Deciphering the Dynamics of Locust Olfactory System

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Motivation

The AL is a dense network of excitatory (PN) and inhibitory (LN) neurons that generate elaborate spatiotemporal patterns in response to an odor. Contrary to a number of *in-vivo* experiments, most computational models of the antennal lobe have typically assumed narrowly tuned input to the LNs. The goal of this project is to understand the effect of broad odor tuning of LN inputs on the repertoire of spatiotemporal patterns the network can generate and its role in odor discrimination.

Approach

To this end, we first constructed a detailed network model of the Locust (*Schistocerca americana*) AL and observed the dynamics under stimulation with odor inputs based on experimental recordings of a population of ORNs. We then use the responses of projection neurons to drive an array of Kenyon cells in the mushroom body. In addition to projection neuron input, Kenyon cells also received feedback inhibition from a single GABAergic neuron that ensured a sparse response.

Results

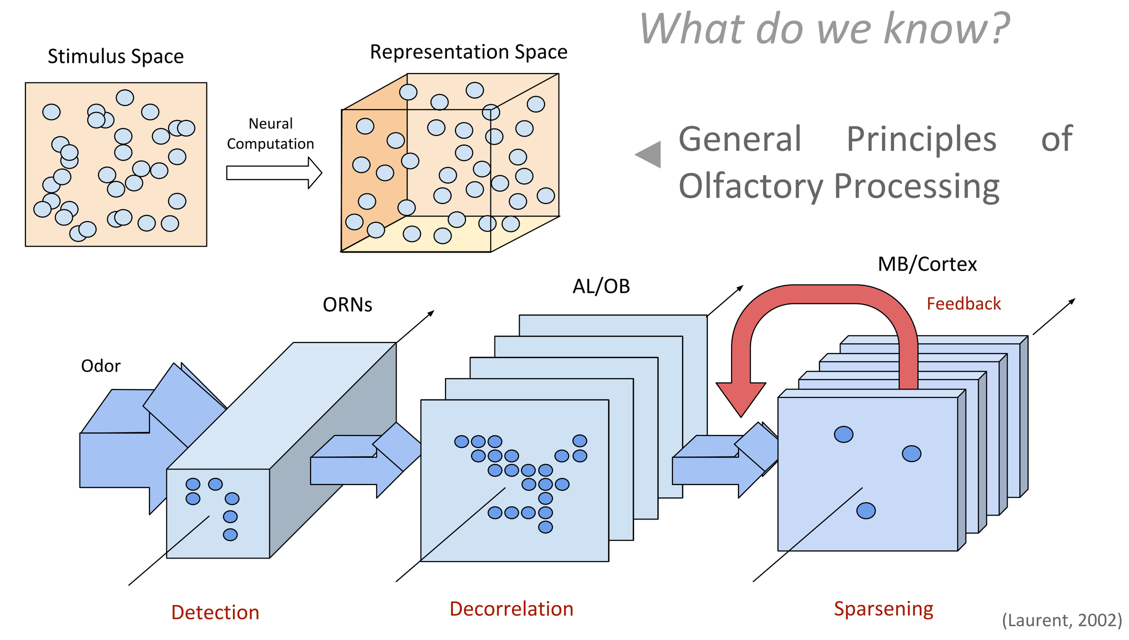
Our model replicated a number of key features of observed in AL and MB activity. The population of PN showed a distinct oscillatory LFP. We were able to tune the parameters of the model to generate an onset and an sustained offset response to odor stimulation. As seen in experiments, the model PNs and LNs showed patterning over multiple time scales. We could tune the inhibitory output of the giant GABAergic neuron (GGN) such that the responses of Kenyon cells were sparse.

