SpiNNaker2 Tutorial: Beyond Neural Simulation

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TECHNISCHE UNIVERSITÄT DRESDEN

SpiNNcloud

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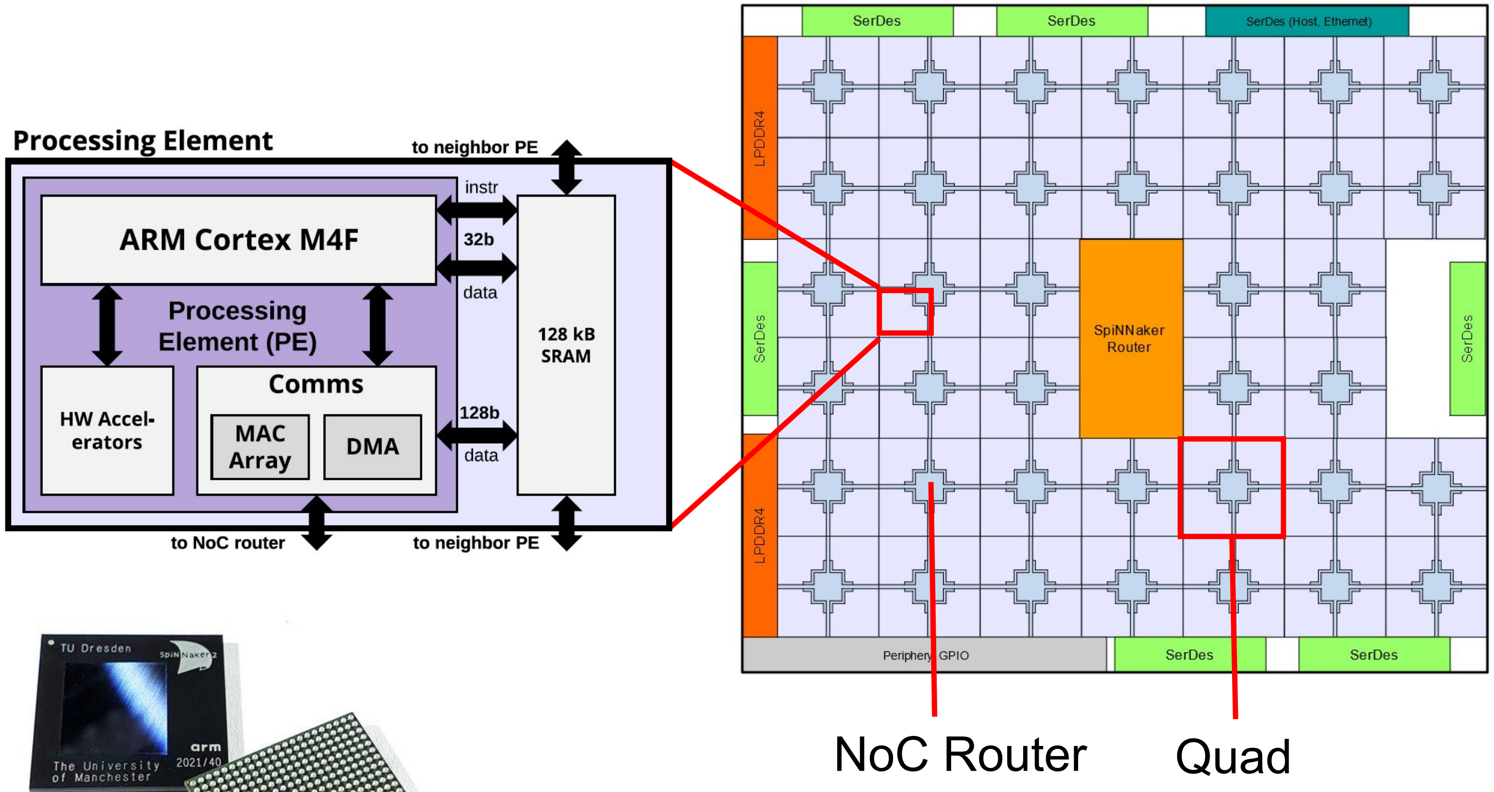
SACHSEN
Diese Maßnahme wird mitfinanziert durch Steuermittel auf der Grundlage des vom Sächsischen Landtag beschlossenen Haushaltes.

