Dynamic Causal Modelling for EEG/MEG: principles

Adapted from the DCM course slides of
J. Daunizeau

Overview

1 DCM: introduction

2 Neural states dynamics

3 Bayesian inference

4 Conclusion

Overview

1 DCM: introduction

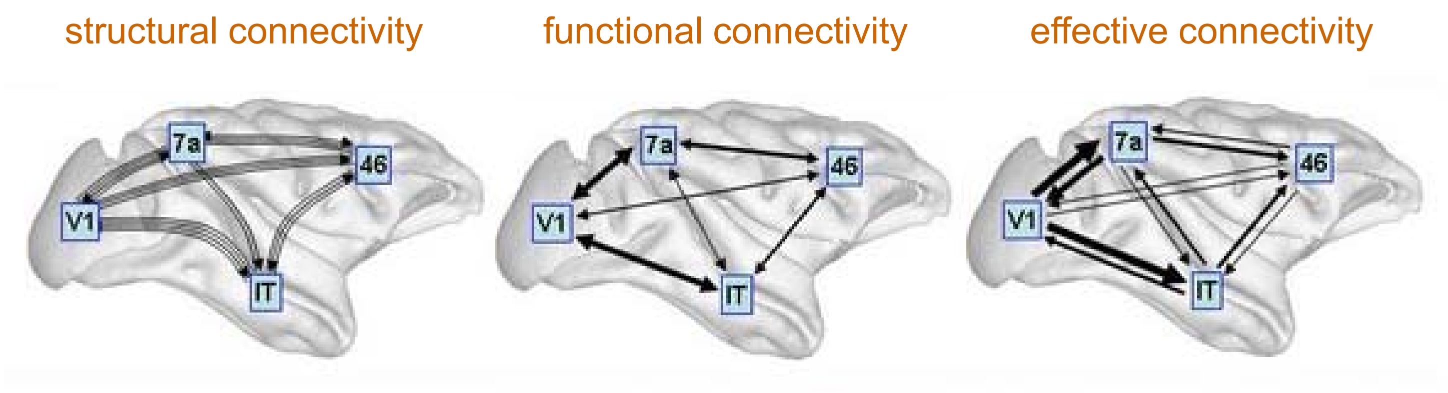
2 Neural states dynamics

3 Bayesian inference

4 Conclusion

Introduction

structural, *functional* and *effective* connectivity



O. Sporns 2007, *Scholarpedia*

- *structural* connectivity
  = presence of axonal connections

- *functional* connectivity
  = statistical dependencies between regional time series

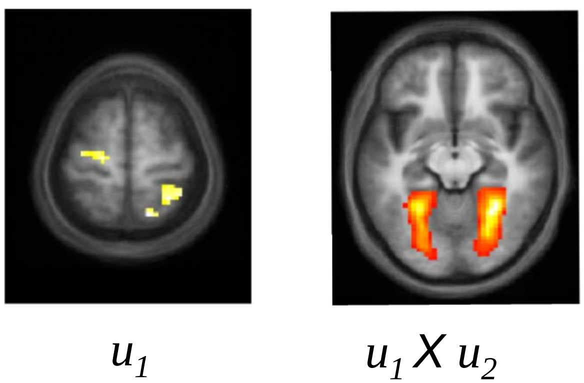
- *effective* connectivity
  = causal (directed) influences between neuronal populations

! connections are recruited in a *context-dependent* fashion

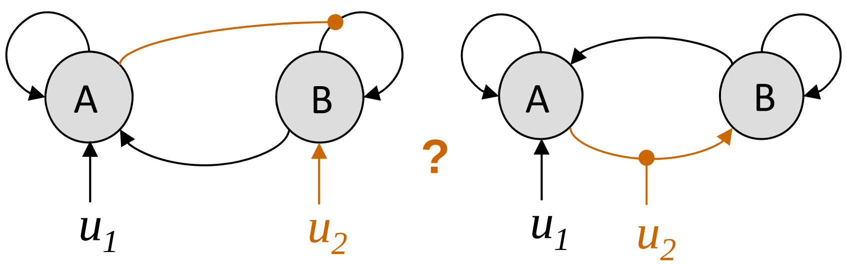
Introduction

from functional segregation to functional integration

localizing brain activity:
functional segregation



effective connectivity analysis:
functional integration



« Where, in the brain, did my experimental manipulation have an effect? »

