A Framework for In-Silico Neuro-Electronic Interface Design

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The physical interface between neurons and engineered substrates influences neural network formation, yet the quantitative relationship between surface geometry and emergent network behavior remains poorly characterized. This gap limits the rational design of substrates for neuromorphic devices, where reproducible and predictable neural integration is essential [1].

With images from primary cortical neurons cultured on varied substrates comprising standard MEAs and multiple micro- and nanostructured geometries, we characterize each condition through two complementary modalities: fluorescence microscopy with MAP2 immunostaining and multi-electrode array (MEA) electrophysiology. A reproducible computer vision pipeline performs automated MAP2 segmentation of dense cultures, extracting neurite density and alignment distributions per substrate condition [2]. Preliminary results show that substrate geometry reproducibly modulates neurite alignment and density, consistent with topography-driven contact guidance reported for silicon micropillar arrays [3, 4]. MEA recordings provide complementary measures of firing rate and burst statistics across the same conditions, though systematic structure-function correlation is ongoing.

Extracted morphological and electrophysiological features populate a statistical model that maps substrate parameters to network-level outcomes. This model quantifies substrate effects in an interpretable, reproducible form and provides a low-cost surrogate environment for computational exploration. Building on frameworks that link physical cues to neural responses [5, 6] and on recent work coupling structural features to network function [7], we are developing a reinforcement learning agent that navigates the substrate parameter space to identify configurations predicted to produce target morphological or functional network states.

The proposed framework connects experimental neuroscience, bioelectronics, and data-driven optimization within a single pipeline. Near-term goals include systematic morpho-functional correlation across all substrate conditions and validation of model predictions against held-out experimental data. In the longer term, the approach aims to reduce the empirical cost of interface optimization and to contribute a principled design tool for neuromorphic and therapeutic device contexts [8, 9].

References

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