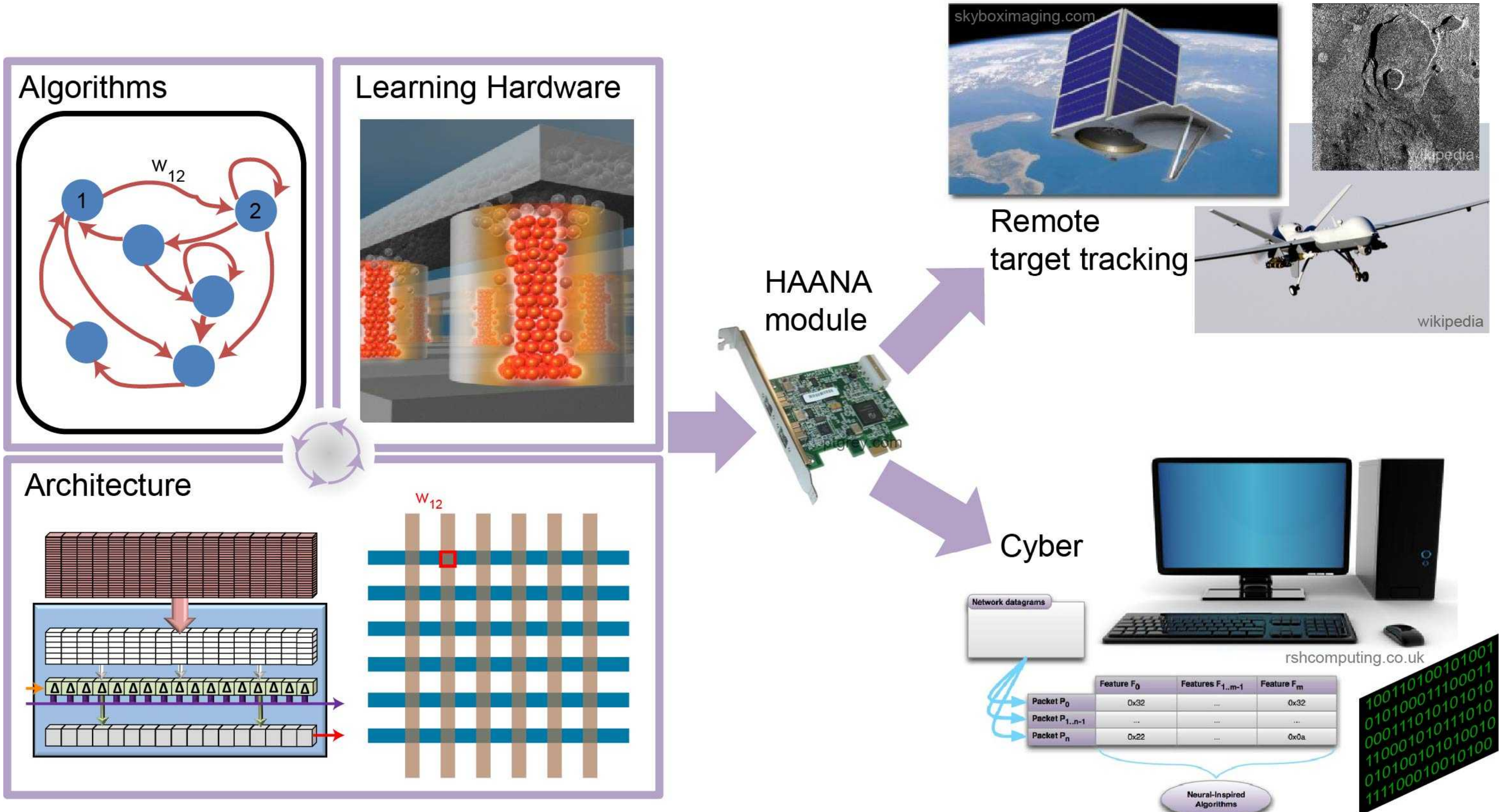
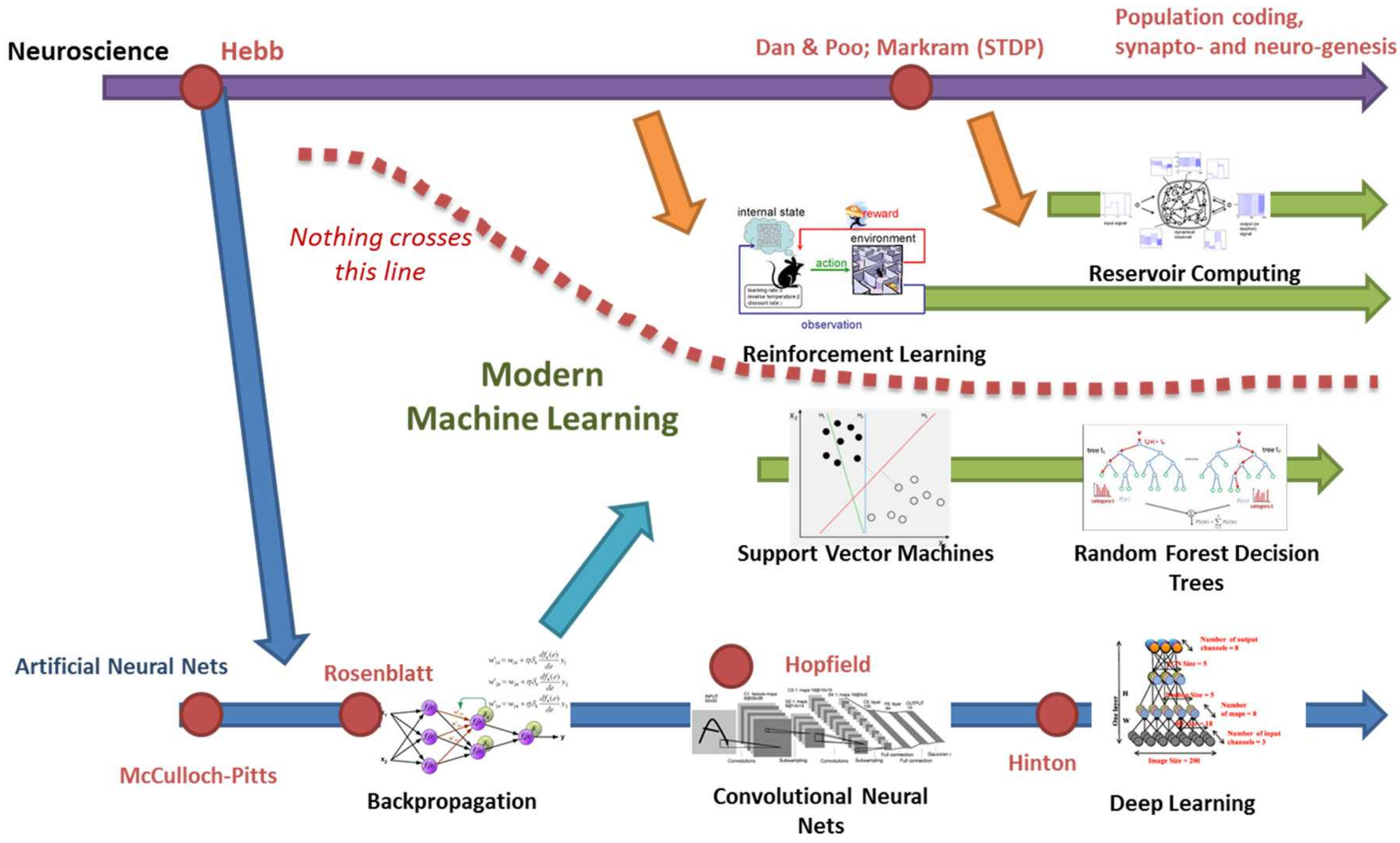
SAND2015-0602PE

