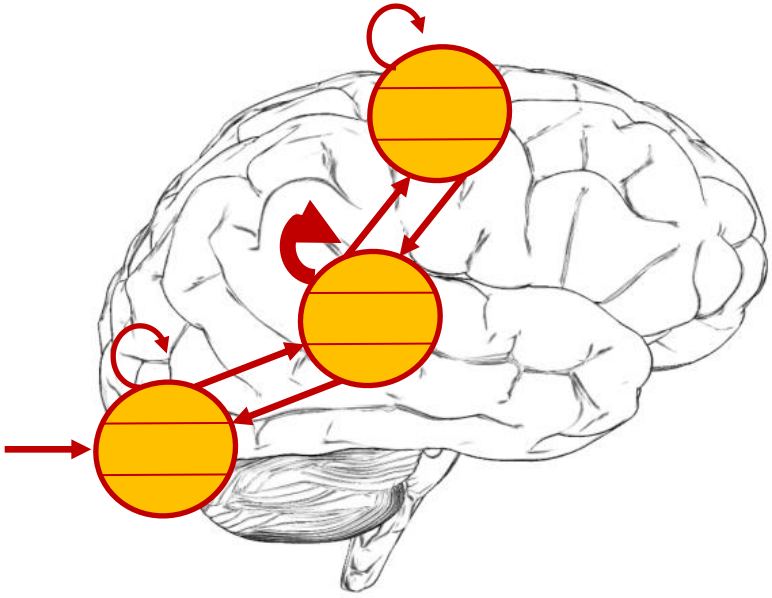
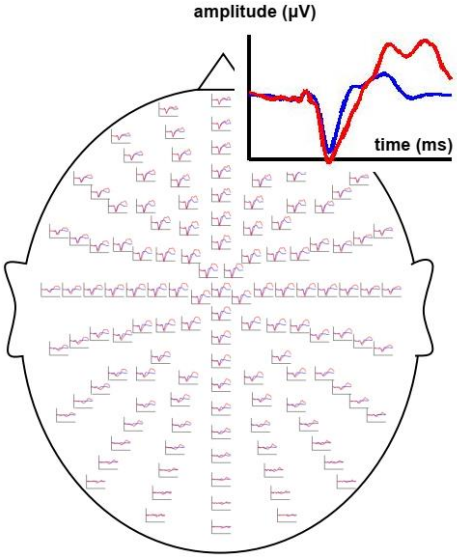
# DCM for evoked responses

Ryszard Auksztulewicz

SPM for M/EEG course



# Modelling aim and approach




*M/EEG are complex data

Analyses / modelling: in time, frequency, time-frequency and space domains

**Modelling Aim**

Explain all data with few parameters

**How to …**

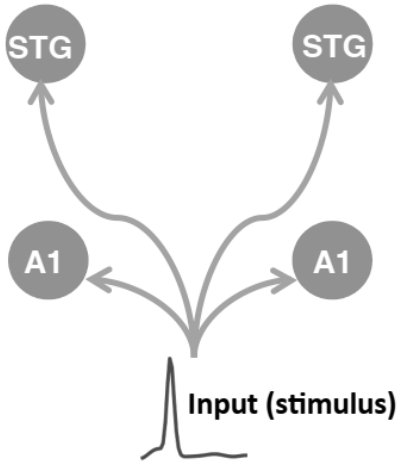
Assume data are caused by few interacting brain sources …

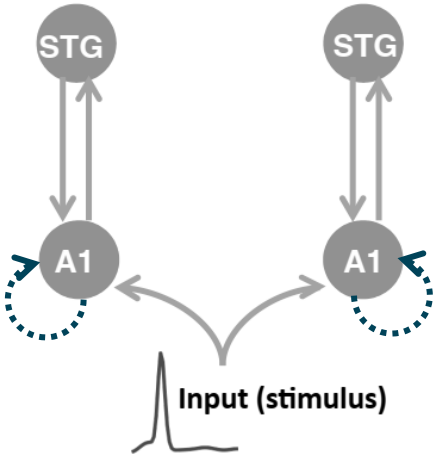
… and / or their respective intrinsic connectivity / intrinsic parameters

Adapted from Kiebel (n.a.), *Dynamic Causal Modelling for EEG and MEG,* Presentation at TU Dresden;
Stoff (n.a.), *DCM for ERP/ERF*, Presentation at UCL

# Conventional analyses vs. DCM

| "Conventional" Analysis | DCM Analysis |
| --- | --- |
| Which regions are involved in a task? | How do regions communicate?<br>What role do intrinsic connections have? |
| Sensor space / functional connectivity | Source space / effective connectivity |




A1 - left and right primary auditory cortex
STG - left and right superior temporal gyrus

Adapted from Kiebel (n.a.), *Dynamic Causal Modelling for EEG and MEG,* Presentation at TU Dresden;
Stoff (n.a.), *DCM for ERP/ERF*, Presentation at UCL

Does network XYZ explain my data better than network XY?

Which XYZ connectivity structure best explains my data?

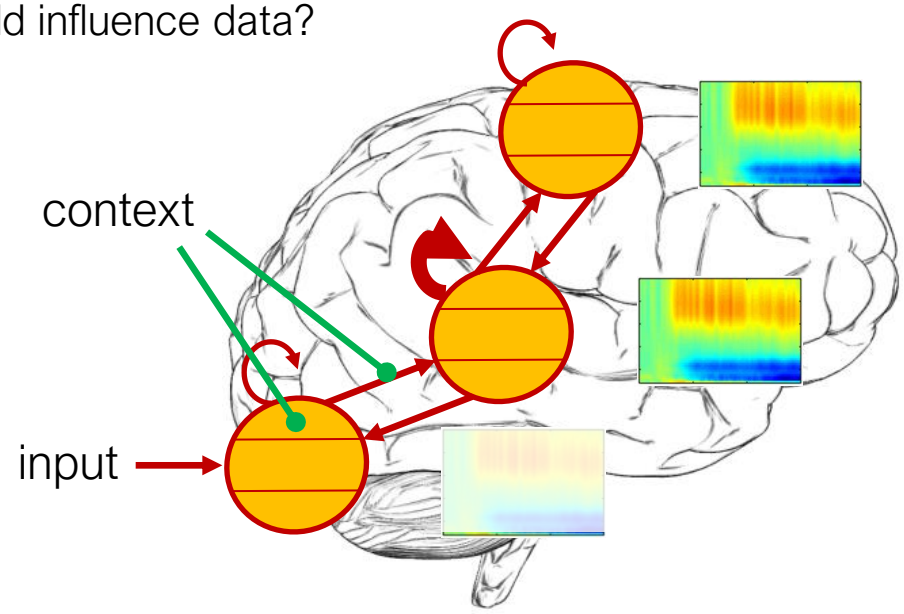
Are X & Y linked in a bottom-up, top-down or recurrent fashion?

Is my effect driven by extrinsic or intrinsic connections?

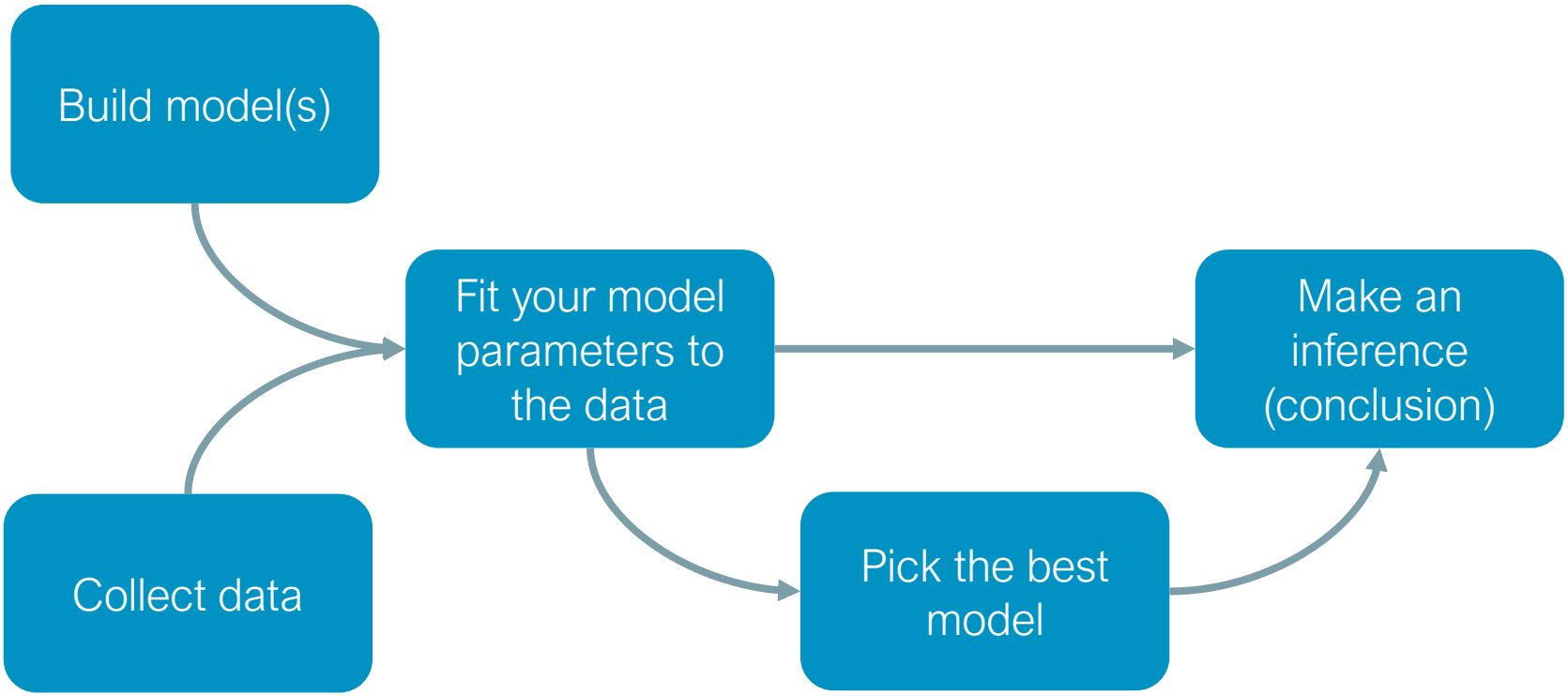
Which neural populations are affected by contextual factors?

Which connections determine observed frequency coupling?

How changing a connection/parameter would influence data?



# The DCM analysis pathway



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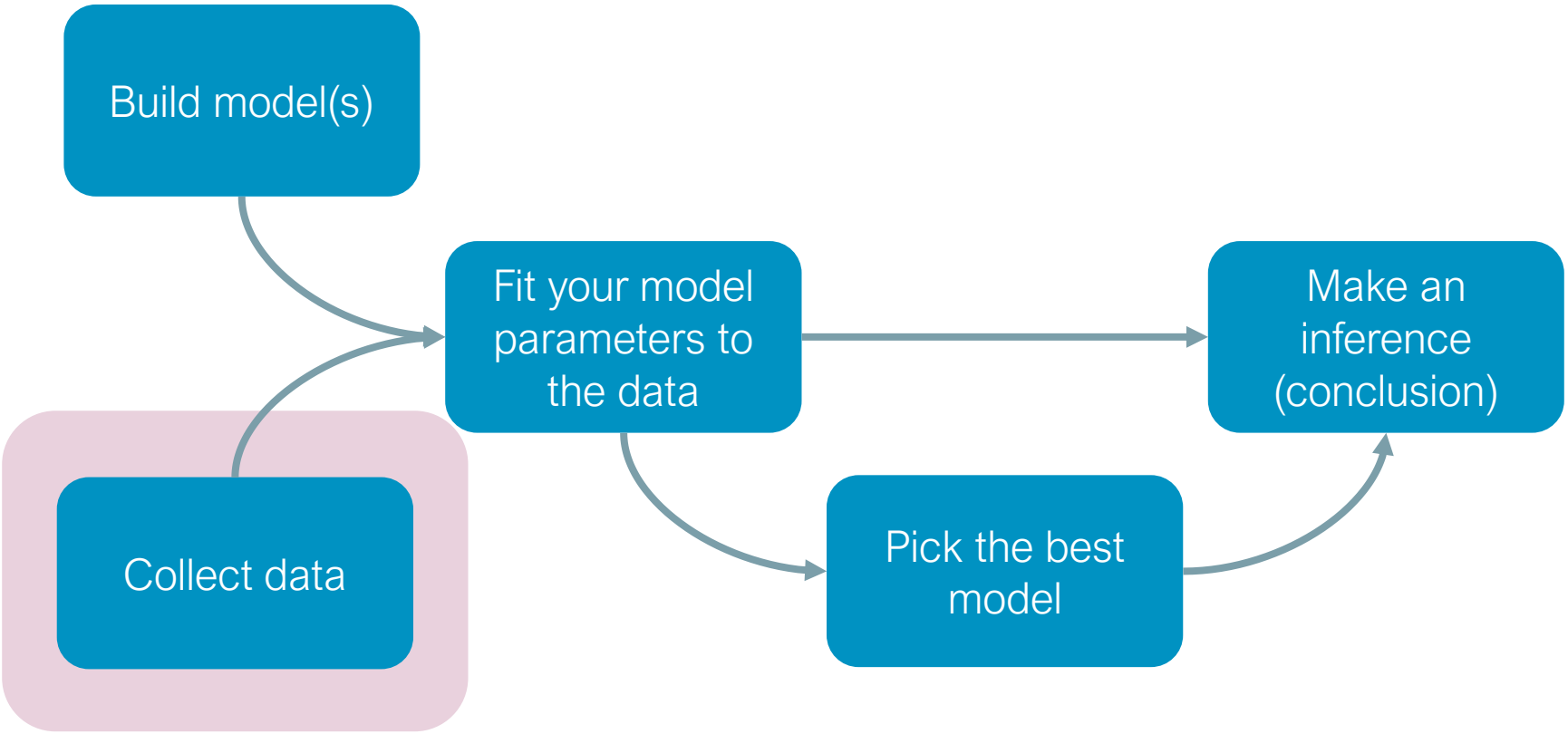
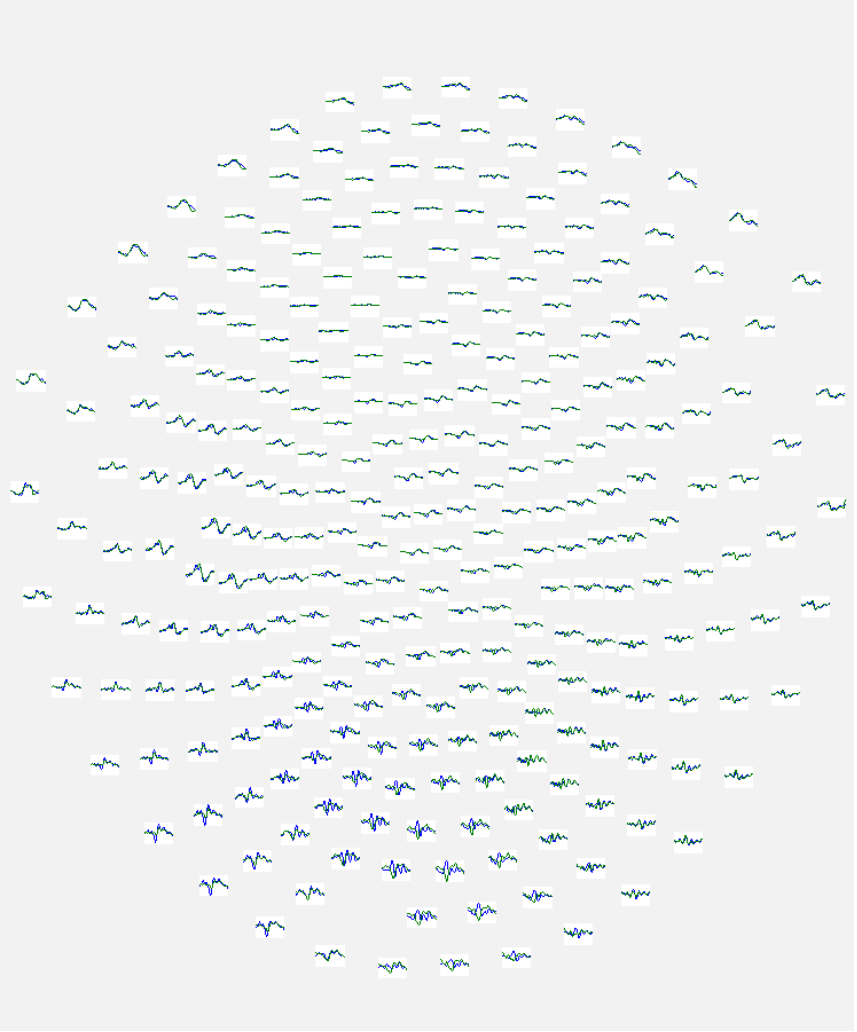


# Data for DCM for ERPs / ERFs

1. Downsample
2. Filter (e.g. 1-40Hz)
3. Epoch
4. Remove artefacts
5. Average
    - Per subject
    - Grand average
6. Plausible sources
    - Literature / a priori
    - Dipole fitting
    - Source reconstruction



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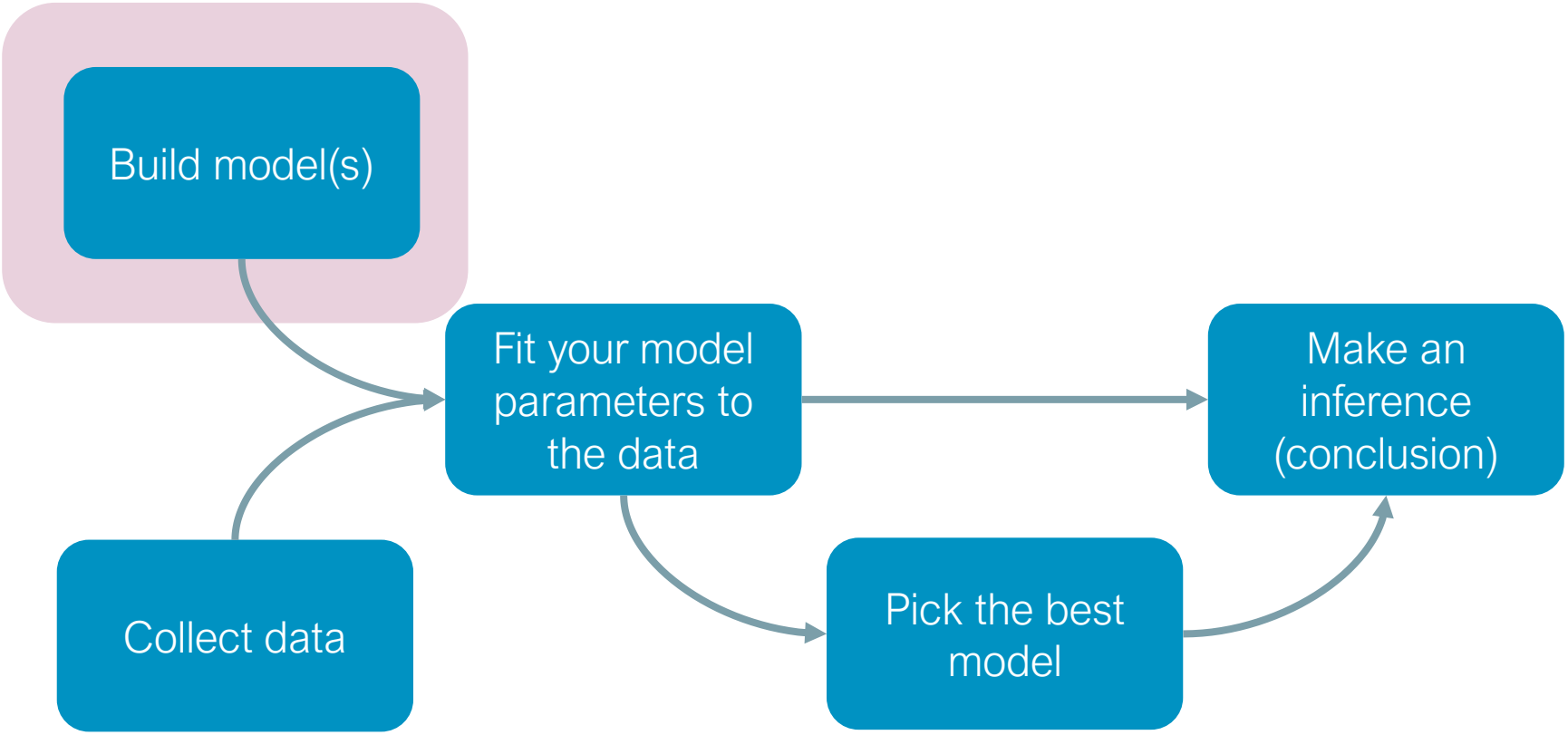

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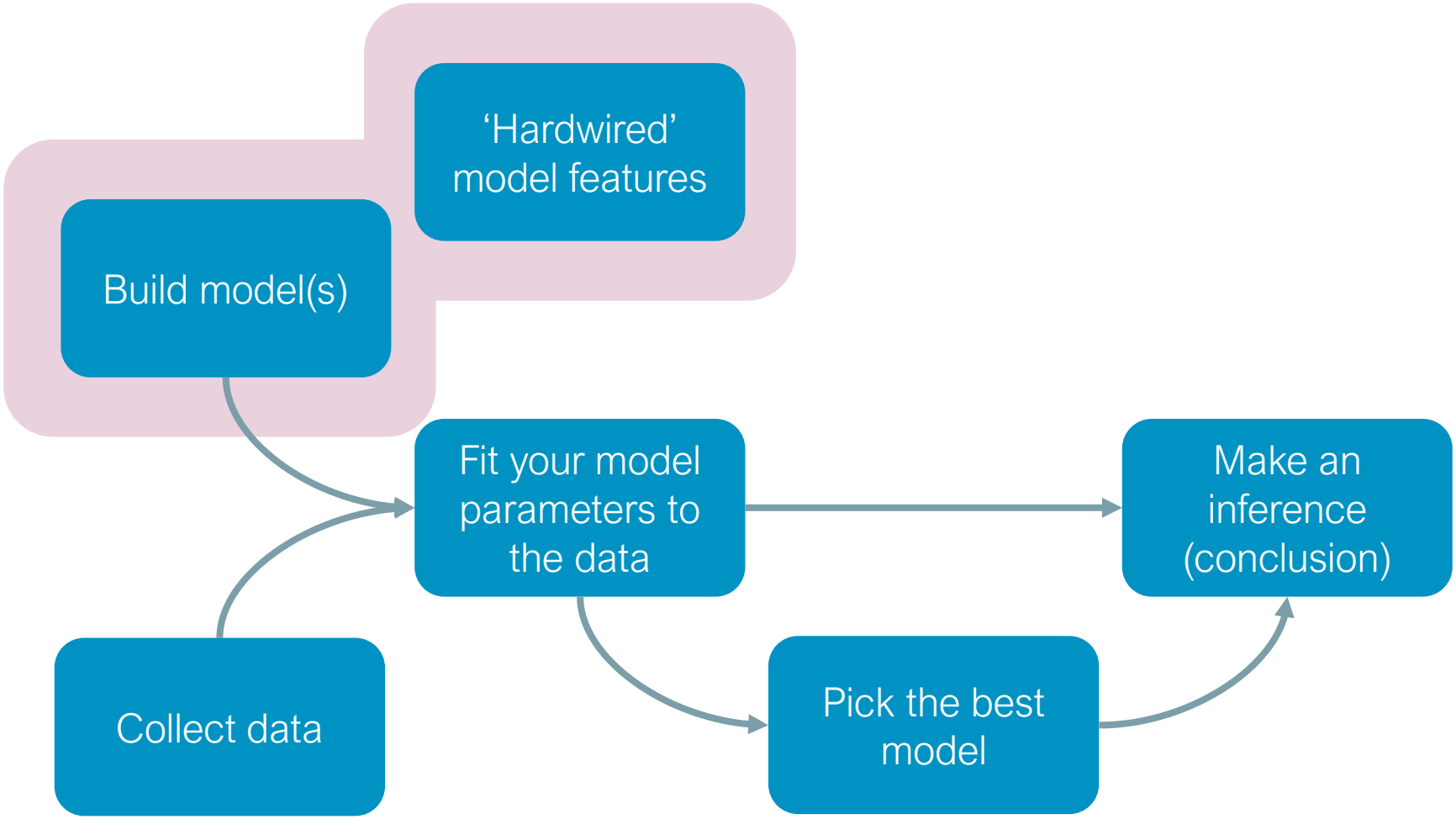
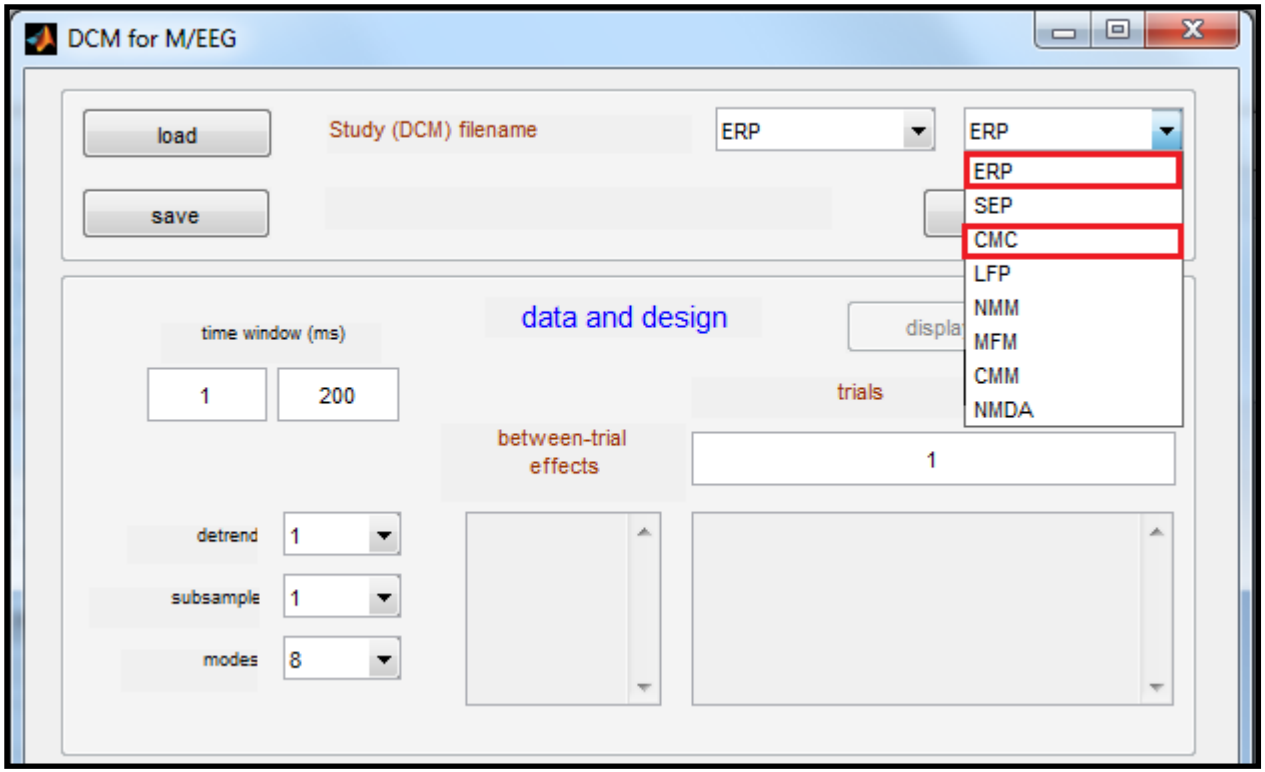


