

The GeNN ecosystem

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GeNN

- Cross-platform C++ library for generating optimised CUDA code for GPU accelerated SNN simulations.
- Hopefully you learnt all about it in Thomas's talk!

Installation

CUDA on Linux

- Each version of CUDA only supports a subset of GCC versions so if you have a very old or very bleeding edge OS you may need to install an additional version of GCC.
- Installing CUDA via the NVIDIA proprietary packages tends to work best if your OS is supported.
- Ensure that the `CUDA_PATH` environment variable is set

CUDA on Windows

- CUDA is nicely integrated into Visual Studio and provided graphical debugging and profiling tools
- Historically, because Visual Studio is frequently updated, compiler/CUDA version mismatches were more prevalent than on Linux **but**, as of CUDA 10 and Visual Studio 2017, this no longer appears to be the case!
- There are performance issues with CUDA on Windows display devices

CUDA on Mac

- Sadly Apple hasn't built any machines with NVIDIA GPUs since 2014
- However, if you're lucky enough to have:
 - MacBook Pro (Retina, 15-inch, Late 2013)
 - MacBook Pro (Retina, 15-inch, Mid 2014)
 - Equivalent iMac models (probably not with you!)
- You **may** have a NVIDIA GPU that's usable with the current version of CUDA!



GeNN

- Download latest release of GeNN from <https://github.com/genn-team/genn/releases>
- Add GeNN's `bin` directory to your path or, on Linux/Mac, `make install`)
- Checkout tutorials from https://github.com/neworderofjamie/new_genn_tutorials

Test your GeNN installation

Navigate to `va_benchmark` folder and run code generator:

Linux/Mac with CUDA:

```
genn-buildmodel.sh model.cc
```

Windows with CUDA:

```
genn-buildmodel.bat model.cc
```

Linux/Mac without CUDA:

```
genn-buildmodel.sh -c model.cc
```

Windows without CUDA:

```
genn-buildmodel.bat -c model.cc
```

Build generated code:

Linux/Mac:

```
make
```

Windows (or double click solution file):

```
msbuild va_benchmark.sln /m /t:va_benchmark /p:Configuration=Release
```

Run model and plot results:

Linux/Mac:

```
./va_benchmark
```

Windows:

```
va_benchmark_Release
```

```
python plot_spikes.py
```

```
python plot_spikes.py
```


Tutorial 1: Neurons

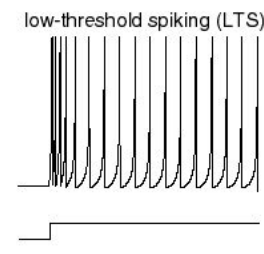
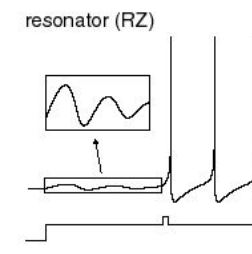
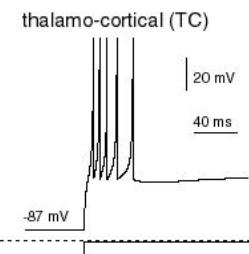
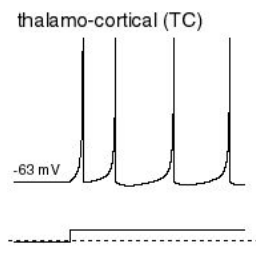
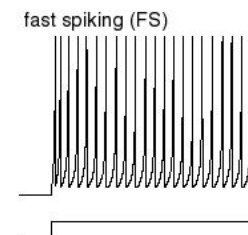
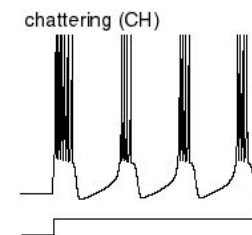
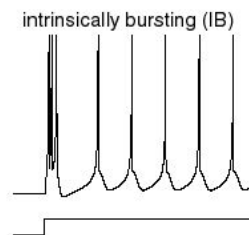
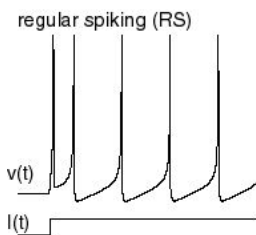
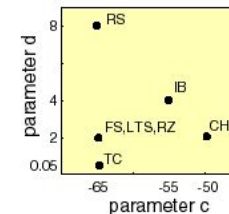
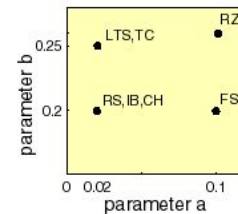
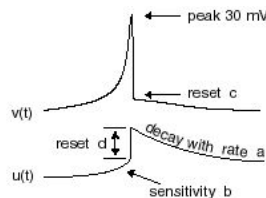
Tutorial 1: Introduction

- Basics of using GeNN
- Explore the dynamics of the Izhikevich neuron model
- Simple recording

$$v' = 0.04v^2 + 5v + 140 - u + I$$

$$u' = a(bv - u)$$

if $v = 30$ mV,
then $v \leftarrow c$, $u \leftarrow u + d$



```
#include "modelSpec.h"
```

```
void modelDefinition(ModelSpec &model)  
{  
}
```

Include GeNN definitions




Function gets linked
against code generator

```
#include "modelSpec.h"
void modelDefinition(NNmodel &model)
{
    model.setDT(0.1);
    model.setName("tutorial1");
}
```

Simulation time step [ms]




