Project1 Documentation

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1 Model

Neurons are modeled as conductance-based leaky integrate-and-fire units. The membrane potential V_i^α of the i-th neuron ($i = 1, \cdots, N_\alpha$) from population $\alpha = E, I, X$ (excitatory, inhibitory and external population, respectively) evolves according to

$$C_m \frac{dV_i^\alpha}{dt} = -g_L(V_i^\alpha - V_L) + I_{i,syn}^\alpha(t) + I_{i,app}^\alpha(t), \text{ if } V_i^\alpha < V_{th} \tag{1.1}$$

When neurons reach the threshold V_{th}, a spike is emitted and they are reset to V_{rt} for an absolute refractory period τ_{ref}. The spike times t_i^α are recorded.

The synaptic currents received by a neuron are given by

$$I_{i,syn}^\alpha(t) = \sum_{\beta=1}^{P} I_i^{\alpha\beta}(t) \tag{1.2}$$

$$= \sum_{\beta=1}^{P} [-g_i^{\alpha\beta}(V_i^\alpha - V_{rev}^\beta)] \tag{1.3}$$

$$= \sum_{\beta=1}^{P} \{-[\sum_{j=1}^{N_\beta} a_{ij}^{\alpha\beta} g_{ij}^{\alpha\beta} s_{ij}^{\alpha\beta}(t)](V_i^\alpha - V_{rev}^\beta)\} \tag{1.4}$$

where V_{rev}^β is the reversal potential of the corresponding current $I_i^{\alpha\beta}$ induced by pre-synaptic population β and mathematically models the excitatory/inhibitory nature of it. $a_{ij}^{\alpha\beta}$ is a binary variable which determines the existence of synapse from the j-th neuron in population β to the i-th neuron in population α, while $g_{ij}^{\alpha\beta}$ reflects the (maximal) strength of the synaptic conductance. The gating variable $s_{ij}^{\alpha\beta}(t)$ models the instananeous value of synaptic conductance in terms of the fraction of open channels, described by

α	E	I
τ_r^α (ms)	1	1
τ_d^α (ms)	5	3
V_{rev}^α (mV)	0	-80
τ_{ref} (ms)	2	
C_m (nF)	0.25	
g_L (μS)	0.0167	
V_L (mV)	-70	
V_{rt} (mV)	-60	
θ (mV)	-50	

Table 1: Model constants

$$\frac{ds_{ij}^{\alpha\beta}}{dt} = -\frac{s_{ij}^{\alpha\beta}}{\tau_d^\beta} + \sum_{t_j^\beta} h^\beta(t - t_j^\beta - d_{ij}^{\alpha\beta})(1 - s_{ij}^{\alpha\beta}) \tag{1.5}$$

where h models the concentration time-course of the channel-opening neurotransmitters, arrived with a conduction delay $d_{ij}^{\alpha\beta}$ after the pre-synaptic spike time t_j^β. The $(1 - s_{ij}^{\alpha\beta})$ term introduces saturation effect. Following the simplification in [1], a rectangular pulse with unitary area is used for h

$$h(t) = \begin{cases} 1/\tau_r, & \text{if } 0 \le t \le \tau_r \\ 0, & \text{otherwise} \end{cases} \tag{1.6}$$

The default parameters are summarized in Table 1. All numerical values are in consistant units unless mentioned otherwise (ms for time, mV for voltage, nA for current, nF for capacitance and μS for conductance). Numerical integration is performed using Euler method with a time-step of 0.1 ms [2].

2 Input File Format

The input files are text files. The default input filename is "input_filename.ygin". The default synapse definition filename is "input_filename.ygin_syn". Non-default synapse definition file path and name can be specified by "SYNF001" command.

Input data format is as following.

```
> INIT001 # number of neurons in each population
        N1, N2, ...,

> INIT002 # time step length and total number of steps
        dt (ms), step_tot,
```

```
> INIT003 # random initial distributions for V
        p_fire_pop1 (range (0,1]), ..., p_fire_popN,

> INIT004 # external Gaussian currents
        pop_ind, mean (nA), std (nA),

> INIT005 # external Poissonian spikes
        pop_ind, type_ext, K_ext (μS), Num_ext,
        rate_1 (Hz), rate_2, ..., rate_step_tot

> INIT006 # chemical connection definition
        type, pop_ind_pre, pop_ind_post,
        I (row vector),
        J (row vector),
        K (row vector),
        D (row vector),

> SYNF001 # non-default synapse definition file name
        path/file_name,

> KILL001 # runaway killer setting
        runaway_steps, runaway_mean_num_ref (range (0,1]),

> PARA001 # non-default neuron population parameter
        pop_ind, number_of_parameters,
        parameter_name1, value1,
        parameter_name2, value2,
        ...

> PARA002 # non-default synapse parameter
        number_of_parameters,
        parameter_name1, value1,
        parameter_name2, value2,
        ...

> SAMP001 # neuronal data sampling
        pop_ind,
        data_type (logical vector),
        ind1, ind2, ..., indX, (sample neuron indices)
        # Note that data_type specifies sample data types
        # and it must correspond to
        # [V,I_leak,I_AMPA,I_GABA,I_NMDA,I_GJ,I_ext]

> SAMP002 # populational data sampling (V)
        pop_ind,
        1, 1, 0, 0, ..., (1-by-step_tot logical values)
```

3 Output File Format

The output files are text files. The default output filename is "input_filename-time_stamp.ygout". For data completeness, the corresponding input file will be attached to the output file. The output data format is as following.

```
> KILL002 # step at which runaway activity is killed
        step_killed,

> POPD001 # spike history of neuron population
        pop_ind,
        spike_neuron_ind (row vector),
        num_spikes_t (1-by-step_tot row vector),
        num_ref_t (1-by-step_tot row vector),

> POPD002 # neuron parameters in the population
        pop_ind, number_of_parameters,
        parameter_name1, value1,
        parameter_name2, value2,
        ...

> POPD003 # sampled populational data
        pop_ind, number_of_time_points,
        V_pop_t1 (row vector),
        V_pop_t2 (row vector),
        ...

> POPD004 # sampled neuronal data
        pop_ind, number_of_sample_neurons,
        data_name1, ..., data_nameX,
        data_1 (sample_size-by-step_tot matrix),
        data_2 (sample_size-by-step_tot matrix),
        ...
        data_X (sample_size-by-step_tot matrix),

> SYND001 # synaptic connection parameters
        number_of_parameters,
        parameter_name1, value1,
        parameter_name2, value2,
        ...
```

References

[1] Alain Destexhe, Zachary F Mainen, and Terrence J Sejnowski. An efficient method for computing synaptic conductances based on a kinetic model of receptor binding. *Neural Computation*, 6(1):14–18, 1994.

[2] Ashok Litwin-Kumar and Brent Doiron. Slow dynamics and high variability in balanced cortical networks with clustered connections. *Nature neuroscience*, 15(11):1498–1505, 2012.