

Guide to Using MATLAB Code from Njap, et. al., 2015

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The code for running mean-field systems and small scale networks is contained in the accompanying zip file. All functions need to be located in the same root folder as MFGRID-SIMULATOR.m. After opening MFGRIDSIMULATOR.m one arrives at the following screen

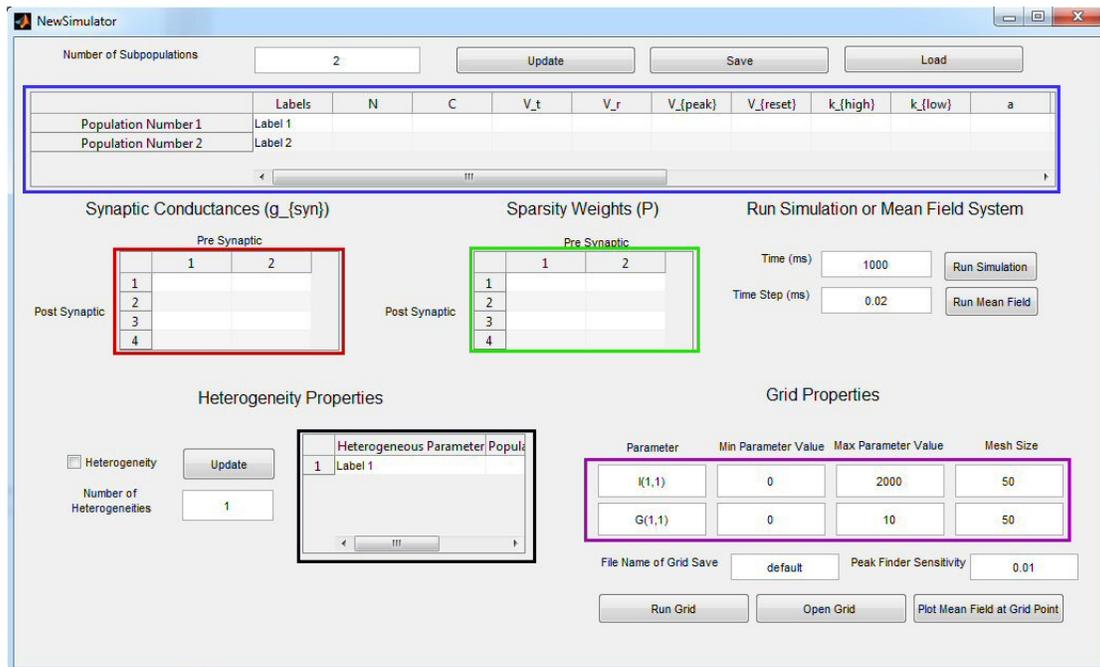


Figure 1: The initial GUI when one opens NewSimulator.m

The GUI contains various empty boxes, as shown in figure 1. These are options to customize the resulting network of Izhikevich neurons. Any parameter in the neurons (blue box) and specific connectivity parameters (red and green boxes) can be specified. Heterogeneity in the applied current can also be specified (black box). A parameter set can be saved with the save button, or loaded with load button. Grid simulations over the

mean-field system can be run with run grid (purple box), and visualized with open grid. Saved grid files can also be opened with the Load button.

