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TVB-multiscale:

interfacing TVB with NEST spiking networks for multiscale co-simulation

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BRAIN
SIMULATION
SECTION

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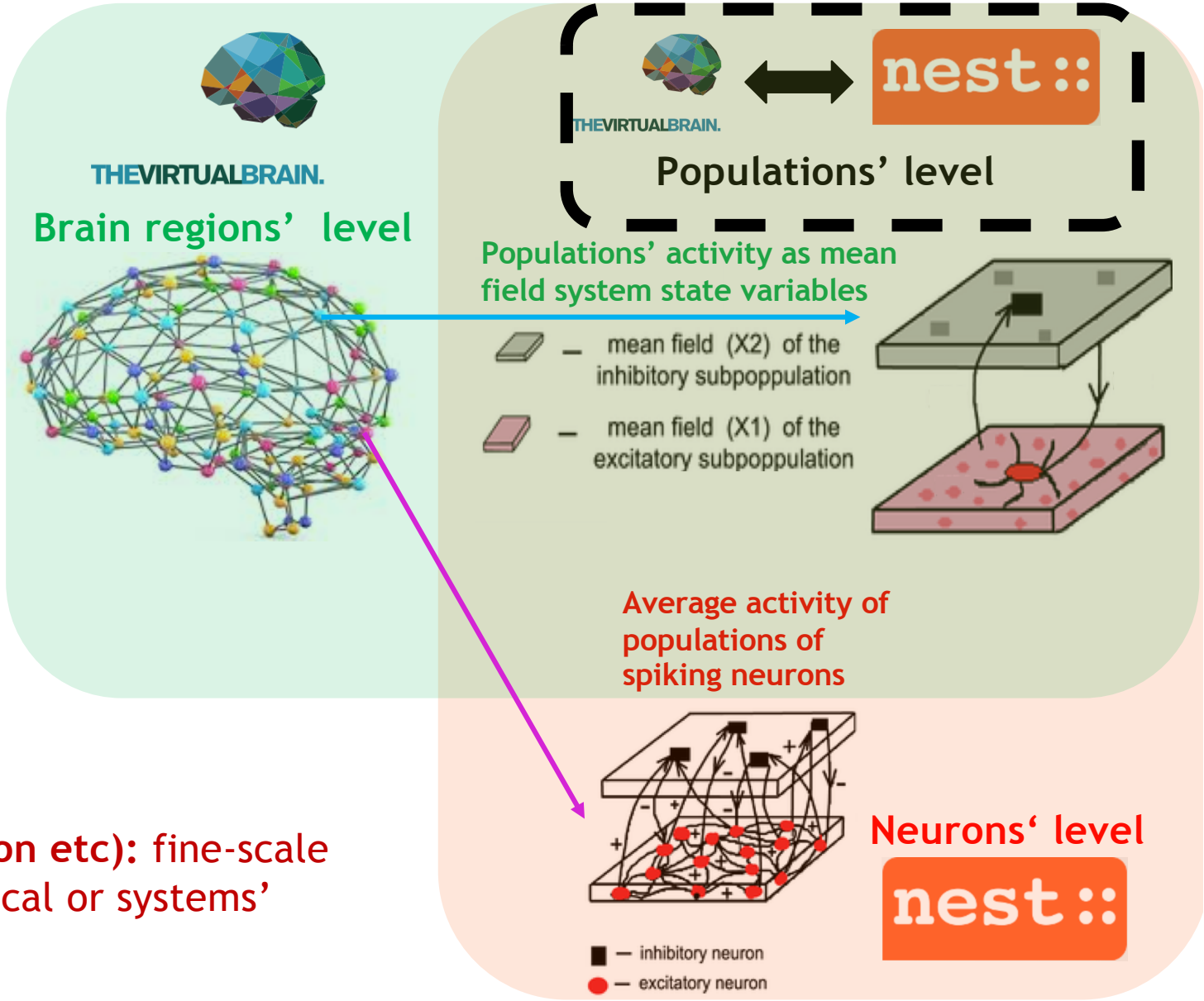
Motivation

TVB: large-scale simulation linking brain anatomical data ((d)MRI, CT etc) to neuroimaging data, by generating virtual neural source activity.

Spiking simulators (NEST, Neuron etc): fine-scale simulation for investigation of local or systems' neural mechanisms



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Software structure

- ***TVB-multiscale/tvb_multiscale:*** extends TVB to perform multiscale co-simulation.
  - spiking_models: region_node, devices, network, and their builders
  - interfaces: tvb_to_spikeNet, spikeNet_to_tvb, and their builders
  - tvb/simulator_builder
  - plot, io (read/write to/from .h5 files),
- ***TVB-multiscale/tvb_nest:*** Python interface of TVB with (Py)NEST, for co-simulation of TVB and NEST models.
  - nest_models: region_node, devices, network, their builders, builders of specific models
  - interfaces: tvb_to_nest, nest_to_tvb, their builders, builders of specific models
- ***TVB-multiscale/tvb_elephant:***
  - spike_stimulus_builder
- docker, examples, tests, docs, tvb_utils (utility scripts)

