bindsnet Documentation

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Contents:

BindsNET is built on top of the PyTorch deep learning platform. It is used for the simulation of spiking neural networks (SNNs) and is geared towards machine learning and reinforcement learning.

BindsNET takes advantage of the `torch.Tensor` object to build spiking neurons and connections between them, and simulate them on CPUs or GPUs (for strong acceleration / parallelization) without any extra work. Recently, `torchvision.datasets` has been integrated into the library to allow the use of popular vision datasets in training SNNs for computer vision tasks. Neural network functionality contained in `torch.nn.functional` module is used to implement more complex connections between populations of spiking neurons.

Spiking neural networks are sometimes referred to as the third generation of neural networks. Rather than the simple linear layers and nonlinear activation functions of deep learning neural networks, SNNs are composed of neural units which more accurately capture properties of their biological counterparts. An important difference between spiking neurons and the artificial neurons of deep learning are the former's integration of input *in time*; they are naturally short-term memory devices by their maintenance of a (possibly decaying) membrane voltage. As a result, some have argued that SNNs are particularly well-suited to model time-varying data.

Neurons are connected together with directed edges (*synapses*) which are (in general) plastic. Synapses may have their own dynamics as well, which may or may not *depend on pre- and post-synaptic neural activity https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3395004/* or *other biological signals https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4717313/*. The modification of synaptic strengths is thought to be an important mechanism by which organisms learn. Accordingly, BindsNET provides a module (**bindsnet.learning**) which contains functions used for the updating of synapse weights.

At its core, BindsNET provides software objects and methods which support the simulation of groups of different types of neurons (**bindsnet.network.nodes**), as well as different types of connections between them (**bindsnet.network.topology**). These may be arbitrarily combined together under a single **bindsnet.network.Network** object, which is responsible for the coordination of the simulation logic of all underlying components. On creation of a network, the user can specify a simulation timestep constant, dt, which determines the granularity of the simulation. Choosing this parameter induces a trade-off between simulation speed and numerical precision: large values result in fast simulation, but poor simulation accuracy, and vice versa. Monitors (**bindsnet.network.monitors**) are available for recording state variables from arbitrary network components (e.g., the voltage v of a group of neurons).

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CHAPTER 1

Installation

1.1 Pip install

Issue:

```
pip install git+https://github.com/BindsNET/bindsnet.git
```

1.2 Installing from source

On *nix systems, issue one of the following in a shell:

```
git clone https://github.com/Hananel-Hazan/bindsnet.git  # HTTPS
git clone git@github.com:Hananel-Hazan/bindsnet.git  # SSH
```

Change directory into `bindsnet` and issue one of the following:

```
pip install . # Typical install
pip install -e .  # Editable mode (package code can be edited without reinstall)
```

This will install `bindsnet` and all its dependencies.

1.3 Running the tests

If BindsNET is installed from source, install `pytest` and issue the following from BindsNET's installation directory:

```
python -m pytest test
```

CHAPTER 2

Quickstart

Check out some example use cases for BindsNET in the `examples/` folder (link). For example, changing directory to *[bindsnet-root]/examples/mnist* and running the following will result in a near-replication of the architecture of Diehl & Cook 2015:

```
python eth_mnist.py [options]
```

The token `[options]` should be replaced with any command-line arguments you'd like to use to modify the behavior of the program.

CHAPTER 3

BindsNET User Manual

Welcome to BindsNET's user manual! To get started, click on one of the links below.

3.1 Part I: Creating and Adding Network Components

3.1.1 Creating a Network

The `bindsnet.network.Network` object is BindsNET's main offering. It is responsible for the coordination of simulation of all its constituent components: neurons, synapses, learning rules, etc. To create one:

```
from bindsnet.network import Network

network = Network()
```

The `bindsnet.network.Network` object accepts optional keyword arguments `dt`, `batch_size`, `learning`, and `reward_fn`.

The `dt` argument specifies the simulation time step, which determines what temporal granularity, in milliseconds, simulations are solved at. All simulation is done with the Euler method for the sake of computational simplicity. If instability is encountered in your simulation, use a smaller `dt` to resolve numerical instability.

The `batch_size` argument specifies the expected minibatch size of the input data. However, since BindsNET supports dynamics minibatch size, this argument can safely be ignored. It is used to initialize stateful neuronal and synaptic variables, and may provide a small speedup if specified beforehand.

The `learning` argument acts to enable or disable updates to adaptive parameters of network components; e.g., synapse weights or adaptive voltage thresholds. See **'Using Learning Rules'_** for more details.

The `reward_fn` argument takes in class that specifies how a scalar reward signal will be computed and fed to the network and its components. Typically, the output of this callable class will be used in certain "reward-modulated", or "three-factor" learning rules. See **'Using Learning Rules'_** for more details.

3.1.2 Adding Network Components

BindsNET supports three categories of network component: *layers* of neurons (`nodes`), *connections* between them (*bindsnet.network.topology*), and *monitors* for recording the evolution of state variables (*bindsnet.network.monitors*).

Note: Names of components in a network are arbitrary, and need only be unique within their component group (`layers`, `connections`, and `monitors`) in order to address them uniquely. We encourage our users to develop their own naming conventions, using whatever works best for them.

Creating and adding layers

To create a layer (or *population*) of nodes (in this case, leaky integrate-and-fire (LIF) neurons:

```
from bindsnet.network.nodes import LIFNodes

# Create a layer of 100 LIF neurons with shape (10, 10).
layer = LIFNodes(n=100, shape=(10, 10))
```

Each *bindsnet.network.nodes* object has many keyword arguments, but one of either `n` (the number of nodes in the layer, or `shape` (the arrangement of the layer, from which the number of nodes can be computed) is required. Other arguments for certain nodes objects include `thresh` (scalar or tensor giving voltage threshold(s) for the layer), `rest` (scalar or tensor giving resting voltage(s) for the layer), `traces` (whether to keep track of "spike traces" for each neuron in the layer), and `tc_decay` (scalar or tensor giving time constant(s) of the layer's neurons' voltage decay).

To add a layer to the network, use the `add_layer` function, and give it a name (a string) to call it by:

```
network.add_layer(
    layer=layer, name="LIF population"
)
```

Such layers are kept in the dictionary attribute `network.layers`, and can be accessed by the user; e.g., by `network.layers['LIF population']`.

Other layer types include *bindsnet.network.nodes.Input* (for user-specified input spikes), *bindsnet.network.nodes.McCullochPitts* (the McCulloch-Pitts neuron model), *bindsnet.network.nodes.AdaptiveLIFNodes* (LIF neurons with adaptive thresholds), and *bindsnet.network.nodes.IzhikevichNodes* (the Izhikevich neuron model). Any number of layers can be added to the network.

Custom nodes objects can be implemented by sub-classing *bindsnet.network.nodes.Nodes*, an abstract class with common logic for neuron simulation. The functions `forward(self, x: torch.Tensor)` (computes effects of input data on neuron population; e.g., voltage changes, spike occurrences, etc.), `reset_state_variables(self)` (resets neuron state variables to default values), and `_compute_decays(self)` must be implemented, as they are included as abstract functions of *bindsnet.network.nodes.Nodes*.

Creating and adding connections

Connections can be added between different populations of neurons (a *projection*), or from a population back to itself (a *recurrent* connection). To create an all-to-all connection:

```
from bindsnet.network.nodes import Input, LIFNodes
from bindsnet.network.topology import Connection

# Create two populations of neurons, one to act as the "source"
# population, and the other, the "target population".
source_layer = Input(n=100)
target_layer = LIFNodes(n=1000)

# Connect the two layers.
connection = Connection(
    source=source_layer, target=target_layer
)
```

Like nodes, each connection object has many keyword arguments, but both `source` and `target` are required. These must be objects that subclass *bindsnet.network.nodes.Nodes*. Other arguments include `w` and `b` (weight and bias tensors for the connection), `wmin` and `wmax` (minimum and maximum allowable weight values), `update_rule` (`bindsnet.learning.LearningRule`; used for updating connection weights based on pre- and post-synaptic neuron activity and / or global neuromodulatory signals), and `norm` (a floating point value to normalize weights by).

To add a connection to the network, use the `add_connection` function, and pass the names given to source and target populations as `source` and `target` arguments. Make sure that the source and target neurons are added to the network as well:

```
network.add_layer(
    layer=source_layer, name="A"
)
network.add_layer(
    layer=target_layer, name="B"
)
network.add_connection(
    connection=connection, source="A", target="B"
)
```

Connections are kept in the dictionary attribute `network.connections`, and can be accessed by the user; e.g., by `network.connections['A', 'B']`. The layers must be added to the network with matching names (respectively, `A` and `B`) in order for the connection to work properly. There are no restrictions on the directionality of connections; layer “A” may connect to layer “B”, and “B” back to “A”, or “A” may connect directly back to itself.

