Time series analysis

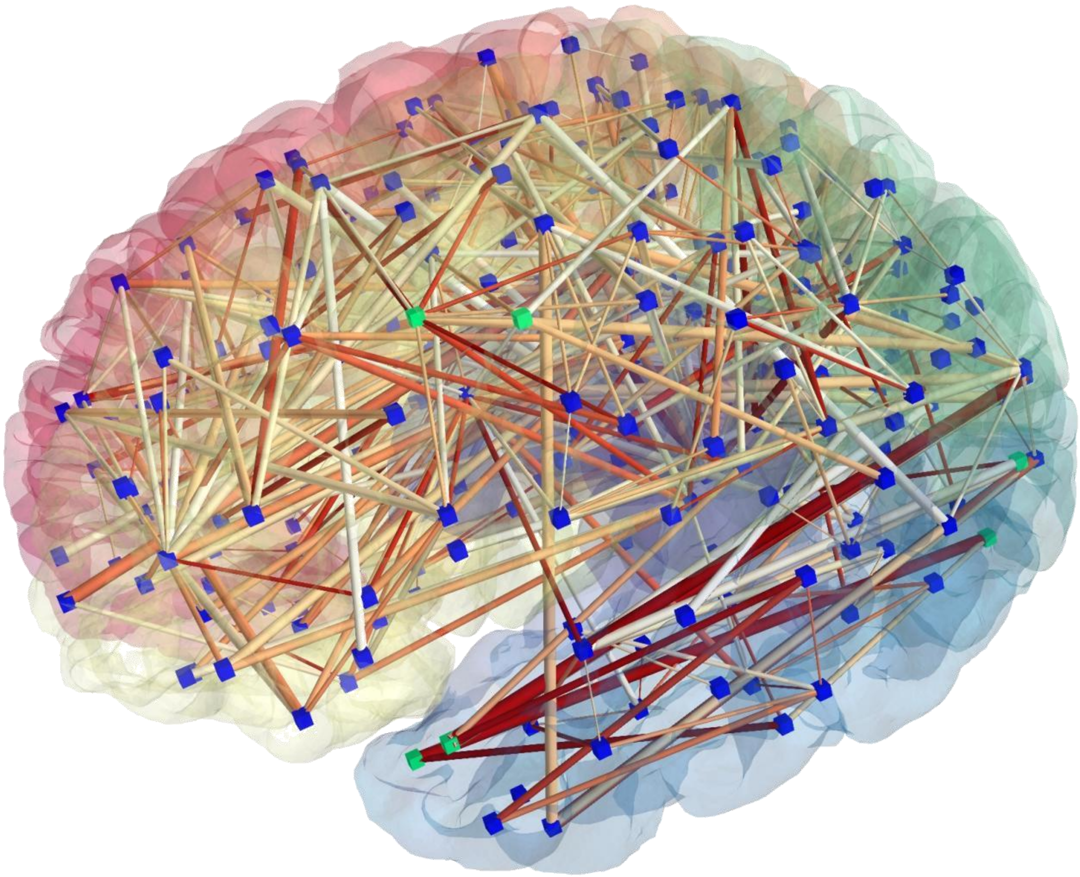
Lecture 10. Causality in time series

Dr. Khamidov Obidjon

- Theory
  - **Why DCM?**
  - **What DCM does**
  - **The State Equation**

- Application
  - Planning DCM studies
  - Hypotheses
  - How to complete in SPM

Brains as Systems



Background to DCM

"DCM is used to test the specific hypothesis that motivated the experimental design. It is not an exploratory technique [...]; the results are specific to the tasks and stimuli employed during the experiment."

[Friston et al. 2003 *Neuroimage*]

Connectivity analyses

	Whole time series	Condition specific	
Not causal	**FUNCTIONAL CONNECTIVITY**	**PSYCHOPHYSICAL INTERACTIONS**	Classical inferential P(Data)
Causal	STRUCTURAL EQUATION MODELLING	DYNAMIC CAUSAL MODELLING	Bayesian P(Model)

Model evidence = Model fit – model complexity

Key features of DCM

DCM is a generative model

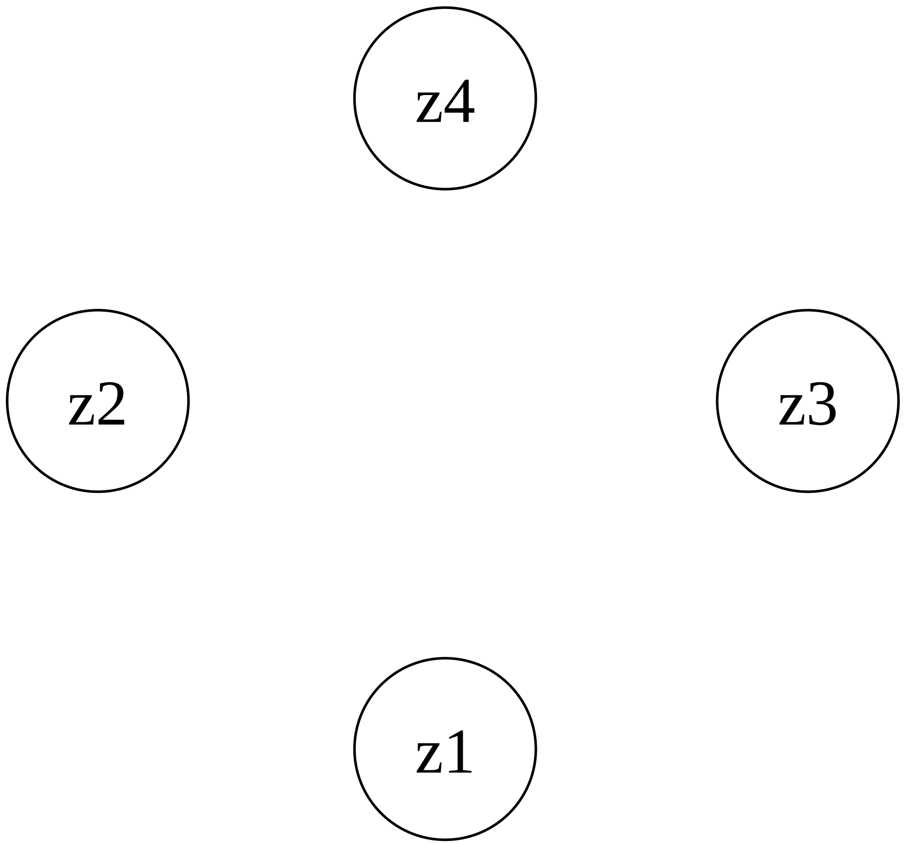
= a quantitative / mechanistic description of how observed data are generated.

- **1- Dynamic**
- **2- Causal**
- **3- Neuro-physiologically motivated**
- **4- Operate at hidden neuronal interactions**
- **5- Bayesian in all aspects**
- **6- Hypothesis-driven**
- **7- Inference at multiple levels.**

How do we do DCM?

1. Create a neural model to represent our hypothesis
2. Convolve it with a haemodynamic model to predict real signal from the scanner
3. Compare models in terms of model fit and complexity

