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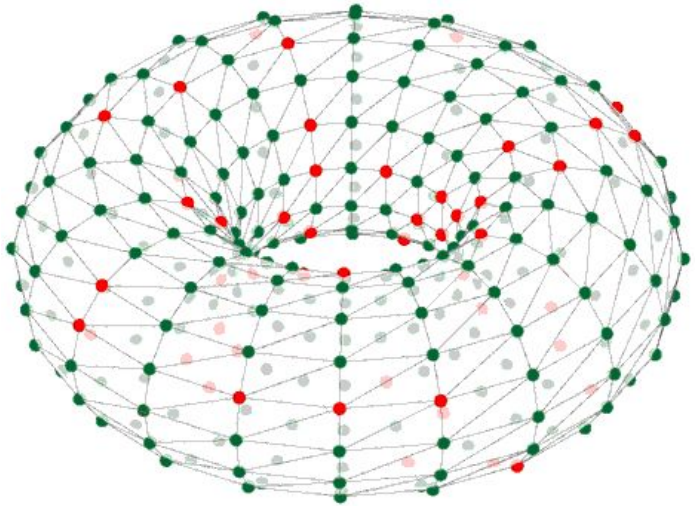
# SpiNNaker Tutorial



SpiNNaker

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# Accessing SpiNNaker

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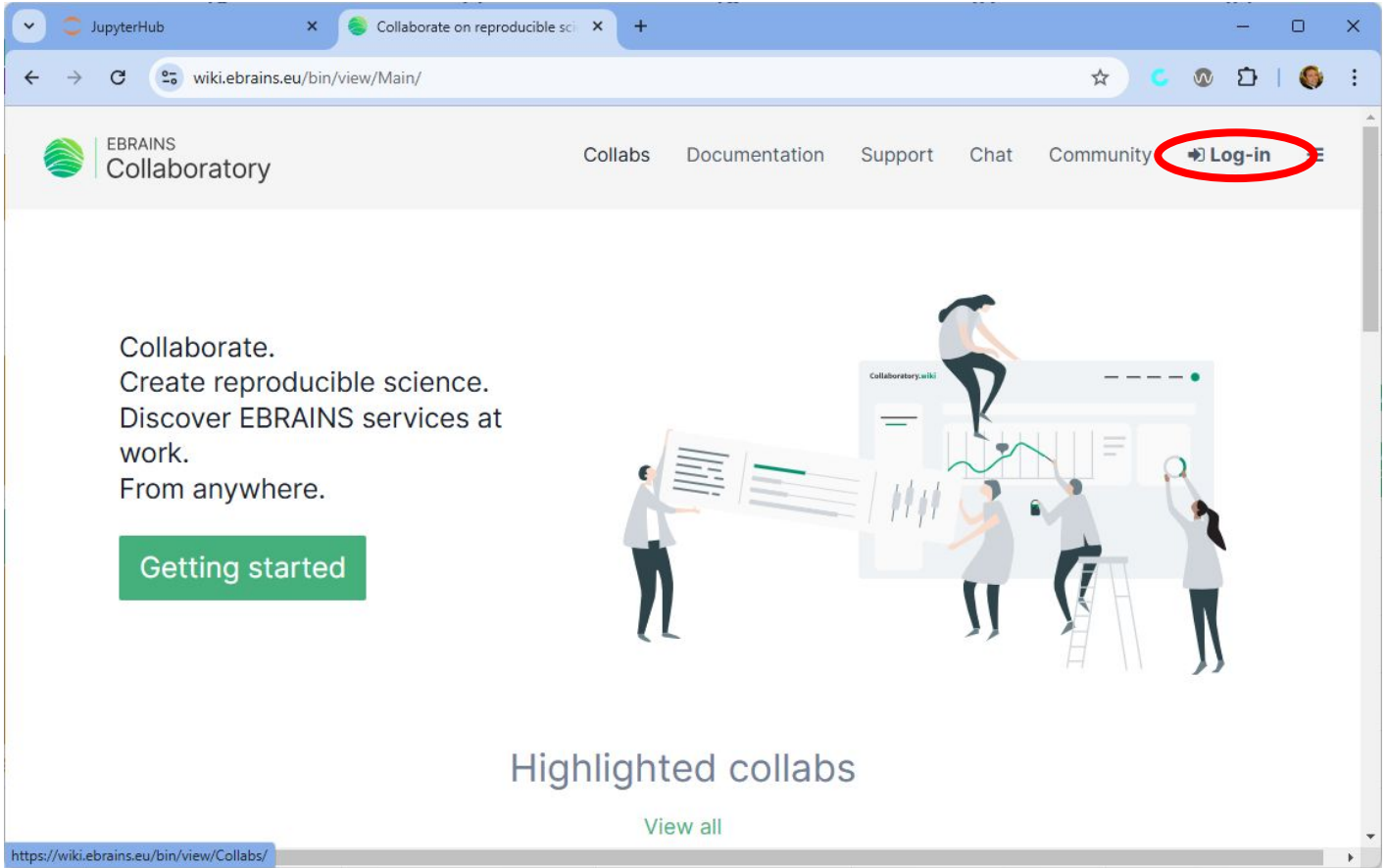
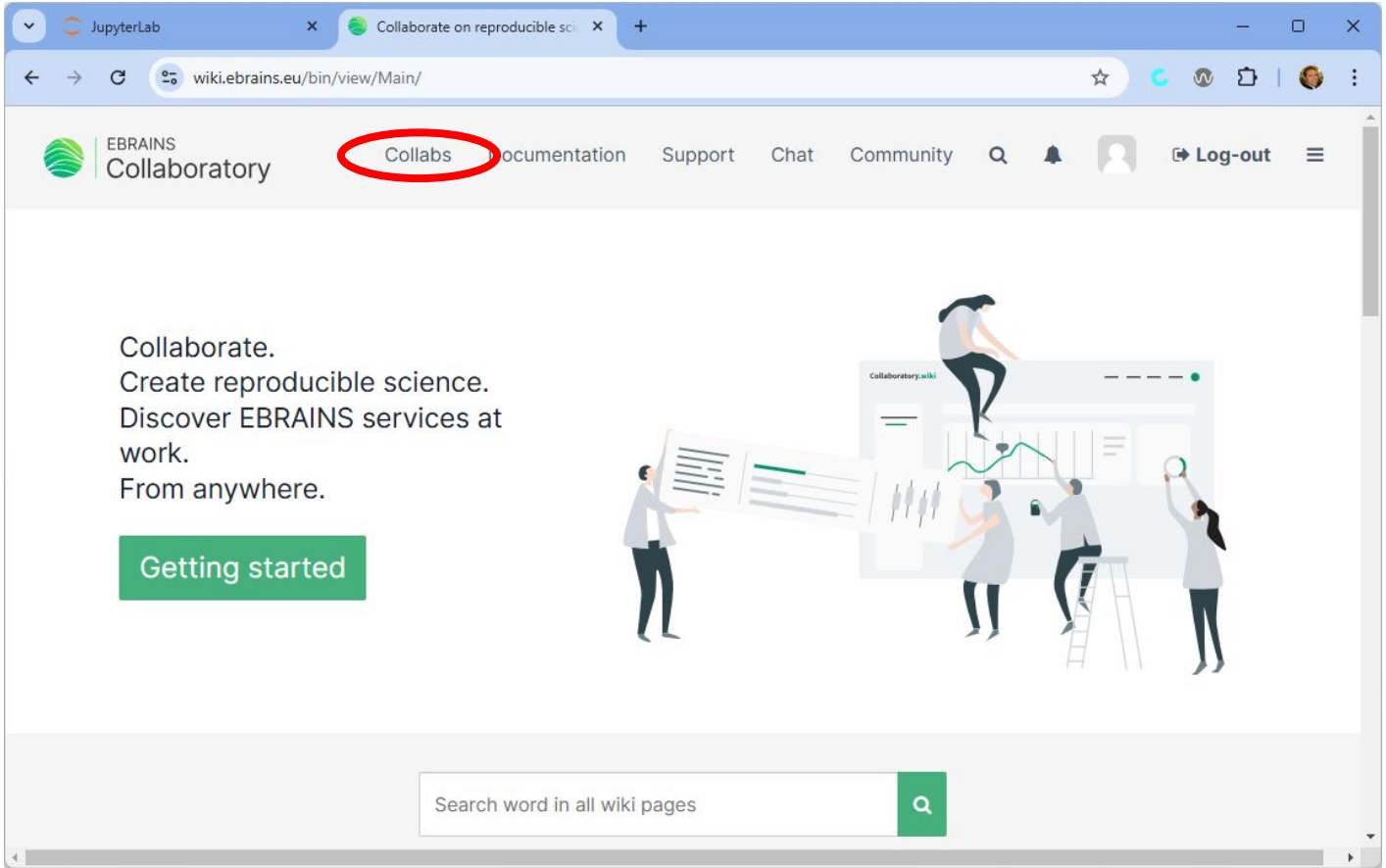
# Accessing SpiNNaker via Jupyter - Create a Collaboratory

https://wiki.ebrains.eu/

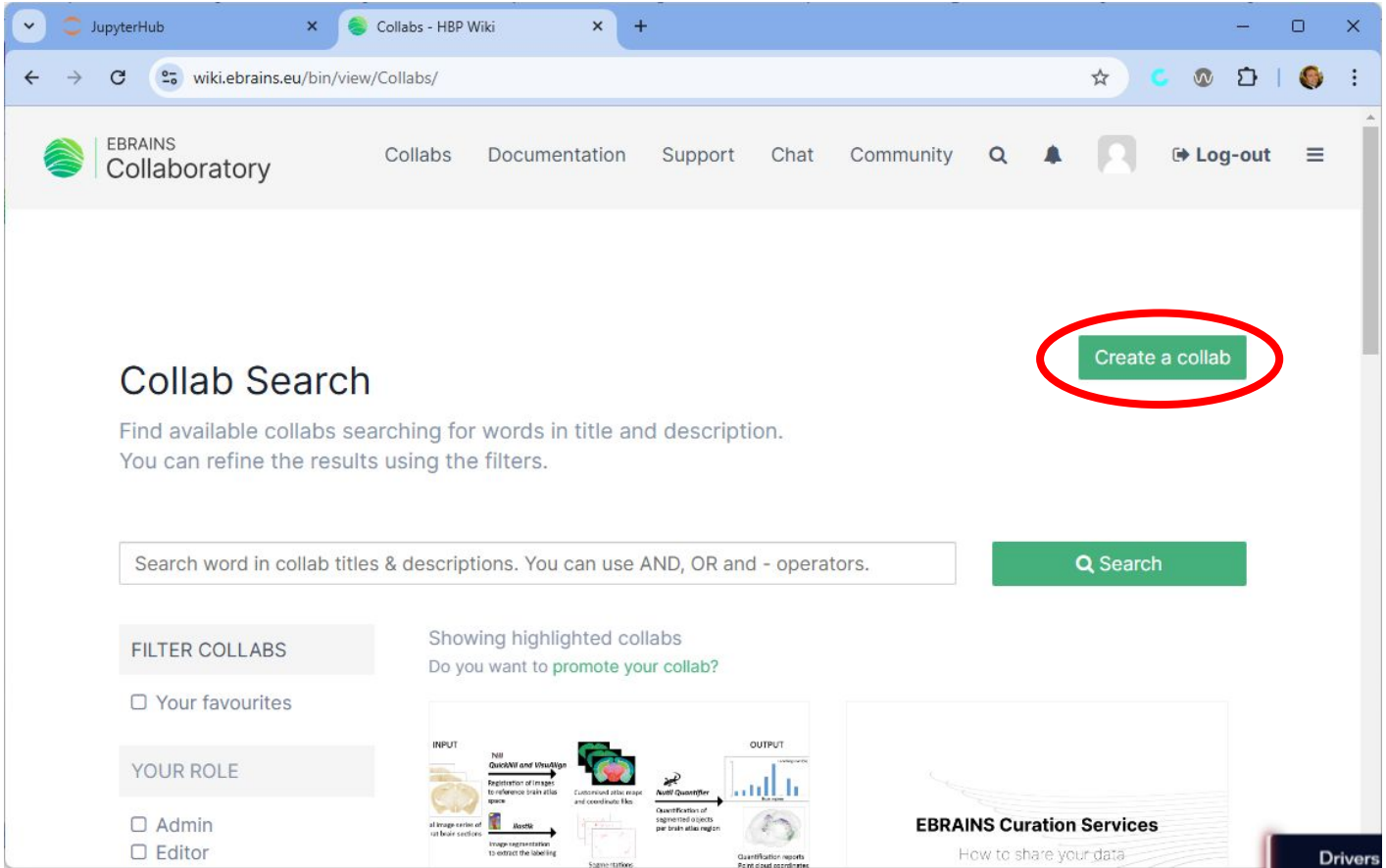
# Log in to Wiki



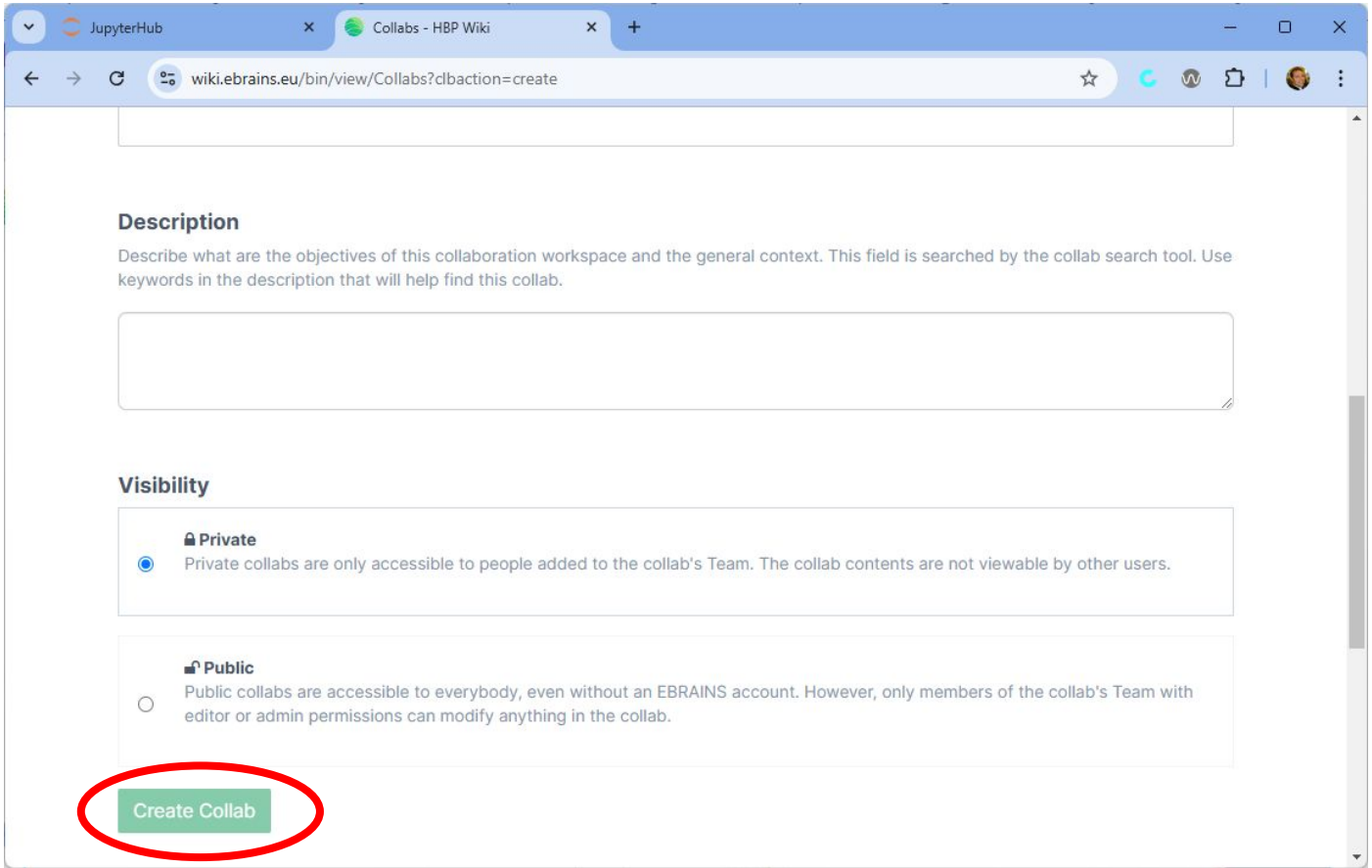
# Create a Collaboratory



# Create a Collaboratory



# Create a Collaboratory



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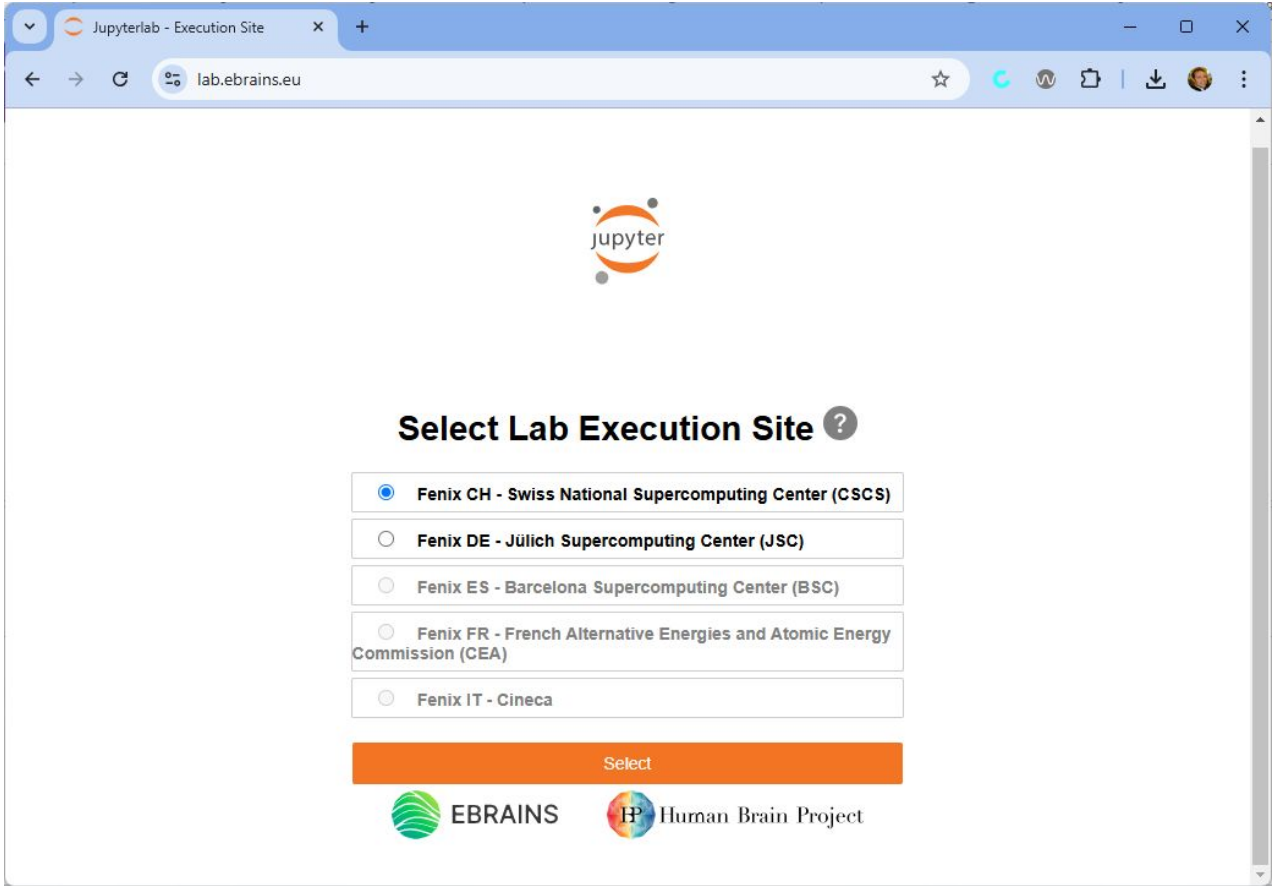
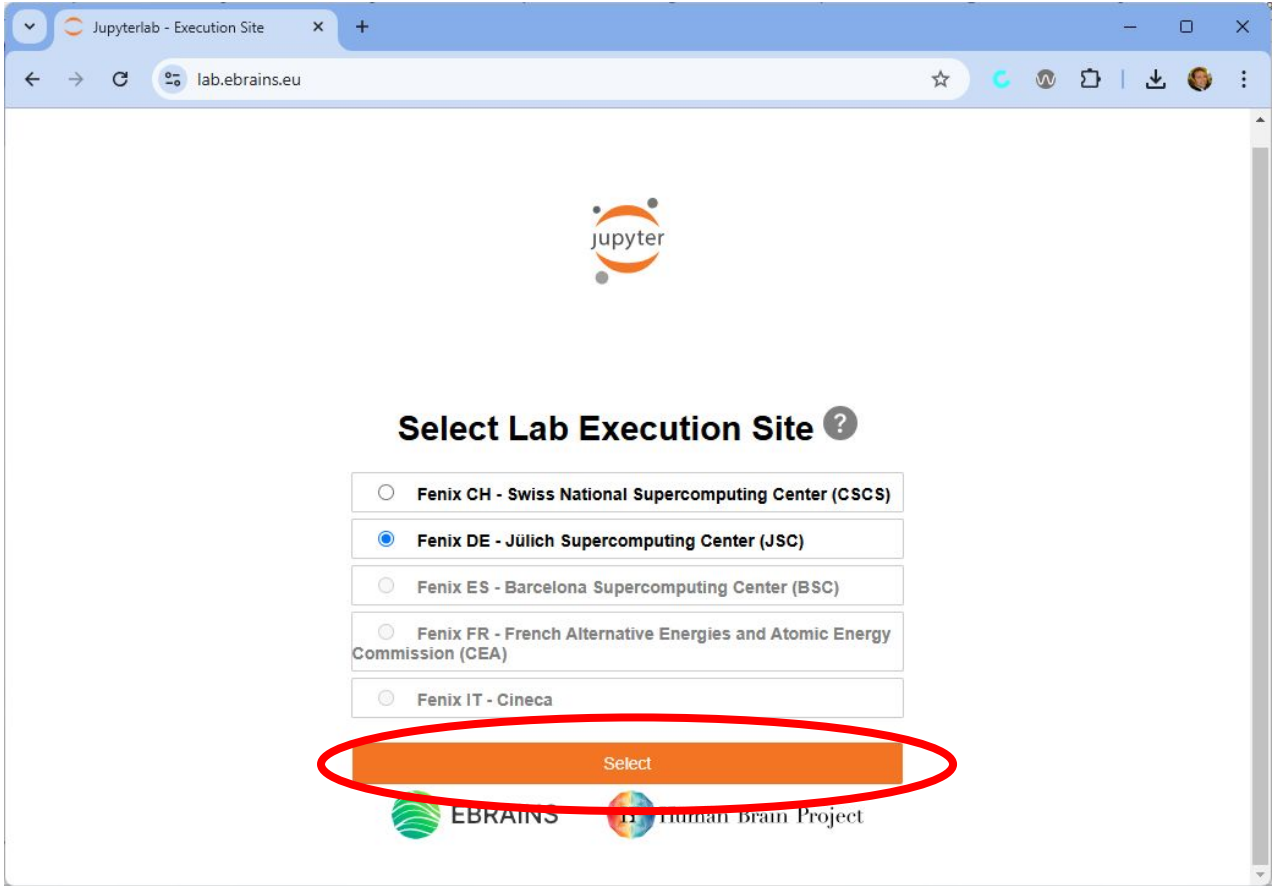
# Accessing SpiNNaker via Jupyter - Go to EBRAINS Lab

