Wikno, 16th–20th September 2025

THE MATHEMATICAL HALLMARKS OF CANCER: YESTERDAY, TODAY, AND TOMORROW

Nikolaos Sfakianakis

University of St. Andrews, Scotland

ABSTRACT

Cancer, a complex and multifaceted disease, is characterised by distinct biological capabilities often referred to as the Hallmarks of Cancer. These include sustaining proliferative signalling, evading growth suppressors, resisting cell death, enabling replicative immortality, inducing angiogenesis, activating invasion and metastasis, and, more recently, avoiding immune destruction, deregulating cellular energetics, and promoting genome instability.

Over the past five decades, Mathematical Oncology has focused on studying these hallmarks through various qualitative and quantitative approaches. Such models aim to capture the dynamics of tumour growth, metastasis, and potential treatment and have direct impact on our understanding of cancer biology and medical interventions.

In this talk, we will review the most important developments in the mathematical analysis of the Hallmarks of Cancer, from their initial conceptualisation to their applications in biology and medicine today. We will compare a range of modelling strategies and show how the incorporation of biological data helps to shed light on the interaction between tumour cells and their microenvironment. We will place particular attention on aspects of tumour growth, invasion, metastasis, therapeutic response, and drug resistance development.

We will also consider the challenges and opportunities in applying mathematical models to diverse cancer types and treatment contexts. These include addressing infection-related malignancies, exploring how disease progression and treatment efficacy vary under different clinical and environmental conditions, and highlighting the importance of robust data collection and computational tools. By emphasising context-specific approaches and studies, we will show the value of mathematical models in informing both policy decisions and patient care.

We will conclude by discussing avenues for future research, such as new modelling paradigms, the integration of artificial intelligence and virtual reality technologies, and the challenges of translating mathematical insights into clinical applications. Our aim is to illustrate both the progress made and the open questions that remain at the frontier of Mathematical Oncology, ultimately shedding light on how these advancements might lead to enhanced patient care and personalised medicine.