

- The model Dominic is proposing is to correlate pattern of stimuli, e.g., different informational inputs to changes in neural plasticity. He designs a microfluidic chamber with 5 compartments: 3 compartments containing rat cortical neurons, injected with ChR2 opsin, are triggered optically and are connected to a central well. This well contains primary rat cortical neurons which are loaded with a Rhod-2 Calcium indicator to detect synapse activities. A last isolated compartment contains a hippocampal brain slice and is only connected to the central compartment, its main purpose is to act as a terminal neural pathway. The initiator neurons (compartment 1, 2, and 3) are injected with AAV2-ChR2V to be excited with light at different frequencies: constant, random and increasing-decreasing pulses.
- Dominic's intention is to show the connection between potential for information and neural plasticity with a focus on synapse activity. Therefore, we keep the design of the microfluidic chambers of the initial model. It has been observed that active network of neurons as it grows, produces, action potentials concomitantly with increases in the number of synapses. The overall pattern of firing gradually evolves during the formation of these networks with initially isolated action potential to localized train of spikes or bursts. If the nature of the stimuli has an impact of neuroplasticity, we will be able to measure it by characterizing the action potentials (spikes) or bursts detected in the central chamber in connection with the nature (constant, random, monotonically increasing-decreasing) pulses of the activation lights and the amount of information that can be transmitted from one chamber to the opposite chamber.
- To avoid phosphorescence inference and have a fine independent optical control of the 3 populations of neurons in each "AP originator" compartments, we will use three different excitatory (depolarizing) opsins actuators: the fast temporal kinetics blue light-sensitive ChETA with a peak response 490 nm, one red-shifted opsin Chrimson (peak response of 590 nm) and Chronos (peak response of 500 nm), a blue light-and green light-sensitive. They will be delivered using an AAV Vector. Note that this combination allows to have 3 different ranges of light activation of neuronal spiking without detectable crosstalk in mouse brain neurons. The probes will be excited sequentially and we may need to use different lasers.
- Calcium indicator like Rho-2 may not be the most appropriate indicator for this model for which we seek to target specific subpopulations of neurons, to measure spiking dynamics and subthreshold voltage fluctuations. Furthermore, genetically voltage indicators (GEVIs) can detect neuronal depolarization and hyperpolarization when  $\text{Ca}^{2+}$  does not decrease below cytosolic concentration. Genetically encoded  $\text{Ca}^{2+}$  indicators Ace-mScarlet is a red fluorescent GEVI that fuses Ace2N voltage sensitive inhibitory rhodopsin with mScarlet, a bright red fluorescent protein. With paired with the appropriate optics, it can report voltage from dozens of neurons and capable of readouts of single action potentials firing at frequencies as high as 100 Hz. Upon depolarization, this electrochromic (eFRET), Ace2N, acts as a FRET acceptor, quenching a proportion of mScarlet's emitted photons via FRET. The peak fluorescence response of Ace-mScarlet decreases nearly as a function of membrane voltage. So, we will replace Rho-2 by the Ace-mScarlet indicator in the central chamber.
- In addition, studies have shown that the Ace-mScarlet probe responds to single action potentials with high SNR in fluorescence in cultured hippocampal rat neurons. So, we will use in chamber 4 and 5, hippocampal rat neurons.
- We will drive action potentials in the Ace-mScarlet neurons using 1 ms pulses of 450 nm light. As the excitatory pulse frequency changes in compartment 1,2 and 3, neurons may form new synapses and update the communication strength of existing synapses which in turn should increase the fluorescence response when subsequently the Ace-mScarlet probe is activated in chamber 4 with the excitation light.
- As suggested in previous experiments, we will test variable fluorescence levels to avoid overexpression of the cells.
- Similarly, to Dominic experiment, there will also be an initial setup in which the reference fluorescence in chamber 4 is measured when the same constant pulse rate is applied in chambers 1, 2 and 3.
- To obtain the electrophysiology of the neurons we will measure the ratio  $\Delta F / F$  which kinetics should closely track action potentials.  $\Delta F / F$  is defined as the ratio between the difference between the fluorescence measured in compartment 4 during excitation of neurons on the peripheral chambers

