WIRING THE EYE AND THE ANTENNA


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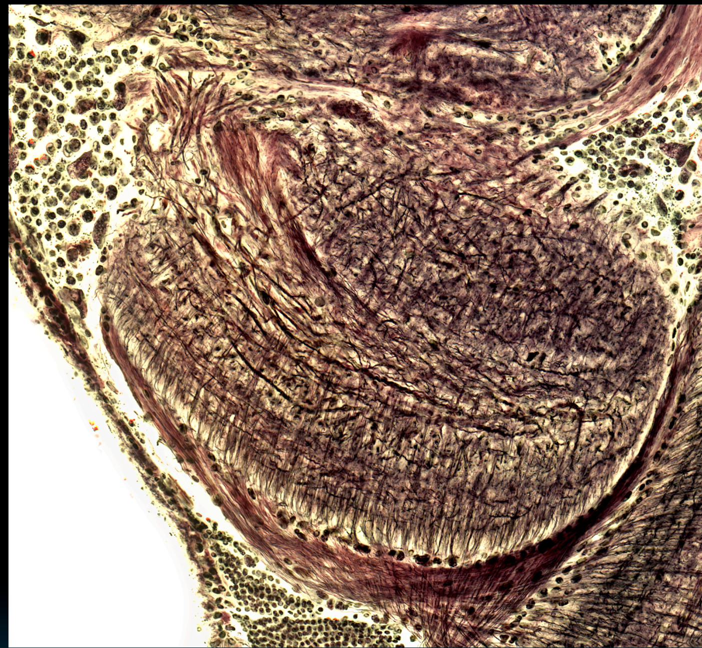
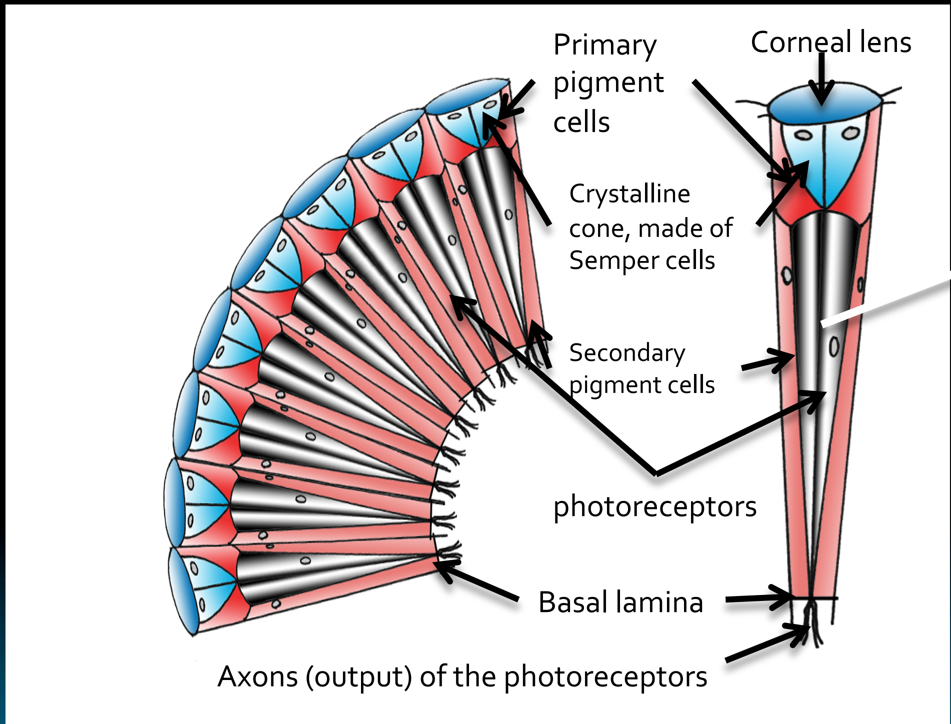
Objectives, part 1: vision

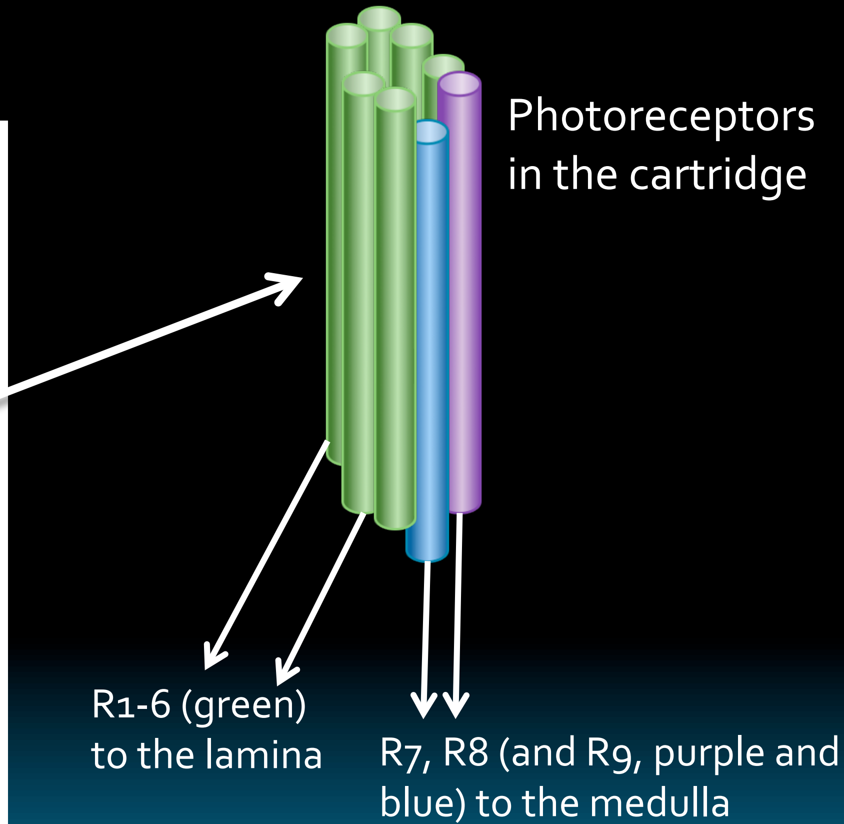
- The wiring of the eye is just as important as eye design
- How do you wire the system to detect light, color, and motion?
- What is the basic layout of the visual system?



The eye: from the photoreceptor to the brain

Review: the ommatidial structure





Eight or nine photoreceptors can be within each ommatidium cartridge

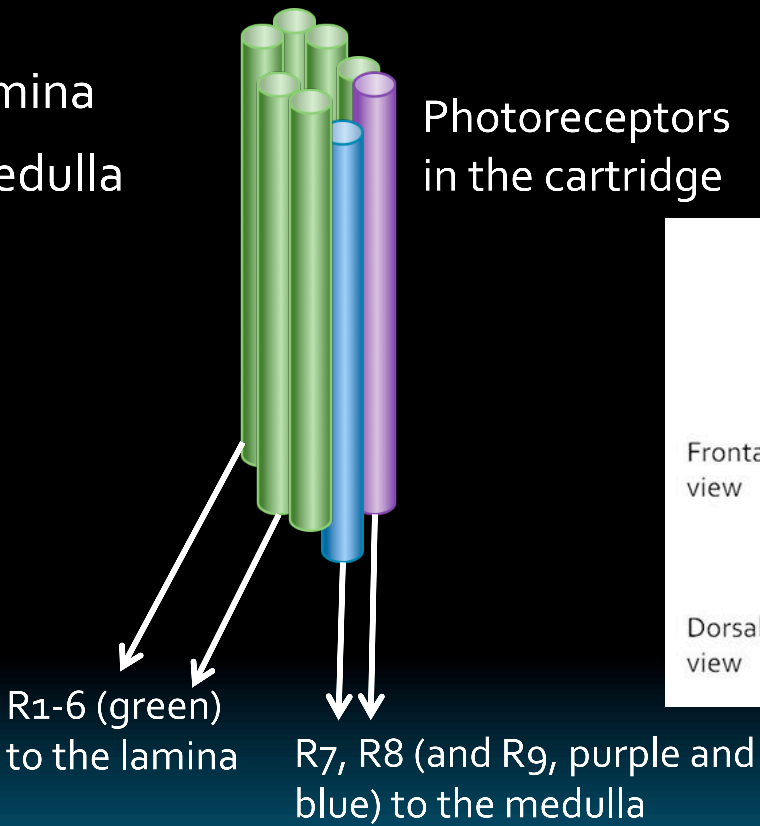
The area where the light-detecting microvilli are located is called the rhabdom

