Theory and Applications of Dynamical Systems in Biology
Théorie et applications des systèmes dynamiques en biologie
(Org: **Afroditi Talidou** (University of Calgary))

MUHAMMAD AHMAD, McGill University
What I_h does to a primate stress neuron

Parvocellular neurons of the paraventricular nucleus sit at the top of the hypothalamic–pituitary–adrenal axis, which is a feedback loop rather than a chain, so the gain of its first step matters. Our collaborators' recordings show a far more prominent voltage sag in marmoset parvocellular neurons than in mouse; in marmoset, blocking the hyperpolarisation-activated cyclic nucleotide-gated (HCN) current removes it.

We ask what that current does in a conductance-based model of one marmoset neuron, fitted to recordings from the same cell with and without HCN block.

In the fitted cell the current makes the membrane band-pass, and removing it abolishes the peak and raises the steady-state impedance, in the model and in the recording. The same removal turns a train of synaptic inputs that stays subthreshold into one that fires. Spike onset, however, is a saddle-node on an invariant circle with and without the current, so the cell is Class I in both conditions; the change is subthreshold.

Receptor antagonists for this axis that showed promise in rodents failed to separate from placebo in human trials and were abandoned as a class; species differences in ion channel complement are one suspected reason. A model fitted to the primate cell makes one such difference quantitative. Extending the same question to the population is the next step.

CHRISTINA ATHANASOULI, Williams College
Modeling Individual Variability in Developmental Sleep Transitions

Sleep patterns undergo substantial changes during early childhood, as many children transition from a daily nap and nighttime sleep to a single consolidated nocturnal sleep episode. This transition occurs gradually across development, with considerable individual variability in its timing and characteristics. In this talk, we present a neurophysiologically based mathematical model of the sleep-wake network that incorporates interactions between arousal circuitry and circadian and homeostatic processes. Using longitudinal and cross-sectional sleep data from preschool-aged children, we calibrate the model to reproduce representative sleep patterns of habitual nappers and children who have transitioned to consolidated nighttime sleep. We then investigate how changes in key model parameters drive the transition from biphasic to monophasic sleep. Combining bifurcation analysis with numerical simulations, we identify different pathways through which naps may disappear, including abrupt and gradual transitions. Our results provide insight into the dynamical mechanisms underlying individual differences in nap cessation and suggest how external influences, such as light exposure and sleep schedules, may affect the timing and stability of these developmental transitions.

MAURICE CHACRON, McGill University
Stimulus Complexity Shapes the Optimal Balance of Cortical Excitation and Inhibition

How cortical networks process sensory inputs encountered in everyday life remains poorly understood. Recent experiments in vestibular cortex reveal marked differences between neuronal responses to natural self-motion and simple artificial stimuli, raising the question of which circuit mechanisms support these distinct coding regimes. In this talk, I will present spiking-network simulations and linear-response analyses that link stimulus complexity, recurrent inhibition, and population information transmission. We compare responses to periodic and natural stimuli while controlling neuronal firing rates and systematically varying excitation and inhibition. For natural stimulation, reconstruction-based information estimates are greatest near excitatory–inhibitory balance, where neurons exhibit diverse temporal response profiles. For periodic stimulation, the information optimum shifts toward excitation-dominated conditions. In reduced models, increasing inhibitory strength can improve information transmission for natural inputs while impairing it for periodic inputs. Approximations help provide a mechanistic

explanation for the association between balance and response diversity: when excitatory and inhibitory contributions nearly cancel, small changes in their relative strength can produce large changes in the neural response shape. This local sensitivity peaks near balance. Together, these results suggest that stimulus-dependent recruitment of recurrent inhibition can reconcile distinct cortical responses to artificial and natural sensory inputs. Rather than requiring a single optimal coding regime, cortical networks may optimize information transmission by tuning the balance of excitation and inhibition depending on stimulus complexity.

WEN CHUNG, Toronto Metropolitan University

Beyond pure chance: explaining cytomegalovirus infection outcomes using a cytokine response model

Cytomegalovirus (CMV) is one of the most ubiquitous herpesviruses, usually causing asymptomatic or mild primary infections in immunocompetent individuals as it establishes latency in the host. However, in neonatal infants, primary infections originating from contact with individuals shedding CMV can have more serious consequences and are particularly dangerous for pre-term infants. Observational studies have found that the majority of CMV infections in neonatal infants tend to be transient infections, where latency is not established in the host. Previous mathematical modelling efforts have claimed this to be a stochastic effect. Using a deterministic differential equation model of CMV infection in the salivary glands and virtual populations, this presentation will show that a significant fraction of these transient infections, as well as the increased vulnerability of pre-term infants to CMV infection, may be explained by the action of cytokines such as interferon and age-related differences in their effectiveness and production rates.

