Transient Dynamical Processing in the Moth Macroglomerulus

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My Background

- Degree in Physics (Edinburgh University).
- Ph.D in Neural Network Theory (Southampton University).

My Remit

Focus on the properties of the response of a single glomerulus to a single pheromone component.

- Sensitivity of the MGC to low pheromone concentrations.
- Dynamic Range.
- Role of disinhibition.

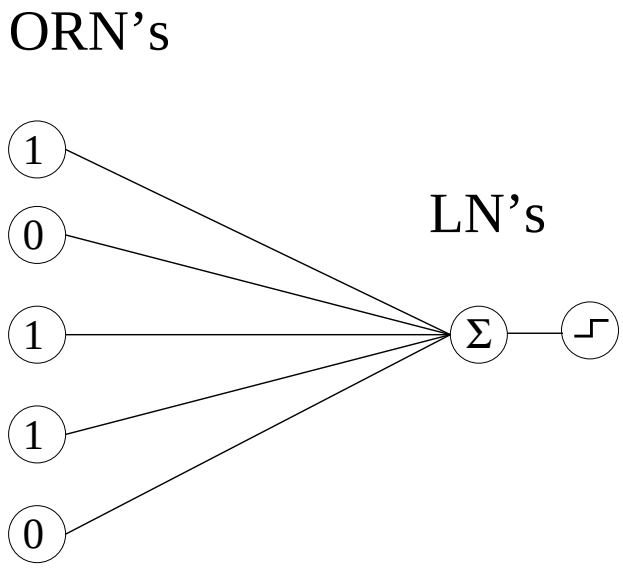
This Talk

- Sensitivity and convergence.
- Disinhibition and the MGC architecture.
- A transient dynamical model.
- Future work.

Sensitivity and Convergence

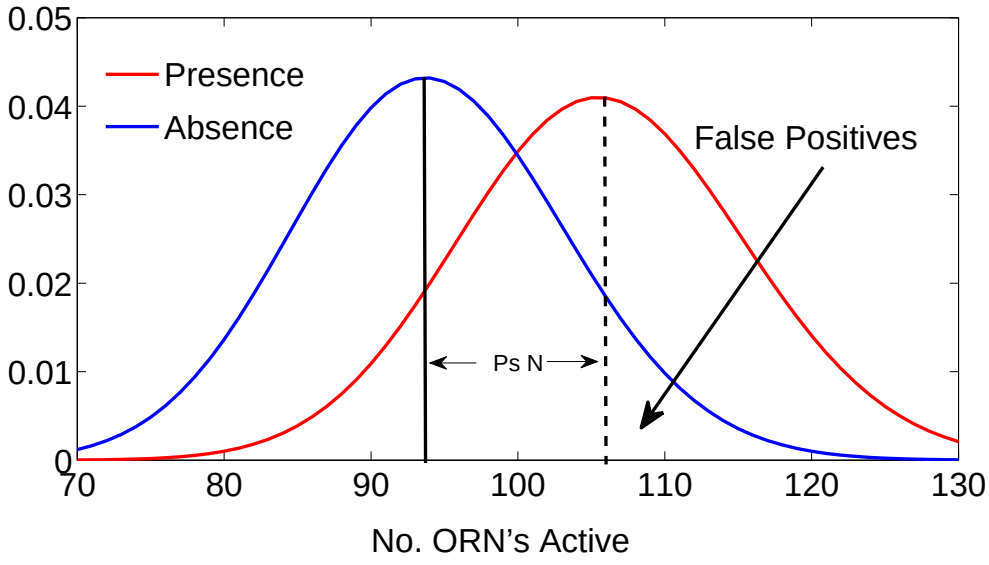
- Behavioural response is sensitive to 300 molecular events on the antennae of *Bombyx mori* (Schneider, D. 1970).
- The cardiac rhythm is sensitive to 6 molecular events on the antennae of *Spodoptera littoralis* (Angioy, AM. 2003)?
- The convergence from ORN's onto the MGC is thought to explain this sensitivity (hyperacuity).
- Question: Can the convergence of the ORN's onto a single LN account for this sensitivity?

