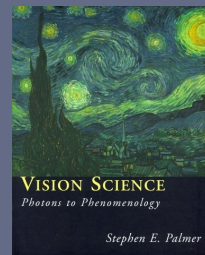


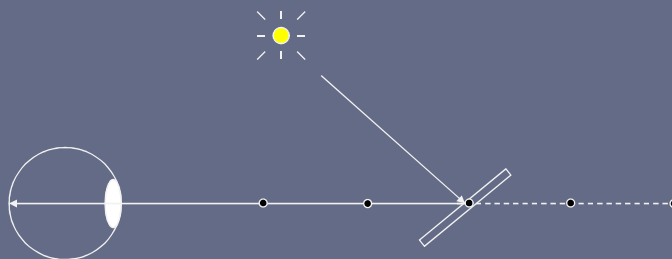
# Perception of Space

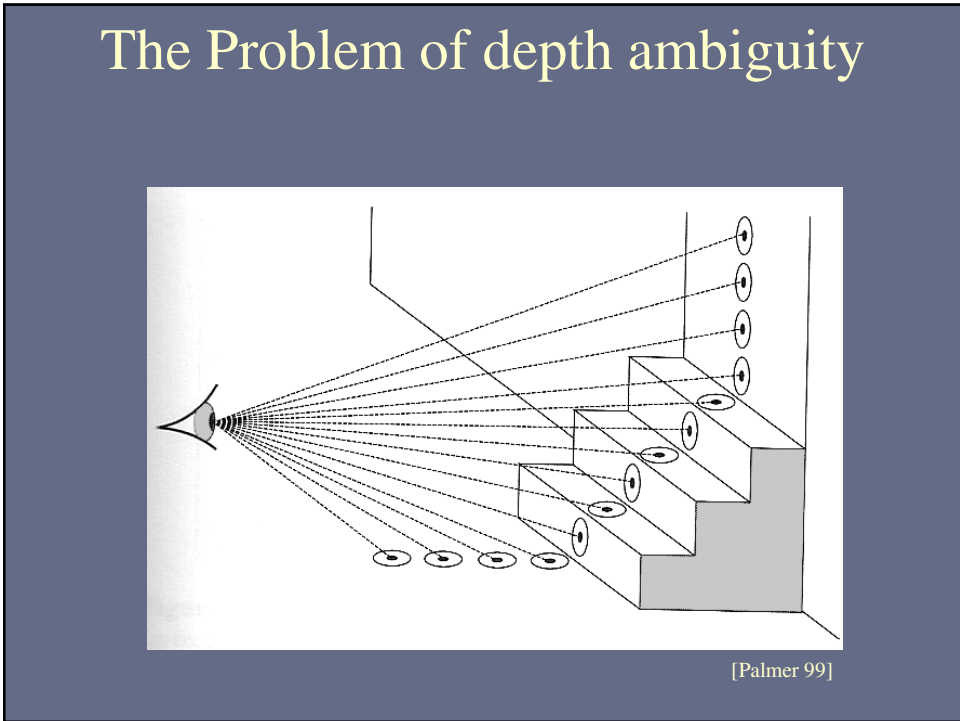
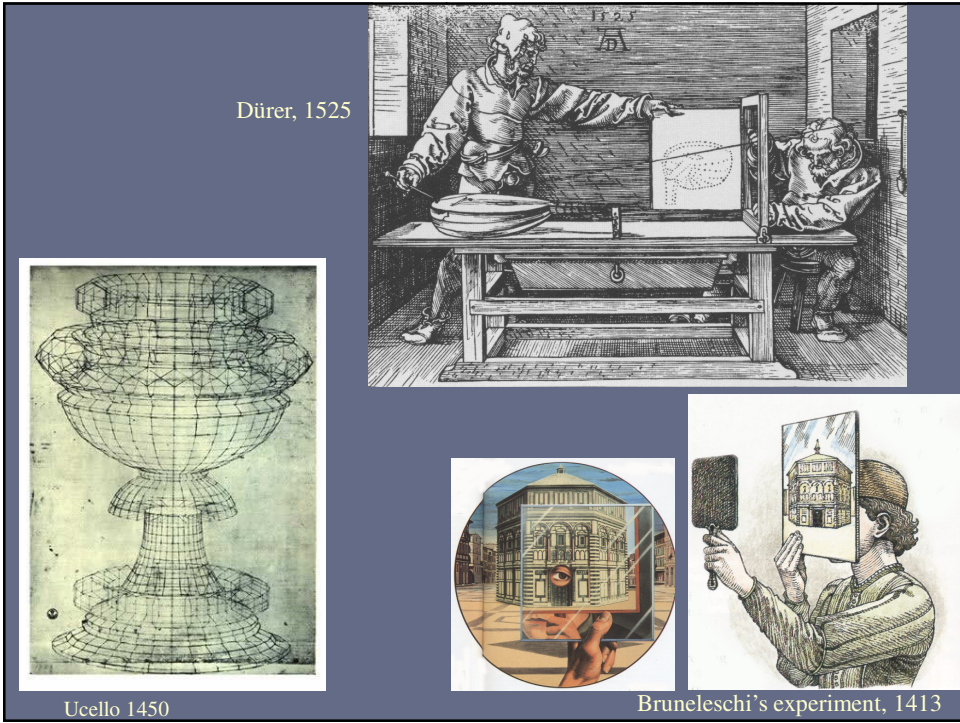
Source:



