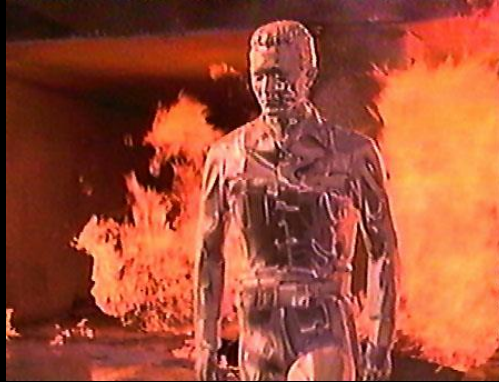


Non-Photorealistic Rendering

Computer Graphics:

What impresses people most is the photorealistic quality of the images





Photorealism

**Simple graphics rendering techniques
produce rather dull, 'dead' images**

**Hence the research into achieving greater and
greater photorealism**

- textures
- bump mapping
- environment mapping
- ray tracing
- radiosity

This research continues...

Photorealism

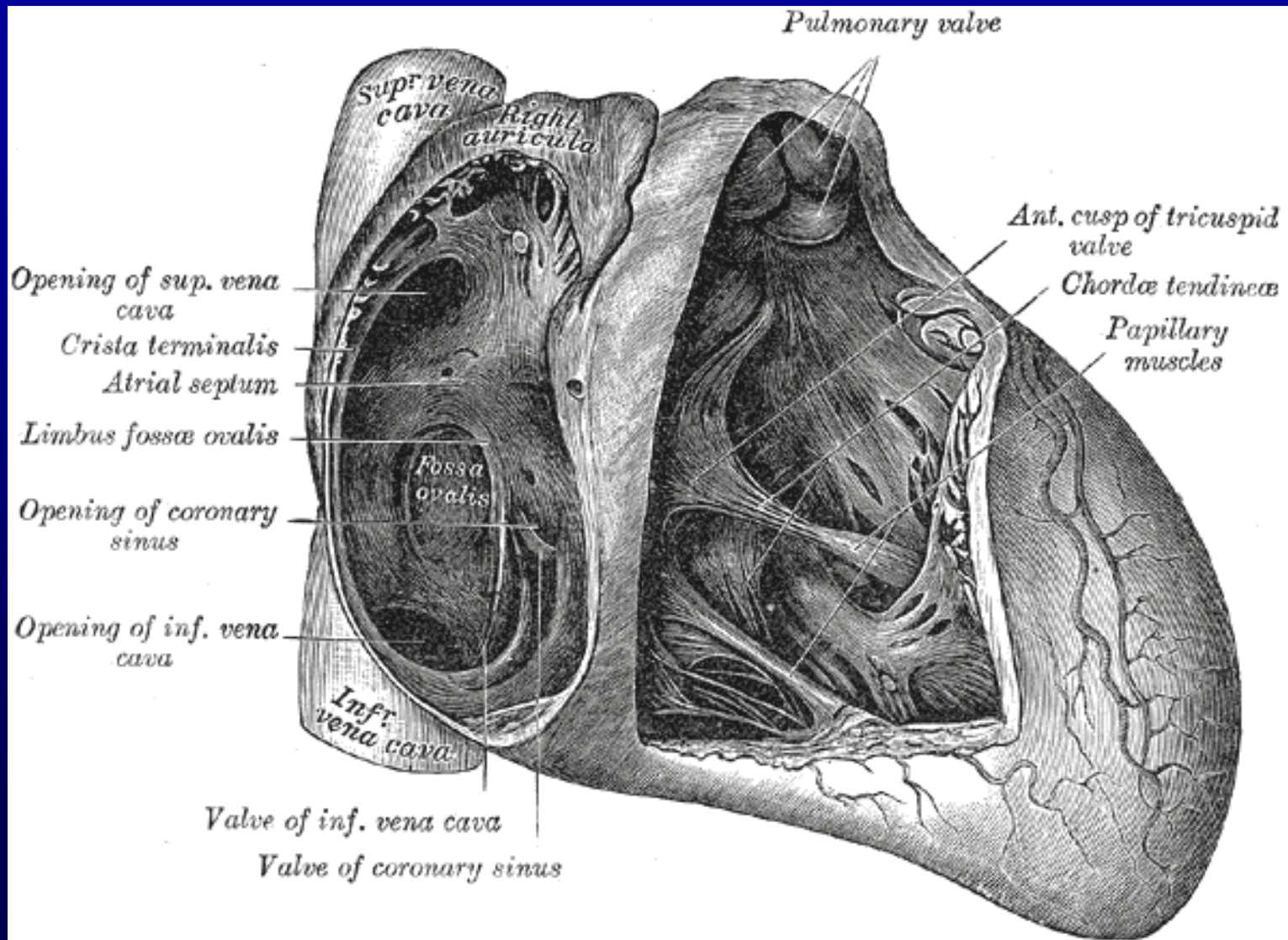
- **Driving force behind computer graphics for the past 50 years**
- **Quality of image judged by how closely they resemble a photograph**
- **Images are rendered by running a physics-simulation which emulates the behavior of light inside the modeled scene**

Effects needed for realism

- **Shadows**
- **Reflections (Mirrors)**
- **Transparency**
- **Interreflections**
- **Detail (Textures etc.)**
- **Complex Illumination**
- **Realistic Materials**
- **And many more**



What's Wrong with Photorealism?



Computers: Process, Transform, *Communicate*



Information Theory



**Origin (where does information come from?)
Throughput (how frequent?)
Latency (how long do I have to wait)?
Presentation (what does it look like?)**

Computers Graphics:
technology for presenting information

**Information transported
by an image can take
many different forms**

Photograph of a sailboat



Vast amount of information:

Time of day

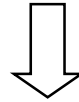
The weather

Wind direction

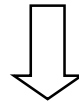
Speed

**Relationships between boat and environment
etc...**

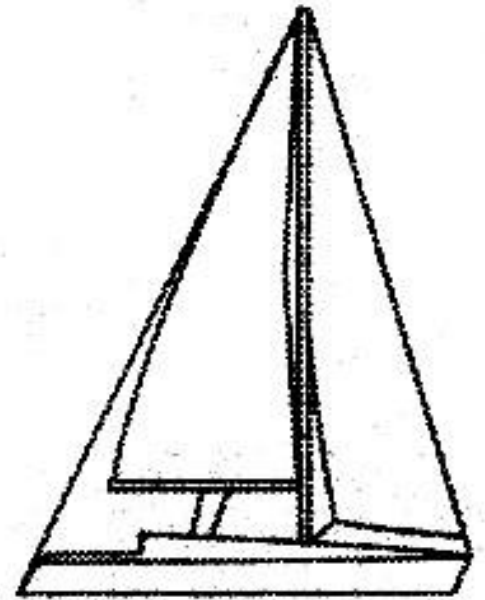
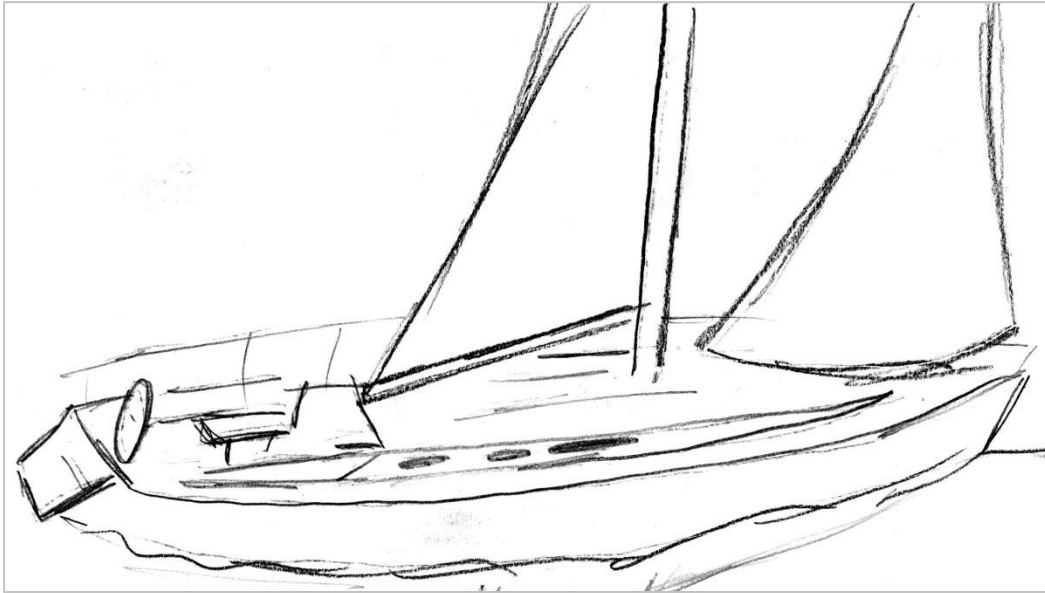
HOWEVER...



Little use to someone attempting to build a sailboat!



A sailboat builder would certainly prefer:
Technical drawings, blueprints
Line drawing representations of boat parts
Sketches of design ideas








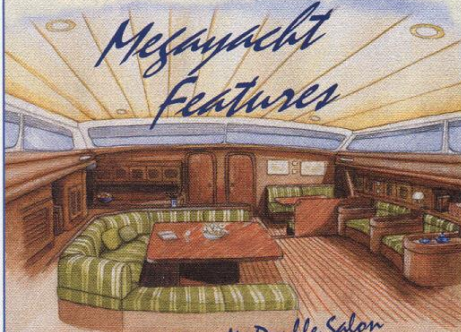
Megayacht Features

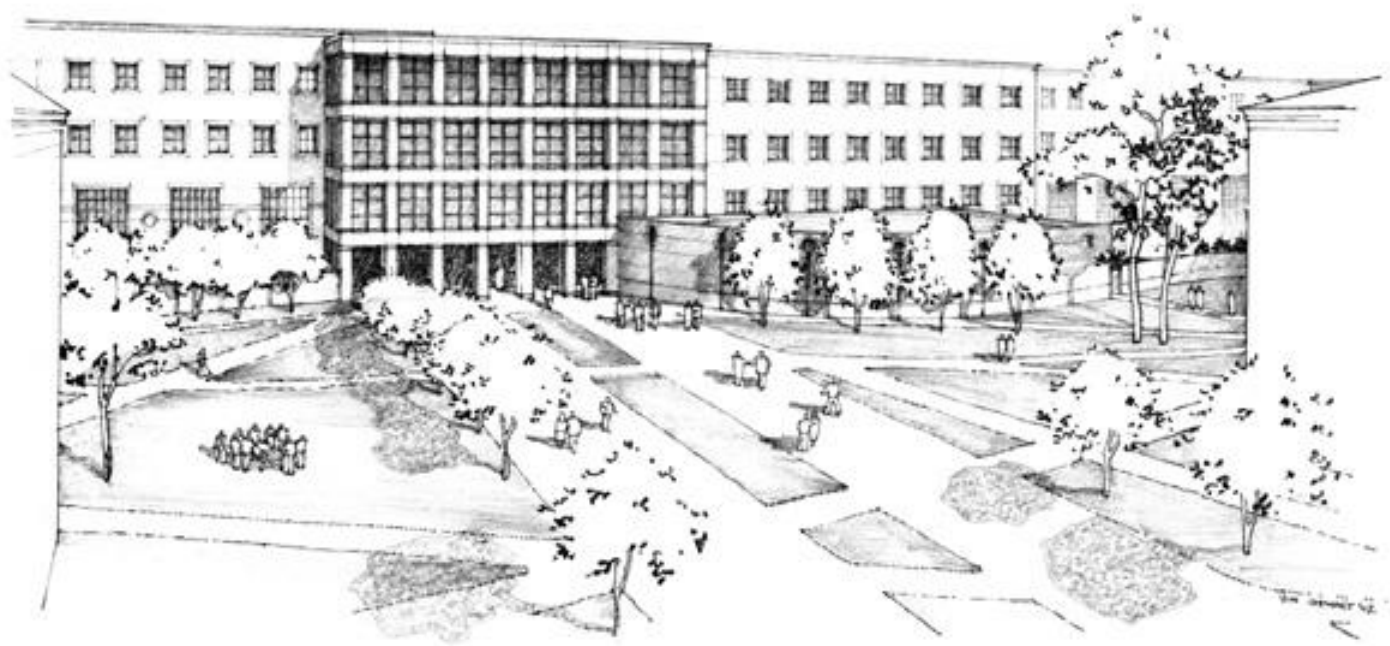
226 sq. ft. Double Salon

Fantastic panoramic views from the main salon

Automatic safe companion way door

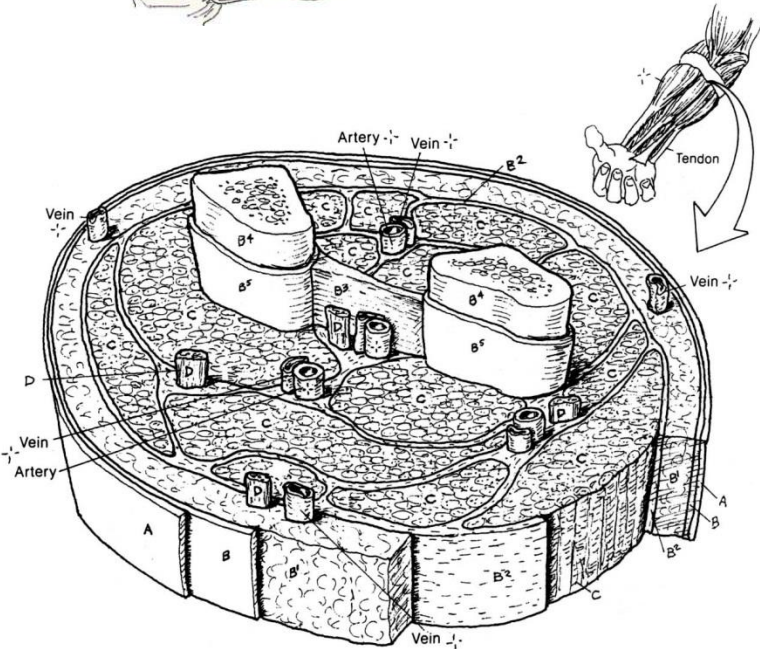
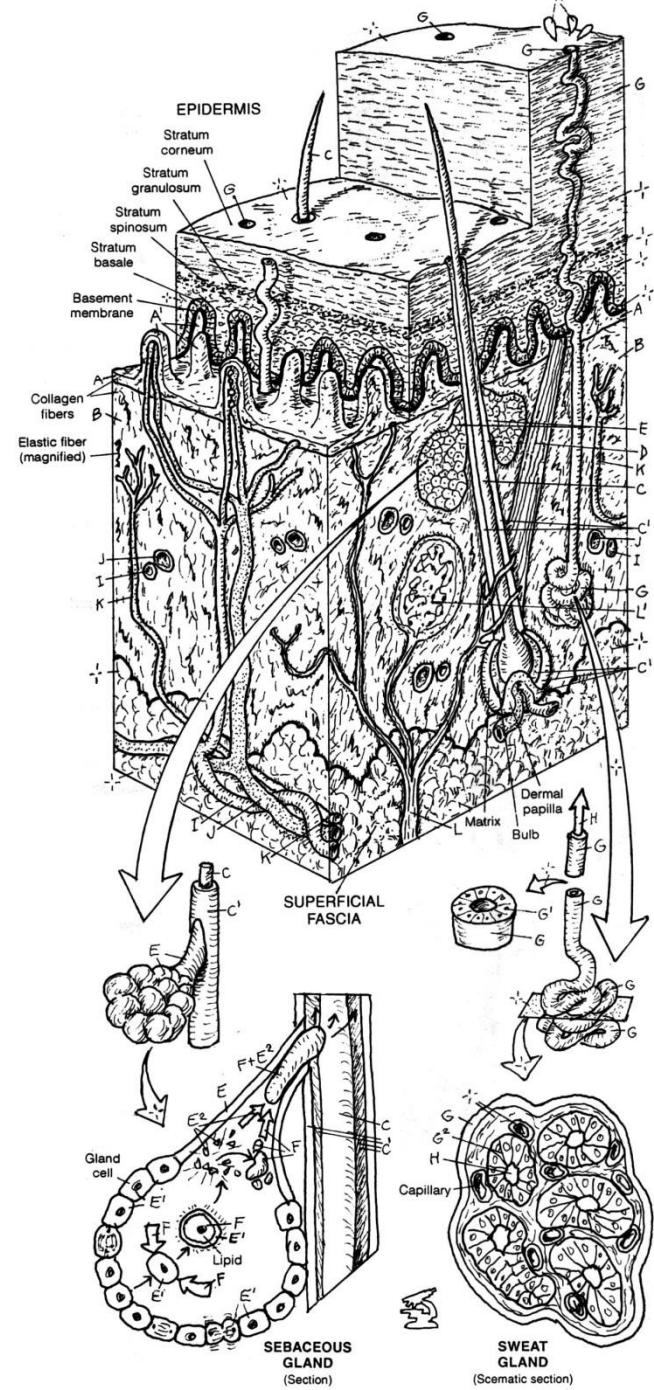
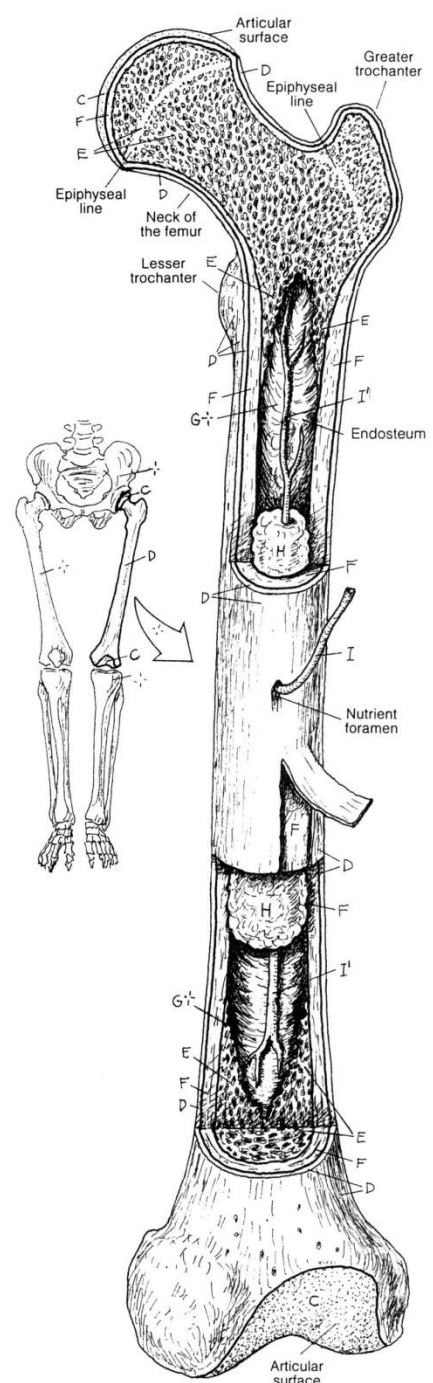
Flush fitted Bimini











Why Non-Photorealistic Rendering

In real-life, photographs are not always the best imagery

Schematic diagrams more useful in many applications

Artist is often able to convey greater expressiveness than a photographer

This has given rise to the field of non-photorealistic rendering

Non-Photorealistic Rendering

- **Departs from the limits of photorealism to better communicate visual information**
- **Uses concepts from art instead of physics**
- **Two fundamental visual cues**
 - *Silhouette – the visible edges of a surface*
 - *Hatching – the use of texture to indicate the local orientation (shading) of a surface*

Traditionally...

Imagery generated by illustrators (artistic, technical, scientific) has been used to provide information that may not be readily apparent in photographs or real life.

Traditionally...

Imagery generated by illustrators (artistic, technical, scientific) has been used to provide information that may not be readily apparent in photographs or real life.

Non-Photorealistic Rendering (NPR):

- Apply a similar goal to computer generated-images
- New field of research in computer graphics

Non-Photorealistic Rendering (NPR)

- Images are judged by **how effectively they communicate**
- Involves **stylization** and **communication**, usually driven by **human perception**
- Knowledge and techniques long used by artists and illustrators
- Emphasis on specific features of a scene, expose subtle attributes, omit extraneous information
- Brings together **art** and **science**

Non-Photorealistic Rendering (NPR)

- **Alternate display models**
- **Increase expressive power of Computer Graphics**
- **Many fields**
- **Computer Graphics revisited**

Pen and Ink Illustration

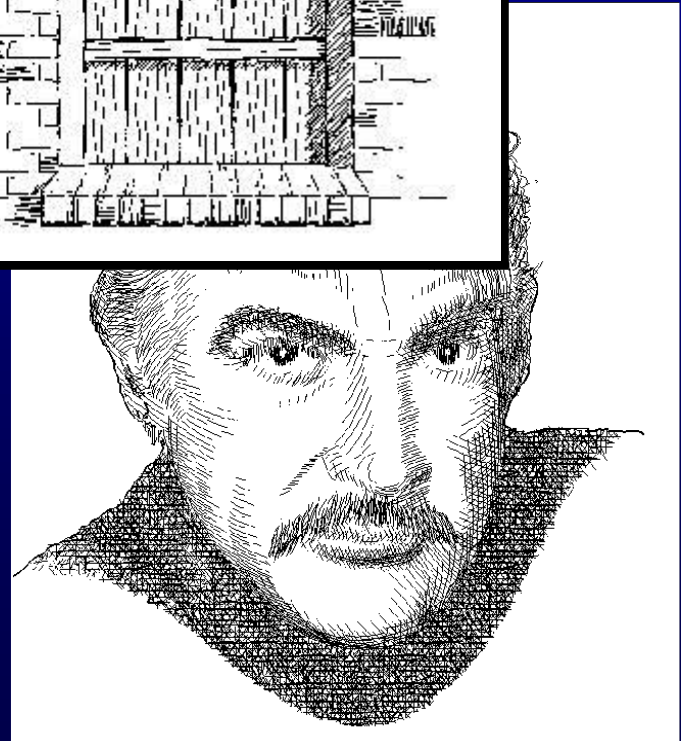
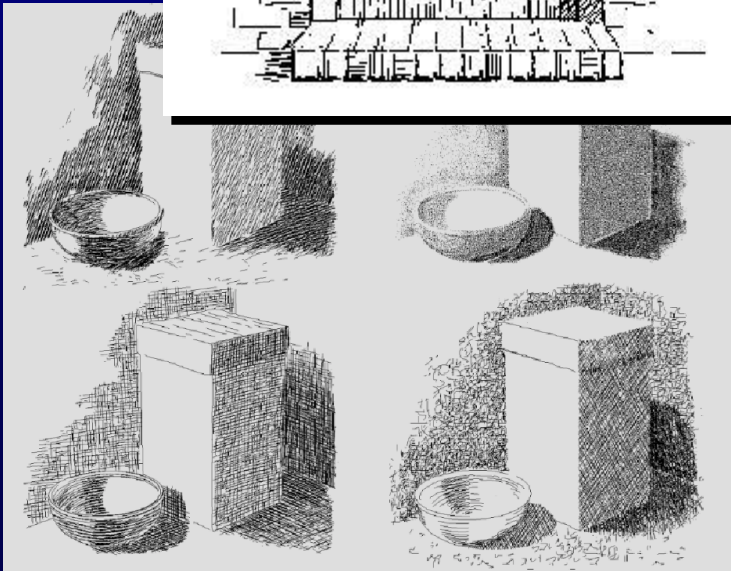
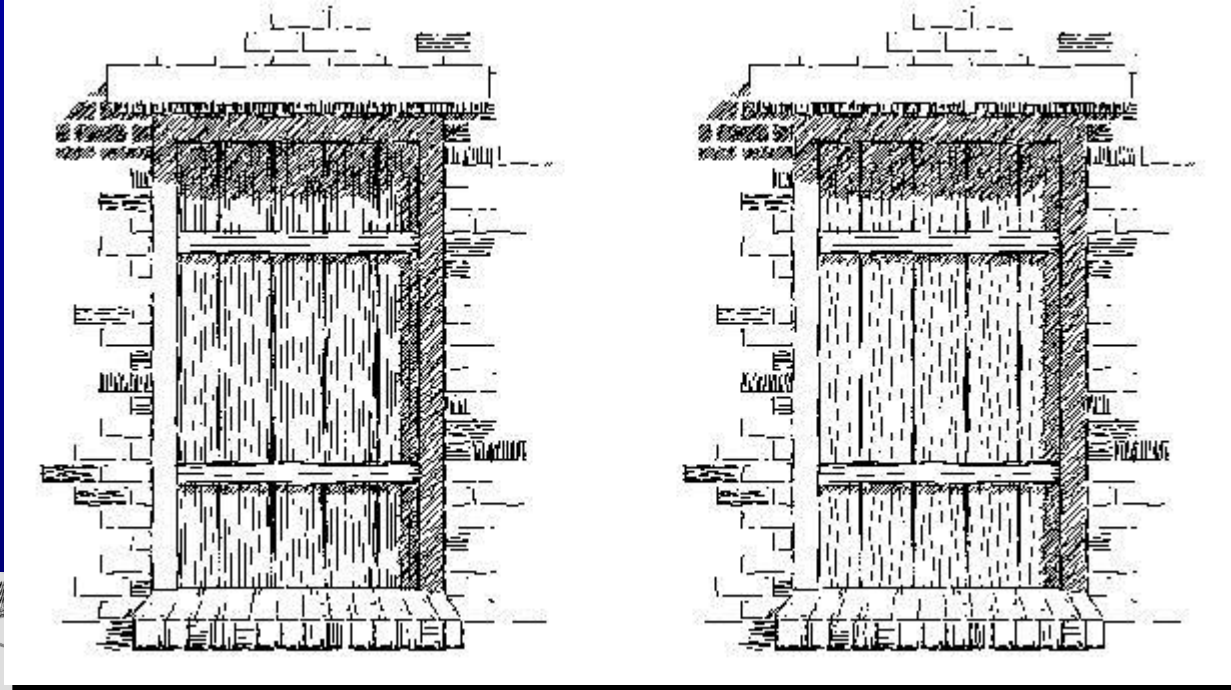
Strokes

- Tracing out a path with nib of pen, different pressure gives different width
- To appear natural, thickness will vary along path, lines will be wavy

Tones and textures:

- combinations of strokes give both tone and texture
- 'indication' used to economise on drawing each and every stroke

Strokes, Tones, Textures, Indication



Pen and Ink Illustration

Outlines:

- realistic scenes have no outlines
- non-photorealism depends heavily on exterior and interior outlines (e.g., leaves)
- thick outlines can indicate shadow
- indication again important

Recipe for Image Generation

Computer Science

Math

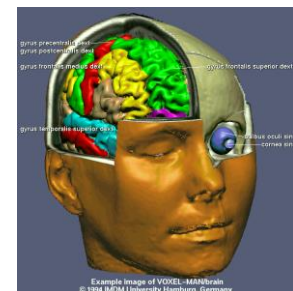
Linear Algebra (Matrices, Vectors)
Discrete representations (Images)

Physics

Lighting/Energy transfer
Color reflections/refraction

Mechanical Engineering

CAD/CAM
Solid Models



Example image of VOXEL-MANBrain
© 1994 BCM University Hamburg, Germany

Recipe for Image Generation

Art and Illustration
Non-Photorealistic Rendering

Computer Science

Math

Linear Algebra (Matrices, Vectors)
Discrete representations (Images)

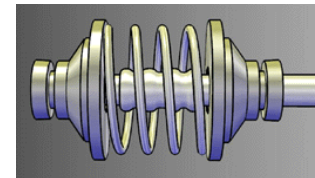
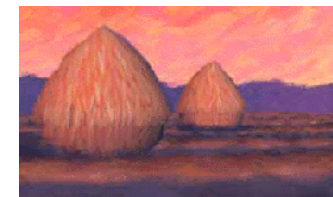
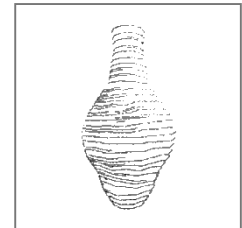
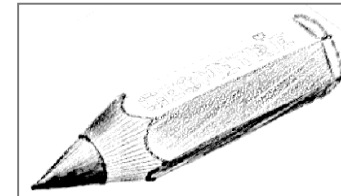
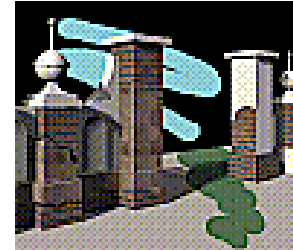
Physics

Lighting/Energy transfer
Color reflections/refraction

Mechanical Engineering

CAD/CAM

Solid Models



Applications → NPR == CG&Viz!