Sensitivity and Convergence



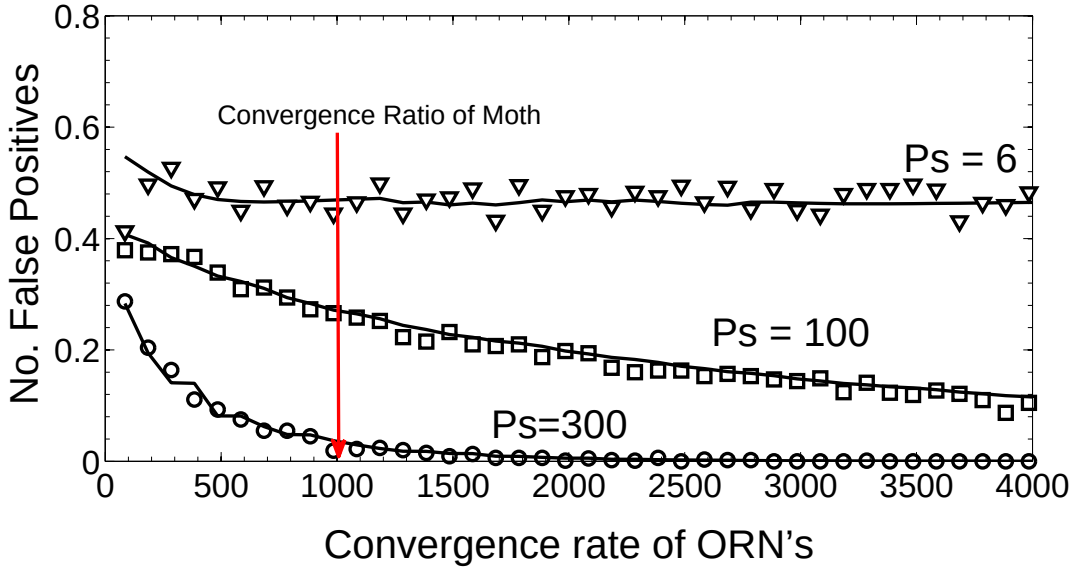
- Model the ORN's as a Bernoulli process.
- The probability of an ORN firing (state 1) in the absence of pheromone is $Pn = (1600/17000)$.
- The probability of an ORN firing in the presence of pheromone is $Pn + Ps = 1600/17000 + 300/17000)$.
- The convergence rate from ORN's to LN's in the moth is about 1000.

Sensitivity and Convergence



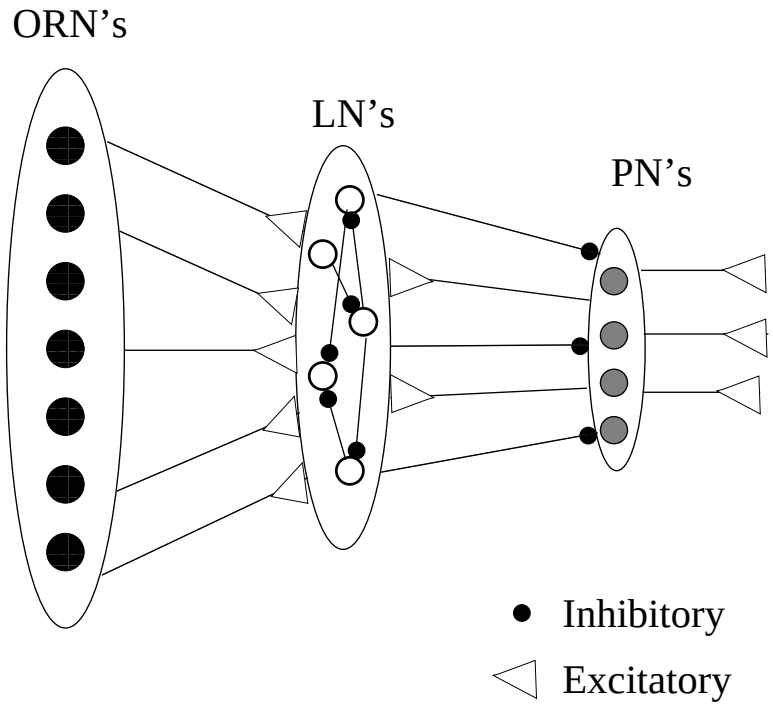
- 50% behavioural response rate (Schneider, D. 1970).
- In 30 specimens not one responded in the absence of pheromone (Schneider, D. 1970).
- Consequently we want the number of false positives to be less than about 3%.

