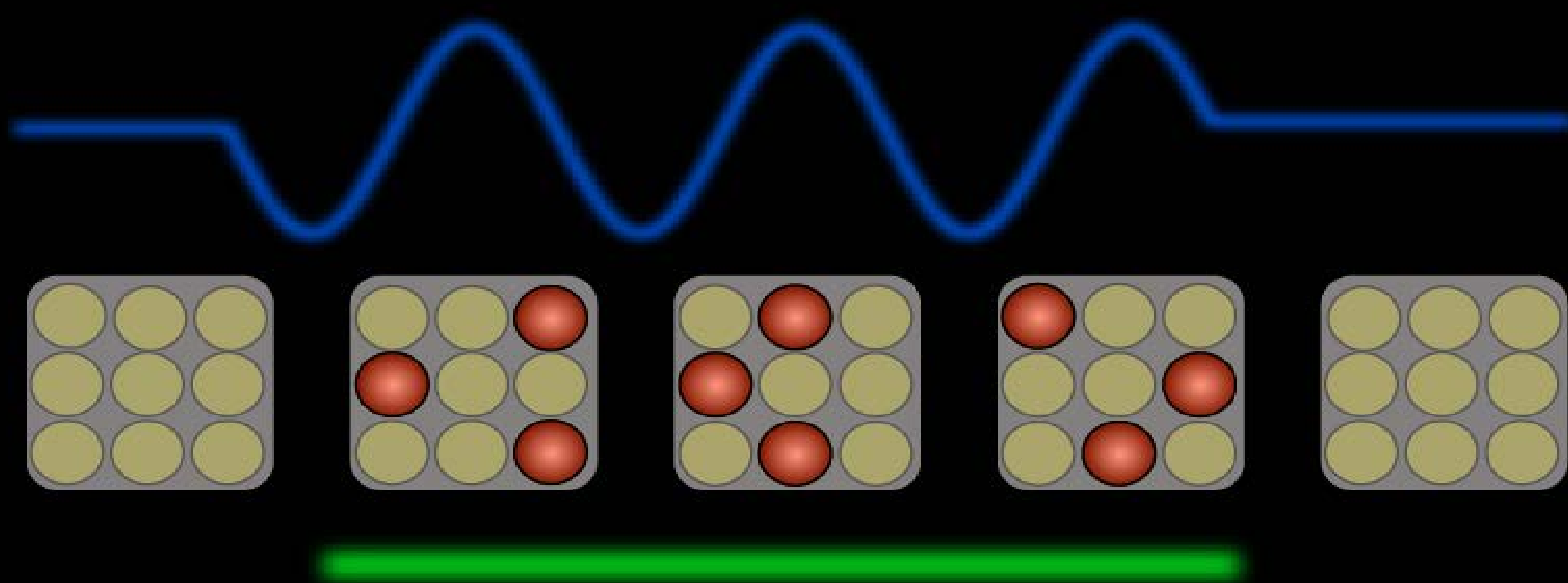
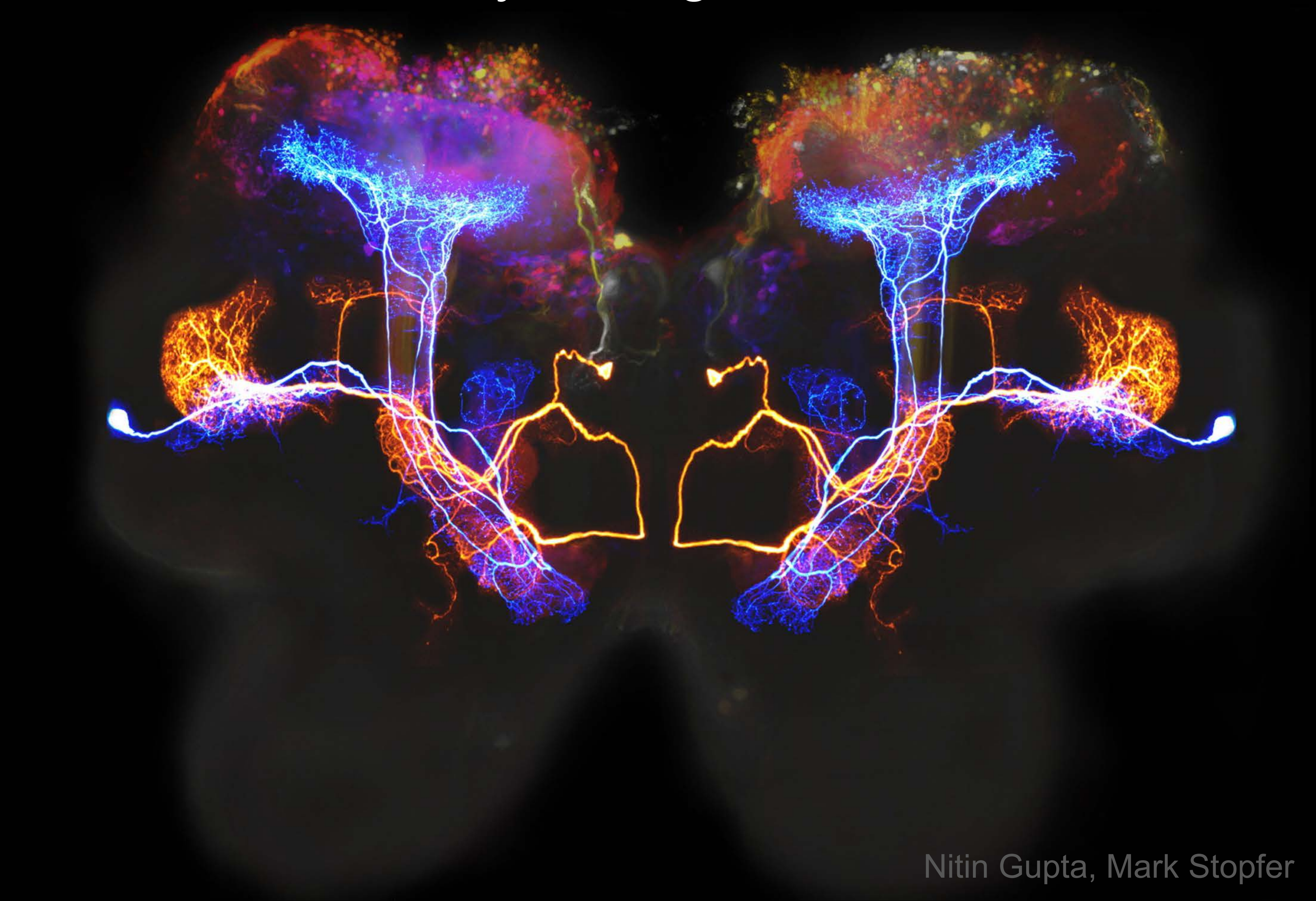
Neural codes for the sense of taste

Mark Stopfer
NIH / NICHD



Section on sensory coding and neural ensembles

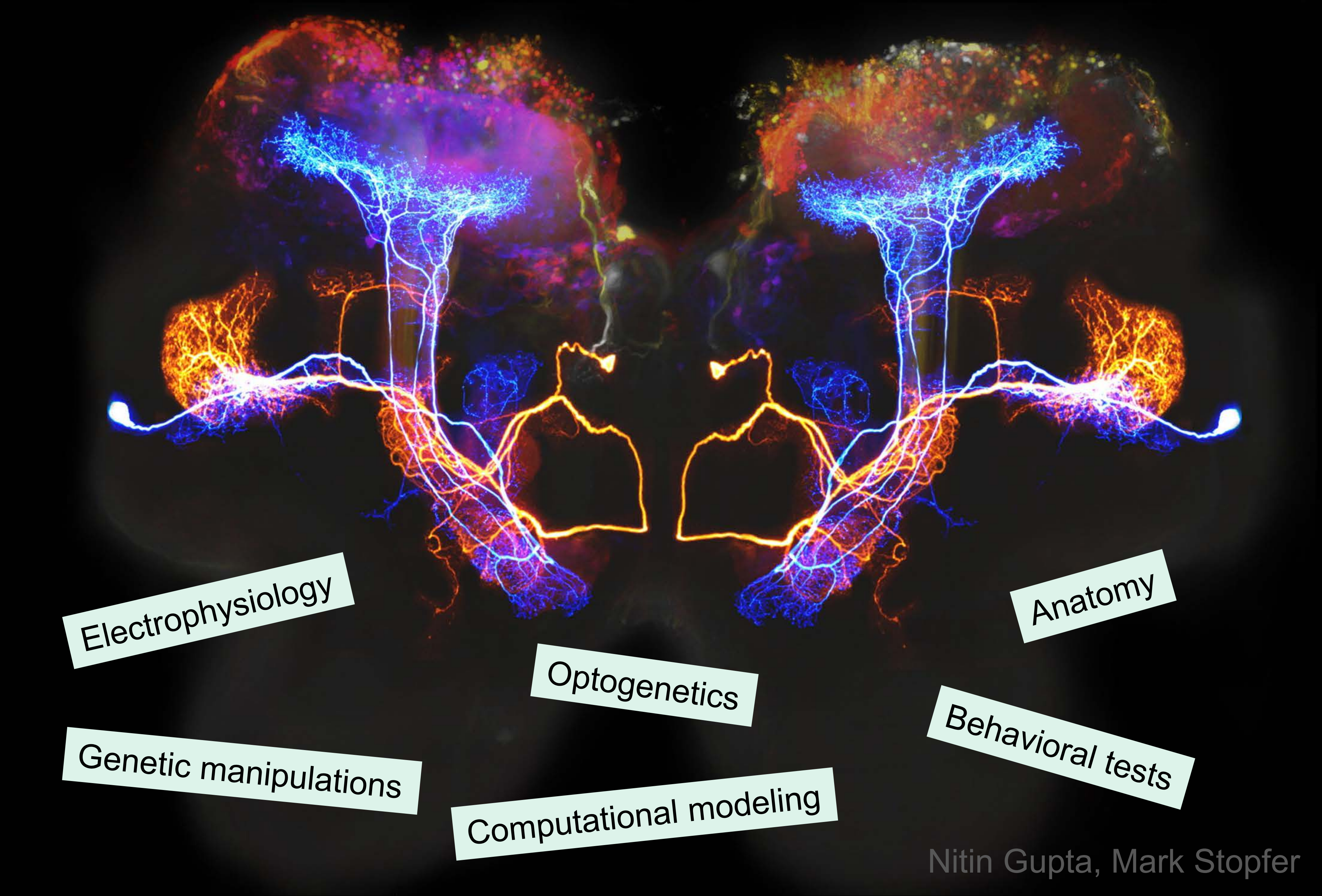


Section on sensory coding and neural ensembles

Basic rules populations of neurons
use to process information

Nitin Gupta, Mark Stopfer

Section on sensory coding and neural ensembles



The sense of taste is important!

What we learned in school

4 basic tastes

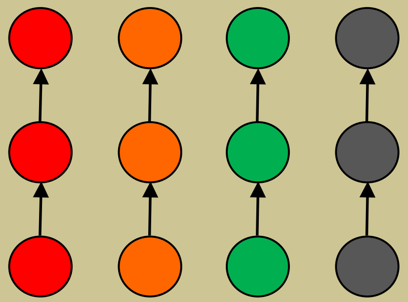
Sweet
Sour
Salty
Bitter

What we learned in school

4 basic tastes

Sweet
Sour
Salty
Bitter

Labeled line coding



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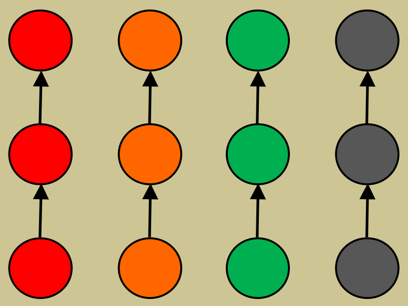
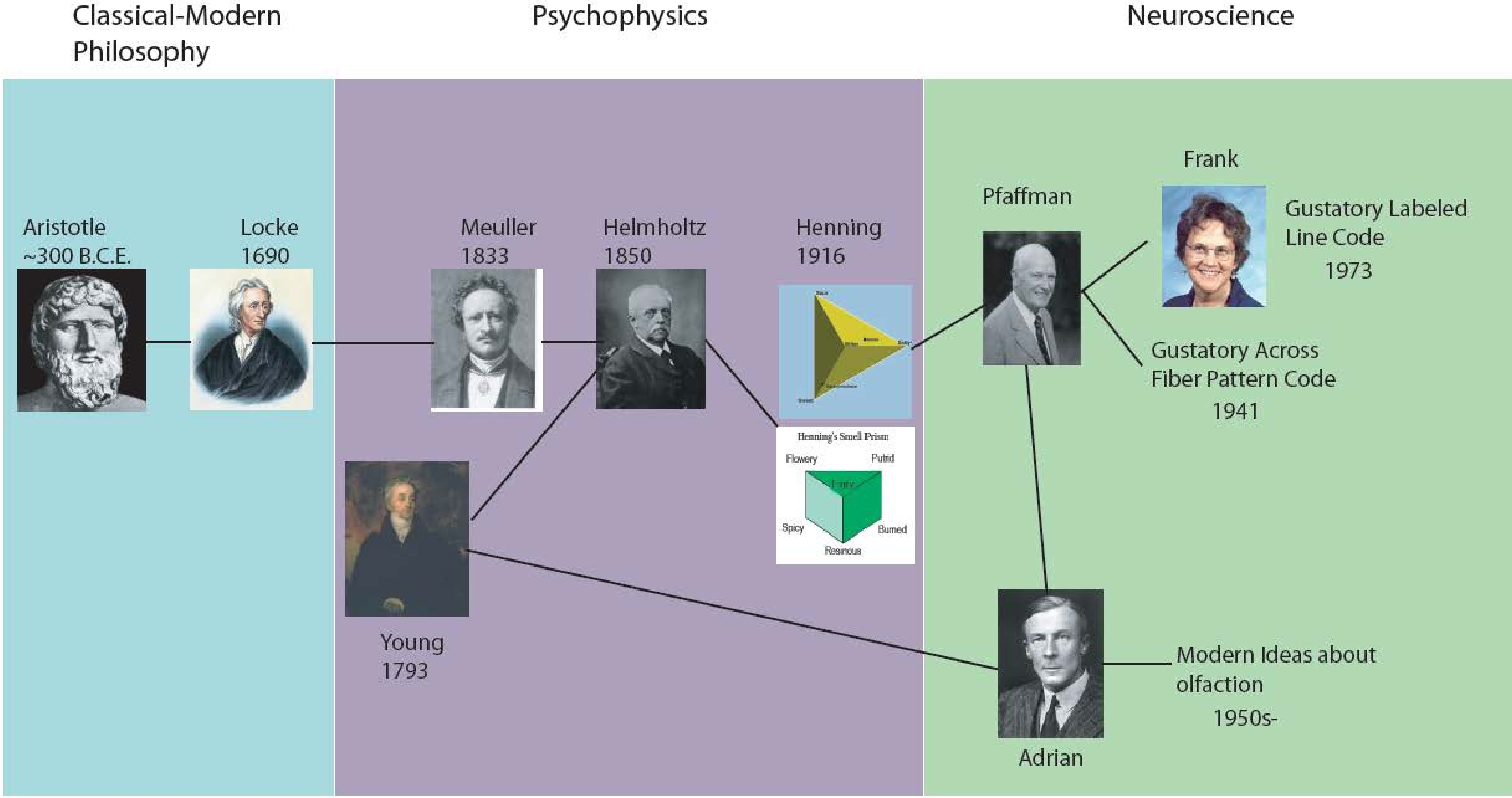


Must be quick

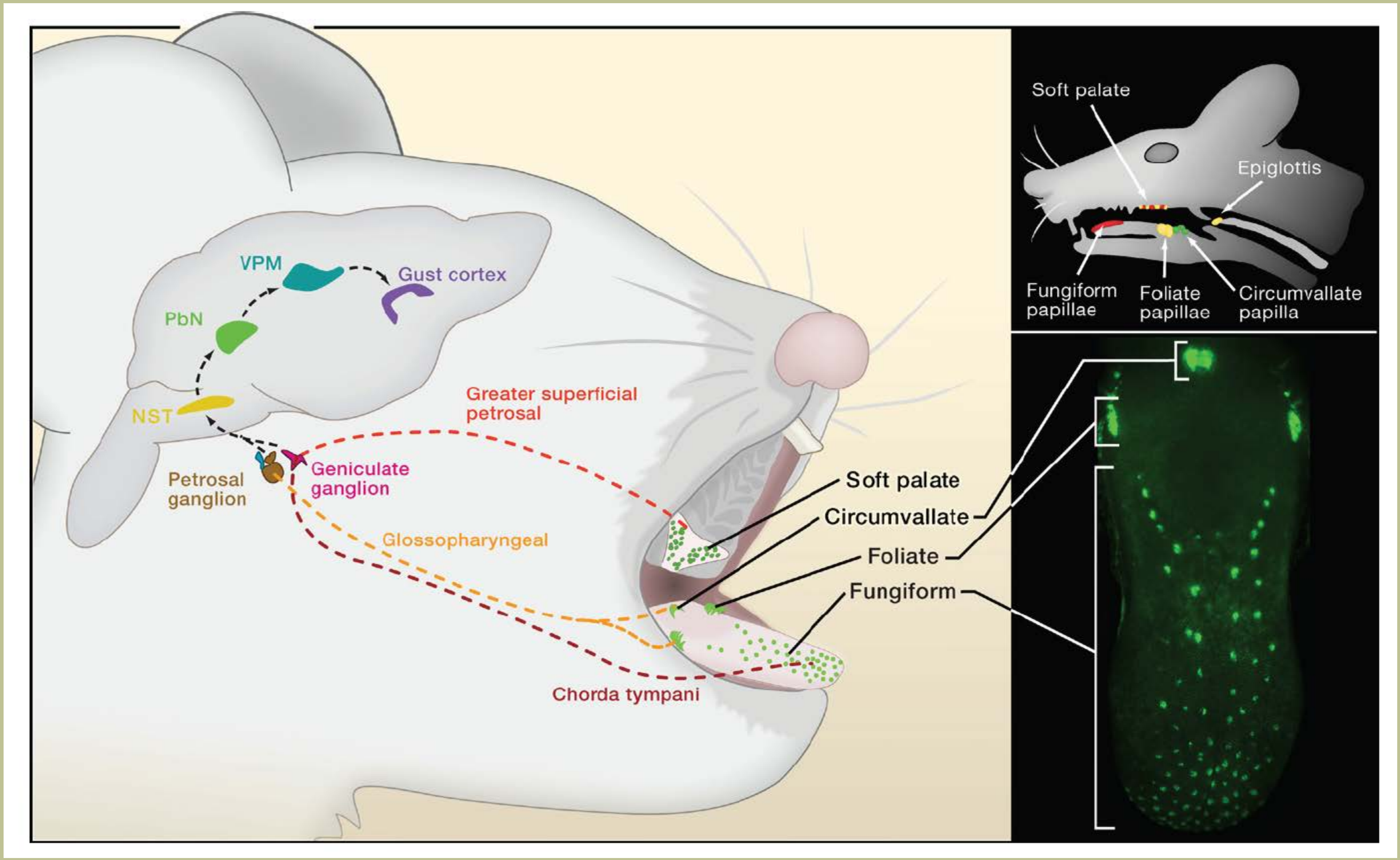
Must be accurate

Ideas about taste are not new...



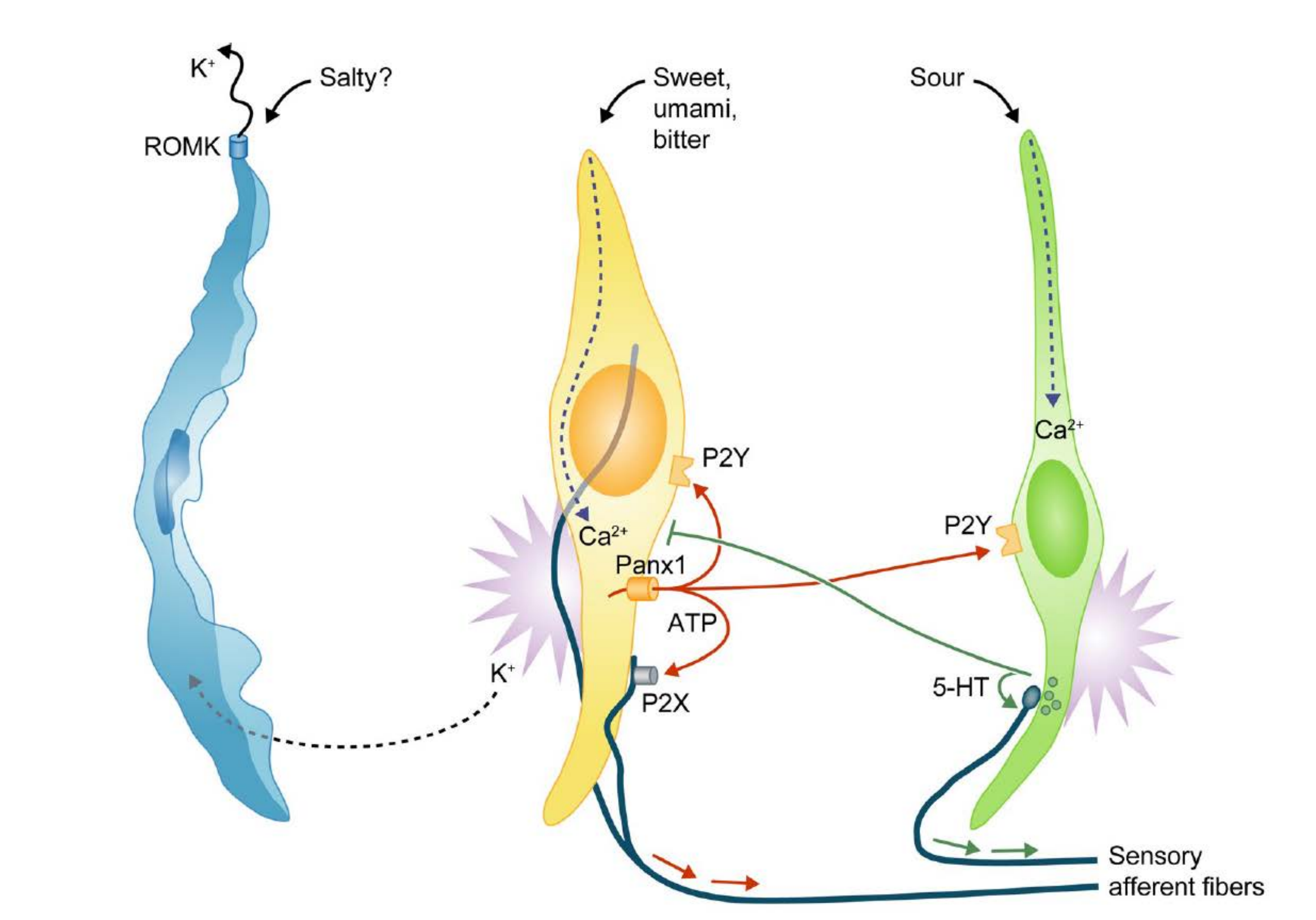
… but they're very hard to test

Vertebrates are complicated!



Yarmolinsky et al 2009

Vertebrates are complicated!

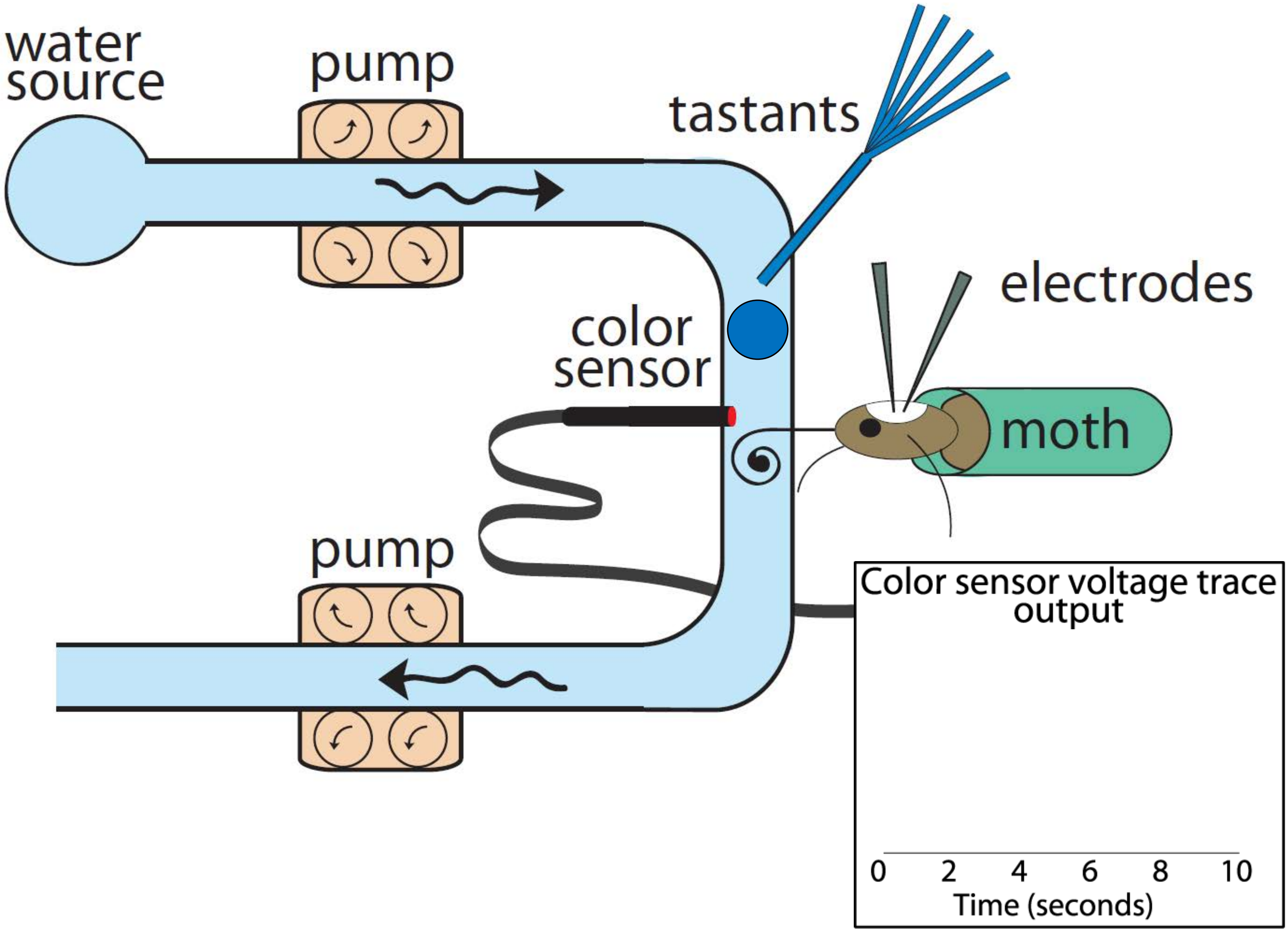


Chaudri and Roper 2010

A simple systems approach

- Fewer neurons than vertebrates
- Work with intact, awake animals
- Point – by – point analysis of function


