Whitening of odor representations by the wiring diagram of the olfactory bulb

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Presented By:
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Typos

- Figure 1(d): The colors are incorrect. Green should be black; yellow should be red
- Figure 2(d): The black trace is the s.d. of variance and not the mean as stated in the figure legend
- -aj,inf in front of s(t) expression shouldn't be there. If included rectification of s(t) must be done to avoid negative activity
- In the expression for s(t), t should not be in the subscript

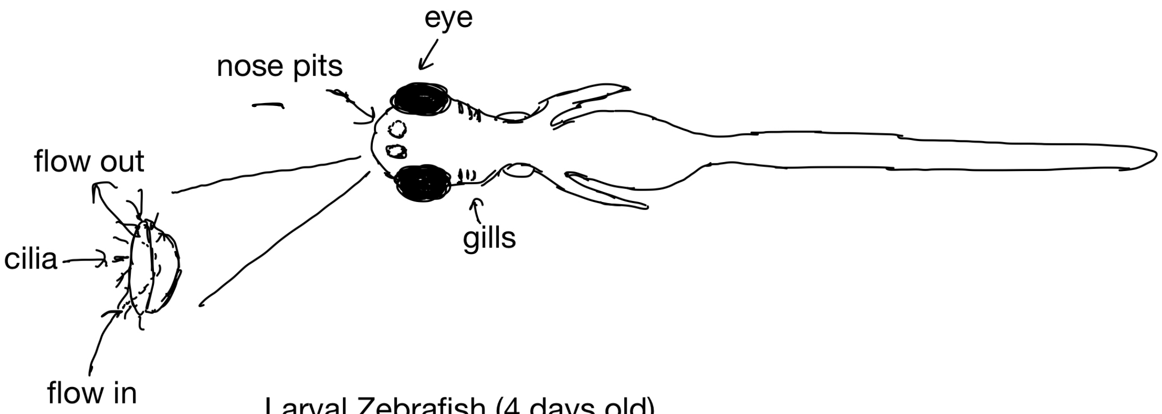
It would be interesting to see your results and of course let me know if you find any other issues in the code etc. Rainer and I will put together a corrigendum for the paper in the next couple of weeks.

Achievements of paper

- Map the connectome of OB of zebrafish larvae
- Stimulus ‘contrast reduction’ is the mechanism of whitening in OB based on wiring diagram

Olfaction at Low Reynolds number

- Aqueous olfaction is around 5 times slower than aerial olfaction



Larval Zebrafish (4 days old)

Organization of Olfactory System

- OB has ~1000 neurons
- ~750 Mitral cells
- ~250 Interneurons
- 2 types of interneurons: Periglomerular cell (PGC) and Short axon cells (SAC)

