Virtual Connectome: Discovering the relationship between structural and functional connectivity during steady-states and transitions

15. June 2016 | Sandra Diaz Pier
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Agenda

- Introduction
  - The Virtual Connectome project
  - The Dynamic Mean Field Model
- Goals
- Current status of the project

Introduction

The Virtual Connectome project is a new collaboration between the Charité Universitätsmedizin Berlin, the Indiana University Network Science Institute and the Neuroscience SimLab, JSC, Forschungszentrum Jülich.

The main goal of the project is to understand the relationship between structural and functional connectivity in the human brain.
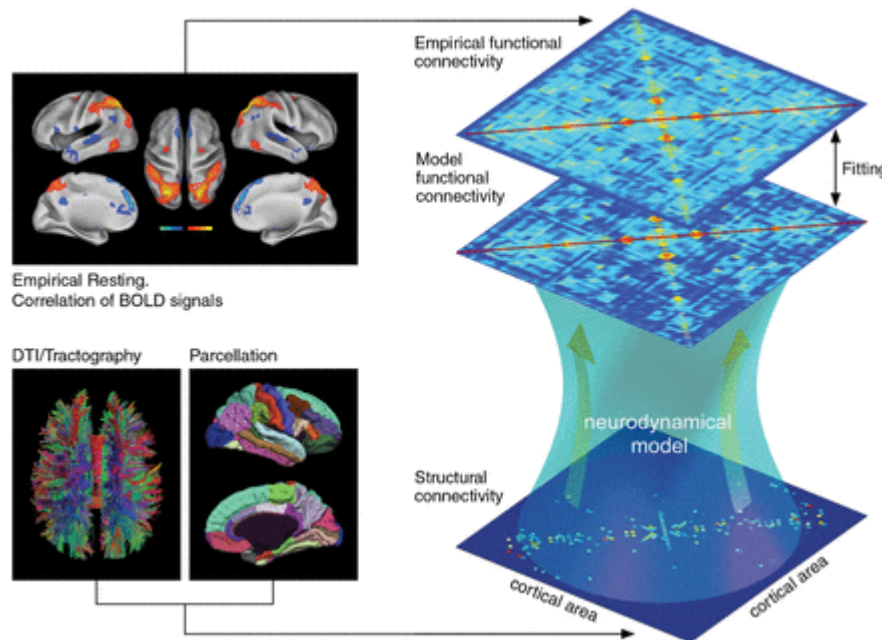
Experimental and simulated data of many subjects over long time spans will be analyzed and compared to identify the particular structural connectivity and brain model parameters which better predict the brain activity of the each individual.