Sensitivity and Convergence



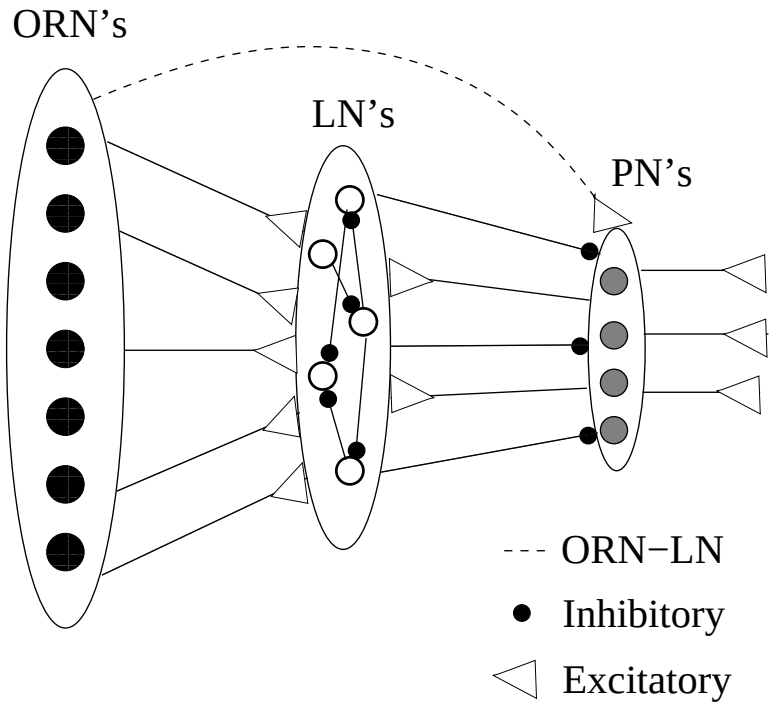
- This can almost explain a sensitivity to 300 events on the antennae.
- Greater sensitivity could be achieved by further integration at the level of the whole MGC.

MGC Architecture and Disinhibition



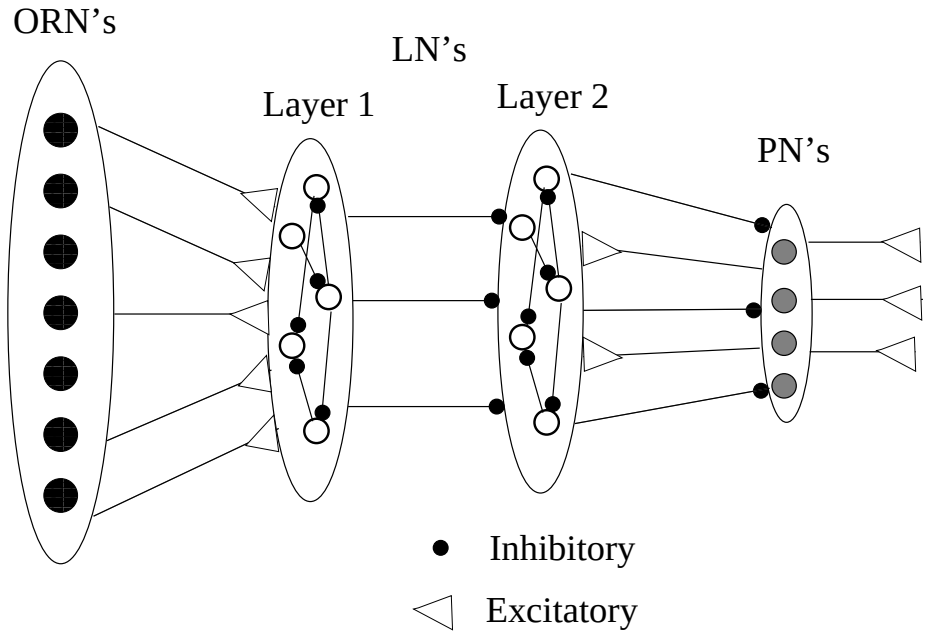
- PN's have a strong positive response to stimulation at the ORN's.
- However LN's only interact with inhibitory connections?

MGC Architecture and Disinhibition



- Consequently, some have modeled direct ORN-PN connections (Linster, C. et. al. 1996).
- However, these connections have never been experimentally observed.