Model name - mostly used as the
name of the code generator output
directory




```
#include "modelSpec.h"
void modelDefinition(NNmodel &model)
{
    model.setDT(0.1);
    model.setName("tutorial1");

    NeuronModels::IzhikevichVariable::ParamValues paramValues;
    NeuronModels::IzhikevichVariable::VarValues initValues(
        -65.0,           // 0 - V
        -20.0,           // 1 - U
        uninitialisedVar(), // 2 - A
        uninitialisedVar(), // 3 - B
        uninitialisedVar(), // 4 - C
        uninitialisedVar()); // 5 - D
}
```

Parameters are constant across population and do not change during simulation (this model doesn't have any)



Var values specify how model's state variables are initialised - in this case we want to manually set A, B, C and D on a per-neuron basis



```

#include "modelSpec.h"
void modelDefinition(NNmodel &model)
{
    model.setDT(0.1);
    model.setName("tutorial1");

    NeuronModels::IzhikevichVariable::ParamValues paramValues;
    NeuronModels::IzhikevichVariable::VarValues initValues(
        -65.0,           // 0 - V
        -20.0,           // 1 - U
        uninitialisedVar(), // 2 - A
        uninitialisedVar(), // 3 - B
        uninitialisedVar(), // 4 - C
        uninitialisedVar()); // 5 - D
    model.addNeuronPopulation<NeuronModels::IzhikevichVariable>("Neurons", 4,
                                                                paramValues, initValues);
}

```

Adds a population called “Neurons” consisting of 4 Izhikevich neurons (1 for each regime) with these parameters and initial state to network

```

#include "modelSpec.h"
void modelDefinition(NNmodel &model)
{
    model.setDT(0.1);
    model.setName("tutorial1");

    NeuronModels::IzhikevichVariable::ParamValues paramValues;
    NeuronModels::IzhikevichVariable::VarValues initValues(
        -65.0,           // 0 - V
        -20.0,           // 1 - U
        uninitialisedVar(), // 2 - A
        uninitialisedVar(), // 3 - B
        uninitialisedVar(), // 4 - C
        uninitialisedVar()); // 5 - D
    model.addNeuronPopulation<NeuronModels::IzhikevichVariable>("Neuron", paramValues, initValues);

    CurrentSourceModels::DC::ParamValues currentSourceParamVals(
        10.0); // 0 - magnitude
    model.addCurrentSource<CurrentSourceModels::DC>("CurrentSource", "Neurons",
        currentSourceParamVals, {});
}

```

Define DC current source parameters (magnitude)

Attach a DC current source called "CurrentSource" to our neuron population with these parameters

Tutorial 1: Generate model code

Linux/Mac with CUDA:

```
genn-buildmodel.sh model.cc
```

Linux/Mac without CUDA:

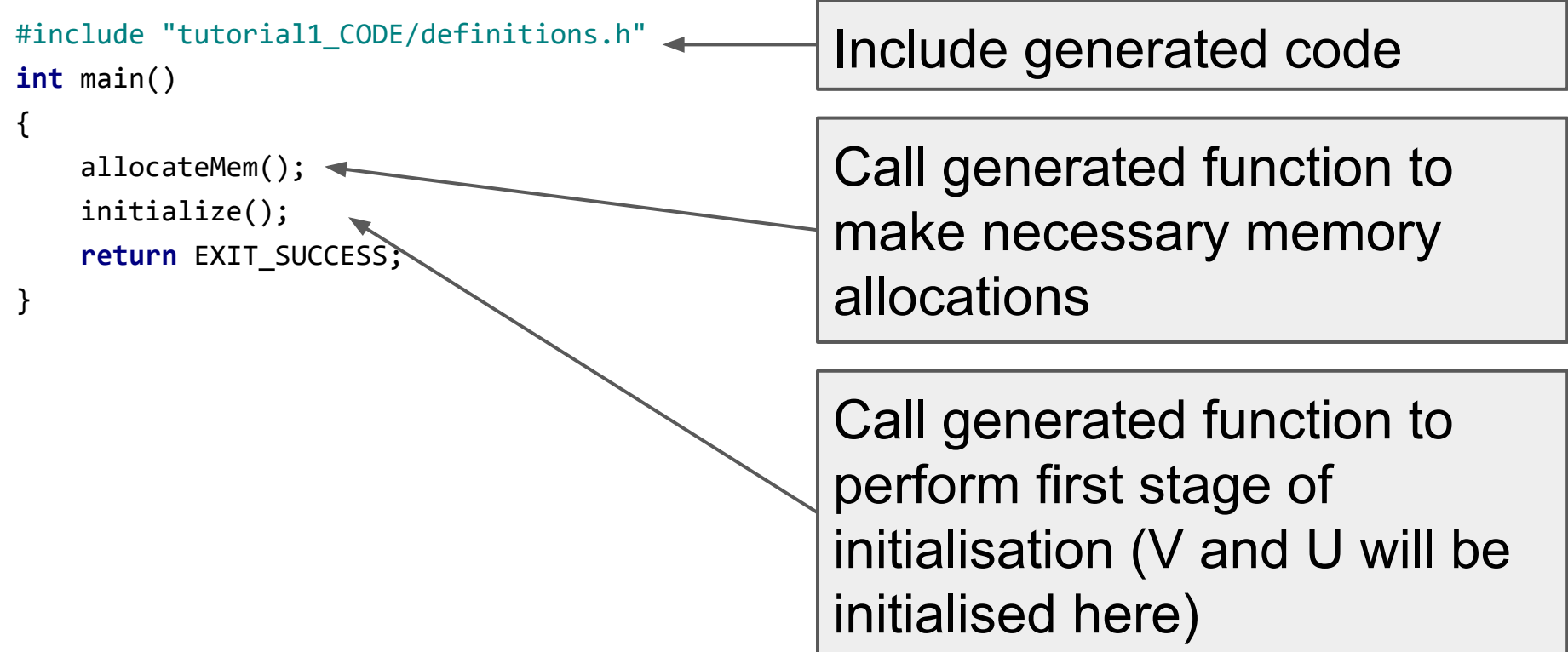
```
genn-buildmodel.sh -c model.cc
```

Windows with CUDA:

```
genn-buildmodel.bat model.cc
```

Windows without CUDA:

```
genn-buildmodel.bat -c model.cc
```

```
#include "tutorial1_CODE/definitions.h"
```

```
int main()
```

```
{
```

```
    allocateMem();
```

```
    initialize();
```

```
    aNeurons[0] = 0.02; bNeurons[0] = 0.2; cNeurons[0] = -65.0; dNeurons[0] = 8.0; // RS
```

```
    aNeurons[1] = 0.1; bNeurons[1] = 0.2; cNeurons[1] = -65.0; dNeurons[1] = 2.0; // FS
```

```
    aNeurons[2] = 0.02; bNeurons[2] = 0.2; cNeurons[2] = -50.0; dNeurons[2] = 2.0; // CH
```

```
    aNeurons[3] = 0.02; bNeurons[3] = 0.2; cNeurons[3] = -55.0; dNeurons[3] = 4.0; // IB
```

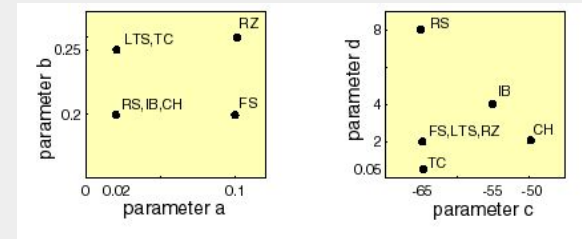
```
    initializeSparse();
```

```
    return EXIT_SUCCESS;
```

```
}
```

Call generated function to perform second stage of initialisation (will upload initial state to GPU)

Manually initialise each neuron's state variables to match different regimes



```

#include "tutorial1_CODE/definitions.h"

int main()
{
    allocateMem();
    initialize();
    aNeurons[0] = 0.02; bNeurons[0] = 0.2; cNeurons[0] = -65.0; dNeurons[0] = 8.0; // RS
    aNeurons[1] = 0.1; bNeurons[1] = 0.2; cNeurons[1] = -65.0; dNeurons[1] = 2.0; // FS
    aNeurons[2] = 0.02; bNeurons[2] = 0.2; cNeurons[2] = -50.0; dNeurons[2] = 2.0; // CH
    aNeurons[3] = 0.02; bNeurons[3] = 0.2; cNeurons[3] = -55.0; dNeurons[3] = 4.0; // IB
    initializeSparse();

    while(t < 200.0f) {
        stepTime();
    }

    return EXIT_SUCCESS;
}

```

Loop until 200ms of
simulated time has elapsed
(t is provided by GeNN)

Call generated functions to
advance simulation state

```
#include "tutorial1_CODE/definitions.h"
```

```
#include <fstream>
```

```
int main()
```

```
{
```

```
    allocateMem();
```

```
    initialize();
```

```
    aNeurons[0] = 0.02; bNeurons[0] = 0.2; cNeurons[0] = -65.0; dNeurons[0] = 8.0; // RS
```

```
    aNeurons[1] = 0.1; bNeurons[1] = 0.2; cNeurons[1] = -65.0; dNeurons[1] = 2.0; // FS
```

```
    aNeurons[2] = 0.02; bNeurons[2] = 0.2; cNeurons[2] = -50.0; dNeurons[2] = 2.0; // CH
```

```
    aNeurons[3] = 0.02; bNeurons[3] = 0.2; cNeurons[3] = -55.0; dNeurons[3] = 4.0; // IB
```

```
    initializeSparse();
```

```
    std::ofstream stream("state.csv");
```

```
    while(t < 200.0f) {
```

```
        stepTime();
```

```
        pullCurrentVNeuronsFromDevice();
```

```
        stream << t << "," << getCurrentVNeurons()[0] << "," << getCurrentVNeurons()[1];
```

```
        stream << "," << getCurrentVNeurons()[2] << "," << getCurrentVNeurons()[3] << std::endl;
```

```
    }
```

```
    return EXIT_SUCCESS;
```

```
}
```

