Perception and Visual Cognition

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Topics

1. Introduction to vision science
2. Theoretical approaches to vision
3. Spatial vision
4. Computational approaches
5. Binocular vision
6. Dynamic and pictorial depth cues
7. Visual awareness
8. Shape representation
9. Motion perception
10. Events perception
11. Perceiving function and category
12. Theories of object recognition
13. Visual memory and imagery

Introduction

1 Physics of Optical Information

2 Biology of the Visual System

3 Psychology of Visual Perception

www.visionscience.com
www.med.uwo.ca/physpharm/courses/sensesweb
viperlib.york.ac.uk

Optical Information

light: characteristics of particles and waves

visible spectrum of light (400-700 nm) and luminance (10^{-3}-10^{5} cd/m^2)

illumination in environment: point source vs diffuse light, reflection, absorption, transmission-refraction

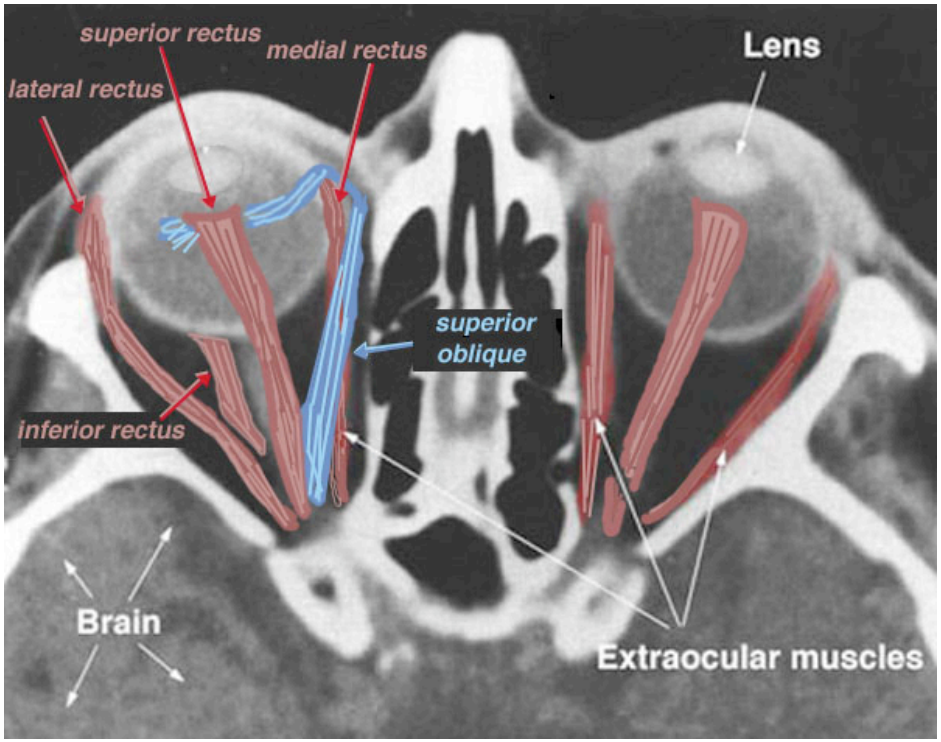
pinhole camera

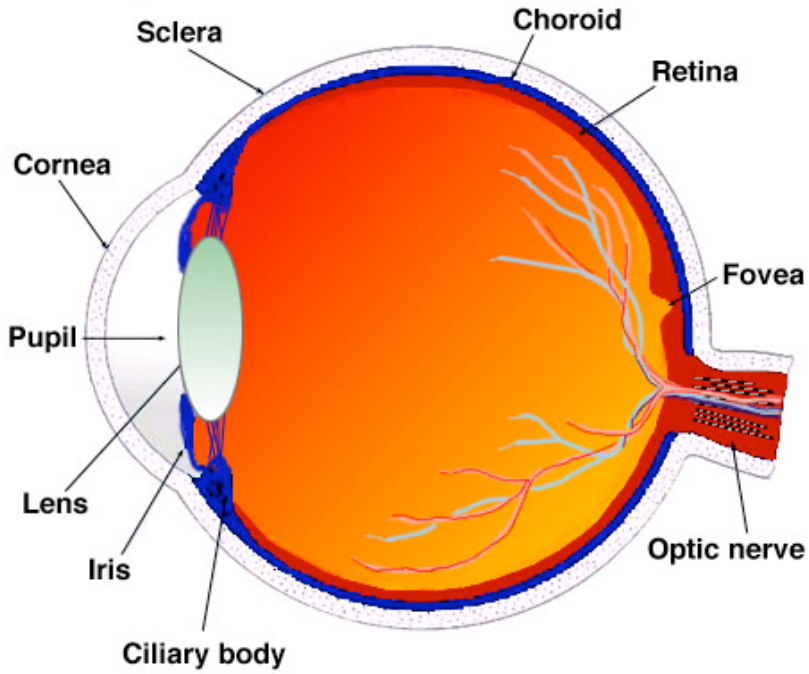
Visual System

evolutionary utility

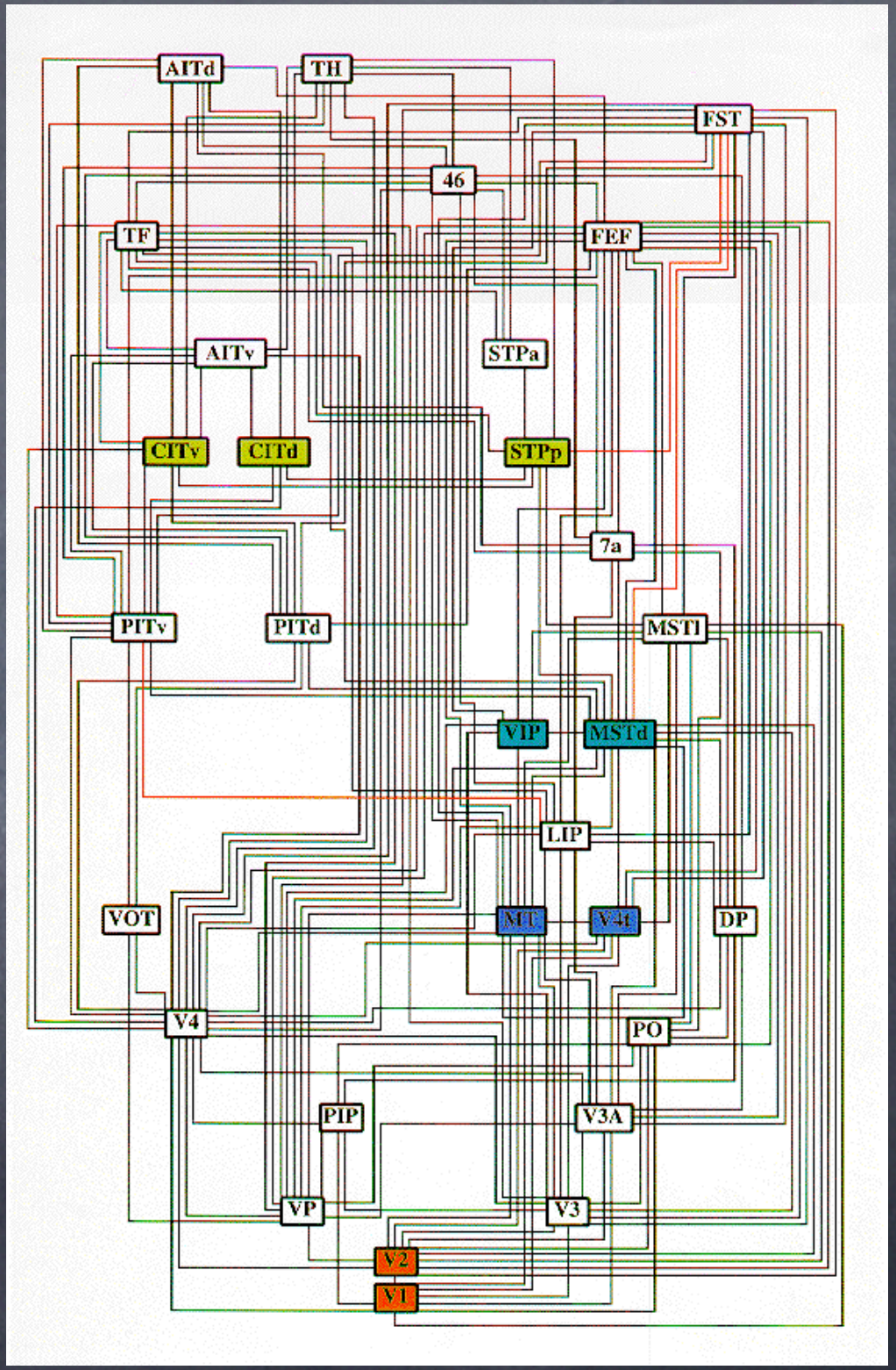
Receptors in retina - cones ($5 \cdot 10^6$), rods (10^8), optic nerve fibres ($1.5 \cdot 10^6$)

