DiPDE: A simulator for population density modeling

http://alleninstitute.github.io/dipde/

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ALLEN INSTITUTE for BRAIN SCIENCE

Overview: DiPDE

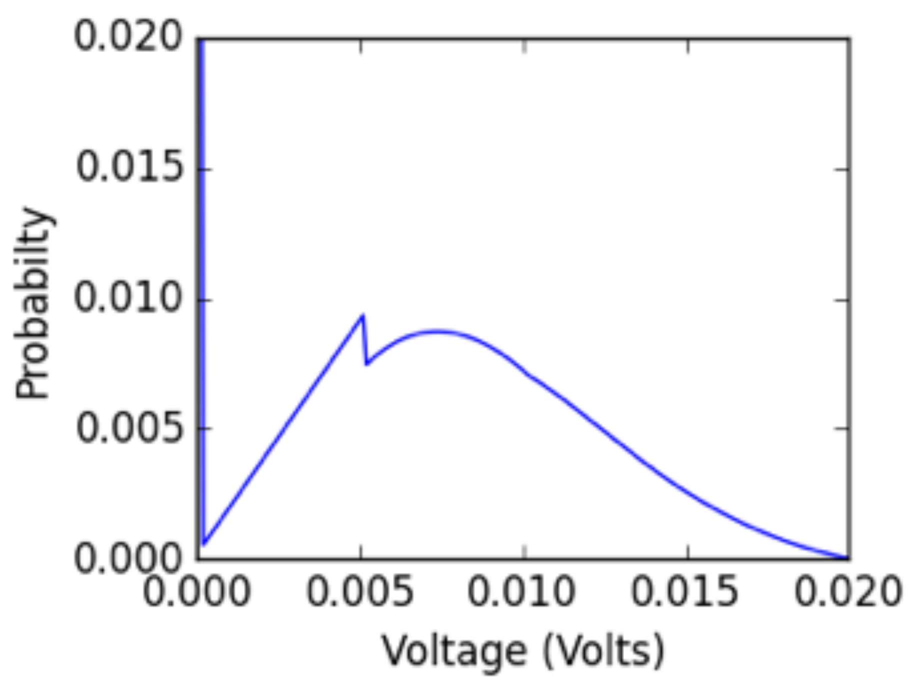
DiPDE (dipde) is a simulation platform for numerically solving the time evolution of coupled networks of neuronal populations. Instead of solving the subthreshold dynamics of individual model leaky-integrate-and-fire (LIF) neurons, dipde models the voltage distribution of a population of neurons with a single population density equation.

In this way, dipde can facilitate the fast exploration of mesoscale (population-level) network topologies, where large populations of neurons are treated as homogeneous with random fine-scale connectivity.

Overview: DiPDE

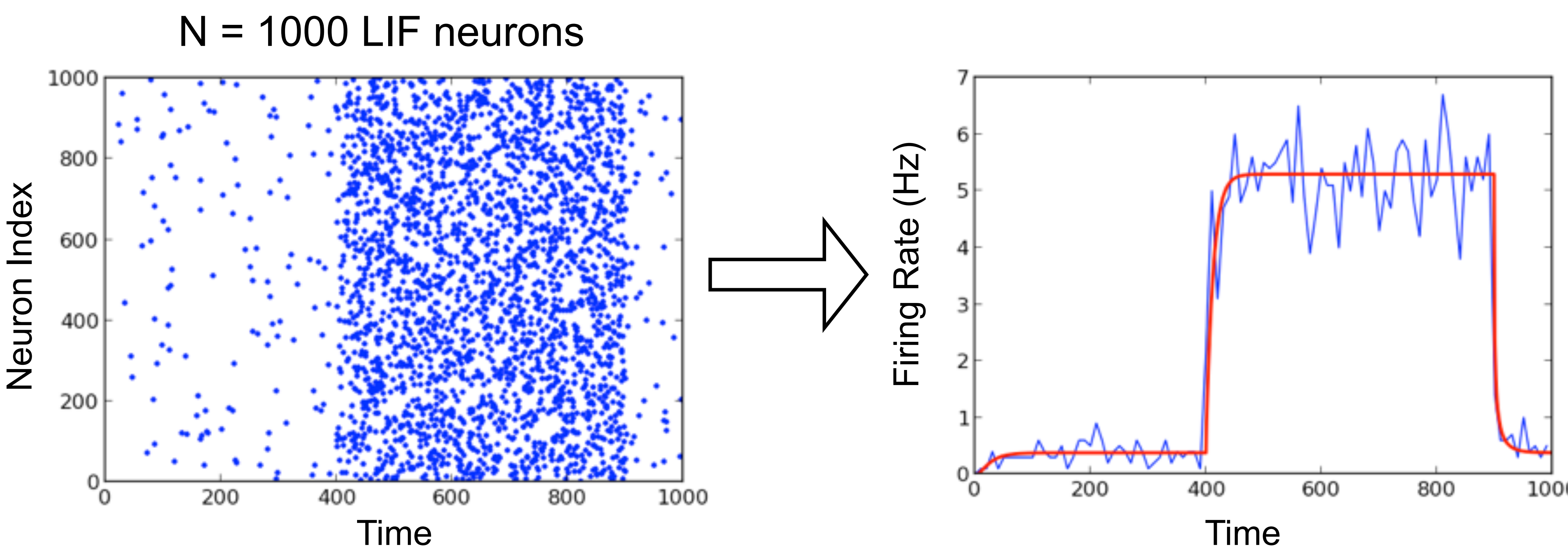
Goal: Provide a fast, flexible, python-based population statistic simulator for coarse-scale modeling

