The Art of Visual Cognition

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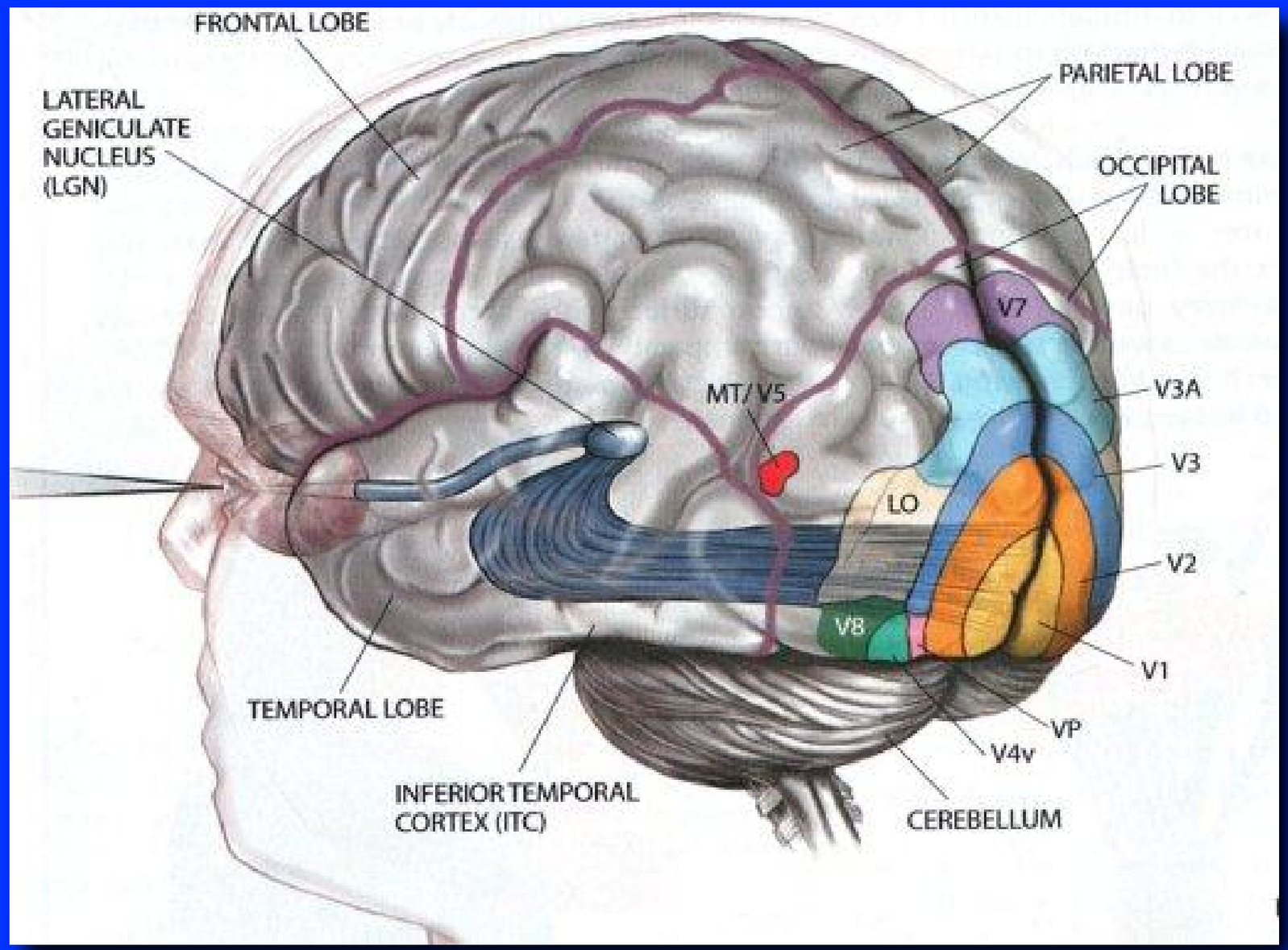
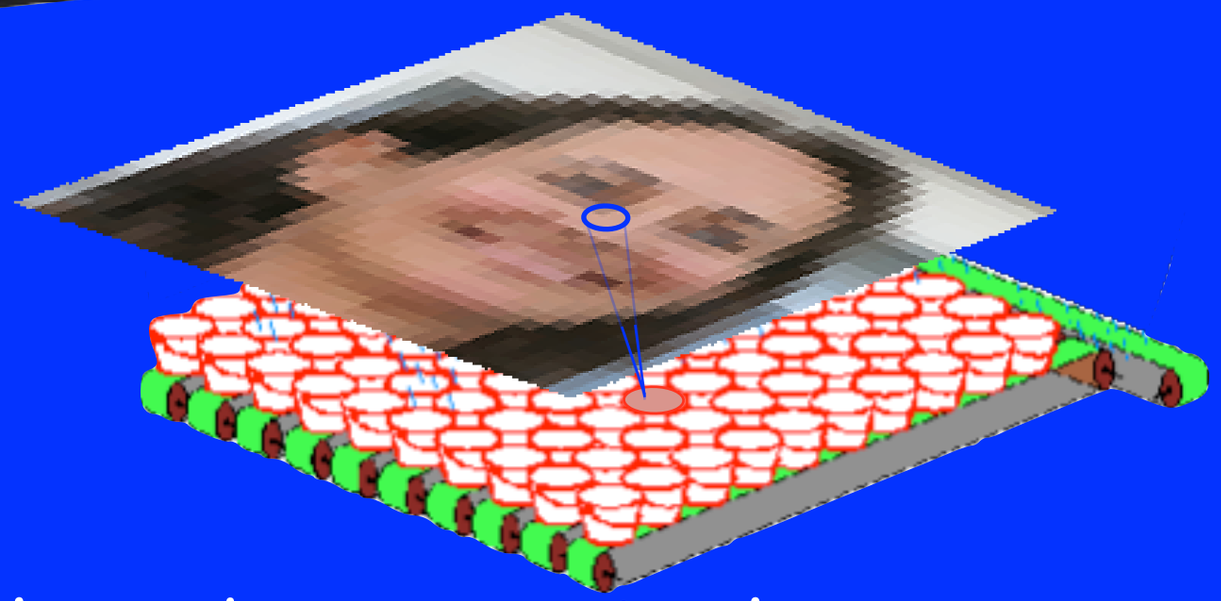
How does vision work?