https://lab.ebrains.eu/

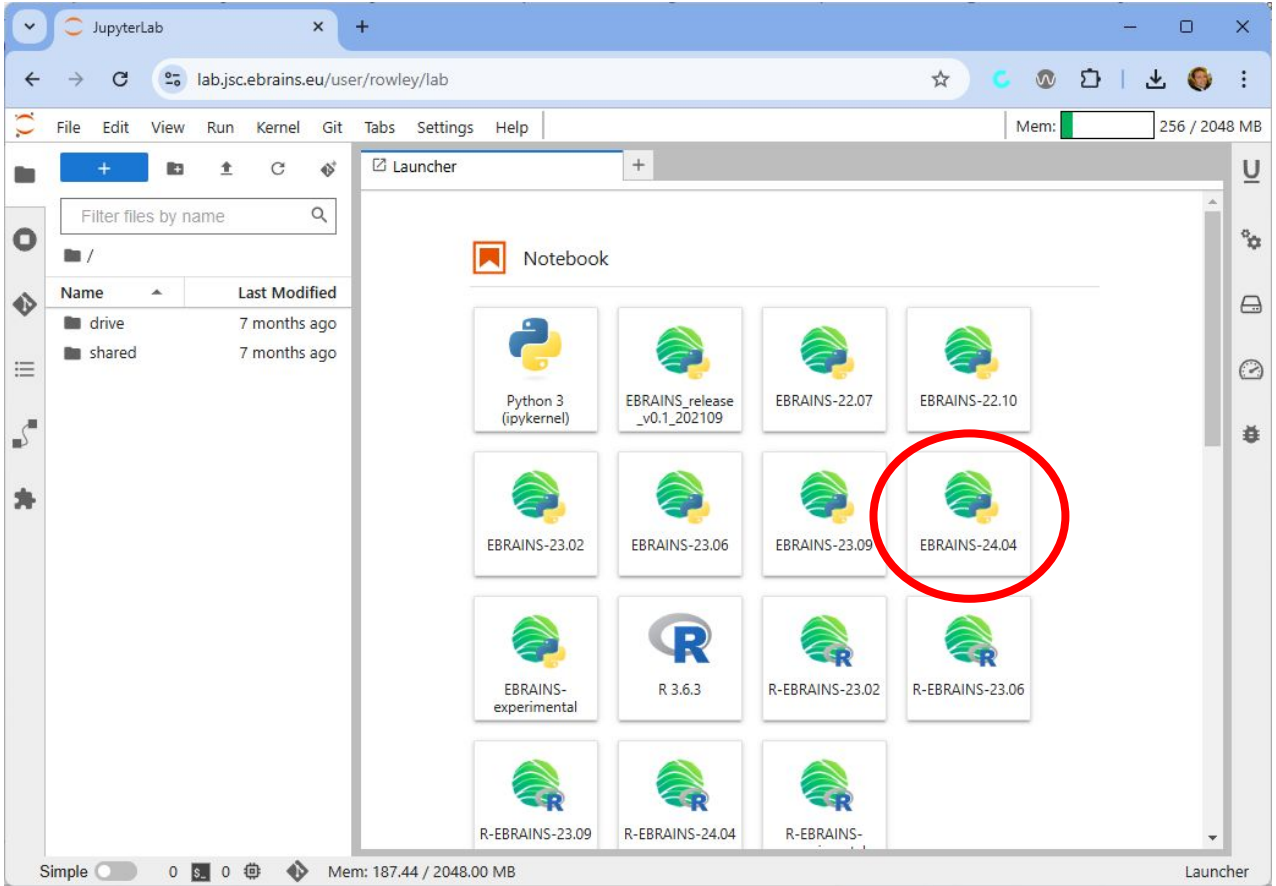
# EBRAINS Lab - Choose a Site



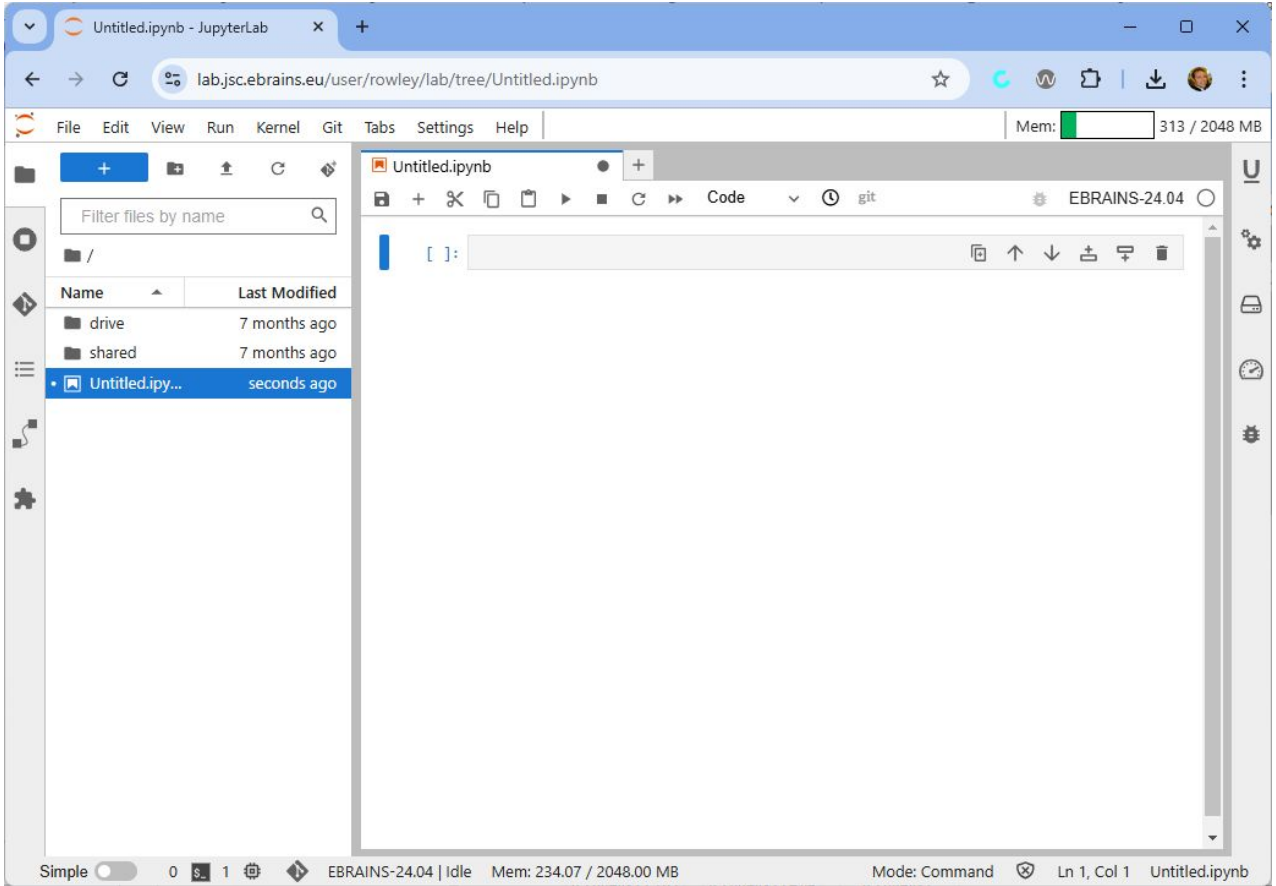
# EBRAINS Lab - Choose a Site



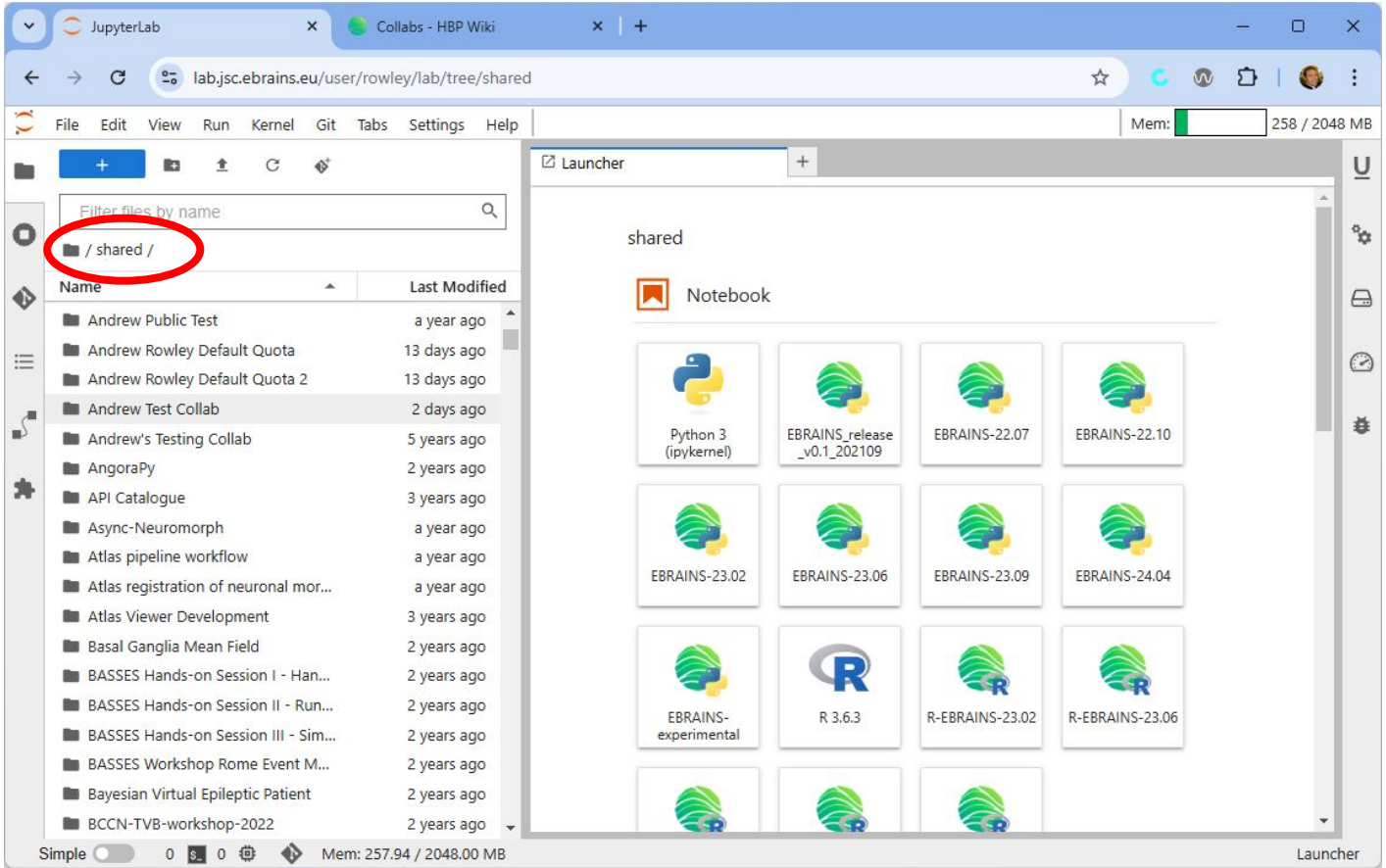
# EBRAINS Lab - Choose a Kernel



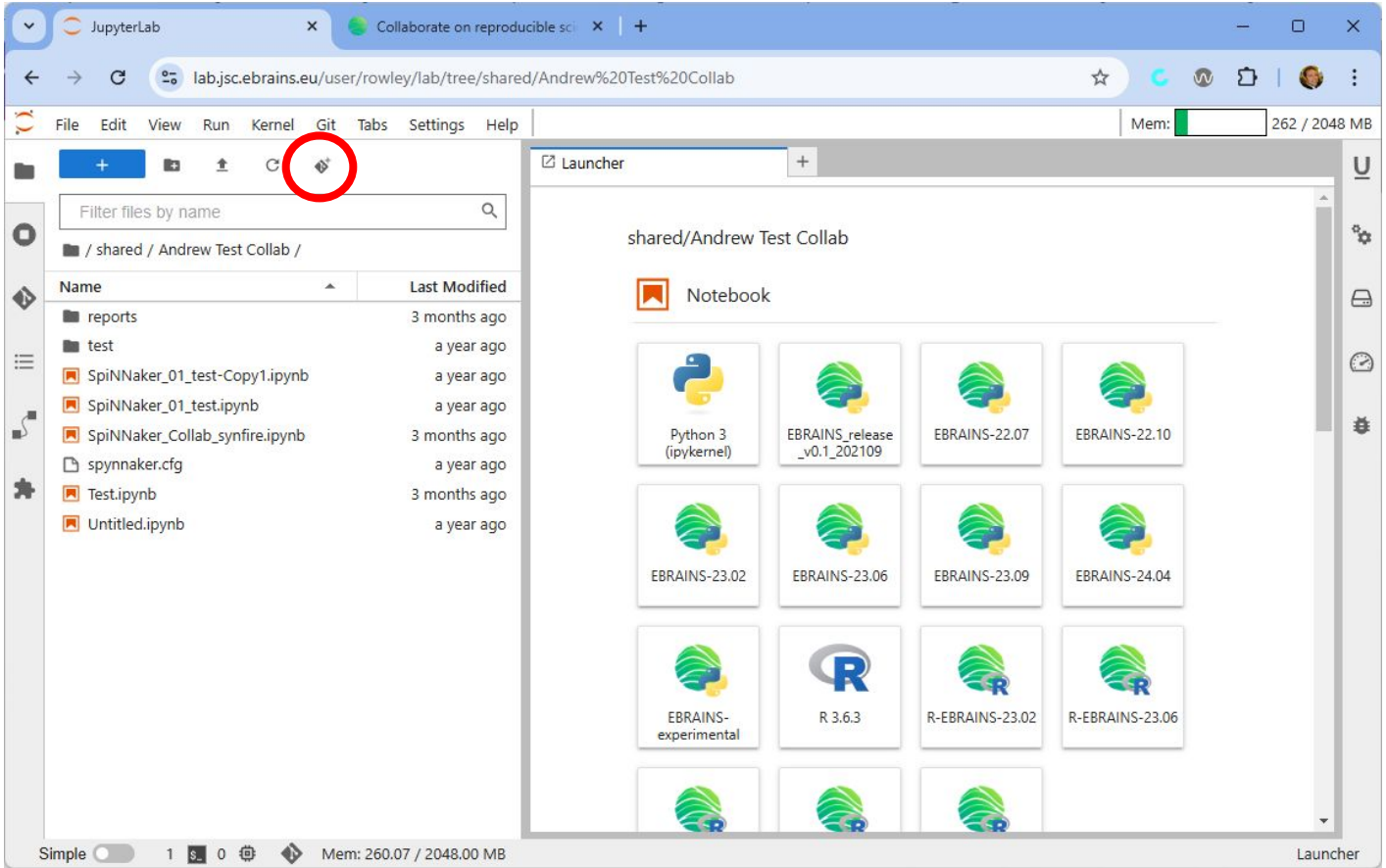
# EBRAINS Lab - Choose a Kernel



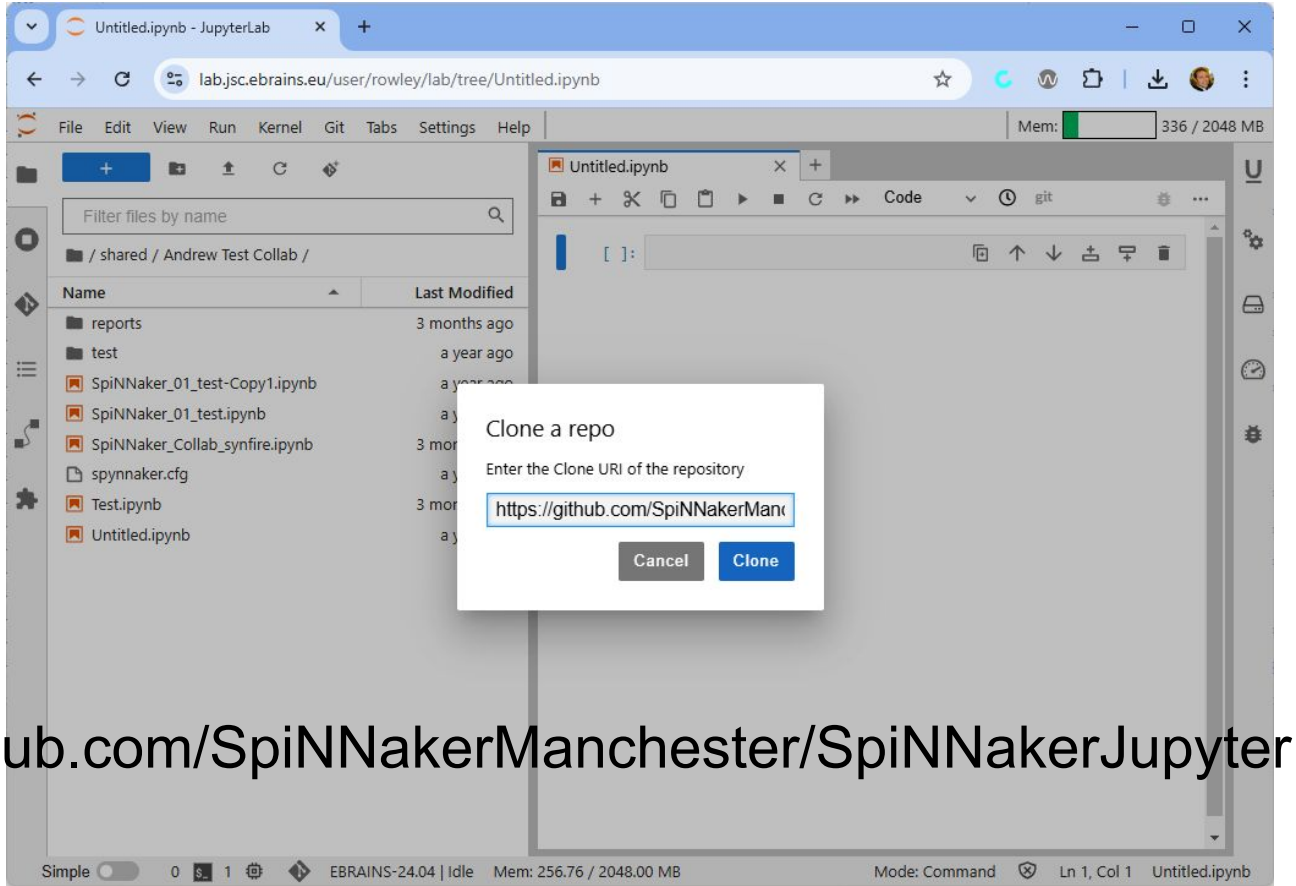
# Find your Collab: /shared/…



# Clone SpiNNaker Repository

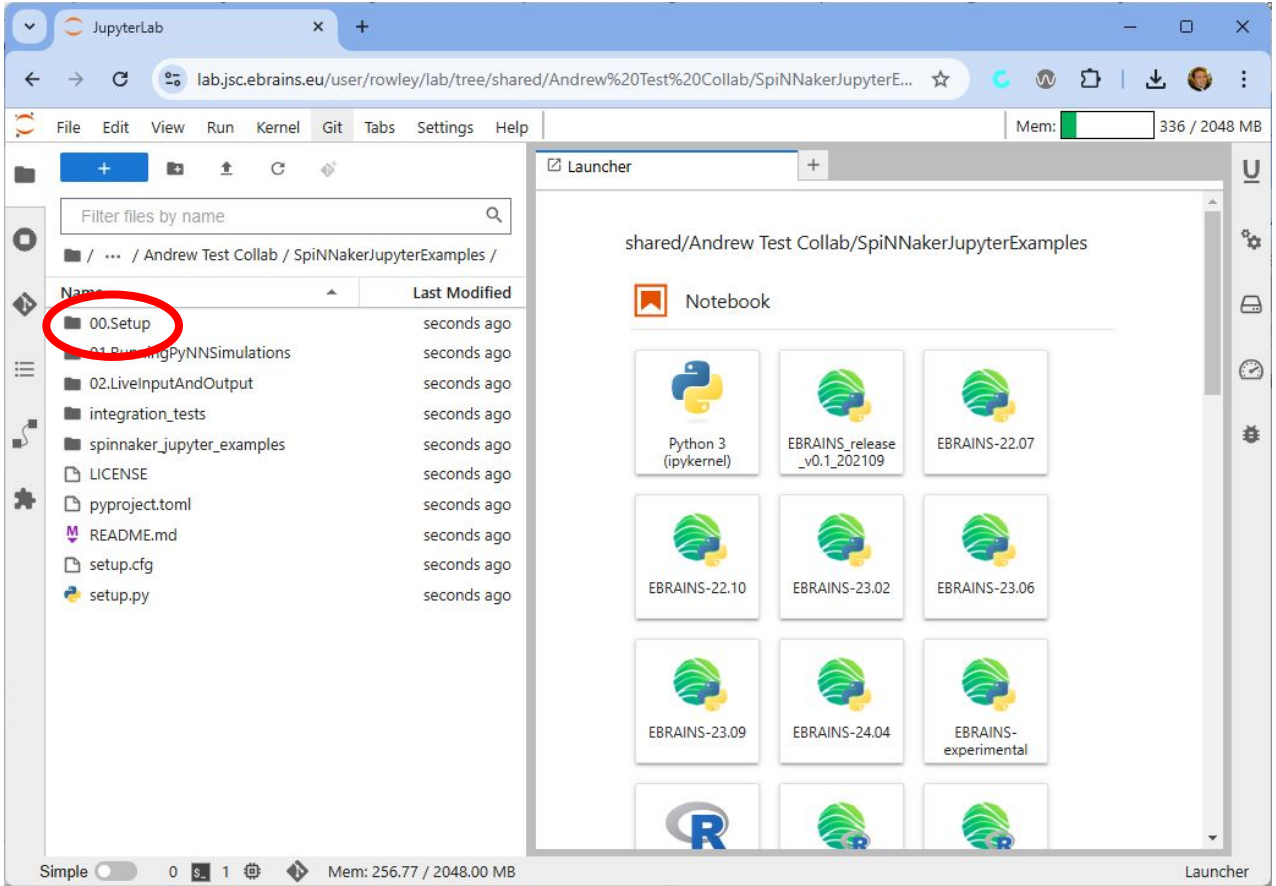


# Clone SpiNNaker Repository

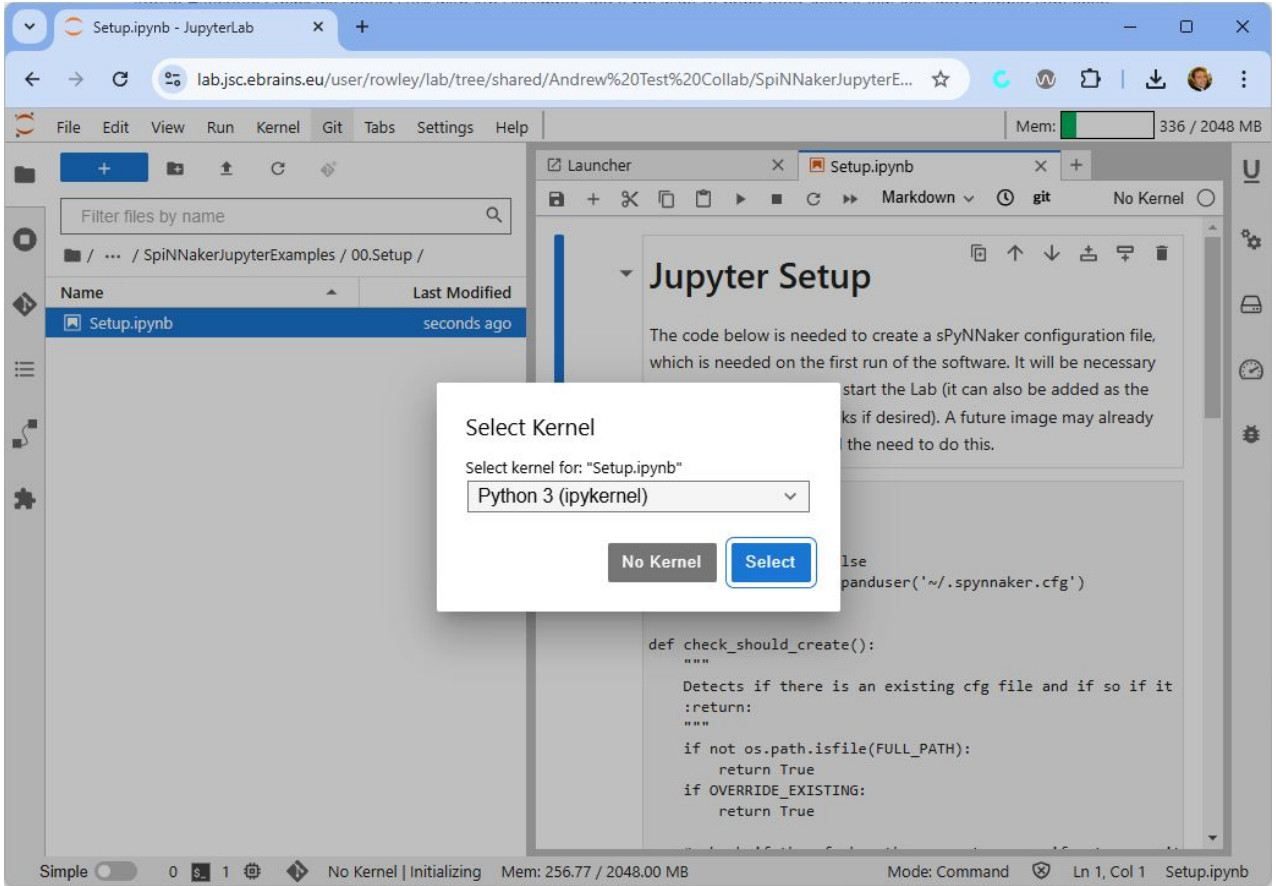



https://github.com/SpiNNakerManchester/SpiNNakerJupyterExamples

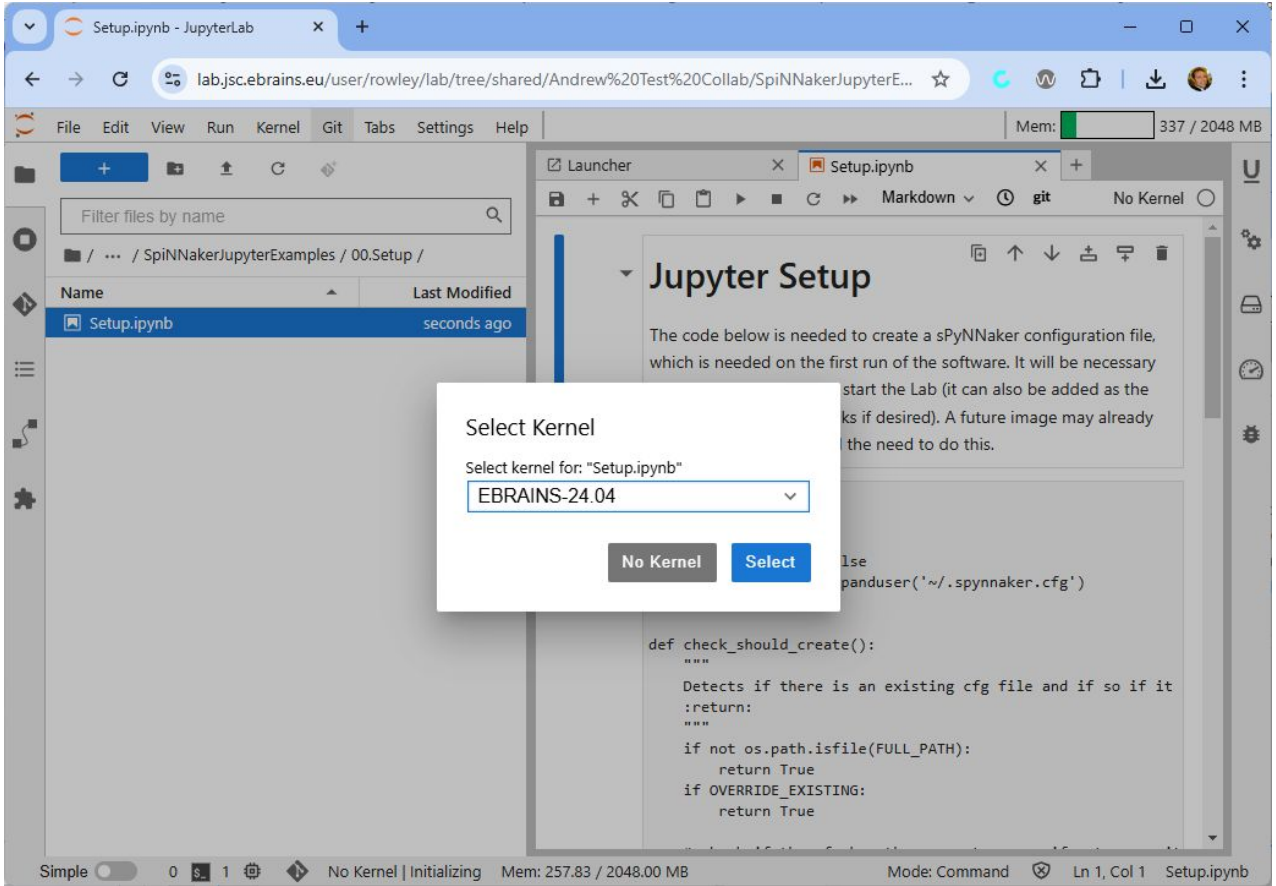
# Clone SpiNNaker Repository



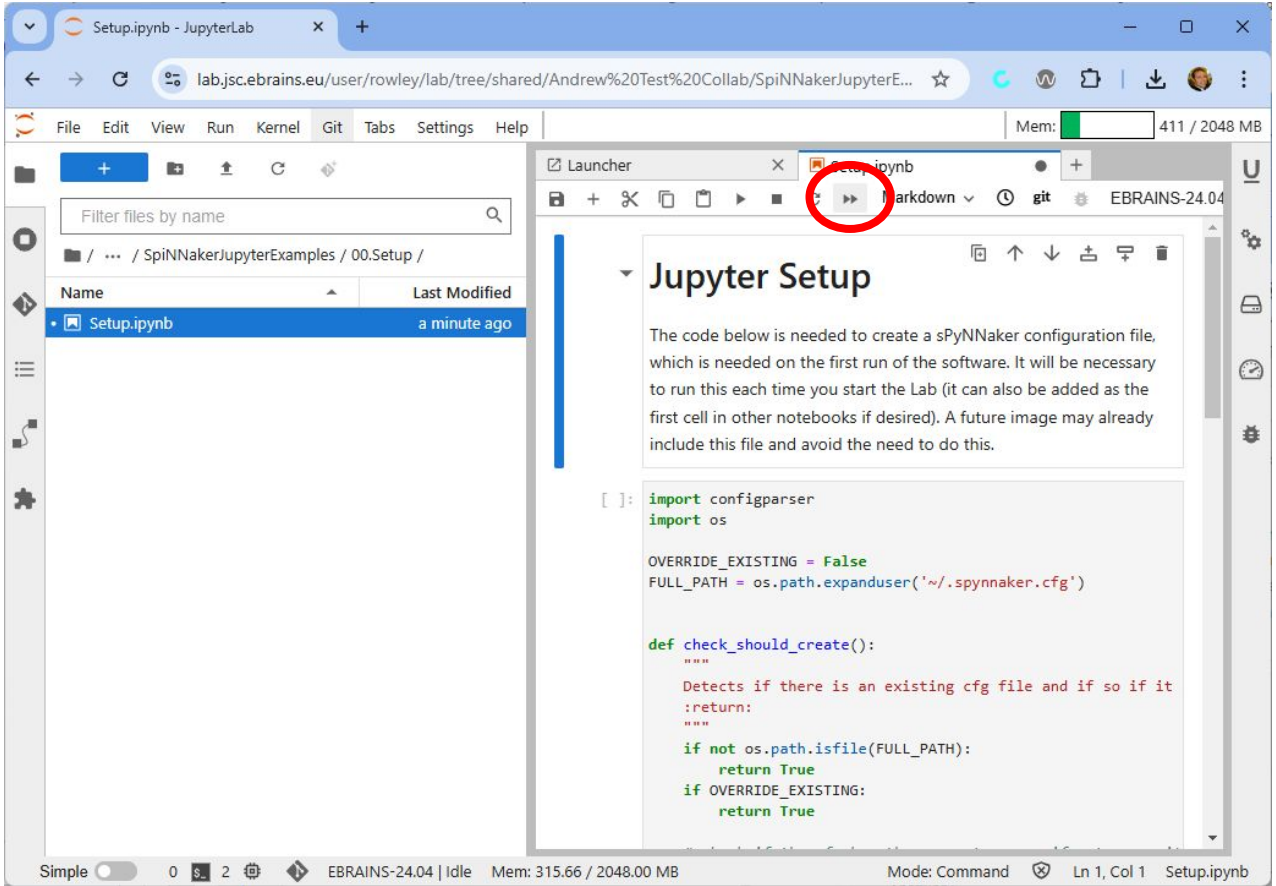
# Open Setup Notebook



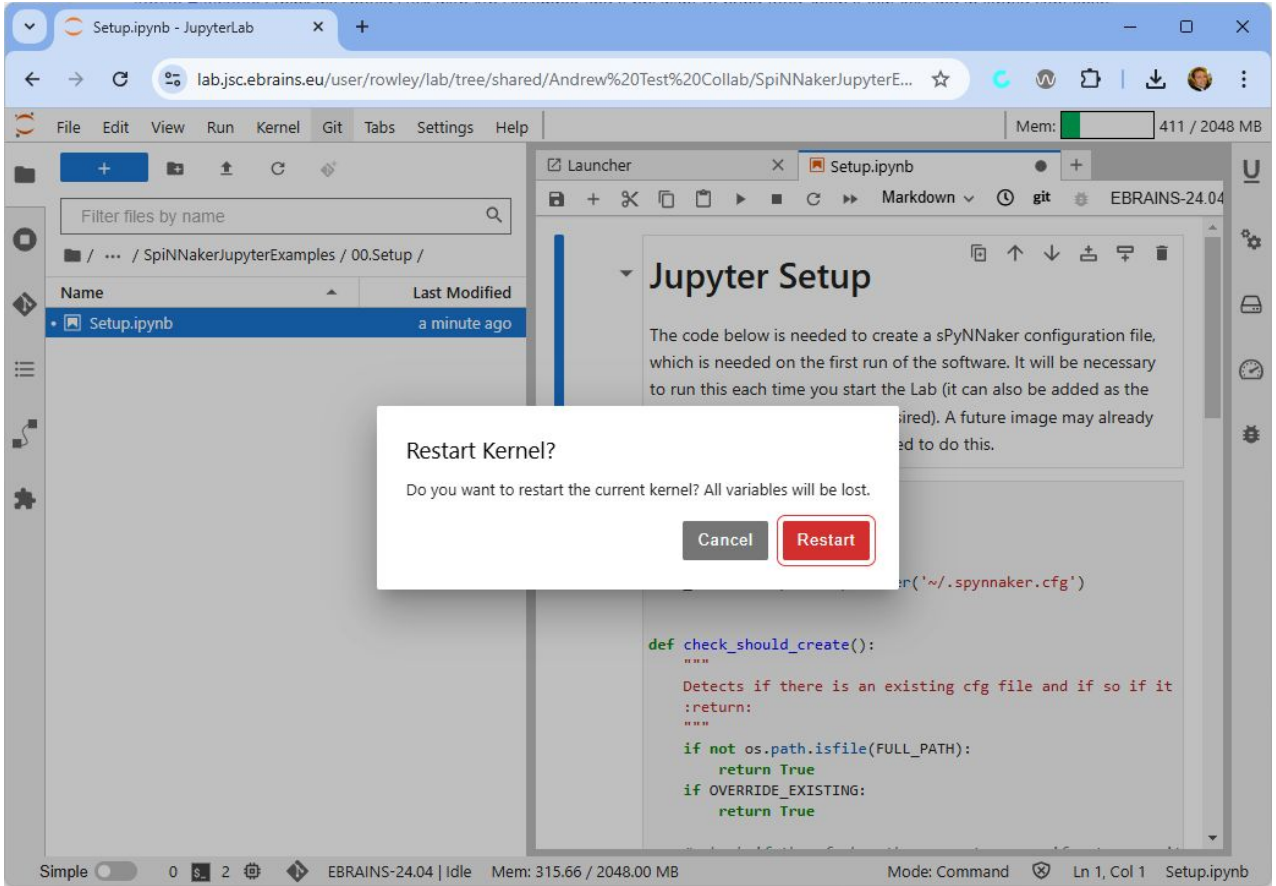
# Open Setup Notebook



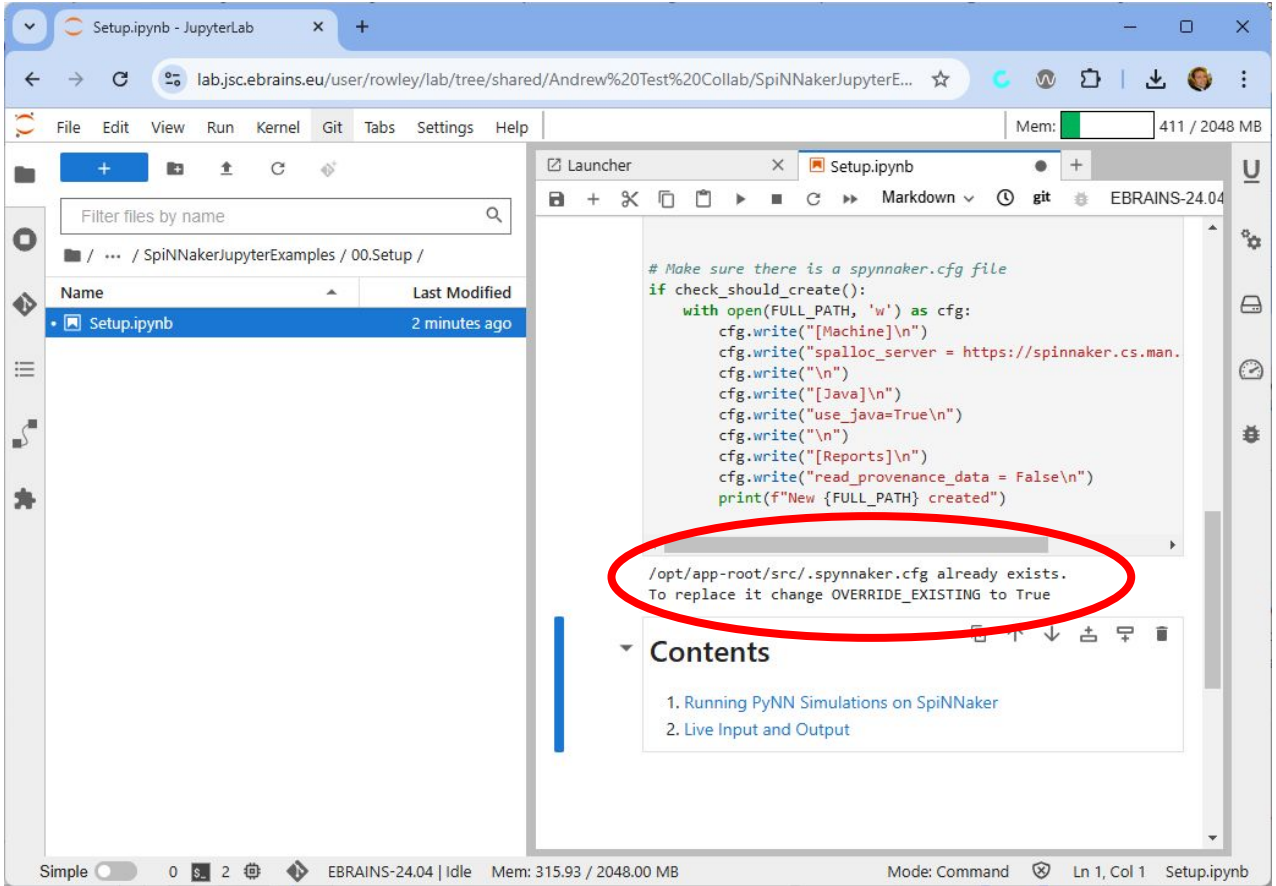
# Open Setup Notebook - Run



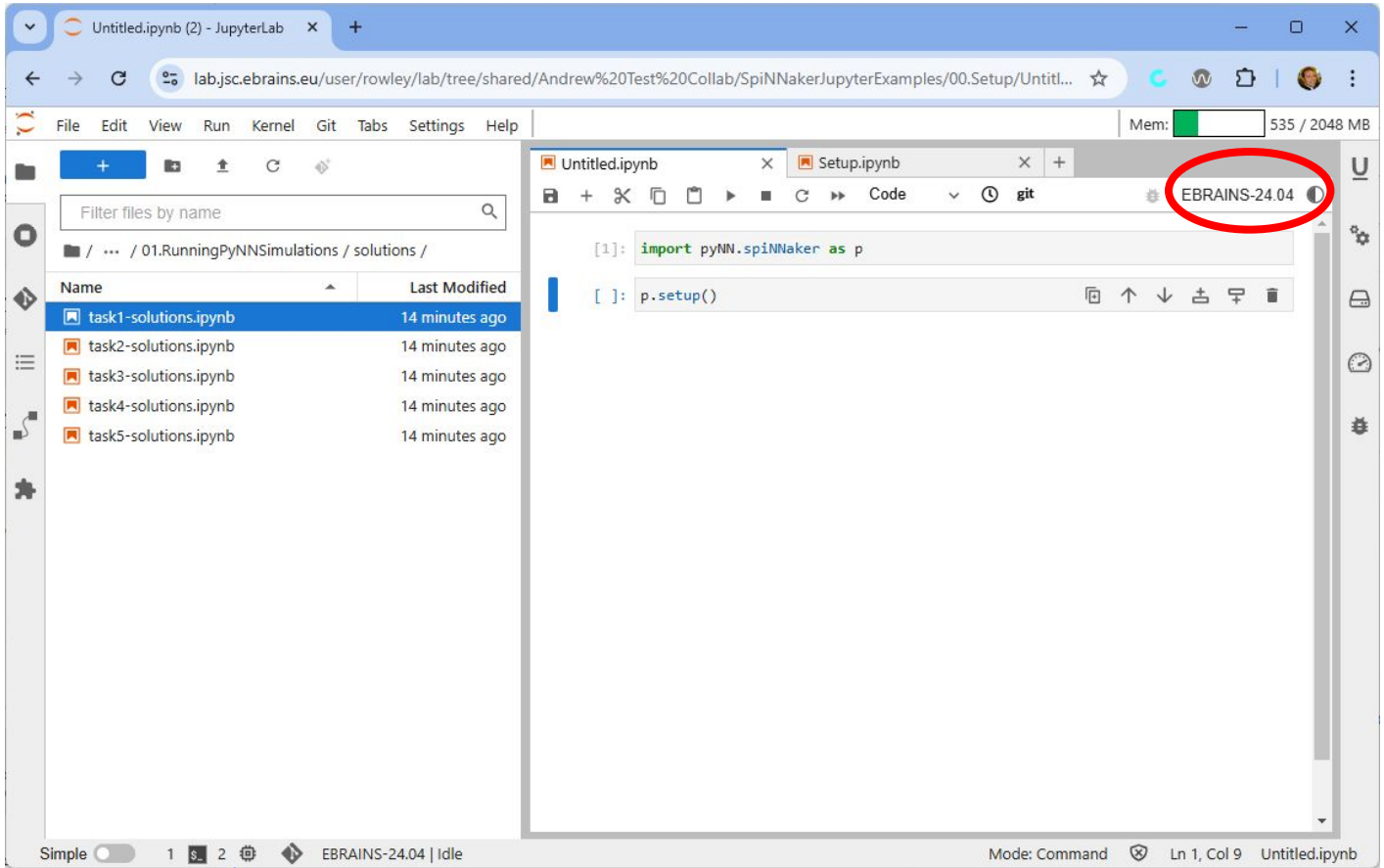
# Open Setup Notebook - Run



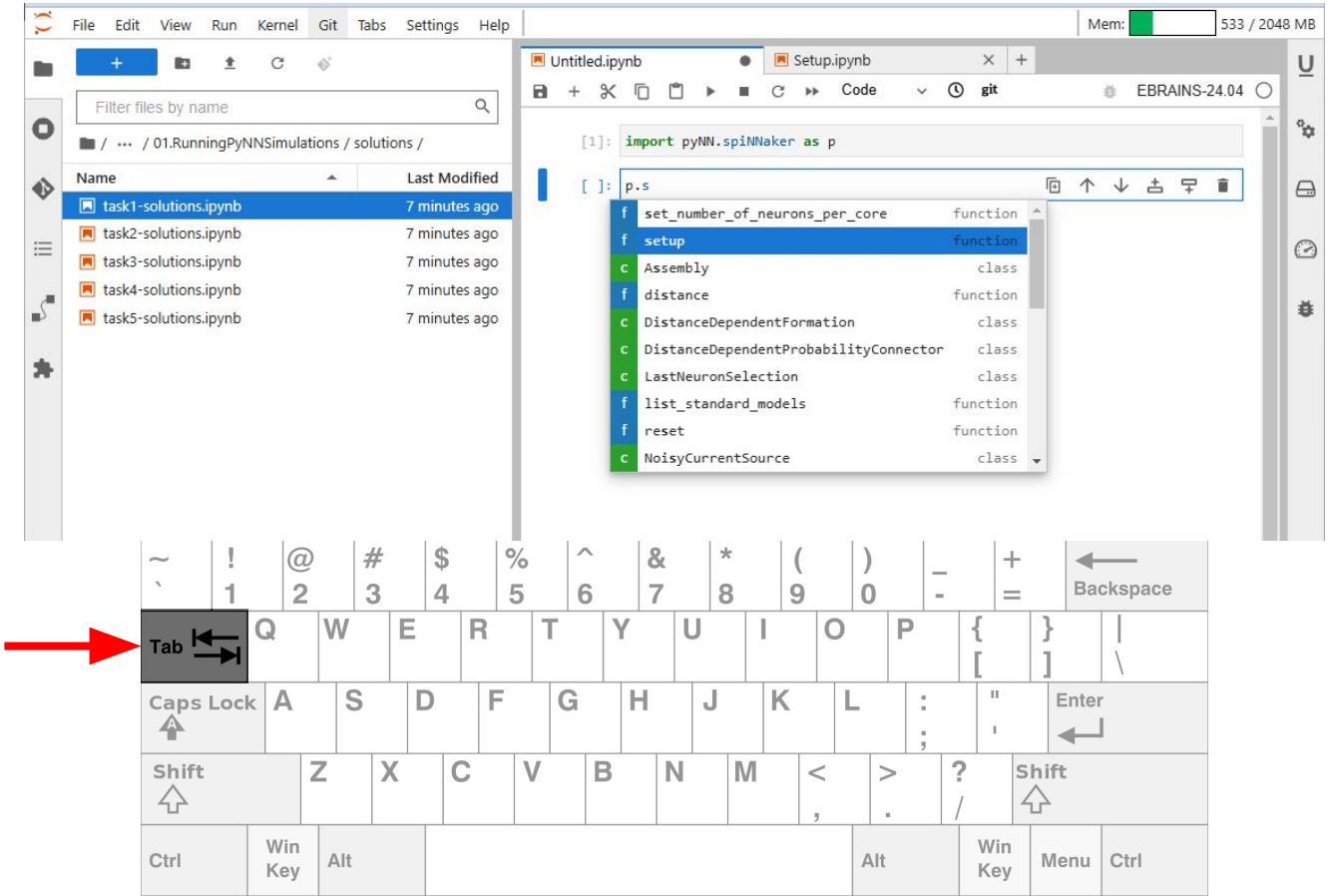
# Open Setup Notebook - Run



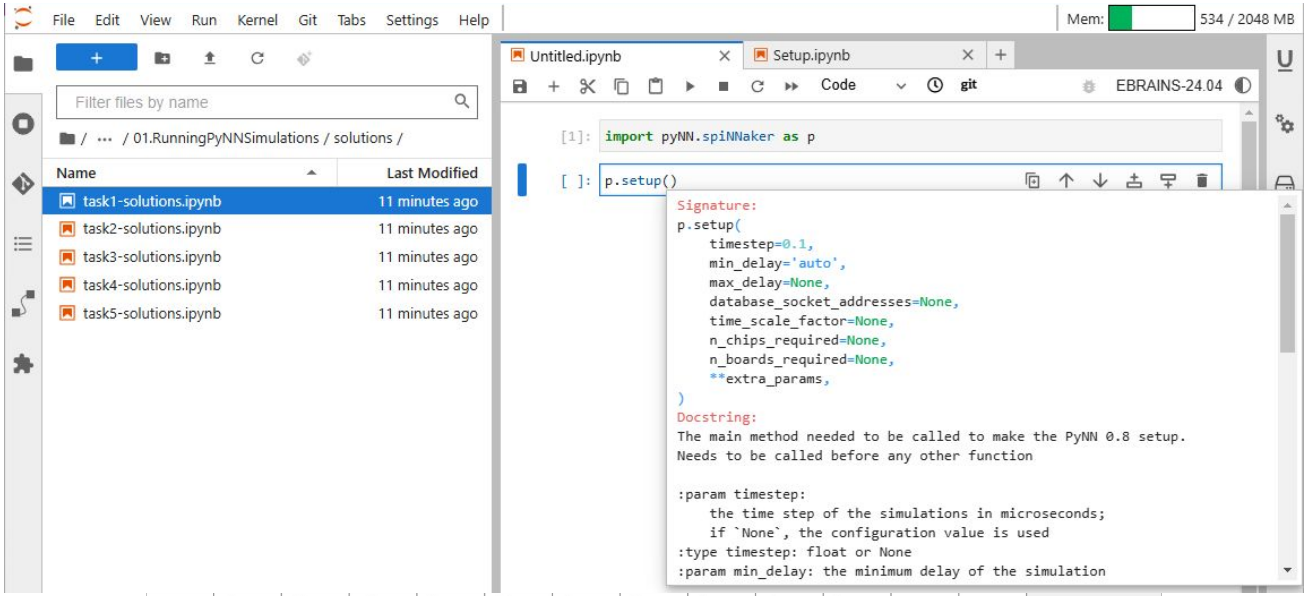
# Changing Kernel



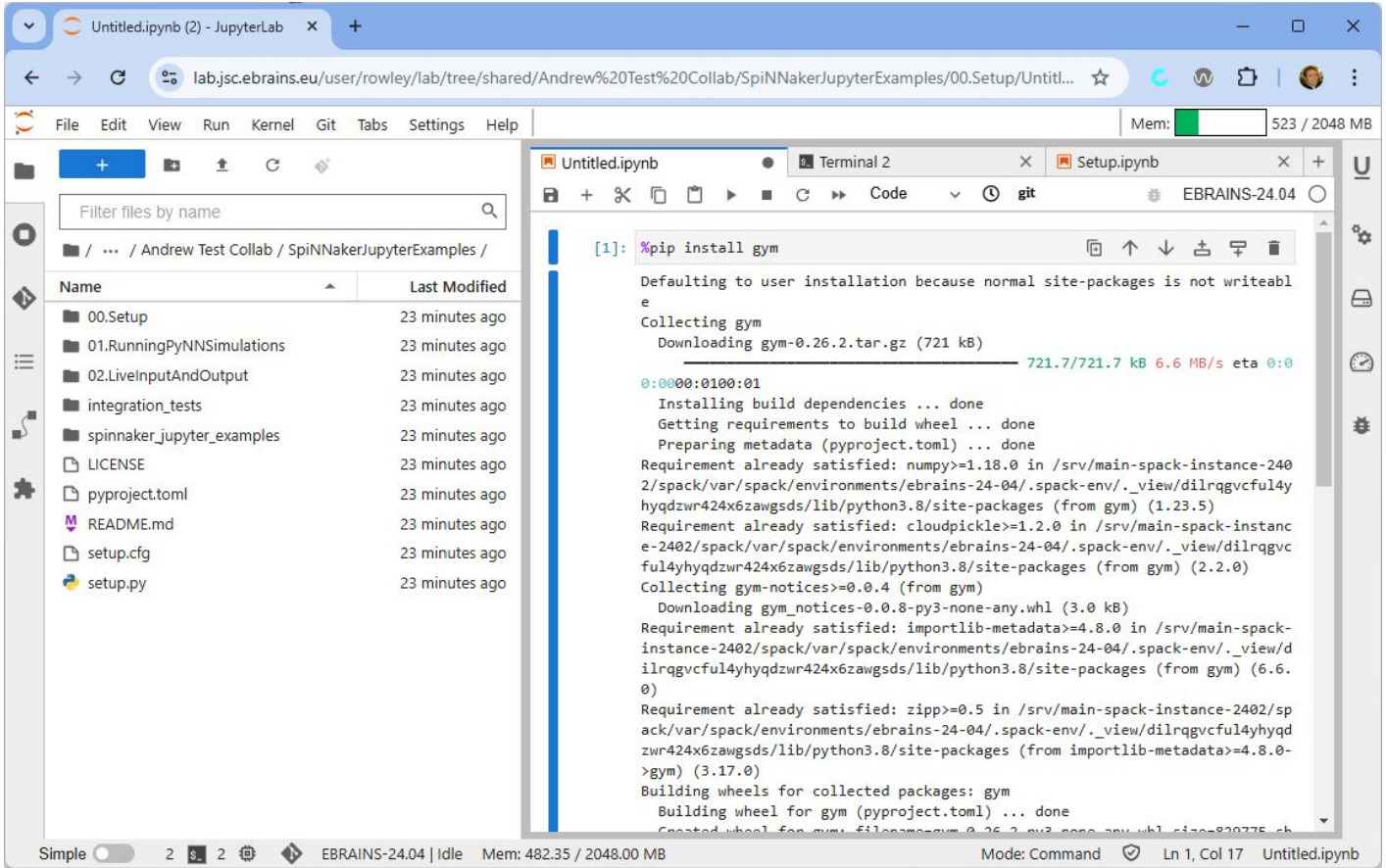
# Jupyter Autocomplete



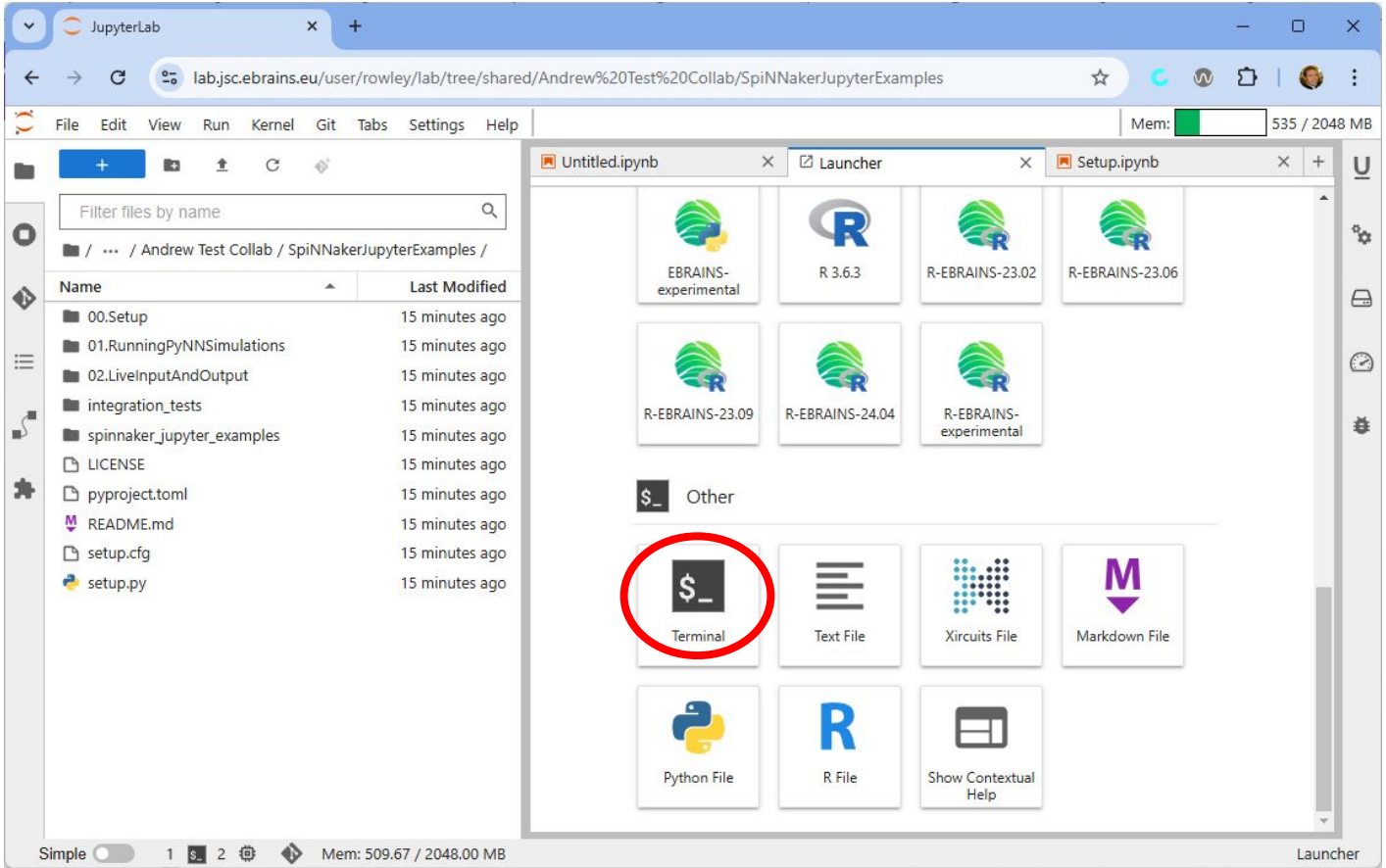
