detection
recognition
segmentation

... 

visual
understanding
1. The Mammalian Visual System

- anatomy and processing pathways
- from processing to perception
1. The Mammalian Visual System
   • anatomy and processing pathways
   • from processing to perception

2. Early Computation
   • first stages of information processing
   • edges: a basis for representing the visual world
1. The Mammalian Visual System
   - anatomy and processing pathways
   - from processing to perception

2. Early Computation
   - first stages of information processing
   - edges: a basis for representing the visual world

3. Object Recognition in the Human Visual System
   - building invariance: pooling and transformation
   - untangling object representations
Mammalian Visual System anatomy and processing pathways
The “Camera”: Retinal Projection
The “Camera”: Retinal Projection
Mammalian Visual System anatomy and processing pathways

Neuron
Neuron

Mammalian Visual System anatomy and processing pathways
Mammalian Visual System anatomy and processing pathways

figure courtesy of A. Alahi
From Retina to Cortex

world

retina
(compression)

LGN

visual cortex
(expansion)
Mammalian Visual System

anatomy and processing pathways

From Retina to Cortex

world
	netra
	(compression)

LGN

visual cortex
	(expansion)
Cortex: At Least Two Dozen Visual Areas

Weiner & Grill-Spector (2012)
Cortex: At Least Two Dozen Visual Areas

plus more: motion areas, “functional” regions, etc.

Weiner & Grill-Spector (2012)
Visual Processing vs. Perception

Weiner & Grill-Spector (2012)
Visual Processing vs. Perception

Weiner & Grill-Spector (2012)
Visual Processing vs. Perception

perception involves integration and higher functions

Weiner & Grill-Spector (2012)
Mammalian Visual System

DiCarlo & Cox (2007)
Mammalian Visual System

visual processing is done in stages

DiCarlo & Cox (2007)
Mammalian Visual System

visual processing is done in stages
but it is not synonymous with perception

DiCarlo & Cox (2007)
2. Early Computation

local information processing
Retinal Projection

picture is inverted, but spatial relationships are preserved
Receptive Fields

extract similar features at each position in the visual field

figure adapted from Ebner & Hameroff (2011)
**Receptive Fields**

extract similar features at each position in the visual field

center-surround receptive fields

figure adapted from Ebner & Hameroff (2011)
Receptive Fields

extract similar features at each position in the visual field

ON ganglion cells
Receptive Fields

extract similar features at each position in the visual field

ON ganglion cells
Early Computation  

First stages of processing

Human retina

Photoreceptors  Cells  Ganglion Cells

Computer Vision

Action potentials

figure courtesy of A. Alahi
Early Computation  first stages of processing

figure courtesy of A. Alahi
Early Computation first stages of processing

Figure courtesy of A. Alahi
Early Computation

first stages of processing

Human retina

Photoreceptors

Cells

Ganglion Cells

Action potentials

Computer Vision

Pixels

Linear

Non-linear

× W₁

× W₂

× W₃

× W₄

Σ

T

- W₅

× W₆

× W₇

Σ

T

1011001

Binary string

DoG

Threshold

figure courtesy of A. Alahi
From Retina to Cortex

world
retina (compression)
LGN
visual cortex (expansion)
Single Electrode Recording
Single Electrode Recording

https://www.youtube.com/watch?v=8VdTf3egwfg

Hubel & Wiesel (1962)
Types of V1 cells

simple cells

On-Center  Off-Center

Hubel & Wiesel (1962)
Types of V1 cells

simple cells

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Types of V1 cells

simple cells

On-Center  Off-Center

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Types of V1 cells

simple cells

On-Center  Off-Center

Hubel & Wiesel (1962)
Types of V1 cells

simple cells

On-Center: - + - +
Off-Center: + - + -

Hubel & Wiesel (1962)
Types of V1 cells

complex cells

On-Center  Off-Center

Hubel & Wiesel (1962)
Types of V1 cells

simple and complex cells are sensitive to:

- center-surround (difference of gaussians!)
- edges (symmetrical and asymmetrical)
- rectangles of various elongation, visual half fields

Hubel & Wiesel (1962)
Types of V1 cells

simple and complex cells are sensitive to:

- center-surround (difference of gaussians!)
- edges (symmetrical and asymmetrical)
- rectangles of various elongation, visual half fields

V1 also has cells that are sensitive to:

- motion (in fact, it’s a separate processing stream!)
- color (groups of cells called “color blobs”)
- other stuff

Hubel & Wiesel (1962)
Why Are Edges Special?

image

neurons

weights

Olshausen & Field (1996)
Why Are Edges Special?

image

neurons

weights

Olshausen & Field (1996)
Why Are Edges Special?

each pixel activated independently

INPUT

BASIS FOUND

Olshausen & Field (1996)
Why Are Edges Special?

images are sums of independent gratings

INPUT

BASIS FOUND

Olshausen & Field (1996)
Why Are Edges Special?

patches of real-world images

Olshausen & Field (1996)
Early Computation

V1 cells encode edge orientation and position across visual field: simple and complex receptive fields

edges are a sufficient basis for real-world images!

Hubel & Wiesel (1962), Olshausen & Field (1996)
3. Object Recognition in the Human Visual System

sequential transformations
Object Recognition building invariance
The Flow of Information

Weiner & Grill-Spector (2012)
Specialization: “What” and “Where” Pathways

monkey lesion studies

“what”

“where”

Mishkin & Ungerleider 1982
Specialization: “What” and “Where” Pathways

monkey lesion studies

lesion “where” pathway: difficulty in spatial reasoning

lesion “what” pathway: difficulty in object recognition

Mishkin & Ungerleider 1982
Specialization: “What” and “Where” Pathways

- monkey lesion studies
- lesion “where” pathway: difficulty in spatial reasoning
- lesion “what” pathway: difficulty in object recognition

Mishkin & Ungerleider 1982
Object Recognition: The “What” Pathway

DiCarlo & Cox (2007)
Object Recognition: The “What” Pathway

Object Recognition: The “What” Pathway

Object as Manifolds in High Dimensional Space

DiCarlo & Cox (2007)
Object as Manifolds in High Dimensional Space

DiCarlo & Cox (2007)
Object as Manifolds in High Dimensional Space

DiCarlo & Cox (2007)
Object as Manifolds in High Dimensional Space

DiCarlo & Cox (2007)
Untangling Object Manifolds

DiCarlo & Cox (2007)
in the human visual system, invariance is built gradually across many successive transformations

Object Recognition: A Step Towards Visual Understanding

in the human visual system, invariance is built gradually across many successive transformations

human and computer vision both strive to achieve invariant representations

Discussion
Discussion

human visual invariance vs. CV features

incremental invariance vs. all-at-once

should we build detectors invariant to “everything”? 
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Mammalian Visual System

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Mid-Quarter Feedback Forms