Shaping connectivity and dynamics of neuronal networks with physical constraints

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Summary

Simulations of neuronal growth in 2D

We study local network properties in simulations of 2500 neurons growing in a disk of diameter 4 mm. The density of neurons is about 200 neurons/mm^2 which corresponds to that seen in experiments on primary cultures.

Figures on the right represent the average values of in-degree (k_in) and clustering coefficient (CC) in square regions of side 0.63 mm, containing ~80 neurons.

Simulations with 2D scaffolds

The box-like scaffold structure is modeled by a 4x4 array of cross shaped obstacles. Data for simulations of one, two and four scaffolds placed in center of the circle are presented.

In all three cases the in-degree (k_in) is reduced and the clustering coefficient (CC) is enhanced in the vicinity of the obstacles.

Distributions of in-degrees (left) and connection lengths (right).

Model

Network growth

Randomly position neurons on in a defined area. Obstacles are modeled as exclusion areas.

Dendritic trees are modeled as circular areas with radius (r_0) drawn from a normal distribution.

Axons grow at random angles and follow a biased random walk with T=1.1 mm, as in [4].

Neuron dynamics

A quadratic integrate and fire model with adaptation was used for the soma dynamics [4,5].

A generated spike is transmitted as a current and the synapse model includes depression [4].

\[ C_v = k(v - v_t)(v - v_r) - u + I + \eta \]

\[ \tau_u = b(v - v_r) - u \]

if \( v \geq v_r \), then \( v \rightarrow v_r, u \rightarrow u + d \)

where \( v, v_r, v_t \) are the soma membrane, resting & threshold potentials, \( u \) is an inhibitory current, \( I \) contains synaptic inputs and \( \eta \) is a noise term.

References


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Cultures on scaffolds

The structure of the culture substrate allows to guide neurite growth cones and neuronal connectivity pattern in vitro [1,2,3].

We employ 3D printed scaffolds within the Mesobrain project to stabilize fragile cultures and build 3D cultures mimicking cortical columns in vitro [mesobrain.eu]

Left: Bright field image of neurons growing on scaffold. Right: SEM image of two level box shaped scaffolds.

Neurons were grown on tower-like scaffolds.

Activity was measured using Ca-fluorescence and the functional network was inferred with GTE as in [6].

Dynamics on scaffolds: Triangles and Towers

An array (24x24) of triangles disposed in a circle favours connections at small angles.

Electronmicrograph of triangular scaffolds.

Neuron positions and axonal paths in simulations.

Neurons were grown on tower-like scaffolds.

Activity was measured using Ca-fluorescence and the functional network was inferred with GTE as in [6].

Neuron index

Initiation point density

Distributions of lengths versus angles for sim.

Distribution of connection lengths.

Image of neurons growing on scaffold.

Inferred functional network.