Mike Bailey
Oregon State University

mjb@cs.oregonstate.edu

SIGGRAPH2012
The 39th International Conference and Exhibition on Computer Graphics and Interactive Techniques

Seminar Goals

- Provide a background for everything else you will see at SIGGRAPH 2012
- 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

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 4,600 students in his classes

- mjb@cs.oregonstate.edu

Specific Topics

- The Graphics Process
- How to Attend SIGGRAPH
- Graphics Hardware
- Modeling
- Rendering
- Animation
- Finding More Information

Schedule

9:00 Welcome and Overview
9:10 How to Attend SIGGRAPH
9:20 The Graphics Process
9:40 Graphics Hardware
10:00 Modeling

10:30 Break

10:45 Maybe our vision isn't as good as we think it is ☺
10:50 Rendering
11:15 Animation
11:50 Finding Additional Information

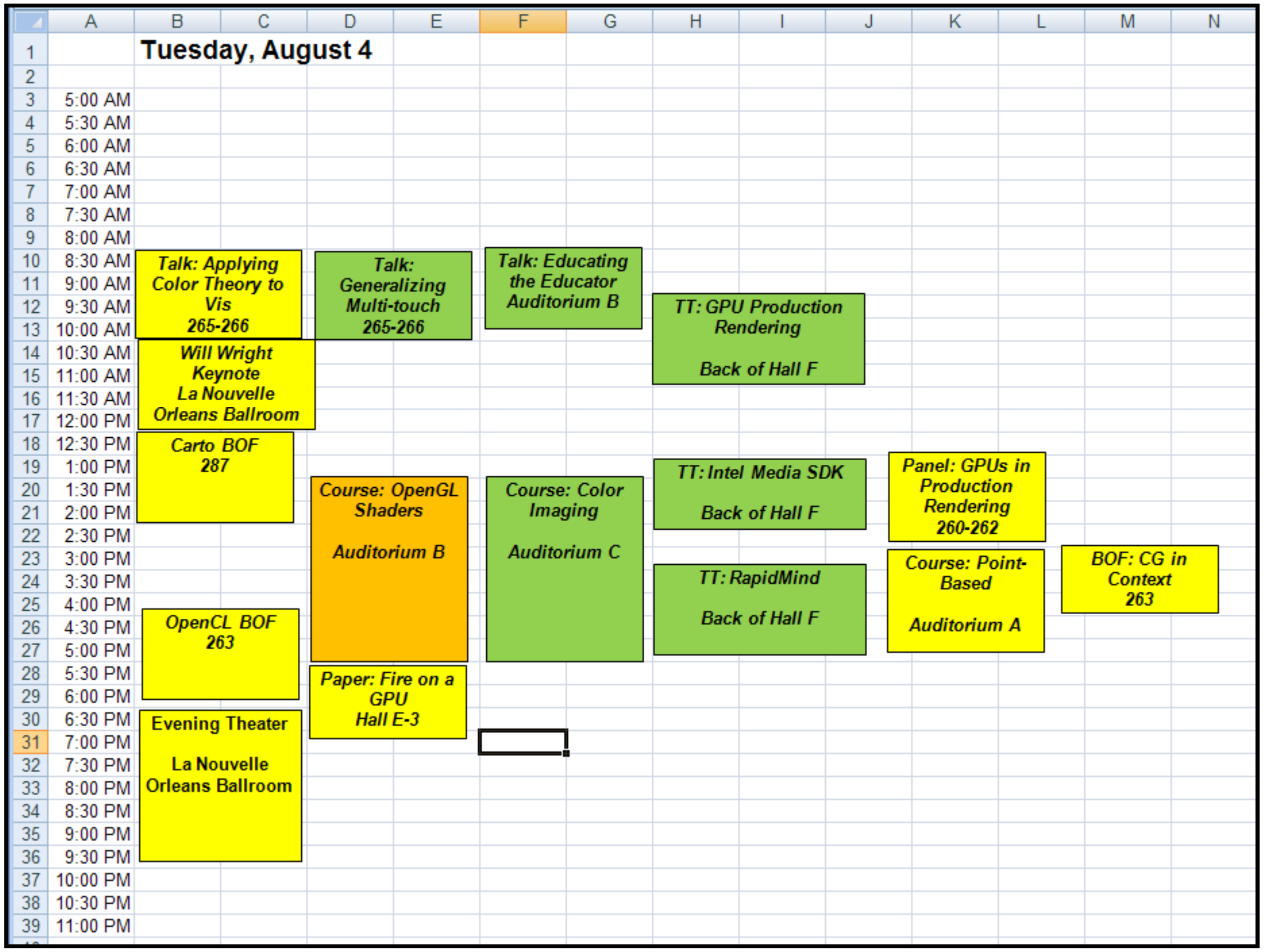
12:00 Finish


How to Attend
SIGGRAPH

You can't see it all, so …

Think Strategically -- Make a Plan, Make a Schedule, Set Priorities !

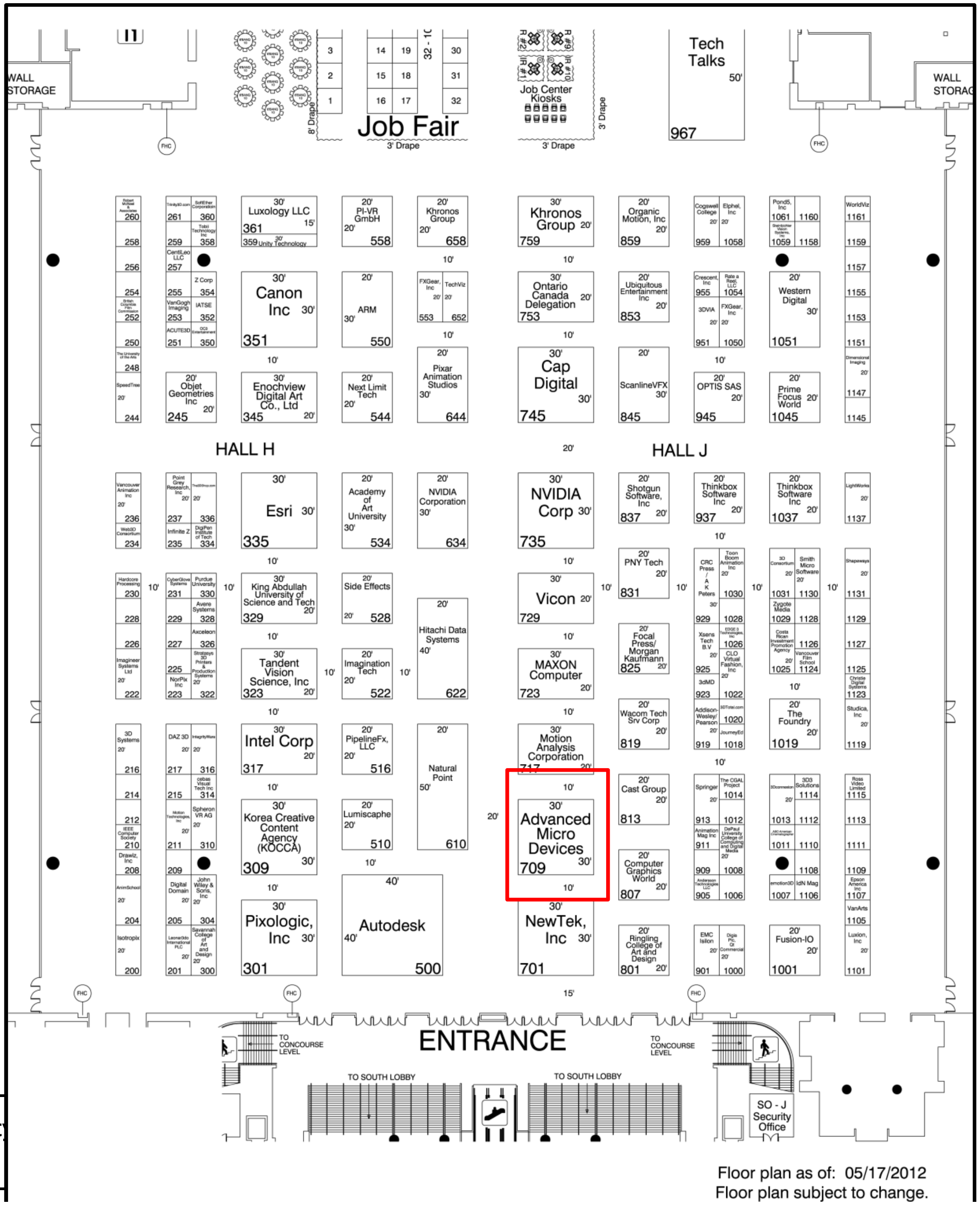
Your time is valuable.



In general, rank your top 3 things you want to see for each timeslot. Then, if one session is boring or not as useful as you'd thought, quickly move to your next priority.

Remember to give priority points to the things you can't "re-live" after it has happened !

OMG – Where do I Start in the Exhibition?



Exhibition Strategy

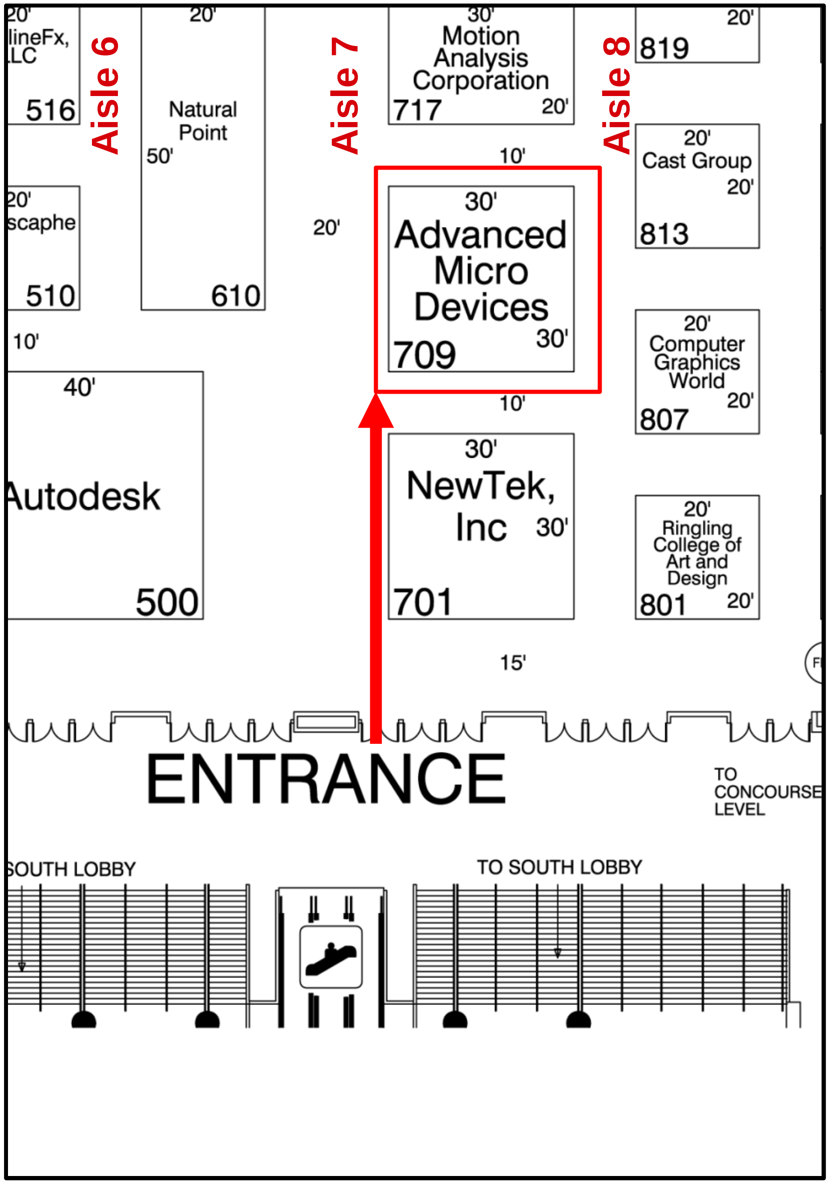
- Look at the list of vendors in the Program and Buyers Guide
- Make a list of the ones you *really* must see and sort the list by booth number
- Booth numbers are XXYY, where XX is the Aisle # and

