Report 4

Computational Neuroscience

Computer Assignment 4

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In [1]:
```
%matplotlib notebook
import torch
import numpy as np
```

In [2]:
```
from cnsproject.network.neural_populations import LIFPopulation
from cnsproject.plotting.plotting import plotting
from cnsproject.utils import noise_function, step_noise_function, incremental_step_noise
_function
from cnsproject.network.monitors import Monitor
from cnsproject.network.connections import Connection, randomNormalConnect, fullyConnect
, randomUniformConnect
```

Global Variables

$time$ parameter shows how often (seconds*scale/dt) we want to run our neuron. dt means with what resolution ($scale$) we want our seconds move forward. Ther will be 3 population which two of them are excitatory an one of thrm is inhibitory. The number of neurons in each population considered 100 neurons.

In [3]:
```
time = 1000
scale = 100
dt = 1
neuron_size = 100
shape_ep1 = (int(neuron_size),)
shape_ep2 = (int(neuron_size),)
shape_ip1 = (int(neuron_size),)
```

Walkthrough

The default implemented model is a normal random connection and heterogeneous population.

First we need to specify the input current.

In [4]:
```
I_ep1 = incremental_step_noise_function(
        time = time, I_value = 20, scale = scale, neuron_size = shape_ep1[0], gap = 5
    )
I_ep2 = incremental_step_noise_function(
        time = time, I_value = 20, scale = scale, neuron_size = shape_ep2[0], gap = 3
    )
I_ip1 = step_noise_function(time = time, I_value = 20, scale = scale, neuron_size = shap
e_ip1[0])
```

Then the 3 population that mentioned before, are created by LIF Population model.

In [5]:
```
ep1 = LIFPopulation(
        shape = shape_ep1, spike_trace = True, additive_spike_trace = True,
        tau_s = 10, trace_scale = 1., is_inhibitory = False,
        learning = False, R = 1, C = 20, threshold = -40, dt = dt
    )
ep2 = LIFPopulation(
        shape = shape_ep2, spike_trace = True, additive_spike_trace = True,
        tau_s = 10, trace_scale = 1., is_inhibitory = False,
        learning = False, R = 1, C = 20, threshold = -40, dt = dt
    )
ip1 = LIFPopulation(
        shape = shape_ip1, spike_trace = True, additive_spike_trace = True,
        tau_s = 10, trace_scale = 1., is_inhibitory = True,
        learning = False, R = 1, C = 20, threshold = -40, dt = dt
    )
```

Here we creat connection between the populations. We have a connection from each excitatory population to the inhibitory population and vice versa. And each excitatory population has a connection with itself.

In [6]:
```
con_ep1_ip1 = Connection(
        pre = ep1, post = ip1, lr = None, weight_decay = 0.0,
        J = 1, tau_s = 10, trace_scale = 1., dt = dt, connectivity= randomNormalConnect,
wmean=20., wstd=5.
    )
con_ep2_ip1 = Connection(
        pre = ep2, post = ip1, lr = None, weight_decay = 0.0,
        J = 1, tau_s = 10, trace_scale = 1., dt = dt, connectivity= randomNormalConnect,
wmean=20., wstd=5.
    )
con_ip1_ep1 = Connection(
        pre = ip1, post = ep1, lr = None, weight_decay = 0.0,
        J = 1, tau_s = 10, trace_scale = 1., dt = dt, connectivity= randomNormalConnect,
wmean=20., wstd=5.
    )
con_ip1_ep2 = Connection(
        pre = ip1, post = ep2, lr = None, weight_decay = 0.0,
        J = 1, tau_s = 10, trace_scale = 1., dt = dt, connectivity= randomNormalConnect,
wmean=20., wstd=5.
    )
con_ep1_ep1 = Connection(
        pre = ep1, post = ep1, lr = None, weight_decay = 0.0,
        J = 1, tau_s = 10, trace_scale = 1., dt = dt, connectivity= randomNormalConnect,
wmean=20., wstd=5.
    )
con_ep2_ep2 = Connection(
        pre = ep2, post = ep2, lr = None, weight_decay = 0.0,
        J = 1, tau_s = 10, trace_scale = 1., dt = dt, connectivity= randomNormalConnect,
wmean=20., wstd=5.
    )
```

For each population we need to configure a monitor.

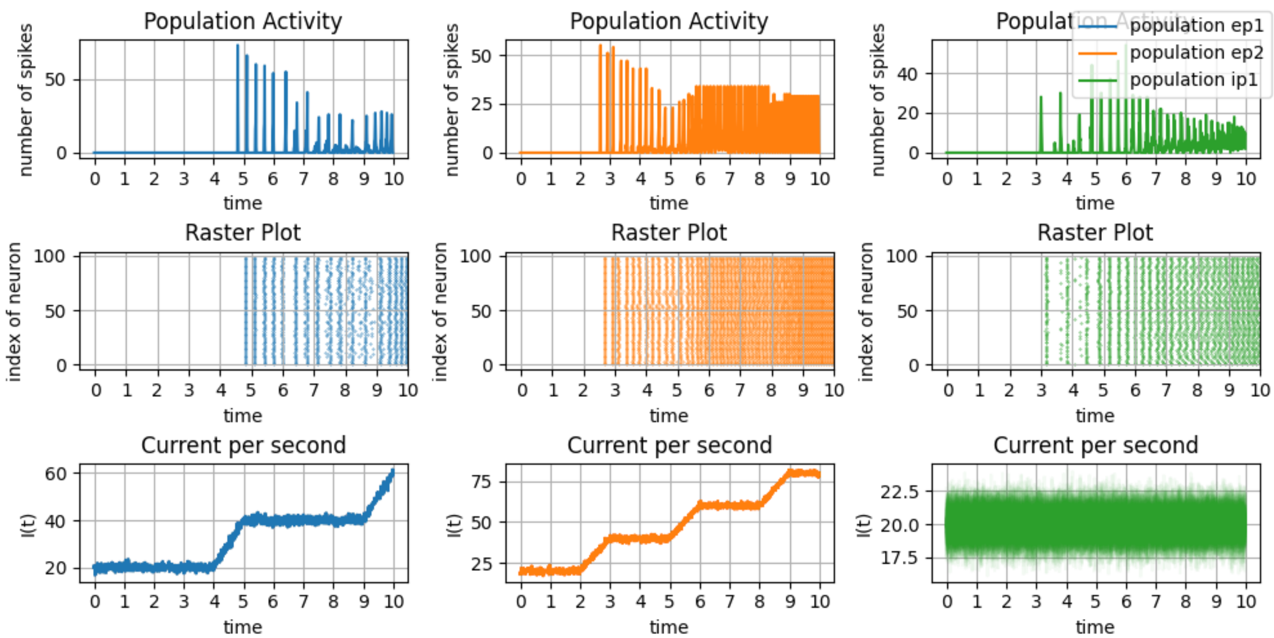
In [7]:
```
monitor_ep1 = Monitor(ep1, state_variables=["s", "u"])
monitor_ep1.set_time_steps(time, dt)
monitor_ep1.reset_state_variables()

monitor_ep2 = Monitor(ep2, state_variables=["s", "u"])
monitor_ep2.set_time_steps(time, dt)
monitor_ep2.reset_state_variables()

monitor_ip1 = Monitor(ip1, state_variables=["s", "u"])
monitor_ip1.set_time_steps(time, dt)
monitor_ip1.reset_state_variables()
```

At a time, each population will forward its current and then compute its effect in each connection.

