NNGT Documentation

Release 0.3

Tanguy Fardet

December 14, 2015

Contents

CHAPTER 1

Introduction

1.1 Yet another graph library?

It is not ;)

This library is based on existing graph libraries (such as graph_tool, and possibly soon SNAP) and acts as a convenient interface to build various networks from efficient and verified algorithms.

Moreover, it also acts as an interface between those graph libraries and the NEST simulator.

1.2 Description

Neural networks are described by four container classes:

- *Graph*: container for simple topological graphs with no spatial structure, nor biological properties
- *SpatialGraph*: container for spatial graphs without biological properties
- *Network*: container for topological graphs with biological properties (to interact with NEST)
- *SpatialNetwork*: container with spatial and biological properties (to interact with NEST)

Using these objects, the user can access to a the `graph` attribute, which contains the topological structure of the network (including the connections' type – inhibitory or excitatory – and its weight which is always positive)

> **Warning:** This object should never be directly modified through its methods but rather using those of the four containing classes. The only reason to access this object should be to perform graph-theoretical measurements on it which do not modify its structure; any other action will lead to undescribed behaviour.

Nodes/neurons are defined by a unique index which can be used to access their properties and those of the connections between them.

In addition to `graph`, the containers can have other attributes, such as:

- `shape` for *SpatialGraph*: and *SpatialNetwork*:, which describes the spatial delimitations of the neurons' environment (e.g. many *in vitro* culture are contained in circular dishes).
- `population` which contains informations on the various groups of neurons that exist in the network (for instance inhibitory and excitatory neurons can be grouped together)
- `connections` which stores the informations about the synaptic connections between the neurons

1.2.1 Graph-theoretical models

Several classical graphs are efficiently implemented and the generation procedures are detailed in the documentation.

Main module

For more details regarding the main classes, see:

Graph container classes

class nngt.**Graph**(*nodes=0*, *name='Graph'*, *weighted=True*, *directed=True*, *libgraph=None*, ***kwargs*)

The basic class that contains a graph_tool.Graph and some of is properties or methods to easily access them.

Variables

- **id** – int unique id that identifies the instance.
- **graph** – GraphObject main attribute of the class instance.

add_edges(*lst_edges*)

Add a list of edges to the graph.

Parameters

- **lst_edges** (*list of 2-tuples or np.array of shape (edge_nb, 2)*) – List of the edges that should be added as tuples (source, target)
- **@todo** (*add example, check the edges for self-loops and multiple edges*)

adjacency_matrix(*weighted=True*)

attributes()

copy()

Returns a deepcopy of the current Graph instance

edge_nb()

excitatory_subgraph()

create a Graph instance which graph contains only the excitatory edges of the current instance's GraphObject

get_betweenness(*use_weights=True*)

get_degrees(*strType='total'*, *use_weights=True*)

get_density()

get_edge_types()

get_name()

get_properties(*a_properties*)

Return a dictionary containing the desired properties

Parameters **a_properties** (*sequence*) – List or tuple of strings of the property names.

Returns **di_result** (*dict*) – A dictionary of values with the property names as keys.

get_property(*s_property*)

Return the desired property or None for an incorrect one.

get_weights()

graph
graph_tool.Graph attribute of the instance

id
unique int identifying the instance

inhibitory_subgraph()
Create a Graph instance which graph contains only the inhibitory edges of the current instance's graph_tool.Graph

is_directed()

is_spatial()

is_weighted()

name

node_nb()

classmethod **num_graphs**()
Returns the number of alive instances.

set_name(*name=''*)
set graph name

set_weights(*elist=None*, *wlist=None*, *distrib=None*, *distrib_prop=None*, *correl=None*, *noise_scale=None*)
Set the synaptic weights.

Parameters

- **elist** (class:*numpy.array*, optional (default: None)) – List of the edges (for user defined weights).
- **wlist** (class:*numpy.array*, optional (default: None)) – List of the weights (for user defined weights).
- **distrib** (class:*string*, optional (default: None)) – Type of distribution (choose among "constant", "uniform", "gaussian", "lognormal", "lin_corr", "log_corr").
- **distrib_prop** (*dict, optional (default: {})*) – Dictoinary containing the properties of the weight distribution.
- **correl** (class:*string*, optional (default: None)) – Property to which the weights should be correlated.
- **noise_scale** (class:*int*, optional (default: None)) – Scale of the multiplicative Gaussian noise that should be applied on the weights.

class nngt.**SpatialGraph**(*nodes=0*, *name='Graph'*, *weighted=True*, *directed=True*, *libgraph=None*, *shape=None*, *positions=None*, ***kwargs*)
The detailed class that inherits from *Graph* and implements additional properties to describe various biological functions and interact with the NEST simulator.

Variables

- **shape** – *Shape* Shape of the neurons environment.
- **positions** – numpy.array Positions of the neurons.
- **graph** – GraphObject Main attribute of the class instance.

classmethod **make_spatial**(*graph*, *shape=<nngt.core.graph_datastruct.Shape instance>*, *positions=None*)

shape

class nngt.**Network**(*name='Graph'*, *weighted=True*, *directed=True*, *libgraph=None*, *population=None*, ***kwargs*)

The detailed class that inherits from *Graph* and implements additional properties to describe various biological functions and interact with the NEST simulator.

Variables

- **neural_model** – list List of the NEST neural models for each neuron.
- **syn_model** – list List of the NEST synaptic models for each edge.
- **graph** – GraphObject Main attribute of the class instance

classmethod ei_network(*size*, *ei_ratio=0.2*, *en_model='aeif_neuron'*, *en_param={}*, *es_model='static_synapse'*, *es_param={}*, *in_model='aeif_neuron'*, *in_param={}*, *is_model='static_synapse'*, *is_param={}*)

classmethod make_network(*graph*, *neural_pop*)

neuron_properties(*idx_neuron*)

classmethod num_networks()

Returns the number of alive instances.

population

classmethod uniform_network(*size*, *neuron_model='iaf_neuron'*, *neuron_param={}*, *syn_model='static_synapse'*, *syn_param={}*)

class nngt.**SpatialNetwork**(*population*, *name='Graph'*, *weighted=True*, *directed=True*, *shape=None*, *graph=None*, *positions=None*, ***kwargs*)

Class that inherits from *Network* and *SpatialGraph* to provide a detailed description of a real neural network in space, i.e. with positions and biological properties to interact with NEST.

