Minimal model of synchronization in cilia carpets
Theoretical biological physics

Inside our airways, thousands of short slender cell appendages termed cilia rhythmically bend with a common rhythm to transport mucus efficiently. Yet, there is no external clock that controls this synchronous periodic motion. Instead, collective synchronization emerges by self-organization from hydrodynamic interactions between the cilia: each cilium "feels" the oscillatory flow generated by the nearby cilia and phase-locks its beat. The resultant metachronal waves represent a microscopic analogue of Mexican "la Ola" waves in a soccer stadium (video).

Our group uses tools from physics to understand the robustness of this (and other) self-organization phenomena. This involves detailed three-dimensional hydrodynamic simulations calibrated by experimental cilia beat patterns. We use statistical physics and nonlinear dynamics to understand how active noise affects the metachronal waves. What is the maximal level of fluctuations that can be tolerated? Does noise induce stochastic transitions between different synchronized states?

Your summer project will explore a minimal model of coupled phase oscillators (a Kuramoto-type model with local coupling) that abstracts from this complex biological system. You will devise linear stability analyses, compute phase diagrams, and find out if phase noise can induce stochastic transitions between several stable wave patterns.
As a second option**,** you will analyze experimental data of cilia carpets dynamics in the zebrafish nose pit, provided by our experimental collaboration partners. Here, we are especially interested in quantifying the competition between the noise strength of the beat of individual cilia and their synchronization.
Depending on your preferences, you can thus choose between either pure theory or hands-on work with experimental data, or a combination of both.

Who are you?
- you have very good math skills, ideally with solid knowledge of linear algebra and ordinary differential equations
- you gained first experience in numerical simulations (e.g. Python, Matlab, C)
- if you got prior exposure to nonlinear dynamics, complex systems, or stochastic dynamics, this will be a plus

About Dresden. Our Biological algorithms group is part of the *cfaed* cluster of the Technical University Dresden. Our institute is located in Dresden, a lively city with half a million inhabitants and a rich history situated in the scenic Elbe valley. Dresden is well known for its technical university, selected as a National University of Excellence, with a strong tradition in engineering and natural sciences. During the last decade, Dresden also transformed into a major European hub for the life sciences, including several research institutes of highest international reputation like the Max Planck Institute of Molecular Cell Biology and Genetics and Max Planck Institute for the Physics of Complex Systems.

Biological Algorithms Group, cfaed, TU Dresden, Germany
benjamin.m.friedrich@tu-dresden.de