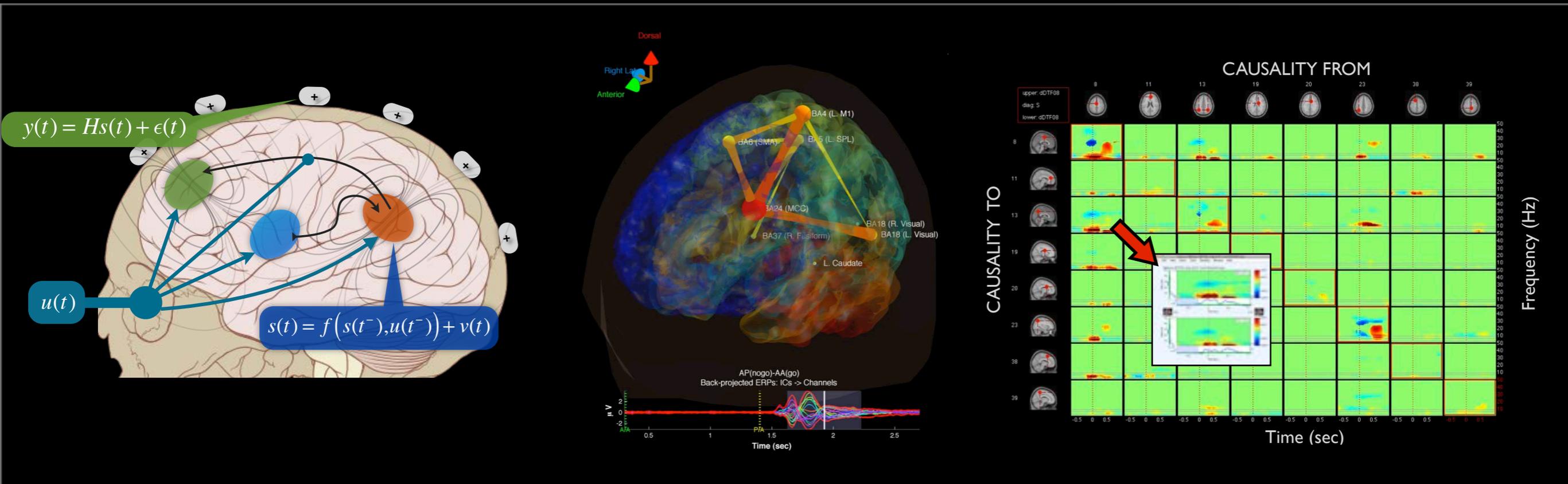
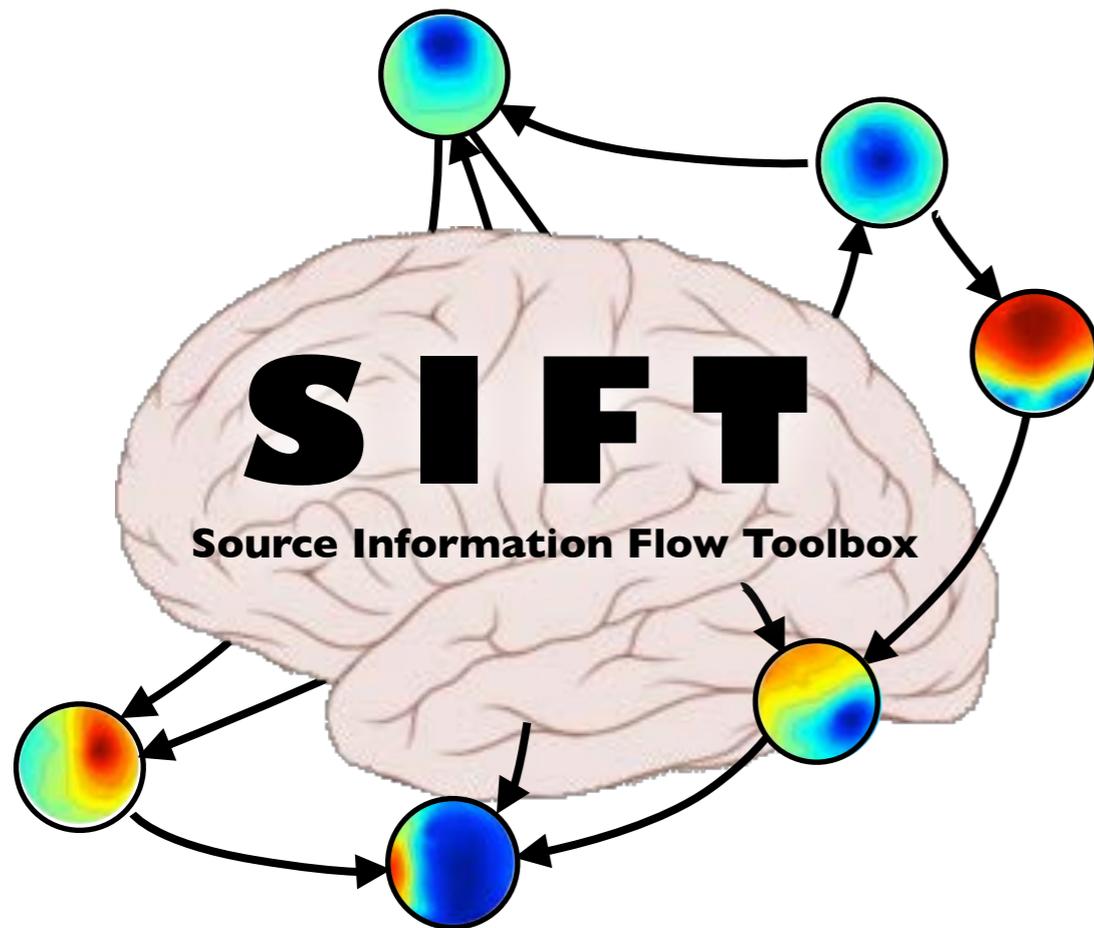


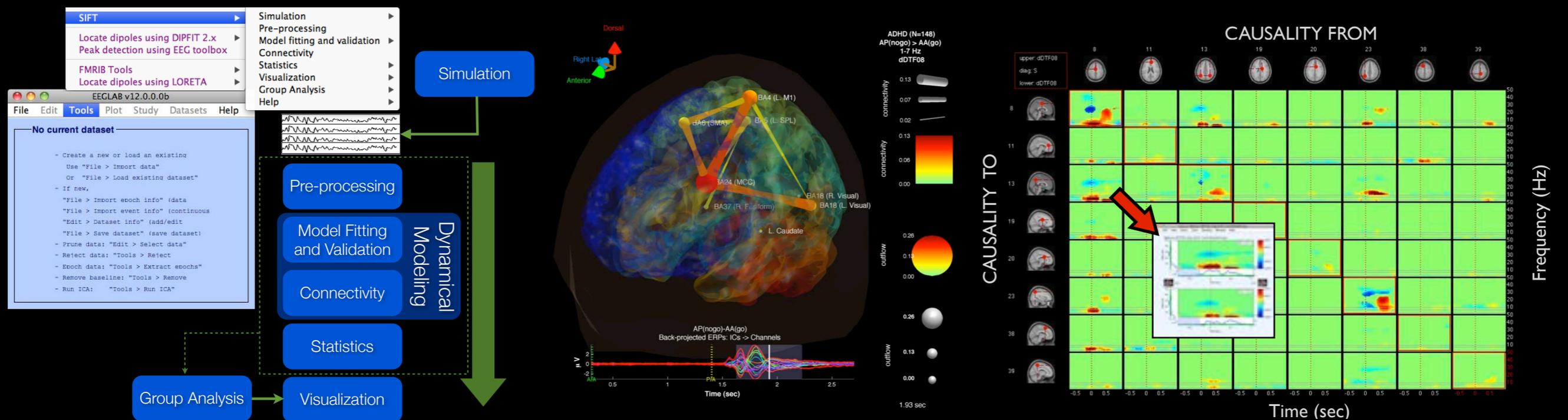
# The Source Information Flow Toolbox



Tim Mullen, PhD



- 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

Saturday, Nov 10th  
2:30-5:30pm  
Track C  
(INC Open Space)

## Theoretical Foundations II

Model Validation

Multivariate vs. Bivariate

Imposing Constraints

Single-trial Estimation and State-Space Models

Statistical Testing

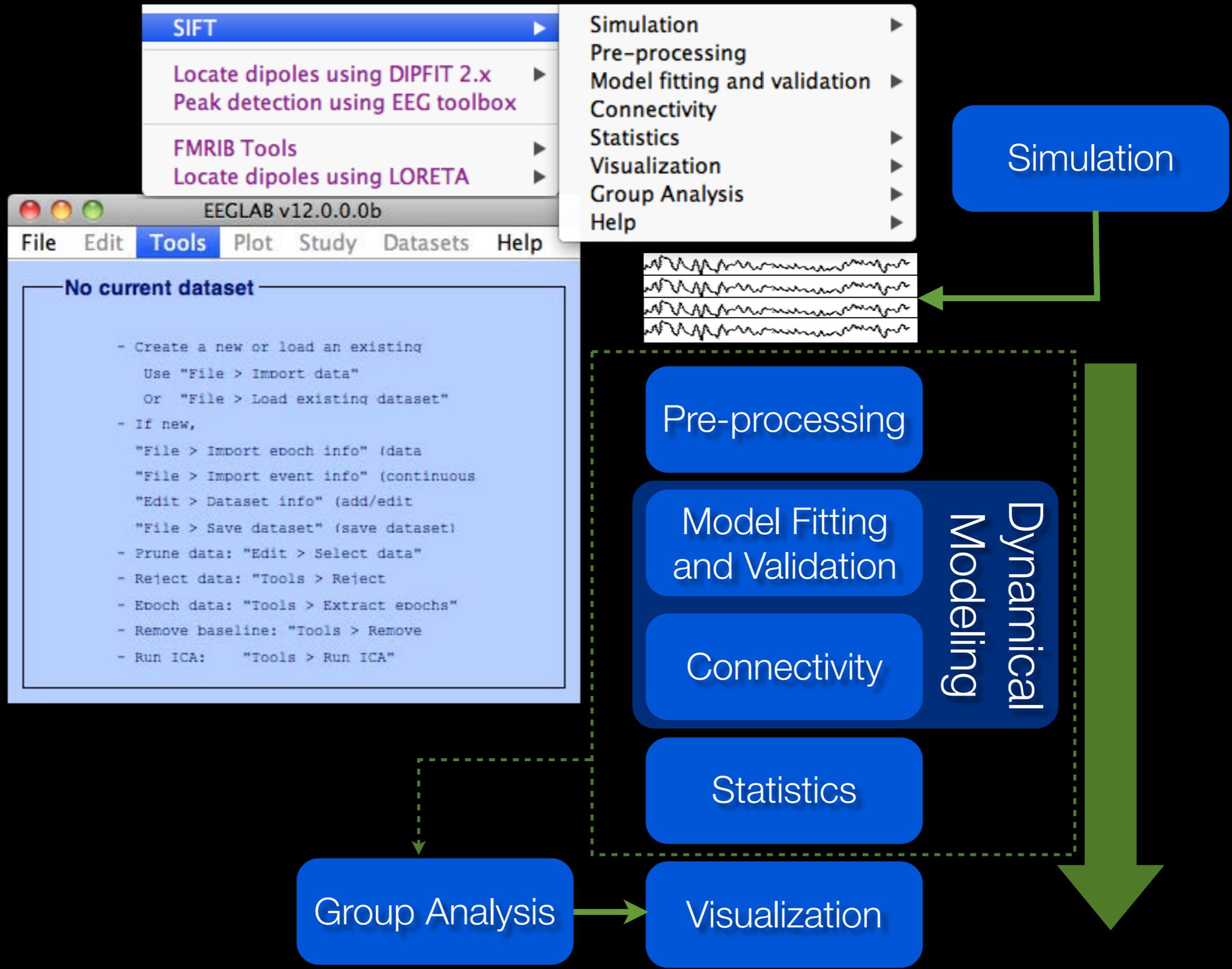
Practicum: Hands-On Simulation-based training