MGC Architecture and Disinhibition



- Others have suggested an explicit disinhibition process through a feedforward layered system (Av-Ron, E. et. al. 1995).
- Consistent with the temporal delays between ORN and PN responses implying polysynaptic pathways.
- More layers could provide extra integration and perhaps more sensitivity to pheromone.

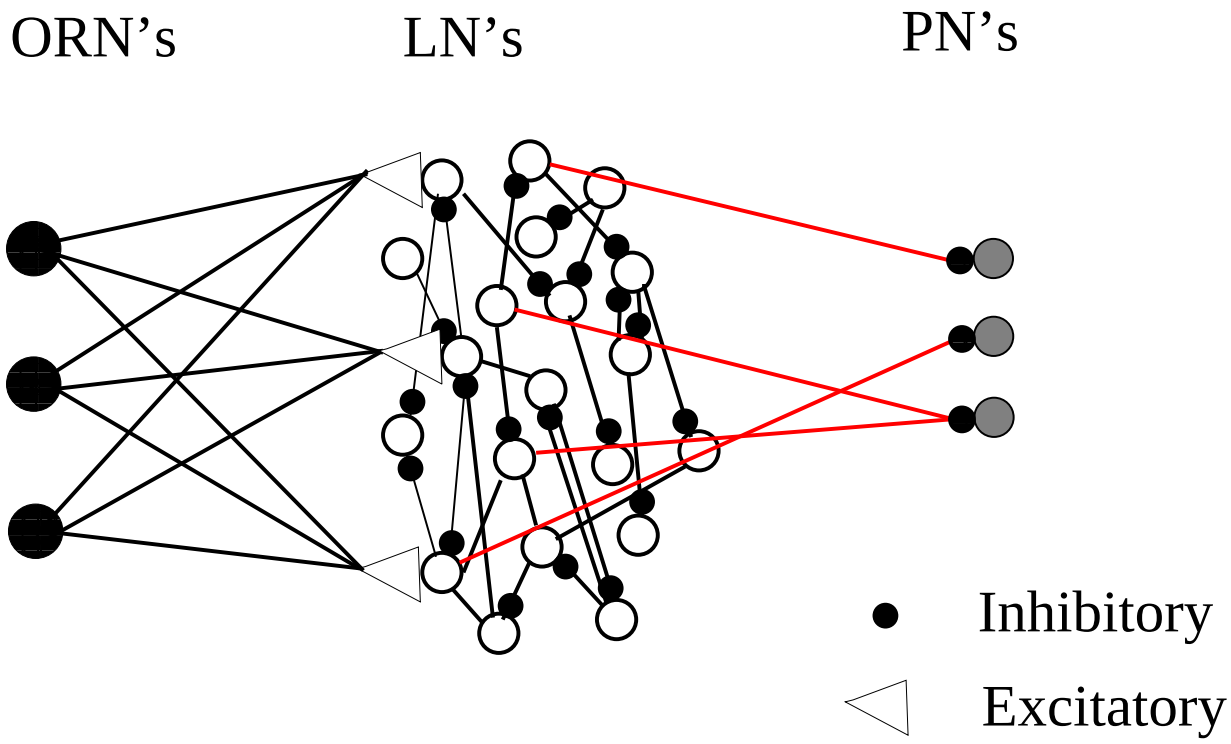
What kind of system is the MGC

- We know little about its connectivity but explicit distinct layers have not been observed.
- There are most certainly recurrent connections (it's not feedforward).
- Question: Can a semi-random recurrent inhibitory network without explicit layers or ORN-PN connections produce both a strong PN response and sensitivity to pheromone?

