Thermodynamic Networks:
Harnessing Non-Equilibrium Steady States for Computation

We introduce thermodynamic networks, a computing paradigm rooted in thermodynamics, as a general physical platform for computation. In this framework, networks of finite-size reservoirs, coupled by microscopic systems (transport channels), redistribute conserved quantities—such as particles, charge, or energy—under gradients of their conjugate potentials. Such a network can solve computational problems, encoded in the input potentials, by autonomously relaxing to a non-equilibrium steady state (NESS). We identify the presence of negative differential conductance as a crucial microscopic mechanism for the network to acquire universal expressibility—leading to a universal model of computation. We also present two possible physical implementations of such a network: quantum dot arrays and enzymatic reaction networks. Finally, we illustrate the performance of these networks for standard tasks, including image classification and function approximation, and benchmark them against standard artificial neural networks. Overall, our results provide an alternative physics-based platform for thermodynamic computing.

This talk is based upon [1, 2].

References:

[1] P. Lipka-Bartosik, M. Perarnau-Llobet, N. Brunner, *Thermodynamic computing via autonomous quantum thermal machines*, Science Advances 10 (36), eadm8792 (2024).

[2] P. Lipka-Bartosik, G. Blasi, J. Lalueza, G. Haack, M. Perarnau-Llobet, N. Brunner, *Thermodynamic Networks: Harnessing Non-Equilibrium Steady States for Computation*, soon to appear in arXiv (2026).