Overview

- Introduction to SpiNNaker2 HW & SW
- Instruction on Access to SpiNNaker2 JupyterHub
- Demos:
  1. Py-spinnaker2 intro
  2. Brunel E/I network
  3. QUBO (Optimization)
  4. NIR for Inference of Spiking CNN for N-MNIST
  5. Event-Prop (Live demo)
- Discussion & Outlook

SpiNNaker2 Chip



102 mm², GF 22FDX technology

SpiNNaker2 Chip

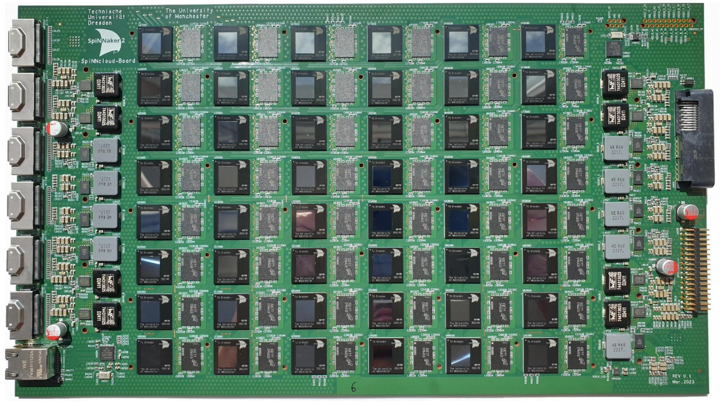
- 152 processing elements
  - Arm Cortex-M4F processor
  - 128 KB SRAM
  - DNN accelerator (MAC array)
  - exp, log, RNG accelerator
- SpiNNaker router
- 6 chip-to-chip links
- LPDDR4 interface

Key Features

- scalable event-based communication
- brain-inspired “neuromorphic” computing using ARM & accelerators
- Efficient DNN processing using MAC array