Custom connection objects can be implemented by sub-classing *`bindsnet.network.topology.AbstractConnection`*, an abstract class with common logic for computing synapse outputs and updates. This includes functions `compute` (for computing input to downstream layer as a function of spikes and connection weights), `update` (for updating connection weights based on pre-, post-synaptic activity and possibly other signals; e.g., reward prediction error), `normalize` (for ensuring weights incident to post-synaptic neurons sum to a pre-specified value), and `reset_state_variables` (for re-initializing stateful variables for the start of a new simulation).

Specifying monitors

`bindsnet.network.monitors.AbstractMonitor` objects can be used to record tensor-valued variables over the course of simulation in certain network components. To create a monitor to monitor a single component:

```
from bindsnet.network import Network
from bindsnet.network.nodes import Input, LIFNodes
from bindsnet.network.topology import Connection
from bindsnet.network.monitors import Monitor
```

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```
network = Network()

source_layer = Input(n=100)
target_layer = LIFNodes(n=1000)

connection = Connection(
    source=source_layer, target=target_layer
)

# Create a monitor.
monitor = Monitor(
    obj=target_layer,
    state_vars=("s", "v"),  # Record spikes and voltages.
    time=500,  # Length of simulation (if known ahead of time).
)
```

The user must specify a `Nodes` or `AbstractConnection` object from which to record, attributes of that object to record (`state_vars`), and, optionally, how many time steps the simulation(s) will last, in order to save time by pre-allocating memory.

To add a monitor to the network (thereby enabling monitoring), use the `add_monitor` function of the `bindsnet.network.Network` class:

```
network.add_layer(
    layer=source_layer, name="A"
)
network.add_layer(
    layer=target_layer, name="B"
)
network.add_connection(
    connection=connection, source="A", target="B"
)
network.add_monitor(monitor=monitor, name="B")
```

The name given to the monitor is not important. It is simply used by the user to select from the monitor objects controlled by a `Network` instance.

One can get the contents of a monitor by calling `network.monitors[<name>].get(<state_var>)`, where `<state_var>` is a member of the iterable passed in for the `state_vars` argument. This returns a tensor of shape `(time, n_1, ..., n_k)`, where `(n_1, ..., n_k)` is the shape of the recorded state variable.

The *`bindsnet.network.monitors.NetworkMonitor`* is used to record from many network components at once. To create one:

```
from bindsnet.network.monitors import NetworkMonitor

network_monitor = NetworkMonitor(
    network: Network,
    layers: Optional[Iterable[str]],
    connections: Optional[Iterable[Tuple[str, str]]],
    state_vars: Optional[Iterable[str]],
    time: Optional[int],
)
```

The user must specify the network to record from, an iterable of names of layers (entries in `network.layers`), an iterable of 2-tuples referring to connections (entries in `network.connections`), an iterable of tensor-valued state variables to record during simulation (`state_vars`), and, optionally, how many time steps the simulation(s) will last, in order to save time by pre-allocating memory.

Similarly, one can get the contents of a network monitor by calling `network.monitors[<name>].get()`. Note this function takes no arguments; it returns a dictionary mapping network components to a sub-dictionary mapping state variables to their tensor-valued recording.

3.1.3 Running Simulations

After building up a `Network` object, the next step is to run a simulation. Here, the function `Network.run` comes into play. It takes arguments `inputs` (a dictionary mapping names of layers subclassing `AbstractInput` to input data of shape `[time, batch_size, *input_shape]`, where `input_shape` is the shape of the neuron population to which the data is passed), `time` (the number of simulation timesteps, generally thought of as milliseconds), and a number of keyword arguments, including `clamp` (and `unclamp`), used to force neurons to spike (or not spike) at any given time step, `reward`, for supplying to reward-modulated learning rules, and `masks`, a dictionary mapping connections to boolean tensors specifying which synapses weights to clamp to zero.

Building on the previous parts of this guide, we present a simple end-to-end example of simulating a two-layer, input-output spiking neural network.

```python
import torch
import matplotlib.pyplot as plt
from bindsnet.network import Network
from bindsnet.network.nodes import Input, LIFNodes
from bindsnet.network.topology import Connection
from bindsnet.network.monitors import Monitor
from bindsnet.analysis.plotting import plot_spikes, plot_voltages

# Simulation time.
time = 500

# Create the network.
network = Network()

# Create and add input, output layers.
source_layer = Input(n=100)
target_layer = LIFNodes(n=1000)

network.add_layer(
    layer=source_layer, name="A"
)
network.add_layer(
    layer=target_layer, name="B"
)

# Create connection between input and output layers.
forward_connection = Connection(
    source=source_layer,
    target=target_layer,
    w=0.05 + 0.1 * torch.randn(source_layer.n, target_layer.n),  # Normal(0.05, 0.01) weights.
)

network.add_connection(
    connection=forward_connection, source="A", target="B"
)
```

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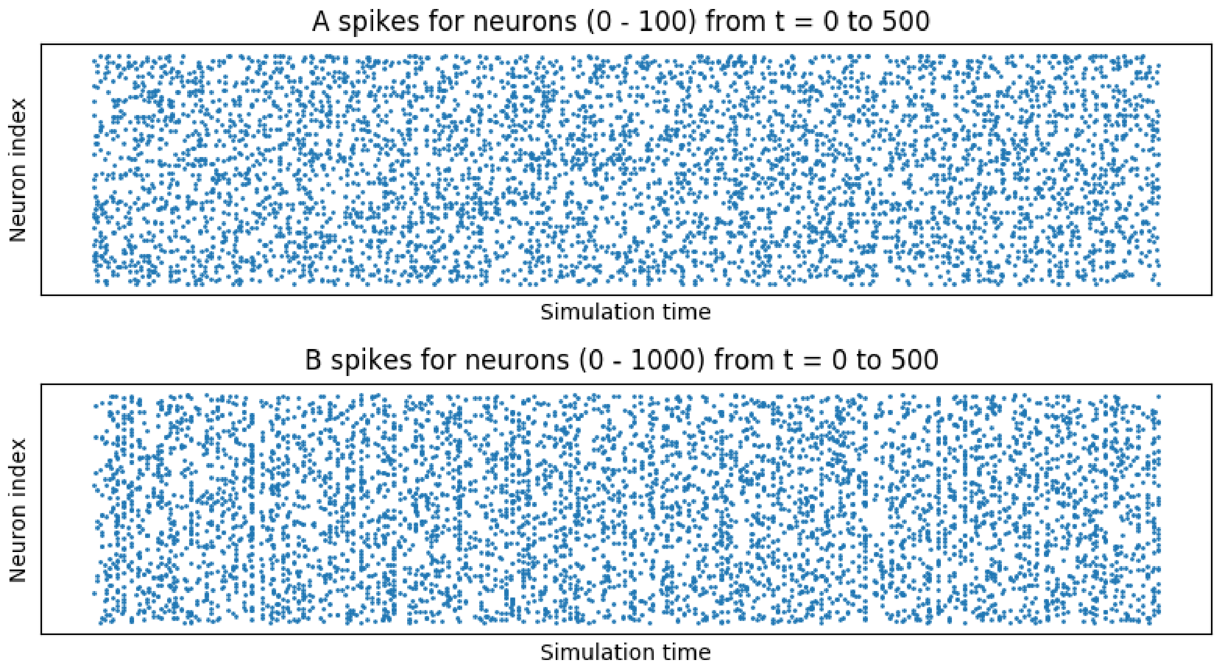
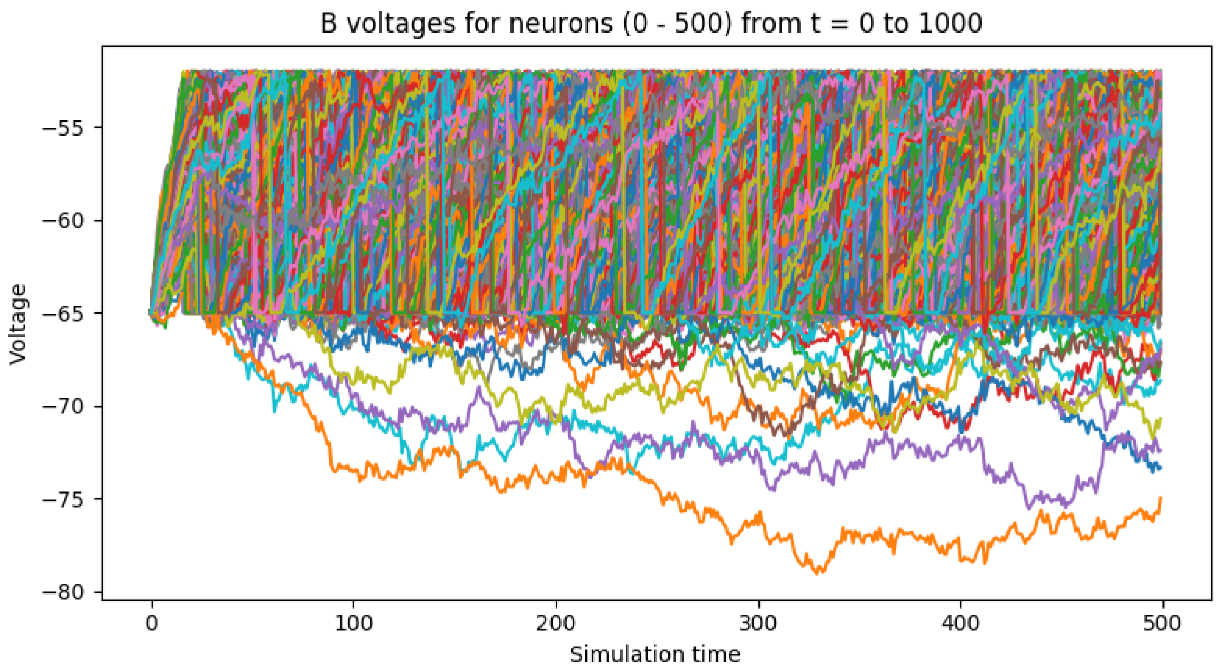
```
# Create recurrent connection in output layer.
recurrent_connection = Connection(
    source=target_layer,
    target=target_layer,
    w=0.025 * (torch.eye(target_layer.n) - 1), # Small, inhibitory "competitive"␣
↪weights.
)

