NeuroField

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Abstract

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1. Introduction

Neural field modeling has proved to be a powerful technique for constructing relatively simple, physiologically based models of the brain that are capable of predicting EEG and correlate well with experimental data **??**. We have developed a neural field corticothalamic model of the brain (**????**) that we have previously used to investigate the alpha rhythm (**??**), age-related changes to the physiology of the brain (**?**), and evoked response potentials (**?**).

alter text, this is from analytic spindles

The key features of the model are captured by the three key equations governing general neural field theory

$$
\begin{aligned}
D_{ab}V_{ab}(\mathbf{r},t) &= \nu_{ab}\phi_{ab}(\mathbf{r},t),\\
Q_a(\mathbf{r},t) &= S_a\big[\sum_b V_{ab}(\mathbf{r},t)\big],\\
\mathcal{D}_{ab}\phi_{ab}(\mathbf{r},t) &= Q_b(\mathbf{r},t-\tau_{ab}).
\end{aligned}
$$

which represent synapto-dendritic smoothing, dendritic summation and firing response, and damped wave propagation, respectively. The differential operators

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are

$$D_\alpha(t) = \frac{1}{\alpha\beta}\frac{d^2}{dt^2} + \left(\frac{1}{\alpha} + \frac{1}{\beta}\right)\frac{d}{dt} + 1,$$
$$\mathcal{D}_a(\mathbf{r}, t) = \frac{1}{\gamma_a^2}\frac{\partial^2}{\partial t^2} + \frac{2}{\gamma_a}\frac{\partial}{\partial t} + 1 - r_a^2\nabla^2,$$

Several factors contribute to making neural field models difficult to implement. In particular, propagation delays between neural populations result in delay-differential equations that require special handling of temporal history in the implementation of the numerical integrator. Further, propagation of neural fields according to a damped wave equation adds two dimensions to the system, and requires a relative sophisticated finite-differencing scheme that takes into account the geometry of the system.

The most challenging part of applying neural field theory is the implementation of the numerical solver. We have developed NeuroField to provide a software package that solves the neural field equations for arbitrary neural populations, and contains library code for analysis and visualization. The software is designed to be easily extensible with basic C++ programming skills, making it simple to expand upon the basic model to include new phenomena.

2. Method and Results

2.1. Key features

As a general integrator for the neural field equations, Neurofield allows users to

- Specify an arbitrary number of populations and connections between populations;
- Specify the parameters for any part of the simulation, including populations, dendritic responses, firing responses, propagators, synapses, stimulus, and output.

NeuroField solves each part of the neural field model with an object:

$$\begin{aligned} P &= \nu_{ab}\phi_{ab}, && \texttt{Couple} \\ D_{ab}V_{ab} &= P, && \texttt{Dendrite} \\ Q_a &= S_a\Big[\sum_b V_{ab}\Big], && \texttt{QResponse/Pop} \\ \mathcal{D}_{ab}\phi_{ab} &= Q_b, && \texttt{Propag} \end{aligned}$$

The behavior of each of these objects encapsulates the details of the neural field equations.

2.1.1. Populations

A population contains a QResponse object, which defines how the population potential is mapped to firing rate. The QResponse may return the sigmoid of the voltage, as written above. Alternatively it could be an arbitrary function, such as a linearized version of the sigmoid. Effects like bursting can also be included.

Code snippets

2.1.2. Propagators

The neural field generated by a population propagates according to the associated Propagator. For populations where spatial propagation effects are insignificant, this propagator may simply be unity. The propagator object takes into account the spatial geometry of the problem, so can be applied to both 2D sheets and spherical geometries.

2.1.3. Couples

The coupling strength of a connection is typically constant, but can be an arbitrary function of a range of different factors, allowing modeling of a wide variety of plasticity effects including STDP and CaDP

2.2. Input and output

- Mention structure of config and output files

- Largely human readable, but relatively simple to construct and parse programatically

2.3. Helper scripts

NeuroField is packaged with several helper scripts written in MATLAB to assist with running, analyzing and visualizing models.

2.3.1. Reading output files

nf_read() allows users to parse the output file from NeuroField into a MATLAB struct object. nf_grid reshapes the output for handling matrices.

2.3.2. Writing config files

nf_eirs() demonstrates writing a configuration file, running it with nf_run(), and then reading it with nf_read(). This demonstrates a complete MATLAB-based toolchain for using NeuroField

2.3.3. Calculating power spectra

The power spectrum can be obtained by FFT, but correct normalization and calculation of the power spectrum including multiple spatial modes can be challenging to implement. We have implemented a 3D FFT algorithm that correctly normalizes the output and includes volume conduction effects that selective attenuate spatial modes depending on their wavenumber. The result can be directly compared to analytical predictions.

2.3.4. Visualizing output

The nf_extract() function makes it easy to select data for plotting from a NeuroField object. nf_movie can plot an animation of the output

3. Results

In this section, we present examples of NeuroField applied to recent research.

3.1. Corticothalamic model (Romesh)

- Sleep spindles
- Wake alpha peak
- Volume conduction

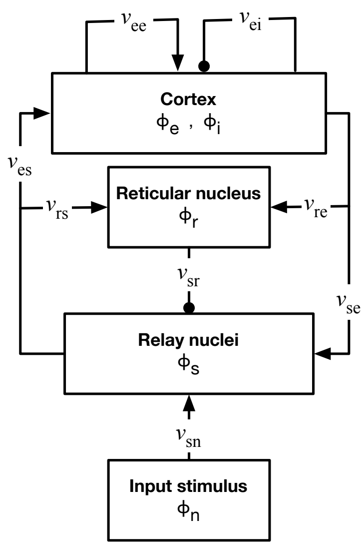

Figure 1: Wake EC, same params as already published

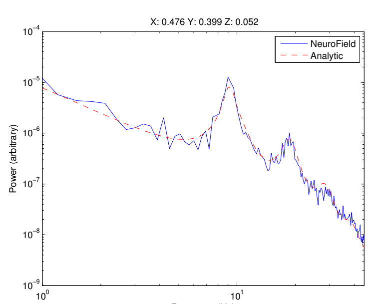

Figure 2: Wake EC, same params as already published

3.2. Plasticity (Felix)

3.3. Bursting (XL)

3.4. Seizures (XL, Romesh)

4. Discussion

We have developed NeuroField to provide an extensible, reliable framework for integrating nonlinear delay differential equations including spatial propagation. NeuroField is aimed for use by researchers who have constructed neural field models of the brain that require numerical integration. In this section, we review some usage and performance considerations.

4.1. White noise stimulus

- White noise requires stocastic DE integrator, effectively Euler
- Noise amplitude depends on grid resolution as this affects the possible bandwidth. Similar features depend on frequency domain power so noise needs to be normalized correctly

4.2. Performance

- Some numbers about the runtime and memory requirements of NeuroField
- Note that the memory requirements scale with the grid size, and the grid size depends on Lx and the propagator lengths (automatically enforced)
- Also that the delays in the system cause O(n) increases in memory usage

5. Acknowledgements

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6. References