DiPDE: A simulator for population density modeling

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

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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

N = 1000 LIF neurons

![Neuron Index vs. Time](image1.png)

![Firing Rate vs. Time](image2.png)
Overview: DiPDE

- LIF Simulation
- Pop Statistics
- Fokker-Planck

DiPDE: Summary

\[
\frac{\partial p(v,t)}{\partial t} = \frac{\partial}{\partial v} (L(v)p(v,t)) - f(t)p(v,t) + f(t) \int_{w_1}^{w_2} p(v-w,t)q(w)H(\theta - v + w)dw + j(v,t)
\]

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

Leak:

Synaptic Activation:

Thresholding:
DiPDE: Summary

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

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

Leak:

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Leak:

Synaptic Activation:

Thresholding:
DiPDE: Summary

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

\[
\frac{\partial p}{\partial t} = - \frac{\partial J}{\partial v} \quad \frac{\partial p_i}{\partial t} = - \frac{\Delta J_i}{\Delta v_i}
\]

\[
\Delta J_i = f_{i+\frac{1}{2}} - f_{i-\frac{1}{2}} = (j_{(s,i)}^- - j_{(l,i)}^+) - (j_{(s,i)}^+ - j_{(l,i)}^-)
\]

\[
j_{(s,i)}^+ = p_k \Delta v_k \lambda_{in}(t)
\]

\[
j_{(s,i)}^- = p_i \Delta v_i \lambda_{in}(t)
\]

\[
j_{(l,i)}^+ = \frac{p_{i+1} v_{i+\frac{1}{2}}}{\tau}
\]

\[
j_{(l,i)}^- = \frac{p_i v_i - \frac{1}{2}}{\tau}
\]
• 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
  - 100% code coverage on tests
  - Pure python; only need numpy/scipy/sympy
- Tutorial features 5 simple examples:
  - [https://goo.gl/kZj2XN](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]:
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

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

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

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

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

```python
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

```python
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

```python
def get_kernel(dt=.0001, tf=.1, seed=None, number_of_processors=2, verbose=True):
    if seed is None: seed = np.random.randint(1,1000000)
    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
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