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Default workflow

1. Setup configuration
   (min_delay, integration time resolution etc)
2. Build TVB model and simulator
   (connectivity, model, coupling, integrator, monitors etc)
3. Build Spiking Network model
   (neural populations, stimulation and measuring devices)
3. Build interfaces
4. (Co-)Simulate
5. Gather results, analyze, plot, write to .h5 files

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EBRAINS collaboratory

- Co-Simulation The Virtual Brain Multiscale

jupyter documentation_example Last Checkpoint: 6 minutes ago (autosaved)

Logout Control Panel

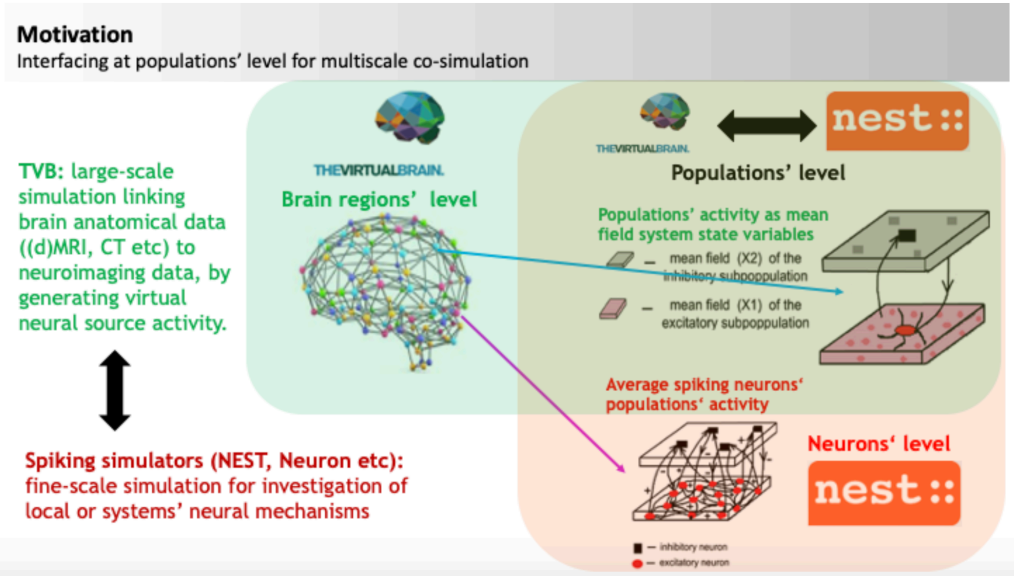
File Edit View Insert Cell Kernel Help Not Trusted Python 3

Run Markdown

TVB-NEST: Bridging multiscale activity by co-simulation

Step-by-step learn how to perform a co-simulation embedding spiking neural networks into large-scale brain networks using TVB.

```
In [1]: from IPython.core.display import Image, display
        display(Image(filename='./ConceptGraph1.png',  width=1000, unconfined=False))
```

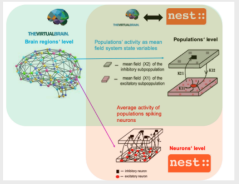


Co-Simulation The Virtual Brain Multiscale

Last modified by Lia Domide on 2020/06/26 22:21

https://wiki.ebrains.eu/bin/view/Collabs/the-virtual-brain-multiscale/

TVB Co-Simulation



Multiscale: TVB - NEST

Authors: D. Perdikis, L. Domide, J. Mersmann, M. Schirner, P. Ritter

For more details on TVB itself, check this: https://wiki.ebrains.eu/bin/view/Collabs/the-virtual-brain/

Contents

- TVB Co-Simulation
  - Use our Jupyter Hub setup online

Use our Jupyter Hub setup online

https://tvb-nest.apps.hbp.eu/user/dionperd/notebooks/TVB-NEST-Examples/documentation_example.ipynb

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TVB-multiscale on EBRAINS collaboratory

❖ **Use case in EBRAINS Collaboratory:**

- 1 excitatory (E) and 1 inhibitory (I) population per region node
- Coarse-scale MF nodes in TVB with a reduced Wong-Wang model
- fine-scale spiking networks SP nodes with a Wong-Wang like spiking neuron model programmed in NEST

