HOW WE SEE ART AND HOW ARTISTS MAKE IT

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Graduate Program in Cognitive and Neural Systems
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S. Grossberg and L. Zajac, 2017,
***Art & Perception*, 5, 1-95**
Published OPEN ACCESS
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I will tell you a little about
HOW OUR BRAINS SEE
and discuss
how various painters struggled to
intuitively understand how THEY see
to
generate desired aesthetic effects
in their paintings

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HOW CAN A TALK ON THIS TOPIC EVEN BE GIVEN?

The results are based on the most advanced neural models of HOW OUR BRAINS SEE

The models emerged through 40 years of research

They also offer an explanation of what goes on in each brain as it consciously sees, hears, feels, or knows something

See

Grossberg, S. (2017). Towards solving the hard problem of consciousness: The varieties of brain resonances and the conscious experiences that they support, *Neural Networks*, 87, 38-95

Also published OPEN ACCESS and on my web page

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WHAT IS THIS TALK ABOUT?

Paintings of visual artists activate multiple brain processes that contribute to conscious perception

Paintings of different artists and artistic movements emphasize different combinations of brain processes to achieve their aesthetic goals

Neural models of how advanced brains see characterize these processes, and were used to analyze paintings of 10 painters:

Jo Baer, Banksy, Ross Bleckner, Gene Davis, Charles Hawthorne, Henry Hensche, Henri Matisse, Claude Monet, Jules Olitski, Frank Stella

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How were such models discovered in the first place?

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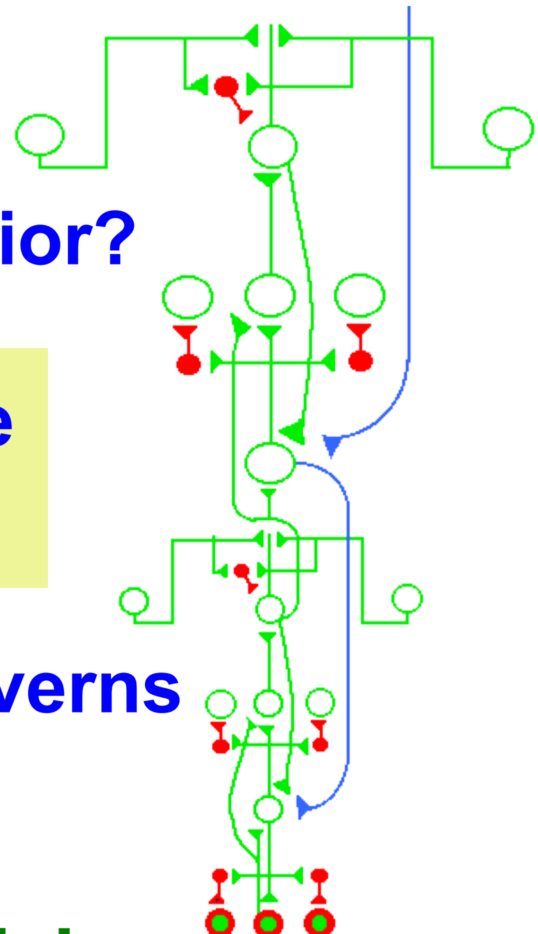
How were such models discovered in the first place?

How much do we know today about how our brains work?

HOW DOES A BRAIN GIVE RISE TO A MIND?

What level of brain organization controls behavior?

What is the functional unit of behavior?



BRAIN evolution needs to achieve BEHAVIORAL success

What level of BRAIN processing governs BEHAVIORAL success?

The NETWORK and SYSTEM levels!

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How does BEHAVIOR arise as EMERGENT PROPERTIES of cells interacting in NEURAL NETWORKS?

Does this mean that individual neurons are unimportant?

Not at all!

How are individual NEURONS designed and connected in NETWORKS whose emergent properties give rise to successful BEHAVIORS?

Need to simultaneously describe 3 levels (at least):

BEHAVIOR
NETWORK
NEURON

and a MODELING language to link them

…one reason why our brains are so hard to understand

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MAIN CONCLUSION

To deeply understand how brains work, you need to understand HOW *EVOLUTION* SELECTS BRAIN DESIGNS based on their BEHAVIORAL SUCCESS

To do this, start with BEHAVIORAL DATA that describe the behavior-environment interactions that are selected by *evolution*

Starting bottom-up with ONLY facts about neurons has not achieved an understanding of brain function for any complex behavior

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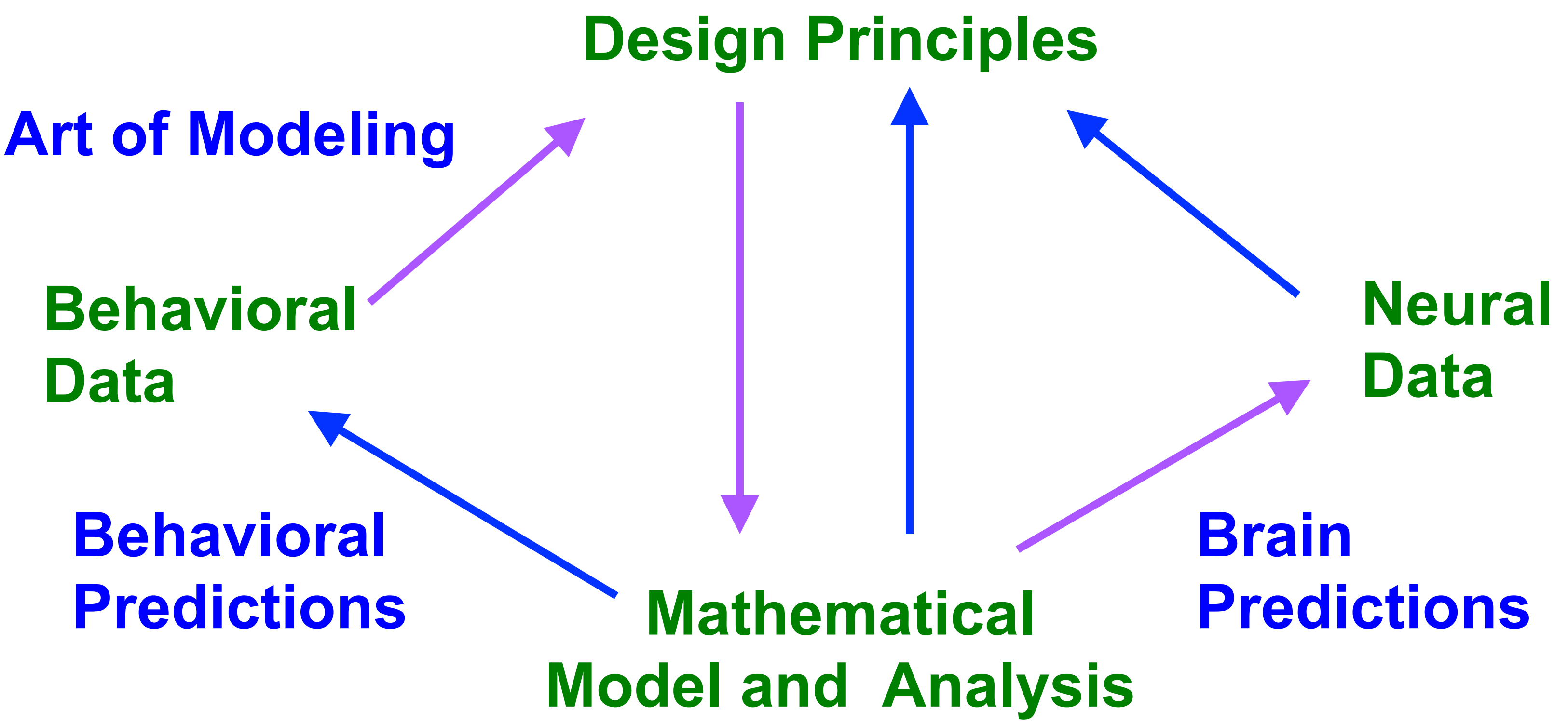
MODELING METHOD AND CYCLE



Embedding Principle: Repeat this cycle to carry out model evolution, progressively unlumping the model to achieve increasing model realism and explanatory power

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AFTER GOING THROUGH THE MODELING CYCLE, WHAT'S THE RESULT?!

IS THE BRAIN JUST A "BAG OF TRICKS"?

Ramachandran, 1990

NO!

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TRUE THEORIES ARE EMERGING

A small number of equations

e.g., shunting activation dynamics (STM)
habituative transmitter gates (MTM)
activity-gated learning (LTM) …

A larger number of modules*

e.g., on-center off-surround nets
resonant matching nets
opponent processing nets
spectral timing nets
boundary completion nets
filling-in nets…

Specialized combinations of modules*, using a few basic equations, are assembled in architectures that solve modal problems

A still larger number of modal architectures

e.g. vision
audition
smell
touch
cognition
emotion…

*Modules are microassemblies, not the "independent modules" of AI

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WHAT PRINCIPLES DETERMINE HOW MODAL ARCHITECTURES ARE DESIGNED?

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BREAKTHROUGHS IN BRAIN COMPUTING

Models that link detailed BRAIN CIRCUITS to the ADAPTIVE BEHAVIORS that they control

Mind/Body Problem

Describe NEW PARADIGMS for brain computing

INDEPENDENT MODULES
Computer Metaphor

COMPLEMENTARY COMPUTING
What is the nature of brain specialization?

LAMINAR COMPUTING
Why are all neocortical circuits organized in layers?
How do laminar circuits give rise to biological intelligence?

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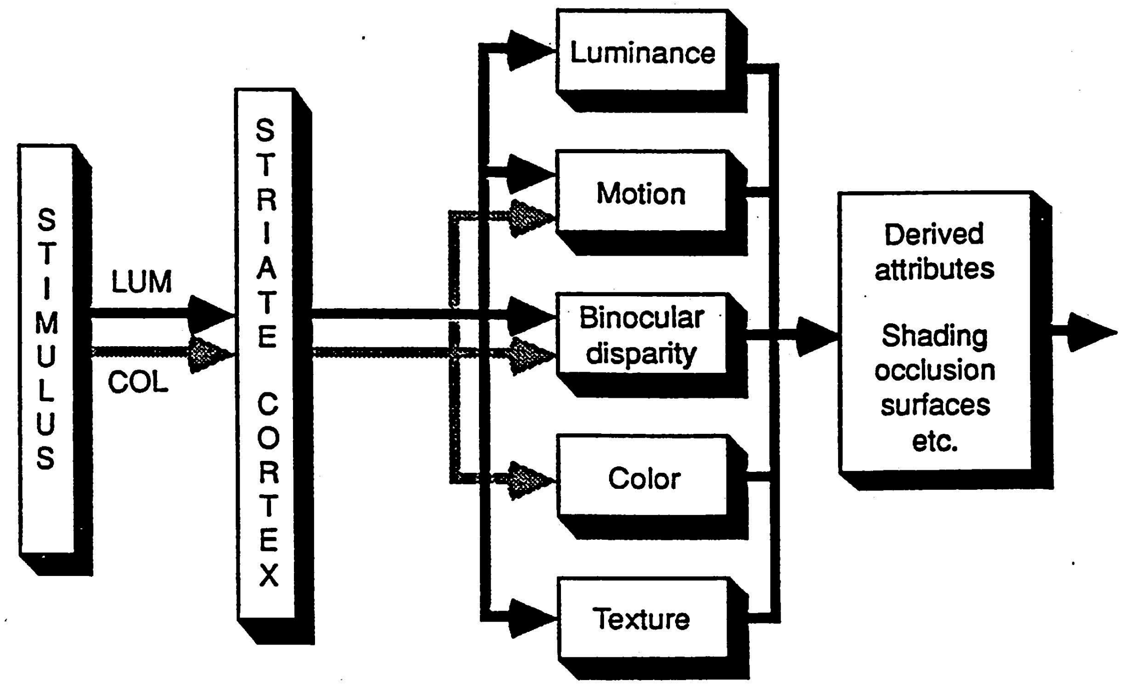
INDEPENDENT MODULES ARE APPEALING, BUT…?



The appeal: Lots of specialized brain regions in the visual cortex

Specialization does not, however, imply independent modules

INDEPENDENT modules should compute each property by itself

However, huge databases show interactions between (e.g.) brightness and depth, motion and color, motion and depth, texture and depth, texture and motion…RELEVANT TO ART!

BREAKTHROUGHS IN BRAIN COMPUTING

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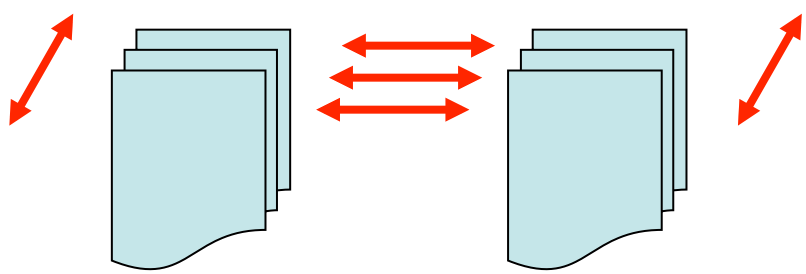
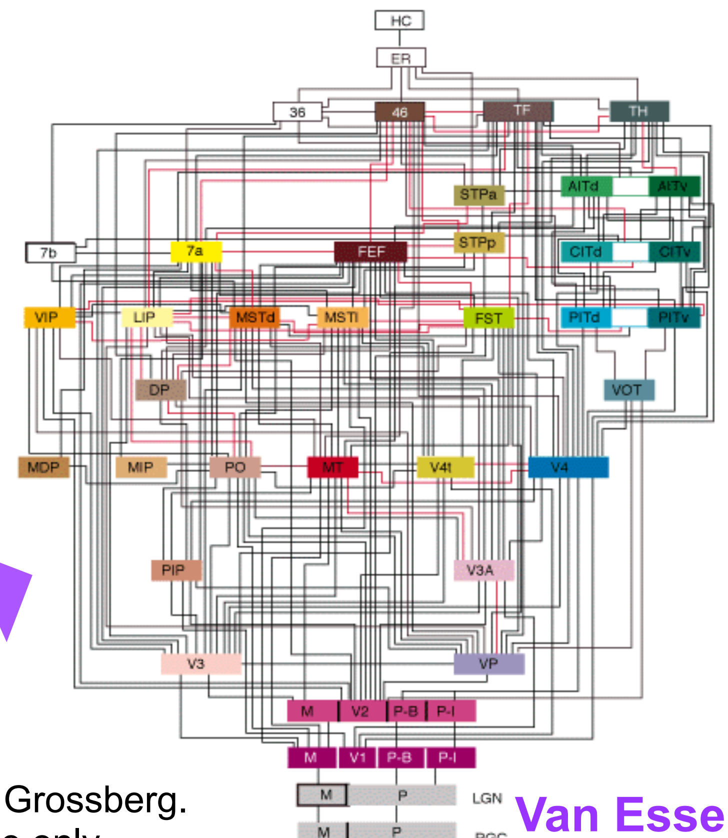
COMPLEMENTARY COMPUTING

New principles of UNCERTAINTY and COMPLEMENTARITY clarify why

Multiple Parallel Processing Streams Exist in the Brain





Lots of specialization!

Van Essen et al

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WHAT ARE COMPLEMENTARY PROPERTIES?

Analogies:

Key fitting in lock, puzzle pieces fitting together

Computing one set of properties at a processing stage prevents that stage from computing a complementary set of properties

Complementary parallel processing streams are BALANCED against one another

INTERACTIONS between streams overcomes their complementary weaknesses and support intelligent and creative behaviors

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SOME COMPLEMENTARY PROCESSES

Visual Boundary **Interbob Stream V1-V4**	**Visual Surface** **Blob Stream V1-V4**
Visual Boundary **Interbob Stream V1-V4**	**Visual Motion** **Magno Stream V1-MT**
WHAT Steam **Perception & Recognition** **Inferotemporal and** **Prefrontal areas**	**WHERE Stream** **Space & Action** **Parietal and** **Prefrontal areas**
Object Tracking **MT Interbands and MSTv**	**Optic Flow Navigation** **MT Bands and MSTd**
Motor Target Position **Motor and Parietal Cortex**	**Volitional Speed** **Basal Ganglia**

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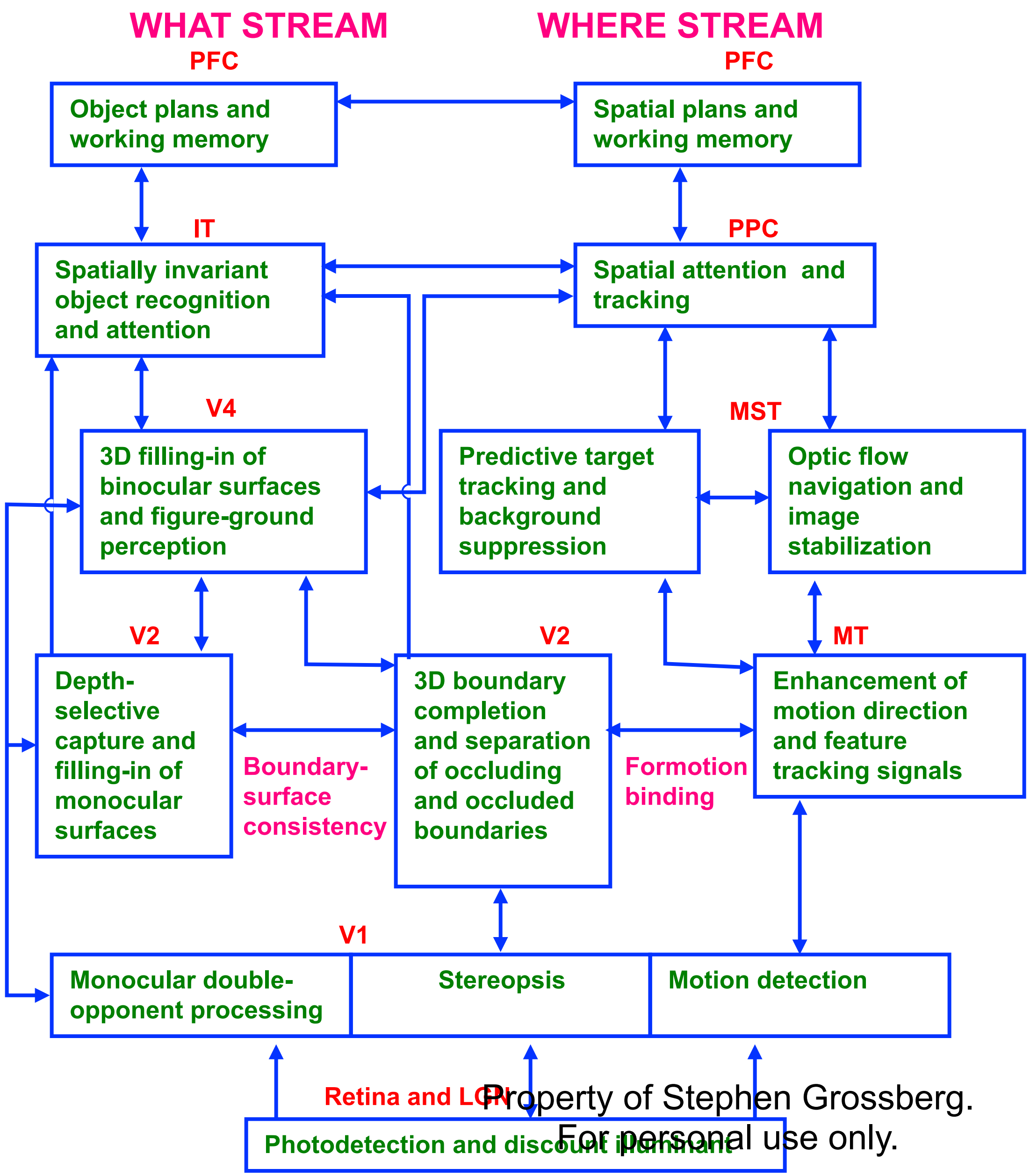
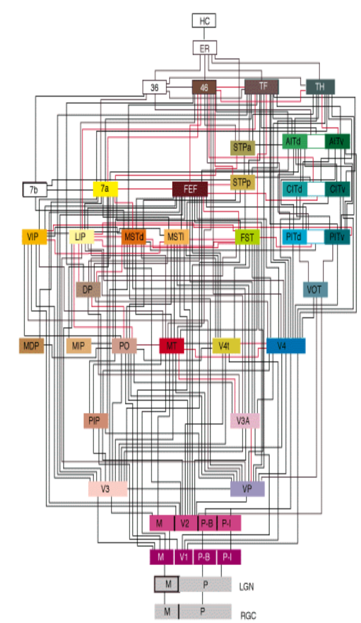
EMERGING UNIFIED THEORY OF VISUAL INTELLIGENCE



Bottom-up horizontal and top-down interactions overcome COMPLEMENTARY processing deficiencies



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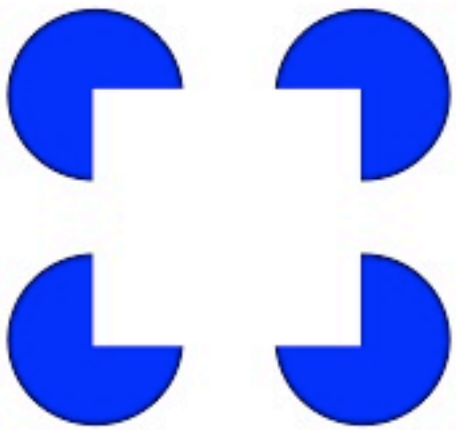
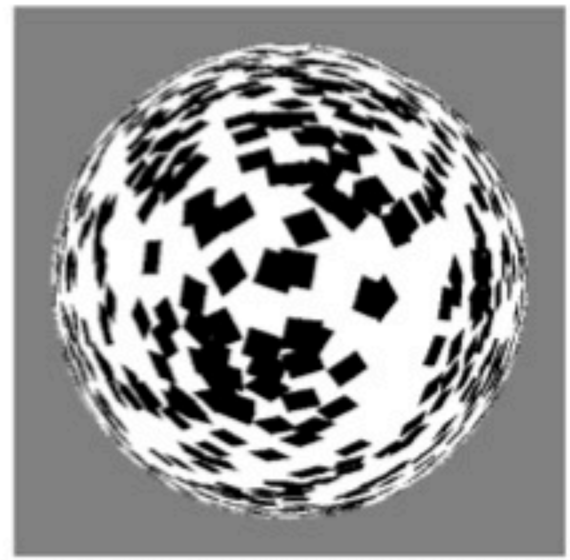
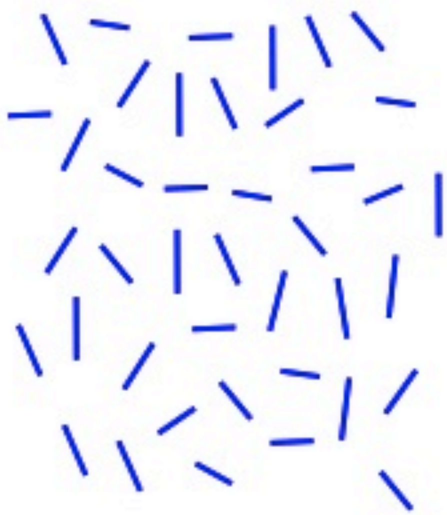
WHAT IS A VISUAL BOUNDARY OR GROUPING?



Illusory contour



3D shape from texture



Texture pop-out

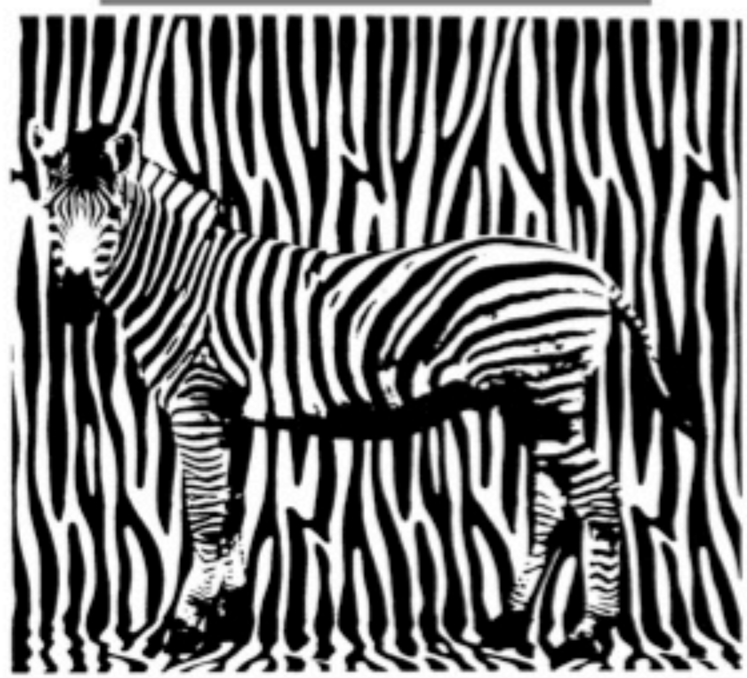
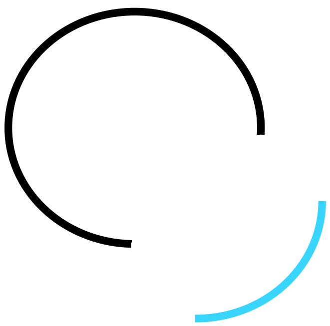
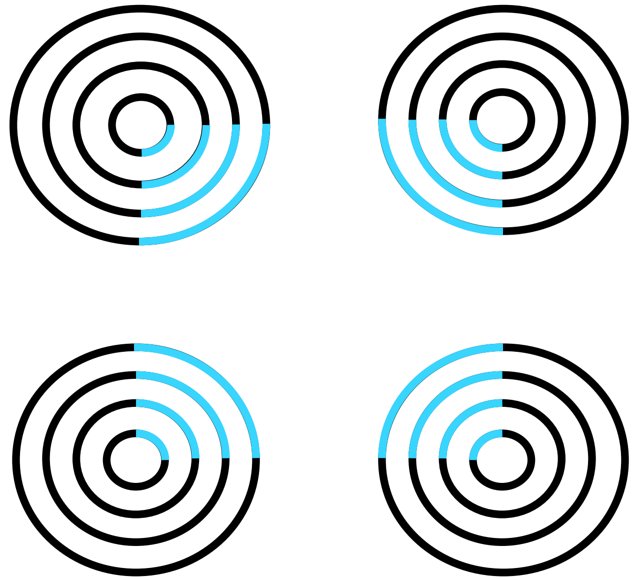


Figure-ground separation

VISUAL BOUNDARY AND SURFACE COMPUTATIONS ARE COMPLEMENTARY

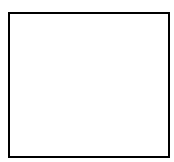
Grossberg (1984)





Neon color spreading

BOUNDARY COMPLETION



oriented
inward
insensitive to
direction-of-contrast

SURFACE FILLING-IN

unoriented
outward
sensitive to
direction-of-contrast

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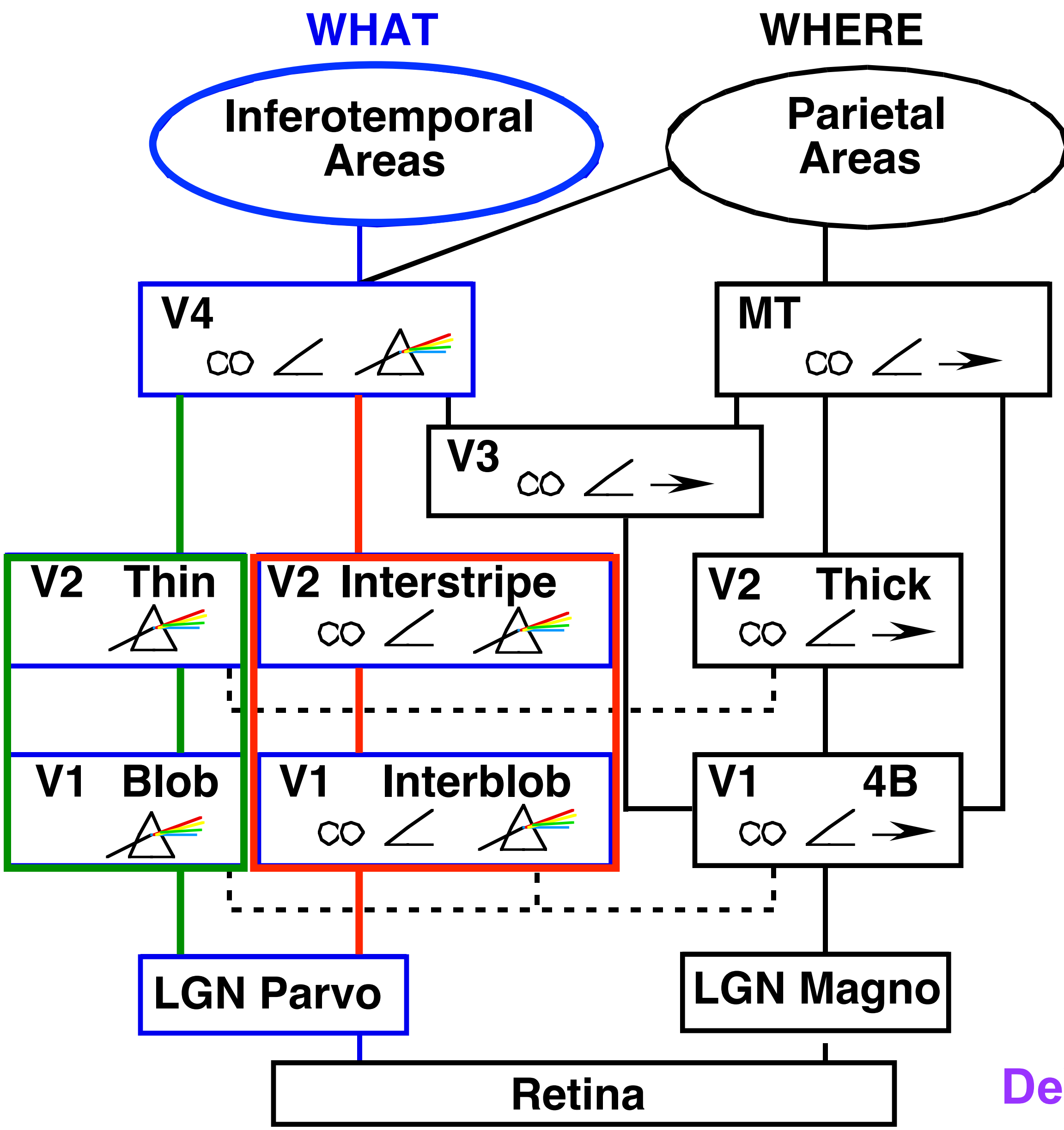
BOUNDARY AND SURFACE CORTICAL STREAMS



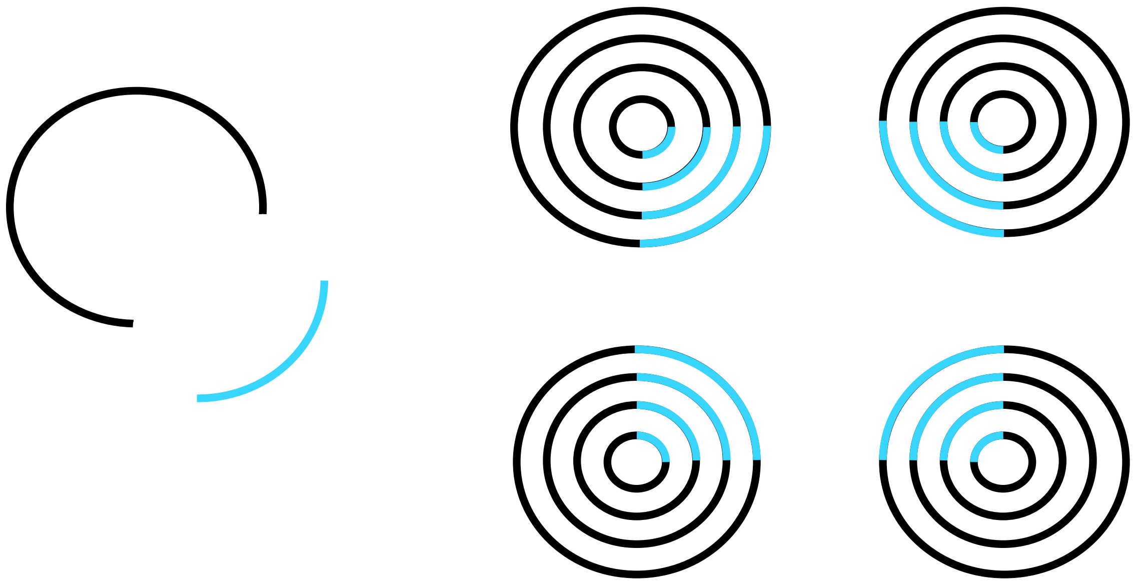
Boundaries
interblob stream

Surfaces
blob stream

DeYoe and van Essen (1988)

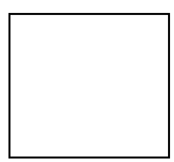
VISUAL BOUNDARY AND SURFACE COMPUTATIONS ARE COMPLEMENTARY

Grossberg (1984)



Neon color spreading

BOUNDARY COMPLETION



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What about

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SEEING vs. KNOWING

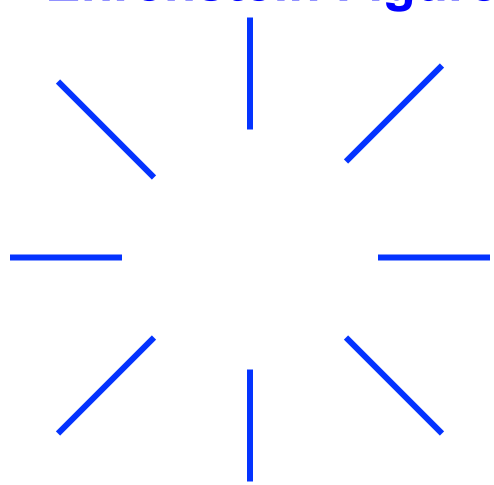
SEEING
an object

vs.

