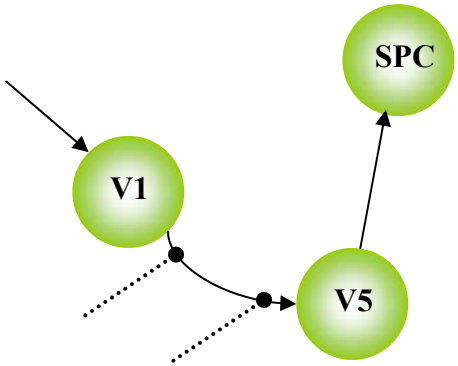
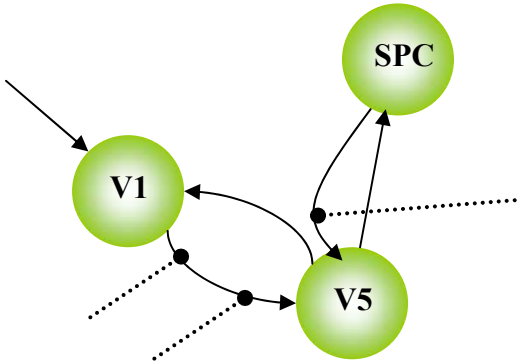
Bayesian selection of dynamic causal models for fMRI



Will Penny



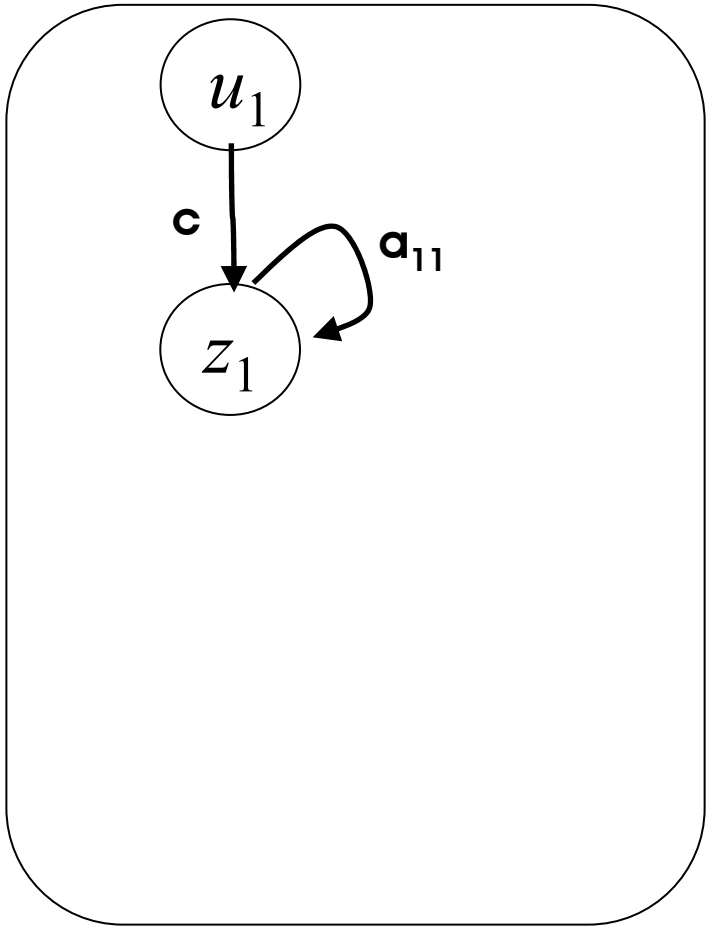
Olivier David, Karl Friston, Lee Harrison,
Andrea Mechelli, Klaas Stephan

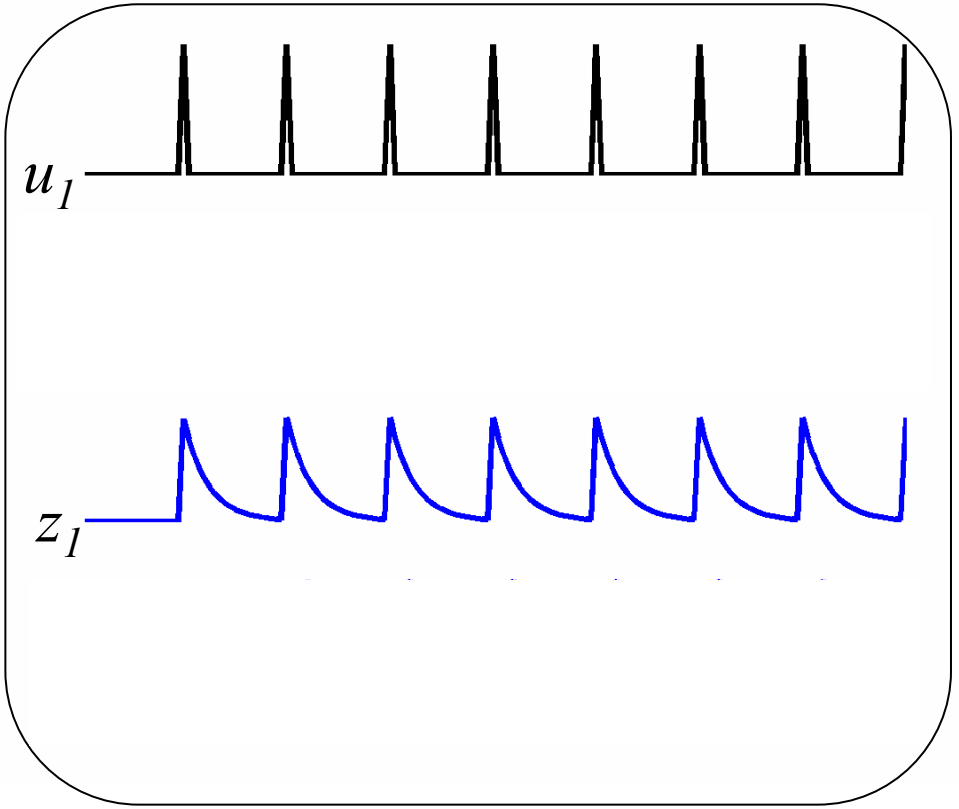
Wellcome Department of Imaging Neuroscience, ION, UCL, UK.

The brain as a dynamical system ? Bridging the gap between models and data, HBM Workshop, Budapest, Hungary, June 16 2004.

