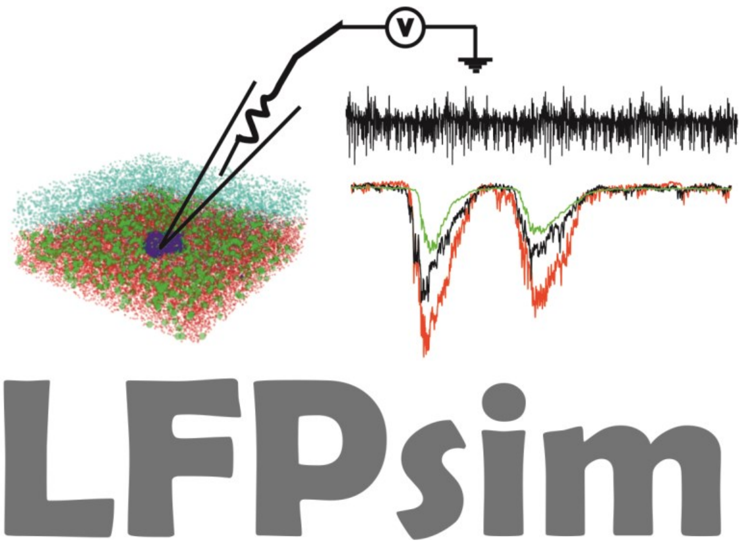

Reconstructing single neuron electric field and population of neurons LFP using LFPsim

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1 LFP NEURON tool

LFP simulation tool is a plug-in for NEURON simulation environment to reconstruct LFP from biophysical models of neurons and networks. LFP simulation tool uses NEURON's inherent extracellular mechanism to calculate total ionic currents from neuronal compartments at each time step (dt). The extracellular potential at a given point (x,y,z) was calculated by setting pointers to lfp.mod and for multiple recording points mea.mod. Point Source Approximation (PSA), Line Source Approximation (LSA) and Simple RC filter techniques were effectively implemented in the tool to calculate extracellular potential of a single cell and LFP of network models.

1.1 Getting familiar with tool Interface

LFP simulation tool interface was created using NEURON's in-build graphics components. Interface mainly consisted of Morphology view window (A), Voltage changes view window (B), Reconstructed LFP view panel (C), Electrode parameters (D), extracellular medium properties set panel (D).