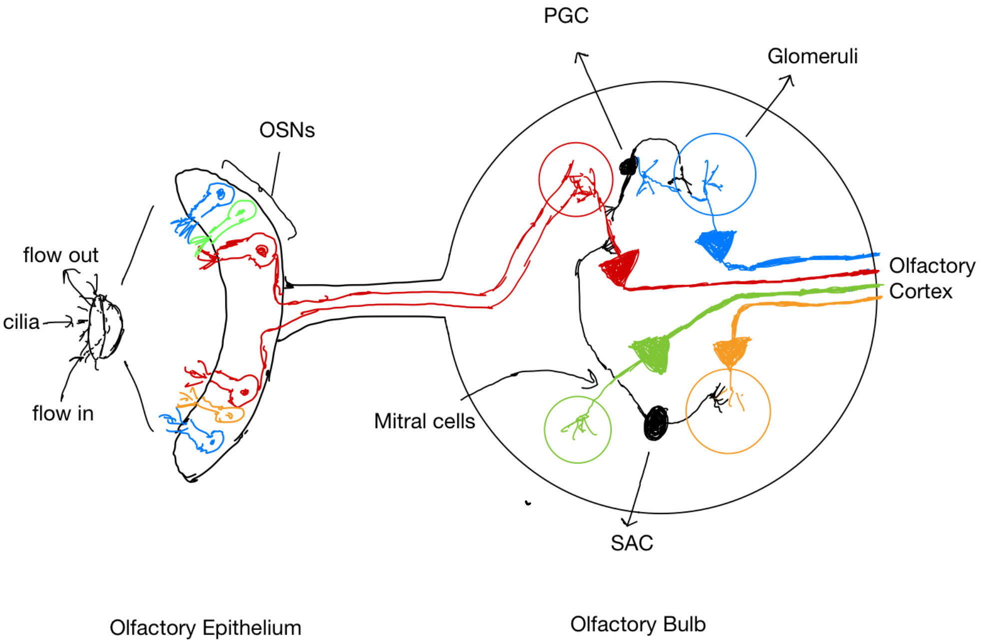
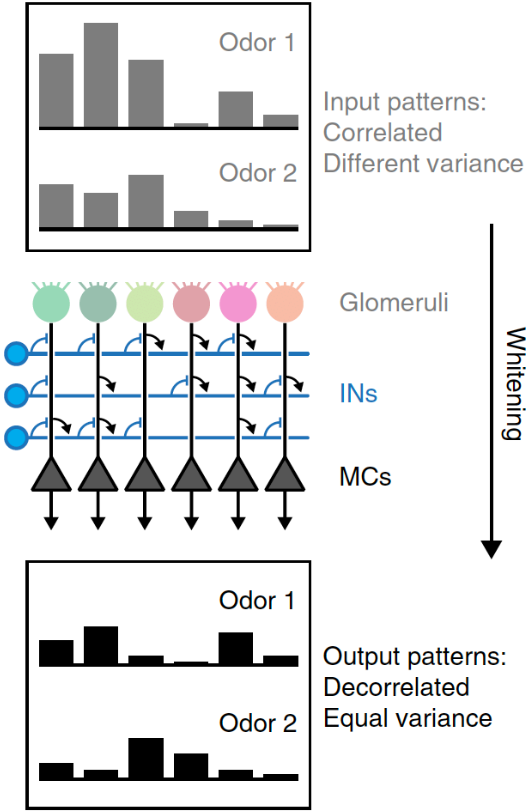
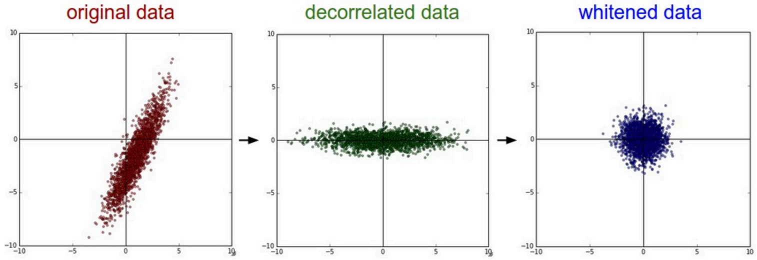


Figure 1

OB performs whitening

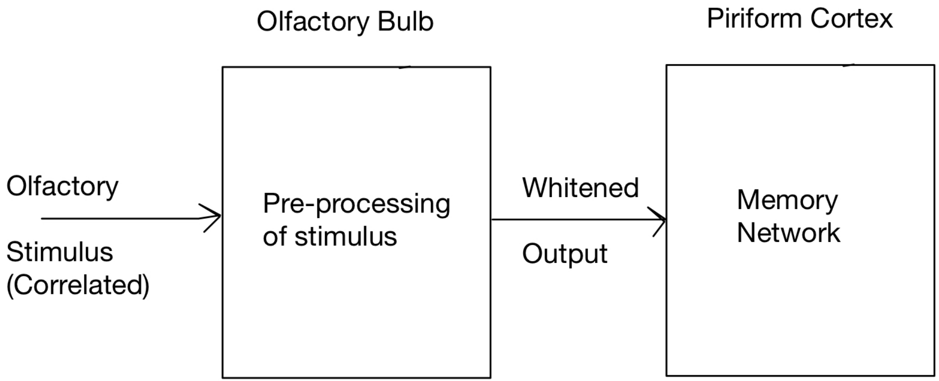


- Response of mitral cells is uncorrelated and has same variance for all odors
- Whitening = Decorrelation + Variance Normalization