Graeme Lowe

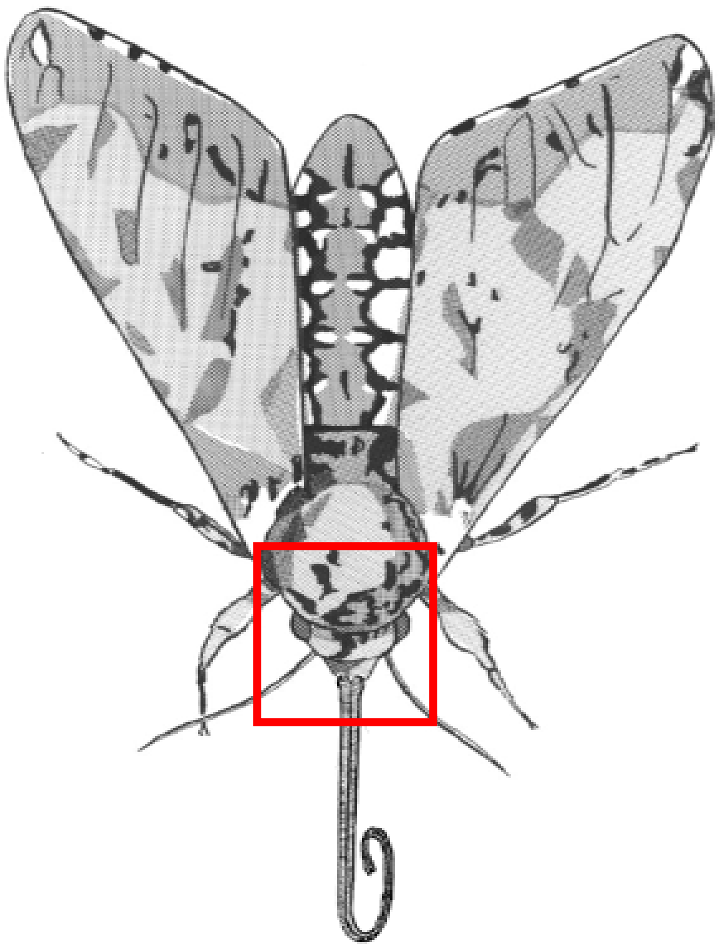

water source
pump
tastants
electrodes
color sensor
moth
pump
Color sensor voltage trace output
0
2
4
6
8
10
Time (seconds)

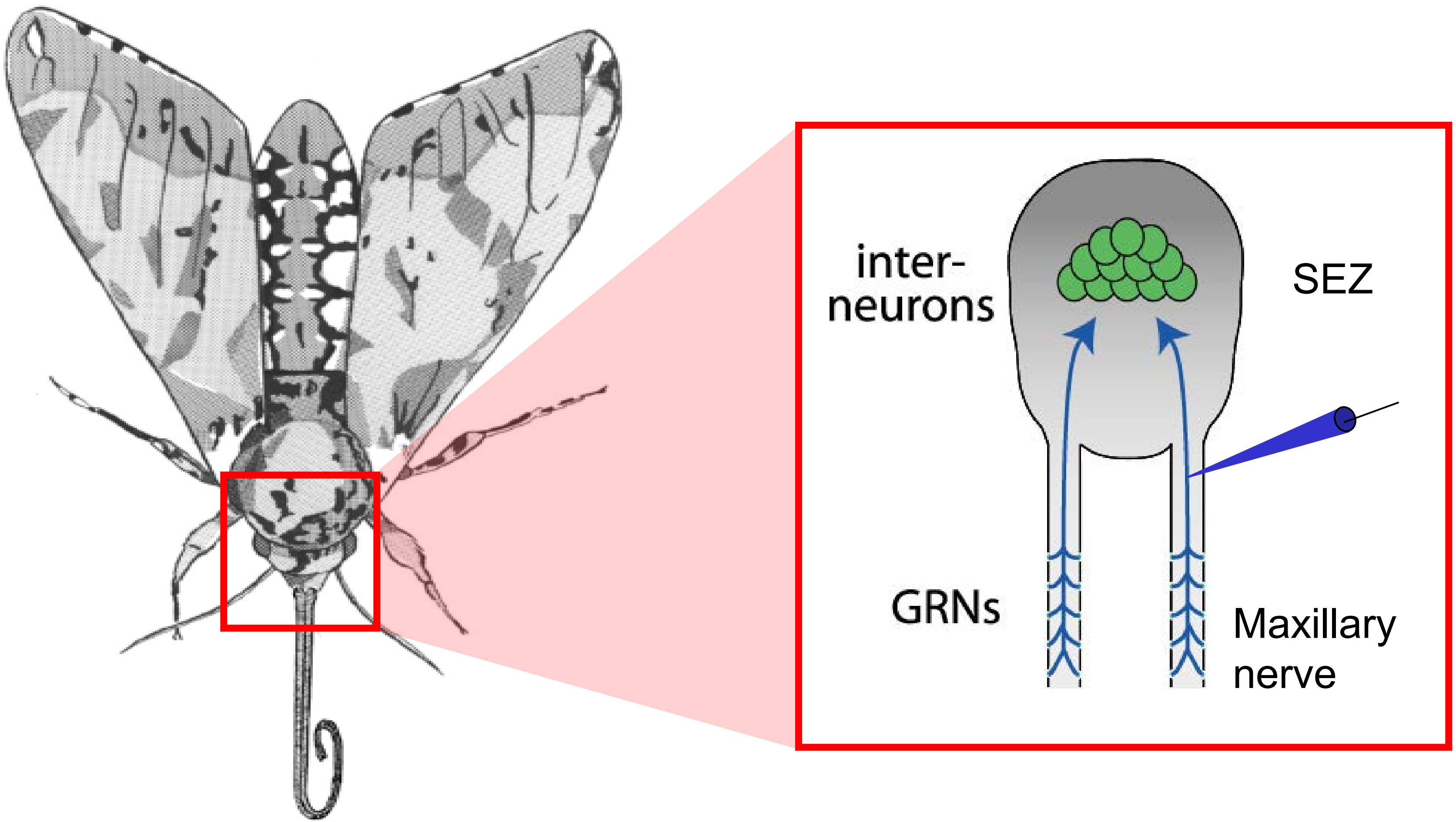
Questions:

- *Are there only a few basic tastes, or are taste chemicals each encoded uniquely?*

- *What is the nature of the neural code for taste? Is it quick and accurate?*

- *Is taste processed by labeled lines?*



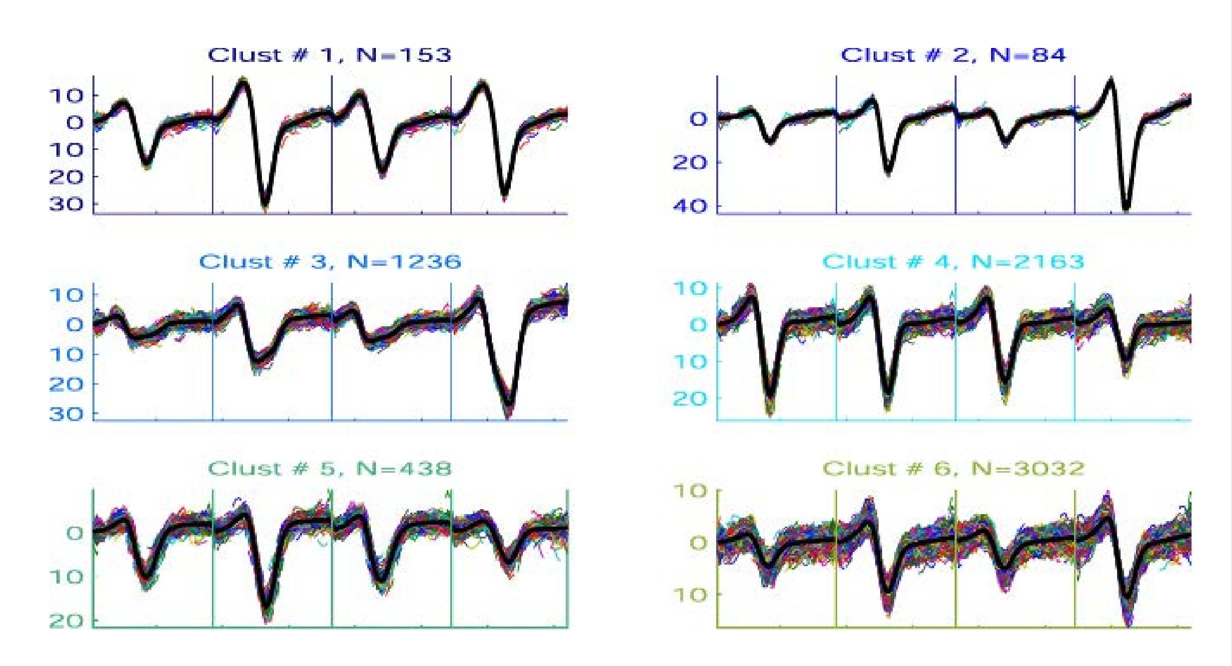


inter-
neurons
SEZ
GRNs
Maxillary
nerve

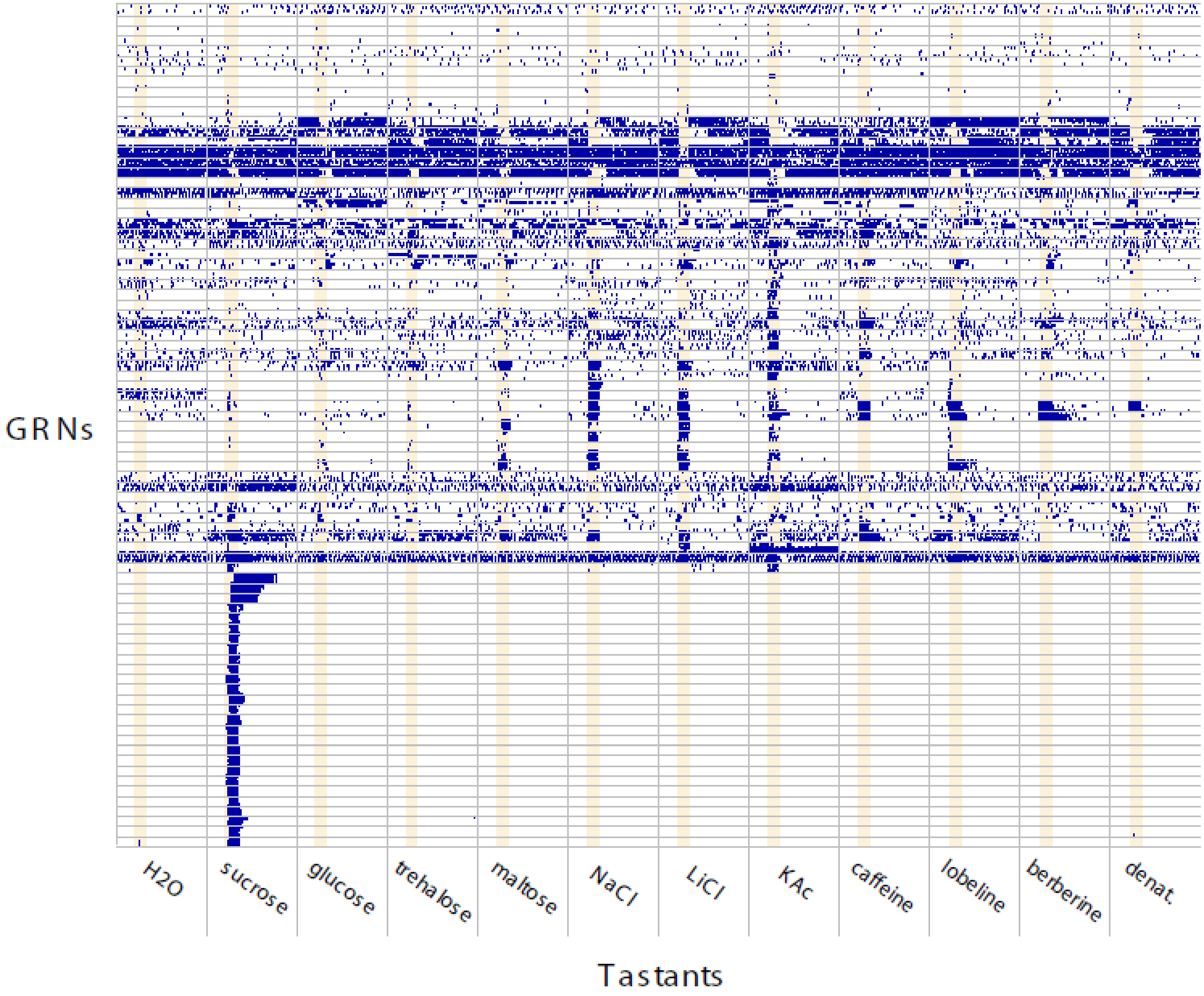
GRNs

Gustatory
Receptor
Neurons

"tetrode" extracellular recordings



Encoding Tastant Identity



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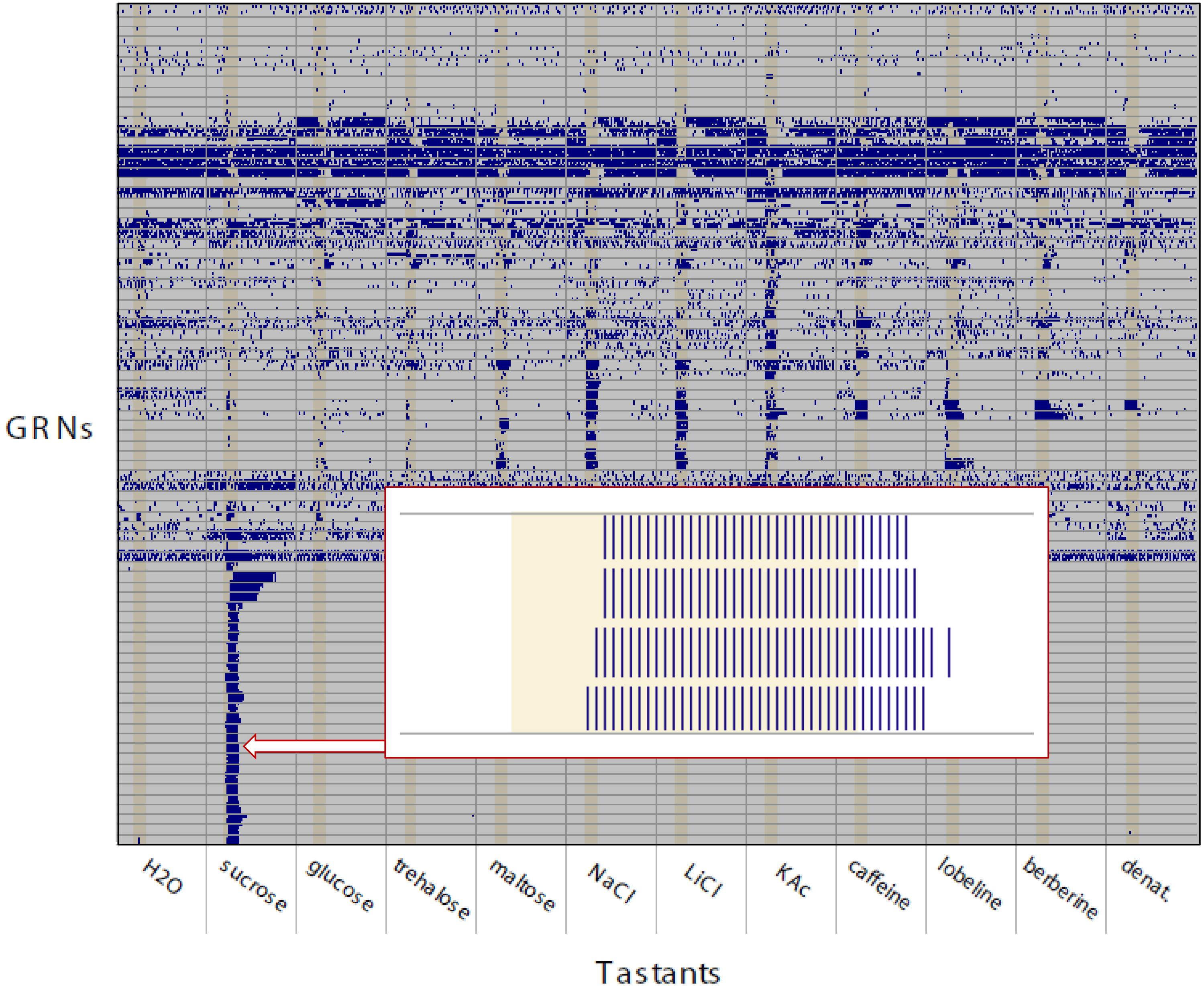

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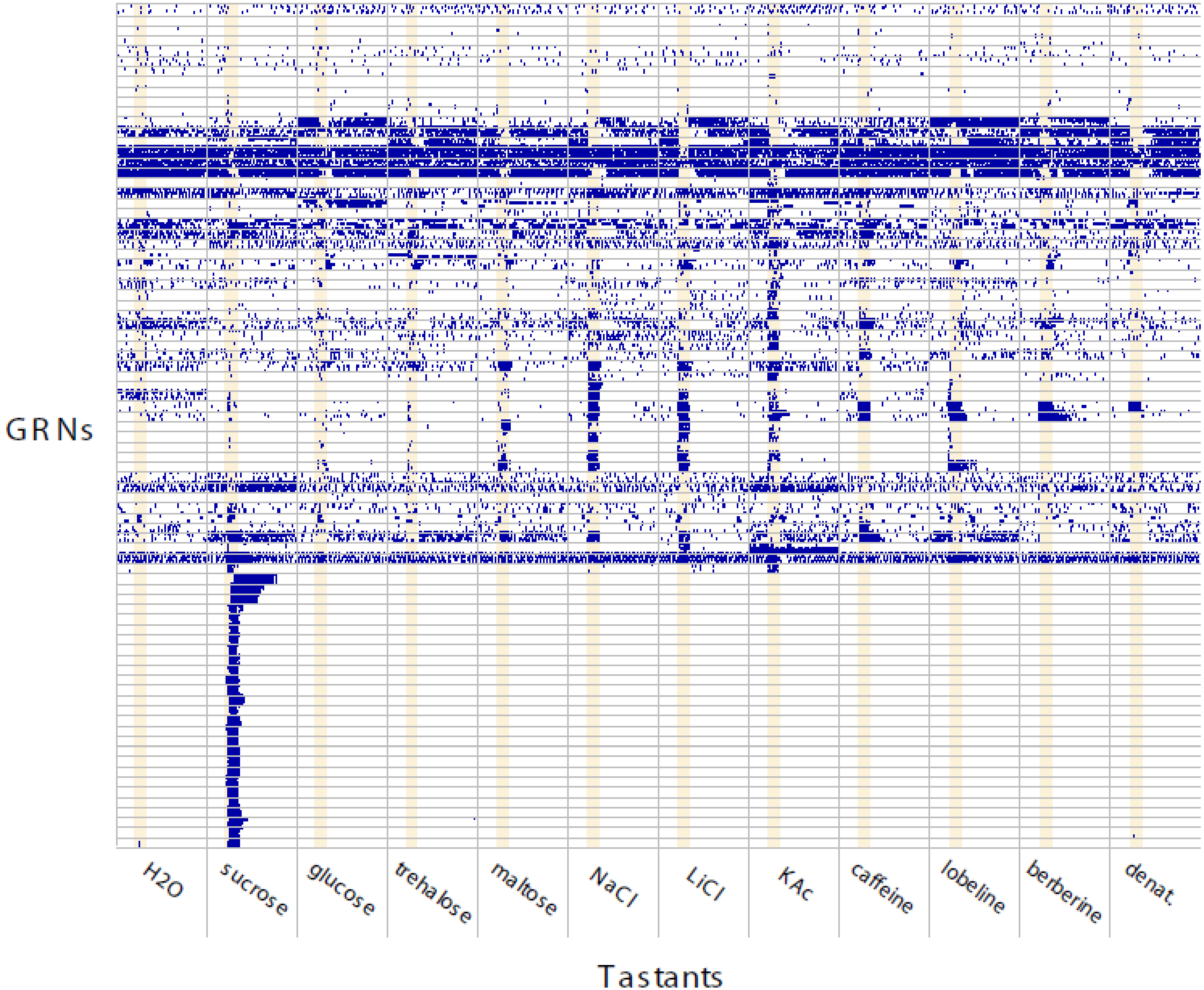

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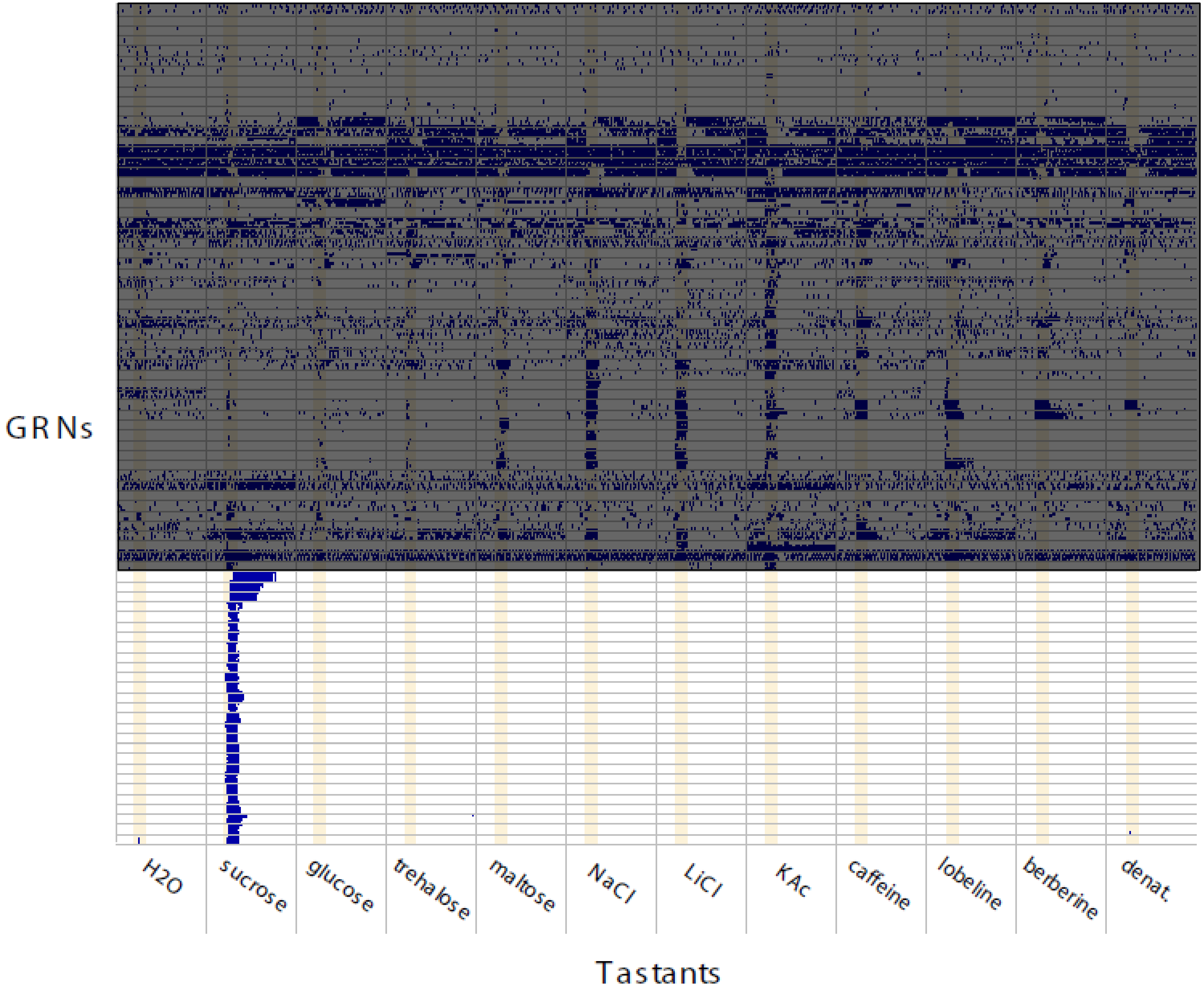

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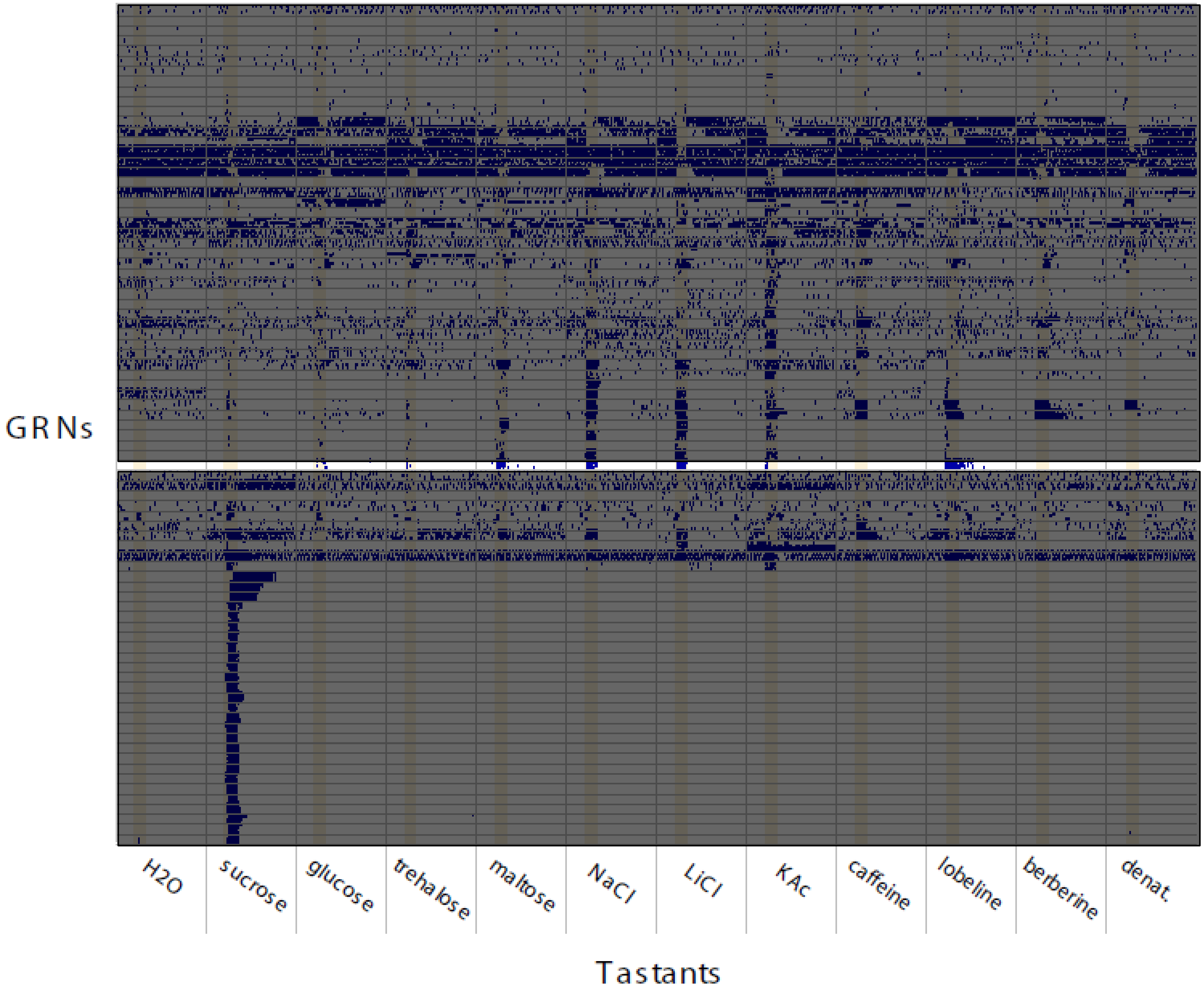