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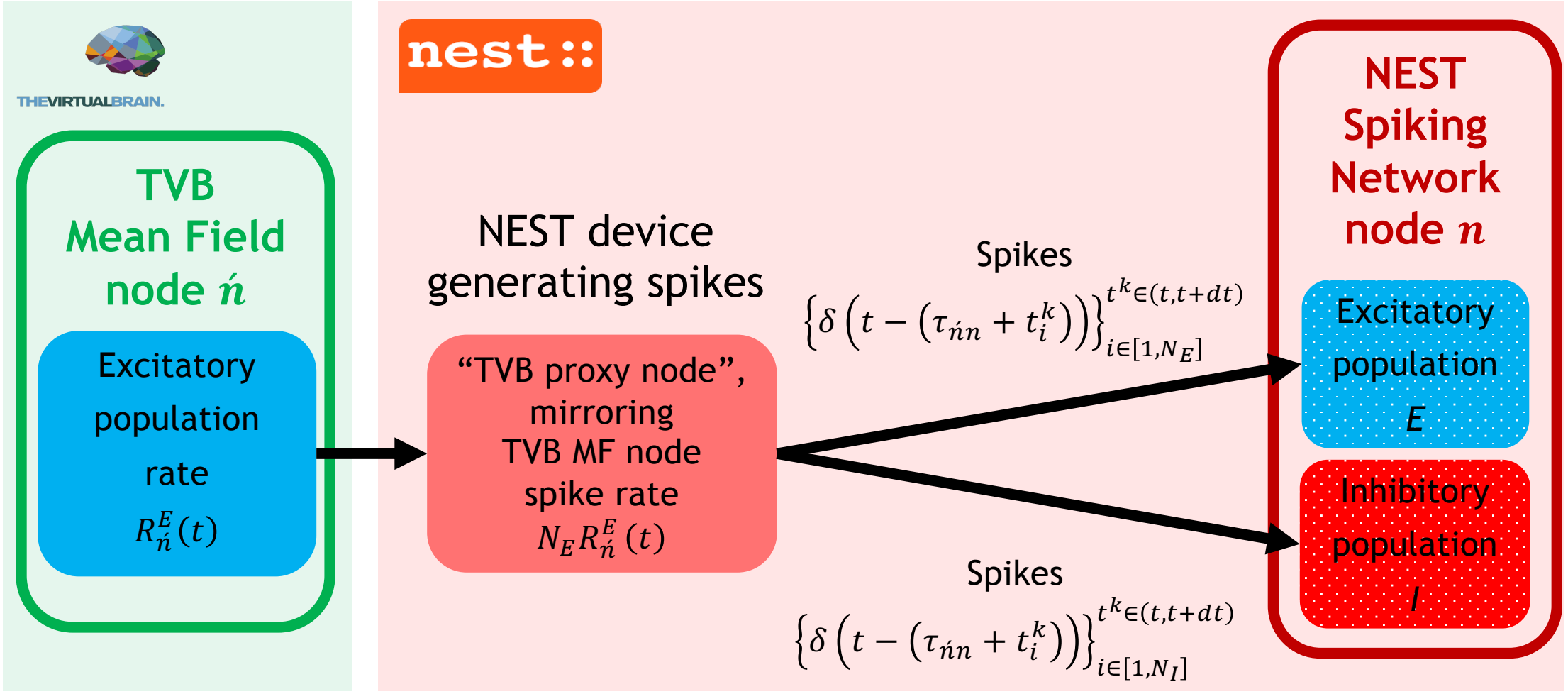
Use case

TVB to NEST coupling via TVB "proxy" nodes: spike rate



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Use case

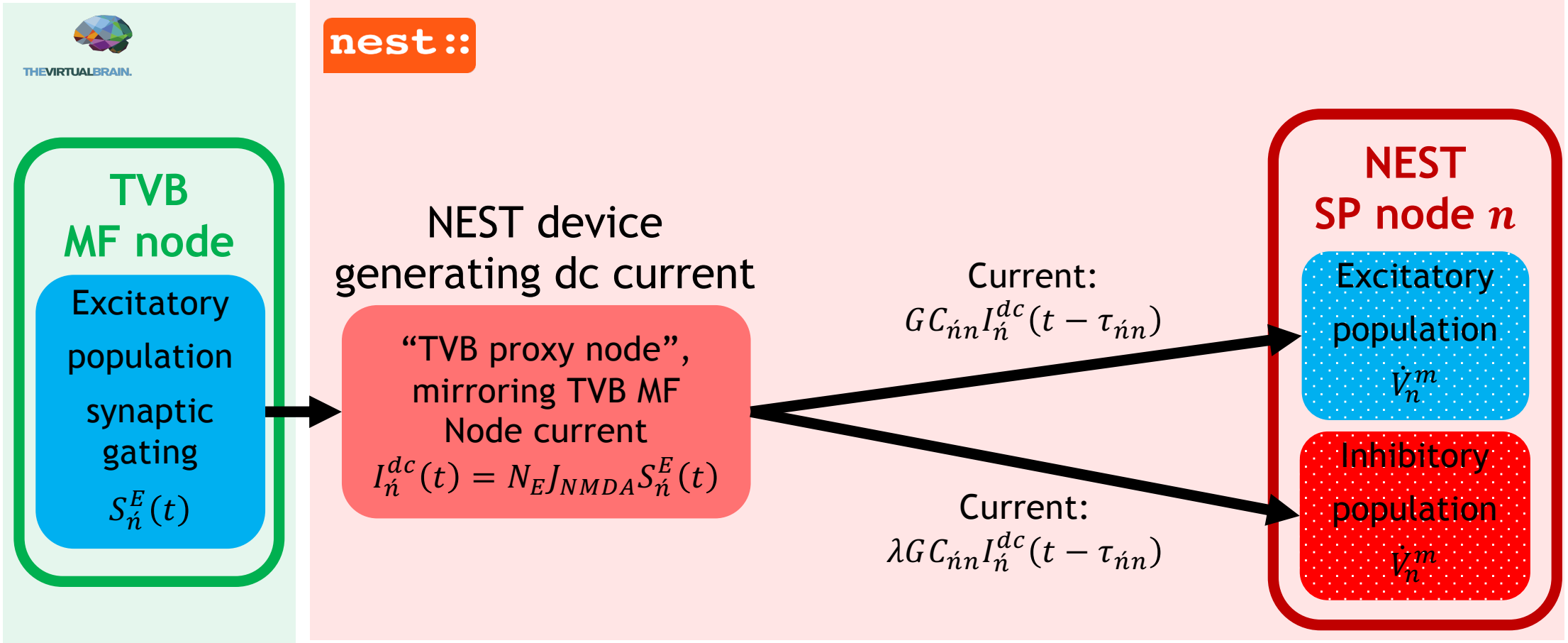
TVB to NEST coupling via TVB "proxy" nodes: spike rate

```
# For spike transmission from TVB to NEST devices acting as TVB proxy nodes with TVB delays:

tvb_nest_builder.tvb_to_nest_interfaces = [
    {"model": "inhomogeneous_poisson_generator",
     "params": {"allow_offgrid_times": False},
# # ---------Properties potentially set as function handles with args (nest_node_id=None)---------------
     "interface_weights": 1.0 * N_E/10,
# Applied outside NEST for each interface device
# -------Properties potentially set as function handles with args (tvb_node_id=None, nest_node_id=None)-
#   To multiply TVB connectivity weight:
    "weights": lambda tvb_node_id, nest_node_id:
                random_normal_tvb_weight(tvb_node_id, nest_node_id,
                                         tvb_nest_builder.tvb_model.G[0]*
                                         tvb_nest_builder.tvb_weights,
                                         sigma=0.1),
#                                       To add to TVB connectivity delay:
    "delays": lambda tvb_node_id, nest_node_id:
                tvb_delay(tvb_node_id, nest_node_id, tvb_nest_builder.tvb_delays),
    "receptor_types": lambda tvb_node_id, nest_node_id:
                          receptor_by_source_region(tvb_node_id, nest_node_id, start=1),
    # ------------------------------------------------------------------------------------------
    #              TVB sv -> NEST population
    "connections": {"R_e": ["E"]},
    "source_nodes": None, "target_nodes": None}]  # None means all here
```