Other Main Assumption

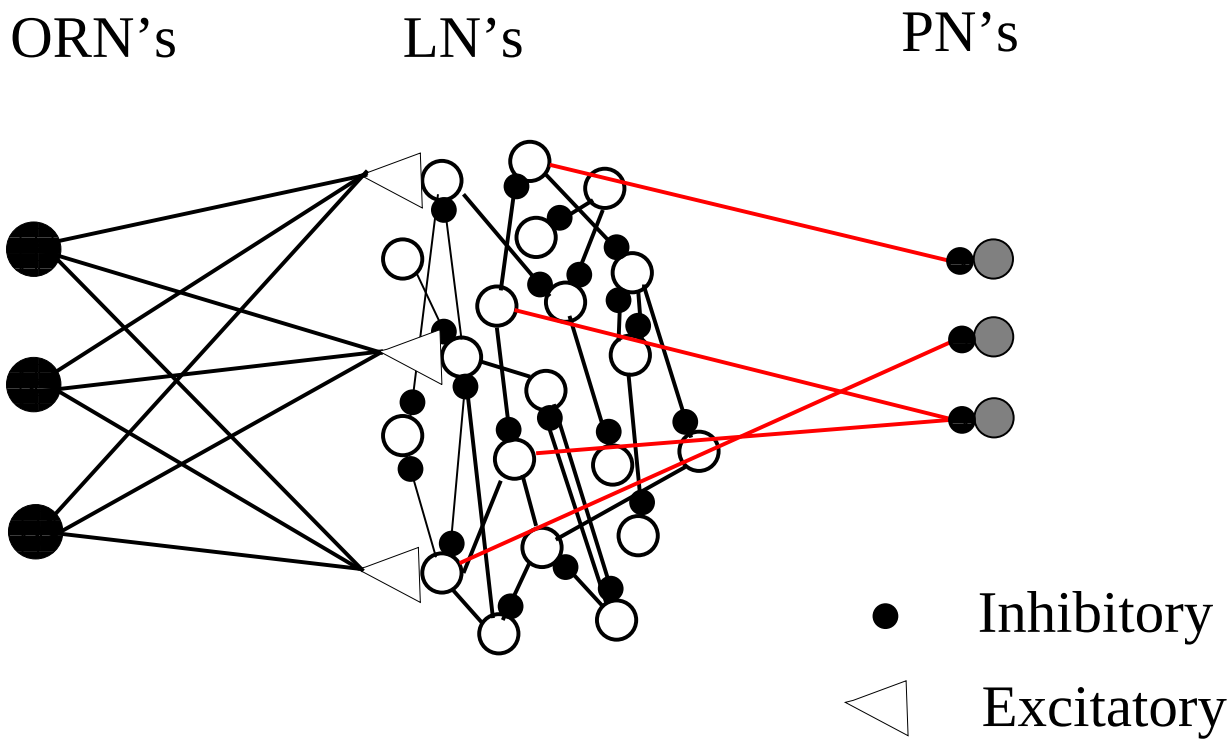
- Only transient response to stimulation.

The Model



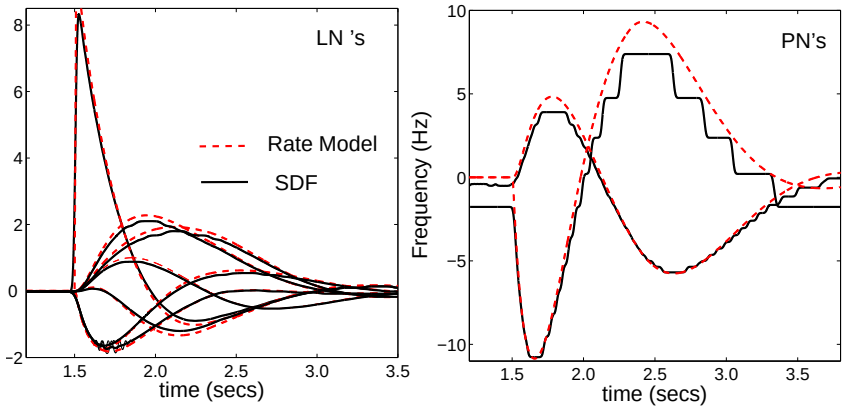
- Spiking network and a formally equivalent rate model.
- Assign connections probabilistically (no PN-LN connections).
- Use formal conditions on the rate model to guarantee only transient dynamics.