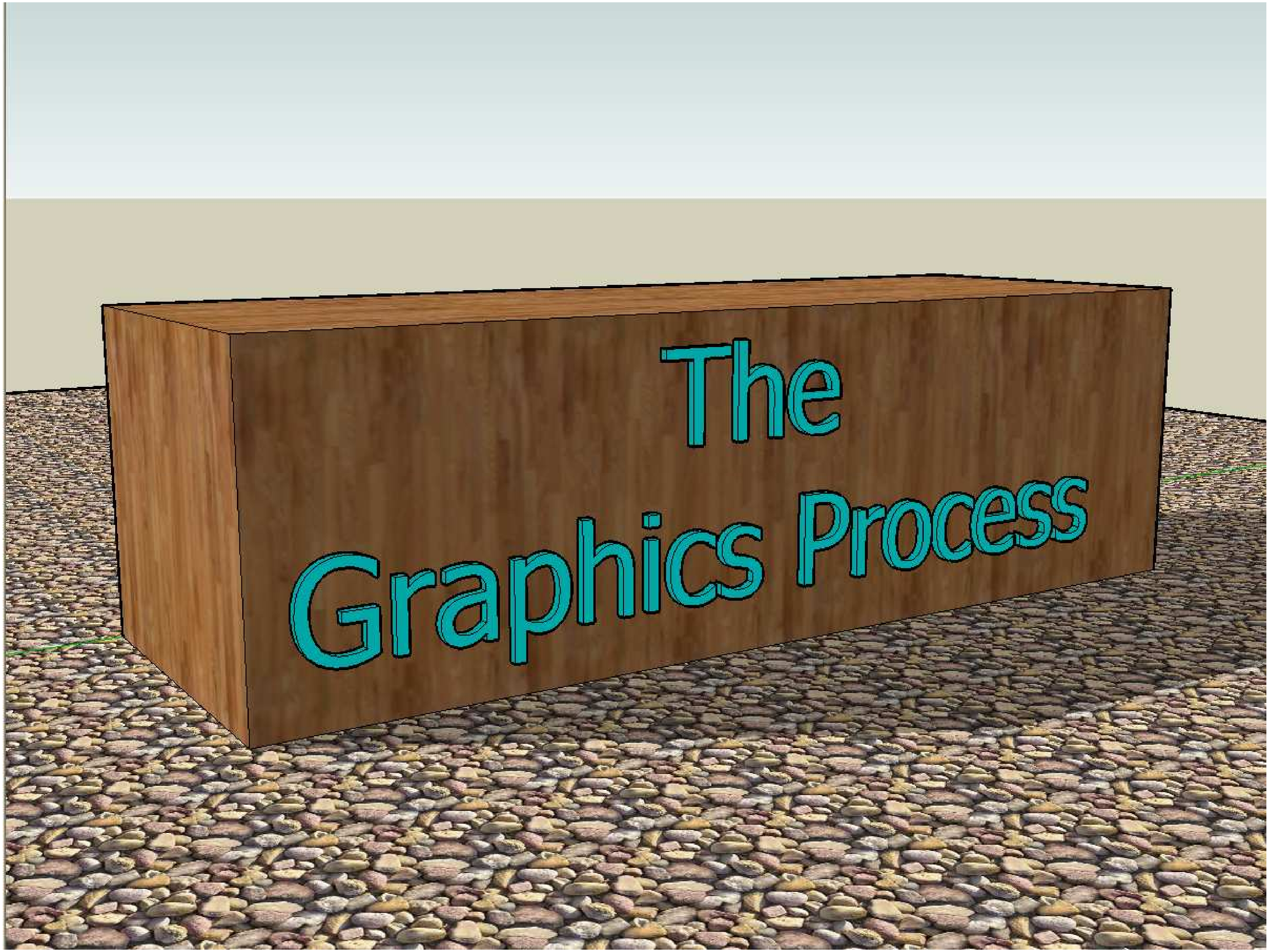
  YY is ($^1/_5$)*the number of feet from the front
- For example, AMD = booth 709, which is Aisle 7; 5*09 = 45 feet from the front
- Start at one end of the floor and work your way across

D	E	F
Animation Magazine	2000	
NVIDIA	2001	
Dimension 3D Printing	2010	
PNY	2017	
3D MD	2018	
Fusion IO	2022	
Caustic Graphics	2026	
T-Splines	2028	
Web3D Consortium	2029	
Lightspeed	2034	
Wolfram Research	2085	
Pixar	2117	
Interityware	2125	
Raven3D	2128	
Vis Trails	2129	
AutoDesk	2201	
Spheren VR	2228	
Natural Point	2401	
AMD / ATI	2417	
Laika	2501	
Wacom	2509	
AK Peters	2527	
Springer	2601	
Xerox	2605	
Addison-Wesley	2609	
Journey Ed	2626	
Future Publishing	2627	
Intelligraphics	2631	
Interactive Data Visualization	2700	
Google	2719	
Wiley	2725	
Digital Domain	2800	
LA Immersive Techmnologies Enterpri	2900	
Rhythm and Hues	3111	
Objet	3125	
RapidMind	3131	
3D Consortium	3200	
Side Effects	3206	
Point Grey	3211	
Fraunhofer	3311	
Purdue	3319	
Weiss	3331	
Baton Rouge Digital Industries	3405	
Immersion Games	3411	
NVIDIA Sketch Match	3424	
Computational Geometry Algorithms	3429	
EON Reality	3430	
JVC	3501	
Turbosquid	3600	
Digipen	3605	
Renderosity	3606	

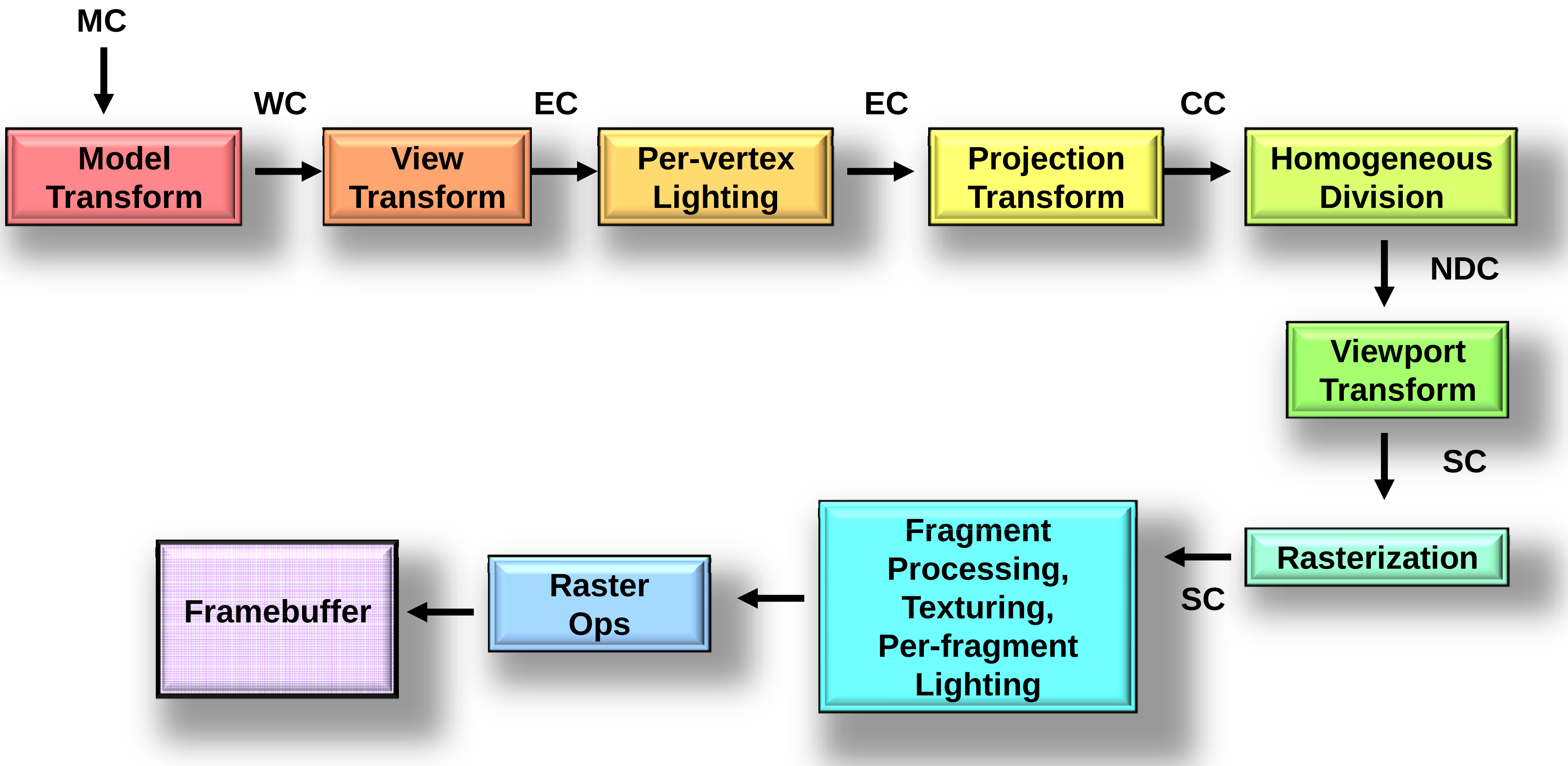
day | Thursday | Friday | Monday - 17 | Misc | Exhibition

