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# **APPLICATIONS OF MATHEMATICS IN BIOLOGY AND MEDICINE**

Wikno, 16–20 September 2025

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# Table of Contents

## Part I: Invited speakers

Yaroslav Bihun, Oleh Ukrainets: <b>Modelling of immune response with ecological factor</b> .....	7
Bruno Buonomo: <b>Incorporating behavioral feedback via information index into epidemic integral models</b> .....	9
Matteo Italia: <b>Mathematical modeling of malignant gliomas: treatment dynamics and in silico trials</b> .....	10
Andrzej Jankowski, Andrzej Skowron, Piotr Artiemjew, Diana Domańska, Soma Dutta, Ewelina Żarłok, Mateusz Dąbkowski, Dominik Wawrzuta: <b>The Changing Role of Mathematics in Medicine and Biology in the 21st Century: An Oncology Perspective</b> .....	11
Eugene Kashdan: <b>Reconstruction and modular response analysis of intracellular transcriptional networks</b> .....	13
Yuri Kogan: <b>A population model for the response of patients with advanced melanoma to the treatment by immune checkpoint inhibitors, based on the real-world data</b> .....	14
Yuri Kogan and Zvia Agur: <b>Death of Patients with COVID-19 and the Role of Mathematical Models in deciphering its cause</b> .....	15
Karolína Korvasová : <b>Interpreting High-Frequency Oscillations in the Brain: Mechanisms and Meanings</b> .....	16
Dawid Larysz: <b>Application of Advanced Technologies in Preoperative Planning of Paediatric Neurosurgical and Craniofacial Procedures</b> .....	17
Krzysztof Puszyński: <b>Mathematical modeling and simulation – from a single cell to the human population</b> .....	18
Pascoal Martins da Silva: <b>Mathematical insights into the dynamics of Acute and Chronic Bacterial Infections</b> .....	19
Nikolaos Sfakianakis: <b>The Mathematical Hallmarks of Cancer: Yesterday, Today, and Tomorrow</b> .....	20

## Part II: Contributed talks

Francesco Albanese, Marcello Edoardo Delitala, Giulia Chiari: <b>A Multicompartment Phenotype-Structured Model of Tumor Response to Hypoxia and Radiotherapy</b> .....	23
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Krzysztof Bartoszek, Bayu Brahmantio, Joao Victor Muñoz-Durán, Jesualdo Fuentes-González, Jason Pienaar, P. David Polly: <b>Short branch singularities in phylogenetic comparative methods</b> .....	26
Agnieszka Bartłomiejczyk: <b>Existence of wave solutions of a glioma model in a porous medium</b> .....	24
Piotr Bartłomiejczyk: <b>Why do computers like Lorenz maps?</b> .....	25
Marek Bodnar, María Vela-Pérez, Aleksandra Tryniecka-Maciążek: <b>Analyzing the impact of proliferation and treatment parameters on low-grade glioma growth using mathematical models</b> .....	28
Marcin Choiński: <b>A continuous-time <i>SIS</i> criss-cross model of co-infection in a heterogeneous population</b> .....	29
Urszula Foryś: <b>2024–2025: several anniversaries important to me</b> .....	31
Krzysztof Fujarewicz: <b>Creation of spots on melting snow — a simple mathematical model</b> .....	33
Beata Jackowska-Zduniak: <b>Dynamics of Age-Related Degradation in the Human Cardiac Conduction System: A Cellular Automata Approach</b> .....	34
Olga Karelkina: <b>Integer programming framework for RNA secondary structure prediction</b> .....	36
Mikhail Kolev: <b>A mathematical model of the interactions between immune system and infectious agents</b> .....	38
Alicja B. Kubik, Benjamin Ivorra, Alain Rapaport, Ángel M. Ramos: <b>Identifiability and observability of some epidemiological systems: SIR vs. SIRS</b> ....	39
Michael Kuhn, Dominika Machowska, Andrzej Nowakowski, Agnieszka Wiszniewska-Matyszekiel, Stefan Wrzaczek: <b>Hospital competition with age-structured patients and congestion effects: a differential game approach</b> ...	40
Vikas Kumar, Agnieszka Wiszniewska-Matyszekiel: <b>How not to trim the branch you are sitting on: two models of a myopic marine economy with a realistic fish dynamics</b> .....	41
Mirosław Lachowicz: <b>Biomathematics — user guide</b> .....	42
Krzysztof Łakomiec, Krzysztof Fujarewicz: <b>Sensitivity analysis of the p53 signaling pathway model</b> .....	43
Anna Marciniak-Czochra: <b>Mechanochemical patterning: a new strain–morphogen PDE modeling framework</b> .....	45
Bartłomiej Morawski, Urszula Foryś: <b>Perceptual binary decision-making model with time delay and Hill function</b> .....	46