The Model



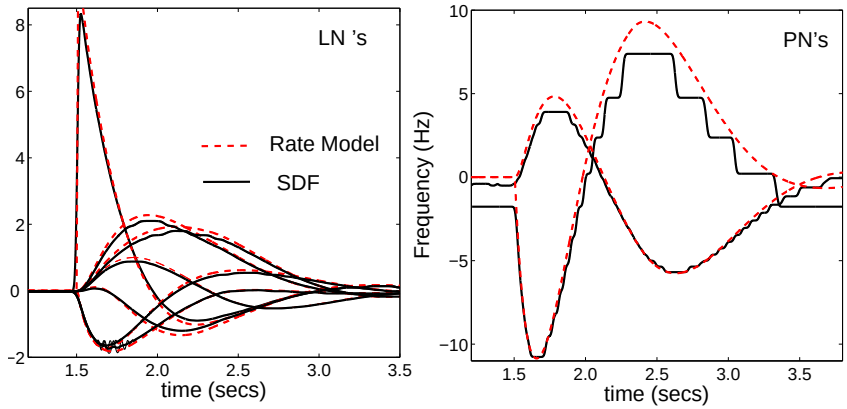
- This architecture has a strong resemblance to the liquid and echo state paradigms (Maas, W. et. al. 2002 and Jaeger, H. 2002).
- They have been suggested as good models of cortical microcolumns.

Some first results



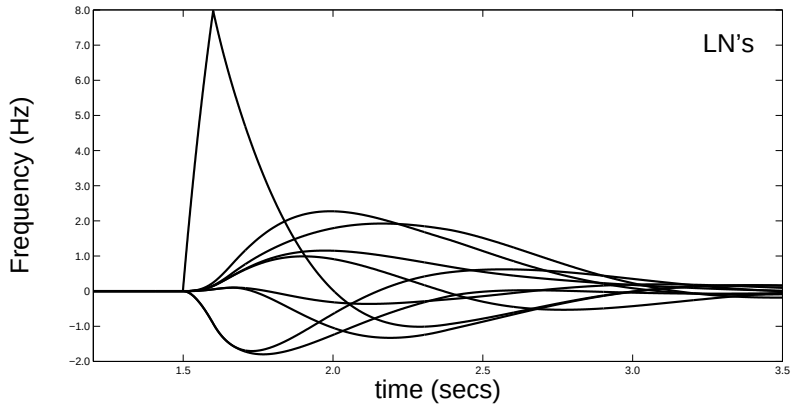
- Rich LN responses because of transient dynamics.
- The PN response is excitatory with a delay and sometimes is preceded by a brief inhibitory period (*Manduca sexta*).

Mechanism



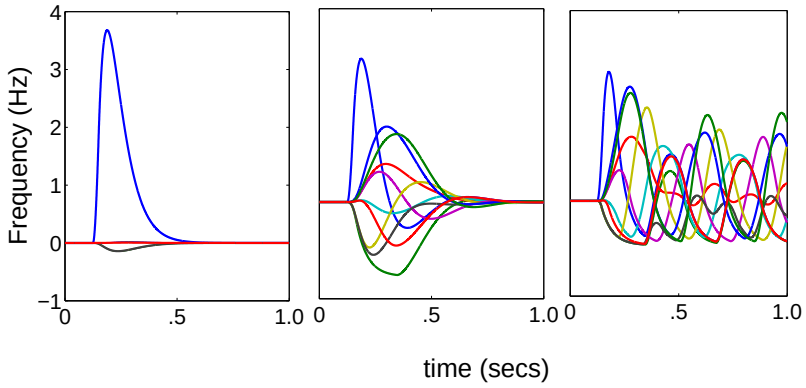
- The fraction of LN's that are connected to ORN's are all winners.
- Most LN's are inhibited by these winners.
- *Many* of losers outweigh the *few* winners disinhibiting the PN's.
- PN's that receive input from LN's that are synapsed by an ORN will have a brief initial inhibitory period.

Inferring Network Structure



- The rate description of the system allows an analytical purchase on the systems dynamics.
- For instance we can see that the periods of excitation and inhibition in the LN response is related to asymmetries in the MGC's connectivity.
- We maybe able to infer a lot about the MGC's connectivity by examining the detailed structure of the LN responses.

Critical Dynamics in the MGC



- Our system exhibits only transient dynamics.
- Too weak or too strong MGC connectivity results in unresponsive or complex cyclic (or chaotic) dynamics respectively.
- Systems poised between these two regimes are said to be critical.

Critical Dynamics in the MGC

- Critical systems have been shown to have a number of desirable properties (Kinouchi et. al. 2006).
  - Sensitivity to input.
  - Increased dynamic range.
  - Rich computational properties.
- Kinouchi et al. have already suggested the olfactory bulb in vertebrates exhibits critical dynamics.
- We may be able to ascertain whether the MGC exhibits critical dynamics by looking at the distribution of sizes of the LN's responses to pheromone.

Thank you!