Projections in Computer Graphics and Computational Photography

Aaron Hertzmann
Adobe Research

SQUARE
PORTRAIT
PHOTO
VIDEO
SLO-MO

Perspective as arrangement

History of perspective

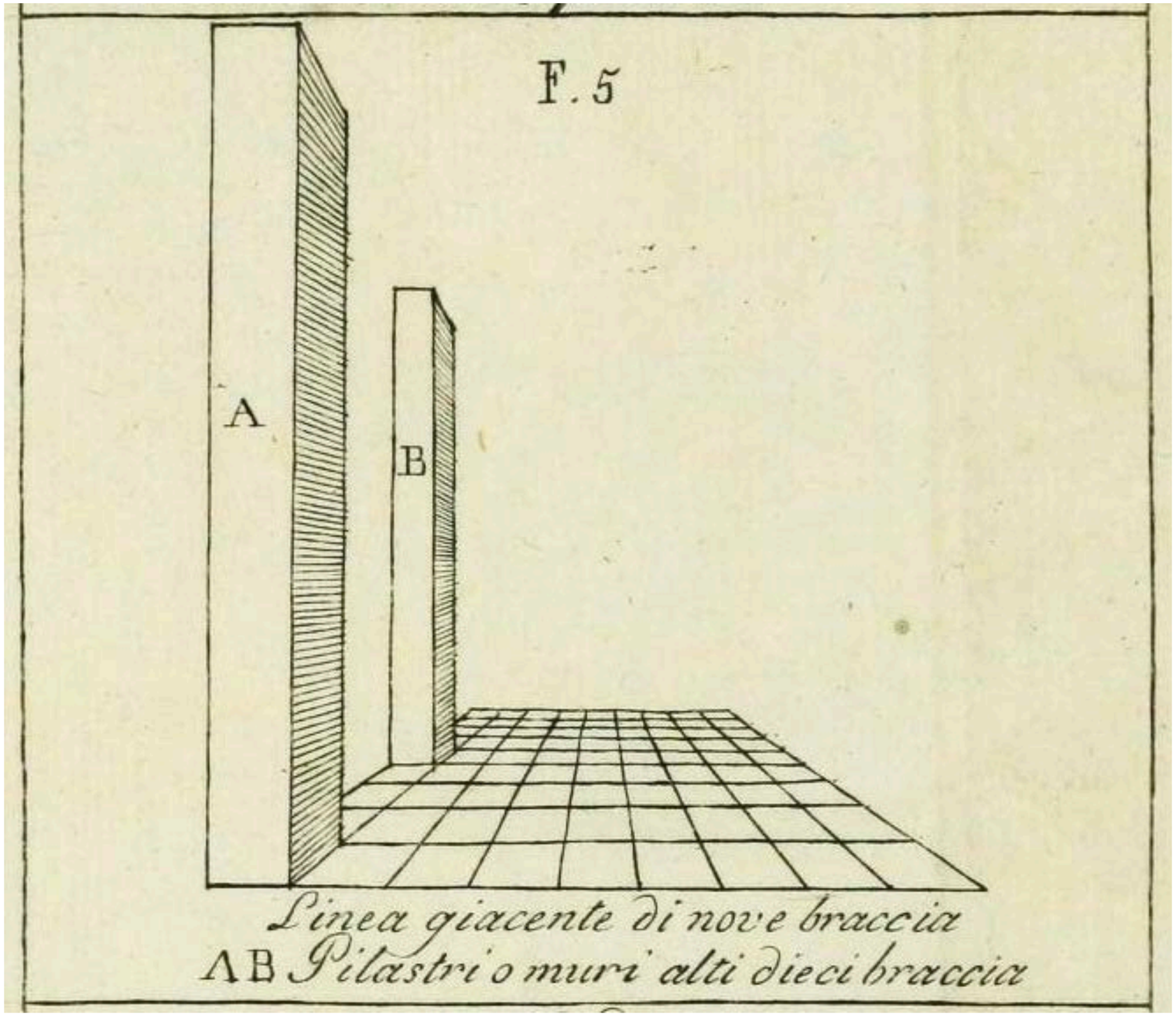
Bhimbetka Rock Shelters, India

Perspective systems

Qiu Ying, 16th century

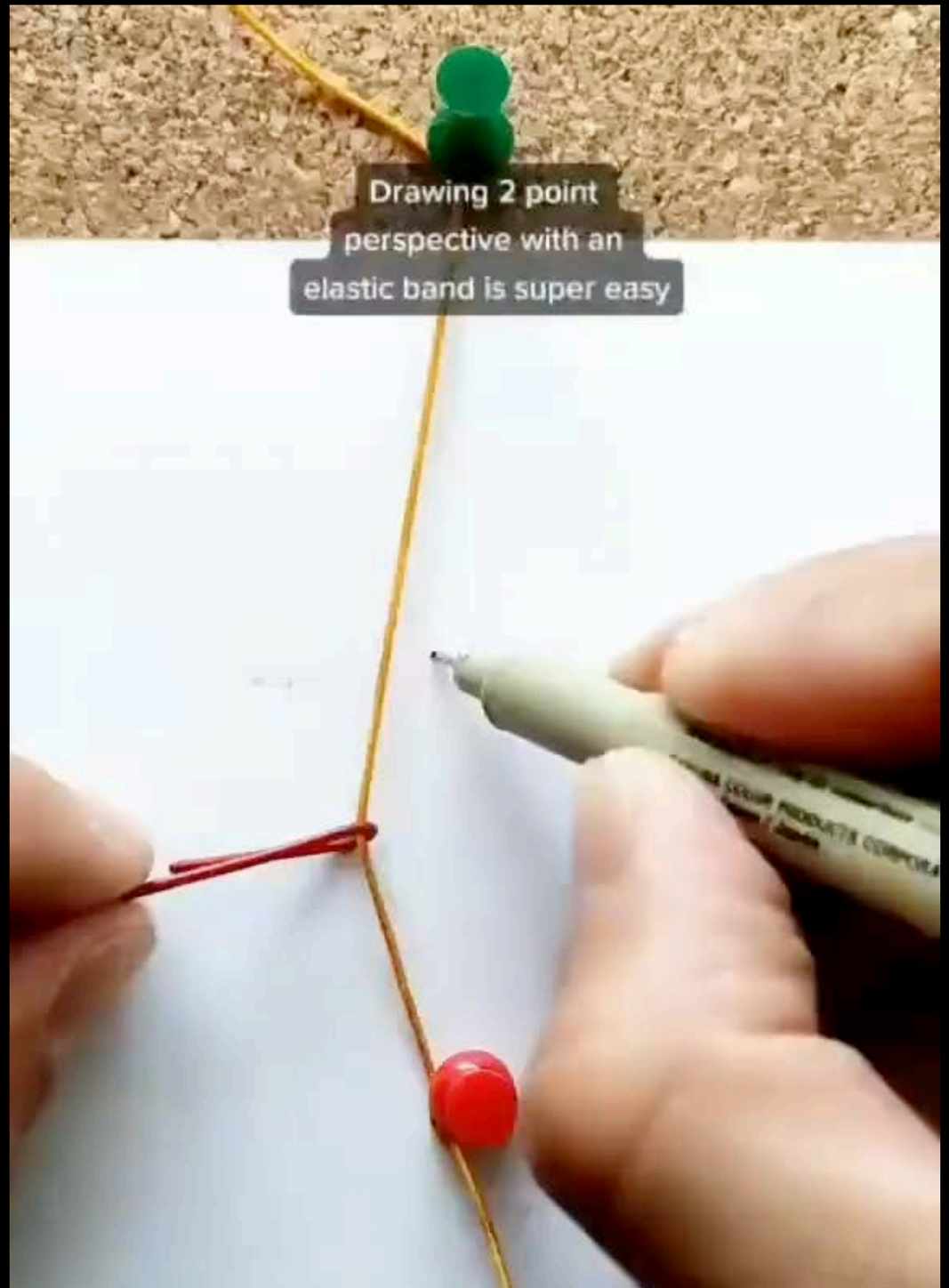
Andrei Rublev, 1411

Van Eyck, Ghent Altarpiece, 1432



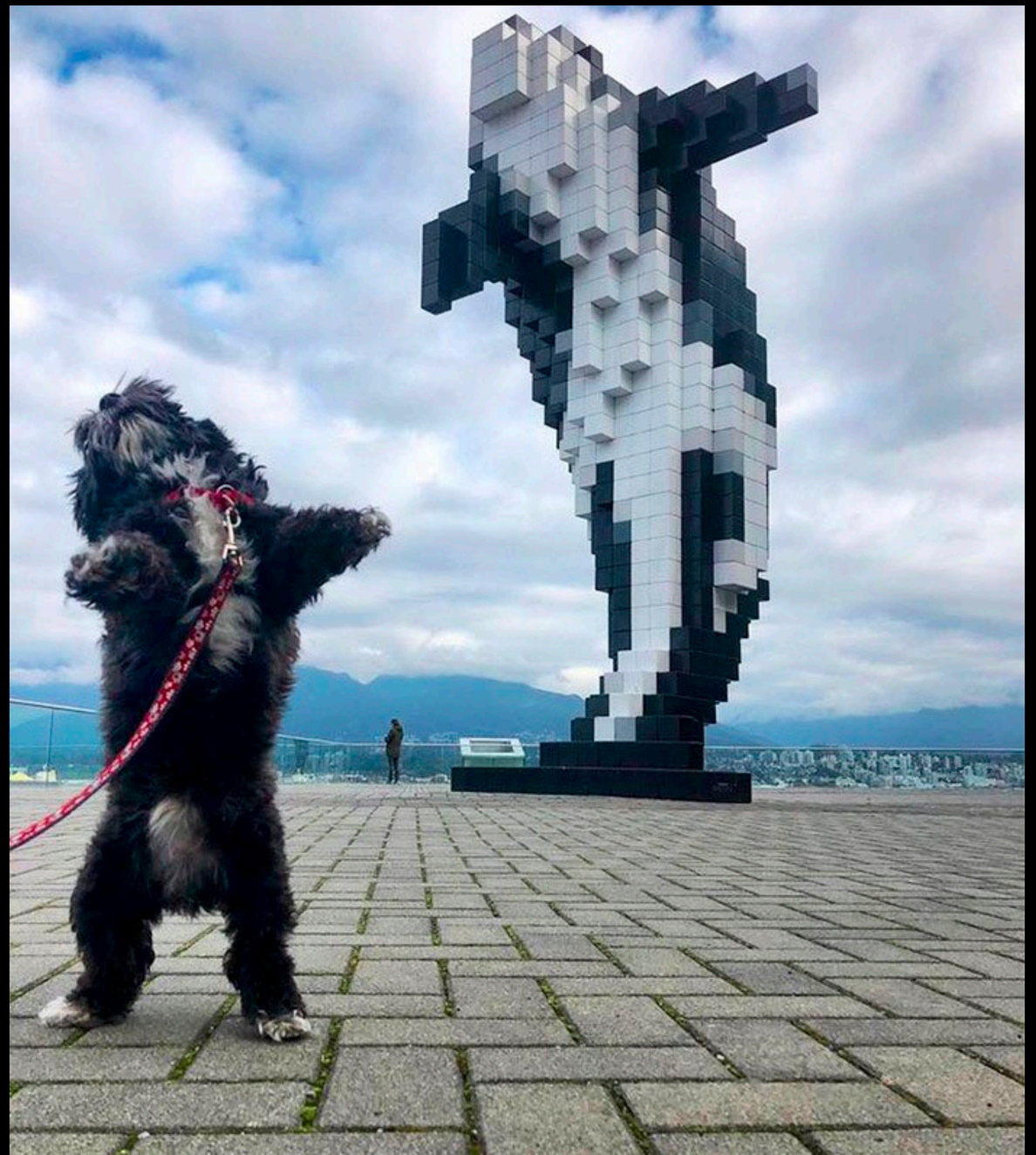
One-point perspective described by Leon Alberti, 1435