Variables

- **shape** – nngt.core.Shape Shape of the neurons environment.
- **positions** – numpy.array Positions of the neurons.
- **neural_model** – list List of the NEST neural models for each neuron.
- **syn_model** – list List of the NEST synaptic models for each edge.
- **graph** – GraphObject Main attribute of the class instance.

Side classes

class nngt.**Shape**(*parent=None*)

Class containing the shape of the area where neurons will be distributed to form a network.

area

double

Area of the shape in mm^2.

com

tuple of doubles

Position of the center of mass of the current shape.

add_subshape: void

Add a AGNet.generation.Shape to a preexisting one.

add_subshape (*subshape*, *position*, *unit='mm'*)
Add a AGNet.generation.Shape to the current one.

Parameters

- **subshape** (*AGNet.generation.Shape*) – Length of the rectangle (by default in mm).
- **position** (*tuple of doubles*) – Position of the subshape's center of gravity in space.
- **unit** (*string (default 'mm')*) – Unit in the metric system among 'um', 'mm', 'cm', 'dm', 'm'

Returns *None*

area

com

rnd_distrib (*nodes=None*)

class nngt.**NeuralPop** (*size=None*, *parent=None*, *with_models=True*, ***kwargs*)
The basic class that contains groups of neurons and their properties.

Variables ***has_models*** – `bool`, `True` if every group has a `model` attribute.

add_to_group (*group_name*, *id_list*)

classmethod copy (*pop*)
Copy an existing NeuralPop

classmethod ei_population (*size*, *iratio=0.2*, *parent=None*, *en_model='iaf_neuron'*, *en_param={}*, *es_model='static_synapse'*, *es_param={}*, *in_model='iaf_neuron'*, *in_param={}*, *is_model='static_synapse'*, *is_param={}*)
Make a NeuralPop with a given ratio of inhibitory and excitatory neurons.

has_models

is_valid

new_group (*name*, *id_list*, *ntype=1*, *neuron_model=None*, *neuron_param={}*, *syn_model='static_synapse'*, *syn_param={}*)

classmethod pop_from_network (*graph*, **args*)
Make a NeuralPop object from a network. The groups of neurons are determined using instructions from an arbitrary number of `GroupProperties`.

set_models (*models=None*)

size

classmethod uniform_population (*size*, *parent=None*, *neuron_model='iaf_neuron'*, *neuron_param={}*, *syn_model='static_synapse'*, *syn_param={}*)
Make a NeuralPop of identical neurons

NNGT

Neural Networks Growth and Topology analyzing tool.

Provides algorithms for

1. growing networks
2. analyzing their activity
3. studying the graph theoretical properties of those networks

How to use the documentation Documentation is not yet really available. I will try to implement more extensive docstrings within the code. I recommend exploring the docstrings using IPython, an advanced Python shell with TAB-completion and introspection capabilities. See below for further instructions. The docstring examples assume that *numpy* has been imported as *np*:

```
>>> import numpy as np
```

Code snippets are indicated by three greater-than signs:

```
>>> x = 42
>>> x = x + 1
```

Use the built-in `help` function to view a function's docstring:

```
>>> help(nggt.GraphClass)
```

Available subpackages

core Contains the main network classes. These are loaded in nngt at import so specifying *nngt.core* is not necessary

generation Functions to generate specific networks

lib Basic functions used by several sub-packages.

io @todo: Tools for input/output operations

nest NEST integration tools

random @todo? Random numbers generation tools

growth @todo: Growing networks tools

Utilities

plot plot data or graphs (@todo) using matplotlib and graph_tool

show_config @todo: Show build configuration

version NNGT version string

Units Functions related to spatial embedding of networks are using milimeters (mm) as default unit; other units from the metric system can also be provided:

- *um* for micrometers
- *cm* centimeters
- *dm* for decimeters
- *m* for meters

class `nngt.`**`Graph`**(*nodes=0*, *name='Graph'*, *weighted=True*, *directed=True*, *libgraph=None*, ***kwargs*)
The basic class that contains a `graph_tool.Graph` and some of is properties or methods to easily access them.

Variables

- **`id`** – `int` unique id that identifies the instance.
- **`graph`** – `GraphObject` main attribute of the class instance.

class nngt.**SpatialGraph**(*nodes=0*, *name='Graph'*, *weighted=True*, *directed=True*, *libgraph=None*, *shape=None*, *positions=None*, ***kwargs*)

The detailed class that inherits from *Graph* and implements additional properties to describe various biological functions and interact with the NEST simulator.

Variables

- **shape** – *Shape* Shape of the neurons environment.
- **positions** – numpy.array Positions of the neurons.
- **graph** – GraphObject Main attribute of the class instance.

class nngt.**Network**(*name='Graph'*, *weighted=True*, *directed=True*, *libgraph=None*, *population=None*, ***kwargs*)

The detailed class that inherits from *Graph* and implements additional properties to describe various biological functions and interact with the NEST simulator.

Variables

- **neural_model** – list List of the NEST neural models for each neuron.
- **syn_model** – list List of the NEST synaptic models for each edge.
- **graph** – GraphObject Main attribute of the class instance

class nngt.**SpatialNetwork**(*population*, *name='Graph'*, *weighted=True*, *directed=True*, *shape=None*, *graph=None*, *positions=None*, ***kwargs*)

Class that inherits from *Network* and *SpatialGraph* to provide a detailed description of a real neural network in space, i.e. with positions and biological properties to interact with NEST.

Variables

- **shape** – nngt.core.Shape Shape of the neurons environment.
- **positions** – numpy.array Positions of the neurons.
- **neural_model** – list List of the NEST neural models for each neuron.
- **syn_model** – list List of the NEST synaptic models for each edge.
- **graph** – GraphObject Main attribute of the class instance.

Core module

Core module

Classes	
GraphClass	Main object
SpatialGraph	Spatially-embedded graph
Network	More detailed network that inherits from GraphClass
SpatialNetwork	Spatially-embedded network
InputConnect	Connectivity to input analogic signals on a graph

Contents GraphObject for subclassing the libraries graphs

nngt.core.**assortativity**(*lib_graph*)

nngt.core.**reciprocity**(*lib_graph*)

nngt.core.**clustering**(*lib_graph*)

nngt.core.**num_iedges**(*lib_graph*)

nngt.core.**num_scc**(*lib_graph*)

nngt.core.**num_wcc**(*lib_graph*)

nngt.core.**diameter**(*lib_graph*)

nngt.core.**spectral_radius**(*lib_graph*)

Generation module

Functions that generates the underlying connectivity of graphs, as well as the synaptic properties (weight/strength and delay).

