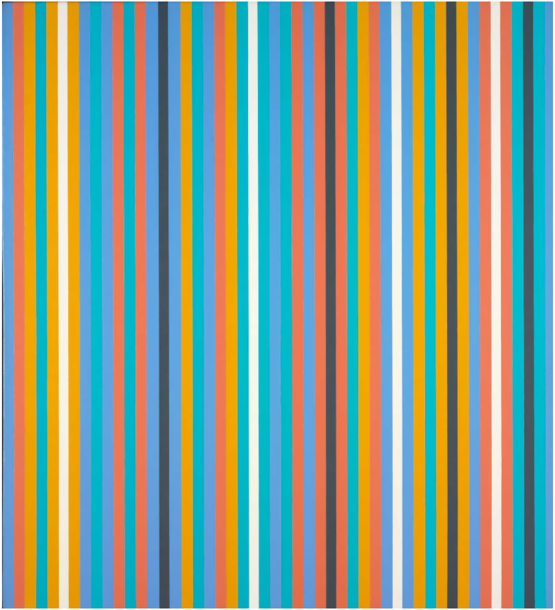
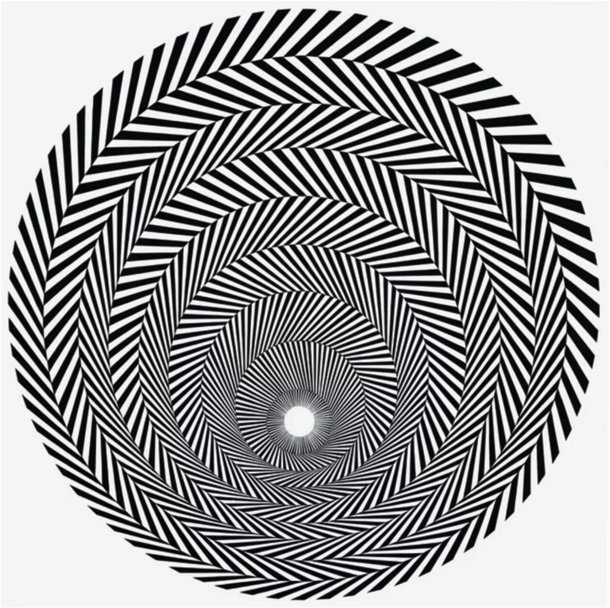
The Visual System

SEMT30003/4



Bridget Riley (1982) *Gather*



Bridget Riley (1964) Blaze 4

This lecture covers:

- Visual System (brain facts)
- Models of visal 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.

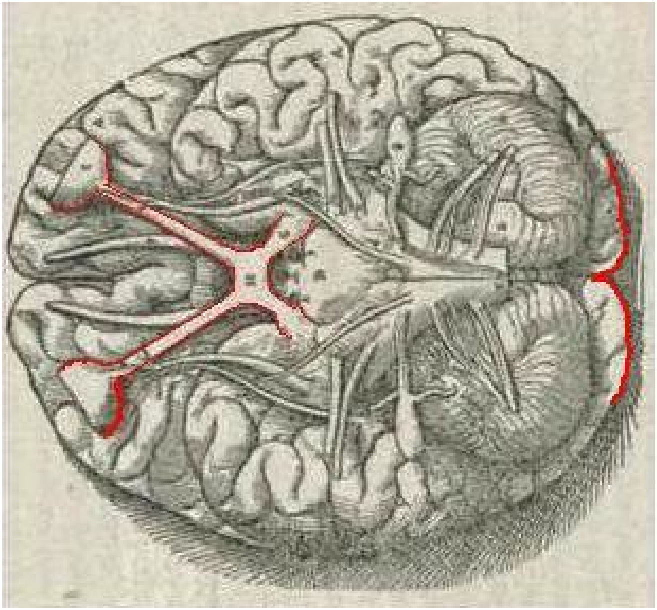
Building on:

