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.

CUDA on Windows

- CUDA is nicely integrated into Visual Studio and provided graphical debugging and profiling tools
- Because Visual Studio is updated (annoyingly) frequently, compiler/CUDA version issues are more prevalent than on Linux
- If installing from scratch we recommend:
  - CUDA 9.2.148
  - Visual Studio 2017 15.6.7
- There are performance issues with CUDA on Windows display devices

https://docs.microsoft.com/en-us/visualstudio/productinfo/installing-an-earlier-release-of-vs2017

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
- If you have CUDA installed, set the `CUDA_PATH` environment variable to its location
- Add `$GENN_PATH/bin` 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
```

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
```

Build generated code:

Linux/Mac:

```
make
```

Windows (or double click solution file):

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

Run model and plot results:

Linux/Mac:

```
./va_benchmark

python plot_spikes.py
```

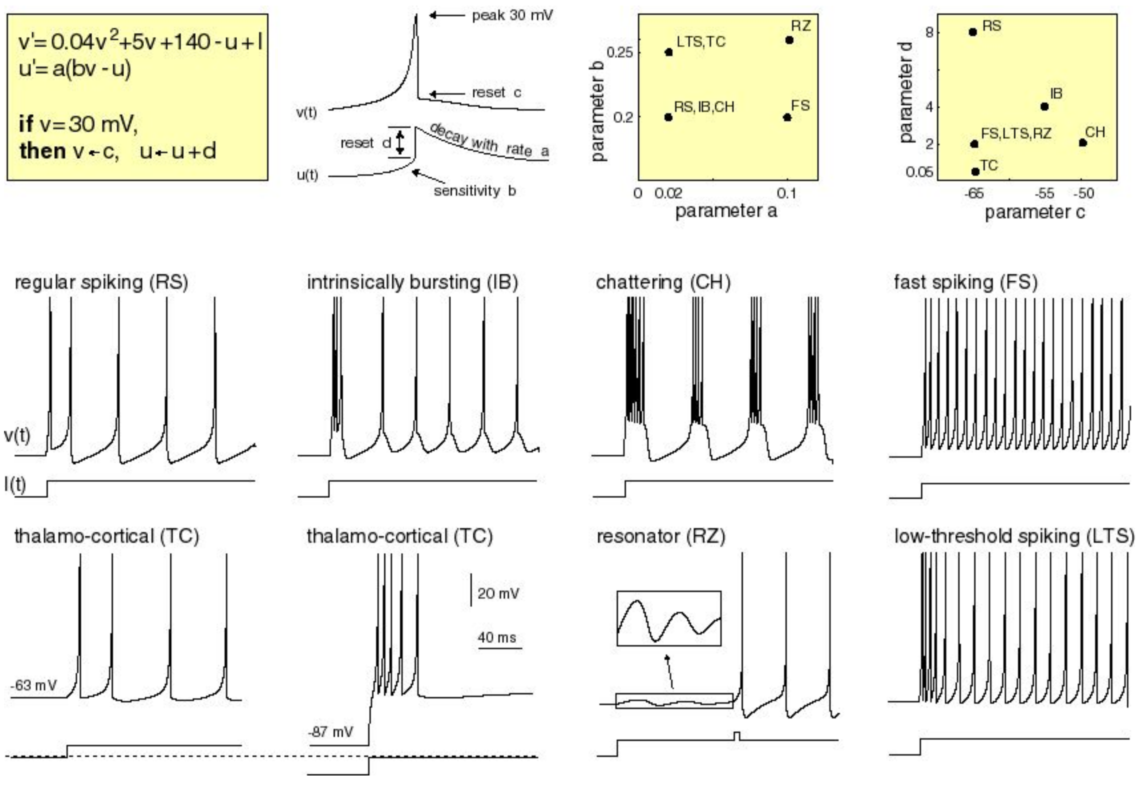
Windows:

```
va_benchmark_Release

python plot_spikes.py
```

Tutorial 1: Neurons

Tutorial 1: Introduction

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



```
#include "modelSpec.h"
void modelDefinition(NNmodel &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

```cpp
#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>("Neur
                                                                 param

