Multiscale Modelling of Biological Systems: A Computational Approach to Studying Natural Phenomena from Cellular to Ecological Levels

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Abstract

The study of natural phenomena gives rich opportunities for those interested in modelling and simulations. The challenge they present lies in the complexity, dynamic nature, and sheer variety of patterns such as wildfires or plant growth. These processes, ranging from the cellular mechanisms that dictate the growth and function of living organisms to the environmental or ecological dynamics that shape our environment manifest unique behaviours and patterns that challenge our understanding and push the boundaries of traditional scientific disciplines.

This thesis shows the development and validation of several computational models that simulate complex biological processes across various scales. The goal of this dissertation is first to demonstrate that computational models can accurately replicate and predict complex biological systems across different scales; second to illustrate the necessity of diverse modelling approaches to address distinct biological phenomena; and third, to illustrate that mathematical models can be utilized to validate or challenge existing biological theories and identify areas requiring further investigation.

I present three models of specific natural phenomena validated against empirical data. These include a discrete model for vascular pattern formation in Arabidopsis thaliana, a continuous model of long-distance signalling in birch trees, and an advanced hybrid simulation of wildfires. The results supported the assumptions posed, Additionally, they allowed us to assess the applicability of modelling paradigms used in different scenarios. The findings underscore the crucial role of interdisciplinary approaches in advancing our knowledge.