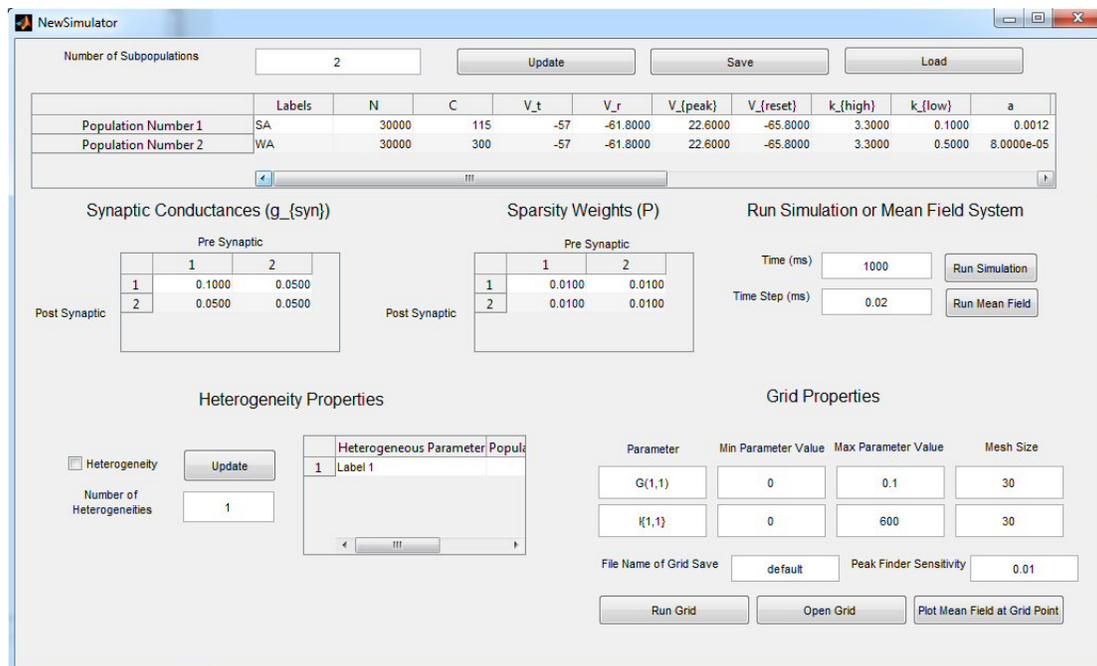


Figure 2: The GUI with a loaded parameter set.

Number of Subpopulations Determines the number of subpopulations of neurons in the network. Each subpopulation is specified by its own parameter set. Once a number of subpopulations is specified (there is no limit), pressing the update button will change all the tables to allow for parameter specification for each subpopulation

Parameter Table The parameter table (outlined in blue in 1 allows one to specify the parameters for the neurons in each population. The parameter labels that correspond to the parameters in Njap et. al., are shown in table 1. Note that the final column T_{syn} has no purpose as it was a parameter for a different synaptic model, but has to be filled with some dummy numerical quantity. One can fill this box with any numerical value without effecting the simulations as it has been removed from the numerics.

Synaptic Conductance This specifies the unitary synaptic conductance between each subpopulation and is located in the red box in figure 1. With m subpopulations, this is an $m \times m$ matrix where one can specify each unitary conductance, \bar{g}_{ij} for $i, j = 1, 2 \dots m$.

Synaptic Connectivity With m subpopulations, this is an $m \times m$ matrix P where $0 < P_{ij} < 1$ and determines the probability a neuron in population i is connected to a neuron in population j . This is located in the green box in figure 1.

Heterogeneity Clicking the heterogeneity box (the black box in figure 1) allows one

Njap et. al., Parameter Label	Software Label	Description
N	N	Network Size
C_m	C	Capacitance
v_t	vt	Threshold Potential
v_r	vr	Resting Membrane Potential
v_{peak}	vpeak	Peak Membrane Potential
c	vreset	Reset membrane Potential
k_{high}	khigh	High scaling factor
k_{low}	klow	Low scaling factor
a	a	Adaptation recovery time constant
b	b	Subthreshold coupling variable
d	d	Adaptation jump current
$I_{applied}$	I	Applied current
E_r	Er	Reversal Potential
$1/\tau_R$	alpha	Reciprocal of synaptic rise time
$1/\tau_D$	beta	Reciprocal of synaptic decay time
\bar{t}	tbar	Length of neurotransmitter release
$[T]$	Tmax	Concentration of neurotransmitter release

Table 1: Shown above are the parameters from Njap et. al., (First Column) in addition to their label in the software (second column) and their description (third column). To use a parameter in the parameter search, one uses the software label followed by the $(j, 1)$ where j specifies the population for the parameter. This is valid for all parameters except $I_{applied}$. To use $I_{applied}$, one has to use $I\{j, 1\}$ with curly brackets

to specify a number of heterogeneous current distributions. The heterogeneity is assumed to be normally distributed with mean $\langle I \rangle$ specified by the parameter value(s) I in the parameter box. The standard deviation is user specified in the heterogeneity box, in addition to the population index. One can specify how many currents are heterogeneous with the number of heterogeneities and subsequently pressing the adjacent update button. In this implementation, only the parameter I (the applied current) is allowable as a source of heterogeneity and thus the heterogeneous parameter label should always be set to I.

Time The total simulation time for the network of neurons and the mean-field system, in milliseconds.