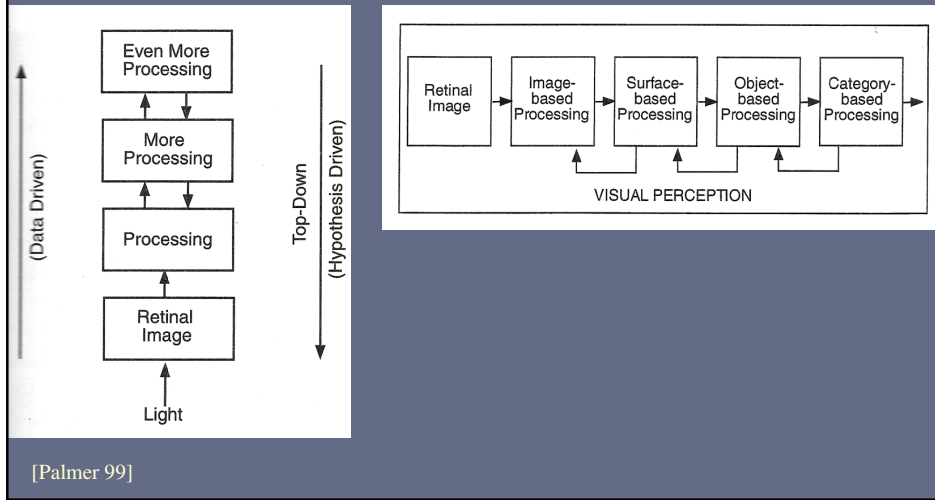
## The Problem of depth ambiguity

Depth perception from 2-d images is inherently ambiguous

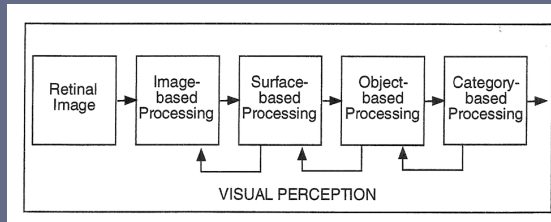
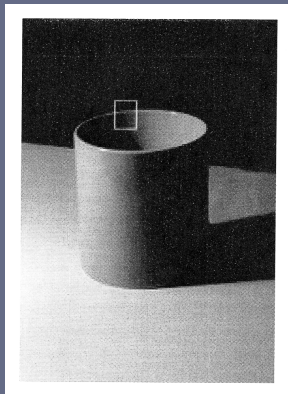




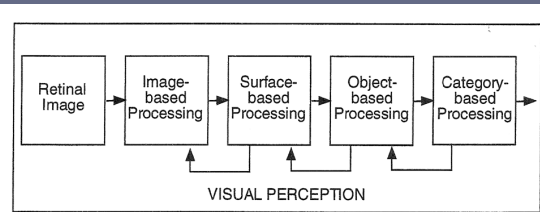
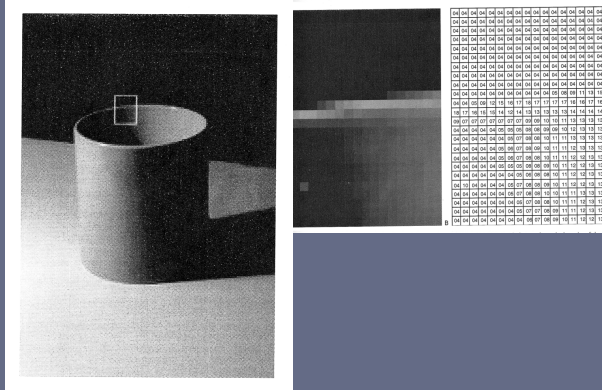
# Four Stages of Visual Processing



# Image of a simple scene

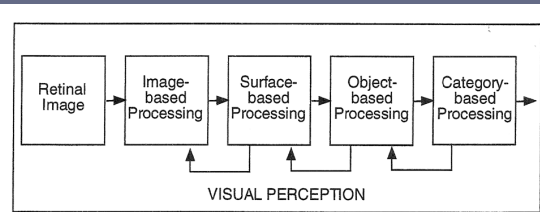
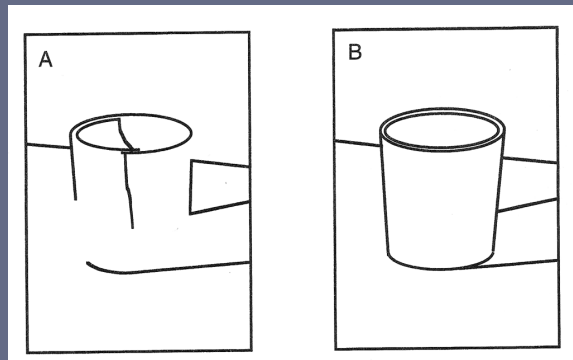


# Image of a simple scene



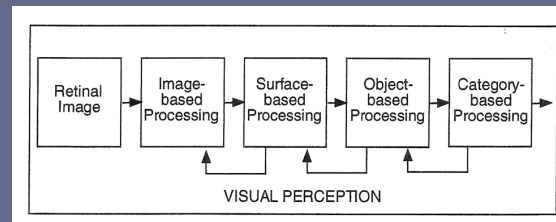
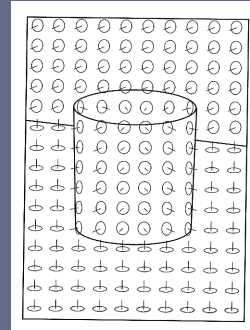
[Palmer 99]