Rate Neurons

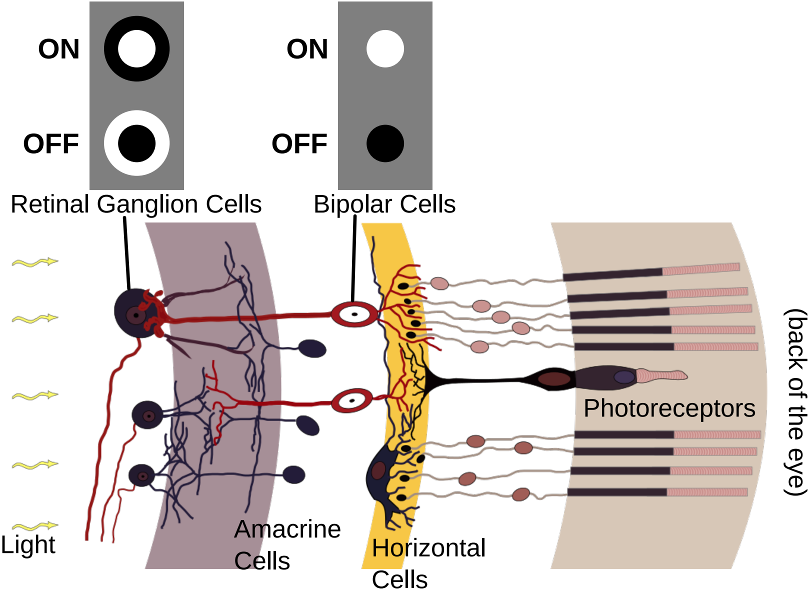
Building up to:

Topics in Computer Science Final exam question

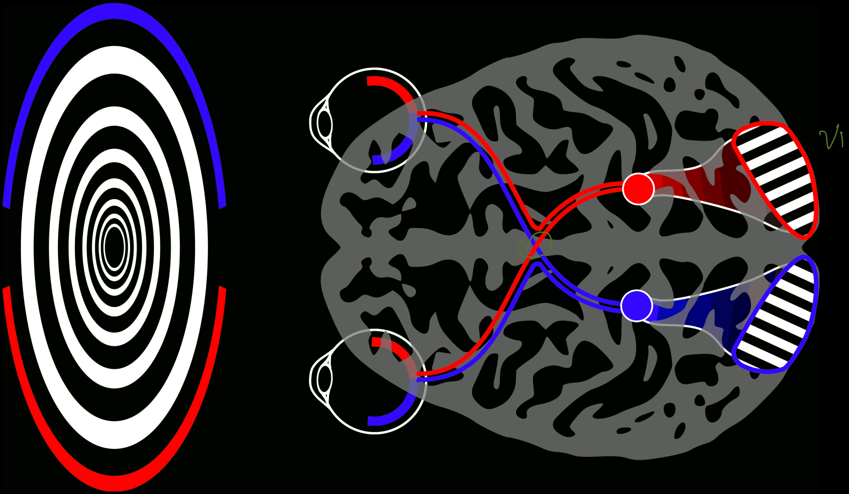
(page left blank for notes)



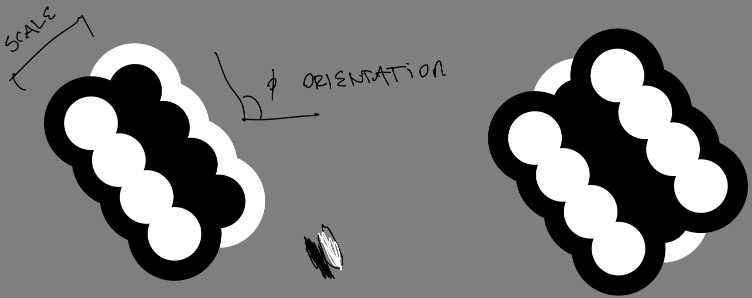
Andreas Vesalius (1543) *De Humani Corporis Fabrica* (Wikimedia)



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

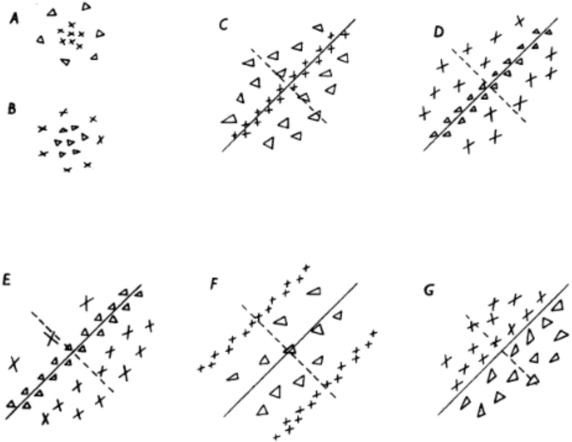

V1

(Similar contrast-based features emerge for colour.)