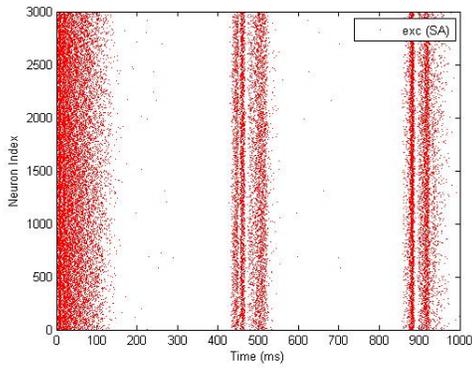
Time Step This is the time step used forward Euler integration of the network of Izhikevich neurons. It has no effect on the mean-field system as that is integrated with the ODE45 subfunction in matlab.

Run Simulation Run a network of neurons with all the specified parameters and plots the resulting output. We recommend not running large networks (> 5000 neurons) with this code. Simulations of larger, more densely coupled networks take longer to run. When one presses this button, the mean values of the synaptic s variables, the adaptation w variables, and a raster plot of spikes for the network is generated, as shown in Figure 3.

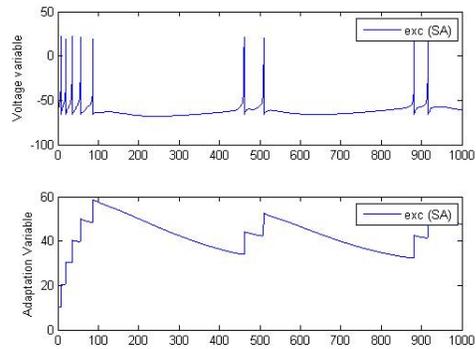
Run Mean-Field Runs the mean-field system with the specified parameter sets, and plots the resulting output

Grid Properties Used to run a two-parameter grid in mean-field simulations. This is located in the purple box in figure 1. The parameters are specified in the Parameter column and are taken to be the labels in the table of parameters (see Table 1) in addition to a cell specifier ($\{, \}$ for the I parameter) or a matrix specifier ($(, .)$ for other parameters). For parameters that require two indices, such as the synaptic conductances or connectivities the first index is the post-synaptic network and the second index is the presynaptic network. For parameters of a single population, such as the capacitance or voltage threshold of the k th population, the correct indexing is $(k, 1)$ (or $\{k, 1\}$ for the I parameter(s)). The button run grid runs the grid with the specified parameters, and saves the grid with the file name default (which can be changed by the user). For example, hitting the run grid button in 2 will run a uniform 30×30 grid in $G(1, 1)$ and $I1, 1$, which is the maximal conductance coupling population 1 to itself and the applied current to population 1, over the range $[0, 0.1] \times [0, 600]$.

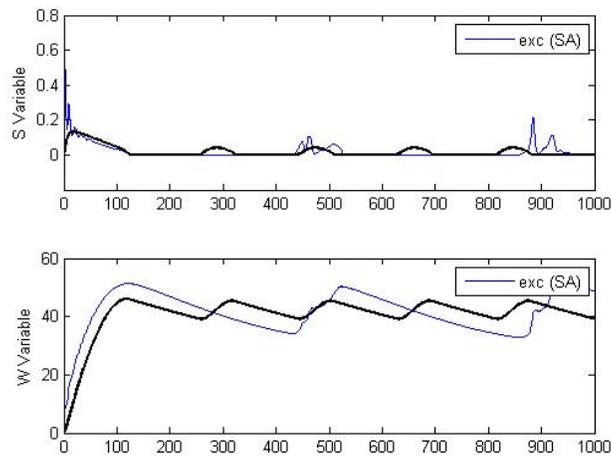
Open Grid Pressing this button opens a saved grid file, and plots the two-parameter bursting frequency diagram. The diagram is computed by using the peakfinder algorithm to find successive burst peaks in the macroscopic variable $\langle w \rangle$ in the mean-field simulations. The reciprocal of the peak to peak interval is used to compute the burst frequency. A minimum of four peaks are required to remove transients. Peakfinder can be found in the mathworks file exchange here and is written by Nathanael Yoder. The sensitivity of peak finder can be controlled by the peak-finder sensitivity parameter. Larger values make it less sensitive to the peaks which aids in filtering out noise caused by numerical errors in the integration process for the mean-field system. See figure 4 for an example two-parameter