Biologically-Inspired Computing at Sandia Labs

HAANA: Real-time, low-power, small footprint, embedded threat-detection system

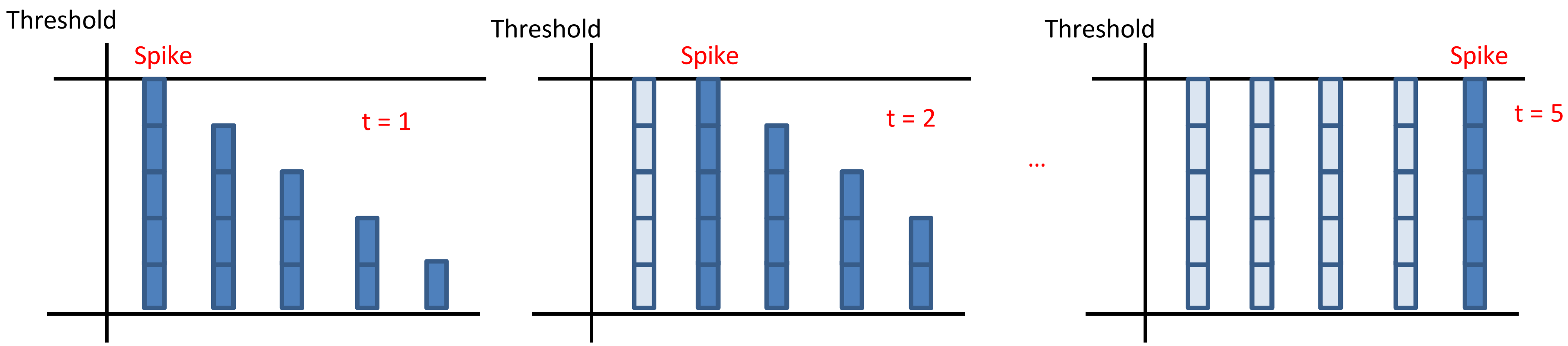


Neural computation and artificial neural networks are not the same



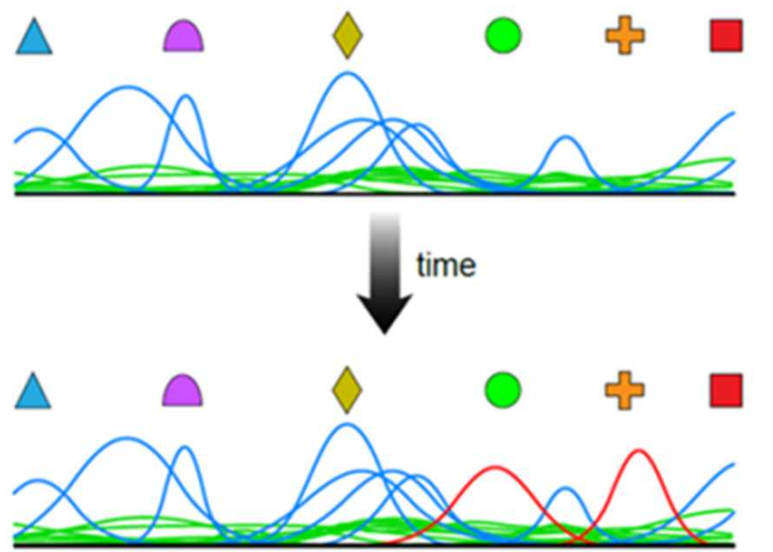
Algorithms Core Objective - Theory

1. Devise machine learning algorithms with functional neural concepts
   - SpikeSort: trade space for computational complexity (time domain);