Single region

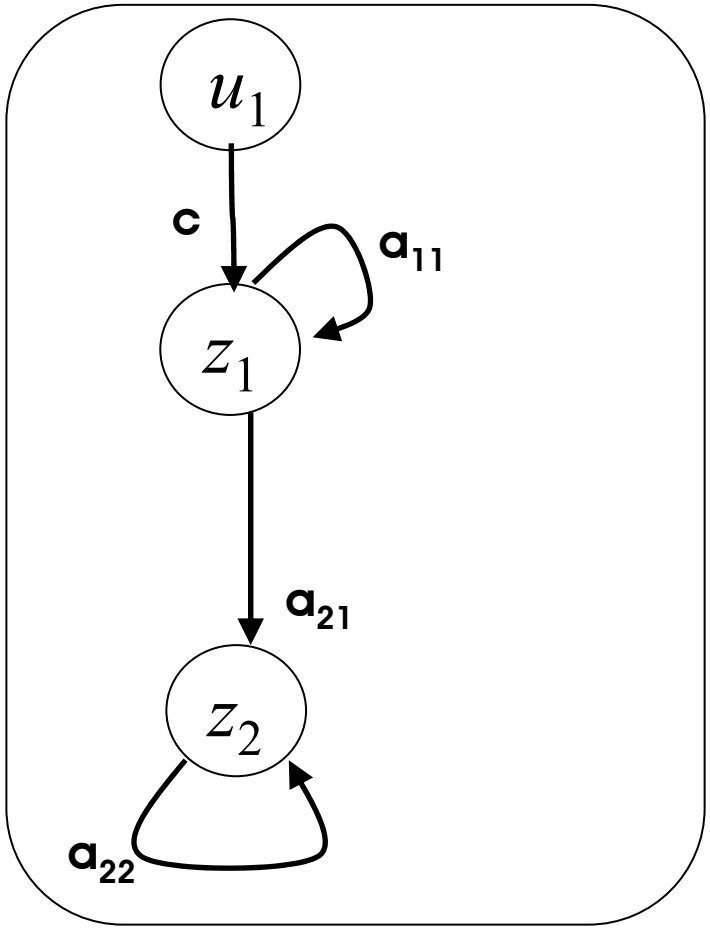
$$\dot{z}_1 = a_{11} z_1 + c u_1$$

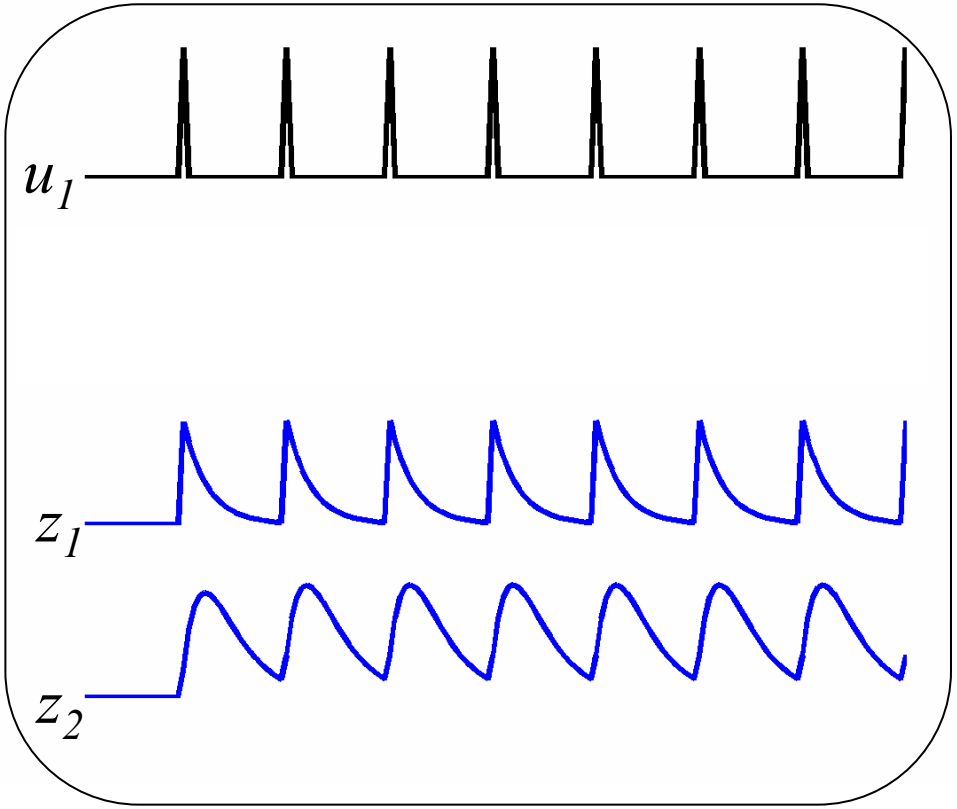




Multiple regions

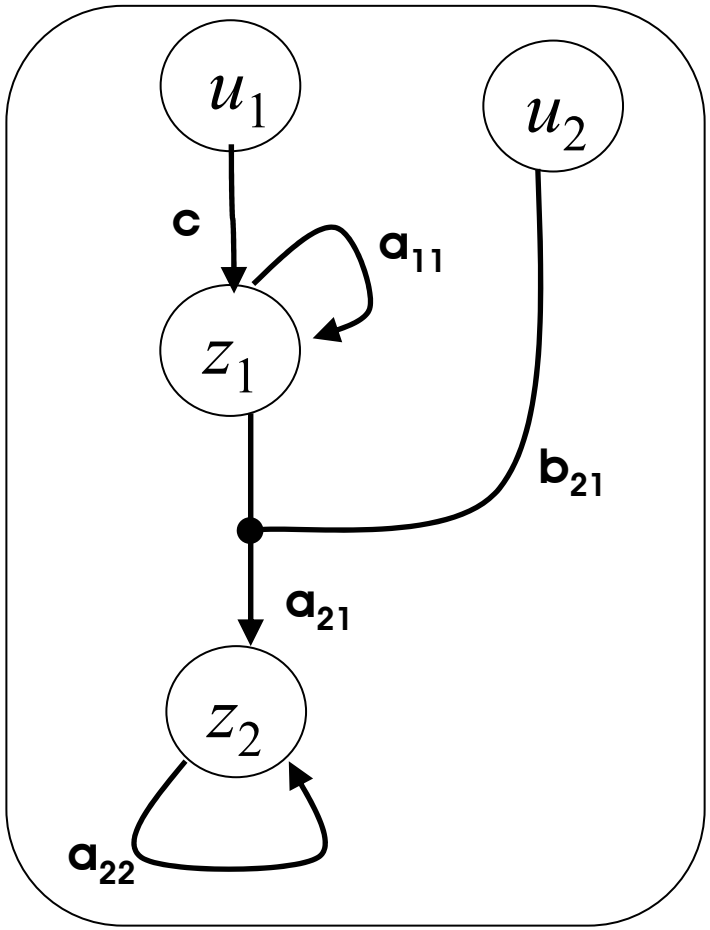
$$\begin{bmatrix} \dot{z}_1 \\ \dot{z}_2 \end{bmatrix} = \begin{bmatrix} a_{11} & 0 \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} z_1 \\ z_2 \end{bmatrix} + \begin{bmatrix} c \\ 0 \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \end{bmatrix}$$