Future Directions

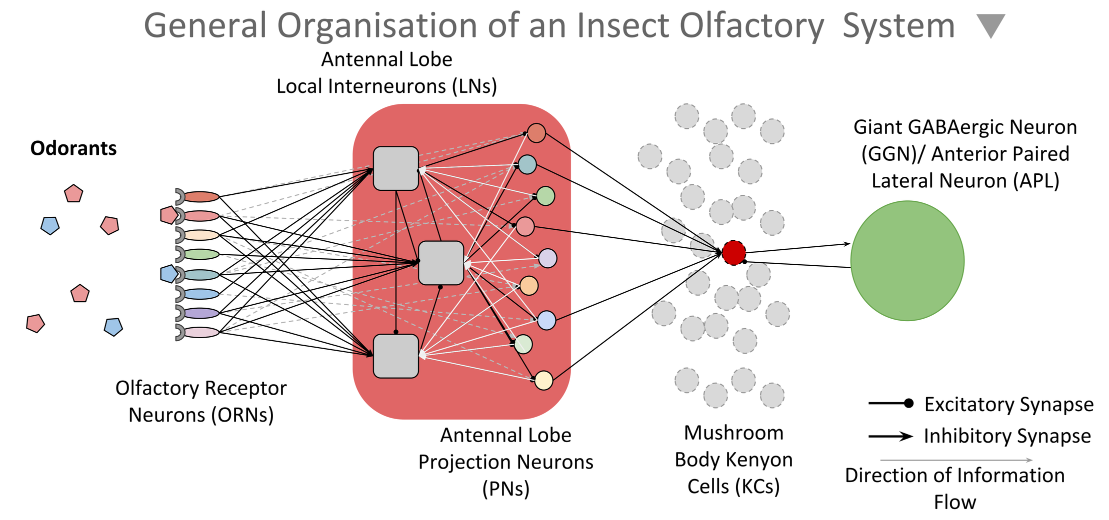
We plan to optimize the PN, KC and GGN responses to further match experimental statistics. In subsequent work, we hope to understand whether broad odor tuning of LNs confers specific advantages to the network that allows it to discriminate between odors. We believe such advantages may have resulted in an evolutionary drive towards the observed connectivity patterns. Further analysis of the PN and LN dynamics are required to test our hypothesis.

The Locust Model for Olfaction

What do we know?