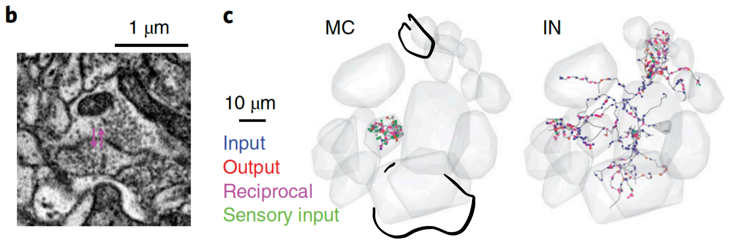
CS231 notes, Stanford University

Central Question: What is the neural mechanism behind whitening in the OB?



Tracing wiring diagram of OB

- Serial-block face electron microscopy (SBEM) was used to create the connectome
- Figure 1(d): The colors are incorrect. Green should be black; yellow should be red



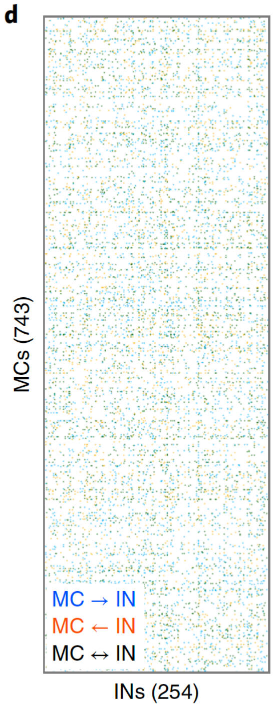
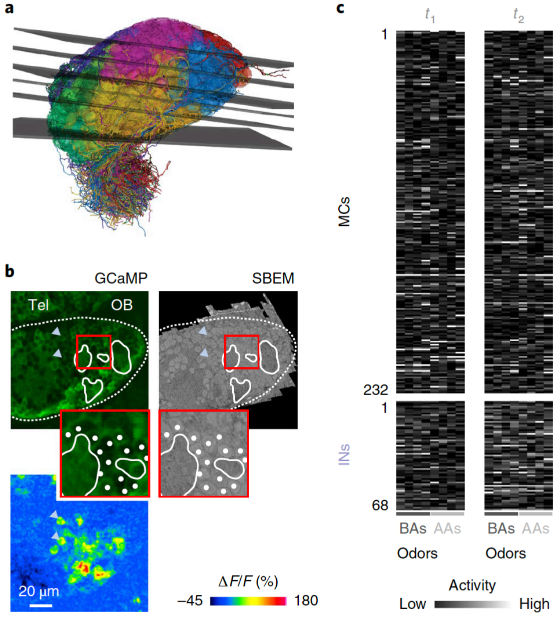
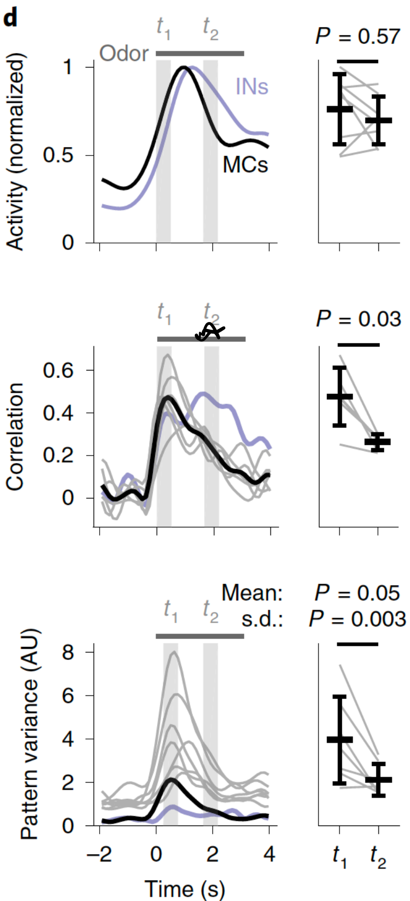


Figure 2

Measuring activity of MC and IN using calcium imaging

- t1~500ms (early time)
- t2~2 sec (late time)



