Mike Bailey
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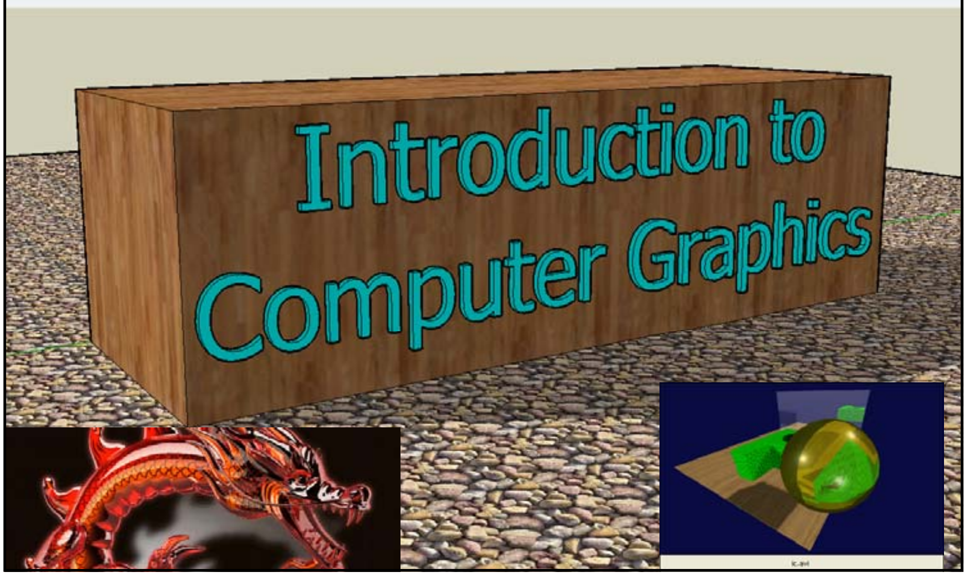

Mike Bailey

- Professor of Computer Science, Oregon State University
- Has worked at Sandia Labs, Purdue University, Megatek, San Diego Supercomputer Center (UC San Diego), and OSU
- Has taught over 4,000 students in his classes
- mjb@cs.oregonstate.edu

Steve Cunningham

- Retired Professor of Computer Science, California State University Stanislaus
- Has served as chair of both the SIGGRAPH Education Board and the Eurographics Education Board
- Has written 7 books on computer graphics topics
- rsc@cs.csustan.edu

Course Goals

- Provide a background for papers, panels, and other courses
- Create a common understanding of computer graphics vocabulary
- Help appreciate the images you will see
- Get more from the Exhibition
- Provide pointers for further study

Specific Topics

- The Graphics Process
- Graphics Hardware
- Modeling
- Rendering
- GPU Shaders
- Finding More Information

Schedule

0:00 Welcome and Overview
0:10 The Graphics Process
0:40 Graphics Hardware
1:10 Modeling

1:45 Break

2:00 Maybe our vision isn't as good as we think it is ☺
2:15 Rendering
2:30 GPU Shaders
2:50 Finding Additional Information
3:10 Discussion and Questions

3:30 Finish

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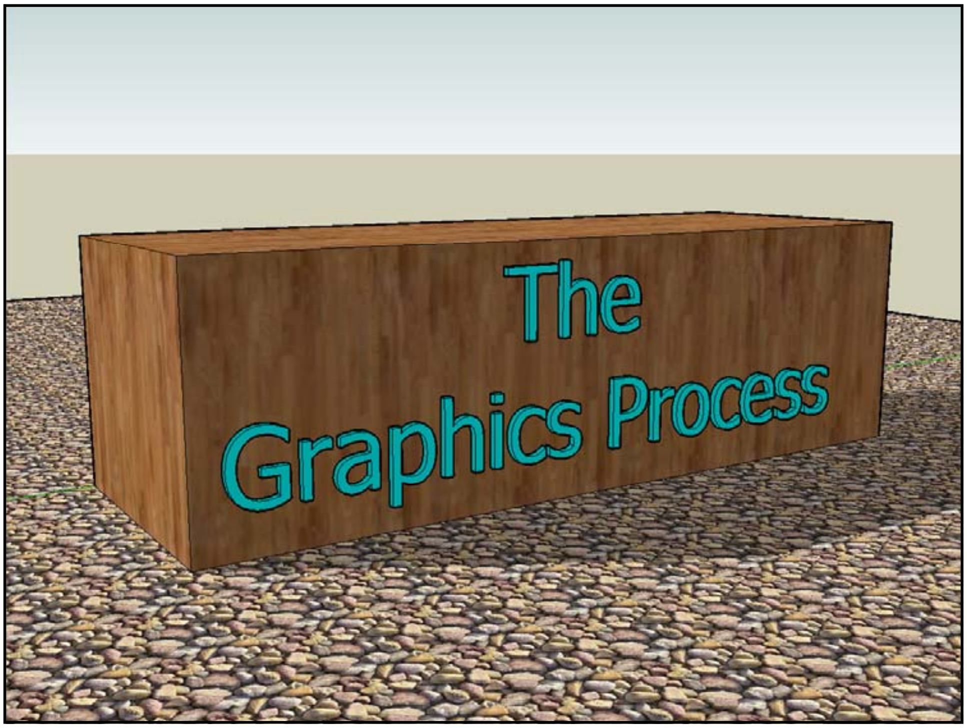
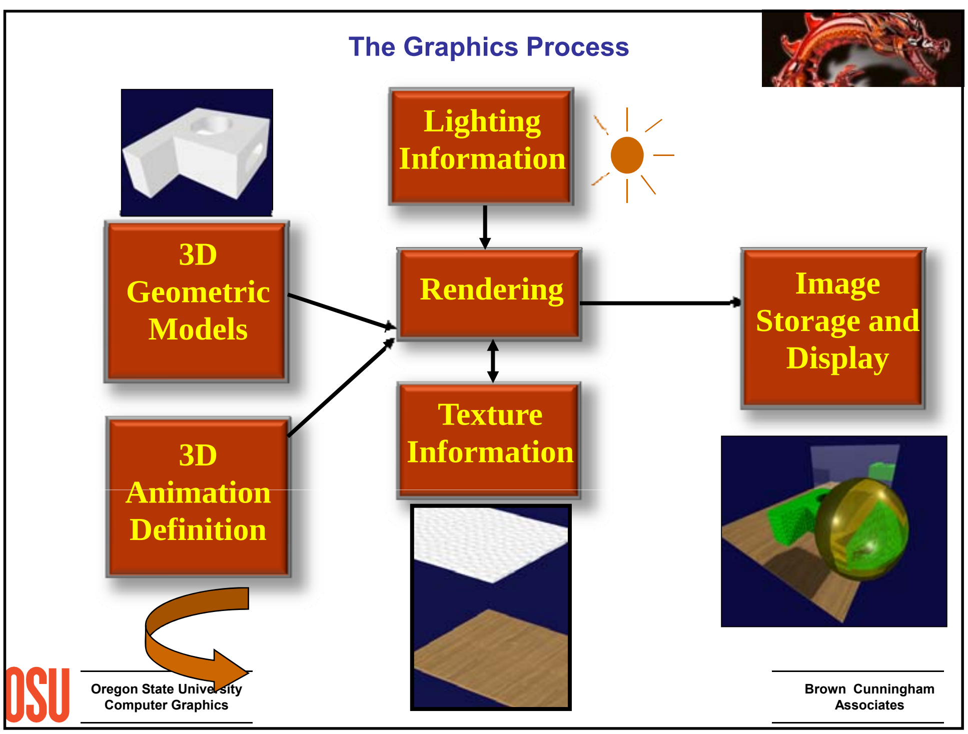

The
Graphics Process


The Graphics Process
Lighting Information
3D Geometric Models
Rendering
Image Storage and Display
3D Animation Definition
Texture Information
OSU
Oregon State University
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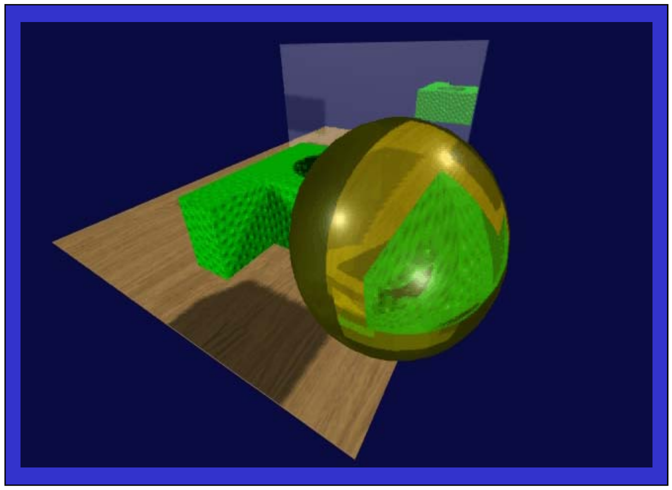
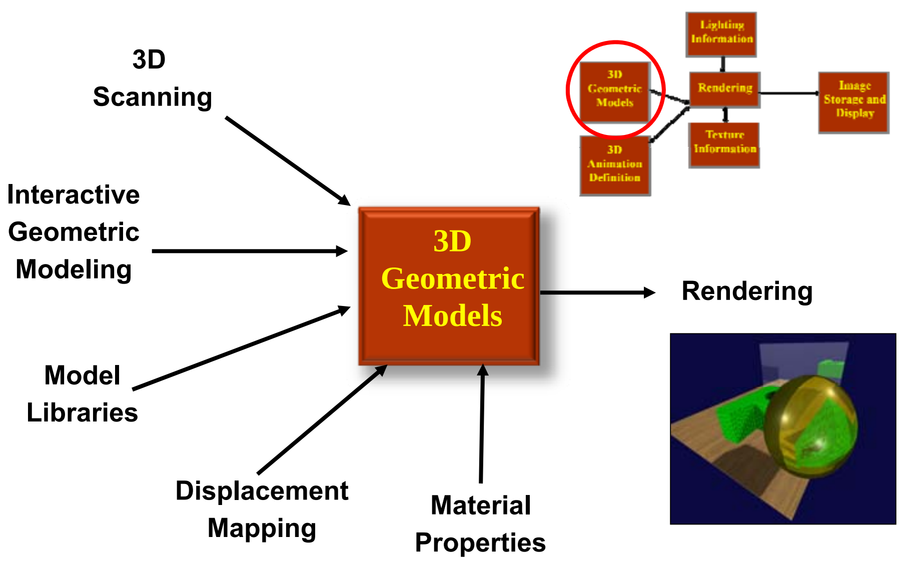
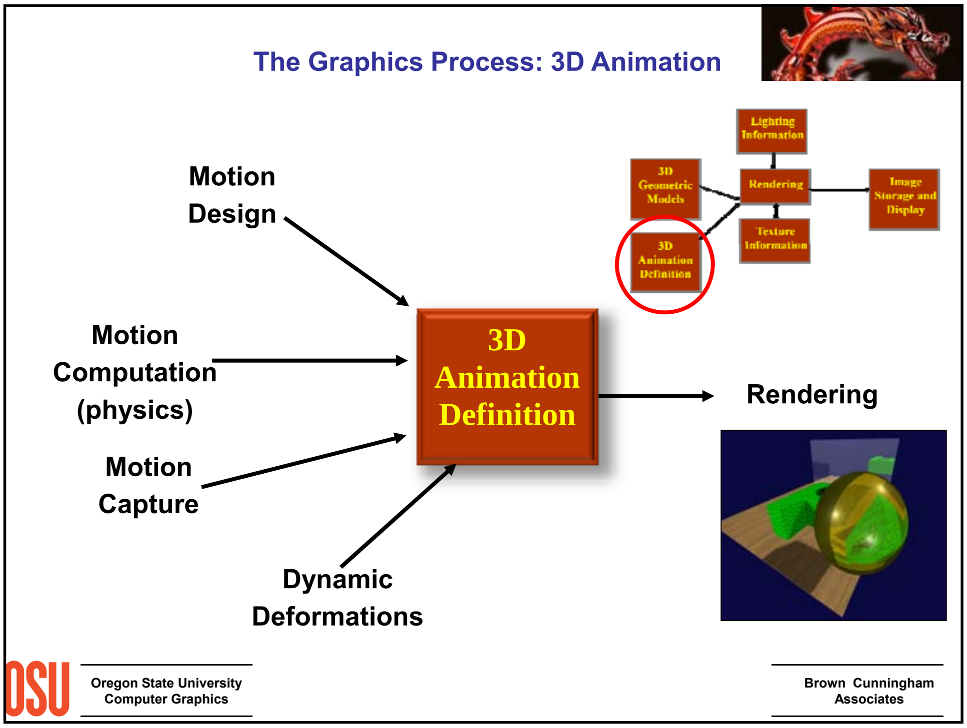