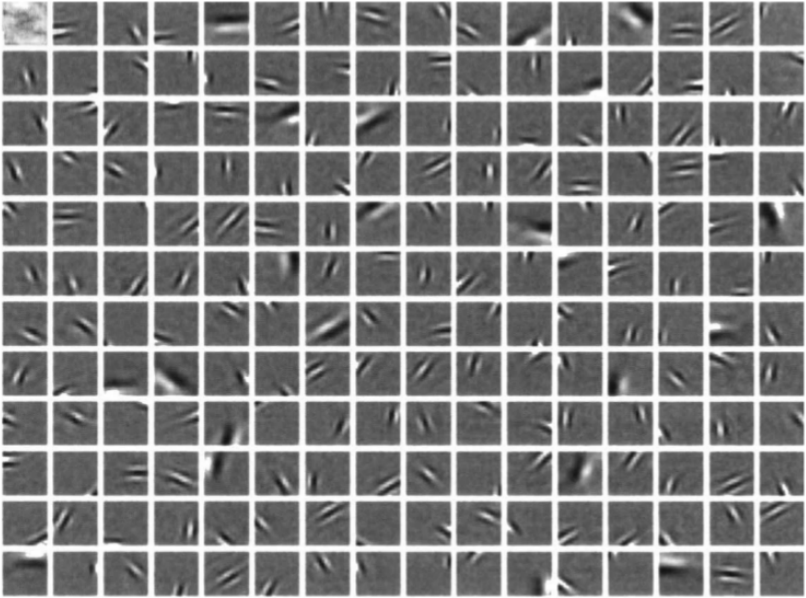
"SIMPLE CELLS"

(NO PHASE INVARIANCE
LIGHT DARK $\neq$ DARKLIGHT)



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. ×, areas giving excitatory responses ('on' responses); △, 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.

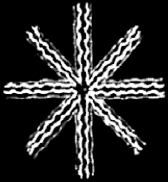
Hubel DH, Wiesel TN. (1962)



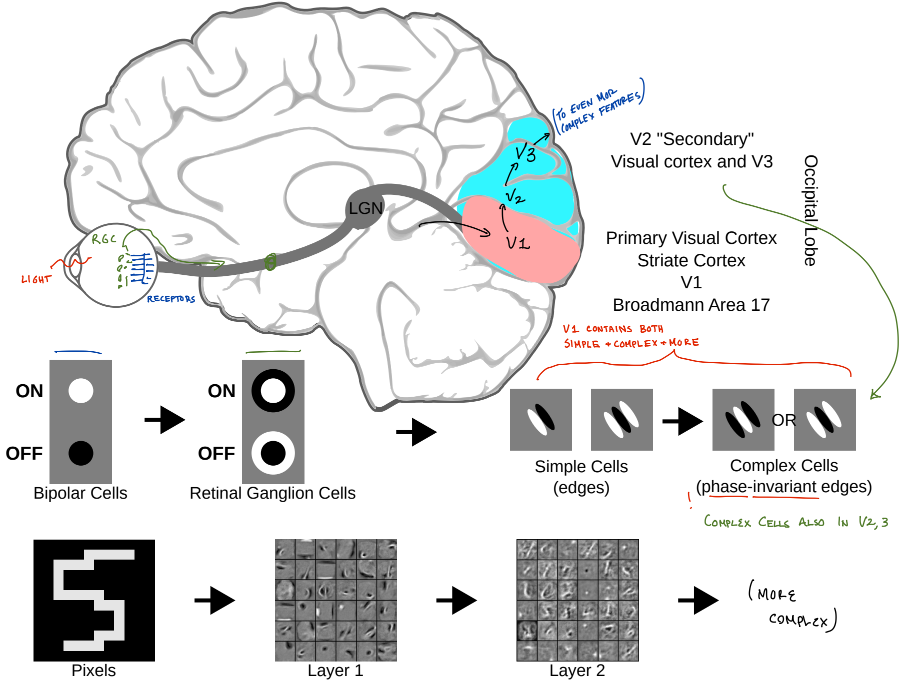
Olshausen BA, Field DJ (1996) *Emergence of simple-cell receptive field properties by learning a sparse code for natural images* *fig. 2*

