DCM for Time Frequency

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(showing the slides of Will Penny)

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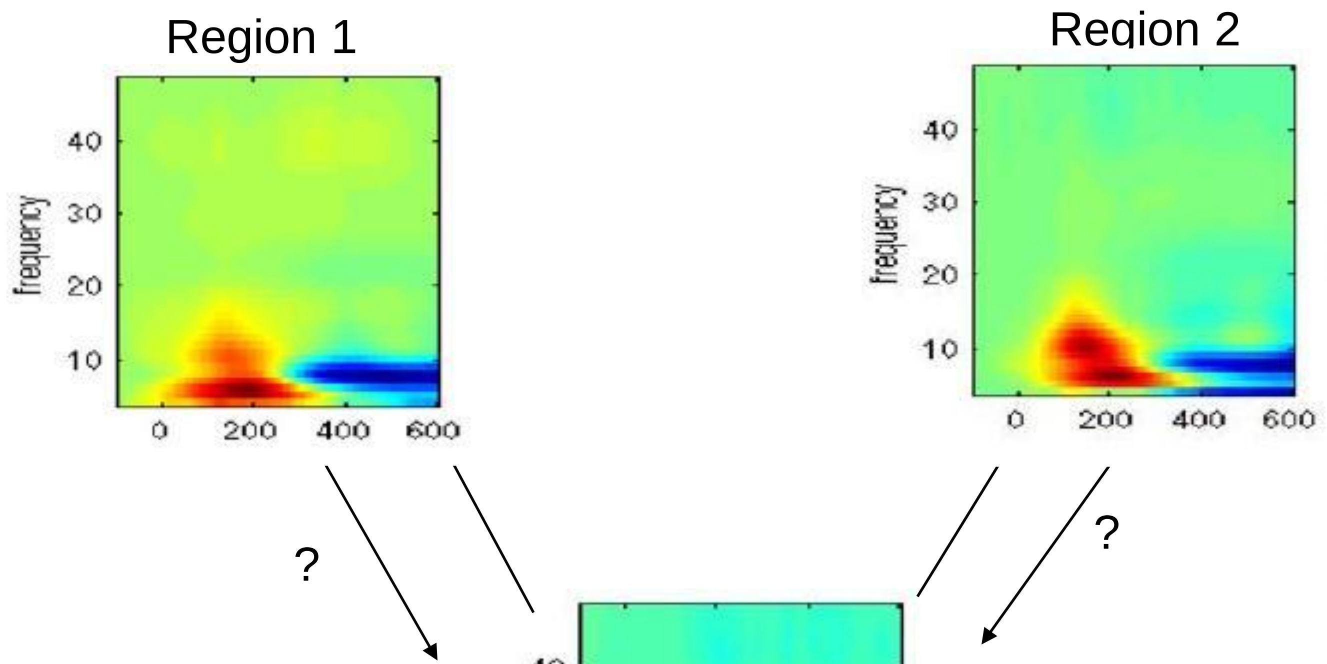
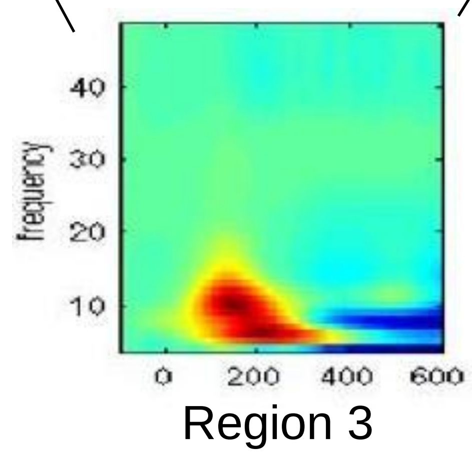
DCM for Induced Responses

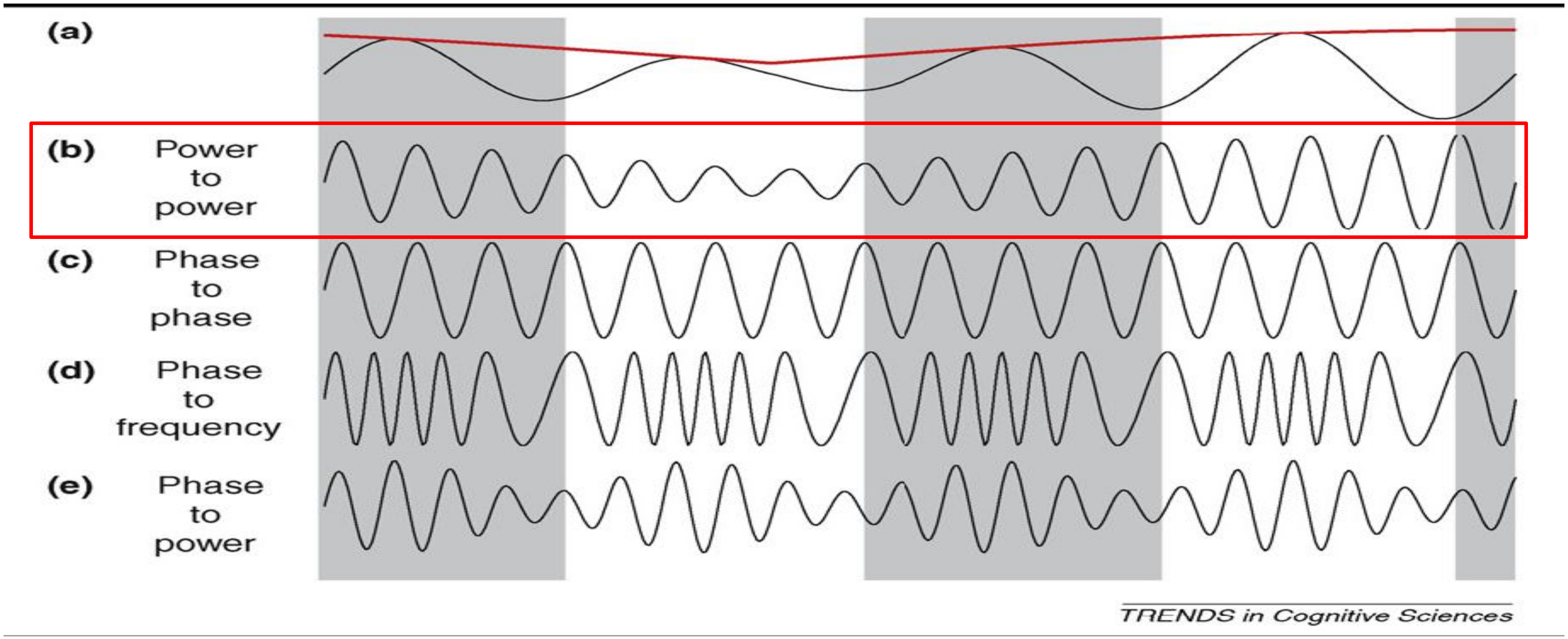




How does slow activity
in one region affect
fast activity in another ?

Relate change of power
in one region and frequency
to power in others.

- **measuring connectivity**
- **linear (within frequency coupling) or/and non-linear (cross frequency coupling)**

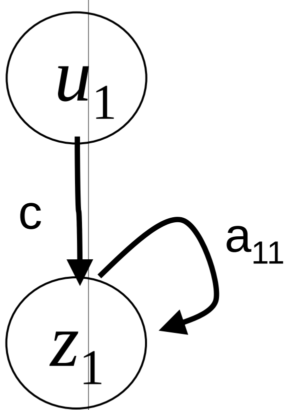


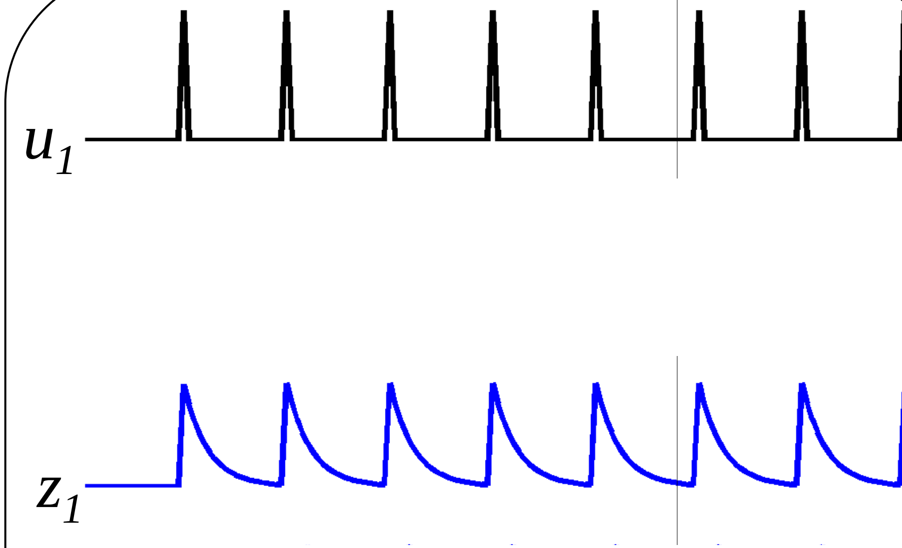
Trends Cogn Sci. 2007 Jul;11(7):267-9. Epub 2007 Jun 4.

DCM for fMRI

Single region

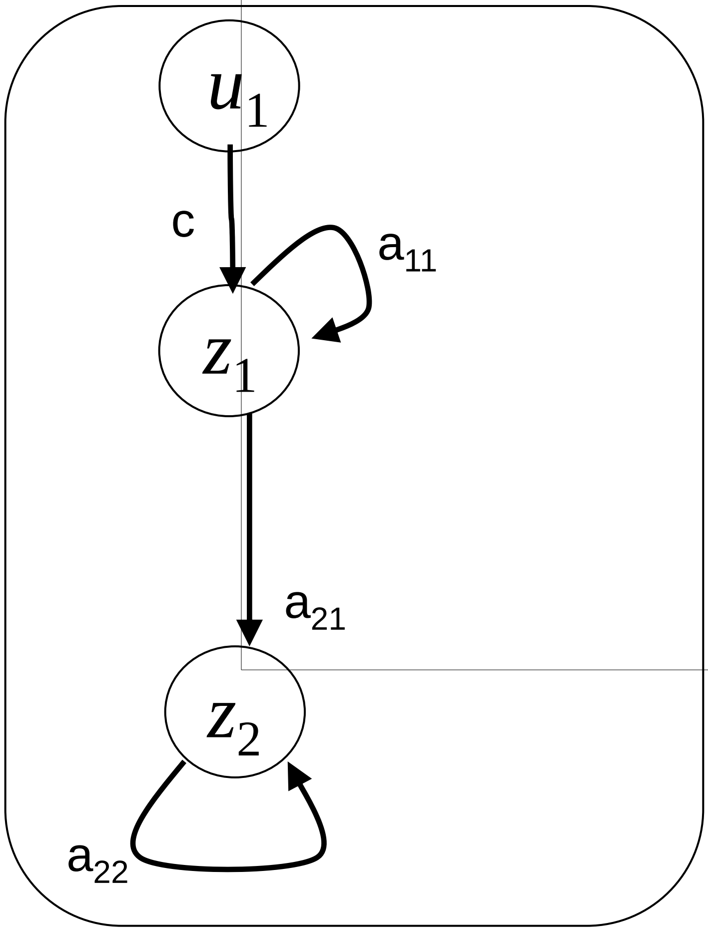
$$\dot{z}_1 = a_{11} z_1 + c u_1$$

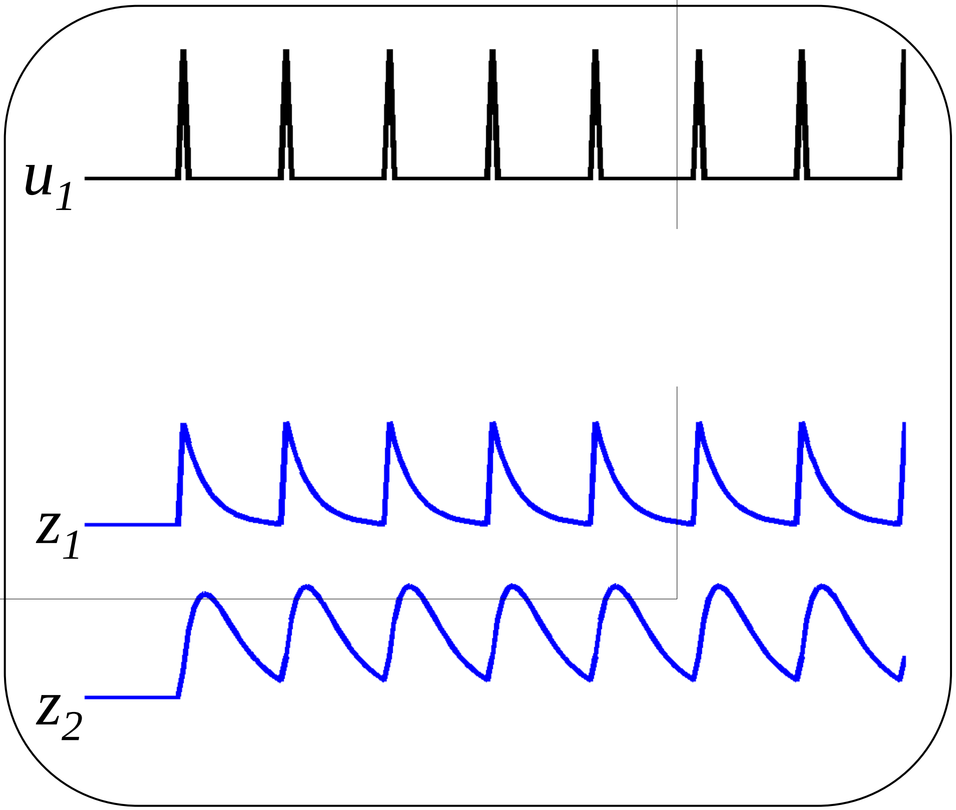




Multiple regions

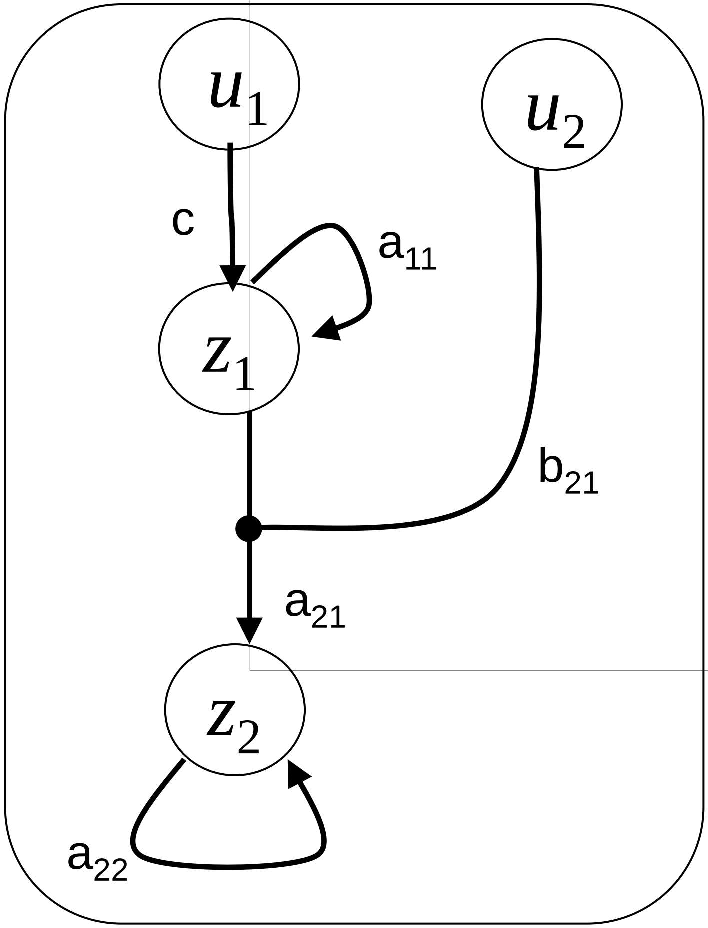
$$\begin{bmatrix} \dot{z}_1 \\ \dot{z}_2 \end{bmatrix} = \begin{bmatrix} a_{11} & 0 \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} z_1 \\ z_2 \end{bmatrix} + \begin{bmatrix} c \\ 0 \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \end{bmatrix}$$