Functions (connectivity)	
erdos_renyi	Random graph studied by Erdos and Renyi
random_free_scale	An uncorrelated free-scale graph
price_free_scale	Price's network (Barabasi-Albert if undirected)
newman_watts	Newman-Watts small world network
distance_rule	Distance-dependent connection probability

Functions (weigths/delays)	
gaussian_eprop	Random gaussian distribution
lognormal_eprop	Random lognormal distribution
uniform_eprop	Random uniform distribution
custom_eprop	User defined distribution
correlated_fixed_eprop	Computed from an edge property
correlated_proba_eprop	Randomly drawn, correlated to an edge property

Contents

nngt.generation.**erdos_renyi**(*nodes=None*, *density=0.1*, *edges=-1*, *avg_deg=-1.0*, *reciprocity=-1.0*, *directed=True*, *multigraph=False*, *name='ER'*, *shape=None*, *positions=None*, *from_graph=None*)

Generate a random graph as defined by Erdos and Renyi but with a reciprocity that can be chosen.

Parameters

- **nodes** (*int, optional (default: None)*) – The number of nodes in the graph.
- **density** (*double, optional (default: 0.1)*) – Structural density given by *edges* / *nodes*^{2}.
- **edges** (*int (optional)*) – The number of edges between the nodes
- **avg_deg** (*double, optional*) – Average degree of the neurons given by *edges* / *nodes*.
- **reciprocity** (*double, optional (default: -1 to let it free)*) – Fraction of edges that are bidirectional (only for directed graphs – undirected graphs have a reciprocity of 1 by definition)
- **directed** (*bool, optional (default: True)*) – Whether the graph is directed or not.
- **multigraph** (*bool, optional (default: False)*) – Whether the graph can contain multiple edges between two nodes.
- **name** (*string, optional (default: "ER")*) – Name of the created graph.
- **shape** (`Shape`, optional (default: None)) – Shape of the neurons' environment
- **positions** (`numpy.ndarray`, optional (default: None)) – A 2D or 3D array containing the positions of the neurons in space
- **from_graph** (`Graph` or subclass, optional (default: None)) – Initial graph whose nodes are to be connected.

Returns **graph_er** (*Graph*, or subclass) – A new generated graph or the modified *from_graph*.

Notes

nodes is required unless *from_graph* is provided. If an *from_graph* is provided, all preexistant edges in the object will be deleted before the new connectivity is implemented.

nngt.generation.**newman_watts**(*coord_nb*, *proba_shortcut*, *nodes=None*, *directed=True*, *multigraph=False*, *name='ER'*, *shape=None*, *positions=None*, *from_graph=None*, ***kwargs*)

Generate a small-world graph using the Newman-Watts algorithm. @todo: generate the edges of a circular graph to not replace the graph of the *from_graph* and implement chosen reciprocity.

Parameters

- **coord_nb** (*int*) – The number of neighbours for each node on the initial topological lattice.
- **proba_shortcut** (*double*) – Probability of adding a new random (shortcut) edge for each existing edge on the initial lattice.
- **nodes** (*int, optional (default: None)*) – The number of nodes in the graph.
- **density** (*double, optional (default: 0.1)*) – Structural density given by *edges* / (*nodes*'*'*nodes*).
- **edges** (*int (optional)*) – The number of edges between the nodes
- **avg_deg** (*double, optional*) – Average degree of the neurons given by *edges* / *nodes*.
- **directed** (*bool, optional (default: True)*) – Whether the graph is directed or not.
- **multigraph** (*bool, optional (default: False)*) – Whether the graph can contain multiple edges between two nodes.
- **name** (*string, optional (default: "ER")*) – Name of the created graph.
- **shape** (`Shape`, optional (default: None)) – Shape of the neurons' environment
- **positions** (`numpy.ndarray`, optional (default: None)) – A 2D or 3D array containing the positions of the neurons in space
- **from_graph** (`Graph` or subclass, optional (default: None)) – Initial graph whose nodes are to be connected.

Returns **graph_nw** (*Graph* or subclass)

Notes

nodes is required unless *from_graph* is provided.

nngt.generation.**connect_neural_types**(*network*, *source_type*, *target_type*, *graph_model*, *model_param*)

Function to connect excitatory and inhibitory population with a given graph model.

Parameters

- **network** (`Network` or `SpatialNetwork`) – The network to connect.
- **source_type** (*int*) – The type of source neurons (`1` for excitatory, ''-1 for inhibitory neurons).
- **source_type** (*int*) – The type of target neurons.
- **graph_model** (*string*) – The name of the connectivity model (among "erdos_renyi", "random_scale_free", "price_scale_free", and "newman_watts").

- **model_param** (*dict*) – Dictionary containing the model parameters (the keys are the keywords of the associated generation function — see above).

nngt.generation.**connect_neural_groups**(*network*, *source_groups*, *target_groups*, *graph_model*, *model_param*)

Function to connect excitatory and inhibitory population with a given graph model.

Parameters

- **network** (`Network` or `SpatialNetwork`) – The network to connect.
- **source_groups** (*tuple of strings*) – Names of the source groups (which contain the presynaptic neurons)
- **target_groups** (*tuple of strings*) – Names of the target groups (which contain the postsynaptic neurons)
- **graph_model** (*string*) – The name of the connectivity model (among "erdos_renyi", "random_scale_free", "price_scale_free", and "newman_watts").
- **model_param** (*dict*) – Dictionary containing the model parameters (the keys are the keywords of the associated generation function — see above).

Lib module

Lib module

Errors	
InvalidArgument	Argument passed to the function are not valid

Properties module

Properties module

Classes	
NeuralPop	Contains neuron populations and their properties
ConnectionsProp	Properties of the connections between neurons
PopIntructions	Instructions to build a population of neurons

CHAPTER 2

Installation

2.1 Dependencies

This package depends on several libraries (the number varies according to which modules you want to use).