KNOWING
what it is

Epstein, Gregory, Helmholtz, Kanizsa, Kellman, Michotte,…

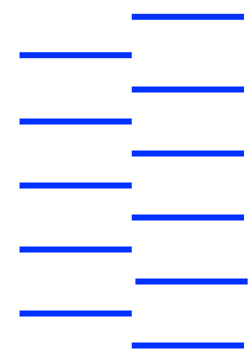
SEEING
Ehrenstein Figure



See
Recognize

vs.

RECOGNIZING
Offset Grating



Some boundaries are invisible, or amodal

Do not see
Recognize

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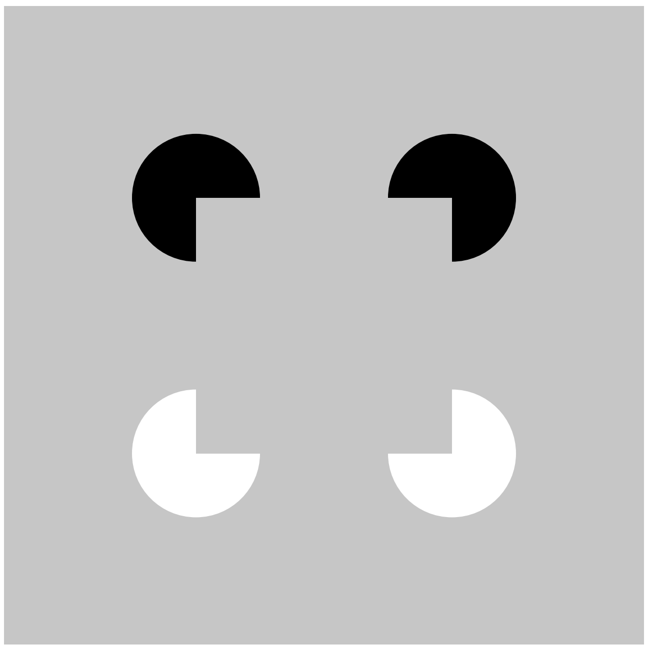
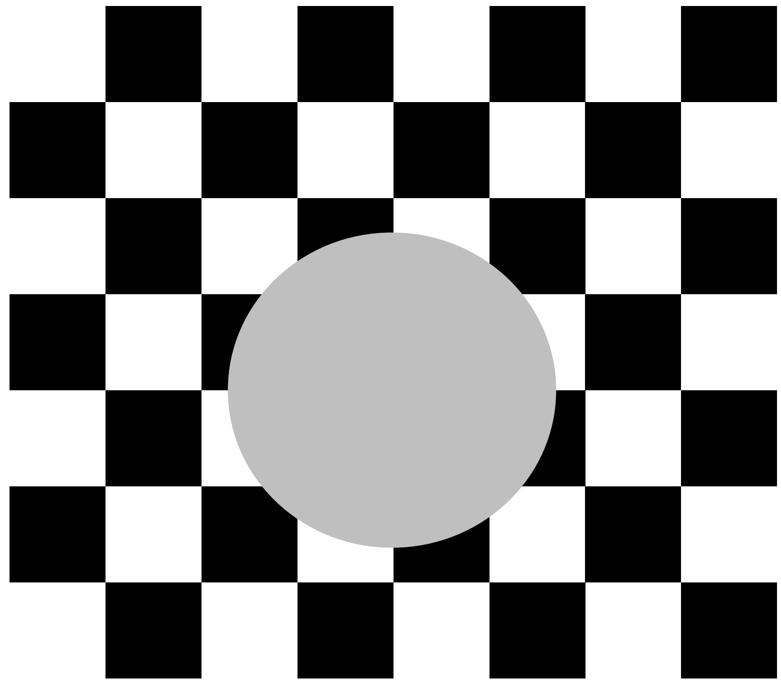
ALL BOUNDARIES ARE INVISIBLE!

Within the Boundary Steam

Grossberg (1984)

WHY? To recognize object boundaries in front of textured backgrounds





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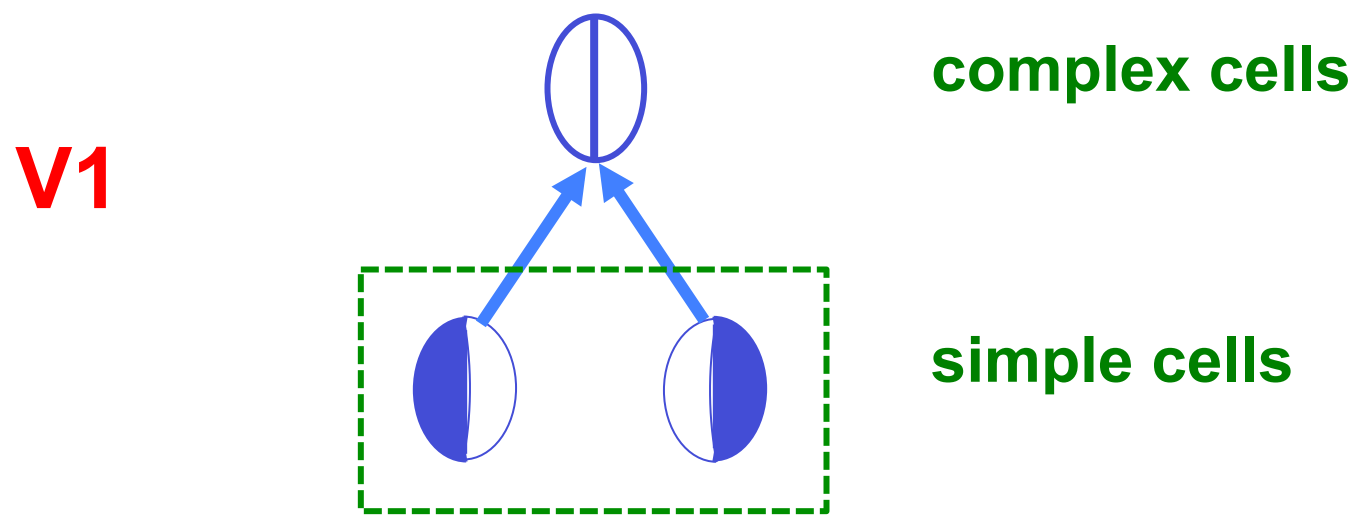
ALL BOUNDARIES ARE INVISIBLE: COMPLEX CELLS

complex cells pool inputs from opposite-polarity simple cells in V1

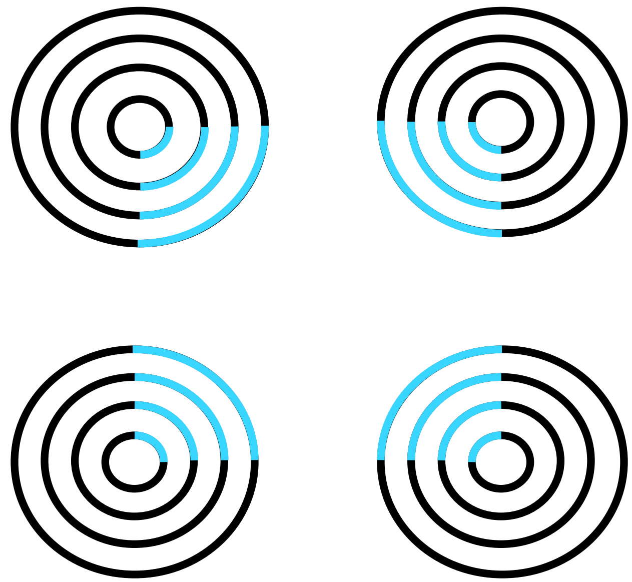


Complex cells are amodal boundary detectors Grossberg (1984)

vs

"color cells in the broadest sense" Thorell, DeValois & Albrecht (1984)

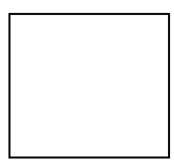
VISUAL BOUNDARY AND SURFACE COMPUTATIONS ARE COMPLEMENTARY



Neon color spreading

All Boundaries Are Invisible!

BOUNDARY COMPLETION



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SURFACE FILLING-IN

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MANY OBJECTS ARE PARTIALLY OCCLUDED IN A 3-DIMENSIONAL WORLD

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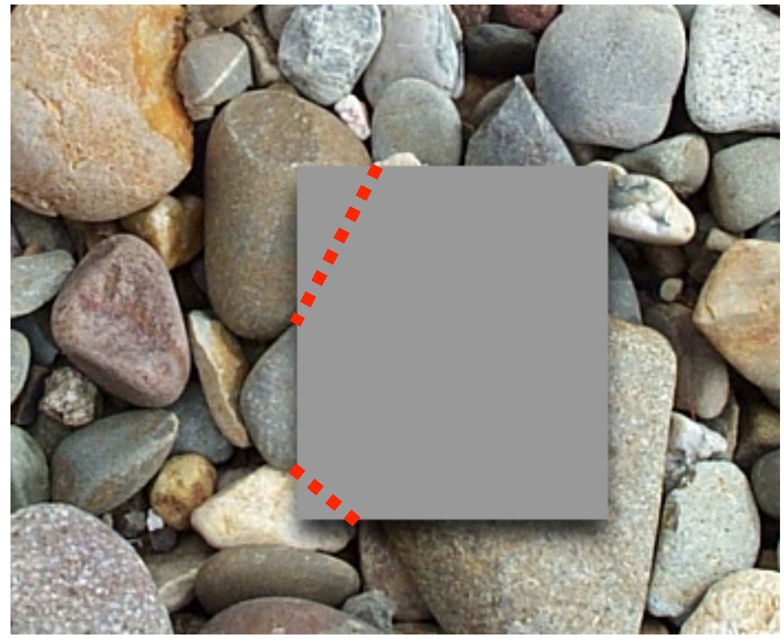
MANY OBJECTS ARE PARTIALLY OCCLUDED IN A 3-DIMENSIONAL WORLD



Amodal, or invisible, completion of partially occluded objects behind their occluding objects allows us to better recognize them

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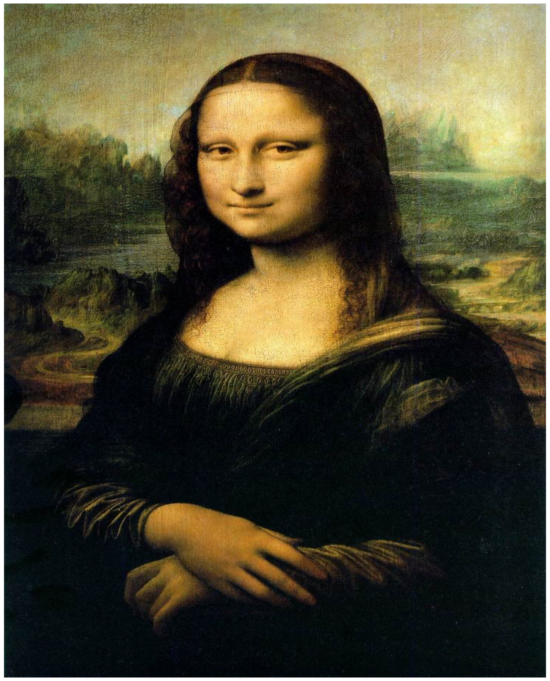
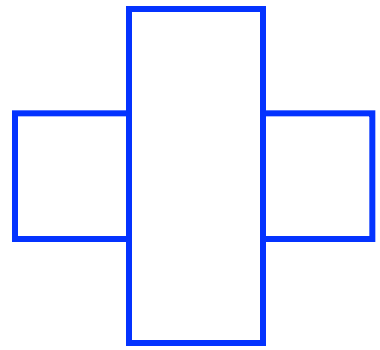
MANY OBJECTS ARE PARTIALLY OCCLUDED IN A 3-DIMENSIONAL WORLD



Mona Lisa



This same process allows 2D pictures to be perceived as 3D representations of occluding and occluded surfaces

It is a key process in all pictorial art, movies, and TV

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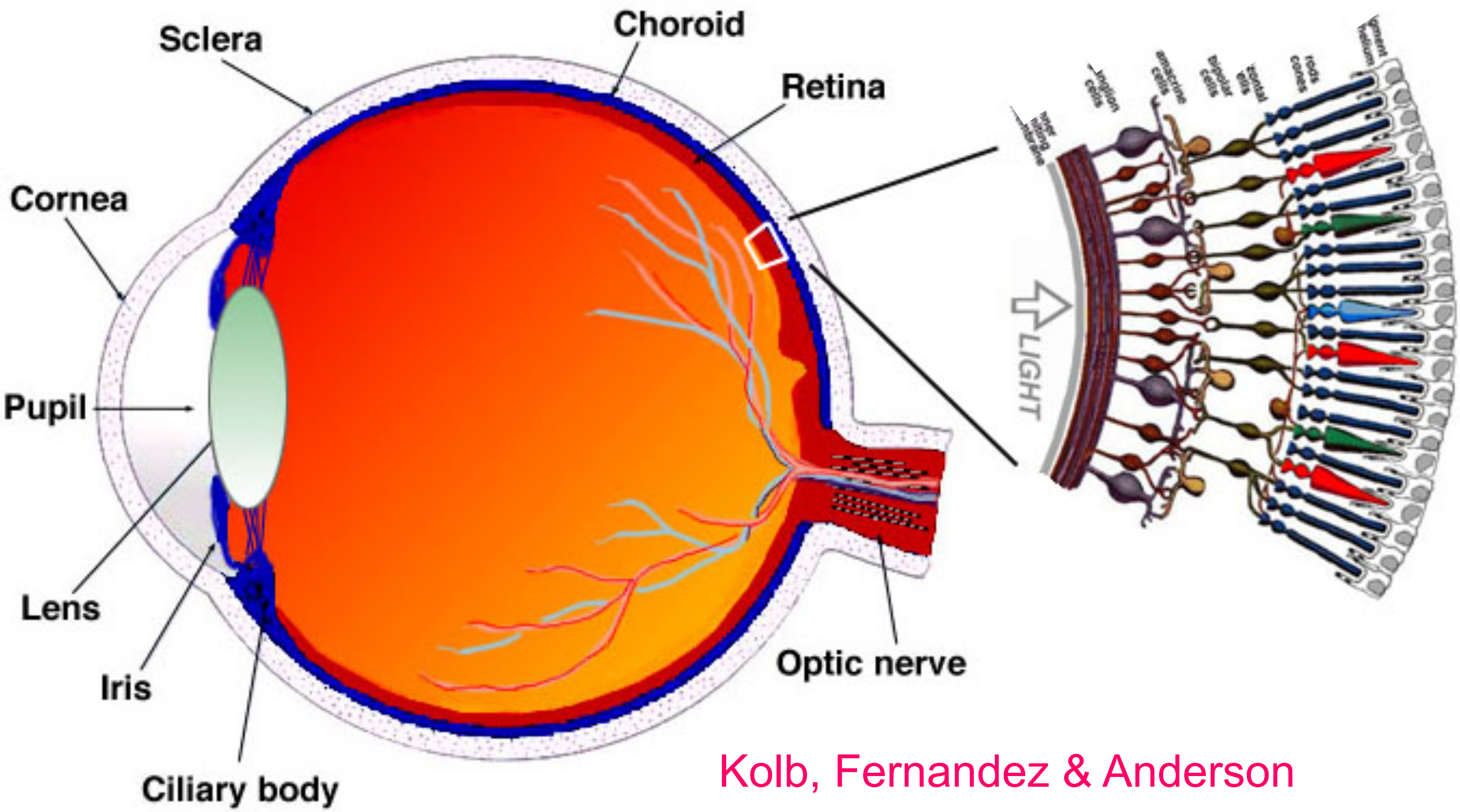
BLIND SPOT AND RETINAL VEINS

another reason for boundary completion and surface filling-in



Kolb, Fernandez & Anderson

http://retina.umh.es/Webvision/sretina.html

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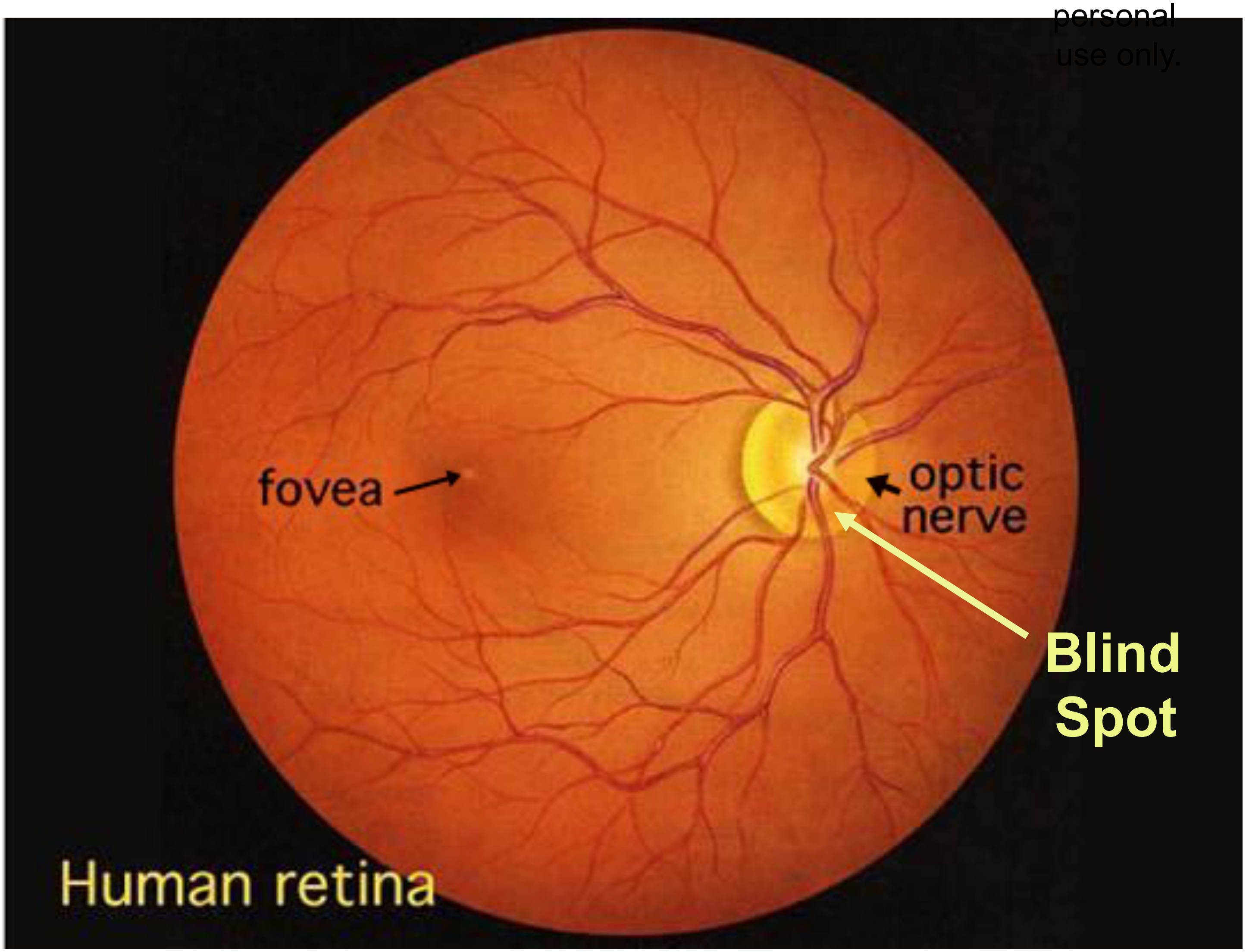
TOP-DOWN VIEW OF THE RETINA



Blind spot, retinal veins, and layers all interfere

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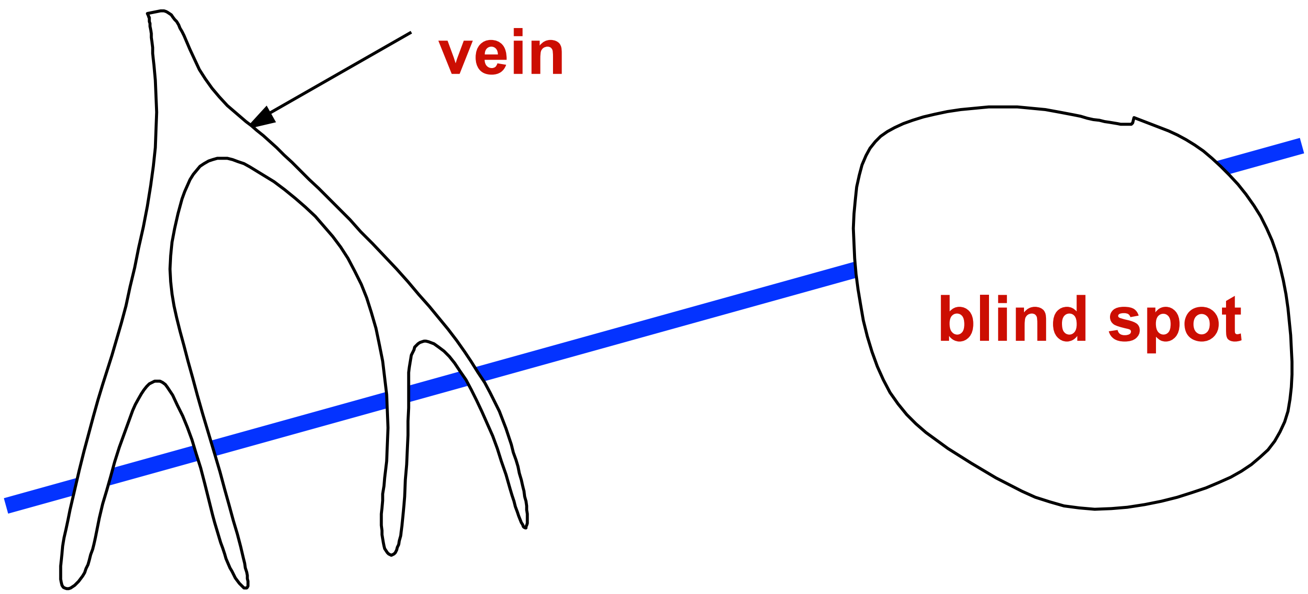
WHY DON'T WE SEE BLIND SPOT AND RETINAL VEINS?!

The pattern formed on a retina **by a dark line**



. . .is not even *connected!*

Eye jiggles in its orbit
Stabilized images fade

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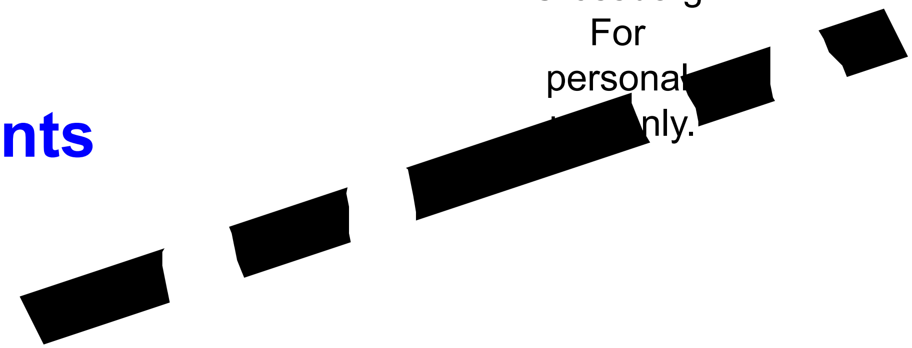
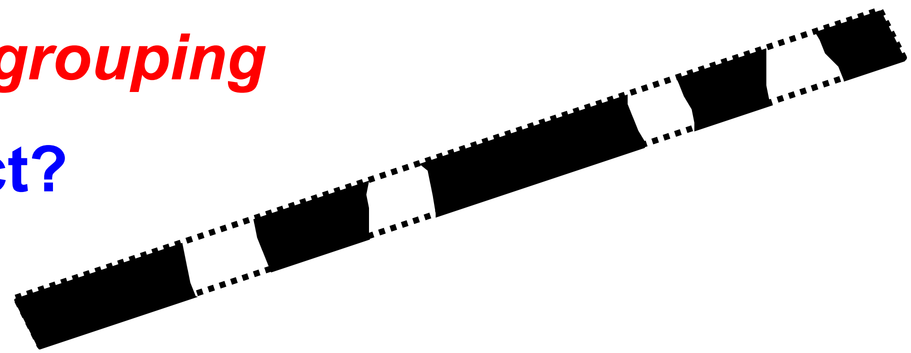
EVERY LINE IS AN ILLUSION!

Line is registered as fragments



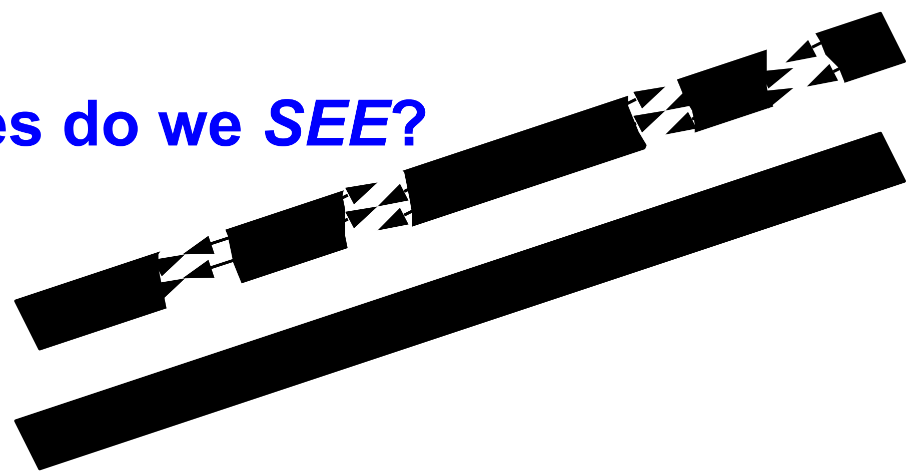
Boundary completion and grouping

Which boundaries to connect?



Surface filling-in

What colors and brightnesses do we *SEE*?



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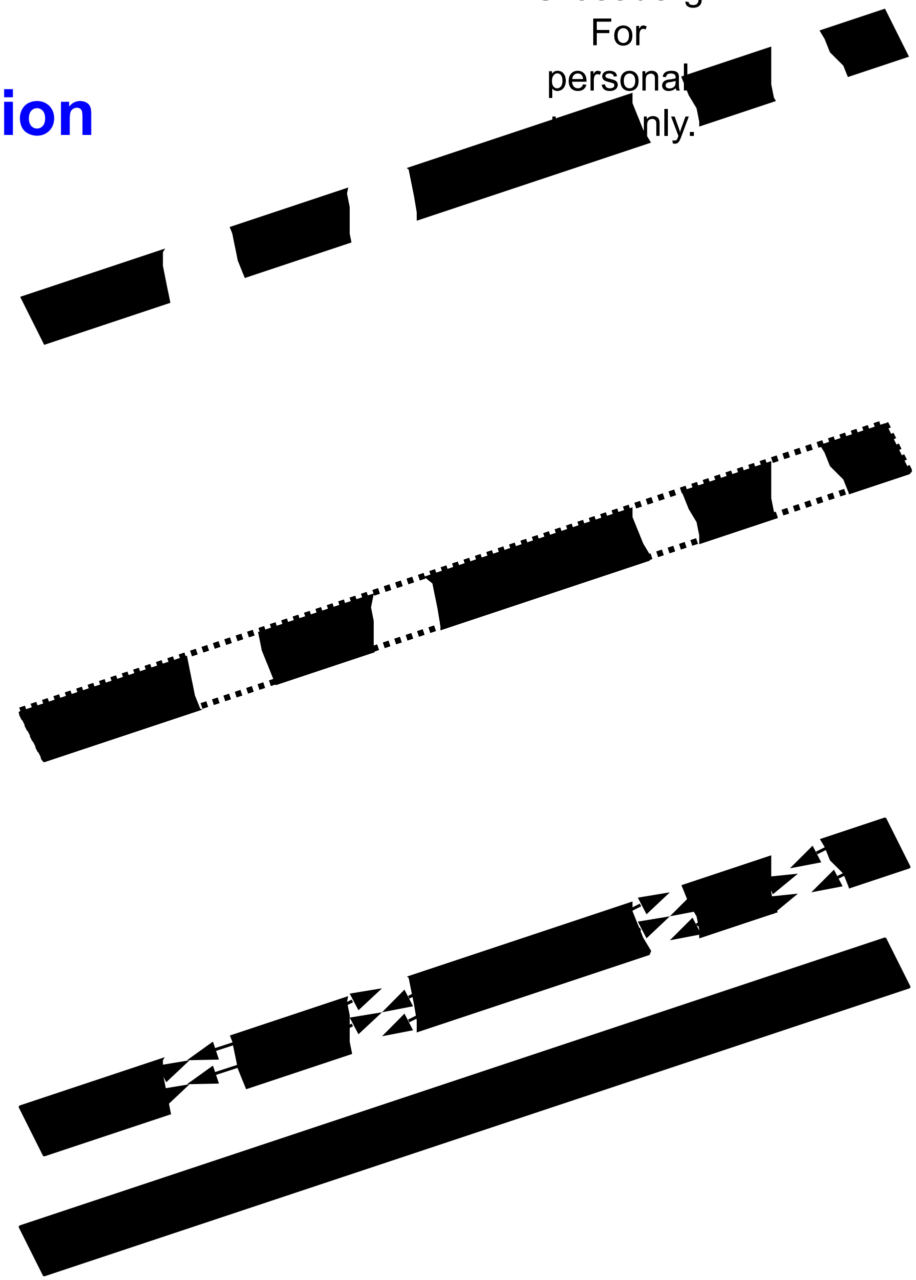
WHAT DO WE *CALL* AN ILLUSION?

…an unexpected combination of boundary completion and surface filling-in



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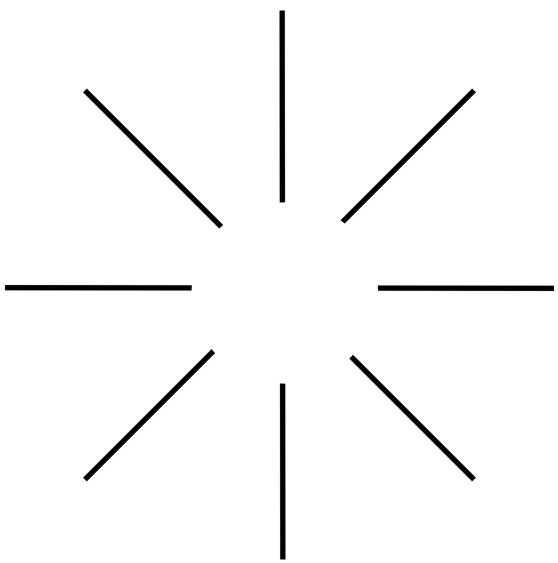
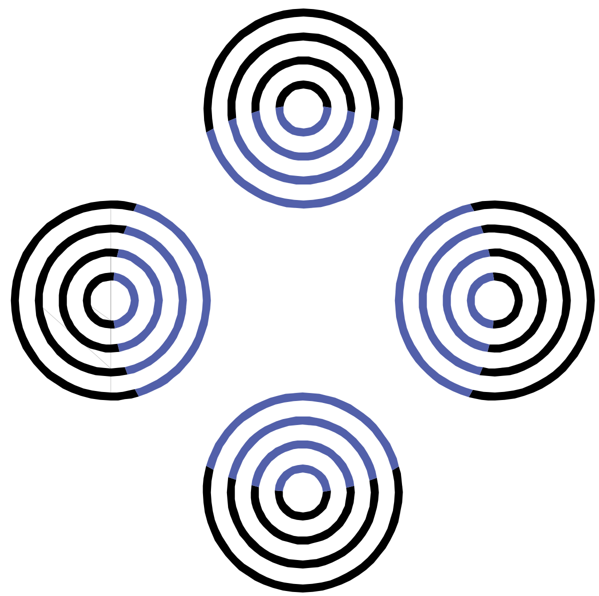
IF BOUNDARIES ARE INVISIBLE, HOW DO WE SEE?

