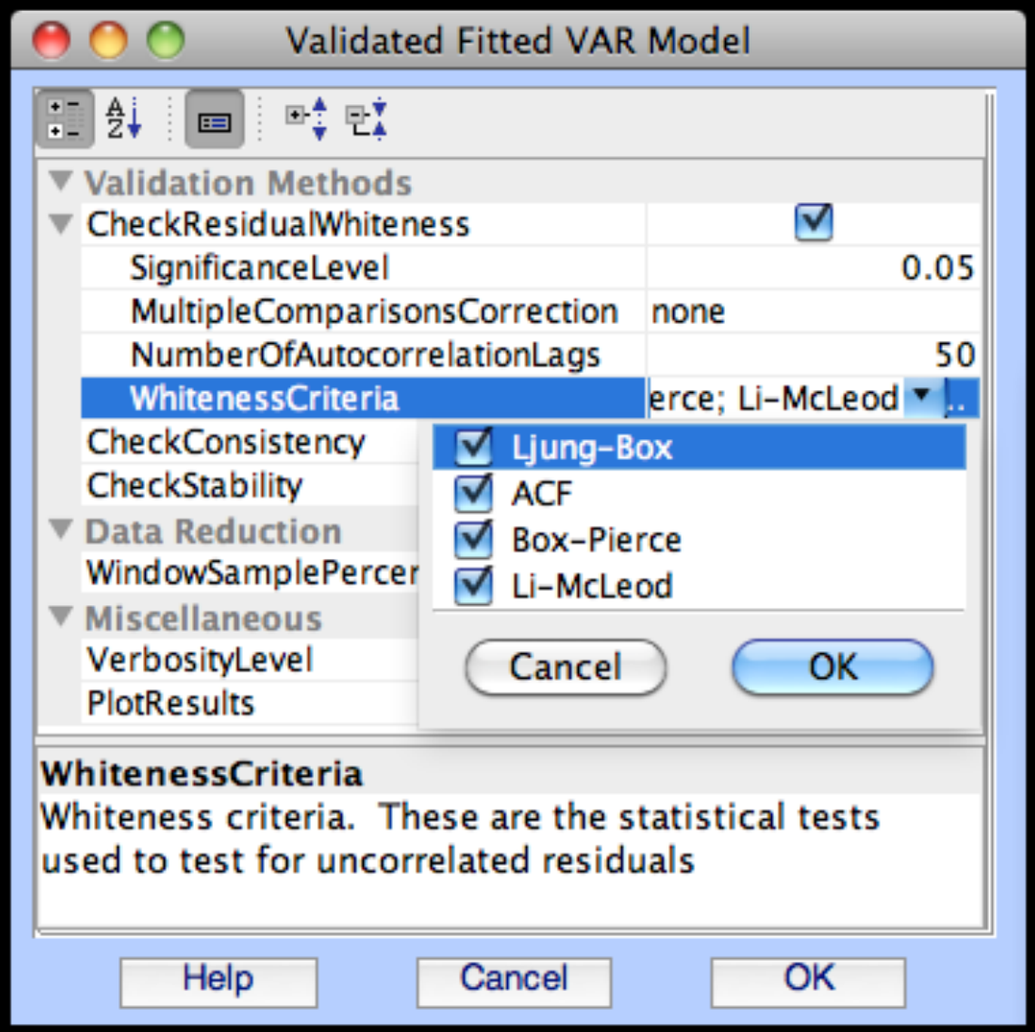
Statistics

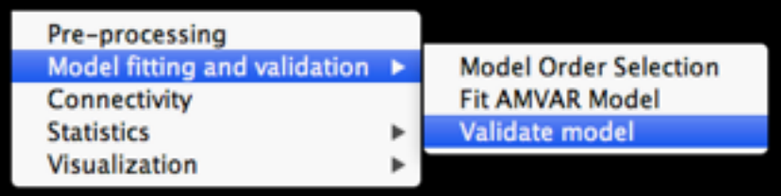
Visualization

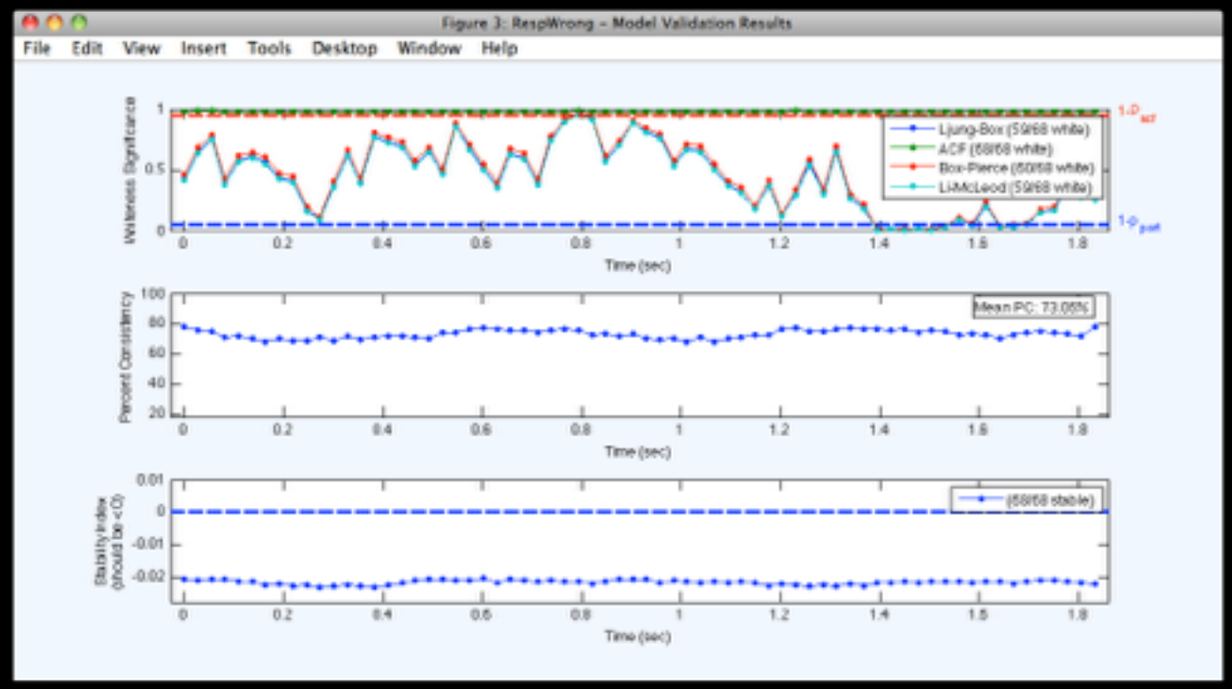
Model Fitting

Validation

Connectivity



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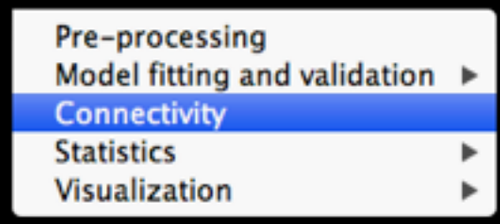
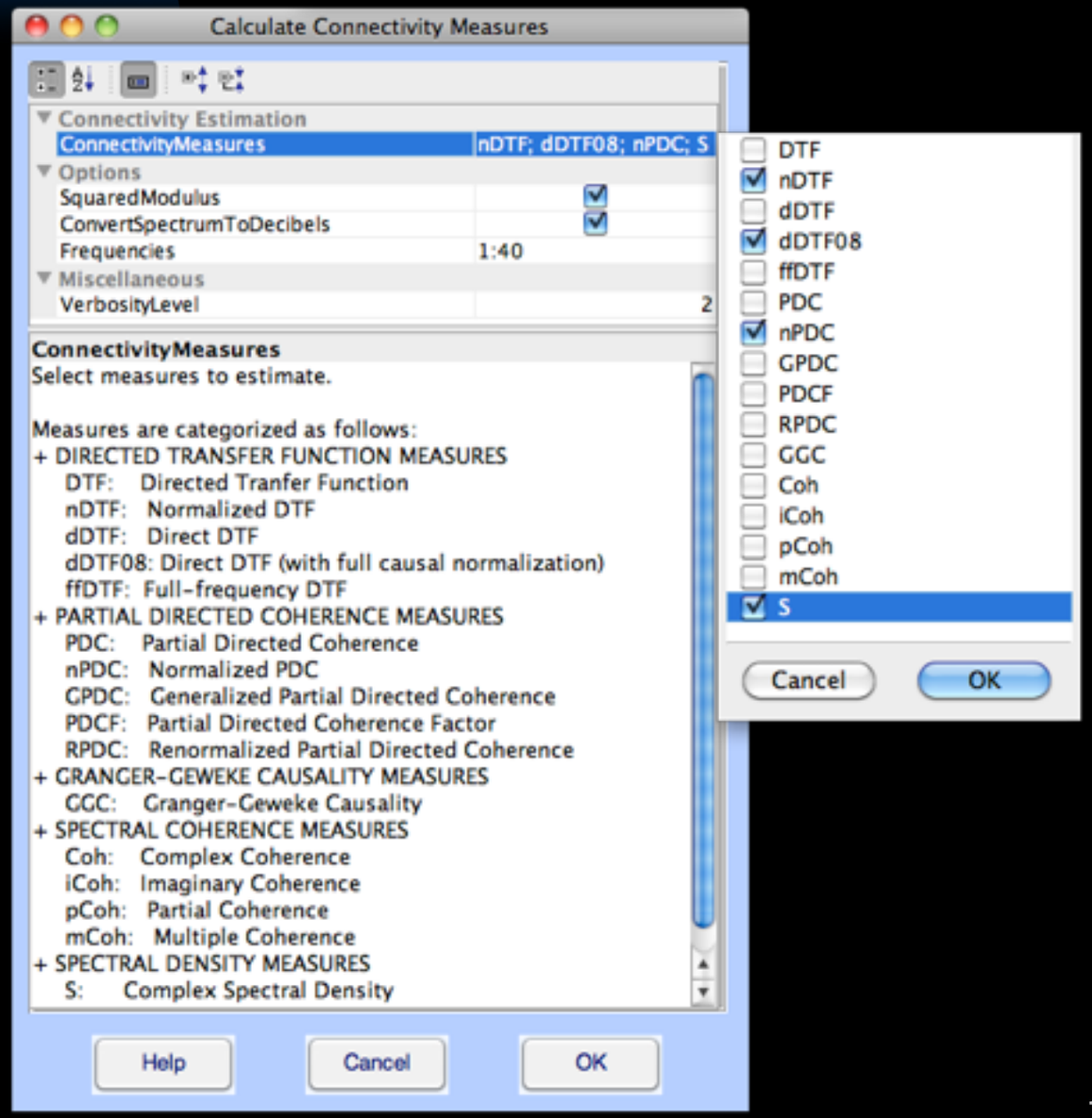
Preprocessing | **Modeling** | Statistics | Visualization

Model Fitting | Validation | Connectivity




## VAR-based Measures

- Power spectrum (ERSP)
- Coherence (Coh), Partial Coherence (pCoh), Multiple Coherence (mCoh)
- Partial Directed Coherence (PDC)
- Generalized PDC (GPDC)
- Partial Directed Coherence Factor (PDCF)
- Renormalized PDC (rPDC)
- Directed Transfer Function (DTF)
- Direct Directed Transfer Function (dDTF)
- Bivariate Granger-Geweke Causality (GGC)
- Principal Oscillation Pattern Analysis (POP)



