DCM for EEG

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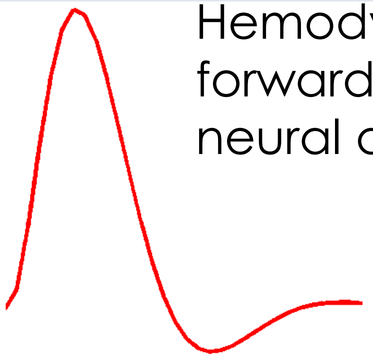
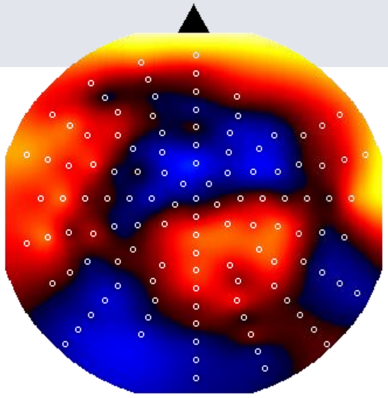
Translational Neuromodeling Unit

Recap: Dynamic Causal Modeling (DCM)



Hemodynamic
forward model:
neural activity→BOLD

Electromagnetic
forward model:
neural activity→EEG
MEG
LFP



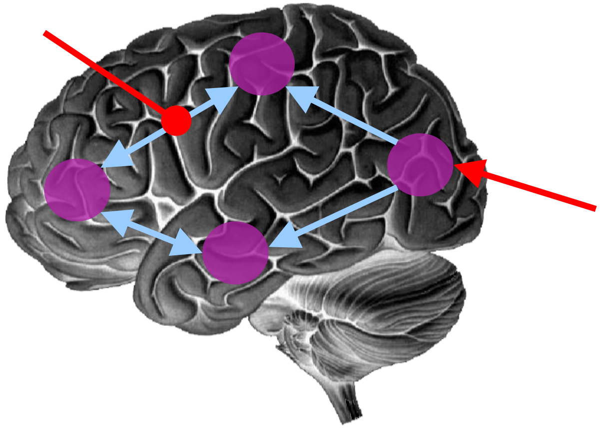
Neural model:

regional interactions →

neural activity:

fMRI

Previous talk

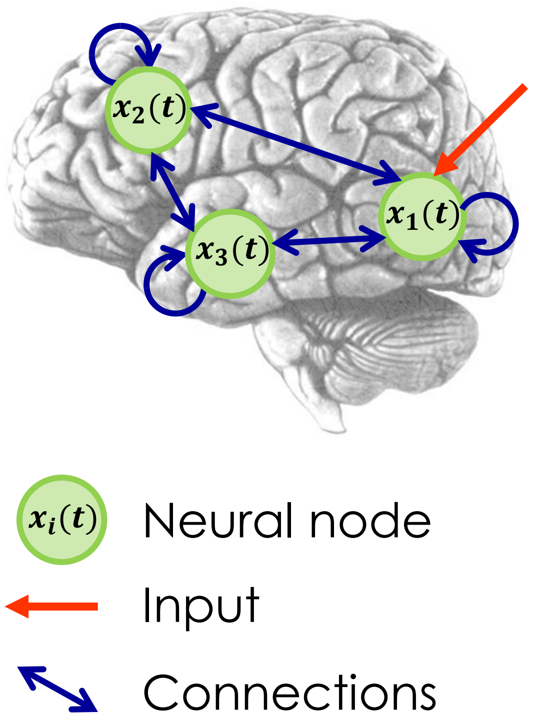


EEG/MEG

This talk

Recap: DCM approach to effective connectivity

A simple model of a neural network …



… described as a dynamical system …

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

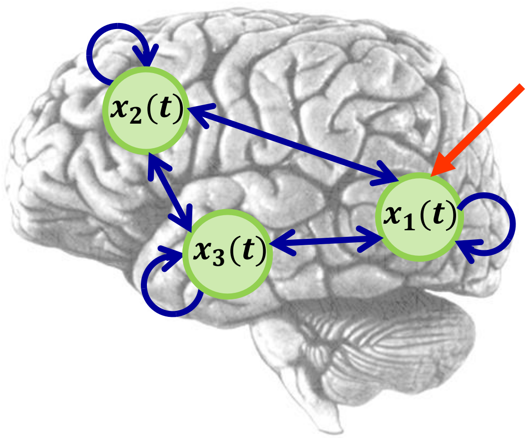
… causes the data (BOLD signal).

$$y = g(x, \theta_y) + \varepsilon$$

Let the system run with input (u) and parameters (θ_x, θ_y), and you will get a BOLD signal time course y that you can compare to the measured data.

Recap: DCM approach to effective connectivity

A simple model of a neural network …



$x_i(t)$ Neural node

Input

Connections

… described as a dynamical system …

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

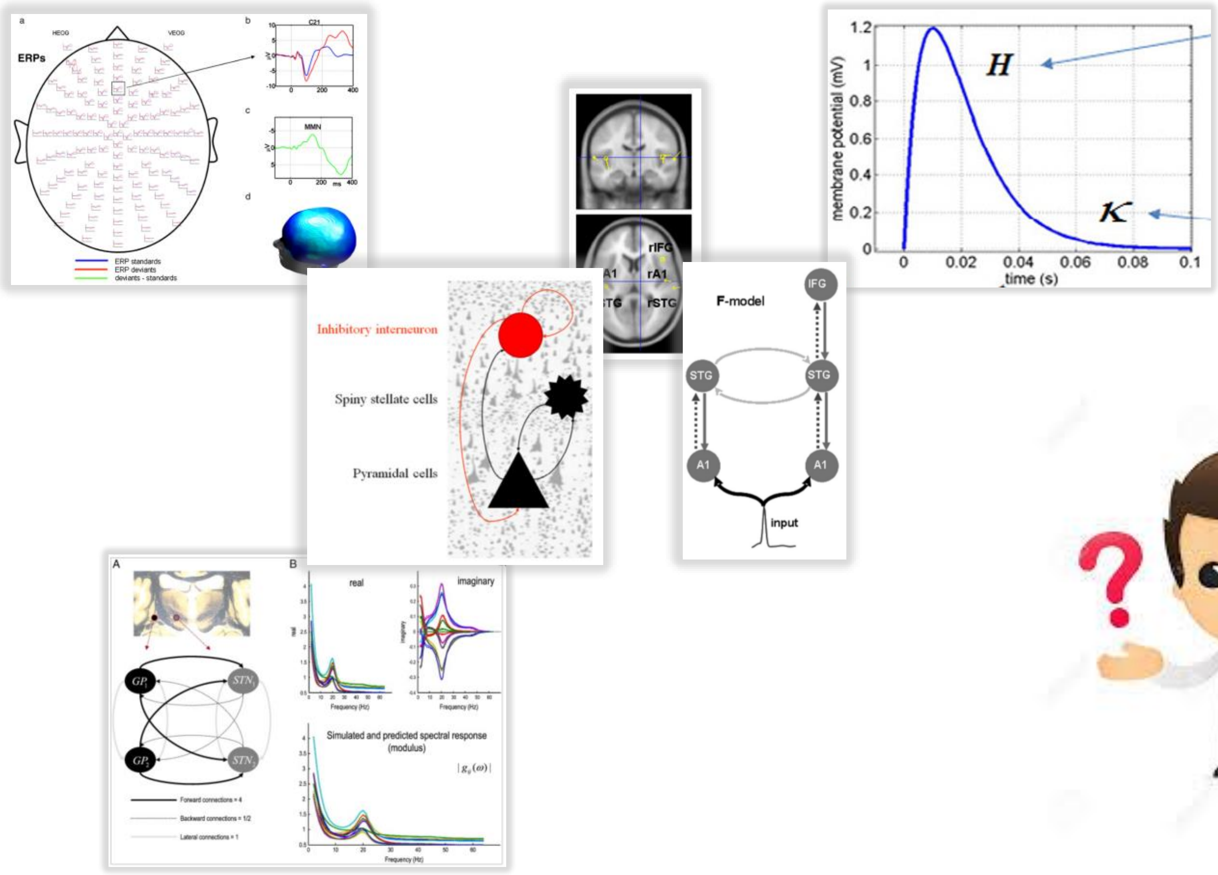
… causes the data (~~BOLD~~ signal).
EEG

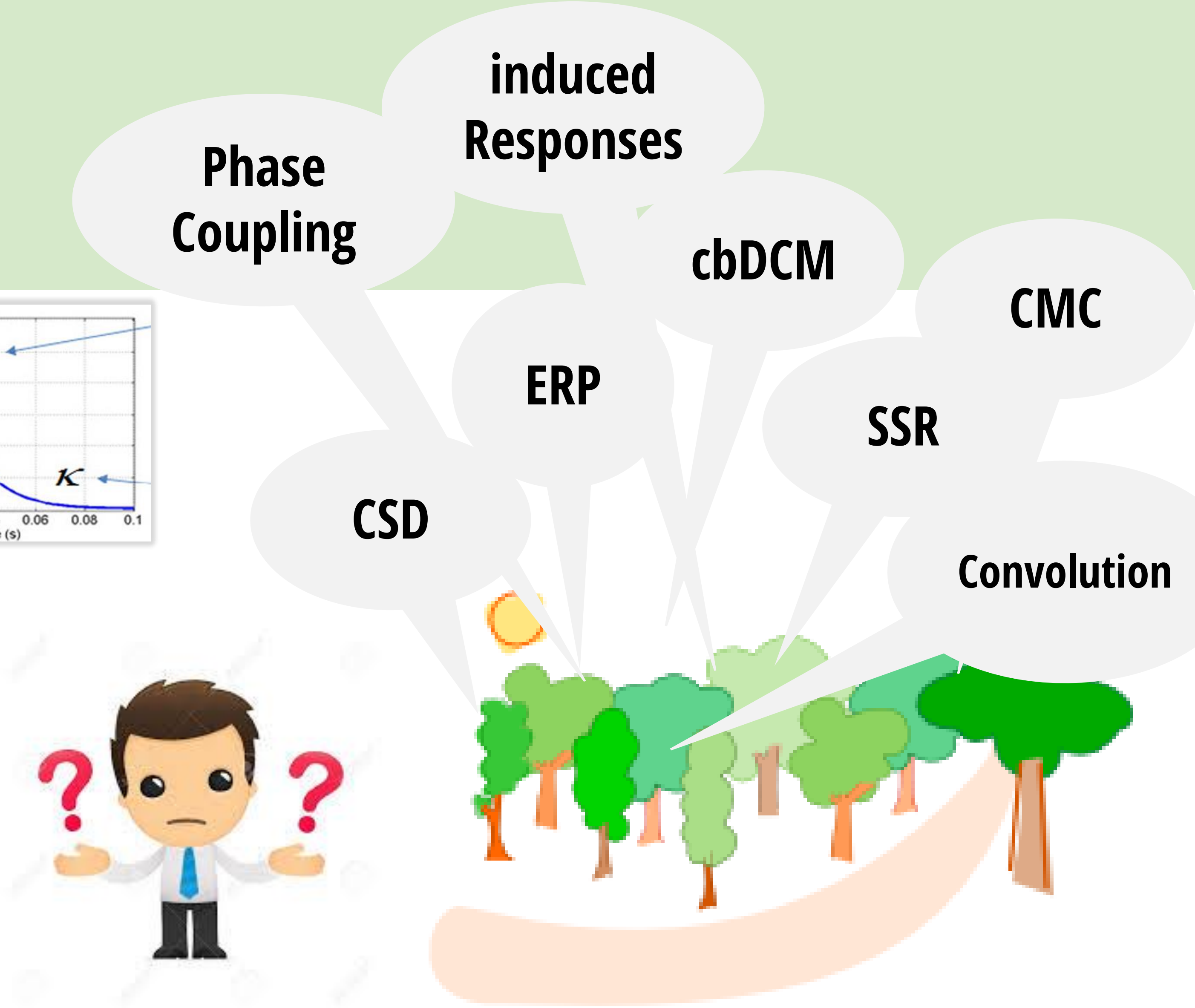
$$y = g(x, \theta_y) + \varepsilon$$

EEG

Let the system run with input (u) and parameters (θ_x, θ_y), and you will get a ~~BOLD~~ signal time course y that you can compare to the measured data.

The variety of DCM for EEG

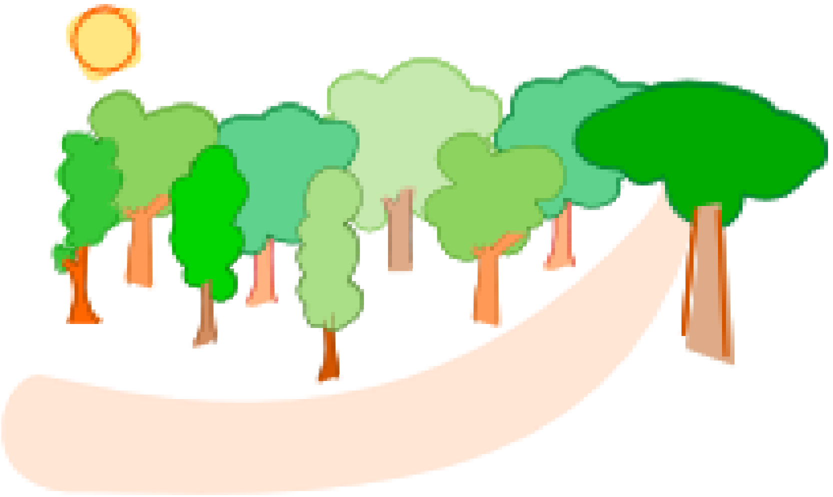


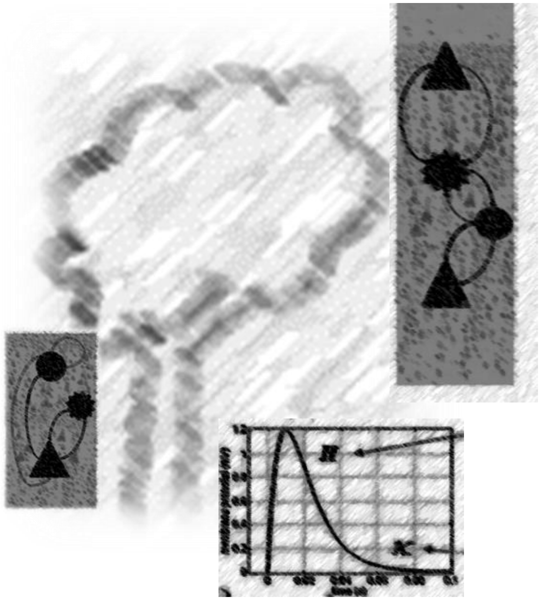


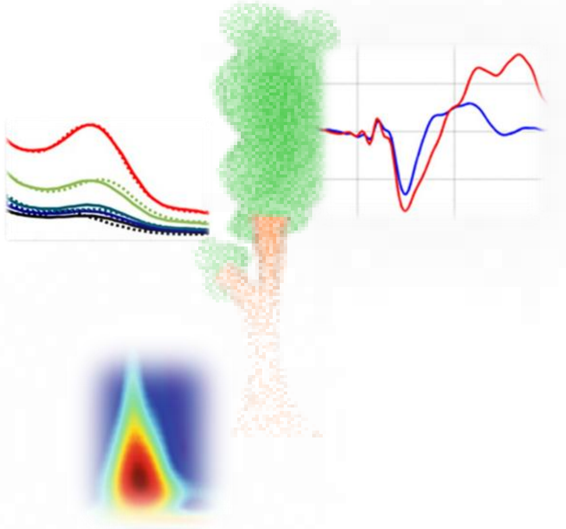
Garrido, Neuroimage, 2007; Moran, frontiers in Comp. Neuroscience, 2013; Friston, Neuroimage, 2012

" ... important distinction between different models and different data features ..."