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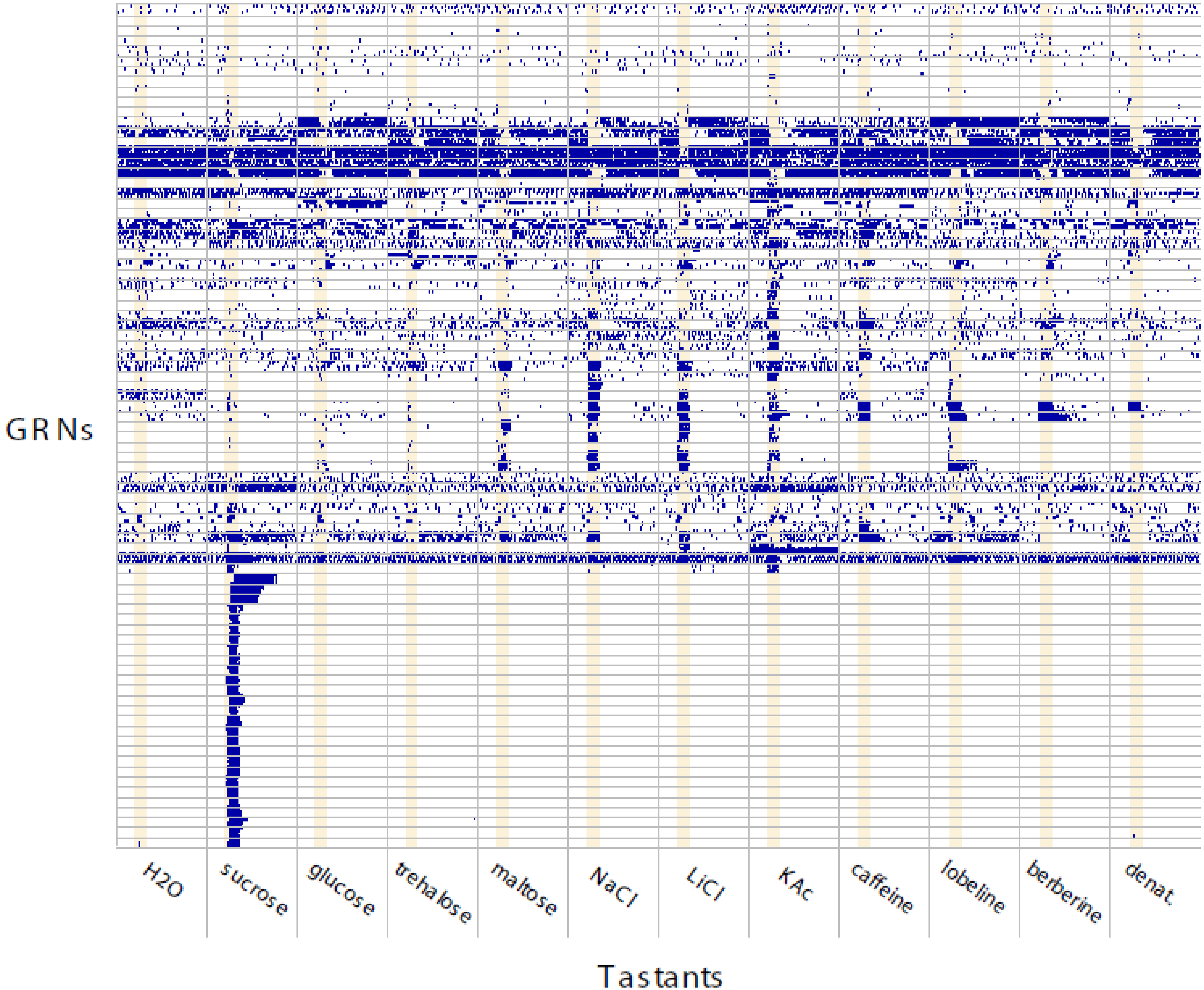
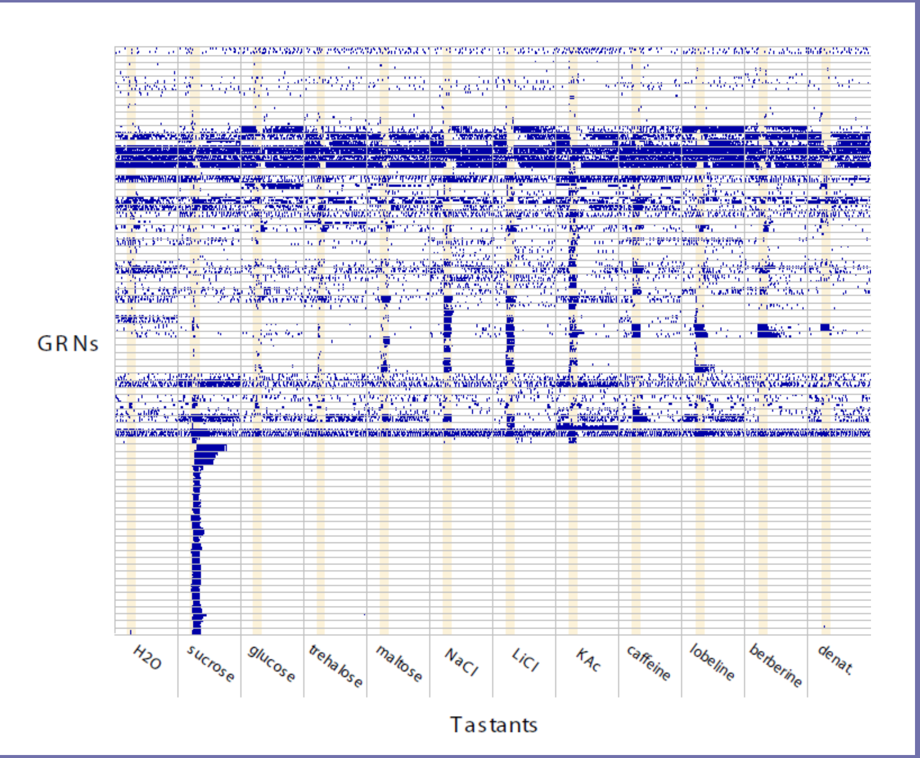


Information content of GRNs



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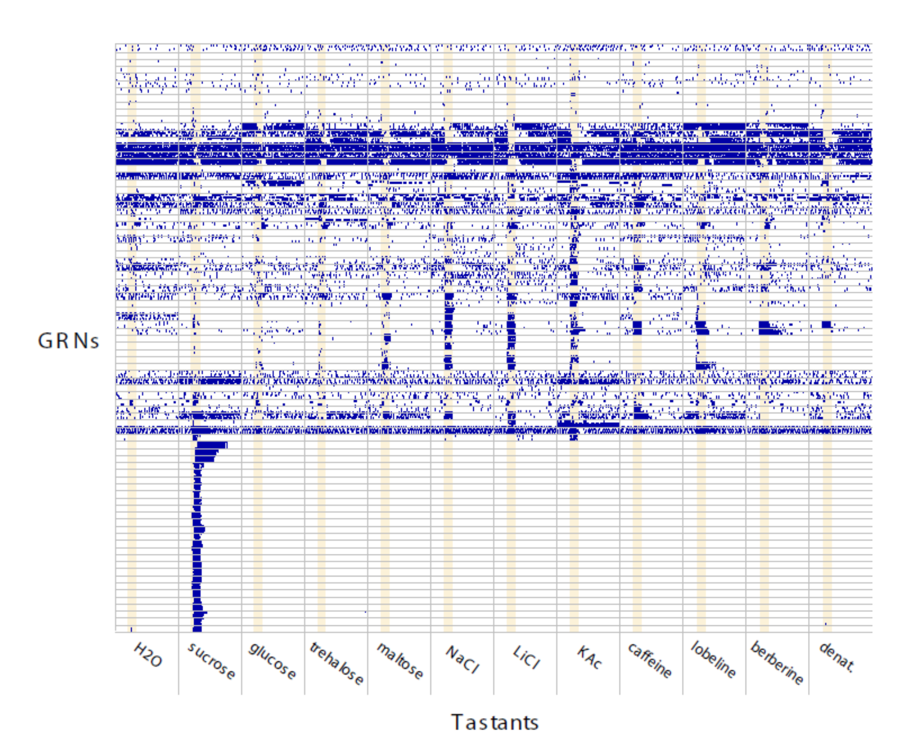

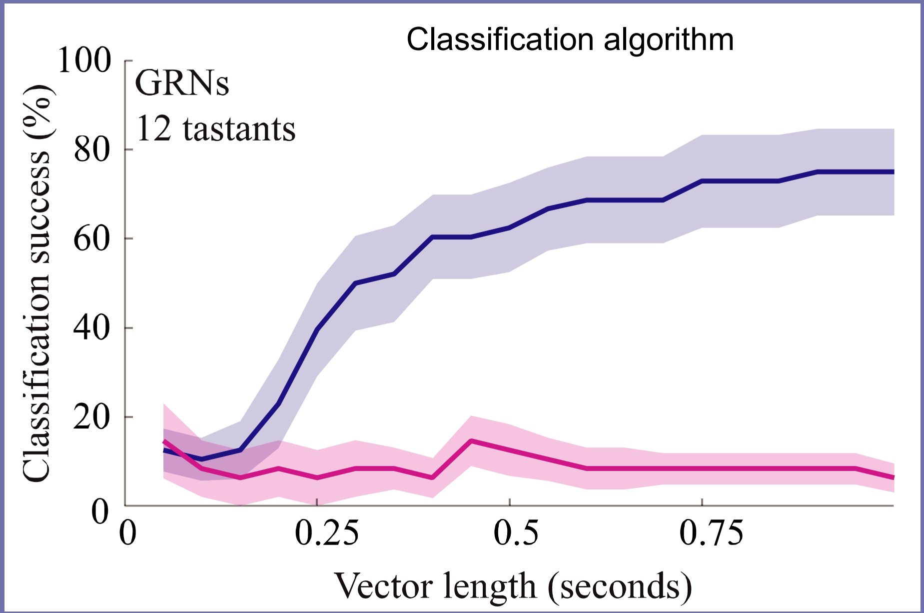

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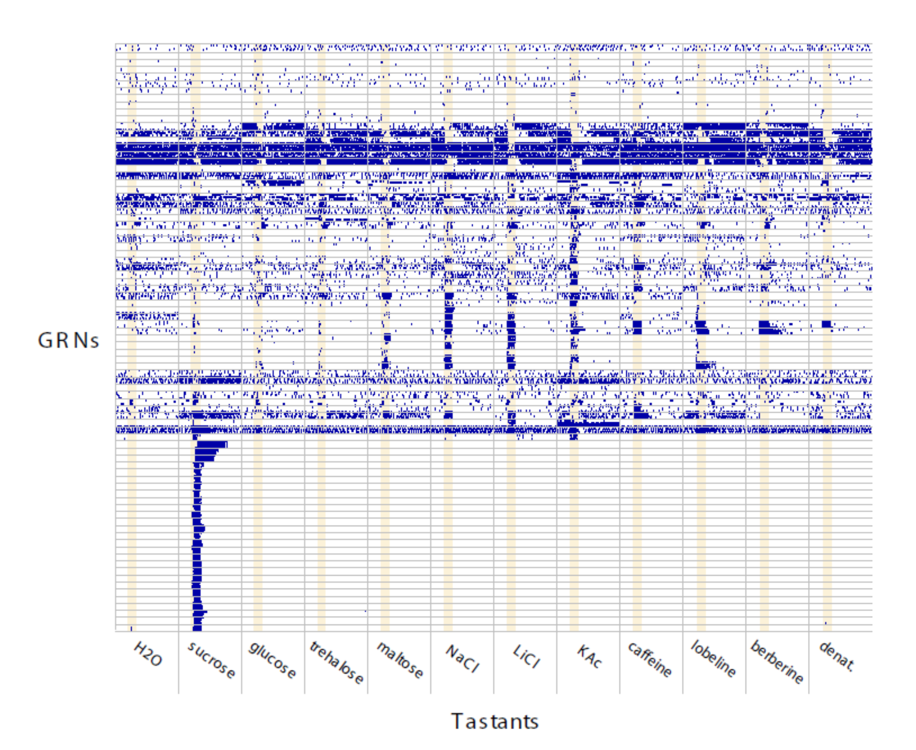

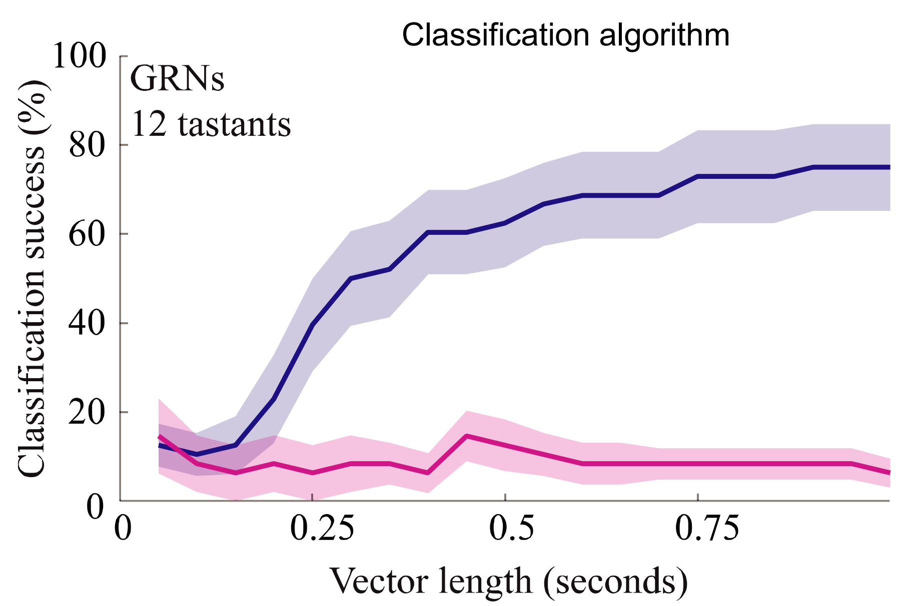

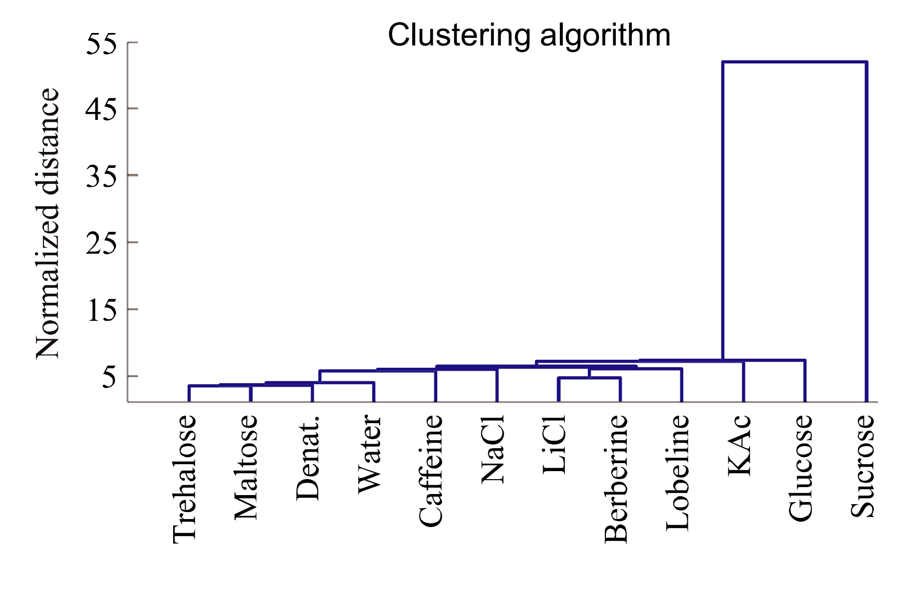

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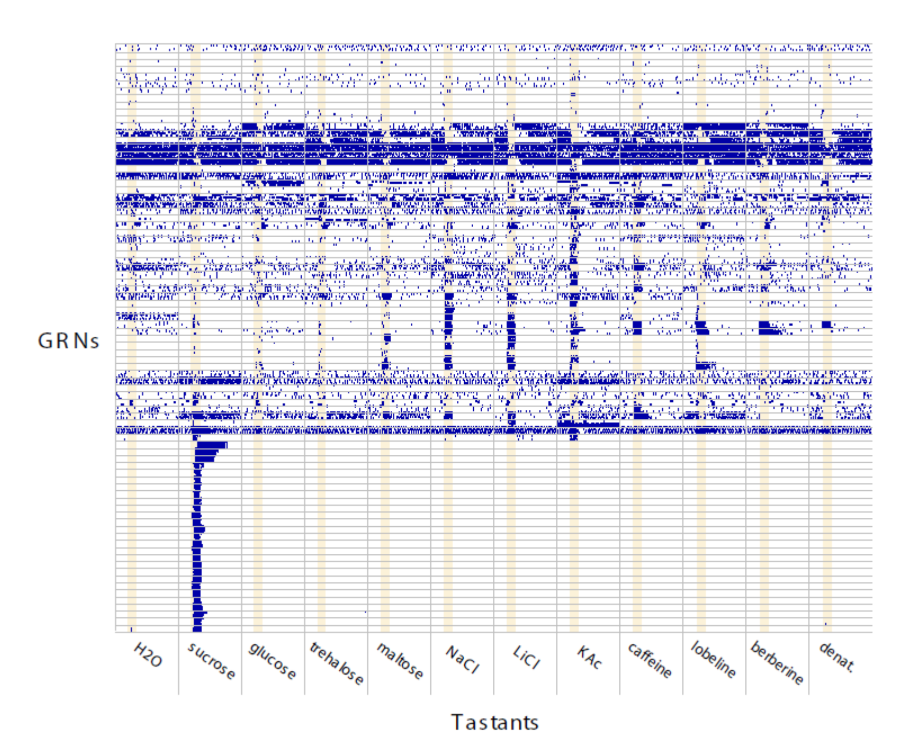

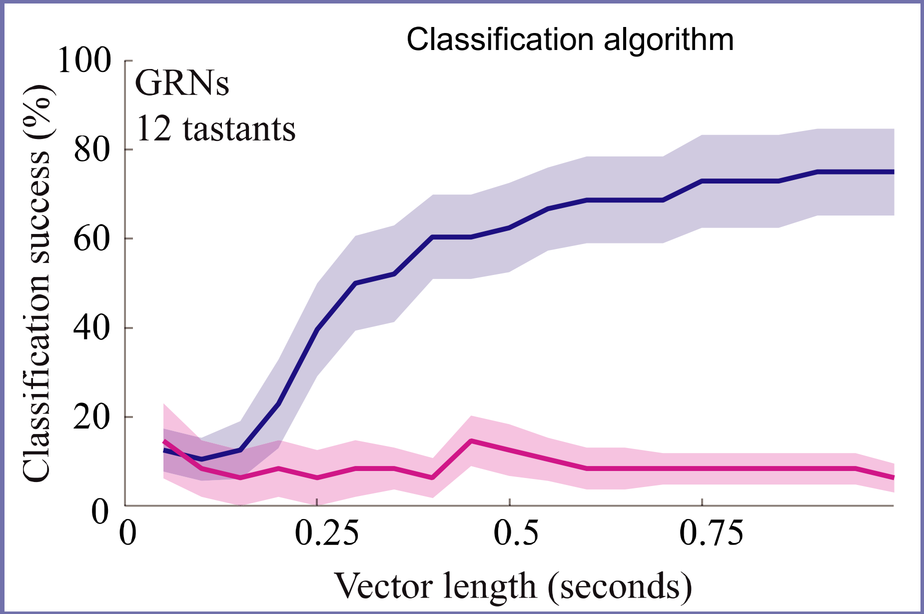

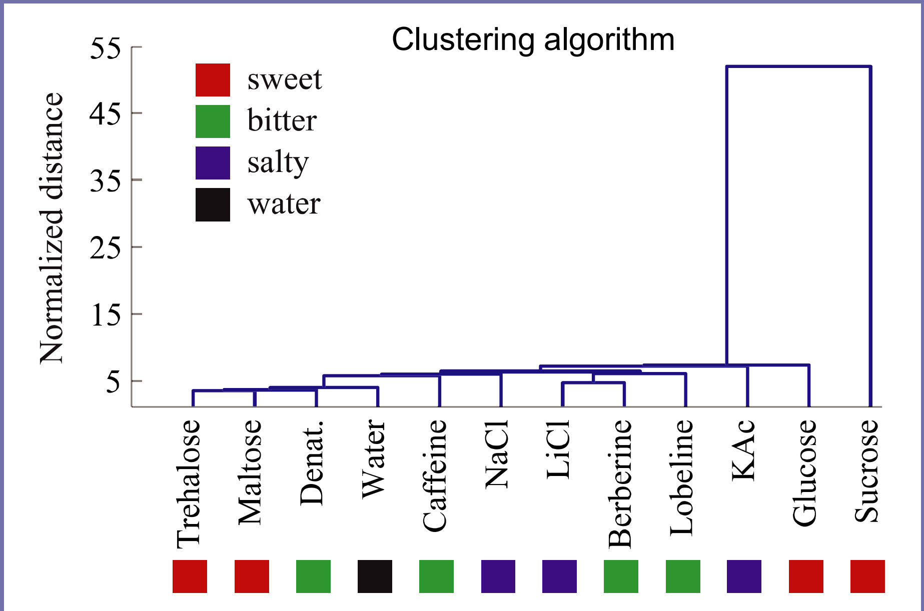

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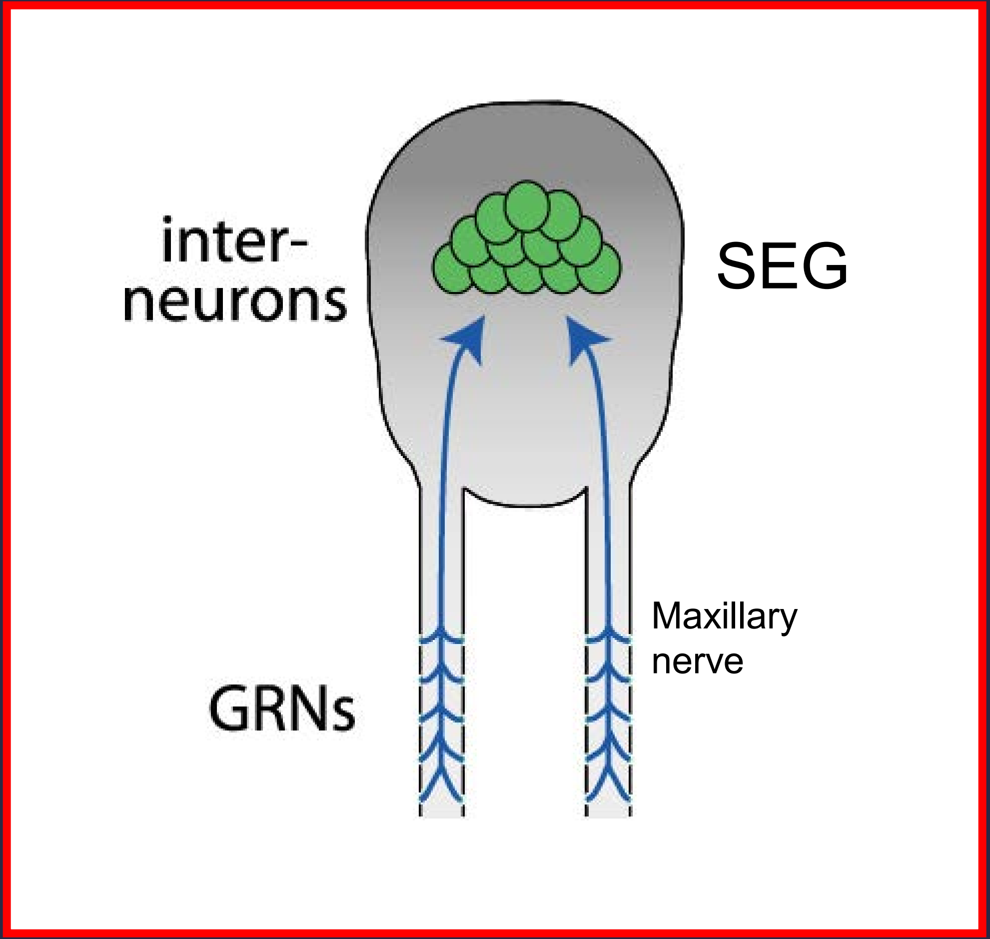
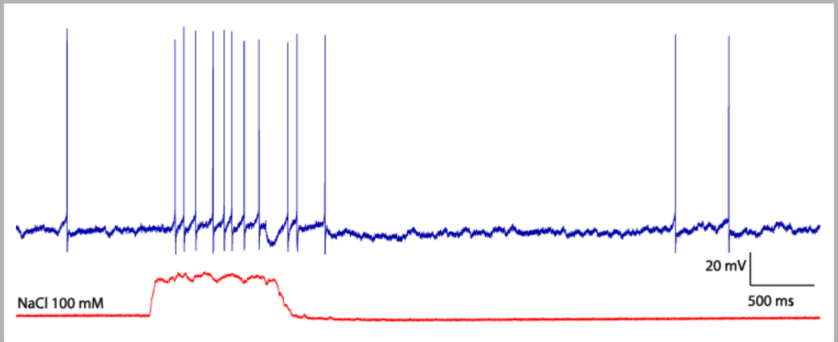
-GRNs show a diversity of temporal responses

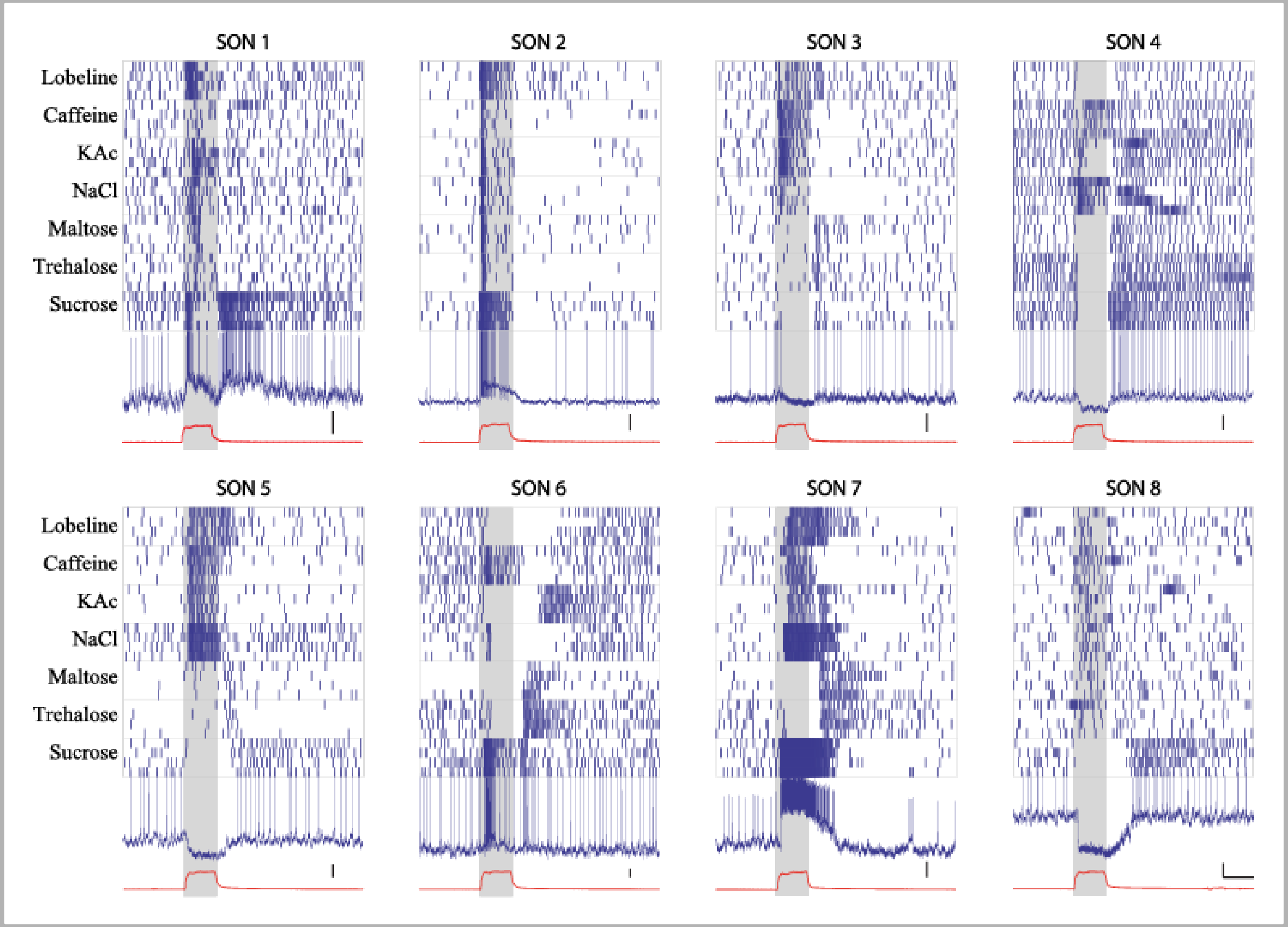
Where does information from GRNs go next?