The Graphics Process: Geometric Modeling




The Graphics Process: 3D Animation
Lighting Information
3D Geometric Models
Rendering
Image Storage and Display
Texture Information
3D Animation Definition
Motion Design
Motion Computation (physics)
Motion Capture
Dynamic Deformations
3D Animation Definition
Rendering
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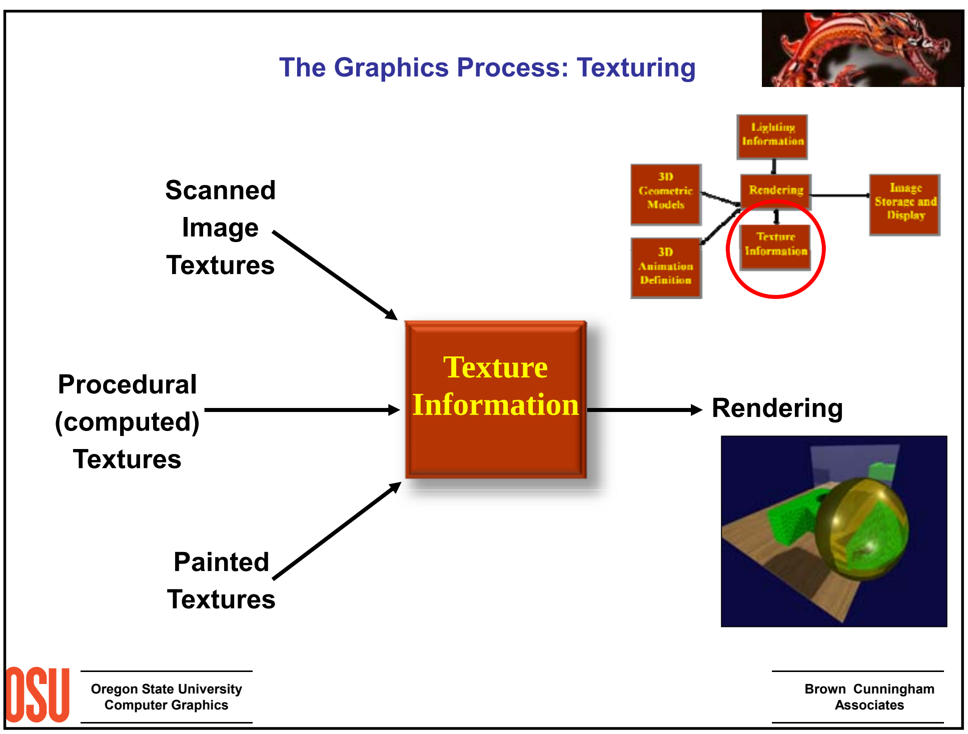
The Graphics Process: Texturing
Lighting Information
3D Geometric Models
Rendering
Image Storage and Display
Texture Information
3D Animation Definition
Scanned Image Textures
Procedural (computed) Textures
Painted Textures
Texture Information
Rendering
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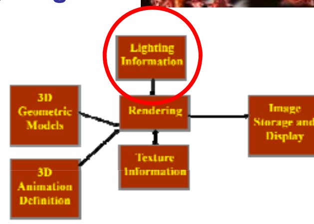
The Graphics Process: Lighting



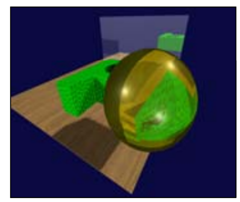
Lighting Types (point, directional, spot) → **Lighting Information**

Light Positions → **Lighting Information**

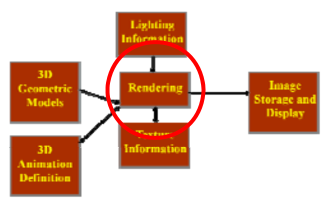
Light Colors → **Lighting Information**

Light Intensities → **Lighting Information**

Lighting Information → Rendering



The Graphics Process: Rendering



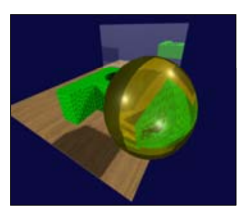
3D Geometric Models → **Rendering**

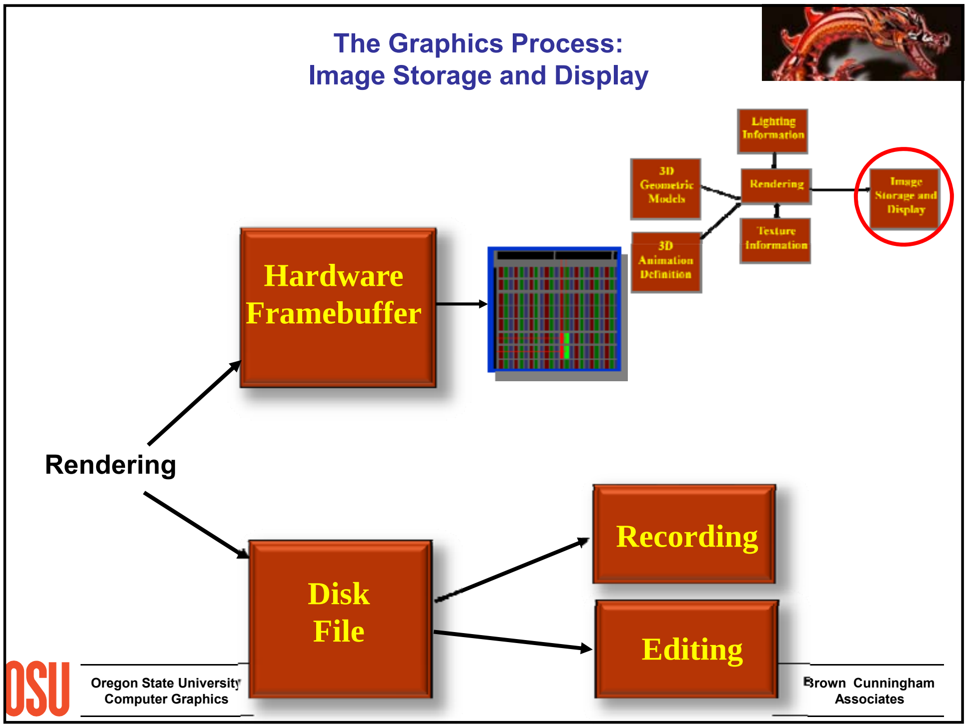
Lighting Information → **Rendering**

3D Animation Definition → **Rendering**

Texture Information ↔ **Rendering**

Rendering → Image Storage and Display




The Graphics Process:
Image Storage and Display
Lighting Information
3D Geometric Models
Rendering
Image Storage and Display
Texture Information
3D Animation Definition
Hardware Framebuffer
Rendering
Recording
Disk File
Editing
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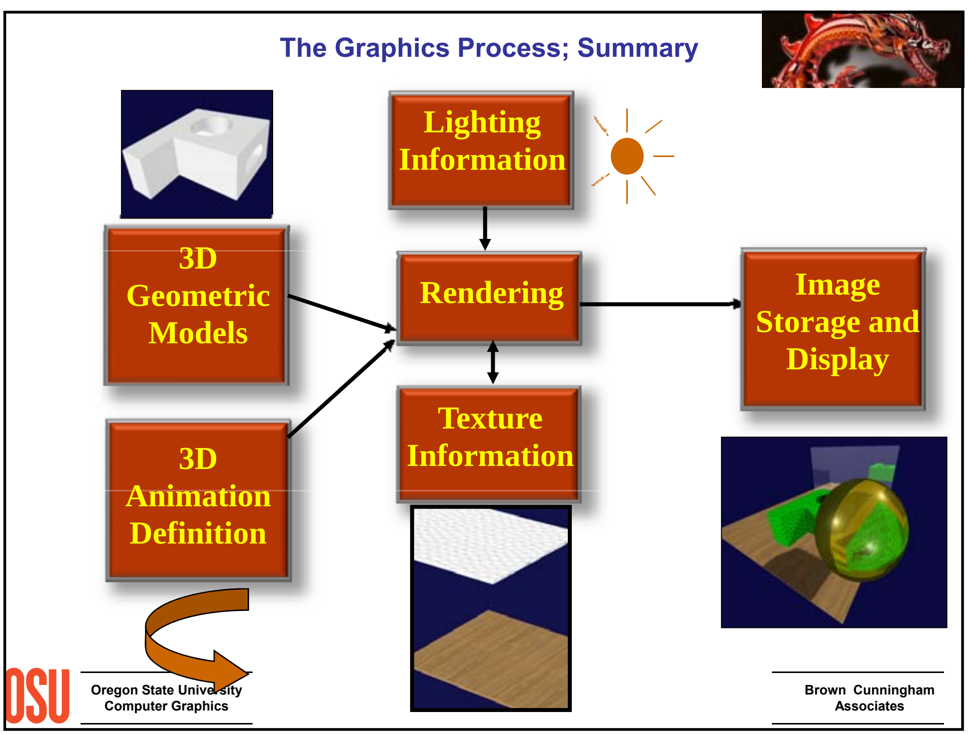
The Graphics Process; Summary
Lighting Information
3D Geometric Models
Rendering
Image Storage and Display
3D Animation Definition
Texture Information
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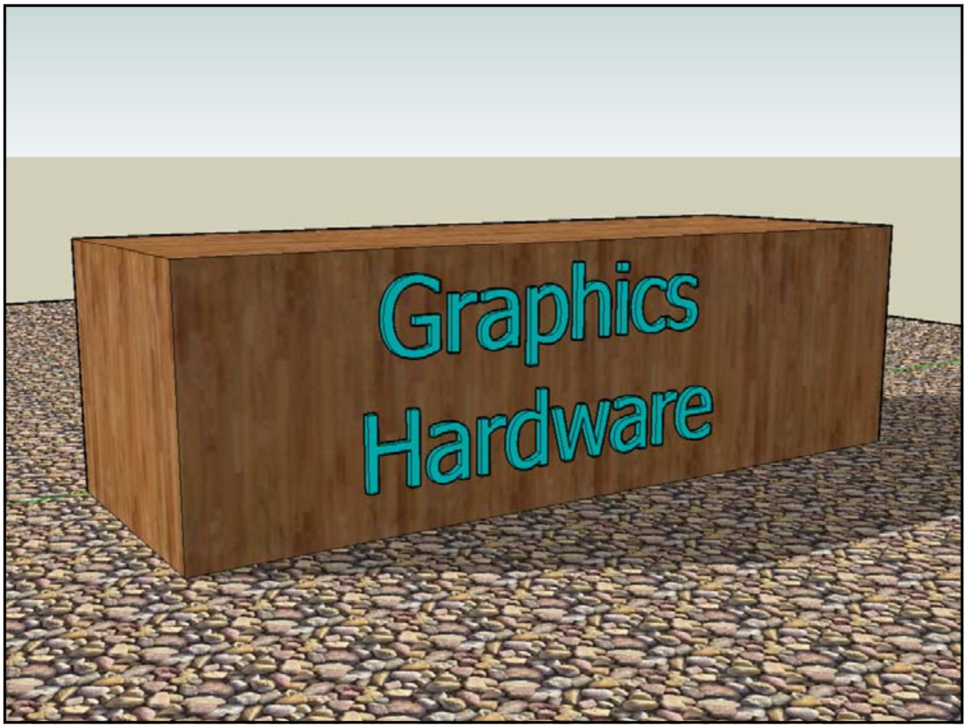
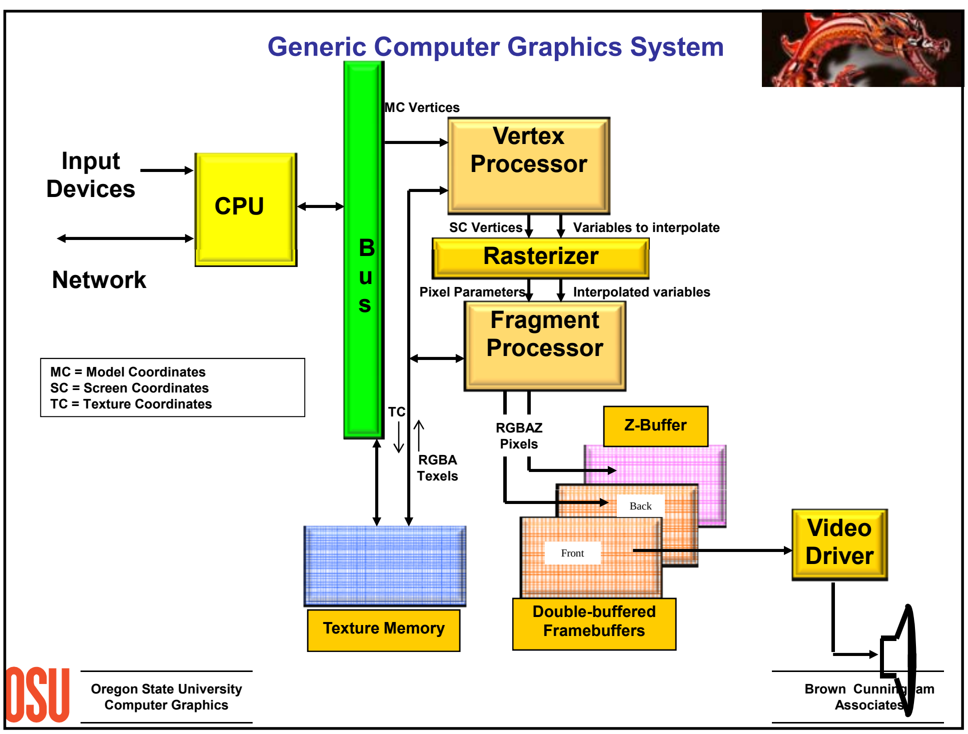