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Introduction: The Virtual Brain Software
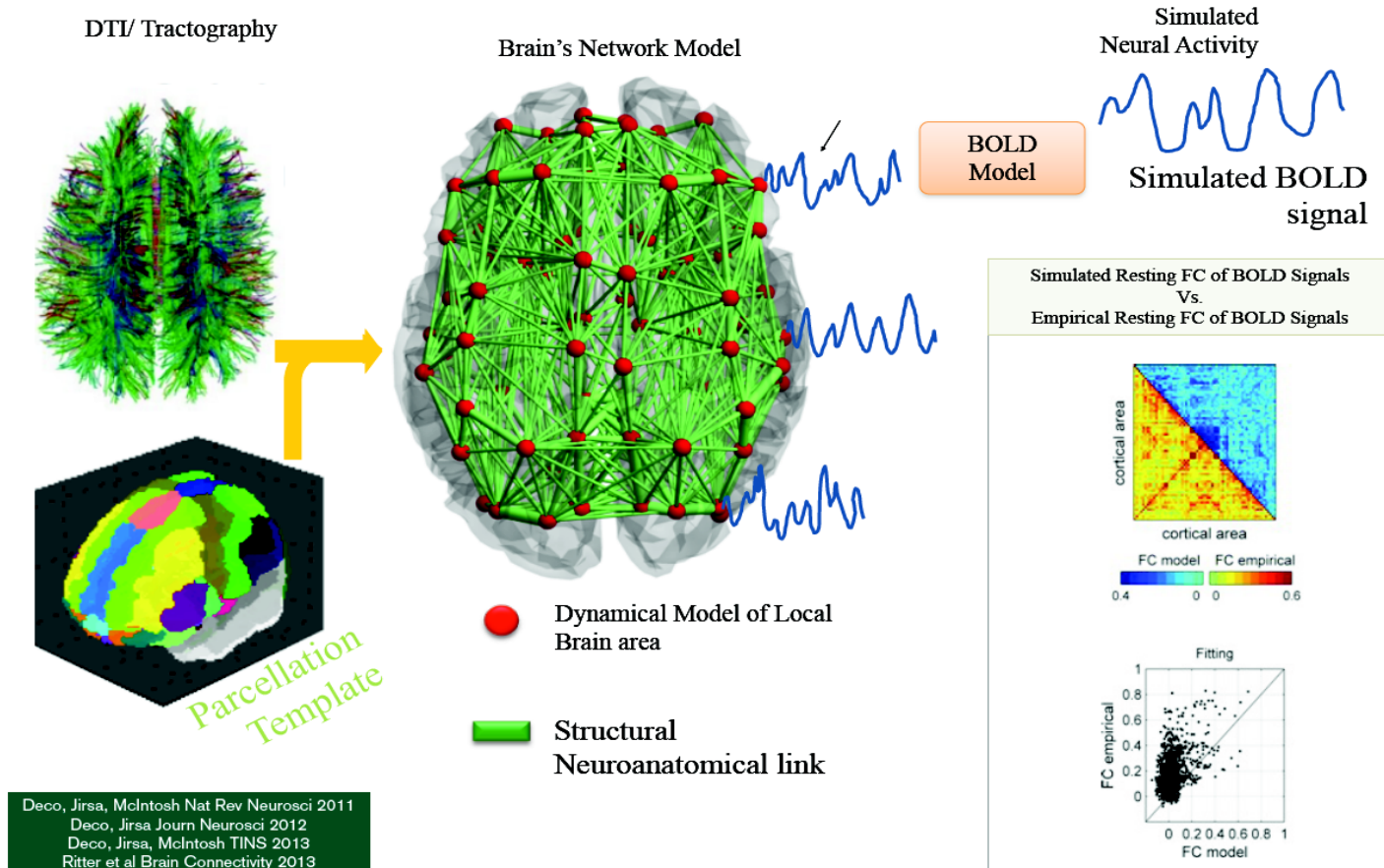
[Jirsa, 2014]

Introduction – Previous work

Empirical functional connectivity

Model functional connectivity

Fitting

neurodynamical model

Structural connectivity

cortical area

cortical area

Empirical Resting. Correlation of BOLD signals

DTI/Tractography   Parcellation

[Deco et al. 2013]

Linking anatomical connections and functional connectivity.

- Neuroanatomical connectivity by DTI Parcellation linking N cortical areas.

- A neurodynamical model coupled according to the connectivity matrix.

- Model fitting and validation comparing the model spatiotemporal patterns to the ones observed in empirical data.

Spiking Neuron populations can be modelled by a Dynamic Mean Field Model
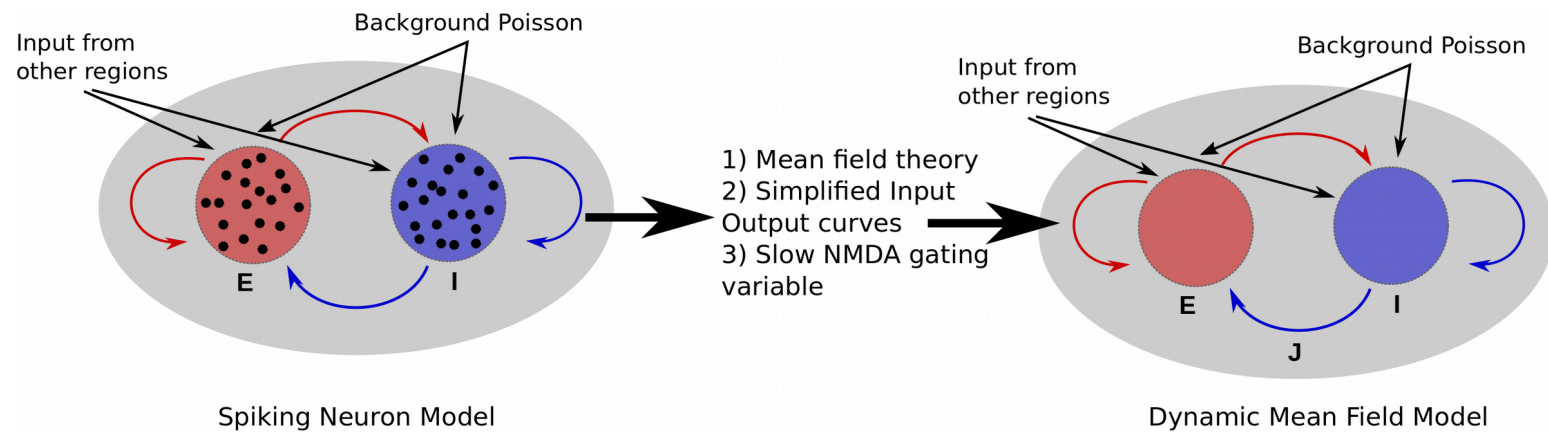
The spiking neurons model