Sunday, Nov 11th  
2:30-5:30pm  
Track C  
(INC Open Space)

# Source Information Flow Toolbox (SIFT)

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

DOWNLOAD SIFT FROM THE EEGLAB EXTENSION MANAGER (File → Manage EEGLAB Extensions → Data Processing Extensions)



Preprocessing

Modeling

Statistics

Visualization

Pre-processing

- Model fitting and validation ▶
- Connectivity
- Statistics ▶
- Visualization ▶

**Preprocessing Options**

Miscellaneous	
VerbosityLevel	2
<b>SignalType</b>	<b>Components</b>
VariableNames	
ResetConfigs	<input checked="" type="checkbox"/>
Filtering	
DifferenceData	<input type="checkbox"/>
Detrend	
DetrendingMethod	linear
Piecewise	
SegmentLength	0.33
StepSize	0.082
Plot	<input type="checkbox"/>
AmplitudeEnvelope	<input type="checkbox"/>
Normalization	
NormalizeData	<input checked="" type="checkbox"/>
Method	time; ensemble

**SignalType**  
Type of signal to analyze. If 'Components', data in EEG.icaact will be processed. If 'Channels' EEG.data will be processed. If 'Sources' EEG.srcpot will be processed.

Buttons: Help, Cancel, OK

## Source reconstruction

(performed externally using EEGLAB or other toolboxes)

Local Detrending or Filtering

Downsampling (EEGLAB)

Differencing

Normalization (temporal or ensemble)

Preprocessing

Modeling

Statistics

Visualization

Model Fitting

Validation

Connectivity

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	✓	



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

Preprocessing

Modeling

Statistics

Visualization

Model Fitting

Validation

Connectivity

- Pre-processing
- Model fitting and validation
  - Model Order Selection
  - Fit AMVAR Model
  - Validate model
- Connectivity
- Statistics
- Visualization

**Model Order Selection Assistant**

Modeling Parameters

- ModelingApproach: Segmentation VAR
- Algorithm: Vieira-Morf
  - Vieira-Morf
  - ARfit
  - Group Lasso DAL/SCSA
  - Group Lasso ADMM
  - Ridge Regression
- WindowLength: [ ]
- WindowStepSize: [ ]
- NormalizeData: [ ]
- Detrend: [ ]
  - DetrendingMethod: [ ]
- ModelOrderRange: [1 30]
- Downdate: [ ]
- InformationCriteria: sbc; aic; fpe; hq; ris
- Data Selection: [ ]
- WindowSamplePercent: 100
- Miscellaneous: [ ]
- PlotResults: [ ]
  - OptimalModelSelectionMethod: min
  - PercentileLimits: 90
  - VerbosityLevel: 2

Algorithm

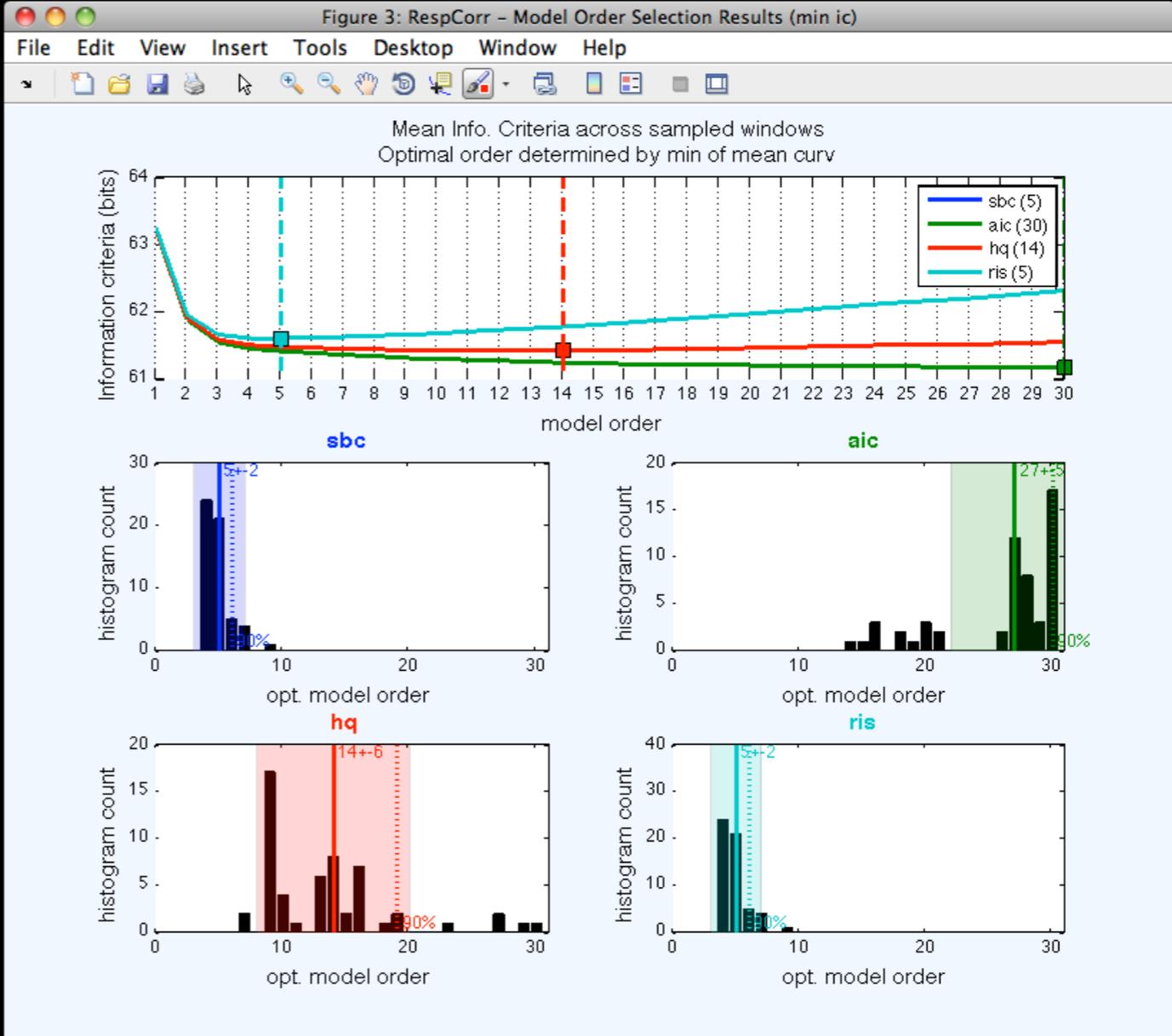
Vieira-Morf:

Unconstrained VAR modeling via Vieira-Morf Maximum Entropy algorithm.

References and code:

[1] A. Schlogl, Comparison of Multivariate

Buttons: Help, Cancel, OK



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

Preprocessing

Modeling

Statistics

Visualization

Model Fitting

Validation

Connectivity

Validated Fitted VAR Model

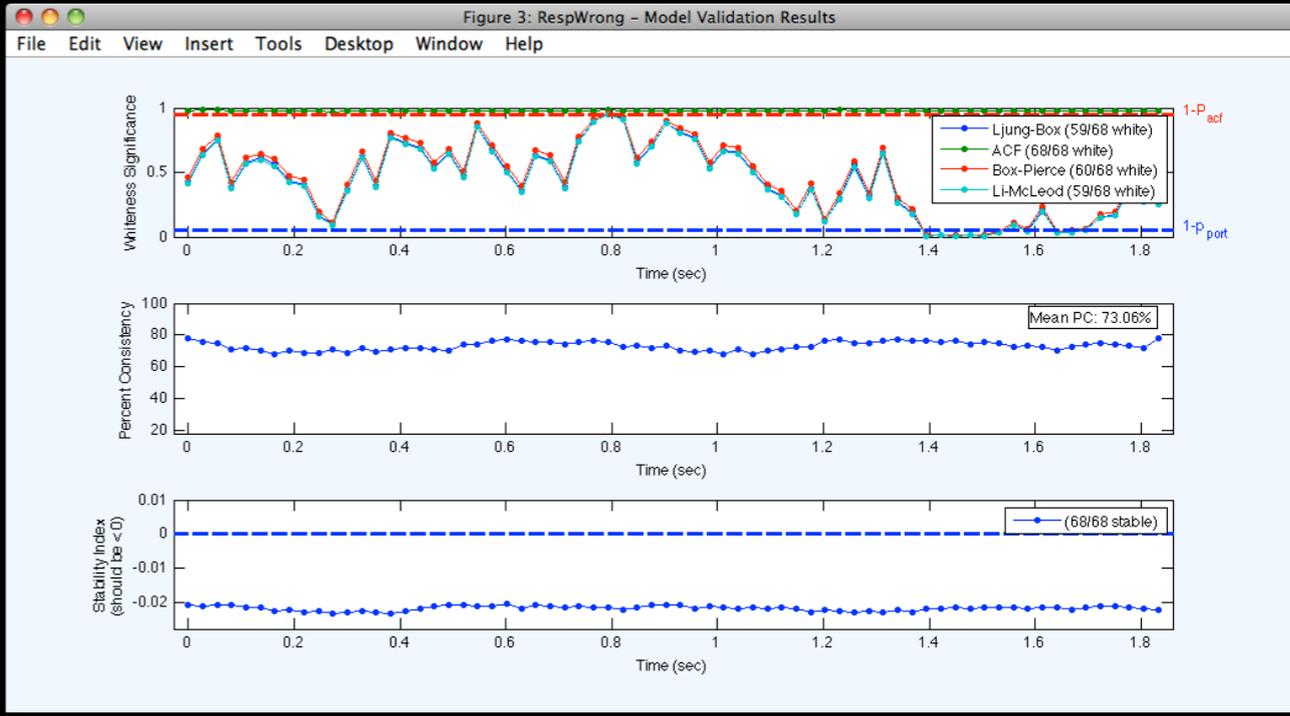
Validation Methods

- CheckResidualWhiteness 
  - SignificanceLevel: 0.05
  - MultipleComparisonsCorrection: none
  - NumberOfAutocorrelationLags: 50
  - WhitenessCriteria: Ljung-Box; Li-McLeod
- CheckConsistency  Ljung-Box
- CheckStability  ACF
- Data Reduction  Box-Pierce
- Miscellaneous  Li-McLeod