# Models



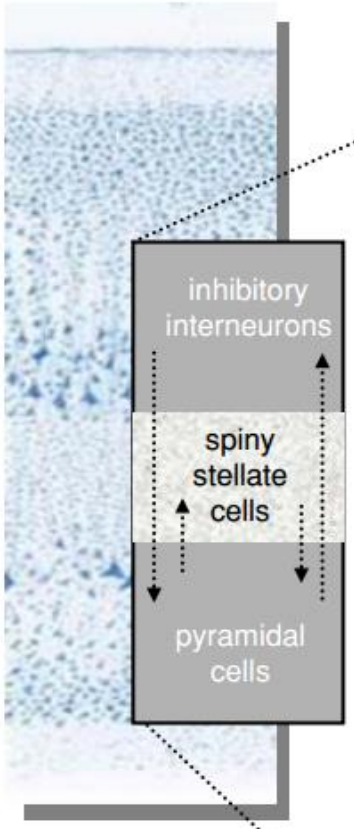

frontiers in
COMPUTATIONAL NEUROSCIENCE

REVIEW ARTICLE
published: 28 May 2013
doi: 10.3389/fncom.2013.00057

## Neural masses and fields in dynamic causal modeling

*Rosalyn Moran*[1,2,3*†], *Dimitris A. Pinotsis*[1†] *and Karl Friston*[1]

# Neuronal (source) model




$$\dot{x}_7 = x_8$$
$$\dot{x}_8 = \frac{H_e}{\tau_e}((A^B + A^L + \gamma_3 I)S(x_0)) - \frac{2x_8}{\tau_e} - \frac{x_7}{\tau_e^2}$$

$$\dot{x}_1 = x_4$$
$$\dot{x}_4 = \frac{H_e}{\tau_e}((A^F + A^L + \gamma_1 I)S(x_0) + Cu) - \frac{2x_4}{\tau_e} - \frac{x_1}{\tau_e^2}$$

$$\dot{x}_0 = x_5 - x_6$$
$$\dot{x}_2 = x_5$$
$$\dot{x}_5 = \frac{H_e}{\tau_e}((A^B + A^L)S(x_0) + \gamma_2 S(x_1)) - \frac{2x_5}{\tau_e} - \frac{x_2}{\tau_e^2}$$
$$\dot{x}_3 = x_6$$
$$\dot{x}_6 = \frac{H_i}{\tau_i}\gamma_4 S(x_7) - \frac{2x_6}{\tau_i} - \frac{x_3}{\tau_i^2}$$

$A^L S(x_0)$

Extrinsic lateral connections

$\gamma_4$ $\gamma_3$

Extrinsic forward connections and input

$A^F S(x_0)$

$Cu$

$\gamma_1$ Intrinsic connections $\gamma_2$

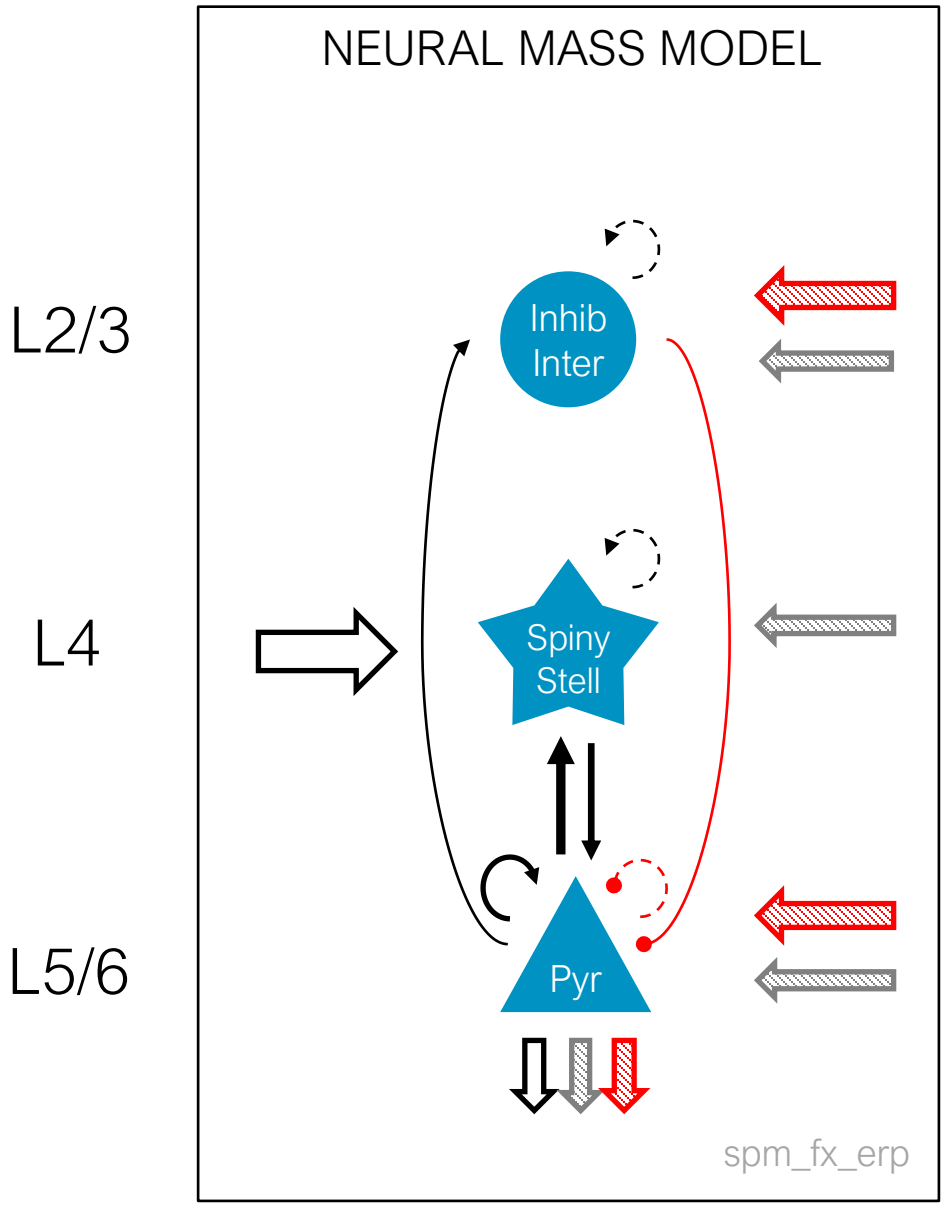
$x_0$

Extrinsic backward connections $A^B S(x_0)$

**State equations**

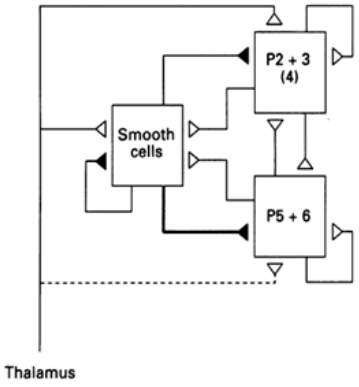
$$\dot{x} = f(x, u, \theta)$$

Kiebel et al., 2008


NEURAL MASS MODEL
L2/3
L4
L5/6
Inhib
Inter
Spiny
Stell
Pyr
spm_fx_erp

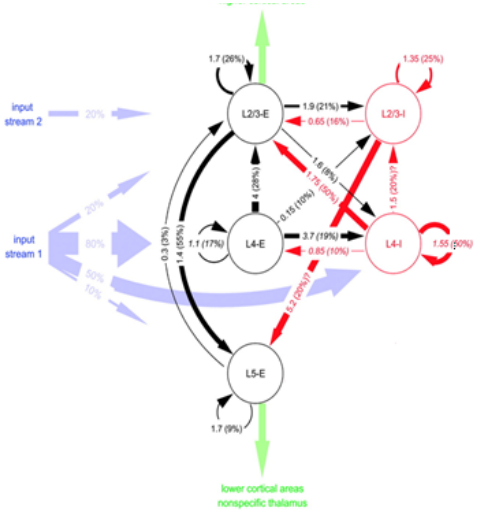
# Canonical Microcircuit Model ('CMC')

Original microcircuit



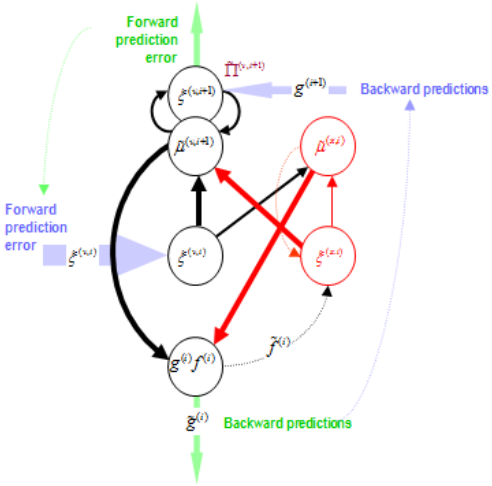

Douglas & Martin (1991)

Updated microcircuit



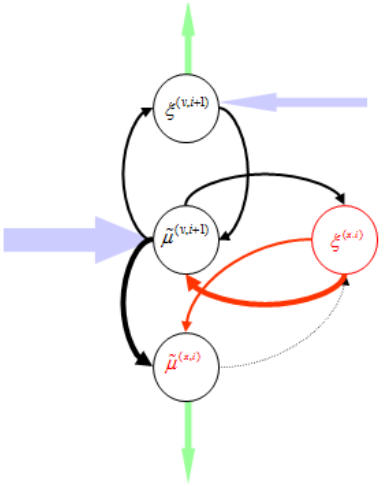

Adapted from Haeusler & Maass (2006)

Canonical microcircuit (predictive coding)




Bastos et al. (2012)

Reduced model (DCM)

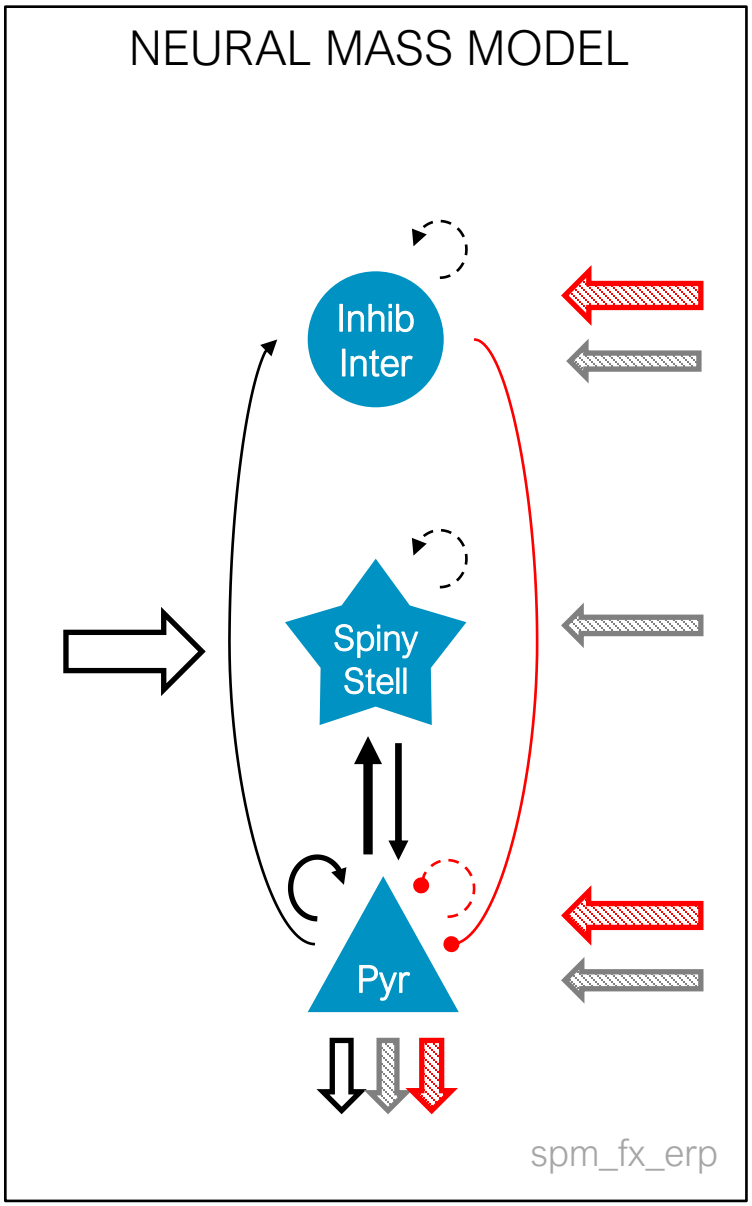


Pinotsis et al. (2012)

L2/3

L4

L5/6


NEURAL MASS MODEL
Inhib Inter
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Pyr
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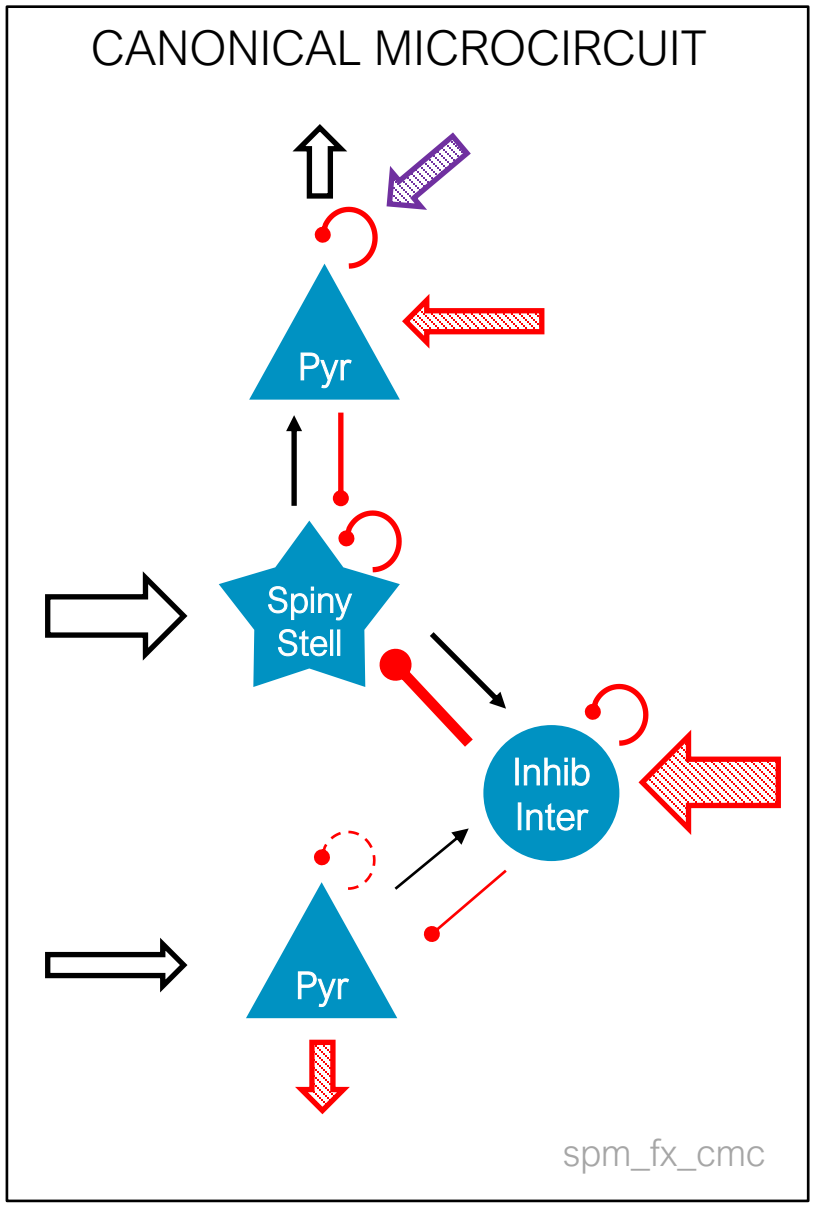
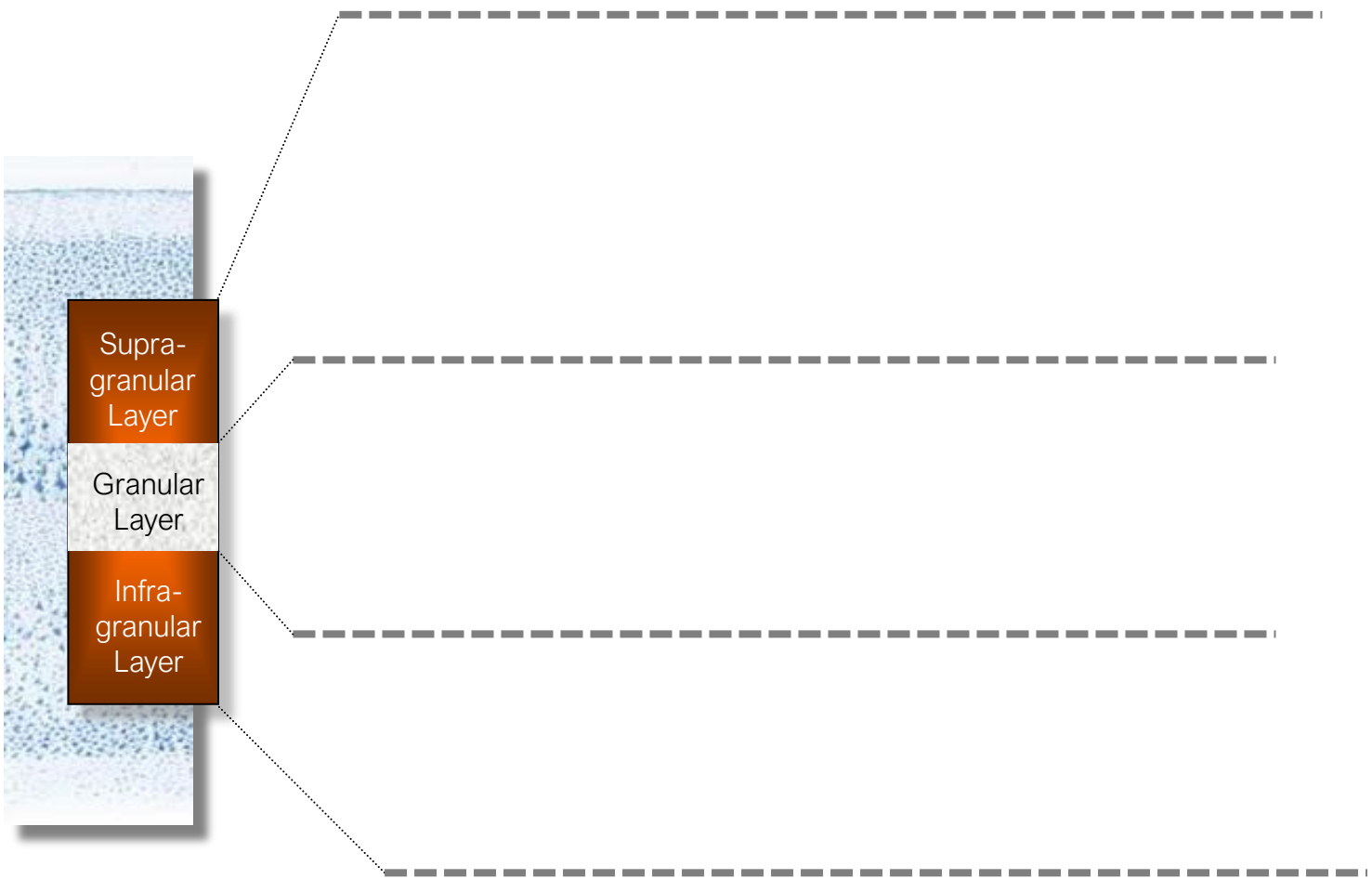

CANONICAL MICROCIRCUIT
Pyr
Spiny Stell
Inhib Inter
Pyr
spm_fx_cmc

# Canonical Microcircuit Model ('CMC')



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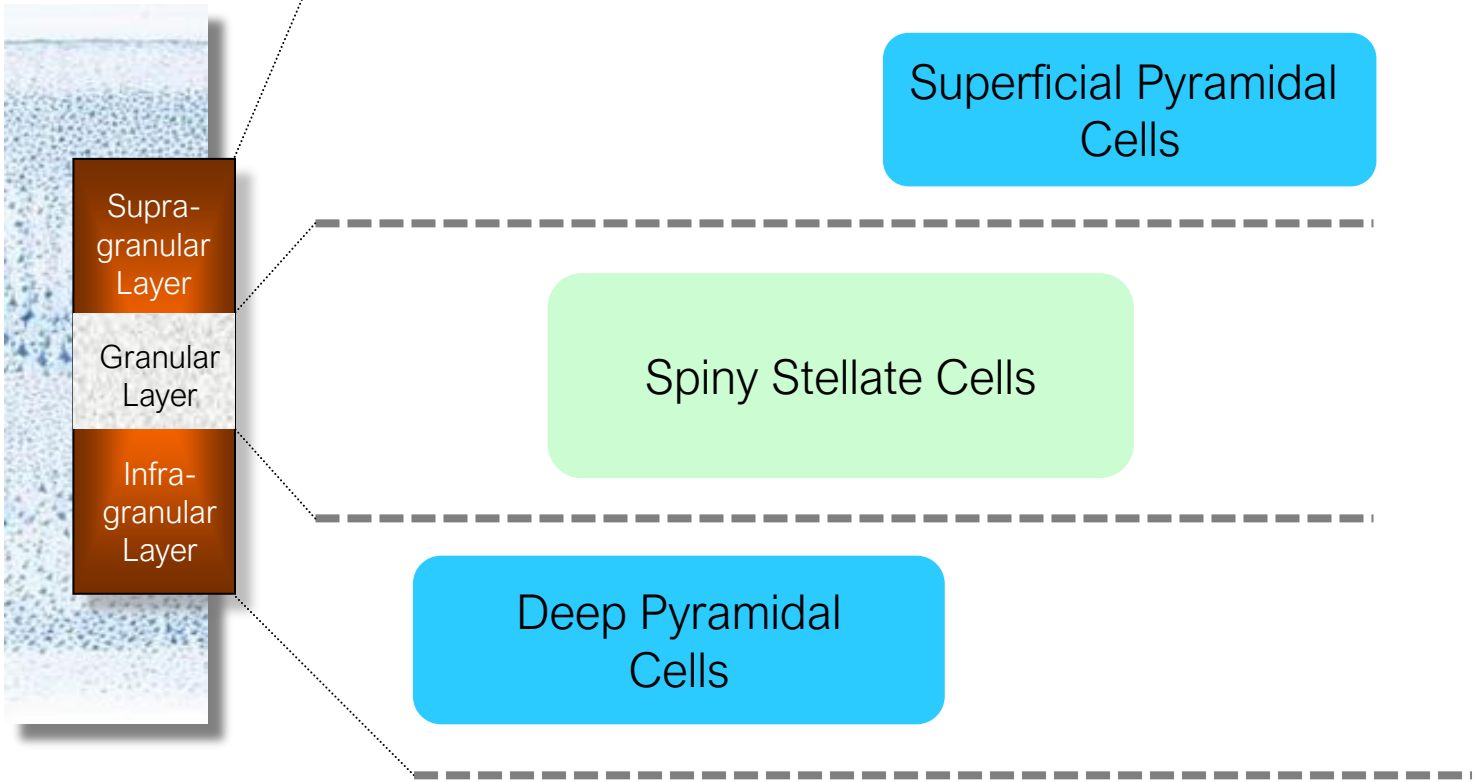


Pinotsis et al., 2012

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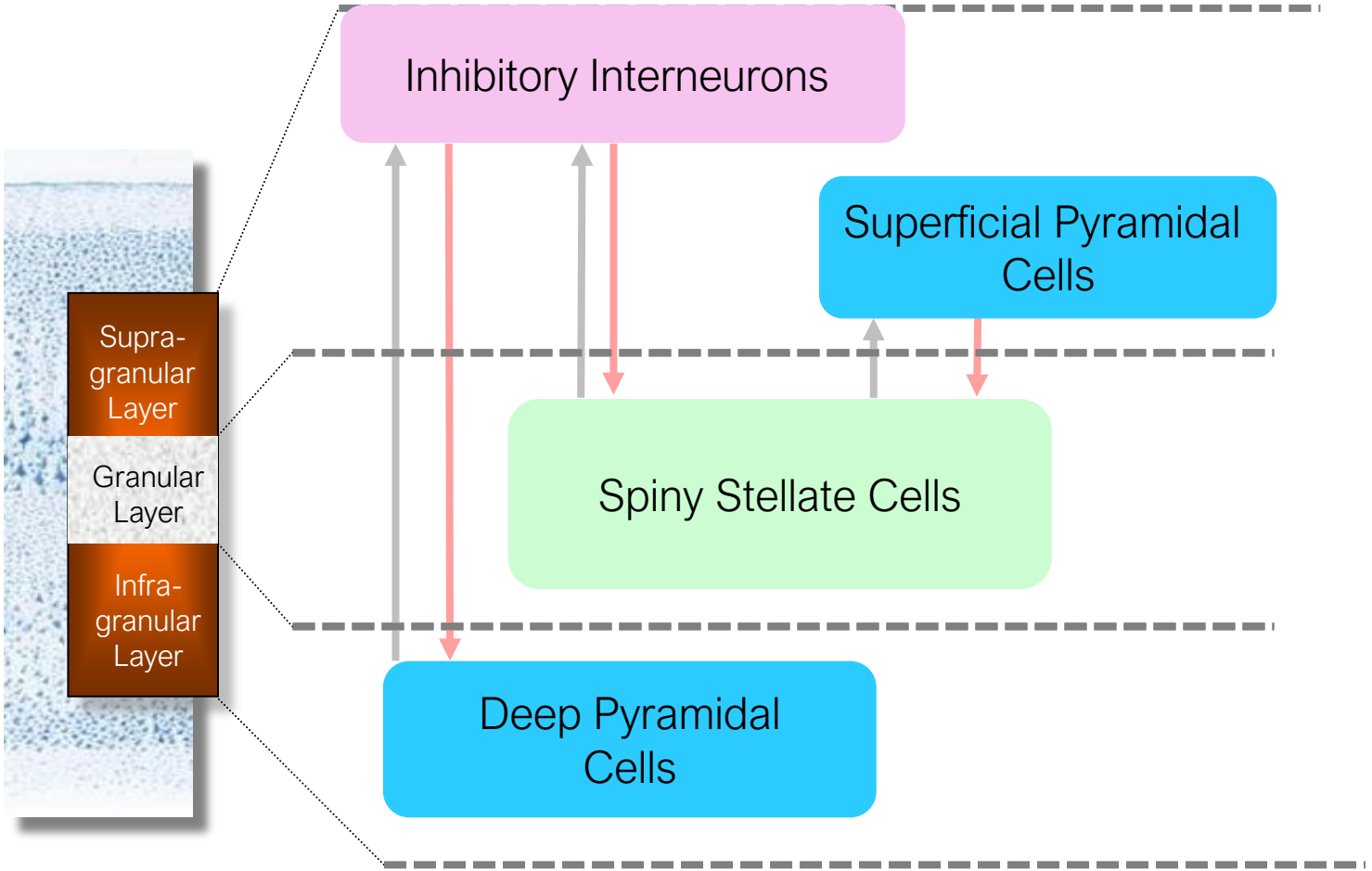