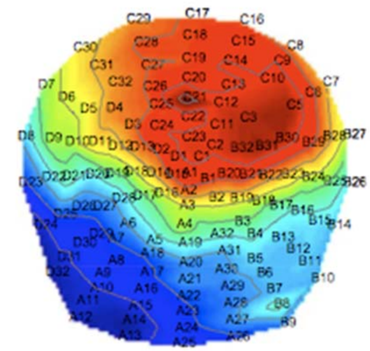
« How did my experimental manipulation propagate through the network? »

Introduction

DCM: evolution and observation mappings

Hemodynamic
observation model:
temporal convolution

Electromagnetic
observation model:
spatial convolution

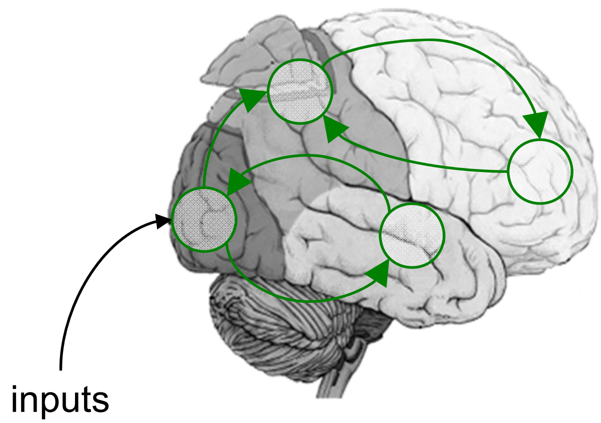


neural states dynamics

$$\dot{x} = f(x, u, \theta)$$

fMRI

EEG/MEG



- simple neuronal model
- realistic observation model

- realistic neuronal model
- simple observation model

Introduction

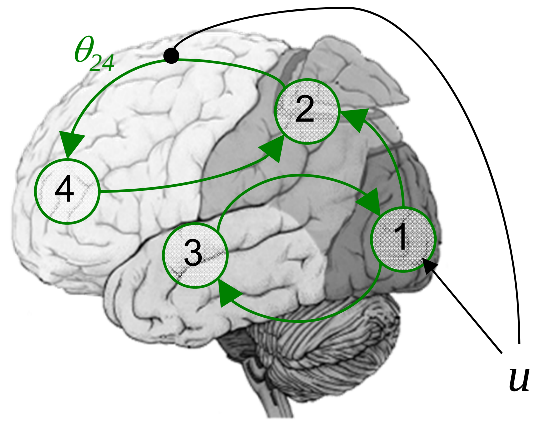
DCM: a parametric statistical approach

- DCM: model structure

$$\begin{cases} y = g(x,\varphi) + \varepsilon \\ \dot{x} = f(x,u,\theta) \end{cases}$$