LGN, pathways, V1, MT, ... modularity





Structure of the Visual System (Felleman & van Essen, 1991)



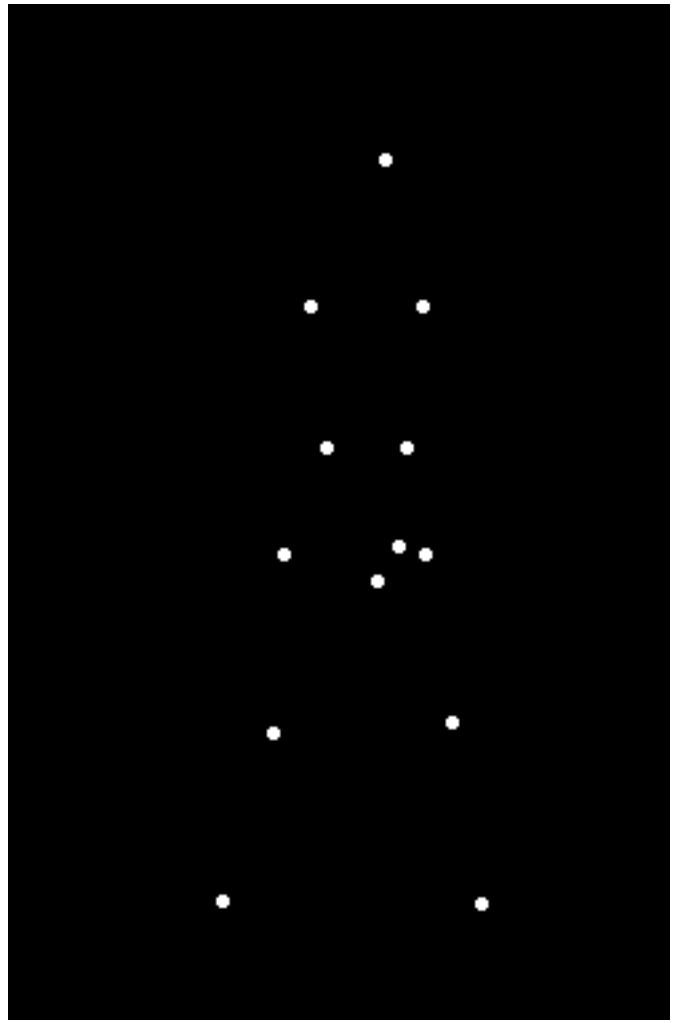
Visual Perception

Inverse Problem

Perception as a constructive act

Modeling the environment

Apprehension of meaning



Summary

Physics of optical information

Biology of the visual system

Psychology of visual perception: perception as a constructive act that involves inference

Theoretical Approaches

Popper (1980): A theory should be ...

1. parsimonious (simple)
2. explanatory (hypotheses generating)
3. falsifiable (testable)
4.