Pinotsis et al., 2012

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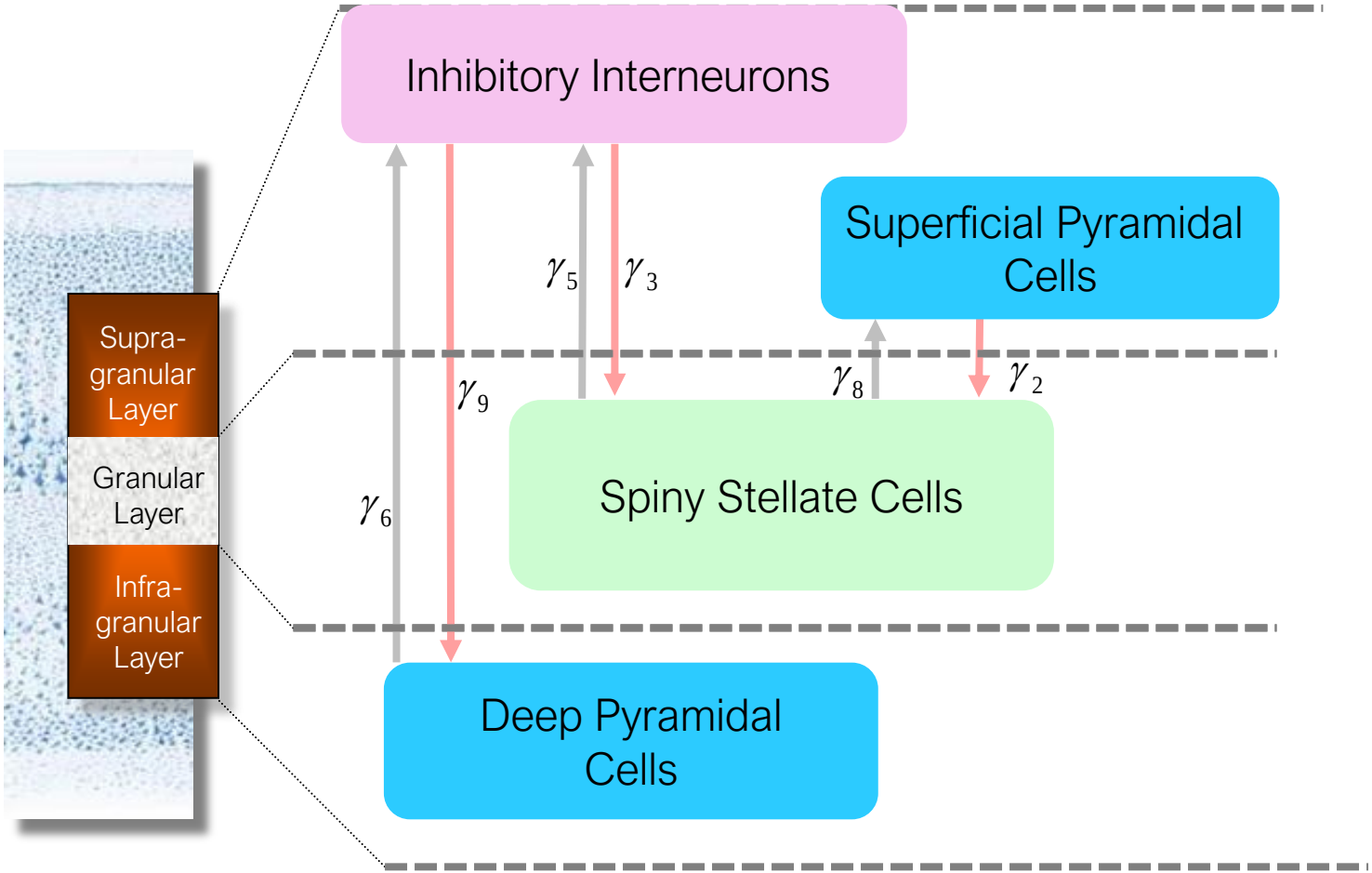


Pinotsis et al., 2012

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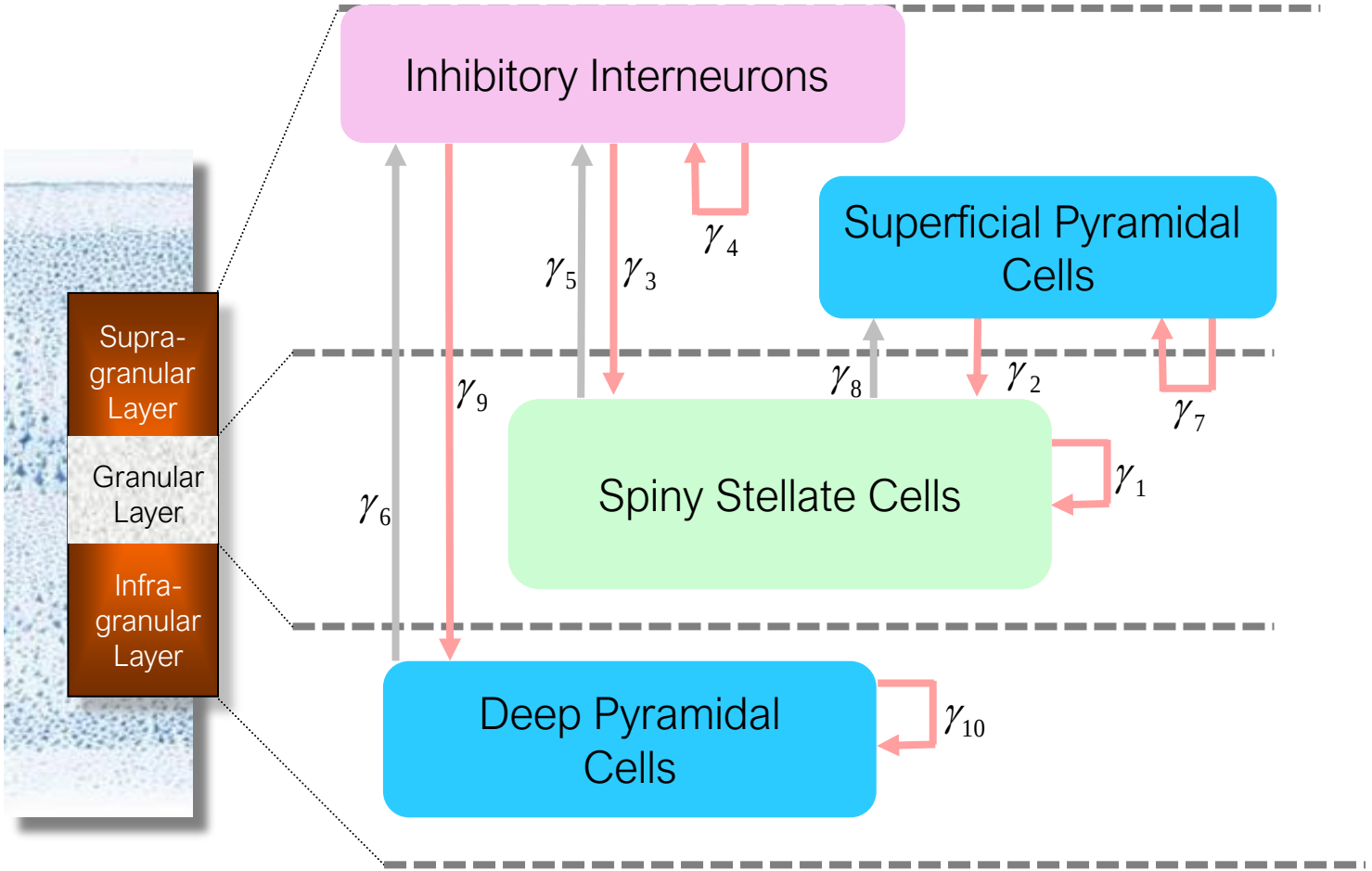


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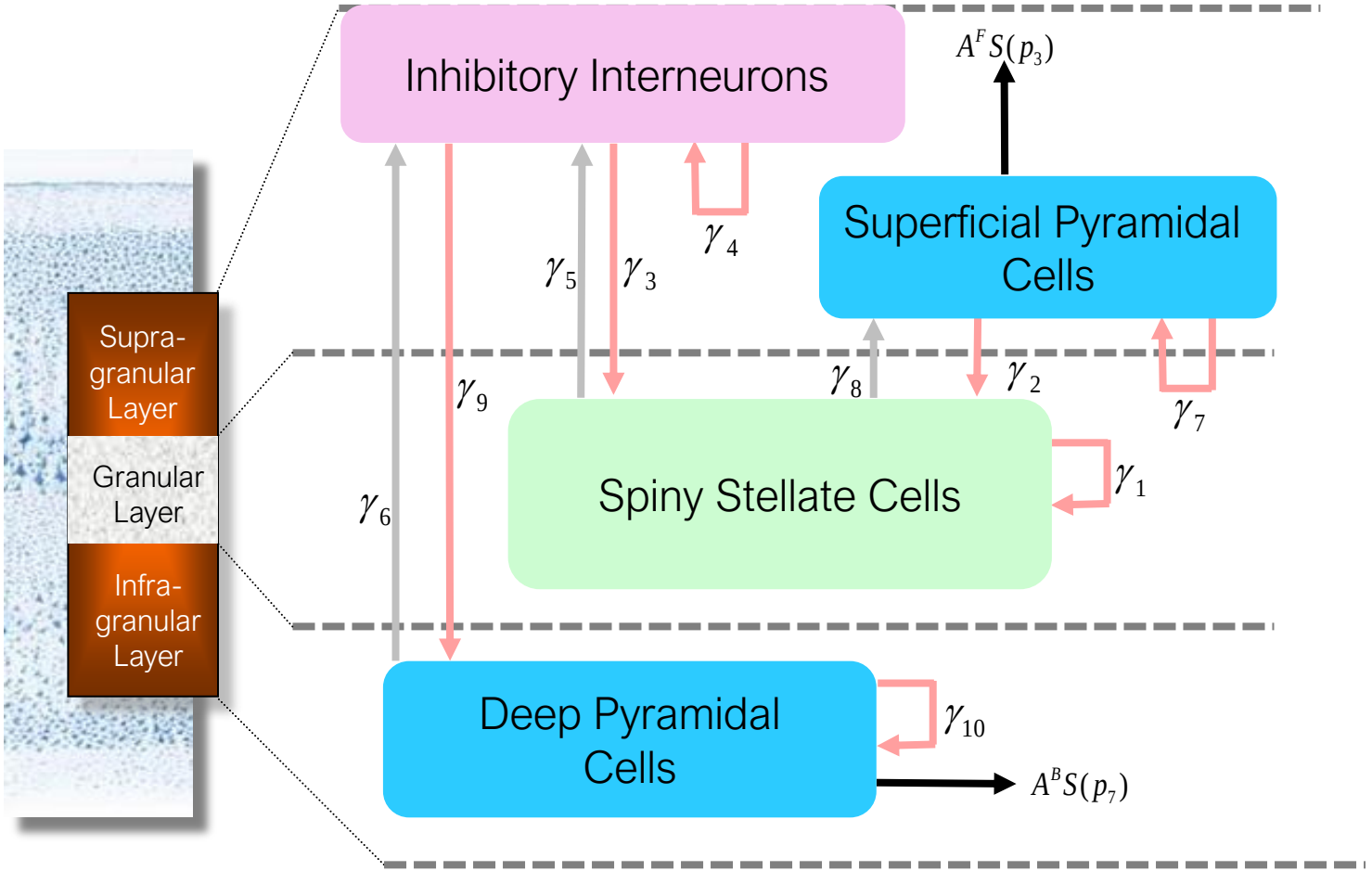


Pinotsis et al., 2012

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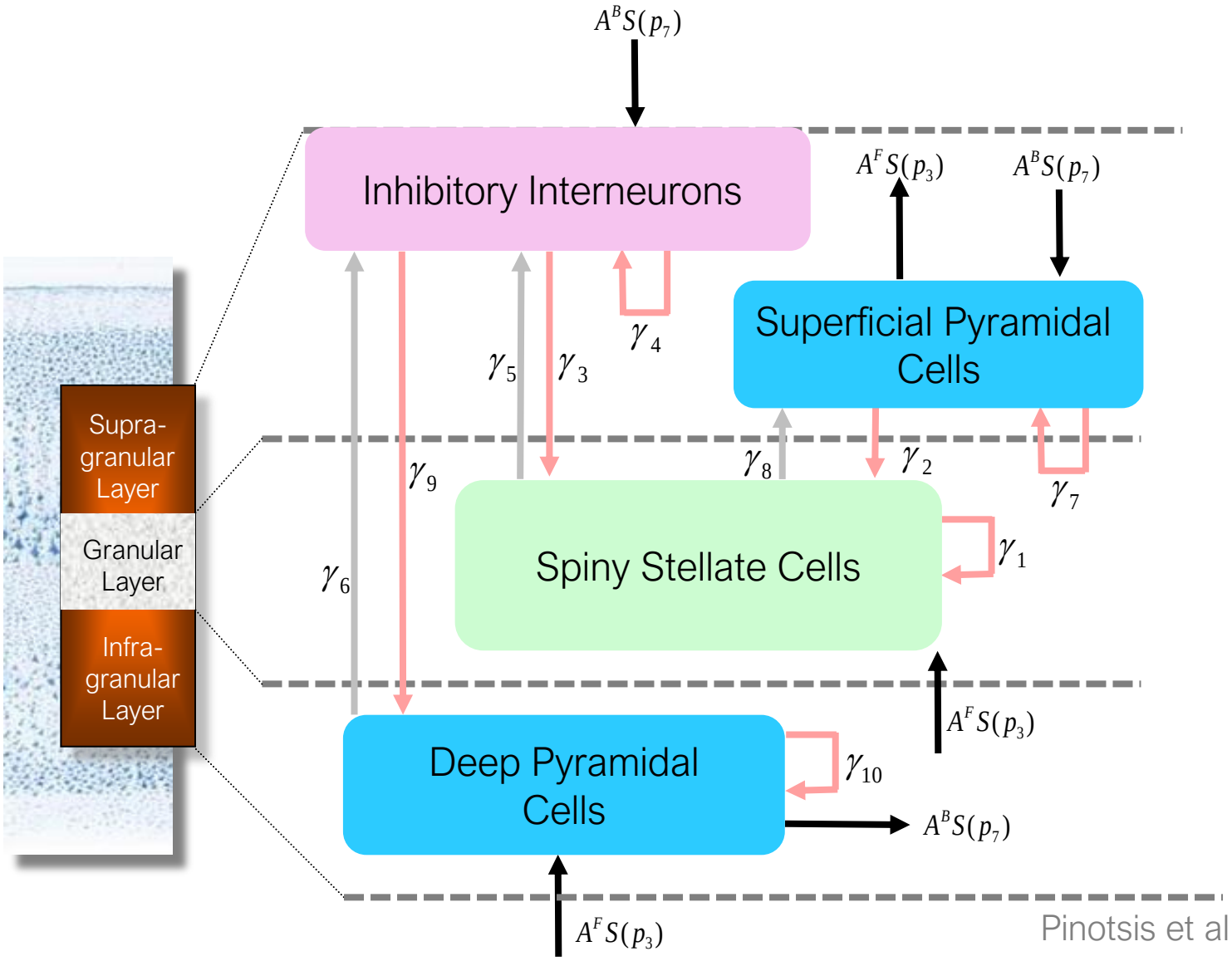


Pinotsis et al., 2012

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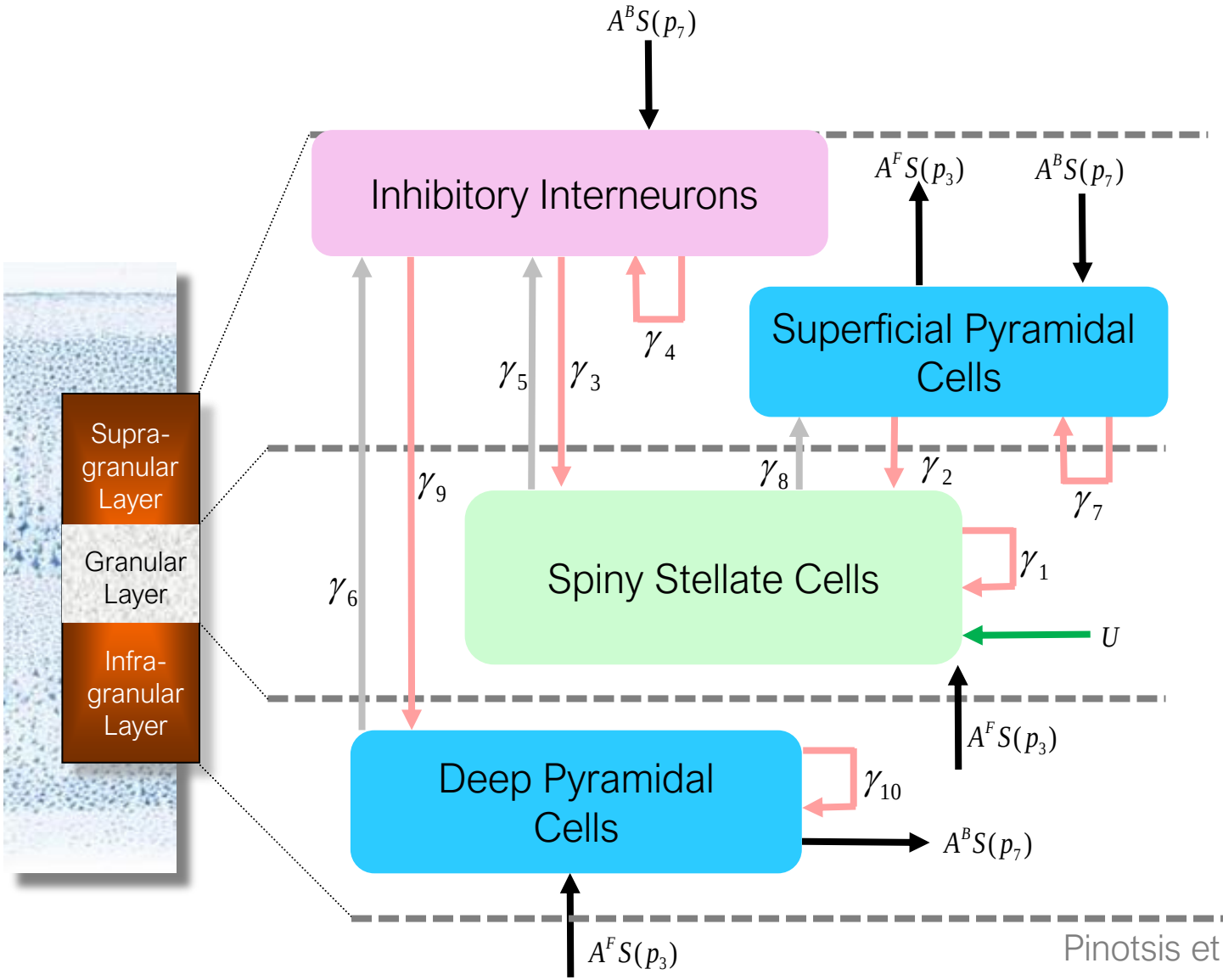


Pinotsis et al., 2012

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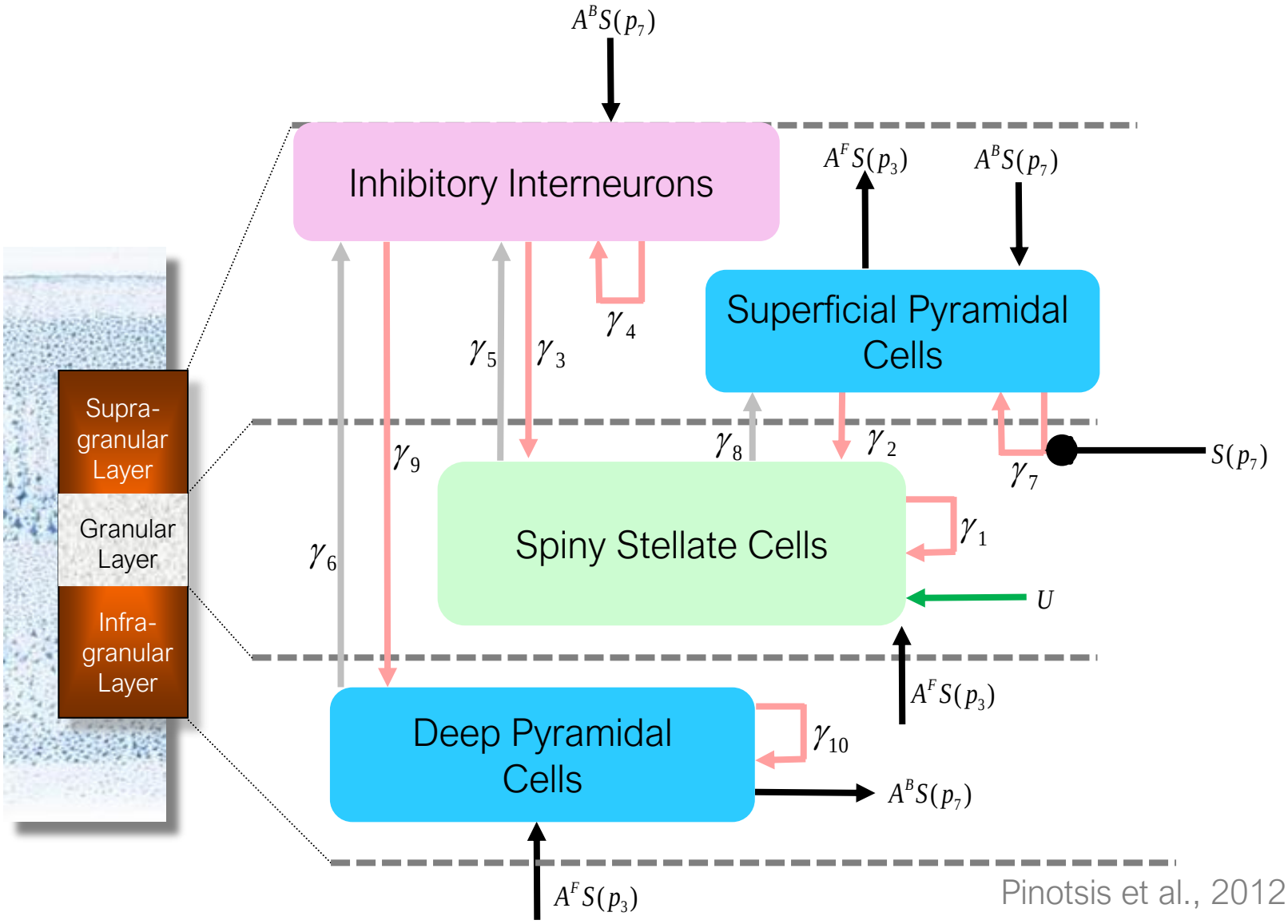


Pinotsis et al., 2012

# Canonical Microcircuit Model ('CMC')

$$\dot{p}_7 = p_8$$

Voltage change rate: f(current)
Current change rate: f(voltage,current)

$$\dot{p}_8 = \frac{H_4}{\tau_4}\left(A^F S(p_2) - \gamma_{10} S(p_7) - \gamma_9 S(p_5)\right) - \frac{2p_8}{\tau_4} - \frac{p_7}{\tau_4^2}$$

Pinotsis et al., 2012

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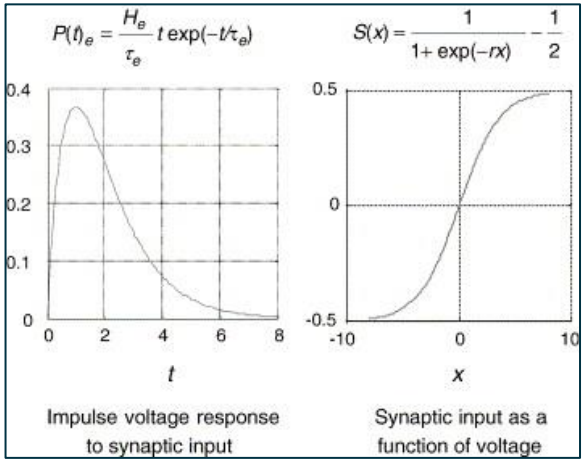
*H, τ* Kernels: pre-synaptic inputs -> post-synaptic membrane potentials
[ *H:* max PSP; *τ:* rate constant ]

*S* Sigmoid operator: PSP -> firing rate




David et al., 2006; Pinotsis et al., 2012

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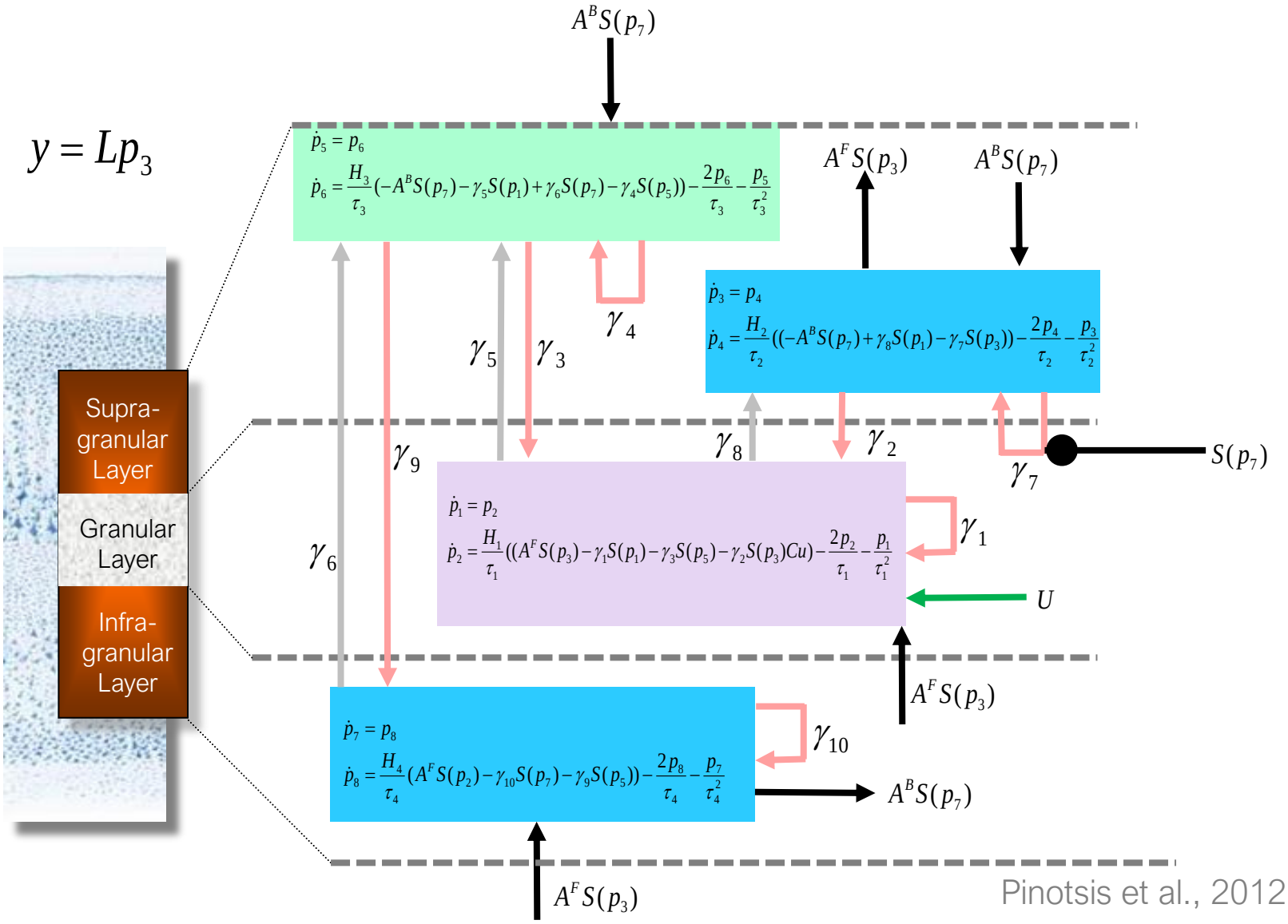
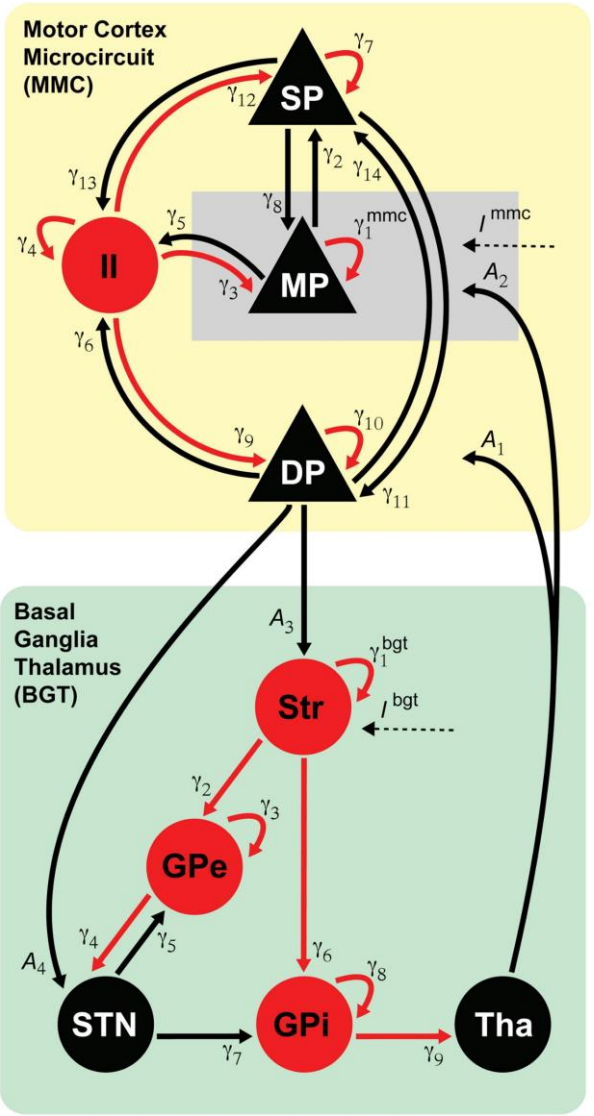
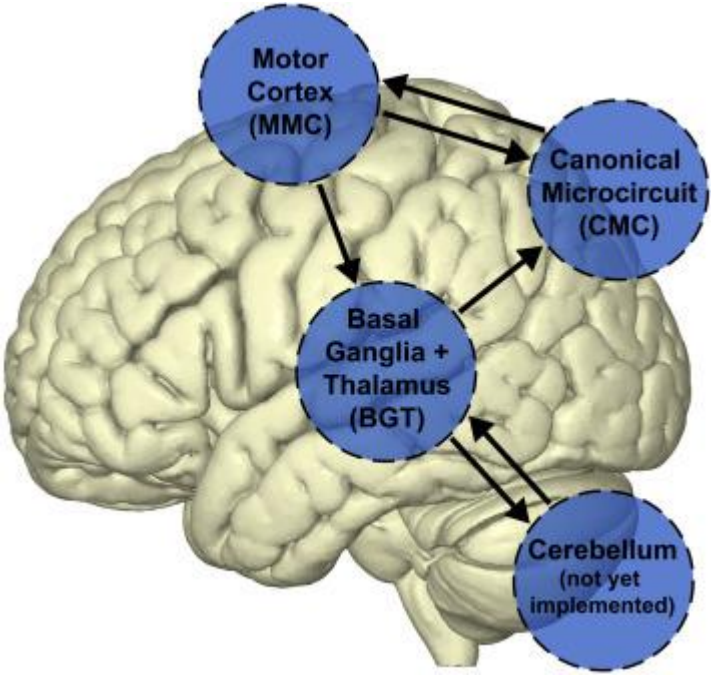


