International Workshop on Mathematics and Physics
in Cardiovascular Research, Gdańsk Tech, April 19, 2023

Controlling and predicting cardiac dynamics

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Currently, the only therapy to terminate life-threatening ventricular fibrillation is the application of very strong electrical shocks with adverse side effects. As an alternative to the clinical single pulse method, low-energy pulse trains have been suggested and successfully applied in ex vivo experiments. In a previous numerical study of cardiac excitable media, we showed that high success rates at low energies are possible with specific combinations of pulse frequency and pulse energy resulting in a non-monotonous behavior of the dose-response curve. Here we show that this sensitive dependence on control parameters can be overcome by decelerated pulse sequences, which can be derived from the Fourier spectrum of the ECG. Furthermore, we will briefly discuss applications of machine learning for reconstructing electrical excitation waves in a 3D excitable medium from surface observations.

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Using semantic data management to facilitate FAIR and reproducible data science for the analysis of cardiac dynamics

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The analysis of cardiac dynamics involves managing large amounts of complex data stemming from experiments, computer simulations and data analysis. Especially for digital workflows, e.g. data analysis, establishing standardized methods and tools that ensure proper documentation, findability and reproducibility can be challenging.

Using an example from wave tracking analysis applied to 3D simulations of cardiac tissue, we will demonstrate a pragmatic approach for proper (human- and computer-readable) documentation that can be embedded into heterogeneous research environments. By combining this approach with semantic data management using the CaosDB crawler framework, we show how this information can be made findable and re-usable.

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Synchronization in a network of controlled oscillatory cellular automata

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In fields from biology to engineering, dynamic processes occur in networks. A prototypical example is a network of interacting myocytes, cells that make up the tissue of the heart and are crucial in performing the heart's main function, which is pumping blood. One would like to understand how the structural properties of the network together with the dynamic models of interacting entities shape the desired goals. In particular, what happens in the Kuramoto model of interacting oscillators that exhibit spontaneous collective synchronization in steady state, when these oscillators are forced to reset to their initial state by an external controller.

The lecture will be devoted to discussing the proposal of vagal nerve control over the rhythm of heart contractions, which is based on the model of oscillatory timed cellular automata as the framework of heart tissue. It turns out that the obtained model agrees well with the observational data. Especially it allows to identify and quantify some of the damage to the heart tissue that manifests as atrial arrhythmia which, if left untreated, can lead to dysregulation of the entire cardiac conduction system.

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Heart rate asymmetry in relation to the respiratory phase in healthy people and patients with hypertension

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Heart rate asymmetry (HRA) is a physiological phenomenon considered a physiological attribute of a healthy subject. In the following, we assess HRA in 18 healthy adults (CG: age: 45±14) and 19 patients with hypertension (HG; age: 53±13). All subjects were examined in supine position and had a regular breathing pattern. The data contains 20-minute recordings of ECG and respiration. We obtain RR signals from the ECG for each patient. Then we assign RR intervals to one of four states corresponding to the phase of breathing: inspiration (IN) or expiration (EX), and two possible breathing phase transitions: from inspiration to expiration (IN→EX) or from expiration to inspiration (EX→IN).

Poincaré plots for pairs of RR intervals from subsequent respiratory phases for both groups were obtained. Then the HRA was estimated by the Guzik's Index (GI) and Porta Index (PI). The indexes estimate the distribution of points relative to the identical line on the Poincare plot.

The calculation for the whole RR signals shows that GI tended to be different in healthy subjects and patients (p¡0.07), and the value of GI for healthy people was significantly different from 50% (p¡0.005), which means that asymmetry has been found in the CG. However, the asymmetry of RR intervals was not detected by PI. At the same time, there are statistically significant differences between values of asymmetry indexes (GI and PI) obtained from RR intervals divided according to the respiratory state. Although, the difference in the heart rate asymmetry between CG and HG groups was not found.

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The Analysis of Asymmetry in Heart Rate Transitions Obtained from Photoplethysmogram

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The Photoplethysmography (PPG) is a convenient method of heart rate measuring. We attempted to evaluate Heart Rate Asymmetry (HRA) using PPG signals by analyzing 413 recordings of healthy young people from an open database (AOMIC). We used common HRA indices and also evaluated the mean Deceleration Input (DI) into heart rate transitions to evaluate HRA in PPG signals. Most of the studied subjects showed DI asymmetry (DI < 0.5 in 63.4% of participants). The analysis of three consecutive heartbeat intervals to investigate the temporal variability in heart rate can be a useful tool in assessing the performance of the autonomic nervous system in healthy people.

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Topological analysis of breathing patterns

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Persistent homology is one of the tools used in topological data analysis. It allows to analyze the topological features of data that persist across multiple scales. The respiratory and cardiovascular systems are strongly interconnected. In particular, breathing pattern heavily impacts the heart rate.

In this work, we apply persistent homology to the dataset that consists of breathing recordings of various patients. Those recordings contain complex patterns that may be difficult to quantify using traditional methods. After preprocessing the time series, which included filtering and transforming it into analytical signal, we were able to compute persistence diagrams. The extracted topological features were then passed to a Machine Learning model that found some patterns. Using this approach, we managed to divide samples from the dataset into two classes that differed in the regularity of the breath.

This work contributes to the growing field of topological data analysis and demonstrates the potential of persistent homology in cardiorespiratory research.

Cardiovascular research data: variety, opportunities and challenges

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The talk will outline the methods for assessing the cardiovascular system structure and function, particularly in patients with hypertension in both clinical practice and modern research studies. Special attention will be paid to the variety of data that cardiovascular studies provide, the challenges of studying them and their potential for using advanced methods of analysis.