- Solve coupled population density equations (instantaneous synapses)
- Absorbing boundary condition at threshold
- Same mean firing rate as LIF population as N increases
- Exact when representing, ex., firing rate code



Overview: DiPDE

- Approximate mean firing rate of a LIF population
- Essentially a coupled PDE solver:
  - Boundary condition of source provides drive for target
  - Coupling through synaptic weight/delay distribution
- Allows fast:
  - Stability analysis
  - Stimulus/network topology/parameter exploration
  - Sensitivity analysis



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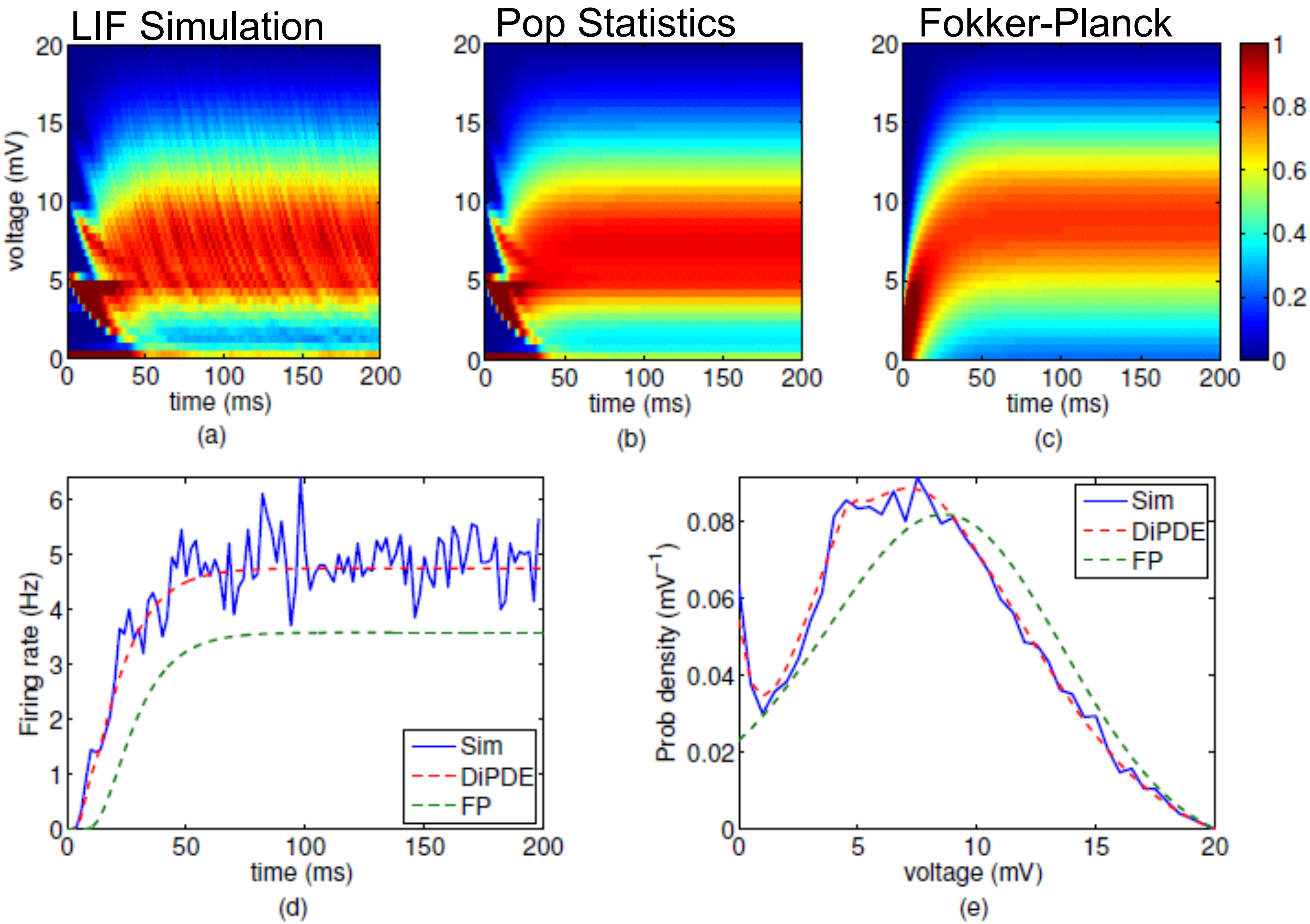