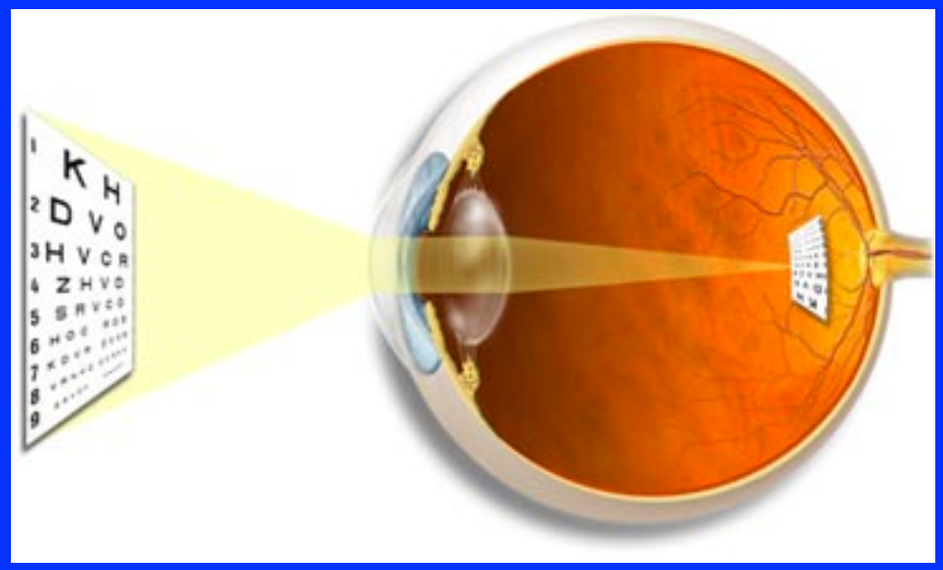
Measurement

Inference

Measurement in cameras and eyes

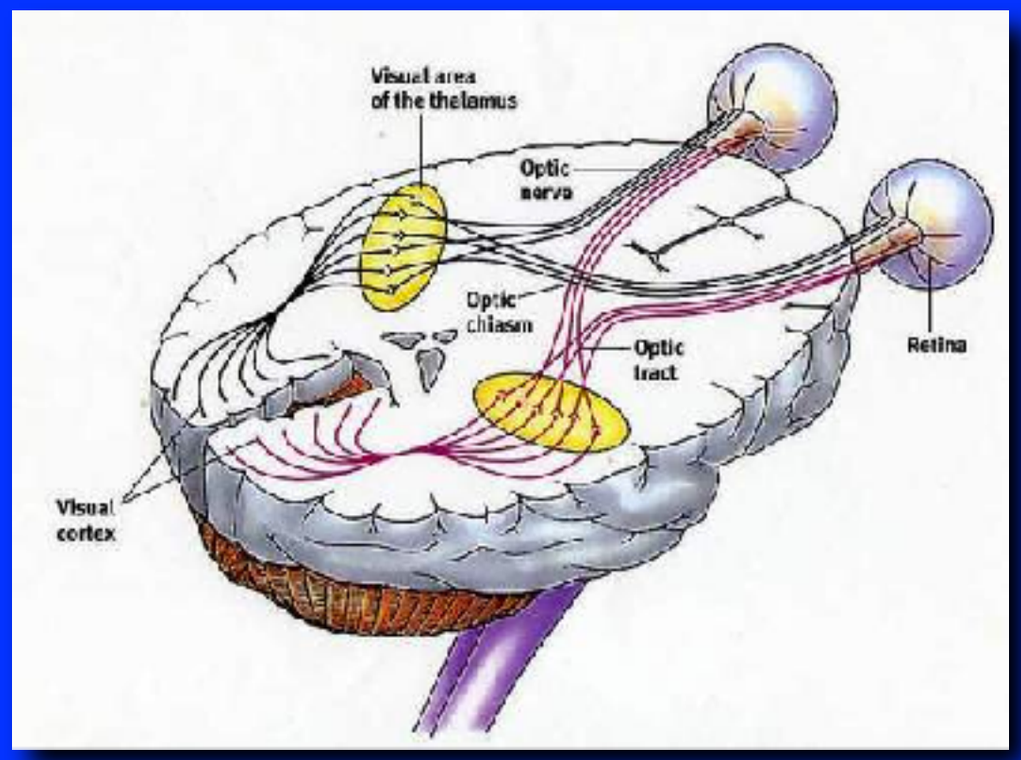


photodetectors in the camera



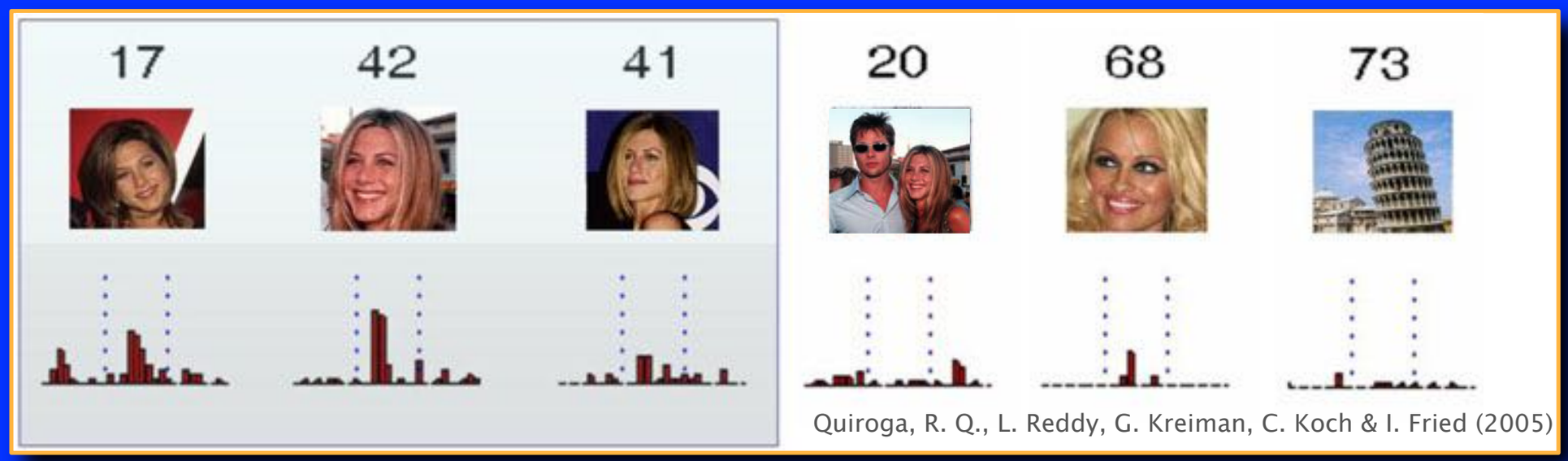
photodetectors in the retina

Each photodetector sees just one small region of the image -- its receptive field



Each cell reports on the presence of its preferred feature in its receptive field

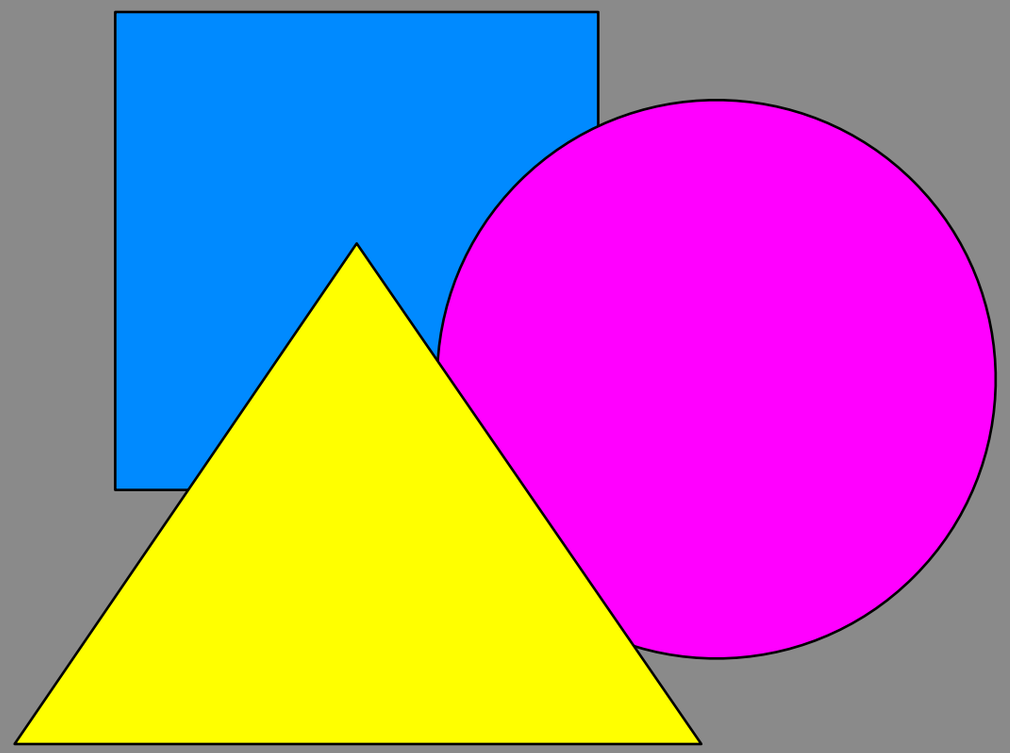
Such as color, motion, angle, even faces



Quiroga, R. Q., L. Reddy, G. Kreiman, C. Koch & I. Fried (2005)

Jennifer Aniston cell

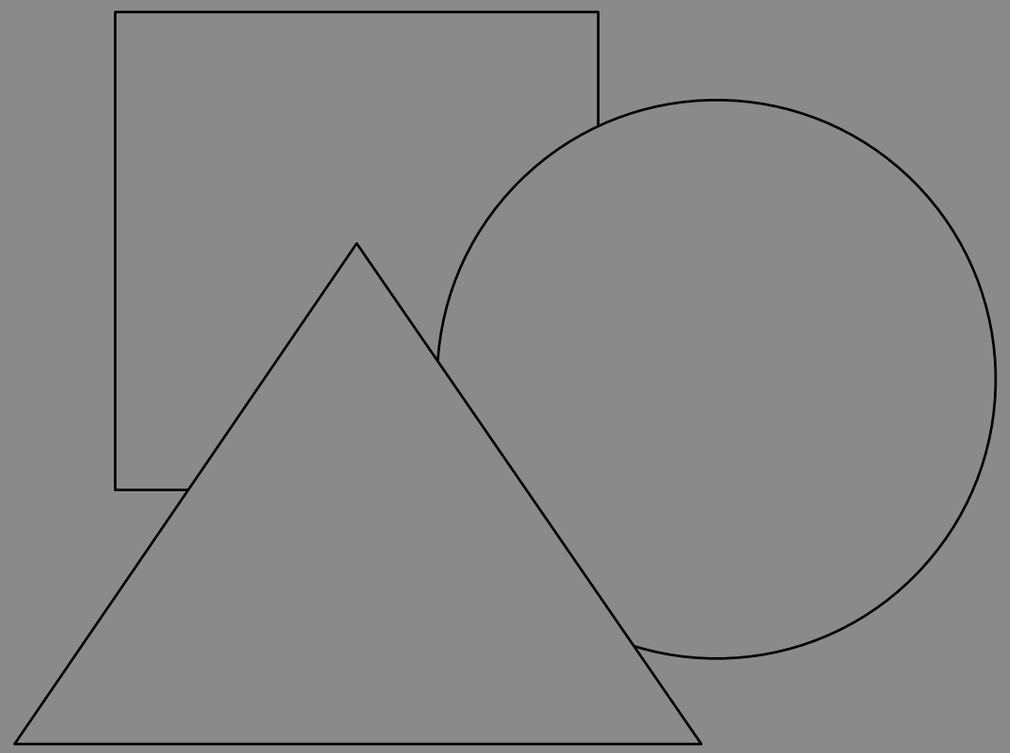
"Errors" in perception can also reveal measurement processes



Color afterimage

Opponent pairs: if one fatigued, other dominates

Errors in perception can also reveal measurement processes



Color afterimage

Opponent pairs: if one fatigued, other dominates

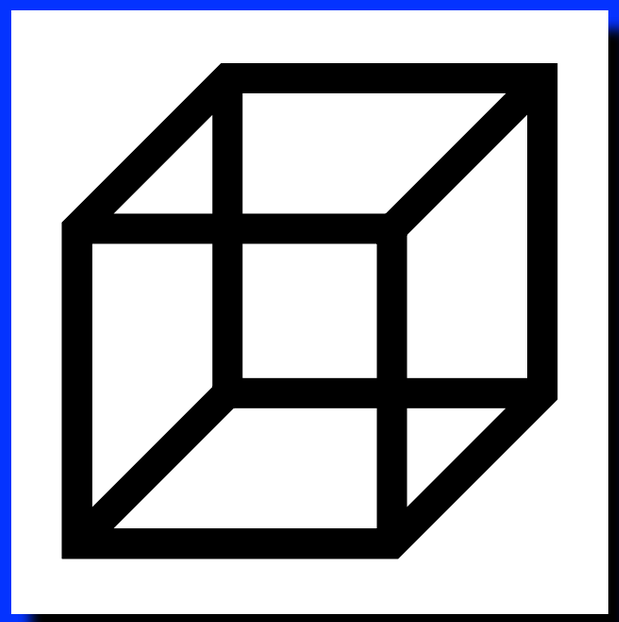
Motion Aftereffect

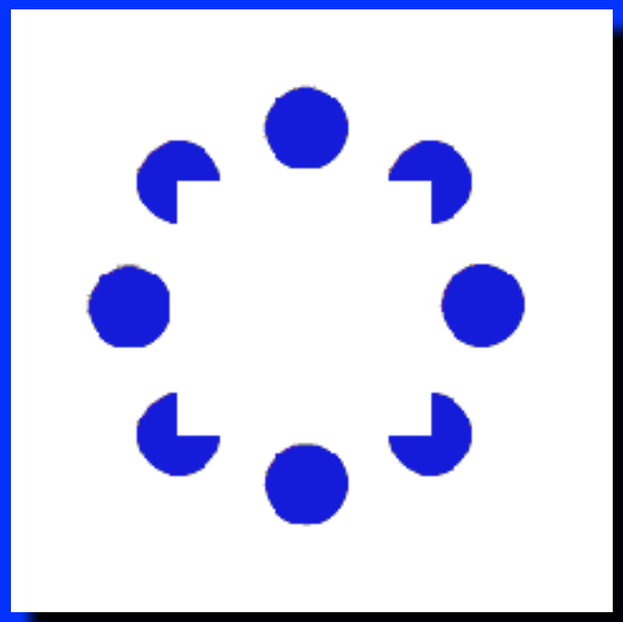
Aftereffect tells us about local motion detectors that reduce their sensitivity with long exposure

Recordings and perceptual "errors" tell us about the basic measurements of vision.