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| Statistical Approach | Test | Parametric | Nonparam. |
|---|---|---|---|
| Asymptotic analytic estimates of confidence intervals.<br>Applies to: PDC, nPDC, DTF, nDTF, rPDC | $H_{null}$, $H_{base}$, $H_{AB}$ | ☑ | |
| Theiler phase randomization<br>Applies to: all | $H_{null}$ | | ☑ |
| Bootstrap, Jacknife, Cross-Validation<br>Applies to: all | $H_{AB}$, $H_{base}$ | | ☑ |
| Confidence intervals using Bayesian B-spline smoothing<br>Applies to: all | $H_{base}$, $H_{AB}$ | ☑ | ☑ |

$H_{null} : \mathbf{C}_{ij} = 0$ $\quad$ $H_{base}: \mathbf{C}_{ij} = \mathbf{C}_{baseline}$ $\quad$ $H_{AB}: \mathbf{C}^{A}_{ij} = \mathbf{C}^{B}_{ij}$

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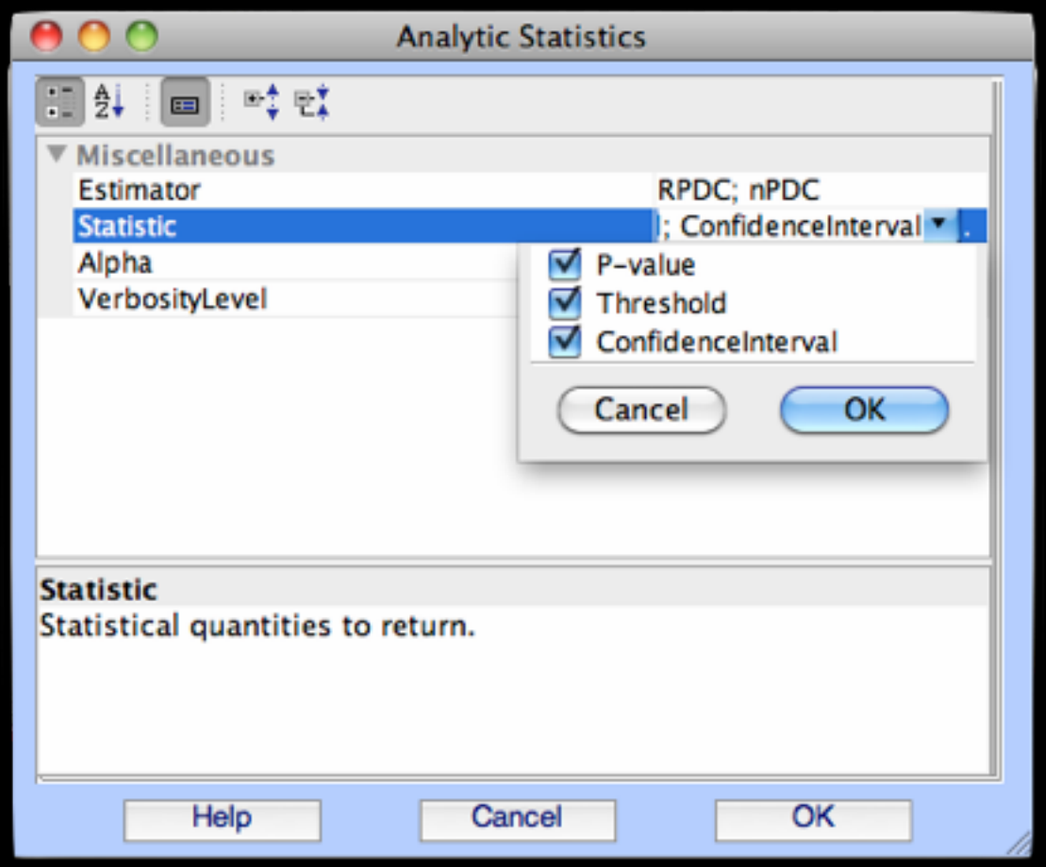
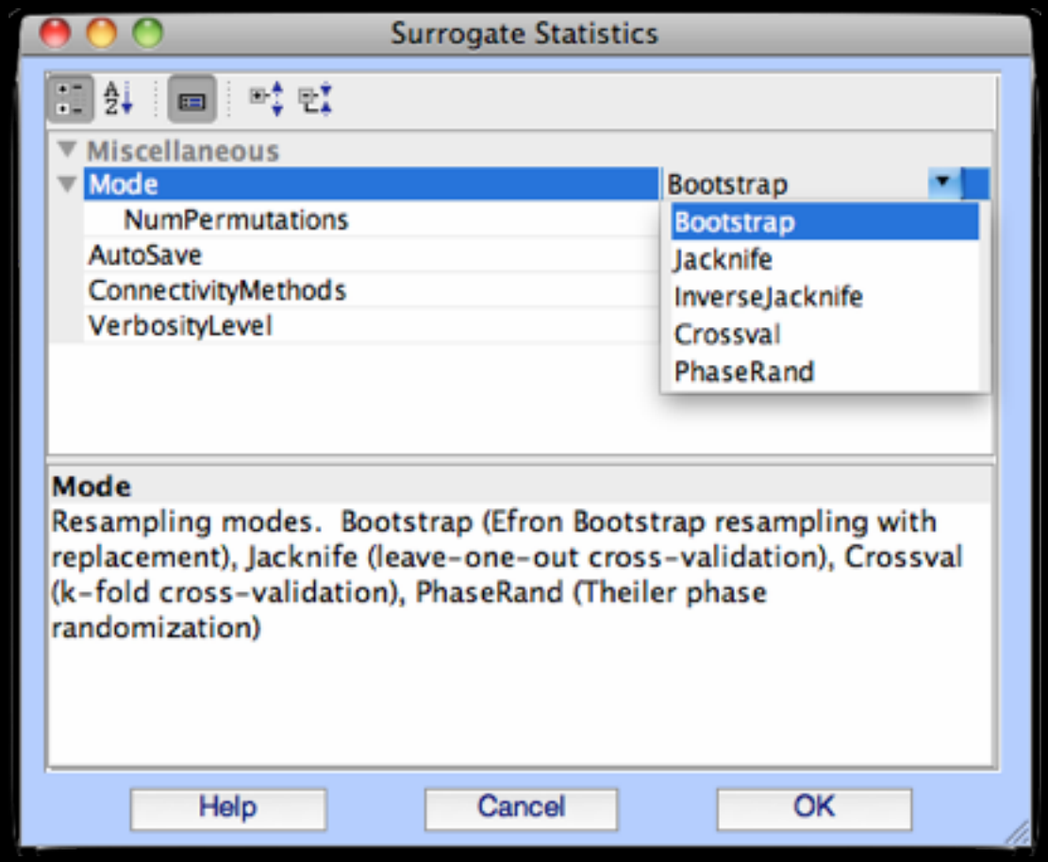
Preprocessing | Modeling | Statistics | Visualization

## Parametric




## Non-parametric



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Preprocessing | Modeling | Statistics | Visualization

## Interactive Visualizers

- Interactive Time-Frequency Grid
- Interactive 3D Causal Brainmovie
- Causal Projection Movie
- Directed Graphs and Graph Theoretic Analysis (Bioinformatics Toolbox Interface)
- and more ...

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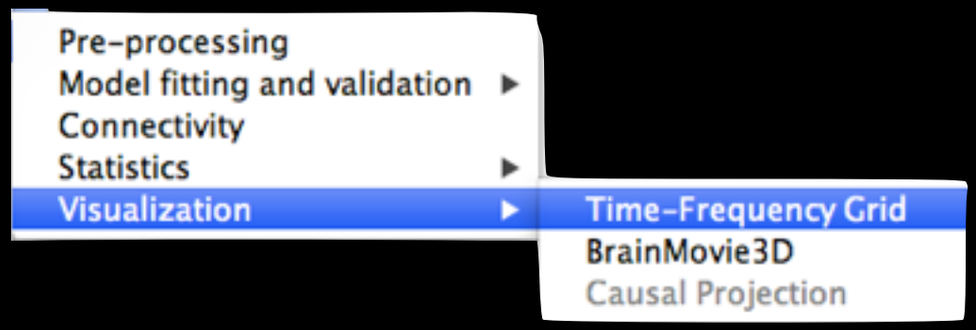
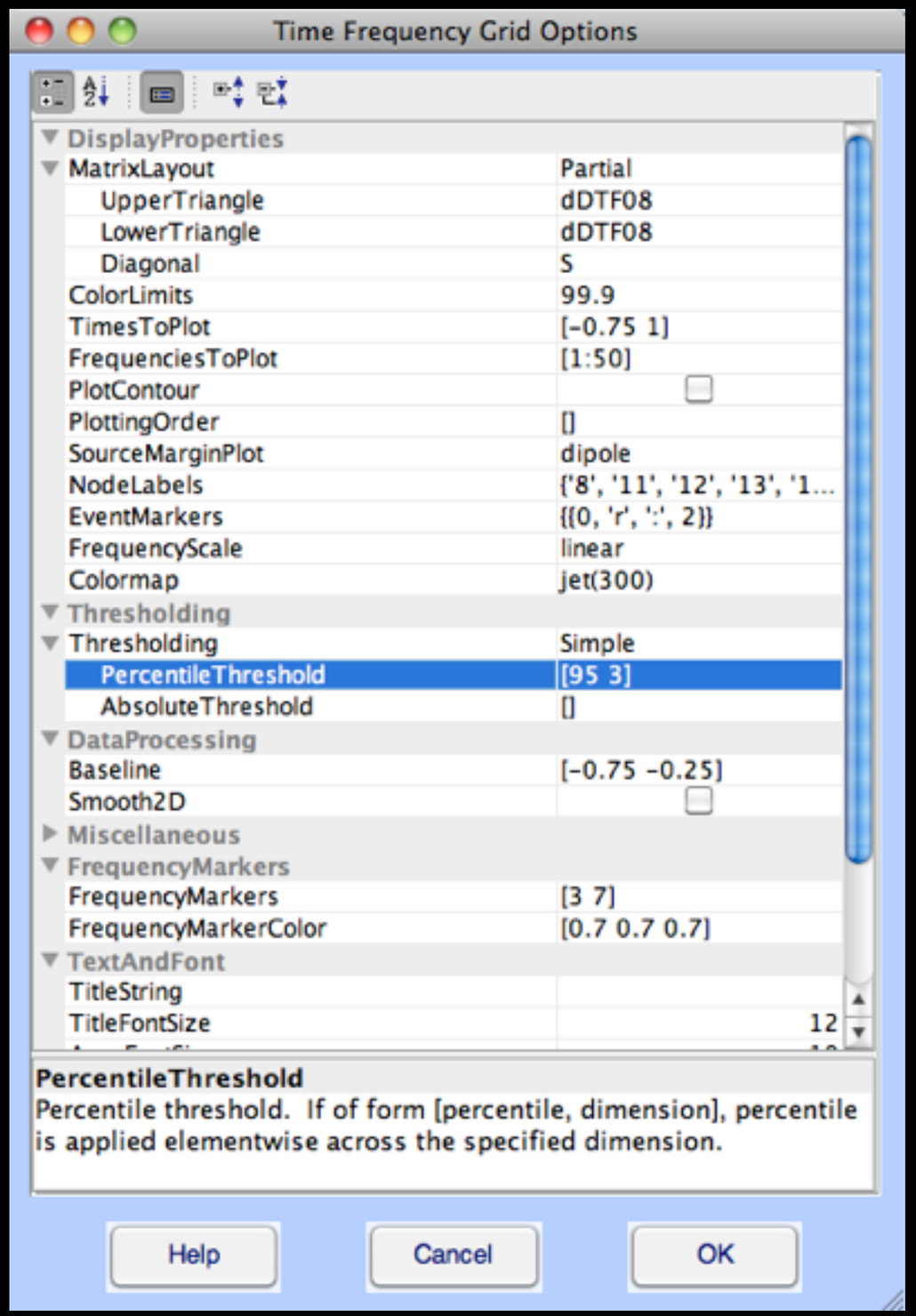
# Interactive Time-Frequency Grid



