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# Neurokernel Documentation

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[Project Website](#) | [GitHub Repository](#) | [Mailing List](#) | [Forum](#)



## Introduction

Neurokernel is an open software platform written in Python for emulation of the brain of the fruit fly (*Drosophila melanogaster*) on multiple Graphics Processing Units (GPUs). It provides a programming model based upon the organization of the fly's brain into fewer than 50 modular subdivisions called *local processing units* (LPUs) that are each characterized by unique populations of local neurons<sup>1</sup>. Using Neurokernel's API, researchers can develop models of individual LPUs and combine them with other independently developed LPU models to collaboratively construct models of entire subsystems of the fly brain. Neurokernel's support for LPU model integration also enables exploration of brain functions that cannot be exclusively attributed to individual LPUs or brain subsystems.

Examples of Neurokernel's use are available on the [project website](#).

## Installation

### Prerequisites

Neurokernel requires

- Linux (other operating systems may work, but have not been tested);
- Python 2.7 (Python 3.0 is not guaranteed to work);
- at least one NVIDIA GPU with [Fermi](#) architecture or later;
- NVIDIA's [GPU drivers](#);
- [CUDA 5.0](#) or later;
- [OpenMPI 1.8.4](#) or later compiled with CUDA support.

To check what GPUs are in your system, you can use the [inxi](#) command available on most Linux distributions:

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<sup>1</sup> Chiang, A.-S., Lin, C.-Y., Chuang, C.-C., Chang, H.-M., Hsieh, C.-H., Yeh, C.-W., et al. (2011), Three-dimensional reconstruction of brain-wide wiring networks in *Drosophila* at single-cell resolution, *Current Biology*, 21, 1, 1–11, doi:10.1016/j.cub.2010.11.056

```
inxi -G
```

You can verify that the drivers are loaded as follows:

```
lsmod | grep nvidia
```

If no drivers are present, you may have to manually load them by running something like:

```
modprobe nvidia
```

as root.

Although some Linux distributions do include CUDA in their stock package repositories, you are encouraged to use those distributed by NVIDIA because they often are more up-to-date and include more recent releases of the GPU drivers. See [this page](#) for download information.

If you install Neurokernel in a virtualenv environment, you will need to install OpenMPI. See [this page](#) for OpenMPI installation information. *Note that OpenMPI 1.8 cannot run on Windows.*

Some of Neurokernel's demos require either `ffmpeg` or `libav` installed to generate visualizations (see [Examples](#)).

## Installation

Download the latest Neurokernel code as follows:

```
git clone https://github.com/neurokernel/neurokernel.git
```

Since Neurokernel requires a fair number of additional Python packages to run, it is recommended that it either be installed in a [virtualenv](#) or [conda](#) environment. Follow the relevant instructions below.

### Virtualenv

See [this page](#) for virtualenv installation information.

Create a new virtualenv environment and install several required dependencies:

```
cd ~/
virtualenv NK
~/NK/bin/pip install numpy cython numexpr pycuda
```

If installation of PyCUDA fails because some of the CUDA development files or libraries are not found, you may need to specify where they are explicitly. For example, if CUDA is installed in `/usr/local/cuda/`, try installing PyCUDA as follows:

```
CUDA_ROOT=/usr/local/cuda/ CFLAGS=-I${CUDA_ROOT}/include \
LDLFLAGS=-L${CUDA_ROOT}/lib64 ~/NK/bin/pip install pycuda
```

Replace `${CUDA_ROOT}/lib` with `${CUDA_ROOT}/lib64` if your system is running 64-bit Linux. If you continue to encounter installation problems, see the [PyCUDA Wiki](#) for more information.

Run the following to install the remaining Python package dependencies listed in `setup.py`:

```
cd ~/neurokernel
~/NK/bin/python setup.py develop
```



## Conda

*Note that conda packages are currently only available for 64-bit Ubuntu Linux 14.04. If you would like packages for another distribution, please submit a request to the [Neurokernel developers](#).*

First, install the following Ubuntu packages:

- libibverbs1
- libnuma1
- libpmi0
- libslurm26
- libtorque2

These are required by the conda OpenMPI packages prepared for Neurokernel. Ensure that the stock Ubuntu OpenMPI packages are not installed because they may interfere with the ones that will be installed by conda. You also need to ensure that CUDA has been installed in `/usr/local/cuda`.

Install conda by either installing [Anaconda](#) or [Miniconda](#). Make sure that the following lines appear in your `~/.condarc` file so that conda can find the packages required by Neurokernel:

```
channels:
- https://conda.binstar.org/neurokernel/channel/ubuntu1404
- defaults
```

Create a new conda environment containing the packages required by Neurokernel by running the following command:

```
conda create -n NK neurokernel_deps
```

PyCUDA packages compiled against several versions of CUDA are available. If you need one compiled against a specific version that differs from the one automatically installed by the above command, you will need to manually install it afterwards as follows (replace `cuda75` with the appropriate version):

```
source activate NK
conda install pycuda=2015.1.3=np110py27_cuda75_0
source deactivate
```

Activate the new environment and install Neurokernel in it as follows:

```
source activate NK
cd ~/neurokernel
python setup.py develop
```

## Examples

Introductory examples of how to use Neurokernel to build and integrate models of different parts of the fly brain are available in the [Neurodriver](#) package. To install it run the following:

```
git clone https://github.com/neurokernel/neurodriver
cd ~/neurodriver
python setup.py develop
```

Other models built using Neurokernel are available on [GitHub](#).

## Building the Documentation

To build Neurokernel’s HTML documentation locally, you will need to install

- `mock` 1.0 or later.
- `sphinx` 1.3 or later.
- `sphinx_rtd_theme` 0.1.6 or later.

Once these are installed, run the following:

```
cd ~/neurokernel/docs
make html
```

## Reference

### Model Development API

#### Local Processing Units

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<code>neurokernel.core.Module</code>	Processing module.
<code>neurokernel.core_gpu.Module</code>	Processing module.

---

#### neurokernel.core.Module

**class** `neurokernel.core.Module` (*sel*, *sel\_in*, *sel\_out*, *sel\_gpot*, *sel\_spike*, *data\_gpot*, *data\_spike*, *columns*=['interface', 'io', 'type'], *ctrl\_tag*=1, *gpot\_tag*=2, *spike\_tag*=3, *id*=None, *device*=None, *routing\_table*=None, *rank\_to\_id*=None, *debug*=False, *time\_sync*=False)

Processing module.

This class repeatedly executes a work method until it receives a quit message via its control network port.

#### Parameters

- **sel** (*str*, *unicode*, or *sequence*) – Path-like selector describing the module’s interface of exposed ports.
- **sel\_out**, **sel\_gpot**, **sel\_spike** (*sel\_in*,) – Selectors respectively describing all input, output, graded potential, and spiking ports in the module’s interface.
- **data\_spike** (*data\_gpot*,) – Data arrays associated with the graded potential and spiking ports in the . Array length must equal the number of ports in a module’s interface.
- **columns** (*list of str*) – Interface port attributes. Network port for controlling the module instance.
- **gpot\_tag**, **spike\_tag** (*ctrl\_tag*,) – MPI tags that respectively identify messages containing control data, graded potential port values, and spiking port values transmitted to worker nodes.
- **id** (*str*) – Module identifier. If no identifier is specified, a unique identifier is automatically generated.
- **device** (*int*) – GPU device to use. May be set to None if the module does not perform GPU processing.

- **routing\_table** (`neurokernel.routing_table.RoutingTable`) – Routing table describing data connections between modules. If no routing table is specified, the module will be executed in isolation.
- **rank\_to\_id** (`bidict.bidict`) – Mapping between MPI ranks and module object IDs.
- **debug** (`bool`) – Debug flag. When True, exceptions raised during the work method are not be suppressed.
- **time\_sync** (`bool`) – Time synchronization flag. When True, debug messages are not emitted during module synchronization and the time taken to receive all incoming data is computed.

**interface**

*Interface* – Object containing information about a module’s ports.

**pm**

*dict* – `pm[‘gpot’]` and `pm[‘spike’]` are instances of `neurokernel.pm.PortMapper` that map a module’s ports to the contents of the values in *data*.

**data**

*dict* – `data[‘gpot’]` and `data[‘spike’]` are arrays of data associated with a module’s graded potential and spiking ports.