BUT, measurement is not perception,

the same image can produce multiple percepts





Need inference, plausible guesses based on rules

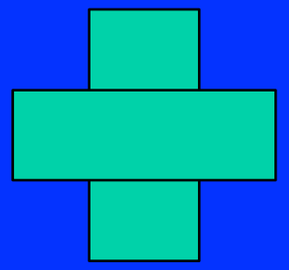
Unconscious visual cognition. Alhazen, 1024; Helmholtz, 1865

The shadow on the cloud touches the mountain
therefore the mountain touches the cloud

Inference

The visual brain constructs the best story to explain the measurements

Are there three rectangles or two?



Alternatives are compared based on rules or properties each should have

To understand inference, need to study errors, where rules go wrong

Little modeling or physiology here, need some help

Errors in art tell us about the rules of vision

Artists have to master the processes of inference in representing objects and scenes in flat paintings

40,000 years of experiments in vision

Look for errors in paintings that we don't notice.

Shortcuts that work even though they break the rules of physics ➠reveal the rules that are used.

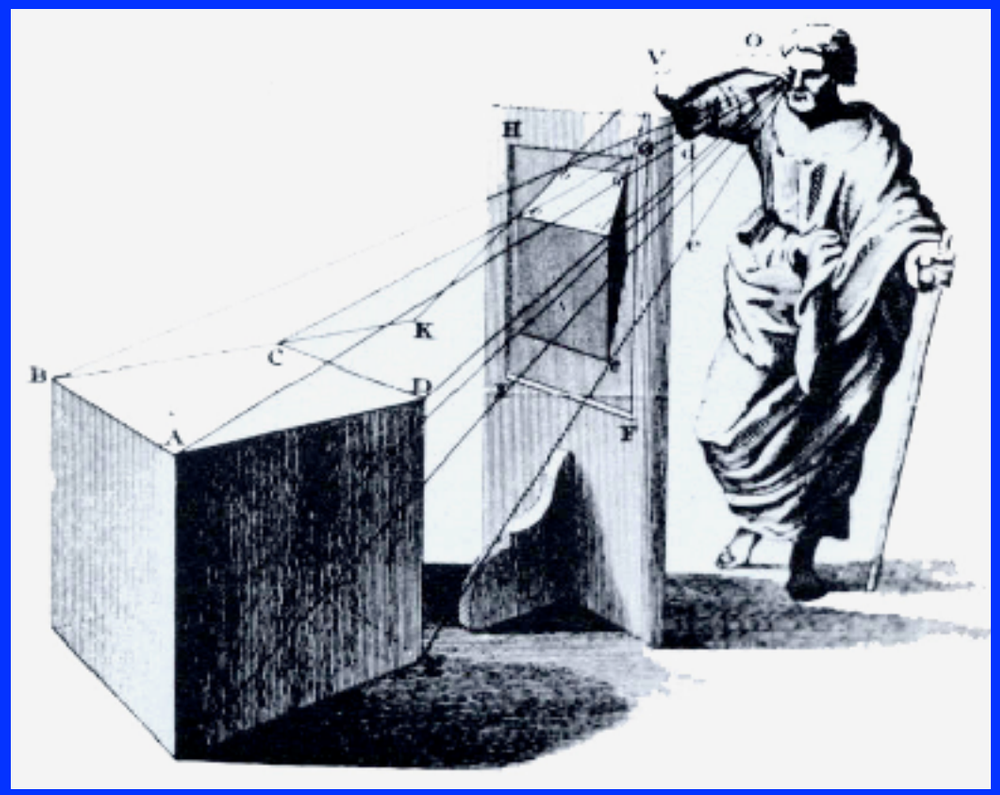
Science by looking, free neuroscience research

Cavanagh, Nature 2005

What can art tell us about the brain?

Paintings copy what we would see for the real object (Gibson)

If so, they tell us nothing that we could not learn from real scenes or photographs



The visual cone. Taylor 1715

True in some cases: perspective

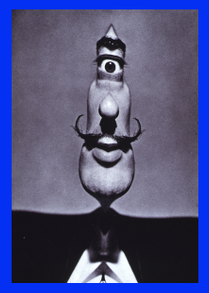
➠ no error, no insight

But not in others: line drawings

➠ not realistic but they work. Why?