# Edge Detection



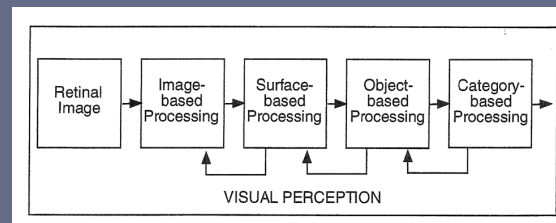
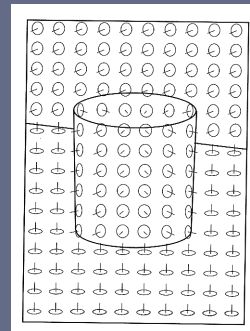
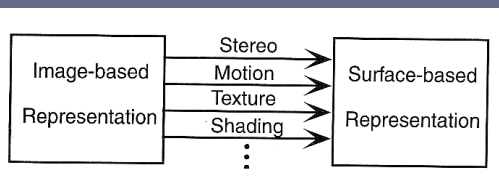
[Palmer 99]

# Surface-Based Representation



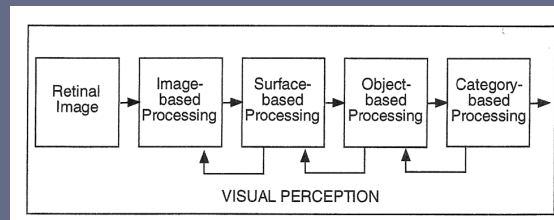
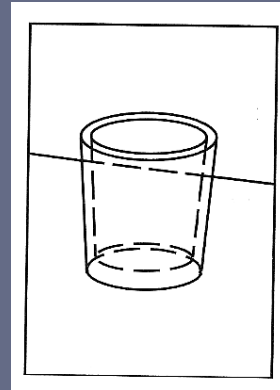
[Palmer 99]

# Surface-Based Representation



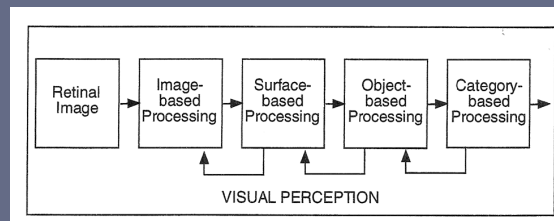
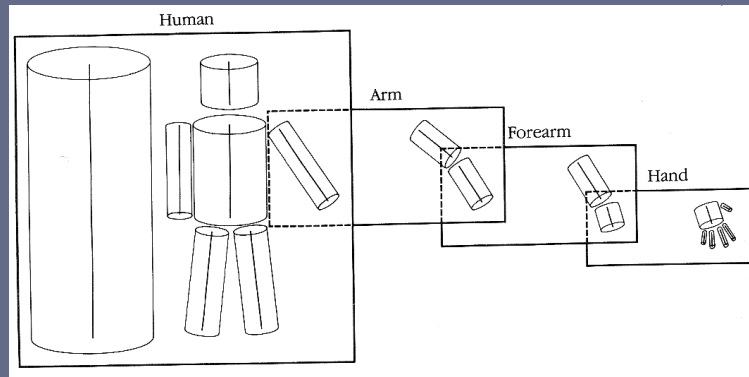
[Palmer 99]

# Object-Based Representation

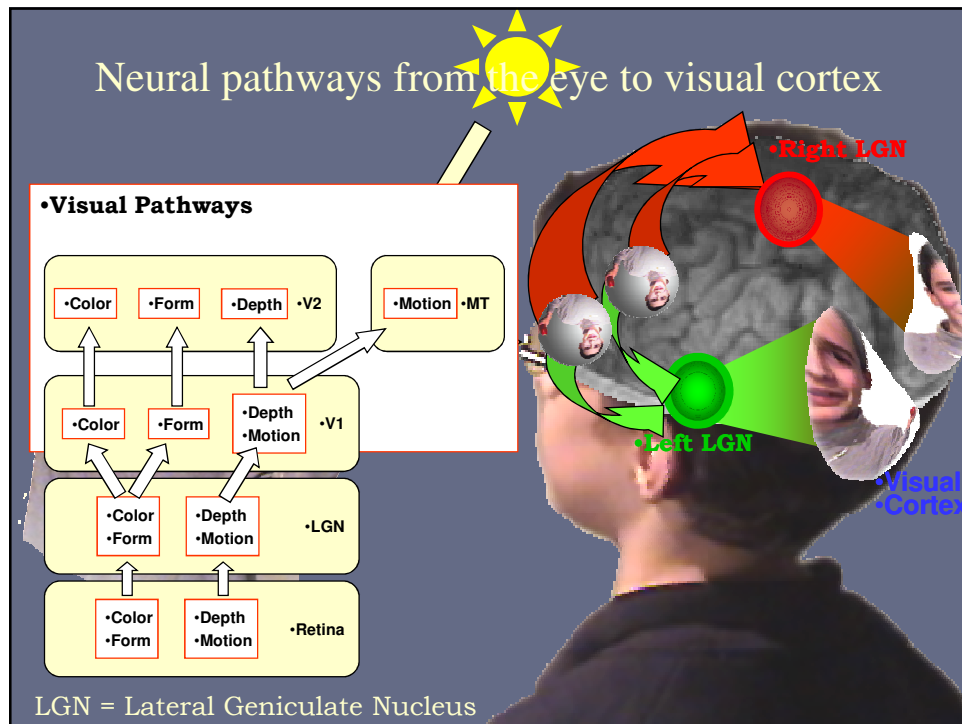


[Palmer 99]

# Category-Based Representation



[Palmer 99]