In [8]:
```
out_ep1_ip1 = 0
out_ep2_ip1 = 0
out_ip1_ep1 = 0
out_ip1_ep2 = 0
out_ep1_ep1 = 0
out_ep2_ep2 = 0
for i in range(time):
    ep1.forward(I_ep1[i] - out_ip1_ep1 + out_ep1_ep1)
    ep2.forward(I_ep2[i] - out_ip1_ep2 + out_ep2_ep2)
    ip1.forward(I_ip1[i] + out_ep1_ip1 + out_ep2_ip1)
    out_ep1_ip1 = con_ep1_ip1.compute()
    out_ep2_ip1 = con_ep2_ip1.compute()
    out_ip1_ep1 = con_ip1_ep1.compute()
    out_ip1_ep2 = con_ip1_ep2.compute()
    out_ep1_ep1 = con_ep1_ep1.compute()
    out_ep2_ep2 = con_ep2_ep2.compute()
    monitor_ep1.record()
    monitor_ep2.record()
    monitor_ip1.record()

s_ep1 = torch.transpose(monitor_ep1.get("s")*1, 0, 1)
s_ep2 = torch.transpose(monitor_ep2.get("s")*1, 0, 1)
s_ip1 = torch.transpose(monitor_ip1.get("s")*1, 0, 1)
```

In the end lets plot the output.

In [9]:
```
plot = plotting()

plot.plot_three_population_activity_init(time/scale)
plot.plot_three_population_activity_update(s_ep1, I_ep1, s_ep2, I_ep2, s_ip1, I_ip1, n1=
"ep1", n2="ep2", n3="ip1")
plot.show()
```



Population Behavior

Zero Current to Inhibitory Population

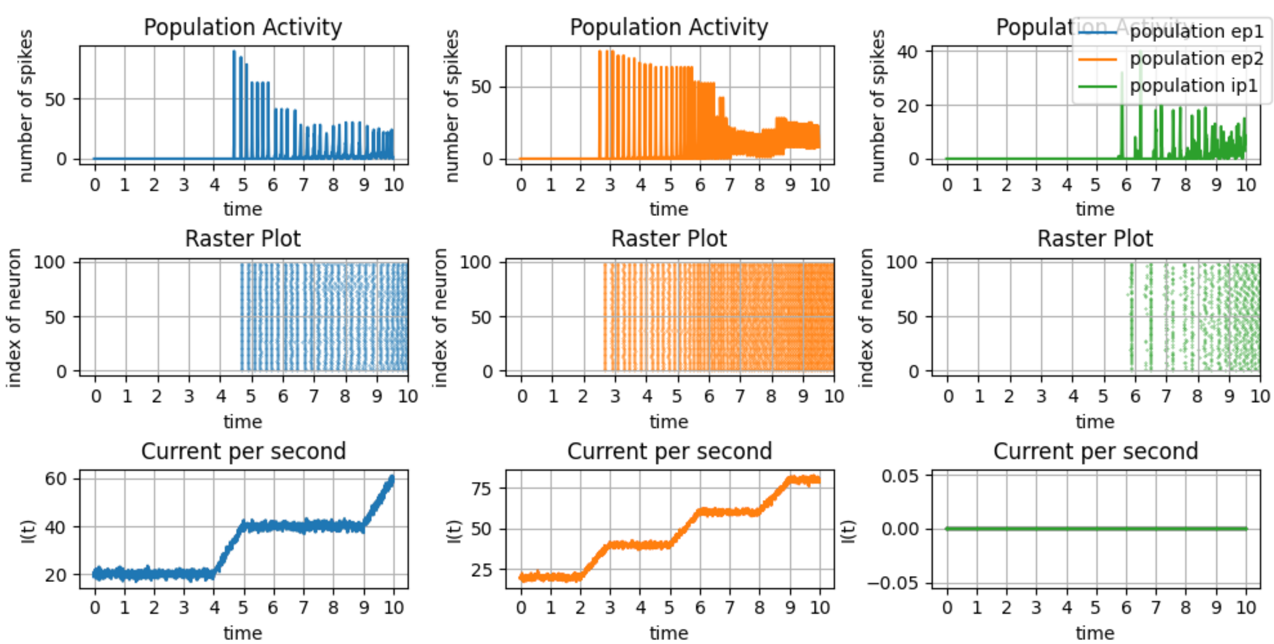
If we change the input of the inhibitory population to zero, we can see the effect of the other excitatory populations on it and they cause it to spike.