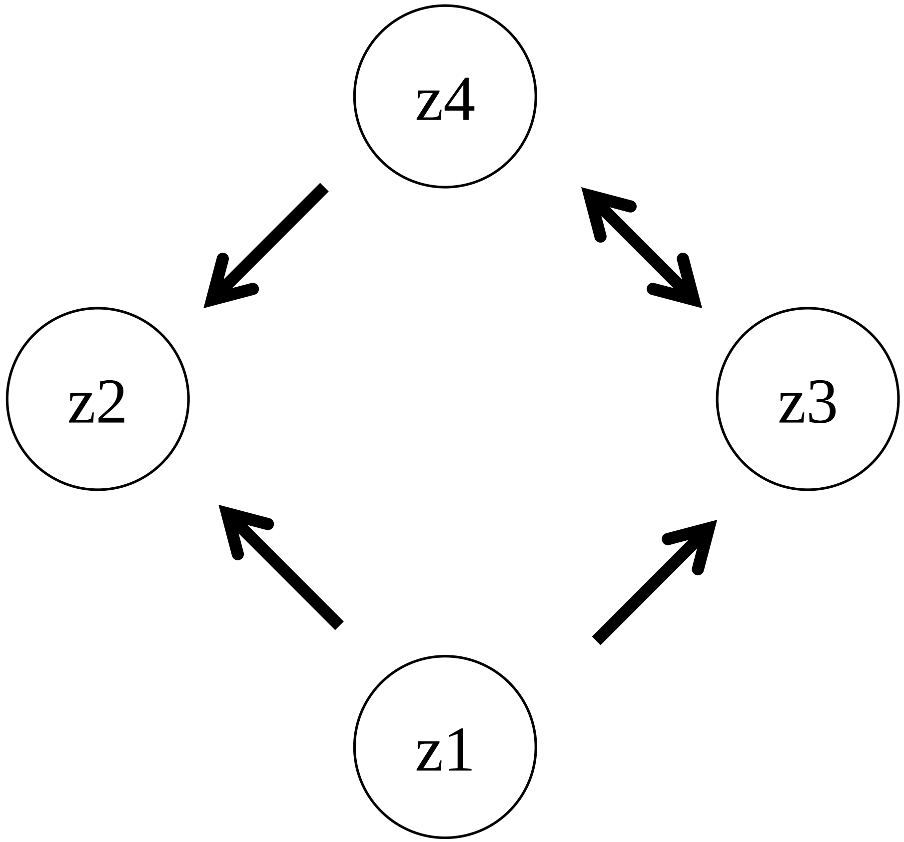
The Neural Model for the state equation



<u>Recipe</u>

Z - Regions

The Neural Model

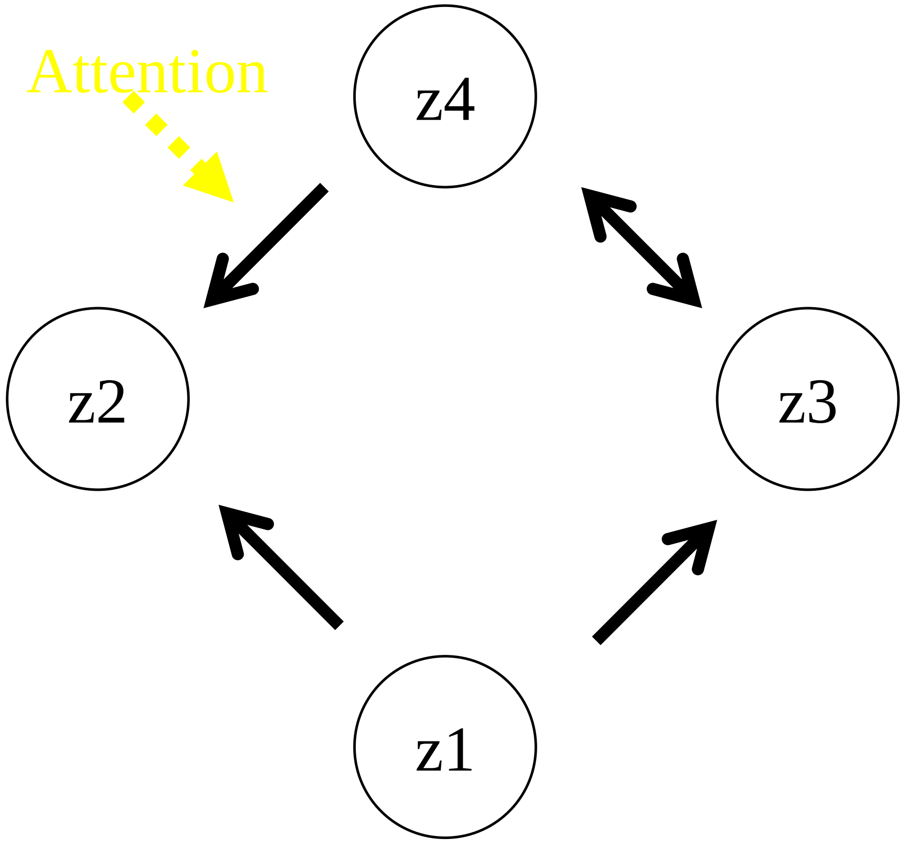


Recipe

Z - Regions

A - Average connections

The Neural Model



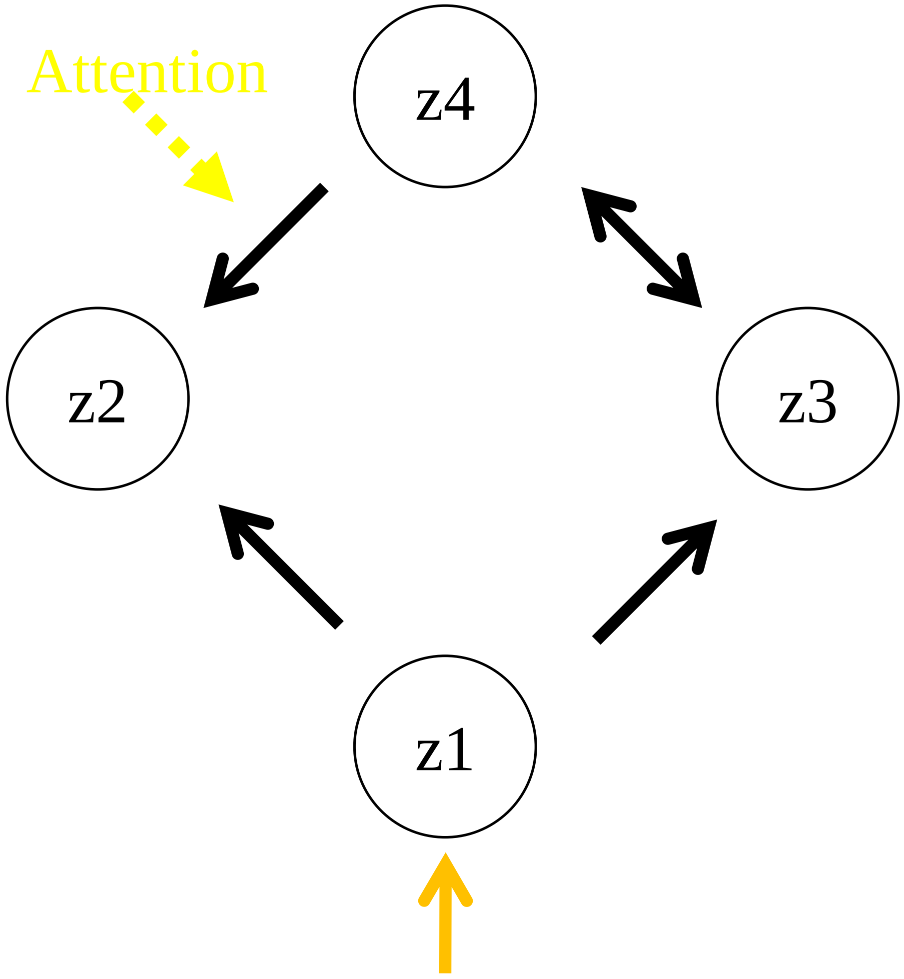
<u>Recipe</u>

Z - Regions

A - Average connections

B - Modulatory Inputs

The Neural Model



<u>Recipe</u>

Z - Regions

A - Average Connections

B - Modulatory Inputs

C - External Inputs

$$\dot{z} = \left(A + \sum_{j=1}^{m} u_j B^j\right) z + Cu$$

"C", the direct or driving effects:

- extrinsic influences of inputs on neuronal activity.

"A", the endogenous coupling or the latent connectivity:

- fixed or intrinsic effective connectivity;
- first order connectivity among the regions in the absence of input;
- average/baseline connectivity in the system (DCM10/DCM8).

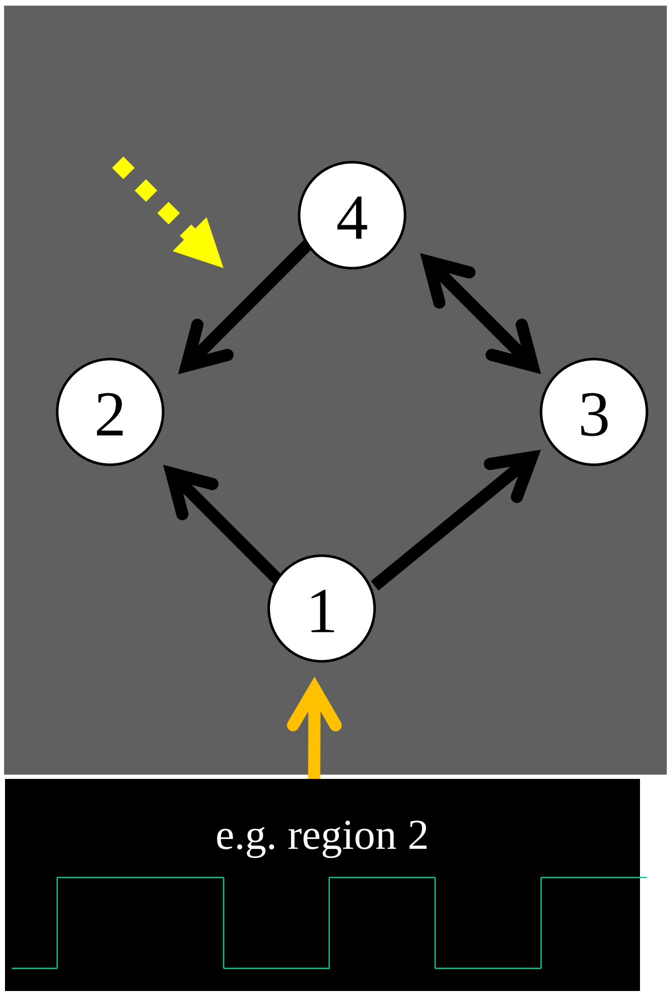
"B", the bilinear term, modulatory effects, or the induced connectivity:

- context-dependent change in connectivity;
- eq. a second-order interaction between the input and activity in a source region when causing a response in a target region.

[Units]: rates, [Hz];
Strong connection = an effect that is influenced quickly or with a small time constant.

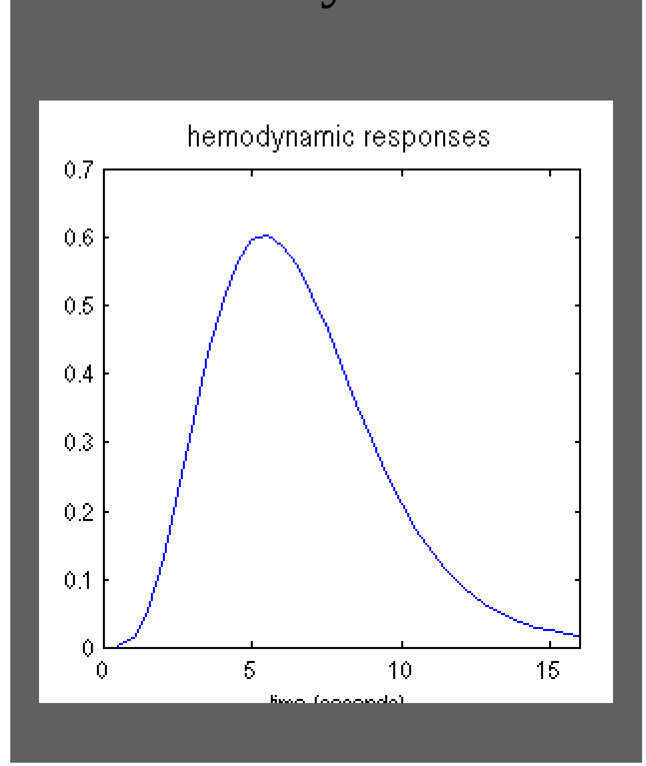
DCM Overview

Neural Model



x

Haemodynamic Model



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DCM Overview

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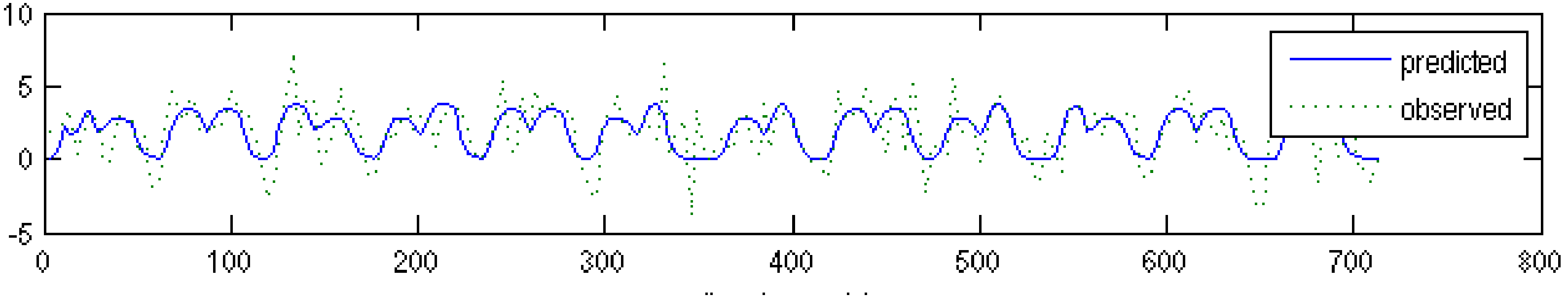