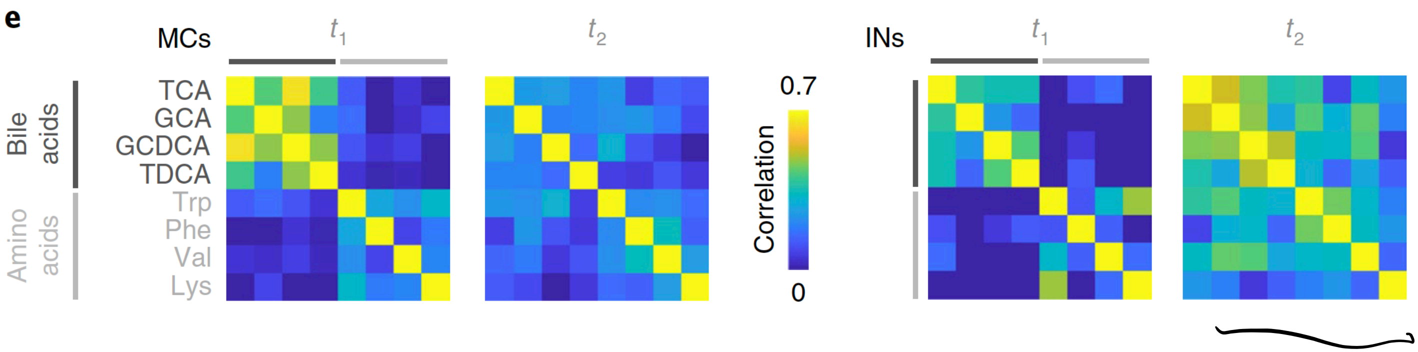


Decorrelation by t_2 (MC-black)

Correlation maintained in IN (blue)

Variance normalization by t_2

Correlation matrix of MC/INH activity for different odors

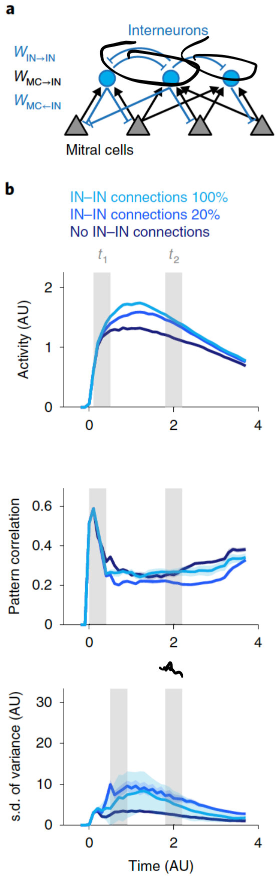


Whitened activity of mitral cells by t_2

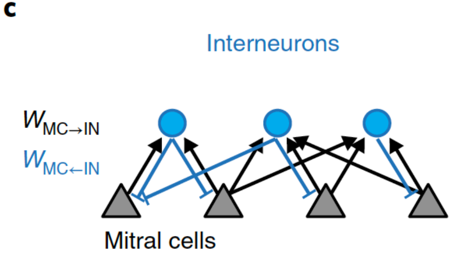
Interneurons don't show whitening

Figure 3: Computer Model of OB

Firing rate model of OB



INH-INH
Projections
Are unimportant
for decor relation
So ignored



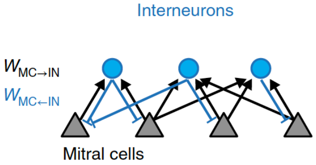
$$\tau^i_{\mathrm{MC}} \cdot \frac{dr^i(t)}{dt} = -r^i(t) + G^i_{\mathrm{sen}} S^i(t) - G^i_{\mathrm{inh}} W^i_{\mathrm{MC} \leftarrow \mathrm{IN}} \cdot [\mathbf{u}(t) - \boldsymbol{\theta}_{\mathrm{IN}}]_+$$

$$\tau^j_{\mathrm{IN}} \cdot \frac{du^j(t)}{dt} = -u^j(t) + G^j_{\mathrm{exc}} W^j_{\mathrm{IN} \leftarrow \mathrm{MC}} \cdot [\mathbf{r}(t) - \boldsymbol{\theta}_{\mathrm{MC}}]_+$$