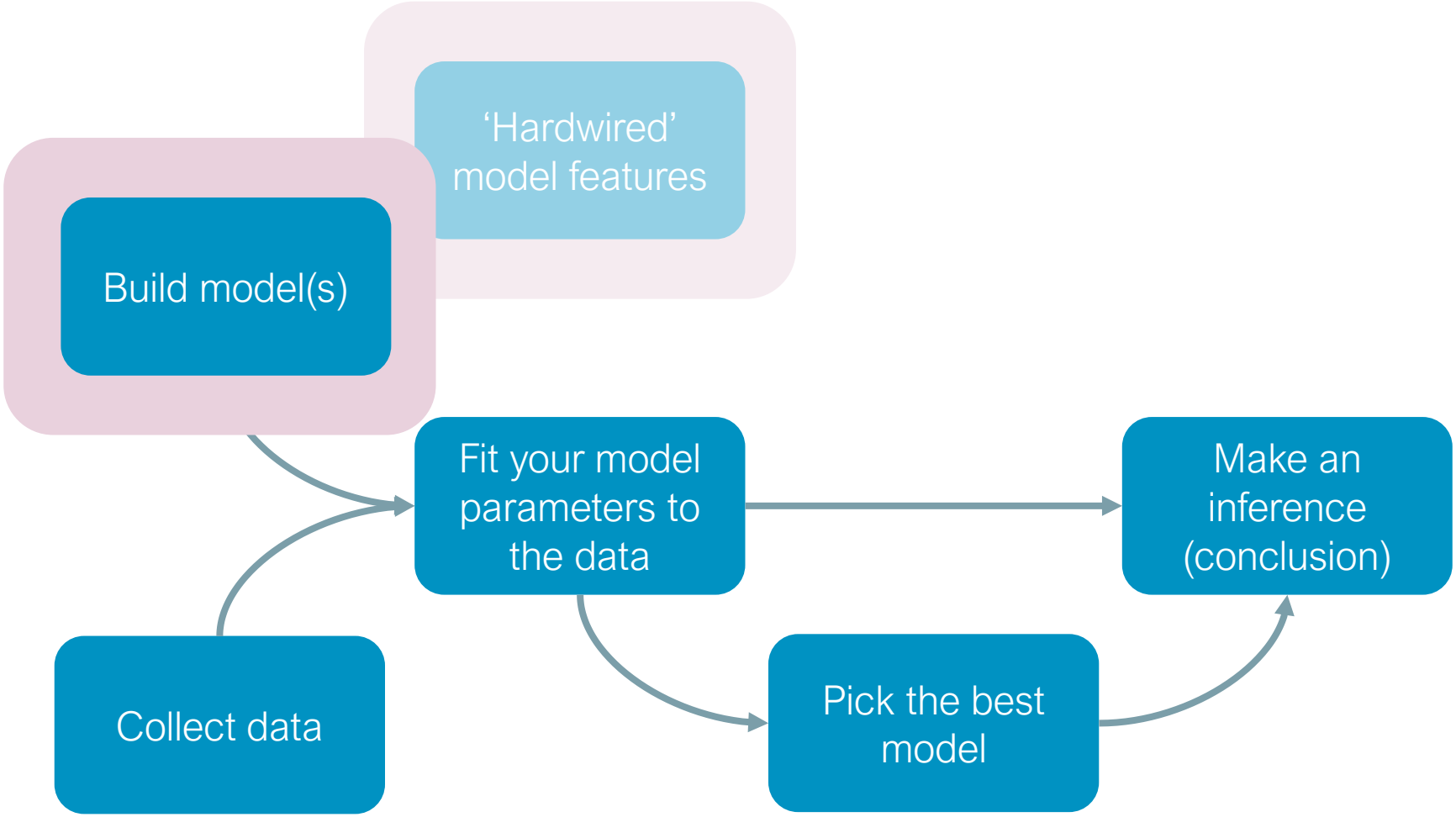

Pinotsis et al., 2012

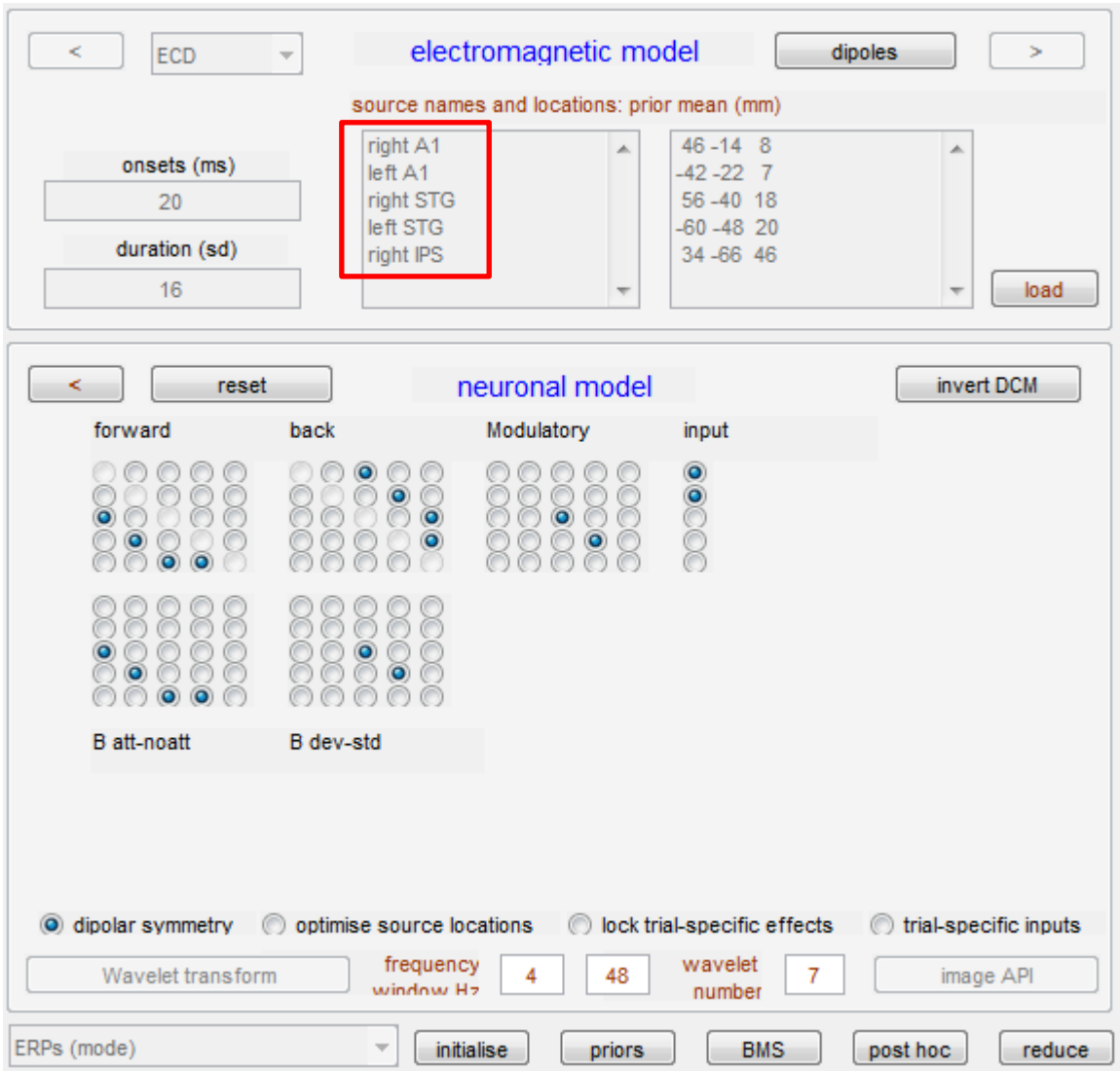



Van Wijk et al., 2018

# The DCM analysis pathway




electromagnetic model
ECD
dipoles
source names and locations: prior mean (mm)
onsets (ms)
20
duration (sd)
16
right A1
left A1
right STG
left STG
right IPS
46 -14 8
-42 -22 7
56 -40 18
-60 -48 20
34 -66 46
load
neuronal model
reset
invert DCM
forward
back
Modulatory
input
B att-noatt
B dev-std
dipolar symmetry
optimise source locations
lock trial-specific effects
trial-specific inputs
Wavelet transform
frequency
4
48
wavelet number
7
image API
ERPs (mode)
initialise
priors
BMS
post hoc
reduce

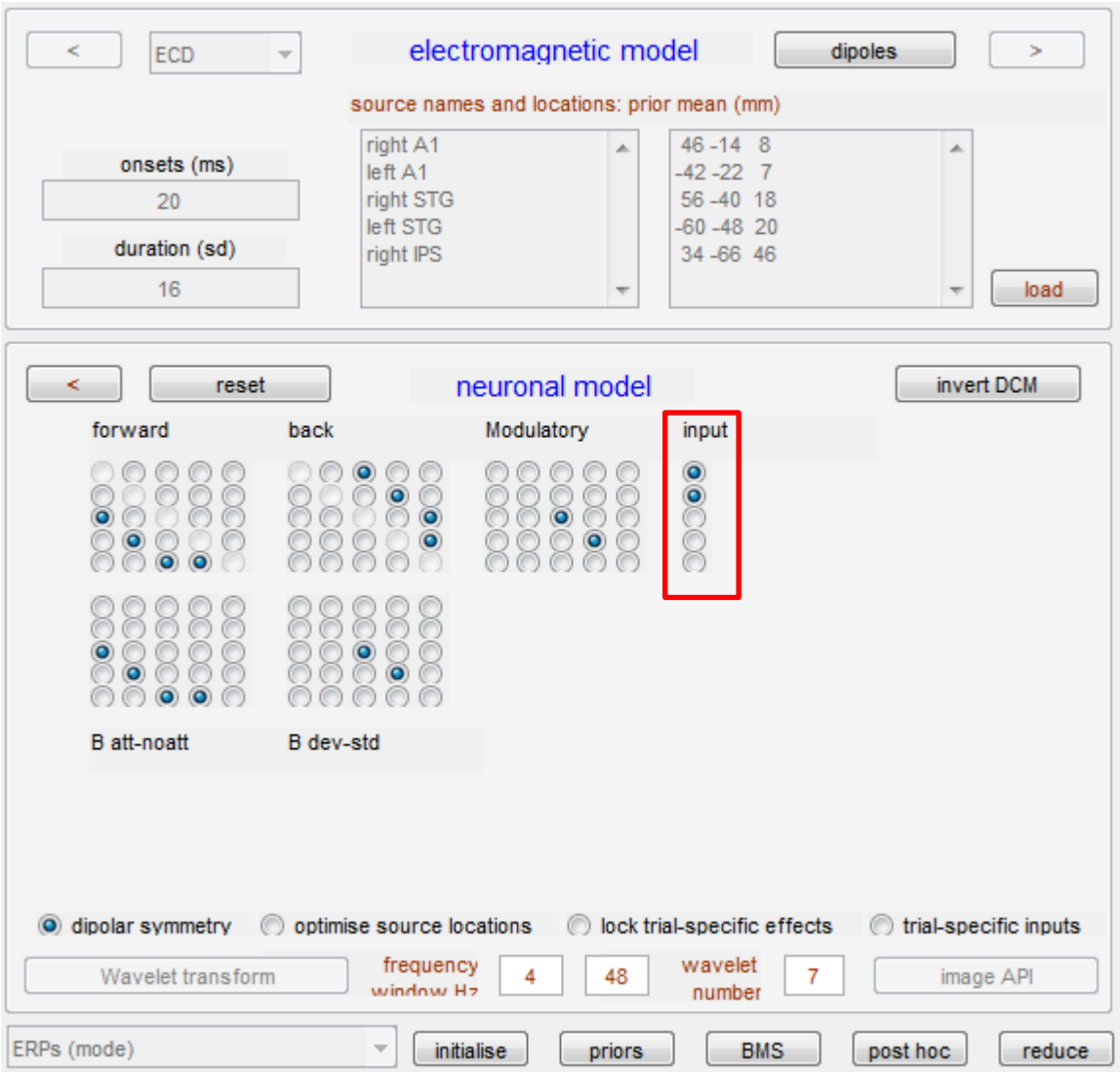
5

4

3

2

1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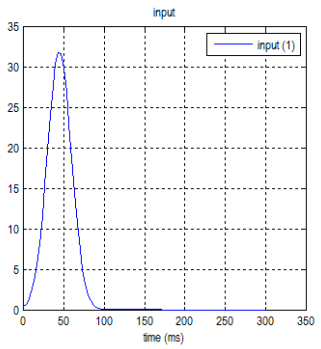
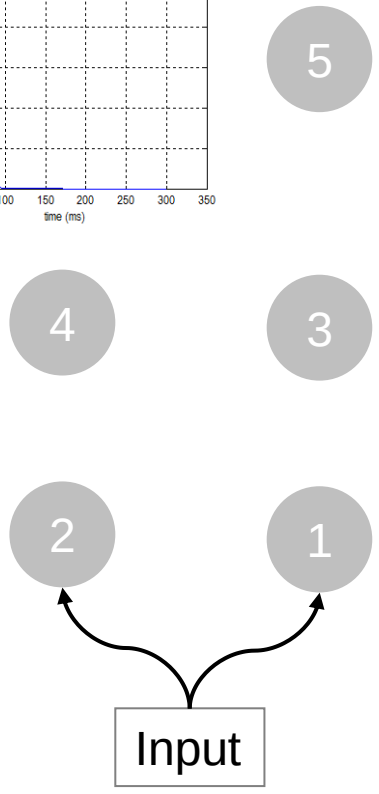
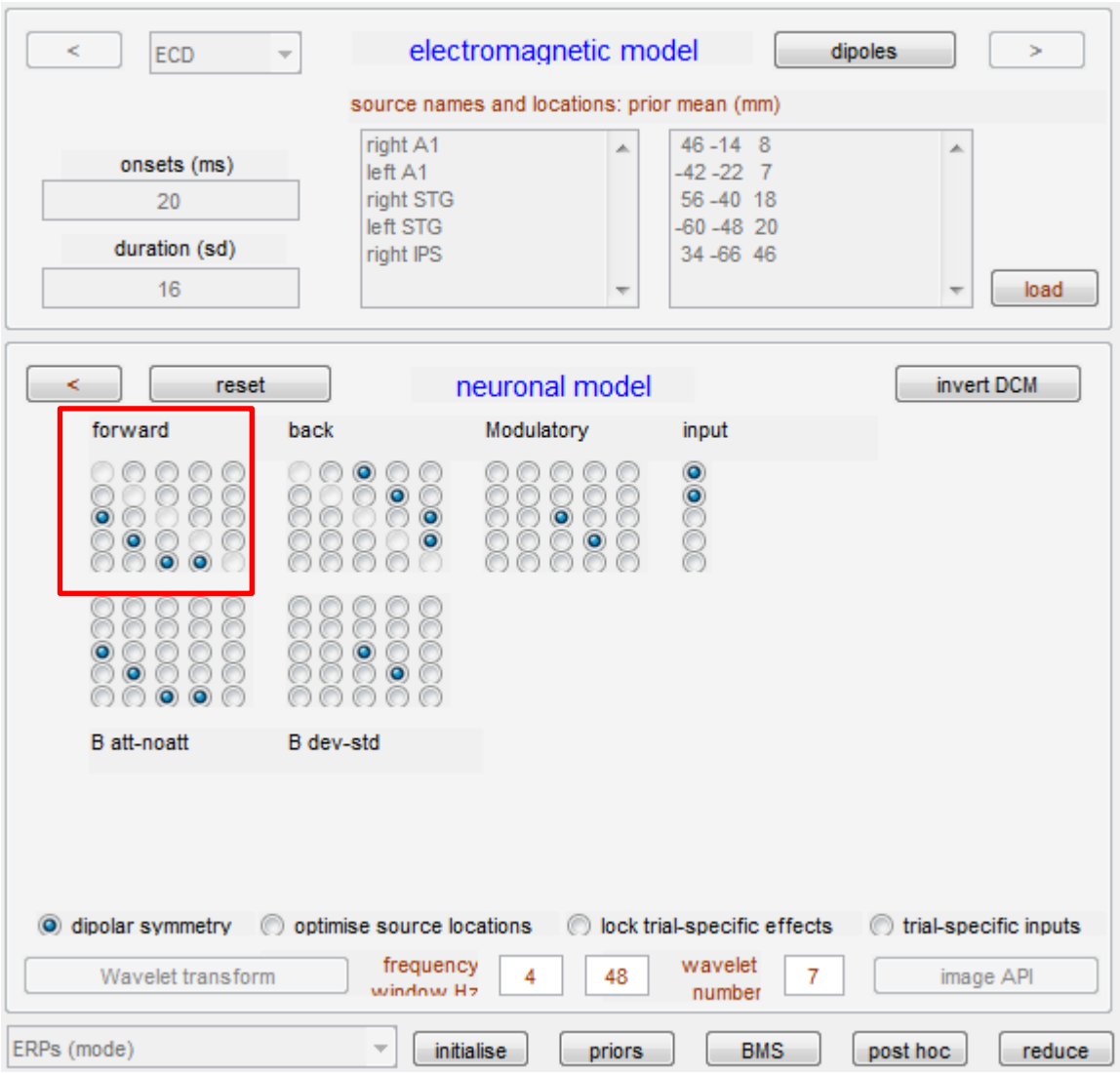

input
input (1)
time (ms)


5
4
3
2
1
Input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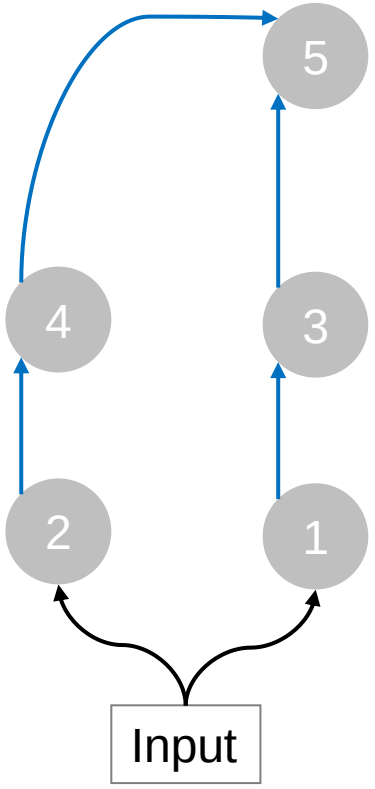
5
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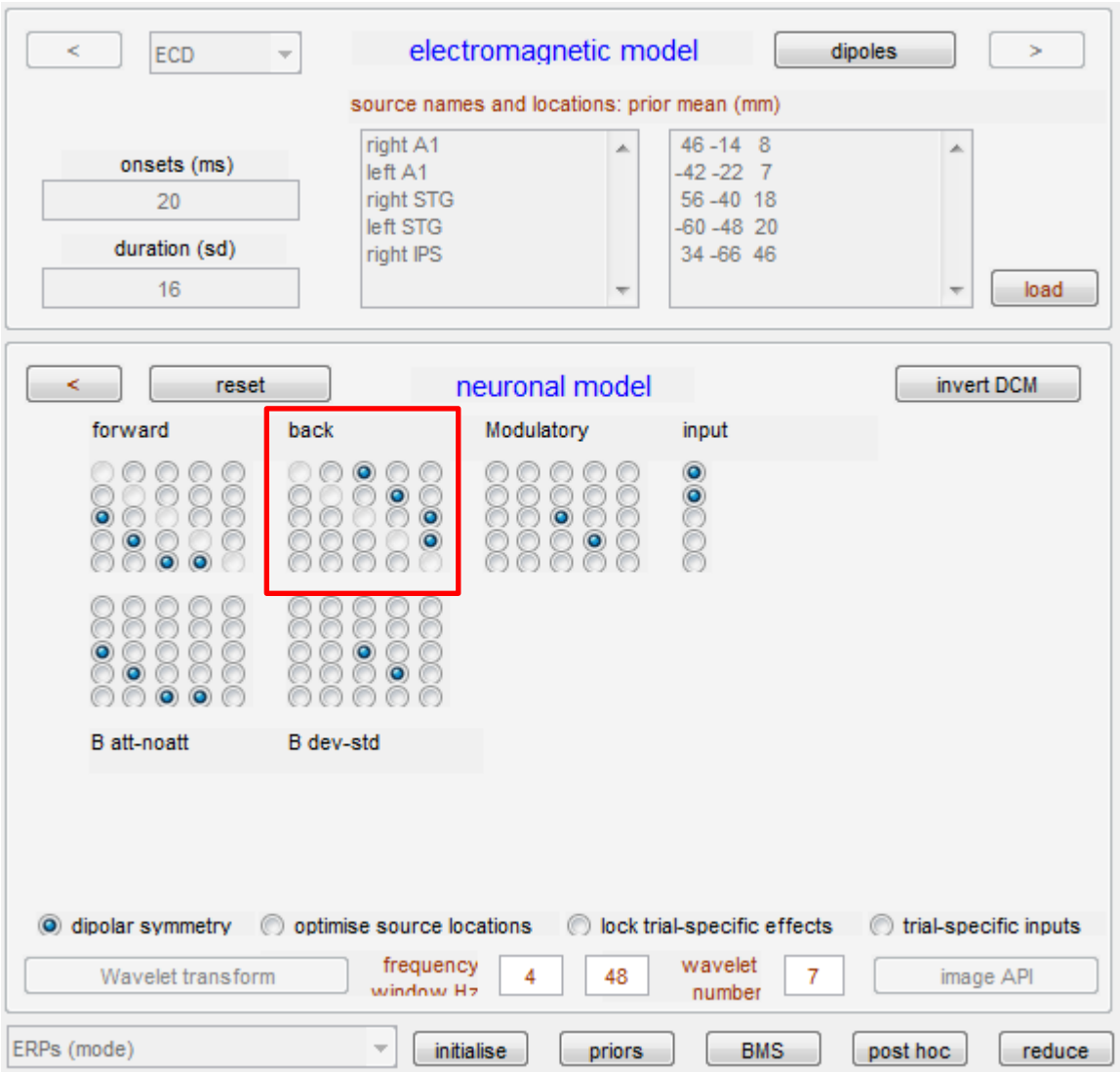
Input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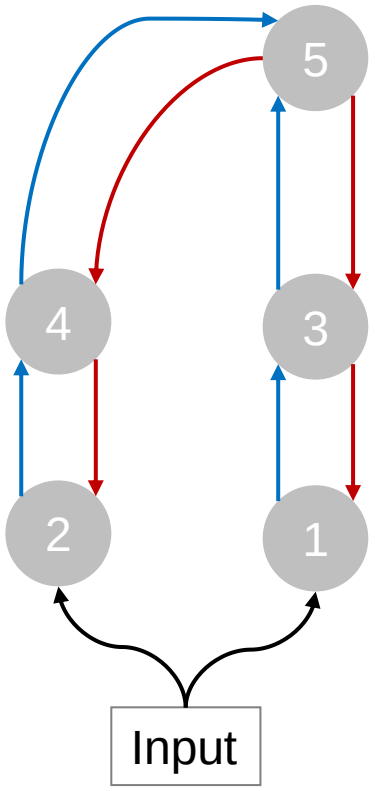
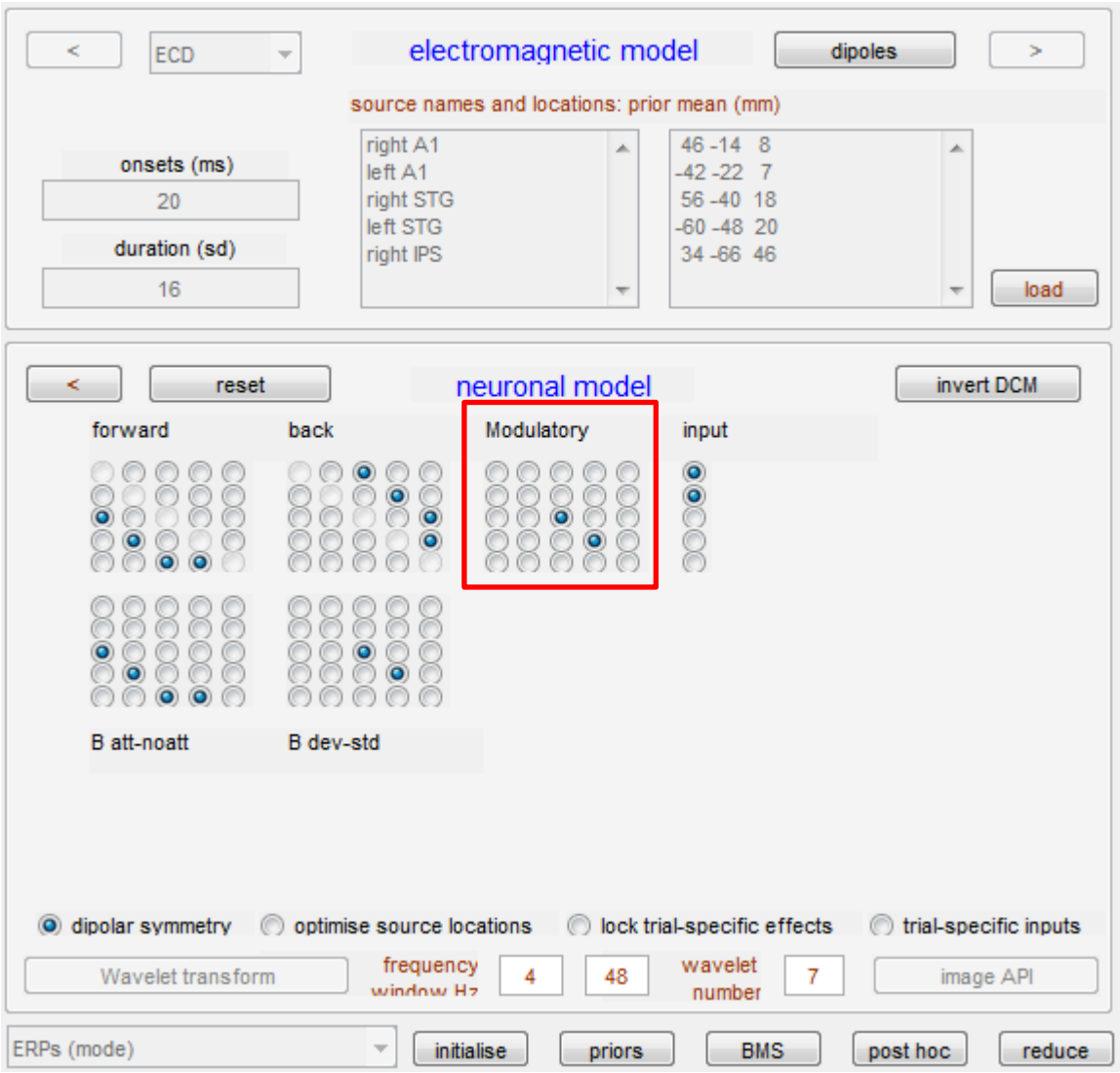