Region 2 Timeseries

The hemodynamic model

- 6 hemodynamic parameters:

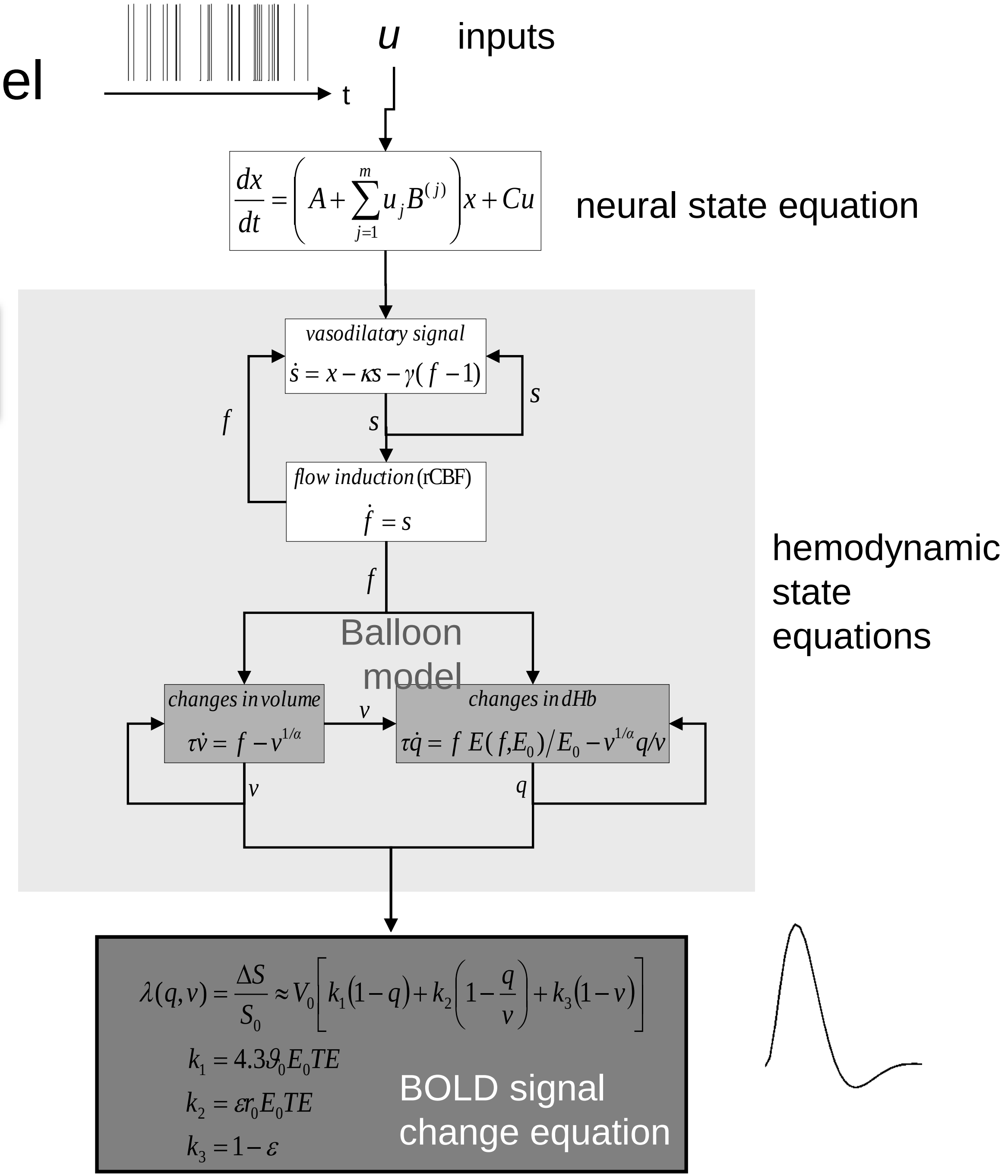
$$\theta^h = \{\kappa, \gamma, \tau, \alpha, \rho, \varepsilon\}$$

important for model fitting, but of no interest for statistical inference

- Empirically determined *a priori* distributions.

- Area-specific estimates (like neural parameters) $\rightarrow$ <u>region-specific</u> HRFs!

[Friston et al. 2003, *NeuroImage*]
[Stephan et al. 2007, *NeuroImage*]



DCM: Methods and Practice

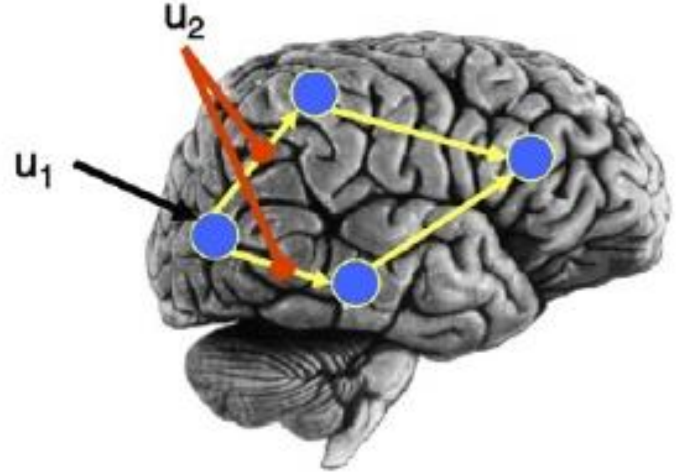
- Experimental Design and Motivation
  - Simulated data
- How to conduct DCM in SPM
  - A practical example and guide
  - Basic steps
  - Interpreting results
- Bayesian Model Selection
- Parameter estimates and group level statistics

Experimental Design and Motivation

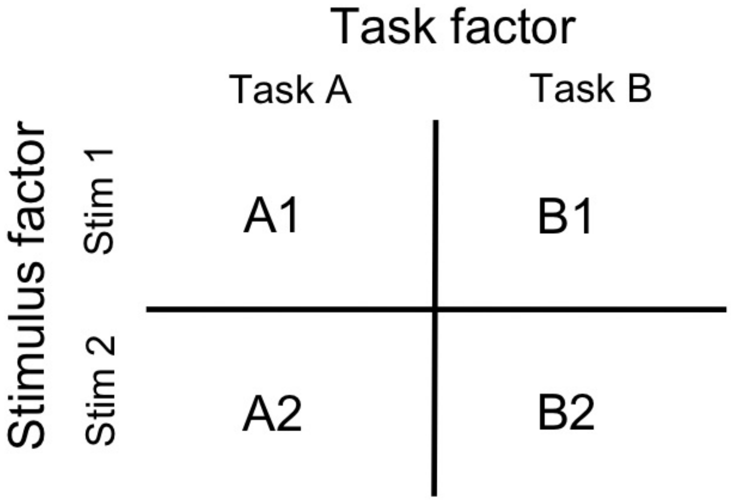
– Can apply DCM to any design used in a GLM analysis

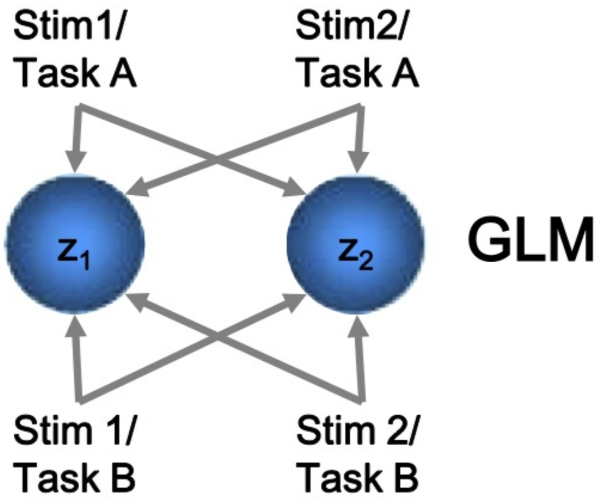
– If the GLM does not detect activation in a given region, there is no motivation to include this region in a (deterministic) DCM