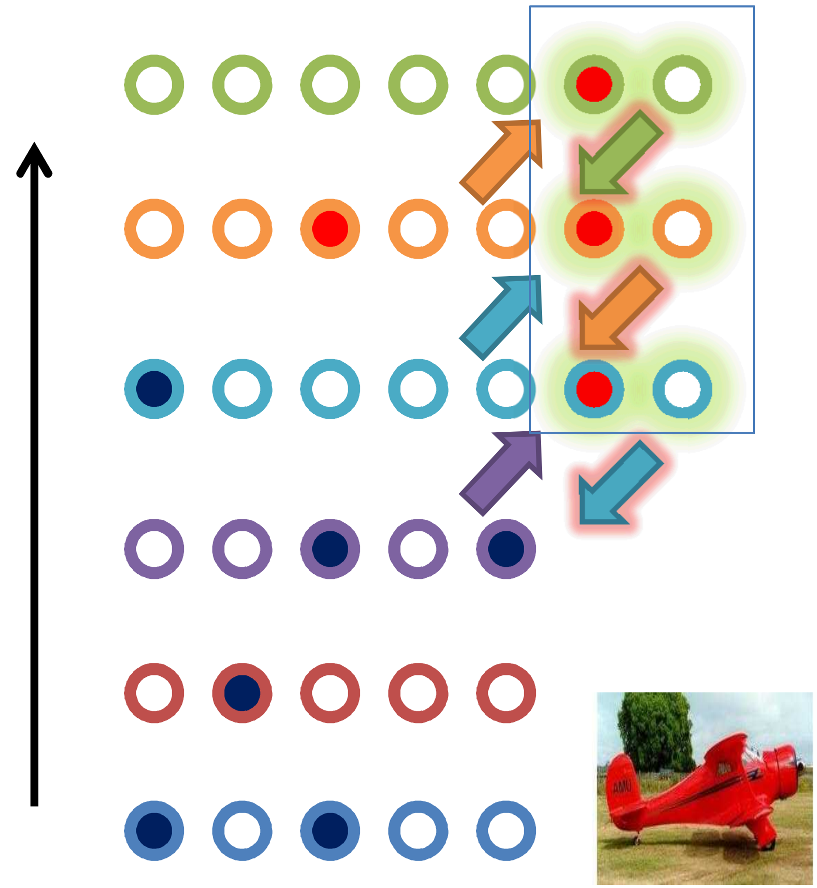


Algorithms Core Objective - Design

2. Incorporate neuroscience concepts (e.g. structural plasticity) to provide machine learning methods with novel capabilities (e.g. evolving feature sets)

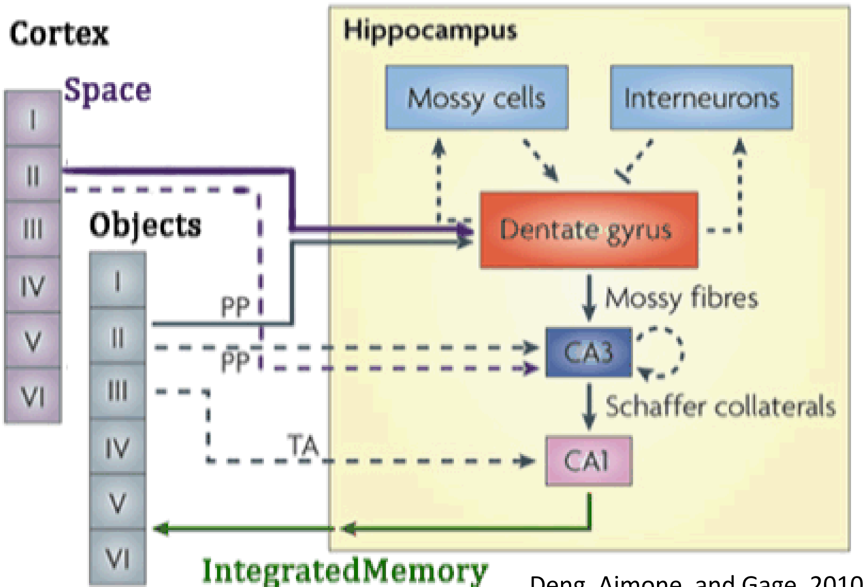


<u>Neural computation:</u> creation of new features based on changes in context, *Aimone et al. 2011*

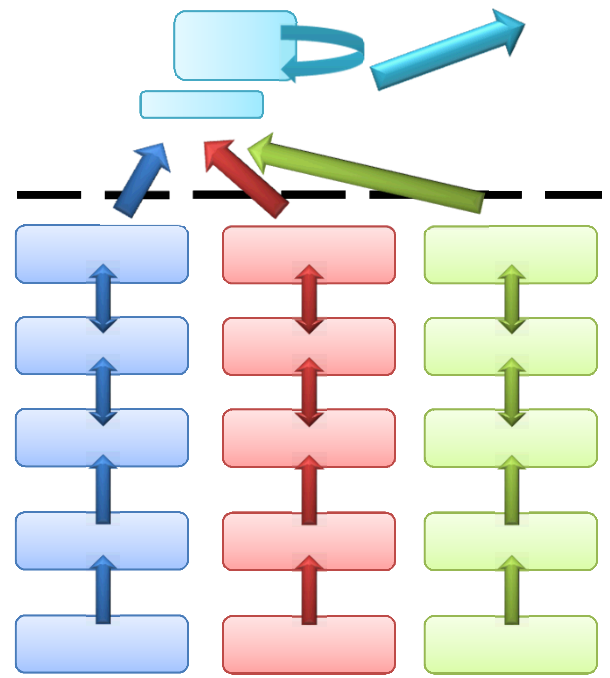


Algorithms Core Objective - Model

3. Extract novel algorithms from neural circuit models
   – multimodal integration and historical context referencing based on hippocampal circuit