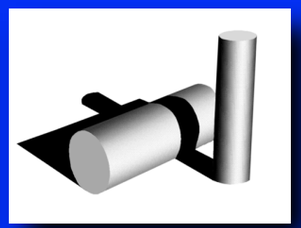
Art as 3D mimicry

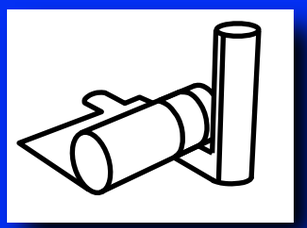
#1 2D can look 3D

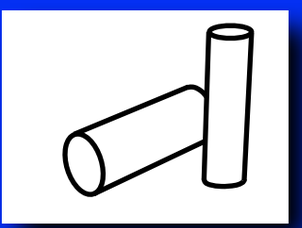


Cavanagh, von Grünau, & Zimmerman, *IEEE* 2004

#2 Lines work







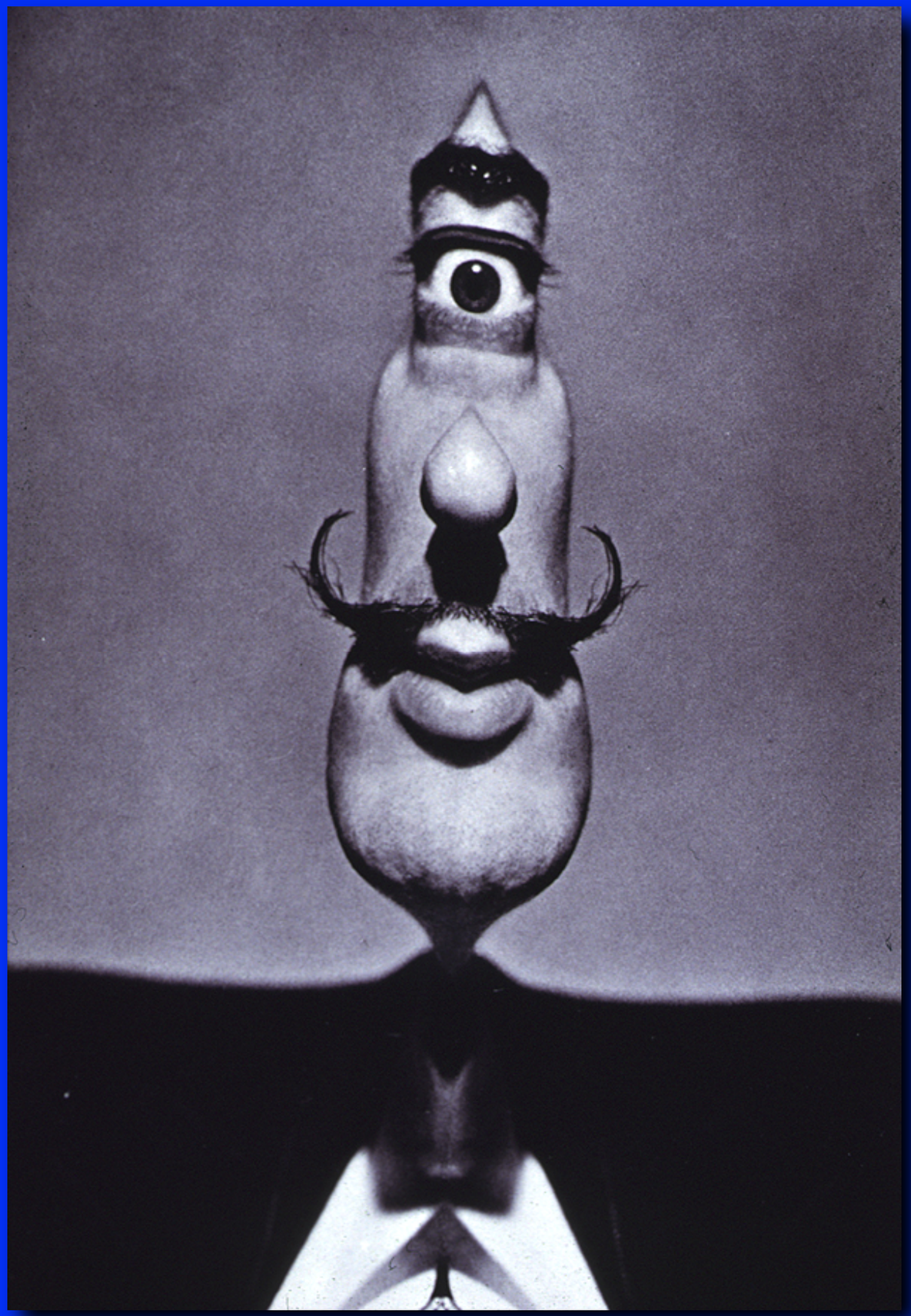
Cavanagh, & Kennedy, *Science* 2000

#3 Light, shadows and reflection

Cavanagh, *Nature* 2005

#4 Sparse is OK

Cavanagh, *Nature* 2005



Salvadore Dali

#1 2D can look 3D

Paintings are flat

Can be viewed from all angles

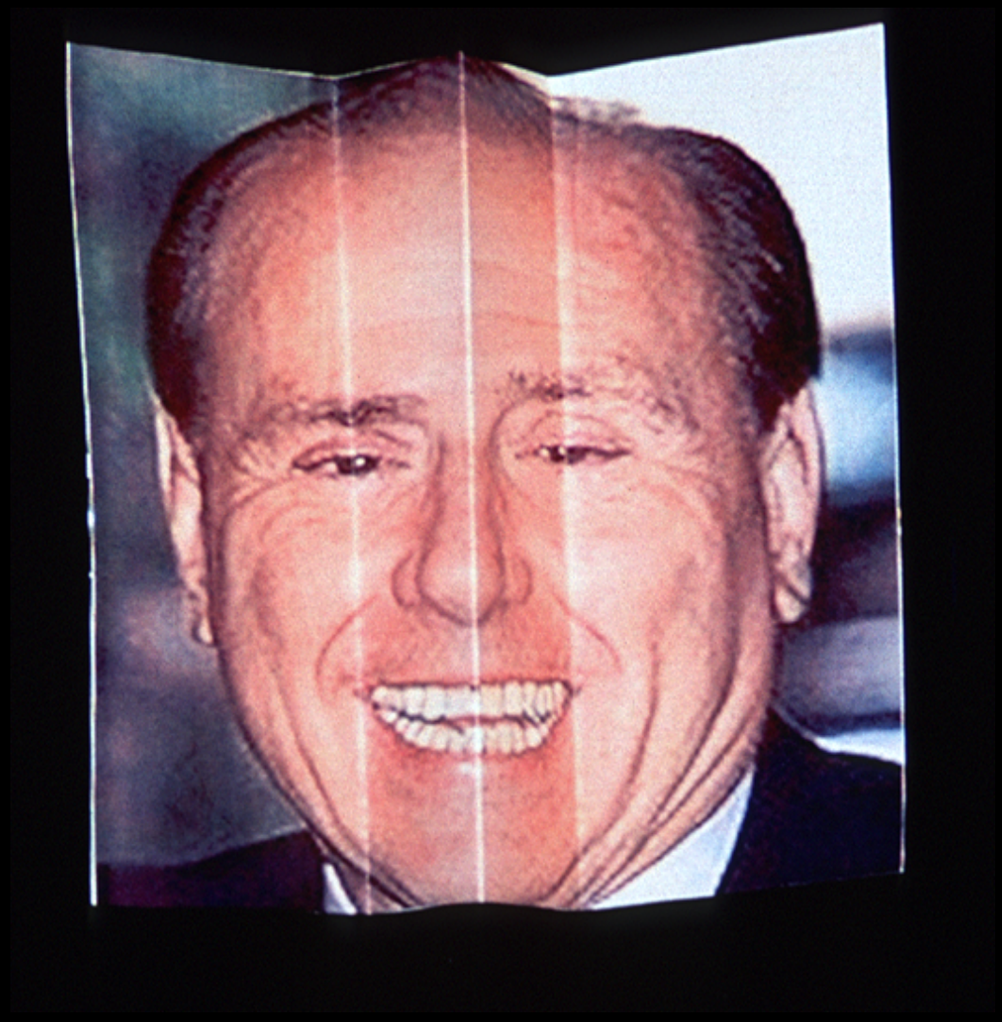
2D better than 3D

The Problem

Why are we not sensitive to distortions of paintings created at different viewpoints?

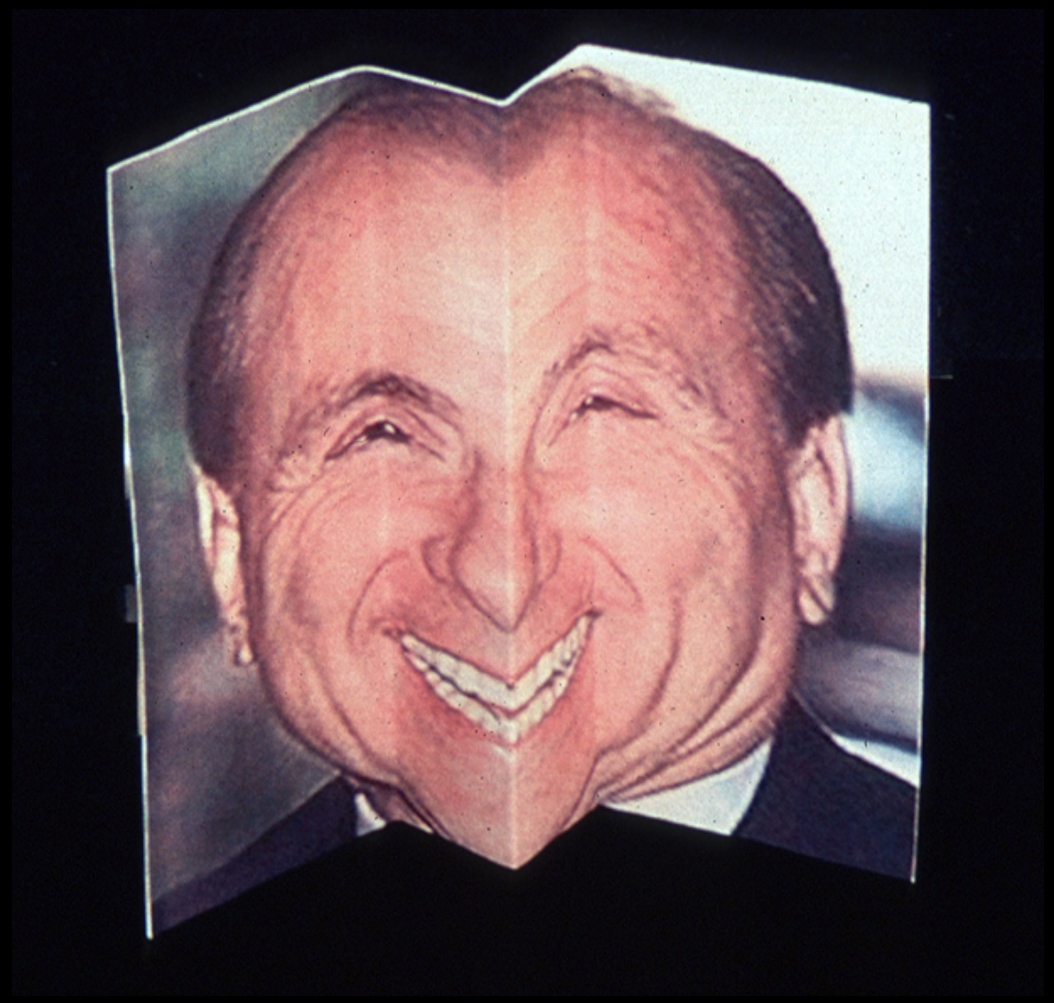
Do we correct for the effect of the viewing angle?

Let's put more than one angle into a picture



Bent drawings create illusions of non rigidity

Cavanagh, von Grünau, & Zimmerman, 2004



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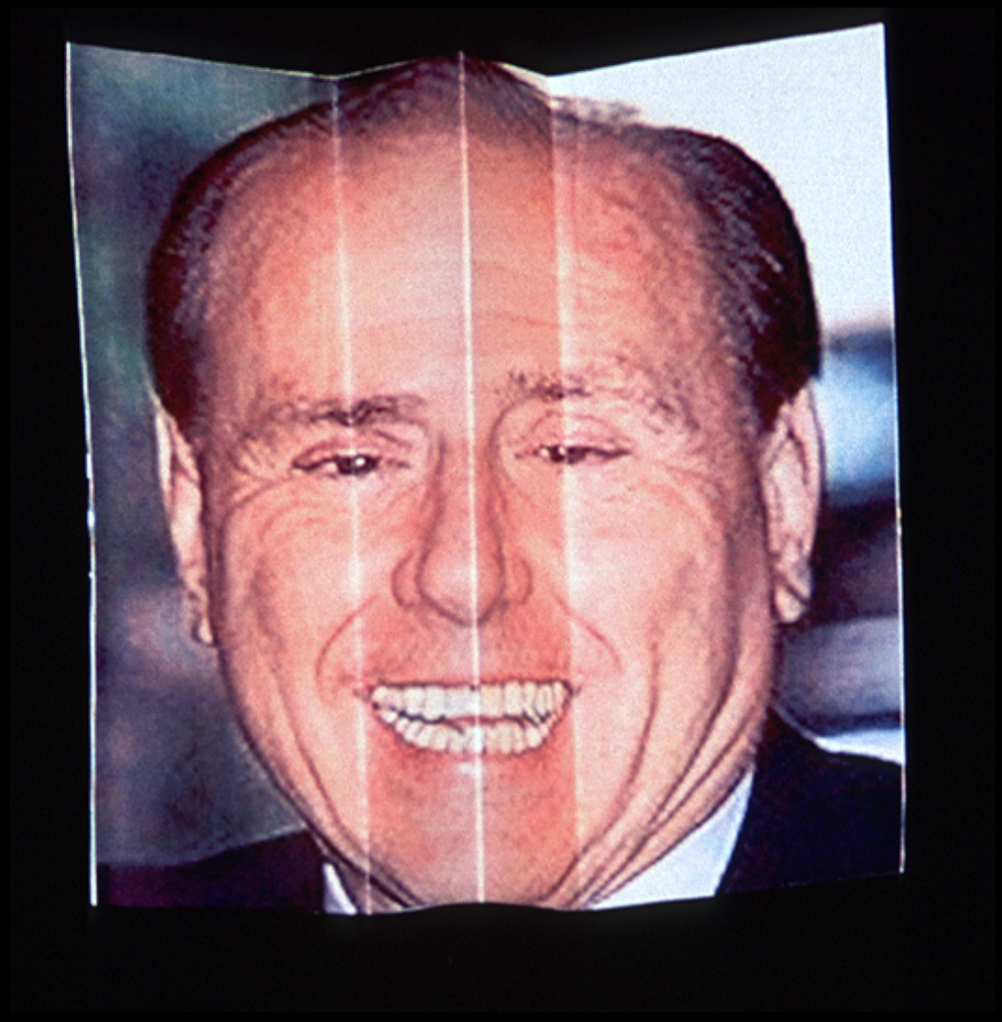