The „SpiNNcloud“ at TU Dresden

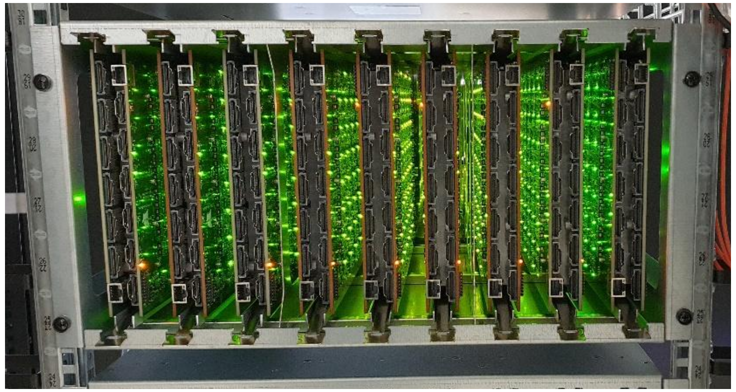
SpiNNcloud Board



48 SpiNNaker2 chips with 2 GB DRAM each

Card frame

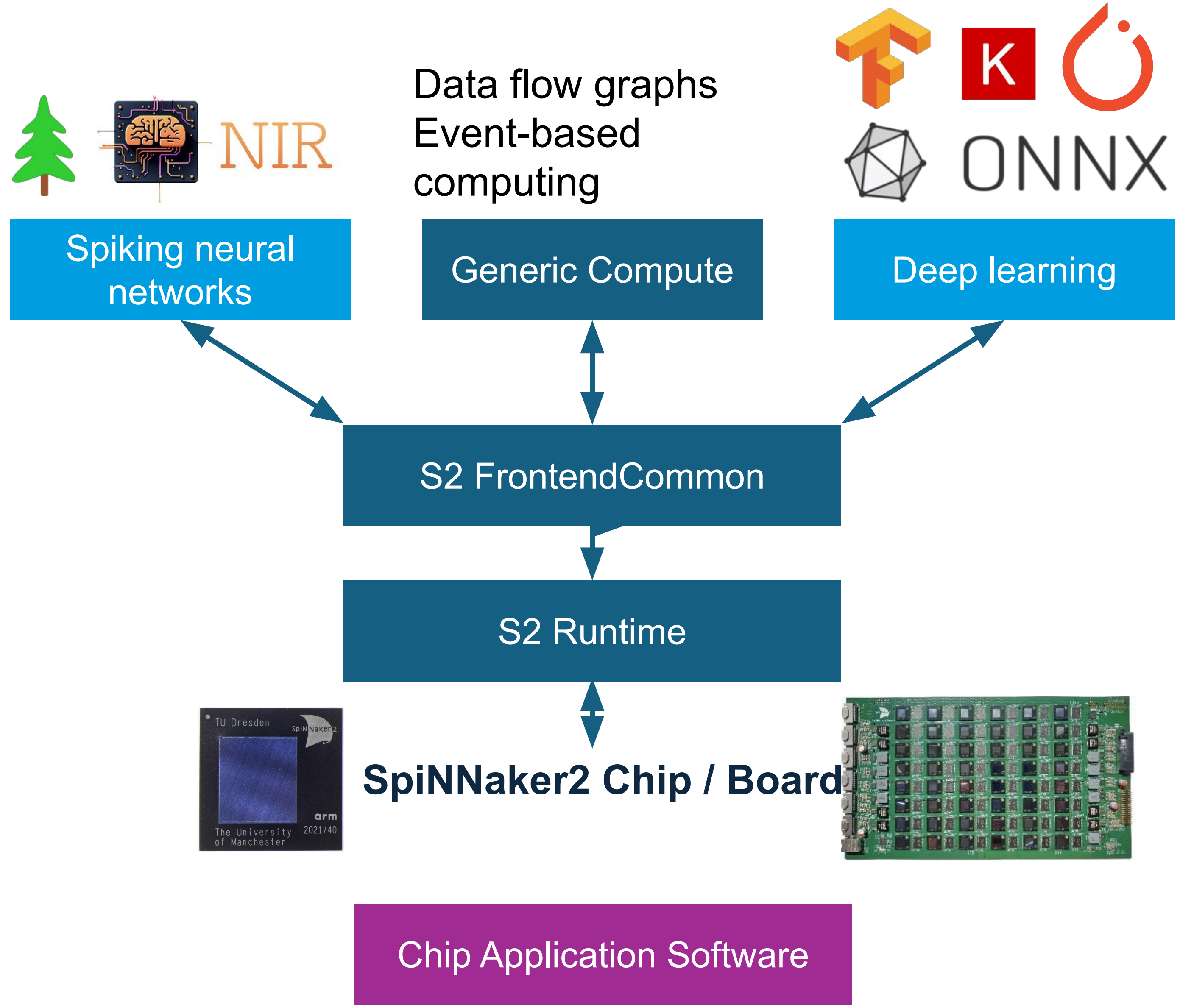
With 18 boards and water cooling



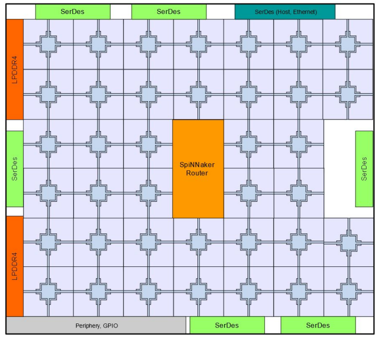
5 Million Core Machine

8 racks with 5 card frames

SpiNNaker2 Software Stack

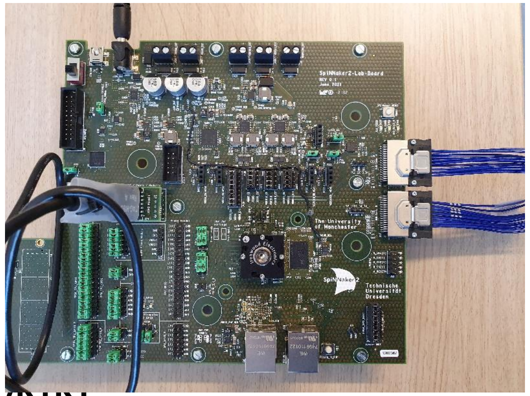


py-spinnaker2: SNN & hybrid SNN/DNN



Light-weight Python interface for SNNs or hybrid networks

- Code: https://gitlab.com/spinnaker2/py-spinnaker2
- Docs: https://spinnaker2.gitlab.io/py-spinnaker2/



User interface:

- Define SNN in terms of Populations and Projections with API similar to PyNN
- Various neuron models and spike sources
- Recording of spikes and voltages
- If no chip available, use brian2 backend

