SOUTH AFRICAN COUNCIL FOR AUTOMATION AND CONTROL

NITheCS
National Institute for Theoretical and Computational Sciences

GUEST LECTURE

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Mustafa Khammash is Professor of Control Theory and Systems Biology at ETH Zurich's Department of Biosystems Science and Engineering. Trained as an electrical engineer (B.S., Texas A&M; Ph.D., Rice University), he began his academic career at Iowa State University and later served as Director of the Center for Control, Dynamical Systems, and Computation at UC Santa Barbara before moving to ETH Zurich in 2011, where he has served as Vice Chair and Head of Department. His research bridges control theory, systems biology, and synthetic biology, establishing the theoretical and experimental foundations of cybergenetic control—the real-time feedback regulation of living cells. He is a Fellow of the IEEE, IFAC, JSPS, and the Asia-Pacific AI Association, an IFAC Distinguished Lecturer, and the recipient of three prestigious Advanced Grants—two from the European Research Council (ERC) and one from the Swiss National Science Foundation (SNSF). His work on robust control, stochastic modeling, and synthetic feedback is shaping the future of adaptive cell-based therapies.

Opto-Cybergenetics for Bioreactor Optimization: Feedback Control of Cellular Function with Light

Abstract: Living cells are dynamic, adaptive systems — rich in feedback, noise, and nonlinear behavior. Opto-cybergenetics is an emerging discipline that merges control theory, synthetic biology, and optogenetics to bring such systems under real-time feedback control. By coupling cells to computers through light-based signaling, we can now measure and modulate gene expression dynamically, enabling precise and optimal control of biological processes. In this talk, I will present recent advances in closed-loop optogenetic control for biotechnology. In one example, feedback regulation of the unfolded protein response in yeast maintained gene expression at near-optimal levels, resulting in increased protein yields. In another, dynamic cybergenetic control was used to stabilize and reprogram the composition of bacterial co-cultures in real time. Finally, I will outline how these ideas extend toward fully autonomous genetic control systems, where engineered circuits within cells perform their own regulation. Together, these developments illustrate how opto-cybergenetics is transforming biotechnology into a truly cyber-physical discipline — one where light, computation, and living matter are seamlessly integrated through feedback.

Date	Time	Venue	More Information
03 February 2025	6:00 pm - 7:00 pm	University of Pretoria	Click Here

The Mathematics of Life's Robustness: Internal Models and Perfect Adaptation in Biological Control

Abstract: Biological systems achieve remarkable robustness: cells maintain homeostasis and adapt precisely to environmental changes despite stochasticity, delays, and parametric uncertainty. How do they accomplish this, and how can we replicate such capabilities in synthetic systems? In this lecture, I will present a theoretical framework for robust perfect adaptation (RPA) in biomolecular networks, revealing deep structural parallels between biological regulation and classical control theory. I will introduce a universal internal model principle (IMP) for living systems, showing how integral feedback and its generalizations emerge naturally as the only architectures capable of achieving kinetics-independent robust perfect adaptation. Using a linear-algebraic characterization of network stoichiometry, I will identify the necessary and sufficient structural conditions for maximal adaptation in both deterministic and stochastic settings. Beyond theory, I will discuss synthetic implementations of these principles in living cells, where engineered integral feedback controllers achieve robust regulation of protein expression and growth. Together, these results demonstrate that the logic of control—long the foundation of engineered systems—is also the mathematics of life's stability, offering a blueprint for designing adaptive, intelligent biological systems.

Date	Time	Venue	More Information
04 February 2025	6:00 pm - 7:00 pm	Stellenbosch University	Click Here

Cybergenetics: From Theory to Therapy

Abstract: The ability to program living cells with designed feedback circuits is transforming biotechnology and medicine. Cybergenetics unites control theory and synthetic biology to endow cells with regulatory functions once limited to engineered systems. In this lecture, I will describe how theoretical insights into feedback and adaptation are being translated into the design and realization of genetic control circuits that operate reliably within the noisy, nonlinear environment of living cells. I will present examples of synthetic feedback architectures implemented in both bacterial and mammalian systems, where precise regulation of gene expression enables new levels of performance in cellular homeostasis. Finally, I will discuss how these same principles are being applied to create therapeutic cells capable of autonomously sensing disease cues and restoring physiological balance. Together, these advances chart a path from the mathematics of feedback to the engineering of adaptive, intelligent cell-based therapies.

Date	Time	Venue	More Information
05 February 2025	1:00 pm - 2:00 pm	University of Cape Town	Click Here