2.1.1 Basic dependencies

Regardless of your needs, the following libraries are required:

- numpy
- scipy
- graph_tool

2.1.2 Using NEST

If you want to simulate activities on your complex networks, AGNet can directly interact with the NEST simulator to implemen

- Python headers (*python-dev* package on most linux distributions)
- autoconf
- automake
- libtool
- libltdl

CHAPTER 3

Graph generation

3.1 Principle

In order to keep the code as generic and easy to maintain as possible, the generation of graphs or networks is divided in several steps:

- **Structured connectivity:** a simple graph is generated as an assembly of nodes and edges, without any biological properties. This allows us to implement known graph-theoretical algorithms in a straightforward fashion.
- **Populations:** detailed properties can be implemented, such as inhibitory synapses and separation of the neurons into inhibitory and excitatory populations – these can be done while respecting user-defined constraints.
- **Synaptic properties:** eventually, synaptic properties such as weight/strength and delays can be added to the network.

3.2 Modularity

The library as been designed so that these various operations can be realized in any order!

Juste to get work on a topological graph/network:

1. Create graph class
2. Connect
3. Set connection weights (optional)
4. Spatialize (optional)
5. Set types (optional: to use with NEST)

To work on a really spatially embedded graph/network:

1. Create spatial graph/network
2. Connect (can depend on positions)
3. Set connection weights (optional, can depend on positions)
4. Set types (optional)

Or to model a complex neural network in NEST:

1. Create spatial network (with space and neuron types)
2. Connect (can depend on types and positions)

3. Set connection weights and types (optional, can depend on types and positions)

3.3 Setting weights

The weights can be either user-defined or generated by one of the available distributions (MAKE A REF). User-defined weights are generated via:

- a list of edges
- a list of weights

Pre-defined distributions require the following variables:

- a distribution name ("constant", "gaussian"...)
- a dictionary containing the distribution properties
- an optional attribute for distributions that are correlated to another (e.g. the distances between neurons)
- a optional value defining the variance of the Gaussian noise that should be applied on the weights

There are several ways of settings the weights of a graph which depend on the time at which you assign them.

At graph creation You can define the weights by entering a `weight_prop` argument to the constructor; this should be a dictionary containing at least the name of the weight distribution: `{"distrib": "distribution_name"}`. If entered, this will be stored as a graph property and used to assign the weights whenever new edges are created unless you specifically assign rules for those new edges' weights.

At any given time You can use the `Connections` class to set the weights of a `graph` explicitely by using: >>> nngt.Connections.weights(graph, elist=edges_to_weigh, distrib="distrib_of_choice", ...)

3.3.1 Generation module

Functions that generates the underlying connectivity of graphs, as well as the synaptic properties (weight/strength and delay).

Functions (connectivity)	
erdos_renyi	Random graph studied by Erdos and Renyi
random_free_scale	An uncorrelated free-scale graph
price_free_scale	Price's network (Barabasi-Albert if undirected)
newman_watts	Newman-Watts small world network
distance_rule	Distance-dependent connection probability

Functions (weigths/delays)	
gaussian_eprop	Random gaussian distribution
lognormal_eprop	Random lognormal distribution
uniform_eprop	Random uniform distribution
custom_eprop	User defined distribution
correlated_fixed_eprop	Computed from an edge property
correlated_proba_eprop	Randomly drawn, correlated to an edge property

Contents

nngt.generation.**erdos_renyi**(*nodes=None*, *density=0.1*, *edges=-1*, *avg_deg=-1.0*, *reciprocity=-1.0*, *directed=True*, *multigraph=False*, *name='ER'*, *shape=None*, *positions=None*, *from_graph=None*)

Generate a random graph as defined by Erdos and Renyi but with a reciprocity that can be chosen.

Parameters

- **nodes** (*int, optional (default: None)*) – The number of nodes in the graph.
- **density** (*double, optional (default: 0.1)*) – Structural density given by *edges* / *nodes*^{2}.
- **edges** (*int (optional)*) – The number of edges between the nodes
- **avg_deg** (*double, optional*) – Average degree of the neurons given by *edges* / *nodes*.
- **reciprocity** (*double, optional (default: -1 to let it free)*) – Fraction of edges that are bidirectional (only for directed graphs – undirected graphs have a reciprocity of 1 by definition)
- **directed** (*bool, optional (default: True)*) – Whether the graph is directed or not.
- **multigraph** (*bool, optional (default: False)*) – Whether the graph can contain multiple edges between two nodes.
- **name** (*string, optional (default: "ER")*) – Name of the created graph.
- **shape** (`Shape`, optional (default: None)) – Shape of the neurons' environment
- **positions** (`numpy.ndarray`, optional (default: None)) – A 2D or 3D array containing the positions of the neurons in space
- **from_graph** (`Graph` or subclass, optional (default: None)) – Initial graph whose nodes are to be connected.

Returns **graph_er** (*Graph*, or subclass) – A new generated graph or the modified *from_graph*.

Notes

nodes is required unless *from_graph* is provided. If an *from_graph* is provided, all preexistant edges in the object will be deleted before the new connectivity is implemented.

nngt.generation.**newman_watts**(*coord_nb*, *proba_shortcut*, *nodes=None*, *directed=True*, *multigraph=False*, *name='ER'*, *shape=None*, *positions=None*, *from_graph=None*, ***kwargs*)

Generate a small-world graph using the Newman-Watts algorithm. @todo: generate the edges of a circular graph to not replace the graph of the *from_graph* and implement chosen reciprocity.

Parameters

- **coord_nb** (*int*) – The number of neighbours for each node on the initial topological lattice.
- **proba_shortcut** (*double*) – Probability of adding a new random (shortcut) edge for each existing edge on the initial lattice.
- **nodes** (*int, optional (default: None)*) – The number of nodes in the graph.
- **density** (*double, optional (default: 0.1)*) – Structural density given by *edges* / (*nodes*'*'*nodes*).
- **edges** (*int (optional)*) – The number of edges between the nodes
- **avg_deg** (*double, optional*) – Average degree of the neurons given by *edges* / *nodes*.

- **directed** (*bool, optional (default: True)*) – Whether the graph is directed or not.
- **multigraph** (*bool, optional (default: False)*) – Whether the graph can contain multiple edges between two nodes.
- **name** (*string, optional (default: "ER")*) – Name of the created graph.
- **shape** (`Shape`, optional (default: None)) – Shape of the neurons' environment
- **positions** (`numpy.ndarray`, optional (default: None)) – A 2D or 3D array containing the positions of the neurons in space
- **from_graph** (`Graph` or subclass, optional (default: None)) – Initial graph whose nodes are to be connected.

Returns **graph_nw** (*Graph* or subclass)

Notes

nodes is required unless *from_graph* is provided.