5
4
3
2
1
Input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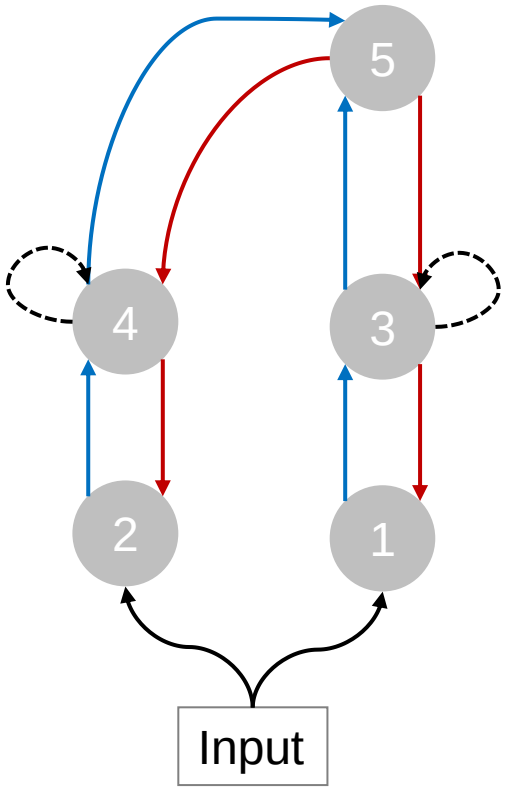
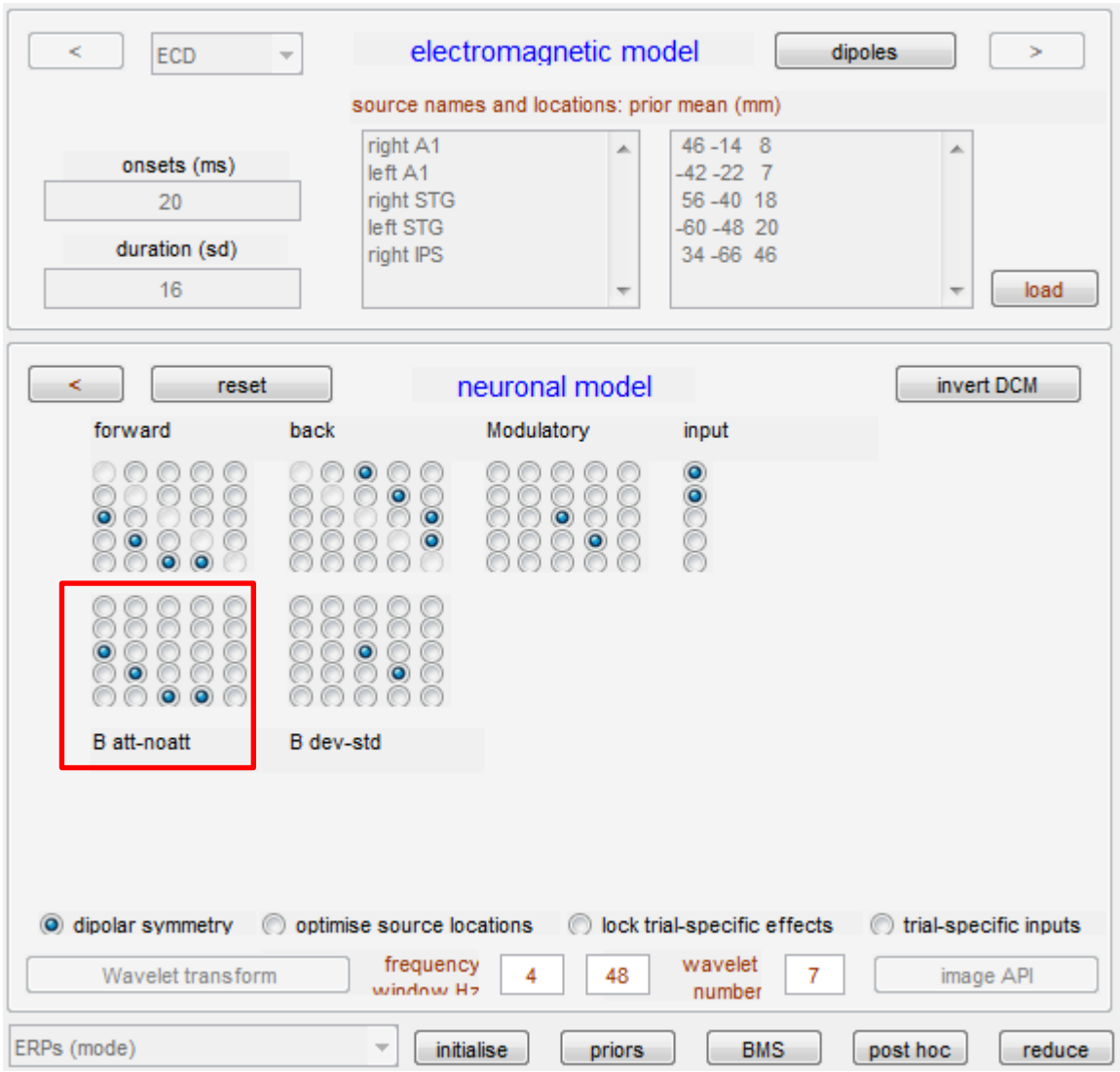
ECD
dipoles
source names and locations: prior mean (mm)
onsets (ms)
20
duration (sd)
16
right A1
left A1
right STG
left STG
right IPS
46 -14 8
-42 -22 7
56 -40 18
-60 -48 20
34 -66 46
load
neuronal model
reset
invert DCM
forward
back
Modulatory
input
B att-noatt
B dev-std
dipolar symmetry
optimise source locations
lock trial-specific effects
trial-specific inputs
Wavelet transform
frequency
4
48
wavelet number
7
image API
ERPs (mode)
initialise
priors
BMS
post hoc
reduce


5
4
3
2
1
Input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dipoles
ECD
source names and locations: prior mean (mm)
right A1
left A1
right STG
left STG
right IPS
46 -14 8
-42 -22 7
56 -40 18
-60 -48 20
34 -66 46
onsets (ms)
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load
neuronal model
reset
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forward
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Modulatory
input
B att-noatt
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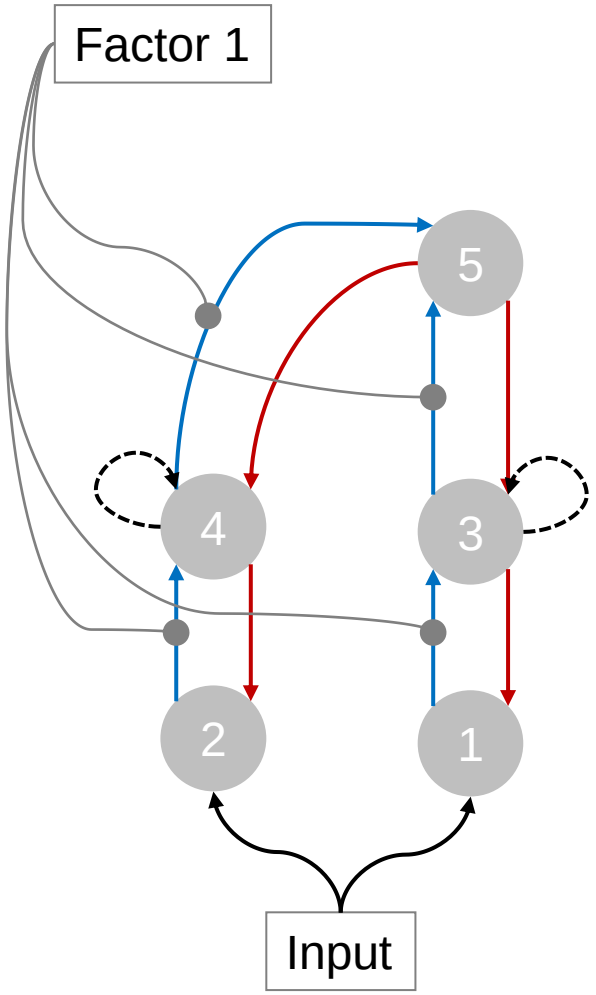
trial-specific inputs
Wavelet transform
frequency
4
48
wavelet number
7
image API
ERPs (mode)
initialise
priors
BMS
post hoc
reduce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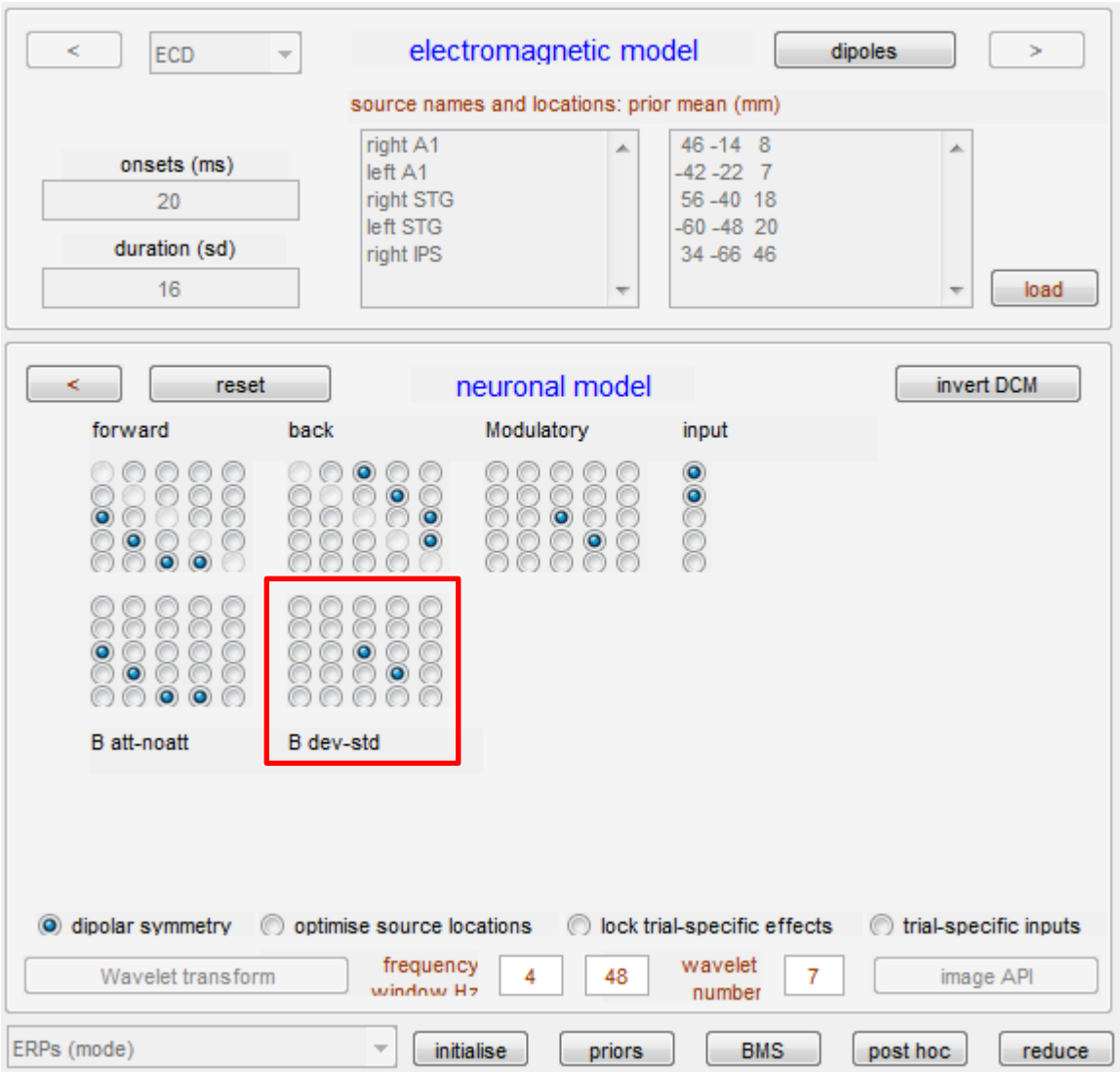
5
4
3
2
1
Input


electromagnetic model
dipoles
ECD
source names and locations: prior mean (mm)
right A1
left A1
right STG
left STG
right IPS
46 -14 8
-42 -22 7
56 -40 18
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onsets (ms)
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reset
invert DCM
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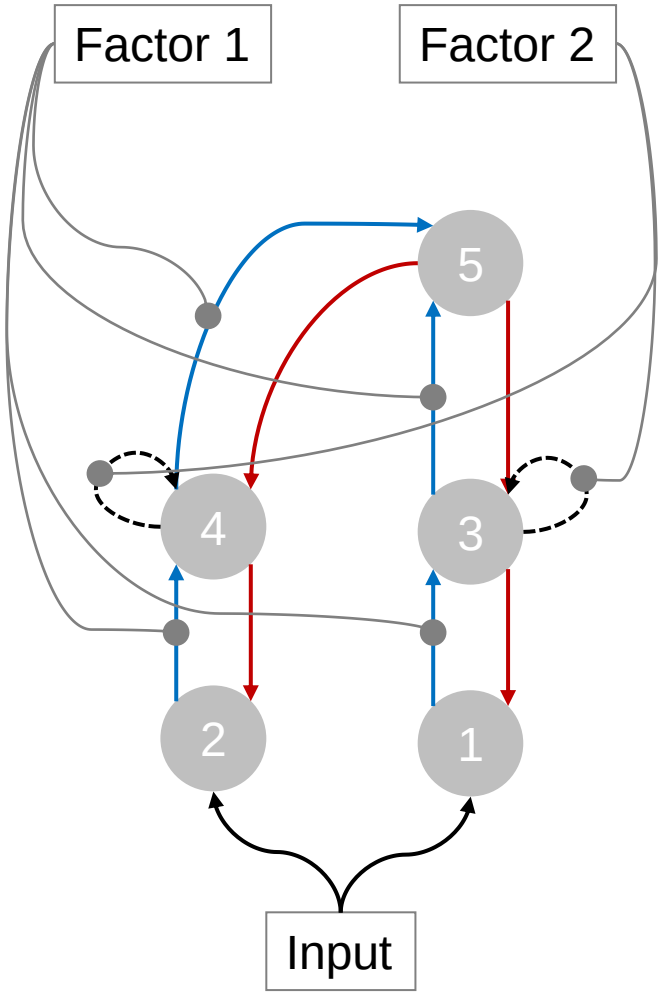
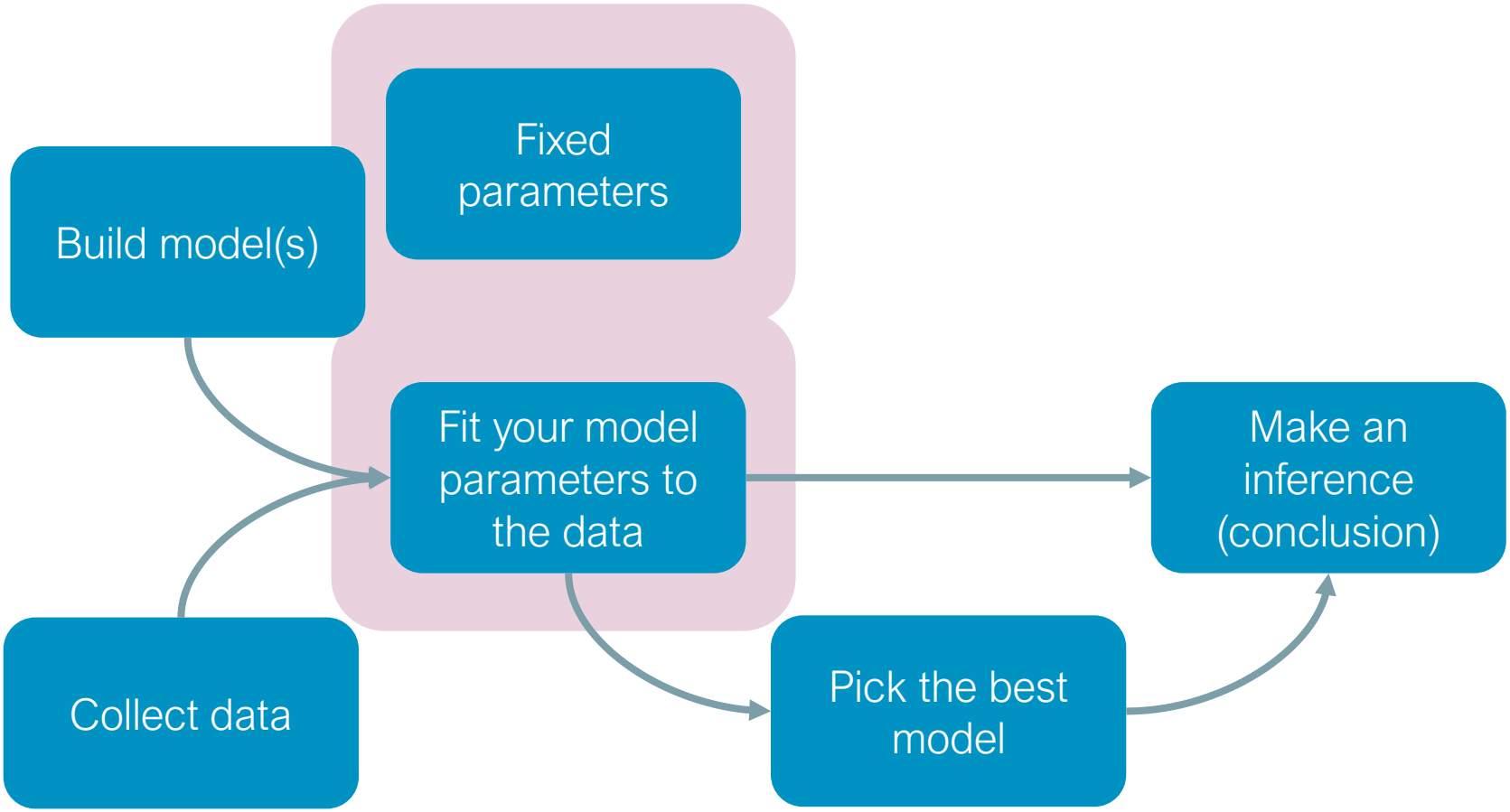
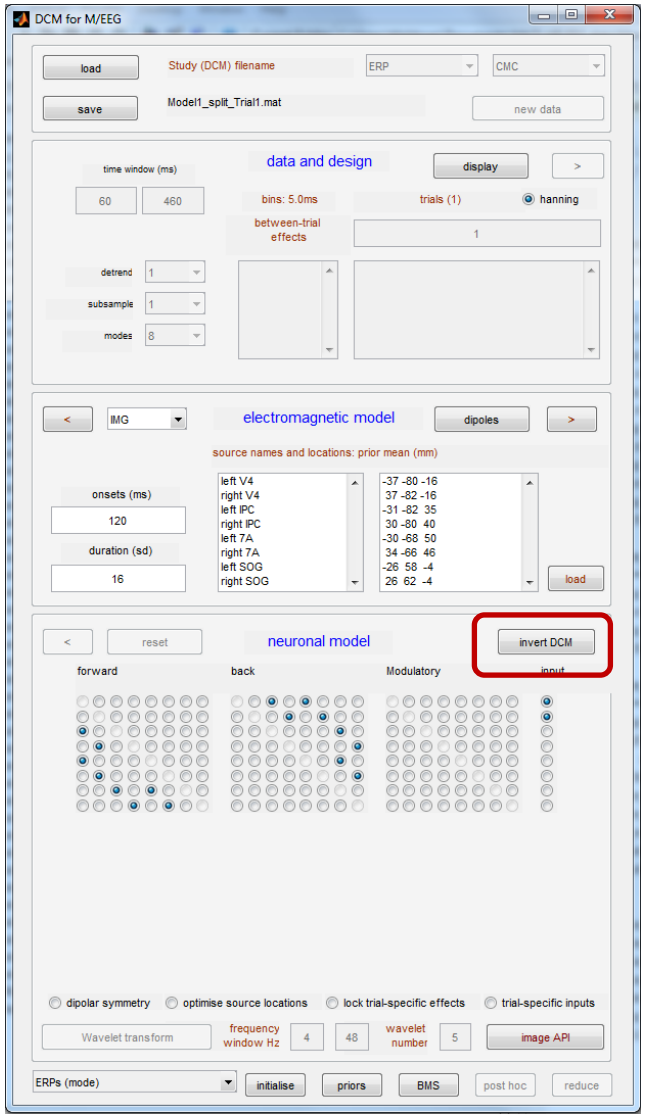
back
Modulatory
input
B att-noatt
B dev-std
dipolar symmetry
optimise source locations
lock trial-specific effects
trial-specific inputs
Wavelet transform
frequency
4
48
wavelet number
7
image API
ERPs (mode)
initialise
priors
BMS
post hoc
reduce