234 MC and 208 INH neurons

$$\tau^i_{\mathrm{MC}} \cdot \frac{dr^i(t)}{dt} = -r^i(t) + G^i_{\mathrm{sen}} S^i(t) - G^i_{\mathrm{inh}} W^i_{\mathrm{MC} \leftarrow \mathrm{IN}} \cdot [\mathbf{u}(t) - \boldsymbol{\theta}_{\mathrm{IN}}]_+$$

c



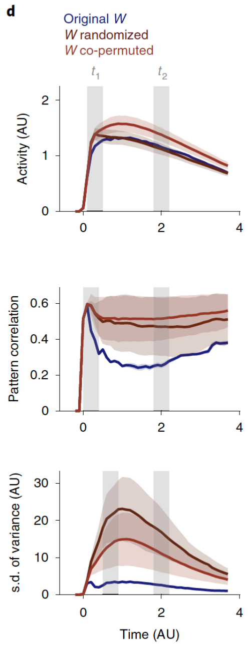
$$\tau^j_{\mathrm{IN}} \cdot \frac{du^j(t)}{dt} = -u^j(t) + G^j_{\mathrm{exc}} W^j_{\mathrm{IN} \leftarrow \mathrm{MC}} \cdot [\mathbf{r}(t) - \boldsymbol{\theta}_{\mathrm{MC}}]_+$$

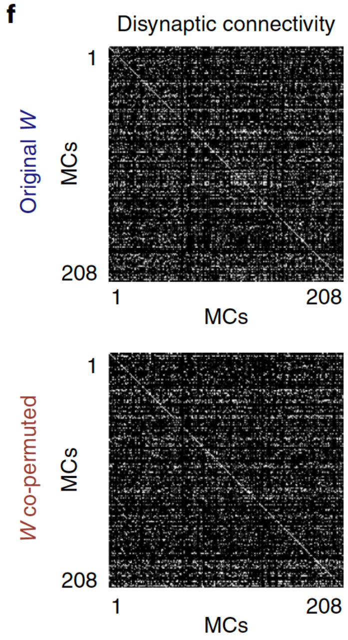
$$\mathrm{G}_{\mathrm{sen}} = 6,\ \mathrm{G}_{\mathrm{exc}} = 0.7,\ \mathrm{G}_{\mathrm{inh}} = 3.5,\ \theta_{\mathrm{MC}} = 2,\ \theta_{\mathrm{IN}} = 50,\ \tau_{\mathrm{MC}} = 1,\ \tau_{\mathrm{IN}} = 80$$

$$\tilde{\mathrm{s}}(t) = -a_{j,\infty} + \frac{a_{j,\infty}}{1-\alpha}\left(1 - e^{-\tau_{\mathrm{r}}t} - \alpha + \alpha e^{-\tau_{\mathrm{d}}t}\right) \text{with } \alpha = 0.8, \tau_{\mathrm{r}} = 1/150, \tau_{\mathrm{d}} = 1/600, a_{j,\infty} = 1/150$$

$$S_i(t) = \hat{a}_i \frac{\tilde{\mathrm{s}}(t)}{\tilde{s}_{\max}}, \text{ where } \tilde{s}_{\max} = \max_{t \geq 0}(\tilde{\mathrm{s}}(t))$$