likelihood

$$\Rightarrow p(y|\theta,\varphi,m)$$



- DCM: Bayesian inference

parameter estimate: $\hat{\theta} = E[\theta|y,m]$

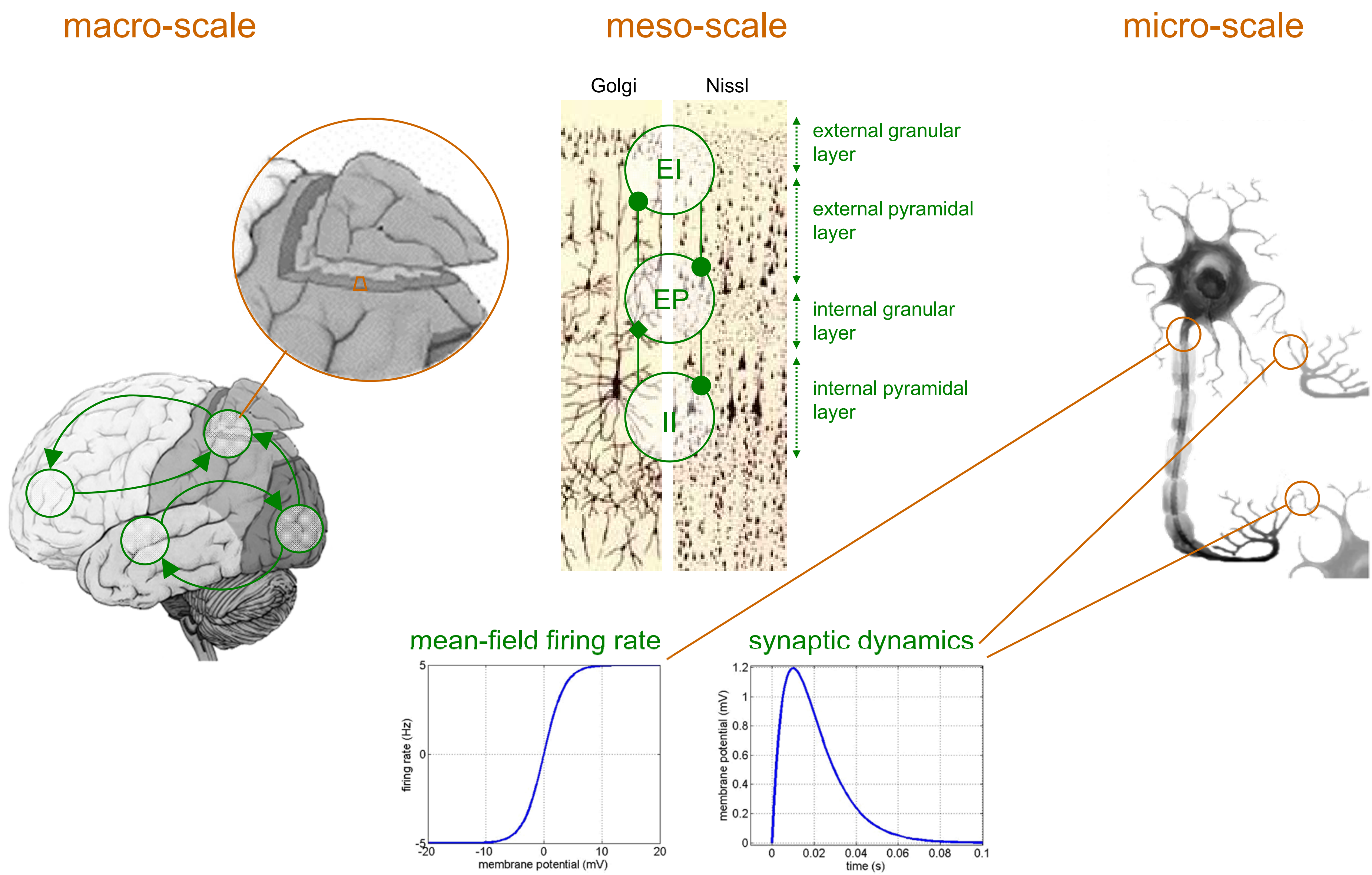
priors on parameters

model evidence: $p(y|m) = \int p(y|\theta,\varphi,m)\, p(\theta|m)\, p(\varphi|m)\, d\varphi d\theta$

