Fast high-dimensional data processing by optically implemented neural networks

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Motivation

- Direct high-dimensional data processing in massively parallel optical devices
- On-the-fly processing of extreme vorticity events in turbulent convection flows
- Optical implementation of a spatially extended recurrent neural network for fast data processing
- Setup of an experimental platform based on optimized beam shaper layers and spatial light modulators
- Development of integration technology

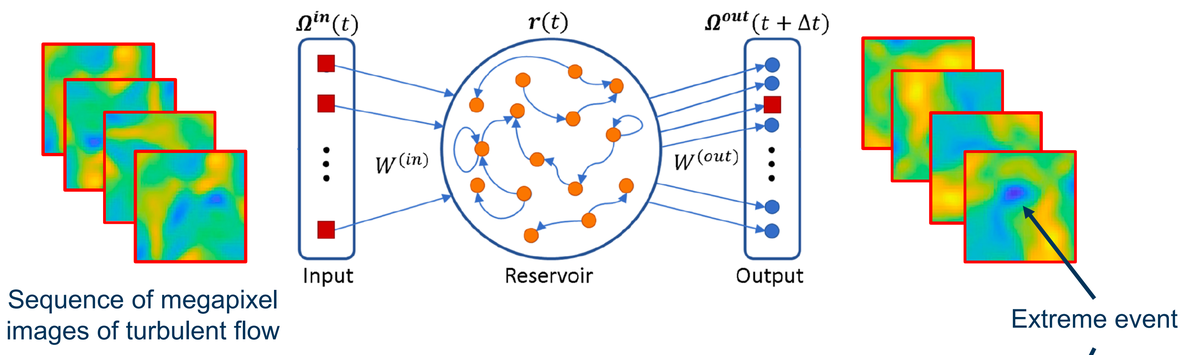
Scientific objectives

- Can the optically implemented recurrent neural networks be used as online models to track and classify high-vorticity events obtained from particle image velocimetry in a turbulent convection flow?
- How do the specific optical network architecture, such as the topology, the number of perceptrons and layers, and the resulting spatio-temporal activity affect the performance of the neural network?
- Which of the modulations – polarisation, amplitude or phase – should be used in the nonlinear transformation of the input data?
- What are the best-suited implementations of perceptrons in the optical network – holograms or optically addressable spatial light modulators?
- Is the optical neural network setup capable to process high-dimensional data, such as megapixel images, faster and more efficiently than standard random network-based reservoir computing models?
- Exploration of optical network capabilities as a generative neural network based on diffusion maps

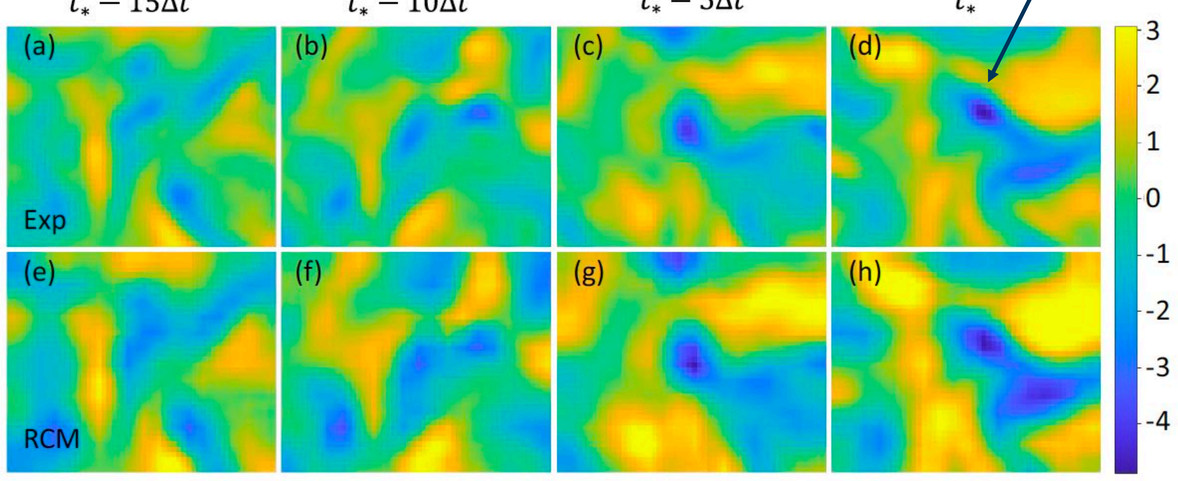
Addressed research foci of the Ilmenau School of Green Electronics