Modifying the Wiring diagram





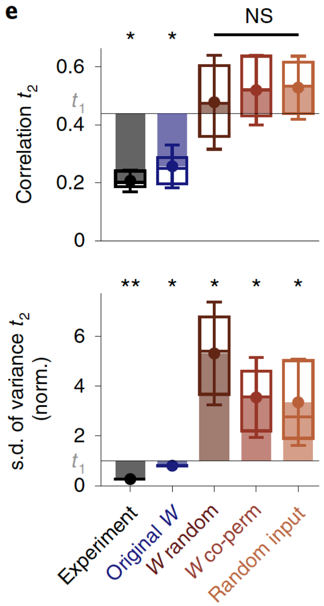
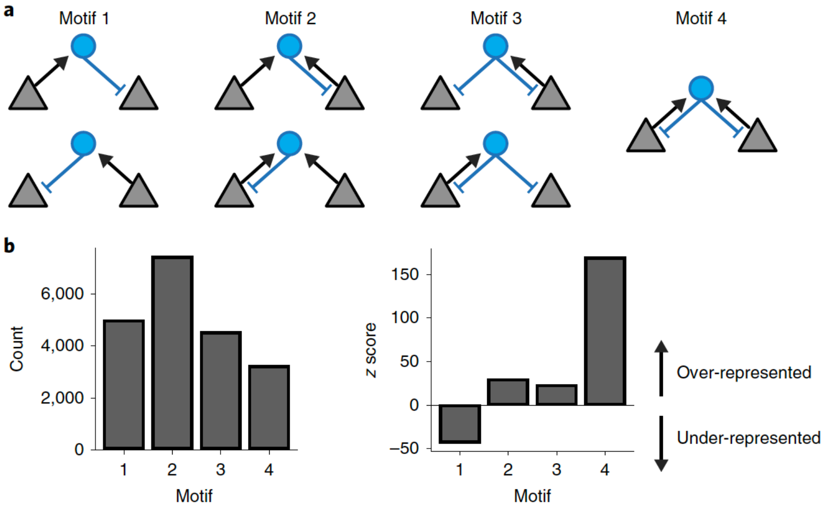


Figure 4: Finding structure in wiring diagram

Over-representation of 2-reciprocal connection motif



Disynaptic connectivity on basis of tuning similarity

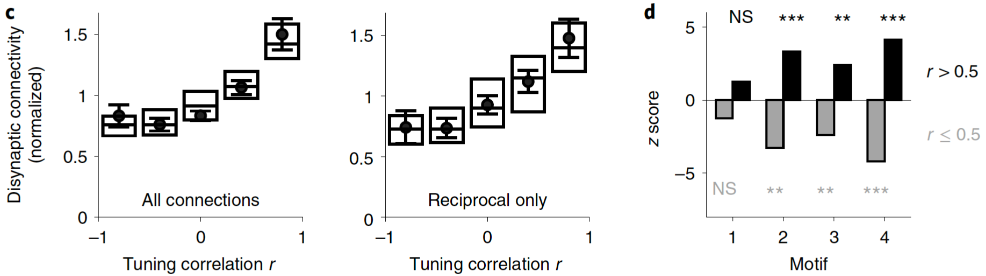
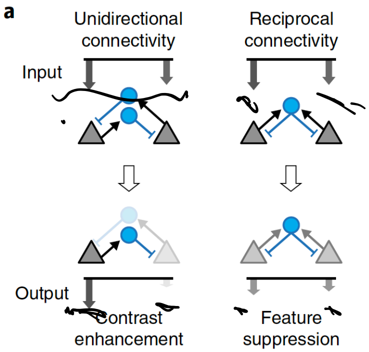
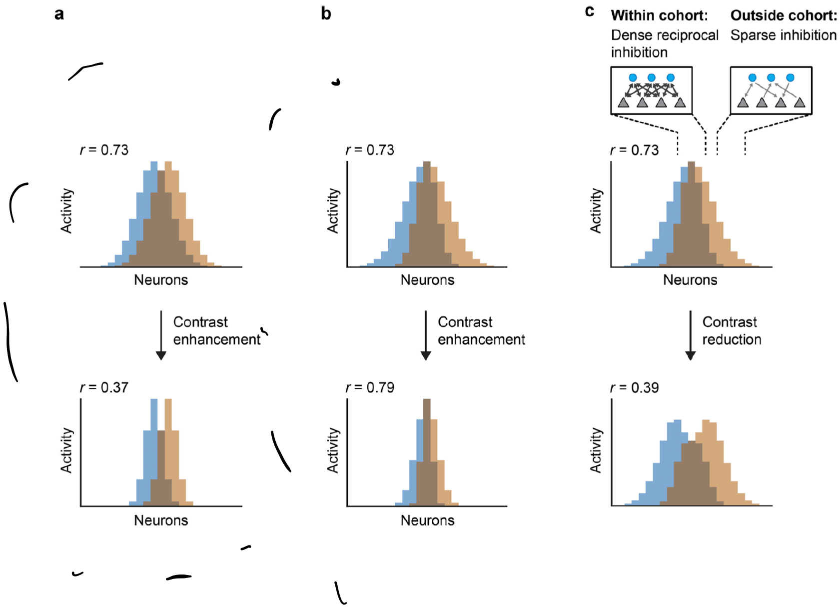


