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# Massively parallel simulations of neurovascular coupling with extracellular diffusion

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**Abstract**

A numerical neurovascular coupling (NVC) model containing a vascular H-tree coupled with multiple neurovascular units (NVUs) comprising a cerebral tissue slice is extended via extracellular potassium diffusion, allowing for direct communication between adjacent NVUs. The model simulates NVC on the macro scale in a parallel environment using high performance computing. A localised neuronal stimulation results in vasodilation with a decreasing gradient in vessel radius from the stimulated to non-stimulated area. The dilation remains sufficiently spatially localised over larger time scales. During vasomotion, there is emergent behaviour in the form of waves of increased vessel radius moving towards the stimulated area.

*Keywords:* neurovascular coupling, parallel computing, computational biology, neurovascular unit, extracellular space

## 1. Introduction

The cerebral cortex contains a multitude of blood vessels that regulate blood supply in response to local changes in a process known as functional hyperaemia. This process is characterised by an increase in neuronal activity followed by a rapid dilation of local blood vessels and hence increased blood supply providing oxygen and glucose necessary for cellular function. Impaired functional hyperaemia resulting in reduced blood supply to brain tissue is associated with several pathological conditions such as Alzheimer's disease, atherosclerosis, stroke, hypertension [12], and in particular cortical spreading depression (CSD) where waves of neuronal depolarisation and high potassium ($K^+$) concentration spread slowly throughout the extracellular space (ECS) of the cortex [2, 28].

Functional hyperaemia is controlled through the process of neurovascular coupling (NVC), which involves an intercellular communication system based on ion exchange through pumps and channels between neurons, astrocytes (glial cells), and vascular cells [8, 14, 16]. Together these communicating cells comprise a neurovascular unit (NVU). Neuronal activity in an NVU is followed by an increase in synaptic $K^+$ concentration leading to an influx of $K^+$ into the astrocyte and consequent efflux into the PVS [1]. The rise in perivascular $K^+$ concentration leads to a further influx of $K^+$ through the inwardly rectifying $K^+$ (KIR) channel from

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