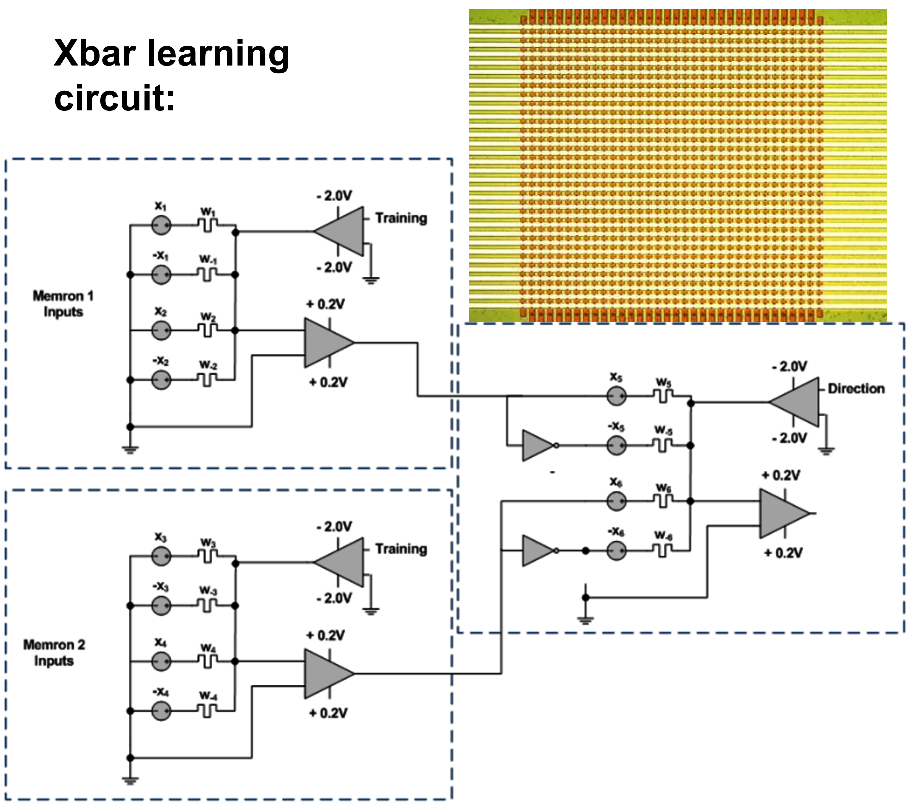
Deng, Aimone, and Gage, 2010

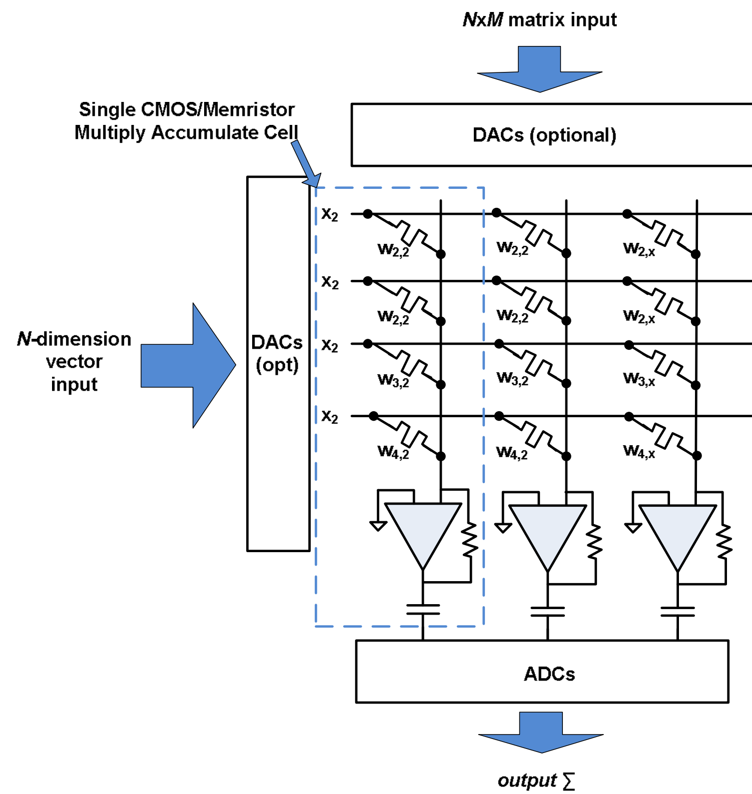


Integration - learning algorithm accelerator

- Learning is computationally intensive
- Crossbar architectures are well suited to accelerate multiply-and-accumulate operations and store weights - demonstrate with candidate algorithms

Xbar learning circuit:





N2A
A neuroinformatics framework

The Challenge

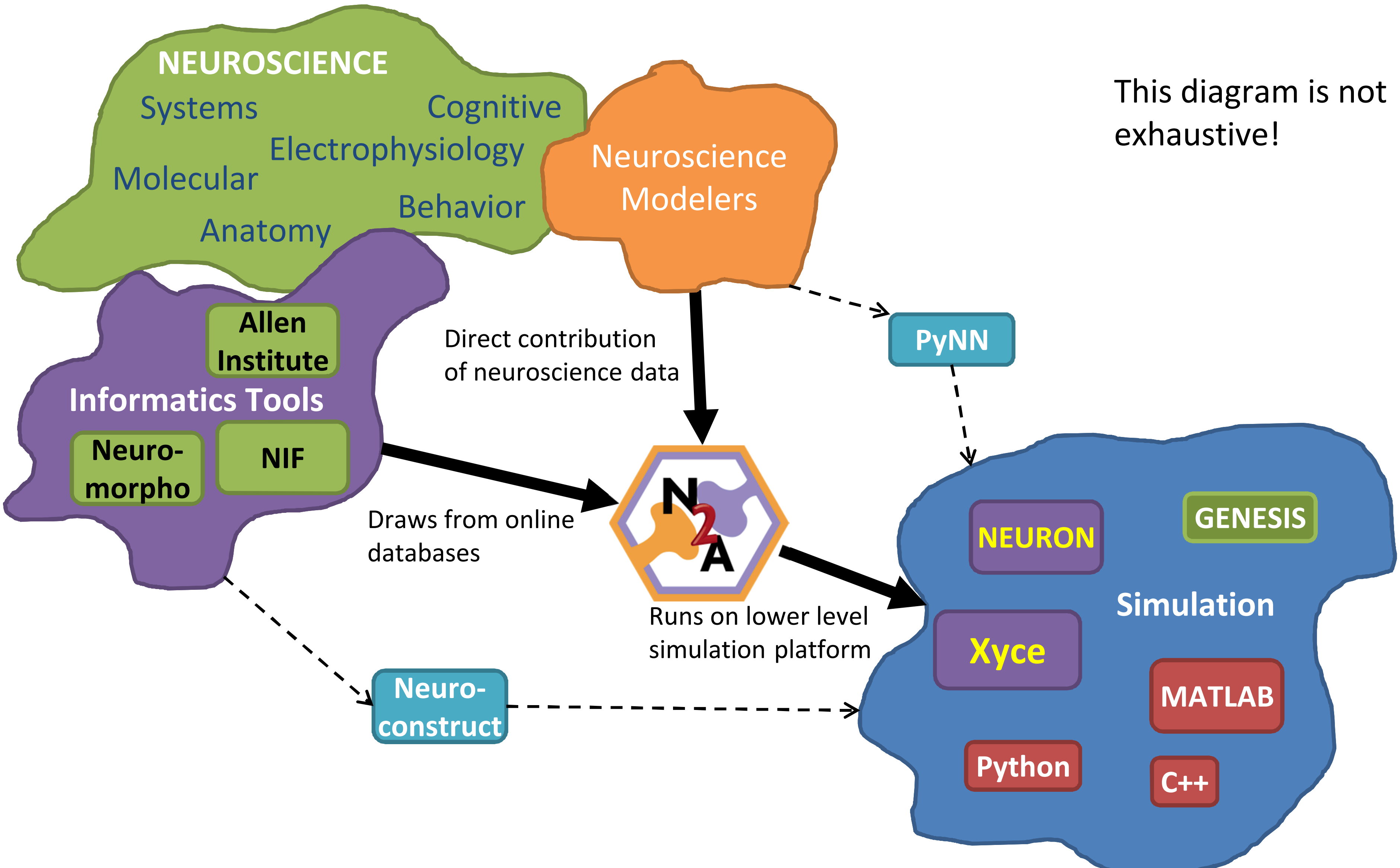
Society for Neuroscience
>30,000 scientists attend
>1,000 topic areas presented

Need to integrate all this knowledge. Beyond capacity of anyone to comprehend.

Complete model of human cognition *cannot* exist as an idea in one person's mind.

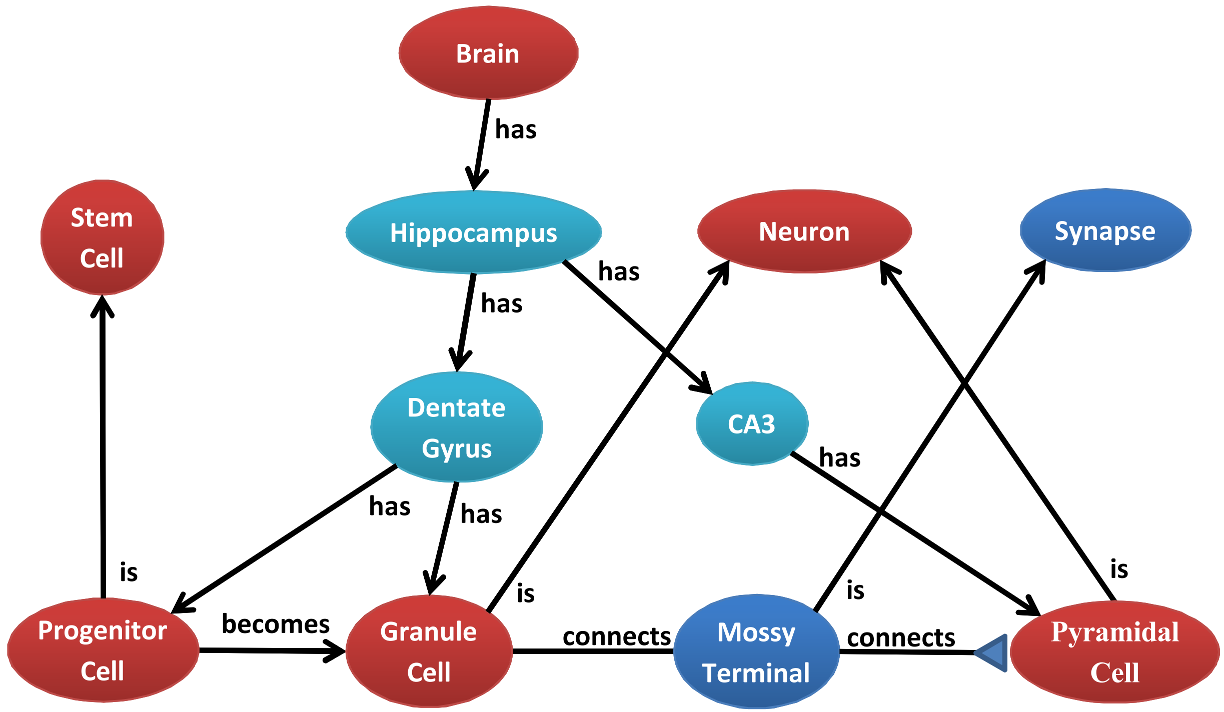
Must be an information structure held in a large computer system.