Iyer et al. PLoS Comp. Biol. 2013

DiPDE: Summary

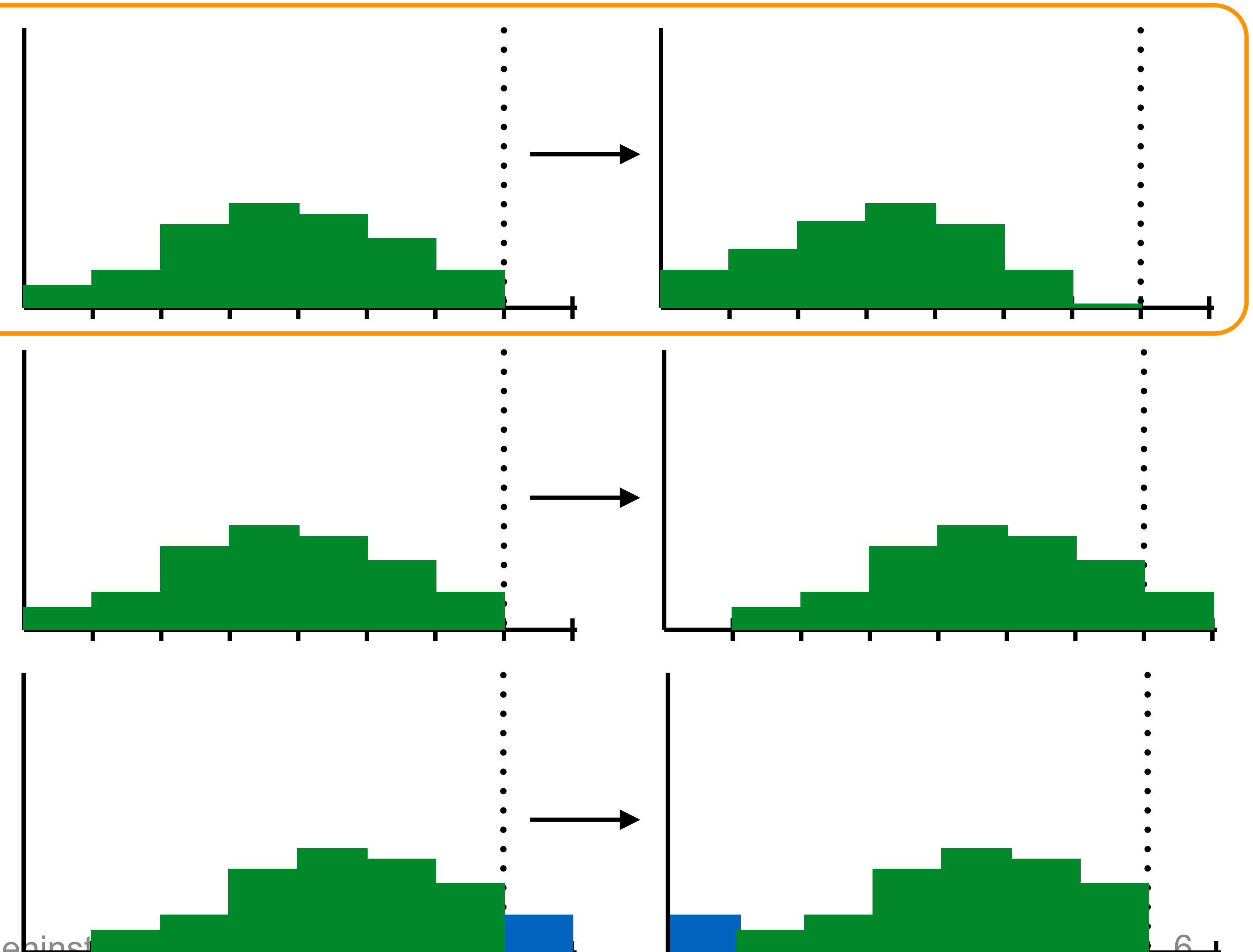
$$\partial_t p(v,t) = \boxed{\partial_v \left(L(v)p(v,t)\right)} - f(t)p(v,t) + f(t)\int_{w_1}^{w_2} p(v-w,t)q(w)H(\theta - v + w)dw + j(v,t)$$

$$j(v,t) = f(t)\int_{w_1}^{w_2} H(v)H(w-v)p(v+\theta-w,t)q(w)dw$$

Leak:

Synaptic Activation:

Thresholding:



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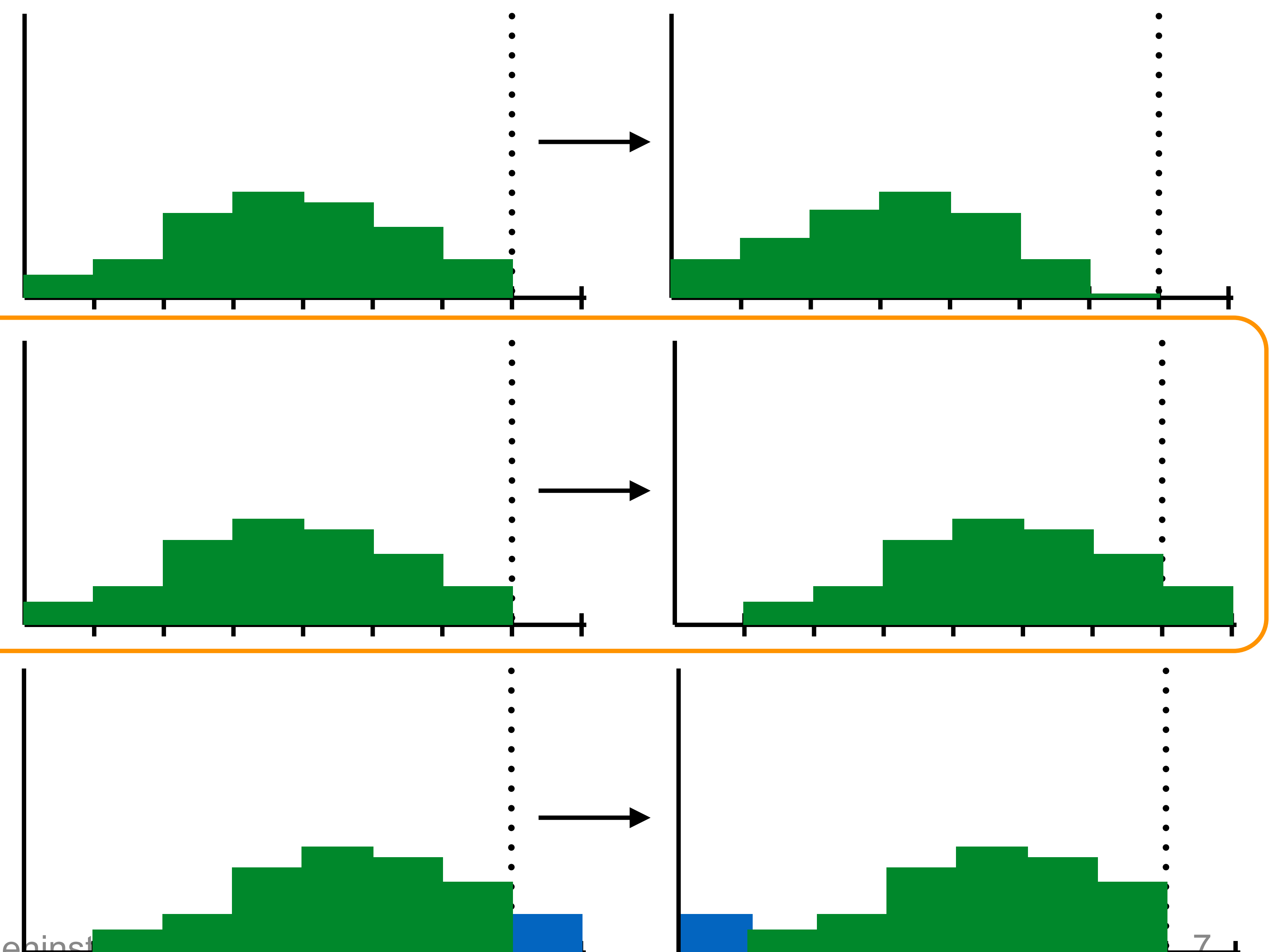

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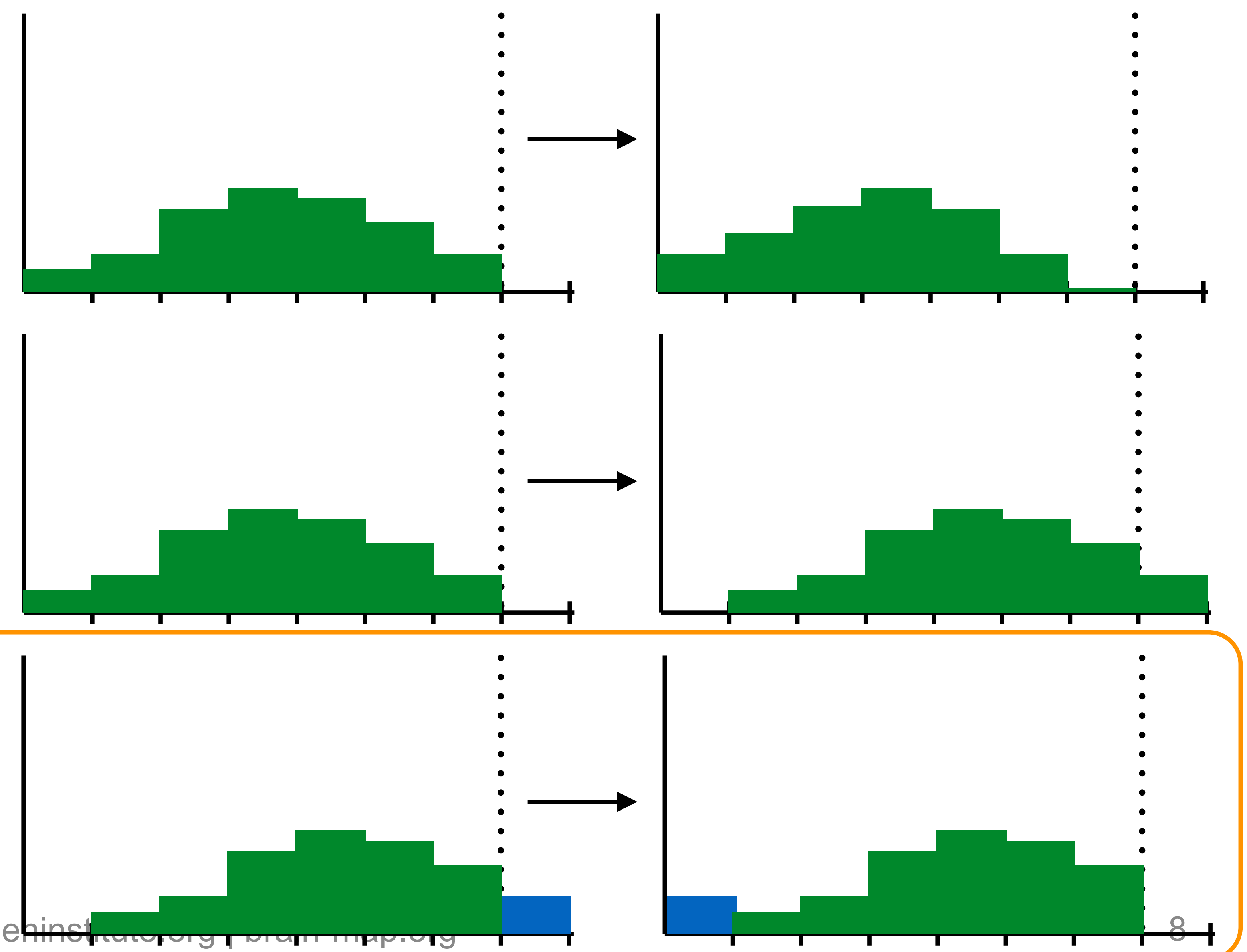
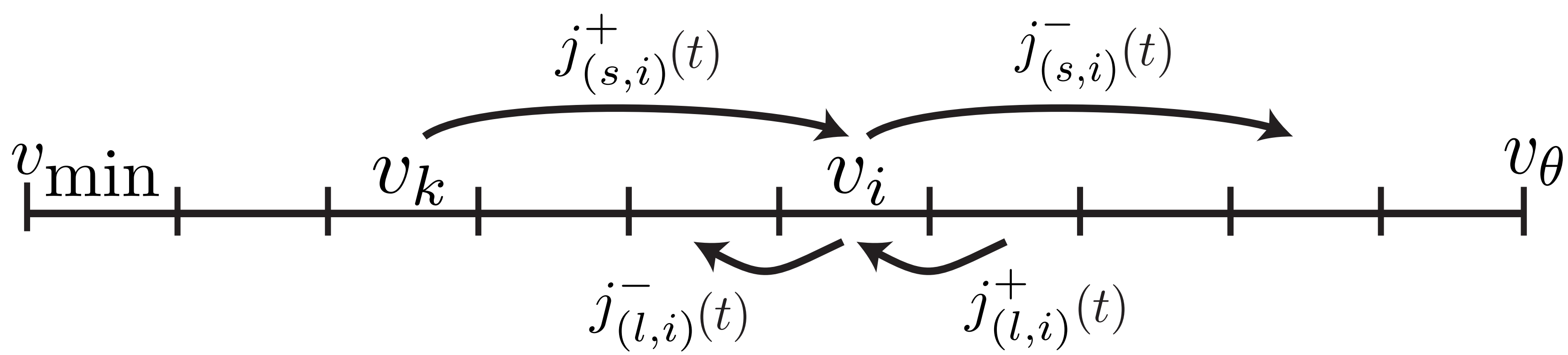