Overview

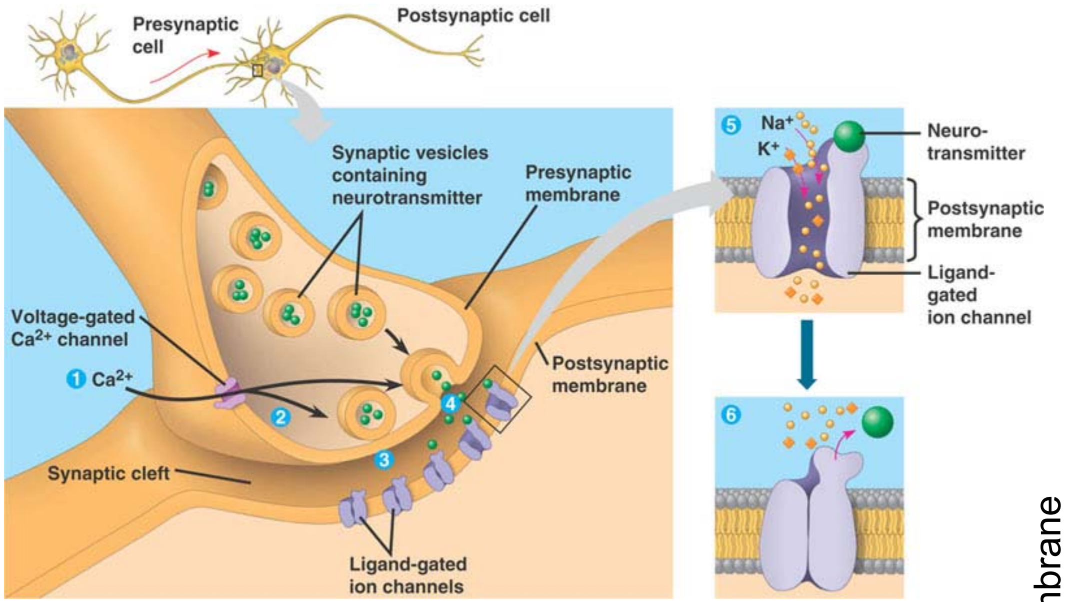
Neural ensembles dynamics

DCM for M/EEG: *systems of neural populations*

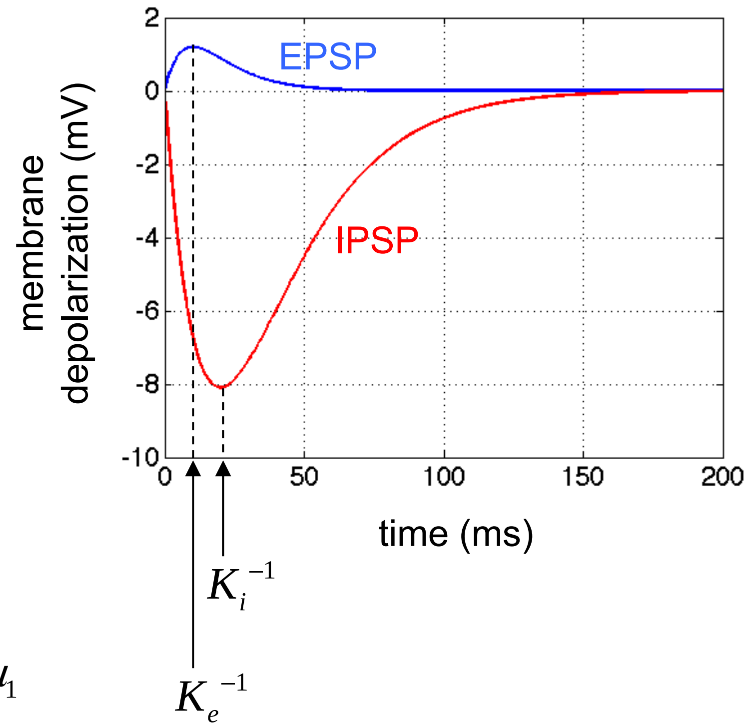


Neural ensembles dynamics

DCM for M/EEG: *synaptic dynamics*