Use case

TVB to NEST coupling via TVB "proxy" nodes: current



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Use case

TVB to NEST coupling via TVB "proxy" nodes: current

```
# For injecting current to NEST neurons via dc generators acting as TVB proxy nodes with TVB delays:
tvb_nest_builder.tvb_to_nest_interfaces = [
    {"model": "dc_generator", "params": {},
# ---------Properties potentially set as function handles with args (nest_node_id=None)----------------
#   Applied outside NEST for each interface device
     "interface_weights": 1.0 * N_E,
# -------Properties potentially set as function handles with args (tvb_node_id=None, nest_node_id=None)-
#    To multiply TVB connectivity weight:
     "weights": lambda tvb_node_id, nest_node_id:
                        random_normal_tvb_weight(tvb_node_id, nest_node_id,
                                                 simulator.model.G[0]*
                                                 tvb_nest_builder.tvb_weights,
                                                 sigma=sigma),
#    To add to TVB connectivity delay:
     "delays": lambda tvb_node_id, nest_node_id:
                      tvb_delay(tvb_node_id, nest_node_id, tvb_nest_builder.tvb_delays),
# ------------------------------------------------------------------------------------------------
#    TVB sv -> NEST population
     "connections": {"S_e": ["E"]},
     "source_nodes": None, "target_nodes": None}]  # None means all here
```

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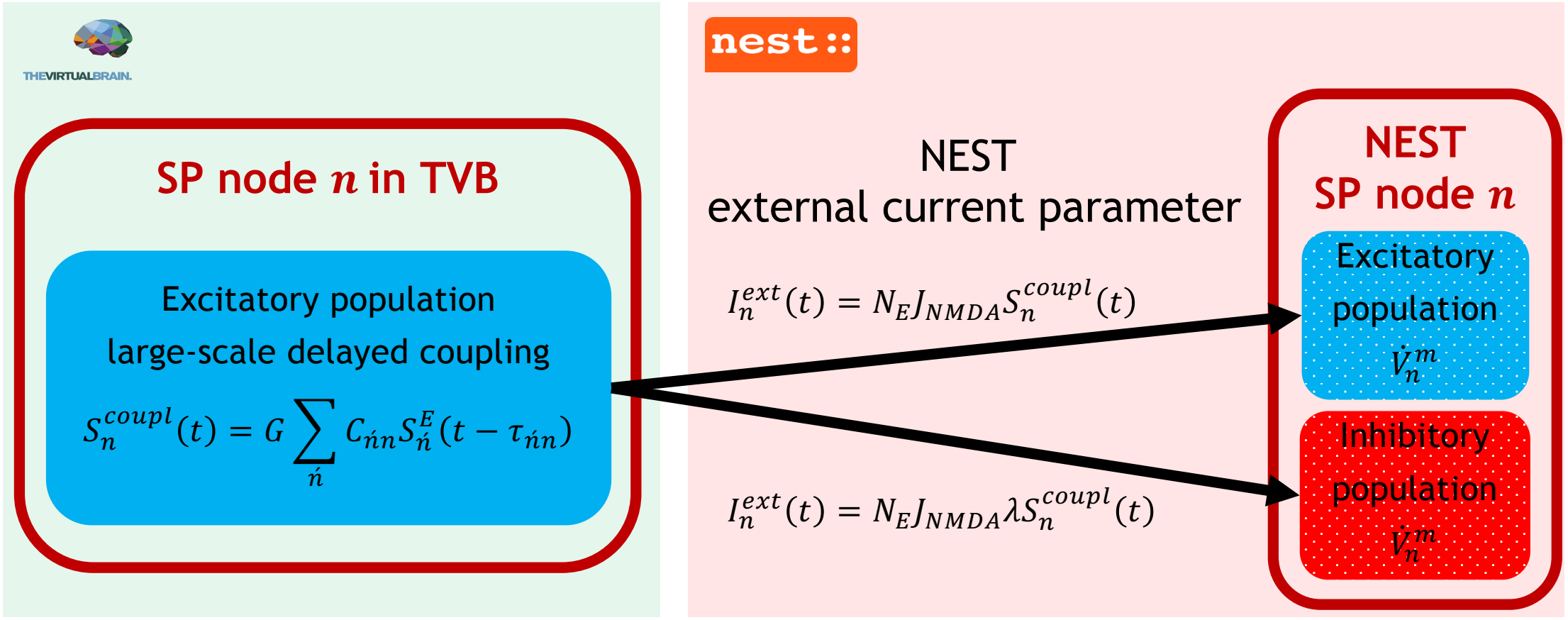
Use case