WhitenessCriteria  
Whiteness criteria. These are the statistical tests used to test for uncorrelated residuals

Buttons: Help, Cancel, OK

- Pre-processing
- Model fitting and validation
  - Model Order Selection
  - Fit AMVAR Model
  - Validate model
- Connectivity
- Statistics
- Visualization



Preprocessing

Modeling

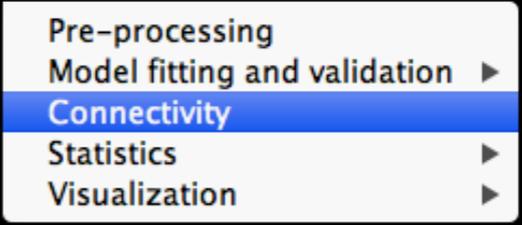
Statistics

Visualization

Model Fitting

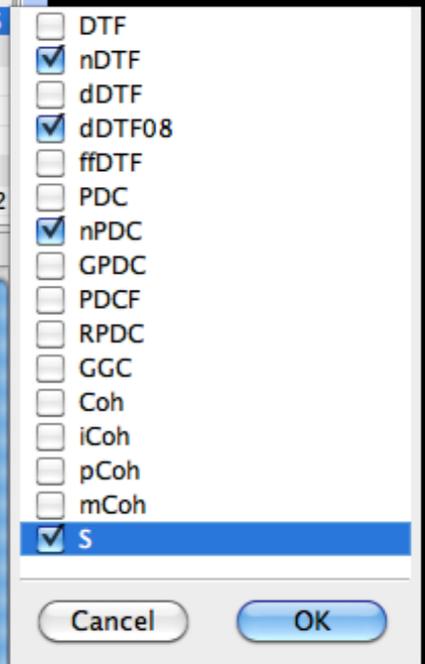
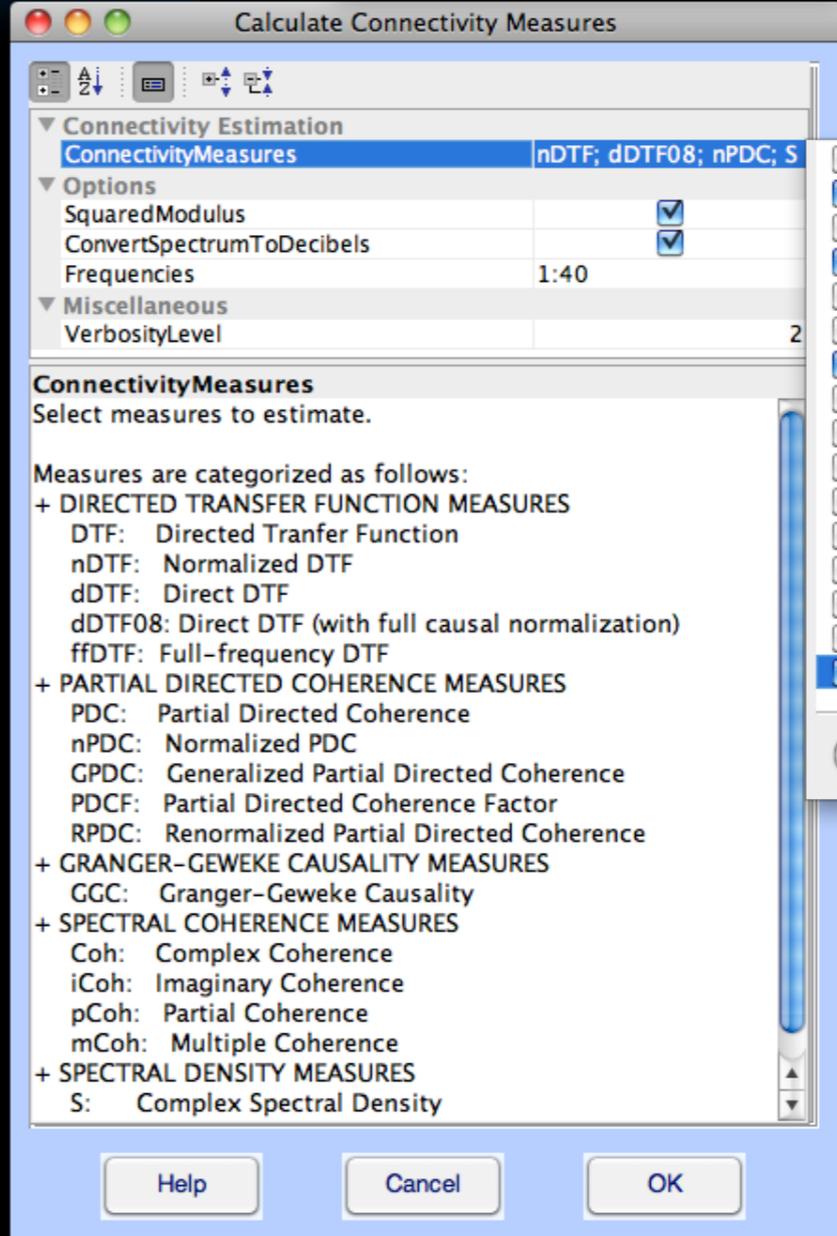
Validation

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)



Preprocessing

Modeling

Statistics

Visualization

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

$$H_{\text{null}} : \mathbf{C}_{ij} = 0$$

$$H_{\text{base}} : \mathbf{C}_{ij} = \mathbf{C}_{\text{baseline}}$$

$$H_{\text{AB}} : \mathbf{C}^{\text{A}}_{ij} = \mathbf{C}^{\text{B}}_{ij}$$

Preprocessing

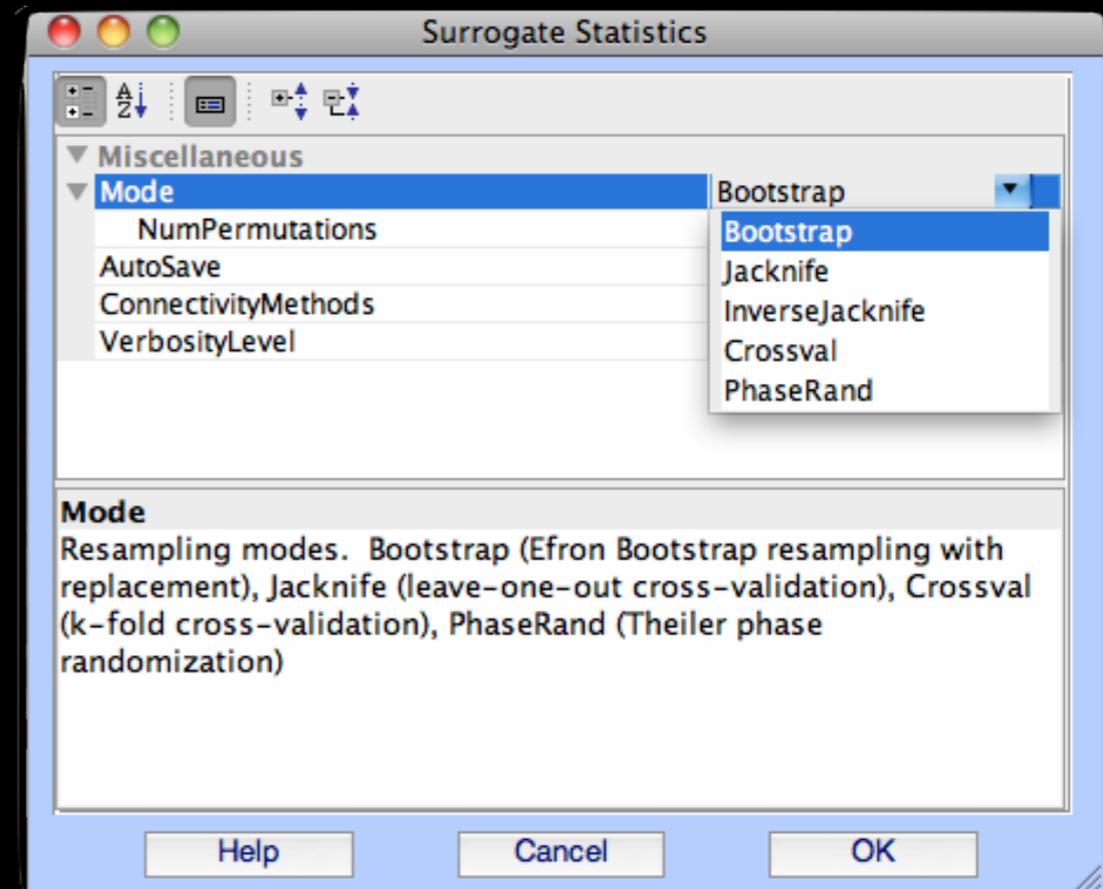
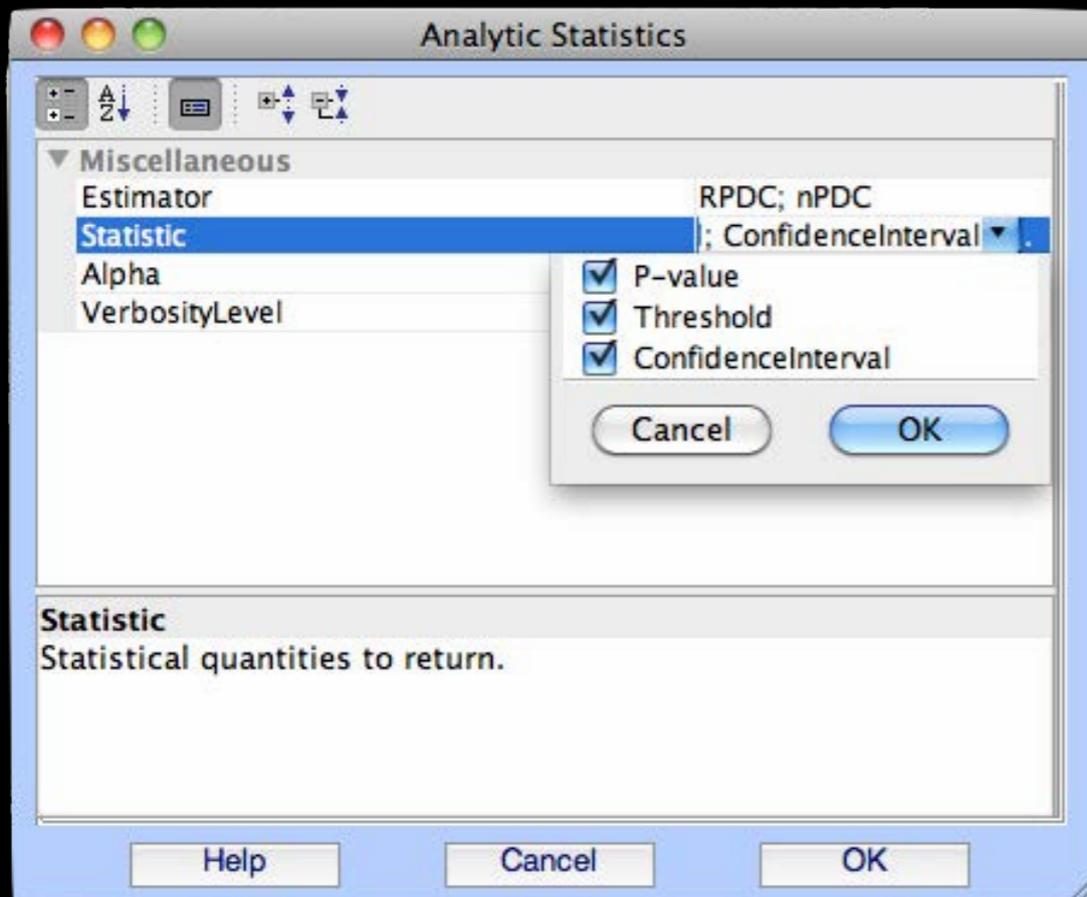
Modeling