# Jupyter Function Help



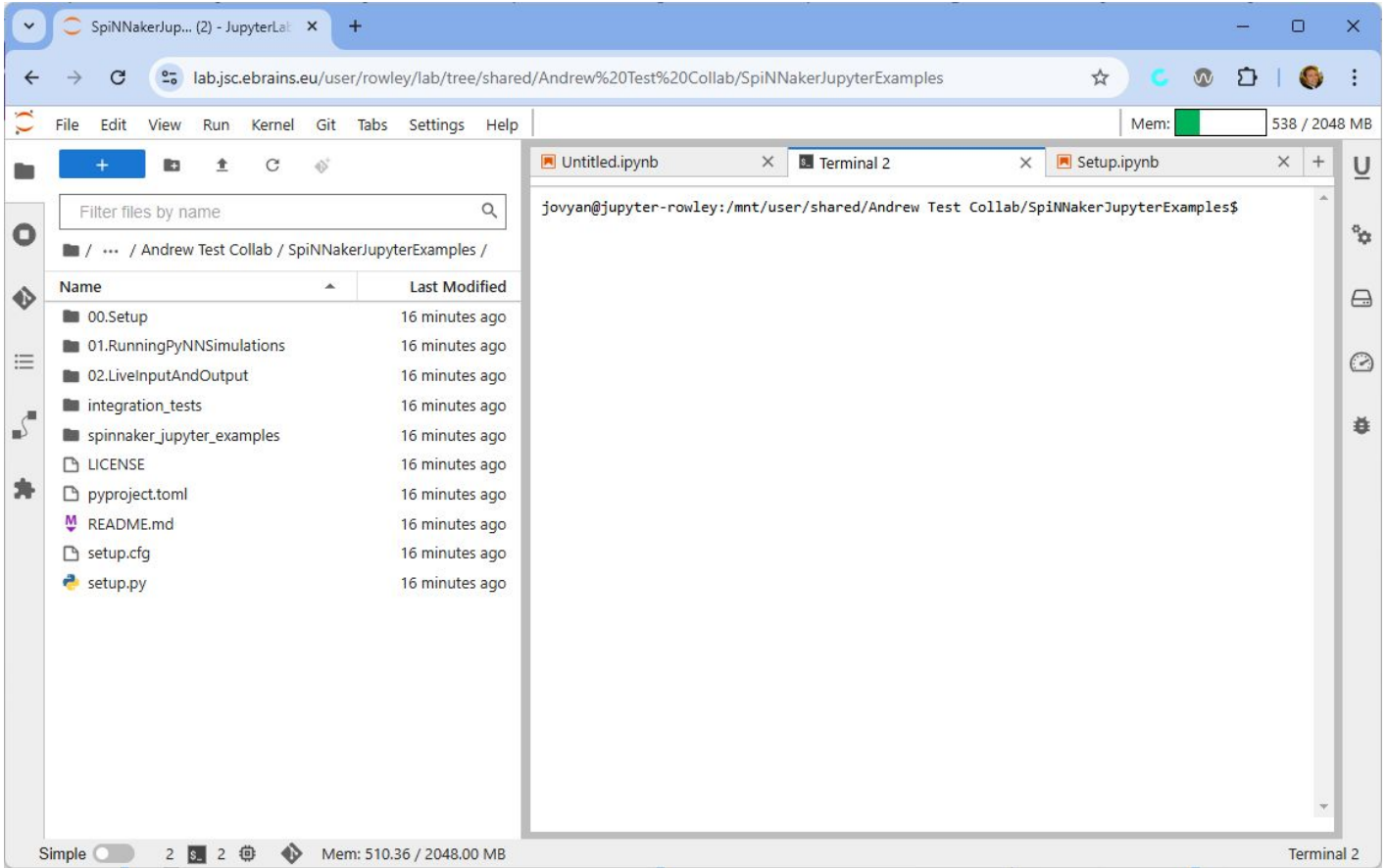
# Install Libraries



# Terminal Access



# Terminal Access



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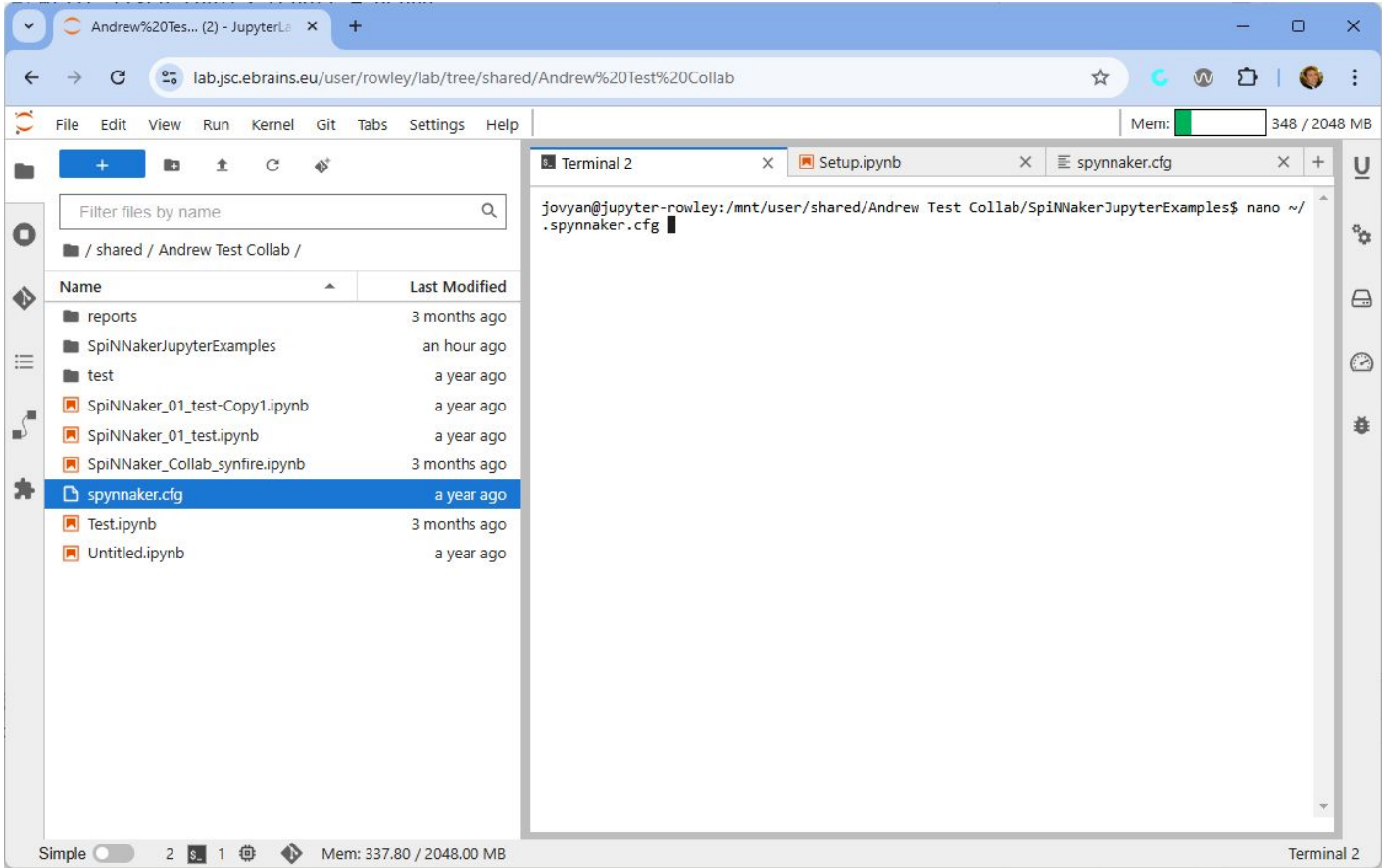
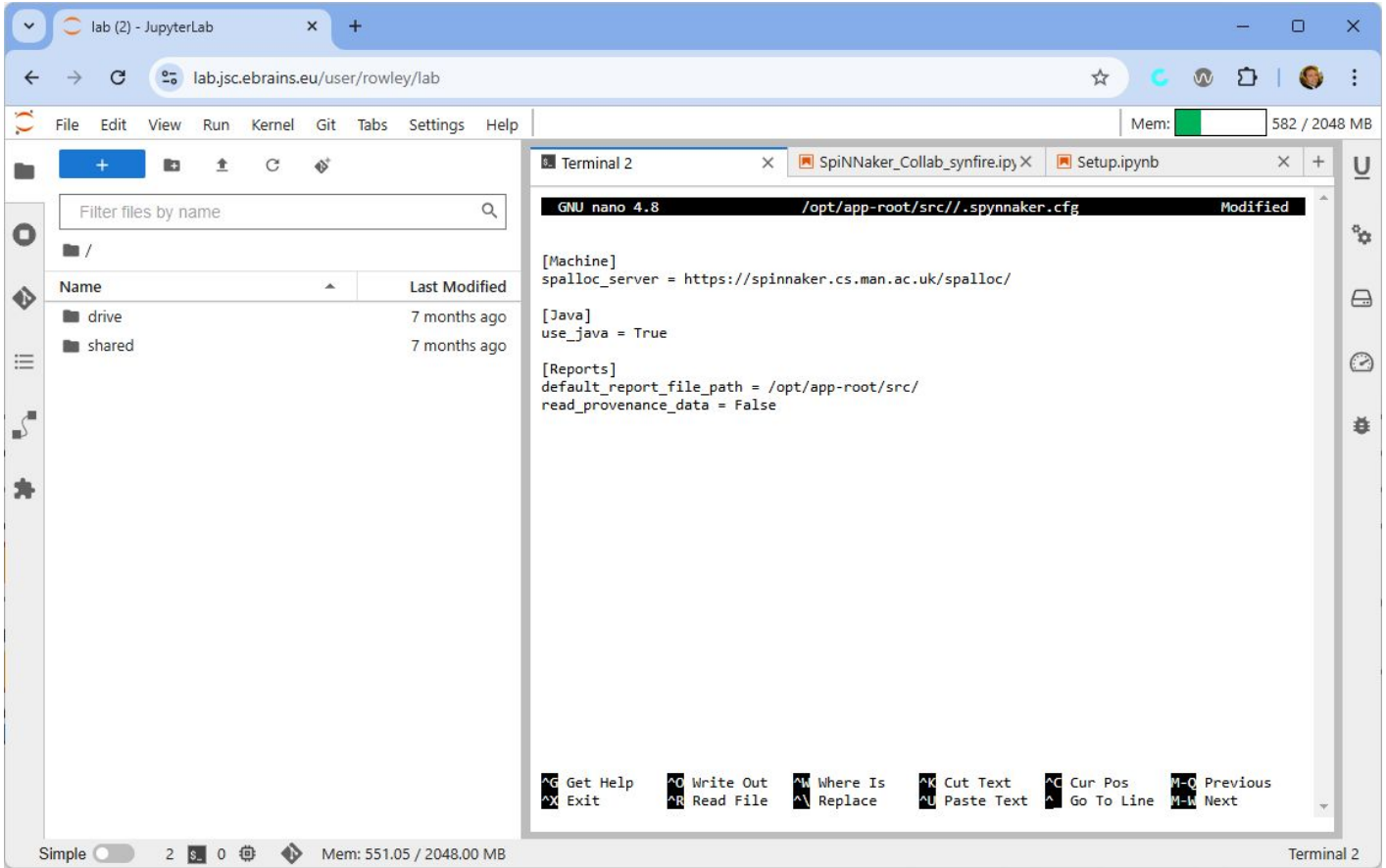


# Set Reports Options



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# Spiking Neural Networks

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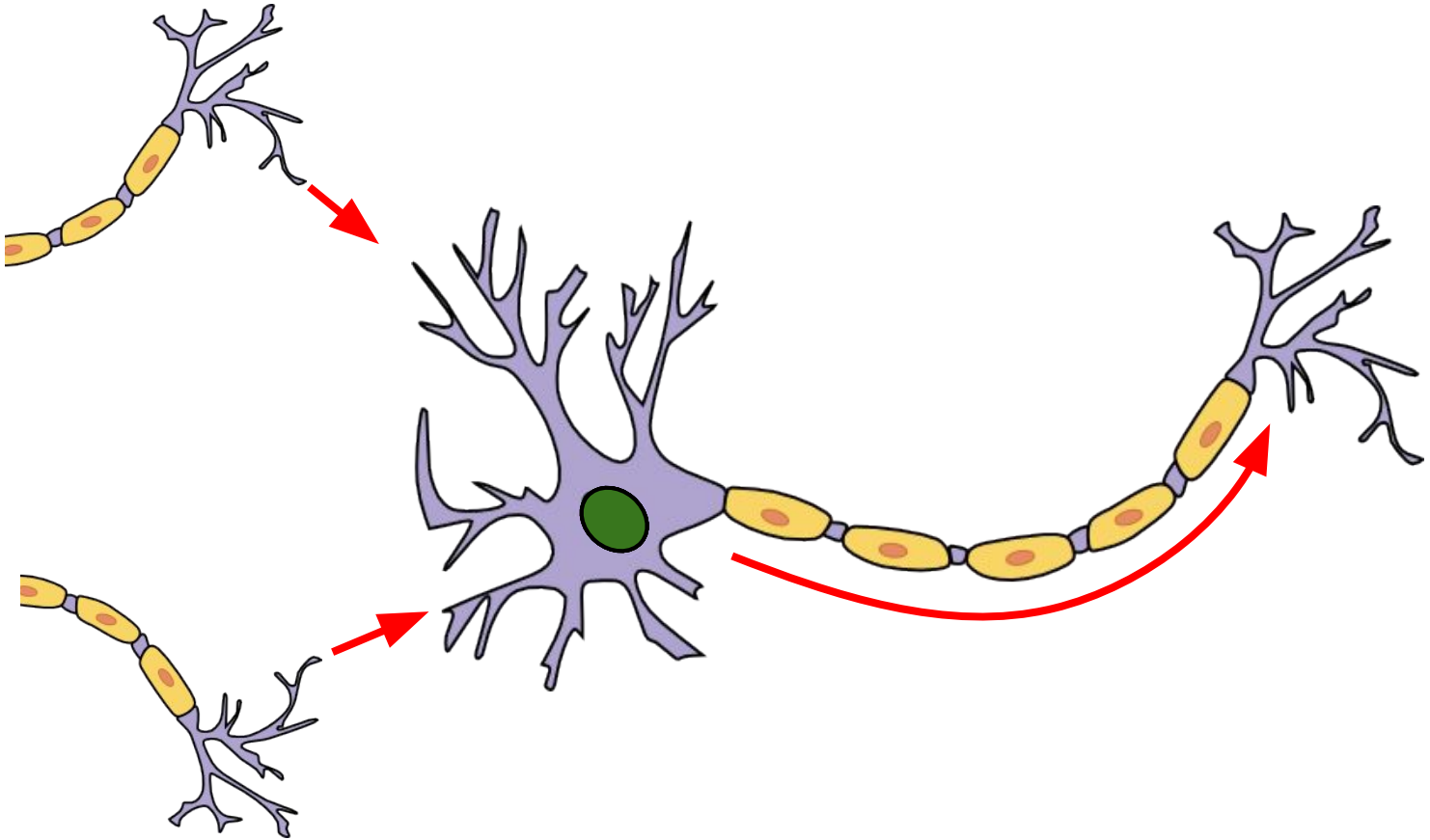
# Spiking Neural Networks



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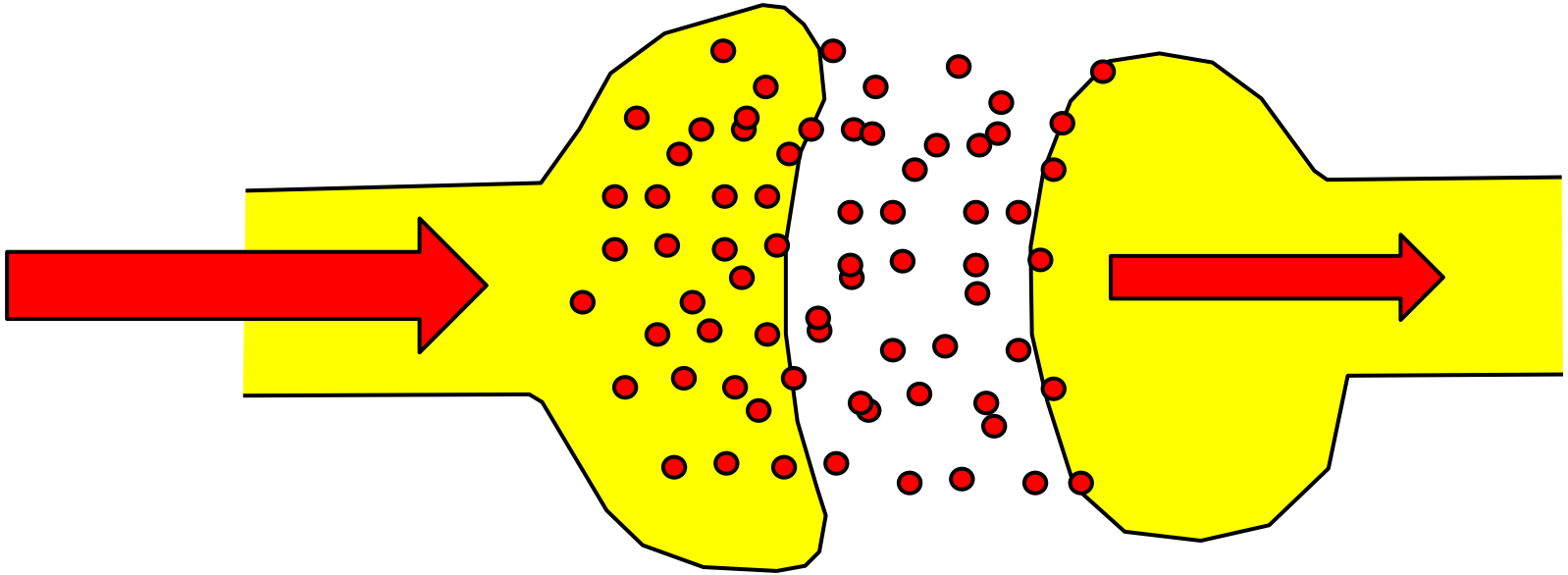
# Spiking Neural Networks



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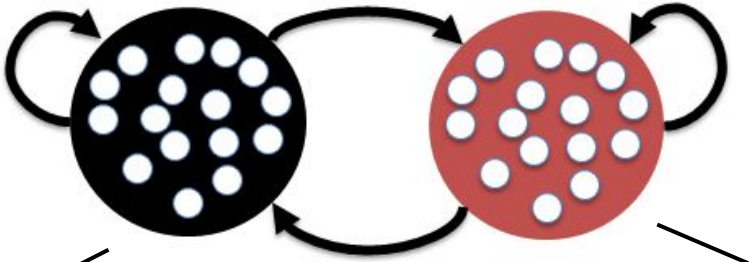
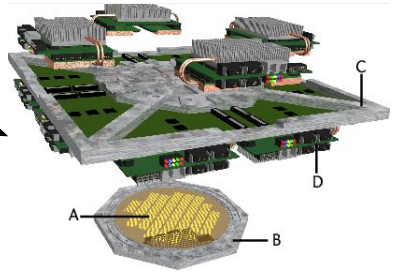
# PyNN

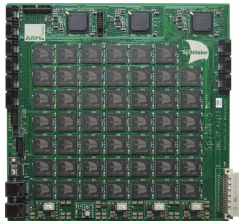
# What is PyNN?

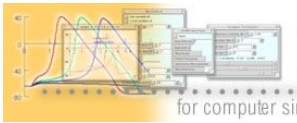


nest :: initiative




BRIAN





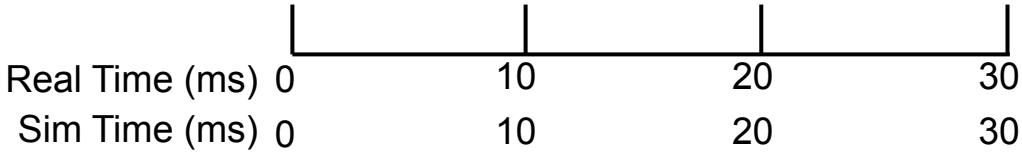
NEURON

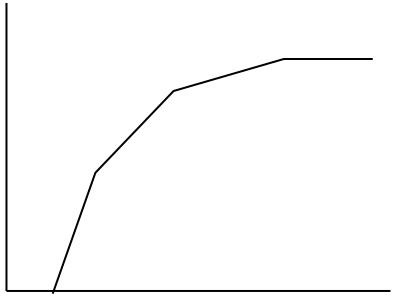
for computer simulations of neurons and neural networks

# PyNN - Setup

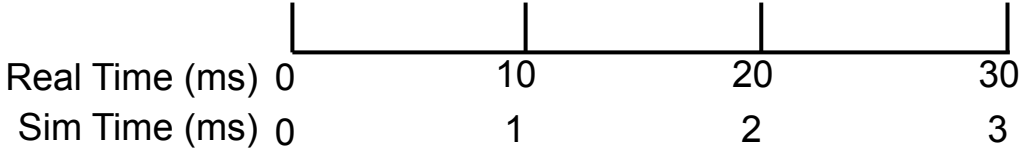
```
import pyNN.spiNNaker as p
```

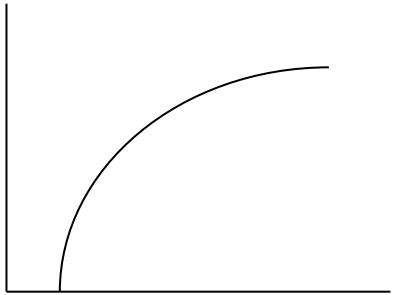
```
p.setup(timestep=1.0)