Filling-In of Surface Color

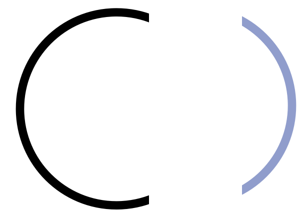
Boundaries define the compartments within which lightness and color spread



Ehrenstein (1941)



Varin (1971)



Neon color spreading

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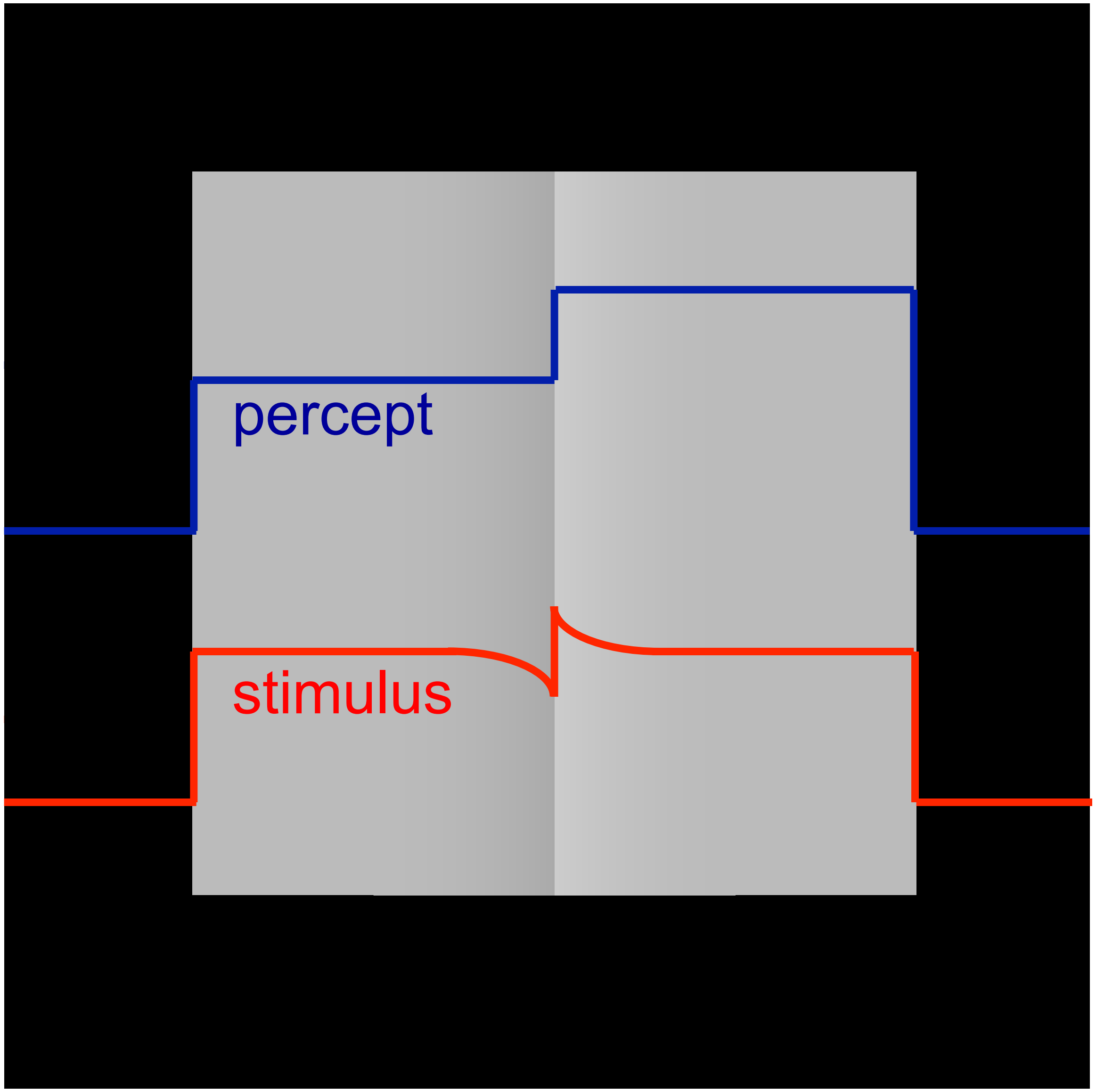
Craik-O'Brien-Cornsweet Effect

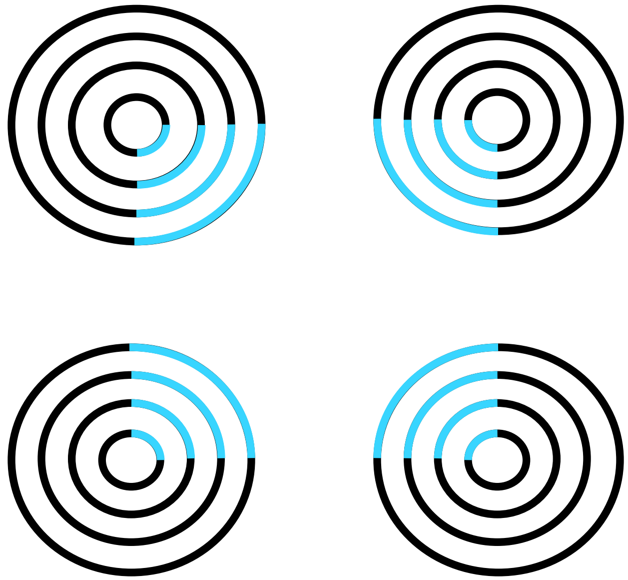


Boundary completion defines filling-in compartments

Filling-in determines what we see in each compartment

Grossberg (1984)
Todorović (1987)

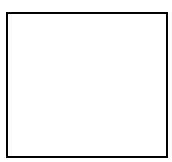
VISUAL BOUNDARY AND SURFACE COMPUTATIONS ARE COMPLEMENTARY



Neon color spreading

All Boundaries Are Invisible!

BOUNDARY COMPLETION



oriented
inward
insensitive to direction-of-contrast

SURFACE FILLING-IN

unoriented
outward
sensitive to direction-of-contrast

Filling-in of Visible Color and Lightness

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PREDICTIONS

Grossberg (1984)

ALL BOUNDARIES ARE INVISIBLE
in the interblob stream

VISIBLE QUALIA ARE SURFACE PERCEPTS
in the blob stream

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WHAT IS THIS TALK ABOUT?

Paintings of visual artists activate multiple brain processes that contribute to conscious perception

Paintings of different artists and artistic movements emphasize different combinations of brain processes to achieve their aesthetic goals

Neural models of how advanced brains see characterize these processes, and were used to analyze paintings of 10 painters:

Jo Baer, Banksy, Ross Bleckner, Gene Davis, Charles Hawthorne, Henry Hensche, Henri Matisse, Claude Monet, Jules Olitski, Frank Stella

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DID ARTISTS LIKE MATISSE KNOW THAT ALL BOUNDARIES ARE INVISIBLE?!

Yes: It was the basis of the Fauve artistic movement

Matisse, The Roofs of Collioure, 1905

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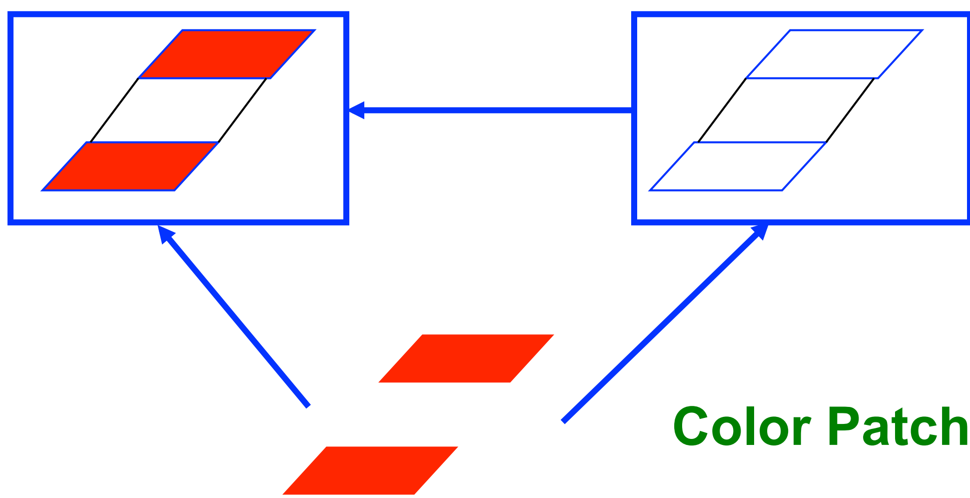
MATISSE KNEW THAT
ALL BOUNDARIES ARE INVISIBLE

He went through a life-long struggle to understand
"the eternal conflict between drawing and color"

"Instead of drawing an outline and filling in the color…
I am drawing directly in color"

H. Matisse, Jazz (1947)

Surface color and form



Amodal boundary web

Color Patches on Canvas

Drawing an explicit boundary could DARKEN THE COLORS!
via color assimilation

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COMPLEMENTARITY! MANY INVISIBLE BOUNDARIES!

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Matisse, The Roofs of Collioure, 1905

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Continuously induced surface

Matisse, Open Window, Collioure 1905

Sparsely induced surfaces

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DRAWING DIRECTLY IN COLOR

Many artists have experienced Matisse's struggle to be "DRAWING DIRECTLY IN COLOR"

PLEIN AIR PAINTERS
CAPE COD SCHOOL OF ART: DRAWING IN COLOR

Charles Hawthorne:

"Beauty in art is the delicious notes of color one against the other …all we have to do is to get the color notes in their proper relation... put down spots of color…the outline and size of each spot of color against every other spot of color it touches, is the only kind of drawing you need bother about…Let color make form—do not make form and color it. Forget about drawing…drawing the form, and painting, are better separated. The first thing is to learn to see color…"

Hawthorne, C. W. (1938/1960). *Hawthorne on painting.* Mineola, New York: Dover.

PLEIN AIR PAINTERS

CAPE COD SCHOOL OF ART: DRAWING IN COLOR

Henry Hensche:

When Monet came along…he revolutionized the 'art of seeing.' …The landscape helped Monet determine how color expressing the light key was the first ingredient in a painting, not drawing… Every form change must be a color change…"

Robichaux, J. W. (1997). *Hensche on painting*. Mineola, New York: Dover.

PLEIN AIR PAINTERS
FRENCH IMPRESSIONISTS: DRAWING IN COLOR

Claude Monet:

"When you go out to paint, try to forget what objects you have before you, a tree, a house, a field, or whatever. Merely think, here is a little square of blue, here an oblong of pink … paint it just as it looks to you, the exact color and shape, until it gives your own naïve impression of the scene before you…"

Perry, 1927, p. 120

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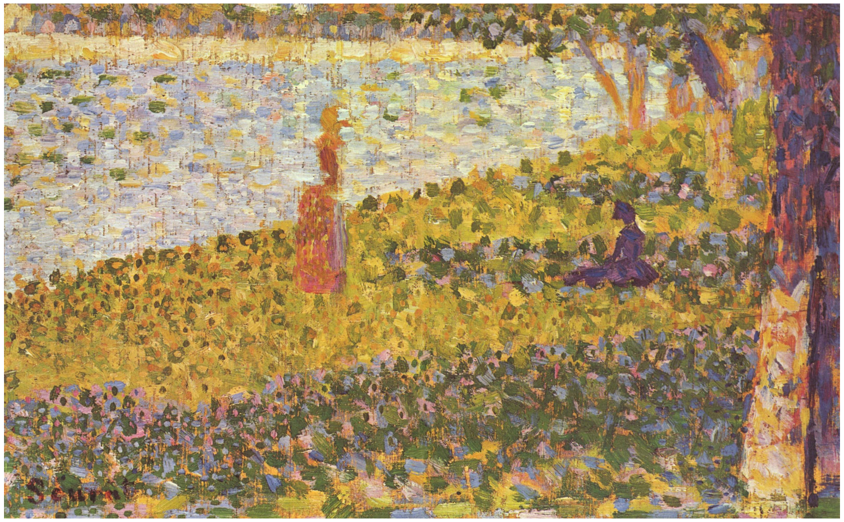
FRENCH IMPRESSIONISTS : SEURAT



Seurat, Femmes au bord de l'eau

Boundaries complete between regions where feature contrasts change

Boundary groupings organize filling-in of colors within them to form visible surface percepts

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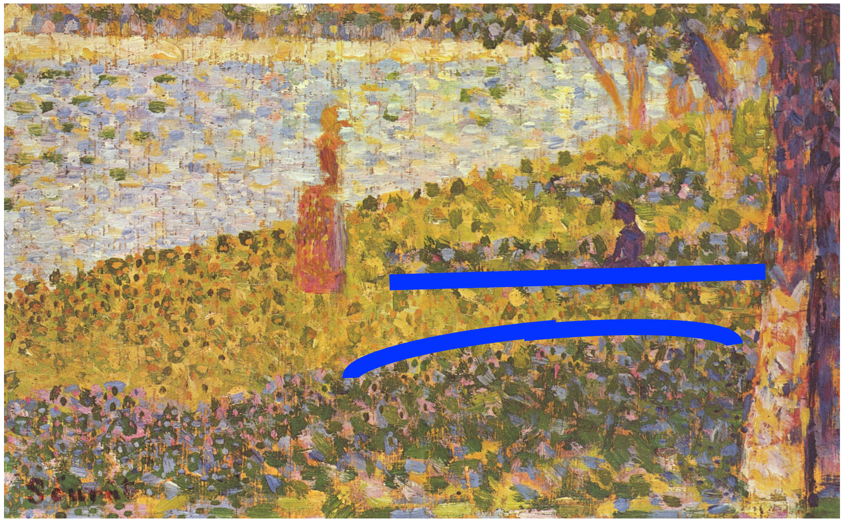
FRENCH IMPRESSIONISTS : SEURAT

On a large scale



Seurat, Femmes au bord de l’eau

Boundaries complete between regions where feature contrasts change

Boundary groupings organize filling-in of colors within them to form visible surface percepts

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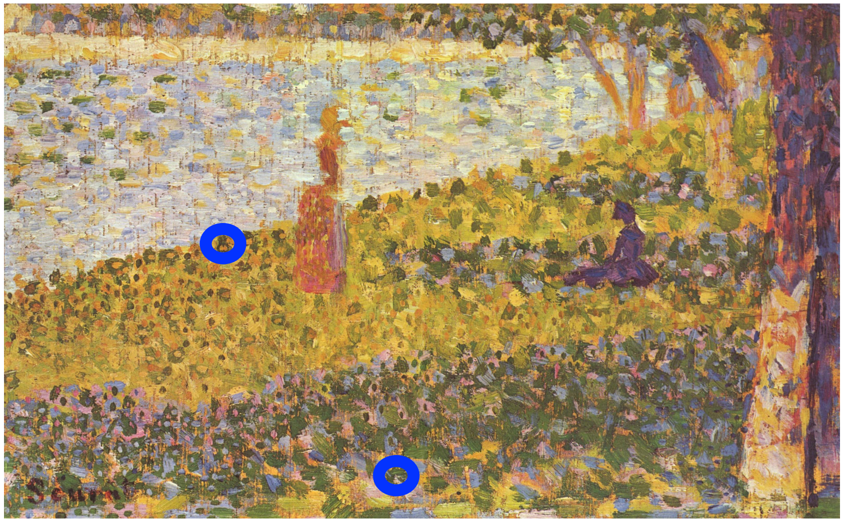
FRENCH IMPRESSIONISTS : SEURAT

And a small scale…e.g., individual dots



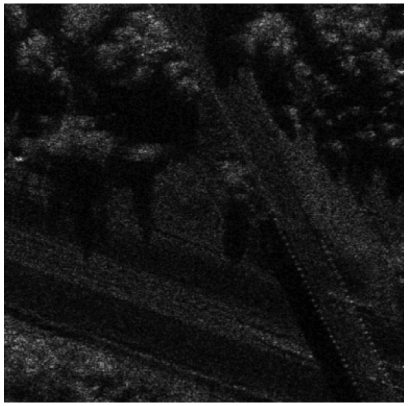
Seurat, Femmes au bord de l'eau

Boundaries complete between regions where feature contrasts change

Boundary groupings organize filling-in of colors within them to form visible surface percepts

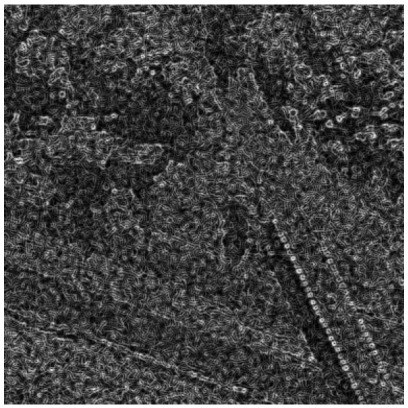
DO THESE IDEAS WORK ON HARD PROBLEMS?

From Seurat to SAR

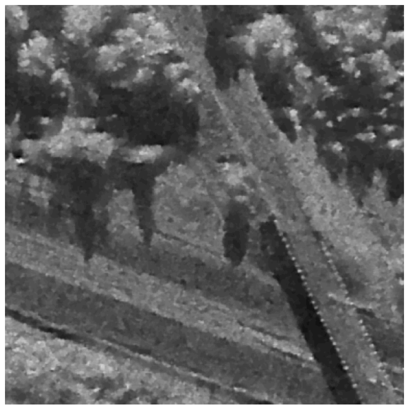


input

feature



boundary



surface filling-in

Application:
Image Enhancement

Synthetic aperture radar sees through the weather

signal: 5 orders of magnitude of power In radar return

multiplicative noise

sparse high-intensity pixels

Clarifies how we see an Impressionistic painting

Mingolla, Ross, and Grossberg (1999)

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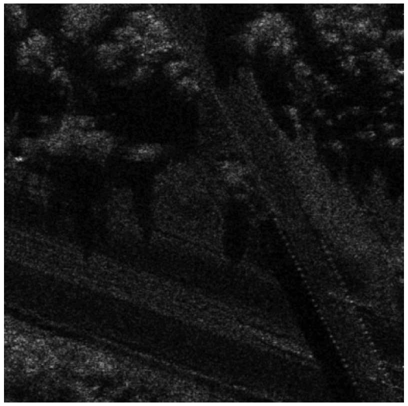
DO THESE IDEAS WORK ON HARD PROBLEMS?
From Seurat to SAR

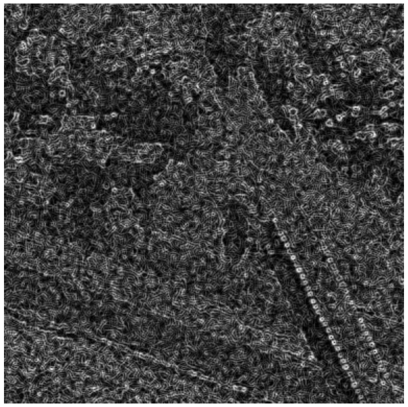


input

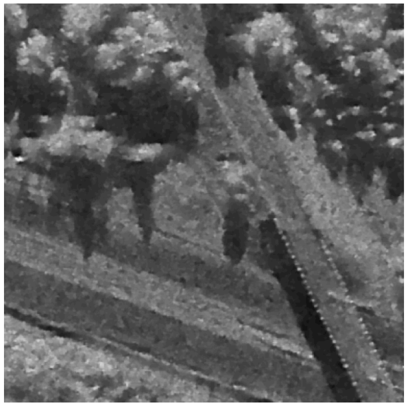
feature

Discounting the Illuminant normalizes the image: It preserves RELATIVE activities without SATURATION

Still shows individual PIXELS



boundary



surface filling-in

Filling-in averages brightnesses within boundary compartments

Boundaries complete between regions where normalized feature contrasts change

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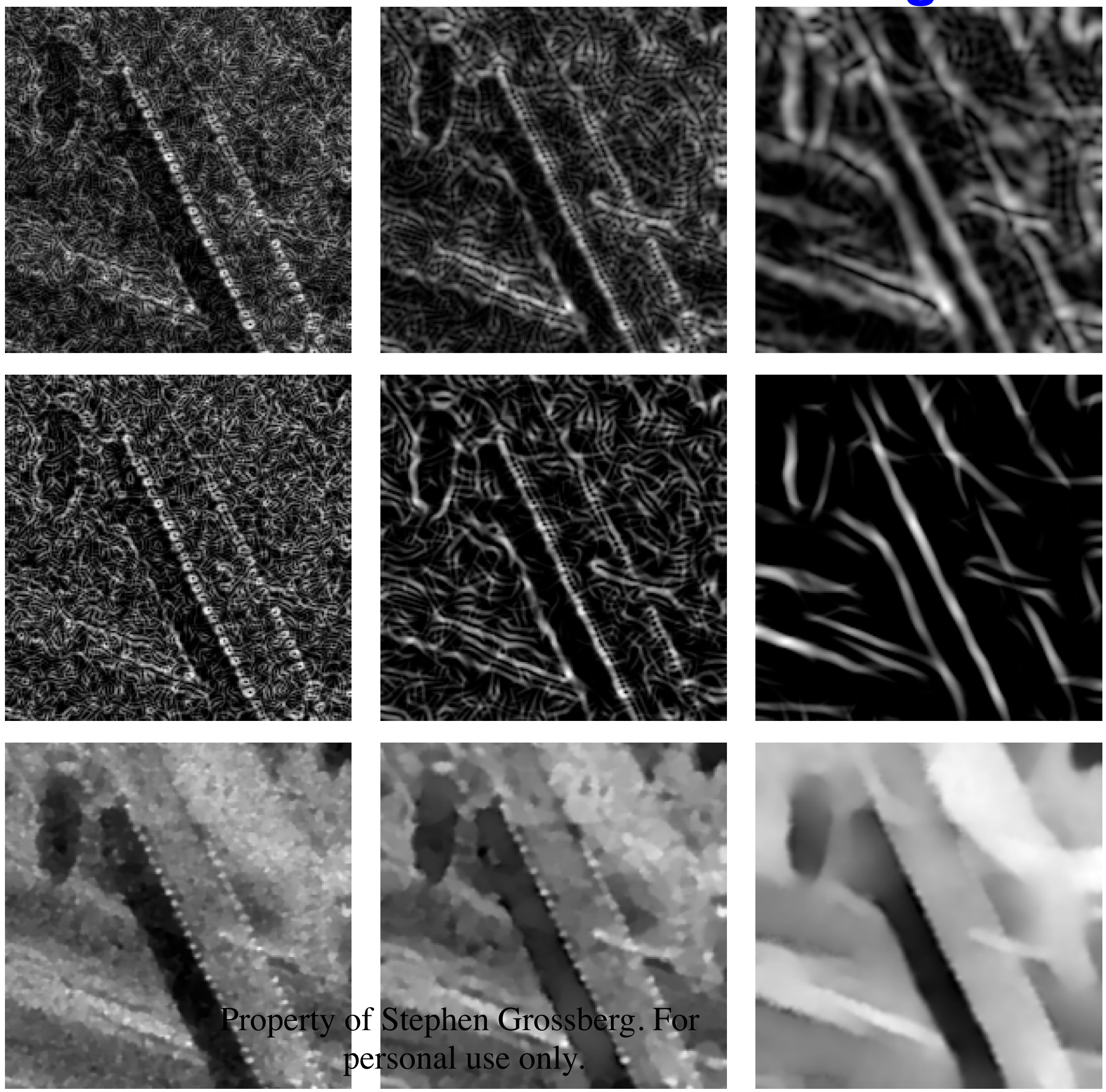
MULTIPLE SCALE BOUNDARIES AND FILLING-IN

Scale: small | medium | large

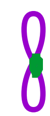
boundaries before completion

boundaries after completion

surface filling-in



large scale bipole:



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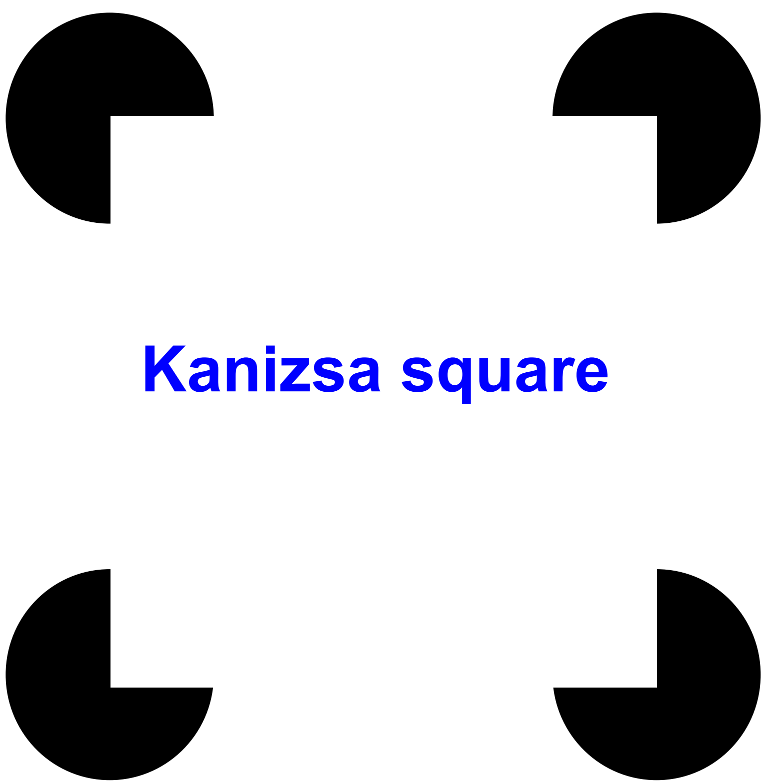
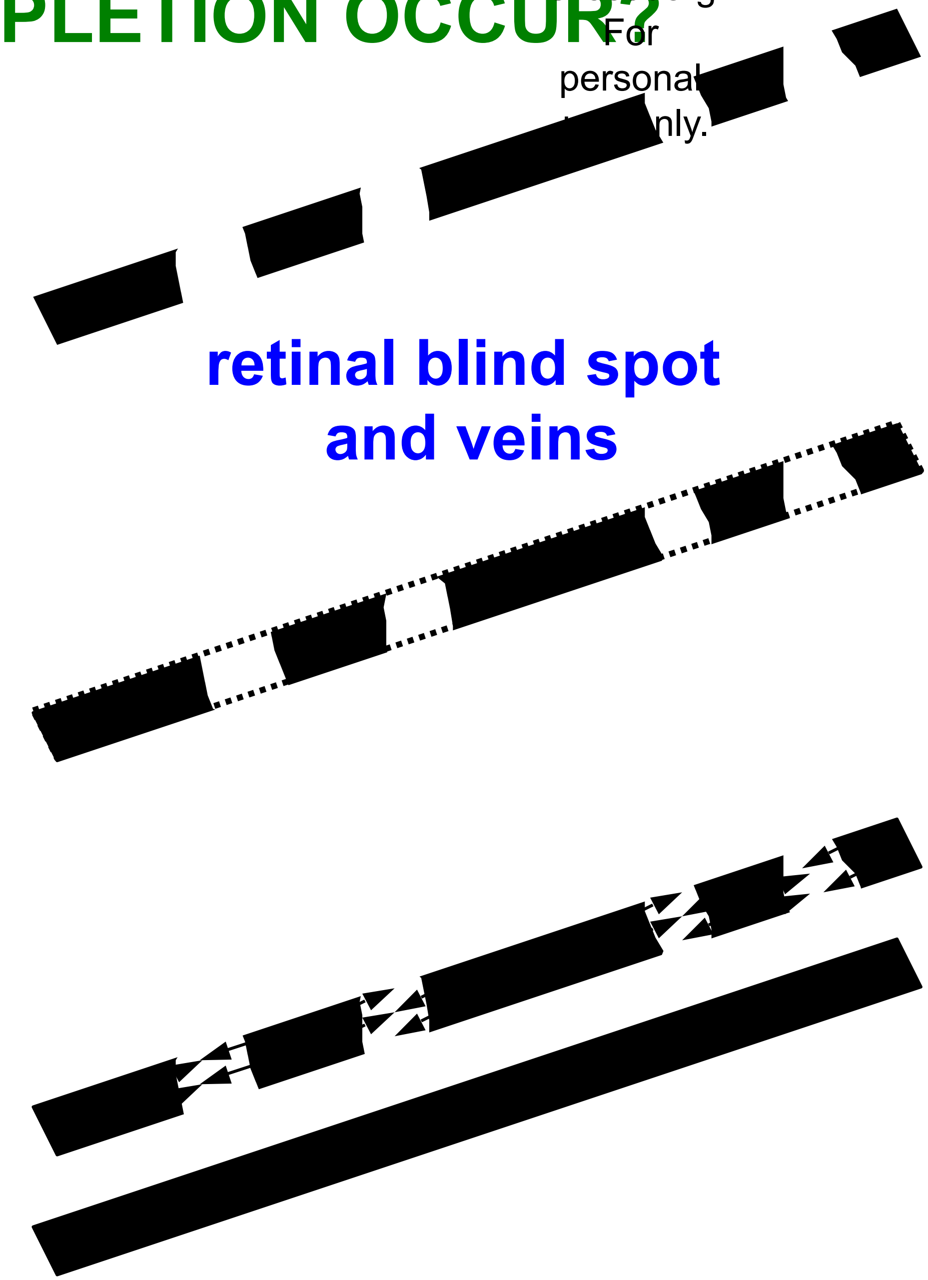
HOW DOES INWARD, ORIENTED BOUNDARY COMPLETION OCCUR?

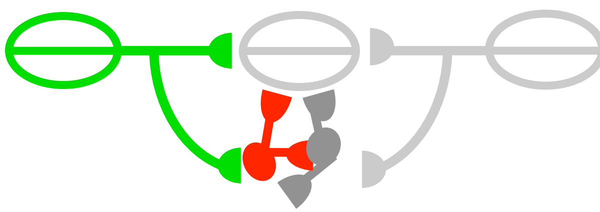


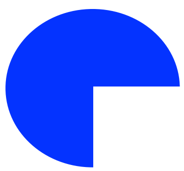
Kanizsa square



retinal blind spot and veins

1984 PREDICTION:
BIPOLE PROPERTY CONTROLS PERCEPTUAL GROUPING

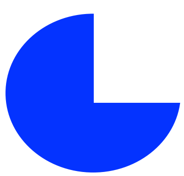




Input on just one side

ONE-AGAINST-ONE:
Balanced Excitation and Inhibition

Cell not excited



Grossberg, 1984
Grossberg & Mingolla, 1985
Laminar: Grossberg, Mingolla & Ross, 1997

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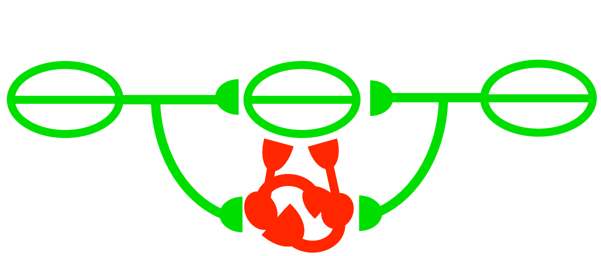
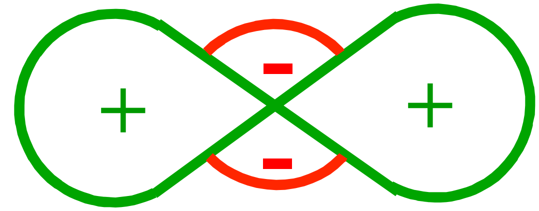
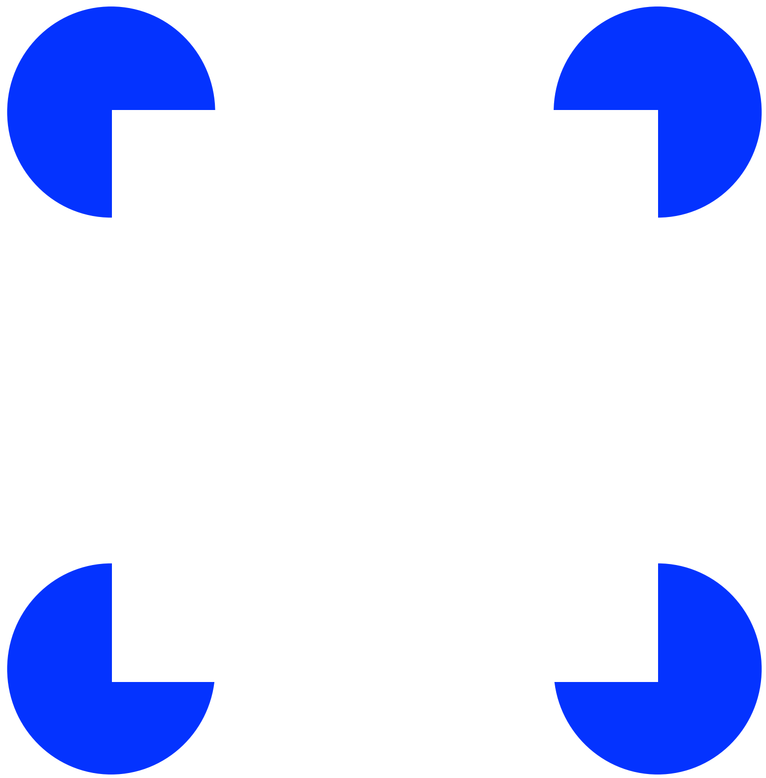
BIPOLE PROPERTY CONTROLS PERCEPTUAL GROUPING



vs.





