Real-Time Simulation of Large-Scale Neural Models using NCS

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Today's Outline

- **First Hour**
  - Introduction
  - Equations and Implementation
  - Requirements and Simulation on a Single Machine
  - Input Language
- **Second Hour**
  - Simple Model
  - Parameters Presentation and Testing
  - Output Analysis
- **Third Hour**
  - Simulation on Multiple Machines
  - Software Tools
  - Robotic System Configuration
  - Larger Networks and Complete Loop Execution
  - Future Directions and Summary

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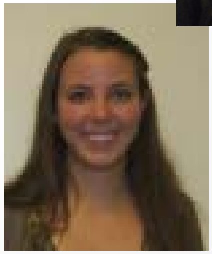
Introduction

Presenters

- Fred Harris
  - Professor – Department of Computer Science and Engineering
    - Ph.D. in Computer Science
- Laurence Bray
  - Post Doctoral Research Associate,
    - Soon to be promoted to Research Assistant Professor
    - Ph.D. in Biomedical Engineering
- Roger Hoang
  - Ph.D. Candidate
    - Planning to graduate this coming school year
    - Majoring in Computer Science
- Emily Barker
  - B.S. Student
    - Starting her Senior year this fall
    - Majoring in Neuroscience

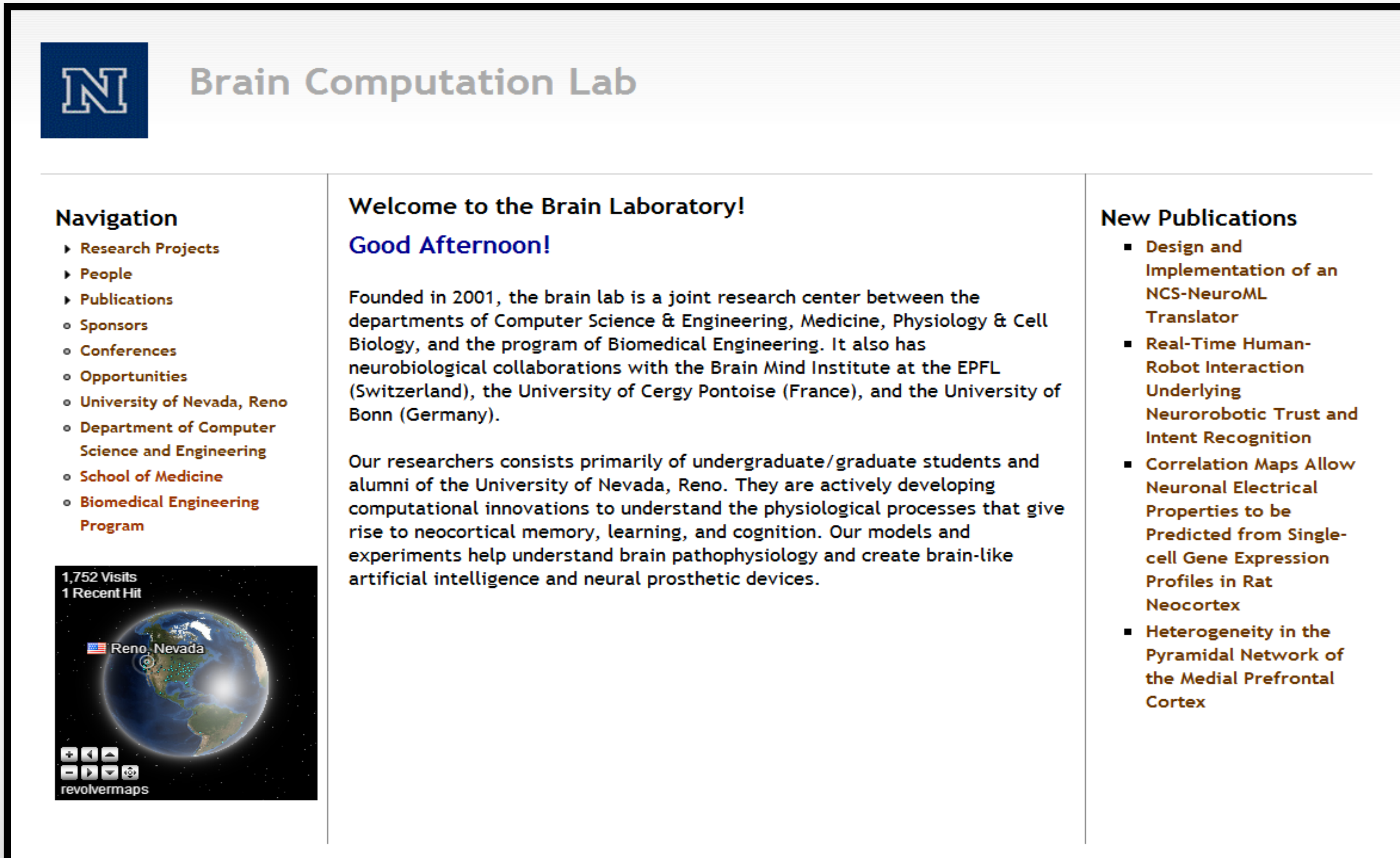


Reno, Nevada

University of Nevada, Reno

Brain Computation Lab

- http://www.cse.unr.edu/brain/



Brain Computation Lab

Navigation

- Research Projects
- People
- Publications
- Sponsors
- Conferences
- Opportunities
- University of Nevada, Reno
- Department of Computer Science and Engineering
- School of Medicine
- Biomedical Engineering Program

1,752 Visits
1 Recent Hit
Reno, Nevada
revolvermaps

Welcome to the Brain Laboratory!

Good Afternoon!

Founded in 2001, the brain lab is a joint research center between the departments of Computer Science & Engineering, Medicine, Physiology & Cell Biology, and the program of Biomedical Engineering. It also has neurobiological collaborations with the Brain Mind Institute at the EPFL (Switzerland), the University of Cergy Pontoise (France), and the University of Bonn (Germany).

Our researchers consists primarily of undergraduate/graduate students and alumni of the University of Nevada, Reno. They are actively developing computational innovations to understand the physiological processes that give rise to neocortical memory, learning, and cognition. Our models and experiments help understand brain pathophysiology and create brain-like artificial intelligence and neural prosthetic devices.

New Publications

- Design and Implementation of an NCS-NeuroML Translator
- Real-Time Human-Robot Interaction Underlying Neurorobotic Trust and Intent Recognition
- Correlation Maps Allow Neuronal Electrical Properties to be Predicted from Single-cell Gene Expression Profiles in Rat Neocortex
- Heterogeneity in the Pyramidal Network of the Medial Prefrontal Cortex

NCS History

- **Version 1:1999**
  - o Matlab – Goodman, Markram, and McKenna
  - o 160-cell, 2-column architecture
    - Each cell was modeled as a single integrative compartment (point neuron) with a spike mechanism,
      - o calcium-dependent (AHP) channels, and
      - o voltage-sensitive A and M (muscarinic) potassium channels
- **Version 1b: 1999**
  - o Direct translation to C from Matlab
  - o 24 times faster.
  - o tested on mixed excitatory-inhibitory networks of up to 1,000 cells
- **Version 2: 1999**
  - o code was then redesigned and rewritten for distributed processing on an existing 20-cpu cluster (Pentium II).
  - o Initial trials of this code were performed on cortical networks of 2 to 1,000 cells

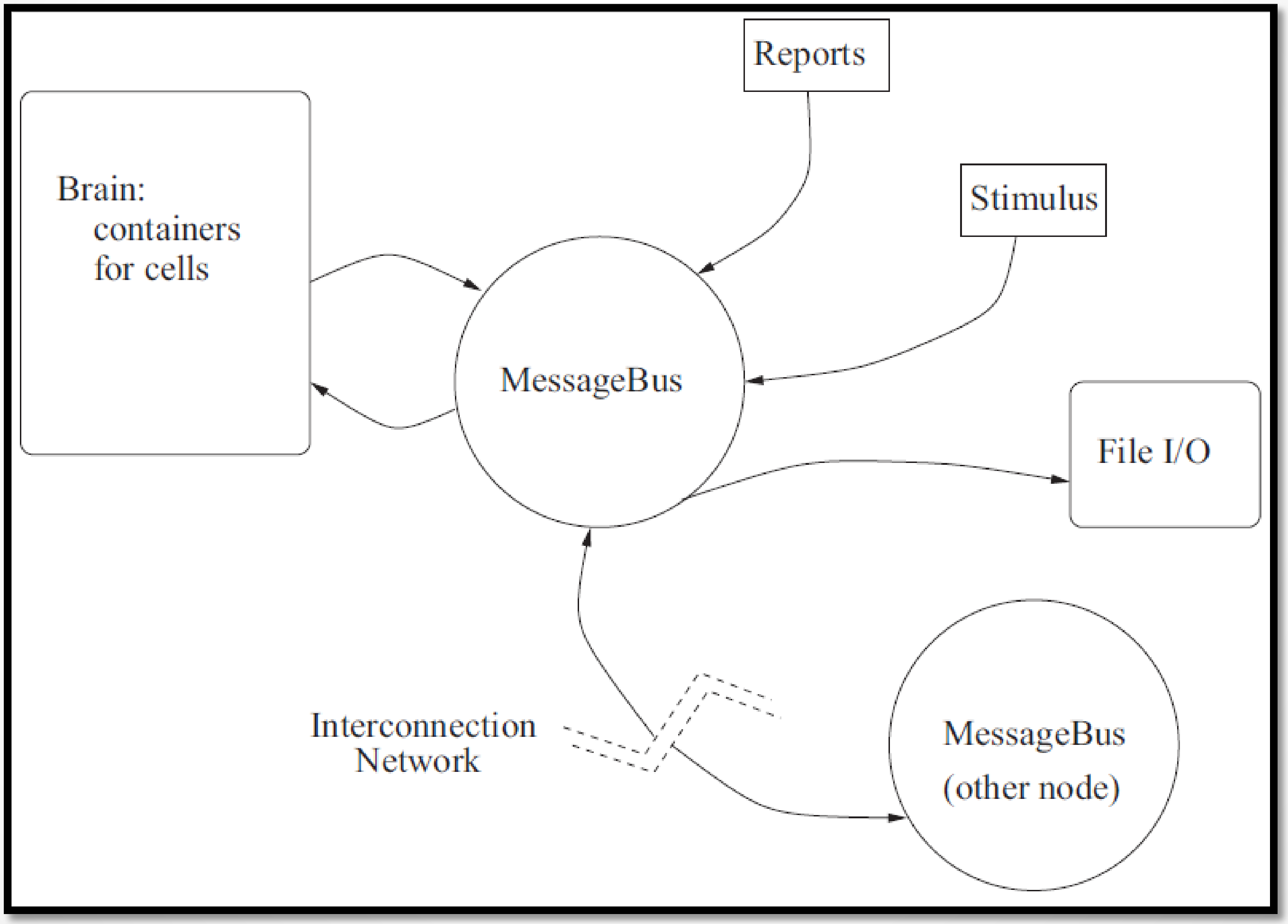
M.M. Kellog, H.R. Wills, and P.H. Goodman. "A biologically realistic computer model of neocortical associative learning for the study of aging and dementia." J. Investig. Med., 47(2), February 1999.

NCS History

- **Version 3: 2001**
  - completely redesigned using object-oriented design principles and recoded in C++
  - objects, such as cells, compartments, channels, and the like, model the corresponding cortical entities.
  - The cells, in turn, communicate via messages passed through synapse objects.
  - Input parameters allow the user to create many variations of the basic objects, in order to model measured or hypothesized biological properties.

E. Courtenay Wilson, Phillip H. Goodman, and Frederick C. Harris, Jr. "Implementation of a biologically realistic parallel neocortical-neural network simulator" in Proceedings of the 10th SIAM Conf. on Parallel Process. for Sci. Computing, Portsmouth, Virginia, March 2001.

NCS History



E. Courtenay Wilson, Frederick C. Harris, Jr., and Phillip H. Goodman. "A large-scale biologically realistic cortical simulator" in Proceedings of SC 2001, Denver, Colorado, November 2001

Code Optimization & Revisions

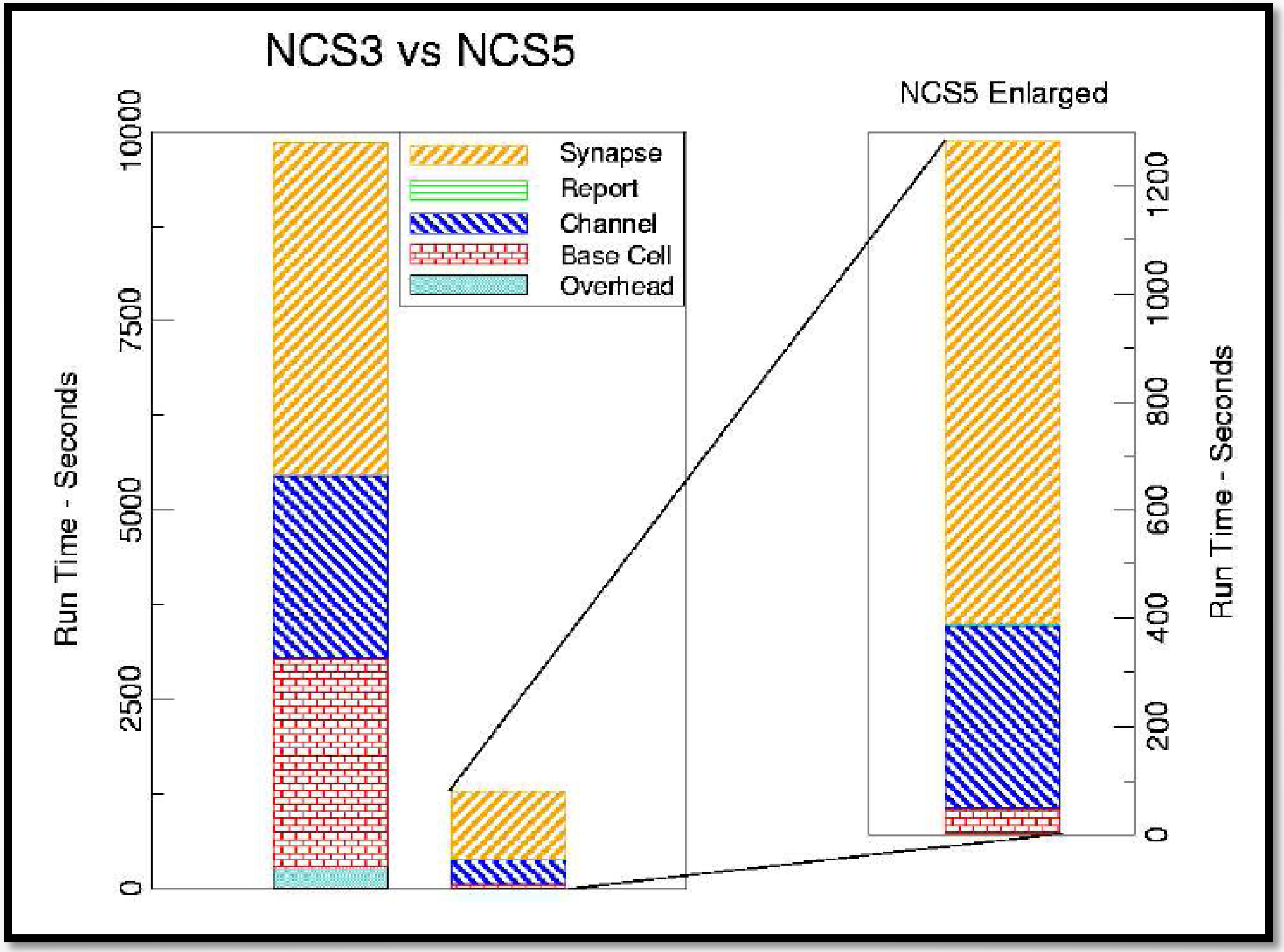
- Rewrote the input parser
- Worked on code base
  - sevenfold sequential speedup over the version 3 code
  - added new features while shrinking our code base by more than 25%.
- Added More Biological Parameters.
- 35,000 cells and approximately 6.1 million synapses using 72% of the available 4GB of memory per node.

Code Optimization

Item	NCS3	NCS5	Ratio
Overhead[a]	294.167	1.897	155.1
Base Cell/Cmp[b]	0.020	3.035	153.6
Channel[b]	0.152	0.398	2.6
Report[c]	0.017	4.113	239.4
Synapse, 0Hebb[b]	0.031	0.383	12.5
Synapse, +-Hebb[b]	0.020	0.368	18.1

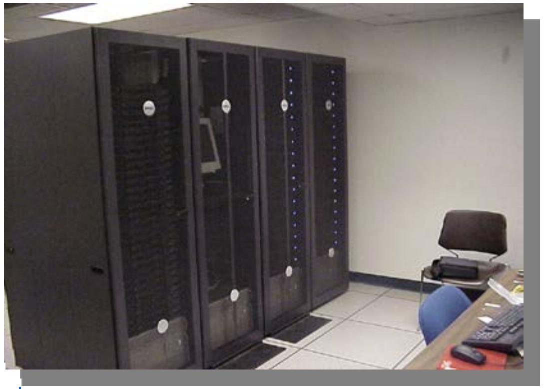
a) Seconds.
b) Millions of Objects Processed per Second
c) Millions of Values Reported per Second

Code Optimization



James Frye, James G. King, Christine J. Wilson, and Frederick C. Harris, Jr. “QQ: Nanoscale timing and profiling” In Proceedings of PMEO-PDS, Denver, CO, April 3-8 2005.

Hardware



2001

2002

PIII 1GHz
(60 CPUs)

P IV Xeon 2.2GHz
(68 CPUs)

Myrinet 2000

ONR DURIP 2002: N000140210557

ONR DURIP 2001: N000140110552

Hardware

2007

2008

Sun v20z Opteron
(60 CPUs)

ONR DURIP 2007:

Sun 4600s and 4500s
16 core boxes with 200GB of RAM
connected by Infiniband
And several 24TB disk arrays

ONR DURIP 2008:

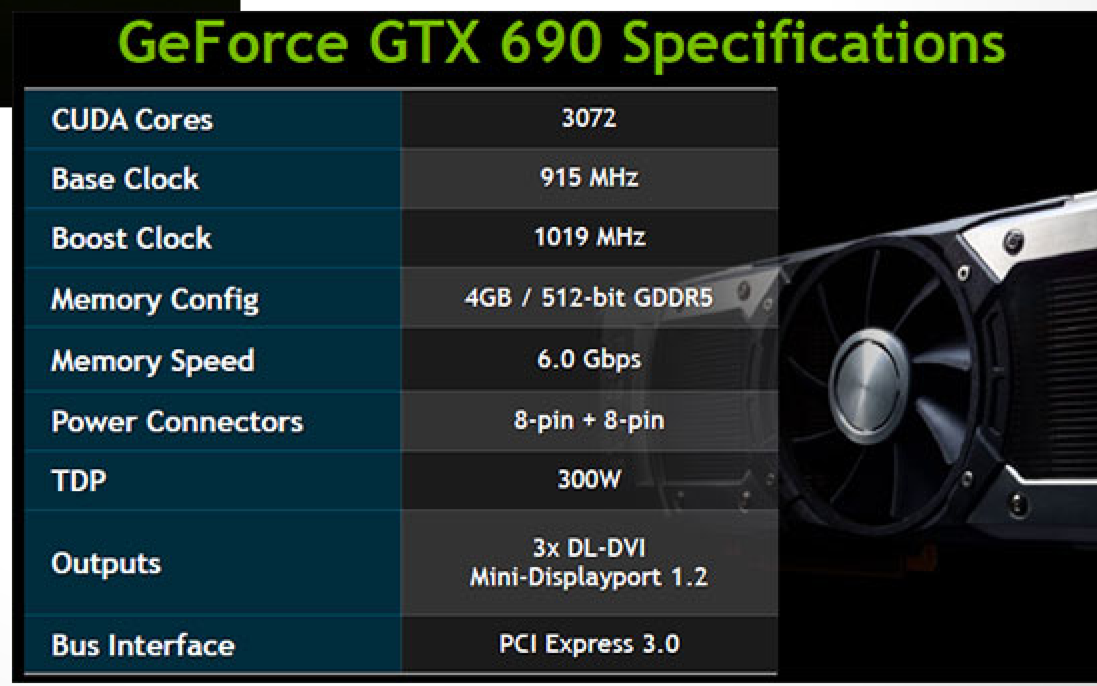
Current NCS version 6

- GPU/CPU/cluster-based
- Multiple neuron types (version 5 + izhikevich + framework for others)
- Ability for multi-scale modeling

Current Hardware

GeForce GTX 480
Fastest GPU in the World

Memory	1536MB / 384-bit GDDR5
Cores	480
Gfx / Proc / Mem Clock	700 / 1401 / 1848 MHz
Power Connectors	6-pin + 8-pin
Power	250W
SLI	3-way
Length	10.5 inches
Thermal	Dual Slot Fansink
Outputs	DL-DVI DL-DVI mini-HDMI



GeForce GTX 690 Specifications

CUDA Cores	3072
Base Clock	915 MHz
Boost Clock	1019 MHz
Memory Config	4GB / 512-bit GDDR5
Memory Speed	6.0 Gbps
Power Connectors	8-pin + 8-pin
TDP	300W
Outputs	3x DL-DVI Mini-Displayport 1.2
Bus Interface	PCI Express 3.0

Current Optimizations

- C++11
- Heavily threaded
  - Latency hiding
  - Increased occupancy
- Modular message passing design
- GPU usage for parallel computation
- Load-balancing across heterogeneous clusters

Current Optimization

Cell Count	Synapse Count	NCS5 Simulation Time (Sec)	NCS6 Simulation Time (Sec)
~1,000	~2700	3.3	<1
~10,000	~250,000	4.4	<1
~100,000	~25,000,000	99.0	1.1

Comparison with other Simulators

- Advantages:
  - No programing language experience
  - Large-scale networks simulation
  - Real-time Execution
  - Good for behavior, systems, and networks
  - Framework for different level of abstraction

- Disadvantages
  - Lack of cellular and subcellular details
  - No anatomical visualization yet

Romain Brette, Michelle Rudolph, Ted Carnevale, Michael Hines, David Beeman, James M. Bower, Markus Diesmann, Abigail Morrison, Philip H. Goodman, Frederick C. Harris, Jr., Milind Zirpe, Thomas Natschlager, Dejan Pecevski, Bard Ermentrout, Mikael Djurfeldt, Anders Lansner, Olivier Rochel, Thierry Vieville, Eilif Muller, Andrew P. Davison, Sami El Boustani and Alain Destexhe "Simulation of networks of spiking neurons: A review of tools and strategies" Journal of Computational Neuroscience December 2007 (Vol 23), pp 349-398.

Equations and Implementation

Compartments

```
int refractoryTime = _refractoryTime[index];
float calcium = _oldCalcium[index];
if (refractoryTime >= 0)
{
    _newVoltage[index] = spikeShapes[index][refractoryTime];
    --refractoryTime;
    _refractoryTime[index] = refractoryTime;
    _newCalcium[index] = _oldCalcium[index];
}
else
{
    float I = 0.0f;
    float voltage = _oldVoltage[index];
    I += inputCurrent[index];
    I += channelCurrent[index];
    I -= leakConductance[index] * (voltage - leakReversal[index]);
    I += synapticCurrent[index];
    if (bit::extract(voltageClamp, index))
    {
        voltage = clampVoltage[index];
    }
    else
    {
        float restVoltage = _restVoltage[index];
        voltage = restVoltage +
                  (voltage - restVoltage) * persistence[index] +
                  dtC[index] * I;
    }
    voltage = voltage < -80.0f? -80.0f : voltage;

    //Check for firing
    if (voltage > threshold[index])
    {
        refractoryTime = spikeShapeLength[index] - 1;
        voltage = spikeShapes[index][refractoryTime];
        _refractoryTime[index] = refractoryTime - 1;
        warpResult = mask;
        calcium += caSpikeIncrement[index];
    }

    calcium *= caPersistence[index];
    _newCalcium[index] = calcium;
    _newVoltage[index] = voltage;
}
```

Ka Channels

```
unsigned int compartmentID = compartmentIDs[index];
float compartmentVoltage = compartmentVoltages[compartmentID];
unsigned int tauMIndex = tauMIndices[index];
unsigned int tauMEnd = tauMIndices[index + 1];
float t_m = 0.0f;
for (; tauMIndex < tauMEnd; ++tauMIndex)
{
    if (compartmentVoltage < tauMVoltage[tauMIndex])
    {
        t_m = tauMValue[tauMIndex];
        break;
    }
}
float m_oo =
    1.0f / (1.0f + exp(-(compartmentVoltage - eHalfMinM[index]) /
                       slopeFactorM[index]));
float m = _m[index];
m += (m_oo - m) * dt / t_m;
m = (m < 0.0f)? 0.0f : (m > 1.0f)? 1.0f : m;
_m[index] = m;

unsigned int tauHIndex = tauHIndices[index];
unsigned int tauHEnd = tauHIndices[index + 1];
float t_h = 0.0f;
for (; tauHIndex < tauHEnd; ++tauHIndex)
{
    if (compartmentVoltage < tauHVoltage[tauHIndex])
    {
        t_h = tauHValue[tauHIndex];
        return;
    }
}
float h_oo =
    1.0f / (1.0f + exp((compartmentVoltage - eHalfMinH[index]) /
                       slopeFactorH[index]));
float h = _h[index];
h += (h_oo - h) * dt / t_h;
h = (h < 0.0f)? 0.0f : (h > 1.0f)? 1.0f : h;
_h[index] = h;

float I = unitaryG[index] * strength[index] * pow(m, mPower[index]) *
          pow(h, hPower[index]) *
          (reversalPotential[index] - compartmentVoltage);
atomicAdd(compartmentCurrents + compartmentID, I);
```

Kahp Channels

```
unsigned int compartmentID = compartmentIDs[index];
float compartmentVoltage = compartmentVoltages[compartmentID];
float funct_m =
    caScaleFactor[index] *
    pow(compartmentCalcium[compartmentID], caExpFactor[index]);
float denominator = (funct_m + caHalfMin[index]);
float t_m = caTauScaleFactor[index] / denominator;
float m_oo = funct_m / denominator;
float m = _m[index];
m += (m_oo - m) * dt / t_m;
m = (m < 0.0f)? 0.0f : (m > 1.0f)? 1.0f : m;
_m[index] = m;
float I = unitaryG[index] * strength[index] * pow(m, mPower[index]) *
          (reversalPotential[index] - compartmentVoltage);
atomicAdd(compartmentCurrents + compartmentID, I);
```

Km Channels

```
unsigned int compartmentID = compartmentIDs[index];
float compartmentVoltage = compartmentVoltages[compartmentID];
float dV = compartmentVoltage - eHalfMinM[index];
float t_m = tauScaleFactorM[index] / (exp(dV / slopeFactorM0[index]) +
                                      exp(-dV / slopeFactorM1[index]));
float m_oo = 1.0f / (1.0f + exp(-dV / slopeFactorM2[index]));
float m = _m[index];
m += (m_oo - m) * dt / t_m;
m = (m < 0.0f)? 0.0f : (m > 1.0f)? 1.0f : m;
_m[index] = m;
float I = unitaryG[index] * strength[index] * pow(m, mPower[index]) *
          (reversalPotential[index] - compartmentVoltage);
atomicAdd(compartmentCurrents + compartmentID, I);
```

Short-Term Learning

```
unsigned int index = indices[block::thread()];
const unsigned char type = RSEType[index];
float USE = _USE[index];
float RSE = _RSE[index];
float USEBase = _USEBase[index];
float dt = elapsedTime - _lastFireTime[index];
float firingValue = maxG[index];
if (type & 0x2u) //Facilitation
{
    USE += (1.0f - USEBase) * USE  *
           exp(1000.0f * -dt / tauFacilitation[index]);
    USE = math::clamp(USE, 0.0f, 1.0f);
    _USE[index] = USE;
}
if (type & 0x1u) //Depression
{
    RSE = 1.0f + ((RSE * (1.0f - USEBase) - 1.0f) *
                  exp(1000.0f * -dt / tauDepression[index]));
    RSE = math::clamp(RSE, 0.0f, 1.0f);
    _RSE[index] = RSE;
}

switch(type)
{
case 0x0: //None
    firingValue *= USEBase;
break;
case 0x1: //Depression
    firingValue *= USEBase * RSE;
break;
case 0x2: //Facilitation
    firingValue *= USE;
break;
case 0x3: //Both
    firingValue *= USE * RSE;
break;
default:
break;
}
```

Long-Term Negative Learning

```
//Negative learning
if (learningOn[index])
{
    float postDT = elapsedTime - lastPostFireTime[index];
    switch(learningType[index])
    {
    case 0: //None
    break;
    case 1: //Exponential
    {
        float positiveLearningModulator = _positiveLearningModulator[index];
        positiveLearningModulator *=
            exp(1000.0f * -dt / positivePeakTime[index]);
        positiveLearningModulator += positivePeakDeltaUSE[index];
        _positiveLearningModulator[index] = positiveLearningModulator;
        USEBase -=
            exp(1000.0f * -postDT / negativePeakTime[index]) *
            negativeLearningModulator[index];
        if (USEBase < 0.0f) USEBase = 0.0f;
        _USEBase[index] = USEBase;
    }
    break;
    case 2: //Triangle
    {
        float _negativeWindowWidth = negativeWindowWidth[index];
        if (postDT < _negativeWindowWidth)
        {
            float peakTime = negativePeakTime[index];
            float dUSE = negativePeakDeltaUSE[index];
            if (postDT < peakTime)
            {
                dUSE *= (postDT / peakTime);
            }
            else
            {
                dUSE *= 1.0f - (postDT - peakTime) /
                        (_negativeWindowWidth - peakTime);
            }
            USEBase -= dUSE;
            if (USEBase < 0.0f) USEBase = 0.0f;
            _USEBase[index] = USEBase;
        }
    }
    break;
    default:
    break;
    };
}
```

Long-Term Positive Learning

```
{
    float USEBase = _USEBase[index];
    float preDT = elapsedTime - lastPreFireTime[index];
    switch(learningType[index])
    {
    case 0: //None
    break;
    case 1: //Exponential
    {
        float postDT = elapsedTime - lastPostFireTime[index];
        float negativeLearningModulator = _negativeLearningModulator[index];
        negativeLearningModulator *=
            exp(1000.0f * -postDT / negativePeakTime[index]);
        negativeLearningModulator += negativePeakDeltaUSE[index];
        _negativeLearningModulator[index] = negativeLearningModulator;
        USEBase +=
            exp(1000.0f * -preDT / positivePeakTime[index]) *
            positiveLearningModulator[index];
        if (USEBase > 1.0f) USEBase = 1.0f;
        _USEBase[index] = USEBase;
    }
    break;
    case 2: //Triangle
    {
        float _positiveWindowWidth = positiveWindowWidth[index];
        if (preDT < _positiveWindowWidth)
        {
            float peakTime = positivePeakTime[index];
            float dUSE = positivePeakDeltaUSE[index];
            if (preDT < peakTime)
            {
                dUSE *= (preDT / peakTime);
            }
            else
            {
                dUSE *= 1.0f - (preDT - peakTime) /
                        (_positiveWindowWidth - peakTime);
            }
            USEBase += dUSE;
            if (USEBase > 1.0f) USEBase = 1.0f;
            _USEBase[index] = USEBase;
        }
    }
    break;
    default:
    break;
    }
} //if learning on
```

Post Synaptic Conductance

```
unsigned int firingIndex = firingIndices[index];
unsigned int PSGCount = PSGCounts[index];
--PSGCount;
float PSGValue = PSGs[firingIndex][PSGCount];
unsigned int postNeuronID = postNeuronIDs[firingIndex];
float voltage = synapticReversal[firingIndex];
voltage -= voltages[postNeuronID];
float firingValue = firingValues[index];
float current = voltage * firingValue * PSGValue;
atomicAdd(synapticCurrents + postNeuronID, current);

bool save = false;
unsigned int saveIndex;
if (PSGCount > 0)
{
    save = true;
    saveIndex = atomicAdd(&numQueued, 1u);
    if (saveIndex < block::size())
    {
        queuedIndices[saveIndex] = firingIndex;
        queuedPSGCounts[saveIndex] = PSGCount;
        queuedFiringValues[saveIndex] = firingValue;
        save = false;
    }
    else
        saveIndex -= block::size();
}
```

NCS 6 Implementation

- Plugin interface for multiple model support
  - Currently have:
    - NCS 5 LIF Neurons
    - Izhikevich Neurons
  - ability to design your own
  - Have a student working on a Neuron CPU plugin.

