

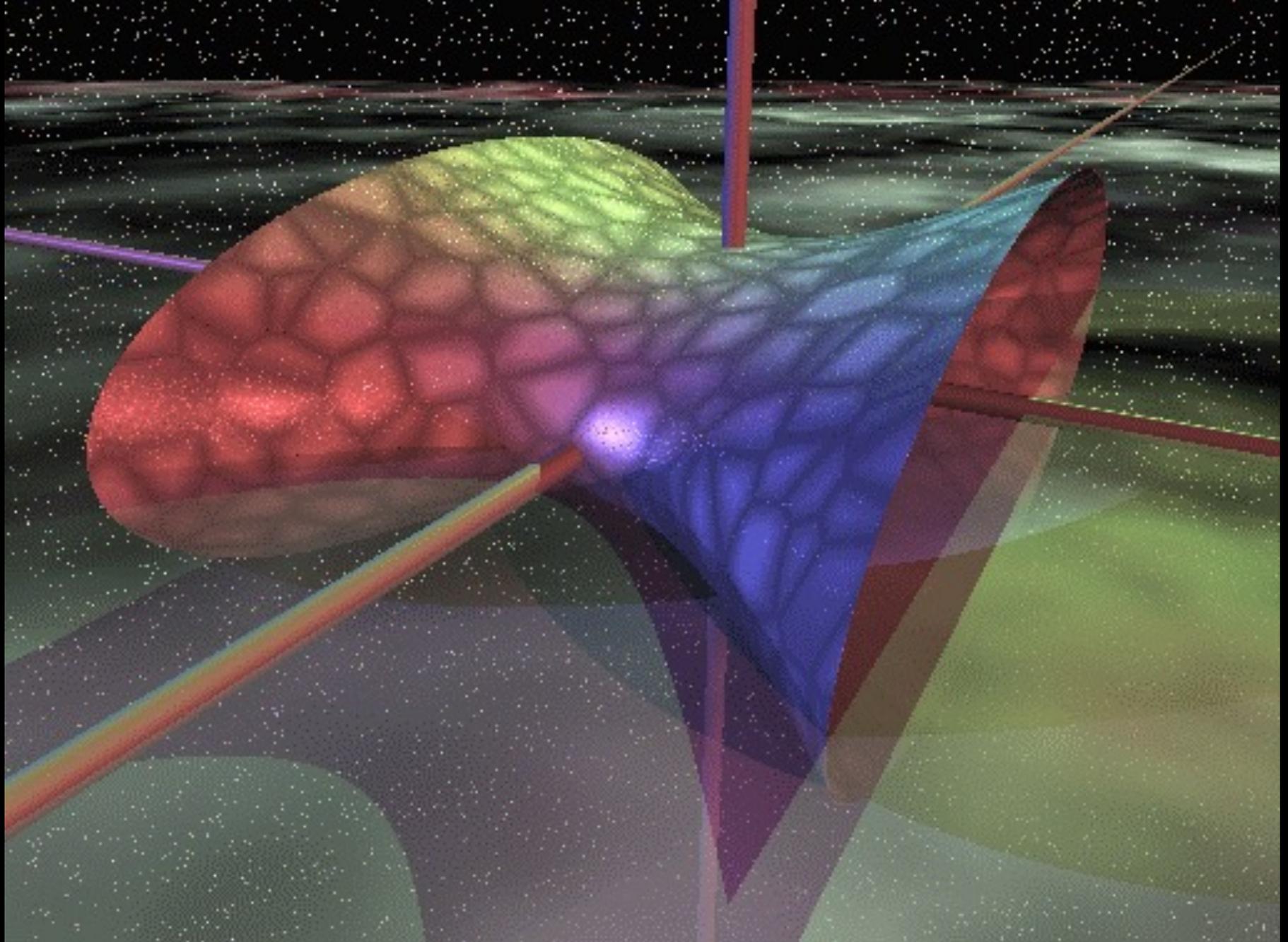
History and Neuroscience

Representation in Art

Christopher W. Tyler
Smith-Kettlewell Institute

<http://christophertyler.org> >> Art Investigations

[Reproduction permitted under the Creative Commons CC BY-NC-SA licence.]



'Hyperboloid' by Danny Thorne (1997)



'Bus Reflections' by Richard Estes (1974)

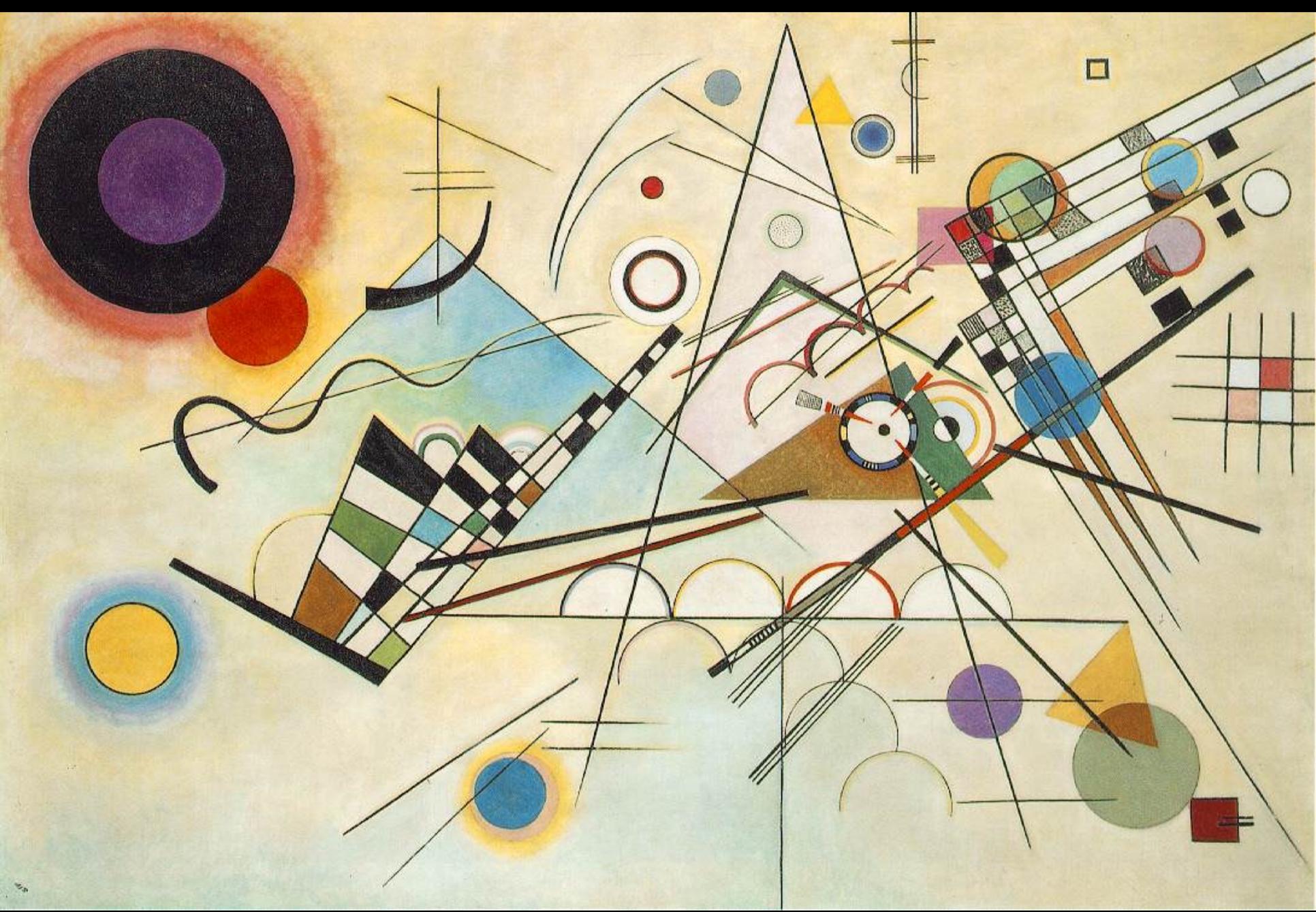
'Christ of Saint John
of the Cross'

by

Salvador Dali

(1951)





'Composition VIII' by Vassily Kandinsky (1923)



'Piazza di San Marco Looking Southeast' by Canaletto (1735-40)

‘The Annunciation’

by

Carlo Crivelli

(1486)





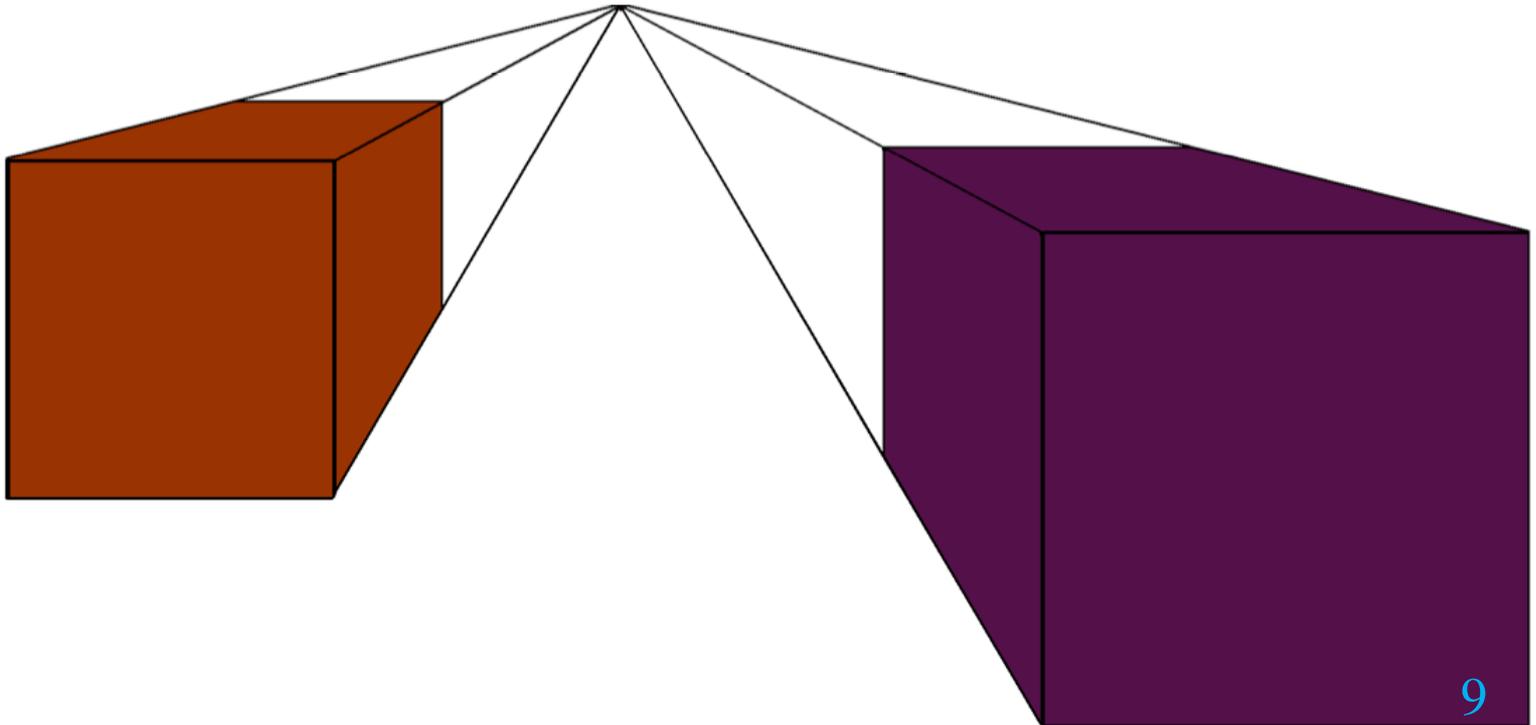
OPUS CARO
LIGNIVELLE
VERE PL

1486

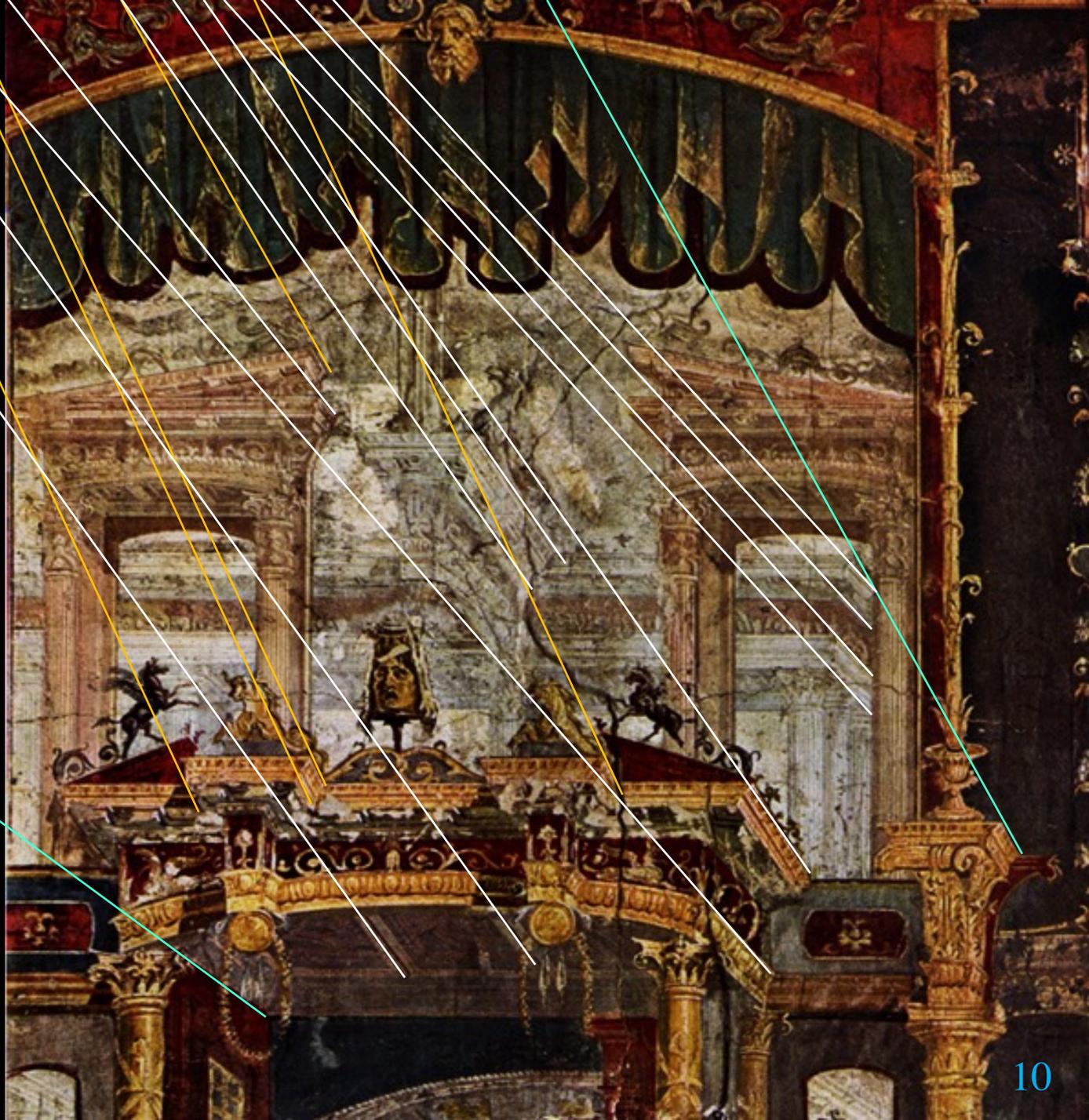
LIBERTAS

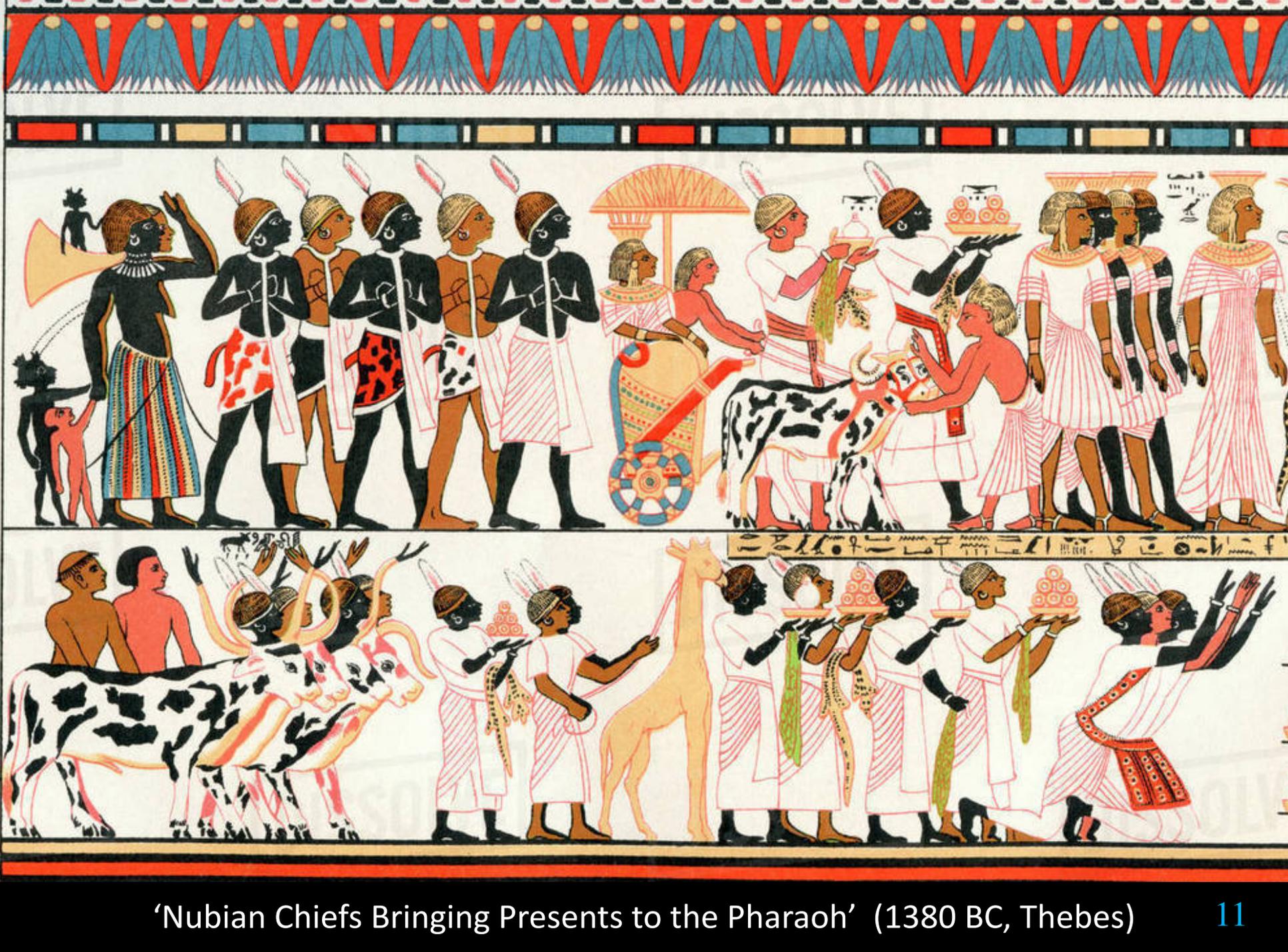
ECCLIASTICA

Convergence to a vanishing point (at infinity)



‘Pompeian
Proscenium’
(3rd Century AD)





‘Nubian Chiefs Bringing Presents to the Pharaoh’ (1380 BC, Thebes)



Distance indicated by overlapping repetition with no size diminution



Distance indicated by overlapping repetition with no size diminution



'Palette of King Narmer' (~3000 BC, Hierakonopolis)



Cave Painting in Vallon Pont D'Arc, France (~30,000 years ago)



Perspective Theory

Perspective Quiz

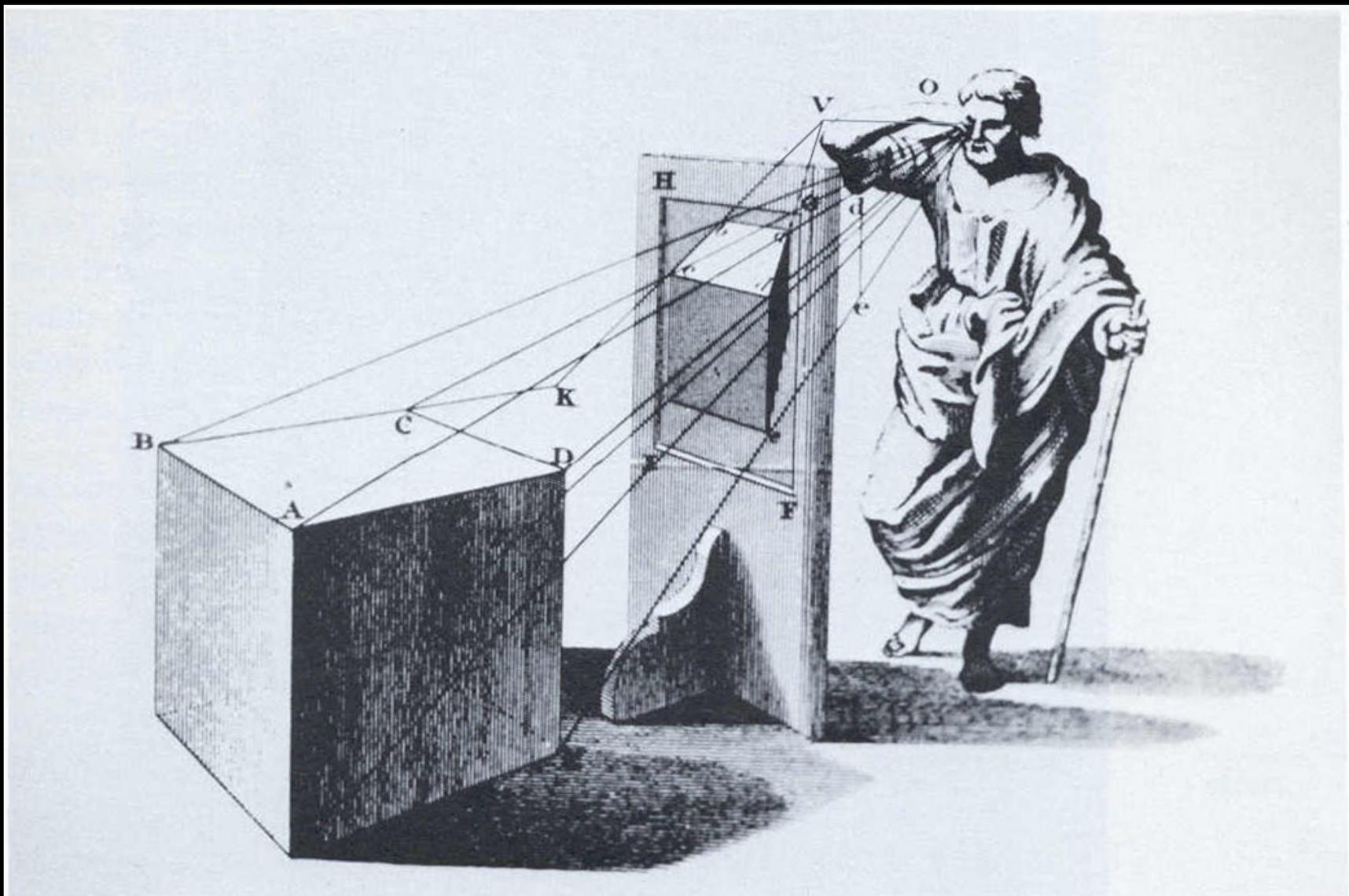
0. How many forms of correct pictorial perspective are there?
1. What do straight lines project to in the picture plane?
2. What is the projection for a set of parallel lines?
3. How do multiple sets of parallel lines project within a single plane in space (such as the ground plane)?
4. How many vanishing points are there in a scene?
5. What is the angle at the eye for two vanishing points from lines at a given angle θ ?
6. How are planar figures in space foreshortened?
7. How do circles in the scene project to the picture plane?
8. Where should the viewer stand to see a picture in proper perspective?
9. Does the viewer need to be fixating on the vanishing point for the perspective to be correct?

Perspective Quiz

0. How many forms of correct pictorial perspective are there?

One: the perspective projection to a picture plane.

(Or, in general, to the surface of projection, such as in a VR headset.)



The visual cone, from B. Taylor, *New Principles of Linear Perspective* (1715).

'Brook Taylor'

by

?Louis Goupy
(1720, NPGL)

[Artist, geometer, and
inventor of the Taylor
Series expansion that
dominates theoretical
physics.]



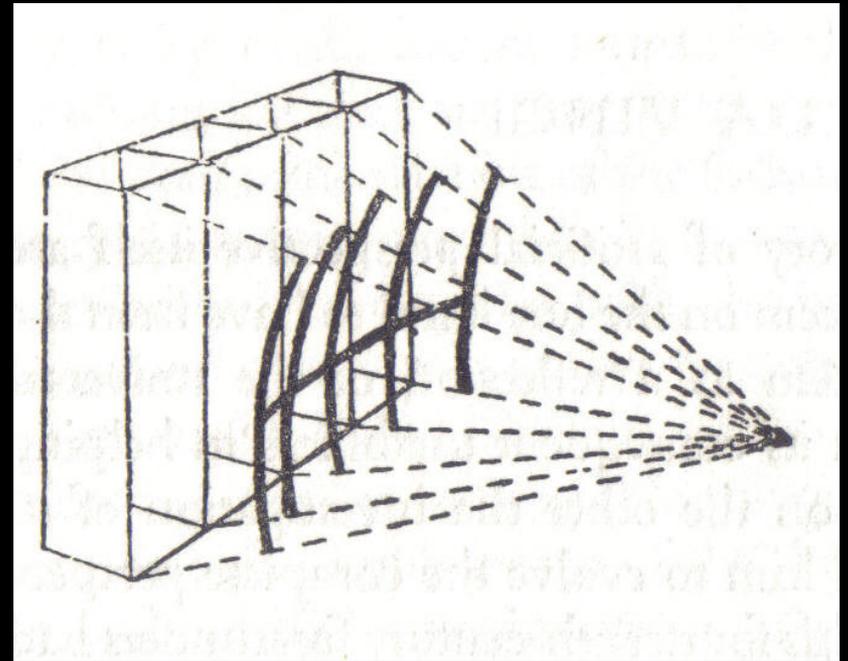
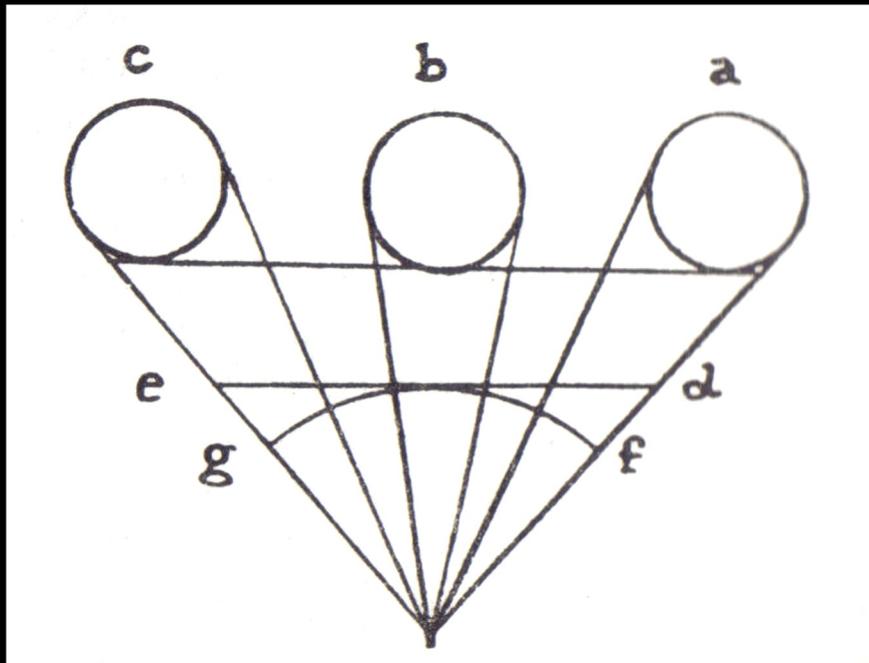
“Natural” and “Artificial” Perspective

There is debate in the art analysis literature about there being two forms of perspective: “natural” and “artificial” perspective.

“Natural” perspective is considered to be the perspective of projection to the light-sensitive surface inside the eye.

“Artificial” perspective is considered to be the projection to a picture plane.

Leonardo's diagram and White's (1957) interpretation of columns in 'distorted' linear perspective and 'curved' in natural perspective



“Simple [natural] perspective is that which is constructed on a surface equally distant from the eye in every part – complex [artificial] perspective is that which is constructed on a surface in which none of the parts are equally distant from the eye.”

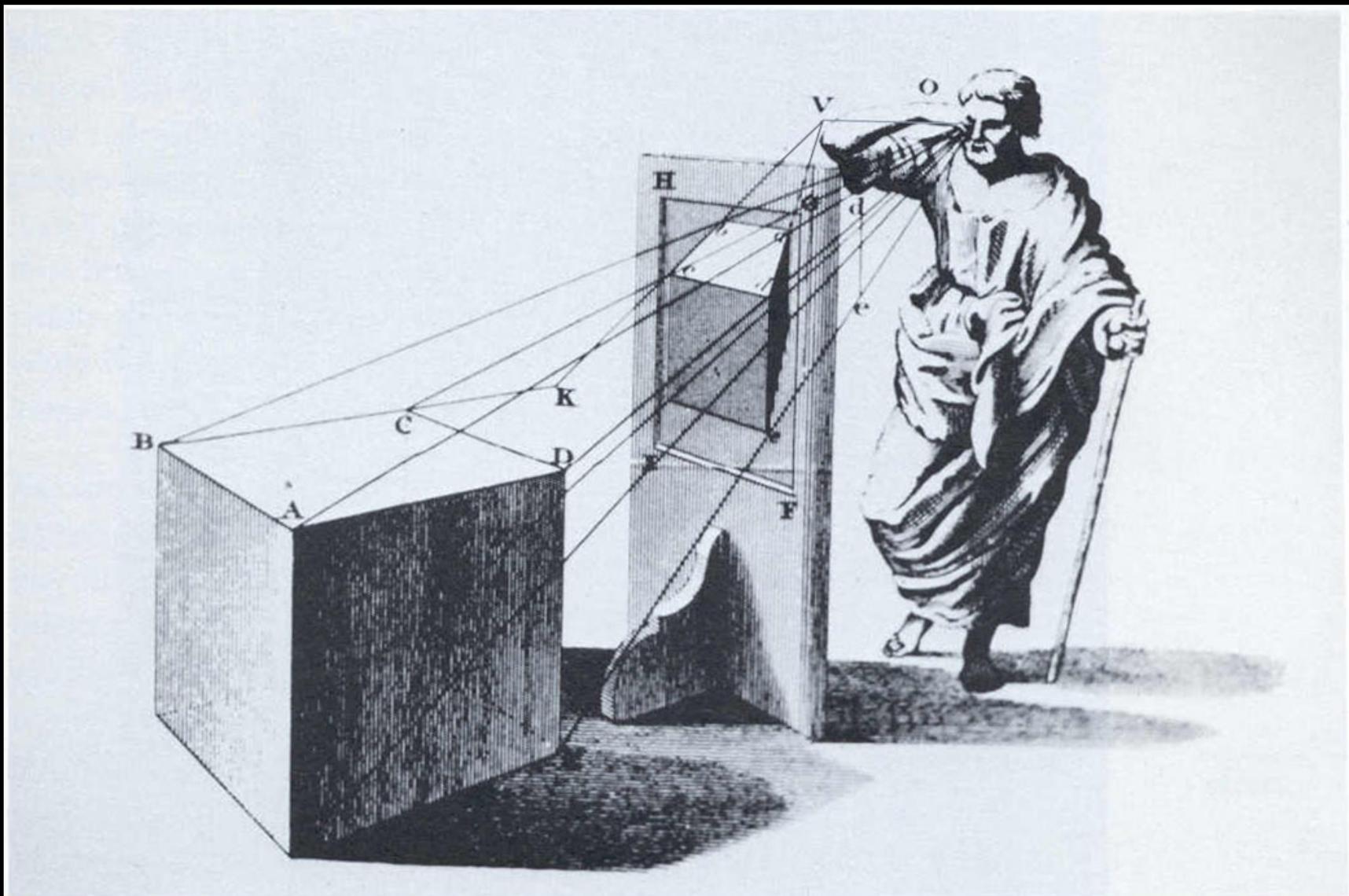
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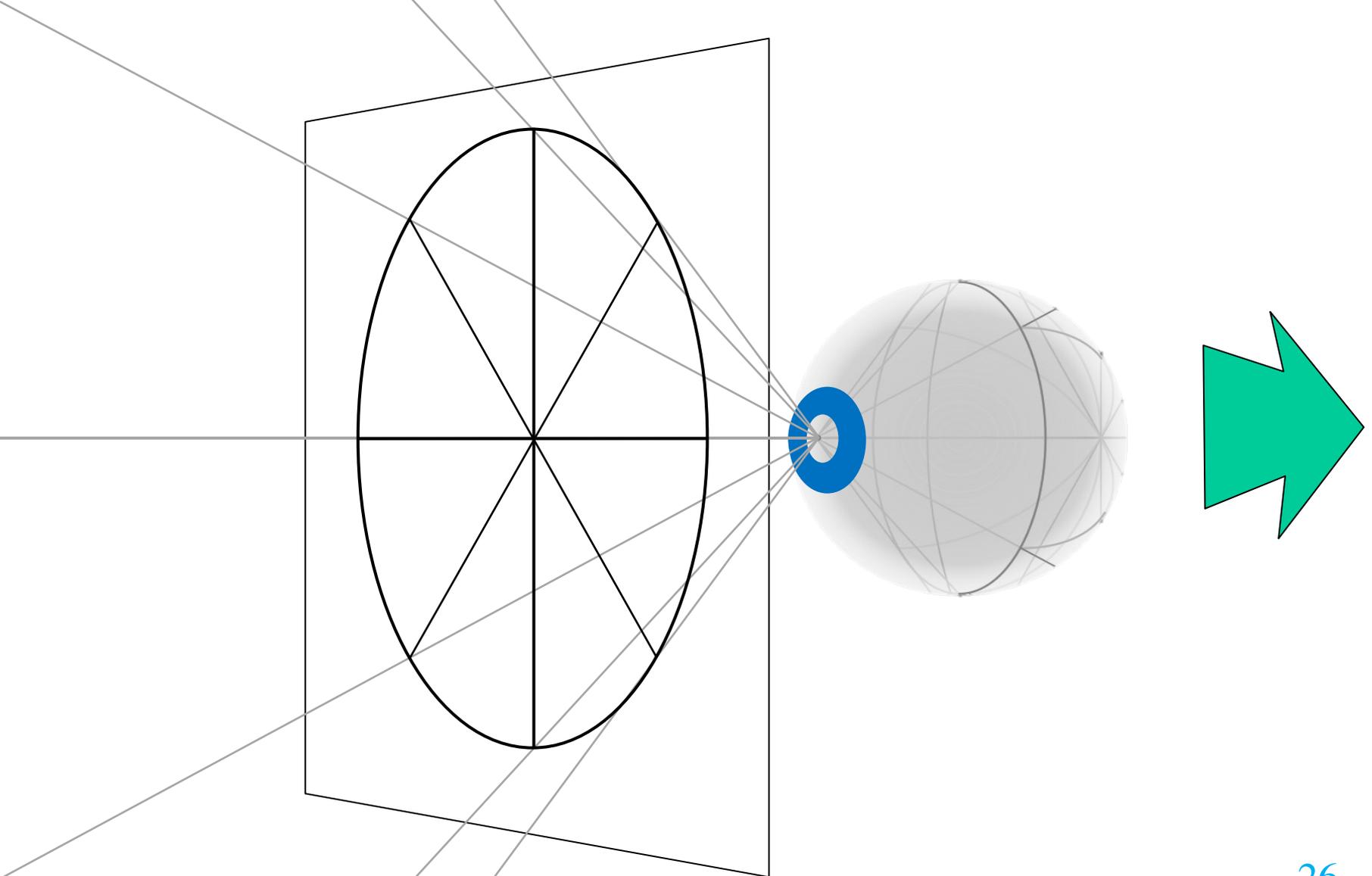
But Brook Taylor’s diagram shows that it is entirely irrelevant what goes on inside the eye, or the further processing by the brain. If the image on the picture plane matches the projection of the world to the eye, it is in fully correct perspective.



The visual cone, from B. Taylor, *New Principles of Linear Perspective* (1715).

Artificial

Natural



“Natural” and “Artificial” Perspective

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“Natural” perspective is considered to be the perspective of projection to the light-sensitive surface inside the eye.

“Artificial” perspective is considered to be the projection to a picture plane.

But Brook Taylor’s diagram shows that it is entirely irrelevant what goes on inside the eye, or the further processing by the brain. If the image on the picture plane matches the projection of the world to the eye, it is in fully correct perspective.

Thus, “natural” perspective is an abstract construct of no relevance to painters (or video game developers).

The only form of perspective amenable to geometric analysis is the so-called “artificial” form.

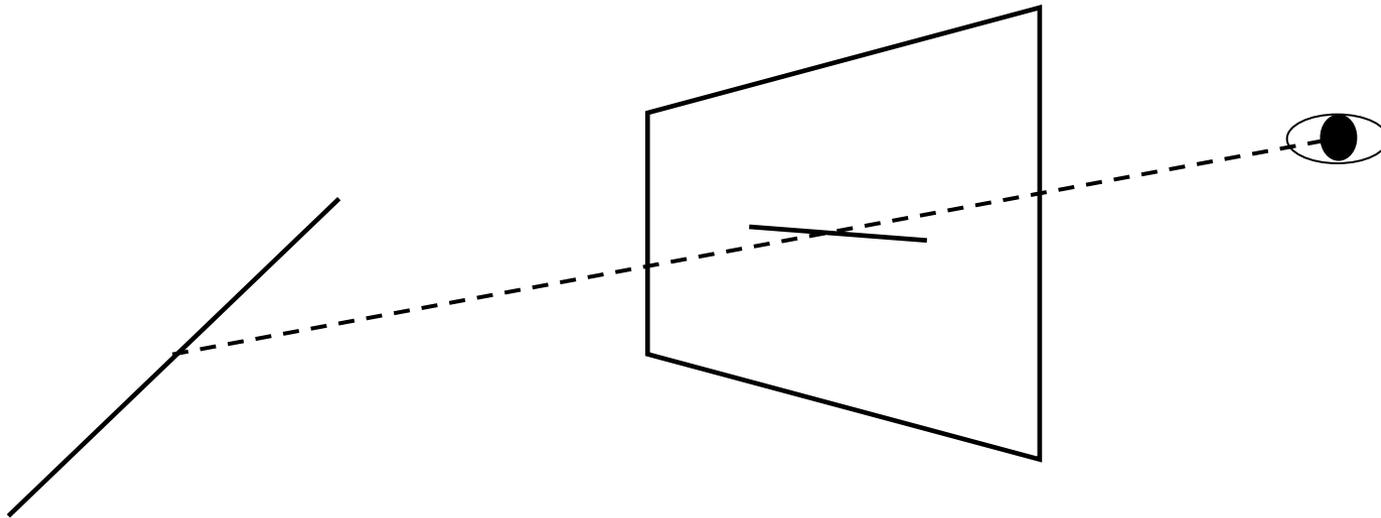
The Rules of Perspective

0. There is only one geometry of perspective projection onto a fixed picture plane.

The Rules of Perspective

0. Singular specificity

1. All straight lines in space project to straight lines (or points, in the limit) in the picture plane.

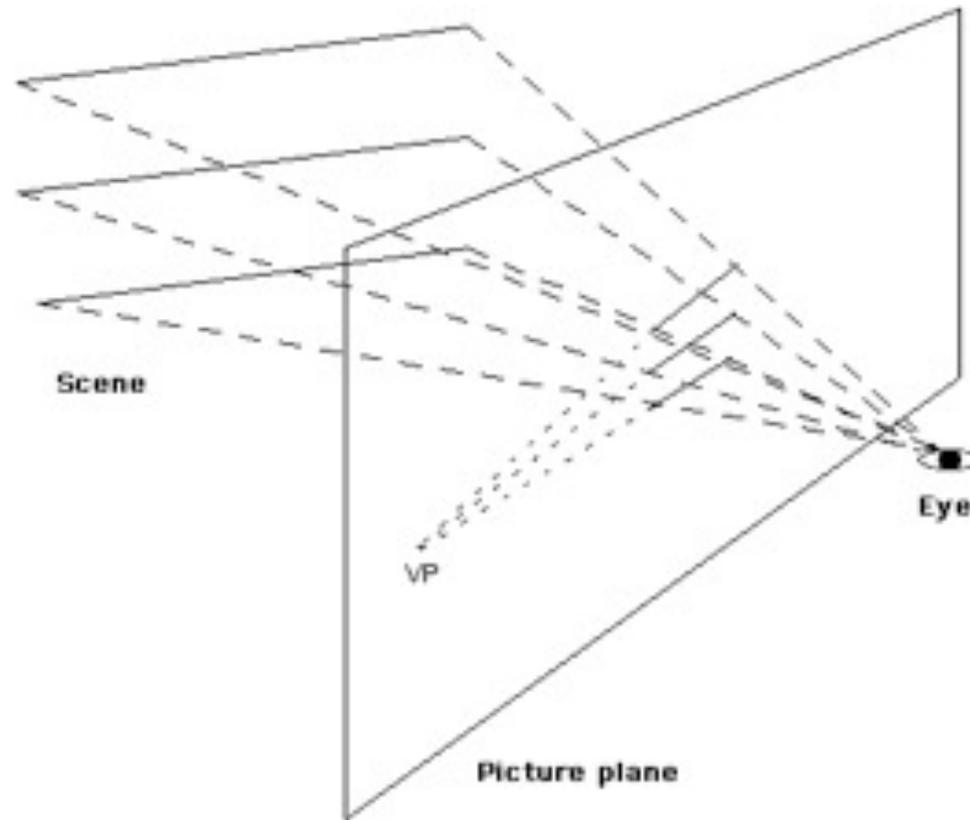


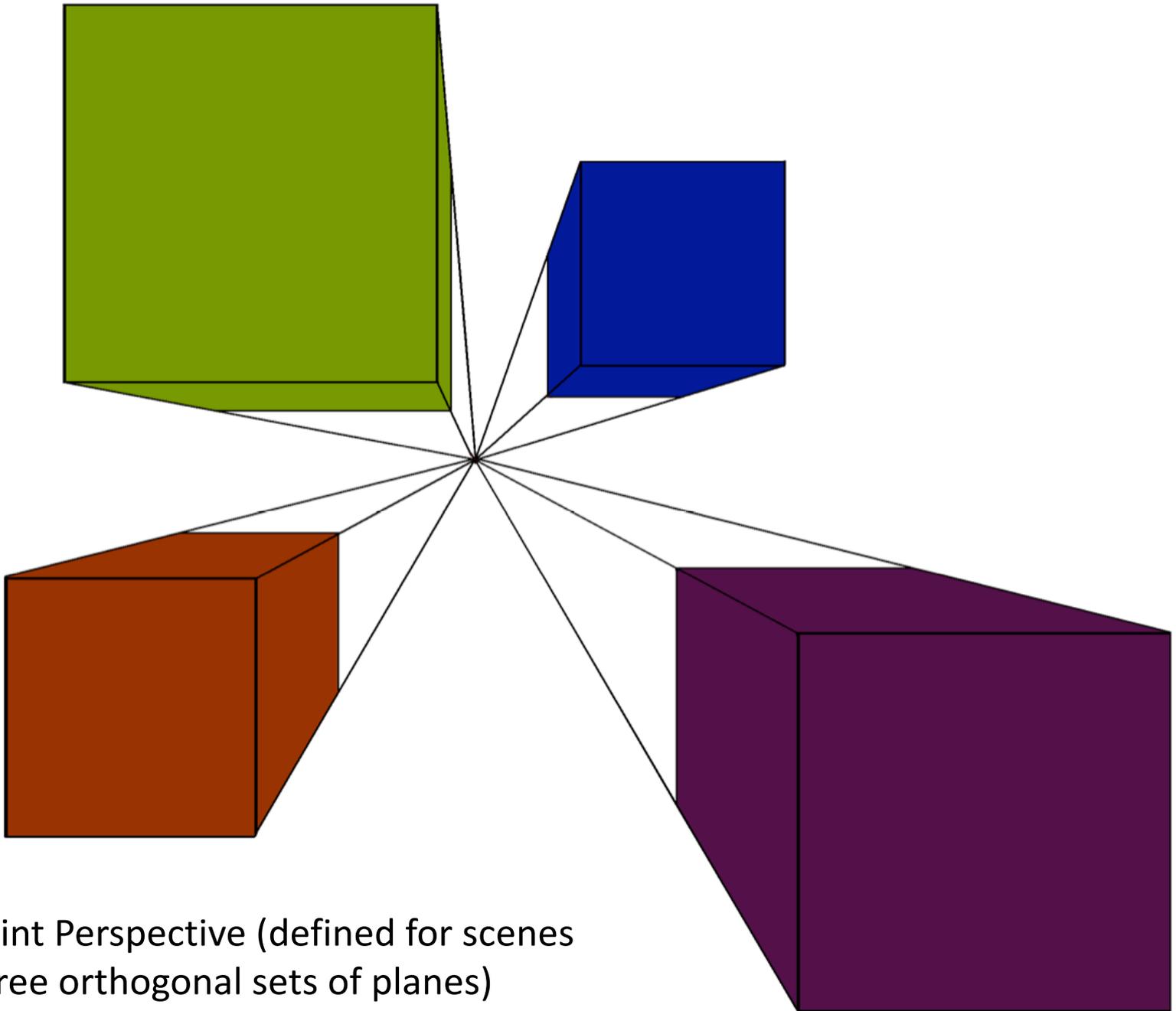
The Rules of Perspective

0. Singular specificity

1. Projective isomorphism

2. The projection of any straight line terminates in a vanishing point in the picture plane (except for lines parallel to the picture plane).





One-point Perspective (defined for scenes with three orthogonal sets of planes)



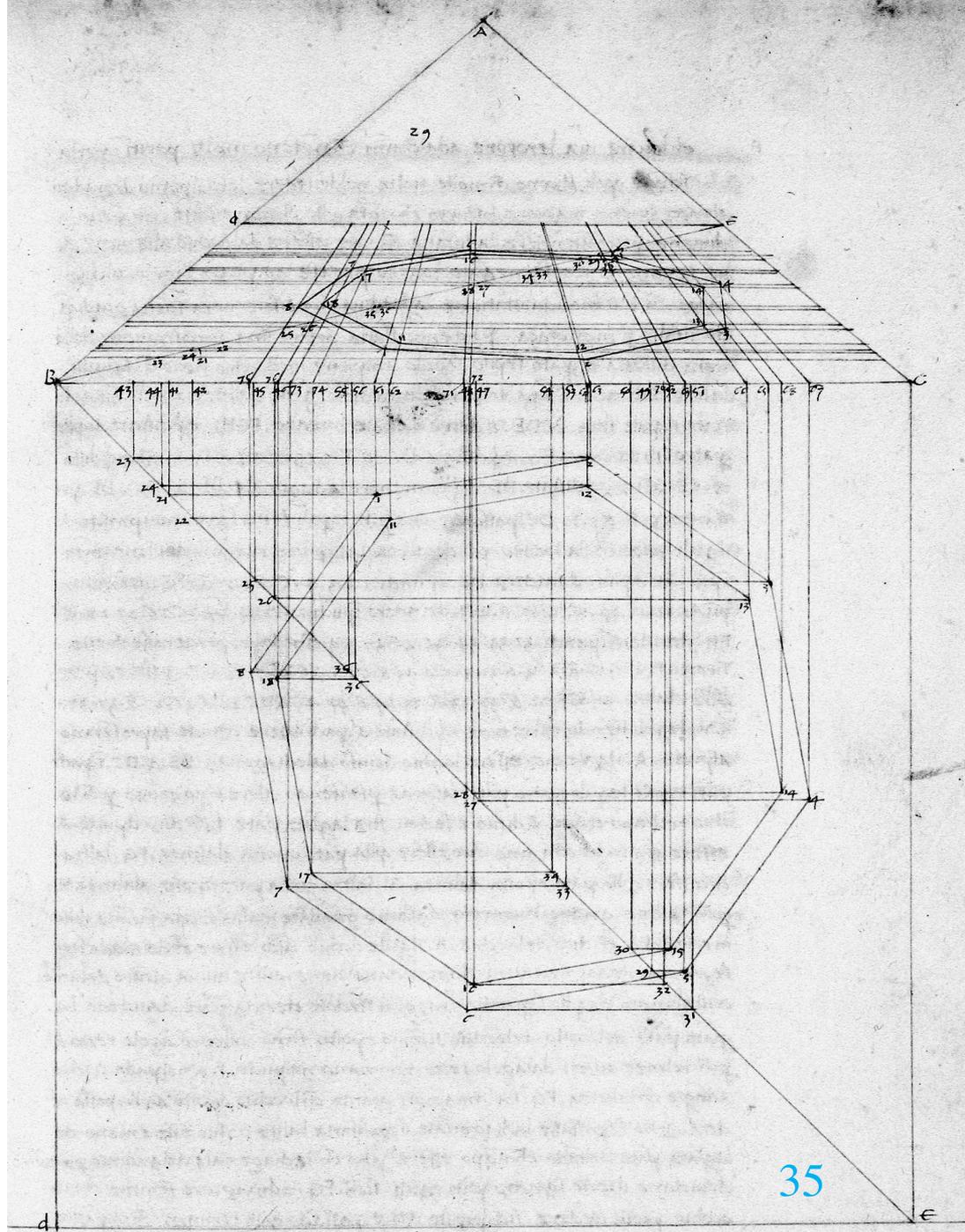
‘St Peter Healing the Cripple and the Raising of Tabitha from the Dead’
by Masolino da Panicale (1425, Brancacci Chapel, Florence)

The earliest known diagram of the vanishing- point construction

by

Piero della Francesca
(1475)

[The key feature is the
projection to the diagonal]



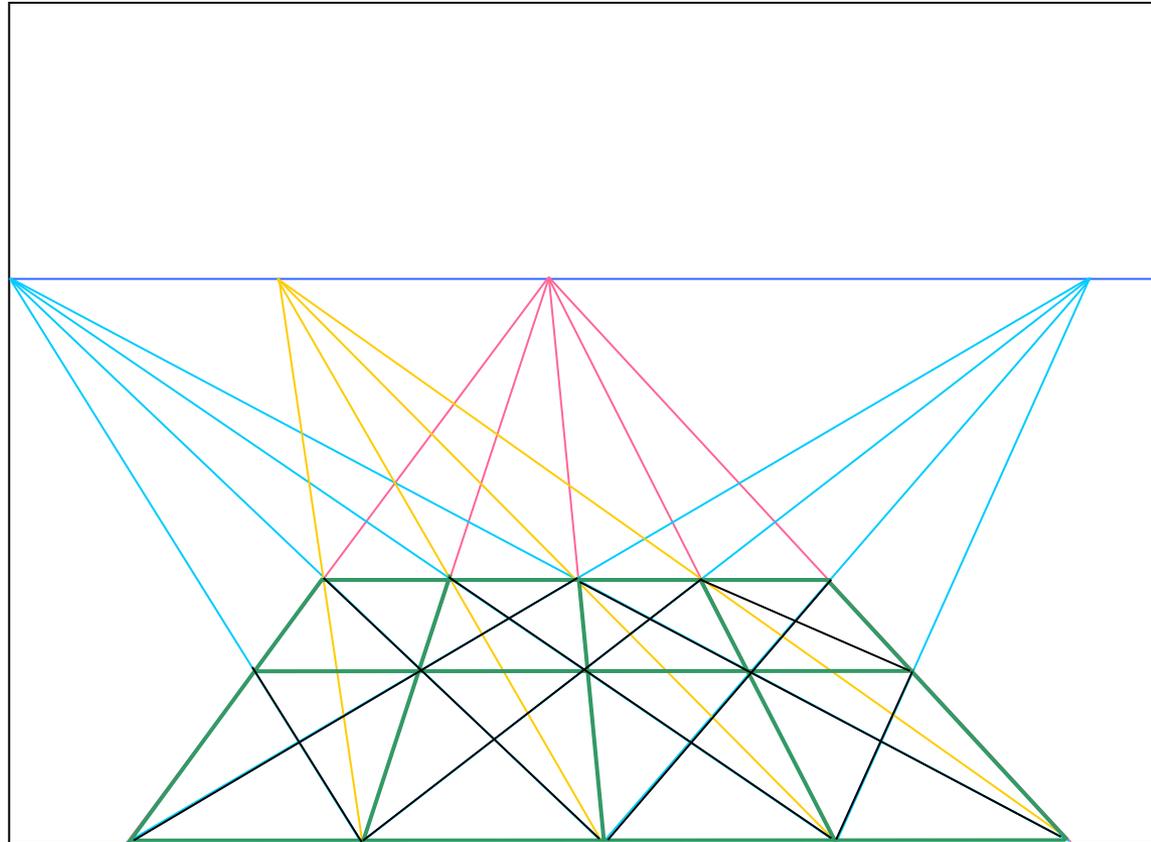
The Rules of Perspective

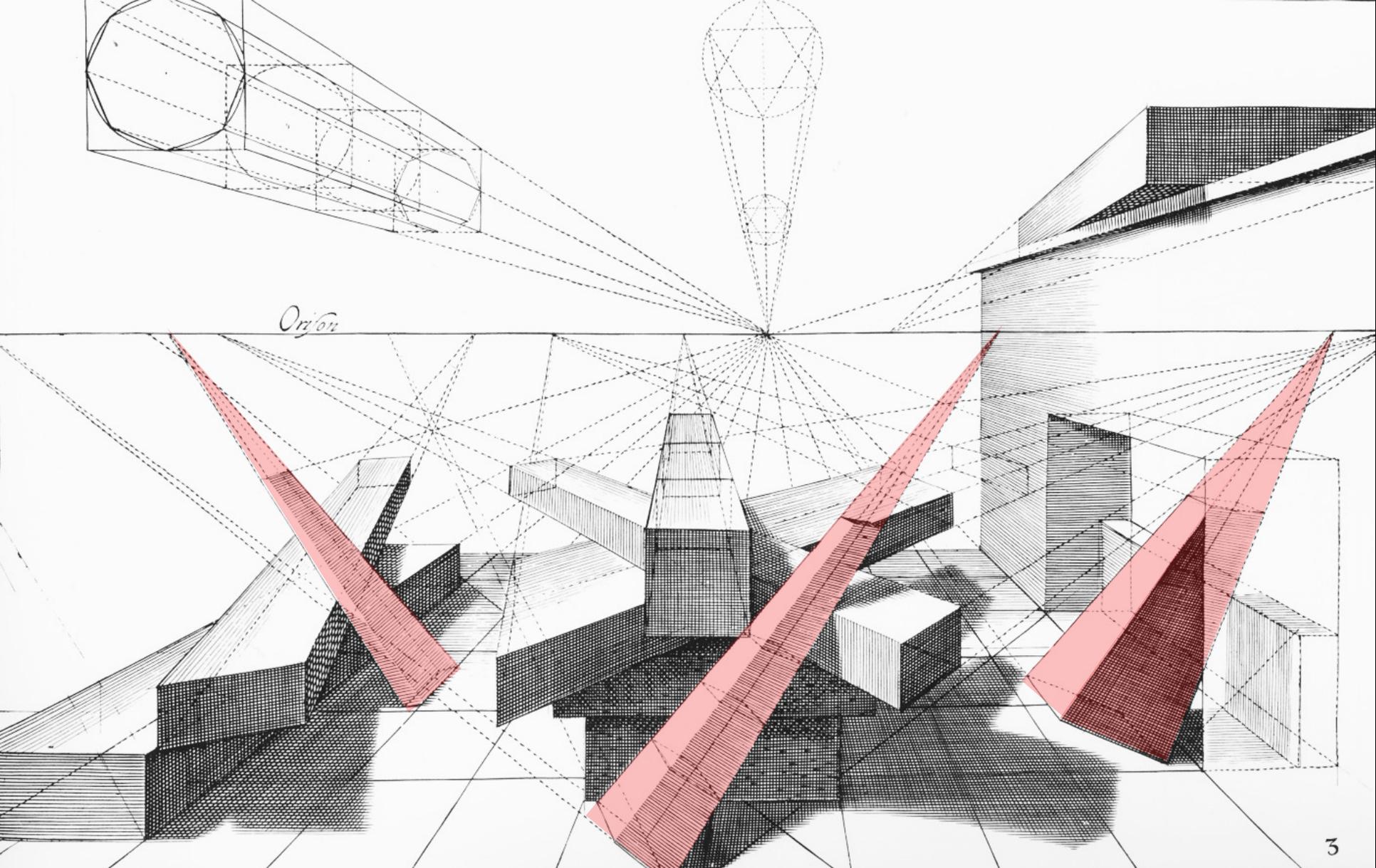
0. Singular specificity
1. Projective isomorphism
2. Convergence of parallels

The Rules of Perspective

0. There is only one geometry of perspective projection onto a fixed picture plane.
1. All straight lines in space project to straight lines (or points, in the limit) in the picture plane.
2. All sets of parallel lines in space project either to parallel lines in the picture plane or to lines intersecting at a single vanishing point.
3. All lines lying at any angle within a plane have vanishing points that fall along the horizon line defined by the orientation of that plane.

3. All sets of parallels lying within a specified plane in space converge to vanishing points in the horizon line for that plane.



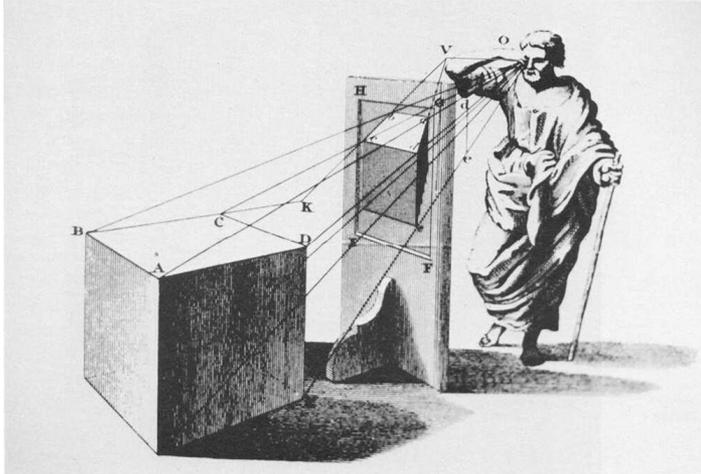


Johan Vredeman de Vries (1604-1605, part II, Figure 3).

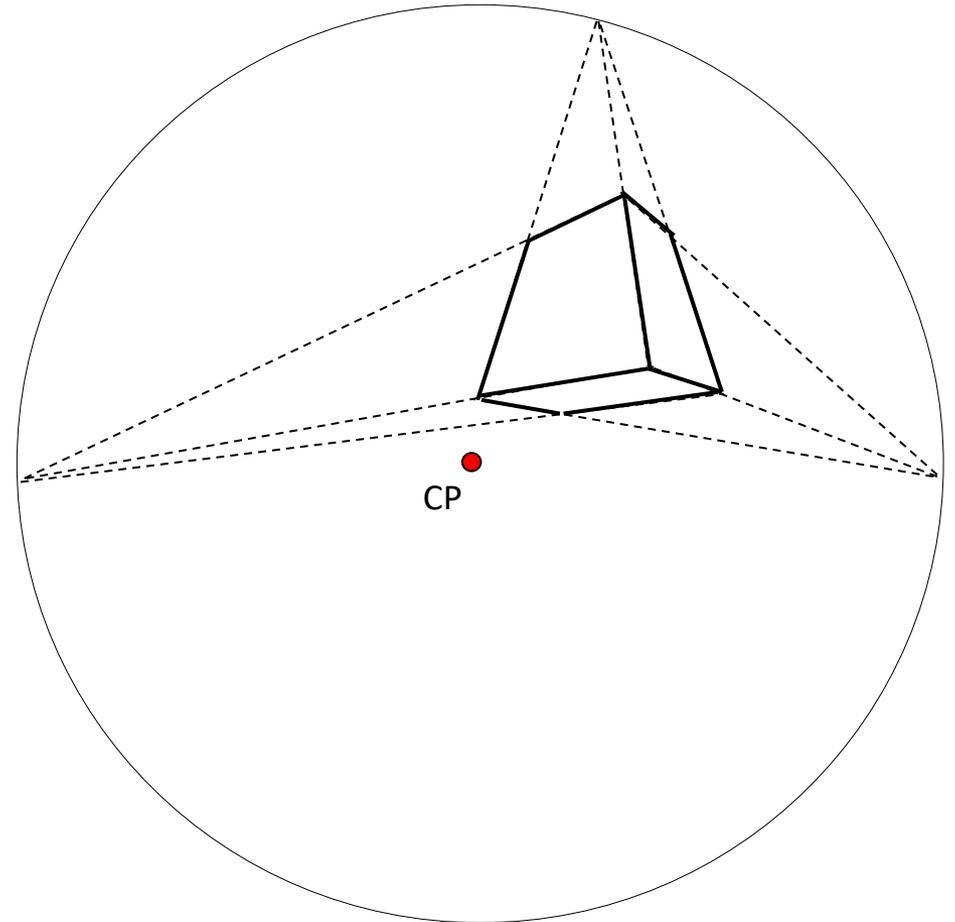
The Rules of Perspective

0. Singular specificity
1. Projective isomorphism
2. Convergence of parallels
3. Planar collinearity

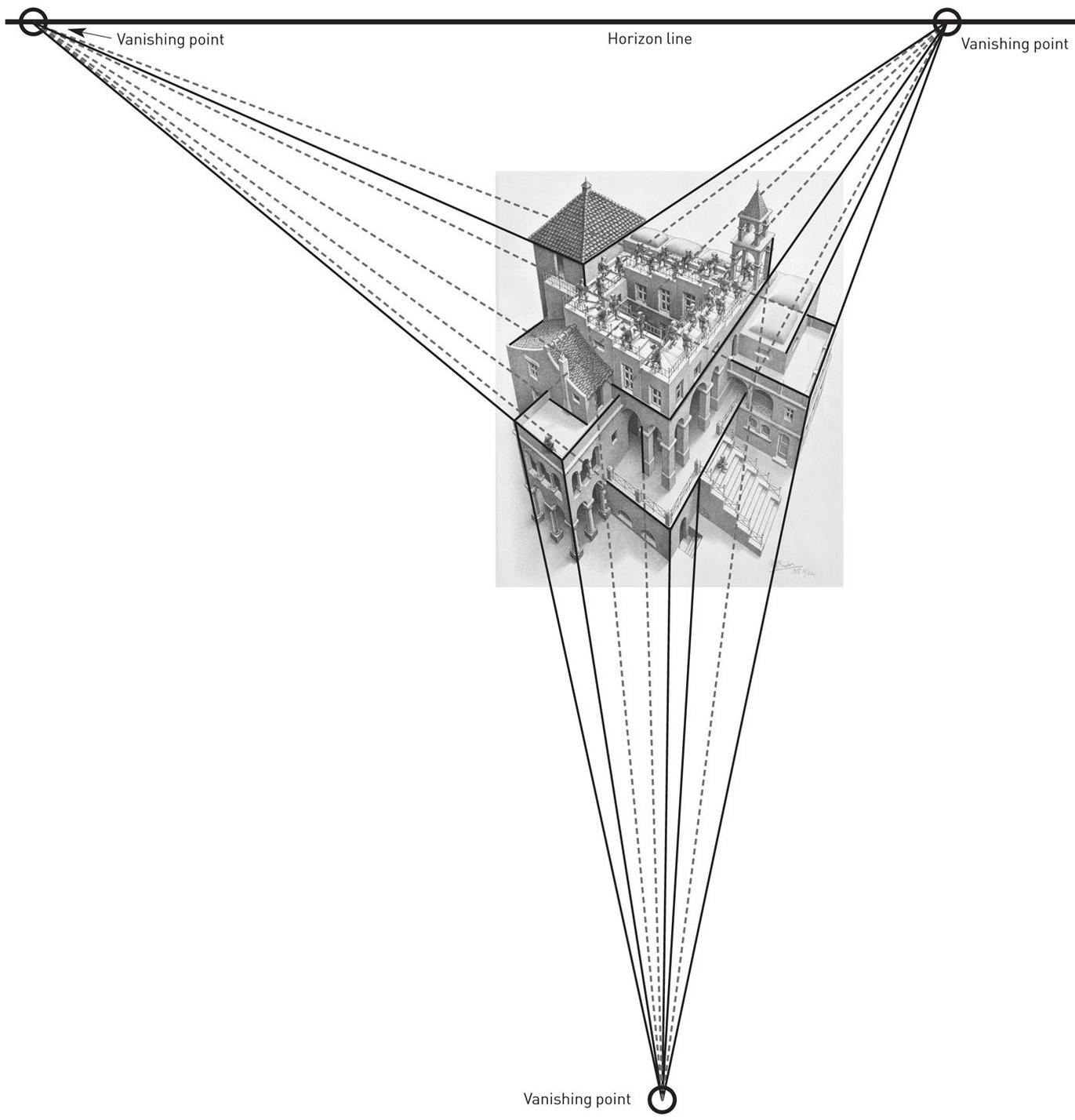
4. The number of vanishing points in the scene = $m - p$, where m is the number of different angles of lines in the scene, and p is the number of different sets of lines parallel to the picture plane.



1-point perspective depicted
in 2-point perspective



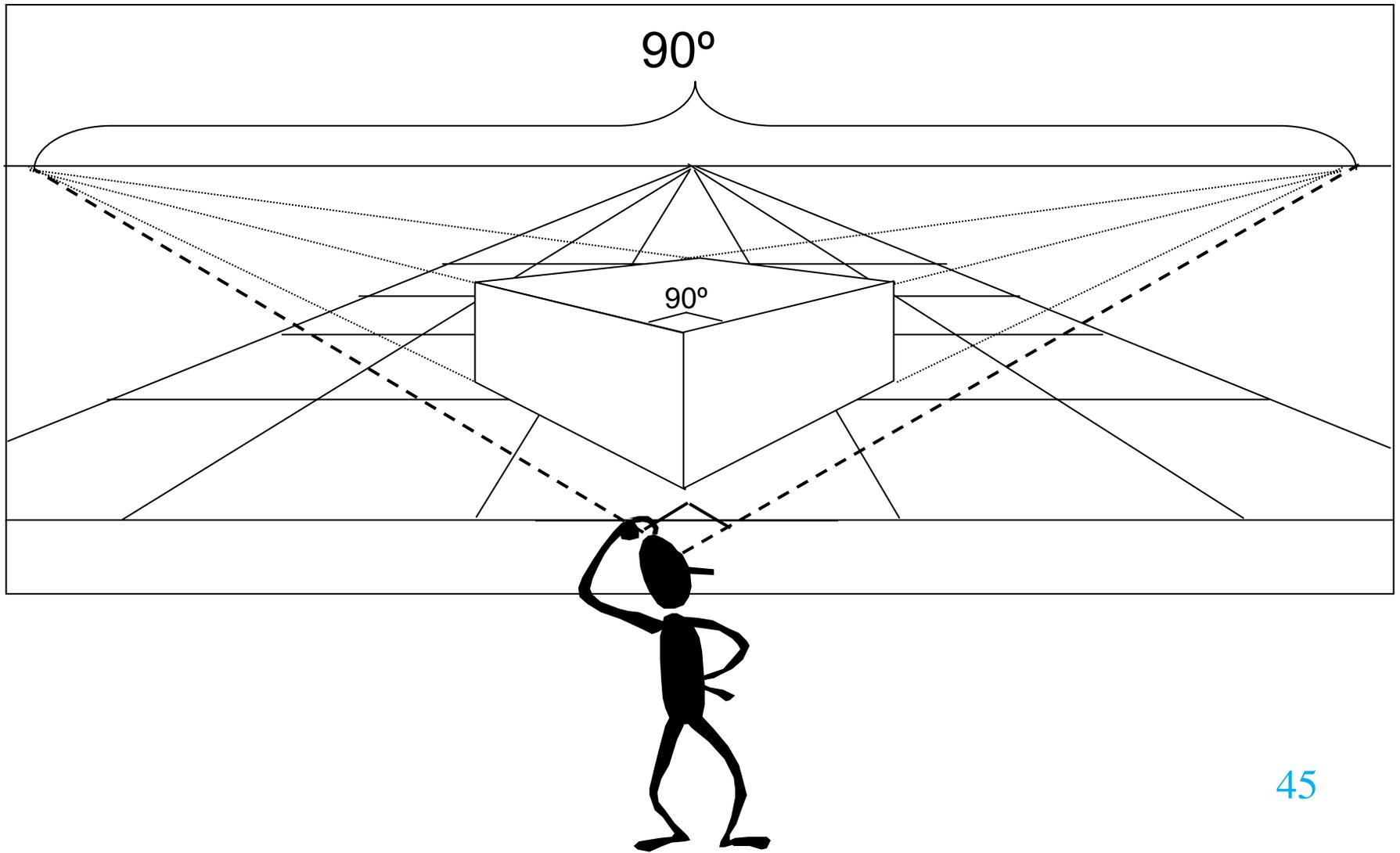
3-point perspective for 3 orthogonal sets of
parallels, none parallel to the picture plane



The Rules of Perspective

0. Singular specificity
1. Projective isomorphism
2. Convergence of parallels
3. Planar collinearity
4. Vanishing point enumeration: $n = m - p$

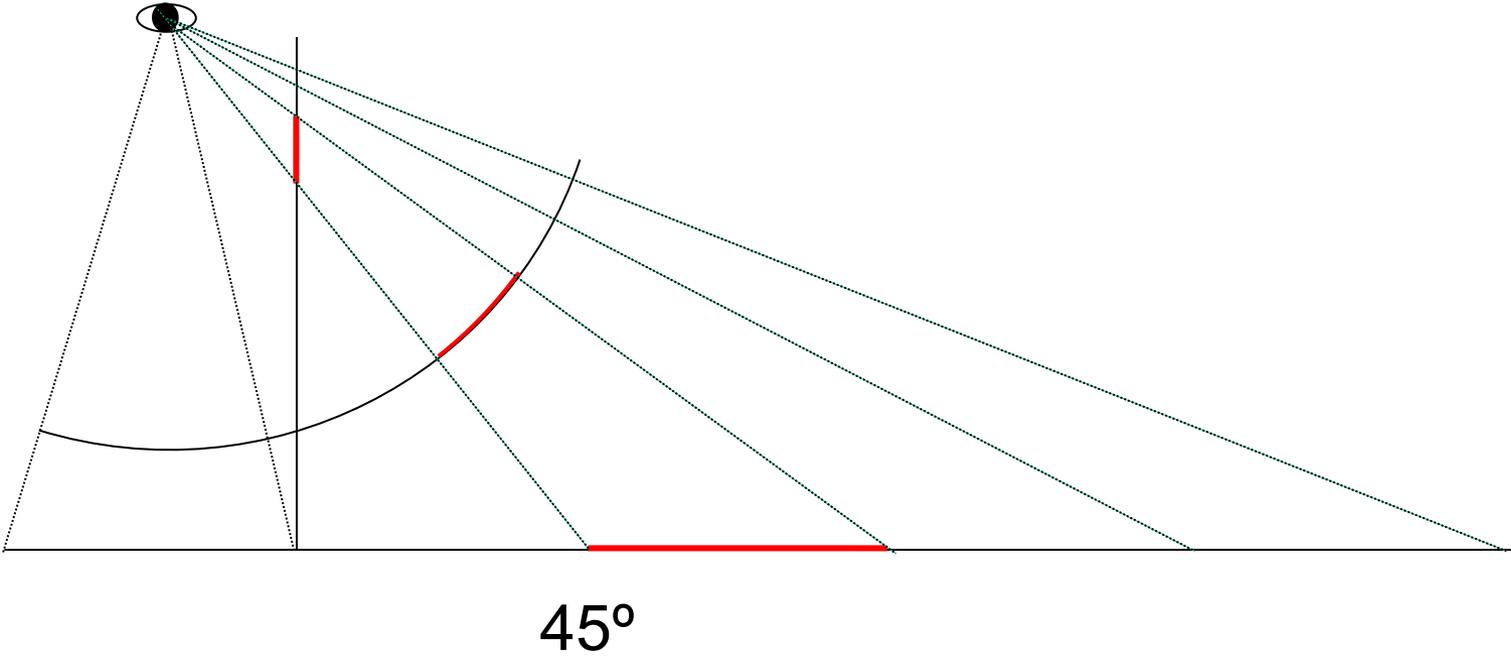
5. The viewer's angle to any pair of vanishing points is the same as the angle between the generating parallels in space, regardless of their angle of projection in the picture.



The Rules of Perspective

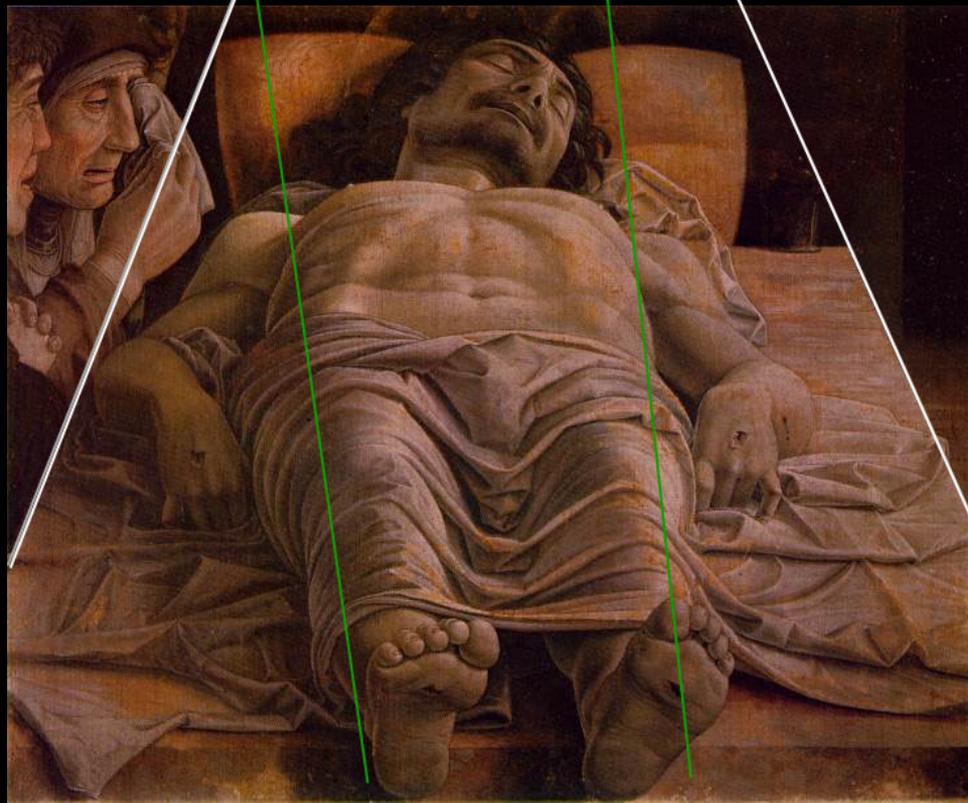
0. Singular specificity
1. Projective isomorphism
2. Convergence of parallels
3. Planar collinearity
4. Vanishing point enumeration: $n = m - p$
5. Angular isomorphism

6. Any planar figure in space is foreshortened in the direction of its slant from the observer (up to a 45° viewing angle).





'The Dead Christ' by Mantegna (~1480)

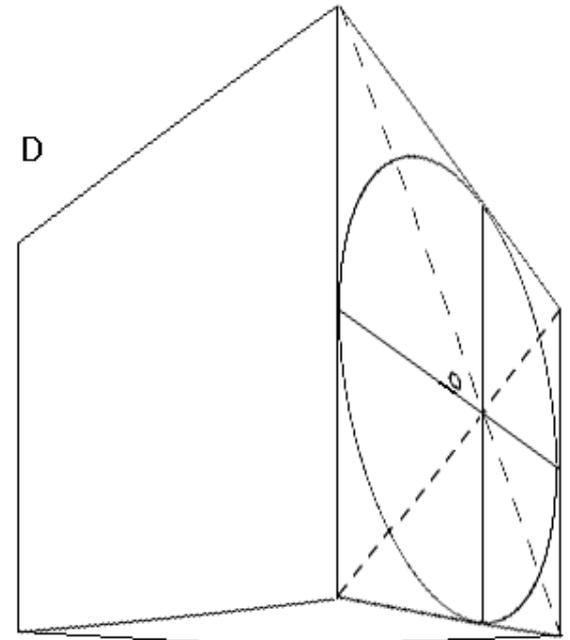
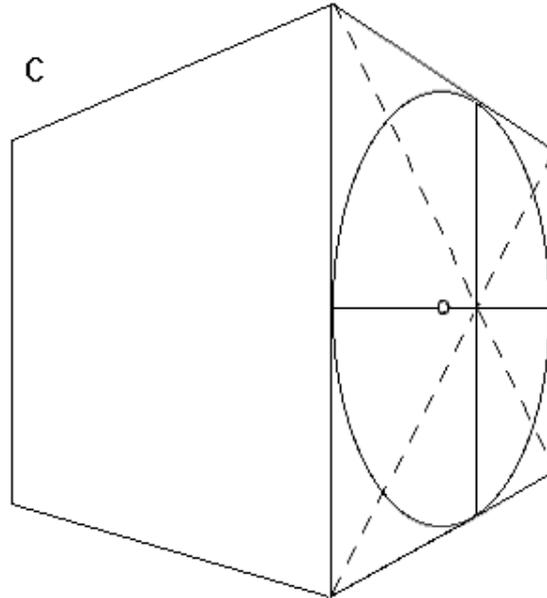
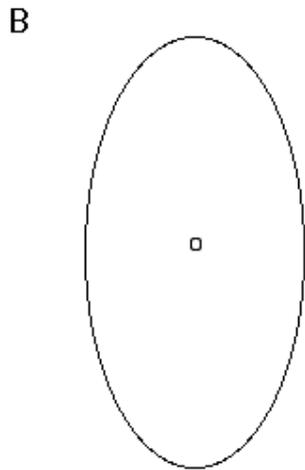
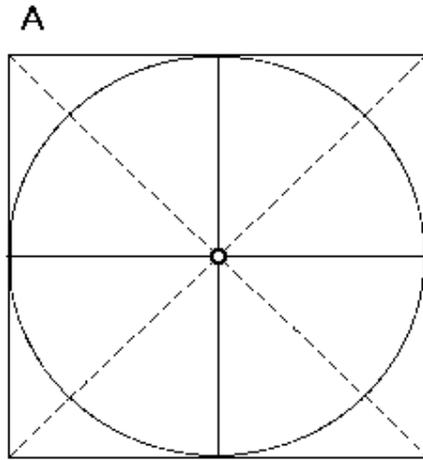




The Rules of Perspective

0. Singular specificity
1. Projective isomorphism
2. Convergence of parallels
3. Planar collinearity
4. Vanishing point enumeration: $n = m - p$
5. Angular isomorphism
6. Planar foreshortening

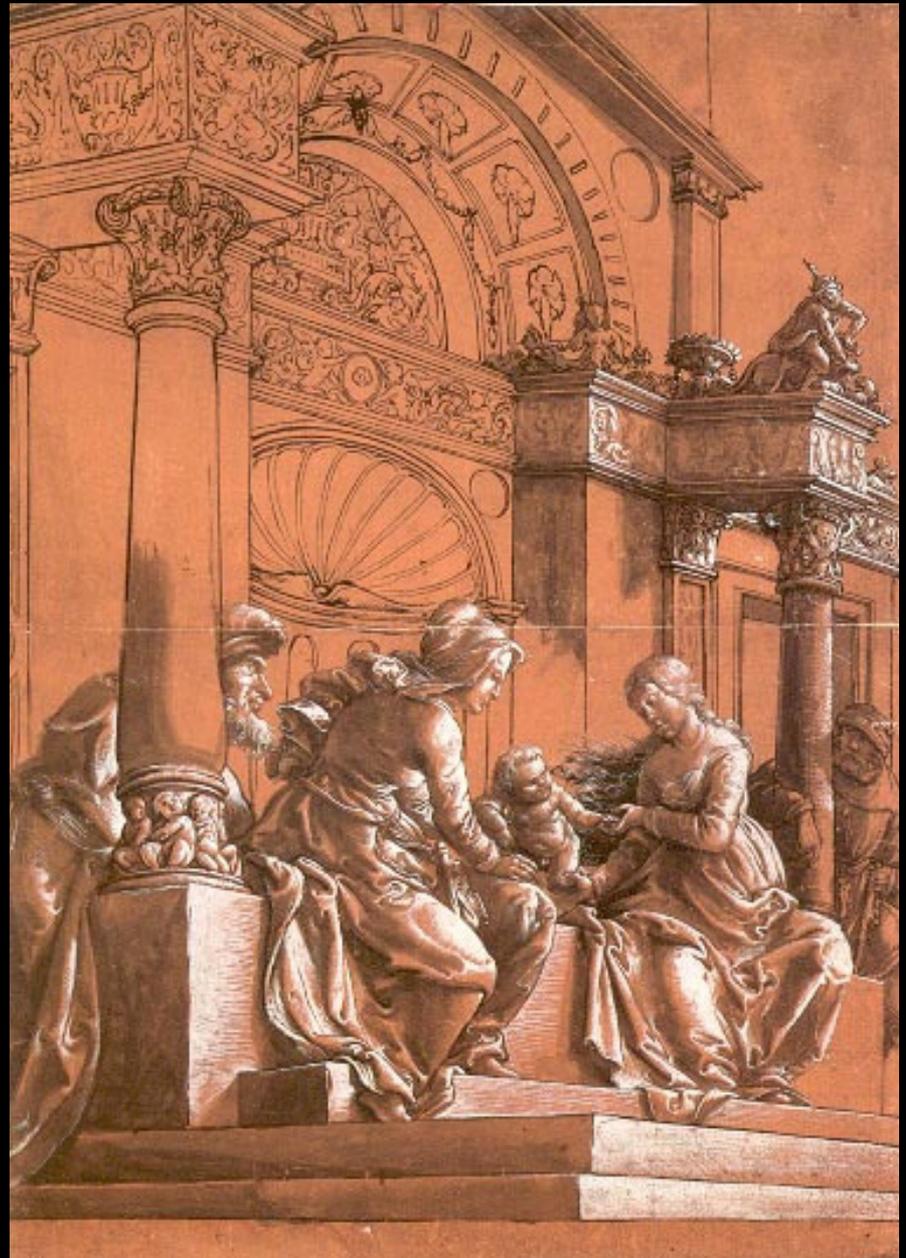
7. Circles in the scene, if foreshortened, project to ellipses in the picture plane. But with the center shifted from that of the ellipse, and rotated for the general case of non=symmetric projection.

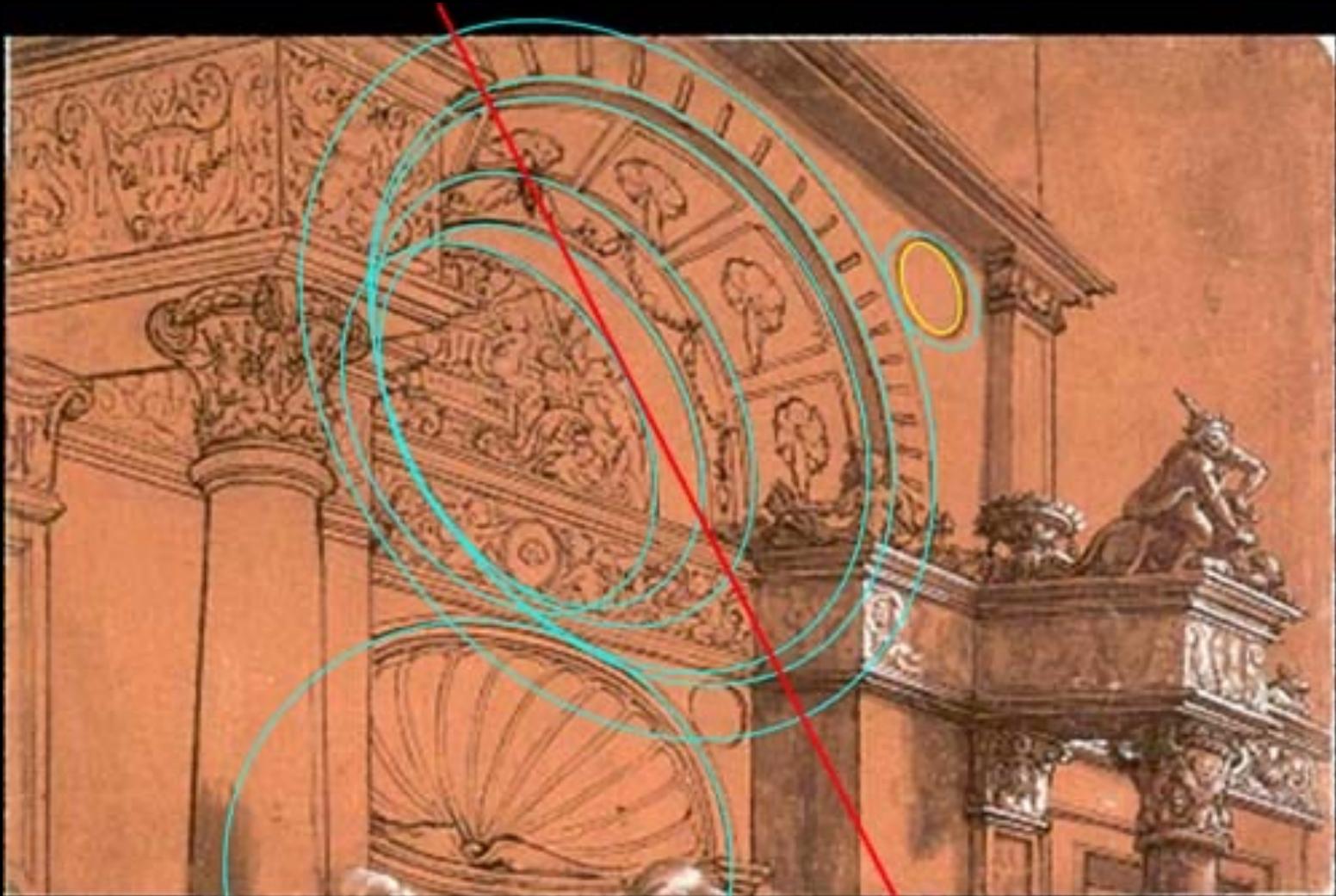


'The Holy Family with St. Anne
and St. Joachim'

by

Holbein
(1518-19)



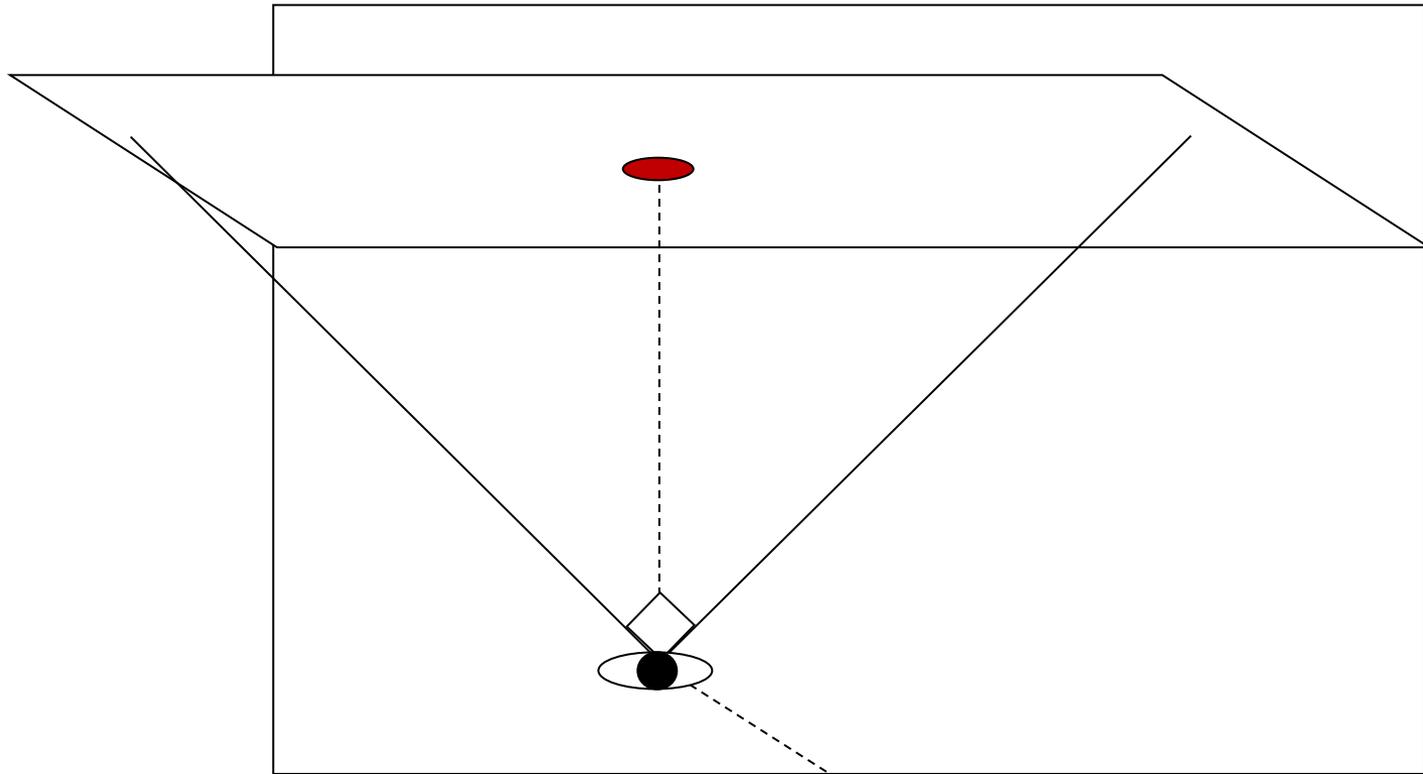


30°

The Rules of Perspective

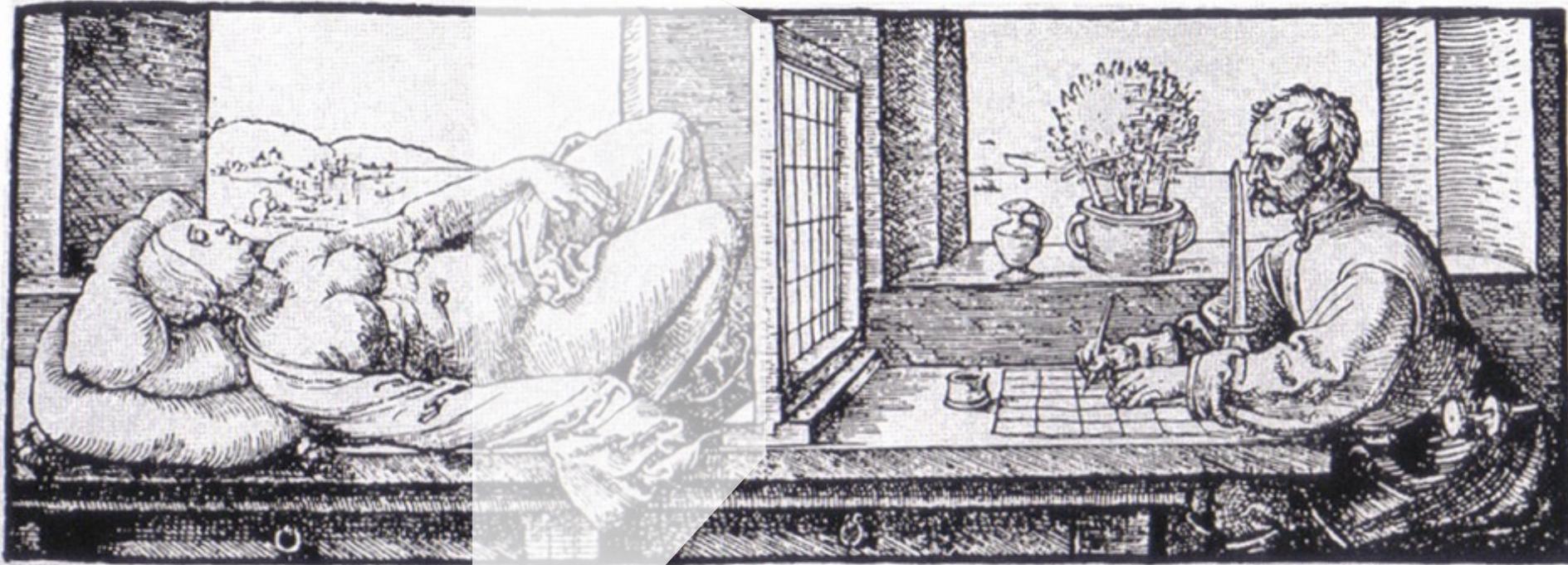
0. Singular specificity
1. Projective isomorphism
2. Convergence of parallels
3. Planar collinearity
4. Vanishing point enumeration: $n = m - p$
5. Angular isomorphism
6. Planar foreshortening
7. Elliptical projection theorem

9. For correct projection of its perspective, a picture should be viewed from its center of projection in space.



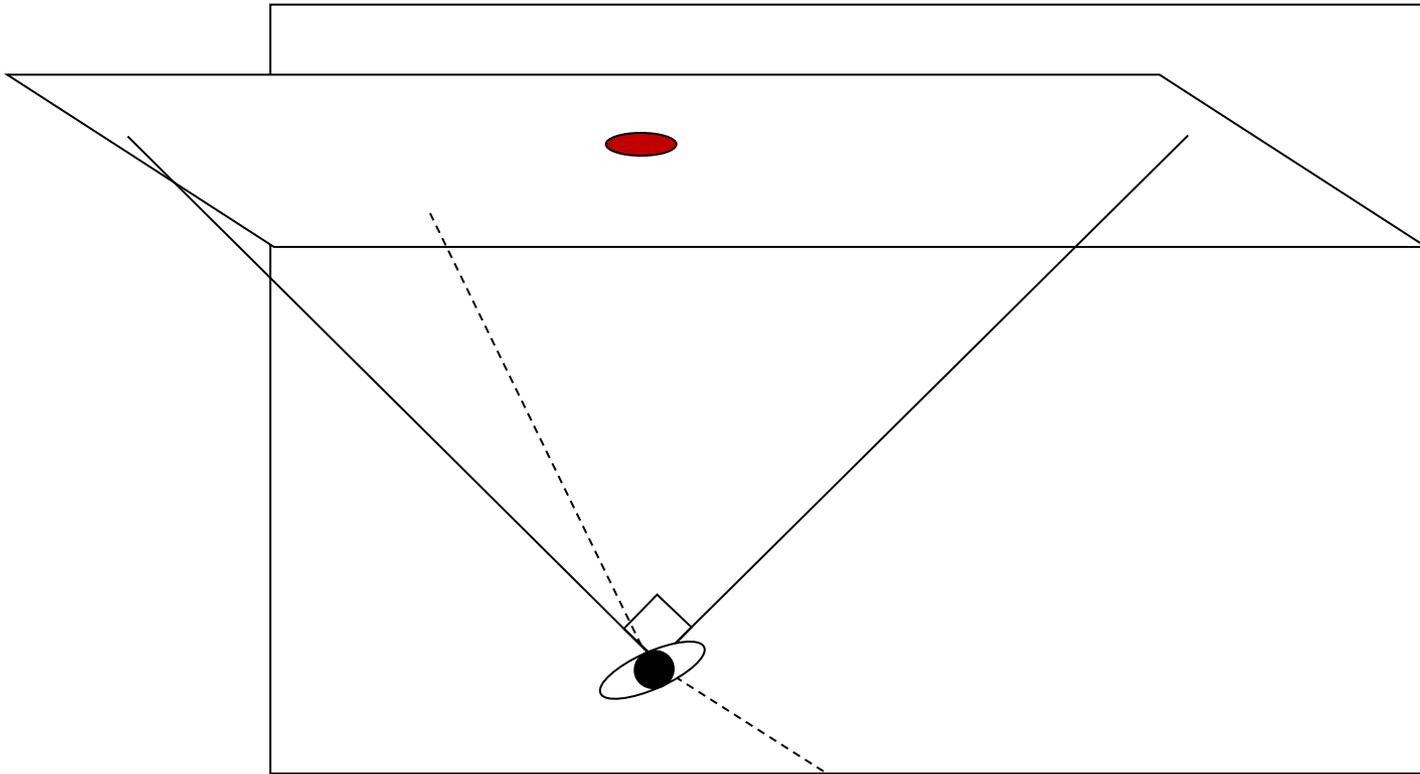
The Rules of Perspective

0. Singular specificity
1. Projective isomorphism
2. Convergence of parallels
3. Planar collinearity
4. Vanishing point enumeration: $n = m - p$
5. Angular isomorphism
6. Planar foreshortening
7. Elliptical projection theorem
8. Center of projection specificity



‘Draughtsman Making a Perspective Drawing of a Reclining Woman’
by Durer (~1500)

8. When the eye is at the center of projection, the perspective geometry in the picture plane is independent of where in the plane the eye is looking.





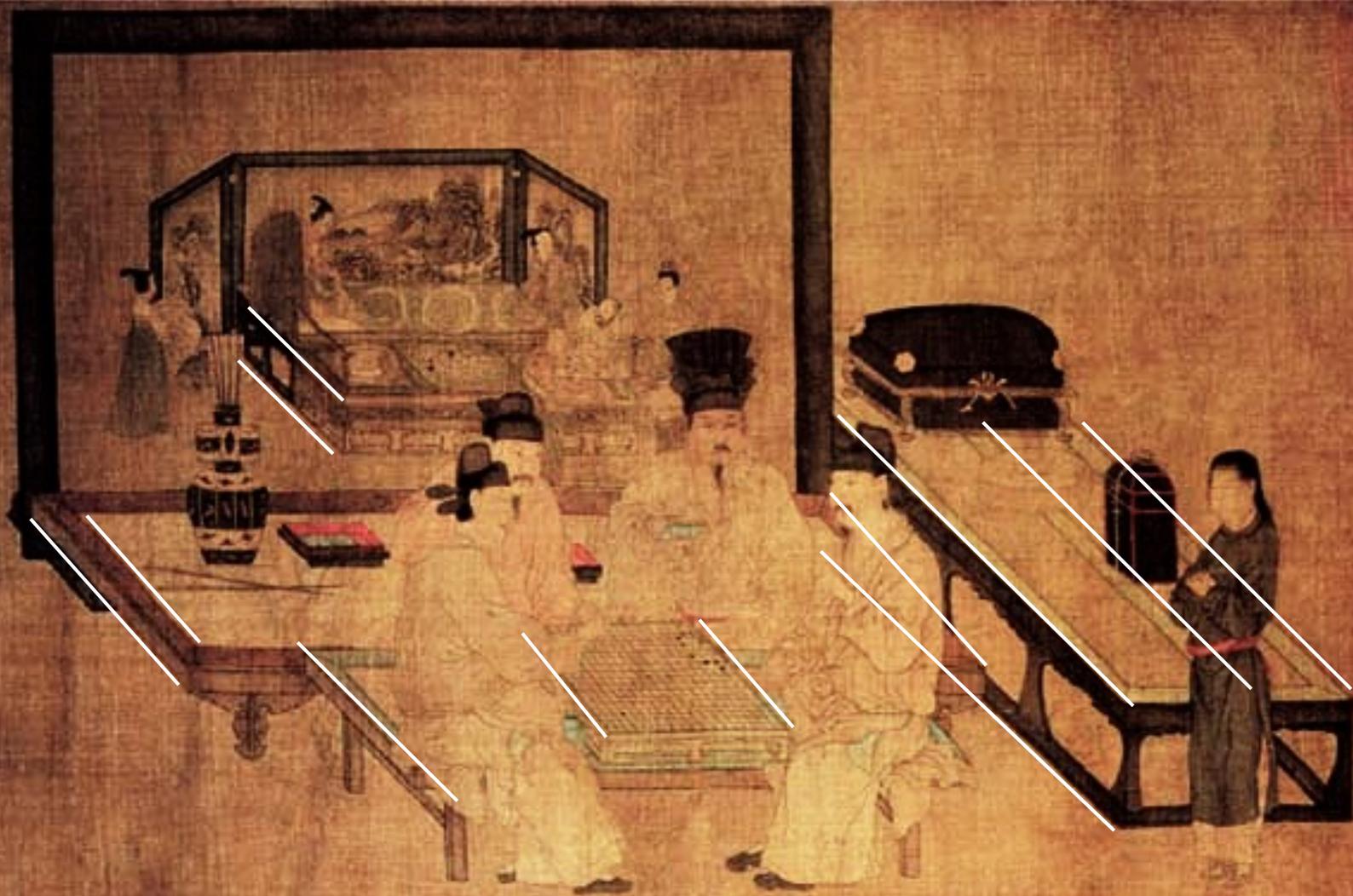
'The School of Athens' by Raphael (1510)

The Rules of Perspective

0. Singular specificity
1. Projective isomorphism
2. Convergence of parallels
3. Planar collinearity
4. Vanishing point enumeration: $n = m - p$
5. Angular isomorphism
6. Planar foreshortening
7. Elliptical projection theorem
8. Center of projection specificity
9. Rotational constancy

Perspective
As Symbolic Form
(Panofsky, 1924)

Chinese Orthographic Perspective



‘Playing chess by the double screens’ by Zhou Wenju
(Five Dynasties, ~ 950 AD)



‘Han XiZai Gives a Banquet’ (sector of extended scroll)
Gu HongZhong (Five Dynasties, ~ 950 AD)



‘Han XiZai Gives a Banquet’ (retouched sector of extended scroll)
Gu HongZhong (Five Dynasties, ~ 950 AD)



'A Ladies Concert' Yuan Dynasty (1271-1368)

Medieval Intuitive Perspective

'The Expulsion
of Joachim
from the Temple'

by
Giotto
(1305)





The Last Supper by Duccio (1340)

‘The Presentation
of the Virgin’

by

di Bartolo
(1400)



**Local One-Point
Perspective
(The Zero-Point Construction)**

'The Annunciation'

by

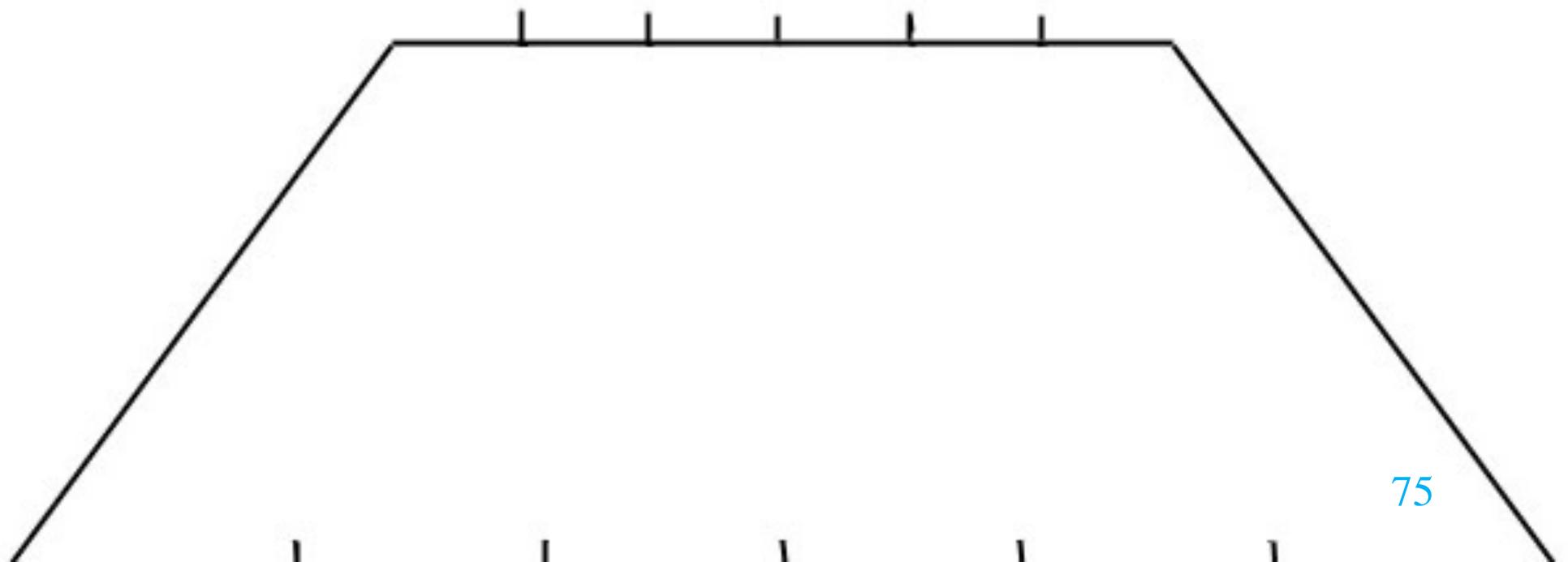
Ambrogio
Lorenzetti

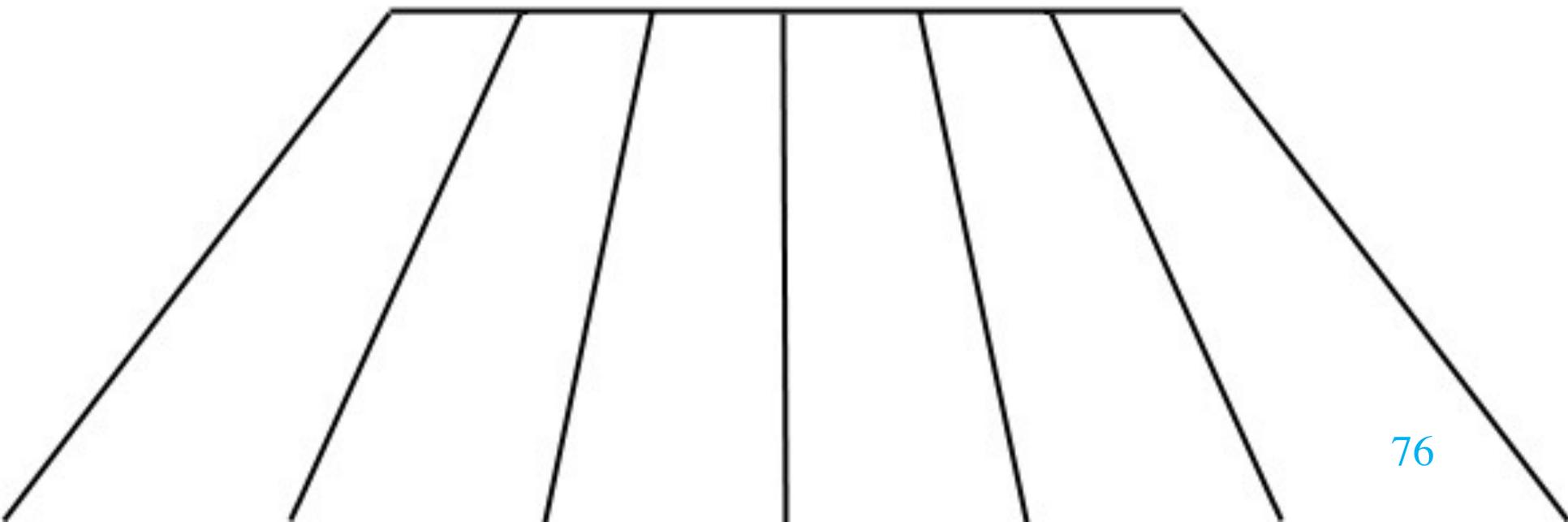
(1344)

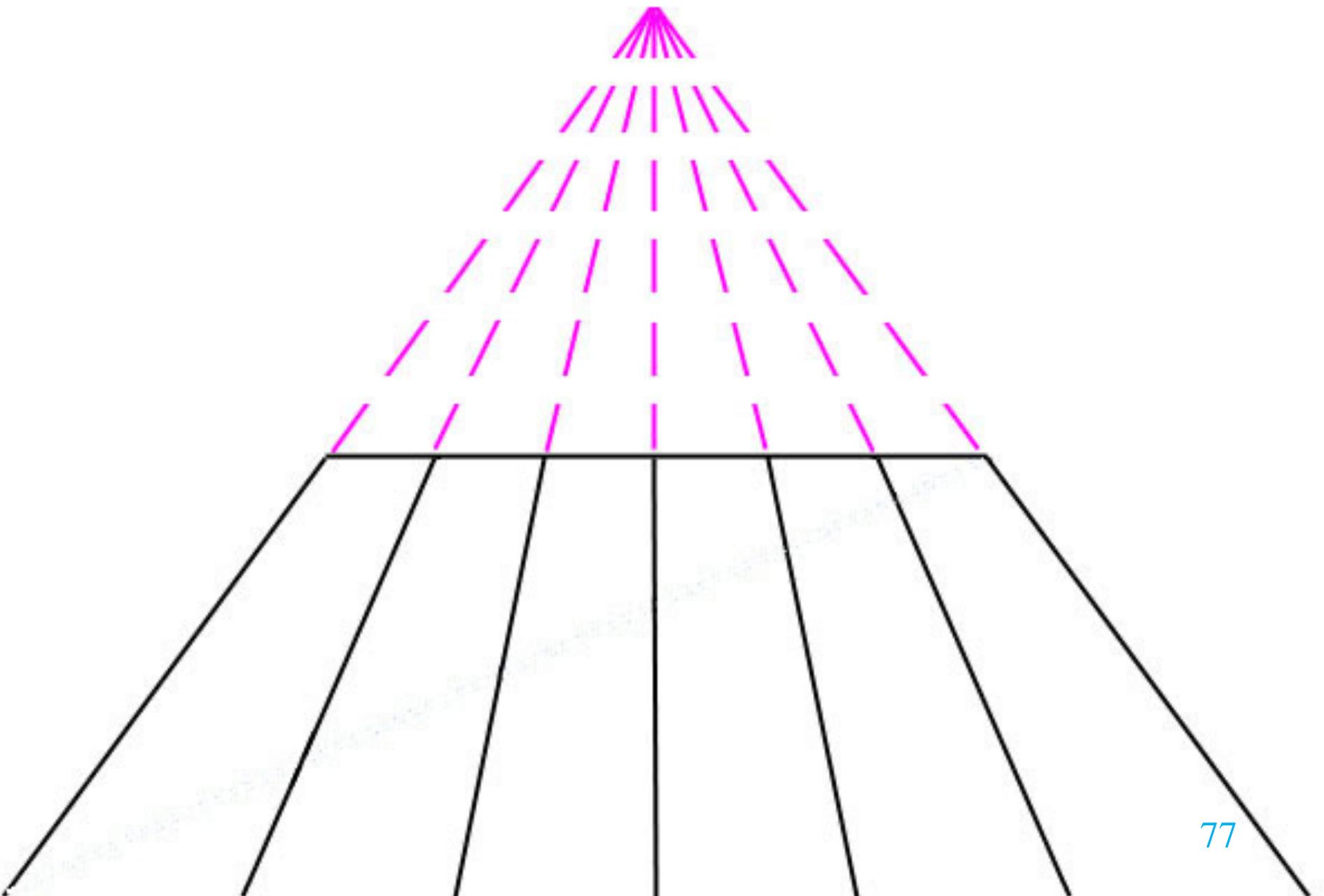


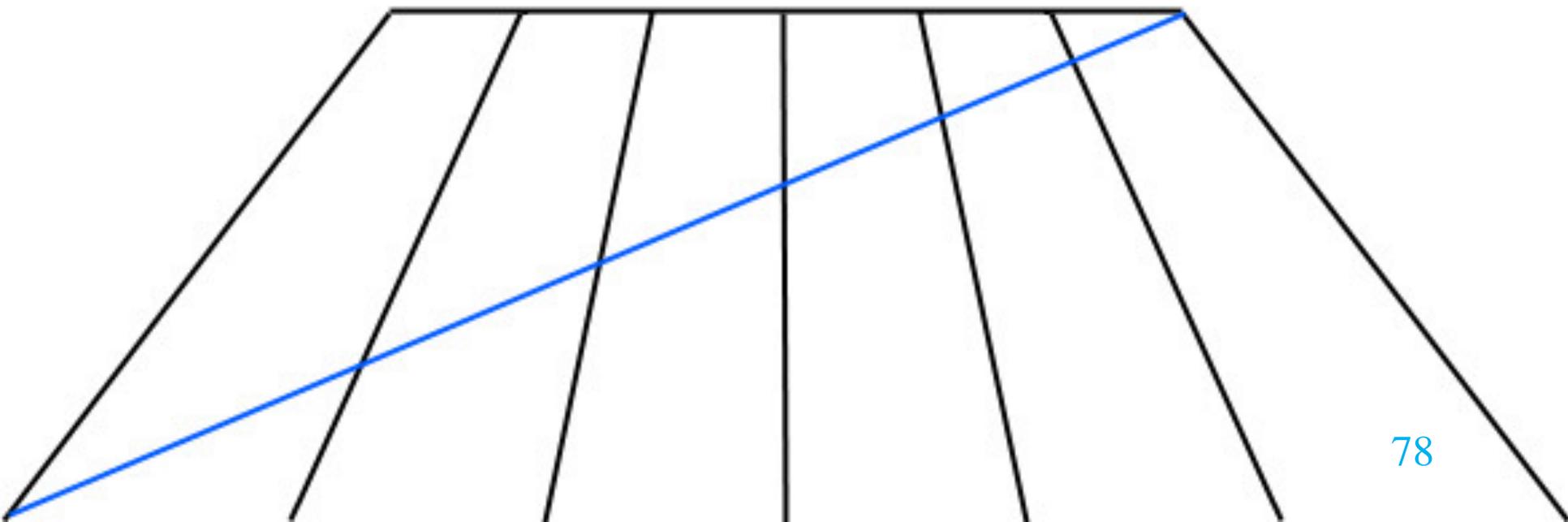
The Zero-Point Perspective Construction (straight-line diminution with distance)

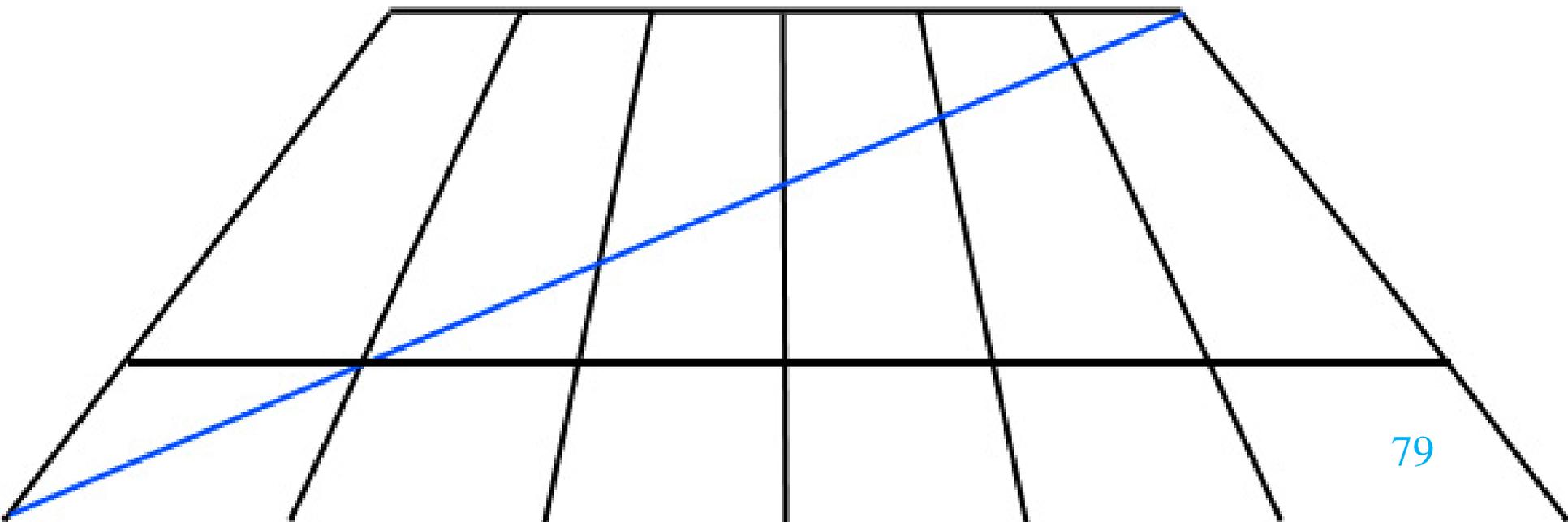


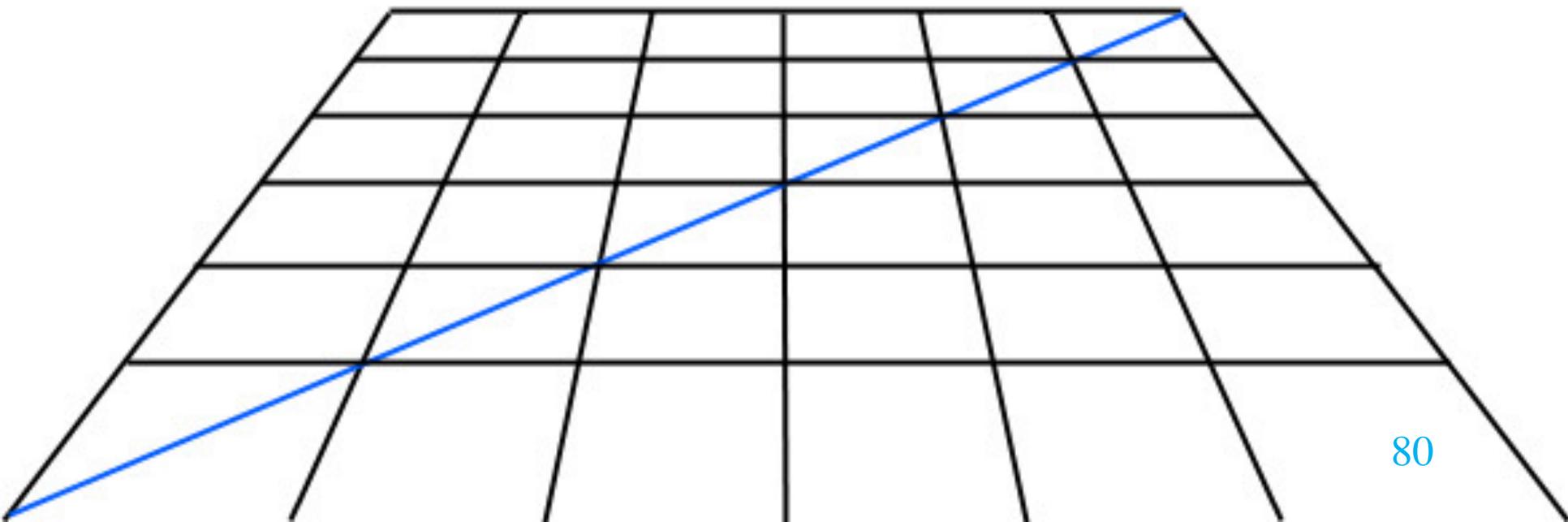


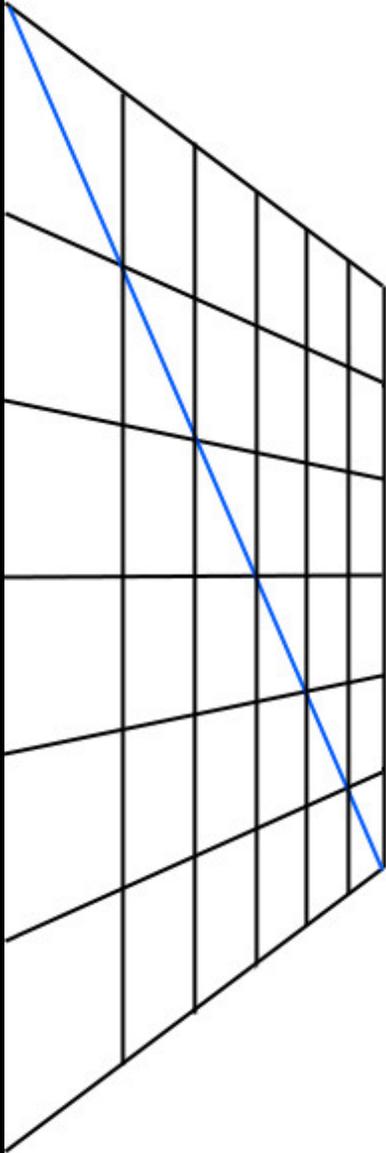




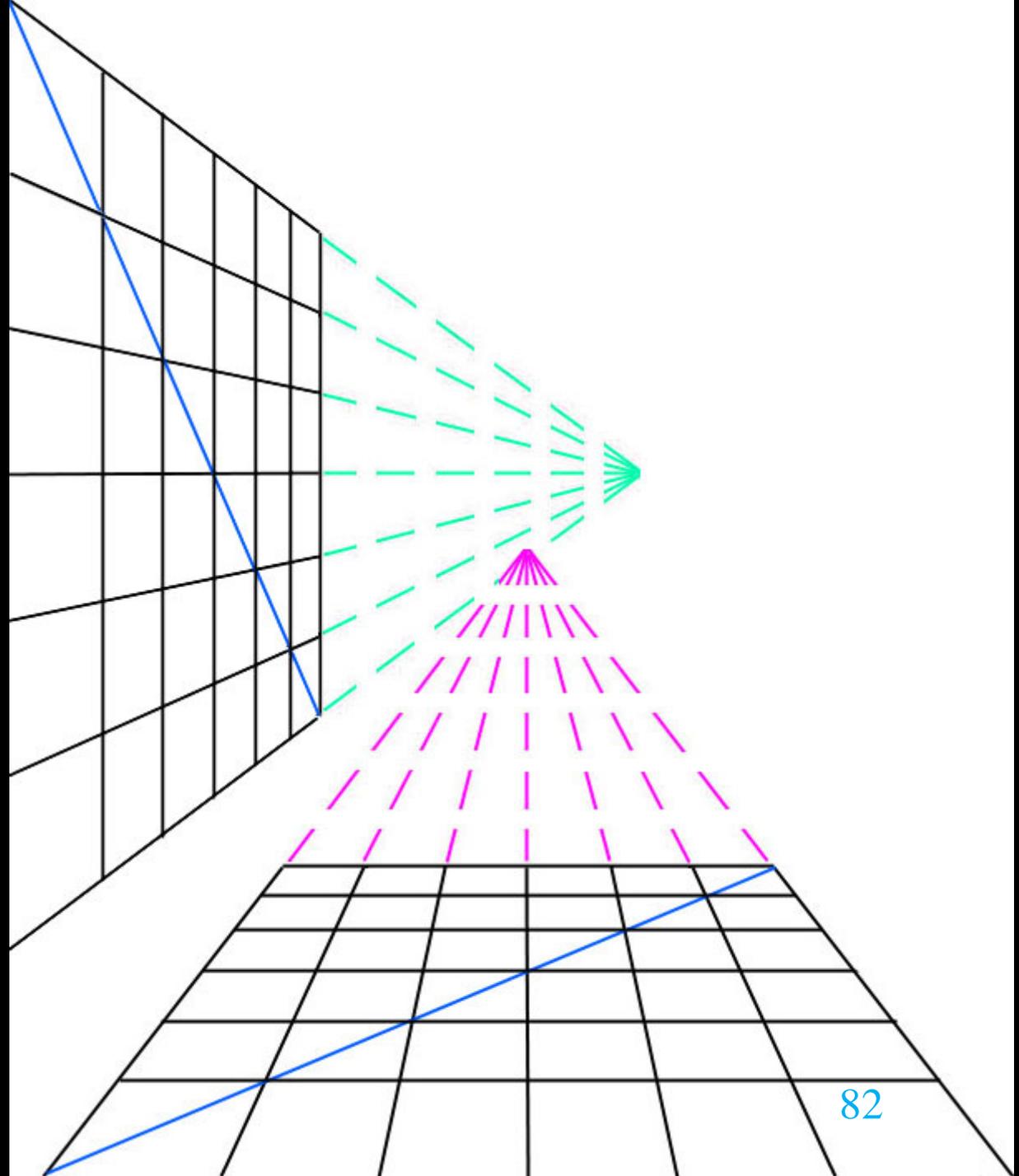


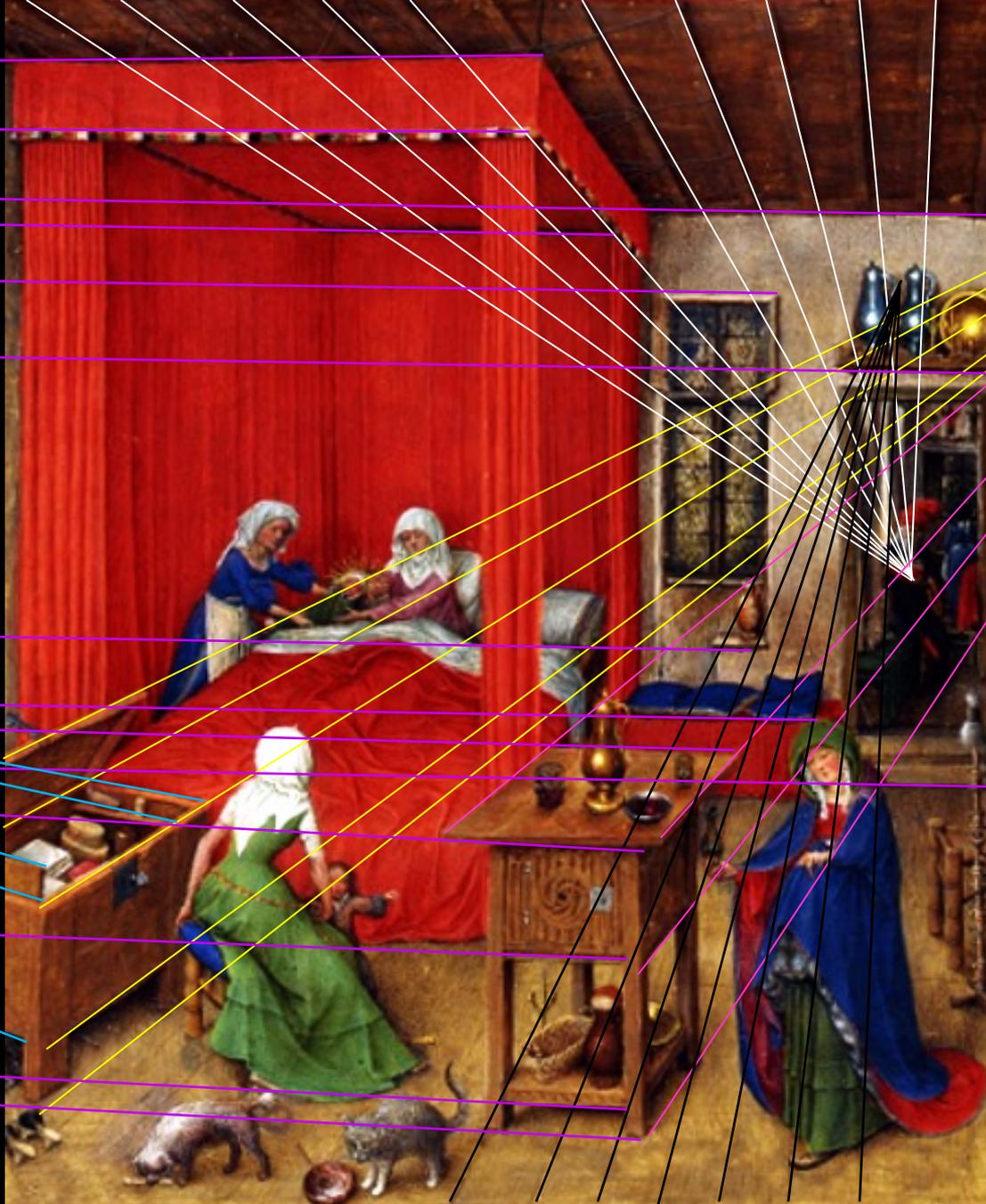






Vanishing-point mismatch from the zero-point construction





'The Birth of John the Baptist' attr. Hubert Van Eyck (1422/1450)

Portrait of
Masolino di Panicale
(1383-1440)

from
Vasari's 'Lives of the
Artists' (1569)



VITA DI MASOLINO PITTORE:

‘The Foundation
of the Church of
Santa Maria Maggiore’
by
Masolino da Panicale
(1423)





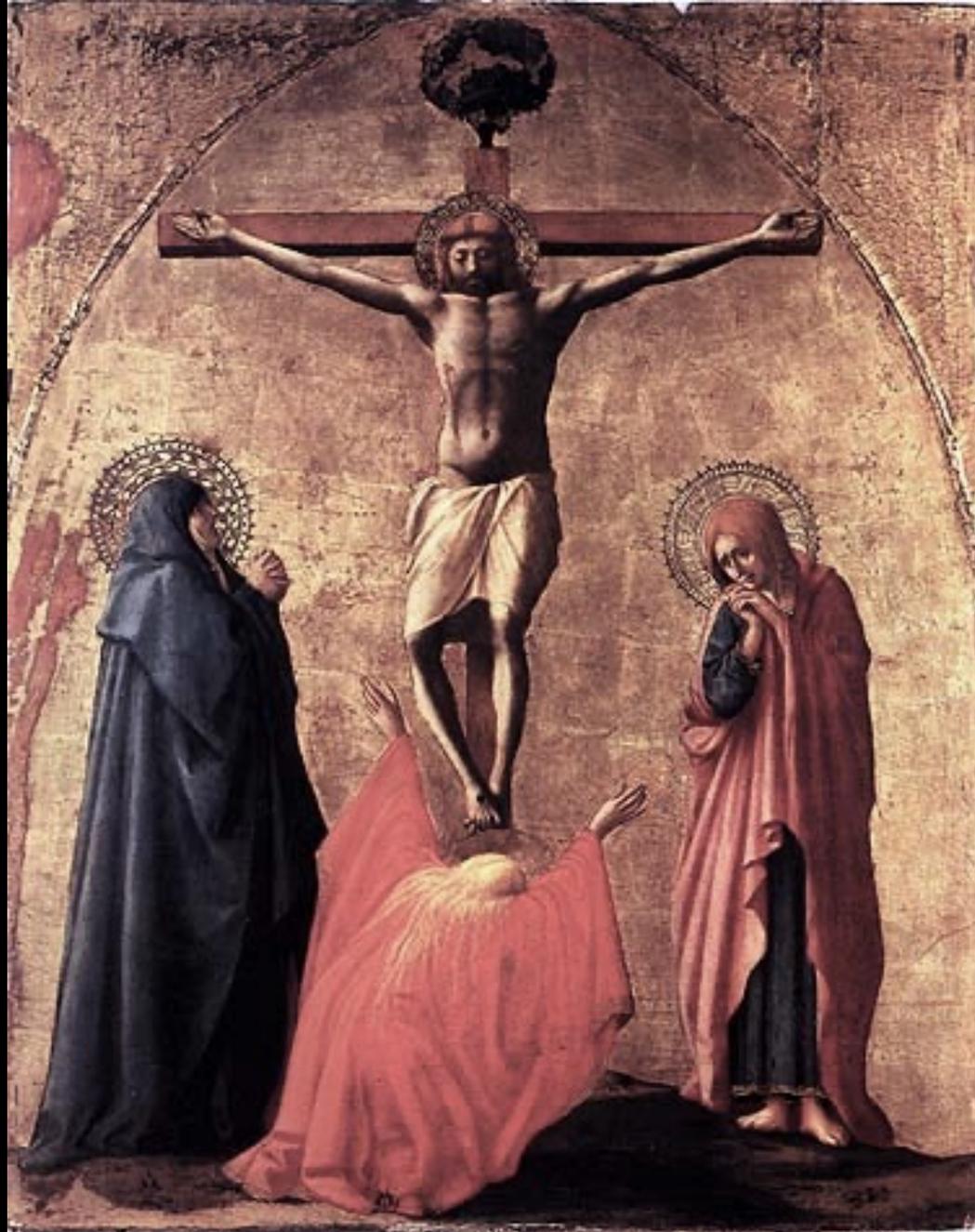
Early
example
of 'people
perspective'



3D
convergence
to a single
vanishing
point



Conversely,
Masaccio shows
no interest in
perspective at this
date



‘The Crucifixion’ by Masaccio (1424)

Who Discovered Perspective?

Brunelleschi, 1415 (? , no surviving paintings,
probably optical projection)

Masolino da Panicale (1423)

Masaccio (later: 1425-8)

Alberti (1435; unclear description)

Donatello (inaccurate until 1439)

Uccello (generally inaccurate)

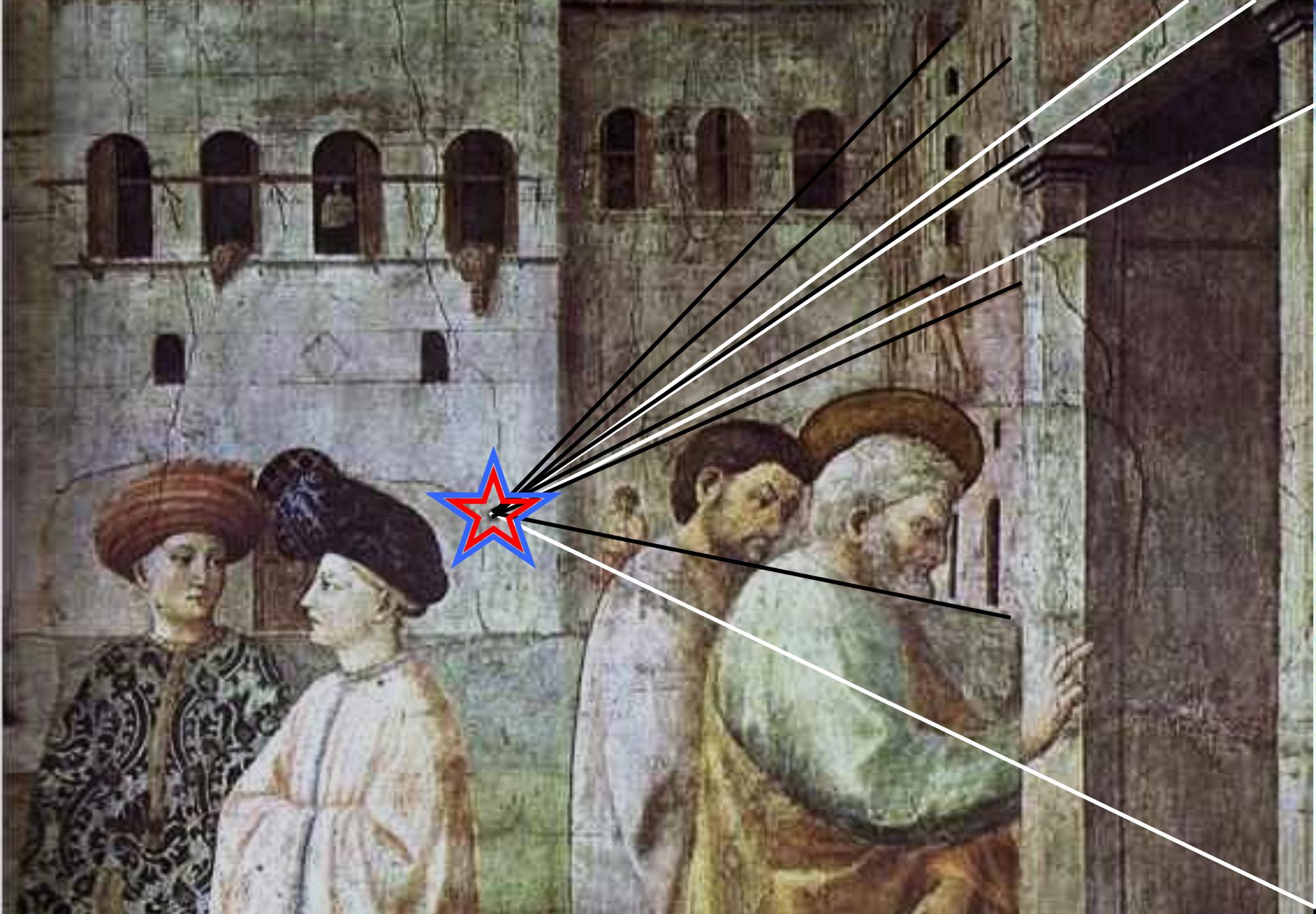
Mantegna (later: 1460s)

Leonardo (much later: 1470s)

Dürer (very much later: 1500s)



‘St Peter Healing the Cripple and the Raising of Tabitha from the Dead’
by Masolino da Panicale (1425)



... with a hole in the plaster at the precise vanishing point

Panels from the St
Catherine Chapel
(San Clemente, Rome)

by

Masolino
(1430)

Showing dramatic use of
perspective after
Masaccio's death. Note
the complex oblique
perspective of the
hexagonal plinth, one of
the finest perspective
constructions of the
entire Renaissance.



**Birth of the Flattened
Perspective of Cubism
(Early 20th Century)**

'The Viaduct of
L'Estaque'

by

Georges Braque
(1908)

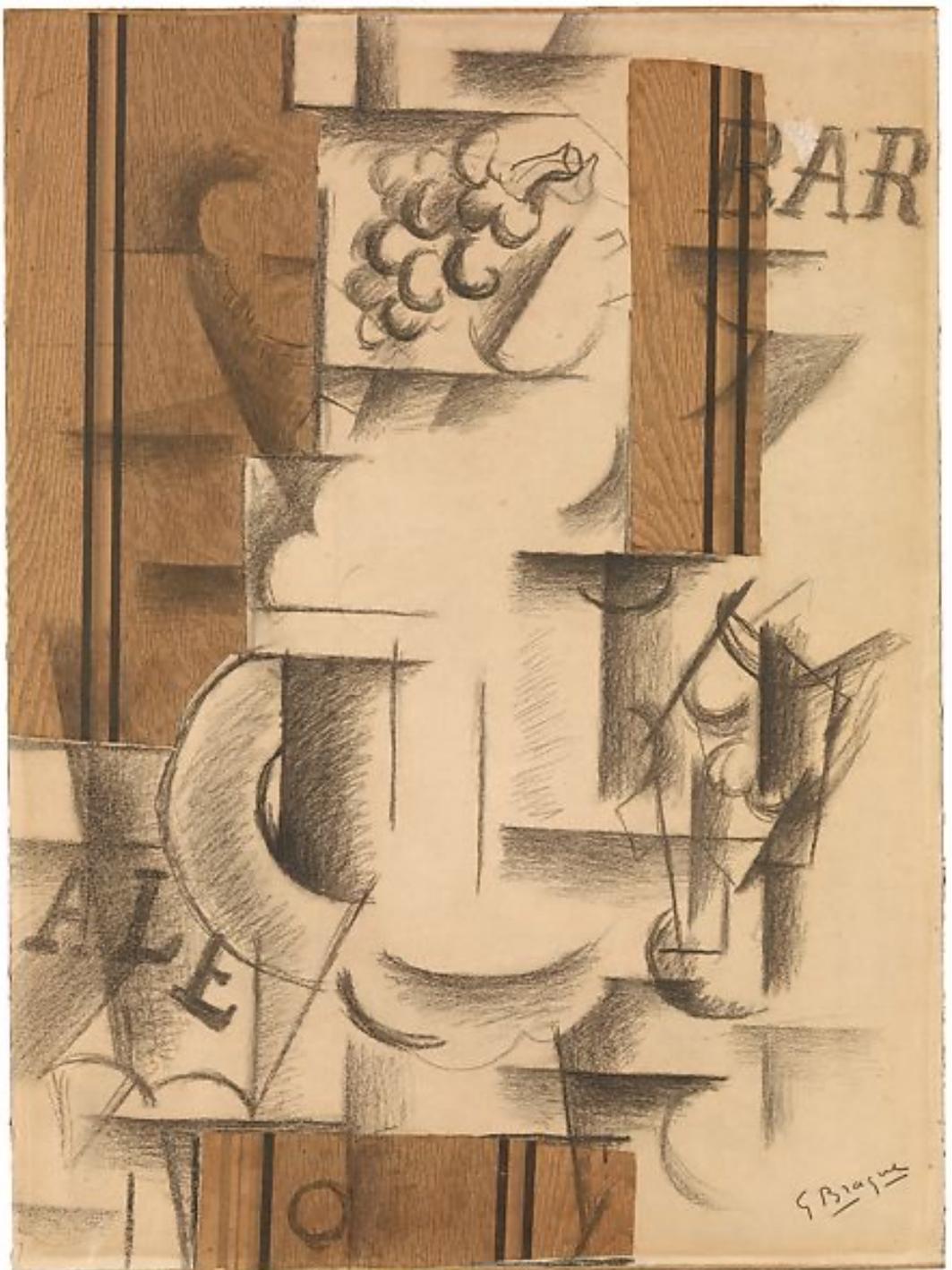


Synthetic Cubism

'Fruit Dish and
Glass Sorgues'

by

Georges Braque
(1912)



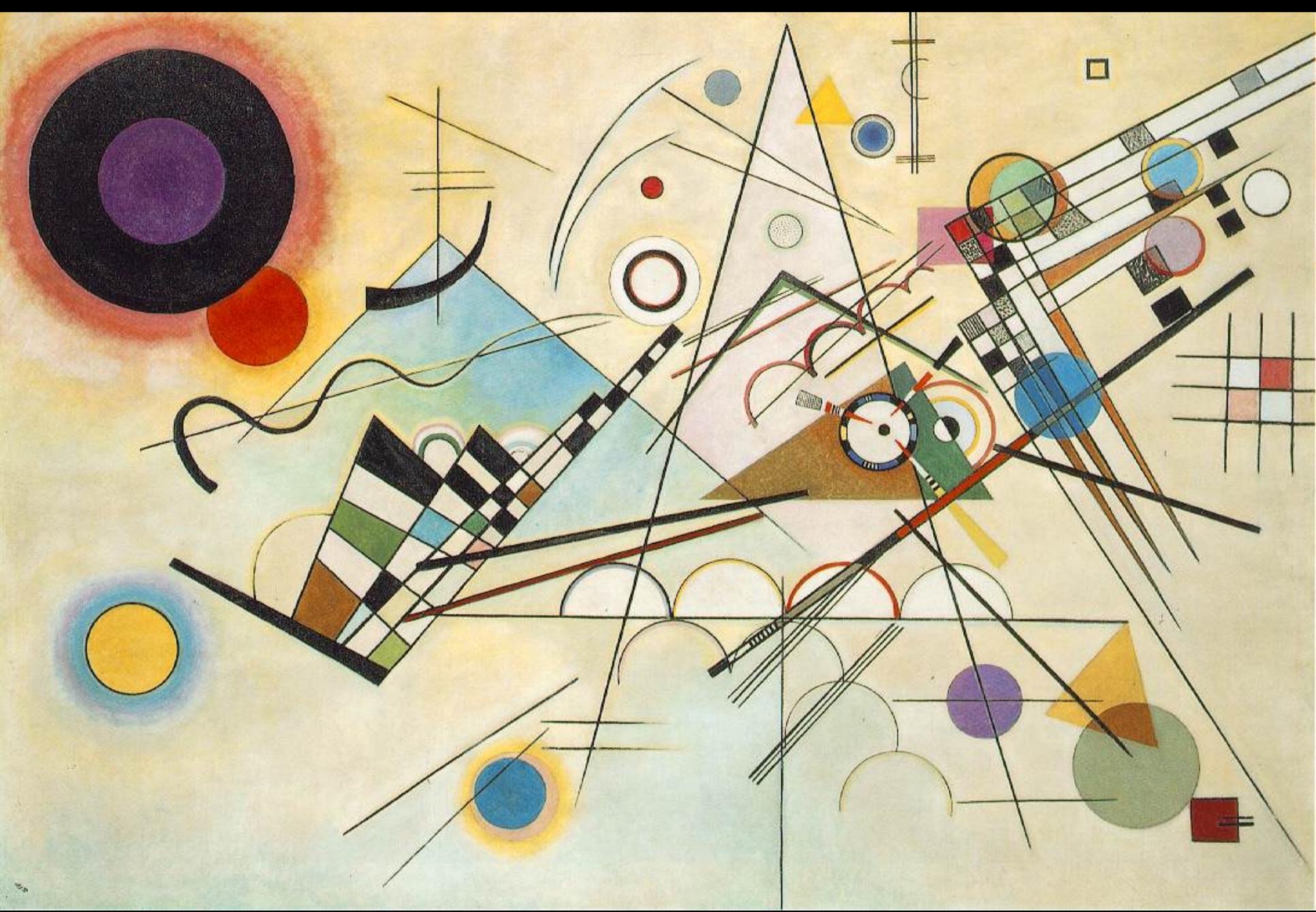
Synthetic Cubism

'Bowl of Fruit,
Violin and Bottle'

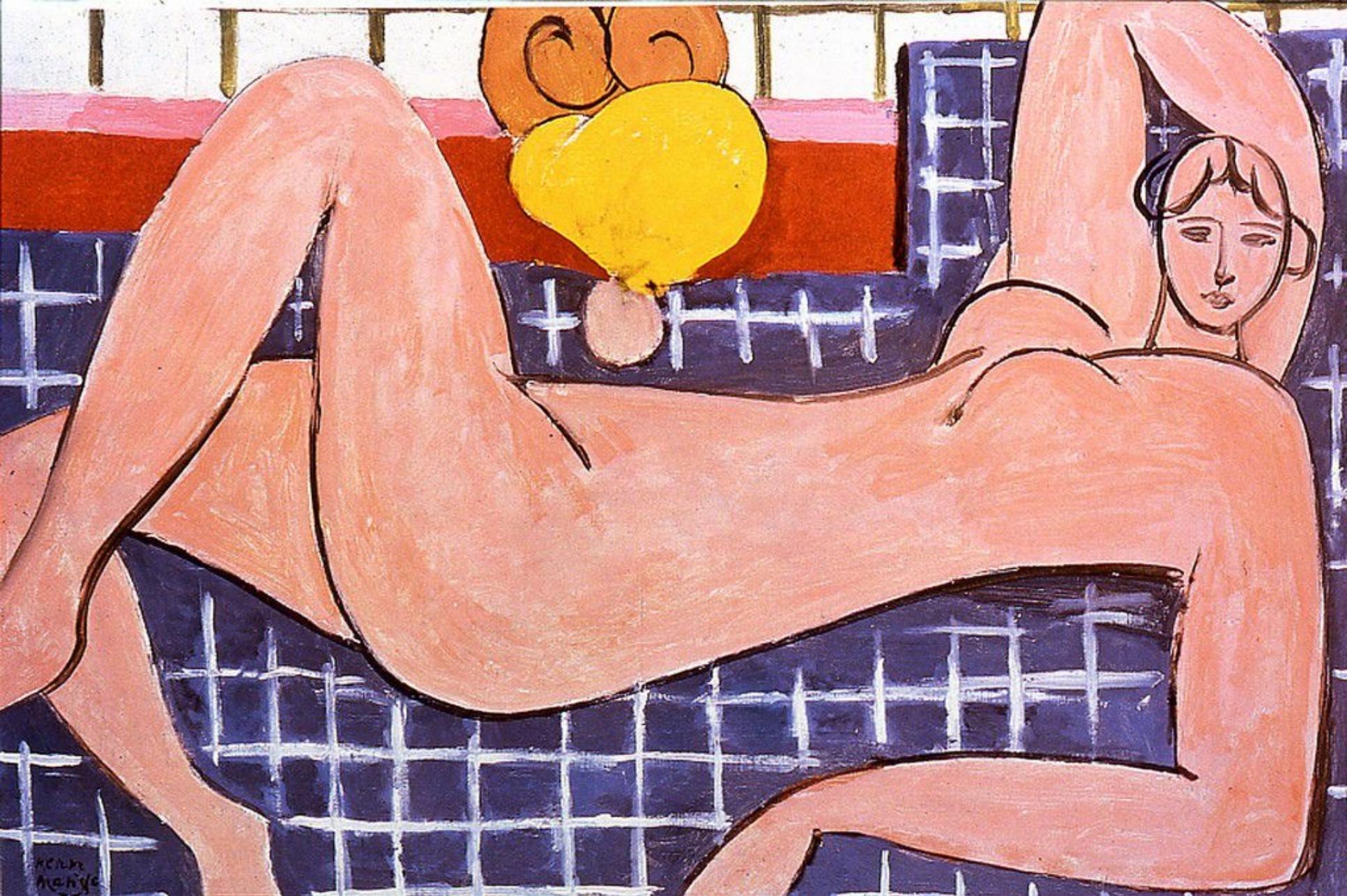
by

Pablo Picasso
(1914)





'Composition VIII' by Vassily Kandinsky (1923)

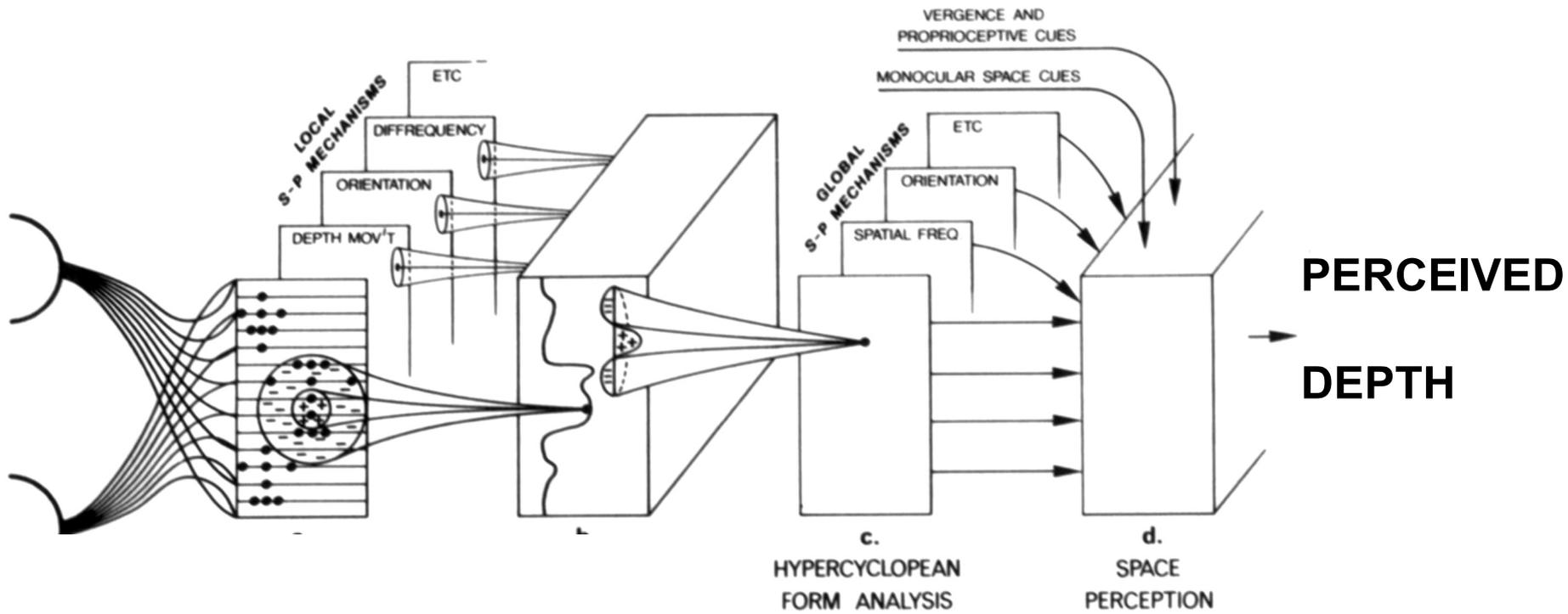


'Pink Nude' by Matisse (1936)

The Logic of Depth Cue Combination



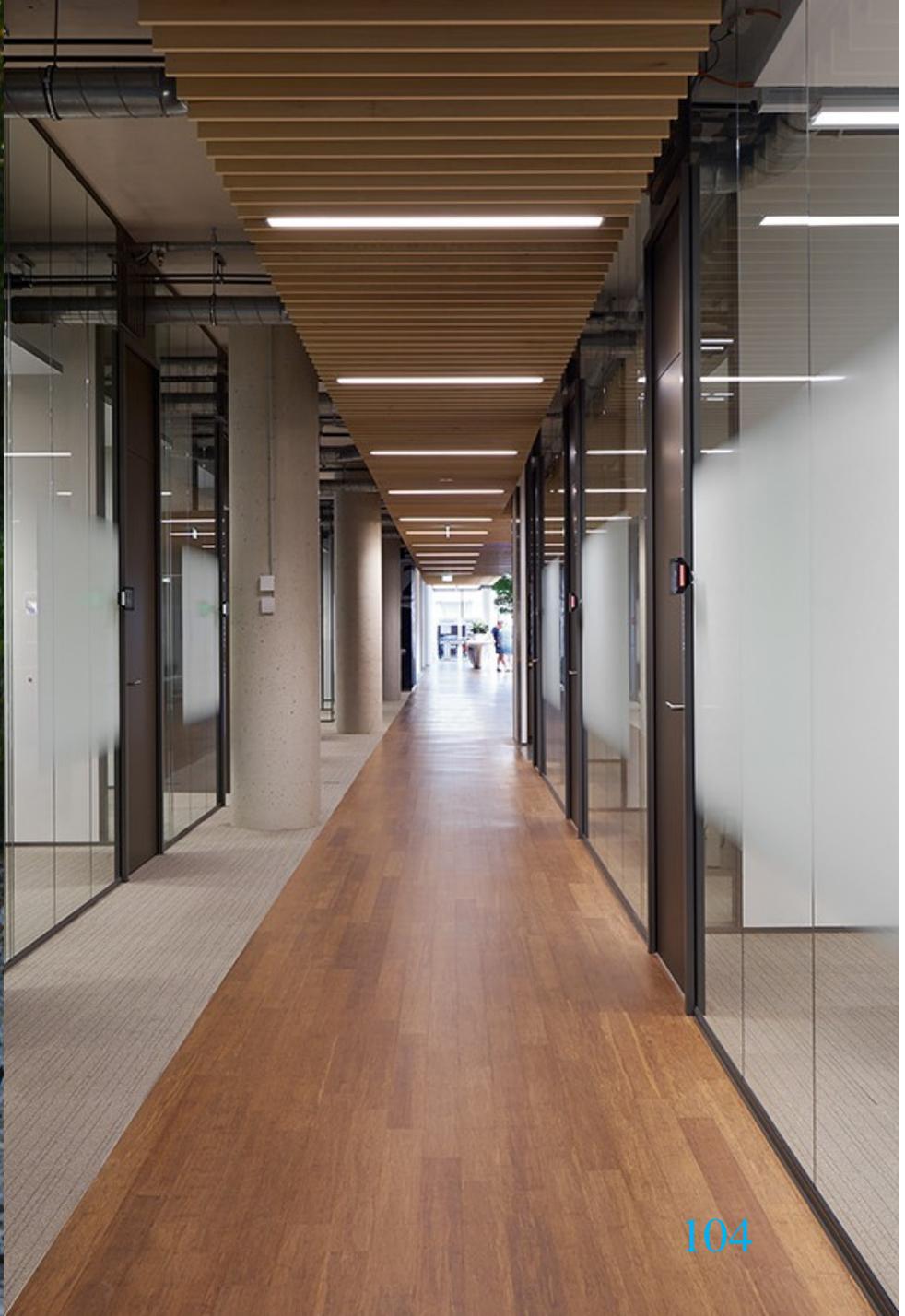
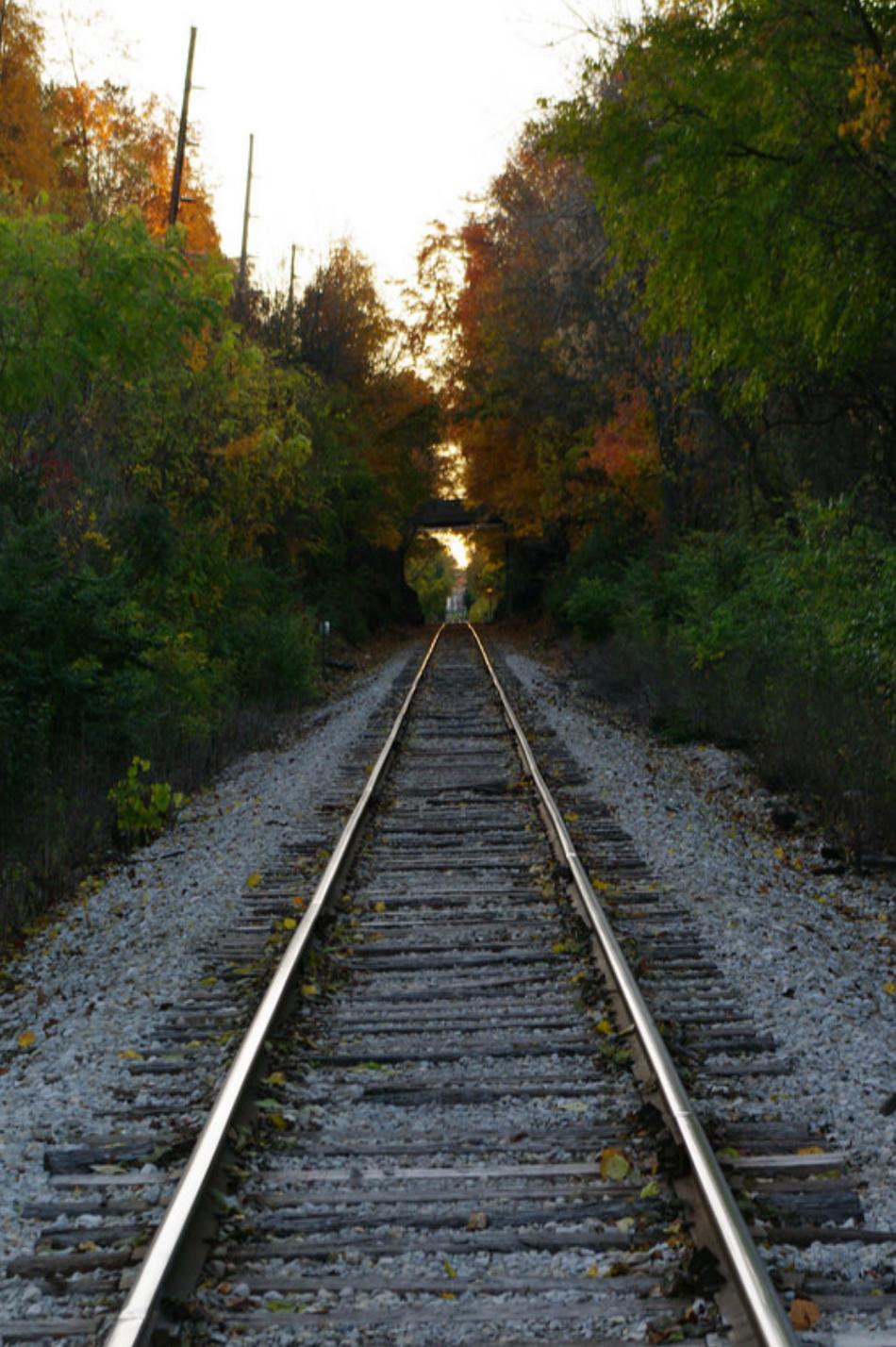
The integration of multiple depth cues into perceived depth



Depth Cues

1. Binocular disparity
2. Vergence angle
3. Motion parallax
4. Linear Perspective
5. Aerial perspective
6. Accommodation
7. Occlusion
8. Texture gradient
9. Shading
10. Defocus blur
11. Elevation
12. Familiar size

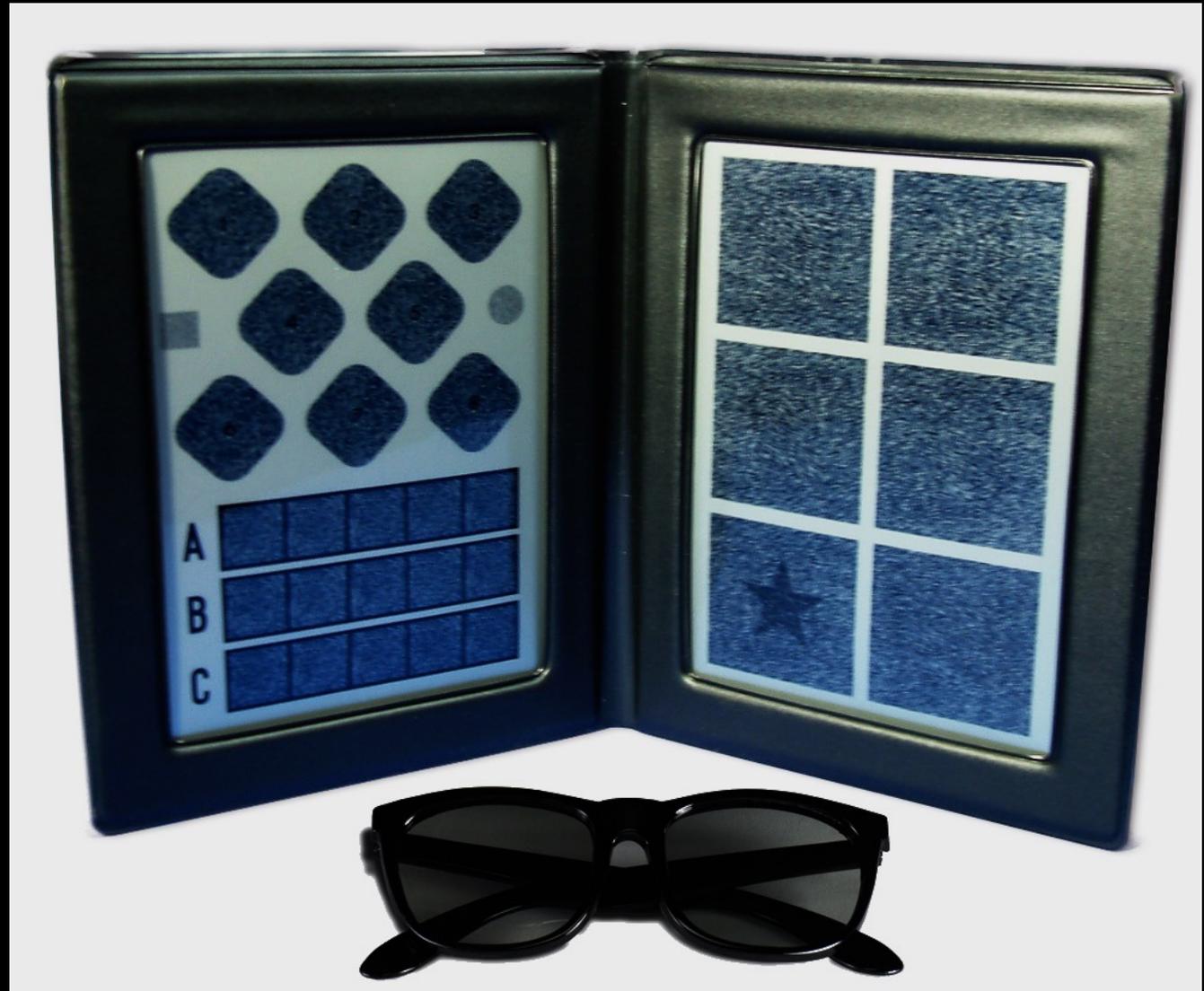
$k = 12$

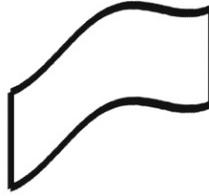


The stereo cue to perceived depth

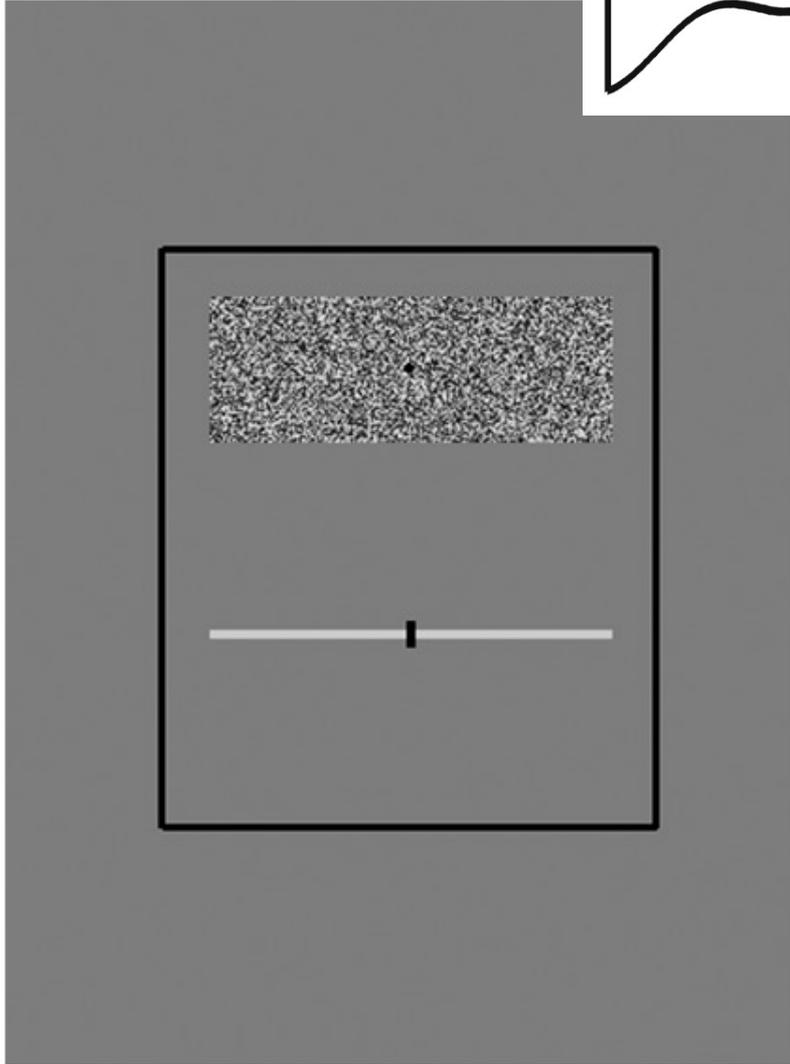
Metric: quantitatively scaled with distance

Rescalable: disparity scales with the inverse square of distance but does not provide absolute distance information

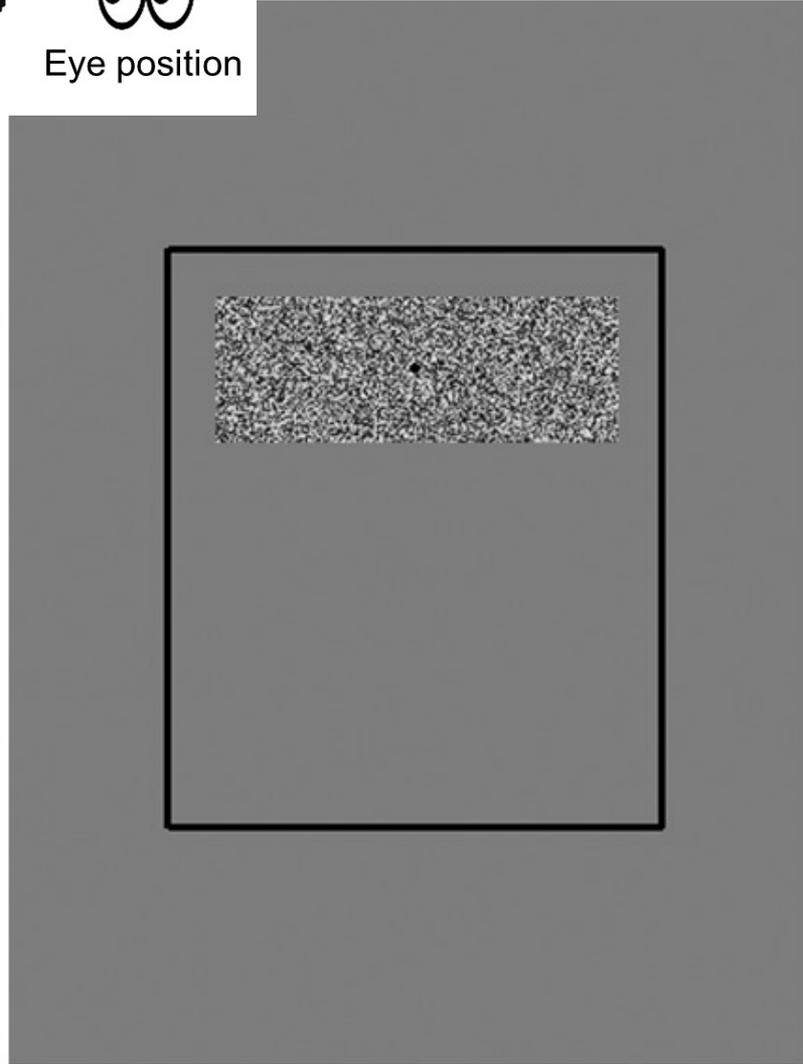




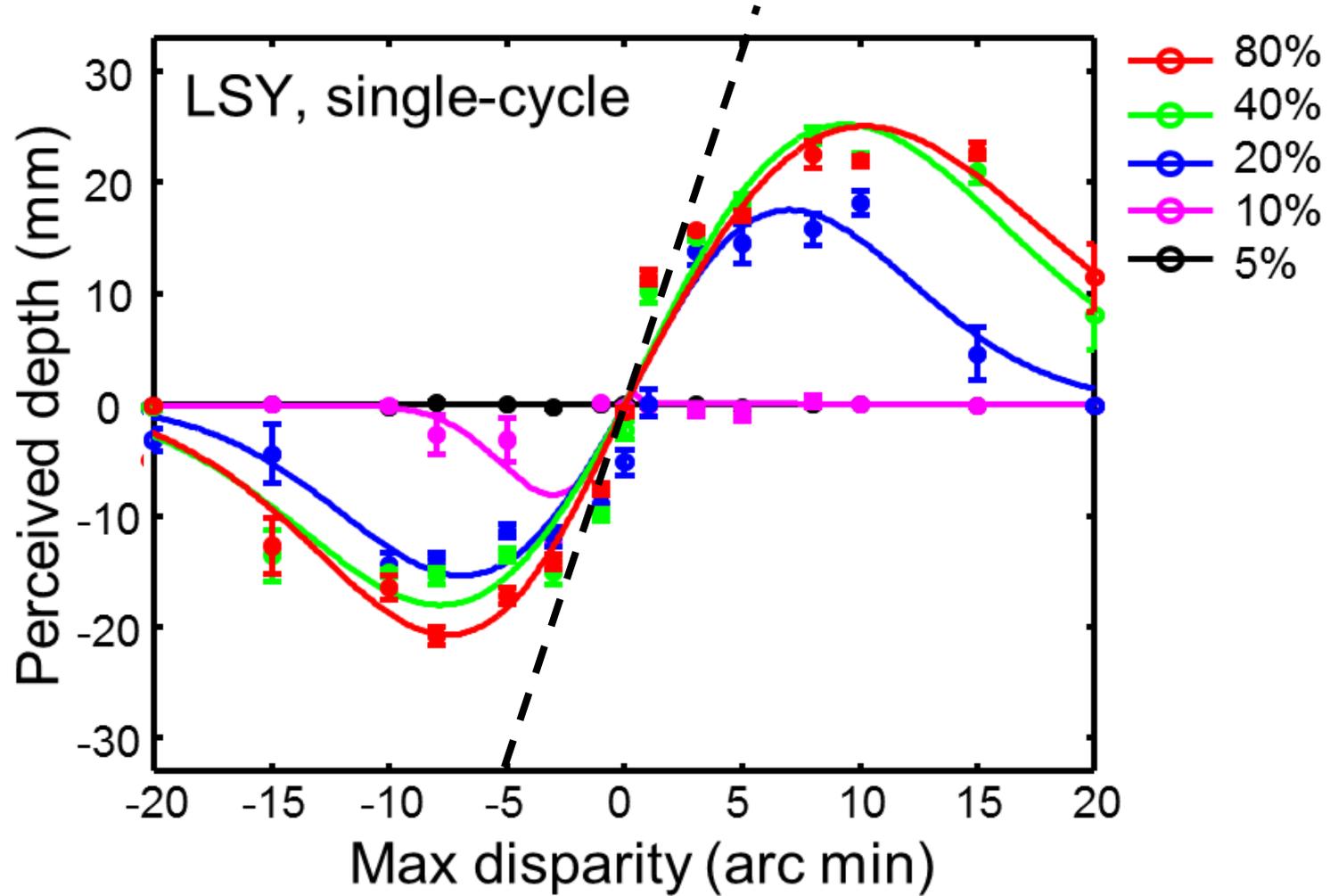
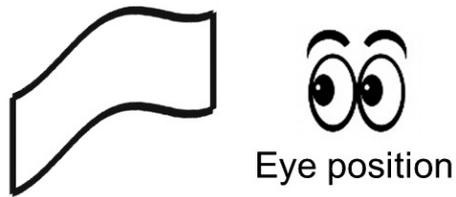
Eye position



Left Eye Image

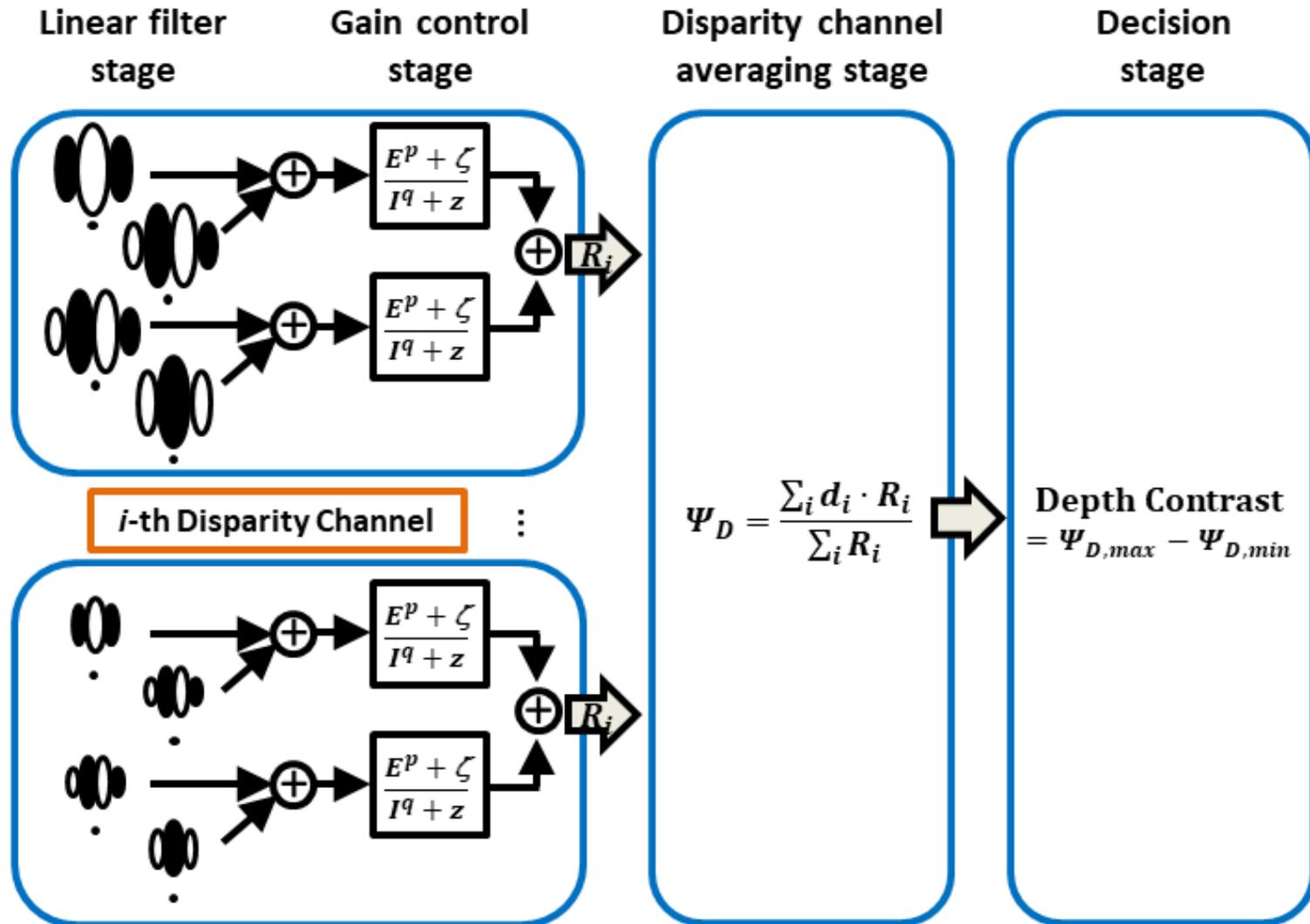


Right Eye Image



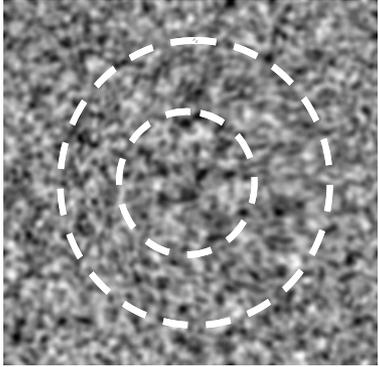
Gain-Control Disparity Energy Model

(P-Y Chen, C-C Chen & Tyler, 2021)

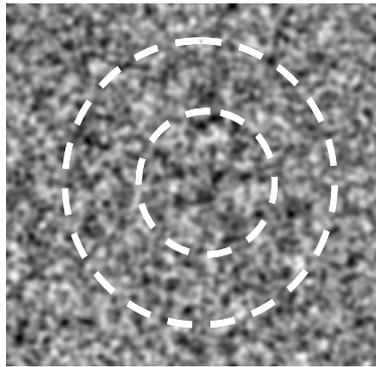


The Time Course of (Bayesian) Depth Cue Rescaling

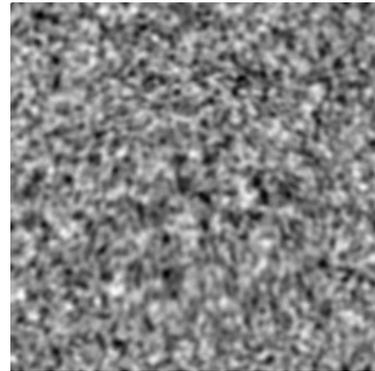
Stimulus Depth Modalities



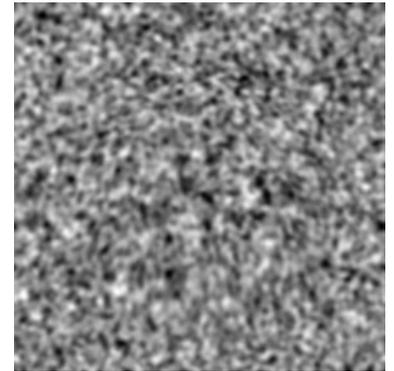
Stereo



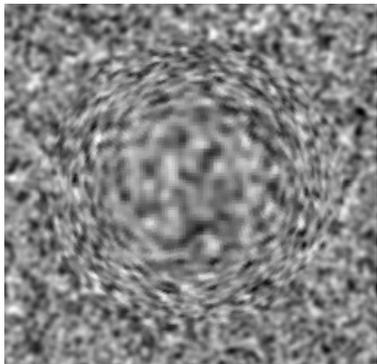
Stereo



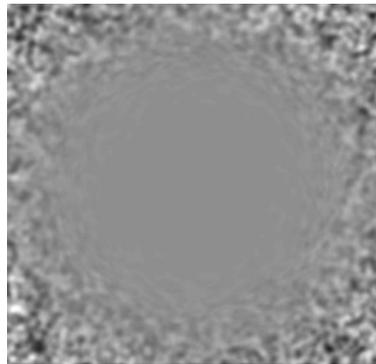
Motion



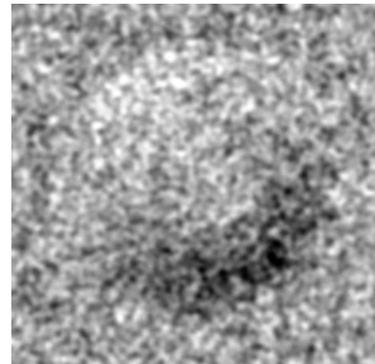
Motion



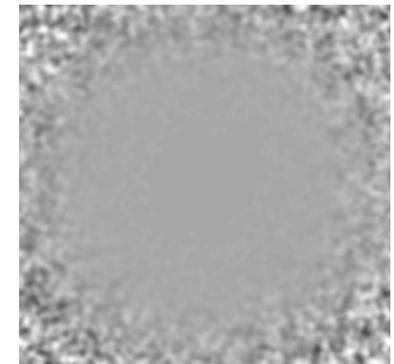
Texture



Texture

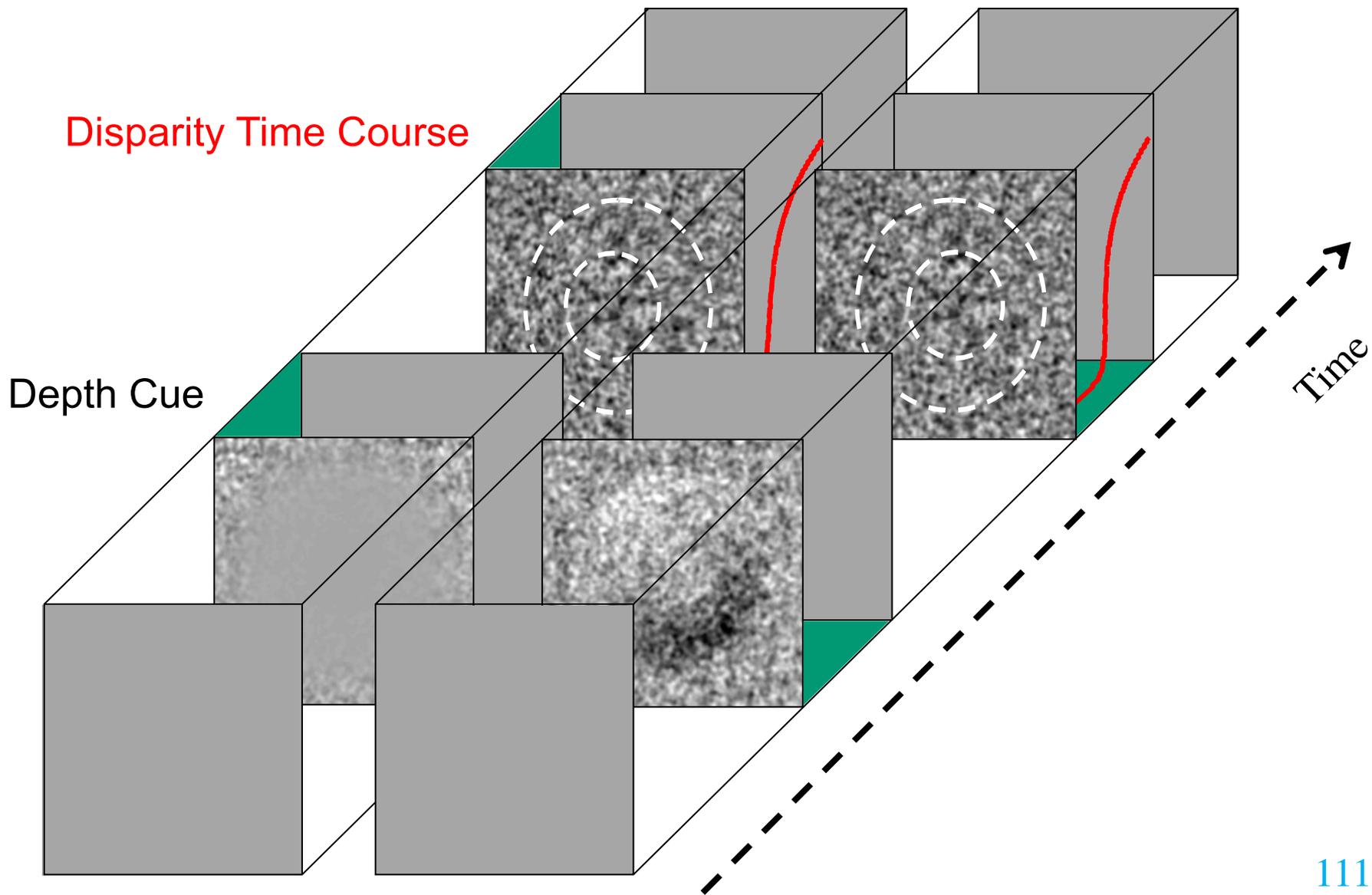


Shading



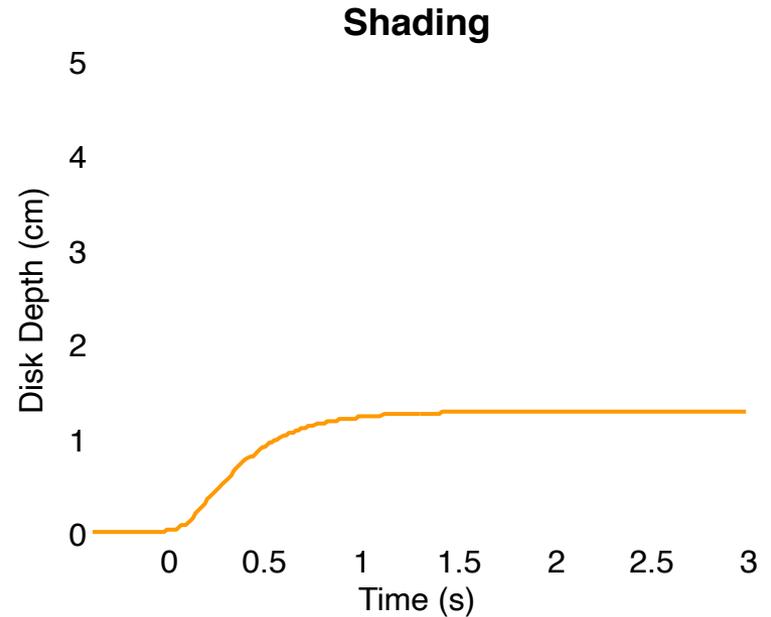
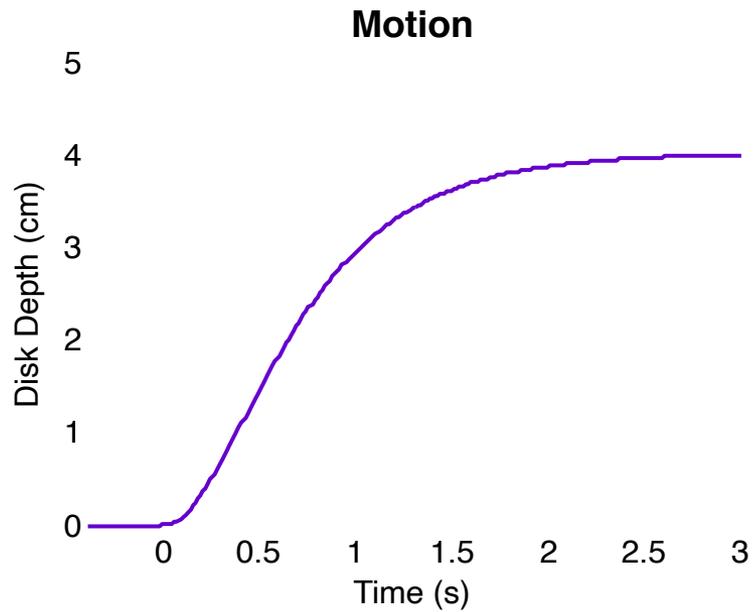
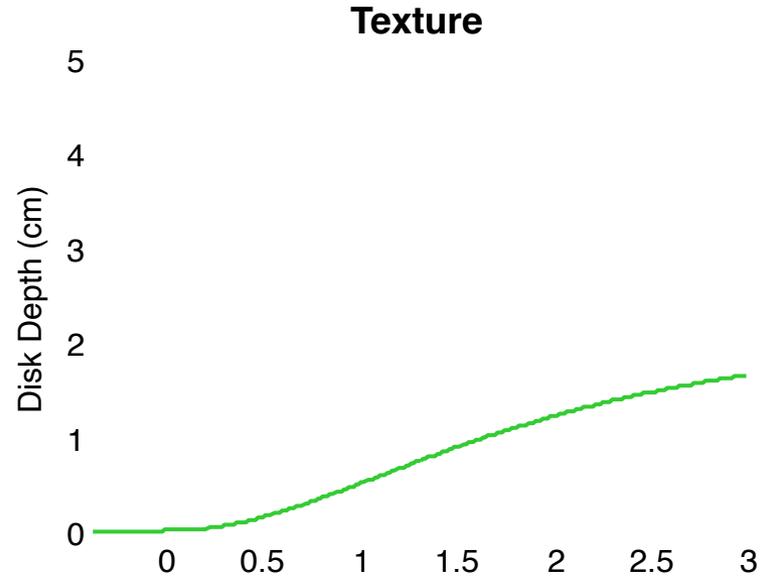
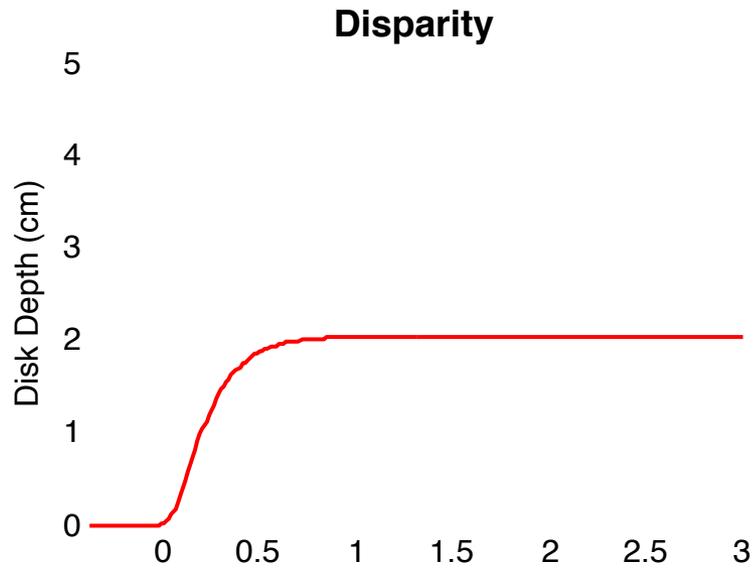
Shading

Two-parameter matching task on **amplitude** and **rate**



Time Course of Perceived Depth

N = 6

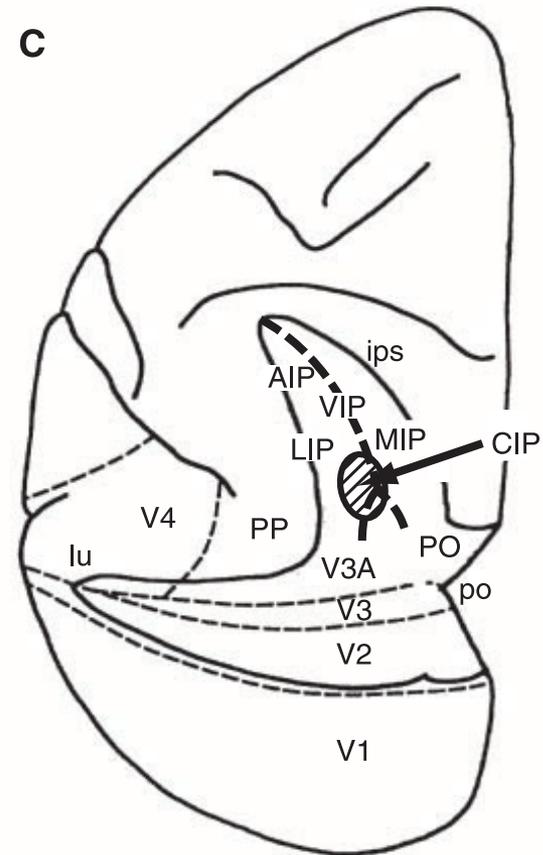
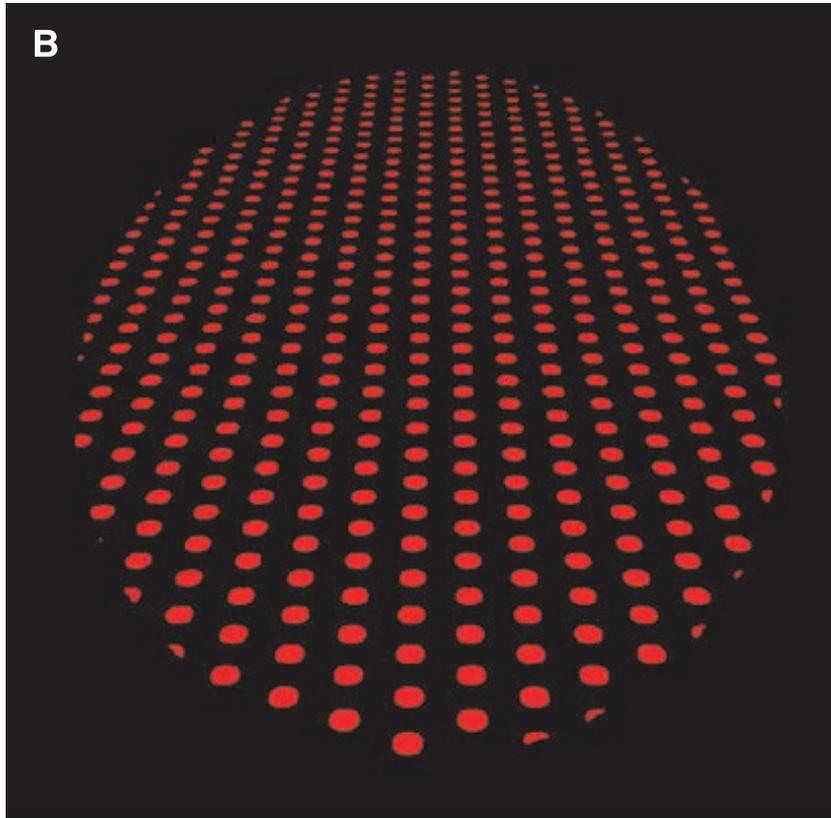


Conclusions

- Perceived depth is not just an intellectual concept but a felt experience of protrusion toward or away from the viewer
- Perceived depth is not cue specific but is a unitary experience (for any particular feature)
- Depth dynamics are specific to each depth cue and may take several seconds to develop to full strength
- Since no cue can be presented in isolation, these dynamics represent a reweighting process among the monocular and stereoscopic depth cues
- The reweighting is assumed to also be Bayesian, i.e., dependent on the reliability of each cue
- Thus the Bayesian reweighting has a complex dynamic for bringing multiple depth cues into a unified depth percept

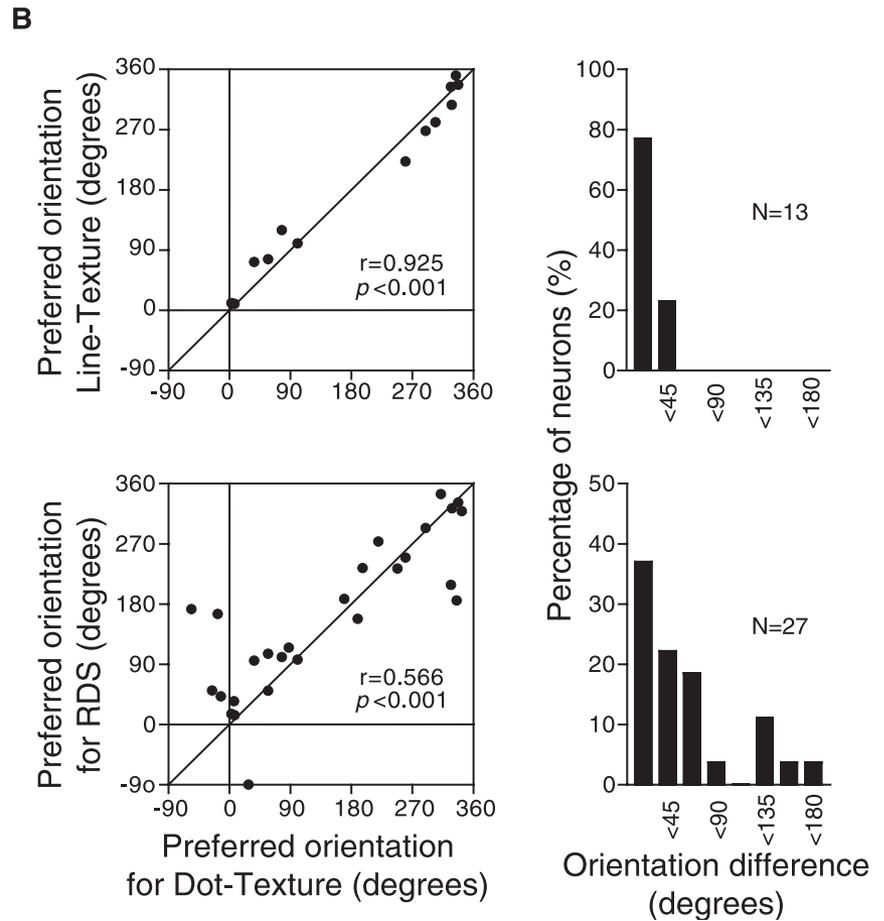
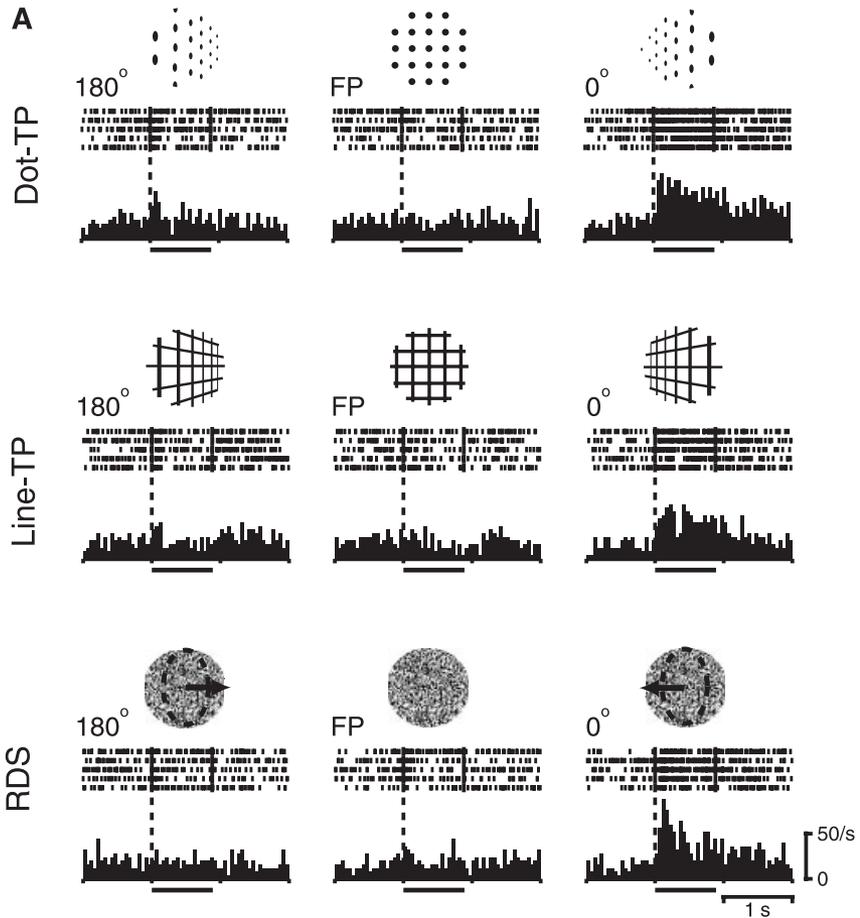
The Representation of Depth Information in the Brain

The Neurophysiology of Texture Gradient Processing



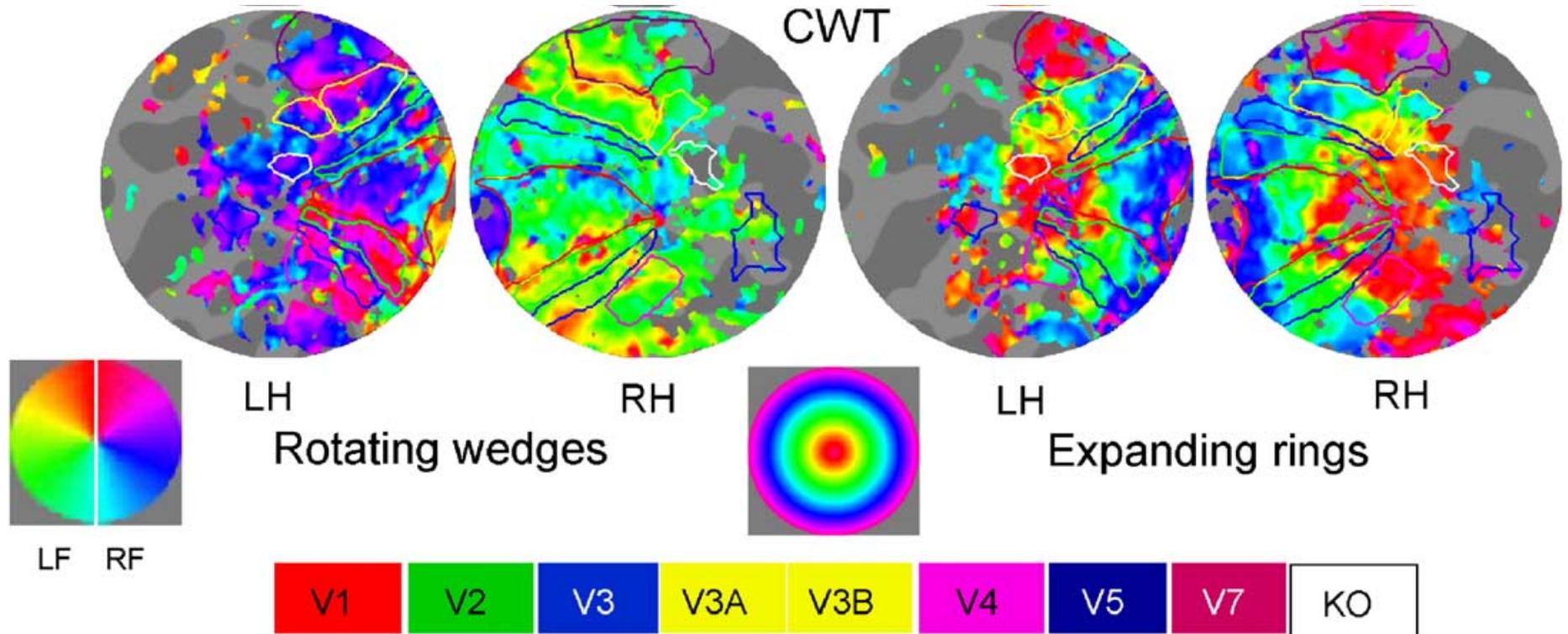
From Tsutsui et al. (2002, Science)

Multimodal Directional Selectivity for Depth Gradient



From Tsutsui et al. (2002, Science)

Retinotopic Organization of the Visual Processing Hierarchy

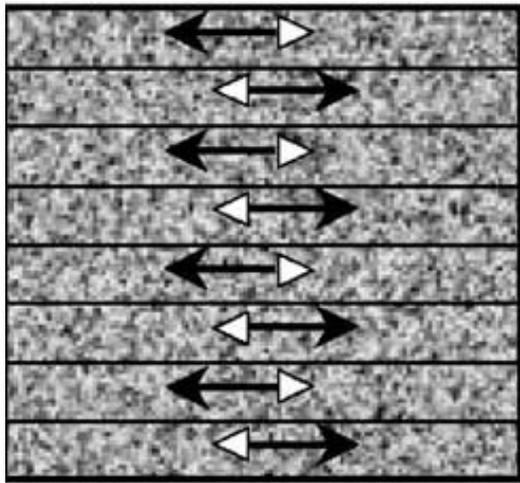


Semi-Inflated Brain Showing Tertiary Visual Areas

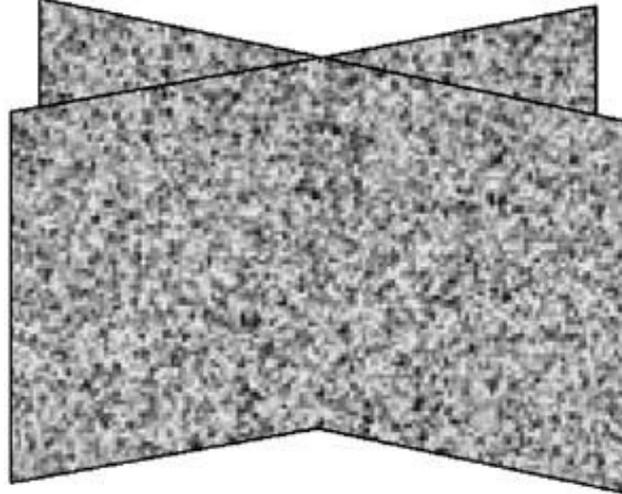


Segmented Stimuli for fMRI Study of Depth Structure Processing

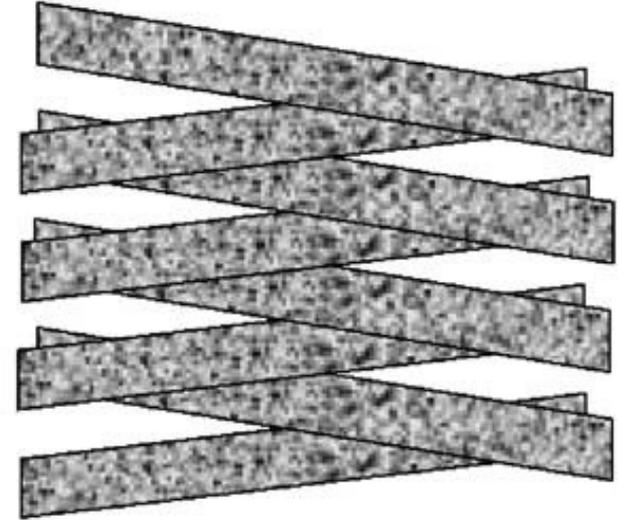
A



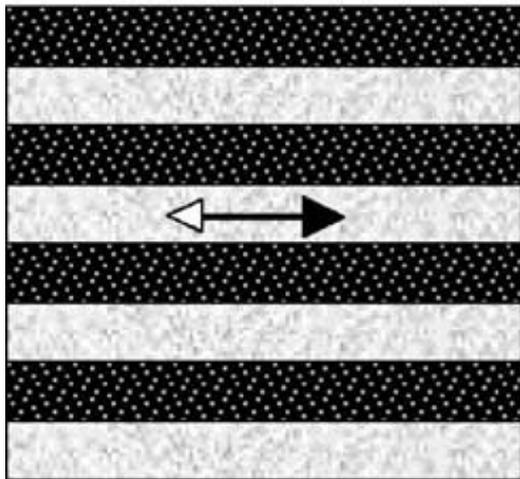
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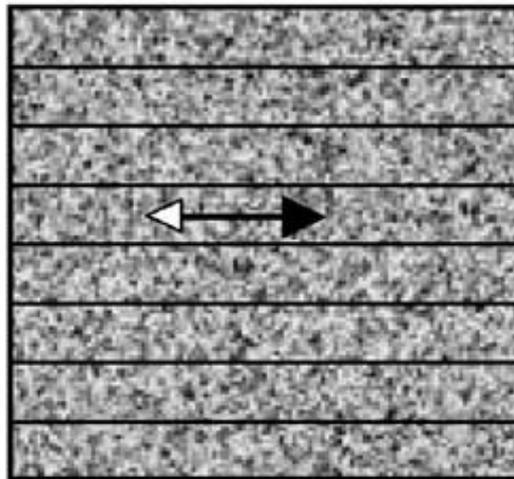
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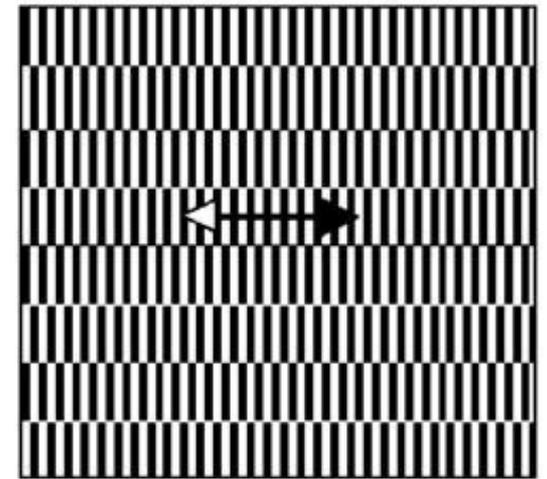
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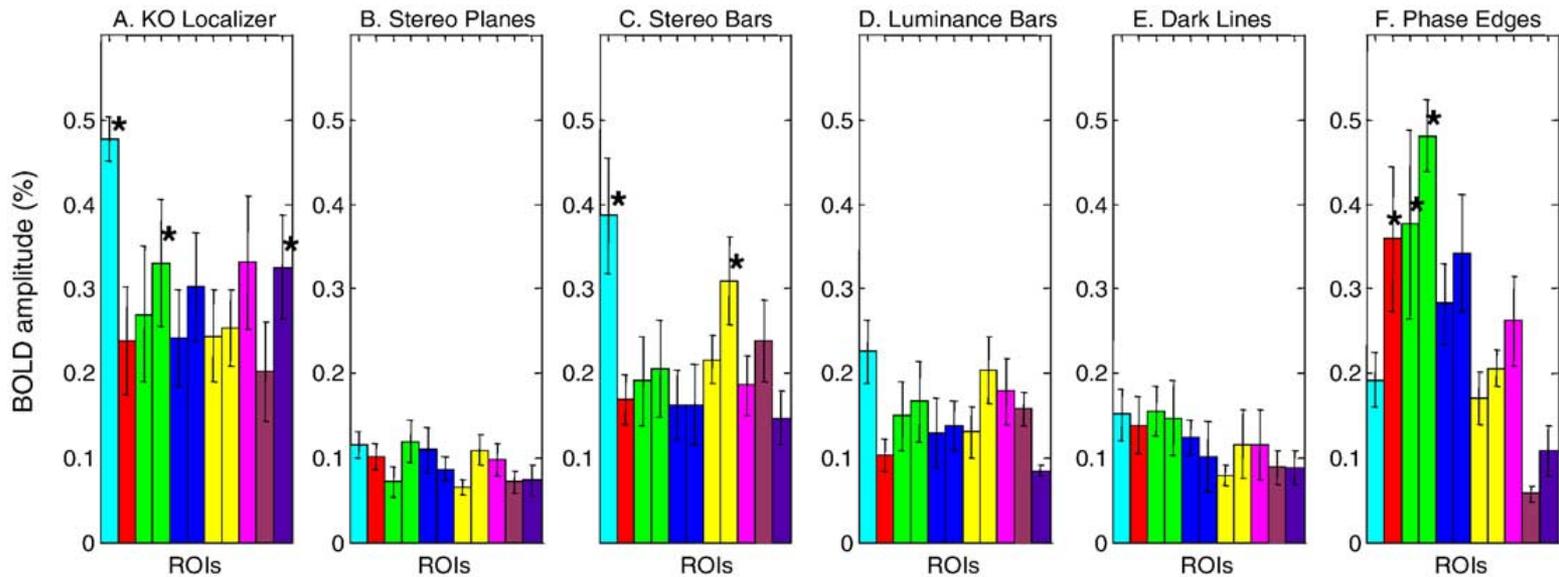
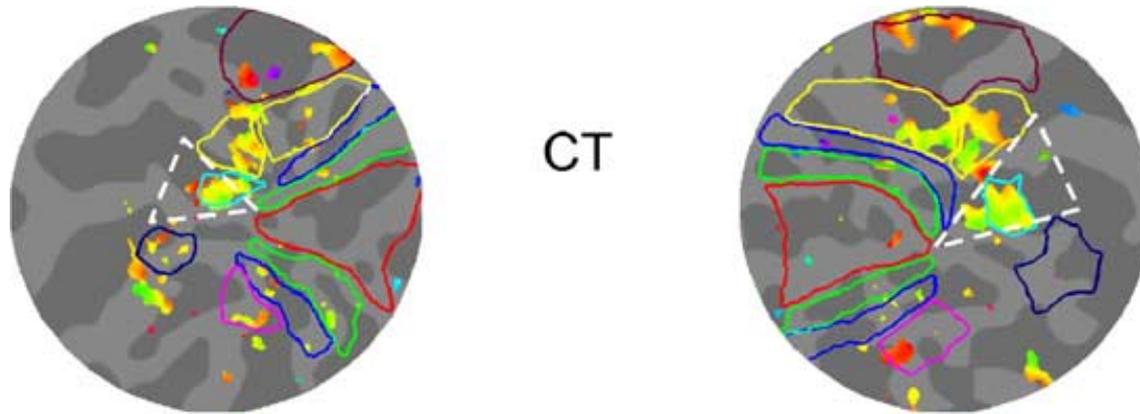
E



F



FMRI Study of Depth Structure Processing

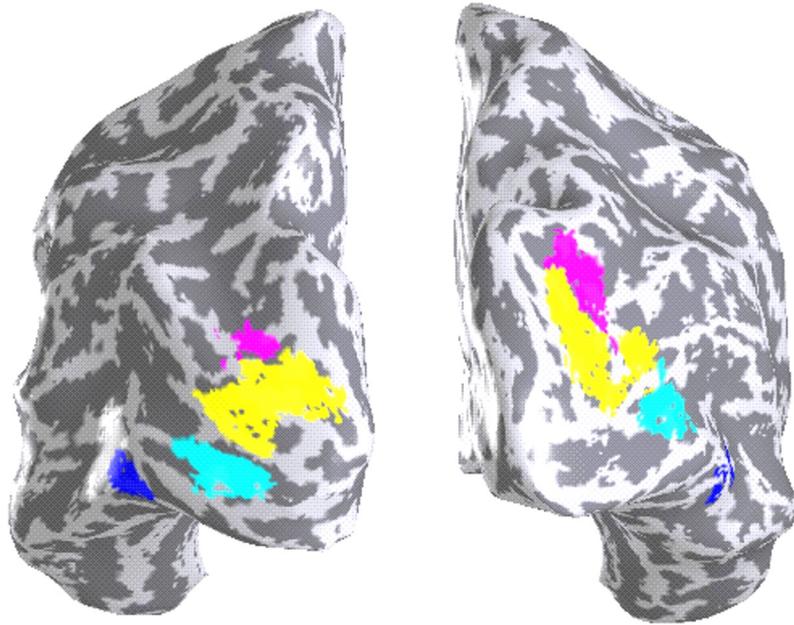


Key to cortical areas

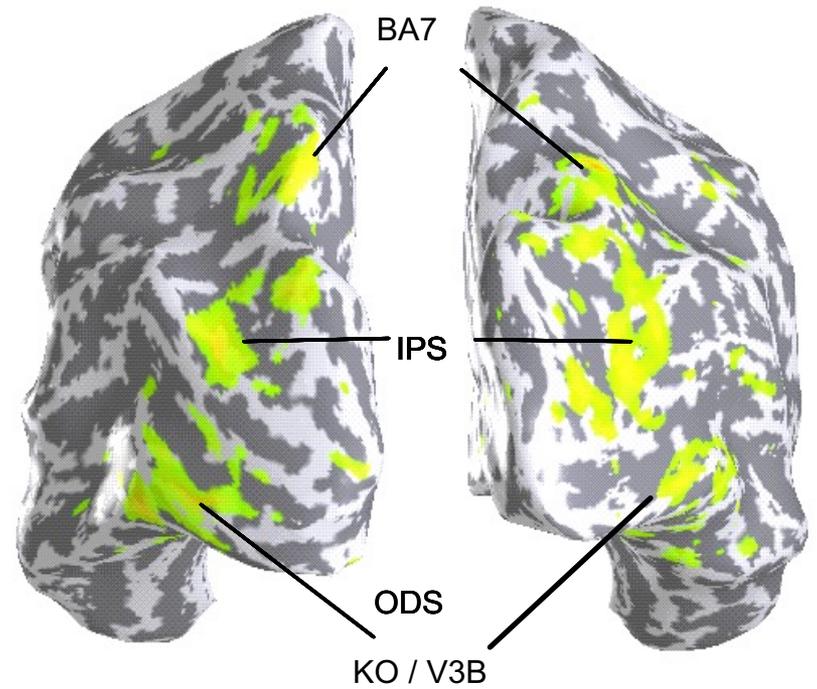


FMRI Depth Response

Localizers



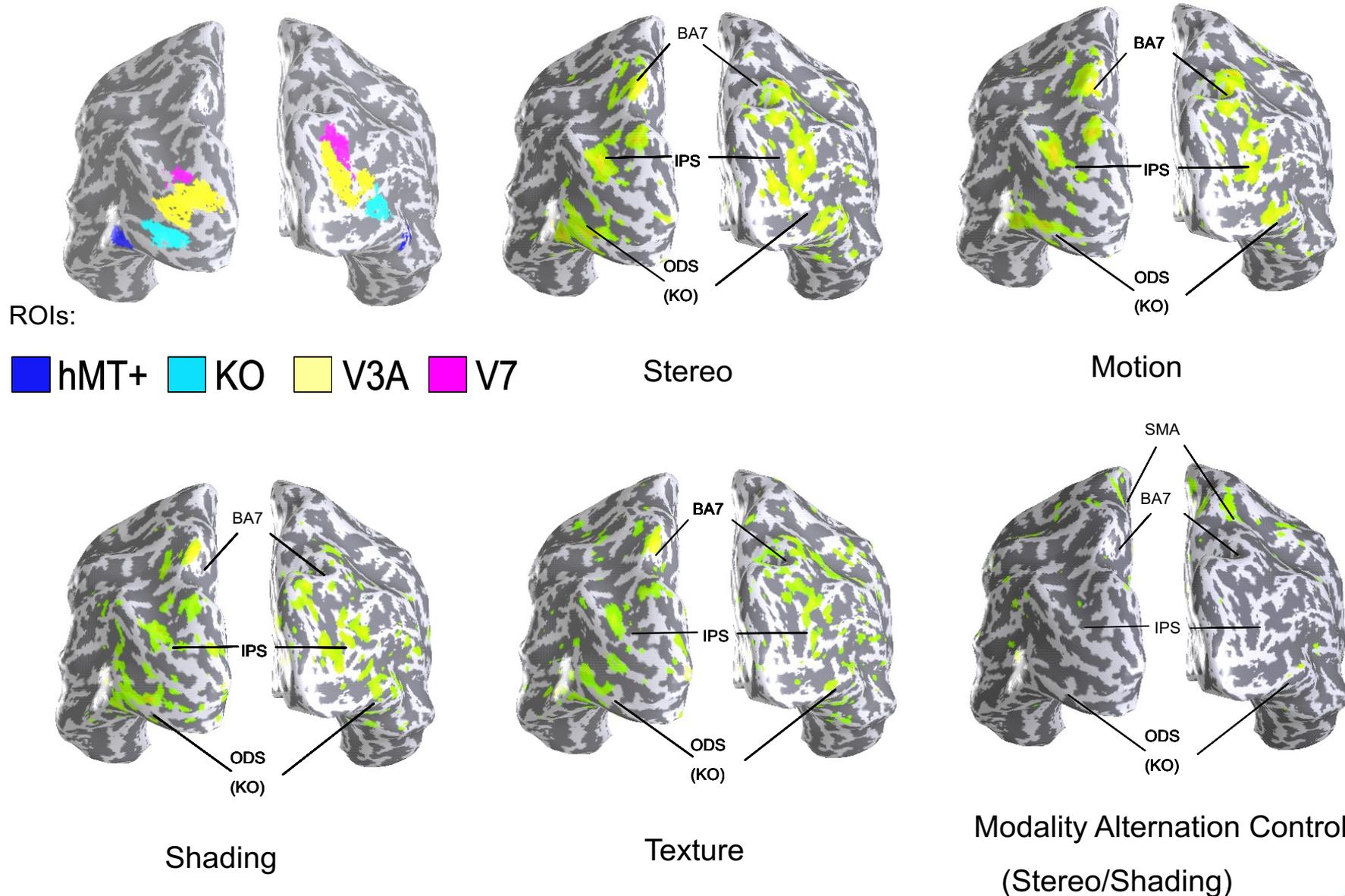
Stereo



ROIs:

■ hMT+ ■ KO ■ V3A ■ V7

FMRI Depth Response



Conclusions

- Neurophysiological studies show that the brain has a specific module for computing depth
- It is early in the dorsal visual pathway, which is generally concerned with analyzing quantitative spatial properties
- Having a perspective processing module is not surprising because it is a primary property of the visual scenes that we see as we walk around
- The brain needs a mechanism for combining the visual depth cues and jointly calibrating them to the scene geometry
- This mechanism has different time constants for the scaling of each cue, on the order of seconds