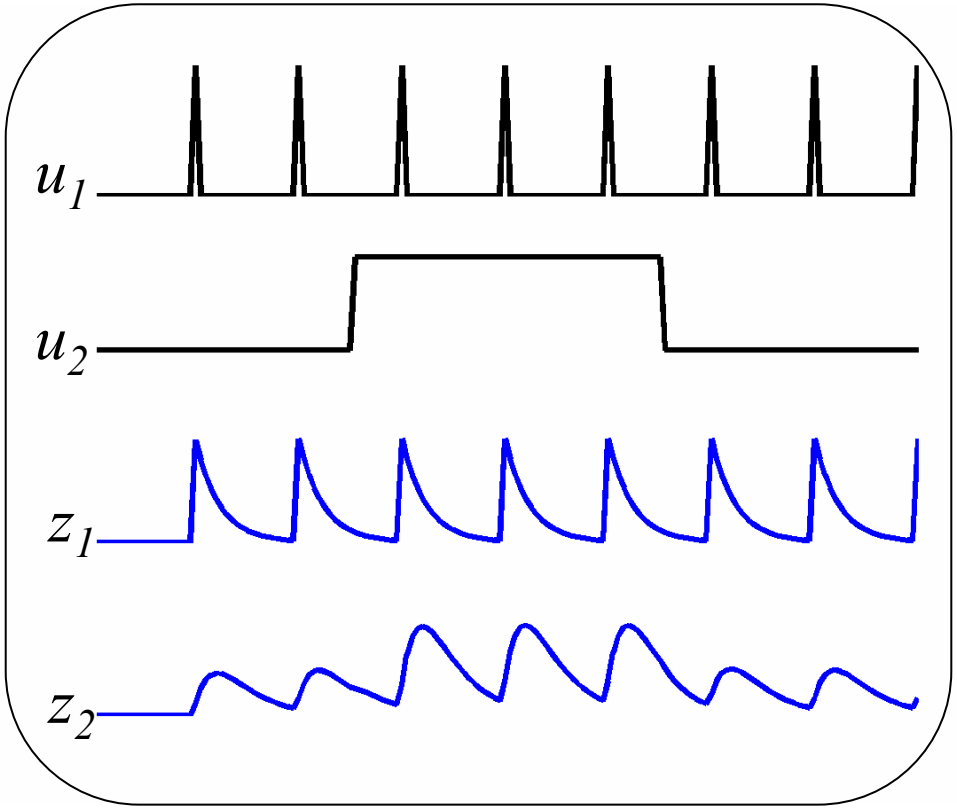




Modulatory inputs

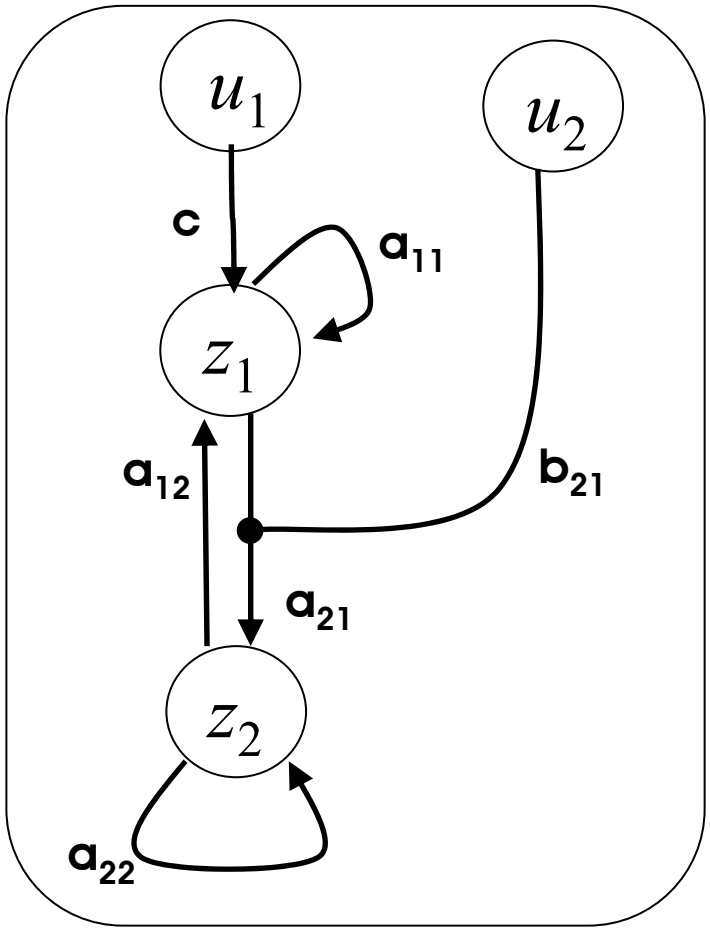
$$\begin{bmatrix} \dot{z}_1 \\ \dot{z}_2 \end{bmatrix} = \begin{bmatrix} a_{11} & 0 \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} z_1 \\ z_2 \end{bmatrix} + u_2 \begin{bmatrix} 0 & 0 \\ b_{21} & 0 \end{bmatrix} \begin{bmatrix} z_1 \\ z_2 \end{bmatrix} + \begin{bmatrix} c \\ 0 \end{bmatrix} \begin{bmatrix}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

