DCM for evoked responses

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SPM for M/EEG course, 2018
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?
Collect data

Build model(s)

Fit your model parameters to the data

Pick the best model

Make an inference (conclusion)

The DCM analysis pathway
The DCM analysis pathway

1. Collect data
2. Build model(s)
3. Fit your model parameters to the data
4. Pick the best model
5. Make an inference (conclusion)
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 / 3D source reconstruction
The DCM analysis pathway

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The DCM analysis pathway

Collect data

Build model(s)

‘Hardwired’ model features

Fit your model parameters to the data

Pick the best model

Make an inference (conclusion)
Models

Neural masses and fields in dynamic causal modeling

Rosalyn Moran¹,²,³*, Dimitris A. Pinotsis¹† and Karl Friston¹
Neuronal (source) model

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

\[ \dot{x}_4 = \frac{H_e}{\tau_e} ((A^F + A^L + \gamma_3 I) S(x_0) + Cu) - \frac{2x_4}{\tau_e} - \frac{x_1}{\tau_e^2} \]

\[ \dot{x}_1 = x_4 \]

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

State equations
\[ \dot{x} = f(x, u, \theta) \]
Canonical Microcircuit Model (‘CMC’)

Original proposal for canonical microcircuit

Updated microcircuit

Canonical microcircuit for predictive coding (full model)

Reduced model (used in DCM)

NEURAL MASS MODEL

L2/3

L4

L5/6

CANONICAL MICROCIRCUIT

Inhib
Inter

Pyr

Spiny
Stell

Inhib
Inter

Pyr

Spiny
Stell

Pyr

spm_fx_erp

spm_fx_cmc
Canonical Microcircuit Model (‘CMC’)
Superficial Pyramidal Cells
Granular Layer
Supra-granular Layer
Inhibitory Interneurons

Spiny Stellate Cells
Deep Pyramidal Cells
Supr-ficial Pyramidal Cells

Canonical Microcircuit Model (‘CMC’)
 Canonical Microcircuit Model (‘CMC’)
Canonical Microcircuit Model (‘CMC’)

- Granular Layer
- Supra-granular Layer
- Infra-granular Layer
- Inhibitory Interneurons
- Superficial Pyramidal Cells
- Spiny Stellate Cells
- Deep Pyramidal Cells

Pinotsis et al., 2012
Canonical Microcircuit Model (‘CMC’)
Canonical Microcircuit Model (‘CMC’)

Supra-granular Layer
Granular Layer
Infra-granular Layer

Inhibitory Interneurons

Superficial Pyramidal Cells

Spiny Stellate Cells

Deep Pyramidal Cells

Pinotsis et al., 2012
Canonical Microcircuit Model (‘CMC’)

Inhibitory Interneurons

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Pinotsis et al., 2012
Canonical Microcircuit Model (‘CMC’)

Suprgranular Layer
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Infra-granular Layer

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\( A^S(p_7) \)
\( A^F(p_3) \)

Pinotsis et al., 2012
Canonical Microcircuit Model (‘CMC’)
Canonical Microcircuit Model (‘CMC’)

\[ \dot{p}_7 = p_8 \]

Voltage change rate: \( f(\text{current}) \)

Current change rate: \( f(\text{voltage, current}) \)

\[ \dot{p}_8 = \frac{H^4}{\tau_4} (A^F S(p_2) - \gamma_{10} S(p_7) - \gamma_9 S(p_5)) - \frac{2p_8}{\tau_4} - \frac{p_7}{\tau_4^2} \]
## Canonical Microcircuit Model (‘CMC’)

\[ \dot{p}_7 = p_8 \]

**Voltage** change rate: \( f(\text{current}) \)

**Current** change rate: \( f(\text{voltage, current}) \)

\[ \dot{p}_8 = \frac{H^4}{\tau_4} \left( A^F S(p_2) - \gamma_{10} S(p_7) - \gamma_9 S(p_5) \right) - \frac{2p_8}{\tau_4} - \frac{p_7}{\tau_4^2} \]

\( H, \tau \) Kernels: pre-synaptic inputs -> post-synaptic membrane potentials

\( [ \text{H: max PSP; } \tau: \text{ rate constant} ] \)