Include standard header for file IO

Open CSV file for writing

Download "Neurons" population membrane voltages from GPU

Write current time and membrane voltage of each of the 4 neurons to CSV file

Tutorial 1: Building on Linux/Mac

Create Makefile

```
genn-create-user-project.sh tutorial1 simulator.cc
```

Build using:

```
make
```

Then run with: `./tutorial1`

Tutorial 1: Building on Windows

Create MSBuild projects

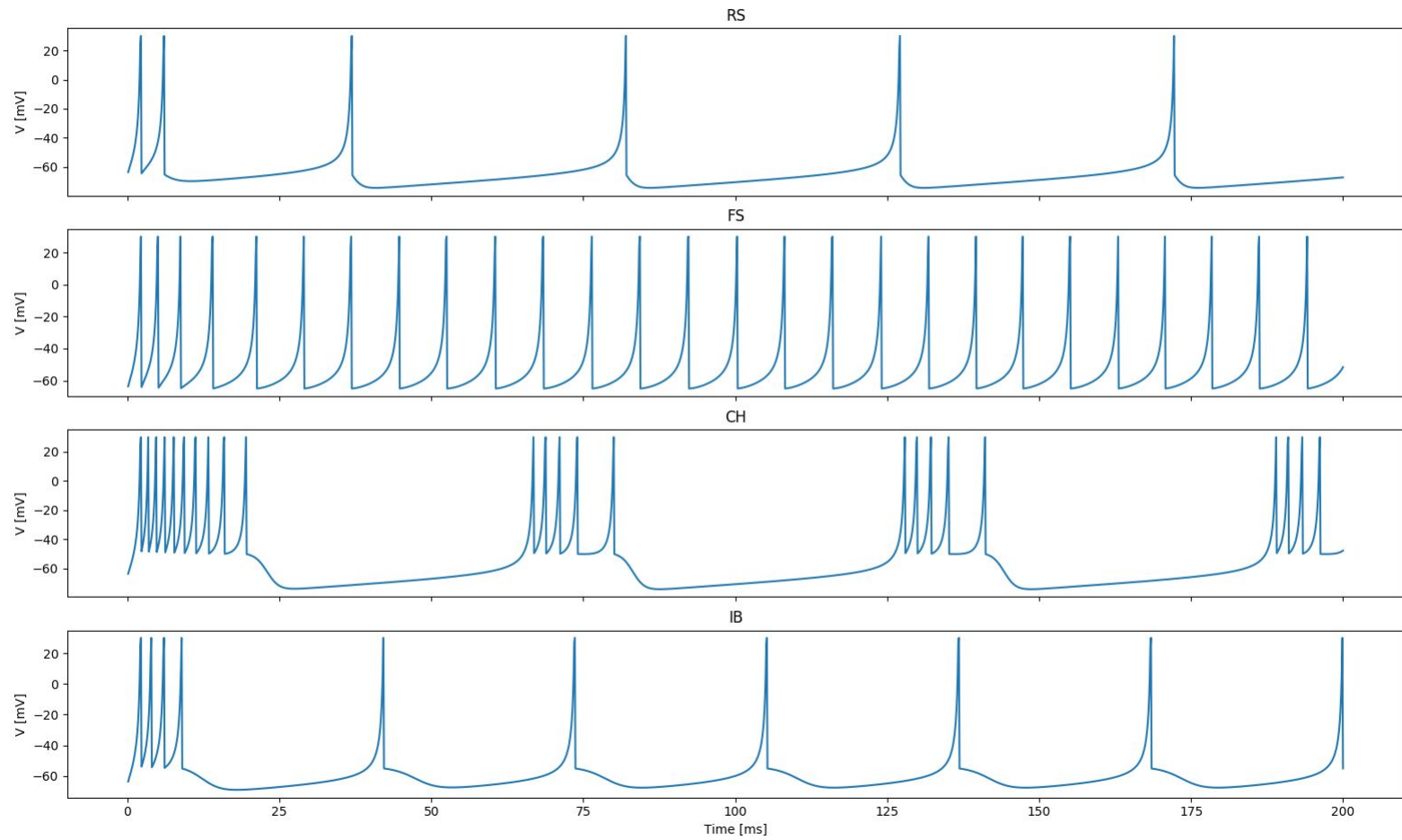
```
genn-create-user-project.bat tutorial1 simulator.cc
```

Build using (or double click solution file):

```
msbuild tutorial1.sln /m /t:tutorial1  
/p:Configuration=Release
```

Then run with: `tutorial1_Release.exe`

Tutorial 1: Results

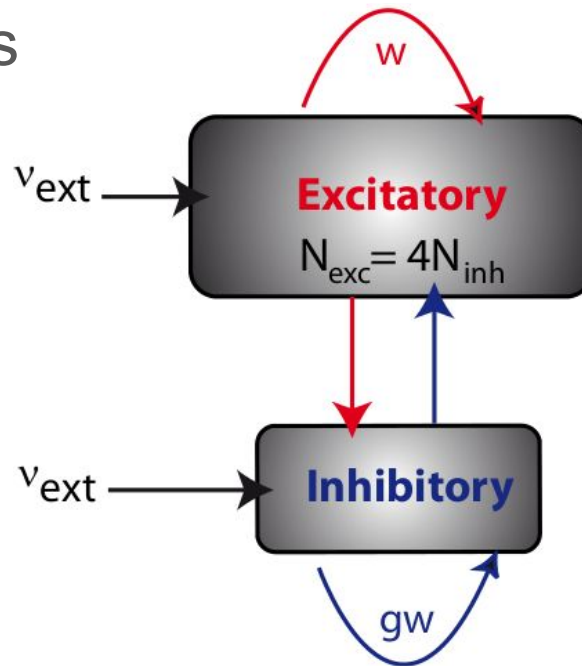


Tutorial 1: Exercises

- Expand the example to include more of the regimes from the diagram
- Look in “tutorial1_CODE” at neuronUpdate.cc and see what GeNN is doing!