Collinear input on both sides

Excitatory inputs summate

Inhibitory inputs normalize

Shunting inhibition!

TWO-AGAINST-ONE

Cell is excited

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BIPOLES: FIRST NEUROPHYSIOLOGICAL EVIDENCE from cortical area V2

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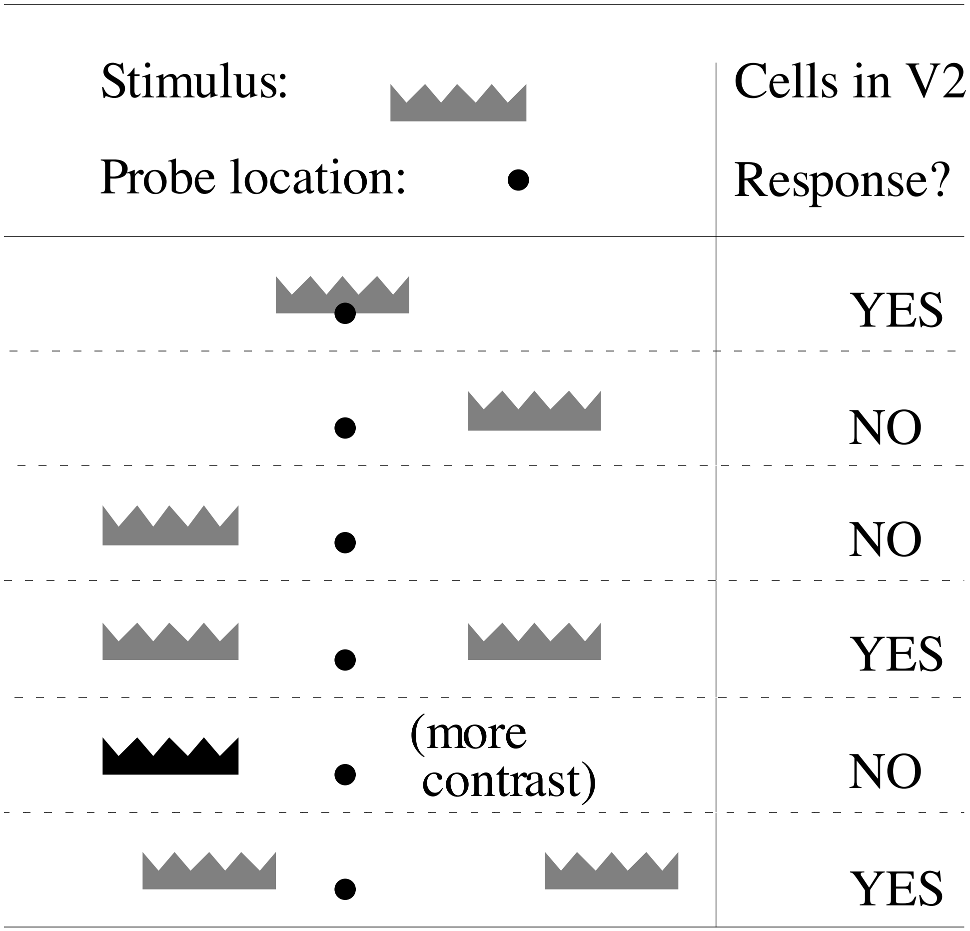
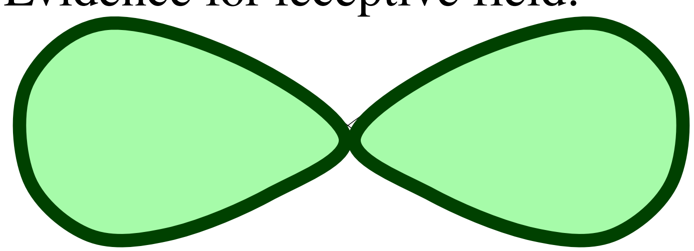


Evidence for receptive field:

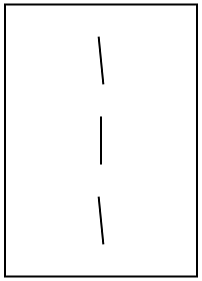


von der Heydt, Peterhans, and Baumgartner, 1984

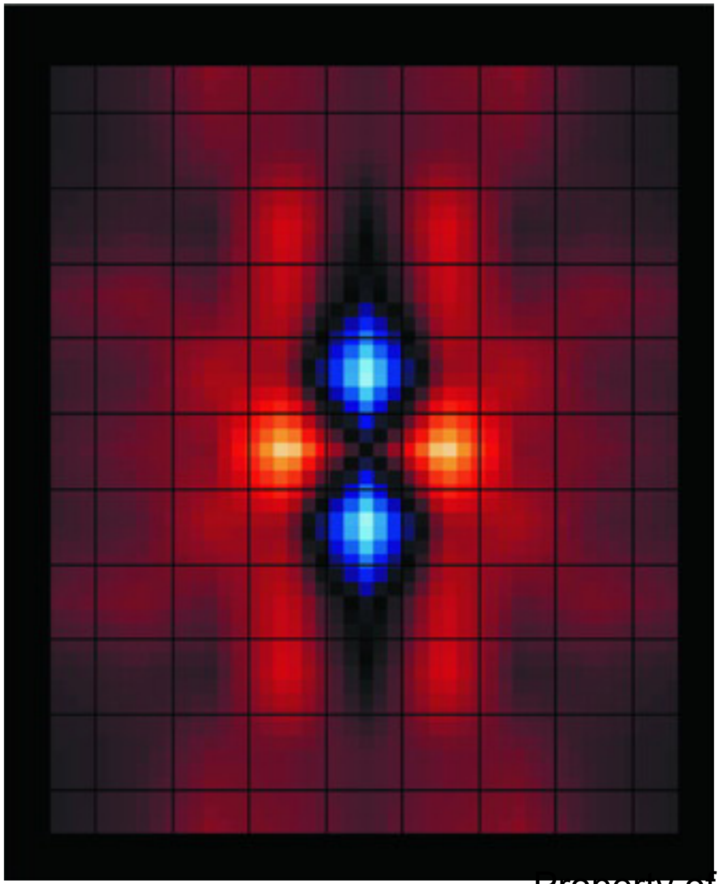
Peterhans and von der Heydt, 1988

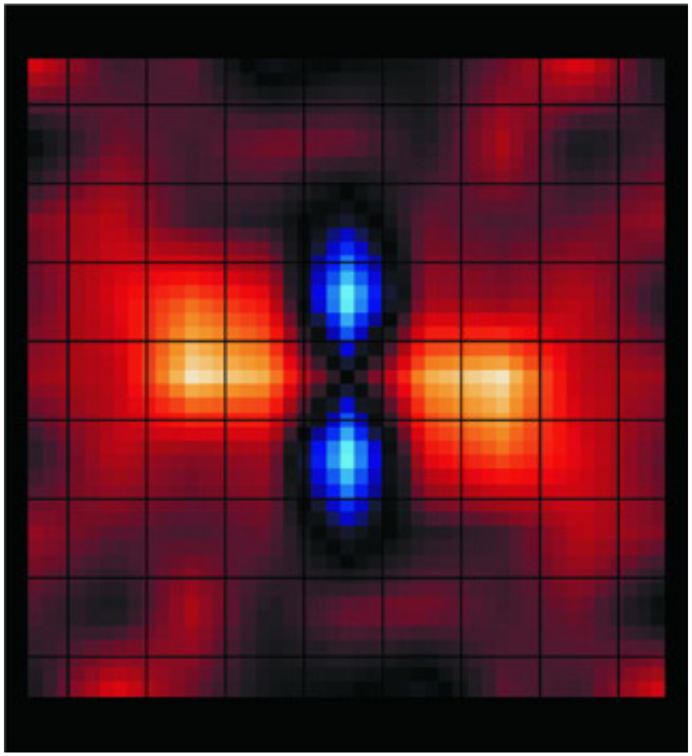
KAPADIA, ITO, GILBERT & WESTHEIMER (1995)

Psychophysics



Neurophysiology V1





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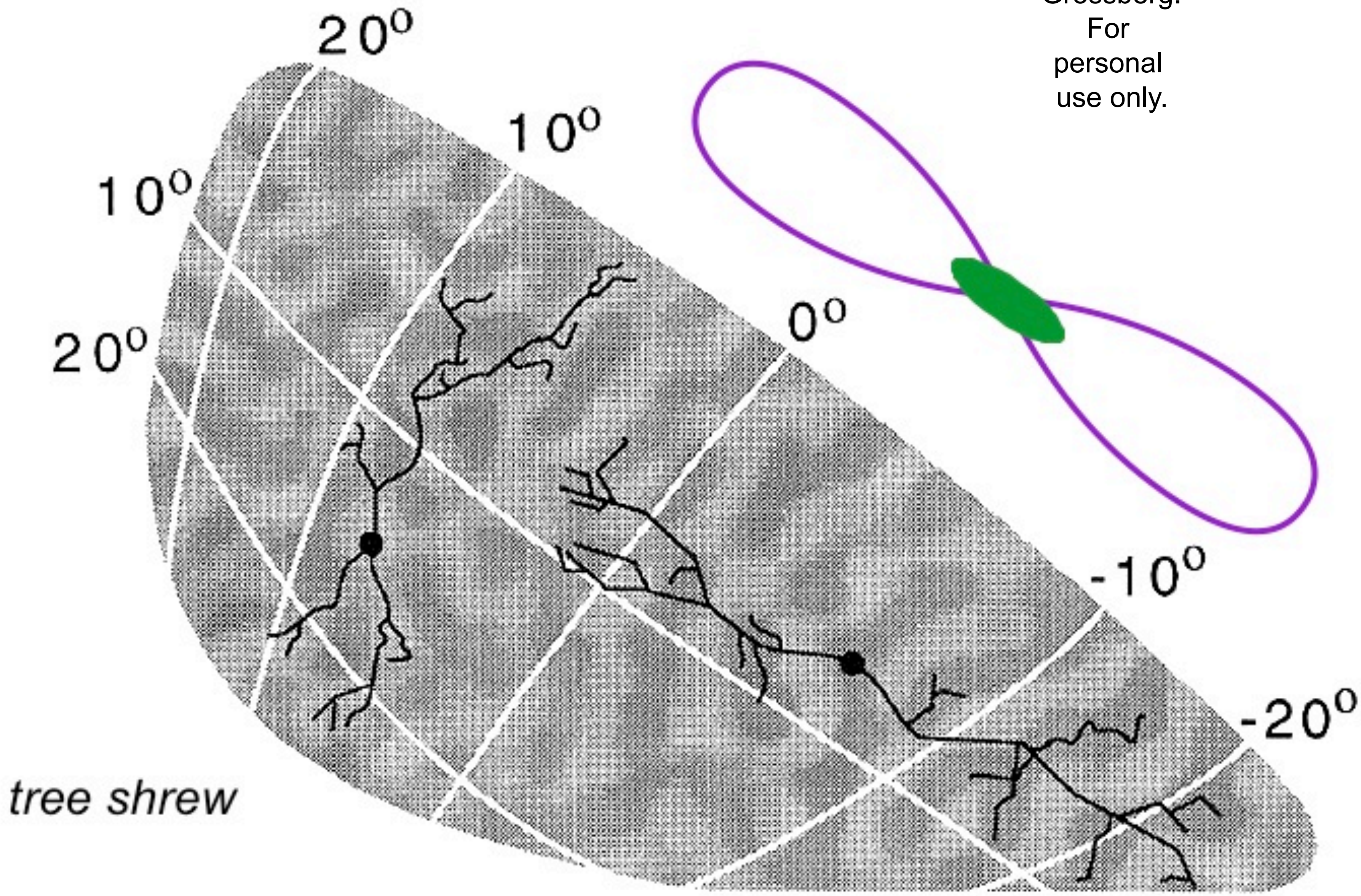
ANATOMY: HORIZONTAL CONNECTIONS (V1)



Bosking, *et al.*, 1997

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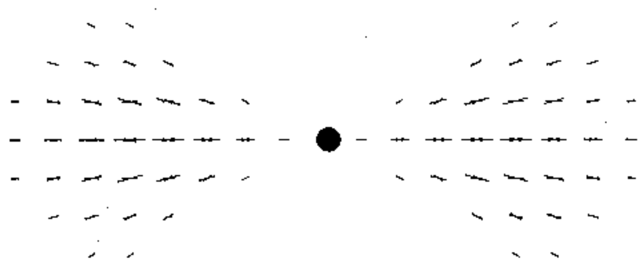
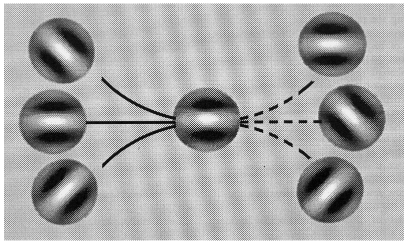
BIPOLES THROUGH THE AGES

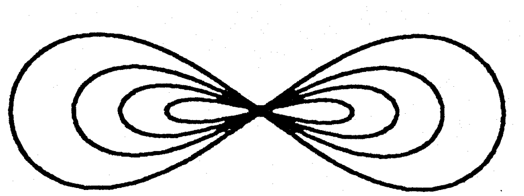
Grossberg and Mingolla, 1985



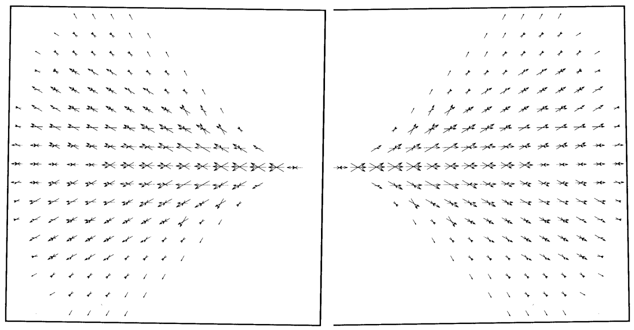
Field, Hayes, and Hess, 1993
"association field"



Heitger and von der Heydt, 1993



Williams and Jacobs, 1997



Cf. "relatability" geometric constraints on which contours get to group with which Kellman & Shipley, 1991

HOW DOES GROUPING OCCUR IN THE VISUAL CORTEX?

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BREAKTHROUGHS IN BRAIN COMPUTING

Models that link detailed BRAIN CIRCUITS to the ADAPTIVE BEHAVIORS that they control

Mind/Body Problem

Describe NEW PARADIGMS for brain computing

INDEPENDENT MODULES
Computer Metaphor

COMPLEMENTARY COMPUTING
What is the nature of brain specialization?

LAMINAR COMPUTING
Why are all neocortical circuits organized in layers?
How do laminar circuits give rise to biological intelligence?

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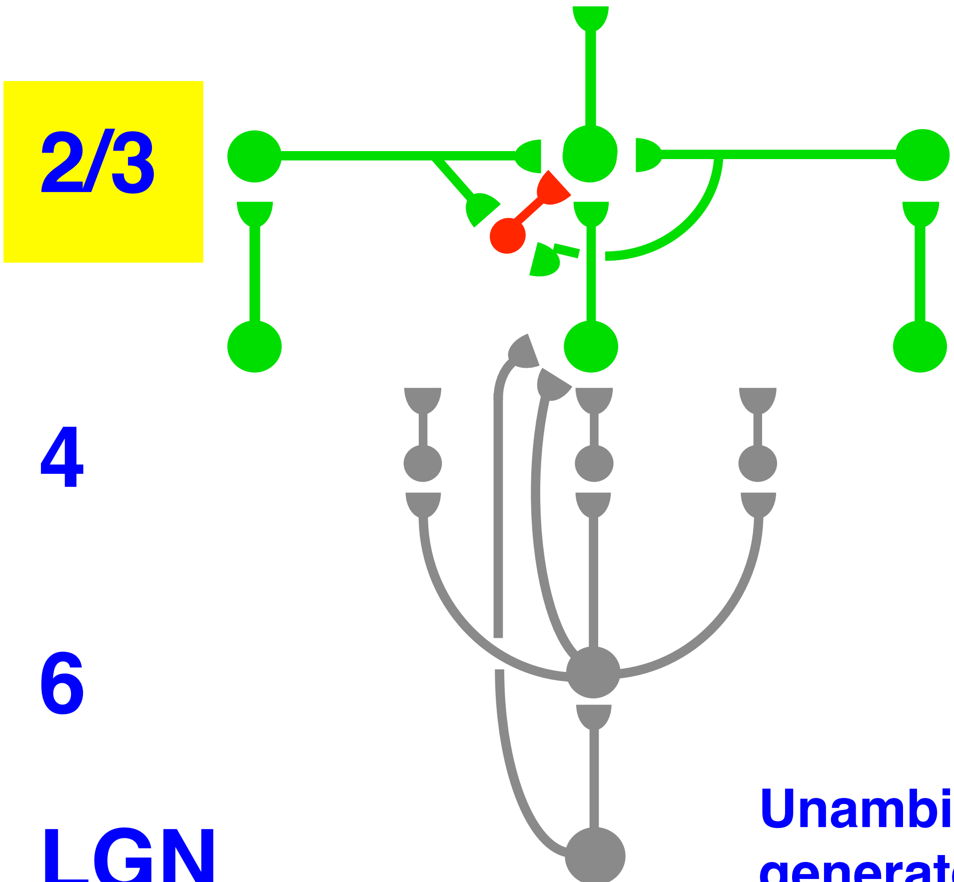
GROUPING STARTS IN LAYER 2/3



Long-range
horizontal excitation links
collinear, coaxial receptive fields

Gilbert & Wiesel, 1989
Bosking et al., 1997
Schmidt et al, 1997

Short-range
disynaptic inhibition of target pyramidal via pool of interneurons

Hirsch & Gilbert, 1991

Unambiguous groupings can form and generate feedforward outputs quickly

Thorpe et al, 1996

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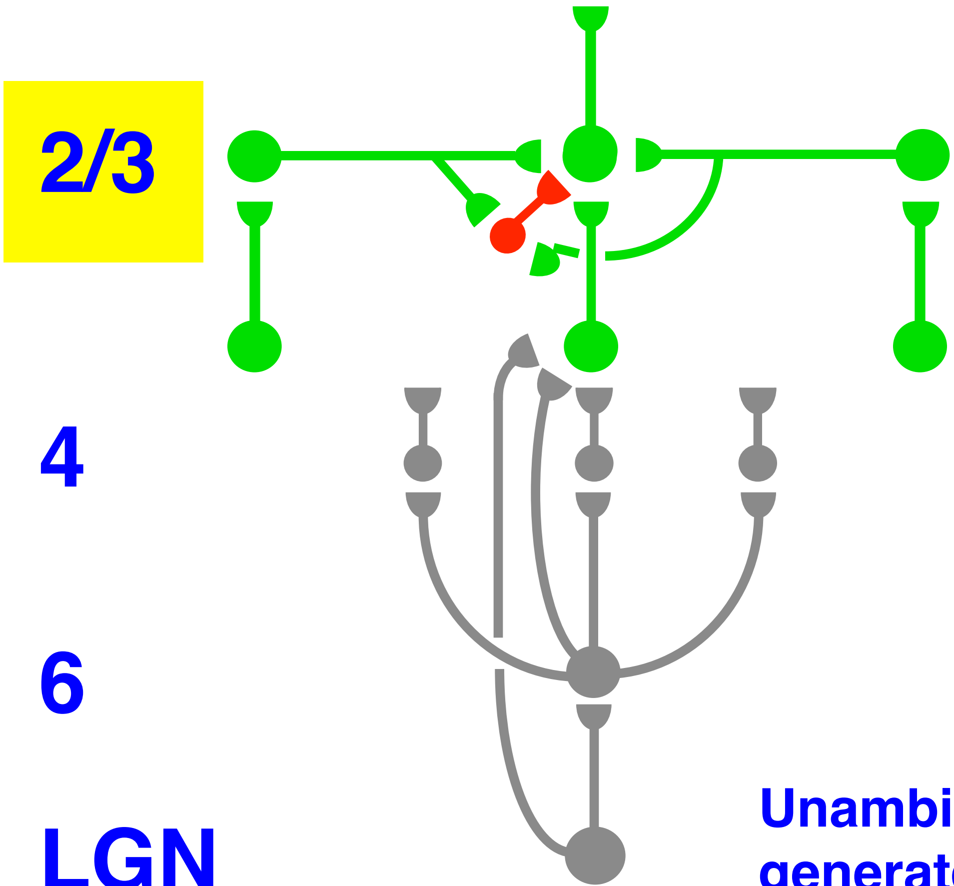
GROUPING STARTS IN LAYER 2/3

What happens before layer 2/3?



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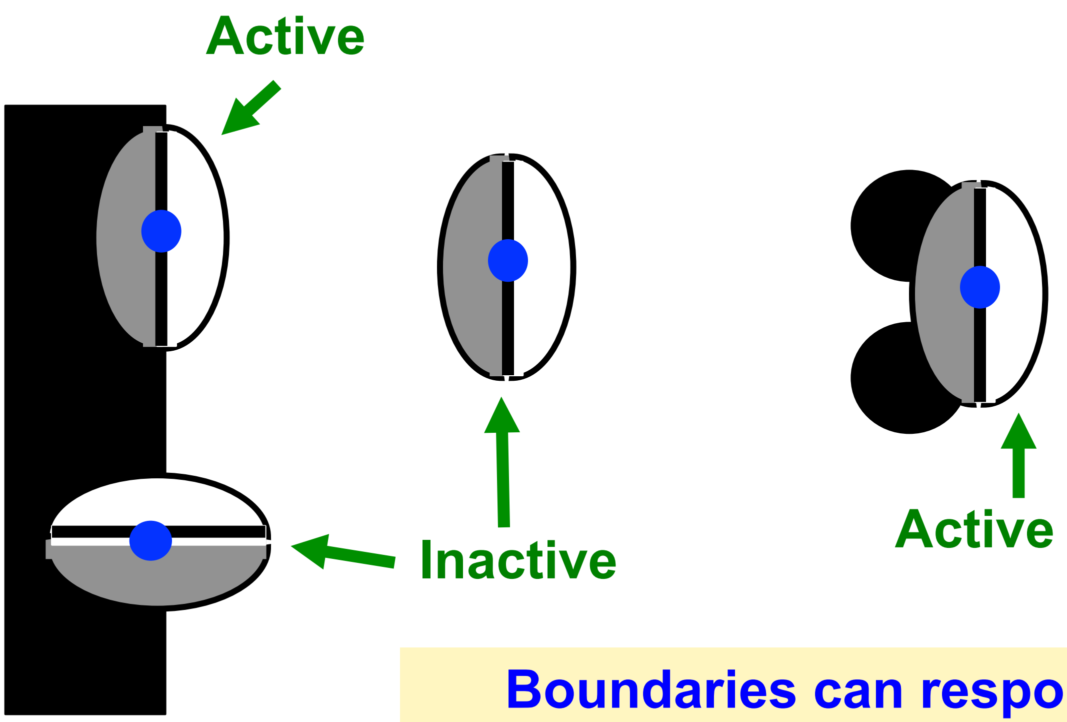
FROM ORIENTED FILTERING TO GROUPING AND BOUNDARY COMPLETION

Oriented Receptive Fields: SIMPLE CELLS

Hubel and Wiesel, 1968



Sensitive to:
- orientation
- amount of contrast
- direction of contrast
- spatial scale

ORIENTED LOCAL CONTRAST DETECTORS

Not EDGE detectors!

Boundaries can respond to edges, textures, and shading in a form-sensitive way

BOUNDARY WEBS!

SIMPLE CELLS ARE NOT SUFFICIENT!

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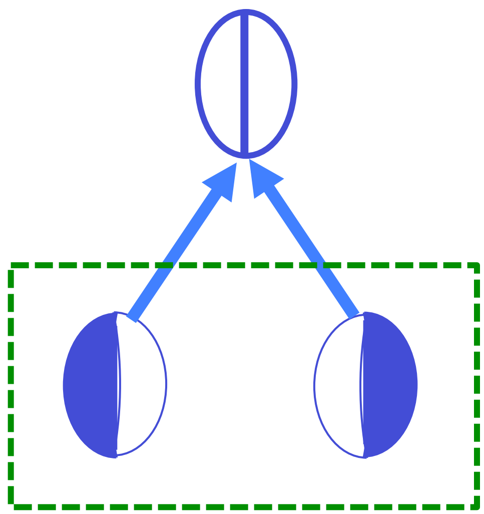
ALL BOUNDARIES ARE INVISIBLE: COMPLEX CELLS

complex cells pool inputs from opposite-polarity simple cells in V1

V1



complex cells

simple cells

Complex cells are amodal boundary detectors Grossberg (1984)

vs

"color cells in the broadest sense" Thorell, DeValois & Albrecht (1984)

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COMPLEX CELLS ARE NOT SUFFICIENT!

They cannot detect places in an image or painting with sudden curvature changes

Corners

Line ends

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BRAINS DO NOT OBEY CLASSICAL GEOMETRY

A line is NOT A COLINEAR SERIES OF POINTS

A line is an
EMERGENT PROPERTY
of
MULIPLE PROCESSING STAGES
that realize a

HIERARCHICAL RESOLUTION OF UNCERTAINTY

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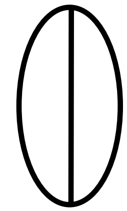
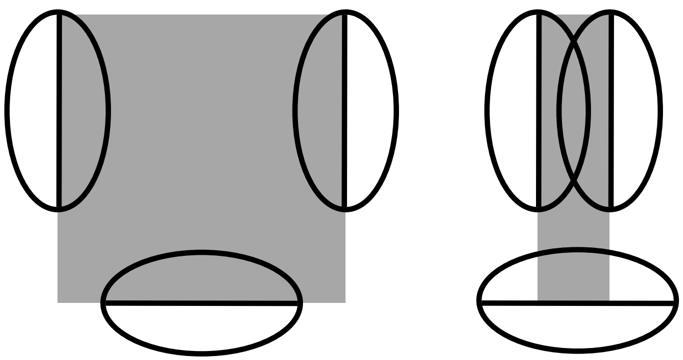
HIERARCHICAL RESOLUTION OF UNCERTAINTY

For a given receptive field size:

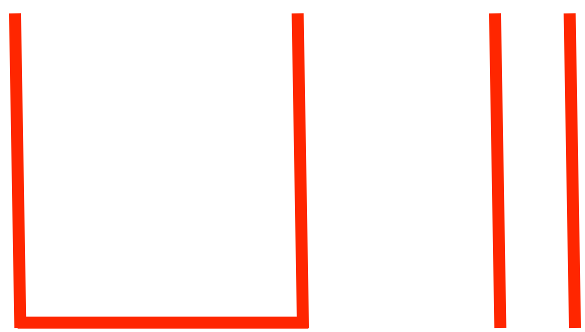


Different responses occur at bar ends and line ends:

bar end line end



For a *thin* line
no detector
perpendicular to line end
can respond enough to
close the boundary there



Network activity

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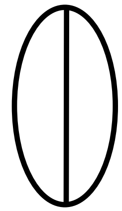
HIERARCHICAL RESOLUTION OF UNCERTAINTY

For a given receptive field size:



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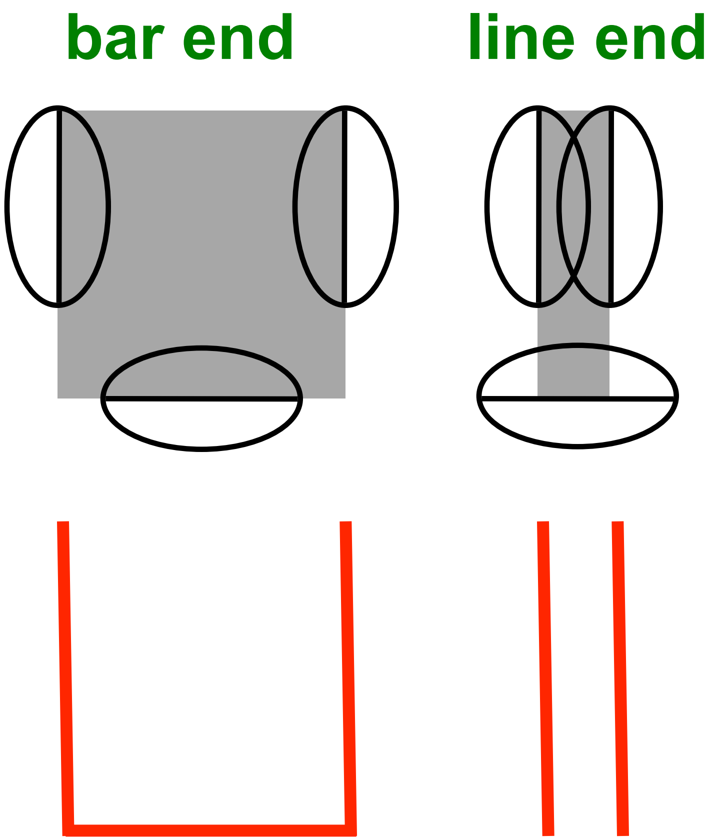

For a *thin* line no detector perpendicular to line end can respond enough to close the boundary there

Network activity

WHO CARES?!

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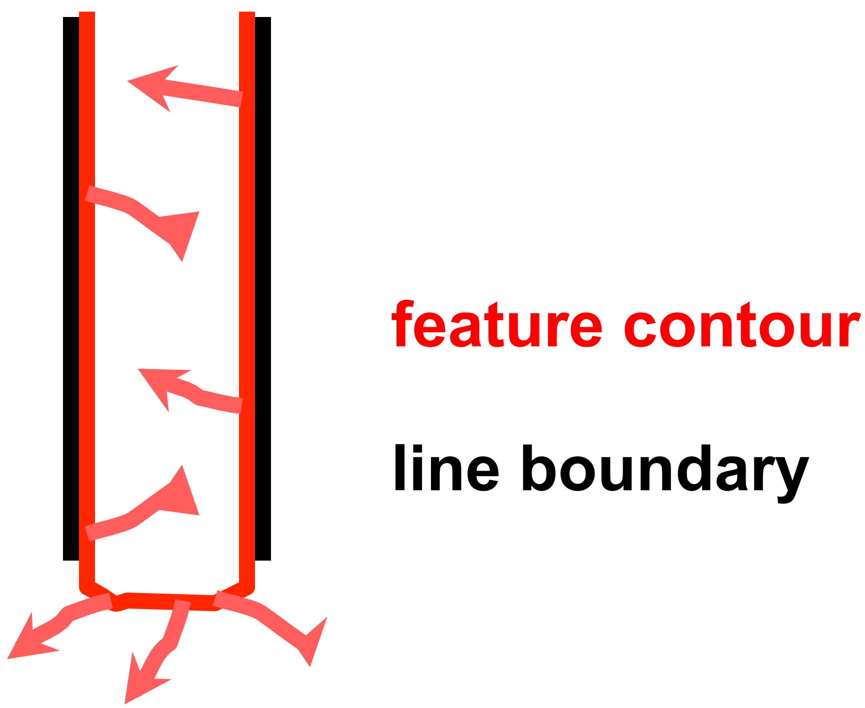
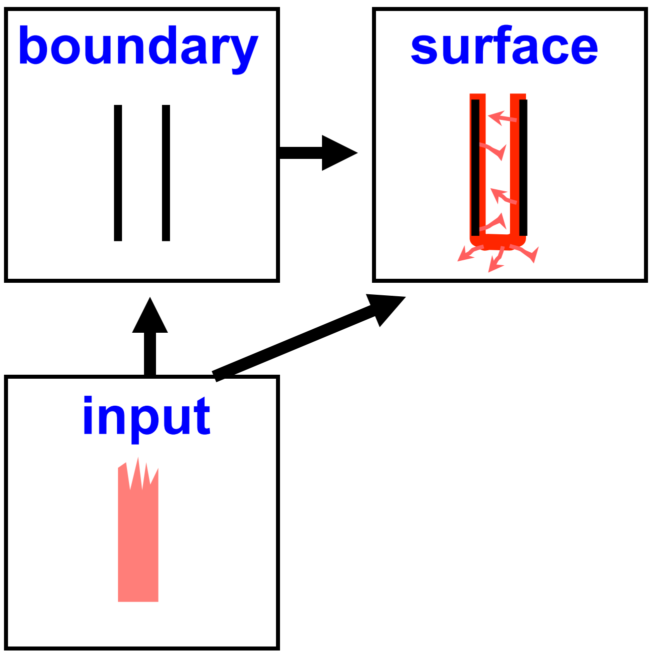
IT WOULD CAUSE A PERCEPTUAL DISASTER WHEN SURFACE FILLING-IN OCCURS





Color would flow from EVERY line end!

