Introuction to Computer graphics

MSC.NGUYEN THUY LINH

What is Computer Graphics?

- Creation, Manipulation, and Storage of geometric objects (modeling) and their images (rendering)
- Display those images on screens or hardcopy devices
- Image processing
- Others: GUI, Haptics, Displays (VR)...

What drives computer graphics?

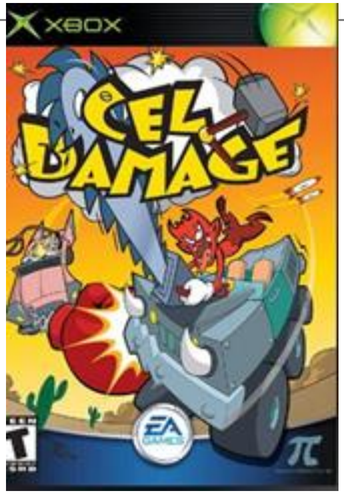
Movie Industry

- Leaders in quality and artistry
- Not slaves to conceptual purity
- Big budgets and tight schedules
- Reminder that there is more to CG than technology
- Hey, How'd they do that?
- Defines our expectations

What drives computer graphics?

Game Industry

- The newest driving force in CG
  - Why? Volume and Profit
  - This is why we have commodity GPUs
- Focus on interactivity
- Cost effective solutions
- Avoiding computating and other tricks
- Games drive the baseline



Slide information from Leonard McMillian's slides

What drives computer graphics?

Medical Imaging and Scientific Visualization

- Tools for teaching and diagnosis
  - No cheating or tricks allowed
- New data representations and modalities
- Drive issues of precision and correctness
- Focus on presentation and interpretation of data
- Construction of models from acquired data

Nanomanipulator, UNC

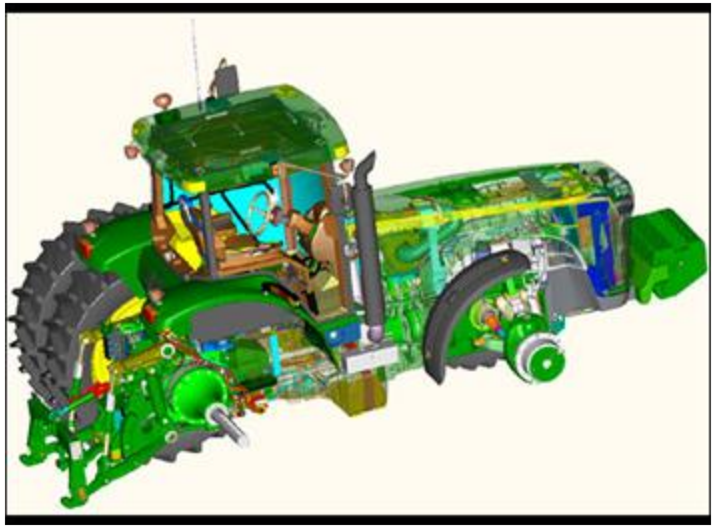
Joe Kniss, Utah

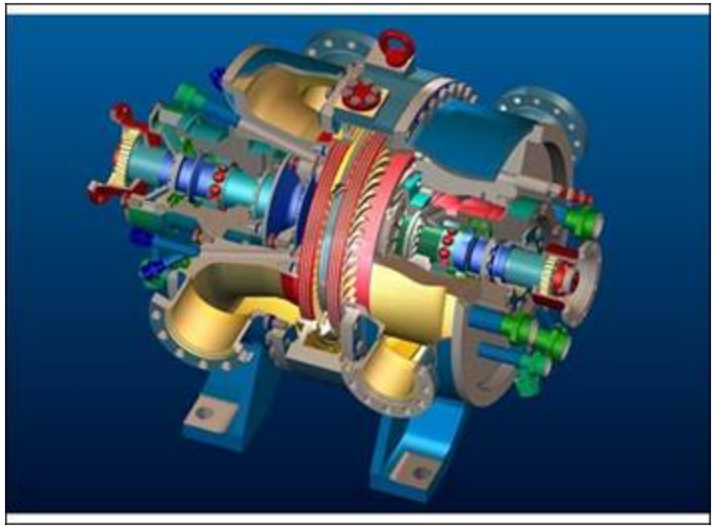
Gordon Kindelman, Utah

What drives computer graphics?

Computer Aided Design

- Mechanical, Electronic, Architecture,...
- Drives the high end of the hardware market
- Integration of computing and display resources
- Reduced design cyles == faster systems, sooner





ProEngineer, www.ptc.com

What drives computer graphics?

Graphic User Interfaces (GUI)

- www.webpagesthatsuck.com

What is Computer Graphics?

Look at 5 areas

- Hardware
- Rendering
- Interaction
- Modeling
- Scientific Visualization

Hardware: Amazing Changes

Fundamental architecture shift

- Dual computing engines:
  - CPU and GPU
  - More in GPU than CPU

Hardware: Amazing Changes

Fast, cheap GPUs

- ~$300

Cheap memory

Displays at low cost

- How many monitors do you have/use?

Hardware: Amazing Changes

Wired -> Unwired

World of Access

Hardware... some not so good

Devices

3D displays

Etc

Hardware

How old is Nvidia

How big is Nvidia

QED

Rendering

Many think/thought graphics synonymous with rendering

Well researched

- Working on second and third order effects
- Fundamentals largely in place

Rendering

Major areas:

- Ealiest: PhotoRealism
- Recent: Non-Photorealistic Graphics (NPR)
- Recent: Image-based Rendering (IBR)

Rendering

Ray Tracing has become practical

- Extremely high quality images
- Photorealism, animation, special effects

Accurate rendering, not just pretty

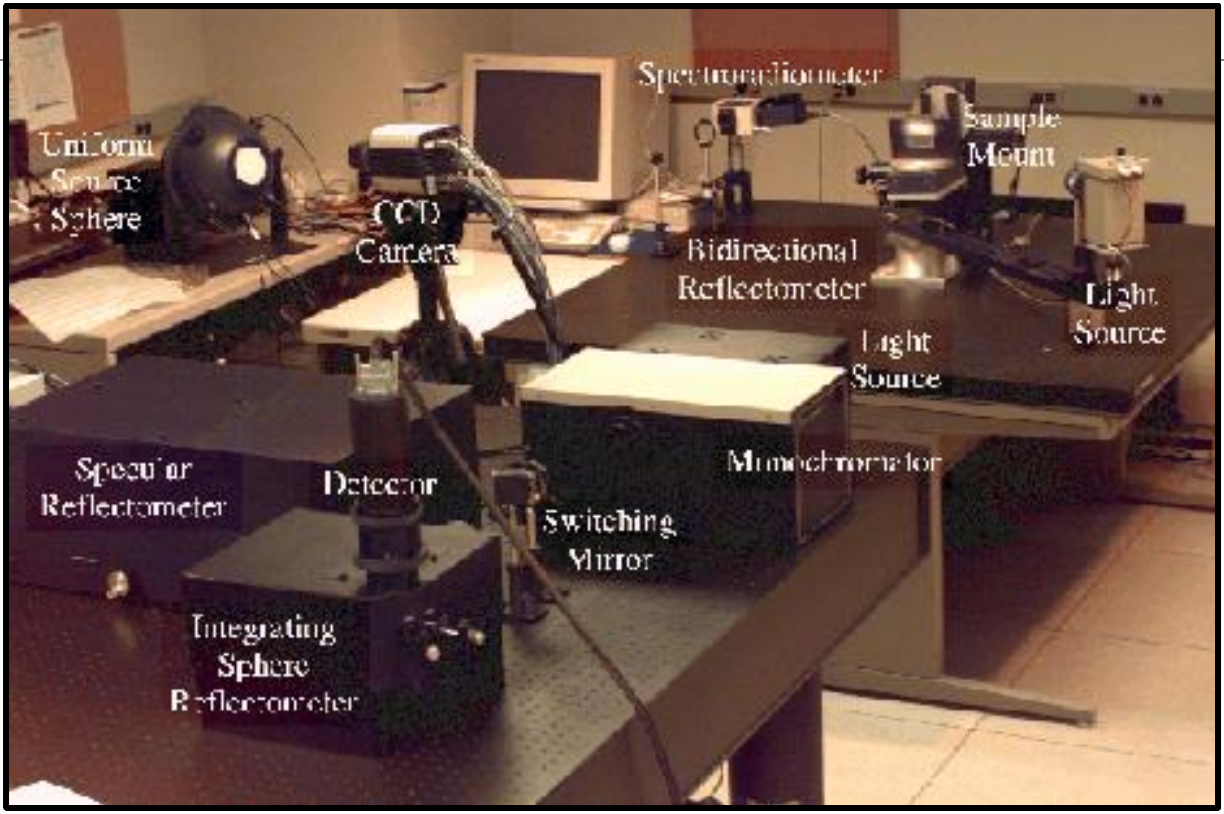
Rendering Realism

Morning

Evening

a preetham, et. al., utah

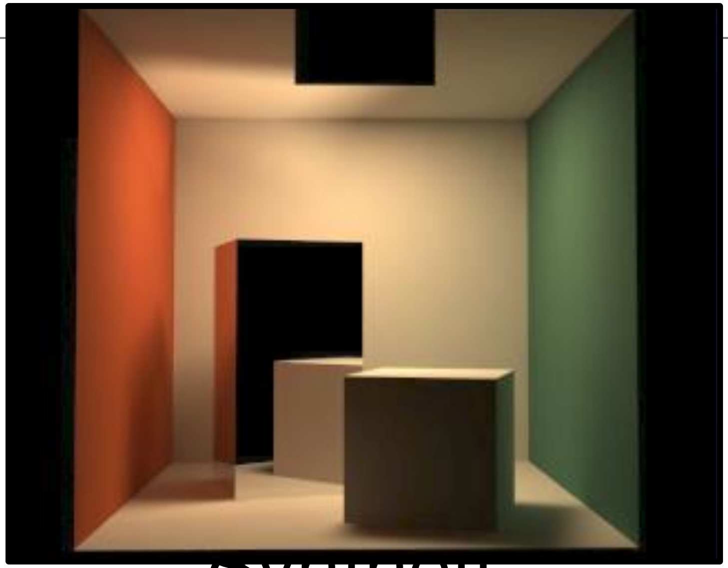
Rendering Realism



Cornel Measurement Lab

Rendering Realism

Real



Synthetic

Shirley, et. al., cornell

Is this real?


www.fordracing.net
Valvoline
Ford
Telefonica MoviStar
MICHELIN
V3 FMC

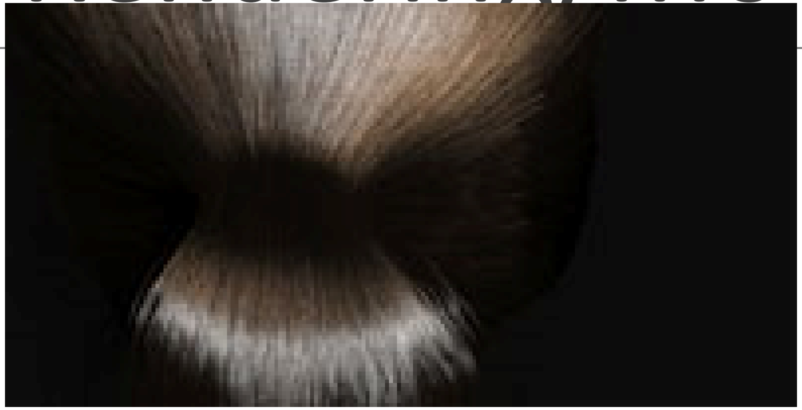
Terrain Modeling:
Snow and Trees Added

s premoze, et.al., utah

Growth Models

o deusson,

Rendering/Modeling Hair



QuickTime™ and a
Photo decompressor
are needed to see this picture.

QuickTime™ and a
Video decompressor
are needed to see this picture.

http://www.rhythm.com/~ivan/hairRender.ht

Humans

Final Fantasy (Sony)

Jensen et al.

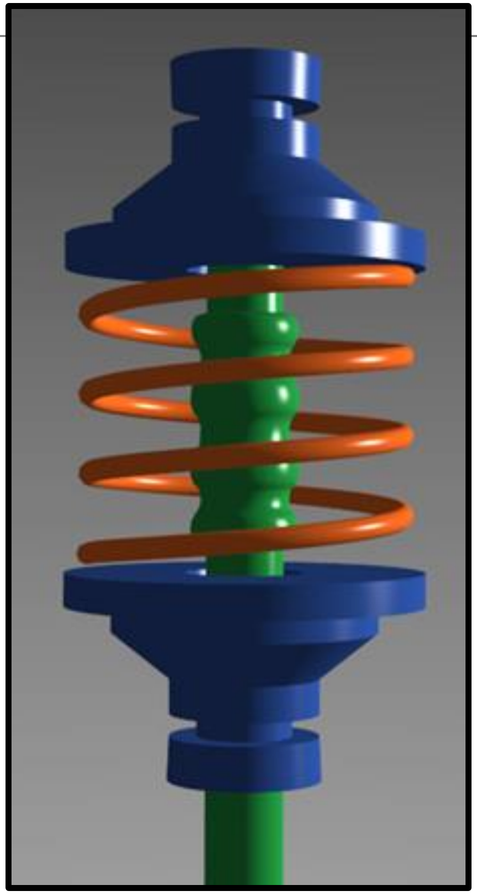
Is Photorealism Everything?

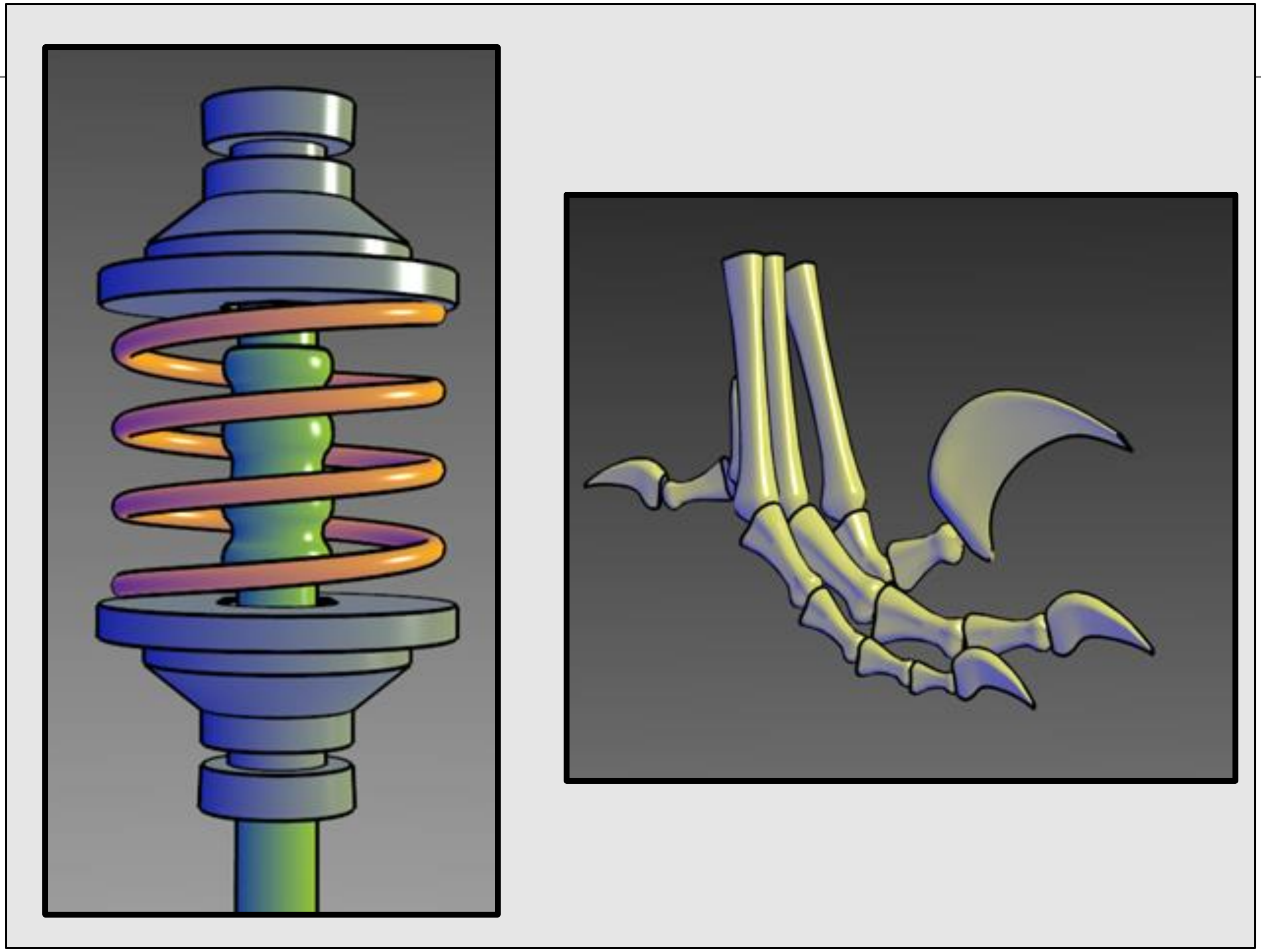
Is Photorealism Everything?

Non-Photorealistic Rendering

b gooch, et.al., utah

Tone Shading





a gooch, et. al., utah

NonPhotorealistic Rendering





Image Based Rendering

Model light field

Do not have to model geometry

Good for complex 3D scenes

Can leave holes where no data is available

3D Scene Capture

Fuchs et.al., UNC

UNC and UVA

3D Scene Recreation

Faugeras et. al

360^{o} Scan

p willemsen, et. al., utah

Interaction

Way behind rest of graphic's spectacular advances

Still doing WIMP:

- Windows, icons, menus, pull-downs/pointing

Once viewed as “soft” research

- Turns out to be one of hardest problems

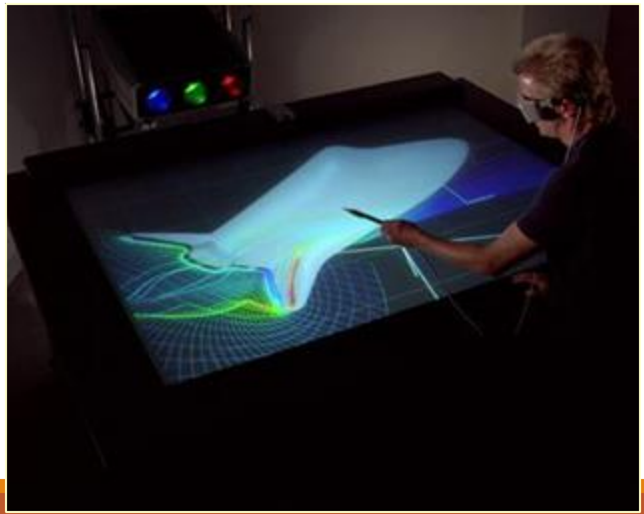
Interaction still needs...

Better input devices

Better output devices

Better interaction paradigms

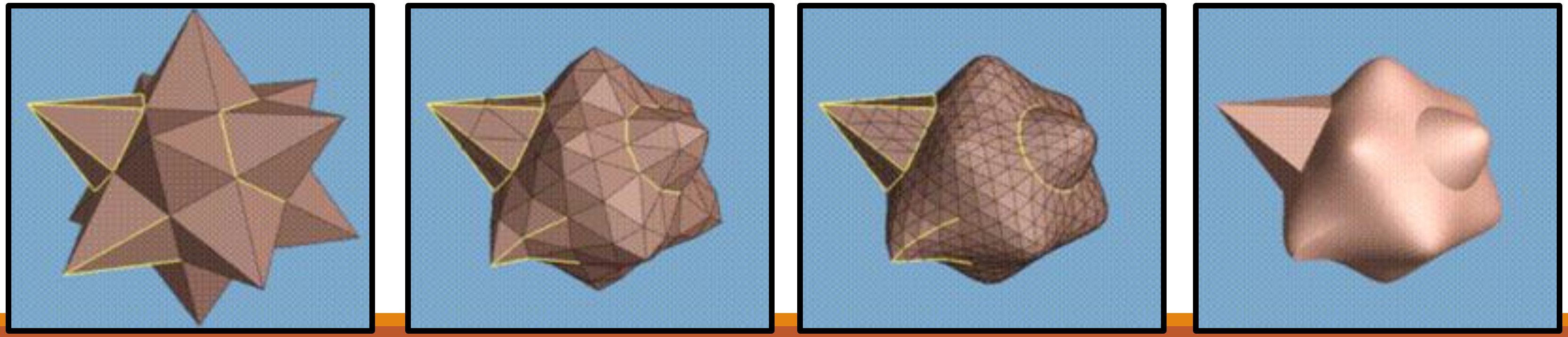
Better understanding of HCI
- Bring in psychologists



Modeling

Many model reps

- Bezier, B-spline, box splines, simplex splines, polyhedral splines, quadrics, super-quadrics, implicit, parametric, subdivision, fractal, level sets, etc (not to mention polygonal)



Modeling

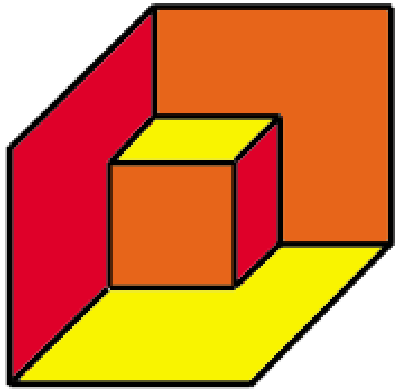
Physically based

- Newton
- Behavior as well as geometry

Materials

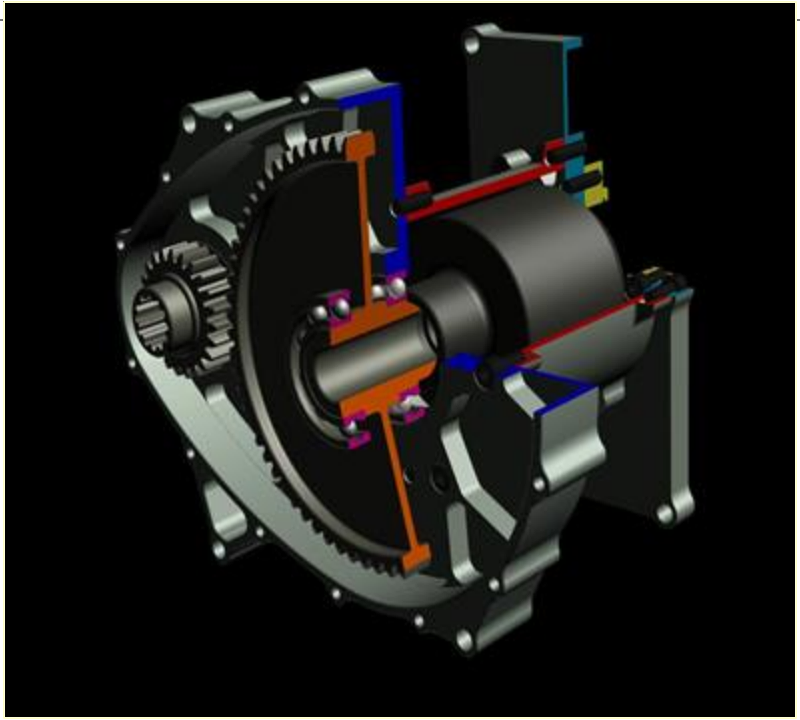
- Metal, cloth, organic forms, fluids, etc

Procedural (growth) models



Modeling… is hard

- Complexity
- Shape
- Specifying
- Realistic constraints
- Detail vs concept
- Tedious, slow



s drake, et. al., utah

Modeling is hard

Mathematical challenge

Computational challenge

Interaction challenge

Display challenge (want 3D)

Domain knowledge, constraints

Growth Models

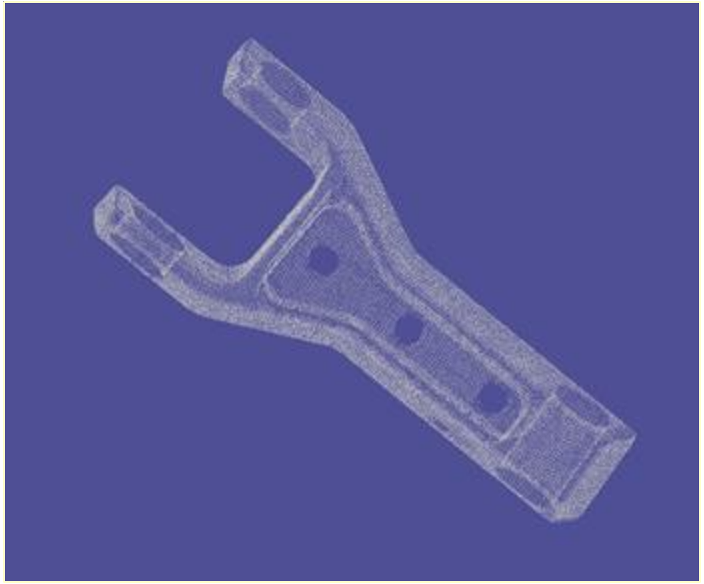
o deusson,

Model Capture

marc levoy, et. al., stanford

Models

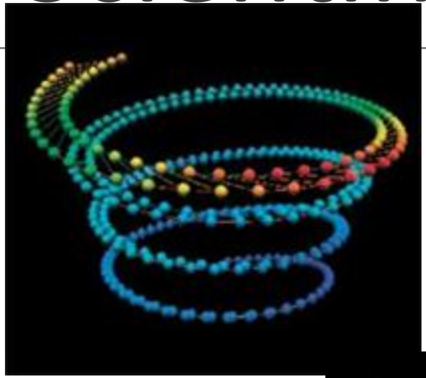
Russ Fish et al., Utah

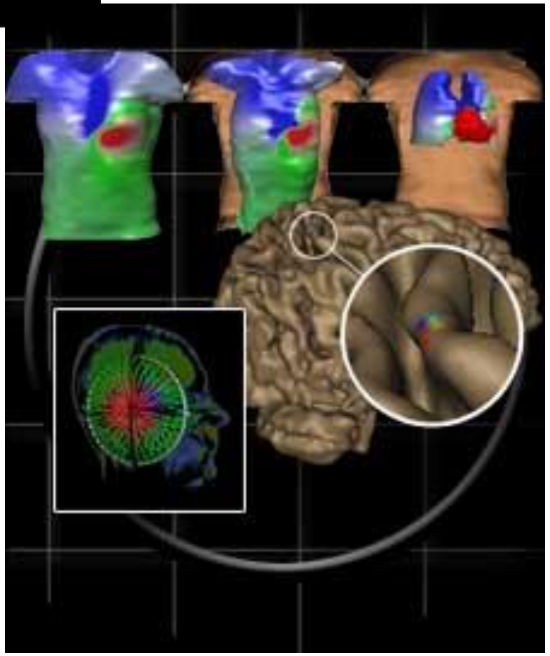


D Johnson and

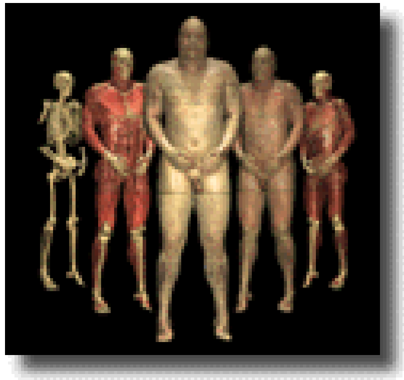
J D St Germain, Utah

Scientific Visualization





Johnson et al., Utah



QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.