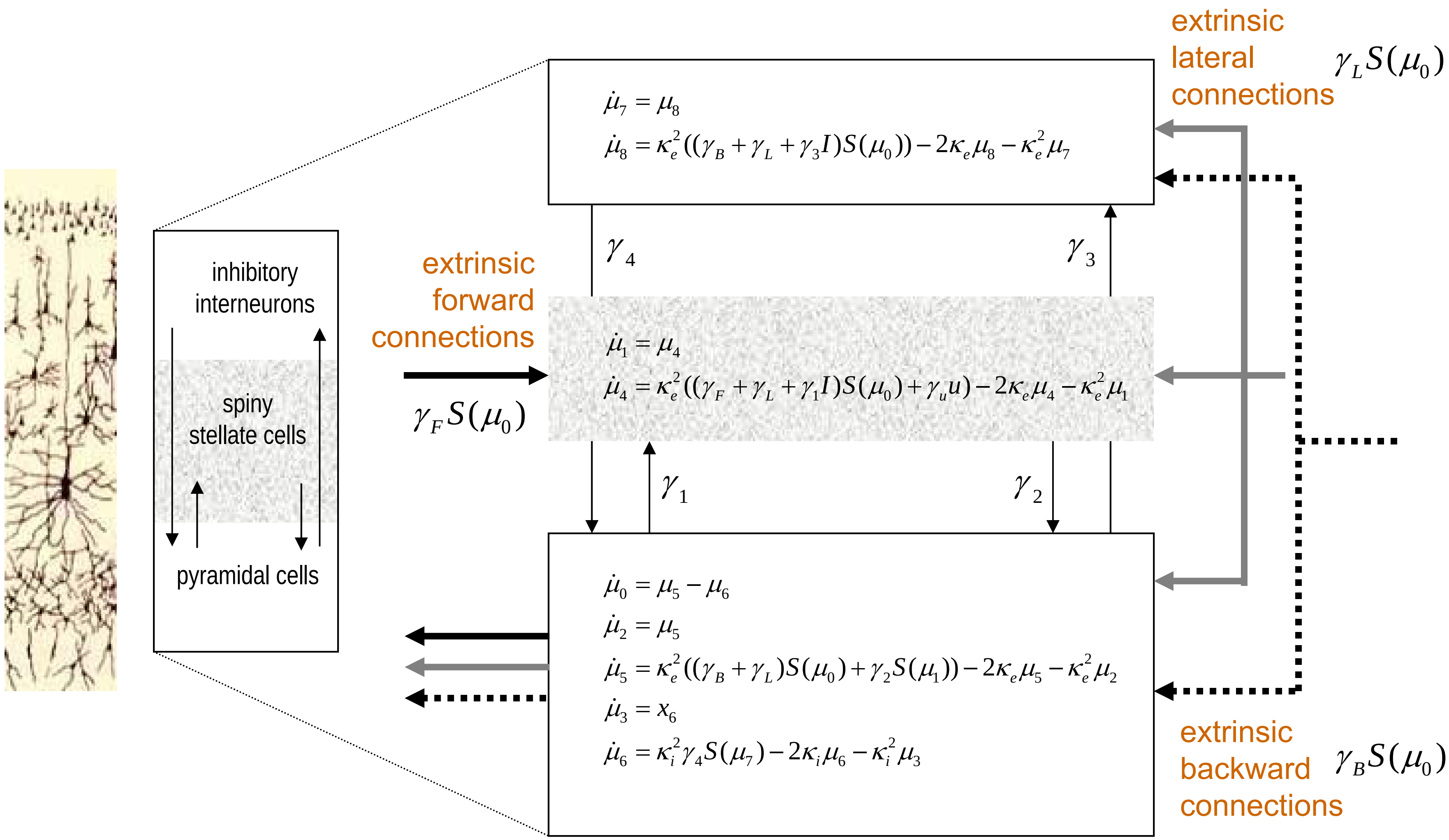
post-synaptic potential



$$\begin{cases} \dot{\mu}_1 = \mu_2 \\ \dot{\mu}_2 = \kappa_{i/e}^2 \, S(\square) - 2\kappa_{i/e}\,\mu_2 - \kappa_{i/e}^2\,\mu_1 \end{cases}$$