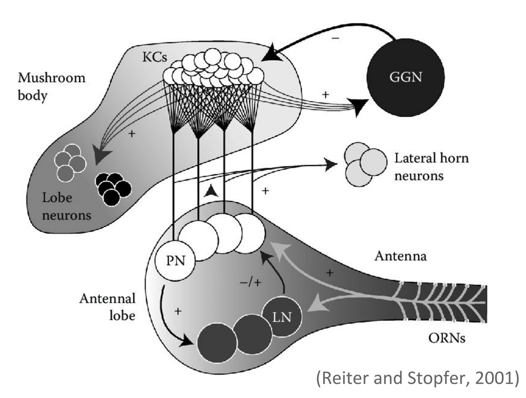


General Organisation of an Insect Olfactory System

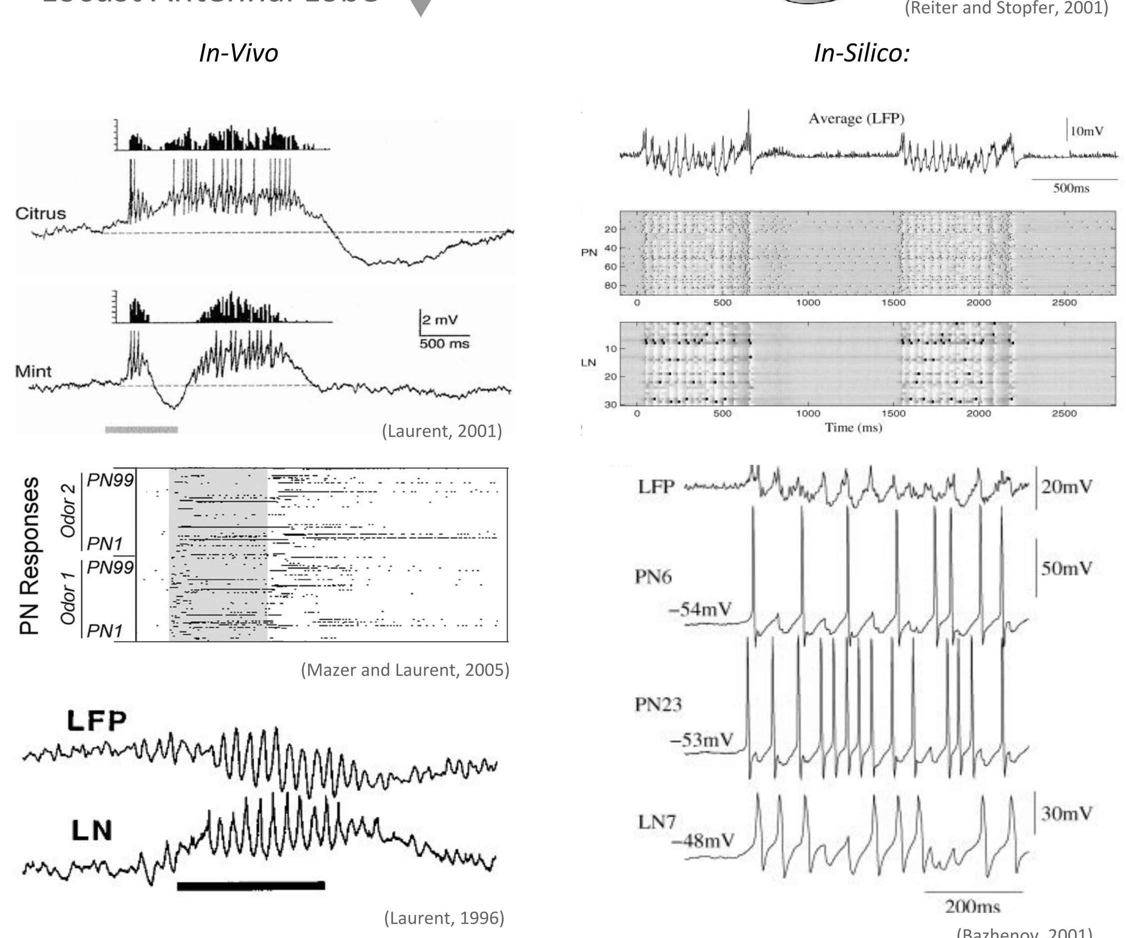


Locusts have kind of an unusual olfactory system that challenges the "one glomerulus-one receptor" principle observed in most insects.