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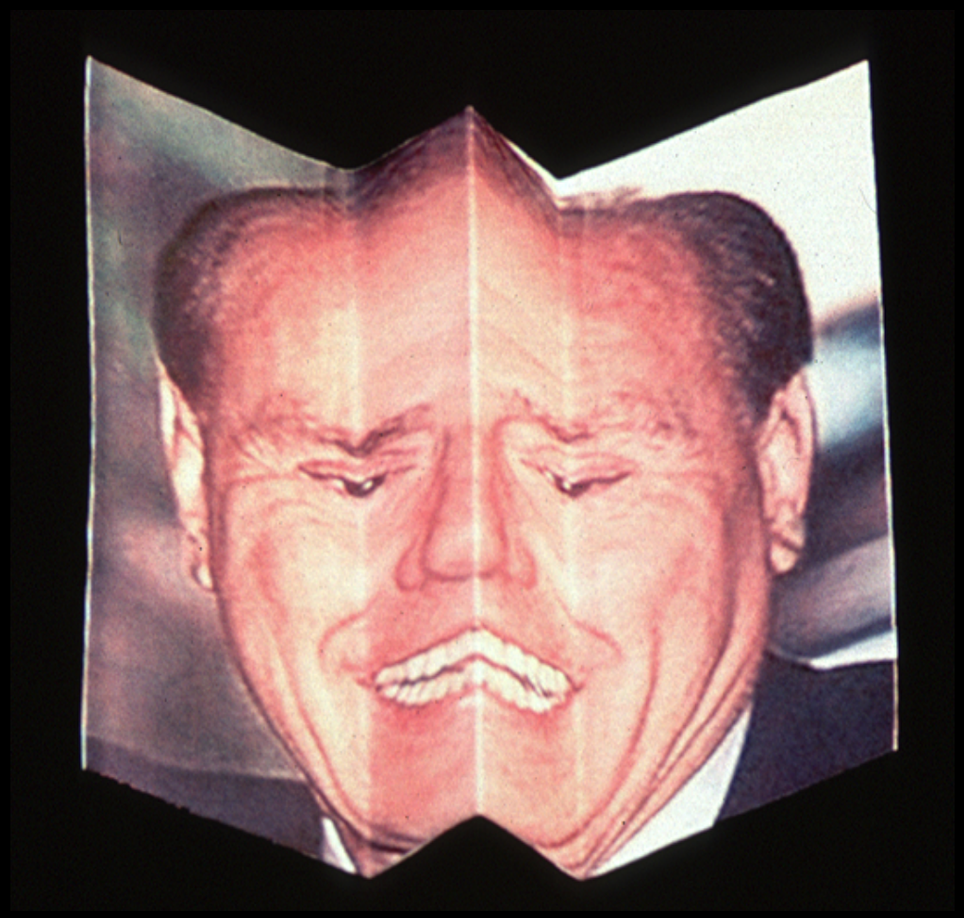


Bent drawings create illusions of non rigidity

Cavanagh, von Grünau, & Zimmerman, 2004

Conclusions: Flat

Bent pictures don't work

No correction for picture slant

Flat works because internal "3D" is not fully 3D, it is non-Euclidean

Indifferent to effects of viewing angle on flat image: stretching

#2 Line Drawings

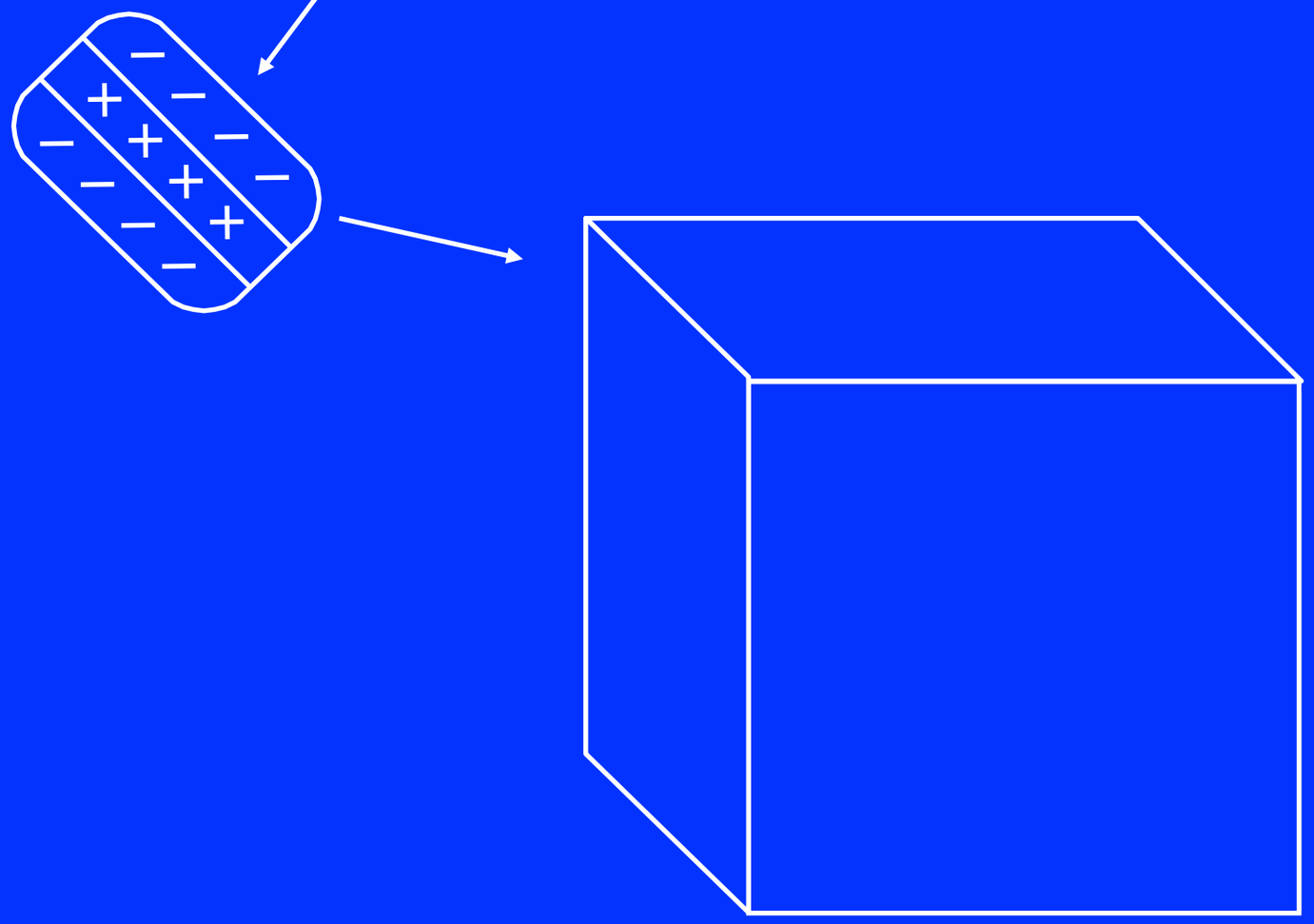
Lascaux, 15000BC

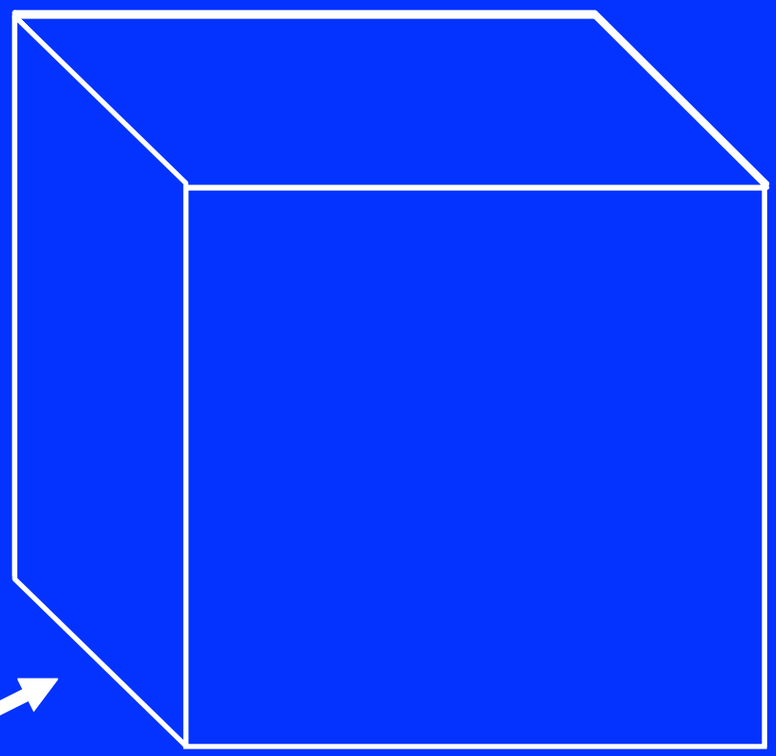
The Lean Horse, Jen Jen-fa, 1254-1327

Lascaux, 15000 BC

Why do lines work?

Contour detector:
Specific to orientation





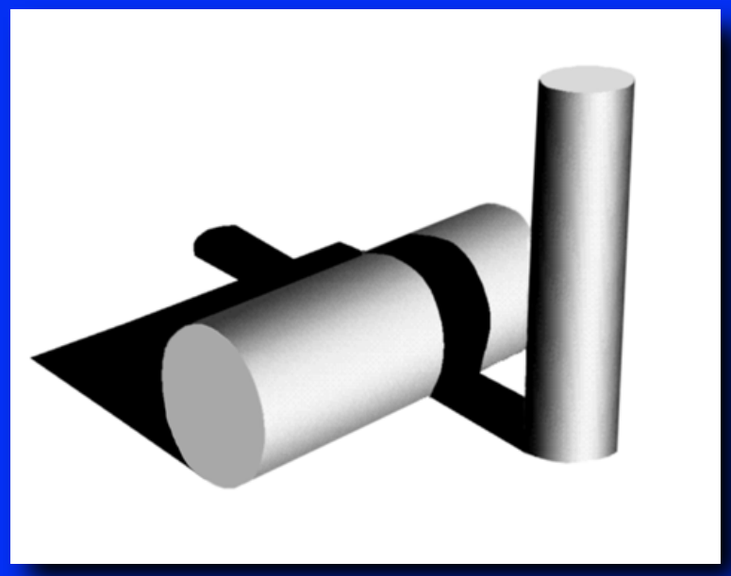
Spatial pattern of cortical response

Design evolved to detect edges
BUT happens to respond to lines as well

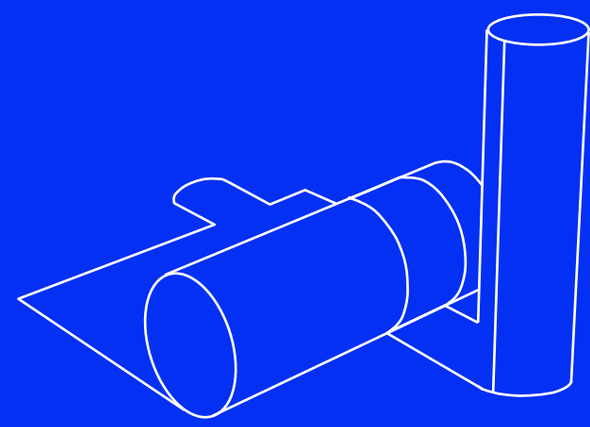
Neurons respond to lines as well as edges

➠ Not the whole story

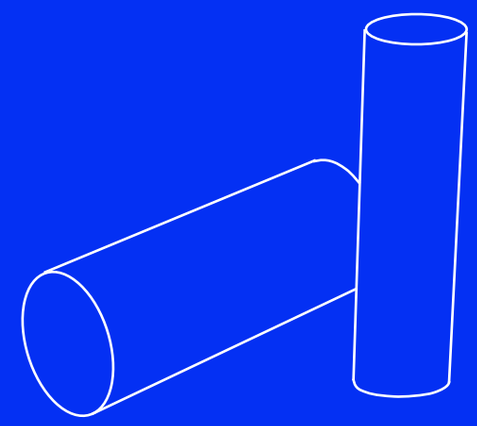
Not all edges and lines are "useful"



Image



All contours



"Depth sketch"

Artists and our visual system know
which lines are important

Cultural convention?