Neural ensembles dynamics

DCM for M/EEG: *extrinsic connections between brain regions*



Overview

1 DCM: introduction

2 Neural states dynamics

3 Bayesian inference

4 Conclusion

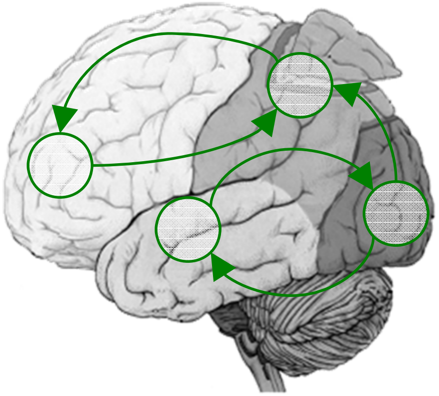
Bayesian inference

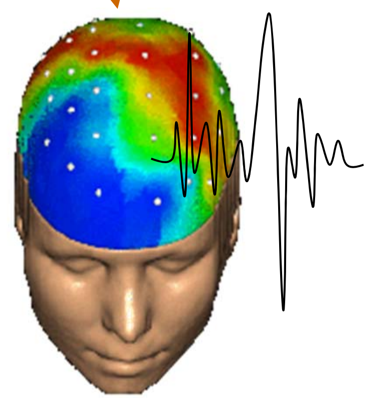
forward and inverse problems

forward problem

$$p\left(y \middle| \vartheta, m\right)$$

likelihood





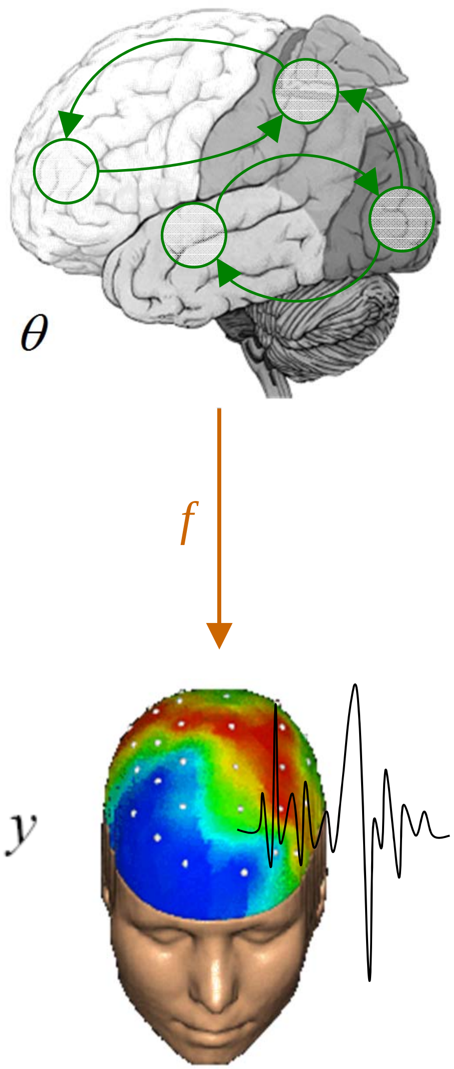
posterior distribution

$$p\left(\vartheta \middle| y, m\right)$$

inverse problem

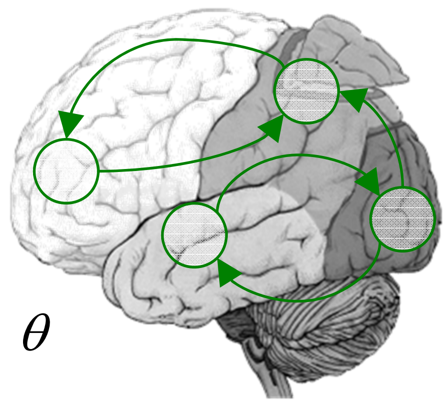
Bayesian paradigm

deriving the likelihood function

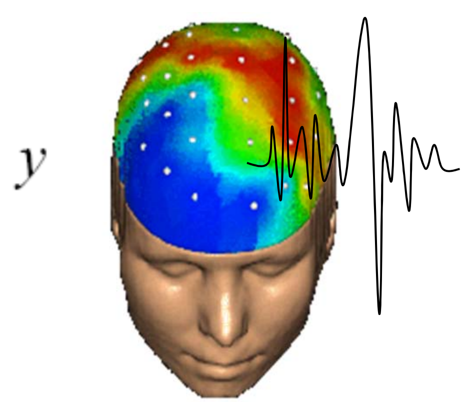


Bayesian paradigm

likelihood, priors and the model evidence



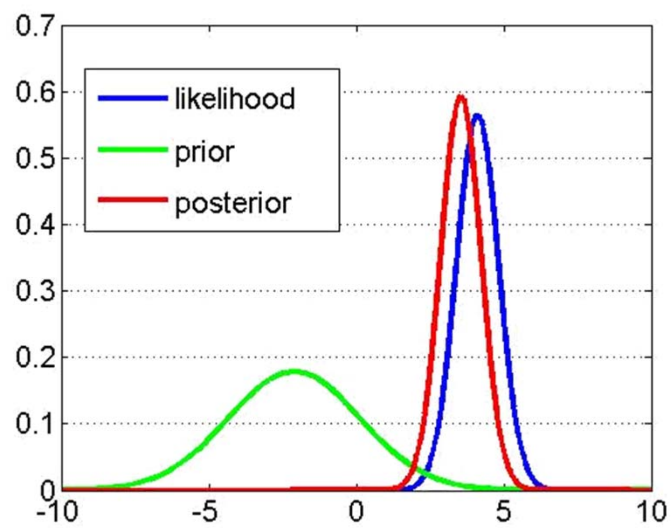
generative model m



Likelihood: $p(y|\theta, m)$

Prior: $p(\theta|m)$

Bayes rule: $$p(\theta|y,m) = \frac{p(y|\theta,m)\,p(\theta|m)}{p(y|m)}$$



Overview

Conclusion

planning a compatible DCM study

- Suitable experimental design:
  - any design that is suitable for a GLM
  - preferably multi-factorial (e.g. 2 x 2)
    - e.g. one factor that varies the driving (sensory) input
    - and one factor that varies the modulatory input

- Hypothesis and model:
  - define specific *a priori* hypothesis
  - which models are relevant to test this hypothesis?
  - check existence of effect on data features of interest
  - there exists formal methods for optimizing the experimental design for the ensuing bayesian model comparison [Daunizeau et al., PLoS Comp. Biol., 2011]