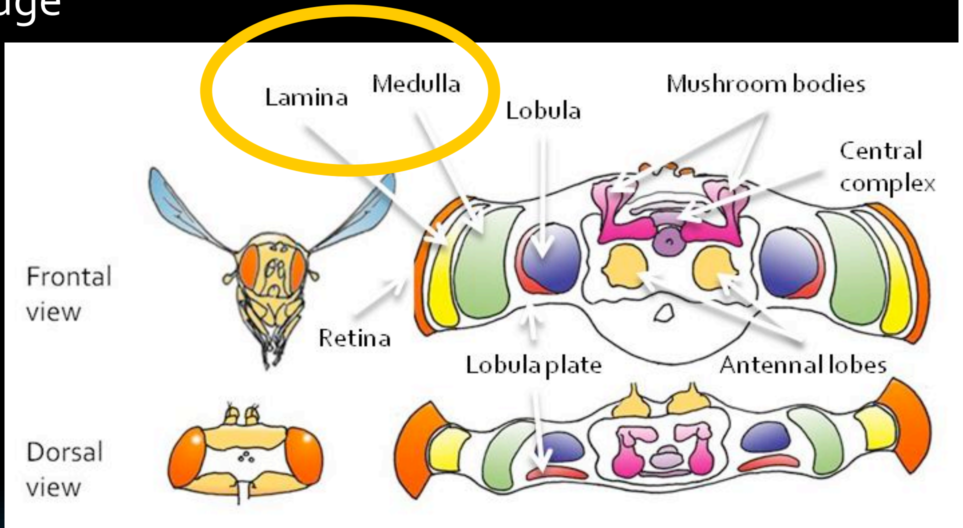
They can be open rhabdom or closed rhabdom

Photoreceptor arrangement

The photoreceptors output to two major visual processing stages in the brain:

- The lamina
- The medulla

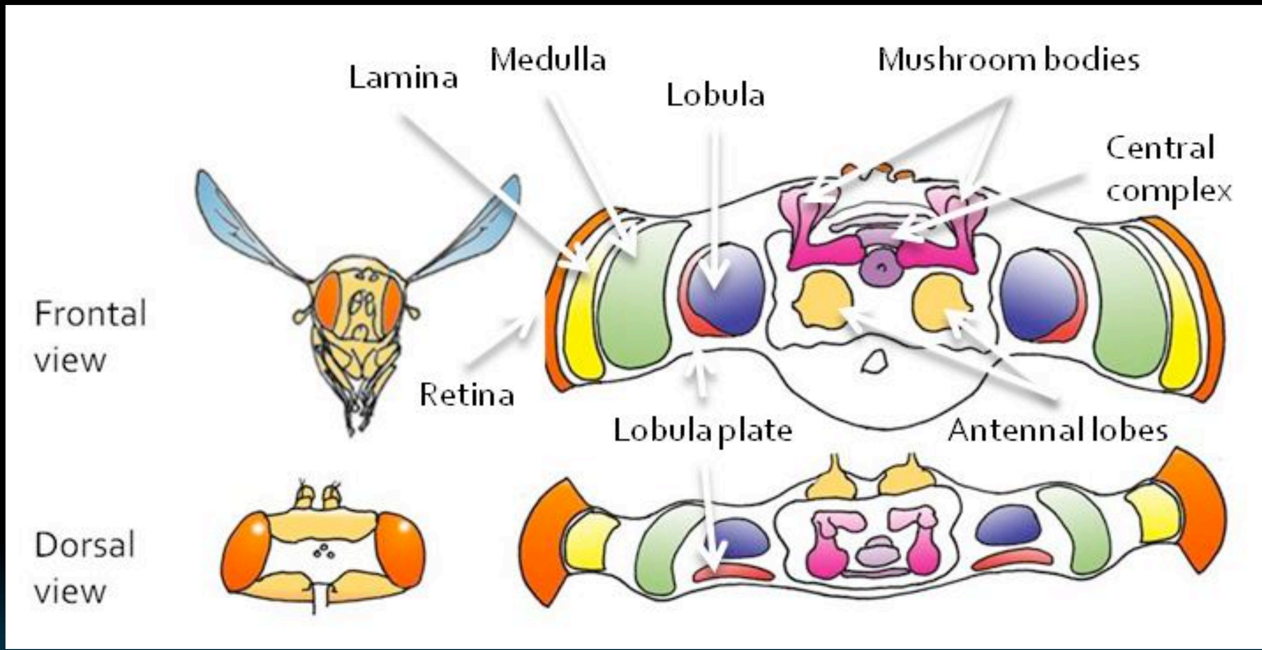




- Photoreceptors 1-6 (labeled R1-6) are often green-sensitive and output to the lamina
- Photoreceptors 7-8 (9) (labeled R7-8 or R9) are often UV or blue sensitive and send their outputs to the medulla

The layout of the visual system

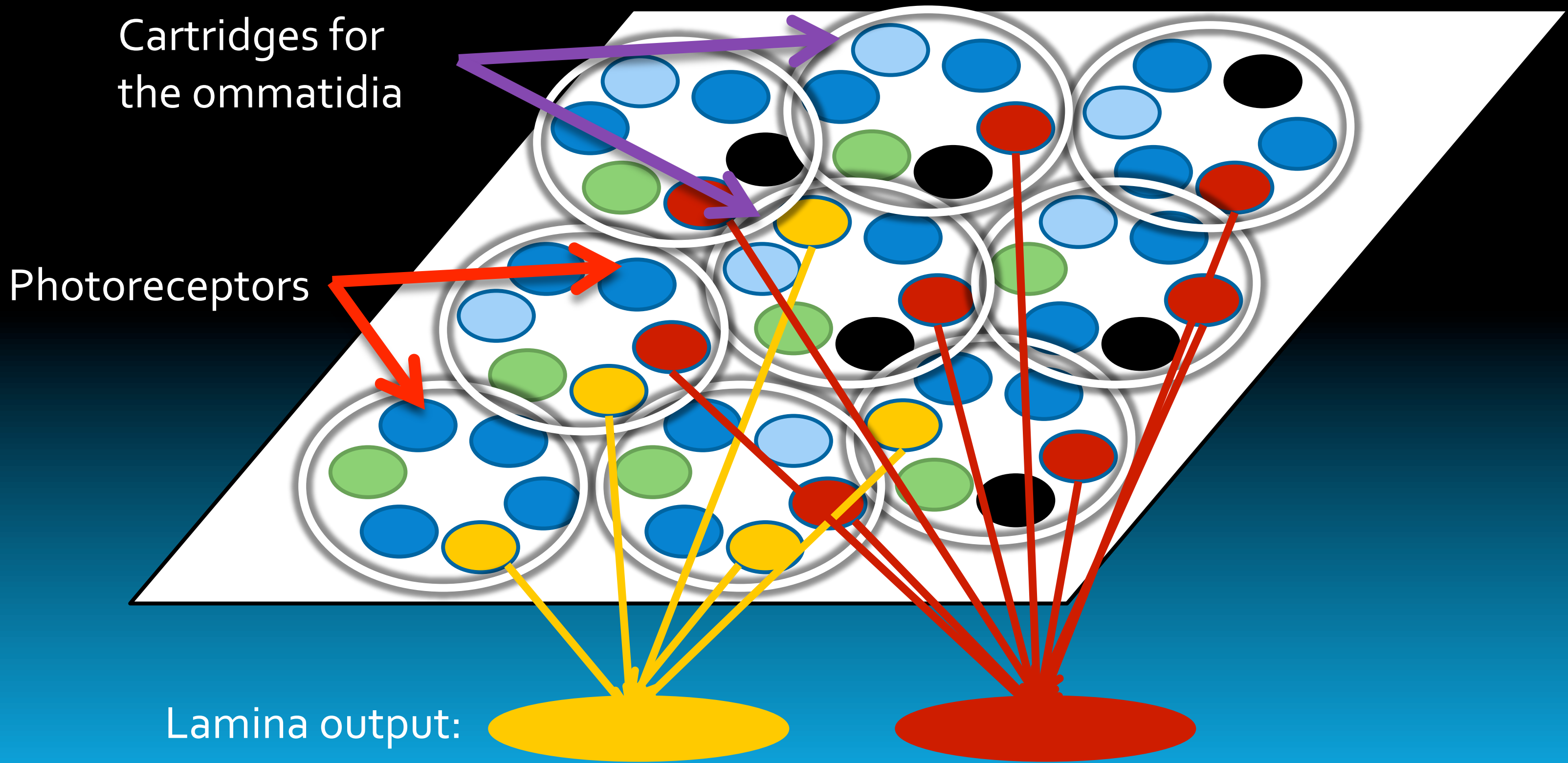
Retina to lamina to medulla to lobula complex to central brain



The system is layered within the visual system, but it is also retinotopic, in that the world outside is represented on the retina in a spatial array, with each ommatidial cartridge represented in columns in the lamina, the medulla, and, sometimes, in the lobula complex

Neural superposition: fly changes in resolution

- Since the rhabdom is open, photoreceptors from neighboring cartridges can view the same area of the world
- By integrating information across neighboring cartridges, the resolution of the input can be increased