Neuroinformatics Vision



This diagram is not exhaustive!

A unified modeling framework



Attributes

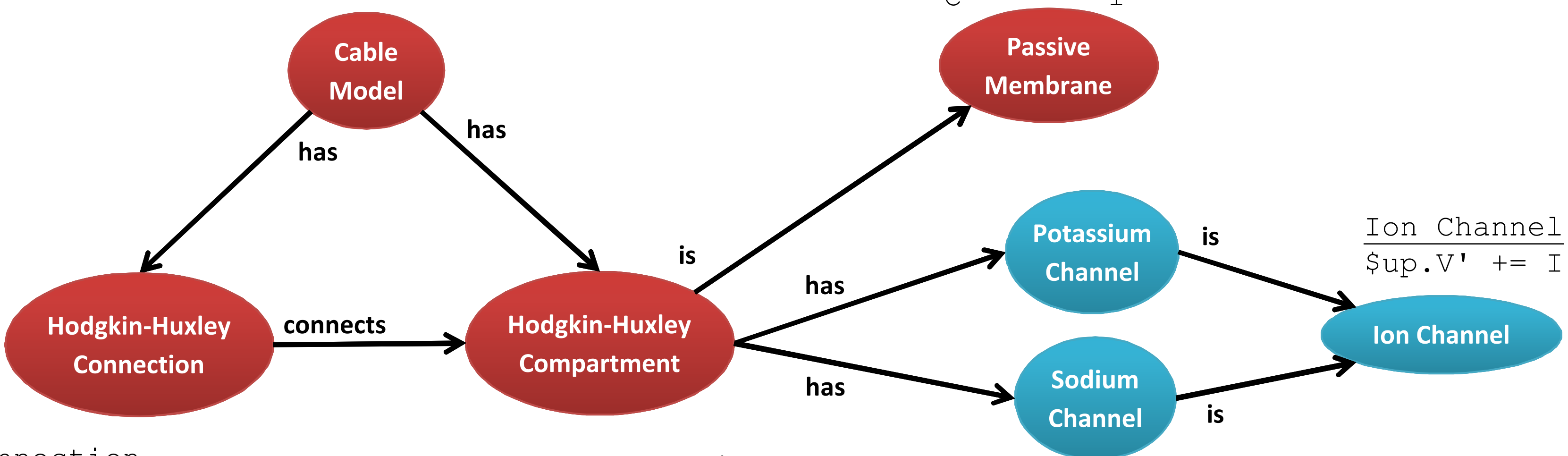
Name = Hippocampus CA3 pyramidal call
Organism = Vertebrata
Neurotransmitter released = Glutamate
Dendrite Length = 12481.9 +- 2998.9 um

Equations (a type of attribute) → V' = (G * (V_rest - V) + I_inj) / C
G = 0.3
...

Example: Cable Model

```
Cable Model
HH     = $include ("HH Compartment")
HH.$n  = 3
C      = $include ("HH Connection")
C.A    = HH
C.B    = HH
C.$p   = C.A.$index == C.B.$index - 1
```

```
Passive Membrane
V'     = (G * (V_rest - V) + I_inj) / C
G      = 0.3
V_rest = 10.613
C      = 1
```




```
Ion Channel
$up.V' += I / C
```

```
HH Connection
A     = $connect ("HH Compartment")
B     = $connect ("HH Compartment")
A.V' += (B.V - A.V) / R
B.V' += (A.V - B.V) / R
R     = 10
```

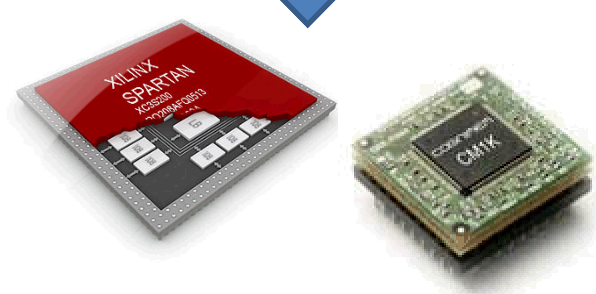
```
HH Compartment
parent = $inherit ("Passive Membrane")
K      = $include ("Potassium Channel")
Na     = $include ("Sodium Channel")
```