network.add_connection(
    connection=recurrent_connection, source="B", target="B"
)

# Create and add input and output layer monitors.
source_monitor = Monitor(
    obj=source_layer,
    state_vars=("s",),  # Record spikes and voltages.
    time=time,  # Length of simulation (if known ahead of time).
)
target_monitor = Monitor(
    obj=target_layer,
    state_vars=("s", "v"),  # Record spikes and voltages.
    time=time,  # Length of simulation (if known ahead of time).
)

network.add_monitor(monitor=source_monitor, name="A")
network.add_monitor(monitor=target_monitor, name="B")

# Create input spike data, where each spike is distributed according to Bernoulli(0.
↪1).
input_data = torch.bernoulli(0.1 * torch.ones(time, source_layer.n)).byte()
inputs = {"A": input_data}

# Simulate network on input data.
network.run(inputs=inputs, time=time)

# Retrieve and plot simulation spike, voltage data from monitors.
spikes = {
    "A": source_monitor.get("s"), "B": target_monitor.get("s")
}
voltages = {"B": target_monitor.get("v")}

plt.ioff()
plot_spikes(spikes)
plot_voltages(voltages, plot_type="line")
plt.show()
```

This script will result in figures that looks something like this:





Notice that, in the voltages plot, no voltage goes above -52mV, the default threshold of the `LIFNodes` object. After hitting this point, neurons' voltage is reset to -64mV, which can also be seen in the figure.

3.1.4 Simulation Notes

The simulation of all network components is *synchronous* (*clock-driven*); i.e., all components are updated at each time step. Other frameworks use *event-driven* simulation, where spikes can occur at arbitrary times instead of at regular multiples of `dt`. We chose clock-driven simulation due to ease of implementation and for computational efficiency considerations.

During a simulation step, input to each layer is computed as the sum of all outputs from layers connecting to it (weighted by synapse weights) from the *previous* simulation time step (implemented by the `_get_inputs` method of the `bindsnet.network.Network` class). This model allows us to decouple network components and perform their simulation separately at the temporal granularity of chosen `dt`, interacting only between simulation steps.

This is a strict departure from the computation of *deep neural networks* (DNNs), in which an ordering of layers is supposed, and layers' activations are computed *in sequence* from the shallowest to the deepest layer in a single time step, with the exclusion of recurrent layers, whose computations are still ordered in time.

3.2 Part II: Creating and Adding Learning Rules

3.2.1 What is considered a learning rule?

Learning rules are necessary for the automated adaption of network parameters during simulation. At present, BindsNET supports two different categories of learning rules:

- **Two factor: Associative learning takes place based on pre- and post-synaptic neural activity. Examples include:**
  - The typical example is Hebbian learning, which may be summarized as "Cells that fire together wire together." That is, co-active neurons causes their connection strength to increase.
  - Spike-timing-dependent plasticity (STDP) stipulates that the ordering of pre- and post-synaptic spikes matters. A synapse is strengthened if the pre-synaptic neuron fires *before* the post-synaptic neuron, and, conversely, is weakened if it fires *after* the post-synaptic neuron. The magnitude of these updates is a decreasing function of the time between pre- and post-synaptic spikes.
- **Three factor: In addition to associating pre- and post-synaptic neural activity, a third factor is introduced which modulate**
  - (Reward, error, attention)-modulated (Hebbian learning, STDP): The same learning rules described above are modulated by the presence of global signals such as reward, error, or attention, which can be variously defined in machine learning or reinforcement learning contexts. These signals act to gate plasticity, turning it on or off and switching its sign and magnitude, based on the task at hand.

The above are examples of local learning rules, where the information needed to make updates are thought to be available at the synapse. For example, pre- and post-synaptic neurons are adjacent to synapses, rendering their spiking activity accessible, whereas chemical signals like dopamine (hypothesized to be a reward prediction error (RPE) signal) are widely distributed across certain neuron populations; i.e., they are *globally* available. This is in contrast to learning algorithms like back-propagation, where per-synapse error signals are derived by computing backwards from a loss function at the network's output layer. Such error derivation is thought to be biologically implausible, especially compared to the two- and three-factor rules mentioned above.

3.2.2 Creating a learning rule in BindsNET

At present, learning rules are attached to specific `Connection` objects. For example, to create a connection with a STDP learning rule on the synapses:

```
from bindsnet.network.nodes import Input, LIFNodes
from bindsnet.network.topology import Connection
from bindsnet.learning import PostPre

```

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```
# Create two populations of neurons, one to act as the "source"
# population, and the other, the "target population".
# Neurons involved in certain learning rules must record synaptic
# traces, a vector of short-term memories of the last emitted spikes.
source_layer = Input(n=100, traces=True)
target_layer = LIFNodes(n=1000, traces=True)

# Connect the two layers.
connection = Connection(
    source=source_layer, target=target_layer, update_rule=PostPre, nu=(1e-4, 1e-2)
)
```

The connection may be added to a `Network` instance as usual. The `Connection` object takes arguments `update_rule`, of type `bindsnet.learning.LearningRule`, as well as `nu`, a 2-tuple specifying pre- and post-synaptic learning rates; i.e., multiplicative factors which modulate how quickly synapse weights change.

Learning rules also accept arguments `reduction`, which specifies how parameter updates are aggregated across the batch dimension, and `weight_decay`, which specifies the time constant of the rate of decay of synapse weights to zero. By default, parameter updates are averaged across the batch dimension, and there is no weight decay.

Other supported learning rules include `Hebbian`, `WeightDependentPostPre`, `MSTDP` (reward-modulated STDP), and `MSTDPET` (reward-modulated STDP with eligibility traces).

Custom learning rules can be implemented by subclassing `bindsnet.learning.LearningRule` and providing implementations for the types of `AbstractConnection` objects intended to be used. For example, the `Connection` and `LocalConnection` objects rely on the implementation of a private method, `_connection_update`, whereas the `Conv2dConnection` object uses the `_conv2d_connection_update` version.

CHAPTER 4

bindsnet package

4.1 Subpackages

4.1.1 bindsnet.analysis package

Submodules

bindsnet.analysis.plotting module

`bindsnet.analysis.plotting.`**`plot_assignments`**(*assignments: torch.Tensor, im: Optional[matplotlib.image.AxesImage] = None, figsize: Tuple[int, int] = (5, 5), classes: Optional[Sized] = None*) → matplotlib.image.AxesImage

Plot the two-dimensional neuron assignments.

Parameters

- **`assignments`** – Vector of neuron label assignments.
- **`im`** – Used for re-drawing the assignments plot.
- **`figsize`** – Horizontal, vertical figure size in inches.
- **`classes`** – Iterable of labels for colorbar ticks corresponding to data labels.

Returns Used for re-drawing the assigments plot.

`bindsnet.analysis.plotting.`**`plot_conv2d_weights`**(*weights: torch.Tensor, wmin: float = 0.0, wmax: float = 1.0, im: Optional[matplotlib.image.AxesImage] = None, figsize: Tuple[int, int] = (5, 5), cmap: str = 'hot_r'*) → matplotlib.image.AxesImage

Plot a connection weight matrix of a Conv2dConnection.

Parameters

- **weights** – Weight matrix of Conv2dConnection object.
- **wmin** – Minimum allowed weight value.
- **wmax** – Maximum allowed weight value.
- **im** – Used for re-drawing the weights plot.
- **figsize** – Horizontal, vertical figure size in inches.
- **cmap** – Matplotlib colormap.

Returns Used for re-drawing the weights plot.