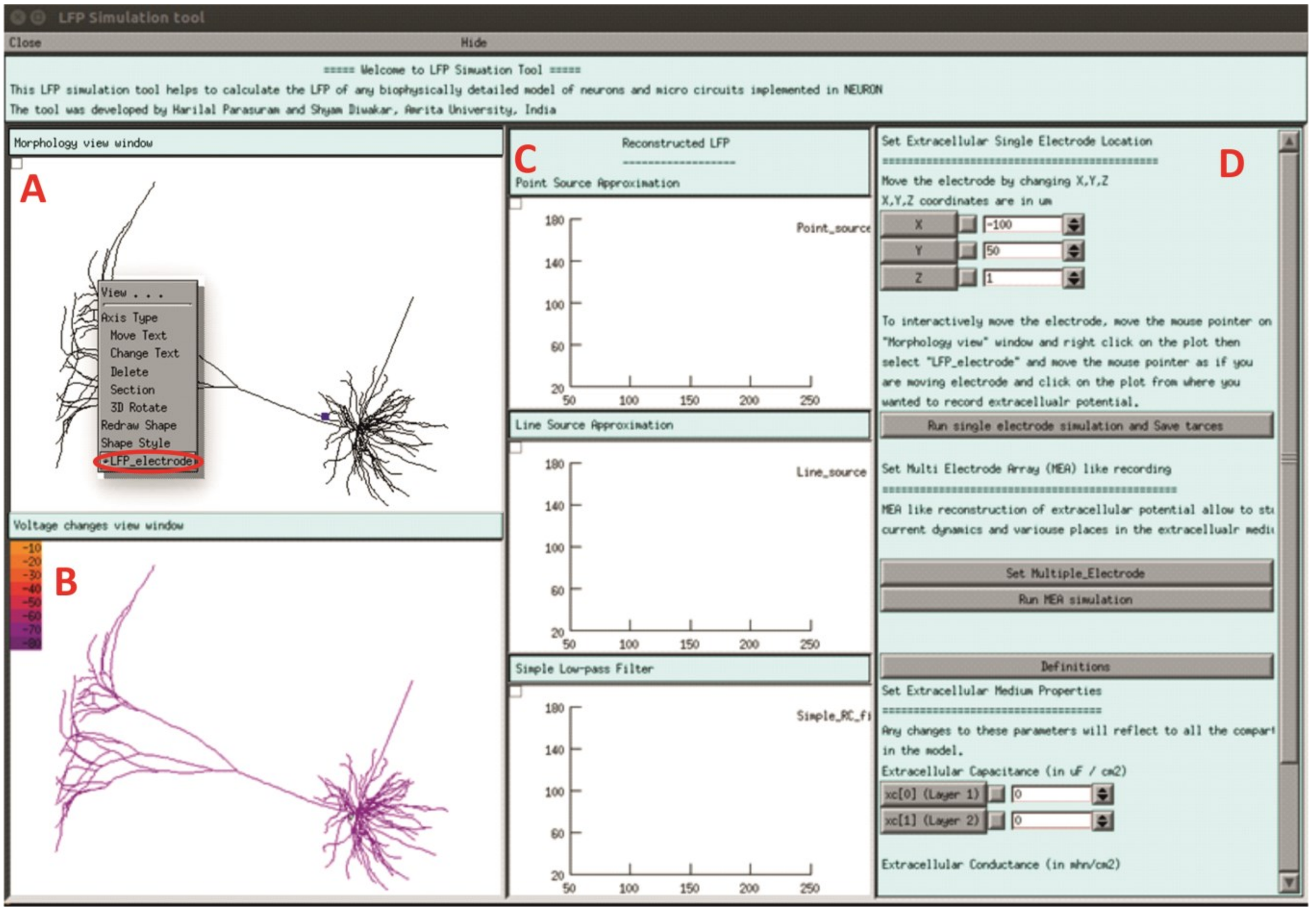


Figure 1. LFP simulation tool interface. A, ***Morphology view window*** is basically NEURON's shape plot which helps to visualize neuron morphology and extracellular electrode location (shown in blue). Right click of mouse on this window give user to interactively select LFP electrode location by selecting "LFP_electrode" menu (red circled). Right click of mouse on this window will also give couple of option to user including view the model at different angles. B, ***Voltage changes view window*** is basically NEURON's space plot which helps to visualize voltages changes across the neuron during the activity. Voltage range from -70 mV to +40 mV was defined as colormap. C, ***Reconstructed LFP view panel***, allow user to view the reconstructed LFP in three different method. D, ***Simulation controls***, which includes controls for setting electrode parameters, extracellular medium properties and running simulation.

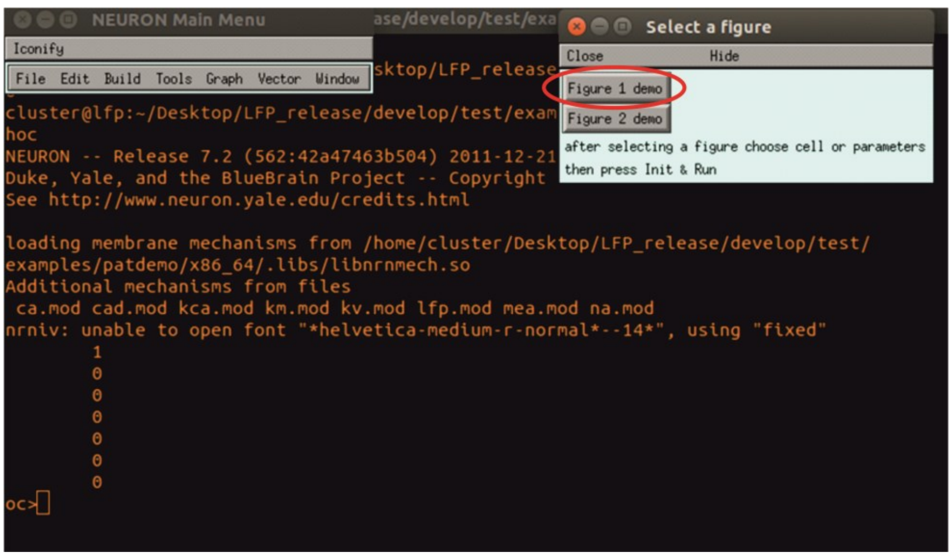
1.2 Reconstructing LFP of detailed neuron models

How to execute the tool and stepwise procedure including detailed explanations and screenshots give below. Please visit NEURON's website if you need any help for installing the simulation environment.