`__init__` (*sel*, *sel\_in*, *sel\_out*, *sel\_gpot*, *sel\_spike*, *data\_gpot*, *data\_spike*, *columns*=['interface', 'io', 'type'], *ctrl\_tag*=1, *gpot\_tag*=2, *spike\_tag*=3, *id*=None, *device*=None, *routing\_table*=None, *rank\_to\_id*=None, *debug*=False, *time\_sync*=False)

**Methods**

<code>__init__</code> ( <i>sel</i> , <i>sel_in</i> , <i>sel_out</i> , <i>sel_gpot</i> , ...)	
<code>do_work()</code>	Work method.
<code>post_run()</code>	Code to run after main loop.
<code>pre_run()</code>	Code to run before main loop.
<code>recv_parent</code> ([ <i>tag</i> ])	Receive data from parent process.
<code>recv_peer</code> ([ <i>source</i> , <i>tag</i> ])	
<code>run()</code>	Body of process.
<code>run_step()</code>	Module work method.
<code>send_parent</code> ( <i>data</i> [, <i>tag</i> ])	Send data to parent process.
<code>send_peer</code> ( <i>data</i> , <i>dest</i> [, <i>tag</i> ])	Send data to peer process.

**Attributes**

<code>intercomm</code>	Intercommunicator to access parent process.
<code>intracomm</code>	Intracommunicator to access peer processes.
<code>log_on</code>	Logger switch.
<code>max_steps</code>	Maximum number of steps to execute.
<code>rank</code>	MPI process rank.
<code>size</code>	Number of peer processes.

## neurokernel.core\_gpu.Module

**class** neurokernel.core\_gpu.Module (*sel, sel\_in, sel\_out, sel\_gpot, sel\_spike, data\_gpot, data\_spike, columns=['interface', 'io', 'type'], ctrl\_tag=1, gpot\_tag=2, spike\_tag=3, id=None, device=None, routing\_table=None, rank\_to\_id=None, debug=False, time\_sync=False*)

Processing module.

This class repeatedly executes a work method until it receives a quit message via its control network port.

### Parameters

- **sel** (*str, unicode, or sequence*) – Path-like selector describing the module’s interface of exposed ports.
- **sel\_out, sel\_gpot, sel\_spike** (*sel\_in,*) – Selectors respectively describing all input, output, graded potential, and spiking ports in the module’s interface.
- **data\_spike** (*data\_gpot,*) – Data arrays associated with the graded potential and spiking ports in the . Array length must equal the number of ports in a module’s interface.
- **columns** (*list of str*) – Interface port attributes. Network port for controlling the module instance.
- **gpot\_tag, spike\_tag** (*ctrl\_tag,*) – MPI tags that respectively identify messages containing control data, graded potential port values, and spiking port values transmitted to worker nodes.
- **id** (*str*) – Module identifier. If no identifier is specified, a unique identifier is automatically generated.
- **device** (*int*) – GPU device to use. May be set to None if the module does not perform GPU processing.
- **routing\_table** (*neurokernel.routing\_table.RoutingTable*) – Routing table describing data connections between modules. If no routing table is specified, the module will be executed in isolation.
- **rank\_to\_id** (*bidict.bidict*) – Mapping between MPI ranks and module object IDs.
- **debug** (*bool*) – Debug flag. When True, exceptions raised during the work method are not be suppressed.
- **time\_sync** (*bool*) – Time synchronization flag. When True, debug messages are not emitted during module synchronization and the time taken to receive all incoming data is computed.

### interface

*Interface* – Object containing information about a module’s ports.

### pm

*dict* – *pm['gpot']* and *pm['spike']* are instances of neurokernel.pm\_gpu.PortMapper that map a module’s ports to the contents of the values in *data*.

### data

*dict* – *data['gpot']* and *data['spike']* are arrays of data associated with a module’s graded potential and spiking ports.

**\_\_init\_\_** (*sel, sel\_in, sel\_out, sel\_gpot, sel\_spike, data\_gpot, data\_spike, columns=['interface', 'io', 'type'], ctrl\_tag=1, gpot\_tag=2, spike\_tag=3, id=None, device=None, routing\_table=None, rank\_to\_id=None, debug=False, time\_sync=False*)

## Methods

<code>__init__(sel, sel_in, sel_out, sel_gpot, ...)</code>	
<code>do_work()</code>	Work method.
<code>post_run()</code>	Code to run after main loop.
<code>pre_run()</code>	Code to run before main loop.
<code>recv_parent([tag])</code>	Receive data from parent process.
<code>recv_peer([source, tag])</code>	
<code>run()</code>	Body of process.
<code>run_step()</code>	Module work method.
<code>send_parent(data[, tag])</code>	Send data to parent process.
<code>send_peer(data, dest[, tag])</code>	Send data to peer process.

## Attributes

<code>intercomm</code>	Intercommunicator to access parent process.
<code>intracomm</code>	Intracommunicator to access peer processes.
<code>log_on</code>	Logger switch.
<code>max_steps</code>	Maximum number of steps to execute.
<code>rank</code>	MPI process rank.
<code>size</code>	Number of peer processes.

## Inter-LPU Connectivity

<code>neurokernel.pattern.Interface</code>	Container for set of interface comprising ports.
<code>neurokernel.pattern.Pattern</code>	Connectivity pattern linking sets of interface ports.

## neurokernel.pattern.Interface

**class** `neurokernel.pattern.Interface` (*selector=''*, *columns=['interface', 'io', 'type']*)  
 Container for set of interface comprising ports.

This class contains information about a set of interfaces comprising path-like identifiers and the attributes associated with them. By default, each port must have at least the following attributes; other attributes may be added:

- `interface` - indicates which interface a port is associated with.
- `io` - indicates whether the port receives input ('in') or emits output ('out').
- `type` - indicates whether the port emits/receives spikes or graded potentials.

All port identifiers in an interface must be unique. For two interfaces to be deemed compatible, they must contain the same port identifiers and their identifiers' 'io' attributes must be the inverse of each other (i.e., every 'in' port in one interface must be mirrored by an 'out' port in the other interface).

## Examples

```
>>> i = Interface('/foo[0:4],/bar[0:3]')
>>> i['/foo[0:2]', 'interface', 'io', 'type'] = [0, 'in', 'spike']
>>> i['/foo[2:4]', 'interface', 'io', 'type'] = [1, 'out', 'spike']
```

**data**

*pandas.DataFrame* – Port attribute data.

**index**

*pandas.MultiIndex* – Index of port identifiers.

**Parameters**

- **selector** (*str*, *unicode*, or *sequence*) – Selector string (e.g., ‘foo[0:2]’) or sequence of token sequences (e.g., [['foo’, (0, 2)]) describing the port identifiers comprised by the interface.
- **columns** (*list*, *default* = ['interface', 'io', 'type']) – Data column names.

**See also:**

`plsel.SelectorMethods`

`__init__` (*selector=''*, *columns=['interface', 'io', 'type']*)

**Methods**

<code>__init__</code> ([ <i>selector</i> , <i>columns</i> ])	
<code>clear</code> ()	Clear all ports in class instance.
<code>copy</code> ()	Make a copy of this object.
<code>data_select</code> ( <i>f</i> , <i>inplace</i> )	Restrict Interface data with a selection function.
<code>equals</code> ( <i>other</i> )	Check whether this interface is equivalent to another interface.
<code>from_csv</code> ( <i>file_name</i> , <i>**kwargs</i> )	Create an Interface from a properly formatted CSV file.
<code>from_df</code> ( <i>df</i> )	Create an Interface from a properly formatted DataFrame.
<code>from_dict</code> ( <i>d</i> )	Create an Interface from a dictionary of selectors and data values.
<code>from_graph</code> ( <i>g</i> )	Create an Interface from a NetworkX graph.
<code>from_selectors</code> ( <i>sel</i> , <i>sel_in</i> , <i>sel_out</i> , ...)	Create an Interface instance from selectors.
<code>get_common_ports</code> ( <i>a</i> , <i>i</i> , <i>b</i> [, <i>t</i> ])	Get port identifiers common to this and another Interface instance.
<code>gpot_ports</code> ( <i>[i, tuples]</i> )	Restrict Interface ports to graded potential ports.
<code>in_ports</code> ( <i>[i, tuples]</i> )	Restrict Interface ports to input ports.
<code>interface_ports</code> ( <i>[i, tuples]</i> )	Restrict Interface ports to specific interface.
<code>is_compatible</code> ( <i>a</i> , <i>i</i> , <i>b</i> [, <i>allow_subsets</i> ])	Check whether two interfaces can be connected.
<code>is_in_interfaces</code> ( <i>s</i> )	Check whether ports comprised by a selector are in the stored interfaces.
<code>out_ports</code> ( <i>[i, tuples]</i> )	Restrict Interface ports to output ports.
<code>port_select</code> ( <i>f</i> , <i>inplace</i> )	Restrict Interface ports with a selection function.
<code>set_pm</code> ( <i>t</i> , <i>pm</i> )	Set port mapper associated with a specific port type.
<code>spike_ports</code> ( <i>[i, tuples]</i> )	Restrict Interface ports to spiking ports.