`bindsnet.analysis.plotting.`**`plot_input`**(*image: torch.Tensor, inpt: torch.Tensor, label: Optional[int] = None, axes: List[matplotlib.axes._axes.Axes] = None, ims: List[matplotlib.image.AxesImage] = None, figsize: Tuple[int, int] = (8, 4)*) → Tuple[List[matplotlib.axes._axes.Axes], List[matplotlib.image.AxesImage]]

Plots a two-dimensional image and its corresponding spike-train representation.

Parameters

- **image** – A 2D array of floats depicting an input image.
- **inpt** – A 2D array of floats depicting an image's spike-train encoding.
- **label** – Class label of the input data.
- **axes** – Used for re-drawing the input plots.
- **ims** – Used for re-drawing the input plots.
- **figsize** – Horizontal, vertical figure size in inches.

Returns Tuple of `(axes, ims)` used for re-drawing the input plots.

`bindsnet.analysis.plotting.`**`plot_locally_connected_weights`**(*weights: torch.Tensor, n_filters: int, kernel_size: Union[int, Tuple[int, int]], conv_size: Union[int, Tuple[int, int]], locations: torch.Tensor, input_sqrt: Union[int, Tuple[int, int]], wmin: float = 0.0, wmax: float = 1.0, im: Optional[matplotlib.image.AxesImage] = None, lines: bool = True, figsize: Tuple[int, int] = (5, 5), cmap: str = 'hot_r'*) → matplotlib.image.AxesImage

Plot a connection weight matrix of a `Connection` with 'locally connected structure <http://yann.lecun.com/exdb/publis/pdf/gregor-nips-11.pdf>_.

Parameters

- **weights** – Weight matrix of Conv2dConnection object.

- **n_filters** – No. of convolution kernels in use.
- **kernel_size** – Side length(s) of 2D convolution kernels.
- **conv_size** – Side length(s) of 2D convolution population.
- **locations** – Indices of input receptive fields for convolution population neurons.
- **input_sqrt** – Side length(s) of 2D input data.
- **wmin** – Minimum allowed weight value.
- **wmax** – Maximum allowed weight value.
- **im** – Used for re-drawing the weights plot.
- **lines** – Whether or not to draw horizontal and vertical lines separating input regions.
- **figsize** – Horizontal, vertical figure size in inches.
- **cmap** – Matplotlib colormap.

Returns Used for re-drawing the weights plot.

`bindsnet.analysis.plotting.`**`plot_performance`**(*performances: Dict[str, List[float]], ax: Optional[matplotlib.axes._axes.Axes] = None, figsize: Tuple[int, int] = (7, 4)*) → matplotlib.axes._axes.Axes

Plot training accuracy curves.

Parameters

- **performances** – Lists of training accuracy estimates per voting scheme.
- **ax** – Used for re-drawing the performance plot.
- **figsize** – Horizontal, vertical figure size in inches.

Returns Used for re-drawing the performance plot.

`bindsnet.analysis.plotting.`**`plot_spikes`**(*spikes: Dict[str, torch.Tensor], time: Optional[Tuple[int, int]] = None, n_neurons: Optional[Dict[str, Tuple[int, int]]] = None, ims: Optional[List[matplotlib.collections.PathCollection]] = None, axes: Union[matplotlib.axes._axes.Axes, List[matplotlib.axes._axes.Axes], None] = None, figsize: Tuple[float, float] = (8.0, 4.5)*) → Tuple[List[matplotlib.image.AxesImage], List[matplotlib.axes._axes.Axes]]

Plot spikes for any group(s) of neurons.

Parameters

- **spikes** – Mapping from layer names to spiking data. Spike data has shape `[time, n_1, ..., n_k]`, where `[n_1, ..., n_k]` is the shape of the recorded layer.
- **time** – Plot spiking activity of neurons in the given time range. Default is entire simulation time.
- **n_neurons** – Plot spiking activity of neurons in the given range of neurons. Default is all neurons.
- **ims** – Used for re-drawing the plots.
- **axes** – Used for re-drawing the plots.
- **figsize** – Horizontal, vertical figure size in inches.

Returns `ims, axes`: Used for re-drawing the plots.

`bindsnet.analysis.plotting.`**`plot_voltages`**(*voltages: Dict[str, torch.Tensor], ims: Optional[List[matplotlib.image.AxesImage]] = None, axes: Optional[List[matplotlib.axes._axes.Axes]] = None, time: Tuple[int, int] = None, n_neurons: Optional[Dict[str, Tuple[int, int]]] = None, cmap: Optional[str] = 'jet', plot_type: str = 'color', thresholds: Dict[str, torch.Tensor] = None, figsize: Tuple[float, float] = (8.0, 4.5)*) → Tuple[List[matplotlib.image.AxesImage], List[matplotlib.axes._axes.Axes]]

Plot voltages for any group(s) of neurons.

Parameters

- **voltages** – Contains voltage data by neuron layers.
- **ims** – Used for re-drawing the plots.
- **axes** – Used for re-drawing the plots.
- **time** – Plot voltages of neurons in given time range. Default is entire simulation time.
- **n_neurons** – Plot voltages of neurons in given range of neurons. Default is all neurons.
- **cmap** – Matplotlib colormap to use.
- **figsize** – Horizontal, vertical figure size in inches.
- **plot_type** – The way how to draw graph. 'color' for pcolormesh, 'line' for curved lines.
- **thresholds** – Thresholds of the neurons in each layer.

Returns `ims, axes`: Used for re-drawing the plots.

`bindsnet.analysis.plotting.`**`plot_weights`**(*weights: torch.Tensor, wmin: Optional[float] = 0, wmax: Optional[float] = 1, im: Optional[matplotlib.image.AxesImage] = None, figsize: Tuple[int, int] = (5, 5), cmap: str = 'hot_r'*) → matplotlib.image.AxesImage

Plot a connection weight matrix.

Parameters

- **weights** – Weight matrix of `Connection` object.
- **wmin** – Minimum allowed weight value.
- **wmax** – Maximum allowed weight value.
- **im** – Used for re-drawing the weights plot.
- **figsize** – Horizontal, vertical figure size in inches.
- **cmap** – Matplotlib colormap.

Returns `AxesImage` for re-drawing the weights plot.

bindsnet.analysis.visualization module

`bindsnet.analysis.visualization.`**`plot_spike_trains_for_example`**(*spikes: torch.Tensor, n_ex: Optional[int] = None, top_k: Optional[int] = None, indices: Optional[List[int]] = None*) → None

Plot spike trains for top-k neurons or for specific indices.

Parameters

- **`spikes`** – Spikes for one simulation run of shape `(n_examples, n_neurons, time)`.
- **`n_ex`** – Allows user to pick which example to plot spikes for.
- **`top_k`** – Plot k neurons that spiked the most for n_ex example.
- **`indices`** – Plot specific neurons' spiking activity instead of top_k.

`bindsnet.analysis.visualization.`**`plot_voltage`**(*voltage: torch.Tensor, n_ex: int = 0, n_neuron: int = 0, time: Optional[Tuple[int, int]] = None, threshold: float = None*) → None

Plot voltage for a single neuron on a specific example.

Parameters

- **`voltage`** – Tensor or array of shape `[n_examples, n_neurons, time]`.
- **`n_ex`** – Allows user to pick which example to plot voltage for.
- **`n_neuron`** – Neuron index for which to plot voltages for.
- **`time`** – Plot spiking activity of neurons between the given range of time.
- **`threshold`** – Neuron spiking threshold.

`bindsnet.analysis.visualization.`**`plot_weights_movie`**(*ws: numpy.ndarray, sample_every: int = 1*) → None

Create and plot movie of weights.

Parameters

- **`ws`** – Array of shape `[n_examples, source, target, time]`.
- **`sample_every`** – Sub-sample using this parameter.

Module contents

4.1.2 bindsnet.datasets package

Submodules

bindsnet.datasets.preprocess module

class bindsnet.datasets.preprocess.**BoundingBox**(*x1*, *y1*, *x2*, *y2*)
Bases: object

compute_output_height()

compute_output_width()

edge_spacing_x()

edge_spacing_y()

get_bb_list()

get_center_x()

get_center_y()

get_height()

get_width()

print_bb()

recenter(*search_loc*, *edge_spacing_x*, *edge_spacing_y*, *bbox_gt_recentered*)

scale(*image*)

shift(*image*, *lambda_scale_frac*, *lambda_shift_frac*, *min_scale*, *max_scale*, *shift_motion_model*, *bbox_rand*)

uncenter(*raw_image*, *search_location*, *edge_spacing_x*, *edge_spacing_y*)

unscale(*image*)

class bindsnet.datasets.preprocess.**NormalizeToTensor**
Bases: object

Returns torch tensor normalized images.

class bindsnet.datasets.preprocess.**Rescale**(*output_size*)
Bases: object

Rescale image and bounding box. Args:

output_size (tuple or int): Desired output size. If int, square crop is made.

bindsnet.datasets.preprocess.**bgr2rgb**(*image*)

bindsnet.datasets.preprocess.**binary_image**(*image: numpy.ndarray*) → numpy.ndarray
Converts input image into black and white (binary)

Parameters **image** – Gray-scaled image.