and the fluorescence at rest in compartment 4 (when pulses at constant frequency are applied in compartment 1,2, and 3, e.g during initial setup) over the fluorescence at rest in compartment 4. To record the fluorescence of the Ace-mScarlet, we will use 2-photon Fluorescent Lifetime Imaging Microscopy (FLIM) FRET techniques. In contrast to confocal microscopy, 2-photon imaging microscopy provides better deep-tissue imaging, less light scattering and absorption, and less photobleaching allowing longer time analysis, and Ace-mScarlet has demonstrated under the FLIM technique high FRET efficiency.

- To detect the burst, we will look for a burslet: a sequence of at least 4 spikes with interspike intervals less than a threshold which will be estimated based on historical analysis. Any group of burslets that overlaps in time is a burst. To eliminate noise: minimum burst duration will be enforced. Peak spike rates during each burst and time associated with that peak will be estimated from a smoothed histogram of spike count. We will investigate a spike train distance which defines the distance (dissimilarity) between two spike trains as the minimum cost of transforming one spike train into the other following a series of edit operations (insertion, deletion, or temporal shifting). The cost of shifting a spike in time will be adjusted by a cost which will take into account the cost of shifting non-coincident spikes. We will be, then, in position to compare the similarity between bursts in chamber 4 depending the nature of the information triggered in compartment 1, 2 and 3.
- Alternatively, we may use Van Rossum's work to produce a similarity score for the spikes<sup>1</sup>.
- Having quantify neuronal activity in response to various stimuli, we will be able to qualitatively infer neuron activity-dependent plasticity.

- 1) Activations of Distinct Channelrhodopsin Variants Engages Different Patterns of Network Activity- eNeuro. 202 Jan-Feb; <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6944482/> ; DOI: [10.1523/ENEURO.0222-18.2019](https://doi.org/10.1523/ENEURO.0222-18.2019)
- 2) Genetically Encoded Voltage Indicators: Opportunities and Challenges Journal of Neuroscience 28 September 2016, 36 (39) 9977-9989; DOI: <https://doi.org/10.1523/JNEUROSCI.1095-16.2016>
- 3) Fluorescence Resonance Energy Transfer (FRET) Microscopy: <https://www.olympus-lifescience.com/en/microscope-resource/primer/techniques/fluorescence/fret/fretintro/>
- 4) Comparing the performance of mScarlet-I, mRuby3, and mCherry as FRET acceptors for mNeonGreen: <https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0219886> <https://doi.org/10.1371/journal.pone.0219886>: "This reflects the difference in extinction coefficient and quantum yield between these two proteins and mCherry and demonstrates how mScarlet-I is a better overall acceptor that will provide more signal and greater dynamic range for intensimetric green-red based FRET experiments."
- 5) Fast two-photon imaging of subcellular voltage dynamics in neuronal tissue with genetically encoded indicators: <https://elifesciences.org/articles/25690>
- 6) Optogenetics guide: <https://www.addgene.org/guides/optogenetics/>
- 7) Victor, J. D., and Purpura, K. P. (1996). Nature and precision of temporal coding in visual cortex: a metric-space analysis. *J. Neurophysiol.* 76, 1310–1326.

---

<sup>1</sup> Spikes are binned into 1 ms intervals and convolved with an exponential kernel with time constant  $\tau_R$  (van Rossum, M. C. (2001). A novel spike distance. *Neural Comput.* 13, 751–763. doi: 10.1162/089976601300014321 ). "The choice of the exponential kernel was originally motivated in van Rossum's work by its causal properties and correspondence to the shape of postsynaptic currents. The time constant of the exponential,  $\tau_R$ , determines the precision with which the distance metric is sensitive". Following convolution with the exponential kernel a similarity between the two convolved spike trains as a Pearson correlation, is calculated to produce a similarity estimate,  $S_R$ , that is bounded from 0 to 1.