fig 3

fig 4



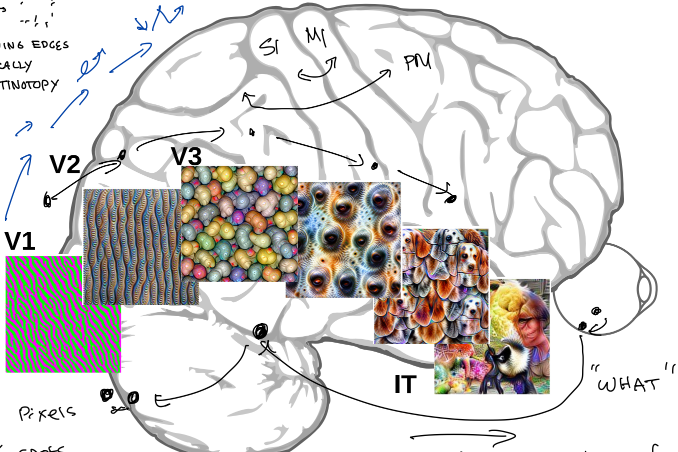
JAN PURKINJIE 1819



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



Pixels

spots

edges

features

larger receptive fields

more specific

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)

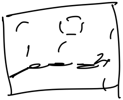
Math (sparsity)

OLHAUSEN & FIELD 1996

DATASET OF IMAGES

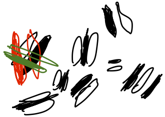
whitening

EDGES ENHANCED

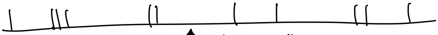


build a sparse code to represent ?

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



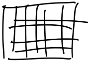
OVERCOMPLETE = MORE DIMENSIONS IN CODE THAN IN PIXELS
BUT, WE WILL CONSTRAIN ACTIVITY TO BE <u>SPARSE</u>



"NEURONS" MOSTLY SILENT
(BUT NEURONS THAT <u>ARE</u> ACTIVE QUITE SPECIFIC / INFORMATIVE)

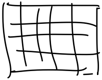
V1: (Simple cells?) Multiple possible edge features for each patch of visual field

Photoreceptor

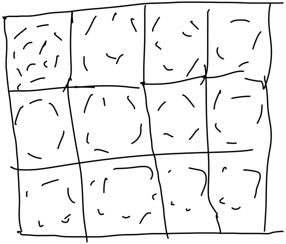


pixels

RGC ?



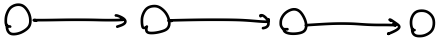
layer 1
"edges"



OLHAUSEN & FIELD 1996

FEED FORWARD NET

SIMPLE FEATURES



ABSTRACT FEATURES

BOTTOM-UP PREDICTION ERRORS

TOP-DOWN PREDICTION

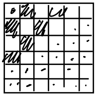
VS. "PREDICTIVE CODING"

V1 (VAGUELY)

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

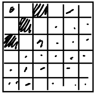
IMAGE INPUT ARRIVING FROM RETINA / LGN (VAGUELY)

TRUE
y^*



—

PREDICT
$\hat{y}$



$\underline{\hat{y}}$

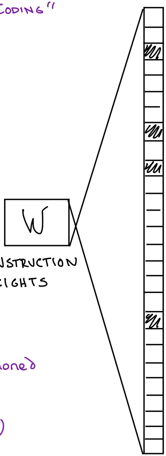
WHITENED NATURAL IMAGE
- EDGES ENHANCED
- ≈ RETINAL GANGLION CELL (VAGUELY!)

VECTOR $\hat{y}$ RE-ODERED AS PIXELS "vec(·)"

PREDICTION

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

$$\hat{y}_k = \sum_\ell W_{k\ell}\, x_\ell$$



RECONSTRUCTION WEIGHTS

$\underline{x}$

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

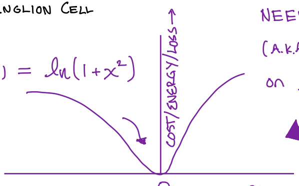
inverse $\hat{y} \longrightarrow x$ ill-conditioned

NEED sparse prior

(A.K.A penalty, regularization)

on $\underline{x}$ activity

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



RECONSTRUCTION ERROR

REG STRENGTH

SPARSE PENALTY

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

(page left blank for notes)

(page left blank for notes)

(page left blank for notes)

(page left blank for notes)

(page left blank for notes)

(page left blank for notes)

(page left blank for notes)

(page left blank for notes)

(page left blank for notes)

(page left blank for notes)