Levels of Explanation

- physical, chemical
- biological, physiological
- behavioural, psychological
- philosophical, metaphysical

Young-Helmholtz theory of colour vision

1. Any perceived colour can be matched by a suitable mixture of 3 primary colours
2. The combined activity of receptors underlies colour sensitivity
3. But intensity of coloured lights can change their appearance
4.

- physical: wavelength of primary colours
- physiological: cone receptors
- psychological: hue and saturation
- philosophical: qualia of colour perception

- Extromission/Intromission .....430 BC
- Structuralism 1690
- Gestalt Psychology 1923
- Ecological Optics 1950
- Constructivism 1856
- Computational Approach 1957
- Neurophysiological Approach 1829

Structuralism

"Perception is based on sensory atoms"

British Empiricists (Locke, 1690; Berkeley, 1709; Hume, 1777)

German Psychophysicists (Weber, 1832; Fechner, 1860)

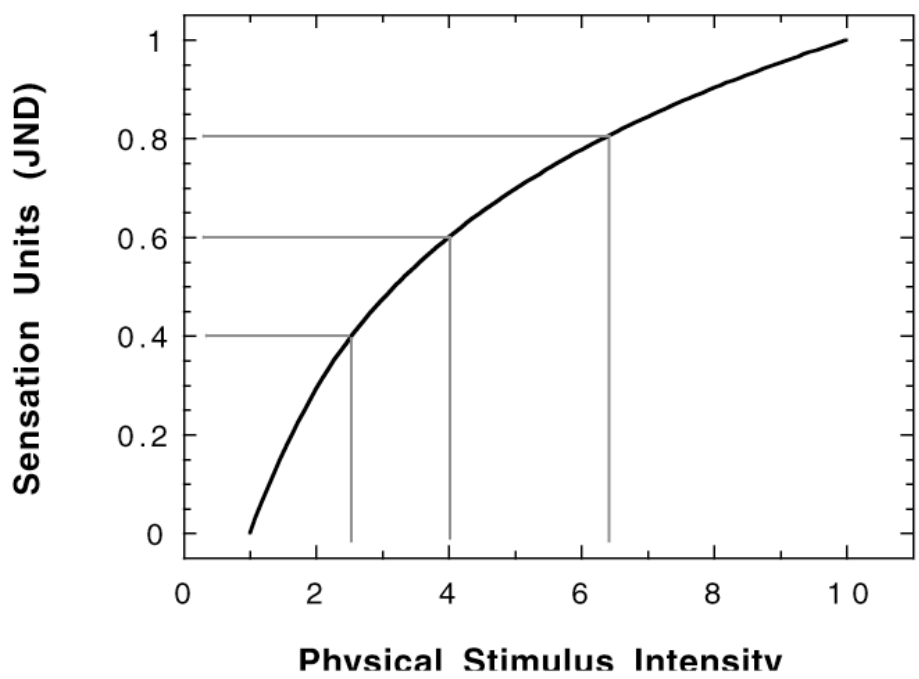
Wundt, Titchener

Examples: Association, psychophysical function

Criticism: (–) atomism, trained introspection, (+) empiricism, psychophysical methods

Psychophysics

Goal: To establish a relationship between physical intensity x and psychological sensation y.



Weber (1834)
Discrimination JND
$\Delta I/I$ = constant

Fechner (1860)
Logarithmic function
$y = a \cdot \log(x) + b$

Gestalt Psychology

"Perception follows a minimum principle"

Gestaltists (Wertheimer, 1923; Koffka, 1935; Köhler, 1947)

Reaction against Structuralsim: Complex perceptions cannot be decomposed into elementary sensations:

"The whole differs from the sum of its parts"

Examples: Figure-ground reversal, phi-movement

Criticism: (–) descriptive, 2-D, nativism, (±) holism
(+) applied principles

Ecological Optics

"Perception is active and direct"

Ecological Optics (Gibson, 1950)

Perception is not matched to past experience, but instead the perceptual system has evolved to resonate to certain invariant information

Examples: Texture gradient, ambient optic array, optic flow, affordances, reachability, graspability

Criticism: (–) direct, nativism, (±) holism, (+) invariances, environment, applied, motion