Andrzej Nowakowski, Anita Krawczyk: <b>Prediction of Alzheimer's disease using Neural CDE and Optimal Control Tools</b> .....	47
Emanuela Penitente, Bruno Buonomo: <b>Modelling behavioural changes and vaccination in the transmission of respiratory viruses with co-infection</b> ...	48
Zbigniew Peradzyński: <b>On instability of prey-predator system</b> .....	50
Krzysztof Psiuk-Maksymowicz: <b>Mathematical modeling of the corrosion process of biodegradable magnesium alloy implants</b> .....	51
Alesandra Puchalska: <b>Pangraphs as models of higher-order interactions</b> ....	52
Joanna Renclawowicz: <b>Two-strain dengue model with a constant recruitment rate</b> .....	54
Sebastian Sakowski and Tomasz Popławski: <b>Programmable biomolecular computing based on CRISPR-CAS: concepts, computational perspectives, and potential applications</b> .....	55
Justyna Signerska-Rynkowska: <b>Dynamic threshold curves and response precision in forced excitable systems</b> .....	57
Akhil Kumar Srivastav, Nico Stollenwerk, Maíra Aguiar: <b>Impact of age-structure dependent control during the first two years of COVID-19 pandemic in the Basque country</b> .....	58
Robert Stańczy: <b>Kolmogorov generalized predator-prey models</b> .....	59
Magdalena Szafrńska-Łęczycka, Urszula Foryś : <b>Mathematical model of CAR-T cell therapy for glioblastoma with the logistic cancer growth with time delay</b> .....	60
Zuzanna Szymańska, Mirosław Lachowicz, Nikolaos Sfakianakis, Mark A.J. Chaplain: <b>Mathematical modelling of cancer invasion: Phenotypic transitioning provides insight into multifocal foci formation</b> .....	62
Radosław Wieczorek: <b>A hybrid stochastic model of retinal angiogenesis</b> ....	63
Artur Wyciślok, Jarosław Śmieja: <b>Feedback-feedforward control in EMT signalling pathway model</b> .....	64
Dariusz Wrzosek: <b>Around Lotka-Volterra models with diffusion and taxis</b> ..	67
Mariusz Ziółko, Ewa Stogowska, Irina Kowalska, Karol Kamiński, Marcin Kondraciuk, Rafał Rzepka, Bartosz Ziółko: <b>Voice Frequency Analysis in PCOS Screening Tests</b> .....	69
<b>List of authors</b> .....	70



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# THE CHANGING ROLE OF MATHEMATICS IN MEDICINE AND BIOLOGY IN THE 21ST CENTURY: AN ONCOLOGY PERSPECTIVE

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## ABSTRACT

Mathematics has long provided the foundation for biomedical discovery — from dynamical systems and biostatistics to evidence-based medicine. In contemporary applications of mathematics, IT, and AI in medicine, the dominant challenge is increasingly one of **essential complexity** (in the sense of Frederick Brooks): the greatest difficulty lies not in the technology itself, but in accurately understanding and adequately modeling the intricacies of clinical reality. Modern tools such as machine learning (ML), retrieval-augmented generation (RAG), and MLOps practices reduce the *accidental complexity*, yet they cannot eliminate the intellectual effort required to design sound models. In other words, we have shifted from the era of asking “*how can we build it?*” to the era of asking “*what exactly should we build, and how should we model it correctly?*”

Breakthrough advances in AI and large language models (LLMs) are now delivering revolutionary tools that can raise diagnosis and therapy to unprecedented levels of quality. Examples such as the *Tsinghua AI Agent Hospital* demonstrate this transformative potential. Yet, the growing deployment of AI in medicine must confront the most critical challenge for contemporary AI: **trust in AI**.

In response, the University of Warmia and Mazury (UWM) and the National Oncology Institute (NIO–PIB) have launched a joint initiative, *OnkoBot* — an oncology-focused AI system with human-in-the-loop (HITL) supervision. OnkoBot is designed to support patients, enhance clinical decision-making, enable medical education and clinical auditing, and improve the overall safety of oncology care.

The OnkoBot project directly addresses two fundamental challenges for any non-trivial applications of mathematics, IT and AI to clinical medicine: *essential complexity* and *trust in AI*. OnkoBot is not just another chatbot; it ensures safe oncology use through uncertainty representation, justified reasoning, and HITL supervision.

This lecture outlines our framework for addressing these challenges in oncology, illustrated by the development of AI-based decision-support systems for prostate cancer diagnosis and treatment. Our objective is not to eliminate essential complexity or uncertainty in trust toward AI, but rather to *maintain them within acceptable bounds for clinical experts* through explicit representations of uncertainty, modular separation of concerns, verifiable reasoning, and human-in-the-loop collaboration. We propose mechanisms that simultaneously minimize uncertainty while maximizing explainability and ensuring alignment with regulatory requirements such as the MDR and AI Act, all under real-world clinical constraints.

The core of our approach lies in modeling medical knowledge via knowledge-representation systems based on granular computing (GrC) and, in particular, interactive granular computing (IGrC). These frameworks can also accommodate non-classical reasoning, including multi-valued, fuzzy, probabilistic, modal, and intuitionistic logics.

For especially complex applications, we recommend **IGrC**, which integrates informational and physical layers (e.g., clinical reality) through *composite granules* (*c-granules*) under explicit CONTROL — Risk Management (RM), Information Management (IM), Decision Management (DM), and Resource Management (ResM), i.e., the full spectrum of clinical decision contexts. This design grounds semantics in the physical domain and synchronizes language, reasoning, perception, and action. This continuous adaptation and synchronization of 'perception and action' takes place in a tight, iterative loop of collaboration with the medical expert, forming the core of the human-in-the-loop approach. From the perspective of rough sets, the focus shifts from approximating concepts to approximating *granules/solutions*, enabling approximate cognitive computations within real oncological workflows. Along these computations, approximate solutions to problems are constructed, e.g., concerning diagnosis or therapy. In this architecture, hallucinations are mitigated through evidence-linked granules, abstention policies, and provenance-based reasoning.

Based on the above considerations, we conclude that the core message of this lecture is a paradigm shift in the application of mathematics to 21st-century medicine. We are transitioning **from computational models that operate on numbers and aggregates (like vectors and matrices) to models of granular computing—particularly interactive ones—that work primarily with granular information (intuitively human-understandable knowledge units) and physical-world entities**. These models must undergo constant adaptation to meet the demands arising from the complexity of the modeled phenomena and concepts. This adaptability allows them to address the challenges of essential complexity and to build the trust demanded by modern medicine.