Returns Black and white image.

bindsnet.datasets.preprocess.**computeCropPadImageLocation**(*bbox_tight*, *image*)

bindsnet.datasets.preprocess.**crop**(*image: numpy.ndarray*, *x1: int*, *x2: int*, *y1: int*, *y2: int*) → numpy.ndarray
Crops an image given coordinates of cropping box.

Parameters

- **image** – 3-dimensional image.
- **x1** – Left x coordinate.

- **x2** – Right x coordinate.
- **y1** – Bottom y coordinate.
- **y2** – Top y coordinate.

Returns Image cropped using coordinates (x1, x2, y1, y2).

`bindsnet.datasets.preprocess.`**`cropPadImage`**(*bbox_tight*, *image*)

`bindsnet.datasets.preprocess.`**`crop_sample`**(*sample*)
Given a sample image with bounding box, this method returns the image crop at the bounding box location with twice the width and height for context.

`bindsnet.datasets.preprocess.`**`gray_scale`**(*image: numpy.ndarray*) → numpy.ndarray
Converts RGB image into grayscale.

Parameters **image** – RGB image.

Returns Gray-scaled image.

`bindsnet.datasets.preprocess.`**`sample_exp_two_sides`**(*lambda_*)

`bindsnet.datasets.preprocess.`**`sample_rand_uniform`**()

`bindsnet.datasets.preprocess.`**`shift_crop_training_sample`**(*sample*, *bb_params*)
Given an image with bounding box, this method randomly shifts the box and generates a training example. It returns current image crop with shifted box (with respect to current image).

`bindsnet.datasets.preprocess.`**`subsample`**(*image: numpy.ndarray*, *x: int*, *y: int*) → numpy.ndarray
Scale the image to (x, y).

Parameters

- **image** – Image to be rescaled.
- **x** – Output value for `image`'s x dimension.
- **y** – Output value for `image`'s y dimension.

Returns Re-scaled image.

Module contents

4.1.3 bindsnet.encoding package

Module contents

4.1.4 bindsnet.environment package

Module contents

4.1.5 bindsnet.evaluation package

Module contents

4.1.6 bindsnet.learning package

Module contents

4.1.7 bindsnet.network package

Submodules

bindsnet.network.monitors module

class bindsnet.network.monitors.**AbstractMonitor**

Bases: abc.ABC

Abstract base class for state variable monitors.

class bindsnet.network.monitors.**Monitor**(*obj: Union[bindsnet.network.nodes.Nodes, bindsnet.network.topology.AbstractConnection], state_vars: Iterable[str], time: Optional[int] = None, batch_size: int = 1*)

Bases: *bindsnet.network.monitors.AbstractMonitor*

Records state variables of interest.

Constructs a Monitor object.

Parameters

- **obj** – An object to record state variables from during network simulation.
- **state_vars** – Iterable of strings indicating names of state variables to record.
- **time** – If not None, pre-allocate memory for state variable recording.

get(*var: str*) → torch.Tensor

Return recording to user.

Parameters **var** – State variable recording to return.

Returns Tensor of shape [time, n_1, ..., n_k], where [n_1, ..., n_k] is the shape of the recorded state variable.

record() → None

Appends the current value of the recorded state variables to the recording.

reset_state_variables() → None

Resets recordings to empty ``torch.Tensor``s.

class bindsnet.network.monitors.**NetworkMonitor**(*network: Network, layers: Optional[Iterable[str]] = None, connections: Optional[Iterable[str]] = None, state_vars: Optional[Iterable[str]] = None, time: Optional[int] = None*)

Bases: *bindsnet.network.monitors.AbstractMonitor*

Record state variables of all layers and connections.

Constructs a NetworkMonitor object.

Parameters

- **network** – Network to record state variables from.
- **layers** – Layers to record state variables from.
- **connections** – Connections to record state variables from.

- **state_vars** – List of strings indicating names of state variables to record.
- **time** – If not `None`, pre-allocate memory for state variable recording.

get() → Dict[str, Dict[str, Union[bindsnet.network.nodes.Nodes, bindsnet.network.topology.AbstractConnection]]]
Return entire recording to user.

Returns Dictionary of dictionary of all layers' and connections' recorded state variables.

record() → None
Appends the current value of the recorded state variables to the recording.

reset_state_variables() → None
Resets recordings to empty `torch.Tensors`.

save(*path: str*, *fmt: str = 'npz'*) → None
Write the recording dictionary out to file.

Parameters

- **path** – The directory to which to write the monitor's recording.
- **fmt** – Type of file to write to disk. One of `"pickle"` or `"npz"`.

bindsnet.network.nodes module

class bindsnet.network.nodes.**AbstractInput**
Bases: `abc.ABC`

Abstract base class for groups of input neurons.

class bindsnet.network.nodes.**AdaptiveLIFNodes**(*n: Optional[int] = None*, *shape: Optional[Iterable[int]] = None*, *traces: bool = False*, *traces_additive: bool = False*, *tc_trace: Union[float, torch.Tensor] = 20.0*, *trace_scale: Union[float, torch.Tensor] = 1.0*, *sum_input: bool = False*, *rest: Union[float, torch.Tensor] = -65.0*, *reset: Union[float, torch.Tensor] = -65.0*, *thresh: Union[float, torch.Tensor] = -52.0*, *refrac: Union[int, torch.Tensor] = 5*, *tc_decay: Union[float, torch.Tensor] = 100.0*, *theta_plus: Union[float, torch.Tensor] = 0.05*, *tc_theta_decay: Union[float, torch.Tensor] = 10000000.0*, *lbound: float = None*, ***kwargs*)
Bases: `bindsnet.network.nodes.Nodes`

Layer of leaky integrate-and-fire (LIF) neurons with adaptive thresholds. A neuron's voltage threshold is increased by some constant each time it spikes; otherwise, it is decaying back to its default value.

Instantiates a layer of LIF neurons with adaptive firing thresholds.

Parameters

- **n** – The number of neurons in the layer.
- **shape** – The dimensionality of the layer.
- **traces** – Whether to record spike traces.
- **traces_additive** – Whether to record spike traces additively.

- **tc_trace** – Time constant of spike trace decay.
- **trace_scale** – Scaling factor for spike trace.
- **sum_input** – Whether to sum all inputs.
- **rest** – Resting membrane voltage.
- **reset** – Post-spike reset voltage.
- **thresh** – Spike threshold voltage.
- **refrac** – Refractory (non-firing) period of the neuron.
- **tc_decay** – Time constant of neuron voltage decay.
- **theta_plus** – Voltage increase of threshold after spiking.
- **tc_theta_decay** – Time constant of adaptive threshold decay.
- **lbound** – Lower bound of the voltage.

compute_decays(*dt*) → None
Sets the relevant decays.

forward(*x: torch.Tensor*) → None
Runs a single simulation step.

Parameters **x** – Inputs to the layer.

reset_state_variables() → None
Resets relevant state variables.

set_batch_size(*batch_size*) → None
Sets mini-batch size. Called when layer is added to a network.

Parameters **batch_size** – Mini-batch size.

class bindsnet.network.nodes.**CurrentLIFNodes**(*n: Optional[int] = None, shape: Optional[Iterable[int]] = None, traces: bool = False, traces_additive: bool = False, tc_trace: Union[float, torch.Tensor] = 20.0, trace_scale: Union[float, torch.Tensor] = 1.0, sum_input: bool = False, thresh: Union[float, torch.Tensor] = -52.0, rest: Union[float, torch.Tensor] = -65.0, reset: Union[float, torch.Tensor] = -65.0, refrac: Union[int, torch.Tensor] = 5, tc_decay: Union[float, torch.Tensor] = 100.0, tc_i_decay: Union[float, torch.Tensor] = 2.0, lbound: float = None, **kwargs*)

Bases: bindsnet.network.nodes.Nodes

Layer of current-based leaky integrate-and-fire (LIF) neurons. Total synaptic input current is modeled as a decaying memory of input spikes multiplied by synaptic strengths.

Instantiates a layer of synaptic input current-based LIF neurons. :param n: The number of neurons in the layer. :param shape: The dimensionality of the layer. :param traces: Whether to record spike traces. :param traces_additive: Whether to record spike traces additively. :param tc_trace: Time constant of spike trace decay. :param trace_scale: Scaling factor for spike trace. :param sum_input: Whether to sum all inputs. :param thresh: Spike threshold voltage. :param rest: Resting membrane voltage. :param reset: Post-spike reset voltage. :param refrac: Refractory (non-firing) period of the neuron. :param tc_decay: Time constant of neuron voltage decay. :param tc_i_decay: Time constant of synaptic input current decay. :param lbound: Lower bound of the voltage.

compute_decays (*dt*) → None
Sets the relevant decays.

forward (*x: torch.Tensor*) → None
Runs a single simulation step.

Parameters **x** – Inputs to the layer.

reset_state_variables () → None
Resets relevant state variables.

set_batch_size (*batch_size*) → None
Sets mini-batch size. Called when layer is added to a network.

Parameters **batch_size** – Mini-batch size.

class bindsnet.network.nodes.**DiehlAndCookNodes** (*n: Optional[int] = None, shape: Optional[Iterable[int]] = None, traces: bool = False, traces_additive: bool = False, tc_trace: Union[float, torch.Tensor] = 20.0, trace_scale: Union[float, torch.Tensor] = 1.0, sum_input: bool = False, thresh: Union[float, torch.Tensor] = -52.0, rest: Union[float, torch.Tensor] = -65.0, reset: Union[float, torch.Tensor] = -65.0, refrac: Union[int, torch.Tensor] = 5, tc_decay: Union[float, torch.Tensor] = 100.0, theta_plus: Union[float, torch.Tensor] = 0.05, tc_theta_decay: Union[float, torch.Tensor] = 10000000.0, lbound: float = None, one_spike: bool = True, **kwargs*)

Bases: *bindsnet.network.nodes.Nodes*

Layer of leaky integrate-and-fire (LIF) neurons with adaptive thresholds (modified for Diehl & Cook 2015 replication).

Instantiates a layer of Diehl & Cook 2015 neurons.

Parameters

- **n** – The number of neurons in the layer.
- **shape** – The dimensionality of the layer.
- **traces** – Whether to record spike traces.
- **traces_additive** – Whether to record spike traces additively.
- **tc_trace** – Time constant of spike trace decay.
- **trace_scale** – Scaling factor for spike trace.
- **sum_input** – Whether to sum all inputs.
- **thresh** – Spike threshold voltage.
- **rest** – Resting membrane voltage.
- **reset** – Post-spike reset voltage.
- **refrac** – Refractory (non-firing) period of the neuron.
- **tc_decay** – Time constant of neuron voltage decay.

- **theta_plus** – Voltage increase of threshold after spiking.
- **tc_theta_decay** – Time constant of adaptive threshold decay.
- **lbound** – Lower bound of the voltage.
- **one_spike** – Whether to allow only one spike per timestep.

compute_decays (*dt*) → None
Sets the relevant decays.

forward (*x: torch.Tensor*) → None
Runs a single simulation step.

Parameters **x** – Inputs to the layer.

reset_state_variables () → None
Resets relevant state variables.

set_batch_size (*batch_size*) → None
Sets mini-batch size. Called when layer is added to a network.

Parameters **batch_size** – Mini-batch size.

class bindsnet.network.nodes.**IFNodes** (*n: Optional[int] = None, shape: Optional[Iterable[int]] = None, traces: bool = False, traces_additive: bool = False, tc_trace: Union[float, torch.Tensor] = 20.0, trace_scale: Union[float, torch.Tensor] = 1.0, sum_input: bool = False, thresh: Union[float, torch.Tensor] = -52.0, reset: Union[float, torch.Tensor] = -65.0, refrac: Union[int, torch.Tensor] = 5, lbound: float = None, **kwargs*)

Bases: *bindsnet.network.nodes.Nodes*

Layer of integrate-and-fire (IF) neurons.

Instantiates a layer of IF neurons.

Parameters

- **n** – The number of neurons in the layer.
- **shape** – The dimensionality of the layer.
- **traces** – Whether to record spike traces.
- **traces_additive** – Whether to record spike traces additively.
- **tc_trace** – Time constant of spike trace decay.
- **trace_scale** – Scaling factor for spike trace.
- **sum_input** – Whether to sum all inputs.
- **thresh** – Spike threshold voltage.
- **reset** – Post-spike reset voltage.
- **refrac** – Refractory (non-firing) period of the neuron.
- **lbound** – Lower bound of the voltage.

forward (*x: torch.Tensor*) → None
Runs a single simulation step.

Parameters **x** – Inputs to the layer.

reset_state_variables() → None
Resets relevant state variables.

set_batch_size(*batch_size*) → None
Sets mini-batch size. Called when layer is added to a network.

Parameters batch_size – Mini-batch size.

class bindsnet.network.nodes.**Input**(*n: Optional[int] = None*, *shape: Optional[Iterable[int]] = None*, *traces: bool = False*, *traces_additive: bool = False*, *tc_trace: Union[float, torch.Tensor] = 20.0*, *trace_scale: Union[float, torch.Tensor] = 1.0*, *sum_input: bool = False*, ***kwargs*)
Bases: *bindsnet.network.nodes.Nodes*, *bindsnet.network.nodes.AbstractInput*

Layer of nodes with user-specified spiking behavior.

Instantiates a layer of input neurons.

Parameters

- **n** – The number of neurons in the layer.
- **shape** – The dimensionality of the layer.
- **traces** – Whether to record decaying spike traces.
- **traces_additive** – Whether to record spike traces additively.
- **tc_trace** – Time constant of spike trace decay.
- **trace_scale** – Scaling factor for spike trace.
- **sum_input** – Whether to sum all inputs.

forward(*x: torch.Tensor*) → None
On each simulation step, set the spikes of the population equal to the inputs.

Parameters x – Inputs to the layer.

reset_state_variables() → None
Resets relevant state variables.

class bindsnet.network.nodes.**IzhikevichNodes**(*n: Optional[int] = None*, *shape: Optional[Iterable[int]] = None*, *traces: bool = False*, *traces_additive: bool = False*, *tc_trace: Union[float, torch.Tensor] = 20.0*, *trace_scale: Union[float, torch.Tensor] = 1.0*, *sum_input: bool = False*, *excitatory: float = 1*, *thresh: Union[float, torch.Tensor] = 45.0*, *rest: Union[float, torch.Tensor] = -65.0*, *lbound: float = None*, ***kwargs*)
Bases: *bindsnet.network.nodes.Nodes*

Layer of Izhikevich neurons.

Instantiates a layer of Izhikevich neurons.

Parameters

- **n** – The number of neurons in the layer.
- **shape** – The dimensionality of the layer.
- **traces** – Whether to record spike traces.

- **traces_additive** – Whether to record spike traces additively.
- **tc_trace** – Time constant of spike trace decay.
- **trace_scale** – Scaling factor for spike trace.
- **sum_input** – Whether to sum all inputs.
- **excitatory** – Percent of excitatory (vs. inhibitory) neurons in the layer; in range `[0, 1]`.
- **thresh** – Spike threshold voltage.
- **rest** – Resting membrane voltage.
- **lbound** – Lower bound of the voltage.

forward(*x: torch.Tensor*) → None
Runs a single simulation step.

Parameters **x** – Inputs to the layer.

reset_state_variables() → None
Resets relevant state variables.

set_batch_size(*batch_size*) → None
Sets mini-batch size. Called when layer is added to a network.

Parameters **batch_size** – Mini-batch size.

class bindsnet.network.nodes.**LIFNodes**(*n: Optional[int] = None, shape: Optional[Iterable[int]] = None, traces: bool = False, traces_additive: bool = False, tc_trace: Union[float, torch.Tensor] = 20.0, trace_scale: Union[float, torch.Tensor] = 1.0, sum_input: bool = False, thresh: Union[float, torch.Tensor] = -52.0, rest: Union[float, torch.Tensor] = -65.0, reset: Union[float, torch.Tensor] = -65.0, refrac: Union[int, torch.Tensor] = 5, tc_decay: Union[float, torch.Tensor] = 100.0, lbound: float = None, **kwargs*)

Bases: `bindsnet.network.nodes.Nodes`

Layer of leaky integrate-and-fire (LIF) neurons.

Instantiates a layer of LIF neurons.

Parameters

- **n** – The number of neurons in the layer.
- **shape** – The dimensionality of the layer.
- **traces** – Whether to record spike traces.
- **traces_additive** – Whether to record spike traces additively.
- **tc_trace** – Time constant of spike trace decay.
- **trace_scale** – Scaling factor for spike trace.
- **sum_input** – Whether to sum all inputs.
- **thresh** – Spike threshold voltage.
- **rest** – Resting membrane voltage.

- **reset** – Post-spike reset voltage.
- **refrac** – Refractory (non-firing) period of the neuron.
- **tc_decay** – Time constant of neuron voltage decay.
- **lbound** – Lower bound of the voltage.

compute_decays(*dt*) → None
Sets the relevant decays.

forward(*x: torch.Tensor*) → None
Runs a single simulation step.

Parameters **x** – Inputs to the layer.

reset_state_variables() → None
Resets relevant state variables.

set_batch_size(*batch_size*) → None
Sets mini-batch size. Called when layer is added to a network.