# Interactive Time-Frequency Grid

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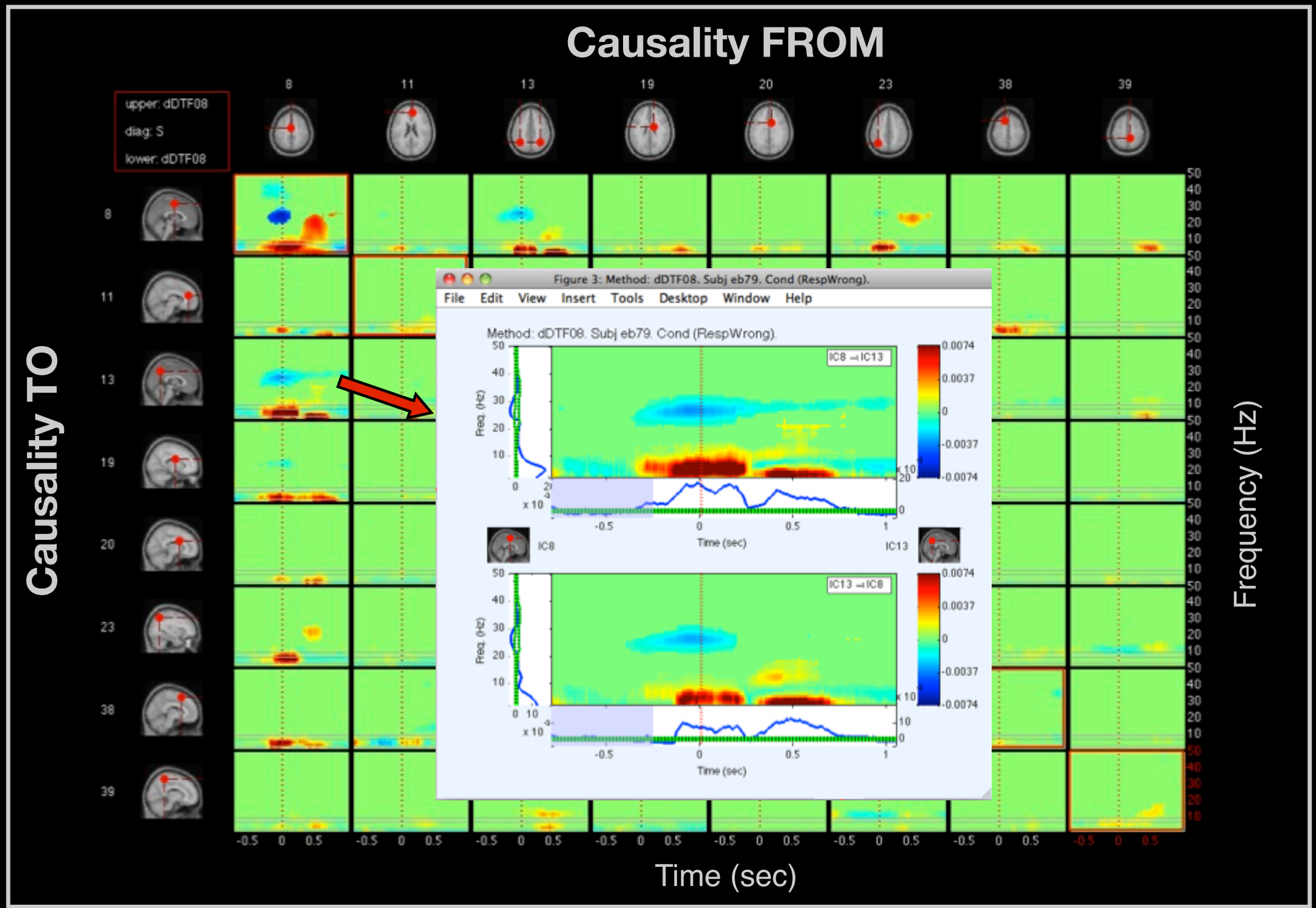

# Interactive Causal BrainMovie3D

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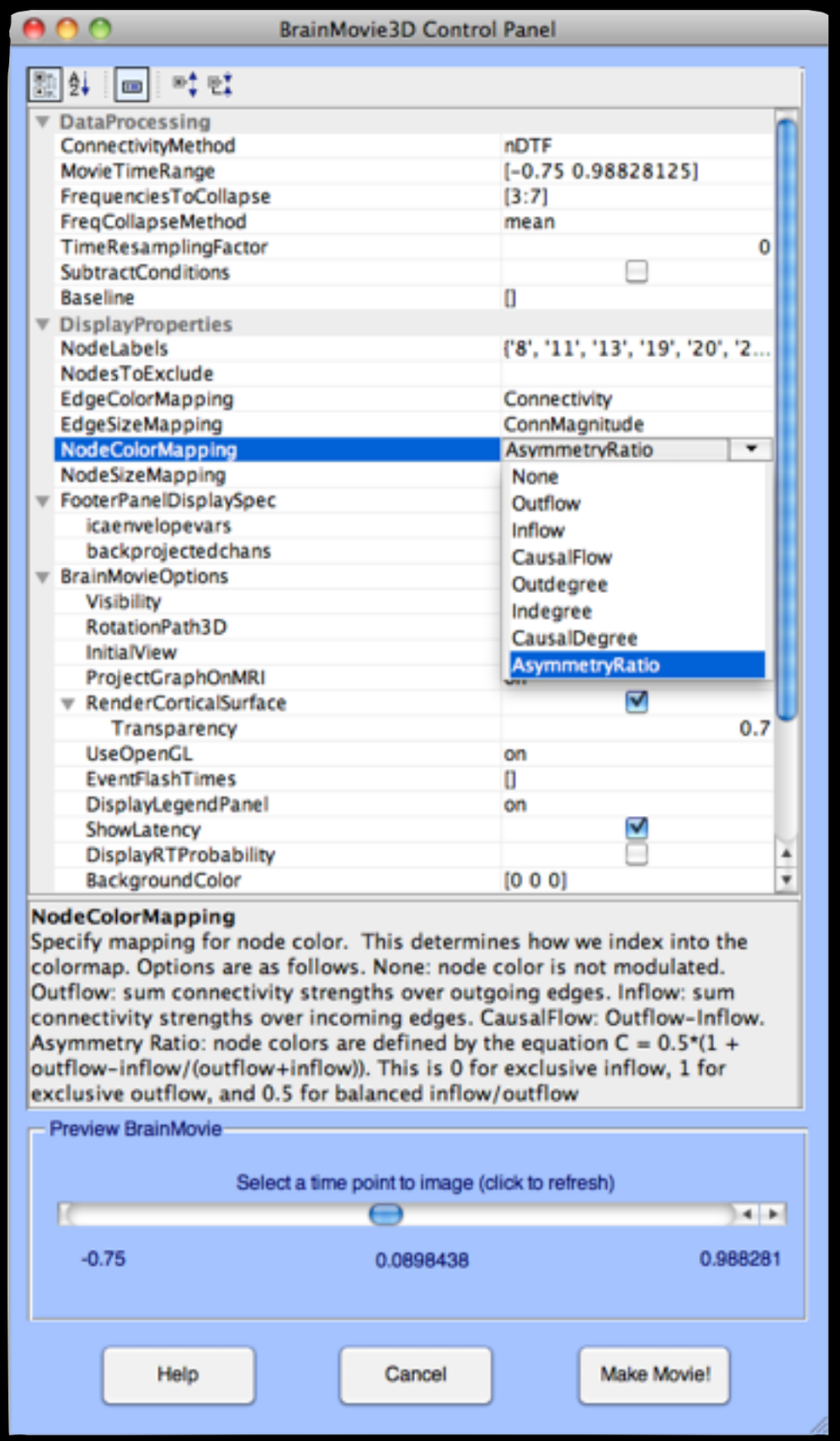


