Demo: Brain Stimulation Simulation with The Virtual Brain

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Introduction

This demo introduces a `region-based simulation on TVB` with a `stimulus` targeting a cortical brain region.

Setup

In [ ]:
```
%pylab inline

# install TVB locally
# !pip install -U tvb-library
# !pip install tvb-data

# TVB functions
from tvb.simulator.lab import *
from tvb.basic.neotraits.api import NArray, List, Range, Final

# python functions
import os
import numpy as np
import scipy.io as sio
import scipy.signal as sig
import matplotlib.pyplot as plt
import matplotlib
from matplotlib.tri import Triangulation
from mpl_toolkits.mplot3d import Axes3D
```

```
%pylab is deprecated, use %matplotlib inline and import the required libraries.
Populating the interactive namespace from numpy and matplotlib
```

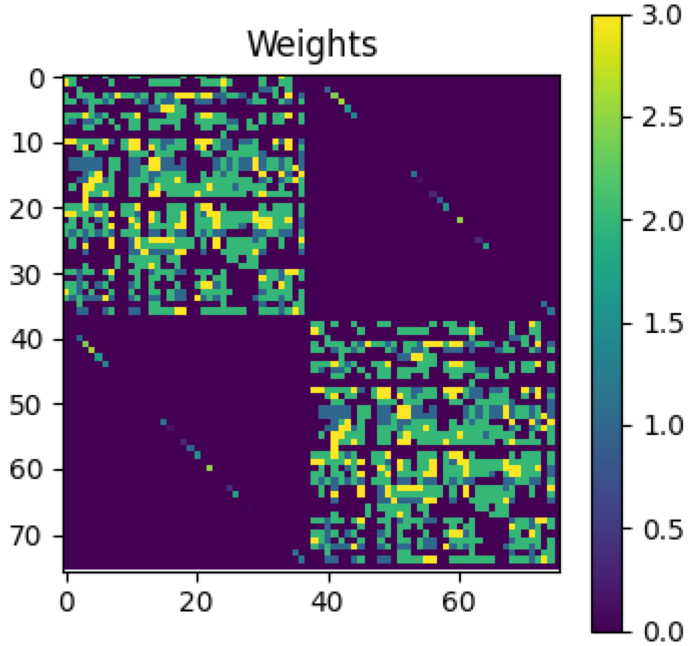
Connectivity

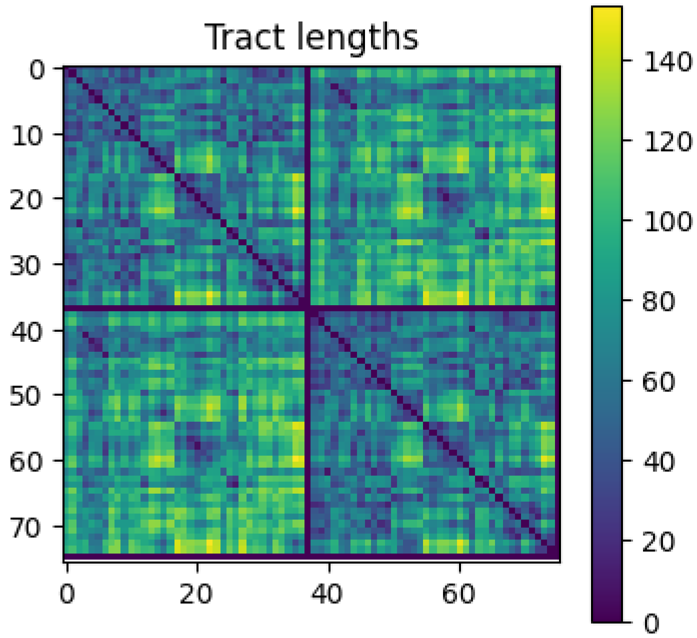
Load connectivity

In [ ]:
```
# default TVB connectivity
conn = connectivity.Connectivity.from_file()
```

```
2024-05-16 10:16:17,492 - WARNING - tvb.basic.readers - File 'hemispheres' not found
in ZIP.
```