Graphics
Hardware


Generic Computer Graphics System
Input
Devices
Network
CPU
B
u
s
MC Vertices
Vertex
Processor
SC Vertices
Variables to interpolate
Rasterizer
Pixel Parameters
Interpolated variables
Fragment
Processor
MC = Model Coordinates
SC = Screen Coordinates
TC = Texture Coordinates
TC
RGBA
Texels
RGBAZ
Pixels
Z-Buffer
Back
Front
Video
Driver
Texture Memory
Double-buffered
Framebuffers
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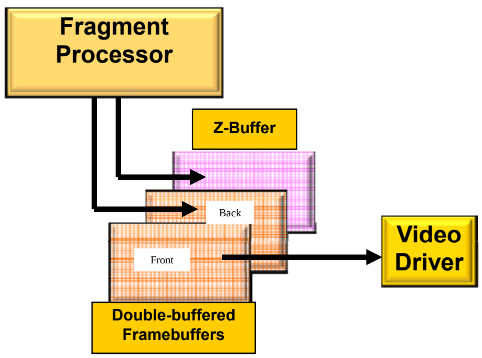
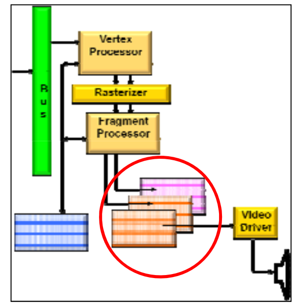
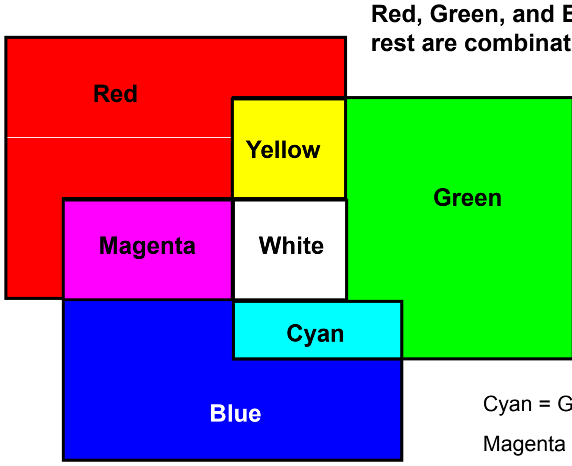
The Framebuffer





The Framebuffer Uses Additive Colors (RGB)

Red, Green, and Blue are provided. The rest are combinations of those three.



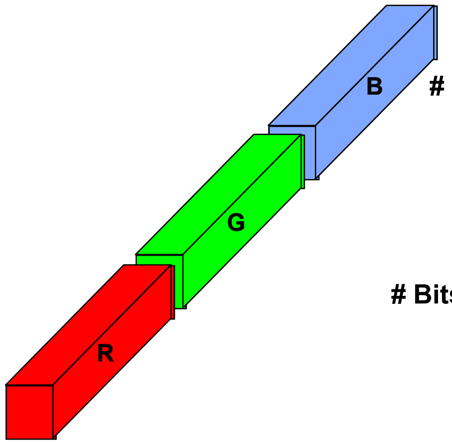
Cyan = Green + Blue

Magenta = Red + Blue

Yellow = Red + Green

White = Red + Green + Blue

The Framebuffer:
Integer Color Storage

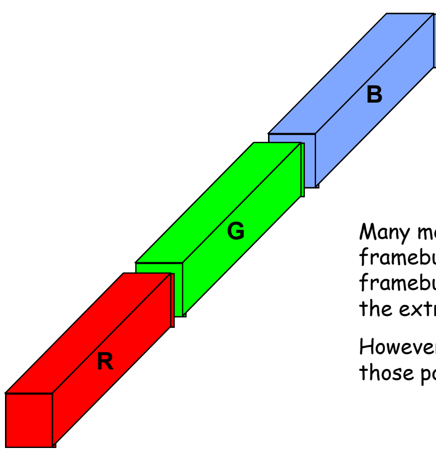


# Bits/color	# Intensities per color
8	$2^8 = 256$
10	$2^{10} = 1024$
12	$2^{12} = 4096$

# Bits/pixel	Total colors:
24	2^{24} = 16.7 M
30	2^{30} = 1 B
36	2^{36} = 69 B

The Framebuffer:
Floating Point Color Storage

- *16- or 32-bit floating point for each color component*



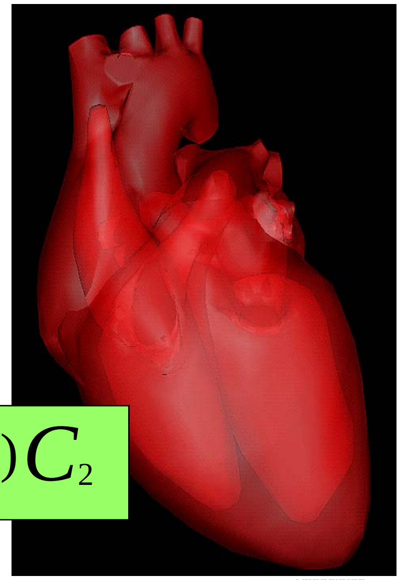
Why so much?

Many modern algorithms do arithmetic on the framebuffer color components, or treat the framebuffer color components as data. They need the extra precision during the arithmetic.

However, the display system cannot display all of those possible colors.

The Framebuffer

- ***Alpha*** values
  - Transparency per pixel
    α = 0. is invisible
    α = 1. is opaque
  - Represented in 8-32 bits
    (integer or floating point)
  - Alpha blending equation:

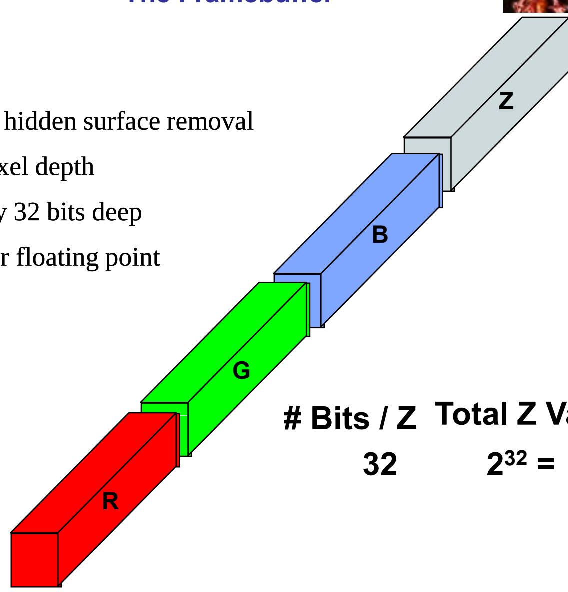


$$Color = \alpha C_1 + (1 - \alpha) C_2$$

$0.0 \leq \alpha \leq 1.0$

The Framebuffer

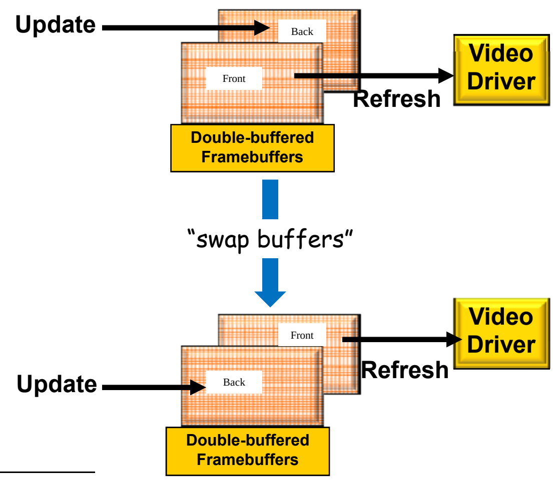
- ***Z-buffer***
  - Used for hidden surface removal
  - Holds pixel depth
  - Typically 32 bits deep
  - Integer or floating point



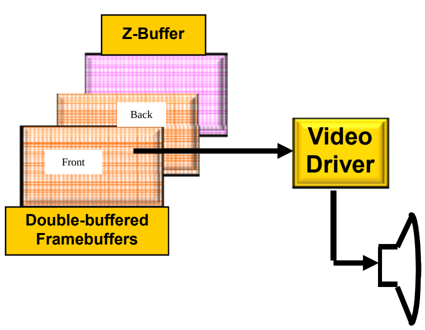
# Bits / Z	Total Z Values:
32	2^{32} = 4 B

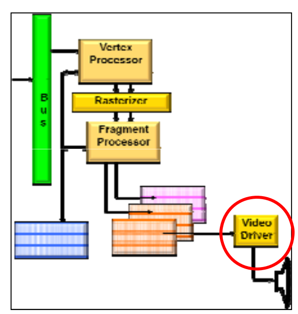
The Framebuffer

Double-buffering: Don't let the viewer see *any* of the scene until the entire scene is drawn



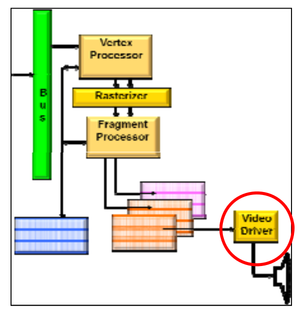
The Video Driver





The Video Driver

- N ***refreshes*/second** (N is usually between 50 and 100)
- Framebuffer contains the R,G,B that define the color at each pixel
- Cursor
  - Appearance is stored near the video driver in a “mini-framebuffer”
  - x,y is given by the CPU
- Video input



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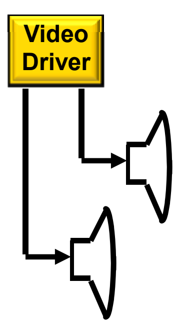
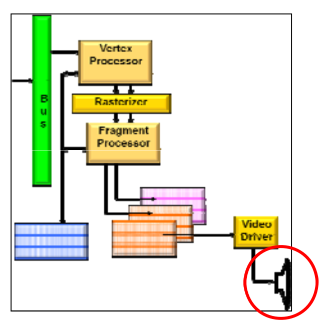
The Computer Graphics Monitor(s)





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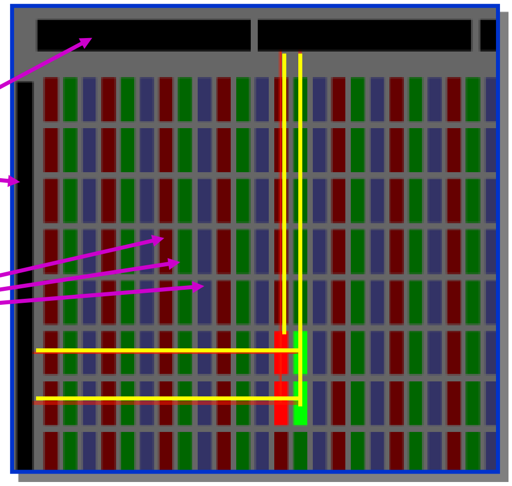
Displaying Color on a Computer Graphics LCD Monitor

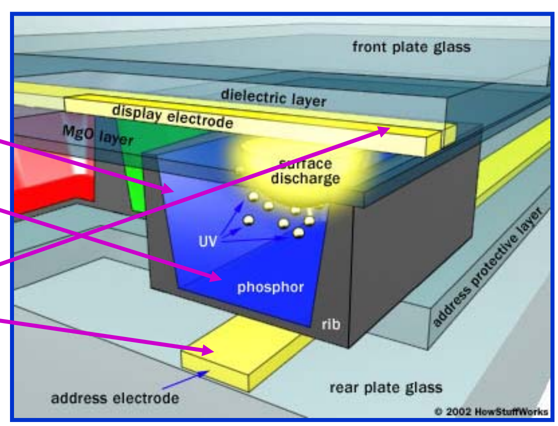
- Grid of electrodes
- Color filters



Source: http://electronics.howstuffworks.com

Displaying Color on a Plasma Monitor

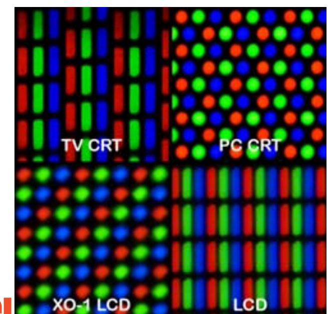
- **Gas cell**
- **Phosphor**
- **Grid of electrodes**



http://electronics.howstuffworks.com

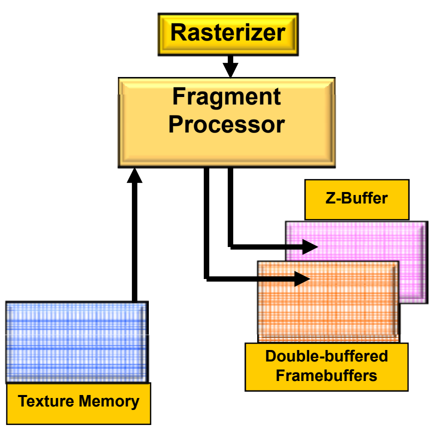
Display Resolution

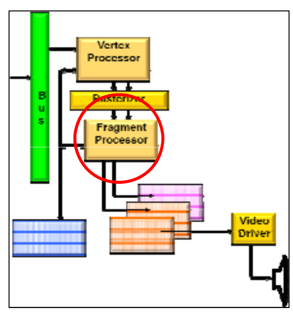
- ***Pixel*** resolutions (1024x768 - 1920x1152 are common)
- Screen size (13", 16", 19", 21" are common)
- Human acuity: 1 arc-minute is achieved by viewing a 19" monitor with 1280x1024 resolution from a distance of ~40 inches



http://en.wikipedia.org/wiki/File:Pixel_geometry_01_Pengo.jpg

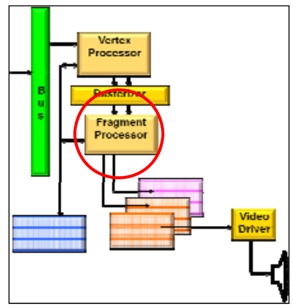
The Fragment Processor



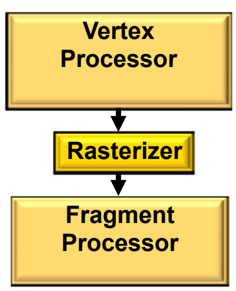


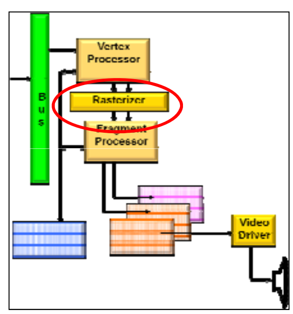
The Fragment Processor

- Takes in all information that describes this pixel
- Produces the RGBA for that pixel’s location in the framebuffer