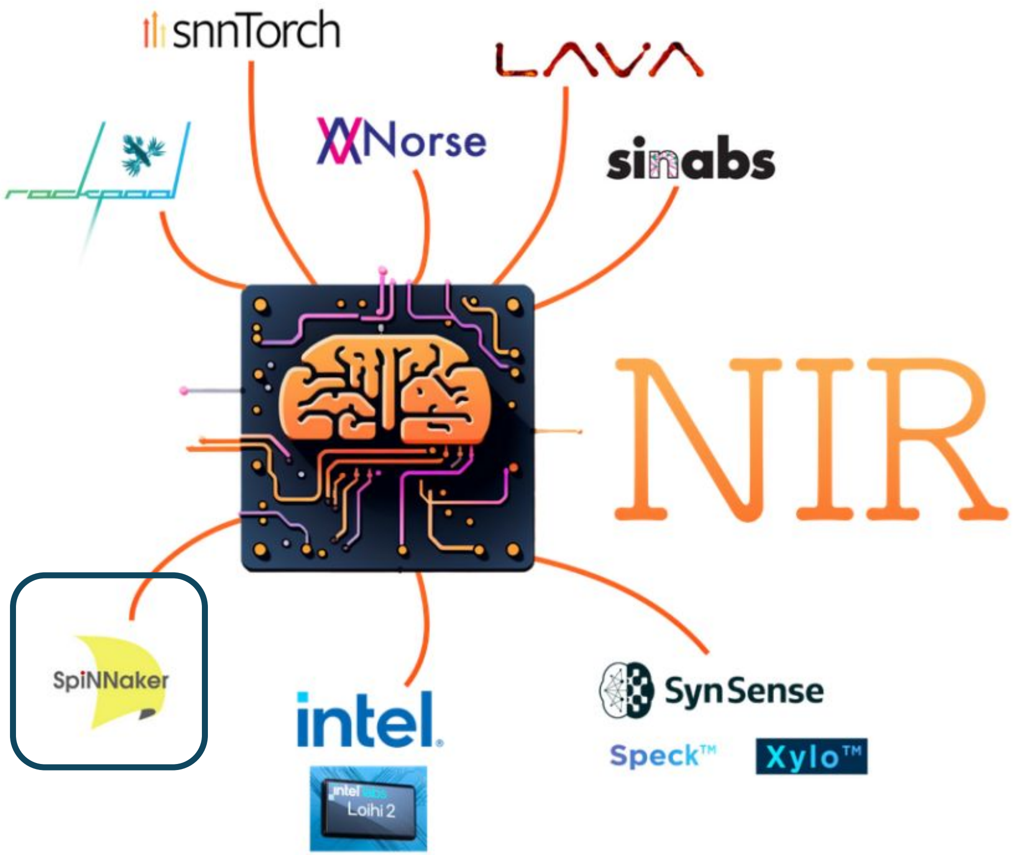
BRIAN

```
from spinnaker2 import snn, hardware

neuron_params = {
        "threshold":1.,
        "alpha_decay":0.9,
        }

stim = snn.Population(
        size=10,
        neuron_model="spike_list",
        params={0:[1,2,3], 5:[20,30]},
        name="stim")

pop1 = snn.Population(
        size=20,
        neuron_model="lif",
        params=neuron_params,
        name="pop1")
```

Used for all hands-on examples

Neuromorphic intermediate representation (NIR)

- Support to run deep SNN on SpiNNaker2:
  Train in any SNN training framework and convert via NIR to py-spinnaker2
- NIR was developed together with the neuromorphic community (started in Telluride 2023)
  Serves as an intermediate representation format similar to ONNX for DNN
  Goal: greater interoperability
  Supports 7 software frameworks (e.g. snnTorch, lava, Norse, NengoDL) and 4 hardware systems
  https://neuroir.org/



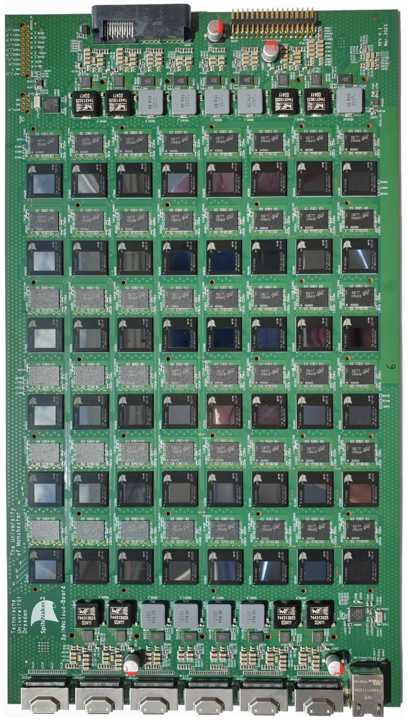
See demo “04-nir”

PyNN: Migration of sPyNNaker

Large-scale SNN simulation using PyNN

- Will support large set of PyNN neuron models and also pasticity mechanisms
- Will re-use large parts from SpiNNaker1 stack (pyNN.sPyNNaker)
- Current work:
  - Adaption of low-level software: scamp2, sark2, SpiNNman2
- Next steps of the migration:
  - Adapt PACMAN for configuration of new SpiNNaker2 router
  - Port first neuron models with static synapses
- Availability: H2/2025 for 48-node boards