DiPDE: Summary

- Finite-volume method on the bounded interval
  - Assumes piecewise constant (over dt) recurrent drive
  - Evolve as a continuous time Markov chain



$$\frac{\partial p}{\partial t} = -\frac{\partial J}{\partial v} \Rightarrow \frac{\partial p_i}{\partial t} = -\frac{\Delta J_i}{\Delta v_i}$$

$$\begin{aligned}\Delta J_i &= f_{i+\frac{1}{2}} - f_{i-\frac{1}{2}} \\ &= (j^-_{(s,i)} - j^+_{(l,i)}) - (j^+_{(s,i)} - j^-_{(l,i)})\end{aligned}$$

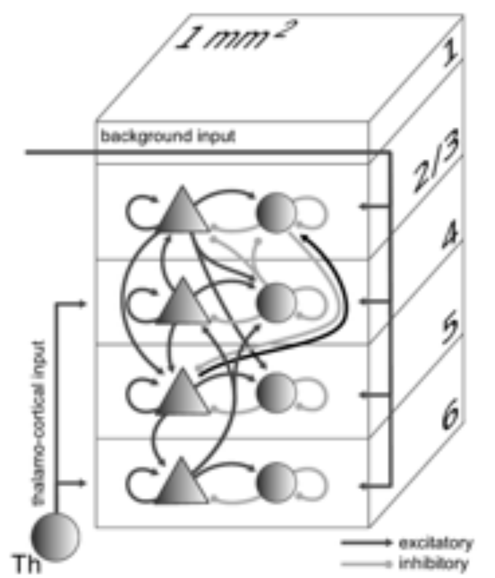
$$j^+_{(s,i)} = p_k \Delta v_k \lambda_{in}(t)$$

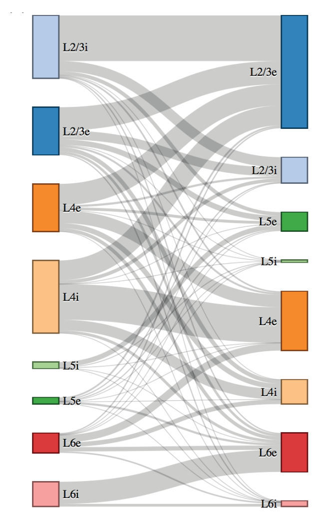
$$j^-_{(s,i)} = p_i \Delta v_i \lambda_{in}(t)$$