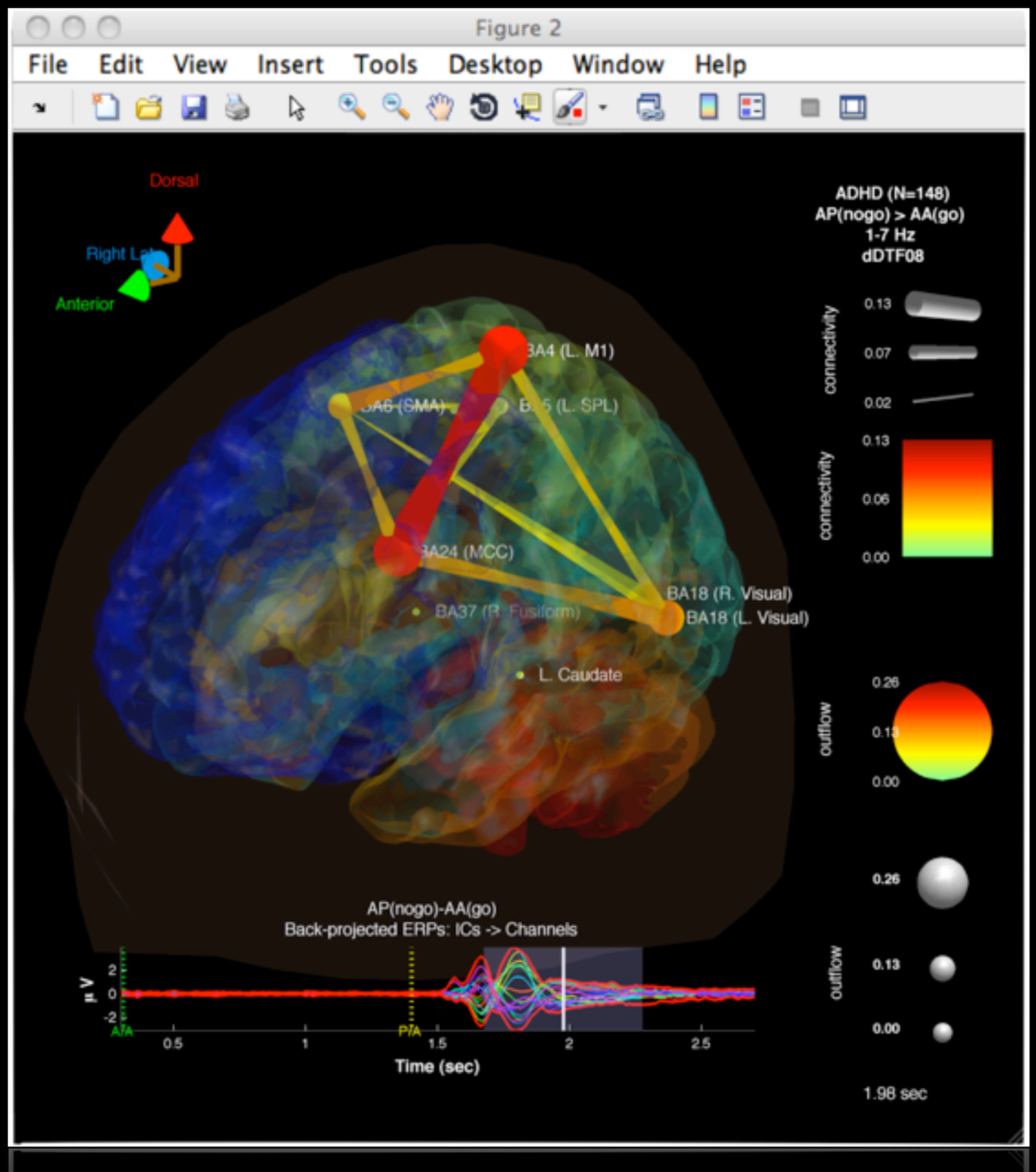

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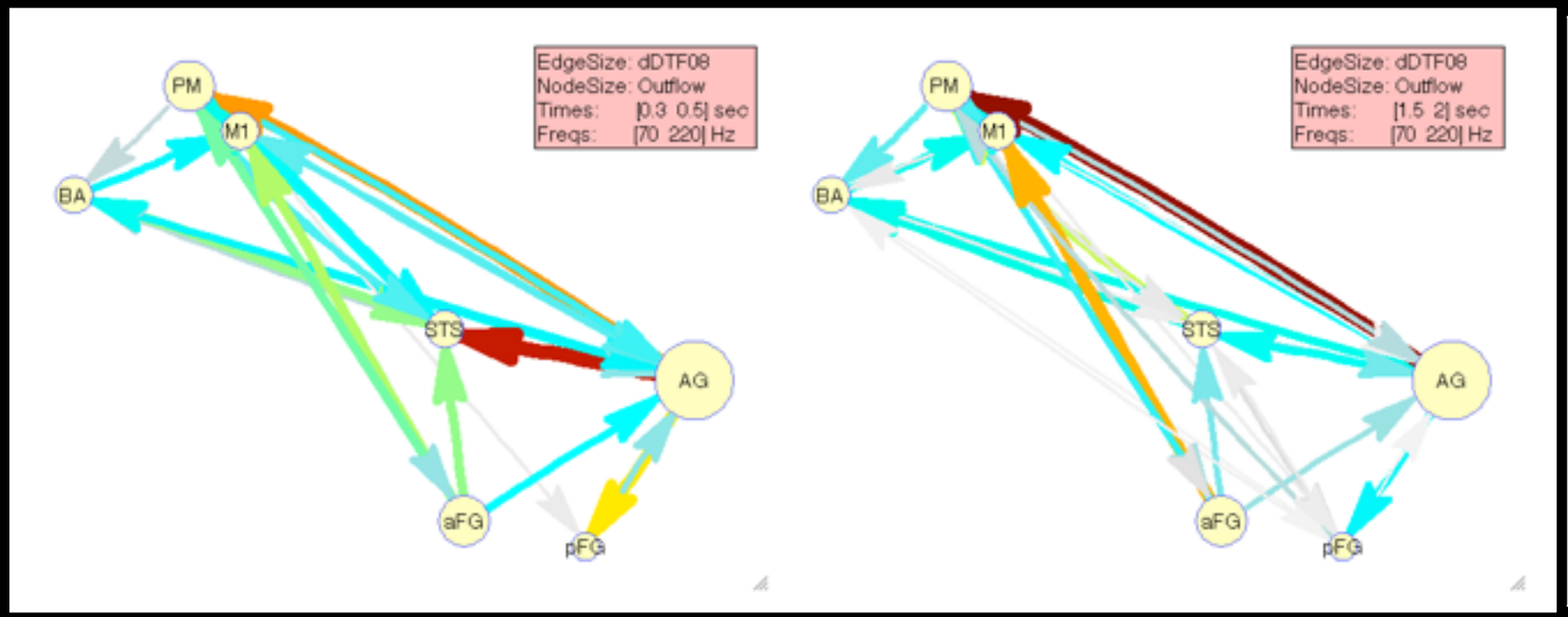
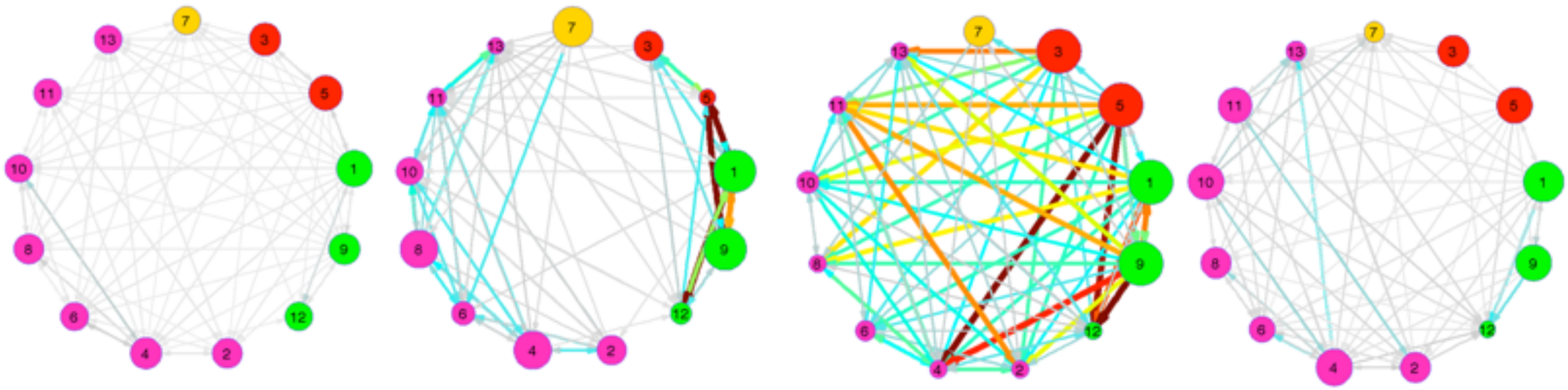
# Bioinformatics Toolbox IFace




- Interactive Directed Graphs
- Radial, Hierarchical, or Customized Node Layout
- Graph-Theoretic Analysis (SCCs, Shortest-Path, MaxFlow, etc)
- Assignment of useful quantities to Node and Edge size/color




Mullen et al, 2011

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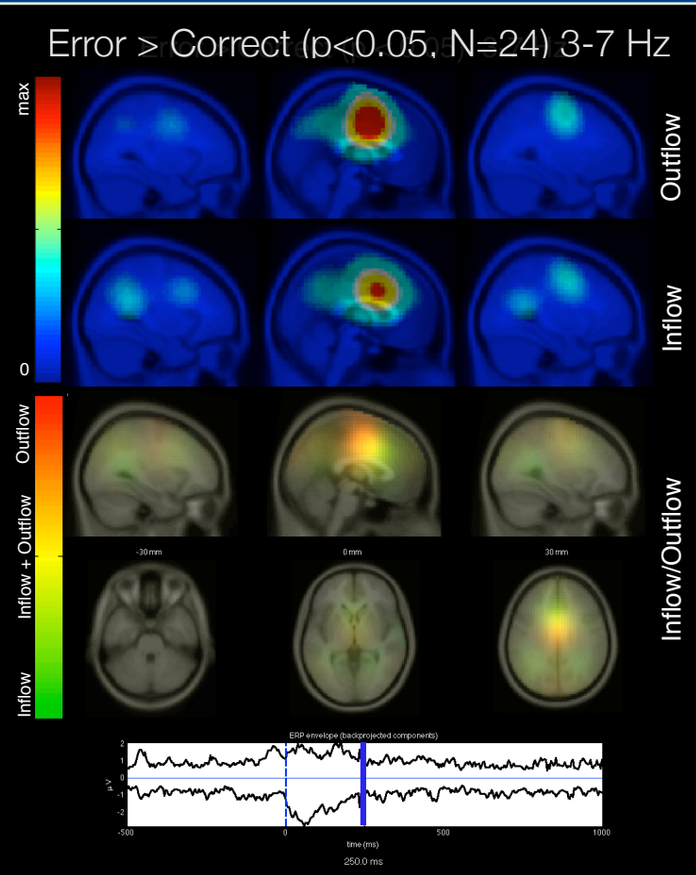
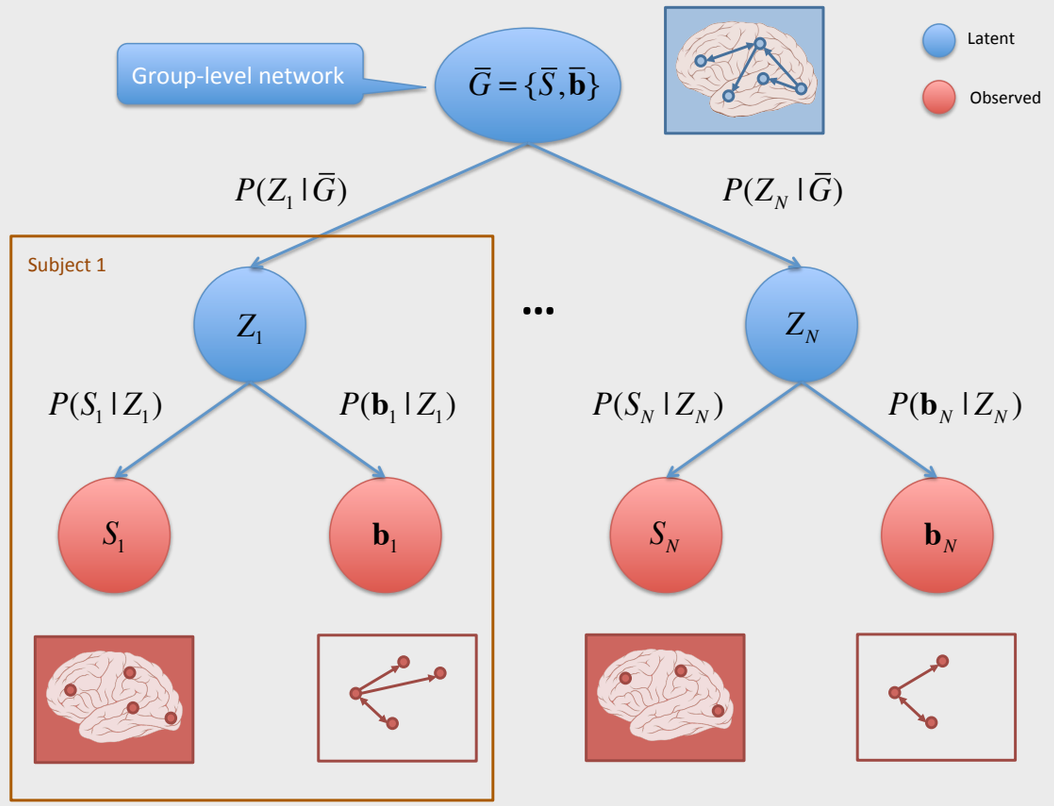
# Group Analysis (beta)