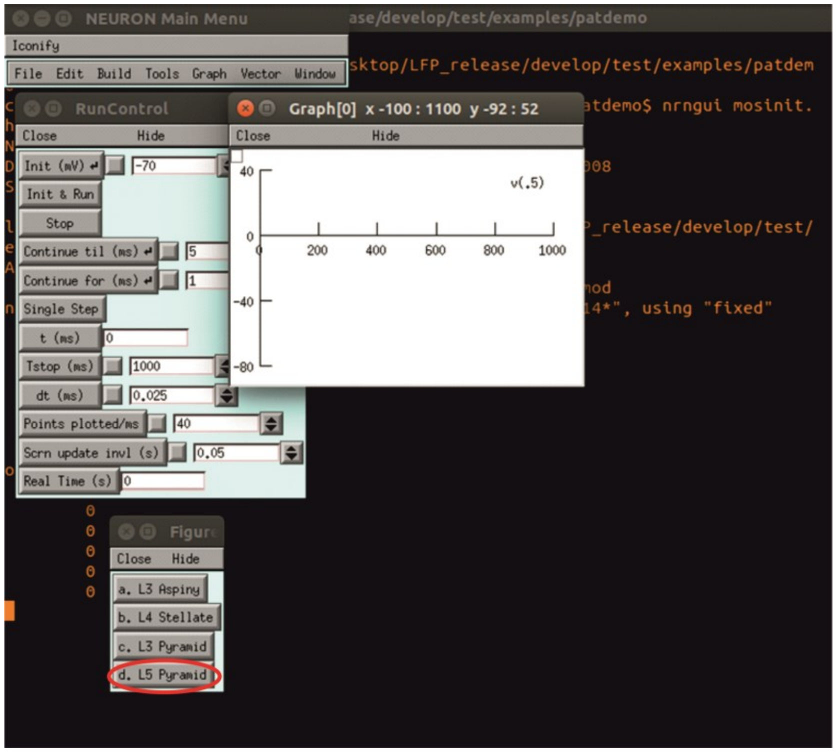
Follow steps from 1 to 14 to run single electrode LFP simulation.

1. Download the LFP simulation tool source code and biophysical model of neuron/network of your interest from ModelDB. LFP tool can be downloaded from: https://senselab.med.yale.edu/ModelDB/ShowModel.cshtml?model=190140 In this example, Pyramidal Neuron models (Deep, Superficial, Aspiny, Stellate) published by (Mainen and Sejnowski 1996) was used, Accession ID: 2488.

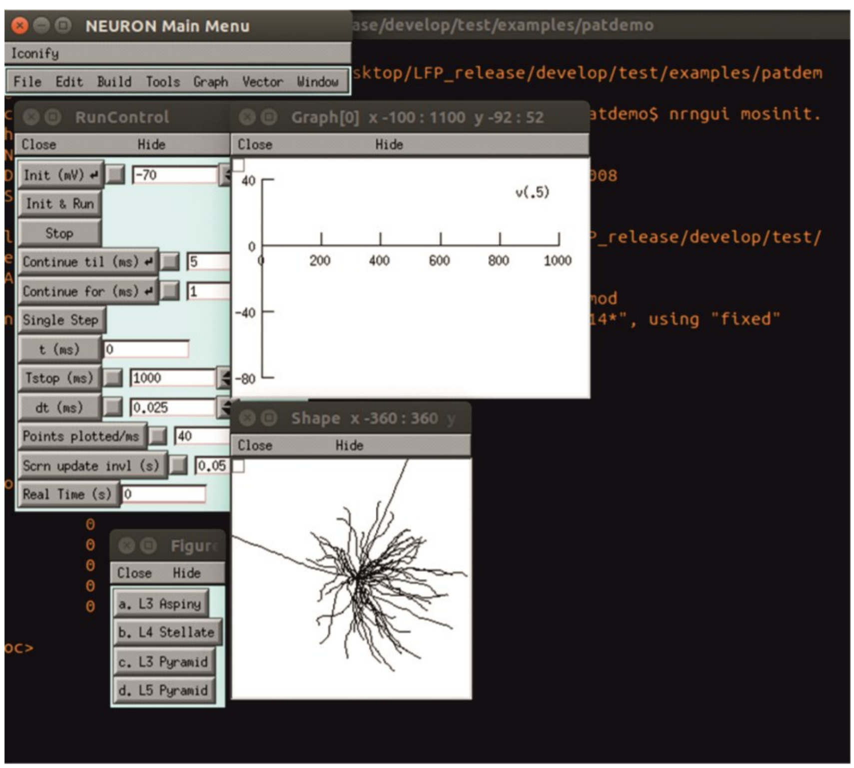
2. Unzip or extract the LFP tool and model neuron/network.
3. Copy and paste all files and folder in the LFP tool folder to neuron/network model folder. Please note, lfp.mod and mea.mod should be placed along with model's mechanism (mod) files.
4. Please follow the model's "readme file" if there is any specific procedure for compiling the model in NEURON.
5. For Linux/Unix user, open a terminal and change present working directory to the neuron model folder, then run *nrnivmodl* to compile the model. If you have already compiled the model, then you may have to re-compile after you copy lfp.mod and mea.mod files to the model directory.
6. For Windows users, double click on "mknrndll" and set the path for where ".mod" files were placed in the model and click on "nrnmech.dll" button for compiling the mechanism files.
7. Please follow model's "read me file" to load the neuron model in NEURON. Here, in this example mosinit.hoc file was used to load neuron models. In terminal, type "nrngui mosinit.hoc" to load the model in Linux. For Windows users, just double click on mosinit.hoc file in the model. If the model is successfully loaded, you can see two NEURON window pop up as showed in the below screenshot. As specified in the neuron model"read me file", click on "Figure 1 demo" button to load the neuron.