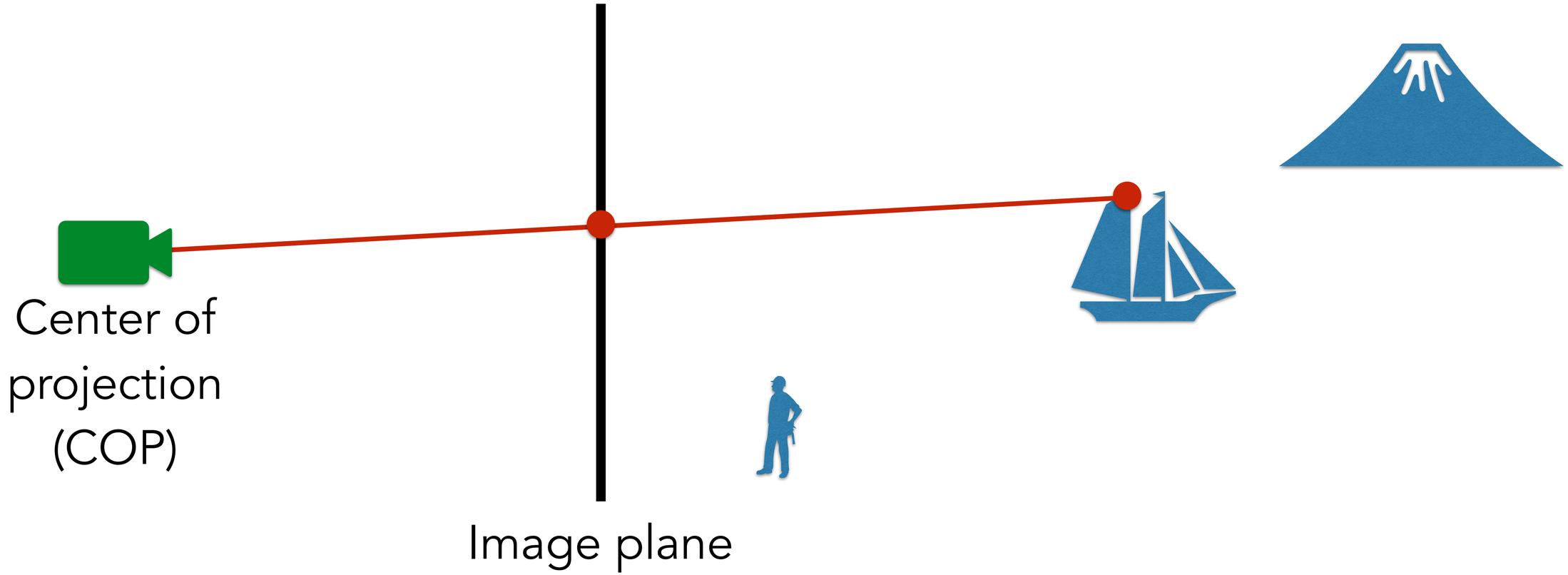
Perugino, 1481

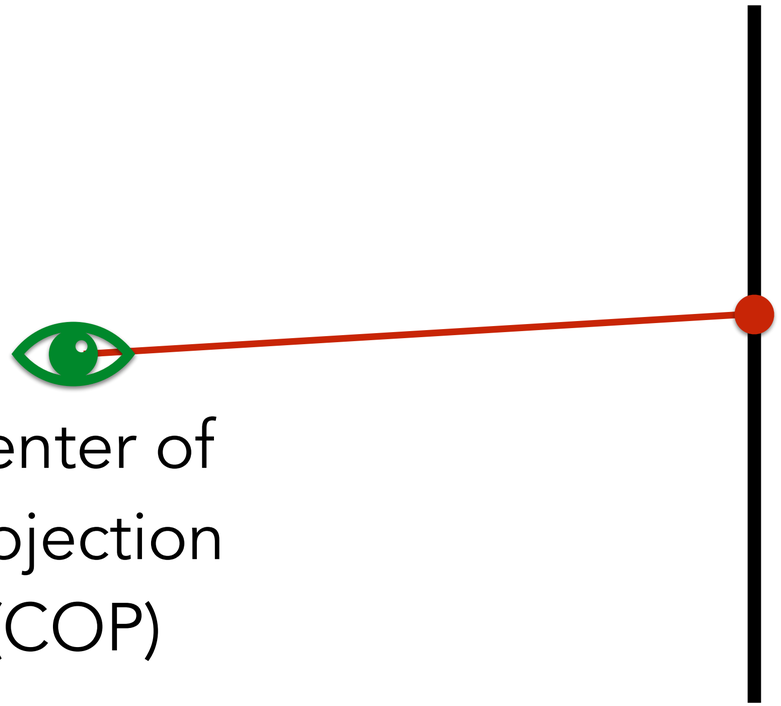


Rafael Araujo

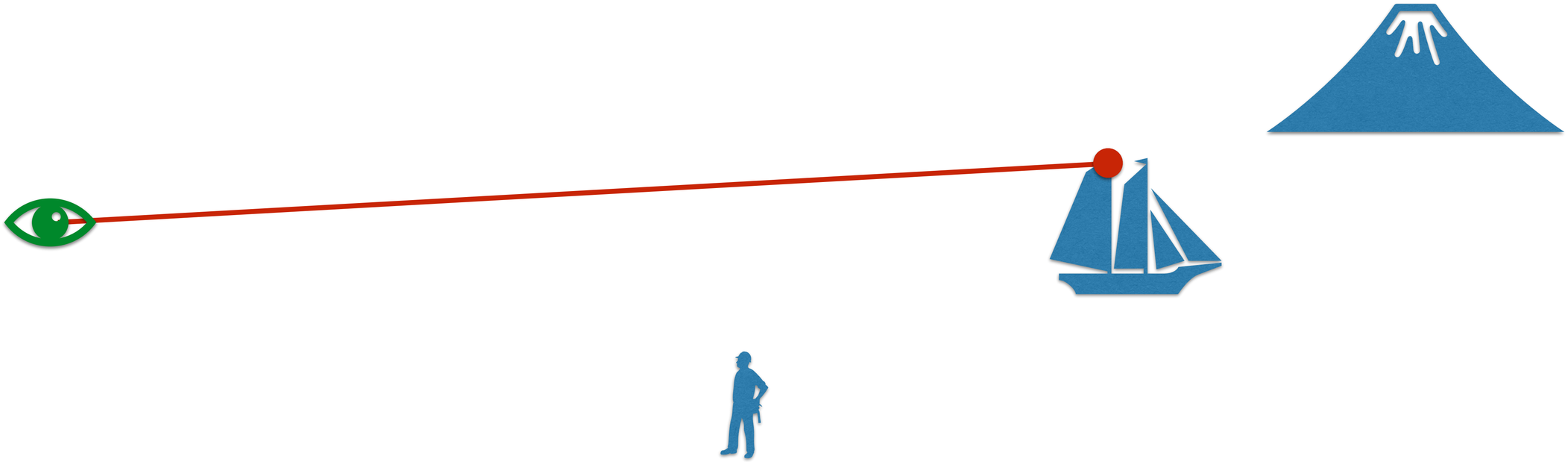
Most cameras approximate linear perspective

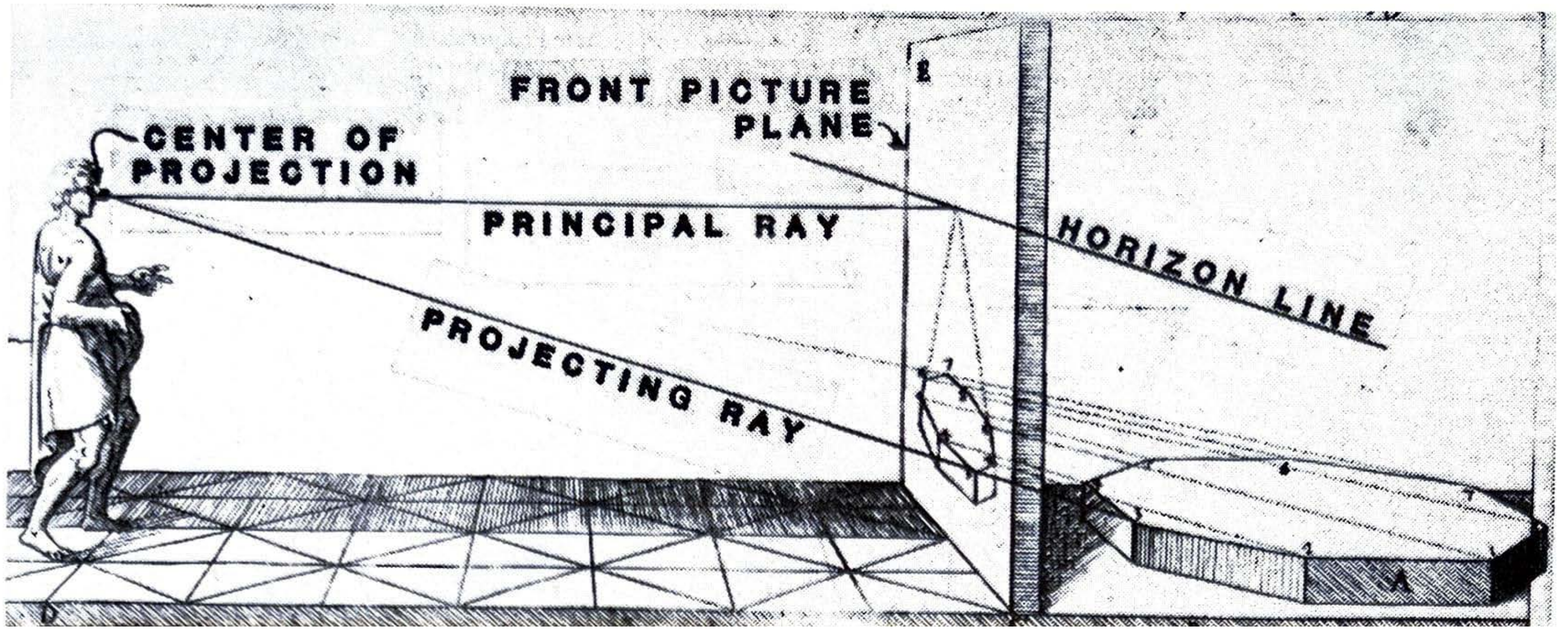



Center of projection (COP)
Image plane


Center of
projection
(COP)
Image plane

Window





G. B. Vignola, 1611

Pictures contain some of the spatial information available in natural scenes. A picture acts like a window into a virtual world;[1] it is a frozen cross-section of light to a fixed viewpoint (the center of projection), providing the pictorial depth information appropriate for that viewpoint.