Tutorial 2: Building networks

- Defining synapse populations
- Using initialisation snippets to configure parameters and connectivity
- Recording spikes



```
#include "modelSpec.h"
void modelDefinition(NNmodel &model)
{
    model.setDT(1.0);
    model.setName("tutorial2");
}
```

Hopefully this is now
all familiar



```

#include "modelSpec.h"
void modelDefinition(ModelSpec &model)
{
    model.setDT(1.0);
    model.setName("tutorial2");

    NeuronModels::Izhikevich::ParamValues izkParams(
        0.02,    // 0 - A
        0.2,     // 1 - B
        -65.0,   // 2 - C
        8.0);    // 3 - D

    InitVarSnippet::Uniform::ParamValues uDist(
        0.0,     // 0 - min
        20.0);   // 1 - max

    NeuronModels::Izhikevich::VarValues ikzInit(
        -65.0,
        initVar<InitVarSnippet::Uniform>(uDist));

    model.addNeuronPopulation<NeuronModels::Izhikevich>("Exc", 8000, izkParams, ikzInit);
    model.addNeuronPopulation<NeuronModels::Izhikevich>("Inh", 2000, izkParams, ikzInit);

    CurrentSourceModels::DC::ParamValues currentSourceParamVals(4.0); // 0 - magnitude
    model.addCurrentSource<CurrentSourceModels::DC>("ExcStim", "Exc", currentSourceParamVals, {});
    model.addCurrentSource<CurrentSourceModels::DC>("InhStim", "Inh", currentSourceParamVals, {});
}

```

Configure our Izhikevich neurons into the RS regime

Define a uniform random **distribution**

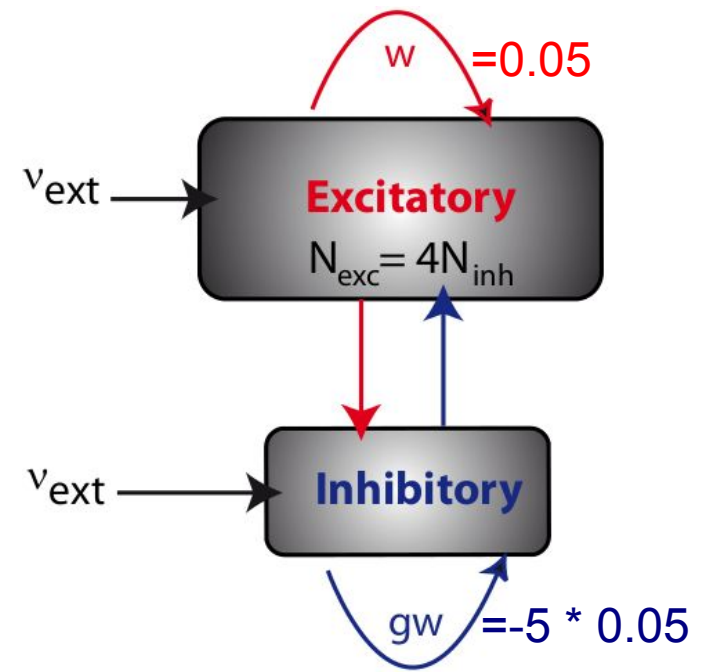
Use distribution to initialise u

Add neuron populations and current sources as before

```
WeightUpdateModels::StaticPulse::VarValues excSynInitValues(0.05);  
WeightUpdateModels::StaticPulse::VarValues inhSynInitValues(-5 * 0.05);  
  
InitSparseConnectivitySnippet::FixedProbability::ParamValues fixedProb(0.1); //  $\theta$  - prob
```

Set strength of connections

Configure parameters for connectivity initialisation.



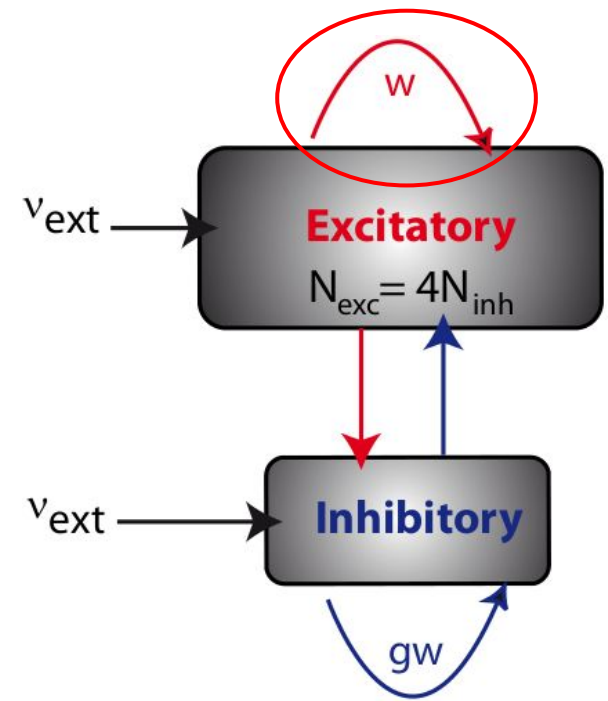
```

WeightUpdateModels::StaticPulse::VarValues excSynInitValues(0.05);
WeightUpdateModels::StaticPulse::VarValues inhSynInitValues(-5 * 0.05);

InitSparseConnectivitySnippet::FixedProbability::ParamValues fixedProb(0.1); //  $\theta$  - prob

model.addSynapsePopulation<WeightUpdateModels::StaticPulse, PostsynapticModels::DeltaCurr>(
    "Exc_Exc", SynapseMatrixType::SPARSE_GLOBALG, NO_DELAY,
    "Exc", "Exc", {}, excSynInitValues, {}, {},
    initConnectivity<InitSparseConnectivitySnippet::FixedProbabilityNoAutapse>(fixedProb));
}

```



```
WeightUpdateModels::StaticPulse::VarValues excSynInitValues(0.05);  
WeightUpdateModels::StaticPulse::VarValues inhSynInitValues(-5 * 0.05);
```

```
InitSparseConnectivitySnippet::FixedProbability::ParamValues fixedProb(0.1); // 0 - prob
```

```
model.addSynapsePopulation<WeightUpdateModels::StaticPulse, PostsynapticModels::DeltaCurr>(  
    "Exc_Exc", SynapseMatrixType::SPARSE_GLOBALG, NO_DELAY,  
    "Exc", "Exc", {}, excSynInitValues, {}, {},  
    initConnectivity<InitSparseConnectivitySnippet::FixedProbabilityNoAutapse>(fixedProb));  
}
```