Then click on "L5 Pyramid" button to load the neuron.



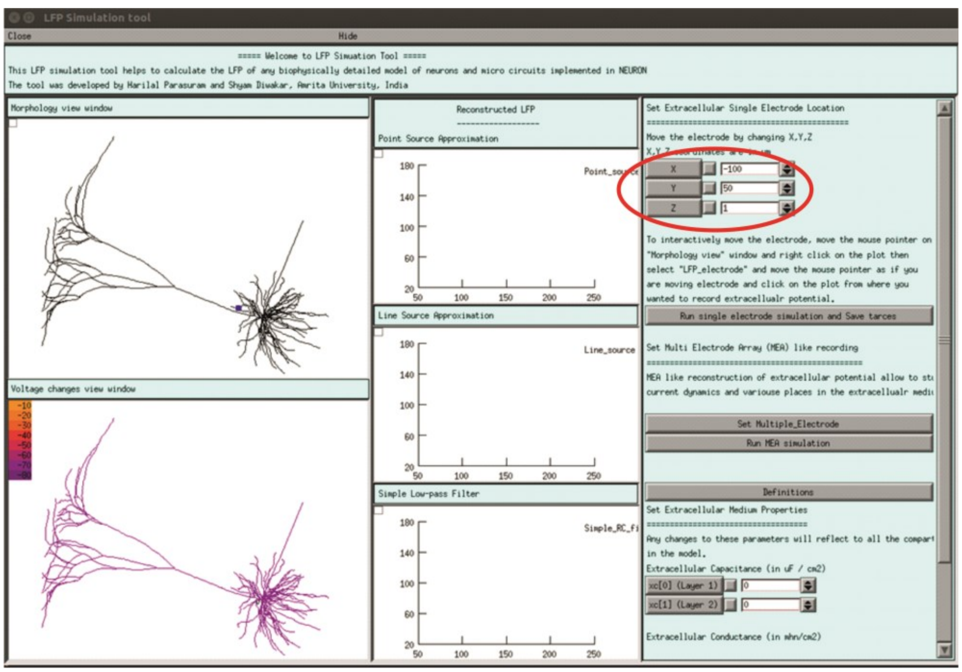
Once the neuron is loaded you can see a shape plot with the neuron created as showed in below screen shot.