TVB to NEST coupling via direct parameter update



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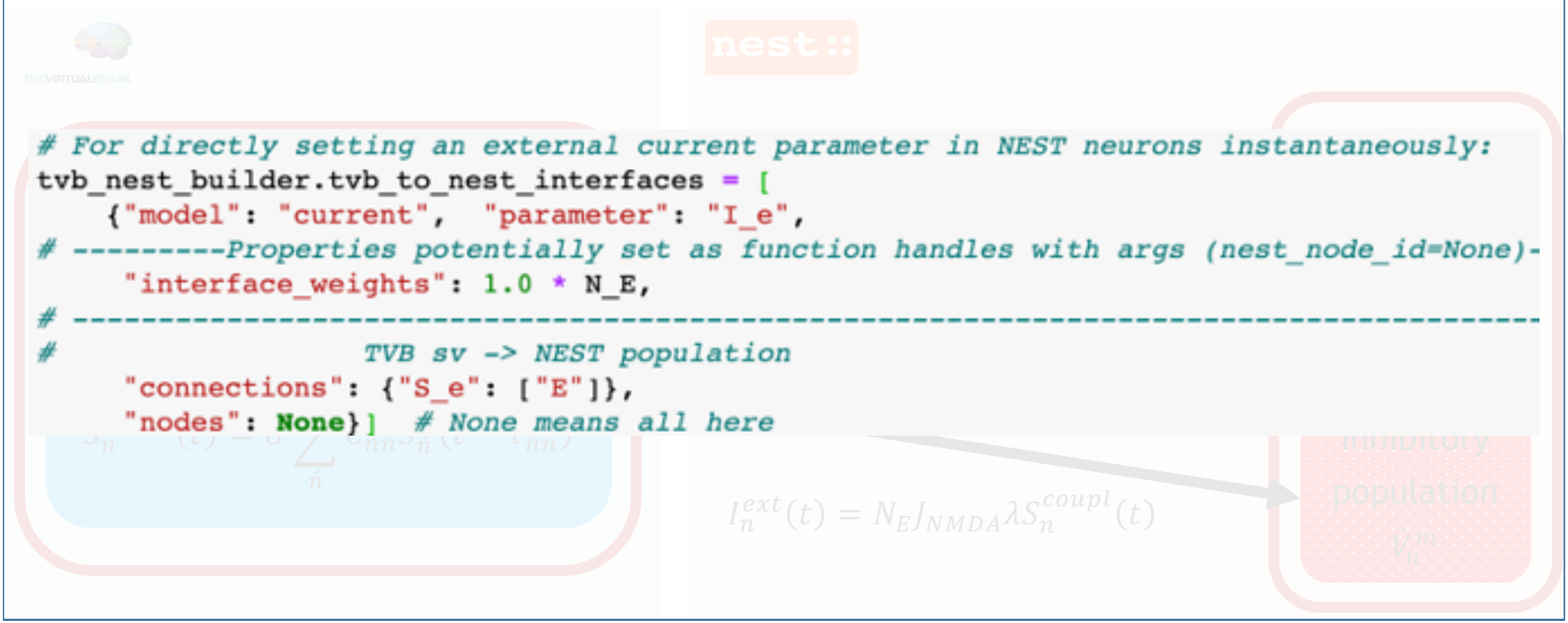
Use case