…as it does during neon color spreading

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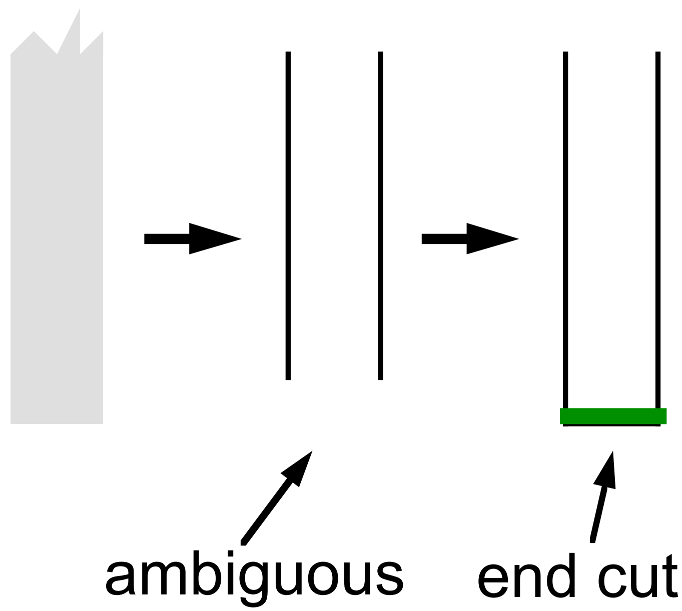
HIERARCHICAL RESOLUTION OF UNCERTAINTY

END CUTS

The boundary system must CREATE a line end at next processing stage:

EVERY LINE END IS ILLUSORY!



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HIERARCHICAL RESOLUTION OF UNCERTAINTY

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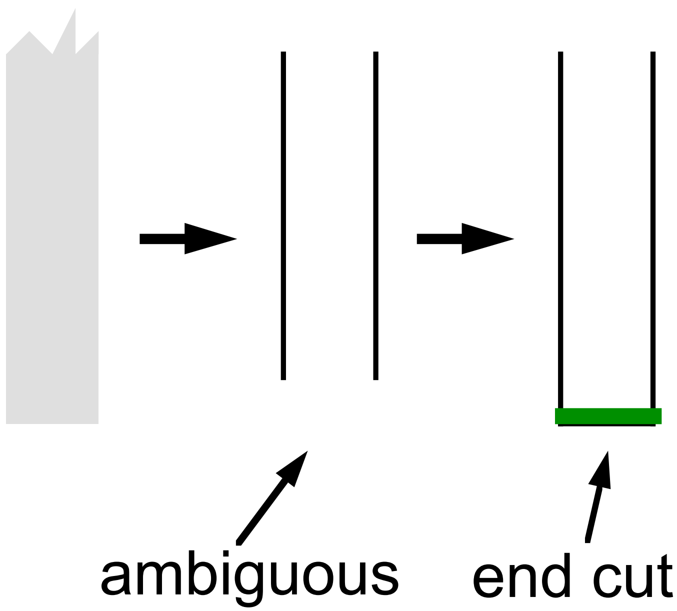

vertical → vertical
ambiguous → horizontal

A Pattern-to-Pattern Map
Not a Pixel-to-Pixel Map

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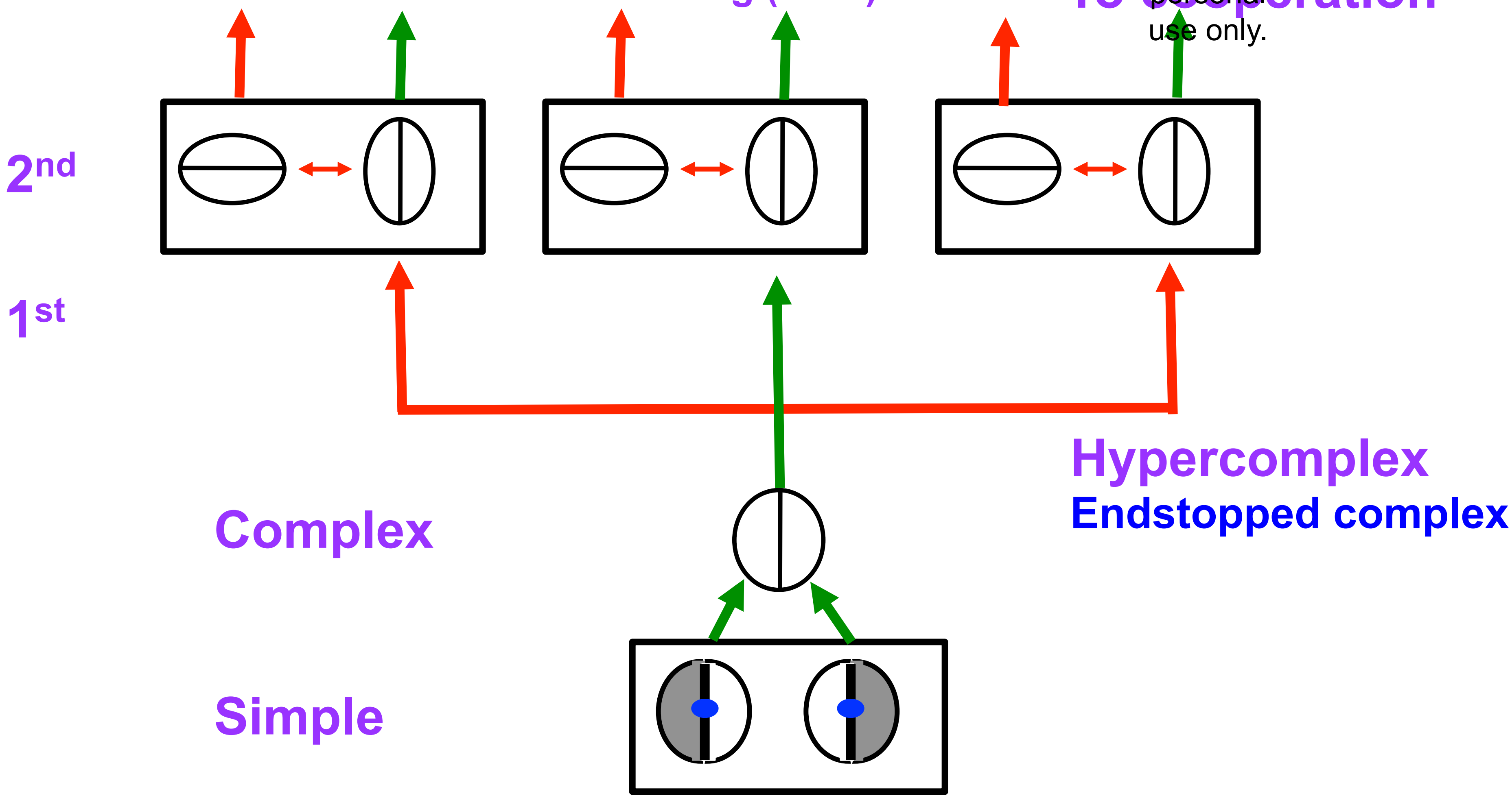
HOW ARE END CUTS CREATED?

Two stages of short-range competition

Grossberg (1984)



First competitive stage

Across position

Same orientation

Second competitive stage

Same position

Across orientation

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HOW END CUTS ARE CREATED

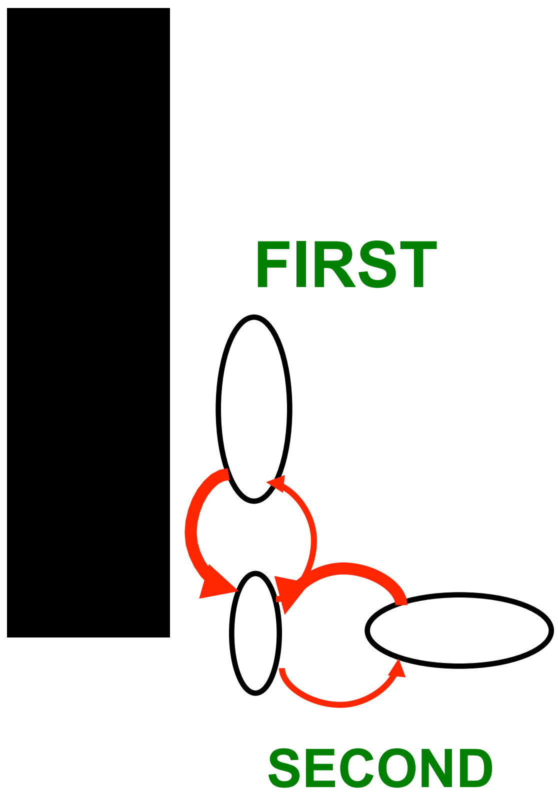
FIRST COMPETITIVE STAGE

Vertically oriented complex cells near line end inhibit vertically oriented hypercomplex cells just beyond the line end
These hypercomplex cells were not previously active, so at the…

SECOND COMPETITIVE STAGE

Inhibited vertically oriented hypercomplex cells near the line end disinhibit horizontally oriented hypercomplex cells at the same positions, thereby creating an end cut

Cells in second competitive stage are TONICALLY active but are held in check by balanced inhibition until an input occurs



END CUT SIMULATION

Grossberg and Mingolla (1985)

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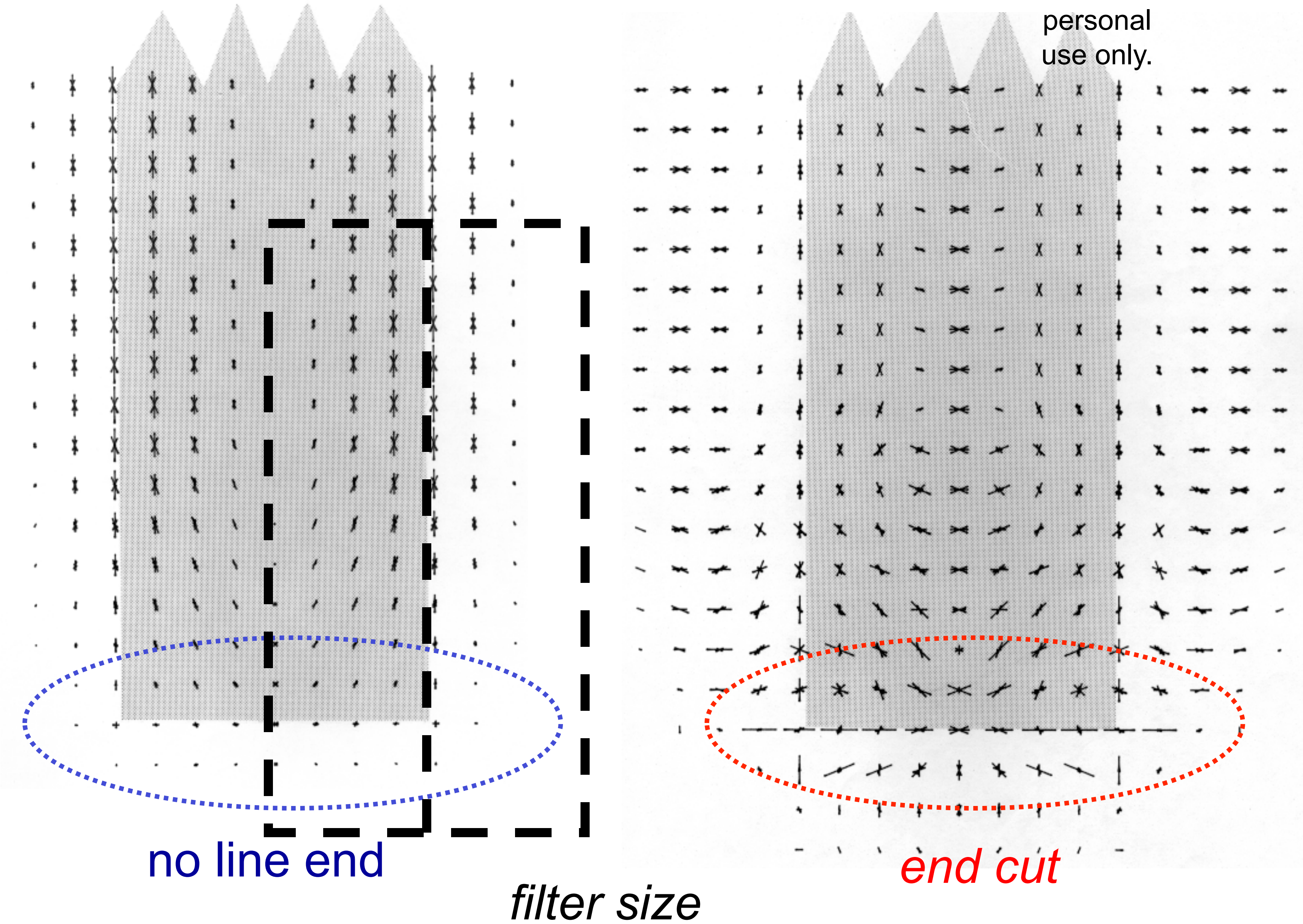

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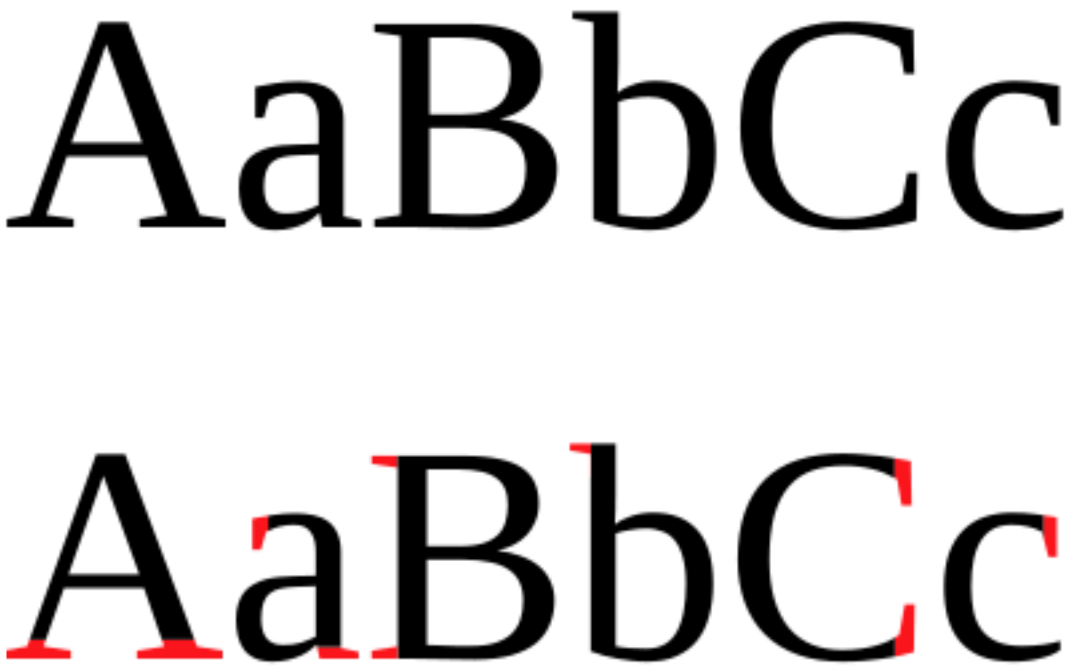
OUR BRAINS TRY TO MAKE THEIR OWN SERIFS!

E.g., Times, Times New Roman



"Serifed fonts are widely used for body text because they are considered easier to read than sans-serif fonts in print."
Serifs, Wikipedia

POSITIONAL HYPERACUITY, ORIENTATIONAL FUZZINESS

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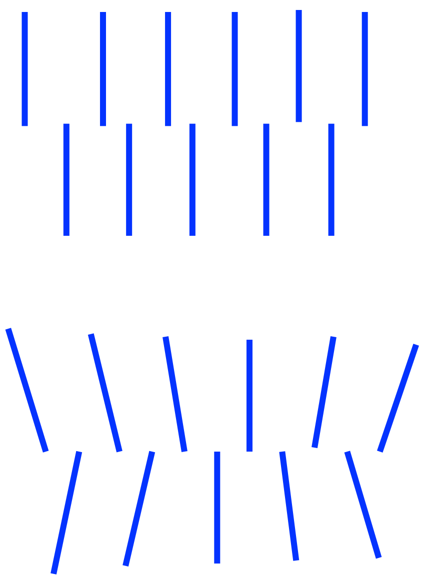
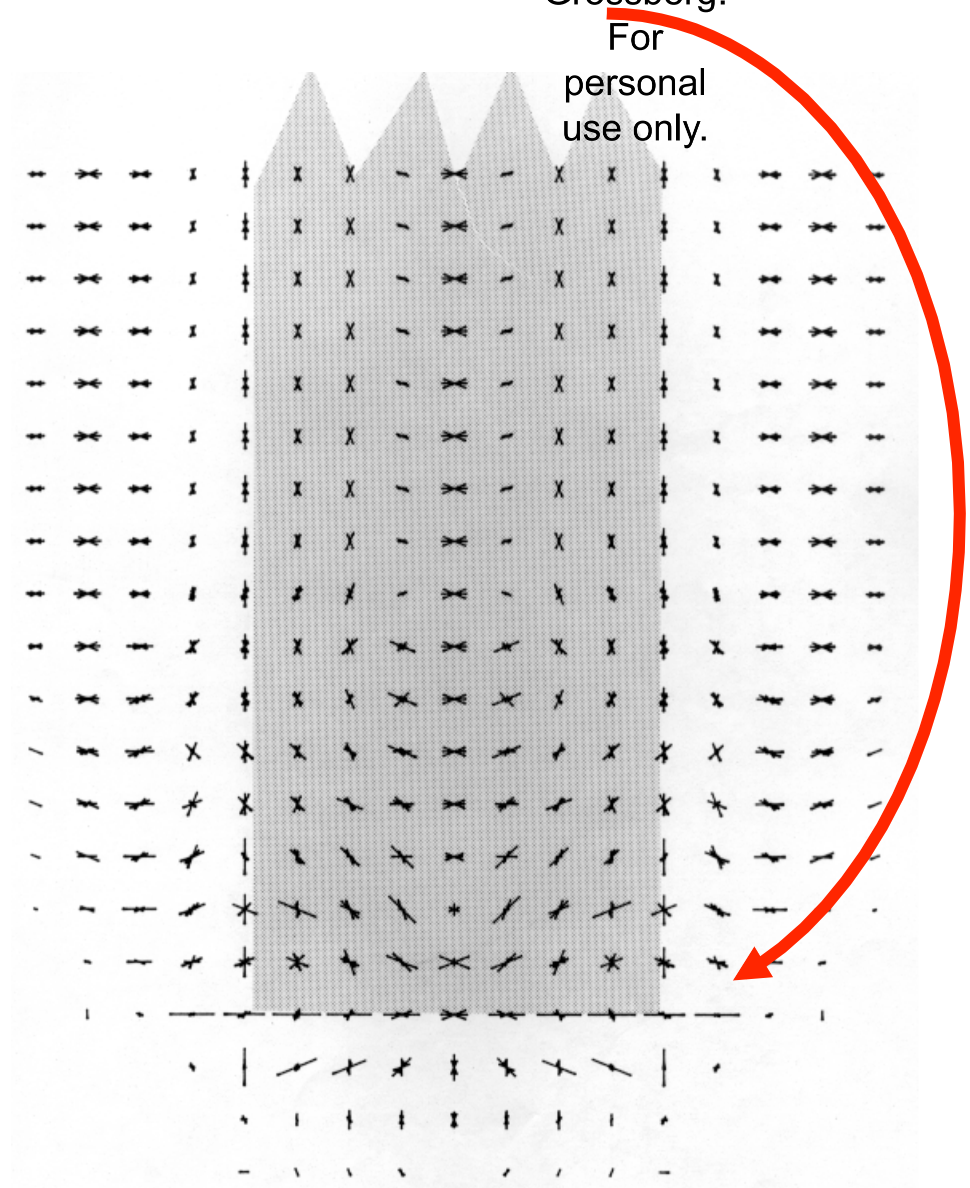
Why is orientational fuzziness useful?

It lets groupings occur at orientations that are not too different from vertical:





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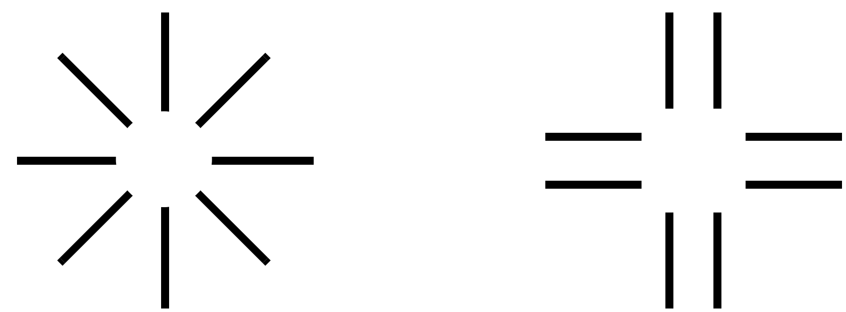
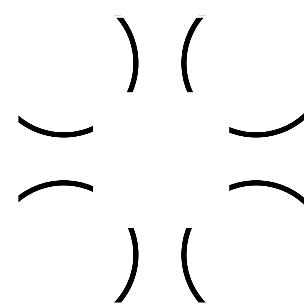
GROUPING AT
PREFERRED AND UNPREFERRED ORIENTATIONS

Locally preferred
and
globally preferred

Perpendicular induction at line ends:



Locally unpreferred
and
globally preferred



Kennedy, 1979

Global grouping can overcome local preferences

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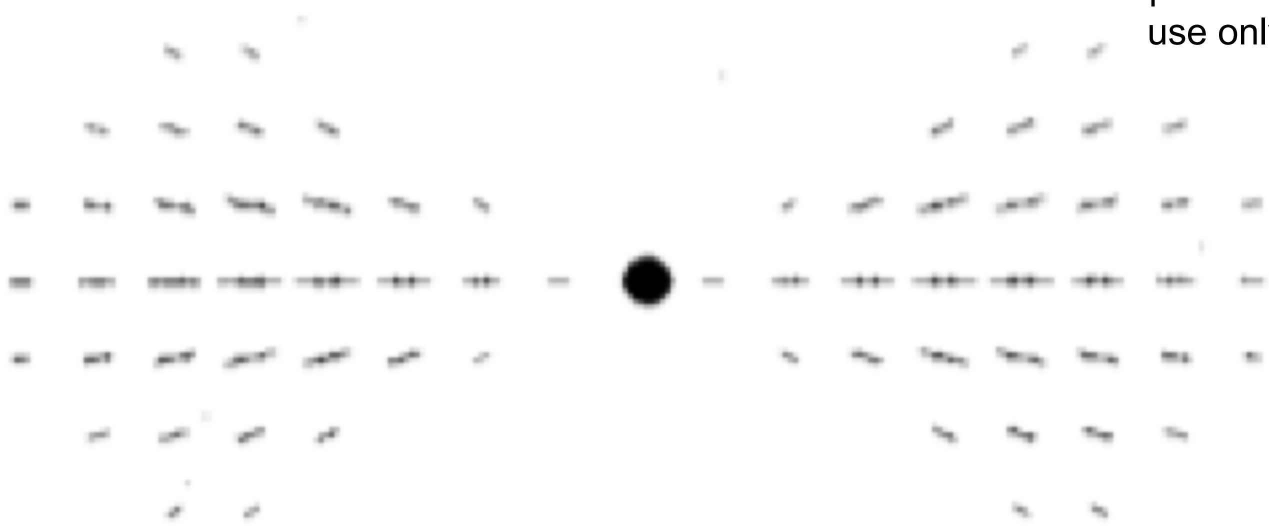
BIPOLE CELLS HAVE FUZZY RECEPTIVE FIELDS



Why are not all the groupings that they form FUZZY?

If they were, acuity would go down a lot!

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FROM FUZZY TO SHARP

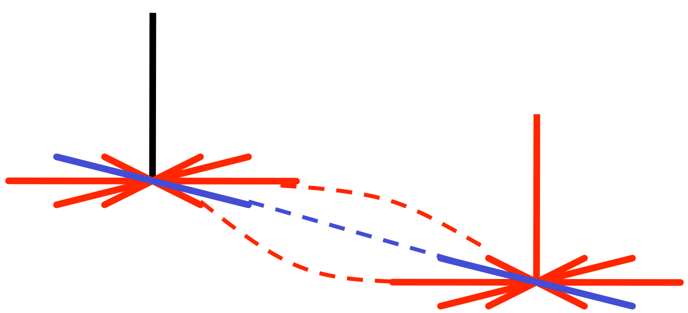
Why do we not always perceive fuzzy illusory contours?

Another hierarchical resolution of uncertainty:
Need fuzziness to initiate grouping
But this risks loss of acuity

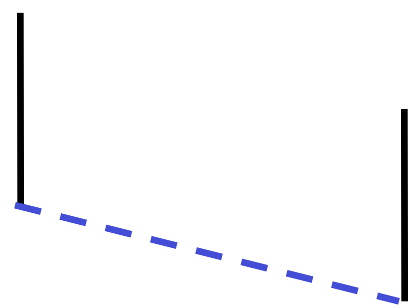
BOUNDARY GROUPING PROCESS MAKES DECISION

CHOOSE: the contextually best orientation − cooperation

SUPPRESS: other local orientations − competition



before choice (transient)



after choice ("equilibrium")

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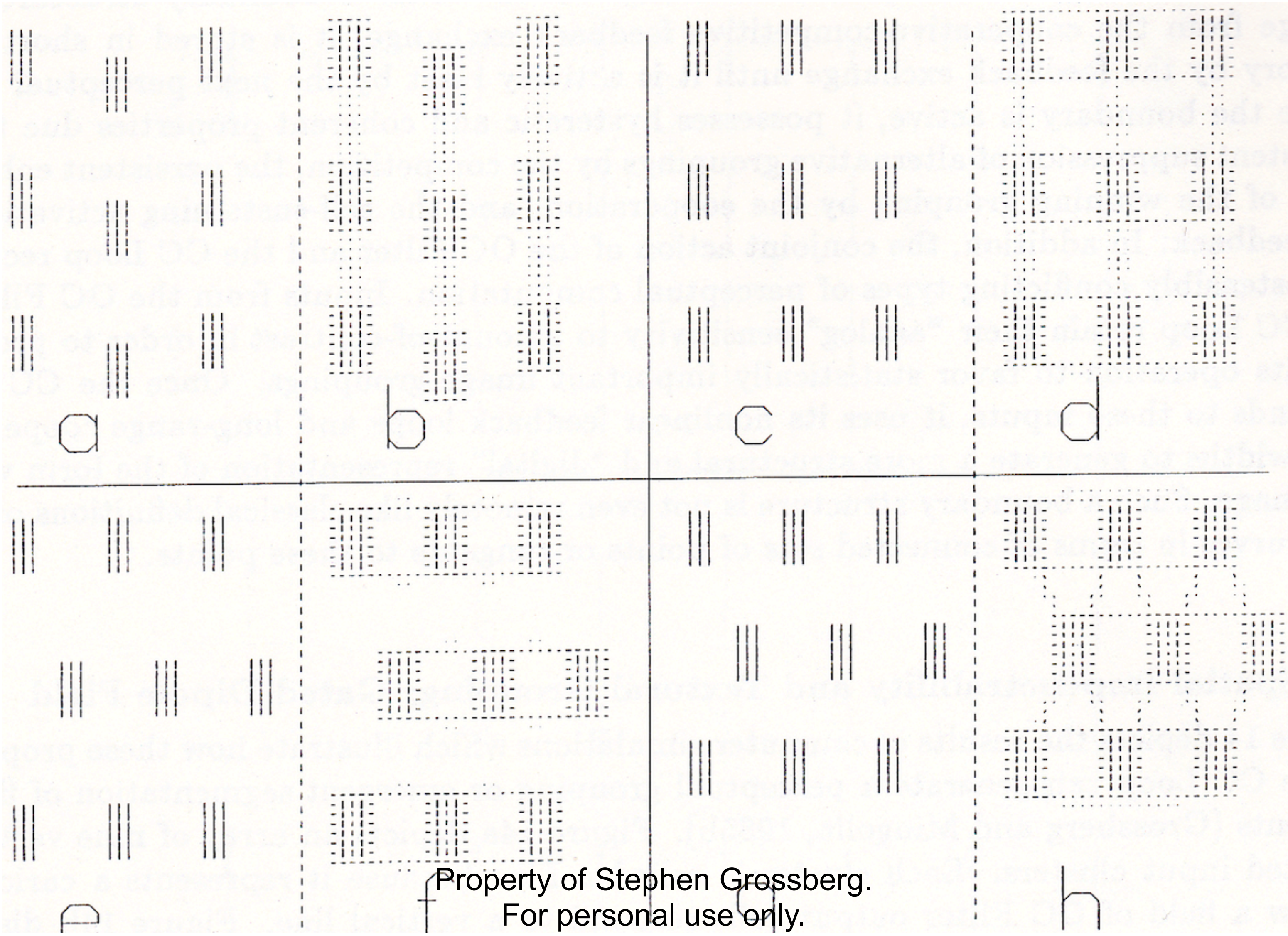
BIPOLE CELLS DO THIS

when they are part of a larger network

COMPUTER SIMULATIONS OF BOUNDARY COMPLETION

Grossberg and Mingolla (1985)



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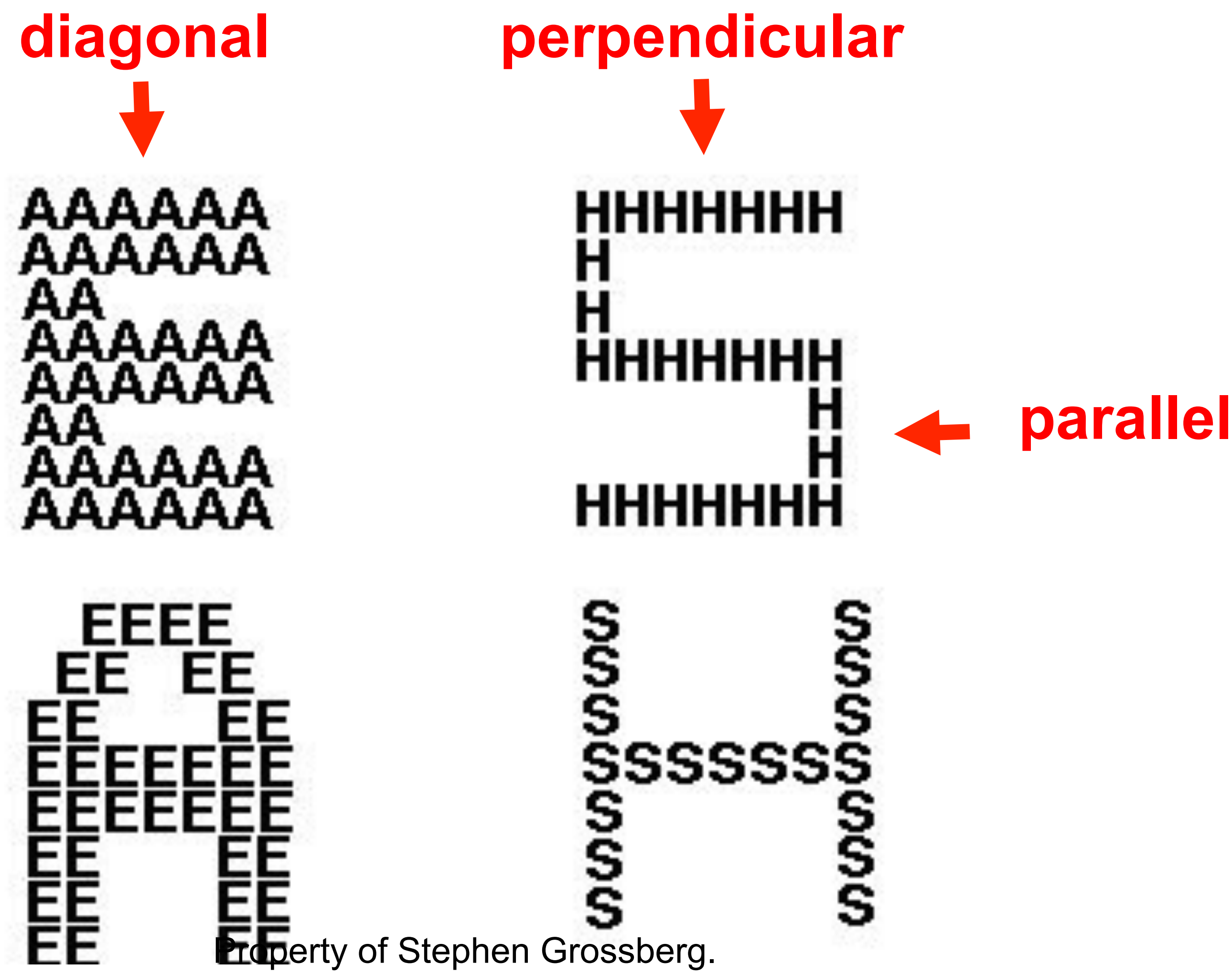
MULTIPLE ORIENTATIONS CAN HEREBY INDUCE SHARP BOUNDARY COMPLETION OF AN OBJECT



