Perceptual and Artistic Principles for Effective Computer Depiction

Perception and Representation of Shape and Depth

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In Making Effective Images

- We can derive inspiration from art
- And insight from fundamental findings in human visual perception

Objectives

To determine how to most effectively represent shape and depth in computer-generated images, we need to understand:
- the various potential sources of shape and depth information
- the effectiveness with which our visual system can use this information

Cues to Shape and Depth

- Perspective
- Occlusion
- Shading
- Color
- Texture

Linear Perspective

- Parallel lines appear to converge as they recede into the distance
- Farther objects appear smaller than closer ones

Linear Perspective

- The effect is most pronounced when the parallel lines originate close to the viewpoint and extend for a considerable distance in depth
- It can be difficult to appreciate depth from the perspective distortion, or foreshortening, of objects that:
  - are located far away from the viewpoint
  - extend only a small distance in depth
  - have smoothly curving, irregular, or unfamiliar shapes
  - lack features that can indicate parallel lines

After zooming in on picture

After zooming in on actual scene

The parameters of the perspective projection, and the location of the viewpoint, can strongly affect one’s impression of size and distance.


Consequences of Perspective

– Zooming in on a picture of a scene is not the same thing as zooming in on the scene itself

Pictorial Depth Cues: relative height

- The relative height of the base of an object in the image plane:
  - is a cue to the relative depths of objects resting on a common horizontal groundplane and viewed from above
  - is not a reliable indicator of relative depth under other circumstances

Pictorial Depth Cues: relative size

- relative familiar size
  - an object subtends a smaller visual angle on the retina as its distance from the viewpoint increases
  - we have learned to interpret information about the relative distances of familiar or self-similar objects from the differences in their relative apparent sizes

Is the man on the left a giant in the distance, or is he simply standing on a hill in the foreground? How much larger is he in the picture than the man on the right?
Occlusion

- integrated into perception at an early stage of visual processing
- the occlusion boundaries are the key elements in conveying the depth order relationships

Occlusion and Object Completion

Transparency in a Purely Opaque Medium

Veiled Nun
Giuseppe Ceruti (1803-1878)
Corcoran, Washington D.C.

Winged Victory of Samothrace
sculpture of Augustus' wife Livia dates from the 1st century (Rome)

excerpt from "Philosophy in the Boudoir", 1947
Rene Magritte. (Private collection, Washington D.C.)
Viewpoint and shape/depth perception

- Observers have preferred views for remembering the sizes/shapes of objects. There is considerable inter-observer agreement on which views are preferred [Perrett and Harries 1988]
- The visual system appears to presume a "generic" viewpoint, favoring interpretations of form that will be stable under slight shifts of orientation [Nakayama and Shimojo 1992]
- People seem to be biased toward perceiving objects as being more closely aligned to the frontoparallel plane [Shapera and Feldman 1986 (and many others)]

Shape from Shading

- Our perception of shape and depth can be greatly affected by how a scene is lit
Shape from Shading

- Our perception of shape from shading appears to be global, or consistent over the extent of a single object


– presumption of light from above (overhead)
– preference for “ground” as opposed to “ceiling” surfaces
– preference for convex rather than concave forms (mask illusion)

Depth Inversion: possible explanations

More on Depth Inversion

- Depth inversion can also occur when shape is defined by texture

Shape as an Organization of Space

- Observers cannot reliably estimate local surface shape or absolute surface curvature solely on the basis of shading information
- Observers can make reliable judgements about the relative slants and curvatures of adjacent surface patches

Relief and its mold. Luckiesh (1916) Light and Shade

Sculpture by Boccioni [1913] Photo credit: Frayling et al. [1992]
Conveying Shape with Shading

- Artists have long stressed the importance of lighting.
- Veridical shape perception may be easier in some light fields than in others.
  - Faces are easier to recognize when lit from above, and look eerie when lit from below.
  - Objects tend to appear flattest when the light field is isotropic (parallel light rays emanating from the viewpoint).

Different lightings of the Laocoon head, from Luckiesh (1916) *Light and Shade*

Image from the Parthenon Frieze (thin relief replica), photographed under indirect illumination

Image from the Parthenon Frieze (thin relief replica), single light source at camera

Image from the Parthenon Frieze (thin relief replica), oblique illumination

Pictorial Depth Cues: cast shadows

- Cast shadows can profoundly affect our perception of depth in an image and height over the groundplane.

Shape from Specular Highlights

- viewed in stereo, a specular highlight will appear to float
  - in front of a convex surface
  - behind a concave one
- observers can use this information to disambiguate convex from concave surfaces

Shape from Specular Highlights

- Apparent location is viewpoint dependent
  - tend to cling to highly curved areas
  - direction of highlight motion can be used to disambiguate surface curvature:
    - on convex surfaces, specular highlights move in the direction of the observer’s motion
    - on concave surfaces, they move in the opposing direction
- Shape perception is facilitated by specular highlights
  [Todd and Mingolla 1983]
Pictorial Depth Cues: atmospheric attenuation

• **aerial perspective**: the visibility of distant objects can be compromised by an accumulation of pollutants or moisture in the air.
  - With increasing depth, objects tend to lose contrast, both internally and with respect to the background.
  - Stimuli that have lower luminance contrast with the background are perceived to be more distant.

Pictorial Depth Cues: depth of field

• In our everyday experience, we are rarely conscious of things appearing to be out-of-focus.
  - However, this phenomenon is not uncommon in photos (where blur increases with distance in depth from the focal point of the lens).
  - Although depth-of-field effects may indicate the existence of a separation in depth, they convey no information about either the sign or magnitude of the depth distance.

Color and Shape

• **Equiluminance reduces perceived depth:**
  - Livingstone and Hubel [1987] report that the following are more difficult to perceive when objects are defined by equiluminant color differences rather than by luminance differences in an image:
    - depth from stereo
    - shape from shading
    - shape from texture
    - depth from motion
    - depth from occlusion
    - depth from linear perspective

Chromostereopsis

• Light slightly diffracts as it passes through the cornea.
• The eye normally accommodates to bring the yellow wavelengths (596nm) into sharpest focus.
• The longer red wavelengths converge behind the retina.
• The shorter green and blue wavelengths converge in front of the retina.
Longer wavelength colors appear to come forward; shorter wavelength colors appear to recede.

Artists Define Color “Temperature”

- “fire and sun” colors, such as red, yellow, and orange are considered warm
- “ice and water” colors, such as blue and white, are considered cool
  (adding white both lightens and cools)


Indicating shape/depth via color temperature ...

G. B. Tiepolo
Shape and Depth from Texture

Texture gradients can be a powerful cue to both shape and depth.

But how, exactly, do we perceive shape and depth from texture, and what kinds of textures show this information best?


Vasarely

Octotropic plaid

with diagonal components only

without diagonal components


Gaps evoke the impression given by inter-ocularly unpaired regions.


Clarifying Depth Discontinuities with Visibility-Impeding Halos.


Essential Lines: inspiration from art

- Silhouettes: separate figure from ground
- Contour lines: demarcate discontinuities in depth (horns)
- Ridge and valley lines: express the underlying form (brow)
- Part boundaries: defined by color/texture/function (eyes)
- Other lines: can be difficult to capture algorithmically (nose)

Pablo Picasso. Study of a Bull’s Head, 5 Nov. 1952.

How to Clarify the Essential Features of an External Transparent Surface?


Using Ridge and Valley Lines to Emphasize Intrinsic Shape Features

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“Enhancing Transparent Skin Surfaces with Ridge and Valley Lines”, IEEE Visualization '95.

Using Locally Important Edges to Capture the Structure of Faceted Objects

Kwan-Liu Ma and Victoria Interrante (1997)

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How to Convey the 3D Shape of Arbitrary Smoothly Curving Surfaces?