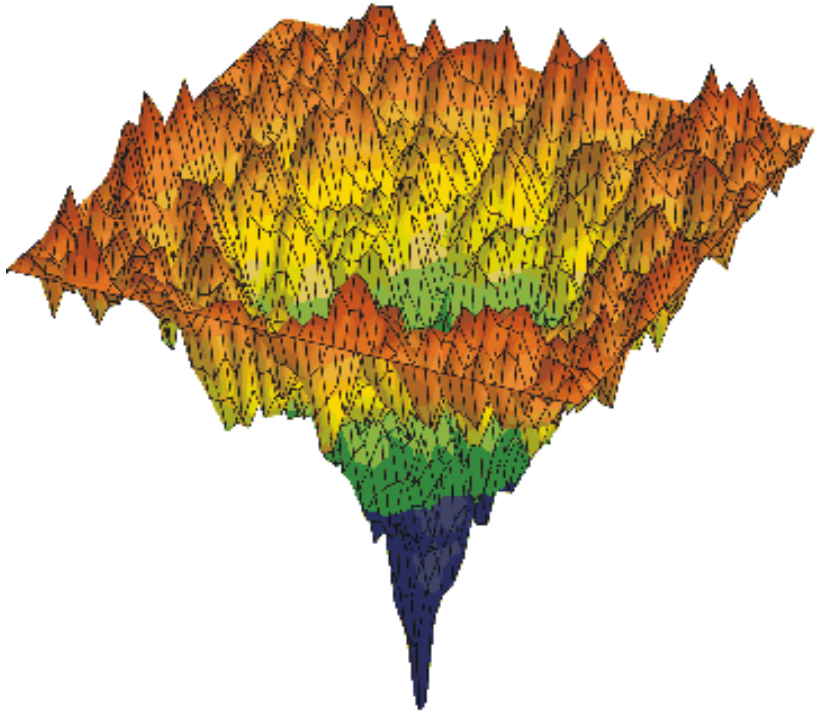

Factor 1
Factor 2
5
4
3
2
1
Input

# The DCM analysis pathway

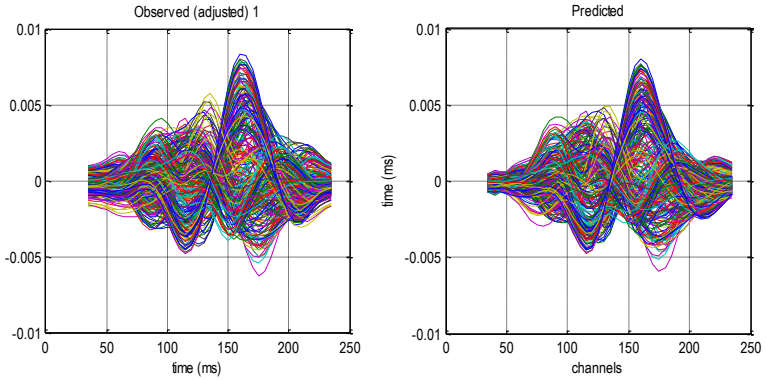


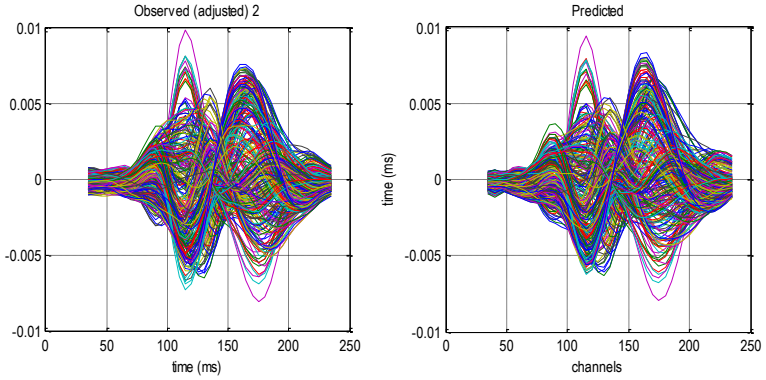
# Fitting DCMs to data

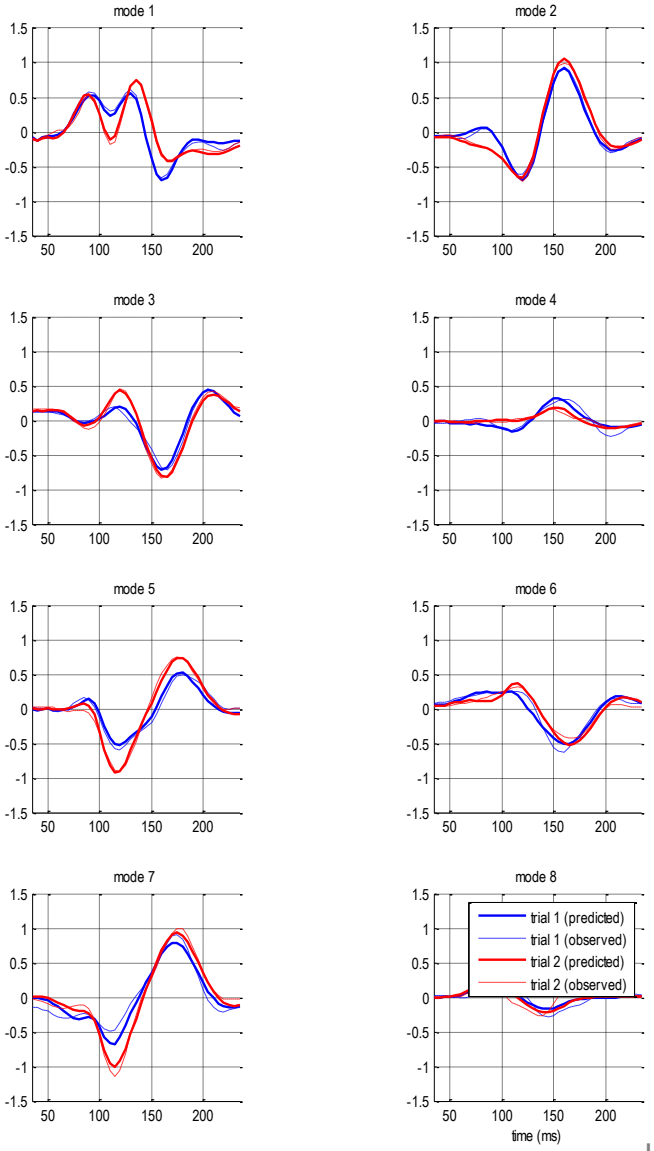


# Fitting DCMs to data

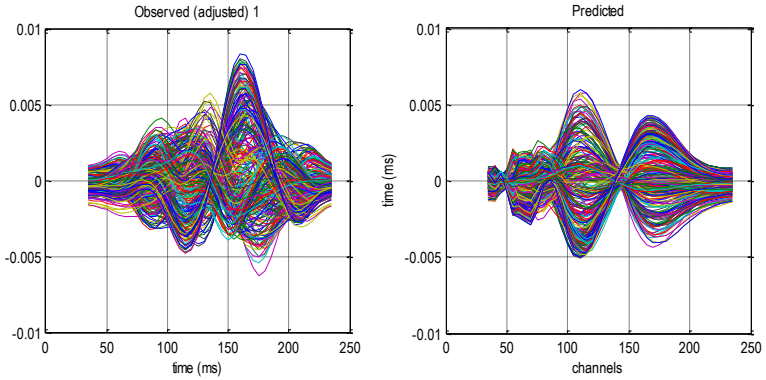


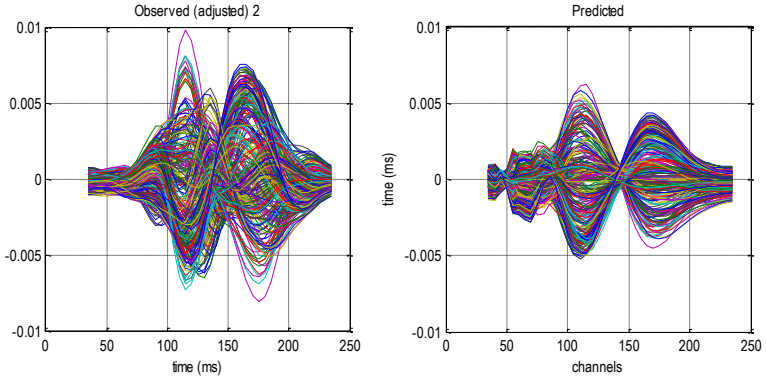



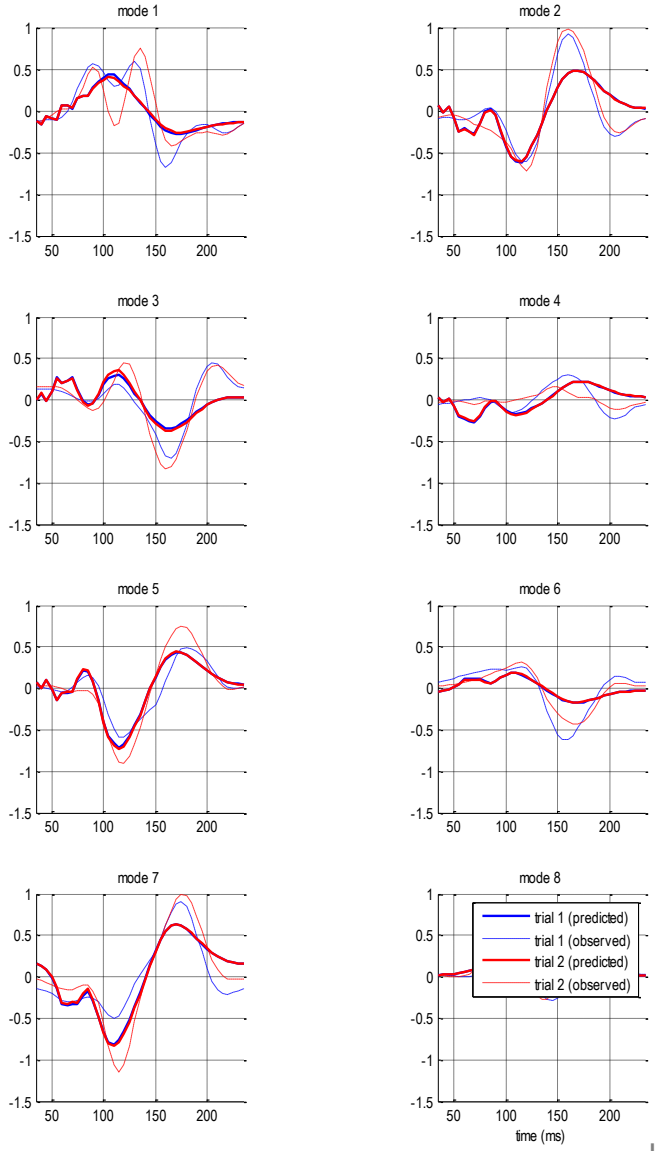




H. Brown

# Fitting DCMs to data



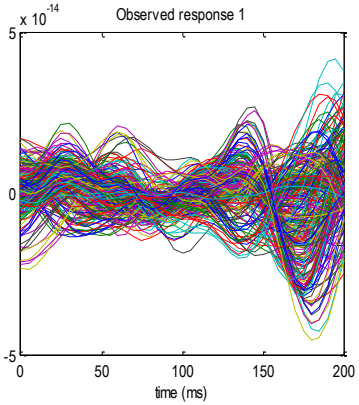



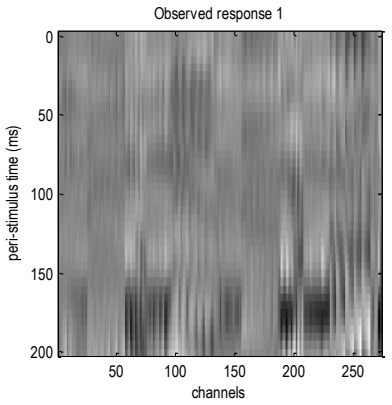



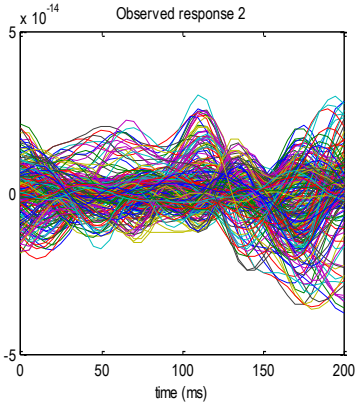

H. Brown

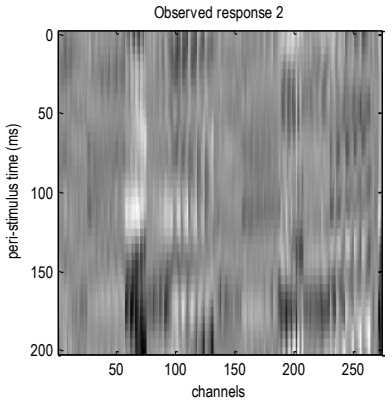
# Fitting DCMs to data

1. Check your data

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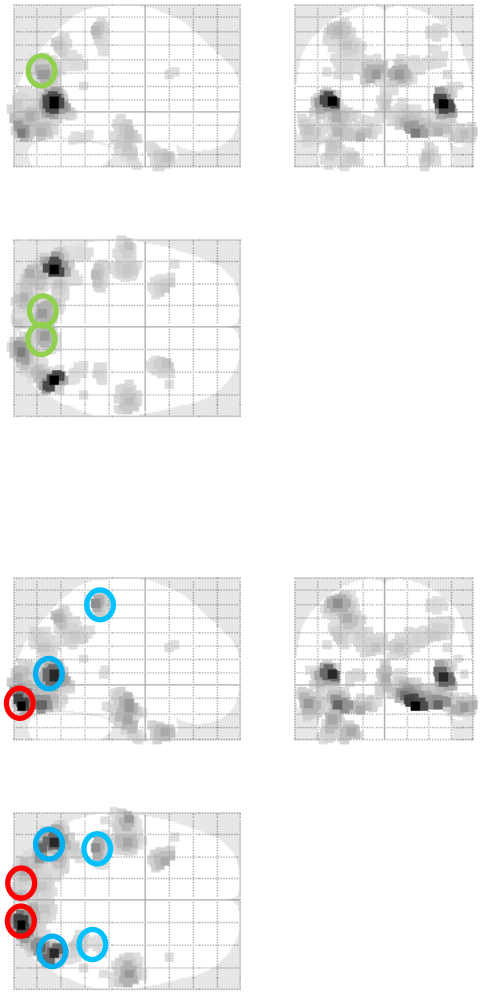
# Fitting DCMs to data

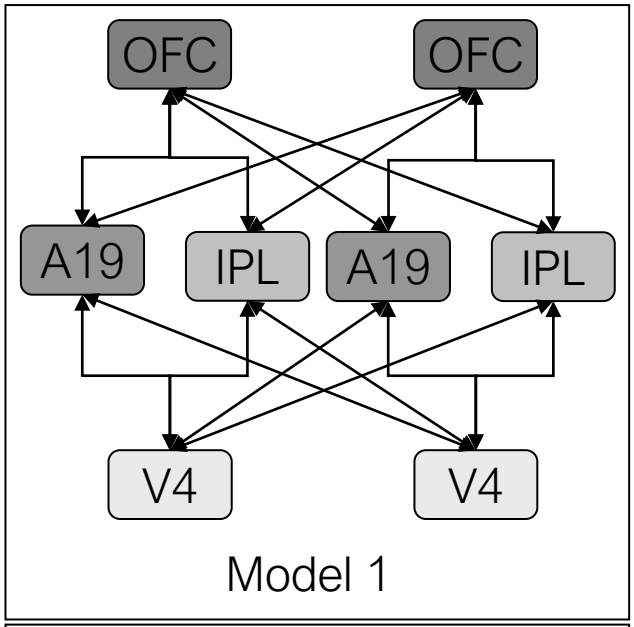
1. Check your data

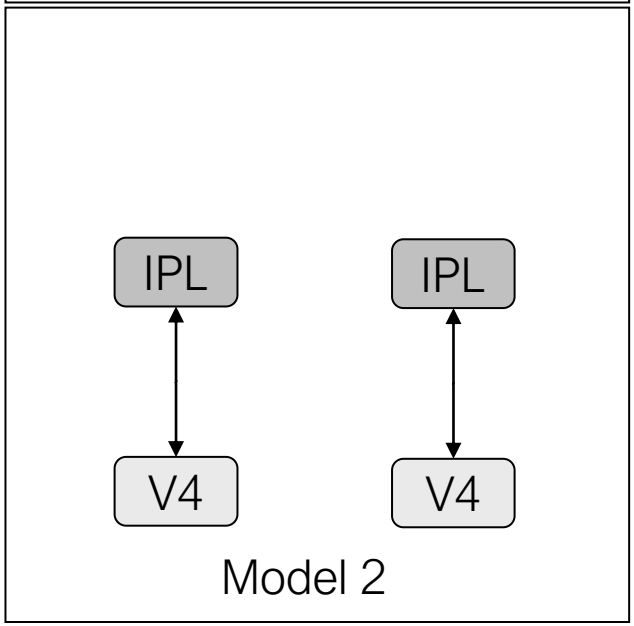
2. Check your sources



# Fitting DCMs to data

1. Check your data
2. Check your sources
3. Check your model

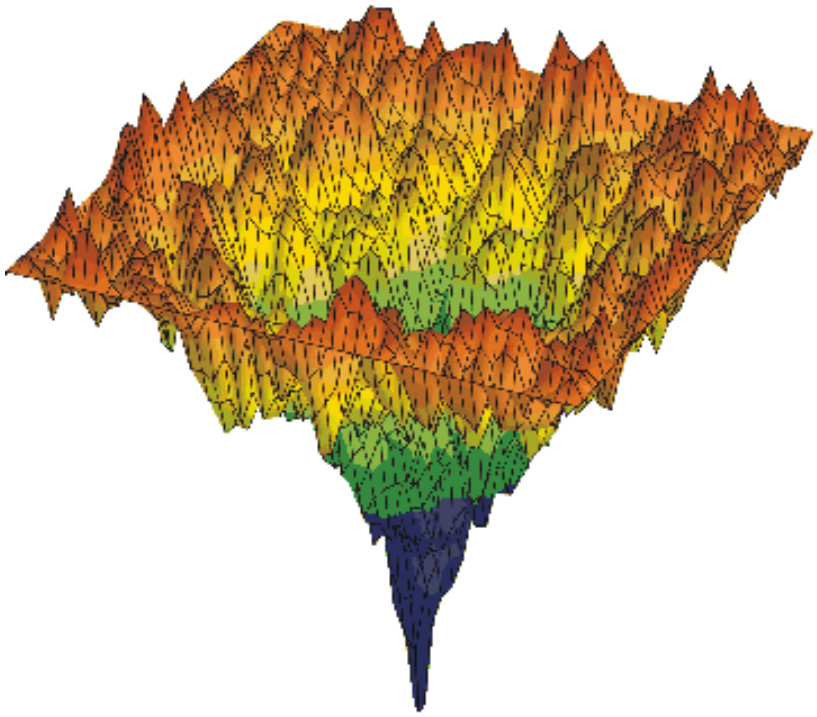


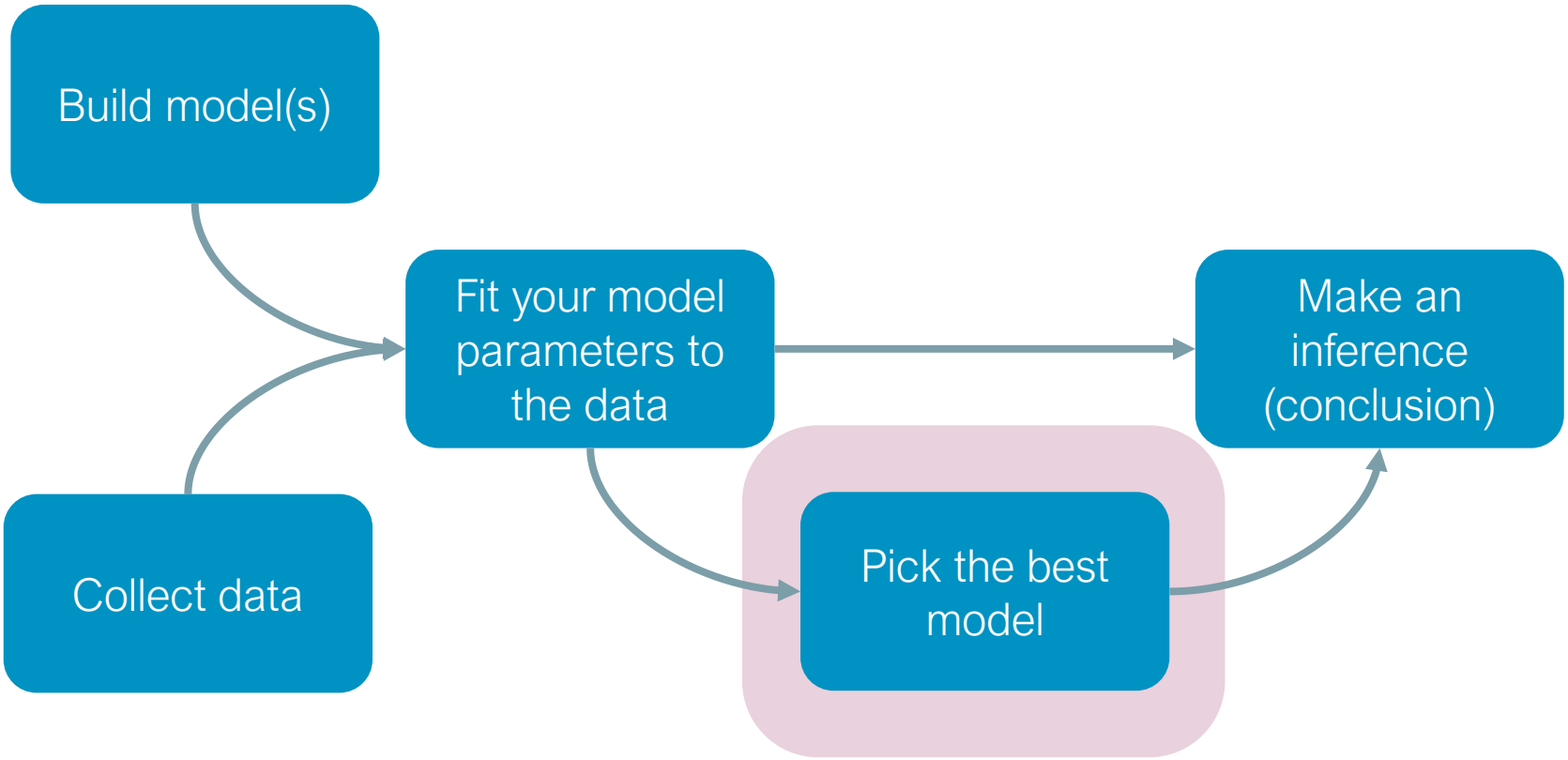

H. Brown

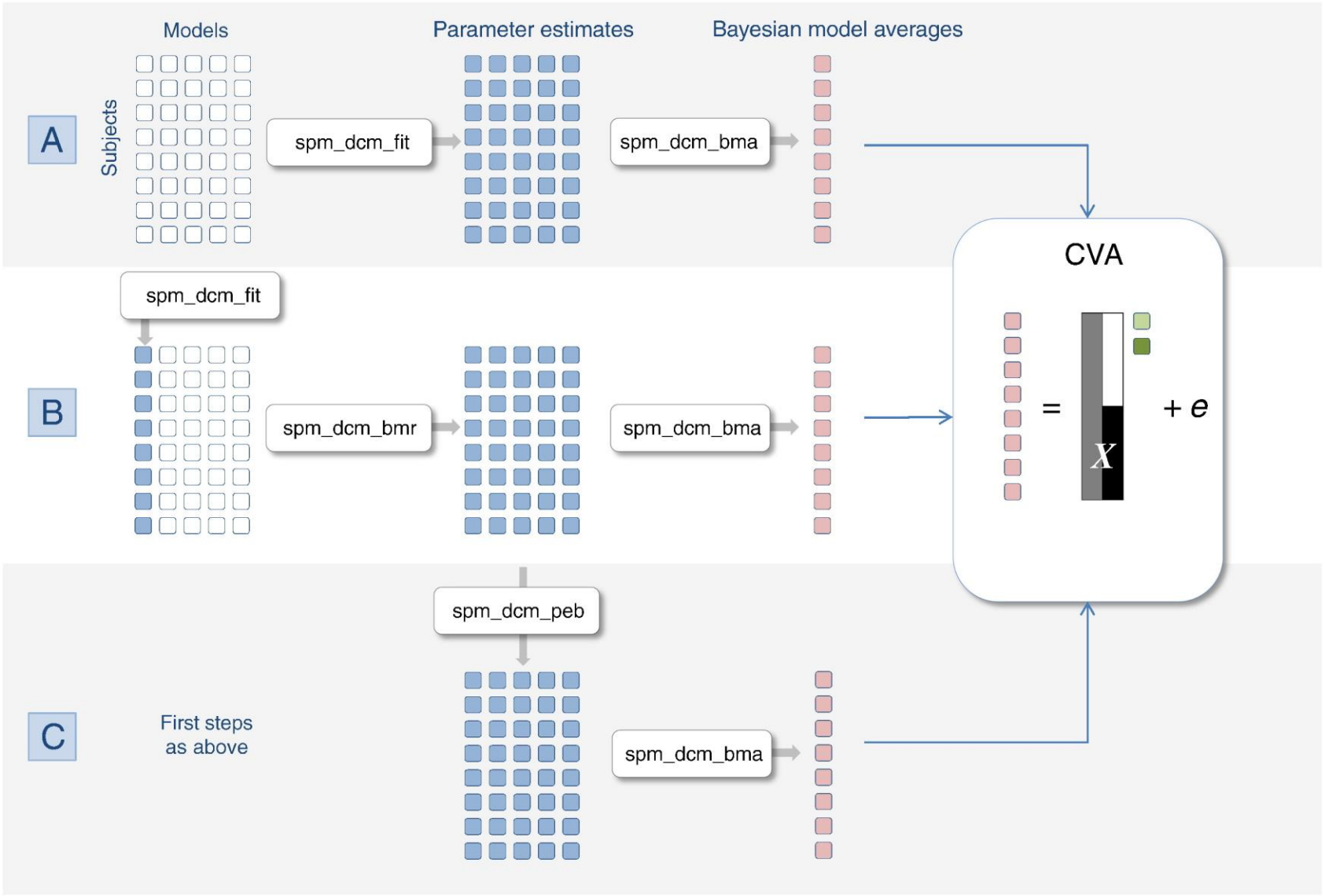
# Fitting DCMs to data

1. Check your data
2. Check your sources
3. Check your model
4. Re-run model fitting



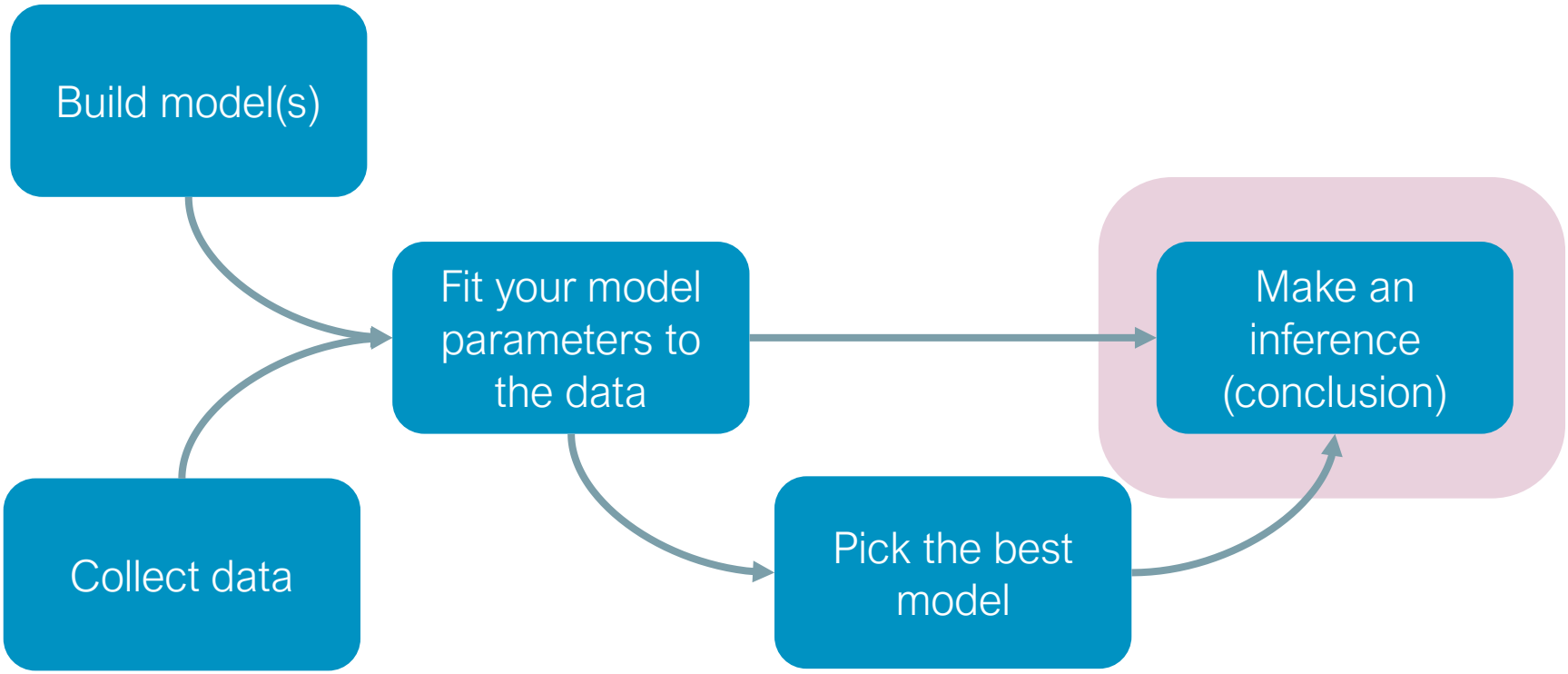
# The DCM analysis pathway






Friston et al., 2016

# The DCM analysis pathway



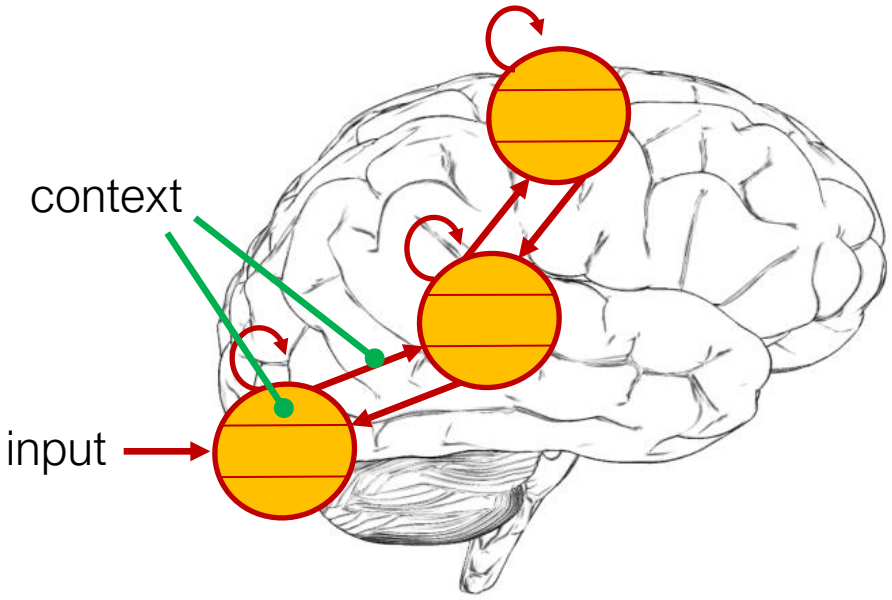
Does network XYZ explain my data better than network XY?

Which XYZ connectivity structure best explains my data?

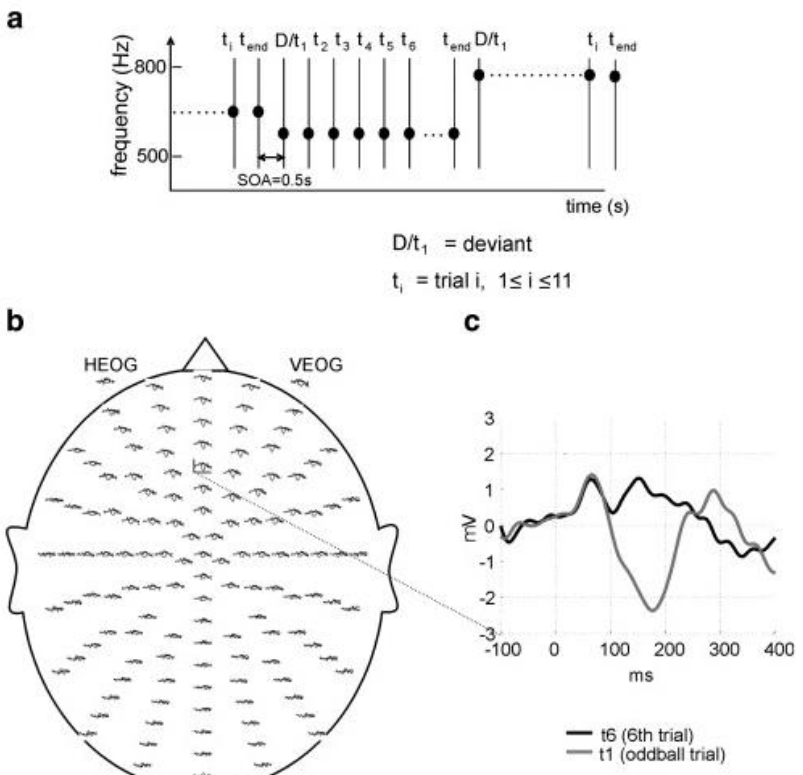
Are X & Y linked in a bottom-up, top-down or recurrent fashion?