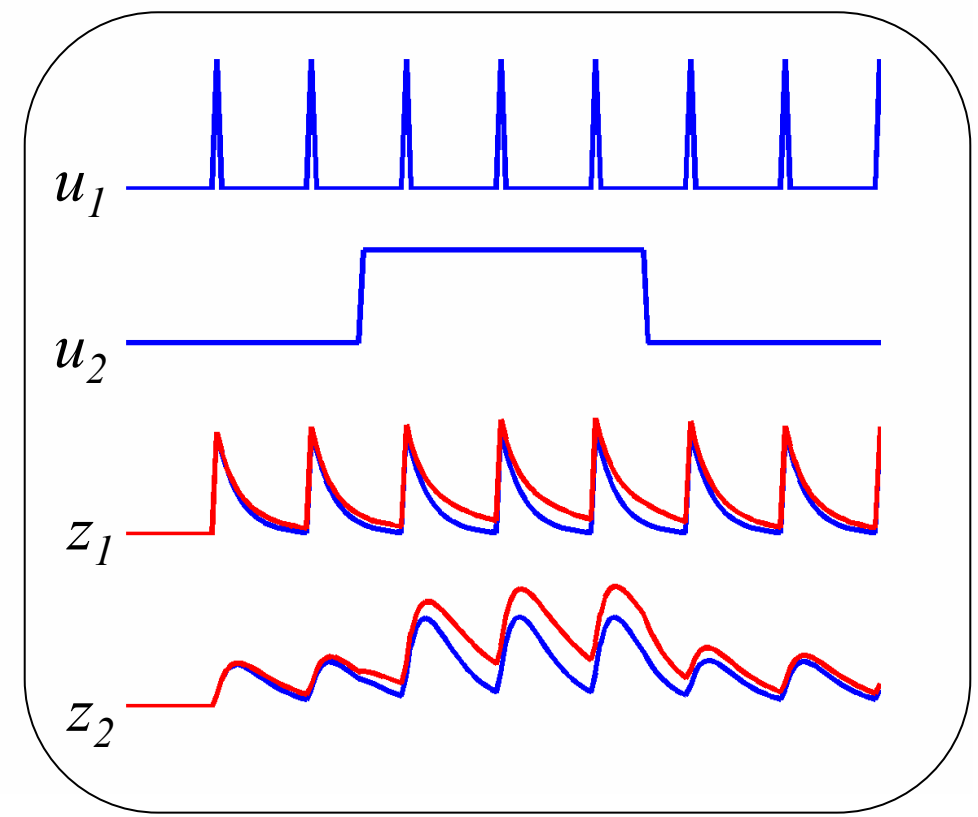




Reciprocal connections

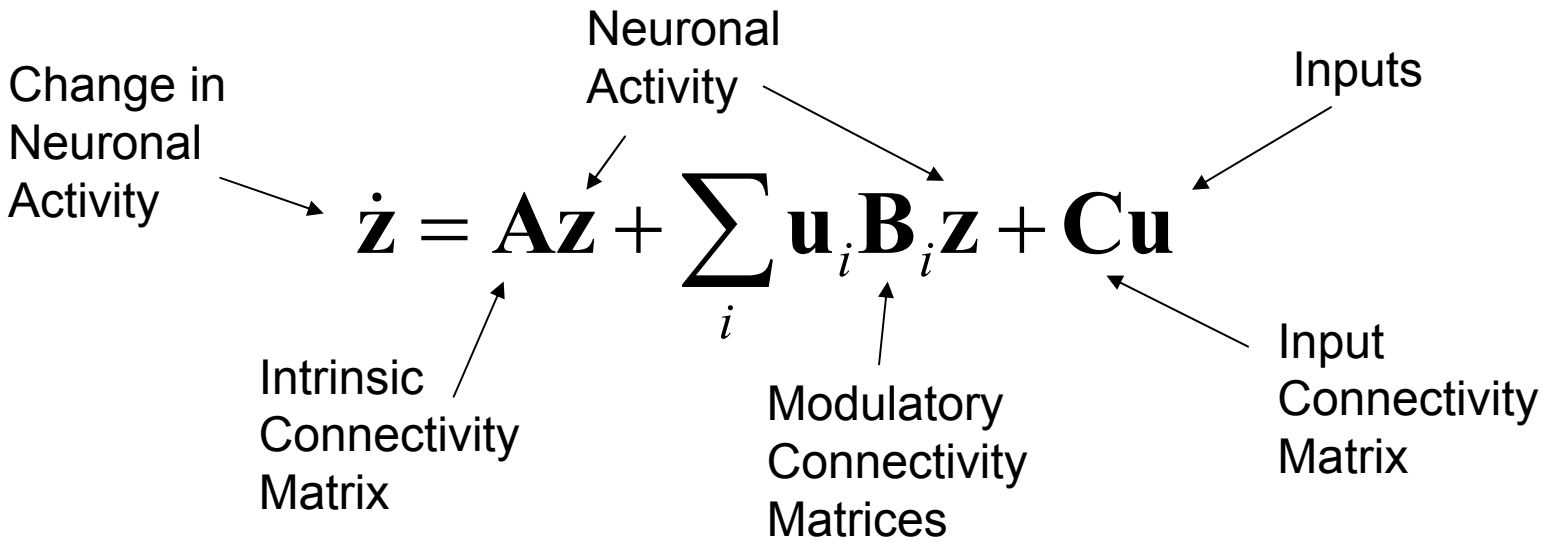
$$\begin{bmatrix} \dot{z}_1 \\ \dot{z}_2 \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} z_1 \\ z_2 \end{bmatrix} + u_2 \begin{bmatrix} 0 & 0 \\ b_{21} & 0 \end{bmatrix} \begin{bmatrix} z_1 \\ z_2 \end{bmatrix} + \begin{bmatrix} c \\ 0 \end{bmatrix} \begin{bmatrix}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

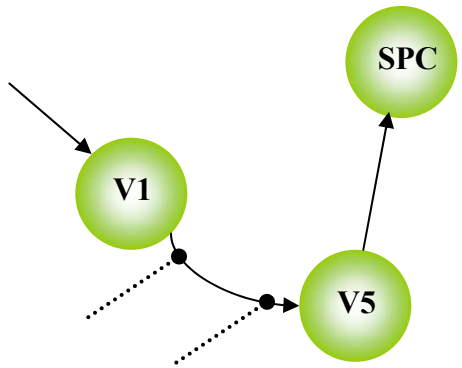




DCM for fMRI

Neurodynamics:





Hemodynamics

For each region:

Hemodynamic variables

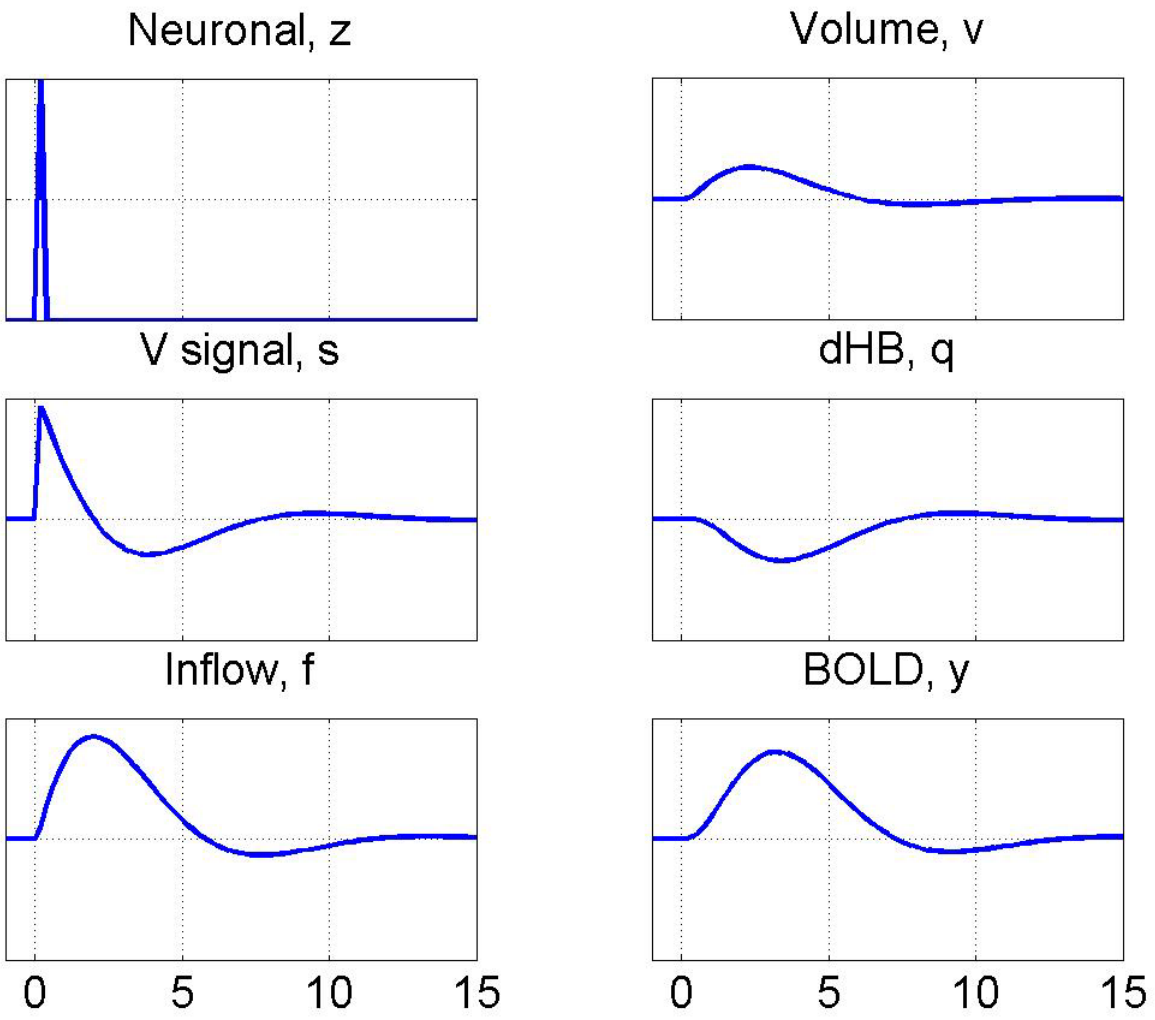
$$\mathbf{x} = [s, f, v, q]$$

Dynamics

$$\dot{\mathbf{x}} = g(\mathbf{x}, z, \mathbf{h})$$

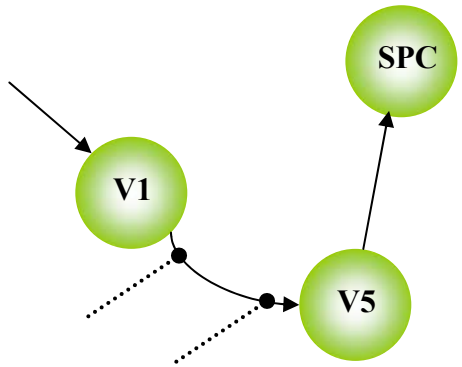
$$y = b(\mathbf{x})$$

Hemodynamic parameters



Model Comparison I

Model, m



Parameters: $\boldsymbol{\theta} = \{\mathbf{A}, \mathbf{B}, \mathbf{C}, \mathbf{h}\}$

Posterior Likelihood Prior

$$p(\boldsymbol{\theta} \mid \mathbf{y}, m) = \frac{p(\mathbf{y} \mid \boldsymbol{\theta}, m)\, p(\boldsymbol{\theta} \mid m)}{p(\mathbf{y} \mid m)}$$

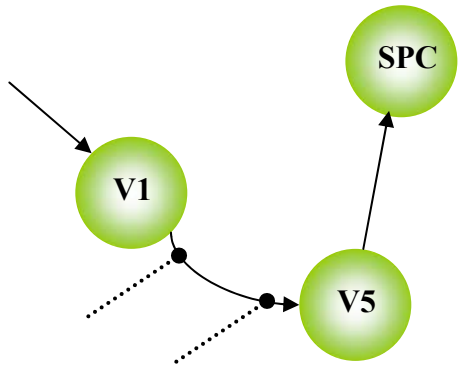
Evidence $\longrightarrow$ $p(\mathbf{y} \mid m) = \int p(\mathbf{y} \mid \boldsymbol{\theta}, m)\, p(\boldsymbol{\theta} \mid m)\, d\boldsymbol{\theta}$

Laplace, AIC, BIC approximations

Model fit + complexity

Model Comparison II

Model, m



Parameters: $\boldsymbol{\theta} = \{\mathbf{A}, \mathbf{B}, \mathbf{C}, \mathbf{h}\}$

Parameter Posterior

Likelihood

Parameter Prior

$$p(\boldsymbol{\theta} \mid \mathbf{y}, m) = \frac{p(\mathbf{y} \mid \boldsymbol{\theta}, m)\, p(\boldsymbol{\theta} \mid m)}{p(\mathbf{y} \mid m)}$$

Model Posterior

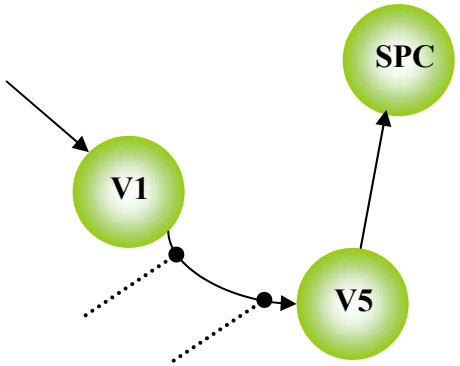
Evidence

Model Prior

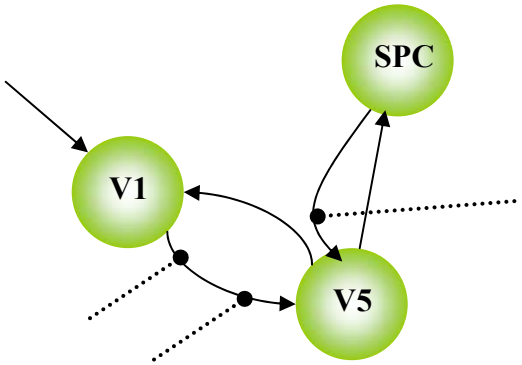
$$p(m \mid \mathbf{y}) = \frac{p(\mathbf{y} \mid m)\, p(m)}{p(\mathbf{y})}$$