– Deterministic DCM tests generative models of how the GLM data arose

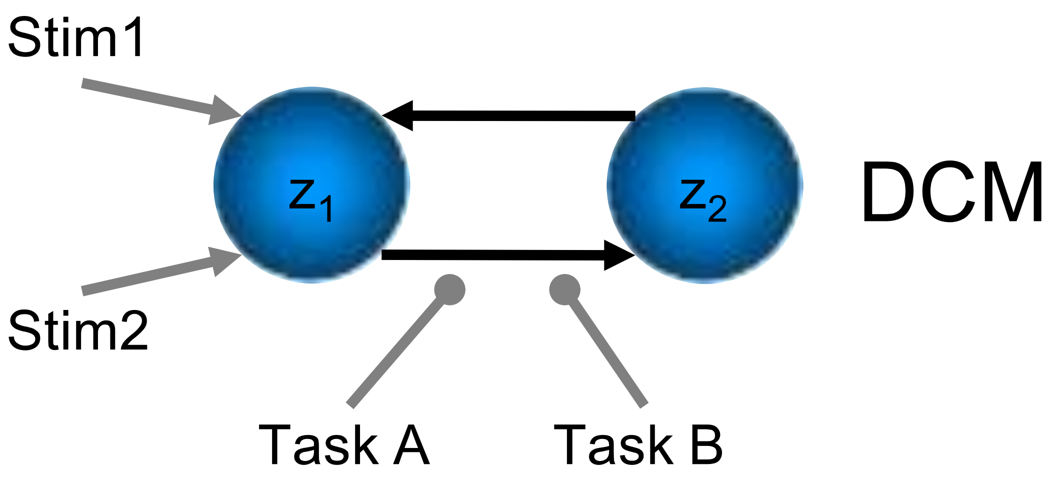


Multifactorial Design

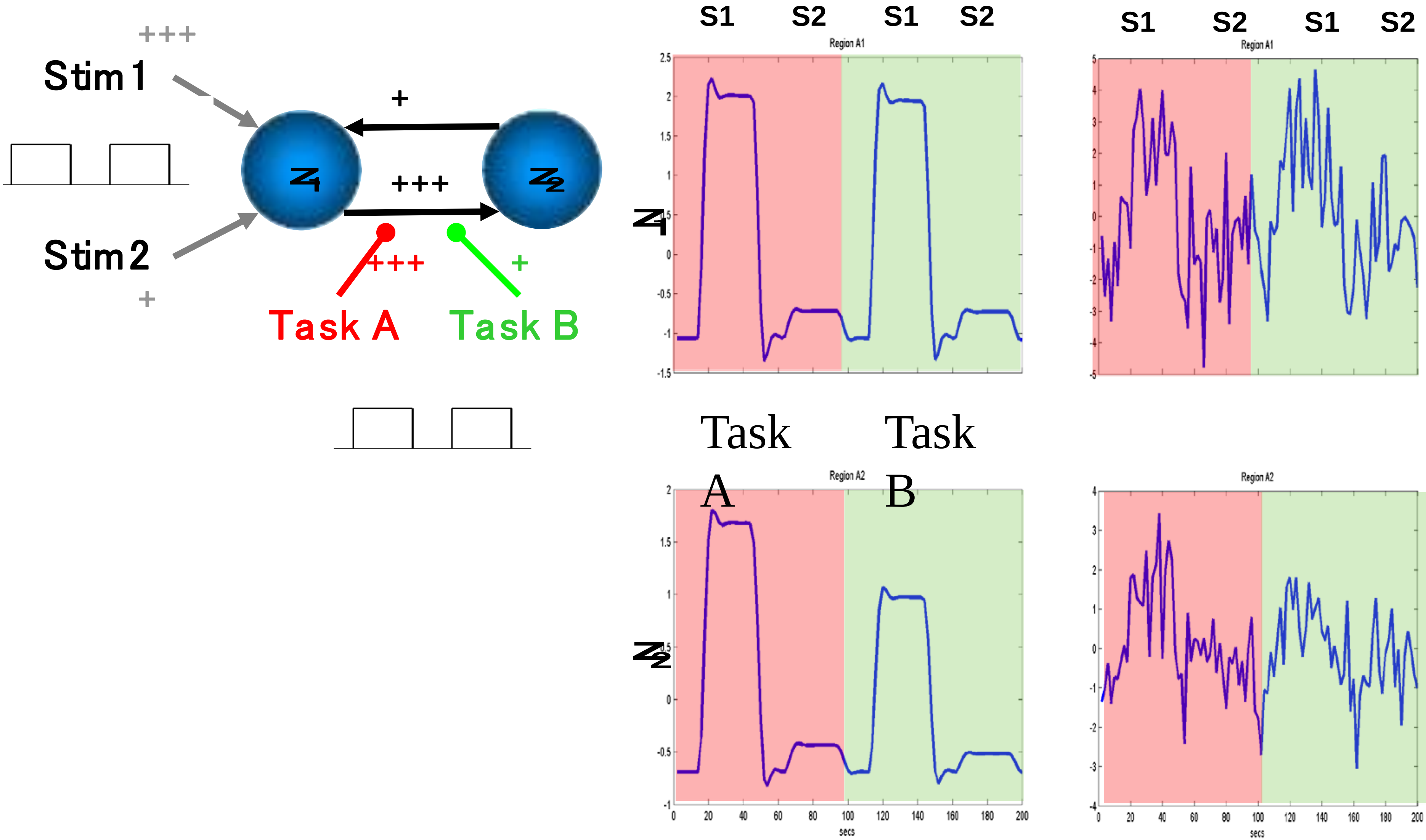




Modeling interactions

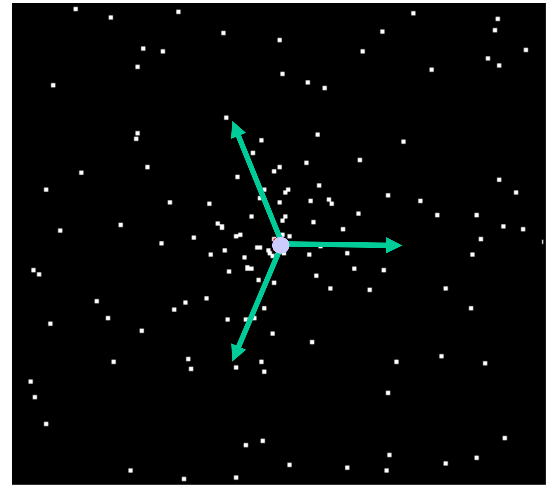


Simulated data



Attention to motion in the visual system

<u>Stimuli</u>



<u>4 Conditions</u>

<u>Sensory input</u>

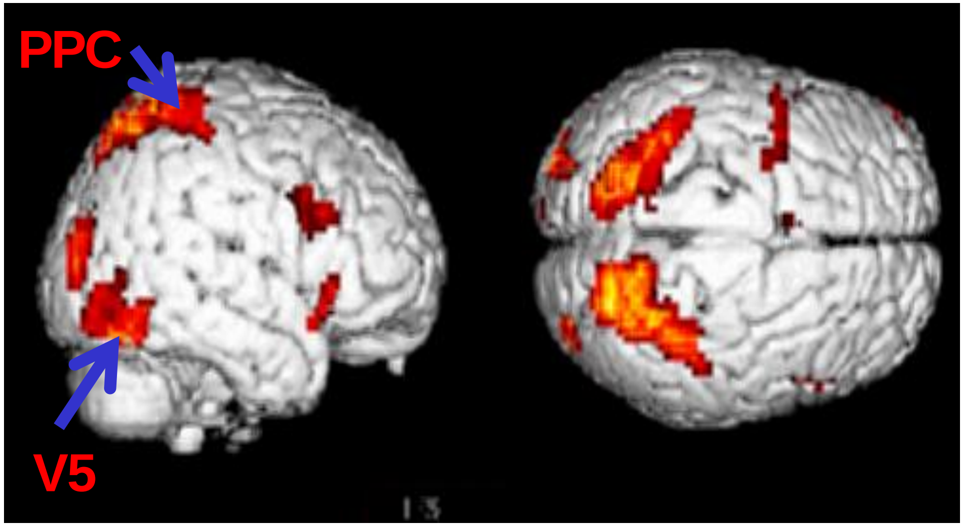
Contextual factor

	static	motion
No attent	No motion/ attention	Motion / no attention
Attent.		Motion / attention

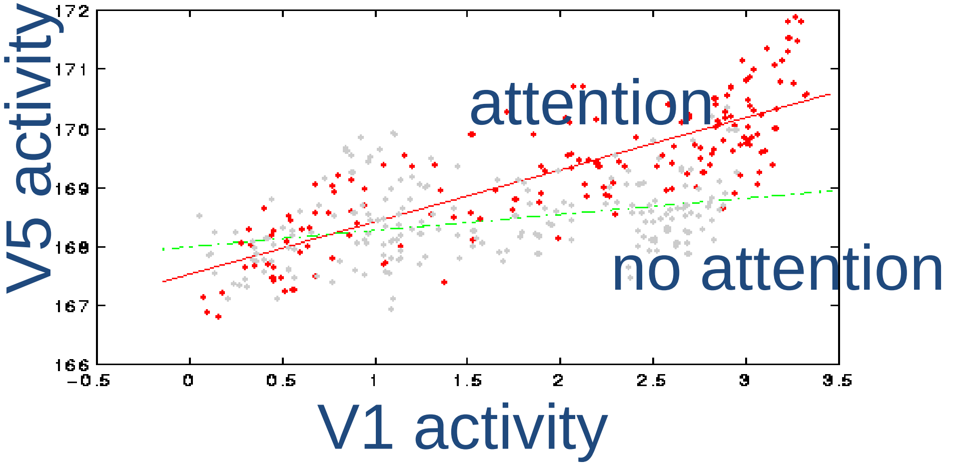
<u>Parameters:</u>

GLM Results

-fixation only – baseline
-observe static dots → V1
-observe moving dots → V5
-attention to moving dots
→ V5 + SPC



- GLM analysis showed that motion activated V5, but that attention enhanced this activity.



Modeling inputs in DCM analysis

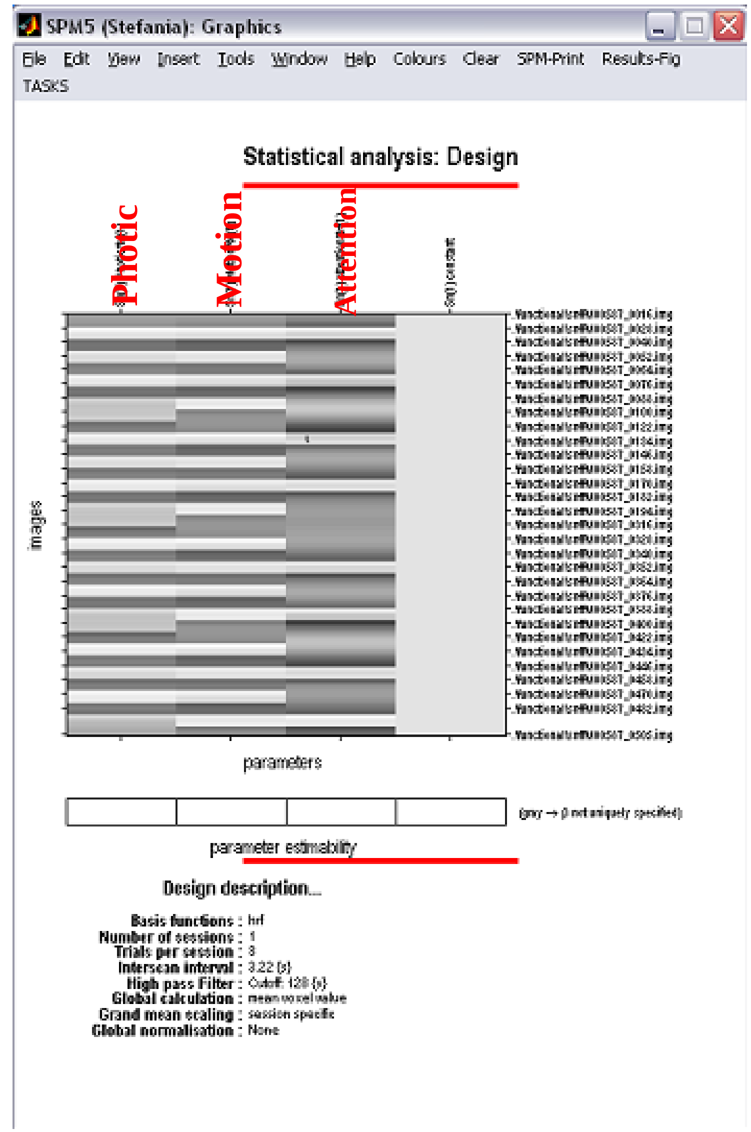
Specify regressors for DCM as driving inputs and modulators:

<u>Driving input</u>

- Photic: all visual input – static+ motion+ attention to motion

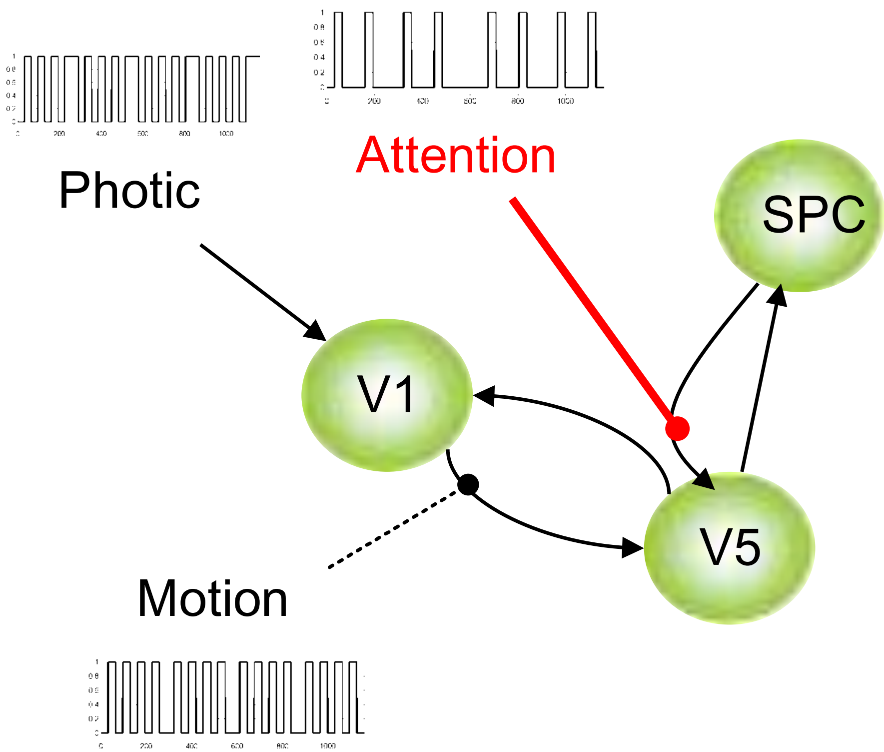
<u>Modulatory input</u>

- Motion
- Attention

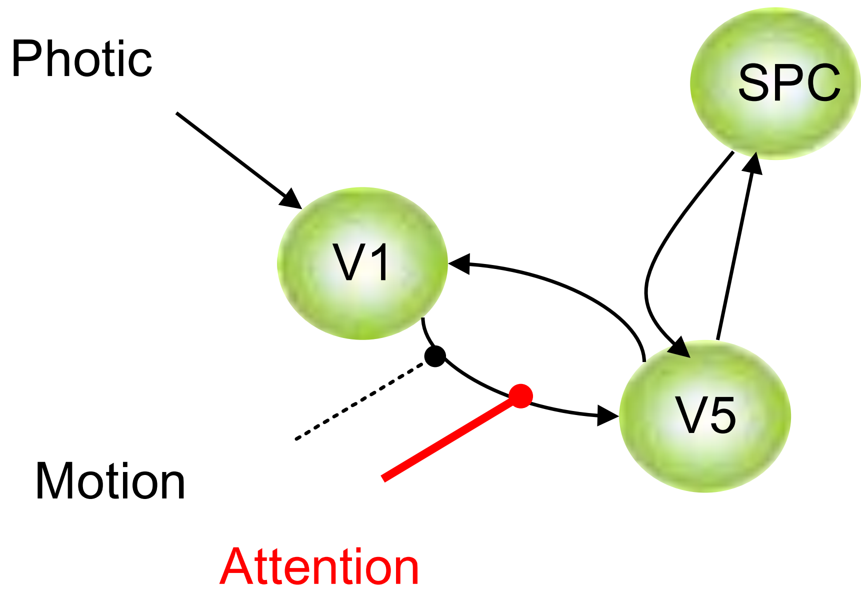


Alternate Dynamic Causal Models

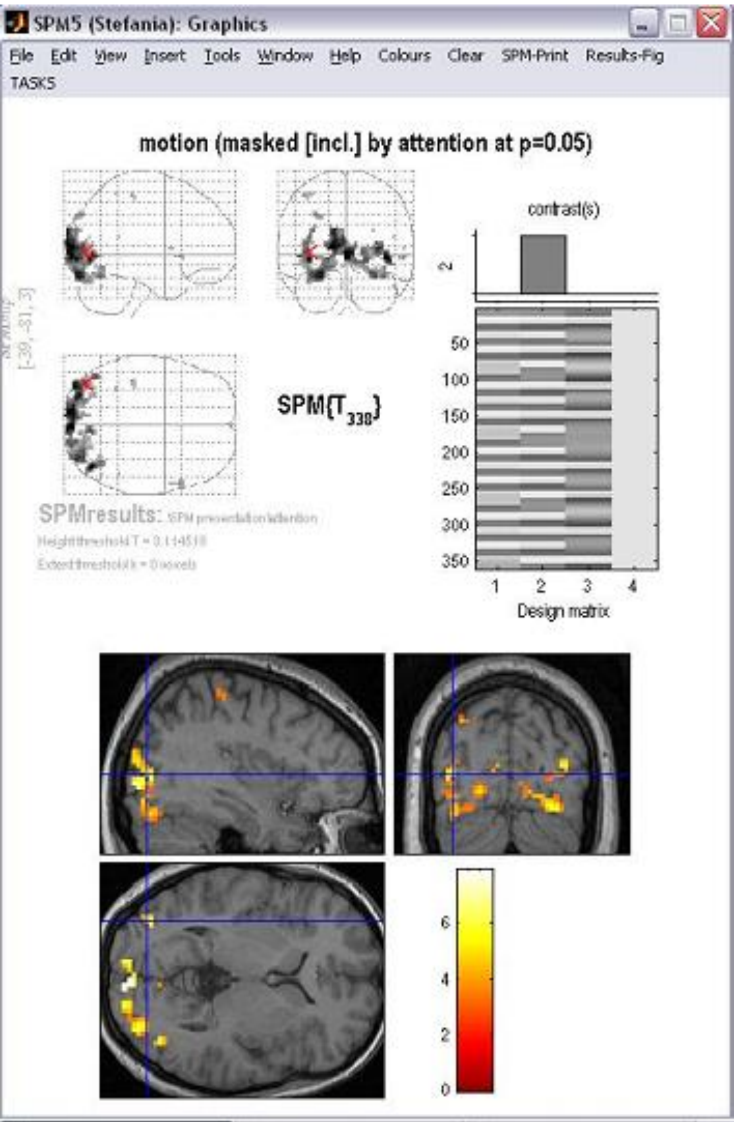
Model 1 (backward):

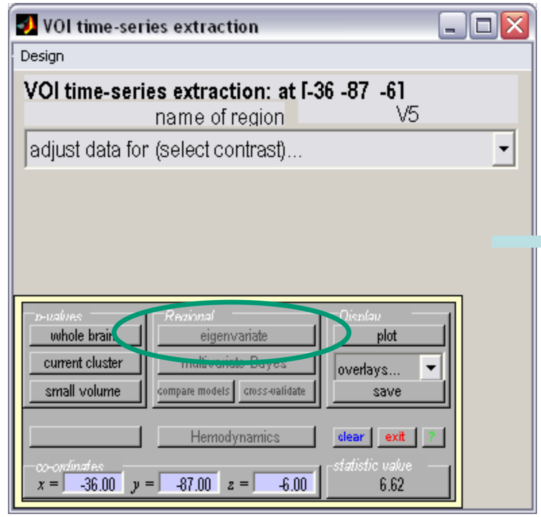


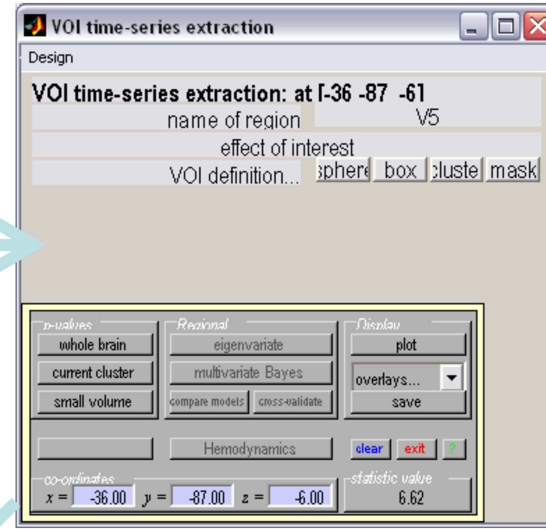
Model 2 (forward):