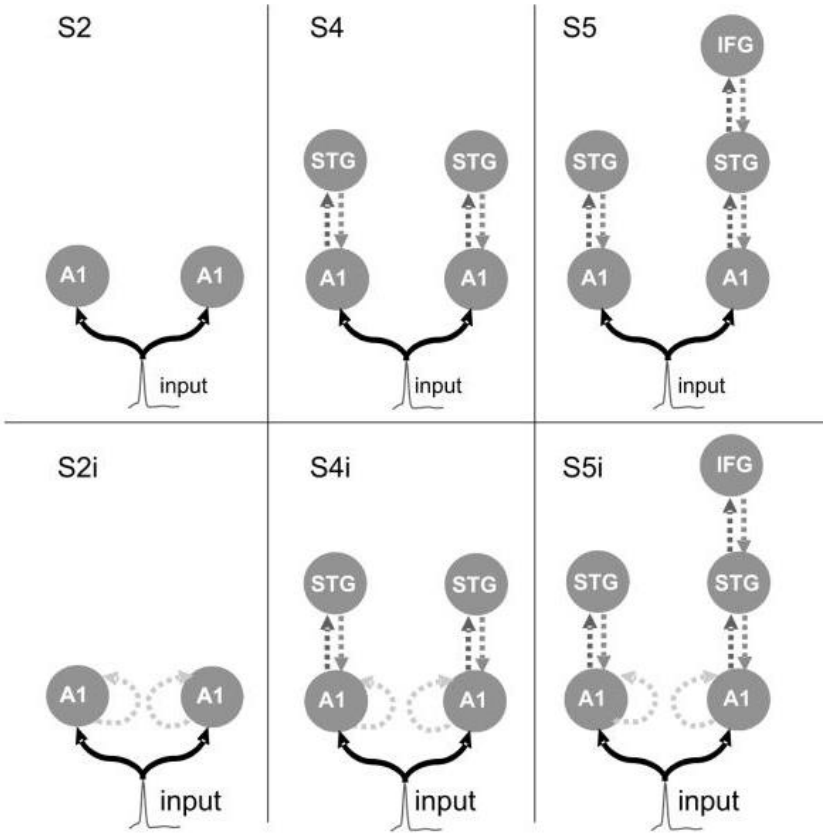
Is my effect driven by extrinsic or intrinsic connections?

Which connections/populations are affected by contextual factors?



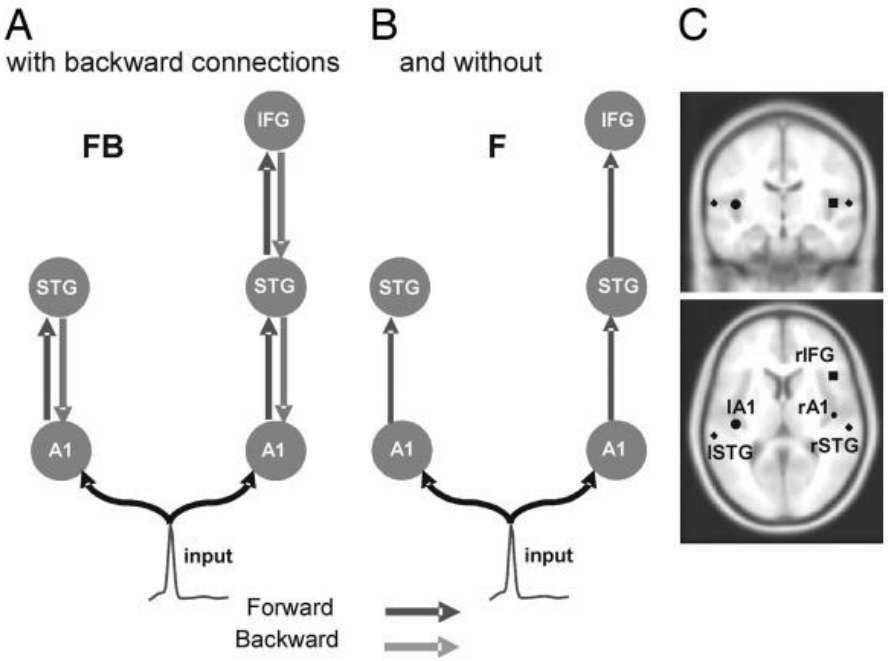
# Example #1: Architecture of MMN

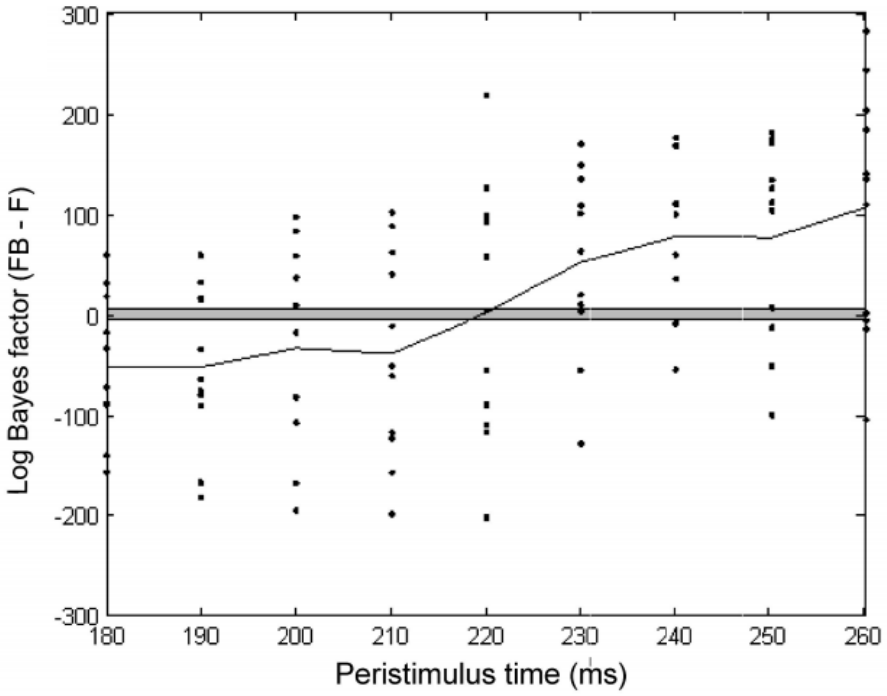



Garrido et al., 2008

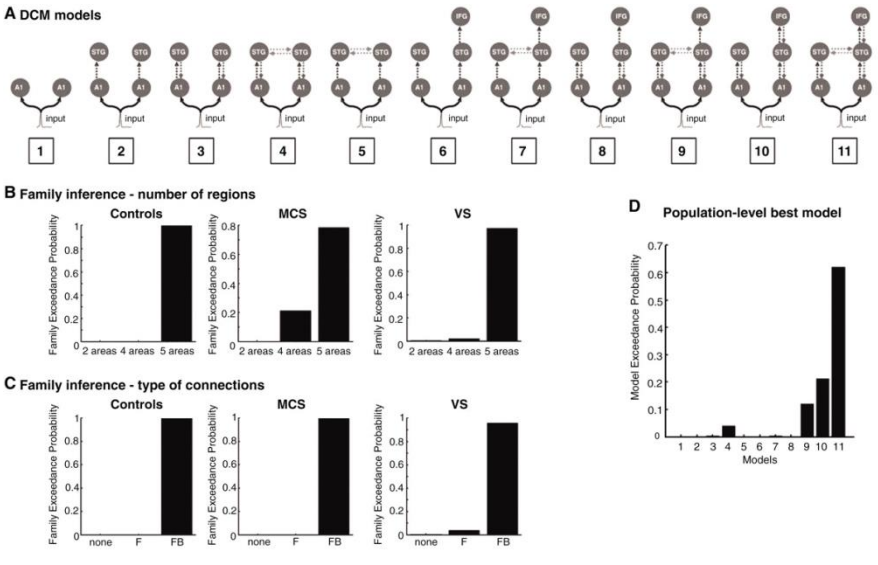
# Example #2: Role of feedback connections

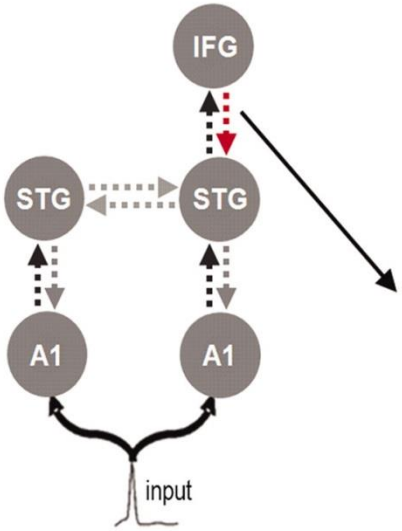


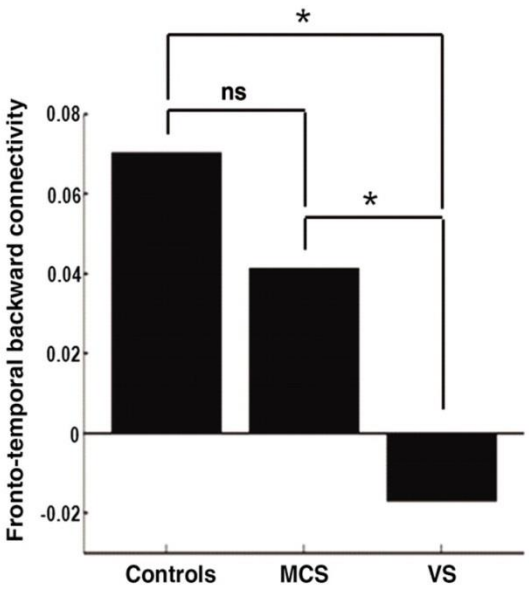




Garrido et al., 2007

# Example #3: Group differences

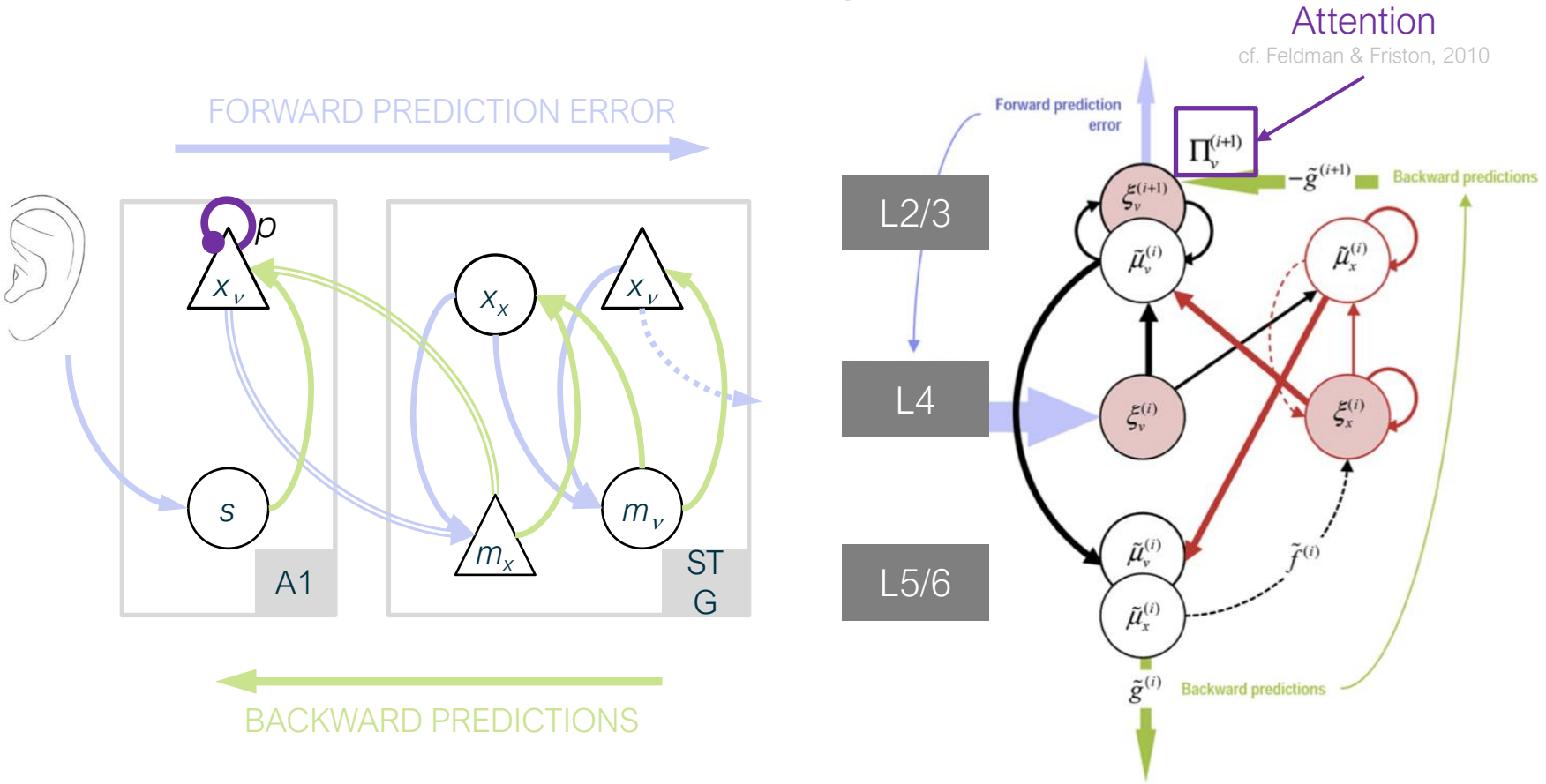


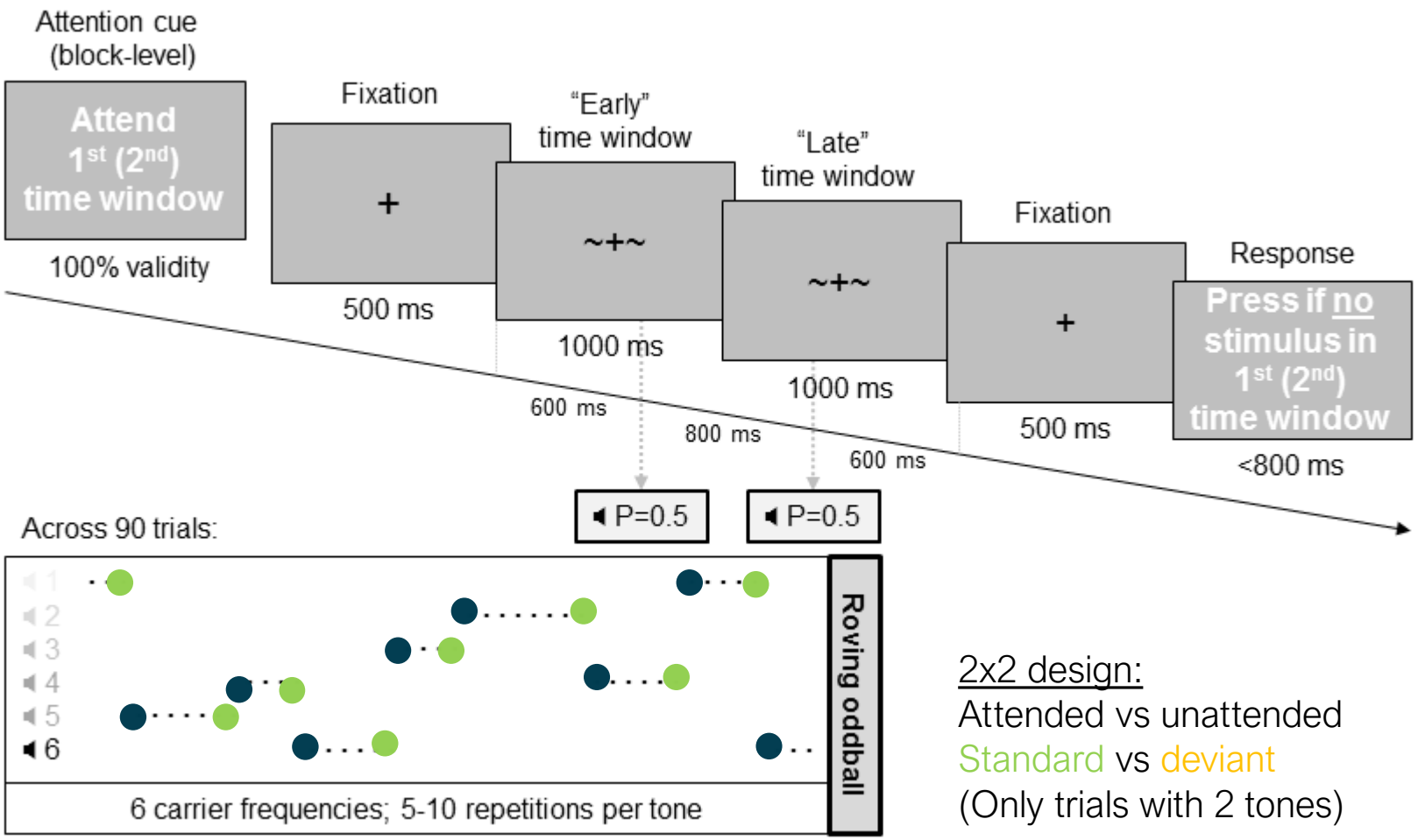

Boly et al., 2011

# Example #4: Factorial design & CMC




Bastos et al., *Neuron* 2012

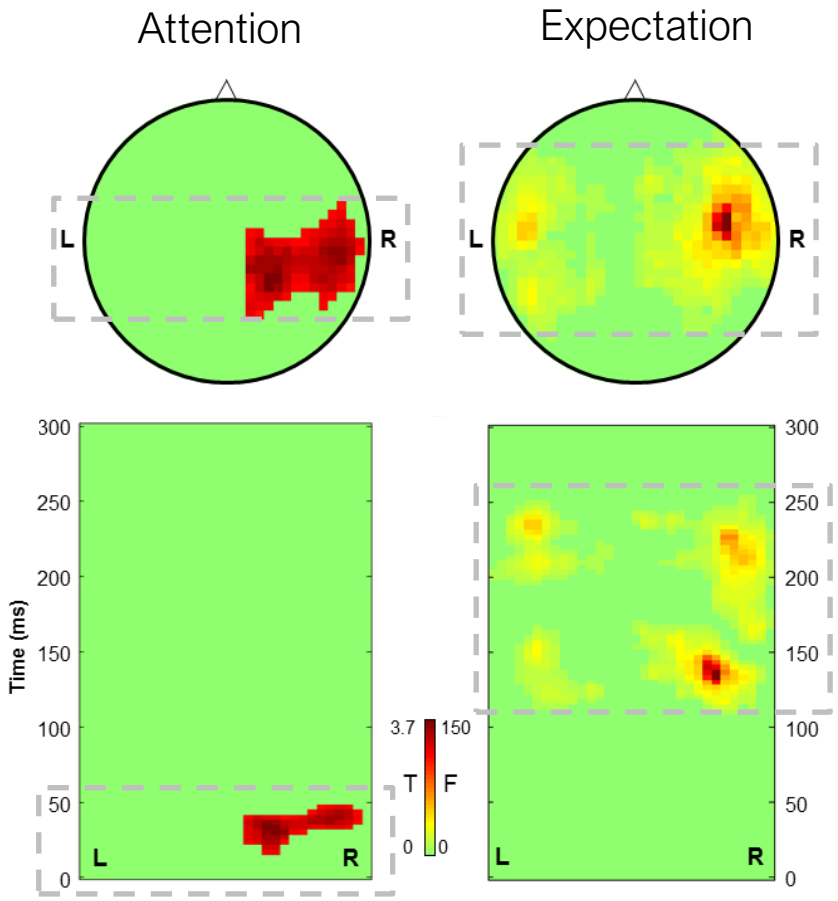
Auksztulewicz & Friston, 2015




2x2 design:
Attended vs unattended
Standard vs deviant
(Only trials with 2 tones)

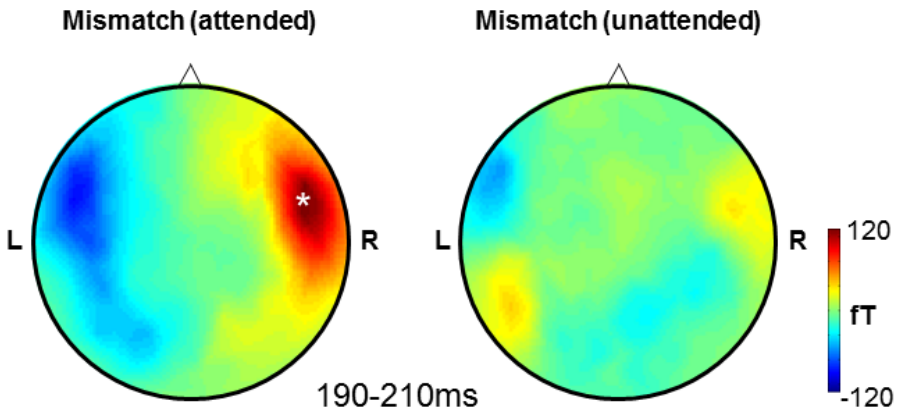
N=20

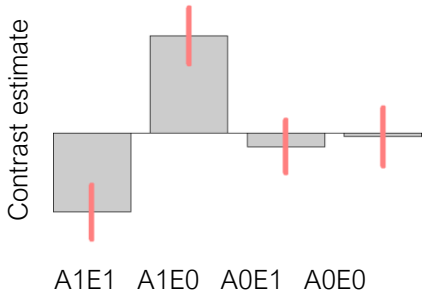
Auksztulewicz & Friston, 2015




Flexible factorial design
Thresholded at p<.005 peak-level
Corrected at a cluster-level pFWE<.05