In [ ]:
```
# Visualize connectivity
plt.figure(figsize=(4,4))
plt.imshow(conn.weights)
plt.title("Weights")
plt.colorbar()
plt.show()

plt.figure(figsize=(4,4))
plt.imshow(conn.tract_lengths)
plt.title("Tract lengths")
plt.colorbar()
plt.show()
```





Brain regions in the connectivity

In [ ]:
```
# check the regions number
conn.region_labels.shape
```

Out[ ]:
```
(76,)
```

In [ ]:
```
# check the regions list
conn.region_labels
```

Out[ ]:
```
array(['rA1', 'rA2', 'rAMYG', 'rCCA', 'rCCP', 'rCCR', 'rCCS', 'rFEF',
       'rG', 'rHC', 'rIA', 'rIP', 'rM1', 'rPCI', 'rPCIP', 'rPCM', 'rPCS',
       'rPFCCL', 'rPFCDL', 'rPFCDM', 'rPFCM', 'rPFCORB', 'rPFCPOL',
       'rPFCVL', 'rPHC', 'rPMCDL', 'rPMCM', 'rPMCVL', 'rS1', 'rS2',
       'rTCC', 'rTCI', 'rTCPOL', 'rTCS', 'rTCV', 'rV1', 'rV2', 'rCC',
       'lA1', 'lA2', 'lAMYG', 'lCCA', 'lCCP', 'lCCR', 'lCCS', 'lFEF',
       'lG', 'lHC', 'lIA', 'lIP', 'lM1', 'lPCI', 'lPCIP', 'lPCM', 'lPCS',
       'lPFCCL', 'lPFCDL', 'lPFCDM', 'lPFCM', 'lPFCORB', 'lPFCPOL',
       'lPFCVL', 'lPHC', 'lPMCDL', 'lPMCM', 'lPMCVL', 'lS1', 'lS2',
       'lTCC', 'lTCI', 'lTCPOL', 'lTCS', 'lTCV', 'lV1', 'lV2', 'lCC'],
      dtype='<U128')
```

Choose a region

In [ ]:
```python
# select LH primary motor cortex example 'lM1'
conn.region_labels[50]
```

Out[ ]:
```
'lM1'
```

Stimulus

Choose a stimulus weighting

In [ ]:
```python
# number of regions in the connectivity
weighting = numpy.zeros((76, ))

# attribution of a stimulus intensity in the targeted region
weighting[[50]] = 0.1

print(weighting)
```

```
[0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
 0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
 0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.1 0.  0.  0.
 0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
 0.  0.  0.  0. ]
```