The time evolution of the membrane potential of a given neuron i obeys the following differential equation:

$$C_m \frac{dV_i(t)}{dt} = -g_m(V_i(t) - V_L)$$

$$-g_{AMPA,ext}(V_i(t) - V_E)s^{AMPA,ext}(t)$$

$$-g_{AMPA,rec}(V_i(t) - V_E)\sum_{j=1}^{N_E} w_{ij}s_j^{AMPA,rec}(t),$$

$$-\frac{g_{NMDA}(V_i(t) - V_E)}{1 + \lambda_{NMDA}e^{-\beta V_i(t)}}\sum_{j=1}^{N_E} w_{ij}s_j^{NMDA}(t)$$

$$-g_{GABA}(V_i(t) - V_I)\sum_{j=1}^{N_I} w_{ij}s_j^{GABA}(t)$$

[Deco et al. 2013]

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The spiking neuron model

The gating variables s_j are the fractions of open channels of neurons and are given by the following:

$$\frac{ds_j^I(t)}{dt} = -\frac{s_j^I(t)}{\tau_I} + \sum_k \delta(t - t_j^k), \quad \text{for } I = \text{AMPA or GABA.}$$

$$\frac{ds_j^{NMDA}(t)}{dt} = -\frac{s_j^{NMDA}(t)}{\tau_{NMDA,decay}} + \alpha x_j^{NMDA}(t)(1 - s_j^{NMDA}(t))$$

$$\frac{dx_j^{NMDA}(t)}{dt} = -\frac{x_j^{NMDA}(t)}{\tau_{NMDA,rise}} + \sum_k \delta(t - t_j^k).$$

[Deco et al. 2013]

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A „Mean Field Theory" describes the population steady-state

The firing rate of each population is expressed as a function of The total synaptic input current. Here, a simplified Input-Output function from Abbott and Chance 2005 is used:

$$\phi(I_{\mathrm{syn}}) = \frac{c_{E,I}I_{\mathrm{syn}} - I_{E,I}}{1 - \exp[-g_{E,I}(c_{E,I}I_{\mathrm{syn}} - I_{E,I})]}.$$

The mean-field theory is a framework derived for steady states but does not describe temporal dynamics far from steady state. In this work it is assumed that the population firing rate follows the Wilson–Cowan type of equations leading to a reduced dynamic mean field model.

[Wong & Wang 2006]

Dynamic Mean Field Model

Reduced Dynamic Mean Field Model

$$I_i^{(E)} = W_E I_0 + w_+ J_{NMDA} S_i^{(E)} + G J_{NMDA} \sum_j C_{ij} S_j^{(E)} - J_i S_i^{(I)} + I_{external},$$

$$\tag{5}$$

$$I_i^{(I)} = W_I I_0 + J_{NMDA} S_i^{(E)} - S_i^{(I)} + \lambda G J_{NMDA} \sum_j C_{ij} S_j^{(E)}, \tag{6}$$

