Perceptual and Artistic Principles for Effective Computer Depiction

Perception and Representation of Shape and Depth

Victoria Interrante
Department of Computer Science and Engineering
University of Minnesota

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:

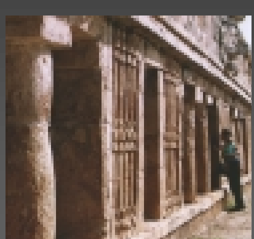
– the various potential sources of shape and depth information
– the effectiveness with which our visual system can use this information

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

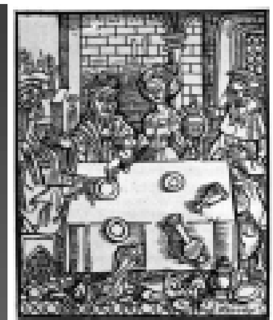


Linear Perspective

– 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

8. Abraham's Hospitality, and scene of 12th-century tapestry. Halberstadt Cathedral Museum

Ernst H. Gombrich, The Image and the Eye, Phaidon, Oxford, 1982.



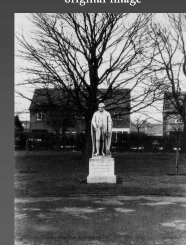
Ernst H. Gombrich, The Image and the Eye

Source: Robert L. Solso, Cognition and the Visual Arts

Consequences of Perspective

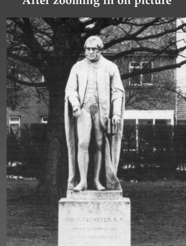
– Zooming in on a **picture** of a scene is not the same thing as zooming in on the scene itself

original image



Nicholas Wade. Visual Allusions, Lawrence Erlbaum Associates, 1990.

After zooming in on picture

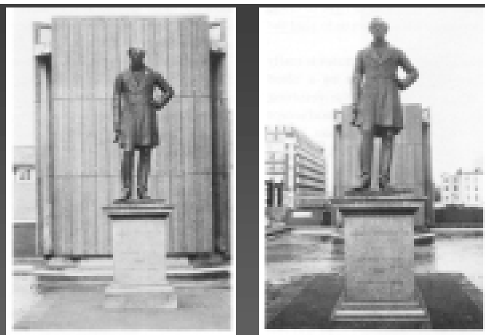


After zooming in on actual scene

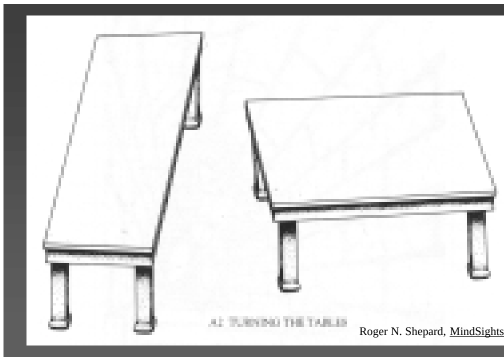
Nicholas Wade. Visual Allusions, Lawrence Erlbaum Associates, 1990.

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

E. H. Gombrich, The Image and the Eye



E. H. Gombrich, The Image and the Eye



Roger N. Shepard, MindSights

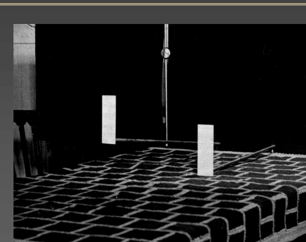
Pictorial Depth Cues: relative height

- 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

James J. Gibson. The Perception of the Visual World, © Houghton Mifflin, 1950.

Pictorial Depth Cues: relative height

- in the absence of indications to the contrary, observers tend to perceive objects as resting on the groundplane in front of which they appear



James J. Gibson. The Perception of the Visual World, © Houghton Mifflin, 1950.

Pictorial Depth Cues: relative size

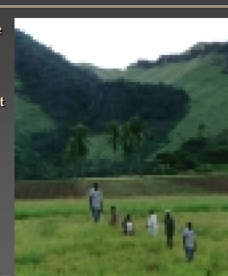
- relative familiar size
  - an object subtends a smaller visual angle on the retina as its distance from the viewpoint increases
  - we have learned to interpret information about the relative distances of familiar or self-similar objects from the differences in their relative apparent sizes

Pictorial Depth Cues: relative size

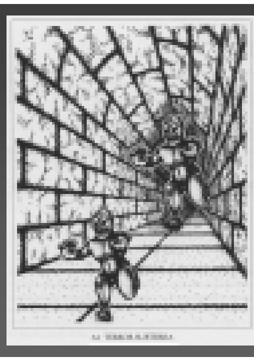
- **Relative size appears to be subordinate to other depth cues**
- **Apparent size can itself be influenced by perceived distance, as in the "moon illusion" (the sky seems farther away at the horizon)**

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?



after Wolfgang Metzger. Gesetze des Sehens, W. Kramer & Co., 1975

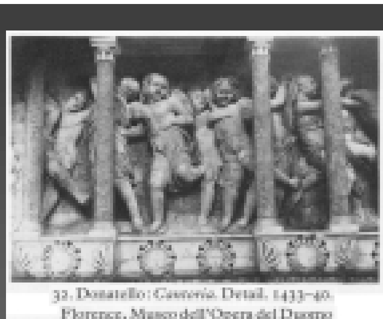


Roger N. Shepard, MindSights

"Credit Union Leaders at the Nolte Center for Continuing Education", 1959.
from: Common Bonds: A Memoir in Photographs of the University of Minnesota, by Andrea Hinding.

"Carte Blanche", or "The Blank Signature"
by Rene Magritte, 1965
National Gallery of Art, Washington D.C.

Jan van Eyck, Annunciation (from Kubovy, The Psychology of Perspective and Renaissance Art)



E. H. Gombrich, The Image and the Eye

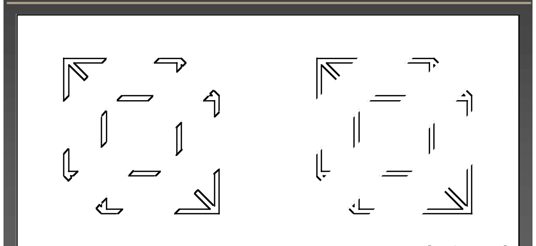
from Art Across Time, vol. 1, Laurie Schneider Adams, McGraw-Hill, 1999.

Occlusion

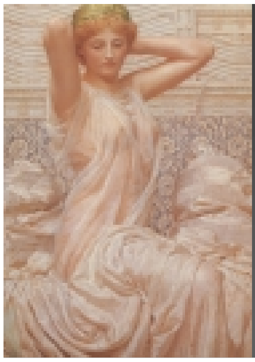
- integrated into perception at an early stage of visual processing
- the occlusion *boundaries* are the key elements in conveying the depth order relationships

after: Ken Nakayama, Shinsuke Shimojo and Gerald H. Silverman. "Stereoscopic Depth: its relation to image segmentation, grouping, and the recognition of occluded objects", *Perception & Psychophysics,* **49**(3): 230-244, 1991.

Occlusion and Object Completion

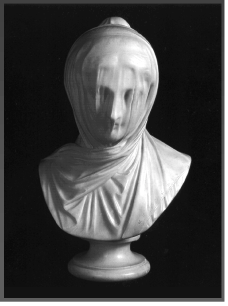


[Kanizsa, 1979]

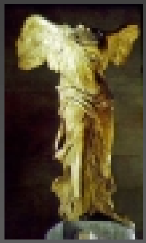


Silver, Albert Joseph Moore (1841-1893)
Fine Art Images, Inc., New York.

Transparency in a Purely Opaque Medium



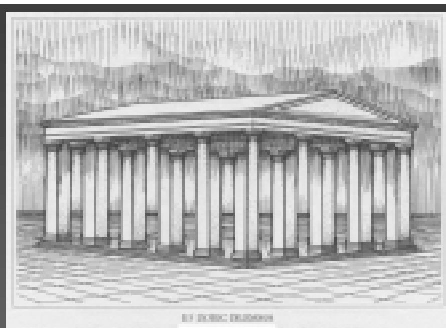
Giuseppe Croff, *Veiled Nun*, 1869.
Corcoran, Washington D.C.



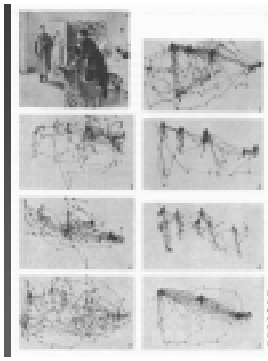
Winged Victory of Samothrace

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.)

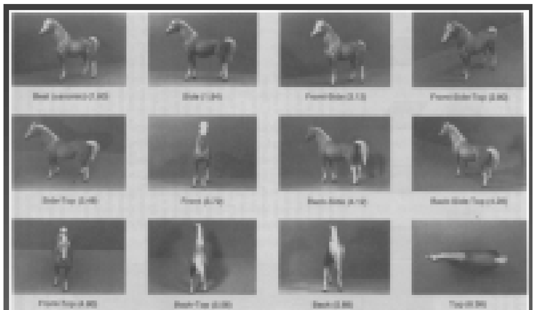


Roger N. Shepard, MindSights



Viewpoint and shape/depth perception

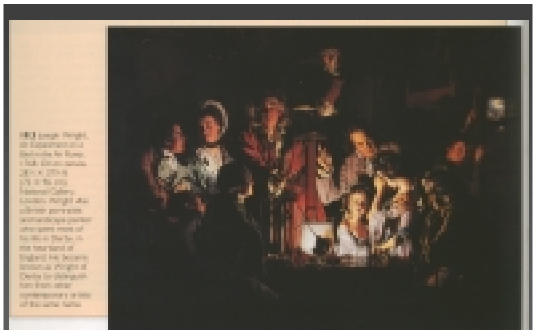
- Observers have **preferred views** for remembering the sizes/shapes of objects. There is considerable inter-observer agreement on which views are preferred [Perrett and Harries 1988]
- The visual system appears to presume a **"generic" viewpoint**, favoring interpretations of form that will be stable 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** [Mingolla and Todd 1986 (and many others)]



9.3 Twelve perspective views of a horse used by Palmer, Rosch, and Chase (1981), with mean "goodness" ratings of the views.

Shape from Shading

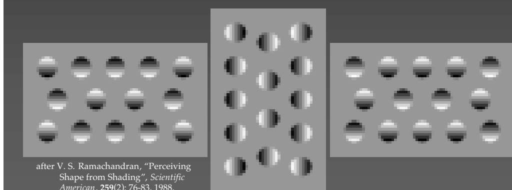
- Our perception of shape and depth can be greatly affected by how a scene is lit



from Art Across Time, vol. 2, Laurie Schneider Adams, McGraw-Hill, 1999.

Shape from Shading

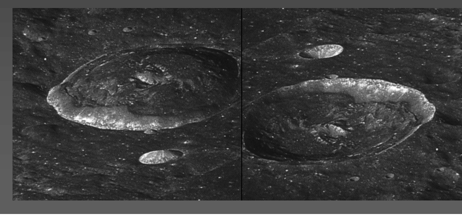
- Our perception of shape from shading appears to be *global*, or consistent over the extent of a single object

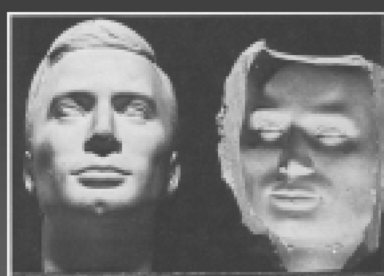


after V. S. Ramachandran, "Perceiving Shape from Shading", *Scientific American*, **259**(2): 76-83, 1988.

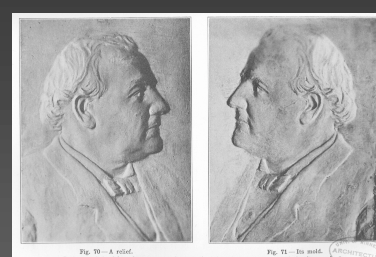
Depth Inversion: possible explanations

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





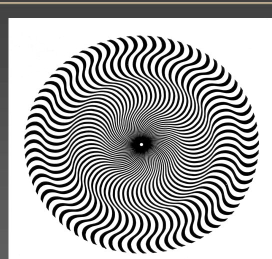
Richard L. Gregory, Illusion in Nature and Art, Duckworth, 1973.



A relief and its mold.
Luckiesh (1916) Light and Shade

More on Depth Inversion

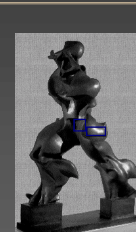
- Depth inversion can also occur when shape is defined by texture



Nicholas Wade. VIsual Allusions.

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

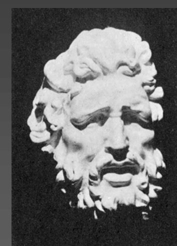


Sculpture by Boccioni [1913]
Photo credit: Frayling *et al.* [1992]

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)

Lit from above



Lit from below

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

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

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

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

Photograph of South Street, New York. Ernest W. Watson.
The Art of Pencil Drawing, Watson-Guptill Publications, 1968.

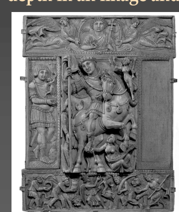
Sketch of the same scene. Ernest W. Watson.
The Art of Pencil Drawing, Watson-Guptill Publications, 1968.

The Dominion of Light, 1954, by Rene Magritte
Musees Royaux des Beaux-Arts de Belgique

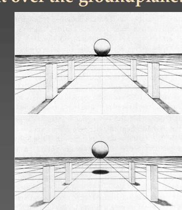
"Le Salon de Dieu", 1958, Rene Magritte.
L. Arnold Weissberger collection, New York.

Pictorial Depth Cues: cast shadows

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



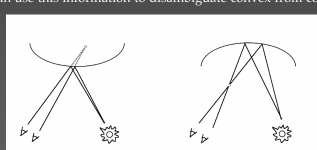
Louvre: guide to the collections



Yonas, Goldsmith and Hallstrom. "Development of Sensitivity to Information Provided by Cast Shadows in Pictures", *Perception*, 7(3): 333-341, 1978.

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



after: Andrew Blake and Heinrich Bulthoff, "Shape from Specularities: computation and psychophysics"
Philosophical Transactions of the Royal Society of London, B, **331**: 237-252, 1991.

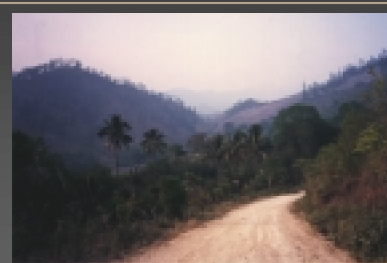
Shape from Specular Highlights

- **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]

Ernst H. Gombrich, The Image and the Eye

Pictorial Depth Cues: atmospheric attenuation

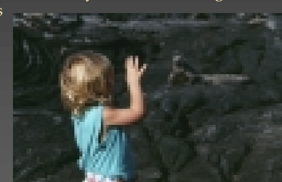


Pictorial Depth Cues: atmospheric attenuation

- ***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

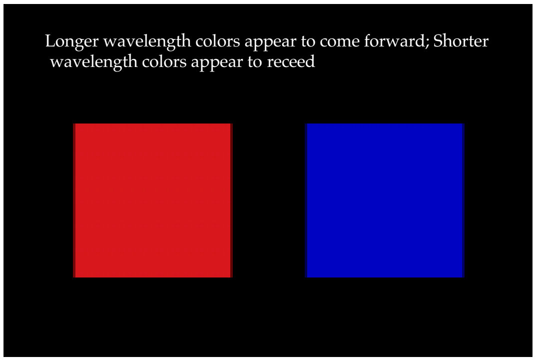


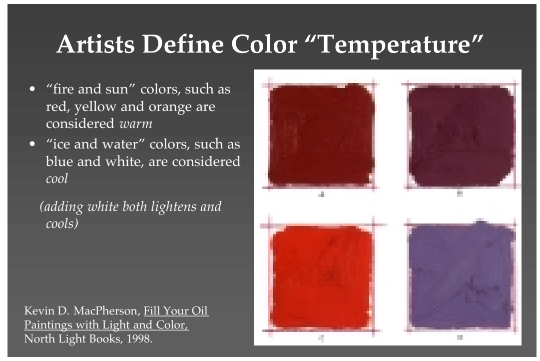
Color and Shape

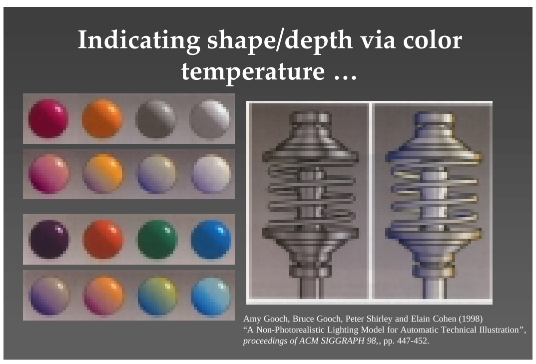
- Equiluminance reduces perceived depth:
  - Livingstone and Hubel [1987] report that the following are more difficult to perceive when objects are defined by equiluminant color differences rather than by luminance differences in an image:
    - depth from stereo
    - shape from shading
    - shape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

Chromostereopsis

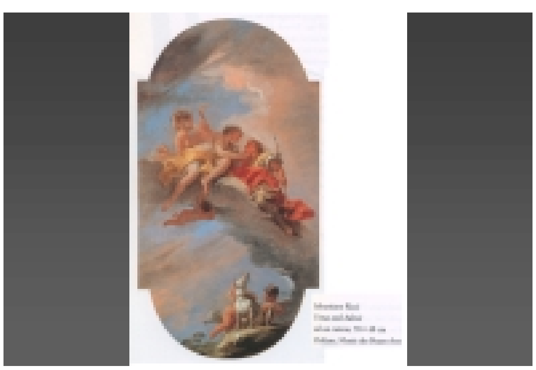
- Light slightly diffracts as it passes through the cornea
- The eye normally accommodates to bring the yellow wavelengths (598nm) into sharpest focus
- The longer red wavelengths converge behind the retina
- The shorter green and blue wavelengths converge in front of the retina


Longer wavelength colors appear to come forward; Shorter wavelength colors appear to receed


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)
Kevin D. MacPherson, Fill Your Oil Paintings with Light and Color, North Light Books, 1998.


Indicating shape/depth via color temperature …
Amy Gooch, Bruce Gooch, Peter Shirley and Elain Cohen (1998)
"A Non-Photorealistic Lighting Model for Automatic Technical Illustration",
proceedings of ACM SIGGRAPH 98,, pp. 447-452.

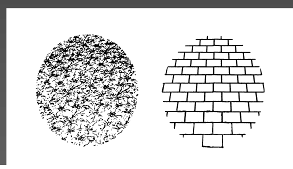
G. B. Tiepolo



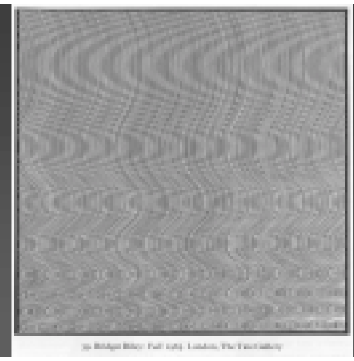
Shape and Depth from Texture

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

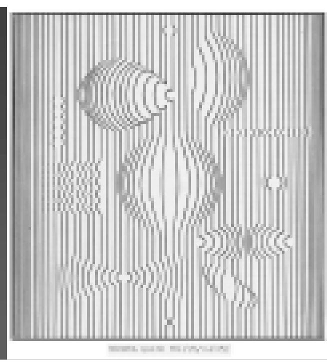
But how, exactly, do we perceive shape and depth from texture, and what kinds of textures show this information best?



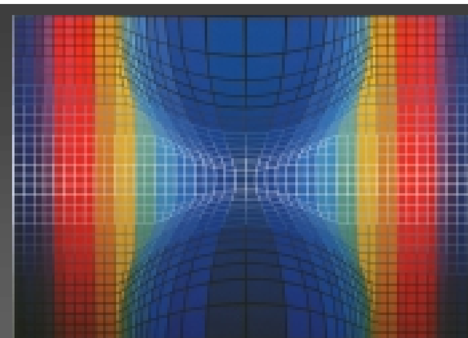
James J. Gibson. The Perception of the Visual World, © Houghton-Mifflin, 1950.



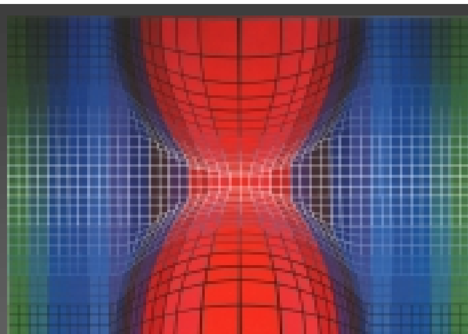
E. H. Gombrich, The Image and the Eye



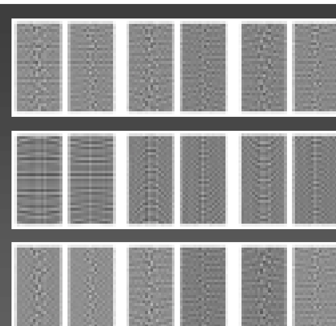
Vasarely



Vasarely



Vasarely

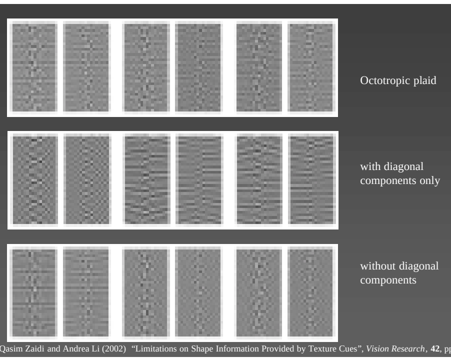


Octotropic plaid

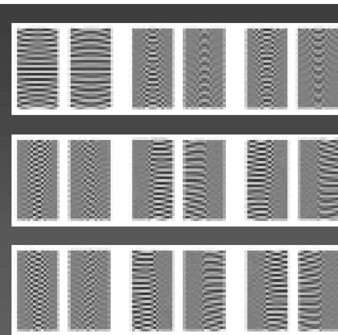
with horizontal and vertical components only

without horizontal component

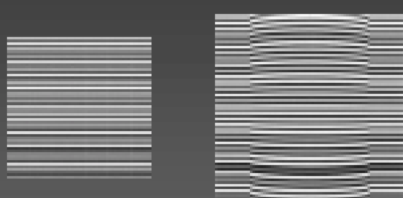
Qasim Zaidi and Andrea Li (2002) "Limitations on Shape Information Provided by Texture Cues", *Vision Research*, **42**, pp. 815-835.



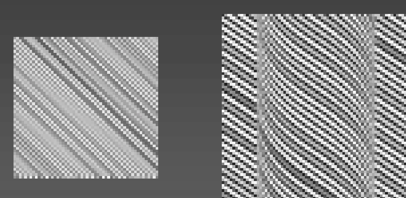
Qasim Zaidi and Andrea Li (2002) "Limitations on Shape Information Provided by Texture Cues", *Vision Research*, **42**, pp. 815-835.



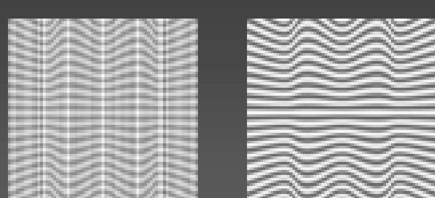
Qasim Zaidi and Andrea Li (2002) "Limitations on Shape Information Provided by Texture Cues", *Vision Research*, **42**, pp. 815-835.



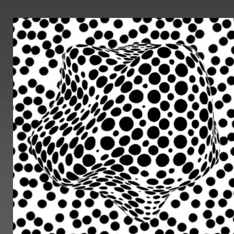
James T. Todd and Augustinus H. J. Oomes (2002) "Generic and Non-Generic Conditions for the Perception of Surface Shape from Texture, *Vision Research*, **42**, pp. 837-850.



James T. Todd and Augustinus H. J. Oomes (2002) "Generic and Non-Generic Conditions for the Perception of Surface Shape from Texture, *Vision Research*, **42**, pp. 837-850.

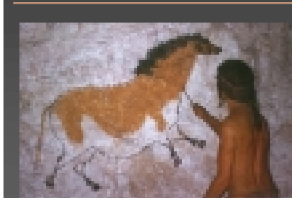


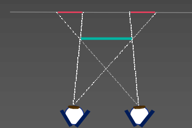
James T. Todd and Augustinus H. J. Oomes (2002) "Generic and Non-Generic Conditions for the Perception of Surface Shape from Texture, *Vision Research*, **42**, pp. 837-850.



James T. Todd and Augustinus H. J. Oomes (2002) "Generic and Non-Generic Conditions for the Perception of Surface Shape from Texture, *Vision Research*, **42**, pp. 837-850.

Clarifying Depth Discontinuities: insights from psychology and art

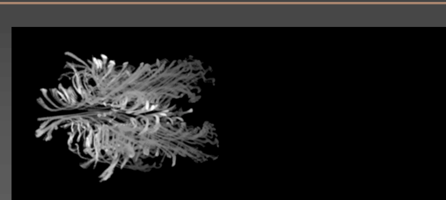




Ken Nakayama and Shinsuke Shimojo (1990)
"Da Vinci Stereopsis: Depth and Subjective Contours from Unpaired Image Points", *Vision Research*.

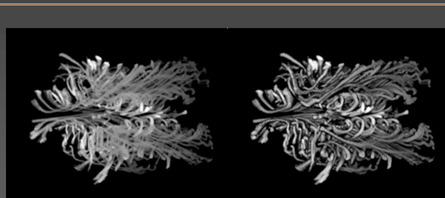
Gaps evoke the impression given by inter-ocularly unpaired regions

Clarifying Depth Discontinuities with Visibility-Impeding Halos



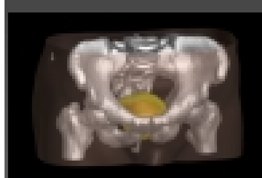
Victoria Interrante and Chester Grosch (1998). "Visualizing 3D Flow",
IEEE Computer Graphics and Applications, **18**(4): 49-53.

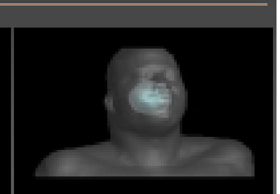
Clarifying Depth Discontinuities with Visibility-Impeding Halos



Victoria Interrante and Chester Grosch (1998). "Visualizing 3D Flow",
IEEE Computer Graphics and Applications, **18**(4): 49-53.

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

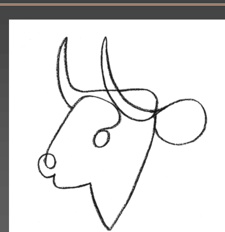




Victoria Interrante, Henry Fuchs and Stephen Pizer (1995)
"Enhancing Transparent Skin Surfaces with Ridge and Valley Lines", *IEEE Visualization'95*.

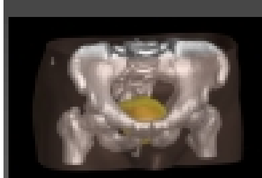
Essential Lines: inspiration from art

- 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)



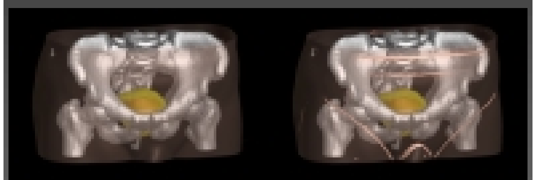
Pablo Picasso. *Study of a Bull's Head*, 5 Nov. 1952.

Using Ridge and Valley Lines to Emphasize Intrinsic Shape Features



Victoria Interrante, Henry Fuchs and Stephen Pizer (1995)
"Enhancing Transparent Skin Surfaces with Ridge and Valley Lines", *IEEE Visualization'95*.

Using Ridge and Valley Lines to Emphasize Intrinsic Shape Features

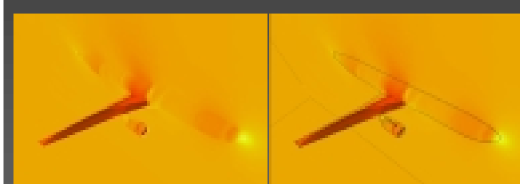


Victoria Interrante, Henry Fuchs and Stephen Pizer (1995)
"Enhancing Transparent Skin Surfaces with Ridge and Valley Lines", *IEEE Visualization'95*.

Using Locally Important Edges to Capture the Structure of Faceted Objects

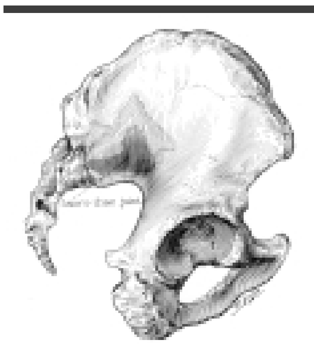
Kwan-Liu Ma and Victoria Interrante (1997)
"Extracting Feature Lines from 3D Unstructured Grids", *IEEE Visualization'97*.

Using Locally Important Edges to Capture the Structure of Faceted Objects



Kwan-Liu Ma and Victoria Interrante (1997)
"Extracting Feature Lines from 3D Unstructured Grids", *IEEE Visualization'97*.

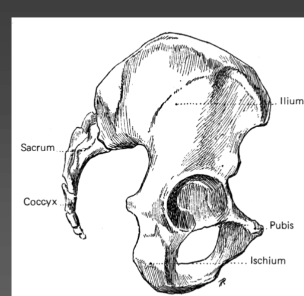
How to Convey the 3D Shape of Arbitrary Smoothly Curving Surfaces?



Inspiration from Illustration

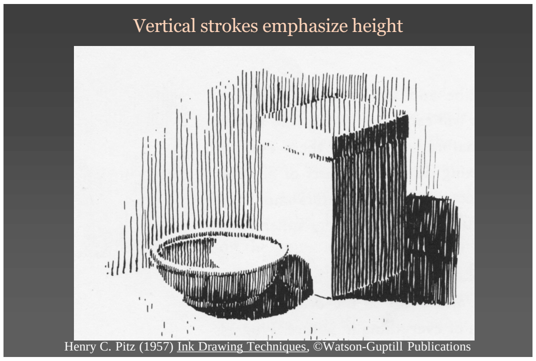
- Russell Drake's "single line system of shading"
  - the flow of the shape is conveyed through the directions of the carefully drawn strokes
  - multiple overlapping surfaces are displayed with clarity

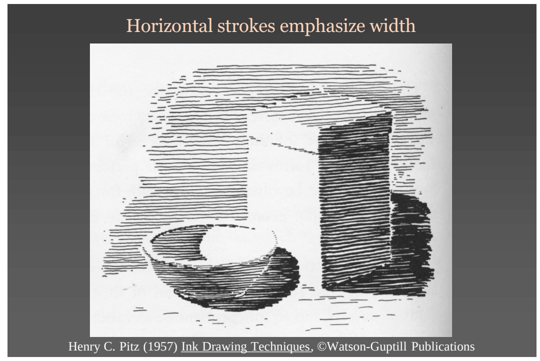
Lumbosacral and Sacro-iliac fusion. Russell Drake, medical illustrator, Mayo Foundation, 1932.

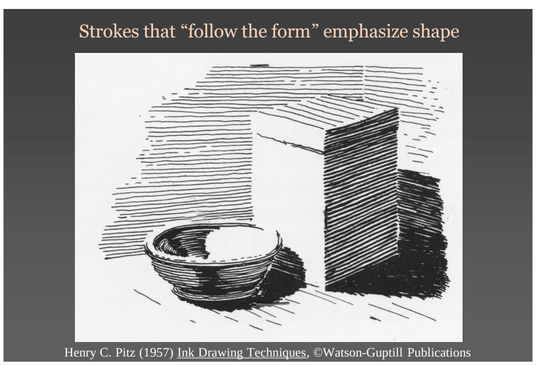


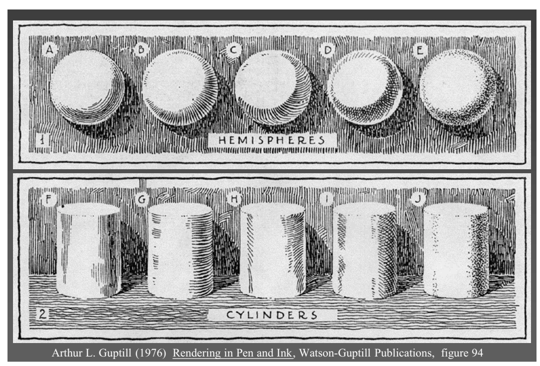
- But not all artists use line in this way

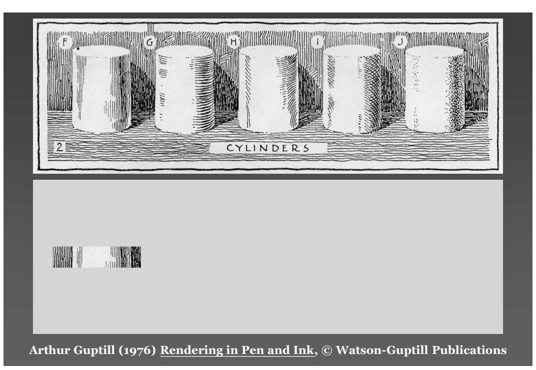
Paul Richer, Artistic Anatomy. Translated and edited by Robert Beverly Hale, Watson-Guptill Publications, 1971.

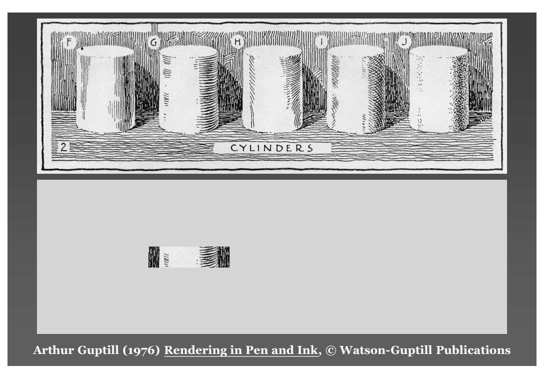

Vertical strokes emphasize height
Henry C. Pitz (1957) Ink Drawing Techniques, ©Watson-Guptill Publications

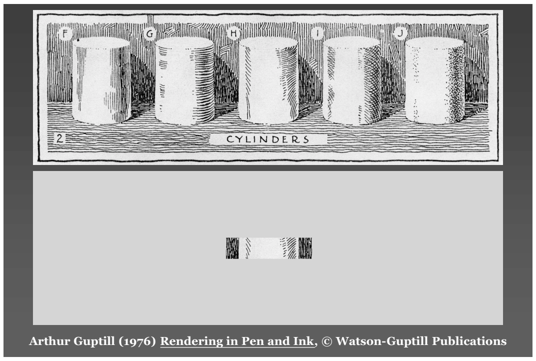

Horizontal strokes emphasize width
Henry C. Pitz (1957) Ink Drawing Techniques, ©Watson-Guptill Publications

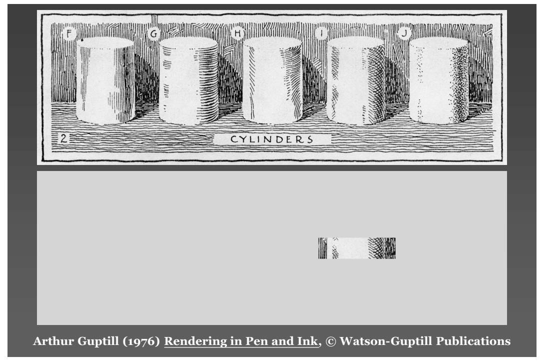

Strokes that “follow the form” emphasize shape
Henry C. Pitz (1957) Ink Drawing Techniques, ©Watson-Guptill Publications

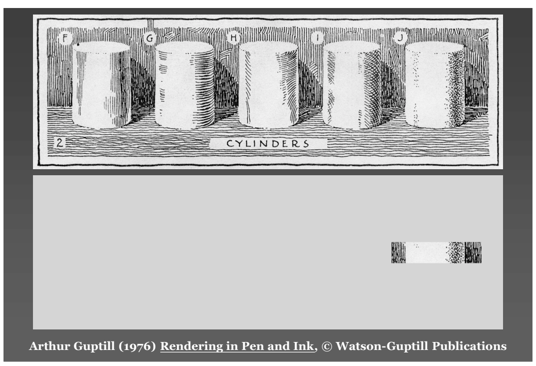

HEMISPHERES
CYLINDERS
Arthur L. Guptill (1976) Rendering in Pen and Ink, Watson-Guptill Publications, figure 94

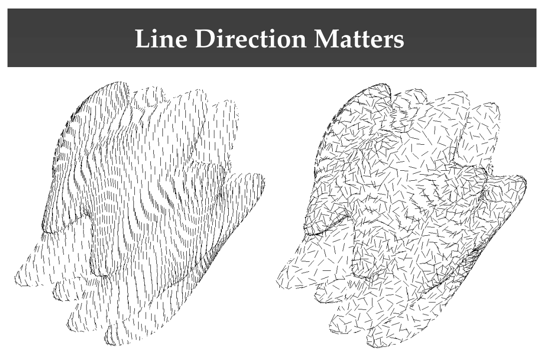

CYLINDERS
Arthur Guptill (1976) Rendering in Pen and Ink, © Watson-Guptill Publications

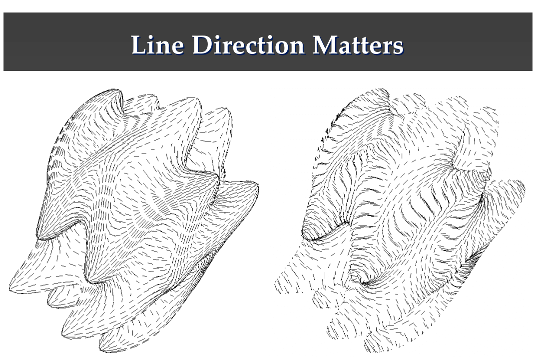

CYLINDERS
Arthur Guptill (1976) Rendering in Pen and Ink, © Watson-Guptill Publications

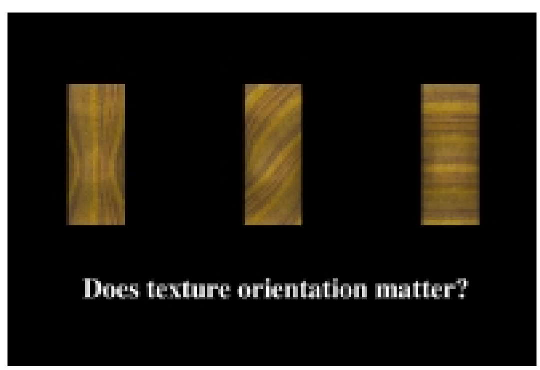

CYLINDERS
Arthur Guptill (1976) Rendering in Pen and Ink, © Watson-Guptill Publications

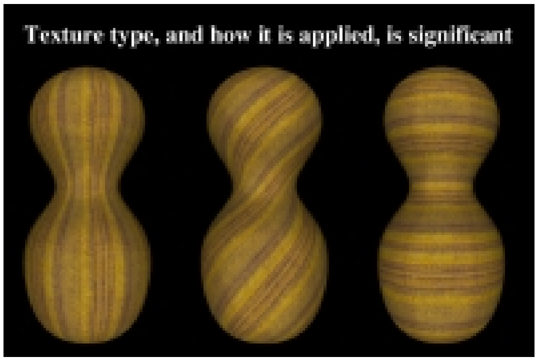

CYLINDERS
Arthur Guptill (1976) Rendering in Pen and Ink, © Watson-Guptill Publications

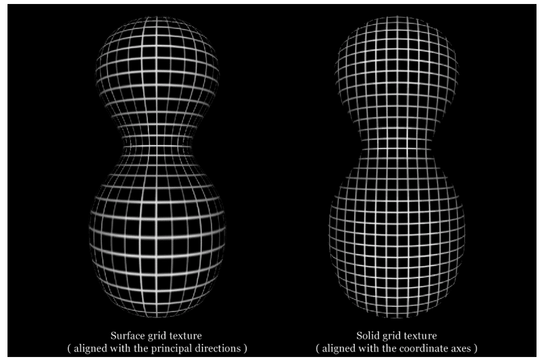

CYLINDERS
Arthur Guptill (1976) Rendering in Pen and Ink, © Watson-Guptill Publications


Line Direction Matters


Line Direction Matters


Does texture orientation matter?

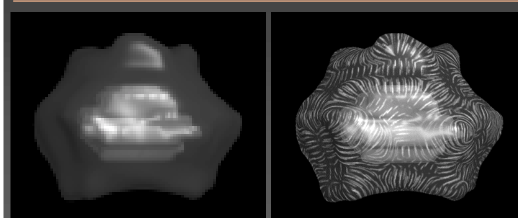




Conveying the 3D Shape of Arbitrary Smoothly Curving Iso-Surfaces

Victoria Interrante (1997) "Illustrating Surface Shape in Volume Data via Principal Direction-Driven 3D Line Integral Convolution", *SIGGRAPH 97*.

Conveying the 3D Shape of Arbitrary Smoothly Curving Iso-Surfaces



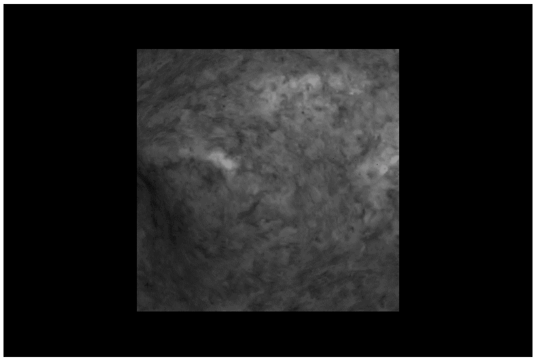
Victoria Interrante (1997) "Illustrating Surface Shape in Volume Data via Principal Direction-Driven 3D Line Integral Convolution", *SIGGRAPH 97*.

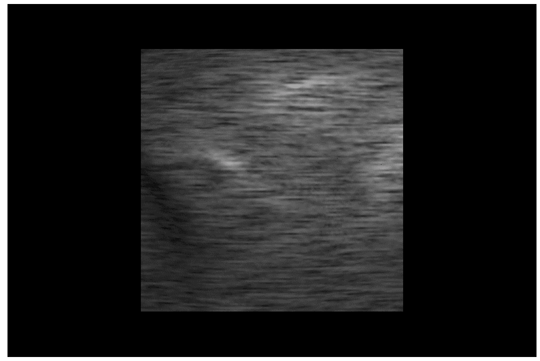
Experiment 1

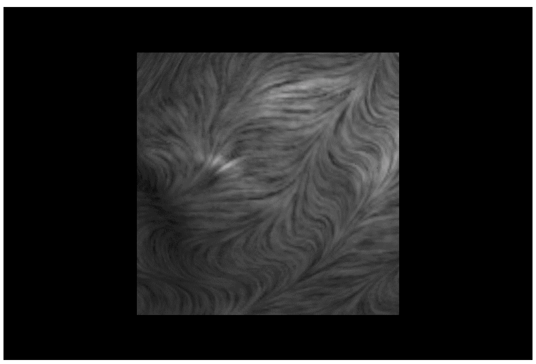
- How does texture orientation affect shape perception?
- Do observers perceive shape more accurately when the texture orientation follows the first principal direction?

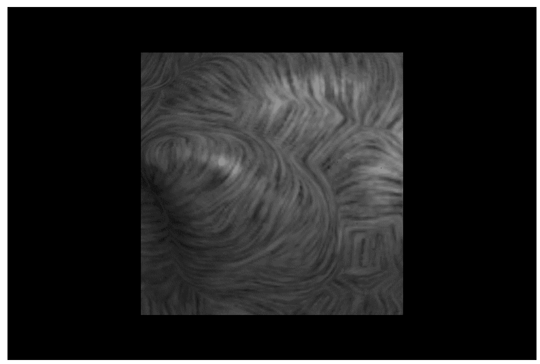
Compared Four Direction Types

- Principal direction (pdir)
- Uniform direction (udir) = (-ny, nx, 0)
  - zero geodesic curvature
- Random direction (rdir) : rotate udir about $\vec{n}$ 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 $\theta = 10\pi(x+y+z/n)$



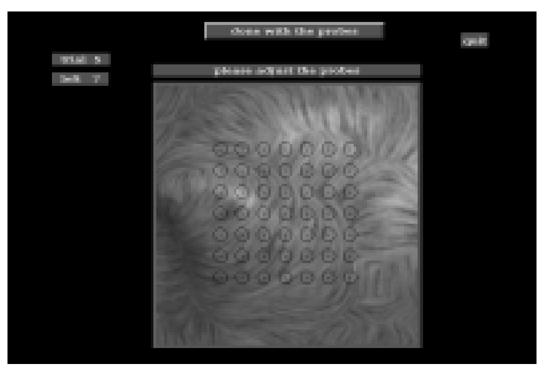




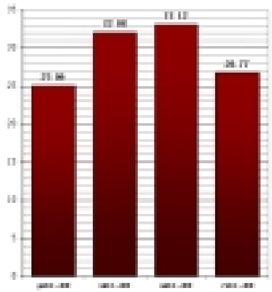


Experiment Details

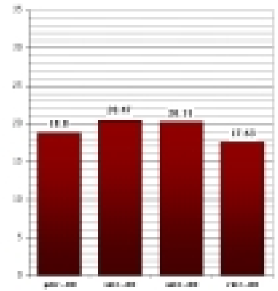
- 4 different texture patterns: pdir, sdir, udir, rdir
- 6 different surface stimuli
- 49 probes per image, same points for each texture
  - users were asked to reconstruct the surface
- 2 different viewing conditions: flat, stereo
- 5 subjects (naïve to purpose of experiment)
  - Split into two groups; 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

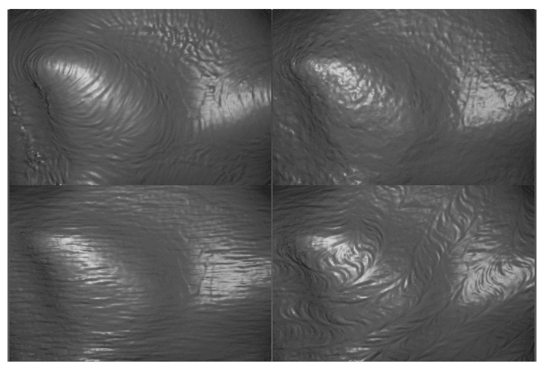


Mean alignment error (3D angle), stereo viewing condition



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



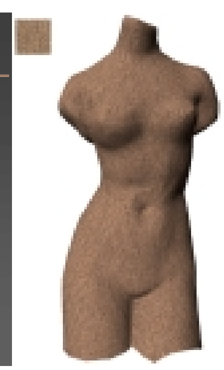
Experiment 2

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

'Fitted' Textures

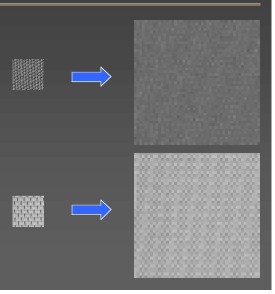
- Synthesize natural texture patterns over arbitrary surfaces
  - without seams or projective distortion, and
  - with the orientation of the texture pattern following the principal directions on a per-pixel basis.

G. Gorla, V. Interrante and G. Sapiro (2002), "Growing Fitted Textures over Surfaces", IEEE TVCG (to appear)

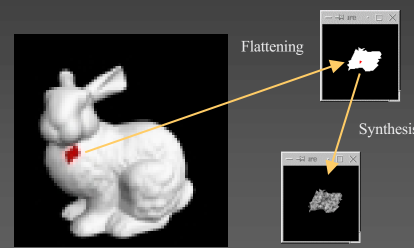


Texture Synthesis

- 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

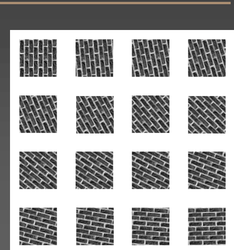


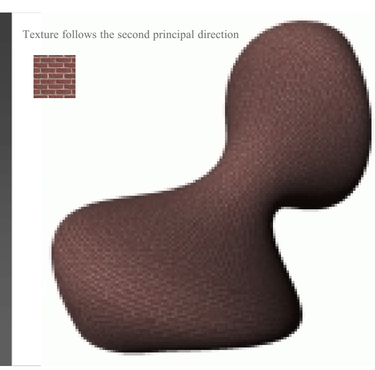
Synthesize Texture at Patches



Orient the Texture

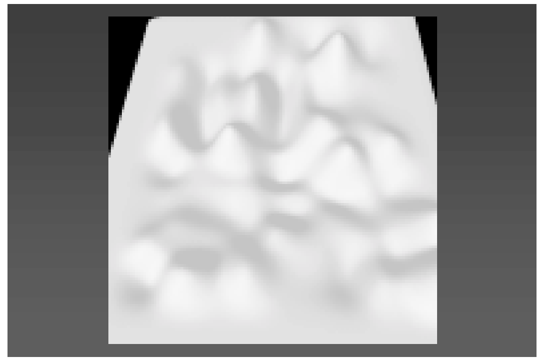
- Change the target of the search *on a per-pixel basis* to follow the specified direction
- Textures are pre-rotated to improve performance

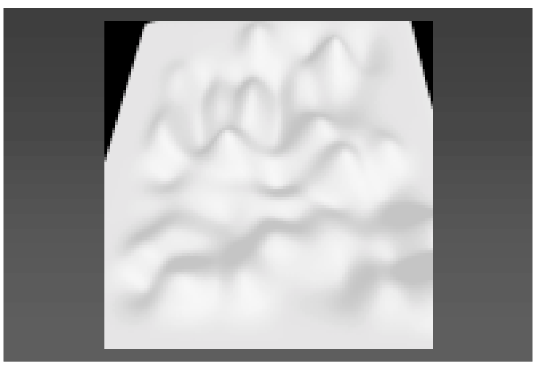


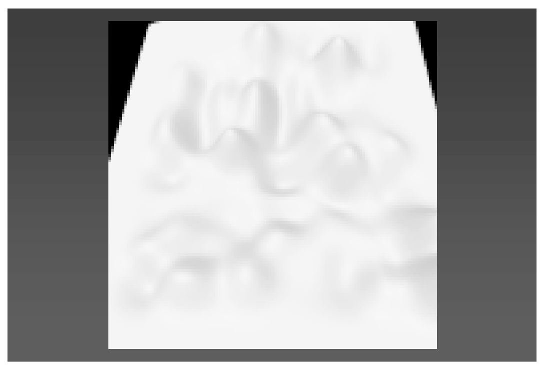


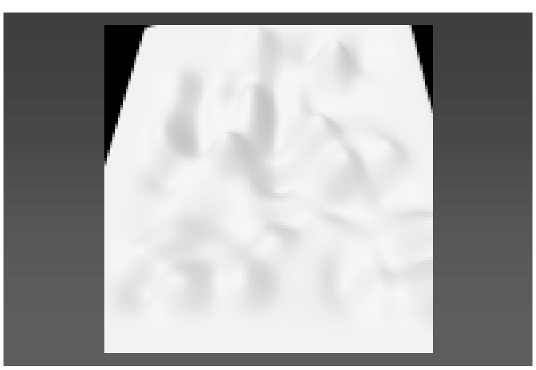
Experiment Details

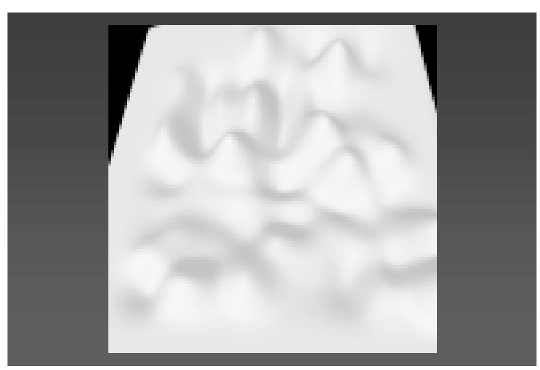
- Four alternative forced choice task: in which quadrant is the surface shape different?
- 3 different texture orientations: pdir, sdir, udir
- 2 different texture patterns: weave, straw
- 4 different quadrants/types of shape changes
- 7 different levels of shape change per quadrant
- 2 different viewing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

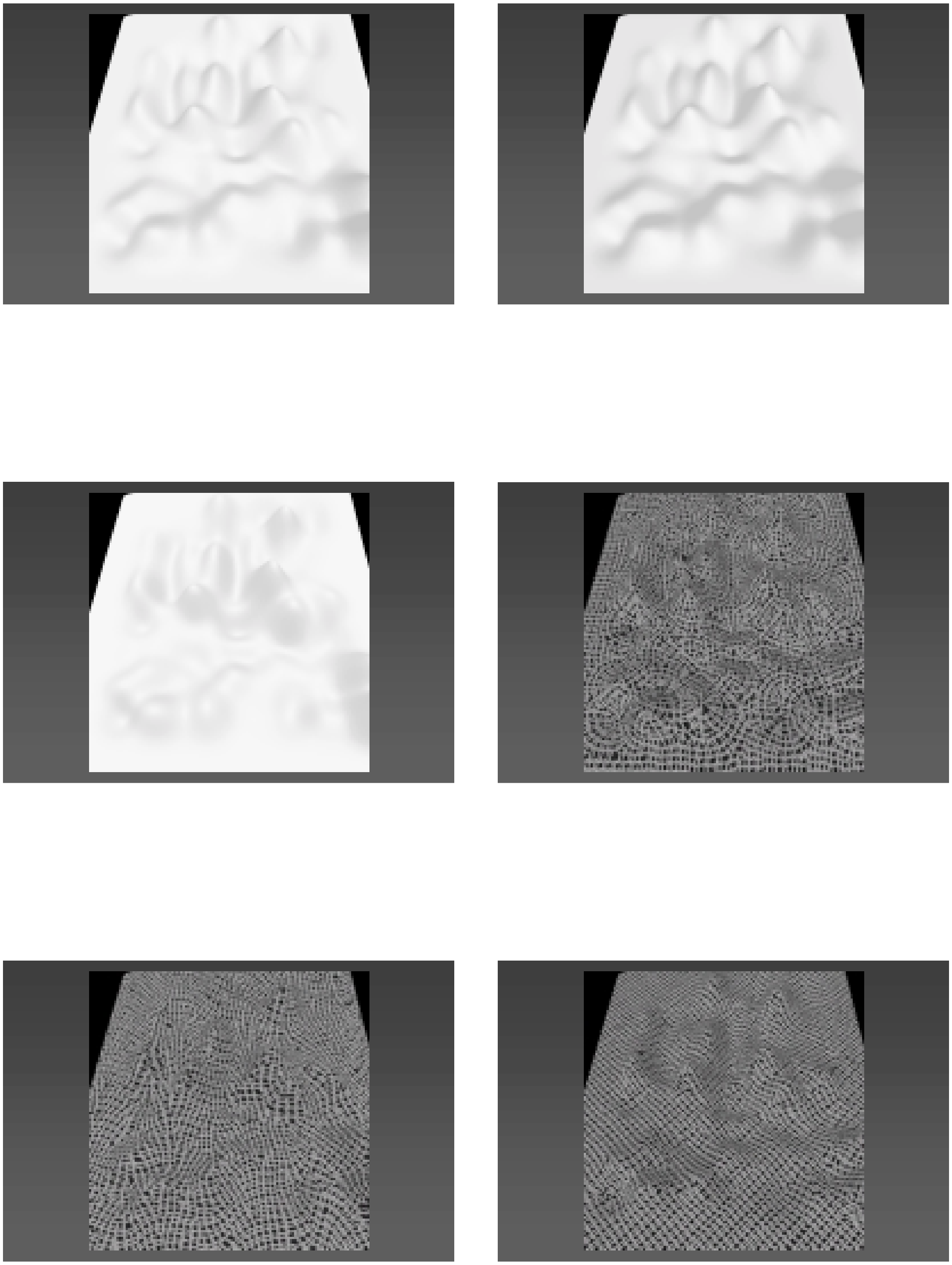






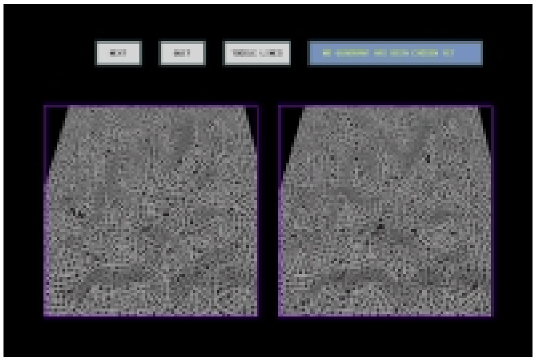


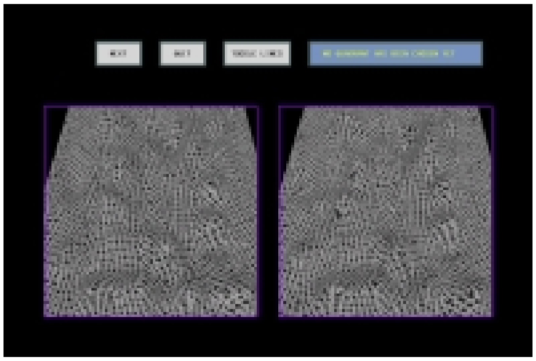


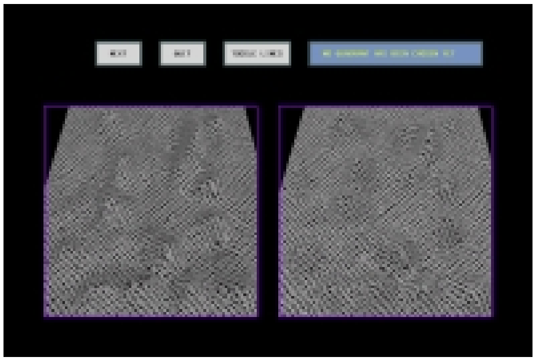


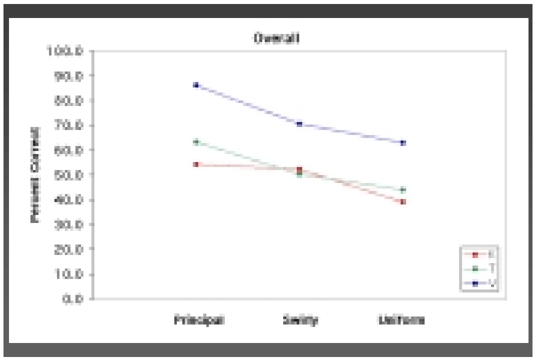
Preventing Picture Matching

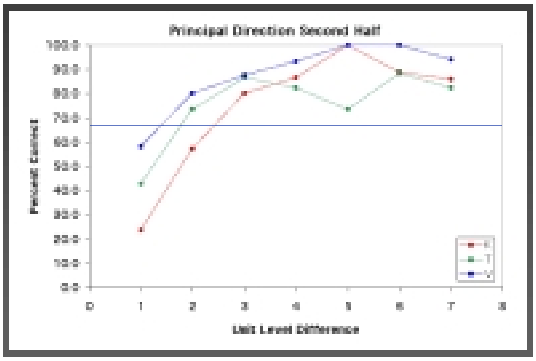
- Each surface was textured using a different random sample from the original texture file
- This resulted in patterns that looked similar, but were not identical at the pixel level

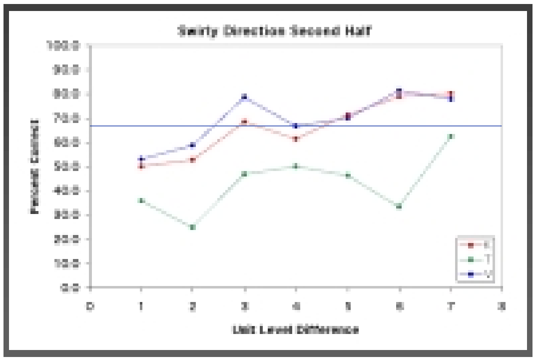


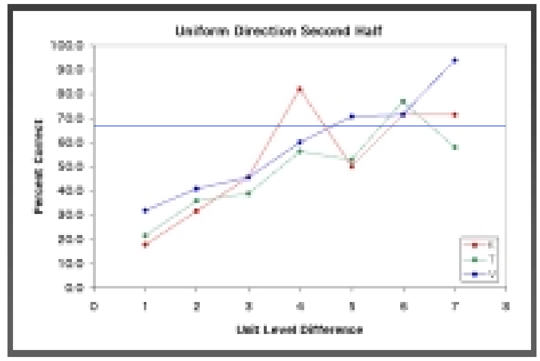










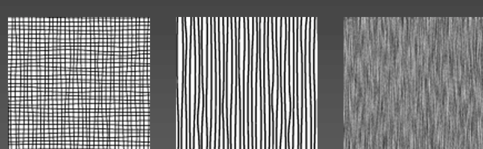


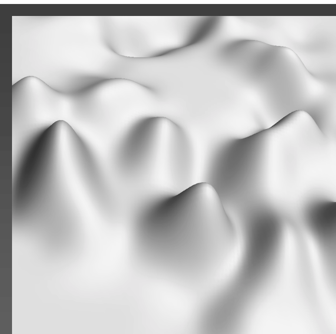
Experiment 3

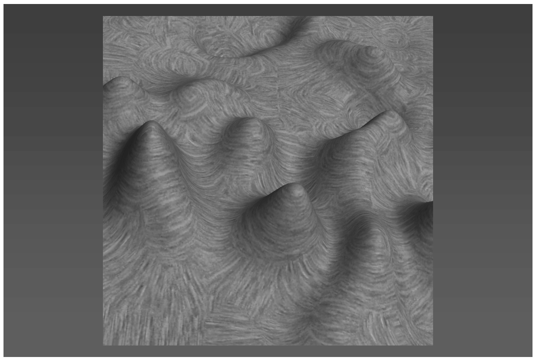
- What other texture characteristics affect shape perception?
- Is a pattern that follows both principal directions more effective than a pattern that follows just one?

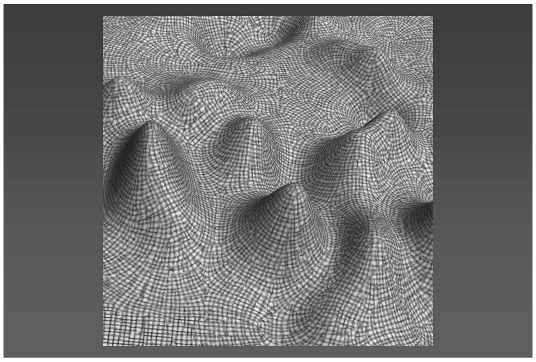
Training Task

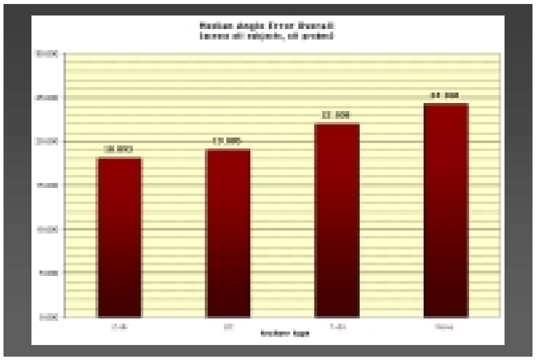
Three Sample Patterns











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

Bibliography

- Giambattista Tiepolo: Venetian Itineraries, by Terisio Pignatti and Filippo Pedrocco, from Canal Guides: Paintings in Original Settings, series edited by Bruno Tassan Din, Canal & Stamperia Editrice srl, Venezia, 1996.
- Cognition and the Visual Arts, by Robert L. Solso, from the MIT Press/Bradford Books Series in Cognitive Psychology, edited by Stephen Palmer, 1994.
- Here I Stand: Perspective from Another Point of View, by Norris Kelly Smith, from Interpretations in Art, a series of Columbia University Press, 1994.
- The Psychology of Perspective and Renaissance Art, by Michael Kubovy, Cambridge University Press, 1986.
- MindSights: Original Visual Illusions, Ambiguities, and other Anomalies, with a Commentary on the Play of Mind in Perception and Art, by Roger N. Shepard, W. H. Freeman and Company, New York, 1990.
- Vasarely, by Gaston Diehl, Crown Publishers, Inc., New York, 1972.
- Great British Paintings from American Collections: Holbein to Hockney, by Malcolm Warner and Robyn Asleson, Yale University Press, 2001.
- Victor Vasarely, by Klaus Albrecht Schröder, Prestel-Verlag, Munich, 1992.
- Magritte, by Sarah Whitfield, the South Bank Centre, London, 1992.
- Magritte, from the series Great Modern Masters, José María Faerna, general editor, Harry N. Abrams, Inc., publishers, 1996.
- Magritte, by Bernard Noël, Crown Publishers, Inc., New York, 1977.
- Illusion in Nature and Art, edited by Richard L. Gregory and Ernst H. Gombrich, with contributions by Colin Blakemore, Jan Deregowski, E. H. Gombrich, R. L. Gregory, H. E. Hinton and Roland Penrose, Gerald Duckworth & Co., Ltd., London, 1973.
- Changing Images of Pictorial Space: A History of Spatial Illusion in Painting, by William V. Dunning, Syracuse University Press, 1991.
- The Image and the Eye: Further Studies in the Psychology of Pictorial Representation, by Ernst H. Gombrich, Phaidon, Oxford, 1982.
- Visual Allusions, by Nicholas Wade, Lawrence Erlbaum Associates, 1990.
- The Perception of the Visual World,by James J. Gibson, Houghton Mifflin, 1950.
- Gesetze des Sehens, by Wolfgang Metzger, W. Kramer & Co., 1975.
- Light and Shade, by Luckiesh, 1916.
- Fill Your Oil Paintings with Light and Color, by Kevin D. MacPherson, North Light Books, 1998.
- The Art of Pencil Drawing, by Ernest W. Watson, Watson-Guptill Publications, 1968.
- Louvre: guide to the collections
- Ink Drawing Techniques, by Henry C. Pitz, Watson-Guptill Publications, 1957.
- Rendering in Pen and Ink, by Arthur L. Guptill, Watson-Guptill Publications, 1976.