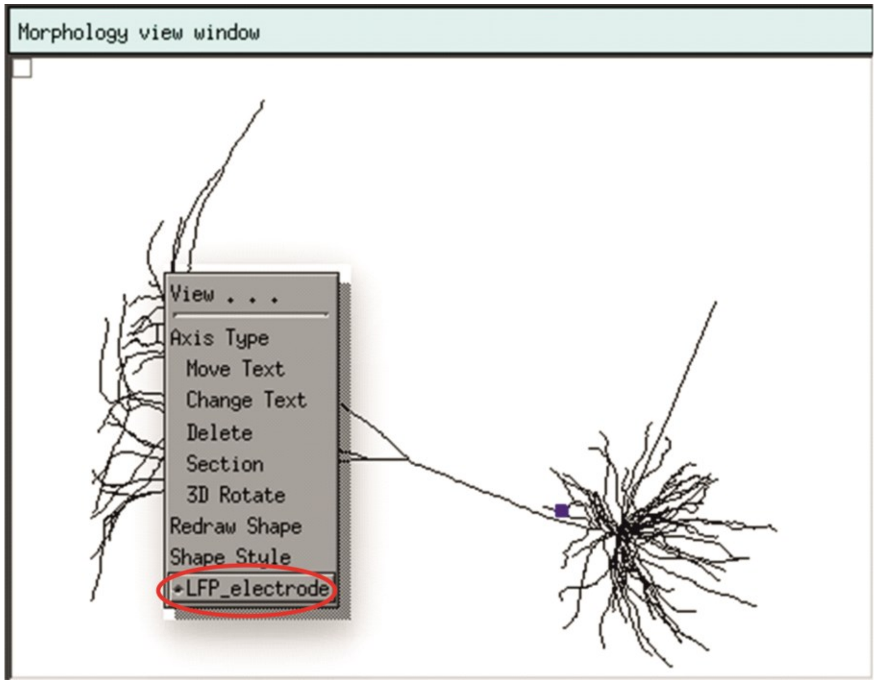
8. After loading the model into NEURON, call "extracellular_electrode.hoc" from NEURON's "oc>" terminal by typing *xopen("extracellular_electrode.hoc")* to load the LFP simulation tool in NEURON.

```
cluster@lfp:~/Desktop/LFP_release/develop/test/examples/patdemo$ nrngui mosinit.
hoc
NEURON -- Release 7.2 (562:42a47463b504) 2011-12-21
Duke, Yale, and the BlueBrain Project -- Copyright 1984-2008
See http://www.neuron.yale.edu/credits.html

loading membrane mechanisms from /home/cluster/Desktop/LFP_release/develop/test/
examples/patdemo/x86_64/.libs/libnrnmech.so
Additional mechanisms from files
 ca.mod cad.mod kca.mod km.mod kv.mod lfp.mod mea.mod na.mod
nrniv: unable to open font "*helvetica-medium-r-normal*--14*", using "fixed"
        1
        0
        0
        0
        0
        0
        0
oc>     1
        0
        0
        0
        0
        0
        0

oc>xopen("extracellular_electrode.hoc")
```

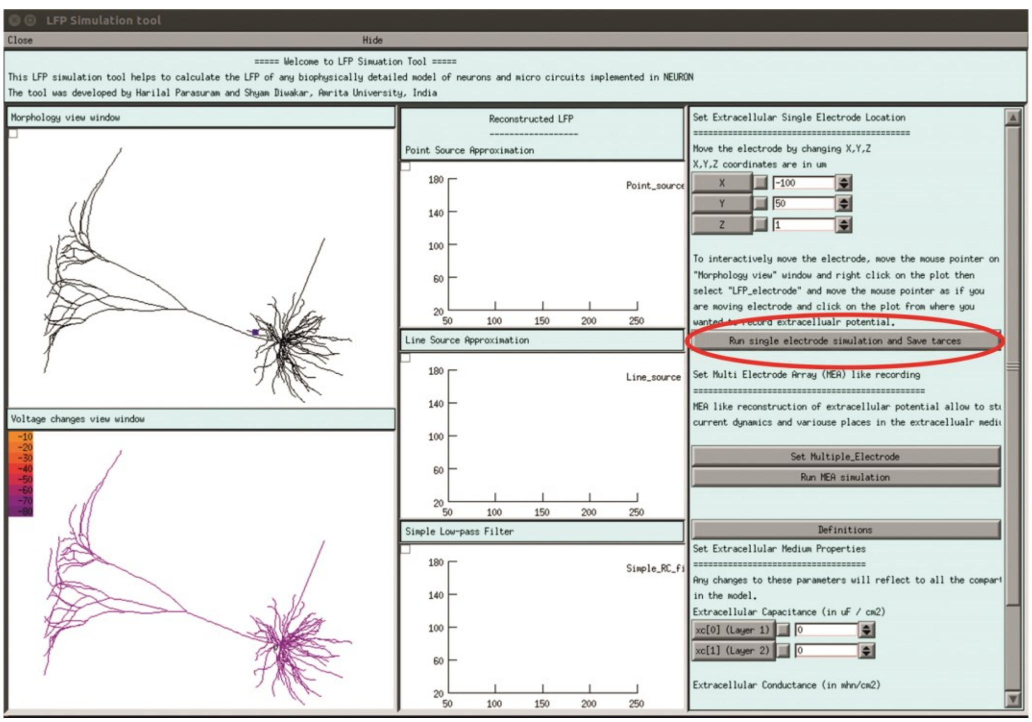
9. If everything went well you can see LFP tool interface on your screen as shown below.