## Causal/Measure Projection




Mullen, et al, 2010, HBM, Barcelona
Bigdely-Shamlo, et al, 2013, *NeuroImage*

## Bayesian Hierarchical Model




Thompson, Mullen, Makeig, 2011, ICONXI
Thompson, Mullen, Makeig, 2012, *in prep*

# Group Analysis (beta)

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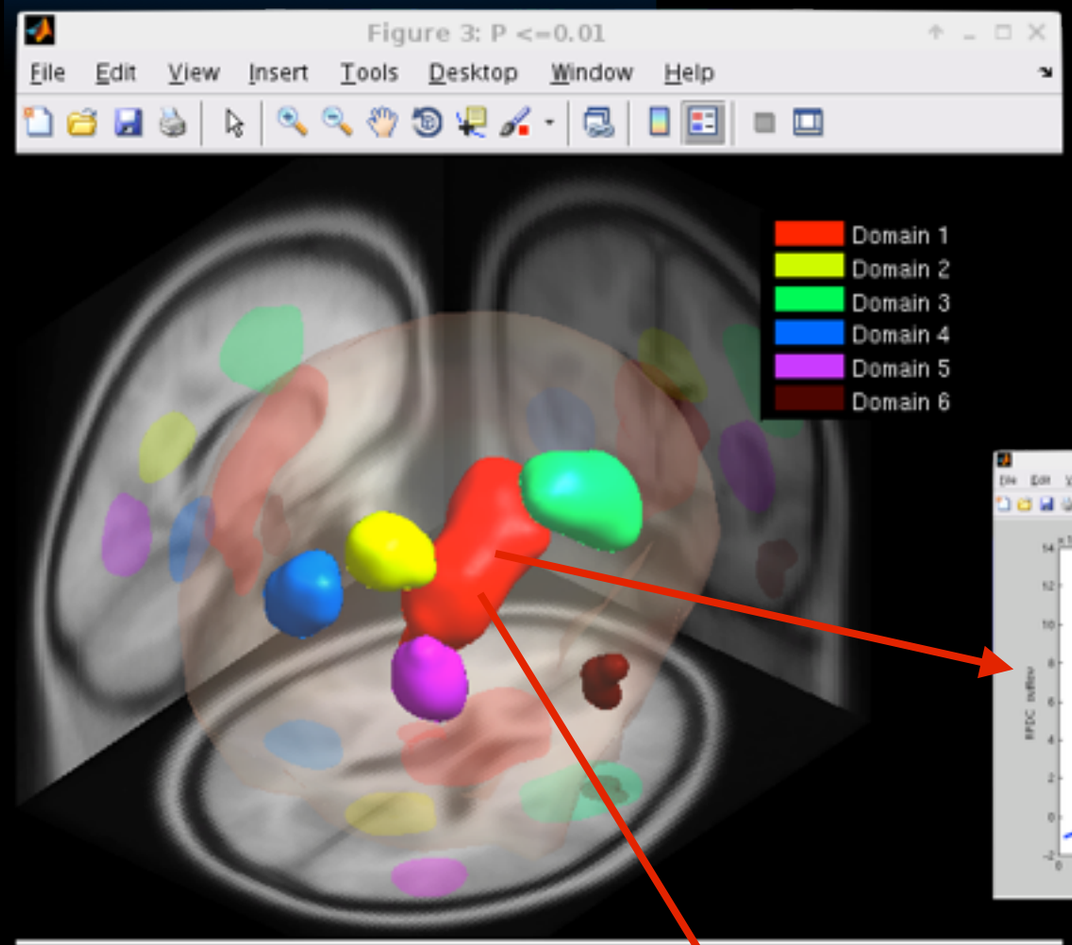
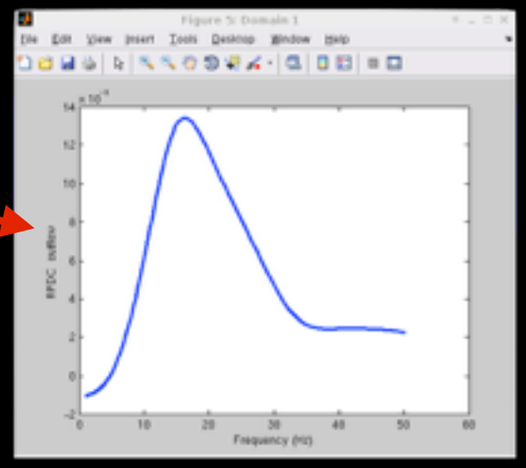
Measure Projection Toolbox

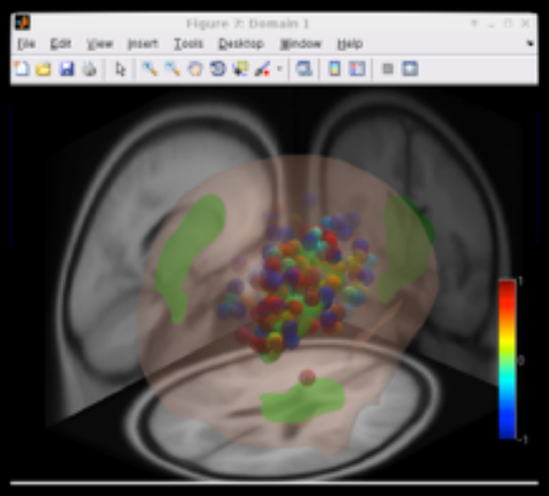
- Simulation ▶
- Pre-processing
- Model fitting and validation ▶
- Connectivity
- Statistics ▶
- Visualization ▶
- Group Analysis ▶
- Help

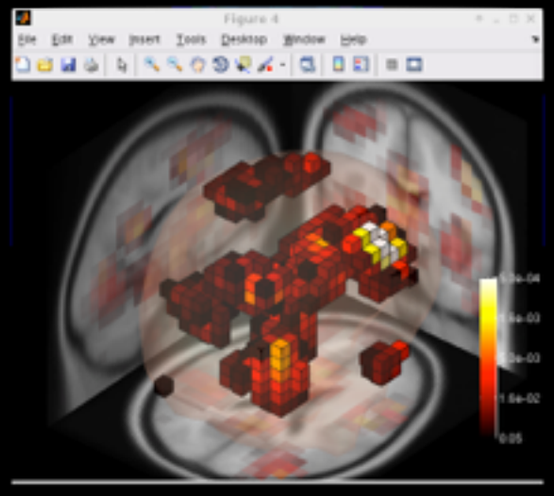
Causal Projection (MPT) ▶

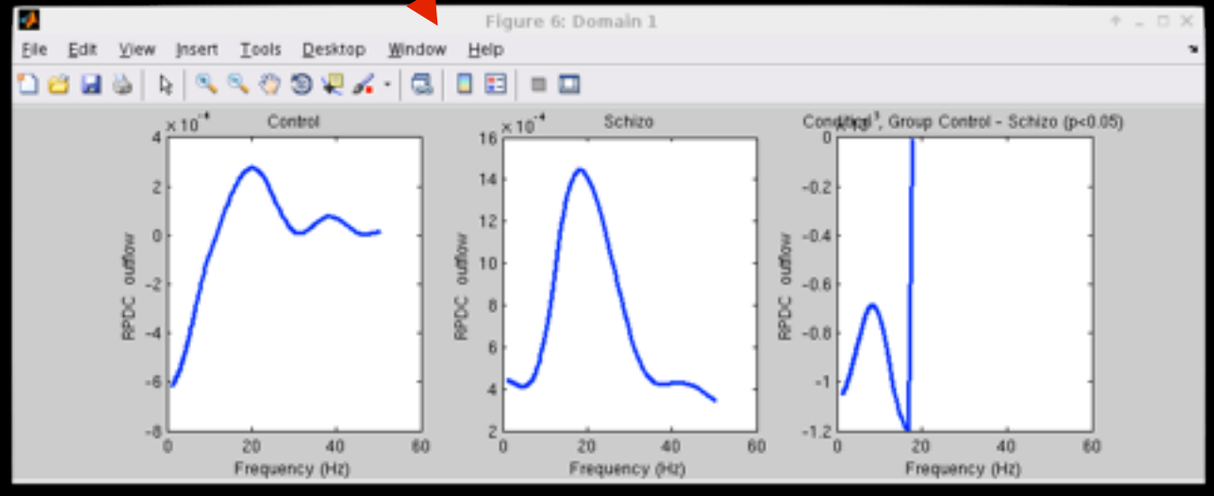
- Project
- Create Domains
- Domains ▶
- Show volume
- Show cortex
- Show colored by Significance
- Show colored by Measure
- Show colored by Domain
- Show volume as MRI
- Options
- About