    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();
    return EXIT_SUCCESS;
}
```

Include generated code

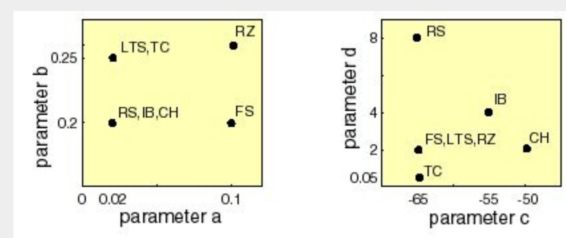
Call generated function to make necessary memory allocations

Call generated function to perform first stage of initialisation (V and U will be initialised here)

```
#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

```cpp
#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();
        pullNeuronsStateFromDevice();

        stream << t << "," << VNeurons[0] << "," << VNeurons[1];
        stream << "," << VNeurons[2] << "," << VNeurons[3] << std::endl;
    }

    return EXIT_SUCCESS;
}
```

Include standard header for file IO

Open CSV file for writing

Download the state of “Neurons” population 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

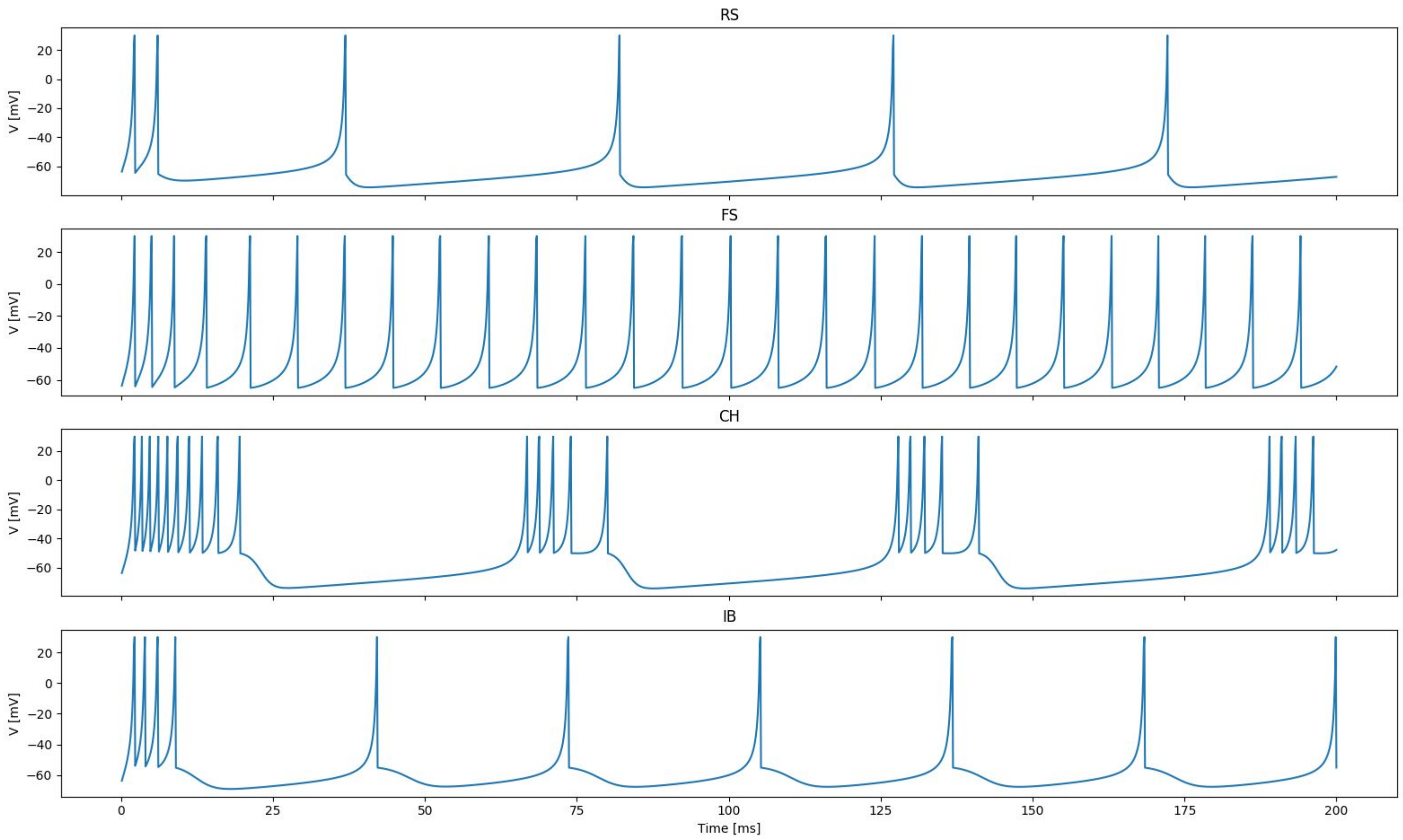
```
genn-create-user-project.bat tutorial1 simulator.cc
```