- Runs on CPUs, CUDA devices, and OpenCL devices simultaneously

Requirements

NCS5 Software / Hardware

- Linux based operating system

NCS6 Software / Hardware

- Linux based operating system
- NVDIA GPUs

NCS5- Packages Needed

- **bison** : sudo apt-get install bison
- **flex** : sudo apt-get install flex
- **mpi-run** : sudo apt-get install openmpi-bin
  : sudo apt-get install openmpi-dev

NCS6- Packages Needed

- **bison** : sudo apt-get install bison
- **cmake** : sudo apt-get install cmake
- **cuda toolkit** : http://developer.nvidia.com/
  - cd /home/userName/Downloads
  - sh <cuda_toolkit_installer_name>
- **doxygen** : sudo apt-get install doxygen
- **flex** : sudo apt-get install flex
- **g++ version 4.4** : sudo apt-get install g++-4.4
- **g++ version 4.6+**
- **mercurial** : sudo apt-get install mercurial
- **mpi-run** : sudo apt-get install openmpi-bin
  : sudo apt-get install openmpi-dev

Simulation on a single machine

NCS5 Steps

- **To compile code:**
  - Make

- After the code is compiled, you run NCS5 in the directory with the input file

- **To run code:**
  - ncs5pe <input file>

NCS6 Steps

- cd /home/userName/NCS6/NCS6/build
- **To specify the number of devices available on the computer for the program (Only do this step once)**
  - mpirun applications/clusterSpecifier/clusterSpecifier single.cluster
  - applications/clusterInfo/clusterInfo single.cluster
- **To compile code:**
  - applications/ncsDistributor/ncsDistributor <space> ../files/NCS6/folderName/fileName single.cluster ncsout
- **To run code:**
  - applications/simulator/simulator/ ncsout

DEMO

Input Language

Brain

- Define the simulation as a whole
- Preliminary outline of other structures
    - Anatomy
    - Stimuli
    - Reports
- Extrinsic connections
- Include files

Brain

```
BRAIN
        TYPE                SIMPLE_MODEL_model
        JOB                 SIMPLE_MODEL_model
        FSV                 1e3
        DURATION            1
        SEED                -21
        DISTANCE            NO

################################ COLUMN TYPE##################################
    COLUMN_TYPE     SIMPLE_MODEL_COLUMN

################################ STIM INJECT##################################
    STIMULUS_INJECT     SIMPLE_MODEL_STIM

############################### REPORTS ######################################
    REPORT      VOLTAGE_CELL_1
    REPORT      VOLTAGE_CELL_2

END_BRAIN
```

Anatomy

- Columns
- Layers
- Cells
- Compartments
- Channels

Anatomy

```
################################ Define Column Shells #########################
COLUMN_SHELL
    TYPE            SIMPLE_MODEL_SHELL
    WIDTH           300
    HEIGHT          800
    LOCATION        0             800
END_COLUMN_SHELL

################################ Fill Columns ##################################
COLUMN
    TYPE            SIMPLE_MODEL_COLUMN
    COLUMN_SHELL    SIMPLE_MODEL_SHELL
    LAYER_TYPE      layer_SIMPLE_MODEL
END_COLUMN

################################ Define Layer Shells #########################
LAYER_SHELL
    TYPE            layer_SIMPLE_MODEL_shell
    LOWER           0
    UPPER           400
END_LAYER_SHELL

################################ Fill Layers ###################################
LAYER
        TYPE                        layer_SIMPLE_MODEL
        LAYER_SHELL                 layer_SIMPLE_MODEL_shell
        CELL_TYPE                   SIMPLE_MODEL_1     10
        CELL_TYPE                   SIMPLE_MODEL_2     10
END_LAYER
```

Stimulus

- External Stimulation (visual, audio...)
- Type of signals
  - Linear
  - Pulse
  - Noise
  - File-based
- Multiple times
- Different Destinations

Stimulus

```
######################   STIMULUS INJECTS   ##############################

STIMULUS_INJECT
    TYPE            SIMPLE_MODEL_STIM
    STIM_TYPE       realstim_SIMPLE_MODEL
    INJECT          SIMPLE_MODEL_COLUMN  layer_SIMPLE_MODEL      SIMPLE_MODEL_1  somaE   1
END_STIMULUS_INJECT

##############################define STIMULUS ##############################

STIMULUS
        TYPE                    realstim_SIMPLE_MODEL
        MODE                    CURRENT
        PATTERN                 PULSE
        DYN_RANGE               0       75
        TIMING                  EXACT
        AMP_START               4
        WIDTH                   .010
        TIME_START              0.500
        TIME_END                0.600
END_STIMULUS
```

Connections

- Extrinsic and intrinsic connections
- Synapse connections
- From the source to the destination
- With or without decaying distance effects
- Recurrent connections

Connections

```
###############################################################################
# ----- connections
###############################################################################
     CONNECT
                     TWO_CELL_MODEL_COLUMN layer_TWO_CELL_MODEL TWO_CELL_MODEL_1 somaE
                     TWO_CELL_MODEL_COLUMN layer_TWO_CELL_MODEL TWO_CELL_MODEL_2 somaE
                     synEE_TWO_CELL_MODEL   1   0
```

Synapses

- Connections between other cells and their compartments
- Excitatory
- Inhibitory
- Synaptic Waveform
- Learning
  - Short term synaptic dynamics
    - Facilitation
    - Depression
  - Long term synaptic dynamics (Hebbian Learning)
    - STDP rule

Synapses

```
##############SYNAPSES SIMPLE_MODEL_MODEL################################

SYNAPSE
    TYPE            synEE_SIMPLE_MODEL
    SFD_LABEL             NO_SFD
    LEARN_LABEL           NO_STDP
    SYN_PSG         PSGexcit
    MAX_CONDUCT     0.4
    DELAY           0.005  0.010
    SYN_REVERSAL    0    0
    ABSOLUTE_USE    0.25    0.1
END_SYNAPSE

######################## SHORT-TERM SYNAPTIC DYNAMICS #########################

SYN_FACIL_DEPRESS
        TYPE                    NO_SFD
        SFD                     NONE
END_SYN_FACIL_DEPRESS

############################### LONG-TERM SYNAPTIC DYNAMICS #################

SYN_LEARNING
        TYPE                    NO_STDP
        LEARNING                NONE
END_SYN_LEARNING


############################### SYNAPTIC CONDUCTANCE WAVEFORMS ###############

SYN_PSG
        TYPE                    PSGexcit
        PSG_FILE                ./input/EPSG_Vogels_FSV1k_TAU05.inc
END_SYN_PSG
```

Reports

- Data about cells
- Report files:
  - Voltage
  - Current
  - Firecount
  - Channel
  - Synaptic strengths
- Automatically generated and saved

Reports

```
################## SIMPLE_MODEL_MODEL REPORTS ###########################

REPORT
    TYPE                    VOLTAGE_CELL_1
    CELLS                   SIMPLE_MODEL_COLUMN layer_SIMPLE_MODEL SIMPLE_MODEL_1 somaE
    PROB                    1
    REPORT_ON               VOLTAGE
    FILENAME                SIMPLE_MODEL_1_VOLTAGE_E.txt
    ASCII
    FREQUENCY               1
    TIME_START              0
    TIME_END                100
END_REPORT

REPORT
    TYPE                    VOLTAGE_CELL_2
    CELLS                   SIMPLE_MODEL_COLUMN layer_SIMPLE_MODEL SIMPLE_MODEL_2 somaE
    PROB                    1
    REPORT_ON               VOLTAGE
    FILENAME                SIMPLE_MODEL_2_VOLTAGE_E.txt
    ASCII
    FREQUENCY               1
    TIME_START              0
    TIME_END                100
END_REPORT
```

DEMO

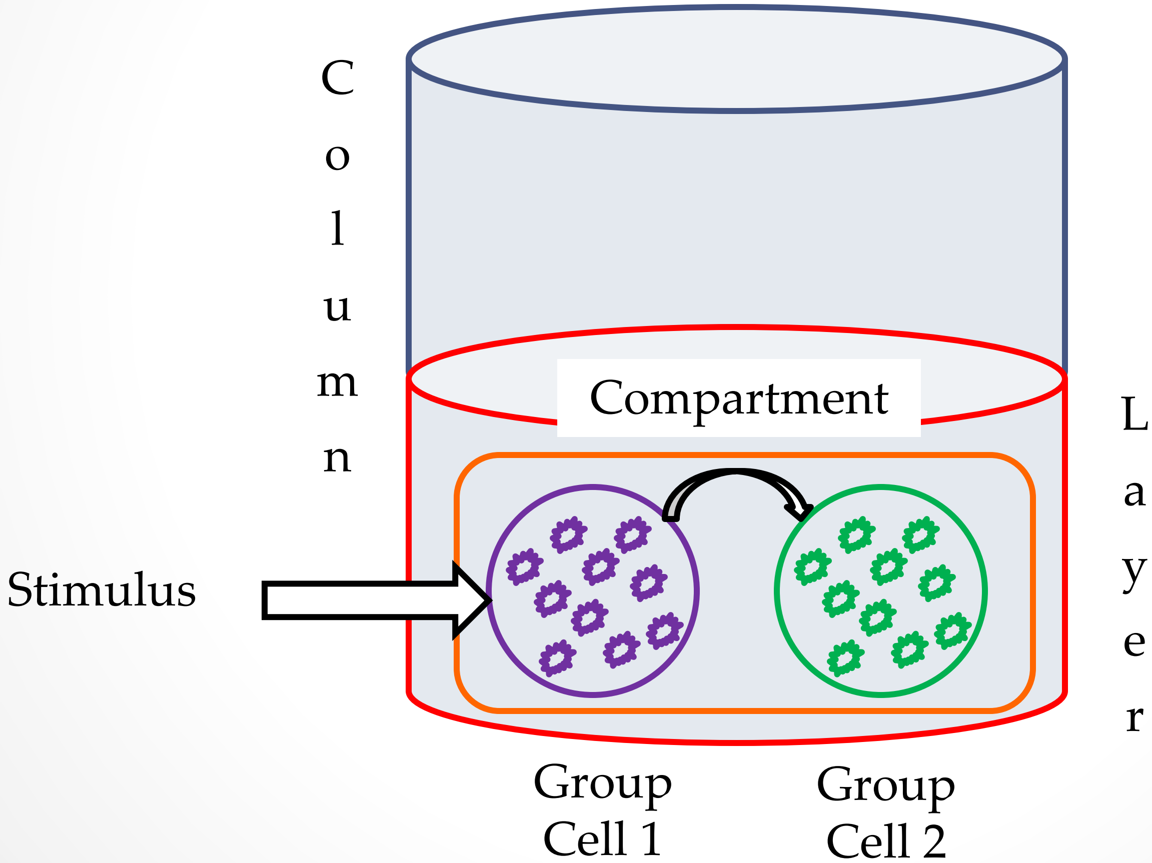
Break

Today’s Outline

- **First Hour**
  - Introduction
  - Equations and Implementation
  - Requirements and Simulation on a Single Machine
  - Input Language
- **Second Hour**
  - Simple Model
  - Parameters Presentation and Testing
  - Output Analysis
- **Third Hour**
  - Simulation on Multiple Machines
  - Software Tools
  - Robotic System Configuration
  - Larger Networks and Complete Loop Execution
  - Future Directions and Summary

Simple Model

Architecture



Brain

```
BRAIN
        TYPE                SIMPLE_MODEL_model
        JOB                 SIMPLE_MODEL_model
        FSV                 1e3
        DURATION            1
        SEED                -21
        DISTANCE            NO

################################ COLUMN TYPE##################################
    COLUMN_TYPE     SIMPLE_MODEL_COLUMN

################################ STIM INJECT##################################
    STIMULUS_INJECT     SIMPLE_MODEL_STIM

############################### REPORTS ######################################
    REPORT      VOLTAGE_CELL_1
    REPORT      VOLTAGE_CELL_2

END_BRAIN
```

Brain

```
BRAIN
        TYPE                SIMPLE_MODEL_model
        JOB                 SIMPLE_MODEL_model
        FSV                 1e3
        DURATION            1
        SEED                -21
        DISTANCE            NO

################################# COLUMN TYPE###################################
    COLUMN_TYPE     SIMPLE_MODEL_COLUMN

################################# STIM INJECT###################################
    STIMULUS_INJECT     SIMPLE_MODEL_STIM

################################ REPORTS ######################################
    REPORT      VOLTAGE_CELL_1
    REPORT      VOLTAGE_CELL_2

END_BRAIN
```

Brain

```
BRAIN
        TYPE                SIMPLE_MODEL_model
        JOB                 SIMPLE_MODEL_model
        FSV                 1e3
        DURATION            1
        SEED                -21
        DISTANCE            NO

################################ COLUMN TYPE##################################
    COLUMN_TYPE     SIMPLE_MODEL_COLUMN

################################ STIM INJECT##################################
    STIMULUS_INJECT     SIMPLE_MODEL_STIM

############################### REPORTS ######################################
    REPORT      VOLTAGE_CELL_1
    REPORT      VOLTAGE_CELL_2

END_BRAIN
```

Brain

```
BRAIN
        TYPE                SIMPLE_MODEL_model
        JOB                 SIMPLE_MODEL_model
        FSV                 1e3
        DURATION            1
        SEED                -21
        DISTANCE            NO

################################ COLUMN TYPE##################################
    COLUMN_TYPE     SIMPLE_MODEL_COLUMN

################################ STIM INJECT##################################
    STIMULUS_INJECT     SIMPLE_MODEL_STIM

############################### REPORTS ######################################
    REPORT      VOLTAGE_CELL_1
    REPORT      VOLTAGE_CELL_2

END_BRAIN
```

Brain

```
BRAIN
        TYPE                SIMPLE_MODEL_model
        JOB                 SIMPLE_MODEL_model
        FSV                 1e3
        DURATION            1
        SEED                -21
        DISTANCE            NO

################################ COLUMN TYPE##################################
    COLUMN_TYPE     SIMPLE_MODEL_COLUMN

################################ STIM INJECT##################################
    STIMULUS_INJECT     SIMPLE_MODEL_STIM

############################### REPORTS ######################################
    REPORT      VOLTAGE_CELL_1
    REPORT      VOLTAGE_CELL_2

END_BRAIN
```

Brain

```
BRAIN
        TYPE                SIMPLE_MODEL_model
        JOB                 SIMPLE_MODEL_model
        FSV                 1e3
        DURATION            1
        SEED                -21
        DISTANCE            NO

################################ COLUMN TYPE##################################
    COLUMN_TYPE     SIMPLE_MODEL_COLUMN

################################ STIM INJECT##################################
    STIMULUS_INJECT     SIMPLE_MODEL_STIM

############################### REPORTS #####################################
    REPORT      VOLTAGE_CELL_1
    REPORT      VOLTAGE_CELL_2

END_BRAIN
```

Brain

```
BRAIN
        TYPE                SIMPLE_MODEL_model
        JOB                 SIMPLE_MODEL_model
        FSV                 1e3
        DURATION            1
        SEED                -21
        DISTANCE            NO

################################ COLUMN TYPE##################################
    COLUMN_TYPE     SIMPLE_MODEL_COLUMN

################################ STIM INJECT##################################
    STIMULUS_INJECT     SIMPLE_MODEL_STIM

############################### REPORTS ######################################
    REPORT      VOLTAGE_CELL_1
    REPORT      VOLTAGE_CELL_2

END_BRAIN
```

Brain

```
BRAIN
        TYPE                SIMPLE_MODEL_model
        JOB                 SIMPLE_MODEL_model
        FSV                 1e3
        DURATION            1
        SEED                -21
        DISTANCE            NO

################################ COLUMN_TYPE##################################
    COLUMN_TYPE     SIMPLE_MODEL_COLUMN

################################ STIM_INJECT##################################
    STIMULUS_INJECT     SIMPLE_MODEL_STIM

############################### REPORTS ######################################
    REPORT      VOLTAGE_CELL_1
    REPORT      VOLTAGE_CELL_2

END_BRAIN
```

Brain

```
BRAIN
        TYPE                SIMPLE_MODEL_model
        JOB                 SIMPLE_MODEL_model
        FSV                 1e3
        DURATION            1
        SEED                -21
        DISTANCE            NO

################################ COLUMN TYPE##################################
    COLUMN_TYPE     SIMPLE_MODEL_COLUMN

################################ STIM INJECT##################################
    STIMULUS_INJECT     SIMPLE_MODEL_STIM

############################### REPORTS ######################################
    REPORT      VOLTAGE_CELL_1
    REPORT      VOLTAGE_CELL_2

END_BRAIN
```

Brain

```
BRAIN
        TYPE            SIMPLE_MODEL_model
        JOB             SIMPLE_MODEL_model
        FSV             1e3
        DURATION        1
        SEED            -21
        DISTANCE        NO

################################ COLUMN TYPE##################################
    COLUMN_TYPE     SIMPLE_MODEL_COLUMN

################################ STIM INJECT##################################
    STIMULUS_INJECT     SIMPLE_MODEL_STIM

############################### REPORTS ######################################
    REPORT      VOLTAGE_CELL_1
    REPORT      VOLTAGE_CELL_2

END_BRAIN
```

Anatomy

```
############################### Define Column Shells ########################
COLUMN_SHELL
    TYPE           SIMPLE_MODEL_SHELL
    WIDTH          300
    HEIGHT         800
    LOCATION       0             800
END_COLUMN_SHELL

############################### Fill Columns #################################
COLUMN
    TYPE           SIMPLE_MODEL_COLUMN
    COLUMN_SHELL   SIMPLE_MODEL_SHELL
    LAYER_TYPE     layer_SIMPLE_MODEL
END_COLUMN

############################### Define Layer Shells #########################
LAYER_SHELL
    TYPE           layer_SIMPLE_MODEL_shell
    LOWER          0
    UPPER          400
END_LAYER_SHELL

############################### Fill Layers ##################################
LAYER
        TYPE                    layer_SIMPLE_MODEL
        LAYER_SHELL             layer_SIMPLE_MODEL_shell
        CELL_TYPE               SIMPLE_MODEL_1     10
        CELL_TYPE               SIMPLE_MODEL_2     10
END_LAYER
```

Anatomy

```
################################ Define Column Shells #########################
COLUMN_SHELL
    TYPE            SIMPLE_MODEL_SHELL
    WIDTH           300
    HEIGHT          800
    LOCATION        0             800
END_COLUMN_SHELL

################################ Fill Columns ##################################
COLUMN
    TYPE            SIMPLE_MODEL_COLUMN
    COLUMN_SHELL    SIMPLE_MODEL_SHELL
    LAYER_TYPE      layer_SIMPLE_MODEL
END_COLUMN

################################ Define Layer Shells #########################
LAYER_SHELL
    TYPE            layer_SIMPLE_MODEL_shell
    LOWER           0
    UPPER           400
END_LAYER_SHELL

################################ Fill Layers ###################################
LAYER
        TYPE                    layer_SIMPLE_MODEL
        LAYER_SHELL             layer_SIMPLE_MODEL_shell
        CELL_TYPE               SIMPLE_MODEL_1      10
        CELL_TYPE               SIMPLE_MODEL_2      10
END_LAYER
```

Anatomy

```
############################### Define Column Shells #########################
COLUMN_SHELL
    TYPE              SIMPLE_MODEL_SHELL
    WIDTH             300
    HEIGHT            800
    LOCATION          0             800
END_COLUMN_SHELL

############################### Fill Columns #################################
COLUMN
    TYPE              SIMPLE_MODEL_COLUMN
    COLUMN_SHELL      SIMPLE_MODEL_SHELL
    LAYER_TYPE        layer_SIMPLE_MODEL
END_COLUMN

############################### Define Layer Shells #########################
LAYER_SHELL
    TYPE              layer_SIMPLE_MODEL_shell
    LOWER             0
    UPPER             400
END_LAYER_SHELL

############################### Fill Layers ##################################
LAYER
        TYPE                        layer_SIMPLE_MODEL
        LAYER_SHELL                 layer_SIMPLE_MODEL_shell
        CELL_TYPE                   SIMPLE_MODEL_1      10
        CELL_TYPE                   SIMPLE_MODEL_2      10
END_LAYER
```

Anatomy

```
################################ Define Column Shells ##########################
COLUMN_SHELL
    TYPE             SIMPLE_MODEL_SHELL
    WIDTH            300
    HEIGHT           800
    LOCATION         0             800
END_COLUMN_SHELL

################################ Fill Columns ##################################
COLUMN
    TYPE             SIMPLE_MODEL_COLUMN
    COLUMN_SHELL     SIMPLE_MODEL_SHELL
    LAYER_TYPE       layer_SIMPLE_MODEL
END_COLUMN

################################ Define Layer Shells ##########################
LAYER_SHELL
    TYPE             layer_SIMPLE_MODEL_shell
    LOWER            0
    UPPER            400
END_LAYER_SHELL

################################ Fill Layers ###################################
LAYER
        TYPE                    layer_SIMPLE_MODEL
        LAYER_SHELL             layer_SIMPLE_MODEL_shell
        CELL_TYPE               SIMPLE_MODEL_1     10
        CELL_TYPE               SIMPLE_MODEL_2     10
END_LAYER
```

Anatomy

```
############################### Define Column Shells #########################
COLUMN_SHELL
    TYPE            SIMPLE_MODEL_SHELL
    WIDTH           300
    HEIGHT          800
    LOCATION        0             800
END_COLUMN_SHELL

############################### Fill Columns #################################
COLUMN
    TYPE            SIMPLE_MODEL_COLUMN
    COLUMN_SHELL    SIMPLE_MODEL_SHELL
    LAYER_TYPE      layer_SIMPLE_MODEL
END_COLUMN

############################### Define Layer Shells #########################
LAYER_SHELL
    TYPE            layer_SIMPLE_MODEL_shell
    LOWER           0
    UPPER           400
END_LAYER_SHELL

############################### Fill Layers ##################################
LAYER
        TYPE                    layer_SIMPLE_MODEL
        LAYER_SHELL             layer_SIMPLE_MODEL_shell
        CELL_TYPE               SIMPLE_MODEL_1     10
        CELL_TYPE               SIMPLE_MODEL_2     10
END_LAYER
```

Anatomy

```
################################ Define Column Shells ##########################
COLUMN_SHELL
    TYPE            SIMPLE_MODEL_SHELL
    WIDTH           300
    HEIGHT          800
    LOCATION        0              800
END_COLUMN_SHELL

################################ Fill Columns ##################################
COLUMN
    TYPE            SIMPLE_MODEL_COLUMN
    COLUMN_SHELL    SIMPLE_MODEL_SHELL
    LAYER_TYPE      layer_SIMPLE_MODEL
END_COLUMN

################################ Define Layer Shells ##########################
LAYER_SHELL
    TYPE            layer_SIMPLE_MODEL_shell
    LOWER           0
    UPPER           400
END_LAYER_SHELL

################################ Fill Layers ##################################
LAYER
        TYPE                    layer_SIMPLE_MODEL
        LAYER_SHELL             layer_SIMPLE_MODEL_shell
        CELL_TYPE               SIMPLE_MODEL_1     10
        CELL_TYPE               SIMPLE_MODEL_2     10
END_LAYER
```

Anatomy

```
################################ Define Column Shells ##########################
COLUMN_SHELL
    TYPE            SIMPLE_MODEL_SHELL
    WIDTH           300
    HEIGHT          800
    LOCATION        0              800
END_COLUMN_SHELL

################################ Fill Columns ##################################
COLUMN
    TYPE            SIMPLE_MODEL_COLUMN
    COLUMN_SHELL    SIMPLE_MODEL_SHELL
    LAYER_TYPE      layer_SIMPLE_MODEL
END_COLUMN

################################ Define Layer Shells ##########################
LAYER_SHELL
    TYPE            layer_SIMPLE_MODEL_shell
    LOWER           0
    UPPER           400
END_LAYER_SHELL

################################ Fill Layers ##################################
LAYER
        TYPE                    layer_SIMPLE_MODEL
        LAYER_SHELL             layer_SIMPLE_MODEL_shell
        CELL_TYPE               SIMPLE_MODEL_1      10
        CELL_TYPE               SIMPLE_MODEL_2      10
END_LAYER
```

Anatomy

```
################################ Define Column Shells #########################
COLUMN_SHELL
    TYPE            SIMPLE_MODEL_SHELL
    WIDTH           300
    HEIGHT          800
    LOCATION        0              800
END_COLUMN_SHELL

################################ Fill Columns ##################################
COLUMN
    TYPE            SIMPLE_MODEL_COLUMN
    COLUMN_SHELL    SIMPLE_MODEL_SHELL
    LAYER_TYPE      layer_SIMPLE_MODEL
END_COLUMN

################################ Define Layer Shells #########################
LAYER_SHELL
    TYPE            layer_SIMPLE_MODEL_shell
    LOWER           0
    UPPER           400
END_LAYER_SHELL

################################ Fill Layers ###################################
LAYER
        TYPE                    layer_SIMPLE_MODEL
        LAYER_SHELL             layer_SIMPLE_MODEL_shell
        CELL_TYPE               SIMPLE_MODEL_1     10
        CELL_TYPE               SIMPLE_MODEL_2     10
END_LAYER
```

Anatomy

```
################################ Define Column Shells ##########################
COLUMN_SHELL
    TYPE            SIMPLE_MODEL_SHELL
    WIDTH           300
    HEIGHT          800
    LOCATION        0              800
END_COLUMN_SHELL

################################ Fill Columns ##################################
COLUMN
    TYPE            SIMPLE_MODEL_COLUMN
    COLUMN_SHELL    SIMPLE_MODEL_SHELL
    LAYER_TYPE      layer_SIMPLE_MODEL
END_COLUMN

################################ Define Layer Shells ##########################
LAYER_SHELL
    TYPE            layer_SIMPLE_MODEL_shell
    LOWER           0
    UPPER           400
END_LAYER_SHELL

################################ Fill Layers ##################################
LAYER
        TYPE                    layer_SIMPLE_MODEL
        LAYER_SHELL             layer_SIMPLE_MODEL_shell
        CELL_TYPE               SIMPLE_MODEL_1     10
        CELL_TYPE               SIMPLE_MODEL_2     10
END_LAYER
```

Anatomy

```
################################ Define Column Shells #########################
COLUMN_SHELL
    TYPE            SIMPLE_MODEL_SHELL
    WIDTH           300
    HEIGHT          800
    LOCATION        0              800
END_COLUMN_SHELL

################################ Fill Columns ##################################
COLUMN
    TYPE            SIMPLE_MODEL_COLUMN
    COLUMN_SHELL    SIMPLE_MODEL_SHELL
    LAYER_TYPE      layer_SIMPLE_MODEL
END_COLUMN

################################ Define Layer Shells #########################
LAYER_SHELL
    TYPE            layer_SIMPLE_MODEL_shell
    LOWER           0
    UPPER           400
END_LAYER_SHELL

################################ Fill Layers ###################################
LAYER
        TYPE                    layer_SIMPLE_MODEL
        LAYER_SHELL             layer_SIMPLE_MODEL_shell
        CELL_TYPE               SIMPLE_MODEL_1      10
        CELL_TYPE               SIMPLE_MODEL_2      10
END_LAYER
```

Anatomy

```
############################### Define Column Shells #########################
COLUMN_SHELL
    TYPE           SIMPLE_MODEL_SHELL
    WIDTH          300
    HEIGHT         800
    LOCATION       0             800
END_COLUMN_SHELL

############################### Fill Columns #################################
COLUMN
    TYPE           SIMPLE_MODEL_COLUMN
    COLUMN_SHELL   SIMPLE_MODEL_SHELL
    LAYER_TYPE     layer_SIMPLE_MODEL
END_COLUMN

############################### Define Layer Shells #########################
LAYER_SHELL
    TYPE           layer_SIMPLE_MODEL_shell
    LOWER          0
    UPPER          400
END_LAYER_SHELL

############################### Fill Layers ##################################
LAYER
        TYPE                    layer_SIMPLE_MODEL
        LAYER_SHELL             layer_SIMPLE_MODEL_shell
        CELL_TYPE               SIMPLE_MODEL_1     10
        CELL_TYPE               SIMPLE_MODEL_2     10
END_LAYER
```

Anatomy

```
############################### Define Column Shells #########################
COLUMN_SHELL
    TYPE           SIMPLE_MODEL_SHELL
    WIDTH          300
    HEIGHT         800
    LOCATION       0             800
END_COLUMN_SHELL

############################### Fill Columns ##################################
COLUMN
    TYPE           SIMPLE_MODEL_COLUMN
    COLUMN_SHELL   SIMPLE_MODEL_SHELL
    LAYER_TYPE     layer_SIMPLE_MODEL
END_COLUMN

############################### Define Layer Shells #########################
LAYER_SHELL
    TYPE           layer_SIMPLE_MODEL_shell
    LOWER          0
    UPPER          400
END_LAYER_SHELL

############################### Fill Layers ##################################
LAYER
        TYPE                    layer_SIMPLE_MODEL
        LAYER_SHELL             layer_SIMPLE_MODEL_shell
        CELL_TYPE               SIMPLE_MODEL_1      10
        CELL_TYPE               SIMPLE_MODEL_2      10
END_LAYER
```

Anatomy

```
################################ Define Column Shells ##########################
COLUMN_SHELL
    TYPE            SIMPLE_MODEL_SHELL
    WIDTH           300
    HEIGHT          800
    LOCATION        0              800
END_COLUMN_SHELL

################################ Fill Columns ##################################
COLUMN
    TYPE            SIMPLE_MODEL_COLUMN
    COLUMN_SHELL    SIMPLE_MODEL_SHELL
    LAYER_TYPE      layer_SIMPLE_MODEL
END_COLUMN

################################ Define Layer Shells ##########################
LAYER_SHELL
    TYPE            layer_SIMPLE_MODEL_shell
    LOWER           0
    UPPER           400
END_LAYER_SHELL

################################ Fill Layers ###################################
LAYER
        TYPE                    layer_SIMPLE_MODEL
        LAYER_SHELL             layer_SIMPLE_MODEL_shell
        CELL_TYPE               SIMPLE_MODEL_1     10
        CELL_TYPE               SIMPLE_MODEL_2     10
END_LAYER
```

Anatomy

```
################################ Define Column Shells ##########################
COLUMN_SHELL
    TYPE            SIMPLE_MODEL_SHELL
    WIDTH           300
    HEIGHT          800
    LOCATION        0              800
END_COLUMN_SHELL

################################ Fill Columns ###################################
COLUMN
    TYPE            SIMPLE_MODEL_COLUMN
    COLUMN_SHELL    SIMPLE_MODEL_SHELL
    LAYER_TYPE      layer_SIMPLE_MODEL
END_COLUMN

################################ Define Layer Shells #########################
LAYER_SHELL
    TYPE            layer_SIMPLE_MODEL_shell
    LOWER           0
    UPPER           400
END_LAYER_SHELL

################################ Fill Layers ###################################
LAYER
        TYPE                        layer_SIMPLE_MODEL
        LAYER_SHELL                 layer_SIMPLE_MODEL_shell
        CELL_TYPE                   SIMPLE_MODEL_1     10
        CELL_TYPE                   SIMPLE_MODEL_2     10
END_LAYER
```

Anatomy

```
############################### Define Column Shells #########################
COLUMN_SHELL
    TYPE            SIMPLE_MODEL_SHELL
    WIDTH           300
    HEIGHT          800
    LOCATION        0             800
END_COLUMN_SHELL

############################### Fill Columns ##################################
COLUMN
    TYPE            SIMPLE_MODEL_COLUMN
    COLUMN_SHELL    SIMPLE_MODEL_SHELL
    LAYER_TYPE      layer_SIMPLE_MODEL
END_COLUMN

############################### Define Layer Shells #########################
LAYER_SHELL
    TYPE            layer_SIMPLE_MODEL_shell
    LOWER           0
    UPPER           400
END_LAYER_SHELL

############################### Fill Layers ##################################
LAYER
        TYPE                    layer_SIMPLE_MODEL
        LAYER_SHELL             layer_SIMPLE_MODEL_shell
        CELL_TYPE               SIMPLE_MODEL_1     10
        CELL_TYPE               SIMPLE_MODEL_2     10
END_LAYER
```

Anatomy

```
################################ Define Column Shells #########################
COLUMN_SHELL
    TYPE           SIMPLE_MODEL_SHELL
    WIDTH          300
    HEIGHT         800
    LOCATION       0              800
END_COLUMN_SHELL

################################ Fill Columns ##################################
COLUMN
    TYPE           SIMPLE_MODEL_COLUMN
    COLUMN_SHELL   SIMPLE_MODEL_SHELL
    LAYER_TYPE     layer_SIMPLE_MODEL
END_COLUMN

################################ Define Layer Shells ##########################
LAYER_SHELL
    TYPE           layer_SIMPLE_MODEL_shell
    LOWER          0
    UPPER          400
END_LAYER_SHELL

################################ Fill Layers ###################################
LAYER
        TYPE                    layer_SIMPLE_MODEL
        LAYER_SHELL             layer_SIMPLE_MODEL_shell
        CELL_TYPE               SIMPLE_MODEL_1     10
        CELL_TYPE               SIMPLE_MODEL_2     10
END_LAYER
```

Anatomy

```
################################ Define Column Shells #########################
COLUMN_SHELL
    TYPE            SIMPLE_MODEL_SHELL
    WIDTH           300
    HEIGHT          800
    LOCATION        0              800
END_COLUMN_SHELL

################################ Fill Columns ##################################
COLUMN
    TYPE            SIMPLE_MODEL_COLUMN
    COLUMN_SHELL    SIMPLE_MODEL_SHELL
    LAYER_TYPE      layer_SIMPLE_MODEL
END_COLUMN

################################ Define Layer Shells #########################
LAYER_SHELL
    TYPE            layer_SIMPLE_MODEL_shell
    LOWER           0
    UPPER           400
END_LAYER_SHELL

################################ Fill Layers ##################################
LAYER
        TYPE                        layer_SIMPLE_MODEL
        LAYER_SHELL                 layer_SIMPLE_MODEL_shell
        CELL_TYPE                   SIMPLE_MODEL_1      10
        CELL_TYPE                   SIMPLE_MODEL_2      10
END_LAYER
```

Anatomy

```
################################ Define Column Shells #########################
COLUMN_SHELL
    TYPE            SIMPLE_MODEL_SHELL
    WIDTH           300
    HEIGHT          800
    LOCATION        0              800
END_COLUMN_SHELL

################################ Fill Columns ##################################
COLUMN
    TYPE            SIMPLE_MODEL_COLUMN
    COLUMN_SHELL    SIMPLE_MODEL_SHELL
    LAYER_TYPE      layer_SIMPLE_MODEL
END_COLUMN

################################ Define Layer Shells ##########################
LAYER_SHELL
    TYPE            layer_SIMPLE_MODEL_shell
    LOWER           0
    UPPER           400
END_LAYER_SHELL

################################ Fill Layers ###################################
LAYER
        TYPE                        layer_SIMPLE_MODEL
        LAYER_SHELL                 layer_SIMPLE_MODEL_shell
        CELL_TYPE                   SIMPLE_MODEL_1      10
        CELL_TYPE                   SIMPLE_MODEL_2      10
END_LAYER
```

Anatomy

```
################################ Define Cells #################################
CELL
    TYPE                SIMPLE_MODEL_1
    COMPARTMENT         soma_SIMPLE_MODEL   somaE   0   0   0
END_CELL

CELL
    TYPE                SIMPLE_MODEL_2
    COMPARTMENT         soma_SIMPLE_MODEL   somaE   0   0   0
END_CELL

#########################
## Define Compartments
#########################

COMPARTMENT
    TYPE                  soma_SIMPLE_MODEL
    SPIKESHAPE            spikeshape_1k_default
    TAU_MEMBRANE          0.020       0.0
    R_MEMBRANE            200         0
    THRESHOLD             -40         0
    VMREST                -60         0
END_COMPARTMENT

########################### Define Spikeshape###########################

SPIKESHAPE
  TYPE            spikeshape_1k_default
  VOLTAGES        -38 30 -43 -60
END_SPIKESHAPE
```

Anatomy

```
############################### Define Cells ################################
CELL
    TYPE                SIMPLE_MODEL_1
    COMPARTMENT         soma_SIMPLE_MODEL  somaE   0   0   0
END_CELL

CELL
    TYPE                SIMPLE_MODEL_2
    COMPARTMENT         soma_SIMPLE_MODEL  somaE   0   0   0
END_CELL

#########################
## Define Compartments
#########################

COMPARTMENT
    TYPE                  soma_SIMPLE_MODEL
    SPIKESHAPE            spikeshape_1k_default
    TAU_MEMBRANE          0.020       0.0
    R_MEMBRANE            200         0
    THRESHOLD             -40         0
    VMREST                -60         0
END_COMPARTMENT

########################### Define Spikeshape###########################

SPIKESHAPE
  TYPE            spikeshape_1k_default
  VOLTAGES        -38 30 -43 -60
END_SPIKESHAPE
```

Anatomy

```
############################### Define Cells ################################
CELL
    TYPE                SIMPLE_MODEL_1
    COMPARTMENT         soma_SIMPLE_MODEL   somaE    0    0    0
END_CELL

CELL
    TYPE                SIMPLE_MODEL_2
    COMPARTMENT         soma_SIMPLE_MODEL   somaE    0    0    0
END_CELL

#########################
## Define Compartments
#########################

COMPARTMENT
    TYPE                  soma_SIMPLE_MODEL
    SPIKESHAPE            spikeshape_1k_default
    TAU_MEMBRANE          0.020         0.0
    R_MEMBRANE            200           0
    THRESHOLD             -40           0
    VMREST                -60           0
END_COMPARTMENT

########################### Define Spikeshape###########################

SPIKESHAPE
  TYPE             spikeshape_1k_default
  VOLTAGES         -38 30 -43 -60
END_SPIKESHAPE
```

Anatomy

```
############################### Define Cells ################################
CELL
    TYPE                SIMPLE_MODEL_1
    COMPARTMENT         soma_SIMPLE_MODEL   somaE    0    0    0
END_CELL

CELL
    TYPE                SIMPLE_MODEL_2
    COMPARTMENT         soma_SIMPLE_MODEL   somaE    0    0    0
END_CELL

#########################
## Define Compartments
#########################

COMPARTMENT
    TYPE                  soma_SIMPLE_MODEL
    SPIKESHAPE            spikeshape_1k_default
    TAU_MEMBRANE          0.020        0.0
    R_MEMBRANE            200          0
    THRESHOLD             -40          0
    VMREST                -60          0
END_COMPARTMENT

########################### Define Spikeshape##########################

SPIKESHAPE
  TYPE            spikeshape_1k_default
  VOLTAGES        -38 30 -43 -60
END_SPIKESHAPE
```