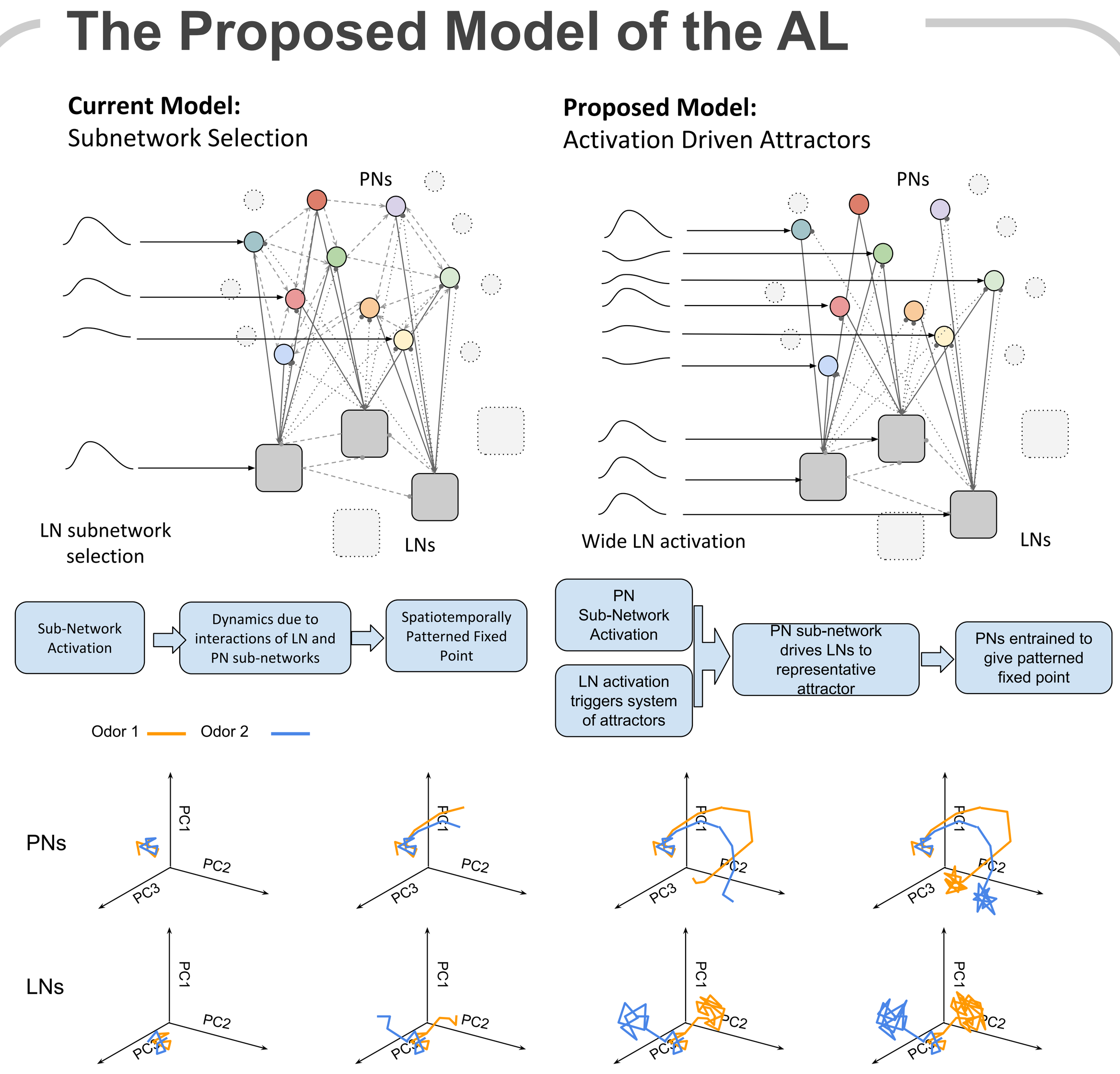
Large number of ORNs (~50000 with ~100 cell types), an order of magnitude more glomerulii in AL (with ~900 PNs and ~300 LNs), and a relatively smaller MB with only ~15000 KCs.



Results from Experiments on Locust Antennal Lobe

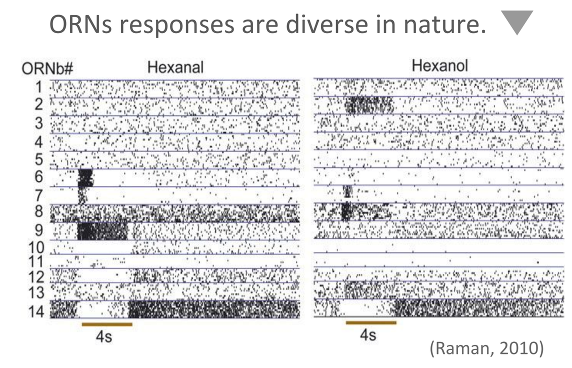


The Proposed Model of the AL



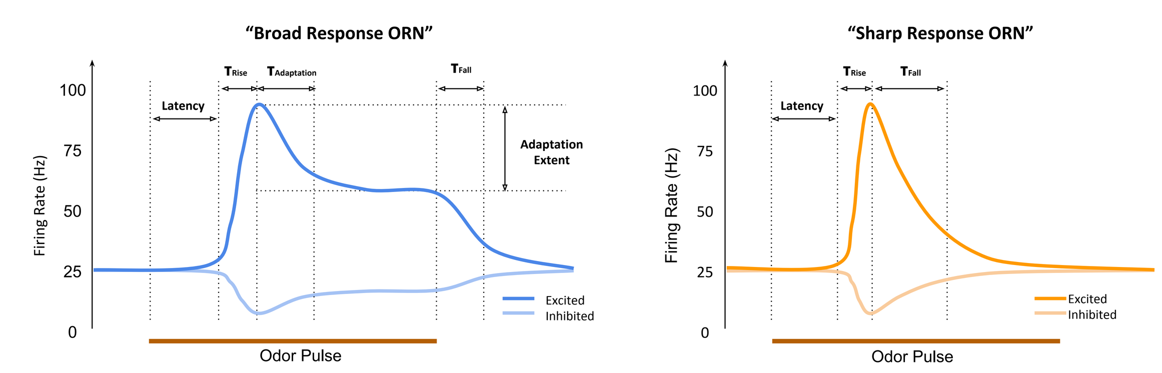
The ORN Model

ORNs responses are diverse in nature.