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SEAN WILLIAMS

Typography Portrait

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THIS CIRCUIT CAN ALSO EXPLAIN…

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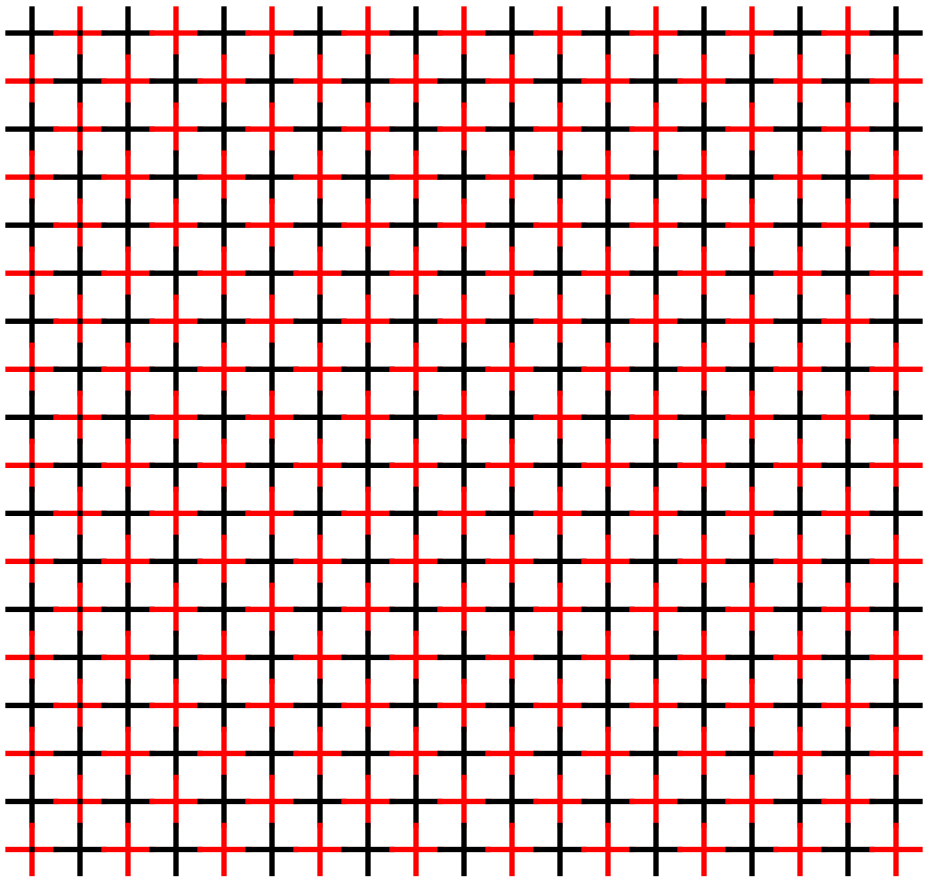
NEON COLOR SPREADING

Redies and Spillmann (1981)

Visible evidence for how groupings form and contain filling-in



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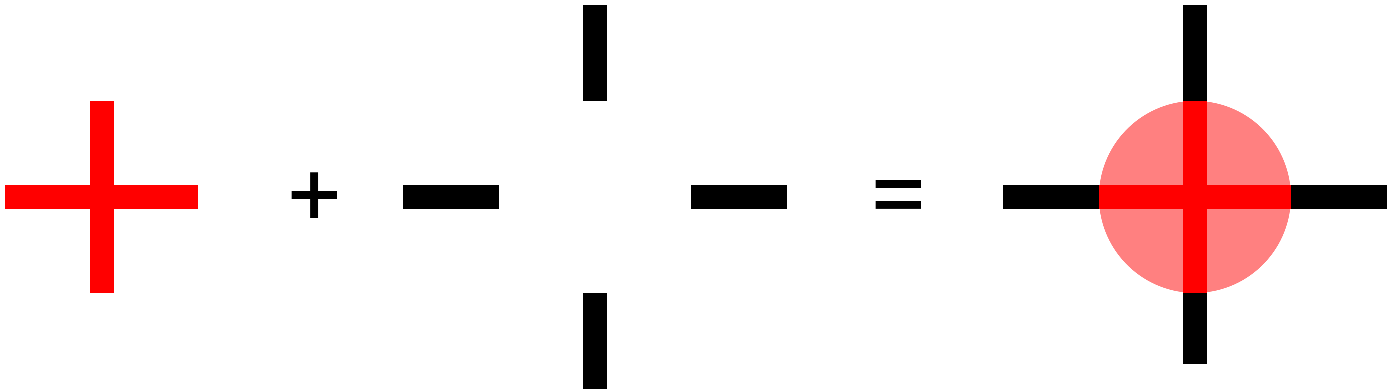
REAL BOUNDARIES BREAK
ILLUSORY BOUNDARIES CONTAIN FILLING-IN

A less contrastive red cross inside an Ehrenstein figure



produces color spreading

“Real” contours of small cross cannot contain red color

“Illusory” contours of Ehrenstein figure *do!*

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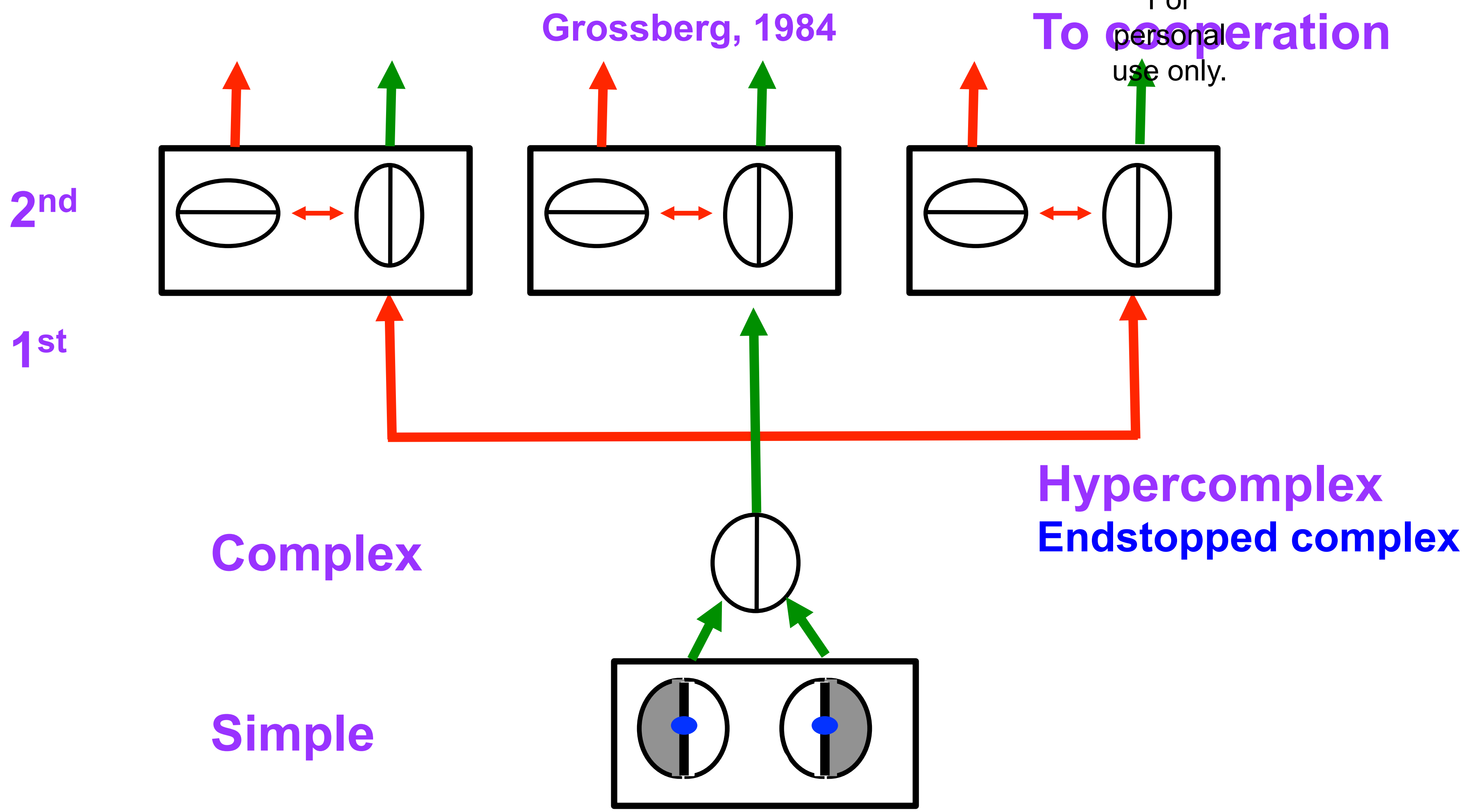
HOW ARE END CUTS CREATED?

Two states of short-range competition



First competitive stage
Across position
Same orientation

Second competitive stage
Same position
Across orientation

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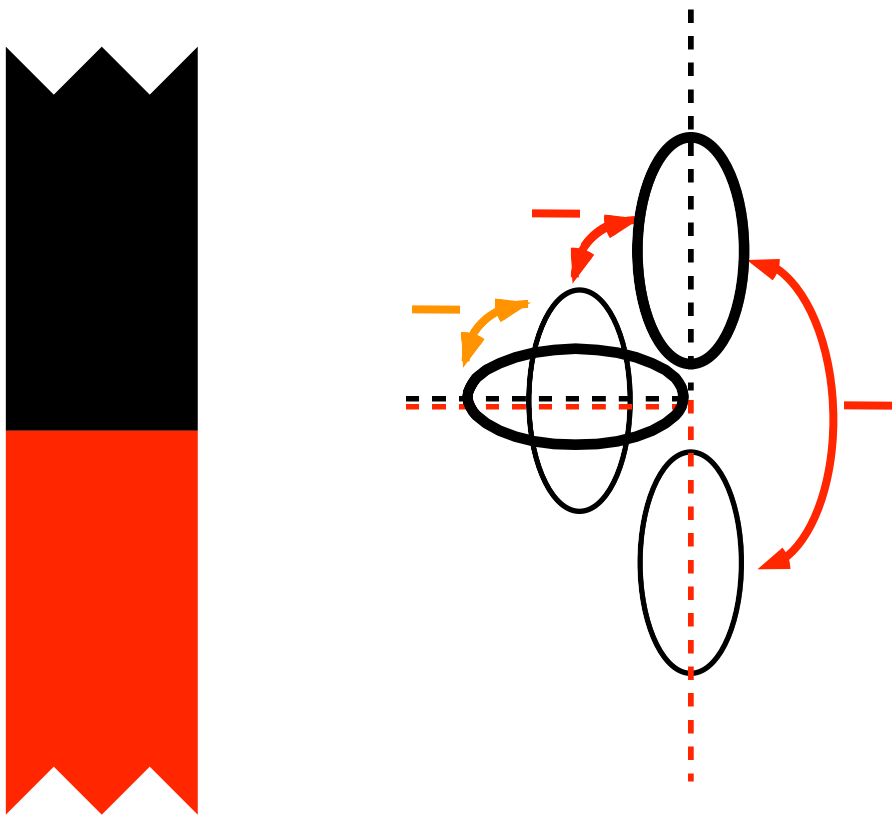
END CUT:COMPLETING BOUNDARY AT LINE END



FIRST COMPETITIVE STAGE

within orientation

across position

end gaps

SECOND COMPETITIVE STAGE

across orientation,

within position

end cuts

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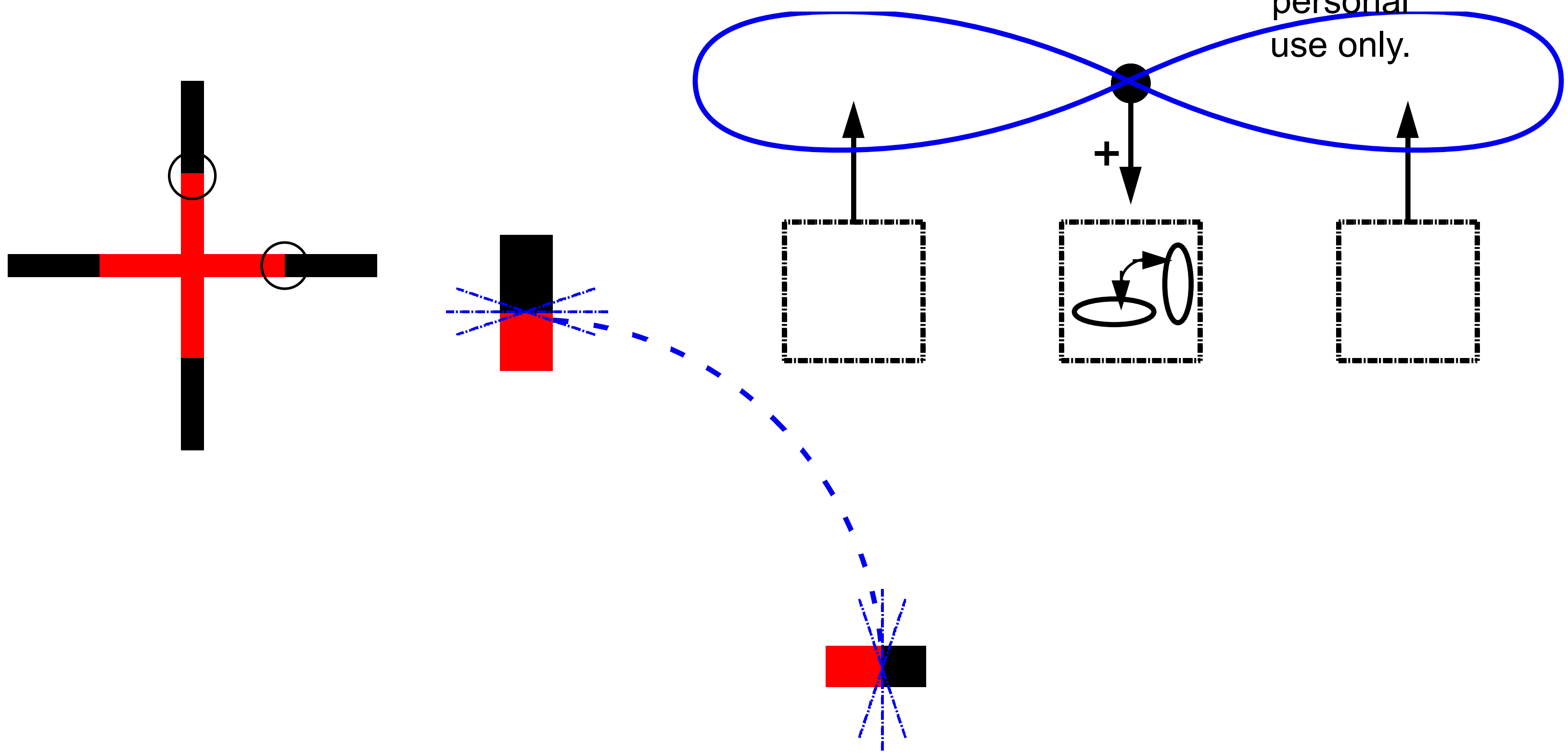
BIPOLE CELLS: BOUNDARY COMPLETION



long-range cooperation and short-range competition complete winning boundary groupings and suppress weaker boundaries

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JO BAER
Primary Light Group: Red, Green, and Blue
1964-1965 (moma.org)

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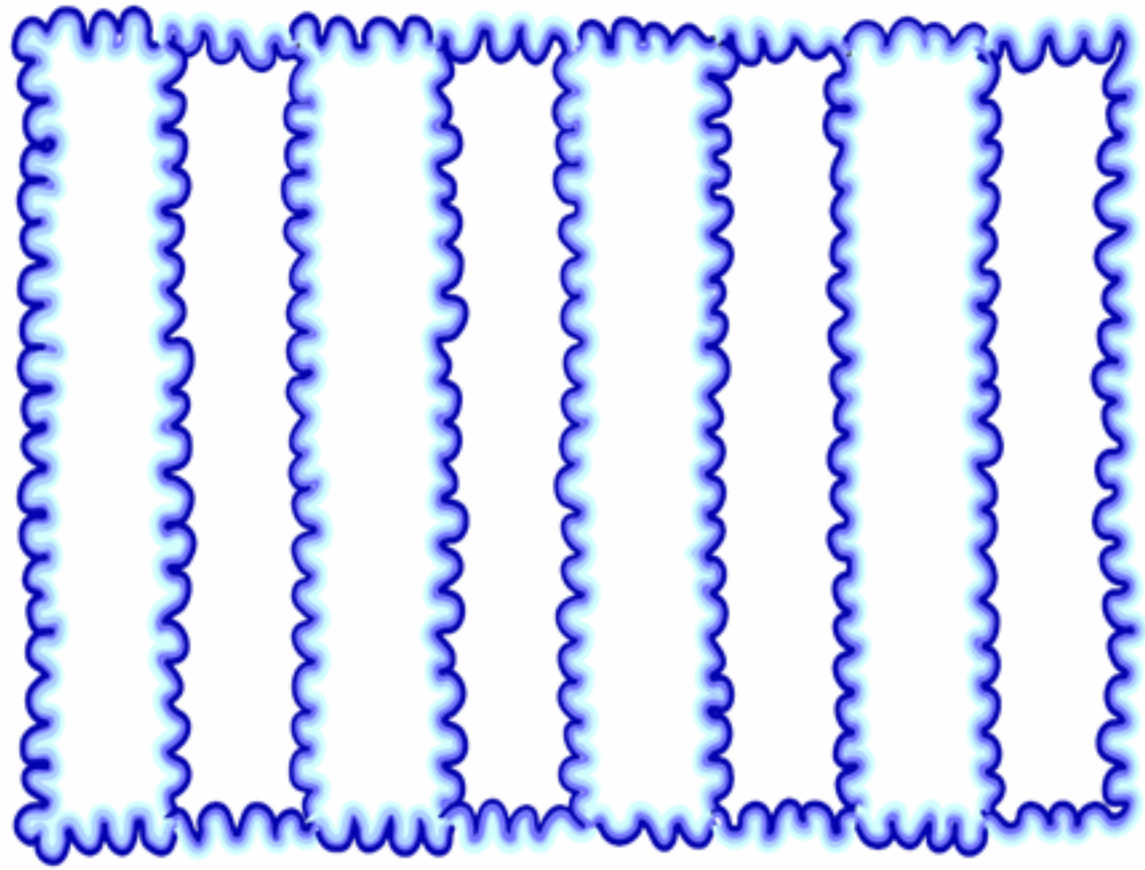
BAINGIO PINNA

Watercolor illusion, 1987

Explain using first competitive stage:

Spatial competition within orientation



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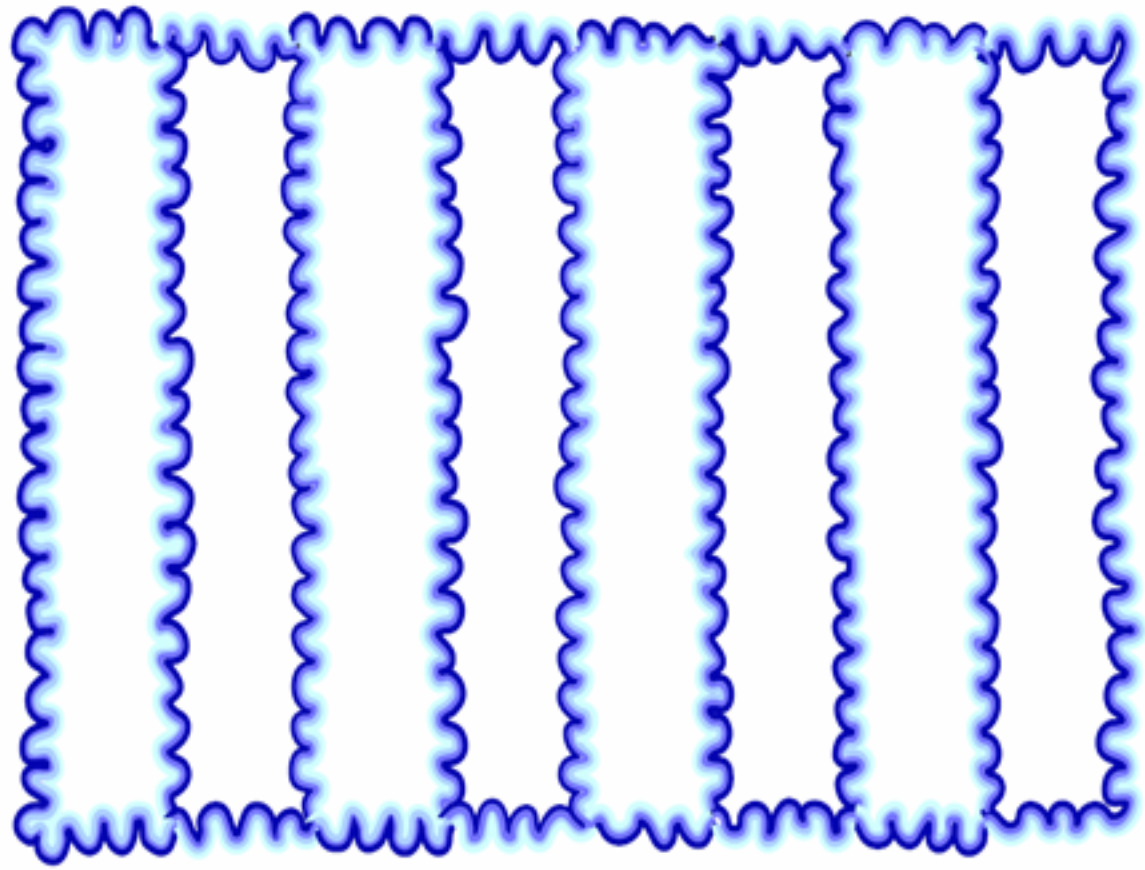

But why do the colored regions seem to bulge in depth?

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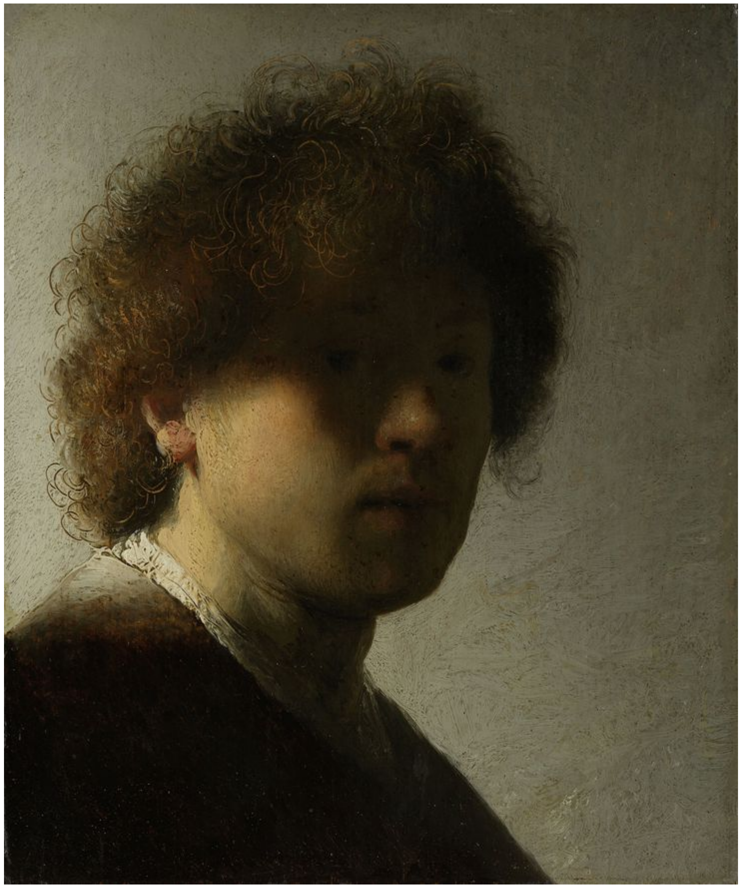
Same question for…

CHIAROSCURO
Rembrandt self-portrait



TROMPE L'OEIL
Graham Rust

HOW CAN 2D PICTURES LOOK 3D?!

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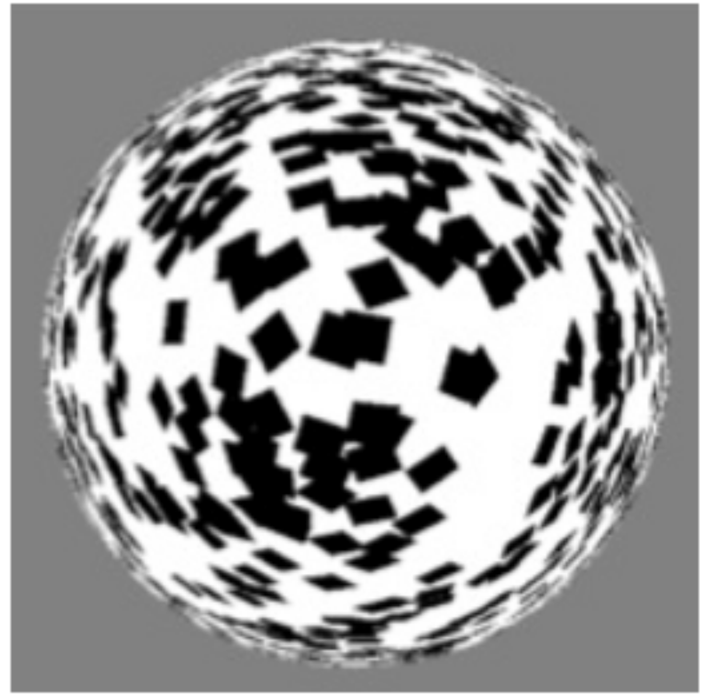
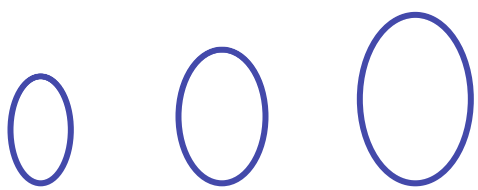
Same question for many
SHADED AND TEXTURED OBJECTS



We need receptive fields with MULTIPLE SIZES



to create boundary webs that represent MULTIPLE DEPTHS

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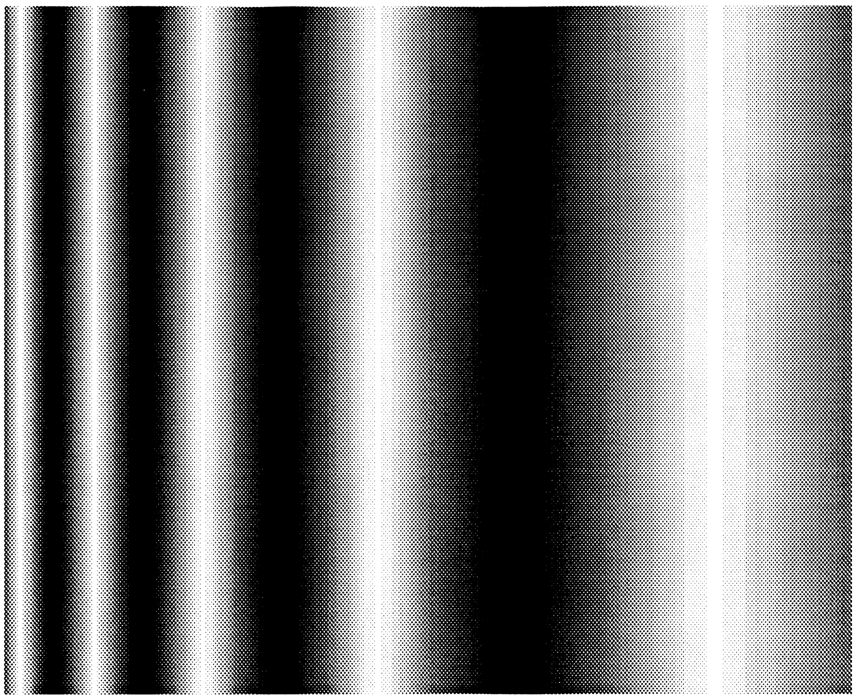
WHY?

As an object approaches, it gets bigger on the retina



FAR NEAR

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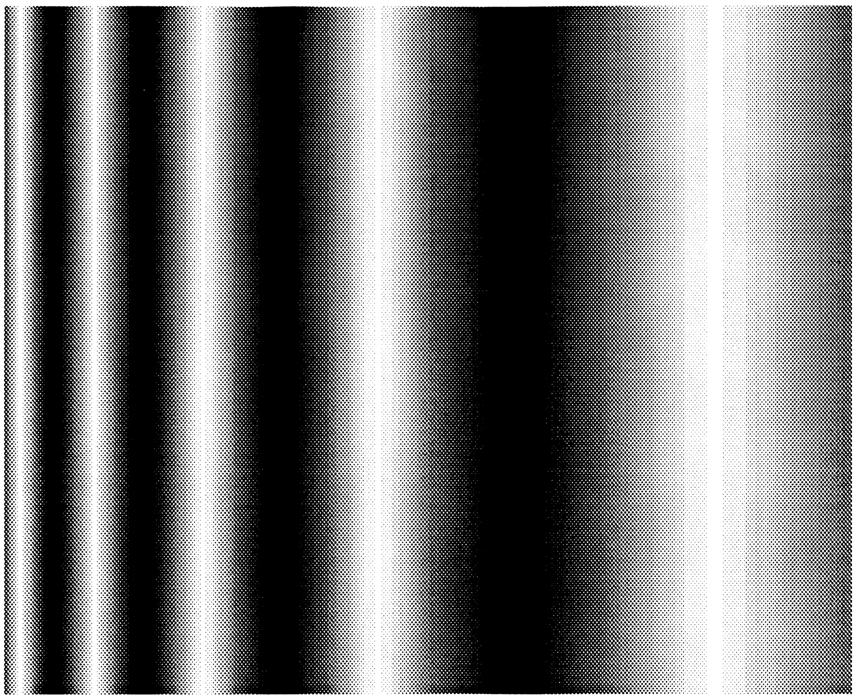
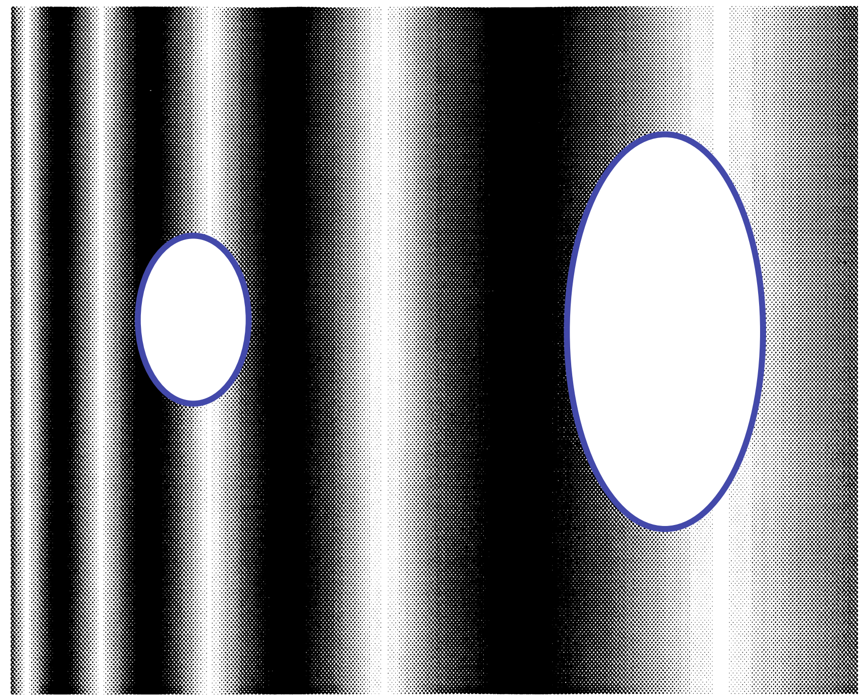
WHY?