Anatomy

```
################################ Define Cells ##################################
CELL
    TYPE                SIMPLE_MODEL_1
    COMPARTMENT         soma_SIMPLE_MODEL   somaE    0    0    0
END_CELL

CELL
    TYPE                SIMPLE_MODEL_2
    COMPARTMENT         soma_SIMPLE_MODEL   somaE    0    0    0
END_CELL

#########################
## Define Compartments
#########################

COMPARTMENT
    TYPE                  soma_SIMPLE_MODEL
    SPIKESHAPE            spikeshape_1k_default
    TAU_MEMBRANE          0.020          0.0
    R_MEMBRANE            200            0
    THRESHOLD             -40            0
    VMREST                -60            0
END_COMPARTMENT

########################### Define Spikeshape###########################

SPIKESHAPE
  TYPE            spikeshape_1k_default
  VOLTAGES        -38 30 -43 -60
END_SPIKESHAPE
```

Anatomy

```
############################### Define Cells ################################
CELL
    TYPE                SIMPLE_MODEL_1
    COMPARTMENT         soma_SIMPLE_MODEL   somaE    0    0    0
END_CELL

CELL
    TYPE                SIMPLE_MODEL_2
    COMPARTMENT         soma_SIMPLE_MODEL   somaE    0    0    0
END_CELL

#########################
## Define Compartments
#########################

COMPARTMENT
    TYPE                  soma_SIMPLE_MODEL
    SPIKESHAPE            spikeshape_1k_default
    TAU_MEMBRANE          0.020        0.0
    R_MEMBRANE            200          0
    THRESHOLD             -40          0
    VMREST                -60          0
END_COMPARTMENT

########################### Define Spikeshape###########################

SPIKESHAPE
  TYPE          spikeshape_1k_default
  VOLTAGES      -38 30 -43 -60
END_SPIKESHAPE
```

Anatomy

```
################################ Define Cells #################################
CELL
    TYPE                SIMPLE_MODEL_1
    COMPARTMENT         soma_SIMPLE_MODEL   somaE    0    0    0
END_CELL

CELL
    TYPE                SIMPLE_MODEL_2
    COMPARTMENT         soma_SIMPLE_MODEL   somaE    0    0    0
END_CELL

#########################
## Define Compartments
#########################

COMPARTMENT
    TYPE                  soma_SIMPLE_MODEL
    SPIKESHAPE            spikeshape_1k_default
    TAU_MEMBRANE          0.020        0.0
    R_MEMBRANE            200          0
    THRESHOLD             -40          0
    VMREST                -60          0
END_COMPARTMENT

########################### Define Spikeshape###########################

SPIKESHAPE
  TYPE            spikeshape_1k_default
  VOLTAGES        -38 30 -43 -60
END_SPIKESHAPE
```

Anatomy

```
############################### Define Cells ################################
CELL
    TYPE                SIMPLE_MODEL_1
    COMPARTMENT         soma_SIMPLE_MODEL  somaE   0   0   0
END_CELL

CELL
    TYPE                SIMPLE_MODEL_2
    COMPARTMENT         soma_SIMPLE_MODEL  somaE   0   0   0
END_CELL

#########################
## Define Compartments
#########################

COMPARTMENT
    TYPE                  soma_SIMPLE_MODEL
    SPIKESHAPE            spikeshape_1k_default
    TAU_MEMBRANE          0.020        0.0
    R_MEMBRANE            200          0
    THRESHOLD             -40          0
    VMREST                -60          0
END_COMPARTMENT

########################### Define Spikeshape##########################

SPIKESHAPE
  TYPE            spikeshape_1k_default
  VOLTAGES        -38 30 -43 -60
END_SPIKESHAPE
```

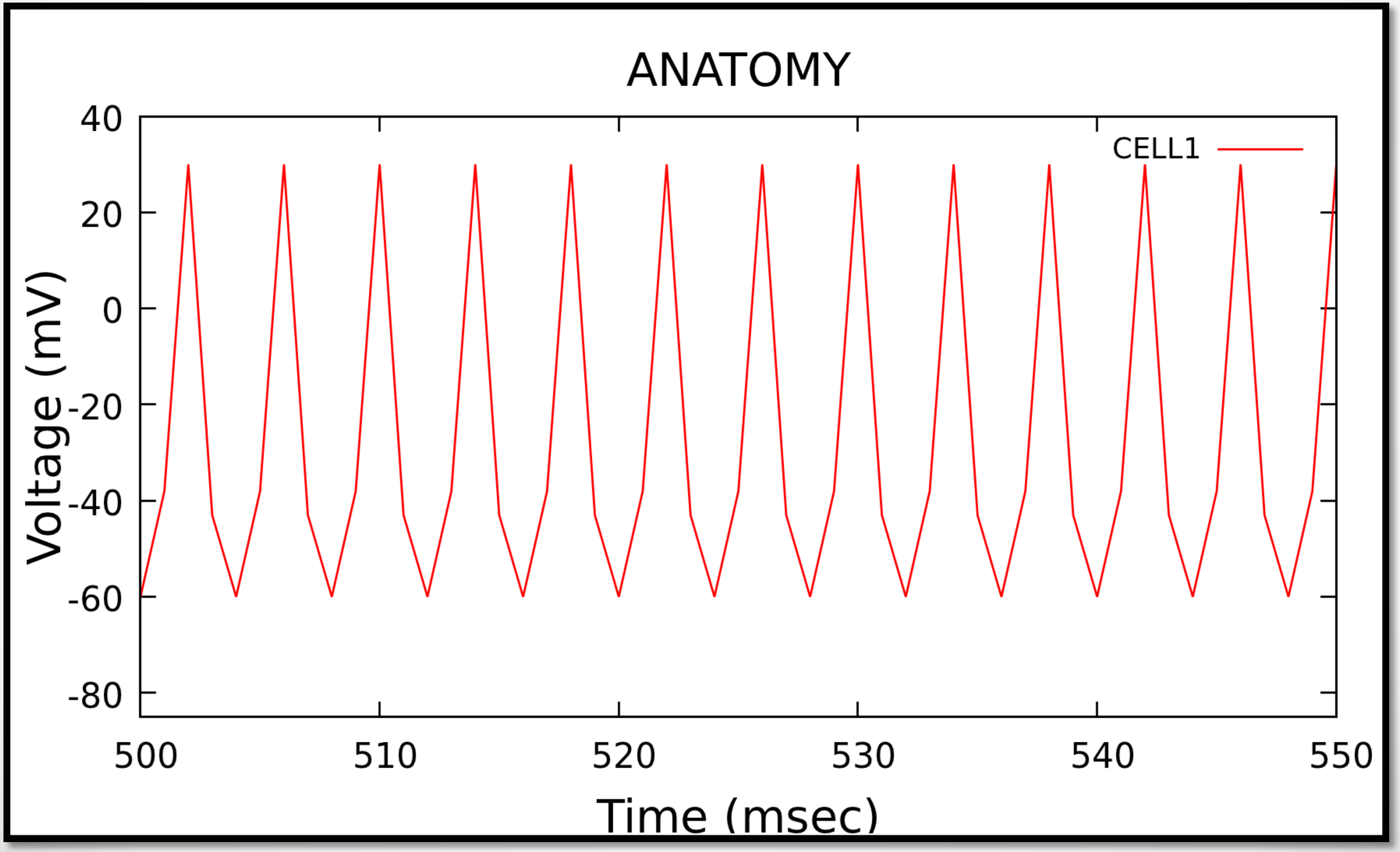
Anatomy

```
################################ Define Cells #################################
CELL
    TYPE                SIMPLE_MODEL_1
    COMPARTMENT         soma_SIMPLE_MODEL   somaE    0    0    0
END_CELL

CELL
    TYPE                SIMPLE_MODEL_2
    COMPARTMENT         soma_SIMPLE_MODEL   somaE    0    0    0
END_CELL

#########################
## Define Compartments
#########################

COMPARTMENT
    TYPE                  soma_SIMPLE_MODEL
    SPIKESHAPE            spikeshape_1k_default
    TAU_MEMBRANE          0.020         0.0
    R_MEMBRANE            200           0
    THRESHOLD             -40           0
    VMREST                -60           0
END_COMPARTMENT

########################### Define Spikeshape###########################

SPIKESHAPE
  TYPE            spikeshape_1k_default
  VOLTAGES        -38 30 -43 -60
END_SPIKESHAPE
```

Anatomy

```
################################ Define Cells #################################
CELL
    TYPE                SIMPLE_MODEL_1
    COMPARTMENT         soma_SIMPLE_MODEL   somaE   0   0   0
END_CELL

CELL
    TYPE                SIMPLE_MODEL_2
    COMPARTMENT         soma_SIMPLE_MODEL   somaE   0   0   0
END_CELL

#########################
## Define Compartments
#########################

COMPARTMENT
    TYPE                  soma_SIMPLE_MODEL
    SPIKESHAPE            spikeshape_1k_default
    TAU_MEMBRANE          0.020         0.0
    R_MEMBRANE            200           0
    THRESHOLD             -40           0
    VMREST                -60           0
END_COMPARTMENT

########################### Define Spikeshape###########################

SPIKESHAPE
  TYPE             spikeshape_1k_default
  VOLTAGES         -38 30 -43 -60
END_SPIKESHAPE
```

Spike shape


ANATOMY
CELL1
40
20
0
-20
-40
-60
-80
Voltage (mV)
500
510
520
530
540
550
Time (msec)

Anatomy

```
################################ Define Cells #################################
CELL
    TYPE                SIMPLE_MODEL_1
    COMPARTMENT         soma_SIMPLE_MODEL   somaE    0    0    0
END_CELL

CELL
    TYPE                SIMPLE_MODEL_2
    COMPARTMENT         soma_SIMPLE_MODEL   somaE    0    0    0
END_CELL

#########################
## Define Compartments
#########################

COMPARTMENT
    TYPE                  soma_SIMPLE_MODEL
    SPIKESHAPE            spikeshape_1k_default
    TAU_MEMBRANE          0.020        0.0
    R_MEMBRANE            200          0
    THRESHOLD             -40          0
    VMREST                -60          0
END_COMPARTMENT

########################### Define Spikeshape###########################

SPIKESHAPE
  TYPE               spikeshape_1k_default
  VOLTAGES           -38 30 -43 -60
END_SPIKESHAPE
```

Anatomy

```
################################ Define Cells ##################################
CELL
    TYPE                SIMPLE_MODEL_1
    COMPARTMENT         soma_SIMPLE_MODEL  somaE   0   0   0
END_CELL

CELL
    TYPE                SIMPLE_MODEL_2
    COMPARTMENT         soma_SIMPLE_MODEL  somaE   0   0   0
END_CELL

#########################
## Define Compartments
#########################

COMPARTMENT
    TYPE                  soma_SIMPLE_MODEL
    SPIKESHAPE            spikeshape_1k_default
    TAU_MEMBRANE          0.020        0.0
    R_MEMBRANE            200          0
    THRESHOLD             -40          0
    VMREST                -60          0
END_COMPARTMENT

########################### Define Spikeshape##########################

SPIKESHAPE
  TYPE            spikeshape_1k_default
  VOLTAGES        -38 30 -43 -60
END_SPIKESHAPE
```

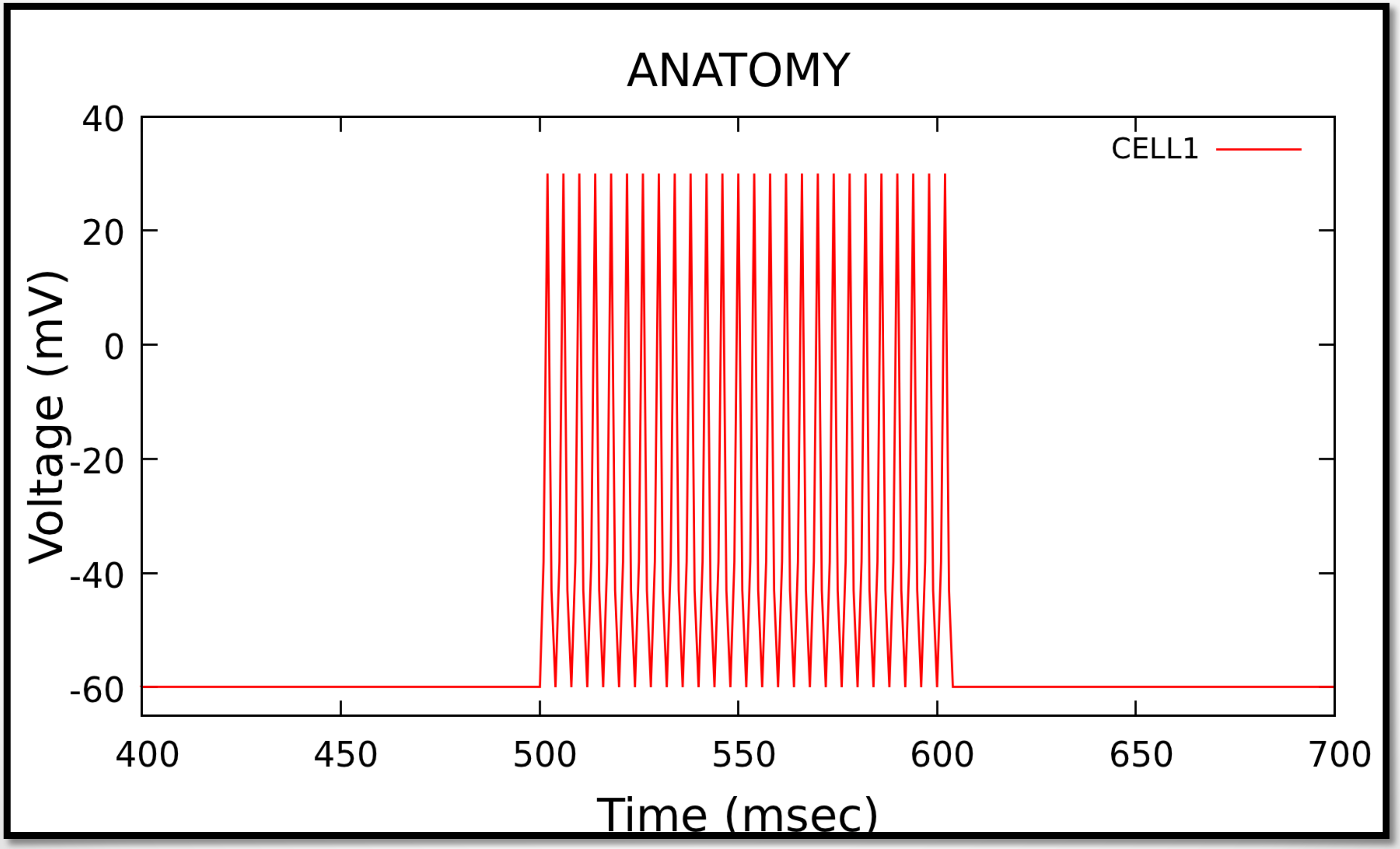
Anatomy

```
############################### Define Cells ################################
CELL
    TYPE                SIMPLE_MODEL_1
    COMPARTMENT         soma_SIMPLE_MODEL  somaE   0   0   0
END_CELL

CELL
    TYPE                SIMPLE_MODEL_2
    COMPARTMENT         soma_SIMPLE_MODEL  somaE   0   0   0
END_CELL

#########################
## Define Compartments
#########################

COMPARTMENT
    TYPE                  soma_SIMPLE_MODEL
    SPIKESHAPE            spikeshape_1k_default
    TAU_MEMBRANE          0.020       0.0
    R_MEMBRANE            200         0
    THRESHOLD             -40         0
    VMREST                -60         0
END_COMPARTMENT

########################### Define Spikeshape############################

SPIKESHAPE
  TYPE          spikeshape_1k_default
  VOLTAGES      -38 30 -43 -60
END_SPIKESHAPE
```

Anatomy

```
################################ Define Cells #################################
CELL
    TYPE                SIMPLE_MODEL_1
    COMPARTMENT         soma_SIMPLE_MODEL   somaE    0    0    0
END_CELL

CELL
    TYPE                SIMPLE_MODEL_2
    COMPARTMENT         soma_SIMPLE_MODEL   somaE    0    0    0
END_CELL

#########################
## Define Compartments
#########################

COMPARTMENT
    TYPE                  soma_SIMPLE_MODEL
    SPIKESHAPE            spikeshape_1k_default
    TAU_MEMBRANE          0.020        0.0
    R_MEMBRANE            200          0
    THRESHOLD             -40          0
    VMREST                -60          0
END_COMPARTMENT

########################### Define Spikeshape###########################

SPIKESHAPE
  TYPE          spikeshape_1k_default
  VOLTAGES      -38 30 -43 -60
END_SPIKESHAPE
```

Membrane Potential



Channel a

```
COMPARTMENT
    TYPE                  soma_SIMPLE_MODEL2
    SPIKESHAPE            spikeshape_channels
    TAU_MEMBRANE          0.020       0.0
    R_MEMBRANE            200         0
    THRESHOLD             -40         0
    VMREST                -60         0
    CHANNEL               a
END_COMPARTMENT
```

Channel a

```
CHANNEL Ka
        TYPE                                a
        M_INITIAL                           0.0             0.0
        H_INITIAL                           1.0             0.0
        REVERSAL_POTENTIAL                  -80             0
        M_POWER                             1
        H_POWER                             1
        E_HALF_MIN_M                        11
        E_HALF_MIN_H                        -56
        SLOPE_FACTOR_M                      18
        SLOPE_FACTOR_H                      18
        UNITARY_G                           0.12
        STRENGTH                            2.5
        V_TAU_VALUE_M                       0.0002          9999
        V_TAU_VALUE_H                       0.03    0.08    0.13    0.18    0.23
        V_TAU_VOLTAGE_M                     100
        V_TAU_VOLTAGE_H                     -21     -1      10      21
END_CHANNEL
```

Channel m

```
COMPARTMENT
    TYPE                soma_SIMPLE_MODEL2
    SPIKESHAPE          spikeshape_channels
    TAU_MEMBRANE        0.020       0.0
    R_MEMBRANE          200         0
    THRESHOLD           -40         0
    VMREST              -60         0
    CHANNEL             m
END_COMPARTMENT
```

Channel m

```
CHANNEL Km
        TYPE                                m
        M_INITIAL                           0.0                 0.0
        REVERSAL_POTENTIAL                  -80                 0
        M_POWER                             1
        E_HALF_MIN_M                        -44
        SLOPE_FACTOR_M                      40       20         8.8
        TAU_SCALE_FACTOR_M                  0.303
        UNITARY_G                           5
        STRENGTH                            0.00015
END_CHANNEL
```

Channel ahp

```
COMPARTMENT
    TYPE                  soma_SIMPLE_MODEL2
    SPIKESHAPE            spikeshape_channels
    TAU_MEMBRANE          0.020        0.0
    R_MEMBRANE            200          0
    THRESHOLD             -40          0
    VMREST                -60          0
    CHANNEL               ahp1
END_COMPARTMENT
```

Channel ahp

```
CHANNEL Kahp
        TYPE                                ahp1
        SEED                                999999
        M_INITIAL                           0.0              0.0
        REVERSAL_POTENTIAL                  -80              0
        M_POWER                             2
        UNITARY_G                           6
        STRENGTH                            0.00015
        CA_SCALE_FACTOR                     0.000125
        CA_EXP_FACTOR                       2
        CA_HALF_MIN                         2.5
        CA_TAU_SCALE_FACTOR                 0.01
END_CHANNEL
```

Stimulus

```
#######################   STIMULUS INJECTS   ###############################

STIMULUS_INJECT
    TYPE            SIMPLE_MODEL_STIM
    STIM_TYPE       realstim_SIMPLE_MODEL
    INJECT          SIMPLE_MODEL_COLUMN  layer_SIMPLE_MODEL      SIMPLE_MODEL_1  somaE   1
END_STIMULUS_INJECT

##############################define STIMULUS ###############################

STIMULUS
        TYPE                        realstim_SIMPLE_MODEL
        MODE                        CURRENT
        PATTERN                     PULSE
        DYN_RANGE                   0       75
        TIMING                      EXACT
        AMP_START                   4
        WIDTH                       .010
        TIME_START                  0.500
        TIME_END                    0.600
END_STIMULUS
```

Stimulus

```
#######################  STIMULUS INJECTS  ###############################

STIMULUS_INJECT
    TYPE            SIMPLE_MODEL_STIM
    STIM_TYPE       realstim_SIMPLE_MODEL
    INJECT          SIMPLE_MODEL_COLUMN  layer_SIMPLE_MODEL      SIMPLE_MODEL_1  somaE   1
END_STIMULUS_INJECT

#############################define STIMULUS ###############################

STIMULUS
        TYPE                    realstim_SIMPLE_MODEL
        MODE                    CURRENT
        PATTERN                 PULSE
        DYN_RANGE               0       75
        TIMING                  EXACT
        AMP_START               4
        WIDTH                   .010
        TIME_START              0.500
        TIME_END                0.600
END_STIMULUS
```

Stimulus

```
#######################   STIMULUS INJECTS   ###############################

STIMULUS_INJECT
    TYPE               SIMPLE_MODEL_STIM
    STIM_TYPE          realstim_SIMPLE_MODEL
    INJECT             SIMPLE_MODEL_COLUMN  layer_SIMPLE_MODEL      SIMPLE_MODEL_1  somaE   1
END_STIMULUS_INJECT

#############################define STIMULUS ###############################

STIMULUS
        TYPE                        realstim_SIMPLE_MODEL
        MODE                        CURRENT
        PATTERN                     PULSE
        DYN_RANGE                   0       75
        TIMING                      EXACT
        AMP_START                   4
        WIDTH                       .010
        TIME_START                  0.500
        TIME_END                    0.600
END_STIMULUS
```

Stimulus

```
#######################   STIMULUS INJECTS   ###############################

STIMULUS_INJECT
    TYPE              SIMPLE_MODEL_STIM
    STIM_TYPE         realstim_SIMPLE_MODEL
    INJECT            SIMPLE_MODEL_COLUMN  layer_SIMPLE_MODEL      SIMPLE_MODEL_1  somaE   1
END_STIMULUS_INJECT

#############################define STIMULUS ###############################

STIMULUS
        TYPE                    realstim_SIMPLE_MODEL
        MODE                    CURRENT
        PATTERN                 PULSE
        DYN_RANGE               0       75
        TIMING                  EXACT
        AMP_START               4
        WIDTH                   .010
        TIME_START              0.500
        TIME_END                0.600
END_STIMULUS
```

Stimulus

```
#######################   STIMULUS INJECTS   ###############################

STIMULUS_INJECT
    TYPE               SIMPLE_MODEL_STIM
    STIM_TYPE          realstim SIMPLE_MODEL
    INJECT             SIMPLE_MODEL_COLUMN  layer SIMPLE_MODEL      SIMPLE_MODEL_1   somaE    1
END_STIMULUS_INJECT

#############################define STIMULUS ###############################

STIMULUS
        TYPE                        realstim_SIMPLE_MODEL
        MODE                        CURRENT
        PATTERN                     PULSE
        DYN_RANGE                   0       75
        TIMING                      EXACT
        AMP_START                   4
        WIDTH                       .010
        TIME_START                  0.500
        TIME_END                    0.600
END_STIMULUS
```

Stimulus

```
#######################   STIMULUS INJECTS   ###############################

STIMULUS_INJECT
    TYPE            SIMPLE_MODEL_STIM
    STIM_TYPE       realstim_SIMPLE_MODEL
    INJECT          SIMPLE_MODEL_COLUMN  layer_SIMPLE_MODEL      SIMPLE_MODEL_1  somaE   1
END_STIMULUS_INJECT

##############################define STIMULUS ###############################

STIMULUS
        TYPE                    realstim_SIMPLE_MODEL
        MODE                    CURRENT
        PATTERN                 PULSE
        DYN_RANGE               0       75
        TIMING                  EXACT
        AMP_START               4
        WIDTH                   .010
        TIME_START              0.500
        TIME_END                0.600
END_STIMULUS
```

Stimulus

```
#######################   STIMULUS INJECTS   ###############################

STIMULUS_INJECT
    TYPE            SIMPLE_MODEL_STIM
    STIM_TYPE       realstim_SIMPLE_MODEL
    INJECT          SIMPLE_MODEL_COLUMN  layer_SIMPLE_MODEL      SIMPLE_MODEL_1  somaE   1
END_STIMULUS_INJECT

#############################define STIMULUS ###############################

STIMULUS
        TYPE                        realstim_SIMPLE_MODEL
        MODE                        CURRENT
        PATTERN                     PULSE
        DYN_RANGE                   0       75
        TIMING                      EXACT
        AMP_START                   4
        WIDTH                       .010
        TIME_START                  0.500
        TIME_END                    0.600
END_STIMULUS
```

Stimulus

```
########################   STIMULUS INJECTS   ################################

STIMULUS_INJECT
    TYPE                SIMPLE_MODEL_STIM
    STIM_TYPE           realstim_SIMPLE_MODEL
    INJECT              SIMPLE_MODEL_COLUMN  layer_SIMPLE_MODEL      SIMPLE_MODEL_1  somaE   1
END_STIMULUS_INJECT

##############################define STIMULUS ################################

STIMULUS
        TYPE                        realstim_SIMPLE_MODEL
        MODE                        CURRENT
        PATTERN                     PULSE
        DYN_RANGE                   0       75
        TIMING                      EXACT
        AMP_START                   4
        WIDTH                       .010
        TIME_START                  0.500
        TIME_END                    0.600
END_STIMULUS
```

Stimulus

```
######################## STIMULUS INJECTS ################################

STIMULUS_INJECT
    TYPE            SIMPLE_MODEL_STIM
    STIM_TYPE       realstim_SIMPLE_MODEL
    INJECT          SIMPLE_MODEL_COLUMN  layer_SIMPLE_MODEL      SIMPLE_MODEL_1  somaE   1
END_STIMULUS_INJECT

##############################define STIMULUS ###############################

STIMULUS
        TYPE                    realstim_SIMPLE_MODEL
        MODE                    CURRENT
        PATTERN                 PULSE
        DYN_RANGE               0       75
        TIMING                  EXACT
        AMP_START               4
        WIDTH                   .010
        TIME_START              0.500
        TIME_END                0.600
END_STIMULUS
```

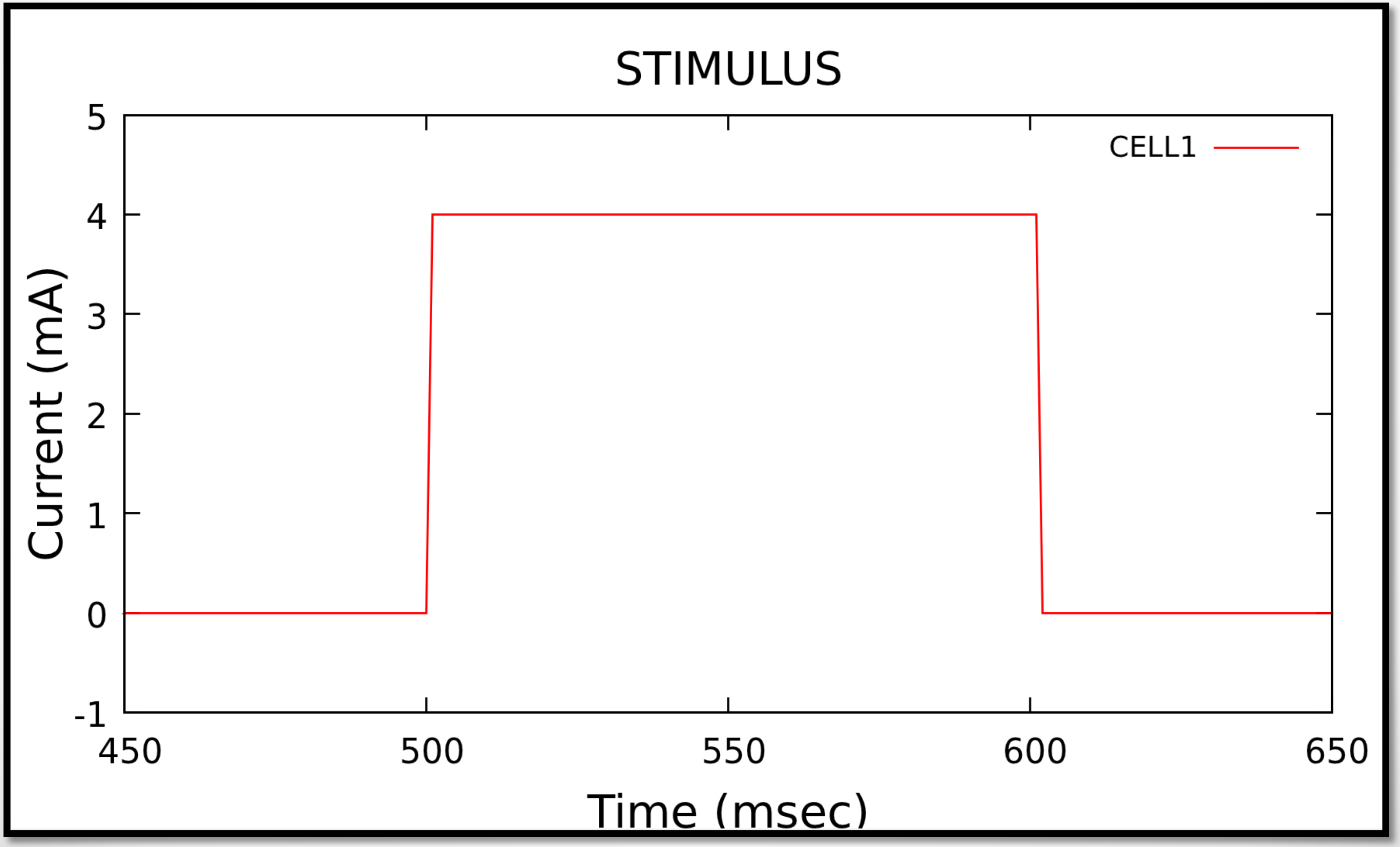
Stimulus

```
#######################   STIMULUS INJECTS   ###############################

STIMULUS_INJECT
    TYPE               SIMPLE_MODEL_STIM
    STIM_TYPE          realstim_SIMPLE_MODEL
    INJECT             SIMPLE_MODEL_COLUMN  layer_SIMPLE_MODEL      SIMPLE_MODEL_1  somaE   1
END_STIMULUS_INJECT

#############################define STIMULUS ###############################

STIMULUS
        TYPE                        realstim_SIMPLE_MODEL
        MODE                        CURRENT
        PATTERN                     PULSE
        DYN_RANGE                   0       75
        TIMING                      EXACT
        AMP_START                   4
        WIDTH                       .010
        TIME_START                  0.500
        TIME_END                    0.600
END_STIMULUS
```

Stimulus

```
#######################   STIMULUS INJECTS   ###############################

STIMULUS_INJECT
    TYPE            SIMPLE_MODEL_STIM
    STIM_TYPE       realstim_SIMPLE_MODEL
    INJECT          SIMPLE_MODEL_COLUMN  layer_SIMPLE_MODEL      SIMPLE_MODEL_1  somaE   1
END_STIMULUS_INJECT

#############################define STIMULUS ###############################

STIMULUS
        TYPE                    realstim_SIMPLE_MODEL
        MODE                    CURRENT
        PATTERN                 PULSE
        DYN_RANGE               0       75
        TIMING                  EXACT
        AMP_START               4
        WIDTH                   .010
        TIME_START              0.500
        TIME_END                0.600
END_STIMULUS
```

Amplitude


STIMULUS
CELL1
5
4
3
2
1
0
-1
Current (mA)
450
500
550
600
650
Time (msec)

Stimulus

```
#######################   STIMULUS INJECTS   ###############################

STIMULUS_INJECT
    TYPE            SIMPLE_MODEL_STIM
    STIM_TYPE       realstim_SIMPLE_MODEL
    INJECT          SIMPLE_MODEL_COLUMN  layer_SIMPLE_MODEL      SIMPLE_MODEL_1  somaE   1
END_STIMULUS_INJECT

#############################define STIMULUS ###############################

STIMULUS
        TYPE                    realstim_SIMPLE_MODEL
        MODE                    CURRENT
        PATTERN                 PULSE
        DYN_RANGE               0       75
        TIMING                  EXACT
        AMP_START               4
        WIDTH                   .010
        TIME_START              0.500
        TIME_END                0.600
END_STIMULUS
```

Stimulus

```
#######################   STIMULUS INJECTS   ###############################

STIMULUS_INJECT
    TYPE               SIMPLE_MODEL_STIM
    STIM_TYPE          realstim_SIMPLE_MODEL
    INJECT             SIMPLE_MODEL_COLUMN  layer_SIMPLE_MODEL      SIMPLE_MODEL_1  somaE   1
END_STIMULUS_INJECT

##############################define STIMULUS ###############################

STIMULUS
        TYPE                        realstim_SIMPLE_MODEL
        MODE                        CURRENT
        PATTERN                     PULSE
        DYN_RANGE                   0       75
        TIMING                      EXACT
        AMP_START                   4
        WIDTH                       .010
        TIME_START                  0.500
        TIME_END                    0.600
END_STIMULUS
```

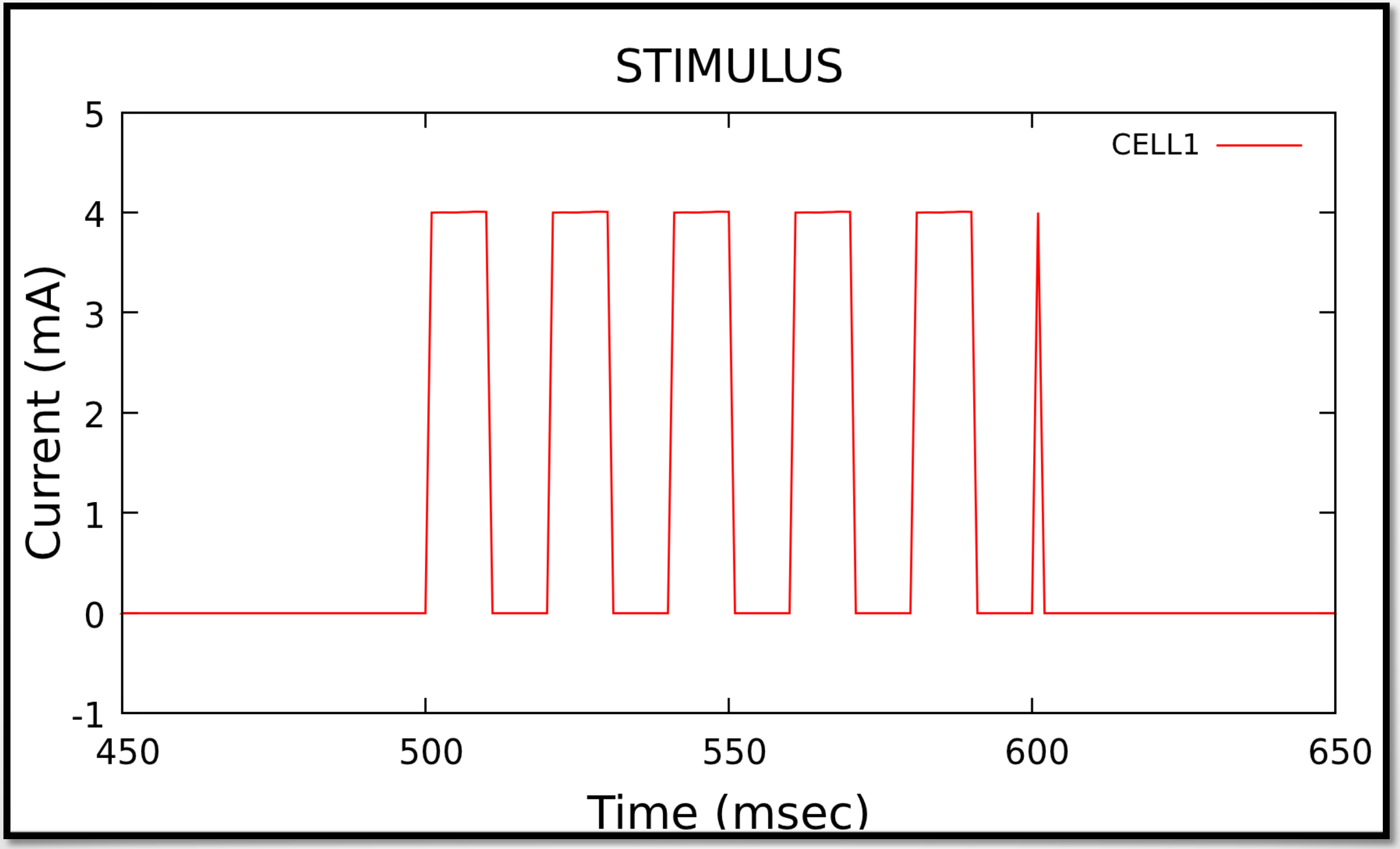
Stimulus

```
#######################   STIMULUS INJECTS   ###############################

STIMULUS_INJECT
    TYPE             SIMPLE_MODEL_STIM
    STIM_TYPE        realstim_SIMPLE_MODEL
    INJECT           SIMPLE_MODEL_COLUMN  layer_SIMPLE_MODEL      SIMPLE_MODEL_1  somaE   1
END_STIMULUS_INJECT

#############################define STIMULUS ###############################

STIMULUS
        TYPE                    realstim_SIMPLE_MODEL
        MODE                    CURRENT
        PATTERN                 PULSE
        DYN_RANGE               0       75
        TIMING                  EXACT
        AMP_START               4
        WIDTH                   .010
        TIME_START              0.500
        TIME_END                0.600
END_STIMULUS
```