**Simplest weight update
model** - no learning etc

Simplest postsynaptic model
- no 'shaping' of input current

```
WeightUpdateModels::StaticPulse::VarValues excSynInitValues(0.05);
WeightUpdateModels::StaticPulse::VarValues inhSynInitValues(-5 * 0.05);
```

```
InitSparseConnectivitySnippet::FixedProbability::ParamValues fixedProb(0.1); // 0 - prob
```

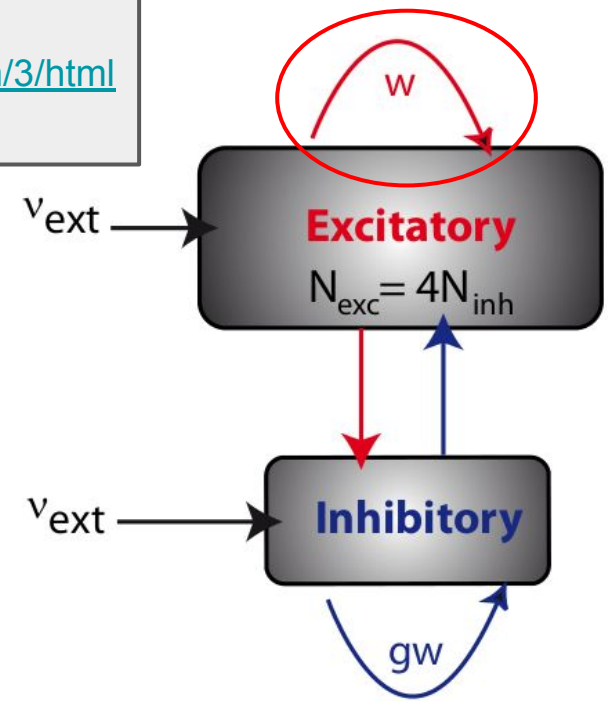
```
model.addSynapsePopulation<WeightUpdateModels::StaticPulse, PostsynapticModels::DeltaCurr>(
    "Exc_Exc", SynapseMatrixType::SPARSE_GLOBALG, NO_DELAY,
    "Exc", "Exc", {}, excSynInitValues, {}, {},
    initConnectivity<InitSparseConnectivitySnippet::FixedProbabilityNoAutapse>(fixedProb));
}
```

No synaptic delays

Name of
synapse
population

Sparse matrix with the same
parameters for each synapse

<http://genn-team.github.io/genn/documentation/3/html/subsect34.html>



```
WeightUpdateModels::StaticPulse::VarValues excSynInitValues(0.05);  
WeightUpdateModels::StaticPulse::VarValues inhSynInitValues(-5 * 0.05);
```

```
InitSparseConnectivitySnippet::FixedProbability::ParamValues fixedProb(0.1); // 0 - prob
```

```
model.addSynapsePopulation<WeightUpdateModels::StaticPulse, PostsynapticModels::DeltaCurr>(   
    "Exc_Exc", SynapseMatrixType::SPARSE_GLOBALG, NO_DELAY,   
    "Exc" "Exc", {}, excSynInitValues, {}, {},   
    initConnectivity<InitSparseConnectivitySnippet::FixedProbabilityNoAutapse>(fixedProb));  
}
```

Name of
source
population

Name of
target
population

Weight update
model parameters
and initial state

Postsynaptic
model parameters
and initial state
(DeltaCurr has
none)


```
WeightUpdateModels::StaticPulse::VarValues excSynInitValues(0.05);
WeightUpdateModels::StaticPulse::VarValues inhSynInitValues(-5 * 0.05);

InitSparseConnectivitySnippet::FixedProbability::ParamValues fixedProb(0.1); // 0 - prob

model.addSynapsePopulation<WeightUpdateModels::StaticPulse, PostsynapticModels::DeltaCurr>(
    "Exc_Exc", SynapseMatrixType::SPARSE_GLOBALG, NO_DELAY,
    "Exc", "Exc", {}, excSynInitValues, {}, {},
    initConnectivity<InitSparseConnectivitySnippet::FixedProbabilityNoAutapse>(fixedProb));
}
```

Use parameters to initialise connectivity of synapse population

```

WeightUpdateModels::StaticPulse::VarValues excSynInitValues(0.05);
WeightUpdateModels::StaticPulse::VarValues inhSynInitValues(-5 * 0.05);

InitSparseConnectivitySnippet::FixedProbability::ParamValues fixedProb(0.1); // 0 - prob

model.addSynapsePopulation<WeightUpdateModels::StaticPulse, PostsynapticModels::DeltaCurr>(
    "Exc_Exc", SynapseMatrixType::SPARSE_GLOBALG, NO_DELAY,
    "Exc", "Exc", {}, excSynInitValues, {}, {},
    initConnectivity<InitSparseConnectivitySnippet::FixedProbabilityNoAutapse>(fixedProb));
model.addSynapsePopulation<WeightUpdateModels::StaticPulse, PostsynapticModels::DeltaCurr>(
    "Exc_Inh", SynapseMatrixType::SPARSE_GLOBALG, NO_DELAY,
    "Exc", "Inh", {}, excSynInitValues, {}, {},
    initConnectivity<InitSparseConnectivitySnippet::FixedProbability>(fixedProb));
model.addSynapsePopulation<WeightUpdateModels::StaticPulse, PostsynapticModels::DeltaCurr>(
    "Inh_Inh", SynapseMatrixType::SPARSE_GLOBALG, NO_DELAY,
    "Inh", "Inh", {}, inhSynInitValues, {}, {},
    initConnectivity<InitSparseConnectivitySnippet::FixedProbabilityNoAutapse>(fixedProb));
model.addSynapsePopulation<WeightUpdateModels::StaticPulse, PostsynapticModels::DeltaCurr>(
    "Inh_Exc", SynapseMatrixType::SPARSE_GLOBALG, NO_DELAY,
    "Inh", "Exc", {}, inhSynInitValues, {}, {},
    initConnectivity<InitSparseConnectivitySnippet::FixedProbability>(fixedProb));
}