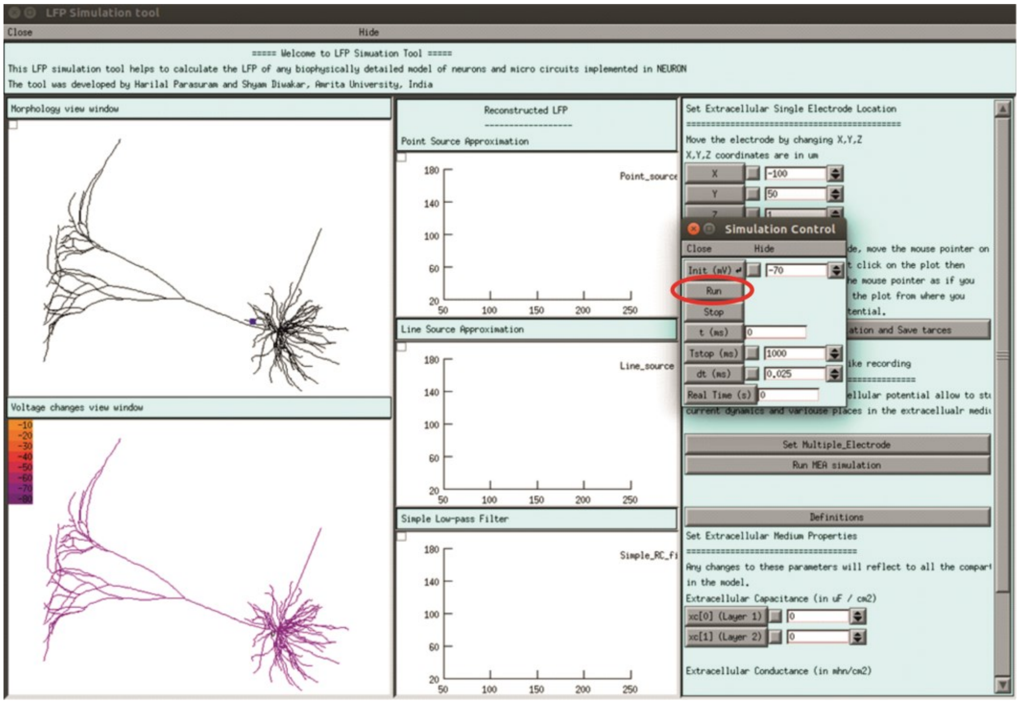


10. Set the stimuli to neuron as per the model.
11. The user can set single electrode location both manually and interactively (see figure 1D of the article). To set manually, the user need to give values for x,y,z of electrode location in panel D (see figure 1 of the article). To interactively change the electrode position, move the mouse pointer on "Morphology view" window and right click on the plot, then select "LFP_electrode" and move mouse pointer as if you are moving electrode and click on the plot from where you wanted to record the extracellular potential.