National Library of Medicine

Visual Human

Foundations of computer graphics

All these applications demand sophisticated theory & systems

Theory

- geometric representations
- sampling theory
- integration and optimization
- radiometry
- perception and color

Systems

- parallel, heterogeneous processing
- graphics-specifc programming languages

Activity

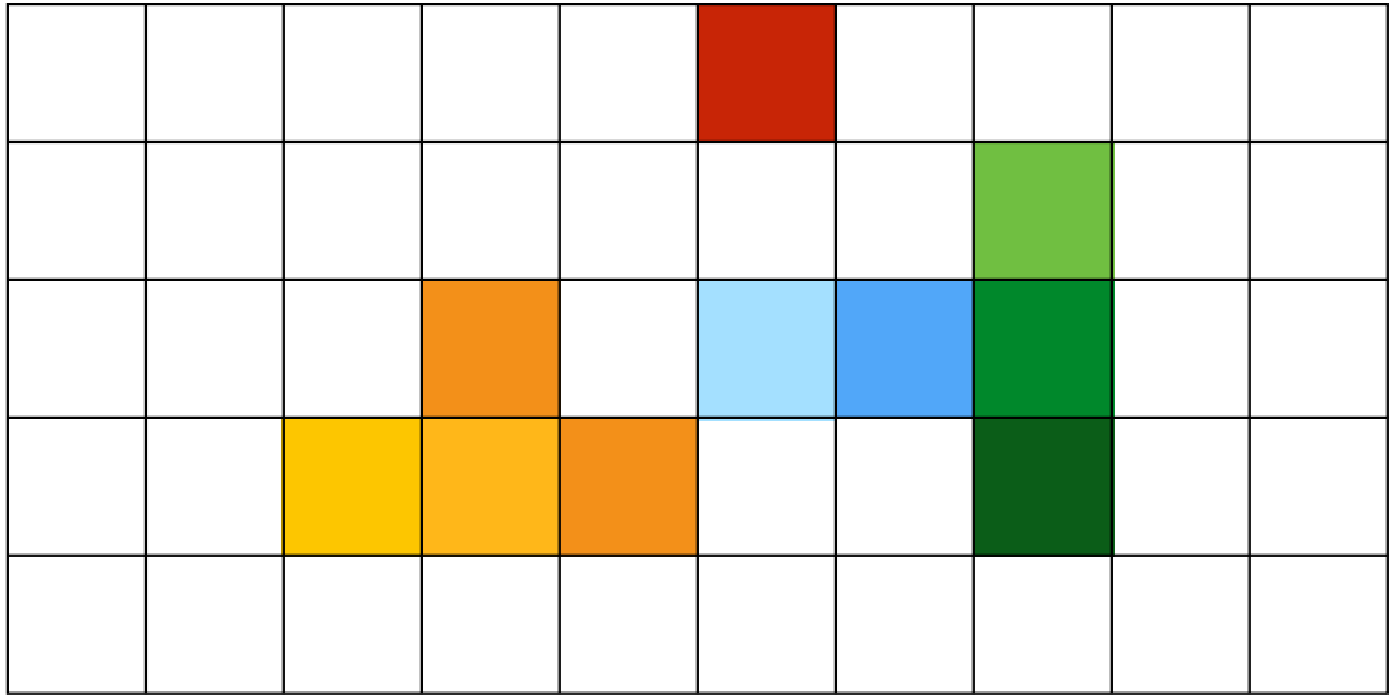
How do we draw lines on a computer?

Output for a raster display

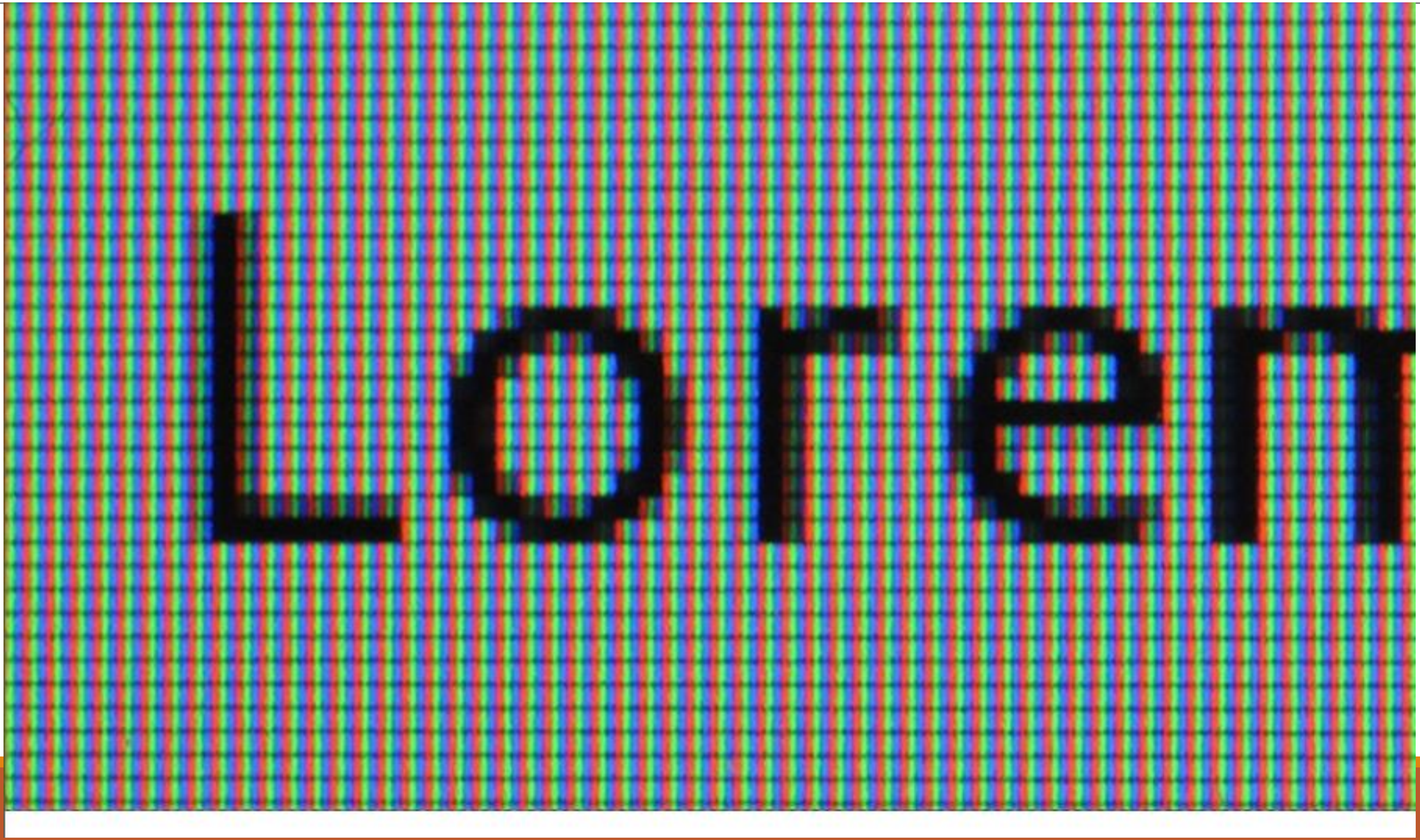
Common abstraction of a raster display:

- Image represented as a 2D grid of “pixels” (picture elements) **

- Each pixel can can take on a unique color value

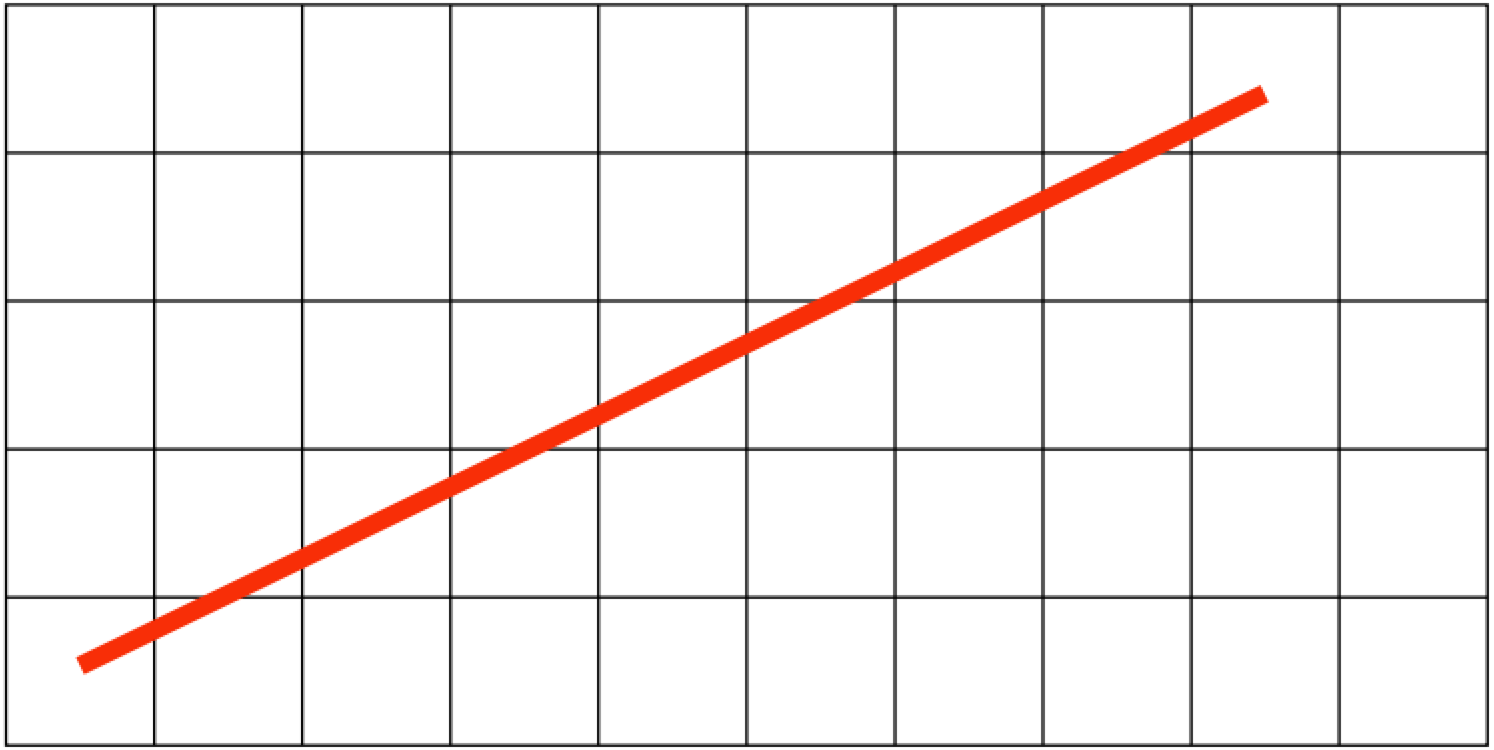


Close up photo of pixels on a modern display



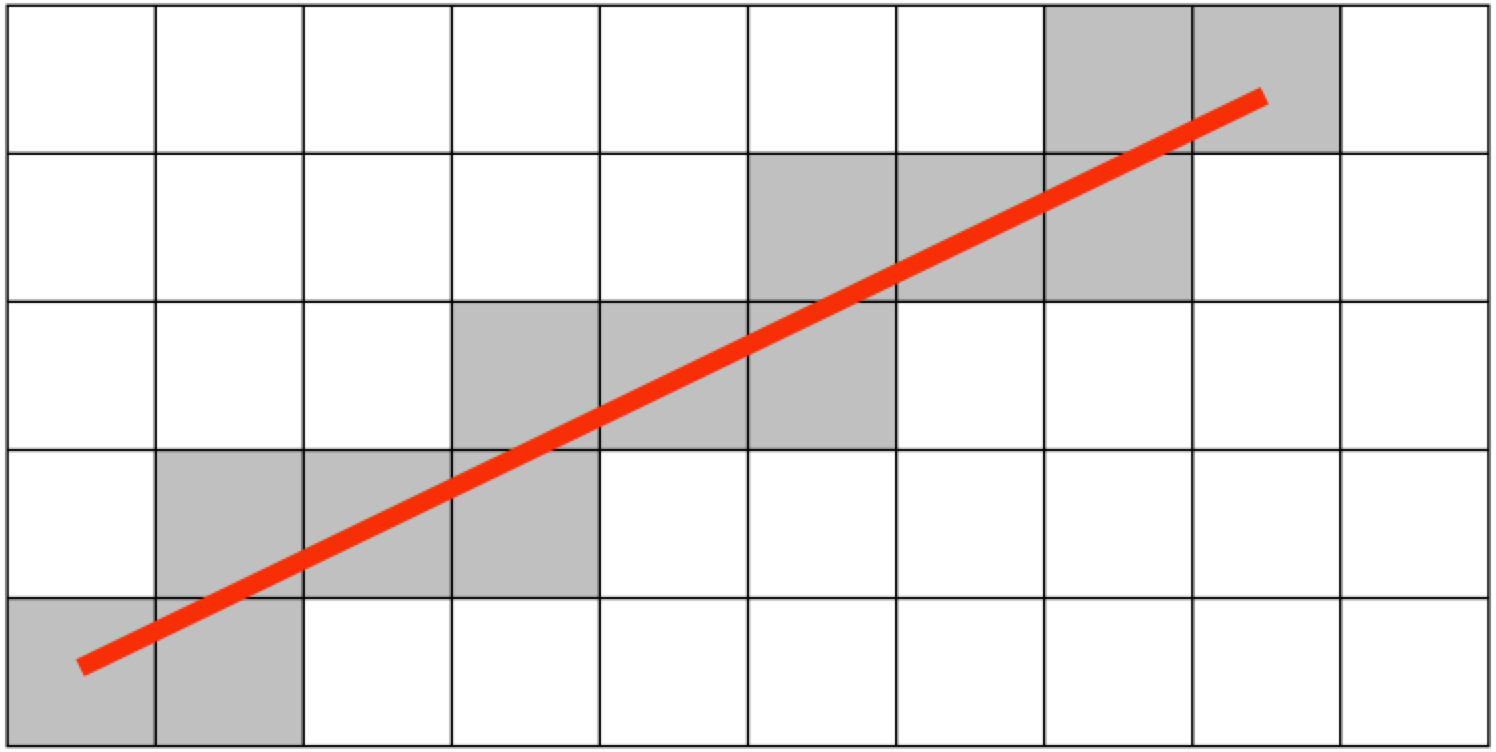
What pixels should we color in to depict a line?

"Rasterization": process of converting a continuous object to a discrete representation on a raster grid (pixel grid)



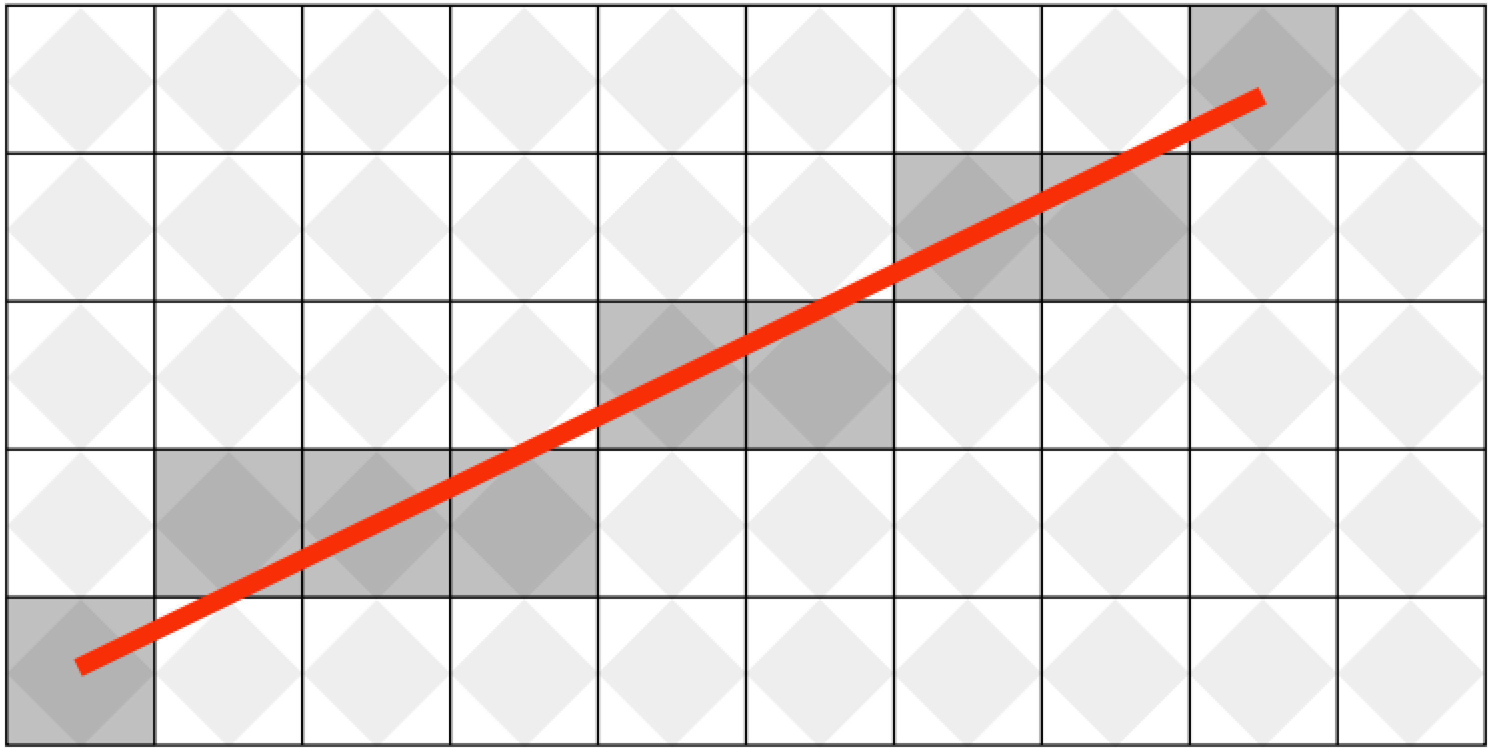
What pixels should we color in to depict a line?

Light up all pixels intersected by the line?



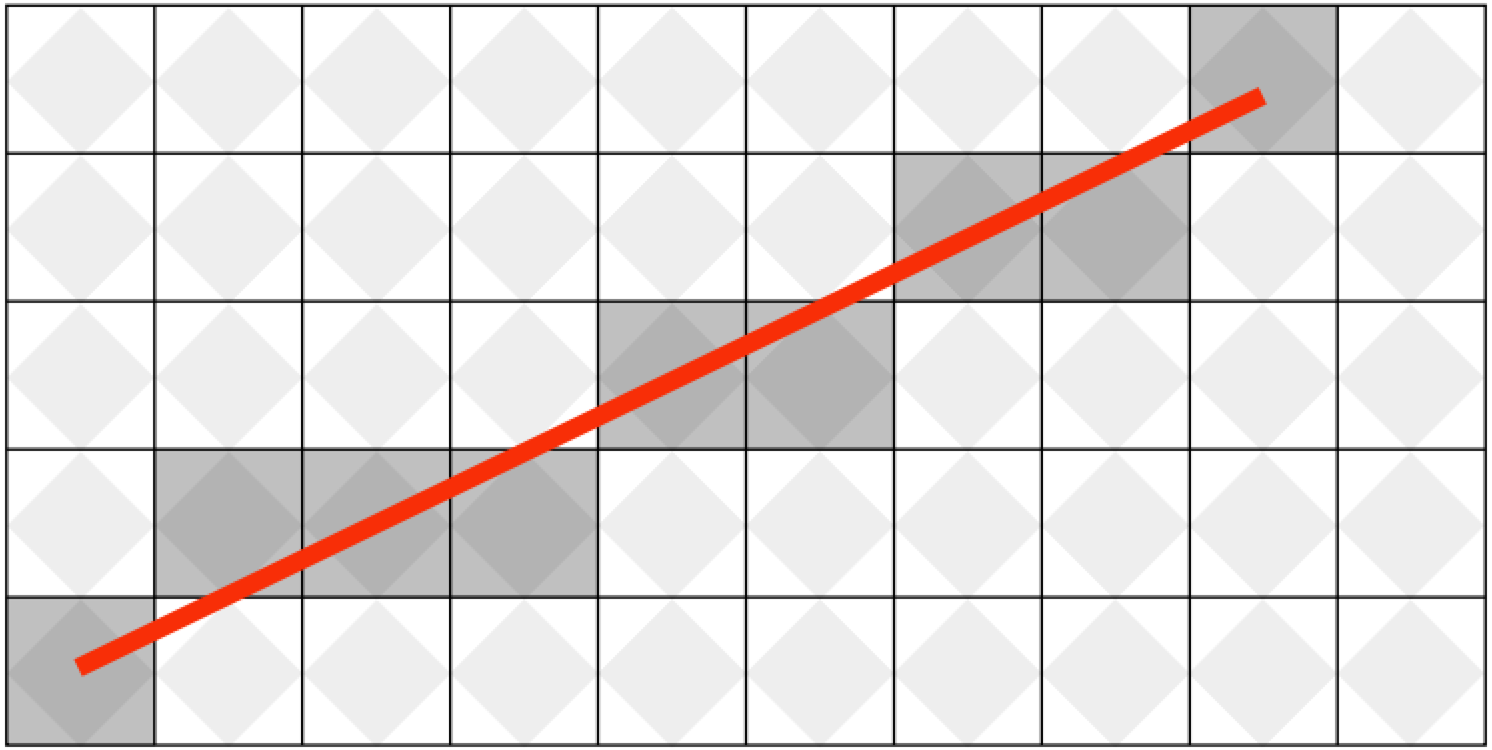
What pixels should we color in to depict a line?