Continued on next page

Table 1.7 – continued from previous page

<code>to_selectors(i)</code>	Retrieve Interface's port identifiers as list of path-like selectors.
<code>to_tuples(i)</code>	Retrieve Interface's port identifiers as list of tuples.
<code>which_int(s)</code>	Return the interface containing the identifiers comprised by a selector.

### Attributes

<code>idx_levels</code>	Number of levels in Interface index.
<code>index</code>	Interface index.
<code>interface_ids</code>	Interface identifiers.
<code>io_inv</code>	Returns new Interface instance with inverse input-output attributes.

## neurokernel.pattern.Pattern

**class** `neurokernel.pattern.Pattern` (*\*selectors, \*\*kwargs*)  
Connectivity pattern linking sets of interface ports.

This class represents connection mappings between interfaces comprising sets of ports. Ports are represented using path-like identifiers; the presence of a row linking the two identifiers in the class' internal index indicates the presence of a connection. A single data attribute ('conn') associated with defined connections is created by default. Specific attributes may be accessed by specifying their names after the port identifiers; if a nonexistent attribute is specified when a sequential value is assigned, a new column for that attribute is automatically created:

```
p['/x[0]', '/y[0]', 'conn', 'x'] = [1, 'foo']
```

The direction of connections between ports in a class instance determines whether they are input or output ports. Ports may not both receive input or emit output. Patterns may contain fan-out connections, i.e., one source port connected to multiple destination ports, but not fan-in connections, i.e., multiple source ports connected to a single destination port.

### Examples

```
>>> p = Pattern('/x[0:3]', '/y[0:4]')
>>> p['/x[0]', '/y[0:2]'] = 1
>>> p['/y[2]', '/x[1]'] = 1
>>> p['/y[3]', '/x[2]'] = 1
```

#### data

*pandas.DataFrame* – Connection attribute data.

#### index

*pandas.MultiIndex* – Index of connections.

#### interface

*Interface* – Interfaces containing port identifiers and attributes.

#### Parameters

- **sel1**, .. (*sel0*,) – Selectors defining the sets of ports potentially connected by the pattern. These selectors must be disjoint, i.e., no identifier comprised by one selector may be in any other selector.
- **columns** (*sequence of str*) – Data column names.

**See also:**

`plsel.SelectorMethods`

`__init__(*selectors, **kwargs)`

**Methods**

<code>__init__(*selectors, **kwargs)</code>	
<code>clear()</code>	Clear all connections in class instance.
<code>connected_port_pairs([as_str])</code>	Return connections as pairs of port identifiers.
<code>connected_ports([i, tuples])</code>	Return ports that are connected by the pattern.
<code>dest_idx(src_int, dest_int[, src_type, ...])</code>	Retrieve destination ports connected to the specified source ports.
<code>from_concat(*selectors, **kwargs)</code>	Create pattern from the concatenation of identifiers in two selectors.
<code>from_csv(file_name, **kwargs)</code>	Read connectivity data from CSV file.
<code>from_df(df_int, df_pat)</code>	Create a Pattern from properly formatted DataFrames.
<code>from_graph(g)</code>	Convert a NetworkX directed graph into a Pattern instance.
<code>from_product(*selectors, **kwargs)</code>	Create pattern from the product of identifiers comprised by two selectors.
<code>gpot_ports([i, tuples])</code>	Restrict Interface ports to graded potential ports.
<code>in_ports([i, tuples])</code>	Restrict Interface ports to input ports.
<code>interface_ports([i, tuples])</code>	Restrict Interface ports to specific interface.
<code>is_connected(from_int, to_int)</code>	Check whether the specified interfaces are connected.
<code>is_in_interfaces(selector)</code>	Check whether a selector is supported by any stored interface.
<code>out_ports([i, tuples])</code>	Restrict Interface ports to output ports.
<code>spike_ports([i, tuples])</code>	Restrict Interface ports to spiking ports.
<code>split_multiindex(idx, a, b)</code>	Split a single MultiIndex into two instances.
<code>src_idx(src_int, dest_int[, src_type, ...])</code>	Retrieve source ports connected to the specified destination ports.
<code>to_graph()</code>	Convert the pattern to a networkx directed graph.
<code>which_int(s)</code>	Return the interface containing the identifiers comprised by a selector.

**Attributes**

<code>from_slice</code>	Slice of pattern index row corresponding to source port(s).
<code>index</code>	Pattern index.
<code>interface_ids</code>	Interface identifiers.
<code>to_slice</code>	Slice of pattern index row corresponding to destination port(s).



## Emulation Management

### Construction and Execution

<code>neurokernel.core.Manager</code>	Module manager.
<code>neurokernel.core_gpu.Manager</code>	Module manager.

### neurokernel.core.Manager

**class** `neurokernel.core.Manager` (*required\_args=['sel', 'sel\_in', 'sel\_out', 'sel\_gpot', 'sel\_spike'], ctrl\_tag=1*)

Module manager.

Instantiates, connects, starts, and stops modules comprised by an emulation. All modules and connections must be added to a module manager instance before they can be run.

**ctrl\_tag**

*int* – MPI tag to identify control messages.

**modules**

*dict* – Module instances. Keyed by module object ID.

**routing\_table**

*routing\_table.RoutingTable* – Table of data transmission connections between modules.

**rank\_to\_id**

*bidict.bidict* – Mapping between MPI ranks and module object IDs.

**\_\_init\_\_** (*required\_args=['sel', 'sel\_in', 'sel\_out', 'sel\_gpot', 'sel\_spike'], ctrl\_tag=1*)

### Methods

<code>__init__([required_args, ctrl_tag])</code>	
<code>add(target, id, *args, **kwargs)</code>	Add a module class to the emulation.
<code>connect(id_0, id_1, pat[, int_0, int_1])</code>	Specify connection between two module instances with a Pattern instance.
<code>process_worker_msg(msg)</code>	
<code>quit()</code>	Tell the workers to quit.
<code>recv([tag])</code>	Receive data from child process.
<code>send(data, dest[, tag])</code>	Send data to child process.
<code>spawn()</code>	Spawn MPI processes for and execute each of the managed targets.
<code>start([steps])</code>	Tell the workers to start processing data.
<code>stop()</code>	Tell the workers to stop processing data.
<code>validate_args(target)</code>	Check whether a class' constructor has specific arguments.
<code>wait()</code>	

### Attributes

<code>average_step_sync_time</code>	Average step synchronization time.
Continued on next page	

Table 1.13 – continued from previous page

average_throughput	Average received data throughput per step.
intercomm	Intercommunicator to spawned processes.
log_on	Logger switch.
total_throughput	Total received data throughput.

## neurokernel.core\_gpu.Manager

**class** neurokernel.core\_gpu.**Manager** (*required\_args*=['sel', 'sel\_in', 'sel\_out', 'sel\_gpot', 'sel\_spike'], *ctrl\_tag*=1)

Module manager.

Instantiates, connects, starts, and stops modules comprised by an emulation. All modules and connections must be added to a module manager instance before they can be run.

### **ctrl\_tag**

*int* – MPI tag to identify control messages.

### **modules**

*dict* – Module instances. Keyed by module object ID.

### **routing\_table**

*routing\_table.RoutingTable* – Table of data transmission connections between modules.

### **rank\_to\_id**

*bidict.bidict* – Mapping between MPI ranks and module object IDs.