Define the stimulus parameters

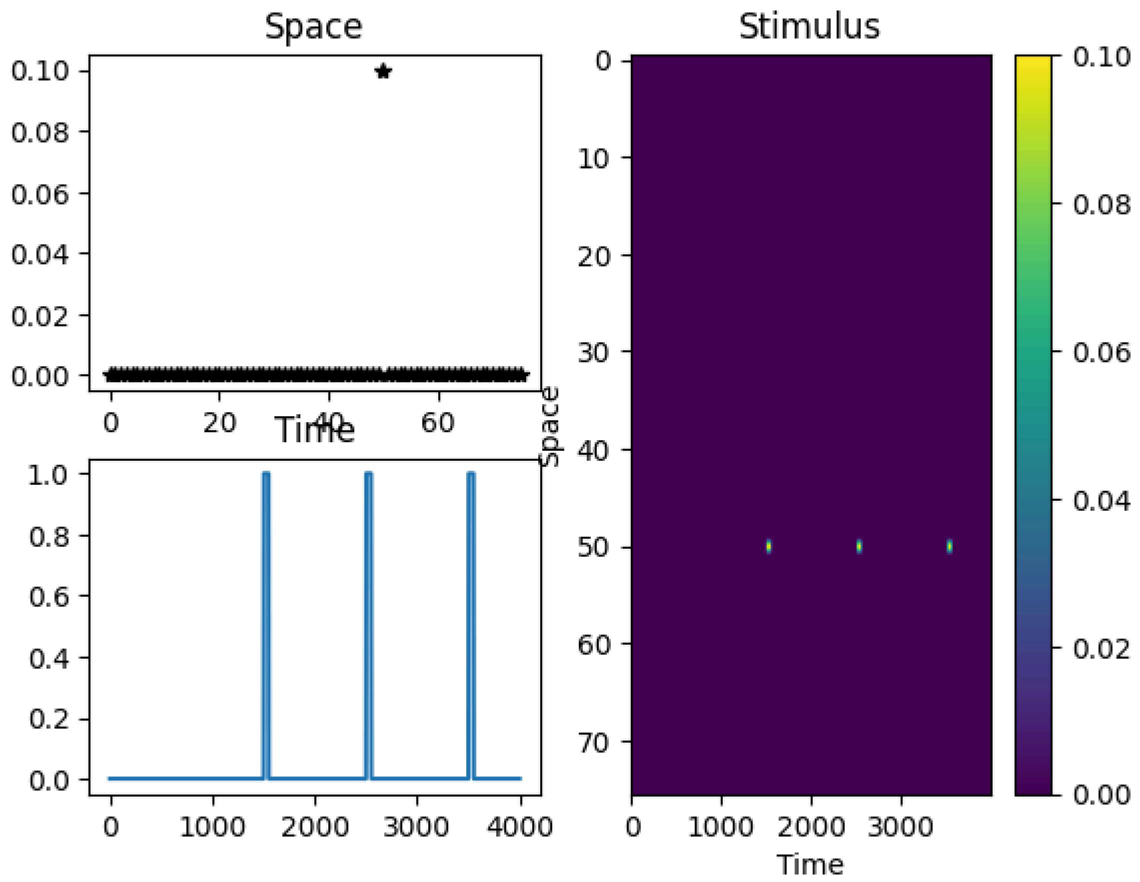
In [ ]:
```python
# Pulse Train type of stimulus: pulse train, offset with respect to the time axis
eqn_t = equations.PulseTrain()

# onset of the stimulus at 1500 ms
eqn_t.parameters['onset'] = 1500

# repetition of the stimulus every 1000 ms
eqn_t.parameters['T'] = 1000.0

# length of the stimulus of 50 ms
eqn_t.parameters['tau'] = 50.0
```

Define the stimulus spatial and temporal components

In [ ]:
```python
stimulus = patterns.StimuliRegion(
    temporal=eqn_t,
    connectivity=conn,
    weight=weighting)
```

Vizualise the stimulus

In [ ]:
```python
# configure space and time
stimulus.configure_space()
stimulus.configure_time(numpy.arange(0., 4e3, 1))

# plot the repetitive pulse train stimulus targetting the region selected
plot_pattern(stimulus)
```



We loaded and defined the parameters of our `connectivity` and `stimulus`.

Let's `run our simulation` now!