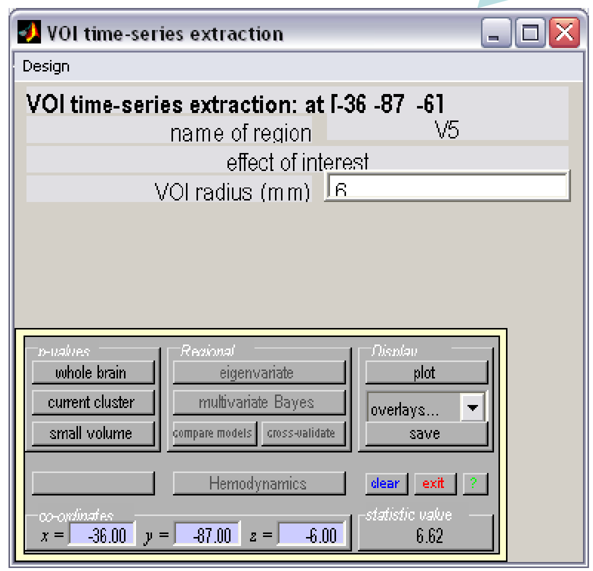


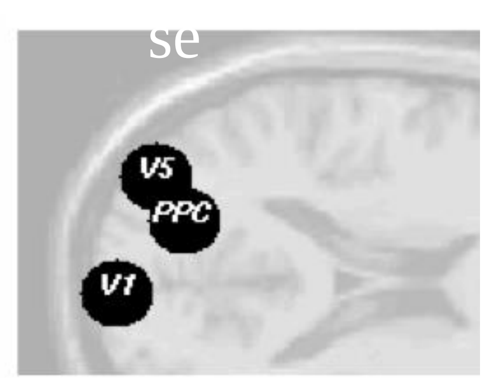
Defining VOIs: time series extraction



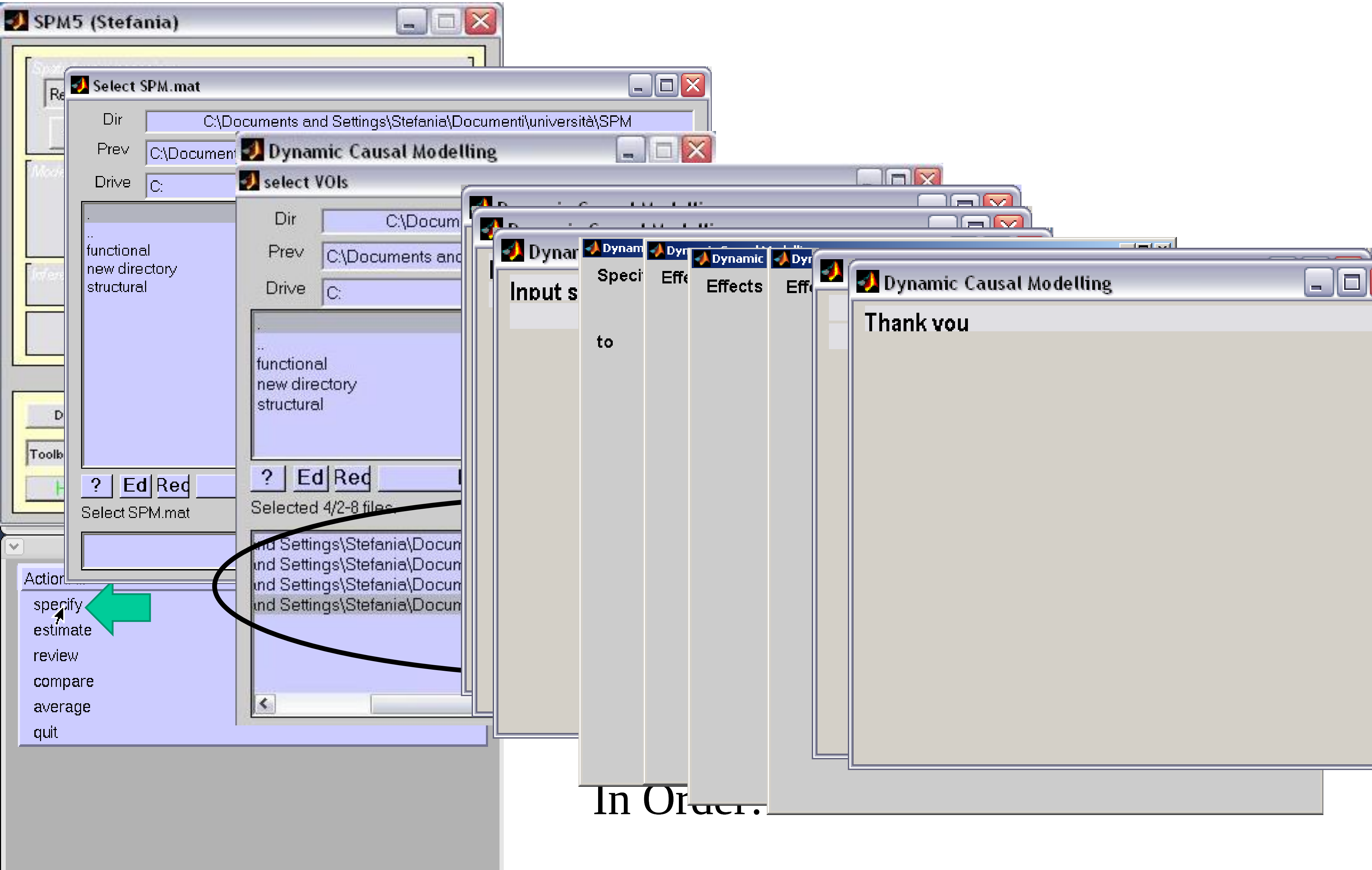


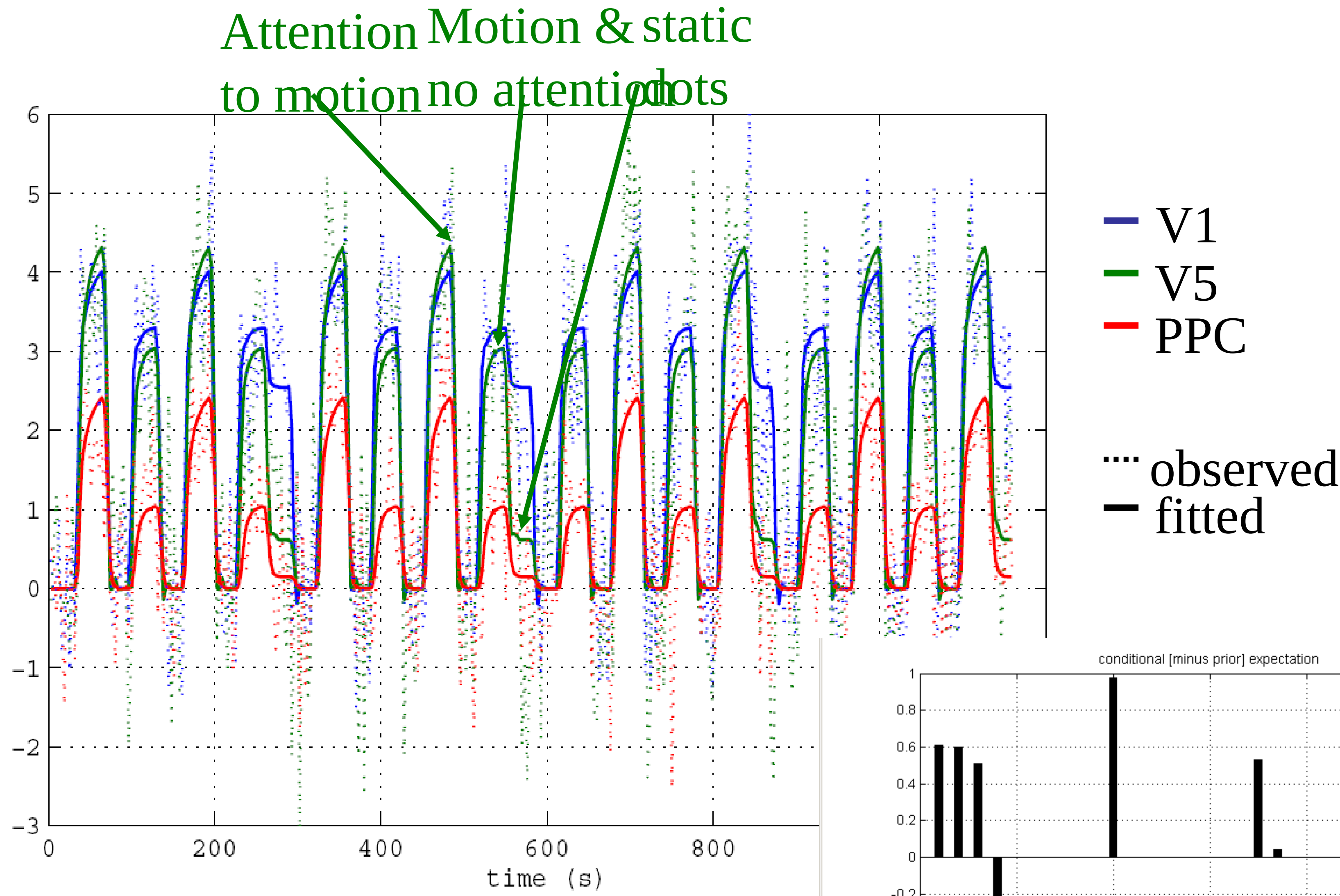


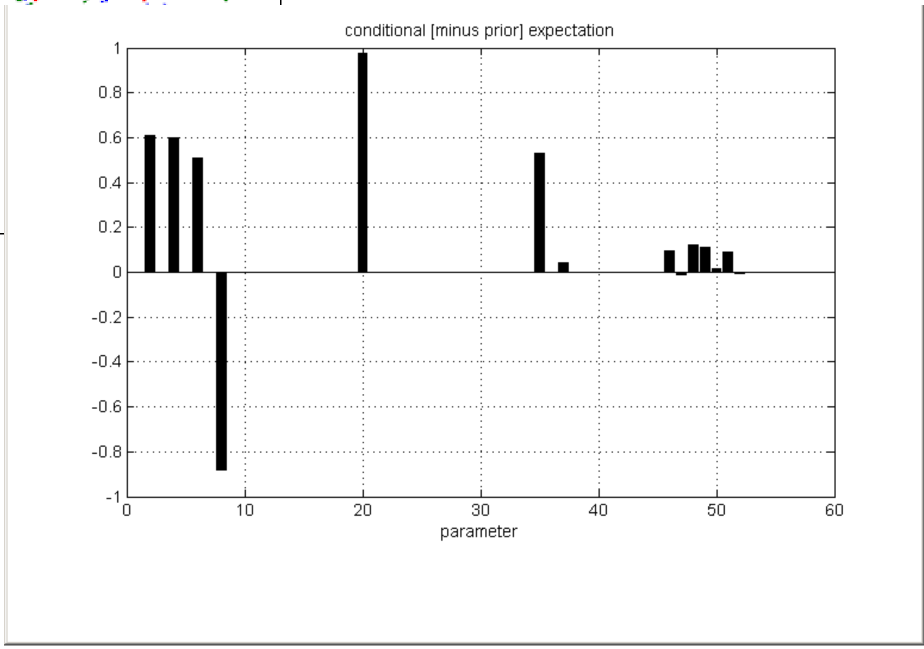




Specifying the model




Attention to motion
Motion & no attention
static dots
V1
V5
PPC
observed
fitted
time (s)