**\_\_init\_\_** (*required\_args*=['sel', 'sel\_in', 'sel\_out', 'sel\_gpot', 'sel\_spike'], *ctrl\_tag*=1)

## Methods

<b>__init__</b> ( <i>required_args</i> , <i>ctrl_tag</i> )	
<b>add</b> ( <i>target</i> , <i>id</i> , <i>*args</i> , <i>**kwargs</i> )	Add a module class to the emulation.
<b>connect</b> ( <i>id_0</i> , <i>id_1</i> , <i>pat</i> [, <i>int_0</i> , <i>int_1</i> ])	Specify connection between two module instances with a Pattern instance.
<b>process_worker_msg</b> ( <i>msg</i> )	
<b>quit</b> ()	Tell the workers to quit.
<b>recv</b> ([ <i>tag</i> ])	Receive data from child process.
<b>send</b> ( <i>data</i> , <i>dest</i> [, <i>tag</i> ])	Send data to child process.
<b>spawn</b> ()	Spawn MPI processes for and execute each of the managed targets.
<b>start</b> ([ <i>steps</i> ])	Tell the workers to start processing data.
<b>stop</b> ()	Tell the workers to stop processing data.
<b>validate_args</b> ( <i>target</i> )	Check whether a class' constructor has specific arguments.
<b>wait</b> ()	

## Attributes

average_step_sync_time	Average step synchronization time.
average_throughput	Average received data throughput per step.

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Table 1.15 – continued from previous page

intercomm	Intercommunicator to spawned processes.
log_on	Logger switch.
total_throughput	Total received data throughput.

## Support Classes

<code>neurokernel.routing_table.RoutingTable</code>	Routing table class.
<code>neurokernel.mpi.Worker</code>	MPI worker class.
<code>neurokernel.mpi.WorkerManager</code>	Self-launching MPI worker manager.

## neurokernel.routing\_table.RoutingTable

**class** `neurokernel.routing_table.RoutingTable` (*g=None*)

Routing table class.

Simple class that stores pairs of strings that can signify one-hop routes between entities in a graph. Assigning a value to a pair that isn't in the class instance will result in the pair and value being added to the class instance. All data associated with a specific connection is stored as a dict; if a non-dict is assigned to a connection, it is stored in a dict with key 'data'. Specific values in the dict can be retrieved by passing the desired key directly to the [] operator.

### Examples

```
>>> r = RoutingTable()
>>> r['a', 'b'] = 1
>>> r['a', 'b']
1
>>> r['a', 'c'] = [1, 2]
>>> r['a', 'c']
[1, 2]
>>> r['a', 'c'] = {'x': 1}
>>> r['a', 'c', 'x']
1
>>> r['a', 'c']['x']
1
```

**Parameters** *g* (`networkx.DiGraph`) – Directed graph that describes the routes between entities.

#### connections

*list* – List of directed connections between identifiers.

#### ids

*list* – Identifiers currently in routing table.

#### copy()

Return a copy of the routing table.

#### dest\_ids (*src\_id*)

Destination identifiers connected to the specified source identifier.

#### has\_node (*n*)

Check whether the routing table contains the specified identifier.

**ids** ()  
IDs currently in routing

**src\_ids** (*dest\_id*)  
Source identifiers connected to the specified destination identifier.

**subtable** (*ids*)  
Return subtable containing only those connections between specified identifiers.

**to\_df** ()  
Return a pandas DataFrame listing all of the connections.

**\_\_init\_\_** (*g=None*)

### Methods

<code>__init__([g])</code>	
<code>copy()</code>	
<code>dest_ids(src_id)</code>	Destination identifiers connected to the specified source identifier.
<code>has_node(n)</code>	Check whether the routing table contains the specified identifier.
<code>src_ids(dest_id)</code>	Source identifiers connected to the specified destination identifier.
<code>subtable(ids)</code>	Return subtable containing only those connections between specified identifiers.
<code>to_df()</code>	Return a pandas DataFrame listing all of the connections.

### Attributes

<code>connections</code>	List of directed connections between identifiers.
<code>ids</code>	Identifiers currently in routing table.

## neurokernel.mpi.Worker

**class** `neurokernel.mpi.Worker` (*ctrl\_tag=1, \*args, \*\*kwargs*)  
MPI worker class.

This class repeatedly executes a work method.

**Parameters** `ctrl_tag` (*int*) – MPI tag to identify control messages transmitted to worker nodes.

**\_\_init\_\_** (*ctrl\_tag=1, \*args, \*\*kwargs*)

### Methods

<code>__init__([ctrl_tag])</code>	
<code>do_work()</code>	Work method.
<code>post_run()</code>	Code to run after main loop.

Continued on next page

Table 1.19 – continued from previous page

<code>pre_run()</code>	Code to run before main loop.
<code>recv_parent([tag])</code>	Receive data from parent process.
<code>recv_peer([source, tag])</code>	
<code>run()</code>	Main body of worker process.
<code>send_parent(data[, tag])</code>	Send data to parent process.
<code>send_peer(data, dest[, tag])</code>	Send data to peer process.

### Attributes

<code>intercomm</code>	Intercommunicator to access parent process.
<code>intracomm</code>	Intracommunicator to access peer processes.
<code>log_on</code>	Logger switch.
<code>max_steps</code>	Maximum number of steps to execute.
<code>rank</code>	MPI process rank.
<code>size</code>	Number of peer processes.

### neurokernel.mpi.WorkerManager

**class** `neurokernel.mpi.WorkerManager` (*ctrl\_tag=1*)

Self-launching MPI worker manager.

This class may be used to construct an MPI application consisting of

- a manager process that spawns MPI processes that execute the `run()` methods of several subclasses of the `Worker` class;
- worker processes that perform some processing task; and

The application should NOT be started via `mpiexec`.

**Parameters** `ctrl_tag` (*int*) – MPI tag to identify control messages transmitted to worker nodes.

May not be equal to `mpi4py.MPI.ANY_TAG`

### Notes

This class requires MPI-2 dynamic processing management.

#### See also:

*Worker*

`__init__` (*ctrl\_tag=1*)

### Methods

<code>__init__</code> ( <i>[ctrl_tag]</i> )	
<code>add(target, *args, **kwargs)</code>	Add a worker to an MPI application.
<code>process_worker_msg(msg)</code>	Process the specified deserialized message from a worker.
<code>quit()</code>	Tell the workers to quit.

Continued on next page

Table 1.21 – continued from previous page

<code>recv([tag])</code>	Receive data from child process.
<code>send(data, dest[, tag])</code>	Send data to child process.
<code>spawn()</code>	Spawn MPI processes for and execute each of the managed targets.
<code>start([steps])</code>	Tell the workers to start processing data.
<code>stop()</code>	Tell the workers to stop processing data.
<code>wait()</code>	Wait for execution to complete.

### Attributes

<code>intercomm</code>	Intercommunicator to spawned processes.
<code>log_on</code>	Logger switch.

## Support Classes and Functions

### Path-Like Port Identifier Handling

<code>Selector</code>	Validated and expanded port selector.
<code>SelectorMethods</code>	Class for manipulating and using path-like selectors.
<code>SelectorParser</code>	This class implements a parser for path-like selectors that can be associated with elements in a sequential data structure such as a Pandas DataFrame; in the latter case, each level of the selector corresponds to a level of a Pandas MultiIndex.

### neurokernel.plsel.Selector

**class** `neurokernel.plsel.Selector` (*s*)

Validated and expanded port selector.

**Parameters** *s* (`Selector`, `str`, or `unicode`) – Existing Selector class instance or string representation. The selector may not be ambiguous. If an existing Selector instance is specified, the new instance is a copy of the existing instance.

**str**

*str* – String representation of selector.

**expanded**

*tuple of tuples* – Expanded selector.

**max\_levels**

*int* – Maximum number of levels in selector.

`__init__` (*s*)

### Methods

<code>__init__</code> ( <i>s</i> )
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Table 1.24 – continued from previous page

<code>add(*sels)</code>	Combine the identifiers in multiple selectors into a single selector.
<code>add_str(*s)</code>	Combine the identifiers in multiple selector strings into a single selector.
<code>concat(*sels)</code>	Concatenate the identifiers in multiple selectors element-wise.
<code>prod(*sels)</code>	Compute the product of identifiers in multiple selectors.
<code>union(*sels)</code>	Compute the union of the identifiers in multiple selectors.

