

Optimized Optical Reservoir Computing

Kathy Lüdge¹, Lina Jaurigue¹, Stefan Sinzinger²

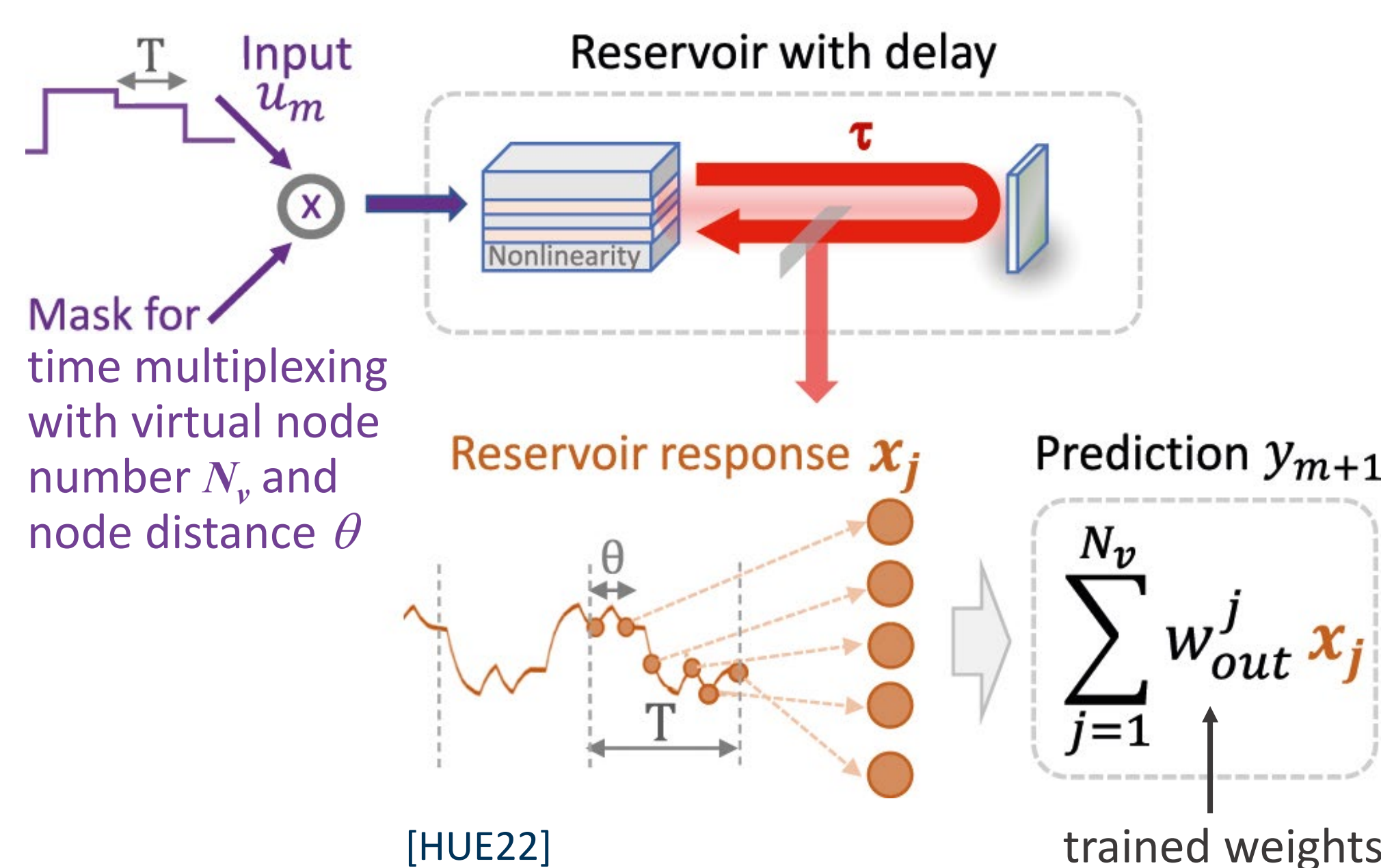
¹ FG Theoretische Physik 2, Fak. Mathematik und Naturwissenschaften, TU Ilmenau