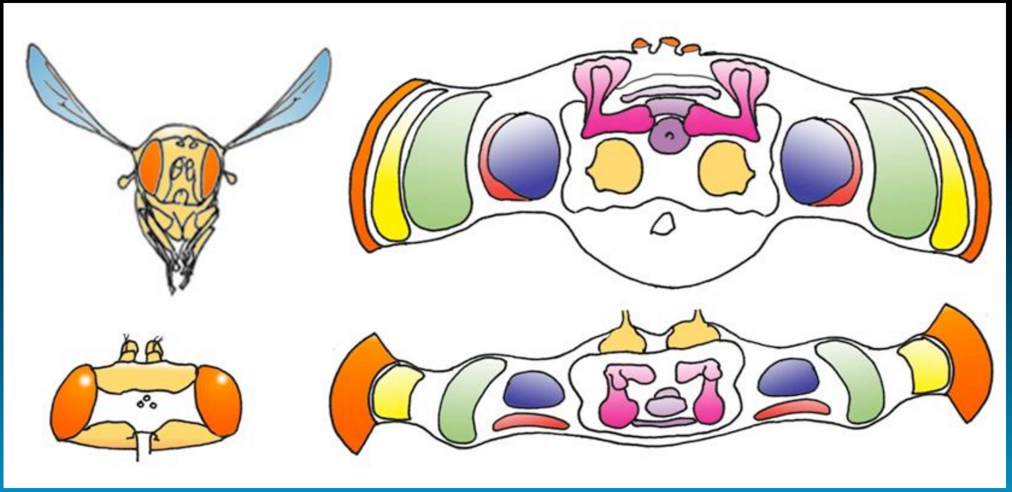
Photoreceptor inputs and the rest

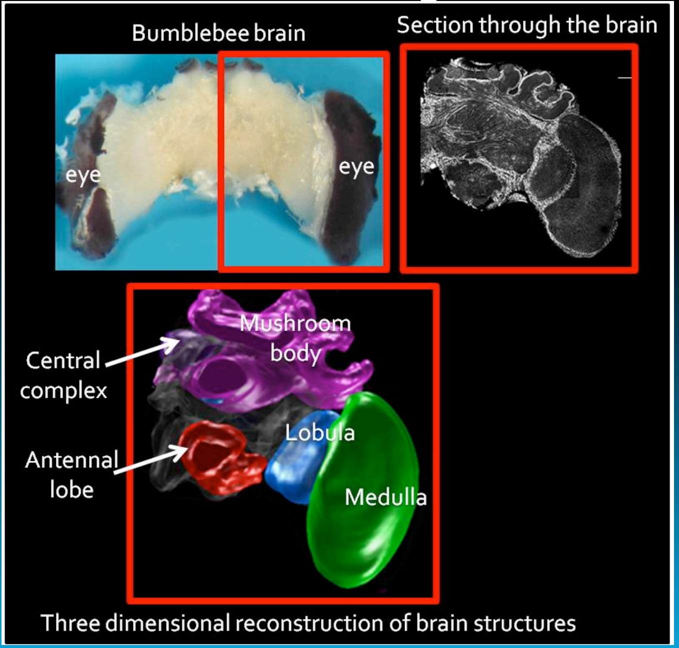
The lamina inputs (R1-6) are thought to feed into the motion detection pathway.

Meanwhile, the medulla inputs (R7-8) are though to be the major inputs to the color and pattern processing pathway

Douglass JK, Strausfeld NJ (1998) Functionally and anatomically segregated visual pathways in the lobula complex of a calliphorid fly. J Comp Neurol 396:84 –104.

- The lamina then sends its inputs into the medulla
- The medulla feeds into the lobula complex, which can be separated into the lobula and lobula plate in many insects (left) or fused (as in bees, right)



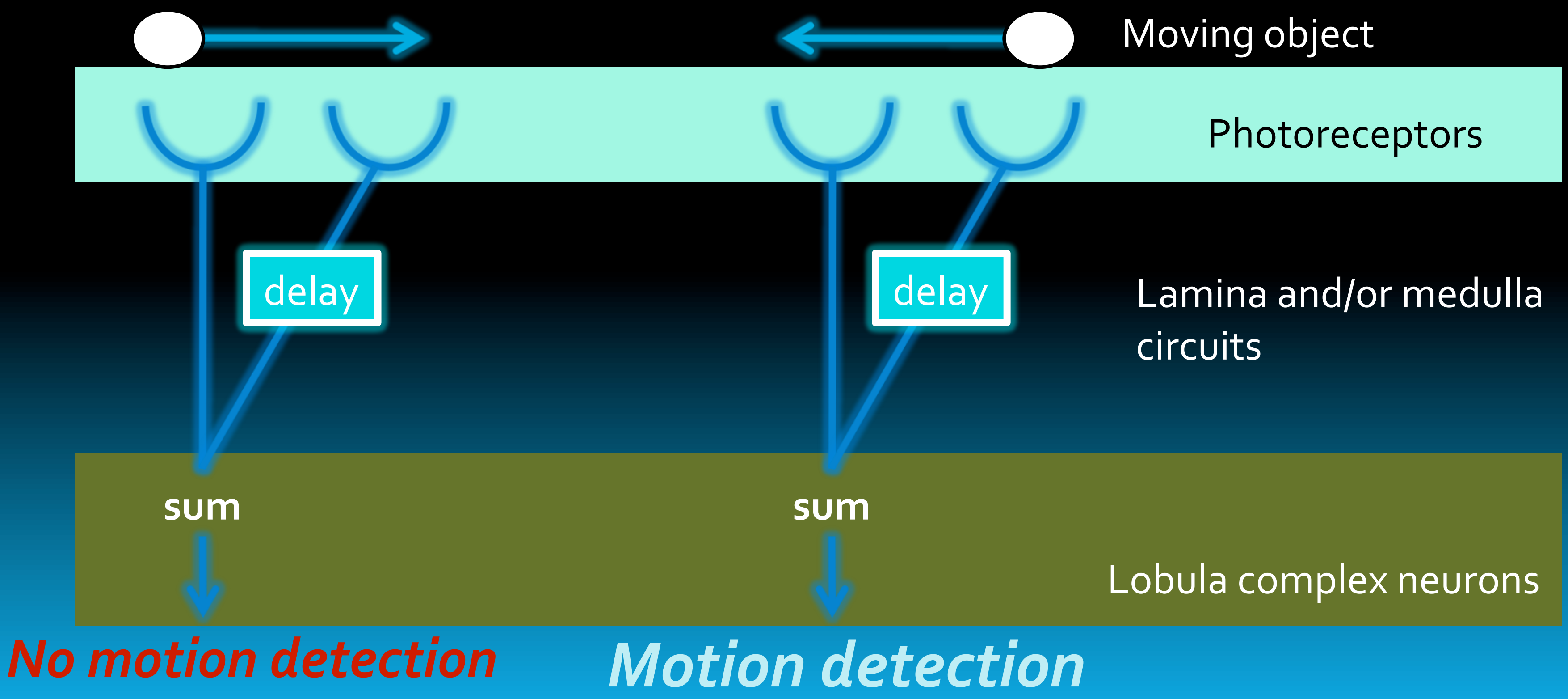


Functions: how motion works

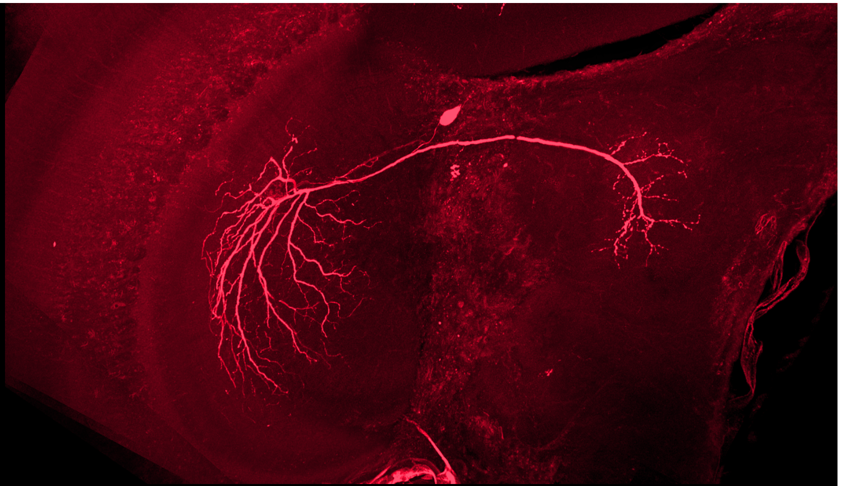
Motion processing involves detecting when objects are moving in the environment.