### Attributes

<code>expanded</code>	Expanded selector.
<code>identifiers</code>	List of individual identifiers in selector.
<code>max_levels</code>	Maximum number of levels in selector.
<code>nonempty</code>	True if the selector contains identifiers.
<code>str</code>	String representation of selector.

### neurokernel.plsel.SelectorMethods

#### class neurokernel.plsel.SelectorMethods

Class for manipulating and using path-like selectors.

Contains class methods for expanding selectors, selecting rows from a Pandas DataFrame using a selector, etc.

The class can also be used to create new MultiIndex instances from selectors that can be fully expanded into an explicit set of identifiers (and therefore contain no ambiguous symbols such as '\*' or '[':]').

```
__init__()
    x.__init__(...) initializes x; see help(type(x)) for signature
```

### Methods

<code>are_consecutive(int_list)</code>	Check whether a list of integers is consecutive.
<code>are_disjoint(*selectors)</code>	Check whether several selectors are disjoint.
<code>collapse(selector)</code>	Collapse a selector into a single string.
<code>count_ports(selector)</code>	Count number of distinct port identifiers in unambiguous selector.
<code>expand(selector[, pad_len])</code>	Expand an unambiguous selector into a list of identifiers.
<code>get_index(df, selector[, start, stop, names])</code>	Return index corresponding to rows selected by specified selector.
<code>get_tuples(df, selector[, start, stop])</code>	Return tuples containing index labels selected by specified selector.
<code>index_to_selector(idx)</code>	Convert an index into an expanded port selector.
<code>is_ambiguous(selector)</code>	Check whether a selector cannot be expanded into an explicit list of identifiers.
<code>is_expandable(selector)</code>	Check whether a selector can be expanded into multiple identifiers.

Continued on next page

Table 1.26 – continued from previous page

<code>is_identifier(s)</code>	Check whether a selector or token sequence can identify a single port.
<code>is_in(s, t)</code>	Check whether all of the identifiers in one selector are comprised by another.
<code>is_selector(s)</code>	Check whether a string or sequence is a valid selector.
<code>is_selector_empty(selector)</code>	Check whether a string or sequence is an empty selector.
<code>is_selector_seq(s)</code>	Check whether a sequence is a valid selector.
<code>is_selector_str(s)</code>	Check whether a string is a valid selector.
<code>make_index(selector[, names])</code>	Create an index from the specified selector.
<code>make_index_two_concat(sel_0, sel_1[, names])</code>	Create an index from two selectors concatenated elementwise.
<code>make_index_two_prod(sel_0, sel_1[, names])</code>	Create an index from the product of two selectors.
<code>max_levels(selector)</code>	Return maximum number of token levels in selector.
<code>p_error(p)</code>	
<code>p_level(p)</code>	level : ASTERISK
<code>p_selector_comma_selector(p)</code>	selector : selector COMMA selector
<code>p_selector_dotplus_selector(p)</code>	selector : selector DOTPLUS selector
<code>p_selector_level(p)</code>	selector : level
<code>p_selector_paren_selector(p)</code>	selector : LPAREN selector RPAREN
<code>p_selector_plus_selector(p)</code>	selector : selector PLUS selector
<code>p_selector_selector_level(p)</code>	selector : selector level
<code>p_selector_selector_plus_level(p)</code>	selector : selector PLUS level
<code>pad_parsed(selector[, pad_len, inplace])</code>	Pad token lists in a parsed selector to some maximum length.
<code>pad_selector(selector[, pad_len])</code>	Expand and pad a selector with blank tokens.
<code>pad_tuple_list(tuple_list, pad_len)</code>	Pad a list of tuples with blank strings.
<code>parse(selector[, pad_len])</code>	Parse a selector string into tokens.
<code>select(df, selector[, start, stop])</code>	Select rows from DataFrame using a path-like selector.
<code>t_ASTERISK(t)</code>	<code>/*</code>
<code>t_COMMA(t)</code>	<code>,</code>
<code>t_DOTPLUS(t)</code>	<code>.+</code>
<code>t_INTEGER(t)</code>	<code>/?d+</code>
<code>t_INTEGER_SET(t)</code>	<code>/?[(?:d+,?)+]</code>
<code>t_INTERVAL(t)</code>	<code>/?[d*:d*]</code>
<code>t_LPAREN(t)</code>	<code>(</code>
<code>t_PLUS(t)</code>	<code>+</code>
<code>t_RPAREN(t)</code>	<code>)</code>
<code>t_STRING(t)</code>	<code>/[^\[\]():,.\d][^+*/\[\]():,.]*</code>
<code>t_STRING_SET(t)</code>	<code>/?[(?:[^\[\]():,.\d][^+*/\[\]():,.]*,?)+]</code>
<code>t_error(t)</code>	
<code>to_identifier(s)</code>	Convert an expanded selector/token sequence into a single port identifier string.
<code>tokenize(selector)</code>	Tokenize a selector string.
<code>tokens_to_str(tokens)</code>	Convert expanded/parsed token sequence into a single selector string.

### Attributes

lexer	Continued on next page
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Table 1.27 – continued from previous page

parser
tokens

## neurokernel.plsel.SelectorParser

### class neurokernel.plsel.SelectorParser

This class implements a parser for path-like selectors that can be associated with elements in a sequential data structure such as a Pandas DataFrame; in the latter case, each level of the selector corresponds to a level of a Pandas MultiIndex. An index level may either be denoted by a string label (e.g., ‘foo’) or a numerical index (e.g., 0, 1, 2); a selector level may additionally be a list of strings (e.g., ‘[foo,bar]’) or integers (e.g., ‘[0,2,4]’) or continuous intervals (e.g., ‘[0:5]’). The ‘\*’ symbol matches any value in a level, while a range with an open upper bound (e.g., ‘[5:]’) will match all integers greater than or equal to the lower bound.

Examples of valid selectors include

Selector	Comments
/foo/bar	
/foo+/bar	equivalent to /foo/bar
/foo/[qux,bar]	
/foo/bar[0]	
/foo/bar/[0]	equivalent to /foo/bar[0]
/foo/bar/0	equivalent to /foo/bar[0]
/foo/bar[0,1]	
/foo/bar[0:5]	
/foo*/baz	
/foo*/baz[5]	
/foo/bar/baz/qux	
(/foo,/bar)+/baz	equivalent to /foo/baz,/bar/baz
/[foo,bar].+/[0:2]	equivalent to /foo[0],/bar[1]

### Notes

An empty string is deemed to be a valid selector.

Since there is no need to maintain multiple instances of the lexer/parser used to process path-like selectors, they are associated with the class rather than class instances; likewise, all of the class’ methods are classmethods.

Numerical indices in selectors are assumed to be zero-based. Intervals do not include the end element (i.e., like numpy, not like Pandas).

`__init__()`  
`x.__init__(...)` initializes x; see `help(type(x))` for signature

### Methods

<code>p_error(p)</code>	
<code>p_level(p)</code>	level : ASTERISK
<code>p_selector_comma_selector(p)</code>	selector : selector COMMA selector
<code>p_selector_dotplus_selector(p)</code>	selector : selector DOTPLUS selector
<code>p_selector_level(p)</code>	selector : level
Continued on next page	

Table 1.28 – continued from previous page

<code>p_selector_paren_selector(p)</code>	selector : LPAREN selector RPAREN
<code>p_selector_plus_selector(p)</code>	selector : selector PLUS selector
<code>p_selector_selector_level(p)</code>	selector : selector level
<code>p_selector_selector_plus_level(p)</code>	selector : selector PLUS level
<code>pad_parsed(selector[, pad_len, inplace])</code>	Pad token lists in a parsed selector to some maximum length.
<code>parse(selector[, pad_len])</code>	Parse a selector string into tokens.
<code>t_ASTERISK(t)</code>	<code>/*</code>
<code>t_COMMA(t)</code>	<code>,</code>
<code>t_DOTPLUS(t)</code>	<code>.+</code>
<code>t_INTEGER(t)</code>	<code>/?d+</code>
<code>t_INTEGER_SET(t)</code>	<code>/?[(?:d+,?)+]</code>
<code>t_INTERVAL(t)</code>	<code>/?[d*:d*]</code>
<code>t_LPAREN(t)</code>	<code>(</code>
<code>t_PLUS(t)</code>	<code>+</code>
<code>t_RPAREN(t)</code>	<code>)</code>
<code>t_STRING(t)</code>	<code>/[^*/[()]:,d][^+*/[()]:,]*</code>
<code>t_STRING_SET(t)</code>	<code>/?[(?:[^+*/[()]:,d][^+*/[()]:,]*,?)+]</code>
<code>t_error(t)</code>	
<code>tokenize(selector)</code>	Tokenize a selector string.