² FG Technische Optik, Fak. Maschinenbau, TU Ilmenau

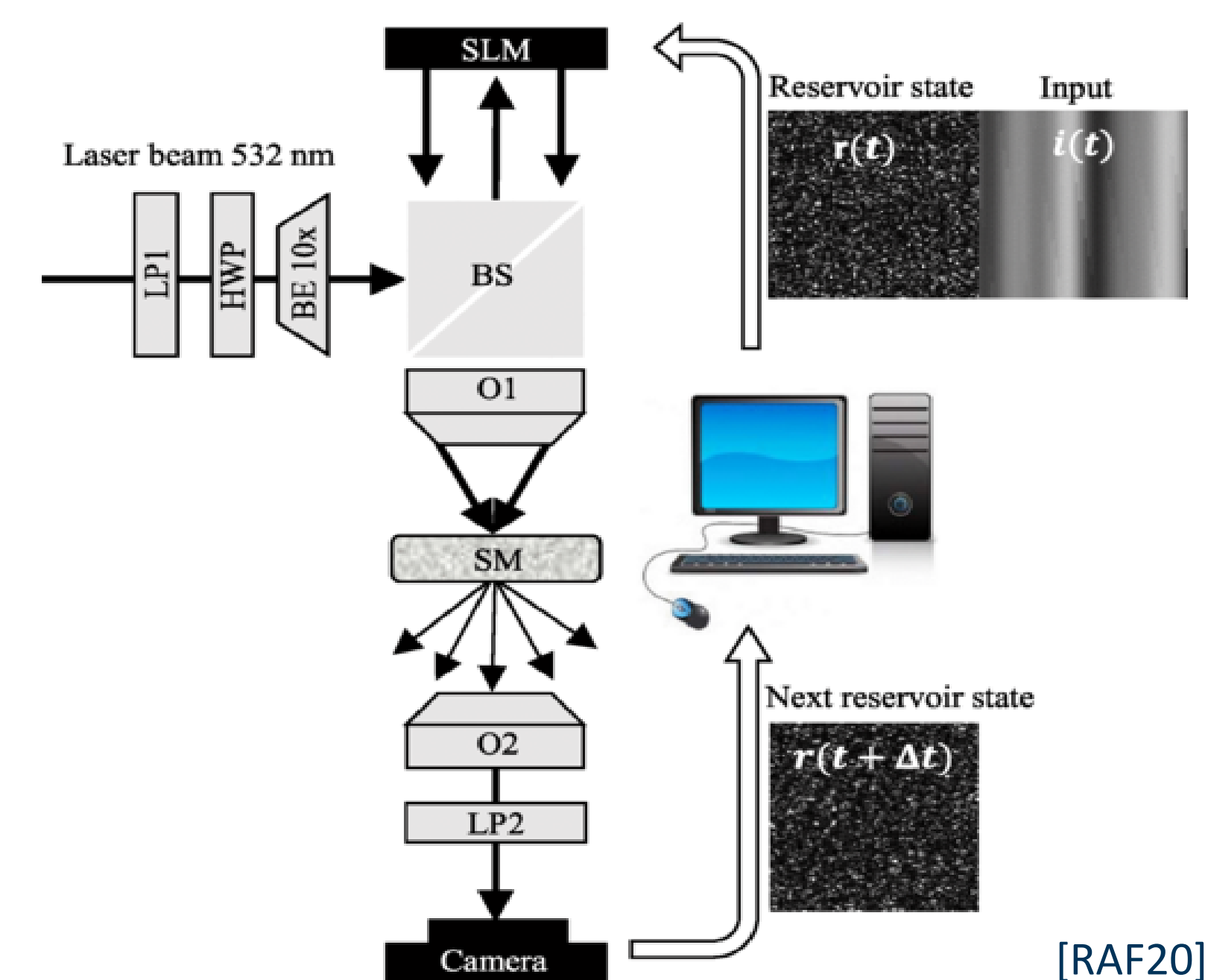
Motivation and state of the art

- Reservoir Computing is a powerful concept for analogue neuromorphic computing
- Due to its properties, this concept is suitable for energy efficient implementation of neural networks
- Advancements in manufacturing processes and design approaches enable the use of complex optical beam-shaping components for controlling the coupling topology
- Based on an existing optical setup for action recognition, various reservoir computing systems will be implemented and investigated regarding their performance, as well as energy and resource efficiency