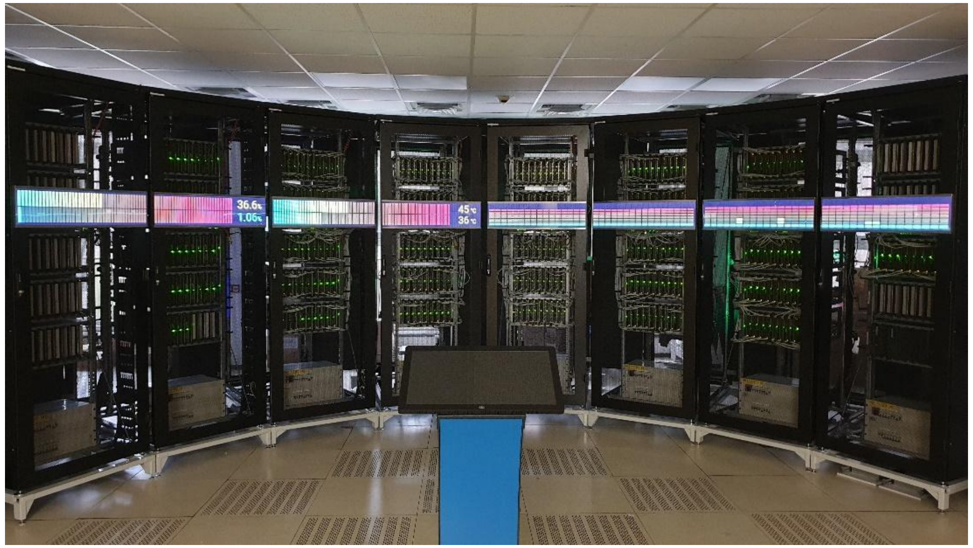
SpiNNcloud Board



48 SpiNNaker2 chips
with 2 GB DRAM each

Hands-on Tutorial

- Jupyterhub (Accessible via TUD-VPN): http://jupyter.spinncloud.et.tu-dresden.de/
- Accounts are temporary and just for this workshop
- Access to one 48-node board per user
- Make sure to set the IP address of your board in the code



SpiNNaker2 Documentation & Resources

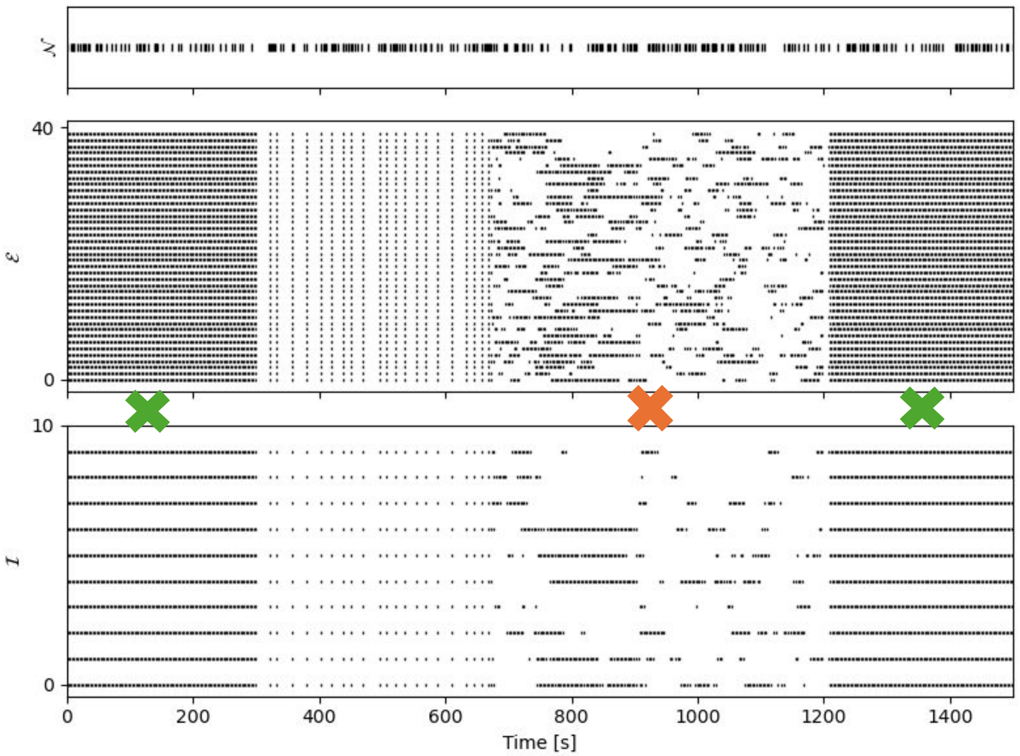
- General SpiNNaker2 Documentation: https://spinnaker2.gitlab.io/
- SNN API: https://spinnaker2.gitlab.io/py-spinnaker2/snn-api/
- Neuron Models: https://spinnaker2.gitlab.io/py-spinnaker2/neuron-models/
- Git repository with Jupyter Notebooks: https://gitlab.com/spinnaker2/tutorial-nice-2025/