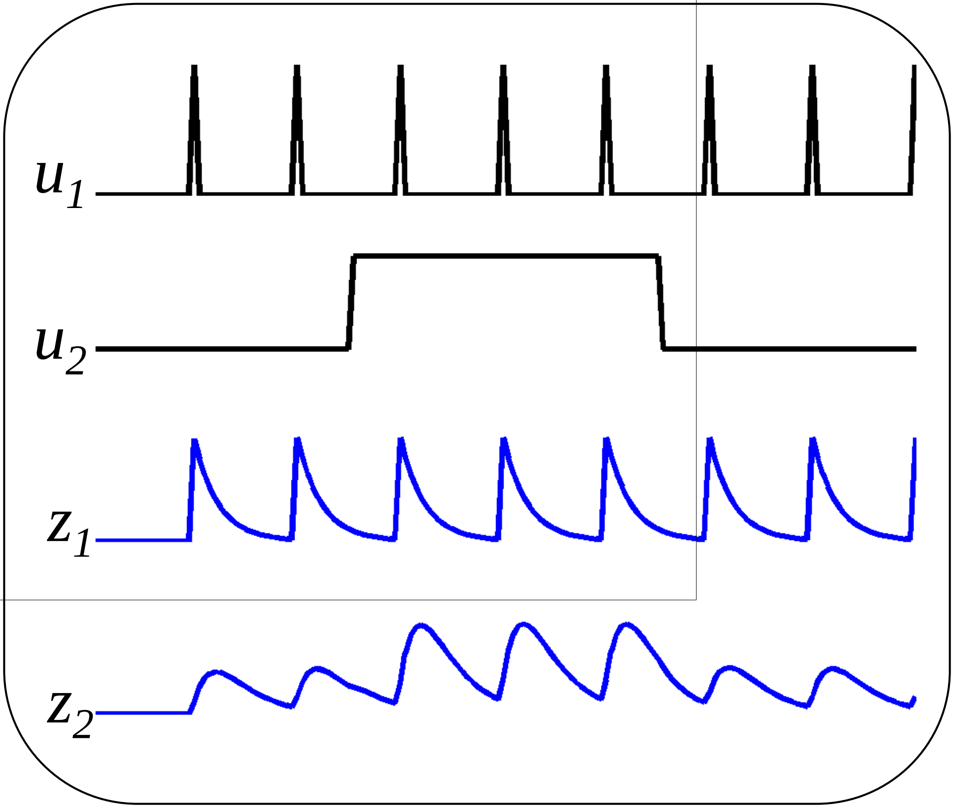




Modulatory inputs

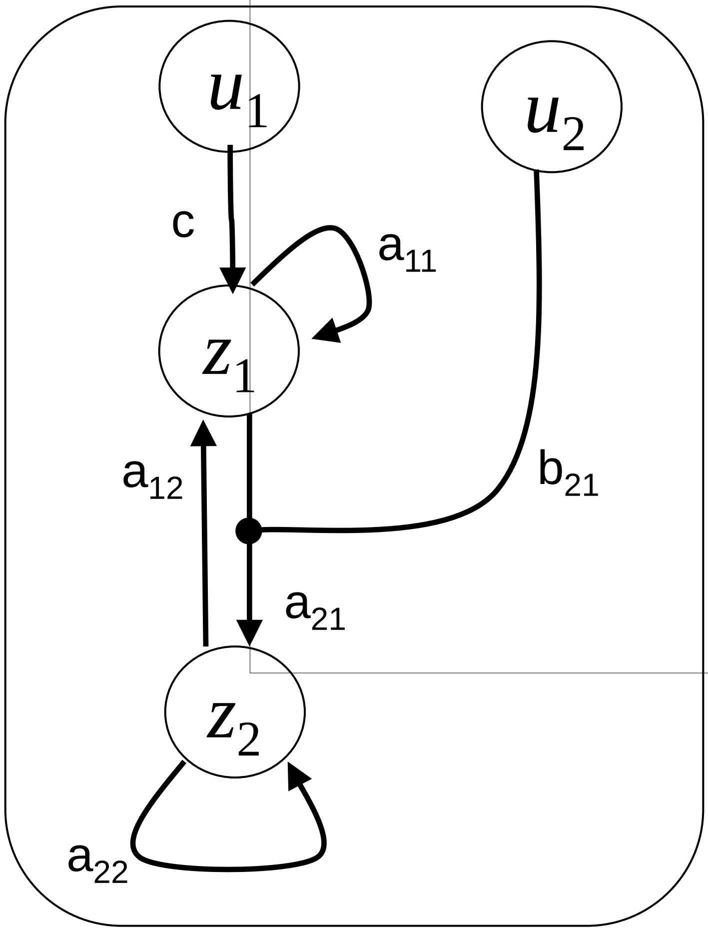
$$\begin{bmatrix} \dot{z}_1 \\ \dot{z}_2 \end{bmatrix} = \begin{bmatrix} a_{11} & 0 \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} z_1 \\ z_2 \end{bmatrix} + u_2 \begin{bmatrix} 0 & 0 \\ b_{21} & 0 \end{bmatrix} \begin{bmatrix} z_1 \\ z_2 \end{bmatrix} + \begin{bmatrix} c \\ 0 \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \end{bmatrix}$$

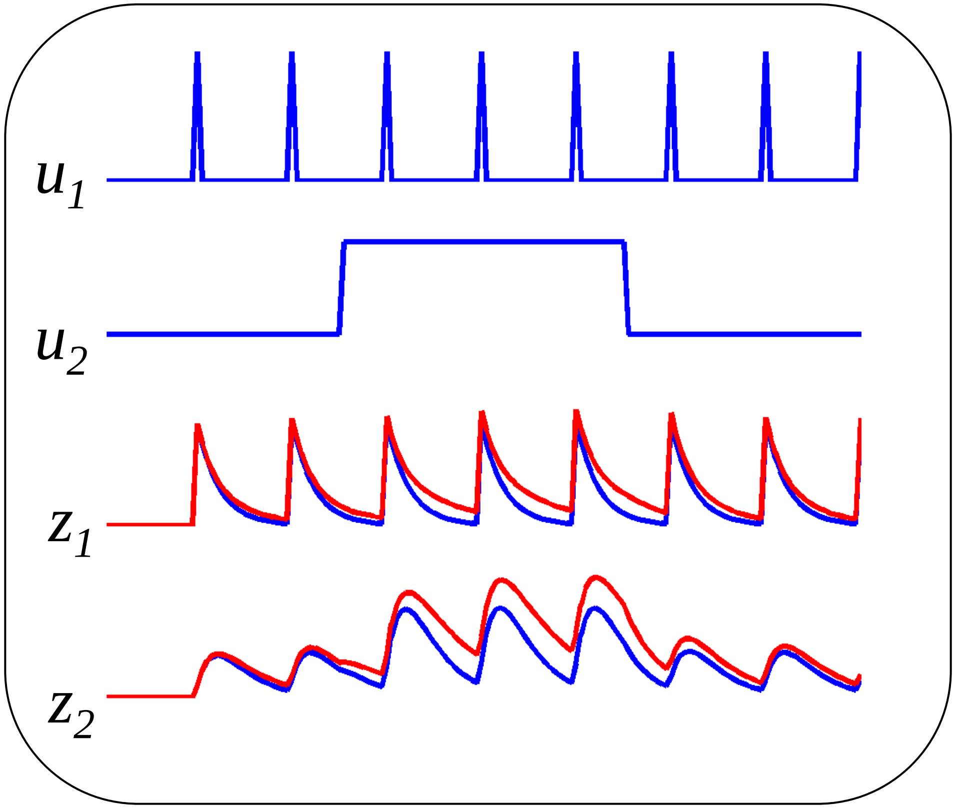




Reciprocal connections

$$\begin{bmatrix} \dot{z}_1 \\ \dot{z}_2 \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} z_1 \\ z_2 \end{bmatrix} + u_2 \begin{bmatrix} 0 & 0 \\ b_{21} & 0 \end{bmatrix} \begin{bmatrix} z_1 \\ z_2 \end{bmatrix} + \begin{bmatrix} c \\ 0 \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \end{bmatrix}$$





Intrinsic (within-source) coupling

$$\tau\dot{g}(t) = \tau\begin{bmatrix} \dot{g}_1 \\ \vdots \\ \dot{g}_J \end{bmatrix} = \begin{bmatrix} A_{11} & \cdots & A_{1J} \\ \vdots & \ddots & \vdots \\ A_{J1} & \cdots & A_{JJ} \end{bmatrix} g(t) + \begin{bmatrix} C_1 \\ \vdots \\ C_J \end{bmatrix} u(t)$$

Extrinsic (between-source) coupling

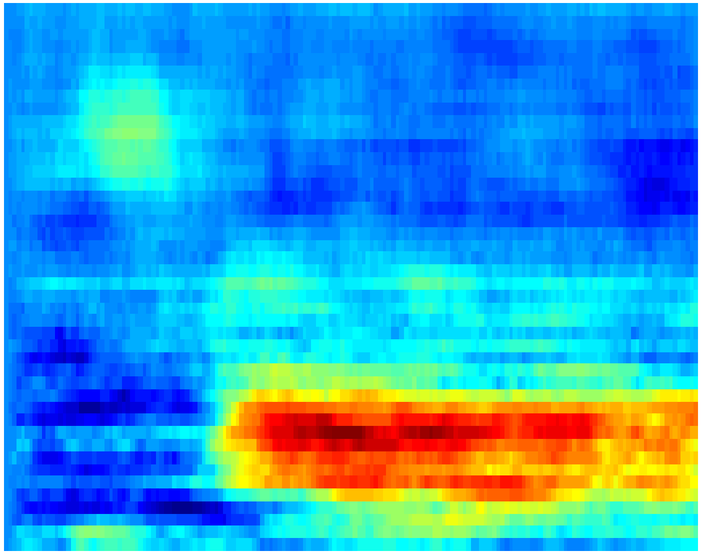
Linear (within-frequency) coupling

$$A_{ij} = \begin{bmatrix} A_{ij}^{11} & \cdots & A_{ij}^{1K} \\ \vdots & \ddots & \vdots \\ A_{ij}^{K1} & \cdots & A_{ij}^{KK} \end{bmatrix}$$

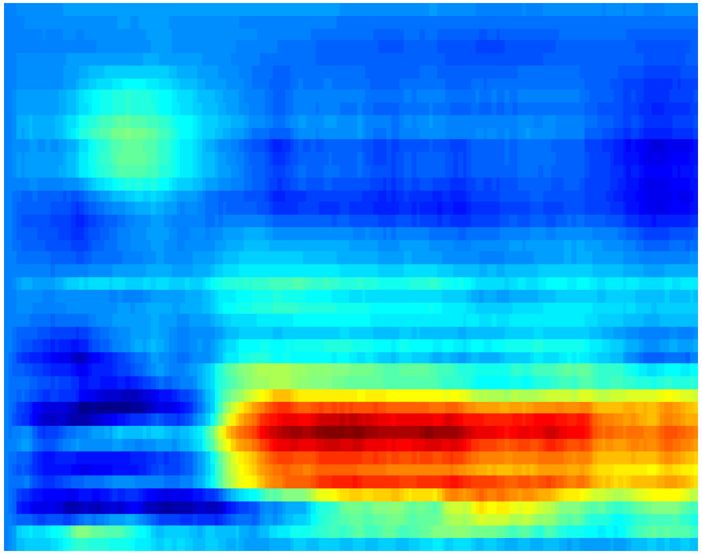
How frequency K in region j affects frequency 1 in region i