Stimulus

```
#######################   STIMULUS INJECTS   ###############################

STIMULUS_INJECT
    TYPE            TWO_CELL_MODEL_STIM
    STIM_TYPE       realstim_TWO_CELL_MODEL
    INJECT          TWO_CELL_MODEL_COLUMN        layer_TWO_CELL_MODEL    TWO_CELL_MODEL_1        somaE 1
END_STIMULUS_INJECT

#############################define STIMULUS ###############################

STIMULUS
        TYPE                    realstim_TWO_CELL_MODEL
        MODE                    CURRENT
        PATTERN                 PULSE
        DYN_RANGE               0       75
        TIMING                  EXACT
        AMP_START               4
        WIDTH                   .010
        TIME_START              0.5
        TIME_END                0.6
        FREQ_START              50
END_STIMULUS
```

Width / Frequency



Connections

```
##############################################################################
# ----- connections
##############################################################################
     CONNECT
                     TWO_CELL_MODEL_COLUMN layer_TWO_CELL_MODEL TWO_CELL_MODEL_1 somaE
                     TWO_CELL_MODEL_COLUMN layer_TWO_CELL_MODEL TWO_CELL_MODEL_2 somaE
                     synEE_TWO_CELL_MODEL   1   0
```

Connections

```
##############################################################################
# ----- connections
##############################################################################
     CONNECT
                     TWO_CELL_MODEL_COLUMN layer_TWO_CELL_MODEL TWO_CELL_MODEL_1 somaE
                     TWO_CELL_MODEL_COLUMN layer_TWO_CELL_MODEL TWO_CELL_MODEL_2 somaE
                     synEE_TWO_CELL_MODEL   1   0
```

Connections

```
##########################################################################
# ----- connections
##########################################################################
     CONNECT
                    TWO_CELL_MODEL_COLUMN layer_TWO_CELL_MODEL TWO_CELL_MODEL_1 somaE
                    TWO_CELL_MODEL_COLUMN layer_TWO_CELL_MODEL TWO_CELL_MODEL_2 somaE
                    synEE_TWO_CELL_MODEL   1   0
```

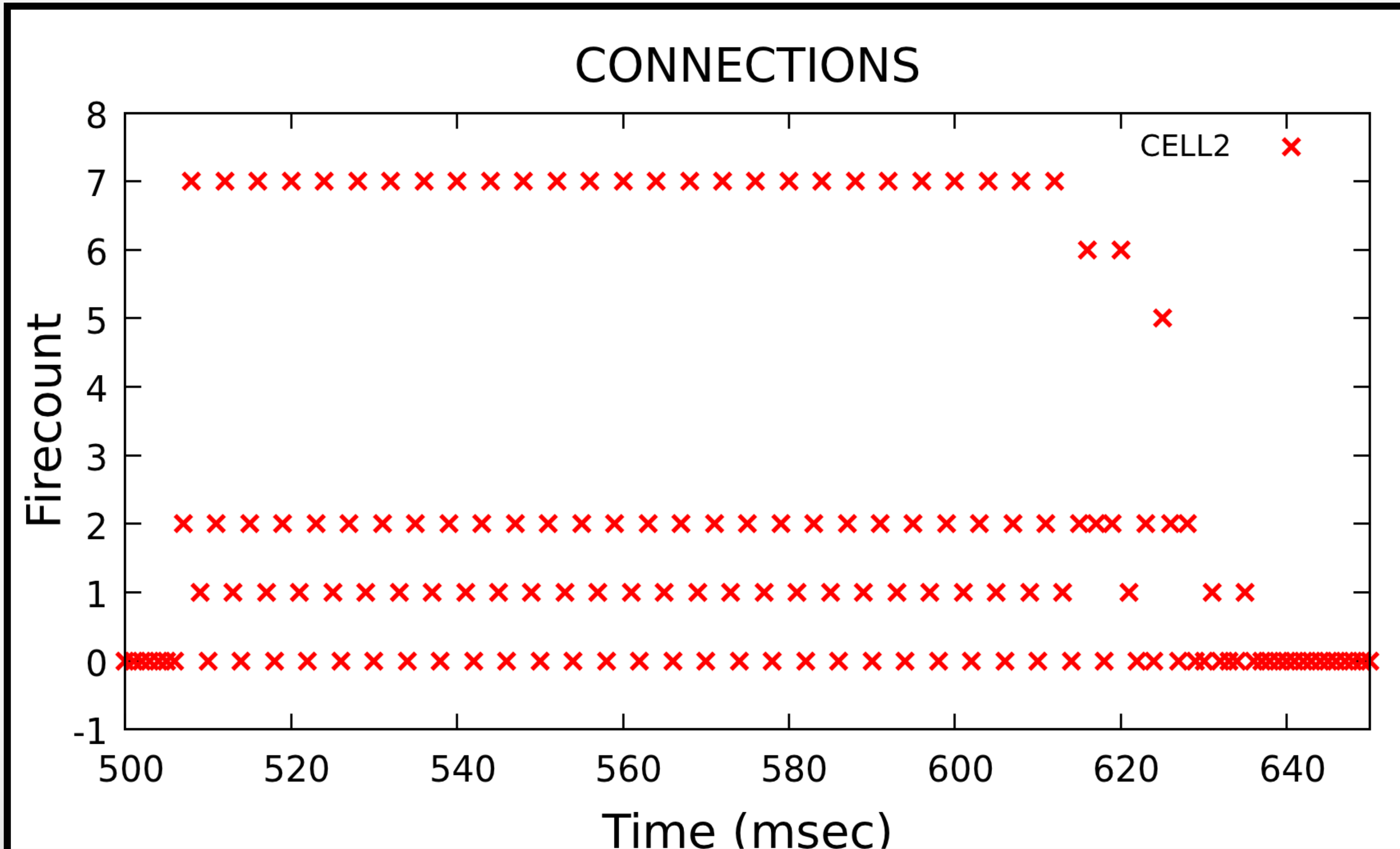
Connections

```
################################################################################
# ----- connections
################################################################################
     CONNECT
                     TWO CELL MODEL COLUMN layer TWO CELL MODEL TWO CELL MODEL 1 somaE
                     TWO CELL MODEL COLUMN layer TWO CELL MODEL TWO CELL MODEL 2 somaE
                     synEE_TWO_CELL_MODEL   1   0
```

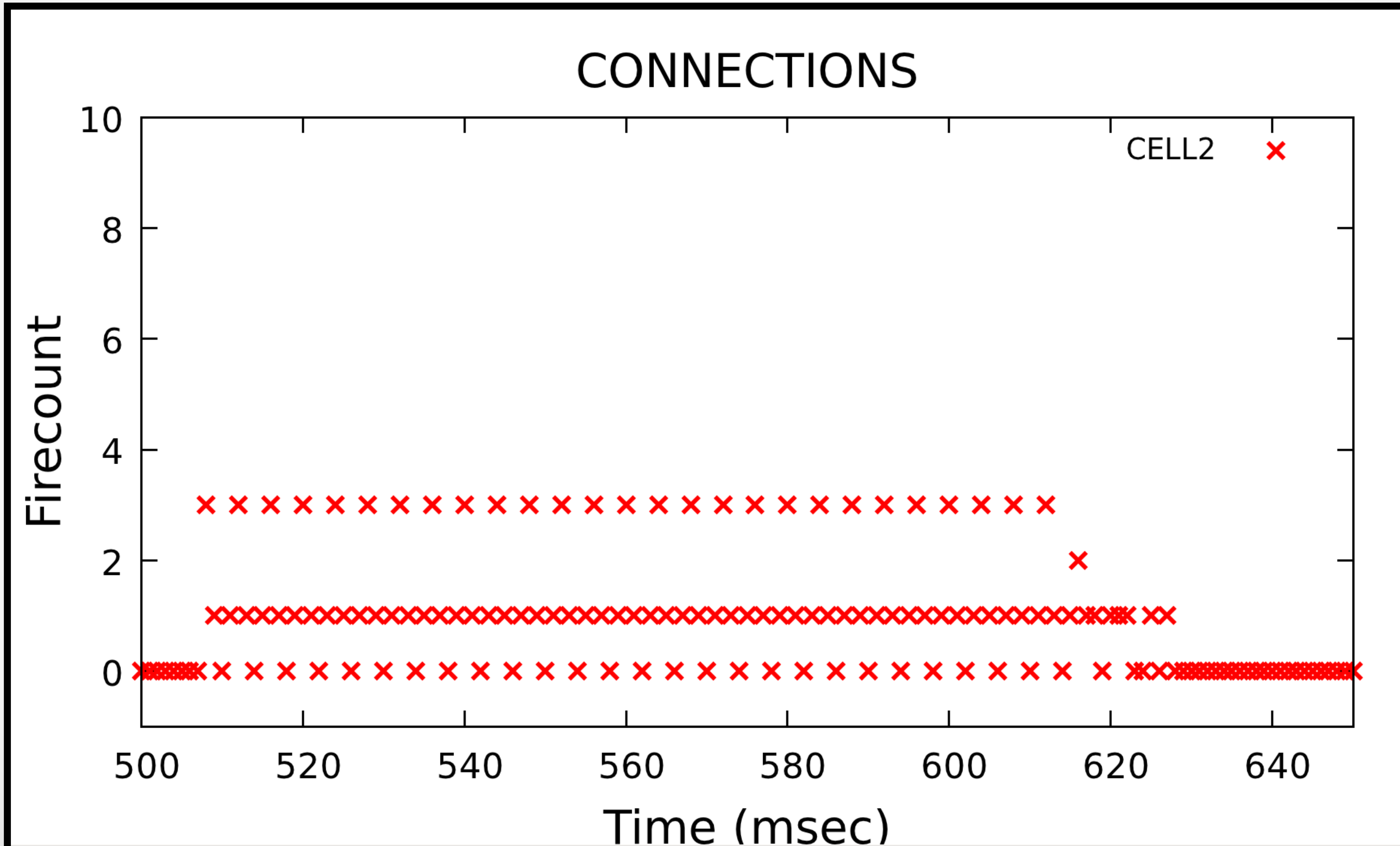
Connections

```
##############################################################################
# ----- connections
##############################################################################
     CONNECT
                     TWO_CELL_MODEL_COLUMN layer_TWO_CELL_MODEL TWO_CELL_MODEL_1 somaE
                     TWO_CELL_MODEL_COLUMN layer_TWO_CELL_MODEL TWO_CELL_MODEL_2 somaE
                     synEE TWO_CELL_MODEL   1   0
```

Probability of Connections



Probability of Connections



Synapses

```
##############SYNAPSES SIMPLE_MODEL_MODEL###############################

SYNAPSE
    TYPE             synEE_SIMPLE_MODEL
    SFD_LABEL              NO_SFD
    LEARN_LABEL            NO_STDP
    SYN_PSG          PSGexcit
    MAX_CONDUCT      0.4
    DELAY            0.005  0.010
    SYN_REVERSAL     0    0
    ABSOLUTE_USE     0.25    0.1
END_SYNAPSE

######################## SHORT-TERM SYNAPTIC DYNAMICS ########################

SYN_FACIL_DEPRESS
        TYPE                    NO_SFD
        SFD                     NONE
END_SYN_FACIL_DEPRESS

############################### LONG-TERM SYNAPTIC DYNAMICS #################

SYN_LEARNING
        TYPE                    NO_STDP
        LEARNING                NONE
END_SYN_LEARNING


############################### SYNAPTIC CONDUCTANCE WAVEFORMS ###############

SYN_PSG
        TYPE                    PSGexcit
        PSG_FILE                ./input/EPSG_Vogels_FSV1k_TAU05.inc
END_SYN_PSG
```

Synapses

```
###############SYNAPSES SIMPLE_MODEL_MODEL################################

SYNAPSE
    TYPE           synEE_SIMPLE_MODEL
    SFD_LABEL            NO_SFD
    LEARN_LABEL          NO_STDP
    SYN_PSG        PSGexcit
    MAX_CONDUCT    0.4
    DELAY          0.005  0.010
    SYN_REVERSAL   0    0
    ABSOLUTE_USE   0.25    0.1
END_SYNAPSE

######################## SHORT-TERM SYNAPTIC DYNAMICS ########################

SYN_FACIL_DEPRESS
        TYPE                    NO_SFD
        SFD                     NONE
END_SYN_FACIL_DEPRESS

############################### LONG-TERM SYNAPTIC DYNAMICS #################

SYN_LEARNING
        TYPE                    NO_STDP
        LEARNING                NONE
END_SYN_LEARNING


############################### SYNAPTIC CONDUCTANCE WAVEFORMS ###############

SYN_PSG
        TYPE                    PSGexcit
        PSG_FILE                ./input/EPSG_Vogels_FSV1k_TAU05.inc
END_SYN_PSG
```

Synapses

```
###############SYNAPSES SIMPLE_MODEL_MODEL################################

SYNAPSE
    TYPE            synEE_SIMPLE_MODEL
    SFD_LABEL             NO_SFD
    LEARN_LABEL           NO_STDP
    SYN_PSG         PSGexcit
    MAX_CONDUCT     0.4
    DELAY           0.005  0.010
    SYN_REVERSAL    0    0
    ABSOLUTE_USE    0.25    0.1
END_SYNAPSE

######################## SHORT-TERM SYNAPTIC DYNAMICS ########################

SYN_FACIL_DEPRESS
        TYPE                    NO_SFD
        SFD                     NONE
END_SYN_FACIL_DEPRESS

############################### LONG-TERM SYNAPTIC DYNAMICS #################

SYN_LEARNING
        TYPE                    NO_STDP
        LEARNING                NONE
END_SYN_LEARNING


############################### SYNAPTIC CONDUCTANCE WAVEFORMS ###############

SYN_PSG
        TYPE                    PSGexcit
        PSG_FILE                ./input/EPSG_Vogels_FSV1k_TAU05.inc
END_SYN_PSG
```

Synapses

```
##############SYNAPSES SIMPLE_MODEL_MODEL##############################

SYNAPSE
    TYPE             synFF_SIMPLE_MODEL
    SFD_LABEL              NO_SFD
    LEARN_LABEL            NO_STDP
    SYN_PSG          PSGexcit
    MAX_CONDUCT      0.4
    DELAY            0.005   0.010
    SYN_REVERSAL     0    0
    ABSOLUTE_USE     0.25     0.1
END_SYNAPSE

######################## SHORT-TERM SYNAPTIC DYNAMICS #########################

SYN_FACIL_DEPRESS
        TYPE                     NO_SFD
        SFD                      NONE
END_SYN_FACIL_DEPRESS

############################### LONG-TERM SYNAPTIC DYNAMICS ##################

SYN_LEARNING
        TYPE                     NO_STDP
        LEARNING                 NONE
END_SYN_LEARNING


############################### SYNAPTIC CONDUCTANCE WAVEFORMS ###############

SYN_PSG
        TYPE                     PSGexcit
        PSG_FILE                 ./input/EPSG_Vogels_FSV1k_TAU05.inc
END_SYN_PSG
```

Synapses

```
##############SYNAPSES SIMPLE_MODEL_MODEL################################

SYNAPSE
    TYPE            synEE_SIMPLE_MODEL
    SFD_LABEL             NO_SFD
    LEARN_LABEL           NO_STDP
    SYN_PSG         PSGexcit
    MAX_CONDUCT     0.4
    DELAY           0.005  0.010
    SYN_REVERSAL    0    0
    ABSOLUTE_USE    0.25    0.1
END_SYNAPSE

######################## SHORT-TERM SYNAPTIC DYNAMICS ########################

SYN_FACIL_DEPRESS
        TYPE                    NO_SFD
        SFD                     NONE
END_SYN_FACIL_DEPRESS

############################### LONG-TERM SYNAPTIC DYNAMICS #################

SYN_LEARNING
        TYPE                    NO_STDP
        LEARNING                NONE
END_SYN_LEARNING


############################### SYNAPTIC CONDUCTANCE WAVEFORMS ###############

SYN_PSG
        TYPE                    PSGexcit
        PSG_FILE                ./input/EPSG_Vogels_FSV1k_TAU05.inc
END_SYN_PSG
```

Synapses

```
##############SYNAPSES SIMPLE_MODEL_MODEL################################

SYNAPSE
    TYPE              synEE_SIMPLE_MODEL
    SFD_LABEL               NO_SFD
    LEARN_LABEL             NO_STDP
    SYN_PSG           PSGexcit
    MAX_CONDUCT       0.4
    DELAY             0.005  0.010
    SYN_REVERSAL      0    0
    ABSOLUTE_USE      0.25    0.1
END_SYNAPSE

######################## SHORT-TERM SYNAPTIC DYNAMICS ########################

SYN_FACIL_DEPRESS
        TYPE                        NO_SFD
        SFD                         NONE
END_SYN_FACIL_DEPRESS

############################### LONG-TERM SYNAPTIC DYNAMICS ##################

SYN_LEARNING
        TYPE                        NO_STDP
        LEARNING                    NONE
END_SYN_LEARNING


############################### SYNAPTIC CONDUCTANCE WAVEFORMS ###############

SYN_PSG
        TYPE                        PSGexcit
        PSG_FILE                    ./input/EPSG_Vogels_FSV1k_TAU05.inc
END_SYN_PSG
```

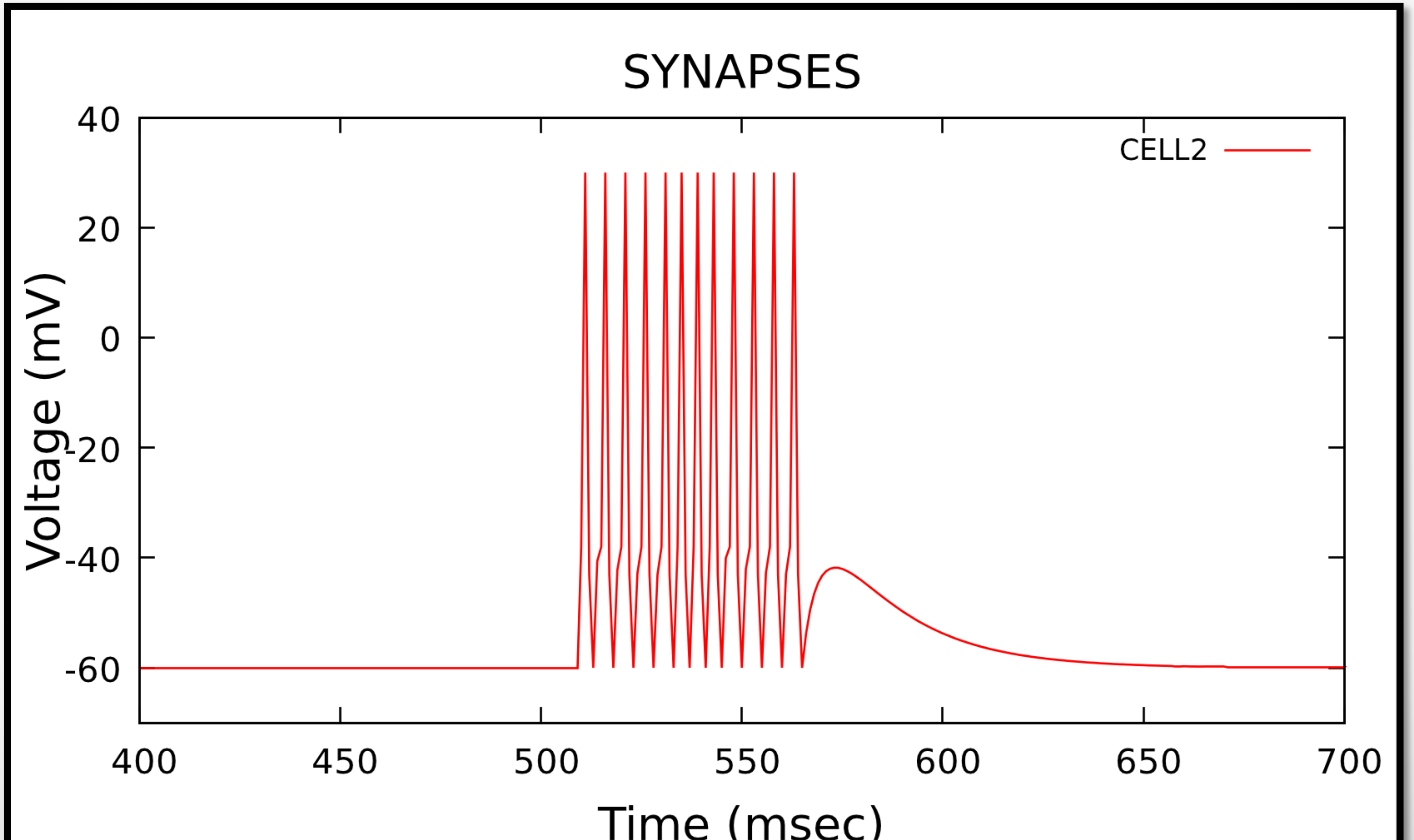
Synapses

```
##############SYNAPSES SIMPLE_MODEL_MODEL################################

SYNAPSE
    TYPE            synEE_SIMPLE_MODEL
    SFD_LABEL             NO_SFD
    LEARN_LABEL           NO_STDP
    SYN_PSG         PSGexcit
    MAX_CONDUCT     0.4
    DELAY           0.005  0.010
    SYN_REVERSAL    0    0
    ABSOLUTE_USE    0.25    0.1
END_SYNAPSE

######################## SHORT-TERM SYNAPTIC DYNAMICS #########################

SYN_FACIL_DEPRESS
        TYPE                    NO_SFD
        SFD                     NONE
END_SYN_FACIL_DEPRESS

############################### LONG-TERM SYNAPTIC DYNAMICS #################

SYN_LEARNING
        TYPE                    NO_STDP
        LEARNING                NONE
END_SYN_LEARNING


############################### SYNAPTIC_CONDUCTANCE_WAVEFORMS ###############

SYN_PSG
        TYPE                    PSGexcit
        PSG_FILE                ./input/EPSG_Vogels_FSV1k_TAU05.inc
END_SYN_PSG
```

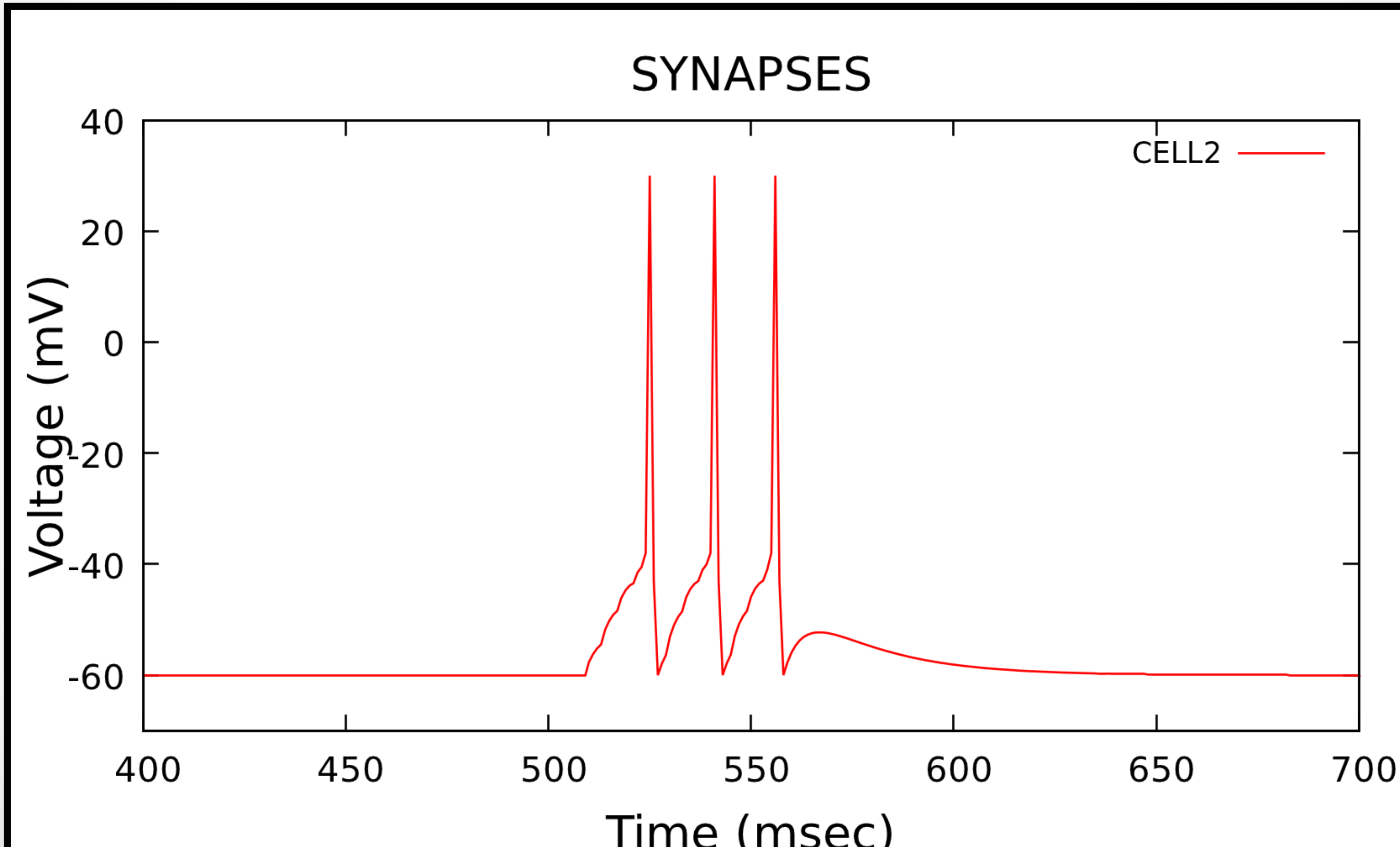
Synapses

```
##############SYNAPSES SIMPLE_MODEL_MODEL################################

SYNAPSE
    TYPE            synEE_SIMPLE_MODEL
    SFD_LABEL             NO_SFD
    LEARN_LABEL           NO_STDP
    SYN_PSG         PSGexcit
    MAX_CONDUCT     0.4
    DELAY           0.005   0.010
    SYN_REVERSAL    0    0
    ABSOLUTE_USE    0.25    0.1
END_SYNAPSE

######################## SHORT-TERM SYNAPTIC DYNAMICS ########################

SYN_FACIL_DEPRESS
        TYPE                    NO_SFD
        SFD                     NONE
END_SYN_FACIL_DEPRESS

############################### LONG-TERM SYNAPTIC DYNAMICS ##################

SYN_LEARNING
        TYPE                    NO_STDP
        LEARNING                NONE
END_SYN_LEARNING


############################### SYNAPTIC CONDUCTANCE WAVEFORMS ###############

SYN_PSG
        TYPE                    PSGexcit
        PSG_FILE                ./input/EPSG_Vogels_FSV1k_TAU05.inc
END_SYN_PSG
```

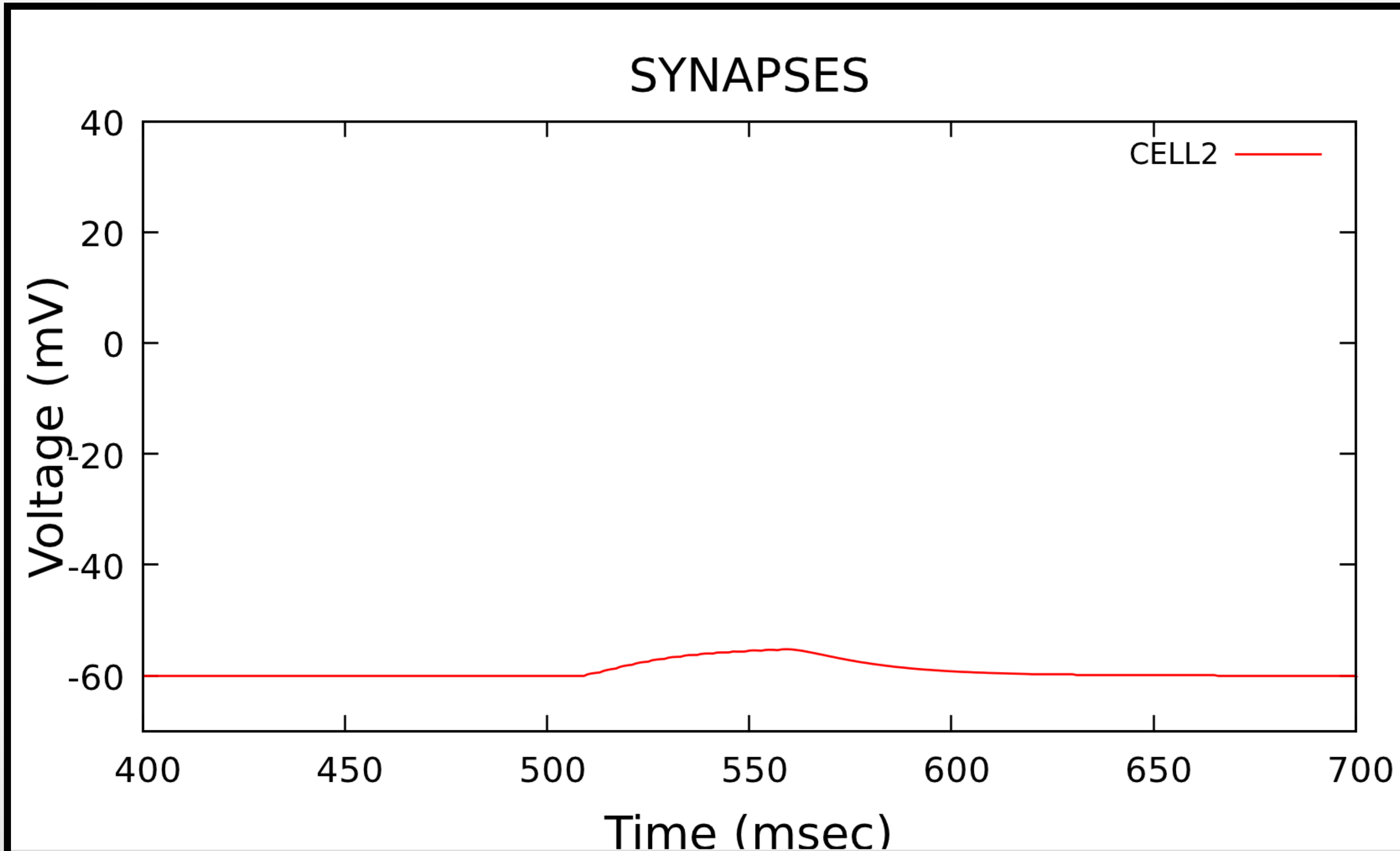
Conductance Strength



Conductance Strength



Conductance Strength



Synapses

```
##############SYNAPSES SIMPLE_MODEL_MODEL################################

SYNAPSE
    TYPE             synEE_SIMPLE_MODEL
    SFD_LABEL              NO_SFD
    LEARN_LABEL            NO_STDP
    SYN_PSG          PSGexcit
    MAX_CONDUCT      0.4
    DELAY            0.005  0.010
    SYN_REVERSAL     0     0
    ABSOLUTE_USE     0.25     0.1
END_SYNAPSE

######################## SHORT-TERM SYNAPTIC DYNAMICS ########################

SYN_FACIL_DEPRESS
        TYPE                        NO_SFD
        SFD                         NONE
END_SYN_FACIL_DEPRESS

############################### LONG-TERM SYNAPTIC DYNAMICS ##################

SYN_LEARNING
        TYPE                        NO_STDP
        LEARNING                    NONE
END_SYN_LEARNING


############################### SYNAPTIC CONDUCTANCE WAVEFORMS ###############

SYN_PSG
        TYPE                        PSGexcit
        PSG_FILE                    ./input/EPSG_Vogels_FSV1k_TAU05.inc
END_SYN_PSG
```

Synapses

```
##############SYNAPSES SIMPLE_MODEL_MODEL################################

SYNAPSE
    TYPE            synEE_SIMPLE_MODEL
    SFD_LABEL             NO_SFD
    LEARN_LABEL           NO_STDP
    SYN_PSG         PSGexcit
    MAX_CONDUCT     0.4
    DELAY           0.005  0.010
    SYN_REVERSAL    0    0
    ABSOLUTE_USE    0.25    0.1
END_SYNAPSE

######################## SHORT-TERM SYNAPTIC DYNAMICS ########################

SYN_FACIL_DEPRESS
        TYPE                    NO_SFD
        SFD                     NONE
END_SYN_FACIL_DEPRESS

############################### LONG-TERM SYNAPTIC DYNAMICS #################

SYN_LEARNING
        TYPE                    NO_STDP
        LEARNING                NONE
END_SYN_LEARNING


############################### SYNAPTIC CONDUCTANCE WAVEFORMS ###############

SYN_PSG
        TYPE                    PSGexcit
        PSG_FILE                ./input/EPSG_Vogels_FSV1k_TAU05.inc
END_SYN_PSG
```

Synapses

```
##############SYNAPSES SIMPLE_MODEL_MODEL################################

SYNAPSE
    TYPE            synEE_SIMPLE_MODEL
    SFD_LABEL             NO_SFD
    LEARN_LABEL           NO_STDP
    SYN_PSG         PSGexcit
    MAX_CONDUCT     0.4
    DELAY           0.005   0.010
    SYN_REVERSAL    0    0
    ABSOLUTE_USE    0.25     0.1
END_SYNAPSE

######################## SHORT-TERM SYNAPTIC DYNAMICS #########################

SYN_FACIL_DEPRESS
        TYPE                    NO_SFD
        SFD                     NONE
END_SYN_FACIL_DEPRESS

############################### LONG-TERM SYNAPTIC DYNAMICS ##################

SYN_LEARNING
        TYPE                    NO_STDP
        LEARNING                NONE
END_SYN_LEARNING


############################### SYNAPTIC CONDUCTANCE WAVEFORMS ###############

SYN_PSG
        TYPE                    PSGexcit
        PSG_FILE                ./input/EPSG_Vogels_FSV1k_TAU05.inc
END_SYN_PSG
```