`nngt.generation.`**`connect_neural_types`**(*network*, *source_type*, *target_type*, *graph_model*, *model_param*)

Function to connect excitatory and inhibitory population with a given graph model.

Parameters

- **network** (`Network` or `SpatialNetwork`) – The network to connect.
- **source_type** (*int*) – The type of source neurons (`1` for excitatory, "-1 for inhibitory neurons).
- **source_type** (*int*) – The type of target neurons.
- **graph_model** (*string*) – The name of the connectivity model (among "erdos_renyi", "random_scale_free", "price_scale_free", and "newman_watts").
- **model_param** (*dict*) – Dictionary containing the model parameters (the keys are the keywords of the associated generation function — see above).

`nngt.generation.`**`connect_neural_groups`**(*network*, *source_groups*, *target_groups*, *graph_model*, *model_param*)

Function to connect excitatory and inhibitory population with a given graph model.

Parameters

- **network** (`Network` or `SpatialNetwork`) – The network to connect.
- **source_groups** (*tuple of strings*) – Names of the source groups (which contain the presynaptic neurons)
- **target_groups** (*tuple of strings*) – Names of the target groups (which contain the postsynaptic neurons)
- **graph_model** (*string*) – The name of the connectivity model (among "erdos_renyi", "random_scale_free", "price_scale_free", and "newman_watts").
- **model_param** (*dict*) – Dictionary containing the model parameters (the keys are the keywords of the associated generation function — see above).

CHAPTER 4

Properties of graph components

4.1 Components

In the graph libraries used by NNGT, the main components of a graph are *nodes* (also called *vertices* in graph theory), which correspond to *neurons* in neural networks, and *edges*, which link *nodes* and correspond to synaptic connections between neurons in biology.

The library supposes for now that nodes/neurons and edges/synapses are always added and never removed. Because of this, we can attribute indices to the nodes and the edges which will be directly related to the order in which they have been created (the first node will have index 0, .

4.2 Node properties

If you are just working with basic graphs (for instance looking at the influence of topology with purely excitatory networks), then your nodes do not need to have properties. This is the same if you consider only the average effect of inhibitory neurons by including inhibitory connections between the neurons but not a clear distinction between populations of purely excitatory and purely inhibitory neurons. To model more realistic networks, however, you might want to define these two types of populations and connect them in specific ways.

4.2.1 Two types of node properties

In the library, there is a difference between:

- spatial properties (the positions of the neurons), which are stored in a specific `numpy.array`,
- biological/group properties, which define assemblies of nodes sharing common properties, and are stored inside a `NeuralPop` object.

4.2.2 Biological/group properties

Note: All biological/group properties are stored in a `NeuralPop` object inside a *`Network`* instance (let us call it `graph` in this example); this attribute can be accessed using `graph.population`. `NeuralPop` objects can also be created from a *`Graph`* or *`SpatialGraph`* but they will not be stored inside the object.

The `NeuralPop` class allows you to define specific groups of neurons (described by a `NeuralGroup`). Once these populations are defined, you can constrain the connections between those populations. If the connectivity already exists, you can use the `GroupProperties` class to create a population with groups that respect specific constraints.

Warning: The implementation of this library has been optimized for generating an arbitrary number of neural populations where neurons share common properties; this implies that accessing the properties of one specific neuron will take O(N) operations, where N is the number of neurons. This might change in the future if such operations are judged useful enough.

4.3 Edge properties

In the library, there is a difference between the (synaptic) weights and types (excitatory or inhibitory) and the other biological properties (delays, synaptic models and synaptic parameters). This is because the weights and types are directly involved in many measurements in graph theory and are therefore directly stored inside the `GraphObject`.

CHAPTER 5

Detailed structure

Here is a small bottom-up approach of the library to justify its structure.

5.1 Rationale for the structure

5.1.1 The basis: a graph

The core object is `nngt.core.GraphObject` that inherits from either `graph_tool.Graph` or `snap.TNEANet` and `Shape` that encodes the spatial structure of the neurons' environment. The purpose of `GraphObject` is simple: implementing a library independant object with a unique set of functions to interact with graphs.

Warning: This object should never be directly modified through its methods but rather using those of the four containing classes. The only reason to access this object should be to perform graph-theoretical measurements on it which do not modify its structure; any other action will lead to undescribed behaviour.

5.1.2 Frontend

Detailed neural networks contain properties that the `GraphObject` does not know about; because of this, direct modification of the structure can lead to nodes or edges missing properties or to properties assigned to nonexistent nodes or edges.

The user can safely interact with the graph using one of the following classes:

- *`Graph`*: container for simple topological graphs with no spatial embedding, nor biological properties
- *`SpatialGraph`*: container for spatial graphs without biological properties
- *`Network`*: container for topological graphs with biological properties (to interact with NEST)
- *`SpatialNetwork`*: container with spatial and biological properties (to interact with NEST)

The reason behind those four objects is to ensure coherence in the properties: either nodes/edges all have a given property or they all don't. Namely:

- adding a node will always require a position parameter when working with a spatial graph,
- adding a node or a connection will always require biological parameters when working with a network.

Moreover, these classes contain the `GraphObject` in their `graph` attribute and do not inherit from it. The reason for this is to make it easy to maintain different addition/deletion functions for the topological and spatial container

by keeping independant of the graph library. (otherwise overwriting one of these function would require the use of library-dependant features).

CHAPTER 6

Graph attributes

The *Graph* class and its subclasses contain several attributes regarding the properties of the edges and nodes. Edges attributes are contained in the graph dictionary; more complex properties about the biological details of the nodes/neurons are contained in the NeuralPop member of the *Graph*. These are briefly described in Properties of graph components; a more detailed description is provided here.

6.1 Attributes and graph libraries

Usual graph libraries can store node and edge properties; as an example, many graphs are weighted and these weights can then be used to compute other properties such as weighted centralities, which is why it is interesting to have those properties stored in the basic graph library class.

The *graph_object.py* file contains the `_GtEProperty` and `_GtNProperty` classes which allow a generic interactions with the various libraries ways of storing properties.

However, several problems occurs:

- for graph_tool, the edge properties are stored in a linear array that is not directly related to the adjacency matrix, thus difficult to handle; this could however be avoided by multiplying the adjacency matrix by the property of interest...
- but for igraph, there is not straightforward way to obtain a scipy adjacency matrix multiplied by an edge property...

To get rid of those problems, the (possibly temporary) solution adopted is to have the weights (synaptic strength) and types (inhibitory or excitatory) attributes stored both in the graph library object and in the *Graph* container.

