RESERVOIR TRANSFER ON ANALOG NEUROMORPHIC HARDWARE

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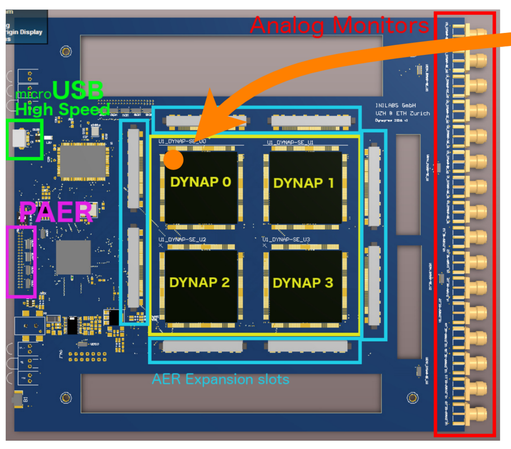
Why? and How?

- Analog spiking neuromorphic microchips: a **great promise** for energy efficiency and processing bandwidth
- Low numerical precision, device mismatch, stochasticity, parameter drift — **crippling** for traditional neural network training methods
- Our **application**: online heartbeat anomality monitoring with a neural network on a neuromorphic microchip
- The **hardware** we used: the analog spiking DYNAP-se microprocessor board developed by our partner (Institute of Neuroinformatics, University Zurich & ETH Zurich)



On-chip neurons:
- **spiking,**
- **unclocked,**
- **analog circuit,**
- **partially unobservable**

- **Key problem: timescale mismatch**. On-chip neurons too fast (few msec) for human heartbeat (1 sec timescale).
- **Approach:** *Reservoir Transfer* to address timescale mismatch AND low bit resolution AND device mismatch AND approximate neuron models.
- **Core idea:**
  - exploit reservoir computing
  - global reservoir dynamics can be slower than local neuron dynamics
  - train generic slow reservoir outside DYNAP-se
  - use mathematics to translate slow high-precision reservoir to DYNAP-se neurons
  - train heartbeat task on DYNAP-se data

Reservoir Transfer — Close-up

An "teacher" ESN

$$\dot{\mathbf{x}}(t) = -\lambda_x \mathbf{x}(t) + \tanh(W\mathbf{x}(t) + W^{\text{in}}\mathbf{u}(t))$$

ESN feature

A "student" SNN

$$\dot{\mathbf{v}}(t) = -\lambda_v \mathbf{v}(t) - \theta \mathbf{s}(t) + \hat{W}\mathbf{r}(t) + W^{\text{in}}\mathbf{u}(t) + I,$$
$$\dot{\mathbf{r}}(t) = -\lambda_s \mathbf{r}(t) + \mathbf{s}(t),$$

SNN feature

"Transfer"

Goal: Find $\hat{W}$ such that
$\hat{W}\mathbf{r}(t) \approx \mathbf{x}(t)$
for all t.

Step 1: "drive"

$$\dot{\mathbf{v}}_x(t) = -\lambda_v \mathbf{v}_x(t) - \theta \mathbf{s}_x(t) + \mathbf{x}(t) + W^{\text{in}}\mathbf{u}(t) + I$$
$$\dot{\mathbf{r}}_x(t) = -\lambda_s \mathbf{r}_x(t) + \mathbf{s}_x(t)$$

In practice: a white noise signal.