Learning

```
##############SYNAPSES SIMPLE_MODEL_MODEL################################

SYNAPSE
    TYPE            synEE_SIMPLE_MODEL
    SFD_LABEL             NO_SFD
    LEARN_LABEL           NO_STDP
    SYN_PSG         PSGexcit
    MAX_CONDUCT     0.4
    DELAY           0.005  0.010
    SYN_REVERSAL    0    0
    ABSOLUTE_USE    0.25    0.1
END_SYNAPSE

######################## SHORT-TERM SYNAPTIC DYNAMICS #########################

SYN_FACIL_DEPRESS
        TYPE                    NO_SFD
        SFD                     NONE
END_SYN_FACIL_DEPRESS

############################### LONG-TERM SYNAPTIC DYNAMICS ##################

SYN_LEARNING
        TYPE                    NO_STDP
        LEARNING                NONE
END_SYN_LEARNING


############################### SYNAPTIC CONDUCTANCE WAVEFORMS ###############

SYN_PSG
        TYPE                    PSGexcit
        PSG_FILE                ./input/EPSG_Vogels_FSV1k_TAU05.inc
END_SYN_PSG
```

Learning

```
###############SYNAPSES SIMPLE_MODEL_MODEL##################################

SYNAPSE
    TYPE              synEE_SIMPLE_MODEL
    SFD_LABEL               FACILITATION
    LEARN_LABEL             NO_STDP
    SYN_PSG           PSGexcit
    MAX_CONDUCT       0.4
    DELAY             0.005  0.010
    SYN_REVERSAL      0    0
    ABSOLUTE_USE      0.25    0.1
END_SYNAPSE

######################## SHORT-TERM SYNAPTIC DYNAMICS #########################

SYN_FACIL_DEPRESS
        TYPE                       FACILITATION
        SFD                        BOTH
        FACIL_TAU                  0.376           0.0
        DEPR_TAU                   0.045           0.0
END_SYN_FACIL_DEPRESS
```

Learning

```
##############SYNAPSES SIMPLE_MODEL_MODEL##############################

SYNAPSE
    TYPE            synEE_SIMPLE_MODEL
    SFD_LABEL             FACILITATION
    LEARN_LABEL           NO_STDP
    SYN_PSG         PSGexcit
    MAX_CONDUCT     0.4
    DELAY           0.005  0.010
    SYN_REVERSAL    0    0
    ABSOLUTE_USE    0.25    0.1
END_SYNAPSE

######################## SHORT-TERM SYNAPTIC DYNAMICS #########################

SYN_FACIL_DEPRESS
        TYPE                    FACILITATION
        SFD                     BOTH
        FACIL_TAU               0.376          0.0
        DEPR_TAU                0.045          0.0
END_SYN_FACIL_DEPRESS
```

Learning

```
##############SYNAPSES SIMPLE_MODEL_MODEL##############################

SYNAPSE
    TYPE            synEE_SIMPLE_MODEL
    SFD_LABEL             FACILITATION
    LEARN_LABEL           NO_STDP
    SYN_PSG         PSGexcit
    MAX_CONDUCT     0.4
    DELAY           0.005  0.010
    SYN_REVERSAL    0    0
    ABSOLUTE_USE    0.25    0.1
END_SYNAPSE

######################## SHORT-TERM SYNAPTIC DYNAMICS #########################

SYN_FACIL_DEPRESS
        TYPE                    FACILITATION
        SFD                     BOTH
        FACIL_TAU               0.376          0.0
        DEPR_TAU                0.045          0.0
END_SYN_FACIL_DEPRESS
```

Learning

```
##############SYNAPSES SIMPLE_MODEL_MODEL##############################

SYNAPSE
    TYPE             synEE_SIMPLE_MODEL
    SFD_LABEL              FACILITATION
    LEARN_LABEL            NO_STDP
    SYN_PSG          PSGexcit
    MAX_CONDUCT      0.4
    DELAY            0.005  0.010
    SYN_REVERSAL     0    0
    ABSOLUTE_USE     0.25    0.1
END_SYNAPSE

######################## SHORT-TERM SYNAPTIC DYNAMICS ########################

SYN_FACIL_DEPRESS
        TYPE                        FACILITATION
        SFD                         BOTH
        FACIL_TAU                   0.376           0.0
        DEPR_TAU                    0.045           0.0
END_SYN_FACIL_DEPRESS
```

Learning

```
##############SYNAPSES SIMPLE_MODEL_MODEL##############################

SYNAPSE
    TYPE            synEE_SIMPLE_MODEL
    SFD_LABEL             FACILITATION
    LEARN_LABEL           NO_STDP
    SYN_PSG         PSGexcit
    MAX_CONDUCT     0.4
    DELAY           0.005  0.010
    SYN_REVERSAL    0    0
    ABSOLUTE_USE    0.25    0.1
END_SYNAPSE

######################## SHORT-TERM SYNAPTIC DYNAMICS #########################

SYN_FACIL_DEPRESS
        TYPE                      FACILITATION
        SFD                       BOTH
        FACIL_TAU                 0.376           0.0
        DEPR_TAU                  0.045           0.0
END_SYN_FACIL_DEPRESS
```

Learning

```
##############SYNAPSES SIMPLE_MODEL_MODEL###############################

SYNAPSE
    TYPE             synEE_SIMPLE_MODEL
    SFD_LABEL              FACILITATION
    LEARN_LABEL            NO_STDP
    SYN_PSG          PSGexcit
    MAX_CONDUCT      0.4
    DELAY            0.005  0.010
    SYN_REVERSAL     0    0
    ABSOLUTE_USE     0.25    0.1
END_SYNAPSE

######################## SHORT-TERM SYNAPTIC DYNAMICS #########################

SYN_FACIL_DEPRESS
        TYPE                        FACILITATION
        SFD                         BOTH
        FACIL_TAU                   0.376           0.0
        DEPR_TAU                    0.045           0.0
END_SYN_FACIL_DEPRESS
```

Learning

```
##############SYNAPSES SIMPLE_MODEL_MODEL################################

SYNAPSE
    TYPE            synEE_SIMPLE_MODEL
    SFD_LABEL             NO_SFD
    LEARN_LABEL           NO_STDP
    SYN_PSG         PSGexcit
    MAX_CONDUCT     0.4
    DELAY           0.005   0.010
    SYN_REVERSAL    0    0
    ABSOLUTE_USE    0.25    0.1
END_SYNAPSE

######################## SHORT-TERM SYNAPTIC DYNAMICS ########################

SYN_FACIL_DEPRESS
        TYPE                        NO_SFD
        SFD                         NONE
END_SYN_FACIL_DEPRESS

############################### LONG-TERM SYNAPTIC DYNAMICS ##################

SYN_LEARNING
        TYPE                        NO_STDP
        LEARNING                    NONE
END_SYN_LEARNING


############################### SYNAPTIC CONDUCTANCE WAVEFORMS ###############

SYN_PSG
        TYPE                        PSGexcit
        PSG_FILE                    ./input/EPSG_Vogels_FSV1k_TAU05.inc
END_SYN_PSG
```

Learning

```
##############SYNAPSES SIMPLE_MODEL_MODEL################################

SYNAPSE
    TYPE           synEE_SIMPLE_MODEL
    SFD_LABEL            NO_SFD
    LEARN_LABEL          HEBBIAN
    SYN_PSG        PSGexcit
    MAX_CONDUCT    0.4
    DELAY          0.005  0.010
    SYN_REVERSAL   0    0
    ABSOLUTE_USE   0.25    0.1
END_SYNAPSE

######################## SHORT-TERM SYNAPTIC DYNAMICS ########################

SYN_FACIL_DEPRESS
        TYPE                    NO_SFD
        SFD                     NONE
END_SYN_FACIL_DEPRESS

############################### LONG-TERM SYNAPTIC DYNAMICS ##################

SYN_LEARNING
        TYPE                    HEBBIAN
        LEARNING                BOTH
        LEARNING_SHAPE          EXPONENT
        NEG_HEB_WINDOW          0.1             0.0
        POS_HEB_WINDOW          0.1             0.0
        POS_HEB_PEAK_DELTA_USE  0.005           0.0
        NEG_HEB_PEAK_DELTA_USE  0.0055          0.0
        POS_HEB_PEAK_TIME       0.02            0.0
        NEG_HEB_PEAK_TIME       0.02            0.0
END_SYN_LEARNING
```

Learning

```
##############SYNAPSES SIMPLE_MODEL_MODEL################################

SYNAPSE
    TYPE          synEE_SIMPLE_MODEL
    SFD_LABEL           NO_SFD
    LEARN_LABEL         HEBBIAN
    SYN_PSG       PSGexcit
    MAX_CONDUCT   0.4
    DELAY         0.005  0.010
    SYN_REVERSAL  0    0
    ABSOLUTE_USE  0.25    0.1
END_SYNAPSE

######################## SHORT-TERM SYNAPTIC DYNAMICS ########################

SYN_FACIL_DEPRESS
        TYPE                    NO_SFD
        SFD                     NONE
END_SYN_FACIL_DEPRESS

############################### LONG-TERM SYNAPTIC DYNAMICS ##################

SYN_LEARNING
        TYPE                    HEBBIAN
        LEARNING                BOTH
        LEARNING_SHAPE          EXPONENT
        NEG_HEB_WINDOW          0.1             0.0
        POS_HEB_WINDOW          0.1             0.0
        POS_HEB_PEAK_DELTA_USE  0.005           0.0
        NEG_HEB_PEAK_DELTA_USE  0.0055          0.0
        POS_HEB_PEAK_TIME       0.02            0.0
        NEG_HEB_PEAK_TIME       0.02            0.0
END_SYN_LEARNING
```

Learning

```
##############SYNAPSES SIMPLE_MODEL_MODEL################################

SYNAPSE
    TYPE          synEE_SIMPLE_MODEL
    SFD_LABEL           NO_SFD
    LEARN_LABEL         HEBBIAN
    SYN_PSG       PSGexcit
    MAX_CONDUCT   0.4
    DELAY         0.005  0.010
    SYN_REVERSAL  0     0
    ABSOLUTE_USE  0.25    0.1
END_SYNAPSE

######################## SHORT-TERM SYNAPTIC DYNAMICS ########################

SYN_FACIL_DEPRESS
        TYPE                    NO_SFD
        SFD                     NONE
END_SYN_FACIL_DEPRESS

############################### LONG-TERM SYNAPTIC DYNAMICS ##################

SYN_LEARNING
        TYPE                    HEBBIAN
        LEARNING                BOTH
        LEARNING_SHAPE          EXPONENT
        NEG_HEB_WINDOW          0.1             0.0
        POS_HEB_WINDOW          0.1             0.0
        POS_HEB_PEAK_DELTA_USE  0.005           0.0
        NEG_HEB_PEAK_DELTA_USE  0.0055          0.0
        POS_HEB_PEAK_TIME       0.02            0.0
        NEG_HEB_PEAK_TIME       0.02            0.0
END_SYN_LEARNING
```

Learning

```
##############SYNAPSES SIMPLE_MODEL_MODEL################################

SYNAPSE
    TYPE          synEE_SIMPLE_MODEL
    SFD_LABEL           NO_SFD
    LEARN_LABEL         HEBBIAN
    SYN_PSG       PSGexcit
    MAX_CONDUCT   0.4
    DELAY         0.005  0.010
    SYN_REVERSAL  0     0
    ABSOLUTE_USE  0.25    0.1
END_SYNAPSE

######################## SHORT-TERM SYNAPTIC DYNAMICS ########################

SYN_FACIL_DEPRESS
        TYPE                    NO_SFD
        SFD                     NONE
END_SYN_FACIL_DEPRESS

############################### LONG-TERM SYNAPTIC DYNAMICS ##################

SYN_LEARNING
        TYPE                    HEBBIAN
        LEARNING                BOTH
        LEARNING_SHAPE          EXPONENT
        NEG_HEB_WINDOW          0.1             0.0
        POS_HEB_WINDOW          0.1             0.0
        POS_HEB_PEAK_DELTA_USE  0.005           0.0
        NEG_HEB_PEAK_DELTA_USE  0.0055          0.0
        POS_HEB_PEAK_TIME       0.02            0.0
        NEG_HEB_PEAK_TIME       0.02            0.0
END_SYN_LEARNING
```

Learning

```
##############SYNAPSES SIMPLE_MODEL_MODEL#################################

SYNAPSE
    TYPE          synEE_SIMPLE_MODEL
    SFD_LABEL           NO_SFD
    LEARN_LABEL         HEBBIAN
    SYN_PSG       PSGexcit
    MAX_CONDUCT   0.4
    DELAY         0.005  0.010
    SYN_REVERSAL  0     0
    ABSOLUTE_USE  0.25    0.1
END_SYNAPSE

######################## SHORT-TERM SYNAPTIC DYNAMICS ########################

SYN_FACIL_DEPRESS
        TYPE                    NO_SFD
        SFD                     NONE
END_SYN_FACIL_DEPRESS

############################### LONG-TERM SYNAPTIC DYNAMICS ##################

SYN_LEARNING
        TYPE                    HEBBIAN
        LEARNING                BOTH
        LEARNING_SHAPE          EXPONENT
        NEG_HEB_WINDOW          0.1             0.0
        POS_HEB_WINDOW          0.1             0.0
        POS_HEB_PEAK_DELTA_USE  0.005           0.0
        NEG_HEB_PEAK_DELTA_USE  0.0055          0.0
        POS_HEB_PEAK_TIME       0.02            0.0
        NEG_HEB_PEAK_TIME       0.02            0.0
END_SYN_LEARNING
```

Learning

```
##############SYNAPSES SIMPLE_MODEL_MODEL################################

SYNAPSE
    TYPE          synEE_SIMPLE_MODEL
    SFD_LABEL           NO_SFD
    LEARN_LABEL         HEBBIAN
    SYN_PSG       PSGexcit
    MAX_CONDUCT   0.4
    DELAY         0.005  0.010
    SYN_REVERSAL  0     0
    ABSOLUTE_USE  0.25    0.1
END_SYNAPSE

######################## SHORT-TERM SYNAPTIC DYNAMICS ########################

SYN_FACIL_DEPRESS
        TYPE                    NO_SFD
        SFD                     NONE
END_SYN_FACIL_DEPRESS

############################### LONG-TERM SYNAPTIC DYNAMICS ##################

SYN_LEARNING
        TYPE                    HEBBIAN
        LEARNING                BOTH
        LEARNING_SHAPE          EXPONENT
        NEG_HEB_WINDOW          0.1             0.0
        POS_HEB_WINDOW          0.1             0.0
        POS_HEB_PEAK_DELTA_USE  0.005           0.0
        NEG_HEB_PEAK_DELTA_USE  0.0055          0.0
        POS_HEB_PEAK_TIME       0.02            0.0
        NEG_HEB_PEAK_TIME       0.02            0.0
END_SYN_LEARNING
```

Learning

```
##############SYNAPSES SIMPLE_MODEL_MODEL################################

SYNAPSE
    TYPE          synEE_SIMPLE_MODEL
    SFD_LABEL           NO_SFD
    LEARN_LABEL         HEBBIAN
    SYN_PSG       PSGexcit
    MAX_CONDUCT   0.4
    DELAY         0.005  0.010
    SYN_REVERSAL  0     0
    ABSOLUTE_USE  0.25    0.1
END_SYNAPSE

######################## SHORT-TERM SYNAPTIC DYNAMICS ########################

SYN_FACIL_DEPRESS
        TYPE                    NO_SFD
        SFD                     NONE
END_SYN_FACIL_DEPRESS

############################### LONG-TERM SYNAPTIC DYNAMICS ##################

SYN_LEARNING
        TYPE                    HEBBIAN
        LEARNING                BOTH
        LEARNING_SHAPE          EXPONENT
        NEG_HEB_WINDOW          0.1             0.0
        POS_HEB_WINDOW          0.1             0.0
        POS_HEB_PEAK_DELTA_USE  0.005           0.0
        NEG_HEB_PEAK_DELTA_USE  0.0055          0.0
        POS_HEB_PEAK_TIME       0.02            0.0
        NEG_HEB_PEAK_TIME       0.02            0.0
END_SYN_LEARNING
```

Learning

```
##############SYNAPSES SIMPLE_MODEL_MODEL##################################

SYNAPSE
    TYPE          synEE_SIMPLE_MODEL
    SFD_LABEL           NO_SFD
    LEARN_LABEL         HEBBIAN
    SYN_PSG       PSGexcit
    MAX_CONDUCT   0.4
    DELAY         0.005  0.010
    SYN_REVERSAL  0     0
    ABSOLUTE_USE  0.25    0.1
END_SYNAPSE

######################## SHORT-TERM SYNAPTIC DYNAMICS ########################

SYN_FACIL_DEPRESS
        TYPE                    NO_SFD
        SFD                     NONE
END_SYN_FACIL_DEPRESS

############################### LONG-TERM SYNAPTIC DYNAMICS ##################

SYN_LEARNING
        TYPE                    HEBBIAN
        LEARNING                BOTH
        LEARNING_SHAPE          EXPONENT
        NEG_HEB_WINDOW          0.1             0.0
        POS_HEB_WINDOW          0.1             0.0
        POS_HEB_PEAK_DELTA_USE  0.005           0.0
        NEG_HEB_PEAK_DELTA_USE  0.0055          0.0
        POS_HEB_PEAK_TIME       0.02            0.0
        NEG_HEB_PEAK_TIME       0.02            0.0
END_SYN_LEARNING
```

Learning

```
###############SYNAPSES SIMPLE_MODEL_MODEL################################

SYNAPSE
    TYPE          synEE_SIMPLE_MODEL
    SFD_LABEL           NO_SFD
    LEARN_LABEL         HEBBIAN
    SYN_PSG       PSGexcit
    MAX_CONDUCT   0.4
    DELAY         0.005  0.010
    SYN_REVERSAL  0     0
    ABSOLUTE_USE  0.25    0.1
END_SYNAPSE

######################## SHORT-TERM SYNAPTIC DYNAMICS ########################

SYN_FACIL_DEPRESS
        TYPE                    NO_SFD
        SFD                     NONE
END_SYN_FACIL_DEPRESS

############################### LONG-TERM SYNAPTIC DYNAMICS ##################

SYN_LEARNING
        TYPE                    HEBBIAN
        LEARNING                BOTH
        LEARNING_SHAPE          EXPONENT
        NEG_HEB_WINDOW          0.1             0.0
        POS_HEB_WINDOW          0.1             0.0
        POS_HEB_PEAK_DELTA_USE  0.005           0.0
        NEG_HEB_PEAK_DELTA_USE  0.0055          0.0
        POS_HEB_PEAK_TIME       0.02            0.0
        NEG_HEB_PEAK_TIME       0.02            0.0
END_SYN_LEARNING
```

Learning

```
##############SYNAPSES SIMPLE_MODEL_MODEL################################

SYNAPSE
    TYPE          synEE_SIMPLE_MODEL
    SFD_LABEL           NO_SFD
    LEARN_LABEL         HEBBIAN
    SYN_PSG       PSGexcit
    MAX_CONDUCT   0.4
    DELAY         0.005  0.010
    SYN_REVERSAL  0     0
    ABSOLUTE_USE  0.25    0.1
END_SYNAPSE

######################## SHORT-TERM SYNAPTIC DYNAMICS ########################

SYN_FACIL_DEPRESS
        TYPE                    NO_SFD
        SFD                     NONE
END_SYN_FACIL_DEPRESS

############################### LONG-TERM SYNAPTIC DYNAMICS ##################

SYN_LEARNING
        TYPE                    HEBBIAN
        LEARNING                BOTH
        LEARNING_SHAPE          EXPONENT
        NEG_HEB_WINDOW          0.1             0.0
        POS_HEB_WINDOW          0.1             0.0
        POS_HEB_PEAK_DELTA_USE  0.005           0.0
        NEG_HEB_PEAK_DELTA_USE  0.0055          0.0
        POS_HEB_PEAK_TIME       0.02            0.0
        NEG_HEB_PEAK_TIME       0.02            0.0
END_SYN_LEARNING
```

Learning

```
##############SYNAPSES SIMPLE_MODEL_MODEL################################

SYNAPSE
    TYPE          synEE_SIMPLE_MODEL
    SFD_LABEL           NO_SFD
    LEARN_LABEL         HEBBIAN
    SYN_PSG       PSGexcit
    MAX_CONDUCT   0.4
    DELAY         0.005  0.010
    SYN_REVERSAL  0    0
    ABSOLUTE_USE  0.25    0.1
END_SYNAPSE

######################## SHORT-TERM SYNAPTIC DYNAMICS ########################

SYN_FACIL_DEPRESS
        TYPE                    NO_SFD
        SFD                     NONE
END_SYN_FACIL_DEPRESS

############################### LONG-TERM SYNAPTIC DYNAMICS ##################

SYN_LEARNING
        TYPE                    HEBBIAN
        LEARNING                BOTH
        LEARNING_SHAPE          EXPONENT
        NEG_HEB_WINDOW          0.1             0.0
        POS_HEB_WINDOW          0.1             0.0
        POS_HEB_PEAK_DELTA_USE  0.005           0.0
        NEG_HEB_PEAK_DELTA_USE  0.0055          0.0
        POS_HEB_PEAK_TIME       0.02            0.0
        NEG_HEB_PEAK_TIME       0.02            0.0
END_SYN_LEARNING
```

Reports

```
################## SIMPLE_MODEL_MODEL REPORTS ###########################

REPORT
    TYPE                    VOLTAGE_CELL_1
    CELLS                   SIMPLE_MODEL_COLUMN layer_SIMPLE_MODEL SIMPLE_MODEL_1 somaE
    PROB                    1
    REPORT_ON               VOLTAGE
    FILENAME                SIMPLE_MODEL_1_VOLTAGE_E.txt
    ASCII
    FREQUENCY               1
    TIME_START              0
    TIME_END                100
END_REPORT

REPORT
    TYPE                    VOLTAGE_CELL_2
    CELLS                   SIMPLE_MODEL_COLUMN layer_SIMPLE_MODEL SIMPLE_MODEL_2 somaE
    PROB                    1
    REPORT_ON               VOLTAGE
    FILENAME                SIMPLE_MODEL_2_VOLTAGE_E.txt
    ASCII
    FREQUENCY               1
    TIME_START              0
    TIME_END                100
END_REPORT
```

Reports

```
################## SIMPLE MODEL MODEL REPORTS ##########################

REPORT
    TYPE                VOLTAGE_CELL_1
    CELLS               SIMPLE_MODEL_COLUMN layer_SIMPLE_MODEL SIMPLE_MODEL_1 somaE
    PROB                1
    REPORT_ON           VOLTAGE
    FILENAME            SIMPLE_MODEL_1_VOLTAGE_E.txt
    ASCII
    FREQUENCY           1
    TIME_START          0
    TIME_END            100
END_REPORT

REPORT
    TYPE                VOLTAGE_CELL_2
    CELLS               SIMPLE_MODEL_COLUMN layer_SIMPLE_MODEL SIMPLE_MODEL_2 somaE
    PROB                1
    REPORT_ON           VOLTAGE
    FILENAME            SIMPLE_MODEL_2_VOLTAGE_E.txt
    ASCII
    FREQUENCY           1
    TIME_START          0
    TIME_END            100
END_REPORT
```

Reports

```
################## SIMPLE_MODEL_MODEL REPORTS ########################

REPORT
    TYPE                    VOLTAGE_CELL_1
    CELLS                   SIMPLE_MODEL_COLUMN layer_SIMPLE_MODEL SIMPLE_MODEL_1 somaE
    PROB                    1
    REPORT_ON               VOLTAGE
    FILENAME                SIMPLE_MODEL_1_VOLTAGE_E.txt
    ASCII
    FREQUENCY               1
    TIME_START              0
    TIME_END                100
END_REPORT

REPORT
    TYPE                    VOLTAGE_CELL_2
    CELLS                   SIMPLE_MODEL_COLUMN layer_SIMPLE_MODEL SIMPLE_MODEL_2 somaE
    PROB                    1
    REPORT_ON               VOLTAGE
    FILENAME                SIMPLE_MODEL_2_VOLTAGE_E.txt
    ASCII
    FREQUENCY               1
    TIME_START              0
    TIME_END                100
END_REPORT
```

Reports

```
################## SIMPLE_MODEL_MODEL REPORTS ########################

REPORT
    TYPE                    VOLTAGE_CELL_1
    CELLS                   SIMPLE_MODEL_COLUMN layer_SIMPLE_MODEL SIMPLE_MODEL_1 somaE
    PROB                    1
    REPORT_ON               VOLTAGE
    FILENAME                SIMPLE_MODEL_1_VOLTAGE_E.txt
    ASCII
    FREQUENCY               1
    TIME_START              0
    TIME_END                100
END_REPORT

REPORT
    TYPE                    VOLTAGE_CELL_2
    CELLS                   SIMPLE_MODEL_COLUMN layer_SIMPLE_MODEL SIMPLE_MODEL_2 somaE
    PROB                    1
    REPORT_ON               VOLTAGE
    FILENAME                SIMPLE_MODEL_2_VOLTAGE_E.txt
    ASCII
    FREQUENCY               1
    TIME_START              0
    TIME_END                100
END_REPORT
```

Reports

```
################## SIMPLE_MODEL_MODEL REPORTS ###########################

REPORT
    TYPE                    VOLTAGE_CELL_1
    CELLS                   SIMPLE_MODEL_COLUMN layer_SIMPLE_MODEL SIMPLE_MODEL_1 somaE
    PROB                    1
    REPORT_ON               VOLTAGE
    FILENAME                SIMPLE_MODEL_1_VOLTAGE_E.txt
    ASCII
    FREQUENCY               1
    TIME_START              0
    TIME_END                100
END_REPORT

REPORT
    TYPE                    VOLTAGE_CELL_2
    CELLS                   SIMPLE_MODEL_COLUMN layer_SIMPLE_MODEL SIMPLE_MODEL_2 somaE
    PROB                    1
    REPORT_ON               VOLTAGE
    FILENAME                SIMPLE_MODEL_2_VOLTAGE_E.txt
    ASCII
    FREQUENCY               1
    TIME_START              0
    TIME_END                100
END_REPORT
```

Reports

```
################## SIMPLE_MODEL_MODEL REPORTS ########################

REPORT
    TYPE                VOLTAGE_CELL_1
    CELLS               SIMPLE_MODEL_COLUMN layer_SIMPLE_MODEL SIMPLE_MODEL_1 somaE
    PROB                1
    REPORT_ON           VOLTAGE
    FILENAME            SIMPLE_MODEL_1_VOLTAGE_E.txt
    ASCII
    FREQUENCY           1
    TIME_START          0
    TIME_END            100
END_REPORT

REPORT
    TYPE                VOLTAGE_CELL_2
    CELLS               SIMPLE_MODEL_COLUMN layer_SIMPLE_MODEL SIMPLE_MODEL_2 somaE
    PROB                1
    REPORT_ON           VOLTAGE
    FILENAME            SIMPLE_MODEL_2_VOLTAGE_E.txt
    ASCII
    FREQUENCY           1
    TIME_START          0
    TIME_END            100
END_REPORT
```

Reports

```
################## SIMPLE_MODEL_MODEL REPORTS #########################

REPORT
    TYPE                    VOLTAGE_CELL_1
    CELLS                   SIMPLE_MODEL_COLUMN layer_SIMPLE_MODEL SIMPLE_MODEL_1 somaE
    PROB                    1
    REPORT_ON               VOLTAGE
    FILENAME                SIMPLE_MODEL_1_VOLTAGE_E.txt
    ASCII
    FREQUENCY               1
    TIME_START              0
    TIME_END                100
END_REPORT

REPORT
    TYPE                    VOLTAGE_CELL_2
    CELLS                   SIMPLE_MODEL_COLUMN layer_SIMPLE_MODEL SIMPLE_MODEL_2 somaE
    PROB                    1
    REPORT_ON               VOLTAGE
    FILENAME                SIMPLE_MODEL_2_VOLTAGE_E.txt
    ASCII
    FREQUENCY               1
    TIME_START              0
    TIME_END                100
END_REPORT
```

Reports

```
################## SIMPLE_MODEL_MODEL REPORTS #########################

REPORT
    TYPE                    VOLTAGE_CELL_1
    CELLS                   SIMPLE_MODEL_COLUMN layer_SIMPLE_MODEL SIMPLE_MODEL_1 somaE
    PROB                    1
    REPORT_ON               VOLTAGE
    FILENAME                SIMPLE_MODEL_1_VOLTAGE_E.txt
    ASCII
    FREQUENCY               1
    TIME_START              0
    TIME_END                100
END_REPORT

REPORT
    TYPE                    VOLTAGE_CELL_2
    CELLS                   SIMPLE_MODEL_COLUMN layer_SIMPLE_MODEL SIMPLE_MODEL_2 somaE
    PROB                    1
    REPORT_ON               VOLTAGE
    FILENAME                SIMPLE_MODEL_2_VOLTAGE_E.txt
    ASCII
    FREQUENCY               1
    TIME_START              0
    TIME_END                100
END_REPORT
```

Reports

```
################## SIMPLE_MODEL_MODEL REPORTS ##########################

REPORT
    TYPE                    VOLTAGE_CELL_1
    CELLS                   SIMPLE_MODEL_COLUMN layer_SIMPLE_MODEL SIMPLE_MODEL_1 somaE
    PROB                    1
    REPORT_ON               VOLTAGE
    FILENAME                SIMPLE_MODEL_1_VOLTAGE_E.txt
    ASCII
    FREQUENCY               1
    TIME_START              0
    TIME_END                100
END_REPORT

REPORT
    TYPE                    VOLTAGE_CELL_2
    CELLS                   SIMPLE_MODEL_COLUMN layer_SIMPLE_MODEL SIMPLE_MODEL_2 somaE
    PROB                    1
    REPORT_ON               VOLTAGE
    FILENAME                SIMPLE_MODEL_2_VOLTAGE_E.txt
    ASCII
    FREQUENCY               1
    TIME_START              0
    TIME_END                100
END_REPORT
```

Reports

```
################## SIMPLE_MODEL_MODEL REPORTS ########################

REPORT
    TYPE                    VOLTAGE_CELL_1
    CELLS                   SIMPLE_MODEL_COLUMN layer_SIMPLE_MODEL SIMPLE_MODEL_1 somaE
    PROB                    1
    REPORT_ON               VOLTAGE
    FILENAME                SIMPLE_MODEL_1_VOLTAGE_E.txt
    ASCII
    FREQUENCY               1
    TIME_START              0
    TIME_END                100
END_REPORT

REPORT
    TYPE                    VOLTAGE_CELL_2
    CELLS                   SIMPLE_MODEL_COLUMN layer_SIMPLE_MODEL SIMPLE_MODEL_2 somaE
    PROB                    1
    REPORT_ON               VOLTAGE
    FILENAME                SIMPLE_MODEL_2_VOLTAGE_E.txt
    ASCII
    FREQUENCY               1
    TIME_START              0
    TIME_END                100
END_REPORT
```

Reports

```
################## SIMPLE_MODEL_MODEL REPORTS #########################

REPORT
    TYPE                    VOLTAGE_CELL_1
    CELLS                   SIMPLE_MODEL_COLUMN layer_SIMPLE_MODEL SIMPLE_MODEL_1 somaE
    PROB                    1
    REPORT_ON               VOLTAGE
    FILENAME                SIMPLE_MODEL_1_VOLTAGE_E.txt
    ASCII
    FREQUENCY               1
    TIME_START              0
    TIME_END                100
END_REPORT

REPORT
    TYPE                    VOLTAGE_CELL_2
    CELLS                   SIMPLE_MODEL_COLUMN layer_SIMPLE_MODEL SIMPLE_MODEL_2 somaE
    PROB                    1
    REPORT_ON               VOLTAGE
    FILENAME                SIMPLE_MODEL_2_VOLTAGE_E.txt
    ASCII
    FREQUENCY               1
    TIME_START              0
    TIME_END                100
END_REPORT
```

Reports

```
################## SIMPLE_MODEL_MODEL REPORTS ##########################

REPORT
    TYPE                    VOLTAGE_CELL_1
    CELLS                   SIMPLE_MODEL_COLUMN layer_SIMPLE_MODEL SIMPLE_MODEL_1 somaE
    PROB                    1
    REPORT_ON               VOLTAGE
    FILENAME                SIMPLE_MODEL_1_VOLTAGE_E.txt
    ASCII
    FREQUENCY               1
    TIME_START              0
    TIME_END                100
END_REPORT

REPORT
    TYPE                    VOLTAGE_CELL_2
    CELLS                   SIMPLE_MODEL_COLUMN layer_SIMPLE_MODEL SIMPLE_MODEL_2 somaE
    PROB                    1
    REPORT_ON               VOLTAGE
    FILENAME                SIMPLE_MODEL_2_VOLTAGE_E.txt
    ASCII
    FREQUENCY               1
    TIME_START              0
    TIME_END                100
END_REPORT
```