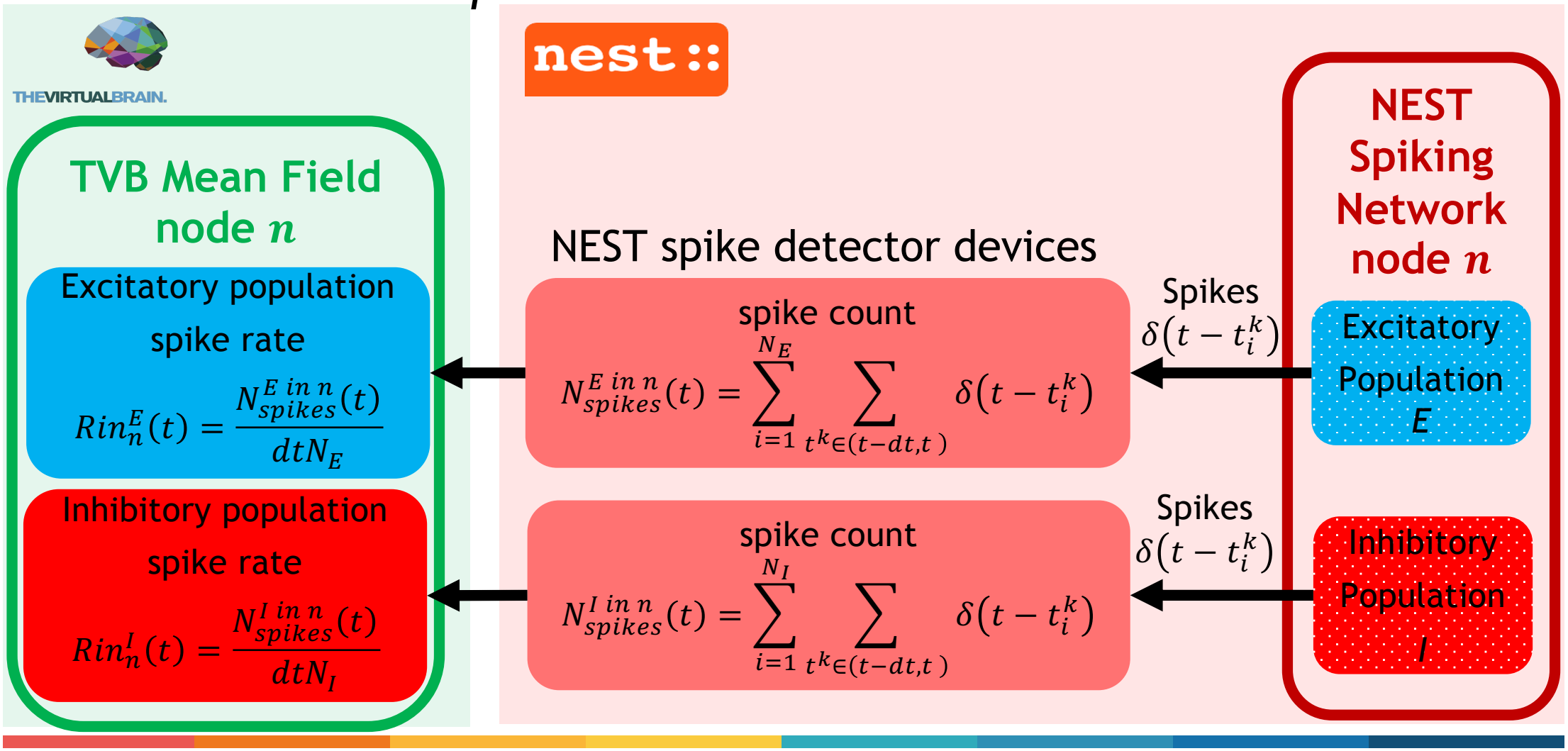
TVB to NEST coupling via direct parameter update

```
# For directly setting an external current parameter in NEST neurons instantaneously:
tvb_nest_builder.tvb_to_nest_interfaces = [
    {"model": "current",  "parameter": "I_e",
# ---------Properties potentially set as function handles with args (nest_node_id=None)-
     "interface_weights": 1.0 * N_E,
# ------------------------------------------------------------------------------------
#                    TVB sv -> NEST population
     "connections": {"S_e": ["E"]},
     "nodes": None}]  # None means all here
```



Use case

NEST to TVB update



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Use case

NEST to TVB update

```
# NEST -> TVB:
# Use S_e and S_i instead of r_e and r_i
# for transmitting to the TVB state variables directly
connections = OrderedDict()
#             TVB <- NEST
connections["R_e"] = ["E"]
connections["R_i"] = ["I"]
tvb_nest_builder.nest_to_tvb_interfaces = [
    {"model": "spike_detector", "params": {},
# ------------------Properties potentially set as function handles with args (nest_node_id=None)--
     "weights": 1.0, "delays": 0.0,
# -----------------------------------------------------------------------------------------------
     "connections": connections, "nodes": None}]  # None means all here
```

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Use case

NEST network builder: define neural populations

```
# Populations' configurations
# When any of the properties model, params and scale below depends on regions,
# set a handle to a function with
# arguments (region_index=None) returning the corresponding property
nest_model_builder.default_population["model"] = "aeif_cond_beta_multisynapse"
nest_model_builder.populations = [
    {"label": "E", "model": nest_model_builder.default_population["model"],
     "nodes": None,  # None means "all"
     "params": nest_model_builder.params_ex,
     "scale": exc_pop_scale},
    {"label": "I", "model": nest_model_builder.default_population["model"],
     "nodes": None,  # None means "all"
     "params": nest_model_builder.params_in,
     "scale": 1.0}
  ]
```