Moran, frontiers in Comp. Neuroscience, 2013



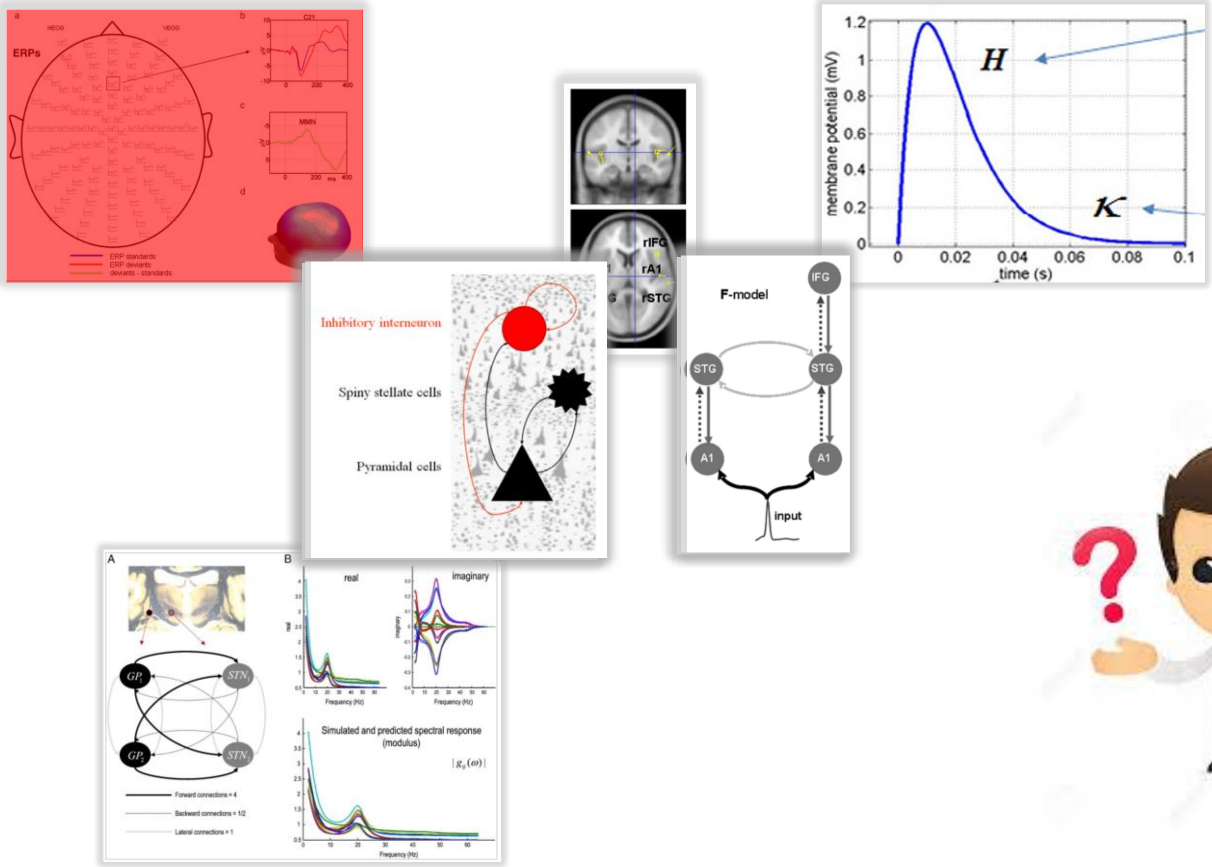


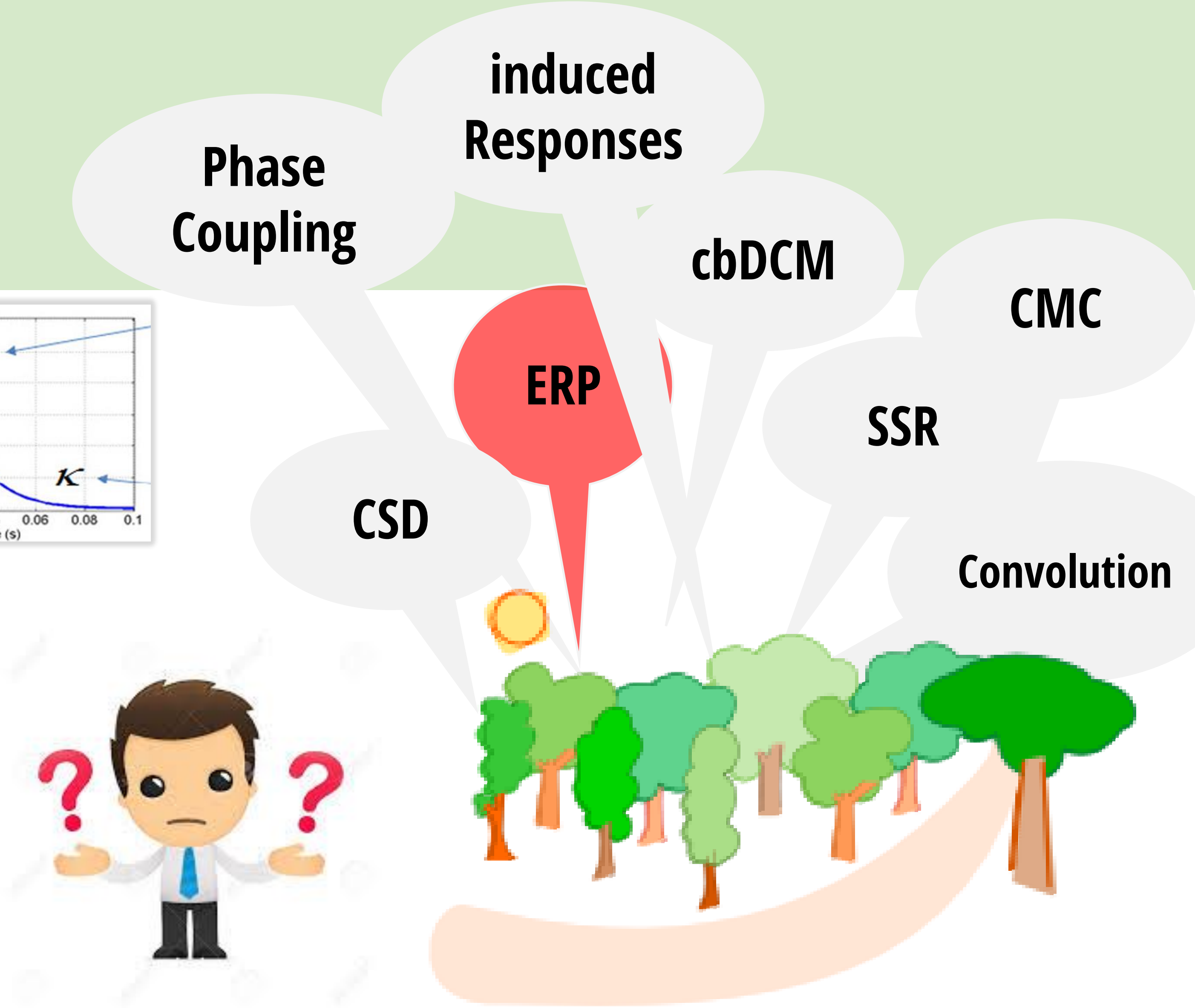


The naming refers to either data feature, within source connectivity, or dynamics.

There is usually not a unique model to model a data feature, but some might be more suited than others.

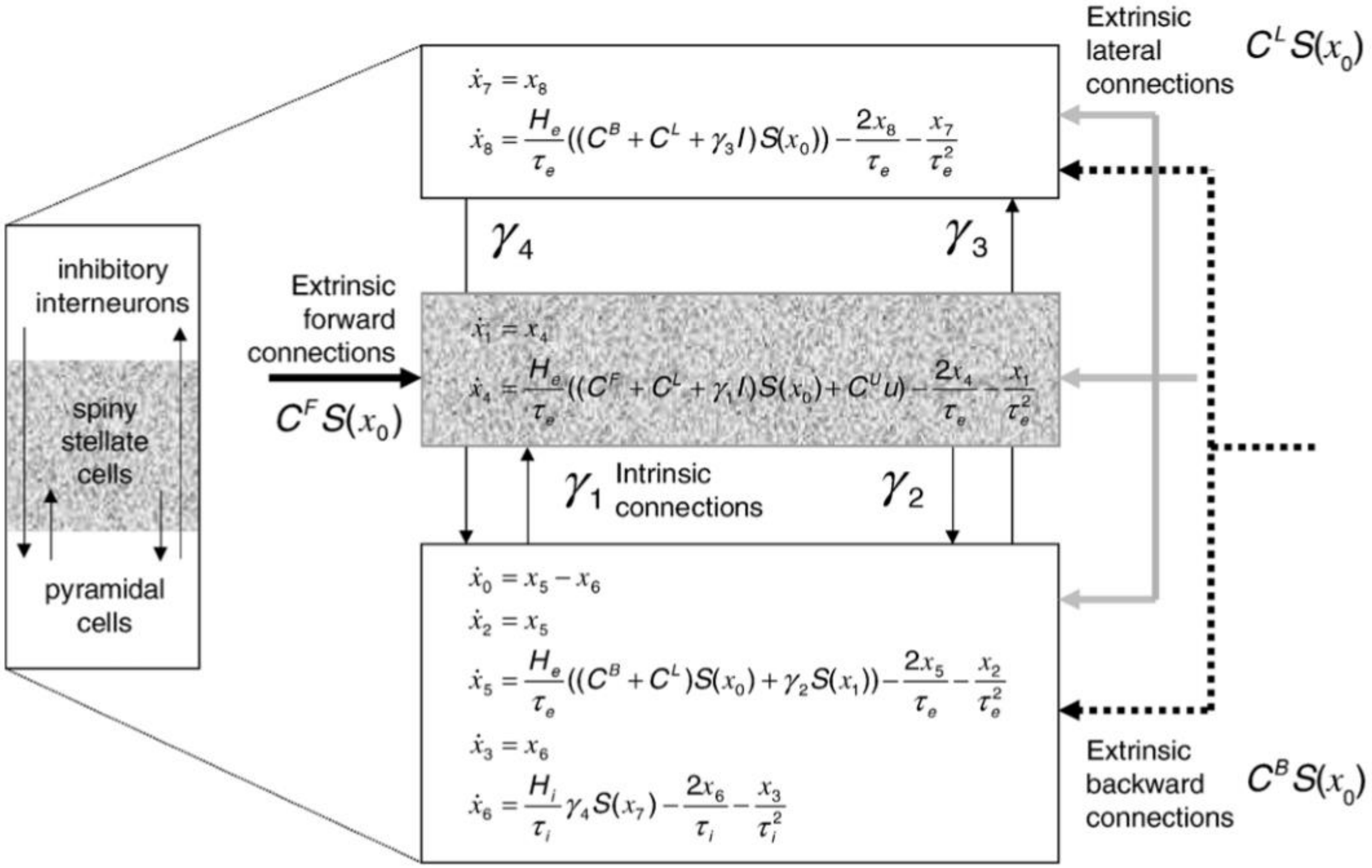
The variety of DCM for EEG





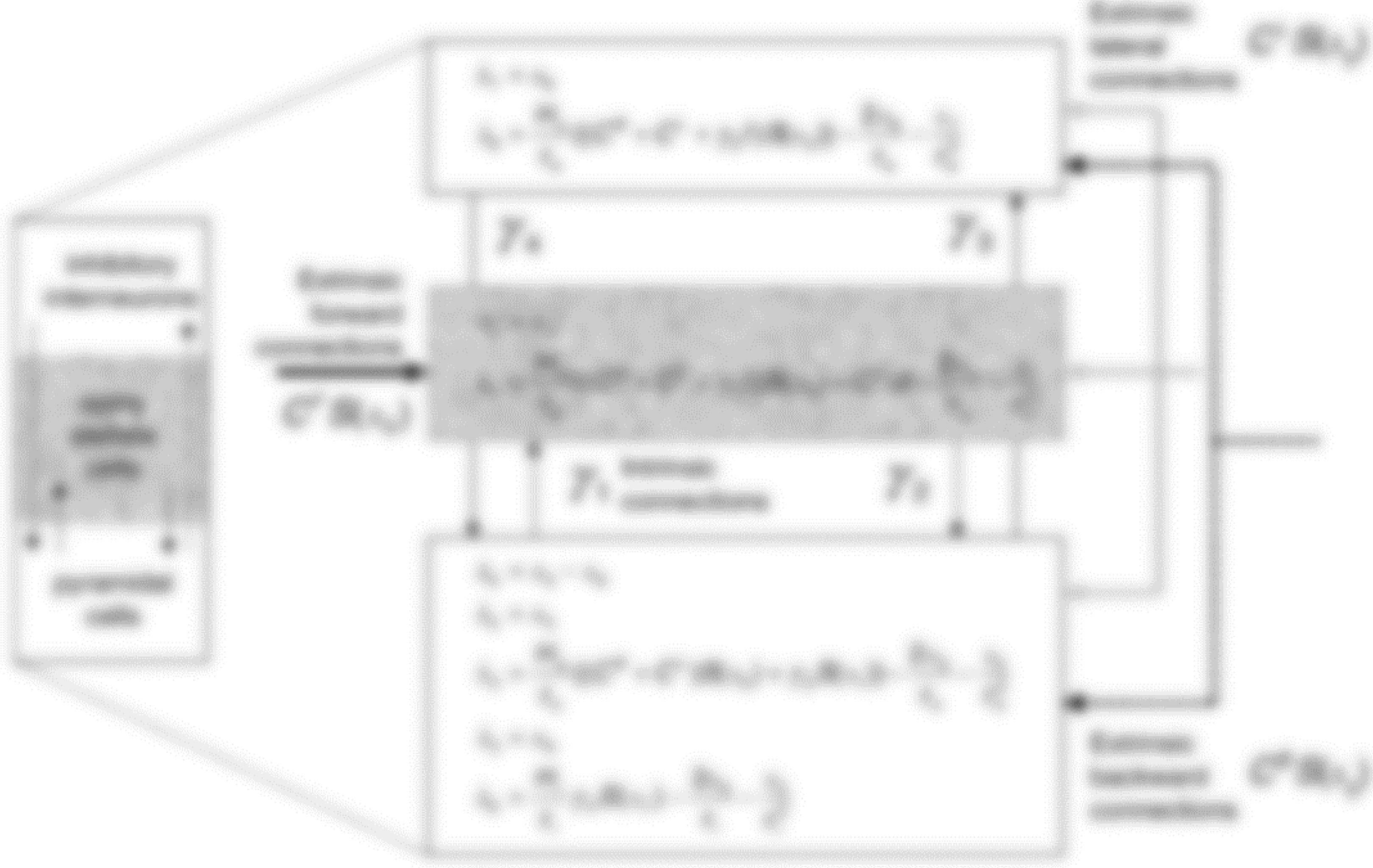
Garrido, Neuroimage, 2007; Moran, frontiers in Comp. Neuroscience, 2013; Friston, Neuroimage, 2012