Nonlinear (between-frequency) coupling

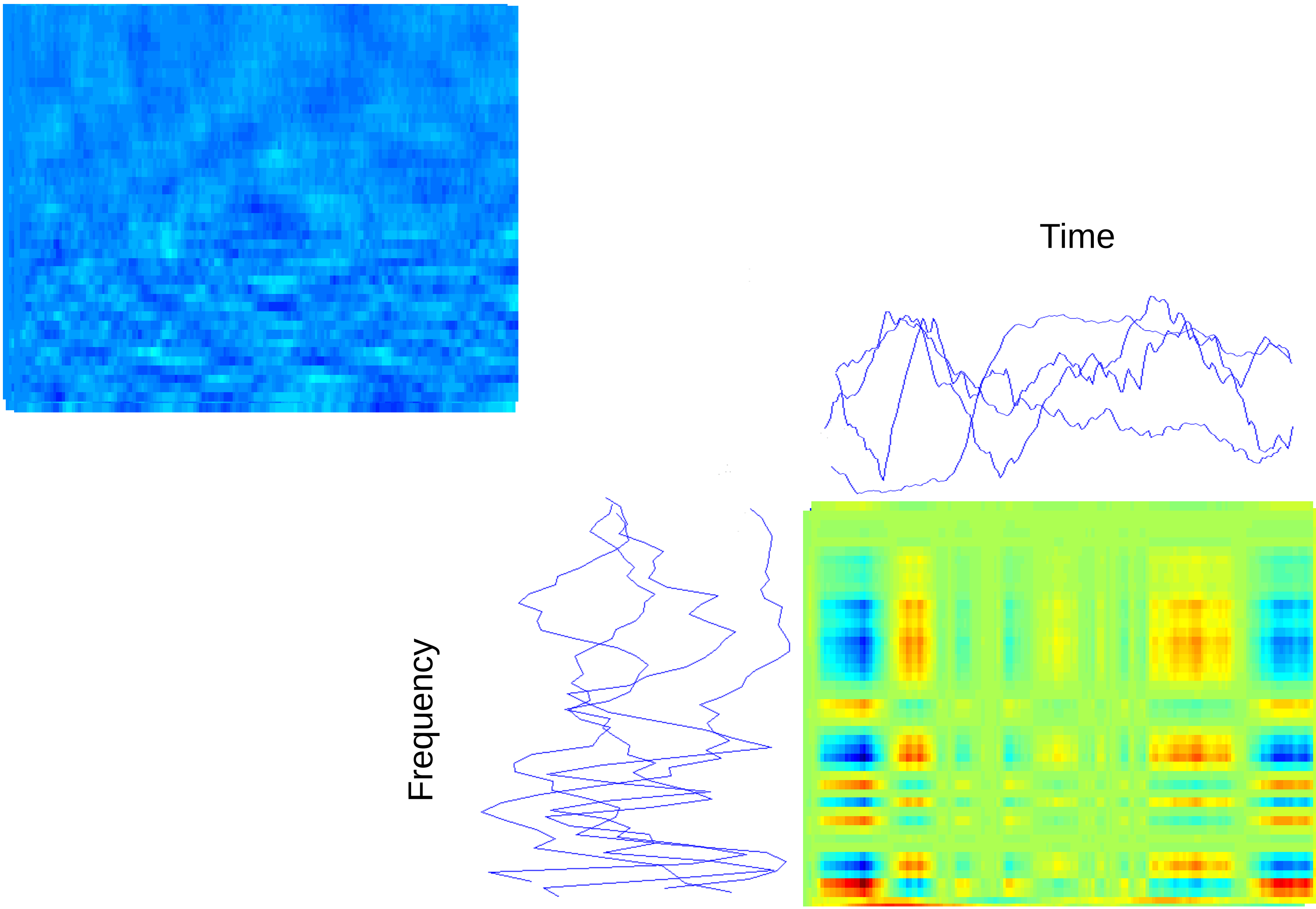
Original



Reconstructed from 4 modes

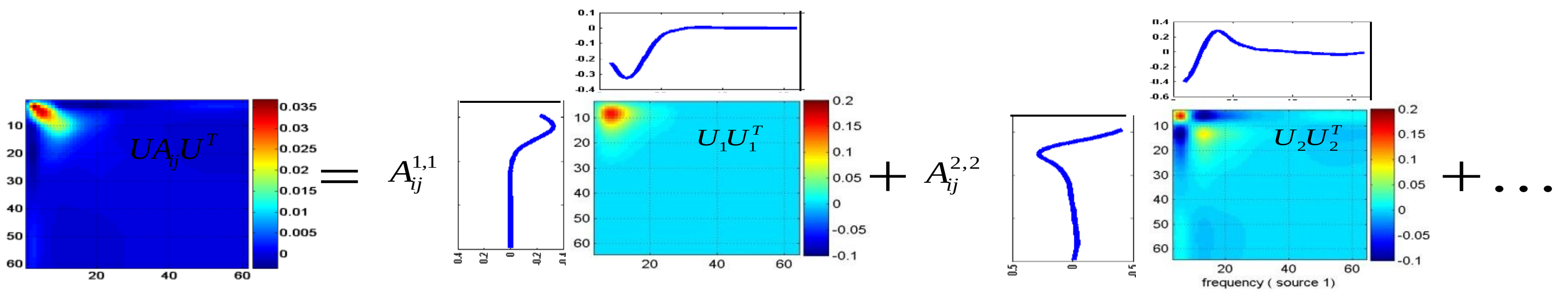


- In theory, we can consider the states as spectral densities at a discrete number of frequencies.
- In practice, we use only several significant singular components (modes) obtained by SVD of the spectral responses over time and sources so that we reduce the problem to modelling only the coupling among modes that cover all frequencies in different proportions.

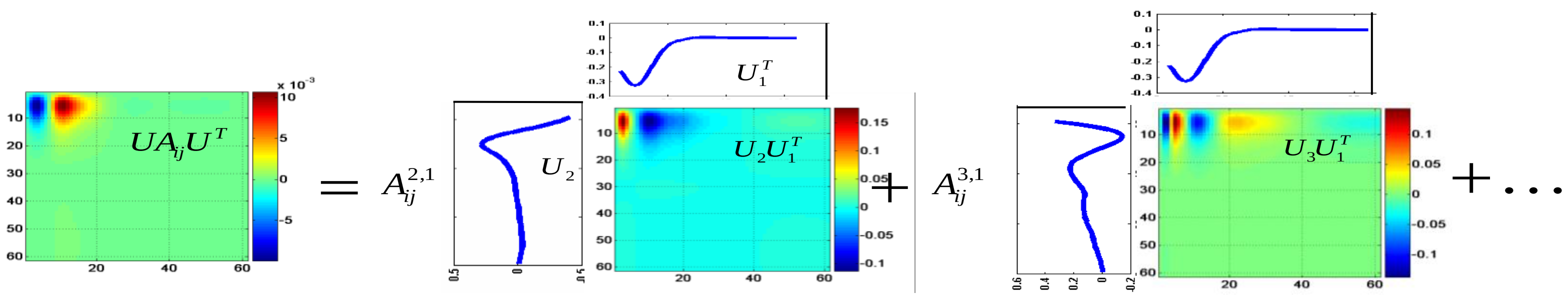

Time
Frequency

The coupling between two regions can be seen as a function of source and target frequencies

$$UA_{ij}U^T = \sum_k \sum_l A_{ij}^{kl} U_k U_l^T$$



An example of linear (within-mode) coupling



An example of nonlinear (between-mode) coupling

Modulatory connections

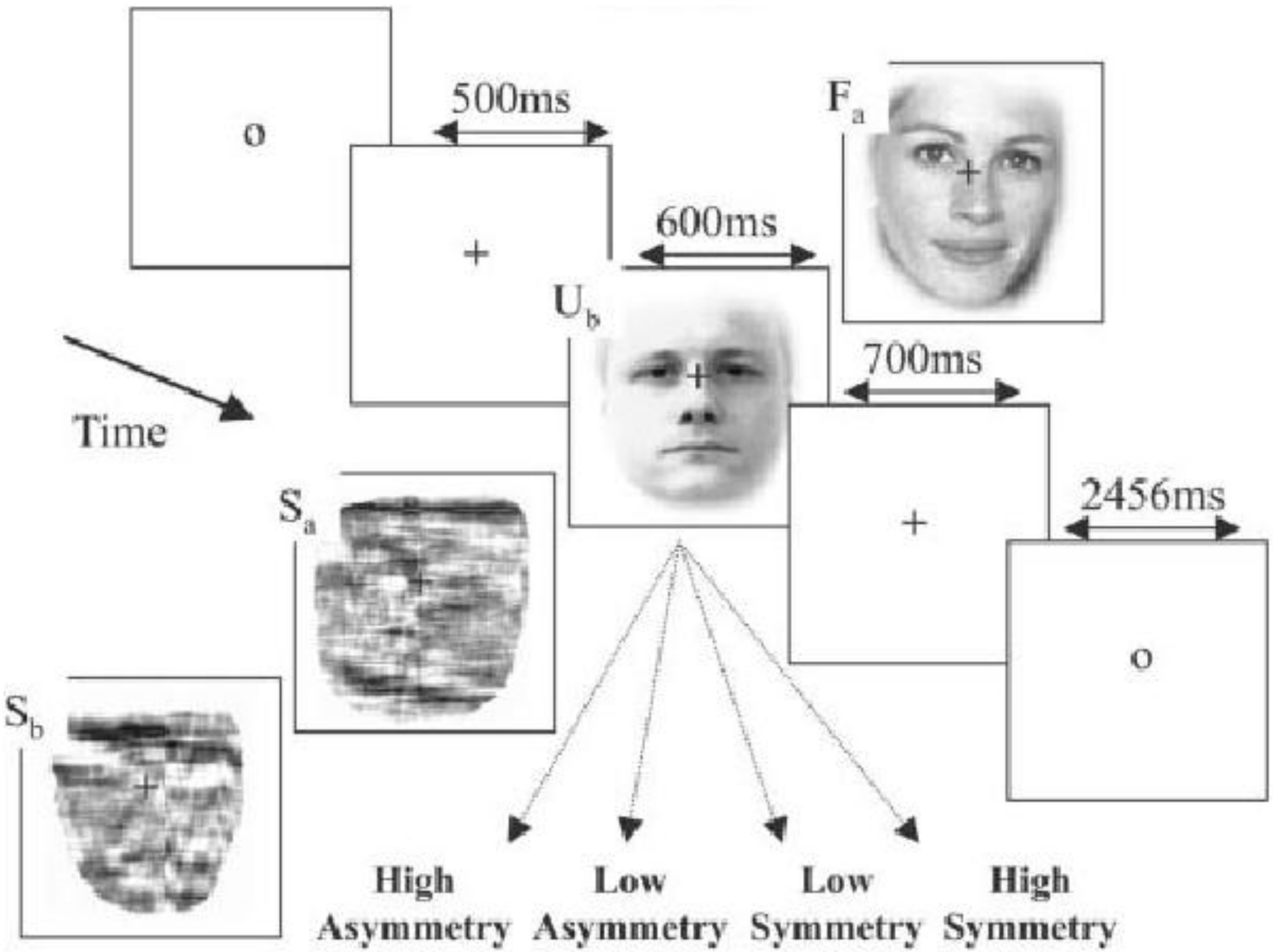
state equation

Intrinsic (within-source) coupling

$$\tau\dot{g}(W,t) = \begin{pmatrix} \dot{x}_1 \\ \vdots \\ \dot{x}_J \end{pmatrix} = \left(\begin{bmatrix} A_{11} & \cdots & A_{1J} \\ \vdots & \ddots & \vdots \\ A_{J1} & \cdots & A_{JJ} \end{bmatrix} + \sum u(t) \begin{bmatrix} B_{11} & \cdots & B_{1J} \\ \vdots & \ddots & \vdots \\ B_{J1} & \cdots & B_{JJ} \end{bmatrix} \right) x(w,t) + u(t) \begin{bmatrix} C_1 \\ \vdots \\ C_J \end{bmatrix}$$

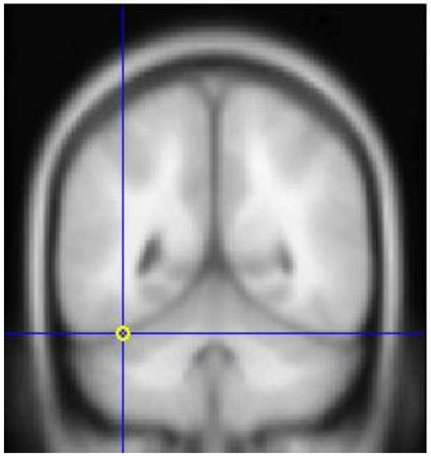
Extrinsic (between-source) coupling

MEG Data



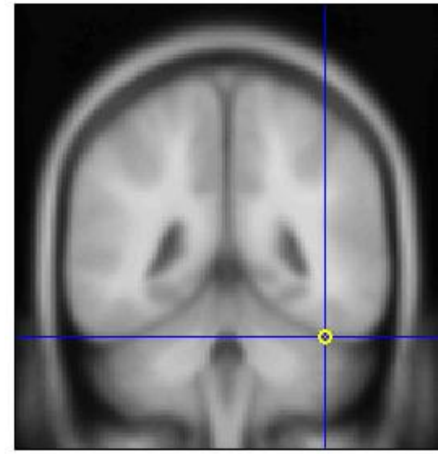
500ms
F a
o
+
600ms
U b
700ms
Time
S a
2456ms
+
o
S b
High Asymmetry
Low Asymmetry
Low Symmetry
High Symmetry