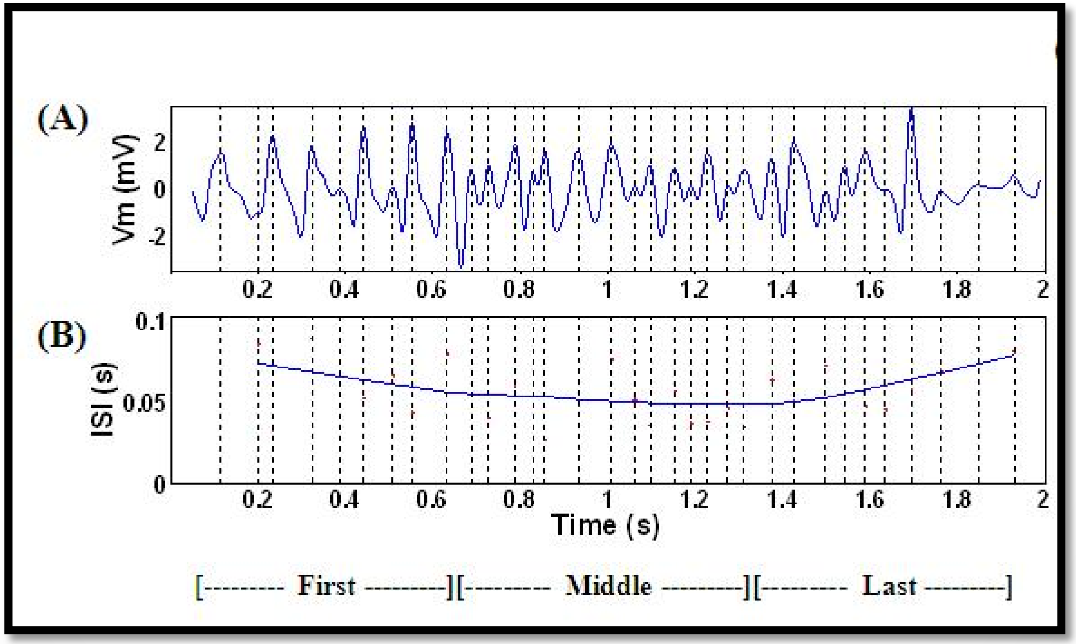
Output Analysis

Graphing

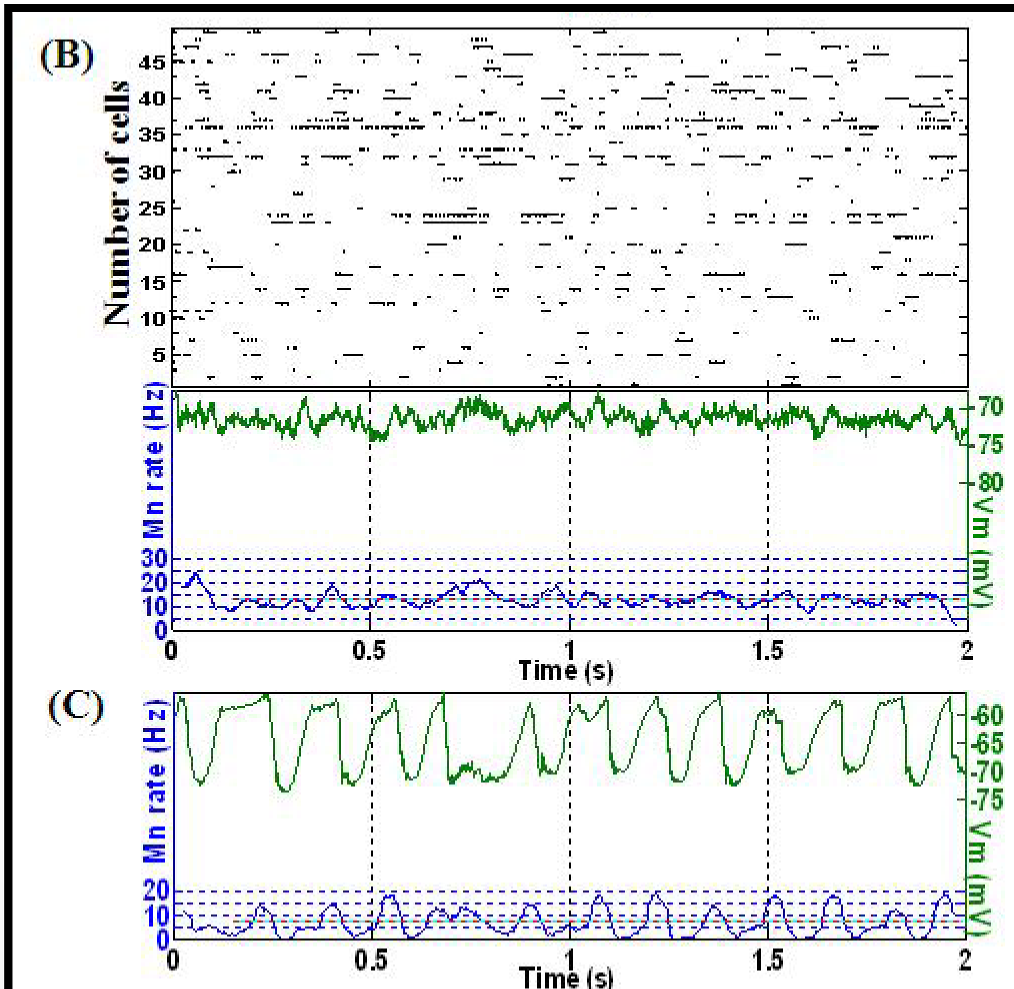
- Tools:
  - Matlab
  - GNUplot

- Types of plots
  - Dot and Line graphs
  - Raster plots
  - Spectrogram

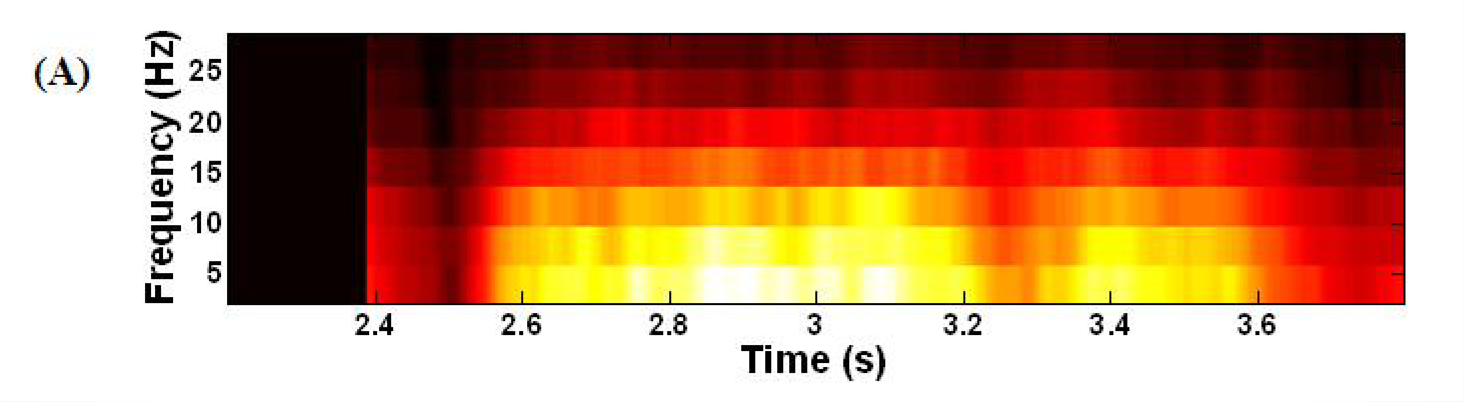
Types of Plots



Types of Plots



Types of Plots



DEMO

Break

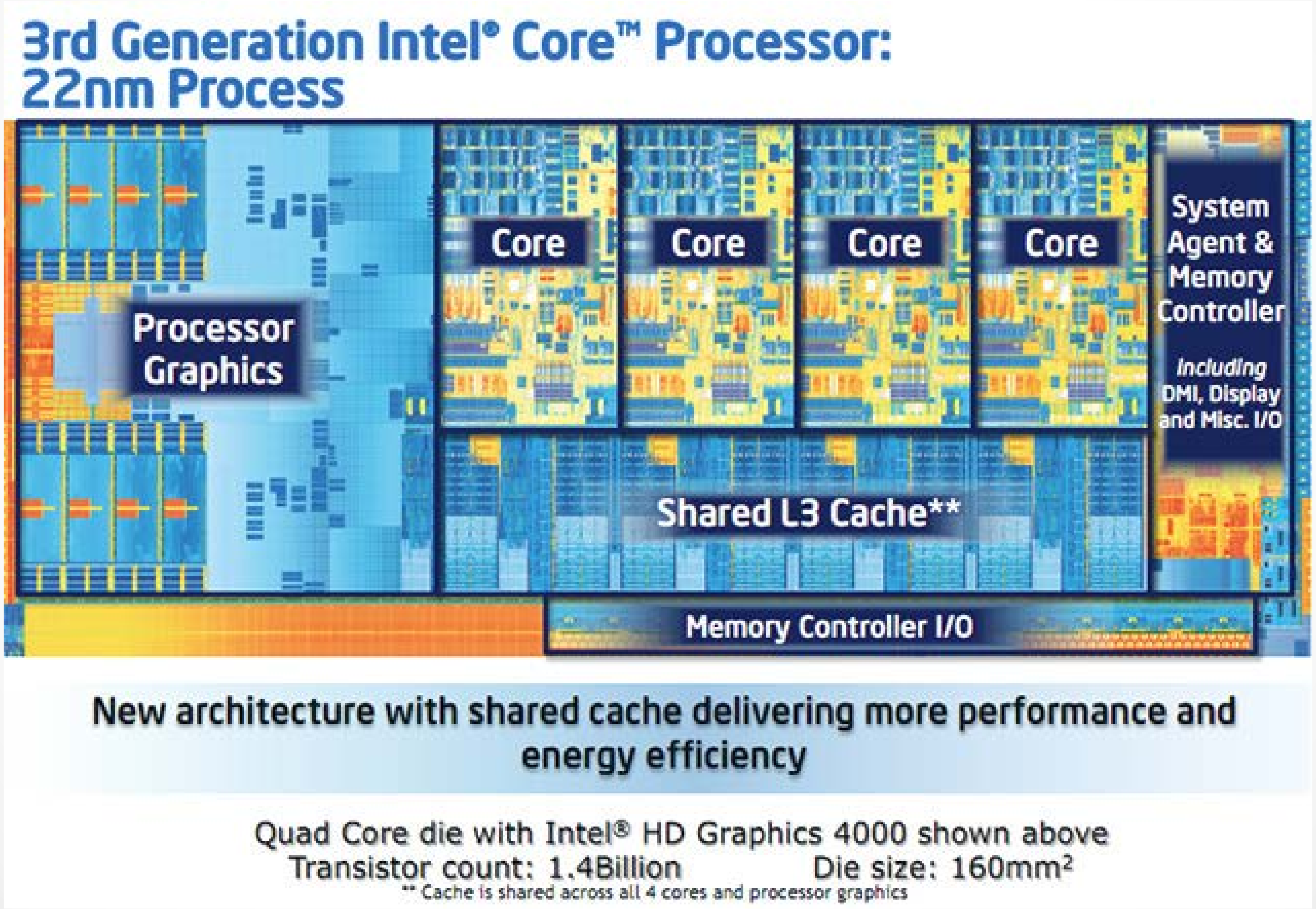
Today's Outline

- **First Hour**
  - Introduction
  - Equations and Implementation
  - Requirements and Simulation on a Single Machine
  - Input Language
- **Second Hour**
  - Simple Model
  - Parameters Presentation and Testing
  - Output Analysis
- **Third Hour**
  - Simulation on Multiple Machines
  - Software Tools
  - Robotic System Configuration
  - Larger Networks and Complete Loop Execution
  - Future Directions and Summary

CPU

- A single unit of execution (Core)
  - Often times sold with multiple cores
- A single instruction executed once per cycle per core
  - i.e. add X and Y
- Most of the silicon in the chip devoted to:
  - Branch Handling
  - Cache and Memory controllers
  - Out of order execution
  - etc.
- Design optimized for general preformance

CPU Layout

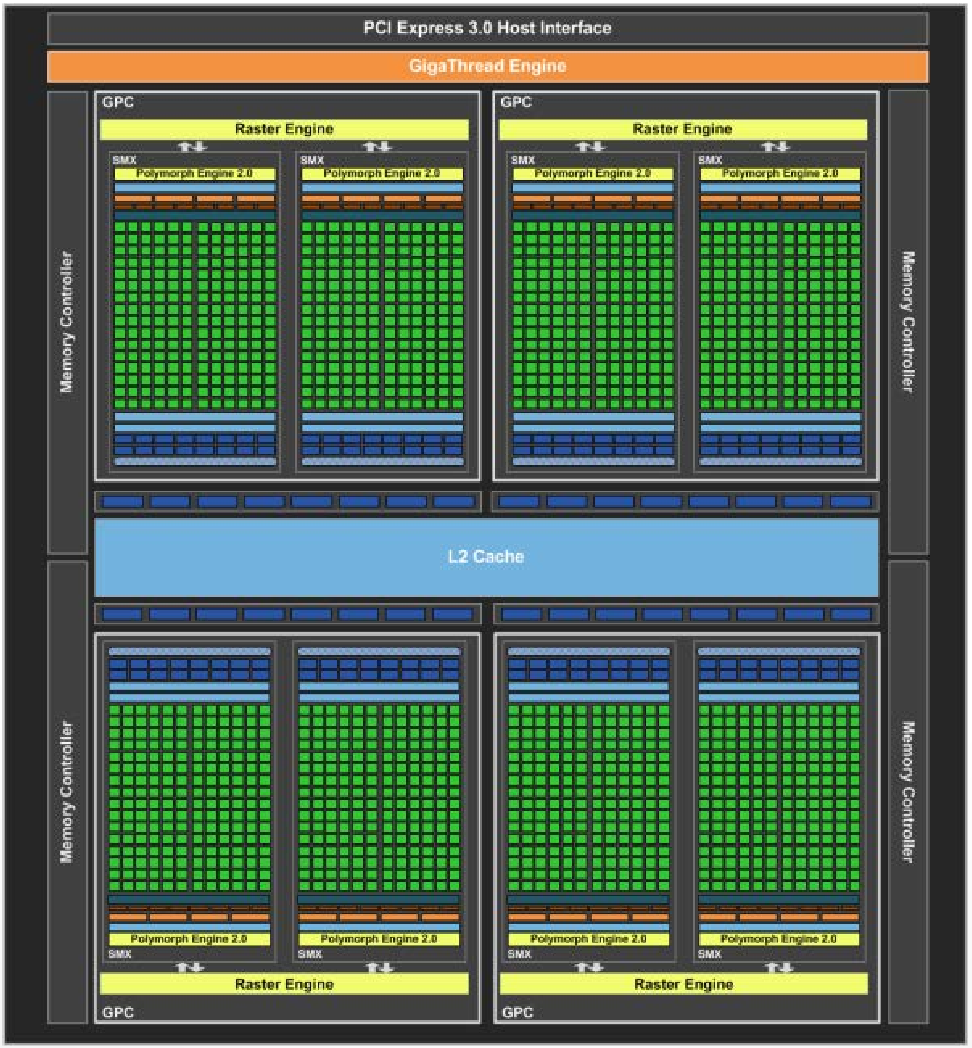


3rd Generation Intel® Core™ Processor:
22nm Process
Processor Graphics
Core
Core
Core
Core
System Agent & Memory Controller
Including DMI, Display and Misc. I/O
Shared L3 Cache**
Memory Controller I/O
New architecture with shared cache delivering more performance and energy efficiency
Quad Core die with Intel® HD Graphics 4000 shown above
Transistor count: 1.4Billion
Die size: 160mm²
** Cache is shared across all 4 cores and processor graphics

GPU

- Groupings of 32 simple cores
- Single instruction executed 32 times per cycle
  - i.e. add X_i Y_i
- Most of the silicon is devoted to ALUs(Arithmetic Logic Units)
- Design optimized for parallelism and floating point math performance

GPU Layout



PCI Express 3.0 Host Interface
GigaThread Engine
GPC
Raster Engine
SMX
Polymorph Engine 2.0
Memory Controller
L2 Cache

CPU vs GPU

- Access to Memory
  - CPU much closer to RAM and other memory
  - GPU has onboard memory, but
- Programming model
  - GPU much more suited to data parallel problems
    - typically image processing, graphics, matrix multiplication
    - Very array centric
    - Avoids pointer manipulation and branching
  - CPU much more suited to general computing problems
- Raw floating point performance
  - CPU - 100 GFLOPS (i7 980 XE)
  - GPU - 1300 GFLOPS (GTX 480)
  - Both from 2010

MPI

- Message Passing Interface
- Handles the dirty details of networking
  - Endianness
  - Managing sockets
  - Grouping Nodes
- Provides many methods for sending data out
  - Single Node to Single Node (Send Receive)
  - Single Node to Many Nodes (Scatter)
  - Many Nodes to Single Node (Gather)
- Designed for use in high performance networks

Simulation on multiple machines

One-Time Step

- SSH keys allow password free access to all computers.
  - ssh <computerName>
  - ssh-keygen -t rsa

    accept default options
  - cd ~/.ssh
  - cp id_rsa.pub authorized_keys

One-Time Step

- cd /home/userName/NCS6/NCS6/build
- Create a file with .mpi extension. This file specifies the number of devices available on each computer in the cluster. For example, we have marbles.mpi file that contains the following information:

  Brain1 slots=2

  Brain2 slots=2
- After creating a file with .mpi extension, run these commands:
  - mpirun --hostfile marbles.mpi <space> applications/clusterSpecifier/clusterSpecifier <space> marbles.cluster
  - applications/clusterInfo/clusterInfo marbles.cluster

Steps

- **To compile code:**

 applications/ncsDistributor/ncsDistributor <space> ../files/NCS6/ marbles.cluster ncsout

- **To run code:**

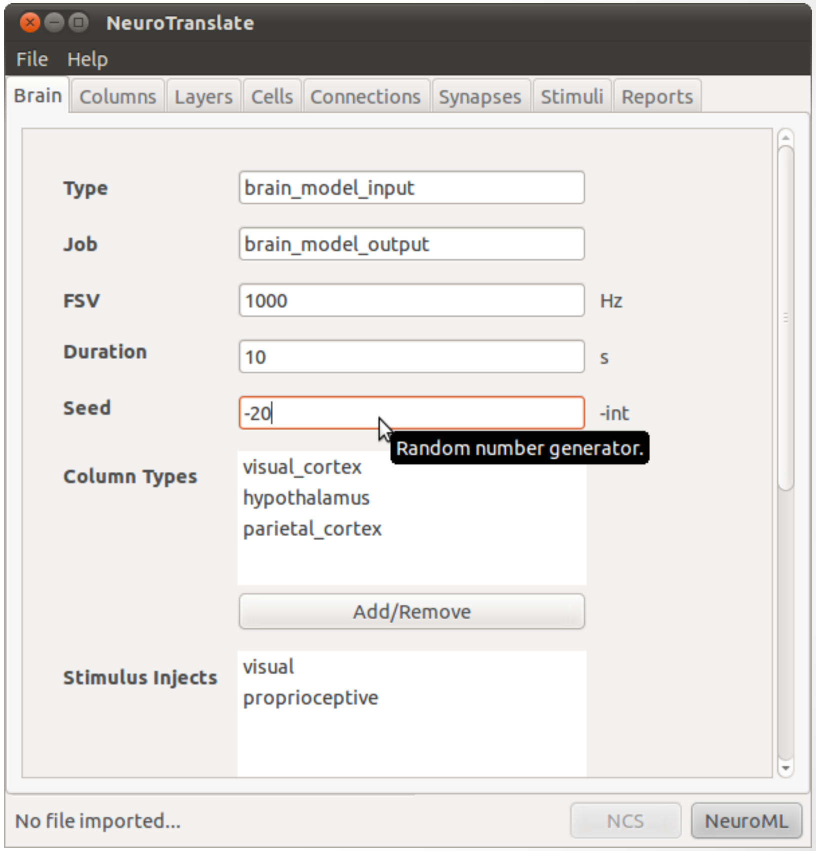
mpirun -np numberOfDevices –hostfile <space> marbles.mpi <space> applications/simulator/simulator ncsout/

DEMO

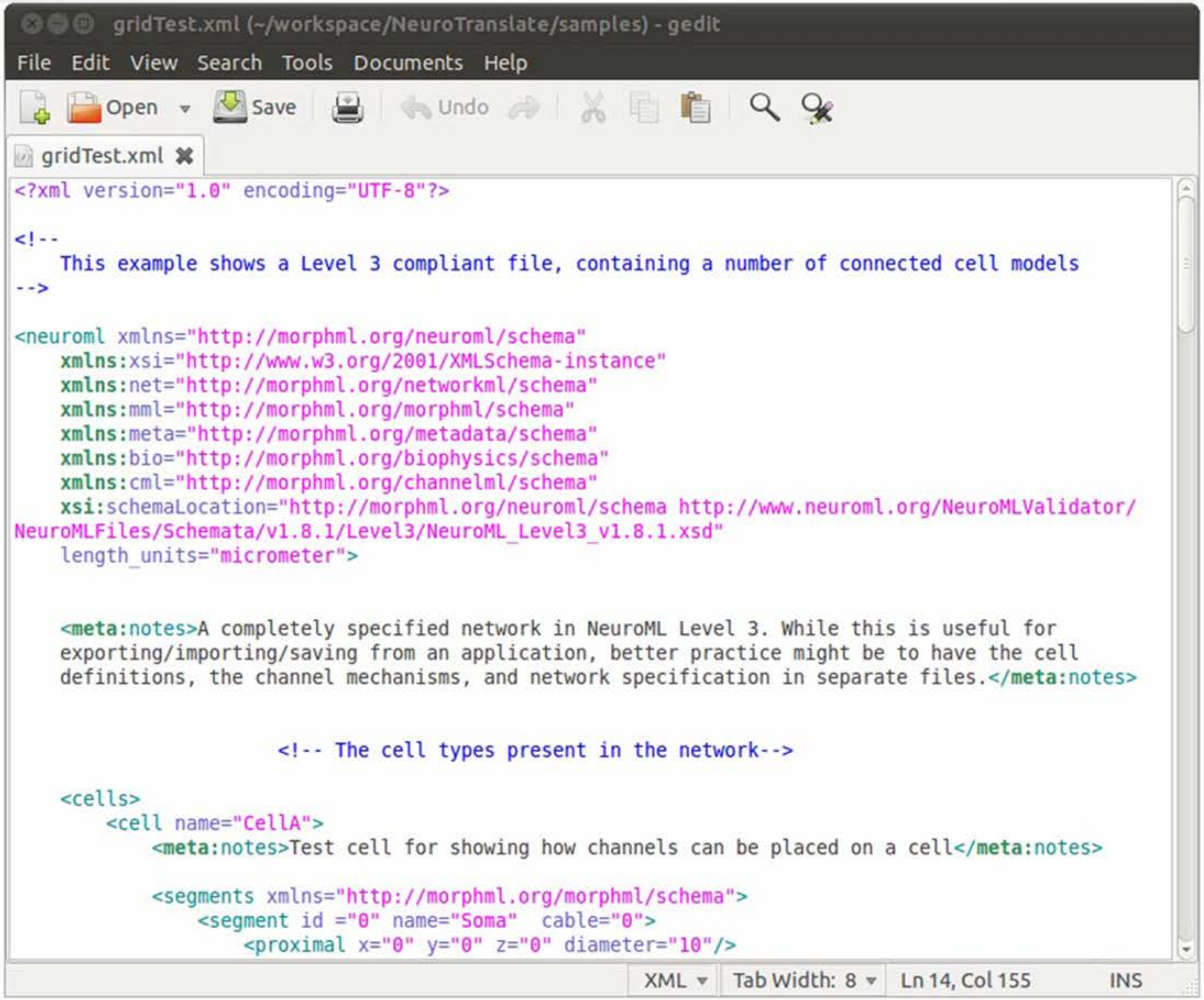
Software Tools

NeuroTranslate

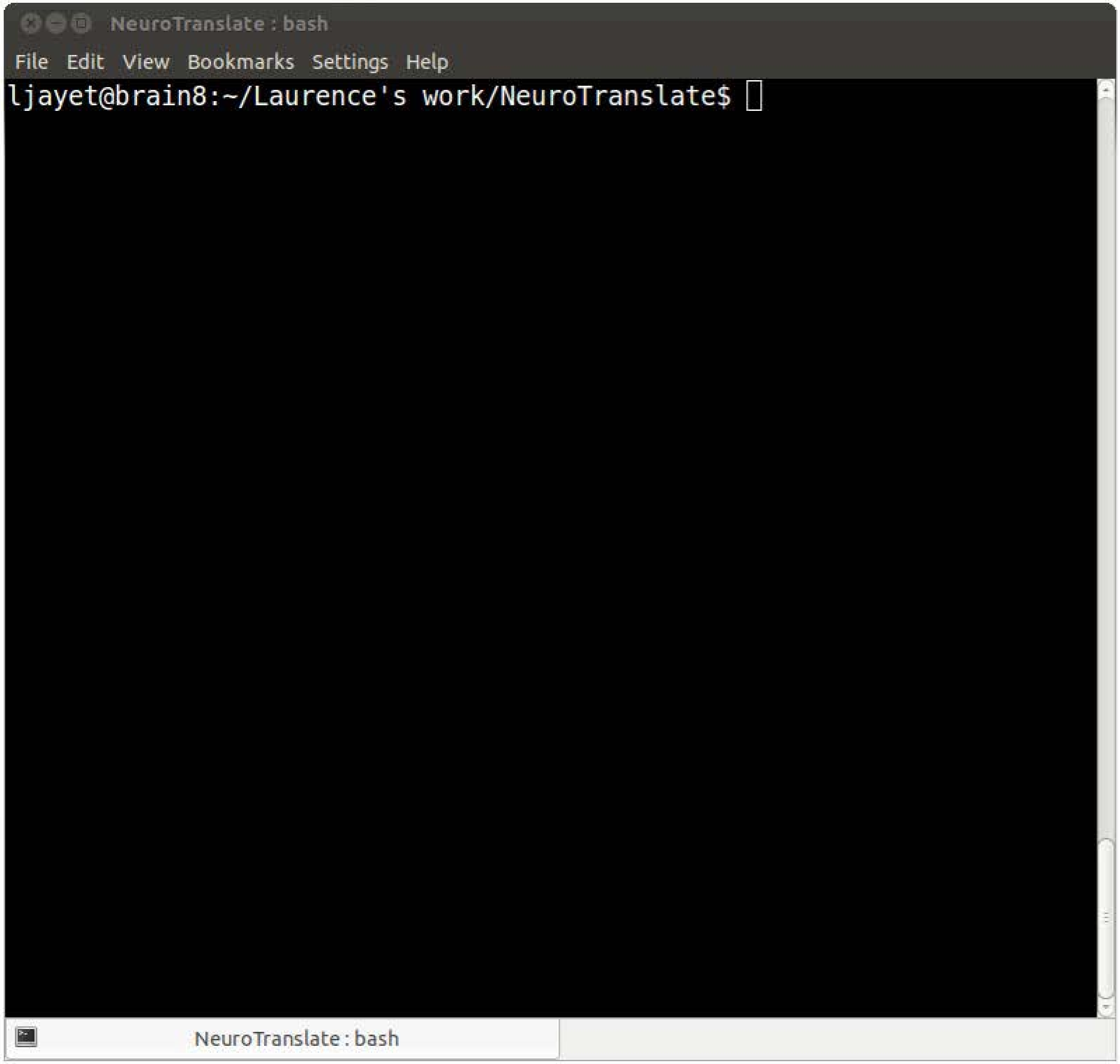
- NeuroTranslate
  - o Software tool that translates input files between NCS and NeuroML



N. Jordan, K. Perry, N. Narala, L. C. Jayet Bray, and F. C. Harris, Jr. Design and implementation of an NCS-NeuroML translator. In Proceedings of the International Conference on Software Engineering and Data Engineering (SEDE). Los Angeles, CA, June 2012.

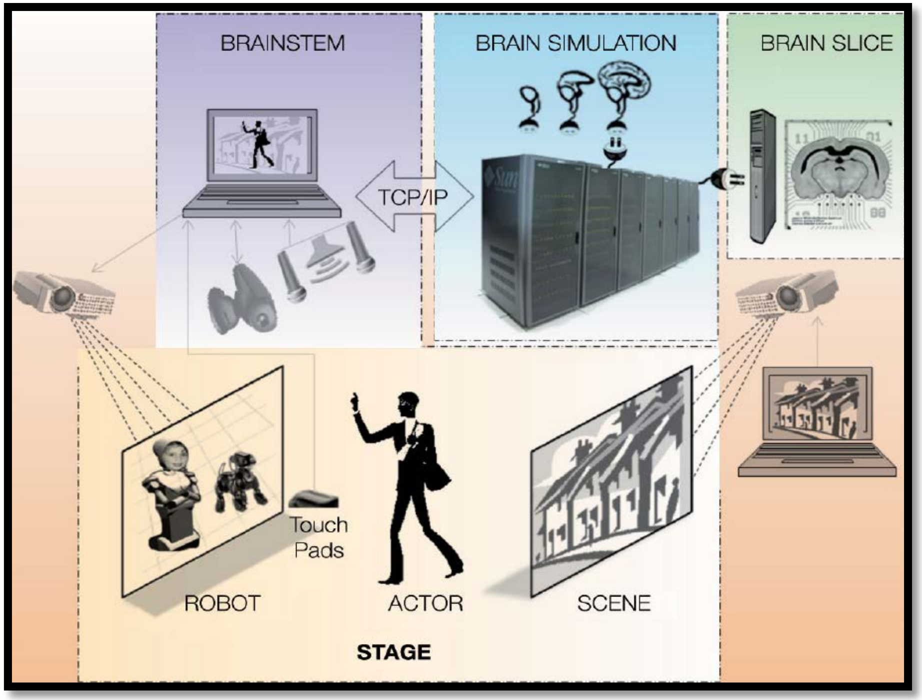



```xml
<?xml version="1.0" encoding="UTF-8"?>

<!--
    This example shows a Level 3 compliant file, containing a number of connected cell models
-->

<neuroml xmlns="http://morphml.org/neuroml/schema"
    xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
    xmlns:net="http://morphml.org/networkml/schema"
    xmlns:mml="http://morphml.org/morphml/schema"
    xmlns:meta="http://morphml.org/metadata/schema"
    xmlns:bio="http://morphml.org/biophysics/schema"
    xmlns:cml="http://morphml.org/channelml/schema"
    xsi:schemaLocation="http://morphml.org/neuroml/schema http://www.neuroml.org/NeuroMLValidator/
NeuroMLFiles/Schemata/v1.8.1/Level3/NeuroML_Level3_v1.8.1.xsd"
    length_units="micrometer">


    <meta:notes>A completely specified network in NeuroML Level 3. While this is useful for
    exporting/importing/saving from an application, better practice might be to have the cell
    definitions, the channel mechanisms, and network specification in separate files.</meta:notes>


                    <!-- The cell types present in the network-->

    <cells>
        <cell name="CellA">
            <meta:notes>Test cell for showing how channels can be placed on a cell</meta:notes>

            <segments xmlns="http://morphml.org/morphml/schema">
                &lt;segment id ="0" name="Soma"  cable="0">
                    <proximal x="0" y="0" z="0" diameter="10"/>
```


NeuroTranslate : bash
File Edit View Bookmarks Settings Help
ljayet@brain8:~/Laurence's work/NeuroTranslate$
NeuroTranslate : bash

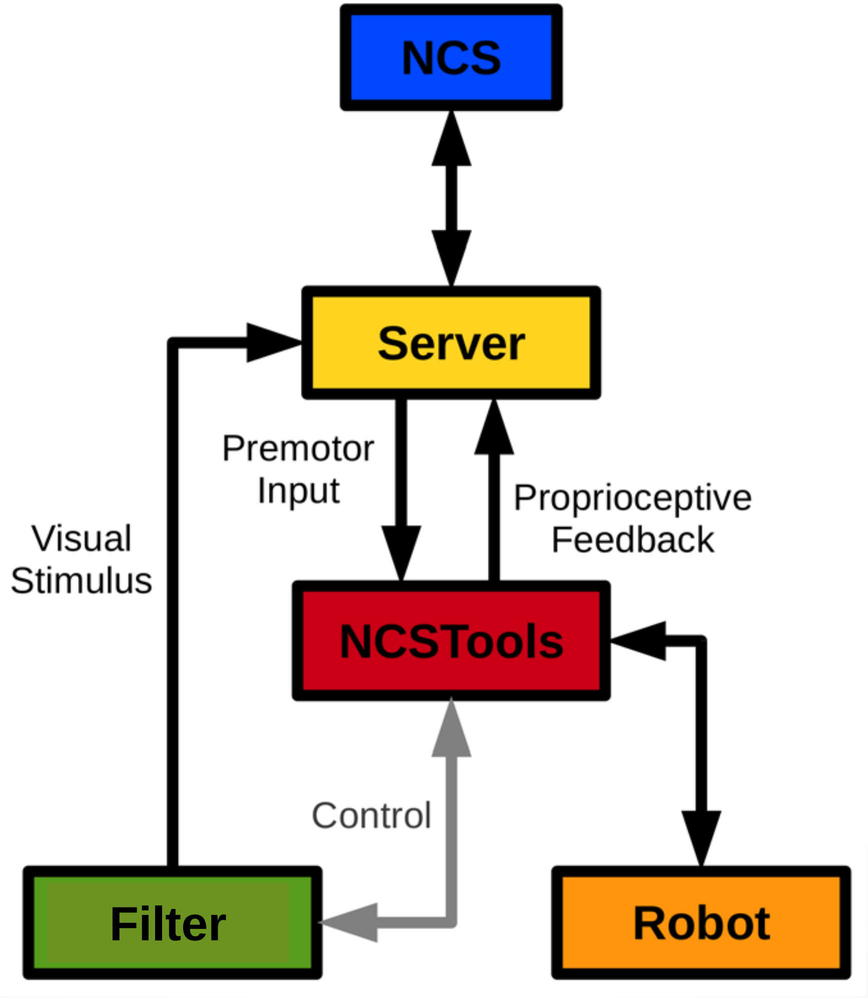
Robotic System Configuration

Virtual NeuroRobotic (VNR)



1. The robot is sufficiently embodied for the human to tentatively accept the robot as a social, emotional partner
2. The human-robot interaction loop operates in real time, with no pre-specified parcellation into receptive and responsive time windows
3. The cognitive control is a neuromorphic brain emulation incorporating realistic neuronal dynamics with time constants that reflect synaptic activation and learning, established membrane and circuitry properties
4. The neuromorphic architecture can potentially provide circuitry underlying intrinsic motivation and intentionality, using "emotional" rather than rule-based learning & reinforcement
5. The neuromorphic architecture is expandable to progressively larger scale and complexity to support brain model development and validation

Overview



NCS
Server
Premotor Input
Proprioceptive Feedback
Visual Stimulus
NCSTools
Control
Filter
Robot

NCS

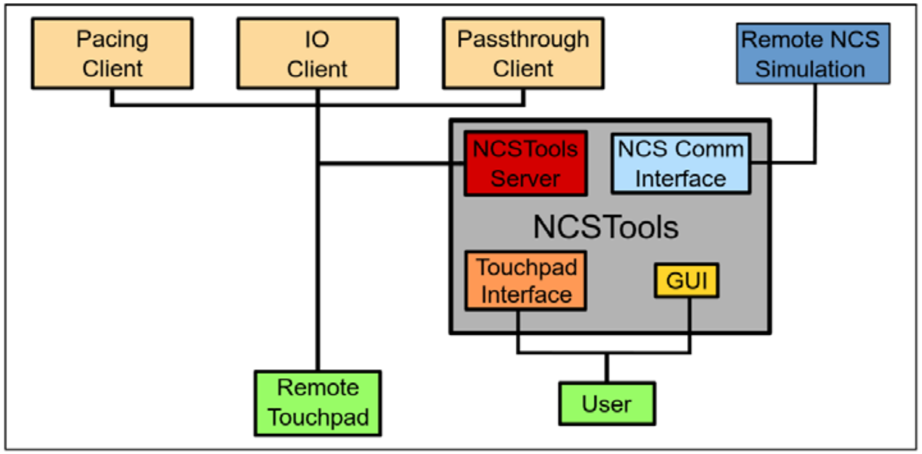
- Models integrate-and-fire neurons with conductance-based synapses
- First simulator to support real-time neurorobotics applications
- Experiments demonstrate biologically realistic behavior in real time

Server

- Brain Communication Server (BCS)
- Monitors the robotic avatar and creates the appropriate stimulus for proprioceptive feedback and premotor movement to replicate the role of a biological brainstem

NCSTools

- NCSTools
  - Software package that simplifies interaction and communication between NCS and remote agents



C. M. Thibeault, J. Hegie, L. Jayet Bray, and F. C. Harris, Jr. Simplifying neurorobotic development with ncstools. In Proceedings of the 2012 Conference on Computers and Their Applications. Las Vegas, NV, March 2012.