(a) Example two-parameter bifurcation diagram



(b) Example mean-field trajectory for $\langle W \rangle$

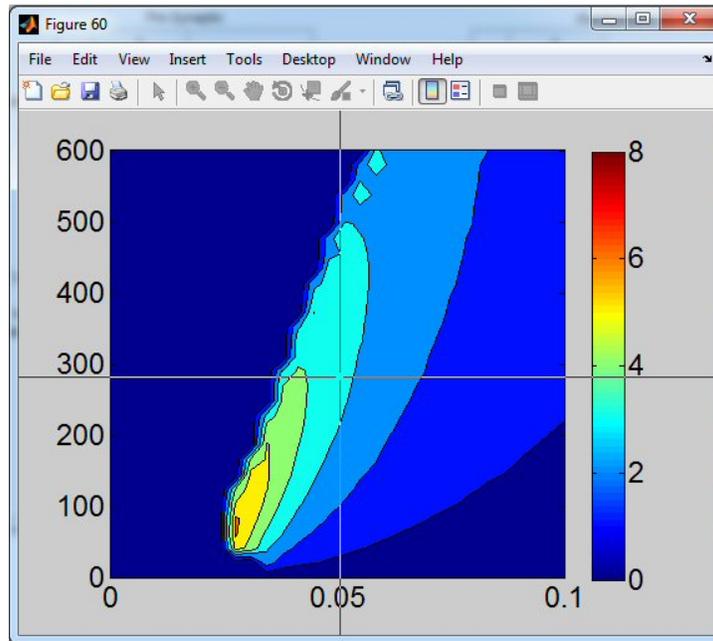


(c) Example mean-field trajectory for $\langle W \rangle$

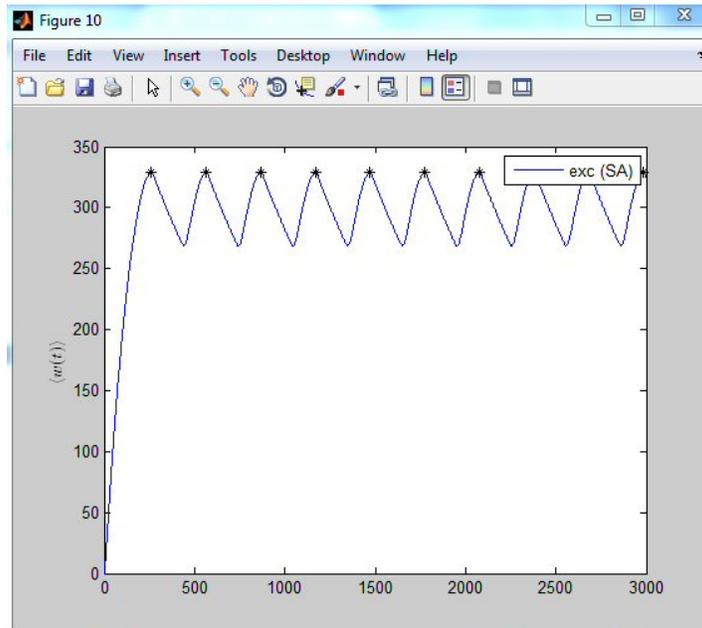
Figure 3: When the run simulation button is pressed, the network of neurons with specified parameters is simulated with a forward Euler integration scheme. The resulting output is the rasterplot in 3(a), a sample trajectory for a neuron in the network in 3(b), a plot of the mean adaptation and synaptic connectivity variables in 3(c). Pressing the run mean-field button also plots the mean-field simulations in the same plot as the moments in 3(c).

bifurcation diagram plotted in the window

Plot Mean Field at Grid Point After opening a particular grid file with open grid, one can use the plot mean field at grid point to plot a particular mean-field simulation. Hitting this button and clicking on the two-parameter bifurcation diagram creates a reticule on this bifurcation diagram. Moving the crosshair over the diagram and subsequently clicking a point opens the mean-field simulation for the grid point nearest to the point that was clicked. This can be done as many times as one wishes, and can be stopped by hitting the Enter/Return button on your keyboard twice. This is used as a spot-check of peak-finders accuracy in determining the burst frequencies. See figure 4 for an example of using the two-parameter bifurcation/burst frequency diagram



(a) Example two-parameter bifurcation diagram



(b) Example mean-field trajectory for $\langle W \rangle$

Figure 4: Once a grid file is selected after pressing open grid, a two-parameter burst frequency diagram is plotted as shown in Figure 4(a). The colours correspond to the bursting frequency in Hz. Pressing the plot mean field at grid point button and clicking on the burst frequency diagram creates a crosshair. The crosshair can be moved and clicked again to display the $\langle W \rangle$ variable for the nearest grid point, as shown in figure 4(b). The asterisks in figure 4(b) denote the peak times as determined by peak-finder. Average peak-to-peak intervals are used to compute the burst frequencies after removal of transients and edge effects