The way some neurons work is to detect changes in light across neighboring cartridges and integrate it, finally responding when things move in one direction or another (the model is called the Hassenstein-Reichert elementary motion detector)

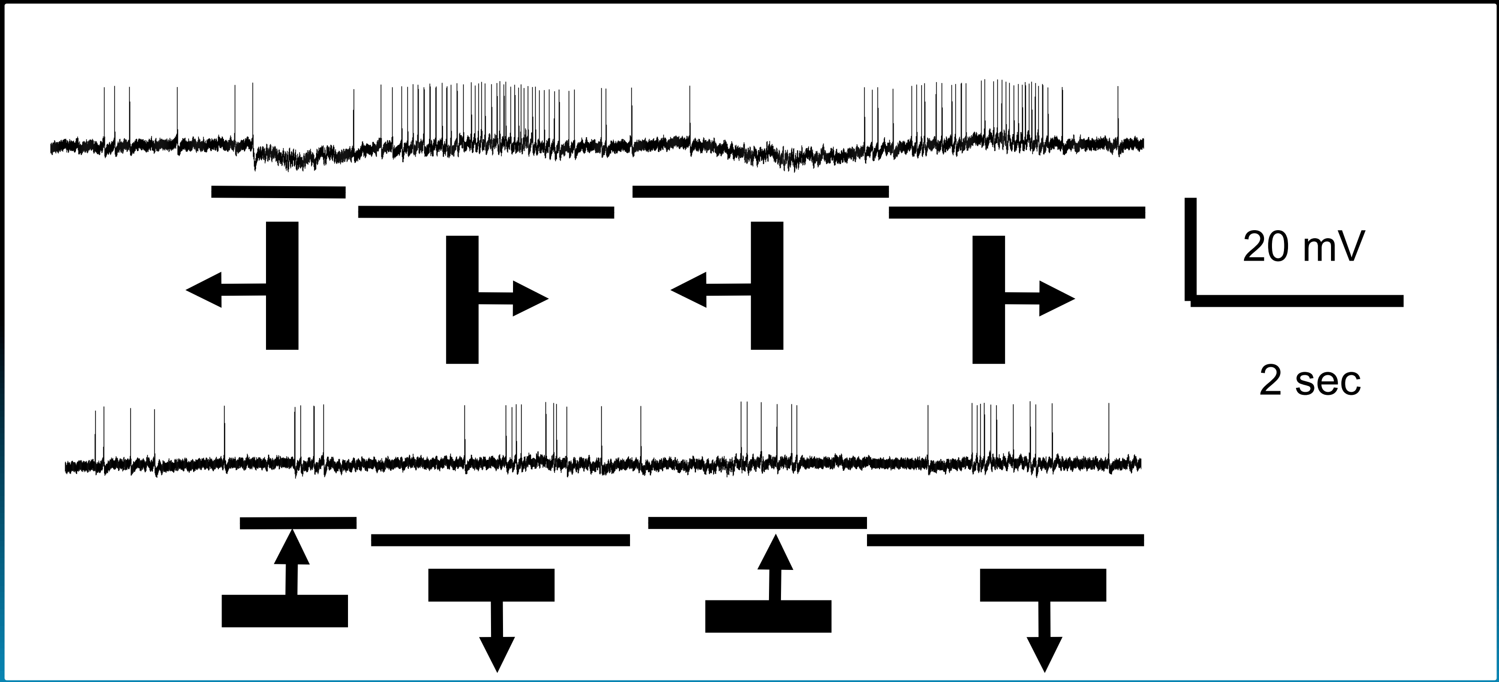
Borst, A. (2000) Models of motion detection. Nature Neuroscience 3, 1168. doi:10.1038/81435



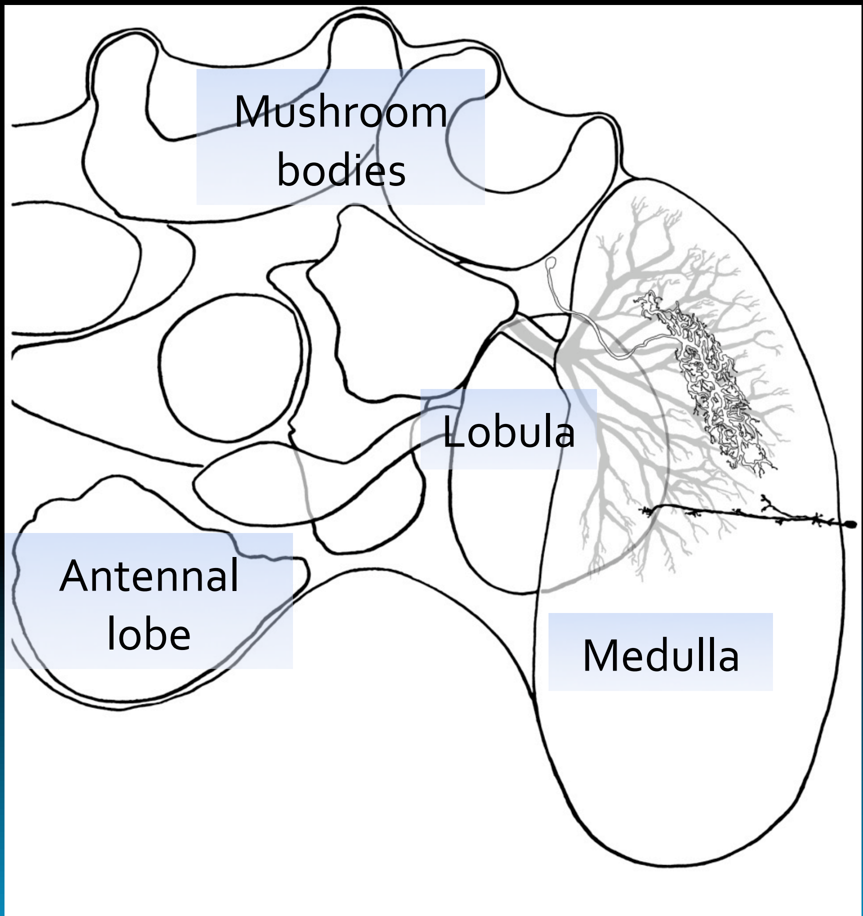
Motion responses



Other neurons can respond to moving bars
such as this bumblebee neuron



Different types of cells: wide field versus small field:



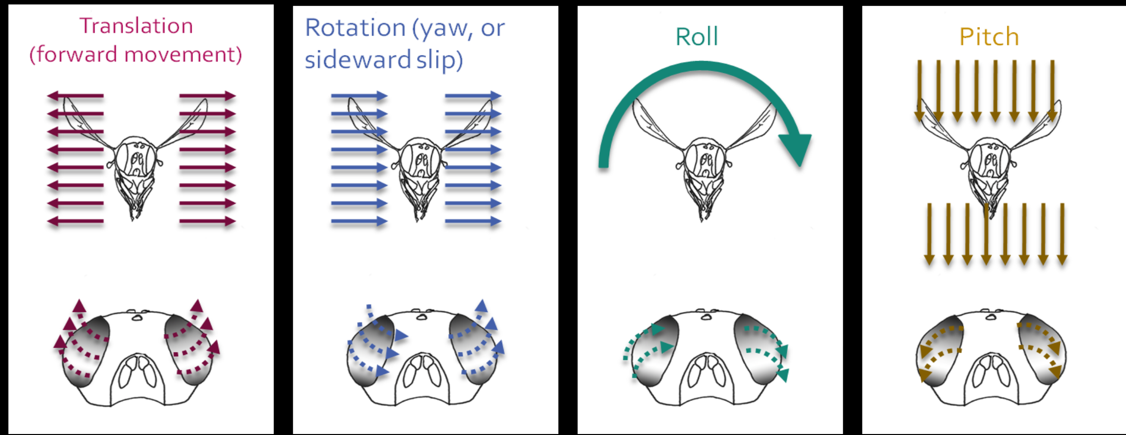
- Cells in the visual system can be wide field (grey and white cells) or small field (black cell) or somewhere in between (white cell)
- These different types of visual neurons can perform different roles, such as detecting changes in colour in a small area of the visual field, or detecting motion across the whole visual scene.

Functions: how motion detection works

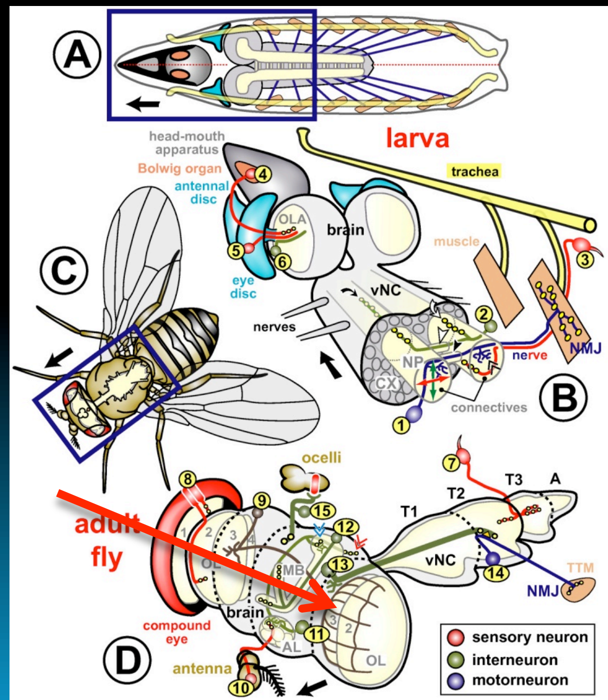
The lobula plate neurons in the fly have been some of the best-studied neurons in any insect

These neurons are separated into two systems (11):

1. The horizontal system, which detects front to back motion, back to front motion
2. The vertical system, which detects up and down motion



Borst, A. (2000) Models of motion detection. Nature Neuroscience 3, 1168. doi:10.1038/81435



Sánchez-Soriano N, Tear G, Whitington P, Prokop A. Wikipedia Commons
http://commons.wikimedia.org/wiki/File:Neurons_used_for_studies_on_neuronal_growth_at_different_stages_of_Drosophila_development.jpg

Motion responses in neurons

Still other neurons respond to the movement of small objects, such as for tracking prey or flying in a swarm

Neural mechanisms underlying target detection in a dragonfly centrifugal neuron
Bart R. H. Geurten, Karin Nordström, Jordanna D. H. Sprayberry, Douglas M. Bolzon and David C. O'Carroll. The Journal of Experimental Biology 210, 3277-3284. doi:10.1242/jeb.008425

DCMD cell: navigating a swarm

When insects are avoiding a collision or moving through a swarm, like locusts, specific neural circuits allow the insects to avoid collision.

Interneurons like the descending contralataral motion detector cell (DCMD) sends inputs to the motor centers to allow the insect to move away from an object.

Prof. Claire Rind has some good examples of how collision avoidance circuits can be involved in locust behaviour

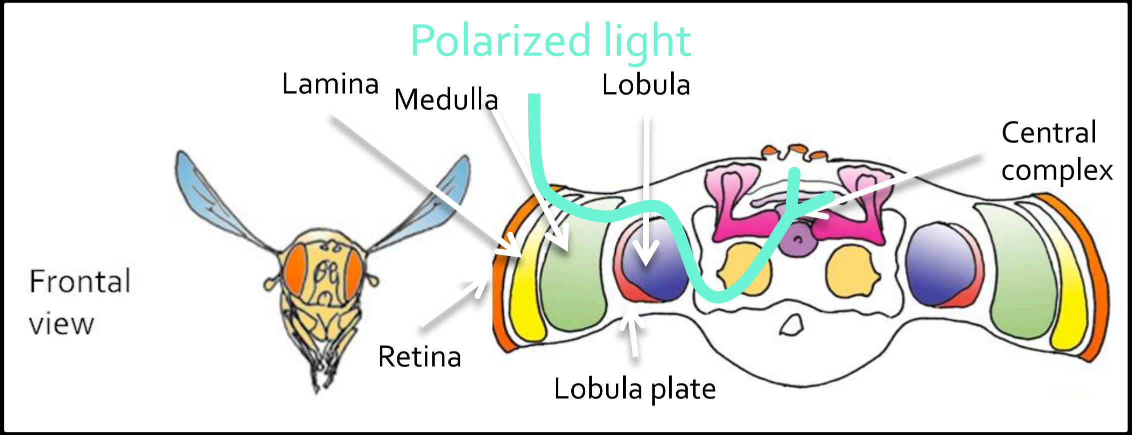
http://www.staff.ncl.ac.uk/claire.rind/try1.htm

Dr. Martina Wicklein works on a number of visual systems. Check out her website under 'current work/ preliminary results'!

http://www.cnl.salk.edu/~martina/

Polarized light processing

Polarized light information enters via the photoreceptors, goes through the medulla into a portion of the lobula and projects into the central brain



Polarized light information does arrive at the central complex in locusts, where there is a 'polarization map' detecting different polarized light directions

Check out this website by Prof. Uwe Homberg, a researcher on how the polarization information is processed in the locust brain:

http://www.uni-marburg.de/fb17/forschung/foberichtneu/Foberichtneu/homberg

Recommended reading:
Transformation of Polarized Light Information in the Central Complex of the Locust
Stanley Heinze, Sascha Gotthardt, and Uwe Homberg
The Journal of Neuroscience, September 23, 2009, 29(38):11783-11793; doi:10.1523/JNEUROSCI.1870-09.2009
http://www.jneurosci.org/cgi/content/abstract/29/38/11783

Colour processing

Colour processing is not well understood in insects beyond the photoreceptor level, but evidence has indicated that it is a complex process and can occupy a different pathway from the motion pathway

References

Hertel H (1980) Chromatic properties of identified interneurons in the optic lobes of the bee. J Comp Physiol A 137:215-231.

Paulk AC, Phillips-Portillo J, Dacks AM, Fellous JM, Gronenberg W. (2008) The processing of color, motion, and stimulus are anatomically segregated in the bumblebee brain. Journal of Neuroscience 28:6319–6332.

Paulk AC, Dacks AM, Gronenberg W. (2009) Color processing in the medulla of the bumblebee (Apidae: Bombus impatiens). Journal of Comparative Neurology 513: 441-456.

Paulk AC, Dacks AM, Phillips-Portillo J, Fellous JM, Gronenberg W. (2009) Visual processing in the central bee brain. Journal of Neuroscience 29: 9987-9999.

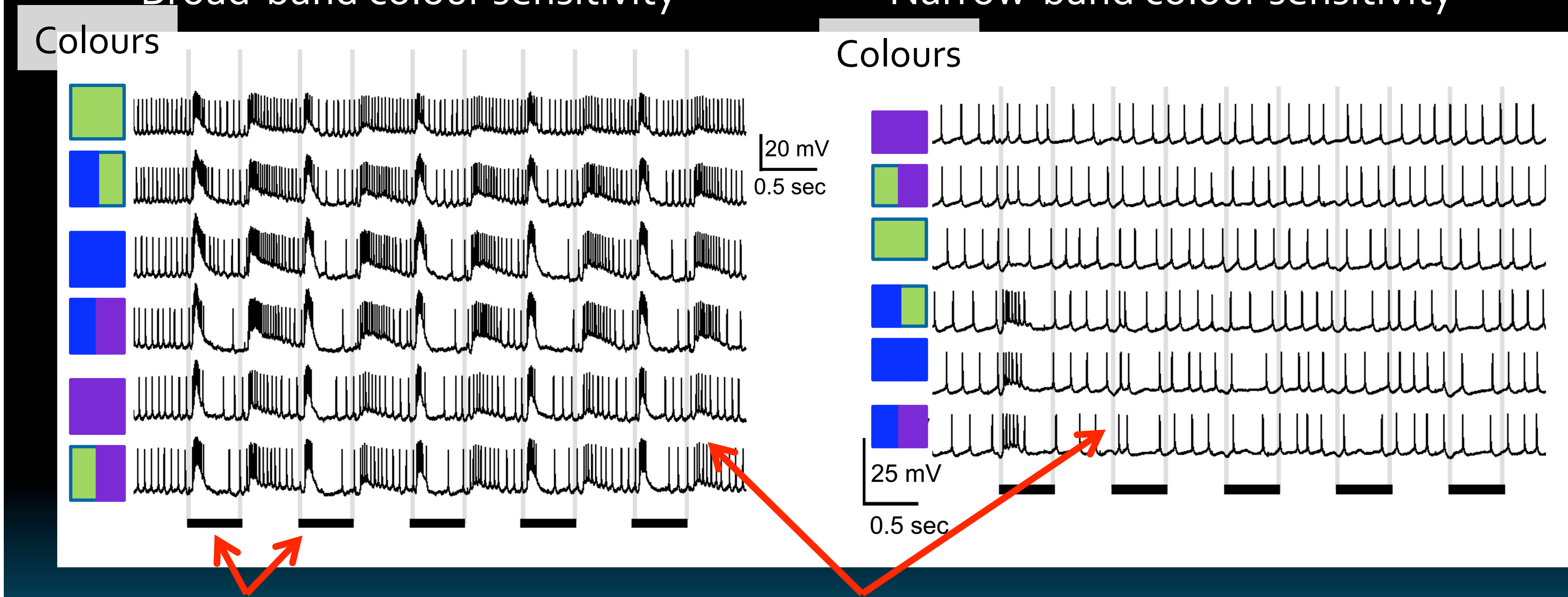
Kien J, Menzel R (1977a) Chromatic properties of interneurons in the optic lobes of the bee-I. Broad-band neurons. J Comp Physiol 113:17-34.

Kien J, Menzel R (1977b) Chromatic properties of interneurons in the optic lobes of the bee-II. Narrow band and color opponent neurons. J Comp Physiol 113:35-53.

Yang EC, Lin HC, Hung YS (2004) Patterns of chromatic information processing in the lobula of the honeybee, *Apis mellifera* L. J Insect Physiol 50:913-925.

Chromatic sensitivity: classifications

Broad-band colour sensitivity   Narrow-band colour sensitivity

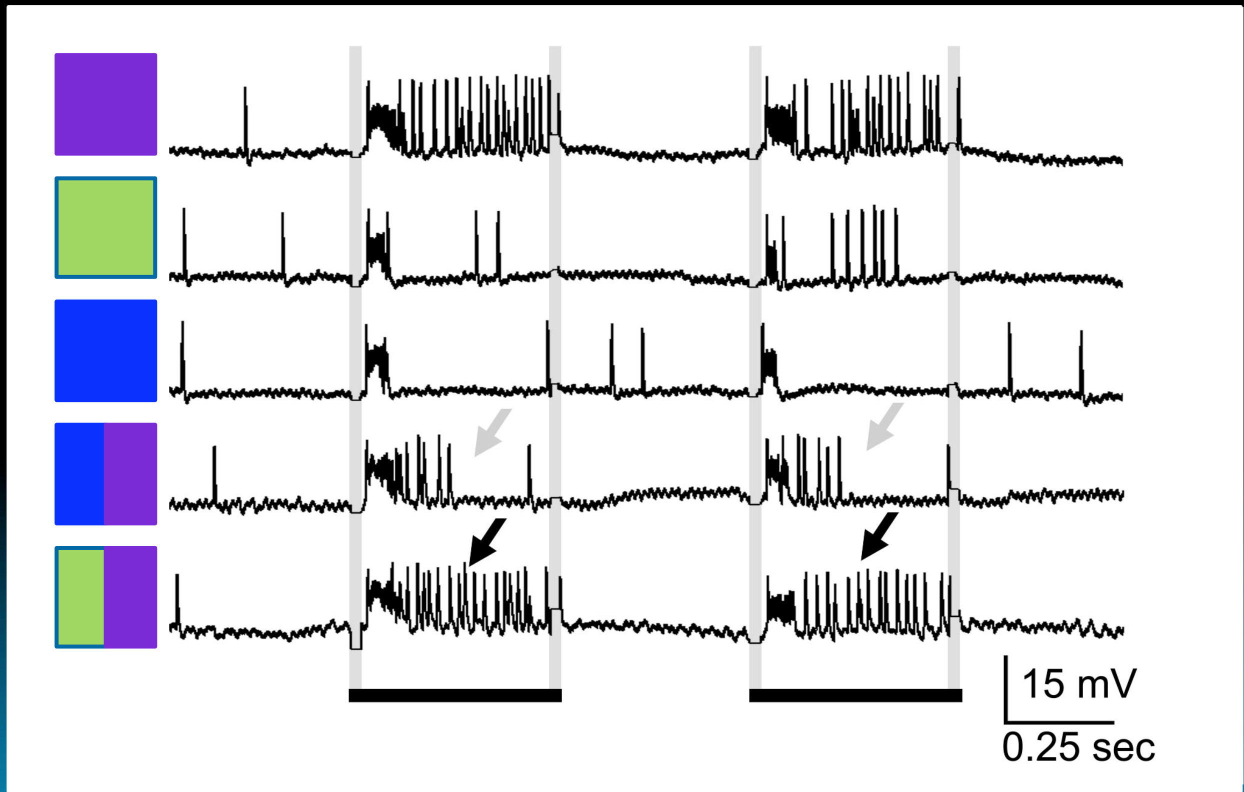


Light flashes   Responses of the neurons

Some cells respond the same way to all the colours the same way

Other cells respond to only one or two colours, which is called narrow-band colour sensitivity

Color opponency: basis for color vision



Functional layout of the visual system

Visual input pathways: where does colour, motion, pattern, and polarized light processing go?

Colour processing may happen in the front of the brain while motion processing may be along the back of the brain

Objectives, part 2: smell

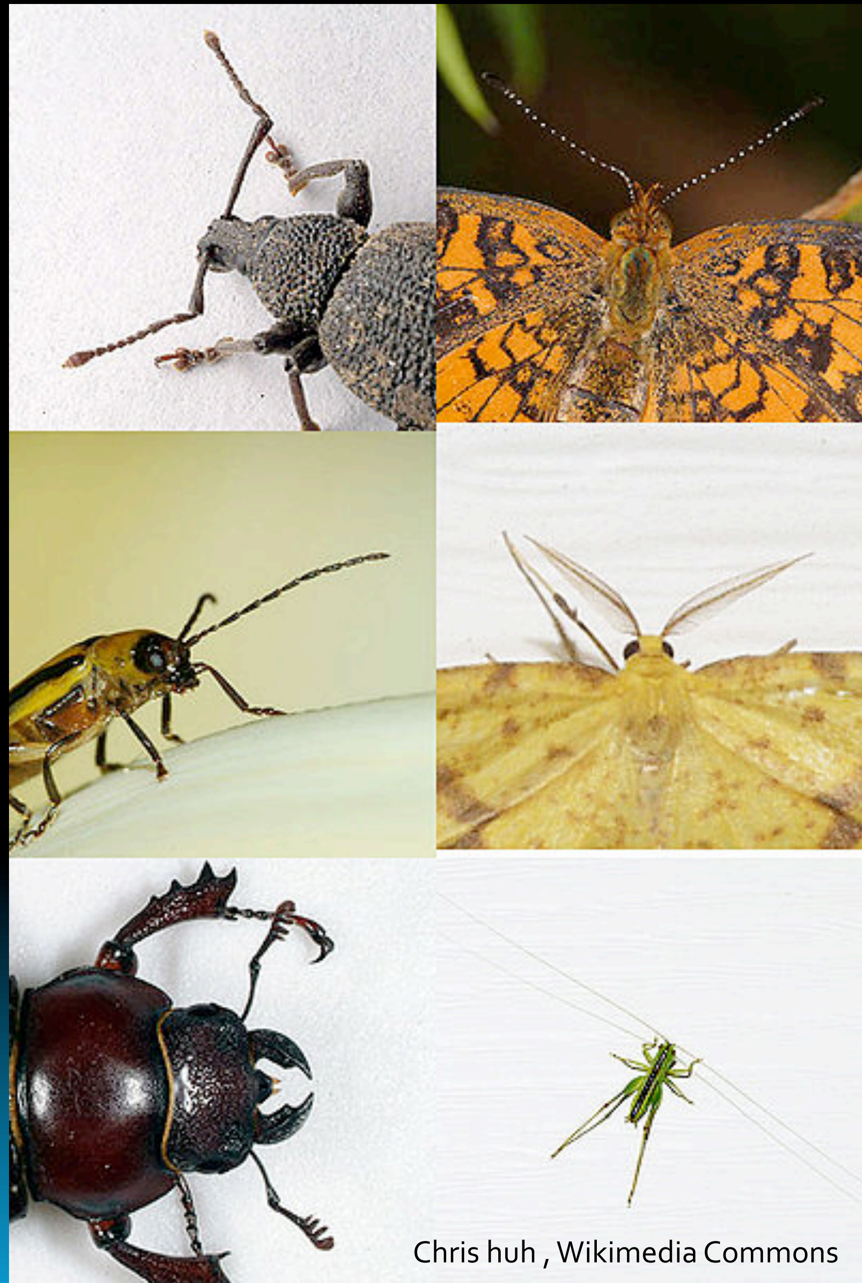
- The wiring of the antenna can be essential for olfaction
- How do you detect olfactory cues?
- What is the basic layout of the olfactory system?

Fritz Geller-Grimm (modified by gian_d) Wikimedia Commons

IvanTortuga Wikimedia Commons

Antennal diversity

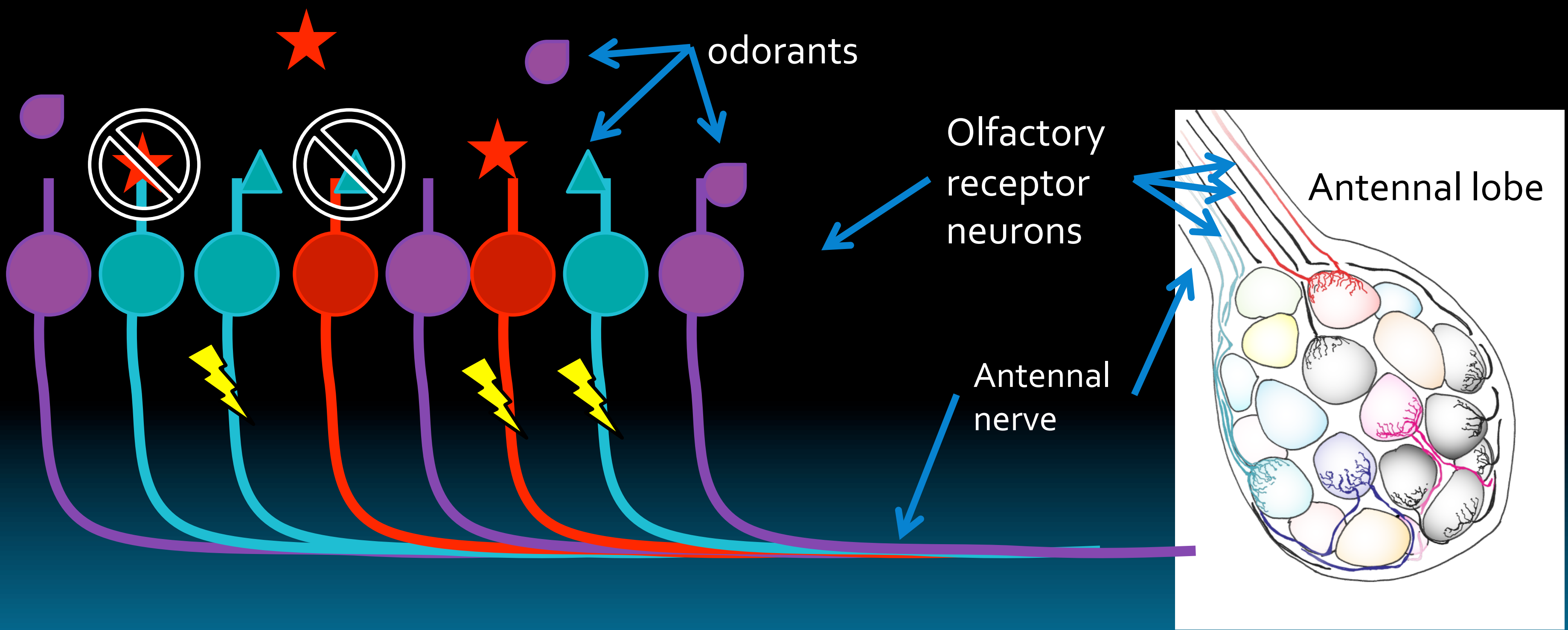
Siga, Wikimedia Commons



Chris huh , Wikimedia Commons

The antenna: from the olfactory receptor cells to the brain

Review: the olfactory receptor cells are located in the antenna, where specific odorants can bind to receptor proteins and induce a spiking response in the olfactory receptors (see Module 13: Sensing Tastes and Odours: Function)

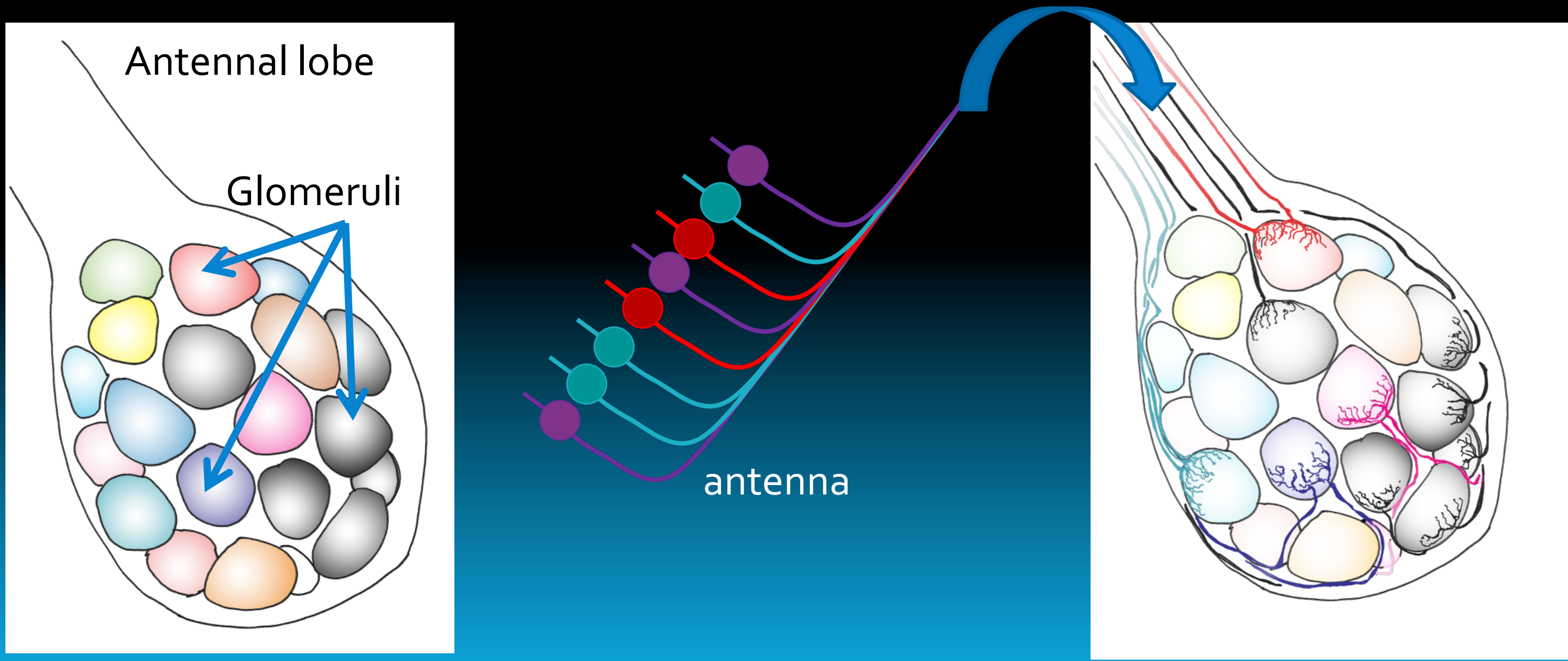


Olfactory receptor cells then form a bundle along the antennal nerve and enter the brain at the antennal lobe

The antenna: from the olfactory receptor neurons (ORNs) to the brain

The ORNs then enter the antennal lobe, where they project to specific structures called glomeruli (spheriodal structures which include synapses and connections between the inputs and the outputs of the antennal lobe)

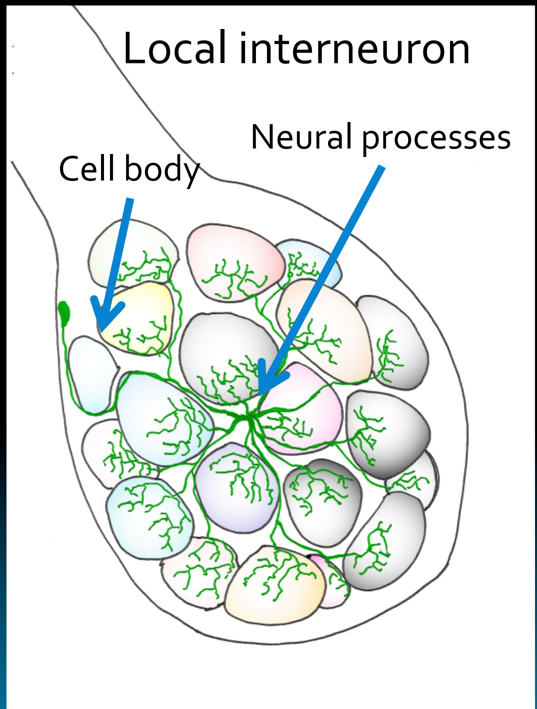
The ORNs of specific odorant receptor types go to the same glomerulus

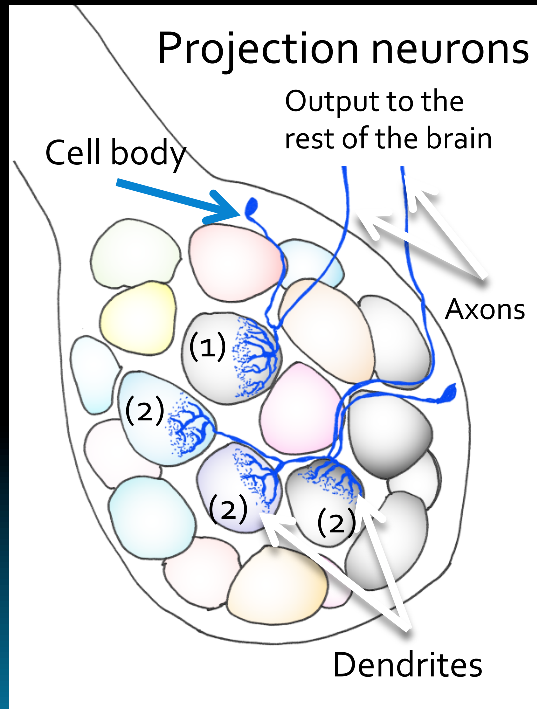


Outputs from the antennal lobe

The glomeruli are connected by a number of inhibitory *local interneurons* (LNs)

The outputs from the antennal lobe are called the *projection neurons* (PNs), which can receive inputs from single glomeruli (1) or from multiple glomeruli (2)

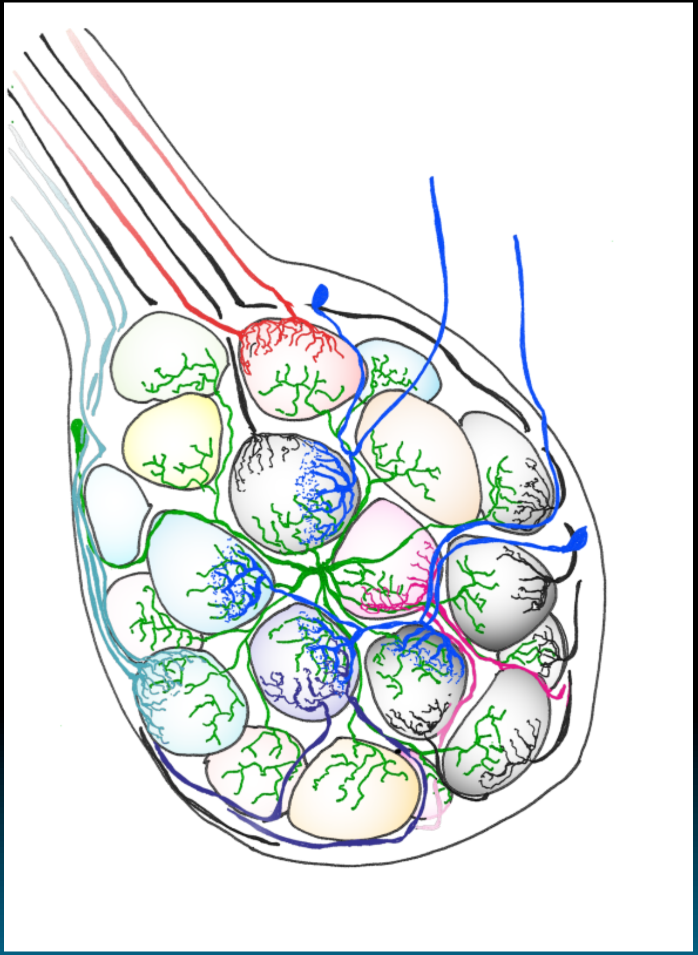




The PNs project to the lateral horn, in the lateral protocerebrum, and to the mushroom bodies

Olfactory processing: how does it work?

- A lot of debate has occurred in the field as to how olfactory processing may work.
- The insect models used have been *Drosophila melanogaster* (fly), *Apis mellifera* (honeybee), *Manduca sexta* (tobacco hornworm moth), and the locust (*Schistocerca gregaria*)
- Due to the diversity of the antennal lobe arrangements, there are a very few agreed-upon mechanisms
- There is the idea that each glomerulus is an 'odour' address, and similar odours are encoded in the same glomerulus, which indicates there could be an odotopic map
- On the other hand, olfactory processing could be a combinatorial type of processing, where each odour has a multiple glomerulus address.

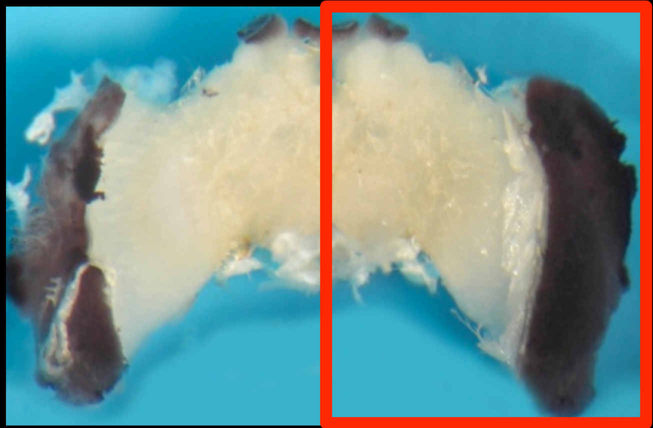


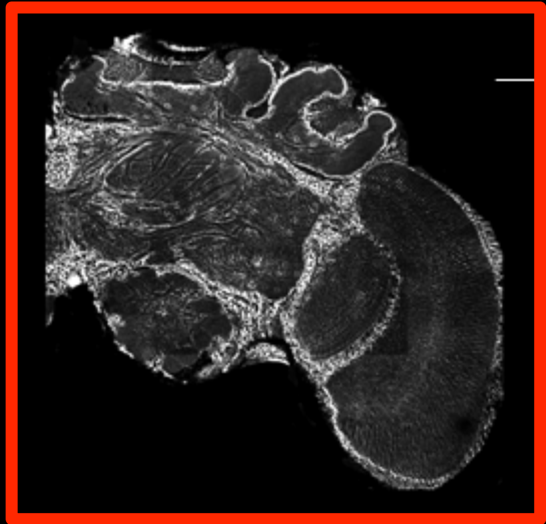
Olfactory and visual processing: where to go from here?

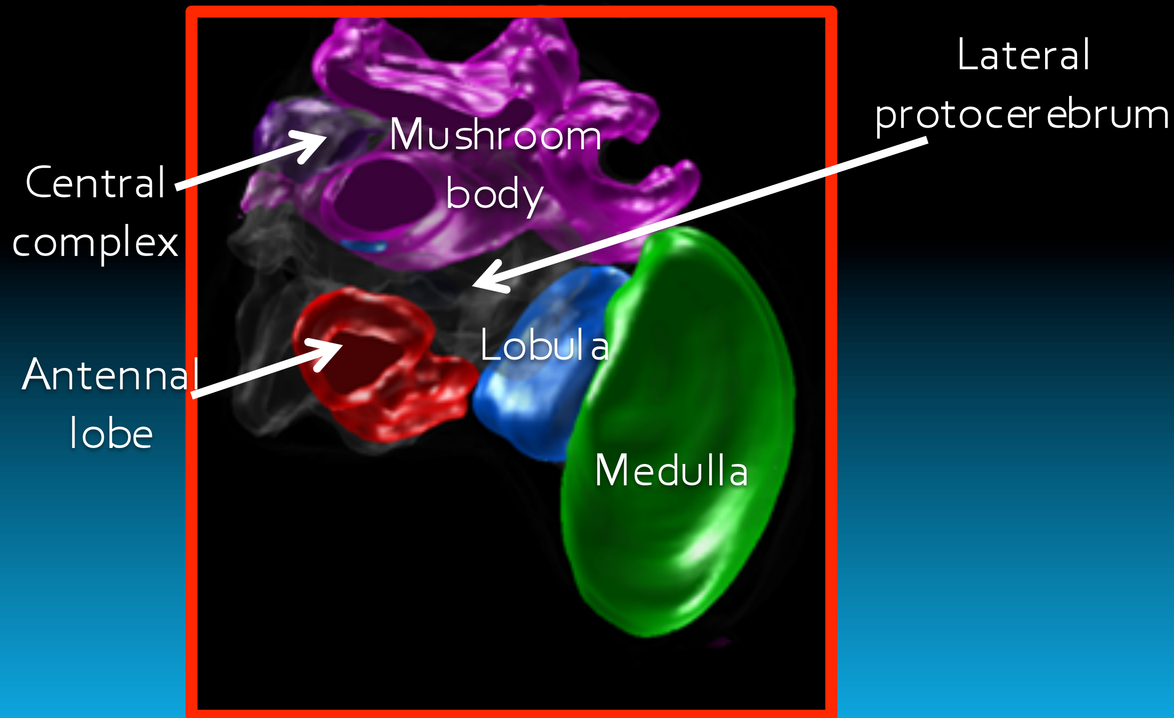
- How is all of this information, including mechanosensory information from the thorax and head as well as auditory processing, integrated?
- Where does all this information go?

- To the protocerebrum and central brain!

Brain areas

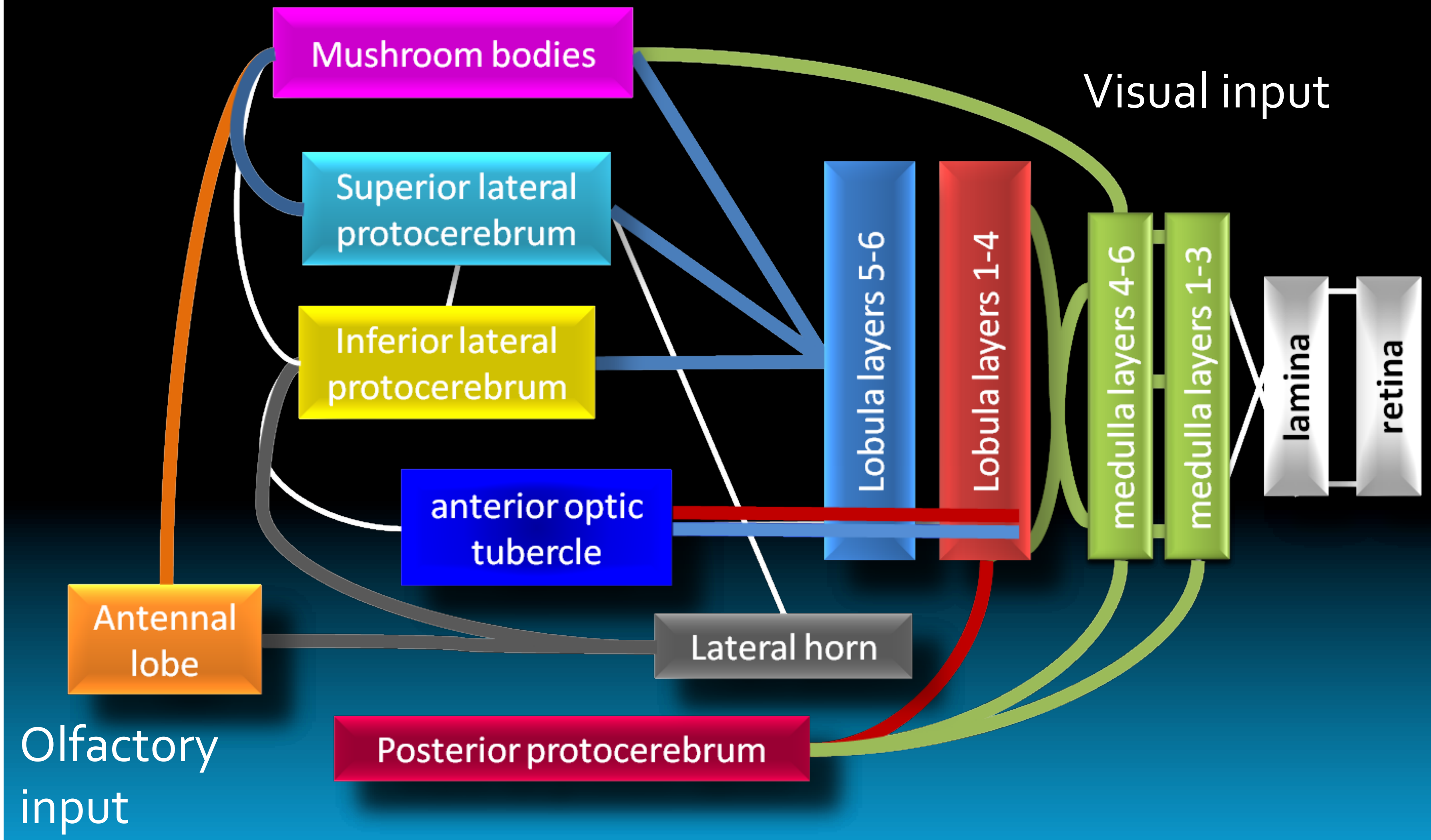





Lateral protocerebrum
Mushroom body
Central complex
Antennal lobe
Lobula
Medulla

Integration into the rest of the system

The visual system, of course, then inputs to the central brain, with numerous connections throughout the circuit



The rest of the system

Learning, memory, and everything else insects do!