The libraries indices the edges in the order they are created; because of this, weights must be added to the library using the edge list, which is stored inside the *Graph* container (access it through the `''edges''` key). The addition is performed in the following way: let `lil_matrix_attribute` contain the attribute of interest and `network` be the graph container to which we want to add the property, then the following code is used,

```
>>> sources, targets = network["edges"][:,0], network["edges"][:,1]
>>> list_ordered_weights = lil_matrix_attribute[sources,targets].data[0]
>>> network.graph.new_edge_attribute("weight", "double", values=list_ordered_weights)
```

6.2 Use of attributes in a graph object

This allows for fast graph filtering: we can keep only the edges or nodes we are interested in.

This property is invaluable if you want to study the graph properties of only the inhibitory network or look a the squeleton of the strongest synapses in the graph...

CHAPTER 7

Main module

For more details regarding the main classes, see:

7.1 Graph container classes

class nngt.**Graph**(*nodes=0*, *name='Graph'*, *weighted=True*, *directed=True*, *libgraph=None*, ***kwargs*)

The basic class that contains a graph_tool.Graph and some of is properties or methods to easily access them.

Variables

- **id** – int unique id that identifies the instance.
- **graph** – GraphObject main attribute of the class instance.

add_edges(*lst_edges*)

Add a list of edges to the graph.

Parameters

- **lst_edges** (*list of 2-tuples or np.array of shape (edge_nb, 2)*) – List of the edges that should be added as tuples (source, target)
- **@todo** (*add example, check the edges for self-loops and multiple edges*)

adjacency_matrix(*weighted=True*)

attributes()

copy()

Returns a deepcopy of the current Graph instance

edge_nb()

excitatory_subgraph()

create a Graph instance which graph contains only the excitatory edges of the current instance's GraphObject

get_betweenness(*use_weights=True*)

get_degrees(*strType='total'*, *use_weights=True*)

get_density()

get_edge_types()

get_name()

get_properties(*a_properties*)
Return a dictionary containing the desired properties

Parameters **a_properties** (*sequence*) – List or tuple of strings of the property names.

Returns **di_result** (*dict*) – A dictionary of values with the property names as keys.

get_property(*s_property*)
Return the desired property or None for an incorrect one.

get_weights()

graph
graph_tool.Graph attribute of the instance

id
unique int identifying the instance

inhibitory_subgraph()
Create a Graph instance which graph contains only the inhibitory edges of the current instance's graph_tool.Graph

is_directed()

is_spatial()

is_weighted()

name

node_nb()

classmethod num_graphs()
Returns the number of alive instances.

set_name(*name=''*)
set graph name

set_weights(*elist=None*, *wlist=None*, *distrib=None*, *distrib_prop=None*, *correl=None*, *noise_scale=None*)
Set the synaptic weights.

Parameters

- **elist** (class:*numpy.array*, optional (default: None)) – List of the edges (for user defined weights).
- **wlist** (class:*numpy.array*, optional (default: None)) – List of the weights (for user defined weights).
- **distrib** (class:*string*, optional (default: None)) – Type of distribution (choose among "constant", "uniform", "gaussian", "lognormal", "lin_corr", "log_corr").
- **distrib_prop** (*dict, optional (default: {})*) – Dictoinary containing the properties of the weight distribution.
- **correl** (class:*string*, optional (default: None)) – Property to which the weights should be correlated.
- **noise_scale** (class:*int*, optional (default: None)) – Scale of the multiplicative Gaussian noise that should be applied on the weights.

class nngt.**SpatialGraph**(*nodes=0*, *name='Graph'*, *weighted=True*, *directed=True*, *libgraph=None*, *shape=None*, *positions=None*, ***kwargs*)
The detailed class that inherits from *Graph* and implements additional properties to describe various biological functions and interact with the NEST simulator.

Variables

- **shape** – *Shape* Shape of the neurons environment.
- **positions** – numpy.array Positions of the neurons.
- **graph** – GraphObject Main attribute of the class instance.

classmethod make_spatial(*graph*, *shape=<nngt.core.graph_datastruct.Shape instance>*, *positions=None*)

shape

class nngt.**Network**(*name='Graph'*, *weighted=True*, *directed=True*, *libgraph=None*, *population=None*, ***kwargs*)

The detailed class that inherits from *Graph* and implements additional properties to describe various biological functions and interact with the NEST simulator.

Variables

- **neural_model** – list List of the NEST neural models for each neuron.
- **syn_model** – list List of the NEST synaptic models for each edge.
- **graph** – GraphObject Main attribute of the class instance

classmethod ei_network(*size*, *ei_ratio=0.2*, *en_model='aeif_neuron'*, *en_param={}*, *es_model='static_synapse'*, *es_param={}*, *in_model='aeif_neuron'*, *in_param={}*, *is_model='static_synapse'*, *is_param={}*)

classmethod make_network(*graph*, *neural_pop*)

neuron_properties(*idx_neuron*)

classmethod num_networks()

Returns the number of alive instances.

population

classmethod uniform_network(*size*, *neuron_model='iaf_neuron'*, *neuron_param={}*, *syn_model='static_synapse'*, *syn_param={}*)

class nngt.**SpatialNetwork**(*population*, *name='Graph'*, *weighted=True*, *directed=True*, *shape=None*, *graph=None*, *positions=None*, ***kwargs*)

Class that inherits from *Network* and *SpatialGraph* to provide a detailed description of a real neural network in space, i.e. with positions and biological properties to interact with NEST.

Variables

- **shape** – nngt.core.Shape Shape of the neurons environment.
- **positions** – numpy.array Positions of the neurons.
- **neural_model** – list List of the NEST neural models for each neuron.
- **syn_model** – list List of the NEST synaptic models for each edge.
- **graph** – GraphObject Main attribute of the class instance.

7.2 Side classes

class nngt.**Shape**(*parent=None*)

Class containing the shape of the area where neurons will be distributed to form a network.

area
double

Area of the shape in mm^2.

com
tuple of doubles

Position of the center of mass of the current shape.

add_subshape: void
Add a AGNet.generation.Shape to a preexisting one.

add_subshape(*subshape*, *position*, *unit='mm'*)
Add a AGNet.generation.Shape to the current one.