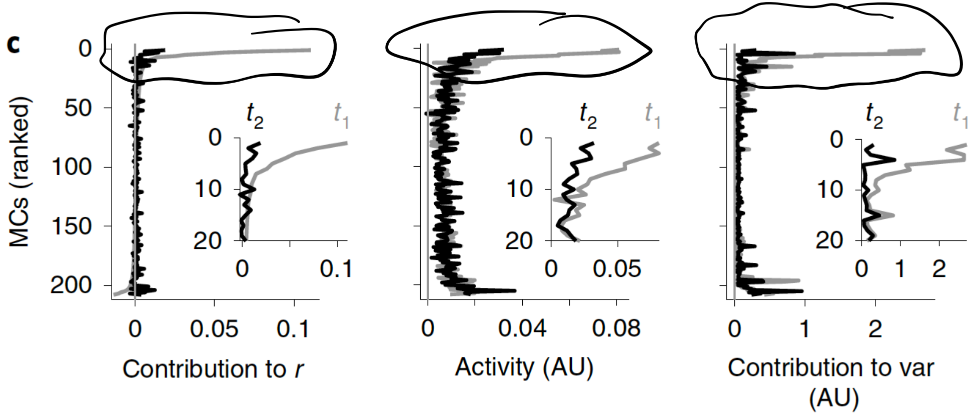
Figure 5: Understanding mechanism of whitening

Mechanism of whitening: Contrast reduction





Evidence for contrast suppression

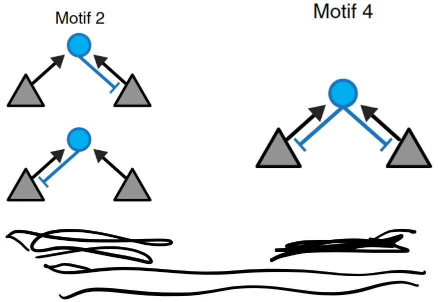


$$\rho = \bar{x}_1 \cdot \bar{x}_2 = \sum_i x_1^{(i)} x_2^{(i)}$$

i^{th} term

$$x_1^{(i)} x_2^{(i)}$$

Overrepresented motifs

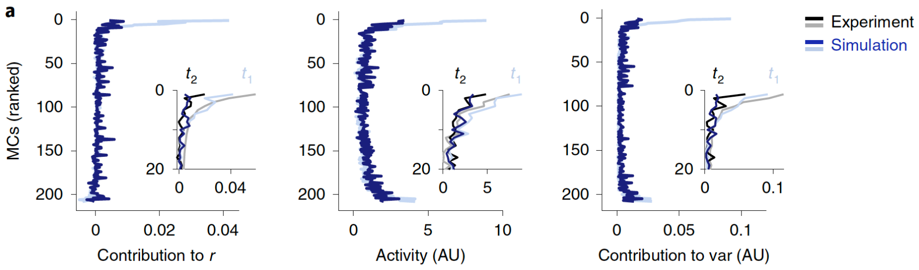


“Cohorts therefore function as ‘feature detectors’, where a ‘feature’ is a molecular stimulus property that efficiently activates many MCs in the ensemble”