We represent each odorant as a vector in an 2-dimensional space (which can be interpreted as the first 2 PCs of properties of the odorant that trigger population response), where the magnitude of the vector is a proxy for the concentration of the odorant.

A Firing Rate Model based on Sampling

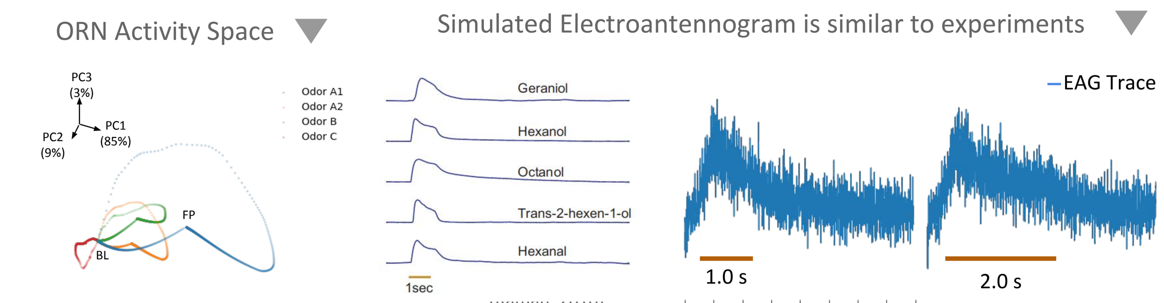


Modelled ORNs have diverse response to odors

ORN Model Spiking

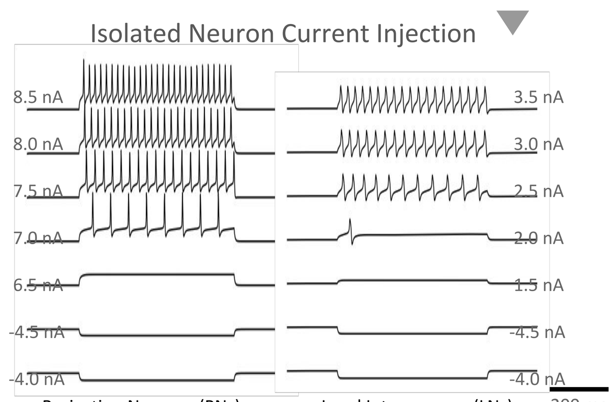
ORN Activity Space

Simulated Electroantennogram is similar to experiments



The Antennal Lobe Model

Isolated Neuron Current Injection



There is no clear evidence of stereotyped network connectivity in the Locust AL, we assume probabilistic connections. The probabilities are set as P(PN->PN) = 0, P(PN->LN) = 0.5, P(LN->PN) = 0.5 and P(LN->LN) = 0.5. PNs are known to be Cholinergic while all LNs are believed to be GABAergic. PNs are believed to express both GABAa and GABAb type receptors.

Projection Neurons (PNs)

$$C_m\frac{dV_{PN}}{dt} = I_{stim} - I_L - I_{Na} - I_K - I_A - I_{GABA_a} - I_{GABA_b} - I_{Ach}$$

$$I_L = g_L(V-E_L),\ g_L = 0.3,\ \mu S\ E_L = -64\ mV$$

$$I_{Na} = g_{Na}m_{Na}^3h_{Na}(V-E_{Na}),\ g_{Na} = 7.15\ \mu S,\ E_{Na} = 50\ mV$$

$$I_A = g_Am_A^4h_A(V-E_A),\ g_A = 1.43\ \mu S,\ E_A = -95\ mV$$

$$I_K = g_Kn_K^4(V-E_K),\ g_K = 3.6\ \mu S,\ E_K = -95\ mV$$

Local Interneurons (LNs)