## Retinal Cells

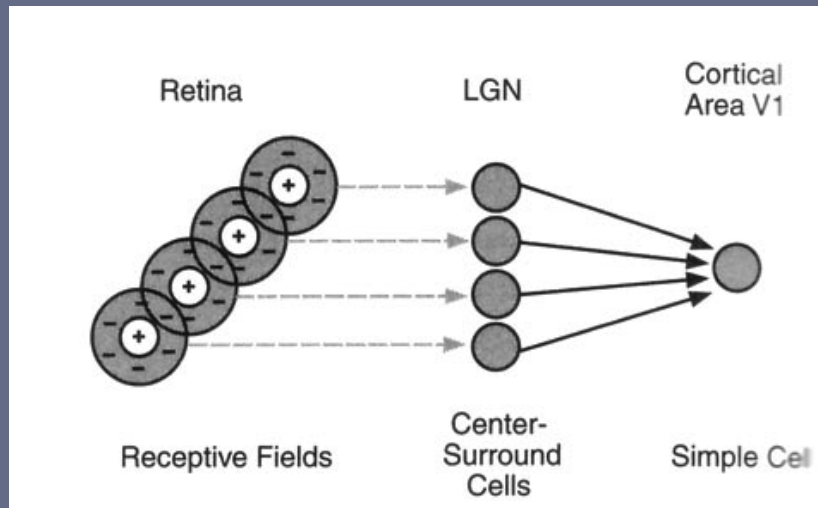
- Bipolar Cells
  - Graded potentials
  - Intracellular recording
- Ganglion Cells
  - 2D sheet parallel to retina
  - Discrete discharging
  - Extracellular recording
  - On-center cells
  - Off-center cells

Esquema de la estructura de la retina de los mamíferos.  
 1. Capa de los conos y bastones. 2. Capa limitante externa. 3. Capa de los granos externos. 4. Capa plexiforme externa. 5. Capa de los granos internos. 6. Capa plexiforme interna. 7. Capa de las células amacrianas. 8. Capa de las fibras del nervio óptico. 9. Capa limitante interna.

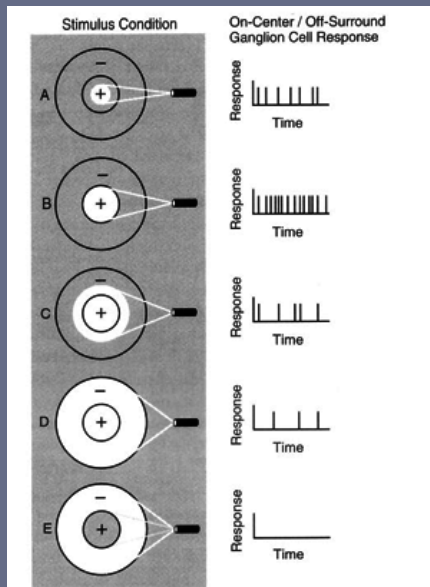
A. Células pigmentarias. B. Células epiteliales.  
 a. bastones. b. conos. c. rodos de los bastones. d. túbulos de los conos. e. célula horizontal grande. f. bipolar relacionada con los conos. g. bipolar relacionada con los bastones. h. célula amacriana. i. célula ganglionar gigante. j. células ganglionares pequeñas.



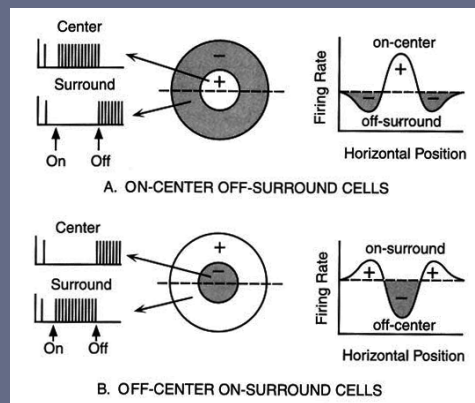
Possible neural wiring of cortical simple cells from LGN cells



Responses of on-center, off-surround ganglion cells



Receptive field structure of ganglion cells



[Palmer 99]



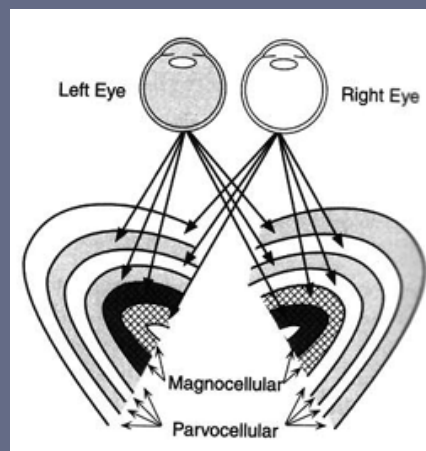
## Lateral Geniculate Nucleus (LGN)

- Located in the thalamus
- 3D structure
- Receives input from both eyes
- Each cell is monocular
- Divided into 6 layers of 2D sheets of neurons
- Lower 2 layers : Magnocellular “Large”
  - Large cells
  - Sensitive to contrast
  - Not very sensitive to color
  - Large receptive field
  - Short response to retinal stimulation

### - Upper 4 layers : Parvocellular “Small”

- Insensitive to contrast
- Highly selective to color
- Small receptive field
- More sustained response

Diagram of the mapping from eyes to layers of the LGN



Retinotopic mapping or topographic mapping :

Nearby regions on the retina project to adjacent regions of the LGN

[Palmer 99]

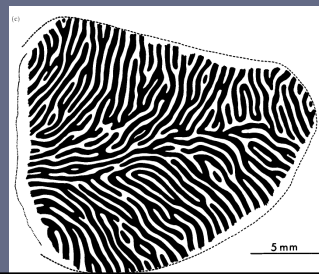
## Striate Cortex

- Primary cortical region for vision
- Hubel and Wiesel (1959)
  - Simple cells
  - Complex cells
  - Hypercomplex cells