conditional [minus prior] expectation
parameter

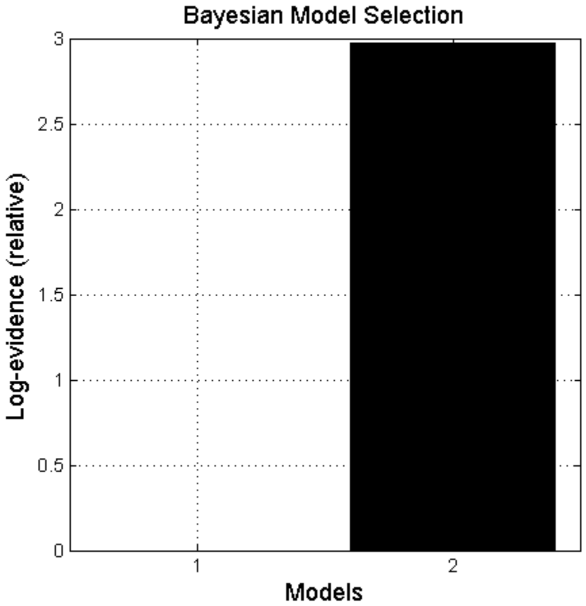
Bayesian Model Comparison

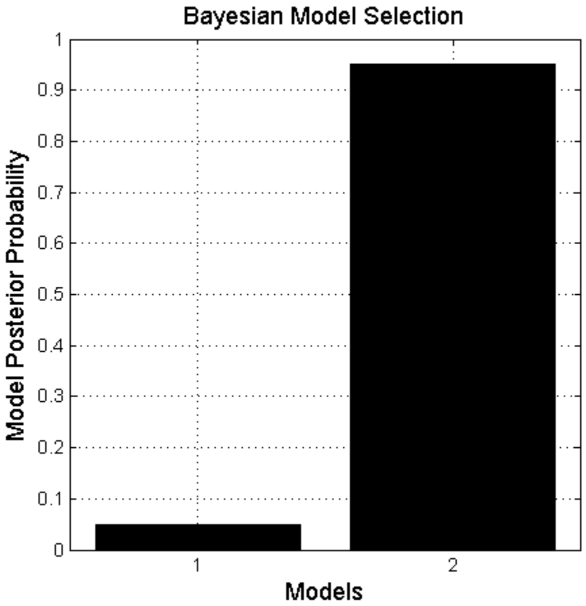
$$p(y|m) = \int p(y|\theta, m) \cdot p(\theta|m)\, d\theta$$

$$\log p(y|m) = accuracy(m) - complexity(m)$$

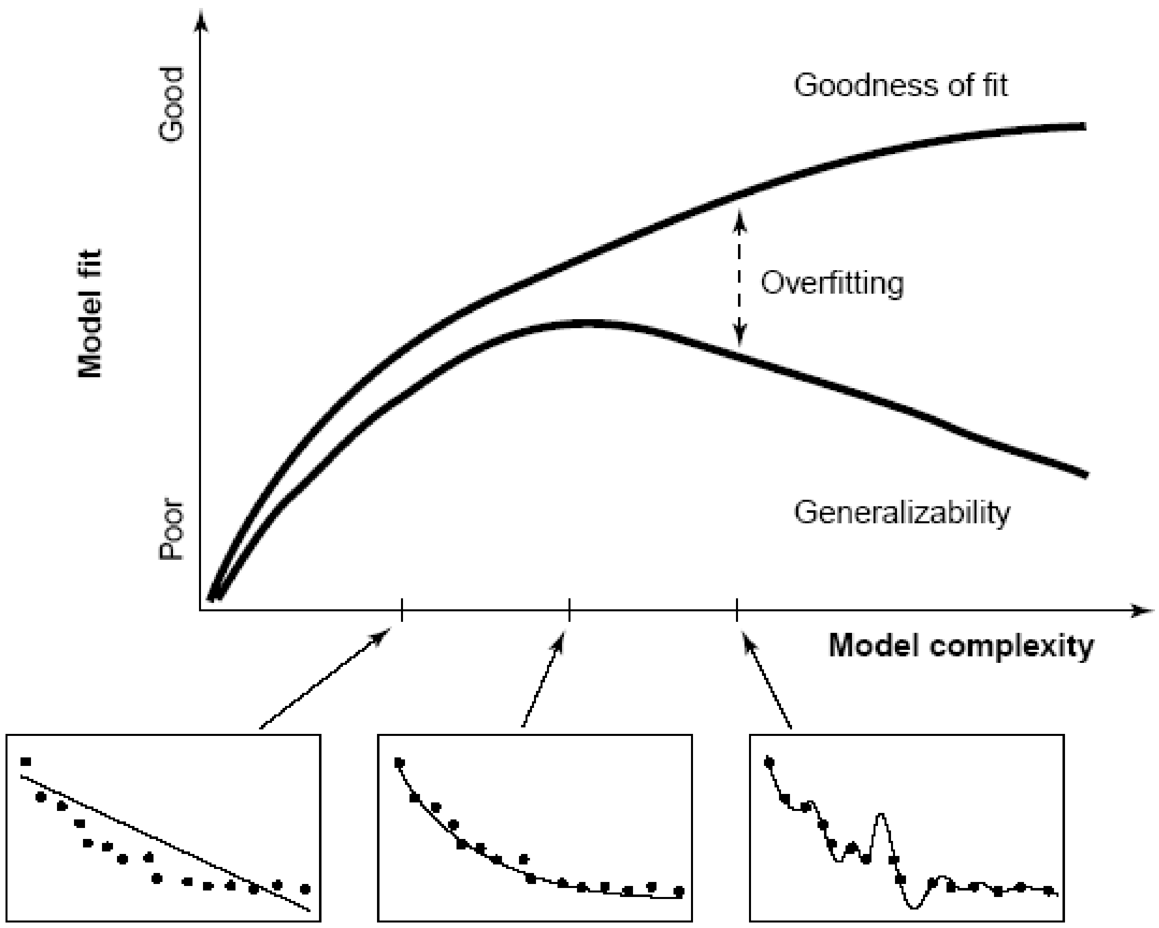
$$B_{ij} = \frac{p(y|m=i)}{p(y|m=j)}$$

B_{12}	$p(m_1\|y)$	Evidence
1 to 3	50-75%	weak
3 to 20	75-95%	positive
20 to 150	95-99%	strong
≥ 150	≥ 99%	Very strong

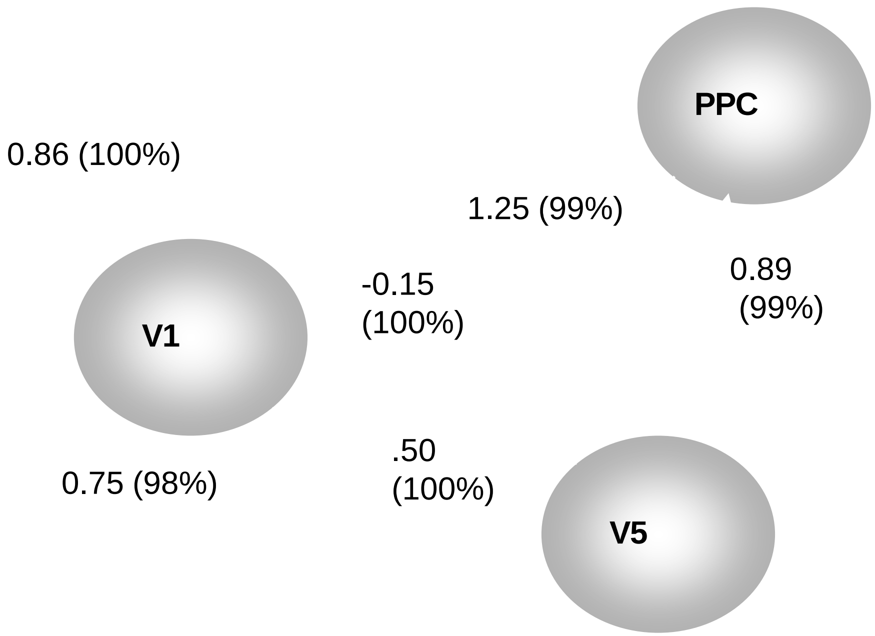


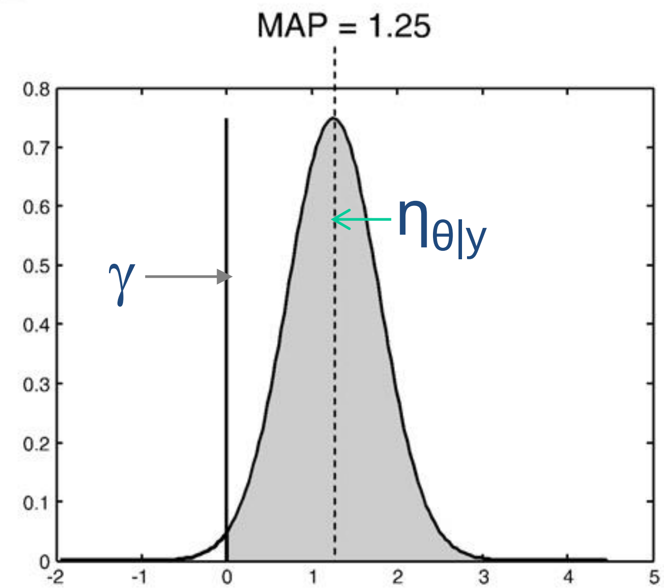


Model evidence and selection



Review Winning Model and Parameters





$$p(D_{V5,}^{PPC} > 0 \mid y) = 99.1\%$$

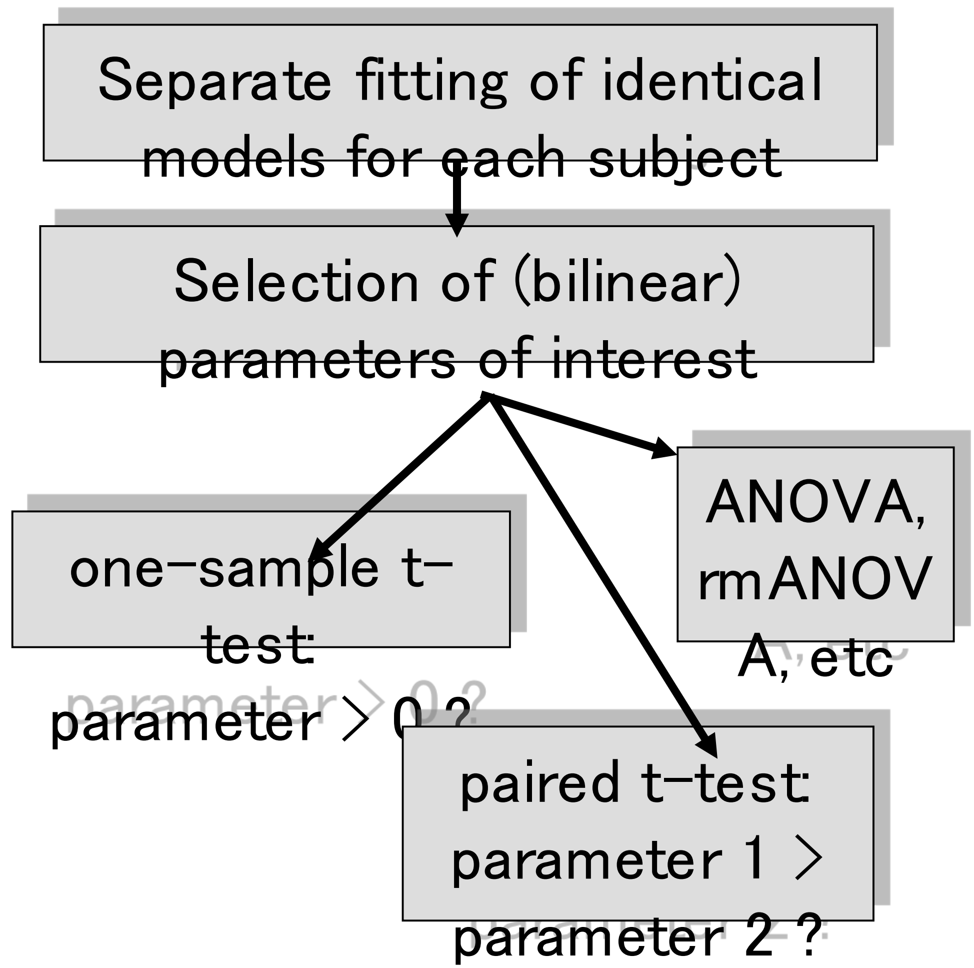
Inference about DCM parameters: Group level