GRNs project to the SEG



Sharp-electrode intracellular: second order neurons





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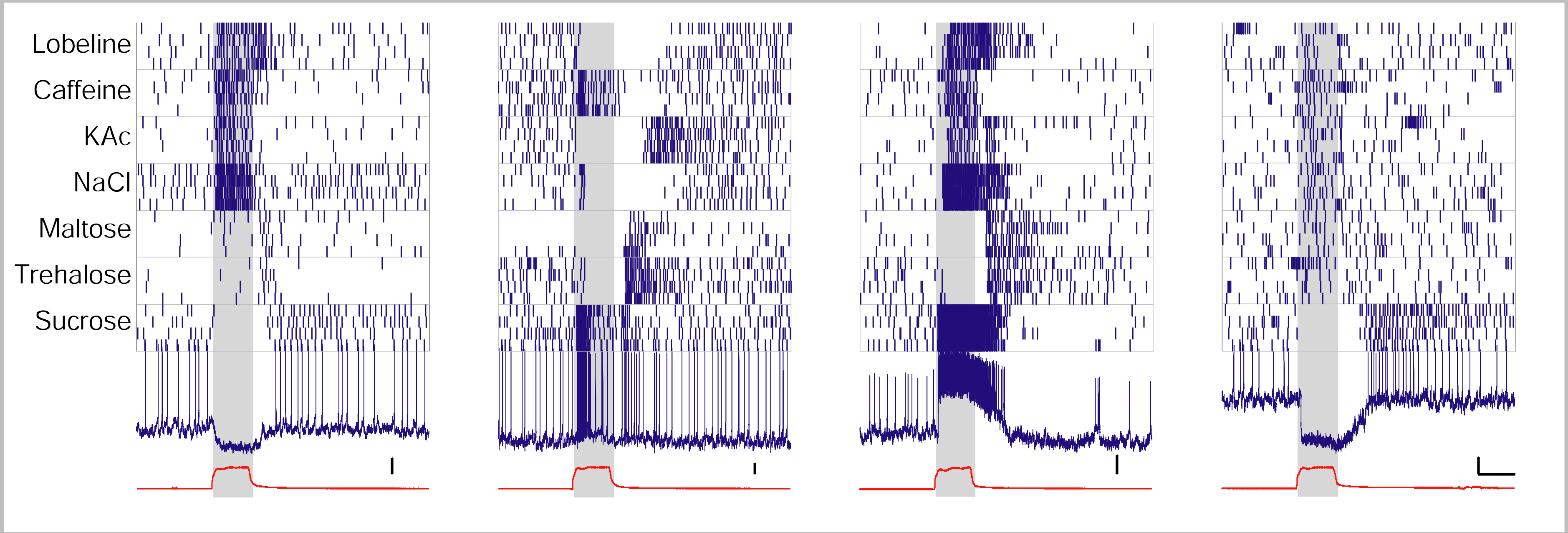
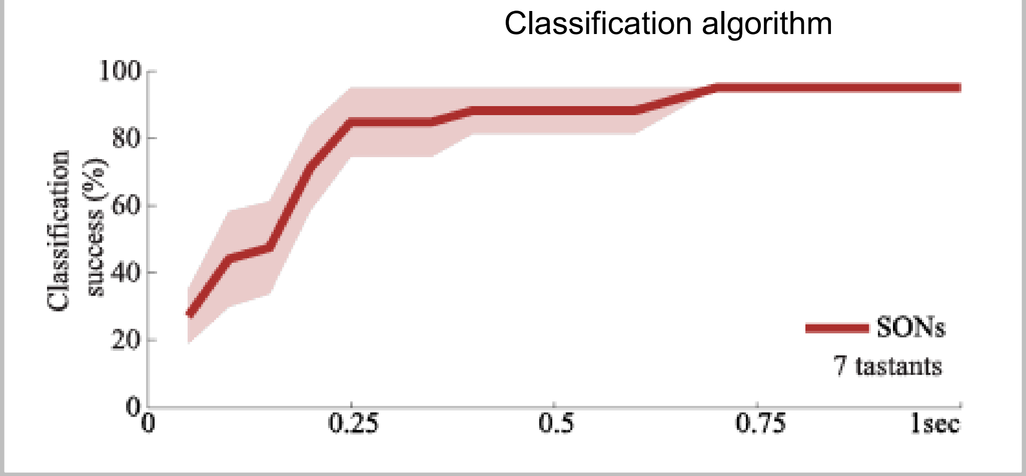


Information content of SONs



Classification accuracy and speed

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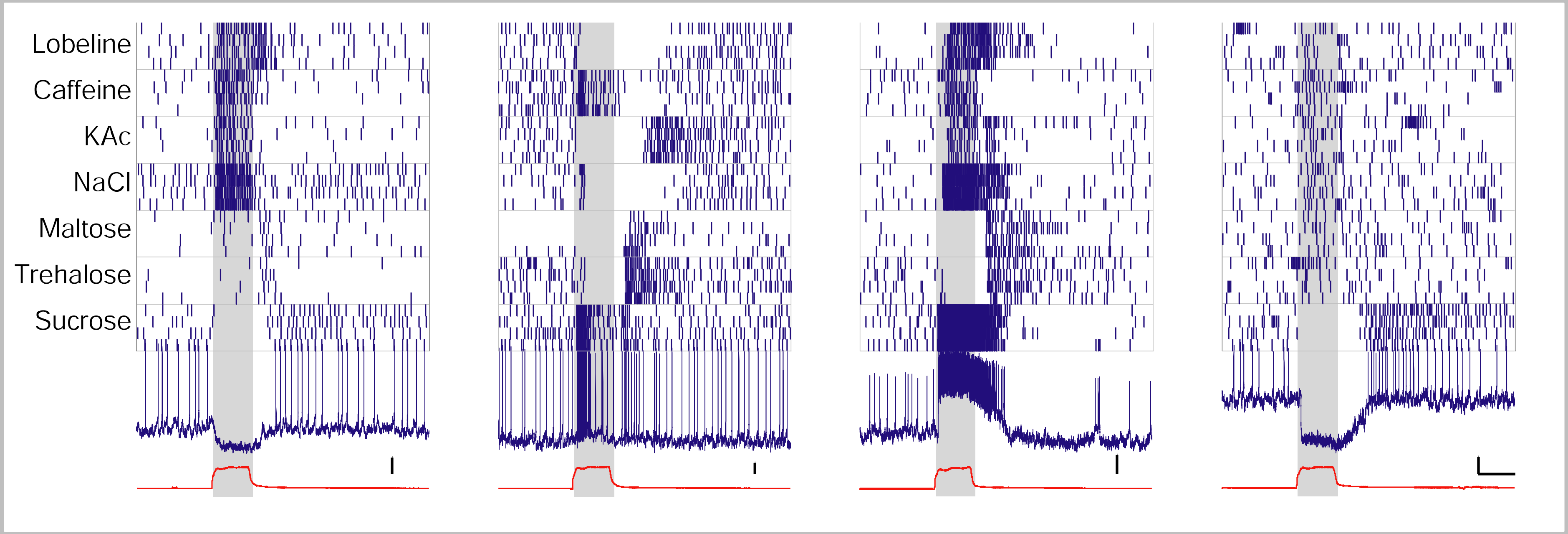

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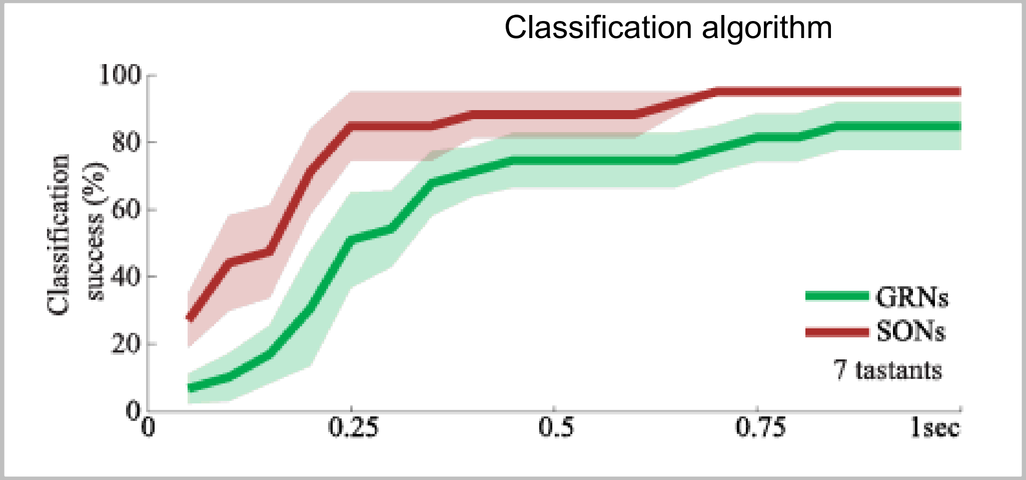
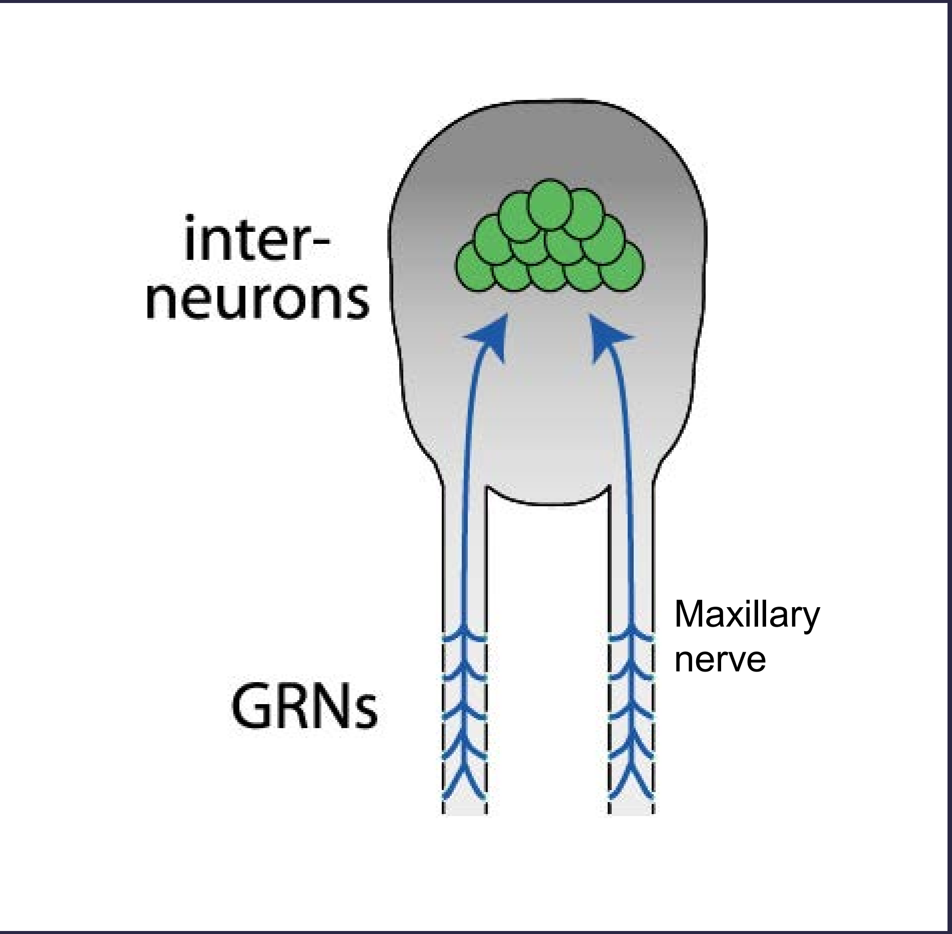
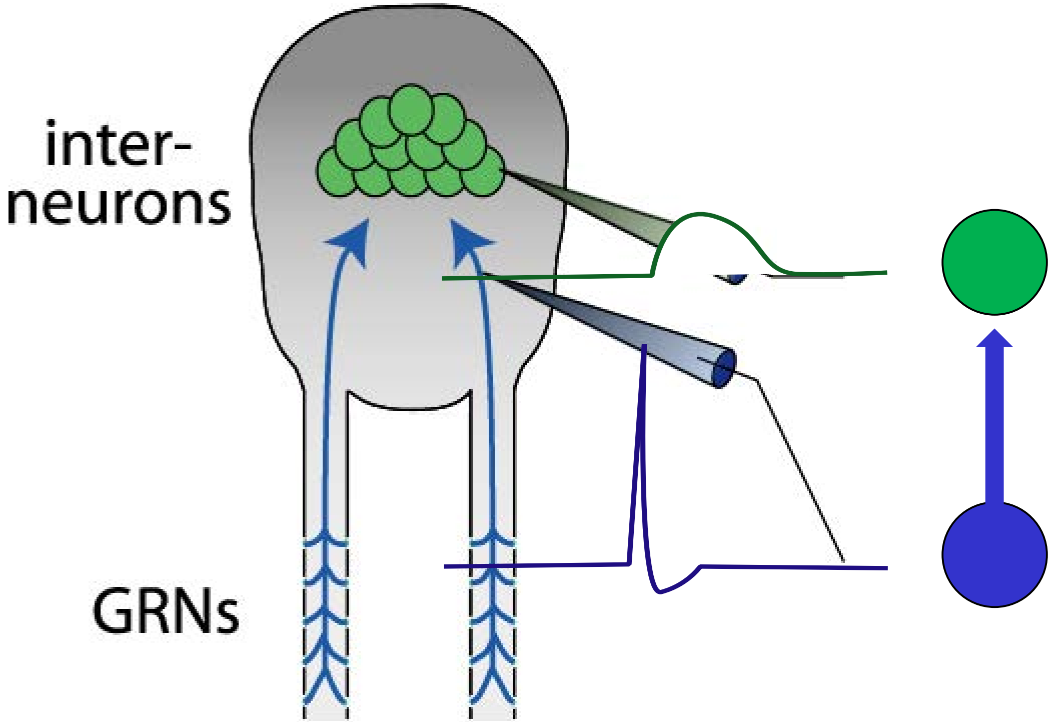


Classification accuracy and speed

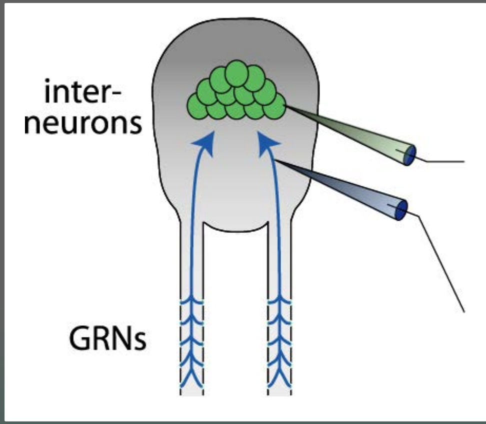
How are these cells wired? As labeled lines?

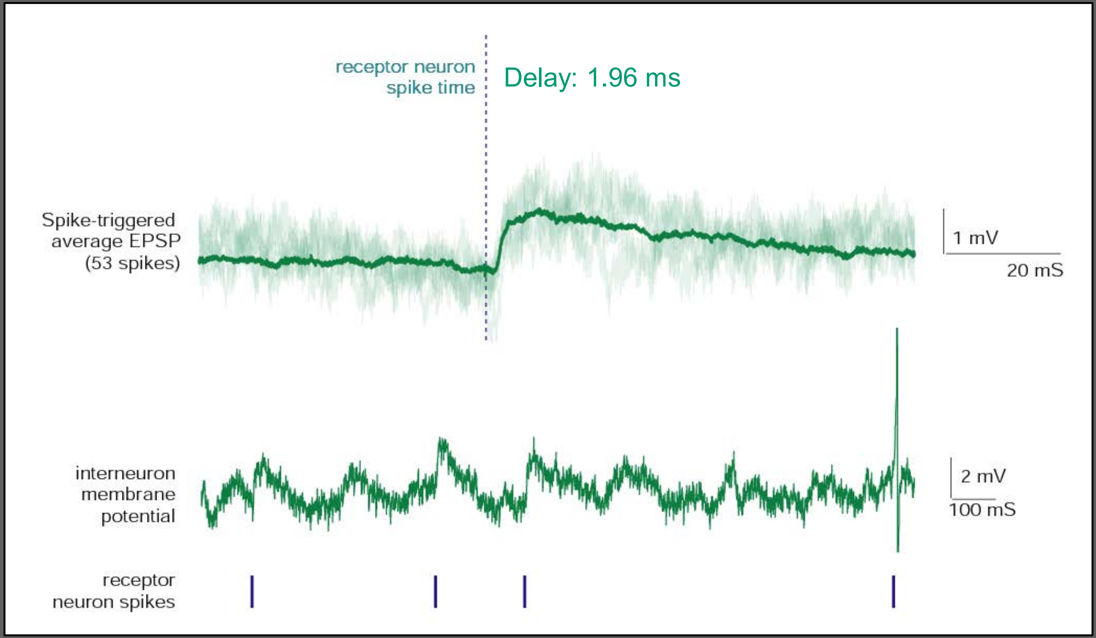


Finding direct, monosynaptic connections



GRN→follower connectivity and integration





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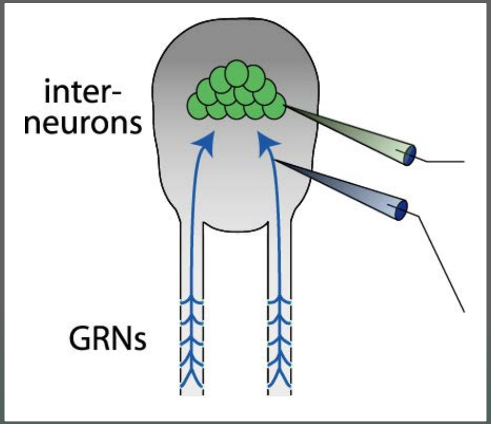

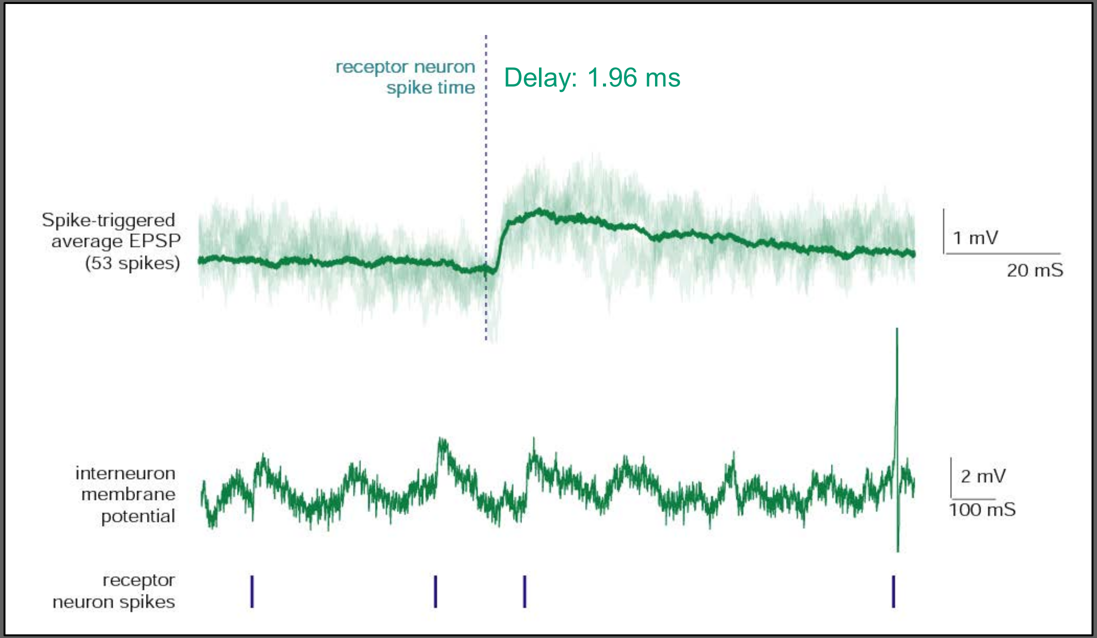

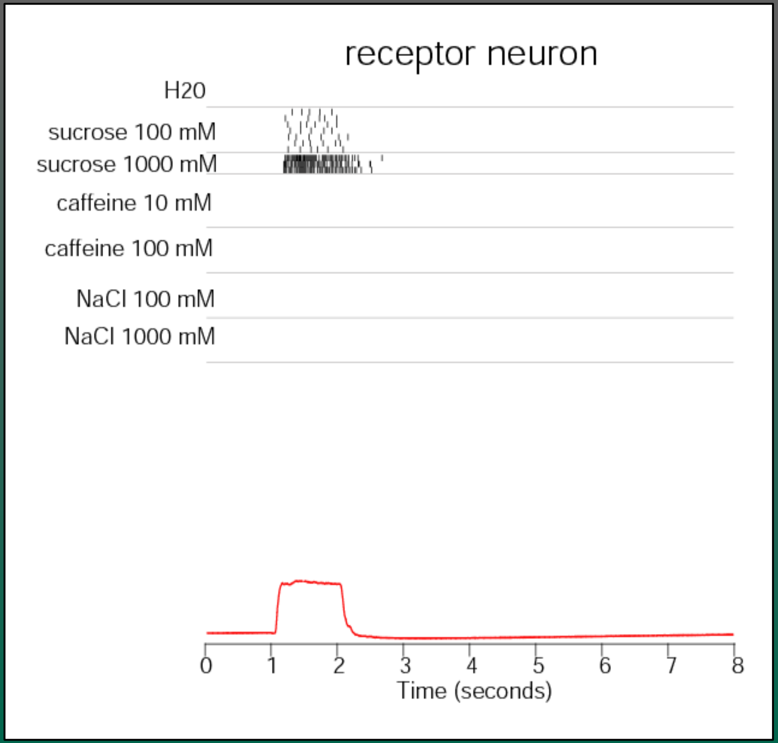

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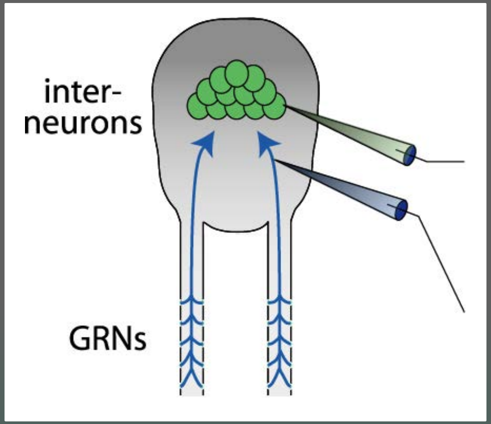

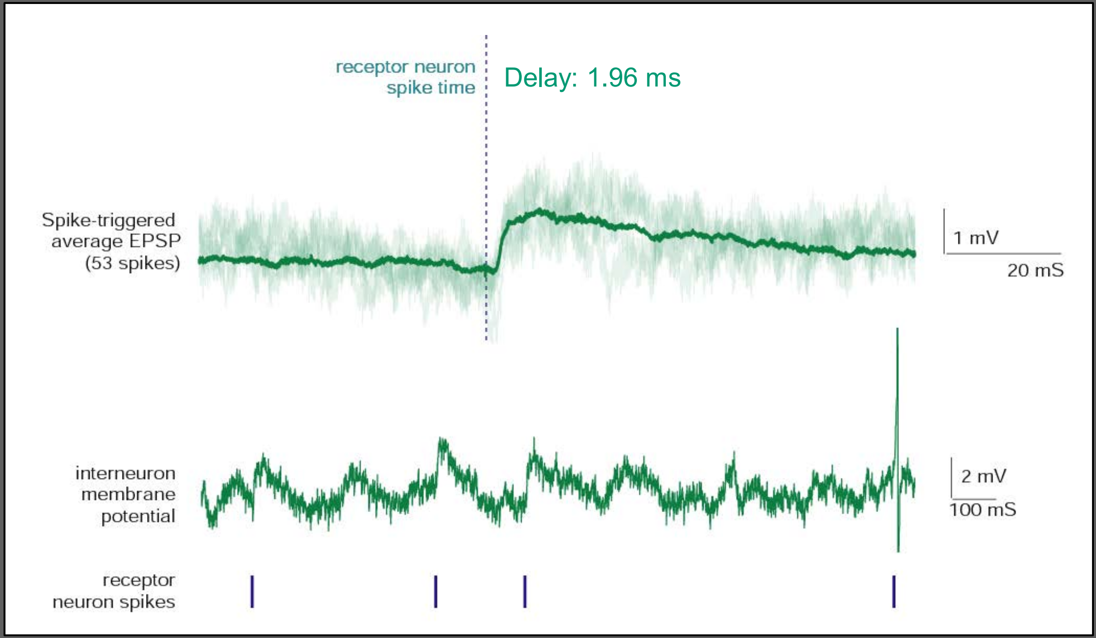

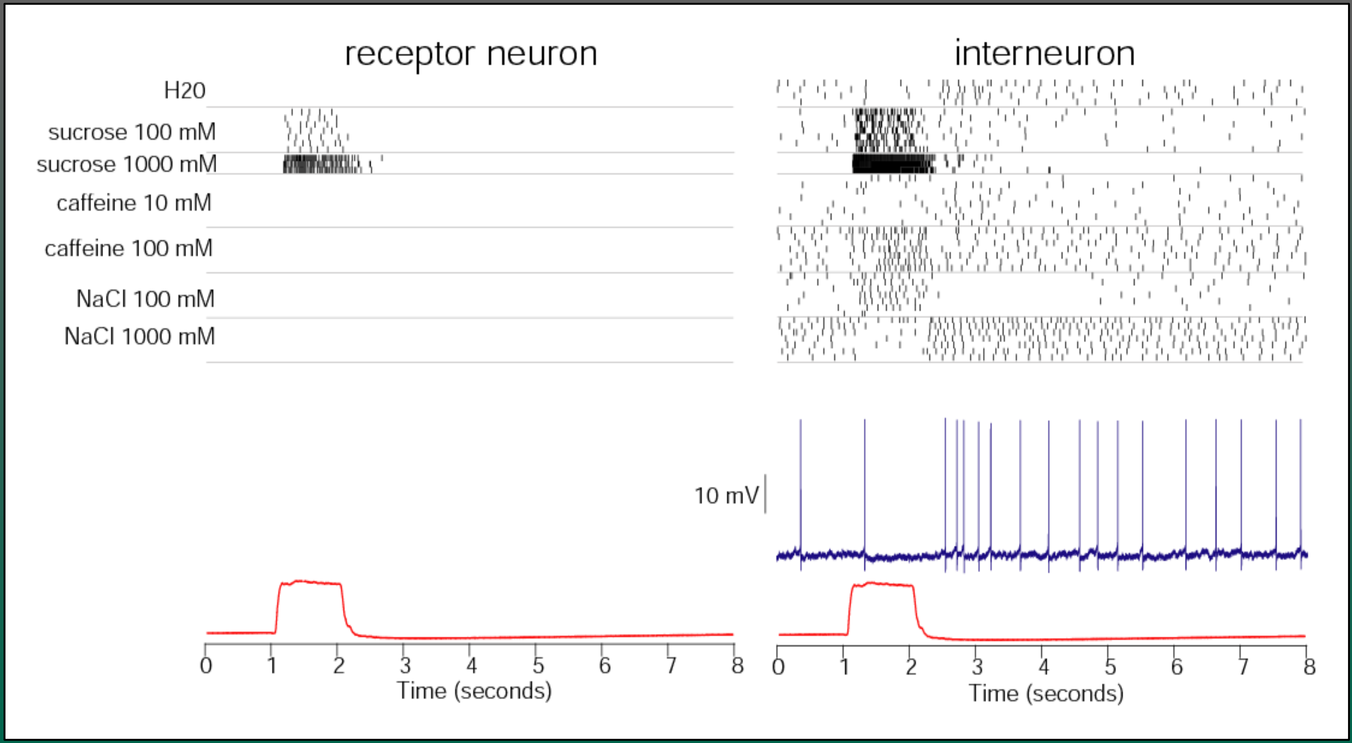

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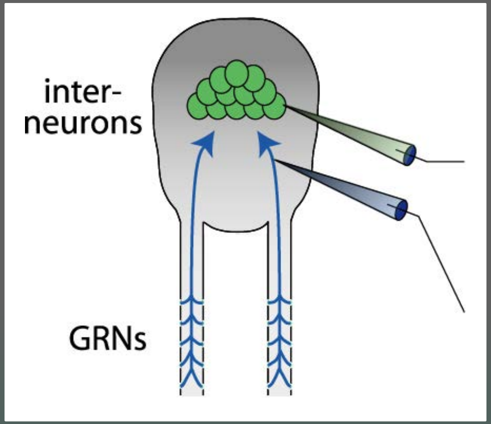