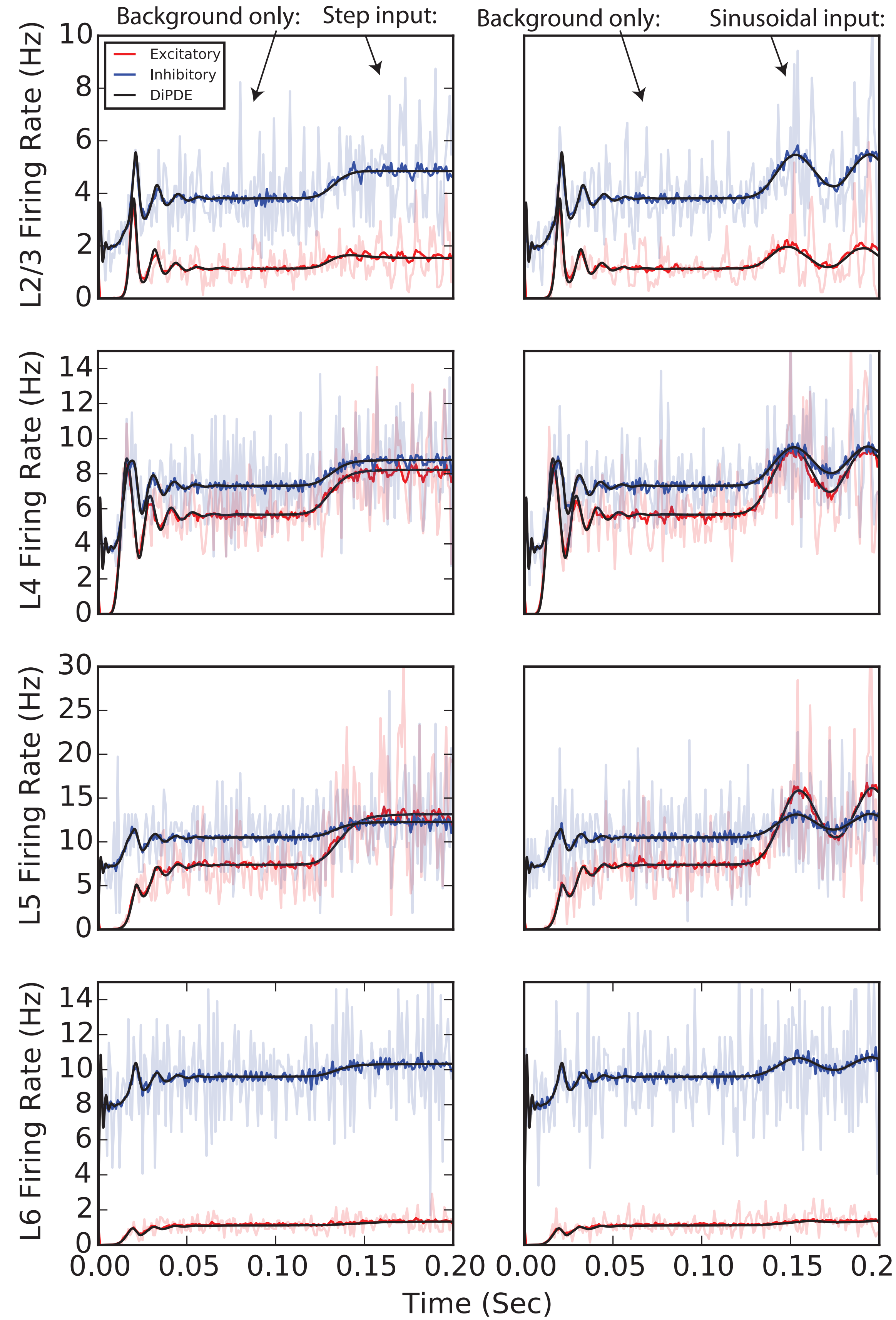
$$j^+_{(l,i)} = \frac{p_{i+1} v_{i+\frac{1}{2}}}{\tau}$$

$$j^-_{(l,i)} = \frac{p_i v_{i-\frac{1}{2}}}{\tau}$$

- DiPDE well-approximates a simplified cortical column
- Modified version of Potjans and Diesmann (2014)







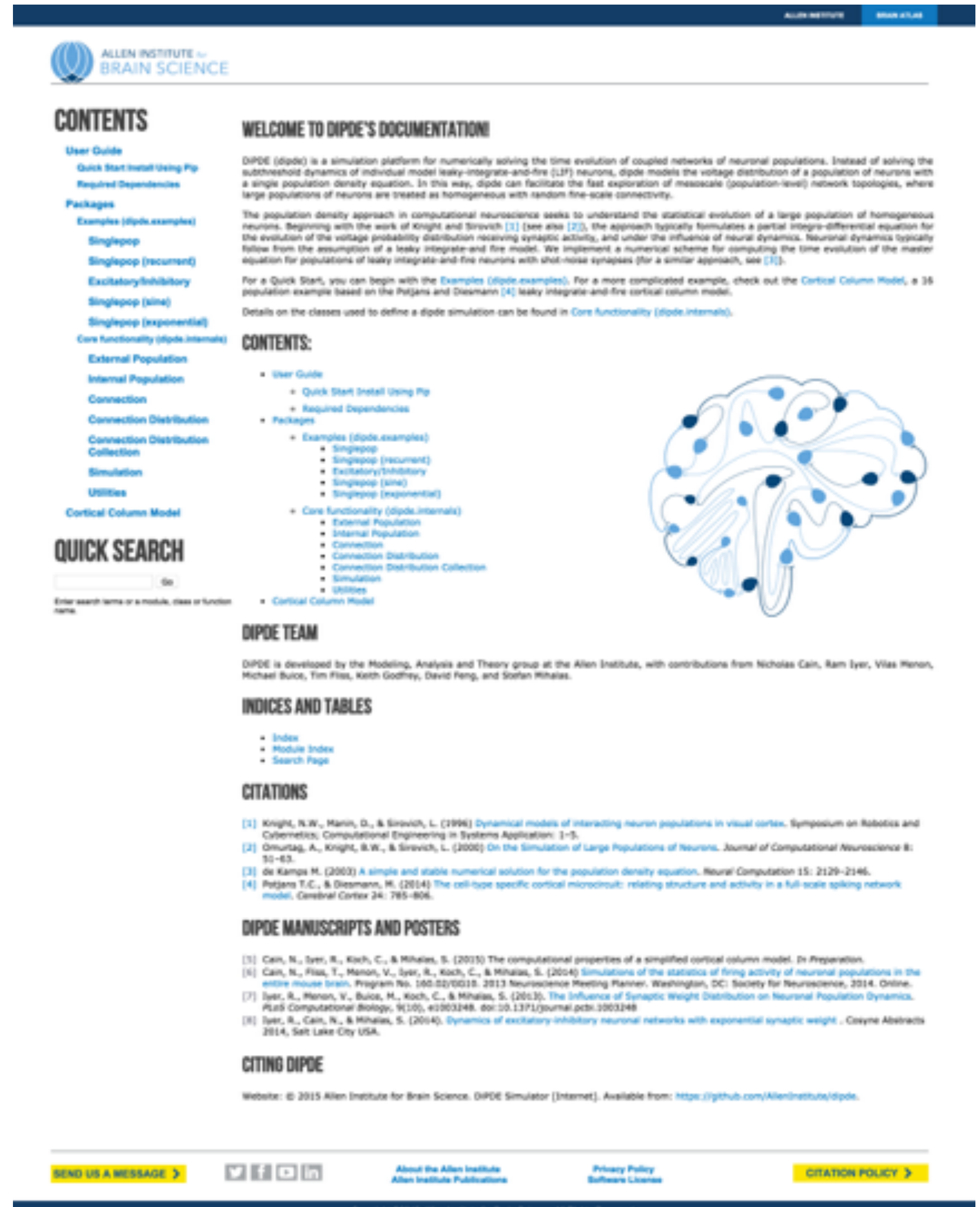
- Plotted: averaged results from 100 LIF simulations (NEST)
- ~30 second run-time