Parameters

- **subshape** (*AGNet.generation.Shape*) – Length of the rectangle (by default in mm).
- **position** (*tuple of doubles*) – Position of the subshape's center of gravity in space.
- **unit** (*string (default 'mm')*) – Unit in the metric system among 'um', 'mm', 'cm', 'dm', 'm'

Returns *None*

area

com

rnd_distrib(*nodes=None*)

class nngt.**NeuralPop**(*size=None*, *parent=None*, *with_models=True*, ***kwargs*)
The basic class that contains groups of neurons and their properties.

Variables ***has_models*** – bool, True if every group has a model attribute.

add_to_group(*group_name*, *id_list*)

classmethod copy(*pop*)
Copy an existing NeuralPop

classmethod ei_population(*size*, *iratio=0.2*, *parent=None*, *en_model='iaf_neuron'*, *en_param={}*, *es_model='static_synapse'*, *es_param={}*, *in_model='iaf_neuron'*, *in_param={}*, *is_model='static_synapse'*, *is_param={}*)
Make a NeuralPop with a given ratio of inhibitory and excitatory neurons.

has_models

is_valid

new_group(*name*, *id_list*, *ntype=1*, *neuron_model=None*, *neuron_param={}*, *syn_model='static_synapse'*, *syn_param={}*)

classmethod pop_from_network(*graph*, **args*)
Make a NeuralPop object from a network. The groups of neurons are determined using instructions from an arbitrary number of GroupProperties.

set_models(*models=None*)

size

classmethod uniform_population(*size*, *parent=None*, *neuron_model='iaf_neuron'*, *neuron_param={}*, *syn_model='static_synapse'*, *syn_param={}*)
Make a NeuralPop of identical neurons

7.3 NNGT

Neural Networks Growth and Topology analyzing tool.

Provides algorithms for

1. growing networks
2. analyzing their activity
3. studying the graph theoretical properties of those networks

7.3.1 How to use the documentation

Documentation is not yet really available. I will try to implement more extensive docstrings within the code. I recommend exploring the docstrings using IPython, an advanced Python shell with TAB-completion and introspection capabilities. See below for further instructions. The docstring examples assume that *numpy* has been imported as *np*:

```
>>> import numpy as np
```

Code snippets are indicated by three greater-than signs:

```
>>> x = 42
>>> x = x + 1
```

Use the built-in `help` function to view a function's docstring:

```
>>> help(nggt.GraphClass)
```

7.3.2 Available subpackages

core Contains the main network classes. These are loaded in nngt at import so specifying *nngt.core* is not necessary

generation Functions to generate specific networks

lib Basic functions used by several sub-packages.

io @todo: Tools for input/output operations

nest NEST integration tools

random @todo? Random numbers generation tools

growth @todo: Growing networks tools

7.3.3 Utilities

plot plot data or graphs (@todo) using matplotlib and graph_tool

show_config @todo: Show build configuration

version NNGT version string

7.3.4 Units

Functions related to spatial embedding of networks are using milimeters (mm) as default unit; other units from the metric system can also be provided:

- *um* for micrometers
- *cm* centimeters
- *dm* for decimeters
- *m* for meters

class nngt.**Graph**(*nodes=0*, *name='Graph'*, *weighted=True*, *directed=True*, *libgraph=None*, ***kwargs*)
The basic class that contains a graph_tool.Graph and some of is properties or methods to easily access them.

Variables

- **id** – int unique id that identifies the instance.
- **graph** – GraphObject main attribute of the class instance.

class nngt.**SpatialGraph**(*nodes=0*, *name='Graph'*, *weighted=True*, *directed=True*, *libgraph=None*, *shape=None*, *positions=None*, ***kwargs*)
The detailed class that inherits from *Graph* and implements additional properties to describe various biological functions and interact with the NEST simulator.

Variables

- **shape** – *Shape* Shape of the neurons environment.
- **positions** – numpy.array Positions of the neurons.
- **graph** – GraphObject Main attribute of the class instance.

class nngt.**Network**(*name='Graph'*, *weighted=True*, *directed=True*, *libgraph=None*, *population=None*, ***kwargs*)
The detailed class that inherits from *Graph* and implements additional properties to describe various biological functions and interact with the NEST simulator.

Variables

- **neural_model** – list List of the NEST neural models for each neuron.
- **syn_model** – list List of the NEST synaptic models for each edge.
- **graph** – GraphObject Main attribute of the class instance

class nngt.**SpatialNetwork**(*population*, *name='Graph'*, *weighted=True*, *directed=True*, *shape=None*, *graph=None*, *positions=None*, ***kwargs*)
Class that inherits from *Network* and *SpatialGraph* to provide a detailed description of a real neural network in space, i.e. with positions and biological properties to interact with NEST.

Variables

- **shape** – nngt.core.Shape Shape of the neurons environment.
- **positions** – numpy.array Positions of the neurons.
- **neural_model** – list List of the NEST neural models for each neuron.
- **syn_model** – list List of the NEST synaptic models for each edge.
- **graph** – GraphObject Main attribute of the class instance.

7.4 Core module

7.4.1 Core module

Classes	
GraphClass	Main object
SpatialGraph	Spatially-embedded graph
Network	More detailed network that inherits from GraphClass
SpatialNetwork	Spatially-embedded network
InputConnect	Connectivity to input analogic signals on a graph

Contents

GraphObject for subclassing the libraries graphs

nngt.core.**assortativity**(*lib_graph*)

nngt.core.**reciprocity**(*lib_graph*)

nngt.core.**clustering**(*lib_graph*)

nngt.core.**num_iedges**(*lib_graph*)

nngt.core.**num_scc**(*lib_graph*)

nngt.core.**num_wcc**(*lib_graph*)

nngt.core.**diameter**(*lib_graph*)

nngt.core.**spectral_radius**(*lib_graph*)

7.5 Generation module

Functions that generates the underlying connectivity of graphs, as well as the synaptic properties (weight/strength and delay).

Functions (connectivity)	
erdos_renyi	Random graph studied by Erdos and Renyi
random_free_scale	An uncorrelated free-scale graph
price_free_scale	Price's network (Barabasi-Albert if undirected)
newman_watts	Newman-Watts small world network
distance_rule	Distance-dependent connection probability

Functions (weigths/delays)	
gaussian_eprop	Random gaussian distribution
lognormal_eprop	Random lognormal distribution
uniform_eprop	Random uniform distribution
custom_eprop	User defined distribution
correlated_fixed_eprop	Computed from an edge property
correlated_proba_eprop	Randomly drawn, correlated to an edge property

7.5.1 Contents

nngt.generation.**erdos_renyi**(*nodes=None*, *density=0.1*, *edges=-1*, *avg_deg=-1.0*, *reciprocity=-1.0*, *directed=True*, *multigraph=False*, *name='ER'*, *shape=None*, *positions=None*, *from_graph=None*)

Generate a random graph as defined by Erdos and Renyi but with a reciprocity that can be chosen.