Hubel

Wiesel

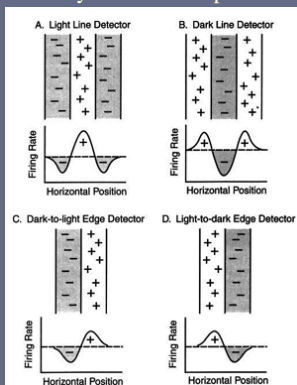


## Simple cells

“Their responses to complex stimuli can be predicted from their responses to individual spots of light”

- Edges detectors (light-to-dark \ dark-to-light)
- Line detectors (bright or dark lines)

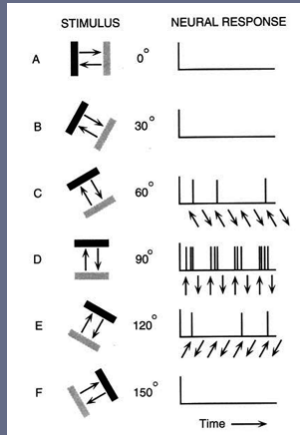
Receptive fields and response profile of vertically oriented simple cells in V1



[Palmer 99]

### Complex cells (~ 75% of the cells in striate cortex)

- Nonlinearity
- Motion sensitivity
- Position insensitivity
- Spatial extension
- Receive input from multiple simple cells or from LGN

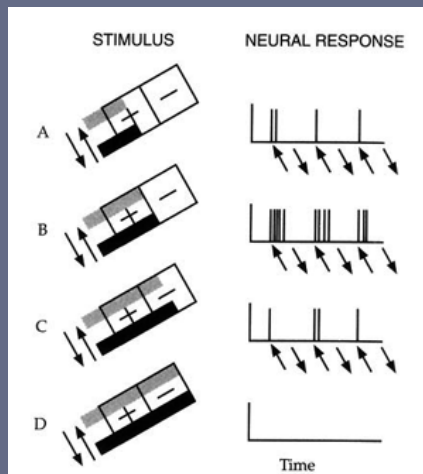


Response of a complex cell in visual cortex of a cat

[Palmer 99]

### Hypercomplex cells “end-stopped cells”

- Extending a line or edge beyond a certain length causes them to fire less vigorously than they do for a shorter line or edge



Response of a hypercomplex (end-stopped) cell in visual cortex of a cat to moving bars of different lengths

[Palmer 99]

## Striate Architecture

We know that :

- Cells in visual cortex respond selectively to a limited set of spatial features :
  - Orientation
  - Position
  - Size
  - Color
  - Motion

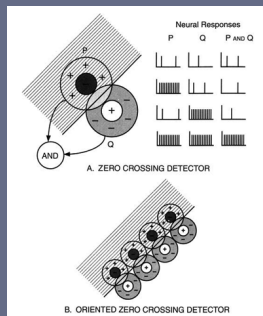
- Each hemisphere → Retinotopic map of half the visual field
- Retinal topography is preserved
- Distortion occurs due to cortical magnification of central areas relative to peripheral ones
  - “small portion of the retina (fovea) occupies a disproportionately large area of cortex”

## Computational Approach

Edge detection : luminance edge

- change in the reflectance of the surface (e.g. change of material)
- change in the amount of light falling on it (e.g. shadow)
- change in the surface orientation relative to the light source

Marr & Hildreth Zero-Crossing Algorithm



A neural model of the Marr-Hildreth zero-crossing algorithm

[Palmer 99]

-Vision is a heuristic process in which inferences are made about the most likely environmental condition that could have produced a given image

-Most of the time in everyday circumstances we are right

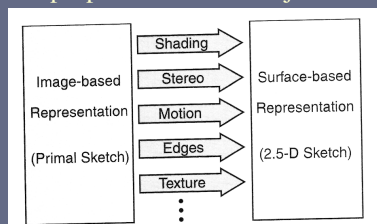
-We perceive the spatial arrangement of surfaces by determining

-Depth

-Surface orientation

### Marr's 2.5-D Sketch

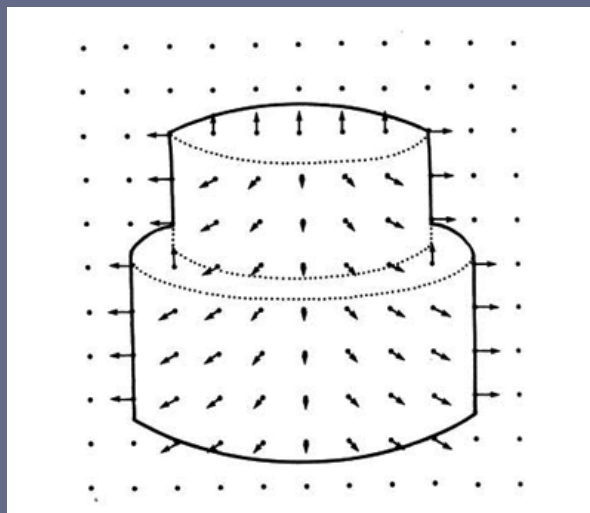
- Between the 2D properties of an image-based representation and the 3D properties of a true object-based representation



Flowchart of depth-processing modules

[Palmer 99]

### Marr's 2.5-D Sketch



[Palmer 99]