Statistics

Visualization

Parametric

Non-parametric



Preprocessing

Modeling

Statistics

Visualization

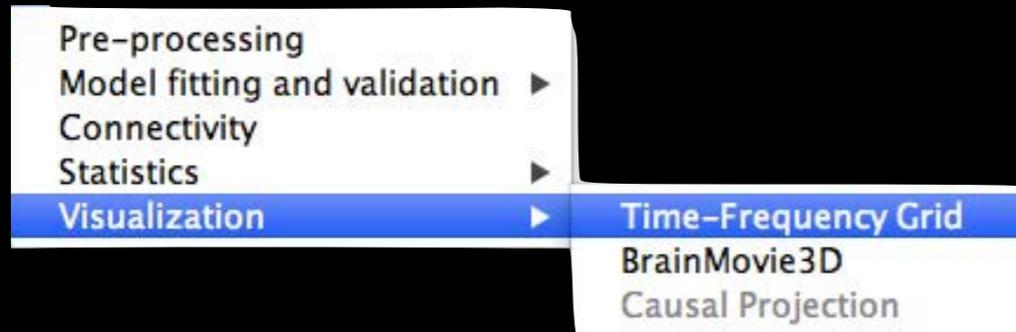
## Interactive Visualizers

Interactive Time-Frequency Grid

Interactive 3D Causal Brainmovie

and others ...

# Interactive Time-Frequency Grid



Time Frequency Grid Options

▼ DisplayProperties	
▼ MatrixLayout	Partial
UpperTriangle	dDTF08
LowerTriangle	dDTF08
Diagonal	S
ColorLimits	99.9
TimesToPlot	[-0.75 1]
FrequenciesToPlot	[1:50]
PlotContour	<input type="checkbox"/>
PlottingOrder	[]
SourceMarginPlot	dipole
NodeLabels	{'8', '11', '12', '13', '1...
EventMarkers	{{0, 'r', ':', 2}}
FrequencyScale	linear
Colormap	jet(300)
▼ Thresholding	
▼ Thresholding	Simple
PercentileThreshold	[95 3]
AbsoluteThreshold	[]
▼ DataProcessing	
Baseline	[-0.75 -0.25]
Smooth2D	<input type="checkbox"/>
▶ Miscellaneous	
▼ FrequencyMarkers	
FrequencyMarkers	[3 7]
FrequencyMarkerColor	[0.7 0.7 0.7]
▼ TextAndFont	
TitleString	
TitleFontSize	12

**PercentileThreshold**  
 Percentile threshold. If of form [percentile, dimension], percentile is applied elementwise across the specified dimension.

Help    Cancel    OK



# Interactive Causal BrainMovie3D

BrainMovie3D Control Panel

▼ DataProcessing	
ConnectivityMethod	nDTF
MovieTimeRange	[-0.75 0.98828125]
FrequenciesToCollapse	[3:7]
FreqCollapseMethod	mean
TimeResamplingFactor	0
SubtractConditions	<input type="checkbox"/>
Baseline	[]
▼ DisplayProperties	
NodeLabels	('8', '11', '13', '19', '20', '2...
NodesToExclude	
EdgeColorMapping	Connectivity
EdgeSizeMapping	ConnMagnitude
NodeColorMapping	AsymmetryRatio
NodeSizeMapping	None
▼ FooterPanelDisplaySpec	
icaenvelopevars	
backprojectedchans	
▼ BrainMovieOptions	
Visibility	
RotationPath3D	
InitialView	
ProjectGraphOnMRI	
▼ RenderCorticalSurface	<input checked="" type="checkbox"/>
Transparency	0.7
UseOpenGL	on
EventFlashTimes	[]
DisplayLegendPanel	on
ShowLatency	<input checked="" type="checkbox"/>
DisplayRTPProbability	<input type="checkbox"/>
BackgroundColor	[0 0 0]

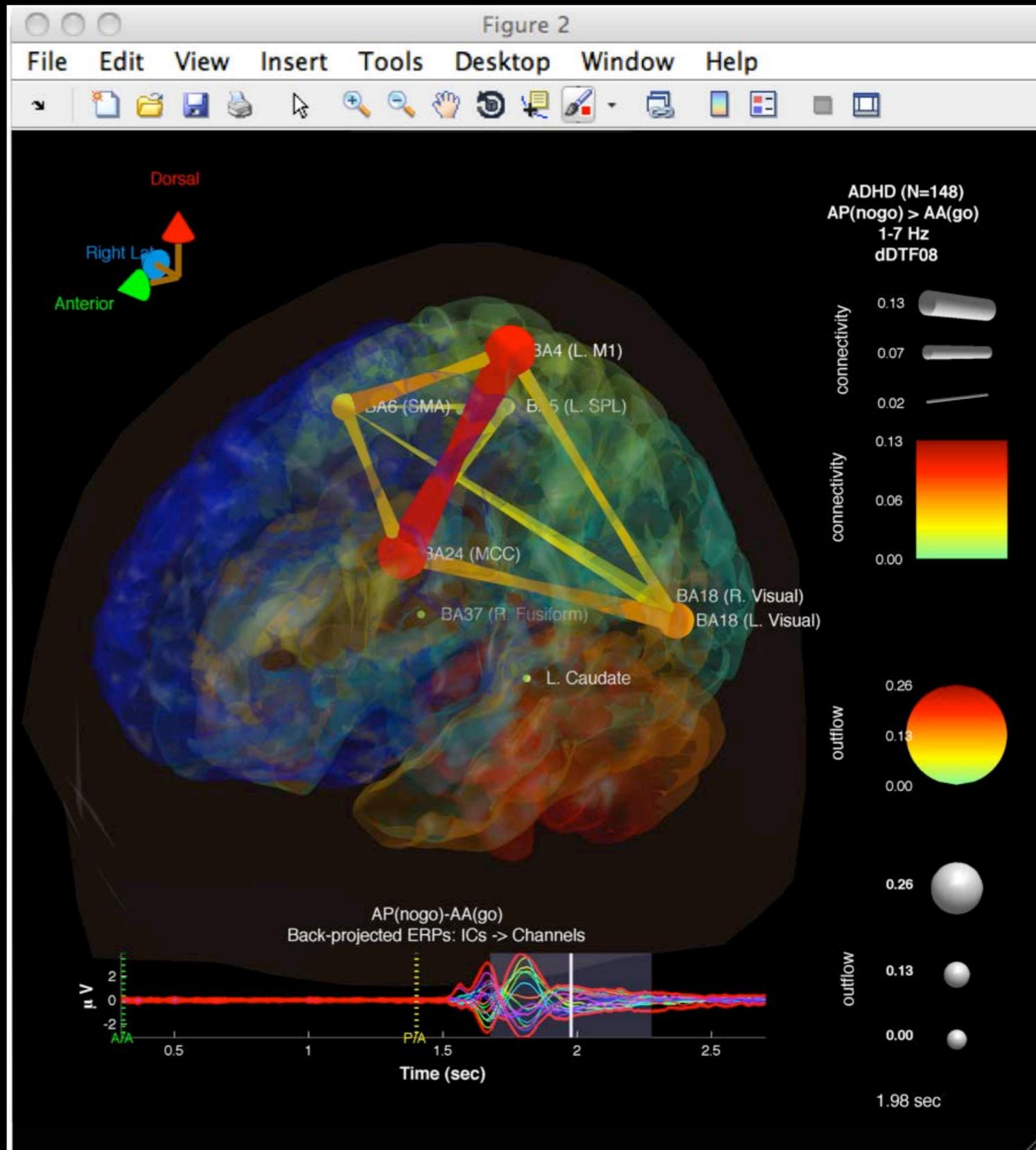
**NodeColorMapping**  
Specify mapping for node color. This determines how we index into the colormap. Options are as follows. None: node color is not modulated. Outflow: sum connectivity strengths over outgoing edges. Inflow: sum connectivity strengths over incoming edges. CausalFlow: Outflow-Inflow. Asymmetry Ratio: node colors are defined by the equation  $C = 0.5 * (1 + \text{outflow} - \text{inflow} / (\text{outflow} + \text{inflow}))$ . This is 0 for exclusive inflow, 1 for exclusive outflow, and 0.5 for balanced inflow/outflow