Yang and Kubovy (1989)

“Linear perspective is correct”

Linear perspective derives from laws of physical optics

Artists use linear perspective to create realistic images

We interpret images as linear perspective

Problems with linear perspective as "correct"

Lots of kinds of pictures

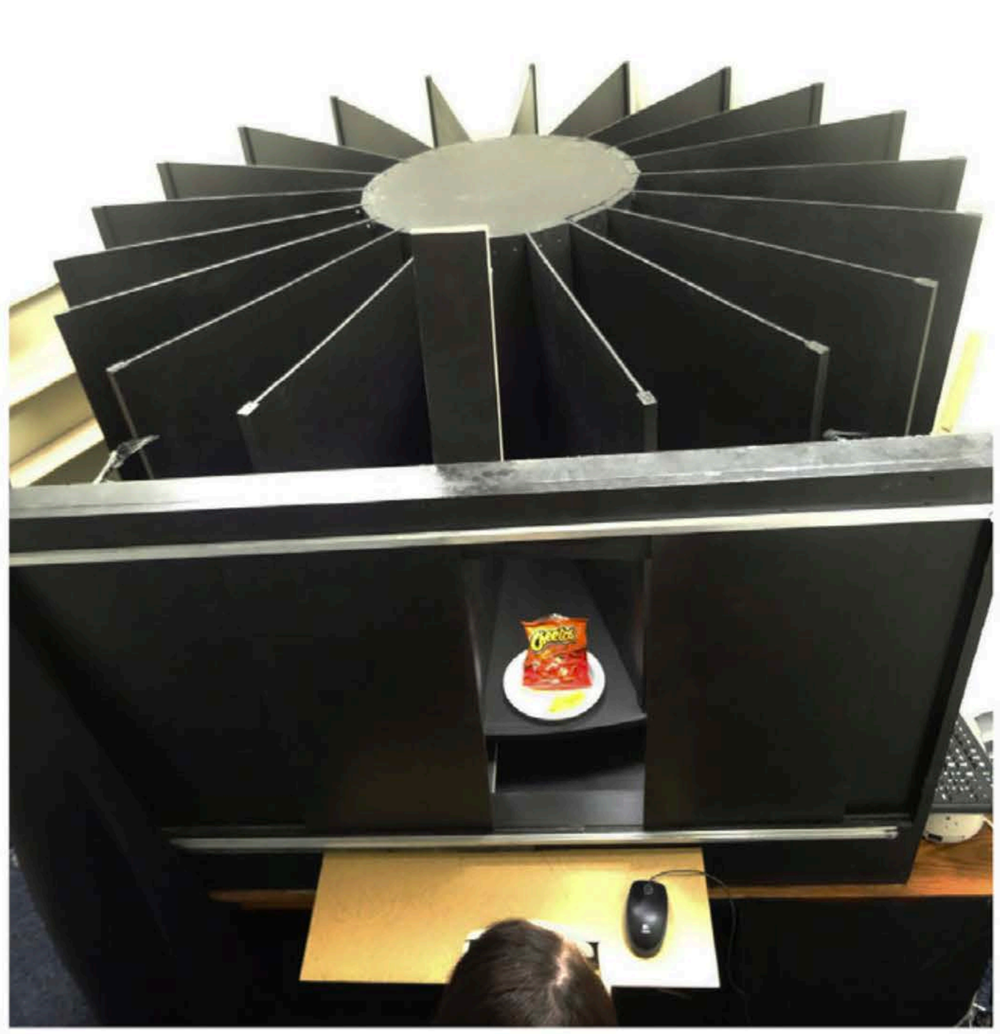
Qiu Ying

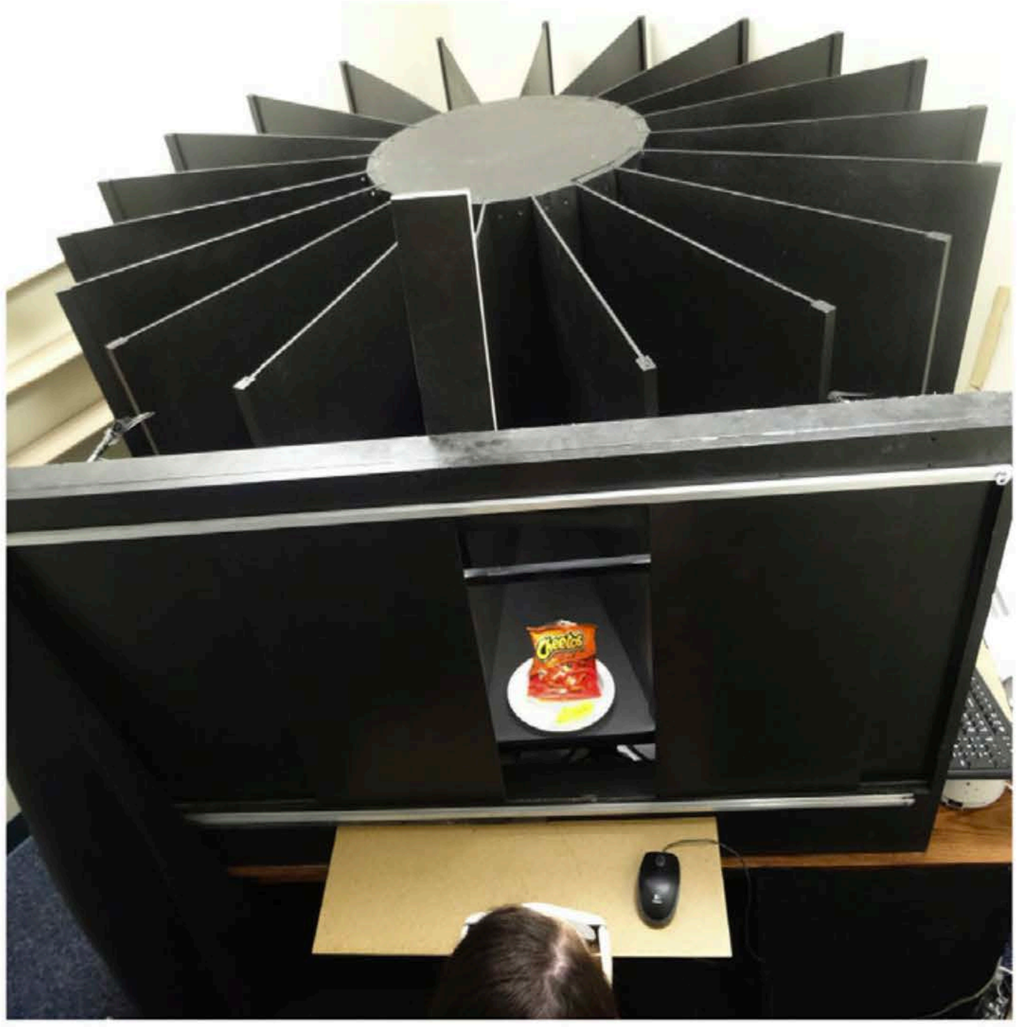
Matisse

Ringgold

Human vision “knows” pictures aren’t reality

Human vision “knows” pictures aren’t reality



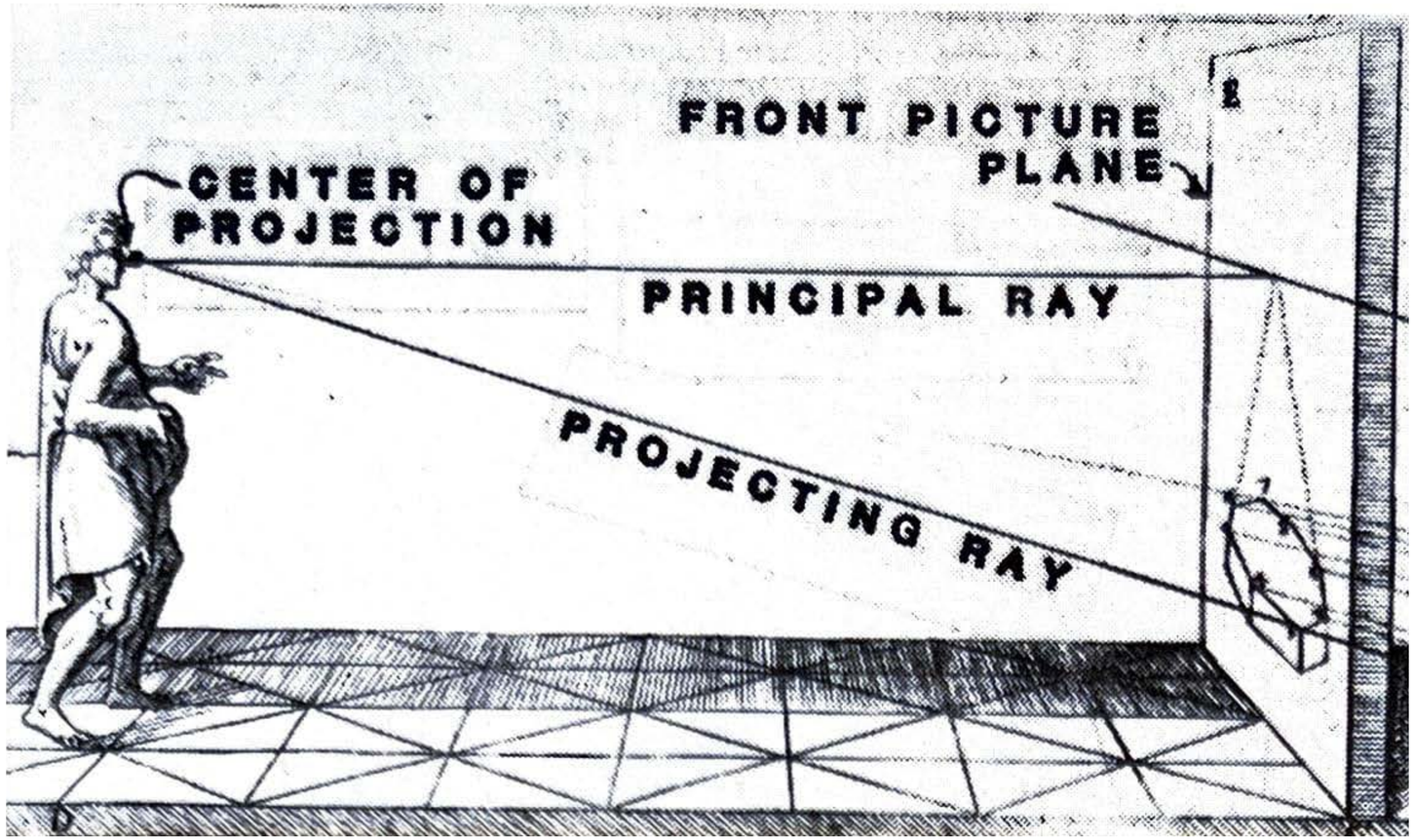


Romero (2018), Snow and Culham (2021)

The light your eyes would see

ignoring:

- Binocular vision
- Accommodation/focus cues
- Limited dynamic range
- Lack of motion cues



COP viewing

Center of projection (COP)

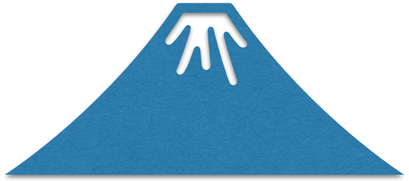


Image plane

Where is the COP?

What is COP viewing distance?

On my iPhone 13:

~3/4 W, where W = image width

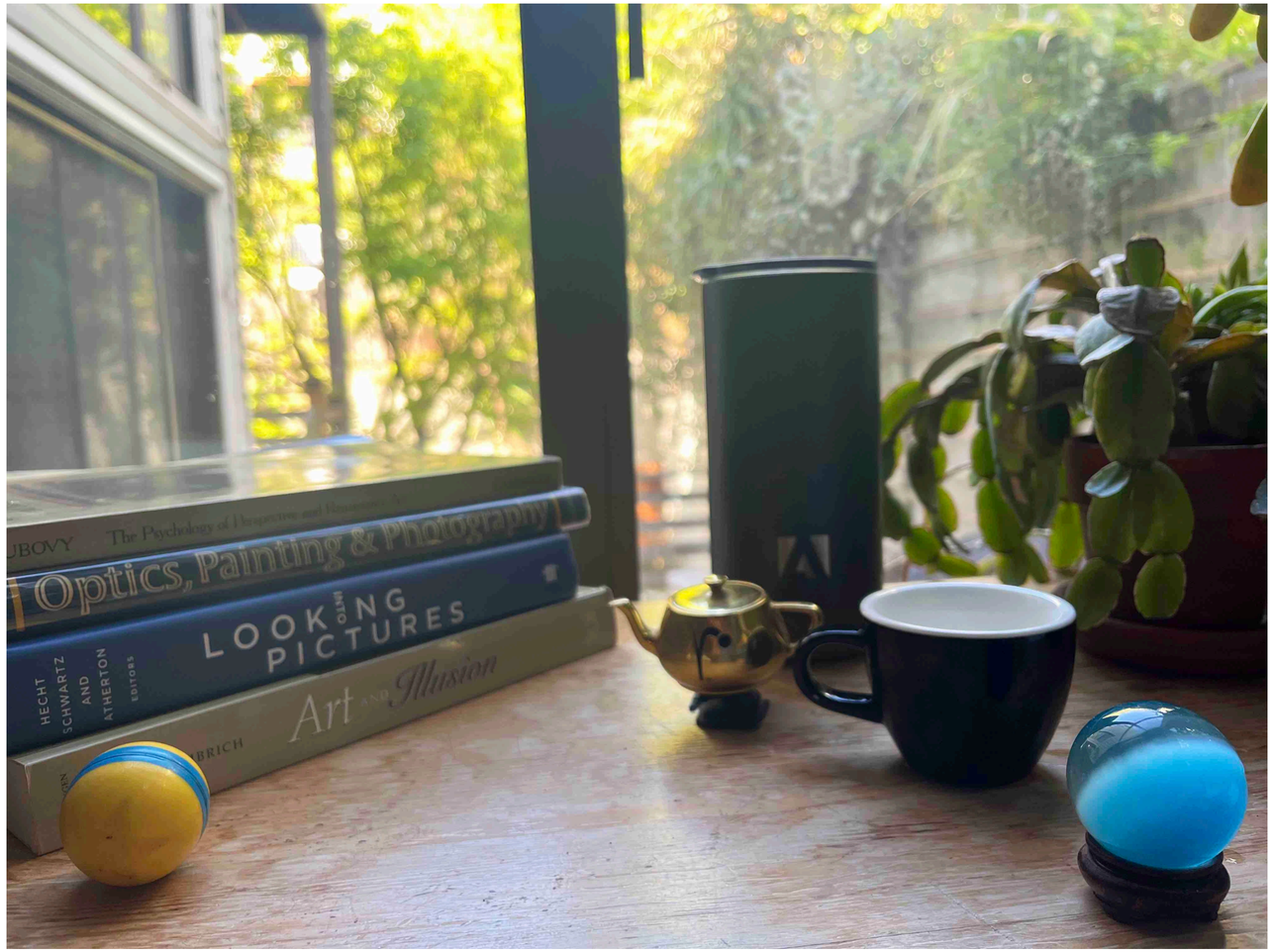
in landscape orientation, default zoom (1x)

For 8” (or 20cm) wide image, your eyeball should be 6” (or 15cm) from the screen

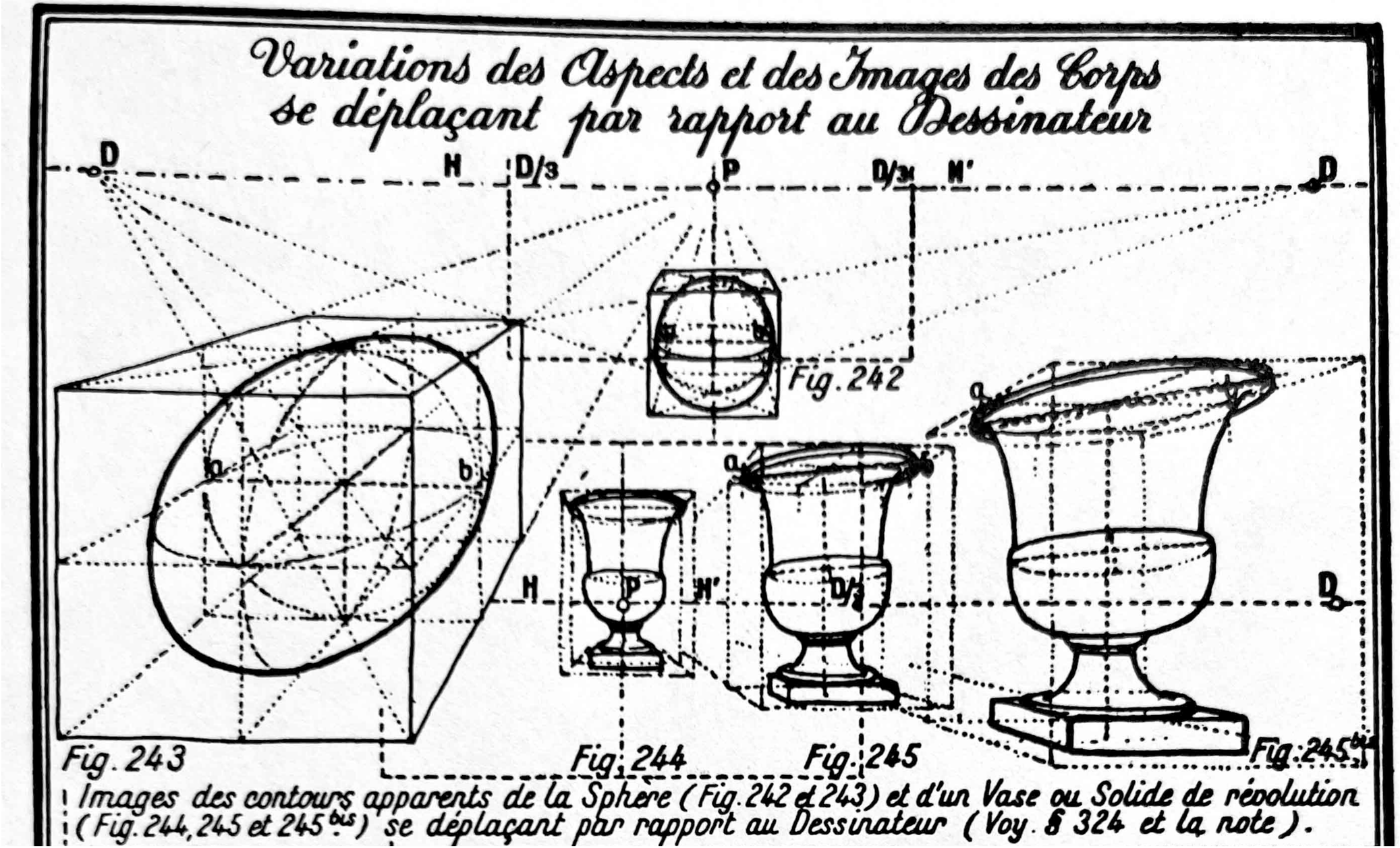
We rarely view from focal center

KANE

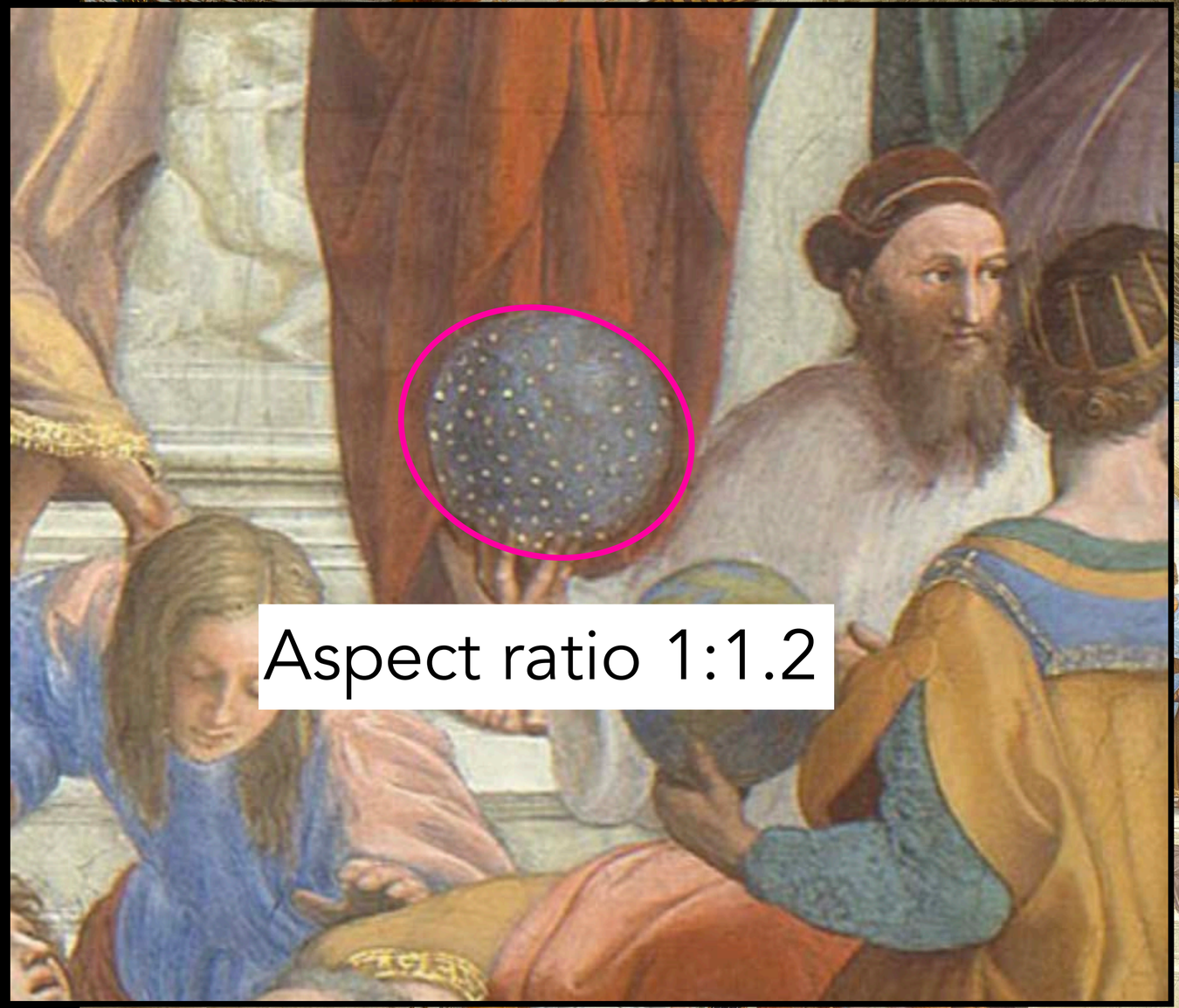
Marginal distortions



Marginal distortions


Variations des Aspects et des Images des Corps
se déplaçant par rapport au Dessinateur
D
H
D/3
P
D/3
H'
D
Fig. 242
Fig. 243
Fig. 244
Fig. 245
Fig. 245bis
Images des contours apparents de la Sphère (Fig. 242 et 243) et d'un Vase ou Solide de révolution
(Fig. 244, 245 et 245bis) se déplaçant par rapport au Dessinateur (Voy. § 324 et la note).

Olmer, 1943


Aspect ratio 1:1.2

Shih (2019)

that is not centered on the principal ray is an ellipse. Nevertheless, if the projectively correct ellipses were substituted for the circles with which Raphael represented the spheres in his *School of Athens*[3] (Figure 7-9 and the detail in Figure 7-10), they would not look like spheres (unless the fresco were viewed through a peephole at the center of projection). This misperception of the correct projection of a sphere is a marginal distortion very much like the misperception of projectively correct representations of the vertices of cubes when they are outside the area of normal perspective (because they are likely to violate Perkins's

Kubovy 1989, p112

Do artists use linear perspective?

Kemp (2022): only 3% of classical paintings strictly followed linear perspective

See also Haertel (2014), Koenderink (2016)

Linear perspective is “**a working tool** that delivered convincing results when used in a pragmatic manner, without following the rules slavishly.” (Kemp 2022)

Pieter Jansz, 1641

“Linear perspective is correct”

Linear perspective derives from laws of physical optics

- Viewer is rarely at the COP; binocular vision, focus, etc.

Artists use linear perspective to create realistic images

- Strict linear perspective artwork is very rare

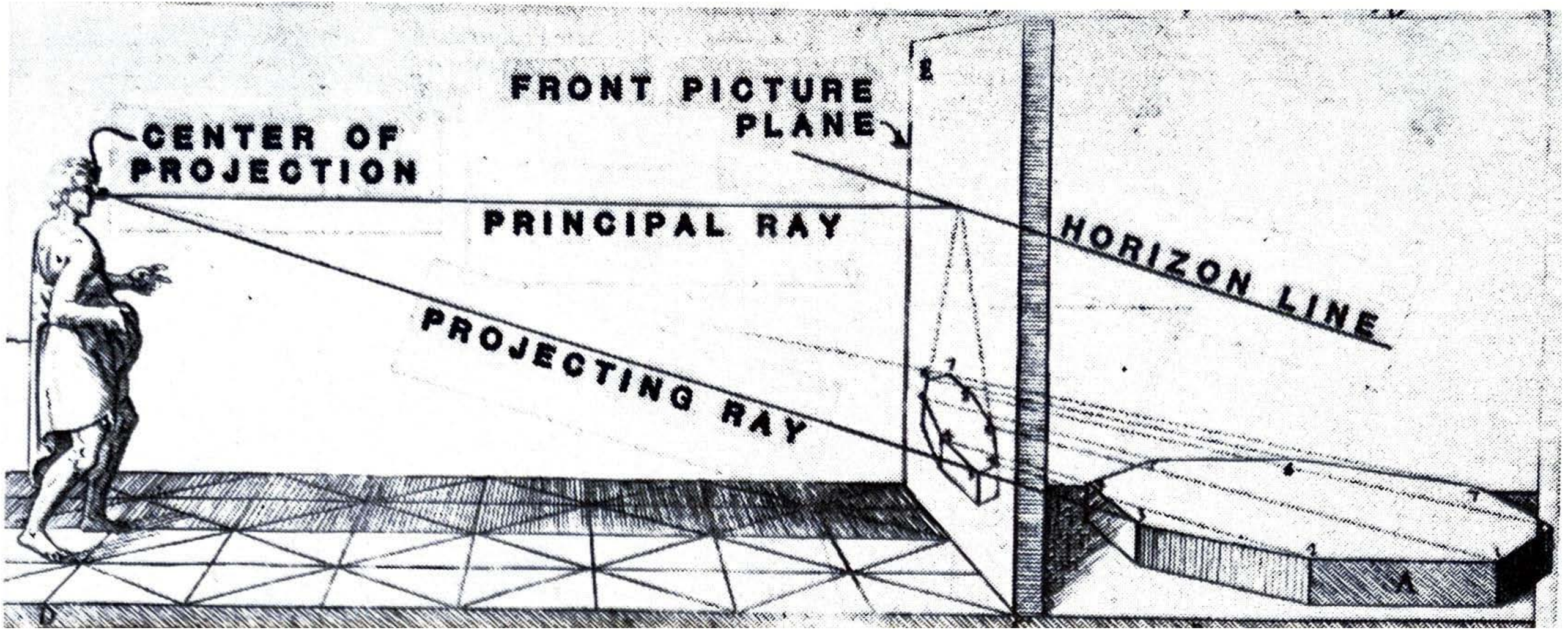
We interpret images as linear perspective

- Why does strictly linear imagery have distortions?

Bryan et al. (2012), Cooper et al. (2012), Fried et al. (2016)

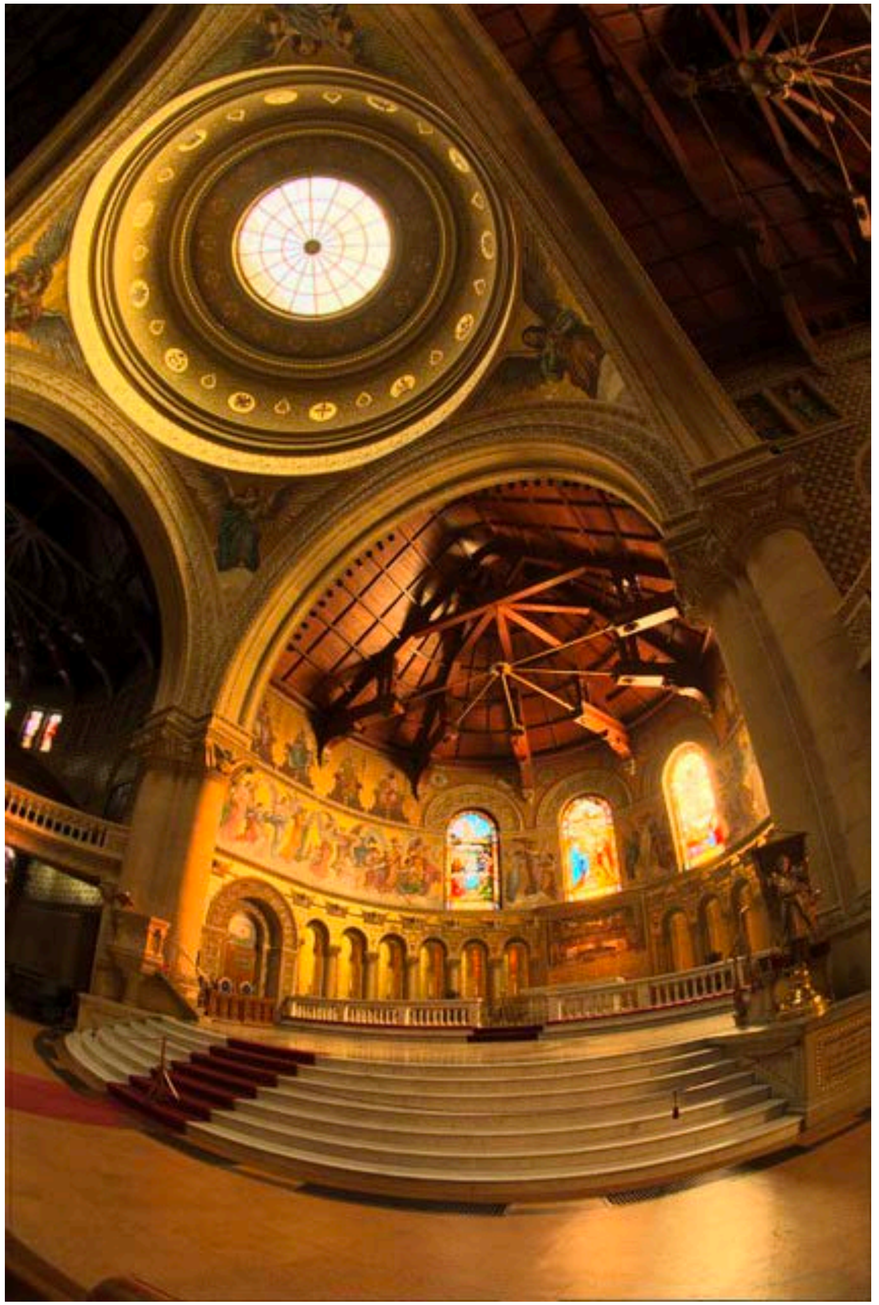
Linear perspective is important,
but it isn’t everything

Tone mapping



Most display devices cannot reproduce outdoor brightnesses

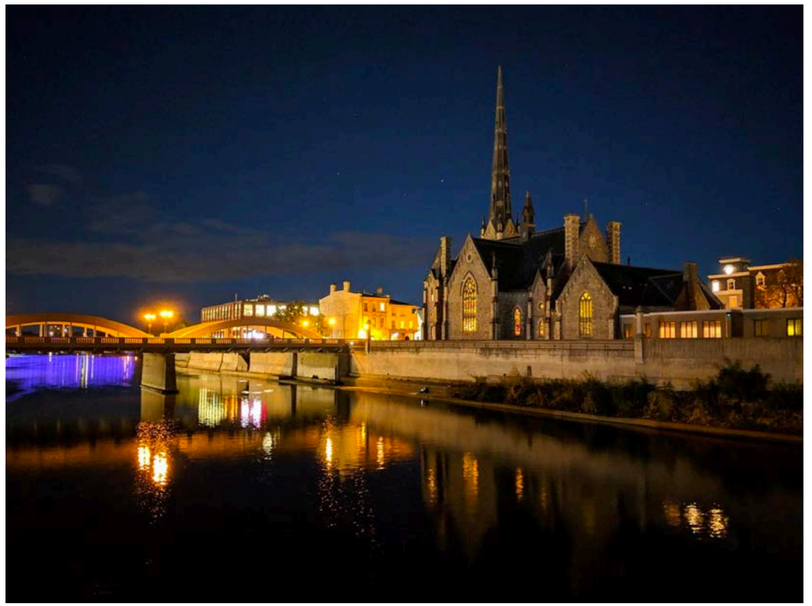
Real scenes can have dynamic range of 30,000:1



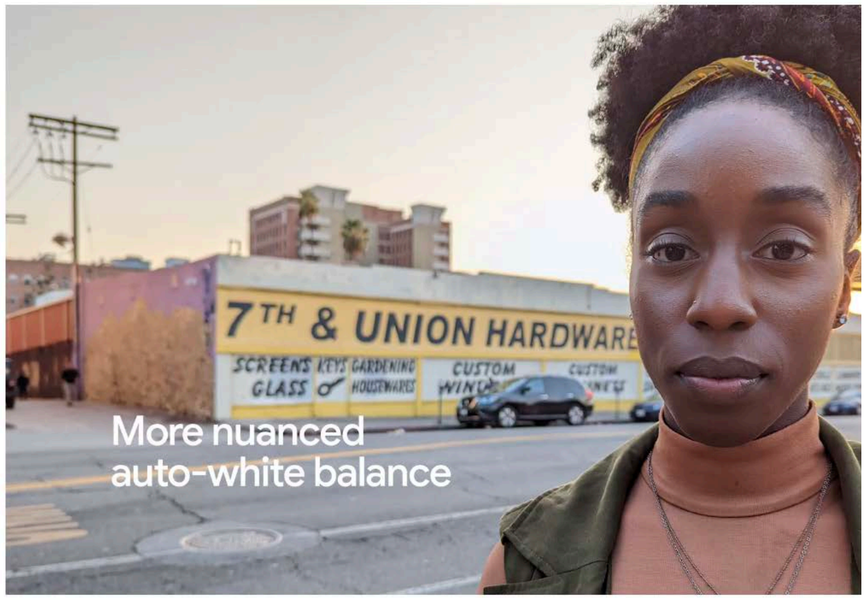
Debevec and Malik (1997)

Artists and photographers do spatially-varying, content-dependent tone-mapping

Gharbi (2017)



NightSight (Liba 2019)



Google RealTone

Smartphones do content-dependent, spatially-varying tone-mapping (e.g., Levoy 2018, Liba 2019, Chayka 2022)

But perspective is entirely linear

Computer graphics/ computational photography

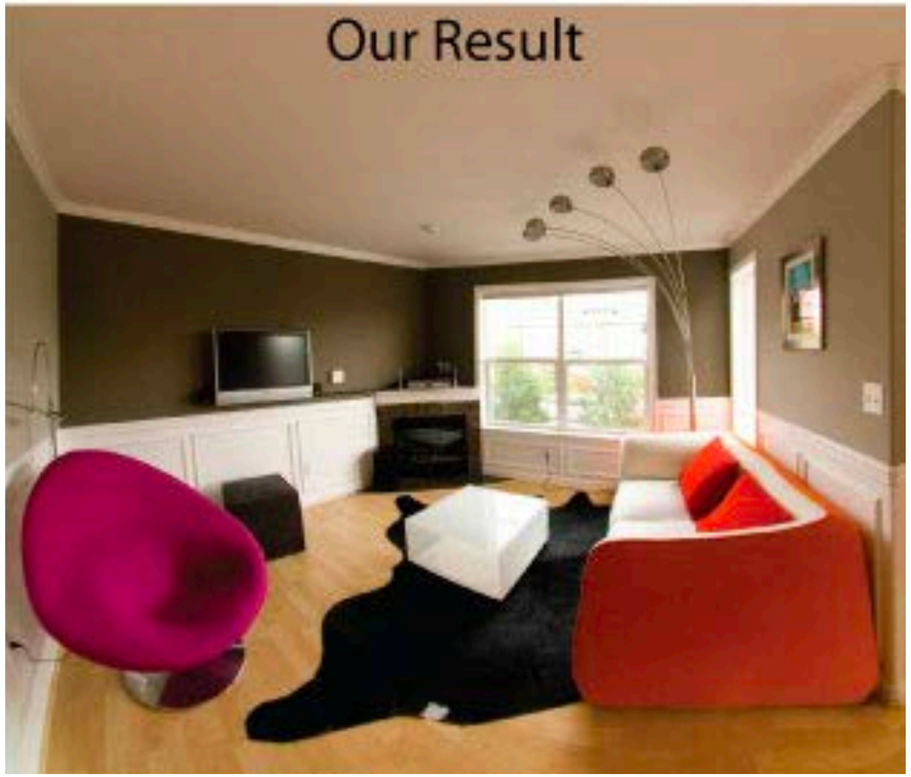
Considerations

Distortion

Scene perception

Composition/arrangement

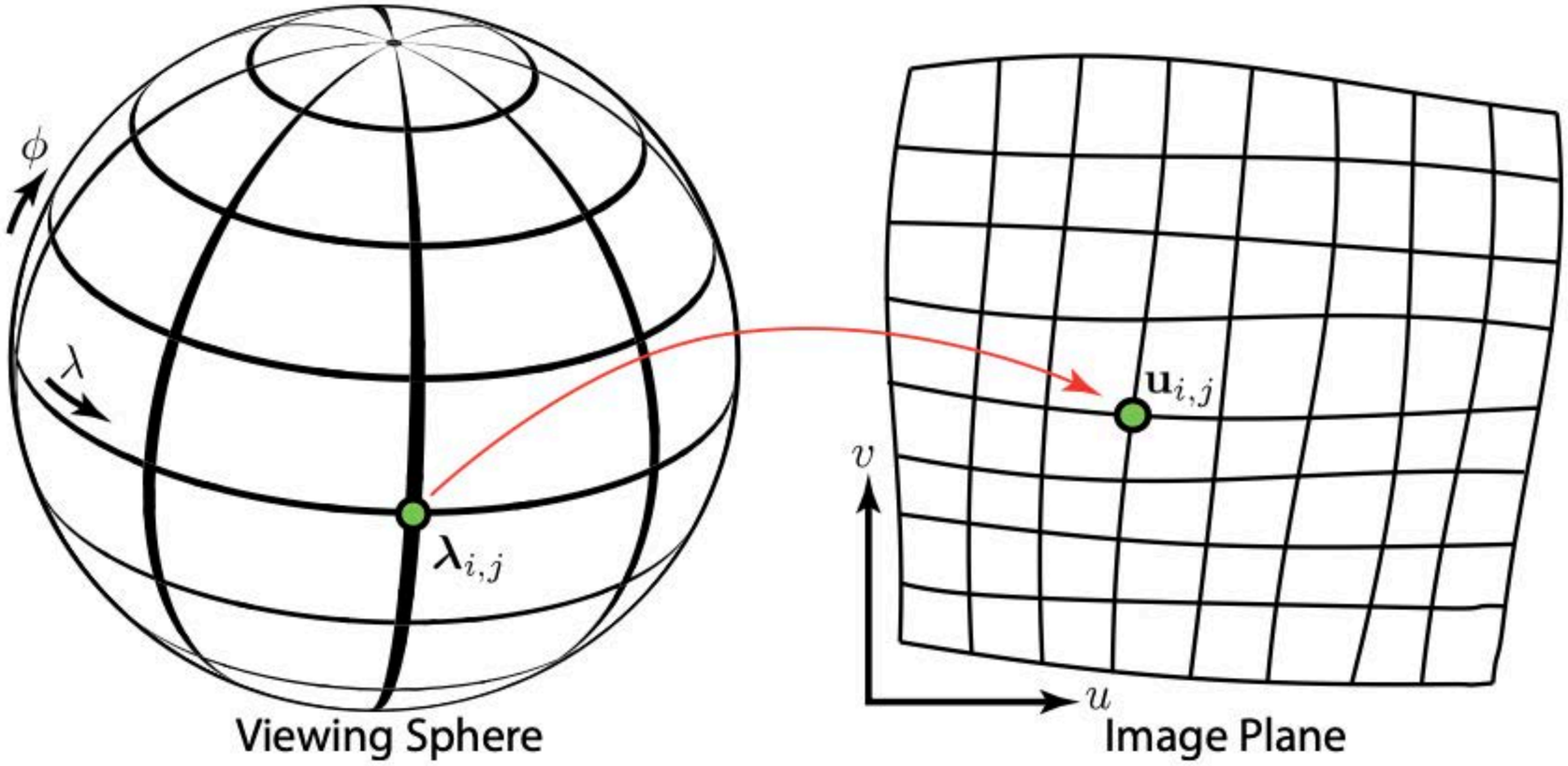
Two goals



Wide-angle
without distortion

“Artistic” effects

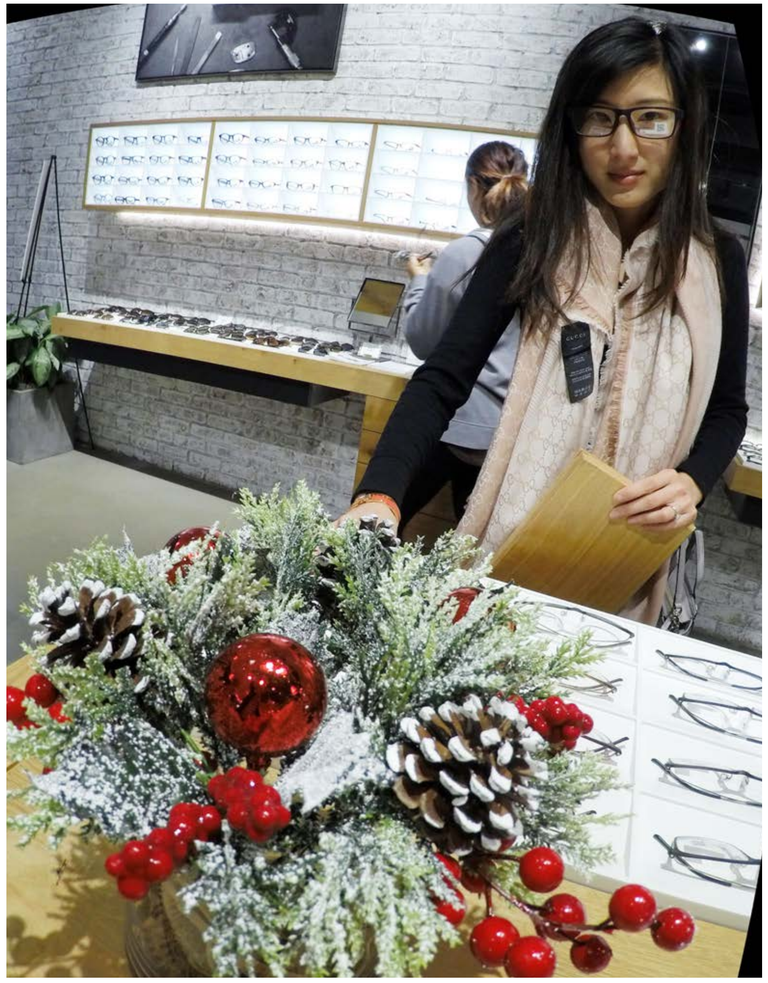
Parameterizing projection



Carroll, Agrawala, Agarwala (2009)

Stereographic projection

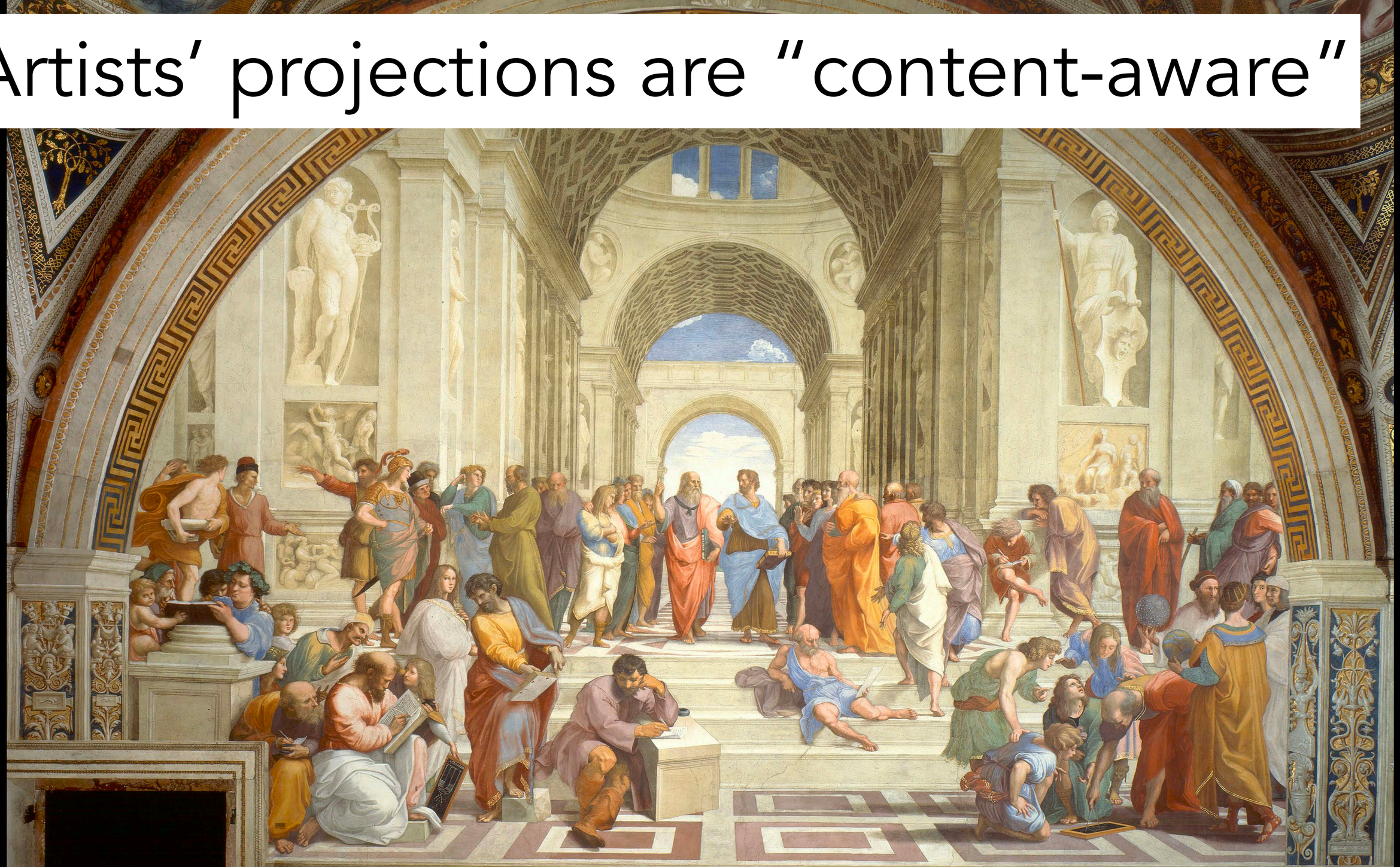
Input Photo (linear)



Stereographic

Shi, Lai, Liang (2019)

Artists' projections are "content-aware"



Direct View Condition

“Objects in the image should look as if they are viewed directly — as they appear in the middle of a photograph.”

— Zorin and Barr (1995)

Direct View Condition special cases

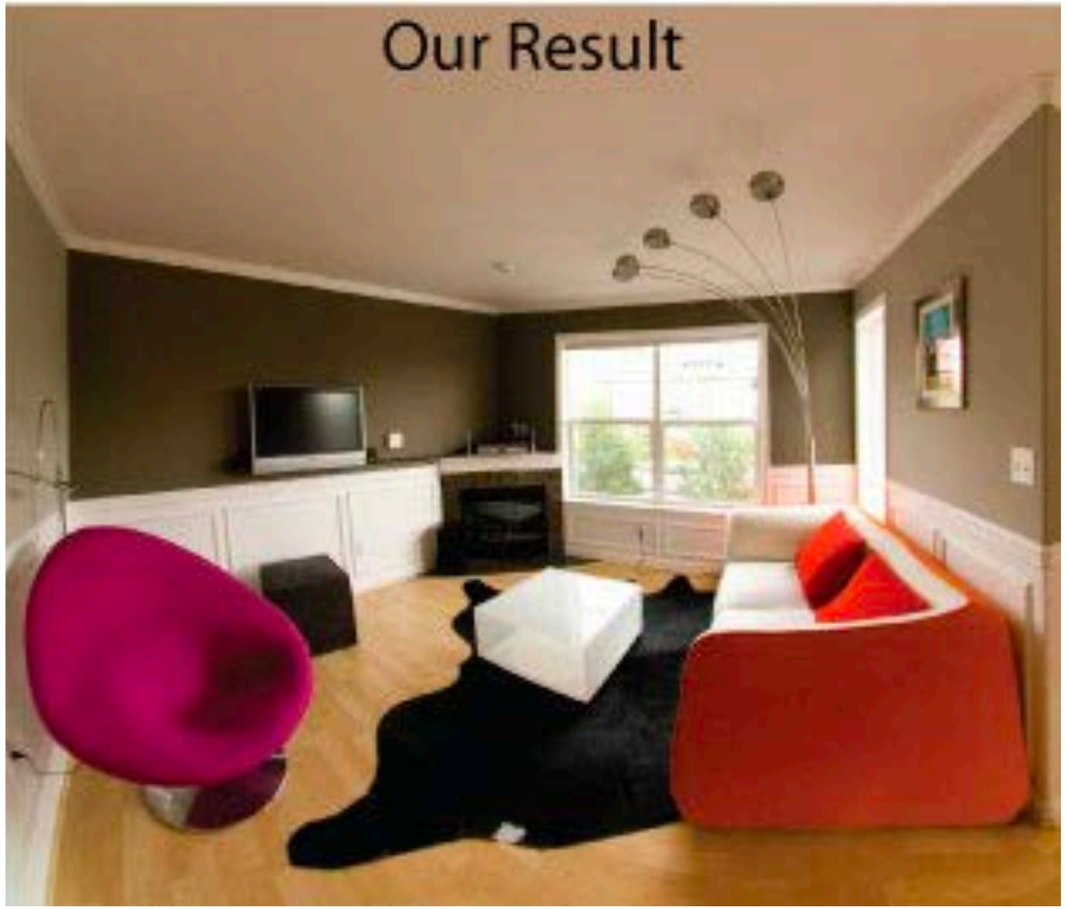
Empty patches

Straight lines

Spheres

Texture

Content-Aware projection



Carroll, Agrawala, Agarwala (2009)

Content-Aware Projection

Input Photo (linear)

Output

Shi, Lai, Liang (2019)

Shih et al (TIP 2022)

Input 105° FOV
(perspective projection)