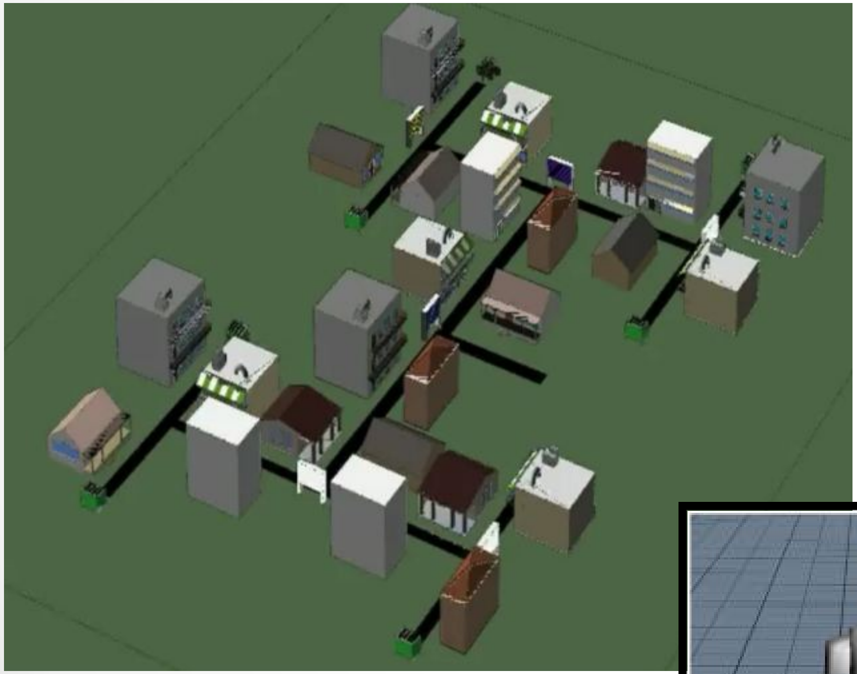
Visual / Audio

- Computer vision / audio
- Machine vision / audio
- Image / sound processing

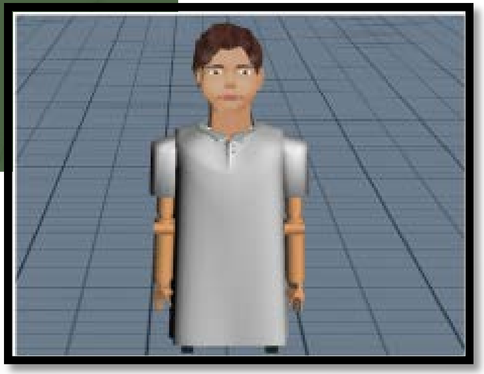
- Filtering mechanisms (e.g. Gabor)

- Applications:
  - external input
  - reward-based learning

Robotic Interface

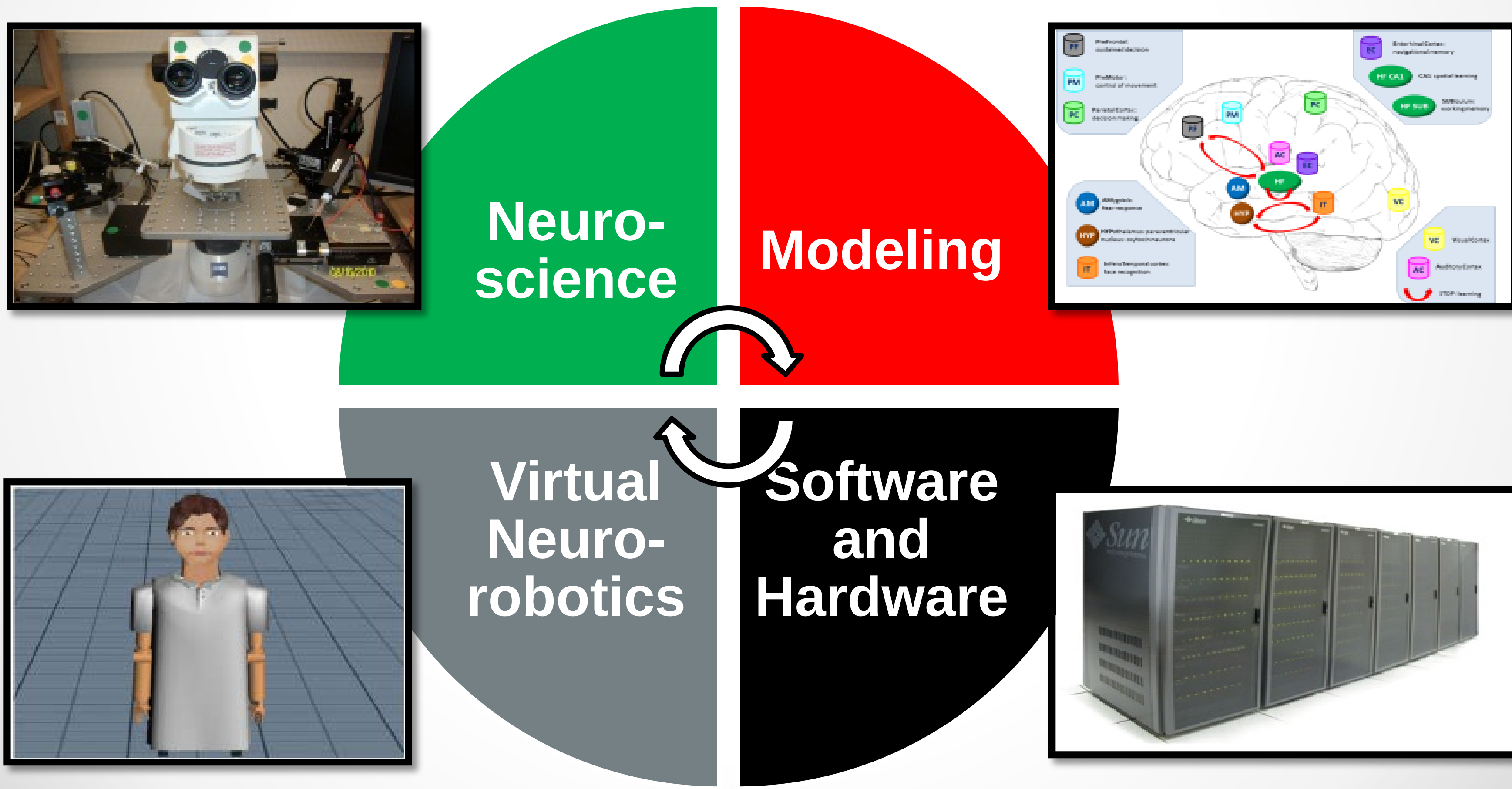


- Constructed using Webots 5
- Motions were programmed in C++ using the provided interfaces and the communication was accomplished using the NCSTools C++ client

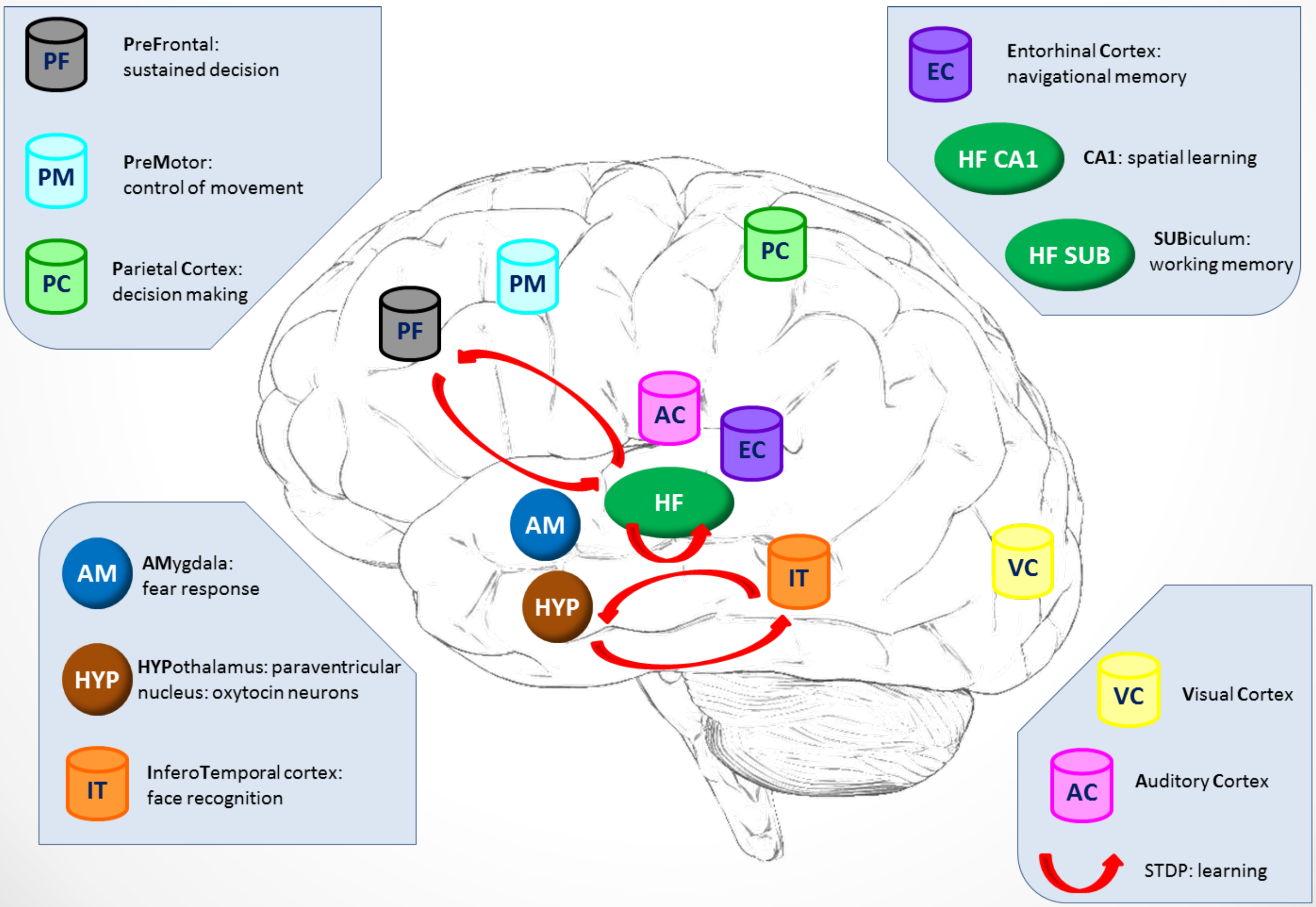


Large Networks

Technical Approach



Brain Model



PF
PreFrontal: sustained decision
PM
PreMotor: control of movement
PC
Parietal Cortex: decision making
EC
Entorhinal Cortex: navigational memory
HF CA1
CA1: spatial learning
HF SUB
SUBiculum: working memory
PC
PM
PF
AC
EC
HF
AM
HYP
IT
VC
AM
AMygdala: fear response
HYP
HYPothalamus: paraventricular nucleus: oxytocin neurons
IT
InferoTemporal cortex: face recognition
VC
Visual Cortex
AC
Auditory Cortex
STDP: learning

Trust

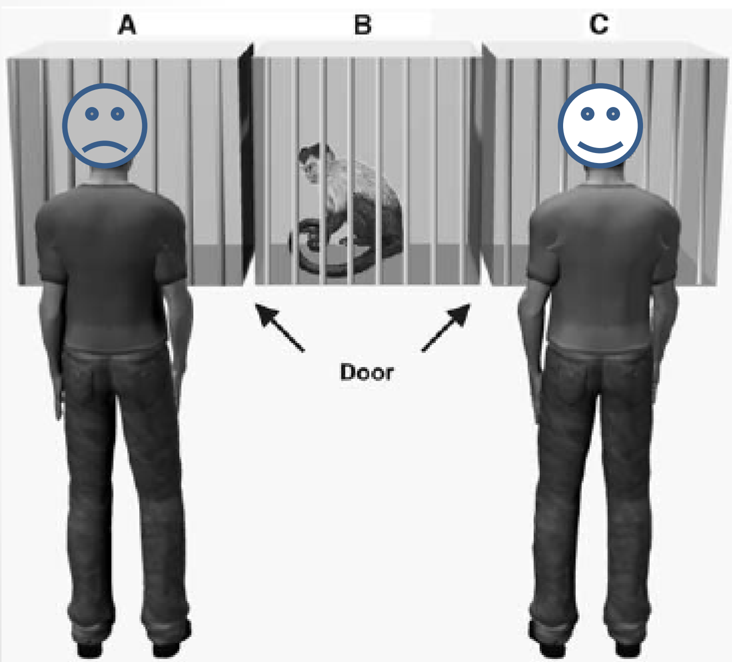
- Behavior between a humanoid neurorobot and human actor
  - Oxytocin release
    - Social reinforcement
    - Reduction of inhibition
- Experiment has two conceptual phases:
  - Learning
    - Neurorobot initiates a sequence of motions
    - Human performs concordant or discordant action
    - Neurorobot learns to trust the human
  - Challenge
    - Human reaches for another object
    - Depending on whether or not the neurorobot trusts the human the robot will hand over the object or retract the object

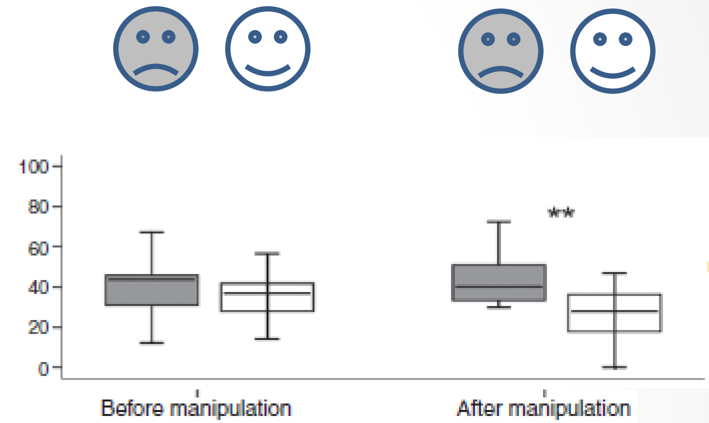
Trust and Affiliation

Capuchin Monkeys Display Affiliation Toward Humans Who Imitate Them

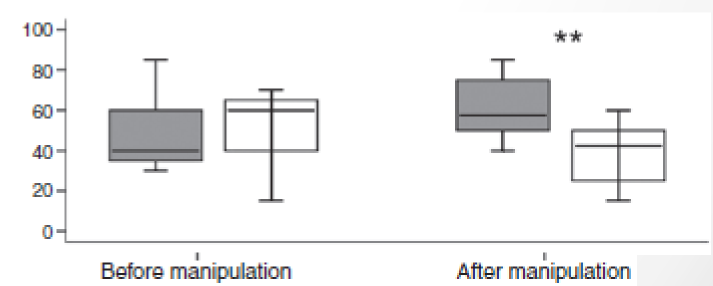
Annika Paukner,[1]* Stephen J. Suomi,[1] Elisabetta Visalberghi,[2] Pier F. Ferrari[1,3]

SCIENCE VOL 325 14 AUGUST 2009





Time spent facing



Willingness to exchange token for food

Paradigm

LEARNING

Robot Initiates Action

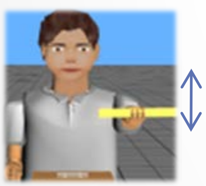
1. **Robot brain initiates arbitrary sequence of motions**

Human Responds

2. **Human moves object in either a similar ("match"), or different ("mismatch") pattern**

Match*:* robot learns to trust

Mismatch: don't trust



CHALLENGE (at any time)

Human Acts

3. **Human slowly reaches for an object on the table**

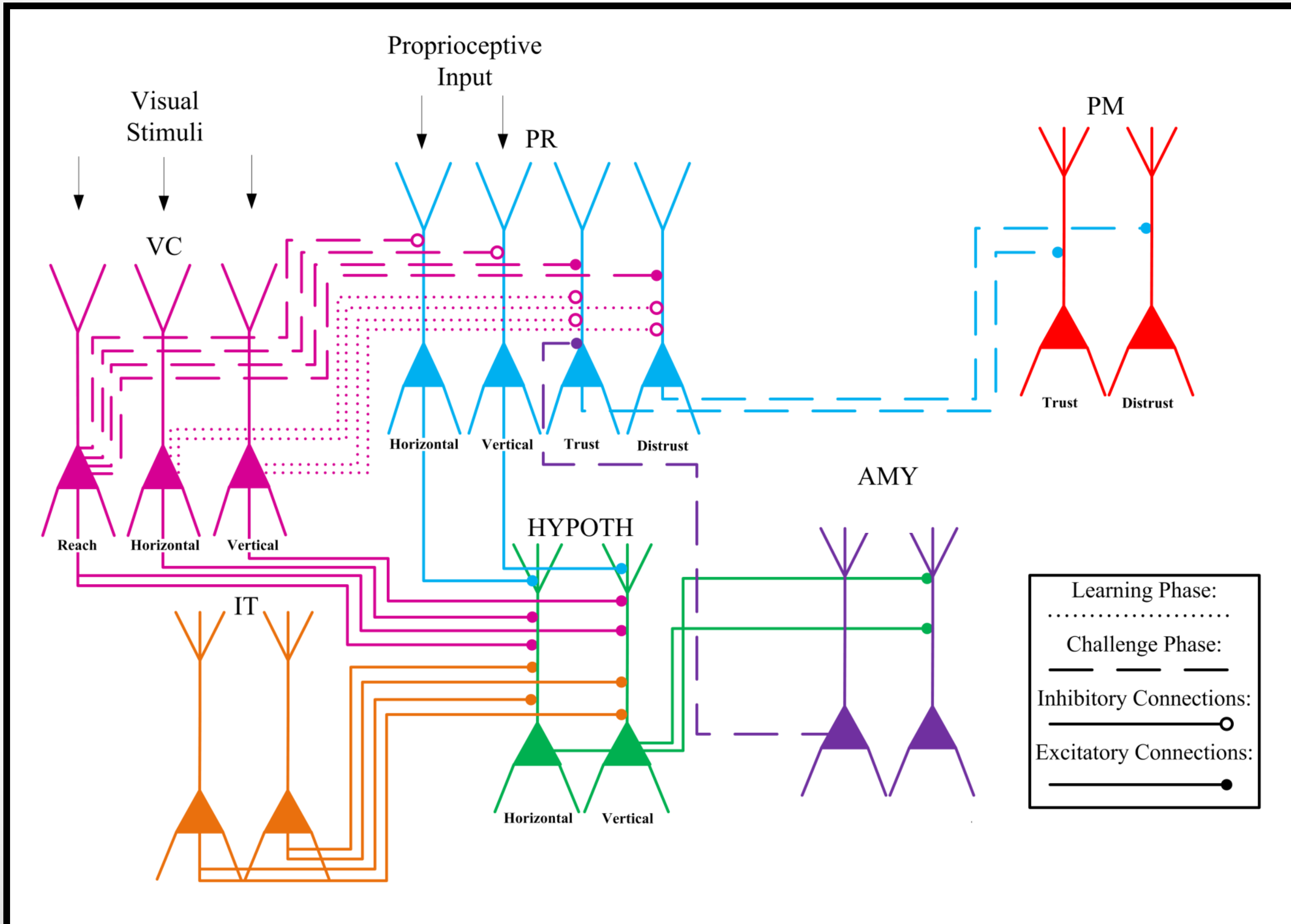
Robot Reacts

4. **Robot either "trusts", (assists/offers the object), or "distrusts", (retract the object).**

trusted

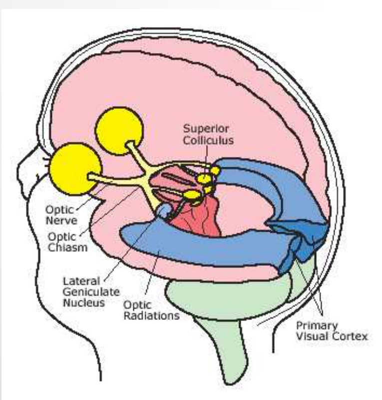
distrusted

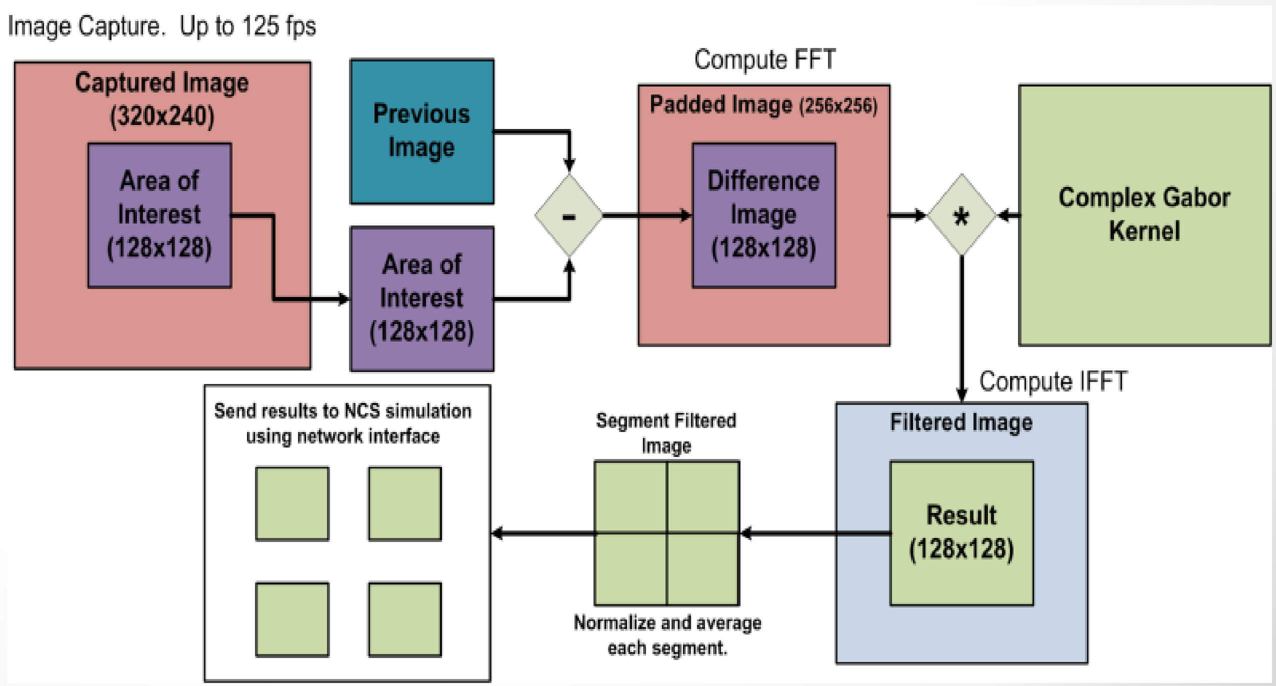
Microcircuitry



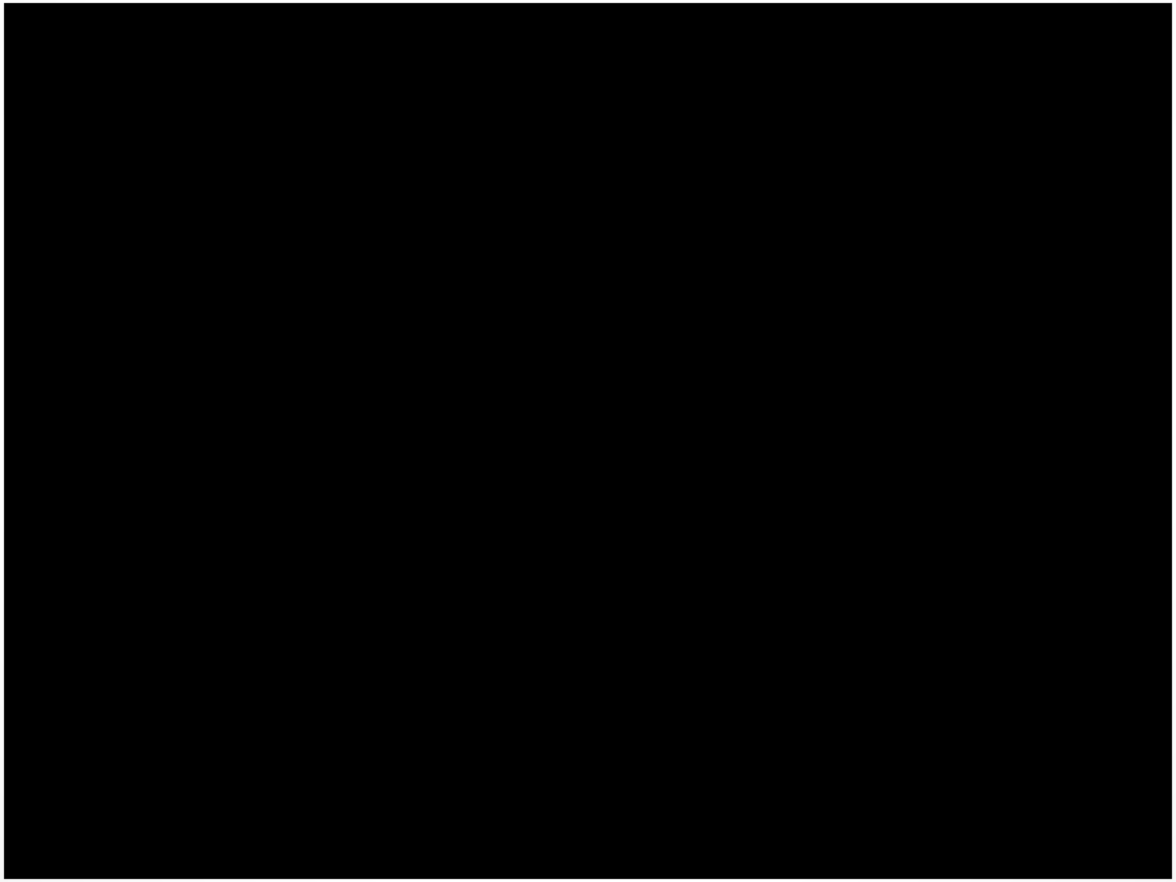
Video Input – Gabor Filtering

- Images are processed and values are sent to the simulated visual pathways (V1, V2 and V4)
- Input closely resembles how visual information is processed in a biologically realistic brain



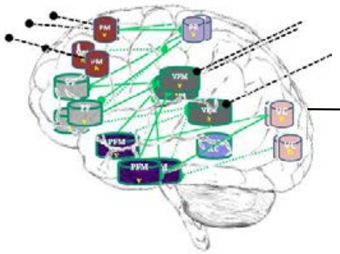


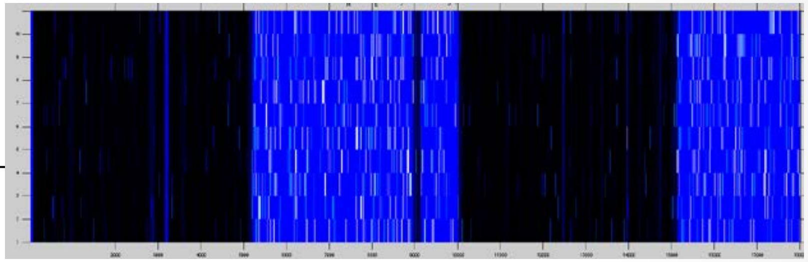
Trust the Intent Recognition Discordant Motions

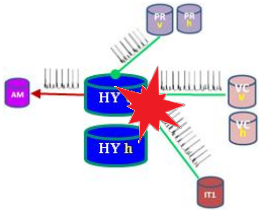


Trust the Intent Recognition Concordant Motions

Results

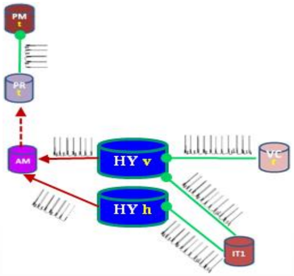




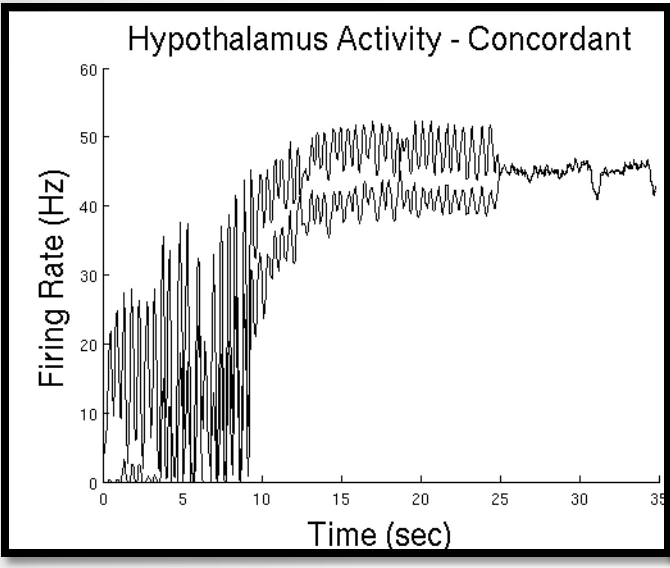


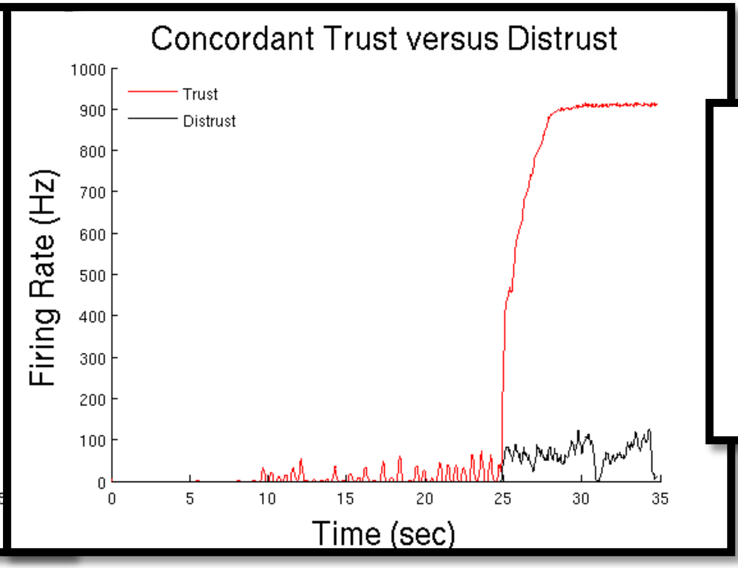
Discordant > Distrust

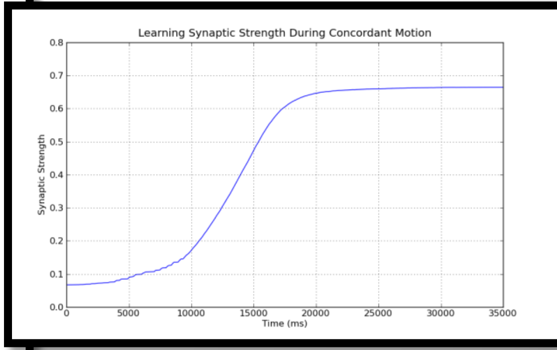
Concordant > Trust

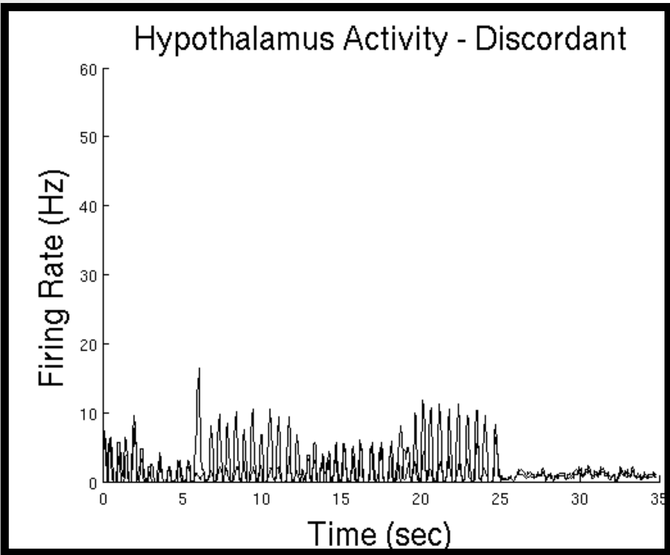


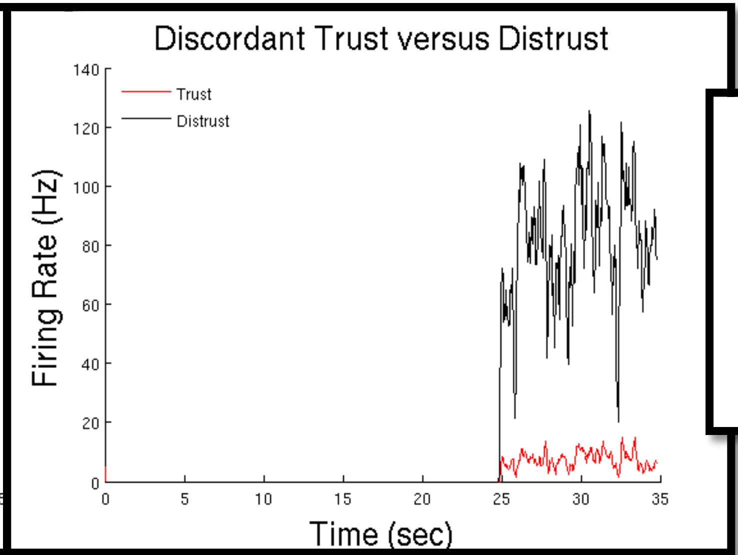
Results

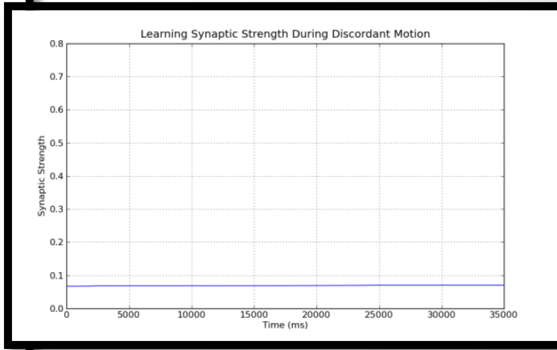

Hypothalamus Activity - Concordant
Firing Rate (Hz)
Time (sec)


Concordant Trust versus Distrust
Trust
Distrust
Firing Rate (Hz)
Time (sec)


Learning Synaptic Strength During Concordant Motion
Synaptic Strength
Time (ms)


Hypothalamus Activity - Discordant
Firing Rate (Hz)
Time (sec)

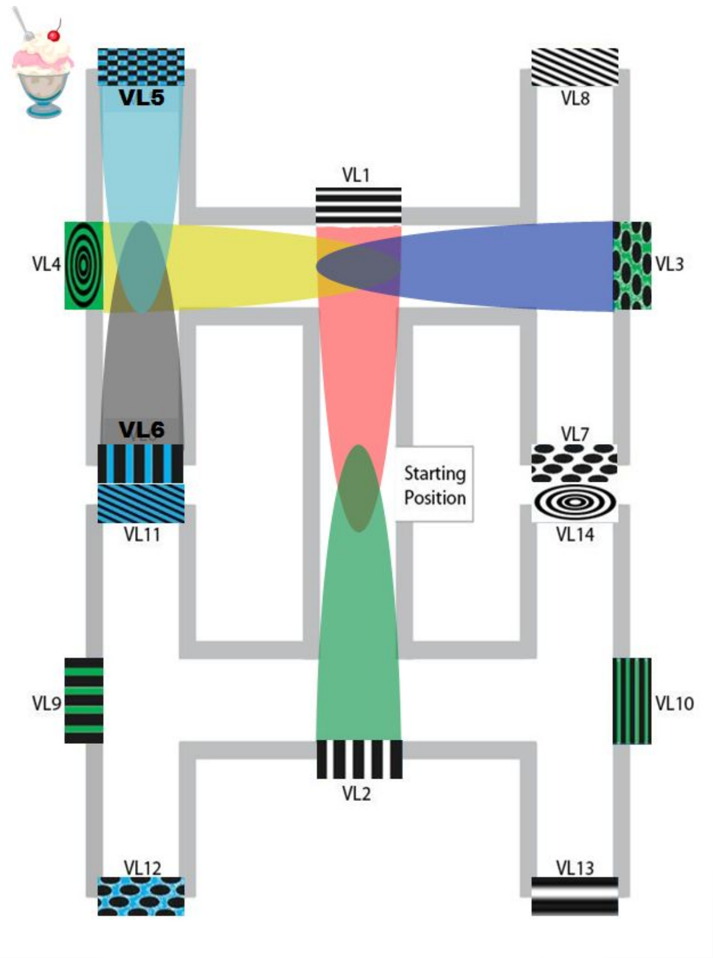

Discordant Trust versus Distrust
Trust
Distrust
Firing Rate (Hz)
Time (sec)