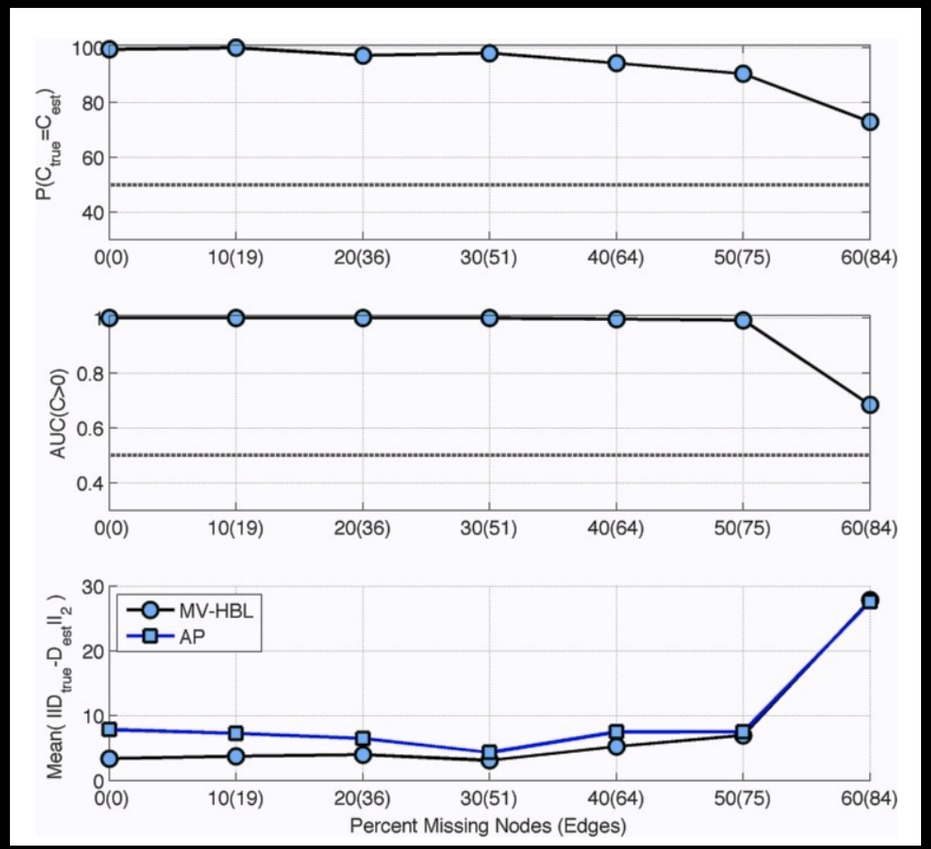


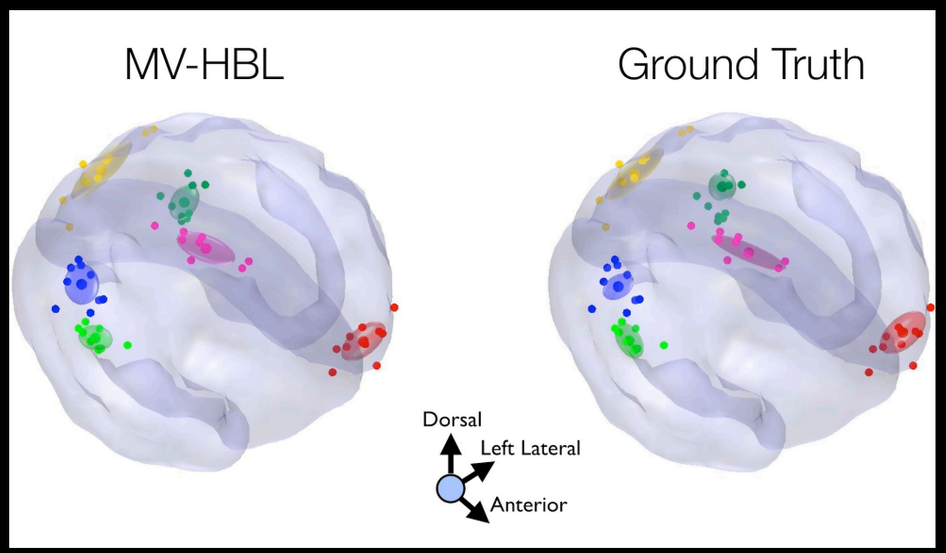


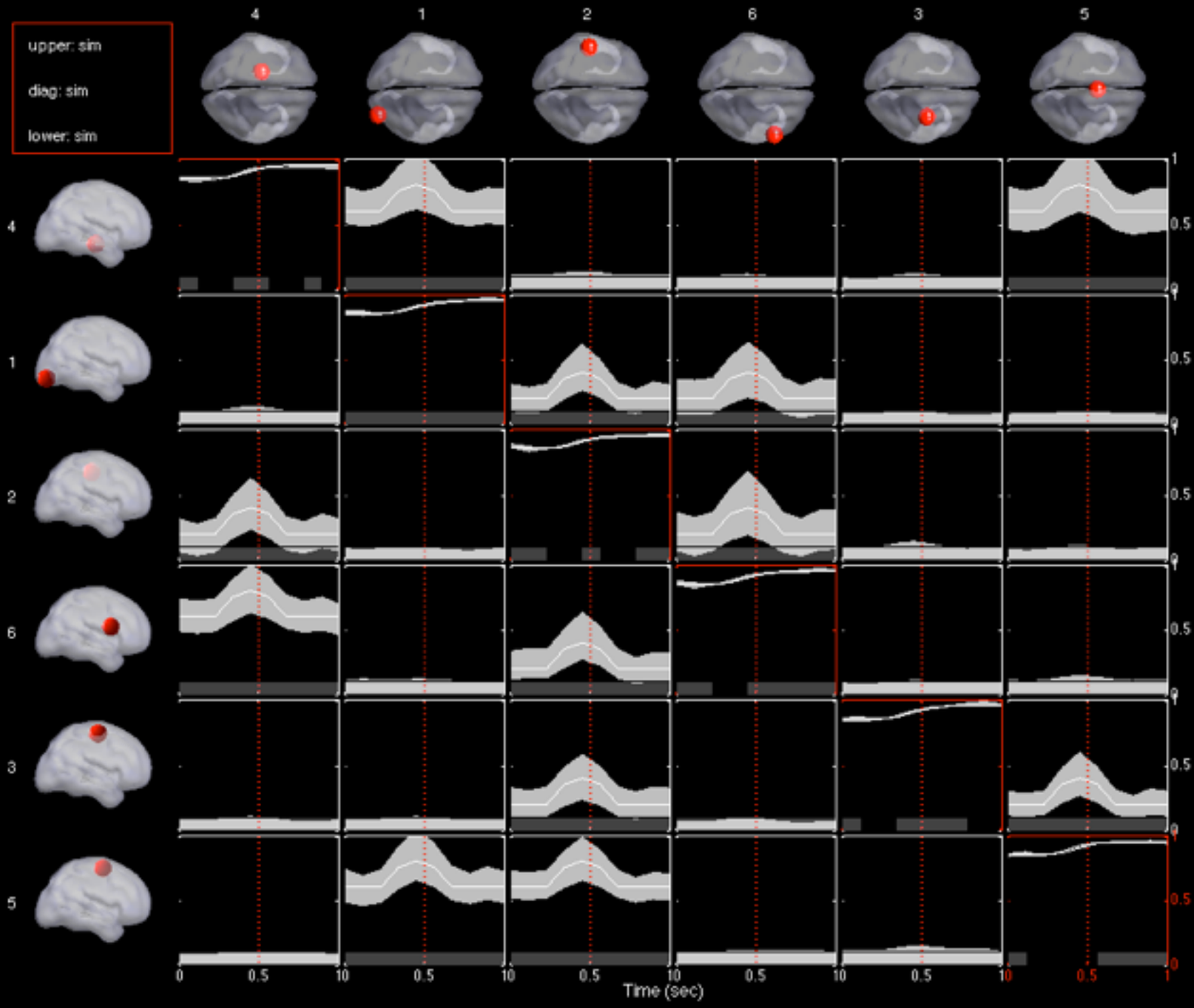
# MV-HBL

## Sim: 10 Subjects, 30% missing dipoles

### Estimated 95% CI (gray) with Ground Truth Superimposed (white)




Est = True ($p < 0.05$)

Est. 95% CI

Mullen, T., 2014 “The Dynamic Brain”; Mullen & Thompson, in prep

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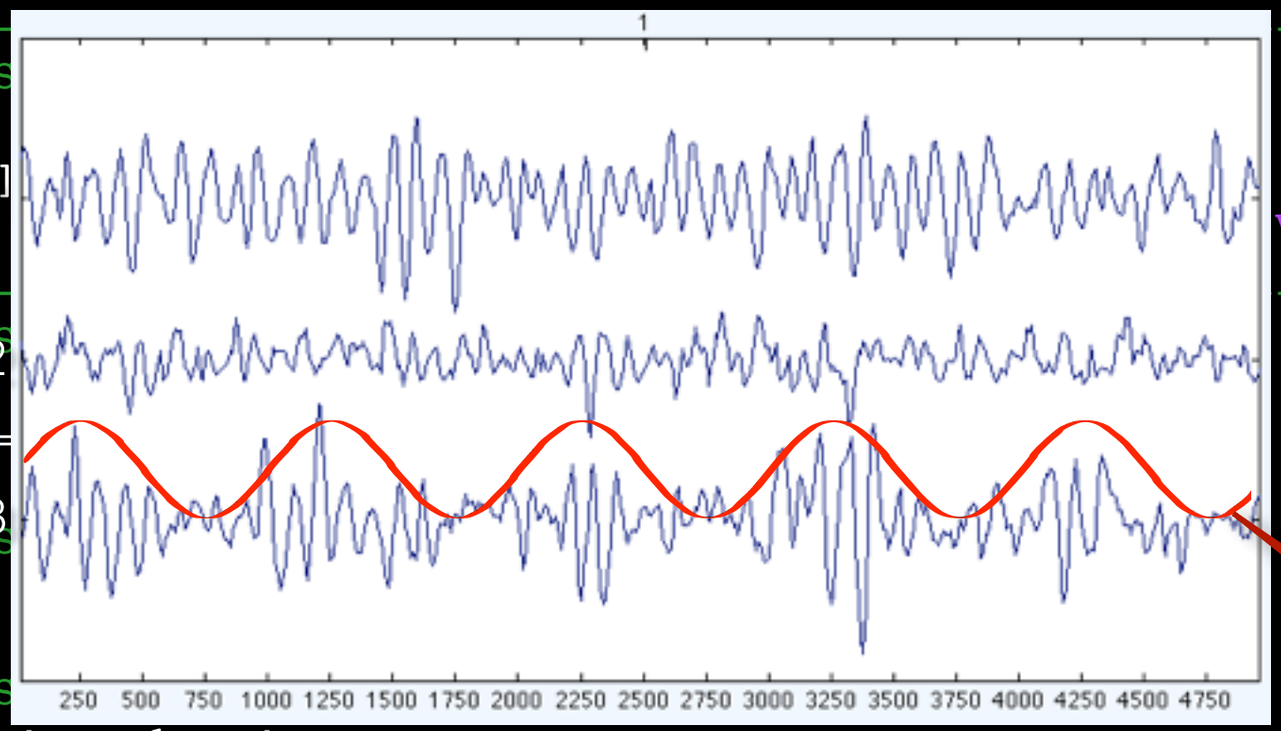
# Simulation

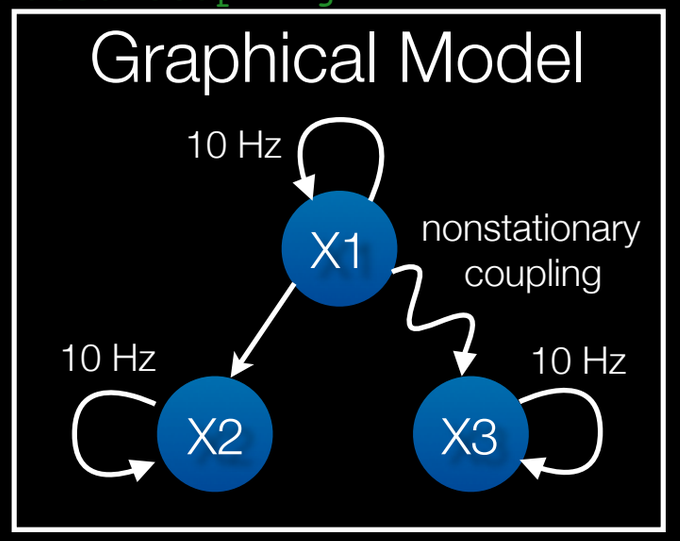
## Dynamical System Simulation Workbench