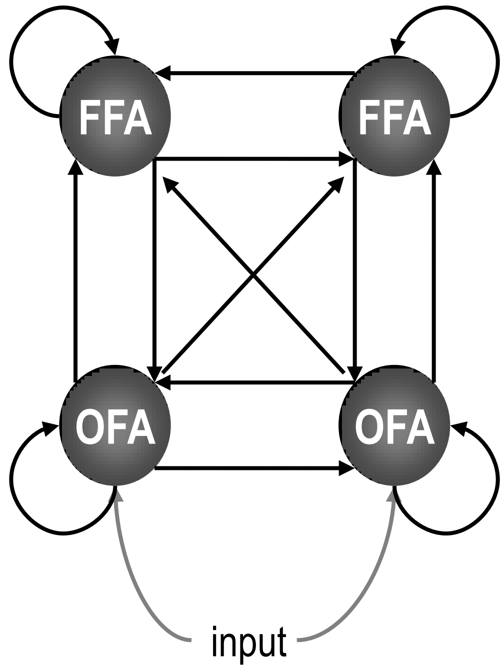
The “core” system

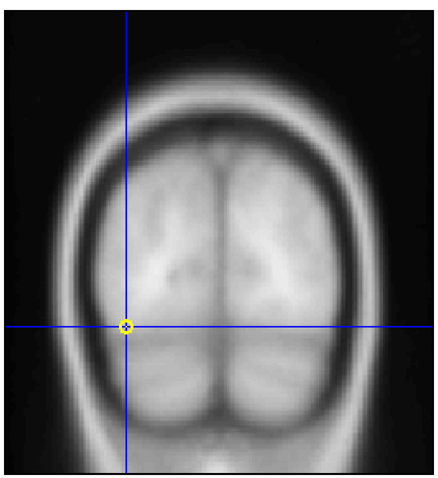


$x = -39$
$y = -51$
$z = -24$

$x = 42$
$y = -45$
$z = -27$

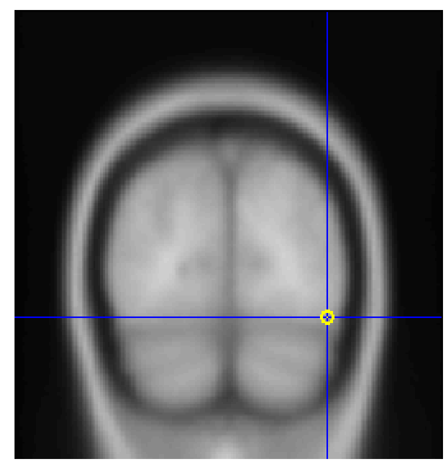




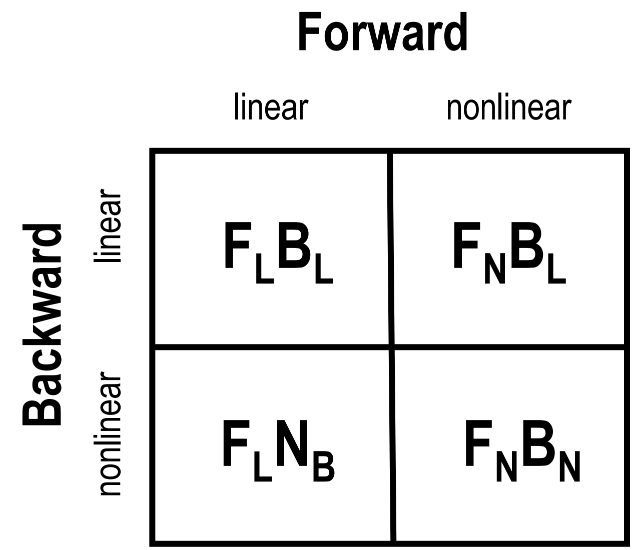


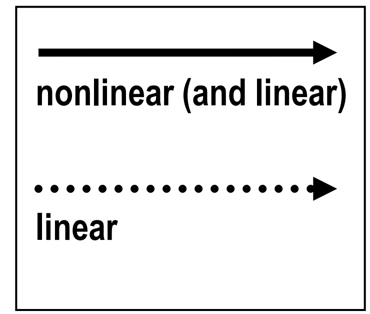
$x = -39$
$y = -81$
$z = -15$

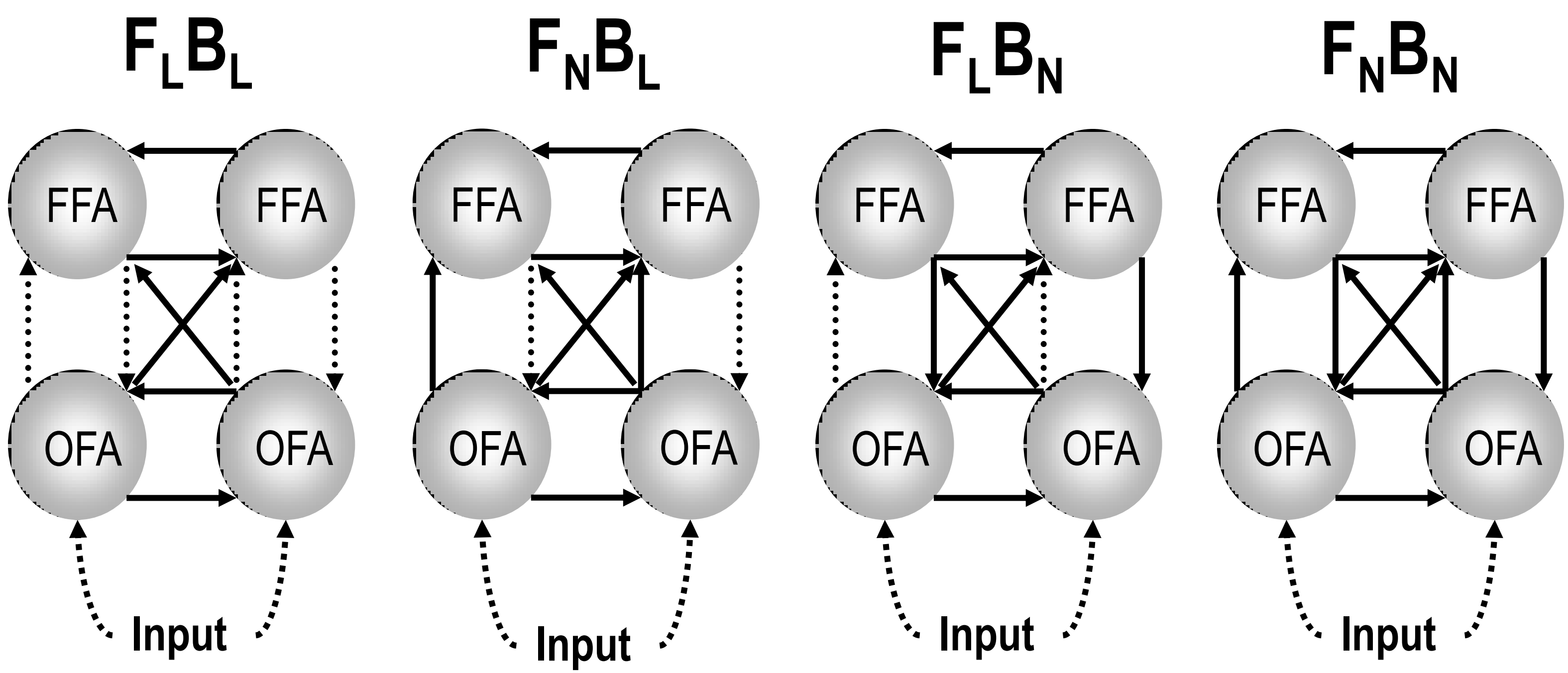
$x = 42$
$y = -81$
$z = -15$



Face selective effects modulate within hemisphere forward and backward cxs

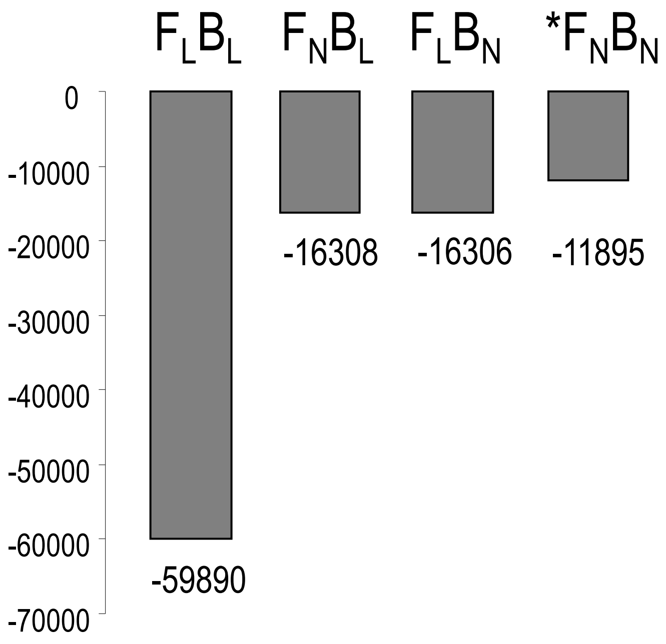


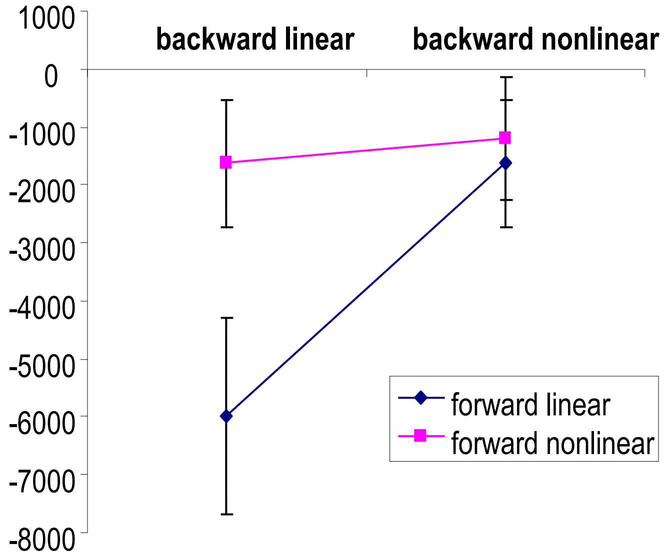




Model Inference

- Both forward and backward connections are nonlinear

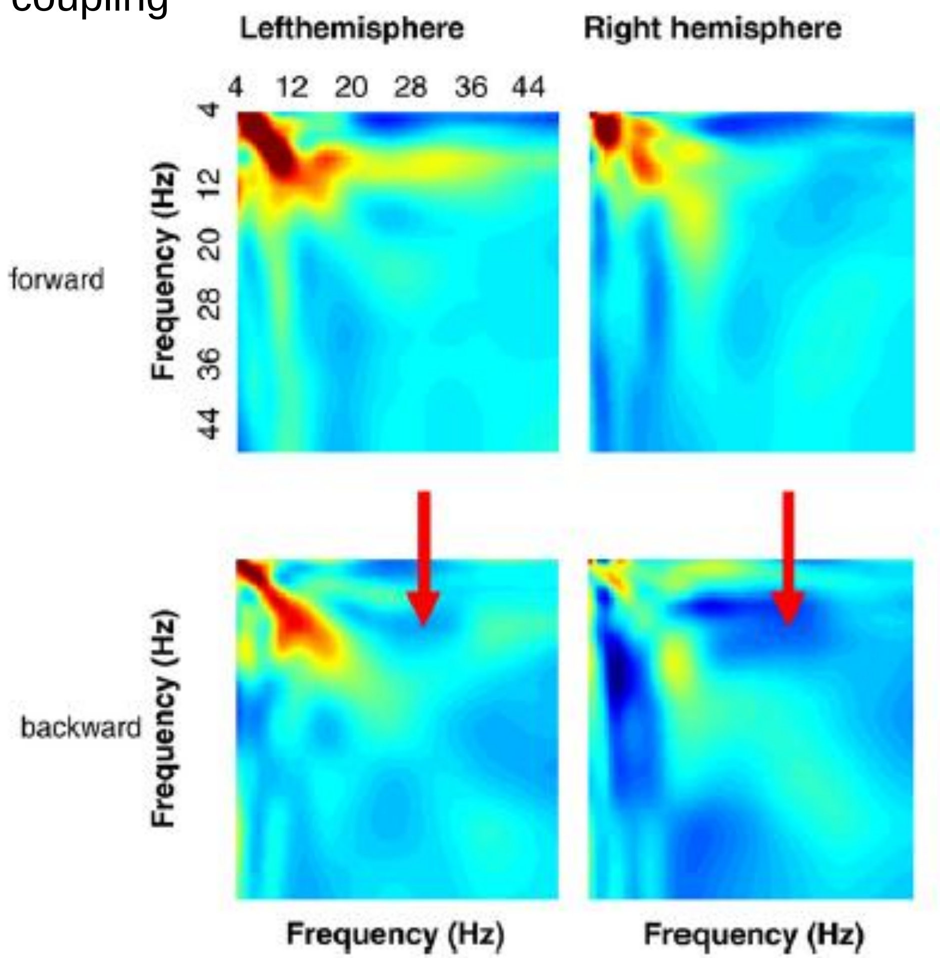




Parameter Inference: gamma affects alpha

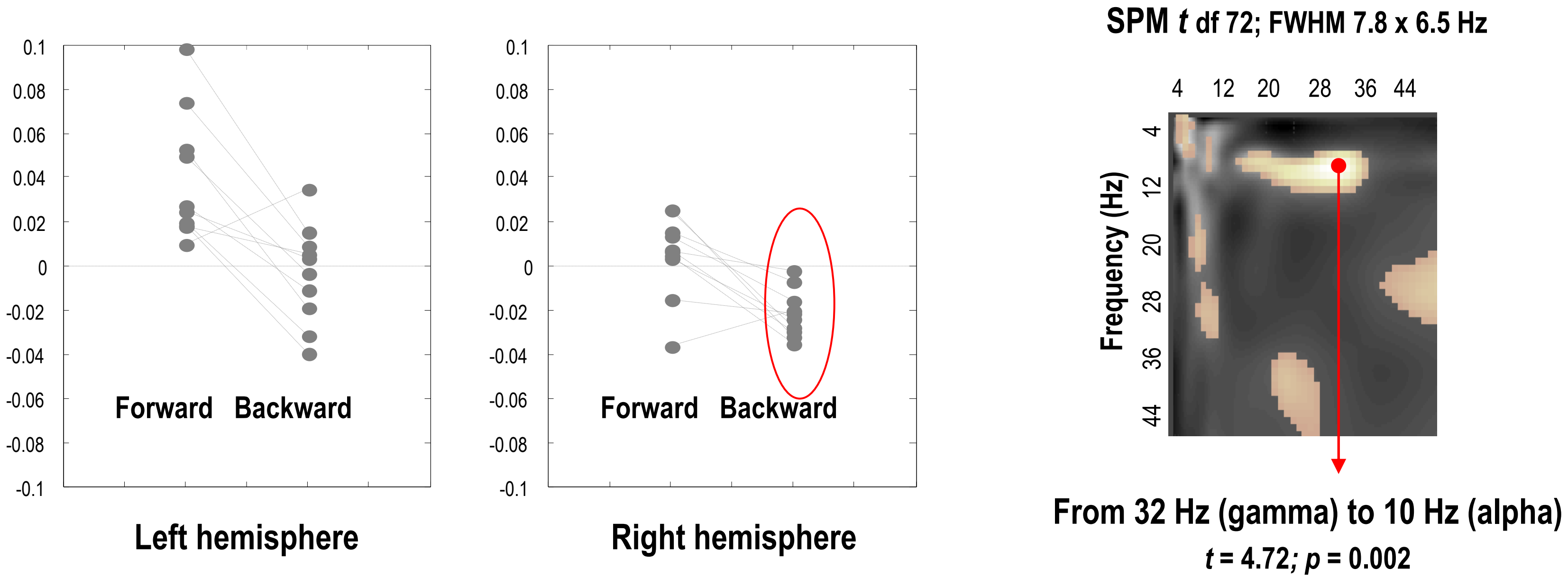
Left forward – excitatory - activating effect of gamma-alpha coupling in the forward connections

During face processing



Right backward - inhibitory – suppressive effect of gamma-alpha coupling in backward connections

Parameter Inference: gamma affects alpha

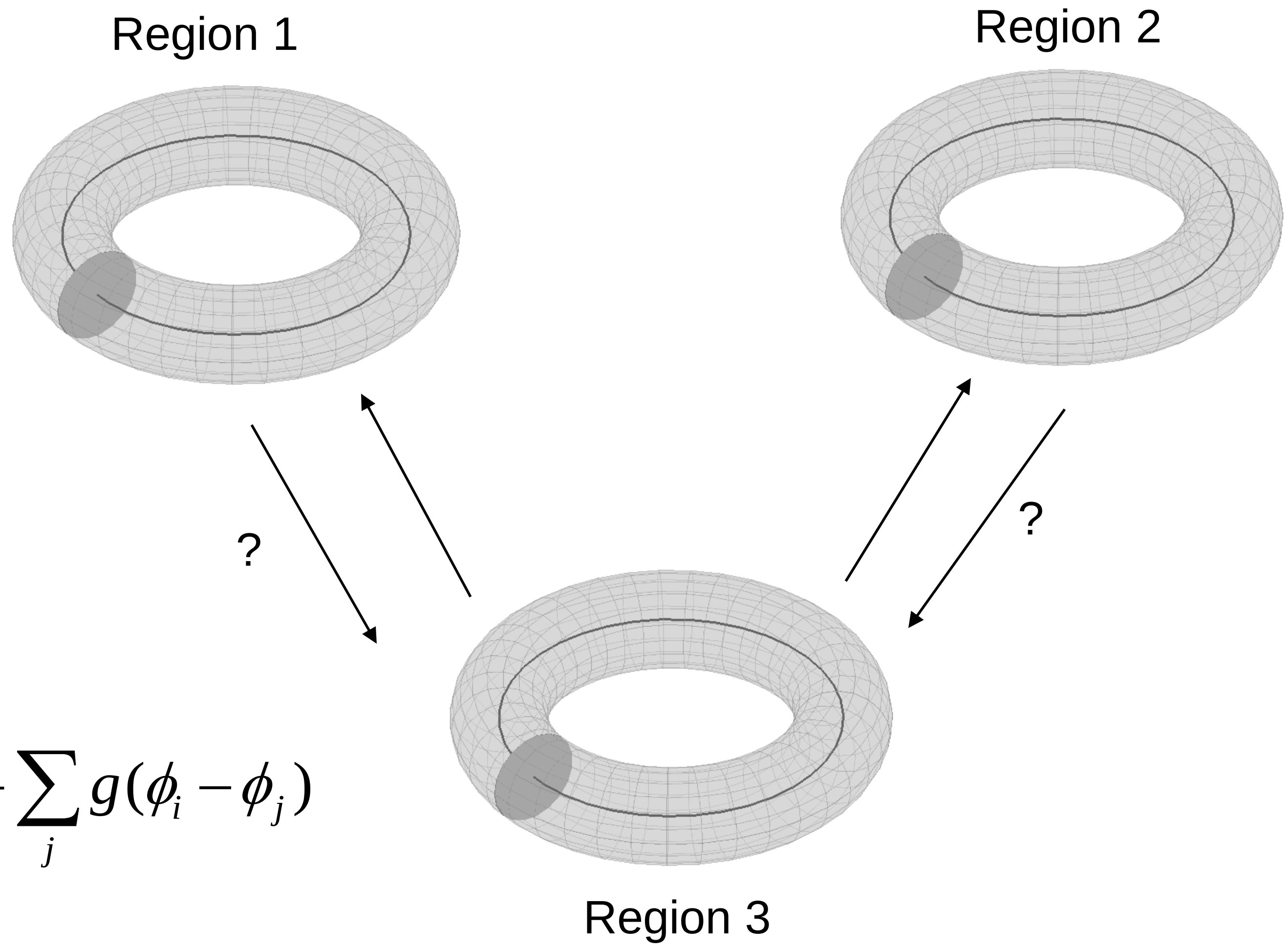


“Gamma activity in input areas induces slower dynamics in higher areas as prediction error is accumulated. Nonlinear coupling in high-level area induces gamma activity in that higher area which then accelerates the decay of activity in the lower level. This decay is manifest as damped alpha oscillations.”