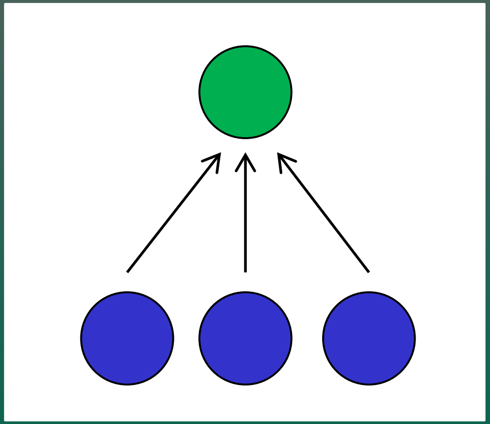

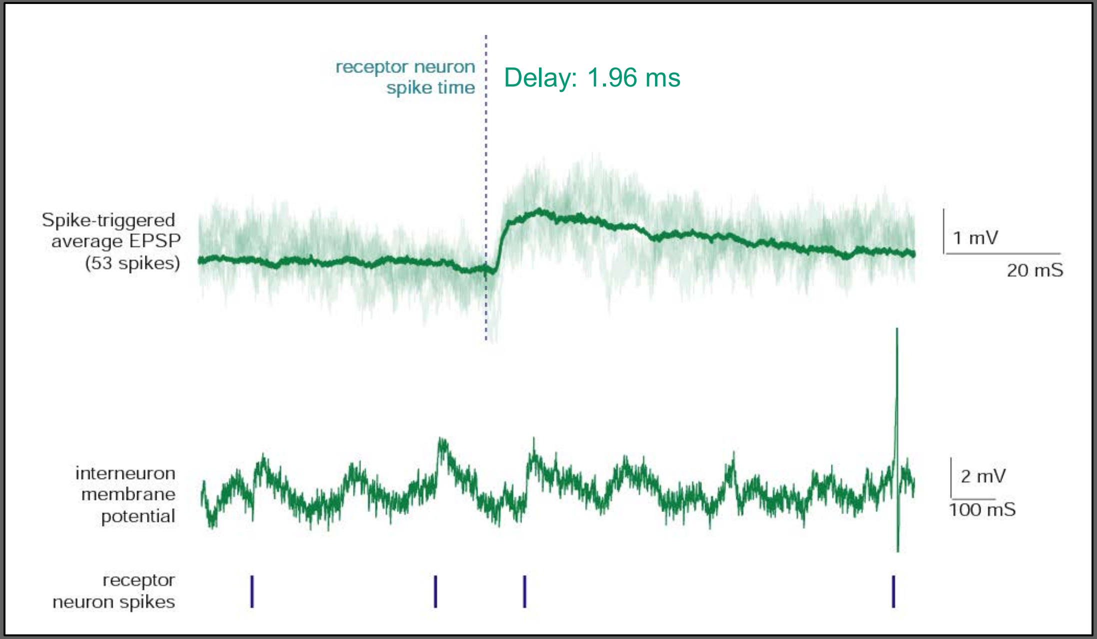

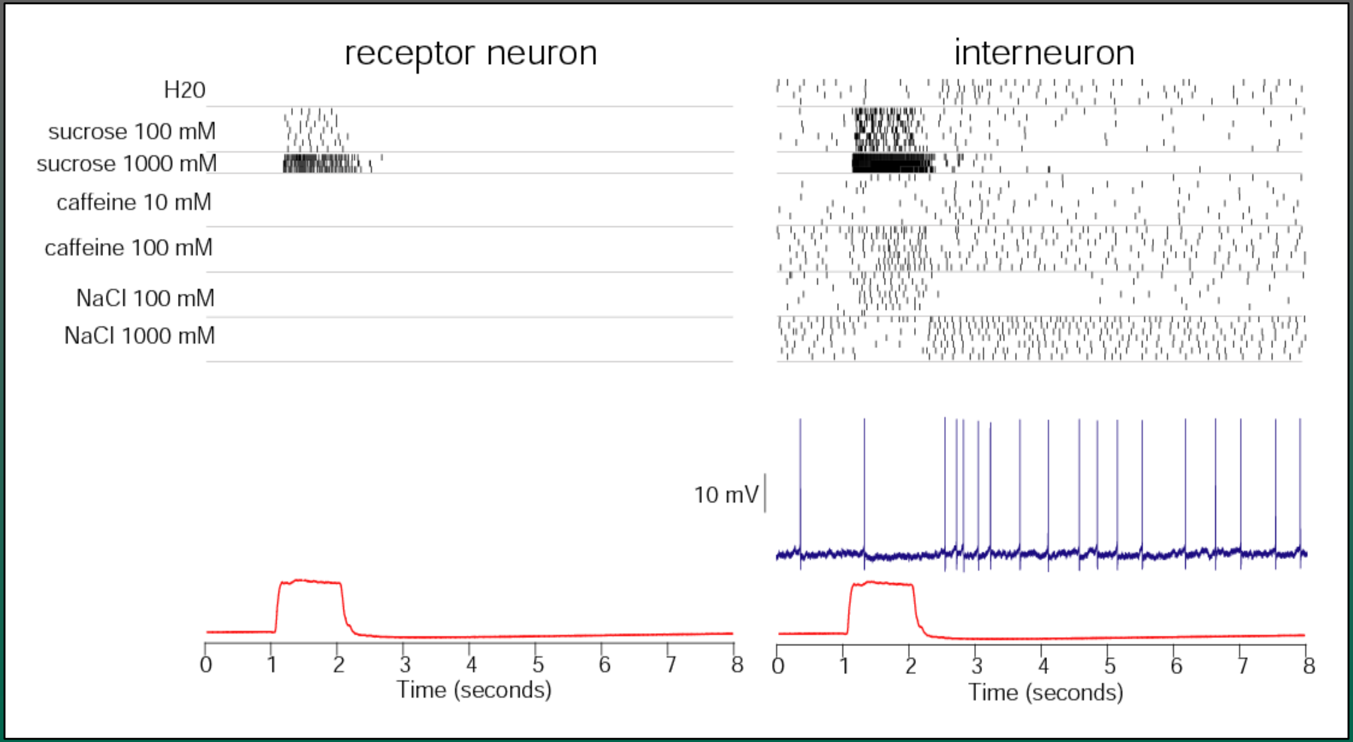

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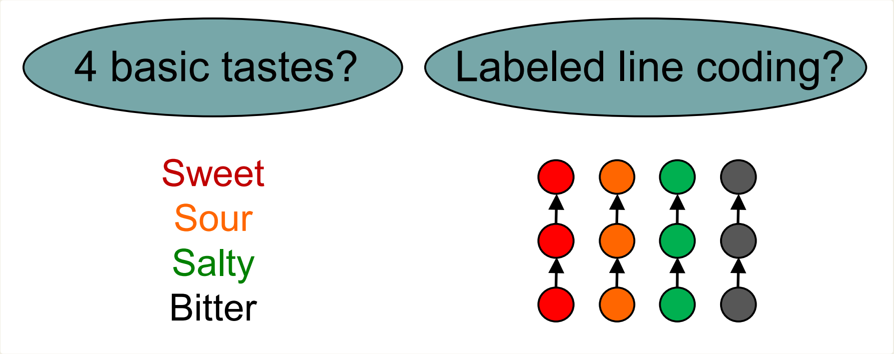
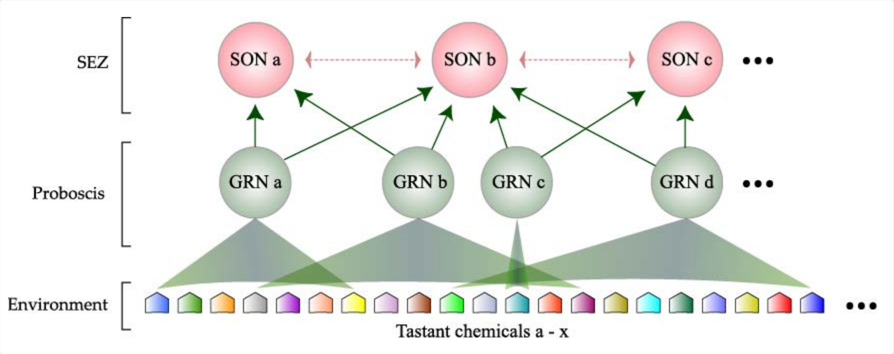
Where does that leave us?

Questions:

- *Are there only a few basic tastes, or are taste chemicals each encoded uniquely?*
- *What is the nature of the neural code for taste? Is it quick and accurate?*
- *Is taste processed by labeled lines?*





Quick Accurate

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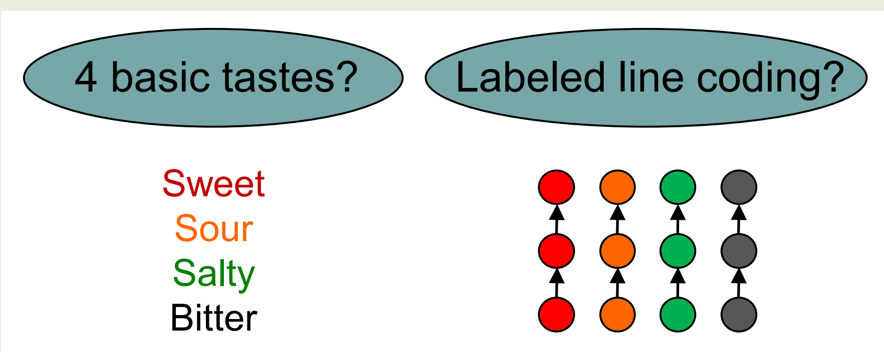

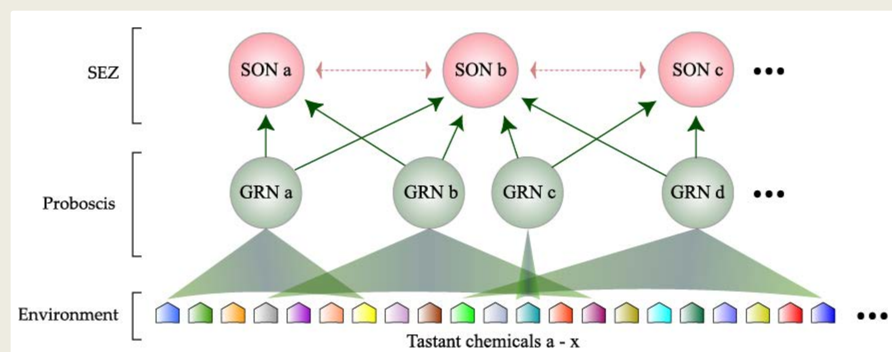

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  Spatio-temporal, combinatorial code
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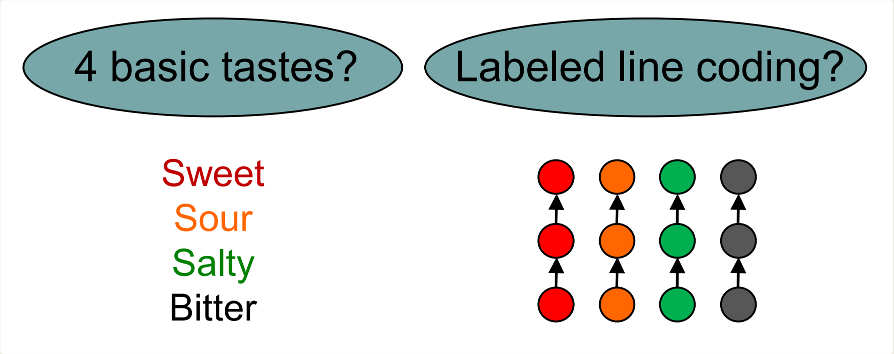

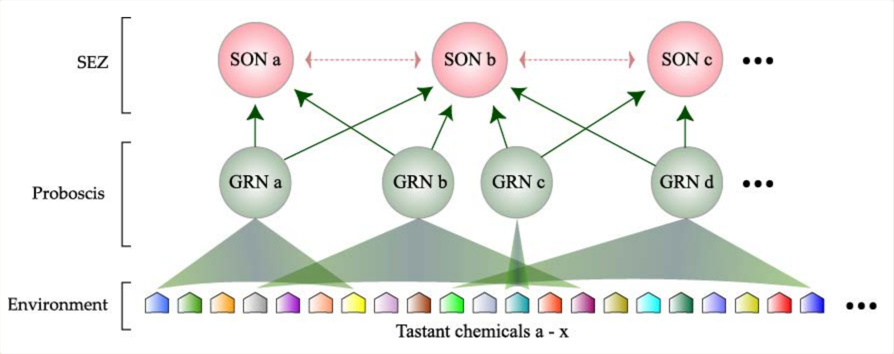

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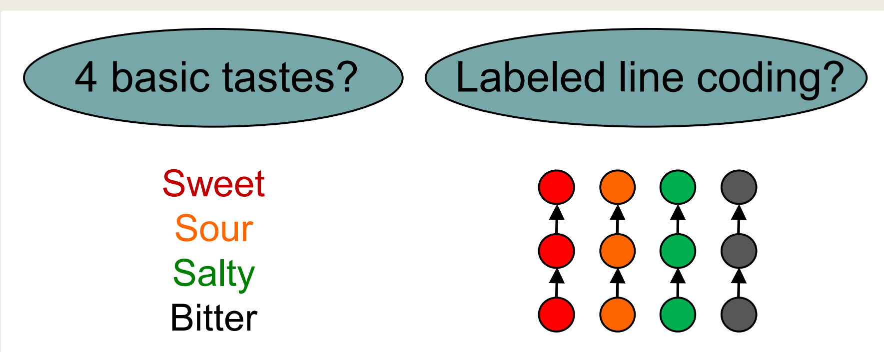
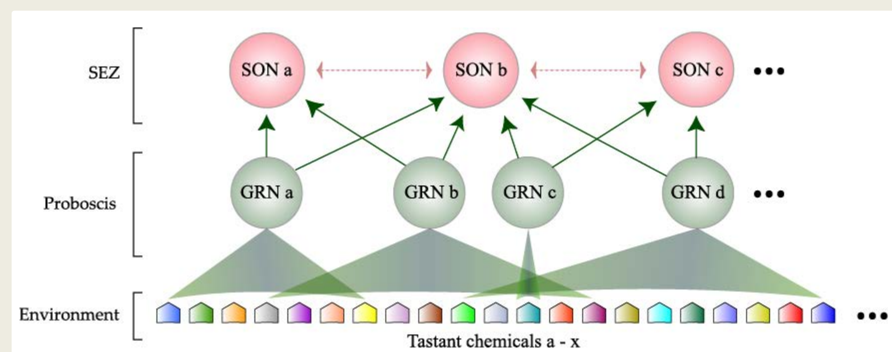
- *Is taste processed by labeled lines?* No





Quick Accurate

Is this just a moth thing?

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Broad GRN tuning in *Drosophila* and vertebrates…

- GRNs have been shown to respond to only some, but not all, tastants from a basic taste category (Dahanukar et al., 2007; Weiss et al., 2011; Miyamoto et al., 2012; Caicedo and Roper, 2001; Caicedo et al., 2002).
- GRNs have been shown to respond to some, but not all, tastants from multiple categories (Wisotsky et al., 2011; Charlu et al., 2013; Jeong et al., 2013; Masek and Keene, 2013, Caicedo et al., 2002; Nelson et al., 2002; Oka et al., 2013).

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Informative spike timing in gustatory neurons…

- The timing of spikes has been shown to contain information about tastants in neurons at several stages along the gustatory pathway (Katz et al., 2001; Hallock and DiLorenzo, 2006; Lemon and Katz, 2007; Fontanini et al., 2009; Rosen et al., 2011; Wilson et al., 2012).

Let's change the way we think about taste:

Let’s change the way we think about taste:

- **Lots and lots of tastes, not just four**
- **A different neural coding mechanism**

Sam Reiter

NIH-Brown-GPP
PhD 2014

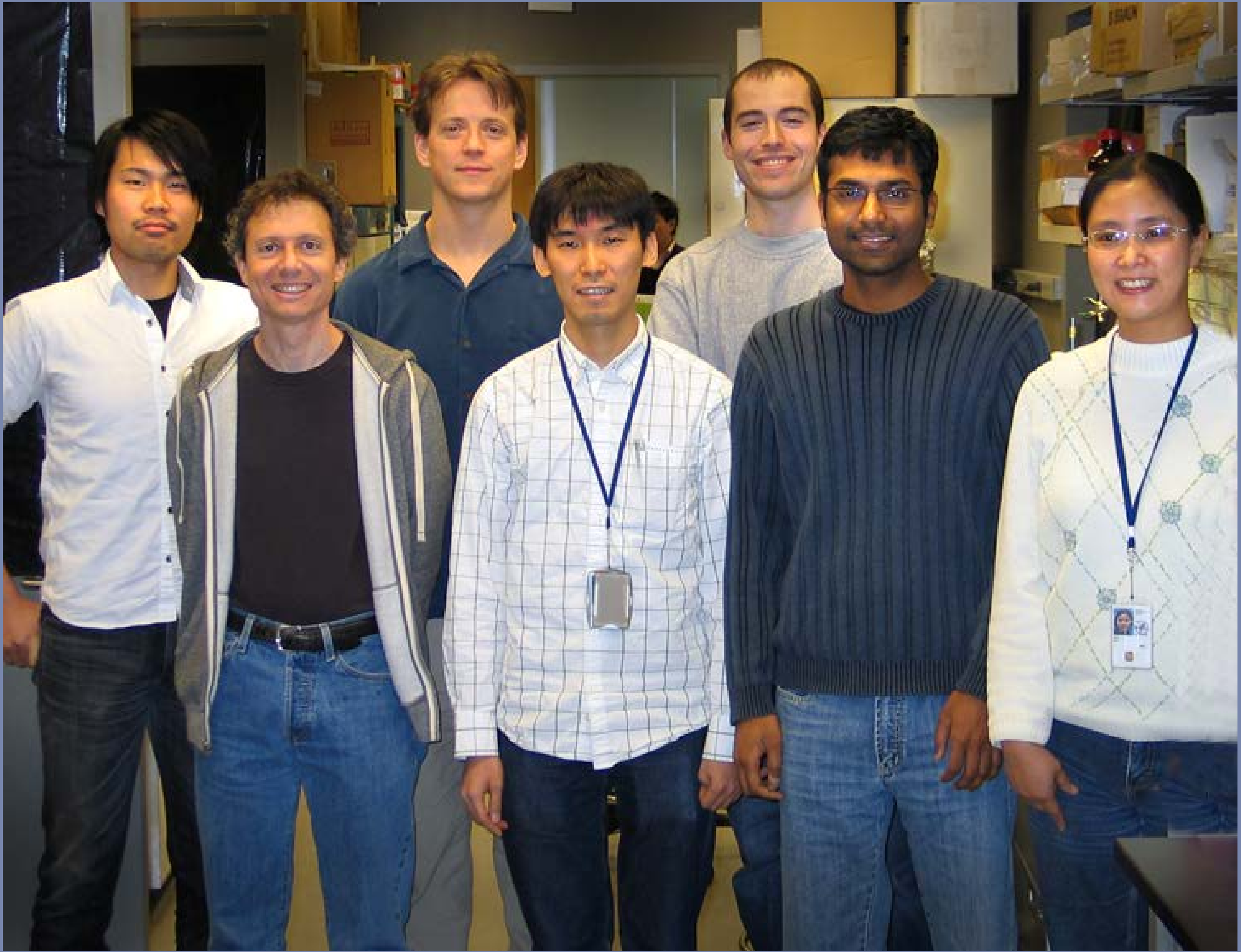
Chelsey Campillo Rodriguez

High school intern

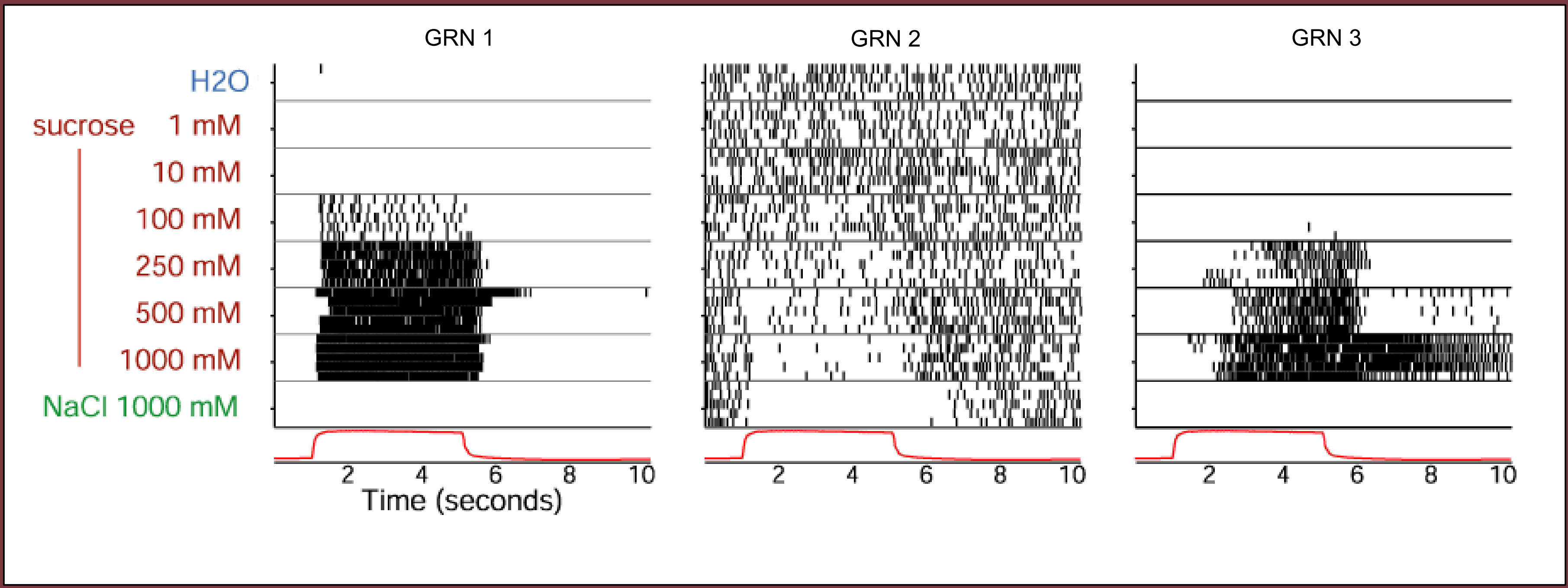
Kui Sun

technician

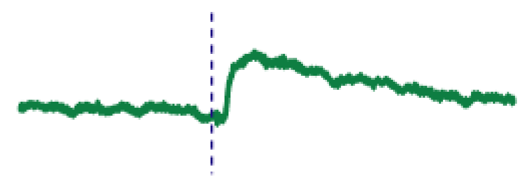
Sam's thesis committee:	Gilad Barnea Leonardo Belluscio David Berson Chi-Hon Lee Chris McBain Dmitry Rinberg
Tastant delivery system:	George Dold Tom Talbot
Light microscopy:	Vincent Shram
Scanning electron microscopy:	Pat Zerfas Chris Brantner

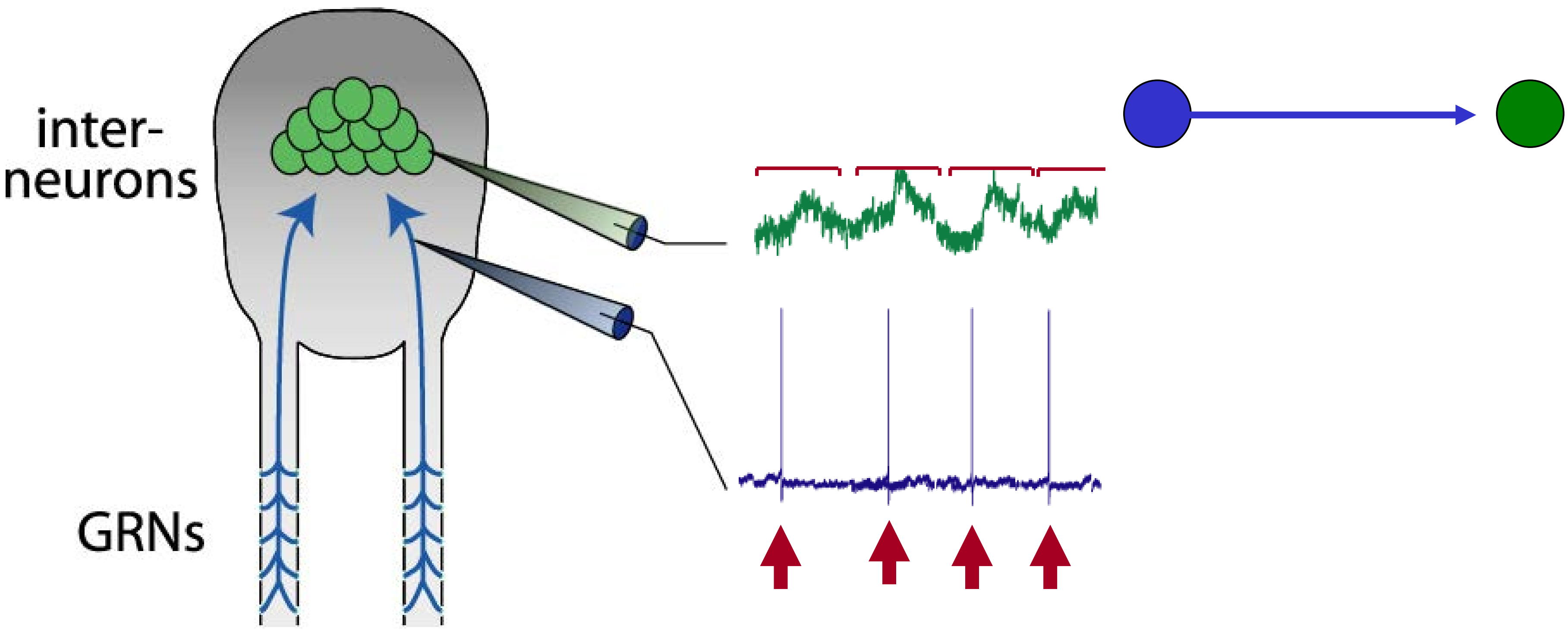


As tastant concentration increases, more types of GRNs respond, and more strongly