Exhibition Strategy



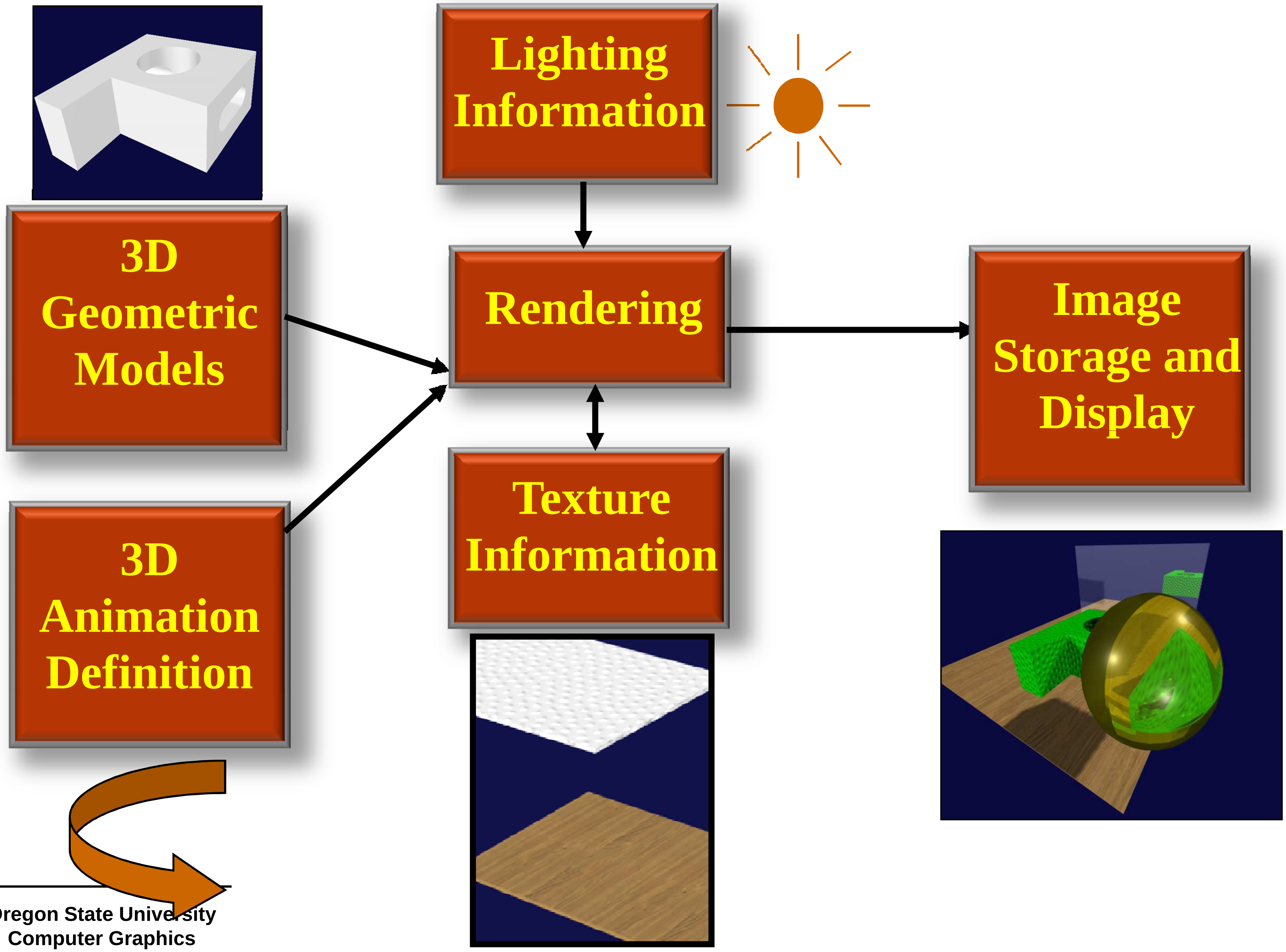

The
Graphics Process

The Basic Computer Graphics Pipeline

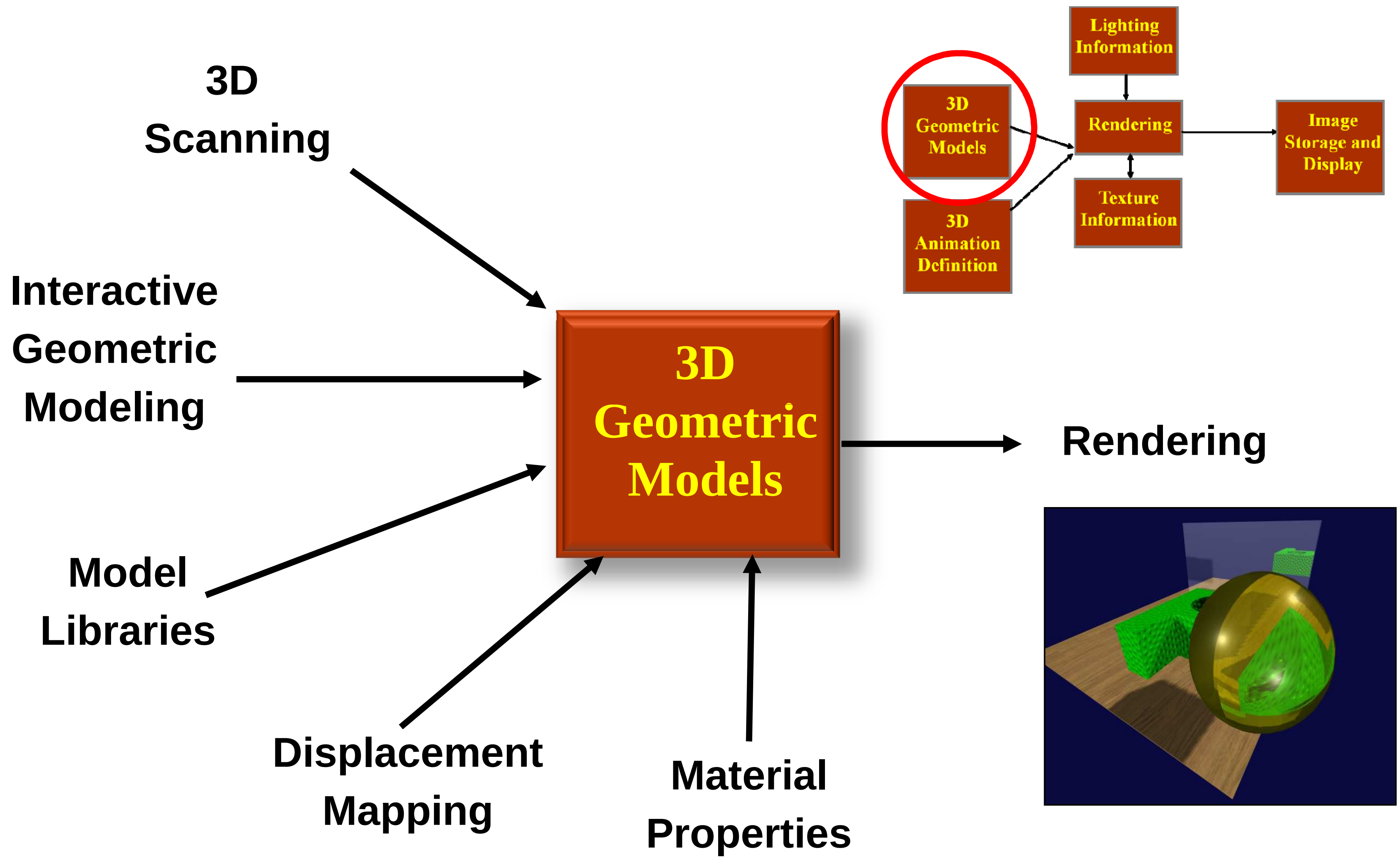


- MC = Model Coordinates
- WC = World Coordinates
- EC = Eye Coordinates
- CC = Clip Coordinates
- NDC = Normalized Device Coordinates
- SC = Screen Coordinates

The Graphics Process



The Graphics Process: Geometric Modeling



The Graphics Process: 3D Animation

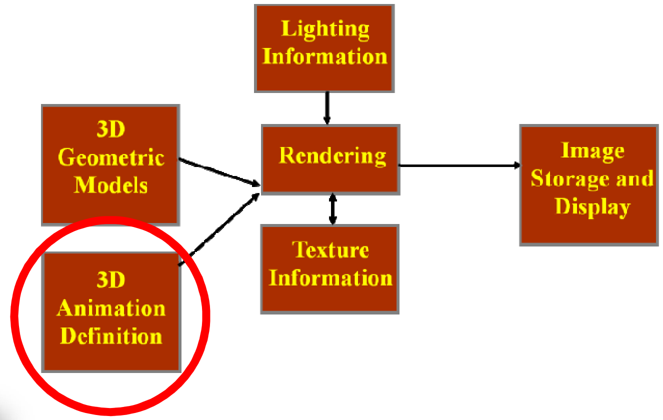
Motion Design

Motion Computation (physics)