Simulation

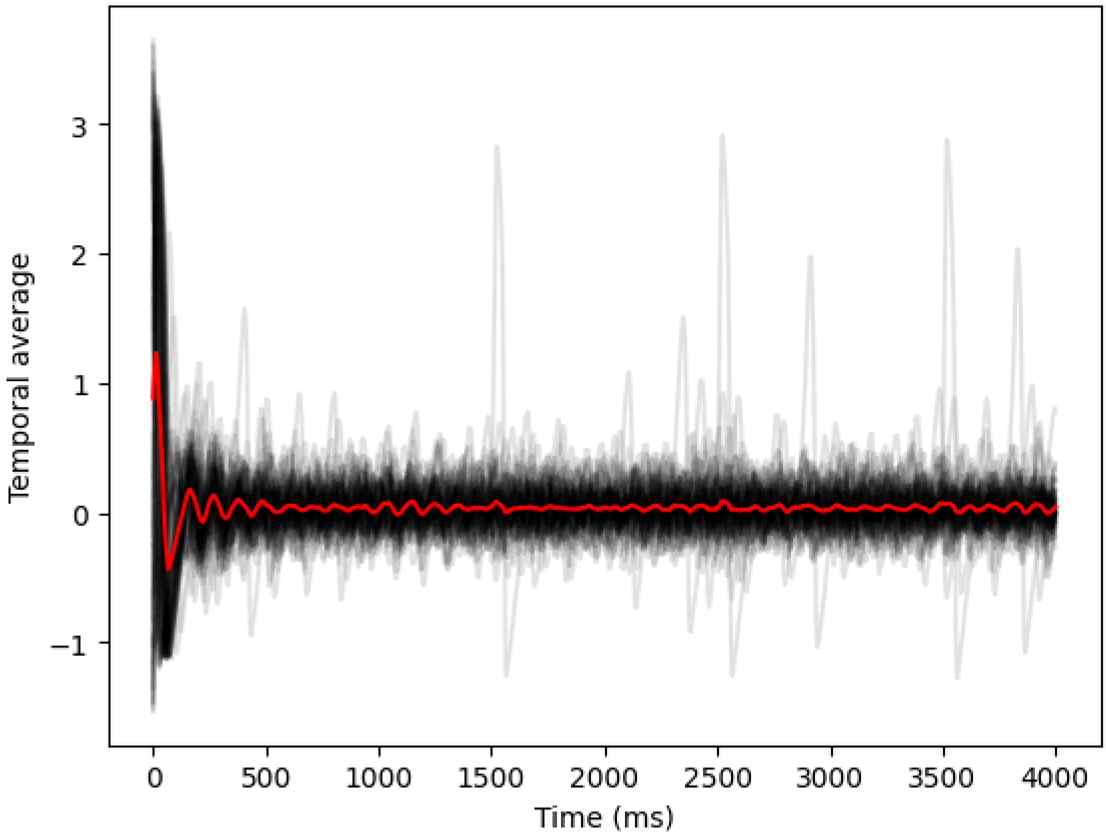
In [ ]:
```
sim = simulator.Simulator(

    model=models.Generic2dOscillator(a=numpy.array([0.3]), tau=numpy.array([2])),
    # dynamic system model describing one neural mass (m=1) with two state variables

    connectivity=conn,
    # connectivity defined previously (here default TVB connectivity)

    coupling=coupling.Difference(a=numpy.array([7e-4])),
    # difference coupling function between pre and post synaptic activity of the form

    integrator=integrators.HeunStochastic(dt=0.5, noise=noise.Additive(nsig=numpy.arr
    # example of a predictor-corrector method with noise addition

    monitors=(
        monitors.TemporalAverage(period=1.0),
    # average of raw time series for each sampling period
        ),

    stimulus=stimulus,
    # implementing the stimulus defined previously

    simulation_length=4e3,
    # length of the simulation in ms

).configure()

(tavg_time, tavg_data),  = sim.run()
```

Plot the results

Time series plot

In [ ]:
```
# propagation of the stimulus in the cortical regions
figure()

# individual region time series superposed in black
plot(tavg_time, tavg_data[:, 0, :, 0], 'k', alpha=0.1)

# time series mean in red
plot(tavg_time, tavg_data[:, 0, :, 0].mean(axis=1), 'r', alpha=1)
ylabel("Temporal average")
xlabel('Time (ms)')
```

Out[ ]:
```
Text(0.5, 0, 'Time (ms)')
```



Visualize the stimulus propagation on the surface brain

Credits to *John Griffiths* for the function to visualise the propagation on the template brain (https://nbviewer.jupyter.org/urls/s3.amazonaws.com/replicating_spiegler2016/replicating_spiegler2016