Parameters **batch_size** – Mini-batch size.

class bindsnet.network.nodes.**McCullochPitts**(*n: Optional[int] = None*, *shape: Optional[Iterable[int]] = None*, *traces: bool = False*, *traces_additive: bool = False*, *tc_trace: Union[float, torch.Tensor] = 20.0*, *trace_scale: Union[float, torch.Tensor] = 1.0*, *sum_input: bool = False*, *thresh: Union[float, torch.Tensor] = 1.0*, ***kwargs*)

Bases: *bindsnet.network.nodes.Nodes*

Layer of McCulloch-Pitts neurons.

Instantiates a McCulloch-Pitts layer of neurons.

Parameters

- **n** – The number of neurons in the layer.
- **shape** – The dimensionality of the layer.
- **traces** – Whether to record spike traces.
- **traces_additive** – Whether to record spike traces additively.
- **tc_trace** – Time constant of spike trace decay.
- **trace_scale** – Scaling factor for spike trace.
- **sum_input** – Whether to sum all inputs.
- **thresh** – Spike threshold voltage.

forward(*x: torch.Tensor*) → None
Runs a single simulation step.

Parameters **x** – Inputs to the layer.

reset_state_variables() → None
Resets relevant state variables.

set_batch_size(*batch_size*) → None
Sets mini-batch size. Called when layer is added to a network.

Parameters **batch_size** – Mini-batch size.

class bindsnet.network.nodes.**Nodes**(*n: Optional[int] = None*, *shape: Optional[Iterable[int]] = None*, *traces: bool = False*, *traces_additive: bool = False*, *tc_trace: Union[float, torch.Tensor] = 20.0*, *trace_scale: Union[float, torch.Tensor] = 1.0*, *sum_input: bool = False*, *learning: bool = True*, ***kwargs*)

Bases: `torch.nn.modules.module.Module`

Abstract base class for groups of neurons.

Abstract base class constructor.

Parameters

- **n** – The number of neurons in the layer.
- **shape** – The dimensionality of the layer.
- **traces** – Whether to record decaying spike traces.
- **traces_additive** – Whether to record spike traces additively.
- **tc_trace** – Time constant of spike trace decay.
- **trace_scale** – Scaling factor for spike trace.
- **sum_input** – Whether to sum all inputs.
- **learning** – Whether to be in learning or testing.

compute_decays(*dt*) → None

Abstract base class method for setting decays.

forward(*x: torch.Tensor*) → None

Abstract base class method for a single simulation step.

Parameters **x** – Inputs to the layer.

reset_state_variables() → None

Abstract base class method for resetting state variables.

set_batch_size(*batch_size*) → None

Sets mini-batch size. Called when layer is added to a network.

Parameters **batch_size** – Mini-batch size.

train(*mode: bool = True*) → bindsnet.network.nodes.Nodes

Sets the layer in training mode.

Parameters **mode** (`bool`) – Turn training on or off

Returns self as specified in *torch.nn.Module*

class bindsnet.network.nodes.**SRM0Nodes**(*n: Optional[int] = None*, *shape: Optional[Iterable[int]] = None*, *traces: bool = False*, *traces_additive: bool = False*, *tc_trace: Union[float, torch.Tensor] = 20.0*, *trace_scale: Union[float, torch.Tensor] = 1.0*, *sum_input: bool = False*, *thresh: Union[float, torch.Tensor] = -50.0*, *rest: Union[float, torch.Tensor] = -70.0*, *reset: Union[float, torch.Tensor] = -70.0*, *refrac: Union[int, torch.Tensor] = 5*, *tc_decay: Union[float, torch.Tensor] = 10.0*, *lbound: float = None*, *eps_0: Union[float, torch.Tensor] = 1.0*, *rho_0: Union[float, torch.Tensor] = 1.0*, *d_thresh: Union[float, torch.Tensor] = 5.0*, ***kwargs*)

Bases: `bindsnet.network.nodes.Nodes`

Layer of simplified spike response model (SRM0) neurons with stochastic threshold (escape noise). Adapted from (Vasilaki et al., 2009).

Instantiates a layer of SRM0 neurons.

Parameters

- **n** – The number of neurons in the layer.
- **shape** – The dimensionality of the layer.
- **traces** – Whether to record spike traces.
- **traces_additive** – Whether to record spike traces additively.
- **tc_trace** – Time constant of spike trace decay.
- **trace_scale** – Scaling factor for spike trace.
- **sum_input** – Whether to sum all inputs.
- **thresh** – Spike threshold voltage.
- **rest** – Resting membrane voltage.
- **reset** – Post-spike reset voltage.
- **refrac** – Refractory (non-firing) period of the neuron.
- **tc_decay** – Time constant of neuron voltage decay.
- **lbound** – Lower bound of the voltage.
- **eps_0** – Scaling factor for pre-synaptic spike contributions.
- **rho_0** – Stochastic intensity at threshold.
- **d_thresh** – Width of the threshold region.

compute_decays(*dt*) → None
Sets the relevant decays.

forward(*x: torch.Tensor*) → None
Runs a single simulation step.

Parameters **x** – Inputs to the layer.

reset_state_variables() → None
Resets relevant state variables.

set_batch_size(*batch_size*) → None
Sets mini-batch size. Called when layer is added to a network.

Parameters **batch_size** – Mini-batch size.

bindsnet.network.topology module

class bindsnet.network.topology.**AbstractConnection**(*source: bindsnet.network.nodes.Nodes, target: bindsnet.network.nodes.Nodes, nu: Union[float, Sequence[float], None] = None, reduction: Optional[callable] = None, weight_decay: float = 0.0, **kwargs*)

Bases: abc.ABC, torch.nn.modules.module.Module

Abstract base method for connections between Nodes.

Constructor for abstract base class for connection objects.

Parameters

- **source** – A layer of nodes from which the connection originates.
- **target** – A layer of nodes to which the connection connects.
- **nu** – Learning rate for both pre- and post-synaptic events.
- **reduction** – Method for reducing parameter updates along the minibatch dimension.
- **weight_decay** – Constant multiple to decay weights by on each iteration.

Keyword arguments:

Parameters

- **update_rule** (*LearningRule*) – Modifies connection parameters according to some rule.
- **wmin** (*float*) – The minimum value on the connection weights.
- **wmax** (*float*) – The maximum value on the connection weights.
- **norm** (*float*) – Total weight per target neuron normalization.

compute(*s: torch.Tensor*) → None

Compute pre-activations of downstream neurons given spikes of upstream neurons.

Parameters **s** – Incoming spikes.

reset_state_variables() → None

Contains resetting logic for the connection.

update(***kwargs*) → None

Compute connection's update rule.

Keyword arguments:

Parameters

- **learning** (*bool*) – Whether to allow connection updates.
- **mask** (*ByteTensor*) – Boolean mask determining which weights to clamp to zero.

class bindsnet.network.topology.**Connection**(*source: bindsnet.network.nodes.Nodes, target: bindsnet.network.nodes.Nodes, nu: Union[float, Sequence[float], None] = None, reduction: Optional[callable] = None, weight_decay: float = 0.0, **kwargs*)

Bases: *bindsnet.network.topology.AbstractConnection*

Specifies synapses between one or two populations of neurons.

Instantiates a `Connection` object.

Parameters

- **source** – A layer of nodes from which the connection originates.
- **target** – A layer of nodes to which the connection connects.
- **nu** – Learning rate for both pre- and post-synaptic events.
- **reduction** – Method for reducing parameter updates along the minibatch dimension.
- **weight_decay** – Constant multiple to decay weights by on each iteration.

Keyword arguments:

Parameters

- **update_rule** (*LearningRule*) – Modifies connection parameters according to some rule.
- **w** (*torch.Tensor*) – Strengths of synapses.
- **b** (*torch.Tensor*) – Target population bias.
- **wmin** (*float*) – Minimum allowed value on the connection weights.
- **wmax** (*float*) – Maximum allowed value on the connection weights.
- **norm** (*float*) – Total weight per target neuron normalization constant.

compute(*s: torch.Tensor*) → torch.Tensor
Compute pre-activations given spikes using connection weights.

Parameters **s** – Incoming spikes.

Returns Incoming spikes multiplied by synaptic weights (with or without decaying spike activation).

normalize() → None
Normalize weights so each target neuron has sum of connection weights equal to `self.norm`.

reset_state_variables() → None
Contains resetting logic for the connection.

update(***kwargs*) → None
Compute connection's update rule.

class bindsnet.network.topology.**Conv2dConnection**(*source: bindsnet.network.nodes.Nodes, target: bindsnet.network.nodes.Nodes, kernel_size: Union[int, Tuple[int, int]], stride: Union[int, Tuple[int, int]] = 1, padding: Union[int, Tuple[int, int]] = 0, dilation: Union[int, Tuple[int, int]] = 1, nu: Union[float, Sequence[float], None] = None, reduction: Optional[callable] = None, weight_decay: float = 0.0, **kwargs*)

Bases: *bindsnet.network.topology.AbstractConnection*

Specifies convolutional synapses between one or two populations of neurons.