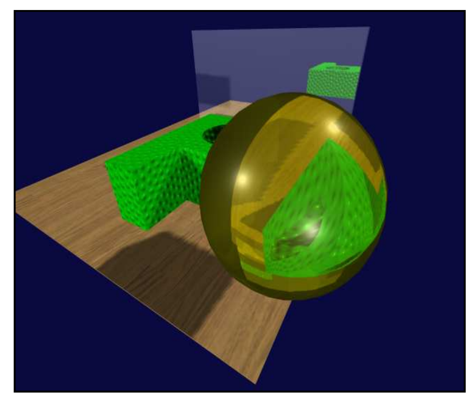
Motion Capture

Dynamic Deformations

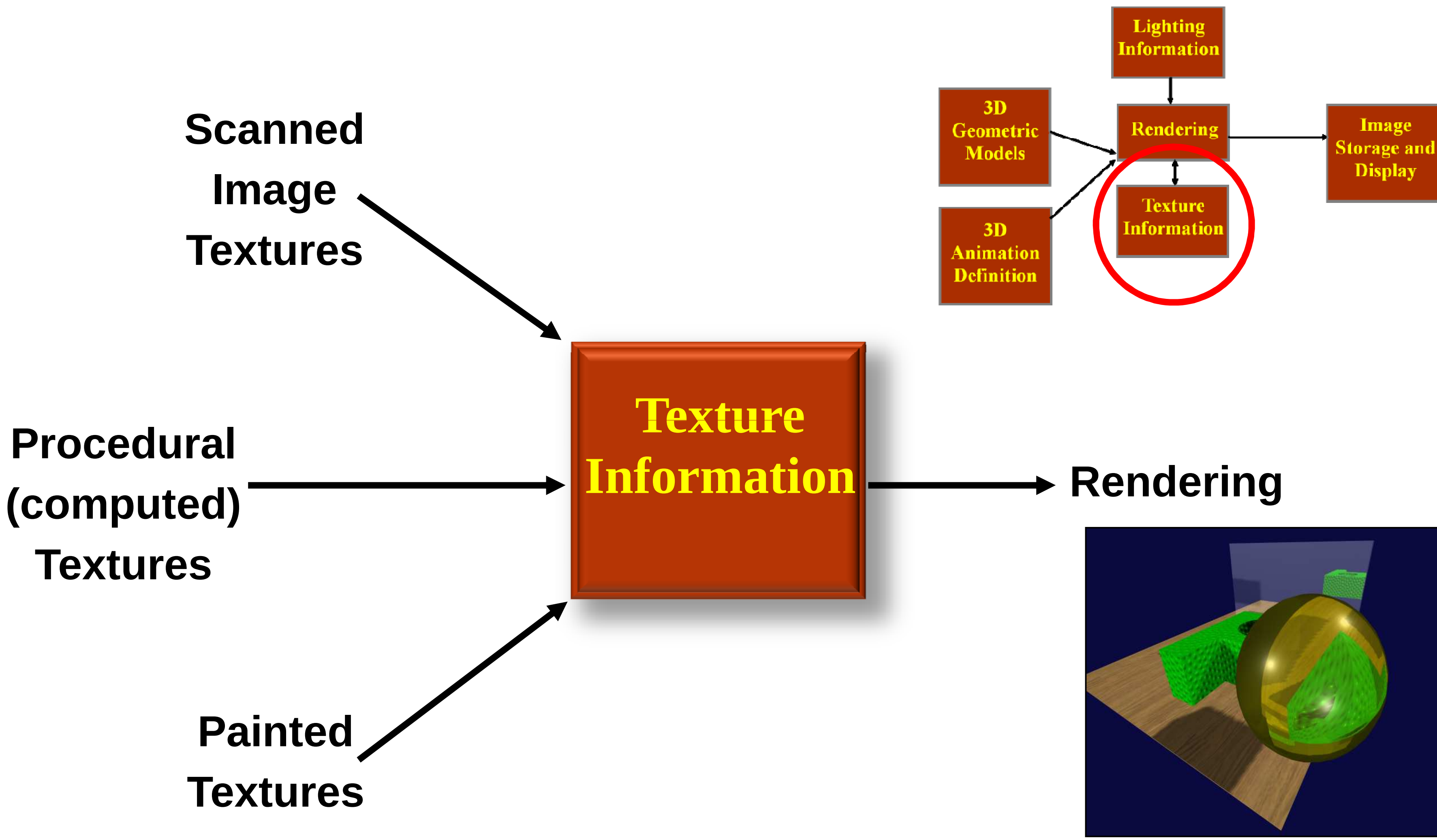
3D Animation Definition



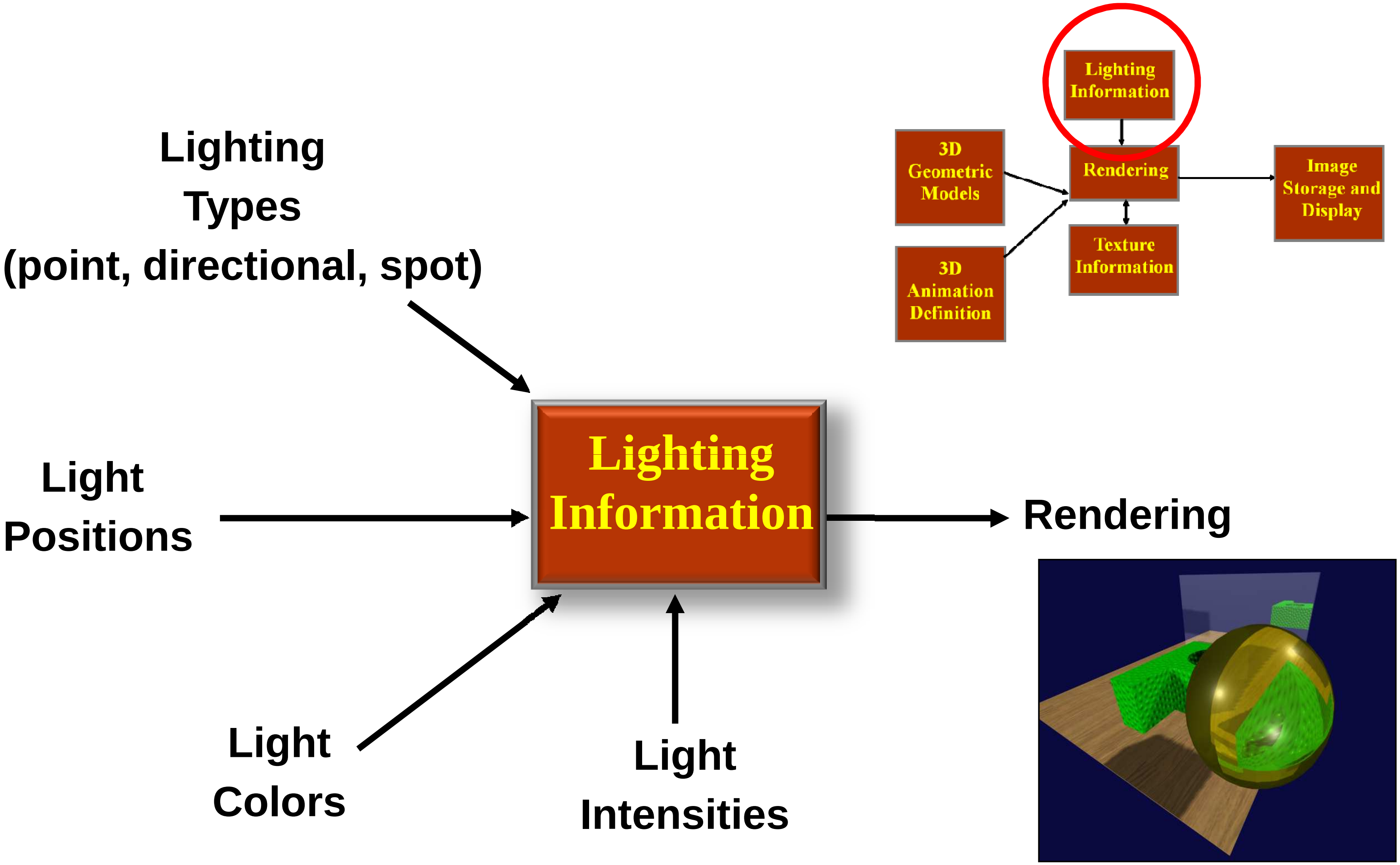
Rendering



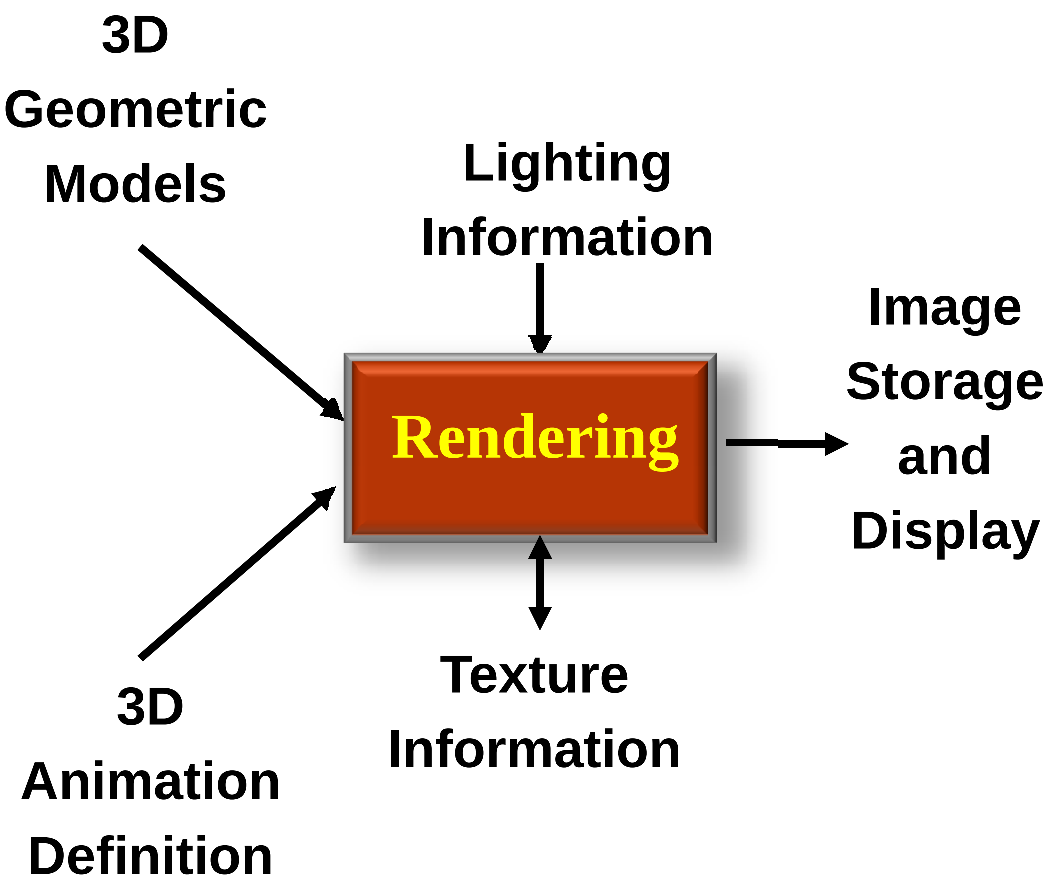
The Graphics Process: Texturing

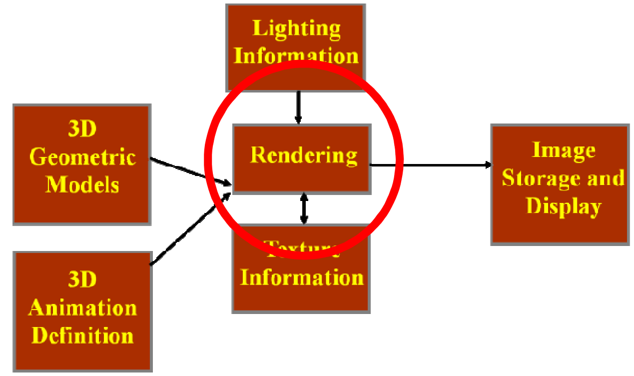


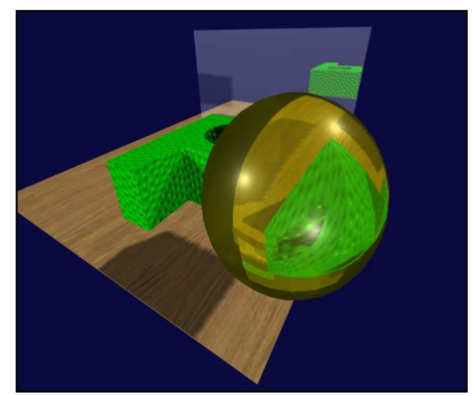
The Graphics Process: Lighting



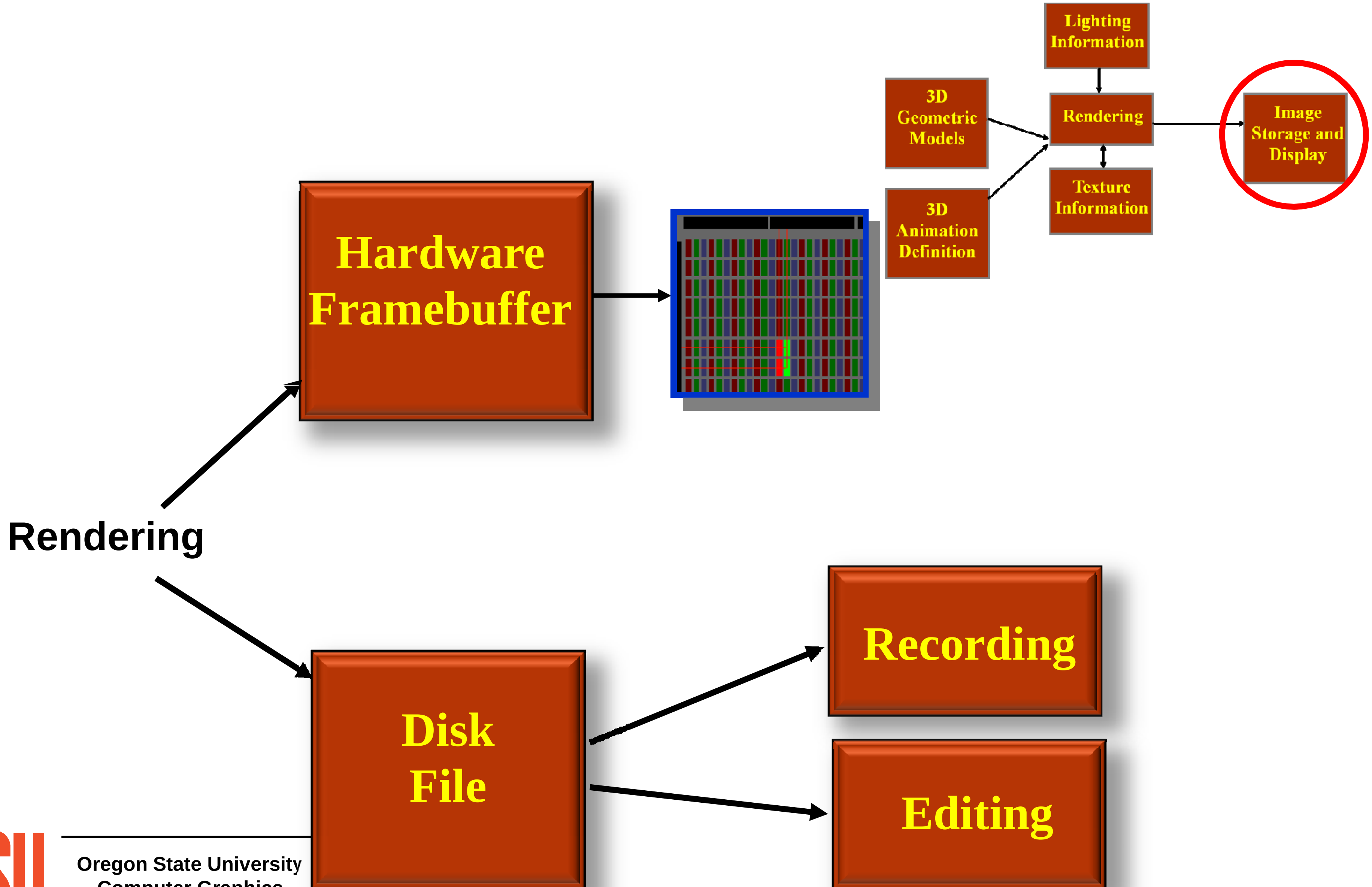
The Graphics Process: Rendering



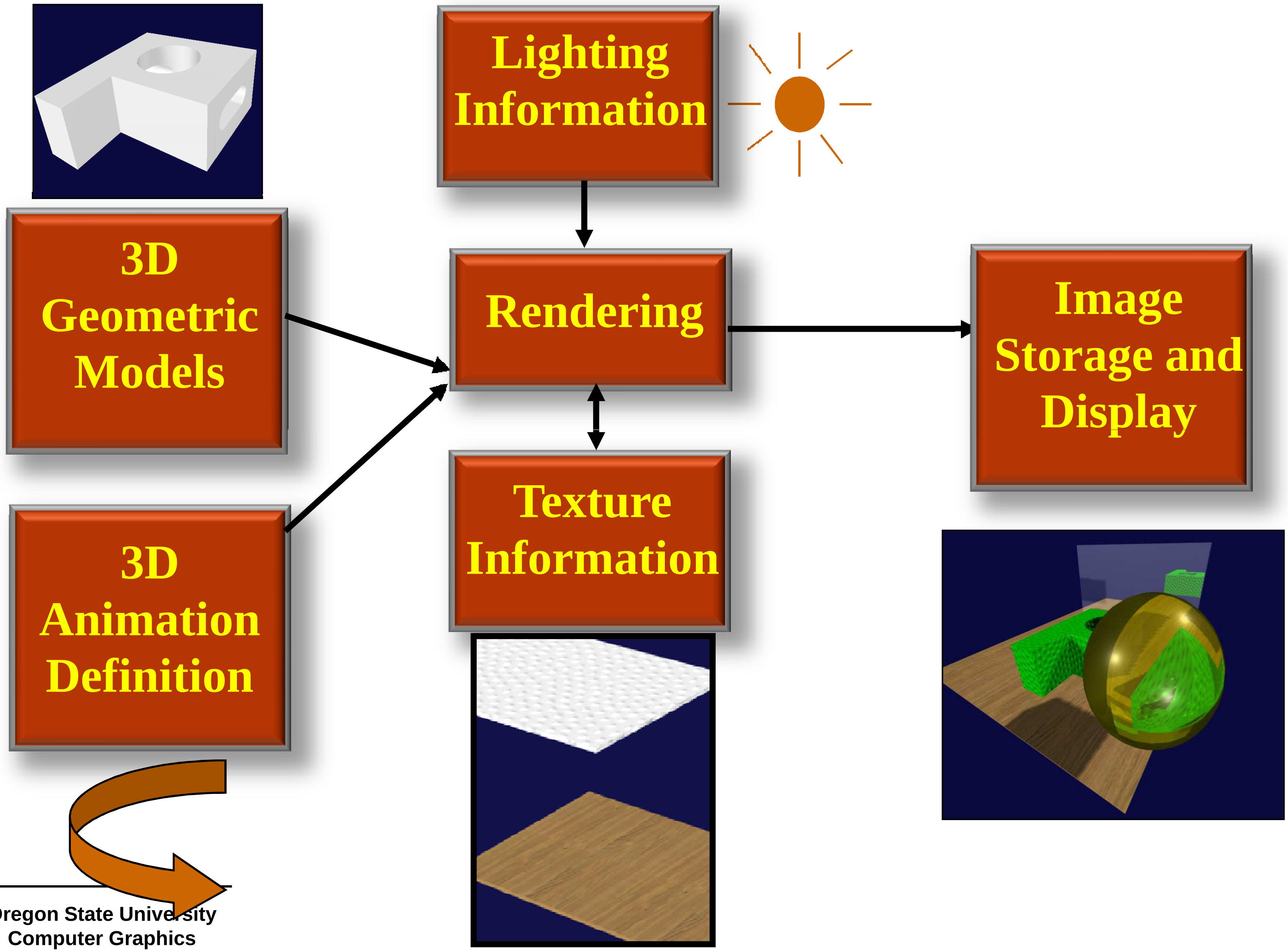