The Rasterizer





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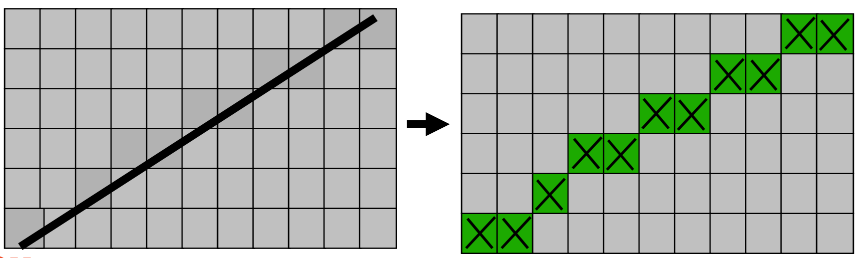
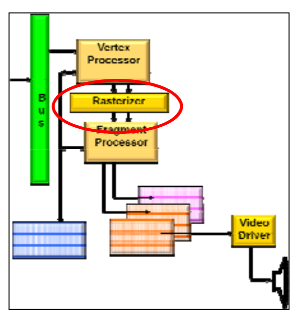
Rasterization

- Turn screen space vertex coordinates into pixels that make up lines and polygons
- A great place for custom electronics

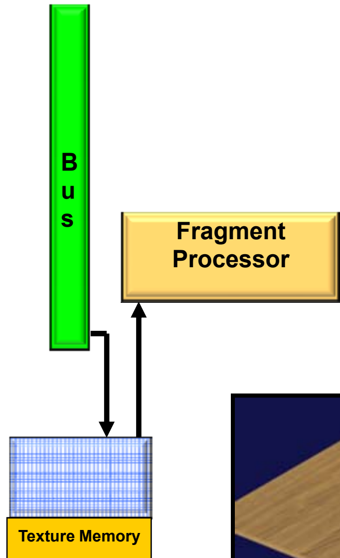


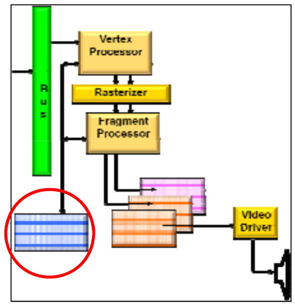
Rasterizers Can Interpolate:

- **X and Y**
- **Red-green-blue values**
- **Alpha values**
- **Z values**
- **Intensities**
- **Surface normals**
- **Texture coordinates**
- **Custom values given by the shaders**



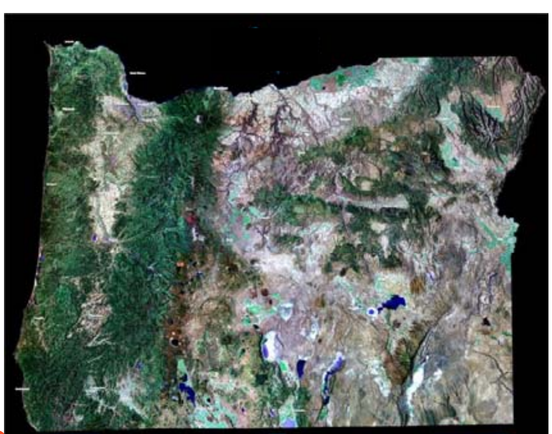
Texture Mapping

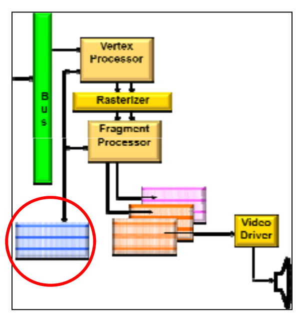




Texture Mapping

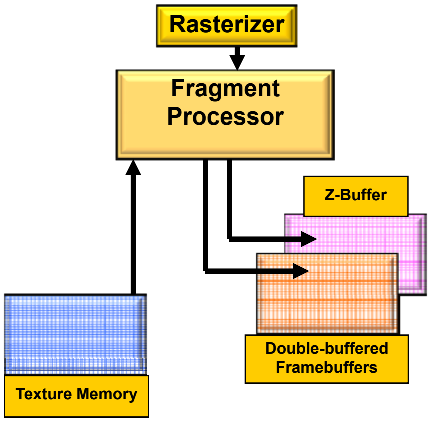
- “Stretch” an image onto a piece of geometry
- Image can be generated by a program or scanned in
- Useful for realistic scene generation

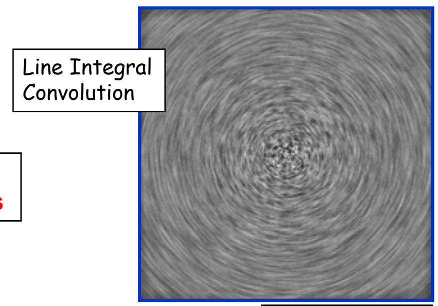




http://2ols.com

Something Cool: Write-Your-Own Fragment-Processor Code

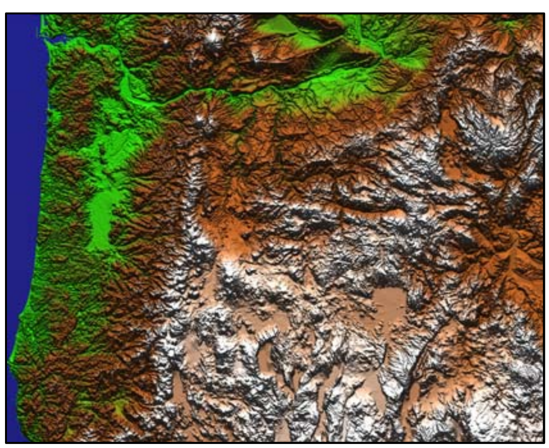




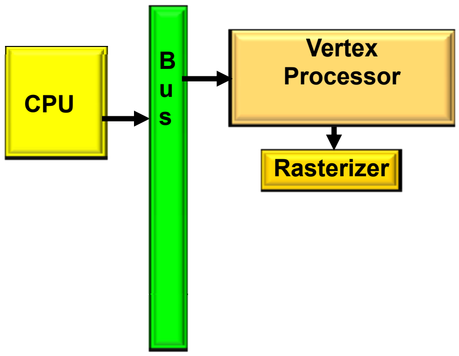
Referred to as:
Pixel Shaders or Fragment Shaders

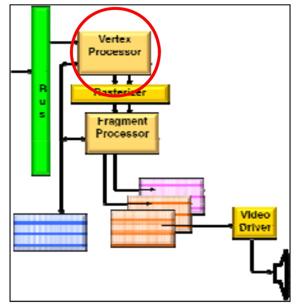
Procedural Texture Mapping

Create a texture from an equation. In this case, the equation takes a grid of heights and produces surface normals for lighting



The Vertex Processor





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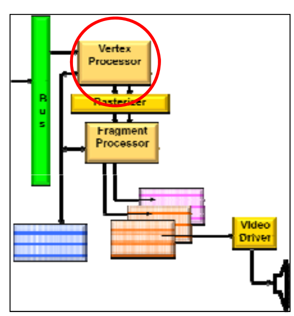
Vertex Processor

- Coordinates enter in model units
- Coordinates leave in screen (pixel) units
- Another great place for custom electronics



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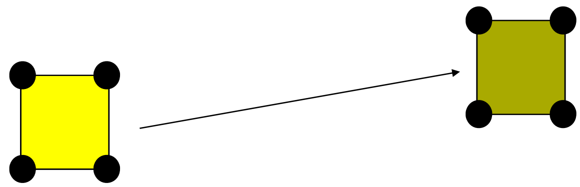
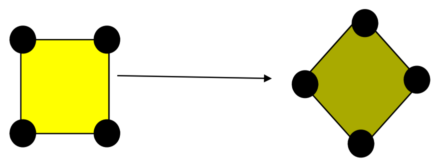
Vertex Processor: Transformations

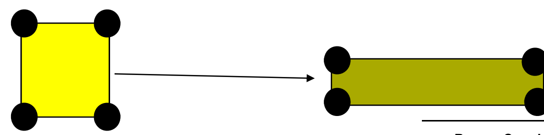
- Used to correctly place objects in the scene
- Translation



- Rotation



- Scaling

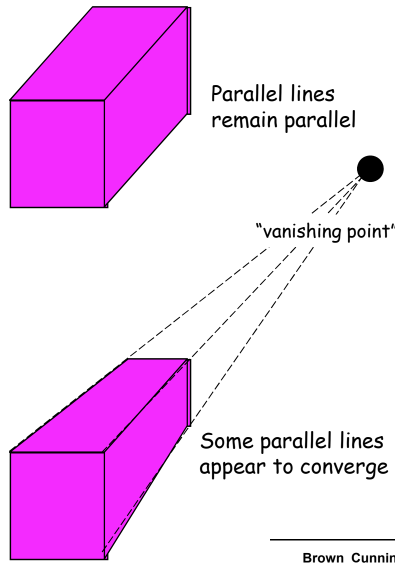


Vertex Processor: Windowing and Clipping

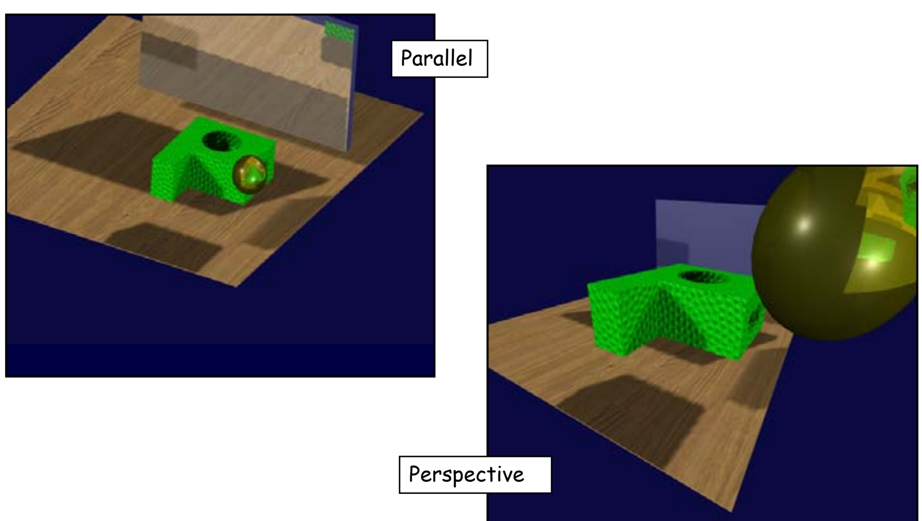
- Declare which portion of the 3D universe you are interested in viewing
- This is called the ***view volume***
- Clip away everything that is outside the viewing volume

Vertex Processor: Projection

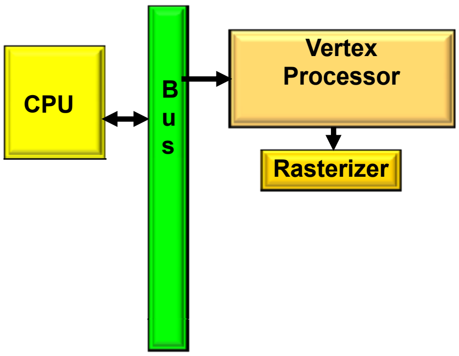
- **Turn 3D coordinates into 2D**
  - ***Parallel projection***
  - ***Perspective projection***