$$C_m\frac{dV_{LN}}{dt} = -I_{stim} - I_L - I_{Ca} - I_K - I_{K(Ca)} - I_{GABA_a} - I_{Ach}$$

$$I_L = g_L(V-E_L),\ g_L = 0.3\ \mu S,\ E_L = -50\ mV$$

$$I_K = g_Kn_K^4(V-E_K),\ g_K = 36\ \mu S,\ E_K = -95\ mV$$

$$I_{Ca} = g_{Ca}m_{Ca}^2h_{Ca}(V-E_{Ca}),\ g_{Ca} = 5\ \mu S,\ E_{Ca} = 140\ mV$$

$$I_{K(Ca)} = g_{K(Ca)}m_{K(Ca)}(V-E_A),\ g_{K(Ca)} = 0.045\ \mu S, E_{K(Ca)} = -90\ mV$$

Ach/GABAa Synapse

$$I_{syn} = g_{syn}[O](V-E_{syn})$$

$$\frac{d[O]}{dt} = \alpha(1-[O])[T] - \beta[O]$$

GABAb Synapse

$$I_{GABAb} = g_{GABAb}\frac{[G]^4}{[G]^4+K}(V-E_{GABAb})$$

$$\frac{d[G]}{dt} = r_3[R] - r_4[G]$$

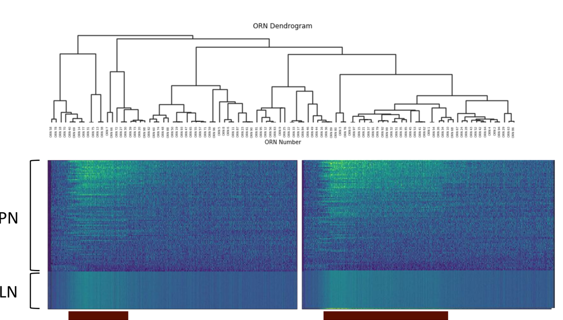
$$\frac{d[R]}{dt} = r_1(1-[R])[T] - r_2[R]$$

(Bazhenov, 2001)

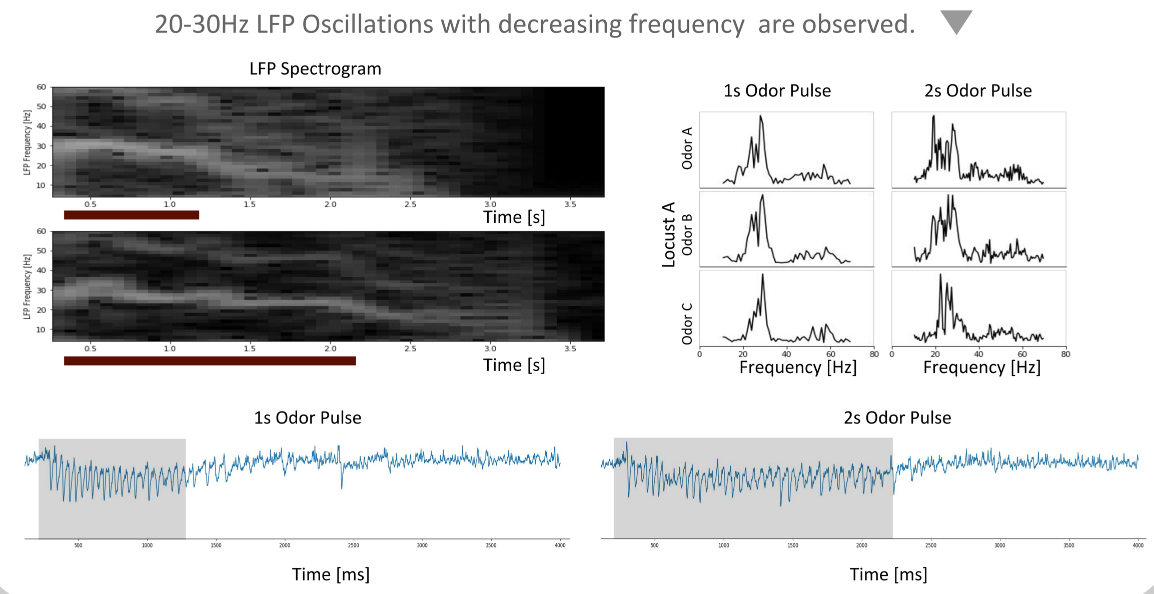
Conductance Input to AL Neurons based on ORN Model