Time Delay Reservoir Computing



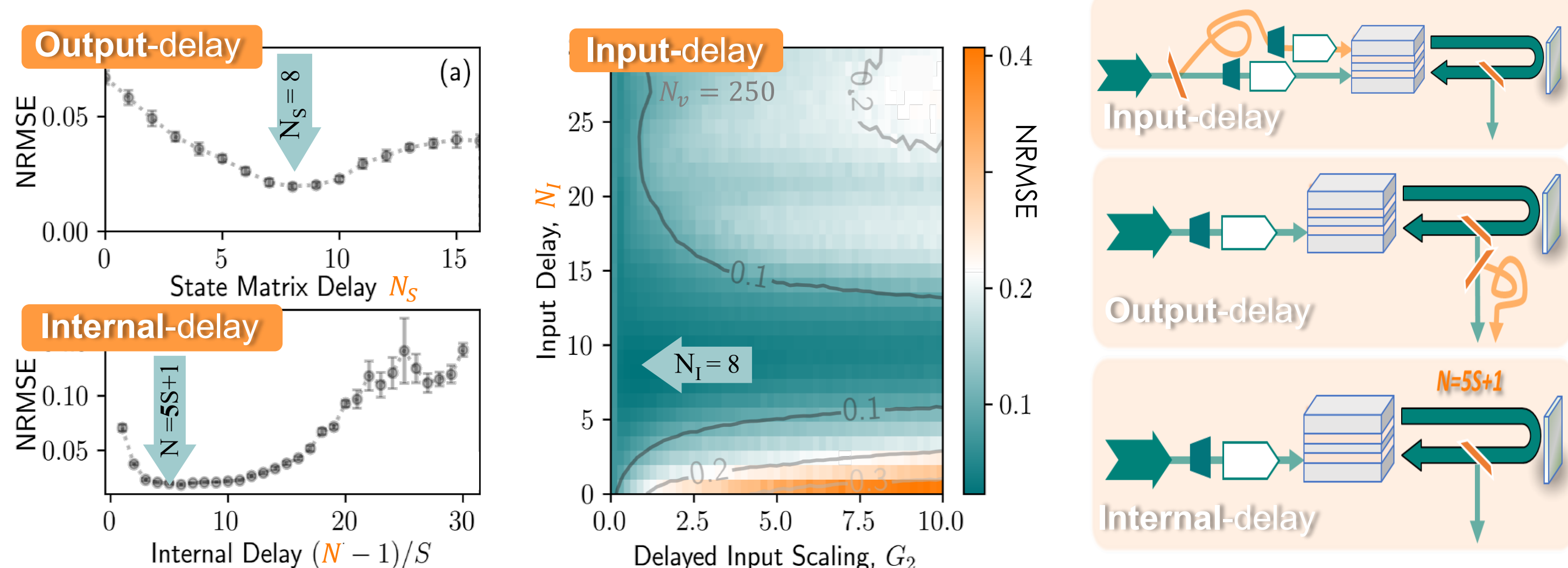
Spatio-temporal Reservoir Computing



Energy efficient algorithms

Expertise

- Reservoir Computing (RC)
- Extreme Learning Machines
- Timescale tuning and delay effects
- Bifurcation analysis and nonlinear dynamics