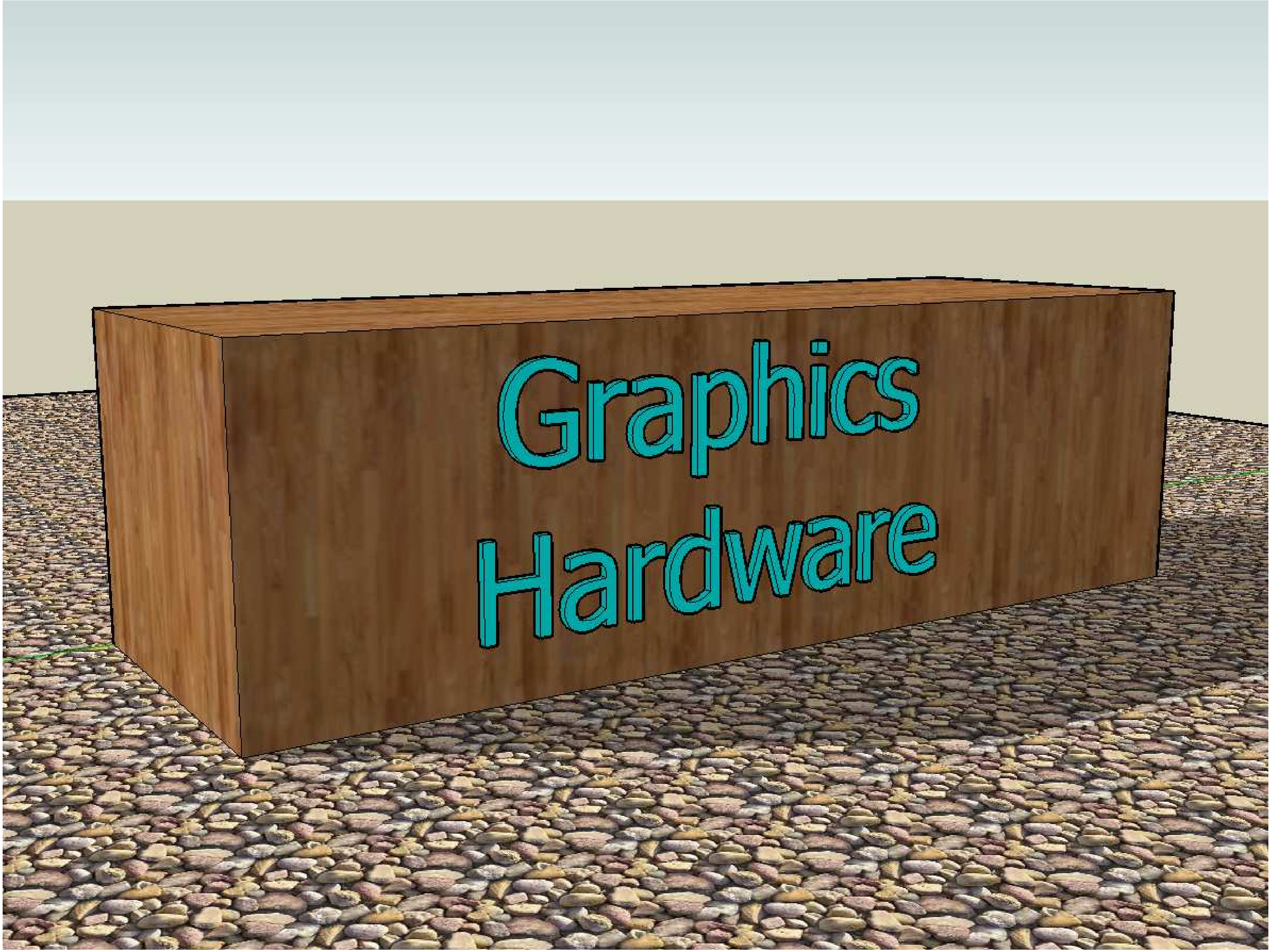


The Graphics Process: Image Storage and Display

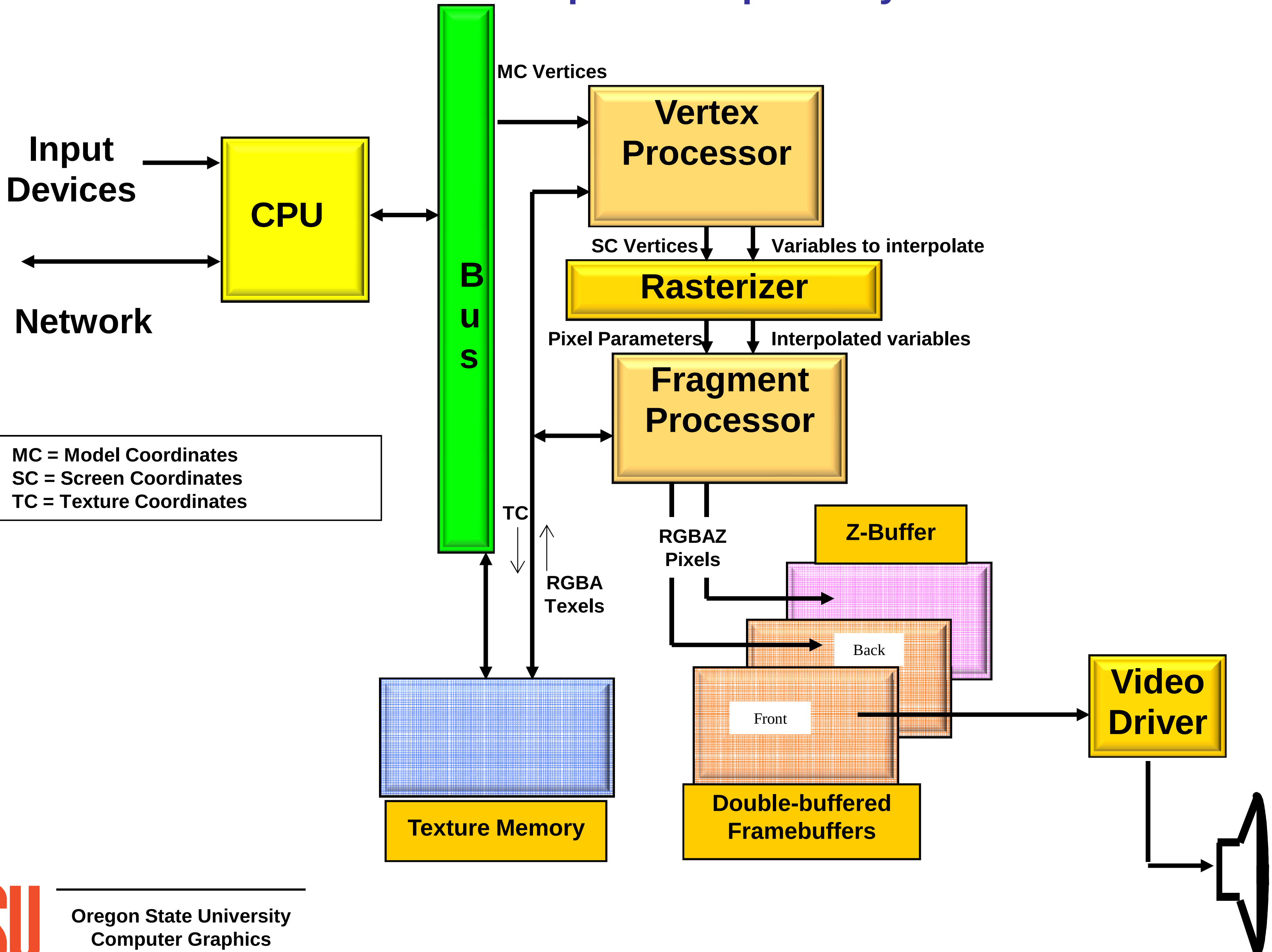


The Graphics Process; Summary



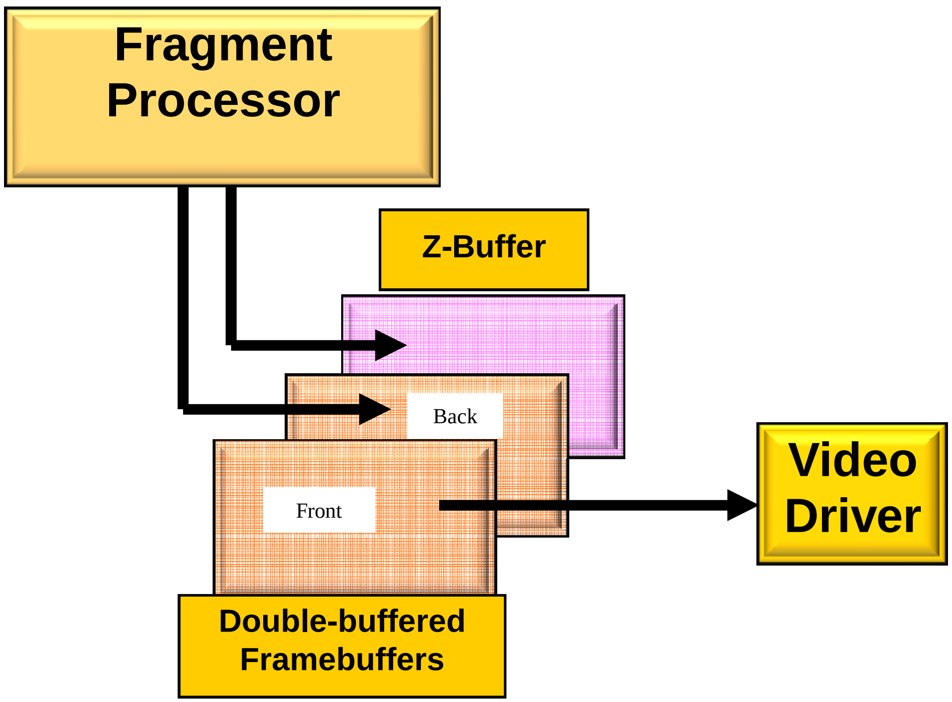

Graphics
Hardware

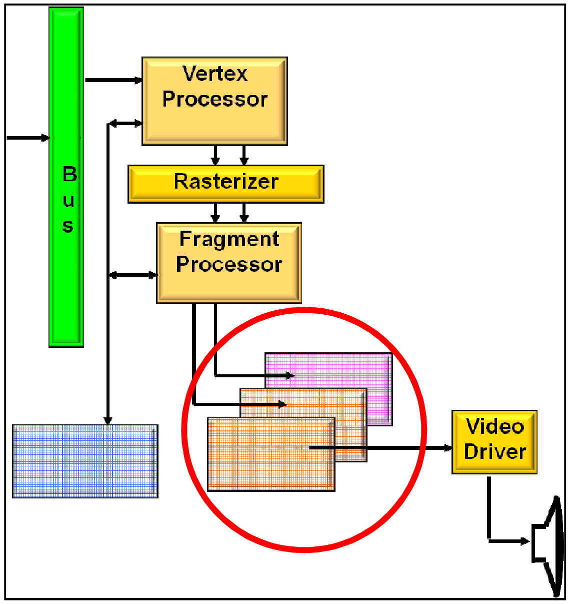
Generic Computer Graphics System



MC = Model Coordinates
SC = Screen Coordinates
TC = Texture Coordinates

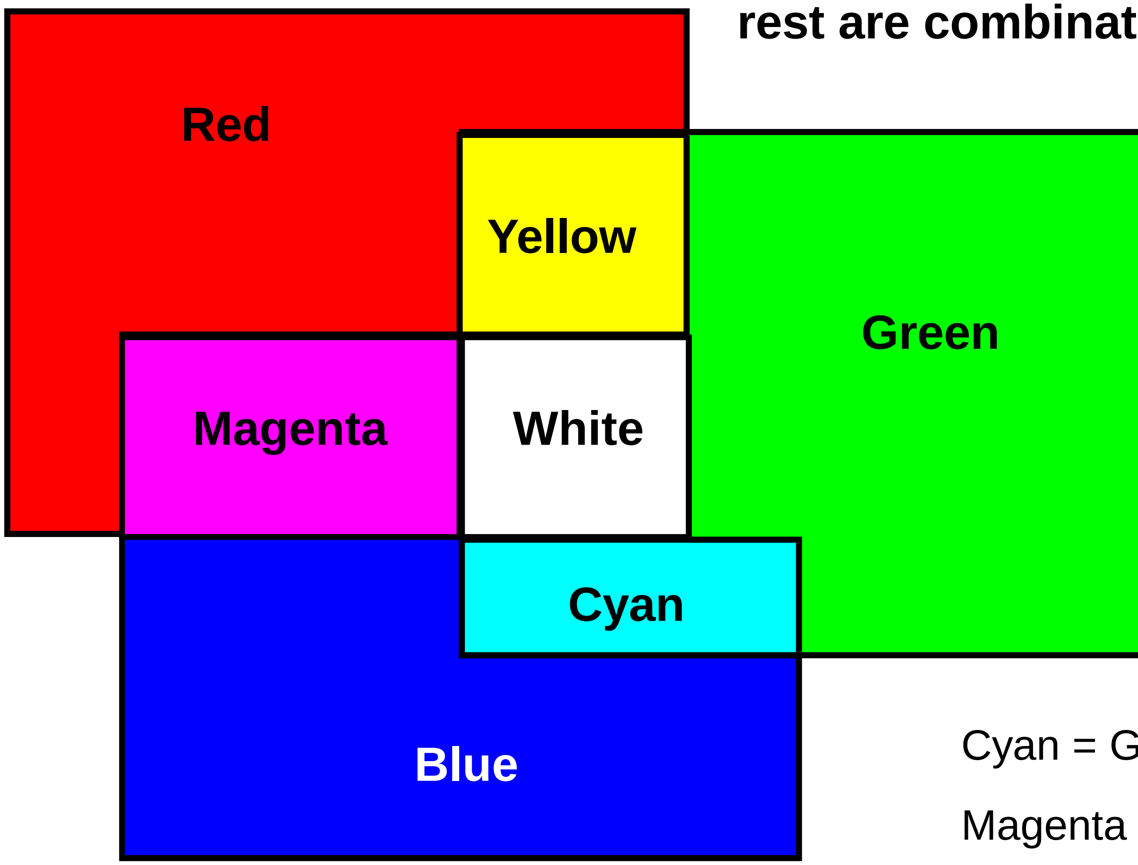
The Framebuffer





The Framebuffer Uses Additive Colors (RGB)