LNs have dense arborization in the Antennal Lobe and receive input from ~70% of all ORNs. P(LN) = 0.7 (decorrelated)

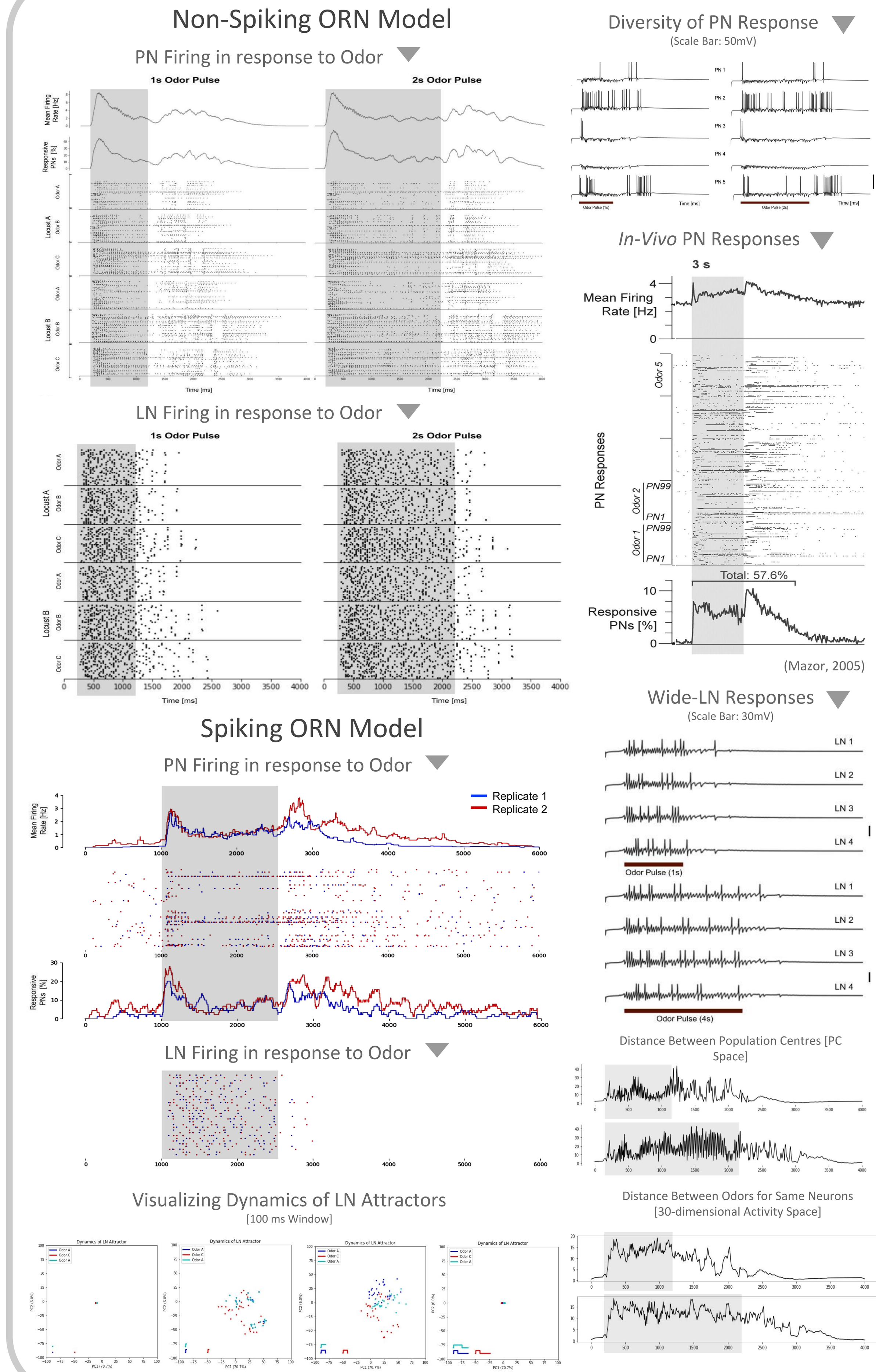
On the other hand, each PN of a glomerulus seem to receive input from 5% of ORN cell types with higher probability for similar cell types. P(PN) = 0.05 (correlated)