Models



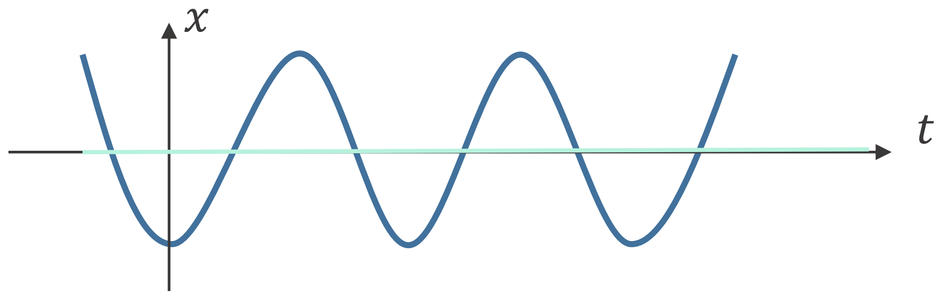
Single source model

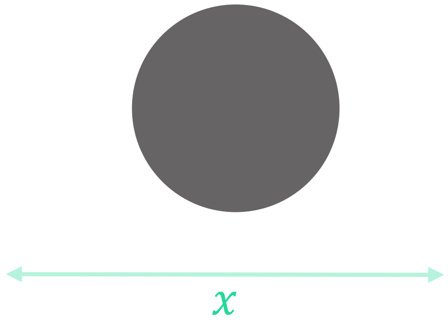
Models

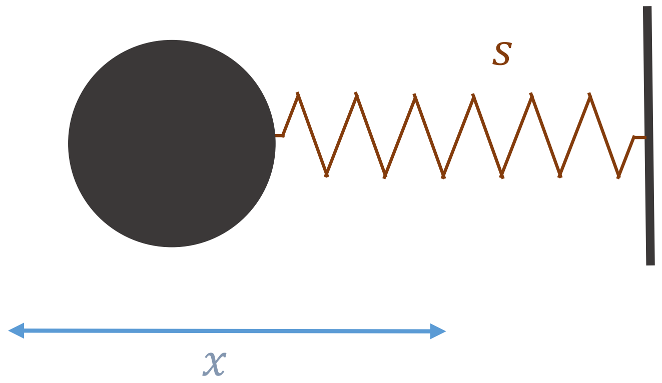


Single source model

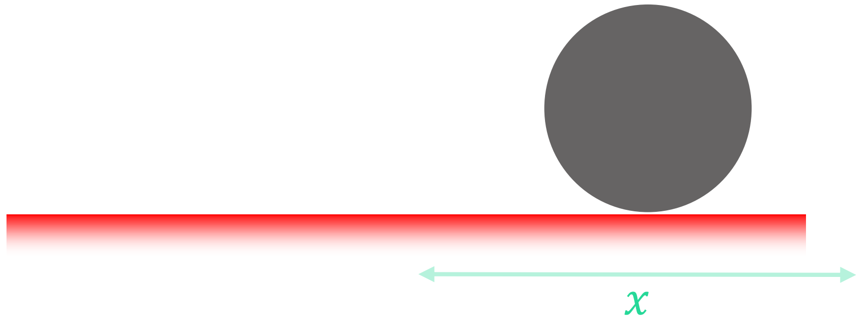
Thought Experiment

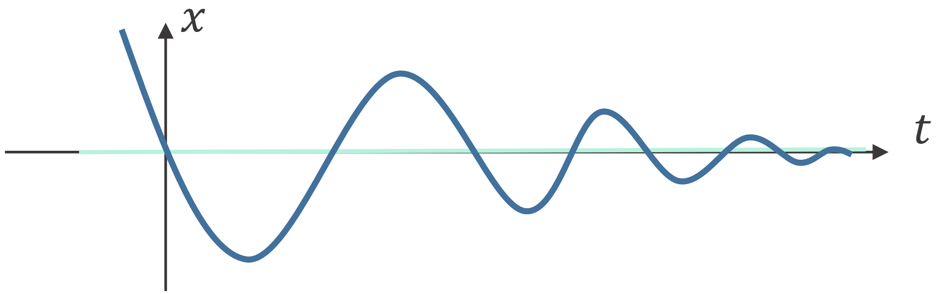


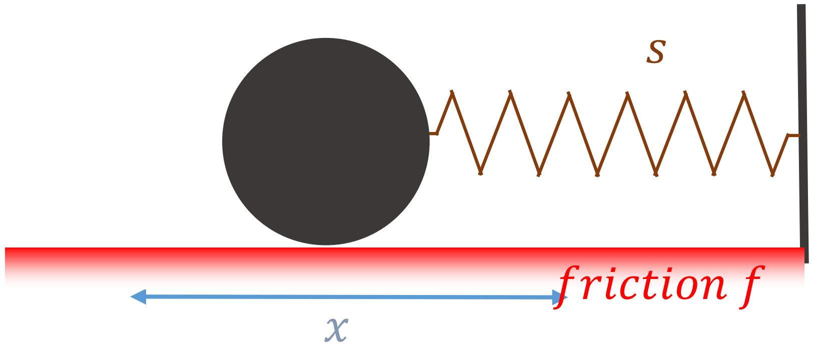




Thought Experiment







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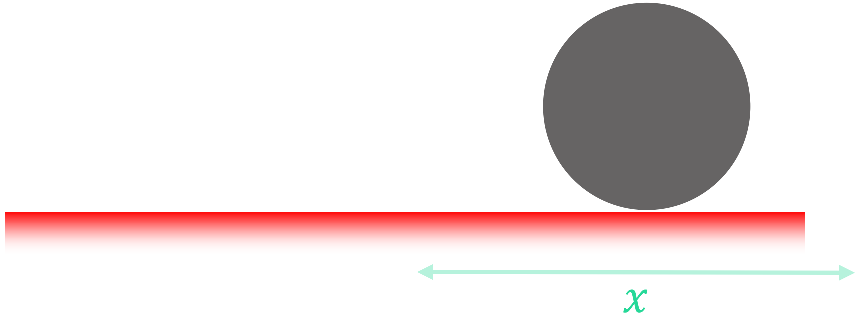

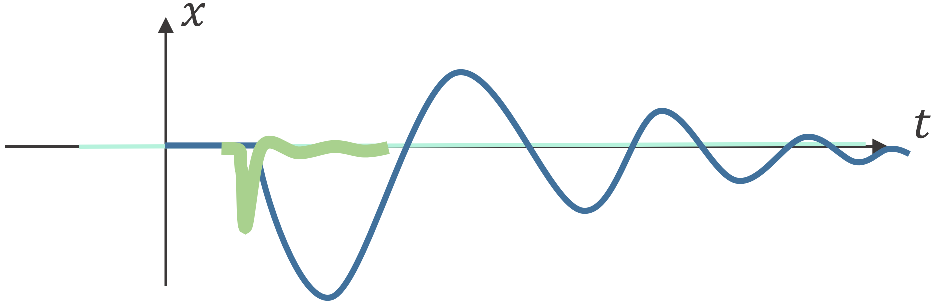

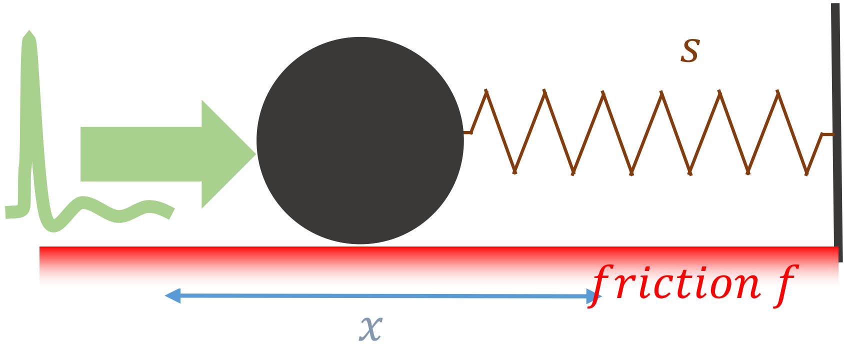

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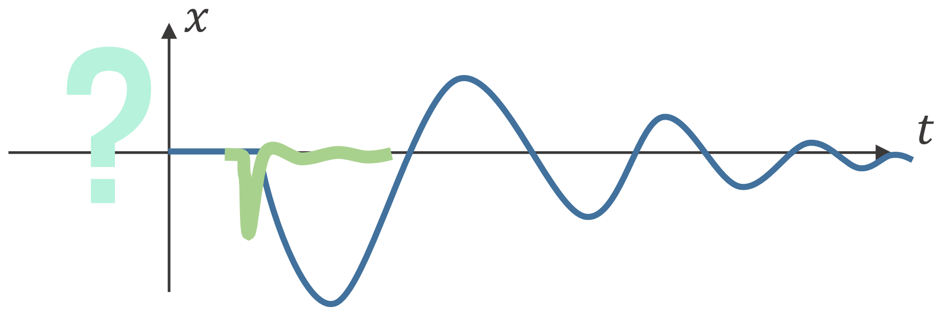
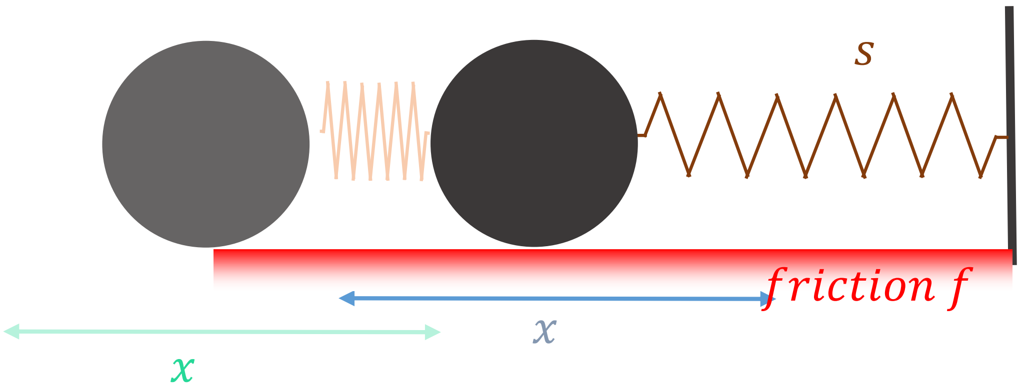
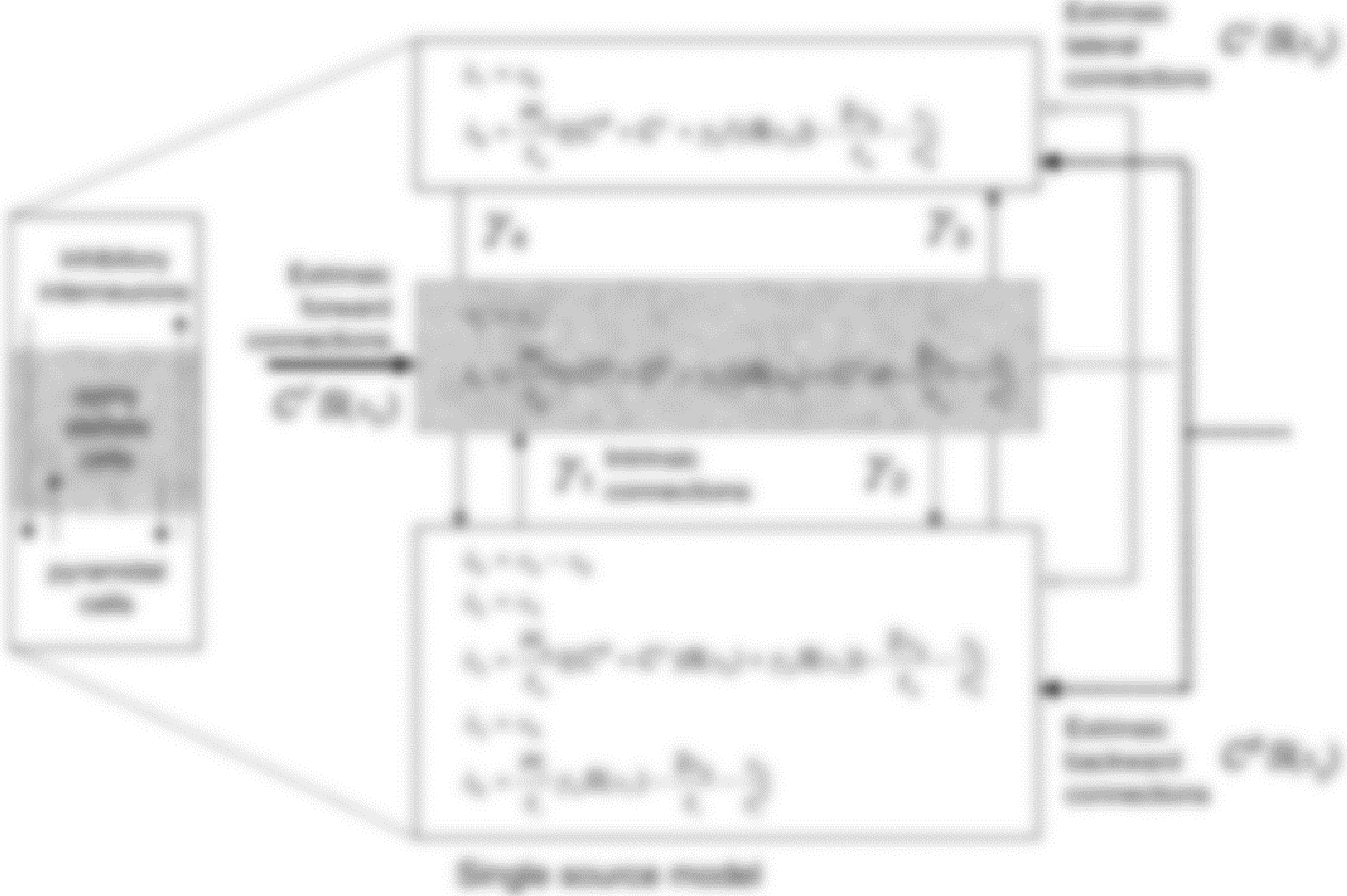
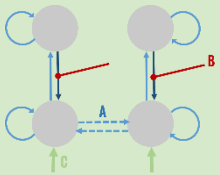