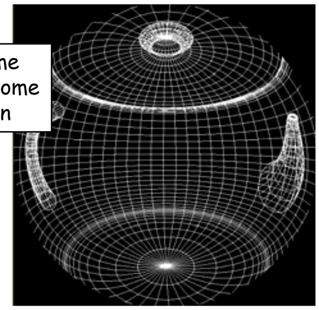


Vertex Processor: Projection

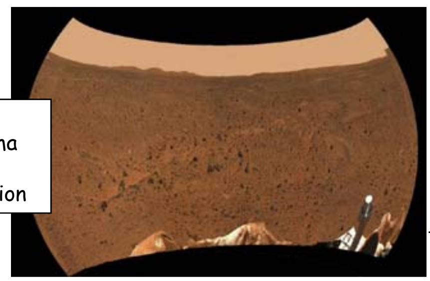


Something Cool:
Write-Your-Own Vertex Code





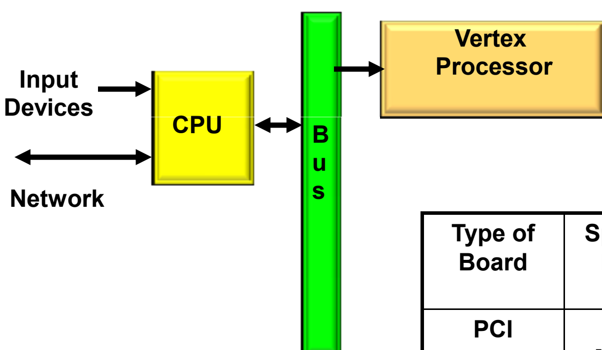
Wireframe Teapot Dome Projection



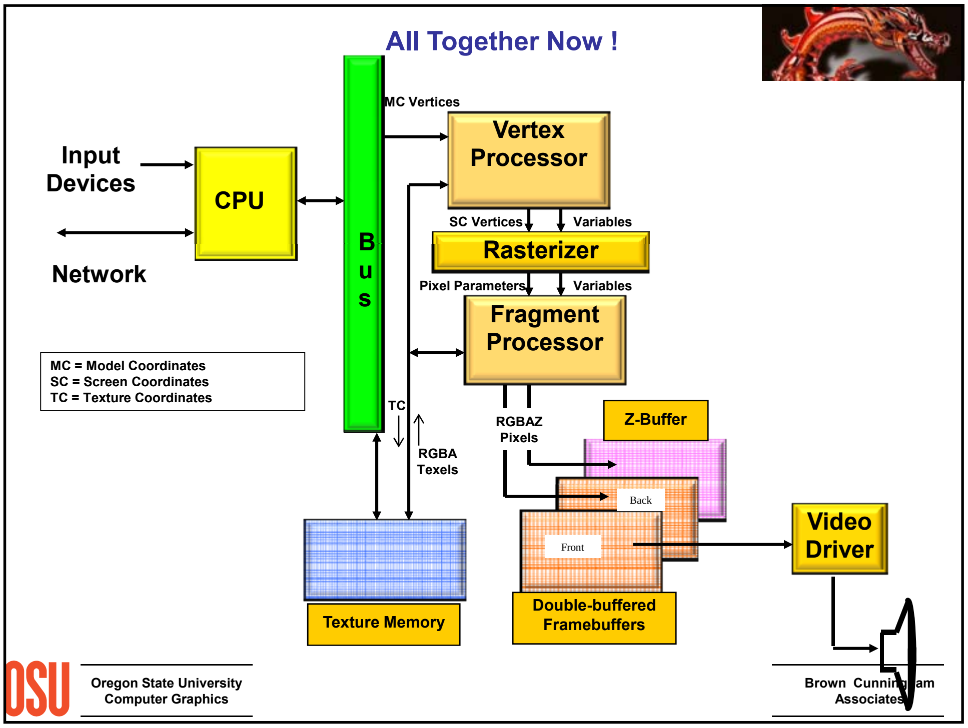
Mars Panorama Dome Projection

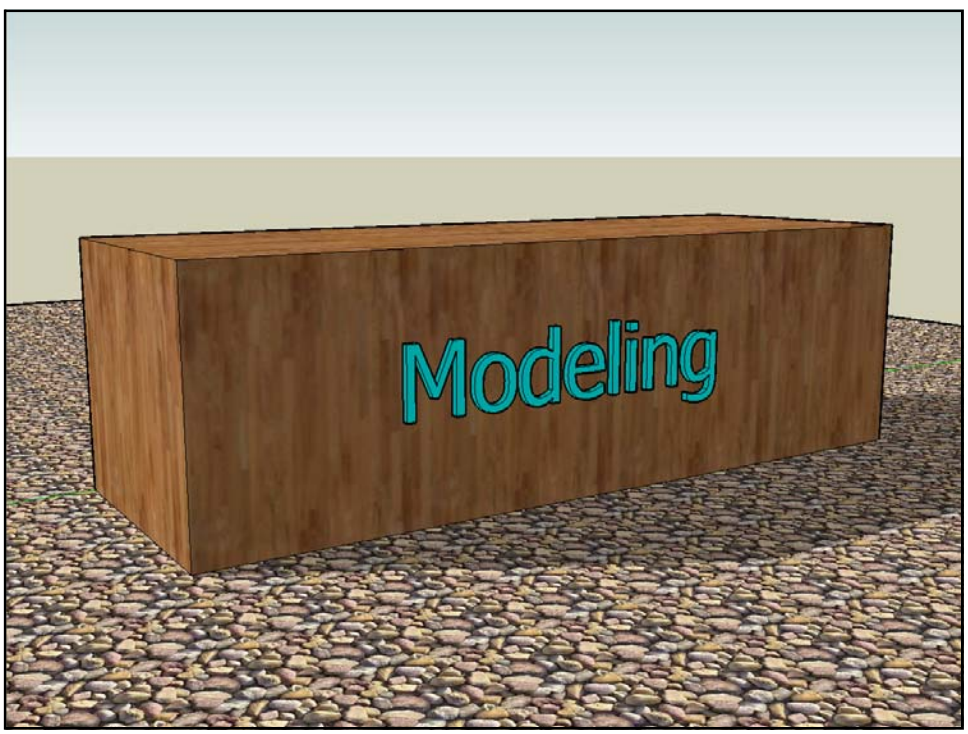
Referred to as:
Vertex Shaders

The CPU and Bus



Type of Board	Speed to Board	Speed from Board
PCI	132 Mb/sec	132 Mb/sec
AGP 8X	2 Gb/sec	264 Mb/sec
PCI Express	4 Gb/sec	4 Gb/sec


All Together Now !
MC Vertices
Vertex Processor
Input Devices
CPU
Network
B u s
SC Vertices
Variables
Rasterizer
Pixel Parameters
Variables
Fragment Processor
MC = Model Coordinates
SC = Screen Coordinates
TC = Texture Coordinates
TC
RGBA Texels
RGBAZ Pixels
Z-Buffer
Back
Front
Video Driver
Texture Memory
Double-buffered Framebuffers
OSU
Oregon State University
Computer Graphics


Modeling

What is a Model?

A is a model of B if A can be used to ask questions about B.

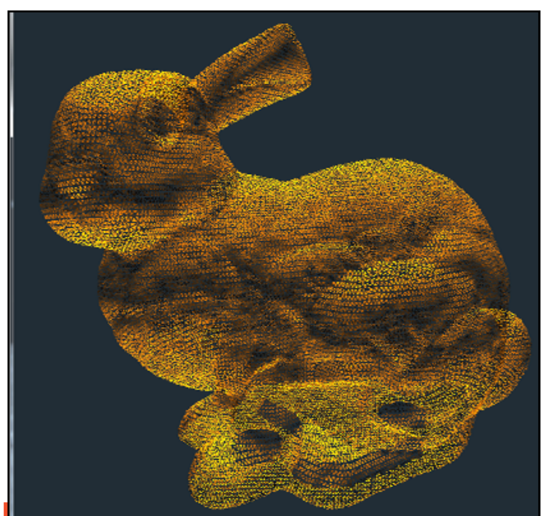
In computer graphics applications, what do we want to ask about B?

- What does B look like?
- How do I want to interact with (shape) B?
- Does B need to be a legal solid?
- How does B interact with its environment?
- What is B's surface area and volume?

These questions, and answers, control what type of geometric modeling you need to do

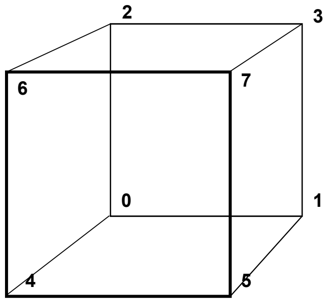
Explicitly Listing Geometry and Topology

Models can consist of thousands of vertices and faces – we need some way to list them efficiently



http://graphics.stanford.edu/data/3Dscanrep

Explicitly Listing Geometry and Topology

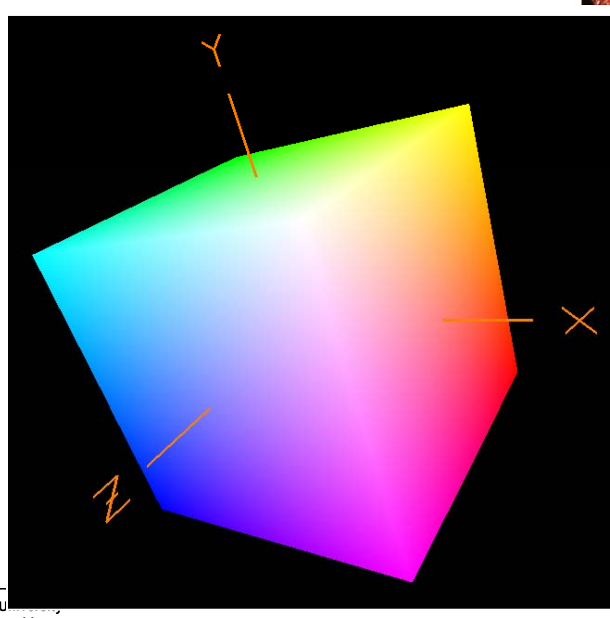



```
static GLfloat CubeVertices[ ][3] =
{
        { -1., -1., -1. },
        {  1., -1., -1. },
        { -1.,  1., -1. },
        {  1.,  1., -1. },
        { -1., -1.,  1. },
        {  1., -1.,  1. },
        { -1.,  1.,  1. },
        {  1.,  1.,  1. }
};
```

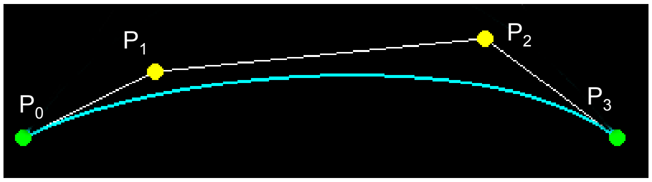
```
static GLfloat CubeColors[ ][3] =
{
        { 0., 0., 0. },
        { 1., 0., 0. },
        { 0., 1., 0. },
        { 1., 1., 0. },
        { 0., 0., 1. },
        { 1., 0., 1. },
        { 0., 1., 1. },
        { 1., 1., 1. },
};
```

```
static GLuint CubeIndices[ ][4] =
{
        { 0, 2, 3, 1 },
        { 4, 5, 7, 6 },
        { 1, 3, 7, 5 },
        { 0, 4, 6, 2 },
        { 2, 6, 7, 3 },
        { 0, 1, 5, 4 }
};
```


Cube Example



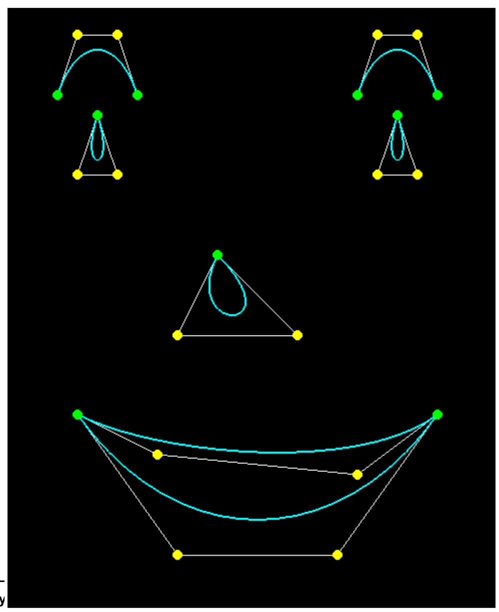
Curve Sculpting – Bezier Curve Sculpting



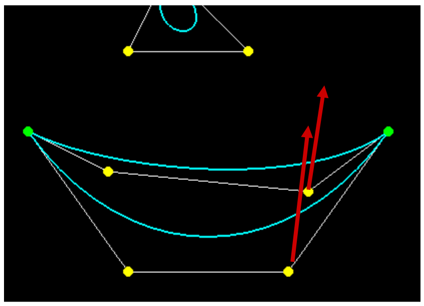
$$P(t) = (1-t)^3 P_0 + 3t(1-t)^2 P_1 + 3t^2(1-t)P_2 + t^3 P_3$$