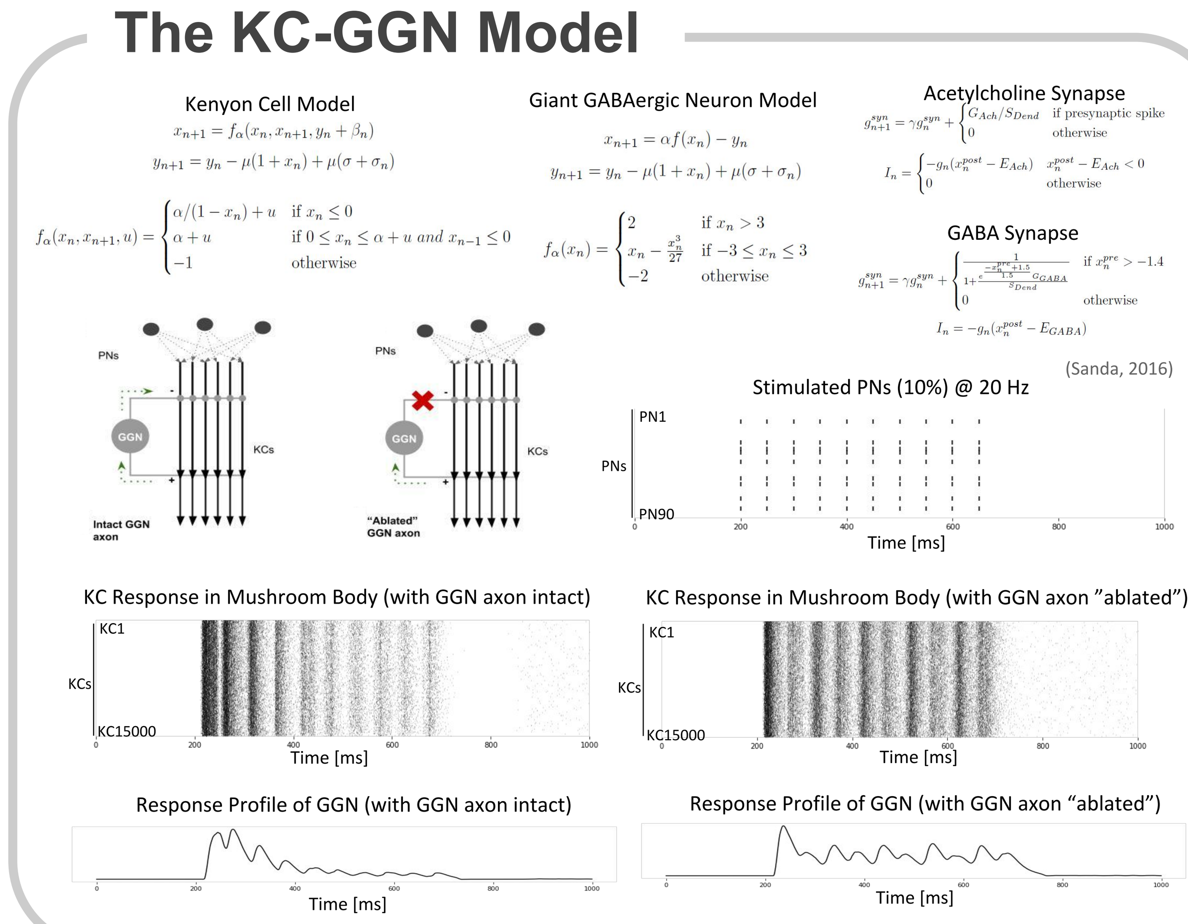
20-30Hz LFP Oscillations with decreasing frequency are observed.



Dynamics in the Locust AL



The KC-GGN Model



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