THEORY	Nativism vs Empiricism	Atomism vs Holism	Organism vs Environment	Principal Analogy	Method
Structuralism	Empiricism	Atomism	Organism	Chemistry	Trained Introspection
Gestaltism	Nativism	Holism	Organism	Physical Field Theory	Naive Introspection
Ecological Optics	Nativism	Holism	Environment	Mechanical Resonance	Stimulus Analysis

Constructivism

"Perception is a constructive act"

Unconscious inference and likelihood principle (Helmholtz, 1856)

American Transactional Functionalists (Ames, 1949; Ittelson, 1952)

"Perception as hypothesis testing" (Gregory, 1974)
"Perception as Bayesian inference" (Rock, 1983)

Examples: Necker cube, Mueller-Lyer illusion, Ames' Room, hollow mask illusion

Criticism: (±) hypothesis, (+) top-down

Neurophysiological Approach

"Perception is based on neural activity"

Specificity theory (Müller, 1829); cell assemblies (Hebb 1949)

Visual cortex (Adrian, 1928; Hubel & Wiesel, 1962; Campbell & Robson, 1968)

New methods: Single cell recording, CT, PET, EEG, MEG, TMS, fMRI, ...

Criticism: (±) Specificity vs pattern theory,
(+) modularity, methods

Computational Approach

"Perception is processing in different modules"

Edge (Horn, 1971), motion (Reichardt, 1957) and disparity detectors (Poggio & Fischer, 1977)

Computational vision (Marr, 1982). Stages: image, primal sketch, 2.5-D sketch, 3-D

Examples: Motion and edge detection, disparity detection, object recognition

Criticism: (-) no integration (±) bottom-up, modularity, (+) implementation

Summary

a. Early theories of visual perception date back to philosophers in ancient Greek.

b. A good theory should be simple, explanatory and falsifiable.

c. There are different levels of explanation.

d. There is no single approach to visual perception.

Spatial Vision

Ganglion Cells (Kuffler, 1953)
extracellular recording of APs, centre-surround organisation of receptive fields, excitatory/ inhibitory regions, on-centre/off-centre cells
magnocellular ganglion cells - rods and cones
parvocellular ganglion cells - cones only

Bipolar cells (Werblin, 1969)
intracellular recording of graded potential
direct excitatory/indirect inhibitory input

Lateral Geniculate Nucleus (LGN)

retinotopic mapping, 3D laminar structure
magno- and parvocellular layers

	parvo	magno
color sensitivity	high	low
contrast sensitivity	low	high
spatial resolution	high	low
temporal resolution	slow	fast
[receptive field size	small	large]

Striate Cortex V1 (Hubel & Wiesel, 1959)

simpe cells: orientation selective, linear, phase sensitive (”edge detectors”)

complex cells: orientation selective, non-linear, phase insensitive (”motion detectors”)

hypercomplex cells: non-linear, end-inhibition (”aperture detectors”)

Functional Architecture: retinotopic map, cortical magnification, ocular dominance slabs, orientation columns, hypercolumns

Spatial Frequency Theory

multiple channels tuned to different spatial frequencies and orientations

contrast sensitivity function (CSF)

selective adaptation to different channels (Campbell & Robson, 1968; Blakemore & Campbell, 1969)

"Early visual system performs a patchwise Fourier analysis" (Robson, 1983)

Gabor patch provides optimal trade-off between spatial location and spatial frequency

Summary

Receptive field properties of retinal, LGN and V1 cells

Functional aspects of image processing: contrast, colour, motion, depth, ...

Spatial frequency theory:
SF channels, CSF, adaptation, patchwise Fourier analysis

Computational Approach

Edge (Horn, 1971), motion (Reichardt, 1957) and disparity detectors (Poggio & Fischer, 1977)

Computational vision (Marr, 1982). Stages: image, primal sketch, 2.5-D sketch, 3-D

Spatial frequency analysis (Malik & Perona, 1990)

Structure from shading (Lehky & Sejnowski, 1988)

Computational neuroscience (Rolls & Deco, 2002)