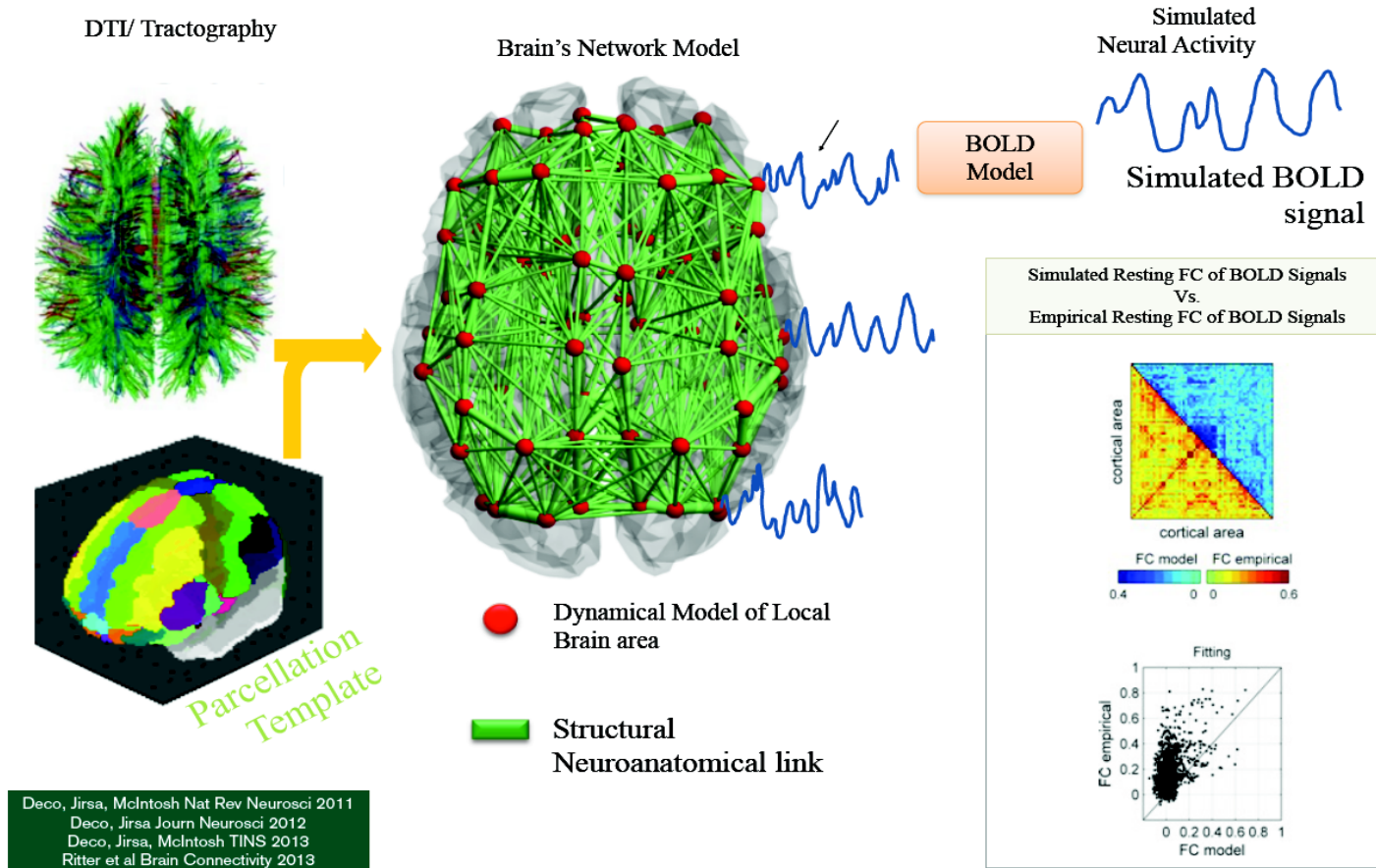$$r_i^{(E)} = H^{(E)}(I_i^{(E)}) = \frac{a_E I_i^{(E)} - b_E}{1 - \exp(-d_E(a_E I_i^{(E)} - b_E))}, \tag{7}$$

$$r_i^{(I)} = H^{(I)}(I_i^{(I)}) = \frac{a_I I_i^{(I)} - b_I}{1 - \exp(-d_I(a_I I_i^{(I)} - b_I))}, \tag{8}$$

$$\frac{dS_i^{(E)}(t)}{dt} = -\frac{S_i^{(E)}}{\tau_E} + (1 - S_i^{(E)})\gamma r_i^{(E)} + \sigma v_i(t), \tag{9}$$

$$\frac{dS_i^{(I)}(t)}{dt} = -\frac{S_i^{(I)}}{\tau_I} + r_i^{(I)} + \sigma v_i(t), \tag{10}$$

[Deco et al. 2014]

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The Virtual Brain is a mean field neural mass model used to predict experimental results

[Jirsa, 2014]

Goals

- To understand the capabilities of a Dynamic Mean Field Model of Neural Networks to model transitions between different dynamic states, and refine the model in order to better predict these states.

- To understand the role of the inner inhibition in this Dynamic Mean Field Model in order to obtain a simplified expression which depends on the strength of the inputs to a brain region.

But will these models need to be augmented with a different theory for transitions between steady-state behavior?

Structural and functional connectomics, and the dynamics of computational models across multiple time-scales, has been identified by the DFG as a point of emphasis. (Priority Programme SPP 2041)

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Current status of the project

- We are currently:

  - Doing simulations with structural plasticity to define the inner inhibition used in the model.

  - Simulating large sets of parameters to identify the simulated output which best matches the experimental data.

  - Defining suitable algorithms to do the parameter search.

  - Detecting the capabilities of the DMF to emulate transitions between different activity states.

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