Thermodynamics of Information Processing: From Theory to Applications

Popular summary

Information processing plays a vital role in our society, driving everything from smartphones to data centers. As these devices become more wide-spread, their energy consumption emerges as a pressing concern. Consequently, increasing their energy efficiency is one of the major technological challenges of our times. The interdisciplinary field of information thermodynamics aims to approach this challenge by using new methodologies and insights from quantum information and stochastic thermodynamics.

This project aims is to establish a link between foundational studies and potential technological applications in information thermodynamics. We will focus on three avenues: optimization of thermodynamic protocols, non-classical phenomena in information processing, and the thermodynamics of computation. While the project is primarily theoretical, we will prioritize establishing connections with experimental implementations, with the ultimate goal of translating the project's findings into real-world applications. The project encompasses research goals divided into three work packages (**WP 1-3**).

In **WP 1**, we will concentrate on optimizing thermodynamic protocols at the nanoscale, with focus on minimizing heat dissipation. Since dissipation is one of the main obstacles towards scaling down information processing devices, this package is expected to have a major potential technological impact. By uncovering new approaches using state-of-the-art machine learning and geometric techniques, we will attempt to improve the performance and efficiency of information-processing devices.

In **WP 2**, we will investigate non-classical aspects of information-processing devices. While quantum effects are known to provide advantages in information processing, the full spectrum of opportunites (and limitations) provided by quantum theory remains largely unexplored. Using the techniques of resource theories we aim to design innovative information-processing devices that harness quantum effects to enhance their performance. This involves utilizing promising new techniques like quantum catalysis and non-asymptotic information theory. The outcomes of this research are anticipated to have a broad impact, notably in quantum computing and quantum sensing.

Finally, in **WP 3**, we will investigate the behavior of computing devices under thermodynamic constraints. We aim to uncover new insights that can guide the development of future energy-efficient computing architectures and novel computational paradigms. For that we will use well-established techniques of stochastic thermodynamics and the novel ideas of thermodynamic computing. This package has the potential to guide towards faster, more efficient, and sustainable computing technologies.

Overall, this is an ambitious and broad project which encompasses practical short-term goals with a guaranteed impact and adaptable high-risk/ high-gain research directions.