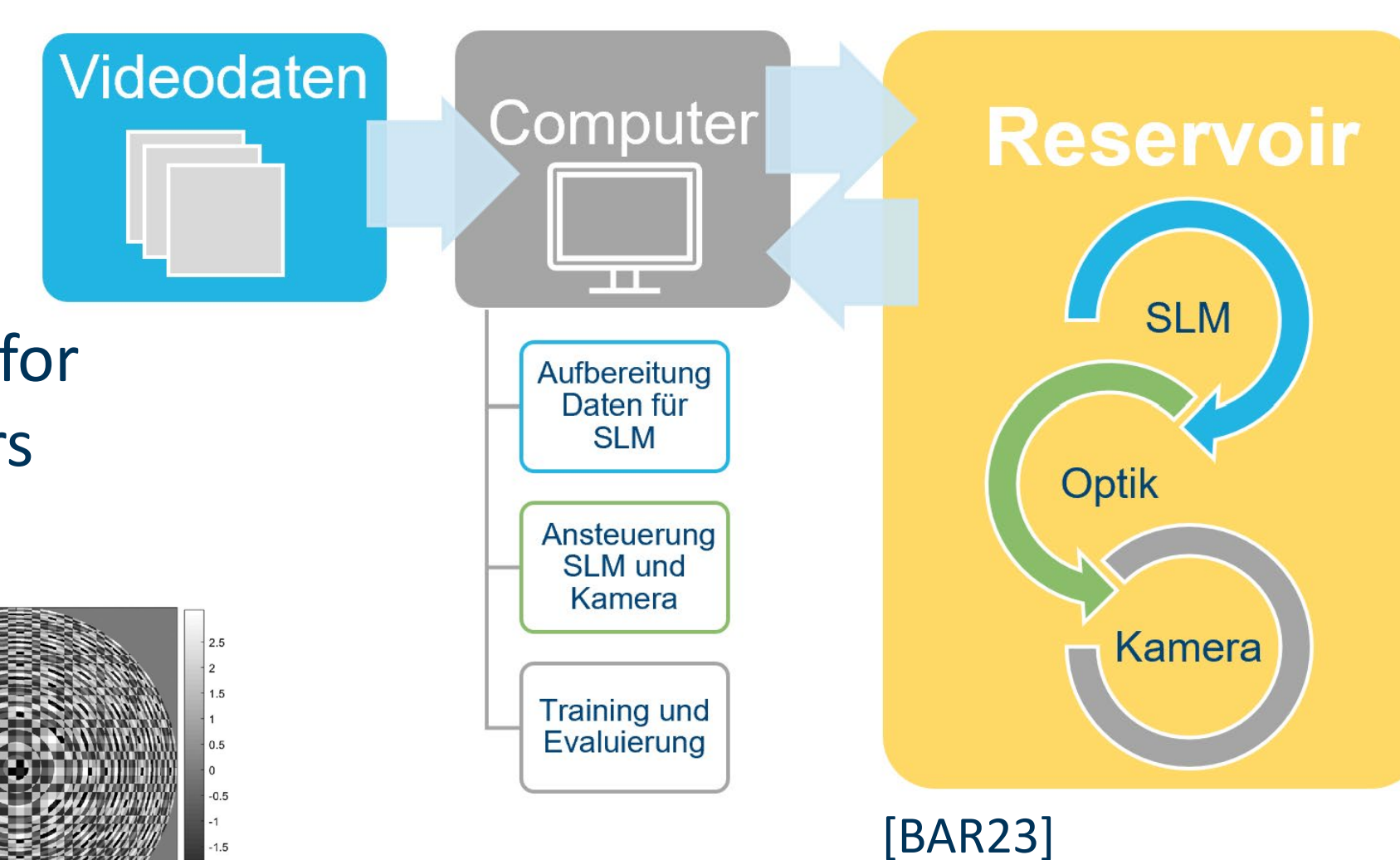
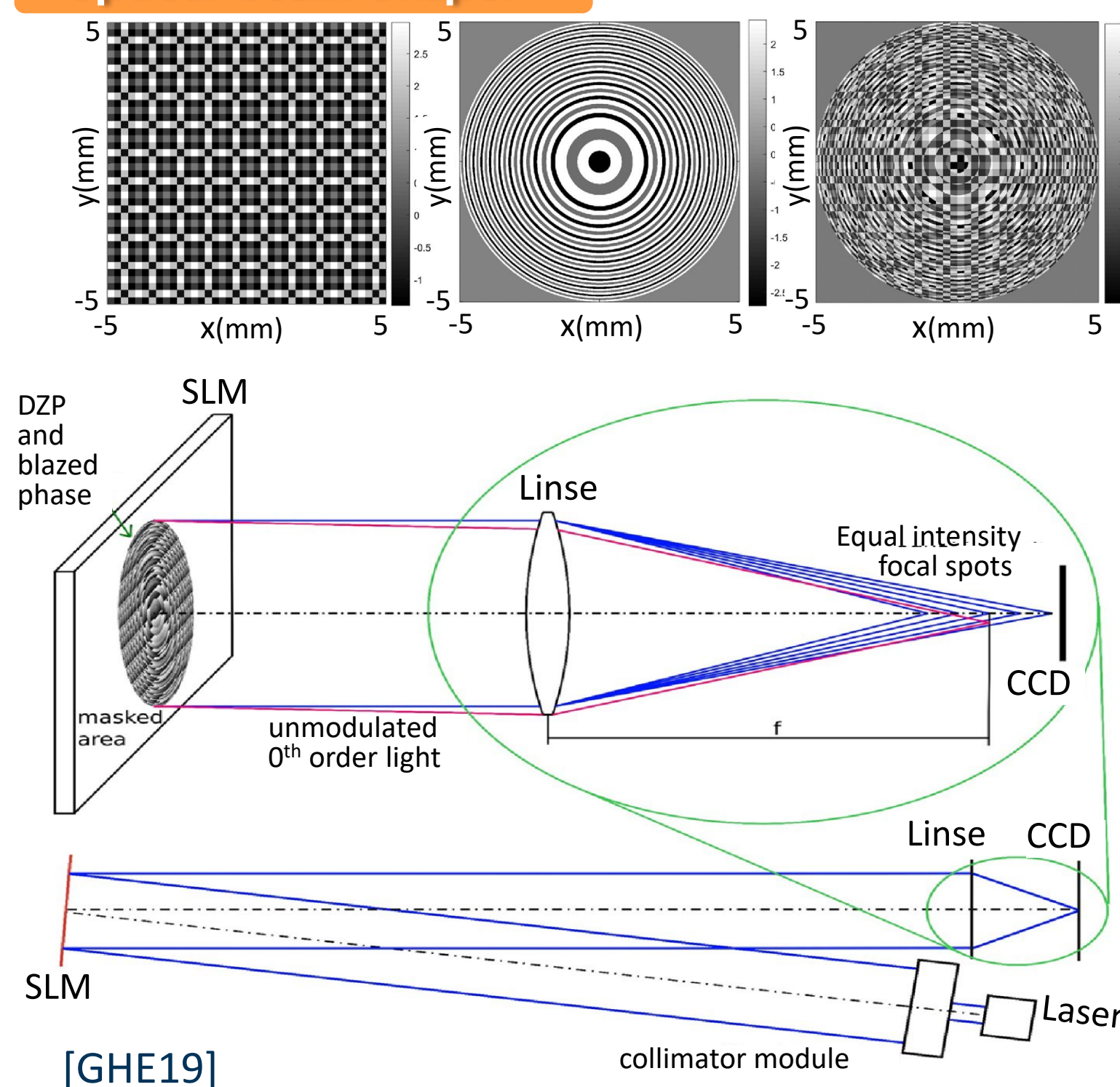
- Delay time strongly influences the prediction error and provides additional memory capacity
- Optimal values of the delay depend on the implementation and the chosen task