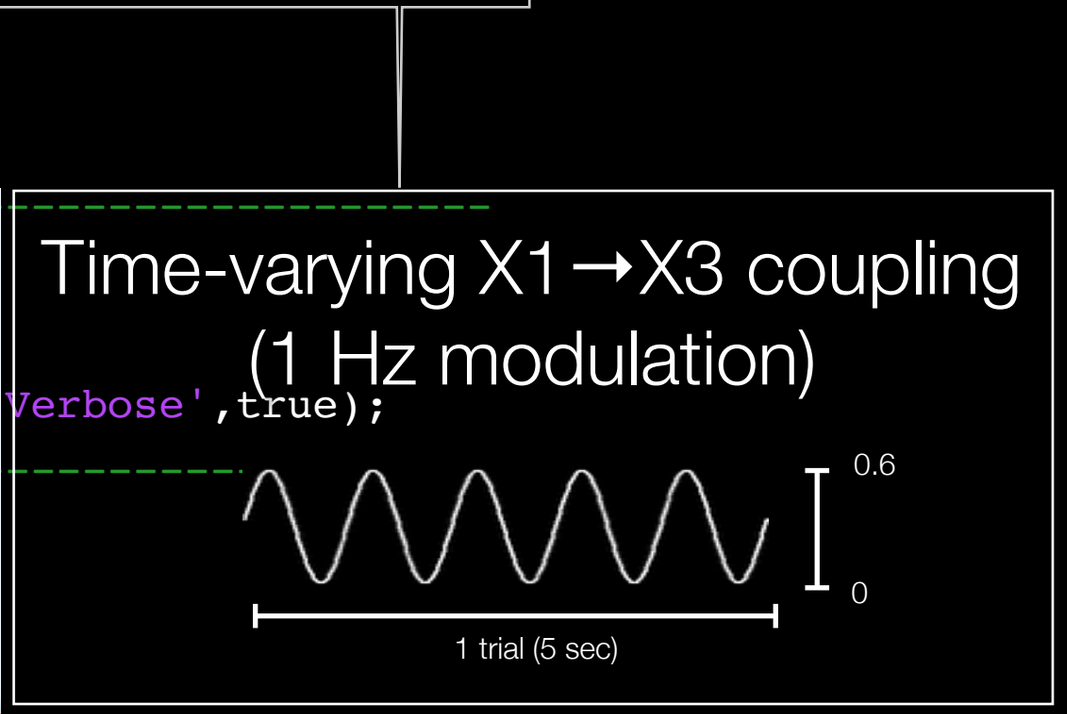
- Realistic source dynamics
  - Systems of linear stochastically-forced damped coupled oscillators
    - Support for arbitrary time-varying (non-stationary) coupling dynamics
    - Intuitive equation-based model definition
    - Support for generalized gaussian or hyperbolic secant innovations
  - Nonlinear Dynamical Systems
    - Rössler and Lorenz Systems
- Realistic scalp EEG generation through forward head model
  - Convenient source definitions via cortical atlas (Mobilab Object)

```
% Example: Trivariate damped coupled oscillators with sinusoidally-modulated coupling
% ------------------------------------------------------------------------
% STEP 1: create prototype VAR structure

Fs = 100;                   % Sampling Rate (Hz)
Nl = 500;                   % length of each epoch (samples)
Nr = 100;                   % number of trials (realizations)
ndisc = 1000;               % number of startup samples to discard
ModelOrder = 2;             % model order
f0 = 10;                    % central oscillation frequency (Hz)

expr = {...
    ['x1(t) = ' sim_dampedOscillator(f0,9,Fs,1) '                                  + e1(t)'] ...
    ['x2(t) = ' sim_dampedOscillator(f0,2,Fs,2) ' + -0.1*x1(t-2)                   + e2(t)'] ...
    ['x3(t) = ' sim_dampedOscillator(f0,2,Fs,3) ' + {0.3*sin(2*pi*t/100)+0.3}*x1(t-2) + e3(t)'] ...
};

Aproto = sim_genVARModelFromEq(expr,ModelOrder);

% ------------------------------------------------------------------------
% S
[A]
X1
% ------------------------------------------------------------------------
% S
X2
M =
X3
% S
Mu
% S
sigma = 1;
E = sigma*eye(M);

% generate simulated data with laplacian (supergaussian) innovations
data = sim_tvarsim(Mu,A,E,[Nl Nr],ndisc,1,1,'gengauss');
```

Verbose',true);




Amplitude Modulation (PAC)

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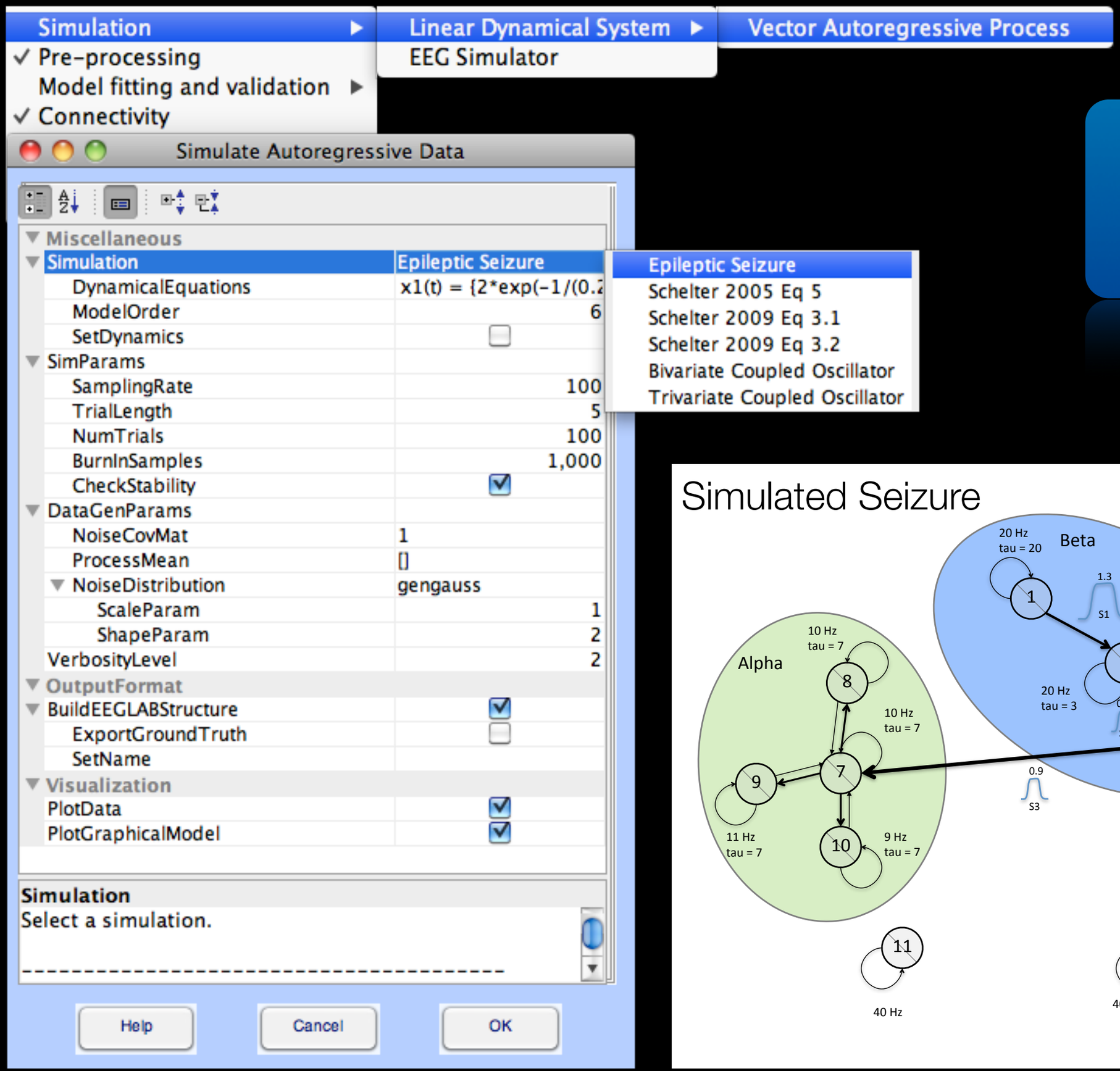


# Simulation

## Simulated Seizure

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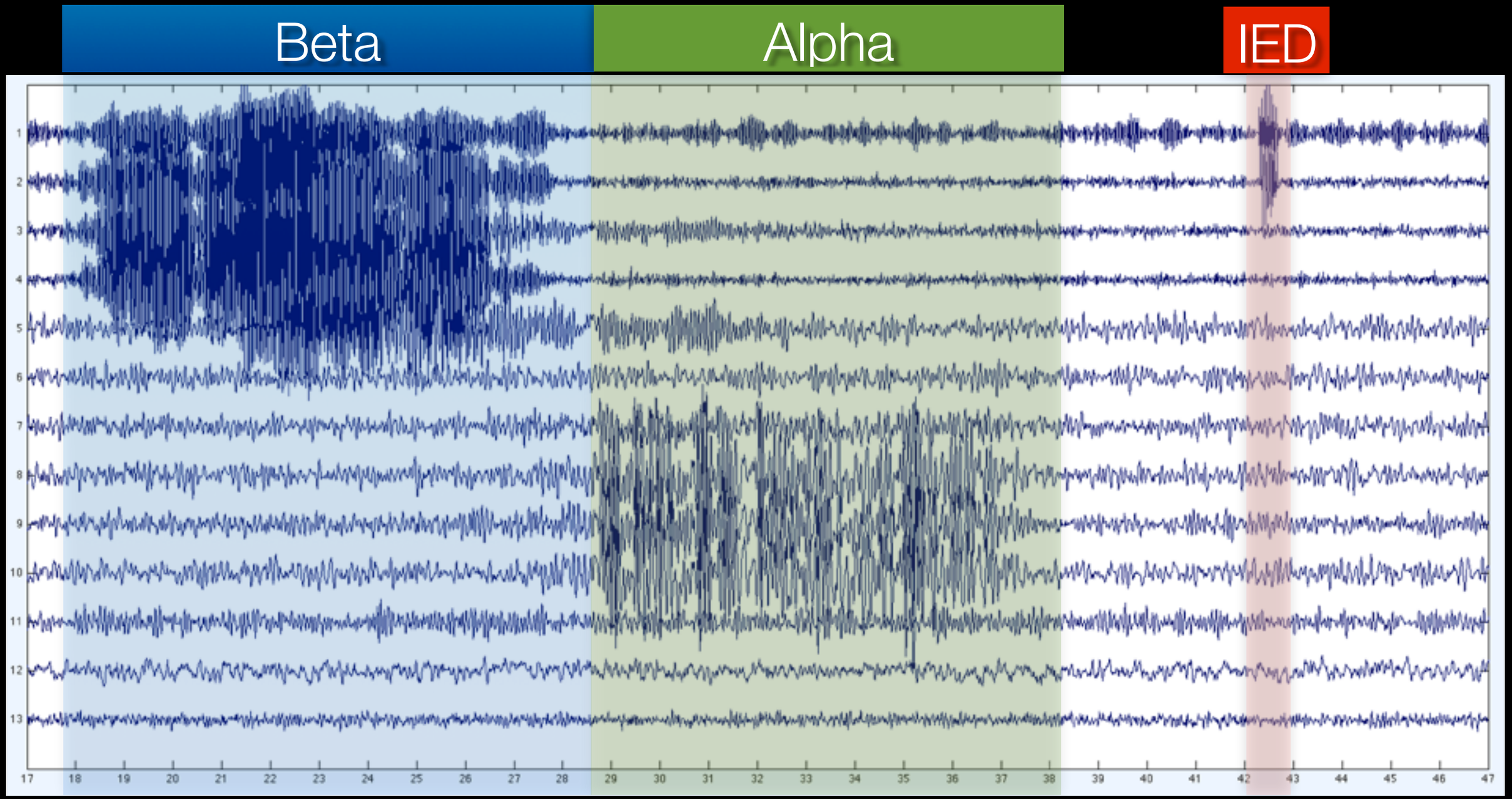
# Simulated Seizure Sources