Odor and heat lines

Sound lines

Motion and mental energy lines

Innate code or
learned convention?

All cultures do it

Babies do it

Monkeys do it

Single cells do it

Bugs do it

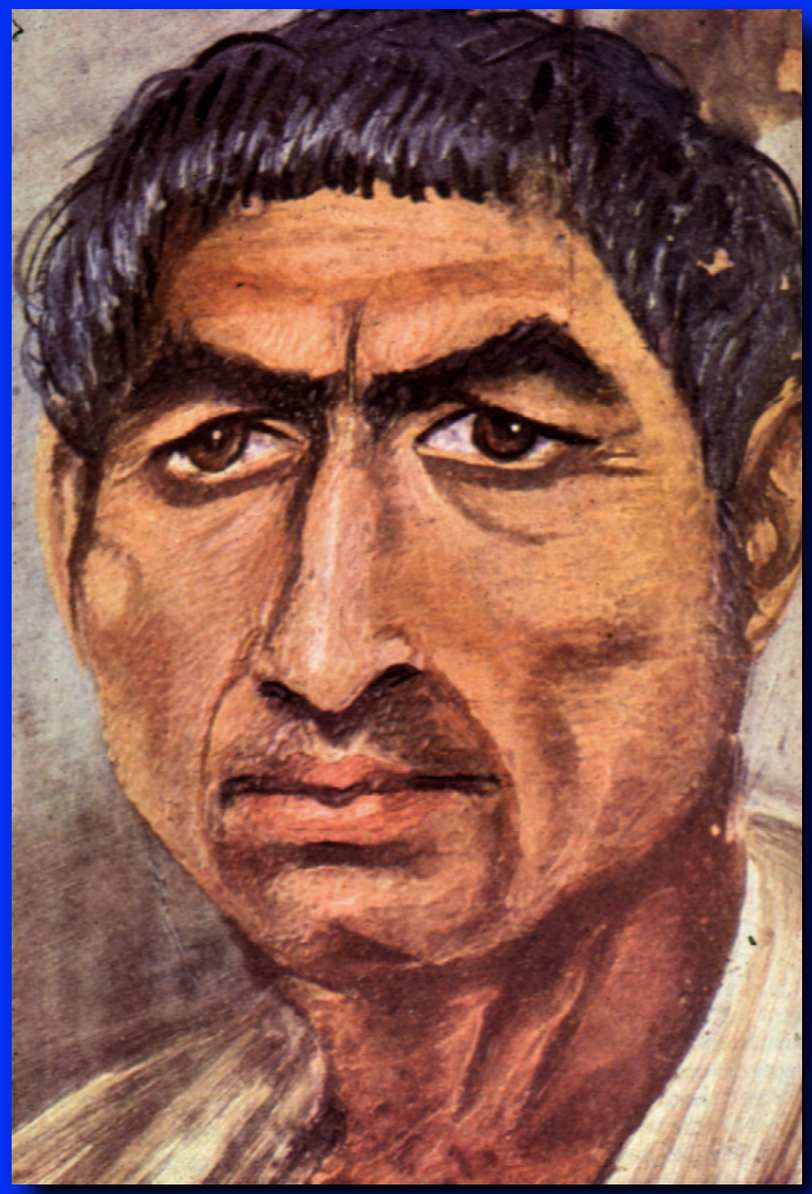
Conclusions: Lines

Lines work because edge detectors happen to respond also to lines

Allows artists to capture shapes with minimum of effort

Helps scientists understand how object contours are analyzed in brain

#3 Artists discover the "rules" of light and shadow and reflection



Fayum Portraits, 69-117 AD

Victoria, Pompeii, c100BC

Greeks introduced light & shadow in paintings 4th c BCE

#3 Artists discover the "rules" of light and shadow and reflection

The Faun, Pompeii, c100BC

A separate shadow makes the object float

A contact shadow grounds the object

Cast shadows become a convention

Piazza Armerina, c.300AD

Absence of cast shadows
300 AD to 1416 AD

Piazza Armerina, c.300AD

Af
shado

Jan van Eyck

Renaissance:
Good perspective, bad shadows

Simple rules for what is a shadow

Cavanagh & Leclerc 1989

No. 277, Jiro Takamatsu, 1968

Can be wrong shape as long as it is darker

Simple rules for what is a shadow

Cavanagh & Leclerc 1989

Can't always check the shape

Out of frame

Often very complicated

Simple rules for what is a shadow

Cavanagh & Leclerc 1989

Maurice de Vlaminck, Still Life

Georges Braque

Can be wrong color

Simple rules for what is a shadow

Cavanagh & Leclerc 1989

Can be

wrong color

but must be

darker

Simple rules for what is a shadow

Cavanagh & Leclerc 1989

A shadow should not have its own contour or texture

Cavanagh & Kennedy, Science 2000

When is an inconsistency noticed?

Pawan Sinha altering newpaper photo
of photographer Cornell Capa

Shadows must be
consistent within object

#2 Reflections and mirrors

Reflections are very complex

Only a few rules used to decide if a surface is reflecting or not

The reflected pattern does not have to match the pattern in front very accurately

Cavanagh, Chao, & Wang, 2008

Impossible reflections still look like reflections

Implement Blue, M. Preston, 1927

Highlights off curved surfaces like eyes and wet rocks are present in natural scenes

But flat vertical mirrors are not

Only humans, great apes, elephants and dolphins recognize their own reflections in mirrors

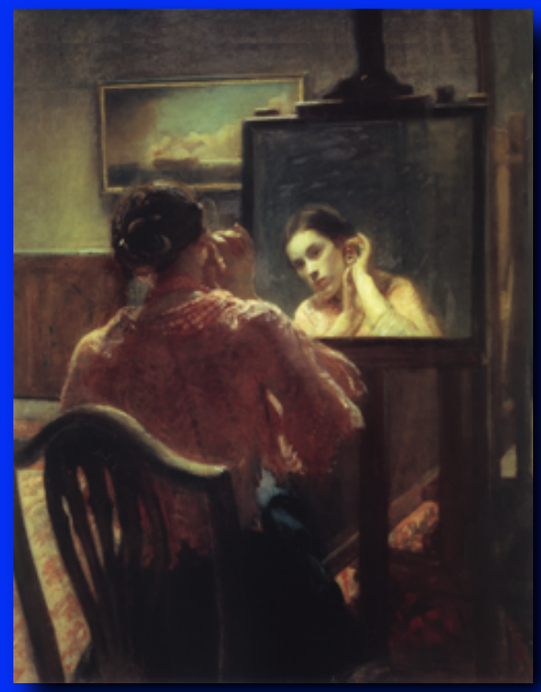
Other species often attack their reflections

Artists have enormous freedom in depicting what is seen in mirrors - Naïve optics, Hecht & colleagues

The Venus effect - Bertamini et al

Roman Mosaic

Diego Velazquez, The Rokeby Venus, 1649



The Earring. McEvoy.

How can we see her face in the mirror if she is looking at herself too?

Natural flat reflective surfaces all horizontal

Is there less tolerance for errors here?

Constraint: reflections must fall on a vertical line below each object

Natural flat reflective surfaces all horizontal

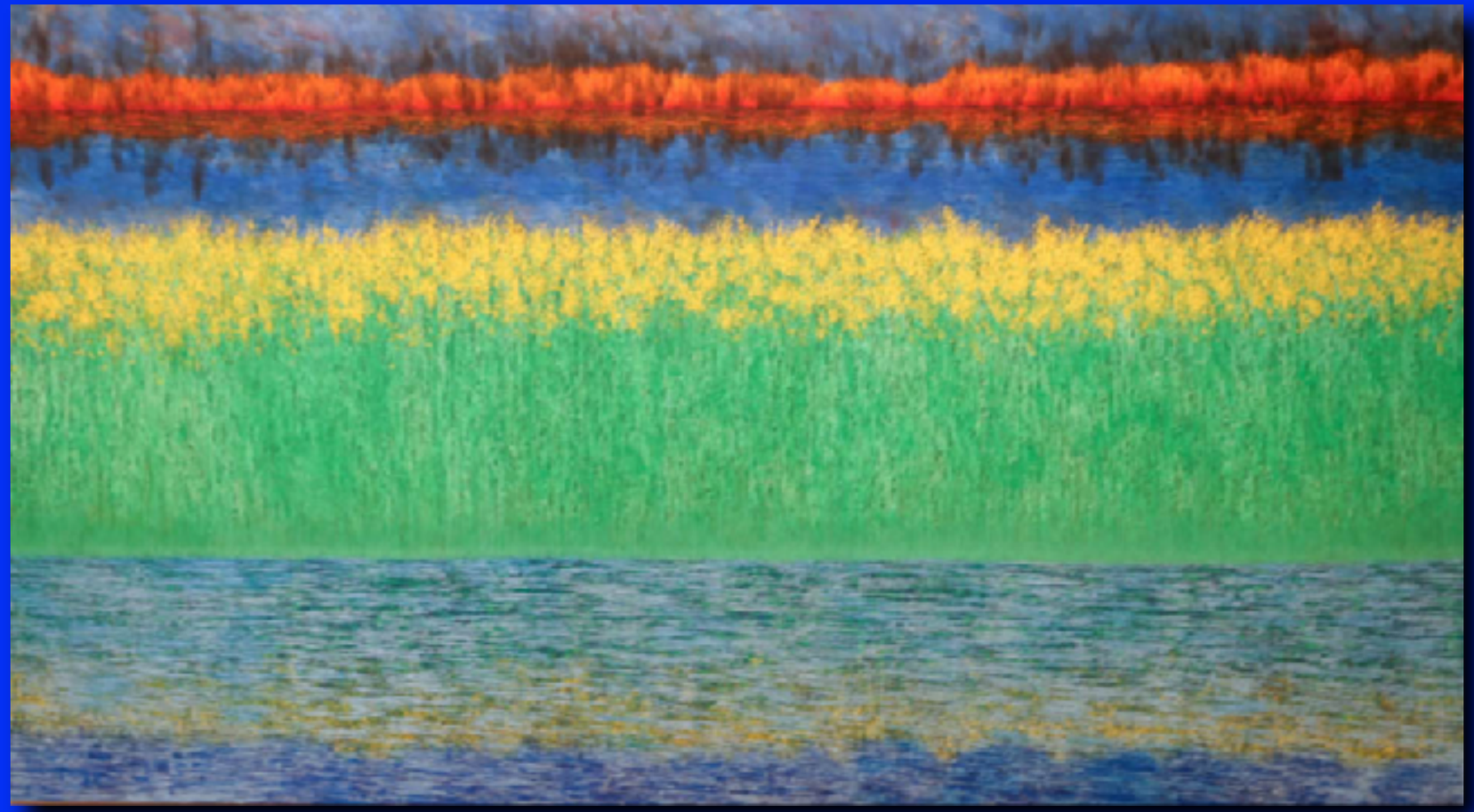
Is there less tolerance for errors here?