Model Comparison III

Model, m=i



Model, m=j



Model Evidences:

$$p(\mathbf{y} \mid m = i) = \int p(\mathbf{y} \mid \boldsymbol{\theta}, m = i)\, p(\boldsymbol{\theta} \mid m = i) d\boldsymbol{\theta}$$

$$p(\mathbf{y} \mid m = j) = \int p(\mathbf{y} \mid \boldsymbol{\theta}, m = j)\, p(\boldsymbol{\theta} \mid m = j) d\boldsymbol{\theta}$$

Bayes factor:

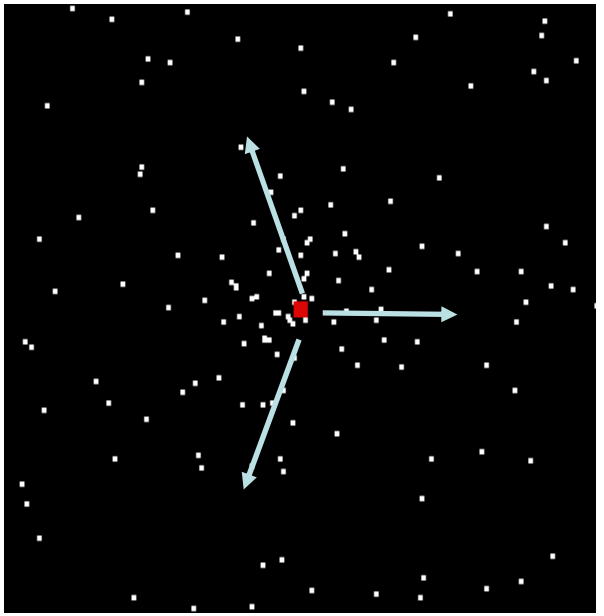
$$B_{ij} = \frac{p(\mathbf{y} \mid m = i)}{p(\mathbf{y} \mid m = j)}$$

1 to 3:	Weak
3 to 20:	Positive
20 to 100:	Strong
>100:	Very Strong

Attention to Visual Motion

Buchel et al. 1997

STIMULI
250 radially moving dots at 4.7 degrees/s



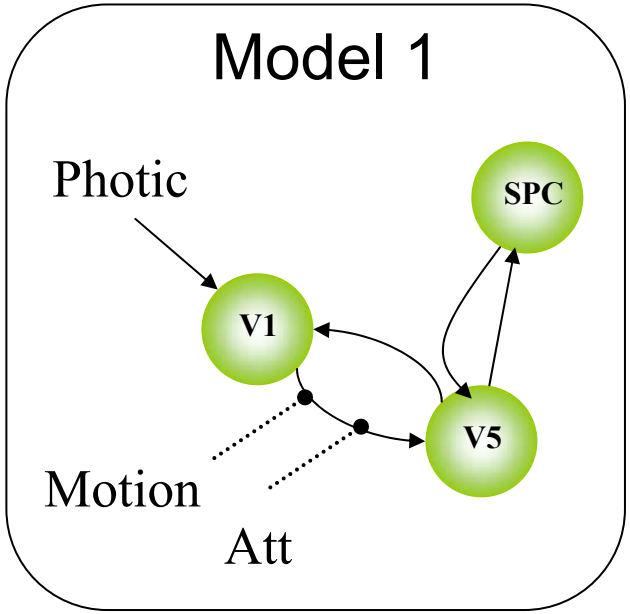
PRE-SCANNING
5 x 30s trials with 5 speed changes (reducing to 1%)
Task - detect change in radial velocity

SCANNING (no speed changes)
6 normal subjects, 4 100 scan sessions;
each session comprising 10 scans of 4 different condition

