Introduction

Illustrative rendering is also often called non-photorealistic rendering (NPR)
- we shall use these terms here interchangeably

NPR offers many opportunities for visualization which conventional photo-realistic rendering does not offer

Compare these renderings of a computer mouse:

- photo-realistic, transparent
- illustrative, transparent

Recall Your Medical Textbooks...

Frank Netter (1906 – 1991)
- often referred to as “Medicine’s Michelangelo”
- illustrative rendering was key to understanding

The Power of Illustrative Rendering

A photorealistic depiction captures the exact appearance of the object as we actually see it
- this can be a limiting paradigm when seeking to convey and communicate information via visuals

A non-photorealistic (illustrative) depiction allows more freedom in this respect:
- allows a greater differentiation in the salience (immediate importance) of the visual representation
- can emphasize critical features
- can minimize the visual salience of secondary details
- allows to hierarchically guide the attentive focus

NPR techniques also:
- allow the expression of multiple style, potentially increasing the ‘dynamic range’ of information that can be communicated
- can establish a ‘mood’ that can influence the subjective context within which the information is perceived and interpreted
NPR Follows Ed Tufte’s Famous Visualization Rules

“Make all visual distinctions as subtle as possible, but still clear and effective.”

“Maximize data-ink; Minimize non-data ink”

“Hide that data which does not make a difference in what you are trying to depict”

“Minimize clutter”

“Separate figure and background”

This Talk...

Frank Netter spent many hours, or even days, on a single illustration

His work required:
• drawing skill
• imagination
• creativity
• many hours in the cadaver lab

Using computers, everyone can be Frank Netter, using:
• various digital interactive tools (facilitated by graphics hardware GPU)
• automated, goal-oriented processing

Illustrative rendering can be a tool for:
• interactive medical text books
• surgery / intervention / treatment planning
• patient education

Agenda:
• some technical detail (only some) on basic techniques
• lots of examples and applications
• mostly in medicine, but also in science and engineering

Basic Techniques: Contours and Outlines

depth-map (edges are due to $C_0$ discontinuities)

normal-map (edges are due to $C_1$ discontinuities)

combined
Basic Techniques: Contours and Outlines

- Depth-map
- Normal-map
- Combined

Mixing outlines with volume rendering

Basic Techniques: Silhouettes

Not an image-space method
- Uses dot product $V \cdot N = 0$ criterion
  - $V$: view vector
  - $N$: surface normal

Finds curves and creases at higher quality
Allows further processing of these (for example hatching)
Must disambiguate occlusions

Suggestive Contours

Curves where the surface bends away from the viewer (as opposed to bending towards them)
Suggestive Contours

Those locations at which the surface is *almost* in contour, from the original viewpoint
- where the radial curvature \((1/\text{curve radius})\) is zero \((w\) is the projection of \(V\) onto the tangent plane)\n- where \(V\cdot N\) is a positive local minimum rather than zero.
- correspond to true contours in relatively nearby viewpoints.

Suggestive Contours

Require the computation of the second derivative at high accuracy
- use high-quality 2\textsuperscript{nd} derivative (curvature-estimation) filters for volume datasets

Curvature Stroke Lines

Semitransparent iso-intensity surface for radiation treatment planning and a tumor inside.
Right: Strokes along the principal curvature are added to convey shape
Hatching

Applies this illustration style as a function of illumination and others

portion of the tonal art map

Stippling

Stippling is yet another illustration technique

- vary the density of points with illumination and/or other attribute

Highlighted Edges

Color interior edges white

- simulates anisotropic reflections at edges

Tone Shading

Standard Computer Graphics

Tonal shading (cool-to-warm shift), along with highlights and edges

B. & A. Gooch
Tone Shading

Different settings for weighted luminance/hue tone rendering. Combines two effects with edges and highlights

B. & A. Gooch

Tone Shading

Specifically for volume visualization

B. & A. Gooch

Metal Shading

Milling creates what is known as “anisotropic reflection.”

Lines are streaked in the direction of the axis of minimum curvature, parallel to the milling axis.

To simulate a milled object, one can map a set of stripes of varying intensity (random) along the parametric axis of maximum curvature.

left: no metal
right: metal rendering

B. & A. Gooch
**Metal Shading**

with edge lines (left) and cool-to-warm tonal shading (right)

---

**Mixing Rendering Techniques**

Assign most appropriate rendering technique for different features:

- skin: silhouette rendering
- eyes: shaded direct volume rendering
- skull: X-ray
- trachea: Maximum Intensity Projection

---

**Mixing Rendering Styles**

First, classify the scene:

- Focus Objects (FO): objects in the center of interest are emphasized in a particular way
- Near Focus Objects (NFO): important objects for the understanding of the functional interrelation or spatial location.
- Context Objects (CO): all other objects (rendered e.g., as silhouettes)
- Container Objects (CAO): one object that contains all other objects

Render these in a certain order to ensure visual consistency

---

**Hidden Structures**

Show with different rendering style

- dotted lines, faint lines

---

B. & A. Gooch

M. Hadwiger

B. Preim

X. Guan
User-Defined Parameters

κ<sub>t</sub> controls *depth of cut*
- Higher values → remove more occluding structures
- Zero → results in conventional direct volume rendering

κ<sub>s</sub> controls *sharpness of cut*
- Higher values → less smooth transition in opacity
- Zero → pure gradient-magnitude opacity modulation

Effect of κ<sub>t</sub>

κ<sub>t</sub>=6.0
κ<sub>s</sub>=0.4

Effect of κ<sub>s</sub>

κ<sub>t</sub>=6.0
κ<sub>s</sub>=0.8

Inconsistent Lighting

I. Viola

C. Lee
Two Levels Of Abstraction

Low-level abstraction:
- concerned with how objects are represented
- stylized depiction: silhouettes, contours, pen+ink, stippling, hatching, etc.
- we have seen this just now

High-level abstraction
- deal with what should be visible and recognizable and at what level of detail
- this should be importance-driven, that is, the current visualization goal controls feature rendering style and visibility
- smart visibility: cutaways, breakaways, ghosting, exploded views
- we will discuss these next

Cut-Aways

Ghosting: Procedure

ghosted view showing both outer and inner structure

I. Viola
Labeling And Other Abstractions

Spatial Exploding
- Volume Splitting
- Dynamic Multi-Volumes

Temporal Exploding

Rendering Mode Composition
The goal is to depict the time-varying behavior of the data in a single frame via illustrative techniques.

Typical illustration metaphors applied in visualization.

Semantic Zooms: Introduction

Ever tried to zoom into a volumetric dataset?
What do you get?

L. Wang

Semantic Zooms: Overview

But there is a solution:
- augment with detail from other sources, such as histology, microscopy, micro-tomography, etc

Use these sample images to synthesize missing detail
- when needed
- into the right places

MRI level  histology level  cell level
Sample Images
Semantic Zooms: Example (Skin Synthesis)

- Sample image
- Distance and gradient fields
- Reference distance and gradient fields
- Synthesized skin histology image

Semantic Zooms: Smooth Transitions

- Magnify low resolution level image
- Synthesize new detail at transition point
- Minify synthesized next high level image
- Weighted Blending

Semantic Zooms: The Infinite Microscope

Visible human liver
- Colorization
- Segmentation

Semantic Zooms in 3D

- Liver
- Histology Sample Volume

L. Wang
Semantic Zooms in 3D

Region of interest

Zooming and Blending

Histology level volume

L. Wang

Generalized Lenses

no lens

L. Wang