In [10]:

```
time = 1000
neuron_size = 100
shape_ep1 = (int(neuron_size),)
shape_ep2 = (int(neuron_size),)
shape_ip1 = (int(neuron_size),)

I_ep1 = incremental_step_noise_function(time = time, I_value = 20, scale = scale, neuron
_size = shape_ep1[0], gap = 5)
I_ep2 = incremental_step_noise_function(time = time, I_value = 20, scale = scale, neuron
_size = shape_ep2[0], gap = 3)
I_ip1 = torch.zeros(time, neuron_size)

ep1 = LIFPopulation(
        shape = shape_ep1, spike_trace = True, additive_spike_trace = True, tau_s = 10,
trace_scale = 1.,
        is_inhibitory = False, learning = False, R = 1, C = 20, threshold = -40, dt = dt
    )
ep2 = LIFPopulation(
        shape = shape_ep2, spike_trace = True, additive_spike_trace = True, tau_s = 10,
trace_scale = 1.,
```

```
        is_inhibitory = False, learning = False, R = 1, C = 20, threshold = -40, dt = dt
    )
ip1 = LIFPopulation(
        shape = shape_ip1, spike_trace = True, additive_spike_trace = True, tau_s = 10,
trace_scale = 1.,
        is_inhibitory = True, learning = False, R = 1, C = 20, threshold = -40, dt = dt
    )

con_ep1_ip1 = Connection(
        pre = ep1, post = ip1, lr = None, weight_decay = 0.0,
        J = 1, tau_s = 10, trace_scale = 1., dt = dt, connectivity= randomNormalConnect,
wmean=20., wstd=5.
    )
con_ep2_ip1 = Connection(
        pre = ep2, post = ip1, lr = None, weight_decay = 0.0,
        J = 1, tau_s = 10, trace_scale = 1., dt = dt, connectivity= randomNormalConnect,
wmean=20., wstd=5.
    )
con_ip1_ep1 = Connection(
        pre = ip1, post = ep1, lr = None, weight_decay = 0.0,
        J = 1, tau_s = 10, trace_scale = 1., dt = dt, connectivity= randomNormalConnect,
wmean=20., wstd=5.
    )
con_ip1_ep2 = Connection(
        pre = ip1, post = ep2, lr = None, weight_decay = 0.0,
        J = 1, tau_s = 10, trace_scale = 1., dt = dt, connectivity= randomNormalConnect,
wmean=20., wstd=5.
    )
con_ep1_ep1 = Connection(
        pre = ep1, post = ep1, lr = None, weight_decay = 0.0,
        J = 1, tau_s = 10, trace_scale = 1., dt = dt, connectivity= randomNormalConnect,
wmean=20., wstd=5.
    )
con_ep2_ep2 = Connection(
        pre = ep2, post = ep2, lr = None, weight_decay = 0.0,
        J = 1, tau_s = 10, trace_scale = 1., dt = dt, connectivity= randomNormalConnect,
wmean=20., wstd=5.
    )


monitor_ep1 = Monitor(ep1, state_variables=["s", "u"])
monitor_ep1.set_time_steps(time, dt)
monitor_ep1.reset_state_variables()

monitor_ep2 = Monitor(ep2, state_variables=["s", "u"])
monitor_ep2.set_time_steps(time, dt)
monitor_ep2.reset_state_variables()

monitor_ip1 = Monitor(ip1, state_variables=["s", "u"])
monitor_ip1.set_time_steps(time, dt)
monitor_ip1.reset_state_variables()

out_ep1_ip1 = 0
out_ep2_ip1 = 0
out_ip1_ep1 = 0
out_ip1_ep2 = 0
out_ep1_ep1 = 0
out_ep2_ep2 = 0
for i in range(time):
```

```
    ep1.forward(I_ep1[i] - out_ip1_ep1 + out_ep1_ep1)
    ep2.forward(I_ep2[i] - out_ip1_ep2 + out_ep2_ep2)
    ip1.forward(I_ip1[i] + out_ep1_ip1 + out_ep2_ip1)
    out_ep1_ip1 = con_ep1_ip1.compute()
    out_ep2_ip1 = con_ep2_ip1.compute()
    out_ip1_ep1 = con_ip1_ep1.compute()
    out_ip1_ep2 = con_ip1_ep2.compute()
    out_ep1_ep1 = con_ep1_ep1.compute()
    out_ep2_ep2 = con_ep2_ep2.compute()
    monitor_ep1.record()
    monitor_ep2.record()
    monitor_ip1.record()

s_ep1 = torch.transpose(monitor_ep1.get("s")*1, 0, 1)
s_ep2 = torch.transpose(monitor_ep2.get("s")*1, 0, 1)
s_ip1 = torch.transpose(monitor_ip1.get("s")*1, 0, 1)

plot = plotting()

plot.plot_three_population_activity_init(time/scale)
plot.plot_three_population_activity_update(s_ep1, I_ep1, s_ep2, I_ep2, s_ip1, I_ip1, n1=
"ep1", n2="ep2", n3="ip1")
plot.show()
```



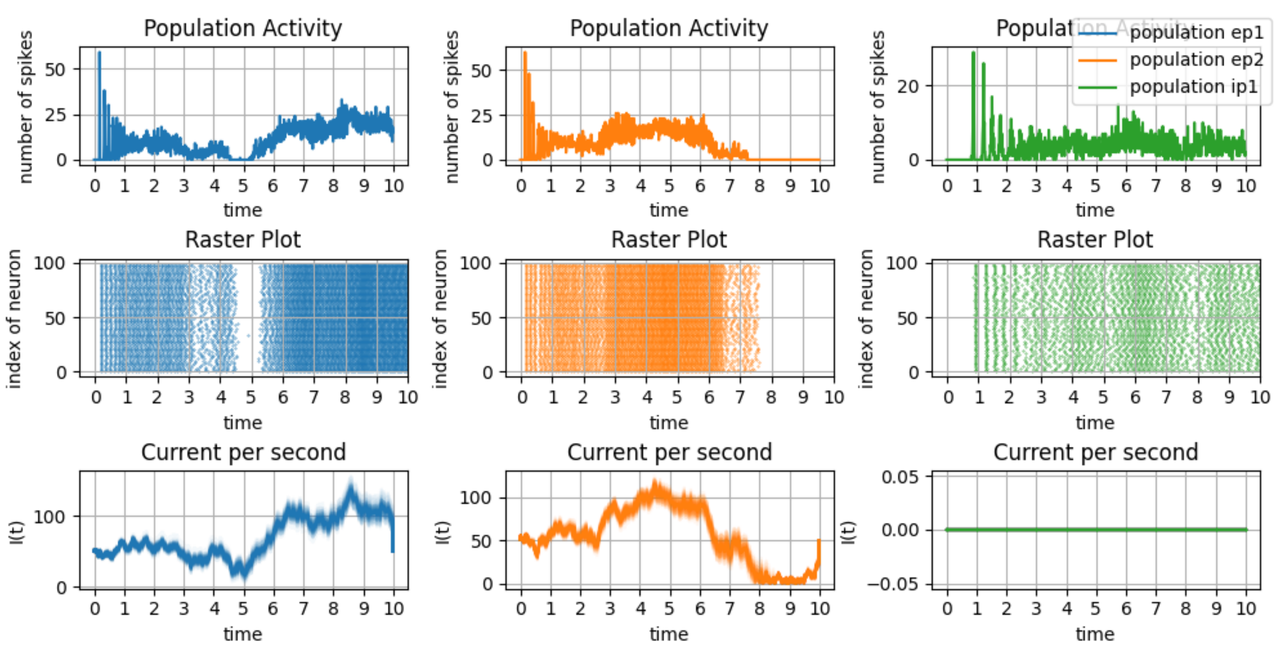
Random Noise as Input

Lets change the input current from a step random current to a random current. It seems that for a period of time we decide based on the first population and for another time we can decide based on the second population.

