Projections in Computer Graphics and Computational Photography

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Perspective as arrangement
History of perspective
Perspective systems

Qiu Ying, 16th century

Andrei Rublev, 1411
One-point perspective described by Leon Alberti, 1435
Drawing 2 point perspective with an elastic band is super easy.
Most cameras approximate linear perspective.
Center of projection (COP)
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.

“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:

\[ \sim \frac{3}{4} W, \text{ where } W = \text{image width} \]

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
Marginal distortions
Marginal distortions
Variations des Aspects et des Images des Corps se déplaçant par rapport au Dessinateur

Fig. 243
Images des contours apparents de la Sphere (Fig. 242 et 243) et d'un Vase ou Solide de révolution (Fig. 244, 245 et 245 bis) se déplaçant par rapport au Dessinateur (Voy. 8 324 et la note).

Olmer, 1943
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* (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
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)
“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
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

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

Input 105° FOV (perspective projection)  

Our method
Using depth or multiple shots
Happy Harvest Moon! 😊

Wow! Look at that moon!

I'm gonna take a picture!
Using multiple shots

“Computational Zoom,” Badki et al., SIGGRAPH 2017
Original  Zoom-in & Crop  ZoomShop

Top-down view of camera volume

ZoomShop (Liu 2022)
Artistic projections in CG/CP
Spherical projections
Artistic multiperspective projection

Giorgio de Chirico (1914)  
Agrawala, Zorin, Munzner (2000)
Cubism

Collomosse and Hall (2003)
Hockney-style “Joiners”
Spatiotemporal effects

“Somewhere Always” Disconnectica
“Ryan” by Chris Landreth

Preproduction artwork

Film still

Coleman and Singh, NPAR 2004
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