In [ ]:
```
def plot_surface_mpl(vtx,tri,data=None,rm=None,reorient='tvb',view='superior',
                     shaded=False,ax=None,figsize=(6,4), title=None,
                     lthr=None,uthr=None, nz_thr = 1E-20,
                     shade_kwargs = {'edgecolors': 'k', 'linewidth': 0.1,
                                     'alpha': None, 'cmap': 'coolwarm',
                                     'vmin': None, 'vmax': None}):
  """
  Parameters
  ----------

  vtx            : N vertices x 3 array of surface vertex xyz coordinates

  tri            : N faces x 3 array of surface faces

  data           : array of numbers to colour surface with

  rm             : region mapping - N vertices x 1 array with (up to) N
                   regions unique values; each element specifies which
                   region the corresponding surface vertex is mapped to
```

```
reorient      : modify the vertex coordinate frame and/or orientation
                so that the same default rotations can subsequently be
                used for image views

view          : specify viewing angle

lthr/uthr     : lower/upper thresholds - set to zero any datapoints below /
                above these values

nz_thr        : near-zero threshold - set to zero all datapoints with absolute
                values smaller than this number

shade_kwargs  : dictionary specifiying shading options

ax            : figure axis

figsize       : figure size (ignore if ax provided)

title         : text string to place above figure
"""


vtx,tri = vtx.copy(),tri.copy()
if data is not None: data = data.copy()


                                  # 1. Set the viewing angle

if reorient == 'tvb':
  # TVB default brain coordinates are yxz
  vtx = np.array([vtx[:,1],vtx[:,0],vtx[:,2]]).T.copy()

  # reflect in the x axis
  vtx[:,0]*=-1

  # rotations for standard view options
if   view == 'lh_lat'    : rots =  [(0,-90),(1,90)  ]
elif view == 'lh_med'    : rots =  [(0,-90),(1,-90) ]
elif view == 'rh_lat'    : rots =  [(0,-90),(1,-90) ]
elif view == 'rh_med'    : rots =  [(0,-90),(1,90)  ]
elif view == 'superior'  : rots =   None
elif view == 'inferior'  : rots =   (1,180)
elif view == 'anterior'  : rots =   (0,-90)
elif view == 'posterior' : rots =  [(0, -90),(1,180)]
elif (type(view) == tuple) or (type(view) == list): rots = view

  # apply rotations
if rots is None: rotmat = np.eye(3)
else:            rotmat = get_combined_rotation_matrix(rots)
vtx = np.dot(vtx,rotmat)



                                  # 2. Sort out the data


  # no data: plot a vector of 1s
  # region data: create corresponding surface vector
if data is None:
  data = np.ones(vtx.shape[0])
elif data.shape[0] != vtx.shape[0]:
  data = np.array([data[r] for r in rm])

  # apply thresholds
if uthr: data *= (data < uthr)
if lthr: data *= (data > lthr)
data *= (np.abs(data) > nz_thr)
```

```
                                        # 3. Create the surface triangulation object

  x,y,z = vtx.T
  tx,ty,tz = vtx[tri].mean(axis=1).T
  tr = Triangulation(x,y,tri[np.argsort(tz)])


                                        # 4. Make the figure

  if ax is None: fig, ax = plt.subplots(figsize=figsize)
  tc = ax.tripcolor(tr, np.squeeze(data), **shade_kwargs)

  ax.set_aspect('equal')
  ax.axis('off')

  if title is not None: ax.set_title(title)


def get_combined_rotation_matrix(rotations):
  '''Return a combined rotation matrix from a dictionary of rotations around
     the x,y,or z axes'''
  rotmat = np.eye(3)

  if type(rotations) is tuple: rotations = [rotations]
  for r in rotations:
    newrot = get_rotation_matrix(r[0],r[1])
    rotmat = np.dot(rotmat,newrot)
  return rotmat


def get_rotation_matrix(rotation_axis, deg):

  '''Return rotation matrix in the x,y,or z plane'''
  th = -deg * (pi/180) # convert degrees to radians

  if rotation_axis == 0:
    return np.array( [[    1,         0,         0    ],
                      [    0,      cos(th),   -sin(th)],
                      [    0,      sin(th),    cos(th)]])
  elif rotation_axis ==1:
    return np.array( [[   cos(th),    0,        sin(th)],
                      [    0,         1,         0    ],
                      [  -sin(th),    0,        cos(th)]])
  elif rotation_axis ==2:
    return np.array([[   cos(th),  -sin(th),     0    ],
                     [    sin(th),    cos(th),     0    ],
                     [     0,         0,          1    ]])
```