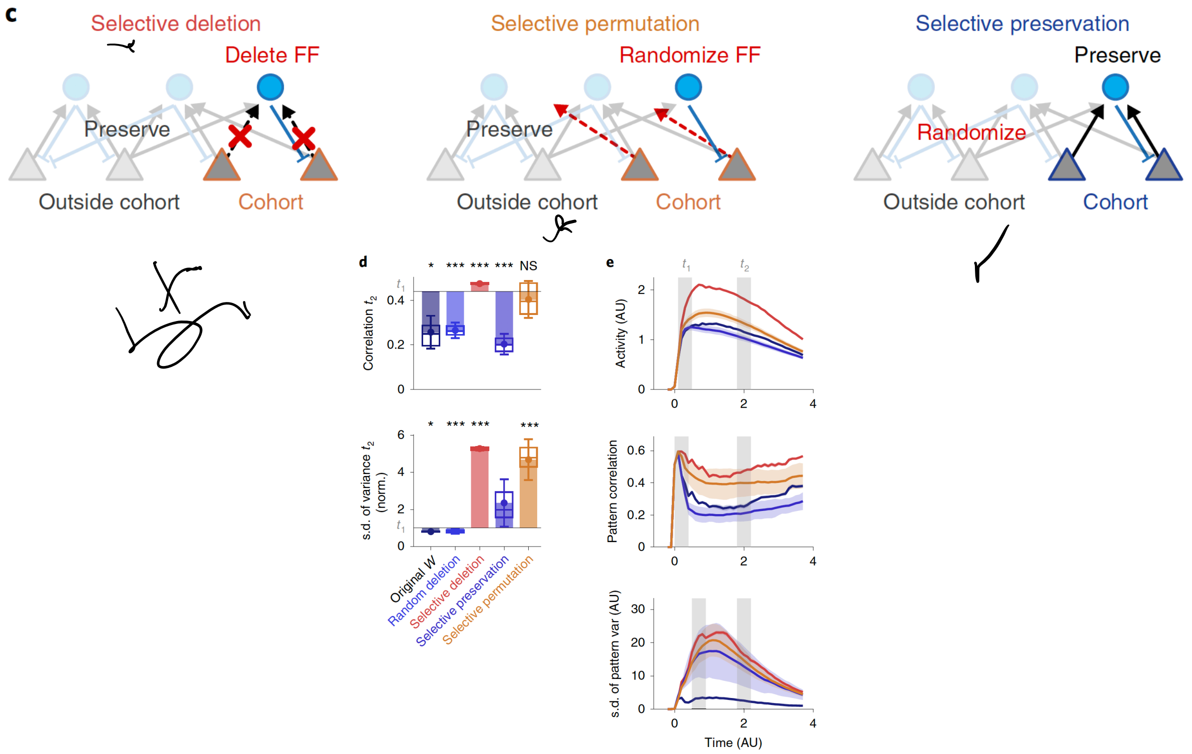
“Features may correspond to functional groups that promote high correlations of afferent activity patterns because they activate overlapping sets of odorant receptors”

Figure 6

Simulations show same statistics as experiments



Testing theory by selectively modifying wiring diagram



Bottom Line: Contrast suppression is the mechanism for whitening in olfactory bulb

Discussion Questions

Question 1: How does aqueous and aerial olfaction differ?

- Air flow is turbulent, water flow is laminar(in zebrafish).
- The olfactory response seems slower in aqueous medium

Question2: Is the dimensionality of odor space also reduced along with whitening?

- Koulakov et. al. claim that olfactory space ~10 dimensional.
- Do we know of papers which talk of dimensionality reduction by neural networks?

Question 3: Do we really need full connectome? Is it an overkill?

- Can we have an incomplete wiring diagram that can allow us to infer over-represented motifs? Is it "complete the matrix" from sparse data.

Air

$\rho = 1\ kg/m^3$

$v = 300\ m/s$

$L = 1\ mm = 10^{-3}\ m$

$\eta = 10^{-5}\ Pa\cdot s$

$$Re = \frac{\rho v L}{\eta} = \frac{10^2 \times 10^{-3}}{10^{-5}} = 10^4$$

Water

$\rho = 10^3\ kg/m^3$

$v = 10^{-3}\ m/s$

$L = 10^{-3}\ m$

$\eta = 10^{-5}\ Pa\cdot s$

$$Re = \frac{\rho v L}{\eta} = \frac{10^3 \times 10^{-3} \times 10^{-3}}{10^{-5}} = \underline{100}$$