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Use case

NEST network builder: define connections within regions

```
# Within region-node connections
# When any of the properties model, conn_spec, weight, delay, receptor_type below
# set a handle to a function with
# arguments (region_index=None) returning the corresponding property
nest_model_builder.populations_connections = [
     #              ->
    {"source": "E", "target": "E",  # E -> E This is a self-connection for population "E"
     "model": nest_model_builder.default_populations_connection["model"],
     "conn_spec": nest_model_builder.default_populations_connection["conn_spec"],
     "weight": nest_model_builder.tvb_model.w_p[0],
     "delay": nest_model_builder.default_populations_connection["delay"],
     "receptor_type": 1, "nodes": None},  # None means "all"
```

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Use case

NEST network builder: define connections among regions

```
nest_model_builder.nodes_connections = [
    #                ->
    {"source": "E", "target": ["E"],
     "model": nest_model_builder.default_nodes_connection["model"],
     "conn_spec": nest_model_builder.default_nodes_connection["conn_spec"],
   #  weight scaling the TVB connectivity weight
     "weight": lambda source_node, target_node:
                 scale_tvb_weight(source_node, target_node,
                                  nest_model_builder.tvb_weights, scale=nest_model_builder.tvb_model.G[0]),
   # additional delay to the one of TVB connectivity
     "delay": lambda source_node, target_node:
                 tvb_delay(source_node, target_node, nest_model_builder.tvb_delays),
    # Each region emits spikes in its own port:
     "receptor_type": lambda source_region_index, target_region_index=None:
                         receptor_by_source_region(source_region_index, target_region_index, start=3),
     "source_nodes": None, "target_nodes": None}  # None means "all"
    ]
```

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Use case

NEST network builder: stimulus input devices

```
# Create a spike stimulus input device
nest_model_builder.input_devices = [
    {"model": "poisson_generator",
     "params": {"rate": 2400.0, "origin": 0.0, "start": 0.1},
     "connections": {"Stimulus": ["E", "I"]},
     "nodes": None,          # None means apply to all
     "weights": w_E,
     "delays": {"distribution": "uniform",
                "low": nest_model_builder.tvb_dt,
                "high": 2*nest_model_builder.tvb_dt},
     "receptor_type": lambda target_node: int(target_node + 1)}
                                          ]  #
```

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Use case

NEST network builder: output measuring devices

```
# Creating  devices to be able to observe NEST activity:
# Labels have to be different
nest_model_builder.output_devices = []
connections = OrderedDict({})
#          label <- target population
connections["E"] = "E"
connections["I"] = "I"
nest_model_builder.output_devices.append(
    {"model": "spike_detector", "params": {},
     "connections": connections, "nodes": None})  # None means "all"

connections = OrderedDict({})
#               label    <- target population
connections["Excitatory"] = "E"
connections["Inhibitory"] = "I"
params = dict(nest_model_builder.config.NEST_OUTPUT_DEVICES_PARAMS_DEF["multimeter"])
params["interval"] = nest_model_builder.nest_instance.GetKernelStatus("resolution")  #
params['record_from'] = ["V_m"]
nest_model_builder.output_devices.append(
    {"model": "multimeter", "params": params,
     "connections": connections, "nodes": None})  # None means "all"
```

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Modifications to the TVB simulator

- TVB-SpikeNet interface properties and configurations
- Dynamical non-state variables (e.g. $R_{\acute{n}}^{E/I}(t)$) that need to be updated in a model specific manner after integration of each time step
- Model specific modifications (e.g. $Rin_{\acute{n}}^{E/I}(t)$ variables to smooth instantaneous spike rate coming from NEST via linear integration acting as a low pass filter)

- Integration loop
  1. TVB to SpikeNet coupling
  2. TVB integration

     SpikeNet integration
  3. (Optional) SpikeNet to TVB update
  4. Compute TVB large-scale coupling and update stimulus, if any
  5. Update non-state dynamical variables (if any)
  6. Update TVB history buffer
  7. Generate TVB monitor outputs

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References

1. Ritter P, Schirner M, McIntosh AR, Jirsa VK. 2013. The Virtual Brain integrates computational modeling and multimodal neuroimaging. Brain Connectivity 3:121–145.

2. Sanz Leon P, Knock SA, Woodman MM, Domide L, Mersmann J, McIntosh AR, Jirsa V. 2013. The Virtual Brain: a simulator of primate brain network dynamics. Frontiers in Neuroinformatics 7:10.

3. Jordan, Jakob, Mørk, Håkon, Vennemo, Stine Brekke, Terhorst, Dennis, Peyser, Alexander, Ippen, Tammo, … Plesser, Hans Ekkehard. (2019, June 27). NEST 2.18.0 (Version 2.18.0). Zenodo.

4. Deco G, Ponce-Alvarez A, Mantini D, Romani GL, Hagmann P, Corbetta M. 2013. Resting-State Functional Connectivity Emerges from Structurally and Dynamically Shaped Slow Linear Fluctuations. The Journal of Neuroscience 33(27): 11239 –11252.