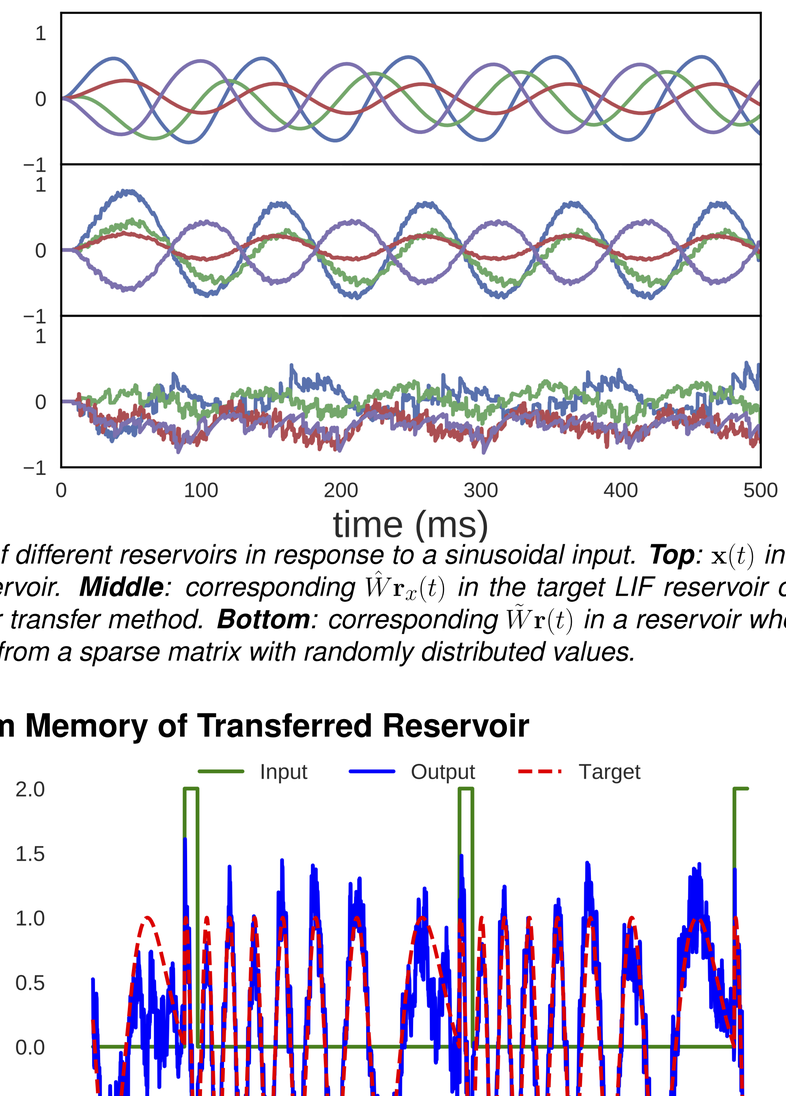
Step 2: "learn"

For some time points t_k :

$$\underset{\hat{W}}{\text{minimize}} \sum_{t_k} ||\hat{W}\mathbf{r}_x(t_k) - \mathbf{x}(t_k)||_2^2$$

Results

Visualize network state variables

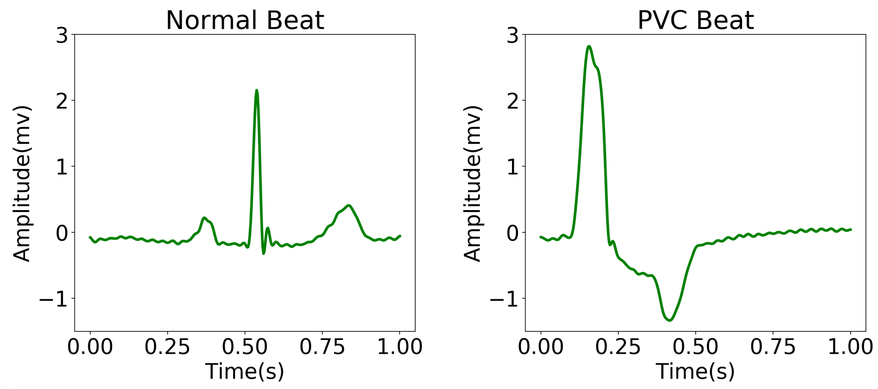


*Dynamics of different reservoirs in response to a sinusoidal input. **Top**: $\mathbf{x}(t)$ in a leaky ESN teacher reservoir. **Middle**: corresponding $\hat{W}\mathbf{r}_x(t)$ in the target LIF reservoir created using the reservoir transfer method. **Bottom**: corresponding $\tilde{W}\mathbf{r}(t)$ in a reservoir whose recurrent weights are from a sparse matrix with randomly distributed values.*

Short-term Memory of Transferred Reservoir

A reverse-chirp signal can be generated by the transferred reservoir of LIF neurons with ternary weights when it is driven by a step signal with very short (10 ms) high signal followed by a long (200 ms) silence.

Case study: Abnormal heartbeat detection using DYNAP-se [1] board



*On-chip SNN with transferred reservoir can classify normal and PVC (Premature Ventricular Contraction) heart beats in a ECG signal. **Left**: a normal heartbeat. **Right**: a PVC heart beat. Dataset: recordings from lead II of file #119 of MIT-BIH ECG arrhythmia database [2].*

	Accuracy	Sensitivity	Precision	F1-score
Standard ESN	98.24 %	92.21 %	100 %	95.95 %
SNN on DYNAP-se board	97.56%	87.50 %	98.00 %	92.45 %

Acknowlegement and references. The work was funded through the European Horizon 2020 project NeuRAM3 (grant 687299).

[1] S. Moradi, N. Qiao, F. Stefanini and G. Indiveri, A scalable multicore architecture with heterogeneous memory structures for dynamic neuromorphic asynchronous processors (DYNAPs). In *IEEE transactions on biomedical circuits and systems*, 12(1):106-122, 2018.

[2] A. L. Goldberger, et al., "PhysioBank, PhysioToolkit, and PhysioNet: components of a new research resource for complex physiologic signals", *Circulation*, 101(23):e215–e220, 2000.

Full paper

Codes on GitHub