```



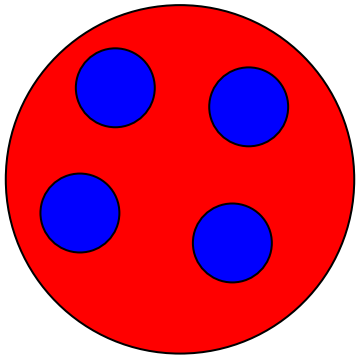
```
p.setup(timestep=0.1)
```

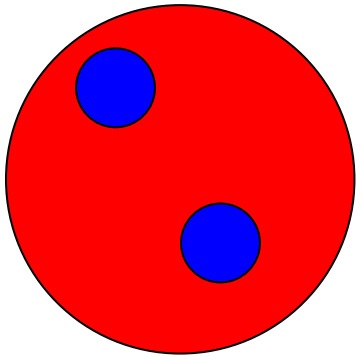


# PyNN - Populations

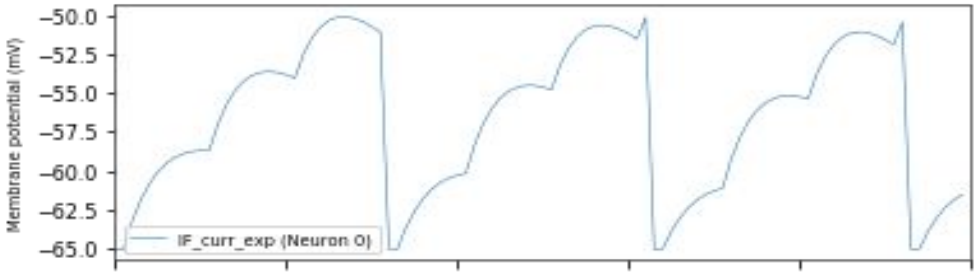
```
pop_1 = p.Population(
    4, p.IF_curr_exp(), label="Fred")
pop_2 = p.Population(
    2, p.IF_curr_exp(), label="Bob")
```



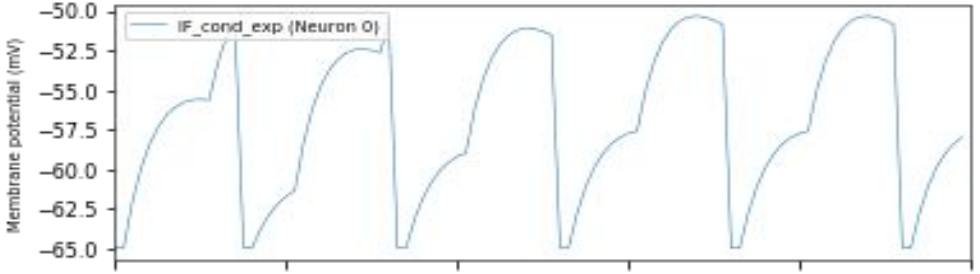


# PyNN Populations - Models

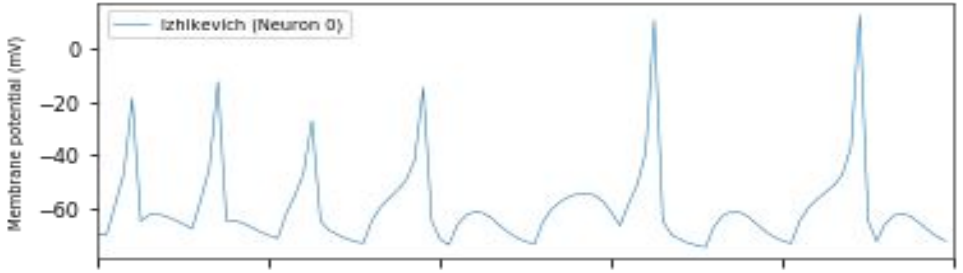
```
p.IF_curr_exp(...)
```




```
p.IF_cond_exp(...)
```

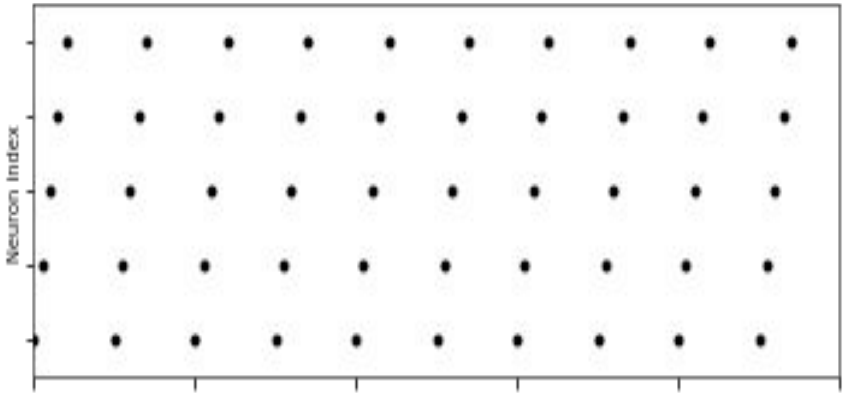



```
p.Izhikevich(...)
```

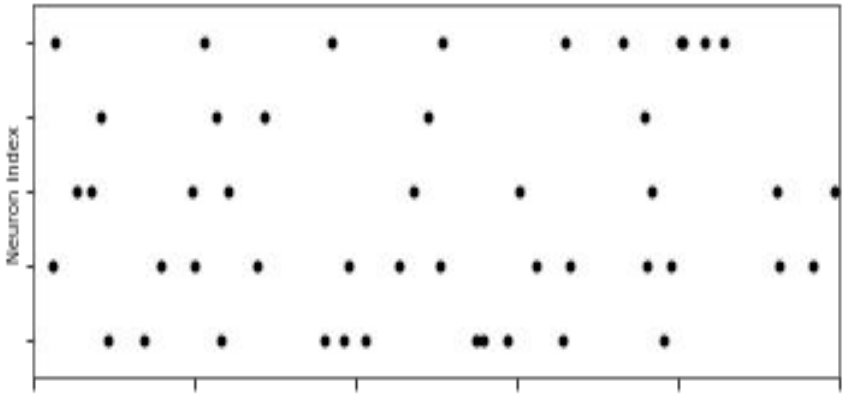


# PyNN Populations - Models

```
p.SpikeSourceArray(
    spike_times=[...])
```

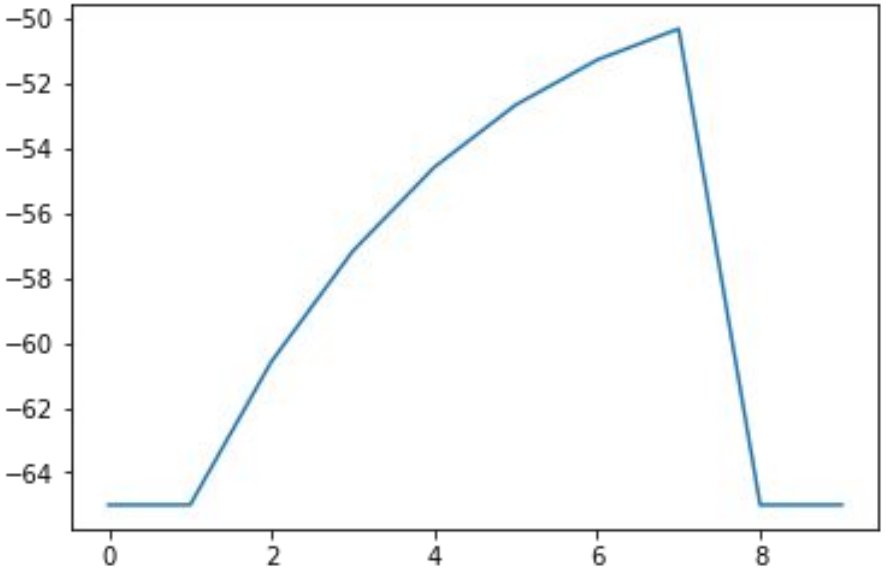


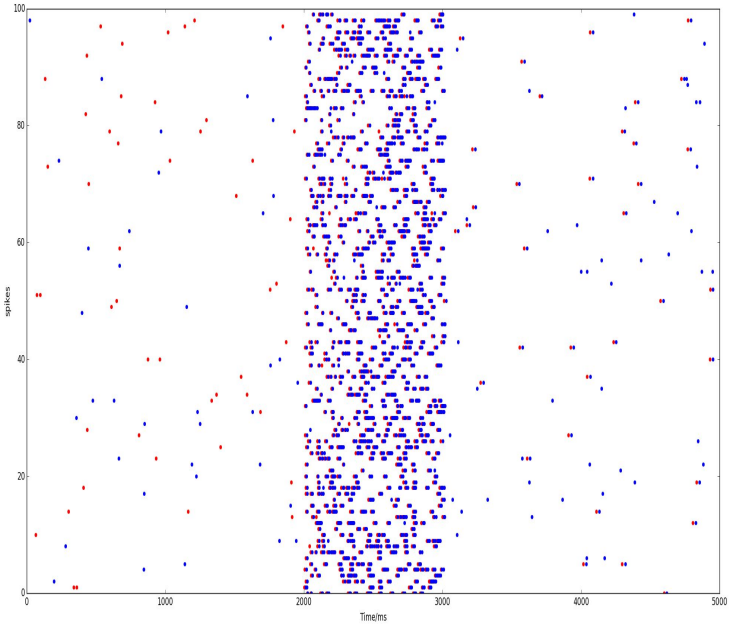

```
p.SpikeSourcePoisson(
    rate=...)
```



# PyNN Populations - Recording

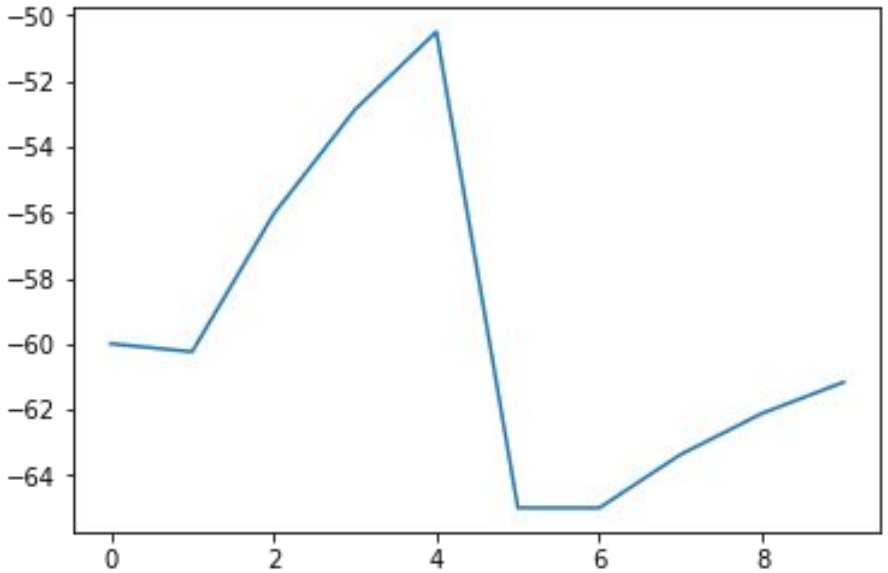
```
pop_1.record(["v", "spikes"])
```



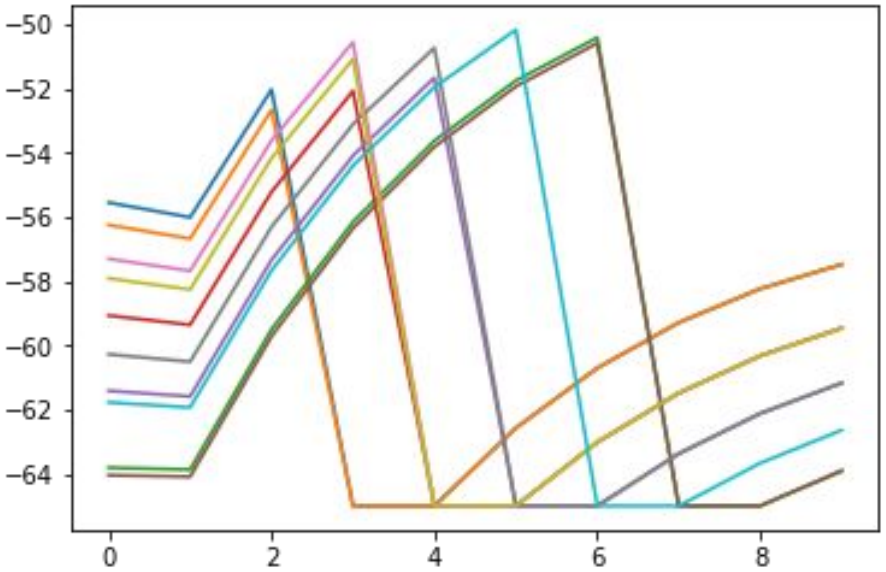
# PyNN Populations - Initialize

```
pop_1.initialize(v=-60)
```



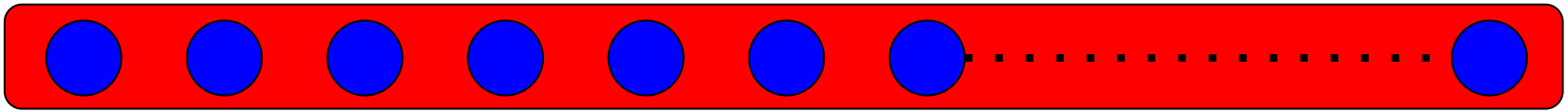
# PyNN - Random Parameters

```
pop_1.initialize(v=p.RandomDistribution(
    "uniform", low=-65.0, high=-55.0))
```