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



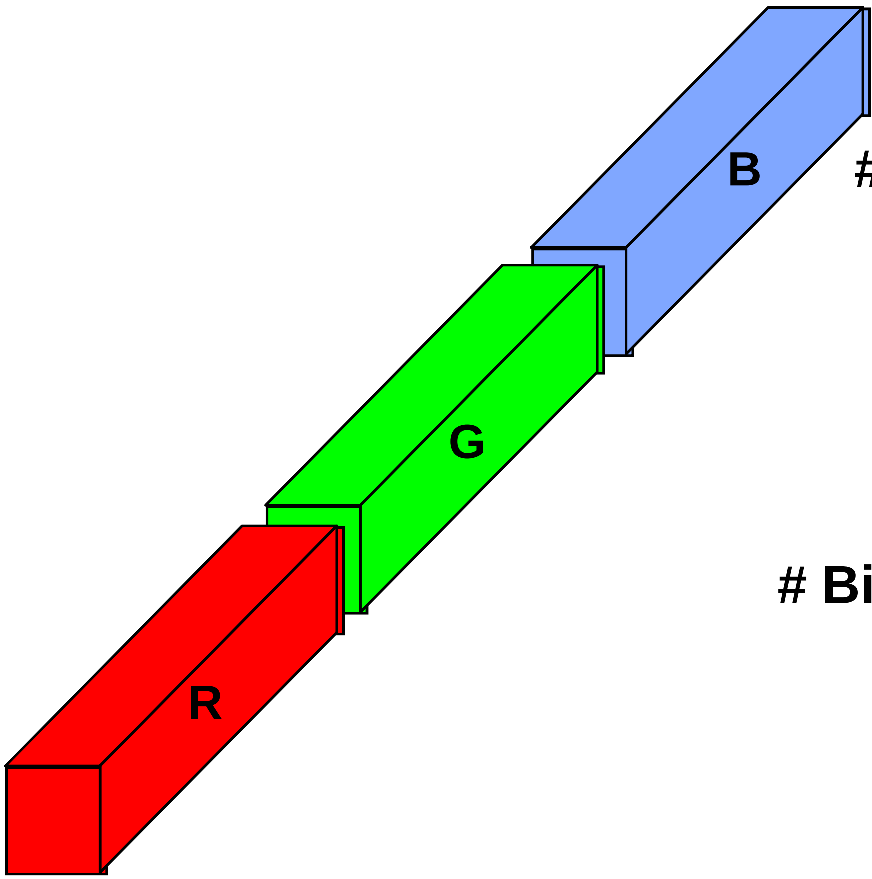
Cyan = Green + Blue

Magenta = Red + Blue

Yellow = Red + Green

White = Red + Green + Blue

The Framebuffer:
Integer Color Storage

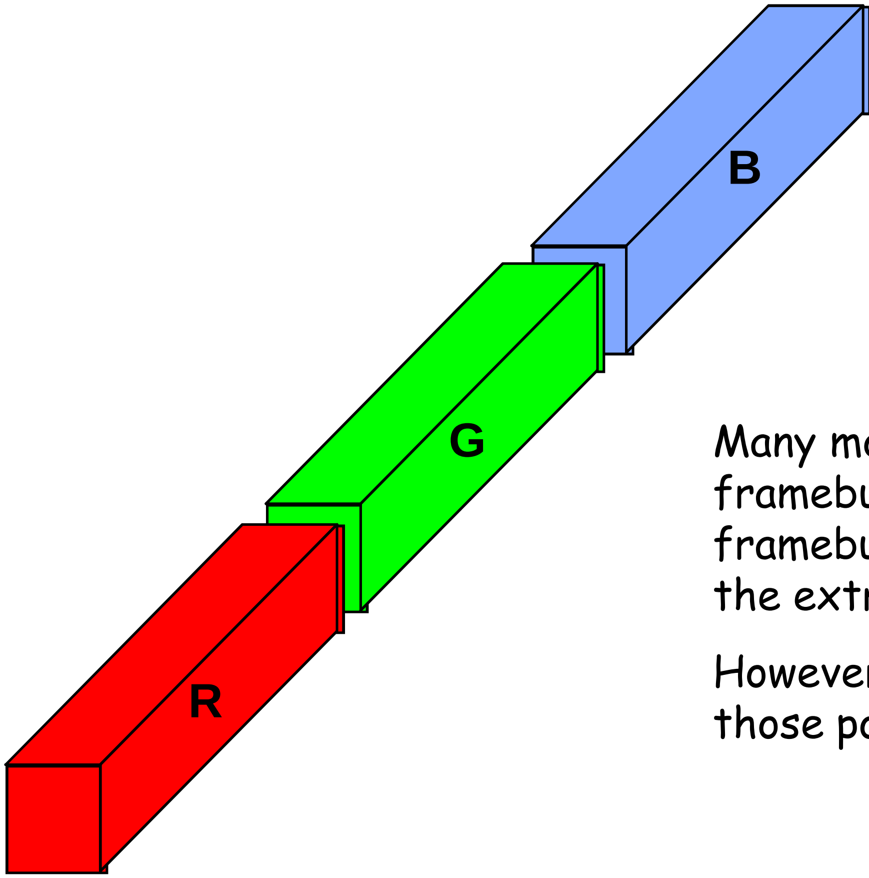


# Bits/color	# Intensities per color
8	$2^8 = 256$
10	$2^{10} = 1024$
12	$2^{12} = 4096$

# 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***



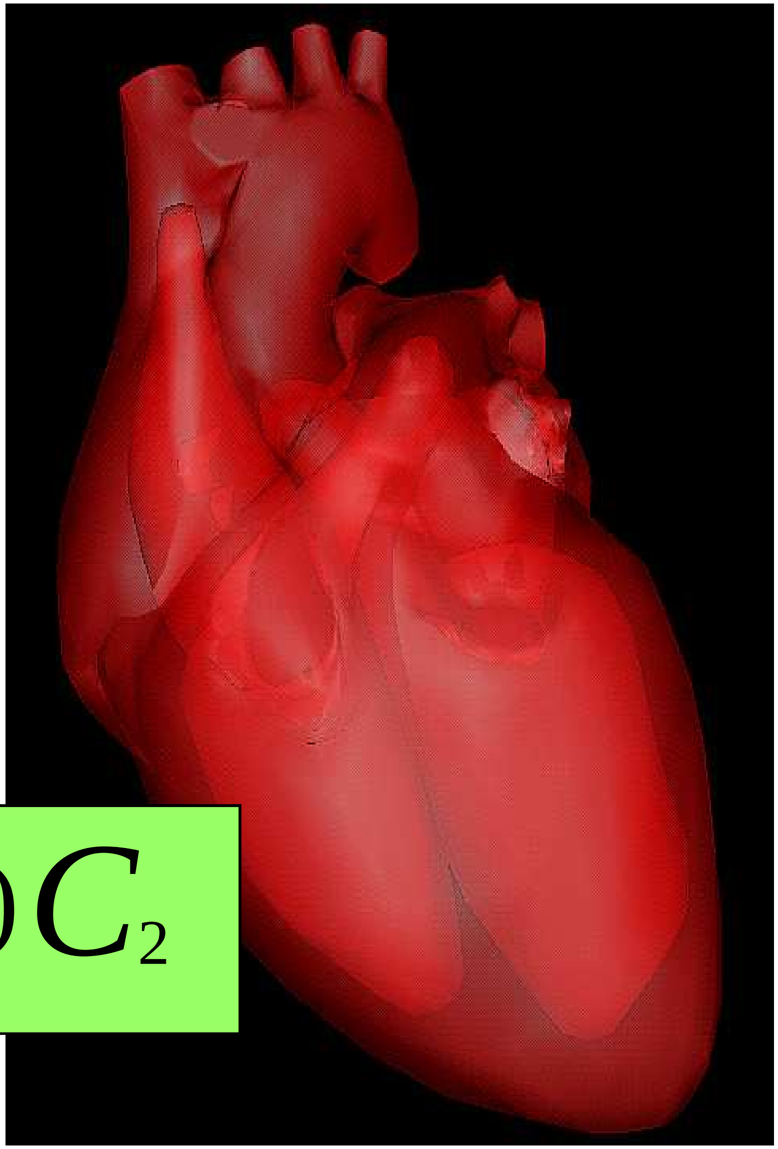
Why so much?

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:

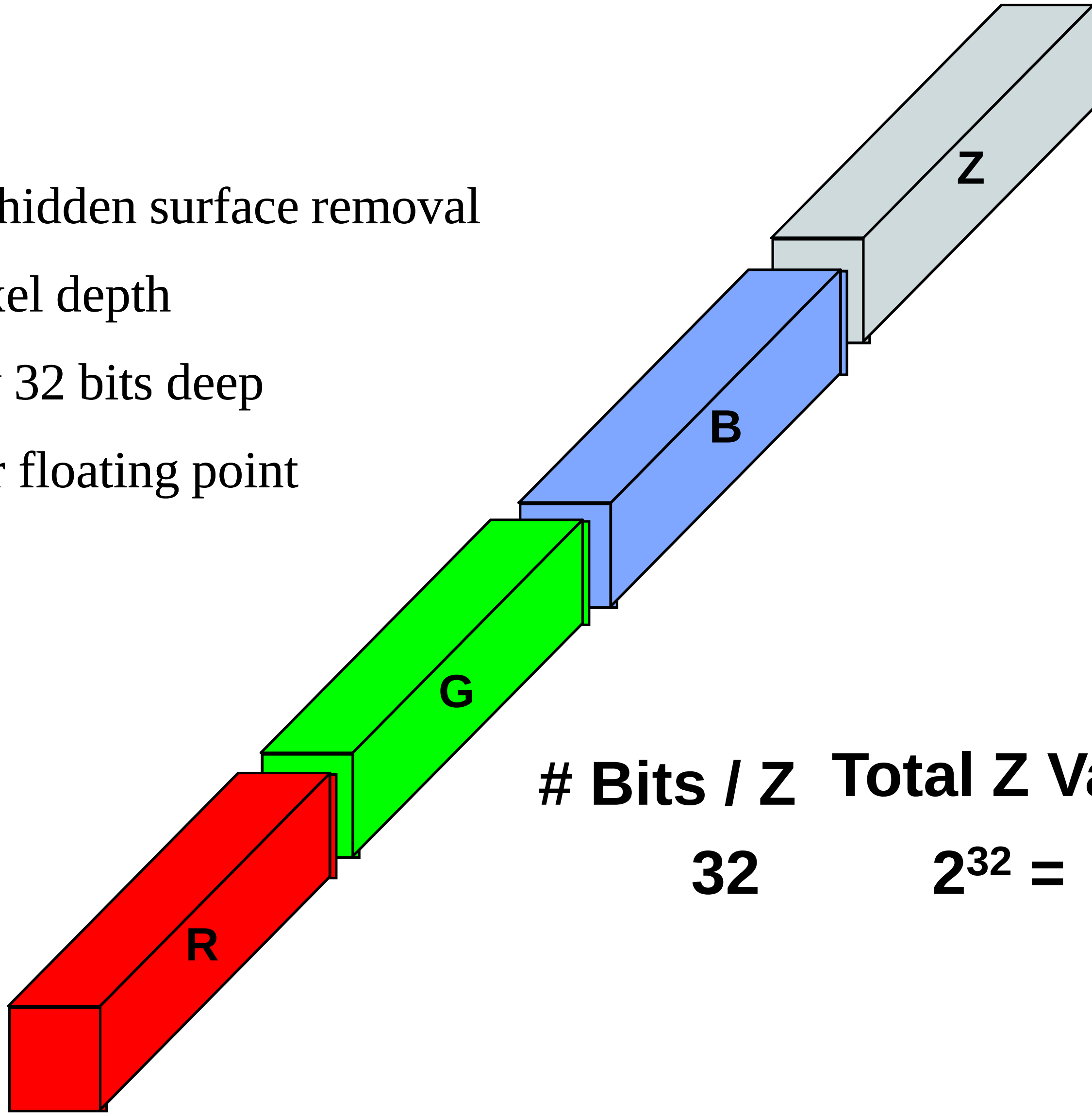


$$Color = \alpha C_1 + (1-\alpha) C_2$$

$$0.0 \leq \alpha \leq 1.0$$

The Framebuffer

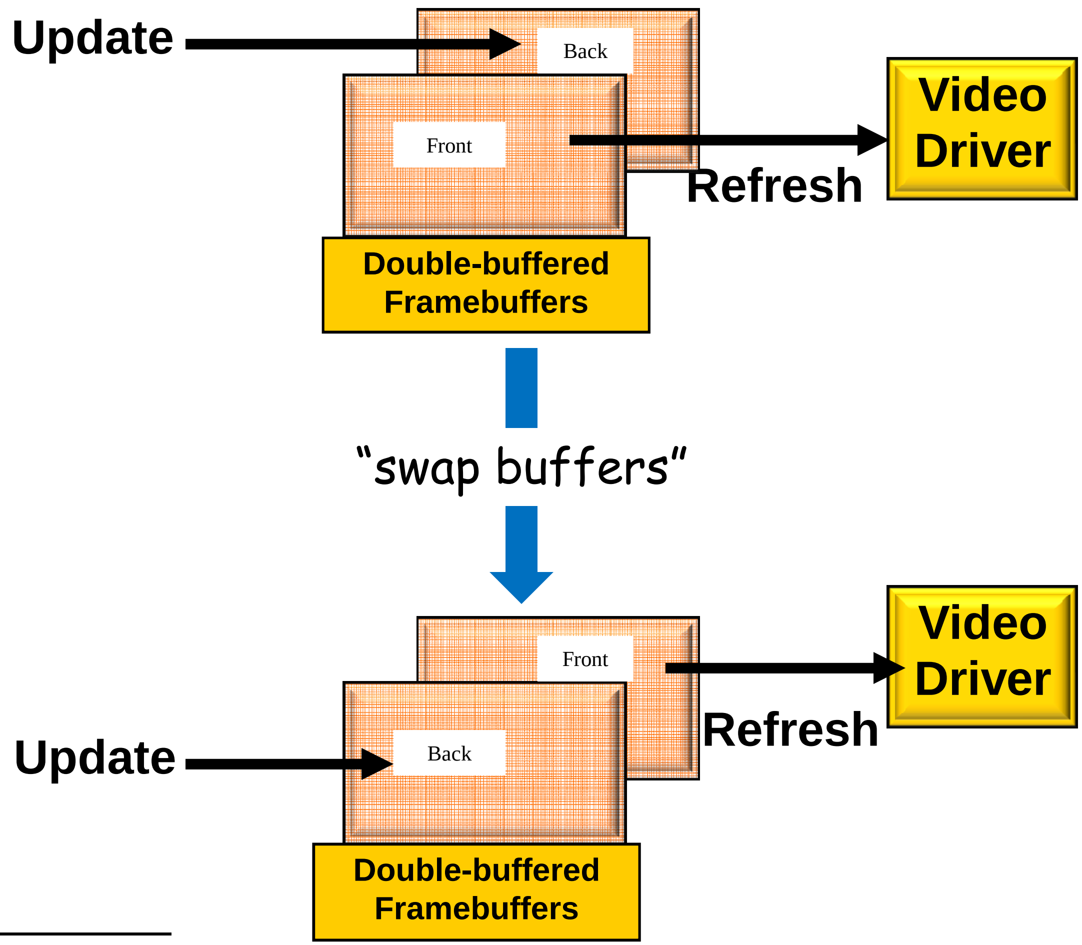
- ***Z-buffer***
  - Used for hidden surface removal
  - Holds pixel depth
  - Typically 32 bits deep
  - Integer or floating point



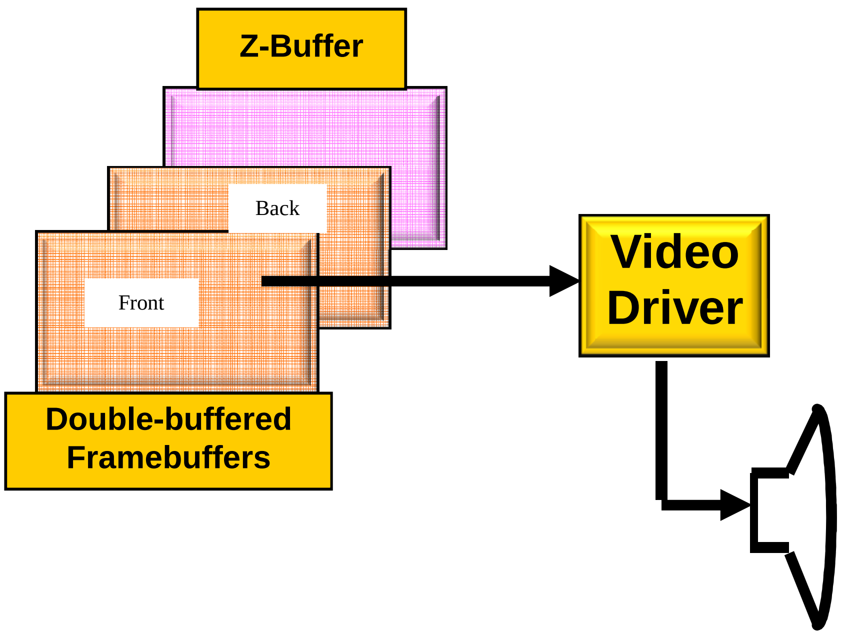
# Bits / Z	Total Z Values:
32	2^{32} = 4 B

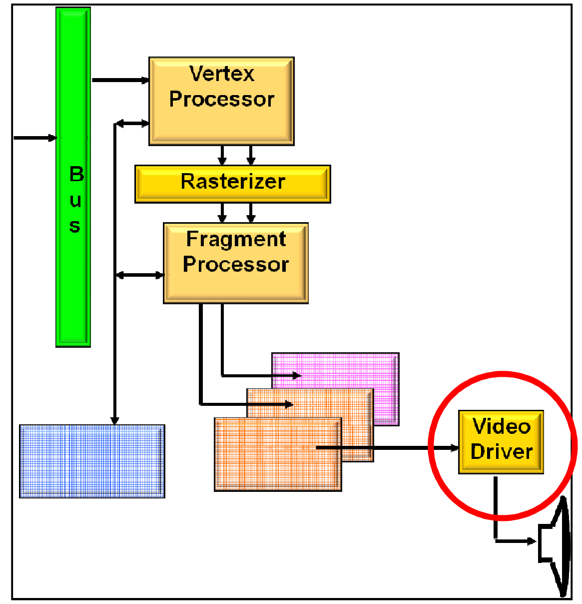
The Framebuffer

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



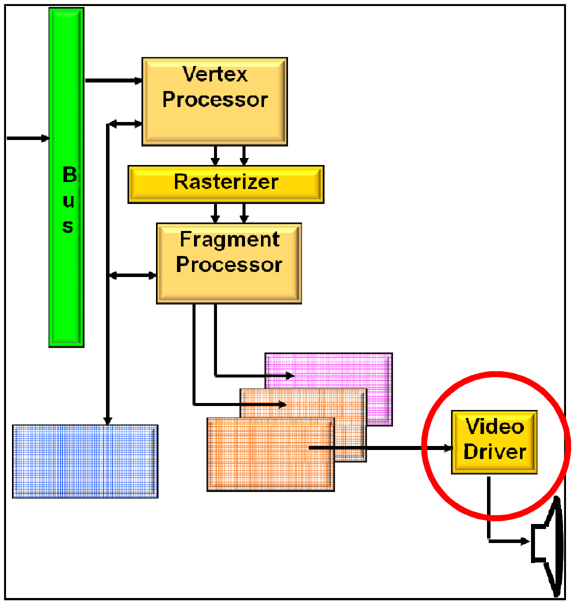
The Video Driver



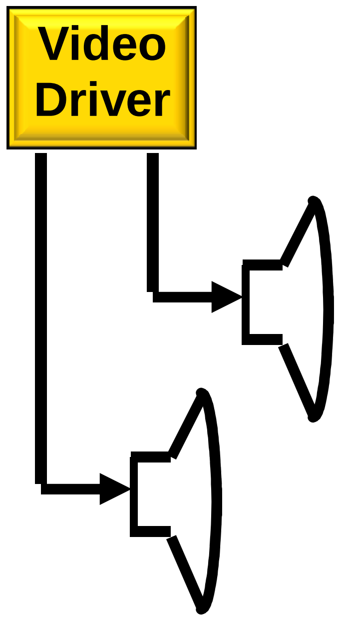


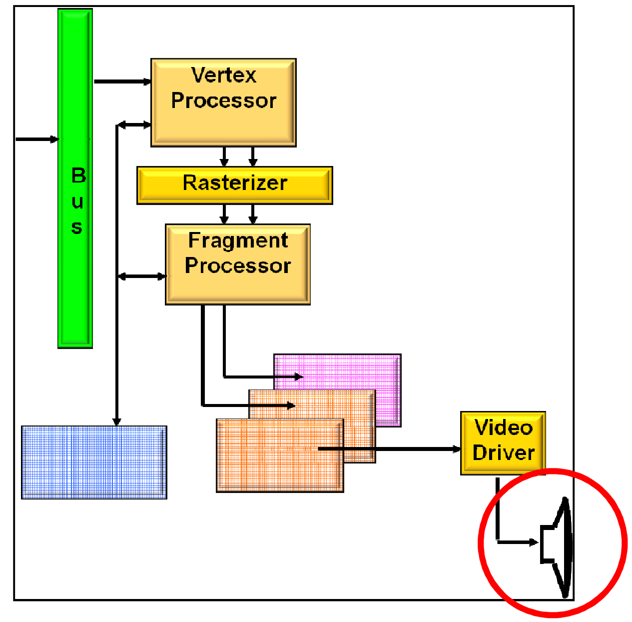
The Video Driver

- 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



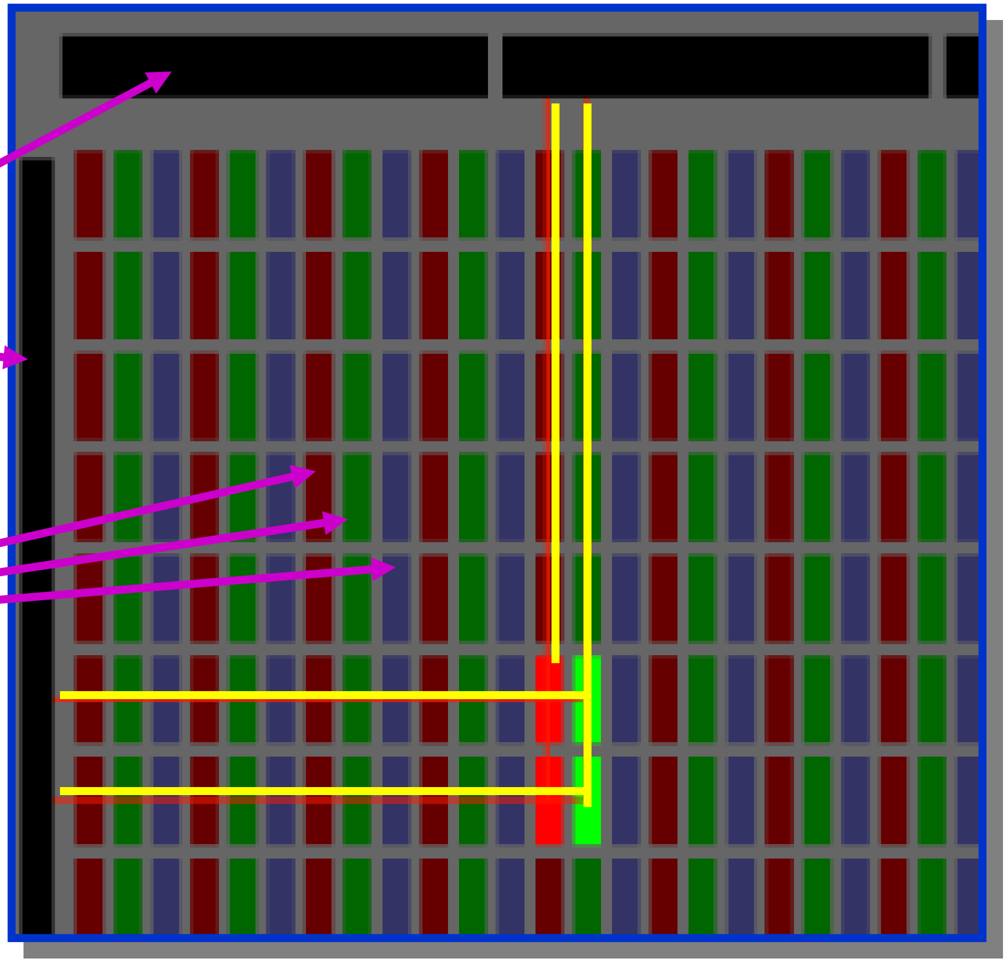
The Computer Graphics Monitor(s)