Preview BrainMovie

Select a time point to image (click to refresh)

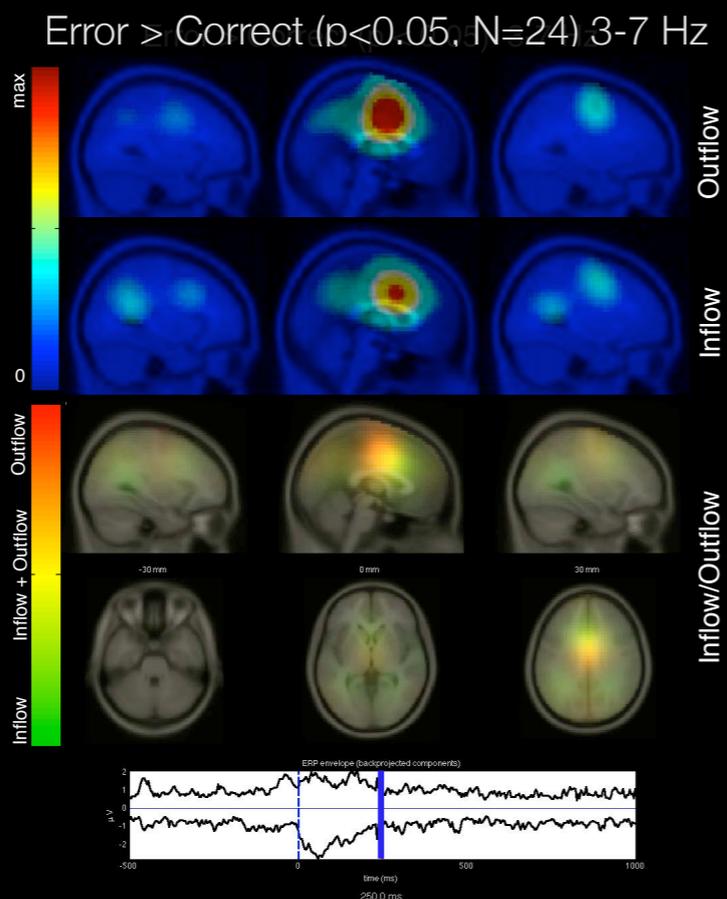
-0.75      0.0898438      0.988281

Help      Cancel      Make Movie!



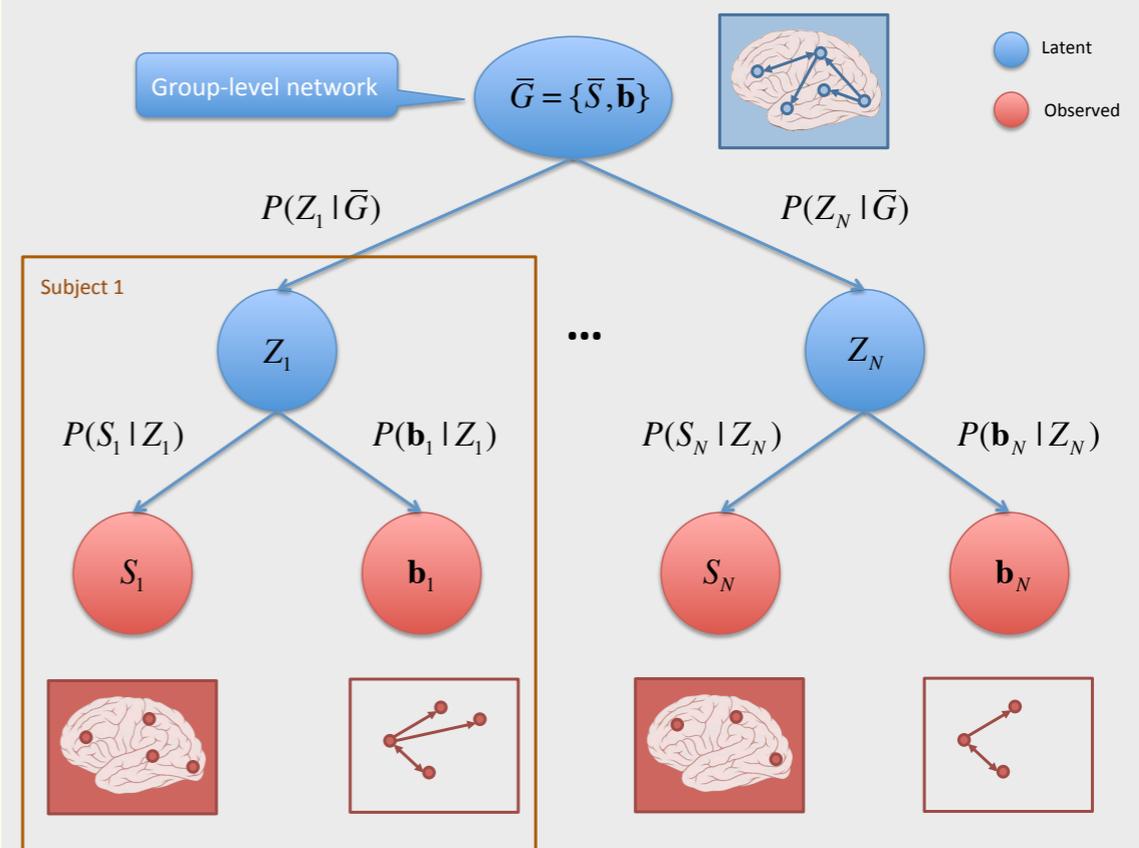
# Group Analysis (beta)

## Causal/Measure Projection



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

## Bayesian Hierarchical Model

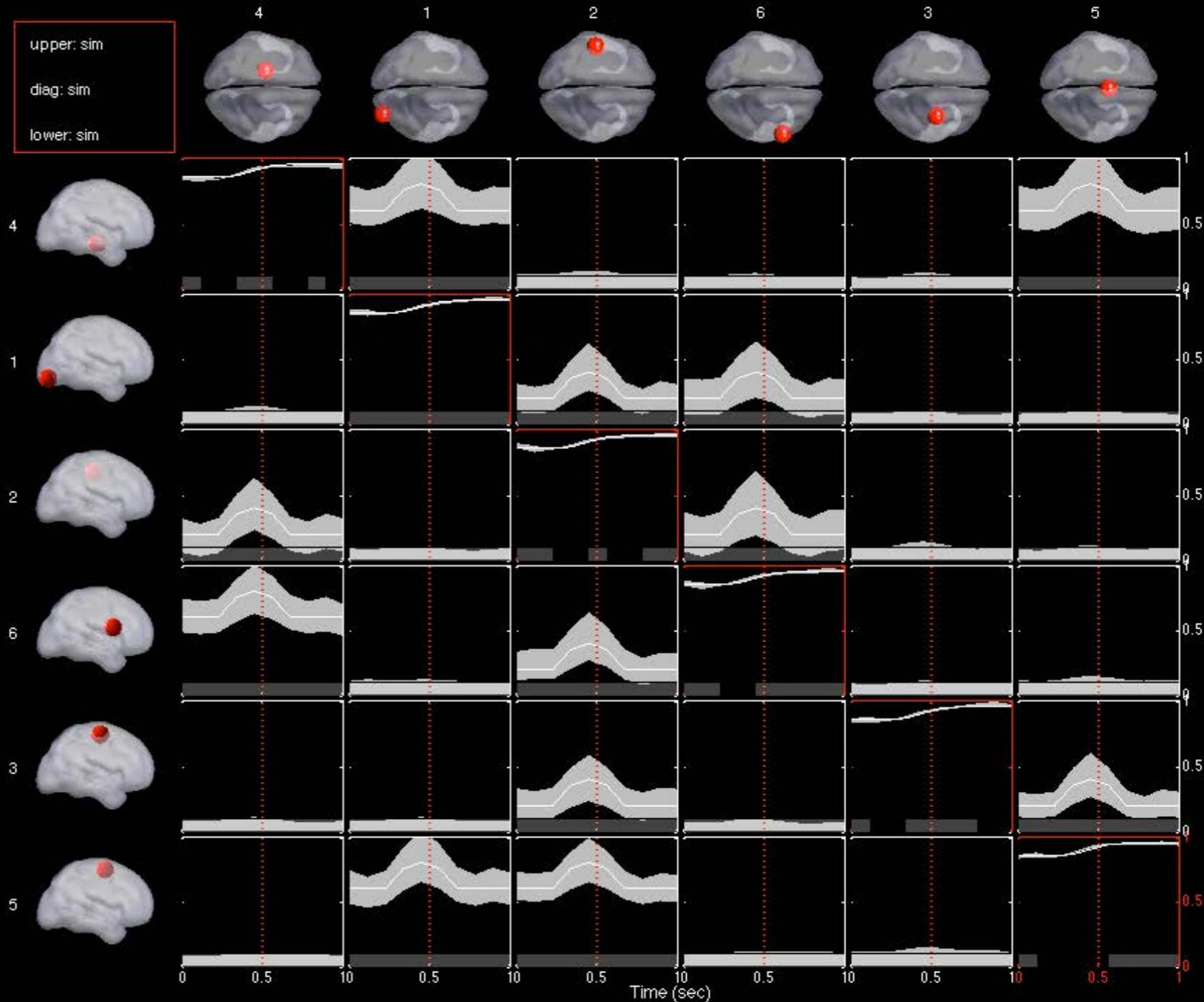
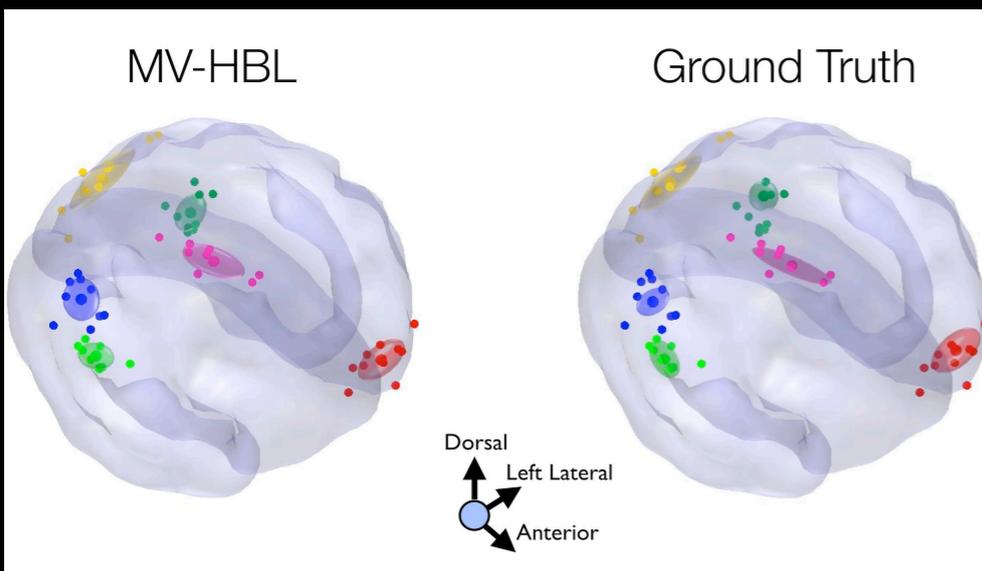
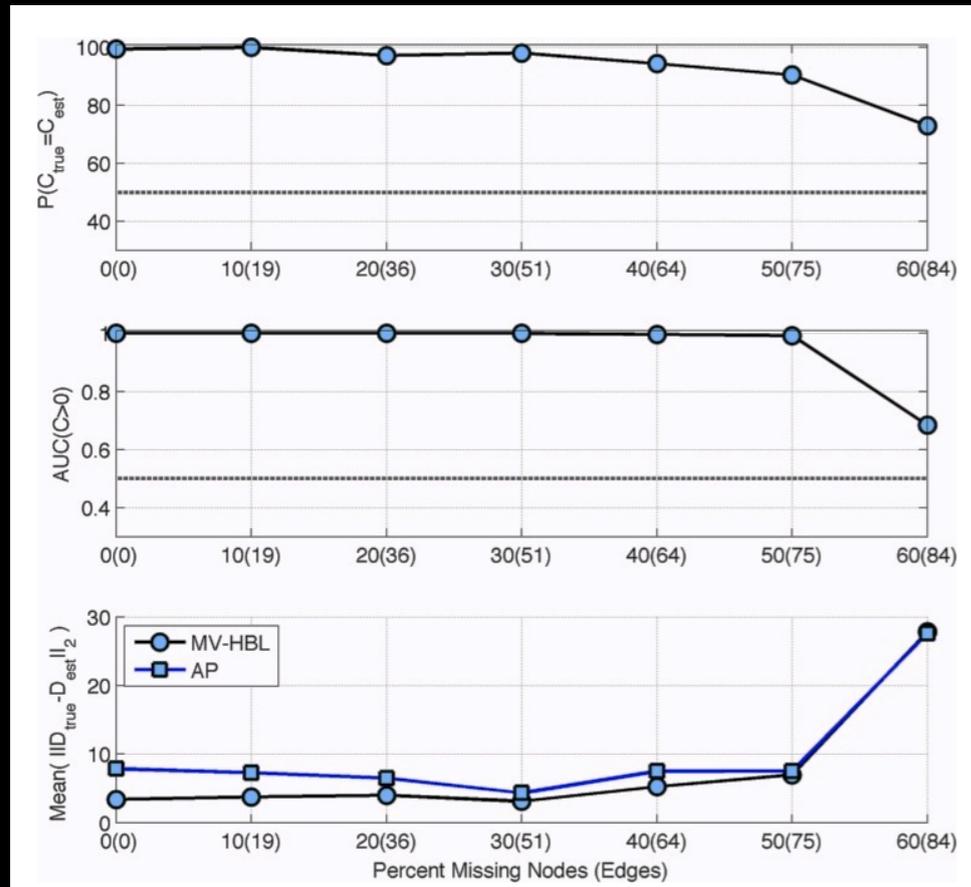