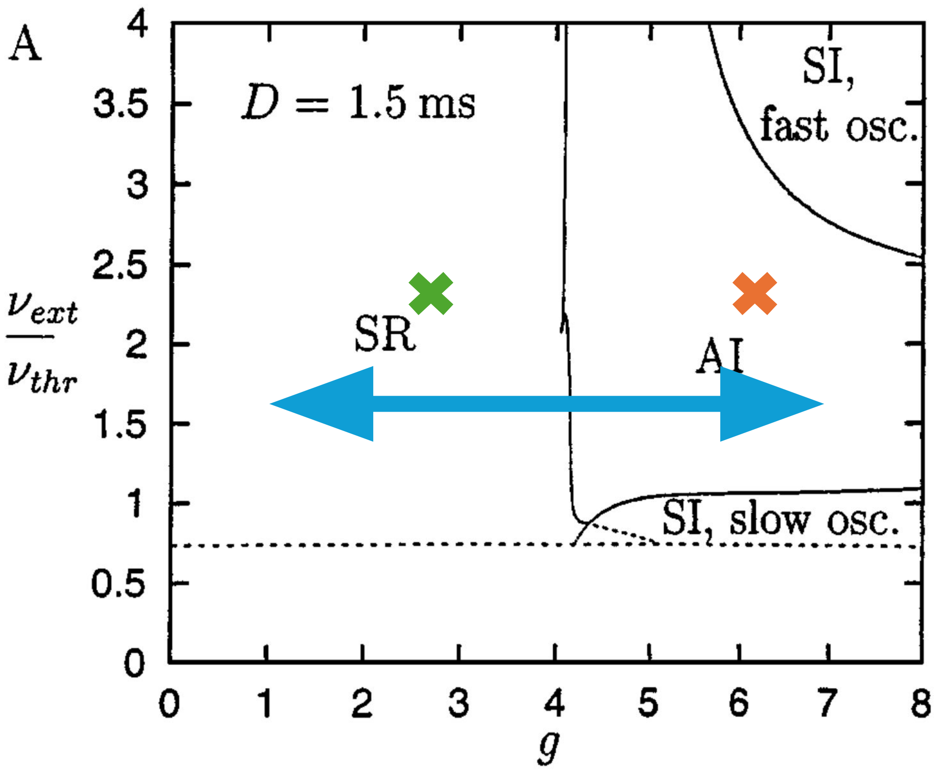
SpiNNcloud

[NEST Source]

Brunel Network

- EI network, all-to-all sparse connectivity incl. autapses, Poisson input to all neurons (1:N)
- N = NE + NI + 1 = scale * (4 + 1) + 1
- Aim: Balanced network of LIF neurons w/ alpha synapses
  - Stable regimes of different behaviour, synchronous vs. asynchronous, regular vs. irregular,…





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Quadratic Unconstrained Binary Optimization (QUBO)

- Numerous combinatorial optimization problems, such as Graph/Number Partitioning, Maxcut, SAT, Graph Coloring, and TSP, can be efficiently represented using **QUBO**'s streamlined mathematical expressions

- QUBO objective function:

Type of problem: depending on the type of the problem, the objective can be to minimize or maximize this function

Q-matrix: usually symmetric or upper-triangular. Coefficients and shape depend on the optimization problem

$$\text{minimize/maximize } y = x^t Q x$$

Vector of binary decision variables: Represents a candidate solution

- QUBO problems are solved using **quantum annealing**, **simulated annealing**, and **genetic algorithms**

QUBO and SNNs

- Natural correspondence between **binary decision variables** and many **neuromorphic primitives** such as **binary neurons**, **spiking neurons**, etc.