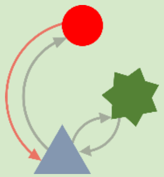
Models



Models

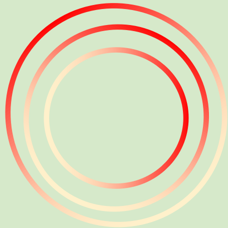


Between Source Connectivity



Within Source Connectivity

Dynamics



Forward Model

Between Source Connectivity

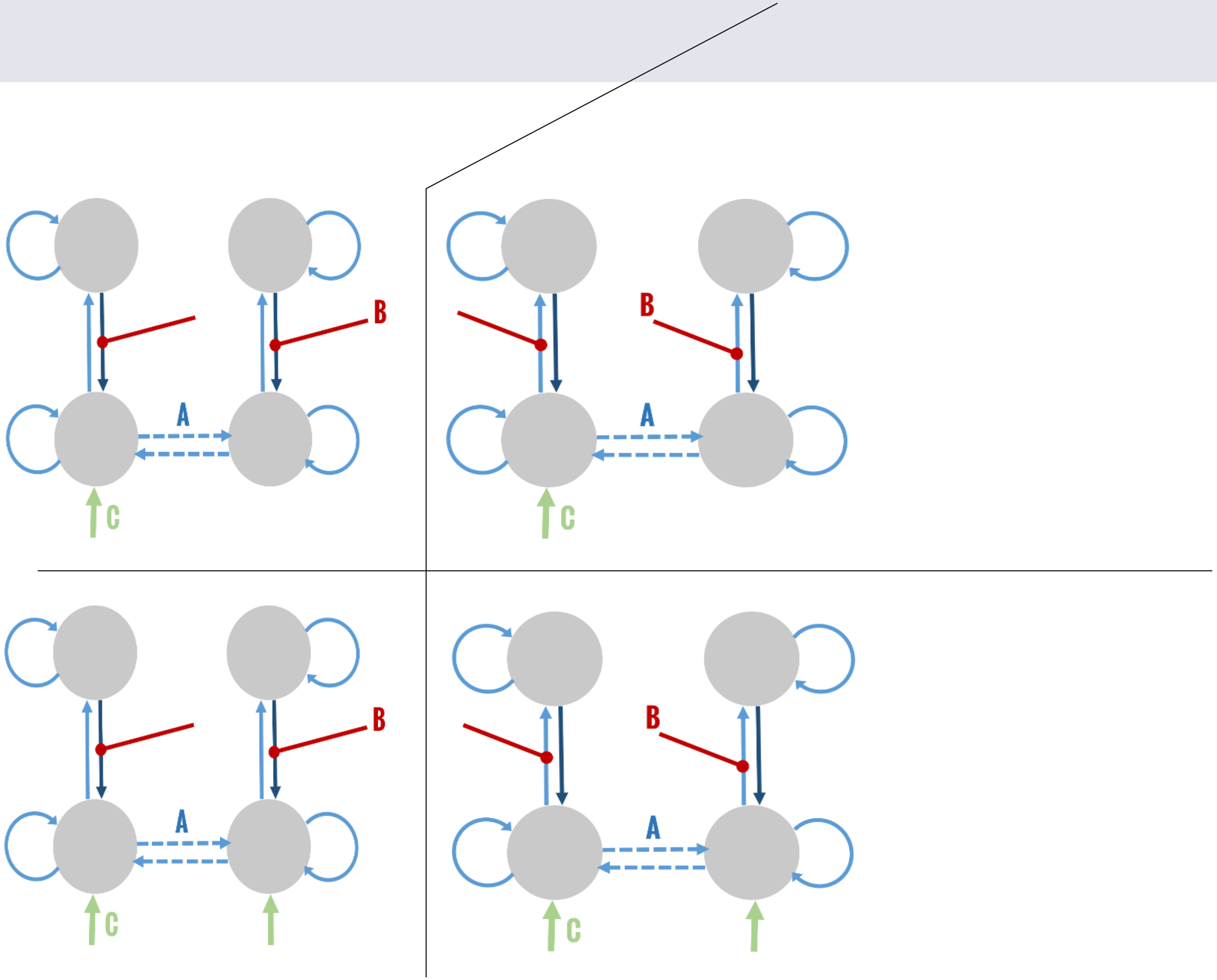
SPM Variable

Sources / Regions	X
Three types of connections: Forward, Backward, Lateral	A
Between condition effects	B
Input	C

Hypotheses

Hypotheses should be based on classical finding.

Once again, you try to explain a difference that is in the data.

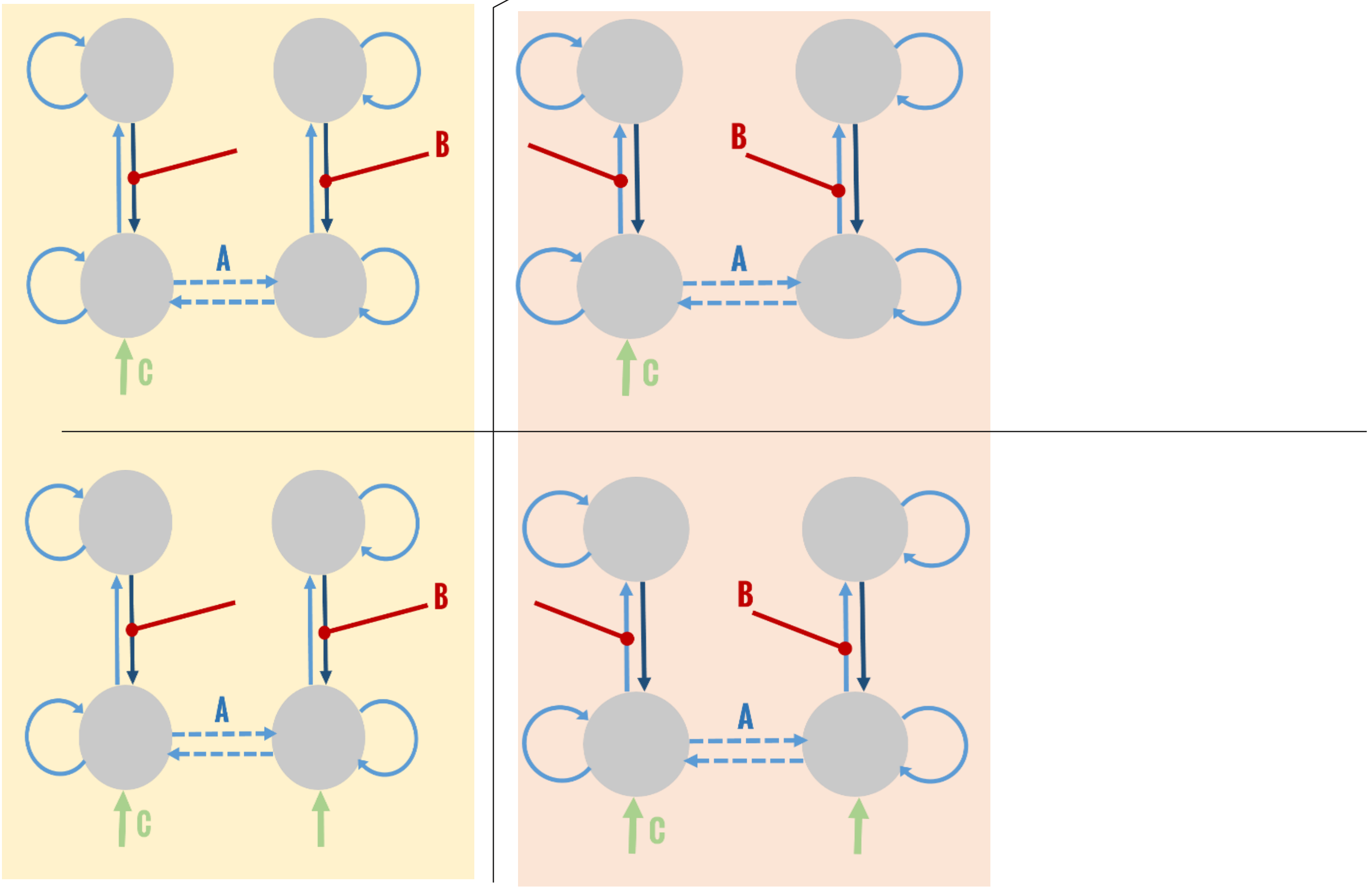


Hypotheses

Hypotheses should be based on classical finding.

Once again, you try to explain a difference that is in the data.

Is there a condition specific forward vs. backward modulation?



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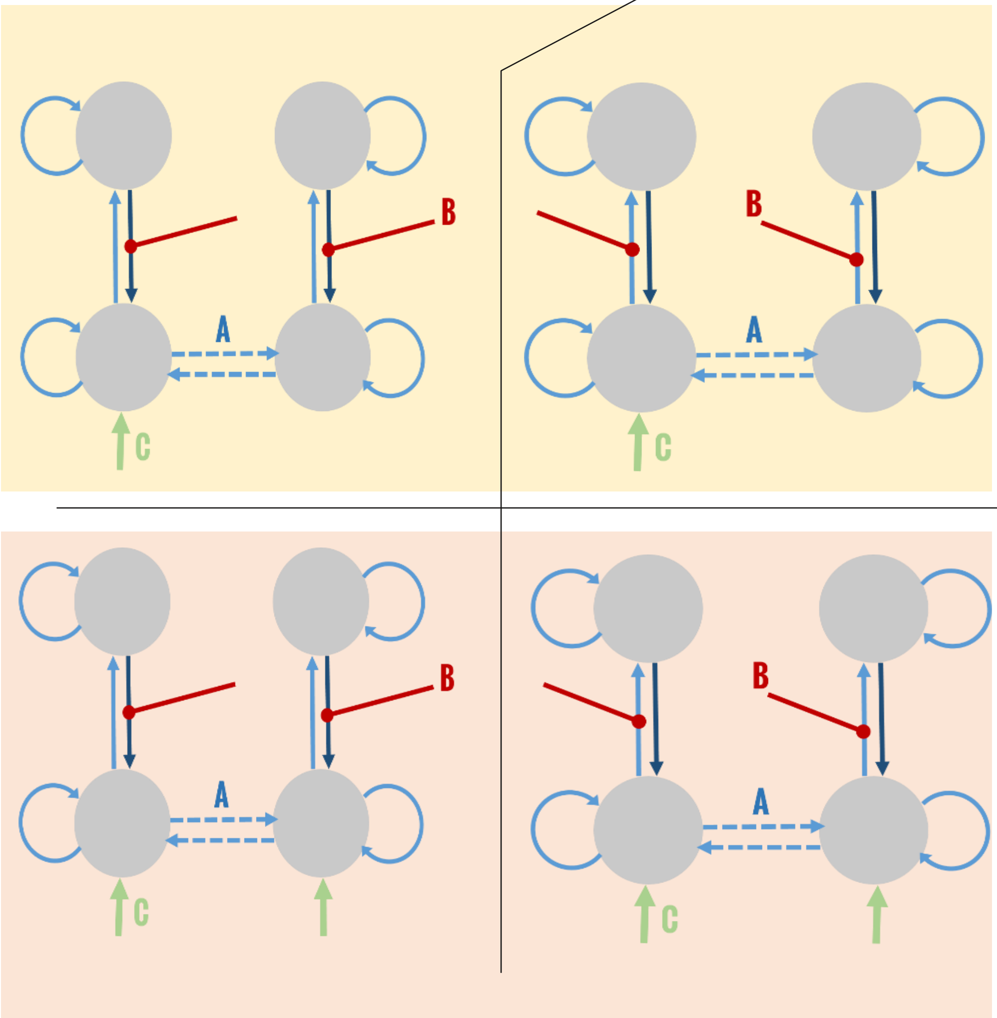


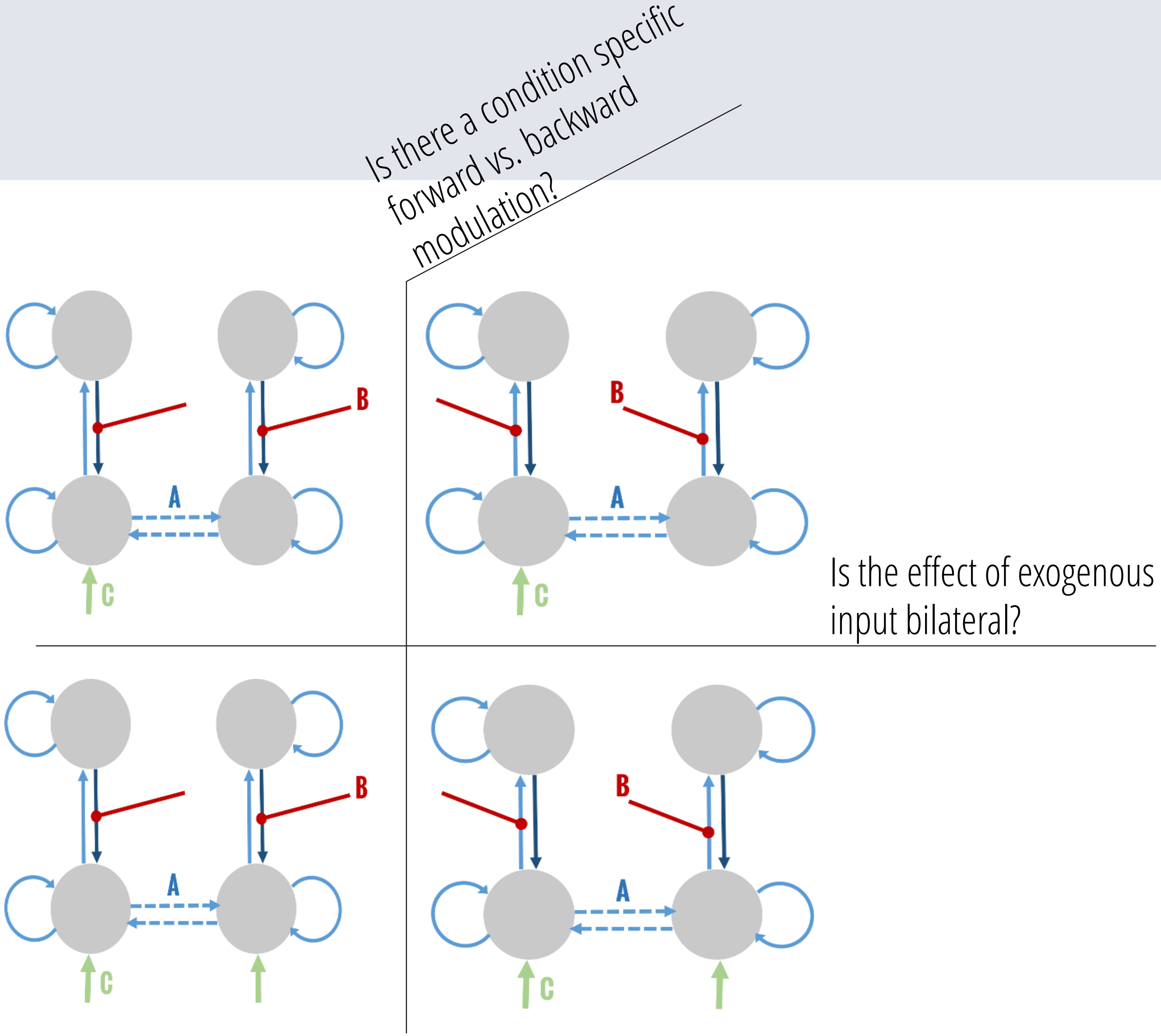
Is the effect of exogenous input bilateral?