Optical technology

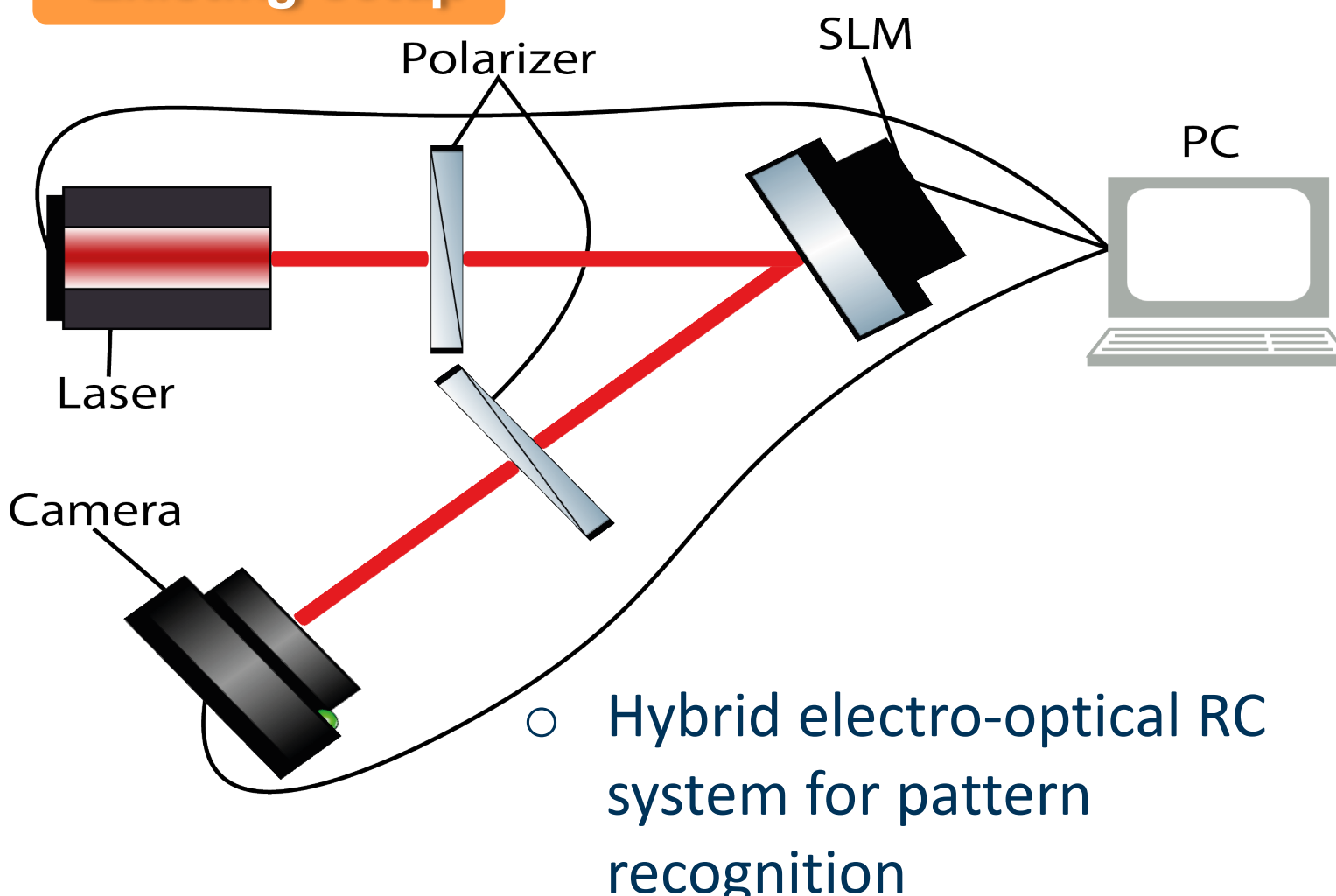
Expertise

- Optical system design
- Microoptics and optical system integration
- Microlithography and holography for fabrication of optical beam shapers