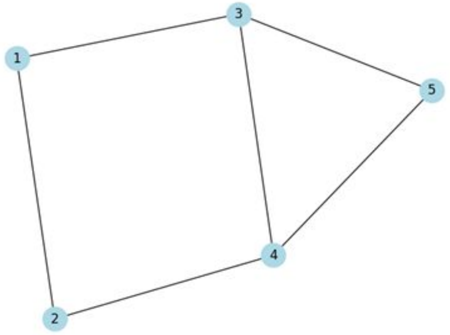
- Linear and quadratic weights correspond to biases and synapses

- The Q-matrix describes the construction of a recurrent network of spiking neurons. The resulting **network dynamics** will attempt to **converge** to a solution

- Random excitation of neurons injects energy into the system. Possible sources of randomness on SpiNNaker: **spike trains**, **input weights**, **synaptic delays**, **noise on membrane potentials**

QUBO: Spinnaker2 pipeline

1. Mapping Problems to QUBO



$$Q = \begin{bmatrix} -2 & 1 & 1 & 0 & 0 \\ 1 & -2 & 0 & 1 & 0 \\ 1 & 0 & -3 & 1 & 1 \\ 0 & 1 & 1 & -3 & 1 \\ 0 & 0 & 1 & 1 & -2 \end{bmatrix}$$

Glover, Fred, Gary Kochenberger, and Yu Du. "Quantum Bridge Analytics I: a tutorial on formulating and using QUBO models." 4or 17 (2019): 335-371.

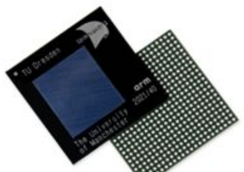
2. Build SNN based on Q-matrix

Graph nodes → neurons
Graph edges → synaptic weights

Specialized **neurons** with similar **dynamics** as simulated annealing, which **evolve towards energy minimum** for optimization

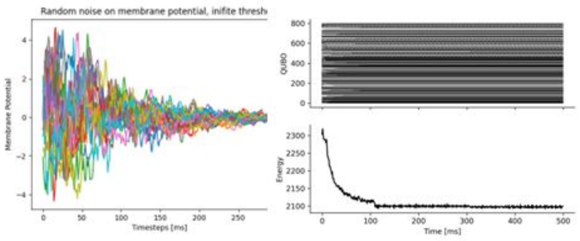
Spikes or membrane potentials can be used to encode the optimal QUBO solution

3. Run on SpiNNaker & evaluate



At each time step we get a new **solution candidate** based on the **output spiking** activity.

Example of **decaying noise** injected into the system and **convergence** to **solution**



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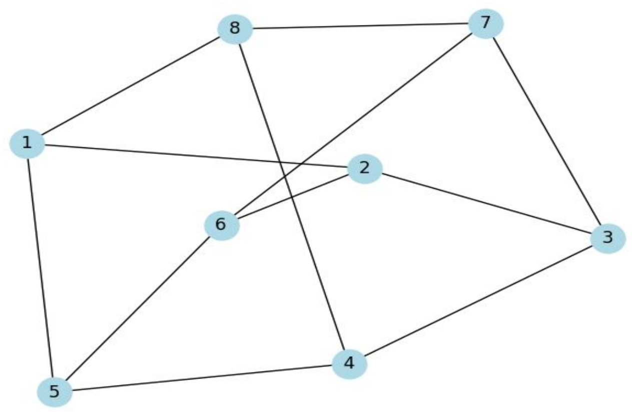
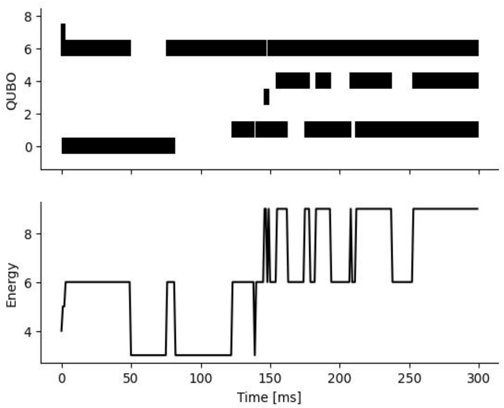
QUBO: Maxcut example

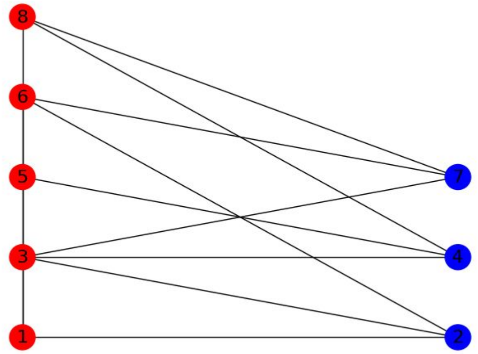
Graph (8 nodes)



