

# Project1 Documentation

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## 1 Model

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

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

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

The synaptic currents received by a neuron are given by

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

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

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

where  $V_{rev}^\beta$  is the reversal potential of the corresponding current  $I_i^{\alpha\beta}$  induced by pre-synaptic population  $\beta$  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  $\beta$  to the  $i$ -th neuron in population  $\alpha$ , while  $g_{ij}^{\alpha\beta}$  reflects the (maximal) strength of the synaptic conductance. The gating variable  $s_{ij}^{\alpha\beta}(t)$  models the instantaneous value of synaptic conductance in terms of the fraction of open channels, described by

$\alpha$	E	I
$\tau_r^\alpha$ (ms)	1	1
$\tau_d^\alpha$ (ms)	5	3
$V_{rev}^\alpha$ (mV)	0	-80
$\tau_{ref}$ (ms)	2	
$C_m$ (nF)	0.25	
$g_L$ ( $\mu$ S)	0.0167	
$V_L$ (mV)	-70	
$V_{rt}$ (mV)	-60	
$\theta$ (mV)	-50	

Table 1: Model constants

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

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  $t_j^\beta$ . The  $(1 - s_{ij}^{\alpha\beta})$  term introduces saturation effect. Following the simplification in [1], a rectangular pulse with unitary area is used for  $h$

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

The default parameters are summarized in Table 1. All numerical values are in consistent units unless mentioned otherwise (ms for time, mV for voltage, nA for current, nF for capacitance and  $\mu$ S 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”. It is advised that synapse definitions always be given in a separate file. 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_1 (nA), mean_2, ..., mean_N, (for each neuron)
      std_1 (nA), std_2, ..., std_N,

> INIT005 # external Poissonian spikes
      pop_ind, type_ext, K_ext ( $\mu$ S), Num_ext, ia, ib,
      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),

> INIT007 # set perturbation (remove one spike)
      pop_ind, step_perturb,

> INIT008 # add short-term depression
      pop_ind_pre, pop_ind_post, STD_on_step,

> INIT009 # add inhibitory STDP
      pop_ind_pre, pop_ind_post, STDP_on_step,

> SYNFO01 # non-default synapse definition file name
      path/to/file_name (no comma!)

> KILL001 # runaway killer setting
      pop_ind, min_ms, runaway_Hz, Hz_ms,

> 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 # neuron data sampling
      pop_ind,
      data_type (logical vector),
      ind1, ind2, ..., indX, (sample neuron indices)

```

```

1, 1, 0, 0, ..., (1-by-step_tot logical values)
# 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 # synapse data sampling
pop_ind_pre, pop_ind_post, syn_type,
ind1, ind2, ..., indX, (post-synaptic sample neuron indices)
1, 1, 0, 0, ..., (1-by-step_tot logical values)

> SAMP003 # neuron population statistical data record
pop_ind,

> SAMP004 # synaptic currents statistical data record
pop_ind_pre, pop_ind_post, syn_type,

```

### 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 # neuron population statistical data
pop_ind,
V_mean_t1, V_mean_t2, ... (1-by-step_tot)
V_std_t1, V_std_t2, ... (1-by-step_tot)
I_input_mean_t1, I_input_mean_t2, ... (1-by-step_tot)
I_input_std_t1, I_input_std_t2, ... (1-by-step_tot)

> POPD004 # sampled neuron data
pop_ind, number_of_sample_neurons,
data_name1, ..., data_nameX,
data_1 (sampled_neurons-by-sampled_steps matrix),

```

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        data_2 (sampled_neurons-by-sampled_steps matrix),
        ...
        data_X (sampled_neurons-by-sampled_steps matrix),

> POPD005 # E-I ratio for each neuron
    pop_ind,
    EI_ratio_1, EI_ratio_2, ... (1-by-N),

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

> SYND002 # sampled synapse data
    pop_ind_pre, pop_ind_post, syn_type, number_of_sample_neurons,
    data (sampled_neurons-by-sampled_steps matrix),

> SYND003 # synapse statistical data
    pop_ind_pre, pop_ind_post, syn_type,
    I_mean_t1, I_mean_t2, ... (1-by-step_tot)
    I_std_t1, I_std_t2, ... (1-by-step_tot)

```

## 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.