0 Neurophotonics for recording and activation of neurons

0.1 Genetically expressed optical-based indicators of intracellular $Ca^{2+}$

These molecules are expressed in vivo in specific cell types and initiate an increase in fluorescence in response to the $Ca^{2+}$ influx that follows an action potential.

Figure 1: The cyclically permutable GFP turned into a detector of intracellular $Ca^{2+}$. From Chen, Wardill, Sun, Pulver, Renninger, Baohan, Schreiter, Kerr, Orger, Jayaraman, Looger, Svoboda and Kim, 2013.

0.2 In vivo recording of neuronal structure and function with two-photon laser scanning microscopy

Two-photon laser scanning microscopy, properly done, allows changes in intracellular $Ca^{2+}$ to be measured in neuronal soma down to spines.

0.3 In vivo recording of calcium signaling with two-photon laser scanning microscopy

In vivo $Ca^{2+}$ signals may be recorded after a single spikes, but still the interpretation in terms of numbers of spikes in imperfect and can be unreliable.
0.4 **In vivo recording of activity in the locomoting animal**

The use of virtual reality in combination with two-photon microscopy permits behavior and circuit dynamics to be concurrently measured.

0.5 **Genetically expressed optical-based drivers of spiking**

Optical activation of channelrhodopsin expressed in the membrane of neurons can be used to photo-excite, or photo-inhibit, neurons.

0.6 **All optical schemes for feedback control of spiking**

The use of two-photon microscopy and concurrent photoactivation permits behavior and circuit dynamics to be concurrently measured and perturbed.
Figure 5: Intracellular responses in superficial V1 of mouse visual cortex using GCaMP6. From Chen, Wardill, Sun, Pulver, Renninger, Baohan, Schreiter, Kerr, Orger, Jayaraman, Looger, Svoboda and Kim, 2019.

Figure 6: Intracellular responses in hippocampal brain slice with cell culture using Oregon Green BABTA. From Sasaki, Takahashi, Matsuki and Ikegaya, 2008.

Figure 7: Intracellular responses in L5 of mouse somatosensory cortex. From Liu, Li, Marvin and Kleinfeld, 2019.

Figure 8: Intracellular $Ca^{2+}$ is an unreliable measure of spike count and may fail to detect single spikes in vivo. From Theis, Berens, Froudarakis, Reimer, Roson, Baden, Euler, Tolias and Bethge 2016.
Figure 9: Intracellular Ca\(^{2+}\) in distal dendrites of L5b neurons can dissociate from somatic electrical activity. From Helmchen and Waters 2002.

Figure 10: In vivo hippocampus preparation. From Dombeck, Harvey, Tian, Looger and Tank 2010.

Figure 11: In vivo recording in hippocampus. From Dombeck, Harvey, Tian, Looger and Tank 2010.

Figure 12: Natural transmembrane proteins that use light to pump ion of open ion selective pores.
Figure 13: One photon absorption and dynamics of channelrhodopsin. From Klapoetke, Murata, Kim, Pulver, Birdsey-Benson, Cho, Morimoto, Chuong, Carpenter, Tian, Wang, Xie, Yan, Zhang, Chow, Surek, Melkonian, Jayaraman, Constantine-Paton, Wong and Boyden, 2014.

Figure 14: Schematic for feedback induced long-term synaptic potentiation. From Zhang, Russell, Packer, Gauld and Hausser 2018.

Figure 15: Test of feedback induced long-term synaptic potentiation. From Zhang, Russell, Packer, Gauld and Hausser 2018.