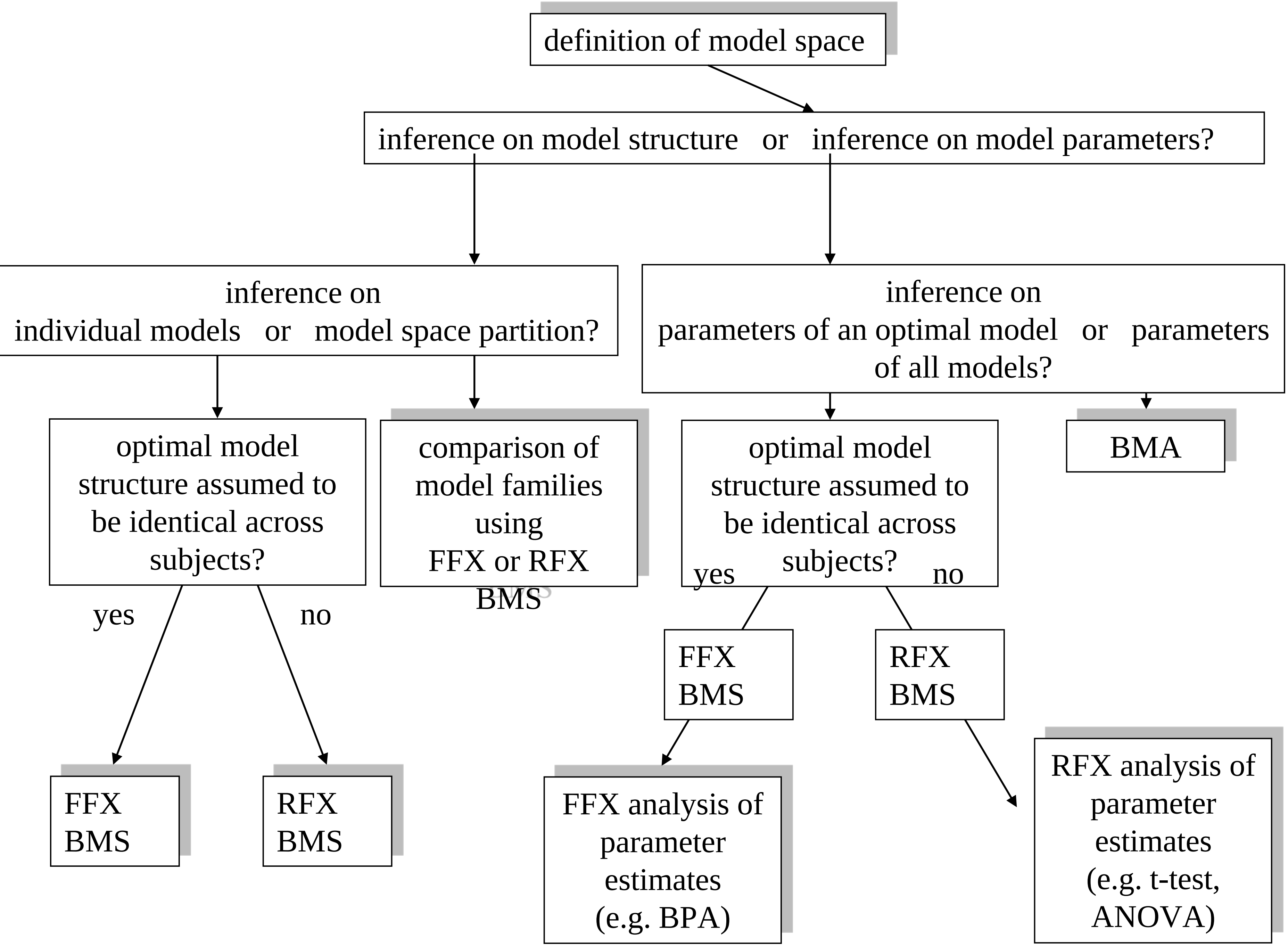
<u>FFX group analysis</u>

- Likelihood distributions from different subjects are independent
- Subject assumed to use identical systems
- One can use the posterior from one subject as the prior for the next

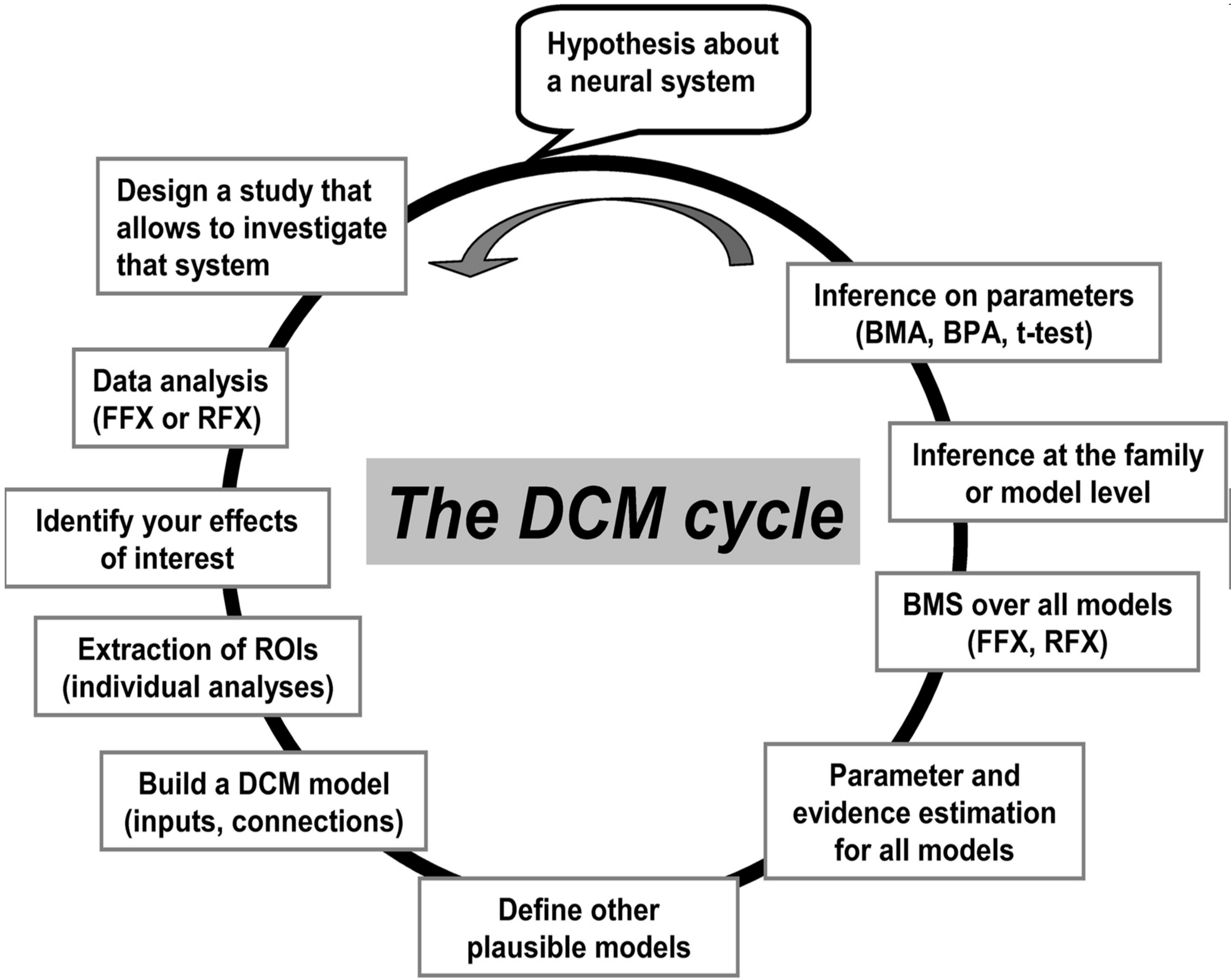
<u>RFX group analysis</u>

- Optimal models vary across subjects





definition of model space
inference on model structure or inference on model parameters?
inference on
individual models or model space partition?
inference on
parameters of an optimal model or parameters
of all models?
optimal model
structure assumed to
be identical across
subjects?
comparison of
model families
using
FFX or RFX
BMS
optimal model
structure assumed to
be identical across
subjects?
BMA
yes
no
yes
no
FFX
BMS
RFX
BMS
FFX
BMS
RFX
BMS
FFX analysis of
parameter
estimates
(e.g. BPA)
RFX analysis of
parameter
estimates
(e.g. t-test,
ANOVA)


Hypothesis about a neural system
Design a study that allows to investigate that system
Data analysis (FFX or RFX)
Identify your effects of interest
Extraction of ROIs (individual analyses)
Build a DCM model (inputs, connections)
Define other plausible models
Parameter and evidence estimation for all models
BMS over all models (FFX, RFX)
Inference at the family or model level
Inference on parameters (BMA, BPA, t-test)
The DCM cycle

DCM Summary

test mechanistic hypotheses

- Operates at the neuronal level

Bayesian framework

Thank you to our expert,
Mohamed Seghier!

References

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- Dynamic Causal Modelling: a critical review of the biophysical and statistical foundations. Daunizeau *et al. Neuroimage* (2010), in press
- SPM Manual, SMP courses slides, last years presentations.