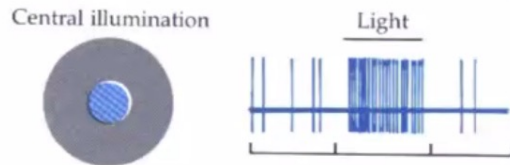
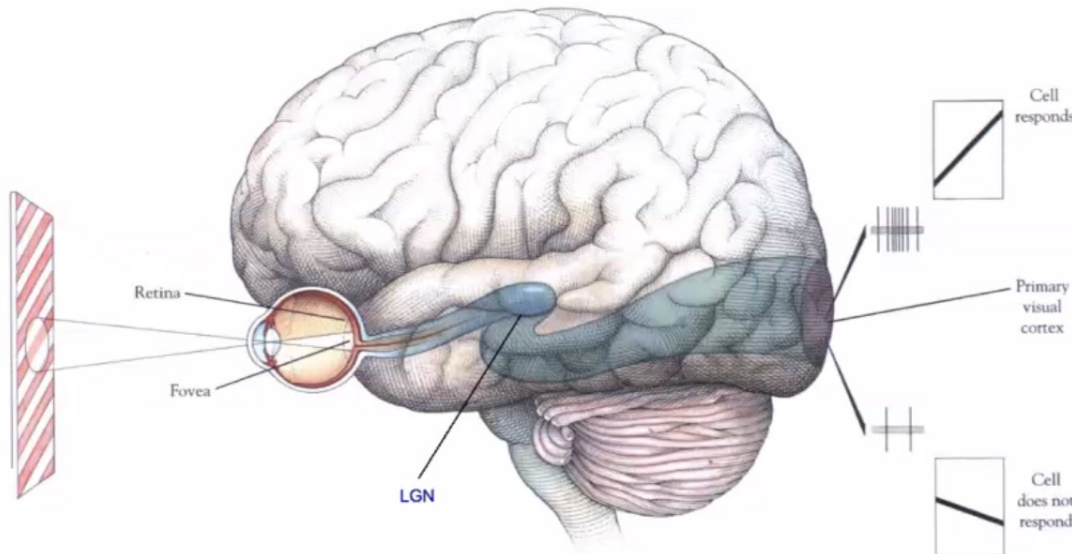


# Perceptual geometry

9.26.2023

vision in art & neuroscience

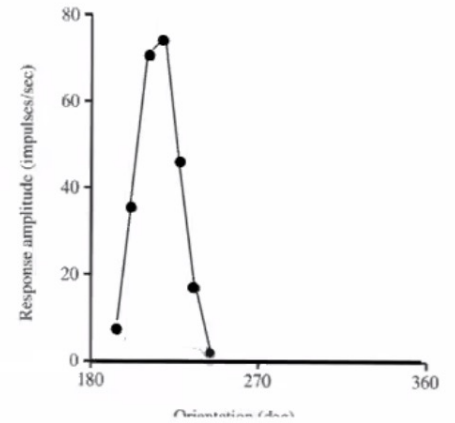
# From photon to primary visual cortex: Receptive Fields and Tuning Curves



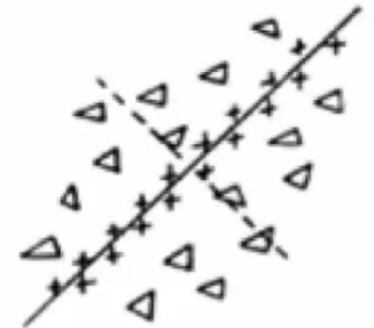
circular RF

*HK Hartline, 1939*

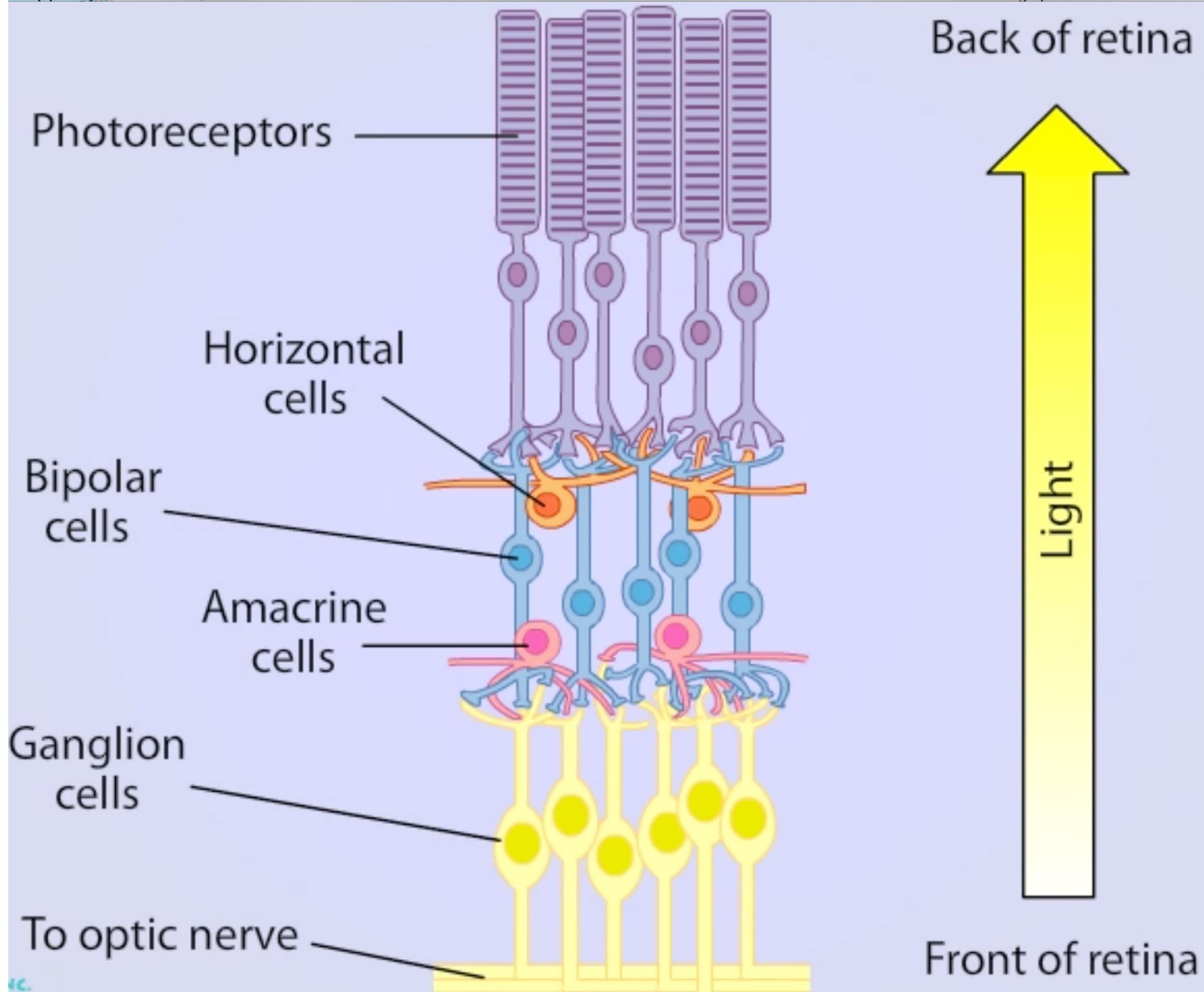
## Orientation tuning

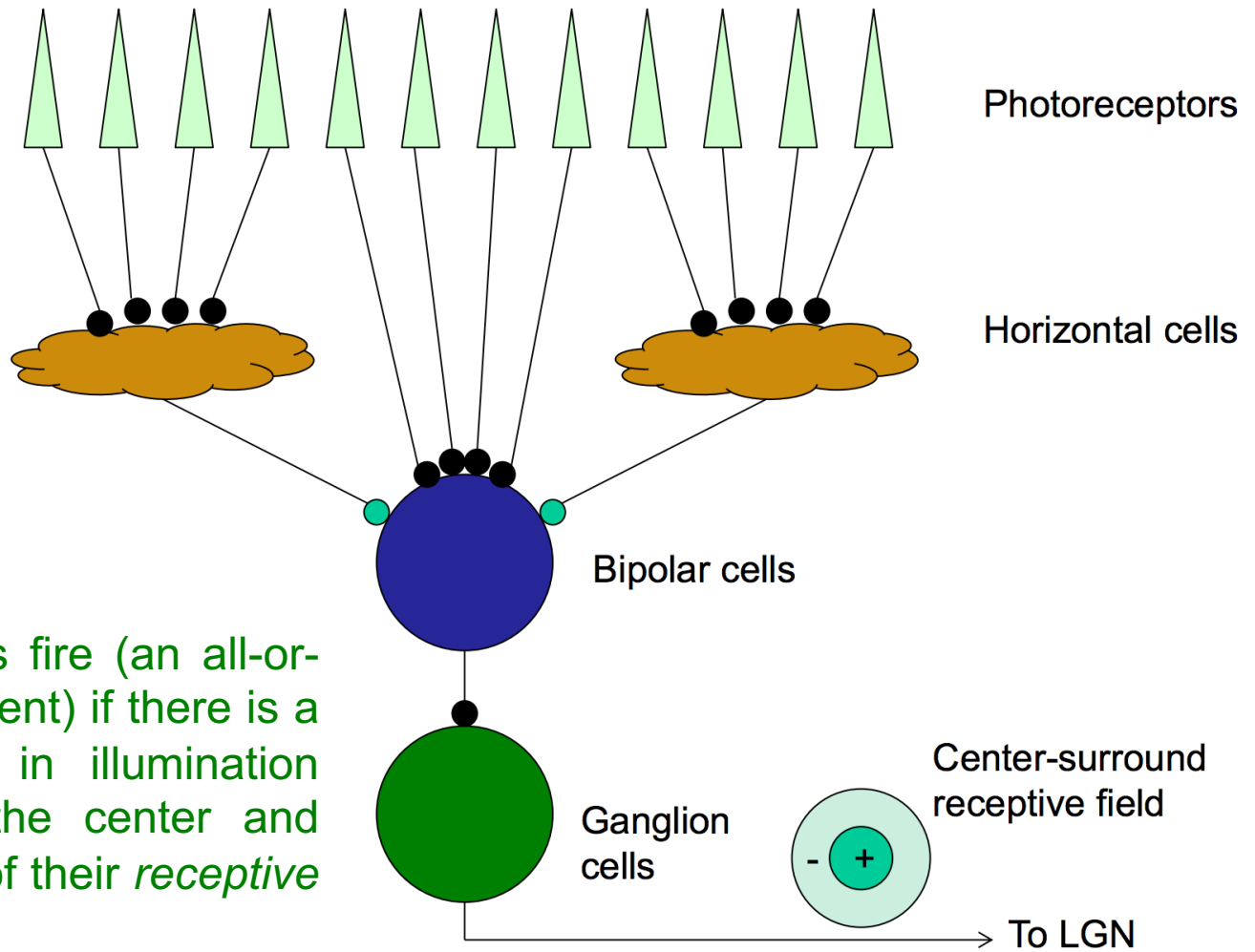


Gabor RF



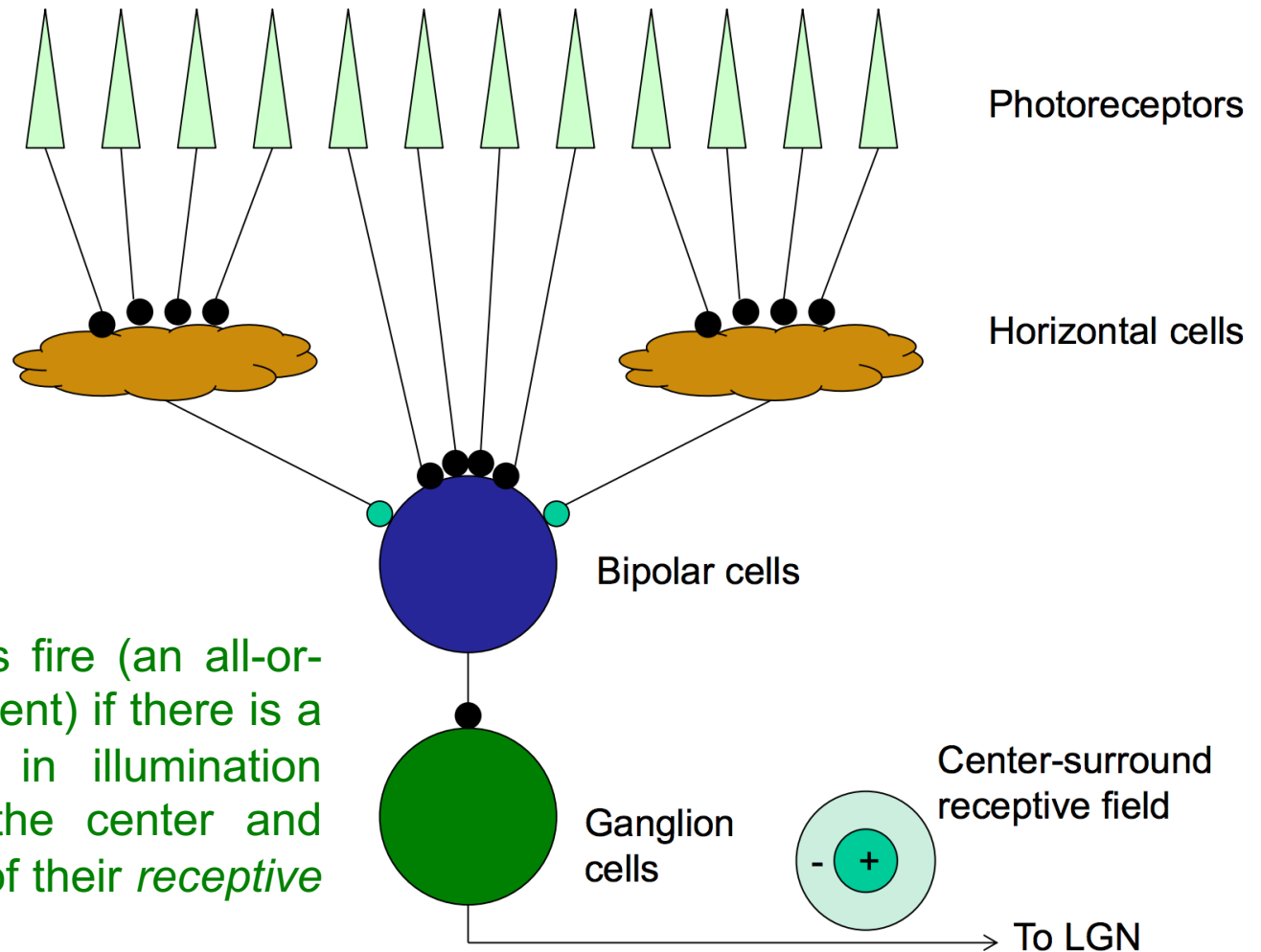
*Hubel and Wiesel, 1959*





these cells fire (an all-or-nothing event) if there is a difference in illumination between the center and surround of their *receptive fields*.

What is a receptive field?



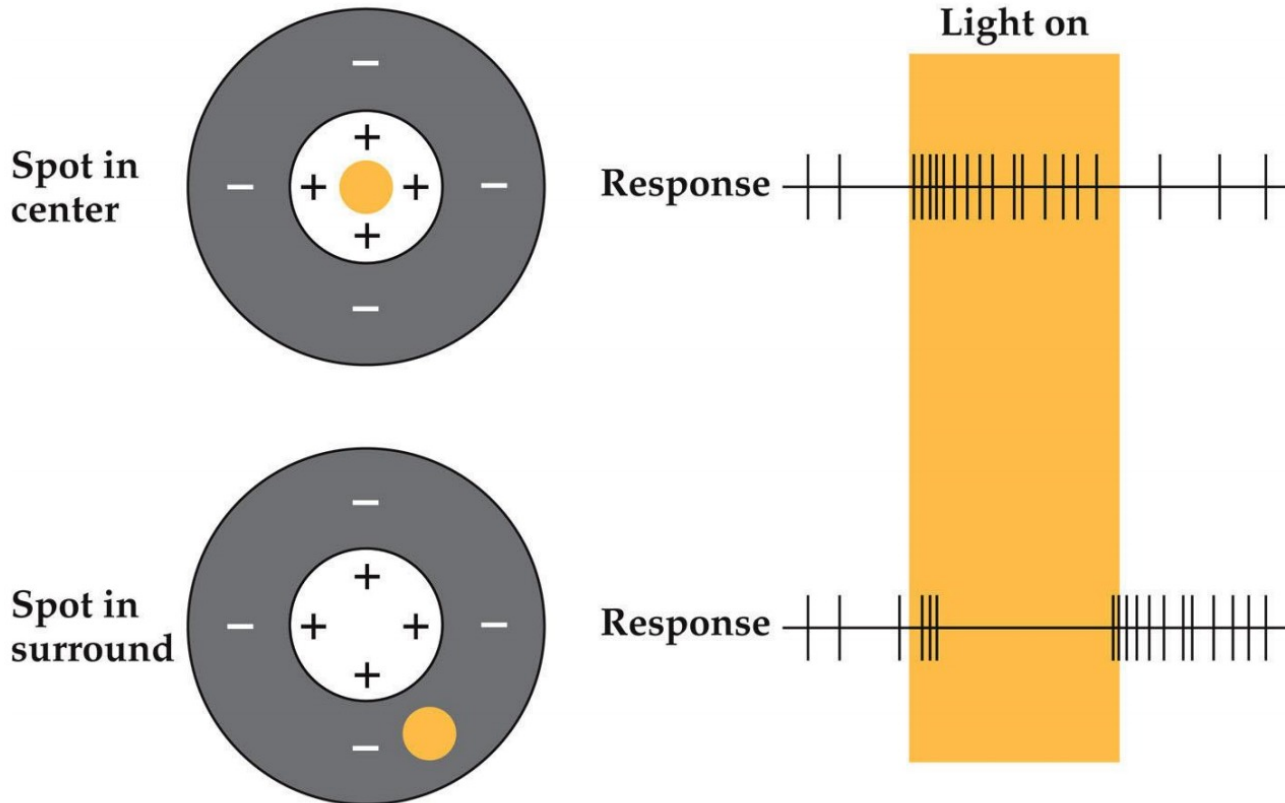
these cells fire (an all-or-nothing event) if there is a difference in illumination between the center and surround of their *receptive fields*.

### What is a receptive field?

a portion of sensory space that can elicit neuronal responses when stimulated  
 e.g. a portion of the skin, a portion of the visual field  
 If many sensory receptors all form synapses with a single cell further up, they collectively form the receptive field of that cell.

# Retinal ganglion cell receptive fields

(a) ON-center ganglion cell

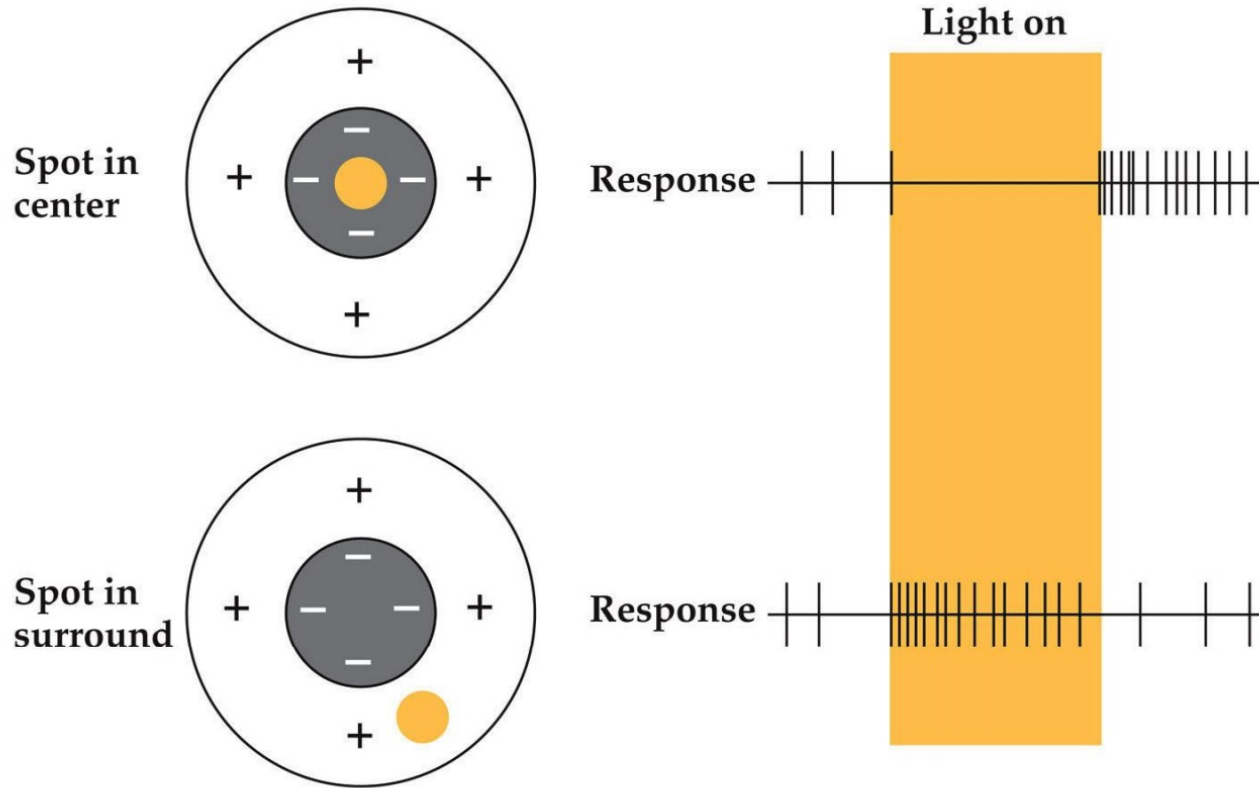


Excited by light falling on center, inhibited by light falling on surround

# Retinal ganglion cell receptive fields

An all-or-nothing event (spike) is determined by the output of a *difference operator*

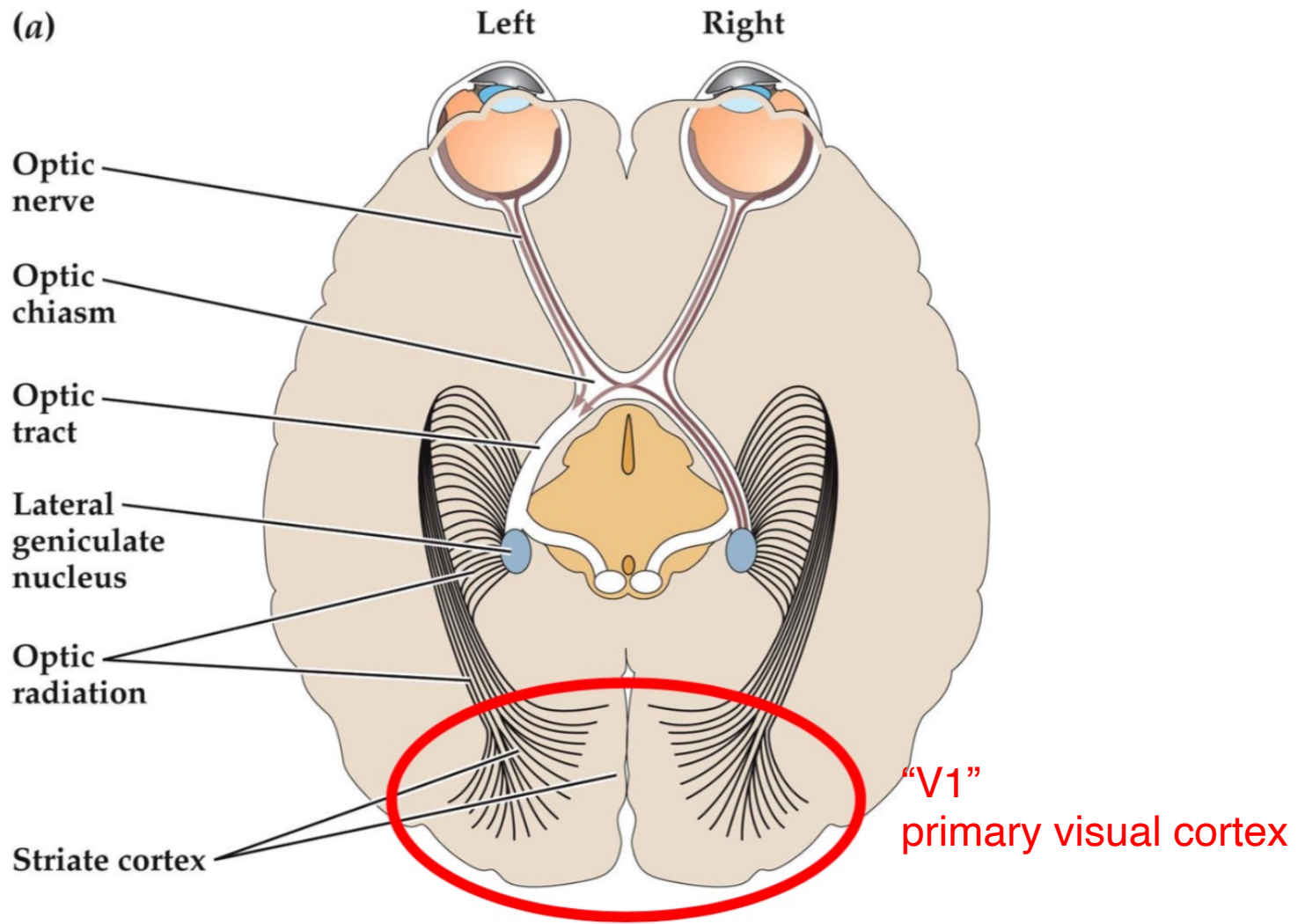
(b) OFF-center ganglion cell



Inhibited by light falling on center, excited by light falling on surround

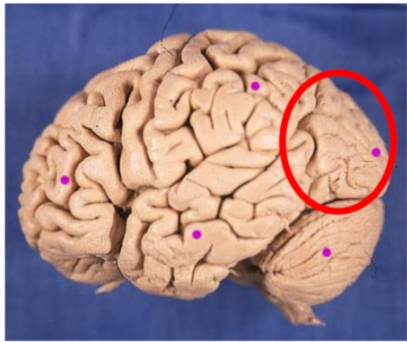


# Central visual pathways



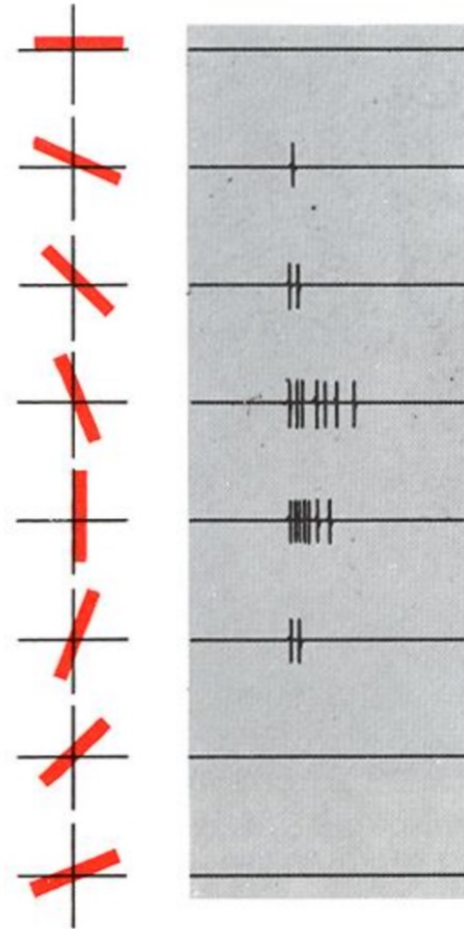
200 million cells!





Primary  
Visual  
Cortex

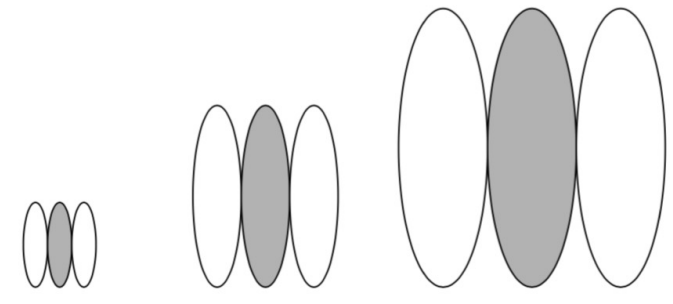
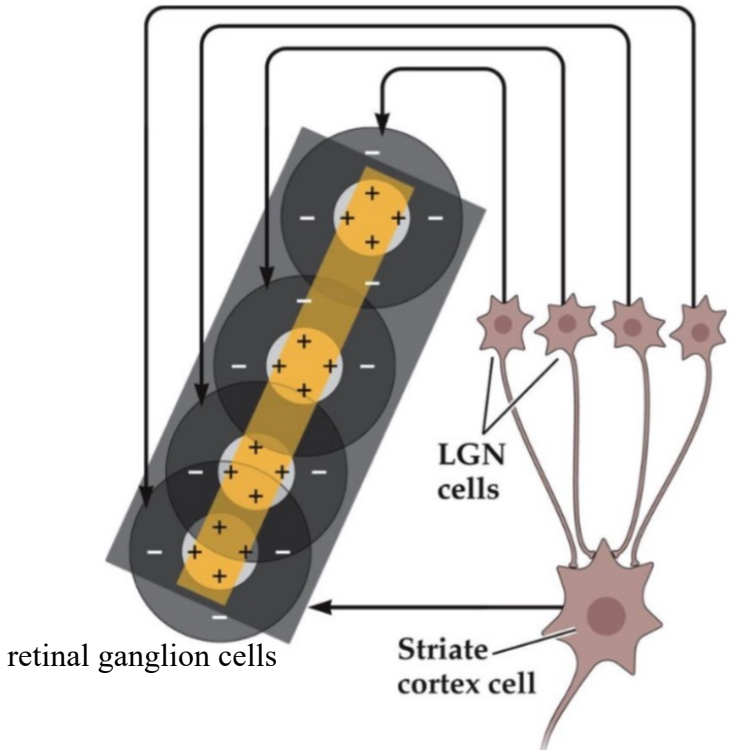
Oriented bar and edge  
detector neurons



Hubel and Wiesel (1977)

<https://www.youtube.com/watch?v=8VdFf3egwfg>

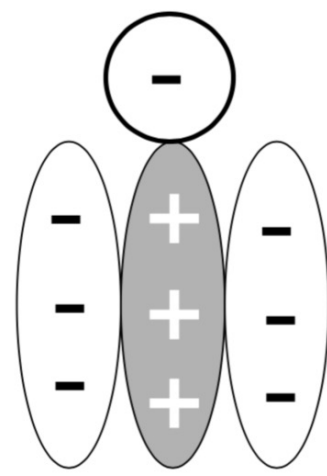
How can orientation tuned cells be  
created from circularly symmetric  
inputs?



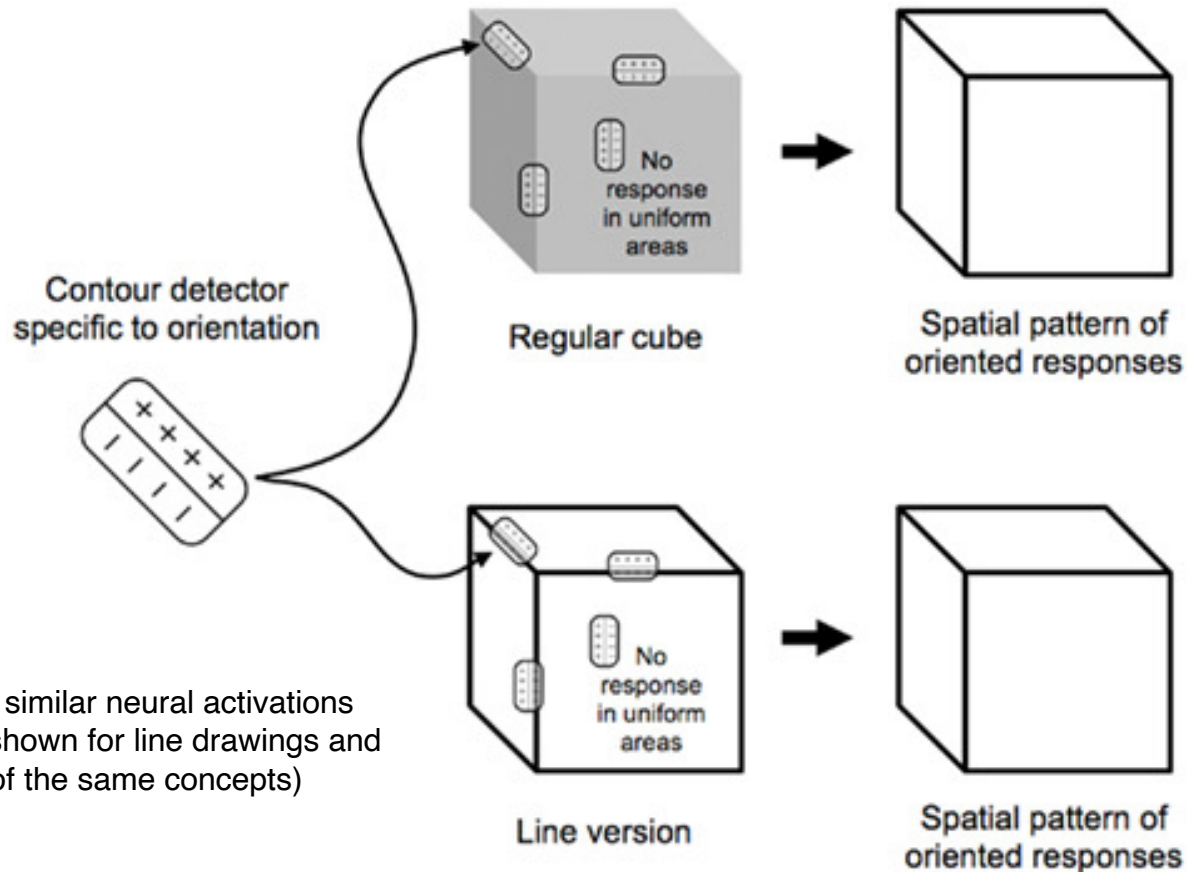
The rfs come in a variety of orientations and also in a variety of sizes to process edges at different scales

- Some of the units are 'end-stopped'

What kind of edges could these configurations not explain?

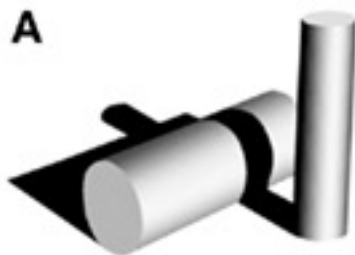


# Activations of contour-sensitive neurons on 3D objects resemble a line drawing of the object

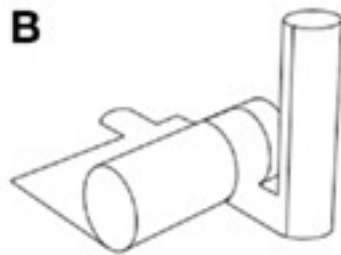


(and in fact, similar neural activations have been shown for line drawings and 3D objects of the same concepts)

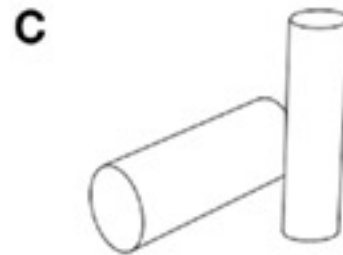
But not all contours are in fact, edges of objects. How do artists get this right?



Image

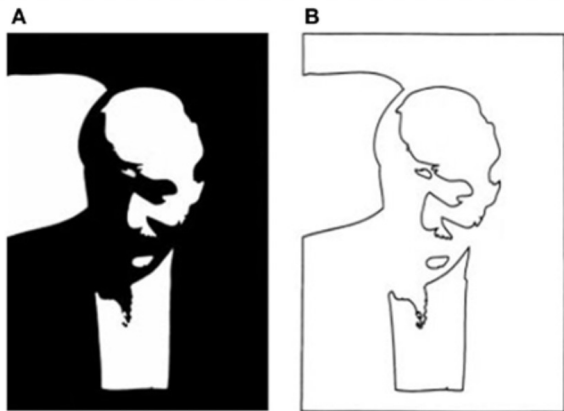


All contours



“Depth sketch”

Pure edge detection is not accurate



Two very different sketches depict a face





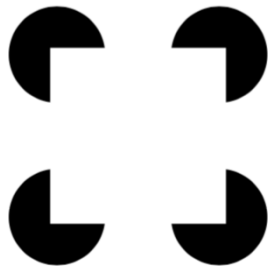


Maurice Denis

## Detecting illusory contours

If I fits I sits: A citizen science investigation into illusory contour susceptibility in domestic cats (*Felis silvestris catus*)

Gabriella E. Smith <sup>a, b, R, B</sup>, Philippe A. Chouinard <sup>c</sup>, Sarah-Elizabeth Byosiere <sup>a, b</sup>



No luminance difference across long sections of the perceived contours

### Illusory Contours and Cortical Neuron Responses

R. Von Der Heydt; E. Peterhans; G. Baumgartner

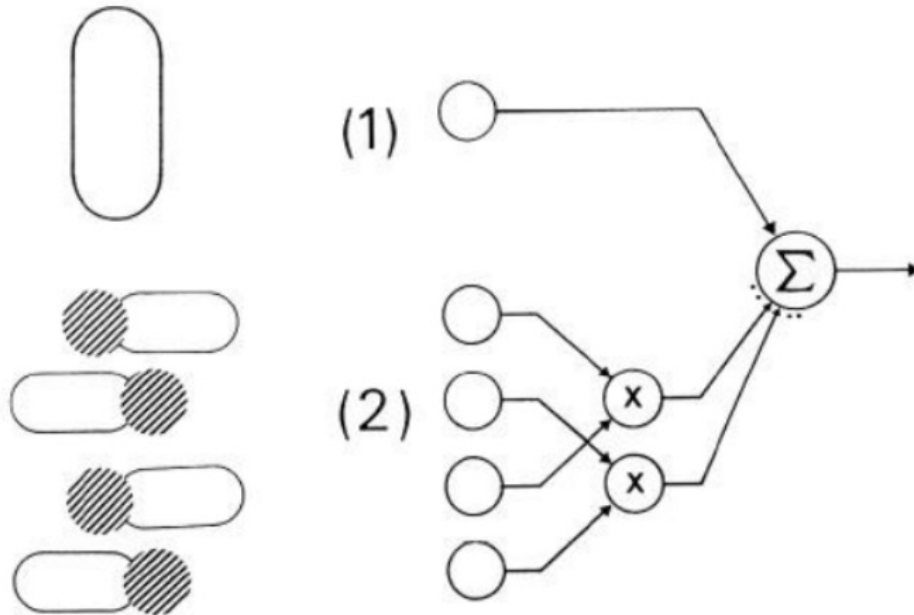
*Science*, New Series, Volume 224, Issue 4654 (Jun. 15, 1984), 1260-1262.

*Abstract. Figures in which human observers perceive "illusory contours" were found to evoke responses in cells of area 18 in the visual cortex of alert monkeys. The cells responded as if the contours were formed by real lines or edges. Modifications that weakened the perception of contours also reduced the neuronal responses. In contrast, cells in area 17 were apparently unable to "see" these contours.*

## Mechanisms of Contour Perception in Monkey Visual Cortex. II. Contours Bridging Gaps

Esther Peterhans and Rüdiger von der Heydt

Department of Neurology, University Hospital Zurich, 8091 Zurich, Switzerland



Illusory contours = likely result of interaction between edge-detecting units and line (corner)-detecting, or grouping units.

These inputs sum at "contour neurons" in secondary visual cortex.

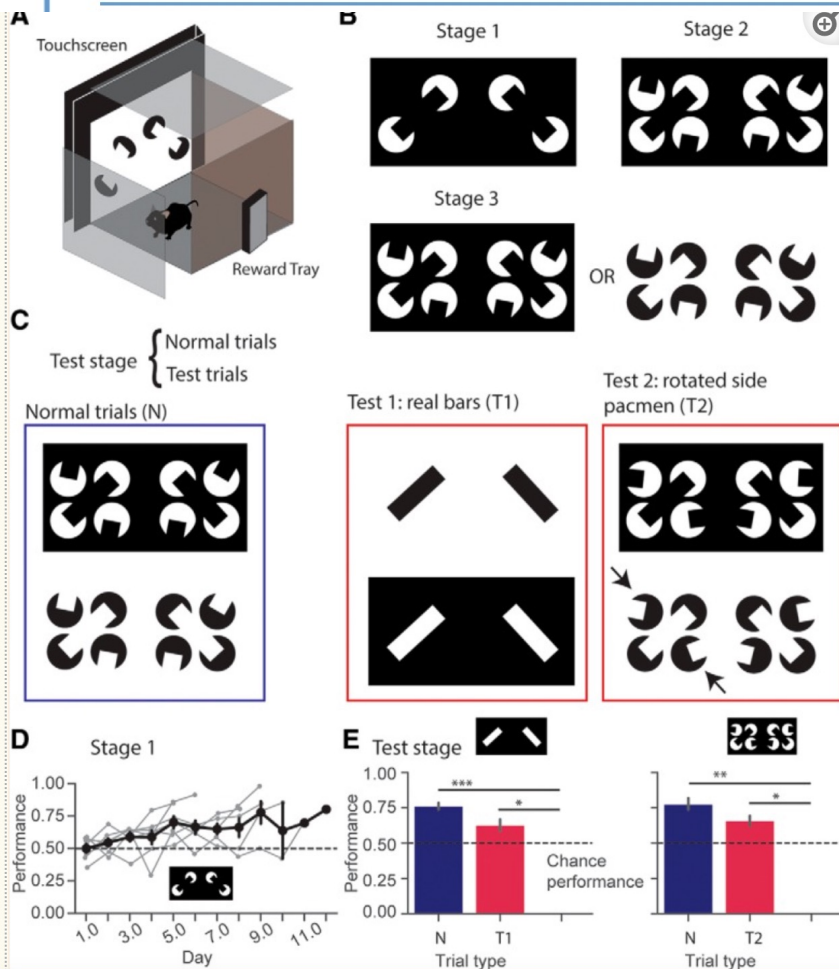
*Figure 15.* Principle of a hypothetical cortical mechanism for the perception of contour. We assume that 2 groups of signals are summed in a contour neuron ( $C$ ), one from edge- or bar-detector units ( $I$ ) and a second originating from units that are sensitive to corners and line-ends (2). The input fields of (1) and (2) are centered on the same patch of retina. The "end-stopped receptive fields" (2) are scattered along the axis of (1) and oriented about perpendicular to it. Only 4 have been drawn, but they are thought to cover the patch of visual field densely. Distant pairs of these fields are connected with multiplying or gating units ( $x$ ), which has the effect that signals sum at  $C$  only if 2 or more of these fields are excited. We call (1) the "edge-detecting input" and (2) the "grouping input." (After Peterhans et al., 1986.)



# Top-Down Feedback Controls the Cortical Representation of Illusory Contours in Mouse Primary Visual Cortex

Alexandr Pak, Esther Ryu, Claudia Li, and Alexander A. Chubykin

▶ Author information ▶ Article notes ▶ Copyright and License information ▶ [PMC Disclaimer](#)



- Neurons sensitive to illusory contours found in V1!
- Potentially a result of recurrent connections (supported by neural network models), and top-down feedback from secondary cortices, in a predictive coding model

... many types of lines  
many different lines  
many different edges  
many different contours  
at different scales

in neural computation

in perceptual experience

can we connect phenomenology to physiology?

what is her dress made of?





+

a blue point here?  
how large is it?  
does it have parts?

consider an equiluminant field, like a  
Ganzfeld

are there POINTS in the blue sky?

your smartphone records millions of them - they're called "pixels"  
but do you **see** them?

at least in my experience i don't  
the blue sky is a blue, undifferentiated area that contains no "parts" such as "points"

how large would such points be anyway?  
next year's smartphone no doubt sports even more "pixels"  
does that imply the blue sky gains so many more "points"?  
of course not!

but if the blue sky does not contain blue points, then what is it made of?  
"blue goo" perhaps?

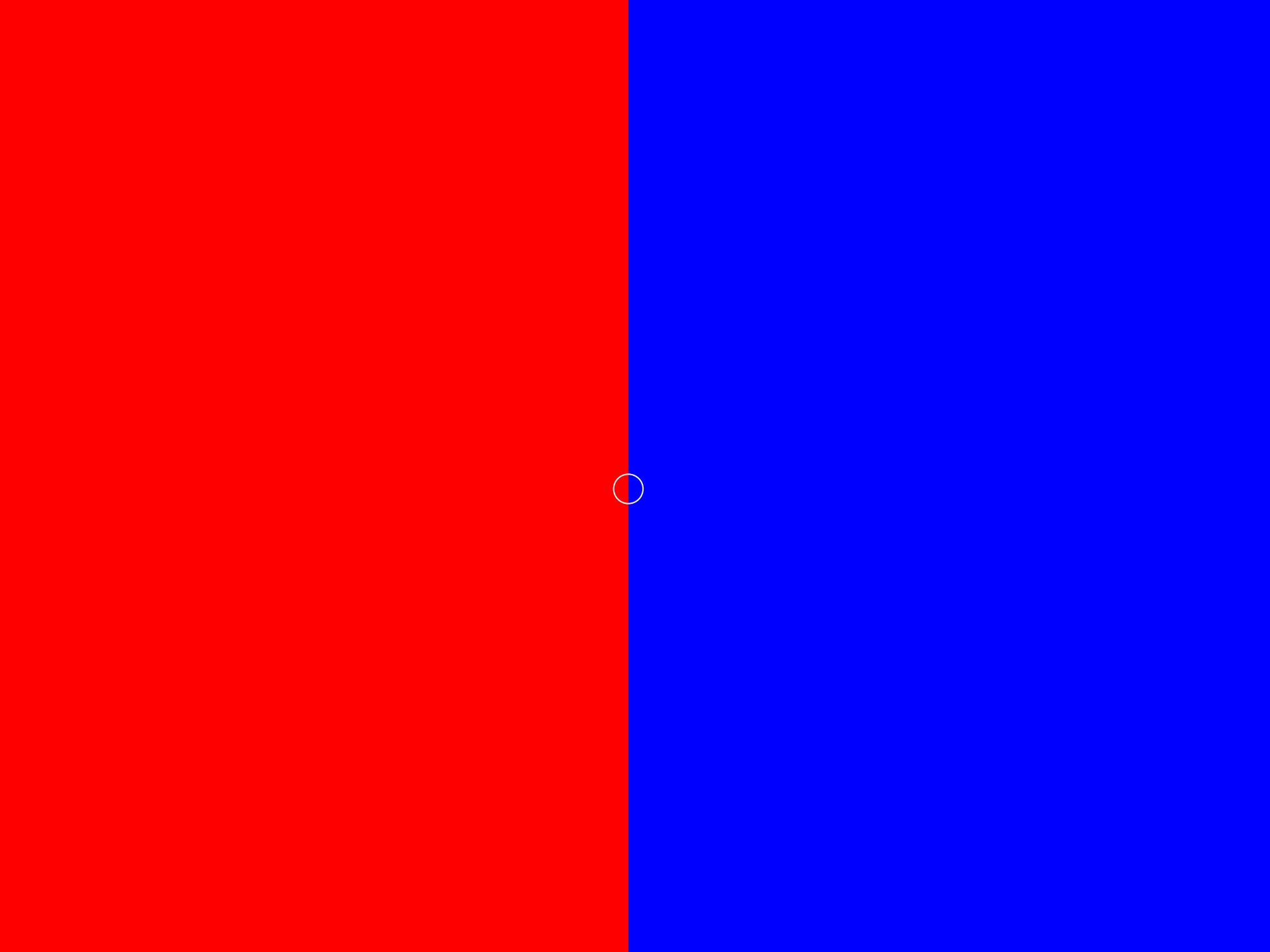
this is the problem of the CONTINUUM in a nutshell

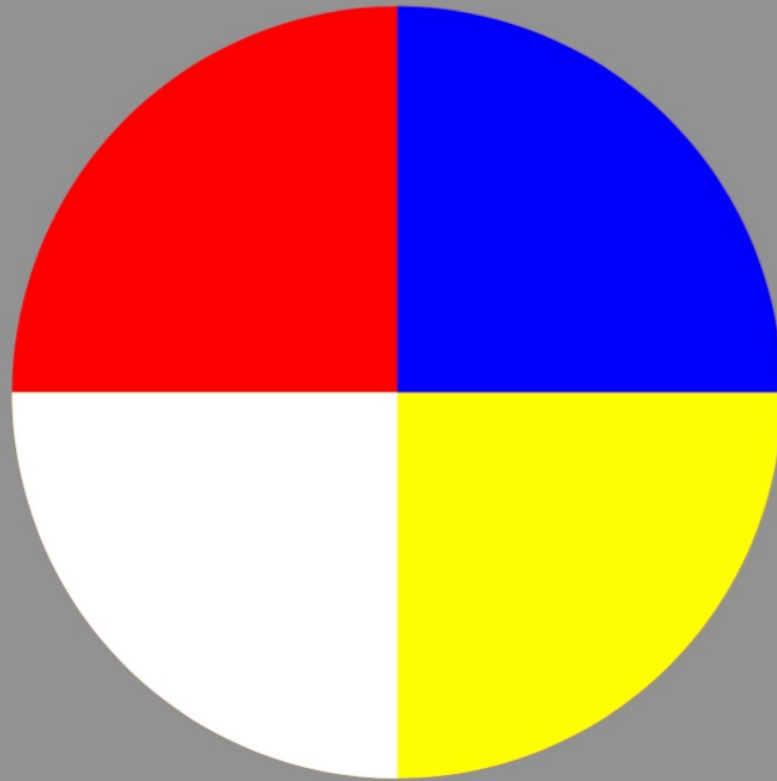
what about points in visual awareness?

what *is* a point in visual awareness?





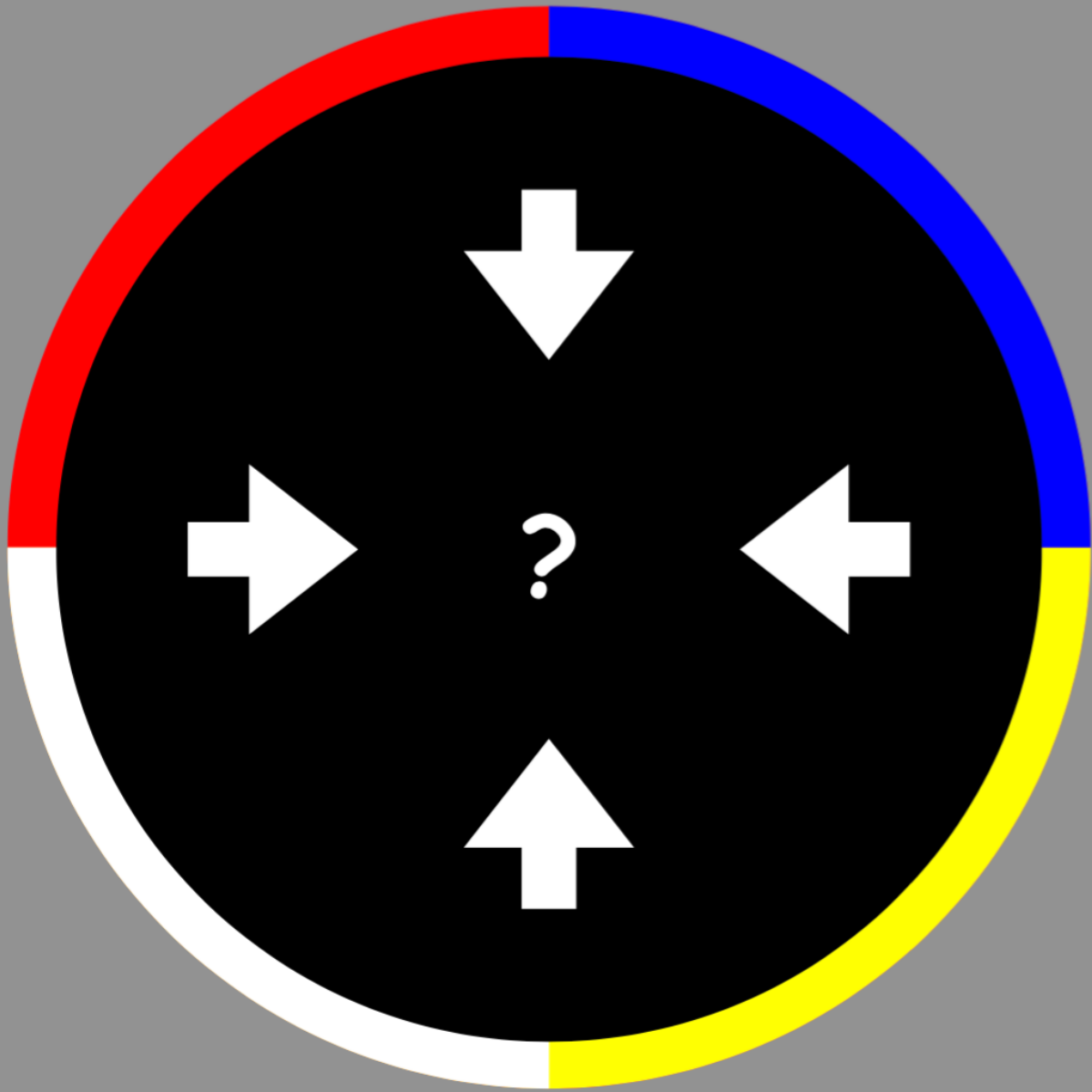




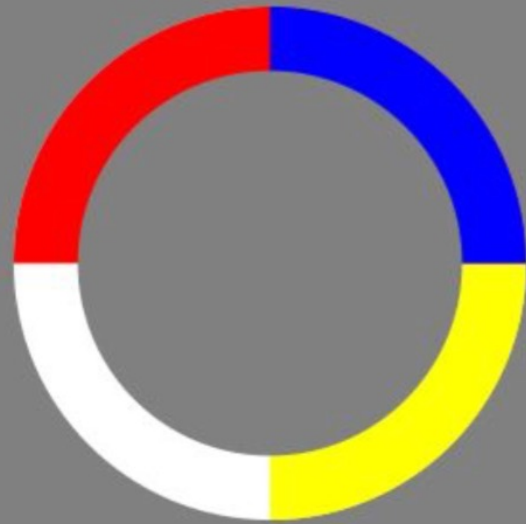
what is the color of the centre?

Galileo has: red, blue, white and yellow!

Brentano considers this "obvious" from a phenomenological perspective



the idea is that the centre is like the circumference







et voilà!



something like this then?

NO! for any part of the line is line-like!

the edge point belongs BOTH to the red  
AND the blue side - it cannot be removed  
from the line

it is a "two-sided" point, Brentano's notion  
of "plerosis" (something like "fullness")





the point has a two-sided plerosis - it is part of the **red** side just as much as it is part of the **blue** side

yet it is a **SINGLE** point, or perhaps an atomic coincidence of **red** and **blue** points

points are *ATOMIC* entities (Euclid: they have no "parts")

but in the plerosis notion they have "sides"

what is an atomic entity in visual awareness?

the edge point belongs just as much to the red as to the blue side, indeed both sides need to exist for the edge point to exist

there is no such a thing as an isolated edge point

an edge point cannot be "removed"

i will refer to such "sided points" as *PERCEPTIVE FIELDS* (PFs)

Brentano's edge point with two-way  
plerosis is both "atomic" AND has "parts"

it is a **perceptive field** much like the  
"receptive fields" from neurophysiology

but: the notion of **receptive field** only  
comes with Hartline in 1938 - Brentano's  
psychology was ahead of brain science!

any white point somewhere here?

like here perhaps?

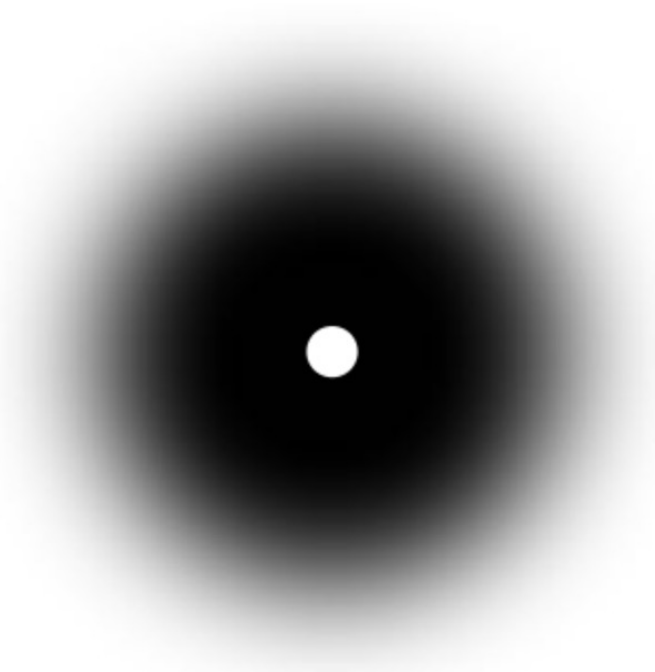


or here?



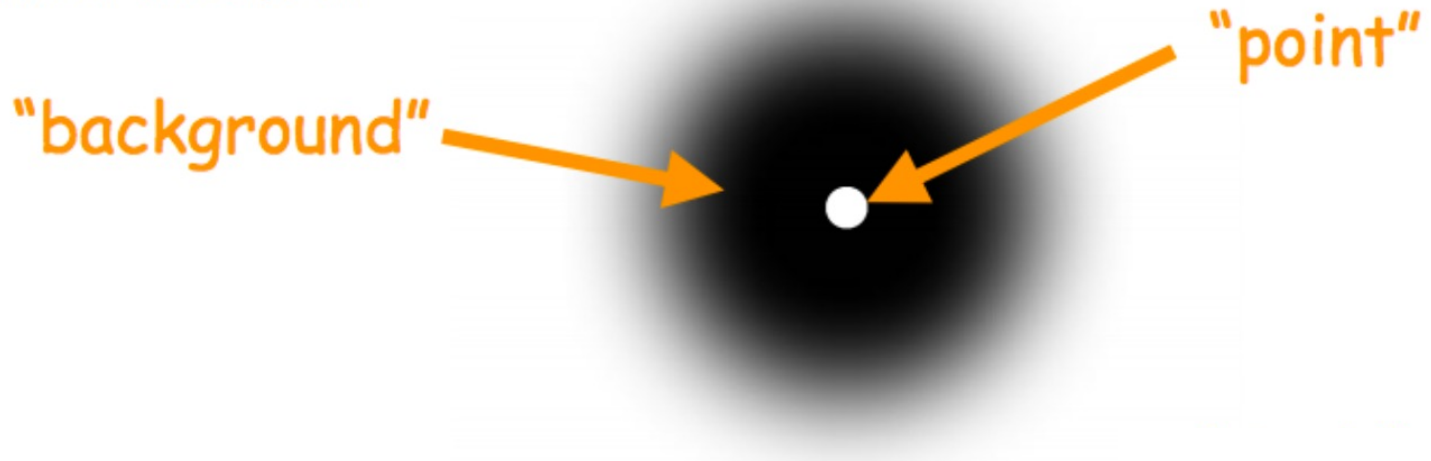


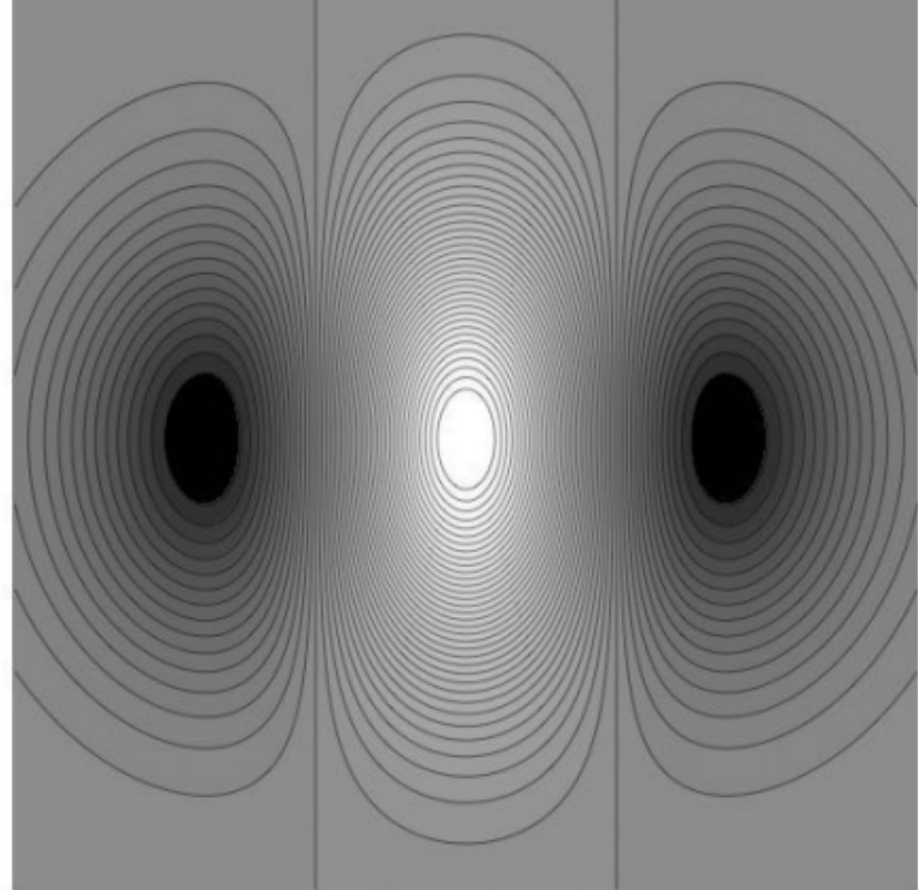
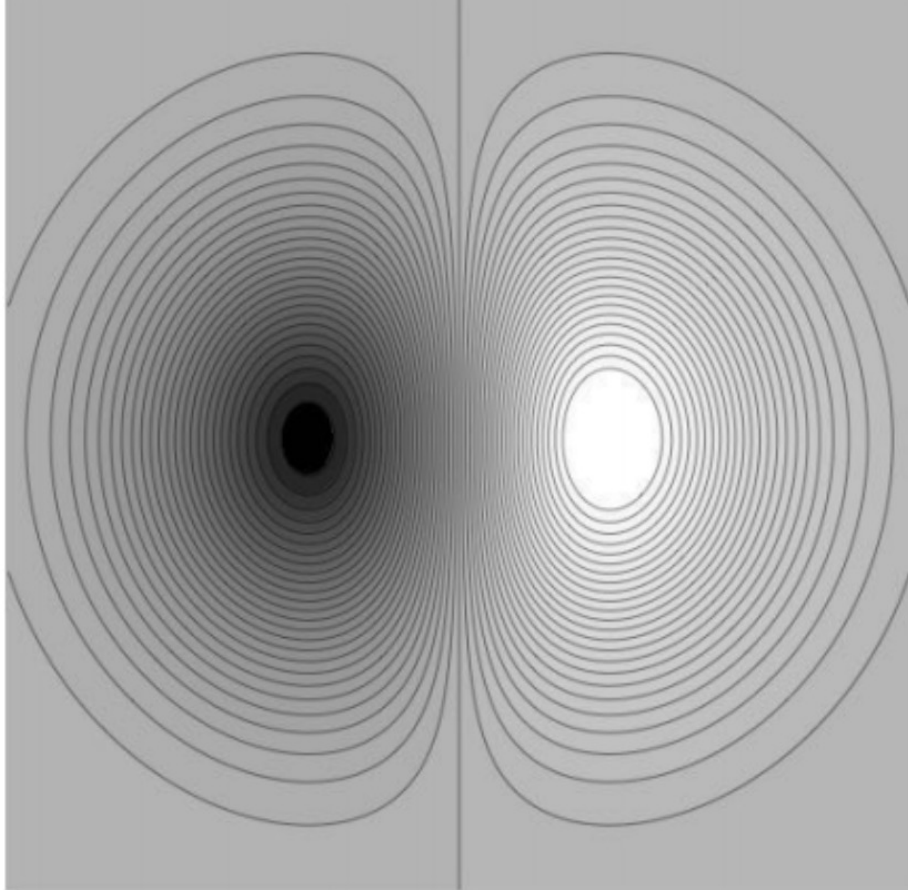
yes, but only if it has a background...



but now we have **two** points,  
a large black one and a small white one

"real" points are like receptive fields that carry their background with them ...



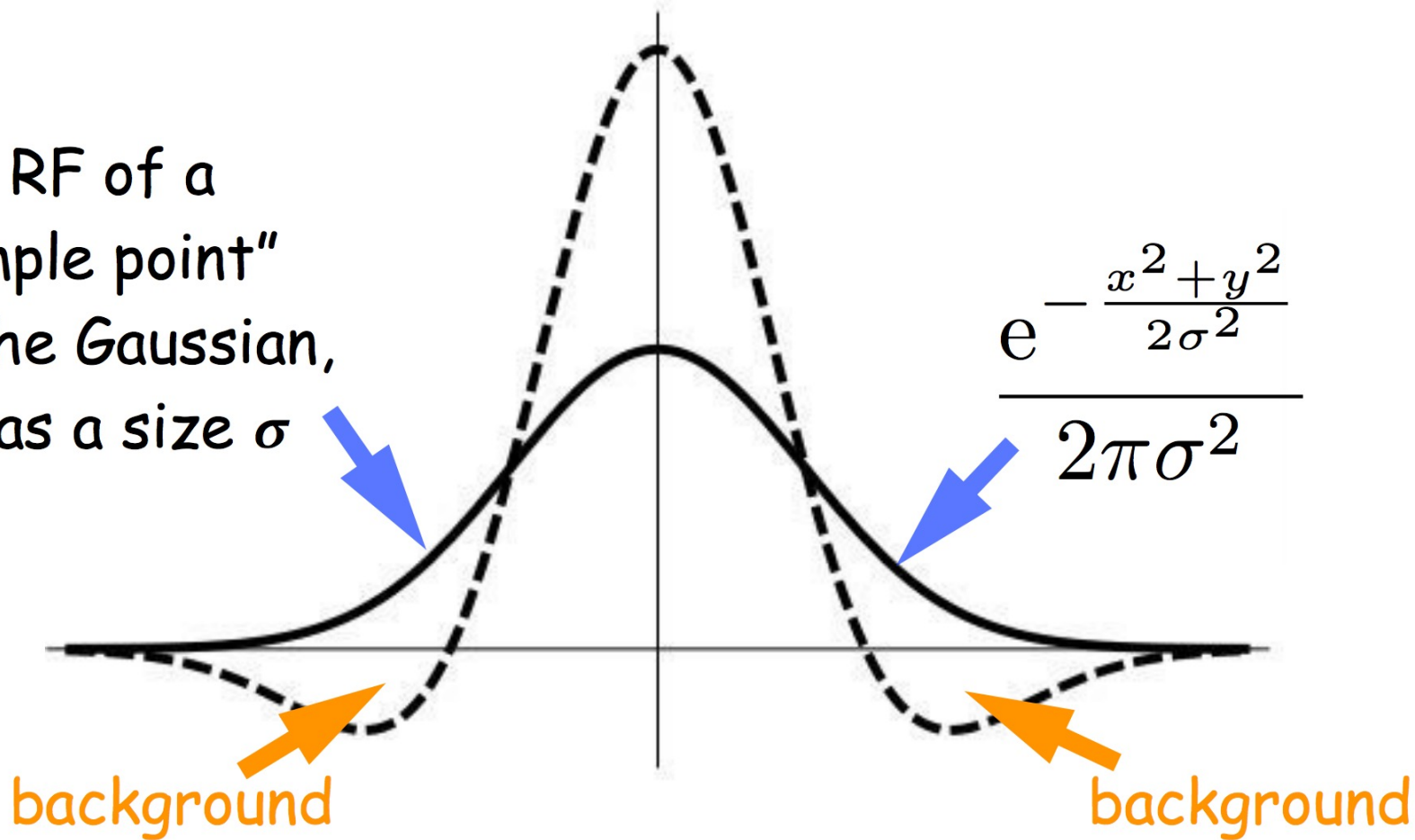


the 1<sup>st</sup> and 2<sup>nd</sup>-order directional derivatives are just the simplest instances of *ATOMIC* multi-point operators (in brain science "atomicity" is implied by a single axon output)

NOTICE: the receptive fields may be considered to be necessarily *ATOMIC* because there is only a single degree of freedom in their activity - the spike frequency of the axon



the RF of a  
"simple point"  
is the *Gaussian*,  
it has a size  $\sigma$



the point with background is visible, the point without background not - it does not exist!

**Points in visual awareness don't just exist on a red screen like pixels** (pick a point out of a field of color? can't do it)

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**a point, an “atomic element” of visual awareness is created out of some differential geometry**

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and same with edges

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and same with edges

you can't read off edges, you can't read off points as discrete entities in space, they are located (by construction!) in a surround

NOTE: this center-surround relationship, captured physiologically by the receptive field, may be considered to be necessarily ATOMIC because

there is only a single degree of freedom in their activity - the spike frequency of the axon

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that center-surround relationship exists at many scales, all of which are at play simultaneously in visual awareness

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**which are you aware of now? can that be manipulated? can we be aware of multiple at once?**

but regardless of scale there is a differential operator at play

and the brain is set up to do this (receptive fields where atomic unit — single UNIT of information — is a created via a difference operator, not a dimensionless “point”)