Build using (or double click solution file):

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

Then run with: `tutorial1_Release.exe`

Tutorial 1: Results

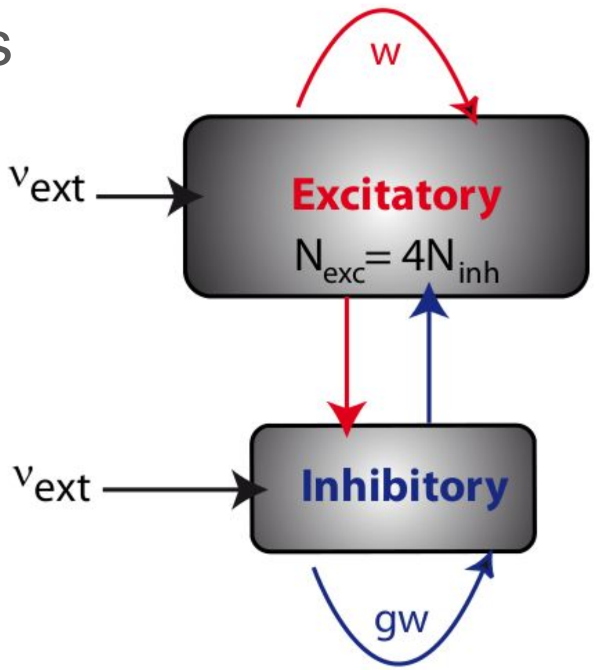


Tutorial 1: Exercises

- 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



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

Hopefully this is now all familiar

```cpp
#include "modelSpec.h"
void modelDefinition(NNmodel &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,                                      // 0 - V
        initVar<InitVarSnippet::Uniform>(uDist));   // 1 - U
    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**

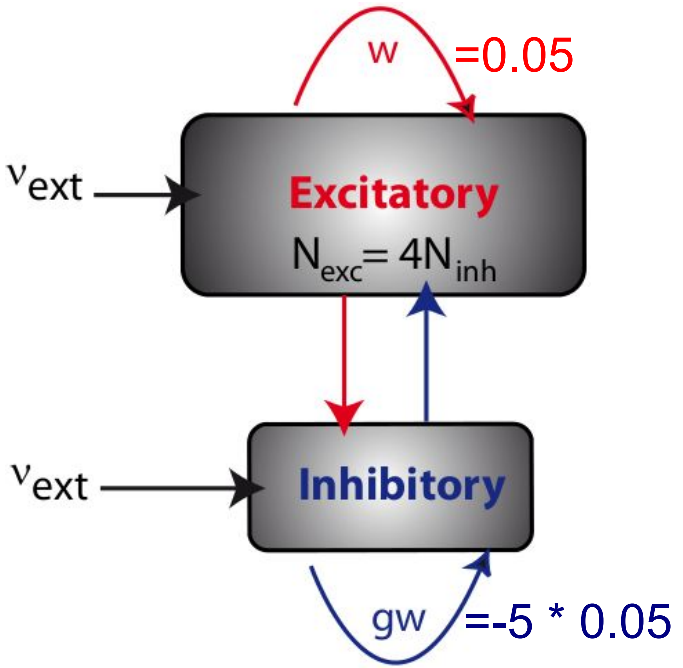
Use distribution to initialise u

Add neuron populations and current sources as before

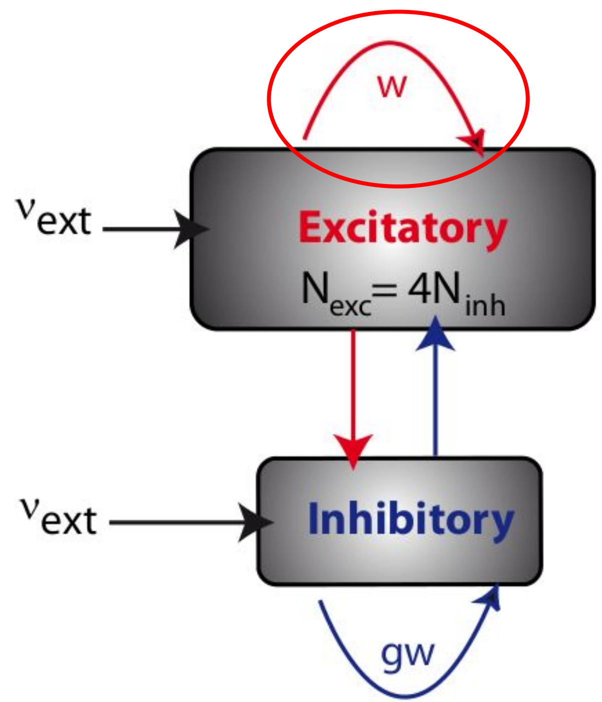
```
    WeightUpdateModels::StaticPulse::VarValues excSynInitValues(0.05);
    WeightUpdateModels::StaticPulse::VarValues inhSynInitValues(-5 * 0.05);