### Attributes

<code>lexer</code>
<code>parser</code>
<code>tokens</code>

### GPU Port Mappers

<code>GPUPortMapper</code>	Maps a PyCUDA GPUArray to/from path-like port identifiers.
----------------------------	--

### neurokernel.pm\_gpu.GPUPortMapper

```
class neurokernel.pm_gpu.GPUPortMapper(selector, data=None, portmap=None,
                                       make_copy=True)
    Maps a PyCUDA GPUArray to/from path-like port identifiers.
    __init__(selector, data=None, portmap=None, make_copy=True)
```

### Methods

<code>__init__(selector[, data, portmap, make_copy])</code>	
<code>copy()</code>	Return copy of this port mapper.
<code>equals(other)</code>	Check whether this mapper is equivalent to another mapper.

Continued on next page

Table 1.31 – continued from previous page

<code>from_index(idx, data[, portmap])</code>	
<code>from_pm(pm)</code>	Create a new port mapper instance given an existing instance.
<code>get(selector)</code>	
<code>get_by_inds(inds)</code>	Retrieve mapped data specified by integer index.
<code>get_inds_nonzero()</code>	
<code>get_map(selector)</code>	Retrieve integer indices associated with selector.
<code>get_ports(f)</code>	Select ports using a data selection function.
<code>get_ports_as_inds(f)</code>	Select integer indices corresponding to ports in map.
<code>get_ports_nonzero()</code>	
<code>inds_to_ports(inds)</code>	Convert list of integer indices to port identifiers.
<code>ports_to_inds(selector)</code>	Convert port selector to list of integer indices.
<code>set(selector, data)</code>	
<code>set_by_inds(inds, data)</code>	Set mapped data by integer indices.
<code>set_by_inds_array(inds, data)</code>	Set mapped data with array by integer indices.
<code>set_by_inds_scalar(inds, data)</code>	Set mapped data with scalar by integer indices.
<code>set_map(selector, portmap)</code>	Set mapped integer index associated with selector.

### Attributes

<code>data</code>	Data associated with ports.
<code>data_ctype</code>	C type corresponding to type of data array.
<code>dtype</code>	Port mapper data type.
<code>index</code>	Port mapper index.

### Python Port Mappers

<code>BasePortMapper</code>	Maps integer sequence to/from path-like port identifiers.
<code>PortMapper</code>	Maps a numpy array to/from path-like port identifiers.

### neurokernel.pm.BasePortMapper

**class** `neurokernel.pm.BasePortMapper` (*selector*, *portmap=None*)  
 Maps integer sequence to/from path-like port identifiers.

### Examples

```
>>> pm = BasePortMapper('/[a,b][0:2]')
>>> print pm.ports_to_inds('/b[0:2]')
array([2, 3])
>>> print pm.inds_to_ports([0, 1])
[('a', 0), ('a', 1)]
```

### Parameters

- **selector** (*str*, *unicode*, or *sequence*) – Selector string (e.g., `'/foo[0:2]'`) or sequence of token sequences (e.g., `[['foo', (0, 2)]]`) to map to *data*.

- **portmap** (*sequence of int*) – Integer indices to map to port identifiers. If no map is specified, it is assumed to be an array of consecutive integers from 0 through one less than the number of ports.

**index**

*pandas.MultiIndex* – Index of port identifiers.

**portmap**

*pandas.Series* – Map of port identifiers to integer indices.

**Notes**

The selectors may not contain any '\*' or '[' characters. A single port identifier may be mapped to multiple integer indices, but not vice-versa.

`__init__` (*selector, portmap=None*)

**Methods**

<code>__init__(selector[, portmap])</code>	
<code>copy()</code>	Return copy of this port mapper.
<code>equals(pm)</code>	Check whether this mapper is equivalent to another mapper.
<code>from_index(idx[, portmap])</code>	Create port mapper from a Pandas index and a sequence of integer indices.
<code>from_pm(pm)</code>	Create a new port mapper instance given an existing instance.
<code>get_map(selector)</code>	Retrieve integer indices associated with selector.
<code>inds_to_ports(inds)</code>	Convert list of integer indices to port identifiers.
<code>ports_to_inds(selector)</code>	Convert port selector to list of integer indices.
<code>set_map(selector, portmap)</code>	Set mapped integer index associated with selector.

**Attributes**

<i>index</i>	Port mapper index.
--------------	--------------------

**neurokernel.pm.PortMapper**

**class** `neurokernel.pm.PortMapper` (*selector, data=None, portmap=None, make\_copy=True*)  
 Maps a numpy array to/from path-like port identifiers.

**Examples**

```

>>> data = np.array([1, 0, 3, 2, 5, 2])
>>> pm = PortMapper('/d[0:5]', data)
>>> print pm['/d[1]']
array([0])
>>> print pm['/d[2:4]']
array([3, 2])
    
```

## Parameters

- **selector** (*str, unicode, or sequence*) – Selector string (e.g., `‘/foo[0:2]’`) or sequence of token sequences (e.g., `[[‘foo’, (0, 2)]]`) to map to *data*.
- **data** (*numpy.ndarray*) – 1D data array to map to ports. If no data array is specified, port identifiers will still be mapped to their sequential indices but `__getitem__()` and `__setitem__()` will raise exceptions if invoked.
- **portmap** (*sequence of int*) – Integer indices to map to port identifiers. If no map is specified, it is assumed to be an array of consecutive integers from 0 through one less than the number of ports.
- **make\_copy** (*bool*) – If True, map a copy of the specified data array to the specified port identifiers.

### **data**

*numpy.ndarray* – Data that has been mapped to ports.

### **dtype**

*numpy.dtype* – Type of mapped data.

### **index**

*pandas.MultiIndex* – Index of port identifiers.

### **portmap**

*pandas.Series* – Map of port identifiers to integer indices into *data*.

## Notes

The selectors may not contain any `‘*’` or `‘[:]’` characters.

`__init__` (*selector, data=None, portmap=None, make\_copy=True*)

## Methods

<code>__init__(selector[, data, portmap, make_copy])</code>	
<code>copy()</code>	Return copy of this port mapper.
<code>equals(other)</code>	Check whether this mapper is equivalent to another mapper.
<code>from_index(idx, data[, portmap])</code>	
<code>from_pm(pm)</code>	Create a new port mapper instance given an existing instance.
<code>get(selector)</code>	Retrieve mapped data specified by given selector.
<code>get_by_inds(inds)</code>	Retrieve mapped data specified by integer index.
<code>get_inds_nonzero()</code>	Select indices of ports with nonzero data.
<code>get_map(selector)</code>	Retrieve integer indices associated with selector.
<code>get_ports(f)</code>	Select ports using a data selection function.
<code>get_ports_as_inds(f)</code>	Select integer indices corresponding to ports in map.
<code>get_ports_nonzero()</code>	Select ports with nonzero data.
<code>inds_to_ports(inds)</code>	Convert list of integer indices to port identifiers.
<code>ports_to_inds(selector)</code>	Convert port selector to list of integer indices.

Continued on next page

Table 1.36 – continued from previous page

<code>set(selector, data)</code>	Set mapped data specified by given selector.
<code>set_by_inds(inds, data)</code>	Set mapped data by integer indices.
<code>set_map(selector, portmap)</code>	Set mapped integer index associated with selector.

### Attributes

<code>data</code>	Data associated with ports.
<code>dtype</code>	Port mapper data type.
<code>index</code>	Port mapper index.

### XML Tools

<code>graph_to_nml_module</code>	Convert a module expressed as NetworkX graphs into Neurokernel NeuroML.
<code>graph_to_nml_pattern</code>	Convert a pattern expressed as a NetworkX graph into Neurokernel NeuroML.
<code>load</code>	Load a Neurokernel NeuroML document.
<code>nml_pattern_to_graph</code>	Convert a pattern expressed in Neurokernel NeuroML into a NetworkX graph.
<code>nml_module_to_graph</code>	Convert a module expressed in Neurokernel NeuroML into NetworkX graphs.
<code>write</code>	Write a Neurokernel NeuroML document to an XML file.