Hypotheses

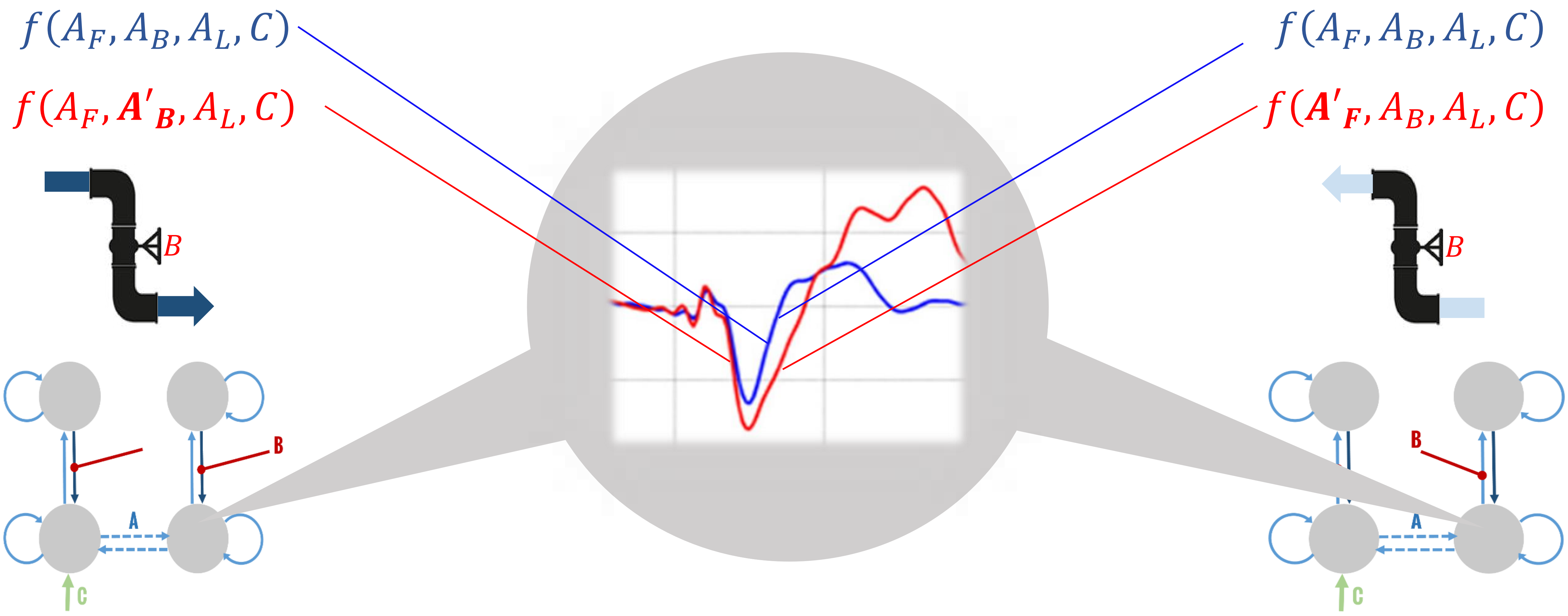
Computation of parameter estimates.

Model Comparisons

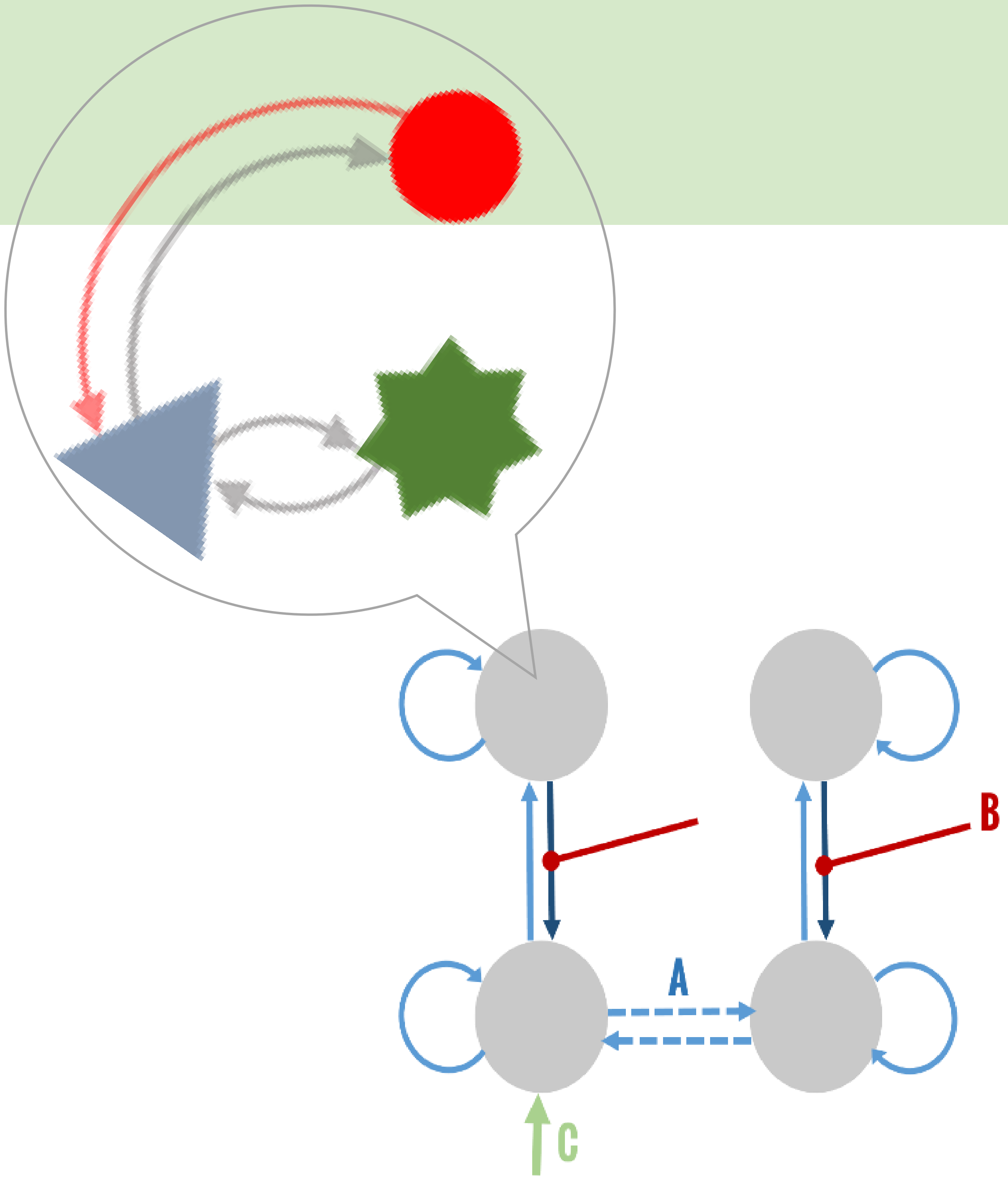
Which one of competing Hypotheses describes the data best.



What it means to have a condition specific effect



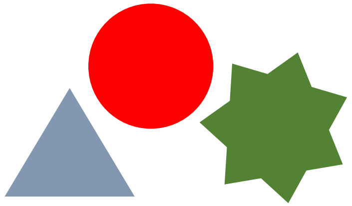
Within Source Connectivity



Within Source Connectivity

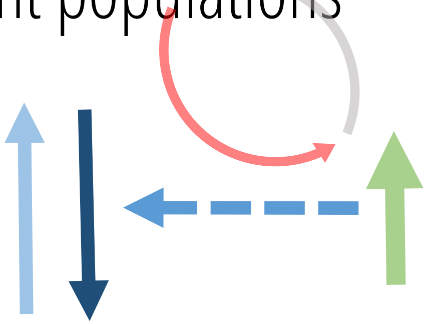
Three types of Cell Populations:

Pyramidal, Inhibitory, Stellate



Inhibitory / Excitatory effects on different populations

Dependence on Extrinsic Connectivity



SPM Variable

X

G

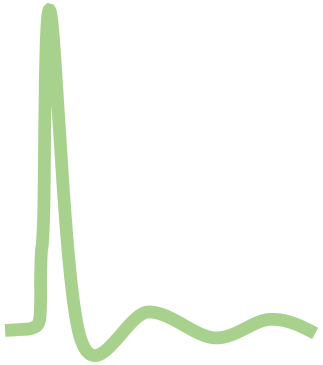
A, C

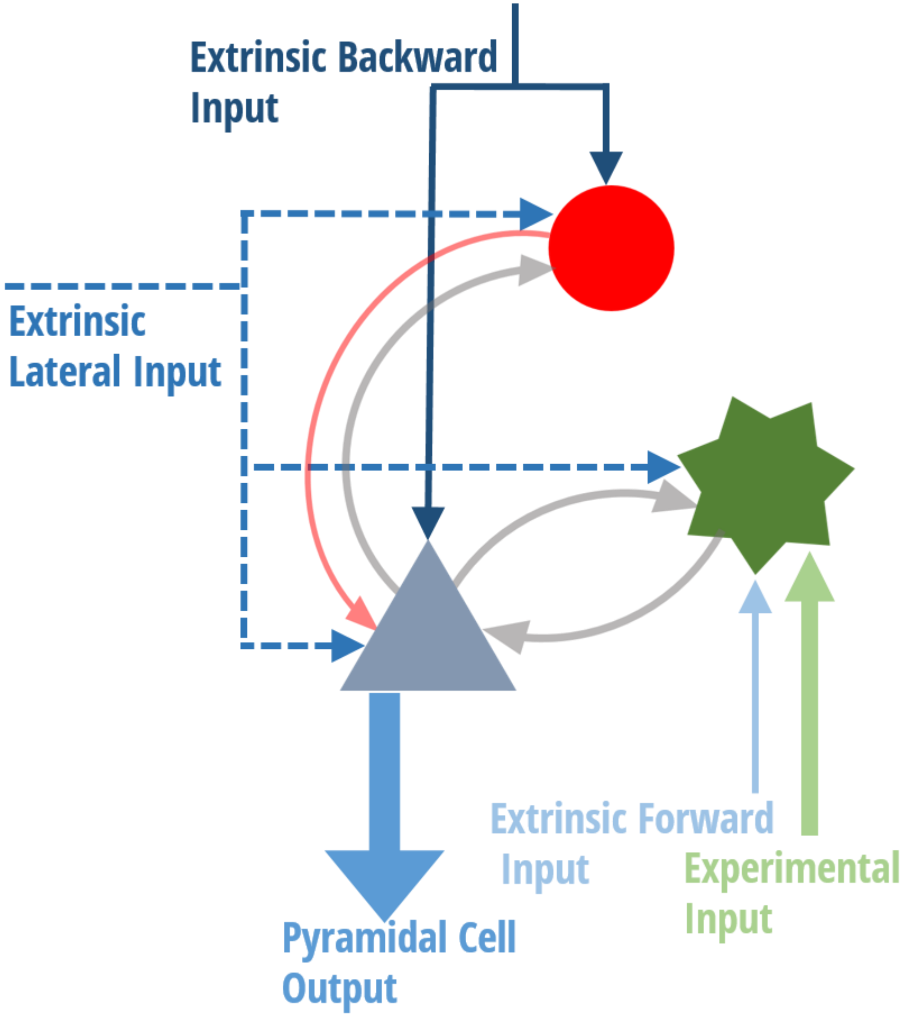
ERP Model

Name of a Between Source Connection refers to the cell population that is being targeted.