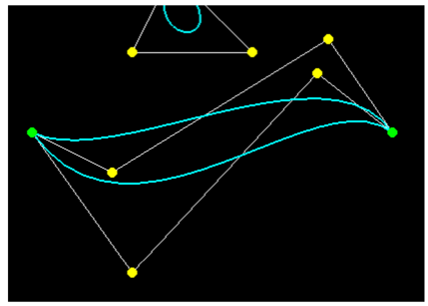
$$0. \le t \le 1.$$

Curve Sculpting – Bezier Curve Sculpting Example

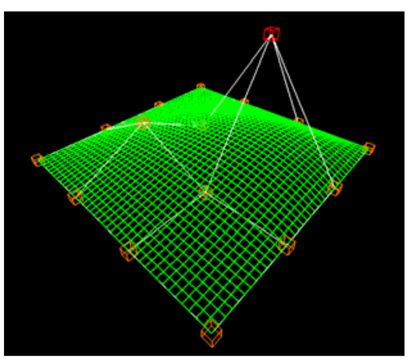


Curve Sculpting – Bezier Curve Sculpting Example

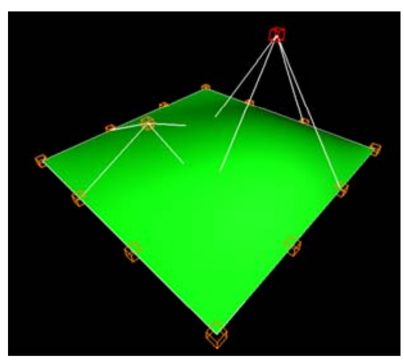




Surface Sculpting

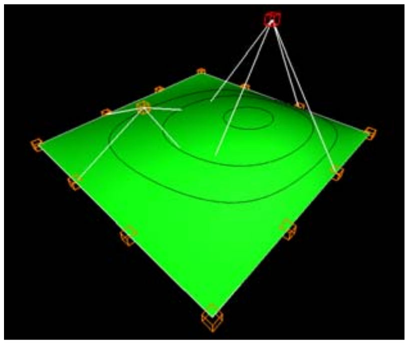


Wireframe

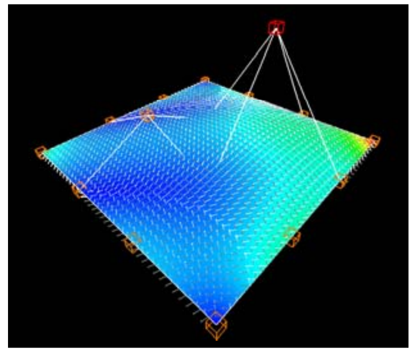


Surface

Surface equations can also be used for Analysis

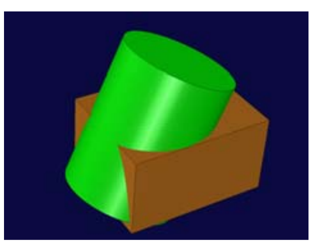


With Contour Lines

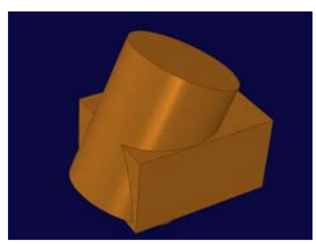


Showing Curvature

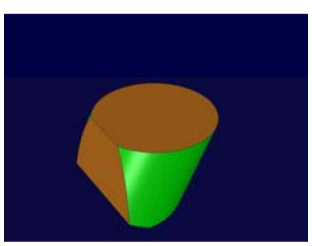
Solid Modeling Using Boolean Operators



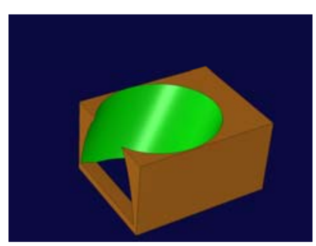
Two Overlapping Solids



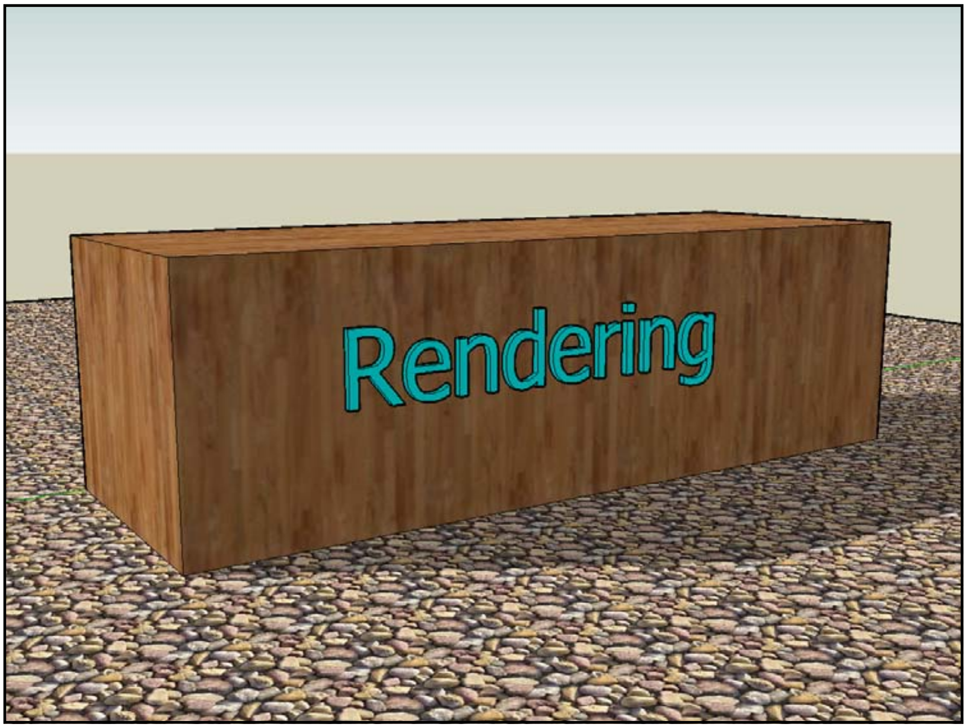
Union



Intersection



Difference

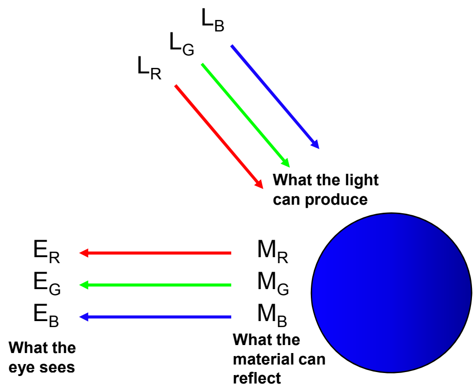


Rendering

Rendering is the process of creating an image of a geometric model. Again, there are questions you need to ask:

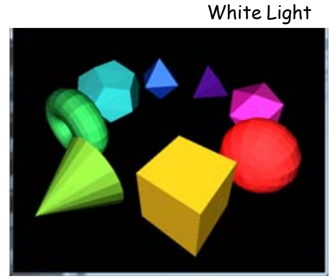
- How realistic do I want this image to be?
- How much compute time do I have to create this image?
- Do I need to take into account lighting?
- Does the illumination need to be global or will local do?
- Do I need to take into account shadows?
- Do I need to take into account reflection and refraction?

Fundamentals of Computer Graphics Lighting

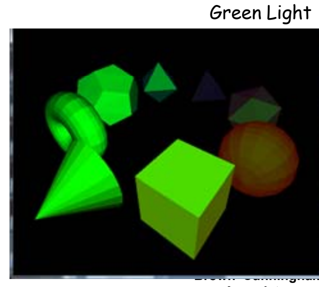


$$E_R = L_R * M_R$$
$$E_G = L_G * M_G$$
$$E_B = L_B * M_B$$

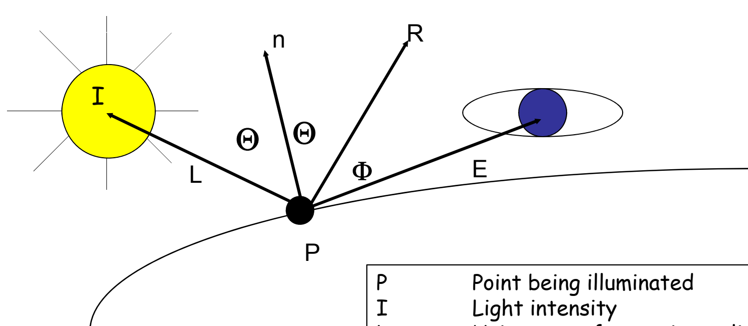
White Light



Green Light



The Computer Graphics Lighting Environment



P	Point being illuminated
I	Light intensity
L	Unit vector from point to light
n	Unit vector surface normal
R	Perfect reflection unit vector
E	Unit vector to eye position

Three Elements of Computer Graphics Lighting

1. Ambient = a constant — Accounts for light bouncing "everywhere"

2. Diffuse = $I * \cos\Theta$ — Accounts for the angle between the incoming light and the surface normal

3. Specular = $I * \cos^{S}\phi$ — Accounts for the angle between the "perfect reflector" and the eye; also the exponent, S, accounts for surface shininess

Note that $\cos\Theta$ is just the dot product between unit vectors L and n

Note that $\cos\phi$ is just the dot product between unit vectors R and E

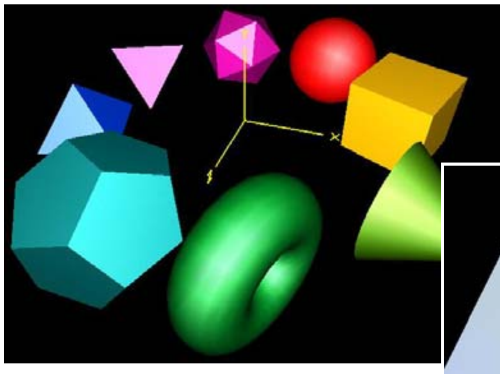
+

+

=

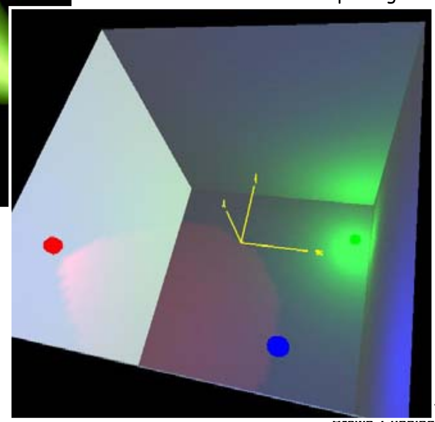
Three Elements of Computer Graphics Lighting

Lighting Examples



Omnidirectional Point Light

Spot Lights

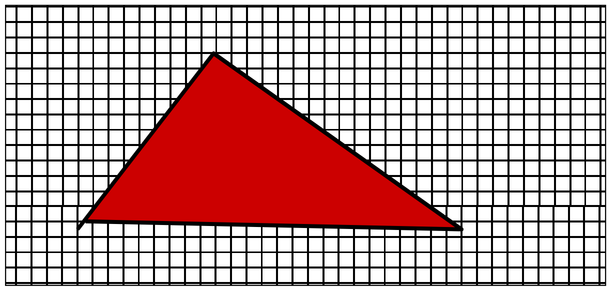


Two Types of Rendering

1. Starts at the object
2. Starts at the eye

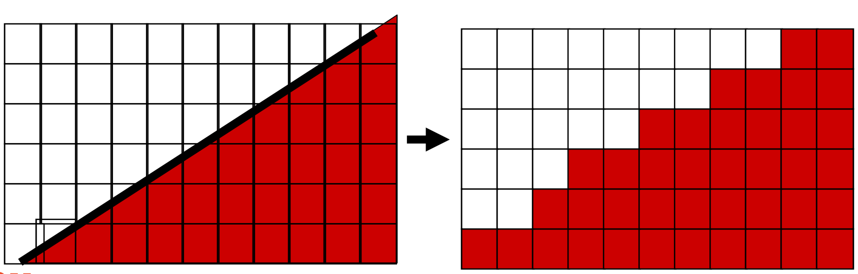
Starts at the Object

This is the typical kind of rendering you get on a graphics card.
Start with the geometry and project it onto the pixels.



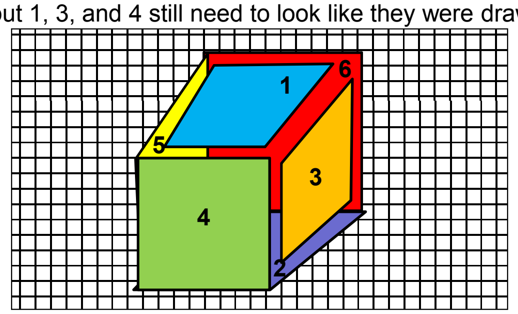
Rasterization

- **Turn screen space vertex coordinates into pixels that make up lines and polygons**
- **A great place for custom electronics**

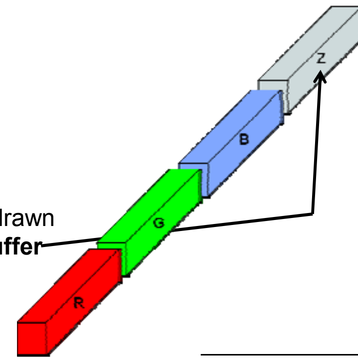


How do things in front *look* like they are really in front?