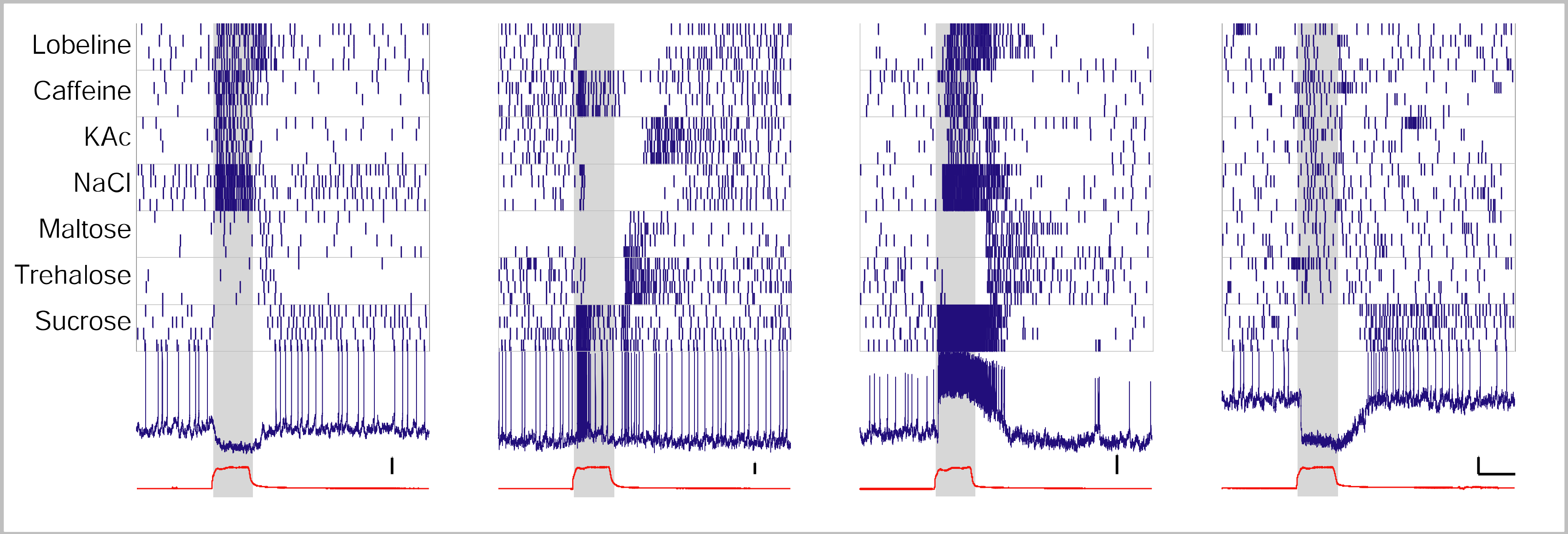


GRN→follower connectivity and integration

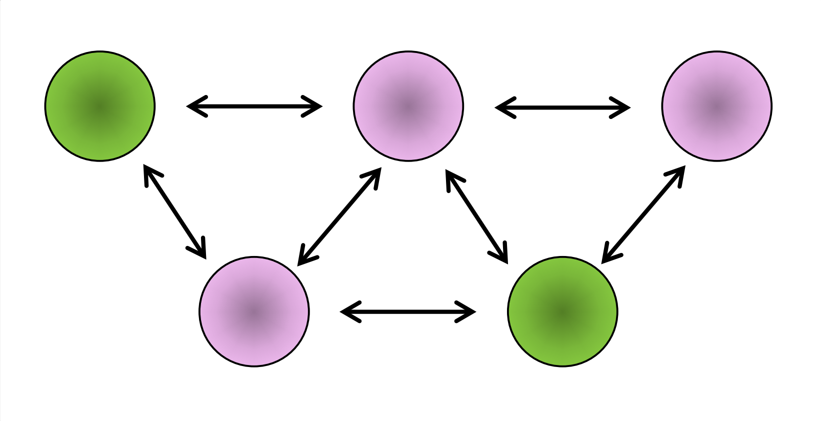




Sharp-electrode intracellular: second order neurons



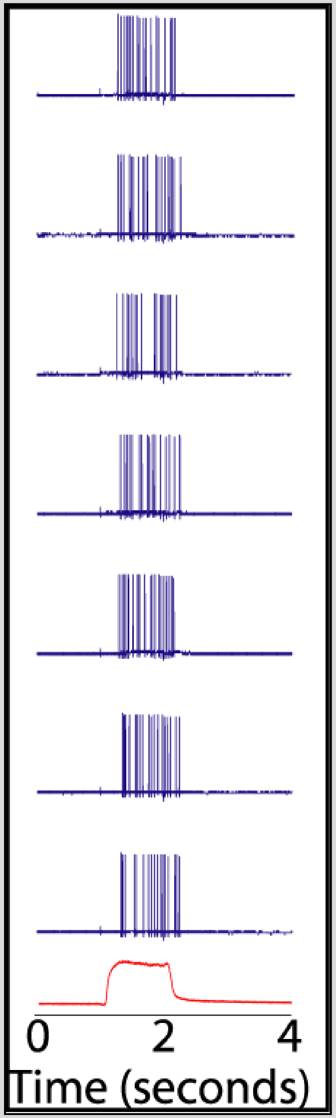
Temporal patterning
In SONs

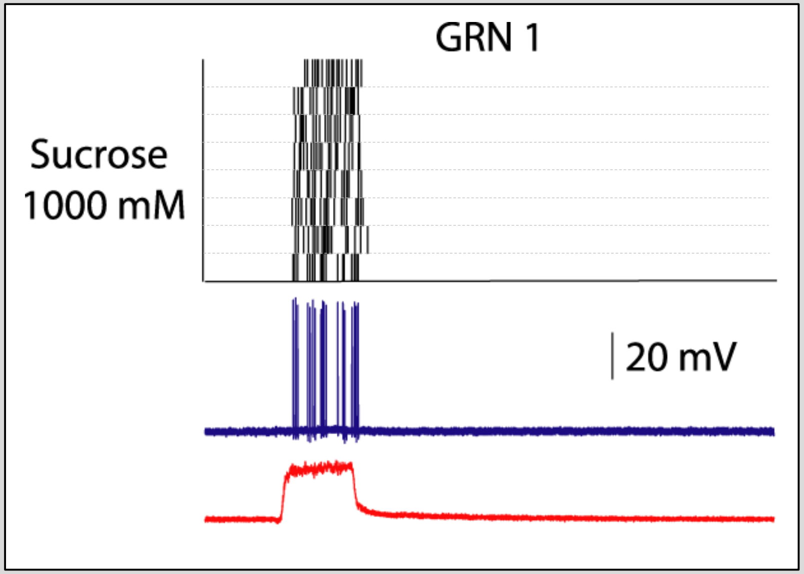


GRNs

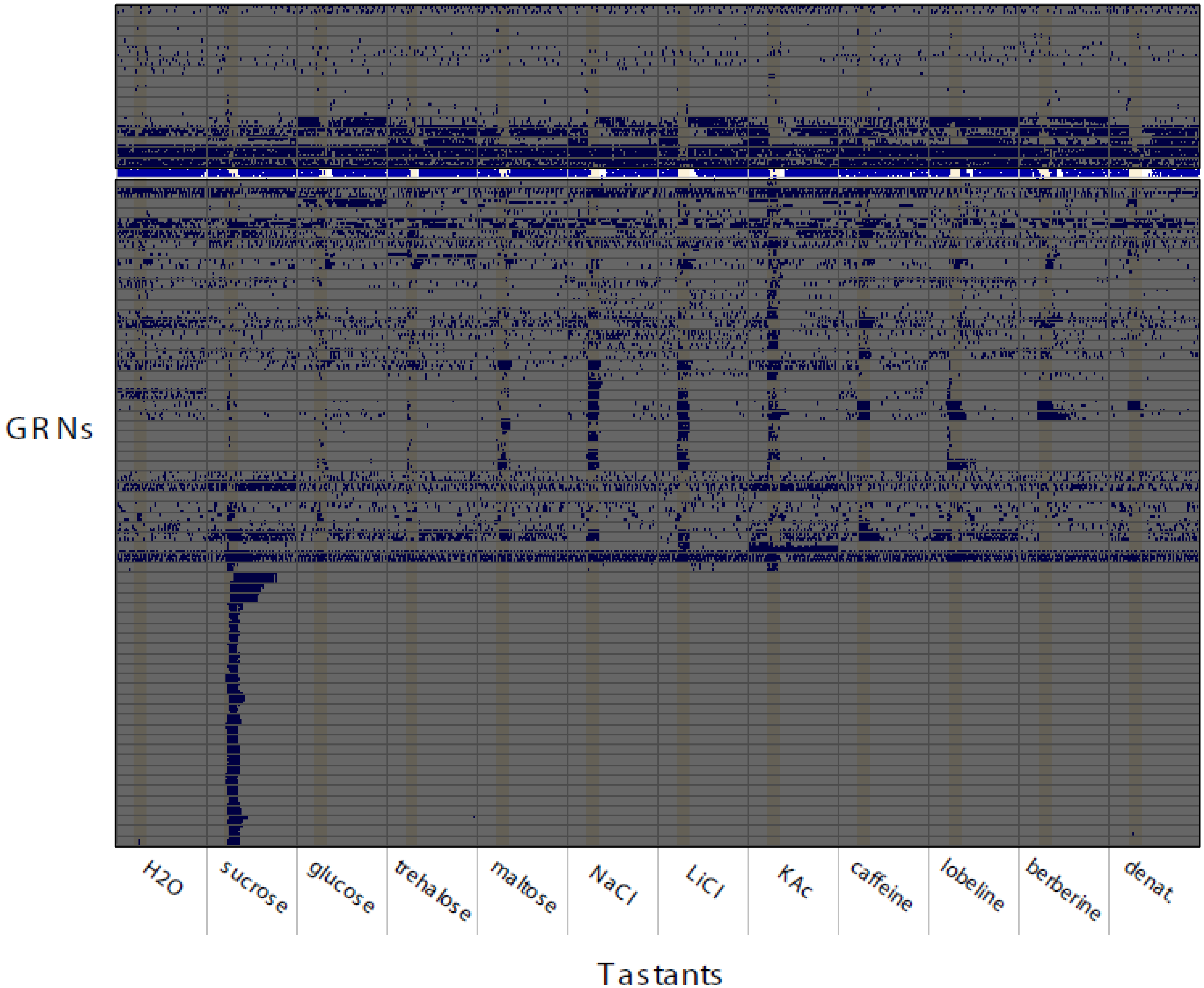
Gustatory
Receptor
Neurons

Sharp-electrode intracellular recordings

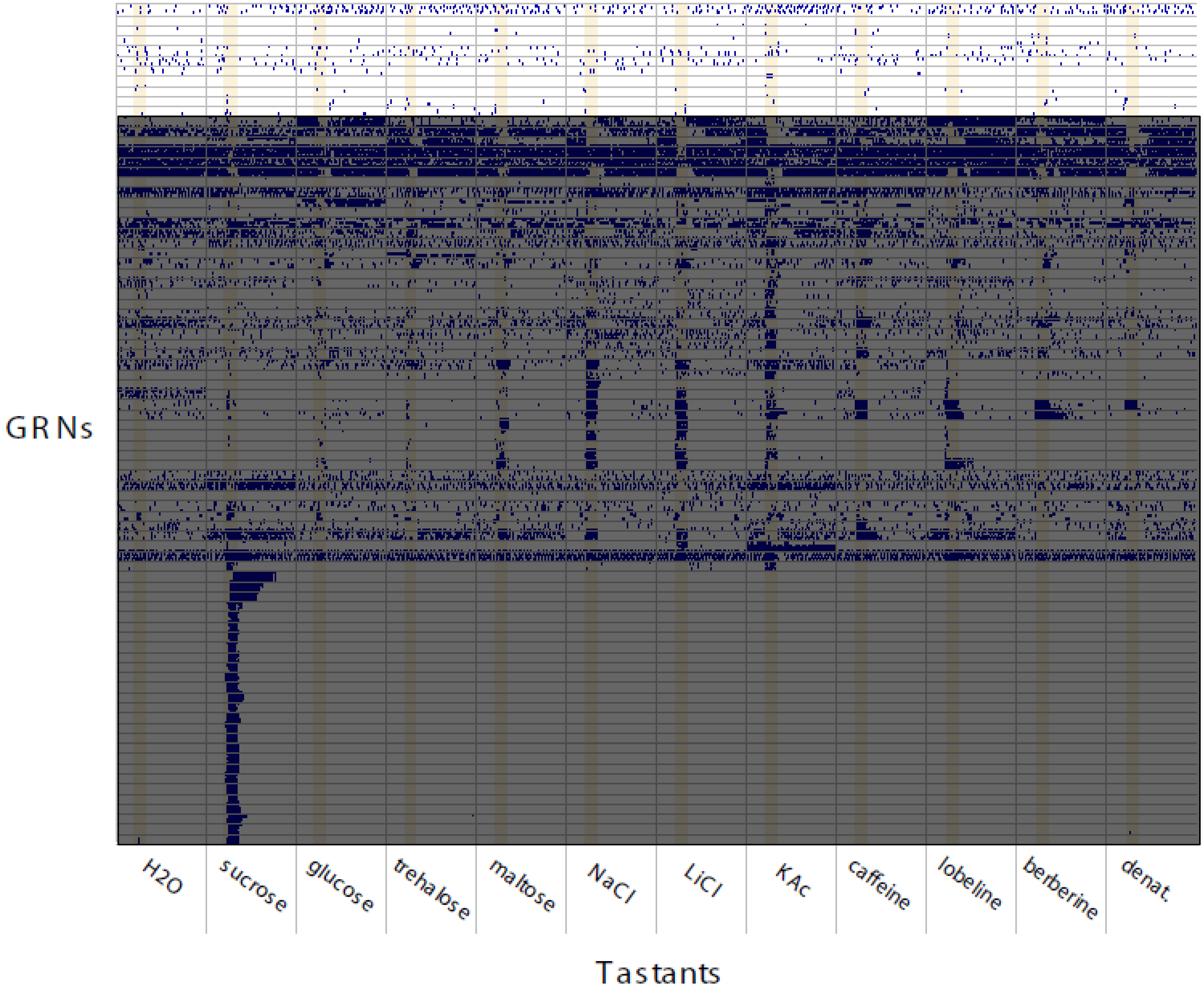




Encoding Tastant Identity



Encoding Tastant Identity



What's wrong with the basic taste framework?

- There is no single clear, useful definition of a basic taste.
- Many GRNs respond to chemicals not readily associated with any of the basic tastes
    - water (Cameron et al., 2010)
    - fatty acids (Cartoni et al., 2010; Masek and Keene, 2013)
    - carbon dioxide (Fischler et al., 2007)
    - contact pheromones (Lacaille et al., 2007).
- It does not provide the best description of the data.
- Sometimes sets limitations for experiments

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An “individual taste framework”

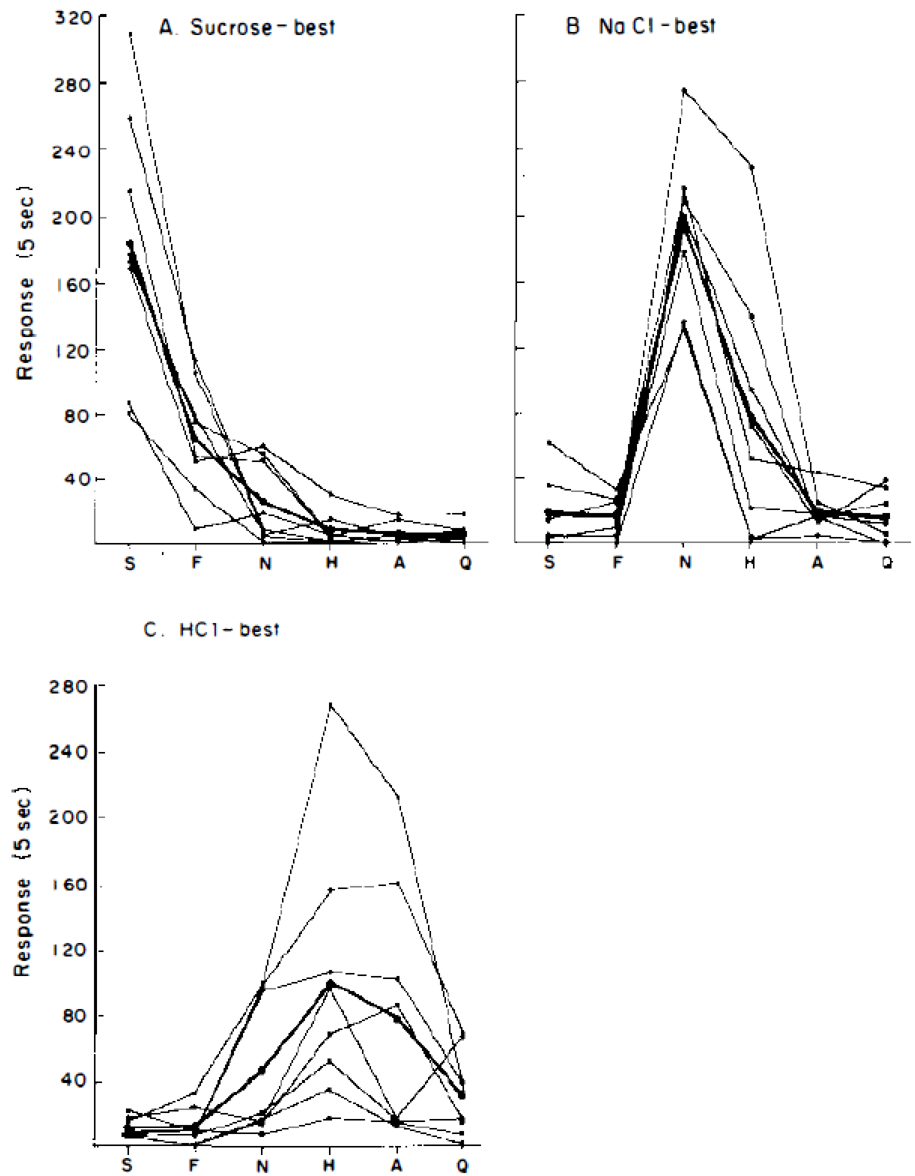
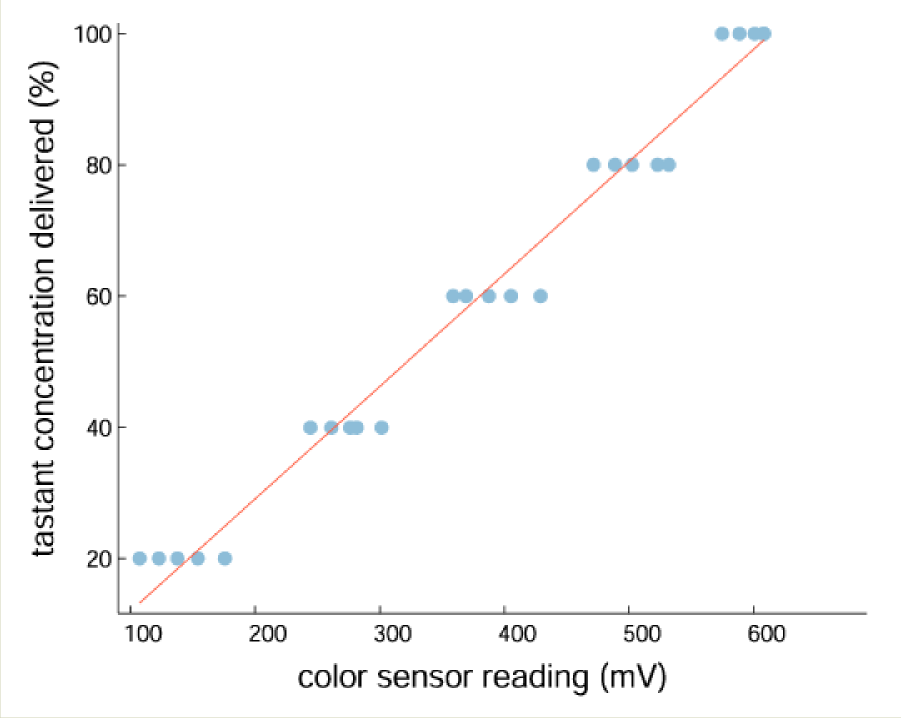
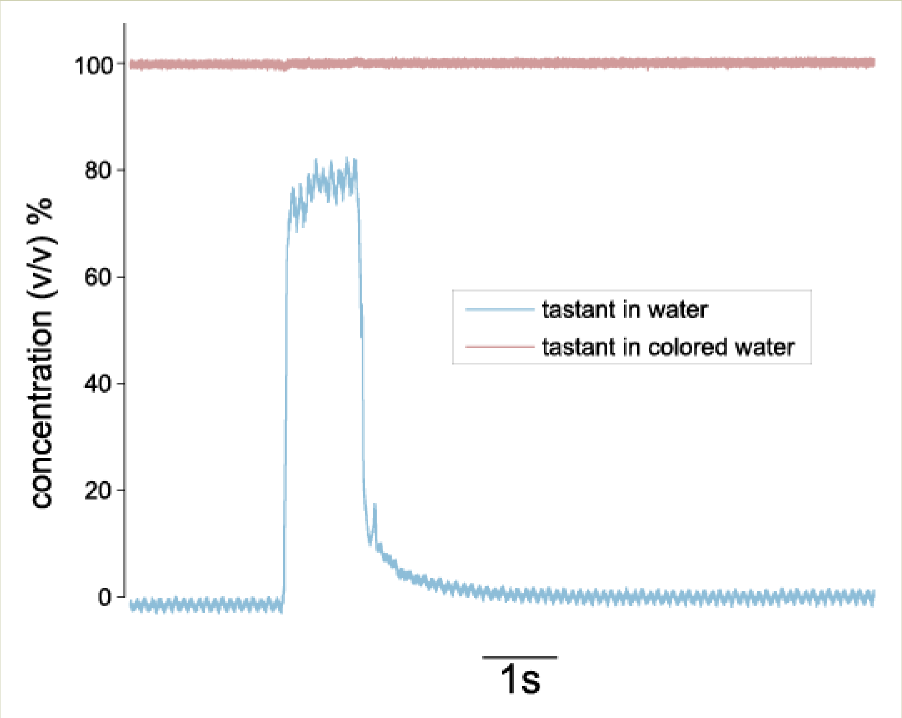


Figure 3 Hamster chorda tympani response profiles. *S* is 0.1 M sucrose; *N*, 0.03 M NaCl; *H*, 0.003 M HCl; *Q*, 0.001 M quinine hydrochloride; *F*, 0.3 M fructose; and *A*, 0.03 M NH_4Cl. Modified from Frank (62)

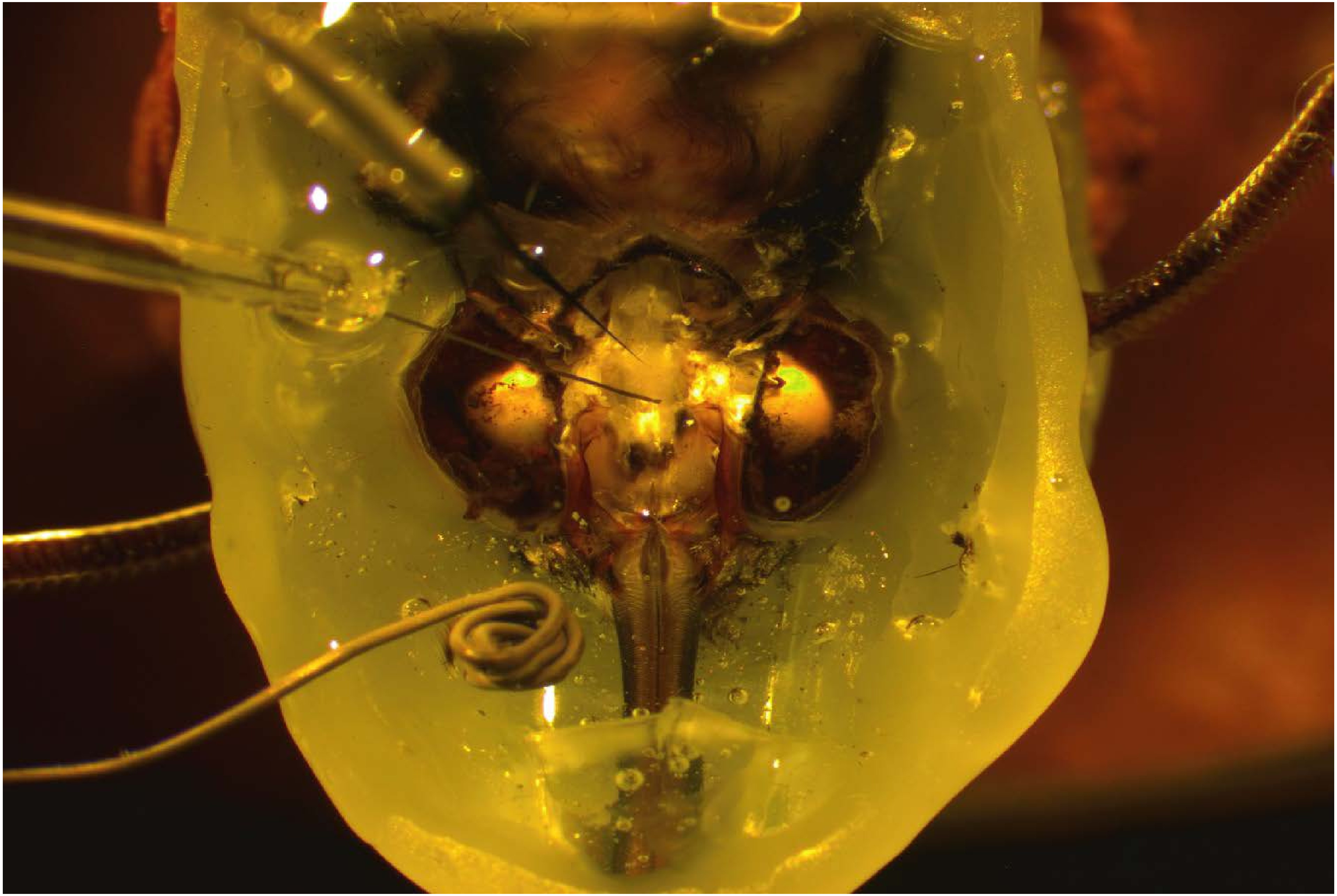
Pfaffmann, Frank, and Norgren, 1979



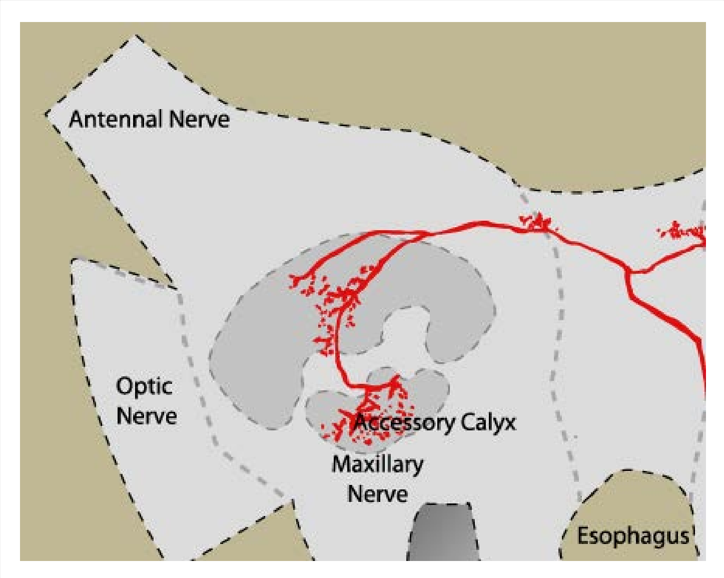
tastant concentration delivered (%)
100
80
60
40
20
100
200
300
400
500
600
color sensor reading (mV)

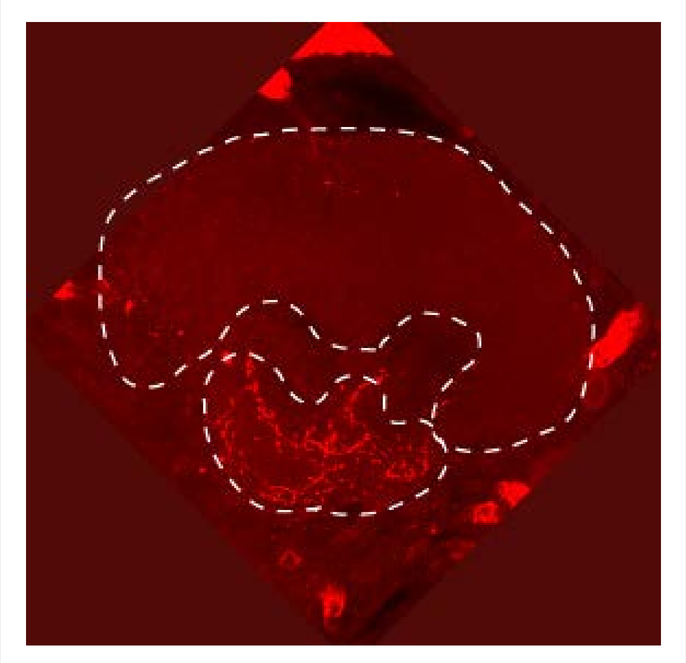


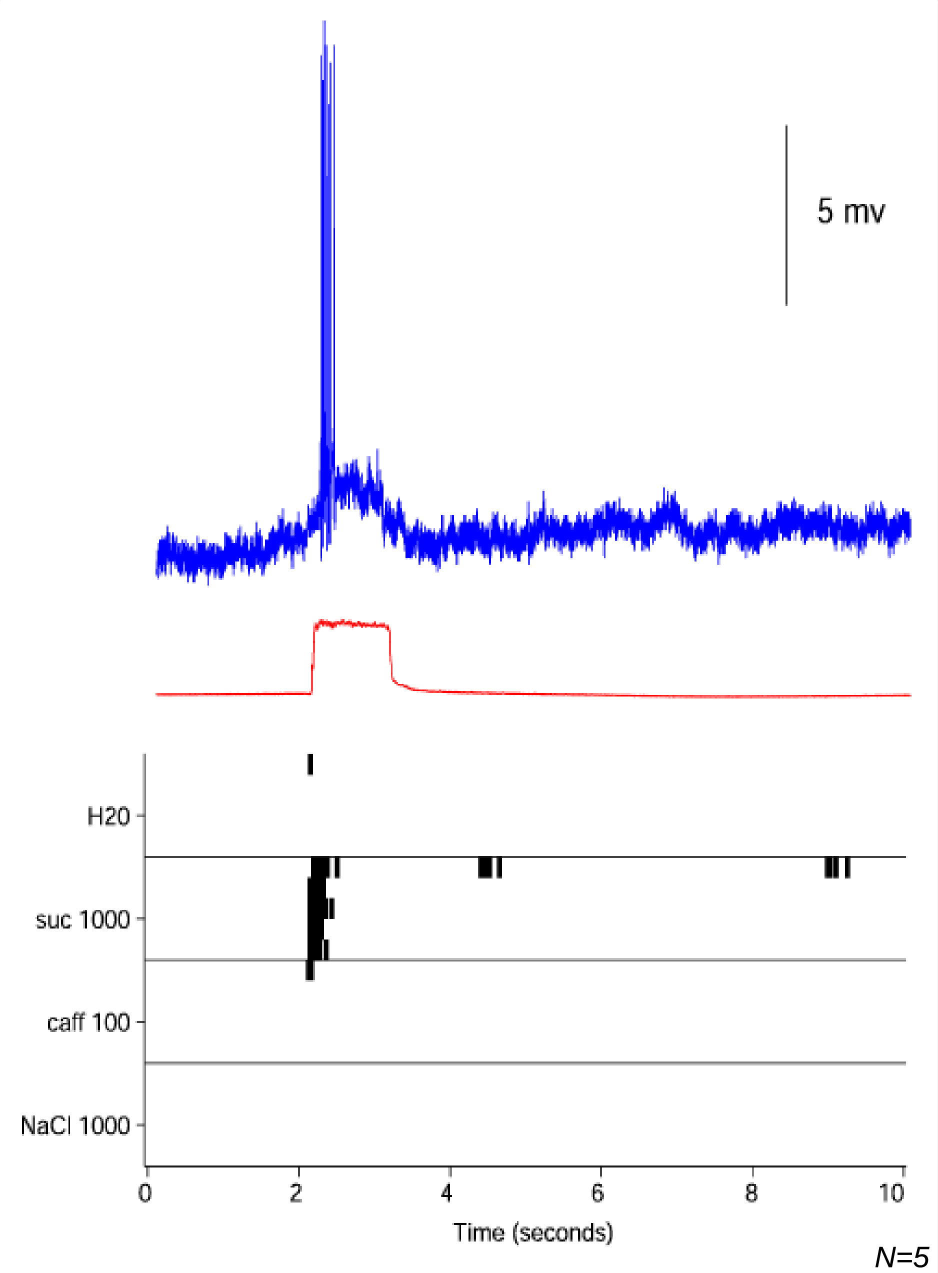
concentration (v/v) %
100
80
60
40
20
0
tastant in water
tastant in colored water
1s



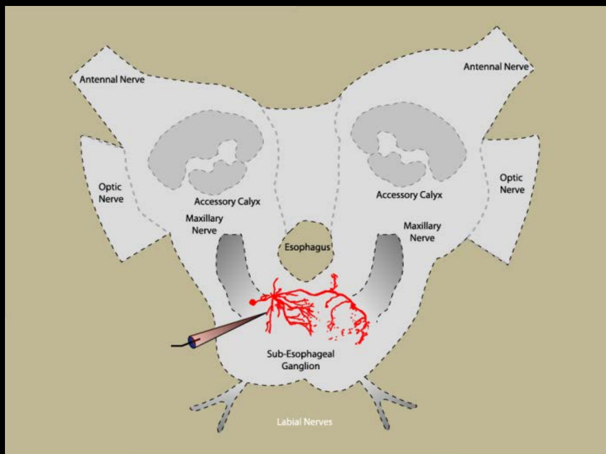
Gustatory Projection Neurons: **Ascending**



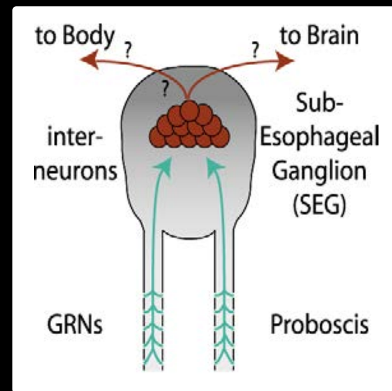


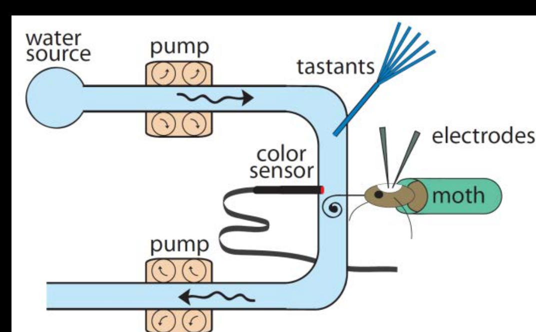


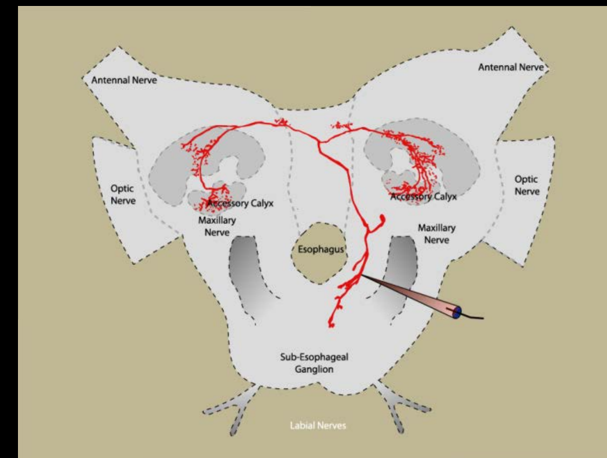
Projection Neurons



descending

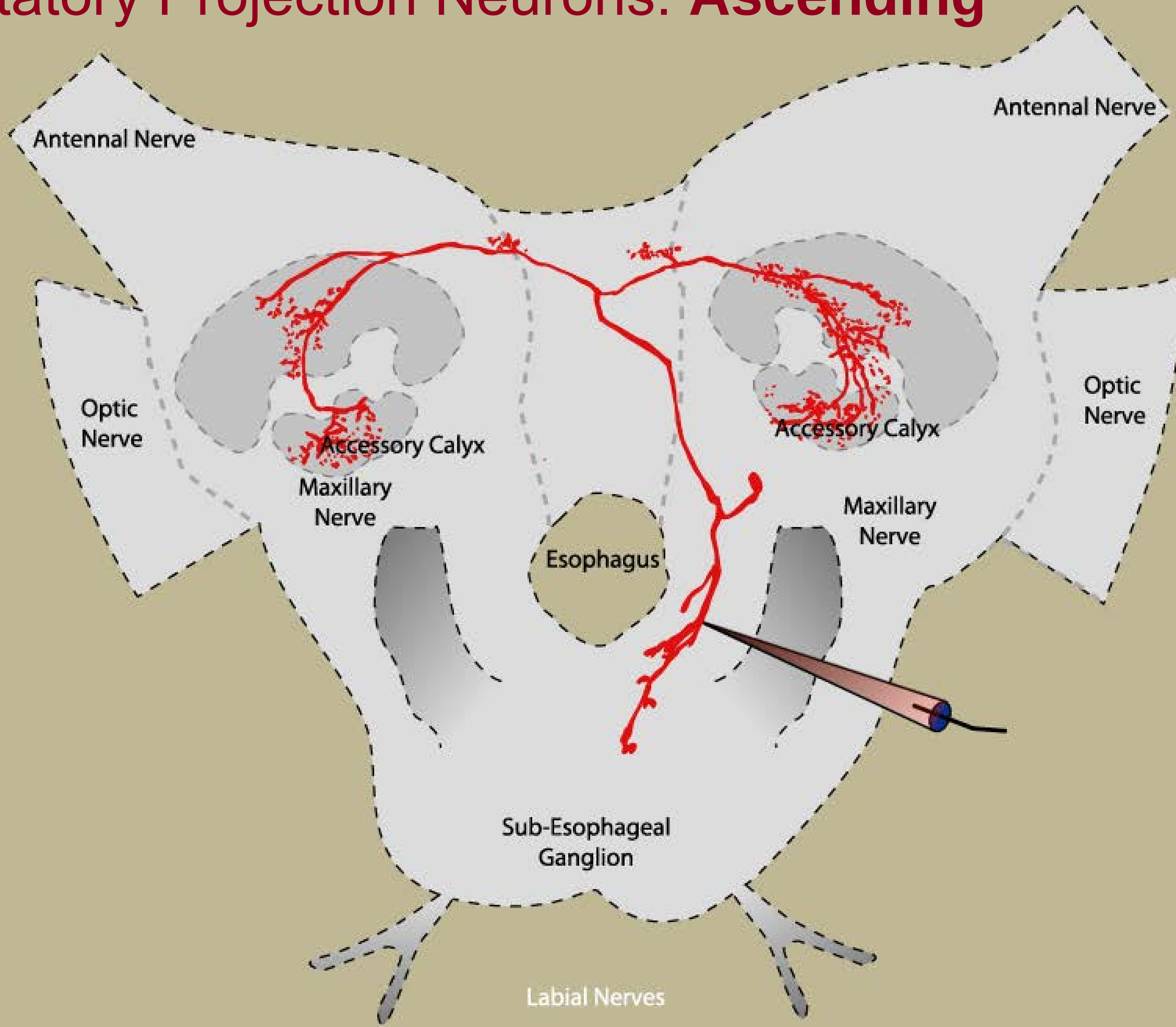




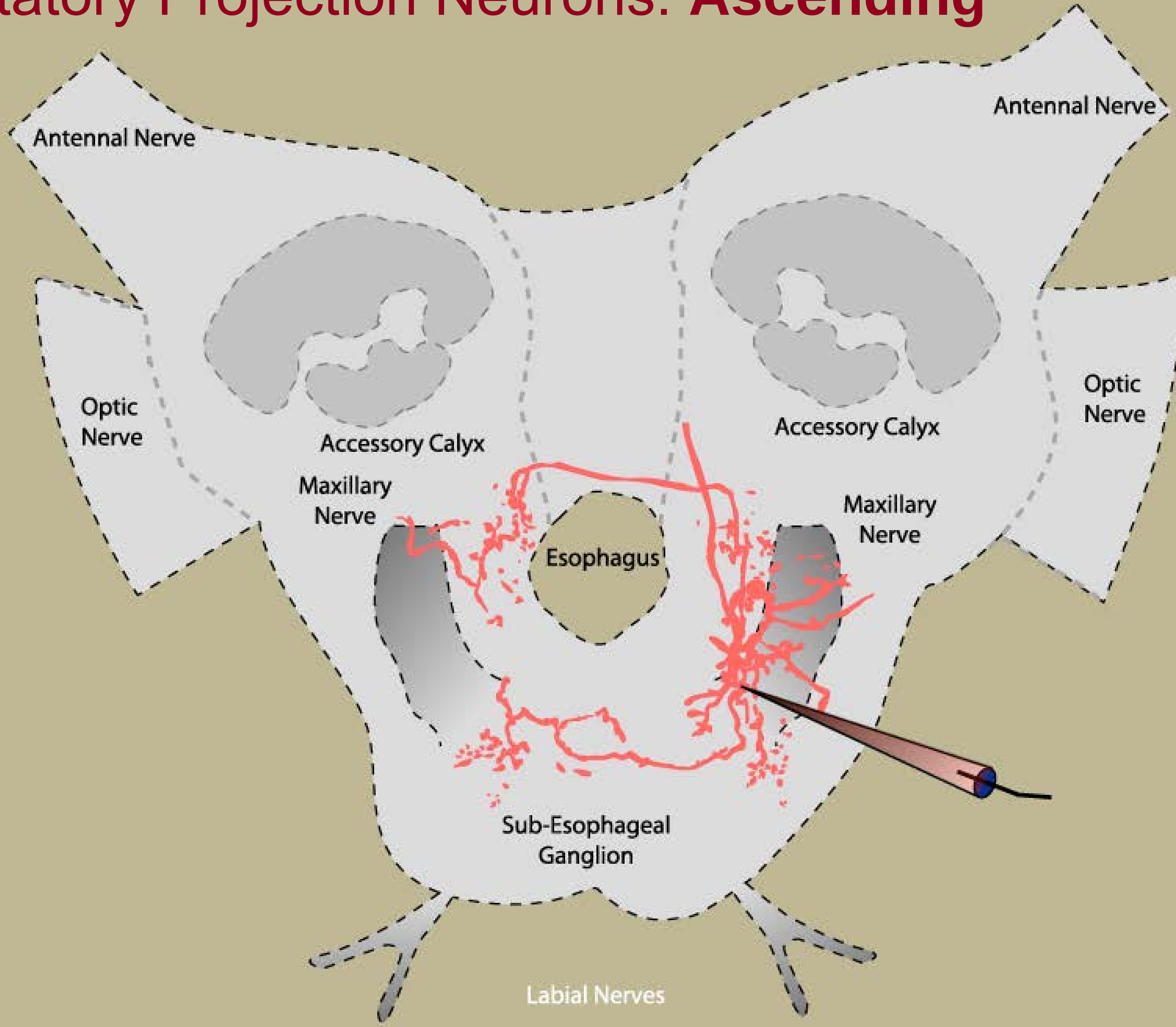


ascending

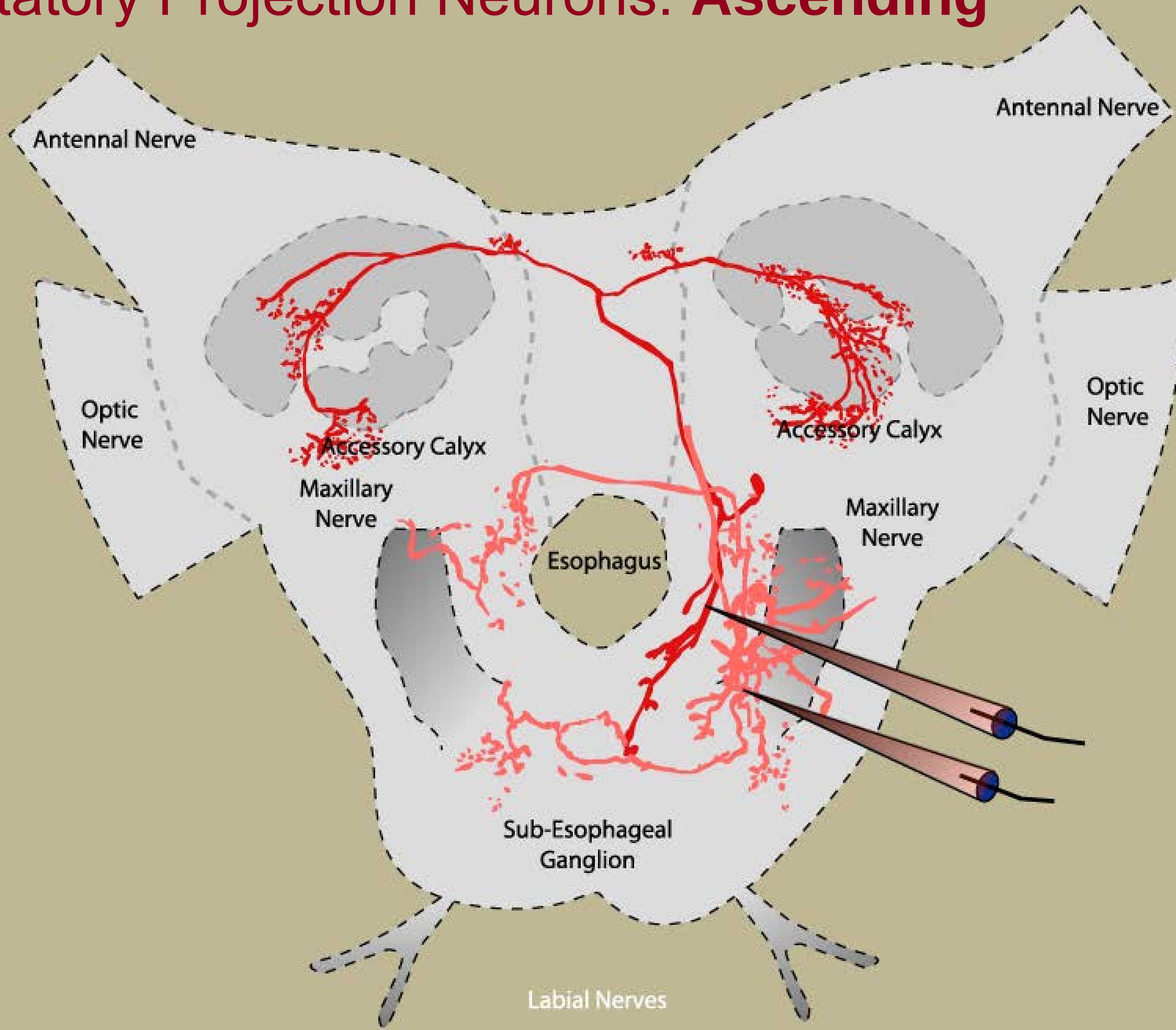
Gustatory Projection Neurons: **Ascending**



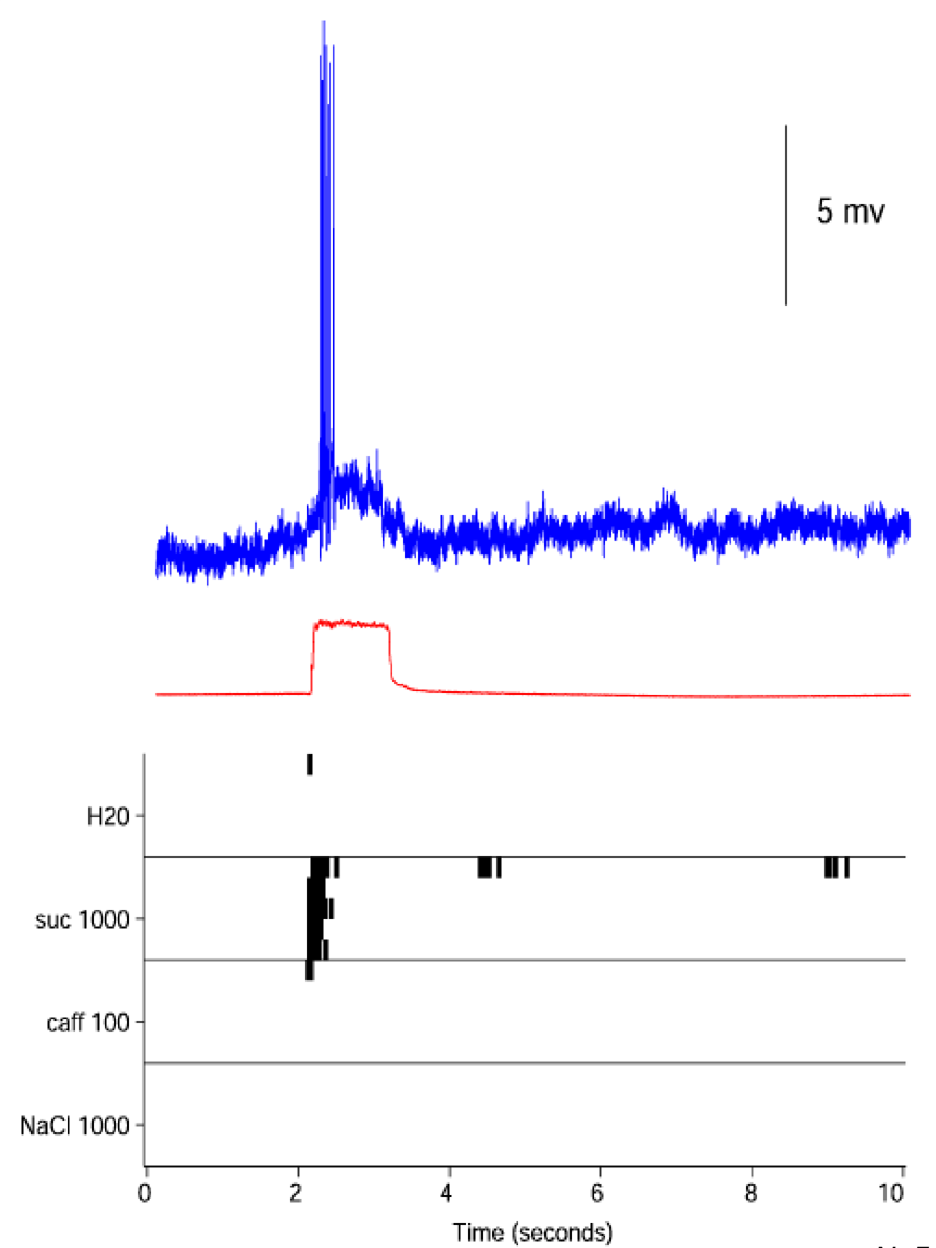
Gustatory Projection Neurons: **Ascending**



Gustatory Projection Neurons: **Ascending**

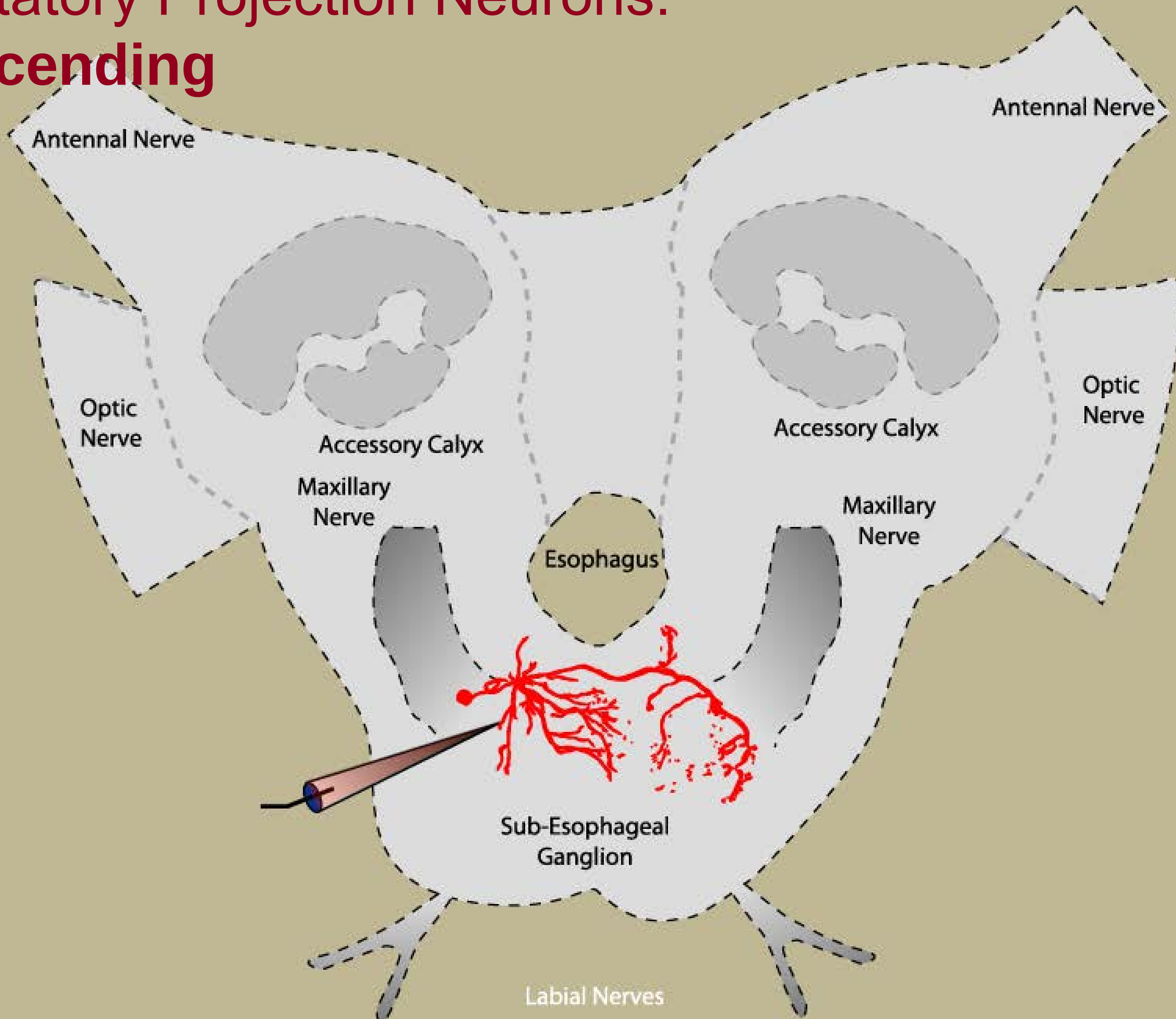


Gustatory Projection Neurons: **Ascending**

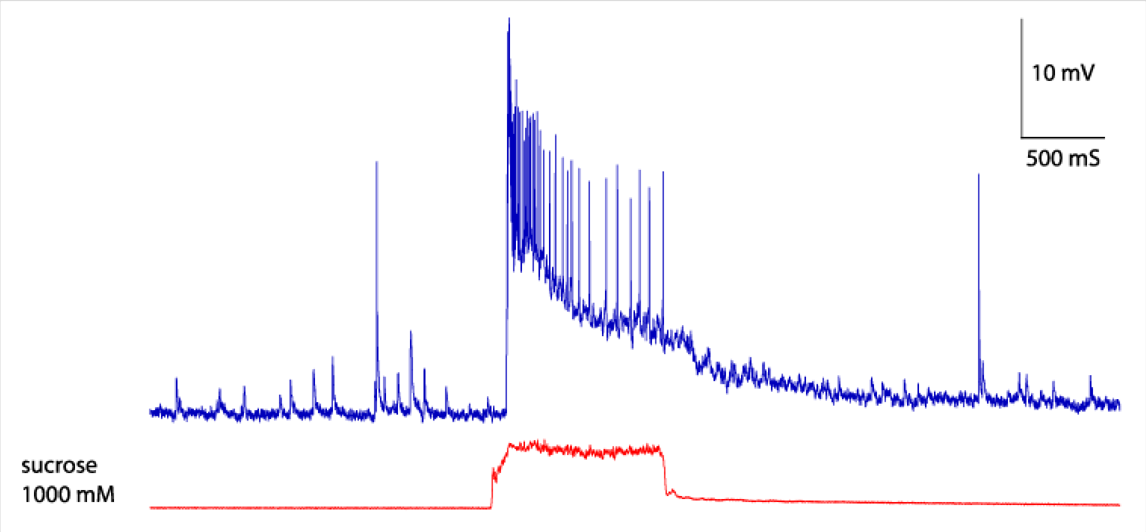


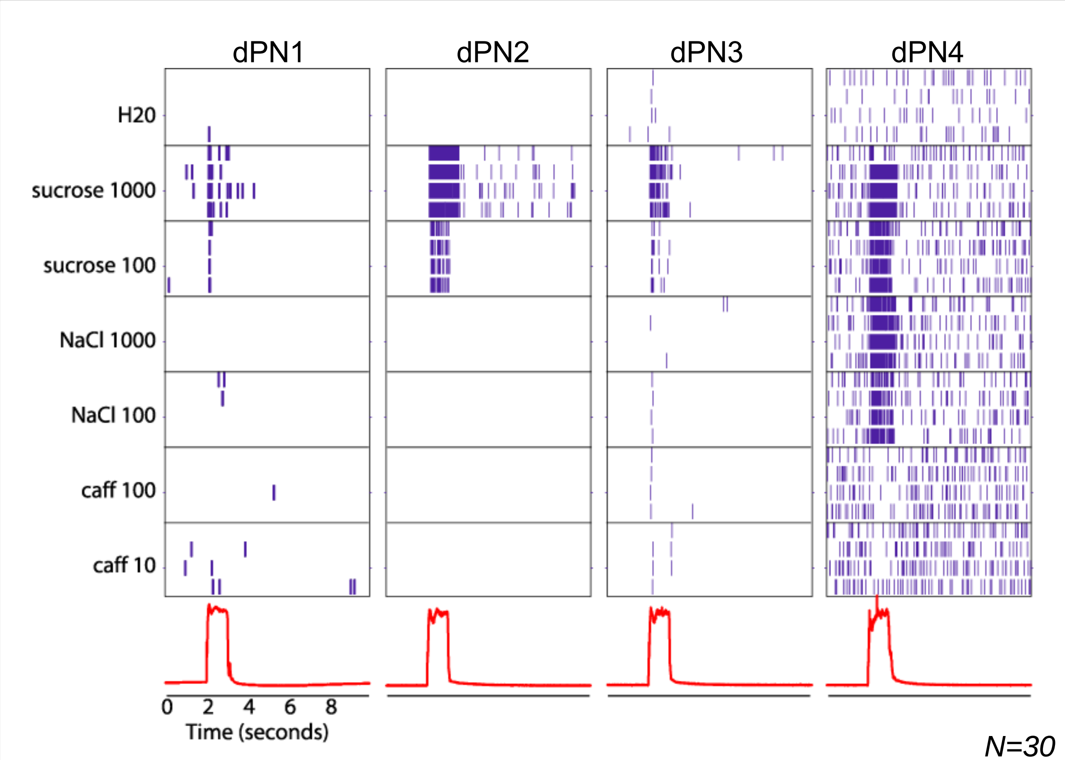
N=5

Gustatory Projection Neurons: **Descending**



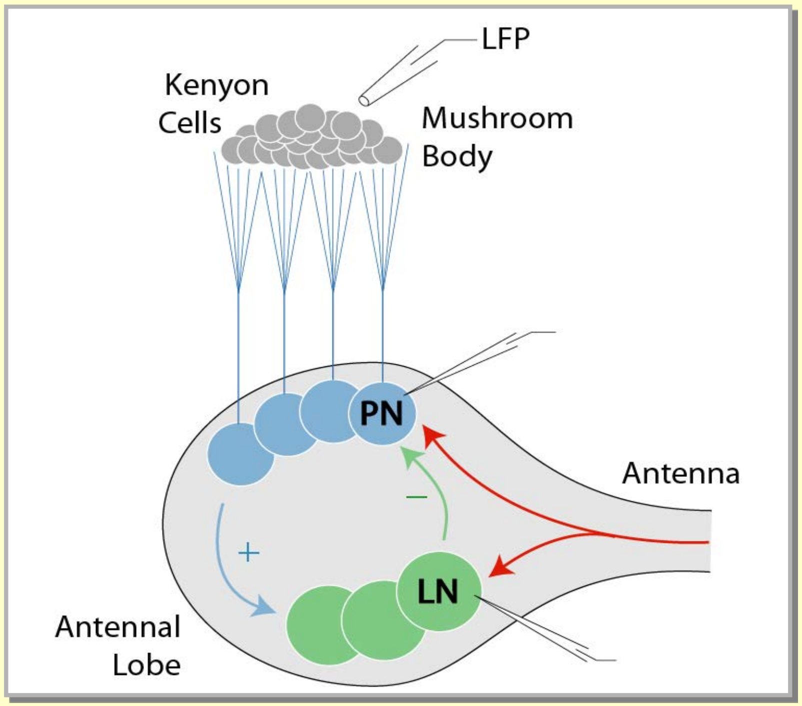
Gustatory Projection Neurons: **Descending**

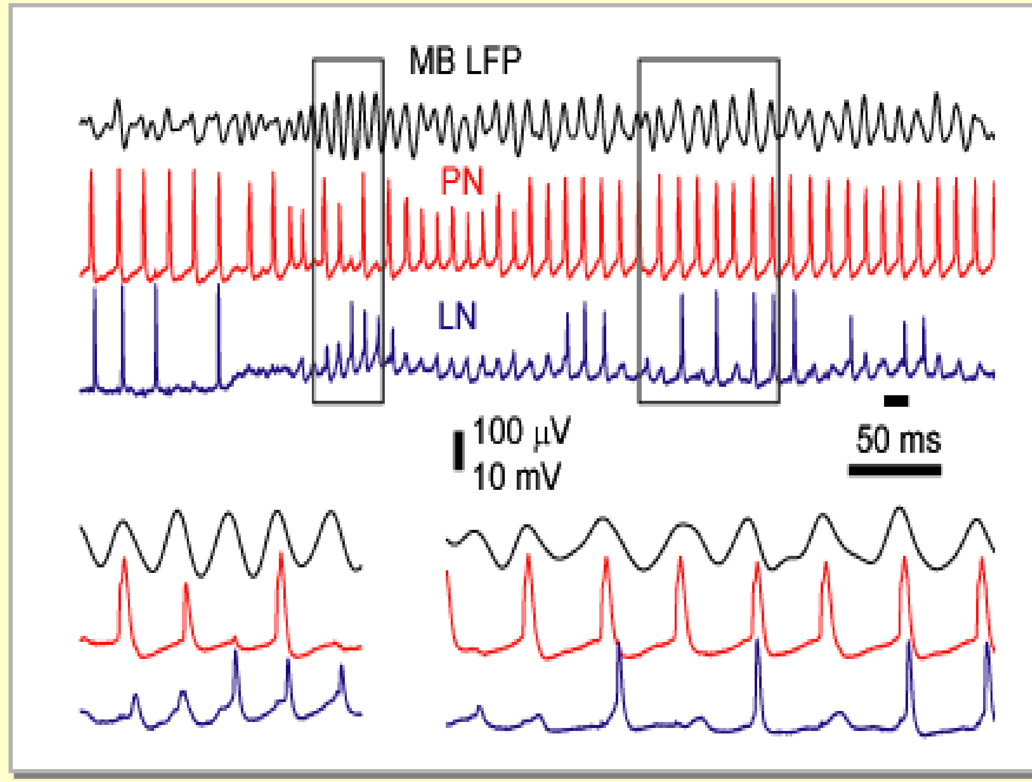




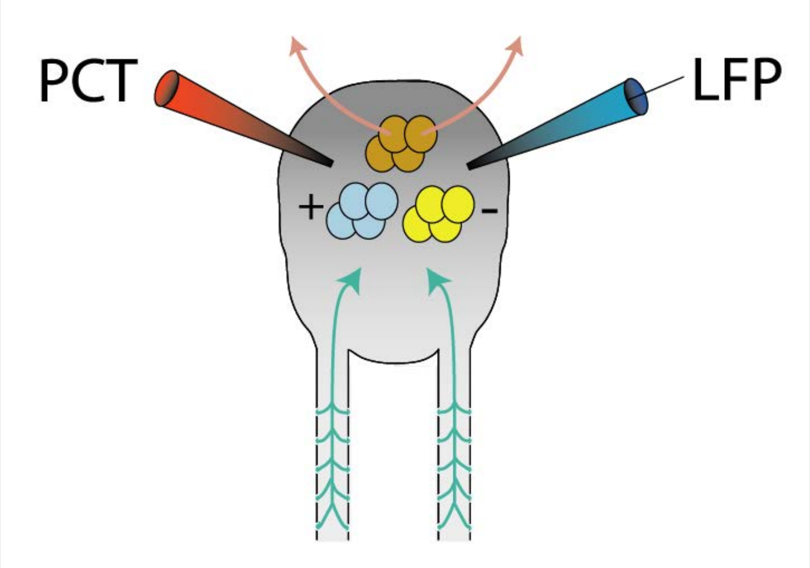
Olfactory System

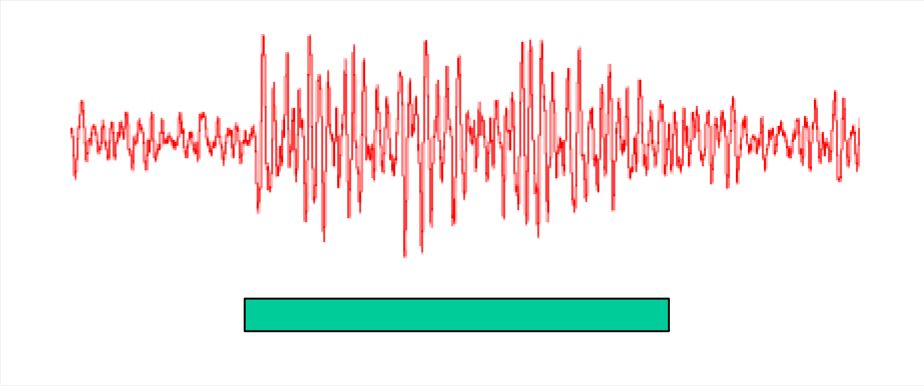
Antennal lobe neurons tend to synchronize

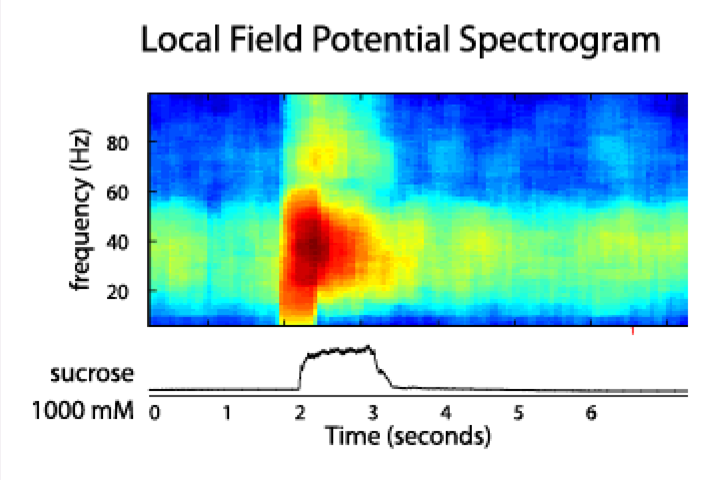




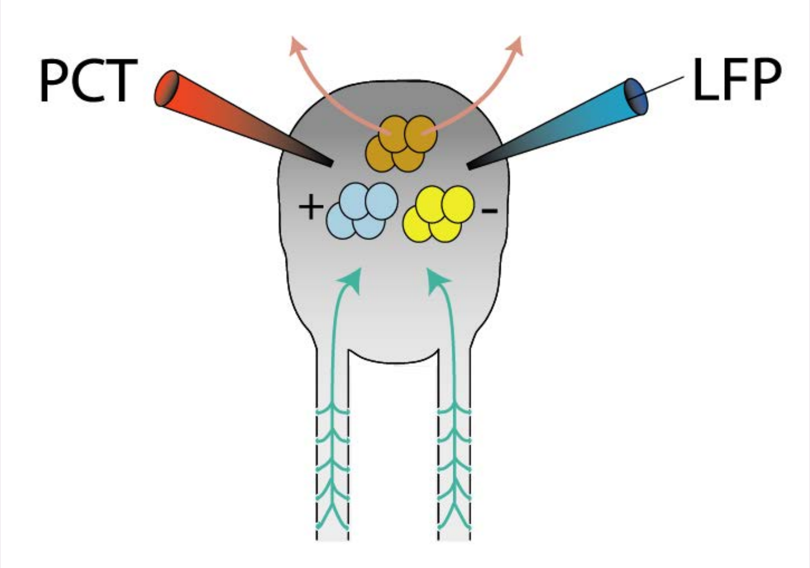
Tastant-elicited oscillations

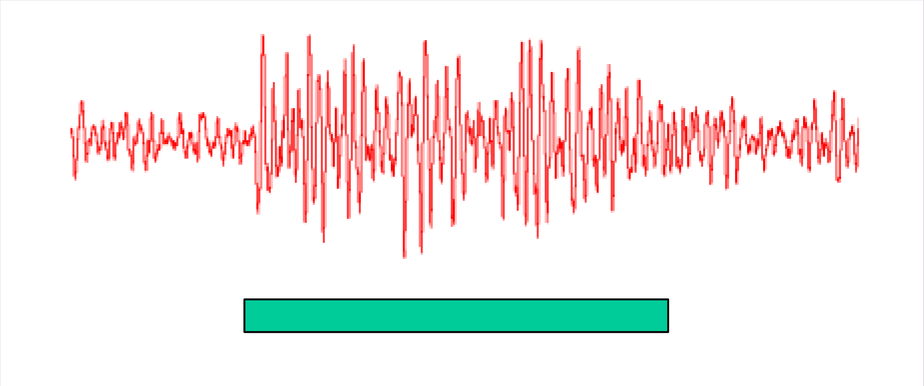


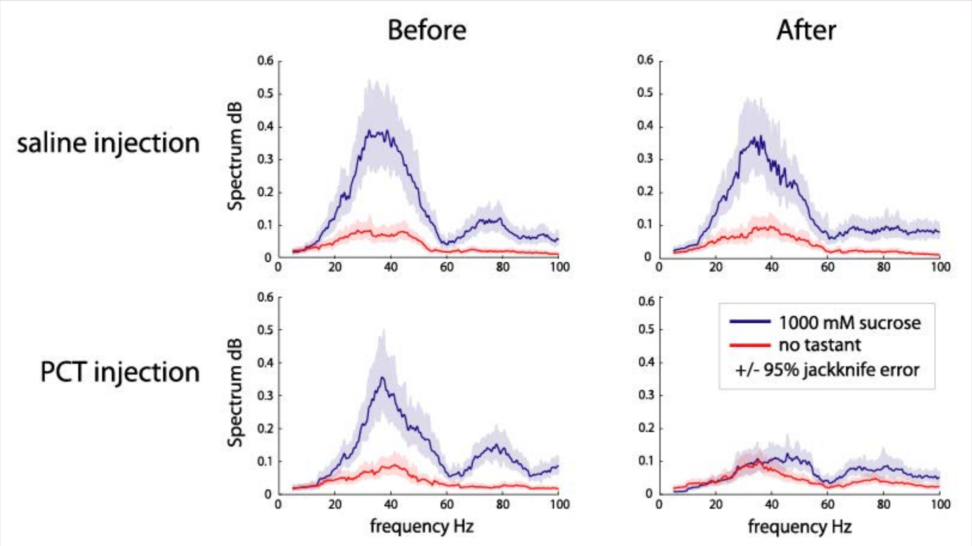


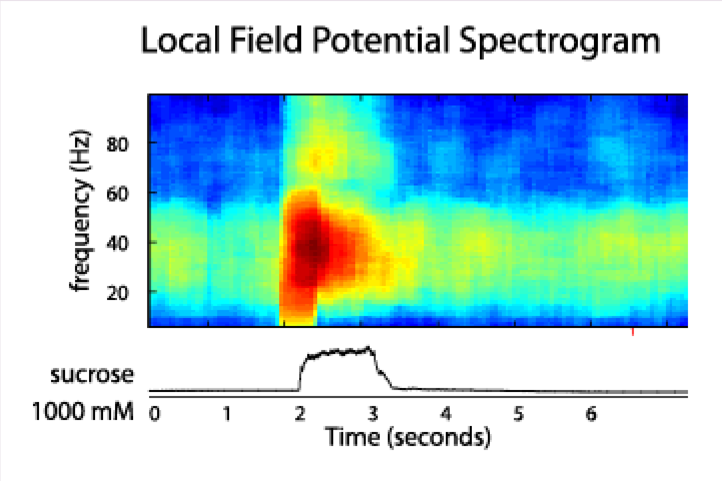


Tastant-elicited oscillations

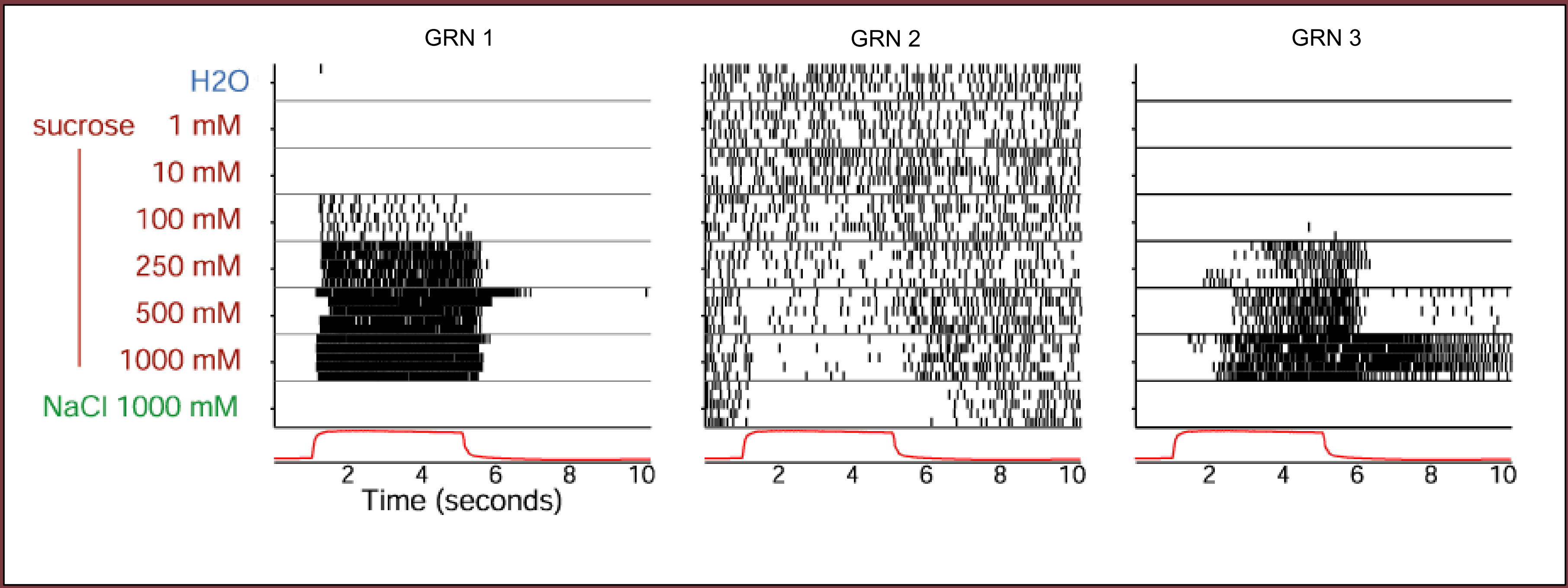








As tastant concentration increases, more types of GRNs respond, and more strongly



The predominant view

"… tastant quality is mediated by labeled lines, whereby distinct and strictly segregated populations of taste receptor cells encode each of the taste qualities."

Common sense about taste: from mammals to insects.

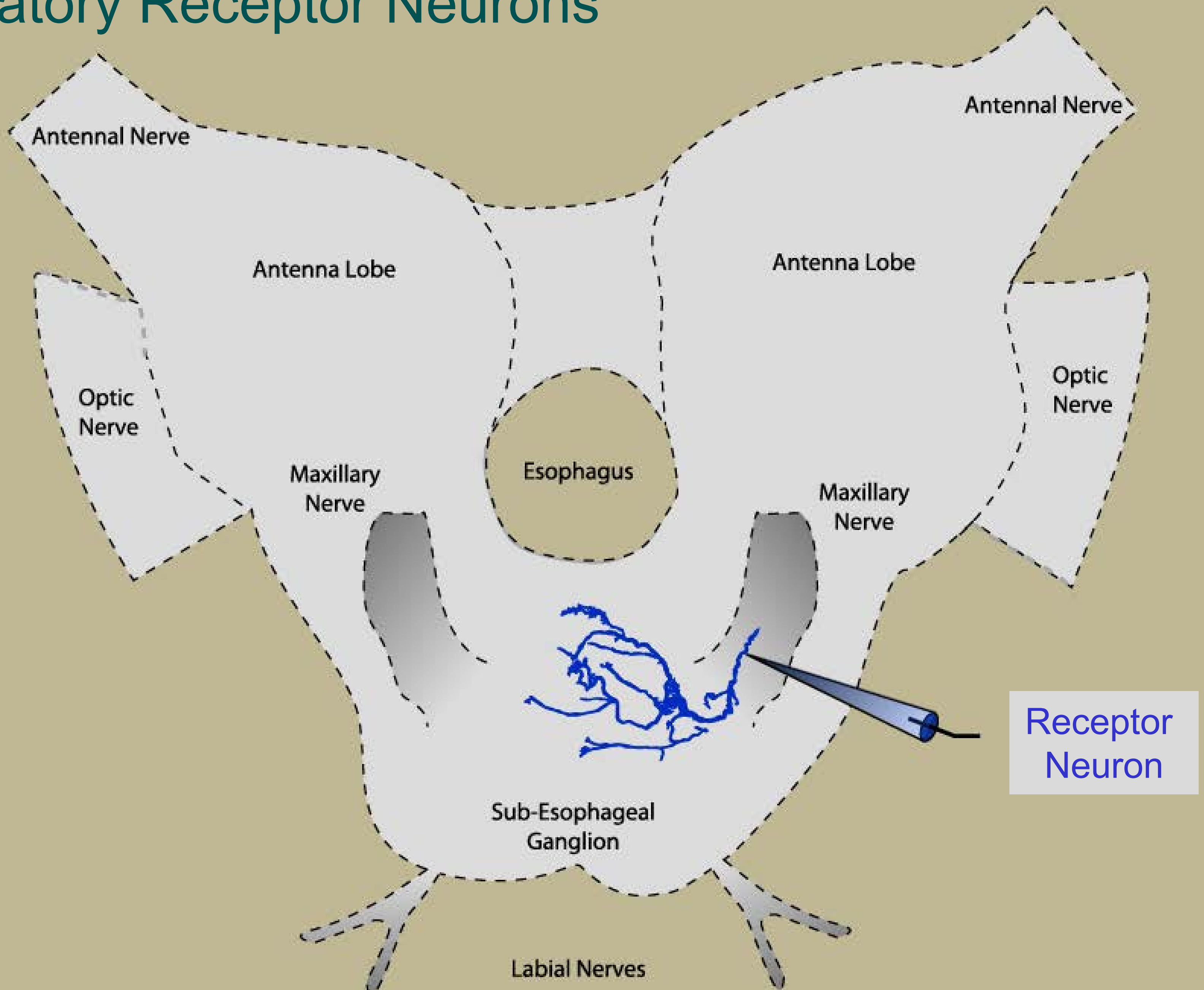
Yarmolinsky, Zuker, & Ryba,

Cell 139(2):234-44. (2009)

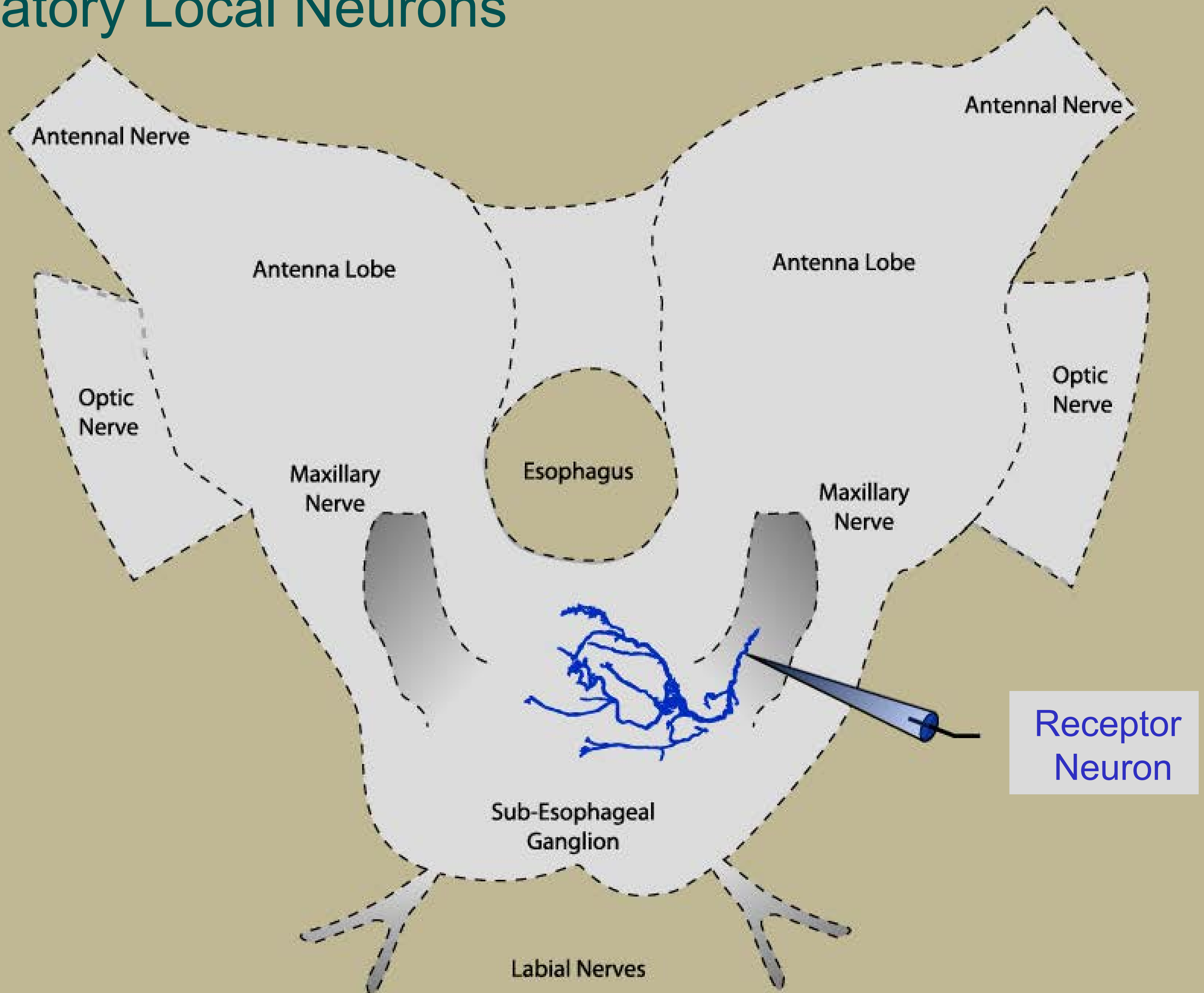
Must be quick

Must be accurate

Gustatory Receptor Neurons



Gustatory Local Neurons



Gustatory Local Neurons