Lumbosacral and Sacro-iliac fusion.

Russell Drake, medical illustrator, Mayo Foundation, 1932.

• Russell Drake’s “single line system of shading”
  – the flow of the shape is conveyed through the directions of the carefully drawn strokes
  – multiple overlapping surfaces are displayed with clarity

Inspiration from Illustration

Paul Richer, Artist; Anatomy
Translated and edited by Bertha

• But not all artists use line in this way
Strokes that "follow the form" emphasize shape

Vertical strokes emphasize height

Horizontal strokes emphasize width
Line Direction Matters

Line Direction Matters

Does texture orientation matter?
Conveying the 3D Shape of Arbitrary Smoothly Curving Iso-Surfaces


Experiment 1

- How does texture orientation affect shape perception?
- Do observers perceive shape more accurately when the texture orientation follows the first principal direction?

Compared Four Direction Types

- Principal direction (pdir)
- Uniform direction (udir) = (-ny, nx, 0) – zero geodesic curvature
- Random direction (rdir) : rotate udir about \( \hat{n} \) by a random angle \( \theta \in [-\pi/2, \pi/2] \) – effectively isotropic
- Sinusoidally varying direction (sdir): rotate udir in the tangent plane by a coherently varying angle \( \theta = 10\pi(x+y+z)/n \)
Experiment Details

• 4 different texture patterns: pdir, sdir, udir, rdir
• 6 different surface stimuli
• 49 probes per image, same points for each texture
  – users were asked to reconstruct the surface
• 2 different viewing conditions: flat, stereo
• 5 subjects (naïve to purpose of experiment)
  – Split into two groups; each saw half of the data
  – Four sessions, 6 surfaces each, randomized presentation order; 2 sessions of flat images followed by 2 sessions with stereo images
Mean alignment error (3D angle), flat viewing condition

Experiment’s Conclusions

- Texture pattern orientation has a statistically significant effect on surface shape perception
- Shape perception is poorer in the presence of anisotropic textures that have nonzero geodesic curvature
- Shape perception seems equivalently good from the anisotropic texture that is aligned with the first principal direction as it is from the isotropic texture

Experiment 2

- Why are non-principal direction oriented textures less effective? Is it because they are more likely to mask (hide) shape information?

‘Fitted’ Textures

- Synthesize natural texture patterns over arbitrary surfaces
  - without seams or projective distortion, and
  - with the orientation of the texture pattern following the principal directions on a per-pixel basis.

Texture Synthesis

- Two-pass version of Efros and Leung's Markov Random Field texture synthesis method
  - Exhaustive small neighbourhood matching
  - Saves the best matches for further processing
  - Selective processing at the most promising locations using the entire neighbourhood

Synthesize Texture at Patches

Orient the Texture

- Change the target of the search on a per-pixel basis to follow the specified direction
- Textures are pre-rotated to improve performance
Experiment Details

- Four alternative forced choice task: in which quadrant is the surface shape different?
- 3 different texture orientations: pdir, sdir, udir
- 2 different texture patterns: weave, straw
- 4 different quadrants/types of shape changes
- 7 different levels of shape change per quadrant
- 2 different viewing conditions: flat, tilted
- 3 subjects
- 2 repeated measures
Preventing Picture Matching

- Each surface was textured using a different random sample from the original texture file
- This resulted in patterns that looked similar, but were not identical at the pixel level
Experiment 3

- What other texture characteristics affect shape perception?
- Is a pattern that follows both principal directions more effective than a pattern that follows just one?

Three Sample Patterns

Training Task
Conclusions

• We can affect the portrayal of shape and depth through many devices, including lighting, camera angle, the setting of the scene, and the defining of objects’ material properties.

• With insights from human visual perception and inspiration from art, we are able to make these choices wisely, and to more effectively convey shape and depth in our images.

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