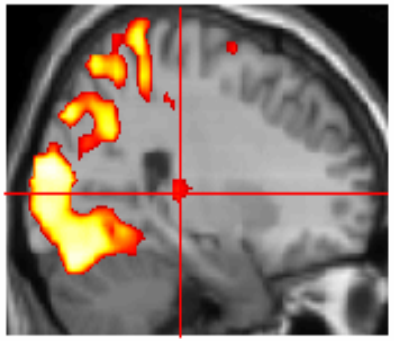
Experimental Factors

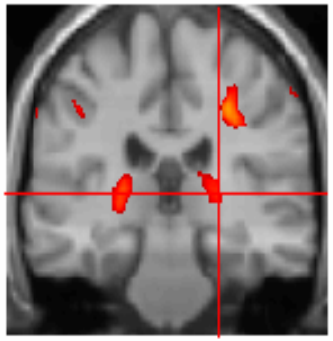
1. Photic
2. Motion
3. Attention

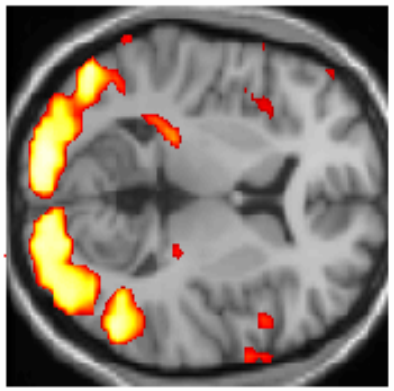
Specify regions of interest



GLM analysis

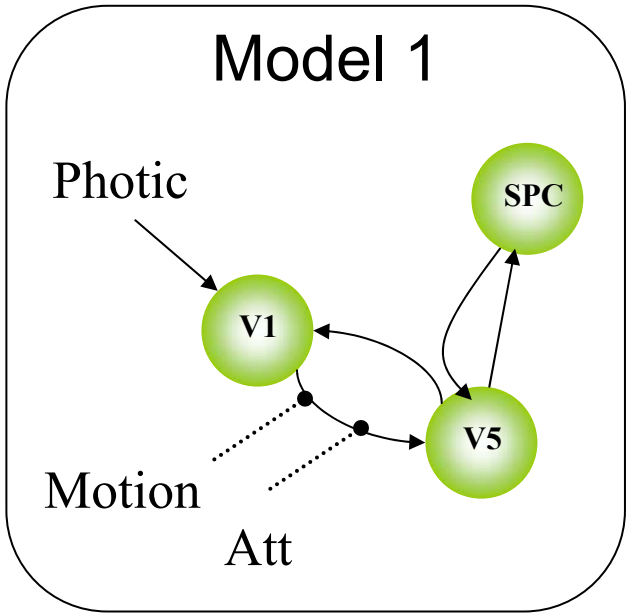


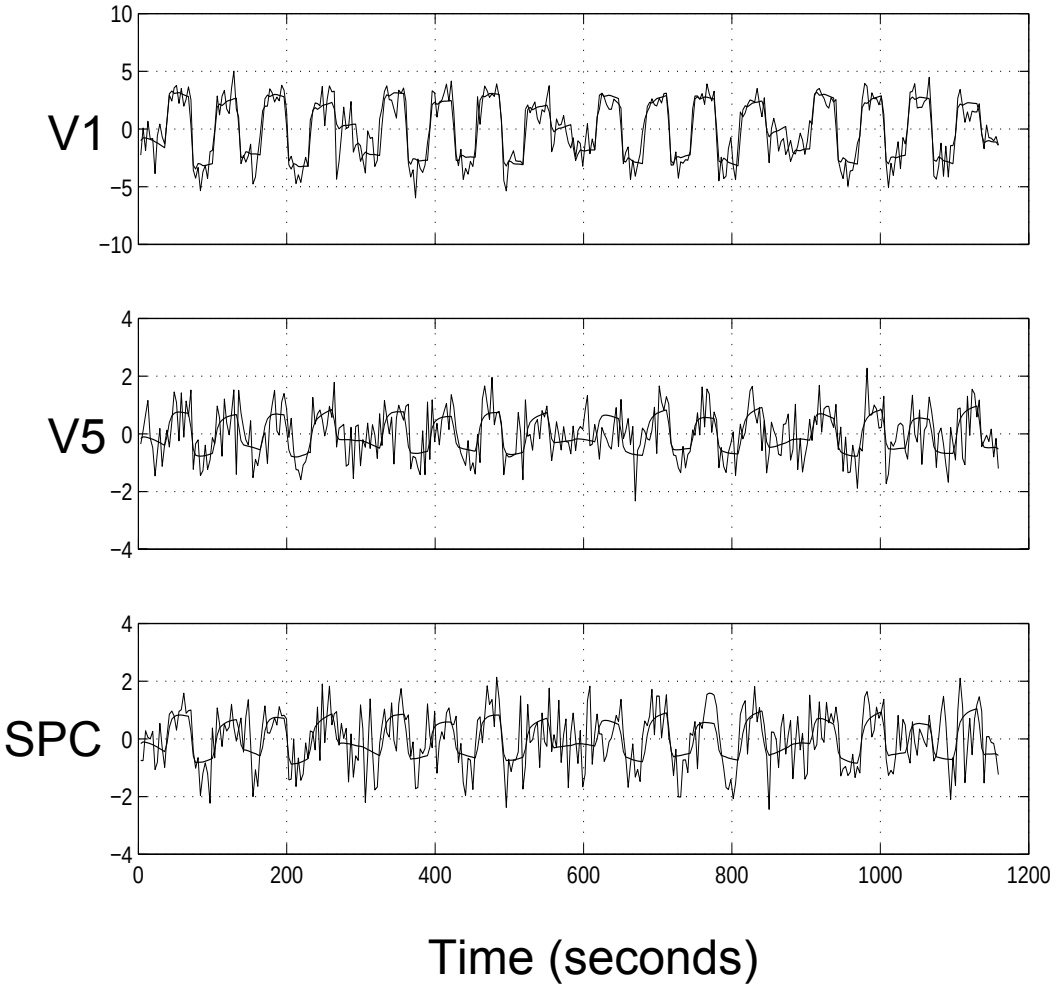


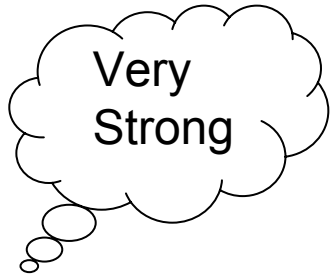


Identify regions of Interest eg. V1, V5, SPC

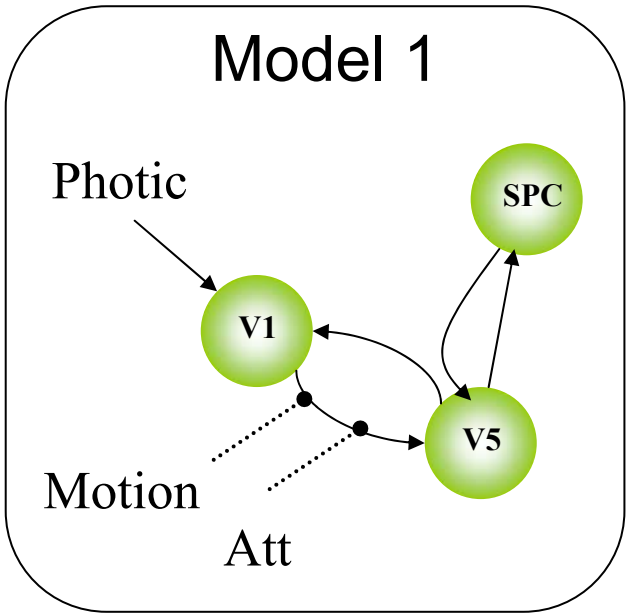
Estimation

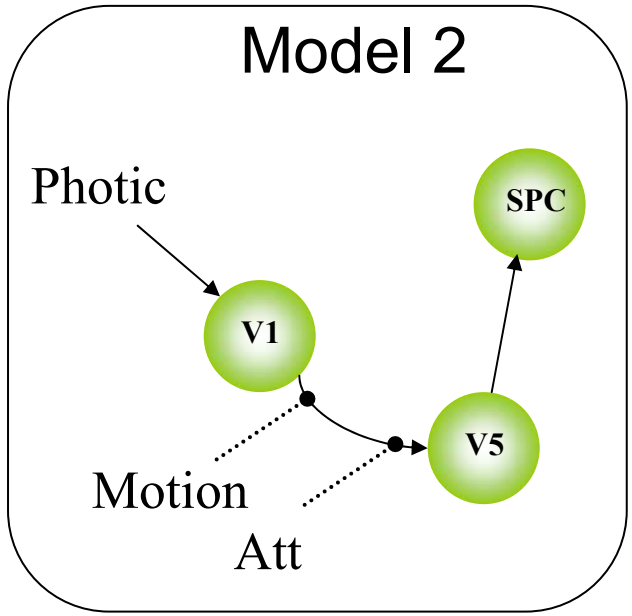

Model 1
Photic
SPC
V1
V5
Motion
Att


V1
V5
SPC
10
5
0
−5
−10
4
2
0
−2
−4
0
200
400
600
800
1000
1200
Time (seconds)