- **Energy–efficient bio-inspired Computing** on the basis of a network of optical elements at room temperature
- **Intelligent Materials, Elements and Technologies** by use of integrated, small-scale optical circuits

Recurrent neural networks for turbulent flows



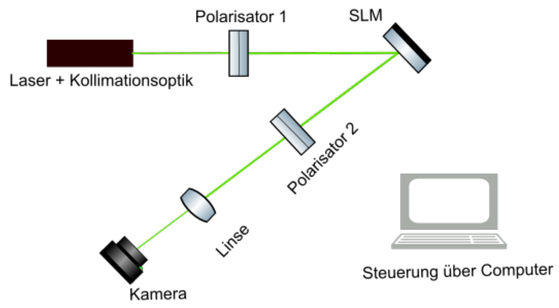
Workflow in recurrent neural network [1,2]

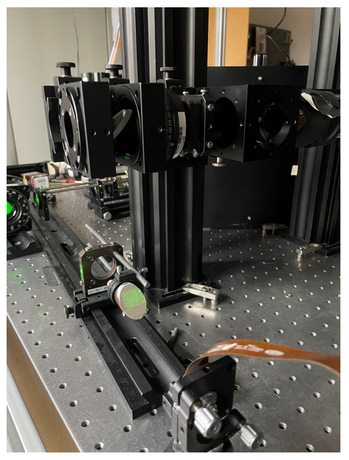


Reconstruction of an extreme out-of-plane vorticity event in the center of a turbulent convection flow in the SCALEX experiment [2]. A reservoir computing model was applied for this open loop task.

Optical implementation of the neural networks

Previous work:





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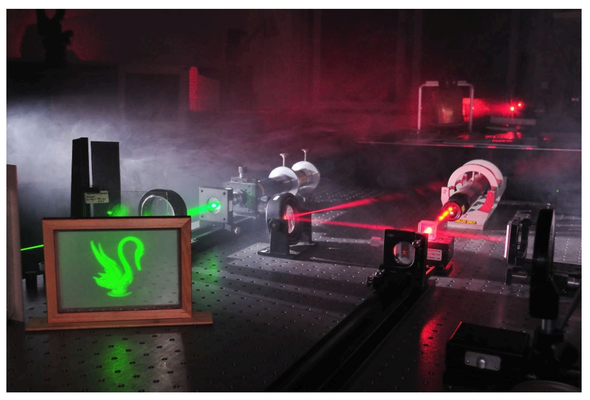
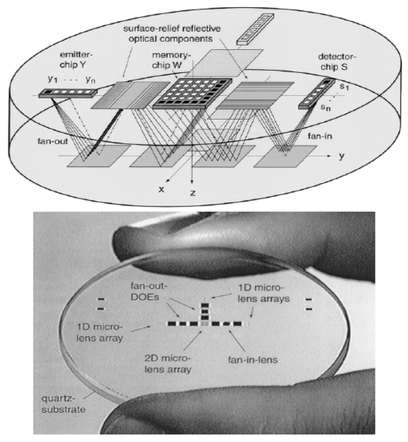
Holographic memories, spatial light modulators and highly integrated optical systems



Volume holograms are highly flexible memories for optical data processing units.



Lithographic techniques enable integrated optical systems [3-5]

References

1. F. Heyder and J. Schumacher (2021) Echo state network for two-dimensional turbulent moist Rayleigh-Bénard convection. Phys. Rev. E 103, 053107.
2. V. Valori, R. Kräuter and J. Schumacher (2022) Extreme vorticity events in turbulent Rayleigh-Bénard convection from stereoscopic measurements and reservoir computing. Phys. Rev. Research 4, 023180.
3. M. Gruber, J. Jahns, S. Sinzinger (2000) Planar-integrated optical vector-matrix multiplier. Appl. Opt., 39 5367-5373.
4. D. Fey, H. Bartelt, W. Erhard, G. Grimm, M. Gruber, L. Hoppe, J. Jahns, S. Sinzinger (2000) Optical interconnects for neural and reconfigurable networks. Proceedings of the IEEE, 88, 838-848.
5. M. Krüger, R. Kampmann, R. Kleindienst and S. Sinzinger (2015) Time-resolved combination of the Mueller–Stokes and Jones calculus for the optimization of a twisted-nematic spatial-light modulator. Appl. Opt. 54, 4239-4248.

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