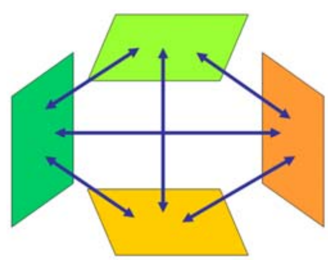
Your application might draw the polygons in 1-2-3-4-5-6 order, but 1, 3, and 4 still need to look like they were drawn last:



Either the polygons need to be re-arranged to be drawn in a back-to-front order, or we need to have a **Z-buffer**



Another From-the-Object Method -- Radiosity



Based on the idea that all surfaces gather light intensity from all other surfaces

The fundamental radiosity equation is an energy balance that says:

"The light energy leaving surface *i* equals the amount of light energy generated by surface *i* plus surface *i*'s reflectivity times the amount of light energy arriving from all other surfaces"

$$B_i A_i = E_i A_i + \rho_i \sum_j B_j A_j F_{j \to i}$$

The Radiosity Equation

$$B_i A_i = E_i A_i + \rho_i \sum_j B_j A_j F_{j \to i}$$

B_i is the light energy intensity shining from surface element *i*

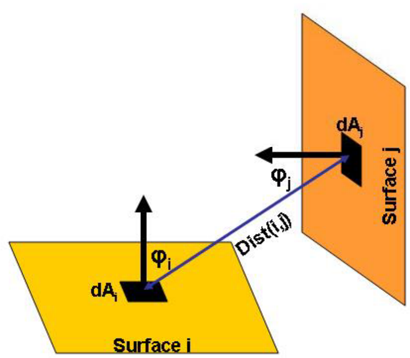
A_i is the area of surface element *i*

E_i is the internally-generated light energy intensity for surface element *i*

ρ_i is surface element *i*'s reflectivity

$F_{j \to i}$ is referred to as the Form Factor, or Shape Factor, and describes what percent of the energy leaving surface element *j* that arrives at surface element *i*

The Radiosity Shape Factor



$$F_{j \to i} = \int_{Ai} \int_{A_j} visibility(di, dj) \frac{\cos \Theta_i \cos \Theta_j}{\pi Dist(di, dj)^2} dA_j dA_i$$

The Radiosity Matrix Equation

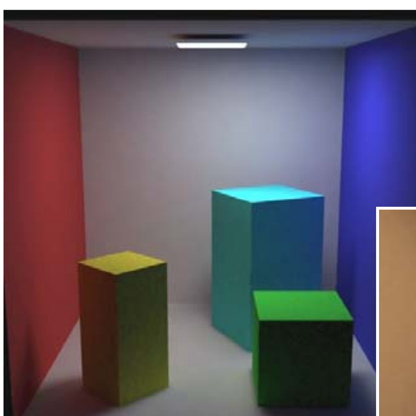
Expand $B_i A_i = E_i A_i + \rho_i \sum_j B_j A_j F_{j \rightarrow i}$

For each surface element, and re-arrange to solve for the surface intensities, the *B*'s:

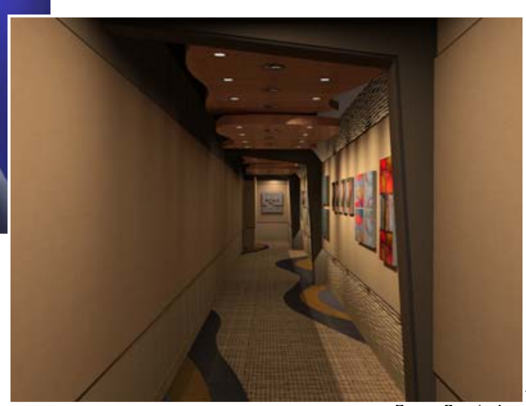
$$\begin{bmatrix} 1-\rho_1 F_{1\rightarrow 1} & -\rho_1 F_{1\rightarrow 2} & \bullet\bullet\bullet & -\rho_1 F_{1\rightarrow N} \\ -\rho_2 F_{2\rightarrow 1} & 1-\rho_2 F_{2\rightarrow 2} & \bullet\bullet\bullet & -\rho_2 F_{2\rightarrow N} \\ \bullet\bullet\bullet & \bullet\bullet\bullet & \bullet\bullet\bullet & \bullet\bullet\bullet \\ -\rho_N F_{N\rightarrow 1} & -\rho_N F_{N\rightarrow 2} & \bullet\bullet\bullet & 1-\rho_N F_{N\rightarrow N} \end{bmatrix} \begin{Bmatrix} B_1 \\ B_2 \\ \bullet\bullet\bullet \\ B_N \end{Bmatrix} = \begin{Bmatrix} E_1 \\ E_2 \\ \bullet\bullet\bullet \\ E_N \end{Bmatrix}$$

This is a lot of equations!

Radiosity Examples



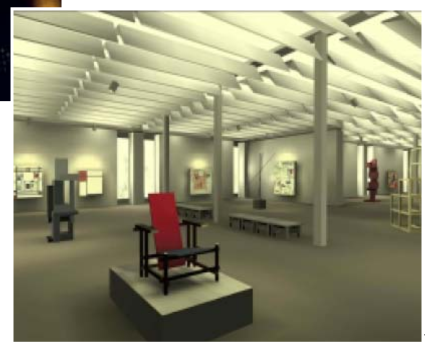
AR Toolkit



Autodesk

Radiosity Examples

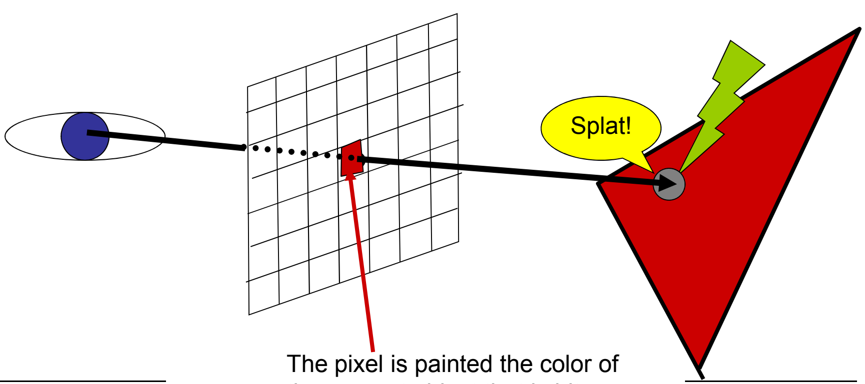
Cornell University



Cornell University

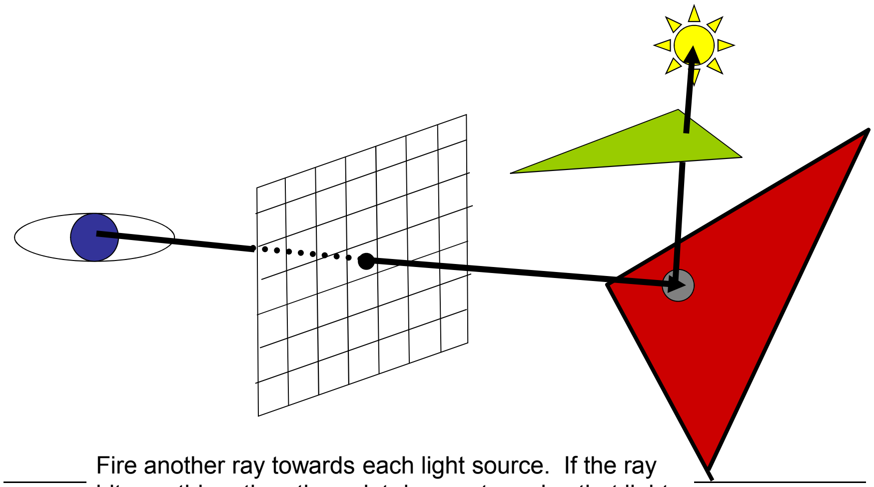
Starts at the Eye

The most common approach in this category is ray-tracing:



Starts at the Eye

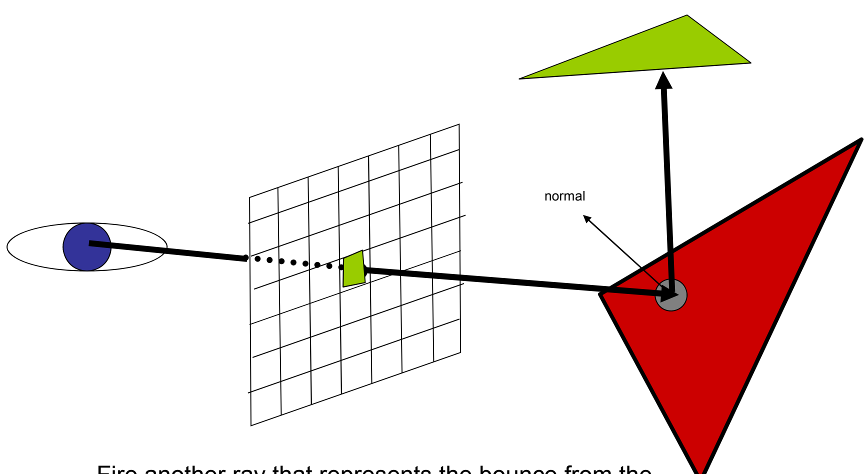
It's also easy to see if this point lies in a shadow:



Fire another ray towards each light source. If the ray hits anything, then the point does not receive that light.

Starts at the Eye

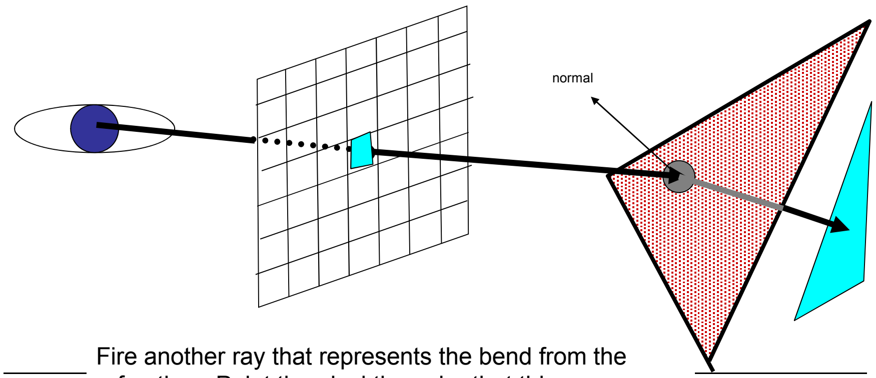
It's also easy to handle reflection



Fire another ray that represents the bounce from the reflection. Paint the pixel the color that this ray sees.

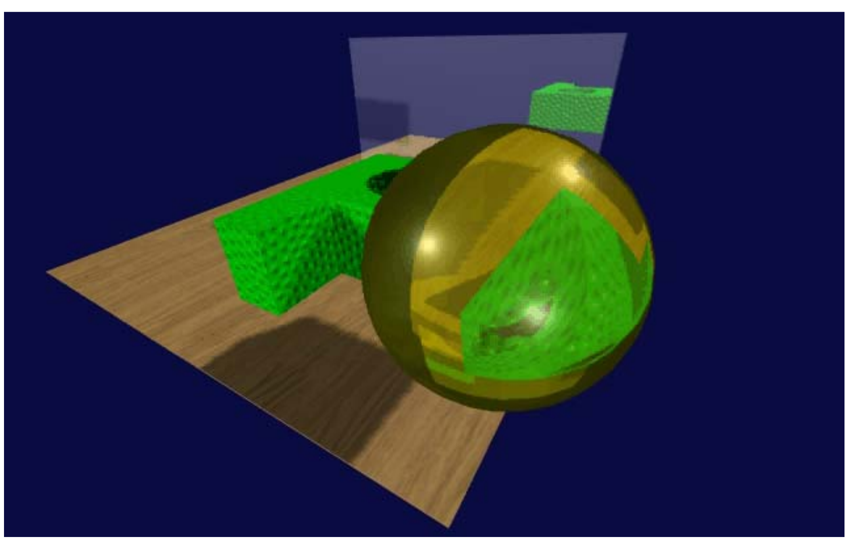
Starts at the Eye

It's also easy to handle refraction

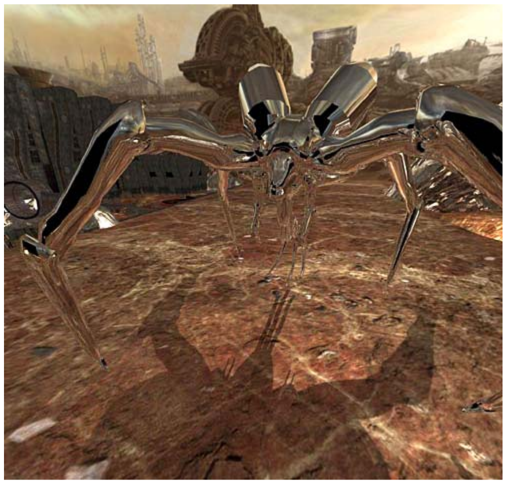


Fire another ray that represents the bend from the refraction. Paint the pixel the color that this ray sees.