Parameters

- **nodes** (*int, optional (default: None)*) – The number of nodes in the graph.
- **density** (*double, optional (default: 0.1)*) – Structural density given by *edges* / *nodes*^{2}.
- **edges** (*int (optional)*) – The number of edges between the nodes
- **avg_deg** (*double, optional*) – Average degree of the neurons given by *edges* / *nodes*.
- **reciprocity** (*double, optional (default: -1 to let it free)*) – Fraction of edges that are bidirectional (only for directed graphs – undirected graphs have a reciprocity of 1 by definition)
- **directed** (*bool, optional (default: True)*) – Whether the graph is directed or not.
- **multigraph** (*bool, optional (default: False)*) – Whether the graph can contain multiple edges between two nodes.
- **name** (*string, optional (default: "ER")*) – Name of the created graph.
- **shape** (`Shape`, optional (default: None)) – Shape of the neurons' environment
- **positions** (`numpy.ndarray`, optional (default: None)) – A 2D or 3D array containing the positions of the neurons in space
- **from_graph** (`Graph` or subclass, optional (default: None)) – Initial graph whose nodes are to be connected.

Returns **graph_er** (*Graph*, or subclass) – A new generated graph or the modified *from_graph*.

Notes

nodes is required unless *from_graph* is provided. If an *from_graph* is provided, all preexistant edges in the object will be deleted before the new connectivity is implemented.

nngt.generation.**newman_watts**(*coord_nb*, *proba_shortcut*, *nodes=None*, *directed=True*, *multigraph=False*, *name='ER'*, *shape=None*, *positions=None*, *from_graph=None*, ***kwargs*)

Generate a small-world graph using the Newman-Watts algorithm. @todo: generate the edges of a circular graph to not replace the graph of the *from_graph* and implement chosen reciprocity.

Parameters

- **coord_nb** (*int*) – The number of neighbours for each node on the initial topological lattice.
- **proba_shortcut** (*double*) – Probability of adding a new random (shortcut) edge for each existing edge on the initial lattice.
- **nodes** (*int, optional (default: None)*) – The number of nodes in the graph.
- **density** (*double, optional (default: 0.1)*) – Structural density given by *edges* / (*nodes*'*'*nodes*).
- **edges** (*int (optional)*) – The number of edges between the nodes
- **avg_deg** (*double, optional*) – Average degree of the neurons given by *edges* / *nodes*.

- **directed** (*bool, optional (default: True)*) – Whether the graph is directed or not.
- **multigraph** (*bool, optional (default: False)*) – Whether the graph can contain multiple edges between two nodes.
- **name** (*string, optional (default: "ER")*) – Name of the created graph.
- **shape** (`Shape`, optional (default: None)) – Shape of the neurons' environment
- **positions** (`numpy.ndarray`, optional (default: None)) – A 2D or 3D array containing the positions of the neurons in space
- **from_graph** (`Graph` or subclass, optional (default: None)) – Initial graph whose nodes are to be connected.

Returns **graph_nw** (*Graph* or subclass)

Notes

nodes is required unless *from_graph* is provided.

nngt.generation.**connect_neural_types**(*network*, *source_type*, *target_type*, *graph_model*, *model_param*)

Function to connect excitatory and inhibitory population with a given graph model.

Parameters

- **network** (`Network` or `SpatialNetwork`) – The network to connect.
- **source_type** (*int*) – The type of source neurons (`1` for excitatory, "-1 for inhibitory neurons).
- **source_type** (*int*) – The type of target neurons.
- **graph_model** (*string*) – The name of the connectivity model (among "erdos_renyi", "random_scale_free", "price_scale_free", and "newman_watts").
- **model_param** (*dict*) – Dictionary containing the model parameters (the keys are the keywords of the associated generation function — see above).

nngt.generation.**connect_neural_groups**(*network*, *source_groups*, *target_groups*, *graph_model*, *model_param*)

Function to connect excitatory and inhibitory population with a given graph model.

Parameters

- **network** (`Network` or `SpatialNetwork`) – The network to connect.
- **source_groups** (*tuple of strings*) – Names of the source groups (which contain the presynaptic neurons)
- **target_groups** (*tuple of strings*) – Names of the target groups (which contain the postsynaptic neurons)
- **graph_model** (*string*) – The name of the connectivity model (among "erdos_renyi", "random_scale_free", "price_scale_free", and "newman_watts").
- **model_param** (*dict*) – Dictionary containing the model parameters (the keys are the keywords of the associated generation function — see above).

7.6 Lib module

7.6.1 Lib module

Errors	
InvalidArgument	Argument passed to the function are not valid

7.7 Properties module

7.7.1 Properties module

Classes	
NeuralPop	Contains neuron populations and their properties
ConnectionsProp	Properties of the connections between neurons
PopIntructions	Instructions to build a population of neurons

CHAPTER 8

Overview

The Neural Network Growth and Topology (NNGT) module provides tools to grow and study detailed biological networks by interfacing efficient graph libraries with highly distributed activity simulators.

CHAPTER 9

Main classes

NNGT uses four main classes:

Graph provides a simple implementation over graphs objects from graph libraries (namely the addition of a name, management of detailed nodes and connection properties, and simple access to basic graph measurements).

SpatialGraph a Graph embedded in space (neurons have positions and connections are associated to a distance)

Network provides more detailed characteristics to emulate biological neural networks, such as classes of inhibitory and excitatory neurons, synaptic properties...

SpatialNetwork combines spatial embedding and biological properties

CHAPTER 10

Generation of graphs

Structured connectivity: connectivity between the nodes can be chosen from various well-known graph models

Populations: populations of neurons are distributed afterwards on the structured connectivity, and can be set to respect various constraints (for instance a given fraction of inhibitory neurons and synapses)

Synaptic properties: synaptic weights and delays can be set from various distributions or correlated to edge properties

CHAPTER 11

Interacting with NEST

The generated graphs can be used to easily create complex networks using the NEST simulator, on which you can then simulate their activity.

CHAPTER 12

Indices and tables

- genindex
- modindex
- search

n