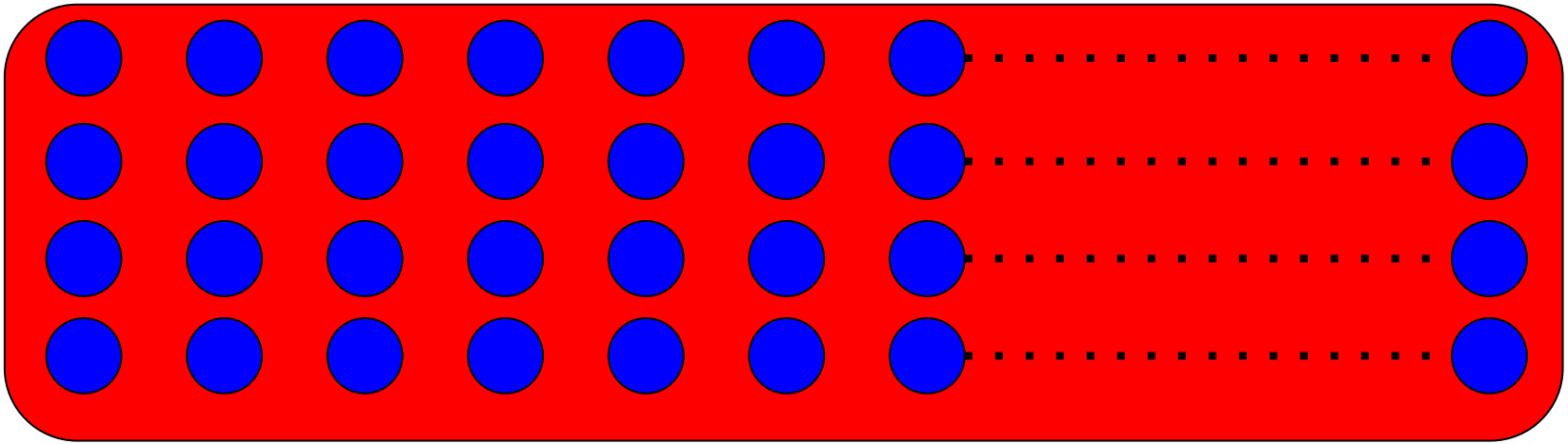
# PyNN Populations - Structure

```
pop_1 = p.Population(
    100, p.IF_curr_exp())
```



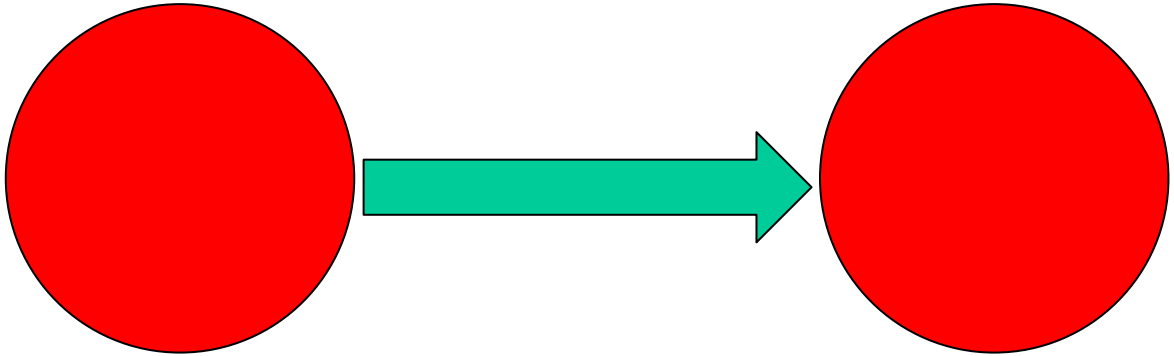
# PyNN Populations - Structure

```
pop_1 = p.Population(
    100, p.IF_curr_exp(),
    structure=Grid2D(4 / 25))
```



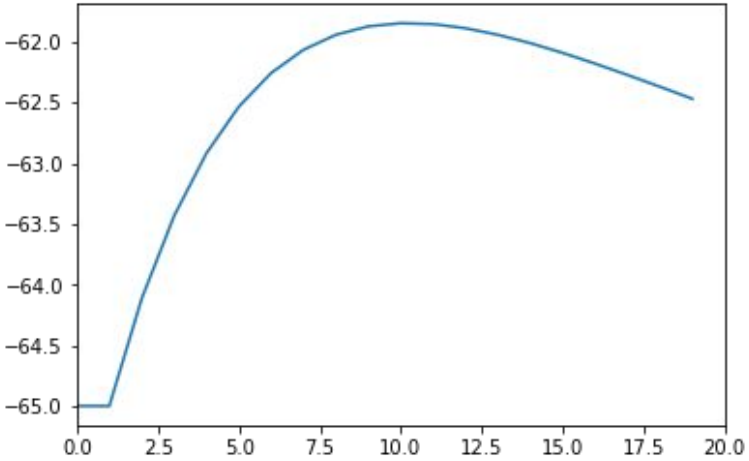
# PyNN - Projections

```
proj = p.Projection(
    pop_1, pop_2,
    p.OneToOneConnector(),
    p.StaticSynapse(
        weight=1.0, delay=2.0))
```



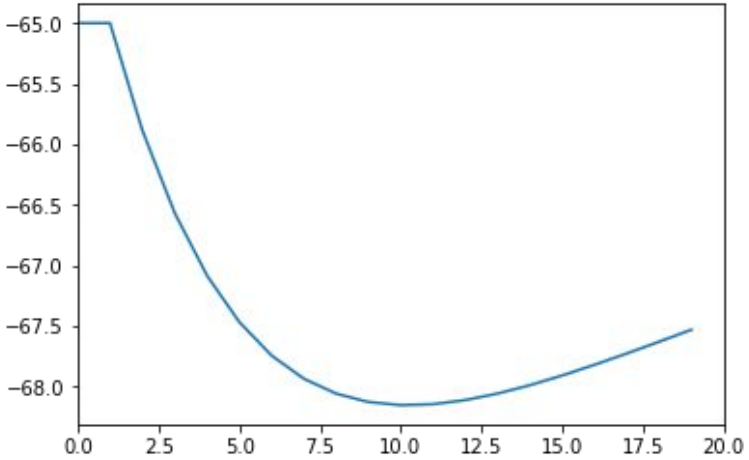
# PyNN - Projections

```
proj = p.Projection(
    pop_1, pop_2,
    p.OneToOneConnector(),
    p.StaticSynapse(weight=1.0),
    receptor_type="excitatory")
```



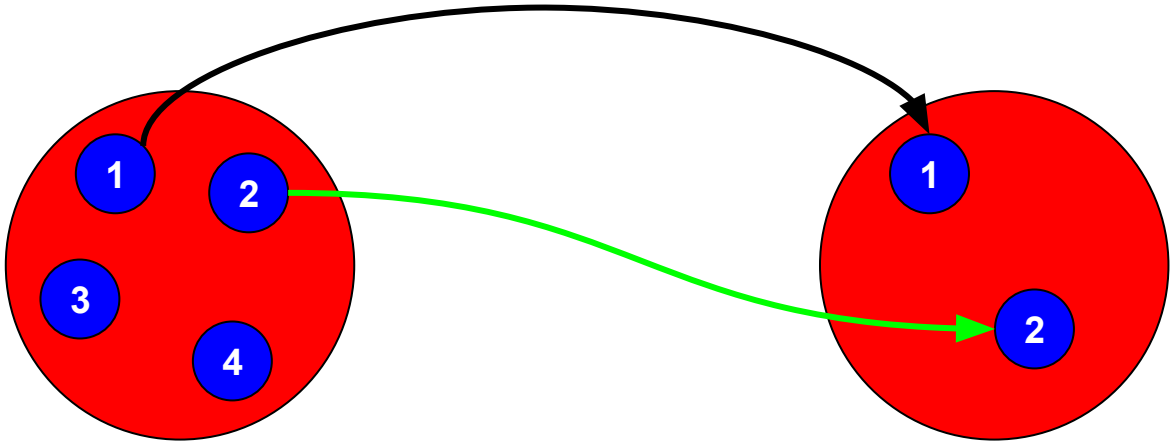
# PyNN - Projections

```
proj = p.Projection(
    pop_1, pop_2,
    p.OneToOneConnector(),
    p.StaticSynapse(weight=1.0),
    receptor_type="inhibitory")
```



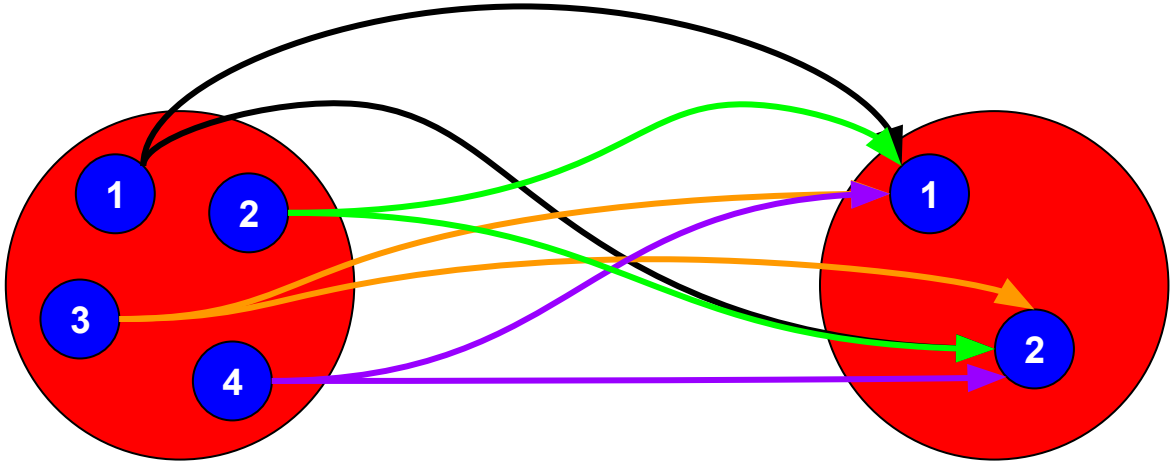
# PyNN Projections - Connectors

```
p.OneToOneConnector()
```



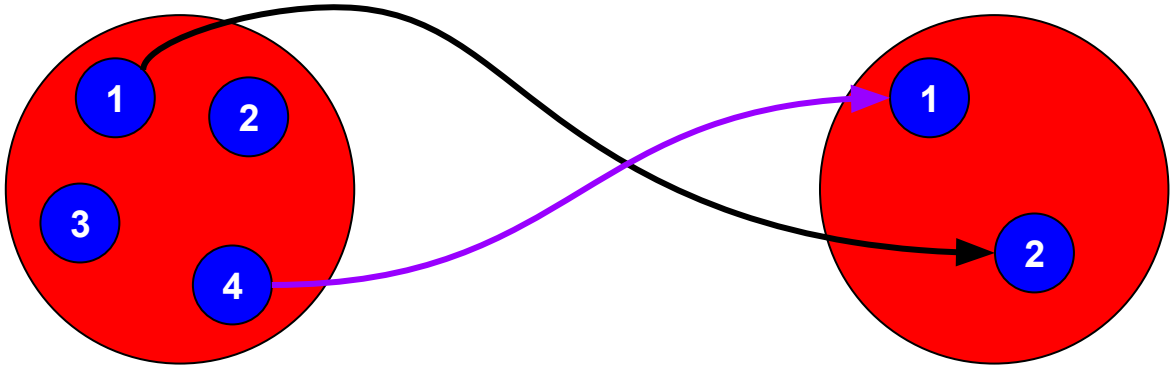
# PyNN Projections - Connectors

```
p.AllToAllConnector()
```



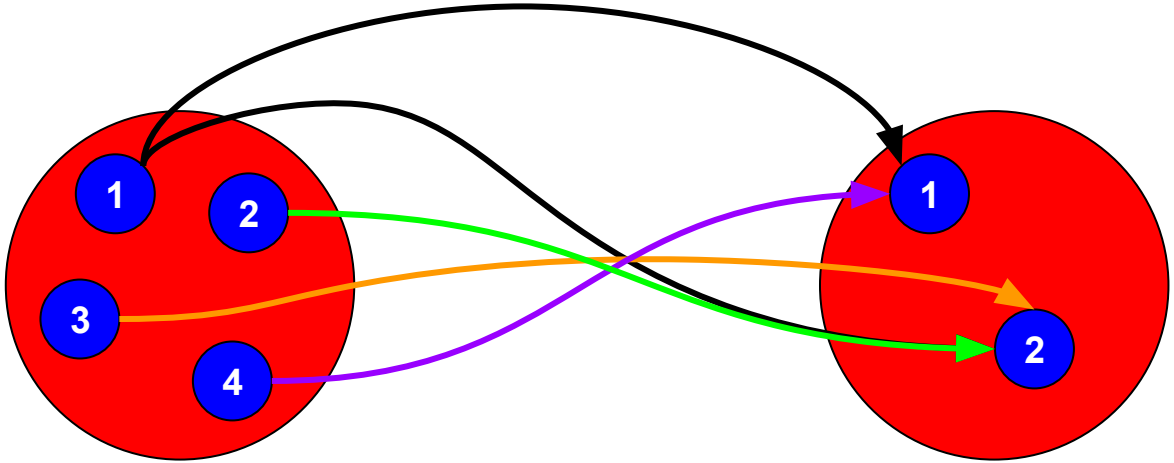
# PyNN Projections - Connectors

```
p.FixedProbabilityConnector(p=0.1)
```



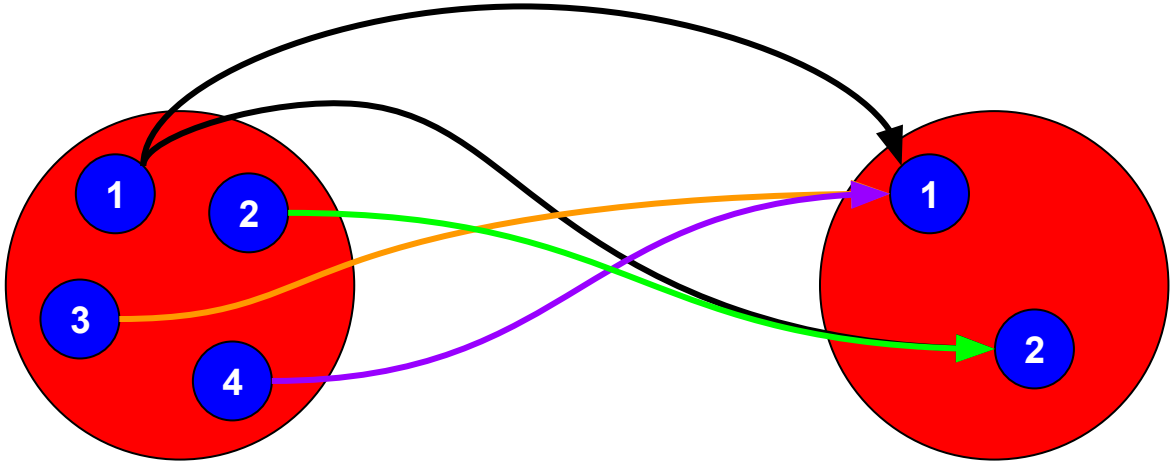
# PyNN Projections - Connectors

```
p.FixedProbabilityConnector(p=0.5)
```



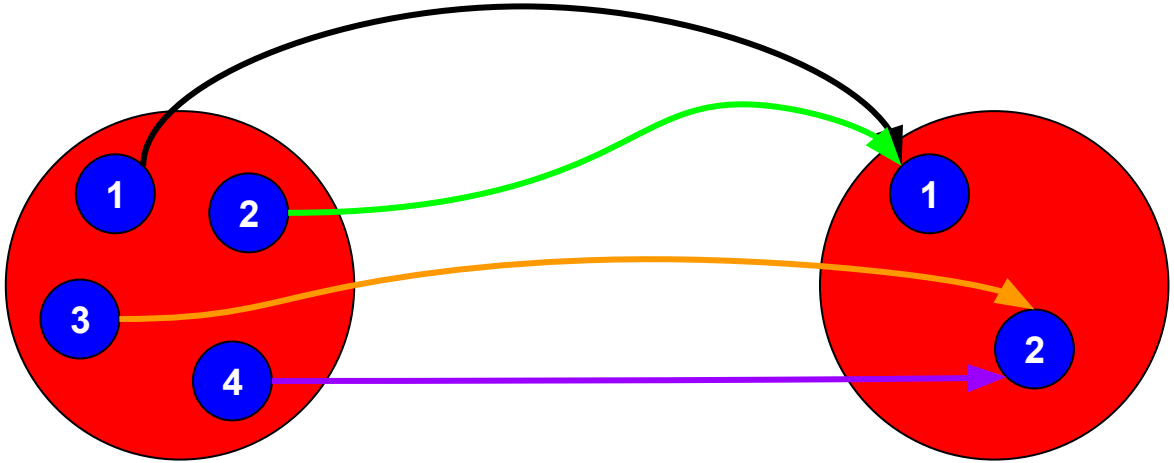
# PyNN Projections - Connectors

```
p.FixedTotalNumberConnector(5)
```



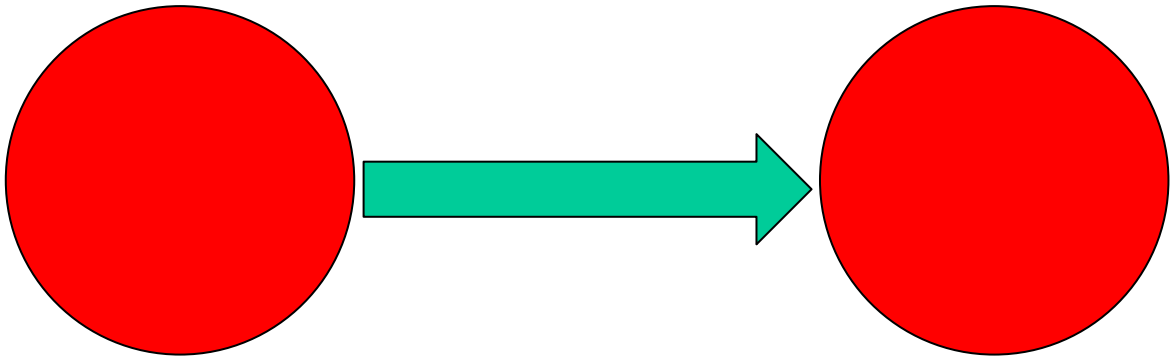
# PyNN Projections - Connectors

```
p.FromListConnector(
    [(1, 1), (2, 1), (3, 2), (4, 2)])
```



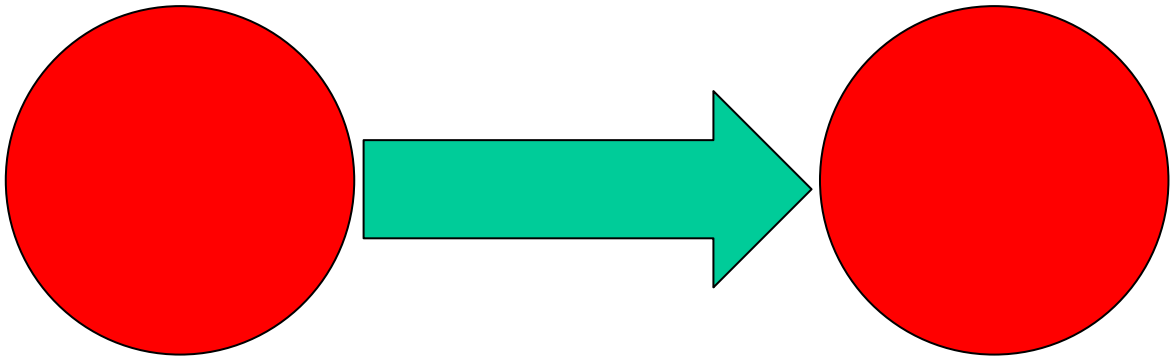
# PyNN - Static Synapse Types

```
p.StaticSynapse(weight=1.0, delay=2.0)
```



# PyNN - Static Synapse Types

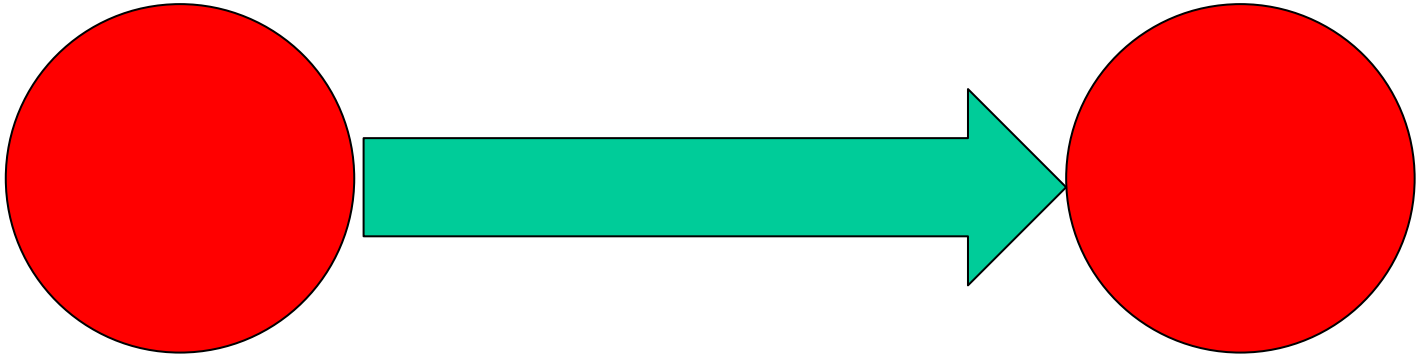
```
p.StaticSynapse(weight=5.0, delay=2.0)
```



# PyNN - Static Synapse Types

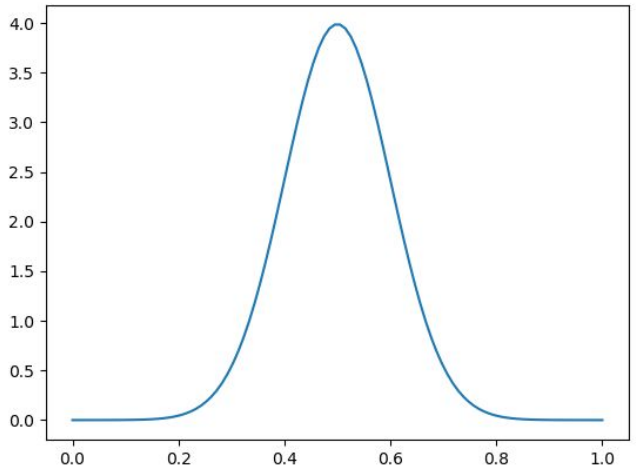
```
p.StaticSynapse(weight=5.0, delay=3.0)
```

(timestep <= delay <= 144 * timestep)



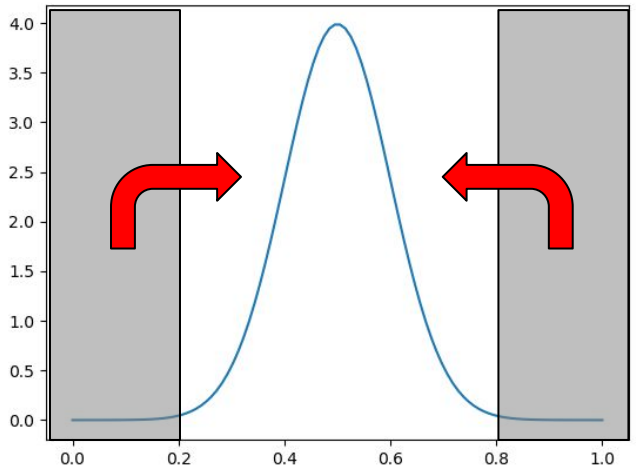
# PyNN - Random Weights and Delays

```
weight_dist = p.RandomDistribution(
    “normal”, mu=0.5, sigma=0.1)
p.StaticSynapse(
    weight=weight_dist, delay=3.0)
```



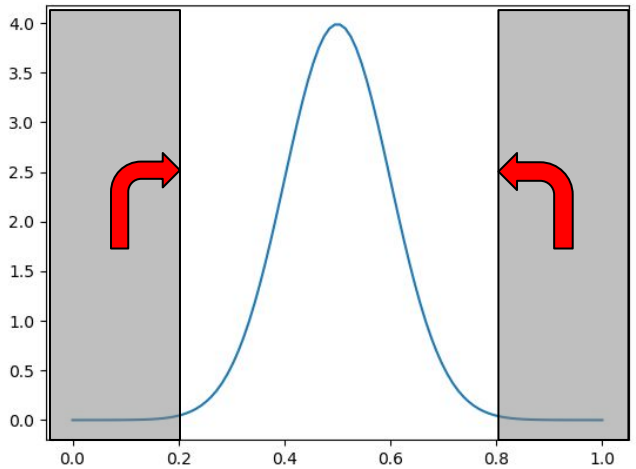
# PyNN - Random Weights and Delays

```
weight_dist = p.RandomDistribution(
    “normal_clipped”,
    mu=0.5, sigma=0.1, low=0.2 high=0.8)
```

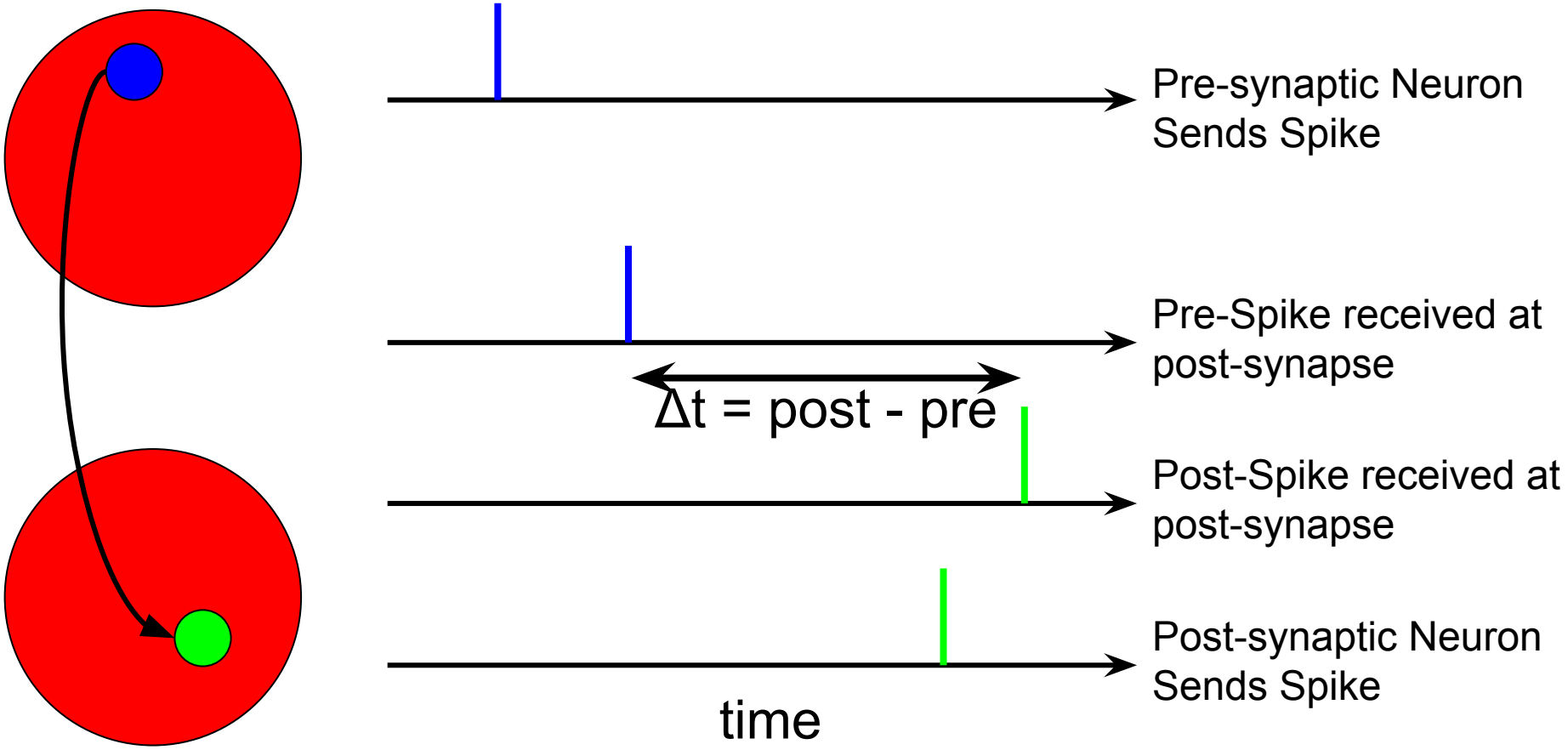


# PyNN - Random Weights and Delays

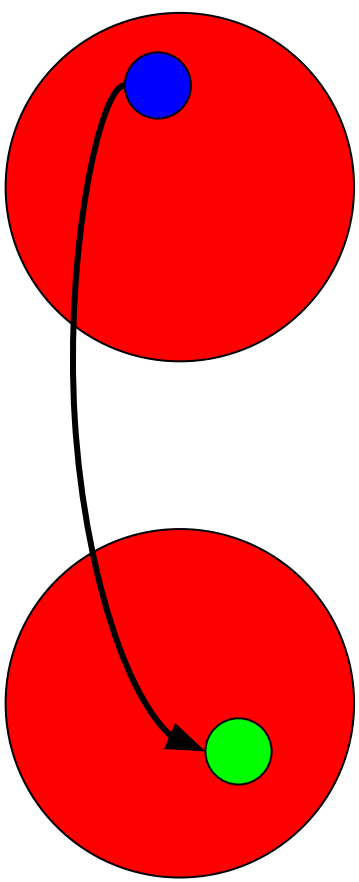
```
weight_dist = p.RandomDistribution(
    “normal_clipped_to_boundary”,
    mu=0.5, sigma=0.1, low=0.2 high=0.8)
```