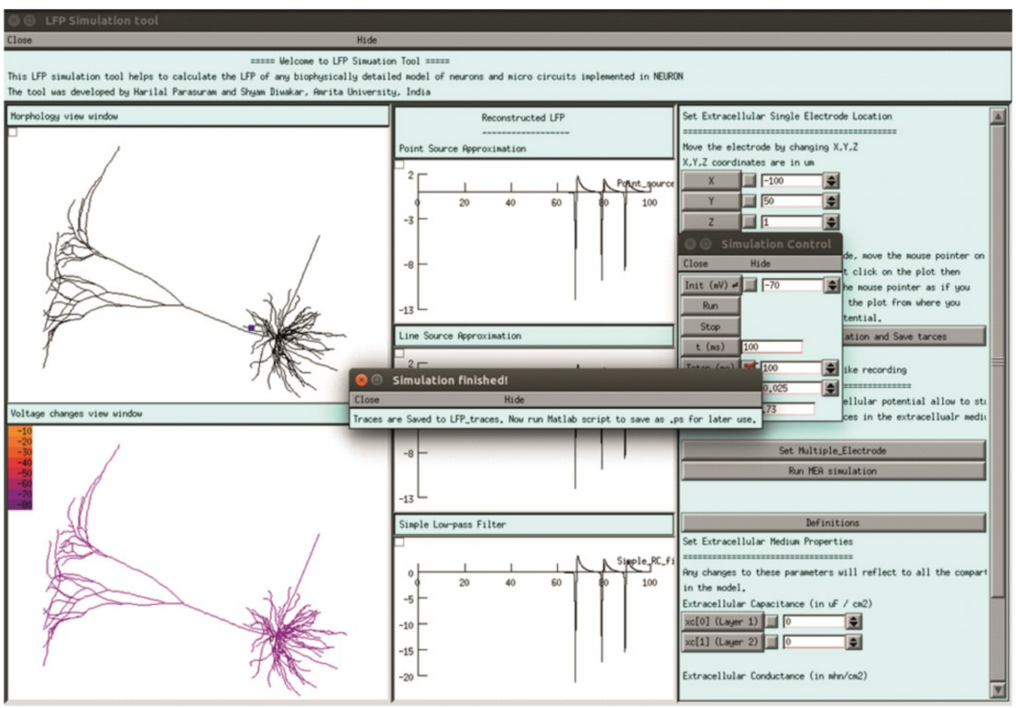


12. Now run single LFP electrode simulation by clicking on “Run single electrode simulation and save trace” button.



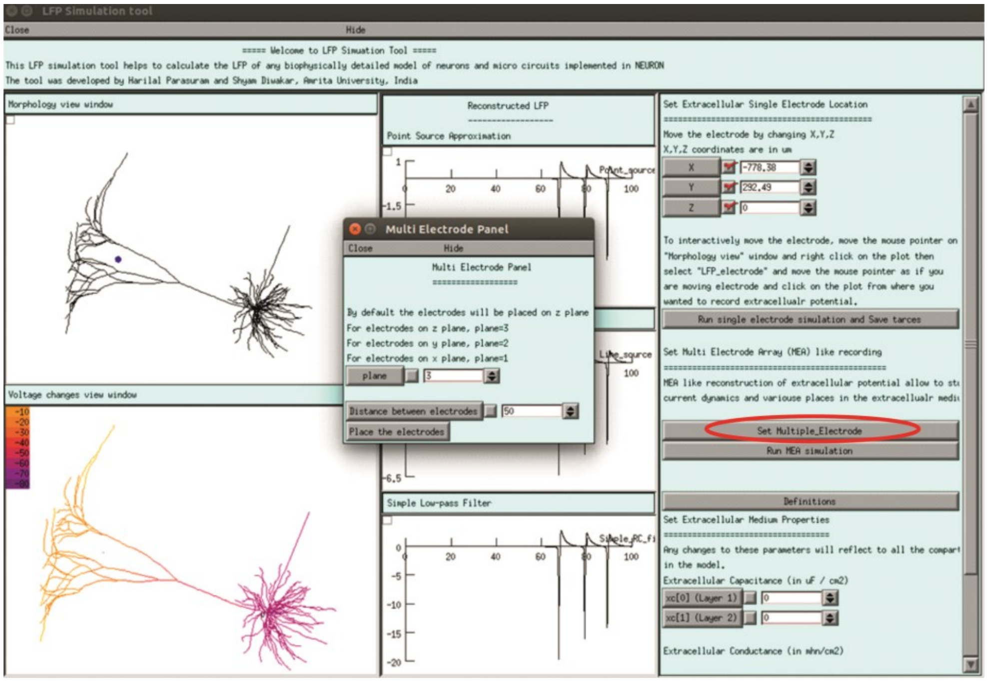


13. Once the simulation is finished, a panel will pop up with a text saying the simulation completed and the traces are saved to "LFP_traces". A sample screenshot is given below.