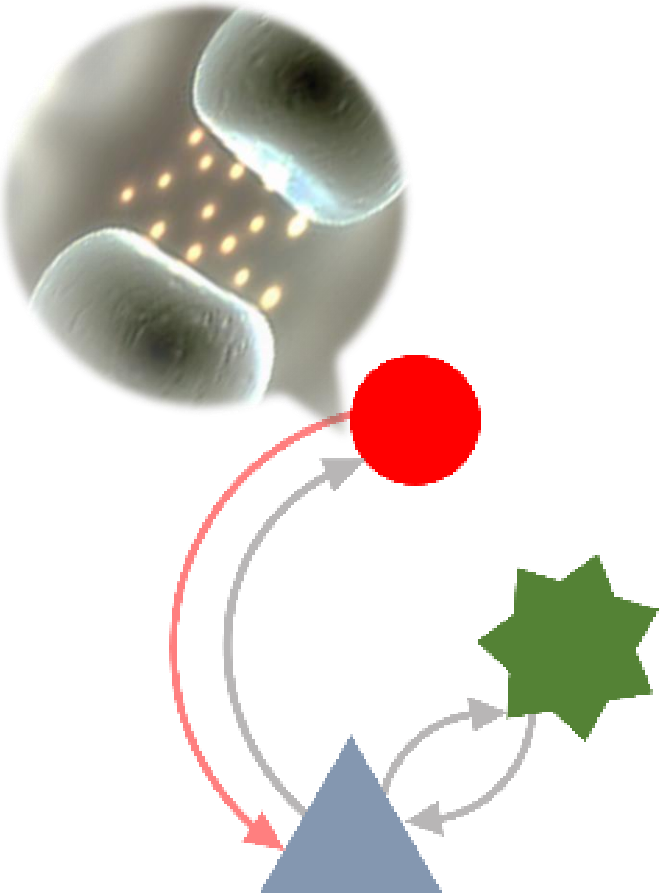
Output from the Pyramidal Cell

Experimental Input





Dynamics



Convolution Based Models

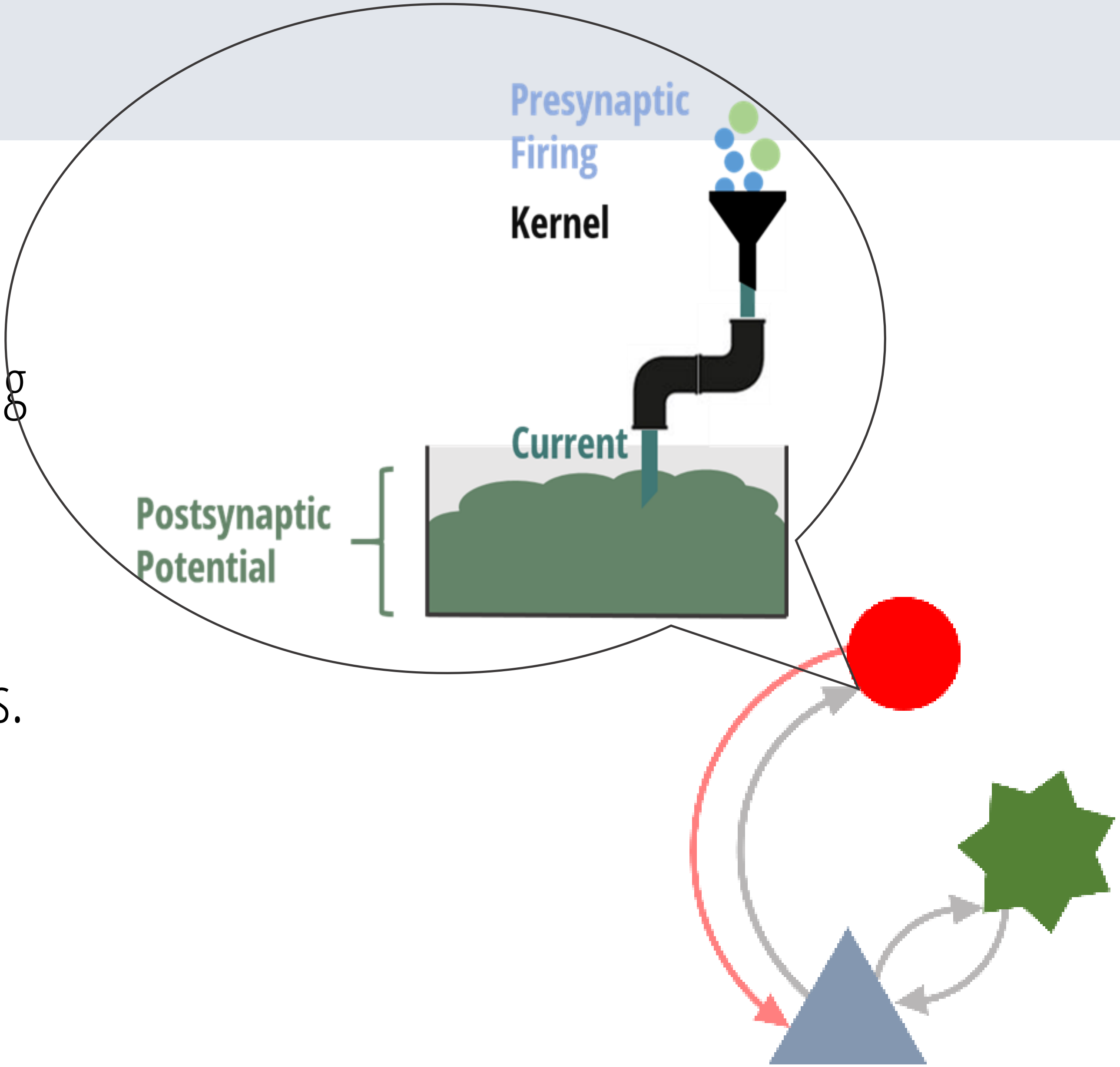
Jansen and Rit (1995)

The Kernel transforms the presynaptic firing rate into a postsynaptic potential.

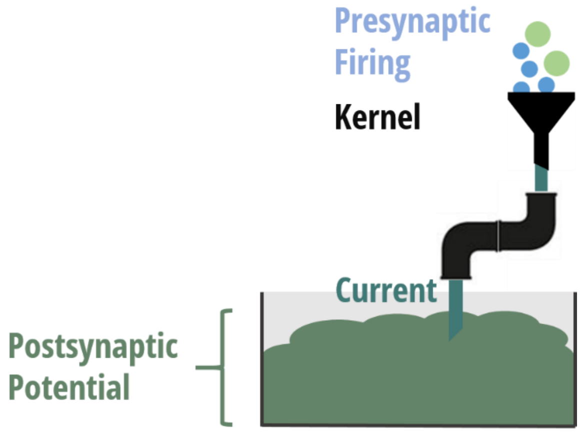
Transformation is a convolution.

Kernel is parameterized by two parameters.

Voltage over time shows similarities with Harmonic Oscillator.