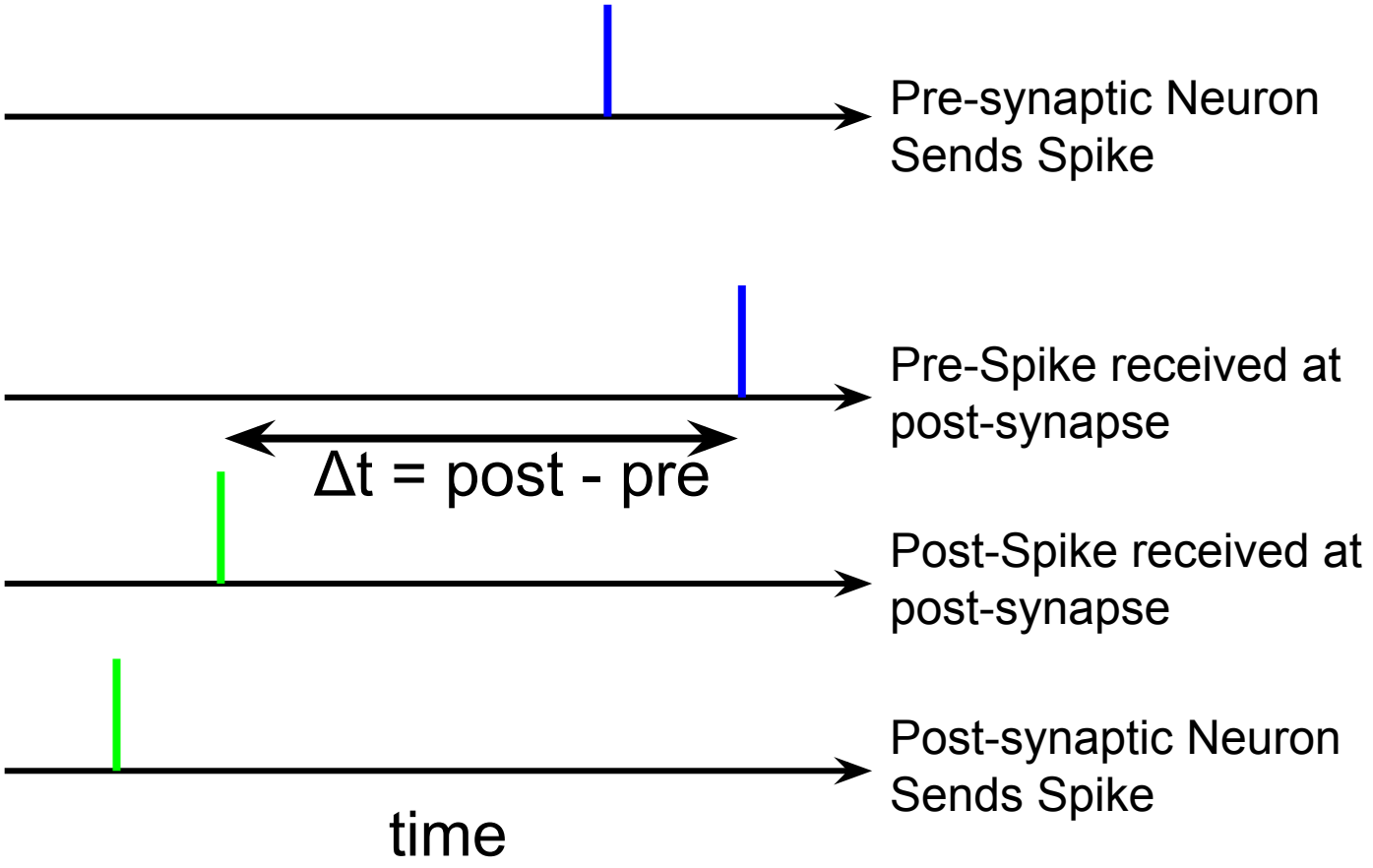


# Spike Timing Dependent Plasticity

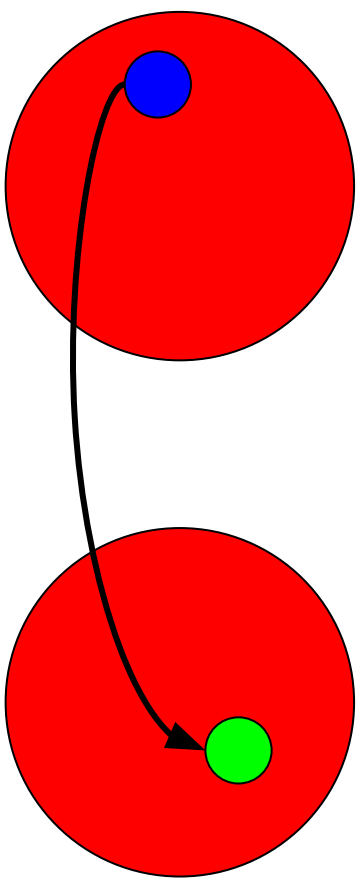


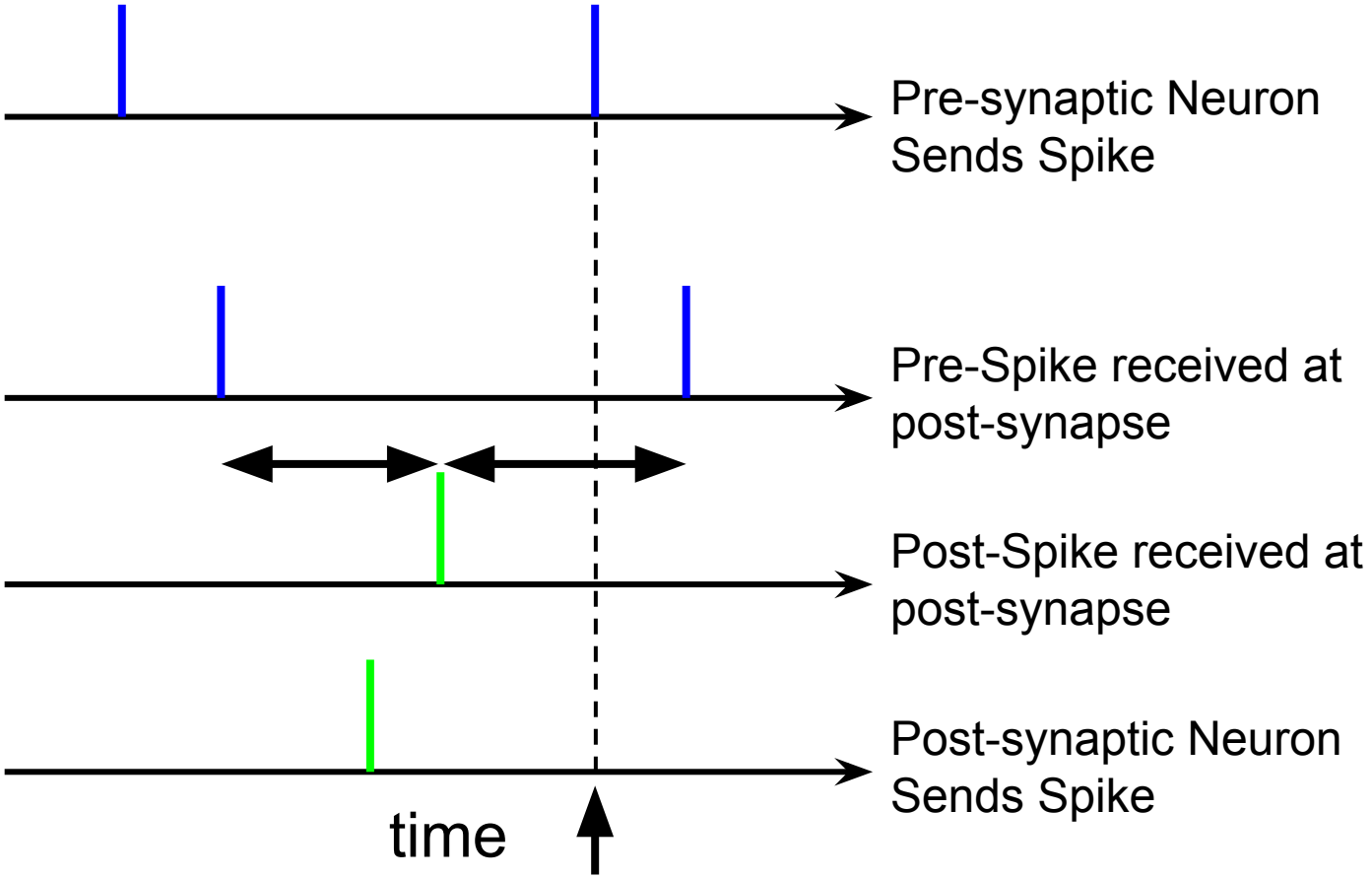
# Spike Timing Dependent Plasticity





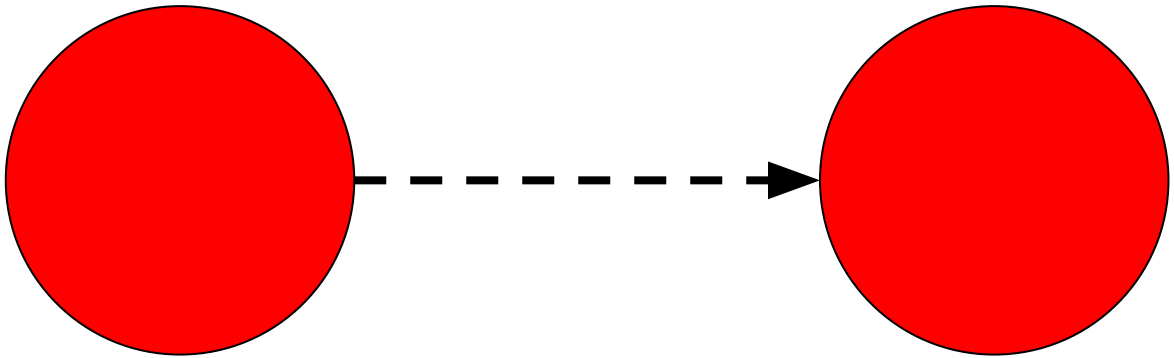
# STDP - Deferred Execution





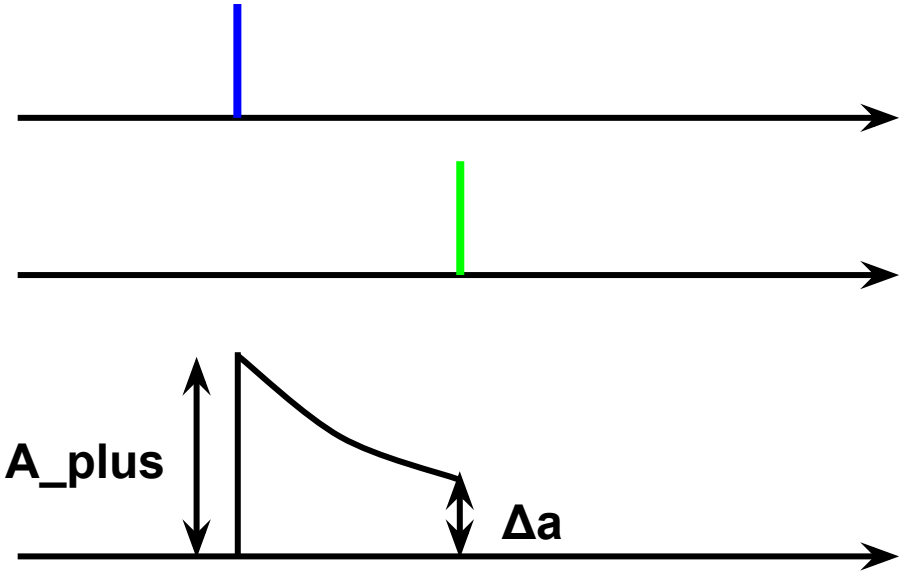
# PyNN - STDP Synapse Types

```
p.STDPMechanism(
    timing_dependence=?,
    weight_dependence=?,
    weight=0.0, delay=2.0)
```



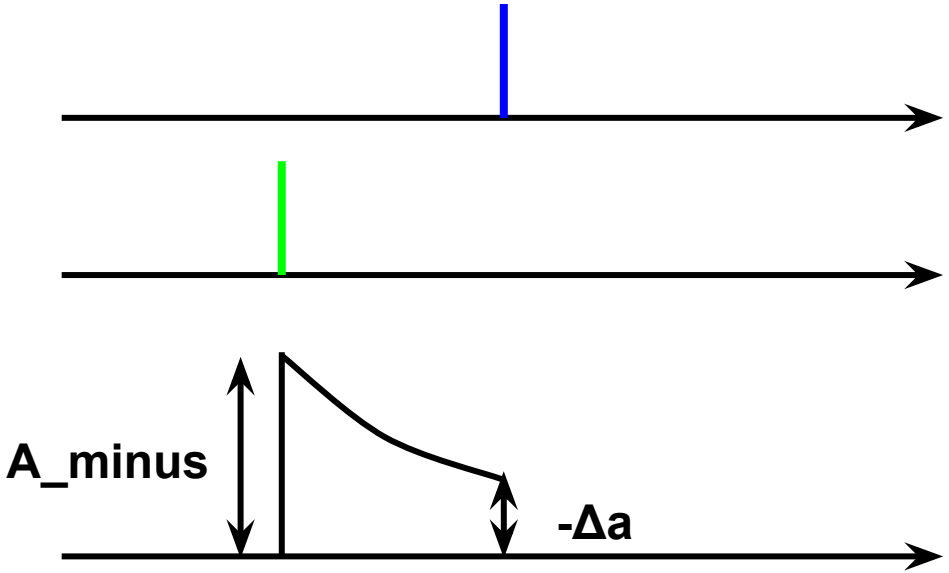
# PyNN - Timing Dependence

```
sim.SpikePairRule(tau_plus=20.0, tau_minus=20.0,
                  A_plus=0.5, A_minus=0.5)
```



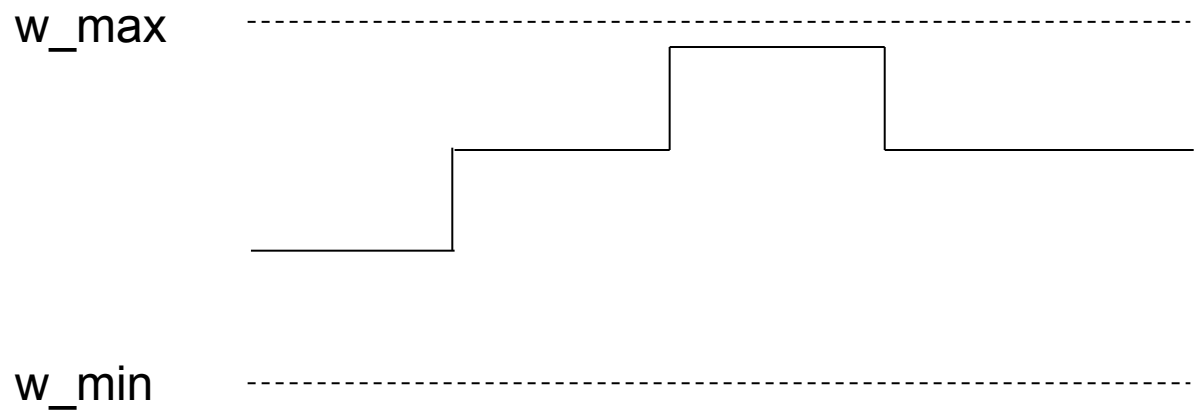
# PyNN - Timing Dependence

```
sim.SpikePairRule(tau_plus=20.0, tau_minus=20.0,
                  A_plus=0.5, A_minus=0.5)
```



# PyNN - Weight Dependence

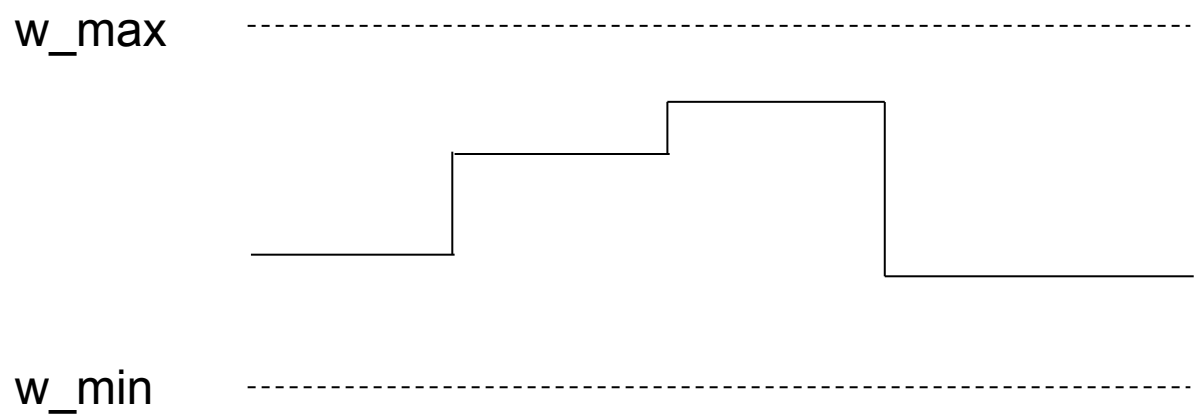
```
sim.AdditiveWeightDependence(w_max=5.0, w_min=0.0)
```




$$\Delta w = \Delta a \, (w\_max - w\_min)$$

# PyNN - Weight Dependence

```
sim.MultiplicativeWeightDependence(w_max=5.0,w_min=0.0)
```




$$\Delta w = \Delta a\ (w - w\_min) \text{ if } \Delta a < 0 \text{ (Depression)}$$

$$\Delta w = \Delta a\ (w\_max - w) \text{ if } \Delta a > 0 \text{ (Potentiation)}$$

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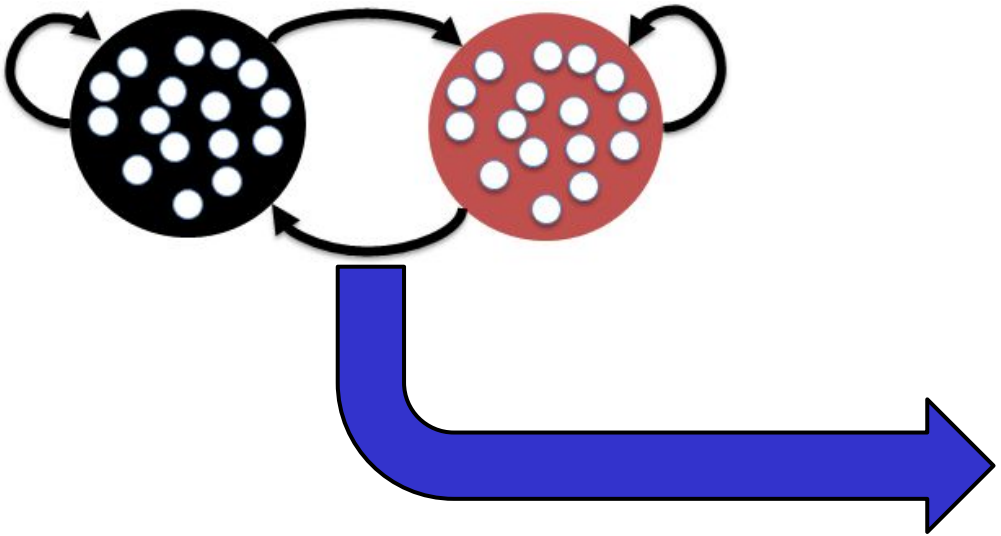
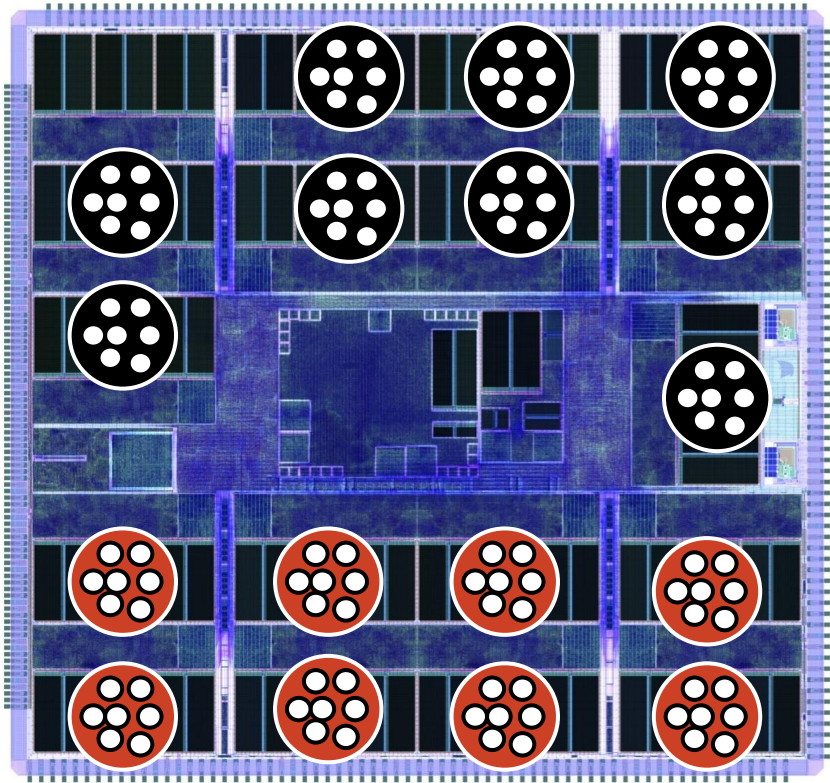
# Running on SpiNNaker