Thompson, Mullen, Makeig, 2011, ICONXI  
Thompson, Mullen, Makeig, *in prep*

# 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

# 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

### Realistic scalp EEG generation through forward head model

Convenient source definitions via cortical atlas (Mobilab Object)

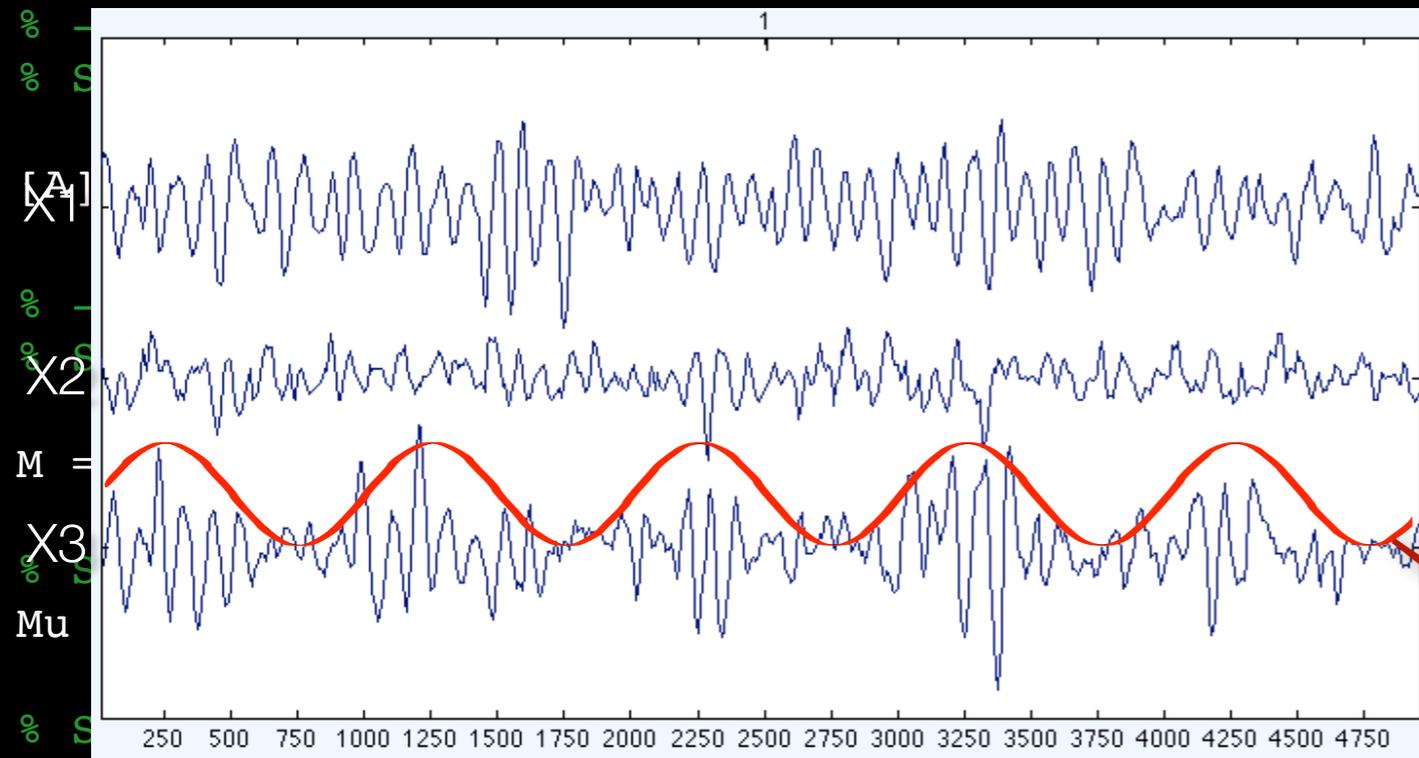
```
% Example: Trivariate damped coupled oscillators with sinusoidally-modulated coupling
```

```
% -----  
% 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)
```

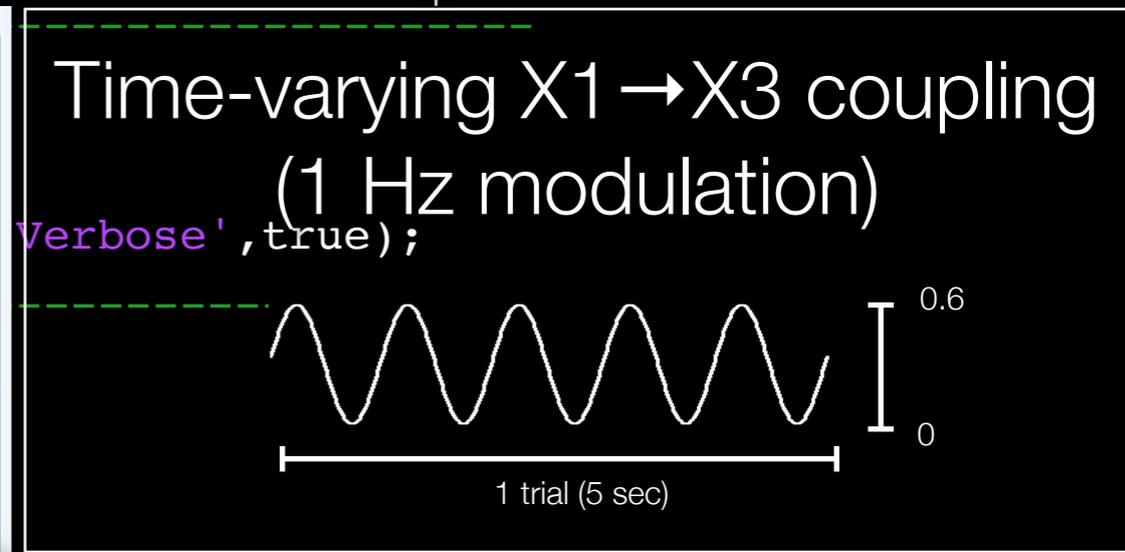
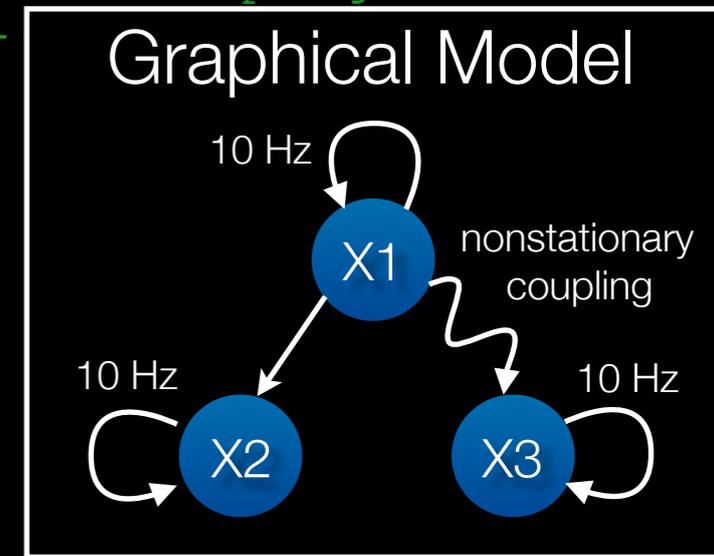
```
expr = { ...  
    ['x1(t) = ' sim_dampedOscillator(f0,9,Fs,1) ' + e1(t)'] ...  
    ['x2(t) = ' sim_dampedOscillator(f0,2,Fs,2) ' + -0.1*x1(t-2) + e2(t)'] ...  
    ['x3(t) = ' sim_dampedOscillator(f0,2,Fs,3) ' + {0.3*sin(2*pi*t/100)+0.3}*x1(t-2) + e3(t)'] ...  
};
```

```
Aproto = sim_genVARModelFromEq(expr,ModelOrder);
```



```
sigma = 1; % 1 sec  
E = sigma*eye(M);
```

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



Amplitude Modulation (PAC)

- Simulation ▶
- Linear Dynamical System ▶
- Vector Autoregressive Process
- EEG Simulator
- Pre-processing
- Model fitting and validation ▶
- Connectivity

Simulate Autoregressive Data

Miscellaneous	
Simulation	
DynamicalEquations	Epileptic Seizure
ModelOrder	$x1(t) = \{2 * \exp(-1/(0.2$
SetDynamics	6
SimParams	
SamplingRate	100
TrialLength	5
NumTrials	100
BurnInSamples	1,000
CheckStability	<input checked="" type="checkbox"/>
DataGenParams	
NoiseCovMat	1
ProcessMean	[]
NoiseDistribution	
ScaleParam	gengauss
ShapeParam	1
VerbosityLevel	2
OutputFormat	
BuildEEGLABStructure	<input checked="" type="checkbox"/>
ExportGroundTruth	<input type="checkbox"/>
SetName	
Visualization	
PlotData	<input checked="" type="checkbox"/>
PlotGraphicalModel	<input checked="" type="checkbox"/>

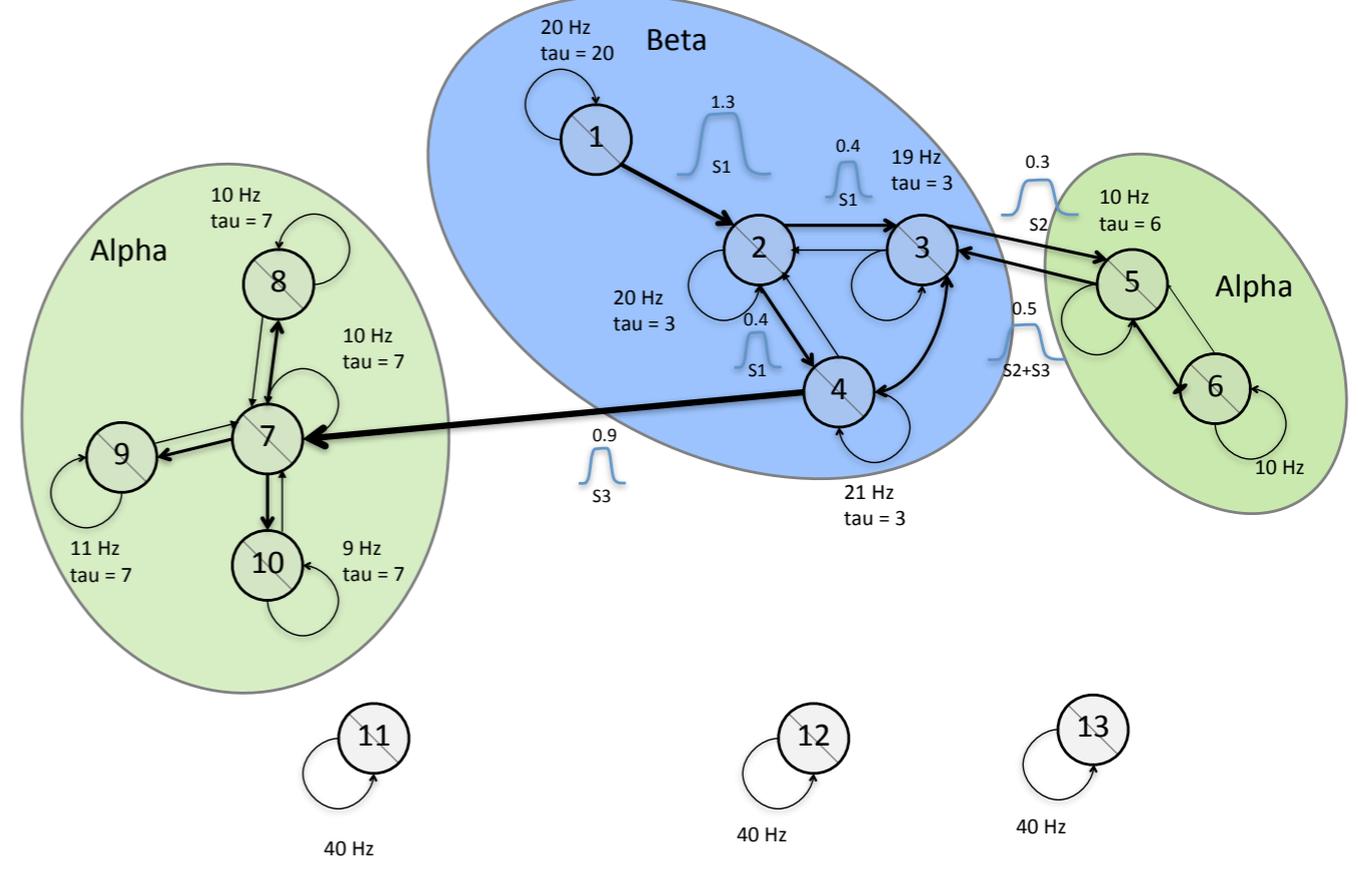
Simulation  
Select a simulation.

Help Cancel OK

- Epileptic Seizure
- Schelter 2005 Eq 5
  - Schelter 2009 Eq 3.1
  - Schelter 2009 Eq 3.2
  - Bivariate Coupled Oscillator
  - Trivariate Coupled Oscillator

# Simulation

## Simulated Seizure

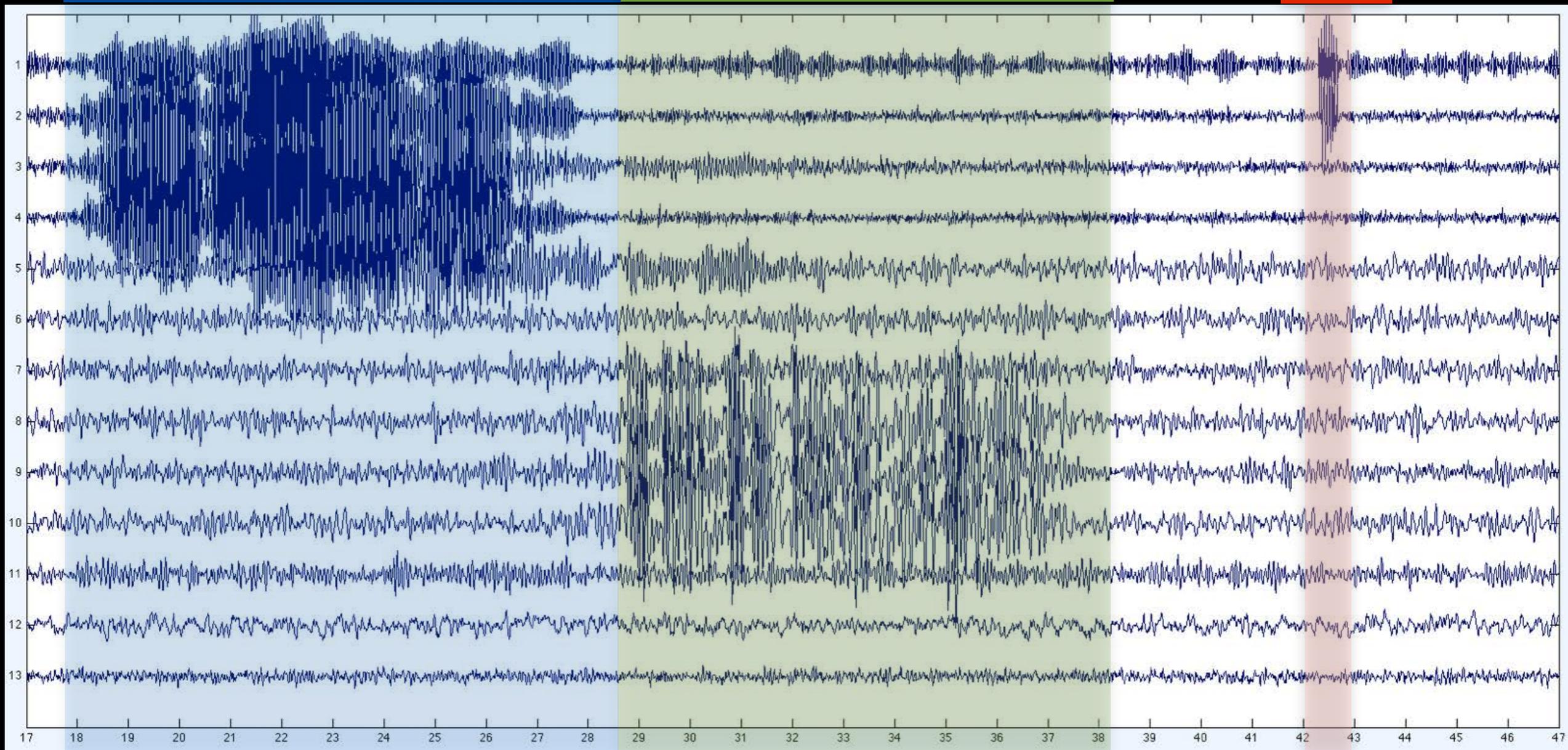


# Simulated Seizure Sources

Beta

Alpha

IED



- Simulation ▶
  - ✓ Pre-processing
  - Model fitting and validation ▶
  - ✓ Connectivity
  - Statistics ▶
  - Visualization ▶
  - Help ▶
- Linear Dynamical System ▶
  - EEG Simulator

# Simulation

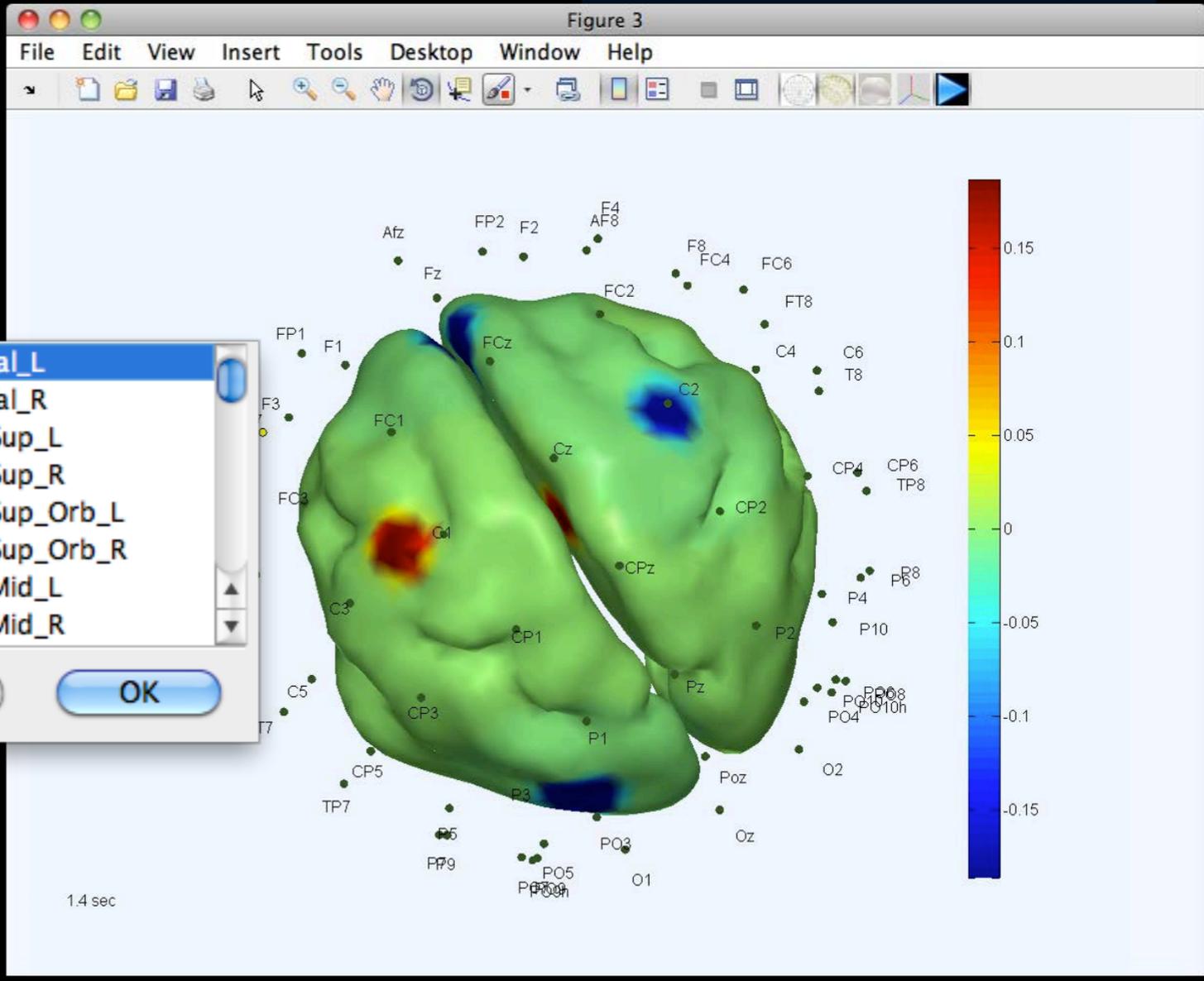
Simulate EEG Data

Source Data Generation	
SourceDynamics	VAR
Scalp Data Generation	
ForwardModel	
HeadModelObject	/Users/timmullen/...
SourceAtlasLabels	Precentral_L; Prece...
Channels	AF7 FP1 Afz FP2 AF8
SourceShape	gausspatch
SourceCoordinates	[]
<b>RoiAtlasLabels</b>	
RoiOrdered	
NearestNeighbor	<input checked="" type="checkbox"/>
Sigma	10
AddNoise	<input checked="" type="checkbox"/>
SignalToNoise	5
VerbosityLevel	2
Miscellaneous	
MakeDipfitStruct	<input checked="" type="checkbox"/>
VisualizeModel	<input type="checkbox"/>
VerbosityLevel	2

RoiAtlasLabels  
ROI Labels.

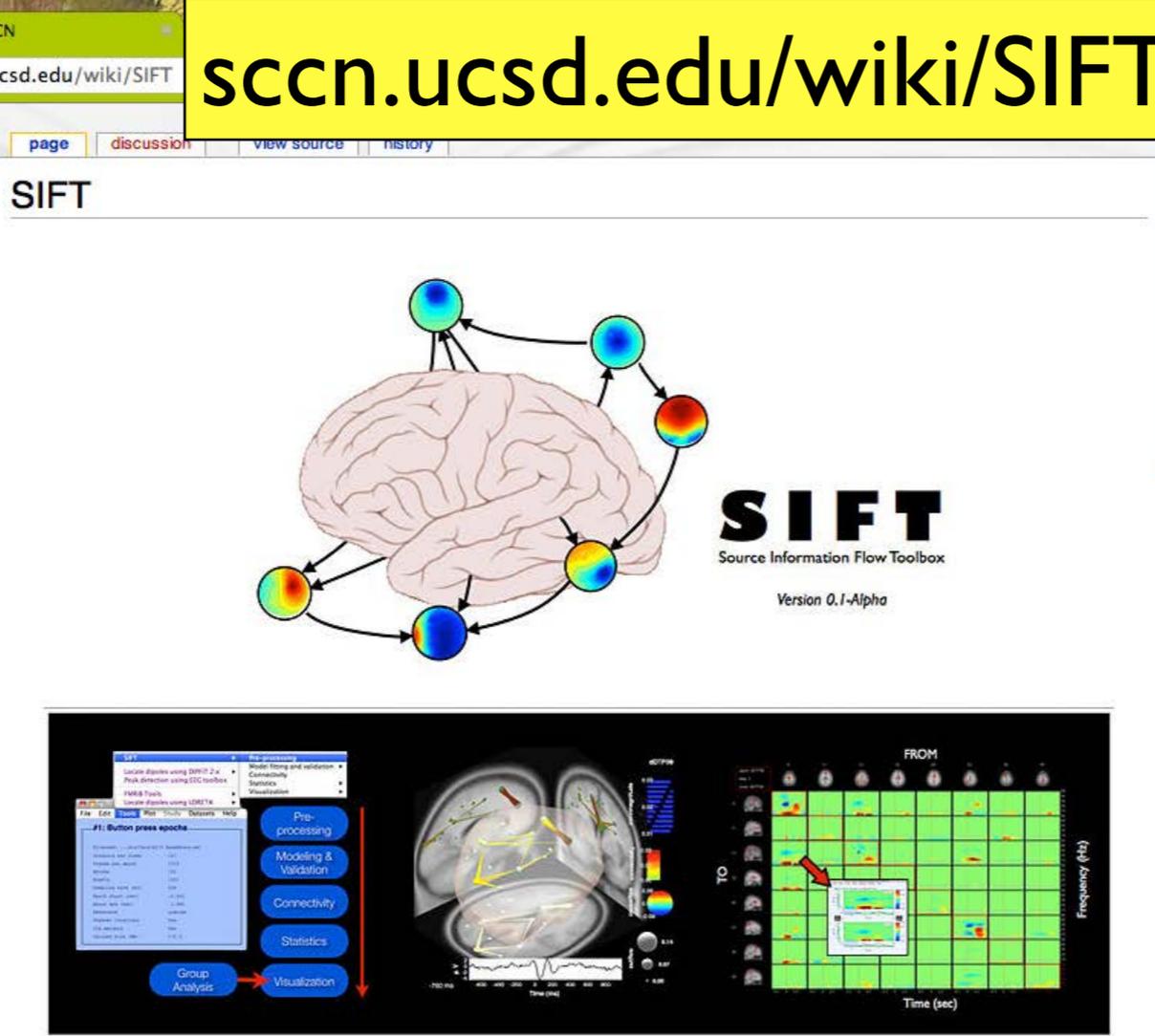
Help Cancel OK

- Precentral\_L
  - Precentral\_R
  - Frontal\_Sup\_L
  - Frontal\_Sup\_R
  - Frontal\_Sup\_Orb\_L
  - Frontal\_Sup\_Orb\_R
  - Frontal\_Mid\_L
  - Frontal\_Mid\_R
- Cancel OK



# Distribution and Educational Resources

[sccn.ucsd.edu/wiki/SIFT](http://sccn.ucsd.edu/wiki/SIFT)



**SIFT**  
Source Information Flow Toolbox  
Version 0.1-Alpha

**Contents [hide]**

- Welcome to the repository for the Source Information Flow Toolbox (SIFT)
  - SIFT Downloads
  - Citing SIFT
- SIFT Online Handbook and User Manual

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 here

**Table of Contents [hide]**

- [Introduction](#)
- [Multivariate Autoregressive Modeling](#)
  - Stationarity and Stability
  - The Multivariate Least-Squares Estimator
  - Frequency-Domain Representation
  - Modeling non-stationary data using adaptive VAR models
    - Segmentation-based Adaptive VAR (AMVAR) models
  - Model order selection
  - Model Validation
    - Checking the whiteness of the residuals
      - Autocorrelation Function (ACF) Test
      - Portmanteau Tests
    - Checking the consistency of the model
    - Checking the stability and stationarity of the model
    - Comparing parametric and nonparametric spectra and coherence
- [Granger Causality and Extensions](#)
  - Time-Domain GC
  - Frequency-Domain GC
  - A partial list of VAR-based spectral, coherence and GC estimators
  - Time-Frequency GC
  - (Cross-) correlation does not imply (Granger-) causation
- [Statistics](#)
  - Asymptotic analytic statistics
  - Nonparametric surrogate statistics
    - Bootstrap resampling
    - Phase Randomization
- [Using SIFT to analyze neural information flow dynamics](#)
  - System Requirements
  - Configuring EEGLAB
  - Loading the data
  - The SIFT analysis pipeline
  - Preprocessing
    - Theory: preprocessing
      - Component Selection
      - Epoching
      - Filtering
- [Conclusions and Future Work](#)

Can also get from  
EEGLAB Plugin  
Manager or  
NITRC.org