In [12]:
```
time = 1000
neuron_size = 100
shape_ep1 = (int(neuron_size),)
shape_ep2 = (int(neuron_size),)
shape_ip1 = (int(neuron_size),)
```

```
I_ep1 = noise_function(time = time, neuron_size = shape_ep1[0])
I_ep2 = noise_function(time = time, neuron_size = shape_ep2[0])
I_ip1 = torch.zeros(time, neuron_size)

ep1 = LIFPopulation(
        shape = shape_ep1, spike_trace = True, additive_spike_trace = True, tau_s = 10,
trace_scale = 1.,
        is_inhibitory = False, learning = False, R = 1, C = 20, threshold = -40, dt = dt
    )
ep2 = LIFPopulation(
        shape = shape_ep2, spike_trace = True, additive_spike_trace = True, tau_s = 10,
trace_scale = 1.,
        is_inhibitory = False, learning = False, R = 1, C = 20, threshold = -40, dt = dt
    )
ip1 = LIFPopulation(
        shape = shape_ip1, spike_trace = True, additive_spike_trace = True, tau_s = 10,
trace_scale = 1.,
        is_inhibitory = True, learning = False, R = 1, C = 20, threshold = -40, dt = dt
    )

con_ep1_ip1 = Connection(
        pre = ep1, post = ip1, lr = None, weight_decay = 0.0,
        J = 1, tau_s = 10, trace_scale = 1., dt = dt, connectivity= randomNormalConnect,
wmean=20., wstd=5.
    )
con_ep2_ip1 = Connection(
        pre = ep2, post = ip1, lr = None, weight_decay = 0.0,
        J = 1, tau_s = 10, trace_scale = 1., dt = dt, connectivity= randomNormalConnect,
wmean=20., wstd=5.
    )
con_ip1_ep1 = Connection(
        pre = ip1, post = ep1, lr = None, weight_decay = 0.0,
        J = 1, tau_s = 10, trace_scale = 1., dt = dt, connectivity= randomNormalConnect,
wmean=20., wstd=5.
    )
con_ip1_ep2 = Connection(
        pre = ip1, post = ep2, lr = None, weight_decay = 0.0,
        J = 1, tau_s = 10, trace_scale = 1., dt = dt, connectivity= randomNormalConnect,
wmean=20., wstd=5.
    )
con_ep1_ep1 = Connection(
        pre = ep1, post = ep1, lr = None, weight_decay = 0.0,
        J = 1, tau_s = 10, trace_scale = 1., dt = dt, connectivity= randomNormalConnect,
wmean=20., wstd=5.
    )
con_ep2_ep2 = Connection(
        pre = ep2, post = ep2, lr = None, weight_decay = 0.0,
        J = 1, tau_s = 10, trace_scale = 1., dt = dt, connectivity= randomNormalConnect,
wmean=20., wstd=5.
    )


monitor_ep1 = Monitor(ep1, state_variables=["s", "u"])
monitor_ep1.set_time_steps(time, dt)
monitor_ep1.reset_state_variables()

monitor_ep2 = Monitor(ep2, state_variables=["s", "u"])
monitor_ep2.set_time_steps(time, dt)
monitor_ep2.reset_state_variables()
```

```
monitor_ip1 = Monitor(ip1, state_variables=["s", "u"])
monitor_ip1.set_time_steps(time, dt)
monitor_ip1.reset_state_variables()

out_ep1_ip1 = 0
out_ep2_ip1 = 0
out_ip1_ep1 = 0
out_ip1_ep2 = 0
out_ep1_ep1 = 0
out_ep2_ep2 = 0
for i in range(time):
    ep1.forward(I_ep1[i] - out_ip1_ep1 + out_ep1_ep1)
    ep2.forward(I_ep2[i] - out_ip1_ep2 + out_ep2_ep2)
    ip1.forward(I_ip1[i] + out_ep1_ip1 + out_ep2_ip1)
    out_ep1_ip1 = con_ep1_ip1.compute()
    out_ep2_ip1 = con_ep2_ip1.compute()
    out_ip1_ep1 = con_ip1_ep1.compute()
    out_ip1_ep2 = con_ip1_ep2.compute()
    out_ep1_ep1 = con_ep1_ep1.compute()
    out_ep2_ep2 = con_ep2_ep2.compute()
    monitor_ep1.record()
    monitor_ep2.record()
    monitor_ip1.record()

s_ep1 = torch.transpose(monitor_ep1.get("s")*1, 0, 1)
s_ep2 = torch.transpose(monitor_ep2.get("s")*1, 0, 1)
s_ip1 = torch.transpose(monitor_ip1.get("s")*1, 0, 1)

plot = plotting()

plot.plot_three_population_activity_init(time/scale)
plot.plot_three_population_activity_update(s_ep1, I_ep1, s_ep2, I_ep2, s_ip1, I_ip1, n1=
"ep1", n2="ep2", n3="ip1")
plot.show()
```