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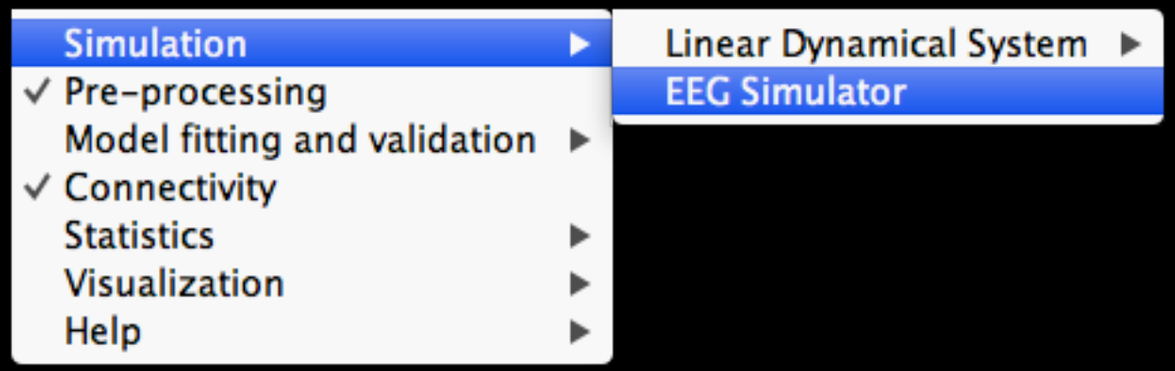
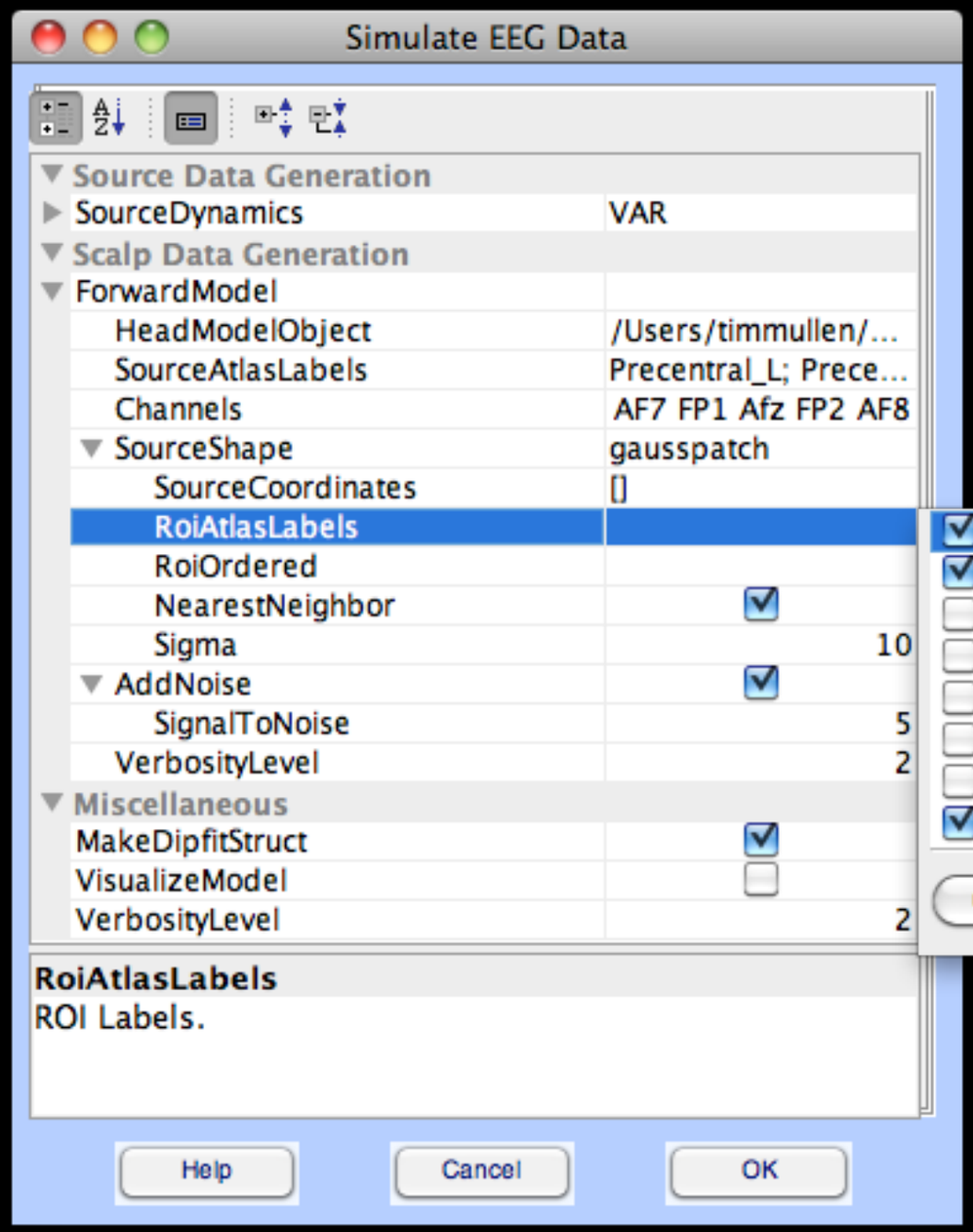
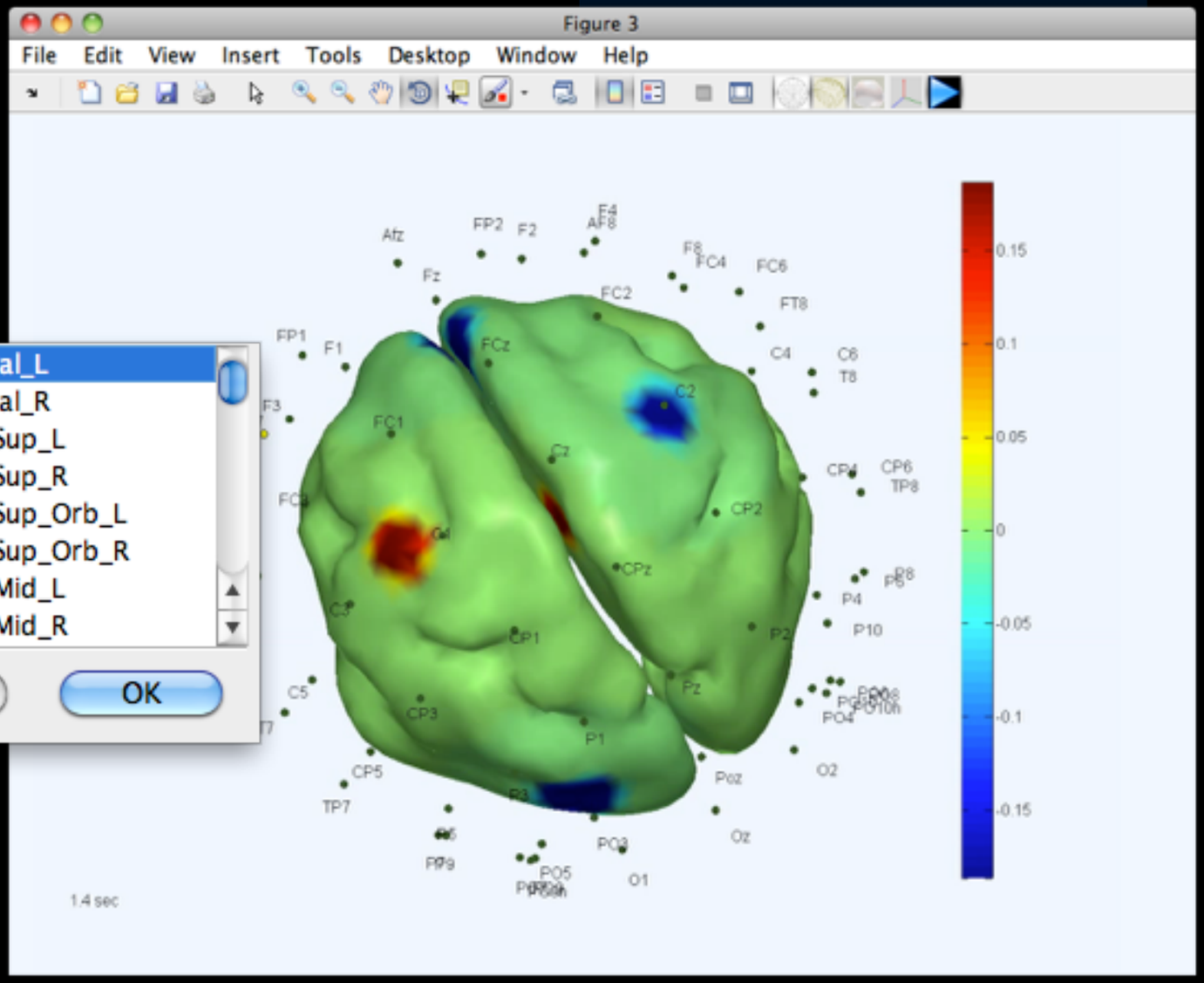
# Simulation



# Distribution and Educational Resources

Tim Mullen

**sccn.ucsd.edu/wiki/SIFT**

SIFT - SCCN

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Swartz Center for Computational Neuroscience

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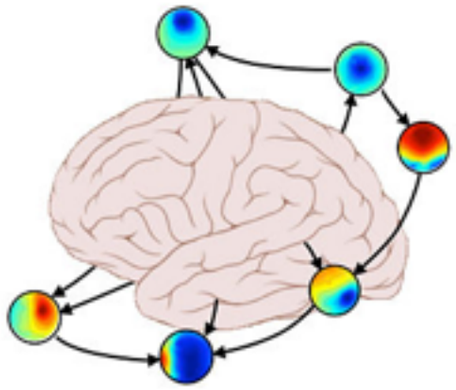
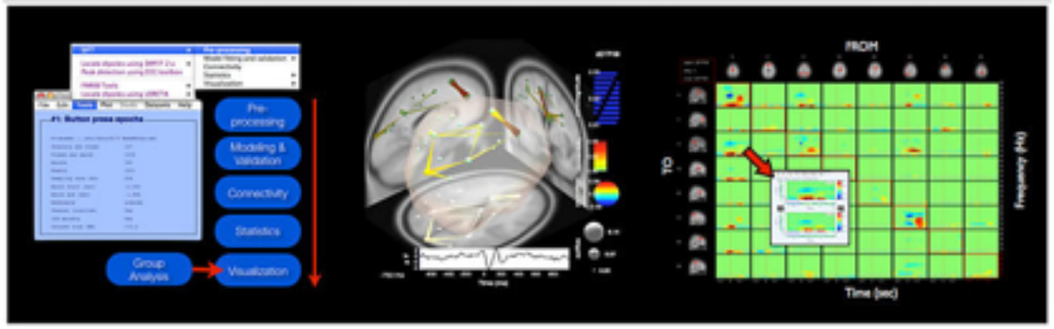


SIFT

Source Information Flow Toolbox

Version 0.1-Alpha

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Welcome to the repository for the Source Information Flow Toolbox (SIFT)

Developed and Maintained by: Tim Mullen (SCCN, INC, UCSD)
Web: http://www.antillipsi.net
Email: <Tim's first name> (at) sccn (dot) ucsd (dot) edu

SIFT is an EEGLAB-compatible toolbox for analysis and visualization of multivariate causality and information flow between sources of electrophysiological (EEG/ECoG/MEG) activity. It consists of a suite of command-line functions with an integrated Graphical User Interface for easy access to multiple features. There are currently four modules: data preprocessing, model fitting and connectivity estimation, statistical analysis, and visualization

SIFT Online Handbook and User Manual

A video-lecture on the (very) basic theory of application of SIFT to modeling distributed brain dynamics in EEG is available he

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Can also get from EEGLAB Plugin Manager or NITRC.org