- **Art, Entertainment, Publishing**
 - *Movie Production, Animation, Special Effects*
 - *Computer Games*
 - *World Wide Web*
 - *Slide, Book, Magazine, Multimedia Design*
- **Science and Engineering**
 - *Computer-Aided Design (CAD)*
 - *Simulations*
 - *Scientific Analysis and Visualization*
 - *Process Control and Monitoring*

Traditional Art & Illustration

- **Art, Entertainment, Publishing**
 - *Artists, Designers, illustrators*
- **Science and Engineering**
 - *Technical Illustrators*
 - *Scientific Illustrators or
Natural Science Illustrators
(medicine, botany, archeology, etc)*

Art, Entertainment, Publishing :

Movie Production, Animation, Special Effects

Tools for artists, painting systems, pre-production



What Dreams May Come
PB14 Final

“What Dreams May Come”
First motion picture with full NPR effects

“Tarzan”
“Star Wars II”
“Matrix II”

...

Art, Entertainment, Publishing :

Computer Games, Interactive Theater

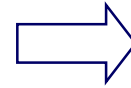
- **Tools for artists**
- **Painting systems**
- **Pre-production**
- **Stylized output**
- **Real-time NPR**
- **...**

Art, Entertainment, Publishing :

WWW, Slide, Book, Magazine, Interactive Multimedia Design

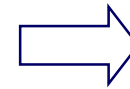
Science and Engineering:

Computer-Aided Design (CAD)



**Mechanical Engineers
Land Developers
Civil Engineers
Landscape Architects
Architects
Civil Planners**

**Scientific Analysis and Visualization
Simulations**



**Medicine
Botany
Archeology
Paintings**

Computer-generated Pen and Ink Illustration

Compared with traditional rendering:

- tone and texture combined
- 2D projection affects rendering

Pipeline includes:

- modeling
- texture assignment
- reflection model to give tone
- outlines added

Strokes

Generated by moving nib along path

Character added by:

- waviness function
- pressure function

Note clipping needs to be adapted to this style of drawing

Stroke Textures

Collection of strokes to give texture and tone

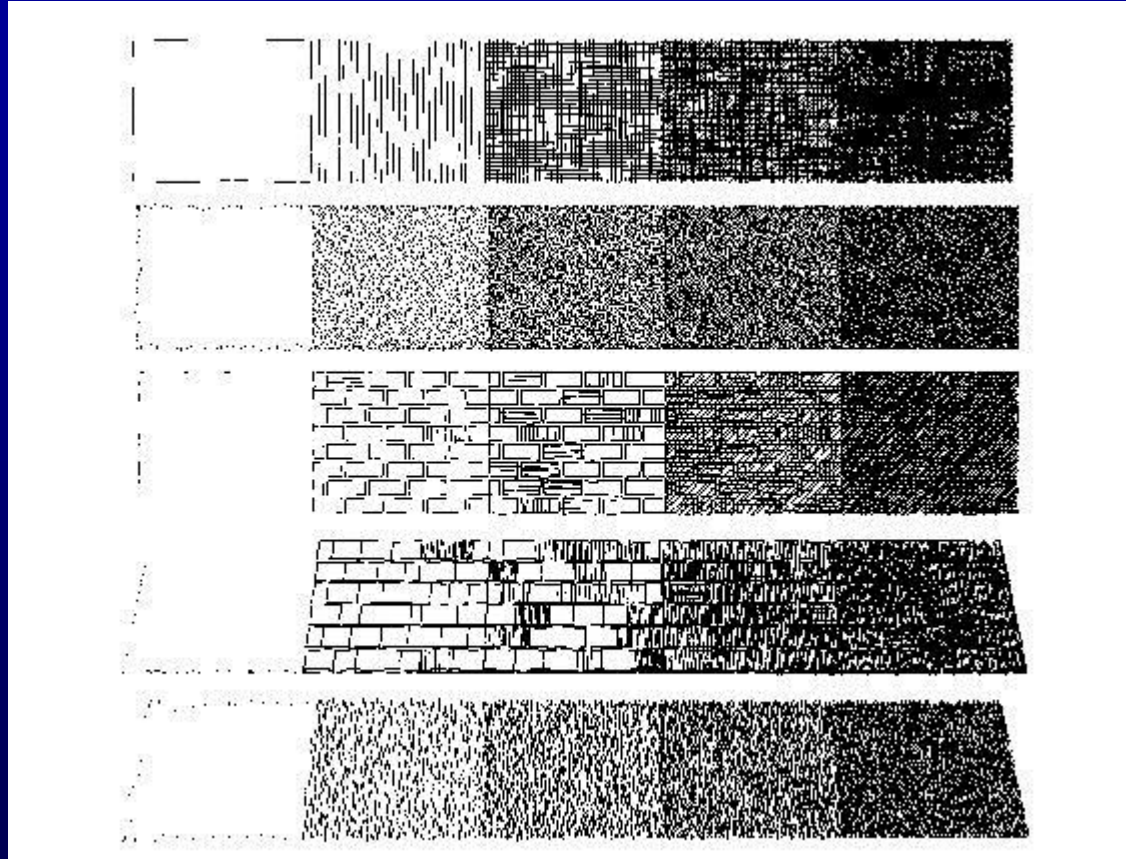
Prioritized so that different tones can be achieved

- first only highest priority drawn
- to increase tone, lower priorities drawn

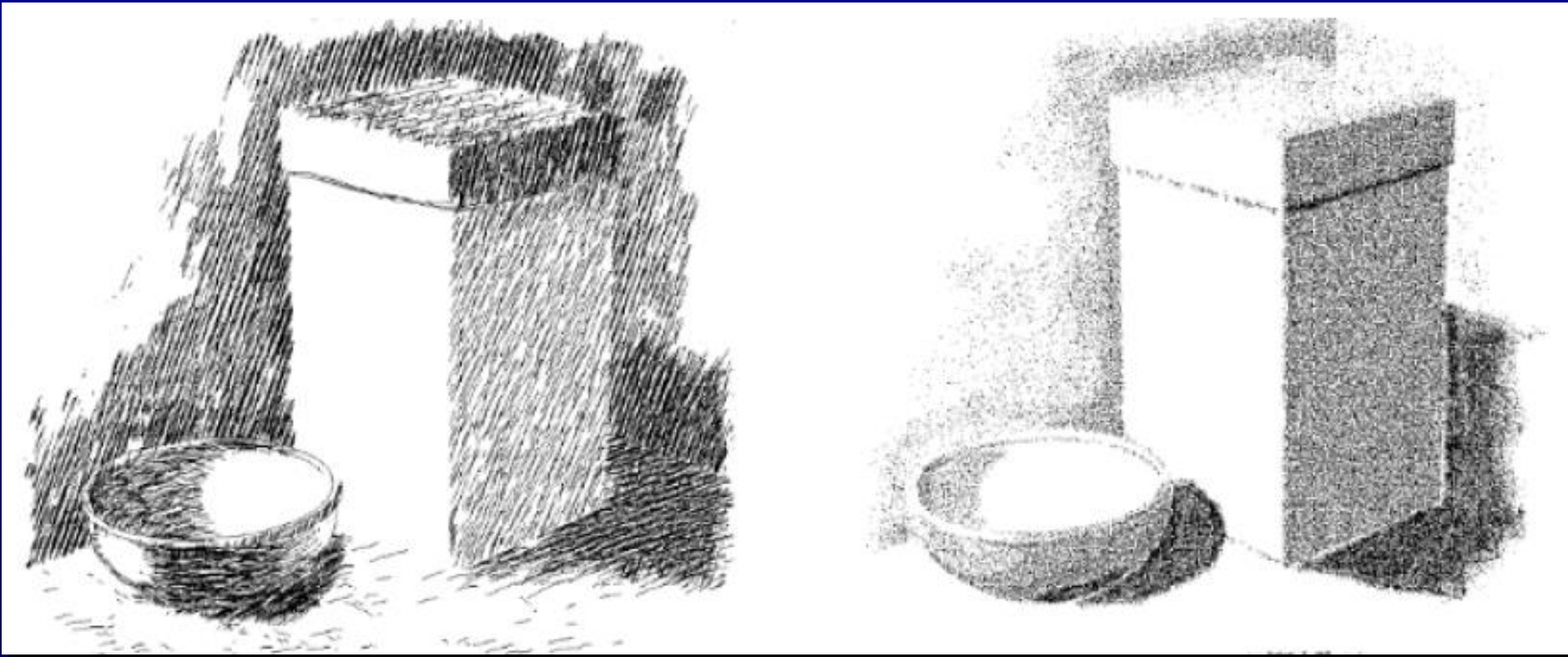
For example:

- highest priority to outline
- next could be horizontal lines
- then vertical, and so on

Stroke Textures

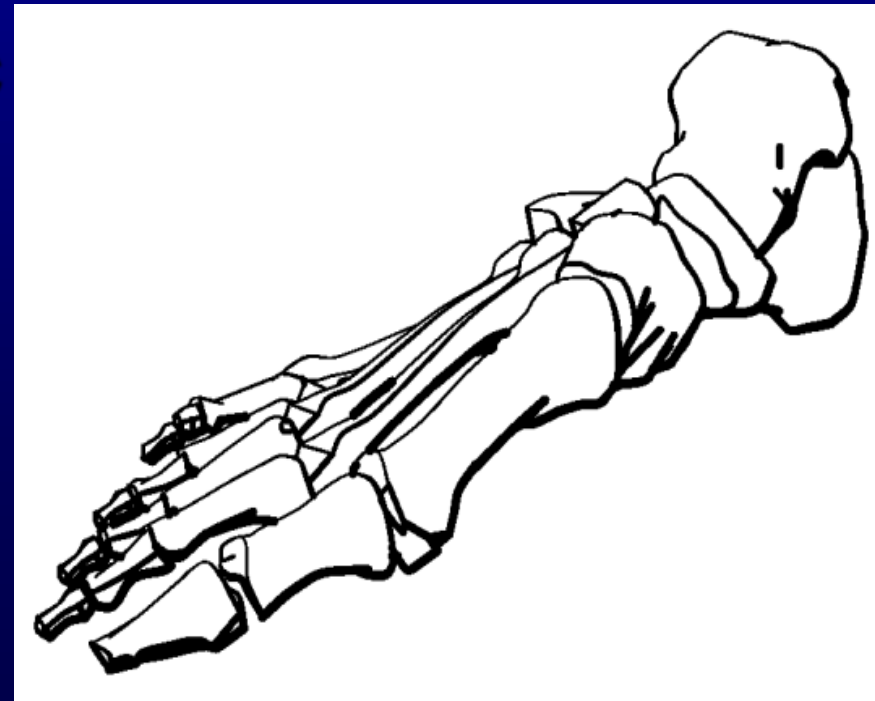
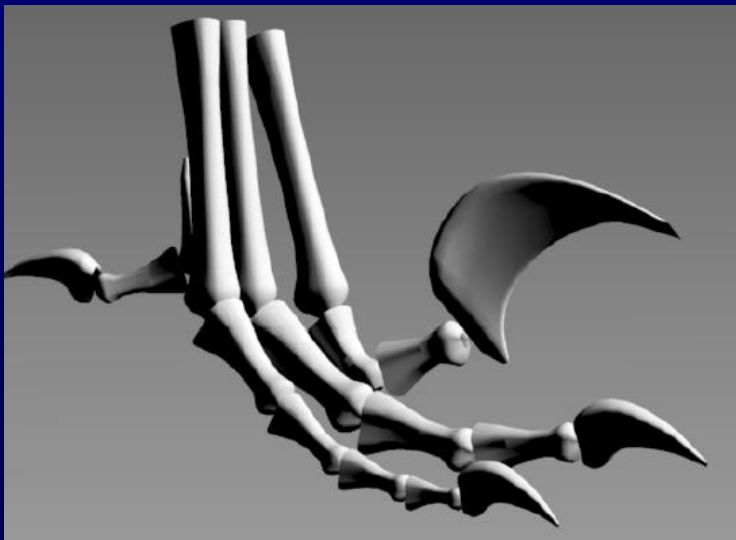


Non-Photorealistic Rendering (NPR)



Non-photorealistic Rendering

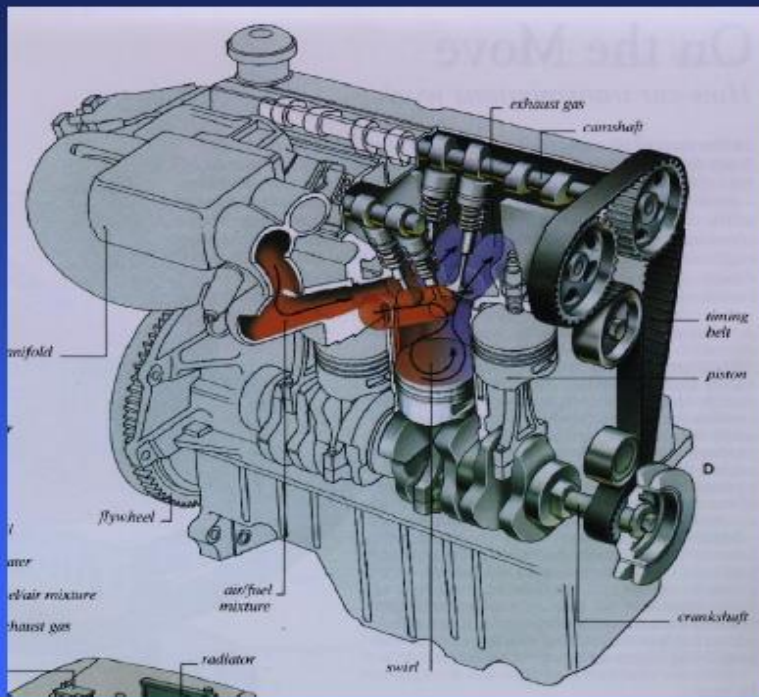
- Most computer graphics work strives for photorealism
- Other types of depiction can be more expressive or artistic



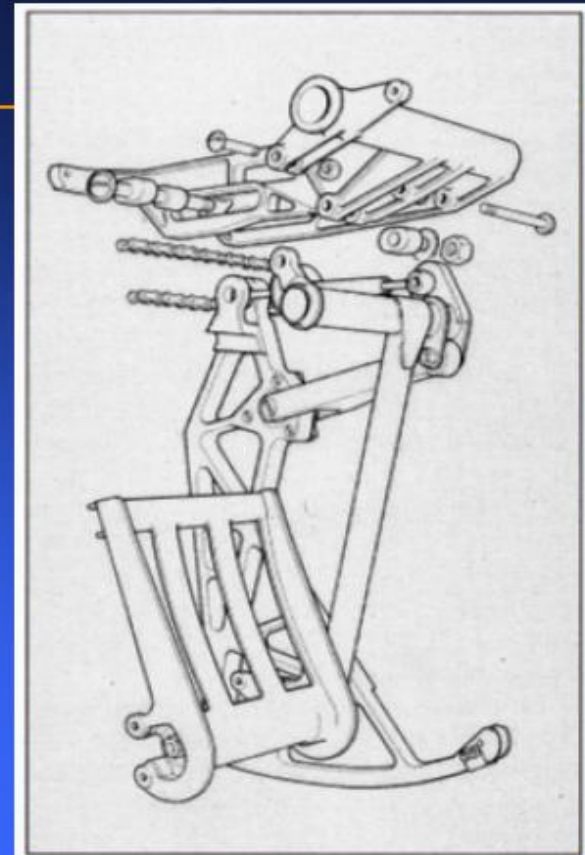
NPR – Technical Illustration

- Illustrate important features

Illustrators Use of Lines



From *The Way Science Works*,
Courtesy of Macmillan Reference USA.



From *Technical Illustration* by Judy Martin

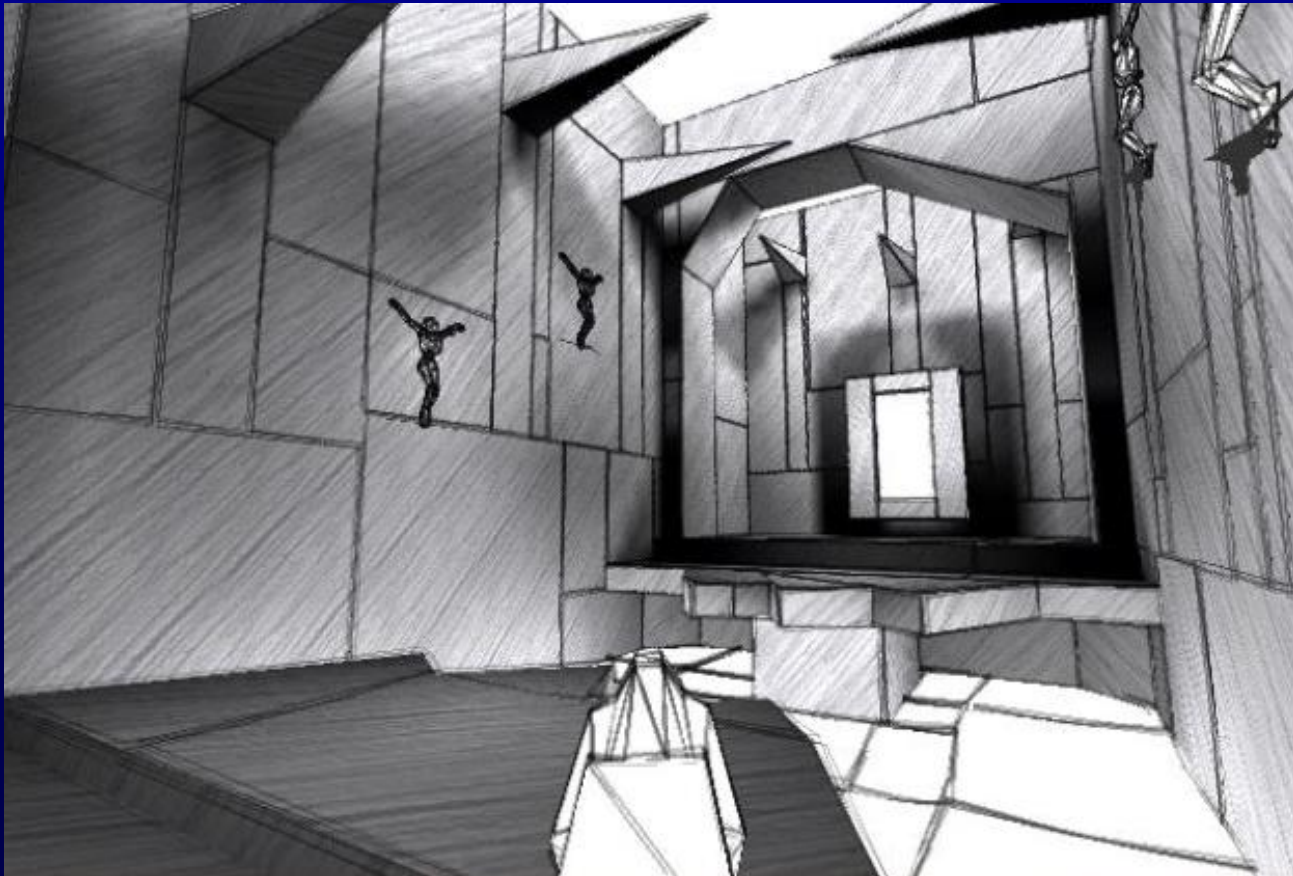
NPR – Painterly Rendering

- **Make it look like being created using brush strokes and paint**



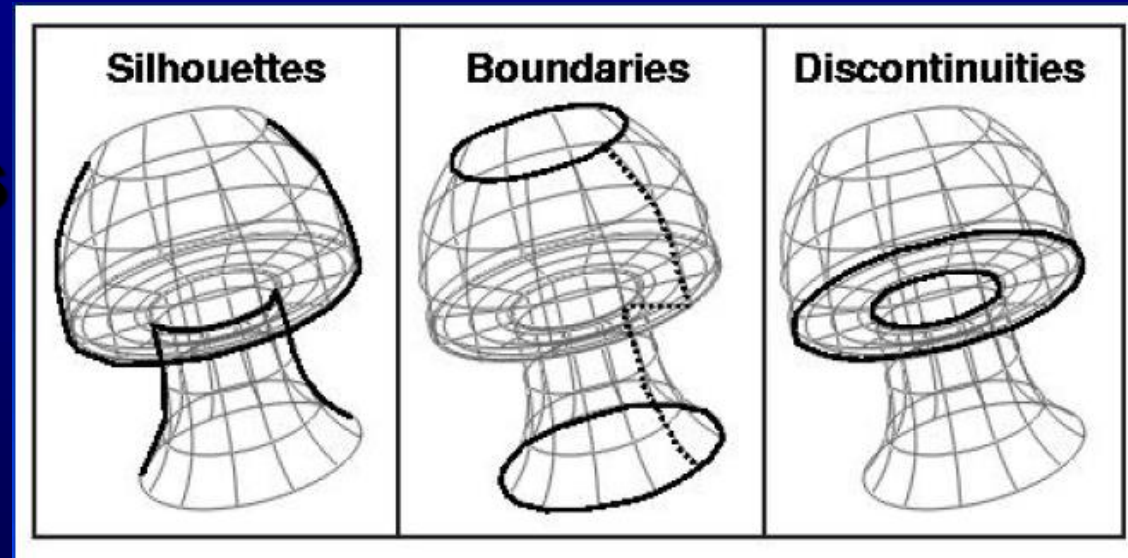
NPR – Sketchy Rendering

- **Make it look like being created with pencil sketch**



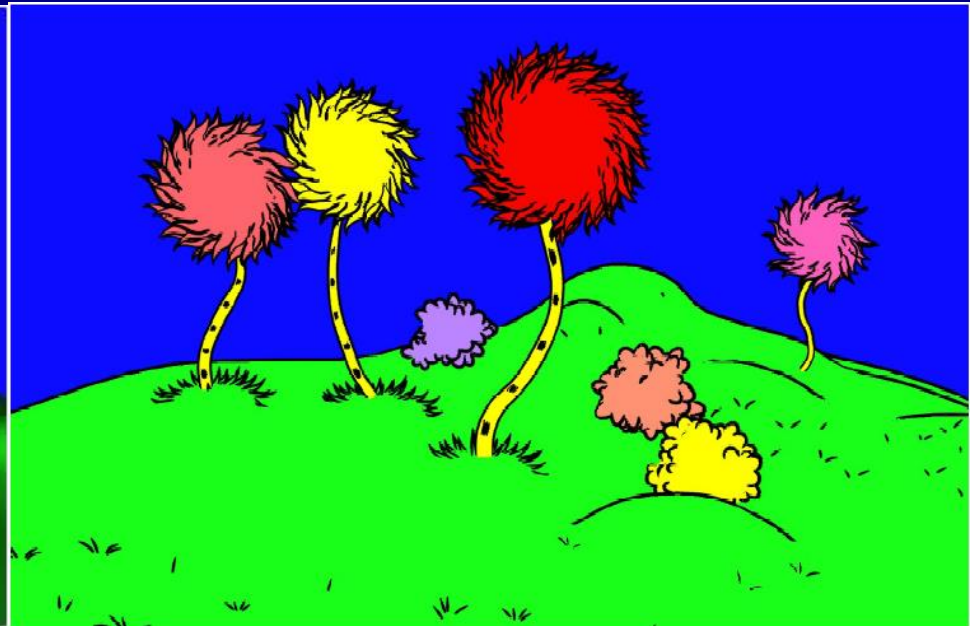
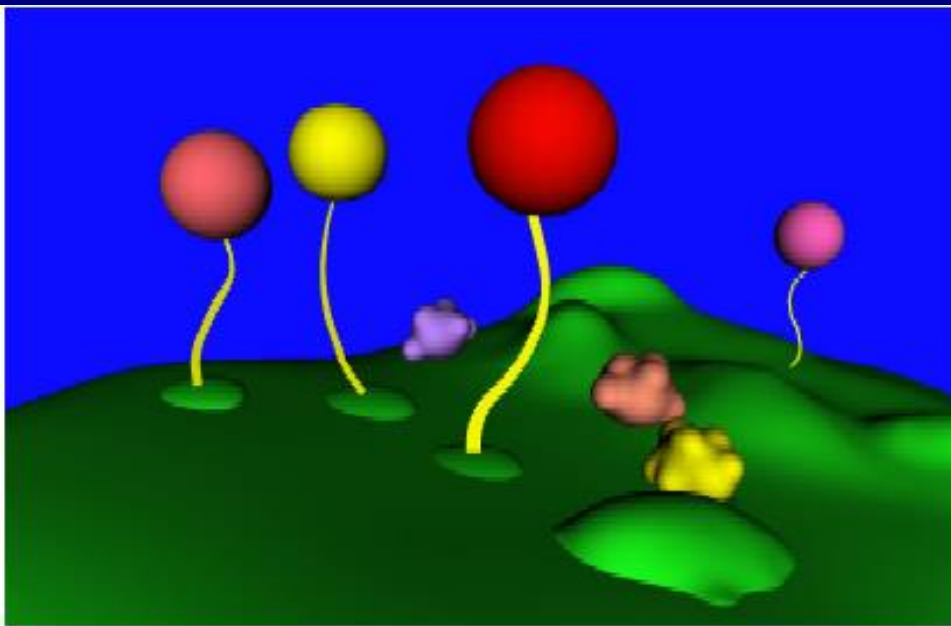
Shape Abstraction by Lines

- **Boundary lines**
- **Silhouette lines**
- **Creases**
- **Material edges**

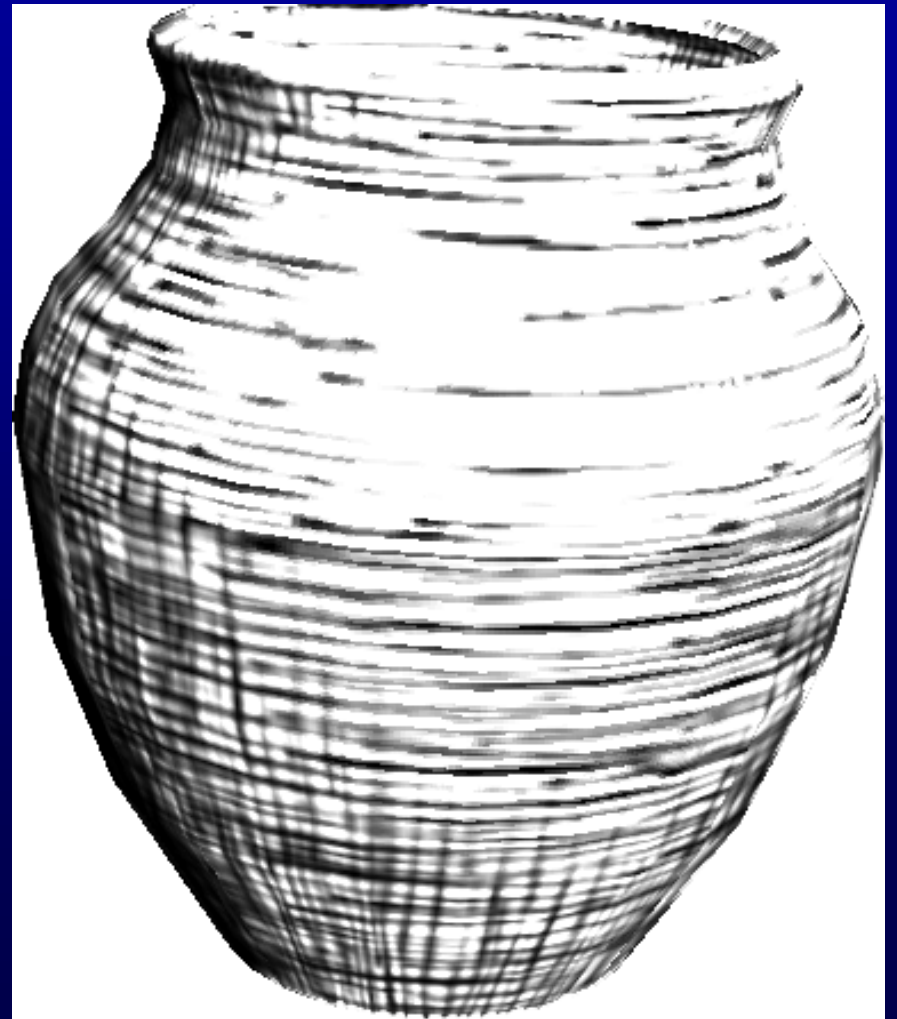


Shape Abstractions by Lines

- Various line styles can be used



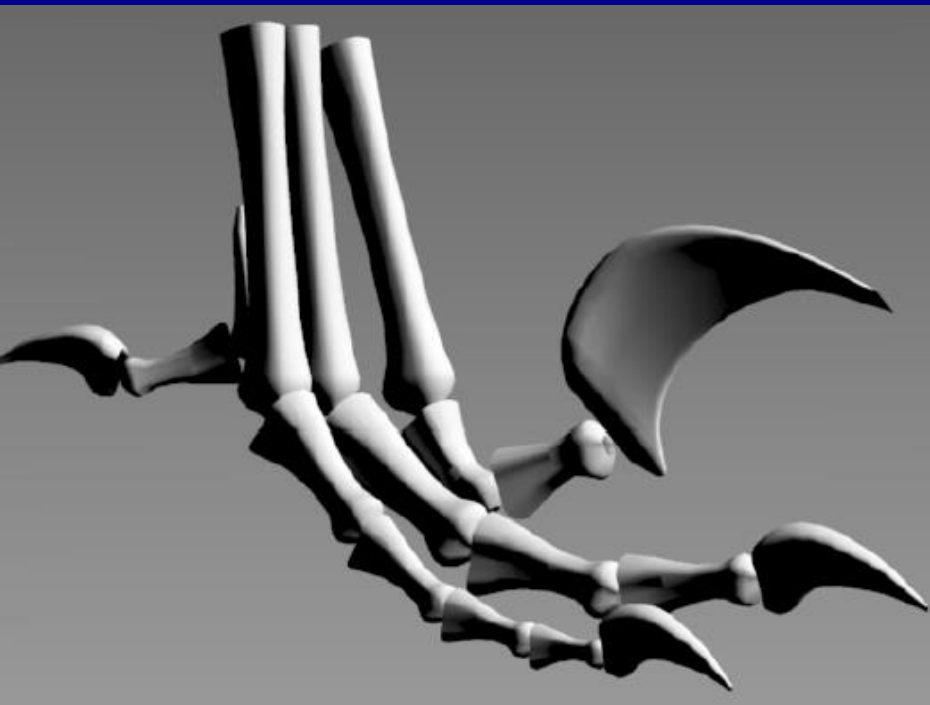
Shape Abstraction by Textures



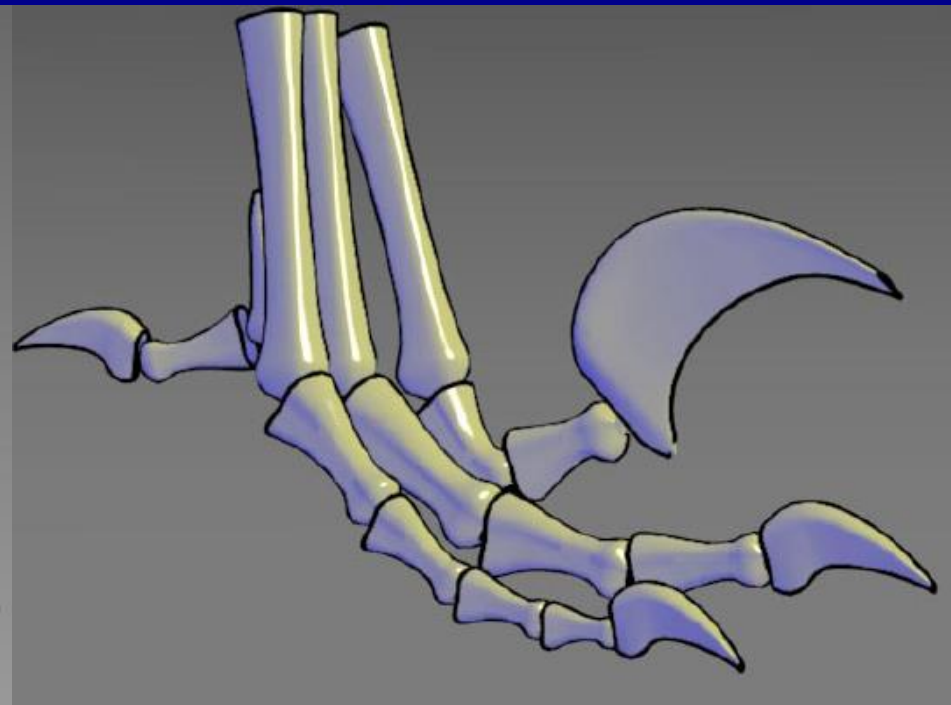
Shape Abstraction by Textures



Shape Abstraction by Shading



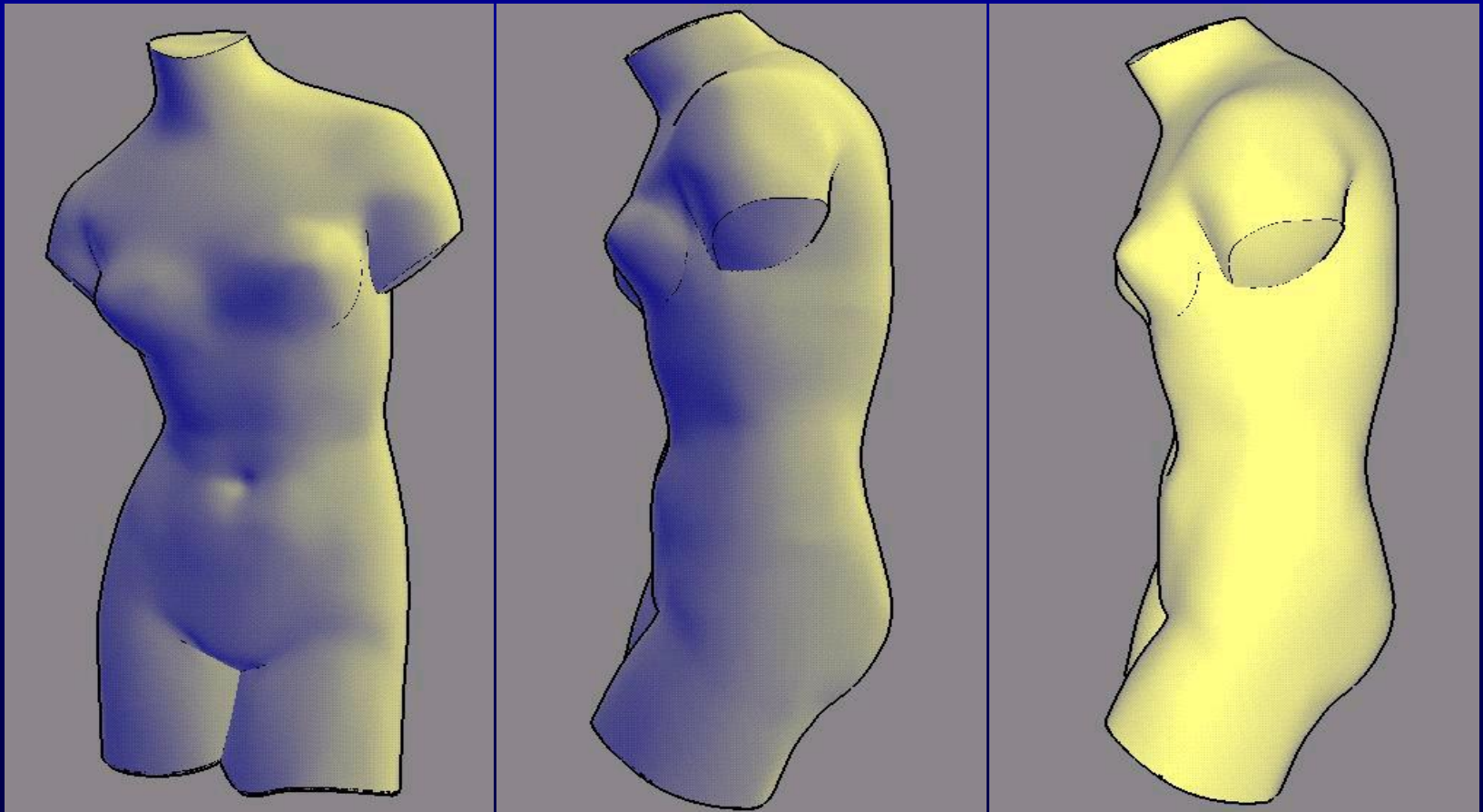
Regular OpenGL Gouraud Shading



Tone Shading

Shape Abstraction by Shading

- **More effective when combined with lines**



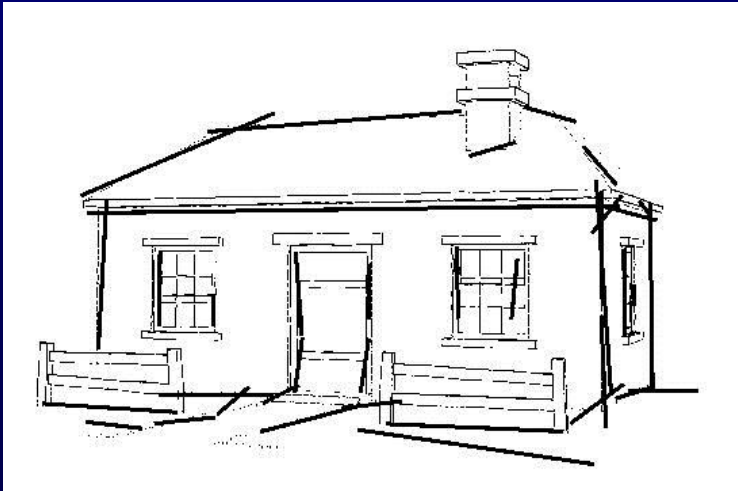
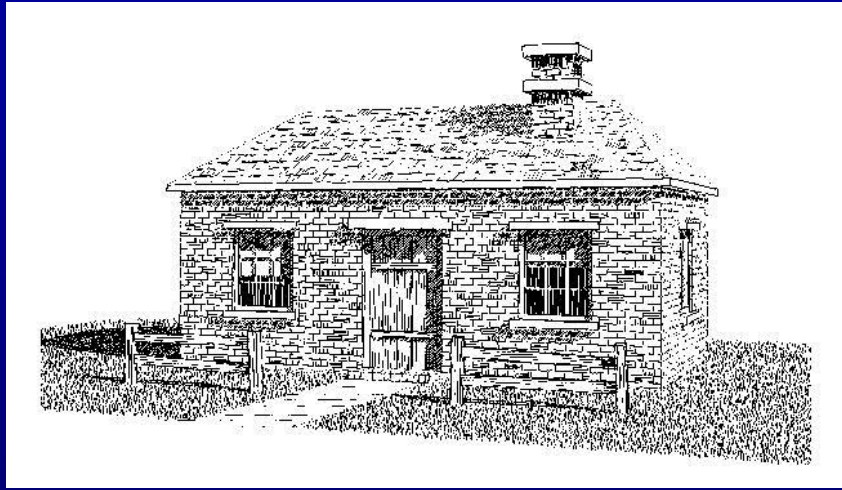
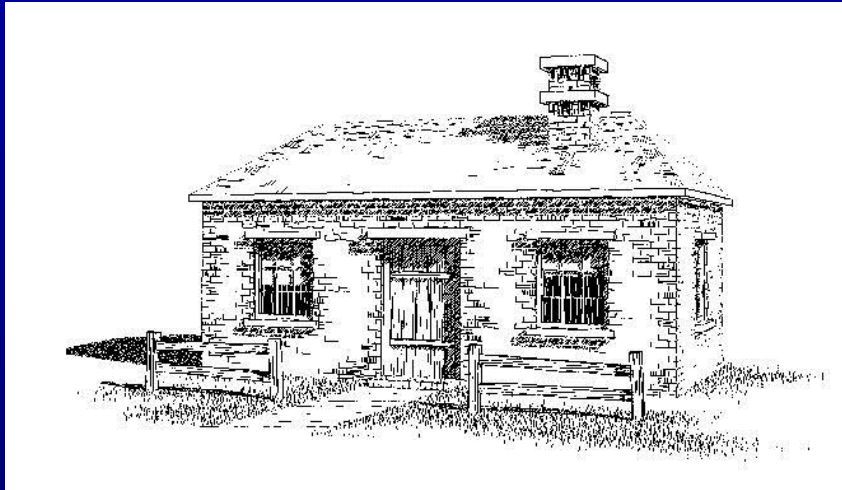
Indication

This can be handled semi-automatically by marking on drawing a set of 'indicator lines'

Strokes closer to indicator lines have higher probability of being drawn

Indication Lines





Indication



Outline

Boundary and interior outlines

Boundary outline texture associated with each stroke texture

Interior outlines drawn when two faces of similar tone are adjacent

Accented outlines for shadows

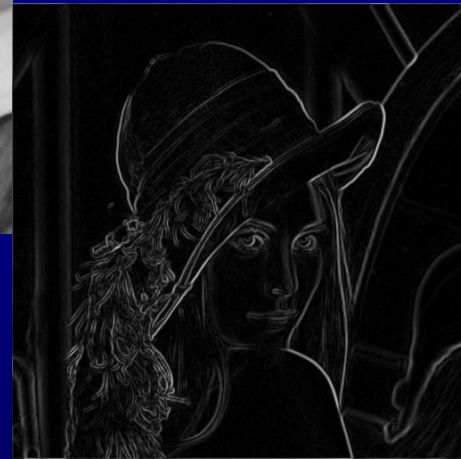
Feature Line Detection

- **Image space method – analyze the rendered images**
- **Object space method – analyze the mesh**

Image Processing Silhouettes

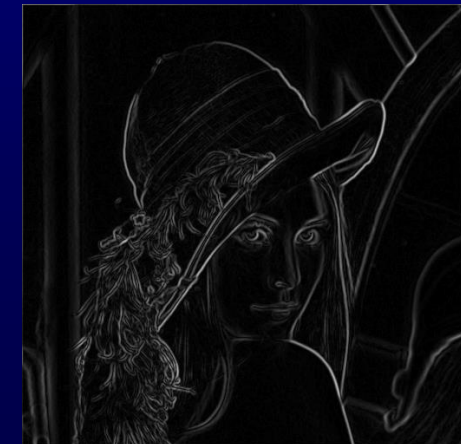
Canny edge detector

- Gaussian smoothing
- First derivative operator
- Non-maximal suppression



Produces image of silhouette edges

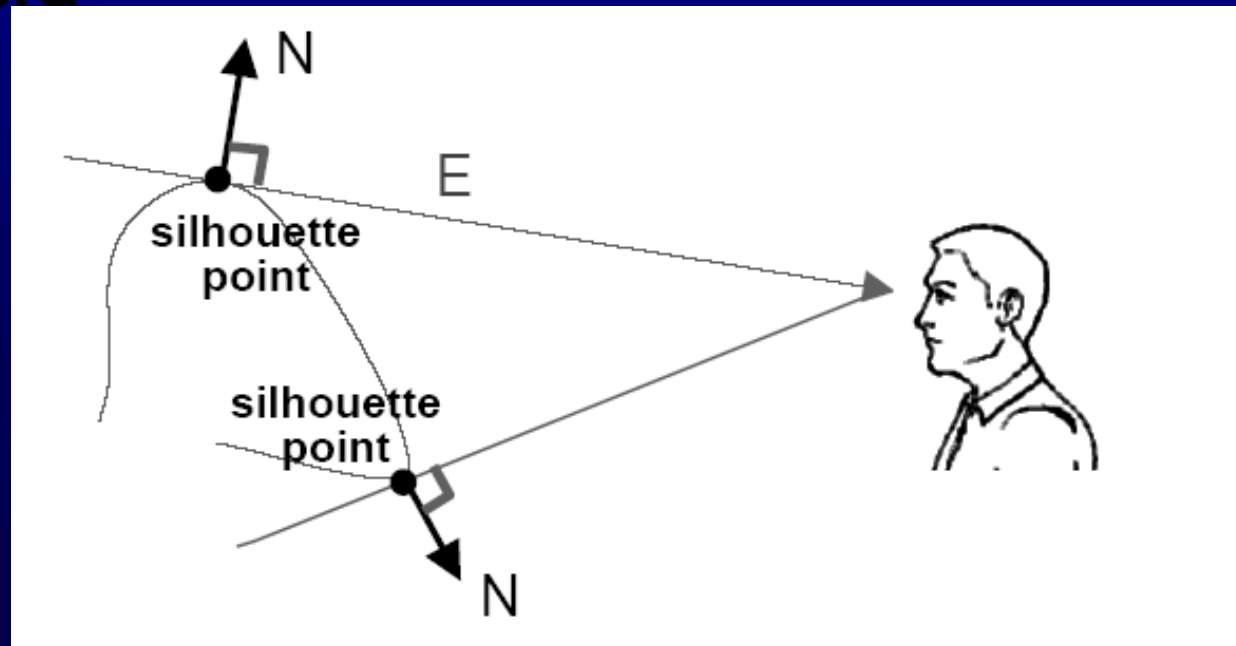
Also yields other non-silhouette edges from illumination, texture that are also useful for illustration



Silhouette

For a smooth surface, a silhouette can be defined as:

- $N \cdot (X - E) = 0$; N: normal, X: silhouette point; E: camera

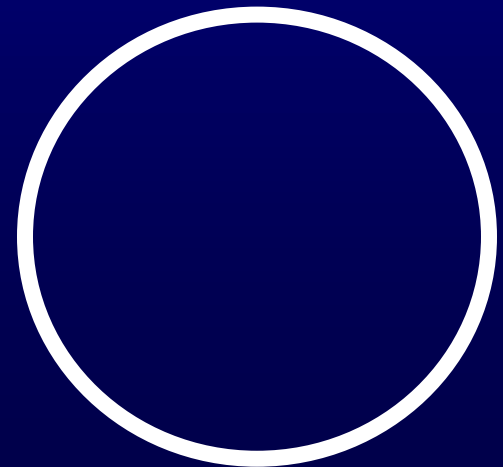


Environment Map Silhouettes

Environment map captures visible light from a given point

Sphere map captures visible light

NPR environment map: white with black border



Edge Detector

- **Discontinuity in depth map or normal map can be detected using edge detector**

$$S_x = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} \quad S_y = \begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix}$$

$$I_x(x,y) = I(x,y) \times S_x; \quad I_y(x,y) = I(x,y) \times S_y$$

$$IM = \text{sqrt} (I_x(x,y)^2 + I_y(x,y)^2)$$

Edge detection by thresholding IM

Image Space Method

- **Analyze the depth buffer – look for depth discontinuity using edge detector**

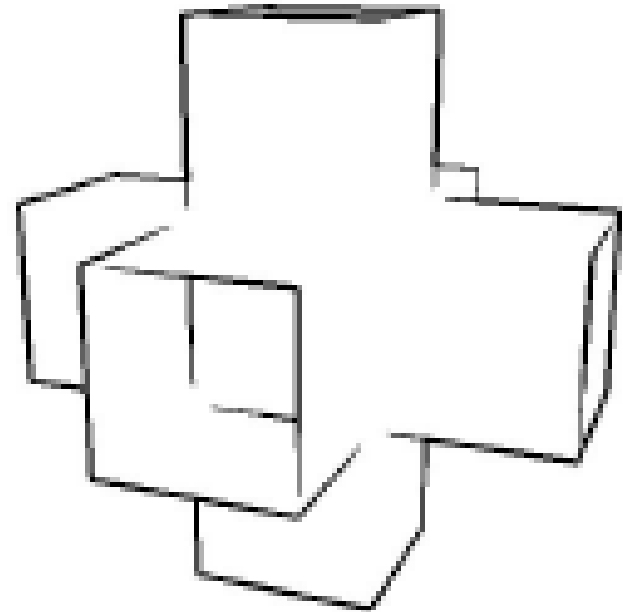
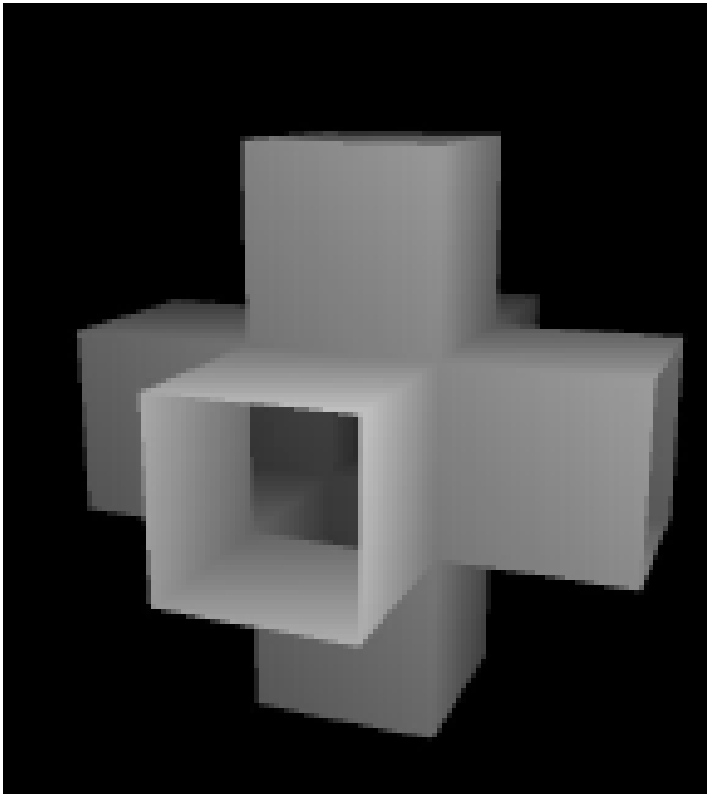


Image Space Method

- Analyze the normal map – convert surface normal (x,y,z) to (R,G,B) and then detect the color discontinuity

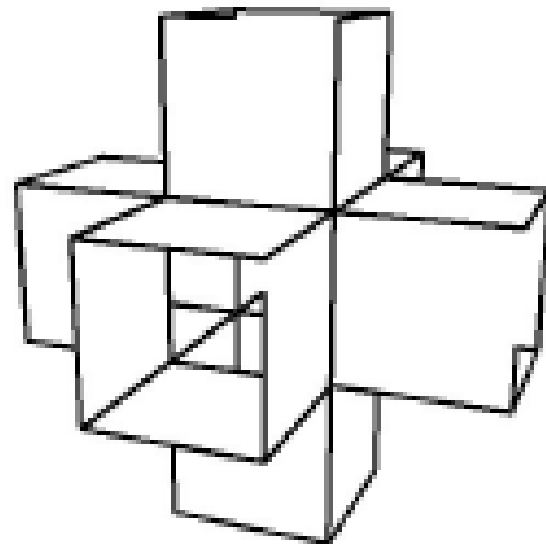
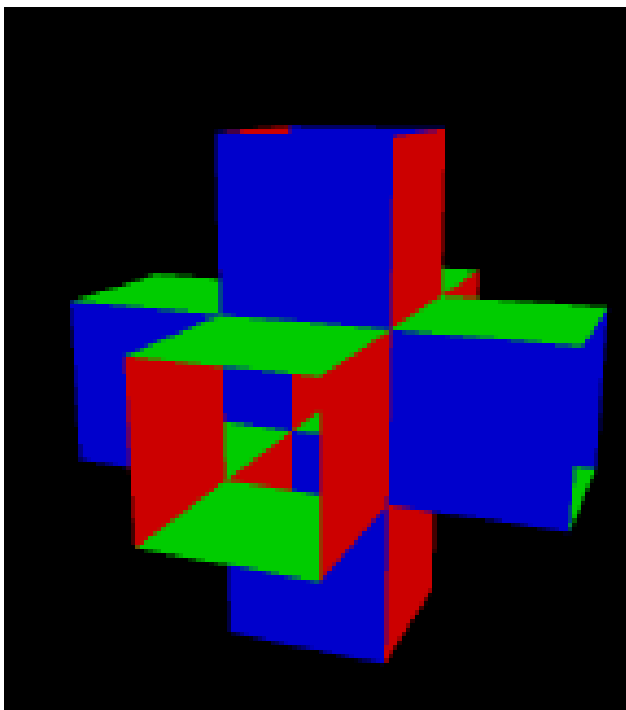
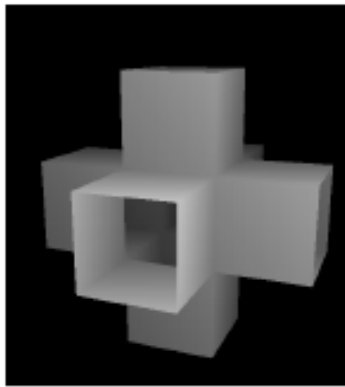
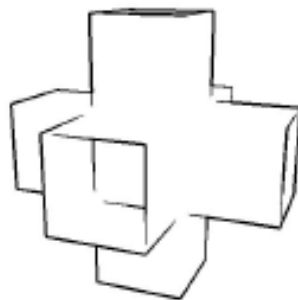


Image Space Method

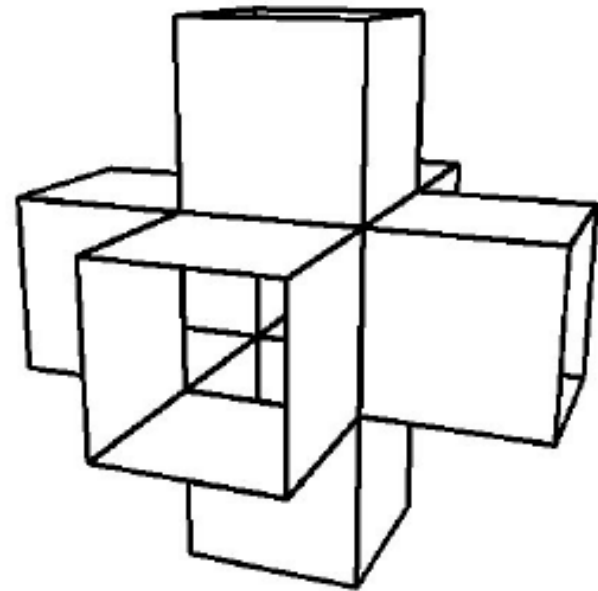
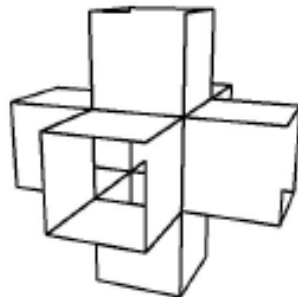
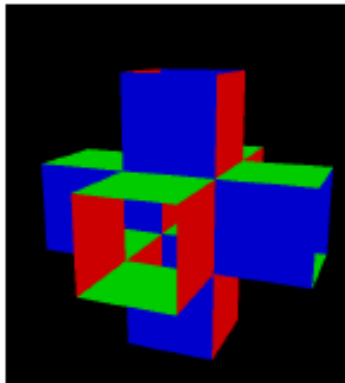
- Better result can be obtained if both edges are combined



(a)



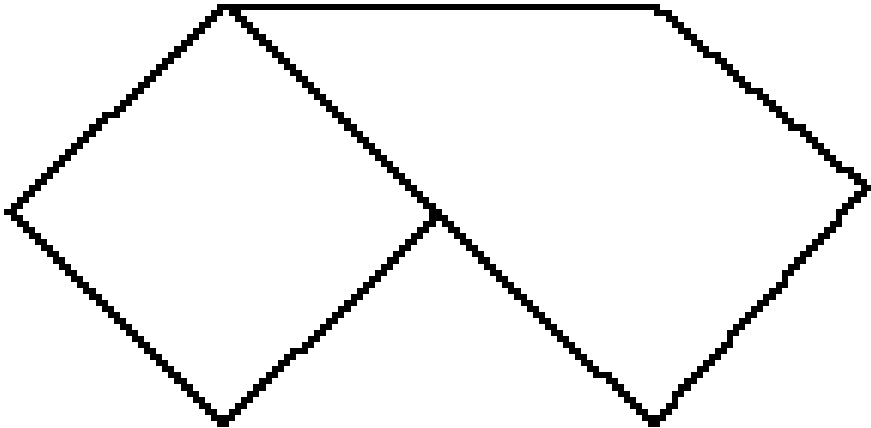
(b)



(c)

Image Space Method Problem

- For a folded piece of a paper, the edge cannot be detected



Object Space Method

- **Mainly used to detect silhouettes and creases**
 - *Silhouettes: edges that connect front and back faces*
 - *Creases: A discontinuity on an otherwise smooth edges*

Silhouette Curves

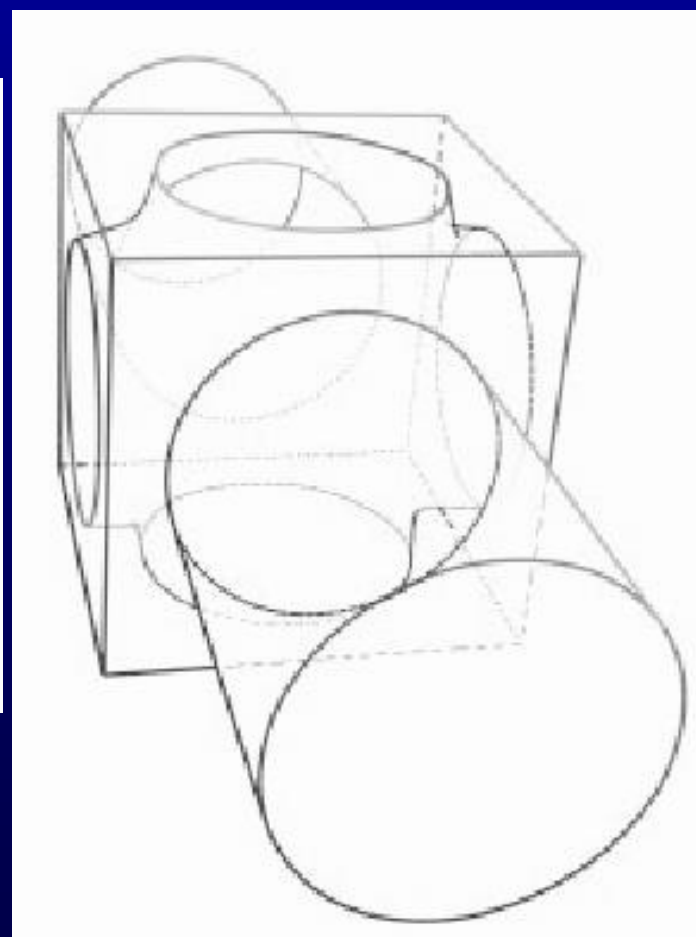
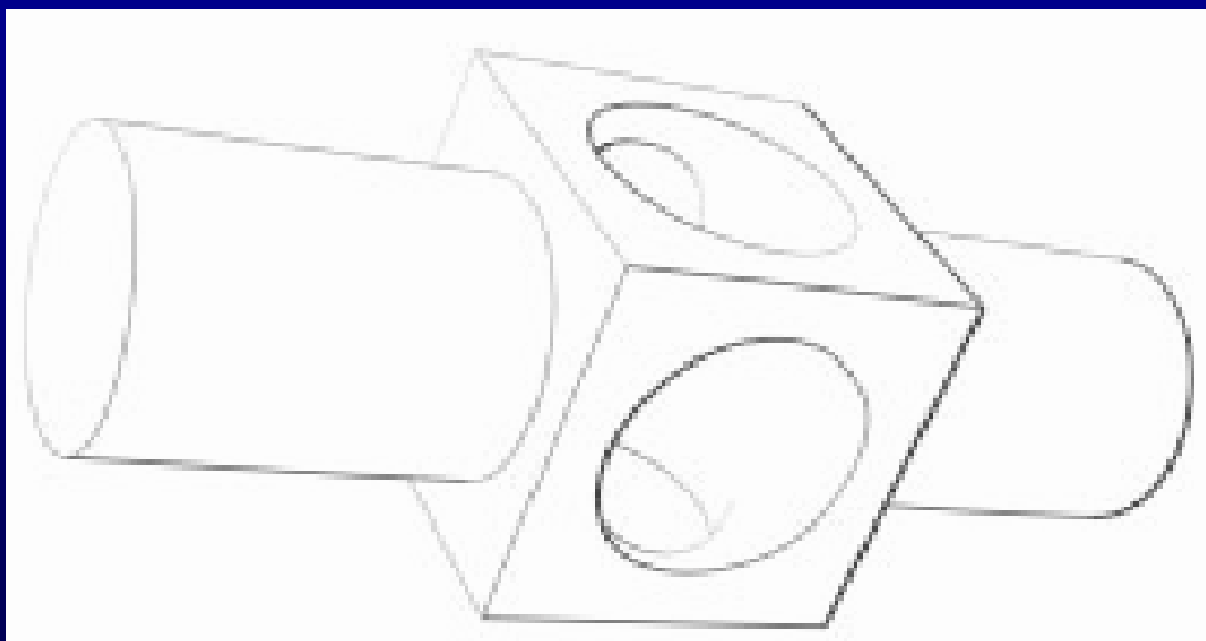
Constructed from edges shared by both front-facing and back-facing mesh polygons

Also include boundary edges

Can be traced incrementally as a string of silhouette edges

May not be visible, or not entirely visible

Probability that an edge is a silhouette is proportional to $\pi - \theta$, where θ is the edge's dihedral angle



Software Method

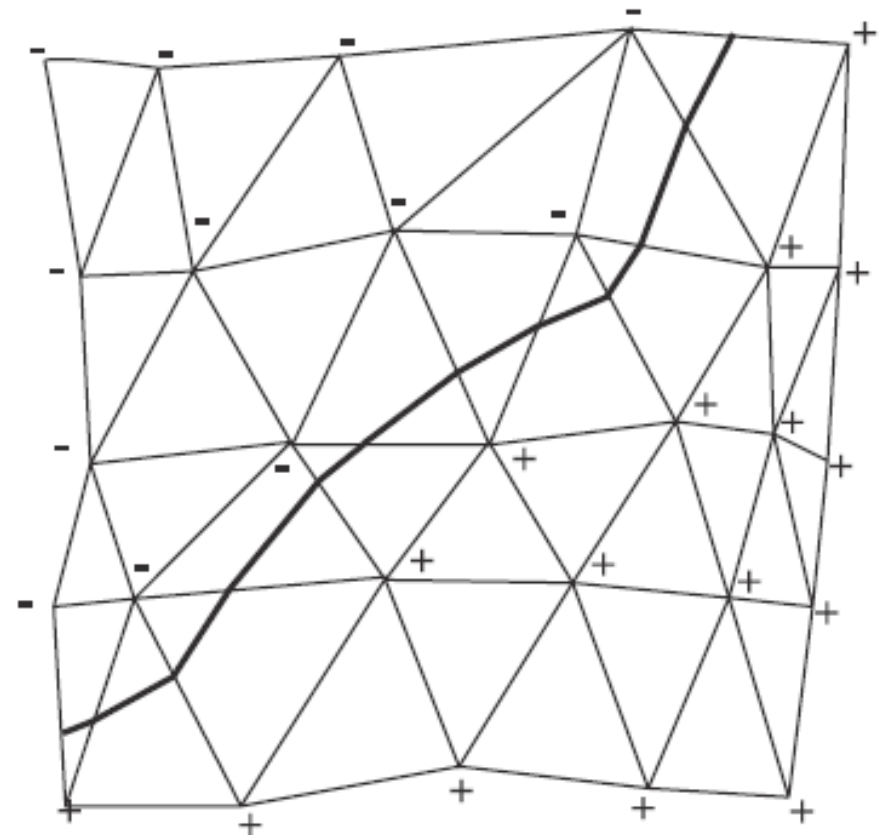
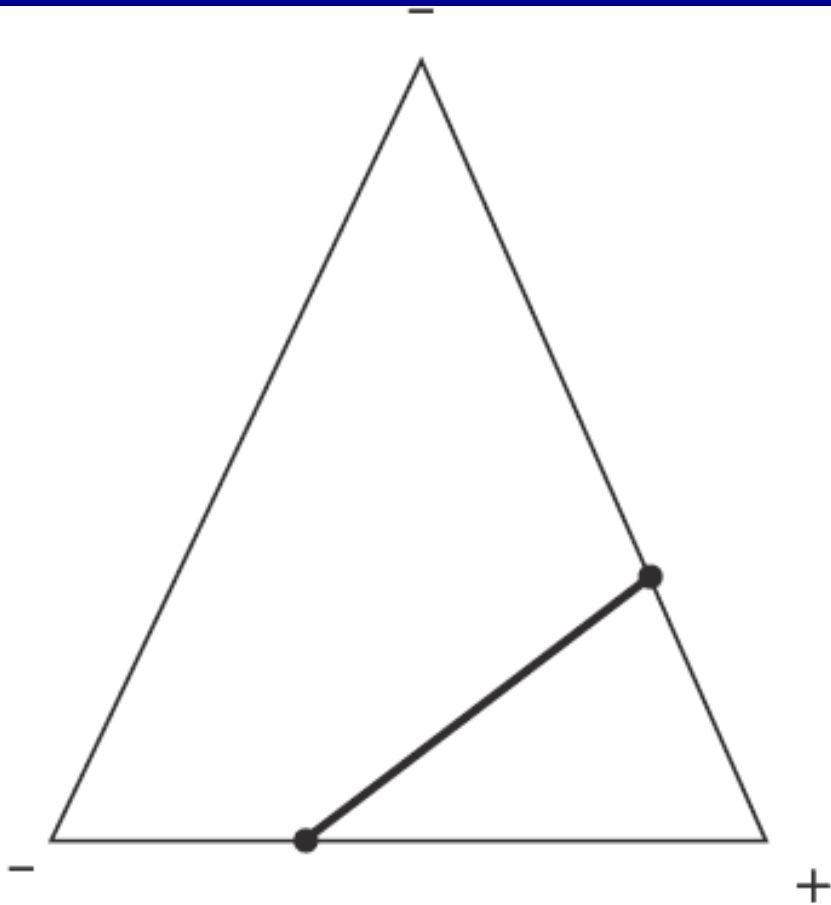
Detect Silhouettes from all triangle edges

For each vertex, evaluate:

- $d = \mathbf{n} \cdot (\mathbf{x} - \mathbf{e}) / |\mathbf{n}| \cdot |(\mathbf{x} - \mathbf{e})|$
- $s = +$ if $d > 0$; else $-$

Find $s = 0$ along face edges

Software Method



Hardware Method

Use OpenGL to draw silhouette edges (no explicit search)

Pseudo code (a three pass method)

draw shaded front faces

draw front faces in line mode, set stencil

draw back faces in line mode where stencil was set;
decrementing stencil

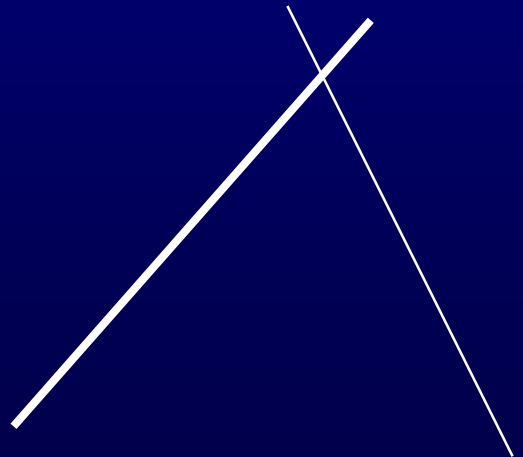
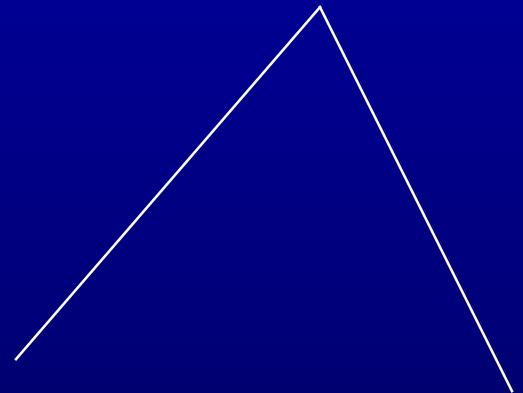
Object-based Silhouettes

Thicken all polygons

Turn two-sided shading on

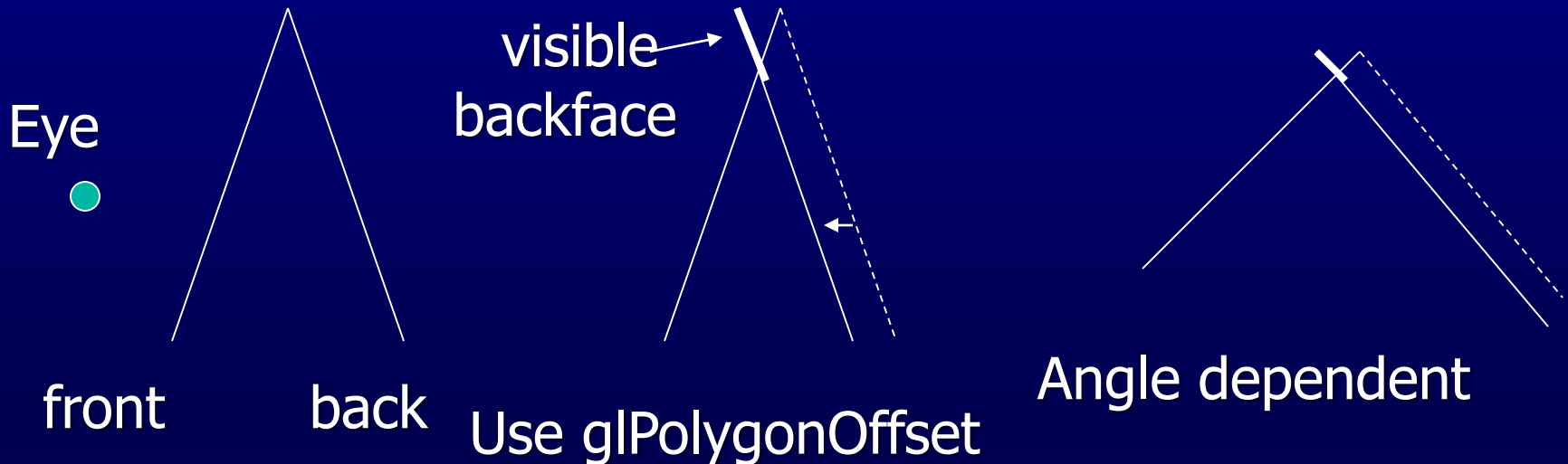
- Front face white
- Back face black

**Ramesh Raskar. Hardware
Support for Non-
photorealistic Rendering,
Proc. Graphics Hardware
2001.**



Hardware Method

Reduce to 2 pass by push the backface forward (z bias)



Issues of the Previous Method

Non-uniform z resolution needs to be taken care of – translate by $k*z$;

- **K: a scaling factor, z: the polygon distance**

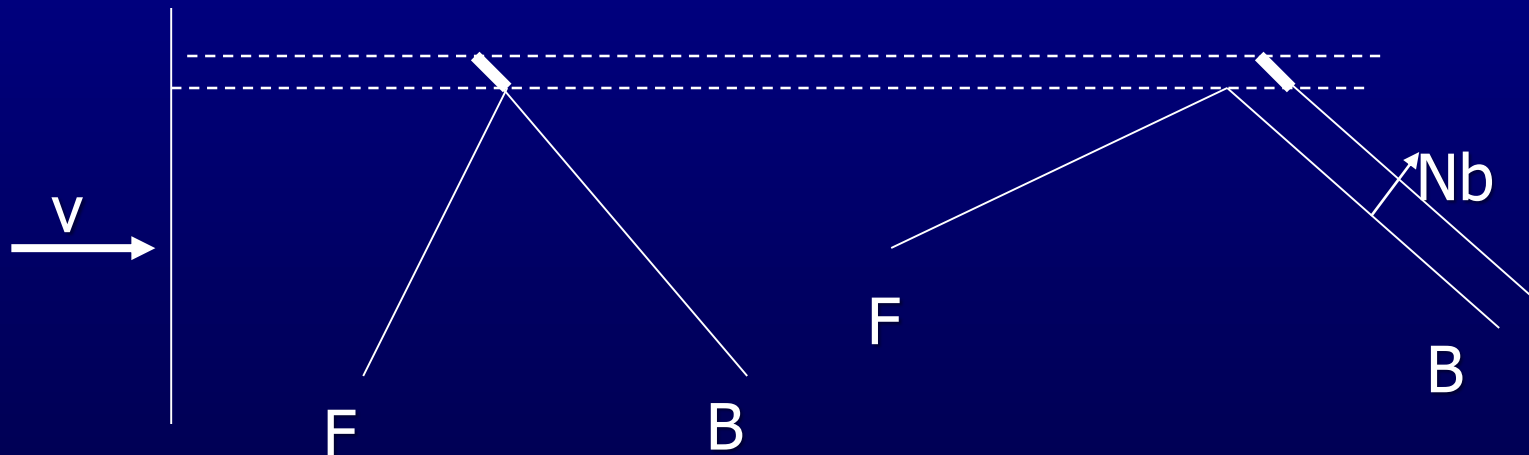
The width of the line will depend on the orientation of the back-facing polygon and front-facing polygon

Raskar and Cohen – fatten the back-facing polygons

Raskar and Cohen's Fix

The back-facing polygon edge is pushed outwards

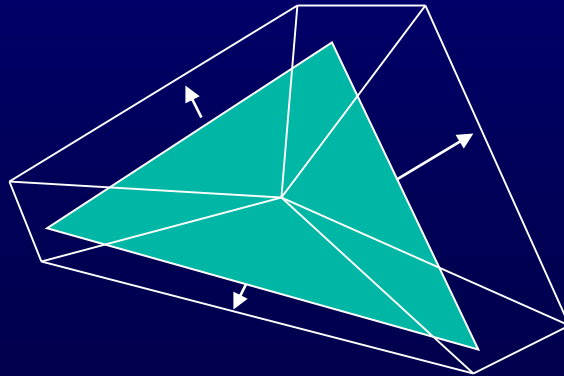
$$\text{By Offset} = K * z/V.Nb$$



The distance to push only depends on the orientation of back-facing polygon

Raskar and Cohen's Fix

In fact, each of the polygon edges needs to be pushed by a different amount: $z \cdot \sin(\alpha) / V \cdot N_b$; where $\cos(\alpha) = v \cdot e$, e is the polygon edge vector



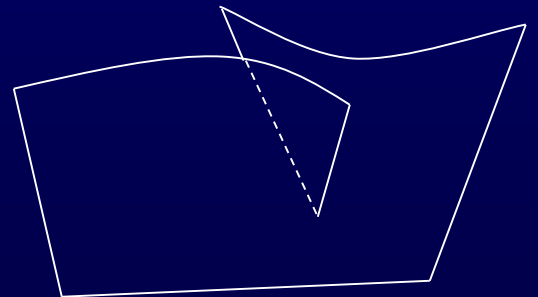
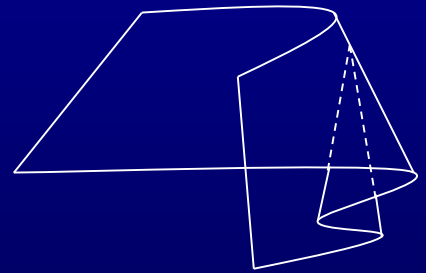
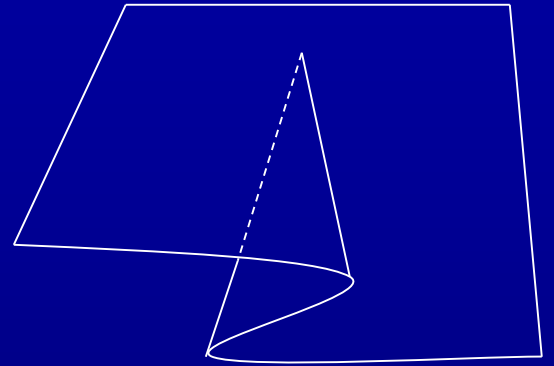
Catastrophes

Cusp vertices

- Connect concave and convex silhouette edges
- Connect more than two silhouette edges
- Connect at least one border edge

Silhouette edges are

- Convex if closer face is front facing
- Concave if closer face is back facing

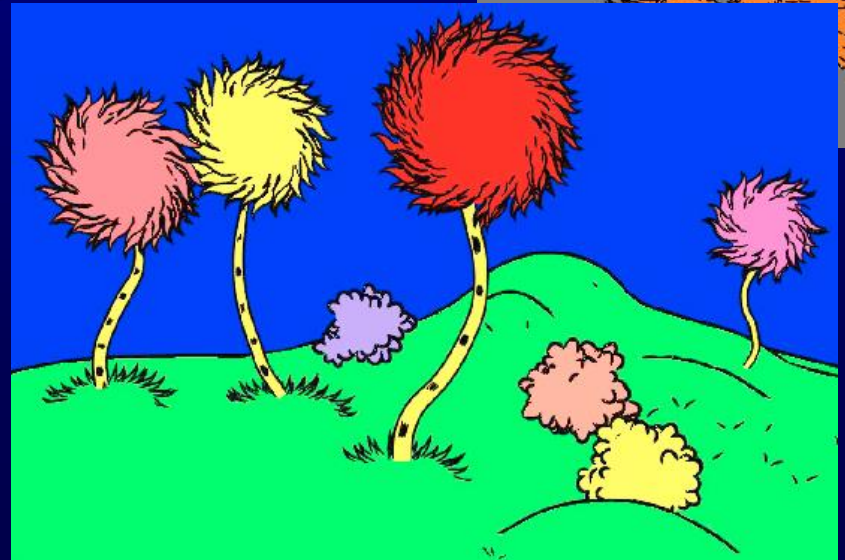
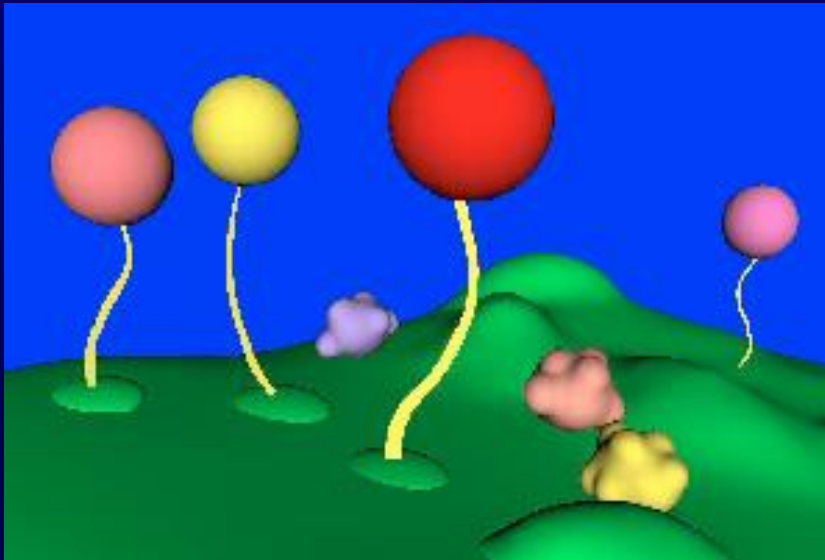
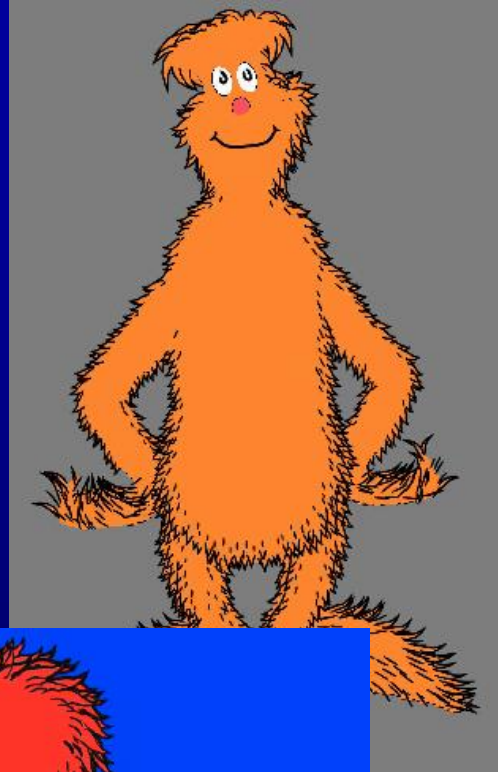


Displacement Silhouettes

Kowalski *et al.*, S99

Add displacement texture to
silhouette

Texture controlled by $N \cdot V$



Charcoal Effect

- Tessellate the polygon to smaller pieces
- Also fatten front-facing polygons with $0 < N \cdot V < 0.1$
- Assign color $I = (1 + V \cdot N) / 3$

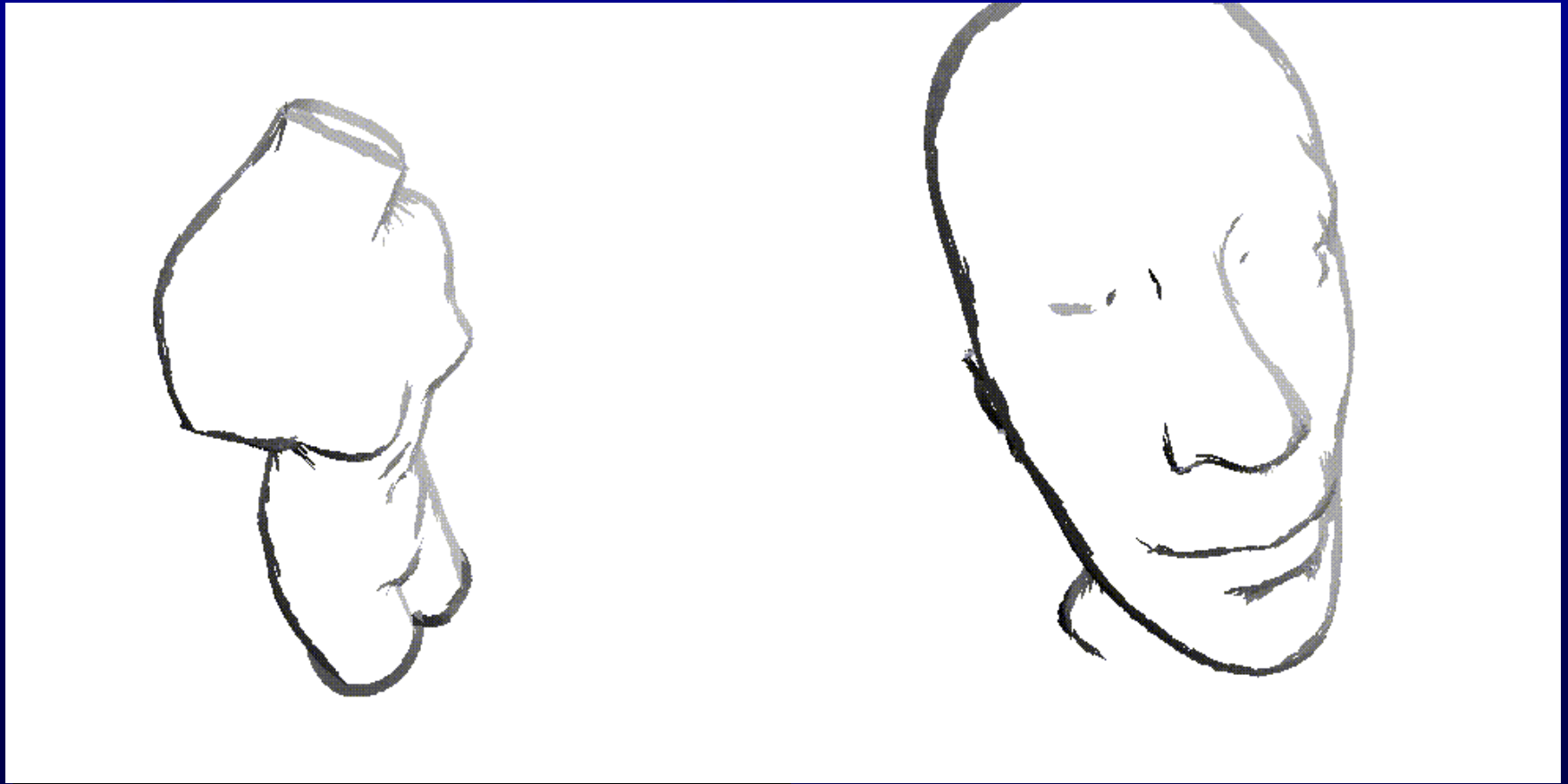
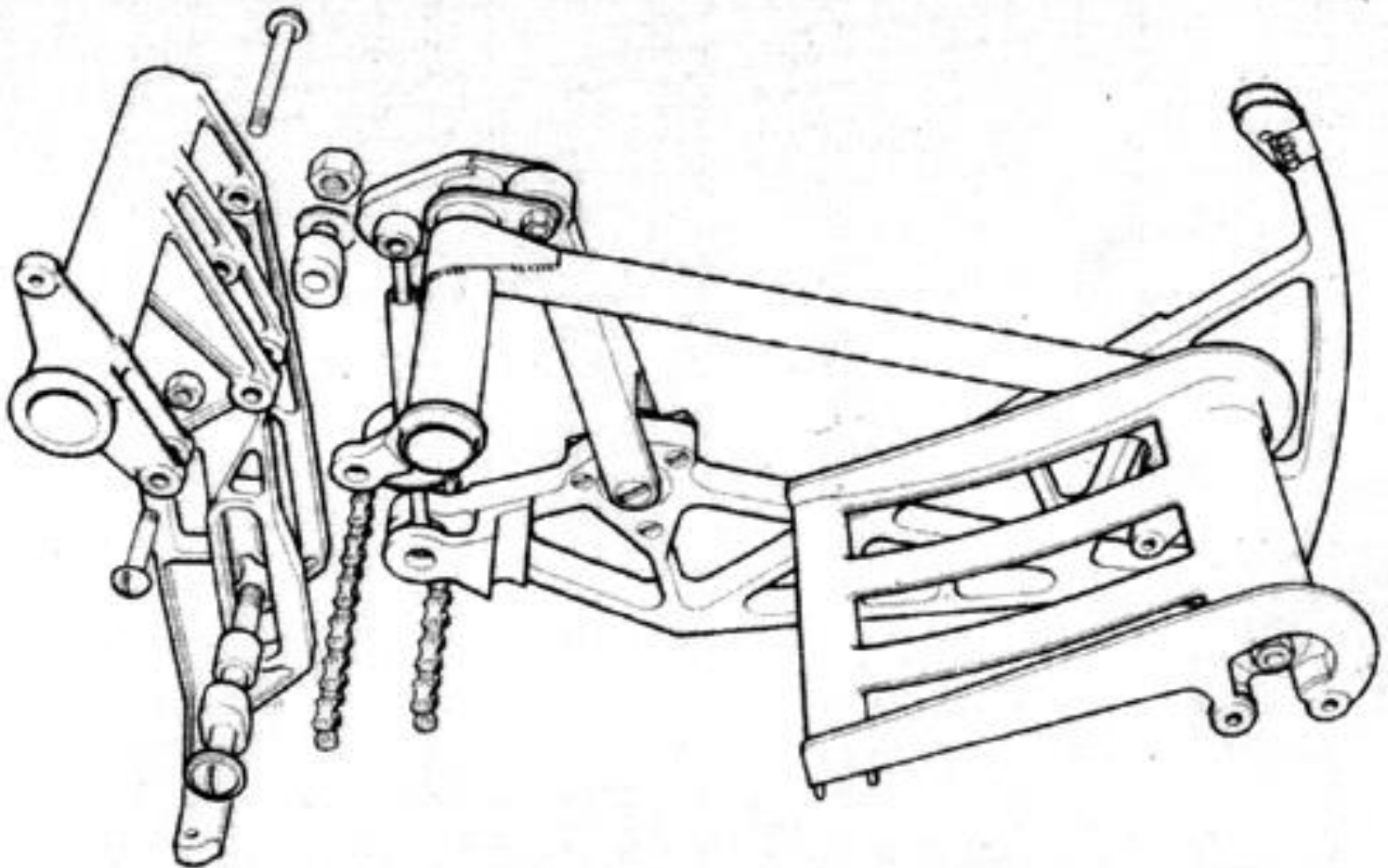


Illustration Example

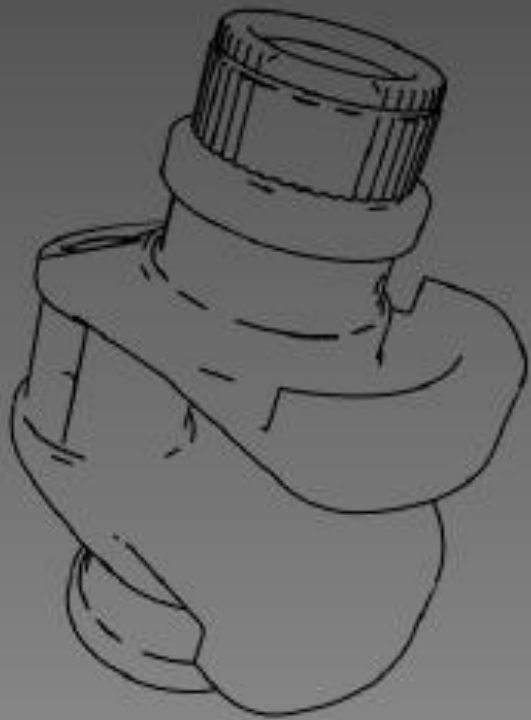


Line Weight

Some possible choices:

- Single line weight used throughout the image
- Two line weights, with heavier describing the outer edges (boundary and silhouette)
- Various light weight along a single line, emphasizing perspective effect (heavy lines in the foreground, tapering toward the farther part of the object)

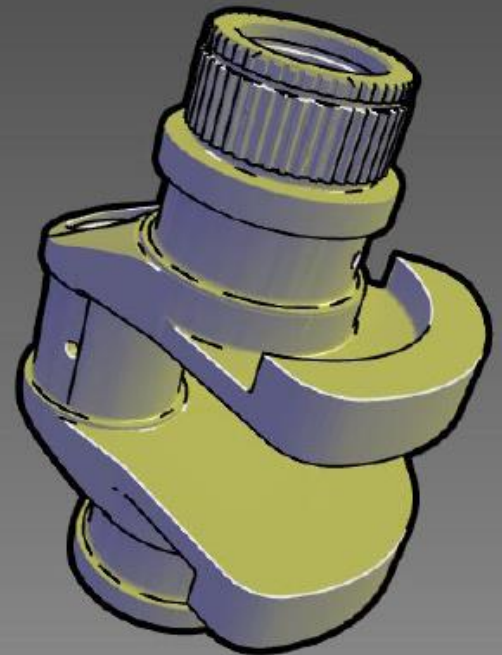
Line Weight



Line Color

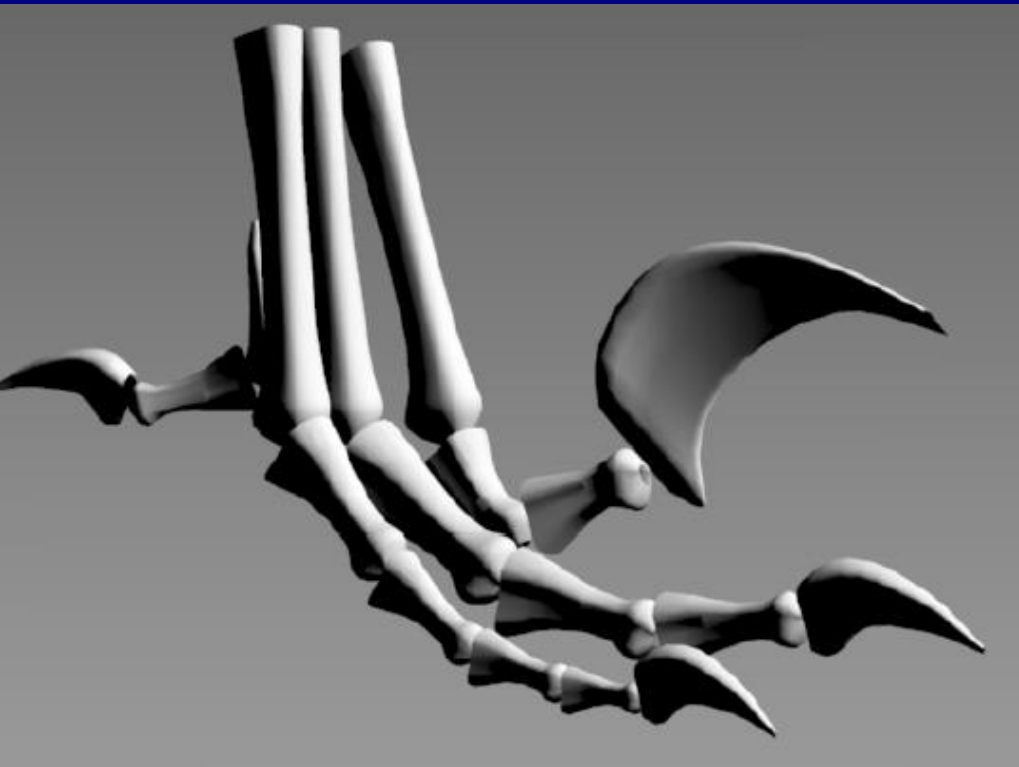
Attempt to incorporate shading

Interior lines can be drawn in white, simulating highlight



Tone Shading

The standard Phong Shading model is not always satisfactory



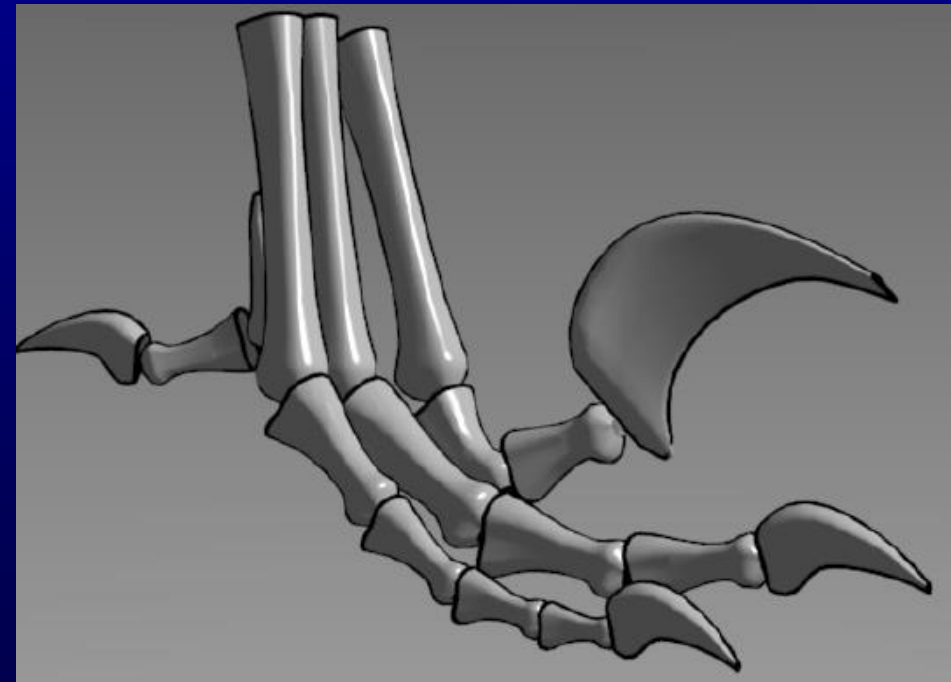
Problems in regions where
 $N \cdot L < 0$

- Only ambient colors are seen
- Difficult to deduce shapes
- Object outlines can not be seen

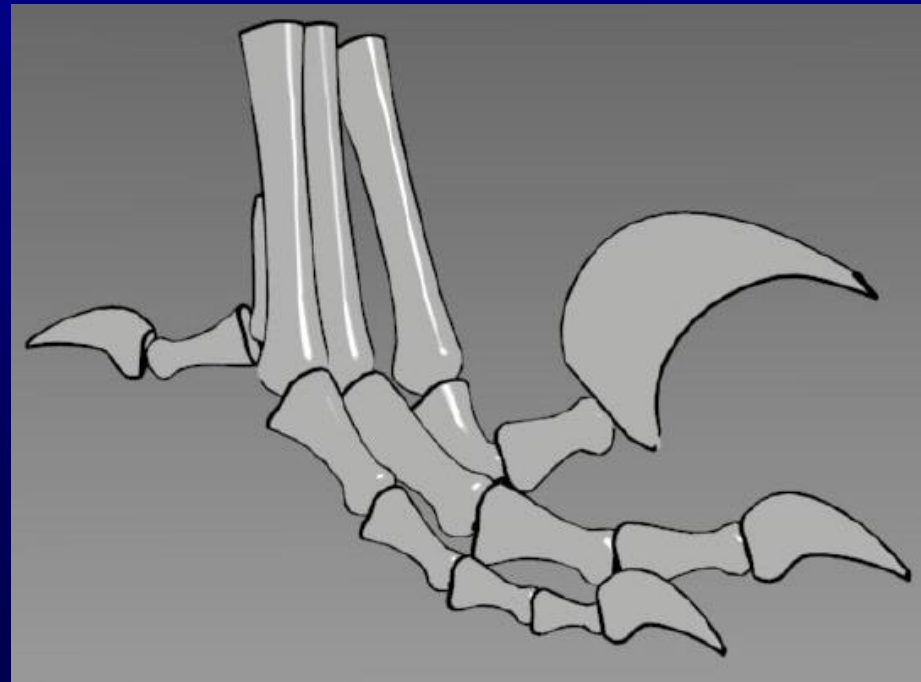
Two ad hoc Solutions

Hand-tuned ambient color

Just highlights and edge lines



Ambient is only a constant ☹️



Not enough surface detail ☹️

Effective Shading Model Needed

Shading model is insufficient

Lost shape information

- Especially in the areas of subtle curvature
(small claws above)

Not automatic, lots of hand-tuning

Tone Shading Goals

To include shading in an image with back edge lines and white highlights visible

- Use a compressed dynamic range for shading
- Use color visually distinct from black and white

Create Undertone

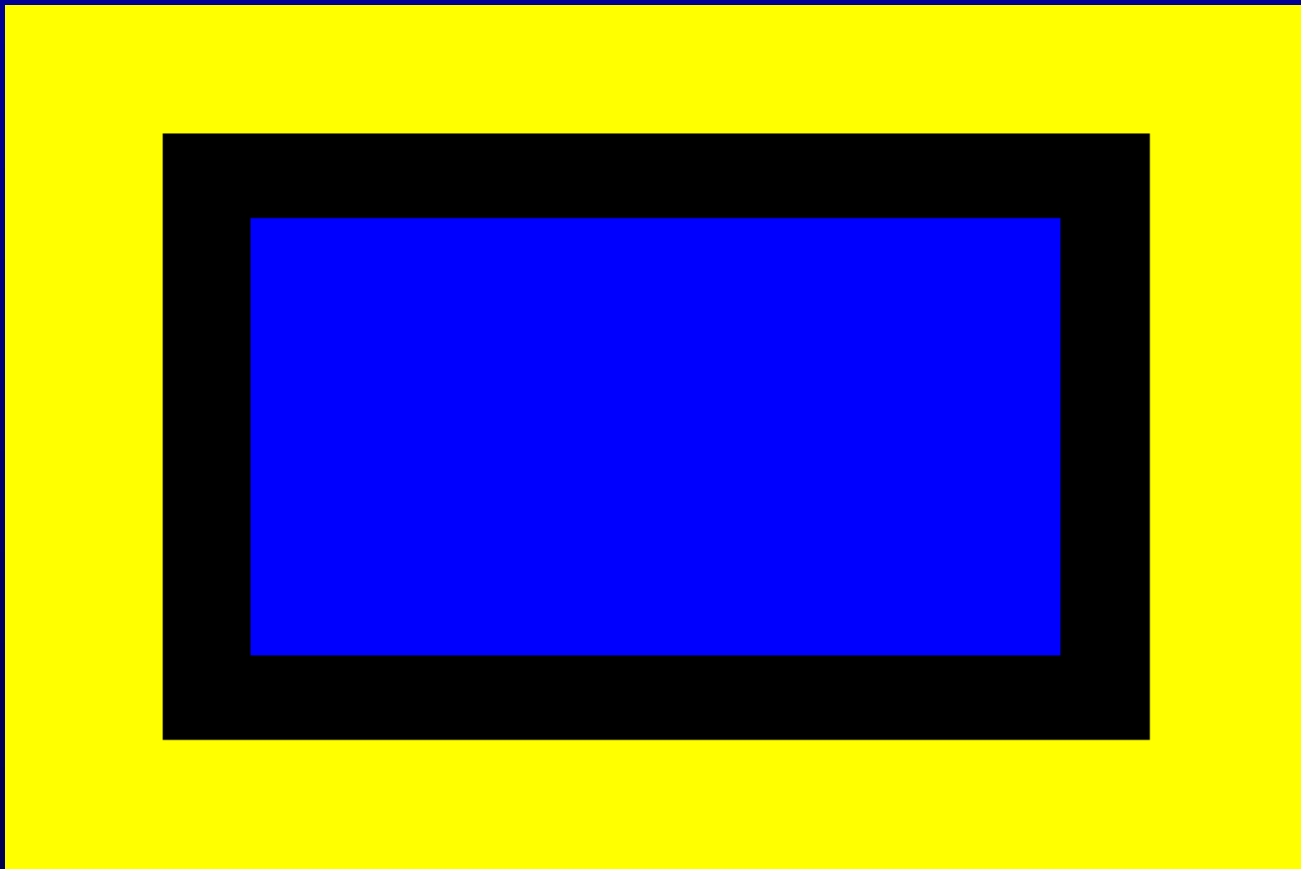
- To further differentiate different surface orientations, we can use cool-to-warm color undertones
- Cool colors – blue, violet, green
- Warm colors – red, orange, yellow



warm

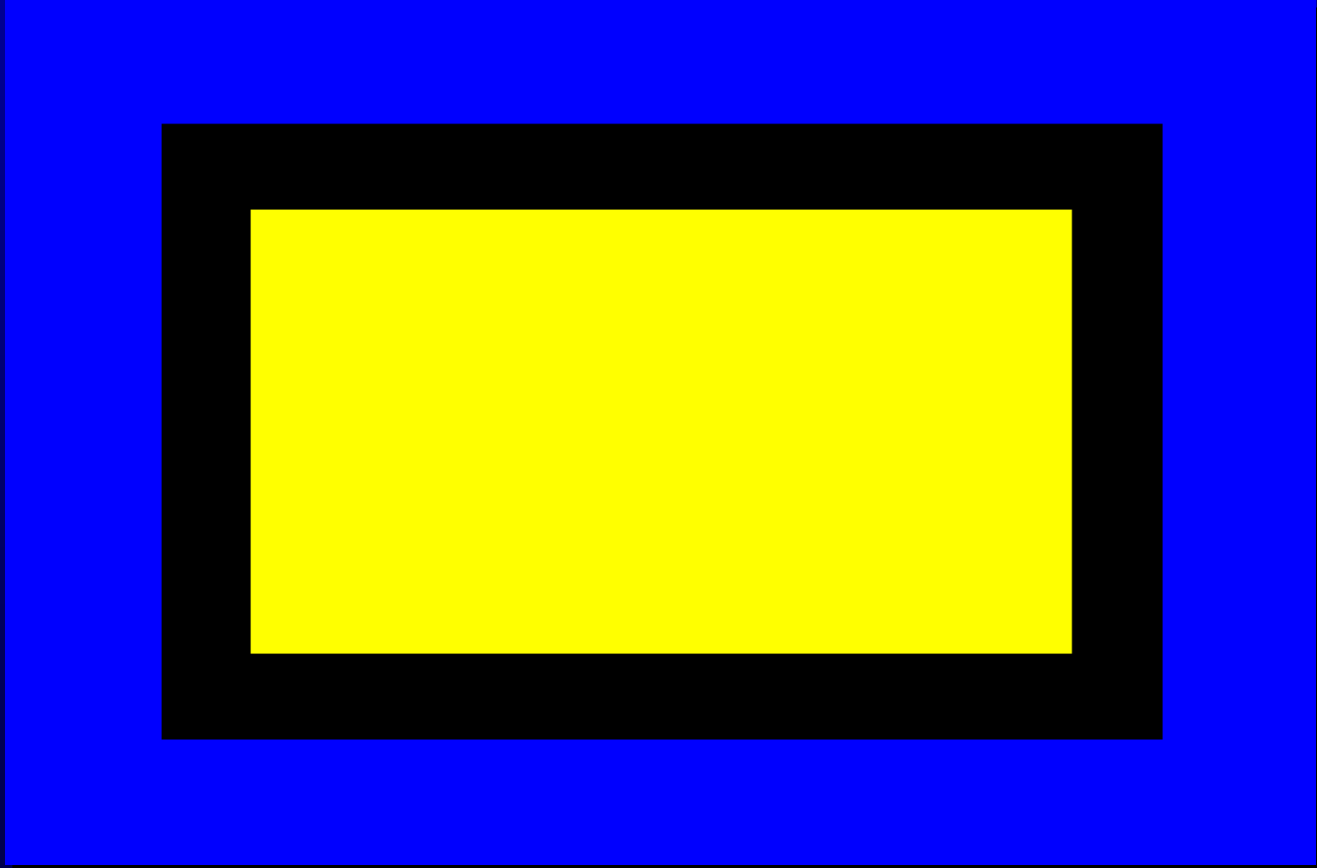
cold

Test Your Perception



Which color (yellow or blue) seems closer?

Test Your Perception



What about now?

Use Warm-to-cool Undertone

We can modify the diffuse Phong Lighting Model
(Blend cool and warm color)

$$I = (1 + L \cdot N) / 2 * K_{cool} + (1 - (1 + L \cdot N) / 2) * K_{warm}$$

The Light vector should be place in perpendicular to the gaze direction (usually place at up and to the right)

Tone Shading Equation

$$\mathbf{K}_{\text{cool}} = \mathbf{K}_{\text{blue}} + \alpha \mathbf{K}_d \text{ (undertone and tone)}$$

$$\mathbf{K}_{\text{warm}} = \mathbf{K}_{\text{yellow}} + \beta \mathbf{K}_d \text{ (undertone and tone)}$$

$$\mathbf{K}_{\text{blue}} = (0, 0, b) \text{ } b \text{ in } [0, 1]$$

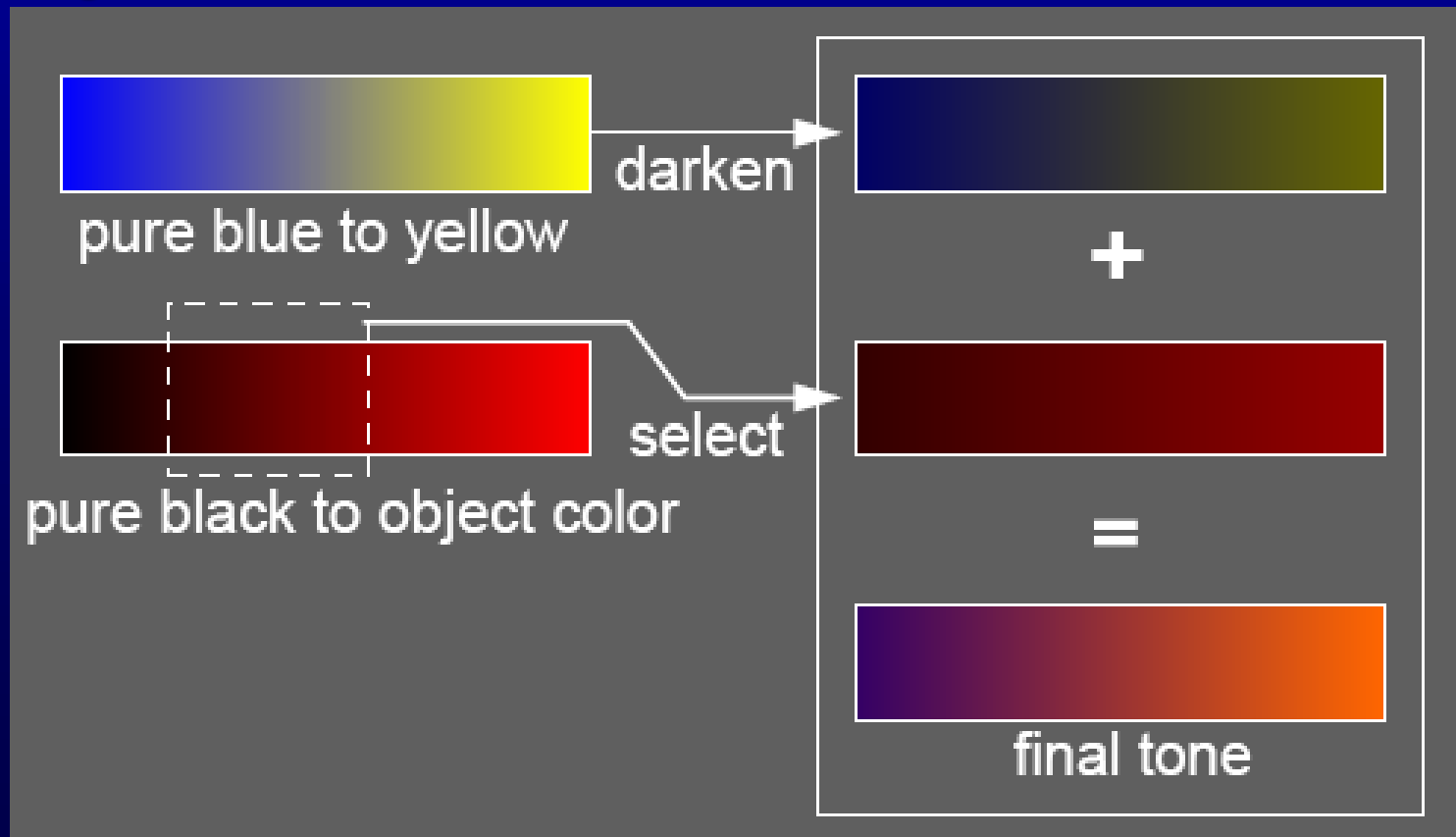
$$\mathbf{K}_{\text{yellow}} = (\gamma, \gamma, 0) \text{ } \gamma \text{ in } [0, 1]$$

α and β are user-specified parameters

\mathbf{K}_d is the object diffuse color

Blend Tone and Undertone

- Add warm-to-cool undertone to a red object

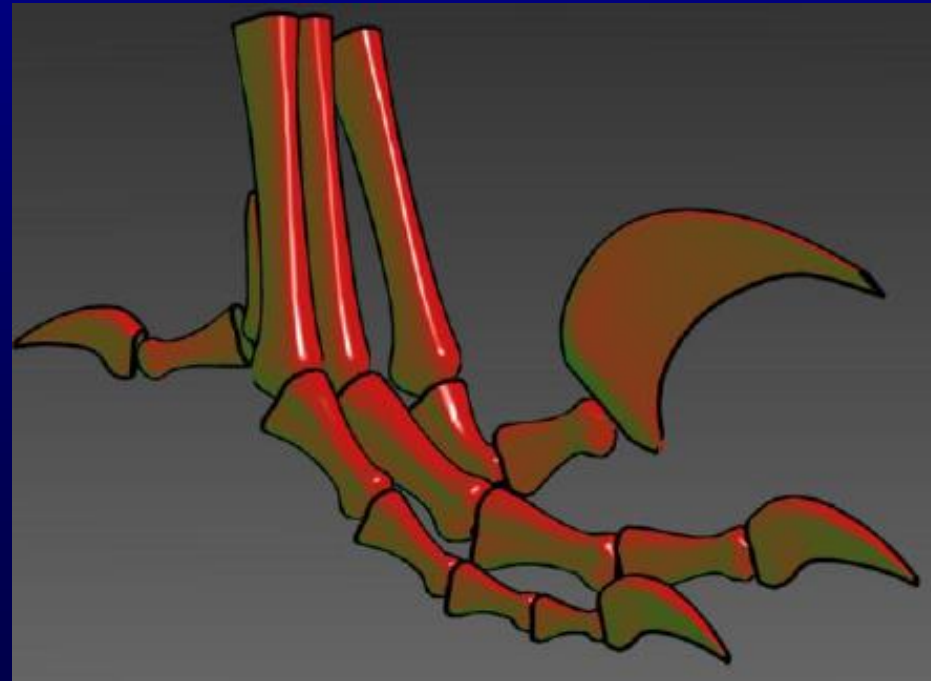


Reduce Dynamic Range

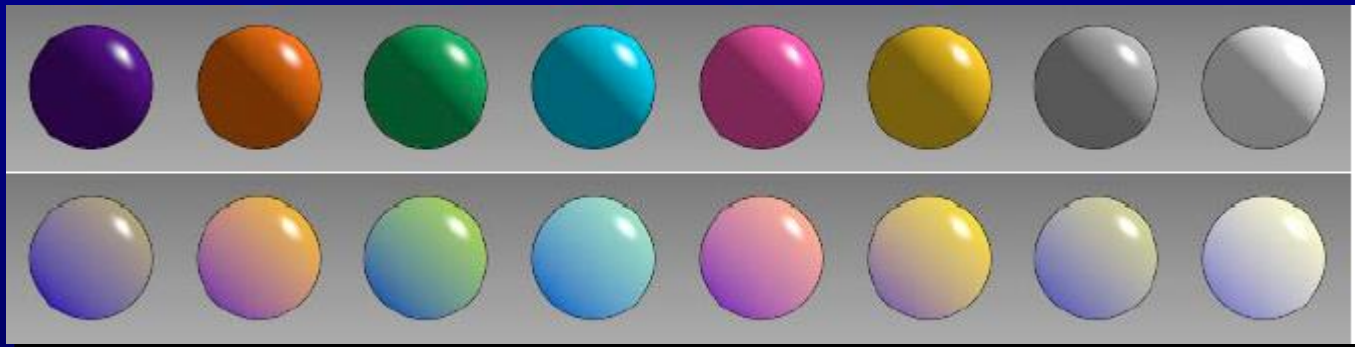
One way to compress dynamic color range is to use colors of different tones

- Add gray to a color to generate different tones

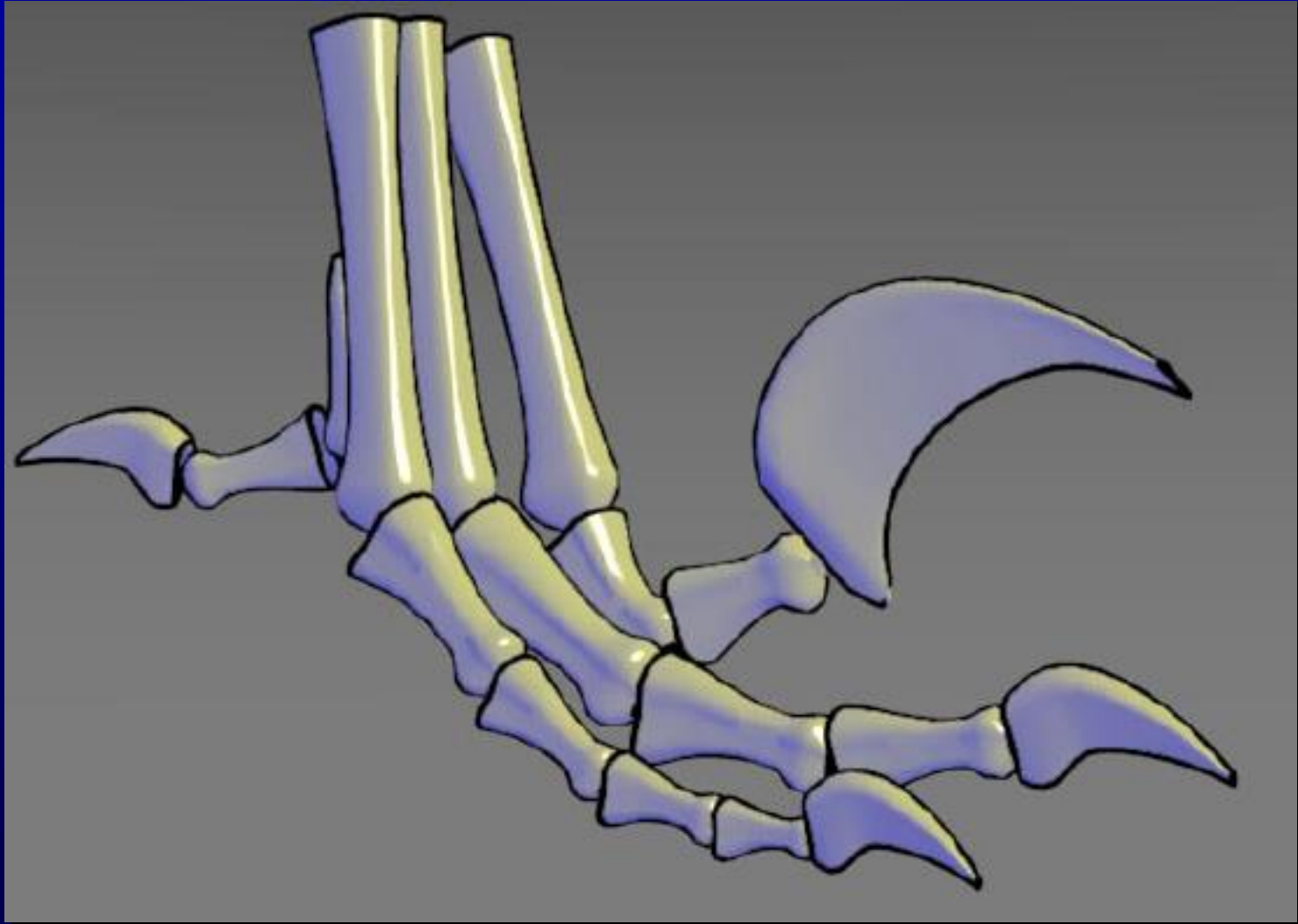
Unnatural color
Lack of luminance
difference



Phong and Tone Shadings

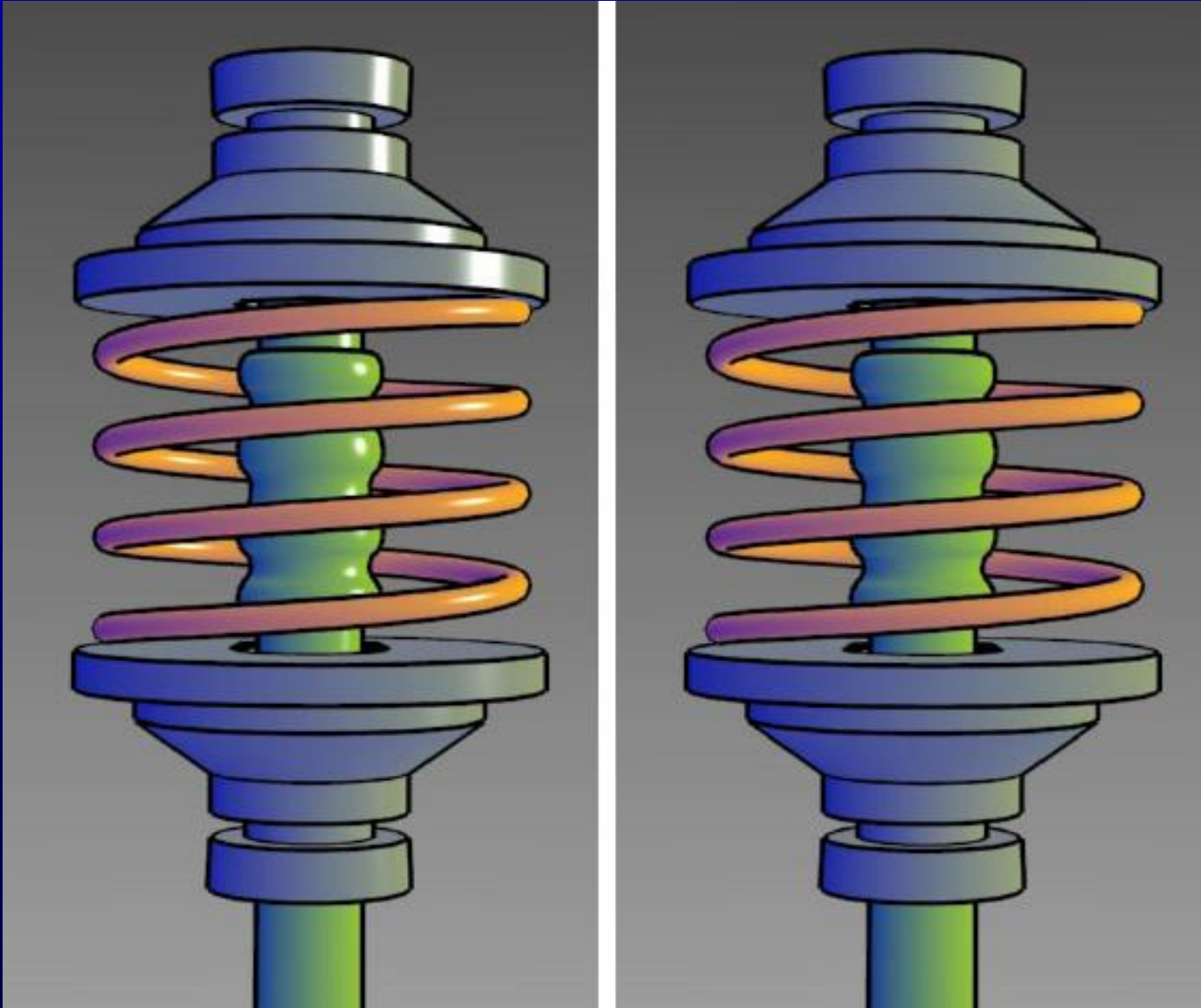


Tone Shading Results

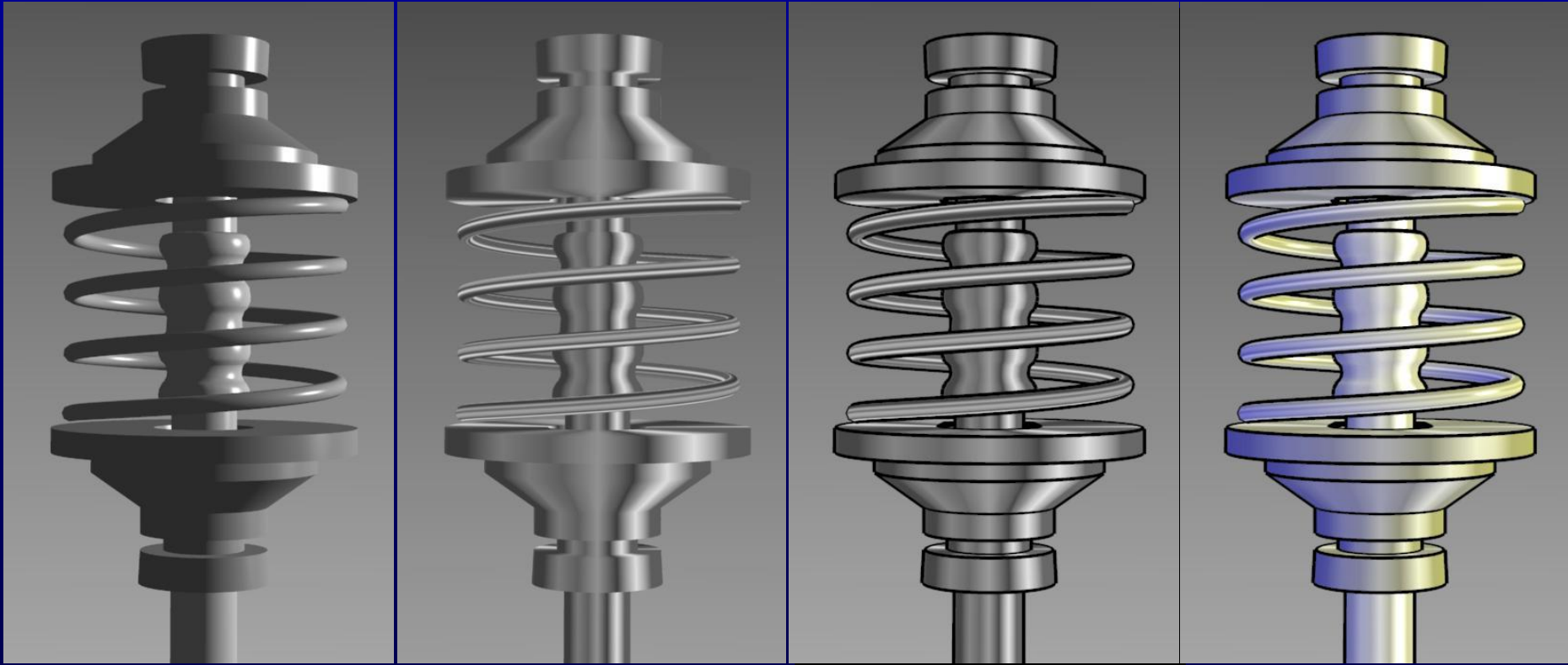


$b = 0:55, \gamma = 0:3, \alpha = 0:25, \beta = 0:5$

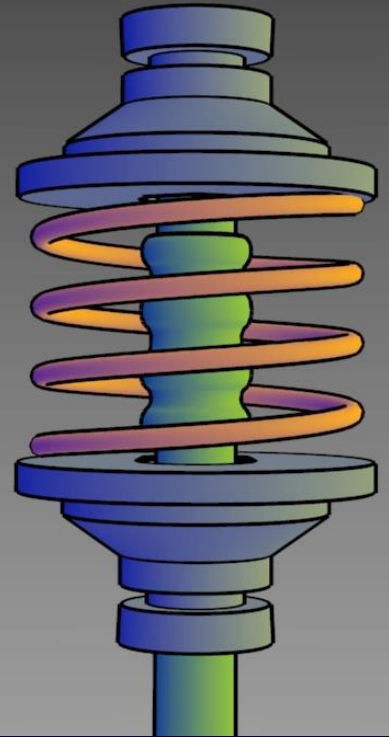
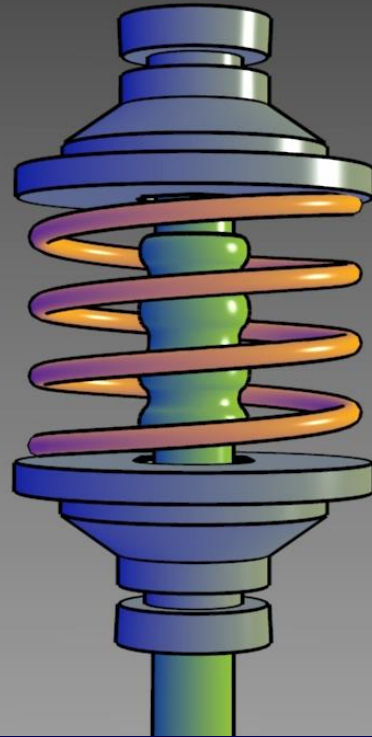
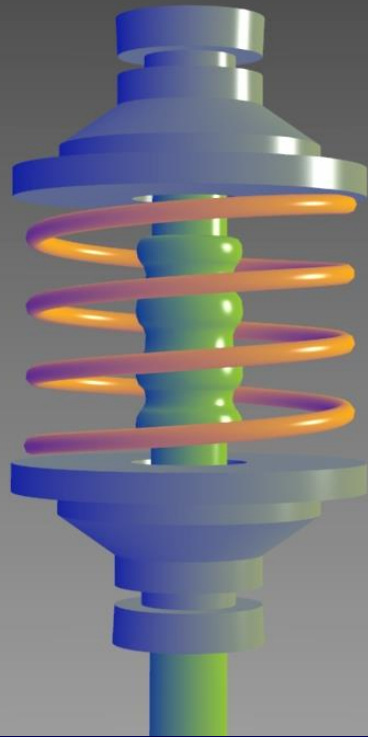
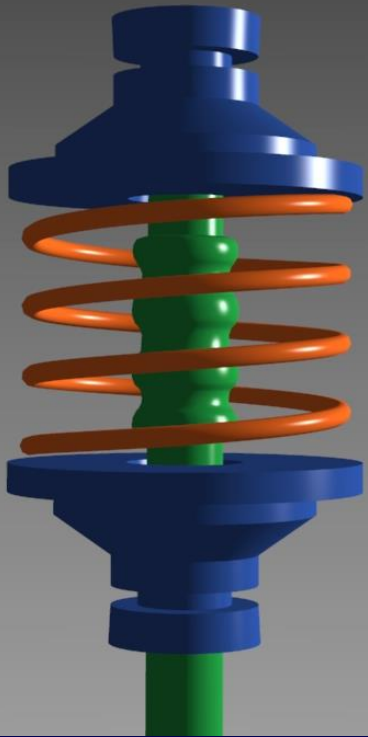
Tone Shading Results



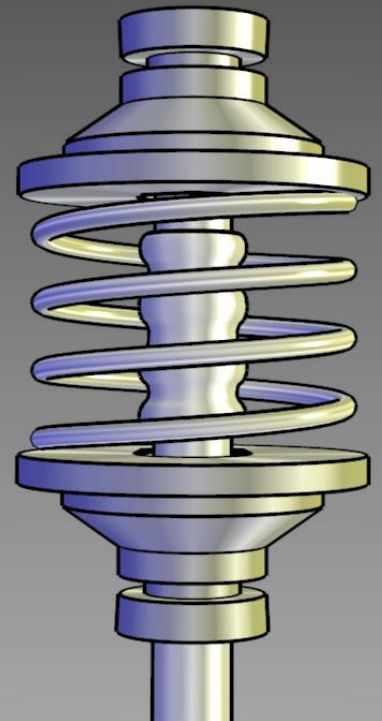
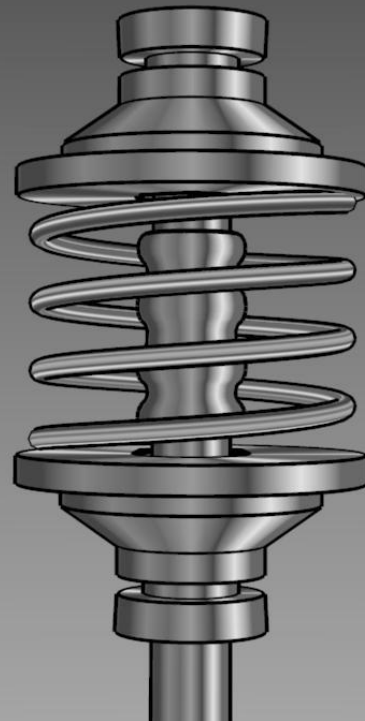
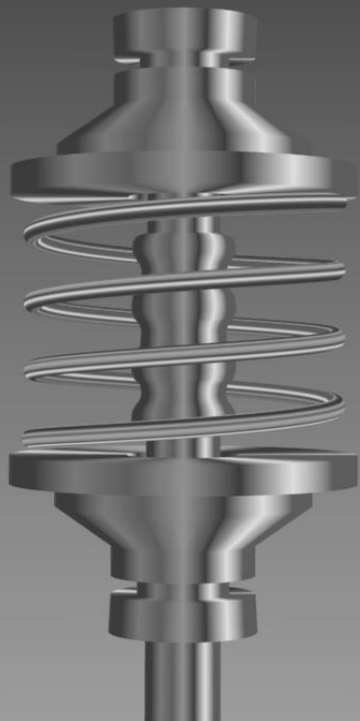
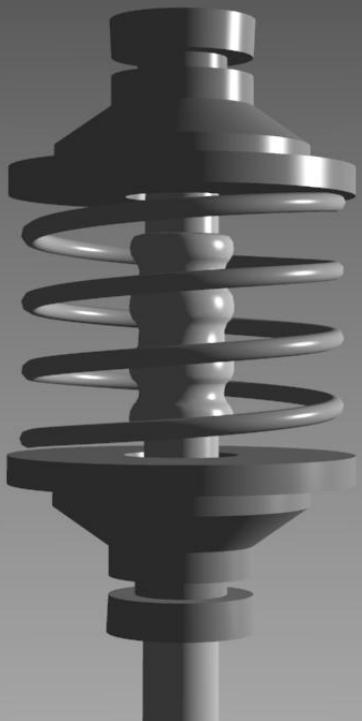
Metal Objects



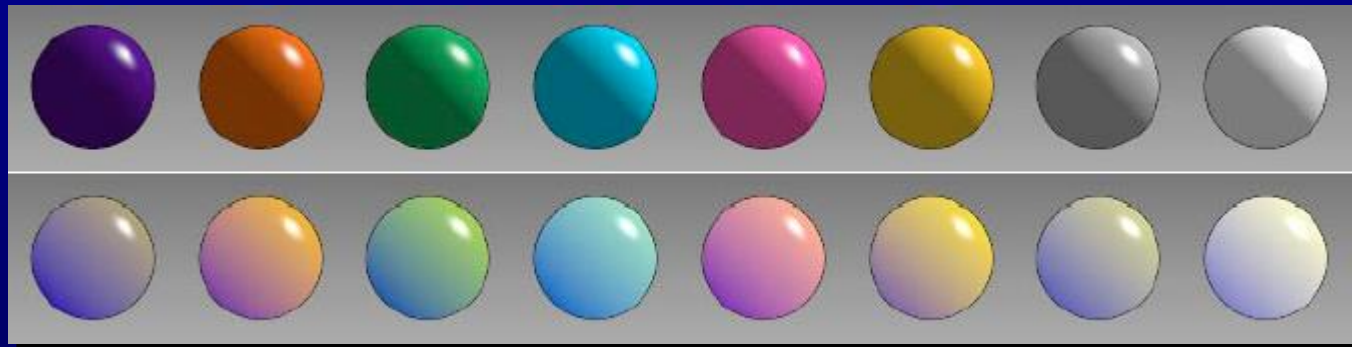
Plastic Renderings



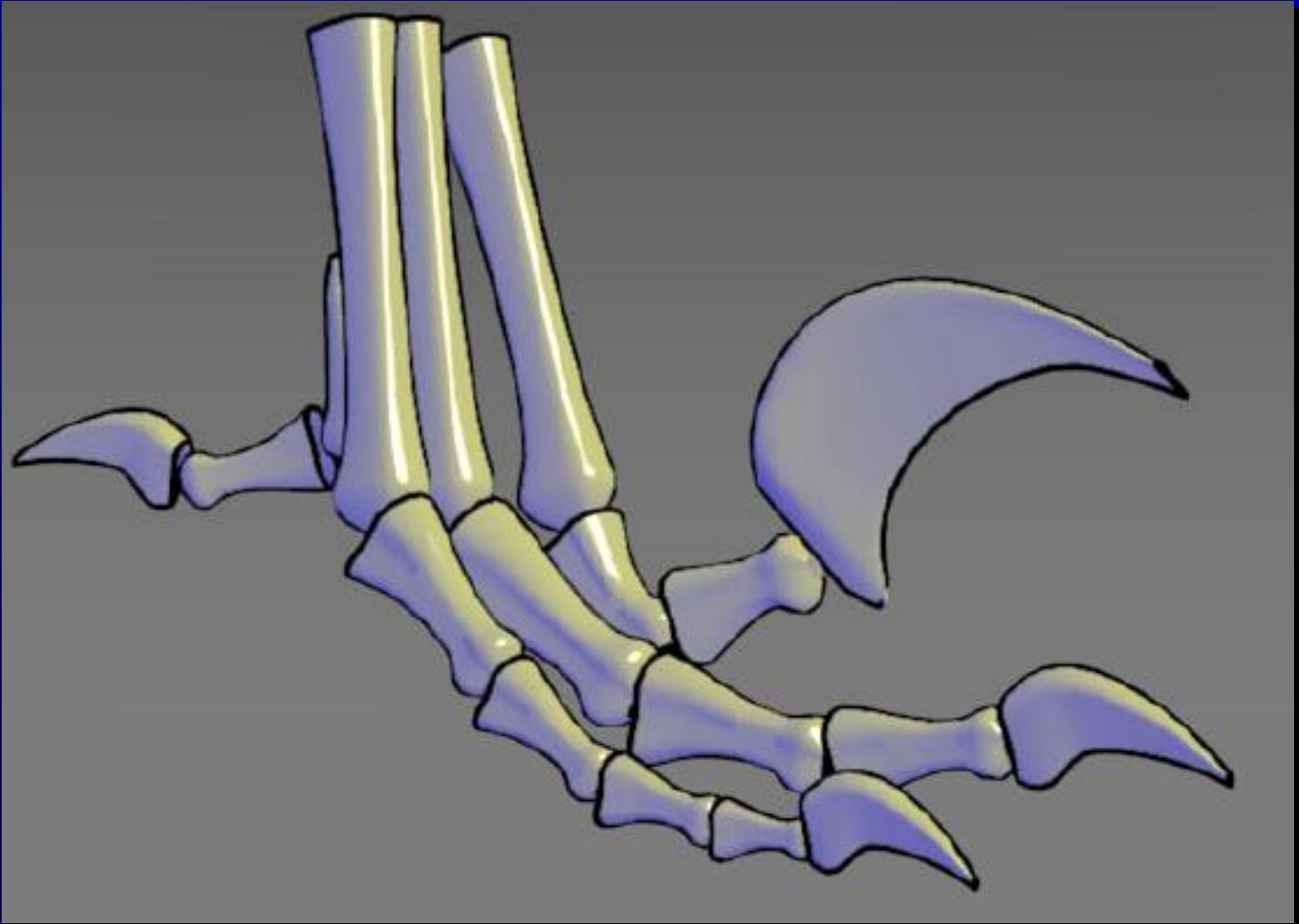
Metallic Renderings



Phong and Tone Shadings

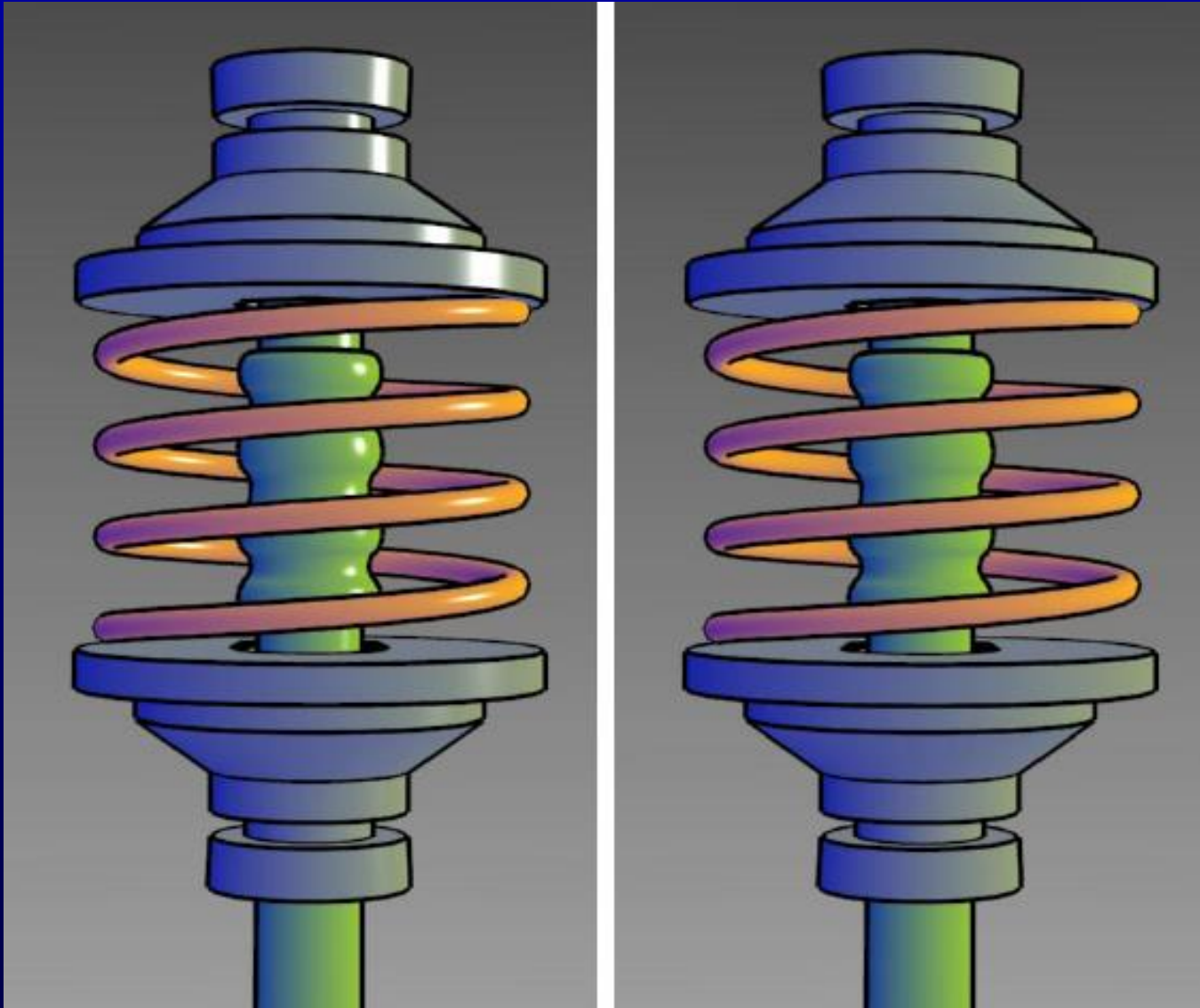


Tone Shading Results

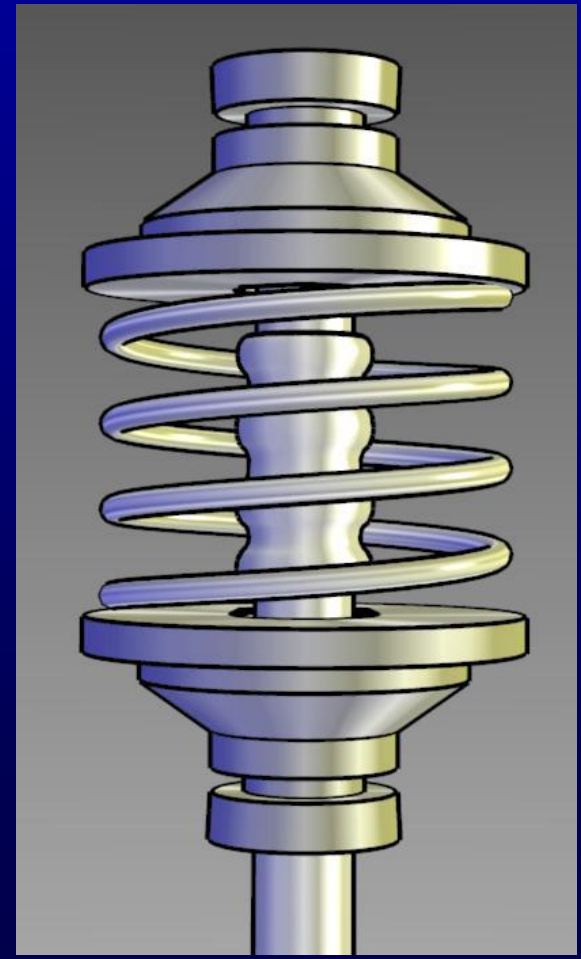
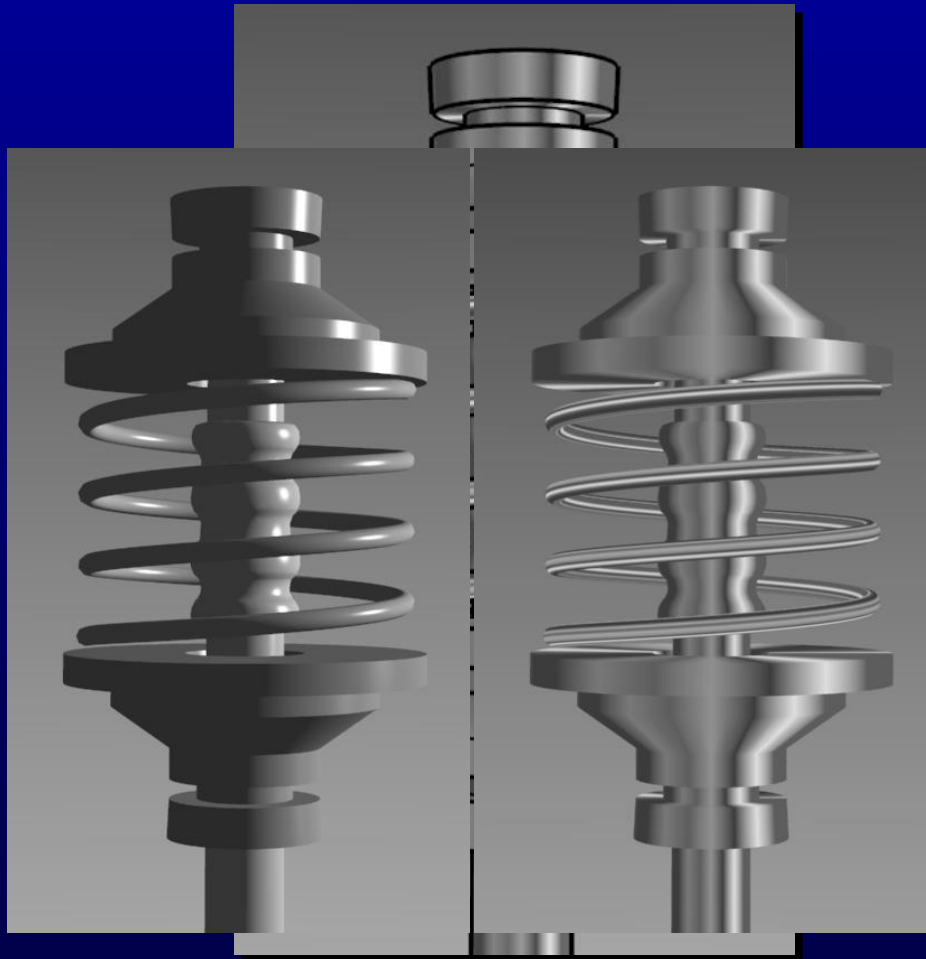


$b = 0:55, \gamma = 0:3, \alpha = 0:25, \beta = 0:5$

Tone Shading Results



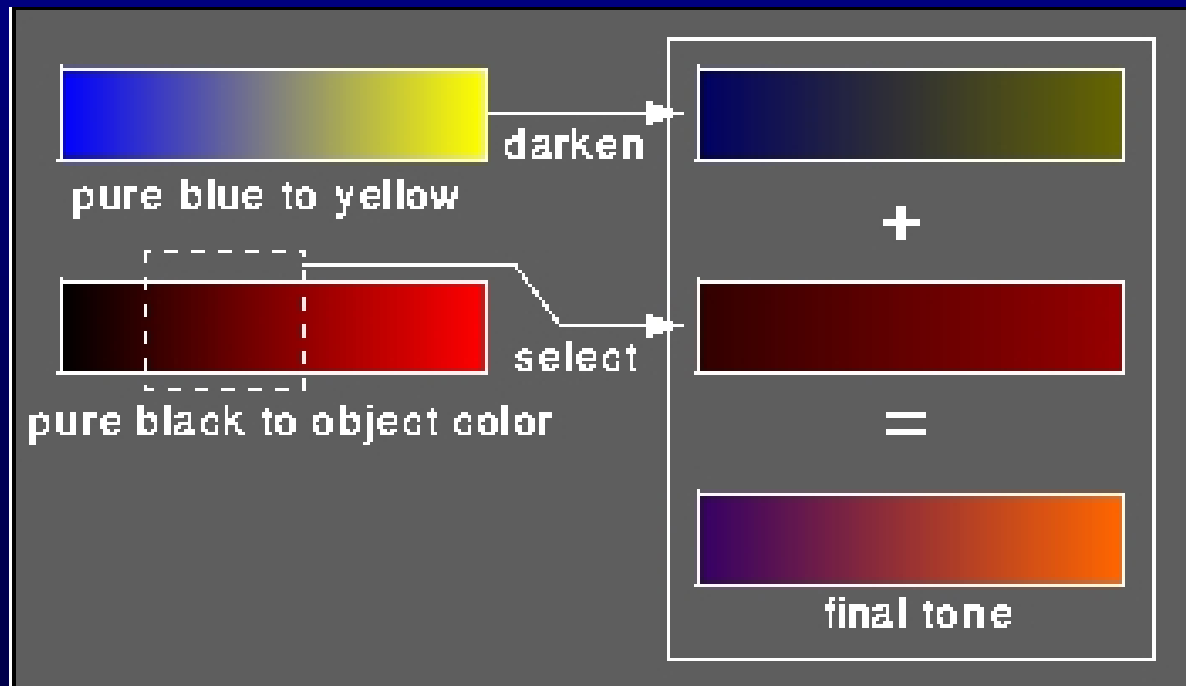
Metal Objects



Hue and Luminance Shifts

Amy Gooch, Bruce Gooch, Peter Shirley,
Elaine Cohen. A Non-Photorealistic Lighting
Model For Automatic Technical Illustration.
Proc. SIGGRAPH 98.

<http://www.cs.utah.edu/~gooch/SIG98/abstract.html>



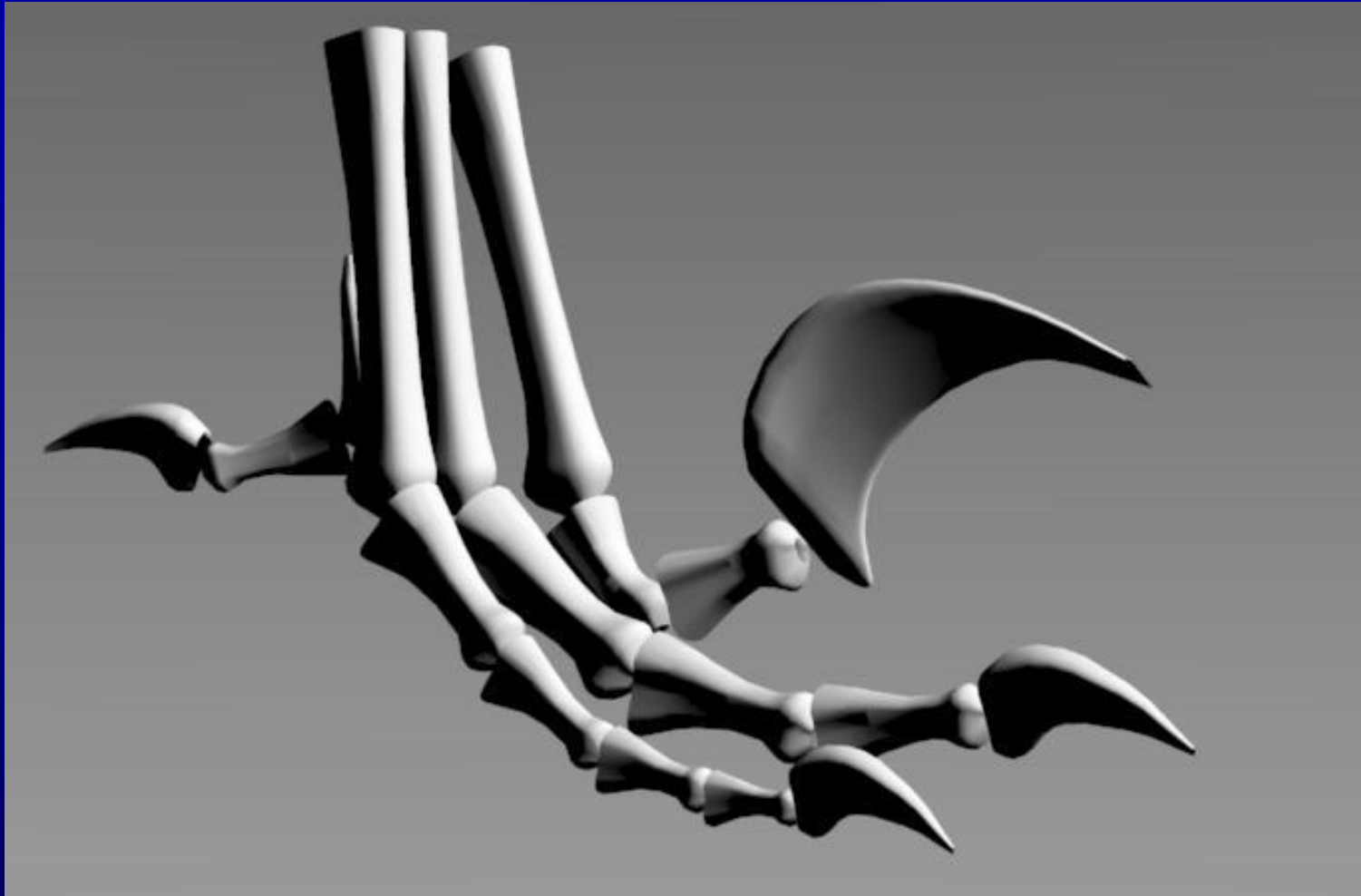
Hue and Luminance Shifts

Phong shaded spheres with edges and highlights



Spheres shaded with hue and luminance shift, and highlights and edges.





Diffuse shaded image. Black shaded regions hide details, especially in the small claws; edge lines could not be seen if added. Highlights and fine details are lost in the white shaded regions.

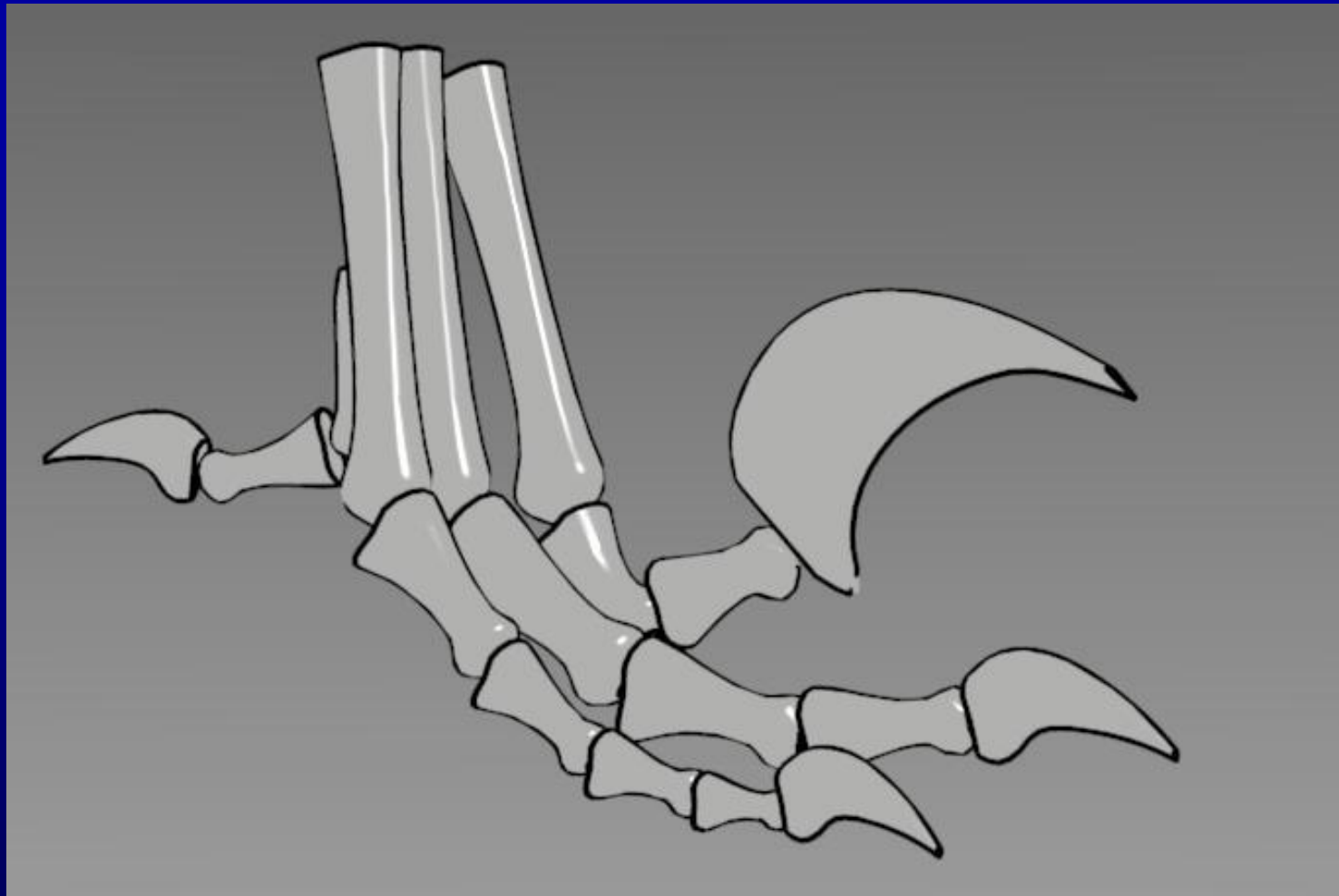
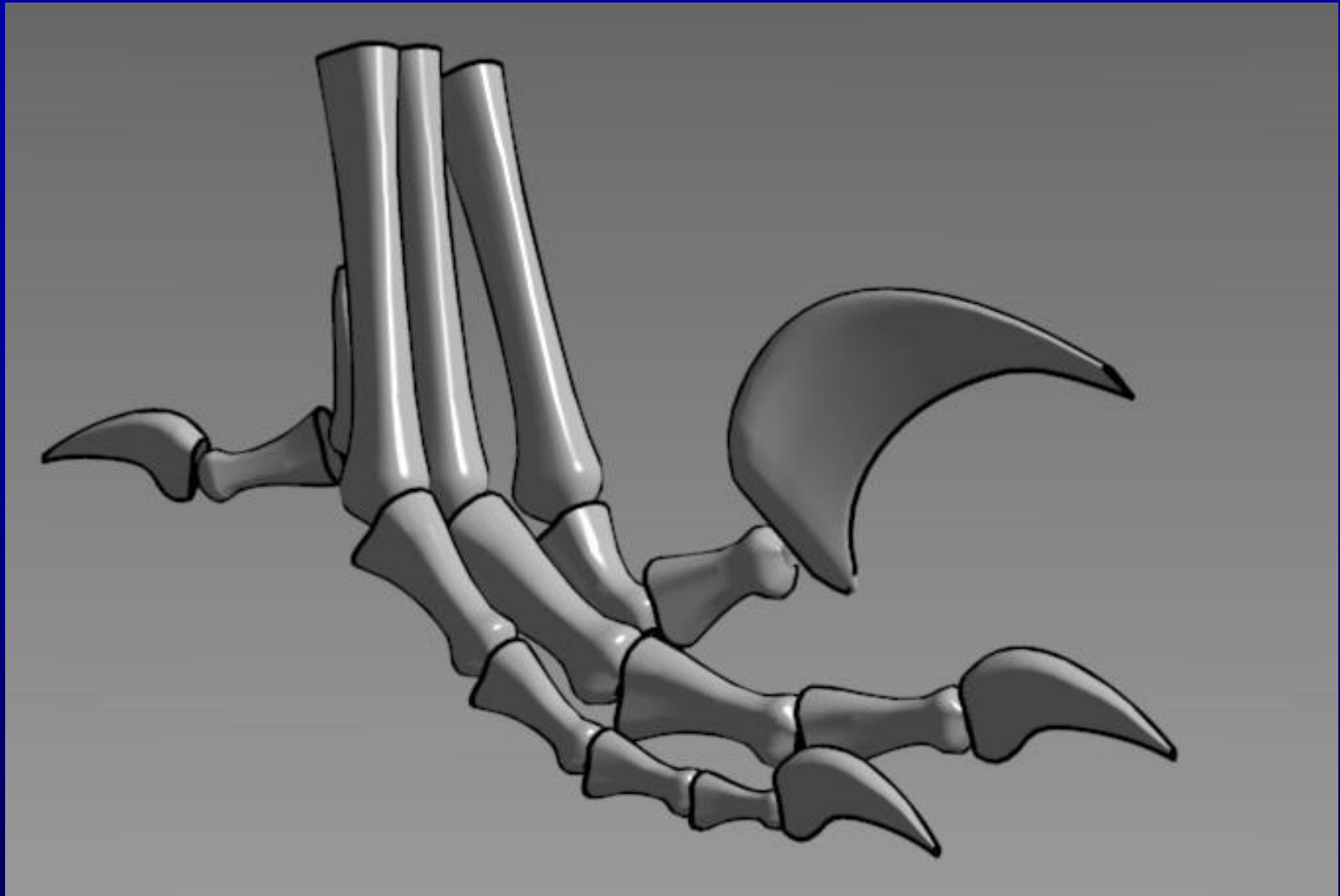
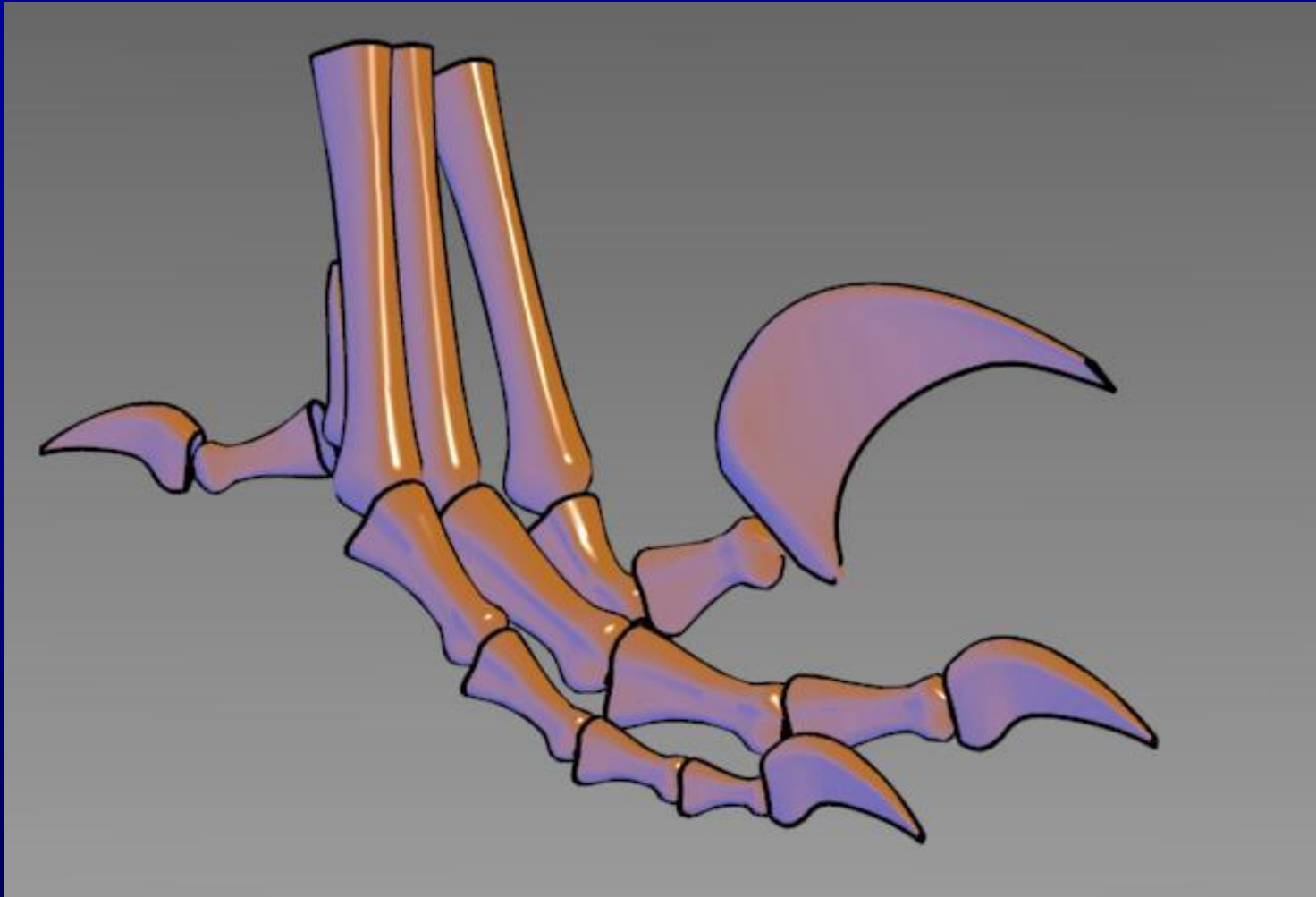


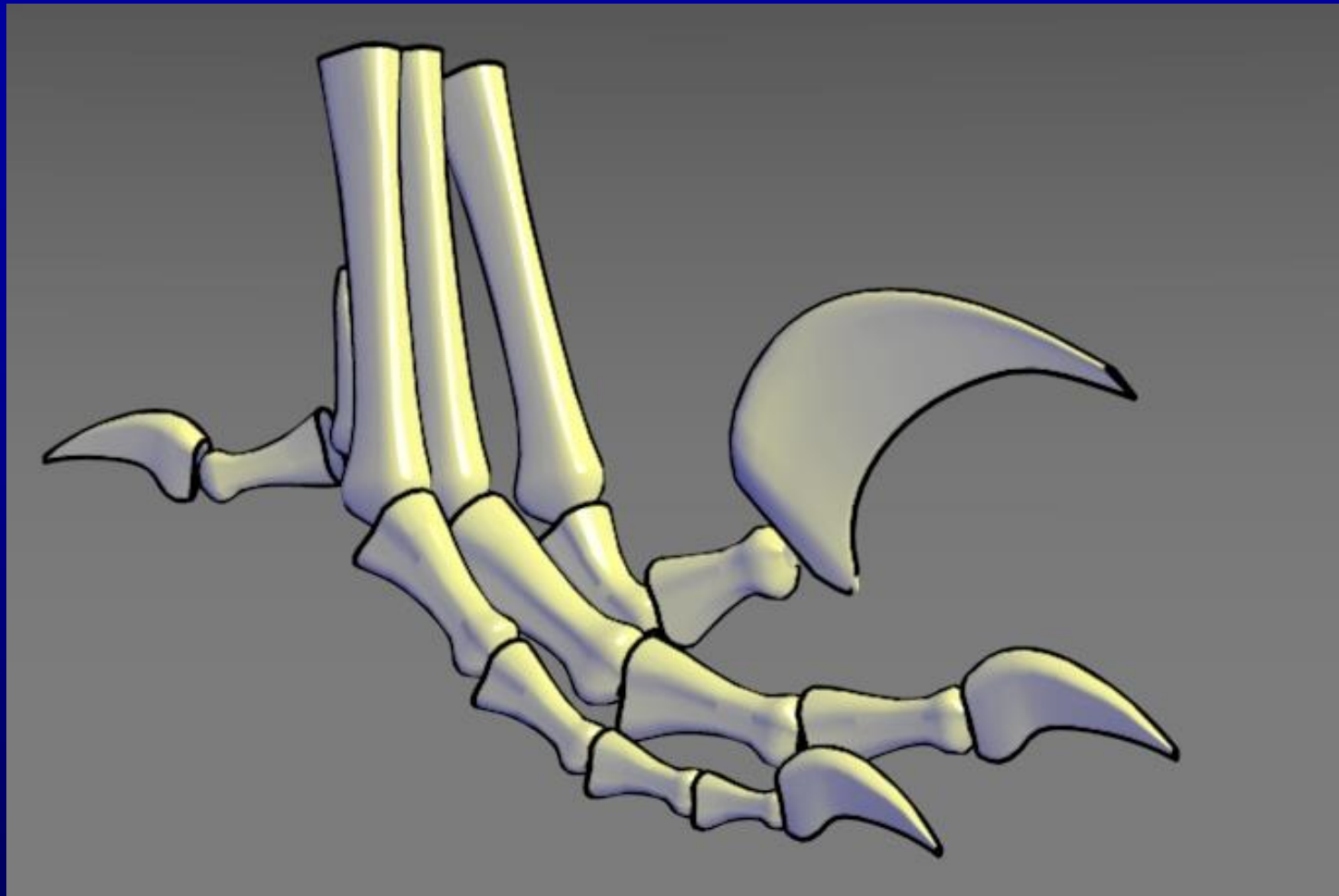
Image with only highlights and edges. The edge lines provide divisions between object pieces and the highlights convey the direction of the light. Some shape information is lost, especially in the regions of high curvature of the object pieces.



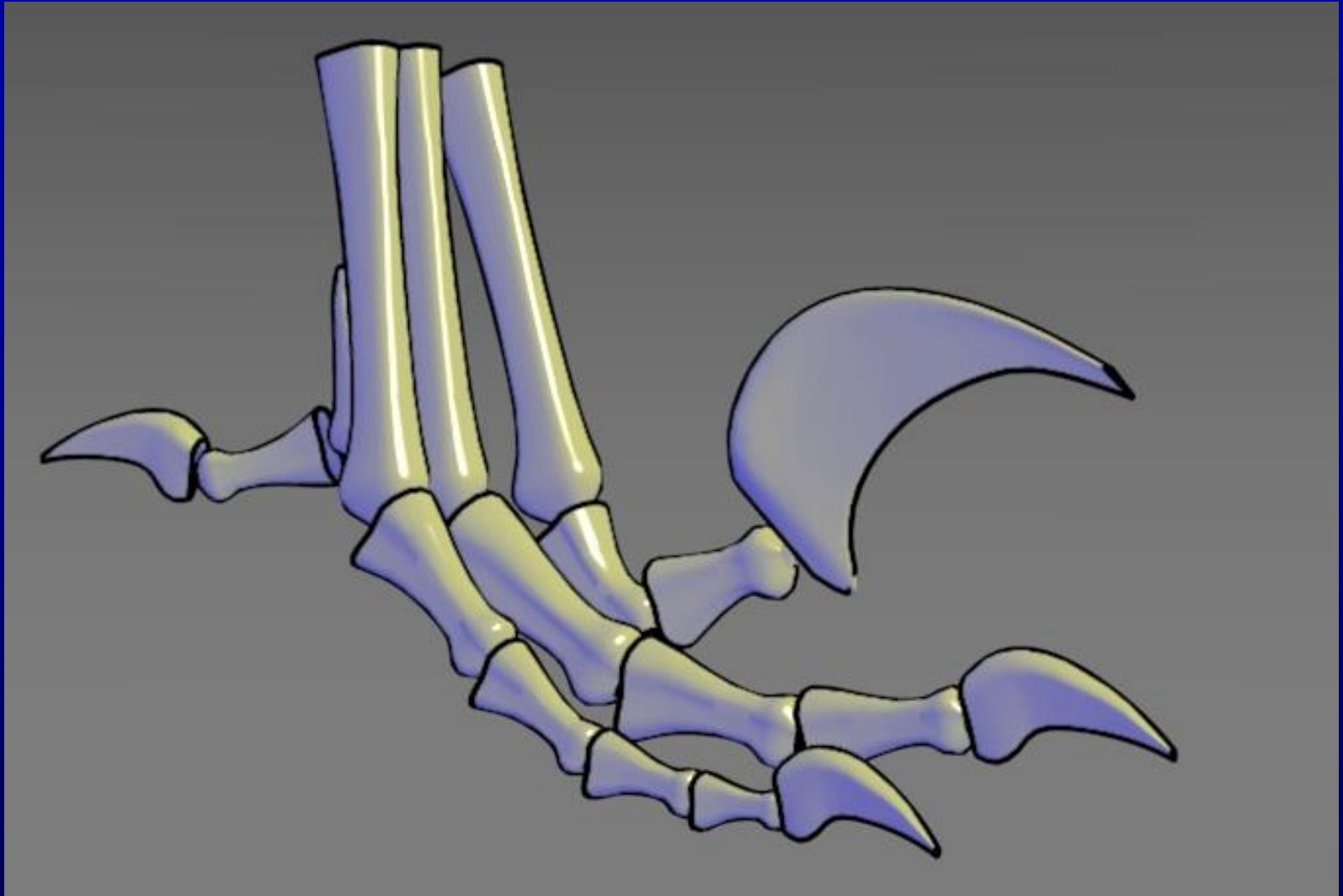
Phong shaded image with edge lines. Details are lost in the dark grey regions, especially in the small claws, where they are entirely ambient.



Approximately constant luminance tone rendering. Edge lines and highlights are clearly noticeable. Some details in shaded regions, like the small claws, are visible. The lack of luminance shift makes these changes subtle.



Luminance/hue tone rendering combining a luminance shift with a hue shift. Edge lines, highlights, fine details in the dark shaded regions such as the small claws, as well as details in the high luminance regions are all visible.



Alternative luminance/hue tone rendering with a different overall temperature shift, prominence of the object color, and strength of the luminance shift.

Digital Facial Engraving