## Sources of Depth Information

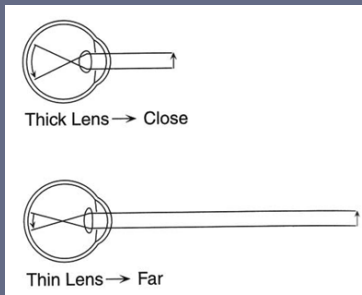
INFORMATION SOURCE	Ocular/ Optical	Binocular/ Monocular	Static/ Dynamic	Relative/ Absolute	Qualitative/ Quantitative
Accommodation	ocular	monocular	static	absolute	quantitative
Convergence	ocular	binocular	static	absolute	quantitative
Binocular Disparity	optical	binocular	static	relative	quantitative
Motion Parallax	optical	monocular	dynamic	relative	quantitative
Texture Accretion/Deletion	optical	monocular	dyanmic	relative	qualitative
Convergence of Parallels	optical	monocular	static	relative	quantitative
Position relative to Horizon	optical	monocular	static	relative	quantitative
Relative Size	optical	monocular	static	relative	quantitative
Familiar Size	optical	monocular	static	absolute	quantitative
Texture Gradients	optical	monocular	static	relative	quantitative
Edge Interpretation	optical	monocular	static	relative	qualitative
Shading and Shadows	optical	monocular	static	relative	qualitative
Aerial Perspective	optical	monocular	static	relative	qualitative

[Palmer 99]

### Accommodation

Accommodation	ocular	monocular	static	absolute	quantitative
---------------	--------	-----------	--------	----------	--------------

- Ciliary muscles in the eye control the optical focus of the lens by temporarily changing its shape
- Information about the tension of the muscle = information about the distance of the focused object
- Weak source of depth perception
- Provide accurate depth information for objects at short range (beyond 6-8 feet accommodation provides little or no depth information )



Depth information from lens accommodation

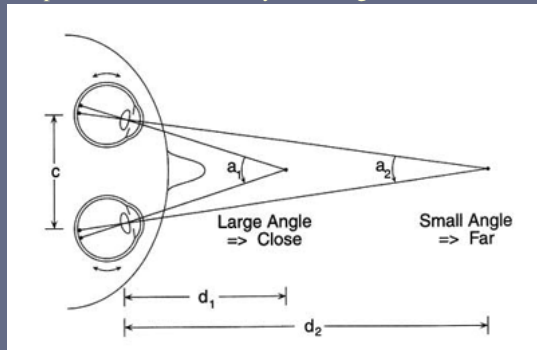
[Palmer 99]

## Convergence

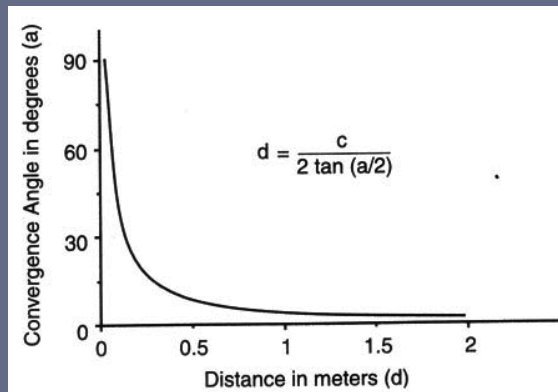
Convergence	ocular	binocular	static	absolute	quantitative
-------------	--------	-----------	--------	----------	--------------

- The extent to which the two eyes are turned inward to fixate an object
- Used by the visual system to determine distance to the fixated point only up to a distance of a few meters

Depth information from eye convergence



Convergence as a function of distance





## Binocular Disparity

Binocular Disparity    optical    binocular    static    relative    quantitative

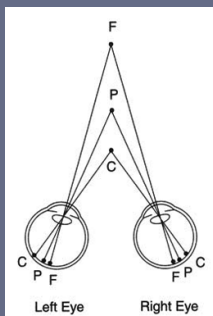
-Stereopsis : The process of perceiving the relative distance to objects based on the binocular disparity

-Binocular disparity : Lateral displacement in the two retinal images

-Finger experiment

-Crossed and uncrossed binocular disparity :

When a point P is fixated, closer points are displaced outwardly in crossed disparity, whereas farther points are displaced inwardly in uncrossed disparity

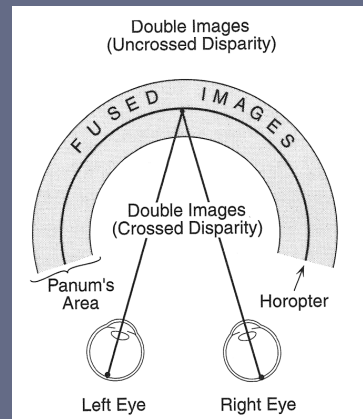
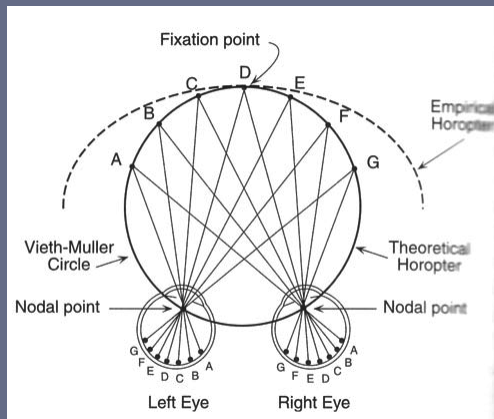


Crossed versus uncrossed binocular disparity

[Palmer 99]

**Horopter** : The set of environmental points that stimulate corresponding points on the two retinae

The horopter in the horizontal plane



The theoretical versus the empirical horopter in the vertical plane

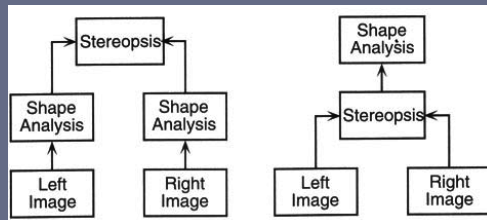
[Palmer 99]

-Effectiveness of stereoscopic vision is limited to a range of less than about 30 m

### Stereograms

-Each eye is presented with an image that differ only by the appropriate lateral displacement of the same object

