DIGS-ILS Project Proposal
Theoretical modeling of silica pattern morphogenesis in diatoms

Diatoms are unicellular microalgae that produce intricately patterned cell walls made of amorphous silica. These cell walls, known as frustules, display extraordinary material properties and highly regular, species-specific designs. Their remarkable architectures make them a model system for studying pattern formation in biomineralization.

In centric diatoms, the “lids” of their barrel-shaped silica cell walls—called valves—exhibit three striking features: (1) branched rib patterns with radial symmetry, (2) regularly spaced nano-pores, and (3) transverse connections between ribs, as shown in Figure 1. Understanding how these patterns form, and how they interact with one another during morphogenesis, remains an open scientific challenge.

Our group develops data-inspired theoretical models of diatom morphogenesis in close collaboration with the experimental Kröger lab at B CUBE (Center for Molecular Bioengineering, Dresden). This collaboration provides us with high-resolution images and quantitative data, which serve as the foundation for developing mechanistic models of rib and pore patterning. A recent study (Babenko et al., PNAS 2024) already established a successful model for rib branching, reproducing experimental morphometrics in several centric species. Building on this, the next step is to explore pore morphogenesis and its interplay with rib formation.

Current progress

During the first year of my PhD, I developed an image analysis pipeline to automatically segment and quantify rib and pore patterns in both nascent and mature valves. This tool is now used across the Kröger group to characterize mutant strains, and it provides a growing database of structural features. Still, there is room for improvement: detecting additional patterns such as fultoportulae and handling large datasets more efficiently.

In parallel, I am developing mathematical models for pore pattern formation, exploring alternative hypotheses. I aim to understand if and how simple local rules are sufficient to explain the remarkable regularity of pore arrays in diatom valves.

Possible tasks for the research assistant

Depending on their aptitude and interests, a DIGS-ILS summer student could:

- Extend and improve the current image analysis code, or develop original methods for detecting new structural features.
- Explore and extend different mathematical models of pore pattern formation, and compare model predictions against experimental data.

Requirements

Basic knowledge of Python is essential. Familiarity with ordinary and partial differential equations, pattern formation, or image analysis would be beneficial but not mandatory.

Research environment
The student will join a vibrant and international scientific community in Dresden. Our group works at the interface of biological physics and materials science, and closely collaborates with experimentalists at B CUBE. The broader Dresden research landscape includes several world-class institutes, such as the Max Planck Institute of Molecular Cell Biology and Genetics, the Max Planck Institute for the Physics of Complex Systems, and the Cluster of Excellence "Physics of Life." English is the working language of our group, ensuring a smooth integration for international students.

About Dresden
Dresden is a lively city of about half a million inhabitants, located in the scenic Elbe valley. It combines a rich cultural heritage—famous for its baroque architecture and art collections—with a modern identity as a hub for science and technology. Students will find a welcoming atmosphere, plenty of opportunities for cultural activities, and easy access to the natural beauty of Saxon Switzerland, a nearby national park known for its sandstone cliffs and hiking trails.

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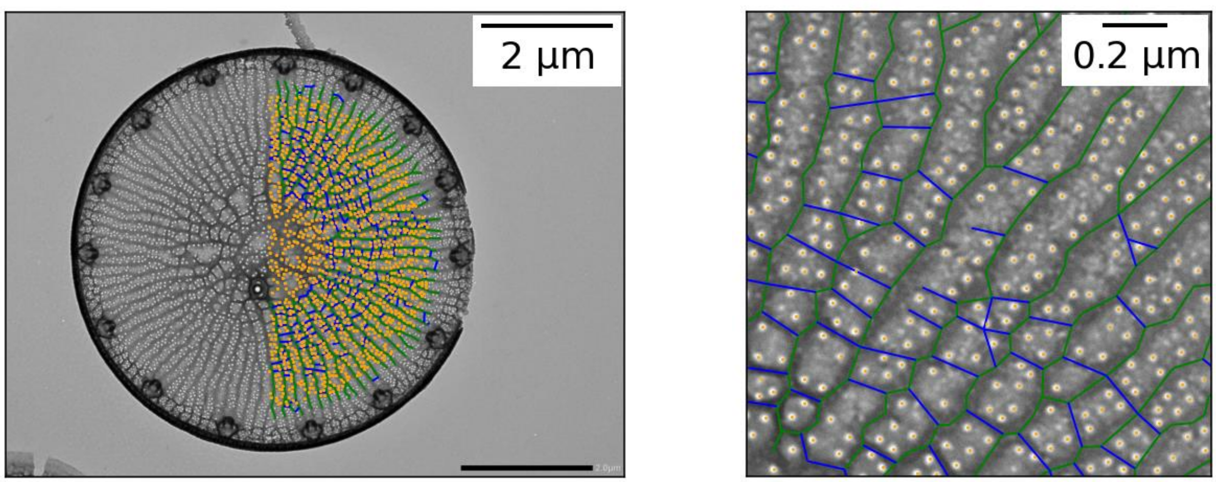

Figure 1: Transmission electron microscopy (TEM) images of a *Cyclotella nana* valve. The left panel shows the full valve, and the right panel is a zoomed-in view of the same region. Key structural features—pores (orange), radial ribs (green), and transverse connections (blue)—were automatically detected using our image analysis pipeline, illustrating the hierarchical organization of the valve surface and enabling quantitative pattern analysis.