A Neurocomputational Model Relating Brain Density to Neural Dynamics in Social Cognition

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What is the Relation of Network Density, Brain Activity & Social Cognition?

Neural activity features that are observed and likely necessary for social interaction likely include:

(1) Persistence activity
(2) Complex, multi-frequency activity
(3) Responsiveness
(4) The concurrent ability to change activity independently of the input (i.e. autonomy).

This study explores structurally based paths to such features using computational models. Two general types of structures are compared: ring and laminar neural networks. The first type of network is representative of small local clusters. The second type aims to capture dynamics in large laminar networks such as cortical layers. The study identifies similarities and differences in population activity for both architectures and considers the implications to neural theory and cognitive research.

Methods

Spatial Network Connectivity

The spatial, laminar, networks consisted of two-layers with inhibitory and excitatory populations of spiking units with columnar connectivity. Networks varied in size (up to 100,000 nodes) as well as in degrees and types of heterogeneity. Units were connected to their neighbors in the same layer as well as to the corresponding cells in the opposite layer.

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Activity Sweeps Due to Changes to Excitatory & Inhibitory Weighting in Ring Networks

The ring models used are recurrent networks composed of a layer of units connected in the form of a ring. Each unit feeds back onto itself and its adjacent neighbors. The activation value $\mathbf{z}$ is the sum of an input $\mathbf{x}$, a bias $\mathbf{b}$ multiplied by the respective weights ($\mathbf{w}_{ij}$, $\mathbf{w}_{i,i+1}$).

Mechanisms of Persistent Activity Propagation: Weights and Frequency

Changes in synaptic connectivity required in order for the spatiotemporal patterns of activity, including frequency changes in population activity and propagating waves, are thus autonomous of any external factors.

Complex Persistent Activity: Density & Autonomous Transitions

Activity Transitions with Changes in Excitatory & Inhibitory Weighting in Large Spatial Networks

As in the ring networks, laminar networks similarly showed changes in frequency as a function of connectivity strength.

Conclusions

- The differences in network dynamics in laminar vs. ring networks can be largely attributed to the two- and three-dimensional nature of propagation in the spatial laminar networks allowing for complex formations such as spiral waves.
- These models help interpret how synchronous and complex oscillations form in different types of neural structures.
- More interestingly, these simulations illustrate that the low-dimensional structure of a focus may be embedded in the activity it generates.
- Certain densities may be critical for maintaining persistent activity that is responsive to the environment and to others while remaining simultaneously self-propagating and autonomous.
- Given that density differs between brain regions, across phenotypes, and social species, we suggest that alterations in density may be an important developmental and evolutionary strategy for dynamical tuning of neural dynamics in social cognition.

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