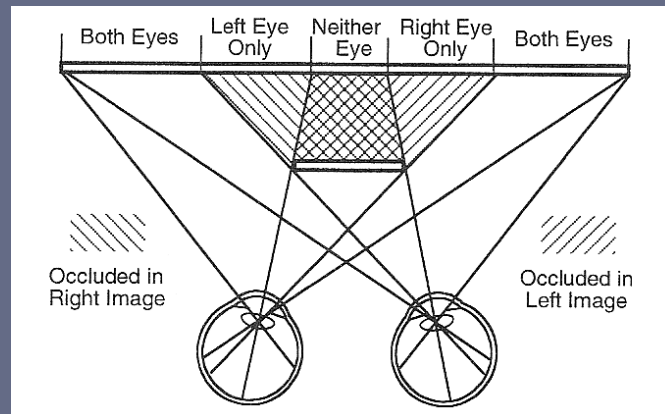
Shape-first or Stereopsis first ?



Flowchart for two theories of stereopsis

[Palmer 99]

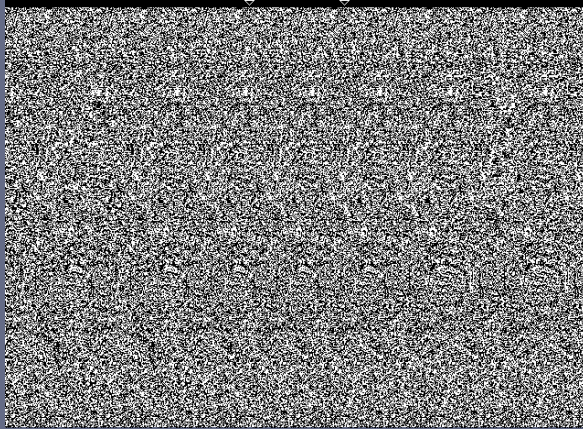
### Da Vinci Stereopsis



-Correspondence problem : The visual system starts with two images and has to discover which features in the left image correspond to which features in the right one

- Random dot stereograms prove stereopsis-first

Random dot stereogram of a face



[ Gareth and Peter's  
SIRDS pages ]

### Physiological Mechanisms

Theory : Two separate physiological systems are involved in stereoscopic depth perception

V1 : Highly sensitive to small or zero disparities (binocular fusion within Panum's area)

V2 : Sensitive to large disparities in both crossed and uncrossed direction (depth perception in front and behind the horopter)

## 3D Displays

- Stereoscopic (aided viewing)
- Autostereoscopic (free viewing)

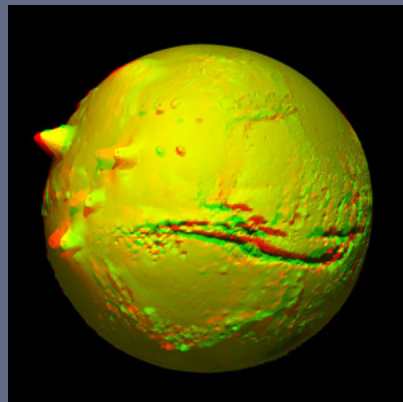


The Viewmaster

## Stereoscopic Techniques

- Color-multiplexed displays (anaglyph)

- The left and right-eye images are filtered with near-complementary colors (red-green, red-cyan, green-magenta)
- Color-filter glasses are used for separation
- Limited color rendition (binocular color mixture)



Example of an anaglyph

[ Paul Bourke ]

-Polarization-multiplexed displays

- Linear or circular polarization
- Orientation has to be good

-Time-multiplexed displays

- The human visual system is capable of merging the constituents of a stereo pair across a time-lag of up to 50ms
- Uses LCS (Liquid Crystal Shutter) glasses
- Impairing cross-talk may result from the persistence of CRT phosphors



[ frosbit.com]

Autostereoscopic Techniques

-Hologvideo : Electronic Holography

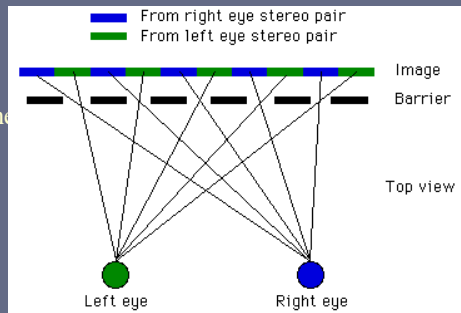
MIT Media Lab Spatial Imaging Group

<http://web.media.mit.edu/~lucenteholo/hologvideo.html>

- Uses lasers \ fringe patterns
- Currently, the scope of this approach is limited to very small and coarse monochromatic holograms
- The pixel rate for a monochrome display with a diameter of 15cm, a depth of 20cm, and a viewing zone of 30° amounts to 2 Gigapixel / sec (at 30 Hz frame rate)

-Parallax methods

- Lenticular she

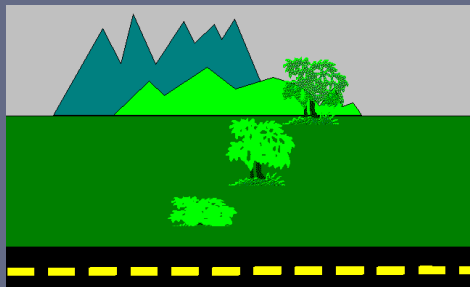


[ Paul Bourke]

## Motion Parallax

Motion Parallax      optical      monocular      dynamic      relative      quantitative

- The images of points at different distances from the observer move at different retinal velocities as the observer's station point changes
- Finger experiment
- Highly used in 2D "scrolling" video games (Game Boy Advance)
- Controlled experiments have shown that motion parallax is sufficient for depth perception when no other sources of depth information are present
- Unlike binocular disparity, motion parallax can provide effective depth information at great distances