# PyNN - Run

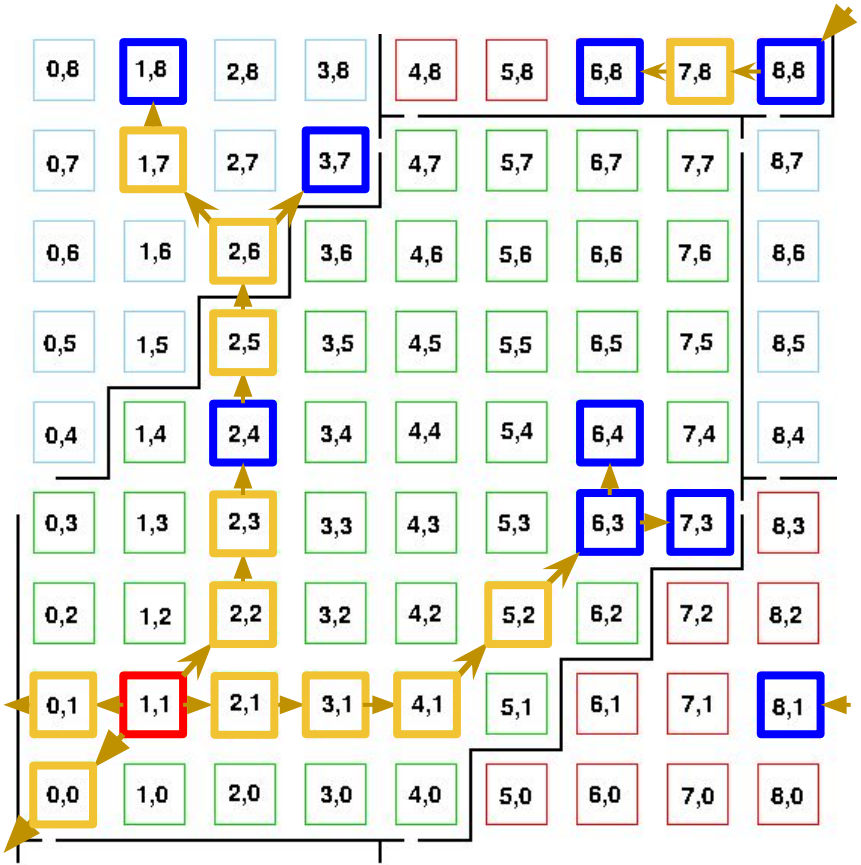
```
p.run(100)
```





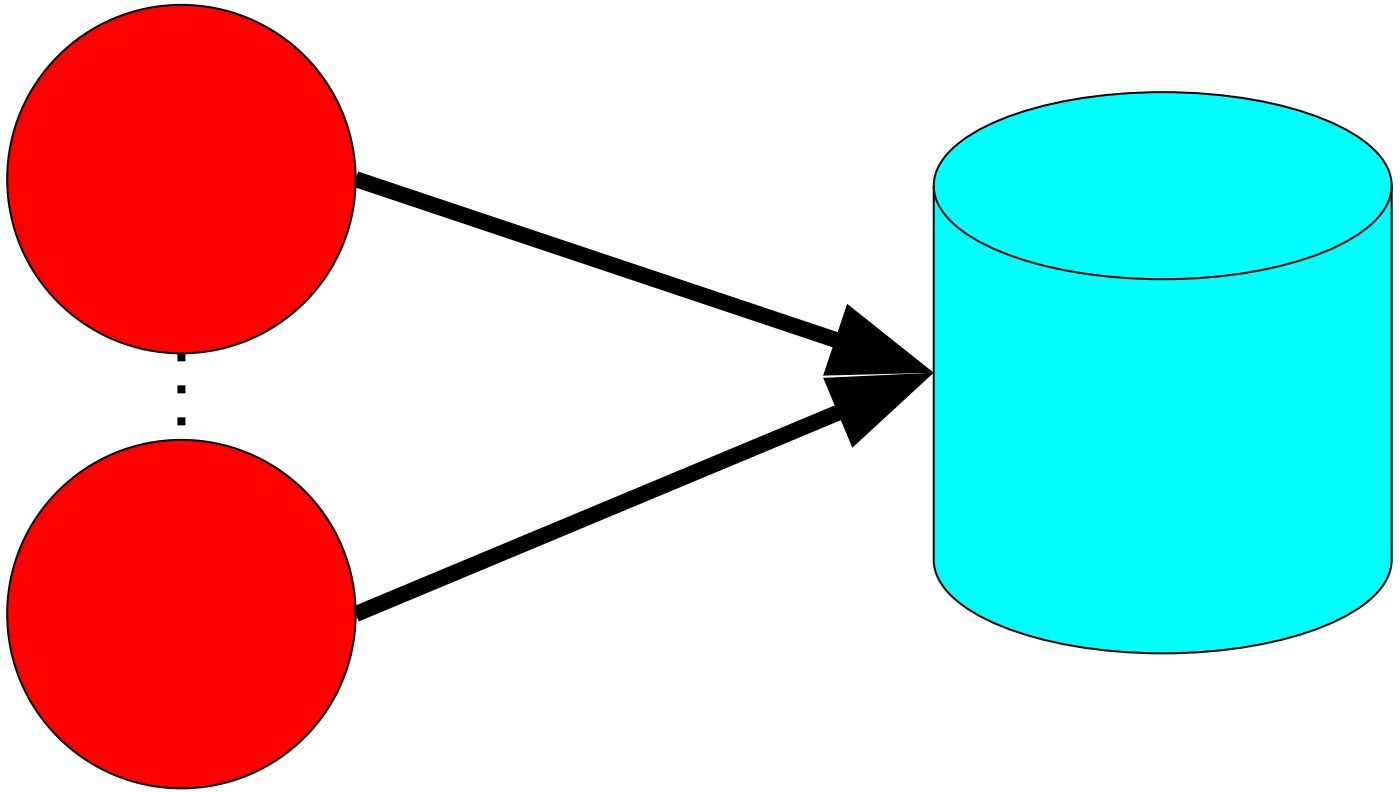
# PyNN - Run

```
p.run(100)
```



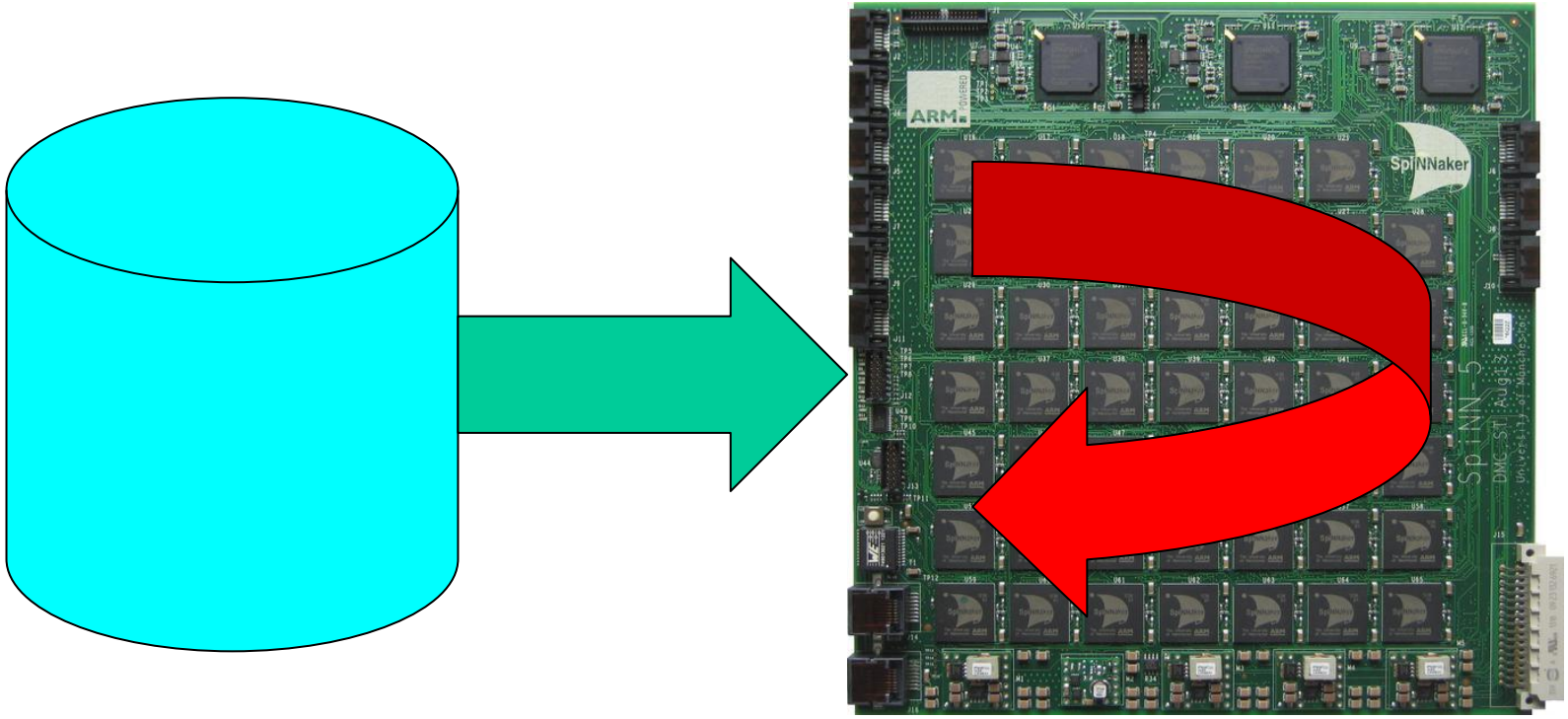
# PyNN - Run

```
p.run(100)
```



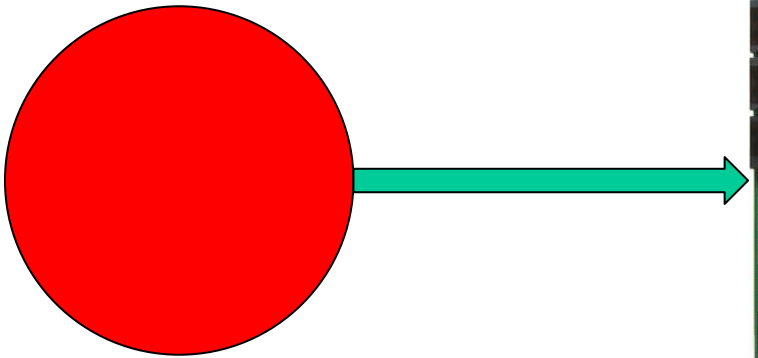
# PyNN - Run

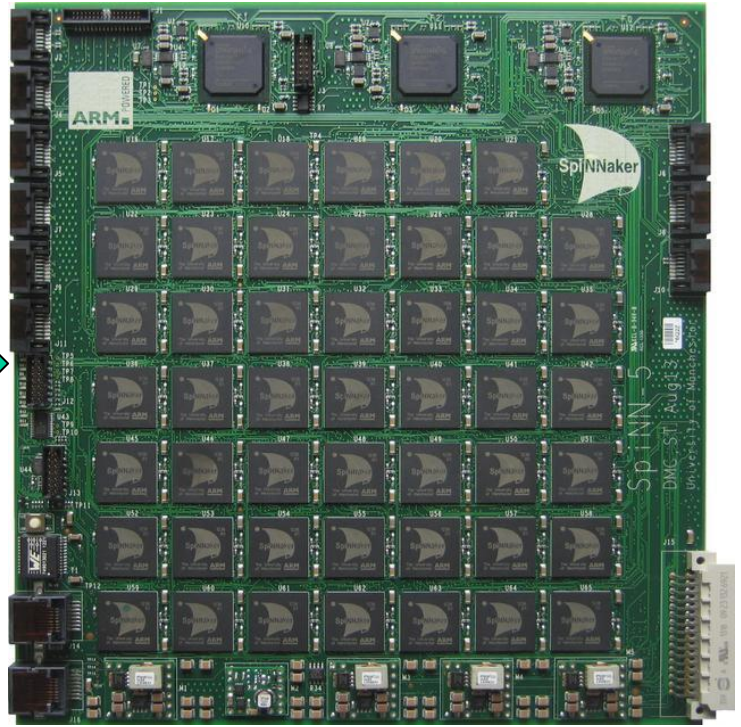
```
p.run(100)
```



# PyNN - Change and Run Again

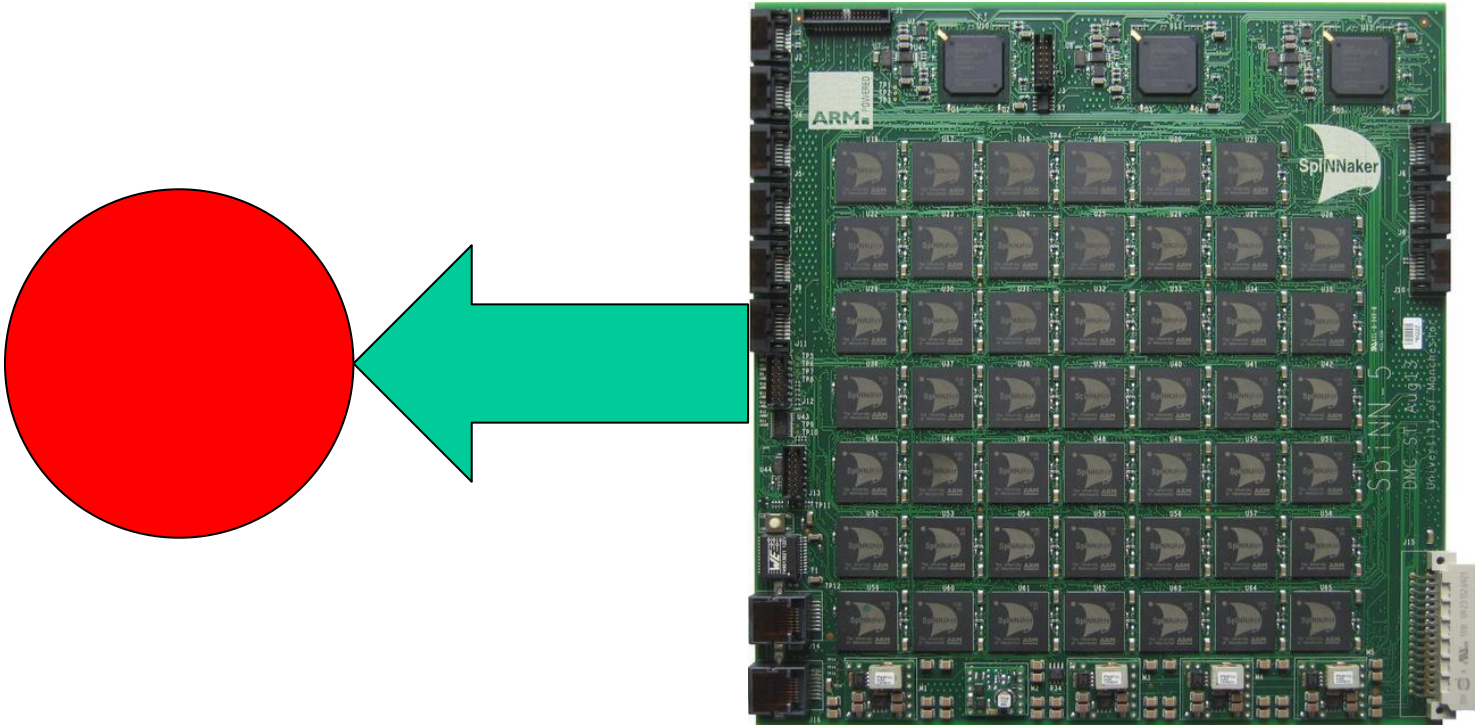
```
pop_1.set(i_offset=5.0)
p.run(50)
```





# PyNN - Get Data

```
data = pop_1.get_data(["v", "spikes"])
```



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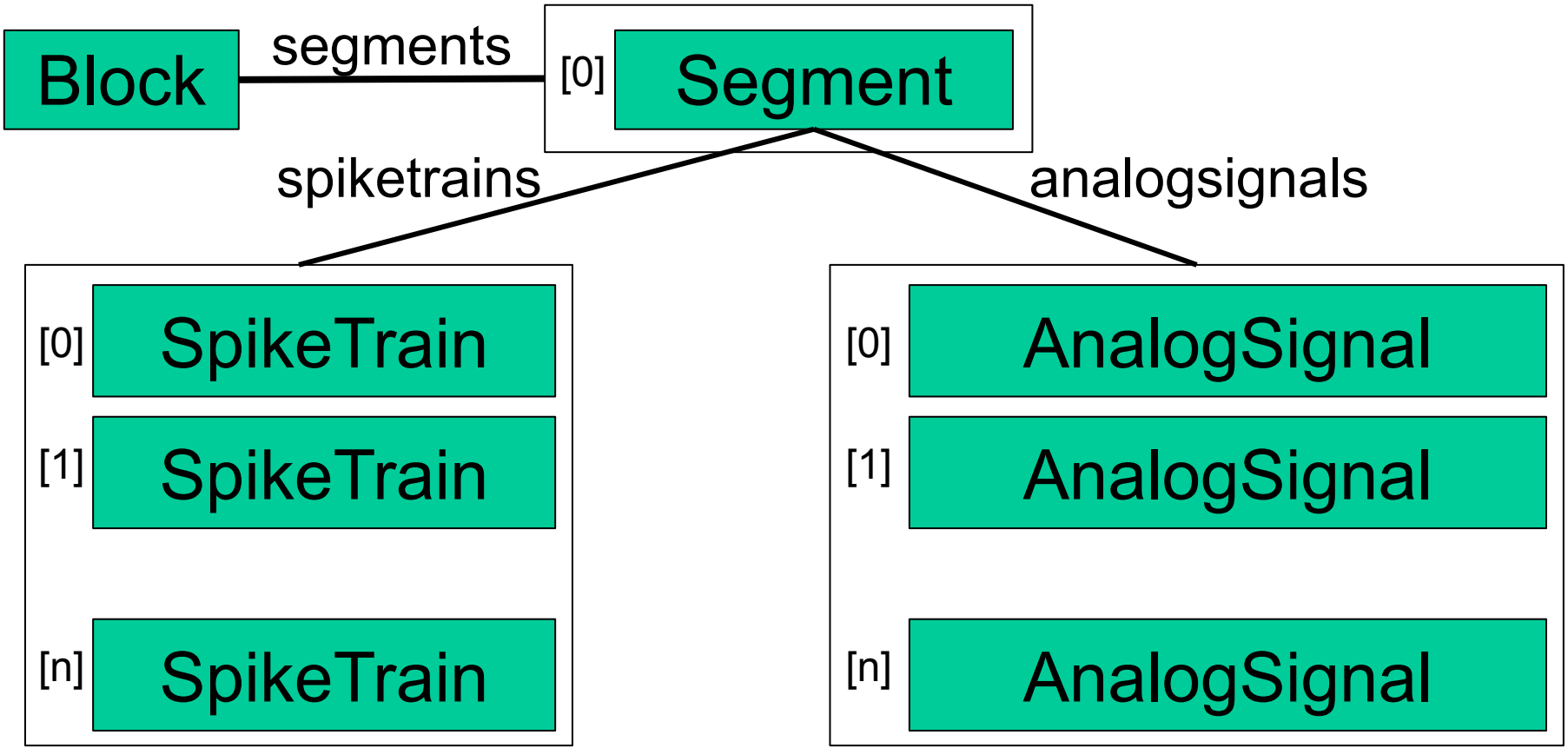
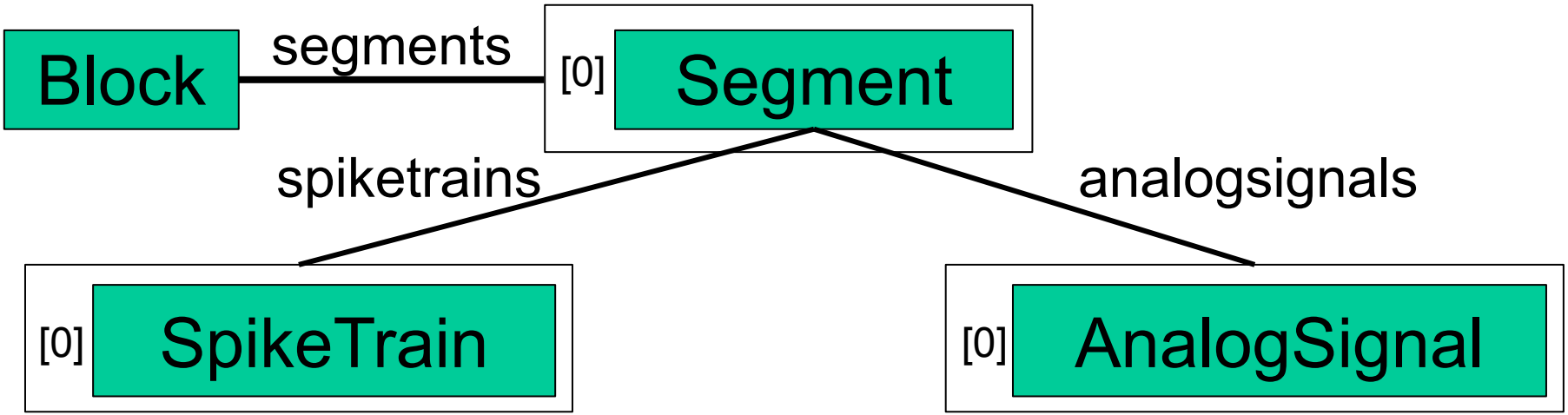
# Reading Results

# PyNN - Neo Data



# PyNN - Neo Data

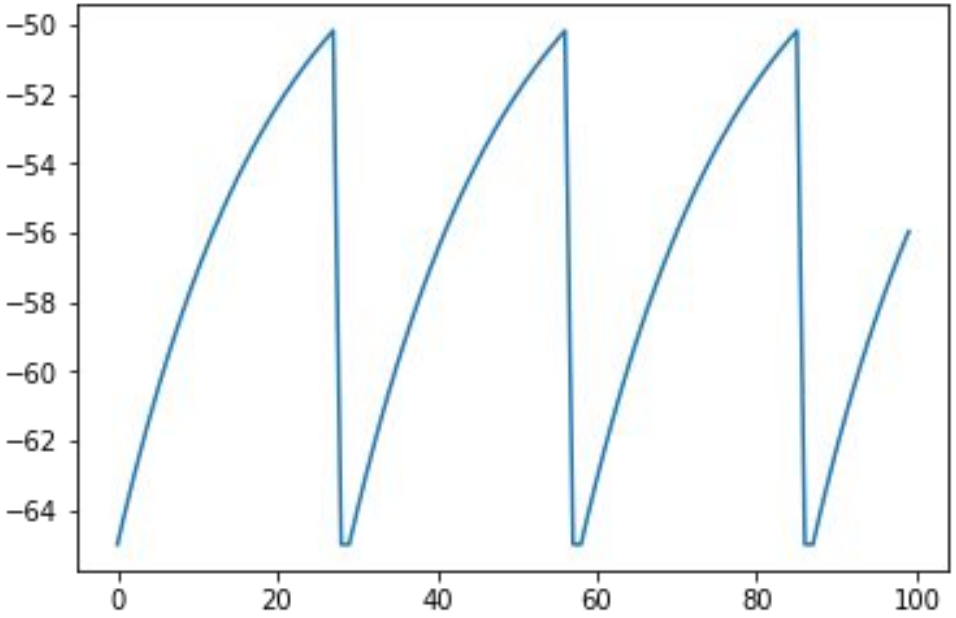



```
data = pop_1.get_data(["v", "spikes"])
v = data.segments[0].analogsignals
V = data.segments[0].filter(name="v")[0]
spikes = data.segments[0].spiketrains
```

# PyNN - Plotting

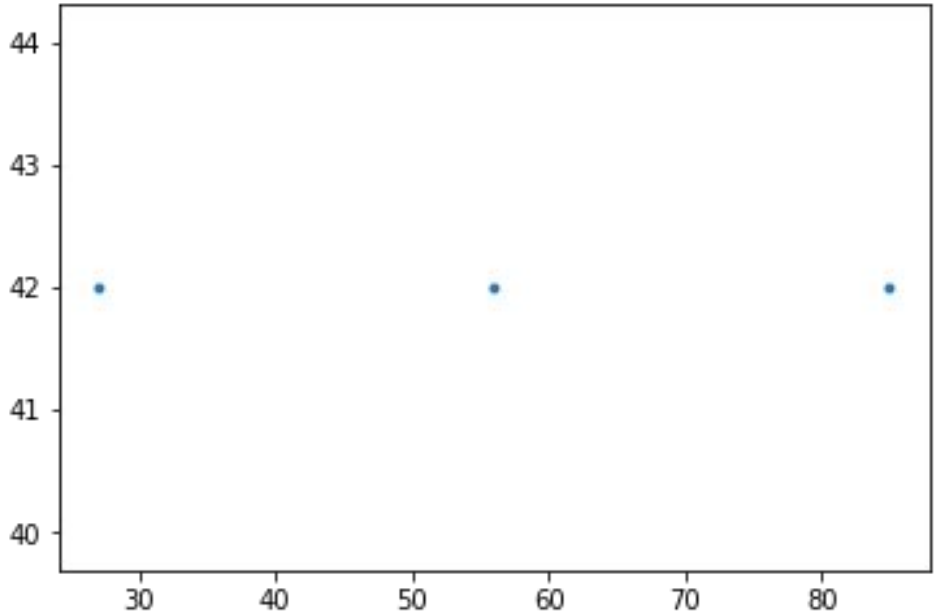
```
import matplotlib.pyplot as plt

plt.figure()
plt.plot(v[0].times, v[0])
plt.show()
```



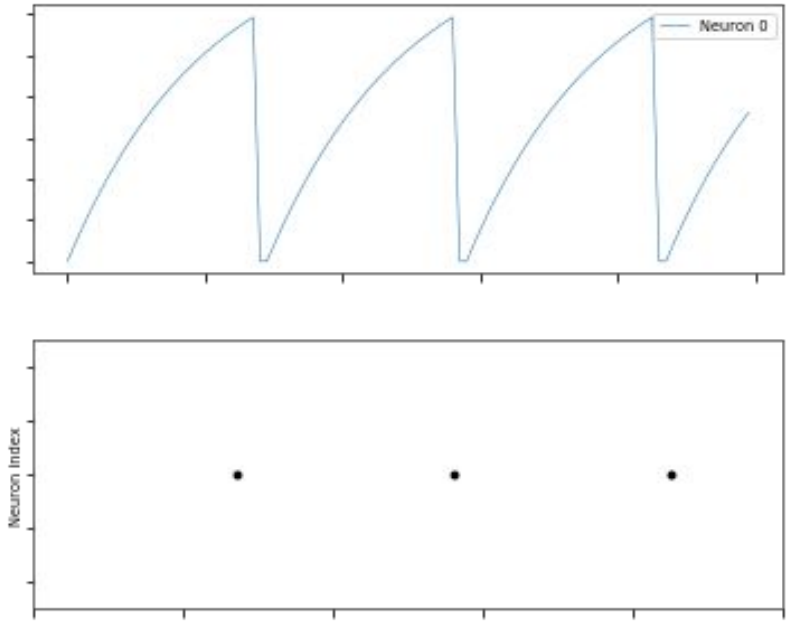
# PyNN - Plotting

```
plt.figure()
y = [1 for i in range(len(spikes[0]))]
plt.plot(spikes[0], y, “.”)
plt.show()
```



# PyNN - Plotting Neo Directly

```
from pyNN.utility.plotting import Figure, Panel
Figure(
    Panel(*data.segments[0].analogsignals),
    Panel(data.segments[0].spiketrains)
)
```



# PyNN - Get Weights and Delays

```
synapses = proj.get(
    ["weight", "delay"], "list")
```

```
array([(0, 5, 0.756, 1.), (0, 6, 0.316, 1.), (0, 7, 0.885, 2.),
       (0, 8, 0.421, 1.), (1, 4, 0.618, 1.), (1, 7, 0.438, 1.),
       (1, 9, 1.607, 1.), (2, 0, 0.129, 1.), (2, 2, 1.055, 1.),
       (2, 3, 1.319, 1.), (2, 9, 0.422, 1.), (3, 1, 0.328, 1.),
       (3, 3, 0.456, 1.), (3, 6, 0.566, 1.), (4, 0, 1.046, 1.),
       (4, 1, 1.199, 1.), (4, 2, 0.831, 1.), (5, 0, 1.643, 1.),
       (5, 2, 1.165, 1.), (5, 3, 0.902, 1.), (5, 5, 1.627, 1.),
       (6, 0, 2.143, 1.), (6, 5, 0.635, 1.), (6, 7, 0.704, 1.),
       (7, 0, 1.914, 1.), (7, 4, 0.289, 1.), (7, 5, 2.058, 1.),
       (7, 6, 0.428, 2.), (7, 7, 0.639, 1.), (7, 9, 0.616, 2.),
       (8, 0, 1.039, 1.), (8, 1, 0.576, 1.), (8, 4, 1.563, 2.),
       (8, 8, 0.995, 1.), (9, 0, 1.686, 1.), (9, 9, 0.631, 2.)]
```

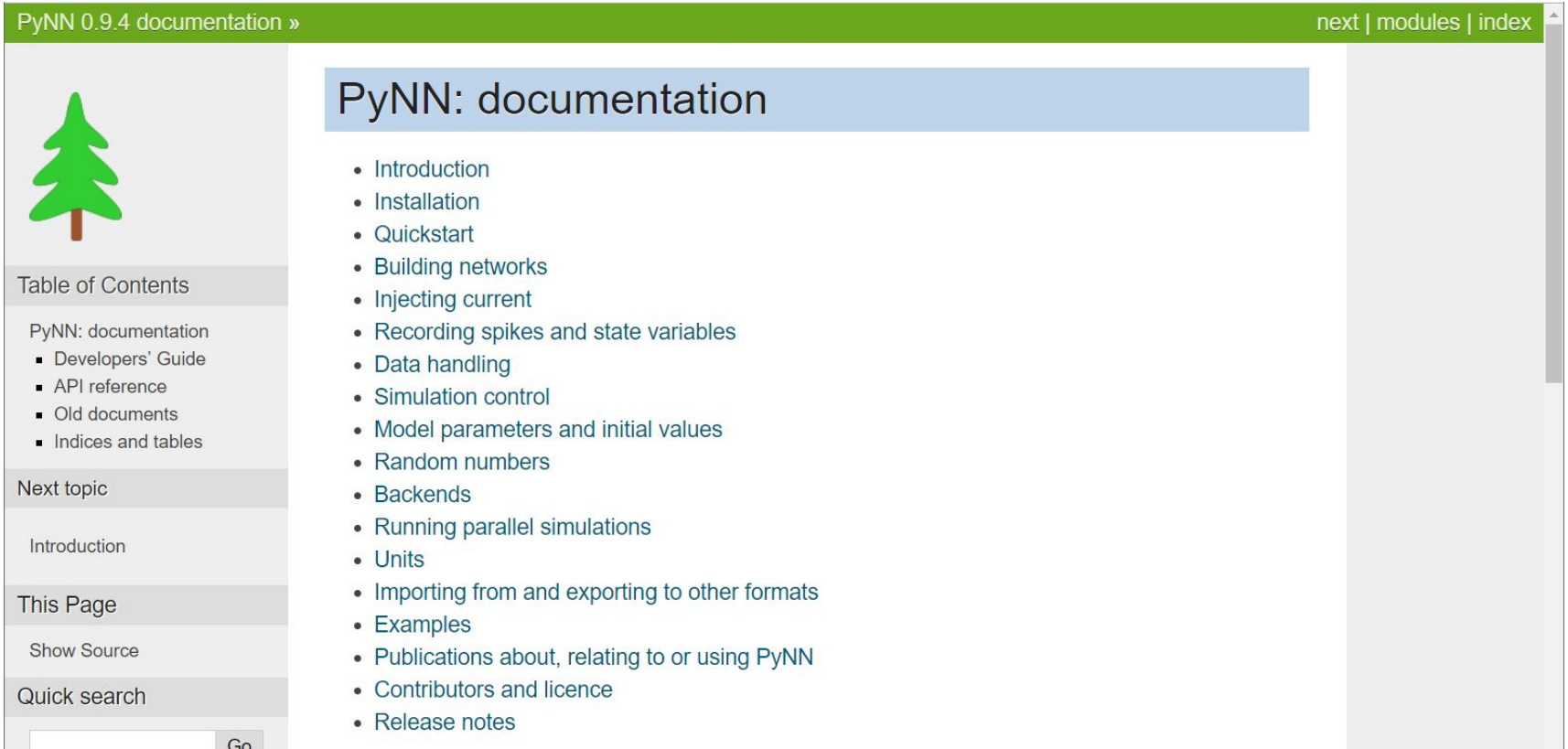
# PyNN - Get Weights and Delays

```
synapses = proj.get(
    "weight", "array")
```

```
array([[  nan,   nan,   nan,   nan,   nan, 0.756, 0.316, 0.885, 0.421,   nan],
       [  nan,   nan,   nan,   nan, 0.618,   nan,   nan, 0.438,   nan, 1.607],
       [0.129,   nan, 1.055, 1.319,   nan,   nan,   nan,   nan,   nan, 0.422],
       [  nan, 0.328,   nan, 0.456,   nan,   nan, 0.566,   nan,   nan,   nan],
       [1.046, 1.199, 0.831,   nan,   nan,   nan,   nan,   nan,   nan,   nan],
       [1.643,   nan, 1.165, 0.902,   nan, 1.627,   nan,   nan,   nan,   nan],
       [2.143,   nan,   nan,   nan,   nan, 0.635,   nan, 0.704,   nan,   nan],
       [1.914,   nan,   nan,   nan, 0.289, 2.058, 0.428, 0.639,   nan, 0.616],
       [1.039, 0.576,   nan,   nan, 1.563,   nan,   nan,   nan, 0.995,   nan],
       [1.686,   nan,   nan,   nan,   nan,   nan,   nan,   nan,   nan, 0.631]])
```

# PyNN Documentation

http://neuralensemble.org/docs/PyNN/



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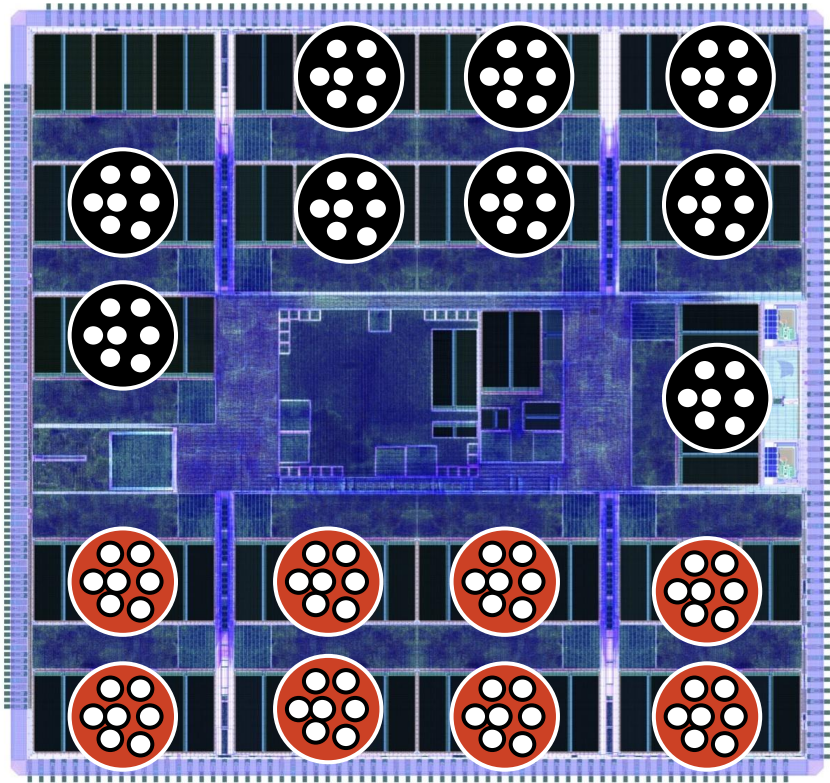
# Additional Non-PyNN Features

# Neurons Per Core

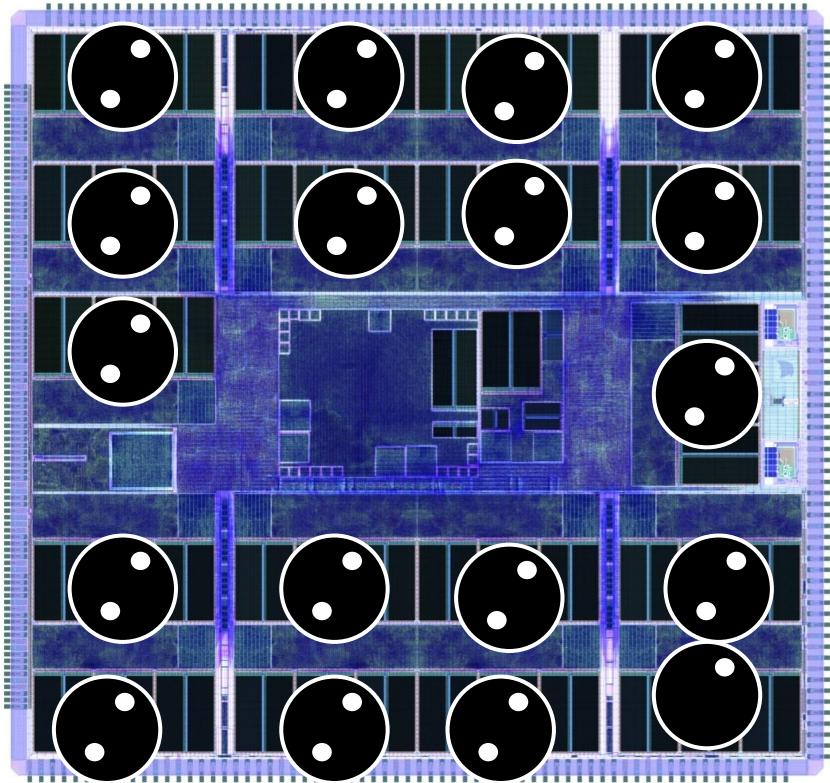
```
p.set_number_of_neurons_per_core(
    p.IF_curr_exp, 7)
```