Constraint: reflections must fall on a vertical line below each object

Painters use this cue faithfully for water

PdF, ~1450, The Triumph of Constantine

PdF, ~1450, St. Jerome



Jimmy Ernst, Sea of Grass-Sunset, 1982

Conclusions: Mirrors and Reflections

Vertical mirrors: cultural artifact, artists take great liberties

Horizontal reflecting surfaces, natural, artists more constrained

#3

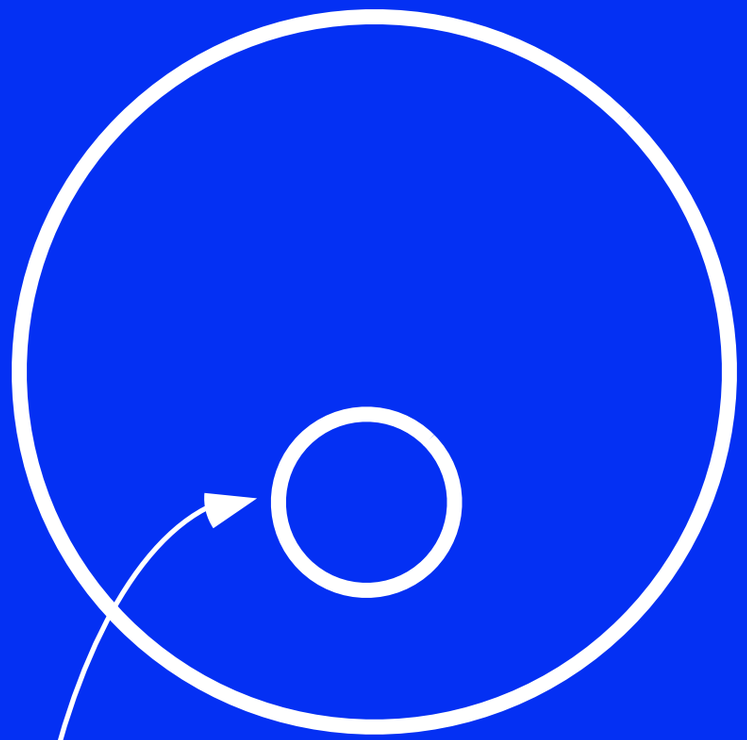
La Promenade, Claude Monet, 1875

Sparse

parse and yet still
ividly 3D

ill in the gaps

ased on access to
tored shapes of
familiar objects



Ambiguous depth

2D recognition

Object knowledge:
first guess
Apply if reasonable,
else abandon

Two-tone images

Cannot tell black shadow
from black pigment

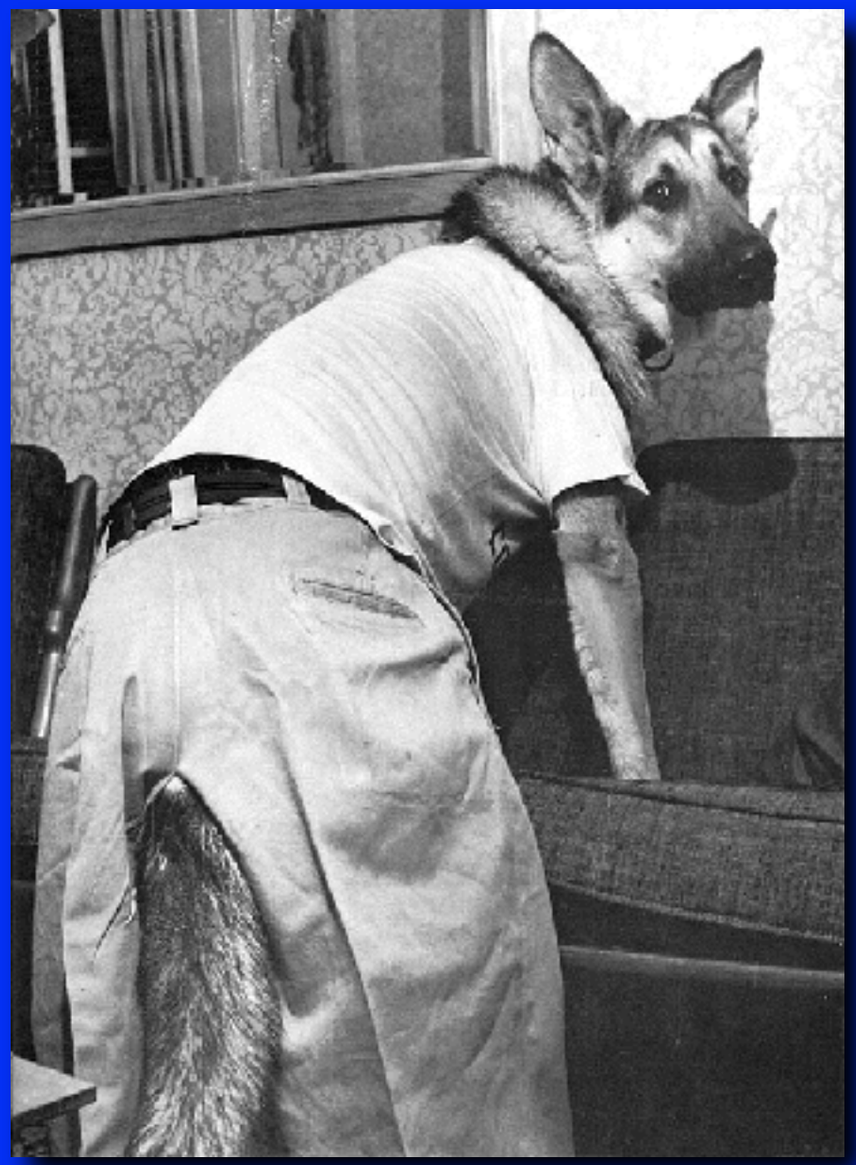
Sourisi, Giorgio Kienerk, 1901

Tolstoy, Giorgio Kienerk, 1904

2D Match!

Image ➠ Contours ➠ Parts ➠ 3D Model ➠ Object

Distinctive feature ➠ Guess ➠ Check ➠ Accept
or Start Over



Distinctive feature ➠ Guess ➠ Check ➠ Accept
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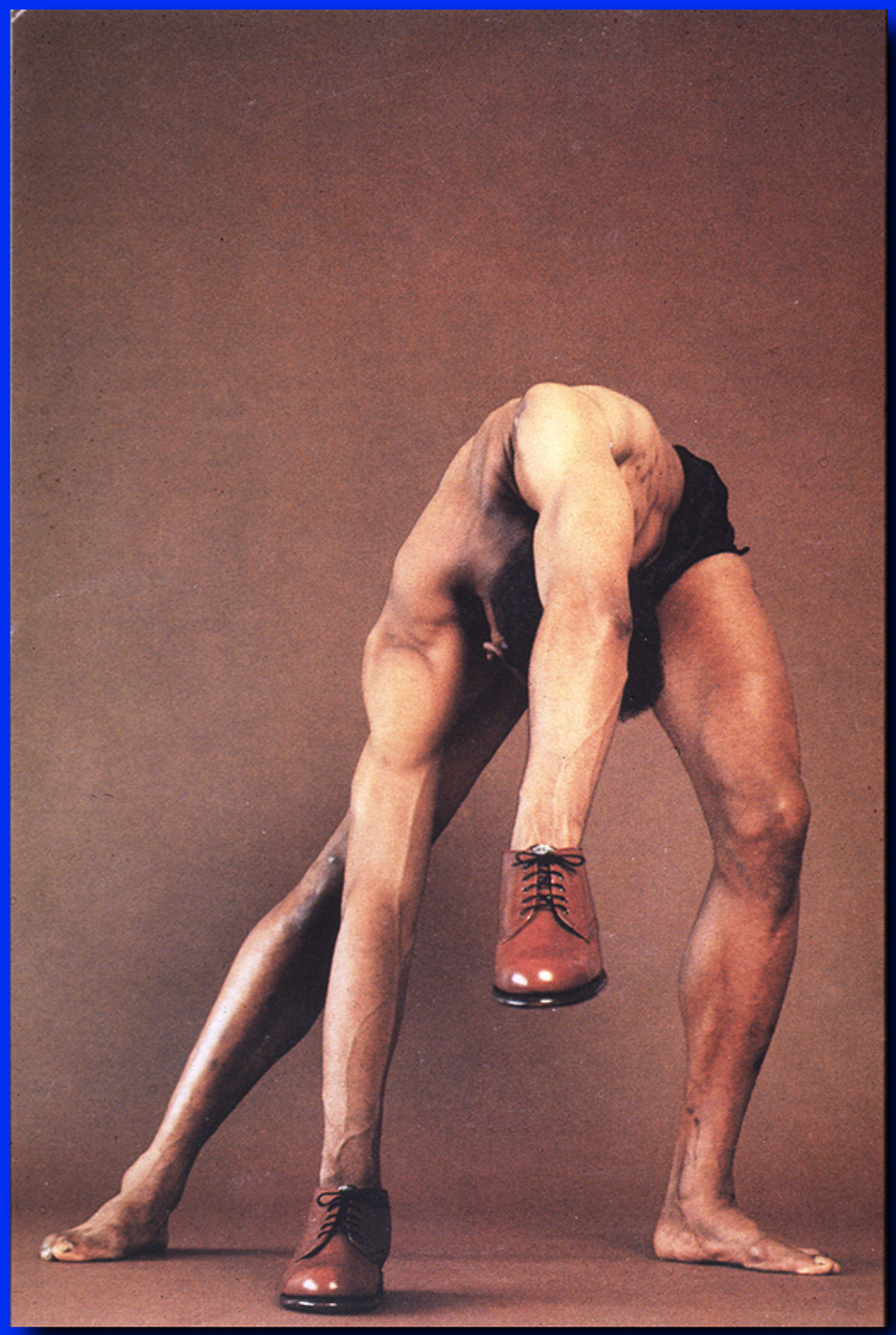