SpiNNaker SNN simulation



Partitioned Graph (maximum energy)



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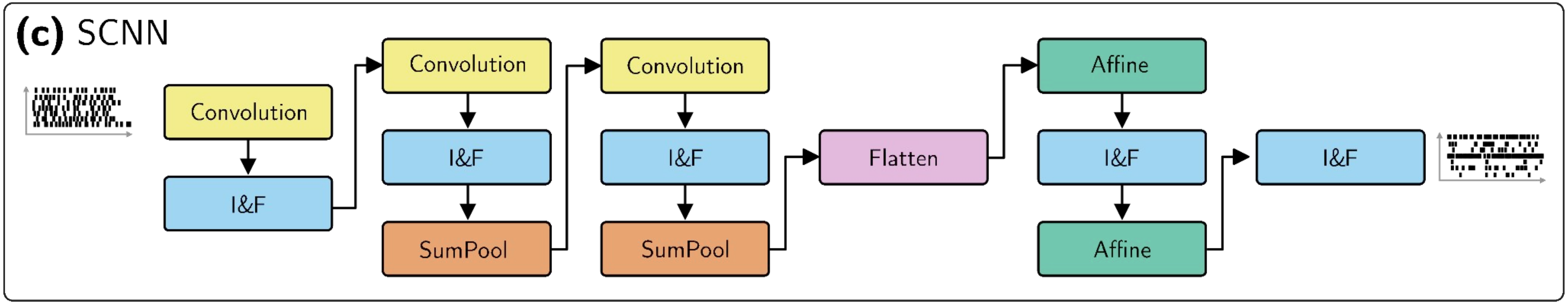
NIR → SpiNNaker2

Demo: Spiking CNN for N-MNIST



Results from paper:

	Simulator						Both	Hardware		
	Nengo	**Norse**	**Rockpool**	**Sinabs**	**snnTorch**	**Spyx**	**Lava**†	**Speck**	**SpiNNaker2**	**Xylo**
SCNN	98.1%	98.1%	N/A	<u>98.5%</u>	97.9%	97.1%	98.2%	95.4%	98.2%	N/A

SCNN in sinabs and py-spinnaker2

```python
model = nn.Sequential(
    nn.Conv2d(2, 20, 5, 1, bias=False),
    backend.IAFSqueeze(shape=[batch_size, 20, 30, 30]),
    nn.AvgPool2d(2, 2),
    nn.Conv2d(20, 32, 5, 1, bias=False),
    backend.IAFSqueeze(shape=[batch_size, 32, 11, 11]),
    nn.AvgPool2d(2, 2),
    nn.Conv2d(32, 128, 3, 1, bias=False),
    backend.IAFSqueeze(shape=[batch_size, 128, 3, 3]),
    nn.AvgPool2d(2, 2),
    nn.Flatten(),
    nn.Linear(128, 500, bias=False),
    backend.IAFSqueeze(shape=[batch_size, 500]),
    nn.Linear(500, 10, bias=False),
)
```

```python
from spinnaker2 import snn

# Populations
pop_in = snn.Population(2312, neuron_model="spike_list", params=input_spikes)
pop_1 = snn.Population(4096, neuron_model="lif_conv2d", params=params_p1)
pop_2 = snn.Population(4096, neuron_model="lif_conv2d", params=params_p2)
pop_3 = snn.Population(512, neuron_model="lif_conv2d", params=params_p3)
pop_4 = snn.Population(256, neuron_model="lif_no_delay", params=params_p4)
pop_out = snn.Population(10, neuron_model="lif_no_delay", params=params_out)

# Projections
proj_1 = snn.Conv2dProjection(pop_in, pop_1, weight_1, params_proj_1)
proj_2 = snn.Conv2dProjection(pop_1, pop_2, weight_2, params_proj_2)
proj_3 = snn.Conv2dProjection(pop_2, pop_3, weight_3, params_proj_3)
proj_4 = snn.Projection(pop_3, pop_4, conn_list_proj_4)
proj_5 = snn.Projection(pop_4, pop_out, conn_list_proj_5)

# Network
net = snn.Network("SCNN")
net.add(pop_in, pop_1, pop_2, pop_3, pop_4, pop_out,
        proj_1, proj_2, proj_3, proj_4, proj_5)
```

Outlook & Discussion

- 5M core machine in Dresden – next 6 months:
  - Applications on single 48-chip boards
  - Set up SLURM
  - Set up remote access for academia