Default: 256



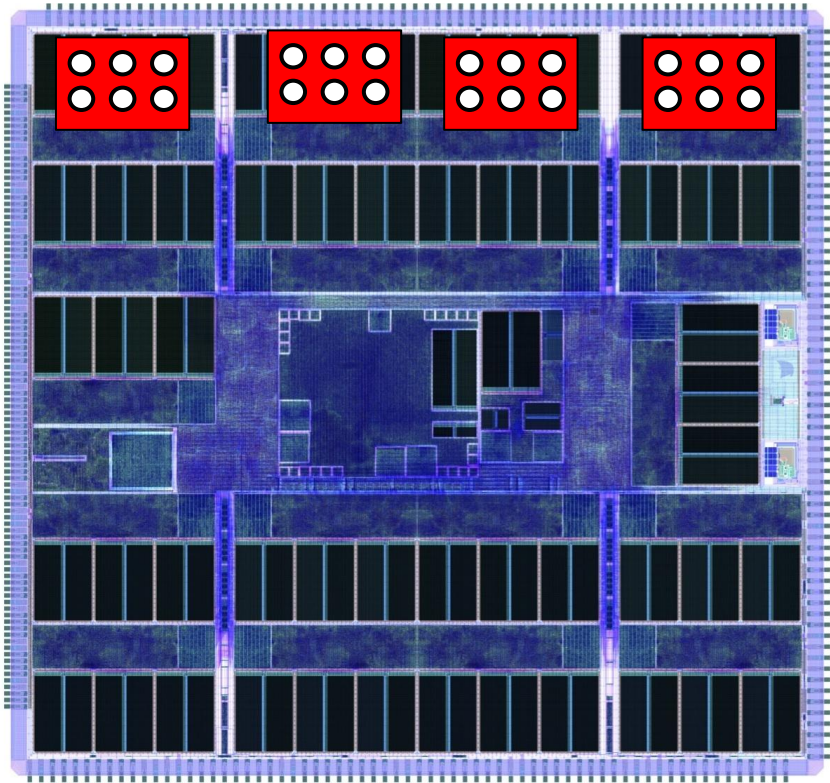
# Neurons Per Core

```
p.set_number_of_neurons_per_core(
    p.IF_curr_exp, 2)
```



# Neurons Per Core

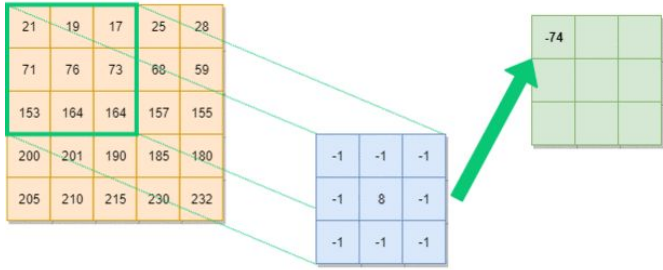
```
p.set_number_of_neurons_per_core(
      p.IF_curr_exp,
      (3, 2))
```



# Convolution Connections

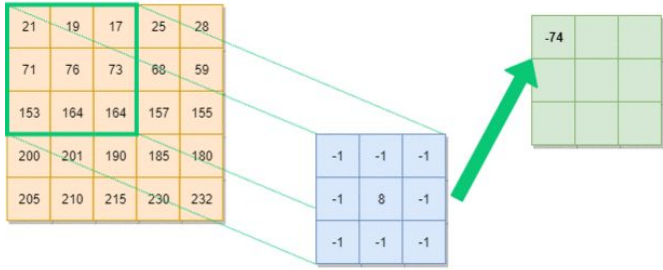
```
con = p.ConvolutionConnector(kernel=[...])

in_sz = (640, 480)
inp = p.Population(
    in_sz[0] * in_sz[1], ...
    structure=Grid2D(in_sz[0] / in_sz[1])
out_sz = conn.get_post_shape(in_sz)
outp = p.Population(
    out_sz[0] * out_sz[1], ...
    structure=Grid2D(out_sz[0] / out_sz[1])
```



# Convolution Connections

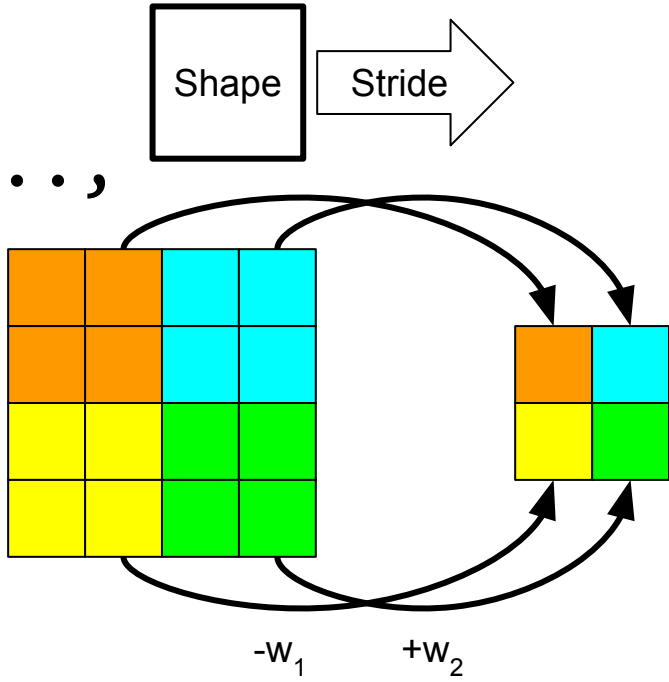
```
con = p.ConvolutionConnector(kernel=[...])
```




```
p.Projection(inp, outp, con, p.Convolution())
```

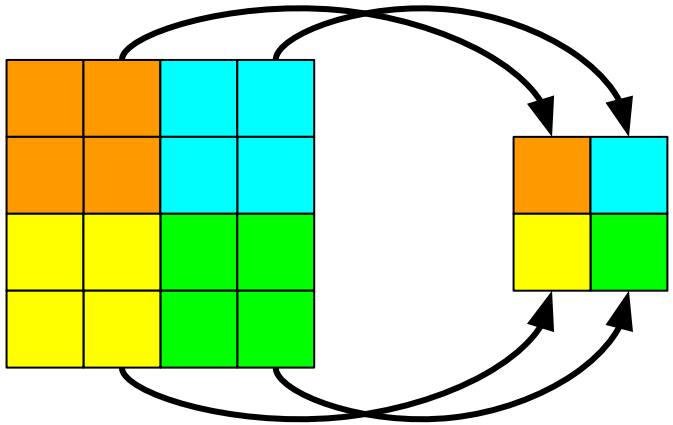
# Pool Dense Connections

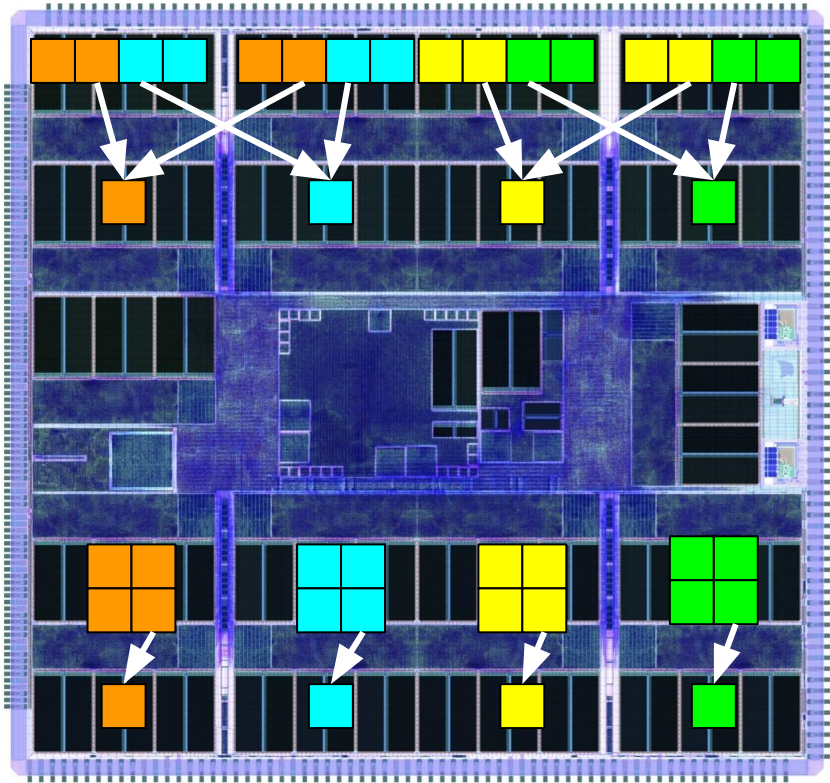
```
con = p.PoolDenseConnector(
    kernel=[...], pool_shape=...,
    pool_stride=...,
    positive_synapse_type=...,
    negative_synapse_type=...)
```




```
p.Projection(inp, outp, con, p.PoolDense())
```

# Use of Population Structure

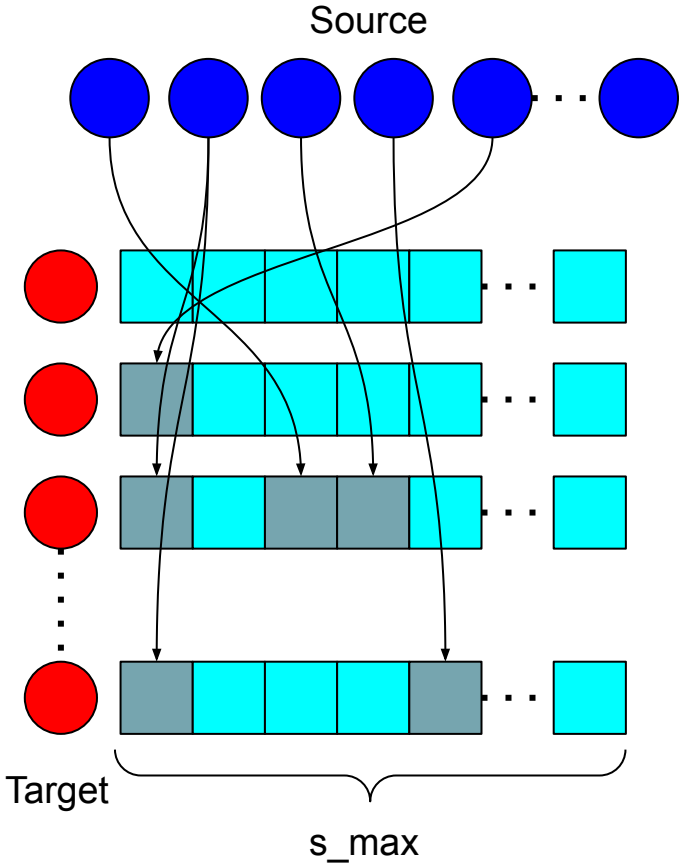




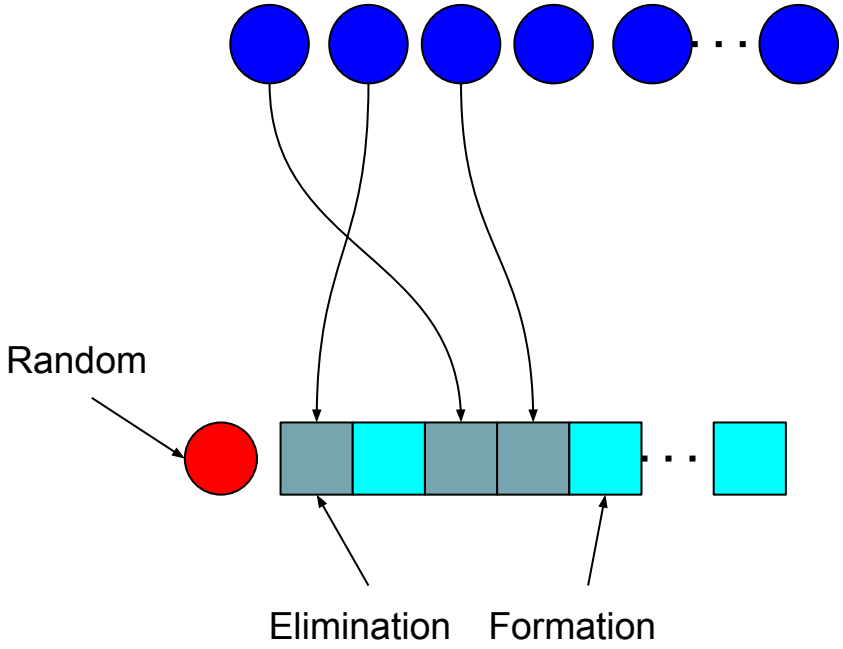
# Structural Plasticity

```
p.StructuralMechanism(
    f_rew=..., s_max=...,
    weight=..., delay=...,
    ...)
```

f_rew

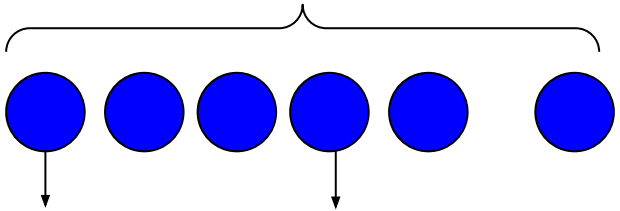


# Structural Plasticity

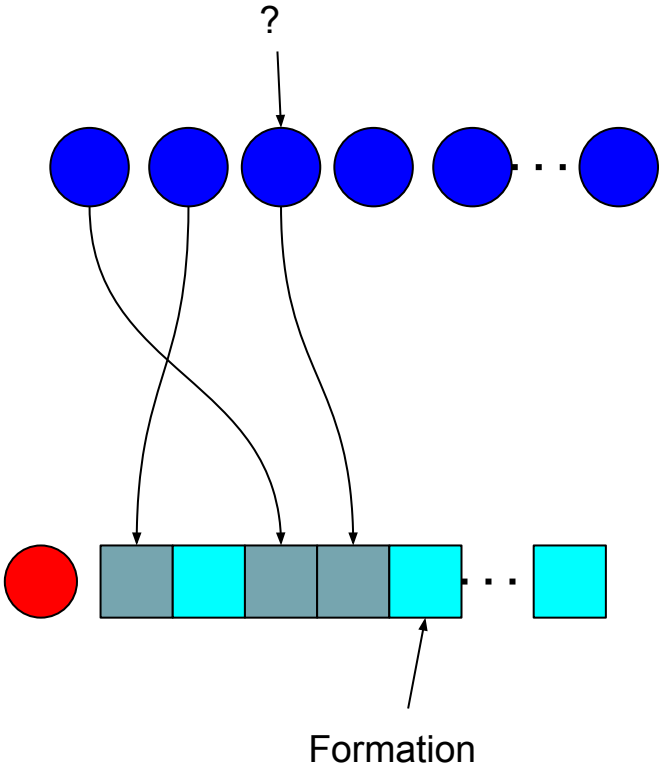


# Structural Plasticity

```
p.StructuralMechanism(
    ...
    partner_selection=,
    with_replacement=, ...)
    p.RandomSelection()
```

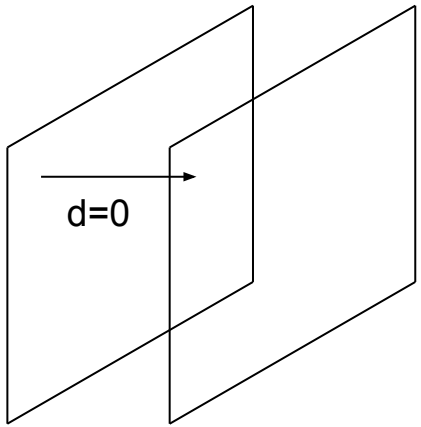


```
  p.LastNeuronSelection()
```



# Structural Plasticity

```
p.StructuralMechanism(
    ...
    formation=p.DistanceDependentFormation(
        grid=[...], p_form_forward=...,
        sigma_form_forward=...),
    ...)
```



# Structural Plasticity

```
p.StructuralMechanism(
    ...
    elimination=p.RandomByWeightElimination(
        threshold=...,
        prob_elim_depressed=...,
        prob_elim_potentiated=...),
    ...)
```

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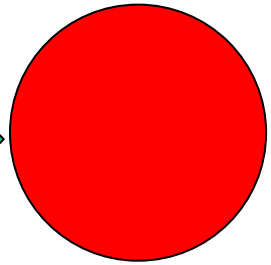
# Live Input and Output

# Input from Environment: Spikes

send_spikes

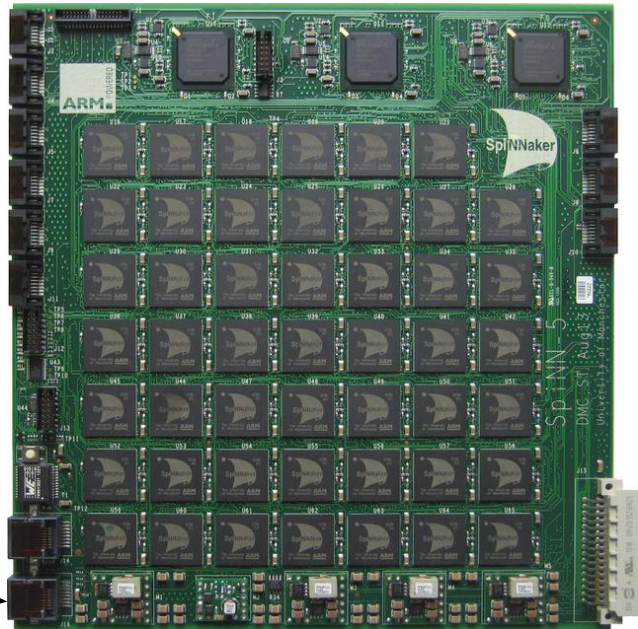
**SpikeInjector**
**label="injector"**



```
send_spikes("injector", [0])
```

```
SpynnakerLiveSpikesConnection(
    send_labels=["injector"])
```

Multicast Key(s)
(Spike)

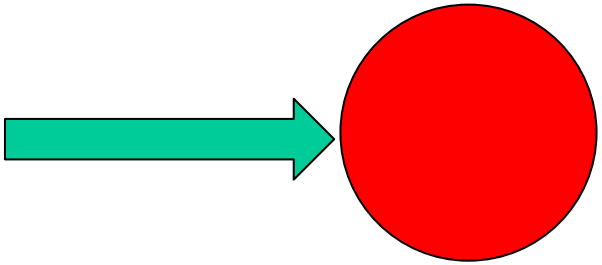


# Input from Environment: Rates

add_poisson_live_rate_control

set_rates

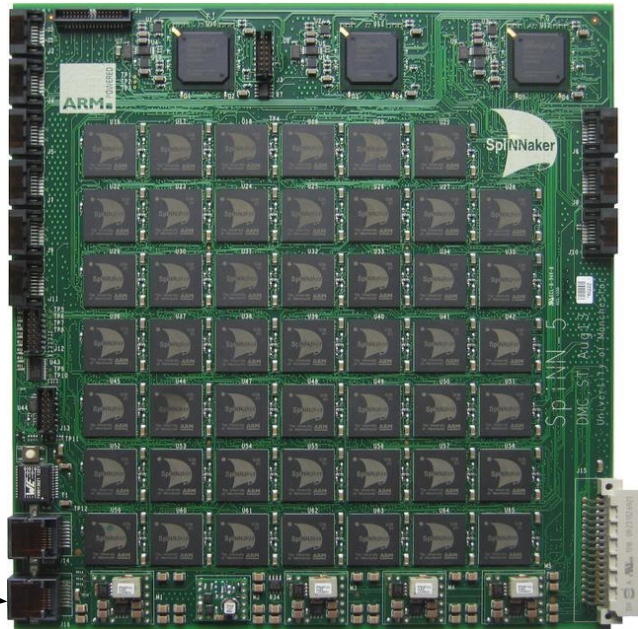
**SpikeSourcePoisson**
**label="input"**



```
set_rates("input", [(0, 10)])
```

```
SpynnakerPoissonControlConnection(
    poisson_labels=["input"])
```

Multicast Key(s)
and Payload(s)



# Output to Environment: Spikes

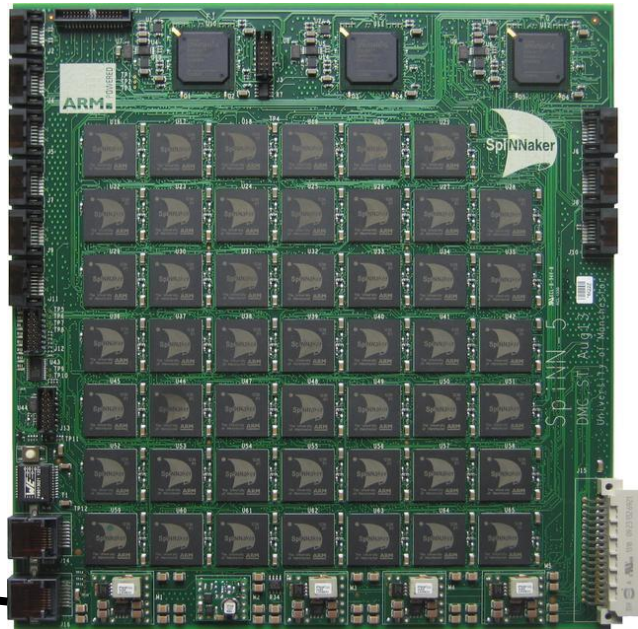
activate_live_output_for

recv

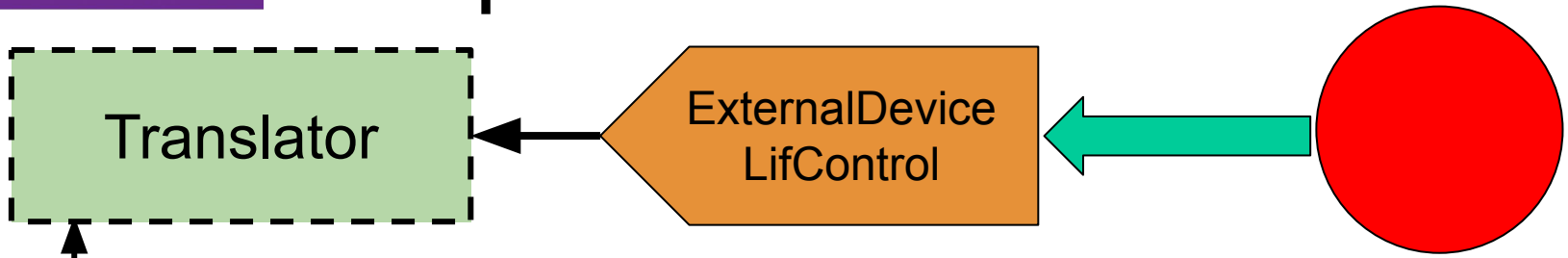
recv("pop", time, neuron_ids)

```
SpynnakerLiveSpikesConnection(
    receive_labels=["pop"])
```

Multicast Key(s)
(Spike)

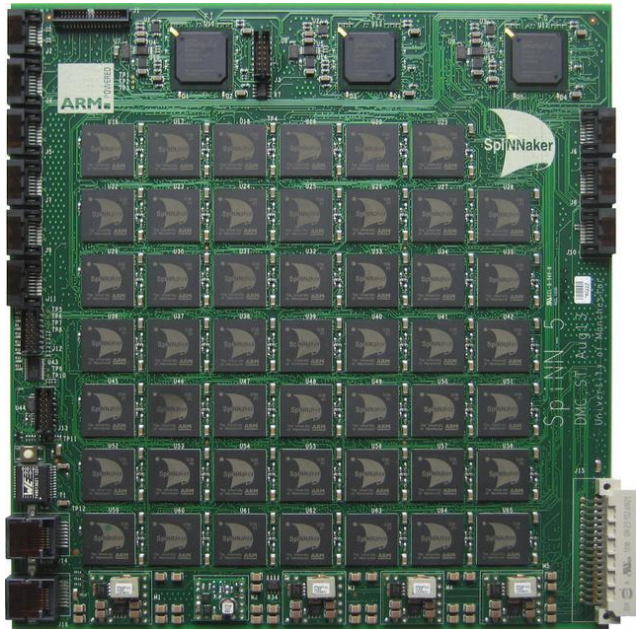


# Output to Environment: Voltage

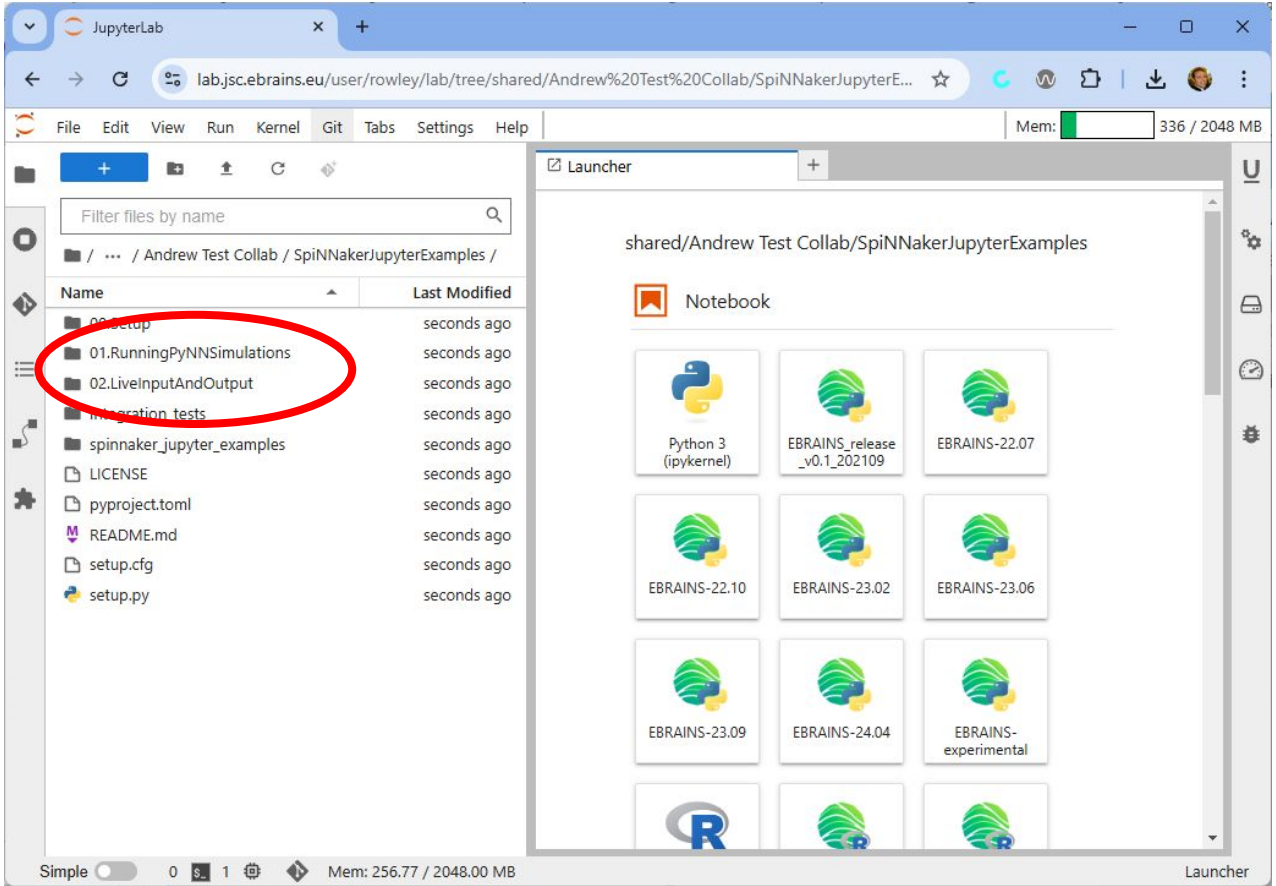



```
translate_control_packet(pkt)
```

```
EthernetControlPopulation(
    lif_device_model)
```



# SpiNNaker Tutorials



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# SpiNNaker Tutorials on Jupyter

## https://lab.ebrains.eu/

## https://github.com/SpiNNakerManchester/SpiNNakerJupyterExamples

```
import matplotlib.pyplot as plt
…
plt.savefig("fig.png")
```

01.RunningPyNNSimulations

02.LiveInputAndOutput

https://shorturl.at/oJWFf

## PyNN Documentation:

## http://neuralensemble.org/docs/PyNN/