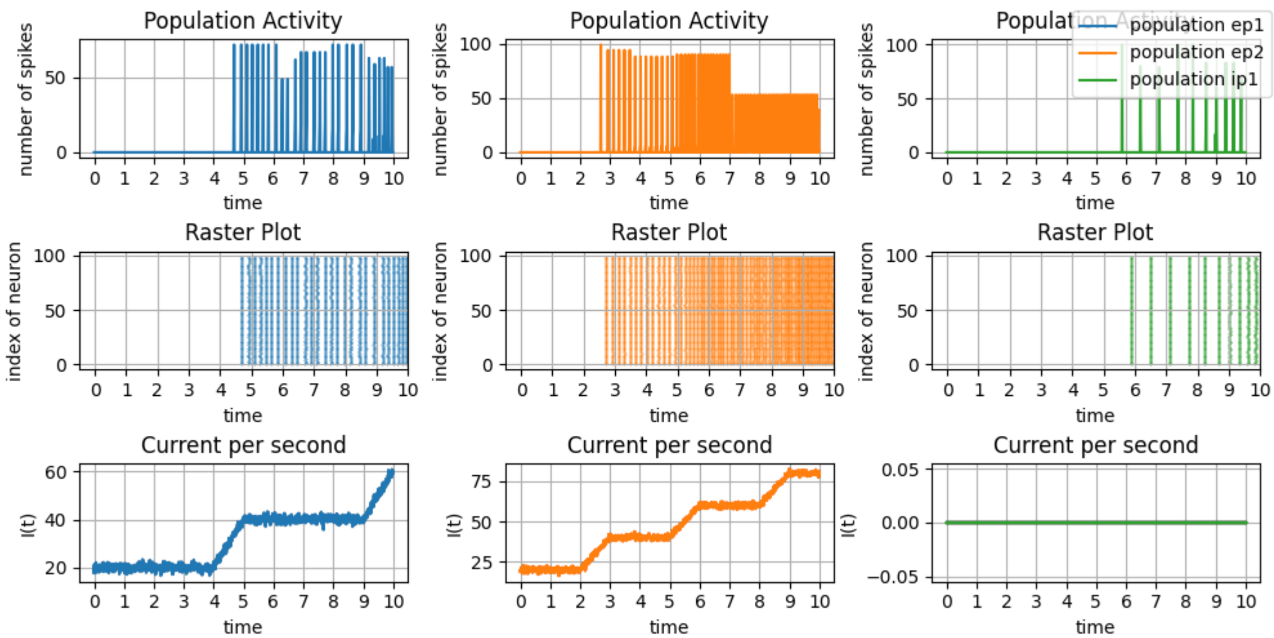


Uniform Random Connection

The next simulation has random step noise but the difference is instead of normal random connection, I used uniform random connection. It cause a more uniform activity for each population and cause for neurons spikes toghether.

In [17]:
```
time = 1000
neuron_size = 100
shape_ep1 = (int(neuron_size),)
shape_ep2 = (int(neuron_size),)
shape_ip1 = (int(neuron_size),)

I_ep1 = incremental_step_noise_function(time = time, I_value = 20, scale = scale, neuron
_size = shape_ep1[0], gap = 5)
I_ep2 = incremental_step_noise_function(time = time, I_value = 20, scale = scale, neuron
_size = shape_ep2[0], gap = 3)
I_ip1 = torch.zeros(time, neuron_size)

ep1 = LIFPopulation(
        shape = shape_ep1, spike_trace = True, additive_spike_trace = True, tau_s = 10,
trace_scale = 1.,
        is_inhibitory = False, learning = False, R = 1, C = 20, threshold = -40, dt = dt
    )
ep2 = LIFPopulation(
        shape = shape_ep2, spike_trace = True, additive_spike_trace = True, tau_s = 10,
trace_scale = 1.,
        is_inhibitory = False, learning = False, R = 1, C = 20, threshold = -40, dt = dt
    )
ip1 = LIFPopulation(
        shape = shape_ip1, spike_trace = True, additive_spike_trace = True, tau_s = 10,
trace_scale = 1.,
        is_inhibitory = True, learning = False, R = 1, C = 20, threshold = -40, dt = dt
    )

con_ep1_ip1 = Connection(
        pre = ep1, post = ip1, lr = None, weight_decay = 0.0,
        J = 1, tau_s = 10, trace_scale = 1., dt = dt, connectivity= randomUniformConnect
, wmax=20., wmind=5.
    )
con_ep2_ip1 = Connection(
        pre = ep2, post = ip1, lr = None, weight_decay = 0.0,
        J = 1, tau_s = 10, trace_scale = 1., dt = dt, connectivity= randomUniformConnect
, wmax=20., wmin=5.
    )
con_ip1_ep1 = Connection(
        pre = ip1, post = ep1, lr = None, weight_decay = 0.0,
        J = 1, tau_s = 10, trace_scale = 1., dt = dt, connectivity= randomUniformConnect
, wmax=20., wmin=5.
    )
con_ip1_ep2 = Connection(
        pre = ip1, post = ep2, lr = None, weight_decay = 0.0,
        J = 1, tau_s = 10, trace_scale = 1., dt = dt, connectivity= randomUniformConnect
, wmax=20., wmin=5.
    )
con_ep1_ep1 = Connection(
        pre = ep1, post = ep1, lr = None, weight_decay = 0.0,
        J = 1, tau_s = 10, trace_scale = 1., dt = dt, connectivity= randomUniformConnect
, wmax=20., wmin=5.
    )
```

```
con_ep2_ep2 = Connection(
        pre = ep2, post = ep2, lr = None, weight_decay = 0.0,
        J = 1, tau_s = 10, trace_scale = 1., dt = dt, connectivity= randomUniformConnect
, wmax=20., wmin=5.
    )


monitor_ep1 = Monitor(ep1, state_variables=["s", "u"])
monitor_ep1.set_time_steps(time, dt)
monitor_ep1.reset_state_variables()

monitor_ep2 = Monitor(ep2, state_variables=["s", "u"])
monitor_ep2.set_time_steps(time, dt)
monitor_ep2.reset_state_variables()

monitor_ip1 = Monitor(ip1, state_variables=["s", "u"])
monitor_ip1.set_time_steps(time, dt)
monitor_ip1.reset_state_variables()

out_ep1_ip1 = 0
out_ep2_ip1 = 0
out_ip1_ep1 = 0
out_ip1_ep2 = 0
out_ep1_ep1 = 0
out_ep2_ep2 = 0
for i in range(time):
    ep1.forward(I_ep1[i] - out_ip1_ep1 + out_ep1_ep1)
    ep2.forward(I_ep2[i] - out_ip1_ep2 + out_ep2_ep2)
    ip1.forward(I_ip1[i] + out_ep1_ip1 + out_ep2_ip1)
    out_ep1_ip1 = con_ep1_ip1.compute()
    out_ep2_ip1 = con_ep2_ip1.compute()
    out_ip1_ep1 = con_ip1_ep1.compute()
    out_ip1_ep2 = con_ip1_ep2.compute()
    out_ep1_ep1 = con_ep1_ep1.compute()
    out_ep2_ep2 = con_ep2_ep2.compute()
    monitor_ep1.record()
    monitor_ep2.record()
    monitor_ip1.record()

s_ep1 = torch.transpose(monitor_ep1.get("s")*1, 0, 1)
s_ep2 = torch.transpose(monitor_ep2.get("s")*1, 0, 1)
s_ip1 = torch.transpose(monitor_ip1.get("s")*1, 0, 1)

plot = plotting()

plot.plot_three_population_activity_init(time/scale)
plot.plot_three_population_activity_update(s_ep1, I_ep1, s_ep2, I_ep2, s_ip1, I_ip1, n1=
"ep1", n2="ep2", n3="ip1")
plot.show()
```