Our method

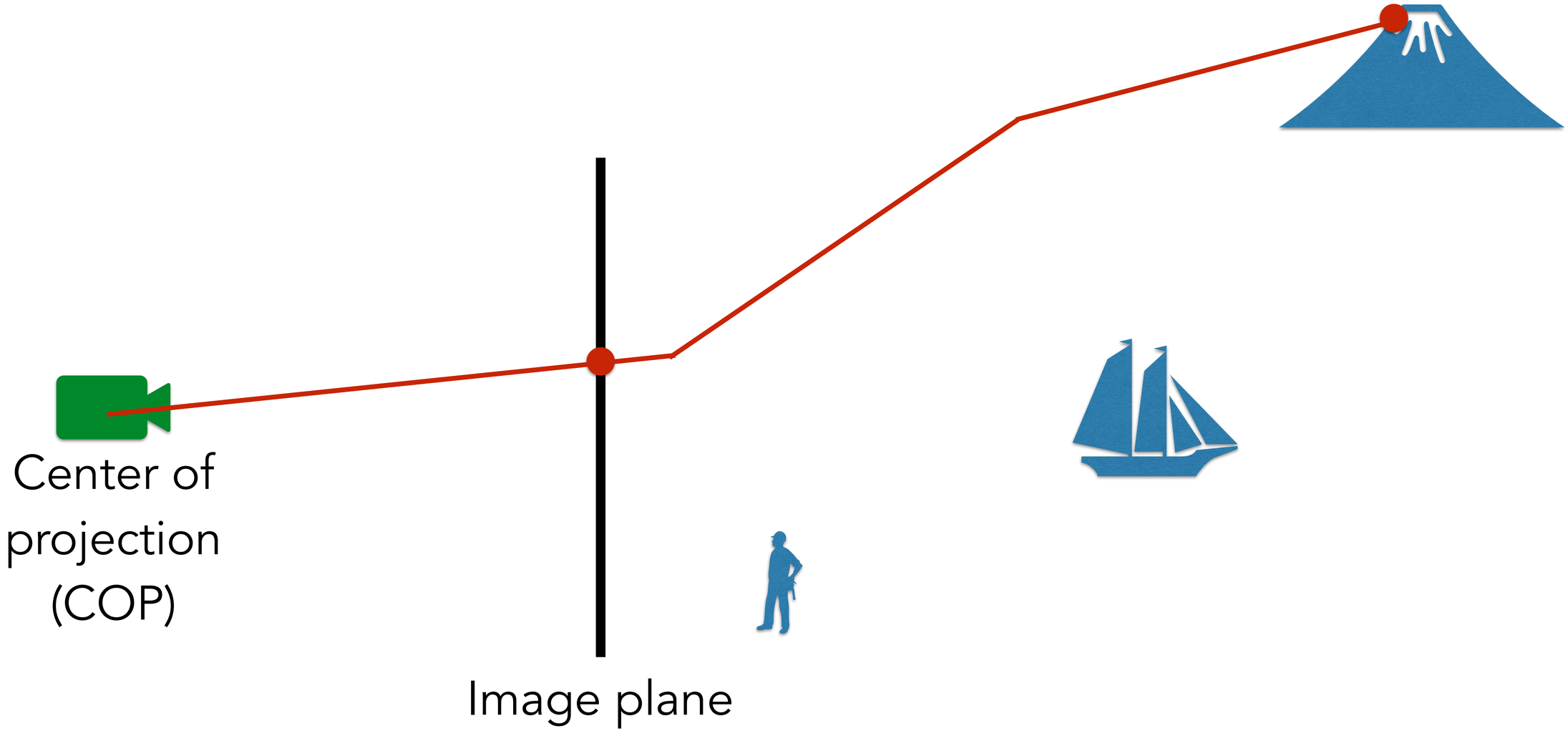
Using depth or multiple shots

Meg Adams
@artbymoga

Happy Harvest Moon!

Using multiple shots

“Computational Zoom,” Badki et al., SIGGRAPH 2017

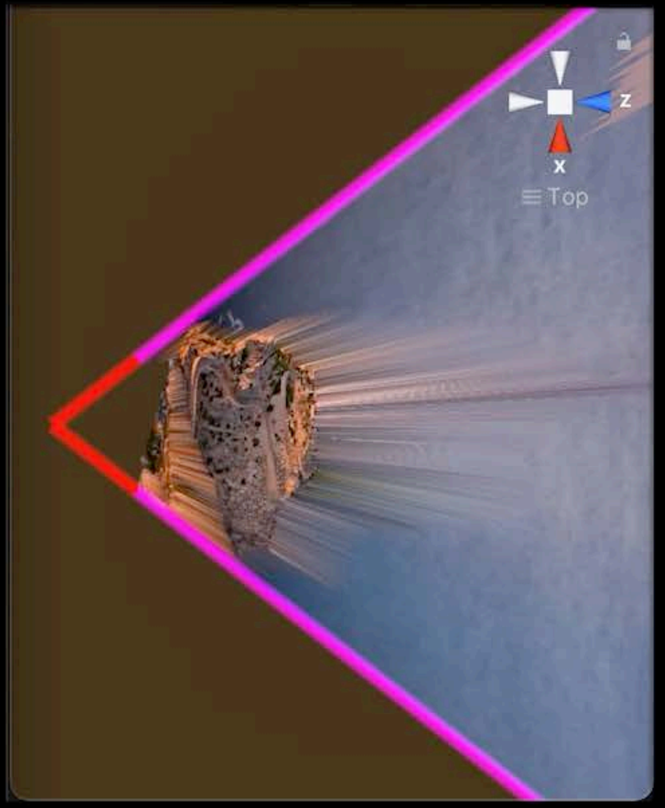

Center of projection (COP)
Image plane

Original

Zoom-in & Crop

ZoomShop

Top-down view
of camera volume



ZoomShop (Liu 2022)

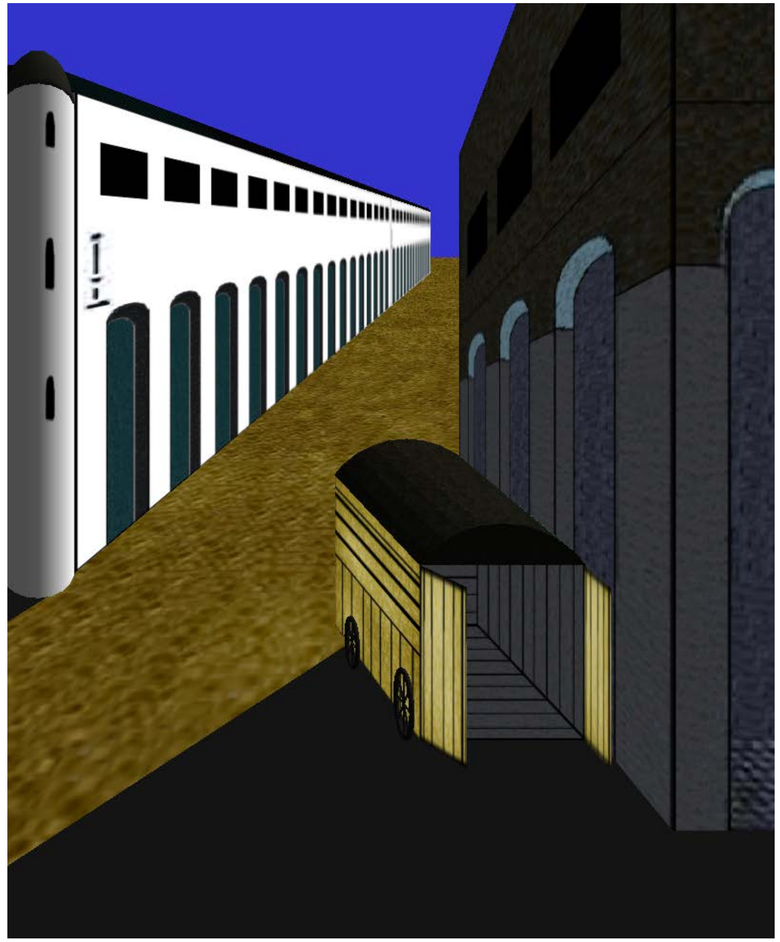
Artistic projections in CG/CP

Spherical projections

Rich Radke

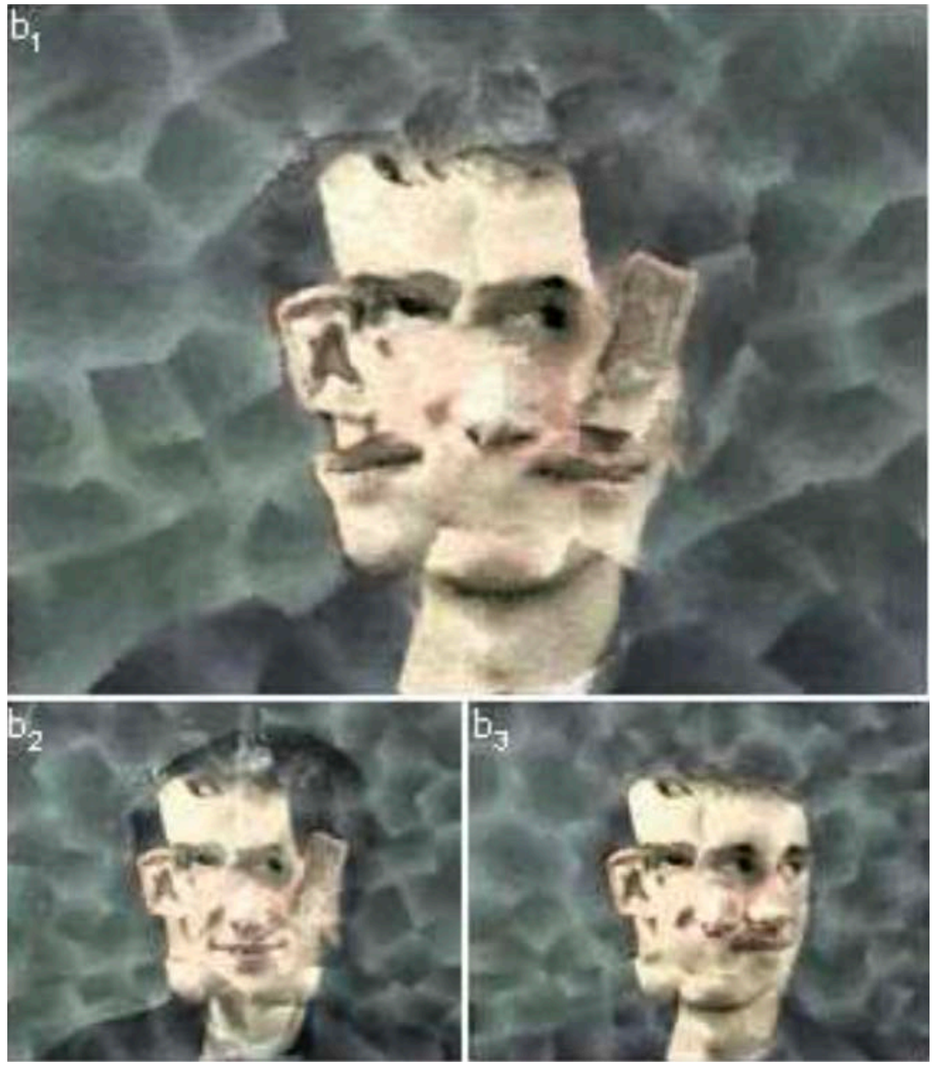
Artistic multiperspective projection

Giorgio de Chirico (1914)



Agrawala, Zorin, Munzner (2000)

Cubism



Collomosse and Hall (2003)

Hockney-style "Joiners"

Zelnik-Manor and Perona (2007)

Spatiotemporal effects

“Somewhere Always” Disconnectica

“Ryan” by Chris Landreth

Preproduction artwork

Film still

Coleman and Singh, NPAR 2004

RACHER
IER
PIT
SINKS

Summary / Questions

There’s no “correct” or “wrong” perspective

How do we perceive/interpret different perspectives?

What are the range of options and space of algorithms?

Depth-based photography opens up new possibilities