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

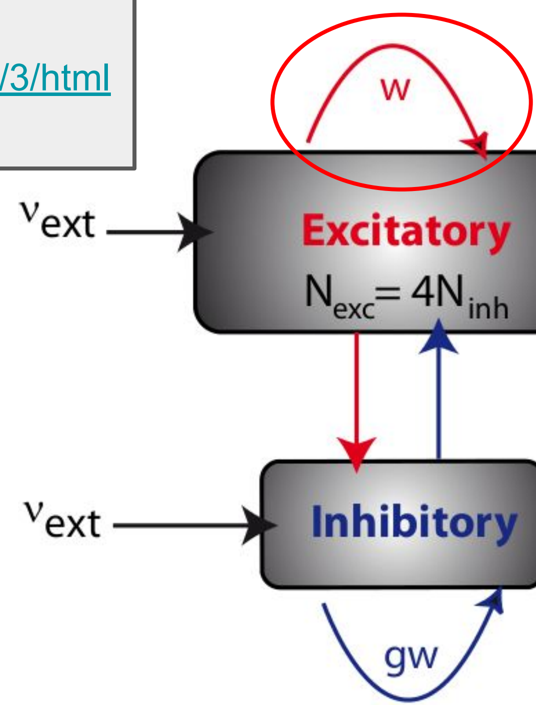
```
    WeightUpdateModels::StaticPulse::VarValues excSynInitValues(0.05);
    WeightUpdateModels::StaticPulse::VarValues inhSynInitValues(-5 * 0.05);

    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

```cpp
    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
```

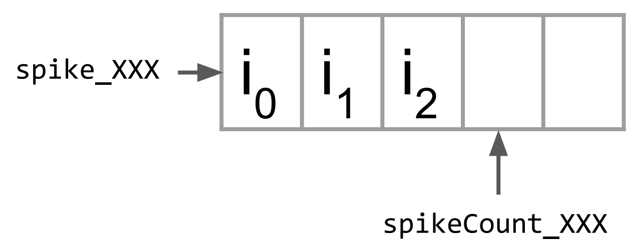
Windows without CUDA:

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

```cpp
#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 < spikeCount_Exc; i++) {
            stream << t << ", " << spike_Exc[i] << std::endl;
        }
        for(unsigned int i = 0; i < spikeCount_Inh; i++) {
            stream << t << ", " << 8000 + spike_Inh[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