Example of motion parallax

[Krantz, Hannover College]

Texture Accretion/Deletion      optical      monocular      dyanmic      relative      qualitative

The appearance (accretion) and disappearance (deletion) of texture behind a moving edge



### Convergence of Parallel Lines

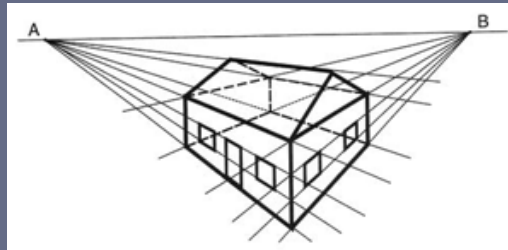
Convergence of Parallels    optical    monocular    static    **relative**    quantitative

- All parallel lines in any plane converge to the same vanishing point

#### The Pyramid of Khufu



A draftsman's drawing in two-point perspective projection



[Palmer 99]

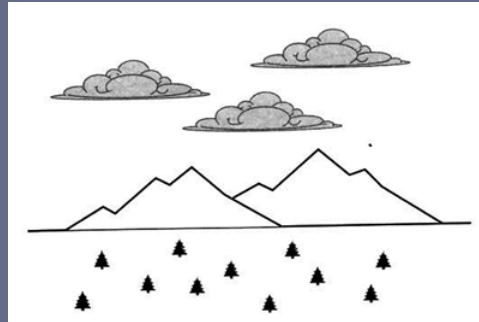
### •Position Relative to the Horizon of a Surface

Position relative to Horizon    optical    monocular    static    **relative**    quantitative

#### The long winding road



Example of position relative to the horizon



[Palmer 99]



•Relative Size

Relative Size      optical      monocular      static      relative      quantitative

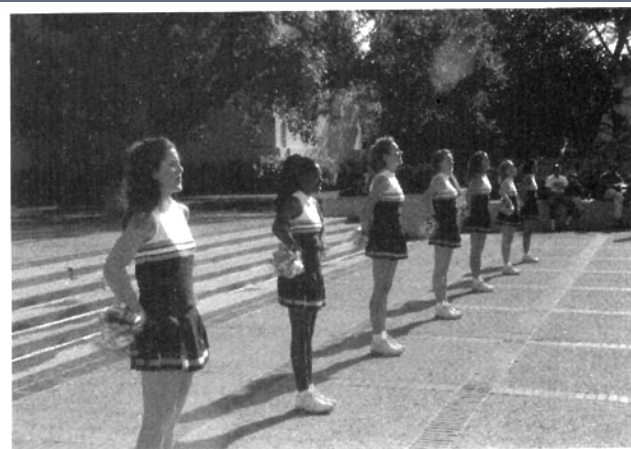
An object's smaller size on your retina when it is farther away from you is called **relative size**



Sculls  
by Gustave  
Caillebotte

- Heuristic used : Two otherwise identical objects have the same objective size so that their relative distances can then be determined from relative image sizes

Example of relative size



[Palmer 99]

### Familiar Size

Familiar Size                      optical    monocular    static    absolute    quantitative

- Most objects tend to have a characteristic size or range of sizes with which experienced perceivers are familiar



### Texture Gradients

Texture Gradients                      optical    monocular    static    relative    quantitative

-Systematic changes in the size and shape of small texture elements that occur on many environmental surfaces

-Provide info about :

- Depth
- Orientation
- Curvature

Heuristic : Objects forming the texture are similar in size

Example of natural texture gradients



[Palmer 99]

Paris Street : A rainy day by Gustave Caillebotte



### Edge Interpretation (contour)

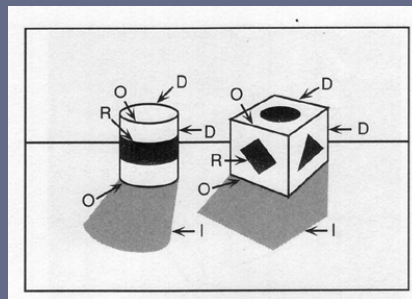
Edge Interpretation	optical	monocular	static	relative	qualitative
---------------------	---------	-----------	--------	----------	-------------

-Specifies only ordinal depth relations

-4 types of edge interpretation :

- 1. Orientation edges
- 2. Depth edges
- 3. Illumination edges
- 4. Reflectance edges

Four kinds of edges



[Palmer 99]

- Orientation and depth edges in objects with flat surfaces are mutually exclusive

## Shading Information

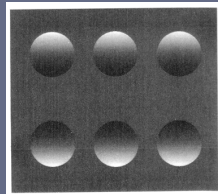
Shading and Shadows      optical    monocular    static    relative    qualitative

-Shading : Variations in the amount of light reflected from the surface as a result of variations in the orientation of the surface relative to a light source

-Experiments by Koenderink, Van Doorn, & Kappers (1992, 1996)

-The brain implicitly assumes that illumination comes from above

Direction of illumination and perceived convexity



[Palmer 99]

Top row looks like convex bumps \ Lower row like concave dents

## Aerial Perspective (Atmospheric Perspective)

Aerial Perspective      optical    monocular    static    relative    qualitative

-Refers to certain systematic differences in the contrast and color of objects that occur when they are viewed from great distances

-Contrast is reduced by the additional atmosphere through which they are viewed (additional particles scatter light)



Example of atmospheric perspective

[Palmer 99]

## Conclusion

Depth perception is a vital element of the human perception system

Depth perception mechanism uses a lot of heuristics and provide accurate results in most everyday life circumstances

It is still not well understood how the different depth cues are integrated together

We do know however from experiences that there exist some sort of hierarchy between them

Discussion