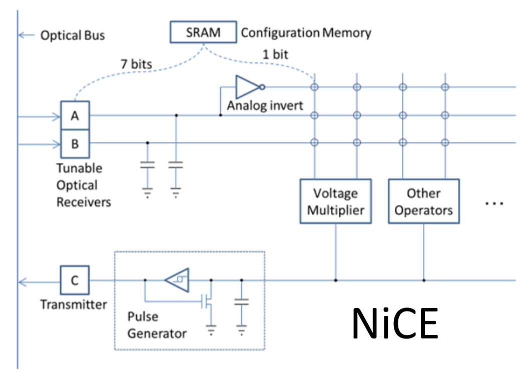
```
Sodium Channel
parent   = $inherit ("Ion Channel")
I        = G * m^3 * h * (E - V)
m'       = alpha_m * (1 - m) - beta_m * m
h'       = alpha_h * (1 - h) - beta_h * h
alpha_m := (25 - V) / (10 * (exp ((25 - V) / 10) - 1))
beta_m  := 4 * exp (- V / 18)
alpha_h := 0.07 * exp (- V / 20)
beta_h  := 1 / (exp ((30 - V) / 10) + 1)
G        = 120
E        = 115
```

Neural Compiler

Neuroscience Results

Device Engineering





Neural Compiler Outputs

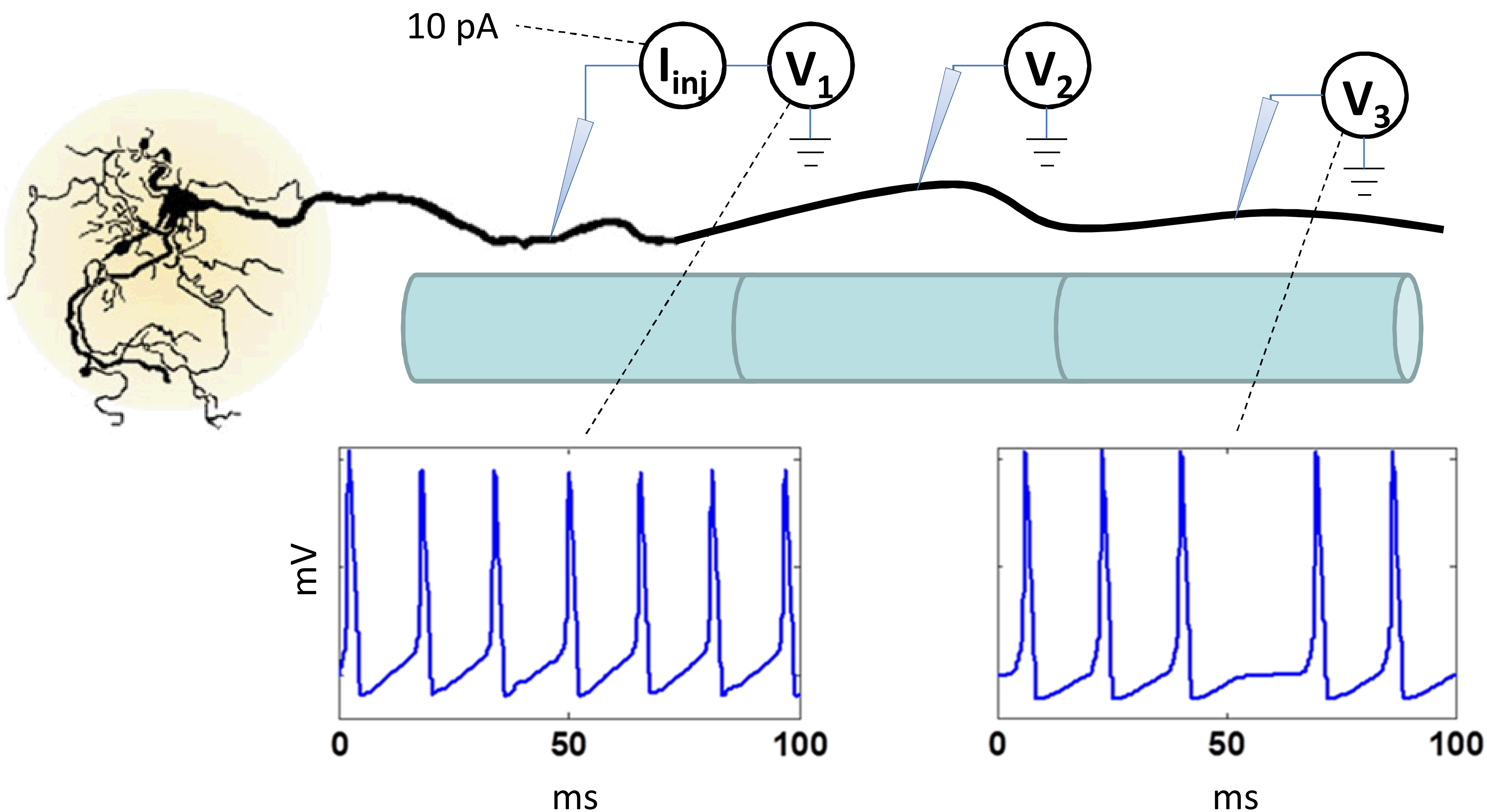
Xyce

```
* seed:  1380077478872
.tran 0 0.0

* initial condition equations for HHmod

* remaining equations for HHmod
CV_1 V_1_node 0 1
BV_1_equ 0 V_1_node I={ (G_m_1 * (V_rest_1 - V(V_1_node)) + I_inj_1) / C_m_1}
.param I_inj_1 = {10.0}
.param C_m_1 = {1.0}
.param V_rest_1 = {10.613}
.param G_m_1 = {0.3}
CV_2 V_2_node 0 1
BV_2_equ 0 V_2_node I={ (G_m_1 * (V_rest_1 - V(V_2_node)) + I_inj_1) / C_m_1}
CV_3 V_3_node 0 1
BV_3_equ 0 V_3_node I={ (G_m_1 * (V_rest_1 - V(V_3_node)) + I_inj_1) / C_m_1}

* initial condition equations for HHmodHHmod

* remaining equations for HHmodHHmod
BB.V_4_equ 0 V_2_node I={ (V(V_1_node) - V(V_2_node)) / (C_m_1 * R_4)}
.param R_4 = {10.0}
BA.V_4_equ 0 V_1_node I={ (V(V_2_node) - V(V_1_node)) / (C_m_1 * R_4)}
BB.V_5_equ 0 V_3_node I={ (V(V_2_node) - V(V_3_node)) / (C_m_1 * R_4)}
BA.V_5_equ 0 V_2_node I={ (V(V_3_node) - V(V_2_node)) / (C_m_1 * R_4)}

* outputs
.print tran
```