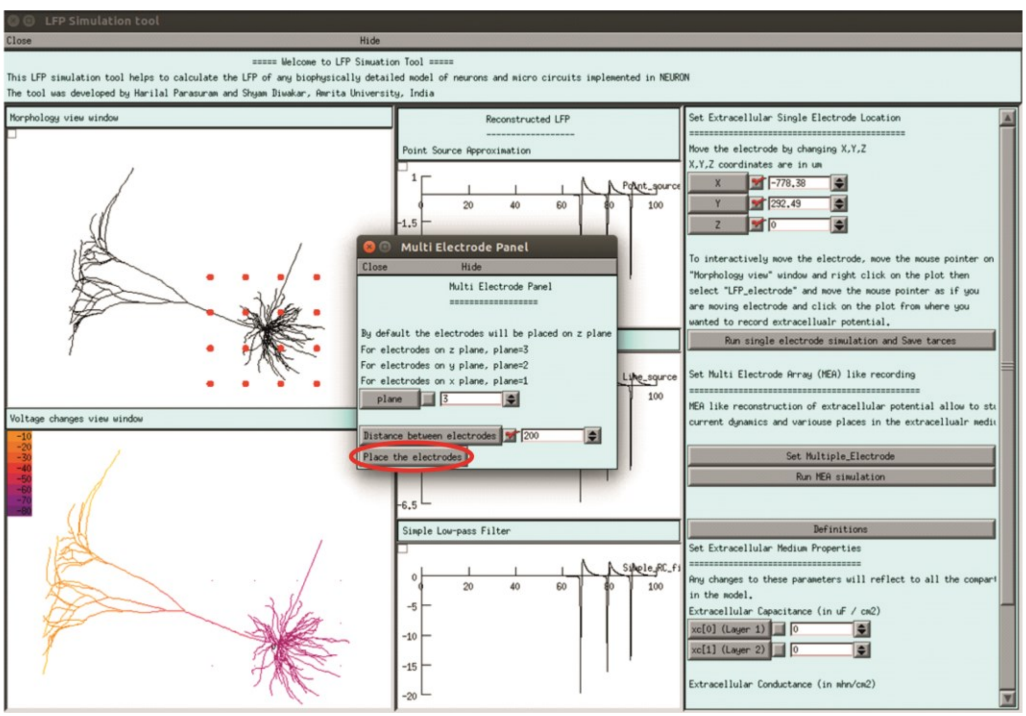


14. Saved traces can be latter used to make plots of your choice in Matlab or Python, sample scripts were given in the "LFP_traces" folder.

15. **For Multiple electrode simulation, Please follow steps upto 10, then** Click on "Set Multiple_Electrode" button in simulation control window (see figure1D of the article), which popup a panel for setting multi electrode locations as shown in the below screenshot.

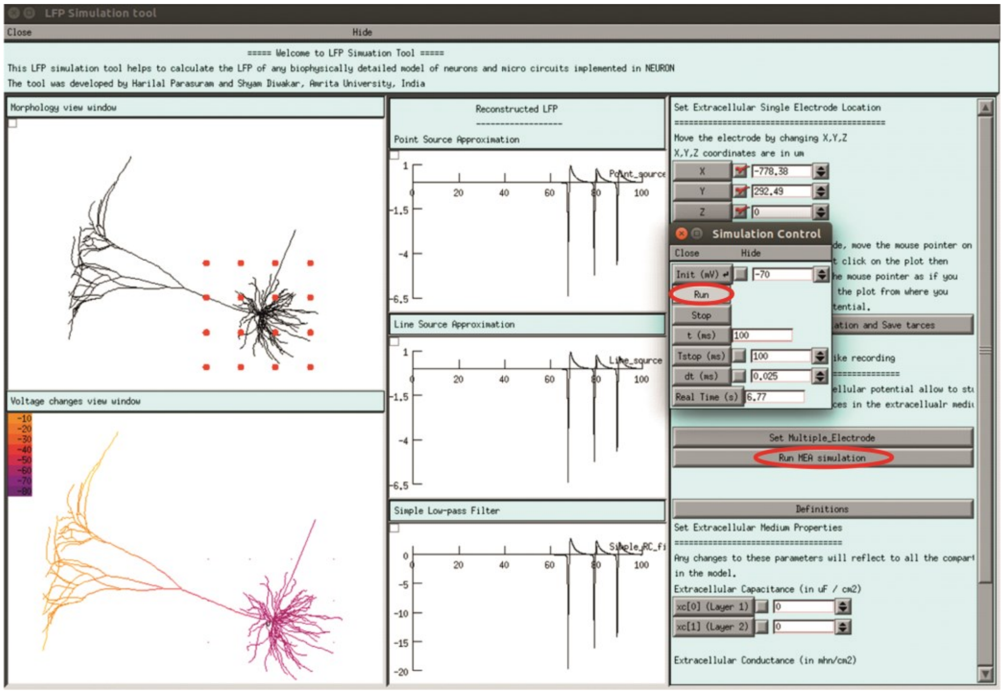


User can change distance between the virtual electrodes (here as an example we set it to 200um). To place the electrode, please click on "Place the electrode" button. User can see multiple virtual electrodes as red dots in Morphology view window as shown in below screenshot.



User also can shift the electrodes to different plane by changing the values for plane variable in the panel according to the need.

16. After placing the MEA electrodes user can run the MEA simulation by clicking on "Run MEA simulation" button. Sample screen short given below.



17. Once the simulation is finished, a panel will pop up with a text saying the "simulation completed" and the mea traces are saved to LFP_traces folder as shown below. Saved traces can be used to make plots of choice in Matlab or Python.