Current Release:

- Current release: 0.1.0
  - http://alleninstitute.github.io/dipde/
  - 100% code coverage on tests
  - Pure python; only need numpy/scipy/sympy
- Tutorial features 5 simple examples:
  - https://goo.gl/kZj2XN

Documented Features:

- Populations:
  - External: Strings, sympy-functions, python functions
  - Internal: Variable dv/dt/time-step accuracy
- Connections:
  - Synaptic weight distributions
  - Discrete transmission delay distributions
- Simulation: run/pause/continue



Example: singlepop.ipynb

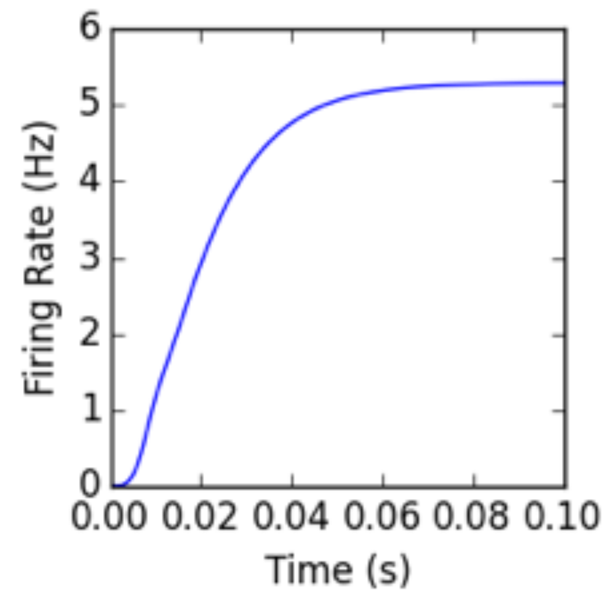
In [12]:
```python
import matplotlib.pyplot as plt
from dipde.internals.internalpopulation import InternalPopulation
from dipde.internals.externalpopulation import ExternalPopulation
from dipde.internals.simulation import Simulation
from dipde.internals.connection import Connection as Connection
%matplotlib inline
```

In [13]:
```python
# Settings:
t0 = 0.
dt = .0001
dv = .0001
tf = .1
tol = 1e-14
verbose = False
```

In [14]:
```python
# Create and run simulation:
b1 = ExternalPopulation('100', record=True)
i1 = InternalPopulation(v_min=0, v_max=.02, dv=dv, tol=tol)
b1_i1 = Connection(b1, i1, 1, weights=[.005], probs=[1.], delay=0.0)
simulation = Simulation([b1, i1], [b1_i1], verbose=verbose)
simulation.run()
```

In [15]:
```python
# Visualize:
i1 = simulation.population_list[1]
plt.figure(figsize=(3,3))
plt.plot(i1.t_record, i1.firing_rate_record)
plt.xlim([0,tf])
plt.ylim(ymin=0)
plt.xlabel('Time (s)')
plt.ylabel('Firing Rate (Hz)')
```

```python
class Simulation(object):

    def run(self):

        for p in self.population_list:
            p.initialize()

        for c in self.connection_list:
            c.initialize()

        while self.t < self.tf:
            self.t += self.dt

            for p in self.population_list:
                p.update()

            for c in self.connection_list:
                c.update()
```



Under Development:

- Next release: 0.2.0 (March 2016)
  - https://github.com/nicain/dipde_dev

Features: (completed, debugged, in-progress)