Optical beam shaper



Existing setup



- Hybrid electro-optical RC system for pattern recognition

Scientific objectives

➤ Novel system concept and algorithmic

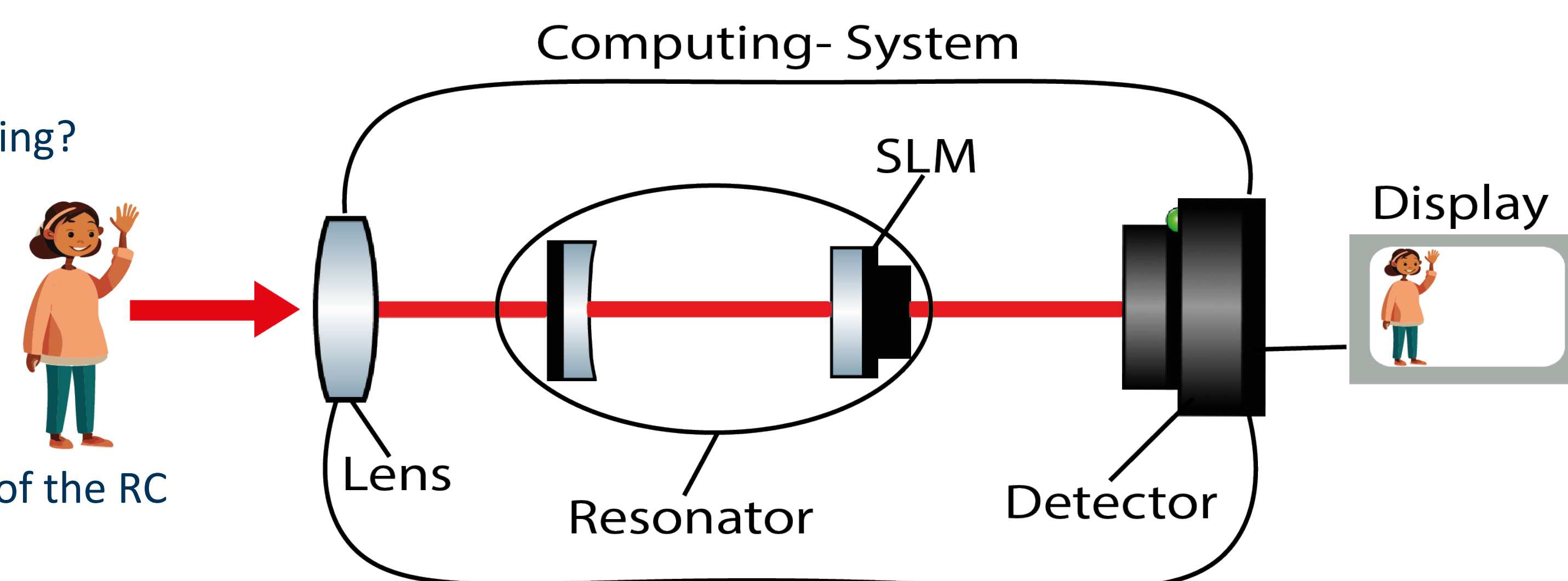
- How can the coupling topology of RC systems be influenced by the use of 3D beam shaping?
- What role does temporal and spatial multiplexing play in RC systems?

➤ System design for optical Reservoir Computing

- Which components are best suited for 3D beam shaping in RC systems?
- What technological constraints have to be considered in design and manufacturing?
- What options does "intra-cavity" beam shaping offer for the dynamics and algorithmics of the RC system?

➤ Benchmarking and evaluation of the system

- Which properties of RC systems can be particularly optimized by using optical elements?
- Which elements of the value chain are the most crucial in regard to their energy and resource efficiency?



- Purely optical system concept for instantaneous motion recognition

References

- [HUE23] T. Hülser, F. Köster, K. Lüdge, and L. Jaurigue, *Deriving task specific performance from the information processing capacity of a reservoir computer*, *Nanophotonics* **12**, 937 (2023).
 [RAF20] M. Rafayelyan, J. Dong, Y. Tan, F. Krzakala, and S. Gigan, *Large-Scale Optical Reservoir Computing for Spatiotemporal Chaotic Systems Prediction*, *Phys. Rev. X* **10**, (2020)
 [JAU24] L. Jaurigue and K. Lüdge, *Reducing hyperparameter dependence by external timescale tailoring*, *Neuromorph. Comput. Eng.* **4**, 014001 (2024).
 [GHE19] S. G. Ghebjagh, D. Fischer, and S. Sinzinger, *Multifocal multi-value phase zone plate for 3d focusing*, *Appl. Opt.* **58**, 8943 (2019).
 [BAR23] A. Bartelmei, *Spatio-temporales Reservoir Computing am Beispiel von Bewegungserkennung* (Technische Universität Ilmenau, Ilmenau, 2023), Masterarbeit.