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Reservoir computing based on delay-dynamical systems

Walking down a street, we are constantly bombarded with sensory impressions. Seeing a vehicle or a familiar face, hearing the ongoing traffic and conversations, smelling the food stalls … All these external impulses instantly produce massive neural activity in our brain, so that we recognize the passing bus, a good friend or a car horn, or that the smell of freshly baked waffles makes us hungry. We can see a blurry photo and still recognize the scene in a fraction of a second, a task for which a computer might take minutes or even hours. Today, except for mathematical operations, our brain functions much faster and more efficient than any supercomputer. It is precisely this form of information processing in neural networks that inspires researchers to create systems that mimic the brain's information processing capabilities, in a way radically different from current computer based schemes.

In this thesis we propose a novel approach to implement these alternative information processing architectures, based on delayed feedback. Time delays are intrinsic in many real systems. In engineering, time delays often arise in feedback loops involving sensors and actuators. In photonic systems, time delayed feedback plays an important role and arises due to unwanted external reflections. On the one hand, time delays tend to destabilize systems such as lasers, but, on the other hand, the chaotic output from e.g. a laser with feedback can put into use e.g. in chaotic communication systems. In general, one an say that systems subject to time-delayed feedback present a rich variety of dynamical regimes.

We propose to exploit the rich dynamics of delayed feedback systems for information processing by using the system’s transient response to an external input. We show that one single nonlinear node with delayed feedback can replace a large network of nonlinear nodes. Our results demonstrate that this new information processing architecture performs well in a variety of tasks, such as e.g. time series prediction and speech recognition. We investigate whether applying this simple architecture in electronic, opto-electronic or photonics systems could potentially be more resource-efficient as hundreds or even thousands of neurons could be replaced by only one single hardware node in combination with a delay line. Moreover, the fact that delay is easily implementable, sometimes even unavoidable, in photonic systems may lead to the implementation of ultra-fast all-optical computational units. First, we numerically investigate the architecture and performance of delayed feedback systems as information processing units. Then we elaborate on electronic and opto-electronic implementations of the concept. Next to evaluating their performance for standard benchmarks, we also study task independent properties of the system, extracting information on how to further improve the initial scheme. Finally, some simple modifications are suggested, yielding improvements in terms of speed, performance or power consumption.