### neurokernel.neuroml.utils.graph\_to\_nml\_module

`neurokernel.neuroml.utils.graph_to_nml_module(g, i, id)`

Convert a module expressed as NetworkX graphs into Neurokernel NeuroML.

#### Parameters

- **g** (`networkx.DiGraph`) – Directed graph containing a module’s neurons and synapses
- **i** (`networkx.Graph`) – Undirected graph containing a module’s interface ports.
- **id** (`str`) – Module identifier.

**Returns** `module` – Module instance.

**Return type** `neurokernel.neuroml.Module`

### neurokernel.neuroml.utils.graph\_to\_nml\_pattern

`neurokernel.neuroml.utils.graph_to_nml_pattern(g, id)`

Convert a pattern expressed as a NetworkX graph into Neurokernel NeuroML.

#### Parameters

- **g** (`networkx.DiGraph`) – Directed graph containing the pattern’s ports (nodes) and connections (edges).
- **id** (`str`) – Pattern identifier.

**Returns** `pattern` – pattern instance.

**Return type** `neurokernel.neuroml.Pattern`

### `neurokernel.neuroml.utils.load`

`neurokernel.neuroml.utils.load` (*file*)

Load a Neurokernel NeuroML document.

**Parameters** `file` (*str* or *file*) – Input file name or handle.

**Returns** `nk_doc` – Neurokernel NeuroML document root.

**Return type** `neurokernel.neuroml.NeurokernelDoc`

### `neurokernel.neuroml.utils.nml_pattern_to_graph`

`neurokernel.neuroml.utils.nml_pattern_to_graph` (*pattern*)

Convert a pattern expressed in Neurokernel NeuroML into a NetworkX graph.

**Parameters** `pattern` (*neurokernel.neuroml.Pattern*) – Pattern instance.

**Returns** `g` – Directed graph containing the pattern’s ports (nodes) and connections (edges).

**Return type** `networkx.DiGraph`

### `neurokernel.neuroml.utils.nml_module_to_graph`

`neurokernel.neuroml.utils.nml_module_to_graph` (*module*)

Convert a module expressed in Neurokernel NeuroML into NetworkX graphs.

**Parameters** `module` (*neurokernel.neuroml.Module*) – Module instance.

**Returns**

- `g` (*networkx.DiGraph*) – Directed graph containing a module’s neurons and synapses
- `i` (*networkx.Graph*) – Undirected graph containing a module’s interface ports.

### `neurokernel.neuroml.utils.write`

`neurokernel.neuroml.utils.write` (*nk\_doc*, *file*, *root\_name='nk'*)

Write a Neurokernel NeuroML document to an XML file.

**Parameters**

- `nk_doc` (*neurokernel.neuroml.NeurokernelDoc*) – Neurokernel NeuroML document root object.
- `file` (*str* or *file*) – Output file name or handle.
- `root_name` (*str*) – Document root name.

## Context Managers

<i>ExceptionOnSignal</i>	Raise a specific exception when the specified signal is detected.
<i>IgnoreKeyboardInterrupt</i>	Ignore keyboard interrupts.
<i>IgnoreSignal</i>	Ignore the specified signal.
<i>OnKeyboardInterrupt</i>	Respond to keyboard interrupt with specified handler.
<i>TryExceptionOnSignal</i>	Check for exception raised in response to specific signal.

### neurokernel.ctx\_managers.ExceptionOnSignal

`neurokernel.ctx_managers.ExceptionOnSignal (*args, **kws)`  
 Raise a specific exception when the specified signal is detected.

### neurokernel.ctx\_managers.IgnoreKeyboardInterrupt

`neurokernel.ctx_managers.IgnoreKeyboardInterrupt (*args, **kws)`  
 Ignore keyboard interrupts.

### neurokernel.ctx\_managers.IgnoreSignal

`neurokernel.ctx_managers.IgnoreSignal (*args, **kws)`  
 Ignore the specified signal.

### neurokernel.ctx\_managers.OnKeyboardInterrupt

`neurokernel.ctx_managers.OnKeyboardInterrupt (*args, **kws)`  
 Respond to keyboard interrupt with specified handler.

### neurokernel.ctx\_managers.TryExceptionOnSignal

`neurokernel.ctx_managers.TryExceptionOnSignal (*args, **kws)`  
 Check for exception raised in response to specific signal.

## GPU Tools

<i>bufint</i>	Return buffer interface to GPU or numpy array.
<i>set_by_inds</i>	Set values in a GPUArray by index.
<i>set_by_inds_from_inds</i>	Set values in a GPUArray by index from indexed values in another GPUArray.
<i>set_realloc</i>	Transfer data into a GPUArray instance.

### neurokernel.tools.gpu.bufint

`neurokernel.tools.gpu.bufint (a)`  
 Return buffer interface to GPU or numpy array.

**Parameters** *a* (*pycuda.gpudarray.GPUArray* or *numpy.ndarray*) – GPU or numpy ar-



ray.

**Returns** **b** – Buffer interface to array. Returns None if *a* has a length of 0.

**Return type** `buffer`

### neurokernel.tools.gpu.set\_by\_inds

`neurokernel.tools.gpu.set_by_inds` (*dest\_gpu*, *ind*, *src\_gpu*, *ind\_which='dest'*)  
Set values in a GPUArray by index.

#### Parameters

- **dest\_gpu** (`pycuda.gpuarray.GPUArray`) – GPUArray instance to modify.
- **ind** (`pycuda.gpuarray.GPUArray` or `numpy.ndarray`) – 1D array of element indices to set. Must have an integer dtype.
- **src\_gpu** (`pycuda.gpuarray.GPUArray`) – GPUArray instance from which to set values.
- **ind\_which** (`str`) – If set to 'dest', set the elements in *dest\_gpu* with indices *ind* to the successive values in *src\_gpu*; the lengths of *ind* and *src\_gpu* must be equal. If set to 'src', set the successive values in *dest\_gpu* to the values in *src\_gpu* with indices *ind*; the lengths of *ind* and *dest\_gpu* must be equal.

### Examples

```
>>> import pycuda.gpuarray as gpuarray
>>> import pycuda.autoinit
>>> import numpy as np
>>> from nk.tools.gpu import set_by_inds
>>> dest_gpu = gpuarray.to_gpu(np.arange(5, dtype=np.float32))
>>> ind = gpuarray.to_gpu(np.array([0, 2, 4]))
>>> src_gpu = gpuarray.to_gpu(np.array([1, 1, 1], dtype=np.float32))
>>> set_by_inds(dest_gpu, ind, src_gpu, 'dest')
>>> np.allclose(dest_gpu.get(), np.array([1, 1, 1, 3, 1], dtype=np.float32))
True
>>> dest_gpu = gpuarray.to_gpu(np.zeros(3, dtype=np.float32))
>>> ind = gpuarray.to_gpu(np.array([0, 2, 4]))
>>> src_gpu = gpuarray.to_gpu(np.arange(5, dtype=np.float32))
>>> set_by_inds(dest_gpu, ind, src_gpu, 'src')
>>> np.allclose(dest_gpu.get(), np.array([0, 2, 4], dtype=np.float32))
True
```

### Notes

Only supports 1D index arrays.

May not be efficient for certain index patterns because of lack of inability to coalesce memory operations.

### neurokernel.tools.gpu.set\_by\_inds\_from\_inds

`neurokernel.tools.gpu.set_by_inds_from_inds` (*dest\_gpu*, *ind\_dest*, *src\_gpu*, *ind\_src*)  
Set values in a GPUArray by index from indexed values in another GPUArray.

### Parameters

- **dest\_gpu** (*pycuda.gpuarray.GPUArray*) – GPUArray instance to modify.
- **ind\_dest** (*pycuda.gpuarray.GPUArray* or *numpy.ndarray*) – 1D array of element indices in *dest\_gpu* to set. Must have an integer dtype.
- **src\_gpu** (*pycuda.gpuarray.GPUArray*) – GPUArray instance from which to set values.
- **ind\_src** (*pycuda.gpuarray.GPUArray* or *numpy.ndarray*) – 1D array of element indices in *src\_gpu* to copy. Must have an integer dtype and be the same length as *ind\_dest*.