Auksztulewicz & Friston, 2015



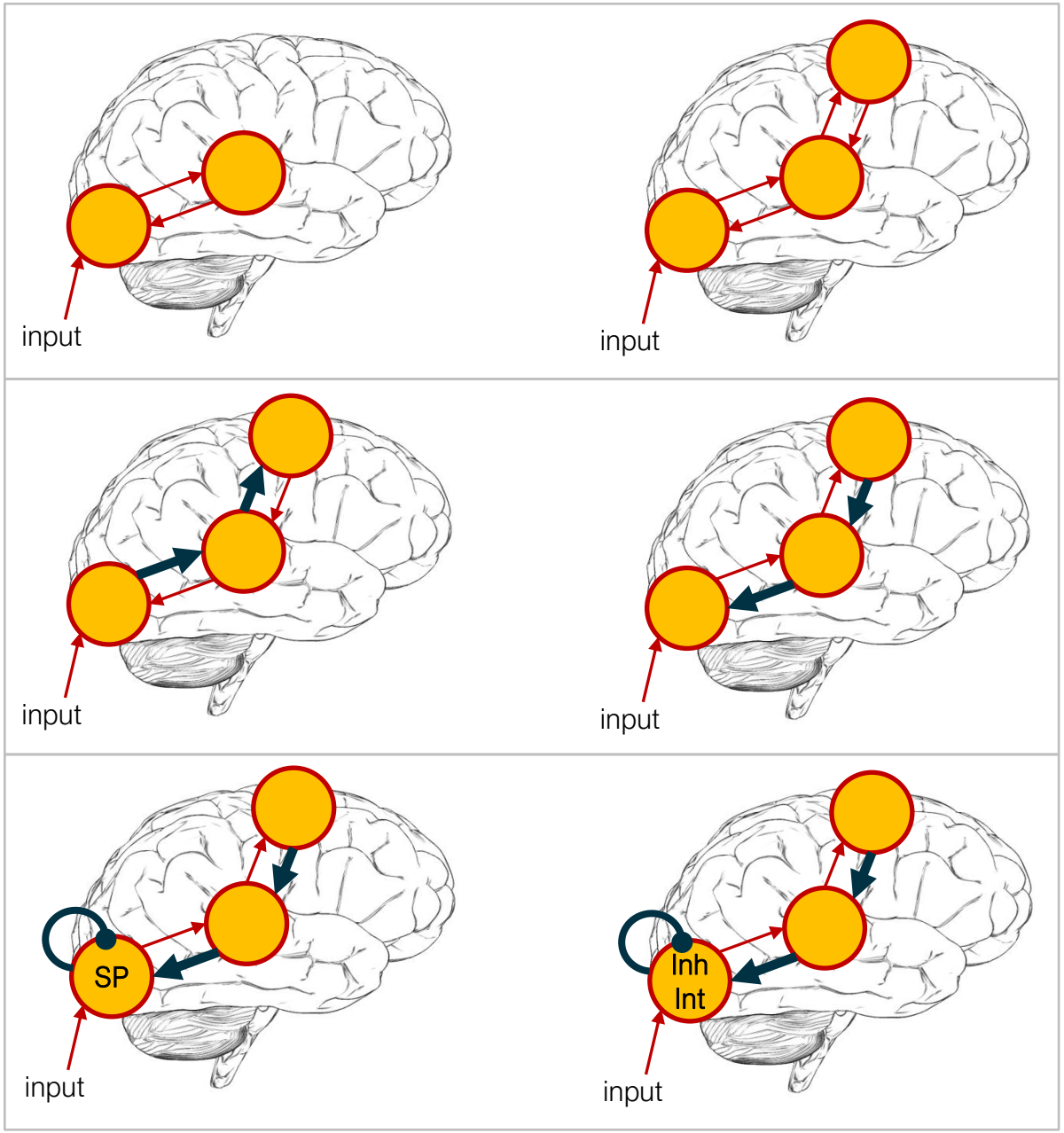



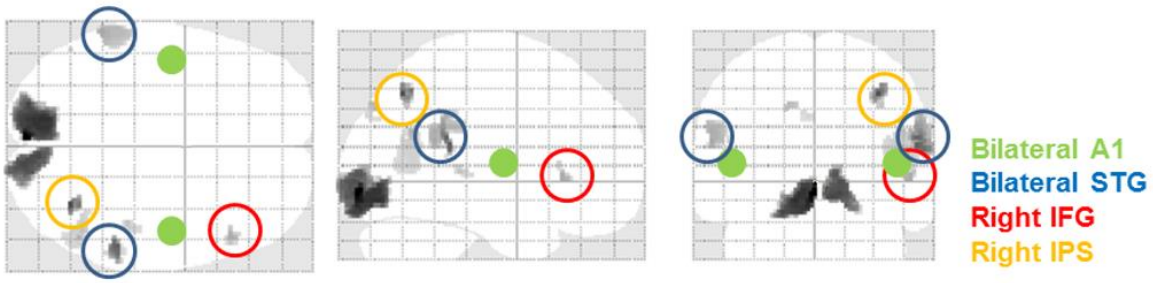

Auksztulewicz & Friston, 2015

Connectivity structure

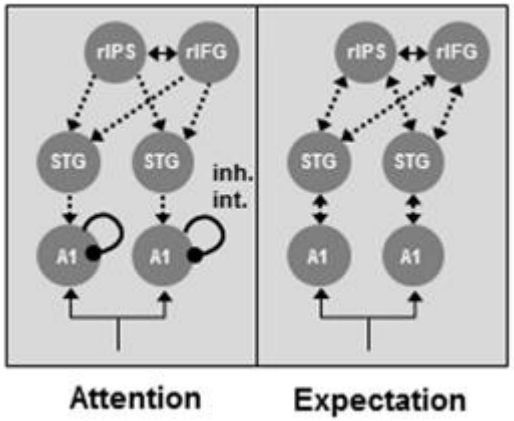
Extrinsic modulation

Intrinsic modulation

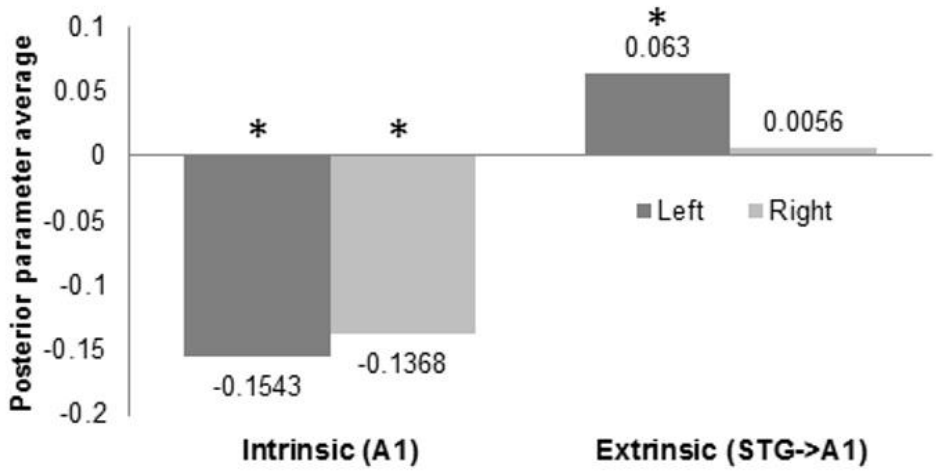


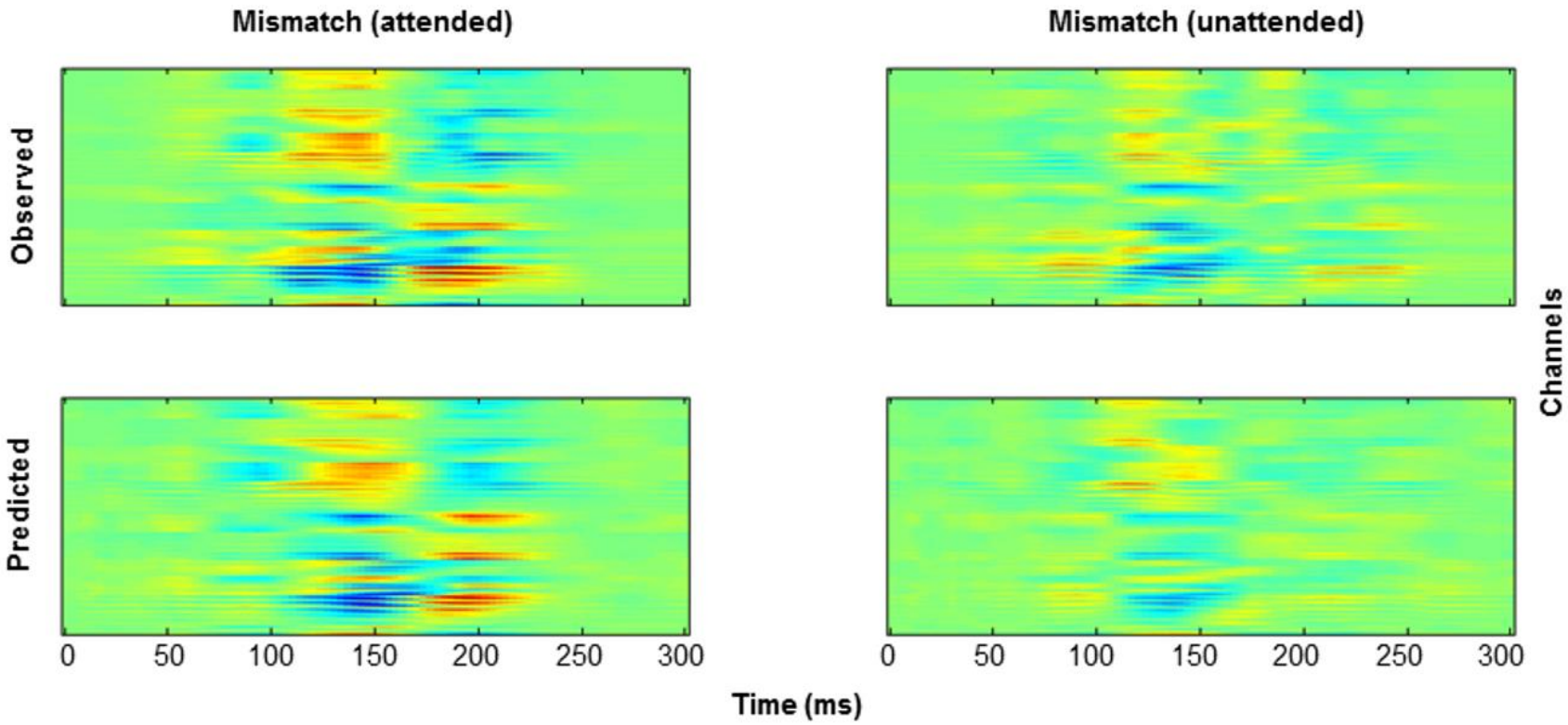



## Winning model



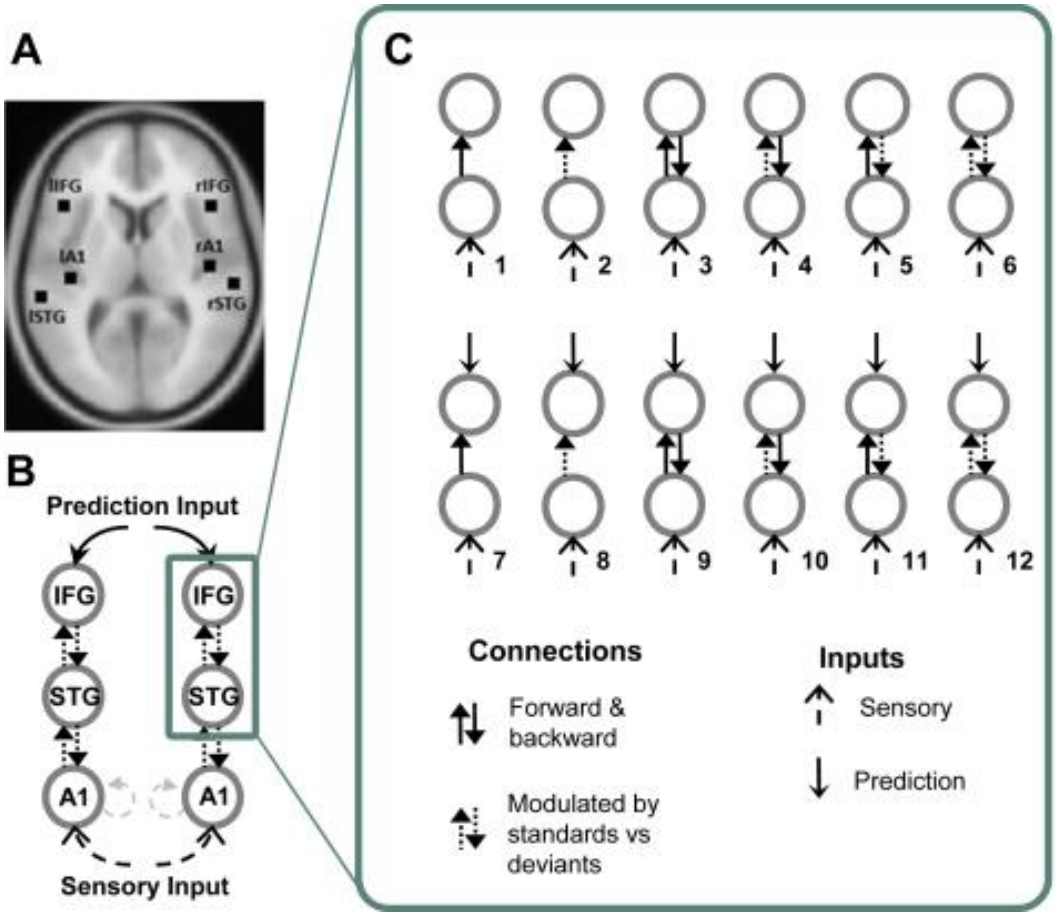

## Parameter inference





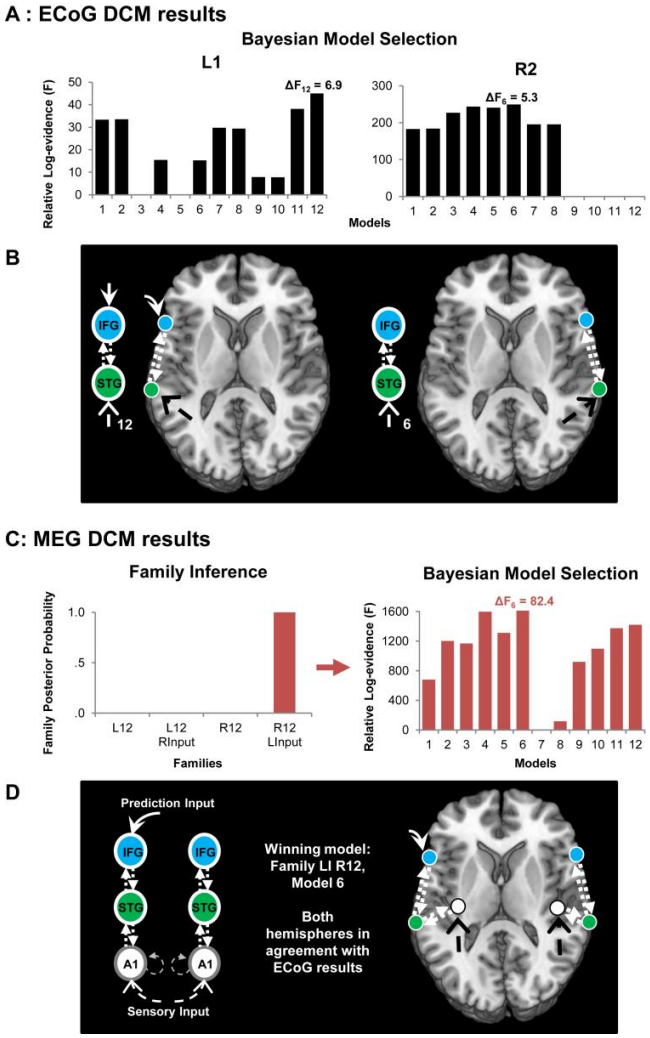

Auksztulewicz & Friston, 2015

# Example #5: Same paradigm, different data



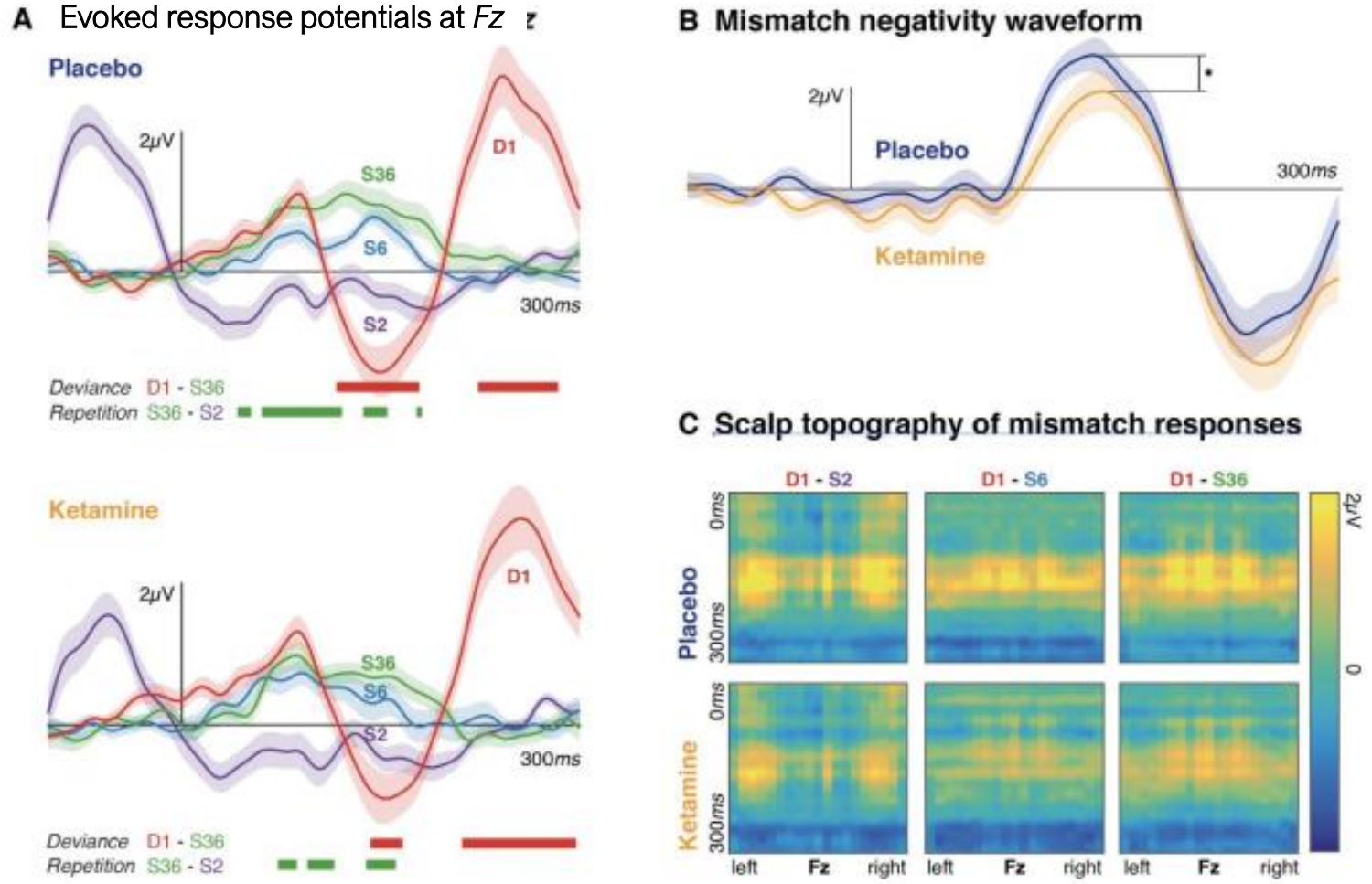

Phillips et al., 2016

# Example #5: Same paradigm, different data



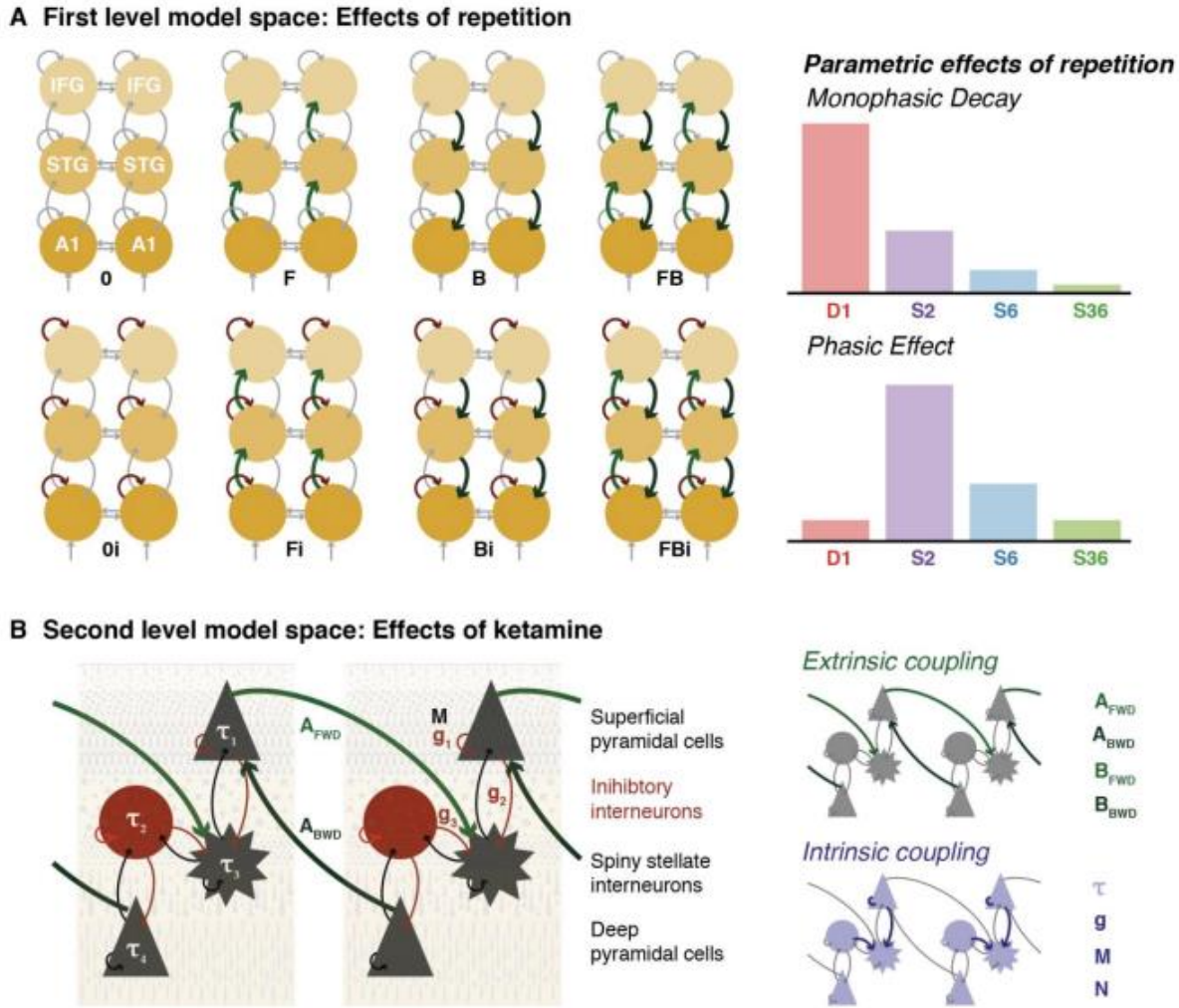

Phillips et al., 2016

# Example #6: Hierarchical modelling



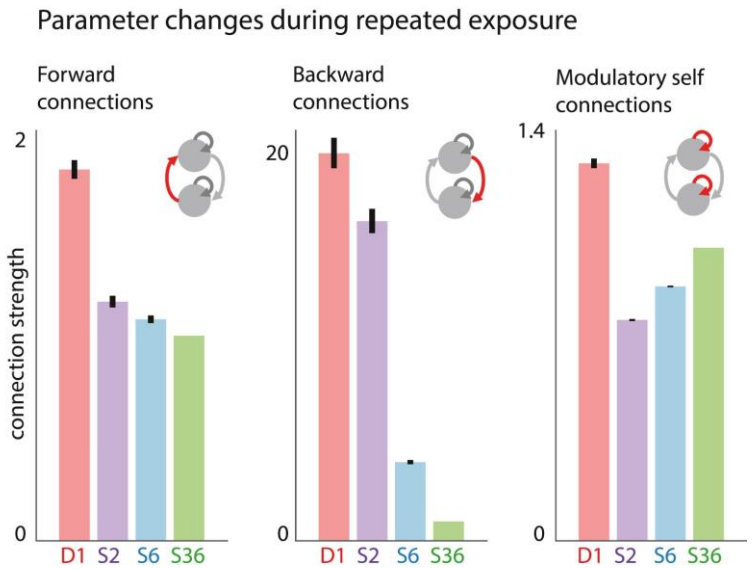

Rosch et al., 2017

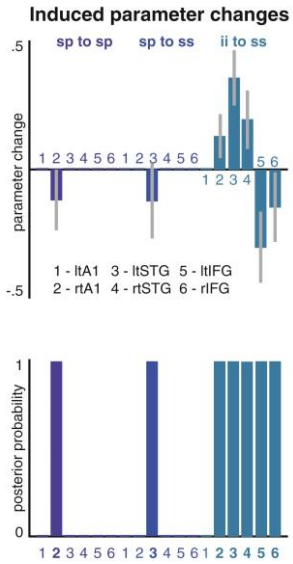
# Example #6: Hierarchical modelling

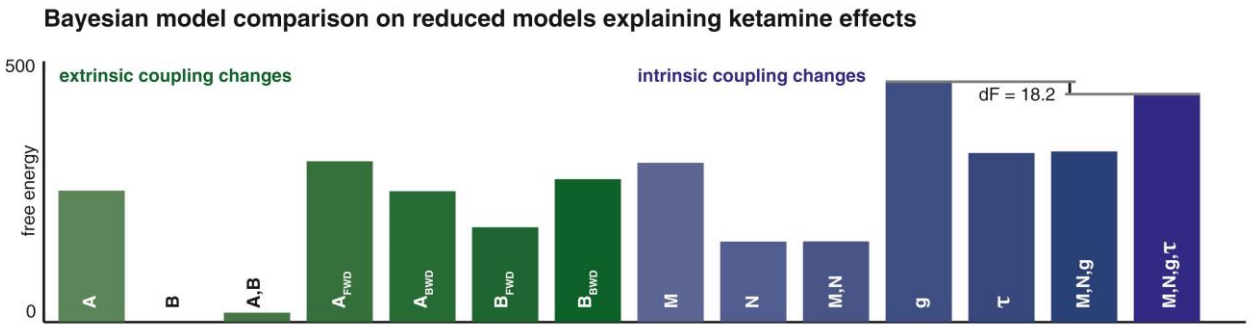



Rosch et al., 2017

# Example #6: Hierarchical modelling

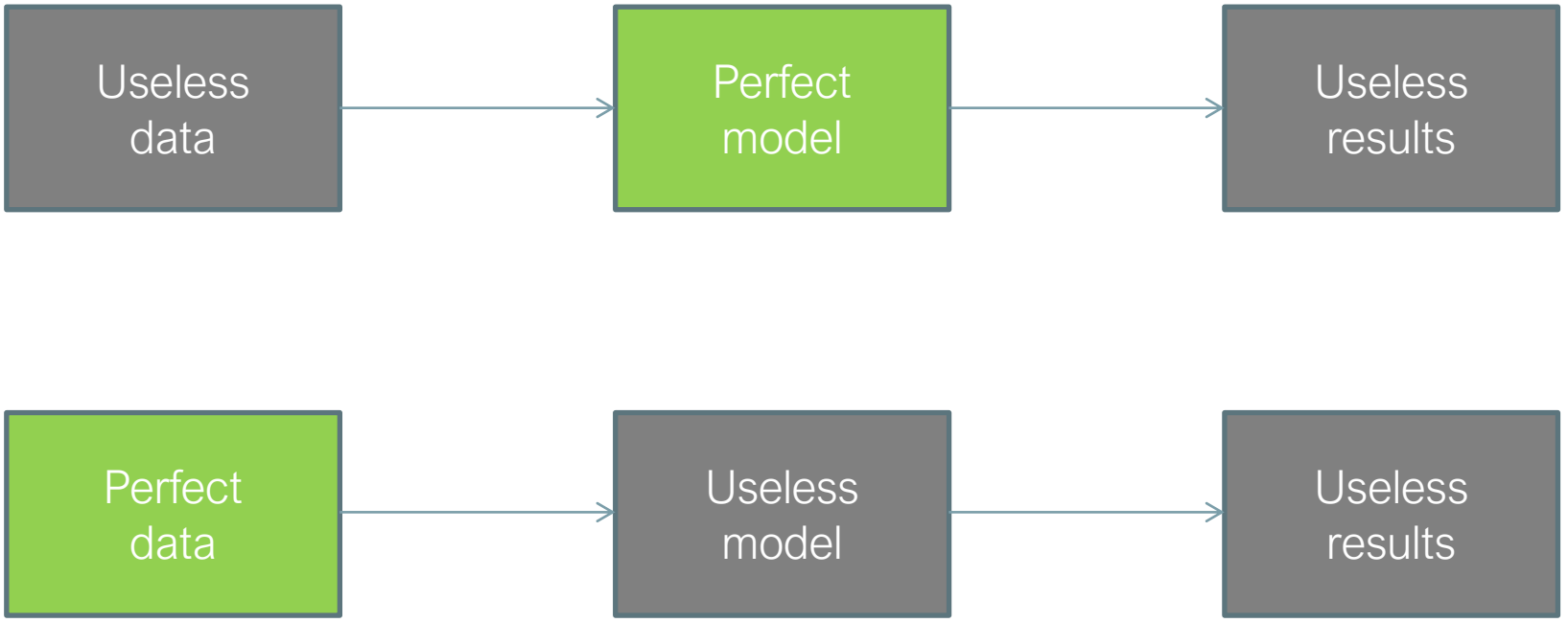



Rosch et al., 2017

# Motivate your assumptions!



# References


### Overview

Moran R, Pinotsis DA, Friston K. Neural masses and fields in dynamic causal modeling.
Front Comput Neurosci. 2013 May 28;7:57. doi: 10.3389/fncom.2013.00057.

Bastos AM, Usrey WM, Adams RA, Mangun GR, Fries P, Friston KJ. Canonical microcircuits for predictive coding.
Neuron. 2012 Nov 21;76(4):695-711. doi: 10.1016/j.neuron.2012.10.038.

### Model specifics

David O, Kilner JM, Friston KJ. Mechanisms of evoked and induced responses in MEG/EEG.
Neuroimage. 2006 Jul 15;31(4):1580-91. doi: 10.1016/j.neuroimage.2006.02.034.

Kiebel SJ, Garrido MI, Moran RJ, Friston KJ. Dynamic causal modelling for EEG and MEG.
Cogn Neurodyn. 2008 Jun;2(2):121-36. doi: 10.1007/s11571-008-9038-0.

Pinotsis DA, Moran RJ, Friston KJ. Dynamic causal modeling with neural fields.
Neuroimage. 2012 Jan 16;59(2):1261-74. doi: 10.1016/j.neuroimage.2011.08.020.

van Wijk BCM, Cagnan H, Litvak V, Kühn AA, Friston KJ. Generic dynamic causal modelling: An illustrative application to Parkinson's disease.
Neuroimage. 2018 Nov 1;181:818-830. doi: 10.1016/j.neuroimage.2018.08.039.

### Group inference

Friston KJ, Litvak V, Zeidman P, et al. Bayesian model reduction and empirical Bayes for group (DCM) studies.
Neuroimage. 2016 Mar;128:413-431. doi: 10.1016/j.neuroimage.2015.11.015.

### Examples

Garrido MI, Kilner JM, Kiebel SJ, Friston KJ. Evoked brain responses are generated by feedback loops.
Proc Natl Acad Sci U S A. 2007 Dec 26;104(52):20961-6. doi: 10.1073/pnas.0706274105.

Garrido MI, Friston KJ, Kiebel SJ, Stephan KE, Baldeweg T, Kilner JM. The functional anatomy of the MMN: a DCM study of the roving paradigm.
Neuroimage. 2008 Aug 15;42(2):936-44. doi: 10.1016/j.neuroimage.2008.05.018.

Boly M, Garrido MI, Friston K, et al. Preserved feedforward but impaired top-down processes in the vegetative state.
Science. 2011 May 13;332(6031):858-62. doi: 10.1126/science.1202043.

Auksztulewicz R, Friston K. Attentional Enhancement of Auditory Mismatch Responses: a DCM/MEG Study.
Cereb Cortex. 2015 Nov;25(11):4273-83. doi: 10.1093/cercor/bhu323.

Phillips HN, Blenkmann A, Rowe JB, et al. Convergent evidence for hierarchical prediction networks from human ECoG and MEG.
Cortex. 2016 Sep;82:192-205. doi: 10.1016/j.cortex.2016.05.001.

Rosch RE, Auksztulewicz R, Baldeweg T, et al. Selective Prefrontal Disinhibition in a Roving Auditory Oddball Paradigm Under NMDAR Blockade.
Biol Psychiatry Cogn Neurosci Neuroimaging. 2019 Feb;4(2):140-150. doi: 10.1016/j.bpsc.2018.07.003.

# Thank you!

Karl Friston
Gareth Barnes
Andre Bastos
Harriet Brown
Hayriye Cagnan
Jean Daunizeau
Marta Garrido
Stefan Kiebel
Vladimir Litvak
Rosalyn Moran
Will Penny
Dimitris Pinotsis
Richard Rosch
Bernadette van Wijk