- Distributions of:
  - Synaptic weights
  - Transmission delays
  - Membrane time-constants
- Simple Serialization (JSON)
- Flexible Interface (extend populations)
- ZMQ server/client inputs/outputs
- Run/pause/marshal/unmarshal/continue
- Callbacks on critical functions
- Logging, profiling
- Adapter to NEST/Brian/PyNN
- Algorithmic improvements:
  - Sparse storage
  - (2x-10x) speed up
- Prototype distributed version
- NWB export interface

Code Example: Distributions

- In 0.2.0, the following are all equivalent ways of specifying a connection distribution:

```
c = Connection(source, target, 1, weights=.005)
c = Connection(source, target, 1, weights=(.005, 1.))
c = Connection(source, target, 1, weights=sps.rv_discrete(values=(.005, 1.)))

c = Connection(source, target, 1, weights=sps.expon(0,.005))
c = Connection(source, target, 1, weights=(sps.expon(0,.005), 201))
c = Connection(source, target, 1, weights={'distribution':'exponential', 'lambda':.005})
```

Code Example: Interface

- Basic interface to create (firing rate) populations

```python
class PopulationInterface(object):
    '''Abstract Base Class for source populations'''

    def initialize(self):
        '''Override with behavior that sets an initial value'''
        self.set_curr_firing_rate(None)

    def update(self):
        '''Override with behavior that gets called once per time step'''
        logger.debug('GID(%s) Firing rate: %s' % (self.gid, self.curr_firing_rate))

    def set_curr_firing_rate(self, curr_firing_rate):
        '''Call to make "curr_firing_rate" visible to other populations.
        Typically invoked once at initialization, and once in update'''
        self._curr_firing_rate = curr_firing_rate

    @property
    def t(self): return self.simulation.t

    @property
    def dt(self): return self.simulation.dt

    @property
    def gid(self): return self.simulation.gid_dict[self]

    @property
    def curr_firing_rate(self): return self._curr_firing_rate

    @property
    def source_connection_list(self): return [c for c in self.simulation.connection_list if c.target == self]

    @property
    def source_firing_rate_dict(self):
        return dict((c.source.gid,self.simulation.get_curr_firing_rate(c.source.gid)) for c in self.source_connection_list)
```

Code Example: ZMQ REQ/REP Servers

- Callable that can be used as the firing_rate arg of an ExternalPopulation

```
class RequestFiringRate(object):

    def __init__(self, port):

        self.port = port
        self.socket = context.socket(zmq.REQ)
        self.socket.connect("tcp://localhost:%s" % port)

    def __call__(self, t):
        self.socket.send('%s' % t)
        message = self.socket.recv_multipart()
        return float(message[0])

class ReplyFiringRateServer(object):

    def __init__(self, port, reply_function):
        self.port = port
        self.reply_function = reply_function
        self.socket = context.socket(zmq.REP)
        self.socket.bind("tcp://*:%s" % self.port)

    def run(self):

        while True:
            message = self.socket.recv()
            if message == 'SHUTDOWN':
                break
            requested_t = float(message)
            self.socket.send_multipart([b"%s" % self.reply_function(requested_t)])
        self.socket.send('DOWN')
```

Code Example: NEST Adapter

- Construct an analogous NEST simulation from a dipde simulation

```
def get_kernel(dt=.0001, tf=.1, seed=None, number_of_processors=2, verbose=True):
    if seed is None: seed = np.random.randint(1,100000)
    import nest as kernel
    kernel.ResetKernel()
    kernel.SetKernelStatus({"local_num_threads": number_of_processors})
    N_vp = kernel.GetKernelStatus(['total_num_virtual_procs'])[0]
    kernel.SetKernelStatus({'grng_seed' : seed+N_vp})
    kernel.SetKernelStatus({'rng_seeds' : range(seed+N_vp+1, seed+2*N_vp+1)})
    kernel.SetKernelStatus({"resolution": dt*1000, "print_time": verbose})
    return kernel


class PoissonPopulation(object):
    def __init__(self, name, firing_rate, number_of_neurons, kernel, start=0.):
        self.name = name
        self.firing_rate = firing_rate
        self.number_of_neurons = number_of_neurons
        self.gids = kernel.Create("poisson_generator", number_of_neurons, params={"rate": float(firing_rate),
                                                                                   'start':float(start)/.001})

class IAFPSCDeltaPopulation(object):
    def __init__(self, name, number_of_neurons, kernel, tau_refrac=0.):
        self.name = name
        if tau_refrac == 0.: tau_refrac = kernel.GetKernelStatus("resolution")/1000
        curr_neuron_params= {   "V_reset"   : 0.,               "tau_m"     : 10.,
                                "C_m"       : 250.,             "V_th"      : 15.,
                                "t_ref"     : tau_refrac*1000,  "V_m"       : 0.,
                                "E_L"       : 0.}
        self.gids = kernel.Create("iaf_psc_delta", number_of_neurons, params=curr_neuron_params)
```

Goals for This CodeJam:

1. Meet as many new people and technologies as I can
2. Have fun writing code with all of you
3. Get feedback on the technical approaches I am taking
4. Help anyone who is interested to learn more about dipde
5. Work in interfacing any/all AIBS code and data formats with community standards. (I do more than just dipde)
6. Work on model construction tools, and description formats/adapters
7. Interface dipde with any relevant visualization tools
8. Get help prioritizing features for the future dipde

THANKS!

THANK YOU

We wish to thank the Allen Institute for Brain Science founders,
Paul G. Allen and Jody Allen, for their vision, encouragement and support.

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