```

Rinse and repeat for the other three connections

Tutorial 2: Generate model code

Linux/Mac with CUDA:

```
genn-buildmodel.sh model.cc
```

Linux/Mac without CUDA:

```
genn-buildmodel.sh -c model.cc
```

Windows with CUDA:

```
genn-buildmodel.bat model.cc
```

Windows without CUDA:

```
genn-buildmodel.bat -c model.cc
```

```
#include "tutorial2_CODE/definitions.h"
#include <fstream>
#include <iostream>
```

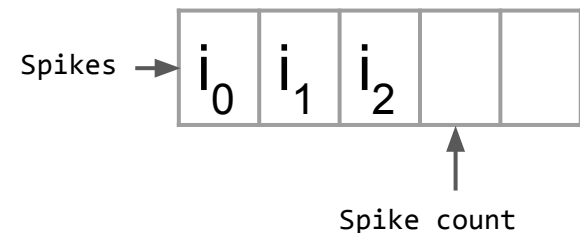
```
int main()
{
    allocateMem();
    std::cout << "Initialising" << std::endl;
    initialize();
    initializeSparse();

    std::cout << "Simulating" << std::endl;
    std::ofstream stream("spikes.csv");
    while(t < 1000.0f) {
        stepTime();
        pullExcCurrentSpikesFromDevice();
        pullInhCurrentSpikesFromDevice();

        for(unsigned int i = 0; i < getExcCurrentSpikeCount(); i++) {
            stream << t << ", " << getExcCurrentSpikes()[i] << std::endl;
        }
        for(unsigned int i = 0; i < getInhCurrentSpikeCount(); i++) {
            stream << t << ", " << 8000 + getInhCurrentSpikes()[i] << std::endl;
        }
    }
    return EXIT_SUCCESS;
}
```

Open CSV file for writing

Download the spikes emitted by the “Exc” and “Inh” populations this timestep from GPU



Tutorial 2: Building on Linux/Mac

Create Makefile

```
genn-create-user-project.sh tutorial2 simulator.cc
```

Build using:

```
make
```

Then run with: `./tutorial2`

Tutorial 2: Building on Windows

Create MSBuild projects

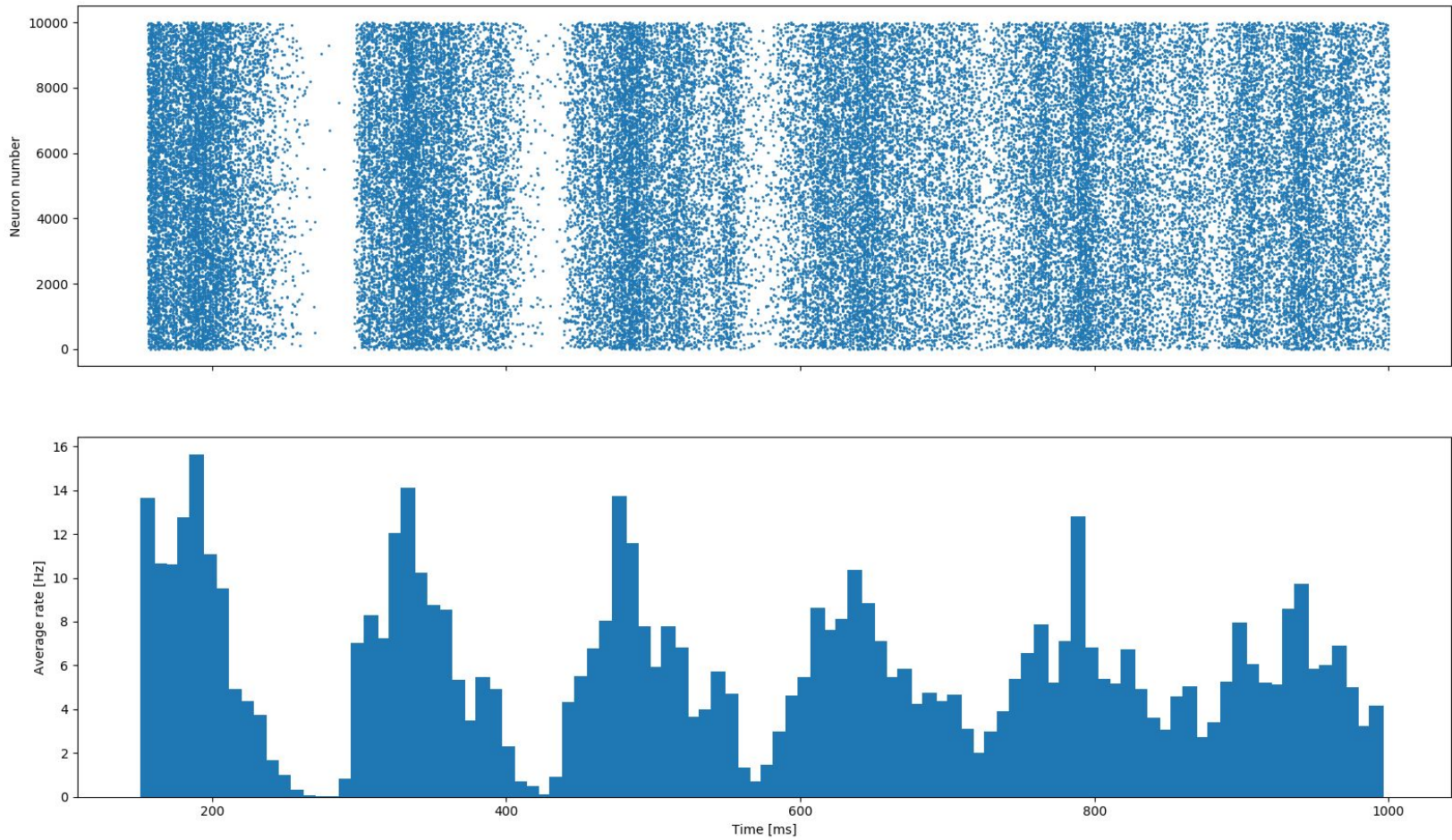
```
genn-create-user-project.bat tutorial2 simulator.cc
```

Build using (or double click solution file):

```
msbuild tutorial2.sln /m /t:tutorial2  
/p:Configuration=Release
```

Then run with: `tutorial2_Release.exe`

Tutorial 2: Results



Tutorial 2: Exercises

- Experiment with what parameters you can change to scale the network while keeping it in the same regime.
- Look in “tutorial2_CODE” at synapseUpdate.cc and see what GeNN is doing!

Brian 2 frontend

```

from brian2 import *
import brian2genn
set_device('genn')

n = 1000
duration = 1*second
tau = 10*ms
eqs = '''
dv/dt = (v0 - v) / tau : volt (unless refractory)
v0 : volt
'''

group = NeuronGroup(n, eqs, threshold='v>10*mV', reset='v=0*mV', refractory=5*ms, method='exact')
group.v = 0*mV
group.v0 = '20*mV * i / (n-1)'
monitor = SpikeMonitor(group)

run(duration)

```

- Probably simplest way of using GeNN
- Currently only compatible with GeNN 3.3.0
- For installation instructions talk to Thomas or see:

<https://brian2genn.readthedocs.io/en/latest/introduction/index.html#installing-the-brian2genn-interface>



Google
Summer of Code

Python interface and PyNN frontend

Installation from binary wheels

1. Select a suitable wheel from the latest release available at <https://github.com/genn-team/genn/releases>

For example, if you have a Linux system with Python 3.7, you would pick `pygenn-0.2-cp37-cp37m-linux_x86_64.whl`

Note: the Mac OS X wheel are built for CUDA 9, all others for CUDA 10

2. Install the wheel using pip e.g.

```
pip install pygenn-0.2-cp37-cp37m-linux_x86_64.whl
```

Installation from source on Linux/Mac

1. Download latest release of GeNN from <https://github.com/genn-team/genn/releases>
2. Make sure you have swig installed
3. From GeNN directory, build as a dynamic library, directly into the PyGeNN directory using:
`make DYNAMIC=1`
`LIBRARY_DIRECTORY=`pwd` /pygenn/genn_wrapper/`
4. Build and install python module with setuptools using:
`python setup.py develop`

Installation from source on Windows

1. Download latest release of GeNN from <https://github.com/genn-team/genn/releases>
2. Make sure you have swig installed
3. From GeNN directory, build as a dynamic library using:
`msbuild genn.sln /m /t:Build
/p:Configuration=Release_DLL`
4. Copy the newly built DLLs into pygenn using
`copy /Y lib\genn*Release_DLL.* pygenn\genn_wrapper`
5. Build and install python module with setuptools using:
`python setup.py develop`

```
import numpy as np
import matplotlib.pyplot as plt
from pygenn import genn_wrapper, genn_model
```

```
model = genn_model.GeNNModel("float", "tutorial1_pygenn")
model.dT = 0.1
```

More Pythonic parameters

```
izk_init = {"V": -65.0, "U": -20.0,
            "a": [0.02, 0.1, 0.02, 0.02], "b": [0.2, 0.2, 0.2, 0.2],
            "c": [-65.0, -65.0, -50.0, -55.0], "d": [8.0, 2.0, 2.0, 4.0]}
pop = model.add_neuron_population("Neurons", 4, "IzhikevichVariable", {}, izk_init)
model.add_current_source("CurrentSource", "DC", "Neurons", {"amp": 10.0}, {})
```

```
model.build()
model.load()
```

Numpy views for efficient io

```
voltage_view = pop.vars["V"].view
v = None
while model.t < 200.0:
    model.step_time()
    model.pull_state_from_device("Neurons")
    v = (np.copy(voltage_view) if v is None else np.vstack((v, voltage_view)))
```

```
figure, axes = plt.subplots(4, sharex=True)
for i, t in enumerate(["RS", "FS", "CH", "IB"]):
    axes[i].plot(np.arange(0.0, 200.0, 0.1), v[:,i])
plt.show()
```



PyNN is a simulator-independent language for building neuronal network models in Python

Installation

Once you have managed to install PyGeNN, this should be easy

1. Clone master branch of PyNN-GeNN from https://github.com/genn-team/pynn_genn
2. Install with setuptools using `python setup.py develop`

Thank you

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