5. Perdikis D, Schirner M, Diaz-Cortes, M-A, Domide L, Mersmann J, Ritter P (*in prep*).

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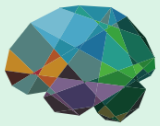
Motivation

TVB: large-scale simulation linking brain anatomical data ((d)MRI, CT etc) to neuroimaging data, by generating virtual neural source activity.



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Brain regions' level

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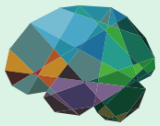
Motivation

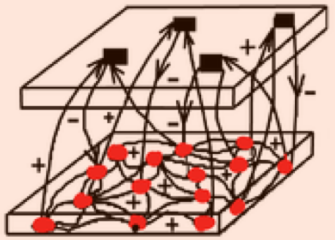
TVB: large-scale simulation linking brain anatomical data ((d)MRI, CT etc) to neuroimaging data, by generating virtual neural source activity.



THEVIRTUALBRAIN.

Brain regions' level

Spiking simulators (NEST, Neuron etc): fine-scale simulation for investigation of local or systems' neural mechanisms



Neurons' level

nest ::

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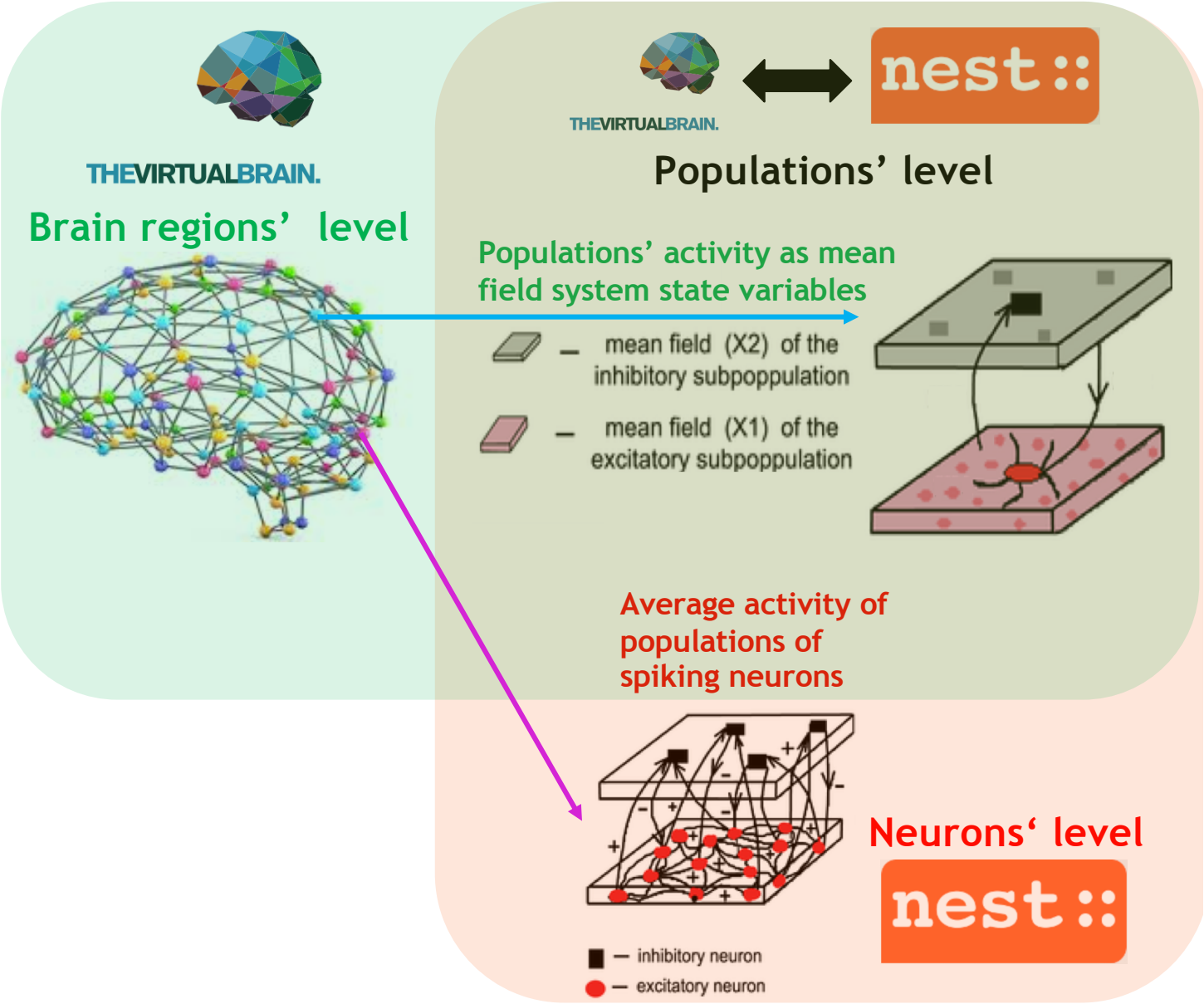
Motivation

TVB-multiscale interfaces for multiscale co-simulation:

- *TVB ➡ Spiking simulators*: Generate biologically realistic spatio-temporal context and large-scale connectivity for local neural networks
- *TVB ⟷ Spiking simulators*: Confirm mean field approximations on large-scale brain statistics (e.g., functional connectivity)



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Benchmarking