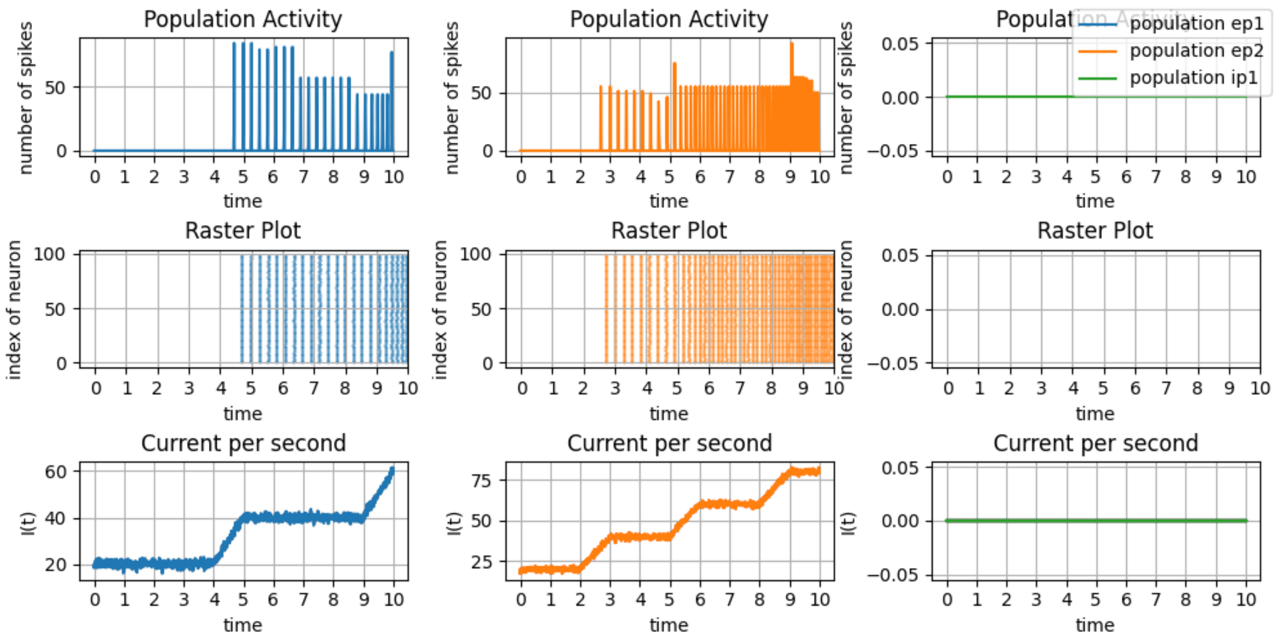
Fully Connected model

The next simulation has random step noise but the difference is instead of normal random connection, I used fully connection. It has less effect on the other population because its output will distribute among all the other population's neuron so it will cause less or no spikes for a inhibitory population without input current.

In [15]:
```
time = 1000
neuron_size = 100
shape_ep1 = (int(neuron_size),)
shape_ep2 = (int(neuron_size),)
shape_ip1 = (int(neuron_size),)

I_ep1 = incremental_step_noise_function(time = time, I_value = 20, scale = scale, neuron
_size = shape_ep1[0], gap = 5)
I_ep2 = incremental_step_noise_function(time = time, I_value = 20, scale = scale, neuron
_size = shape_ep2[0], gap = 3)
I_ip1 = torch.zeros(time, neuron_size)

ep1 = LIFPopulation(
        shape = shape_ep1, spike_trace = True, additive_spike_trace = True, tau_s = 10,
trace_scale = 1.,
        is_inhibitory = False, learning = False, R = 1, C = 20, threshold = -40, dt = dt
    )
ep2 = LIFPopulation(
        shape = shape_ep2, spike_trace = True, additive_spike_trace = True, tau_s = 10,
trace_scale = 1.,
        is_inhibitory = False, learning = False, R = 1, C = 20, threshold = -40, dt = dt
    )
ip1 = LIFPopulation(
        shape = shape_ip1, spike_trace = True, additive_spike_trace = True, tau_s = 10,
trace_scale = 1.,
        is_inhibitory = True, learning = False, R = 1, C = 20, threshold = -40, dt = dt
    )

con_ep1_ip1 = Connection(
        pre = ep1, post = ip1, lr = None, weight_decay = 0.0,
```

```
        J = 1, tau_s = 10, trace_scale = 1., dt = dt, connectivity= fullyConnect
    )
con_ep2_ip1 = Connection(
        pre = ep2, post = ip1, lr = None, weight_decay = 0.0,
        J = 1, tau_s = 10, trace_scale = 1., dt = dt, connectivity= fullyConnect
    )
con_ip1_ep1 = Connection(
        pre = ip1, post = ep1, lr = None, weight_decay = 0.0,
        J = 1, tau_s = 10, trace_scale = 1., dt = dt, connectivity= fullyConnect
    )
con_ip1_ep2 = Connection(
        pre = ip1, post = ep2, lr = None, weight_decay = 0.0,
        J = 1, tau_s = 10, trace_scale = 1., dt = dt, connectivity= fullyConnect
    )
con_ep1_ep1 = Connection(
        pre = ep1, post = ep1, lr = None, weight_decay = 0.0,
        J = 1, tau_s = 10, trace_scale = 1., dt = dt, connectivity= fullyConnect
    )
con_ep2_ep2 = Connection(
        pre = ep2, post = ep2, lr = None, weight_decay = 0.0,
        J = 1, tau_s = 10, trace_scale = 1., dt = dt, connectivity= fullyConnect
    )


monitor_ep1 = Monitor(ep1, state_variables=["s", "u"])
monitor_ep1.set_time_steps(time, dt)
monitor_ep1.reset_state_variables()

monitor_ep2 = Monitor(ep2, state_variables=["s", "u"])
monitor_ep2.set_time_steps(time, dt)
monitor_ep2.reset_state_variables()

monitor_ip1 = Monitor(ip1, state_variables=["s", "u"])
monitor_ip1.set_time_steps(time, dt)
monitor_ip1.reset_state_variables()

out_ep1_ip1 = 0
out_ep2_ip1 = 0
out_ip1_ep1 = 0
out_ip1_ep2 = 0
out_ep1_ep1 = 0
out_ep2_ep2 = 0
for i in range(time):
    ep1.forward(I_ep1[i] - out_ip1_ep1 + out_ep1_ep1)
    ep2.forward(I_ep2[i] - out_ip1_ep2 + out_ep2_ep2)
    ip1.forward(I_ip1[i] + out_ep1_ip1 + out_ep2_ip1)
    out_ep1_ip1 = con_ep1_ip1.compute()
    out_ep2_ip1 = con_ep2_ip1.compute()
    out_ip1_ep1 = con_ip1_ep1.compute()
    out_ip1_ep2 = con_ip1_ep2.compute()
    out_ep1_ep1 = con_ep1_ep1.compute()
    out_ep2_ep2 = con_ep2_ep2.compute()
    monitor_ep1.record()
    monitor_ep2.record()
    monitor_ip1.record()

s_ep1 = torch.transpose(monitor_ep1.get("s")*1, 0, 1)
s_ep2 = torch.transpose(monitor_ep2.get("s")*1, 0, 1)
s_ip1 = torch.transpose(monitor_ip1.get("s")*1, 0, 1)
```

```
plot = plotting()

plot.plot_three_population_activity_init(time/scale)
plot.plot_three_population_activity_update(s_ep1, I_ep1, s_ep2, I_ep2, s_ip1, I_ip1, n1=
"ep1", n2="ep2", n3="ip1")
plot.show()
```



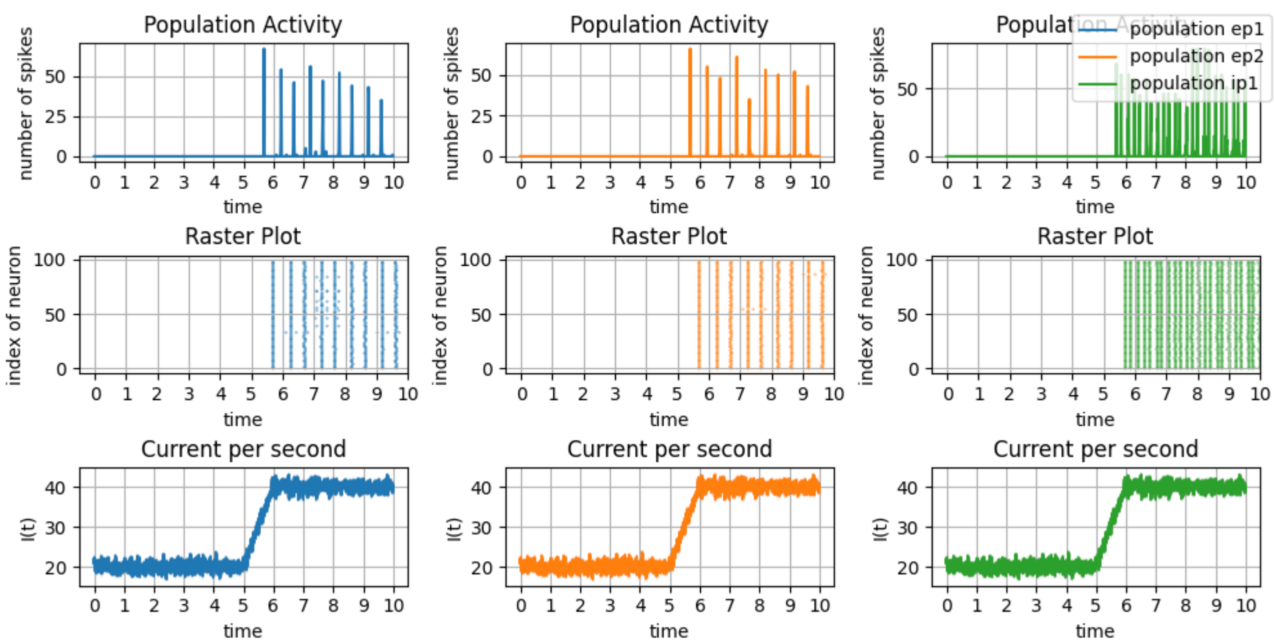
Same Current as Input

If we get a same current to all the populations, the result is as follows:

In [23]:
```
time = 1000
neuron_size = 100
shape_ep1 = (int(neuron_size),)
shape_ep2 = (int(neuron_size),)
shape_ip1 = (int(neuron_size),)

I_ep1 = incremental_step_noise_function(time = time, I_value = 20, scale = scale, neuron
_size = shape_ep1[0], gap = 6)
I_ep2 = torch.clone(I_ep1)
I_ip1 = torch.clone(I_ep1)

ep1 = LIFPopulation(
        shape = shape_ep1, spike_trace = True, additive_spike_trace = True, tau_s = 10,
trace_scale = 1.,
        is_inhibitory = False, learning = False, R = 1, C = 20, threshold = -40, dt = dt
    )
ep2 = LIFPopulation(
        shape = shape_ep2, spike_trace = True, additive_spike_trace = True, tau_s = 10,
trace_scale = 1.,
        is_inhibitory = False, learning = False, R = 1, C = 20, threshold = -40, dt = dt
    )
ip1 = LIFPopulation(
        shape = shape_ip1, spike_trace = True, additive_spike_trace = True, tau_s = 10,
trace_scale = 1.,
```

```
        is_inhibitory = True, learning = False, R = 1, C = 20, threshold = -40, dt = dt
    )

con_ep1_ip1 = Connection(
        pre = ep1, post = ip1, lr = None, weight_decay = 0.0,
        J = 1, tau_s = 10, trace_scale = 1., dt = dt, connectivity= randomNormalConnect,
wmean=20., wstd=5.
    )
con_ep2_ip1 = Connection(
        pre = ep2, post = ip1, lr = None, weight_decay = 0.0,
        J = 1, tau_s = 10, trace_scale = 1., dt = dt, connectivity= randomNormalConnect,
wmean=20., wstd=5.
    )
con_ip1_ep1 = Connection(
        pre = ip1, post = ep1, lr = None, weight_decay = 0.0,
        J = 1, tau_s = 10, trace_scale = 1., dt = dt, connectivity= randomNormalConnect,
wmean=20., wstd=5.
    )
con_ip1_ep2 = Connection(
        pre = ip1, post = ep2, lr = None, weight_decay = 0.0,
        J = 1, tau_s = 10, trace_scale = 1., dt = dt, connectivity= randomNormalConnect,
wmean=20., wstd=5.
    )
con_ep1_ep1 = Connection(
        pre = ep1, post = ep1, lr = None, weight_decay = 0.0,
        J = 1, tau_s = 10, trace_scale = 1., dt = dt, connectivity= randomNormalConnect,
wmean=20., wstd=5.
    )
con_ep2_ep2 = Connection(
        pre = ep2, post = ep2, lr = None, weight_decay = 0.0,
        J = 1, tau_s = 10, trace_scale = 1., dt = dt, connectivity= randomNormalConnect,
wmean=20., wstd=5.
    )


monitor_ep1 = Monitor(ep1, state_variables=["s", "u"])
monitor_ep1.set_time_steps(time, dt)
monitor_ep1.reset_state_variables()

monitor_ep2 = Monitor(ep2, state_variables=["s", "u"])
monitor_ep2.set_time_steps(time, dt)
monitor_ep2.reset_state_variables()

monitor_ip1 = Monitor(ip1, state_variables=["s", "u"])
monitor_ip1.set_time_steps(time, dt)
monitor_ip1.reset_state_variables()

out_ep1_ip1 = 0
out_ep2_ip1 = 0
out_ip1_ep1 = 0
out_ip1_ep2 = 0
out_ep1_ep1 = 0
out_ep2_ep2 = 0
for i in range(time):
    ep1.forward(I_ep1[i] - out_ip1_ep1 + out_ep1_ep1)
    ep2.forward(I_ep2[i] - out_ip1_ep2 + out_ep2_ep2)
    ip1.forward(I_ip1[i] + out_ep1_ip1 + out_ep2_ip1)
    out_ep1_ip1 = con_ep1_ip1.compute()
    out_ep2_ip1 = con_ep2_ip1.compute()
```

```
    out_ip1_ep1 = con_ip1_ep1.compute()
    out_ip1_ep2 = con_ip1_ep2.compute()
    out_ep1_ep1 = con_ep1_ep1.compute()
    out_ep2_ep2 = con_ep2_ep2.compute()
    monitor_ep1.record()
    monitor_ep2.record()
    monitor_ip1.record()

s_ep1 = torch.transpose(monitor_ep1.get("s")*1, 0, 1)
s_ep2 = torch.transpose(monitor_ep2.get("s")*1, 0, 1)
s_ip1 = torch.transpose(monitor_ip1.get("s")*1, 0, 1)

plot = plotting()

plot.plot_three_population_activity_init(time/scale)
plot.plot_three_population_activity_update(s_ep1, I_ep1, s_ep2, I_ep2, s_ip1, I_ip1, n1=
"ep1", n2="ep2", n3="ip1")
plot.show()
```



One Strong Current

As we can see below there may be a time when the inhibitory population won't allow another population spike although in the previous parts it spikes.

In [24]:
```
time = 1000
neuron_size = 100
shape_ep1 = (int(neuron_size),)
shape_ep2 = (int(neuron_size),)
shape_ip1 = (int(neuron_size),)

I_ep1 = incremental_step_noise_function(time = time, I_value = 20, scale = scale, neuron
_size = shape_ep1[0], gap = 6)
I_ep2 = torch.clone(I_ep1)
I_ep2[5*scale:,:] = I_ep2[5*scale:,:] + 20
I_ip1 = I_ep1
```

```
ep1 = LIFPopulation(
        shape = shape_ep1, spike_trace = True, additive_spike_trace = True, tau_s = 10,
trace_scale = 1.,
        is_inhibitory = False, learning = False, R = 1, C = 20, threshold = -40, dt = dt
    )
ep2 = LIFPopulation(
        shape = shape_ep2, spike_trace = True, additive_spike_trace = True, tau_s = 10,
trace_scale = 1.,
        is_inhibitory = False, learning = False, R = 1, C = 20, threshold = -40, dt = dt
    )
ip1 = LIFPopulation(
        shape = shape_ip1, spike_trace = True, additive_spike_trace = True, tau_s = 10,
trace_scale = 1.,
        is_inhibitory = True, learning = False, R = 1, C = 20, threshold = -40, dt = dt
    )

con_ep1_ip1 = Connection(
        pre = ep1, post = ip1, lr = None, weight_decay = 0.0,
        J = 1, tau_s = 10, trace_scale = 1., dt = dt, connectivity= randomNormalConnect,
wmean=20., wstd=5.
    )
con_ep2_ip1 = Connection(
        pre = ep2, post = ip1, lr = None, weight_decay = 0.0,
        J = 1, tau_s = 10, trace_scale = 1., dt = dt, connectivity= randomNormalConnect,
wmean=20., wstd=5.
    )
con_ip1_ep1 = Connection(
        pre = ip1, post = ep1, lr = None, weight_decay = 0.0,
        J = 1, tau_s = 10, trace_scale = 1., dt = dt, connectivity= randomNormalConnect,
wmean=20., wstd=5.
    )
con_ip1_ep2 = Connection(
        pre = ip1, post = ep2, lr = None, weight_decay = 0.0,
        J = 1, tau_s = 10, trace_scale = 1., dt = dt, connectivity= randomNormalConnect,
wmean=20., wstd=5.
    )
con_ep1_ep1 = Connection(
        pre = ep1, post = ep1, lr = None, weight_decay = 0.0,
        J = 1, tau_s = 10, trace_scale = 1., dt = dt, connectivity= randomNormalConnect,
wmean=20., wstd=5.
    )
con_ep2_ep2 = Connection(
        pre = ep2, post = ep2, lr = None, weight_decay = 0.0,
        J = 1, tau_s = 10, trace_scale = 1., dt = dt, connectivity= randomNormalConnect,
wmean=20., wstd=5.
    )


monitor_ep1 = Monitor(ep1, state_variables=["s", "u"])
monitor_ep1.set_time_steps(time, dt)
monitor_ep1.reset_state_variables()

monitor_ep2 = Monitor(ep2, state_variables=["s", "u"])
monitor_ep2.set_time_steps(time, dt)
monitor_ep2.reset_state_variables()

monitor_ip1 = Monitor(ip1, state_variables=["s", "u"])
monitor_ip1.set_time_steps(time, dt)
```

```
monitor_ip1.reset_state_variables()

out_ep1_ip1 = 0
out_ep2_ip1 = 0
out_ip1_ep1 = 0
out_ip1_ep2 = 0
out_ep1_ep1 = 0
out_ep2_ep2 = 0
for i in range(time):
    ep1.forward(I_ep1[i] - out_ip1_ep1 + out_ep1_ep1)
    ep2.forward(I_ep2[i] - out_ip1_ep2 + out_ep2_ep2)
    ip1.forward(I_ip1[i] + out_ep1_ip1 + out_ep2_ip1)
    out_ep1_ip1 = con_ep1_ip1.compute()
    out_ep2_ip1 = con_ep2_ip1.compute()
    out_ip1_ep1 = con_ip1_ep1.compute()
    out_ip1_ep2 = con_ip1_ep2.compute()
    out_ep1_ep1 = con_ep1_ep1.compute()
    out_ep2_ep2 = con_ep2_ep2.compute()
    monitor_ep1.record()
    monitor_ep2.record()
    monitor_ip1.record()

s_ep1 = torch.transpose(monitor_ep1.get("s")*1, 0, 1)
s_ep2 = torch.transpose(monitor_ep2.get("s")*1, 0, 1)
s_ip1 = torch.transpose(monitor_ip1.get("s")*1, 0, 1)

plot = plotting()

plot.plot_three_population_activity_init(time/scale)
plot.plot_three_population_activity_update(s_ep1, I_ep1, s_ep2, I_ep2, s_ip1, I_ip1, n1=
"ep1", n2="ep2", n3="ip1")
plot.show()
```