As an object approaches, it gets bigger on the retina

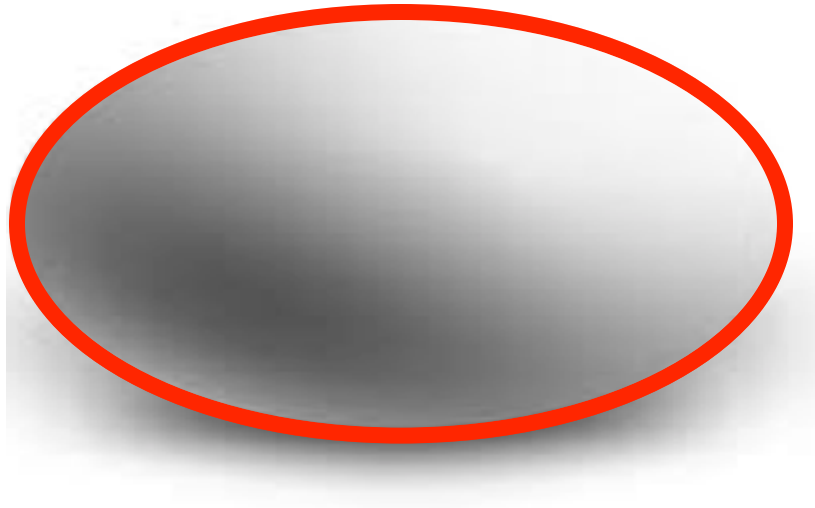
That is why BIGGER scales learn to code NEARER depths





FAR **NEAR**

3D VISION uses
Multiple-scale, depth-selective boundary webs



If boundaries were just edge detectors, there would be just a bounding edge of the ellipse

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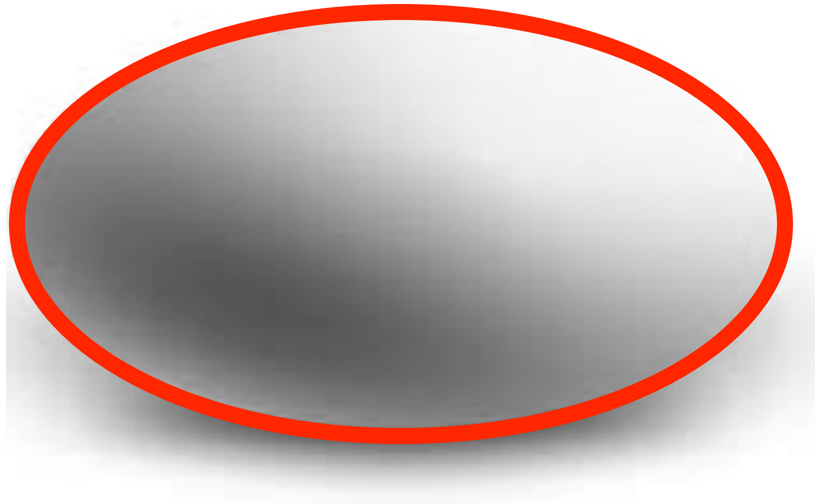
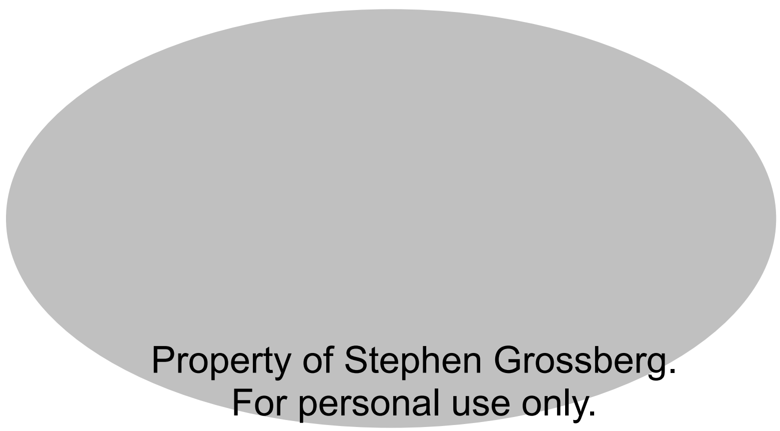
3D VISION uses
Multiple-scale, depth-selective boundary webs



If boundaries were just edge detectors,
there would be just a bounding edge of the ellipse
After filling-in of the shading, it would look like this:



Looks flat!

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3D VISION uses
Multiple-scale, depth-selective boundary webs

Instead, different size detectors generate dense boundary webs at different positions and depths along the shading gradient

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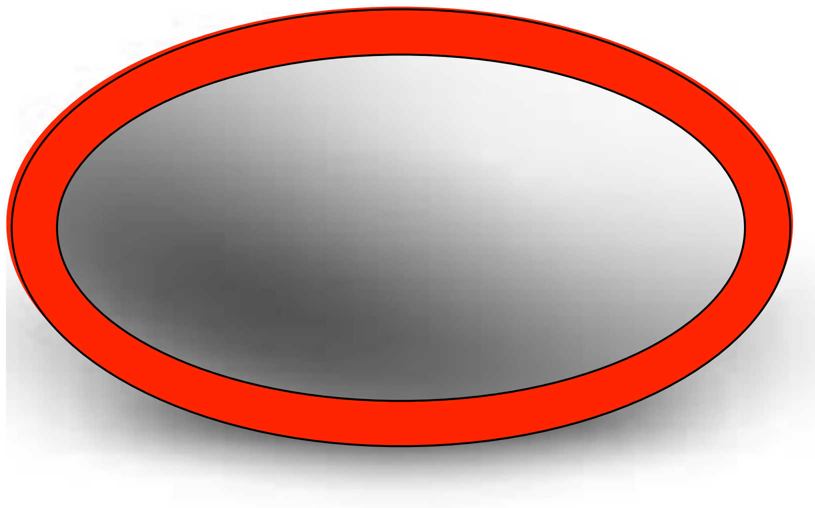
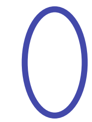
3D VISION uses
Multiple-scale, depth-selective boundary webs



Small size
Far



Instead, different size detectors generate dense boundary webs at different positions and depths along the shading gradient

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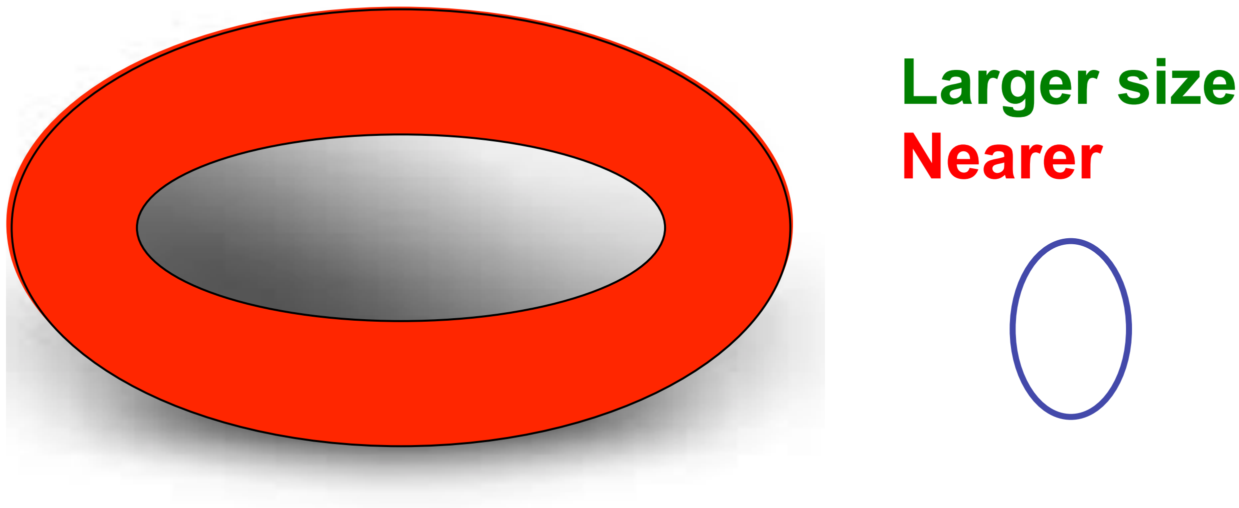
3D VISION and
Multiple-scale, depth-selective boundary webs



Instead, different size detectors generate dense boundary webs at different positions and depths along the shading gradient

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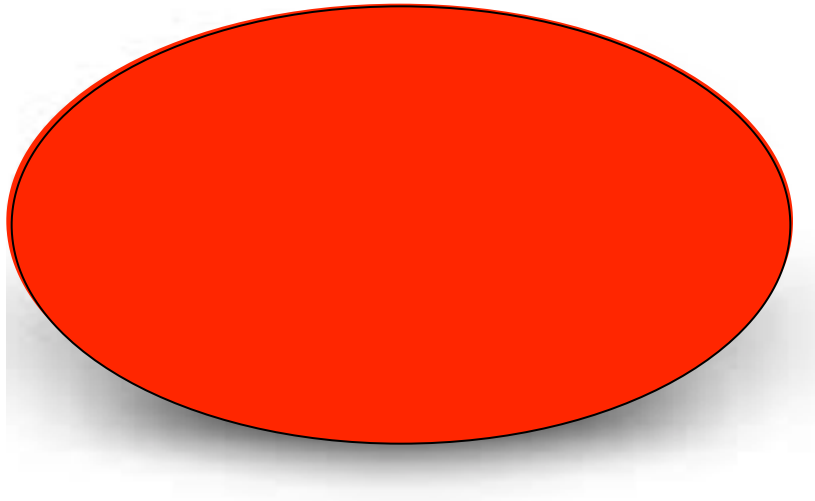
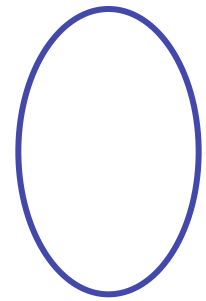
3D VISION uses
Multiple-scale, depth-selective boundary webs



Largest size
Nearest



Instead, different size detectors generate dense boundary webs at different positions and depths along the shading gradient

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3D VISION uses
Multiple-scale, depth-selective boundary webs

Instead, different size detectors generate dense boundary webs at different positions and depths along the shading gradient

Each boundary web captures the gray shading in small compartments at its positions and depths

We SEE this pattern of shading across ALL the depths

A shaded percept in depth results

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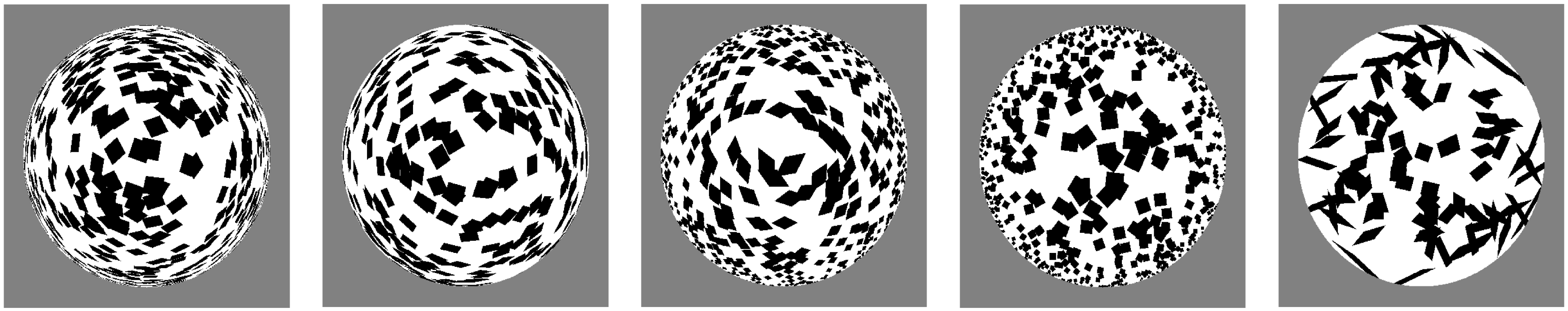
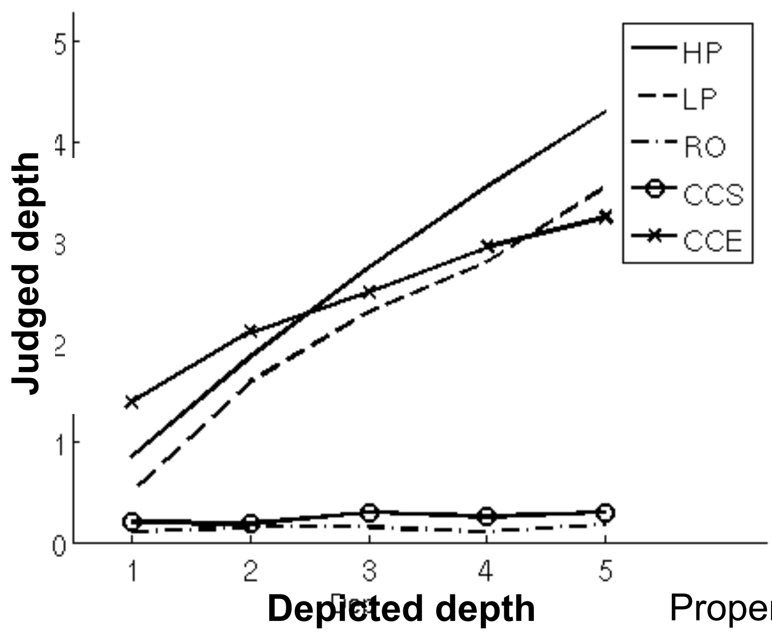
WHY SHOULD YOU BELIEVE THIS?

It explains hard data about shaded and textured surfaces

DEPTHFUL……………………………………….FLAT



HP LP CCE CCS RO



Depthfulness varies with texture element width, but only when elements are elongated and sufficiently aligned with one another so as to form coherent groupings

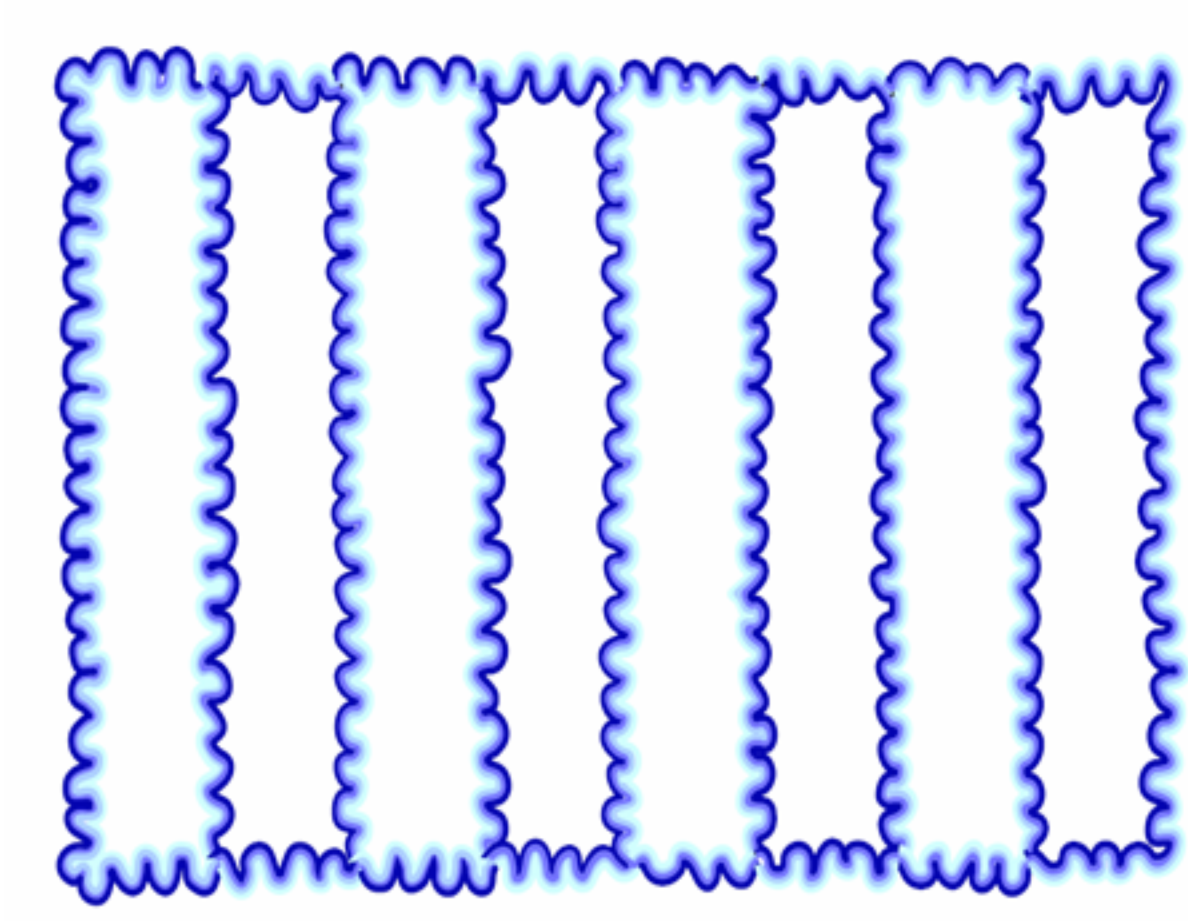
Data of Todd and Akerstrom, 1987; simulated in Grossberg, Kuhlmann, and Mingolla, 2007

BAINGIO PINNA

Watercolor illusion, 1987

Filled-in regions bulge in depth

Multiple-scale, depth-selective boundary web!



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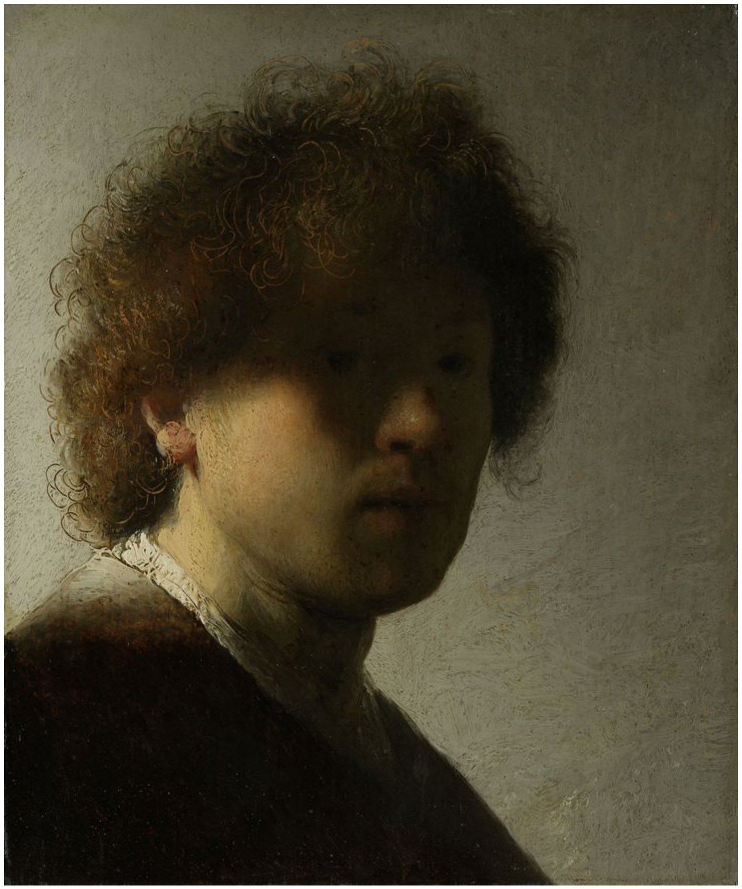
Rembrandt self-portrait



TROMPE L'OEIL
Graham Rust

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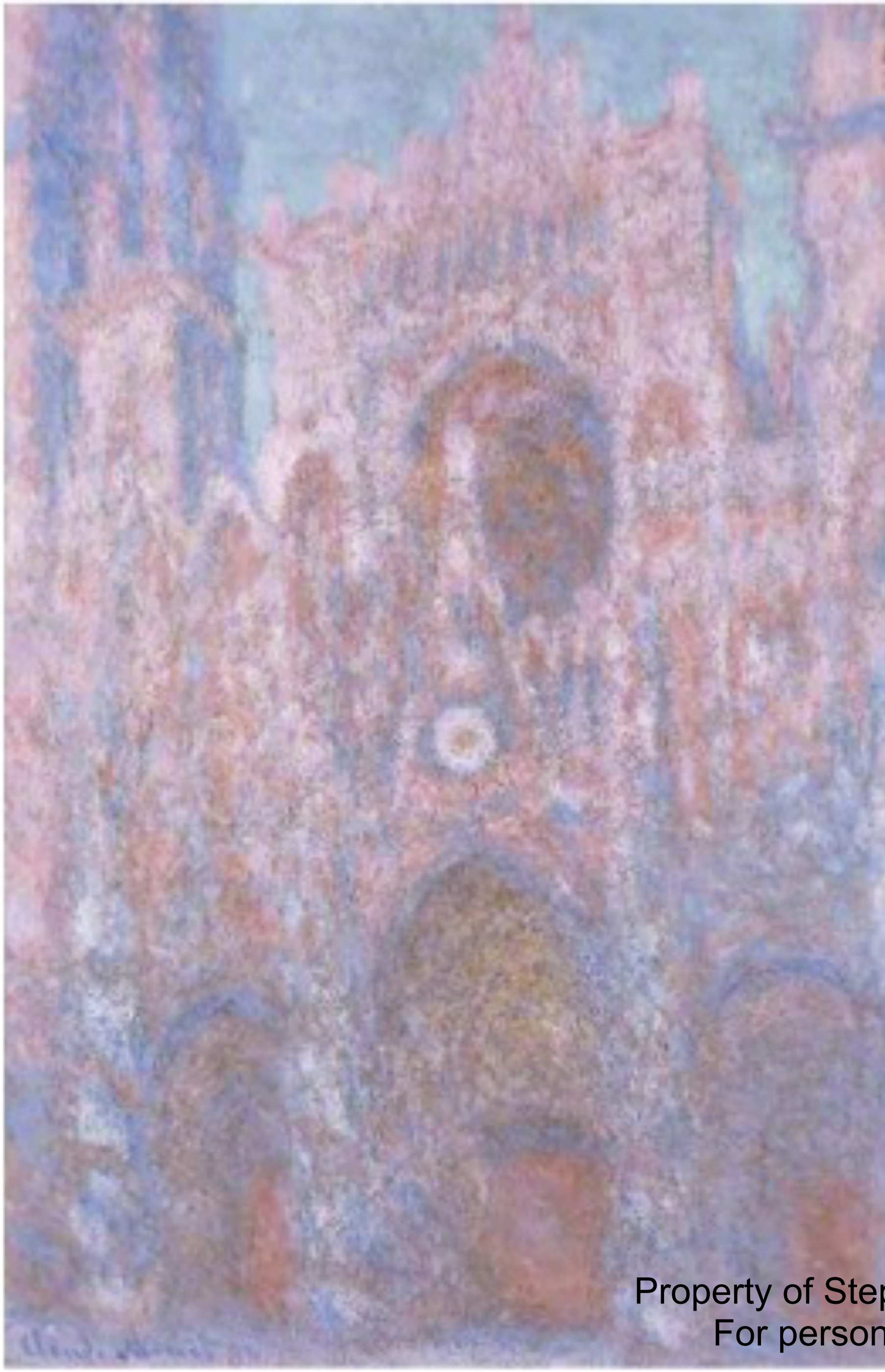

ROUEN CATHEDRAL

Monet, 1892-1894

At sunset

Lighting is almost equiluminant across most of the painting

Here, boundaries are mostly due to color differences, not luminance differences

Fine architectural details are obscured, leading to…

Coarser and more uniform boundary webs, so…

Less depth in the painting

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ROUEN CATHEDRAL
Monet, 1892-1894
Full sunlight

Lighting is strongly non-uniform across most of the painting

Strong boundaries due to both luminance and color differences

Fine architectural details are much clearer, leading to…

Finer and more non-uniform boundary webs, so…

Much more detail and depth

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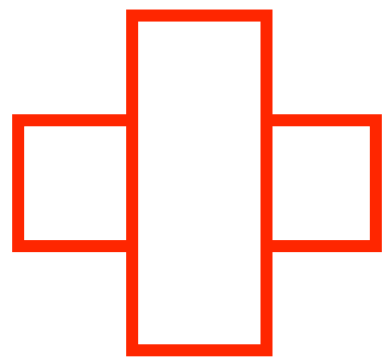
ROUEN CATHEDRAL

Monet, 1892-1894

Full sunlight

There are also more T-junctions where vertical boundaries occlude horizontal boundaries, or conversely…

Leading to even more depth



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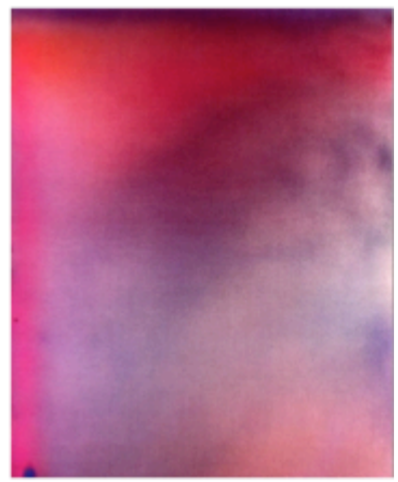
COLOR FIELD PAINTING
Jules Olitski, Spray paintings

Julius and his friends (1967)

Lysander-1 (1970)

Instant Loveland (1968)



Comprehensive Dream (1965)

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COLOR FIELD PAINTING

Jules Olitski, Spray paintings

Lysander-1 (1970)

Unlike Impressionists like Monet, no discrete colored units exist

No structured color or luminance gradients

Boundary webs are spread over the entire surface…

creating a percept of a space filled with a colored fog and a sense of ambiguous depth

"When the conception of internal form is governed by edge, color…appears to remain on or above the surface. I think…of color as being seen in and throughout, not solely on, the surface"

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SELF-LUMINOUS PAINTINGS!
Ross Bleckner




Galaxy Painting (1993) **Galaxy with Birds (1993)**

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SELF-LUMINOUS PAINTINGS!

Two Types of Mechanisms

BOUNDARY WEB GRADIENTS

LIGHTNESS ANCHORING

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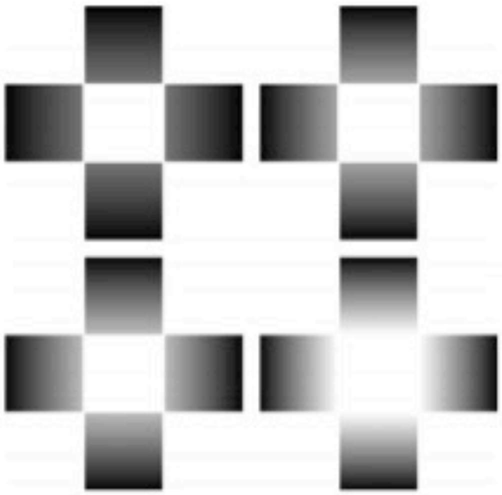
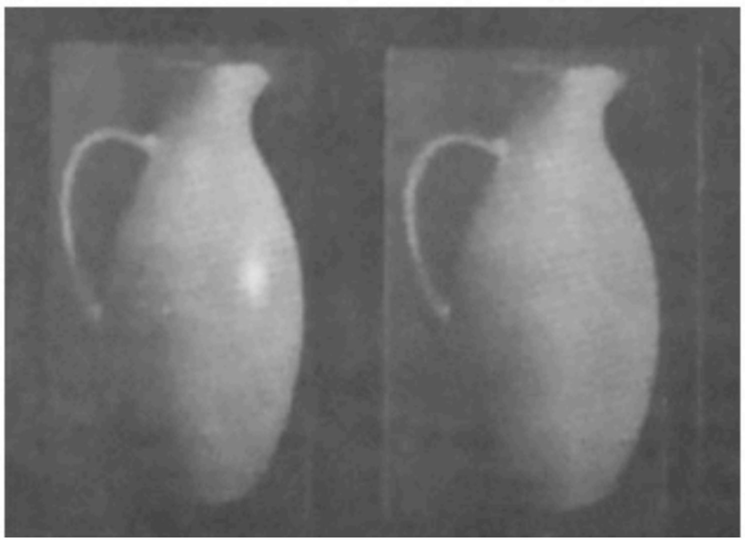
BOUNDARY WEB GRADIENT CAN CAUSE SELF-LUMINOSITY

Similar to WATERCOLOR ILLUSION

Glare



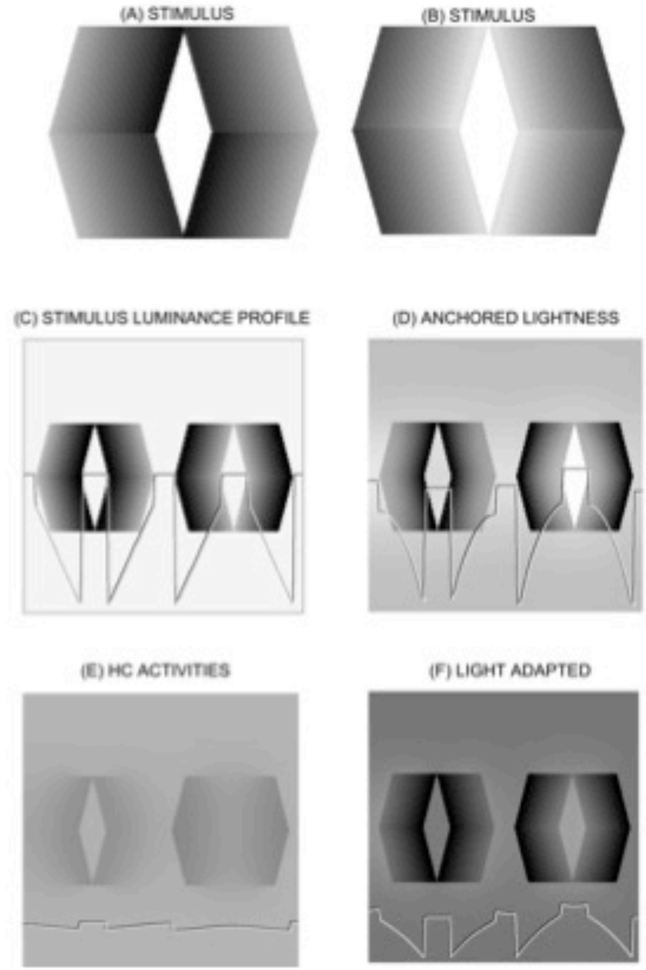


Gloss by Attached Highlight

Beck and Prazdny (1981)

Double Brilliant Illusion

Bressan (2001)



Simulation

Grossberg and Hong (2006)

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What is

LIGHTNESS ANCHORING?