- C.C. Chen , S. Kiebel, KJ Friston , Dynamic causal modelling of induced responses. *NeuroImage*, 2008; (41):1293-1312.
- C.C. Chen, R.N. Henson, K.E. Stephan, J.M. Kilner, and K.J. Friston. Forward and backward connections in the brain: A DCM study of functional asymmetries in face processing. *NeuroImage,* 2009 Apr 1;45(2):453-62

DCM for Phase Coupling

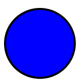
For studying synchronization among brain regions
Relate change of phase in one region to phase in others

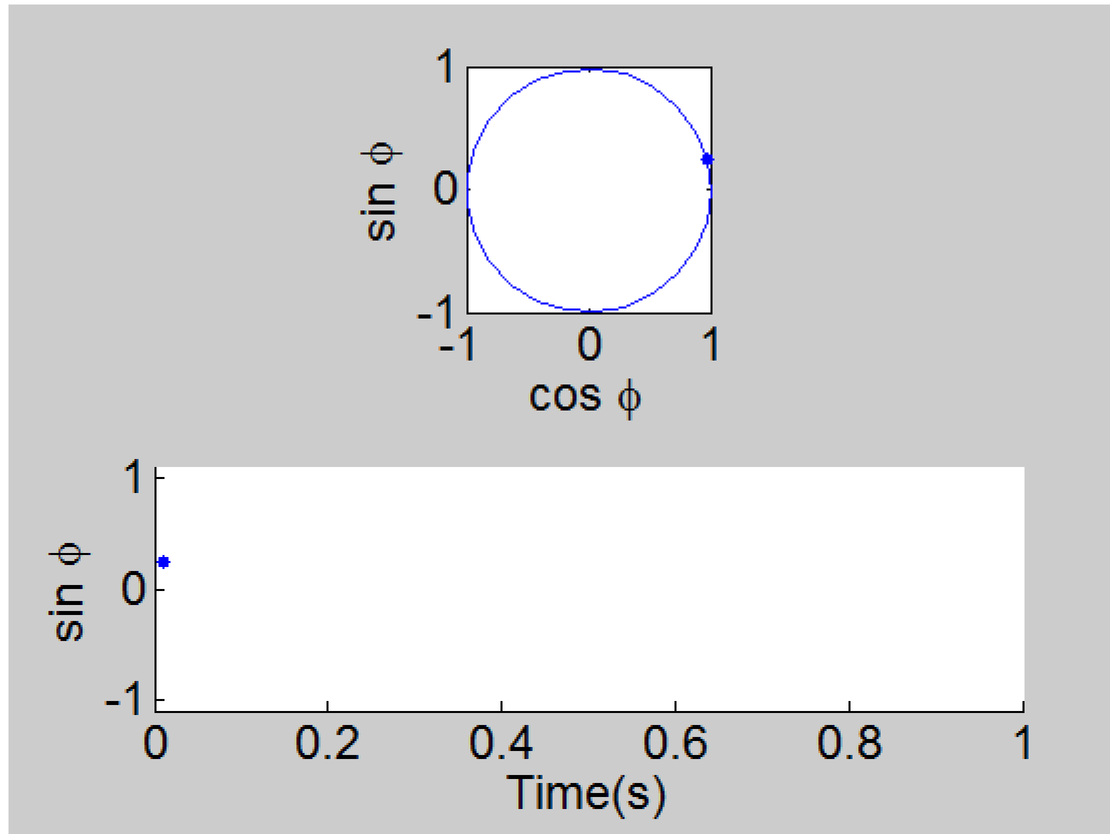


$$\dot{\phi}_i = \omega + \sum_j g(\phi_i - \phi_j)$$

One Oscillator

$$\dot{\phi}_1 = f$$

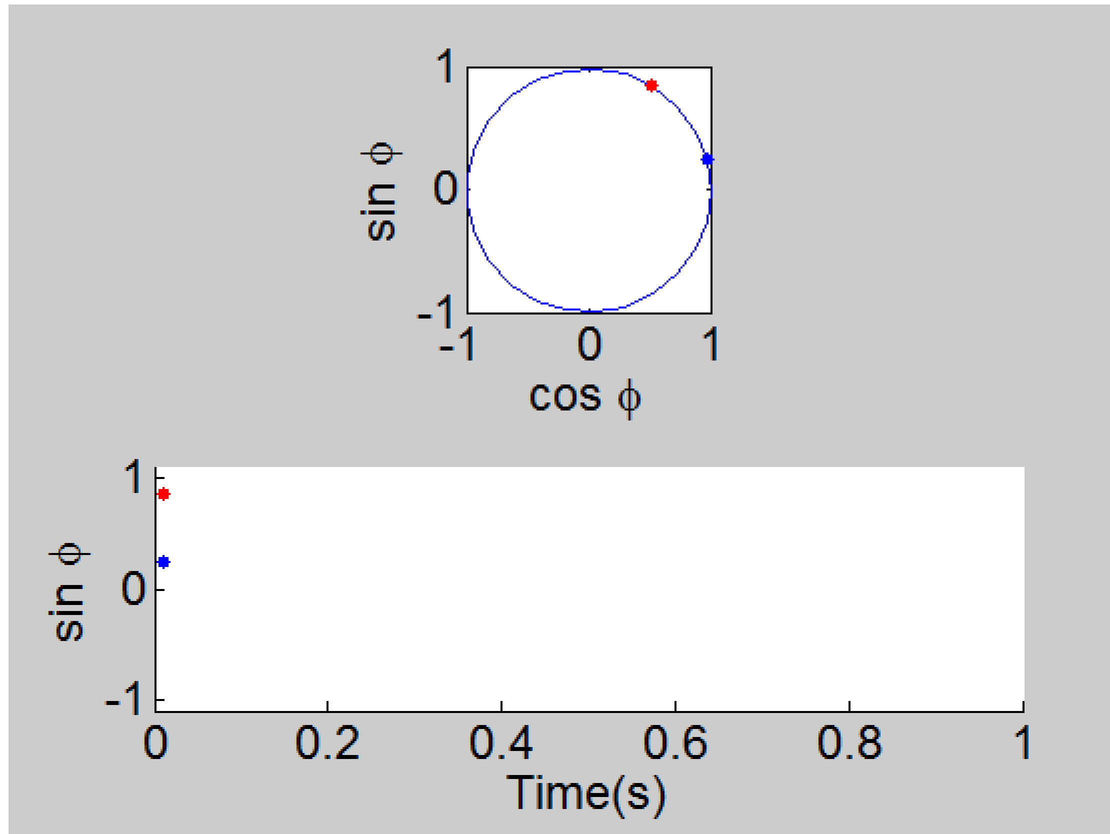




Two Oscillators

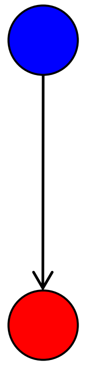
$$\dot{\phi}_1 = f$$

$$\dot{\phi}_2 = f$$

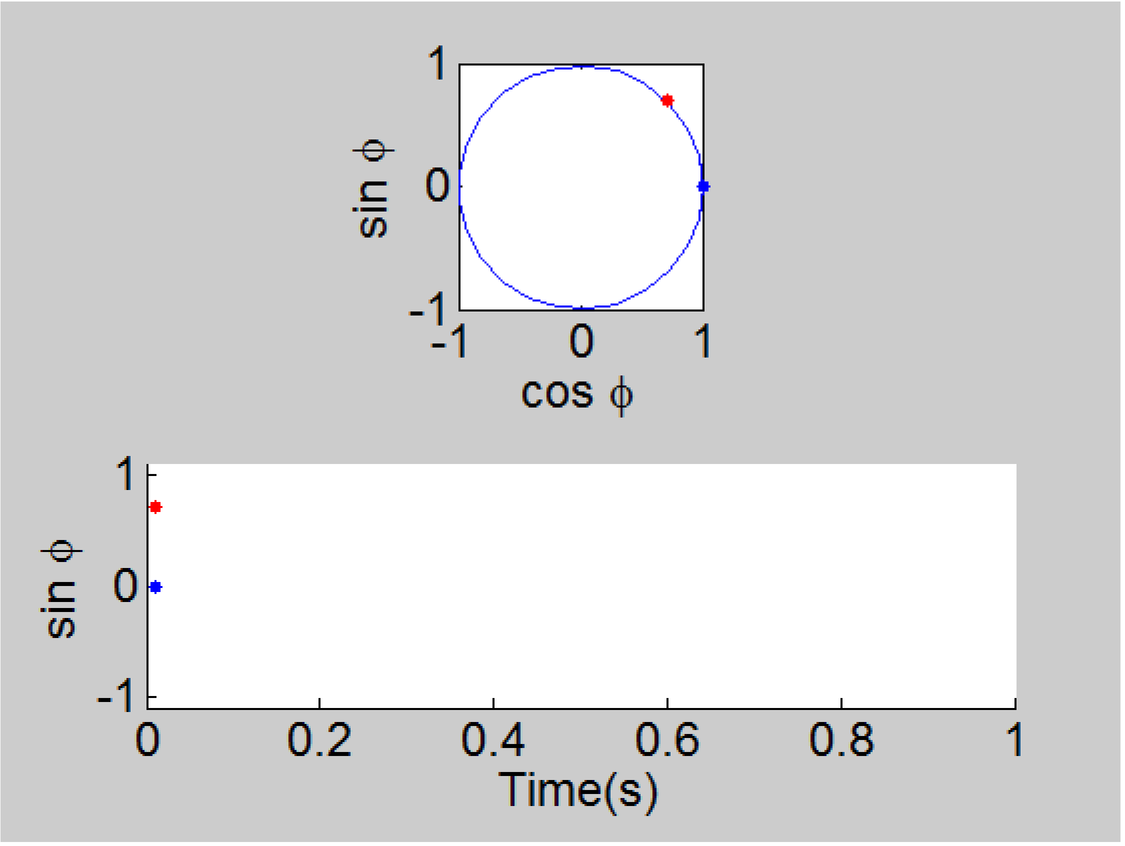


Two Coupled Oscillators

$$\dot{\phi}_1 = f$$



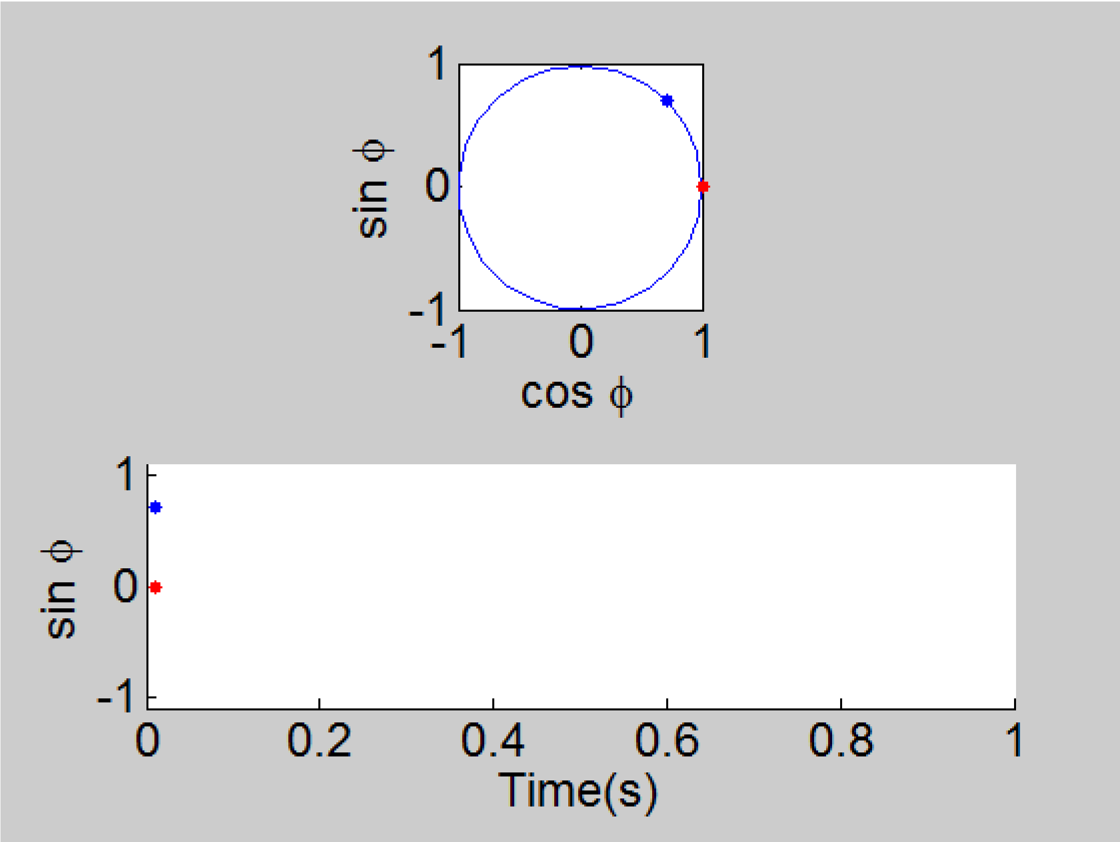
$$\dot{\phi}_2 = f - 0.3\sin(\phi_2 - \phi_1)$$



Different initial phases

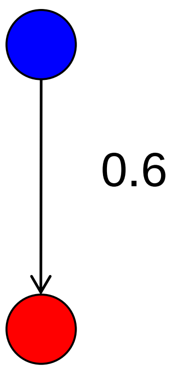
$$\dot{\phi}_1 = f$$

$$\dot{\phi}_2 = f - 0.3\sin(\phi_2 - \phi_1)$$

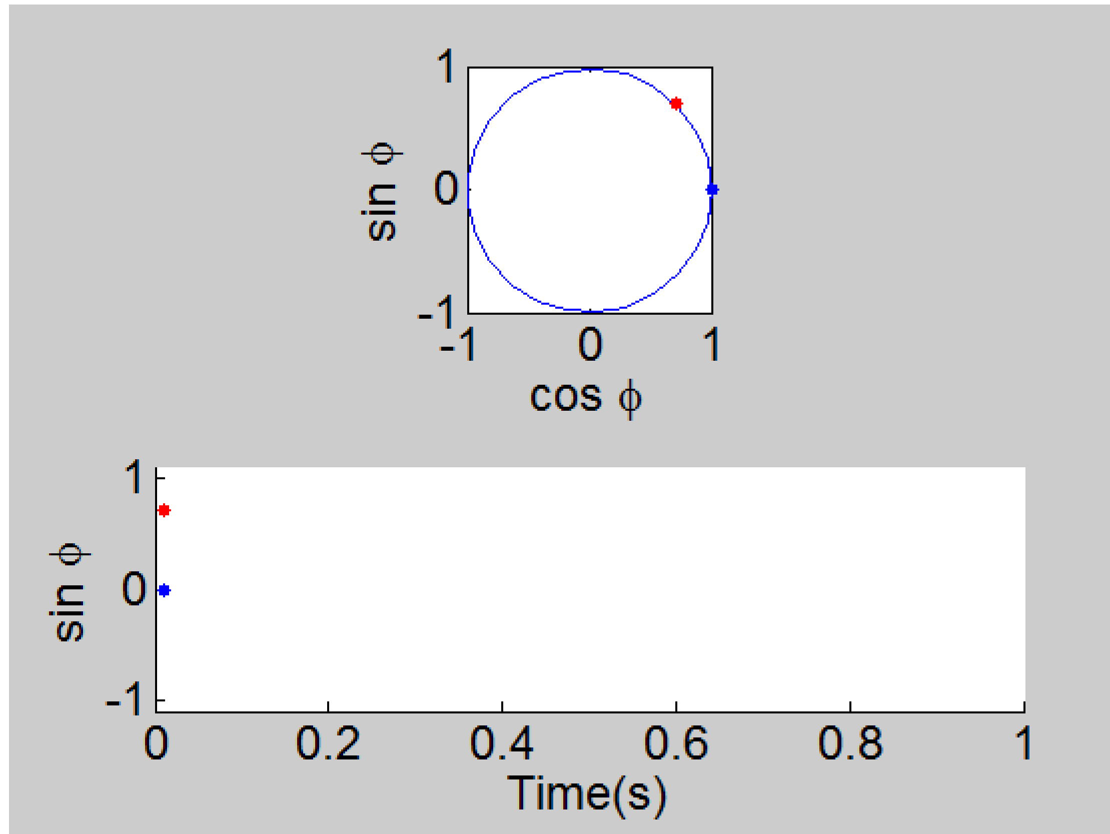


Stronger coupling

$$\dot{\phi}_1 = f$$

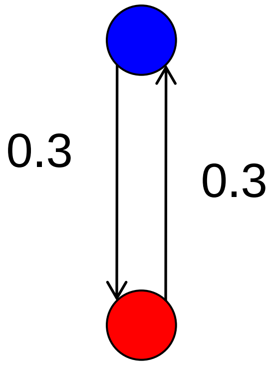


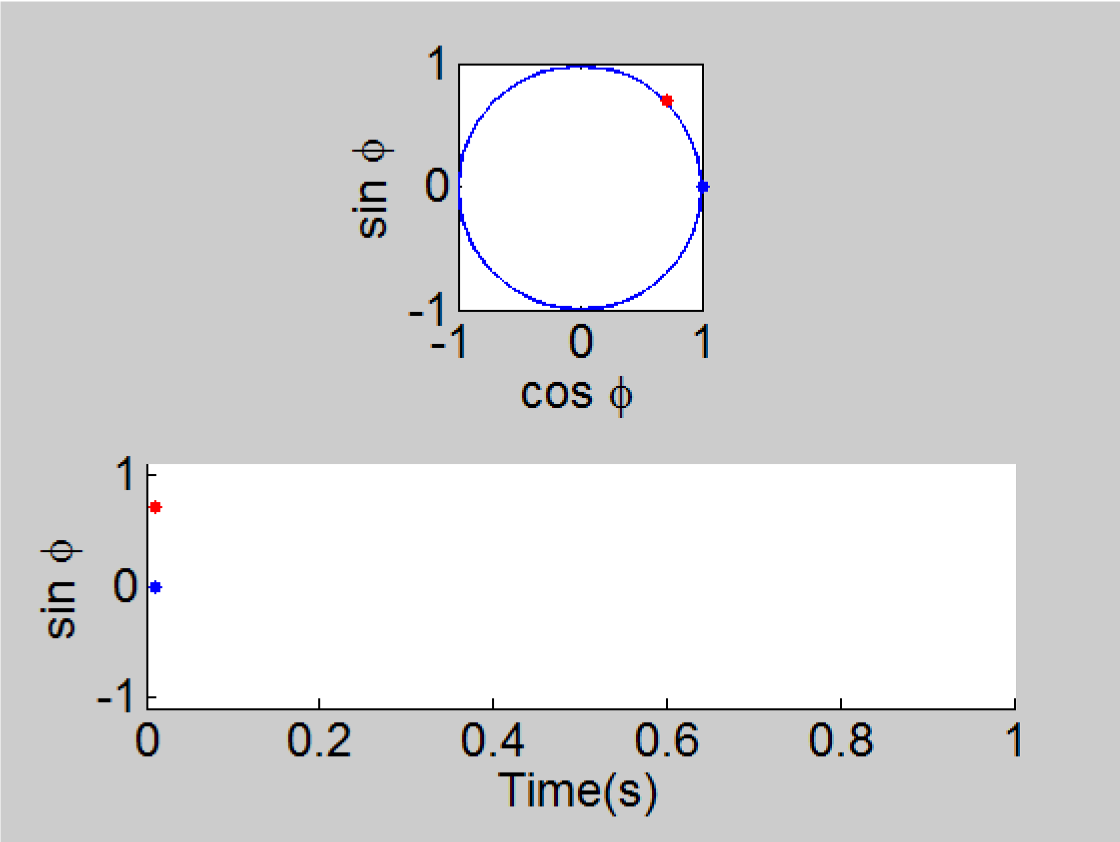
$$\dot{\phi}_2 = f - 0.3\sin(\phi_2 - \phi_1)$$



Bidirectional coupling

$$\dot{\phi}_1 = f - 0.3\sin(\phi_1 - \phi_2)$$

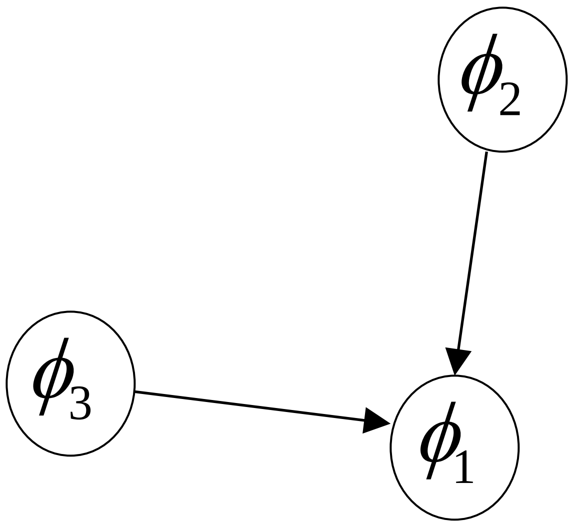




$$\dot{\phi}_2 = f - 0.3\sin(\phi_2 - \phi_1)$$

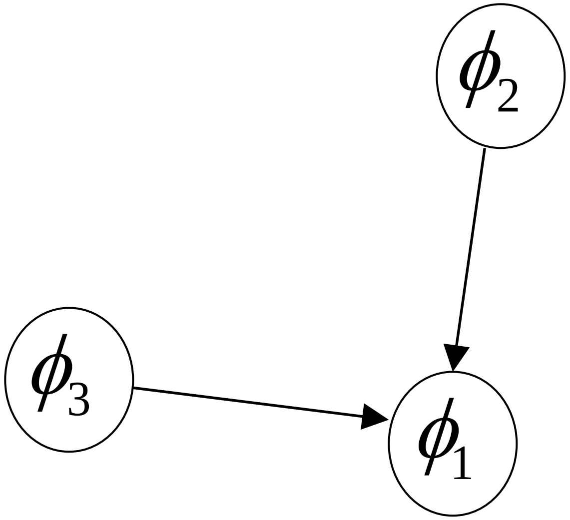
DCM for Phase Coupling

$$\dot{\phi}_i = f_i - \sum_j a_{ij} \sin(\phi_i - \phi_j)$$



DCM for Phase Coupling

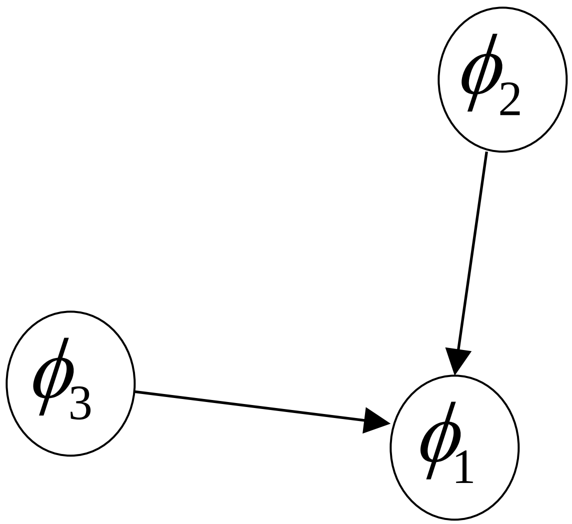
$$\dot{\phi}_i = f_i - \sum_j a_{ij} \sin(\phi_i - \phi_j)$$



$$\dot{\phi}_i = f_i - \sum_k \sum_j a_{ijk} \sin(k[\phi_i - \phi_j])$$

DCM for Phase Coupling

$$\dot{\phi}_i = f_i - \sum_j a_{ij} \sin(\phi_i - \phi_j)$$



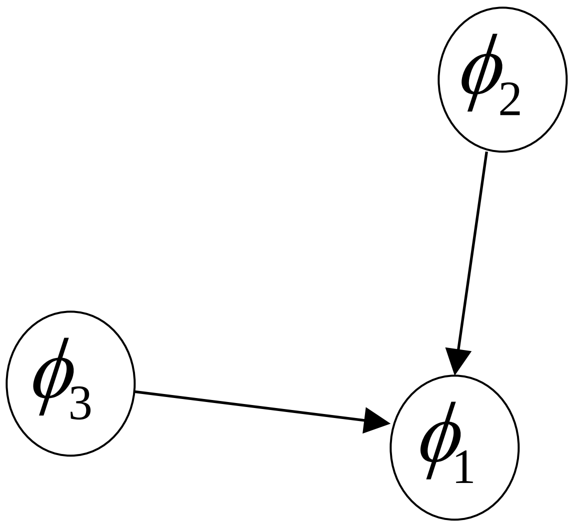
$$\dot{\phi}_i = f_i - \sum_k \sum_j a_{ijk} \sin(k[\phi_i - \phi_j])$$

$$\dot{\phi}_i = f_i - \sum_k \sum_j a_{ijk} \sin(k[\phi_i - \phi_j]) - \sum_k \sum_j b_{ijk} \cos(k[\phi_i - \phi_j])$$