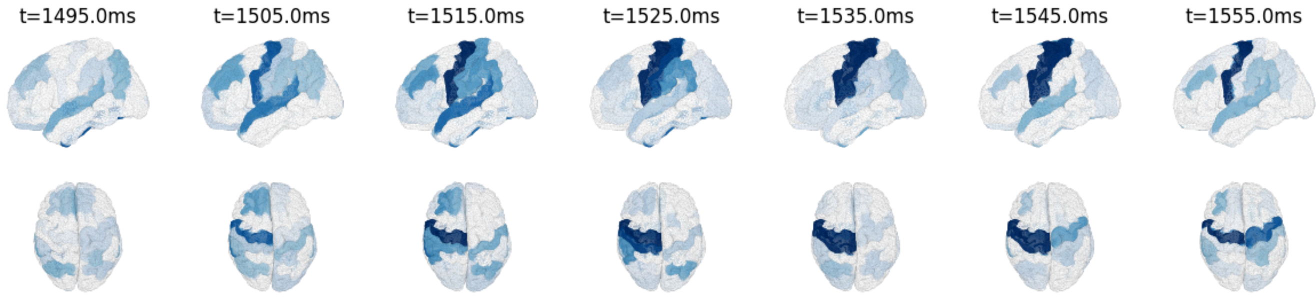
Mapping regions on the respective space on the surface

The `initial stimulus` is on between [1500,1550] ms.

We will plot the `evolution of the propagation of this initial stimulus on the brain surface`.

In [ ]:
```
import copy
ctx = cortex.Cortex.from_file()
# object Cortex: mesh surface defining 2D representation of convoluted cortical surfa

ctx.region_mapping_data.connectivity=conn

vtx,tri,rm = ctx.vertices,ctx.triangles,ctx.region_mapping
# vtx: vertices
# tri: triangles
# rm: region mapping
```

```python
fig, ax = plt.subplots(ncols=7, nrows=2,figsize=(15,3))
#cmap = cm.Blues
cmap = copy.copy(mpl.cm.get_cmap("Blues"))
cmap.set_under(color='w')
kws = {'edgecolors': 'k', 'vmin': 0.1, 'cmap': cmap,
       'vmax': 0.6, 'alpha': None, 'linewidth': 0.01}

ts = [1495, 1505, 1515, 1525, 1535, 1545, 1555]

# time states to plot

for t_it,t in enumerate(ts):

    dat = np.absolute(tavg_data[t, 0, :, 0])

    plot_surface_mpl(vtx=vtx, tri=tri,data=dat,rm=rm,ax=ax[0][t_it],
                     shade_kwargs=kws,
                     view='lh_lat')   # lateral view

    plot_surface_mpl(vtx=vtx,tri=tri,data=dat,rm=rm,ax=ax[1][t_it],
                     shade_kwargs=kws,
                     view='superior') # above view


    ax[0][t_it].set_title('t=%1.1fms' %t)
```



Conclusion

The left/right `primary motor cortex` region targeted corresponds well to the `area with the highest activity impacted by the initial stimulus` (dark blue).

The `stimulus activity propagation` to other areas (premotor areas, sensory areas) is well visible.

We succeeded to do a brain stimulation simulation with The Virtual Brain!

In [ ]: