

Tübingen | Sehen: Menschen, Algorithmen und Maschinen  
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# Was das Auge dem Gehirn erzählt – Die Retina als Hochleistungsrechner

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TÜBINGEN



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# Das Auge ist keine Kamera (Teil 1)

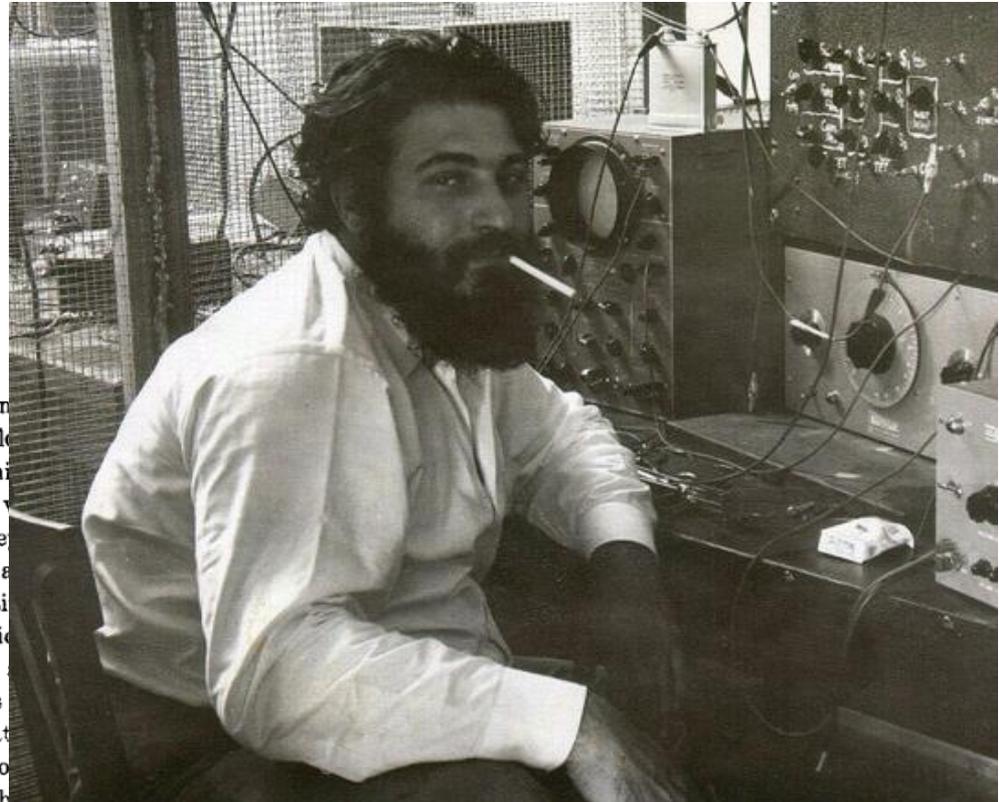
## WHAT THE FROG'S EYE TELLS THE FROG'S BRAIN\* †

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W. S. McCULLOCH,‡ AND W. H. PITTS‡

### I. INTRODUCTION

#### A. Behavior of a Frog

A frog hunts on land by vision. He escapes enemies by seeing them. His eyes do not move, as do ours, to follow suspicious events, or search for things of interest. If his head is rotated with respect to gravity or the whole body is rotated about him, then he shows compensatory eye movements. These movements enter his hunting and evading behavior as he sits on a rocking lily pad. Thus his eyes are active. He has no fovea, or region of greatest acuity in vision. To see he must center a part of the image. He has only one visual system, retina to colliculus, not a double one such as ours. The retina sends fibers not only to colliculus but to the lateral geniculate body which relays to cerebral cortex. Thus, we choose the frog because of the uniformity of his retina, the normal lack of eye and head movements except for those which stabilize the



Jerome Lettvin (\*1920, +2011)  
in Building 20 at MIT in 1952  
[http://en.wikipedia.org/wiki/Jerome\\_Lettvin](http://en.wikipedia.org/wiki/Jerome_Lettvin)

\*This paper originally appeared in the *Proc. Inst. Radio Engrs.*, 1959, vol. 47, pages 1940-1951. Reprinted by permission of Dr. Lettvin and the Institute of Electrical and Electronics Engineers, Inc.

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‡ Research Laboratory of Electronics, Massachusetts Institute of Technology.

§ On leave from the University of Chile, Santiago, Chile.



Sinnesorgane

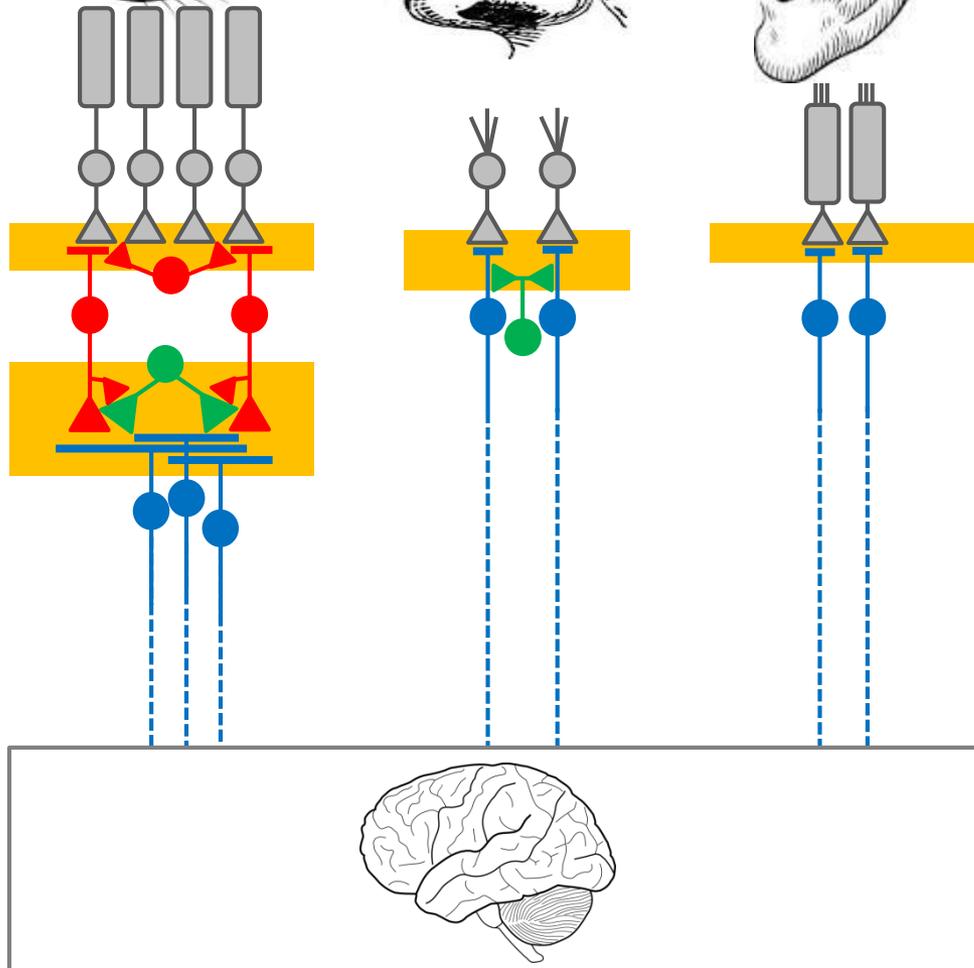
„Sensoren“  
(Rezeptorzellen)

1. synaptische  
Schicht

2. synaptische  
Schicht

„Kabel“  
(Nervenfasern)

höhere Areale  
im Gehirn

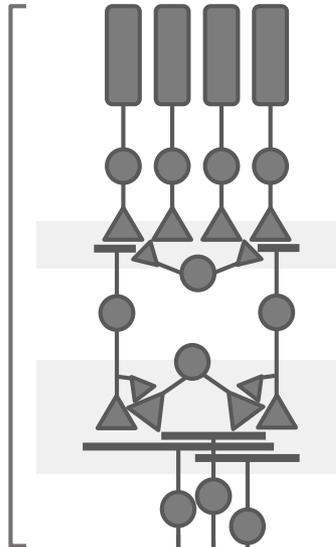




Photorezeptoren

~ 130 Millionen

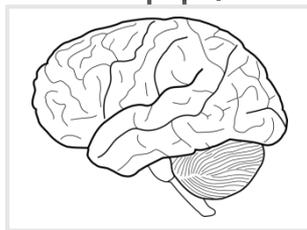
Retina



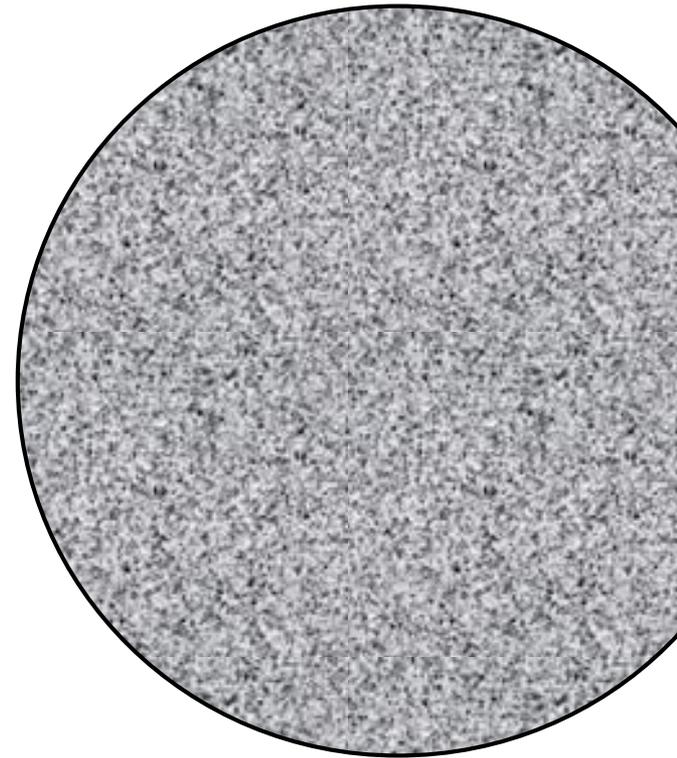
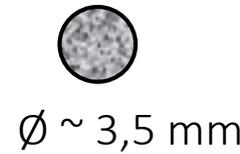
Optischer Nerv

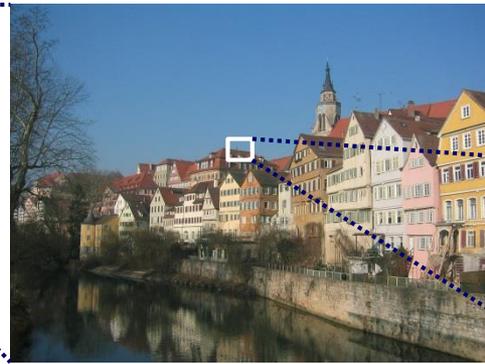
~ 1,3 Millionen Fasern  
= Flaschenhals !!

höhere Areale  
im Gehirn



Maus:  
~ 6.6 Millionen vs. 45,000 (~ 1 : 150)



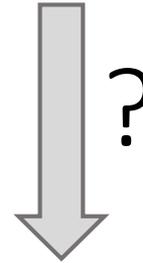
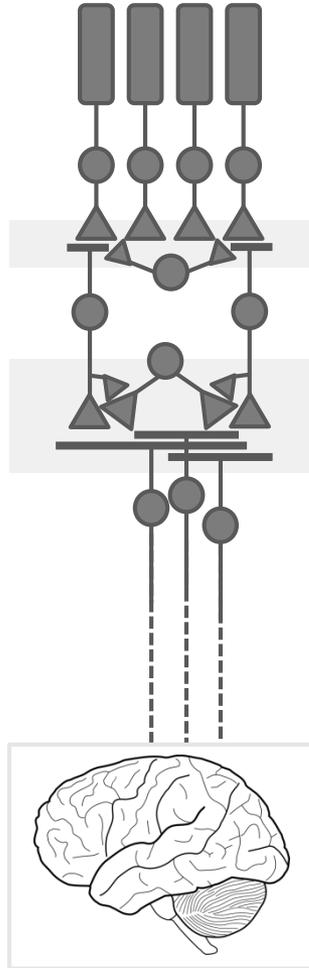


Photorezeptoren

Retina

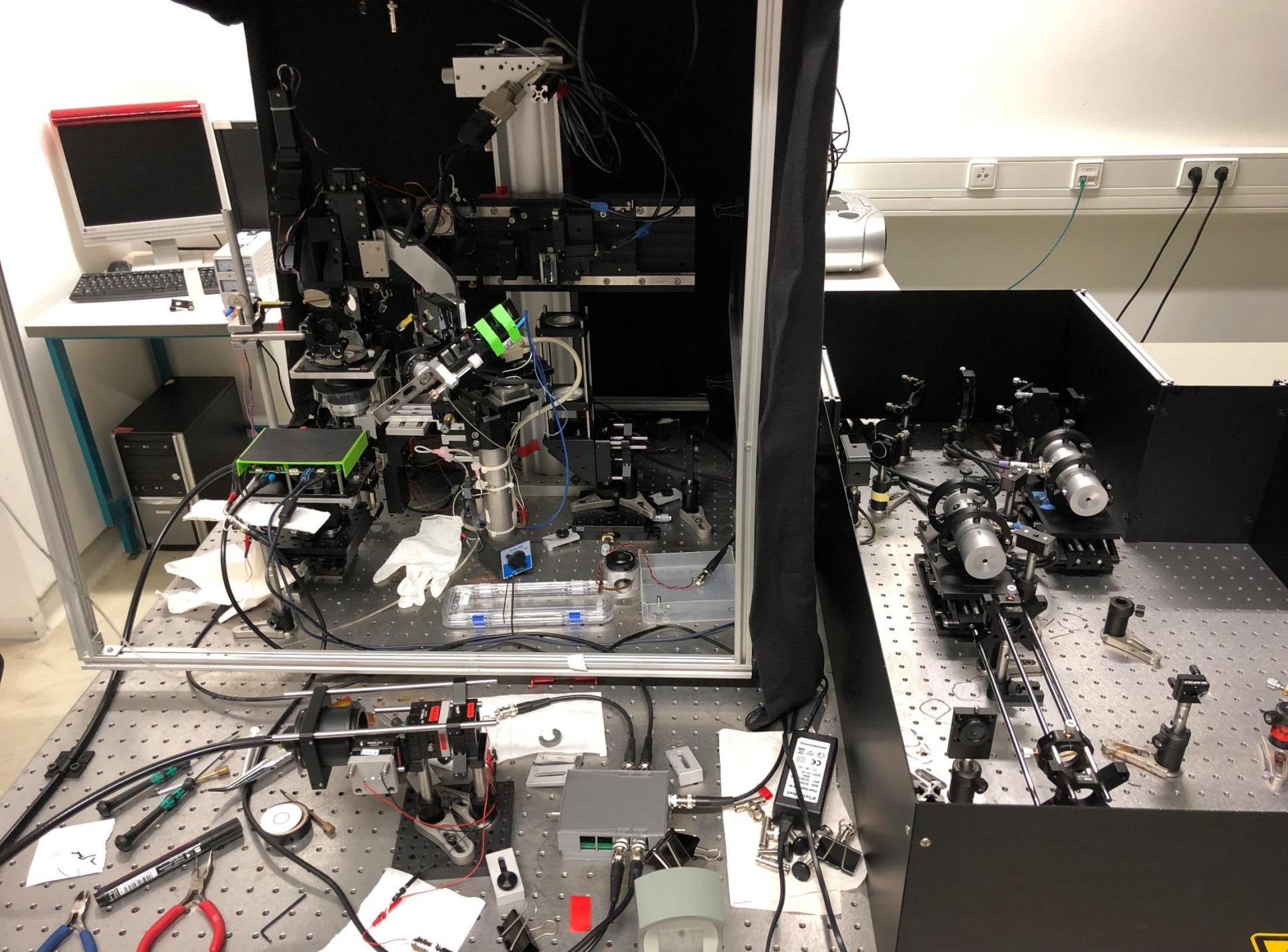
Optischer Nerv

höhere Areale  
im Gehirn



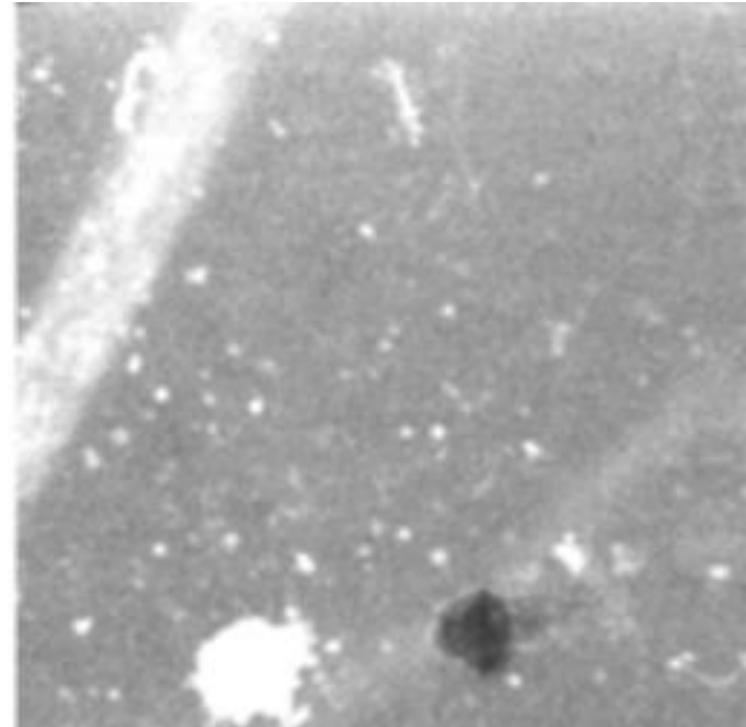
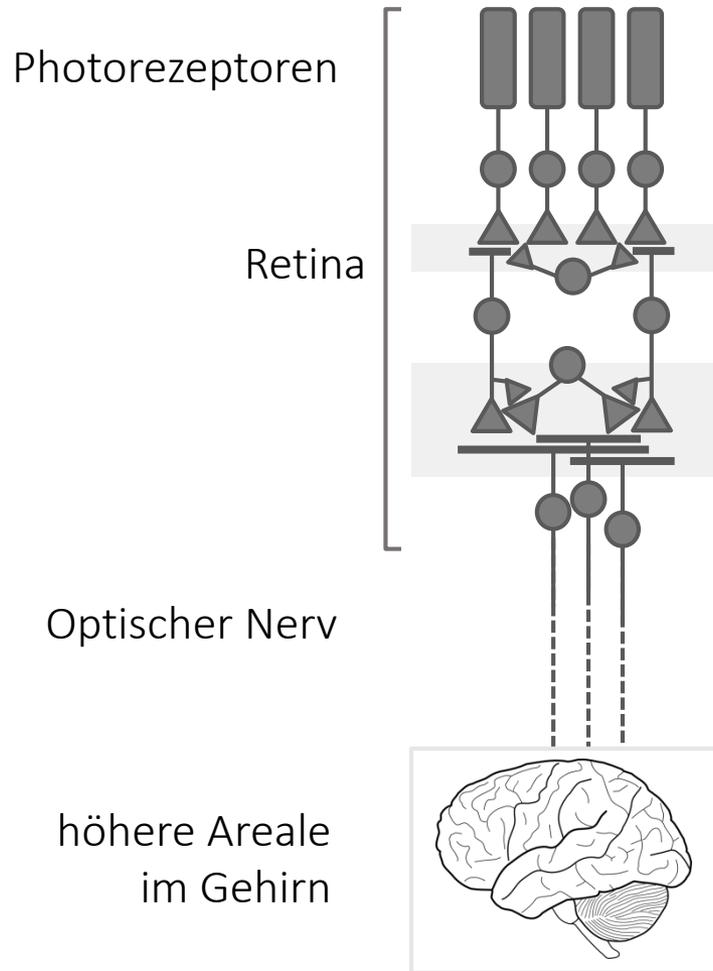
„schräge Kante,  
die sich nicht  
bewegt, an der  
Grenze zwischen  
einer blauen und  
einer rötlichen  
Fläche“

Wie misst man Nervenzell-  
aktivität in der Retina?



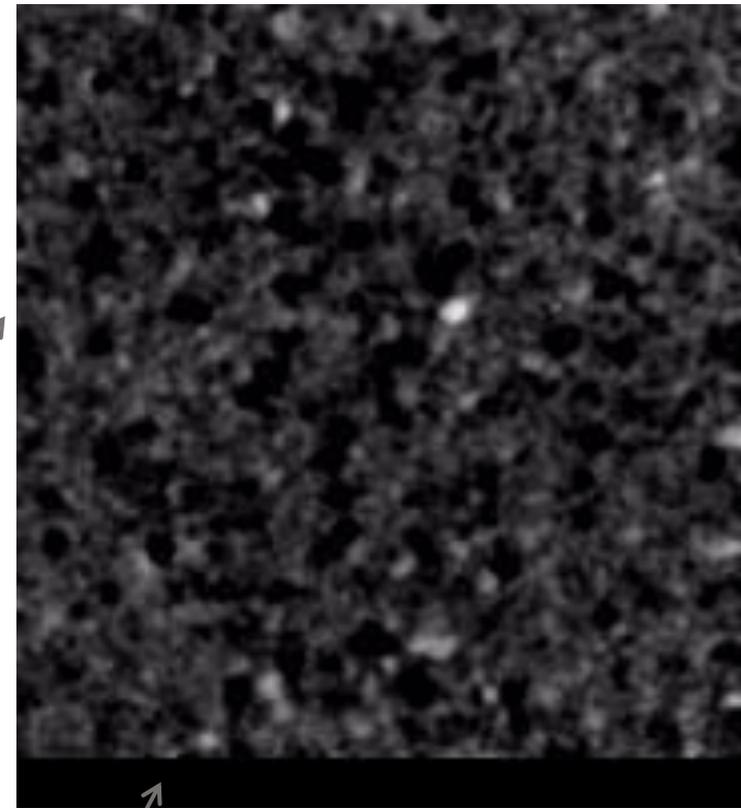
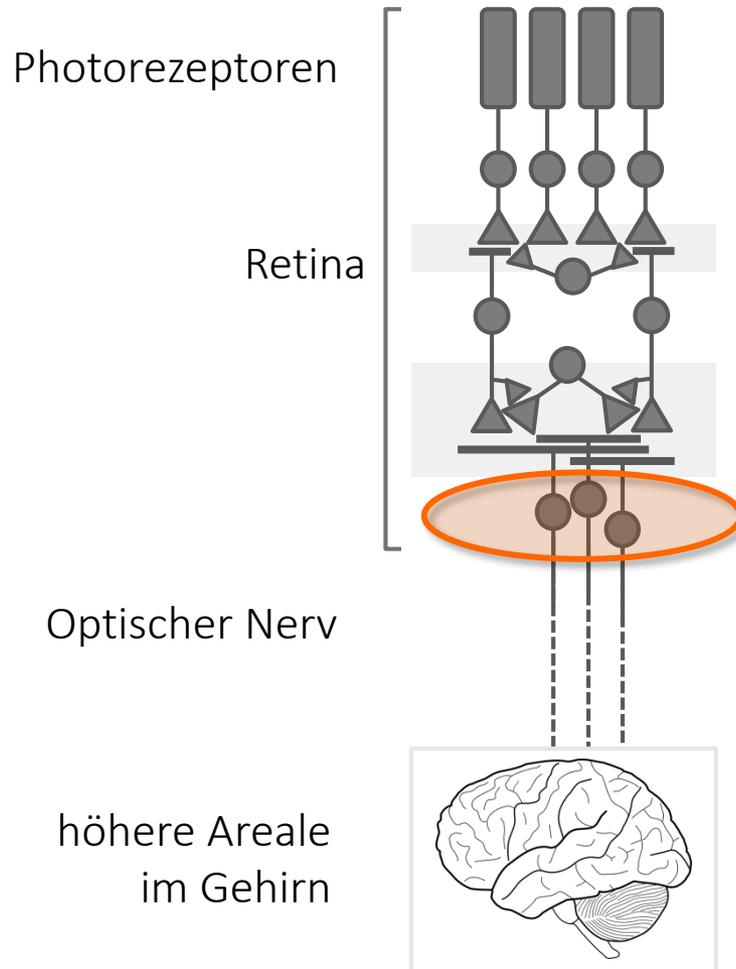


Lebende Retina (Maus)  
unter dem 2-Photonenmikroskop  
angefärbt mit Fluoreszenzfarbstoff





Lebende Retina (Maus)  
unter dem 2-Photonenmikroskop  
Kalziumsignale bei visueller Stimulation



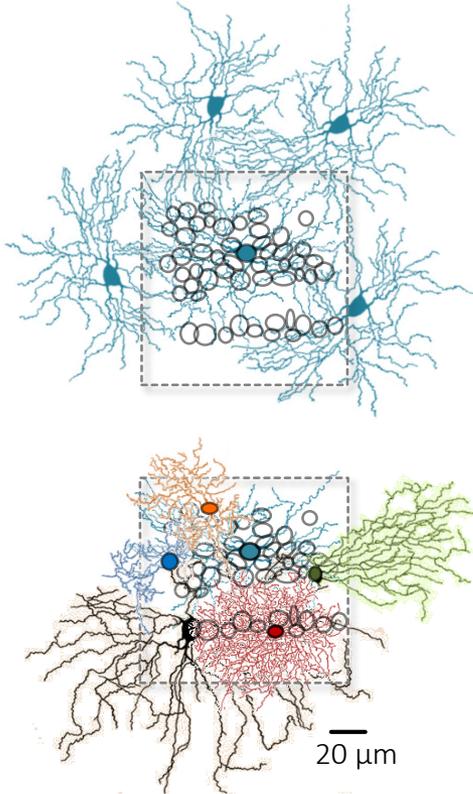
Lichtstimulus

100 μm

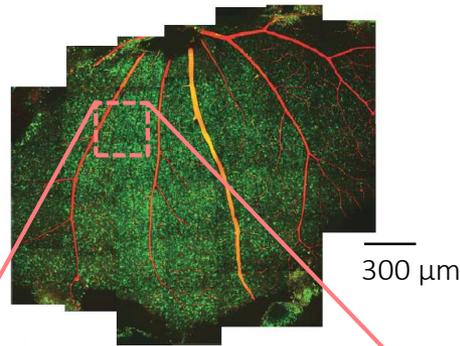
# Das Auge ist keine Kamera (Teil 2)

# Was übermittelt die Retina ans Gehirn?

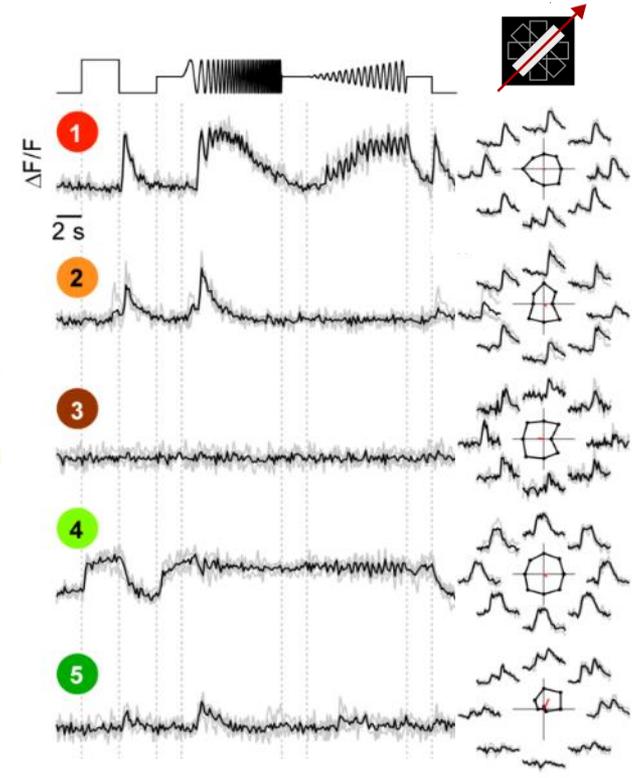
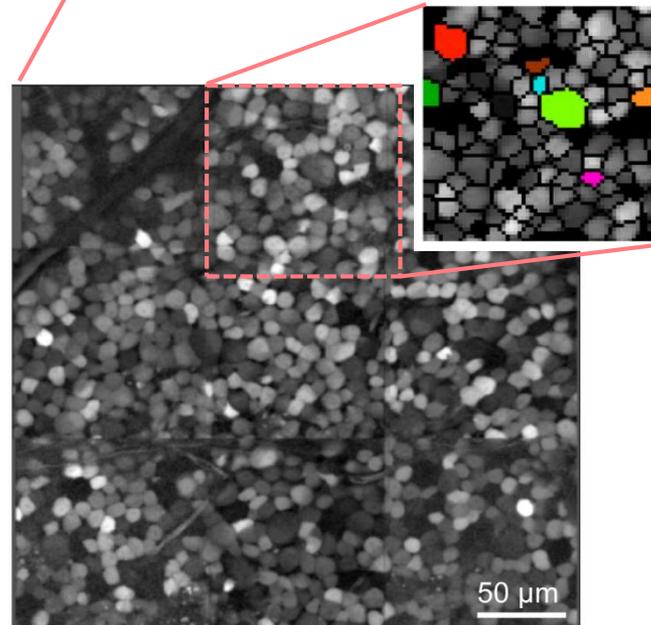
Ziel ist möglichst alle Zellen in einem Gebiet messen



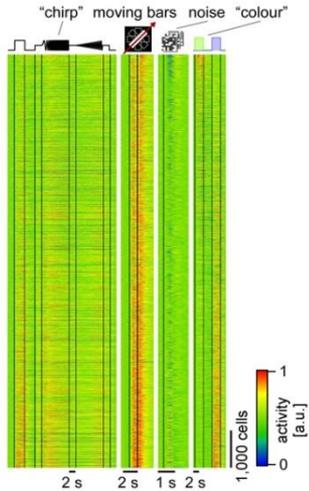
Zellen durch Elektroporation mit Kalziumsensor anfärben



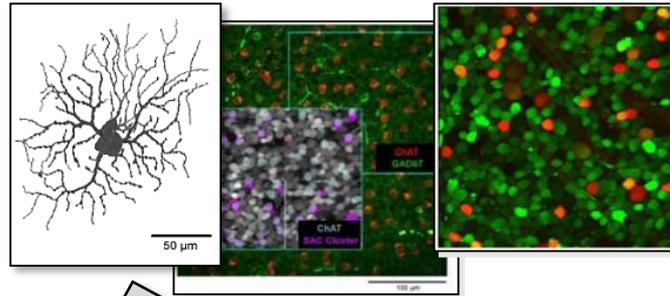
Aktivität der Ganglienzellen bei Lichtstimulation mittels 2-Photonenmikroskopie aufzeichnen



Aktivitätsmessungen von  
> 11,000 Zellen



„Meta-Daten“



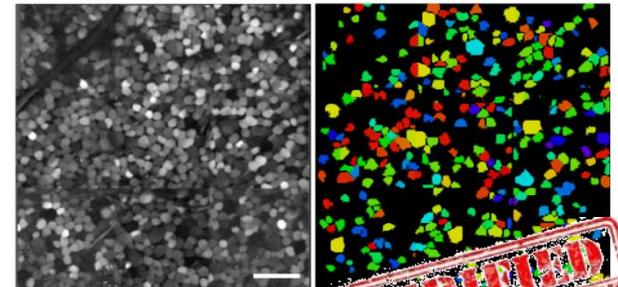
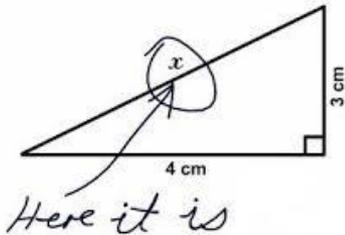
Clustering



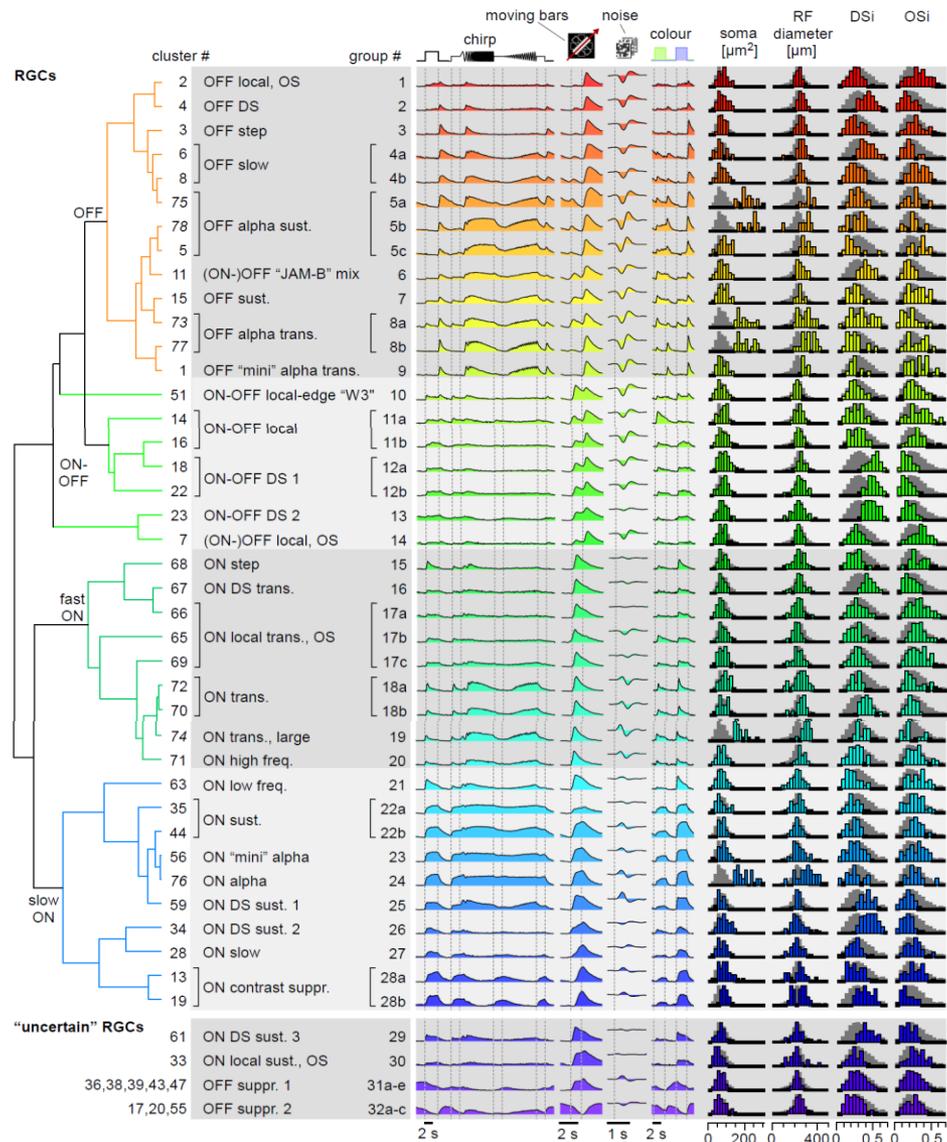
Kompletter Satz von  
retinalen Ganglienzelltypen  
bzw. Informationskanälen  
zum Gehirn

Statistik

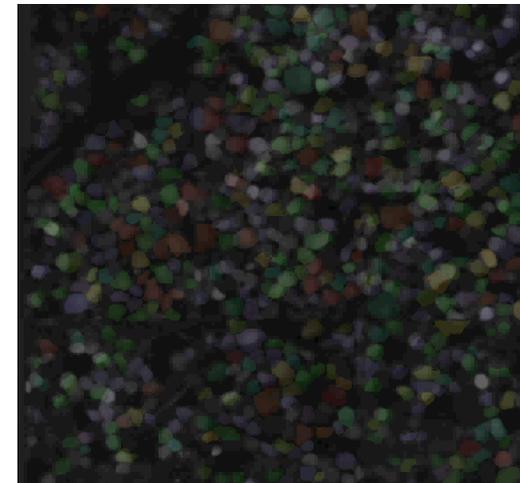
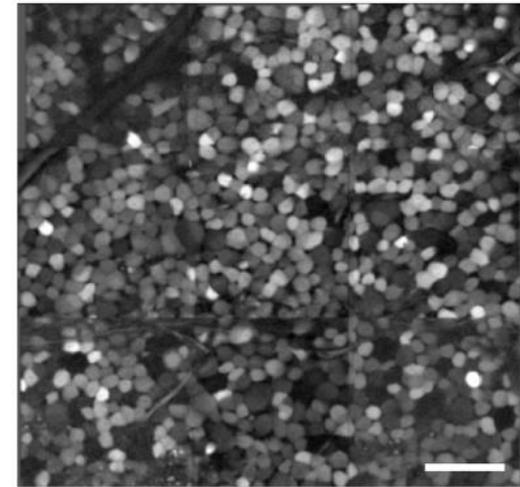
3. Find x.



# Ganglienzelltypen der Retina der Maus



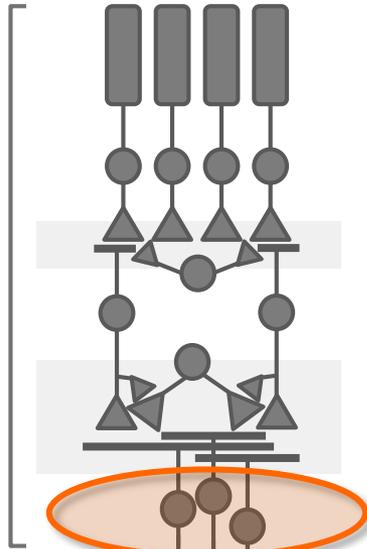
n=11,210 Zellen aus 50 Retinae  
 ≥ 32 funktionelle Ganglienzelltypen





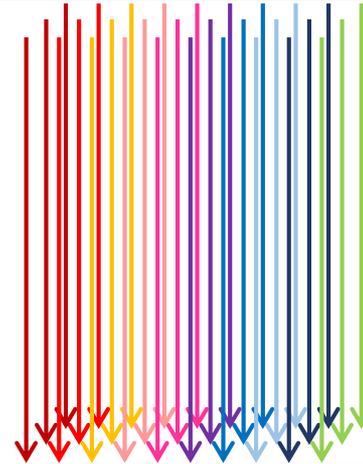
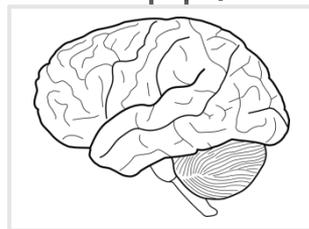
Photorezeptoren

Retina



Optischer Nerv

höhere Areale  
im Gehirn



Die Retina berechnet relevante visuelle Information und schickt diese über **mind. 40** Kanäle ans Gehirn

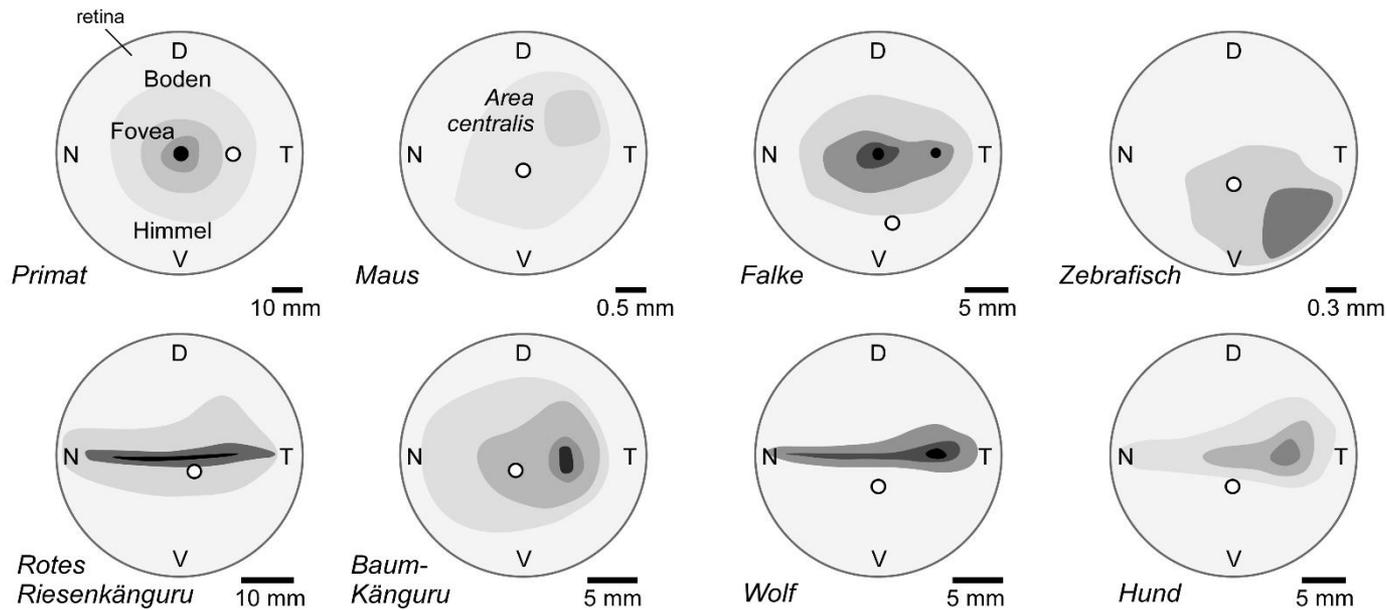


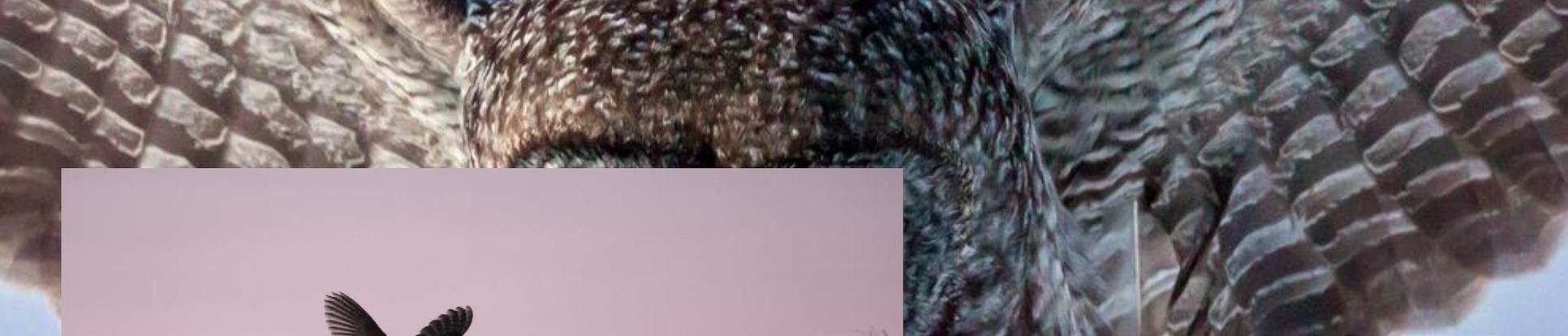
Was sehen Mäuse?

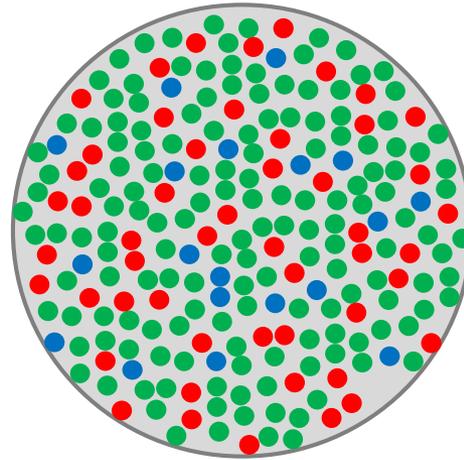
# Tiere leben in unterschiedlichen Umgebungen



# Tiere leben in unterschiedlichen Umgebungen





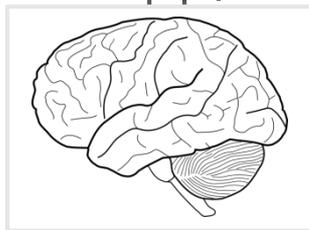


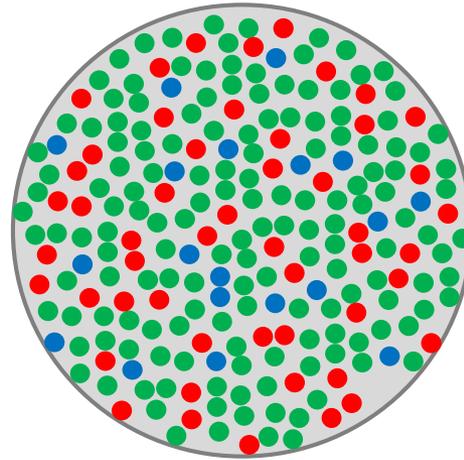
Photorezeptoren

Retina

Optischer Nerv

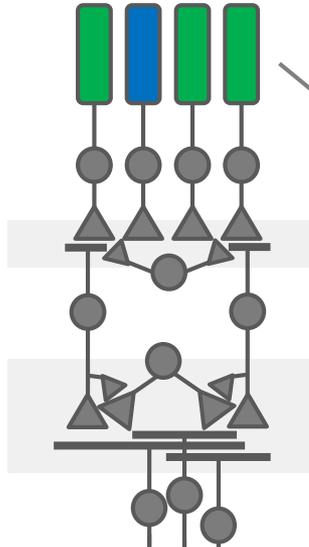
höhere Areale  
im Gehirn





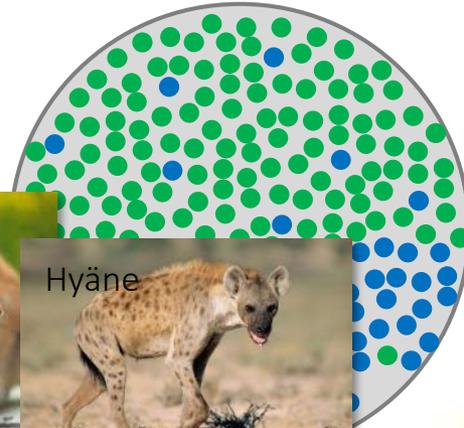
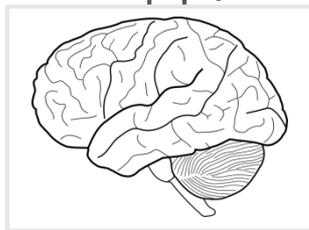
Photorezeptoren

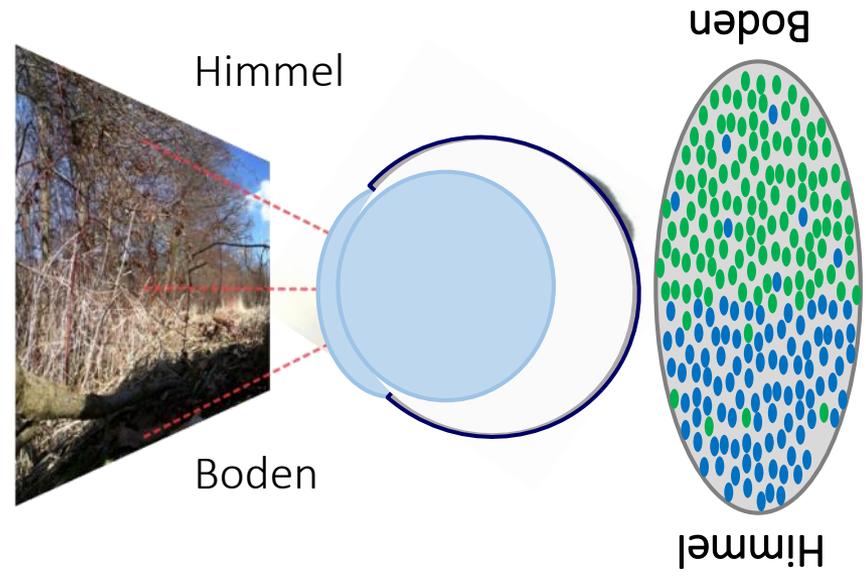
Retina



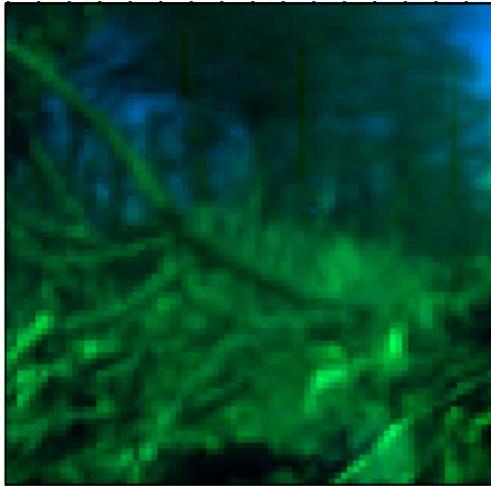
Optischer Nerv

höhere Areale  
im Gehirn





aus Sicht der Maus

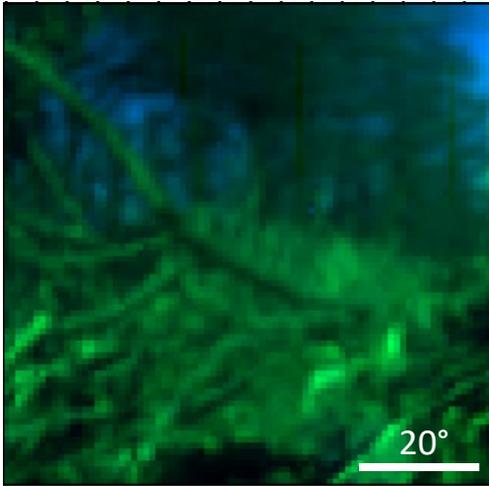


aus unserer Sicht

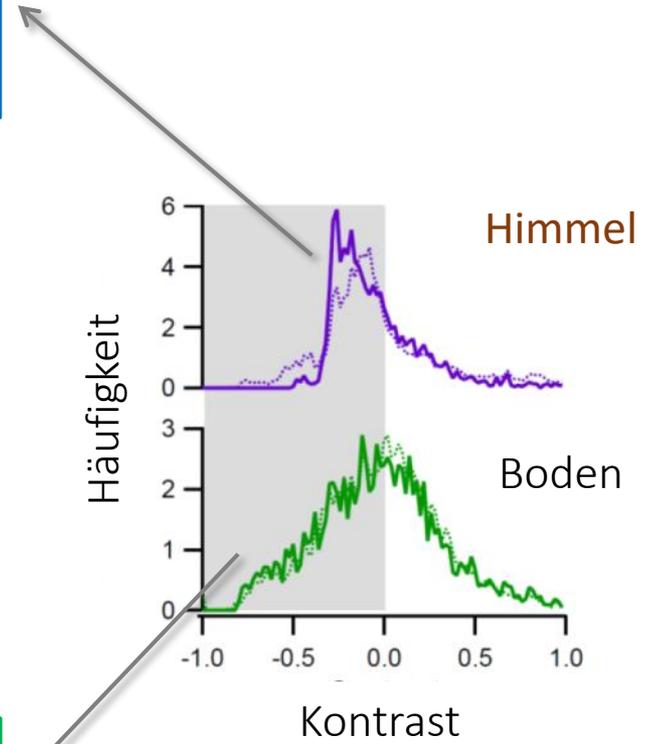
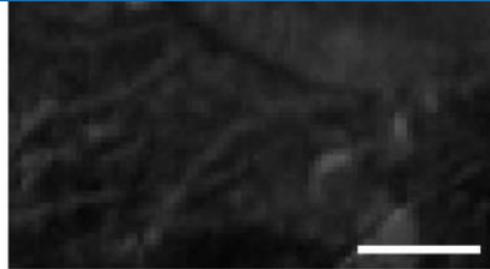
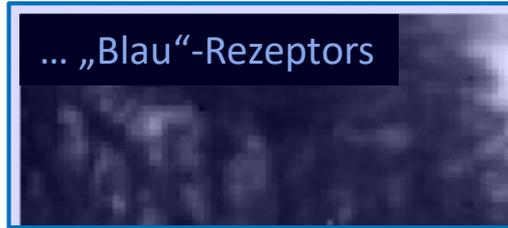


20°

aus Sicht der Maus



aus Sicht des ...



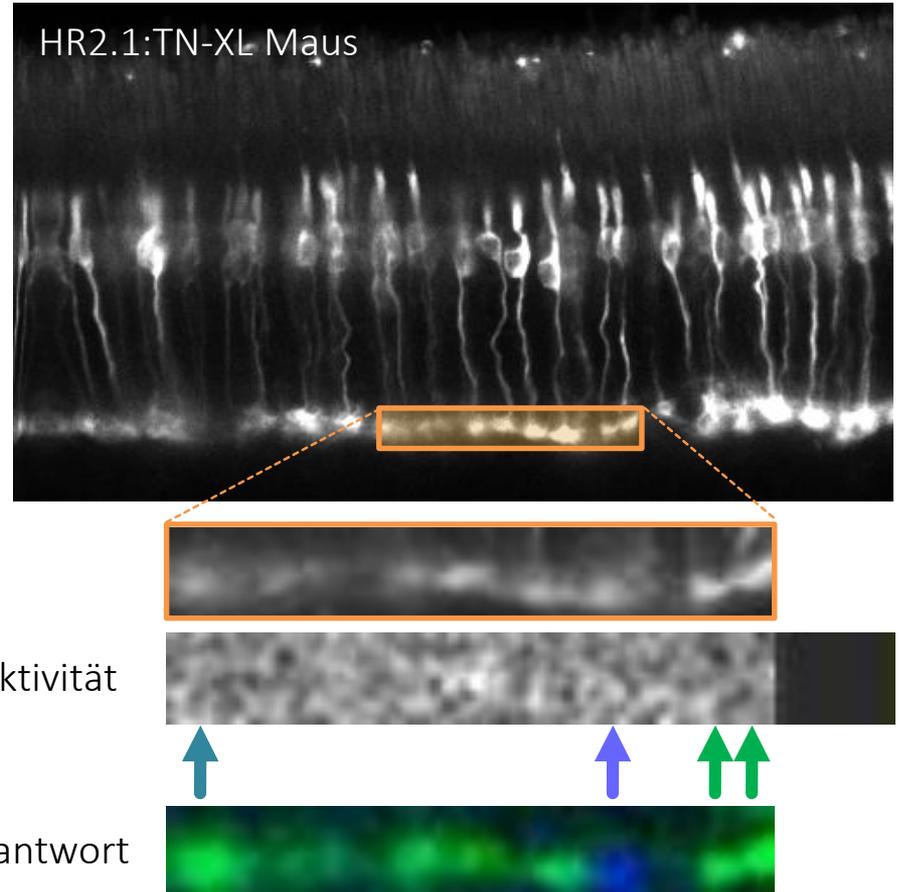
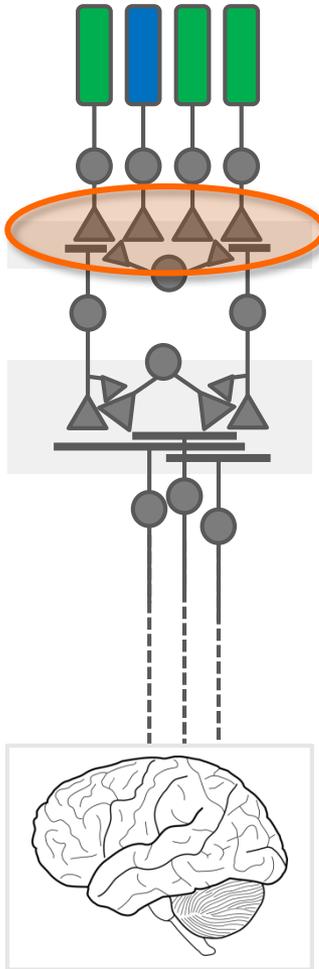


Photorezeptoren

Retina

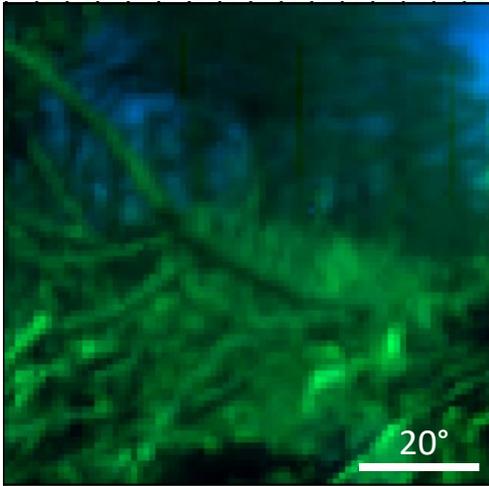
Optischer Nerv

höhere Areale  
im Gehirn

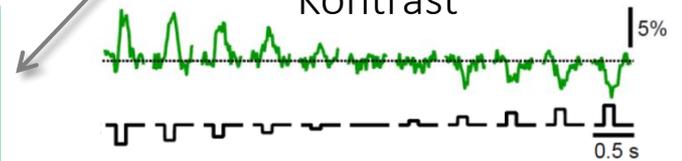
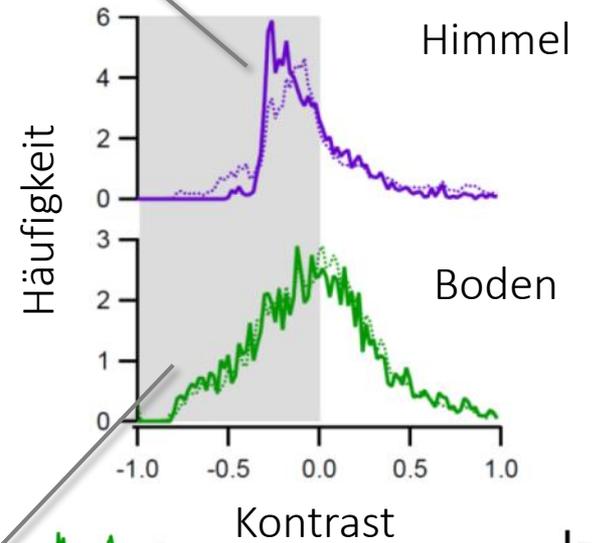
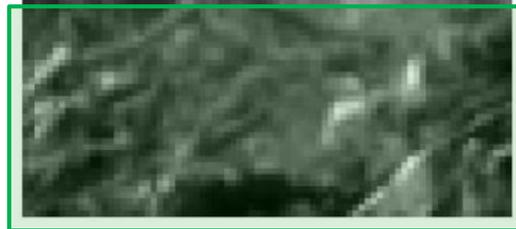
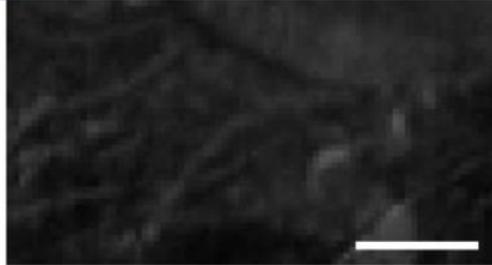


*Baden, Schubert et al. (2013); HR2.1:TN-XL mouse line: Wei et al. (2012)*

aus Sicht der Maus

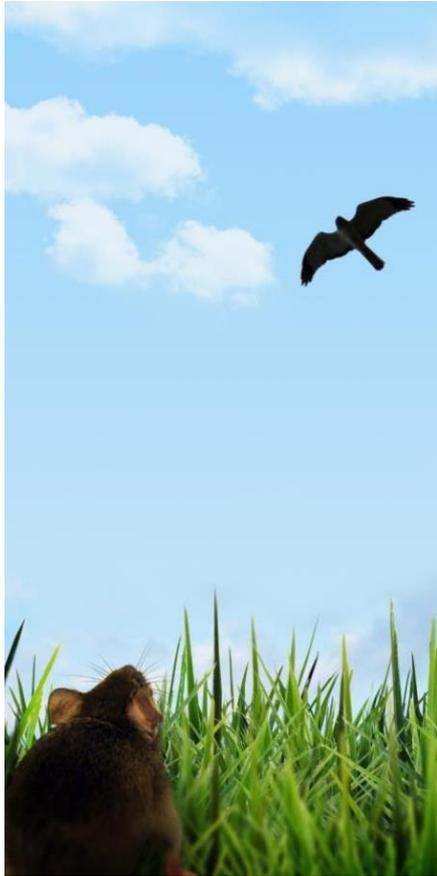


aus Sicht des ...



# Was Mäuse sehen könnten ...

Aus Sicht  
des Menschen:



Aus Sicht  
der Maus:



Grün und "blau"  
+ dunkle Kontraste



...  
+ "W3"-Ganglienzellen



# Was sehen Mäuse wirklich?

Ultraviolett (UV)



Grün



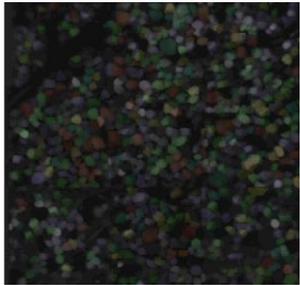
UV + Grün



# Zusammenfassung



Das Auge ist keine einfache Kamera



Die Retina ist ein leistungsfähiger Bildprozessor;  
sie übermittelt visuelle Information über mind. 40 parallele  
Kanäle ans Gehirn



Mäuse sind keine Menschen ...