Phase interaction function is an arbitrary order Fourier series

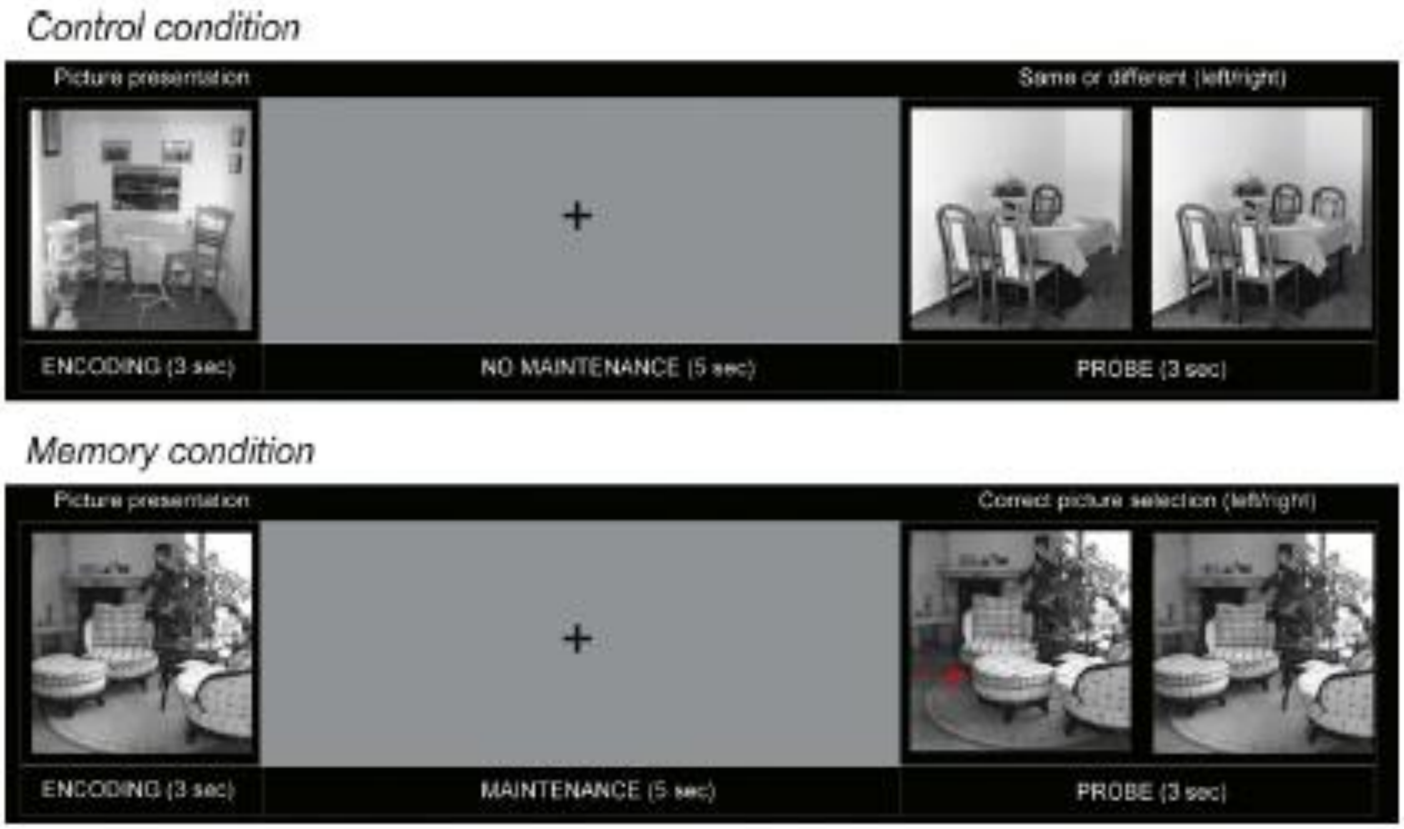
DCM for Phase Coupling

$$\dot{\phi}_i = f_i - \sum_j a_{ij} \sin(\phi_i - \phi_j)$$



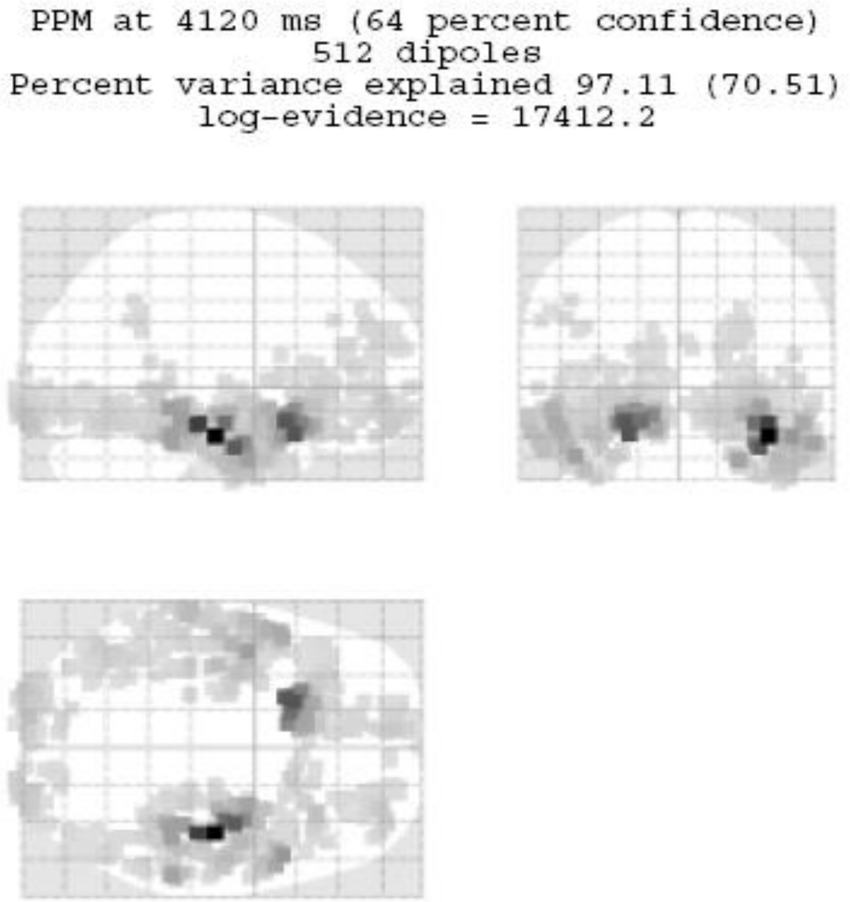
Allow connections to depend on experimental condition

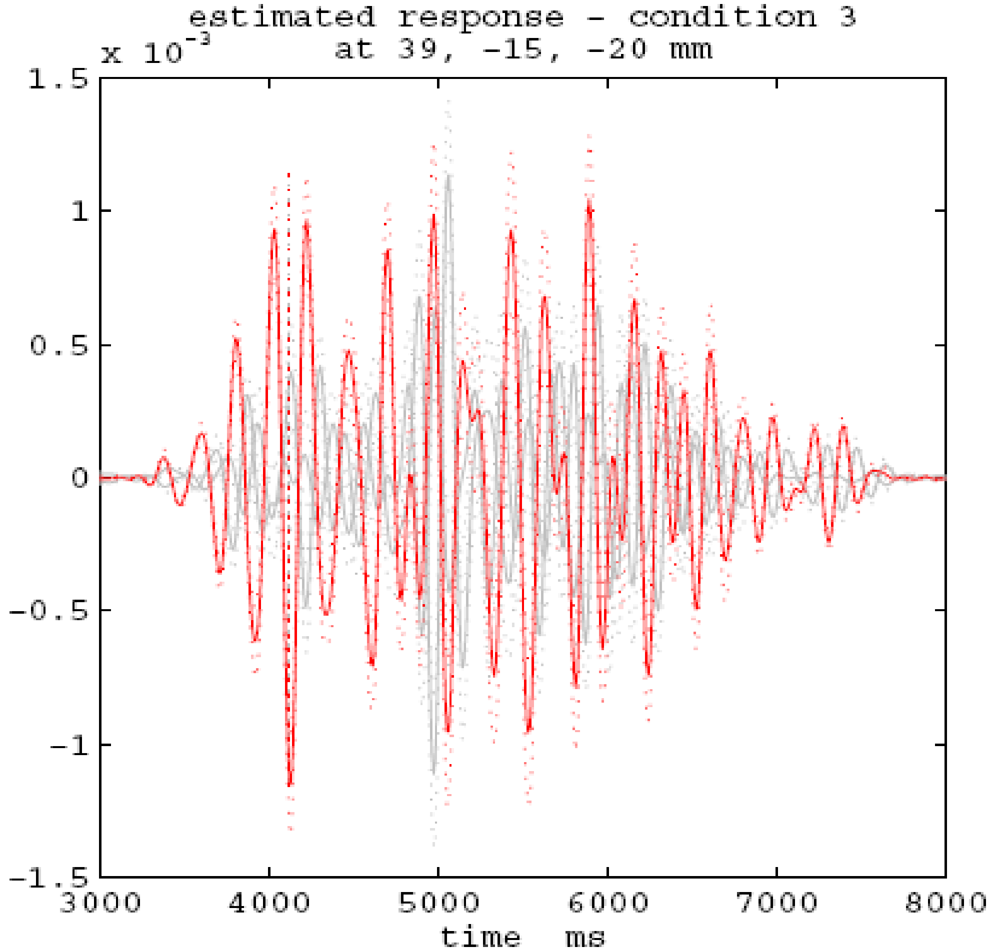
MEG Example



Fuentemilla et al, Current Biology, 2010

Delay activity (4-8Hz)




estimated response - condition 3
at 39, -15, -20 mm
x 10^-3
1.5
1
0.5
0
-0.5
-1
-1.5
3000
4000
5000
6000
7000
8000
time ms

Questions

- Duzel et al. find different patterns of theta-coupling in the delay period dependent on task.

- Pick 3 regions based on [previous source reconstruction]

  1. Right MTL [27,-18,-27] mm
  2. Right VIS [10,-100,0] mm
  3. Right IFG [39,28,-12] mm

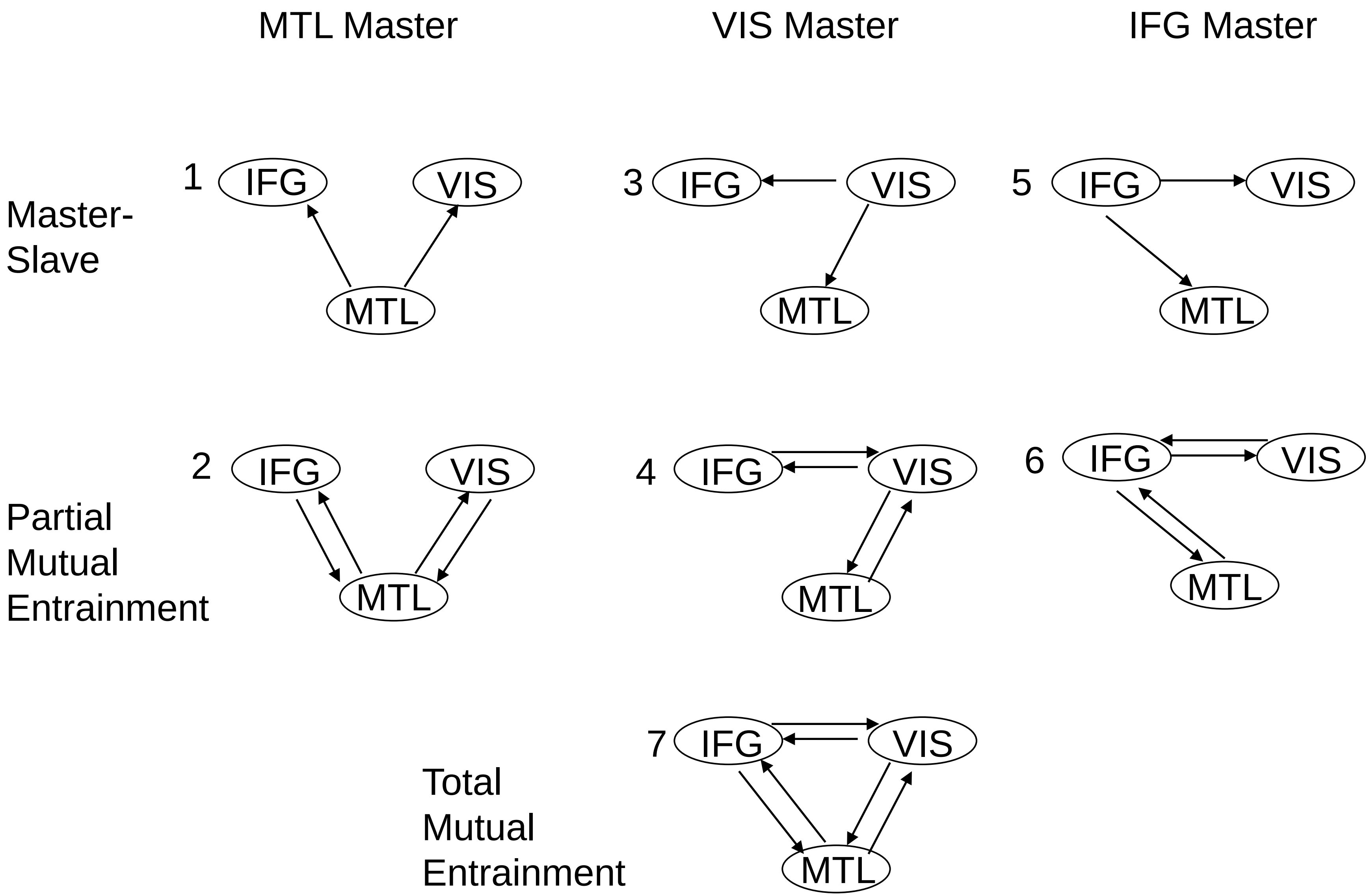
- Fit models to control data (10 trials) and memory data (10 trials). Each trial comprises first 1sec of delay period.

- Find out if structure of network dynamics is Master-Slave (MS) or (Partial/Total) Mutual Entrainment (ME)

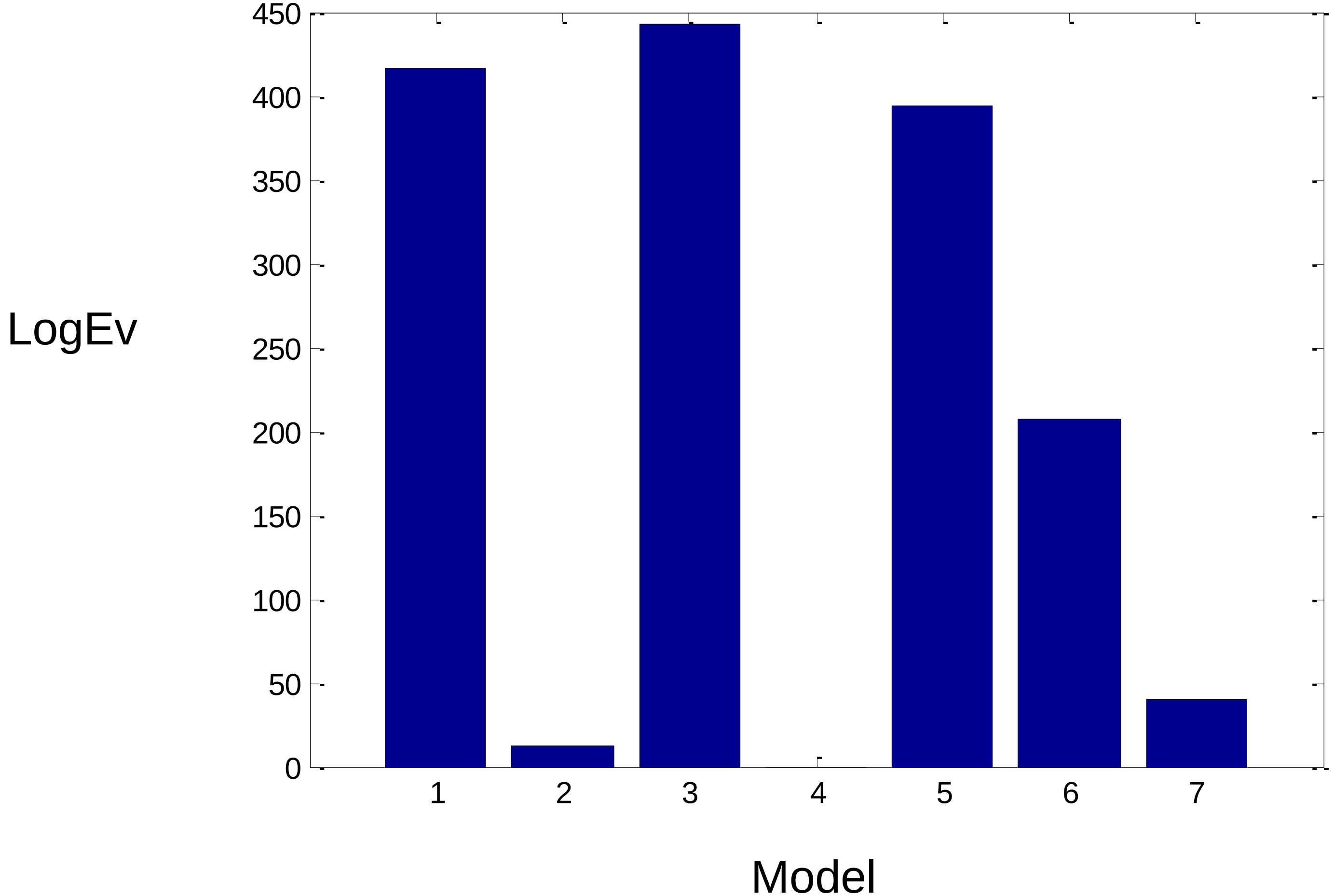
- Which connections are modulated by memory task ?