Instantiates a `Conv2dConnection` object.

Parameters

- **`source`** – A layer of nodes from which the connection originates.
- **`target`** – A layer of nodes to which the connection connects.
- **`kernel_size`** – Horizontal and vertical size of convolutional kernels.
- **`stride`** – Horizontal and vertical stride for convolution.
- **`padding`** – Horizontal and vertical padding for convolution.
- **`dilation`** – Horizontal and vertical dilation for convolution.
- **`nu`** – Learning rate for both pre- and post-synaptic events.
- **`reduction`** – Method for reducing parameter updates along the minibatch dimension.
- **`weight_decay`** – Constant multiple to decay weights by on each iteration.

Keyword arguments:

Parameters

- **`update_rule`** (*`LearningRule`*) – Modifies connection parameters according to some rule.
- **`w`** (*`torch.Tensor`*) – Strengths of synapses.
- **`b`** (*`torch.Tensor`*) – Target population bias.
- **`wmin`** (*`float`*) – Minimum allowed value on the connection weights.
- **`wmax`** (*`float`*) – Maximum allowed value on the connection weights.
- **`norm`** (*`float`*) – Total weight per target neuron normalization constant.

`compute`(*s: torch.Tensor*) → torch.Tensor
Compute convolutional pre-activations given spikes using layer weights.

Parameters **`s`** – Incoming spikes.

Returns Incoming spikes multiplied by synaptic weights (with or without decaying spike activation).

`normalize`() → None
Normalize weights along the first axis according to total weight per target neuron.

`reset_state_variables`() → None
Contains resetting logic for the connection.

`update`(***kwargs*) → None
Compute connection's update rule.

class bindsnet.network.topology.**LocalConnection**(*source: bindsnet.network.nodes.Nodes, target: bindsnet.network.nodes.Nodes, kernel_size: Union[int, Tuple[int, int]], stride: Union[int, Tuple[int, int]], n_filters: int, nu: Union[float, Sequence[float], None] = None, reduction: Optional[callable] = None, weight_decay: float = 0.0, **kwargs*)

Bases: *`bindsnet.network.topology.AbstractConnection`*

Specifies a locally connected connection between one or two populations of neurons.

Instantiates a `LocalConnection` object. Source population should be two-dimensional.

Neurons in the post-synaptic population are ordered by receptive field; that is, if there are `n_conv` neurons in each post-synaptic patch, then the first `n_conv` neurons in the post-synaptic population correspond to the first receptive field, the second `n_conv` to the second receptive field, and so on.

Parameters

- **source** – A layer of nodes from which the connection originates.
- **target** – A layer of nodes to which the connection connects.
- **kernel_size** – Horizontal and vertical size of convolutional kernels.
- **stride** – Horizontal and vertical stride for convolution.
- **n_filters** – Number of locally connected filters per pre-synaptic region.
- **nu** – Learning rate for both pre- and post-synaptic events.
- **reduction** – Method for reducing parameter updates along the minibatch dimension.
- **weight_decay** – Constant multiple to decay weights by on each iteration.

Keyword arguments:

Parameters

- **update_rule** (*LearningRule*) – Modifies connection parameters according to some rule.
- **w** (*torch.Tensor*) – Strengths of synapses.
- **b** (*torch.Tensor*) – Target population bias.
- **wmin** (*float*) – Minimum allowed value on the connection weights.
- **wmax** (*float*) – Maximum allowed value on the connection weights.
- **norm** (*float*) – Total weight per target neuron normalization constant.
- **int] input_shape** (*Tuple[int,*) – Shape of input population if it's not `[sqrt, sqrt]`.

compute (*s: torch.Tensor*) → torch.Tensor

Compute pre-activations given spikes using layer weights.

Parameters **s** – Incoming spikes.

Returns Incoming spikes multiplied by synaptic weights (with or without decaying spike activation).

normalize () → None

Normalize weights so each target neuron has sum of connection weights equal to `self.norm`.

reset_state_variables () → None

Contains resetting logic for the connection.

update (***kwargs*) → None

Compute connection's update rule.

Keyword arguments:

Parameters **mask** (*ByteTensor*) – Boolean mask determining which weights to clamp to zero.

class bindsnet.network.topology.**MaxPool2dConnection**(*source: bindsnet.network.nodes.Nodes, target: bindsnet.network.nodes.Nodes, kernel_size: Union[int, Tuple[int, int]], stride: Union[int, Tuple[int, int]] = 1, padding: Union[int, Tuple[int, int]] = 0, dilation: Union[int, Tuple[int, int]] = 1, **kwargs*)

Bases: `bindsnet.network.topology.AbstractConnection`

Specifies max-pooling synapses between one or two populations of neurons by keeping online estimates of maximally firing neurons.

Instantiates a `MaxPool2dConnection` object.

Parameters

- **source** – A layer of nodes from which the connection originates.
- **target** – A layer of nodes to which the connection connects.
- **kernel_size** – Horizontal and vertical size of convolutional kernels.
- **stride** – Horizontal and vertical stride for convolution.
- **padding** – Horizontal and vertical padding for convolution.
- **dilation** – Horizontal and vertical dilation for convolution.

Keyword arguments:

Parameters **decay** – Decay rate of online estimates of average firing activity.

compute(*s: torch.Tensor*) → torch.Tensor

Compute max-pool pre-activations given spikes using online firing rate estimates.

Parameters **s** – Incoming spikes.

Returns Incoming spikes multiplied by synaptic weights (with or without decaying spike activation).

normalize() → None

No weights -> no normalization.

reset_state_variables() → None

Contains resetting logic for the connection.

update(***kwargs*) → None

Compute connection's update rule.

class bindsnet.network.topology.**MeanFieldConnection**(*source: bindsnet.network.nodes.Nodes, target: bindsnet.network.nodes.Nodes, nu: Union[float, Sequence[float], None] = None, weight_decay: float = 0.0, **kwargs*)

Bases: `bindsnet.network.topology.AbstractConnection`

A connection between one or two populations of neurons which computes a summary of the pre-synaptic population to use as weighted input to the post-synaptic population.

Instantiates a `MeanFieldConnection` object. :param source: A layer of nodes from which the connection originates. :param target: A layer of nodes to which the connection connects. :param nu: Learning rate for both pre- and post-synaptic events. :param weight_decay: Constant multiple to decay weights by on each iteration. Keyword arguments: :param LearningRule update_rule: Modifies connection parameters according to

some rule.

Parameters

- **w** (*torch.Tensor*) – Strengths of synapses.
- **wmin** (*float*) – Minimum allowed value on the connection weights.
- **wmax** (*float*) – Maximum allowed value on the connection weights.
- **norm** (*float*) – Total weight per target neuron normalization constant.

compute (*s: torch.Tensor*) → torch.Tensor
Compute pre-activations given spikes using layer weights. :param s: Incoming spikes. :return: Incoming spikes multiplied by synaptic weights (with or without

decaying spike activation).

normalize () → None
Normalize weights so each target neuron has sum of connection weights equal to `self.norm`.

reset_state_variables () → None
Contains resetting logic for the connection.

update (***kwargs*) → None
Compute connection's update rule.

class bindsnet.network.topology.**SparseConnection** (*source: bindsnet.network.nodes.Nodes, target: bindsnet.network.nodes.Nodes, nu: Union[float, Sequence[float], None] = None, reduction: Optional[callable] = None, weight_decay: float = None, **kwargs*)

Bases: *bindsnet.network.topology.AbstractConnection*

Specifies sparse synapses between one or two populations of neurons.

Instantiates a `Connection` object with sparse weights.

Parameters

- **source** – A layer of nodes from which the connection originates.
- **target** – A layer of nodes to which the connection connects.
- **nu** – Learning rate for both pre- and post-synaptic events.
- **reduction** – Method for reducing parameter updates along the minibatch dimension.
- **weight_decay** – Constant multiple to decay weights by on each iteration.

Keyword arguments:

Parameters

- **w** (*torch.Tensor*) – Strengths of synapses.
- **sparsity** (*float*) – Fraction of sparse connections to use.

- **update_rule** (*LearningRule*) – Modifies connection parameters according to some rule.
- **wmin** (*float*) – Minimum allowed value on the connection weights.
- **wmax** (*float*) – Maximum allowed value on the connection weights.
- **norm** (*float*) – Total weight per target neuron normalization constant.

compute (*s: torch.Tensor*) → torch.Tensor
Compute convolutional pre-activations given spikes using layer weights.

Parameters **s** – Incoming spikes.

Returns Incoming spikes multiplied by synaptic weights (with or without decaying spike activation).

normalize () → None
Normalize weights along the first axis according to total weight per target neuron.

reset_state_variables () → None
Contains resetting logic for the connection.

update (***kwargs*) → None
Compute connection's update rule.

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