C++

```
class Model : public _Compartment
{
public:
  class HHmod : public _Compartment
  {
  public:
    ...
    virtual void update (float _24t, float & _24dt)
    {
      float Na_2ealpha_5fh;
      Na_2ealpha_5fh = 0.07f * exp(-V / 20.0f);
      float Na_2ealpha_5fm;
      Na_2ealpha_5fm = (25.0f - V) / (10.0f * (exp((25.0f - V) / 10.0f) - 1.0f));
      float K_2ealpha_5fn;
      K_2ealpha_5fn = (10.0f - V) / (100.0f * (exp((10.0f - V) / 10.0f) - 1.0f));
      float Na_2ebeta_5fh;
      Na_2ebeta_5fh = 1.0f / (exp((30.0f - V) / 10.0f) + 1.0f);
      float Na_2ebeta_5fm;
      Na_2ebeta_5fm = 4.0f * exp(-V / 18.0f);
      float K_2ebeta_5fn;
      K_2ebeta_5fn = 0.125f * exp(-V / 80.0f);
      _nextV_27 += (0.3f * (10.613f - V) + I_5finj) / 1.0f + K_2eI / 1.0f + Na_2eI / 1.0f;
      Na_2eh_27 = Na_2ealpha_5fh * (1.0f - Na_2eh) - Na_2ebeta_5fh * Na_2eh;
      Na_2eI = 120.0f * pow (Na_2em, 3.0f) * Na_2eh * (115.0f - V);
      K_2eI = 36.0f * pow (K_2en, 4.0f) * (-12.0f - V);
      Na_2em_27 = Na_2ealpha_5fm * (1.0f - Na_2em) - Na_2ebeta_5fm * Na_2em;
      K_2en_27 = K_2ealpha_5fn * (1.0f - K_2en) - K_2ebeta_5fn * K_2en;
      if (_24index == 0.0f)
        I_5finj = 10.0f;
    }
    ...
  };
};
```

Typical behavior



Backup Slides

Workflow

- Contributed models
- Neurophysiology literature
- Online databases

Database of Neural Structure & Dynamics

Simulate

Fit parameters

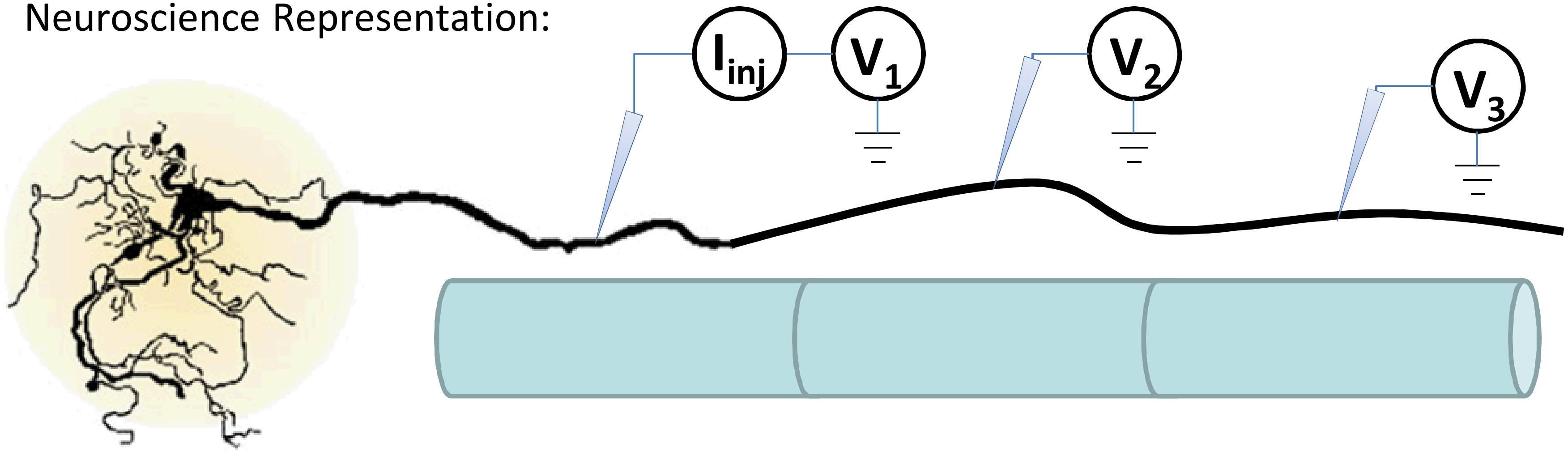
Characterize model behavior

- Visualization
- Automatic analysis

Algorithmic motifs

Simulate spike propagation through a Hodgkin-Huxley cable

Neuroscience Representation:



N2A Representation: