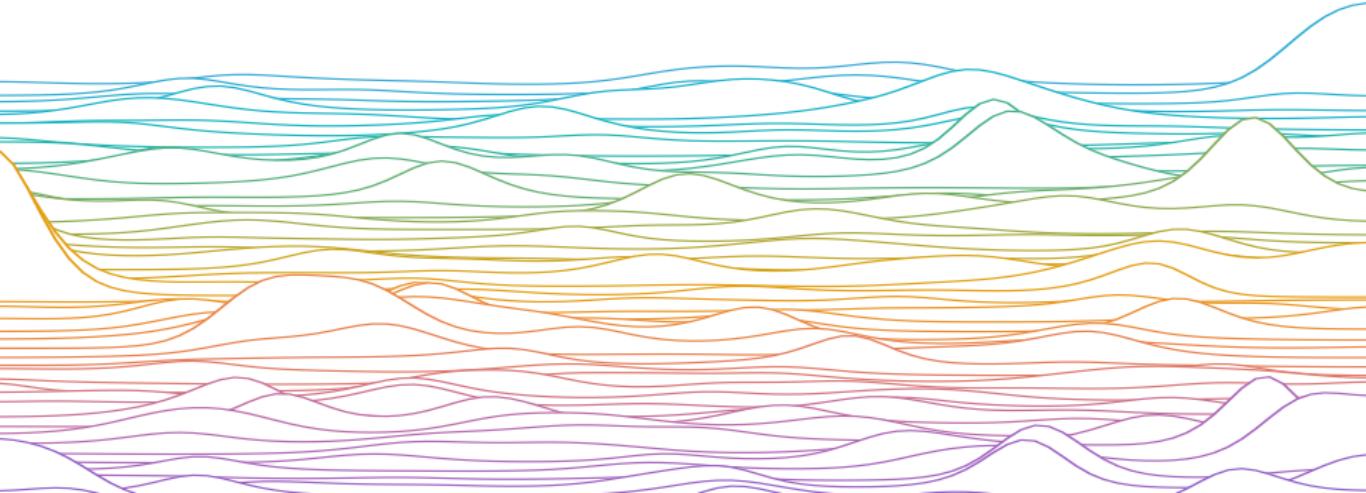
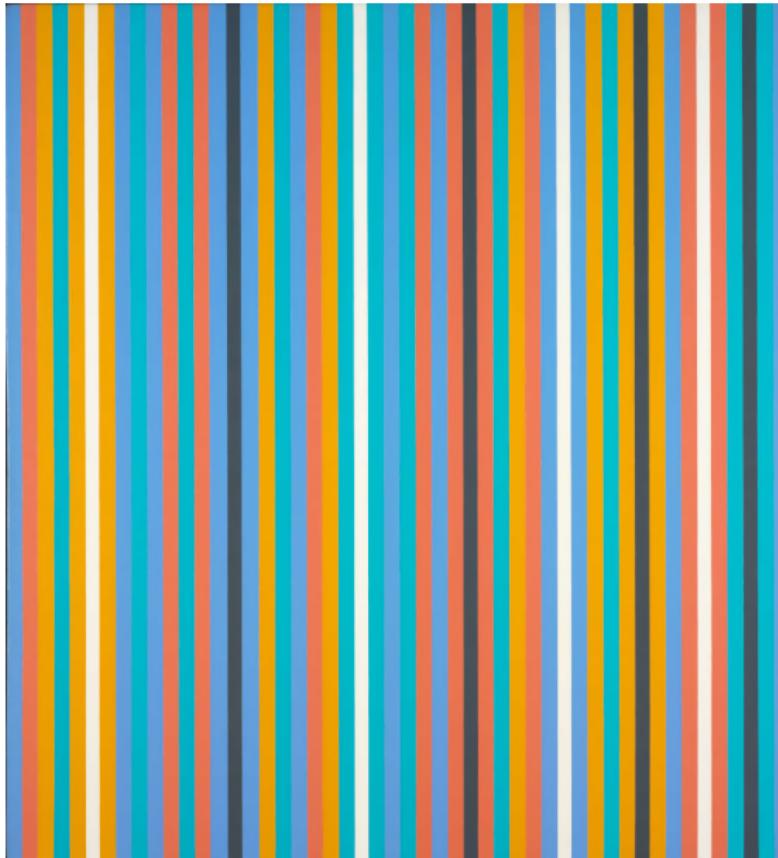


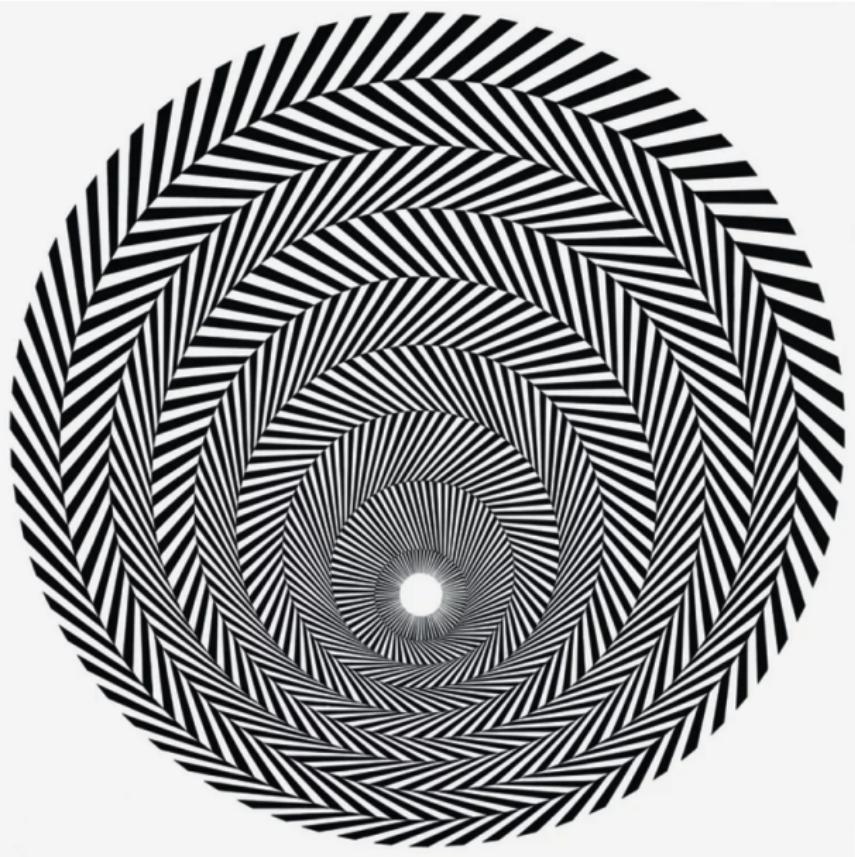
The Visual System

SEMT30003/4





Bridget Riley (1982) *Gather*



Bridget Riley (1964) Blaze 4

This lecture covers:

- ▶ Visual System (brain facts)
- ▶ Models of visual encoding
(sparse coding)

Learning goals:

- 1 Identify the basic anatomy of the visual system.
- 2 Summarize how information is transformed in the early stages of vision, and *describe where each of stage occurs in the brain.*
- 3 Describe the role of sparsity in population coding in the visual system.

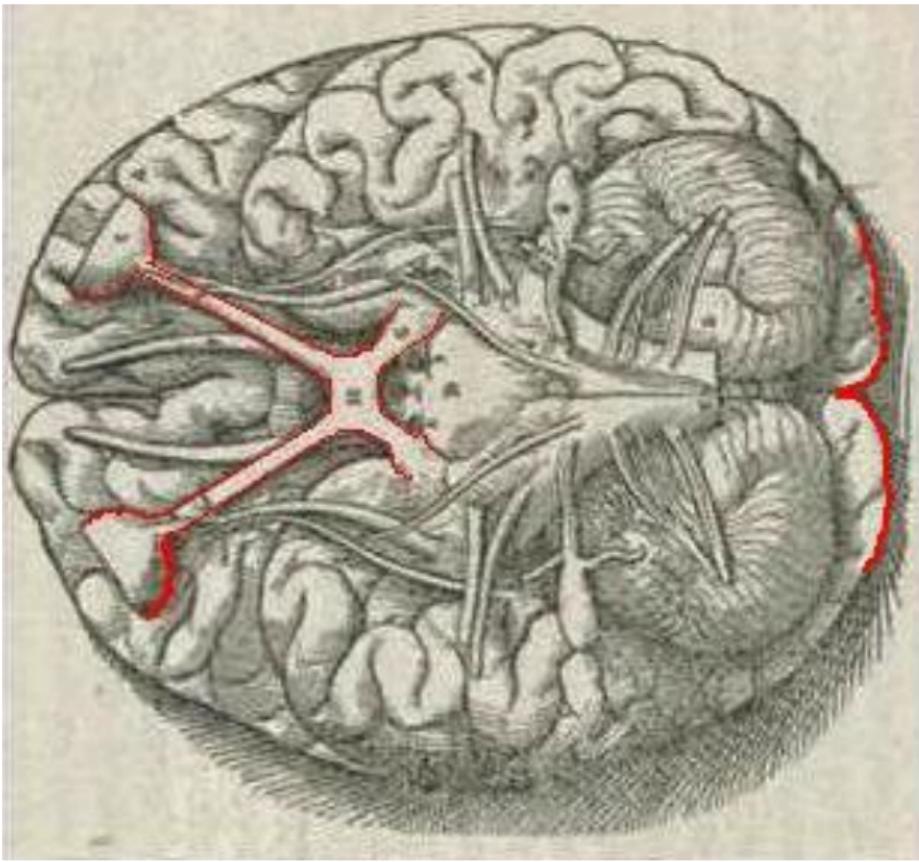
Building on:

Rate Neurons

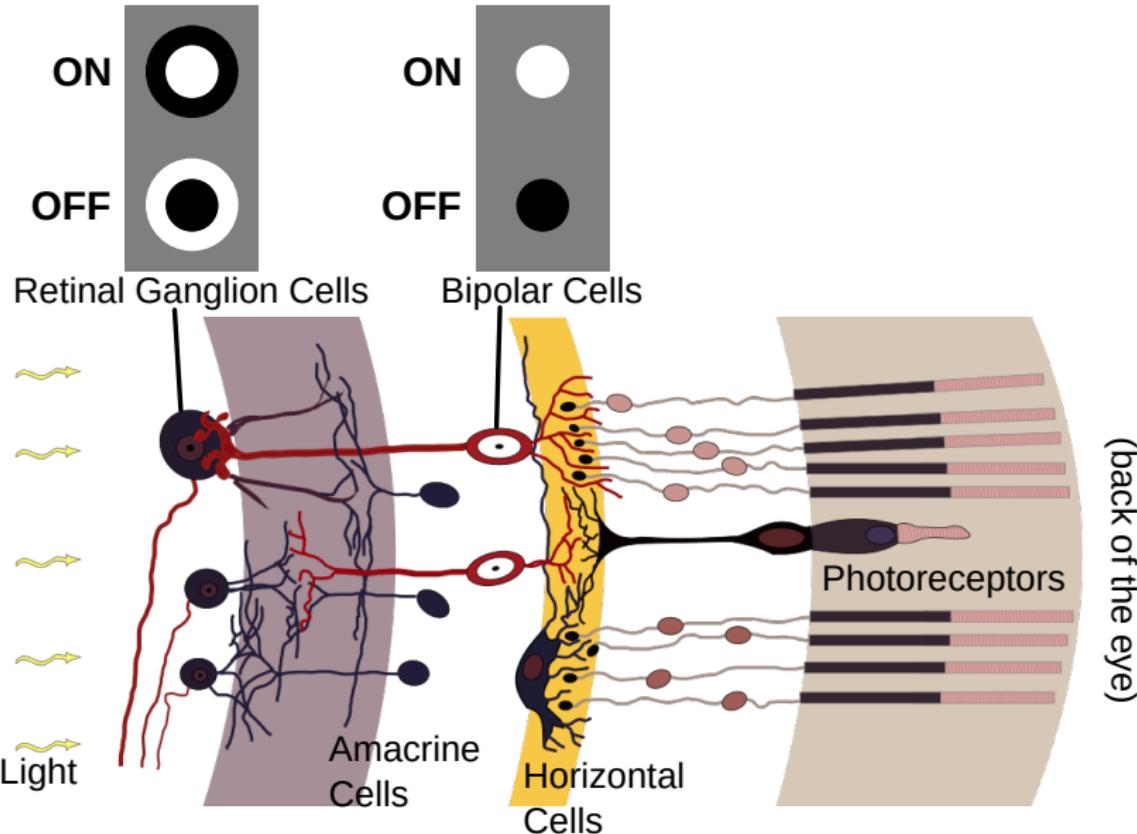
Building up to:

Topics in Computer Science Final exam question

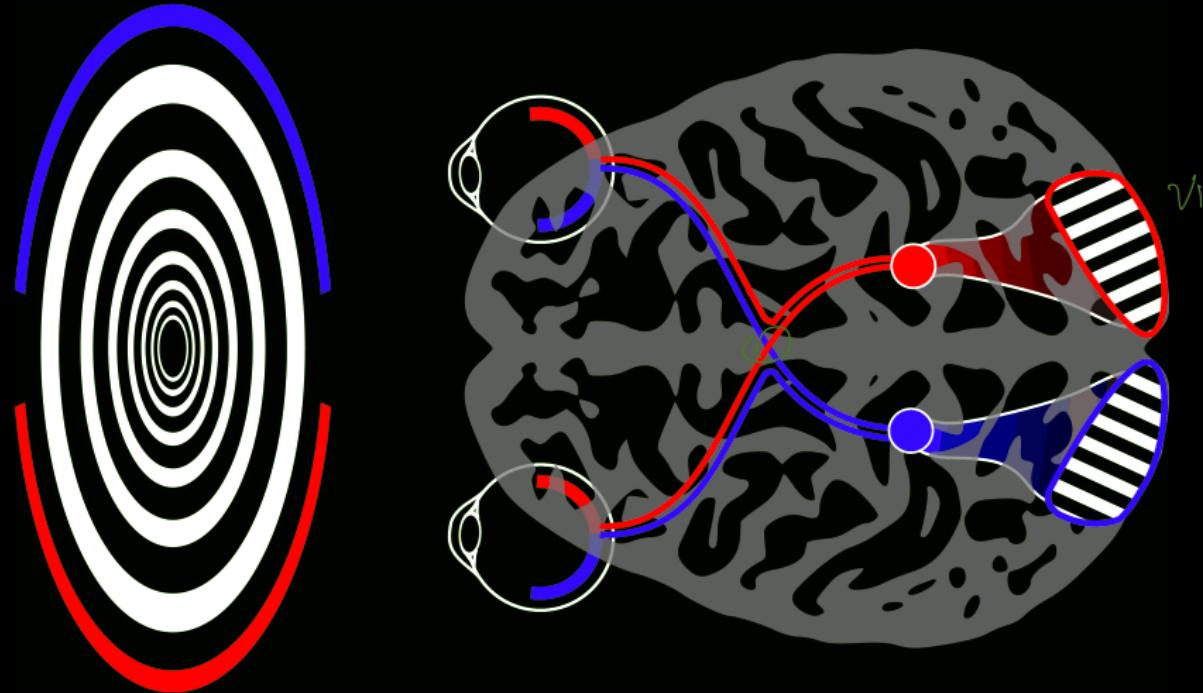
(page left blank for notes)

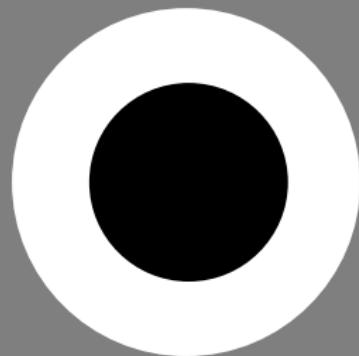


Andreas Vesalius (1543) *De Humanis Corporis Fabrica* (Wikimedia)



Ramoń y Cajal (1911) modified from derivative work by Anka Friedrich via Wikimedia Commons
(true picture is far more complicated)





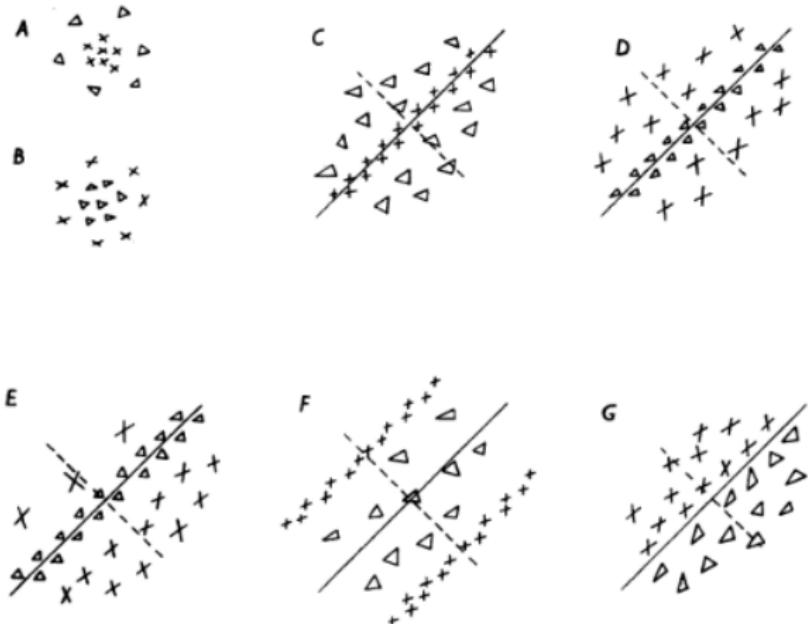
(SIMILAR contrast-based
features emerge for colour.)



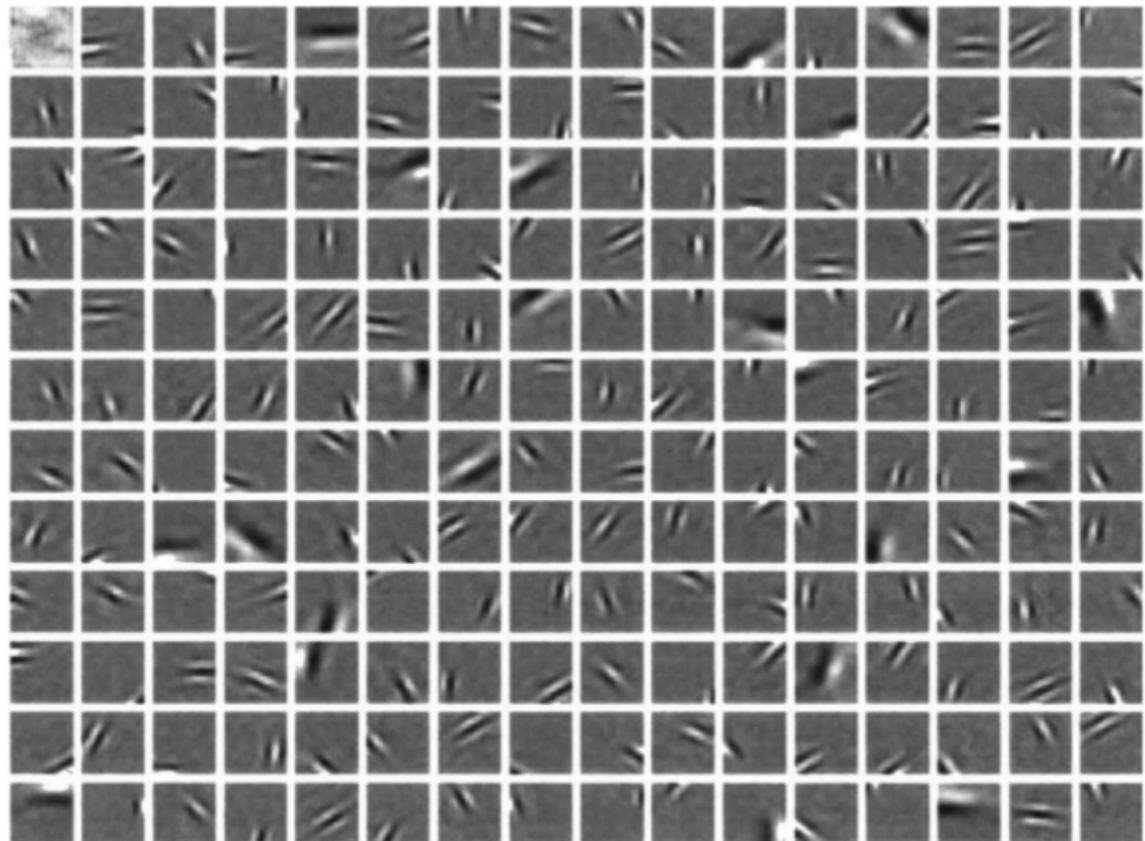
"SIMPLE CELLS"

(NO PHASE INVARIANCE)
LIGHT DARK \neq DARK LIGHT





Text-fig. 2. Common arrangements of lateral geniculate and cortical receptive fields. *A*. 'On'-centre geniculate receptive field. *B*. 'Off'-centre geniculate receptive field. *C-G*. Various arrangements of simple cortical receptive fields. *x*, areas giving excitatory responses ('on' responses); Δ , areas giving inhibitory responses ('off' responses). Receptive-field axes are shown by continuous lines through field centres; in the figure these are all oblique, but each arrangement occurs in all orientations.



Olshausen BA, Field DJ (1996) *Emergence of simple-cell receptive field properties by learning a sparse code for natural images*

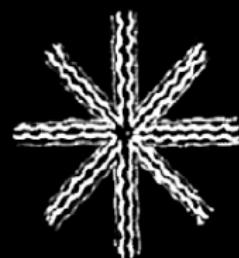
fig. 2



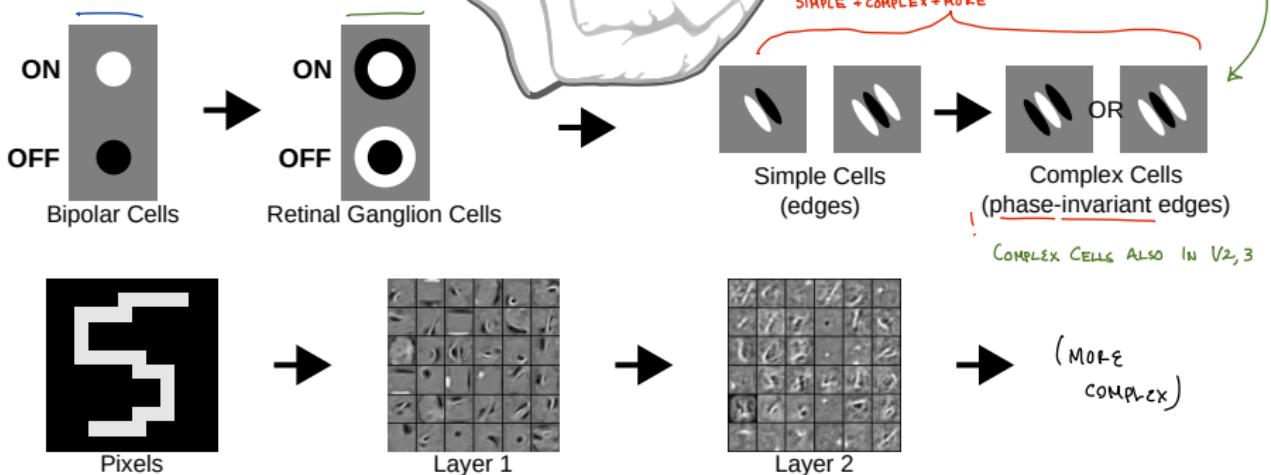
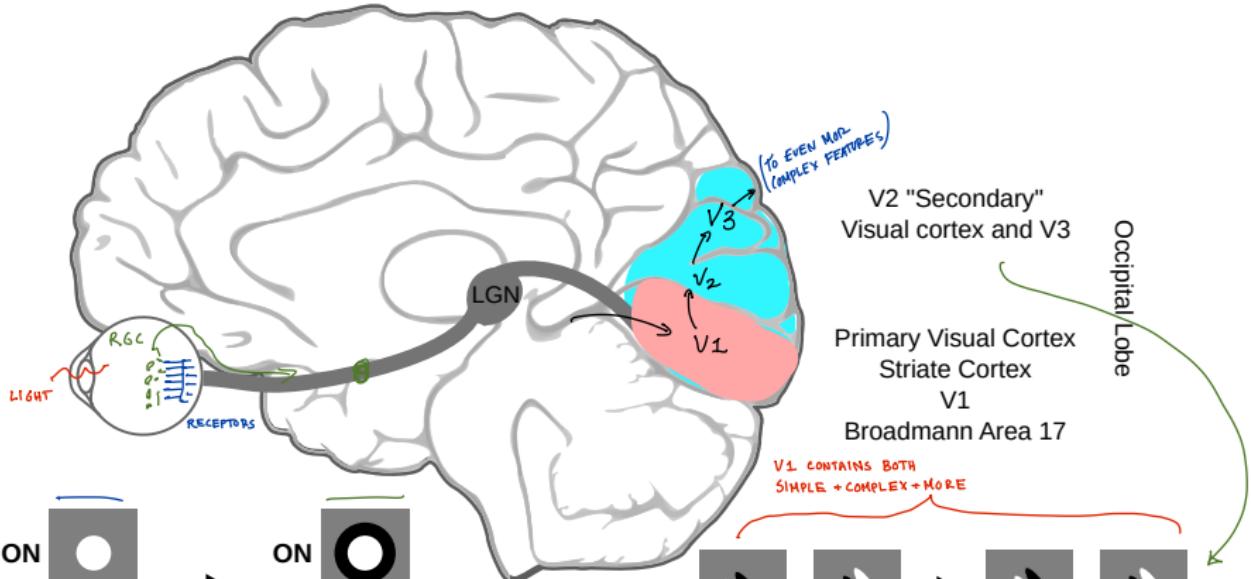
fig. 3



fig. 4



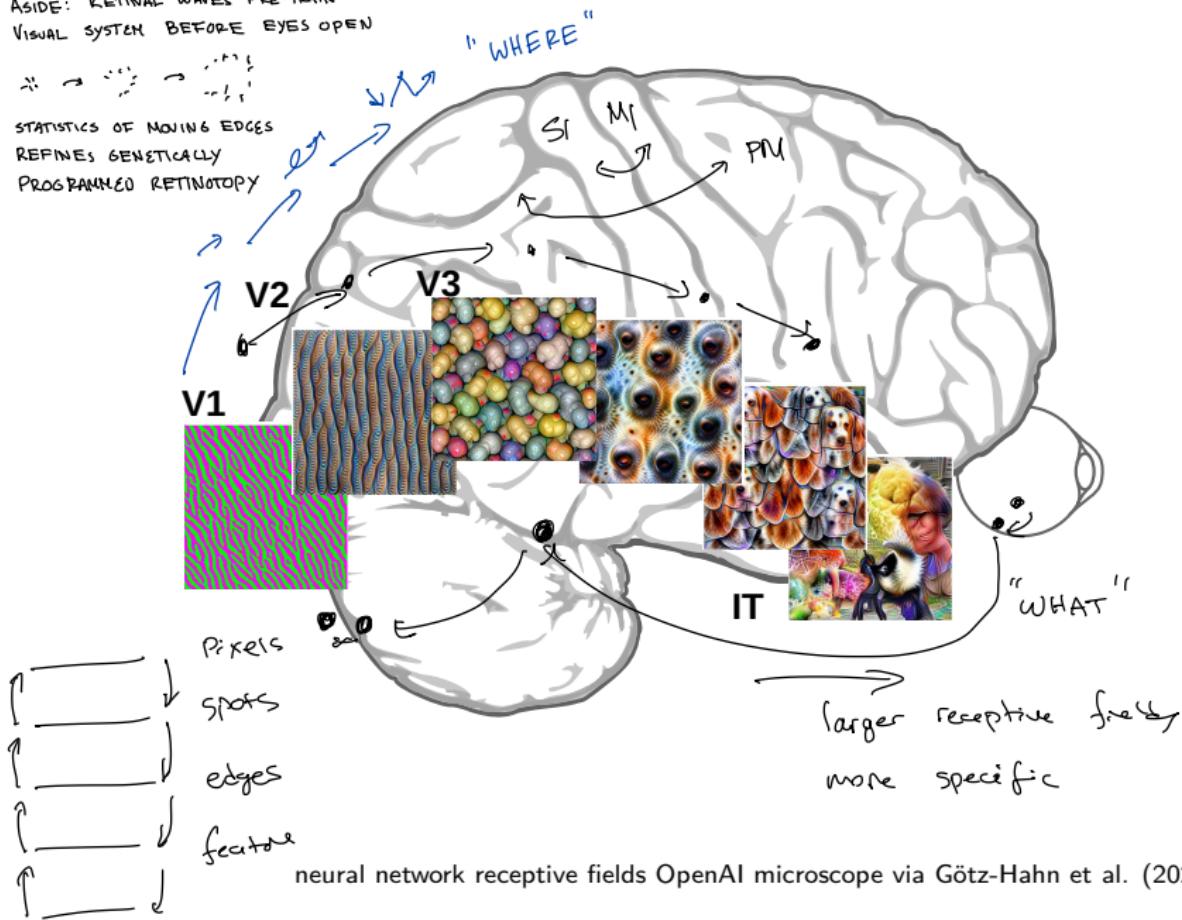
JAN PURFINJIE 1819



neural network receptive fields from Erhan et al. (2009)

ASIDE: RETINAL WAVES PRE-TRAIN
VISUAL SYSTEM BEFORE EYES OPEN

STATISTICS OF MOVING EDGES
REFINES GENETICALLY
PROGRAMMED RETINOTOPY



neural network receptive fields OpenAI microscope via Götz-Hahn et al. (2023)

Brain facts to know

Photoreceptors, bipolar cells:

- ▶ Light/dark
- ▶ Retina

On/off cells:

- ▶ Spots of light surrounded by dark (on), or vice versa (off)
- ▶ Retinal Ganglion Cells (compression, spatial+temporal differentiation)

Simple cells:

- ▶ Primary visual cortex (AKA “V1”, Broadmann Area 17) in occipital lobe
- ▶ Edges (phase matters!)

Complex cells:

- ▶ Primary visual cortex and some higher-level visual areas in occipital lobe
- ▶ Respond to edges, features (invariance to light/dark phase)

Math (sparsity)

DATASET OF IMAGES



Whitening



EDGES ENHANCED



& build a sparse code to represent



V1 SIMPLE CELLS AS "OVERCOMPLETE" BASIS?
ONE "CELL" FOR EACH POSSIBLE EDGE PATCH?



OVERCOMPLETE = MORE DIMENSIONS IN CODE THAN IN PIXELS

BUT, WE WILL CONSTRAIN ACTIVITY TO BE SPARSE

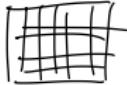


"NEURONS" MOSTLY SILENT

(BUT NEURONS THAT ARE ACTIVE
QUITE SPECIFIC / INFORMATIVE)

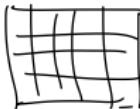
V1: Multiple possible edge features
(Simple?)
cells for each patch of visual field

Photoreceptor



Pixels

RGC?



Layer 1
"edges"

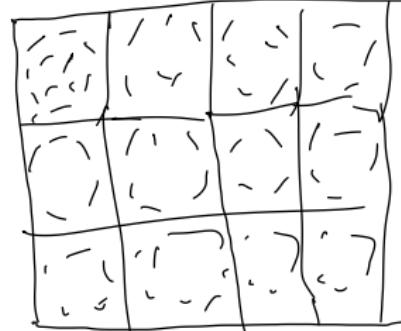
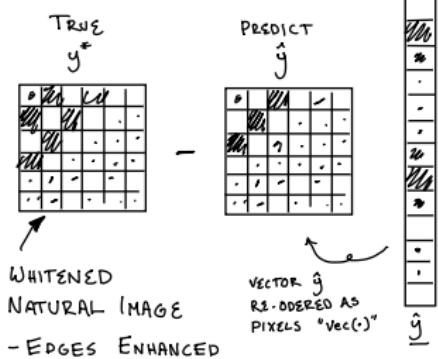
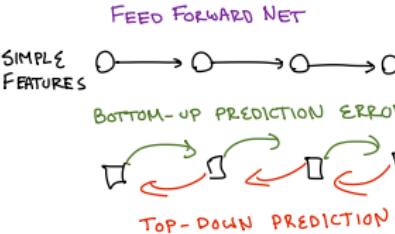
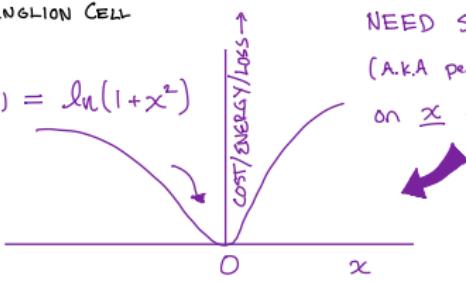


IMAGE INPUT
ARRIVING FROM
RETINA/LGN
(VAGUELY)



$$S(x) = \ln(1+x^2)$$



VS.
"PREDICTIVE
CODING"

V1 (VAGUELY)

SPARSE!
Most neurons silent
 \approx most $x_j \approx 0$

PREDICTION

$$\hat{y} = \underline{W} \underline{x}$$

$$\hat{y}_k = \sum_l W_{kl} x_l$$

$$W$$

RECONSTRUCTION
WEIGHTS

$x \rightarrow \hat{y}$ IS LINEAR

inverse $\hat{y} \rightarrow x$ ill-conditioned

NEED Sparse prior

(A.K.A. penalty, regularization)

on \underline{x} activity

REG STRENGTH
RECONSTRUCTION ERROR
SPARSE PENALTY

$$\text{Loss}(W, \underline{x}, y^*) = \frac{1}{2} \| y^* - W\underline{x} \|^2 + \lambda S(\underline{x})$$

(page left blank for notes)