Ray Tracing Examples



Ray Tracing Examples



Quake 4 Ray-Tracing Project

Oregon State University
Computer Graphics

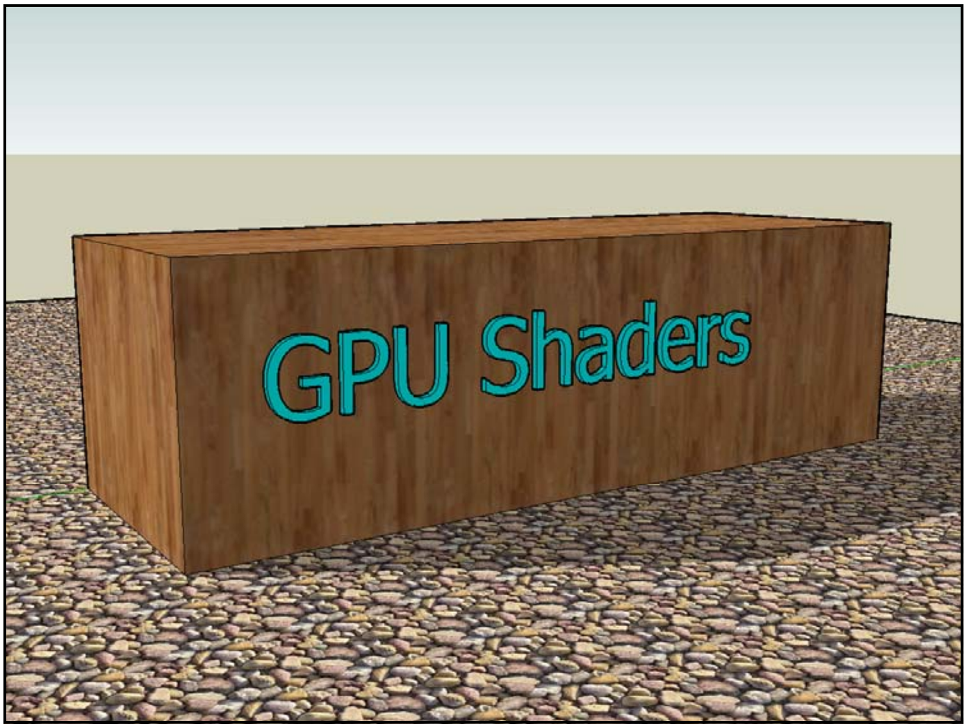
Brown Cunningham
Associates

Ray Tracing Examples

IBM's Cell Interactive Ray-tracer

Oregon State University
Computer Graphics

Brown Cunningham
Associates



GPU Shader Programming

• Allows programmers to load their own code into parts of the hardware graphics pipeline

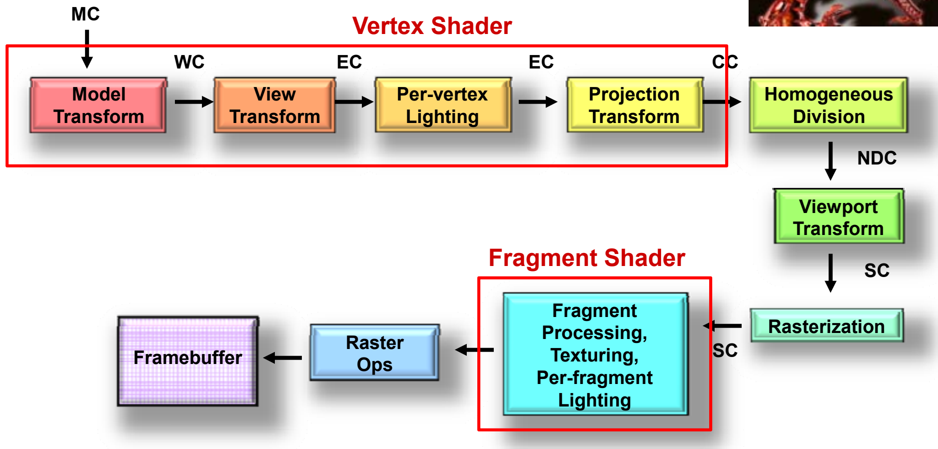
• Gives a unique combination of control and speed

• This is a hot, new area in computer graphics

• These notes will focus on *what* can be done this way, not on *how* to do it (that would take lots more time)

• If you want to know more, there’s another course on just this topic!

The Basic Computer Graphics Pipeline



MC = Model Coordinates
WC = World Coordinates
EC = Eye Coordinates
CC = Clip Coordinates
NDC = Normalized Device Coordinates
SC = Screen Coordinates

A GLSL Vertex Shader Replaces These Operations:

- Vertex transformations
- Normal transformations
- Normal normalization
- Handling of per-vertex lighting
- Handling of per-vertex colors
- Handling of texture coordinates

A GLSL Fragment Shader Replaces These Operations:

- Color computation
- Texturing
- Handling of per-pixel lighting
- Fog
- Blending
- Discarding fragments

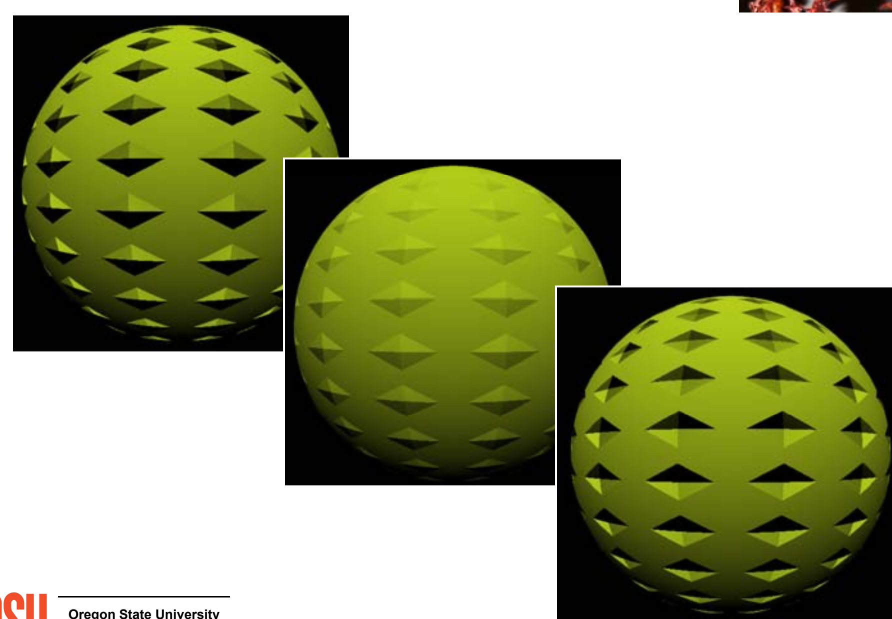
A GLSL Tessellation Shader:

- Breaks geometry into smaller pieces based on adjacent points, size, curvature, etc.

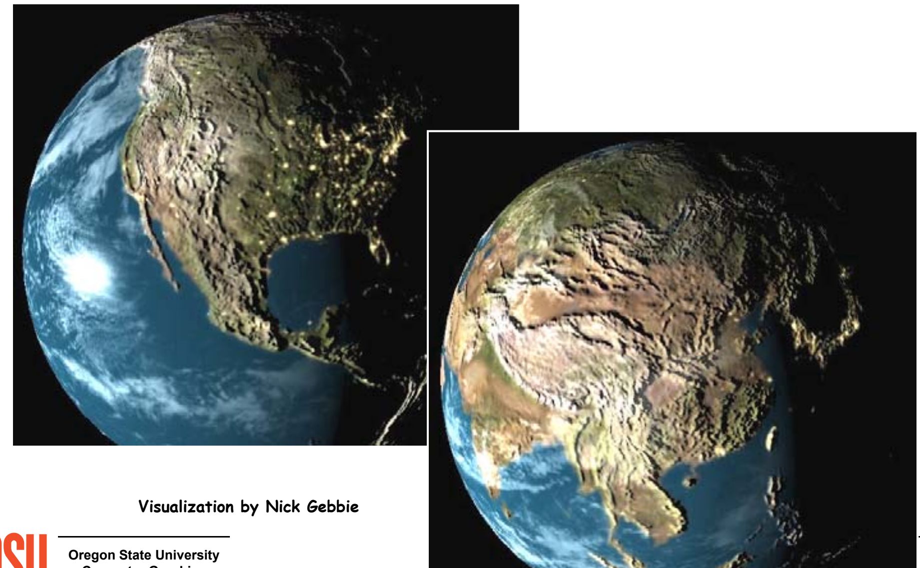
A GLSL Geometry Shader:

- Breaks geometry into smaller pieces based on more limited information
- Changes the geometry's topology type
- Changes the object's coordinates

Bump Mapping with Shaders



Bump Mapping with Shaders



Visualization by Nick Gebbie

Cube Mapping with Shaders

Cube Map of NVIDIA's Lobby

Cube Mapping with Shaders

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Cube Mapping with Shaders

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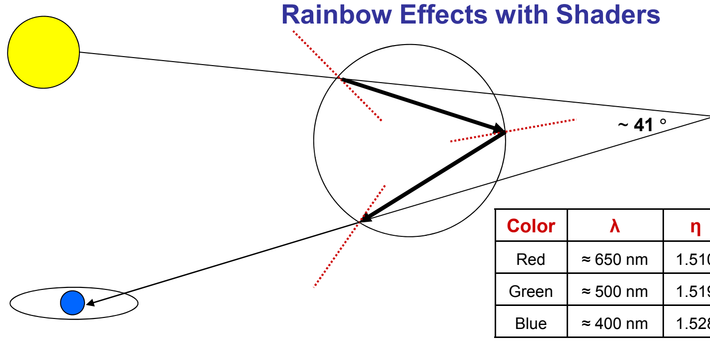
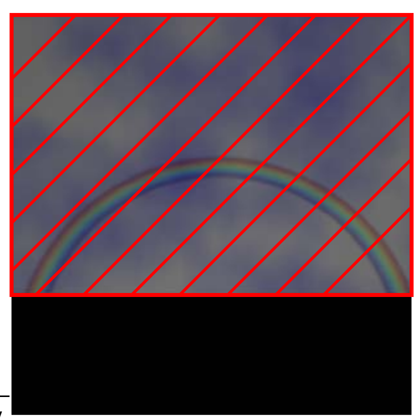
Rainbow Effects with Shaders



Color	λ	η	Θ	cosΘ	ΘΘ
Red	≈ 650 nm	1.510	42°	0.743	50.0°
Green	≈ 500 nm	1.519	41°	0.755	51.5°
Blue	≈ 400 nm	1.528	40°	0.766	53.0°

Rainbow Strategy

1. Draw one big quadrilateral across the scene
2. Anywhere that .7400 ≤ cos(Θ) ≤ .7700, paint the correct color
3. If not, discard that fragment




Finding Additional
Information

Where to Find More Information about Computer Graphics and Related Topics

Mike Bailey
Oregon State University

1. References

1.1 General Computer Graphics

SIGGRAPH Online Bibliography Database:
`http://www.siggraph.org/publications/bibliography`

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Computer Graphics World: published by Pennwell
(`http://www.cgw.com`, 603-891-0123)

Journal of Graphics, GPU, and Game Tools: published by A.K. Peters
(`http://www akpeters.com`, 617-235-2210)

Game Developer: published by CMP Media
(`http://www gdmag.com`, 415-905-2200)
(Once a year publishes the *Game Career Guide*.)

Computer Graphics Quarterly: published by ACM SIGGRAPH
(`http://www.siggraph.org`, 212-869-7440)

Computer Graphics Forum:, published by Eurographics
(http://www.eg.org/EG/Publications/CGF)

Computers & Graphics, published by Elsevier
(http://www.elsevier.com/locate/cag)

Transactions on Visualization and Computer Graphics: published by IEEE
(`http://www.computer.org`, 714-821-8380)

Transactions on Graphics: published by ACM
(`http://www.acm.org`, 212-869-7440)

Cinefex
(`http://www.cinefex.com`, 951-781-1917)

3. Professional organizations

ACM .... Association for Computing Machinery
`http://www.acm.org`
212-869-7440

SIGGRAPH ..... ACM Special Interest Group on Computer Graphics
`http://www.siggraph.org`
212-869-7440

EuroGraphics ... European Association for Computer Graphics
`http://www.eg.org`
Fax: +41-22-757-0318

IEEE................. Institute of Electrical and Electronic Engineers
`http://www.computer.org`
202-371-0101

IGDA .... International Game Developers Association
`http://www.igda.org`
856-423-2990

SIGCHI .... ACM Special Interest Group on Computer-Human Interfaces
`http://www.acm.org/sigchi`
212-869-7440

NAB................. National Association of Broadcasters
`http://www.nab.org`
800-521-8624

ASME .... American Society of Mechanical Engineers
`http://www.asme.org`
800-THE-ASME

4. Conferences

ACM SIGGRAPH:
2012: Los Angeles, CA – August 5-9
2013: Los Angeles, CA – July 28 – August 1
`http://www.siggraph.org/s2012`
`http://www.siggraph.org/s2013`

SIGGRAPH Asia:
2011: Hong Kong – December 12-15
`http://www.siggraph.org/asia2011`

IEEE Visualization:
2011: Providence, RI – October 23-28

http://visweek.org

Eurographics
2012: Cagliari, Italy – May 13-18
http://www.eurographics2012.it

Game Developers Conference:
2012: San Francisco, CA – March 5 - 9
http://www.gdconf.com

E3Expo
2012: Los Angeles, CA – June 7-9
http://www.e3expo.com

PAX (Penny Arcade Expo)
2011: Seattle, WA – August 26-28
http://www.paxsite.com

ASME International Design Engineering Technical Conferences (includes the Computers and Information in Engineering conference):
2012: Chicago, IL – August 12-15
http://www.asmeconferences.org/idetc2012

National Association of Broadcasters (NAB):
2012: Las Vegas, NV – April 14-19
http://www.nab.org

ACM SIGCHI:
2012: Austin, TX – May 5-10
http://www.acm.org/sigchi

ACM SIGARCH / IEEE Supercomputing:
2011: Seattle, WA -- November 12-18
http://www.supercomputing.org

5. Graphics Performance Characterization

The GPC web site tabulates graphics display speeds for a variety of vendors' workstation products. To get the information, visit:

http://www.spec.org/benchmarks.html#gwpg