\( S \) Sigmoid operator: PSP -> firing rate

David et al., 2006; Pinotsis et al., 2012
Canonical Microcircuit Model (‘CMC’)

\[ y = L p_3 \]

\[ \dot{p}_3 = p_6 \]

\[ \dot{p}_6 = \frac{H_2}{\tau_3} \left( -A^B S(p_7) - \gamma_5 S(p_3) + \gamma_1 S(p_1) - \gamma_3 S(p_7) \right) - \frac{2p_6 - p_3}{\tau_3} \]

\[ \dot{p}_1 = p_2 \]

\[ \dot{p}_2 = \frac{H_1}{\tau_1} \left( (A^F S(p_3) - \gamma_7 S(p_7) - \gamma_3 S(p_3) - \gamma_2 S(p_3) \right) - \frac{2p_2}{\tau_1} - \frac{p_1}{\tau_1} \]

\[ \dot{p}_4 = \frac{H_2}{\tau_2} \left( -A^B S(p_7) + \gamma_4 S(p_1) - \gamma_3 S(p_3) \right) - \frac{2p_4}{\tau_2} - \frac{p_3}{\tau_2} \]

\[ \dot{p}_7 = p_4 \]

\[ \dot{p}_8 = \frac{H_1}{\tau_4} (A^F S(p_3) - \gamma_9 S(p_7) - \gamma_3 S(p_3) - \gamma_2 S(p_3) \right) - \frac{2p_8}{\tau_4} - \frac{p_7}{\tau_4} \]

\[ A^F S(p_3) \]

\[ S(p_7) \]

\[ U \]

Pinotsis et al., 2012
The DCM analysis pathway

1. Collect data
2. Build model(s)
3. Fit your model parameters to the data
4. ‘Hardwired’ model features
5. Pick the best model
6. Make an inference (conclusion)
The DCM analysis pathway

1. Collect data
2. Build model(s)
3. Fixed parameters
4. Fit your model parameters to the data
5. Pick the best model
6. Make an inference (conclusion)
Fitting DCMs to data
Fitting DCMs to data

Observed (adjusted) 1

Predicted

mode 1

mode 2

mode 3

mode 4

mode 5

mode 6

mode 7

mode 8

Observed (adjusted) 2

Channels

time (ms)

Predicted

Observed (adjusted)

Predicted

Trial 1

Trial 2

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Fitting DCMs to data

![Graphs showing observed and predicted data for different modes and trials.](image-url)
Fitting DCMs to data

1. Check your data
Fitting DCMs to data

1. Check your data

2. Check your sources

H. Brown
Fitting DCMs to data

1. Check your data

2. Check your sources

3. Check your model
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

1. Collect data
2. Build model(s)
3. Fit your model parameters to the data
4. Fixed parameters
5. Pick the best model
6. Make an inference (conclusion)
Does network XYZ explain my data better than network XY?

Which XYZ connectivity structure best explains my data?

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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

A. with backward connections

B. and without

C. Log Bayes factor (FB - F)

Garrido et al., 2007
Example #3: Group differences

A DCM models

B Family inference - number of regions

C Family inference - type of connections

D Population-level best model

Boly et al., 2011
Example #4: Factorial design & CMC

FORWARD PREDICTION ERROR

BACKWARD PREDICTIONS

A1

ST G

L2/3

L4

L5/6

Attention

cf. Feldman & Friston, 2010

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
Flexible factorial design

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

Contrast estimate

Auksztulewicz & Friston, 2015
Connectivity structure

Extrinsic modulation

Intrinsic modulation

Inh

Int

SP

input
Winning model

Parameter inference

Attention

Expectation

Intrinsic (A1)

Extrinsic (STG→A1)
Mismatch (attended)

Mismatch (unattended)

Observed

Predicted

Time (ms)
Example #5: Same paradigm, different data

Phillips et al., 2016
Example #5: Same paradigm, different data

A: ECoG DCM results

B

C: MEG DCM results

D

Phillips et al., 2016
Example #6: Hierarchical modelling

A  Evoked response potentials at Fz

B  Mismatch negativity waveform

C  Scalp topography of mismatch responses

Rosch et al., 2017
Friston et al., 2016
Example #6: Hierarchical modelling

A First level model space: Effects of repetition

B Second level model space: Effects of ketamine

Parametric effects of repetition

Monophasic Decay

Phasic Effect

Extrinsic coupling

Intrinsic coupling

Rosch et al., 2017
Motivate your assumptions!
Thank you!

Karl Friston
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