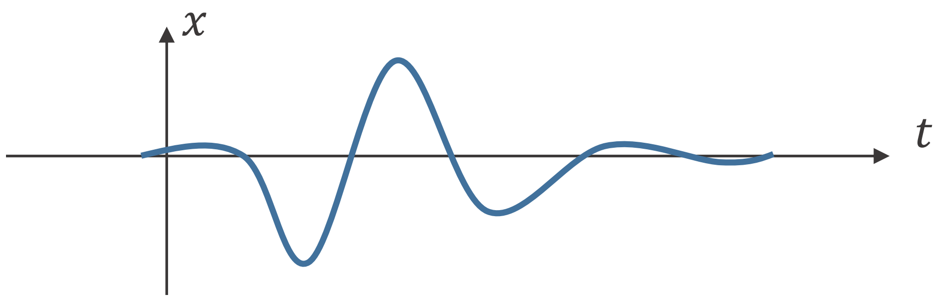


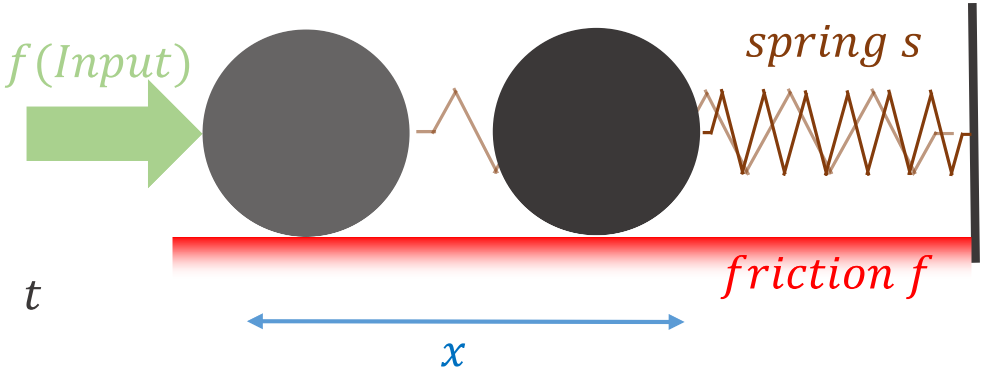
Convolution Based Models



$$\ddot{v} = f(Input) - \frac{2}{\tau}\dot{v} - \frac{1}{\tau^2}v$$

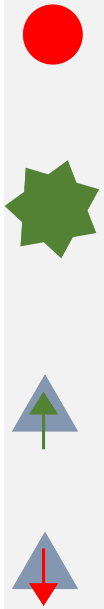
$$\ddot{x} = f(Input) - f\dot{x} - sx$$

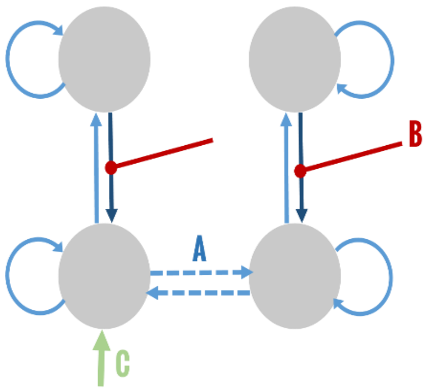


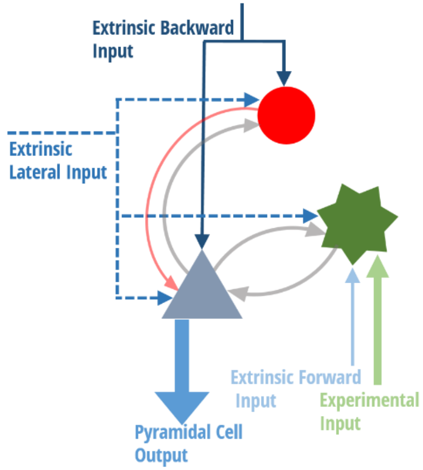


Dynamics

$$\ddot{v} = f(Input) - \frac{2}{\tau}\dot{v} - \frac{1}{\tau^2}v$$

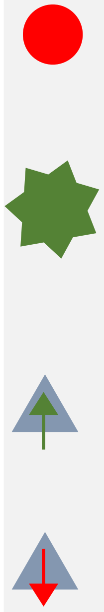




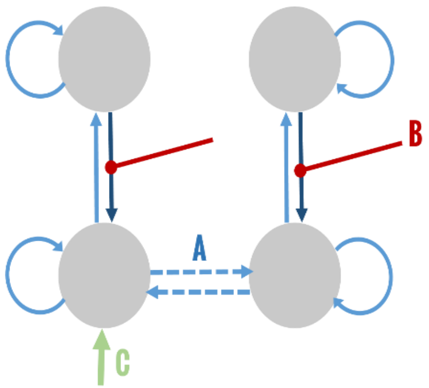


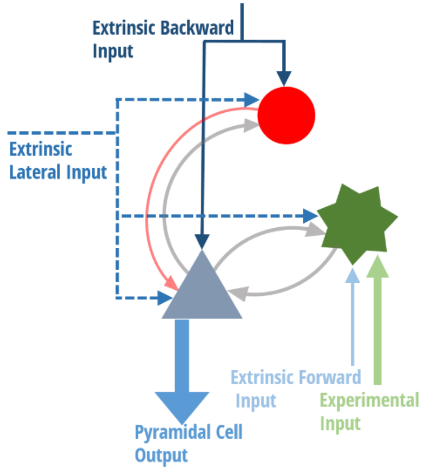
Dynamics

$$\ddot{v} = f(Input) - \frac{2}{\tau}\dot{v} - \frac{1}{\tau^2}v$$



$k_e A_{back}$

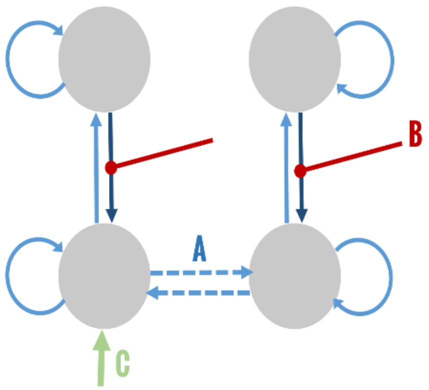


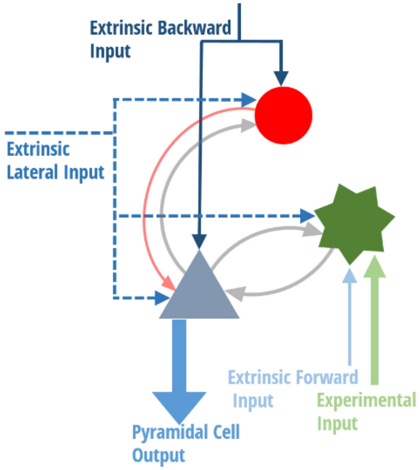


Dynamics

$$\ddot{v} = f(Input) - \frac{2}{\tau}\dot{v} - \frac{1}{\tau^2}v$$

$$k_e A_{back} \quad + k_e A_{lateral}$$

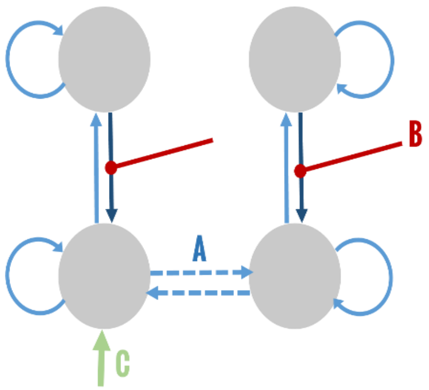


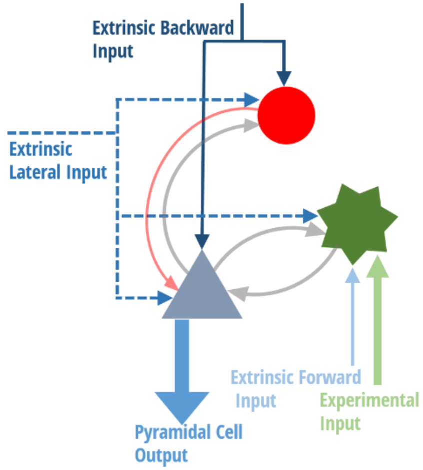


Dynamics

$$\ddot{v} = f(Input) - \frac{2}{\tau}\dot{v} - \frac{1}{\tau^2}v$$

$$k_e A_{back} \quad + k_e A_{lateral} \quad + k_e G$$



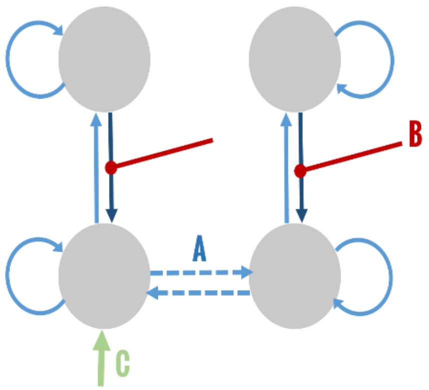


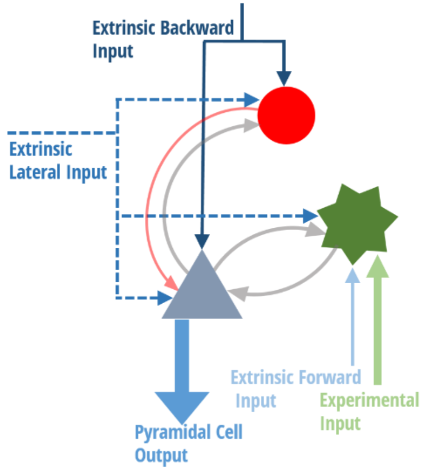
Dynamics

$$\ddot{v} = f(Input) - \frac{2}{\tau}\dot{v} - \frac{1}{\tau^2}v$$

$$k_e A_{back} + k_e A_{lateral} + k_e G$$

$$k_e A_{Forward} + k_e A_{lateral} + k_e G + C$$





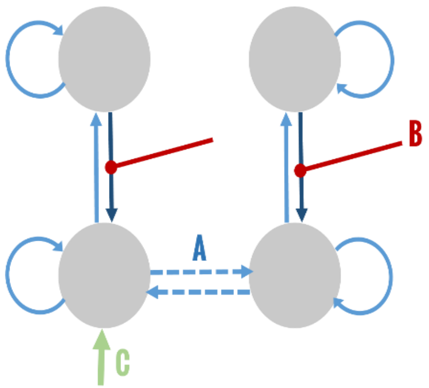
Dynamics

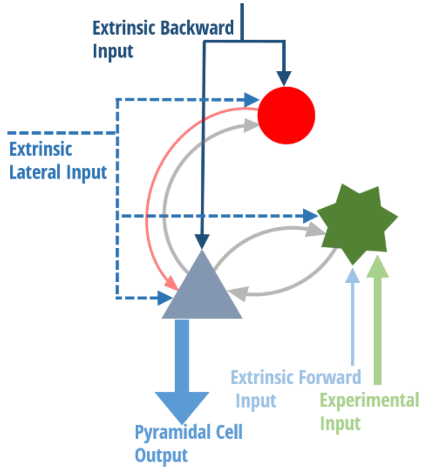
$$\ddot{v} = f(Input) - \frac{2}{\tau}\dot{v} - \frac{1}{\tau^2}v$$

$$k_e A_{back} + k_e A_{lateral} + k_e G$$

$$k_e A_{Forward} + k_e A_{lateral} + k_e G + C$$

$$k_e A_{back} + k_e A_{lateral} + k_e G$$





Dynamics

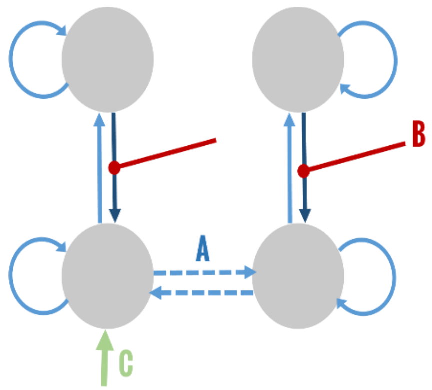
$$\ddot{v} = f(Input) - \frac{2}{\tau}\dot{v} - \frac{1}{\tau^2}v$$

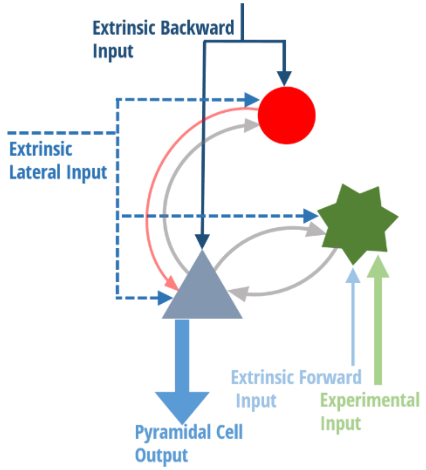
$$k_e A_{back} + k_e A_{lateral} + k_e G$$

$$k_e A_{Forward} + k_e A_{lateral} + k_e G + C$$

$$k_e A_{back} + k_e A_{lateral} + k_e G$$

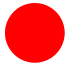
$$k_i G$$





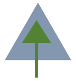
Dynamics

$$\ddot{v} = f(Input) - \frac{2}{\tau}\dot{v} - \frac{1}{\tau^2}v$$

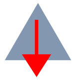


$$\ddot{v} = k_e((A_{back} + A_{lateral}) + G) - \frac{2}{\tau}\dot{v} - \frac{1}{\tau^2}v$$

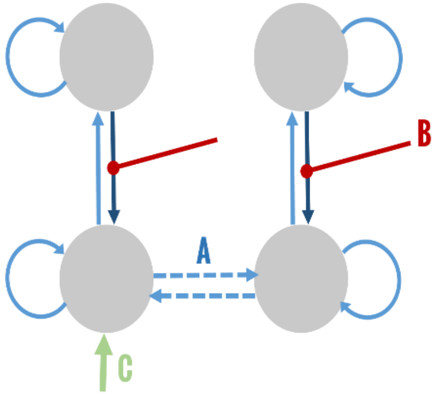
$$\ddot{v} = k_e((A_{Forward} + A_{lateral}) + G) + C \quad - \frac{2}{\tau}\dot{v} - \frac{1}{\tau^2}v$$

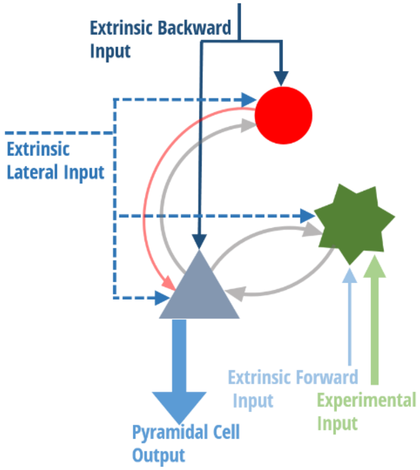


$$\ddot{v} = k_e((A_{back} + A_{lateral}) + G) - \frac{2}{\tau}\dot{v} - \frac{1}{\tau^2}v$$



$$\ddot{v} = k_i G \quad - \frac{2}{\tau}\dot{v} - \frac{1}{\tau^2}v$$





Dynamics

$$\ddot{v} = f(Input) - \frac{2}{\tau}\dot{v} - \frac{1}{\tau^2}v$$

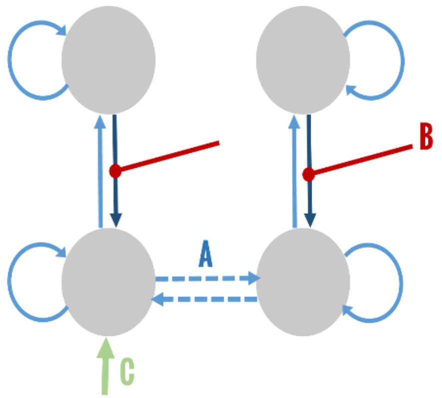
$$\ddot{v} = k_e\big((A_{back} + A_{lateral}) + G\big) \quad -\frac{2}{\tau}\dot{v} \quad -\frac{1}{\tau^2}v$$

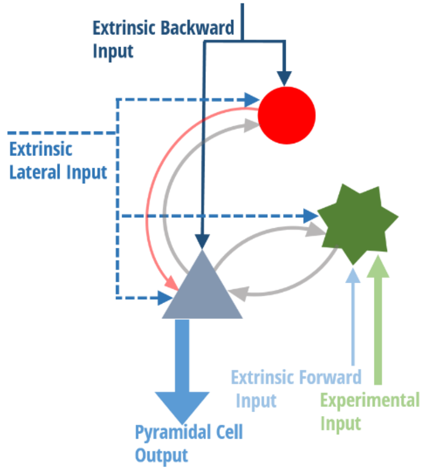
```
f(:,8) = (He.*((A{2} + A{3})*S(:,9) + G(:,3).*S(:,9)) - 2*x(:,8) - x(:,7)./Te)./Te;
```

$$\ddot{v} = k_e\big((A_{forward} + A_{lateral}) + G\big) + C \quad -\frac{2}{\tau}\dot{v} - \frac{1}{\tau^2}v$$

$$\ddot{v} = k_e\big((A_{back} + A_{lateral}) + G\big) -\frac{2}{\tau}\dot{v} - \frac{1}{\tau^2}v$$

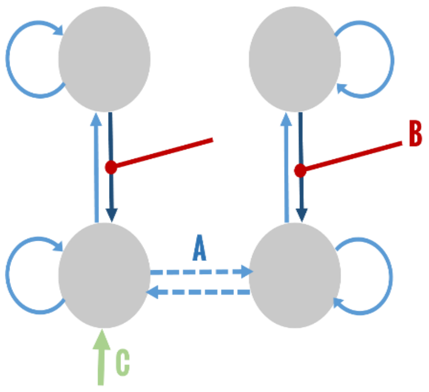
$$\ddot{v} = k_i G \quad -\frac{2}{\tau}\dot{v} - \frac{1}{\tau^2}v$$



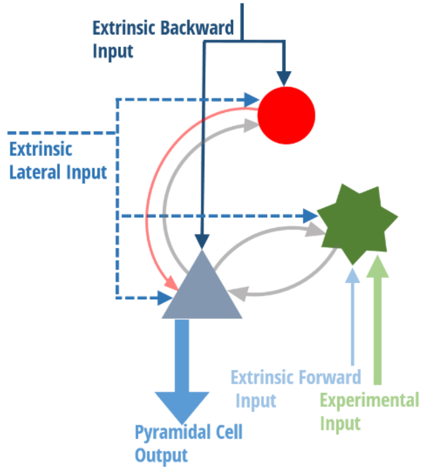


Dynamics

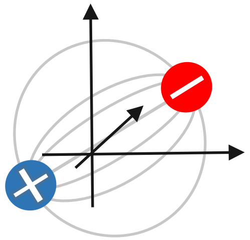
$$\ddot{v} = \qquad f(Input) \qquad -\frac{2}{\tau}\dot{v} - \frac{1}{\tau^2}v$$




```
% Supragranular layer (inhibitory interneurons): Voltage & depolarizing current
%--------------------------------------------------------------------------
f(:,7) = x(:,8);
f(:,8) = (He.*((A{2} + A{3})*S(:,9) + G(:,3).*S(:,9)) - 2*x(:,8) - x(:,7)./Te)./Te;

% Granular layer (spiny stellate cells): Voltage & depolarizing current
%--------------------------------------------------------------------------
f(:,1) = x(:,4);
f(:,4) = (He.*((A{1} + A{3})*S(:,9) + G(:,1).*S(:,9) + U) - 2*x(:,4) - x(:,1)./Te)./Te;

% Infra-granular layer (pyramidal cells): depolarizing current
%--------------------------------------------------------------------------
f(:,2) = x(:,5);
f(:,5) = (He.*((A{2} + A{3})*S(:,9) + G(:,2).*S(:,1)) - 2*x(:,5) - x(:,2)./Te)./Te;

% Infra-granular layer (pyramidal cells): hyperpolarizing current
%--------------------------------------------------------------------------
f(:,3) = x(:,6);
f(:,6) = (Hi.*G(:,4).*S(:,7) - 2*x(:,6) - x(:,3)./Ti)./Ti;

% Infra-granular layer (pyramidal cells): Voltage
%--------------------------------------------------------------------------
f(:,9) = x(:,5) - x(:,6);
```

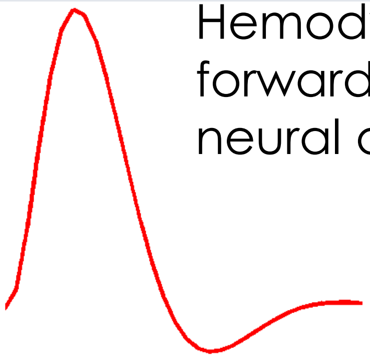


Forward Model



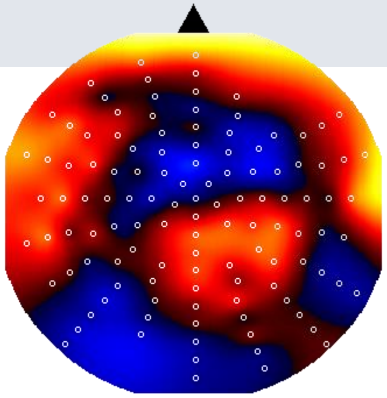
	SPM Variable
Equivalent Current Dipoles	X
Leadfield matrix	L
Measured Data	Y

Recap: Dynamic Causal Modeling (DCM)



Hemodynamic
forward model:
neural activity→BOLD

Electromagnetic
forward model:
neural activity→EEG
MEG
LFP



Neural model:

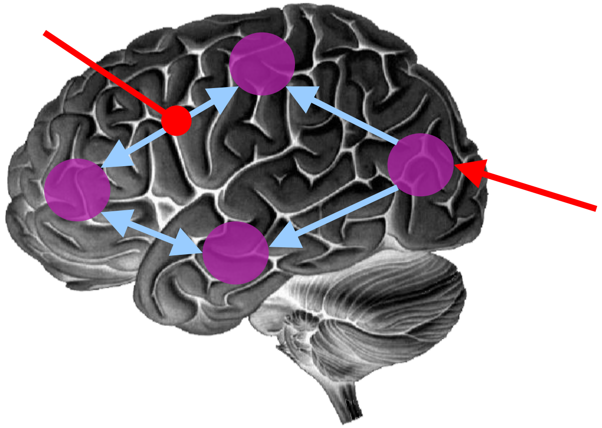
regional interactions →

neural activity:

$$y = g(x, \theta_y) + \varepsilon$$

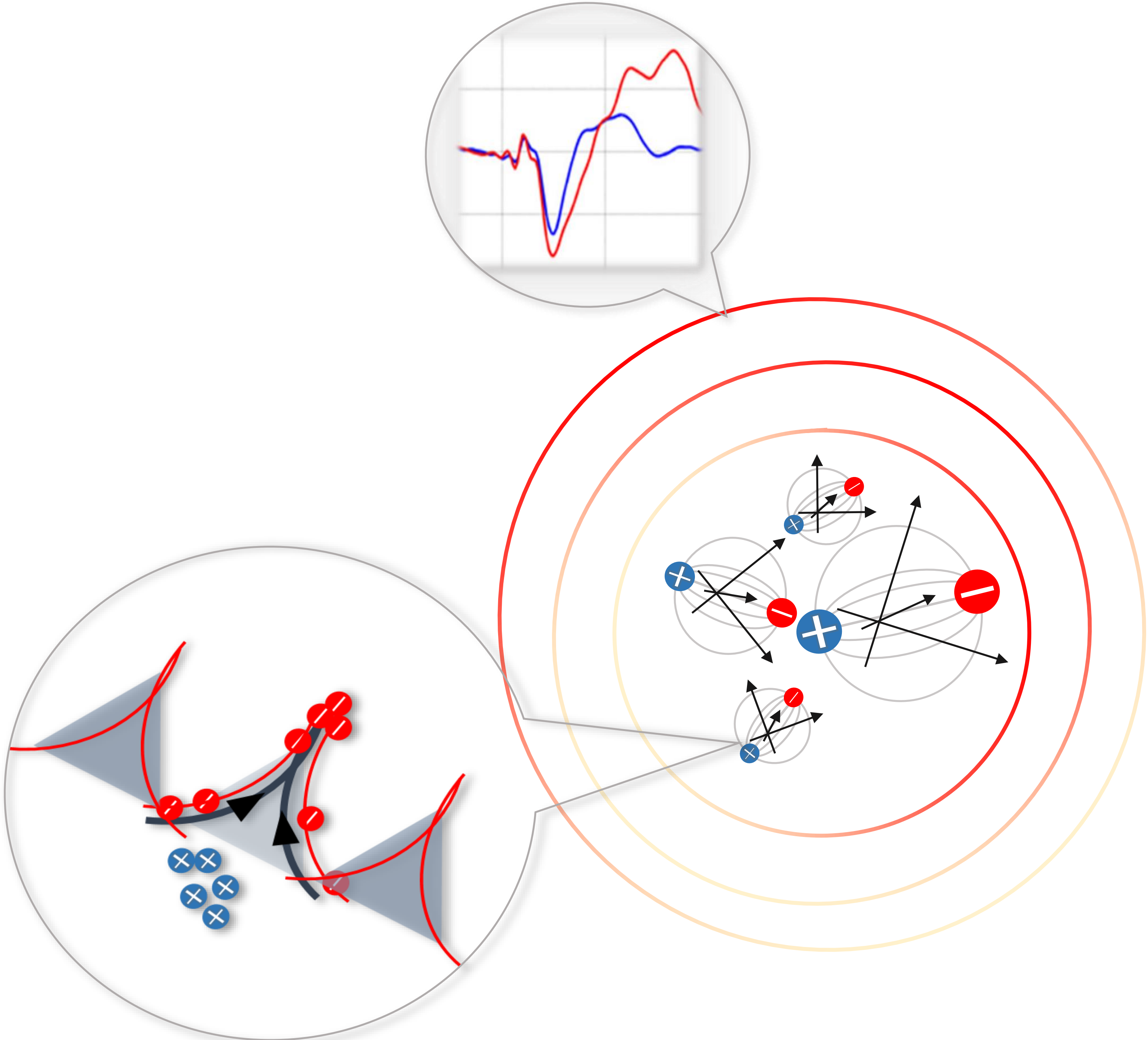
fMRI

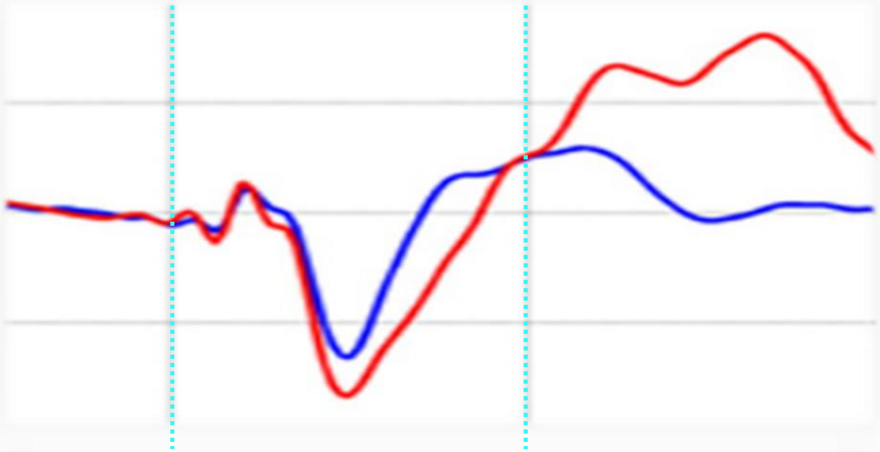
Previous talk



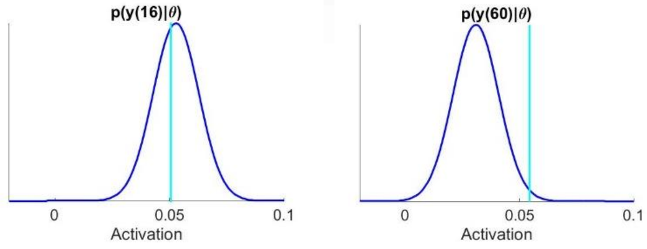
EEG/MEG

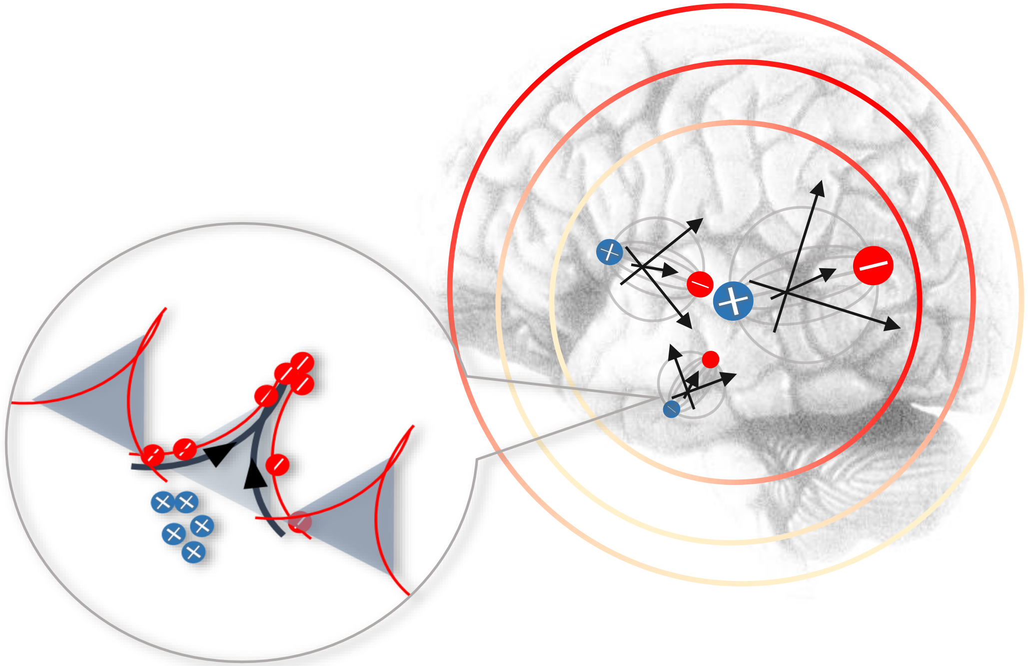
This talk





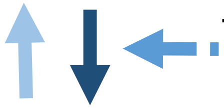
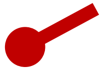
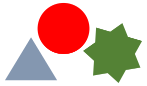
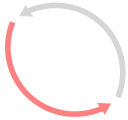
$$y = Lx + \varepsilon$$

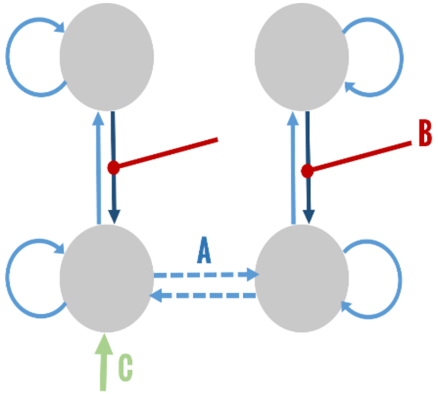


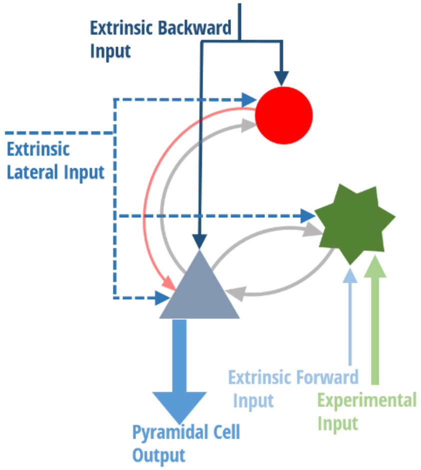


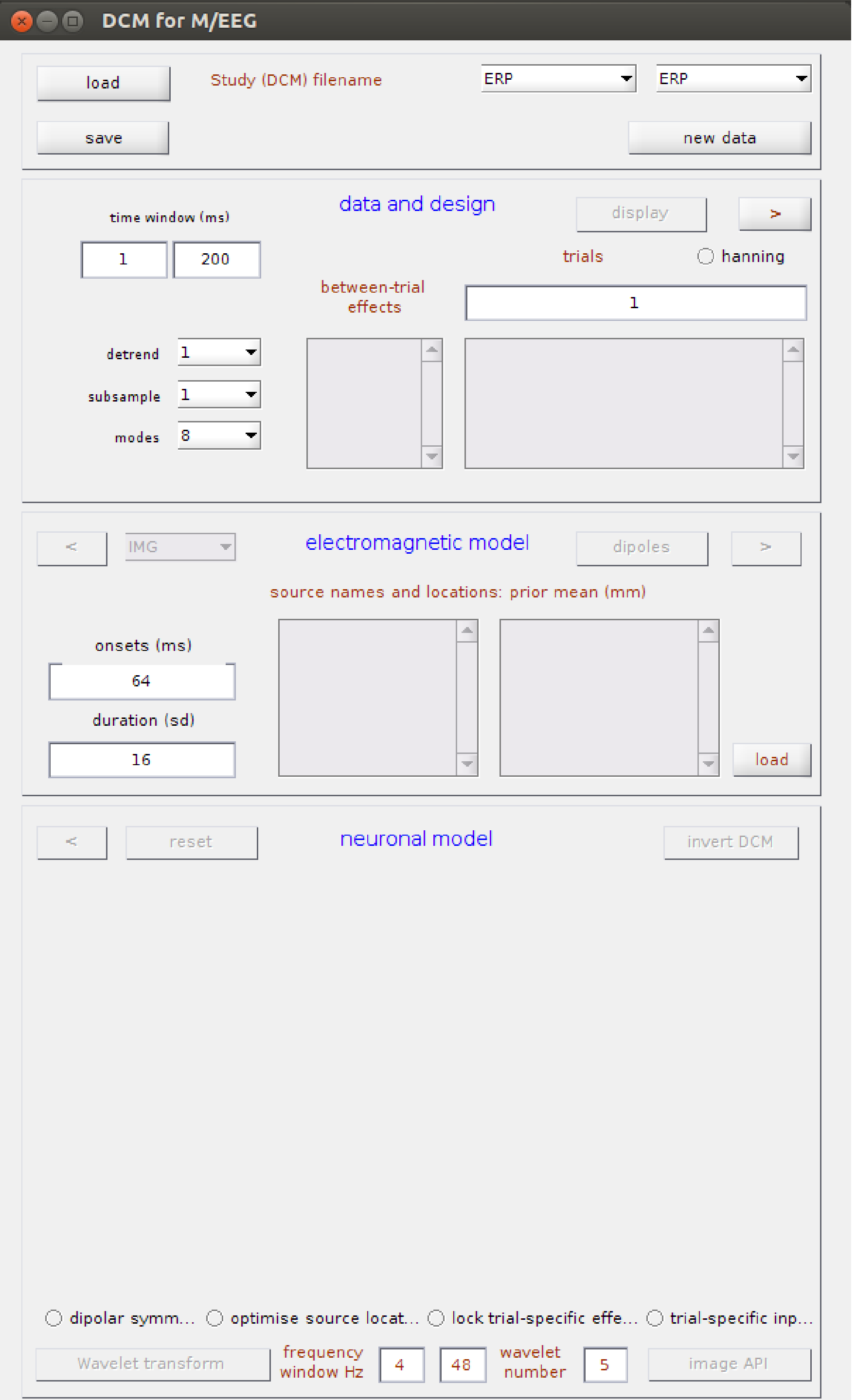
Forward Model

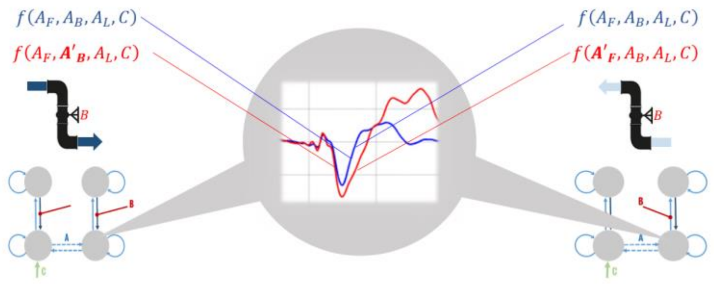
Reminder before SPM

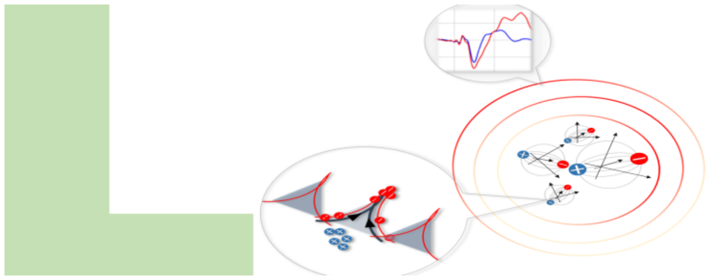
		SPM Variable
	Sources / Regions	X
	Three types of connections	A
	Between conditions effects	B
	Input	C
	Three types of cell populations	X
	Inhibitory / Excitatory effects on different populations	G







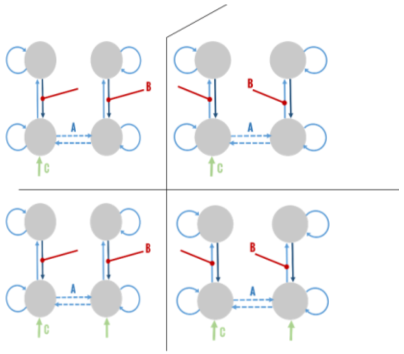




from

to

	lA1	rA1	lSTG	rSTG
lA1				
rA1				
lSTG				
rSTG				



Some weirdly unsorted appendix

Thank you

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University of Zurich[UZH]

ETH zürich

Translational Neuromodeling Unit