Bayes Factor $B_{12} > 10^{19}$

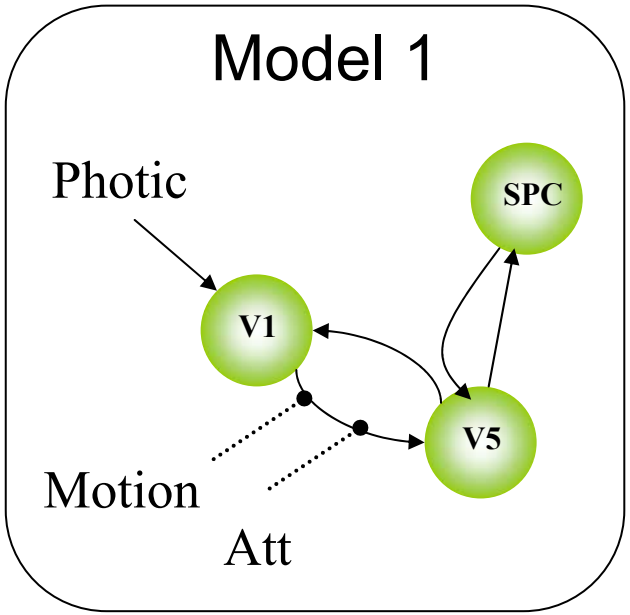


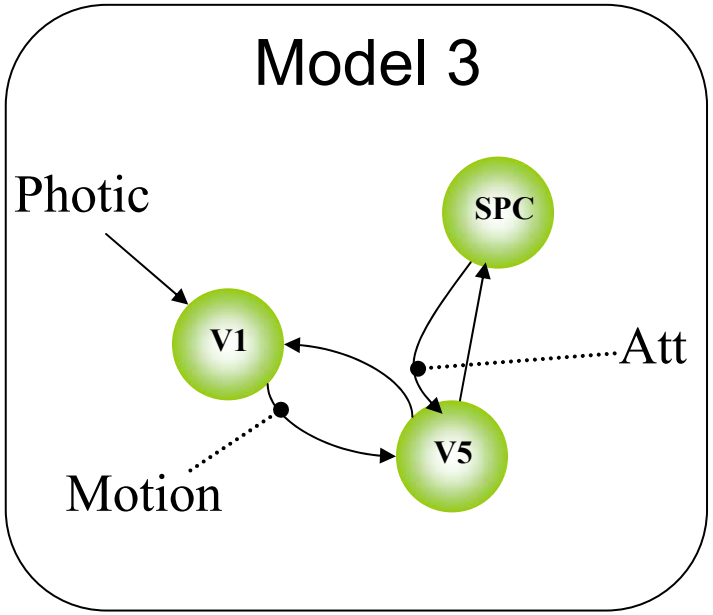


Positive

Bayes Factor

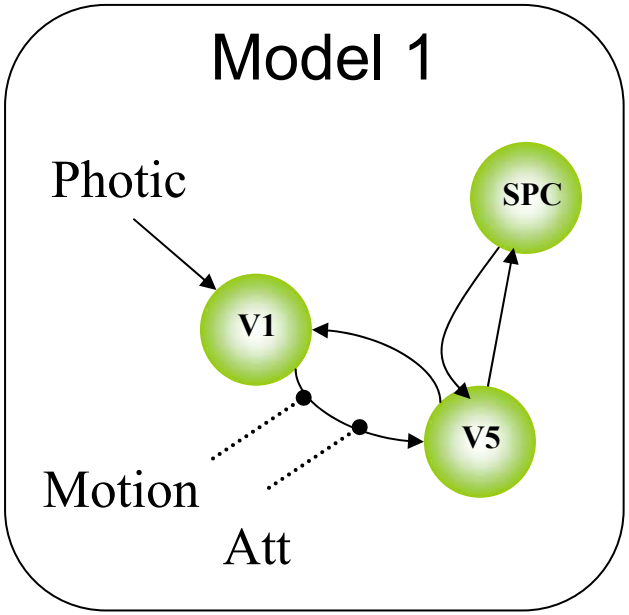
$B_{13}=3.6$

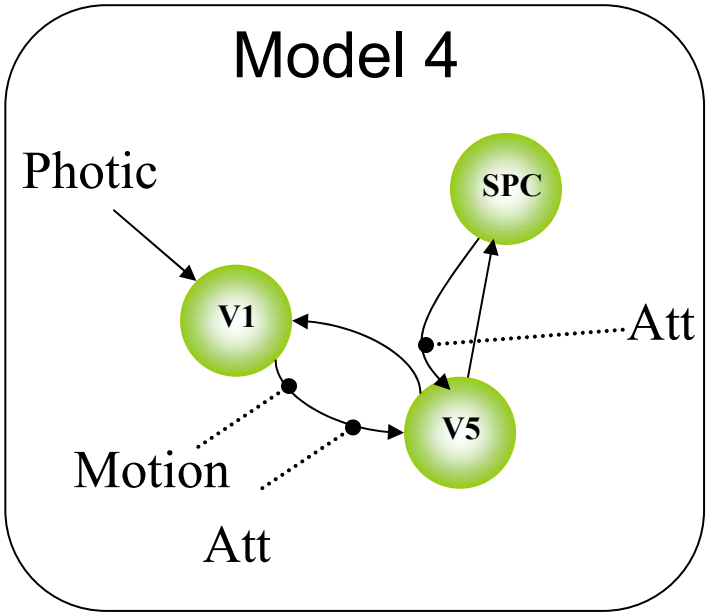




Weak

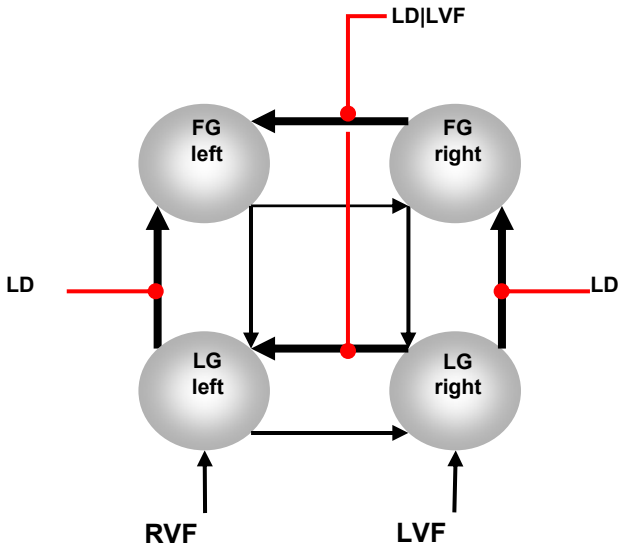
Bayes Factor $B_{14}=2.8$





Further Applications

1. Klaas Stephan et al. HBM 04 – Poster TH154, Thurs 1pm



LD: Letter decision

LVF: left visual field

FG: Fusiform gyrus

LG: Lingual gyrus

Dominant right->left modulation during letter tasks

LG and FG important for hemispheric integration (not MOG)

2. Olivier David et al. BIOMAG 04 – DCM for ERPs