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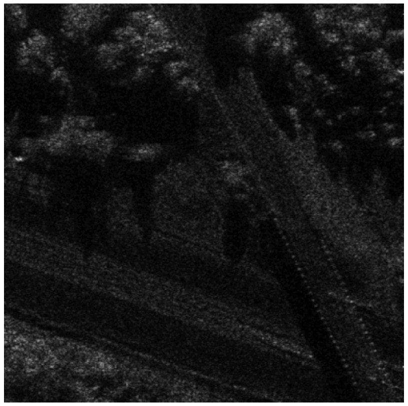
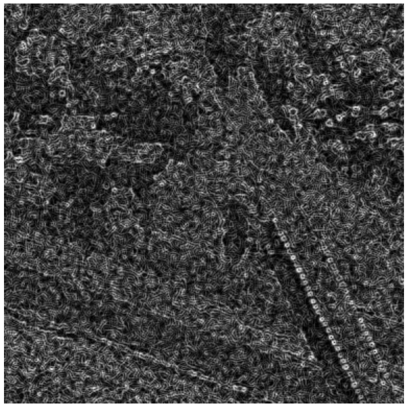
DO THESE IDEAS WORK ON HARD PROBLEMS?
From Seurat to SAR

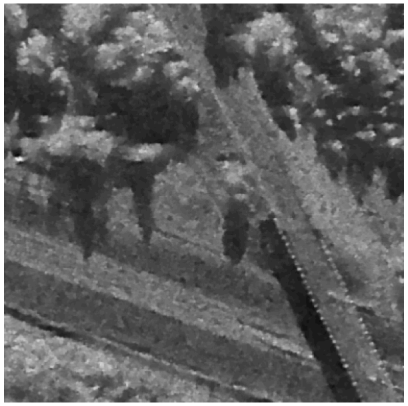

input


feature

Discounting the Illuminant normalizes the image: It preserves RELATIVE activities without SATURATION

Still shows individual PIXELS


boundary


surface filling-in

Filling-in averages brightnesses within boundary compartments

Boundaries complete between regions where normalized feature contrasts change

How Is the FULL DYNAMIC RANGE of a Cell Used?

How does the brain compute what is WHITE in a scene?

LIGHTNESS ANCHORING

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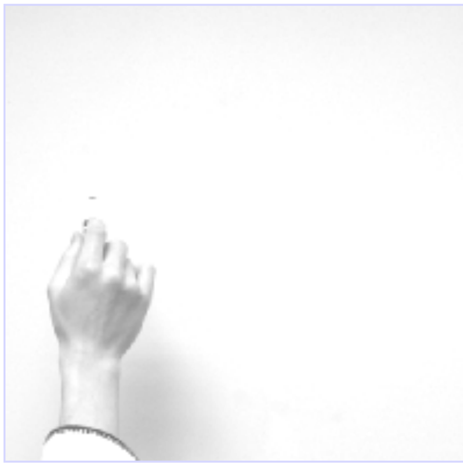
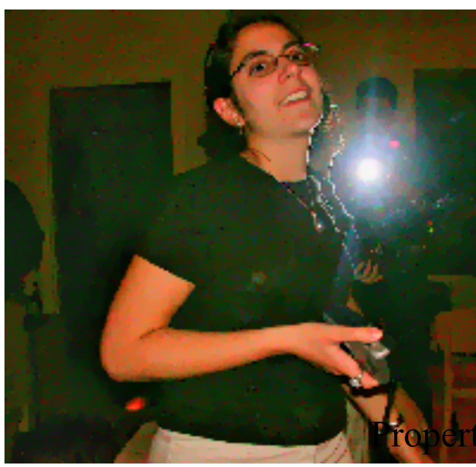
HIGHEST LUMINANCE AS WHITE (HLAW) RULE

Hans Wallach (1948)



Good



Bad!

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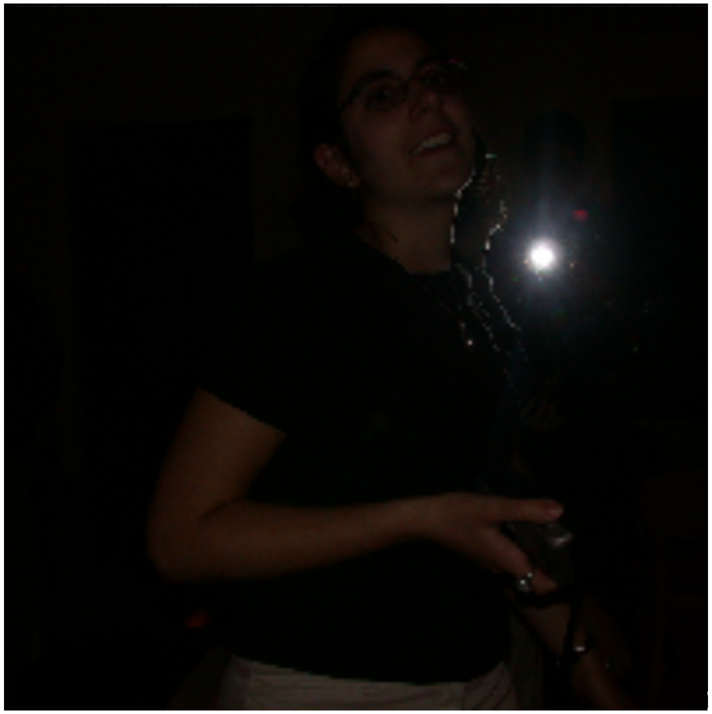
Photo courtesy of Arash Fazl

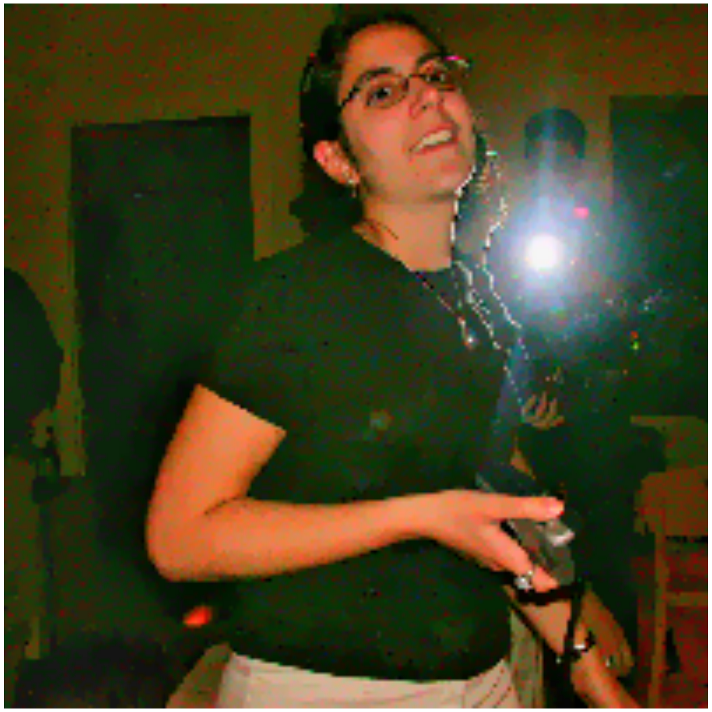
BLURRED HIGHEST LUMINANCE AS WHITE (BHLAW) RULE

Grossberg and Hong (2004, 2006)

HLAW



BHLAW



Spatial integration (blurring) adds spatial context to lightness perception

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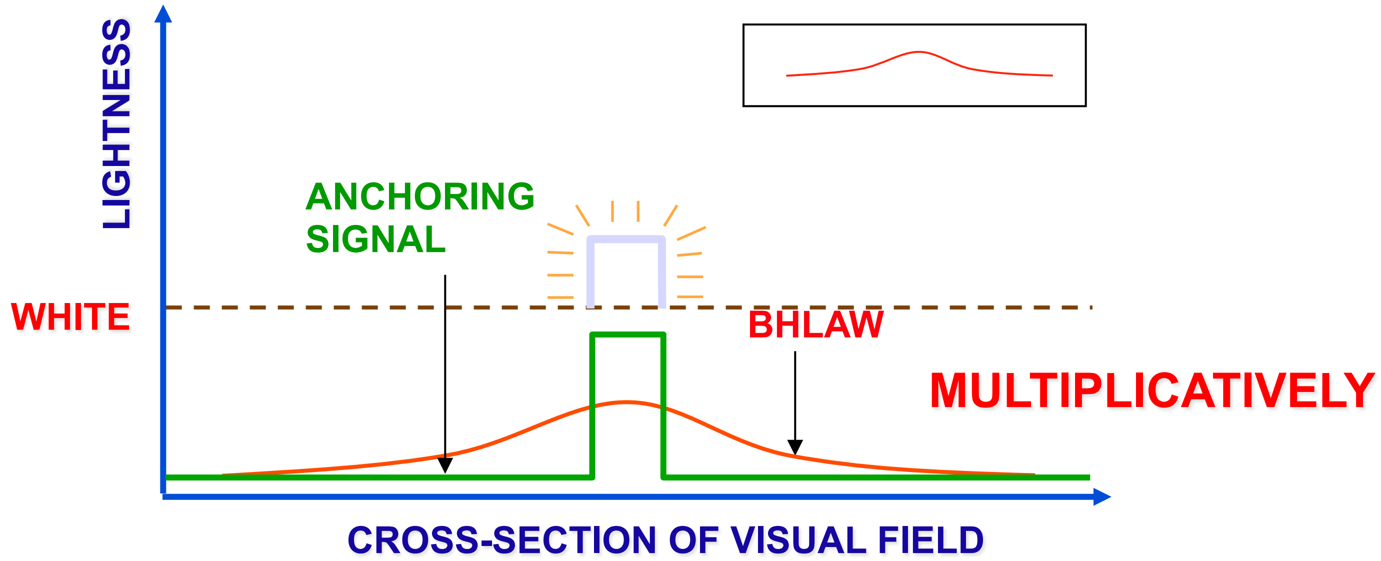
BHLAW RULE



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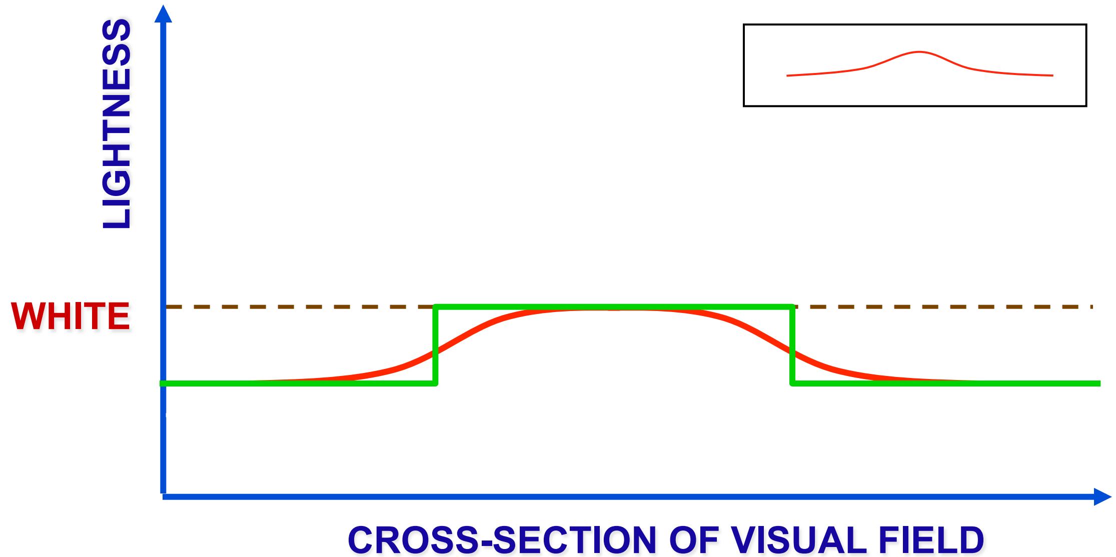
BHLAW RULE



SELF-LUMINOUS PAINTINGS!

Ross Bleckner

Anchoring

Gradient

Galaxy Painting (1993)

Galaxy with Birds (1993)

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HOW DO WE CONSCIOUSLY SEE A PAINTING?

…very briefly…

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What is the
Hard Problem of Consciousness?

Wikipedia

"…is the problem of explaining how and why we have qualia or phenomenal experiences…"

Chalmers (1995):
"The really hard problem of consciousness is the problem of *experience.* When we think and perceive, there is a whir of information-processing, but there is also a subjective aspect…"

What is the
Hard Problem of Consciousness?

Internet Encyclopedia of Philosophy

"The hard problem of consciousness is the problem of explaining
why any physical state is conscious rather than unconscious…
It is the problem of explaining why…conscious mental states
"light up"
and directly appear to the subject….
we can still meaningfully ask the question,
***Why is it conscious?*..."**

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Before jumping in, it is fair to ask:

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What kind of event occurs in the brain that is anything more than a "whir of information processing"

What happens when conscious mental states "light up" and directly appear to a subject?

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Our brains sometimes go into a context-sensitive RESONANT STATE that can involve multiple brain regions

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ALL CONSCIOUS STATES ARE RESONANT STATES

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What kind of event occurs in the brain
that is anything more than a
"whir of information processing"

What happens when conscious mental states
"light up"
and directly appear to a subject?

Our brains sometimes go into a
context-sensitive RESONANT STATE
that can involve multiple brain regions

ALL CONSCIOUS STATES ARE RESONANT STATES
Not all brain dynamics are resonant, so
consciousness is not just a "whir of information processing"

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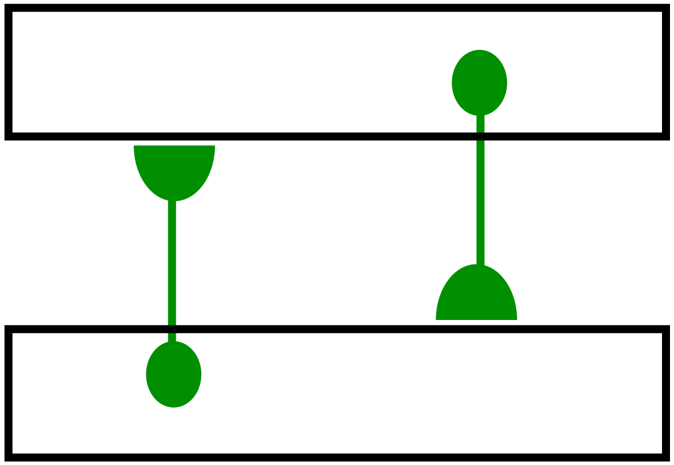
WHAT IS A RESONANT BRAIN STATE?



A dynamical state during which neuronal firings across a brain network are amplified and synchronized when they interact via reciprocal excitatory feedback signals during a matching process that occurs between bottom-up and top-down pathways

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CENTRAL CLAIM

Conscious states are part of larger adaptive behavioral capabilities that help us to adapt to a changing world

Resonances for conscious

seeing help to ensure effective reaching

hearing help to ensure effective speaking

feeling help to ensure effective goal-oriented action

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WHY DID EVOLUTION INVENT CONSCIOUSNESS?

Visual inputs to the retina are ambiguous, noisy, and incomplete

Multiple processing stages are needed to generate a sufficiently complete and stable surface representation with which to control effective looking and reaching

A SURFACE-SHROUD RESONANCE
"lights up" this surface representation
with an extra degree of freedom
CONSCIOUS AWARENESS!
and lets the brain use IT to control
looking and reaching

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CLASSIFICATION OF RESONANCES

Surface-shroud resonances support conscious seeing of visual qualia — **SEEING**

Feature-category resonances support conscious recognition of visual objects and scenes — **KNOWING**

Stream-shroud resonances support conscious hearing of auditory qualia

Spectral-pitch-and-timbre resonances support conscious recognition of sources in auditory streams

Item-list resonances support conscious recognition of speech and language

Cognitive-emotional resonances support conscious feelings and recognition of them

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ADAPTIVE RESONANCE THEORY

ART

Grossberg (1976)

A unifying theme:

Stability-Plasticity Dilemma

How can learning continue into adulthood without causing catastrophic forgetting?

How can we LEARN quickly without being forced to FORGET just as quickly?

e.g., why learning your faces does not force me to forget faces of my family and friends!

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ART has been incrementally developed ever since

ART is currently the most advanced cognitive and neural theory…with the broadest explanatory and predictive range… about how brains learn to

attend

recognize

predict

objects and events in a changing world

ALL of the main ART predictions have been supported by psychological and neurobiological data

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ART WORKS!

LARGE-SCALE APPLICATIONS TO ENGINEERING AND TECHNOLOGY

http://www.cns.bu.edu/techlab (Gail Carpenter)

- Boeing parts design retrieval (used to design Boeing 777)
- satellite remote sensing
- radar identification
- robot sensory-motor control and navigation
- machine vision
- 3D object and face recognition
- Macintosh operating system software
- automatic target recognition
- ECG wave recognition
- protein secondary structure identification
- character classification
- musical analysis
- air quality monitoring and weather prediction
- medical imaging and database analysis
- multi-sensor chemical analysis
- strength prediction for concrete mixes
- signature verification
- decision making and intelligent agents
- machine condition monitoring and failure forecasting
- chemical analysis
- electromagnetic and digital circuit design

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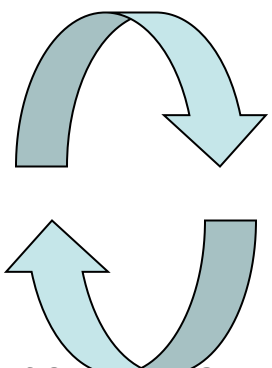
ART MAIN IDEA

Top-down attentive feedback
encodes
learned expectations
that
STABILIZE LEARNING AND MEMORY
in response to
a changing world
that is filled with
unexpected events

Attentive Information Processing

FAST



Learning and Memory

SLOW

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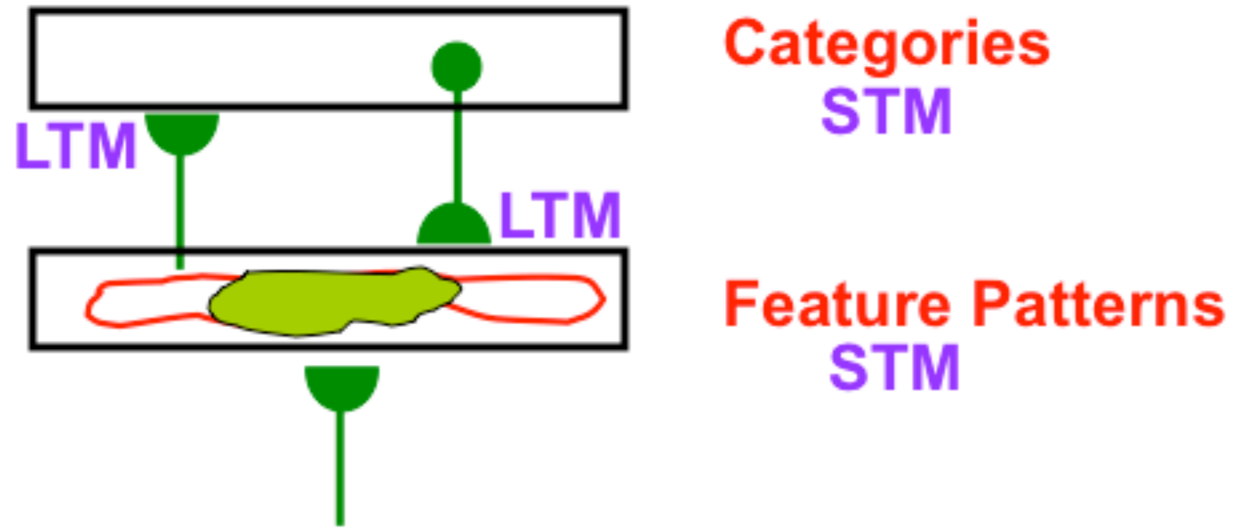
ADAPTIVE RESONANCE

Attended feature clusters reactivate bottom-up pathways

Activated categories reactivate their top-down pathways



Feature-Category resonance synchronizes
amplifies
prolongs system response

Resonance triggers learning in bottom-up and top-down adaptive weights: adaptive resonance!

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WHAT IS AN ATTENTIONAL SHROUD?

Surface-fitting spatial attention

ATTENTIONAL SHROUD!

marks the object-hood of the as-yet-undefined object category

Tyler and Kontsevich (1995)
used shrouds to study perceptual transparency

Cf. Cavanagh, Pylyshyn, Yantis,…

Magritte (1927)

PREDICTION:
Shrouds enable learning of view-invariant object categories

Grossberg (2007, 2009)
Fazl, Grossberg, and Mingolla (2009)
Cao, Grossberg, and Markowitz (2011)
Grossberg, Markowitz, and Cao (2011)
Foley, Grossberg, and Mingolla (2012)
Chang, Grossberg, and Cao (2014)

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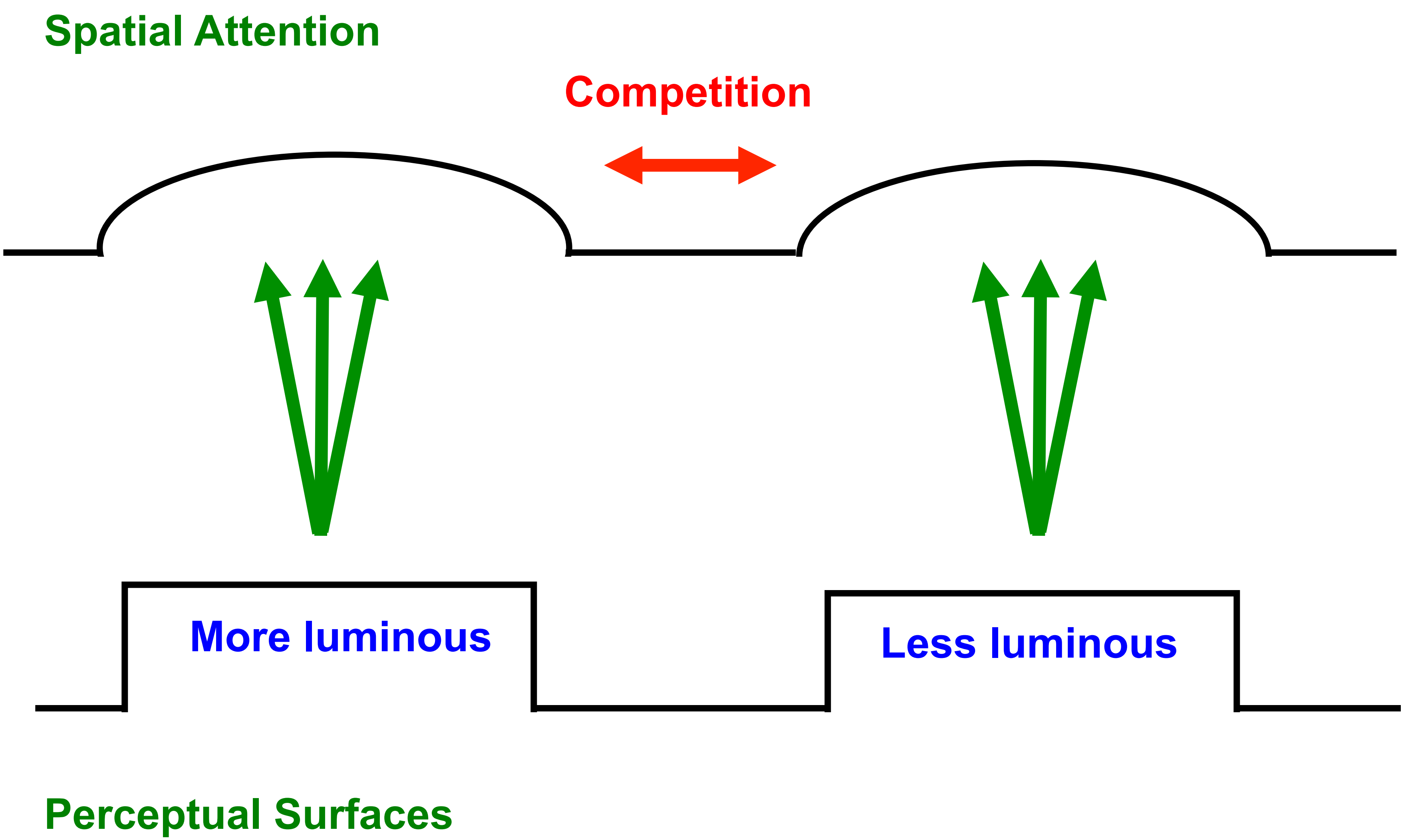
BOTTOM-UP SPATIAL ATTENTIONAL COMPETITION



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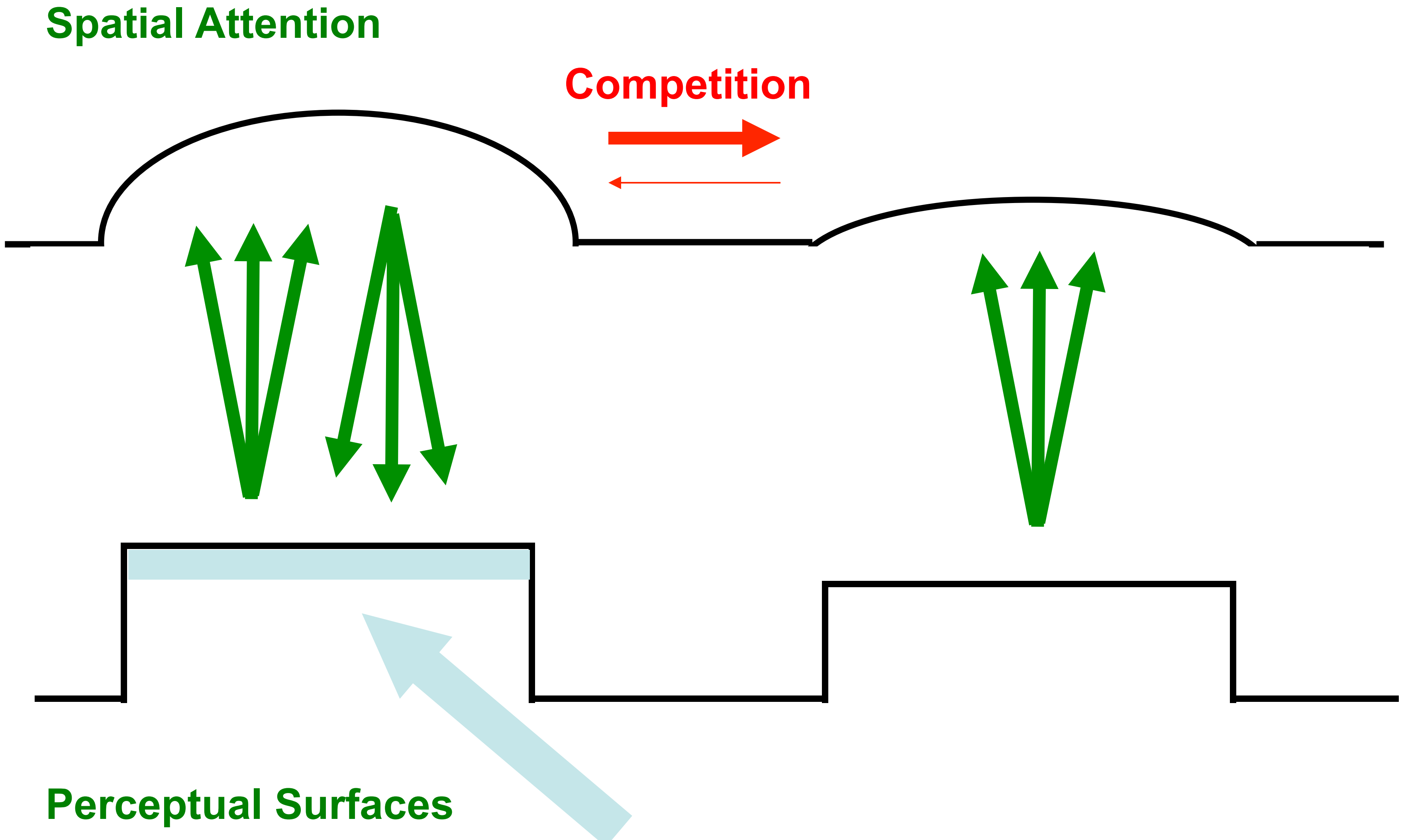
SURFACE-SHROUD RESONANCE



Psychophysics: **Carrasco, Penpeci-Talgar, and Eckstein (2000)**
Neurophysiology: **Reynolds and Desimone (2003)**

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SURFACE-SHROUD RESONANCE

An active
SURFACE-SHROUD RESONANCE
means that sustained
SPATIAL ATTENTION IS FOCUSED
ON THE OBJECT SURFACE

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SURFACE-SHROUD RESONANCE

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means that sustained
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ON THE OBJECT SURFACE

A SURFACE-SHROUD RESONANCE ALSO SUPPORTS
CONSCIOUS SEEING OF
AN ATTENDED OBJECT

THAT IS HOW WE CONSCIOUSLY SEE A PAINTING!

See my 2017 article on the Hard Problem of Consciousness!

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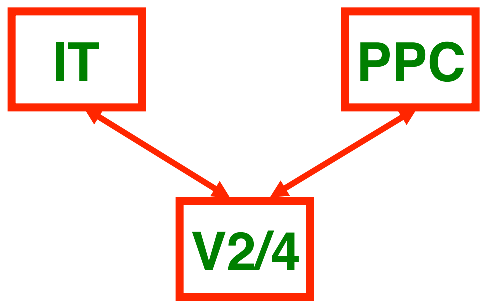
WHAT KINDS OF RESONANCES SUPPORT KNOWING VS. SEEING?

What Stream **Where Stream**



KNOWING
Feature-Category Resonance

SEEING
Surface-Shroud Resonance

Synchronous linkage between resonances enables us to KNOW what the object is as we SEE it

THAT'S A MONET!!!

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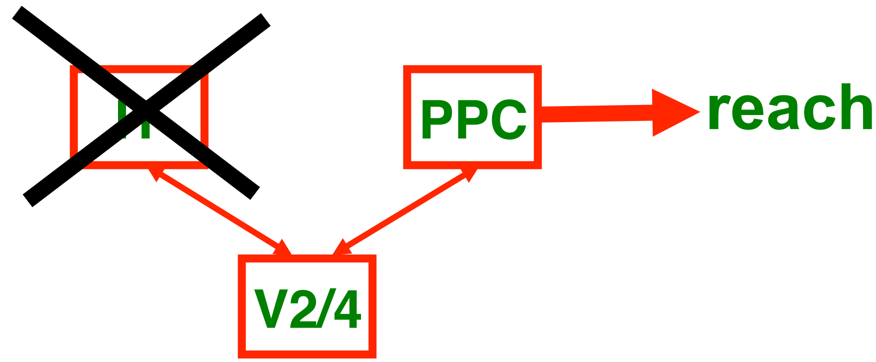
WHAT KINDS OF RESONANCES SUPPORT KNOWING VS. SEEING?

What Stream **Where Stream**



KNOWING
Feature-Category Resonance

SEEING
Surface-Shroud Resonance

VISUAL AGNOSIA: reaching without knowing

Patient DF Goodale et al, 1991

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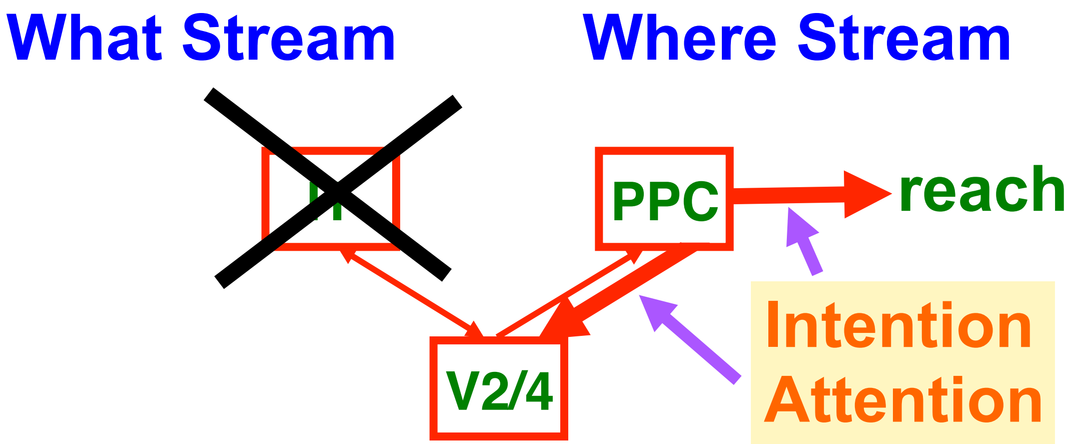
WHAT KINDS OF RESONANCES SUPPORT KNOWING VS. SEEING?



KNOWING
Feature-Category
Resonance

SEEING
Surface-Shroud
Resonance

VISUAL AGNOSIA: reaching without knowing

Patient DF Goodale et al, 1991

Attention and Intention both parietal cortical functions

Andersen, Essick, and Siegel, 1985; Gnadt and Andersen, 1988; Snyder, Batista, and Andersen, 1997, 1998

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HOW WE SEE ART AND HOW ARTISTS MAKE IT

I've sketched some of the brain designs
that help to understand this:

Complementary computing of boundaries and surfaces
Hierarchical resolution of uncertainty
Multiple-scale boundary webs
Lightness anchoring
Surface-shroud resonance

You can begin to see how our brains compute
VERY DIFFERENTLY from traditional computers!
VERY DIFFERENTLY from…e.g.…Deep Learning!

I did NOT mention BEAUTY or how we FEEL about a painting

For that, you need to study how
COGNITIVE-EMOTIONAL
processes occur
a discussion for another day!

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