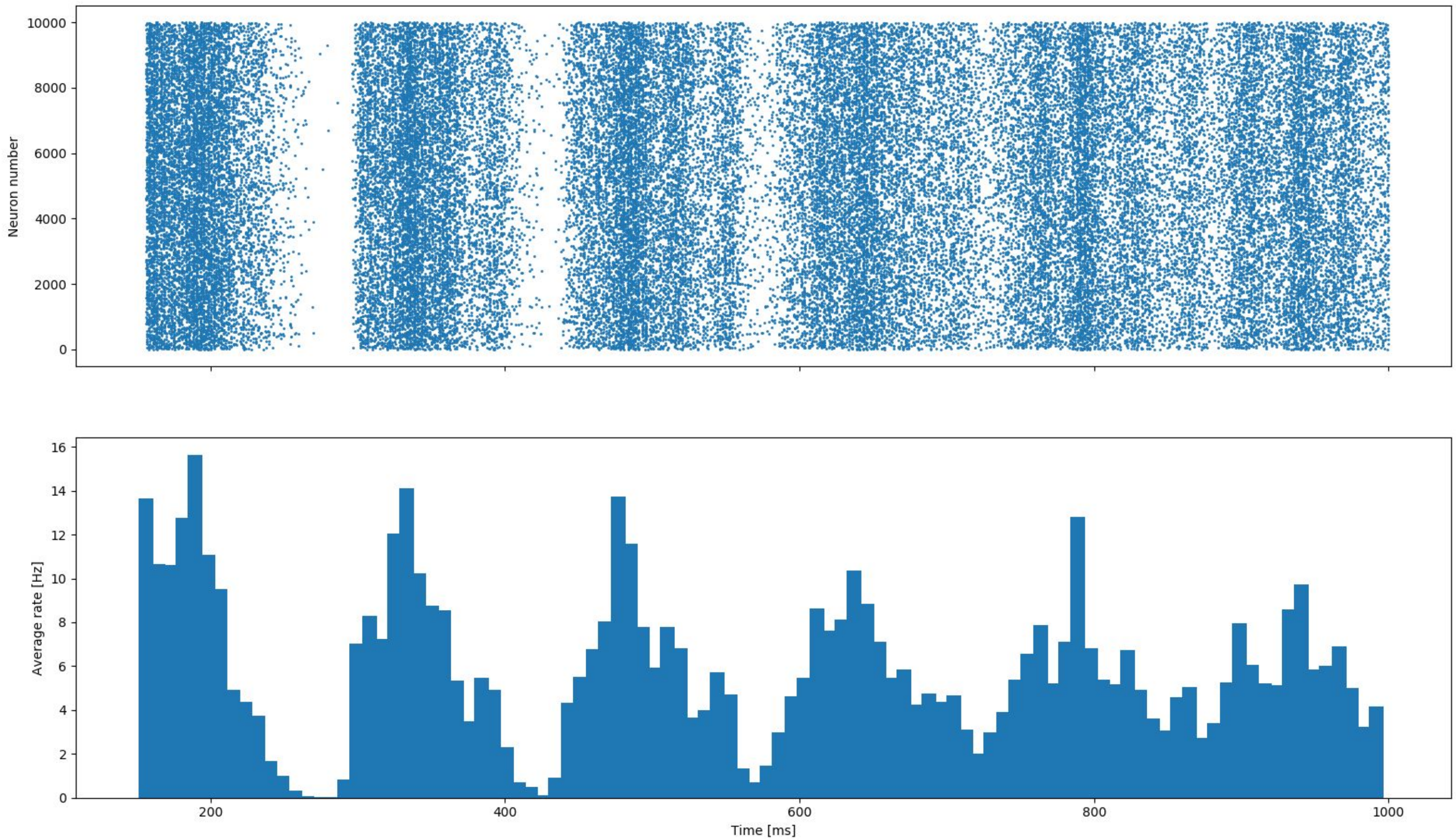
```
genn-create-user-project.bat tutorial2 simulator.cc
```

Build using (or double click solution file):

```
msbuild tutorial2.sln /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

```python
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

build unstable

Google Summer of Code

Python interface and PyNN frontend

Installation from binary wheels

1. Select a suitable wheel from the Releases page. For example, if you have a Linux system with Python 3.7 and CUDA 10, you would pick `cuda10-pygenn-0.2-cp37-cp37m-linux_x86_64.whl`. If you do not have CUDA installed, ignore the CUDA version and pick the wheel that otherwise matches your platform.
2. Install the wheel using pip e.g.
   ```
   pip install cuda10-pygenn-0.2-cp37-cp37m-linux_x86_64.whl
   ```

Installation from source on Linux/Mac

1. Make sure you have swig installed
2. From GeNN directory, build as a dynamic library, directly into the PyGeNN directory using:
   ```
   make DYNAMIC=1
   LIBRARY_DIRECTORY=`pwd`/pygenn/genn_wrapper/
   ```
3. Install python module with setuptools using:
   ```
   python setup.py develop
   ```

Installation from source on Windows

1. Ensure that you have at least Python 3.5 and Visual Studio 2015 installed as well as swig
2. Ensure that your command prompt has Python and Visual studio properly configured i.e. by activating conda within a Visual Studio "x64 Native Tools Command Prompt"
3. From GeNN directory, build as a dynamic library using:
   ```
   msbuild genn.sln /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. Install python module with setuptools using:
   ```
   python setup.py develop
   ```

```python
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

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()

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()
```

More Pythonic parameters

Numpy views for efficient io

PyNN 🌲

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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