Diamond rule (used by modern GPUs):
light up pixel if line passes through associated diamond



What pixels should we color in to depict a line?

Is there a right answer?
(consider a drawing a “line” with thickness)



How do we fnd the pixels satisfying a chosen rasterization rule?

Could check every single pixel in the image to see if it meets

the condition...

- O(n2) pixels in image vs. at most O(n) “lit up” pixels

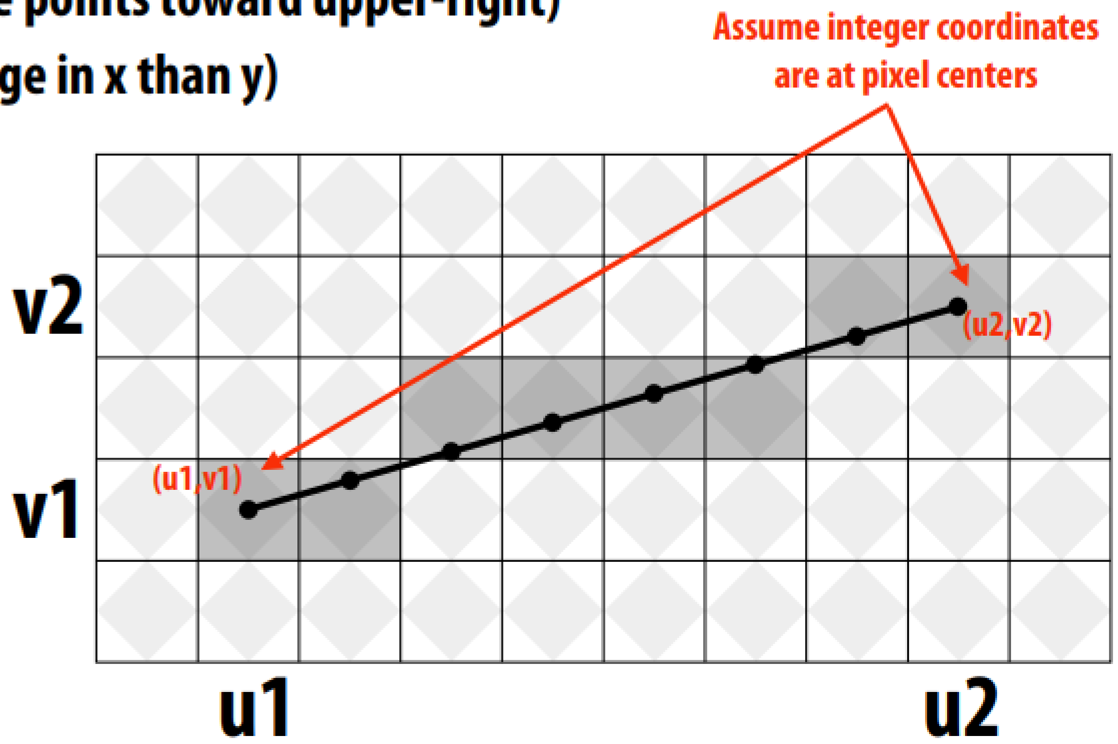
- must be able to do better! (e.g., work proportional to

number of pixels in the drawing of the line)

Incremental line rasterization

- Let's say a line is represented with integer endpoints: (u1,v1), (u2,v2)
- Slope of line: s = (v2-v1) / (u2-u1)
- Consider a very easy special case:
  - u1 < u2, v1 < v2 (line points toward upper-right)
  - 0 < s < 1 (more change in x than y)

```
v = v1;
for( u=u1; u<=u2; u++ )
{
   v += s;
   draw( u, round(v) )
}
```



We just rendered a simple line drawing of a cube.

But to render more realistic pictures (or animations) we need a much richer model of the world.

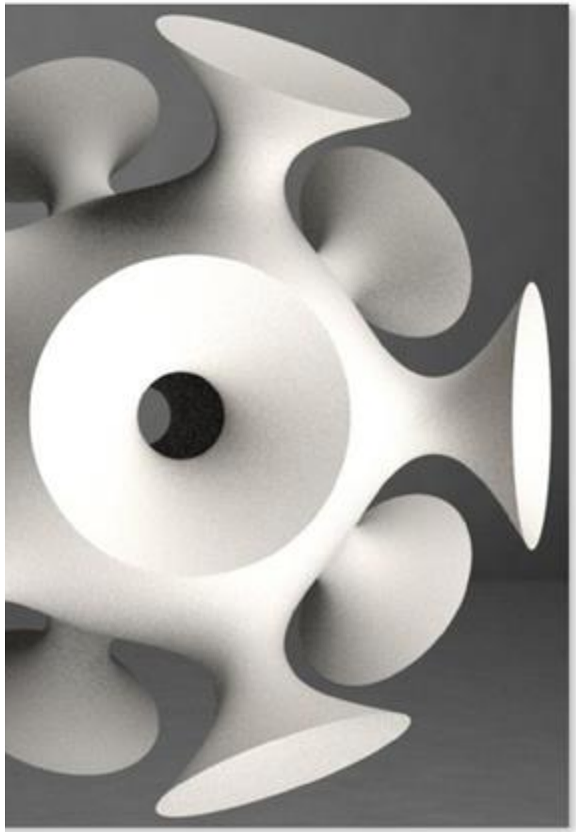
- surfaces
- motion
- materials
- lights
- Cameras

https://www.youtube.com/watch?v=tT81VPk_ukU

https://www.youtube.com/watch?v=wYfYtV_2ezs

2D shapes

[Source: Batra 2015]



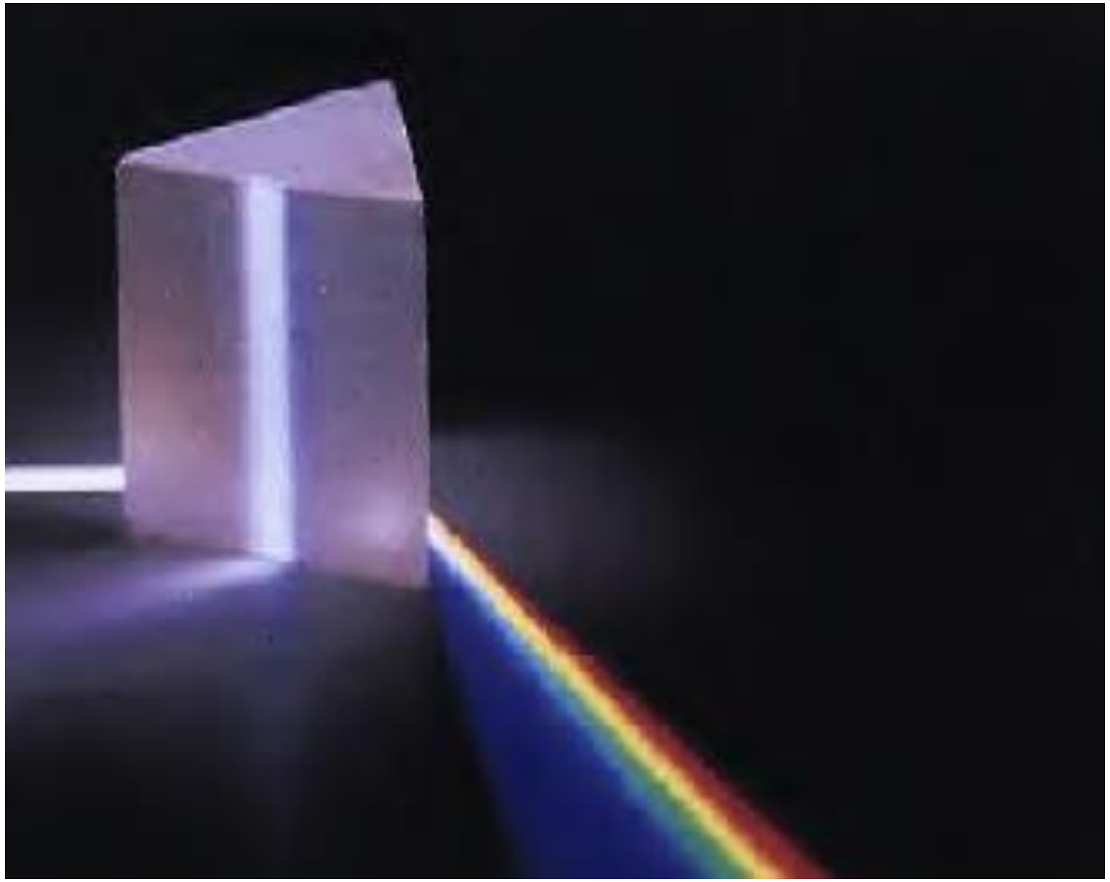
Platonic noid

Week 5: Color

- Isaac Newton was the first to make a systematic study of color. He did this by passing a narrow beam of sunlight through a triangular-shaped glass prism
- His method showed that sunlight is composed of a mixture of all the colors of the rainbow.
- This selection of colors is called a spectrum: red, orange, yellow, green, blue, and violet.

28.1: The Color Spectrum

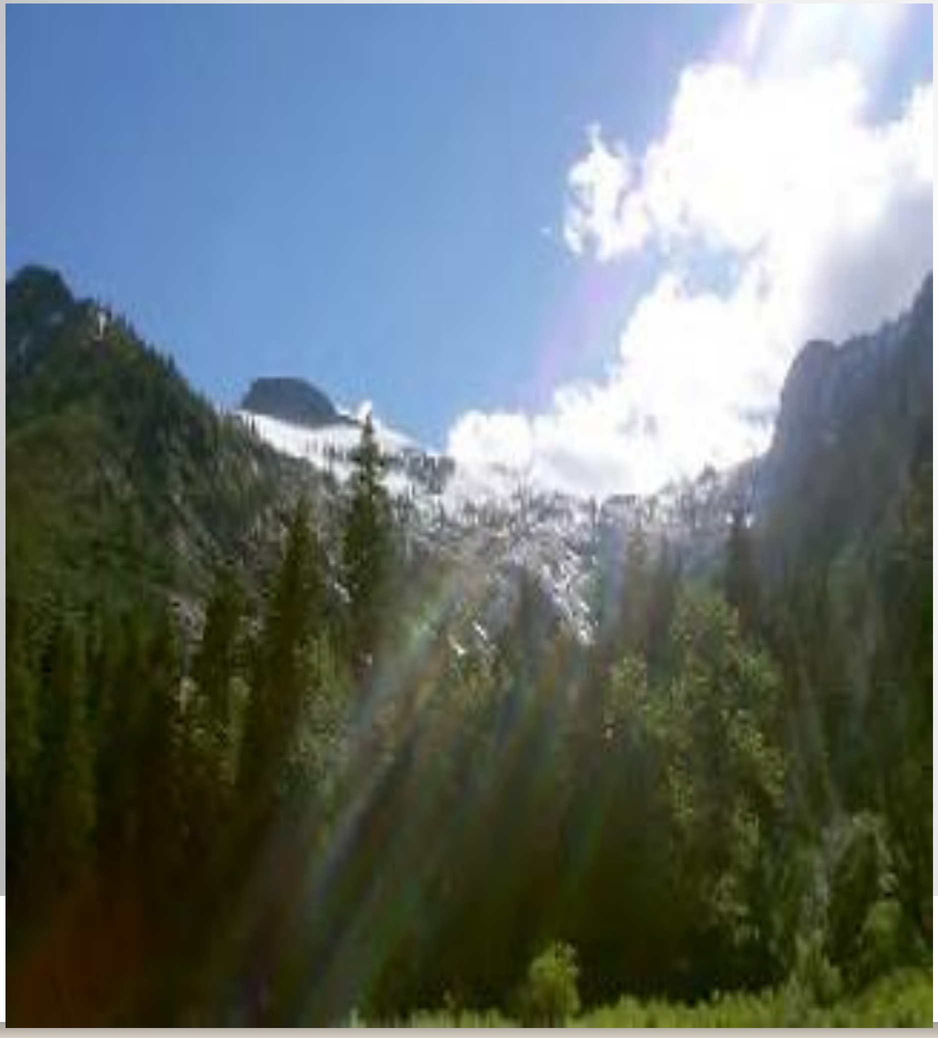
Triangular Prism



- True colors- Newton showed that colors in the spectrum were a property of white light. All the colors added together make white.
- Black is not considered a true color, but it is the absence of light. Objects that are black absorb all other light frequencies. You can see black objects because they cannot absorb all the light, otherwise you would not be able to see the object.

28.1: cont…

28.1: cont…



- Sunlight is an example of white light. Under white light objects that are white will appear white and objects that are colored will show their color

- Objects are a certain color because of the light they reflect. (Ex. Red objects are red because they reflect red light.)
- Molecules are made up of atoms. Atoms contain protons and neutrons. The electrons orbit the nucleus of the atom. These electrons can be excited to higher states and can send out energy waves.

28.2: Color by Reflection

- Different elements have different frequencies for absorbing and emitting radiation. Reflection is when light is bounced back to the source from where it came. When something is transparent the light is not bounced back, but simply transmitted through.

28.2: cont…

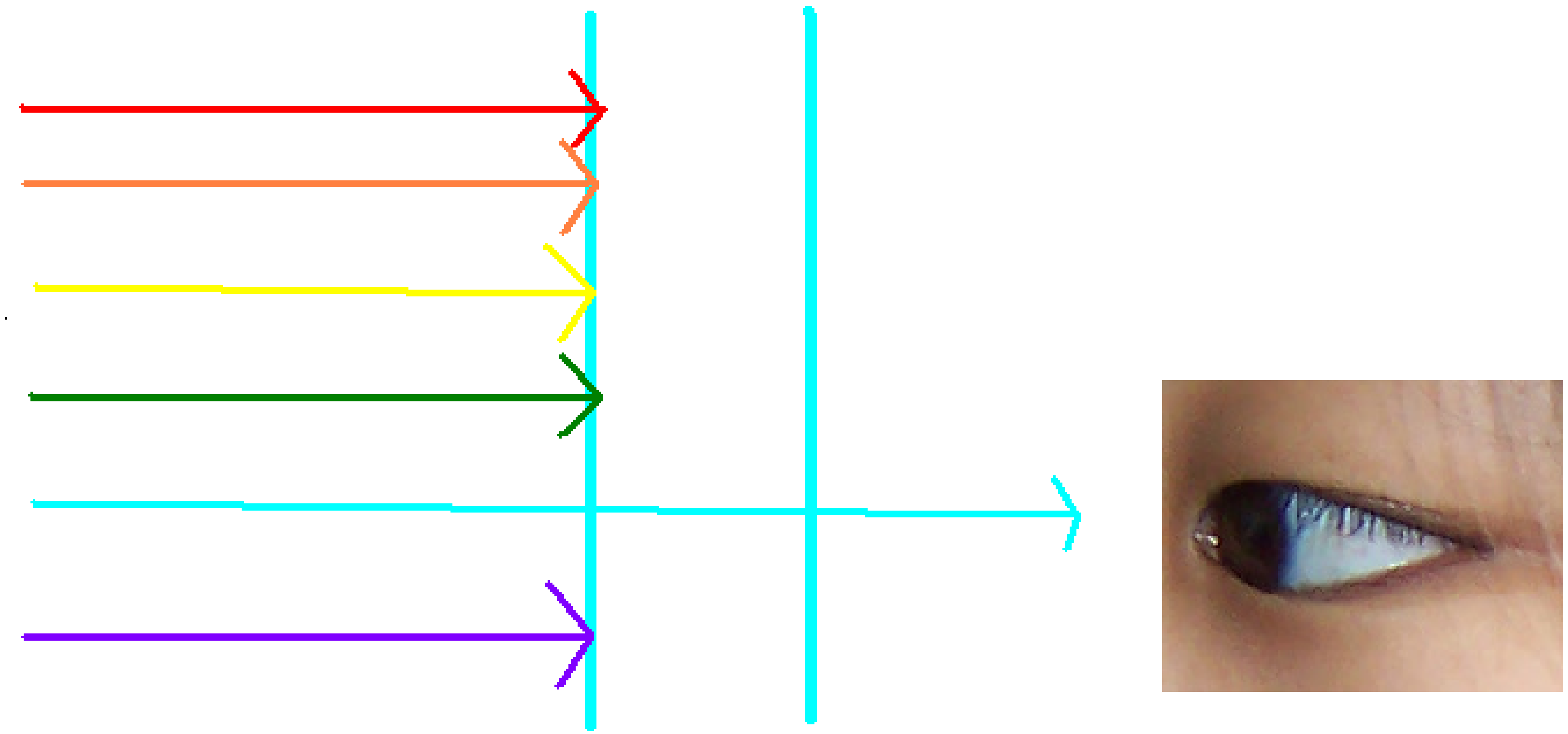
28.2: cont…

- An object can reflect only light of the frequencies present in the illuminating light. The appearance of a colored object therefore depends on the kind of light used to illuminate it.
- Colors in the daylight appear different from the way they appear when illuminated with manmade lamps. The color seen from an object is subjective and depends on the source of the light.

- The color of a transparent object depends on the color of the light that is transmits. A piece of blue glass transmits blue light.
- Pigment is the material in the transparent glass that selectively absorbs colored light.

28.3: Color by Transmission

Light transmitting through blue glass



- Electrons in the pigment selectively absorb light of certain frequencies in the illuminating light.
- Light that is not part of the selective frequencies is reemitted from atom to atom in the glass.
- Ordinary window glass is colorless and it transmits all colors and visible frequencies of light.

28.3: cont…

- The light from the sun is a composite of all the visible frequencies.
- The color frequencies have uneven brightness.
- Yellow-green light is the brightest part of sunlight, (the most heat).

28.4: Sunlight

28.4: cont…

- The human eye is most sensitive to yellow- green, which is why more new fire engines are painted this color; it attracts attention easier. Yellow- green is also easy to see at night because of their illuminating properties

28.5 Mixing Colored Light

When red, blue, and green light are projected onto a screen, the overlapping areas appear different colors. Where all the three overlap, white is produced.

RED GREEN YELLOW

RED BLUE MAGENTA

GREEN BLUE CYAN

Additive primary colors are red, blue, and green because these colors produce the highest number of different colors.

28.6: Complementary Colors

- When two colors are added together to produce white, they are called complementary colors.
- YELLOW + BLUE =WHITE (Yellow a combination of Green + Red)
- MAGENTA + GREEN = WHITE (Magenta a combination of red + blue)
- CYAN + RED = WHITE (Cyan a combination of green+ blue)

- For example : if white light falls on a pigment that absorbs red light, the light reflected appears cyan.
- Not all light incident upon an object is reflected. The ones that are absorbed are subtracted from the incident light.
- Whenever you subtract a color from white light, you end up with the complementary color.

28.6: cont…

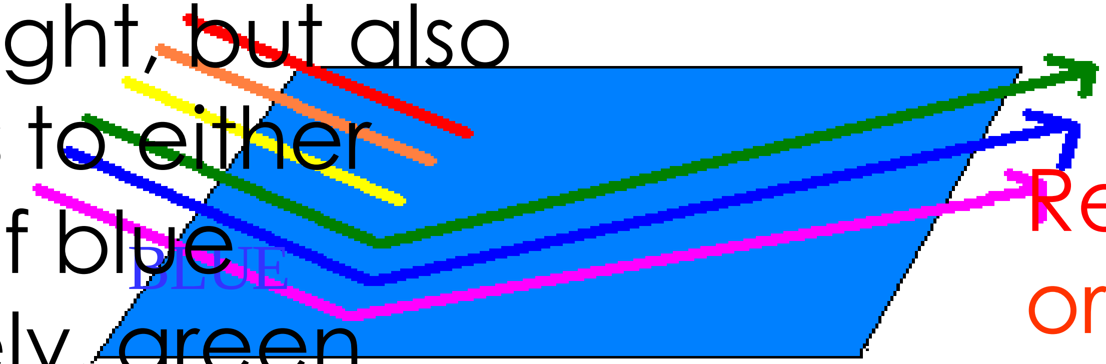
27.7 Mixing Colored Pigments

-Mixing red, green, and blue paint is entirely different from the mixing of colored light.

-Pigments absorb light of a relatively wide range of frequencies.

-Subtractive primary colors are three paint or dye colors that are more useful in color mixing by subtraction are MAGENTA, YELLOW, and CYAN

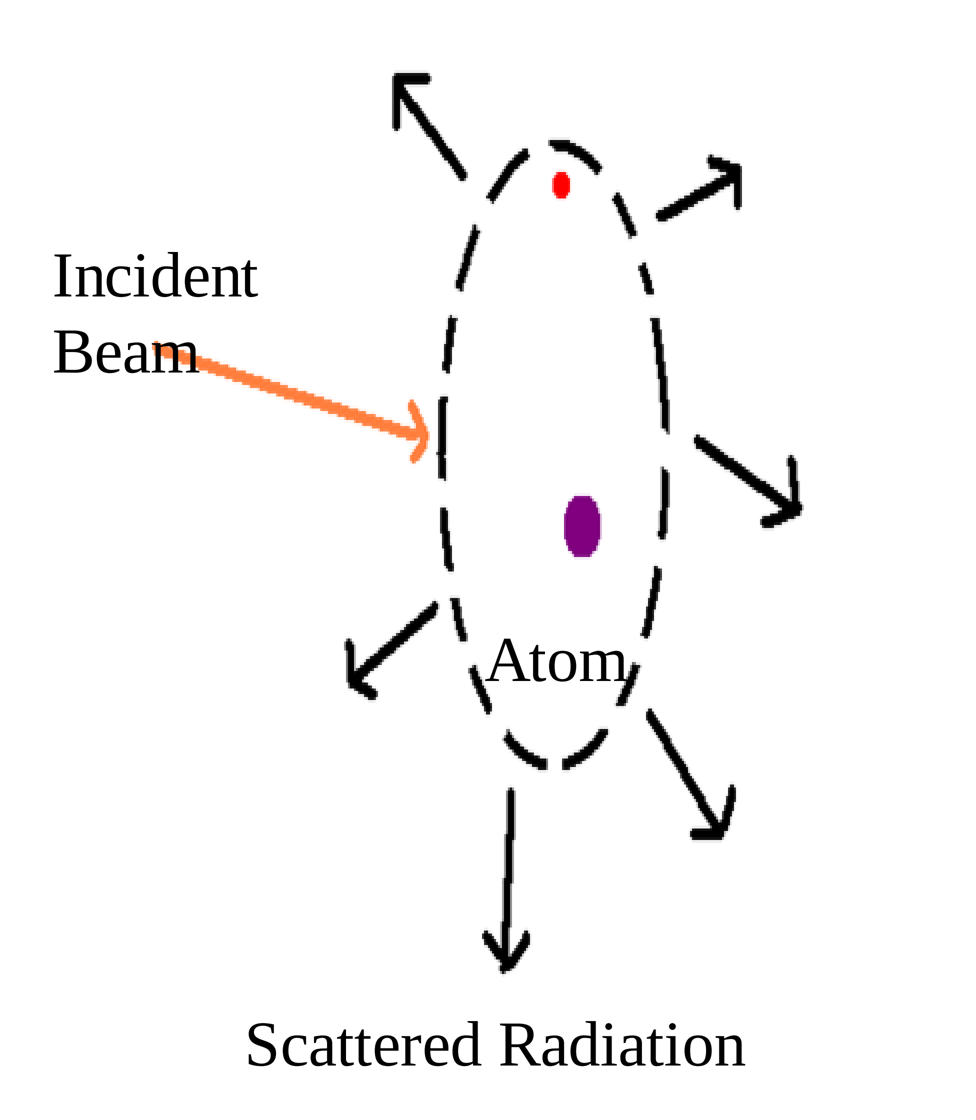
Blue pigment reflects not only blue light, but also colors to either side of blue namely, green and violet. It absorbs red orange and yellow light.



Red orange yellow have been subtracted from the incident light.

Nitrogen and oxygen molecules ring like tiny bells with high frequency when energized by sunlight.

Reemit light in all directions like the sound of a bell.



28.8 Why the Sky is Blue

Ultraviolet light from the sun is absorbed by the protective layer of the ozone gas.

Visible frequencies of violet light is scattered.

Although the violet light is scattered more, our eyes are only sensitive to blue. That's why we see a blue sky.

28.8: cont…


Sunset in the Apostle Islands
Bayfield WISCONSIN
©D & D Imaging

28.9: Wh

- Lower frequencies of light are scattered the least by nitrogen and oxygen molecules
- Red, orange, yellow are transmitted more readily through the atmosphere
- Light of lower frequencies is transmitted while light of higher frequencies are scattered

28.9: cont…

- At dawn and sunset, the sunlight reaches the earth at a longer path
- At noon, the light travels the least
- Blue light is scattered as the path of the sunlight becomes longer

28.9: cont…

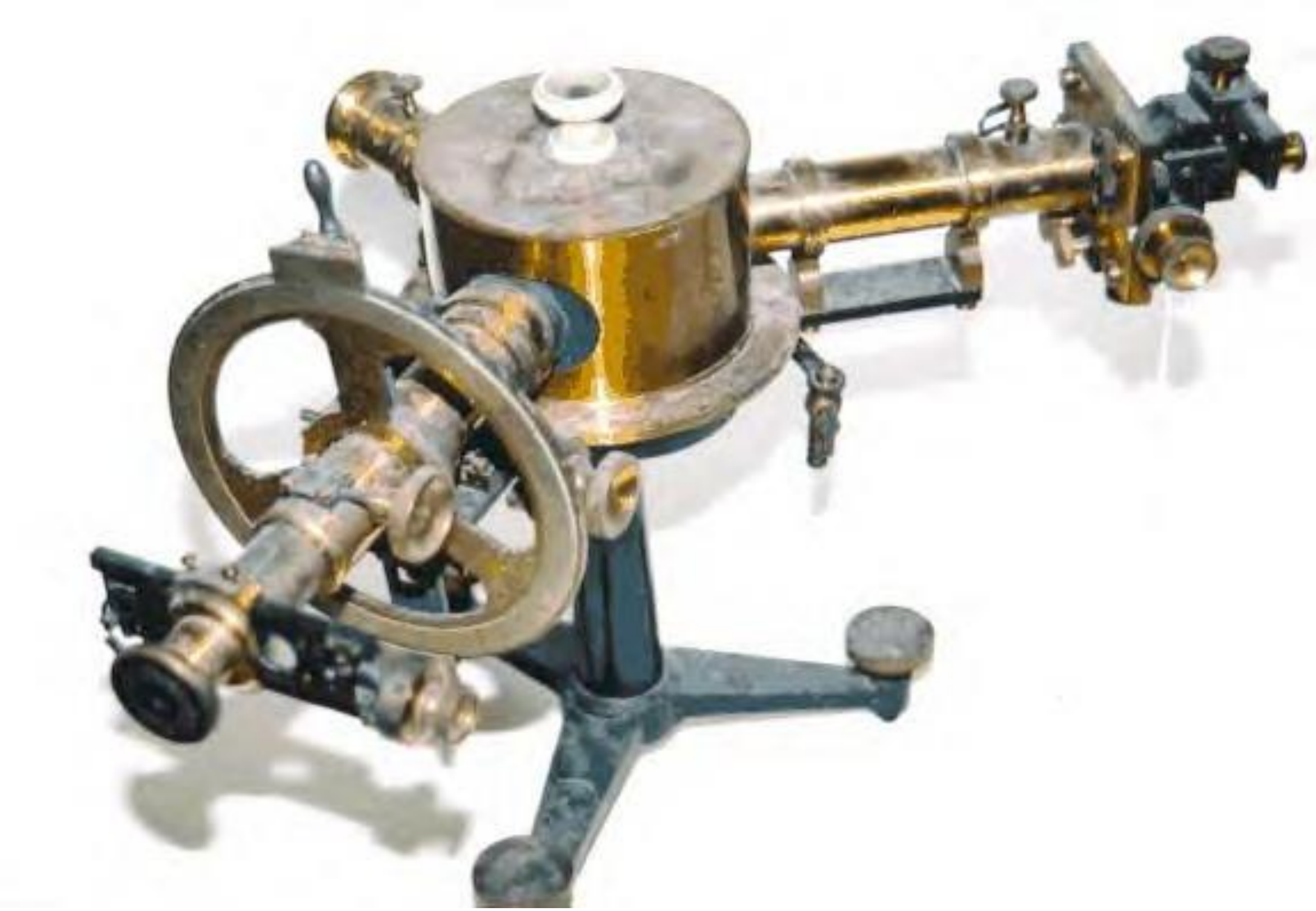
- Water is transparent to almost all the visible frequencies of light.
- The color is actually the reflected color of the sky
- Red is absorbed by the molecules in the water

28.10: Why Water is Greenish Blue

- Every element has its own specific glow
- The light from the elements can be analyzed by a spectroscope
- It is composed of thin slits, lenses, and a prism
- It displays the spectrum of light
- Line spectrum- images of the slit through which the light passes

28.11: The Atomic Color Code- Atomic Spectra

Spectrosc



THE END

2D Drawing and Animation Techniques

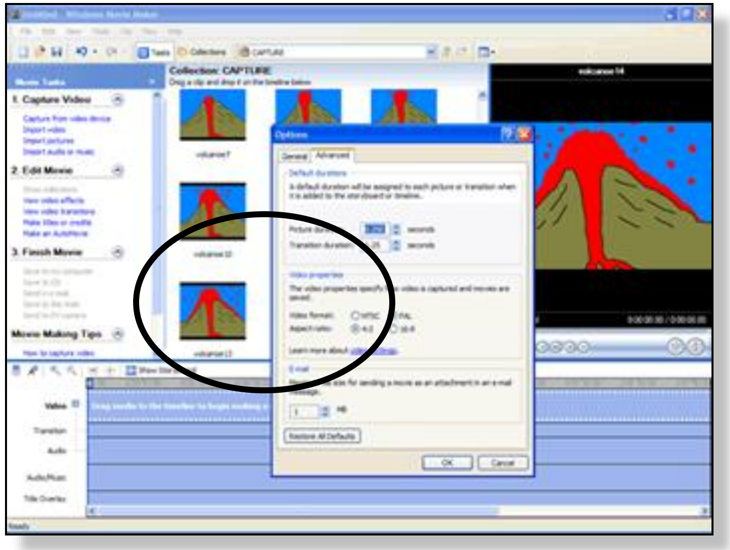
Guilford County SciVis
V106.04

Early Animation Processes

- *Animation* is created when still images are played in rapid succession so that they appear to produce images that are constantly moving.
- Animation appears to have continuous motion because the human eye (brain) “holds-onto” the still image for just a brief moment after it is viewed, and the image is still “there” (in your brain) when the next image is viewed.
- The timing between individual images must be fast enough for the sequence to appear smooth.

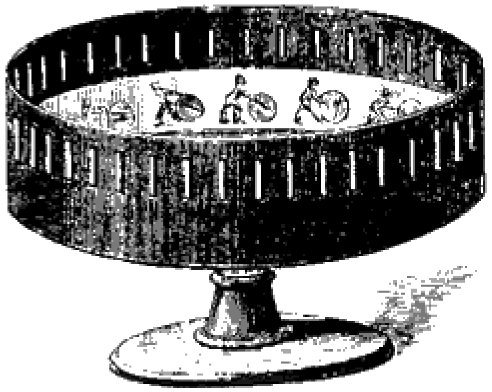
Early Animation Processes

- The National Television Standards Committee (NTSC) frame rate = 30 frames per second for television (North America and Japan).
- PAL (Phase Alternate Line) is the European standard of 25 frames per second.
- The standard rate for film (motion pictures) = 24 frames per second.
- A frame rate of 30 fps will require 1800 images for one minute of animation (30 fps x 60s).



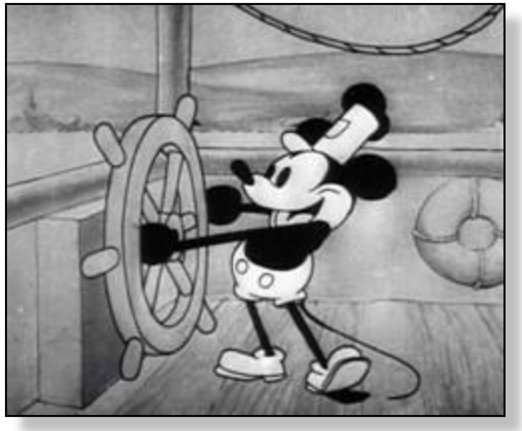
Early Animation Processes

- The *Zoetrope* was a device that was used to produce animation in the 1800s. It consisted of a circular frame holding individual, sequenced images, and a fixed viewpoint through which the spinning pictures were viewed. The term "movies" comes from the moving images.



Early Animation Processes

- The Walt Disney Studios developed animation into a modern art during the 1930s and 1940s.
- The different "layers" of the animated scene were painted onto transparent sheets, called *cels*.
- A hierarchy of artists was developed for drawing and painting the sequences of images.

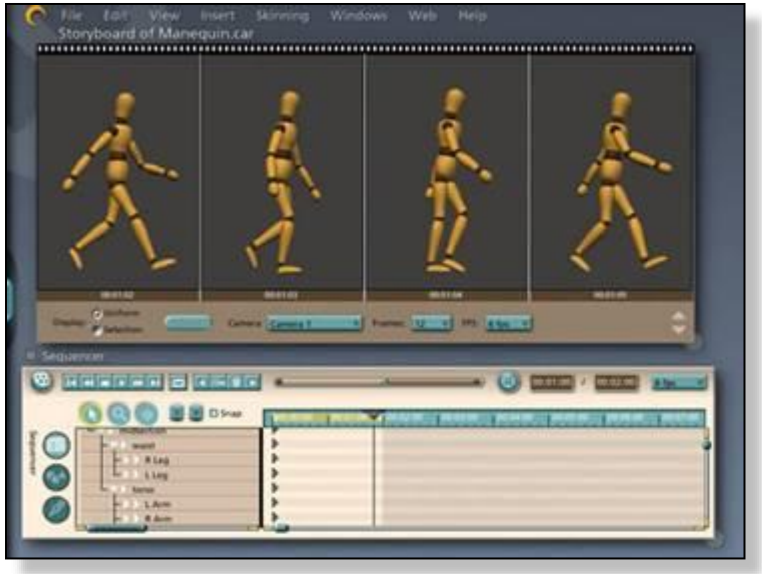


Early Animation Processes

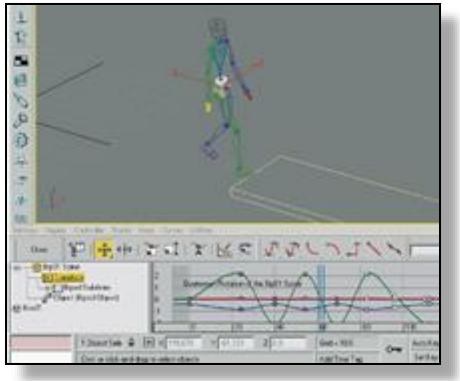
- A master artist would draw the most important or *key frames* (*"keyframes"*), and less-skilled or less-experienced artists would fill in the action for the in-between (*"tweens"*) frames. Other artists would paint or fill the outlines with color.
- *Stop-action animation* uses clay or other models whose positions are sequentially altered and photographed for each frame.

Computer Animation

- Unlike early animation, where every frame must be created to produce movement, in computer animation you define points in time (known as *keyframes*) and the computer draws all of the in-between frames.



Computer Animation

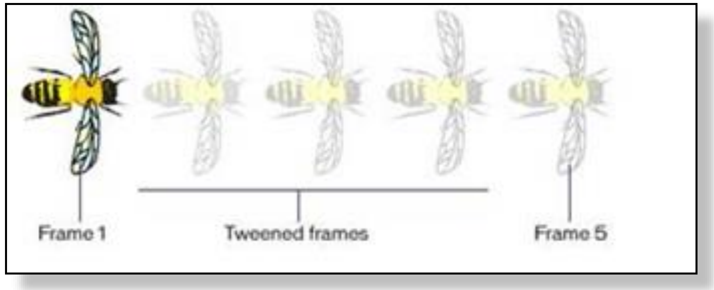


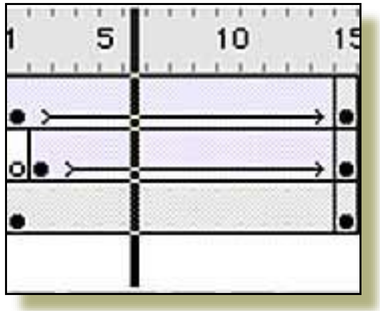
- Position the object to be animated where you want the action to begin; this is first keyframe.
- Set the number of frames that you want to use for the animation sequence. A one second "movie' would typically use 30 frames per second (30 fps NTSC); two seconds would use 60 frames, etc.
- Move, scale, or deform the object to become the next keyframe.

Guilford County SciVis

Computer Animation

- Instruct the computer to calculate all of the transformations that will occur between the first keyframe and the last.
- The computer will produce the 28 additional "in-between" images (*tweens*) needed for the one second of animation (you created the other two frames, the keyframes, for a total of 30).

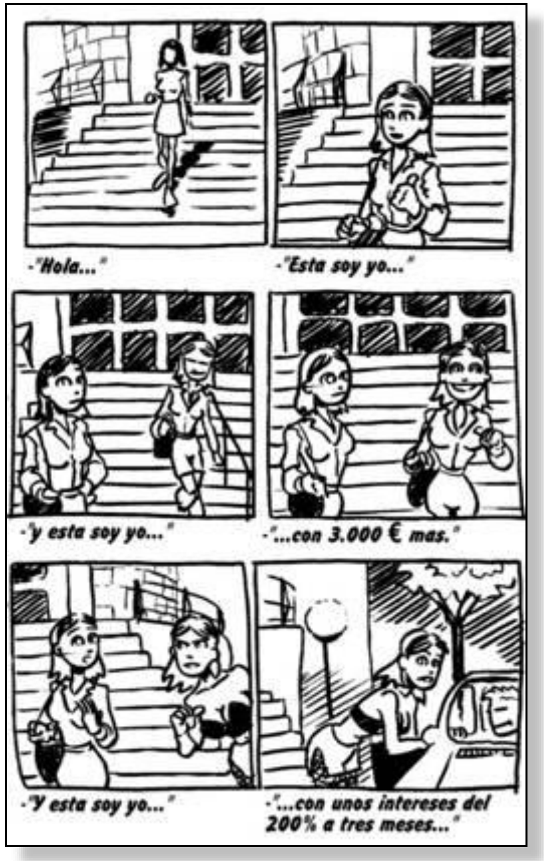




Storyboarding

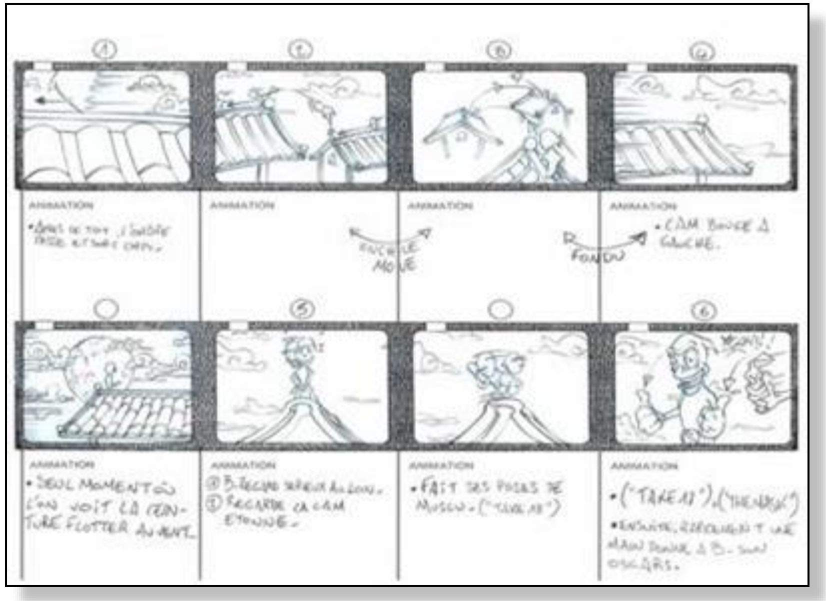
- A *storyboard* is a graphic, sequential depiction of an animation that is going to be created. It is a visual script designed to make it easier to see the animation scenes before they are created.
- A storyboard identifies the major events in the story and illustrates them in cells (small squares or rectangles), which are drawn out in a sequential pattern.

Example Storyboard



Storyboarding

- Storyboards are used for movies, TV, commercials, and animation.
- The artwork does not have to be pretty or complex, but it should be neat and comprehensible.
- The pictures in the storyboard should be accompanied by text.



Guilford County SciVis

The End

Image processing techniques

S. No.	Contents
1.	**Image fundamentals:** A simple image formation model, sampling and quantization, connectivity and adjacency relationships between pixels
2.	**Spatial domain filtering:** Basic intensity transformations: negative, log, power-law and piecewise linear transformations, bit-plane slicing, histogram equalization and matching, smoothing and sharpening filtering in spatial domain, unsharp masking and high-boost filtering
3.	**Frequency domain filtering:** Fourier Series and Fourier transform, discrete and fast Fourier transform, sampling theorem, aliasing, filtering in frequency domain, lowpass and highpass filters, bandreject and bandpass filters, notch filters
4.	**Image restoration:** Introduction to various noise models, restoration in presence of noise only, periodic noise reduction, linear and position invariant degradation, estimation of degradation function
5.	**Image reconstruction:** Principles of computed tomography, projections and Radon transform, the Fourier slice theorem, reconstruction using parallel-beam and fan-beam by filtered backprojection methods
6.	**Mathematical morphology:** Erosion and dilation, opening and closing, the Hit-or-Miss transformation, various morphological algorithms for binary images
7.	**Wavelets and multiresolution processing:** Image pyramids, subband coding, multiresolution expansions, the Haar transform, wavelet transform in one and two dimensions, discrete wavelet transform

Gonzalez, R. C. and Woods, R. E., "Digital Image Processing", Prentice Hall, 3rd Ed.
Jain, A. K., "Fundamentals of Digital Image Processing", PHI Learning, 1st Ed.
Bernd, J., "Digital Image Processing", Springer, 6th Ed.
Burger, W. and Burge, M. J., "Principles of Digital Image Processing", Springer
Scherzer, O., " Handbook of Mathematical Methods in Imaging", Springer

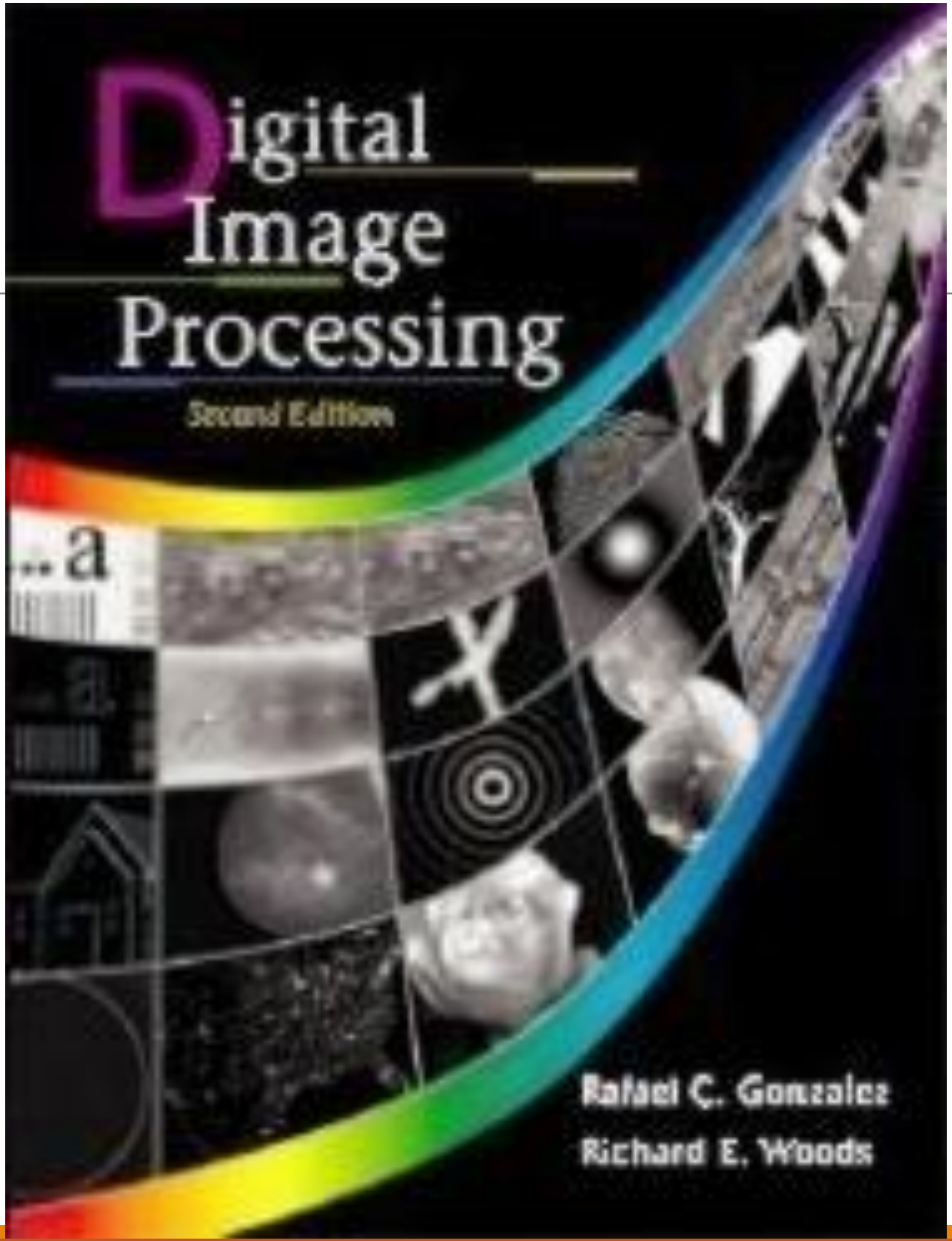

Digital
Image
Processing
Second Edition
Rafael C. Gonzalez
Richard E. Woods

Image Acquisition Process

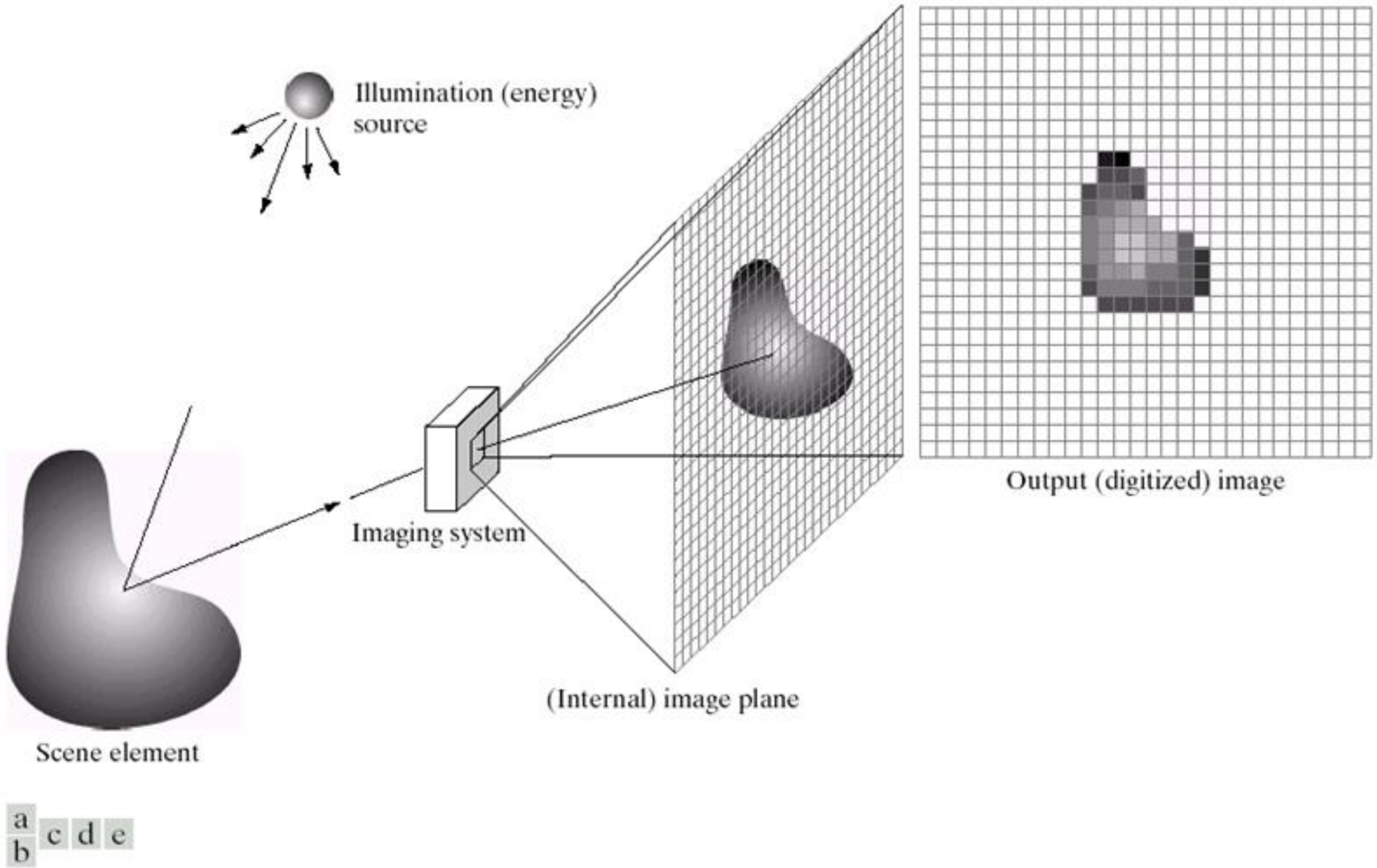


FIGURE 2.15 An example of the digital image acquisition process. (a) Energy ("illumination") source. (b) An element of a scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.

Introduction

What is Digital Image Processing?

Digital Image

— a two-dimensional function $f(x, y)$

***x* and *y* are spatial coordinates**

The amplitude of *f* is called intensity or gray level at the point (x, y)

Digital Image Processing

— process digital images by means of computer, it covers low-, mid-, and high-level processes

low-level: inputs and outputs are images

mid-level: outputs are attributes extracted from input images

high-level: an ensemble of recognition of individual objects

Pixel

— the elements of a digital image

A Simple Image Formation Model

$$f(x, y) = i(x, y) \cdot r(x, y)$$

$f(x, y)$: intensity at the point (x, y)

$i(x, y)$: illumination at the point (x, y)

(the amount of source illumination incident on the scene)

$r(x, y)$: reflectance/transmissivity at the point (x, y)

(the amount of illumination reflected/transmitted by the object)

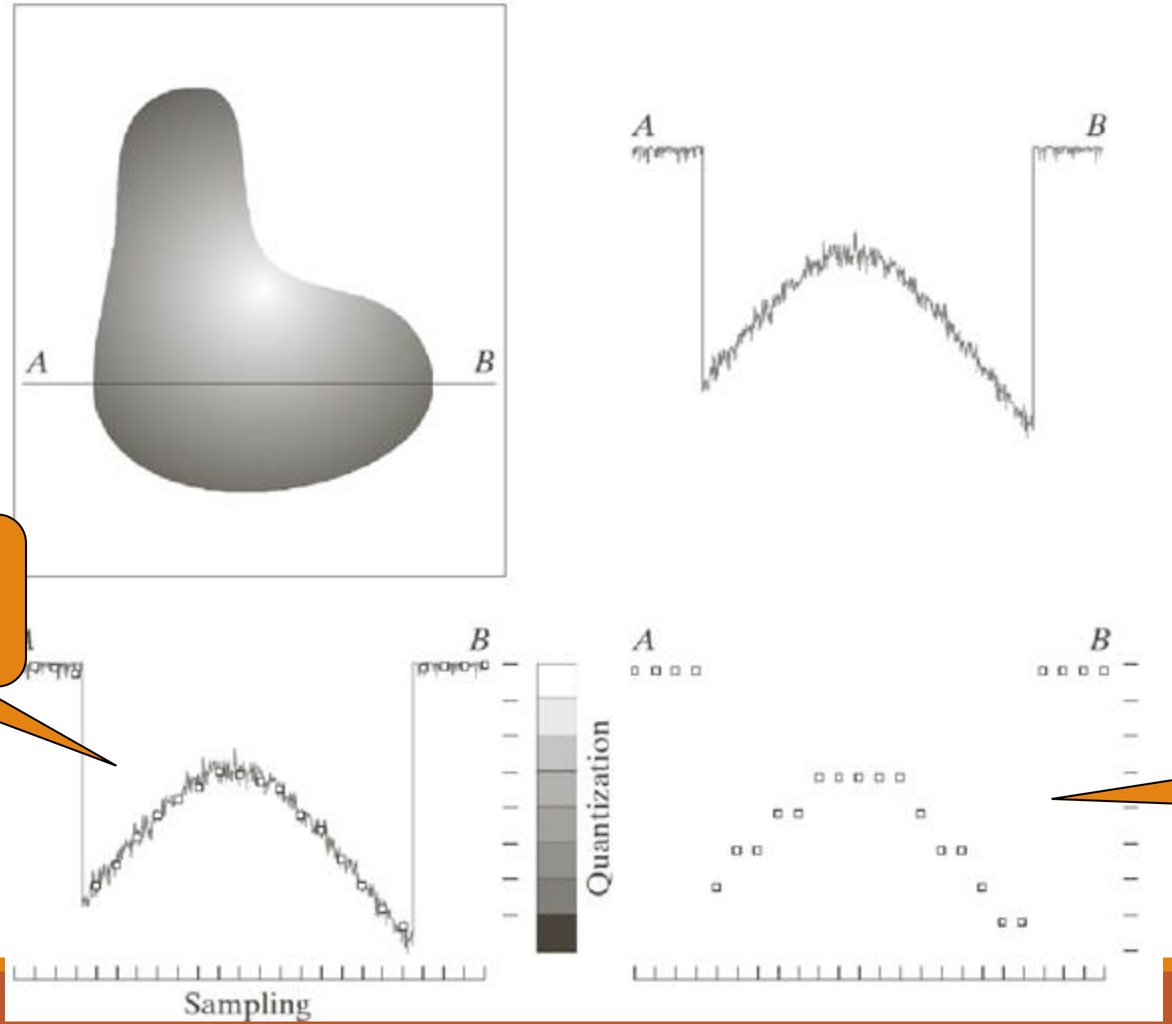
where $0 < i(x, y) < \infty$ and $0 < r(x, y) < 1$

Some Typical Ranges of Reflectance

Reflectance

- 0.01 for black velvet
- 0.65 for stainless steel
- 0.80 for flat-white wall paint
- 0.90 for silver-plated metal
- 0.93 for snow

Image Sampling and Quantization



Digitizing the coordinate values

Digitizing the amplitude values

a b
c d

FIGURE 2.16 Generating a digital image. (a) Continuous image. (b) A scan line from A to B in the continuous image, used to illustrate the concepts of sampling and quantization. (c) Sampling and quantization. (d) Digital scan line.

Image Sampling and Quantization

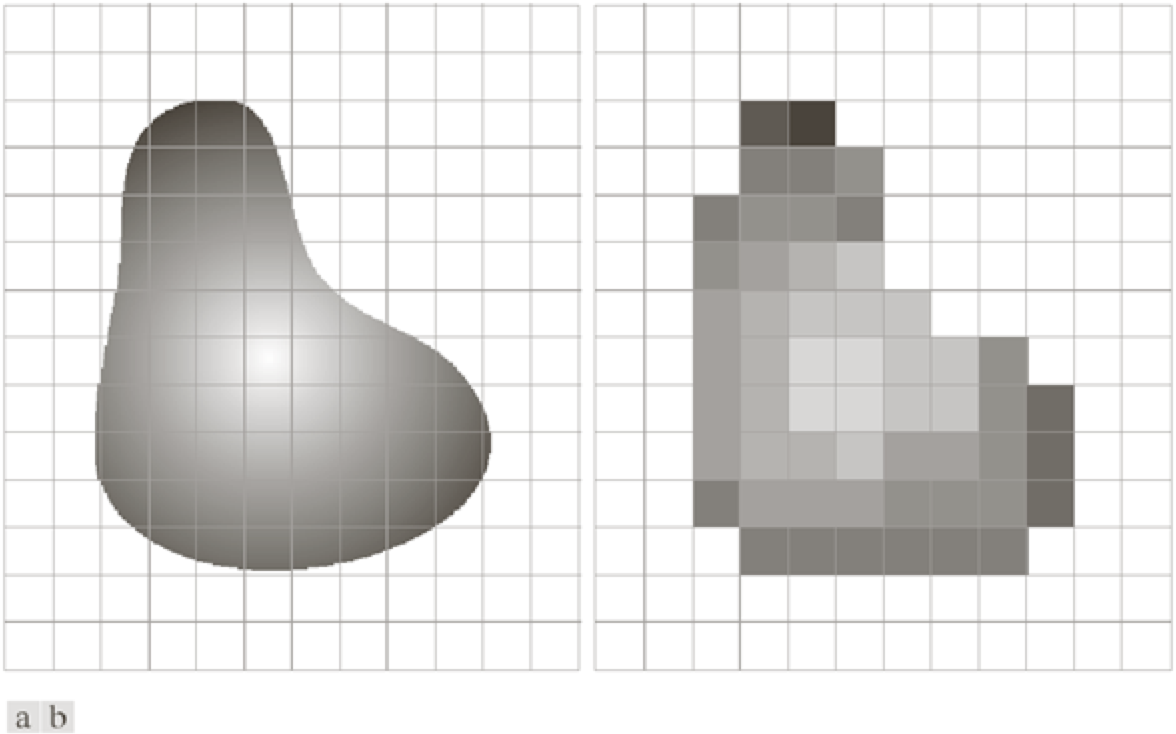


FIGURE 2.17 (a) Continuous image projected onto a sensor array. (b) Result of image sampling and quantization.

Representing Digital Images

The representation of an M×N numerical array as

$$f(x,y) = \begin{bmatrix} f(0,0) & f(0,1) & \ldots & f(0,N-1) \\ f(1,0) & f(1,1) & \ldots & f(1,N-1) \\ \ldots & \ldots & \ldots & \ldots \\ f(M-1,0) & f(M-1,1) & \ldots & f(M-1,N-1) \end{bmatrix}$$

Representing Digital Images

The representation of an M×N numerical array as

$$A = \begin{bmatrix} a_{0,0} & a_{0,1} & \cdots & a_{0,N-1} \\ a_{1,0} & a_{1,1} & \cdots & a_{1,N-1} \\ \cdots & \cdots & \cdots & \cdots \\ a_{M-1,0} & a_{M-1,1} & \cdots & a_{M-1,N-1} \end{bmatrix}$$

Representing Digital Images

The representation of an M×N numerical array in MATLAB

$$f(x,y)=\begin{bmatrix} f(1,1) & f(1,2) & \dots & f(1,N) \\ f(2,1) & f(2,2) & \dots & f(2,N) \\ \dots & \dots & \dots & \dots \\ f(M,1) & f(M,2) & \dots & f(M,N) \end{bmatrix}$$

Representing Digital Images

Discrete intensity interval $[0, L-1]$, $L=2^k$

The number b of bits required to store a $M \times N$ digitized image

$$b = M \times N \times k$$

Representing Digital Images

TABLE 2.1

Number of storage bits for various values of N and k.

N/k	1 (L = 2)	2 (L = 4)	3 (L = 8)	4 (L = 16)	5 (L = 32)	6 (L = 64)	7 (L = 128)	8 (L = 256)
32	1,024	2,048	3,072	4,096	5,120	6,144	7,168	8,192
64	4,096	8,192	12,288	16,384	20,480	24,576	28,672	32,768
128	16,384	32,768	49,152	65,536	81,920	98,304	114,688	131,072
256	65,536	131,072	196,608	262,144	327,680	393,216	458,752	524,288
512	262,144	524,288	786,432	1,048,576	1,310,720	1,572,864	1,835,008	2,097,152
1024	1,048,576	2,097,152	3,145,728	4,194,304	5,242,880	6,291,456	7,340,032	8,388,608
2048	4,194,304	8,388,608	12,582,912	16,777,216	20,971,520	25,165,824	29,369,128	33,554,432
4096	16,777,216	33,554,432	50,331,648	67,108,864	83,886,080	100,663,296	117,440,512	134,217,728
8192	67,108,864	134,217,728	201,326,592	268,435,456	335,544,320	402,653,184	469,762,048	536,870,912









What is a Digital Image? (cont…)

Common image formats include:

- 1 sample per point (B&W or Grayscale)
- 3 samples per point (Red, Green, and Blue)
- 4 samples per point (Red, Green, Blue, and "Alpha", a.k.a. Opacity)

For most of this course we will focus on grey-scale images

Image processing

An **image processing** operation typically defines a new image g in terms of an existing image f.

We can transform either the range of f.

$$g(x, y) = t(f(x, y))$$

Or the domain of f:

$$g(x, y) = f(t_x(x, y), t_y(x, y))$$

What kinds of operations can each perform?

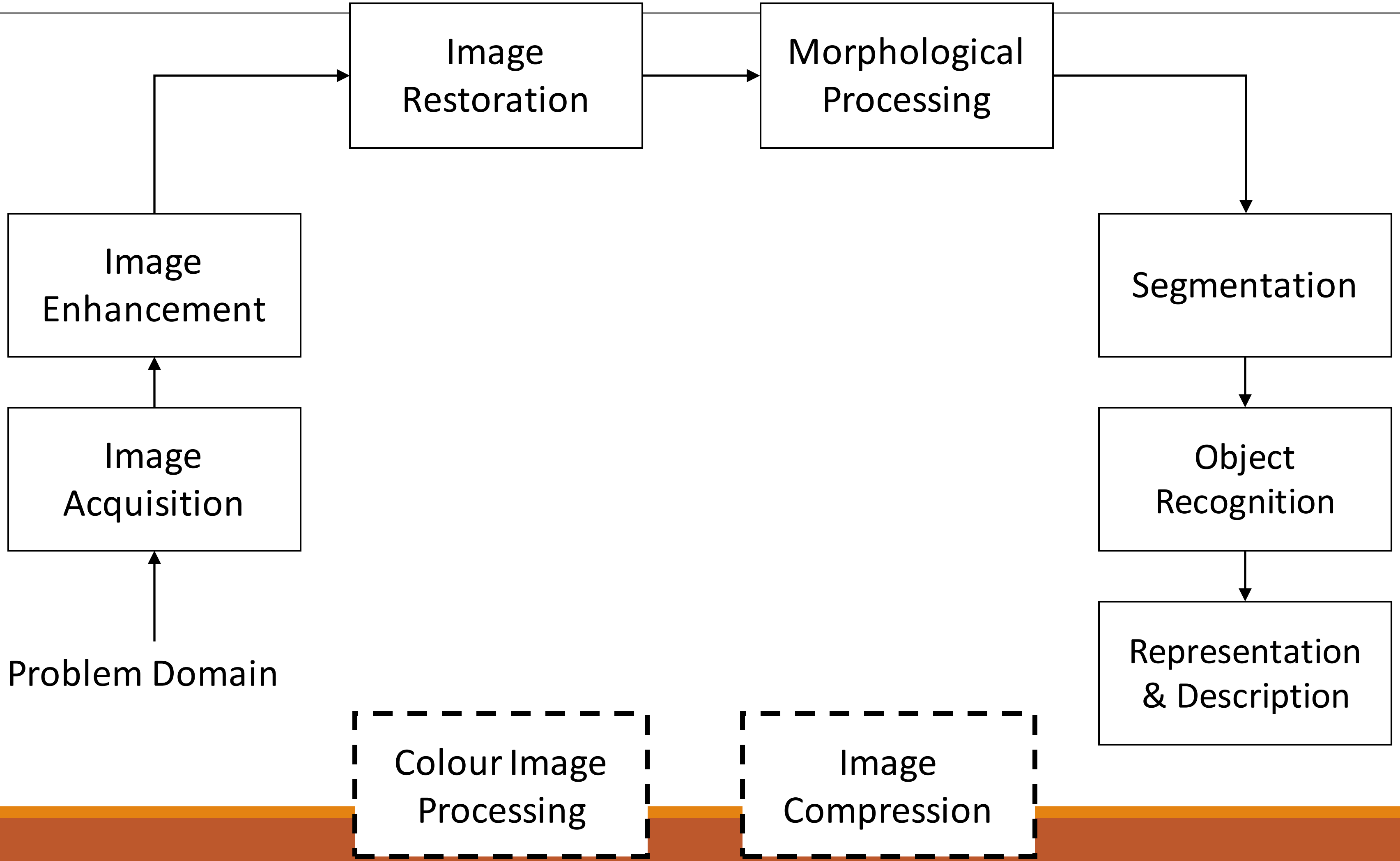
What is DIP? (cont…)

The continuum from image processing to computer vision can be broken up into low-, mid- and high-level processes

Low Level Process	Mid Level Process	High Level Process
Input: Image **Output:** Image	**Input:** Image **Output:** Attributes	**Input:** Attributes **Output:** Understanding
Examples: Noise removal, image sharpening	**Examples:** Object recognition, segmentation	**Examples:** Scene understanding, autonomous navigation

In this course we will stop here

Key Stages in Digital Image Processing



Key Stages in Digital Image Processing: Image Aquisition

Images taken from Gonzalez & Woods, Digital Image Processing (2002)

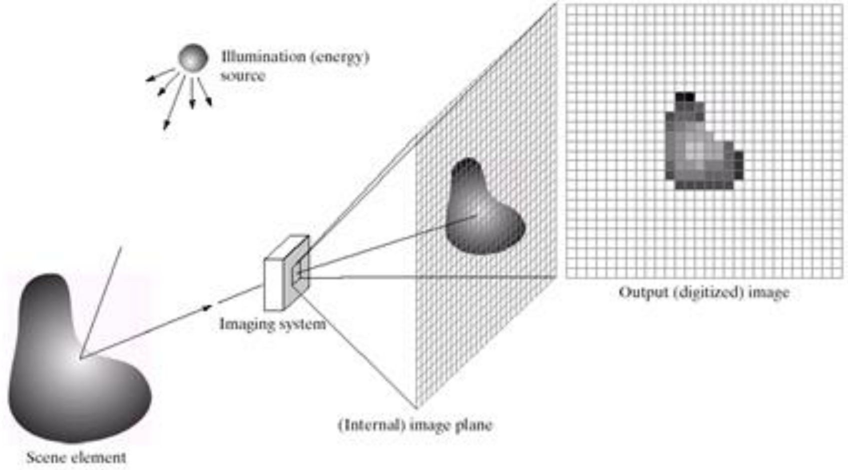
Image Restoration

Morphological Processing

Image Enhancement

Segmentation

Image Acquisition



Object Recognition

Problem Domain

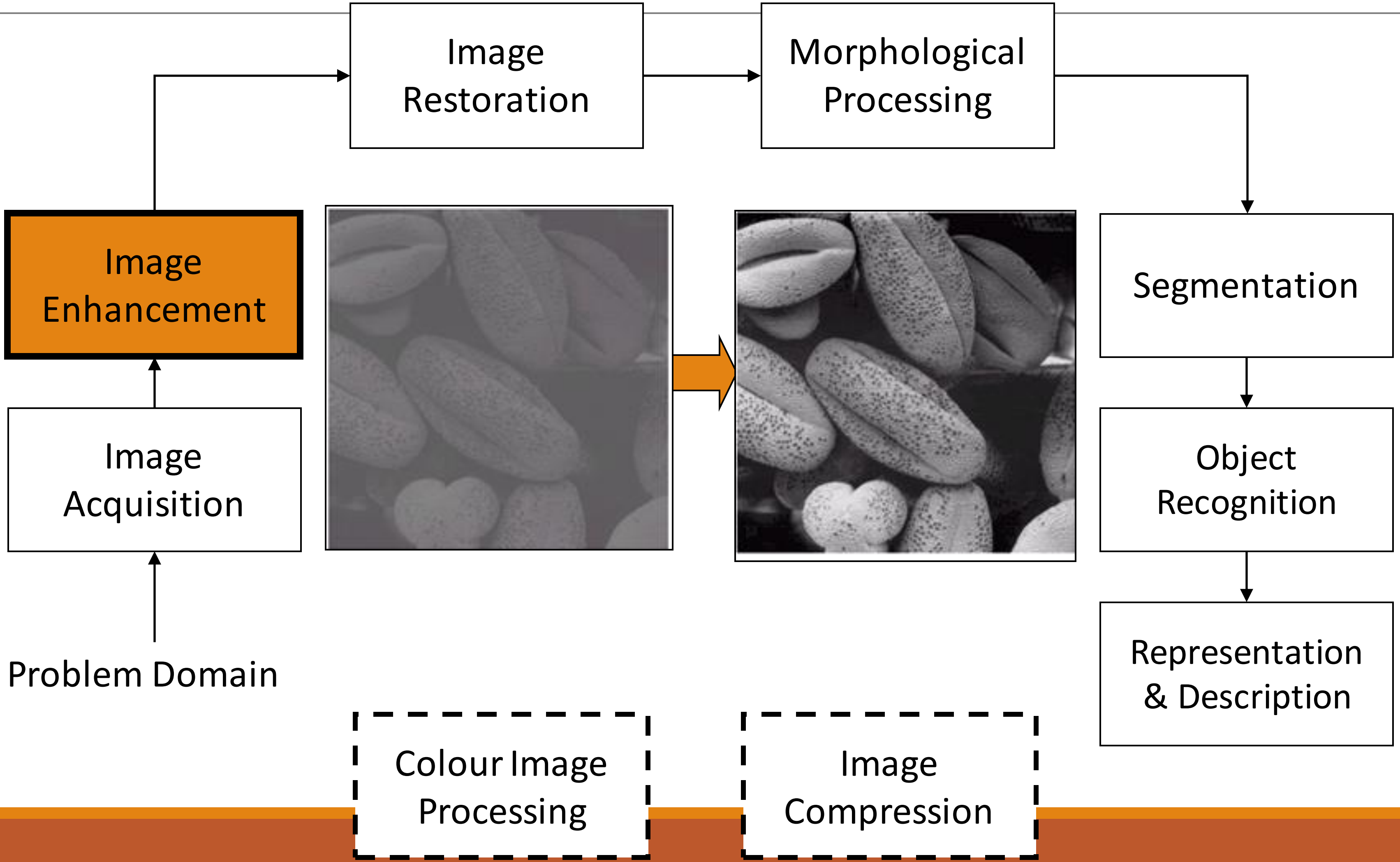
Representation & Description

Colour Image Processing

Image Compression

Key Stages in Digital Image Processing: Image Enhancement

Images taken from Gonzalez & Woods, Digital Image Processing (2002)



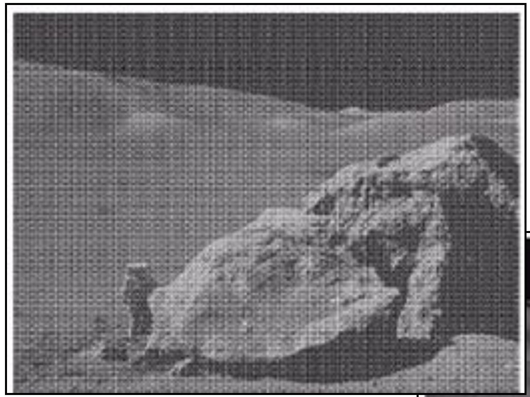
Key Stages in Digital Image Processing: Image Restoration

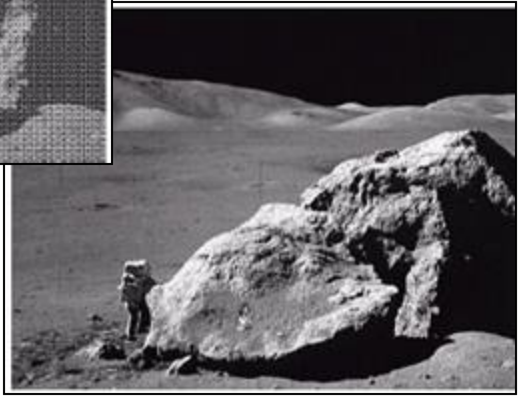
Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Image Restoration

Morphological Processing

Image Enhancement





Segmentation

Image Acquisition

Object Recognition

Problem Domain

Representation & Description

Colour Image Processing

Image Compression

Key Stages in Digital Image Processing: Morphological Processing

Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Problem Domain

Image Acquisition

Image Enhancement

Image Restoration

Morphological Processing

Segmentation

Object Recognition

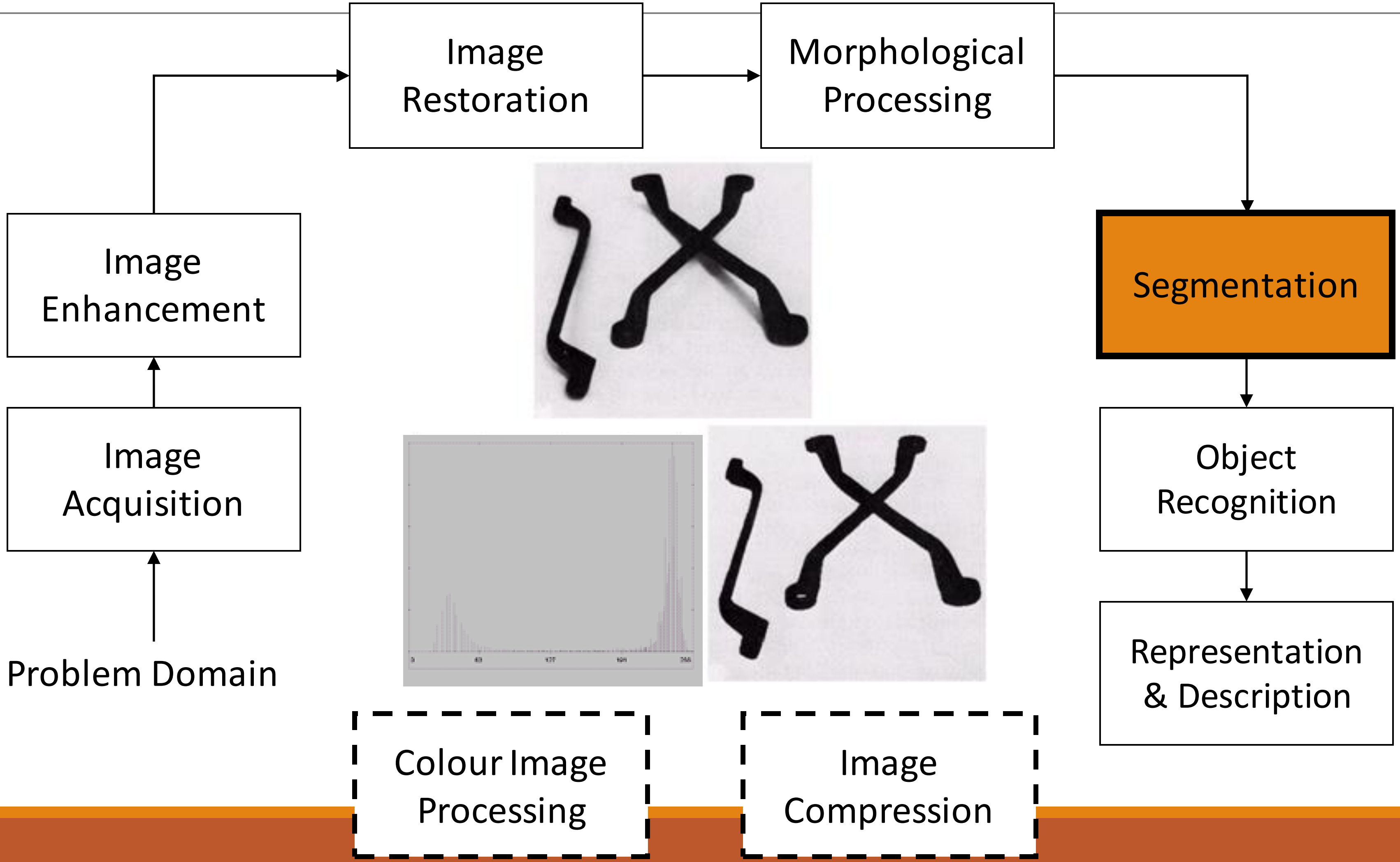
Representation & Description

Colour Image Processing

Image Compression

Key Stages in Digital Image Processing: Segmentation

Images taken from Gonzalez & Woods, Digital Image Processing (2002)



Key Stages in Digital Image Processing: Object Recognition

Images taken from Gonzalez & Woods, Digital Image Processing (2002)

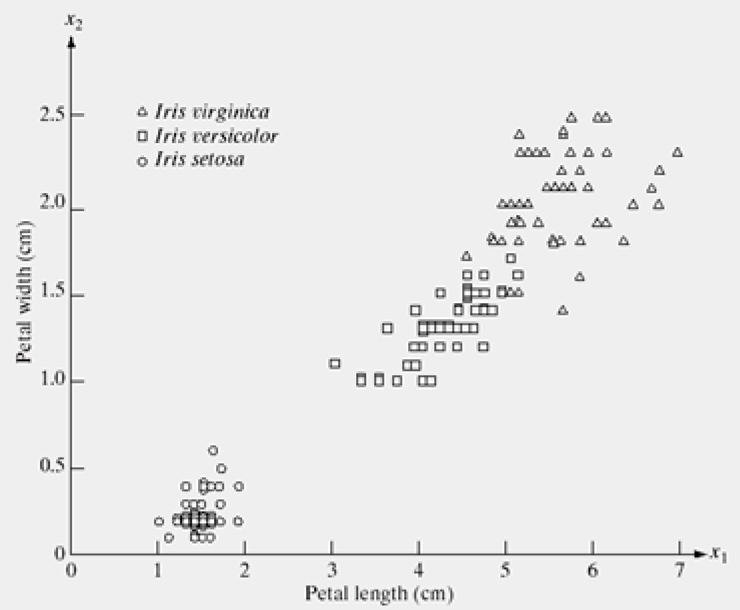
Image Restoration

Morphological Processing

Image Enhancement

Segmentation

Image Acquisition



Object Recognition

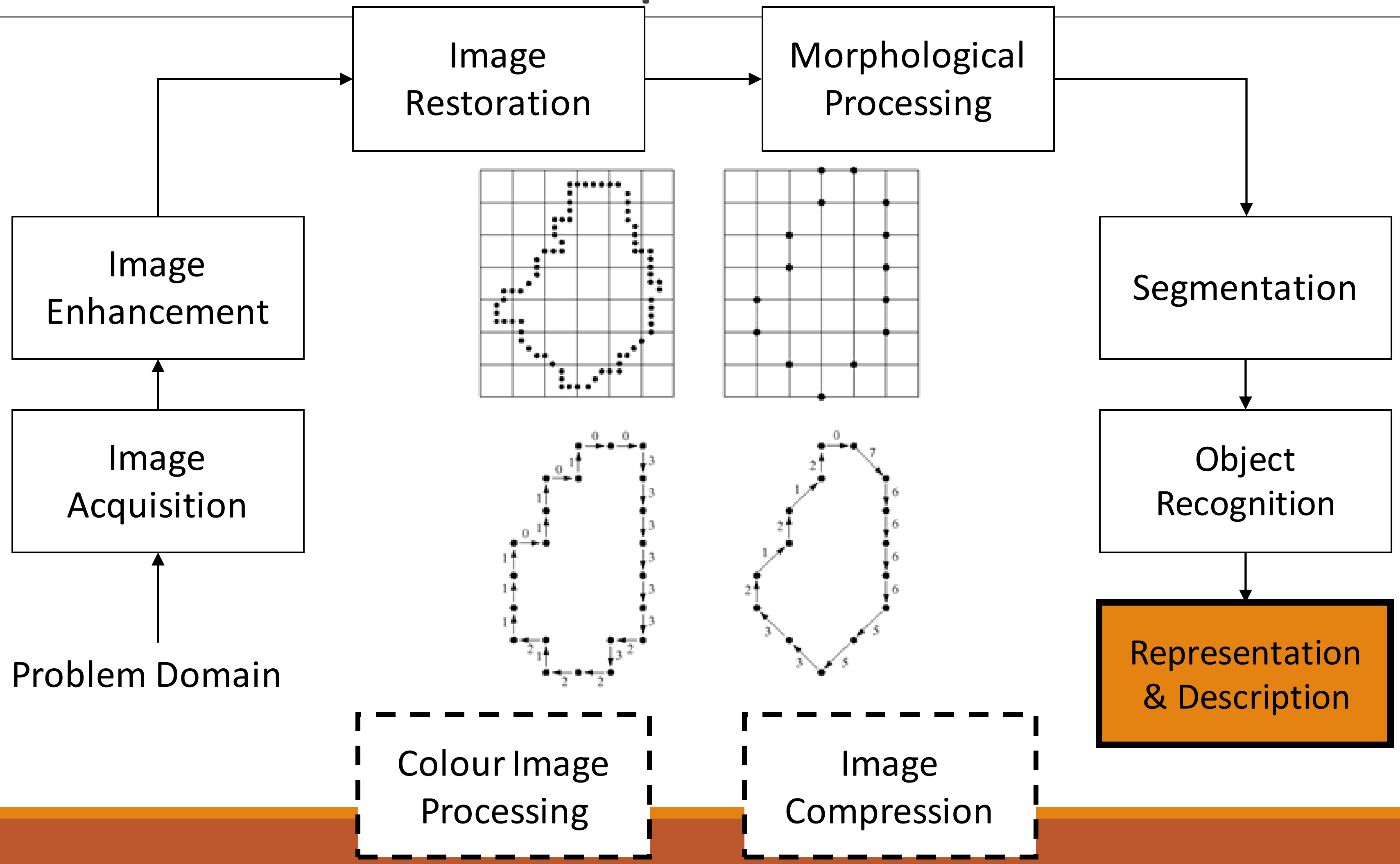
Problem Domain

Representation & Description

Colour Image Processing

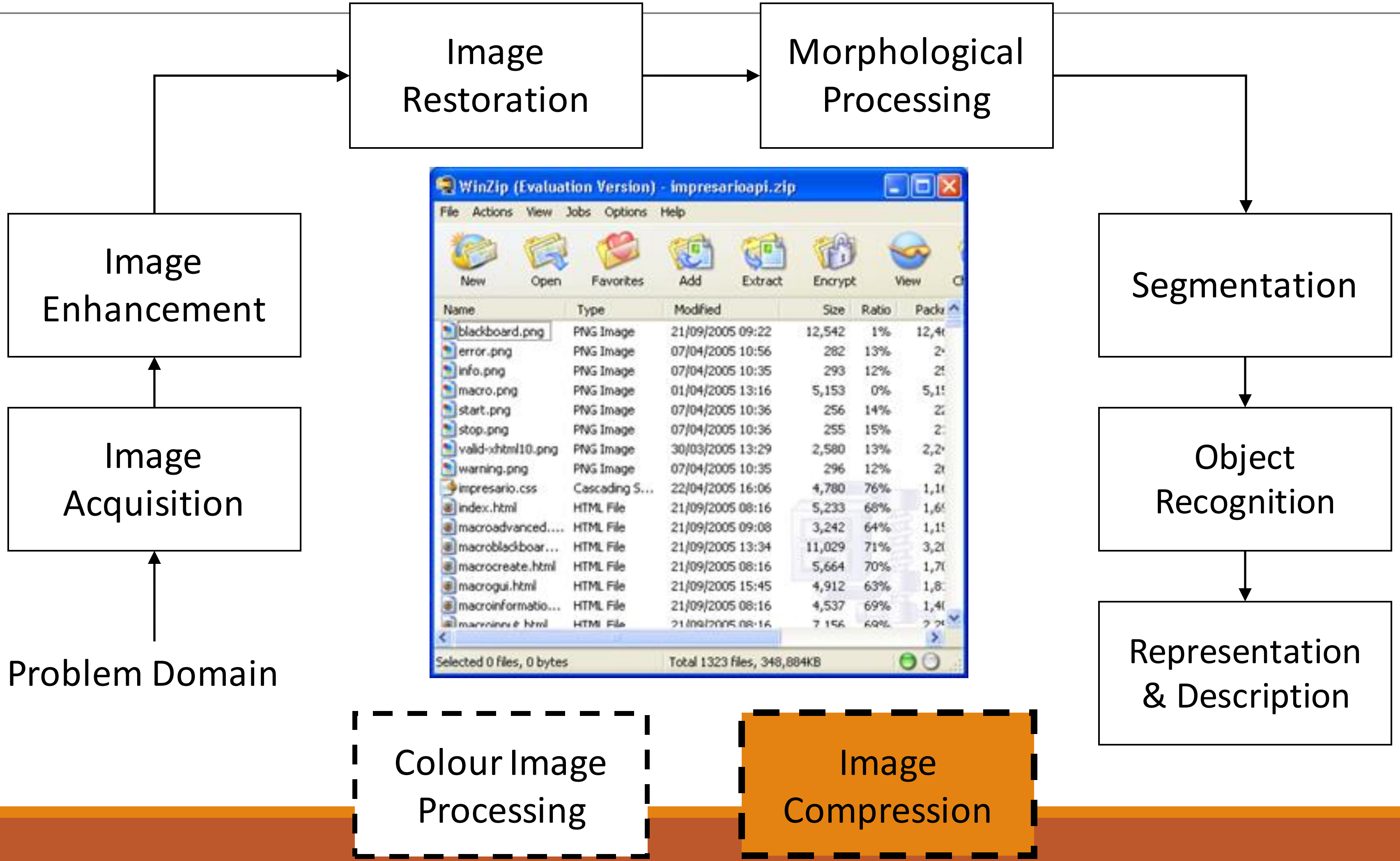
Image Compression

Key Stages in Digital Image Processing: Representation & Description



Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Key Stages in Digital Image Processing: Image Compression

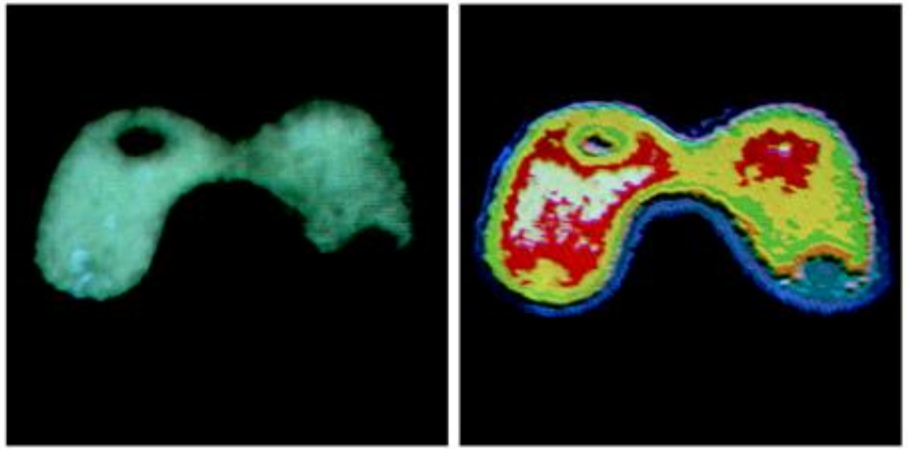


Key Stages in Digital Image Processing: Colour Image Processing

Image Restoration

Morphological Processing

Image Enhancement



Segmentation

Image Acquisition

Object Recognition

Representation & Description

Problem Domain

Colour Image Processing

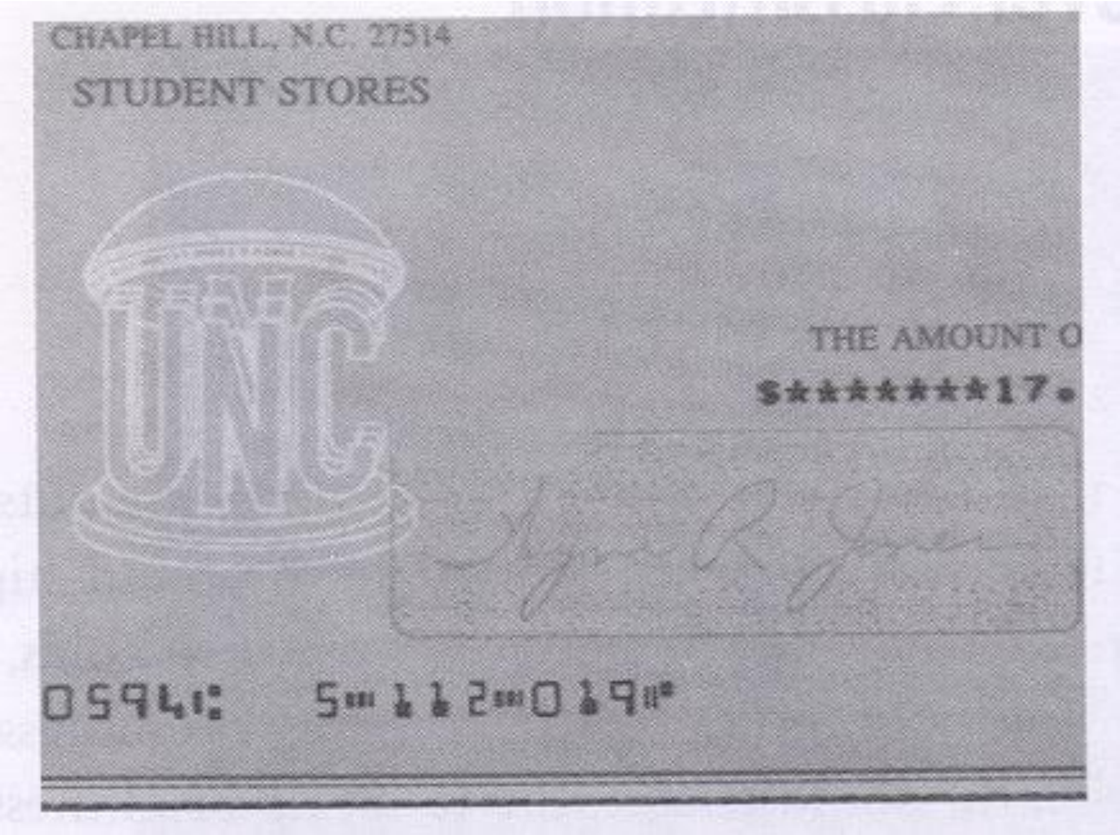
Image Compression

Applications

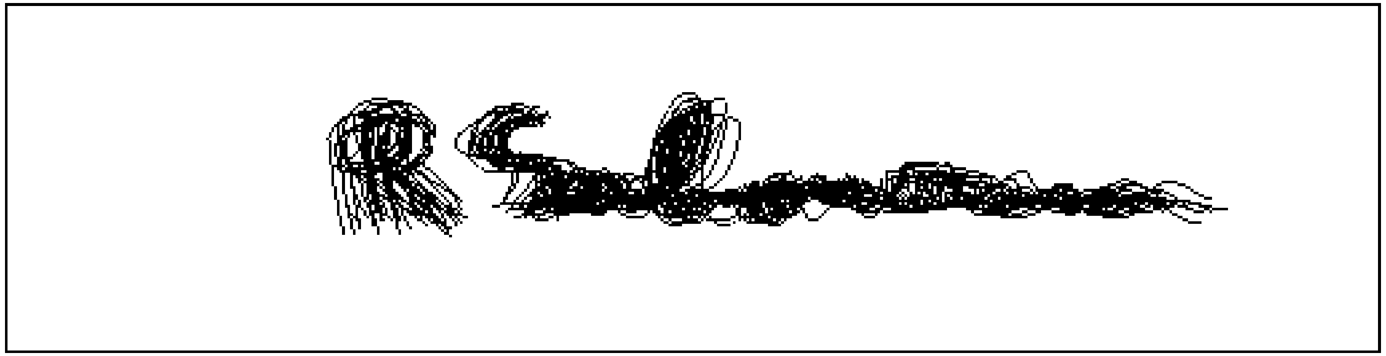
&

Research Topics

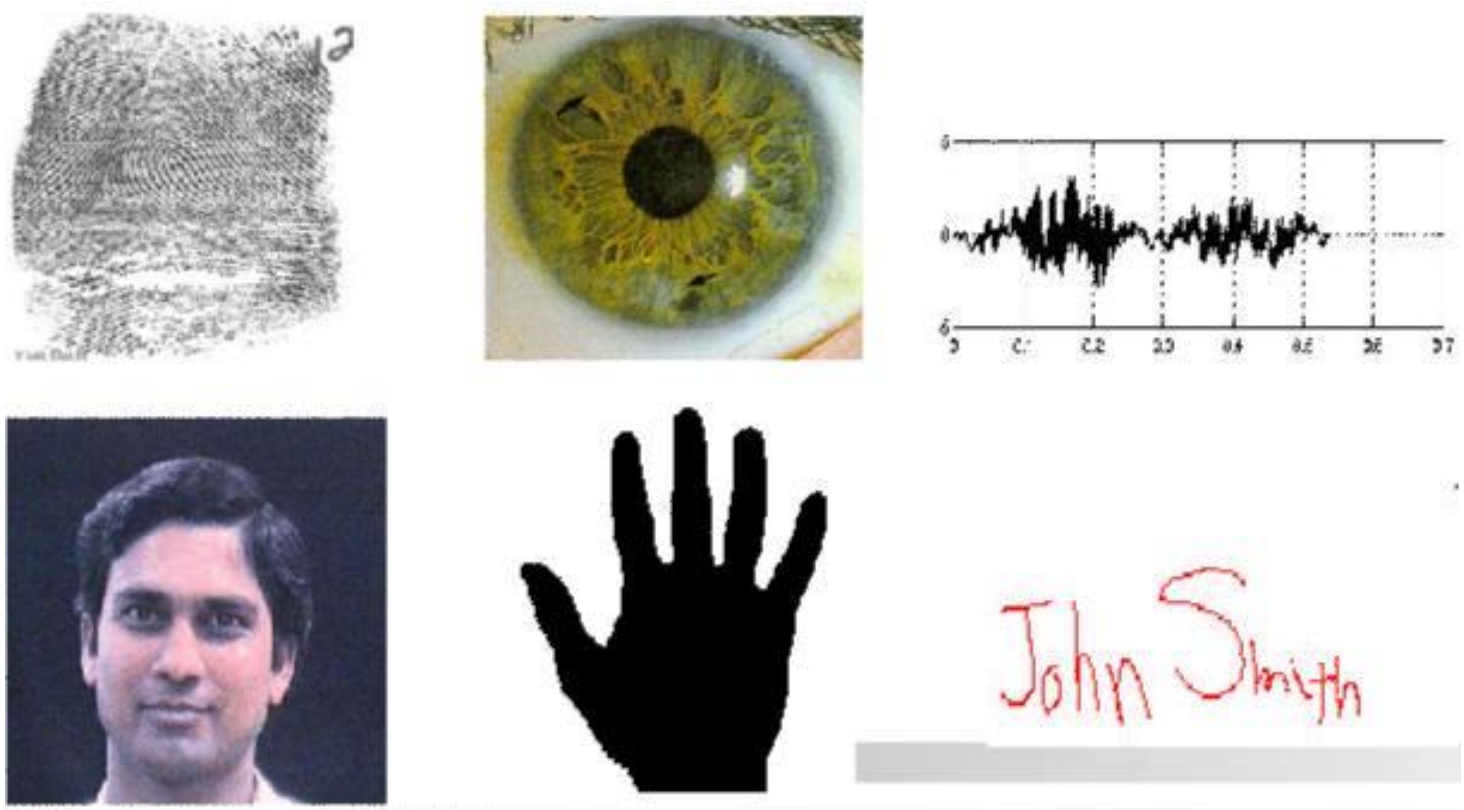
Document Handling



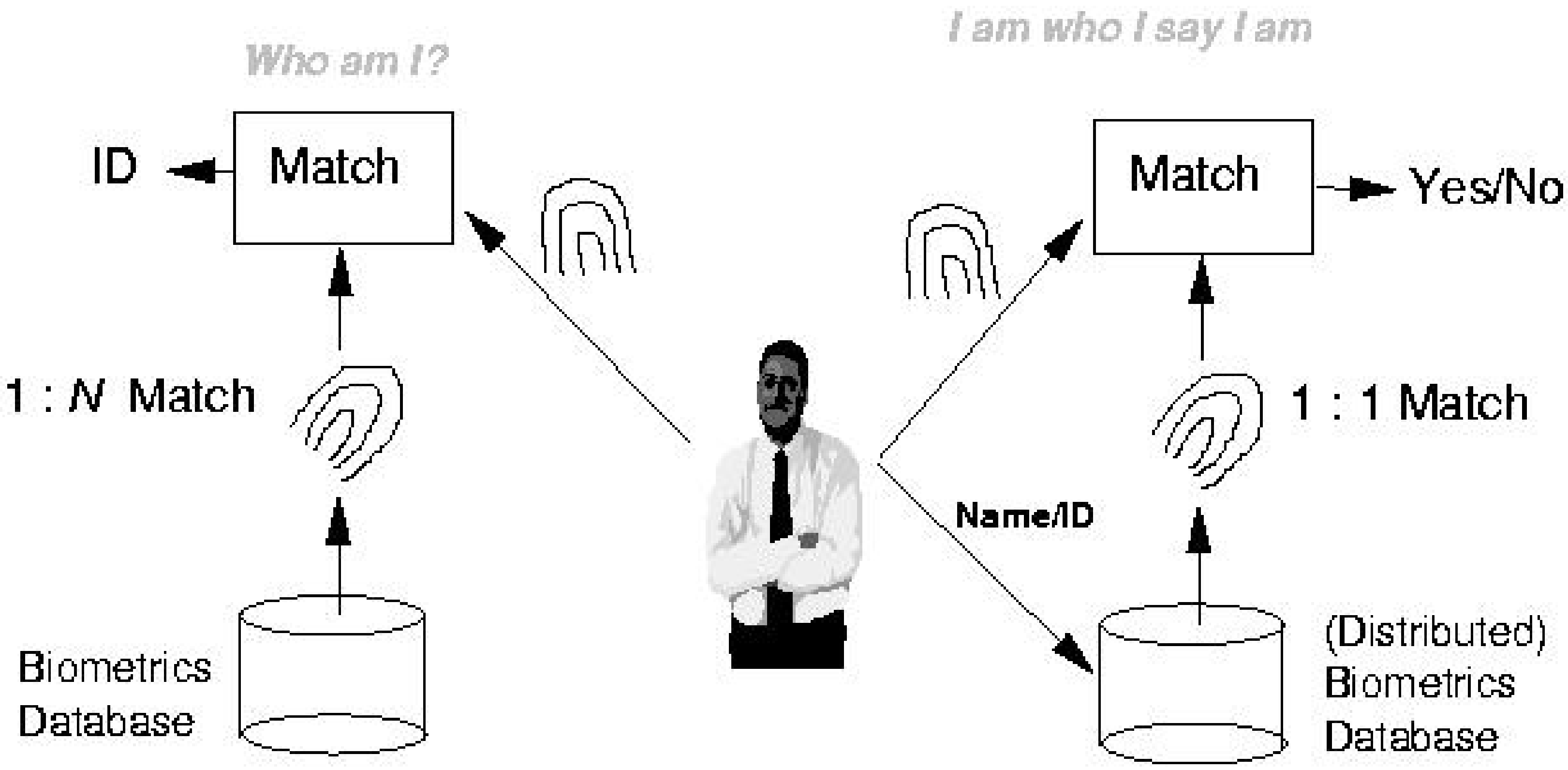
Signature Verification



Biometrics

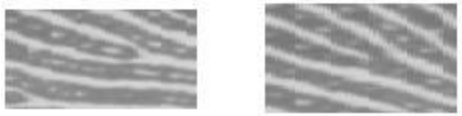


Fingerprint Verification / Identification



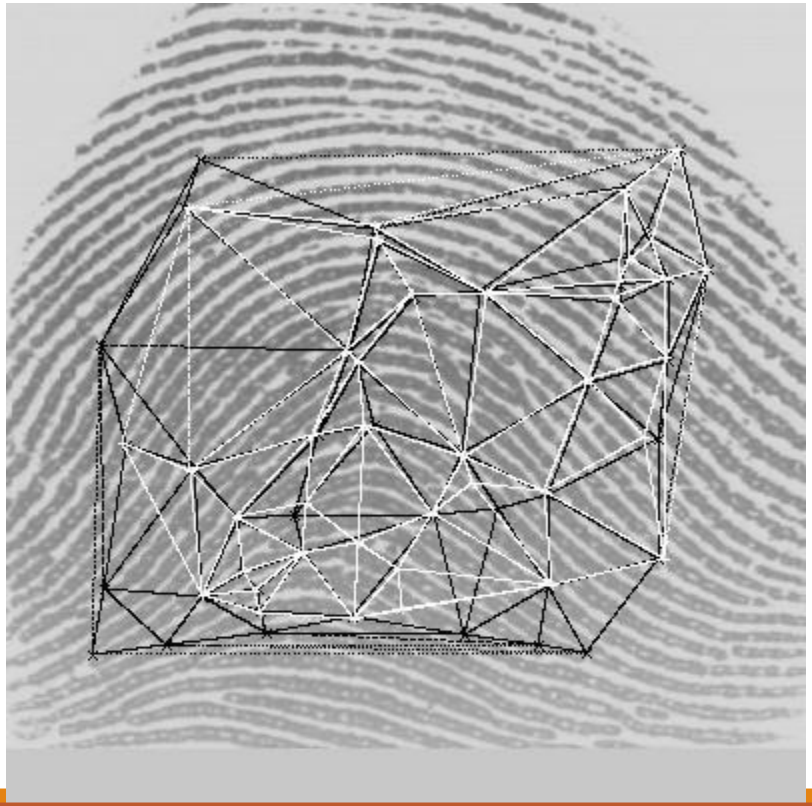
Fingerprint Identification Research at UNR

Minutiae

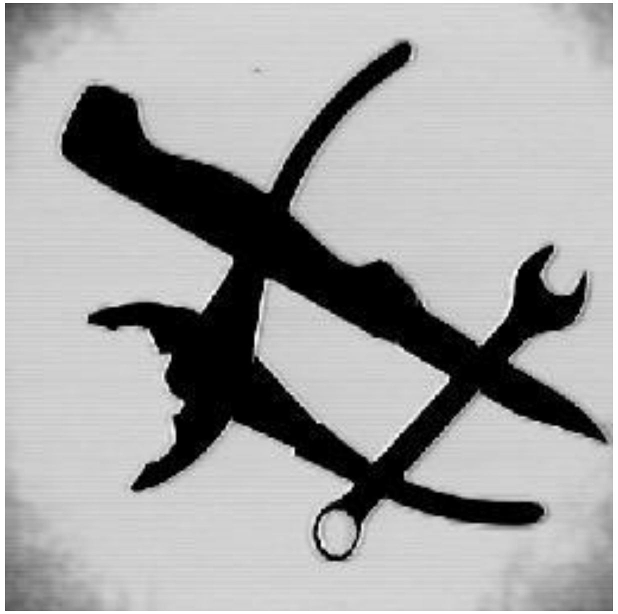


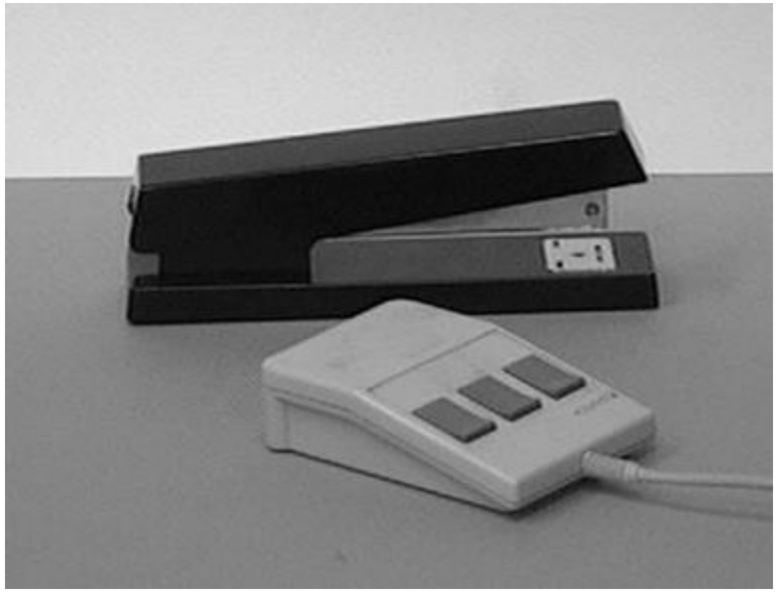
Delaunay Triangulation

Matching



Object Recognition



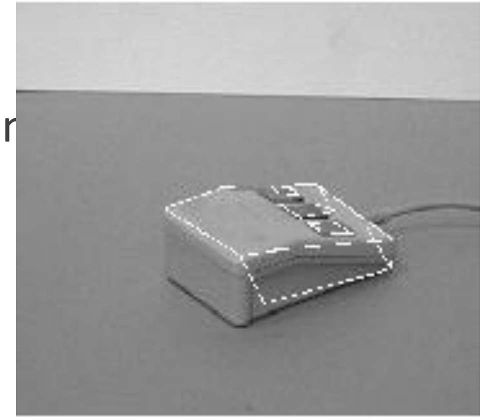


Object Recognition Research

reference view 1

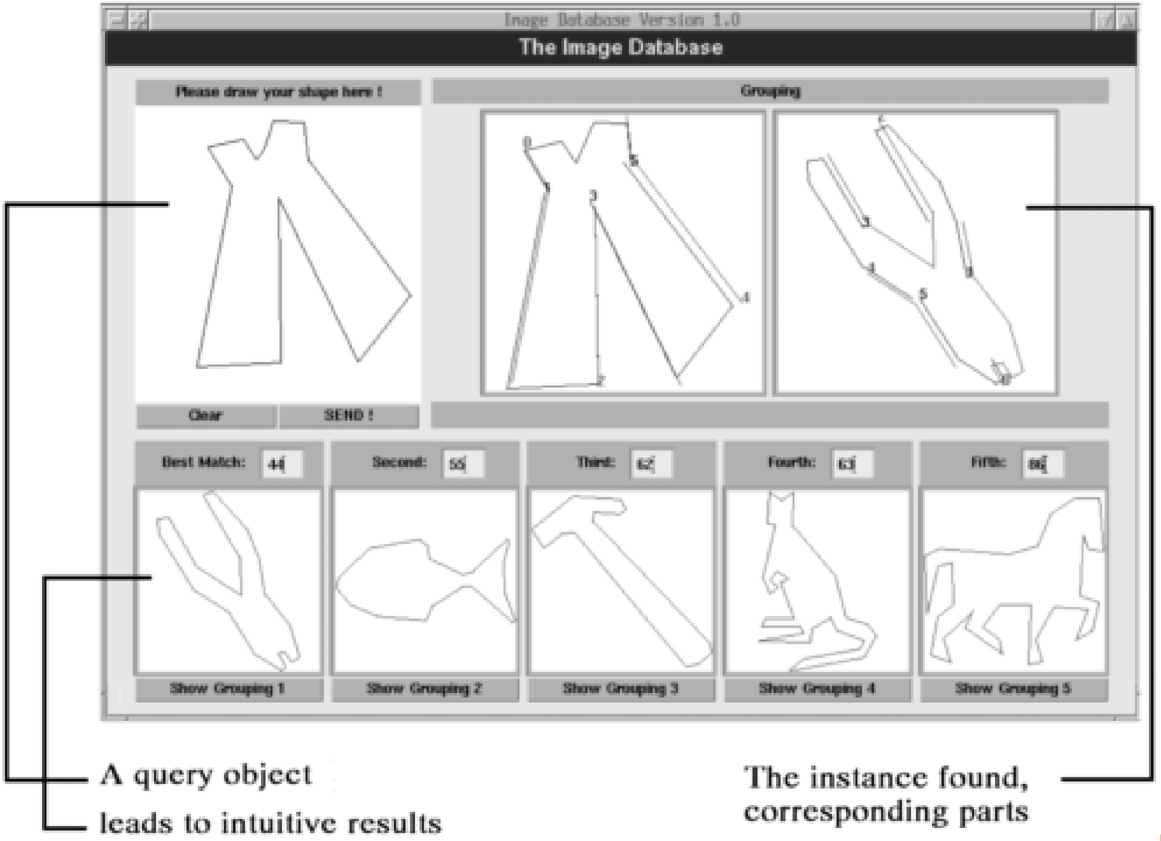
reference view 2

novel view recogn



Indexing into Databases

Shape content



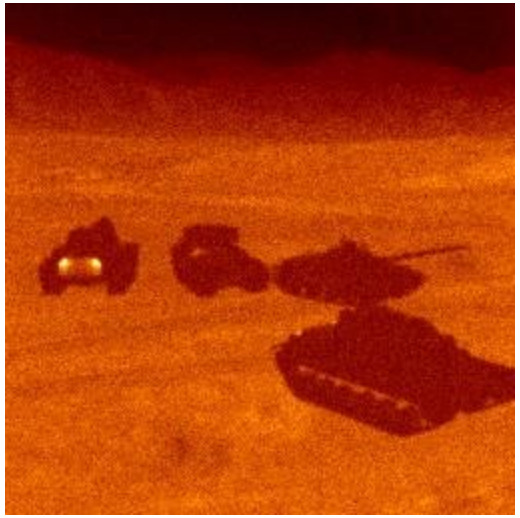
Indexing into Databases (cont’d)

Color, texture

$T = 33.6\text{s}$, found 2 of 2

Target Recognition

Department of Defense (Army, Airforce, Navy)

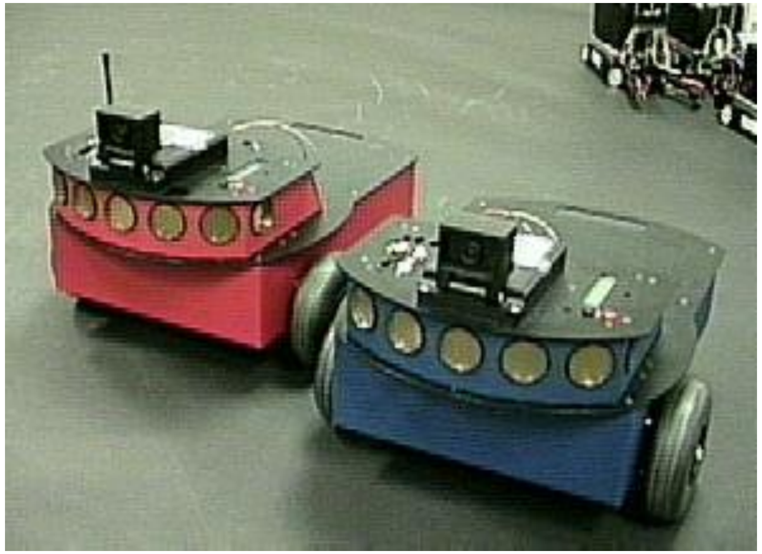


Interpretation of Aerial Photography

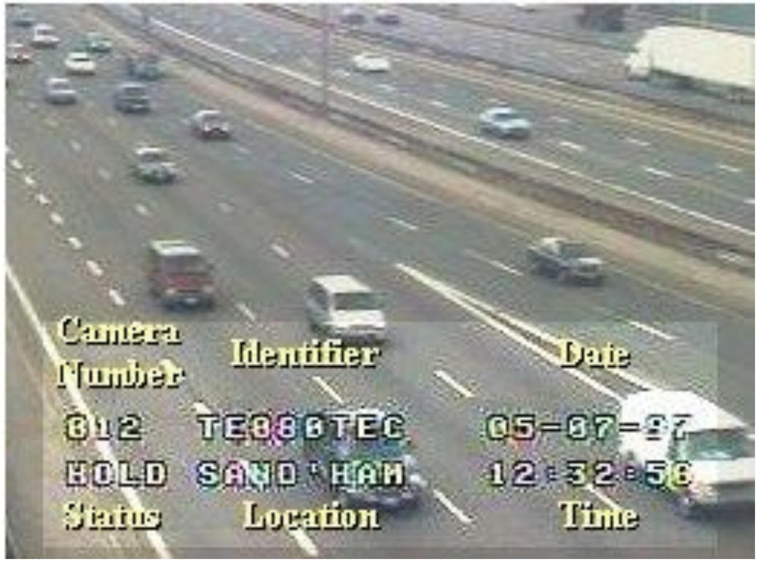
Interpretation of aerial photography is a problem domain in both computer vision and registration.

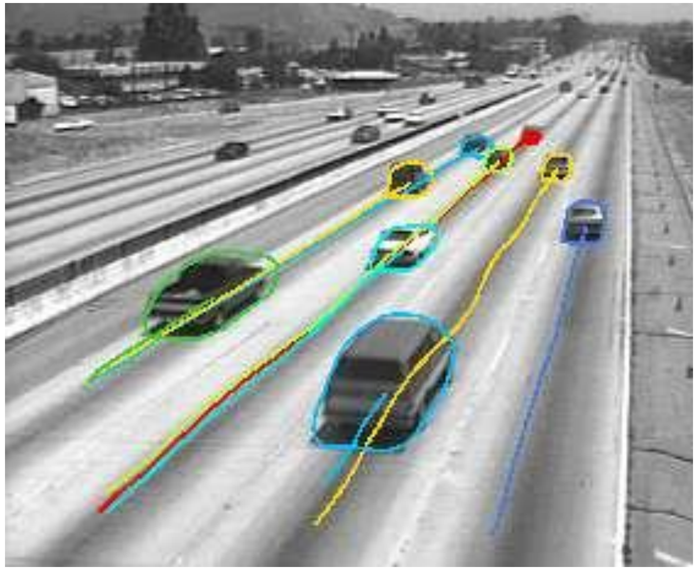
Autonomous Vehicles

Land, Underwater, Space

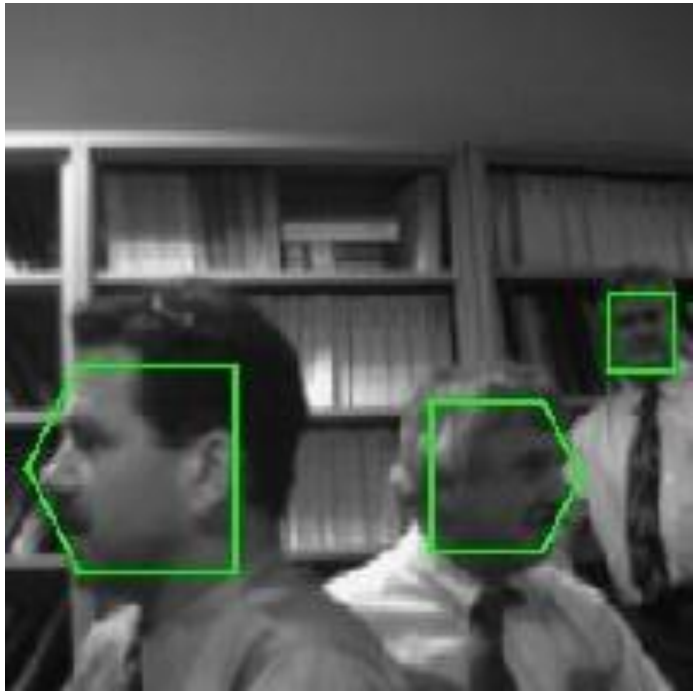


Traffic Monitoring





Face Detection



Face Recognition

Face Detection/Recognition Research at UNR

Facial Expression Recognition

Face Tracking

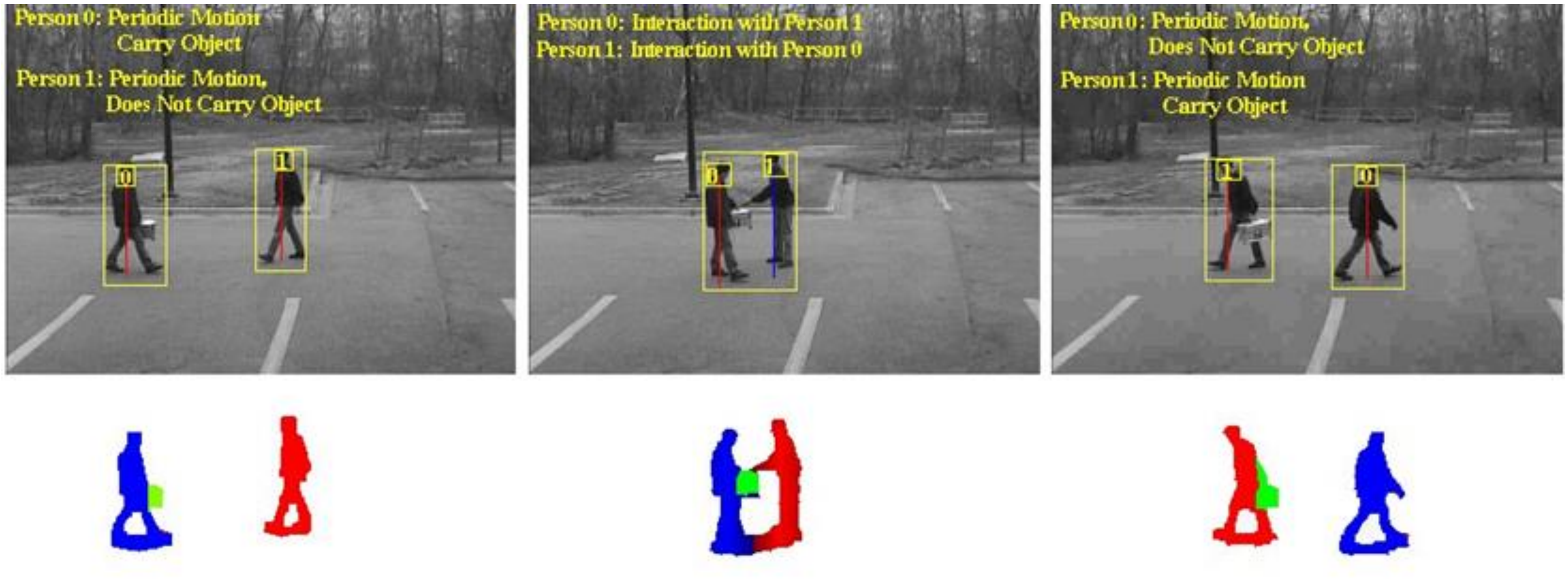
Face Tracking (cont’d)

Hand Gesture Recognition

Smart Human-Computer User Interfaces

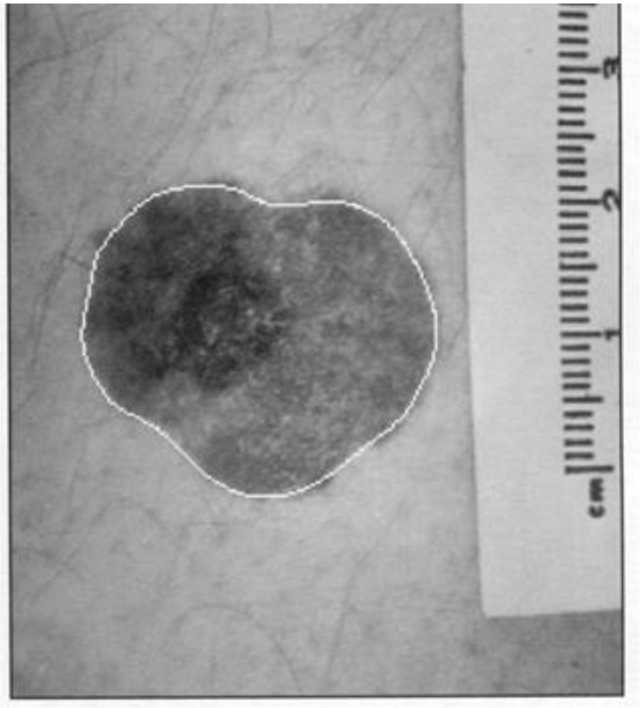
Sign Language Recognition

Human Activity Recognition



Medical Applications

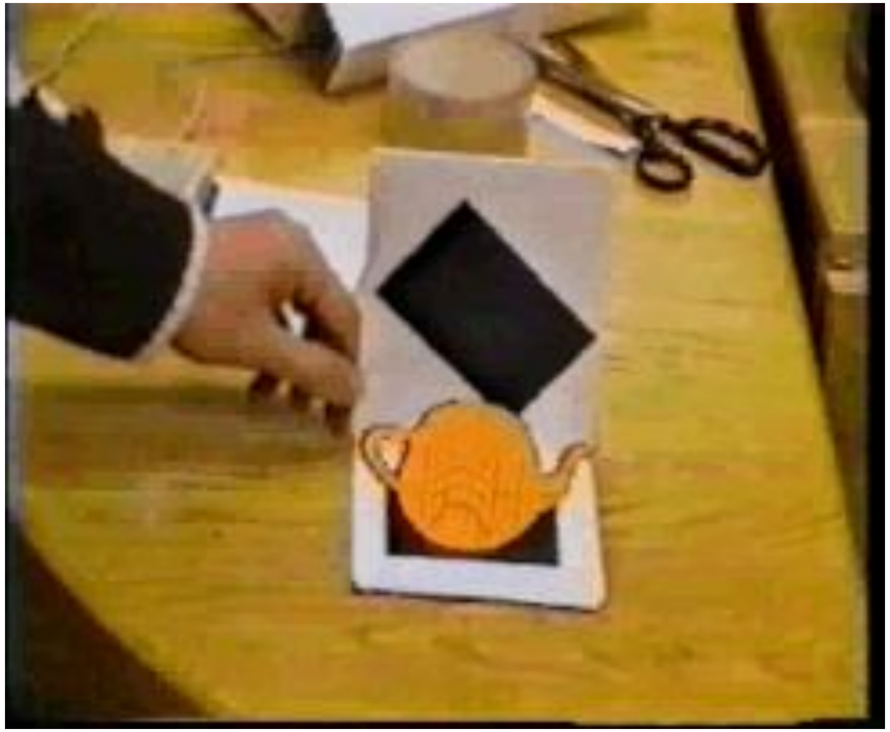
skin cancer



breast cancer

Morphing

Inserting Artificial Objects into a Scene



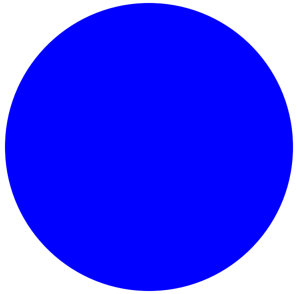
WEEK 12: SHADING

Objectives

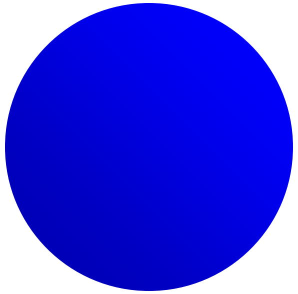
- Learn to shade objects so their images appear three-dimensional
- Introduce the types of light-material interactions
- Build a simple reflection model---the Phong model---that can be used with real time graphics hardware