NICOLAS DOYON, Laval University

Modelling rTMS, how electric field can cure you

Electric stimulation, either through transcranial direct current stimulation (tDCS) or repetitive transcranial magnetic stimulation (rTMS), is gaining increasing attention as an alternative or complementary therapeutic approach to pharmacological treatments. Healthcare practitioners must choose among a large number of possible stimulation protocols, each specifying parameters such as stimulation intensity and location.

Mathematical simulations can help guide this choice by relating stimulation protocols to the resulting electric field distributions across different brain regions. These simulations rely on the finite element method (FEM) to solve partial differential equations and are often performed using software such as SimNIBS.

In this presentation, we first discuss the inherent mathematical challenges involved in electric field simulations and the numerical methods used to perform them. We examine potential sources of numerical error, including the complexity of brain geometry and uncertainties in model inputs, such as skull thickness. We show that, although these sources of error can lead to substantial uncertainty in the estimated electric field magnitudes, they have a more limited impact on the relative ranking of the most strongly stimulated brain regions.

We then combine electric field values extracted from simulations in different regions of interest with findings from published meta-analyses to investigate how stimulation patterns across brain regions relate to treatment efficacy, focusing on applications in tinnitus and addiction treatment.

ANDRÉ RICKES, University of Calgary

How weak competition can affect the persistence of species in a Lotka-Volterra reaction-diffusion system

Lotka-Volterra systems describing two species competing for resources in heterogeneous environments have been widely studied in the context of random diffusion. One of the most striking results states that, when two species undergoing random diffusion are identical in all parameters except for their diffusion rates, the slower diffuser wins the competition. However, the introduction of directed dispersal into reaction-diffusion models can drastically change this outcome. In particular, there exist dispersal strategies, known as evolutionarily stable strategies, that allow a species adopting them to resist invasion by competing species following any other dispersal profile. In this presentation, I explore how species adopting an evolutionarily stable dispersal strategy can still be driven to extinction when interspecific competition is weaker than, but close to, intraspecific competition.

TURNER SILVERTHORNE, University of Toronto
Of Mice and Monodromy: Bifurcation analysis of the circadian-reward system

Humans have tried to predict the behaviour of living systems for at least as long as quadrupedal predators have had sharp teeth. Many aspects of behaviour arise from rhythmic neural activity. Though individual rhythms are highly predictable, their interactions can produce remarkably complex behaviours. Disruptions to these rhythms are widely associated with disease, yet we lack a clear understanding of how changes in their interactions translate into altered behaviour.

Here, we approach this problem through bifurcation theory, asking what can be learned about the dynamics while making minimal assumptions about the interacting system. Taking circadian regulation of the dopamine system as an example, we investigate the generic mechanisms by which stable limit cycles lose stability and give rise to more complex dynamics. We then translate these bifurcations into constraints on Fourier coefficients in harmonic regression, providing a statistical framework for translating between aberrations in observed behaviour and underlying neural regulation.

MARIA SISKAKI, University of California, Los Angeles
Dynamical Systems from Day One: Reimagining the First University Math Course for Life Science Majors

Modern biology requires foundational quantitative competencies such as modeling nonlinear feedback mechanisms, analyzing point and limit cycle attractors, classifying stability, and interpreting bifurcations. However, standard undergraduate curricula channel students through the calculus sequence, which is a pathway that emphasizes analytical techniques at the expense of dynamical systems modeling. Consequently, calculus is increasingly scrutinized as the default math prerequisite for biological sciences. In this talk, I present UCLA's alternative approach: an introductory course on dynamical systems targeting first-year students, without requiring the standard calculus pipeline. This course is aligned with national reports on quantitative biology education, and provides an immediate, relevant foundation in dynamical systems techniques starting from the students' very first term in college.

AFRODITI TALIDOU, University of Calgary
Stability of traveling waves in a geometric extension of the FitzHugh-Nagumo equations

The FitzHugh-Nagumo equations provide a mathematical model for the propagation of electrical signals along neuronal axons. While the stability of traveling wave solutions has been extensively studied in one dimension, considerably less is known in higher-dimensional settings. In this talk, I will present an extension of the FitzHugh-Nagumo equations to cylindrical surfaces with constant and variable radii. The latter geometry provides a more realistic representation of neuronal axon morphology. I will discuss how surface geometry enters the equations, examine conditions for the nonlinear stability of traveling fronts, and illustrate the effects of geometric variations through numerical simulations.