Data Preprocessing

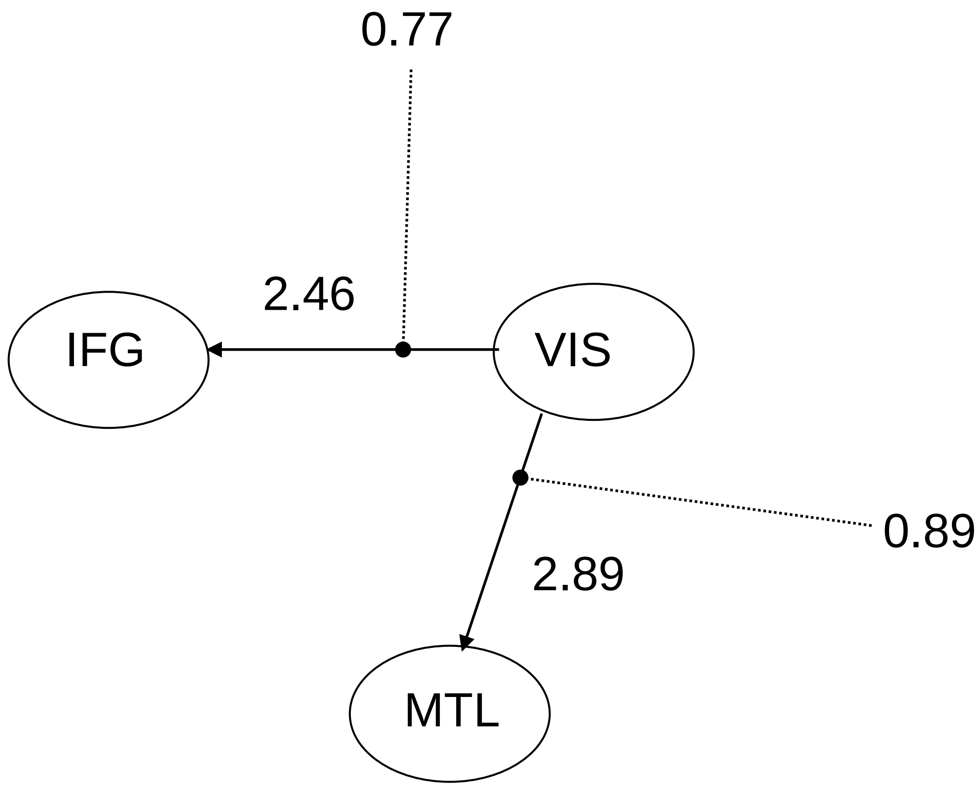
- Source reconstruct activity in areas of interest (with fewer sources than sensors and known location, then pinv will do; Baillet 01)
- Bandpass data into frequency range of interest
- Hilbert transform data to obtain instantaneous phase
- Use multiple trials per experimental condition



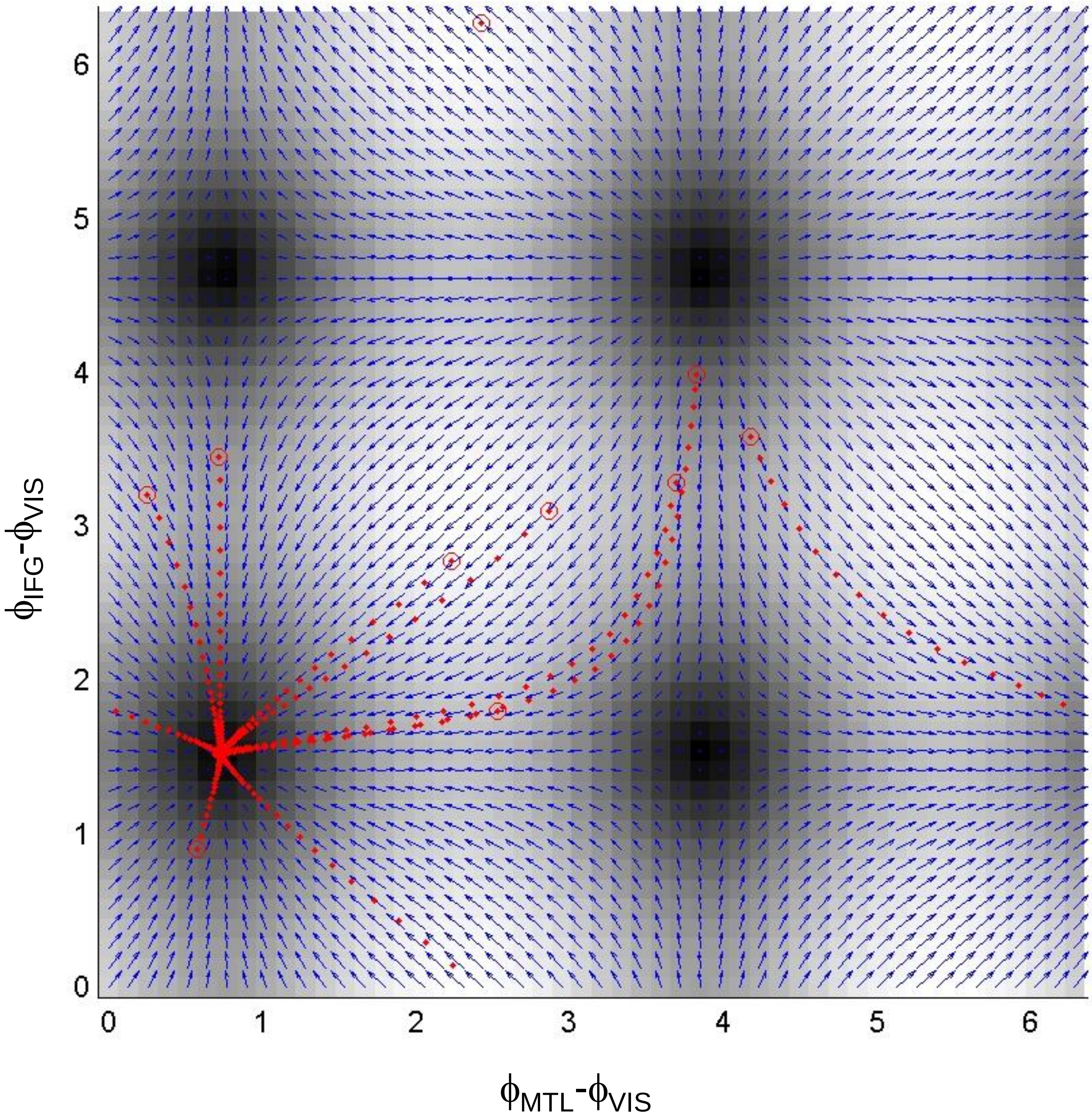
MTL Master
VIS Master
IFG Master
Master-
Slave
Partial
Mutual
Entrainment
Total
Mutual
Entrainment
1
IFG
VIS
MTL
3
IFG
VIS
MTL
5
IFG
VIS
MTL
2
IFG
VIS
MTL
4
IFG
VIS
MTL
6
IFG
VIS
MTL
7
IFG
VIS
MTL



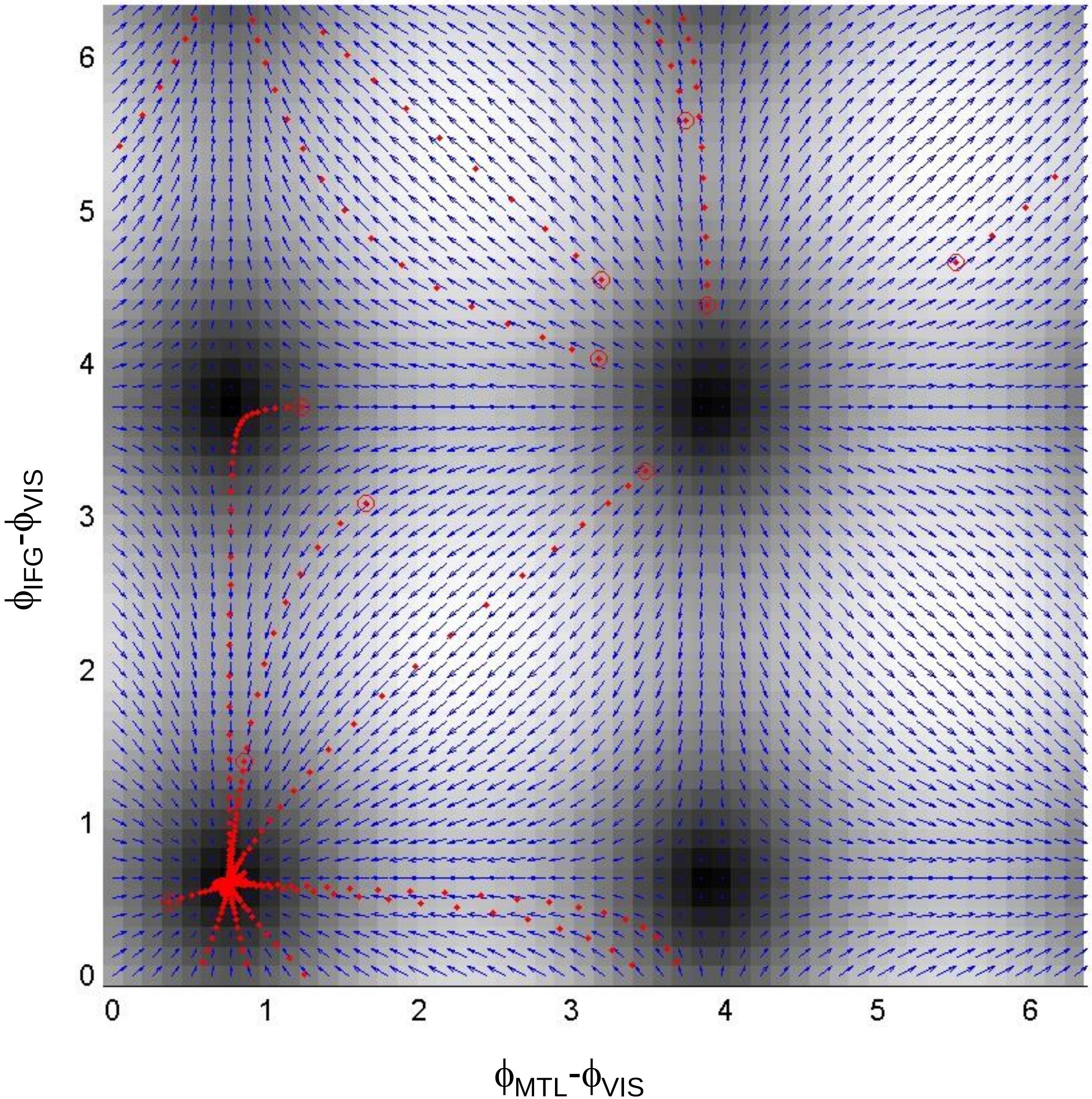
LogEv
450
400
350
300
250
200
150
100
50
0
1
2
3
4
5
6
7
Model

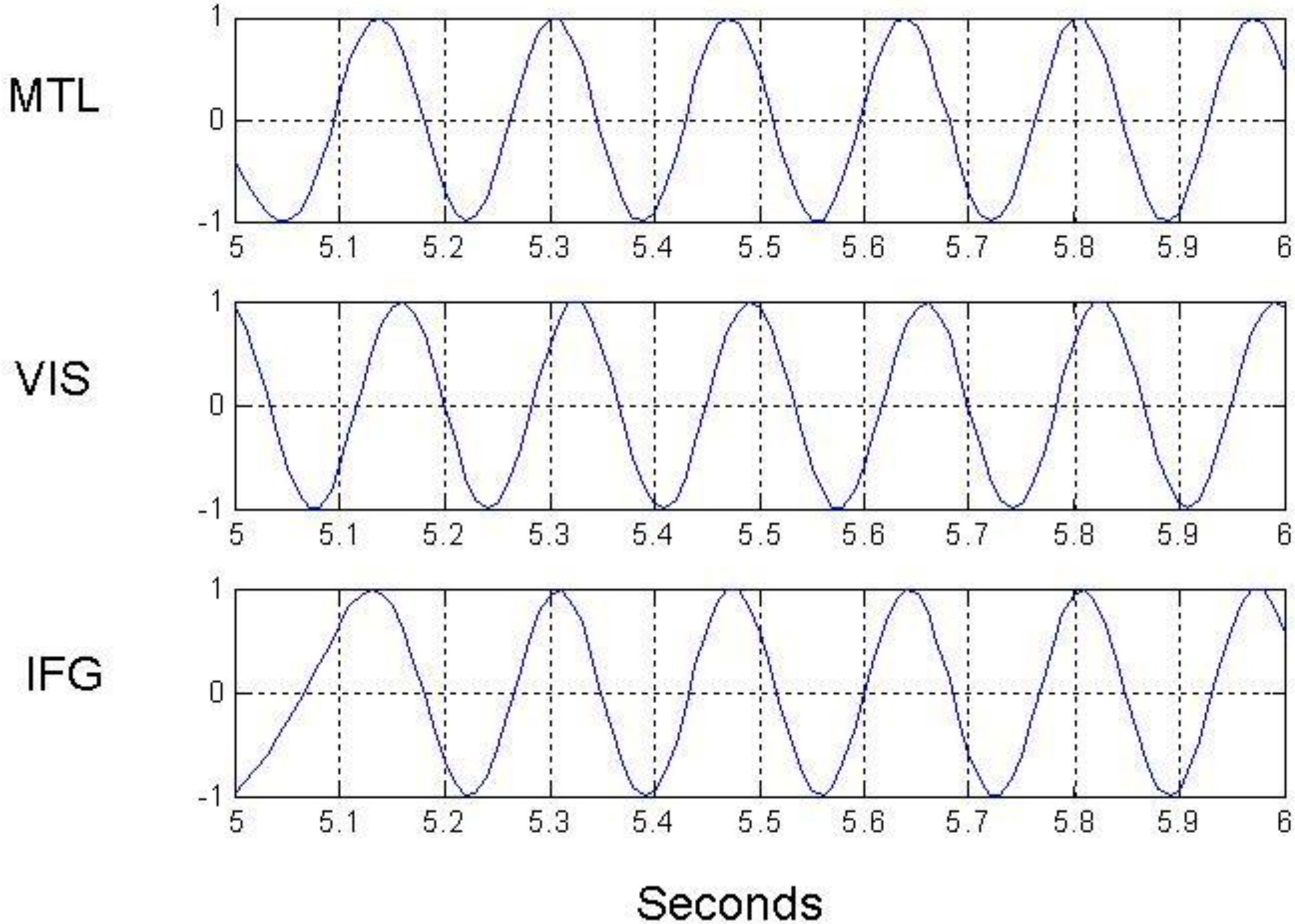

0.77
2.46
IFG
VIS
0.89
2.89
MTL

Control



Memory




MTL
VIS
IFG
1
0
-1
5
5.1
5.2
5.3
5.4
5.5
5.6
5.7
5.8
5.9
6
Seconds

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Dynamic Causal Models for phase coupling

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ABSTRACT

This paper presents an extension of the Dynamic Causal Modelling (DCM) framework to the analysis of phase-coupled data. A weakly coupled oscillator approach is used to describe dynamic phase changes in a network of oscillators. The use of Bayesian model comparison allows one to infer the mechanisms underlying synchronization processes in the brain. For example, whether activity is driven by master-slave versus mutual entrainment mechanisms. Results are presented on synthetic data from physiological models and on MEG data from a study of visual working memory.