Why we need shading

- Suppose we build a model of a sphere using many polygons and color it with `glColor`. We get something like

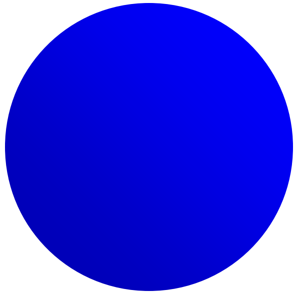


- But we want



Shading

- Why does the image of a real sphere look like



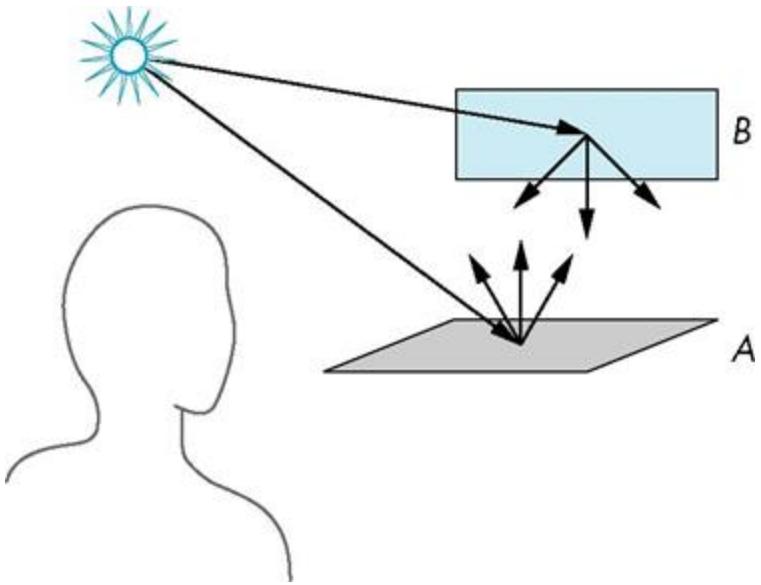
- Light-material interactions cause each point to have a different color or shade
- Need to consider
  - Light sources
  - Material properties
  - Location of viewer
  - Surface orientation

Scattering

- Light strikes A
  - Some scattered
  - Some absorbed
- Some of scattered light strikes B
  - Some scattered
  - Some absorbed
- Some of this scatterd

light strikes A

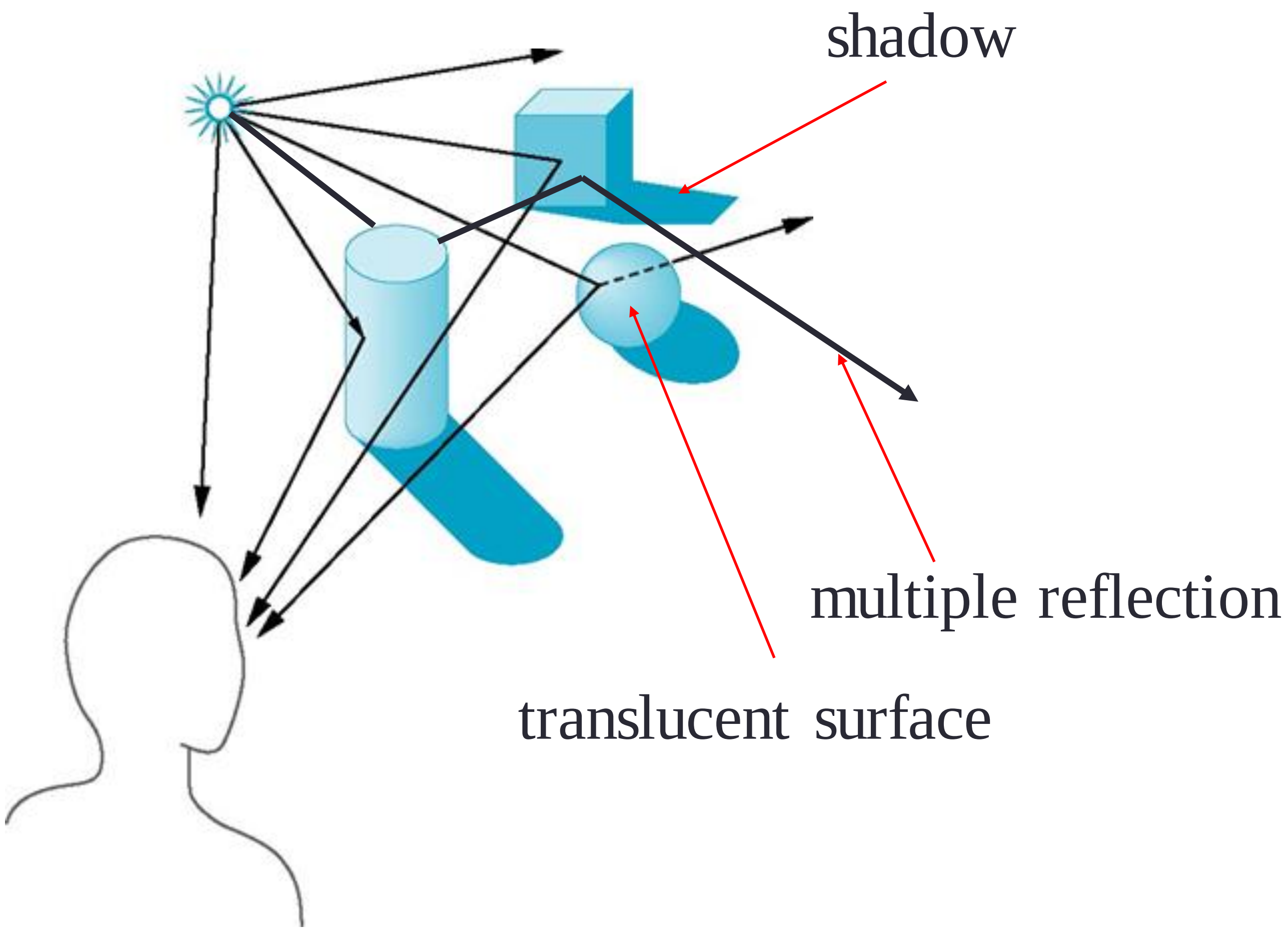
and so on



Rendering Equation

- The infinite scattering and absorption of light can be described by the *rendering equation*
  - Cannot be solved in general
  - Ray tracing is a special case for perfectly reflecting surfaces
- Rendering equation is global and includes
  - Shadows
  - Multiple scattering from object to object

Global Effects



Local vs Global Rendering

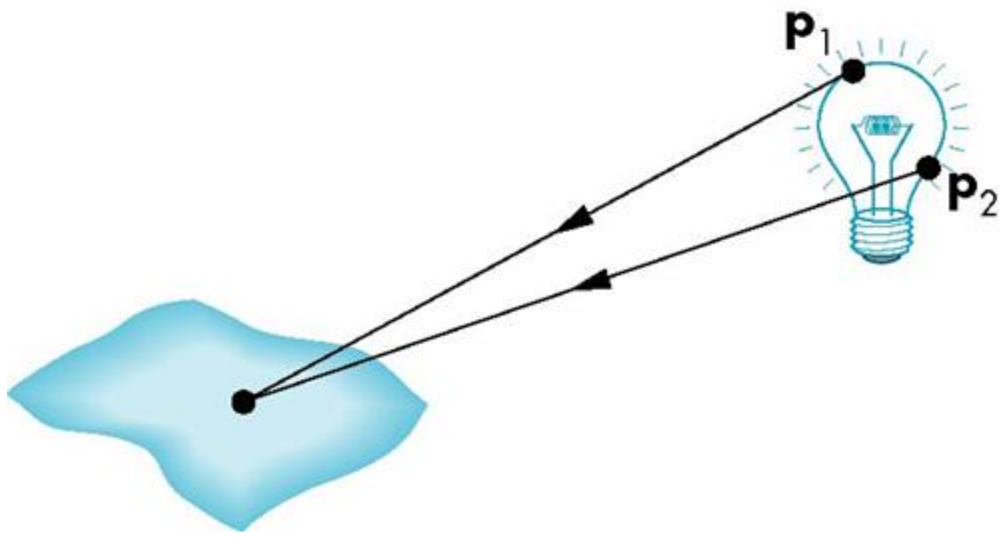
- Correct shading requires a global calculation involving all objects and light sources
  - Incompatible with pipeline model which shades each polygon independently (local rendering)
- However, in computer graphics, especially real time graphics, we are happy if things “look right”
  - Exist many techniques for approximating global effects

Light-Material Interaction

- Light that strikes an object is partially absorbed and partially scattered (reflected)
- The amount reflected determines the color and brightness of the object
  - A surface appears red under white light because the red component of the light is reflected and the rest is absorbed
- The reflected light is scattered in a manner that depends on the smoothness and orientation of the surface

Light Sources

General light sources are difficult to work with because we must integrate light coming from all points on the source

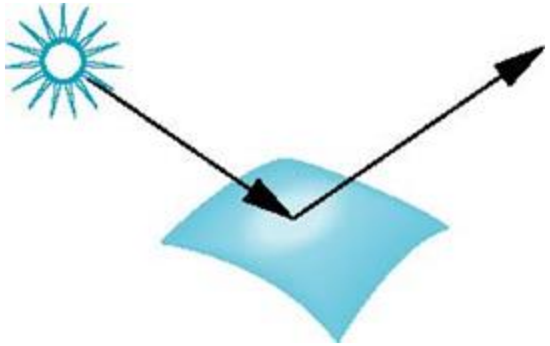


Simple Light Sources

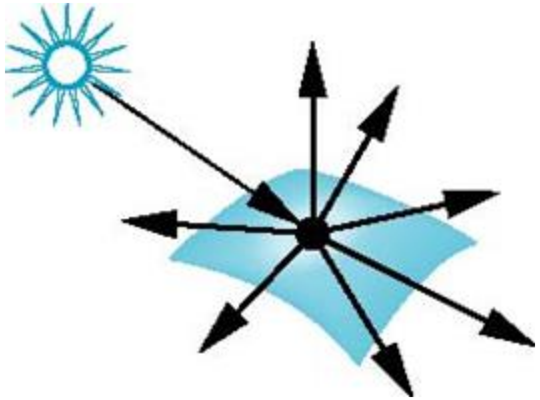
- Point source
  - Model with position and color
  - Distant source = infinite distance away (parallel)
- Spotlight
  - Restrict light from ideal point source
- Ambient light
  - Same amount of light everywhere in scene
  - Can model contribution of many sources and reflecting surfaces

Surface Types

- The smoother a surface, the more reflected light is concentrated in the direction a perfect mirror would reflected the light
- A very rough surface scatters light in all directions



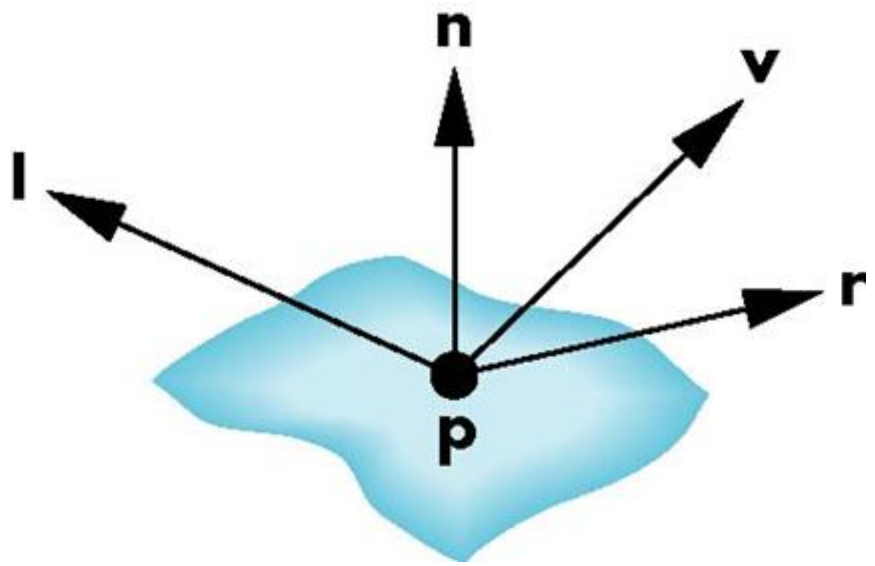
smooth surface



rough surface

Phong Model

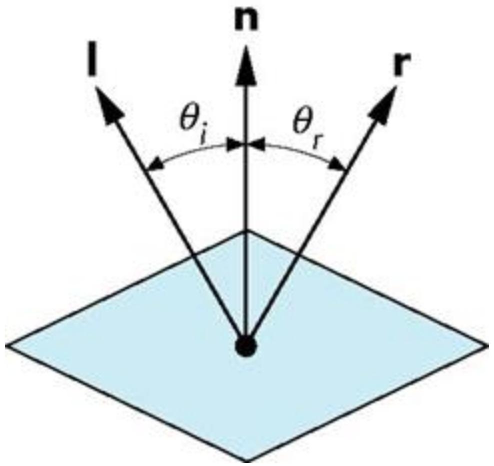
- A simple model that can be computed rapidly
- Has three components
  - Diffuse
  - Specular
  - Ambient
- Uses four vectors
  - To source
  - To viewer
  - Normal
  - Perfect reflector



Ideal Reflector

- Normal is determined by local orientation
- Angle of incidence = angle of relection
- The three vectors must be coplanar

$$\mathbf{r} = 2\,(\mathbf{l} \cdot \mathbf{n})\,\mathbf{n} - \mathbf{l}$$

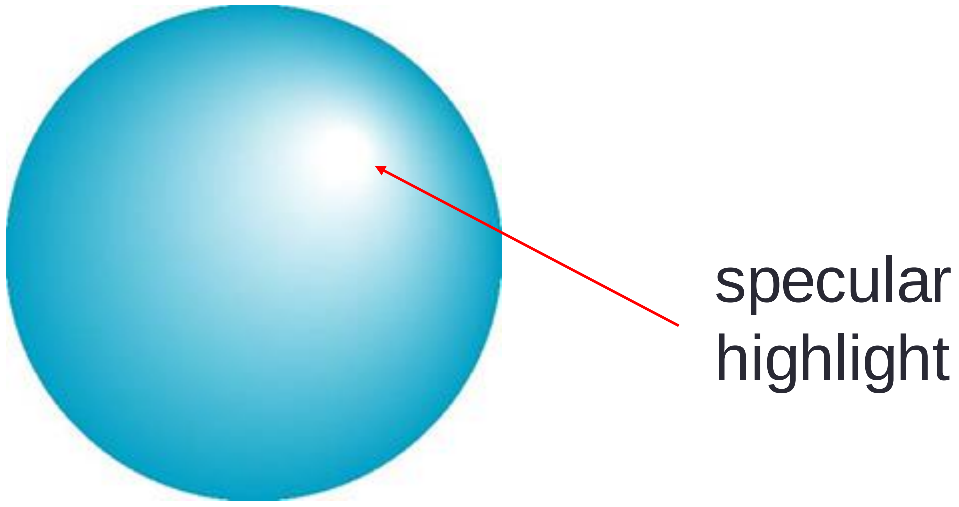


Lambertian Surface

- Perfectly diffuse reflector
- Light scattered equally in all directions
- Amount of light reflected is proportional to the vertical component of incoming light
  - reflected light ~$\cos \theta_i$
  - $\cos \theta_i = \mathbf{l} \cdot \mathbf{n}$ if vectors normalized
  - There are also three coefficients, k_r, k_b, k_g that show how much of each color component is reflected

Specular Surfaces

- Most surfaces are neither ideal diffusers nor perfectly specular (ideal refectors)
- Smooth surfaces show specular highlights due to incoming light being reflected in directions concentrated close to the direction of a perfect reflection



Modeling Specular Relections

- Phong proposed using a term that dropped off as the angle between the viewer and the ideal reflection increased

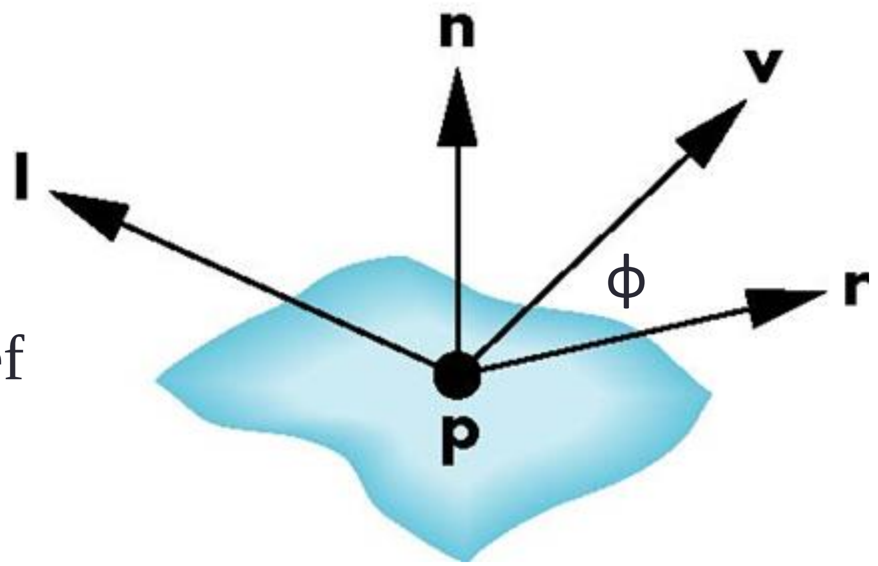
$$\mathbf{I}_r \sim k_s\, \mathbf{I} \cos^{\alpha}\phi$$

reflected intensity

shininess coef

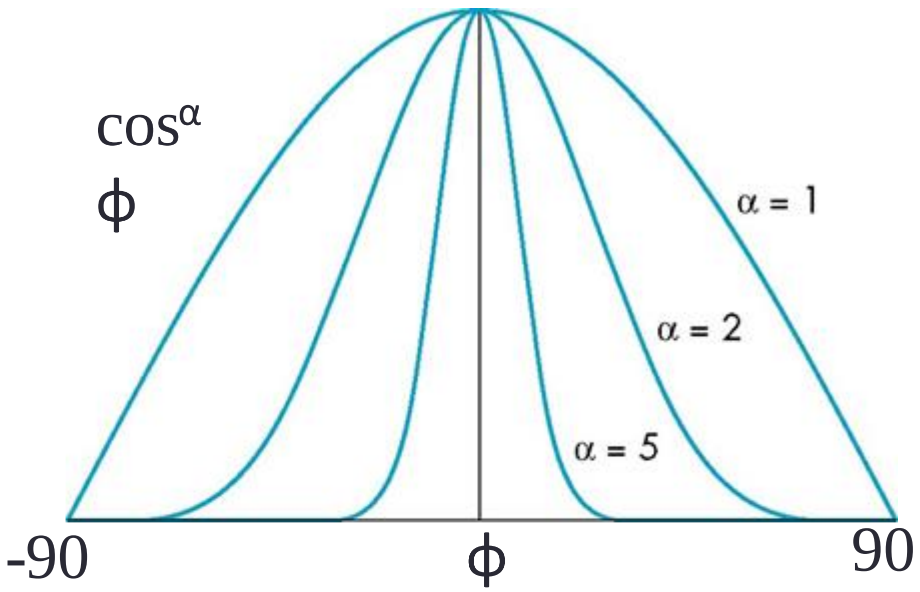
incoming intensity

absorption coef



The Shininess Coefficient

- Values of α between 100 and 200 correspond to metals
- Values between 5 and 10 give surface that look like plastic



Ambient Light

- Ambient light is the result of multiple interactions between (large) light sources and the objects in the environment
- Amount and color depend on both the color of the light(s) and the material properties of the object
- Add k_a I_a to diffuse and specular terms

reflection coef intensity of ambient light

Distance Terms

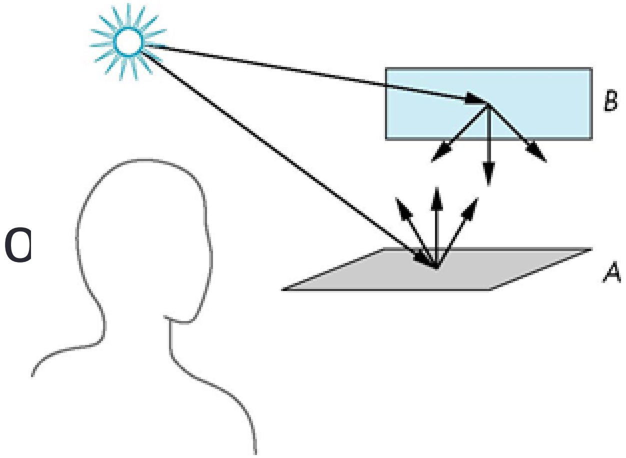
- The light from a point source that reaches a surface is inversely proportional to the square of the distance between them
- We can add a factor of the

form $1/(ad + bd + cd^2)$ to

the diffuse and specular

terms

- The constant and linear terms soften the effect o



Light Sources

- In the Phong Model, we add the results from each light source
- Each light source has separate diffuse, specular, and ambient terms to allow for maximum flexibility even though this form does not have a physical justification
- Separate red, green and blue components
- Hence, 9 coefficients for each point source
  - I_{dr}, I_{dg}, I_{db}, I_{sr}, I_{sg}, I_{sb}, I_{ar}, I_{ag}, I_{ab}

Material Properties

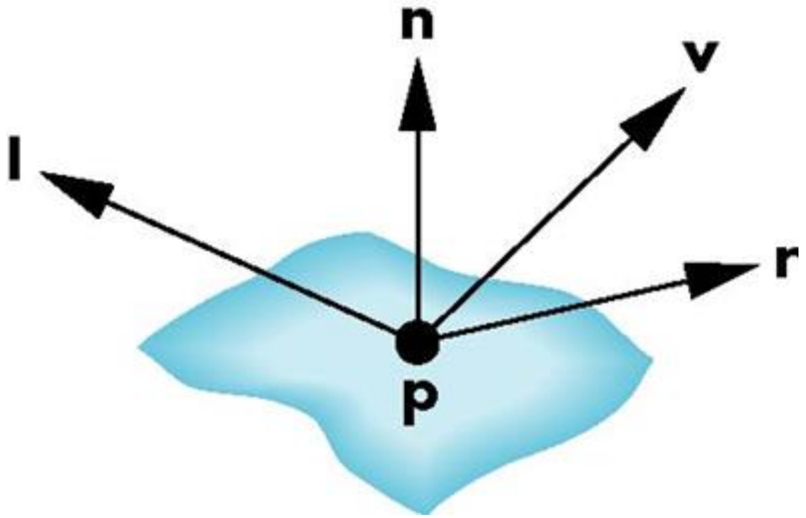
- Material properties match light source properties
  - Nine absorbtion coefficients
    - k_{dr}, k_{dg}, k_{db}, k_{sr}, k_{sg}, k_{sb}, k_{ar}, k_{ag}, k_{ab}
  - Shininess coefficient α

Adding up the Components

For each light source and each color component, the Phong model can be written (without the distance terms) as

$$I = k_d I_d \, \mathbf{l} \cdot \mathbf{n} + k_s I_s (\mathbf{v} \cdot \mathbf{r})^{\alpha} + k_a I_a$$

For each color component we add contributions from all sources



Example

Only differences in these teapots are the parameters in the Phong model