### Examples

```
>>> import pycuda.gpuarray as gpuarray
>>> import pycuda.autotinit
>>> import numpy as np
>>> from nk.tools.gpu import set_by_inds_from_inds
>>> dest_gpu = gpuarray.to_gpu(np.zeros(5, dtype=np.float32))
>>> ind_dest = gpuarray.to_gpu(np.array([0, 2, 4]))
>>> src_gpu = gpuarray.to_gpu(np.arange(5, 10, dtype=np.float32))
>>> ind_src = gpuarray.to_gpu(np.array([2, 3, 4]))
>>> gpu.set_by_inds_from_inds(dest_gpu, ind_dest, src_gpu, ind_src)
>>> assert np.allclose(dest_gpu.get(), np.array([7, 0, 8, 0, 9], dtype=np.
↪float32))
True
```

### neurokernel.tools.gpu.set\_realloc

neurokernel.tools.gpu.**set\_realloc** (*x\_gpu, data*)

Transfer data into a GPUArray instance.

Copies the contents of a numpy array into a GPUArray instance. If the array has a different type or dimensions than the instance, the GPU memory used by the instance is reallocated and the instance updated appropriately.

### Parameters

- **x\_gpu** (*pycuda.gpuarray.GPUArray*) – GPUArray instance to modify.
- **data** (*numpy.ndarray*) – Array of data to transfer to the GPU.

### Examples

```
>>> import pycuda.gpuarray as gpuarray
>>> import pycuda.autotinit
>>> import numpy as np
>>> import misc
>>> x = np.asarray(np.random.rand(5), np.float32)
>>> x_gpu = gpuarray.to_gpu(x)
>>> x = np.asarray(np.random.rand(10, 1), np.float64)
>>> set_realloc(x_gpu, x)
>>> np.allclose(x, x_gpu.get())
True
```

## MPI Tools

---

*MPIOutput*

---

### neurokernel.tools.mpi.MPIOutput

neurokernel.tools.mpi.**MPIOutput** = <Mock spec='str' id='140519020930512'>

## ZeroMQ Tools

---

*get\_random\_port*

Return available random ZeroMQ port.

---

*is\_poll\_in*

Check for incoming data on a socket using a poller.

---

*ZMQOutput*

---

### neurokernel.tools.zmq.get\_random\_port

neurokernel.tools.zmq.**get\_random\_port** (*min\_port=49152, max\_port=65536, max\_tries=100*)  
Return available random ZeroMQ port.

### neurokernel.tools.zmq.is\_poll\_in

neurokernel.tools.zmq.**is\_poll\_in** (*sock, poller, timeout=100*)  
Check for incoming data on a socket using a poller.

### neurokernel.tools.zmq.ZMQOutput

neurokernel.tools.zmq.**ZMQOutput** = <Mock spec='str' id='140519020929232'>

## Visualization Tools

---

*imshow*

Display the specified image file using matplotlib.

---

*show\_pydot*

Display a networkx graph using pydot.

---

*show\_pygraphviz*

---

Display a networkx graph using pygraphviz.

### neurokernel.tools.plot.imshow

neurokernel.tools.plot.**imshow** (*f*)  
Display the specified image file using matplotlib.

### neurokernel.tools.plot.show\_pydot

neurokernel.tools.plot.**show\_pydot** (*g*)  
Display a networkx graph using pydot.

## neurokernel.tools.plot.show\_pygraphviz

`neurokernel.tools.plot.show_pygraphviz` (*g*, *prog*='dot', *graph\_attr*={}, *node\_attr*={}, *edge\_attr*={})

Display a networkx graph using pygraphviz.

### Parameters

- **prog** (*str*) – Executable for generating the image.
- **graph\_attr** (*dict*) – Global graph display attributes.
- **node\_attr** (*dict*) – Global node display attributes.
- **edge\_attr** (*dict*) – Global edge display attributes.

## Logging Tools

<code>log_exception</code>	Log the specified exception data using twiggy.
<code>set_excepthook</code>	Set the exception hook to use the specified logger.
<code>setup_logger</code>	Setup a twiggy logger.

## neurokernel.tools.logging.log\_exception

`neurokernel.tools.logging.log_exception` (*type*, *value*, *tb*, *logger*=<Mock name='mock.log' id='140519020930704'>, *multiline*=False)

Log the specified exception data using twiggy.

### Parameters

- **tb** (*value*,) – Parameters expected by `traceback.print_exception`.
- **logger** (*twiggy.logger.Logger*) – Logger to use. `twiggy.log` is assumed by default.
- **multiline** (*bool*) – If True, print exception using multiple log lines.

## neurokernel.tools.logging.set\_excepthook

`neurokernel.tools.logging.set_excepthook` (*logger*, *multiline*=False)

Set the exception hook to use the specified logger.

### Parameters

- **logger** (*twiggy.logger.Logger*) – Configured logger.
- **multiline** (*bool*) – If True, log exception messages on multiple lines.

## neurokernel.tools.logging.setup\_logger

```
neurokernel.tools.logging.setup_logger (name='', level=<Mock
name='mock.levels.DEBUG'
id='140519020931024'>, fmt=<Mock
name='mock.formats.line_format'
id='140519020931280'>, fmt_name=<built-in
method format of str object>, screen=None,
file_name=None, mpi_comm=None,
zmq_addr=None, log_exceptions=True, multi-
line=False)
```

Setup a twiggy logger.

### Parameters

- **name** (*str*) – Logger name.
- **level** (*twiggy.levels.LogLevel*) – Logging level.
- **fmt** (*twiggy.formats.LineFormat*) – Logging formatter class instance.
- **fmt\_name** (*function*) – Function with one parameter that formats the message name.
- **screen** (*bool*) – Create output stream handler to the screen if True.
- **file\_name** (*str*) – Create output handler to specified file.
- **mpi\_comm** (*mpi4py.MPI.Intracomm*) – If not None, use MPI I/O with the specified communicator for output file handler. Ignored if the *file\_name* parameter is not specified.
- **zmq\_addr** (*str*) – ZeroMQ socket address.
- **log\_exceptions** (*bool*) – If True, exception messages are written to the logger.
- **multiline** (*bool*) – If True, log exception messages on multiple lines.

### Returns

- **logger** (*twiggy.logger.Logger*) – Configured logger.
- *Bug*
- —
- *To use the ZeroMQ output class with multiprocessing, it must be added as an emitter within each process.*

## Other

<code>LoggerMixin(name[, log_on])</code>	Mixin that provides a per-instance logger that can be turned off.
<code>catch_exception</code>	Catch and report exceptions when executing a function.
<code>rand_bin_matrix</code>	Generate a rectangular binary matrix with randomly distributed nonzero entries.

## neurokernel.tools.misc.catch\_exception

neurokernel.tools.misc.**catch\_exception** (*func*, *disp*, \**args*, \*\**kwargs*)

Catch and report exceptions when executing a function.

If an exception occurs while executing the specified function, the exception's message and the line number where it occurred (in the innermost traceback frame) are displayed.

### Examples

```
>>> import sys
>>> def f(x): x/0
>>> catch_exception(f, sys.stdout.write, 1)
f: integer division or modulo by zero (...:1)
```

#### Parameters

- **func** (*function*) – Function to execute.
- **disp** (*function*) – Function to use to display exception message.
- **args** (*list*) – Function arguments.
- **kwargs** (*dict*) – Named function arguments.

## neurokernel.tools.misc.rand\_bin\_matrix

neurokernel.tools.misc.**rand\_bin\_matrix** (*sh*, *N*, *dtype*=<Mock name='mock.double' id='140519020932496'>)

Generate a rectangular binary matrix with randomly distributed nonzero entries.

### Examples

```
>>> m = rand_bin_matrix((2, 3), 3)
>>> set(m.flatten()) == set([0, 1])
True
```

#### Parameters

- **sh** (*tuple*) – Shape of generated matrix.
- **N** (*int*) – Number of entries to set to 1.
- **dtype** (*dtype*) – Generated matrix data type.

## Authors & Acknowledgements

The Neurokernel Project was begun in July 2011 by [Aurel A. Lazar](#) at Columbia University's Department of Electrical Engineering after extensive discussions held during a [research seminar on Massively Parallel Neural Computation](#). The Neurokernel Development Team currently comprises the following [Bionet Group](#) researchers:

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## CHAPTER 2

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