Learning Synaptic Strength During Discordant Motion
Synaptic Strength
Time (ms)

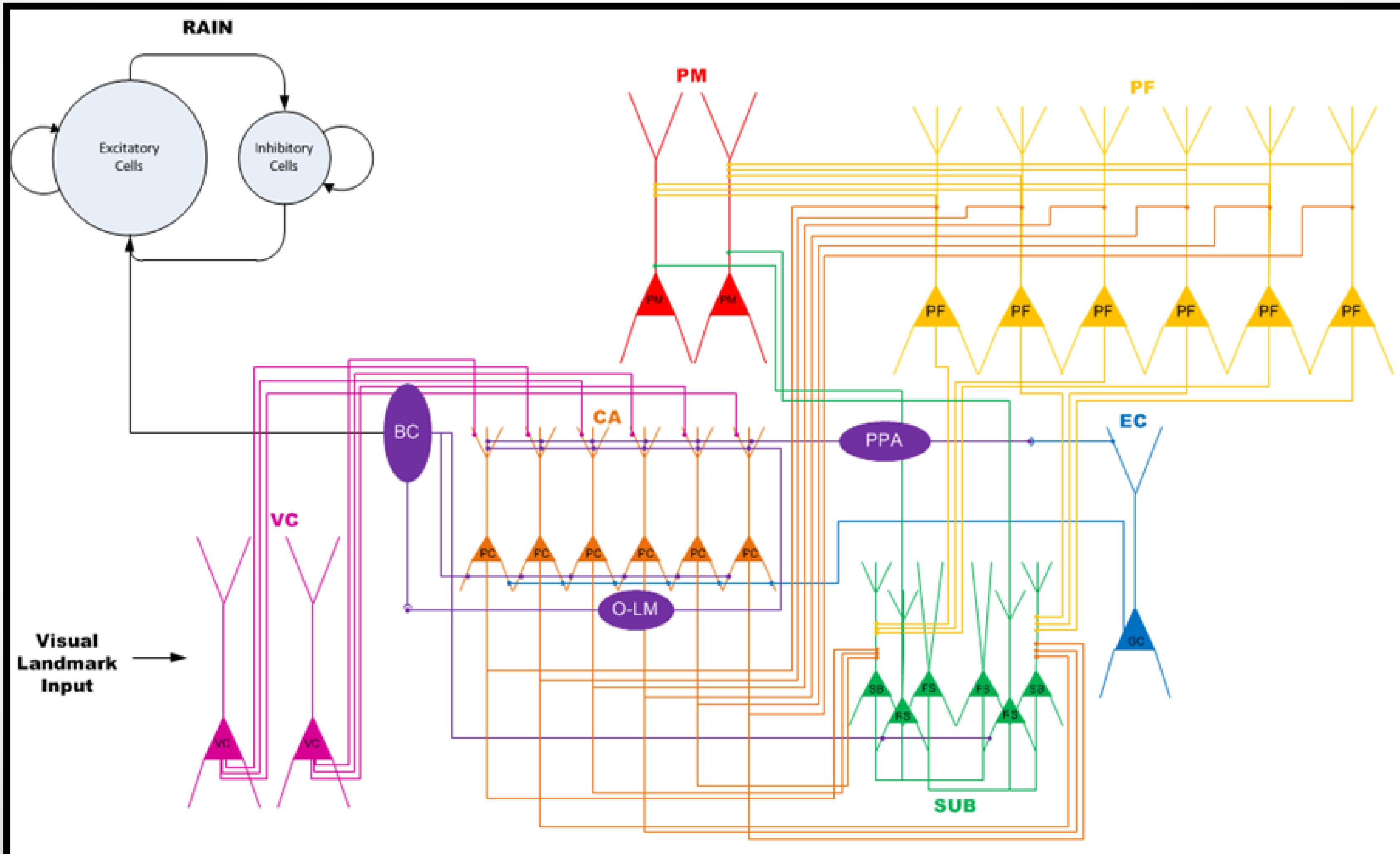
Navigation

- Navigate to familiar location
  - Prefrontal Cortex
  - Hippocampus
  - Subiculum
- Compuational system representing a navigating rodent
- Reward at the end of a sequence of turns
- Showed learning performance without biased decisions
- Short-term memory

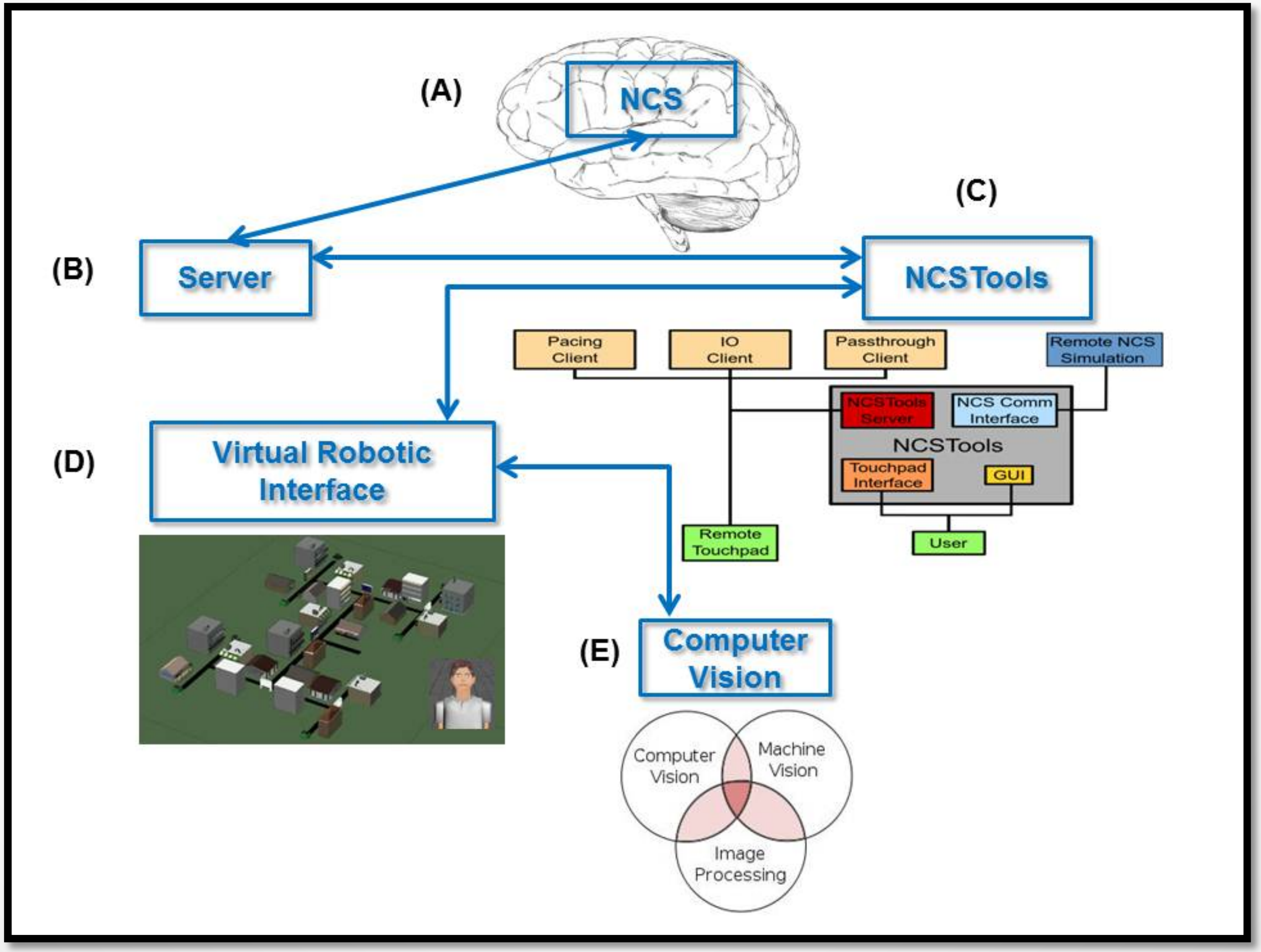
Paradigm


VL5
VL8
VL1
VL4
VL3
VL6
VL7
Starting Position
VL11
VL14
VL9
VL10
VL2
VL12
VL13

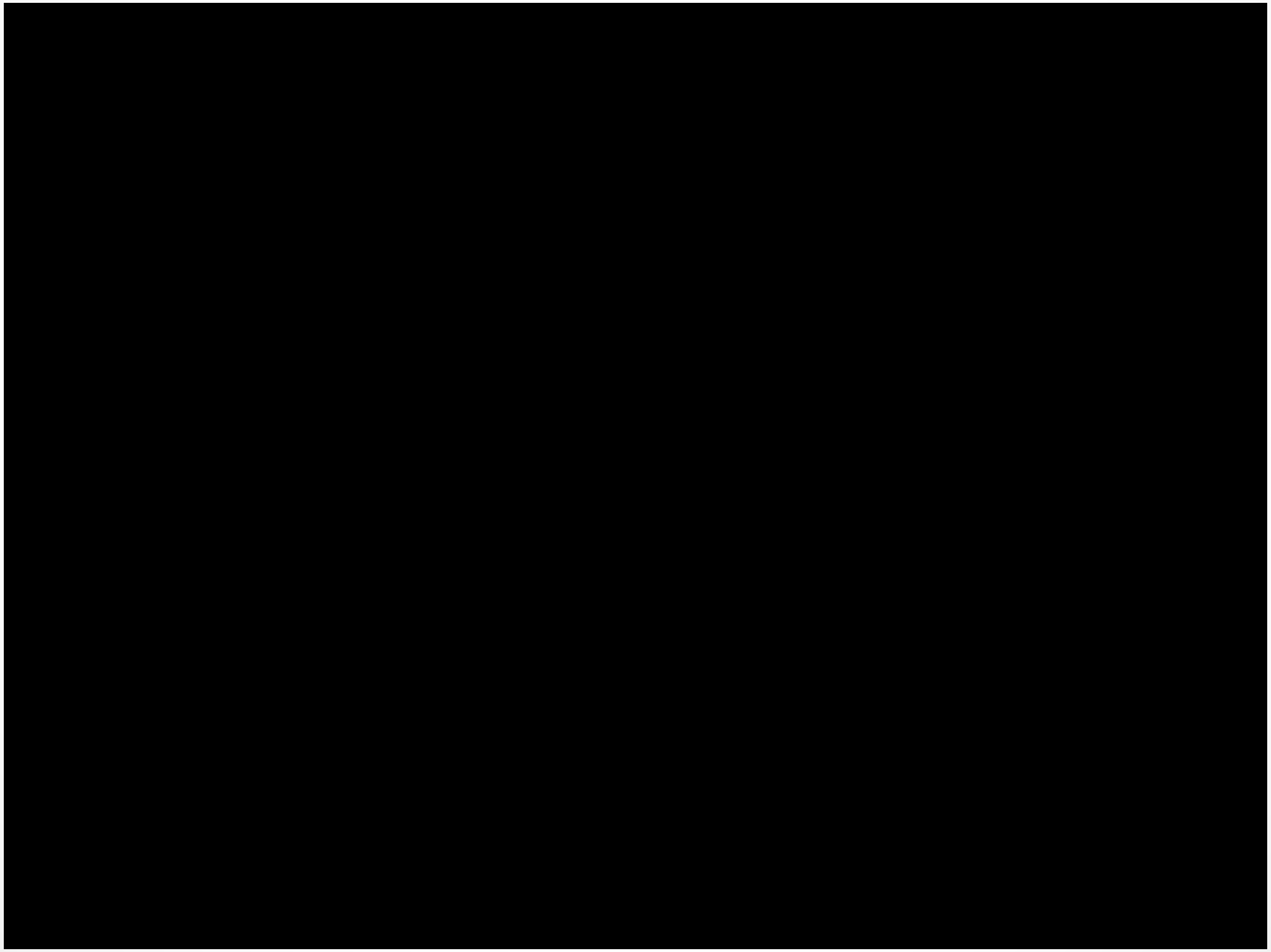
Microcircuitry



Results


(A)
NCS
(C)
(B)
Server
NCSTools
Pacing Client
IO Client
Passthrough Client
Remote NCS Simulation
NCSTools Server
NCS Comm Interface
NCSTools
Touchpad Interface
GUI
(D)
Virtual Robotic Interface
Remote Touchpad
User
(E)
Computer Vision
Computer Vision
Machine Vision
Image Processing

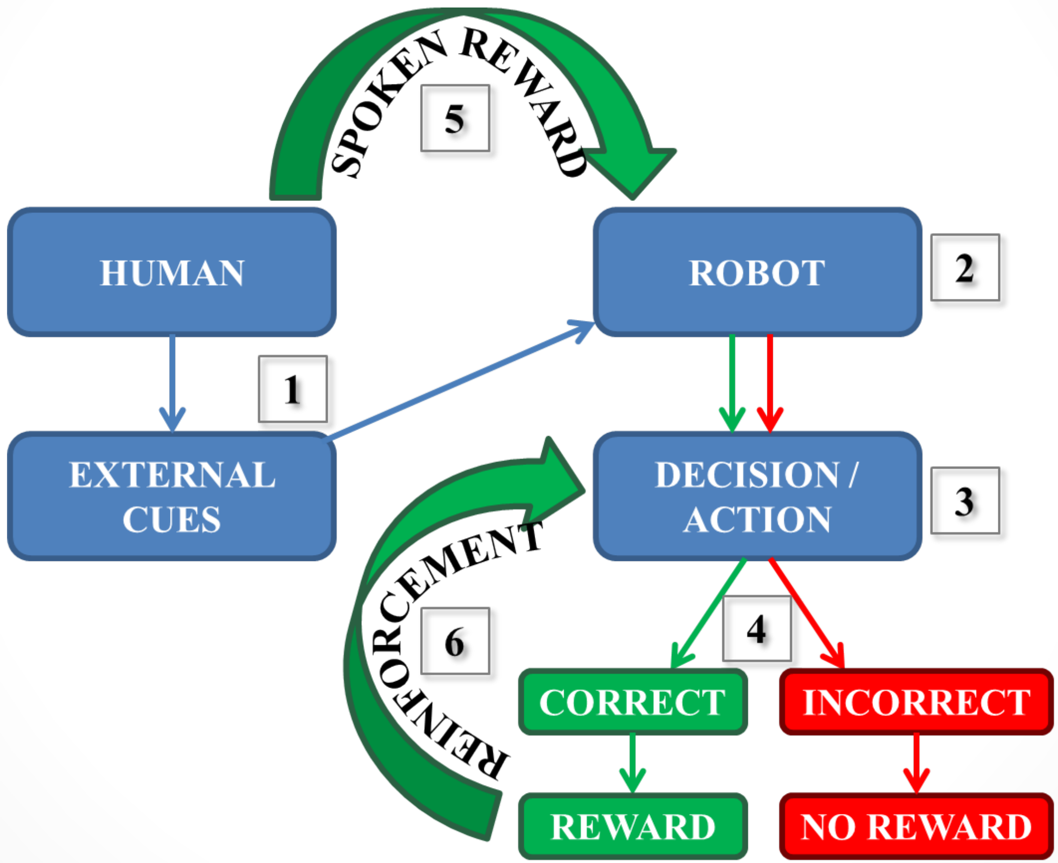
Results



Emotional Speech

- Allows for more natural interaction between humans and robots
  - Determine the ideal behavior from a simple reward feedback
- Emotional Speech processor
  - Successfully distinguished “sad” and “happy” utterances
- Integrated into neurorobotic scenario
  - The robot received a spoken reward if the correct decision was made
- Neurorobot successfully and consistently learned the exerceise
- Step toward the combination of human emotions and virtual neurorobotics

REWARD-BASED LEARNING THROUGH ESP



L. C. Jayet Bray, G. Ferheyhough, E. Barker, C. M. Thibeault, P. H. Goodman, and F. C. Harris, Jr.. Emotional speech processing in neurorobotics. In revision, 2012.

ESP CLASSIFICATION PERFROMANCE

TABLE I
HUMAN CLASSIFICATION CONFUSION MATRIX

Category	Anger	Fear	Happy	Sad	Error
Anger	62	3	5	0	11.4%
Fear	5	62	1	2	11.4%
Happy	5	8	56	1	20.0%
Sad	0	1	1	68	2.9%
Average Error					11.4%

ESP RECOGNITION PERFROMANCE

TABLE II
OFFLINE MODE RECOGNITION CONFUSION MATRIX

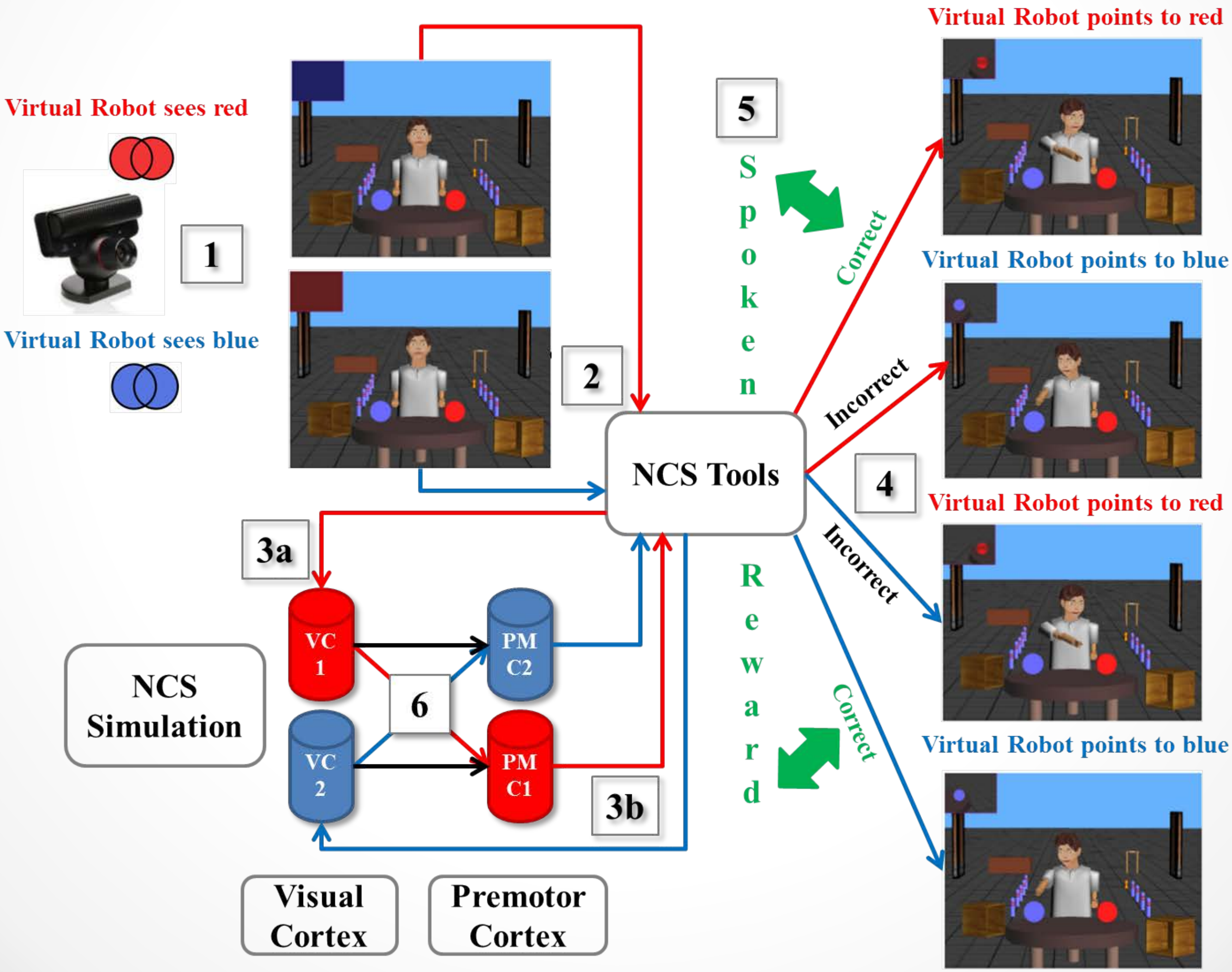
Category	Happy-M	Sad-M	Happy-F	Sad-F	Error
Happy-M	16	0	0	0	0.0%
Sad-M	2	13	0	0	13.3%
Happy-F	0	0	17	1	5.6%
Sad-F	0	0	0	12	0.0%
Average Error					4.7%

ESP RECOGNITION PERFROMANCE

TABLE III
LIVE MODE RECOGNITION CONFUSION MATRIX

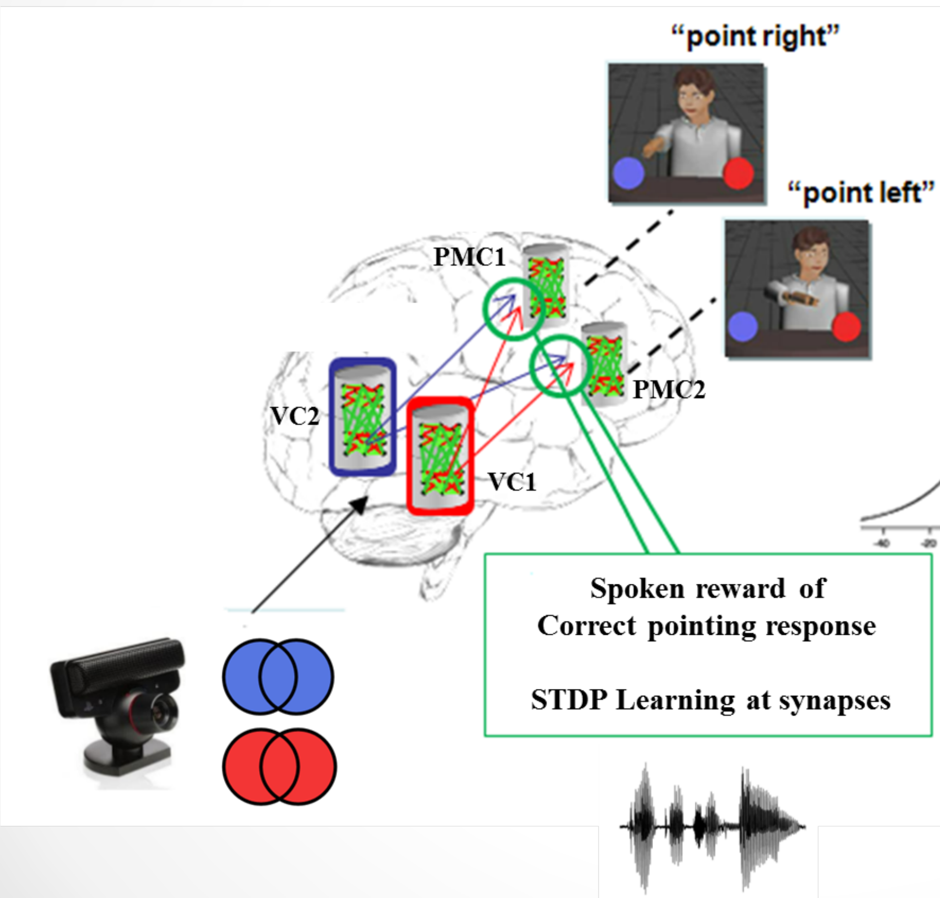
Category	Happy-M	Sad-M	Happy-F	Sad-F	Error
Happy-M	22	0	0	0	0.0%
Sad-M	0	16	0	0	0.0%
Happy-F	0	0	19	1	5.0%
Sad-F	0	0	0	19	0.0%
Average Error					1.3%

Results

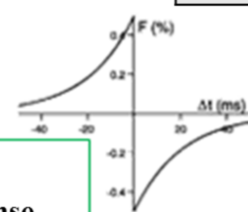


Virtual Robot sees red
1
Virtual Robot sees blue
2
5
Spoken
NCS Tools
Correct
Incorrect
Incorrect
Correct
4
Reward
3a
3b
VC 1
VC 2
PM C2
PM C1
6
NCS Simulation
Visual Cortex
Premotor Cortex
Virtual Robot points to red
Virtual Robot points to blue
Virtual Robot points to red
Virtual Robot points to blue

Results

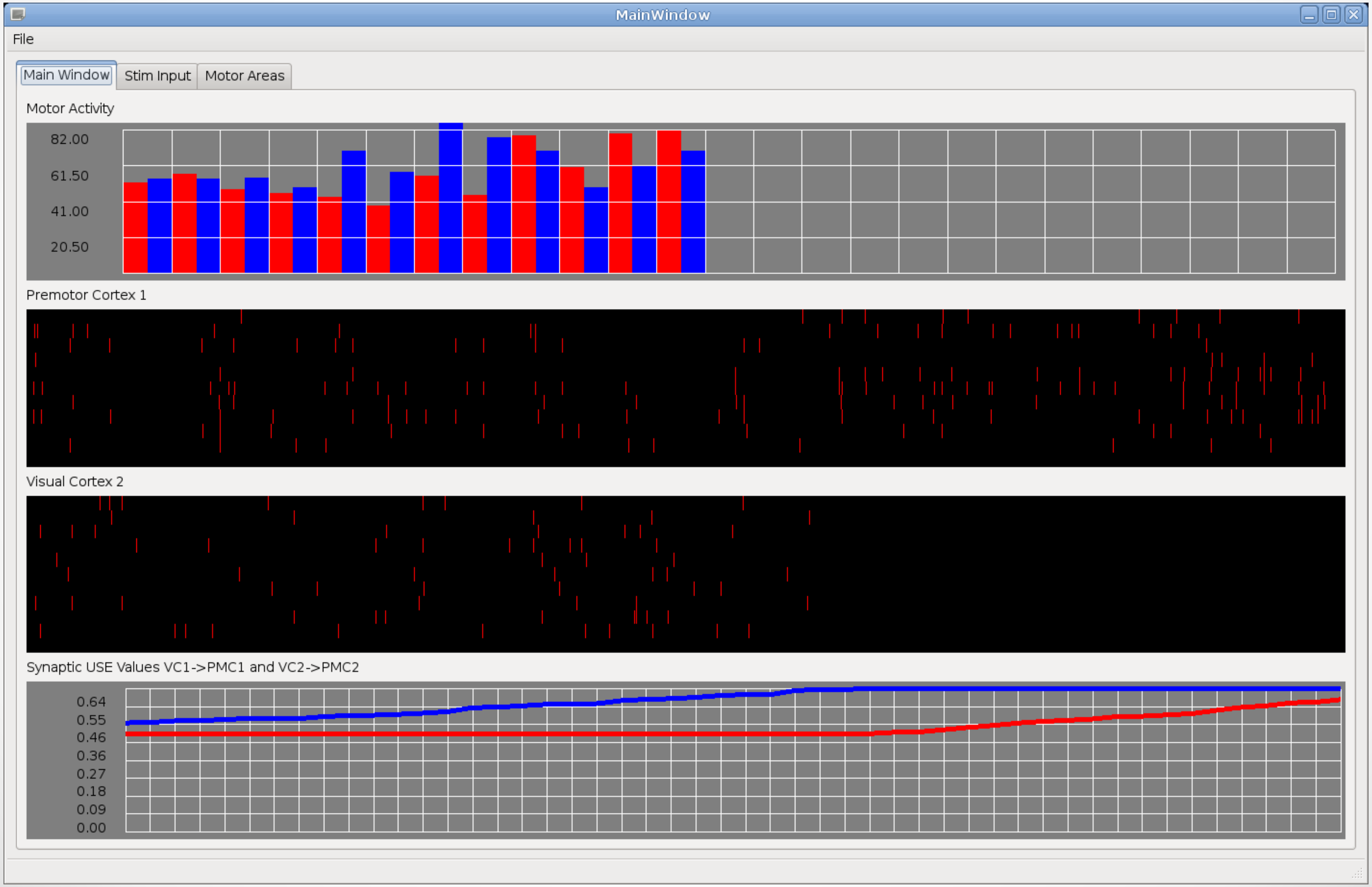


Connections	Probability (%)	Connection Strength (µS)
VC1-PMC1	50	0.006
VC2-PMC2	50	0.006
VC1-PMC2	50	0.006
VC2-PMC1	50	0.006



	VC1	VC2	PMC1	PMC2
Numbers of Excit. Neurons	10	10	10	10

Results


MainWindow
File
Main Window
Stim Input
Motor Areas
Motor Activity
82.00
61.50
41.00
20.50
Premotor Cortex 1
Visual Cortex 2
Synaptic USE Values VC1->PMC1 and VC2->PMC2
0.64
0.55
0.46
0.36
0.27
0.18
0.09
0.00

Complete Loop Execution

Requirements

- **Save**
  - NCS files (NCS_core)
  - Configuration files (Reward_Based_Learning)
  - Robotic files (Webots_Neighborhood)
- **Folders in home directory**

Steps

- **Start voServer on port 20003**
    - cd /home/username/NCS_core/voServer
    - ./server <space> -p <space> 20003
- **Open voInterpreter**
    - cd /home/username/NCS_core/ncstools/bin
    - ./voInterpreter <space> /home/username/Reward_Based_Learning/input/navigation.cfg
- **Start NCS**
    - cd /home/username/Reward_Based_Learning
    - ./ncs5e 1 ./input/navigation.in

Steps

- **Video Capture**
    - cd /home/username/Reward_Based_Learning/card_color_detection
    - ./recognize_card
- **Start webots and load world**
    - webots

DEMO

Future Directions

Future Directions

- Multi-Scale/Mixed Models:
  - Izhikevich and NCS and … all in the same model
- Published Interface for New Neuron/Synapse Models
  - Allow your own coding of neurons and synapses and use our parallel code.
- Speed….
  - Always here ☺
- More Parameters on NCS Neurons/Synapses
- Visualization: 2D and 3D

Future Directions

- Research into Memory:
- Tools:
    - GUI Brain Builder,
    - Output Analysis
- ModelDB
- Input language options
    - PyNN (like)

Summary

First Hour

- Introduction
- NCS history and development
- Current enhancements
- Equations and Implementation
- Software and hardware requirements
- How to run a small model on a single machine
- Overview of the input language

Second Hour

- Detailed description of available parameters
- Demos
- Output analysis

Third Hour

- CPU, GPU, and MPI
- How to run on multiple machines
- Software tools
- Robotic system configuration
- Large scale models
- Complete loop execution
- Future directions

Acknowledgments

- Office of Naval Research
- DARPA Synapse project and HRL

Brain Computation Laboratory

University of Nevada, Reno



Laurence Jayet Bray   Fred Harris, Jr   Sergiu Dascalu

Director

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University of Bonn, Germany

Brain Mind Institute (Blue Brain Project), EPFL, Lausanne, Switzerland


Mathias Quoy

René Doursat

Florian Morman

Henry Markram

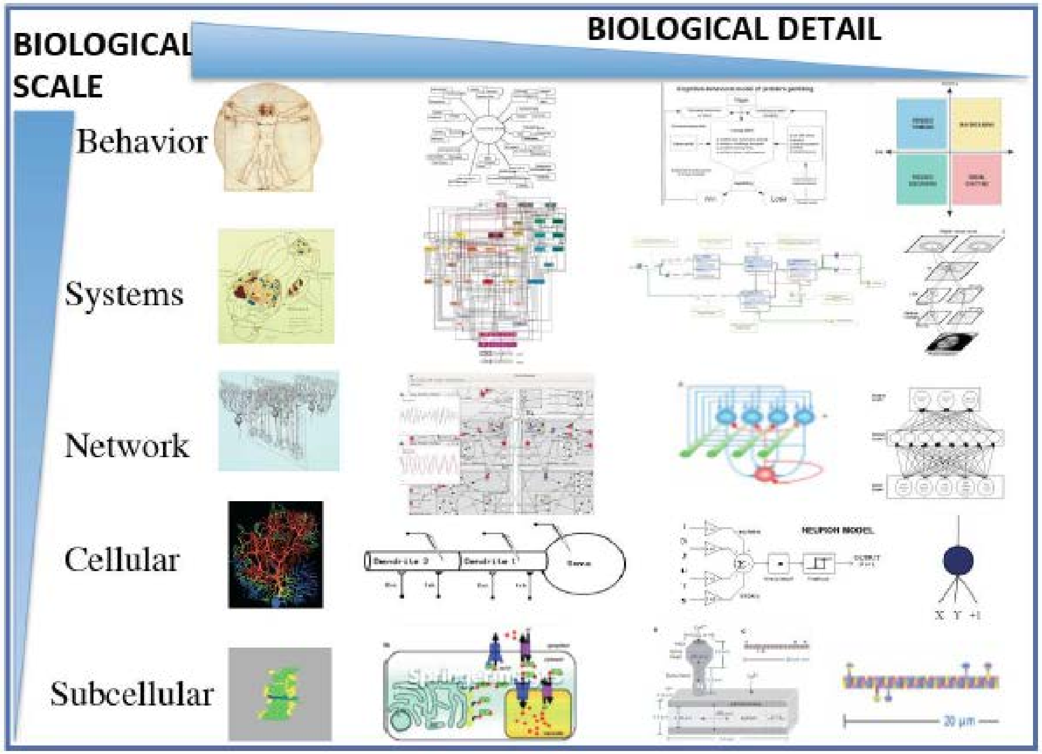
Jim King

Oral session IV: Navigation

- Monday July 23
- 10:40 - 11:00
- Talk: O12
- Goal-Related Navigation of a Neuromorphic Virtual Robot
  - Laurence Jayet Bray, Emily Barker, Gareth Ferneyhough, Roger Hoang, Bobby Bryant, Sergiu Dascalu, and Frederick C Harris

Workshop 4

- Multi-Scale Modeling in Computational Neuroscience II: Challenges and Opportunities
  - Wed: 9-6



Brain Computation Lab

- http://www.cse.unr.edu/brain/

Brain Computation Lab

Navigation

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Welcome to the Brain Laboratory!

Good Afternoon!

Founded in 2001, the brain lab is a joint research center between the departments of Computer Science & Engineering, Medicine, Physiology & Cell Biology, and the program of Biomedical Engineering. It also has neurobiological collaborations with the Brain Mind Institute at the EPFL (Switzerland), the University of Cergy Pontoise (France), and the University of Bonn (Germany).

Our researchers consists primarily of undergraduate/graduate students and alumni of the University of Nevada, Reno. They are actively developing computational innovations to understand the physiological processes that give rise to neocortical memory, learning, and cognition. Our models and experiments help understand brain pathophysiology and create brain-like artificial intelligence and neural prosthetic devices.

New Publications

- Design and Implementation of an NCS-NeuroML Translator
- Real-Time Human-Robot Interaction Underlying Neurorobotic Trust and Intent Recognition
- Correlation Maps Allow Neuronal Electrical Properties to be Predicted from Single-cell Gene Expression Profiles in Rat Neocortex
- Heterogeneity in the Pyramidal Network of the Medial Prefrontal Cortex