Conclusions: Sparse

Get best guess from memory

Check for match in details

Accept or start over

Conclusions: What artists discovered

1. Internal representation of world not really 3D, allows flat representations
2. Lines offer "backdoor" access to object representations
3. Only subset of rules of light and reflection needed, artists can break the rest
4. Vision only need hints, most likely percept retrieved from stored information

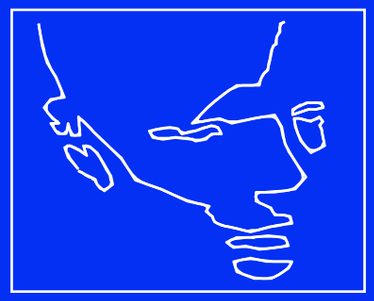
✳ *Artists, the first vision scientists*

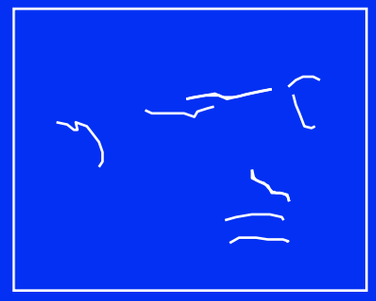
How?

Two-tone image

Cavanagh, 1991

Contours



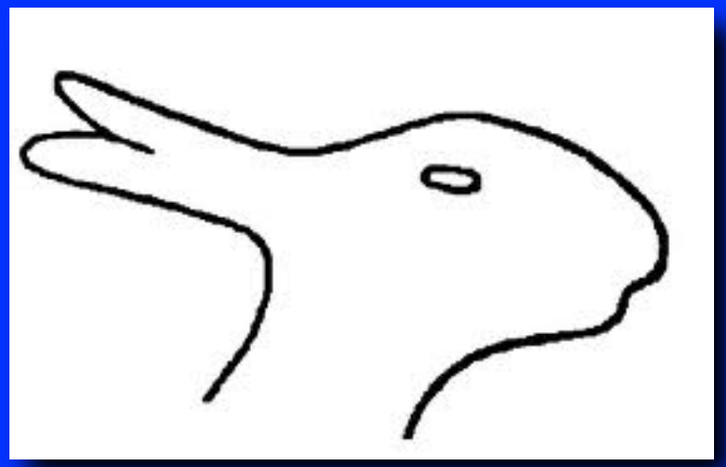


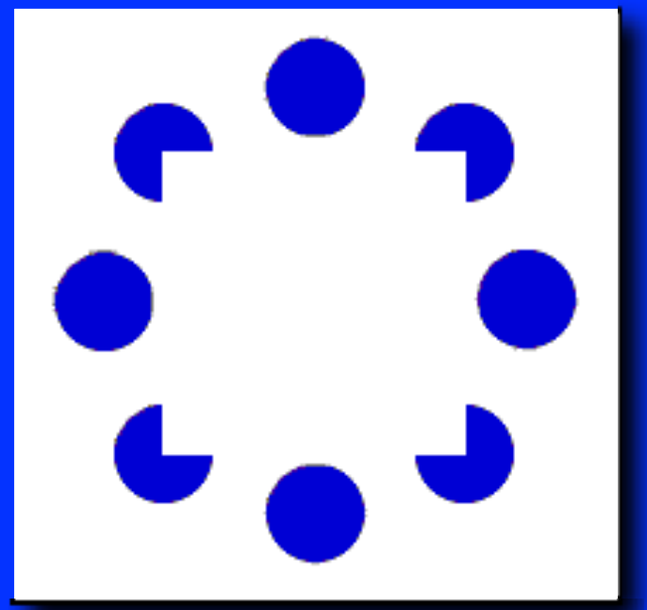
Ignore cast shadow contours

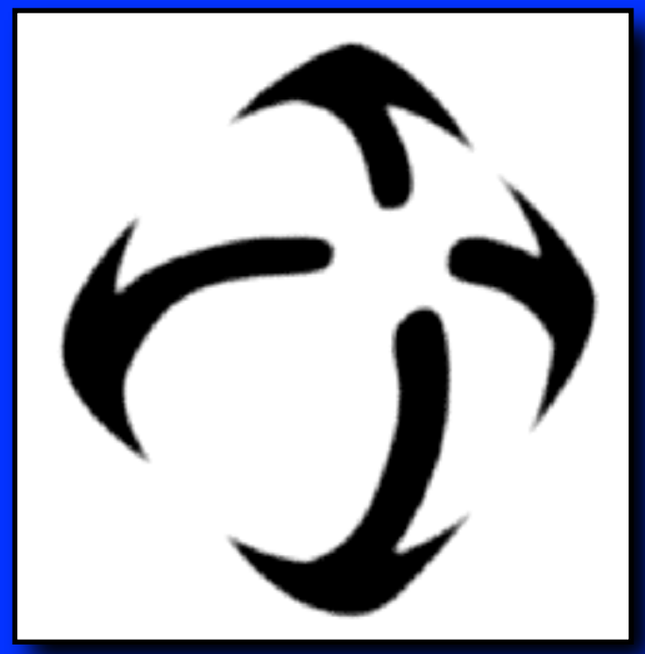
2D match finds some characteristic contours of a face

Retrieve prototypical head from memory, check against image

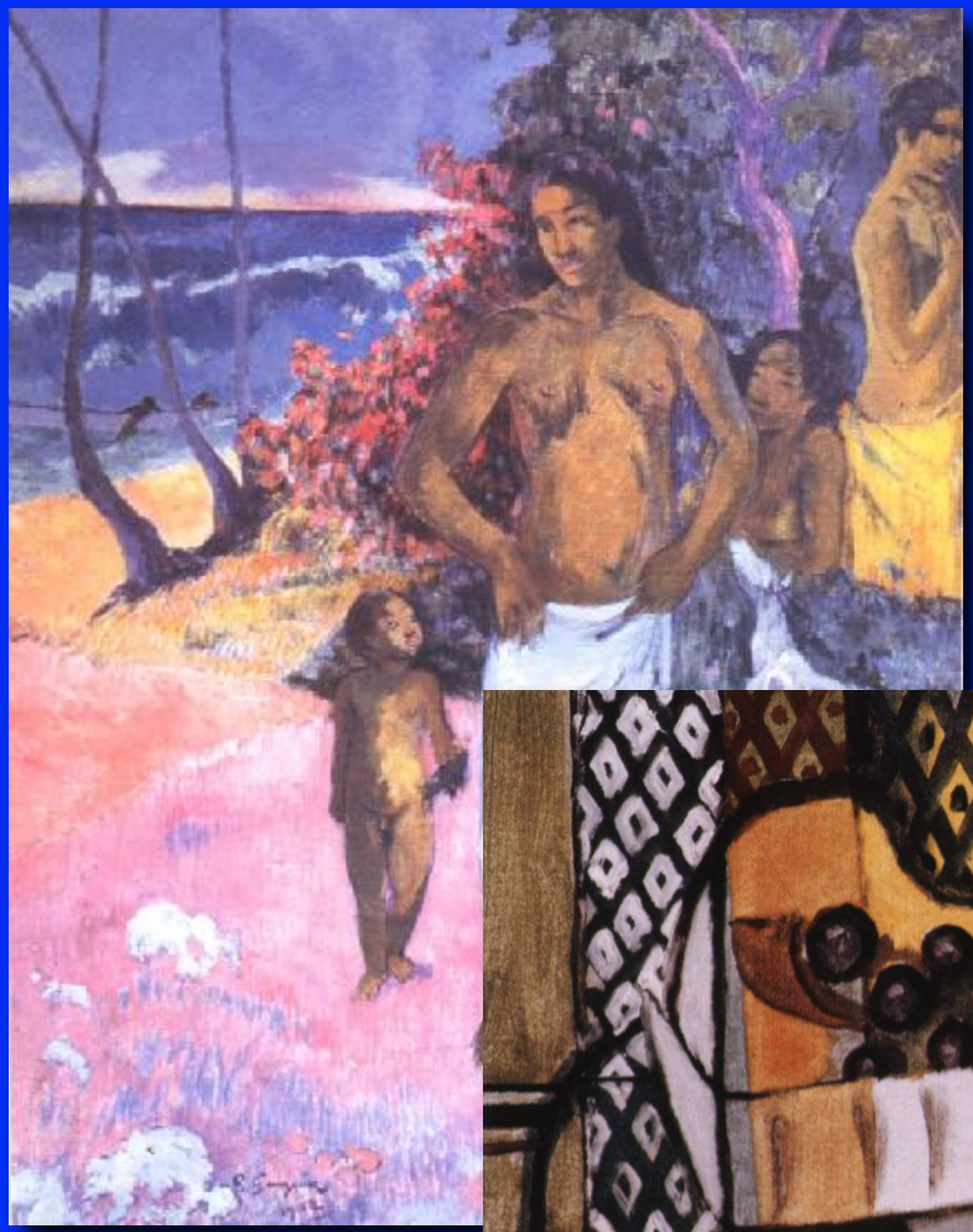
Measurements are important but they often ambiguous







Peter Tse




Sven Začek - www.zacekfoto.ee