Displaying Color on a Computer Graphics LCD Monitor

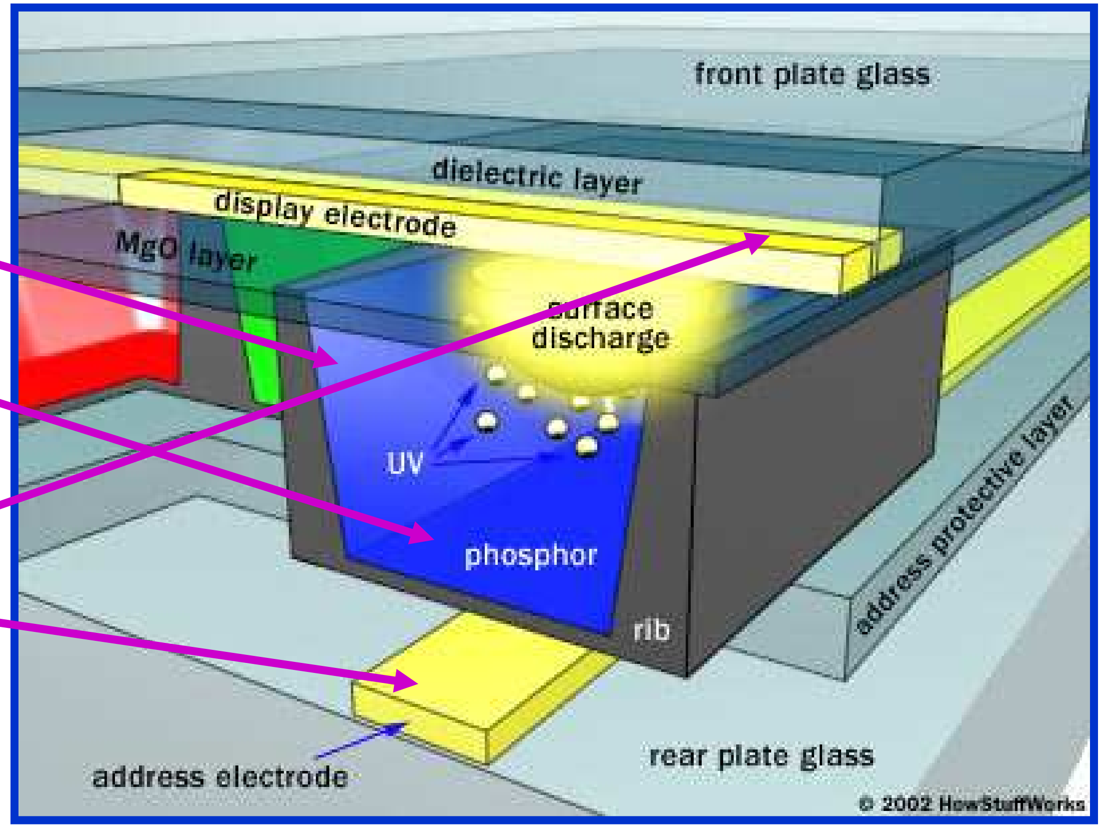
- Grid of electrodes
- Color filters



Source: http://electronics.howstuffworks.com

Displaying Color on a Plasma Monitor

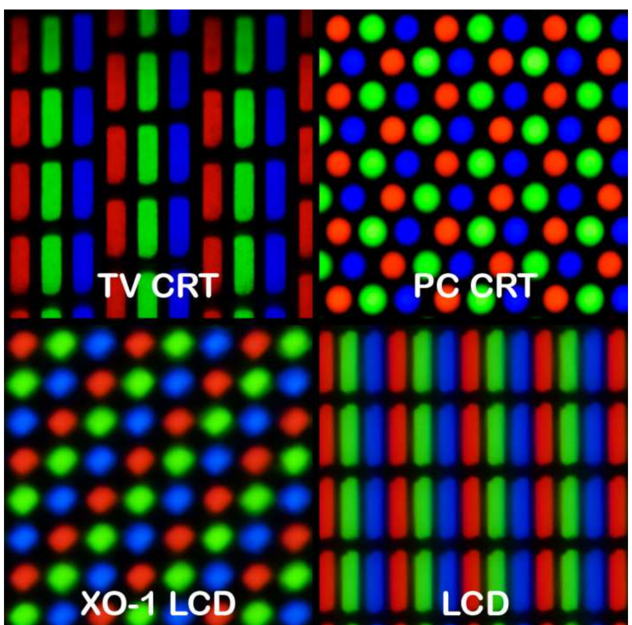
- **Gas cell**
- **Phosphor**
- **Grid of electrodes**



http://electronics.howstuffworks.com

Display Resolution

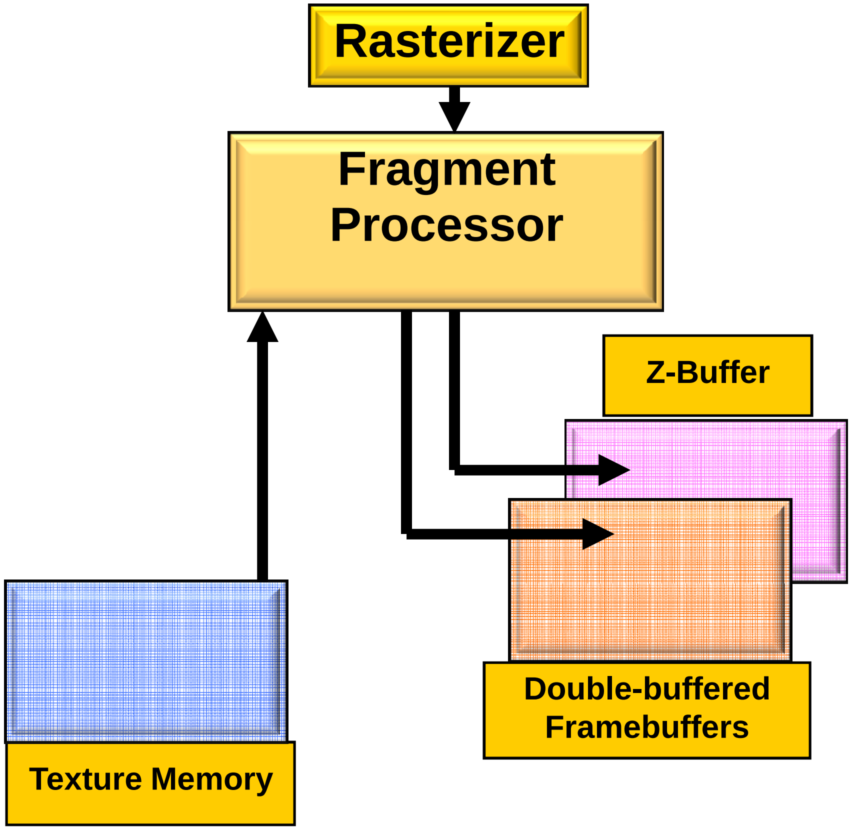
- ***Pixel*** resolutions (1280x1024, 1600x1200, 1920x1152 are common on the desktop)
- Screen size (13", 16", 19", 21" are common)
- Human acuity: 1 arc-minute is achieved by viewing a 19" monitor with 1280x1024 resolution from a distance of ~40 inches

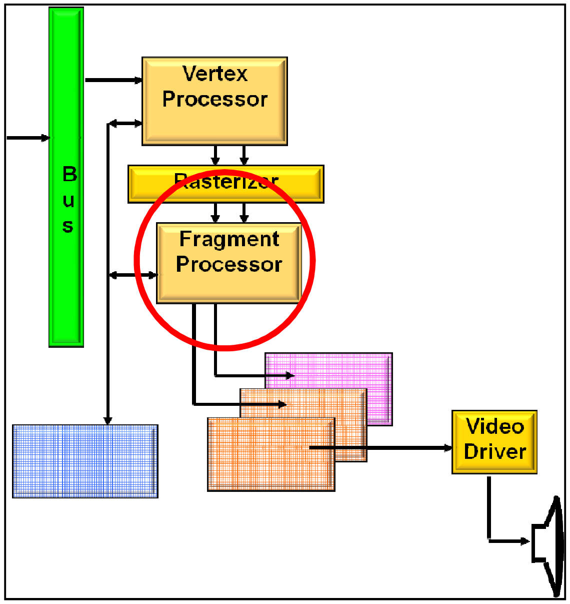


Mobile devices have set this back.

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

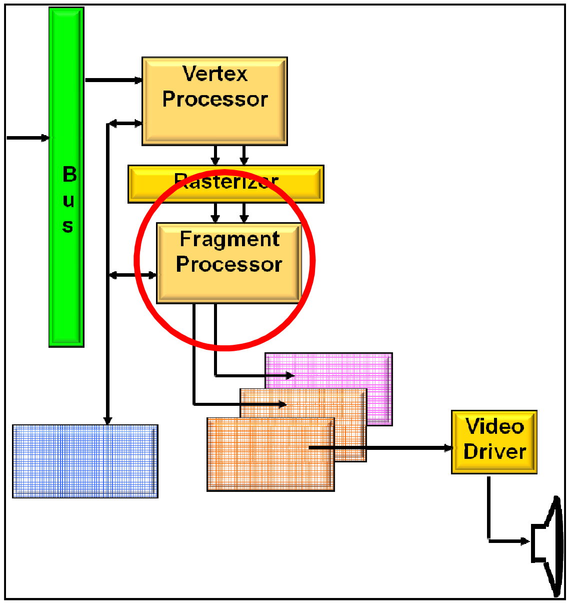
The Fragment Processor



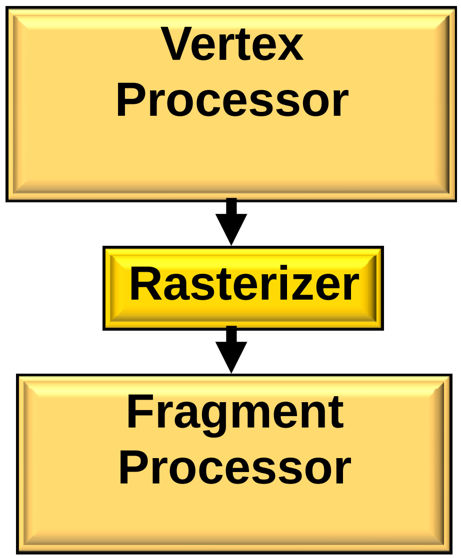


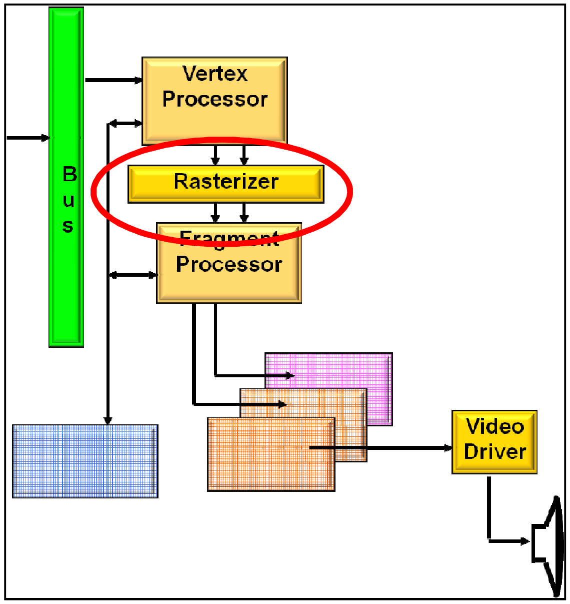
The Fragment Processor

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



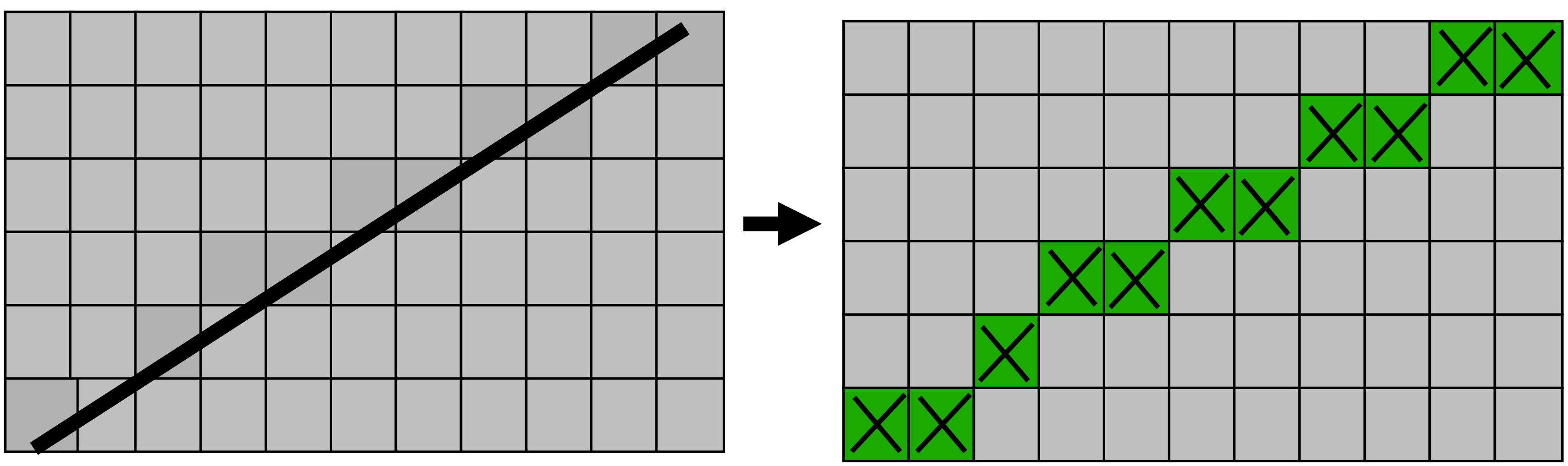
The Rasterizer





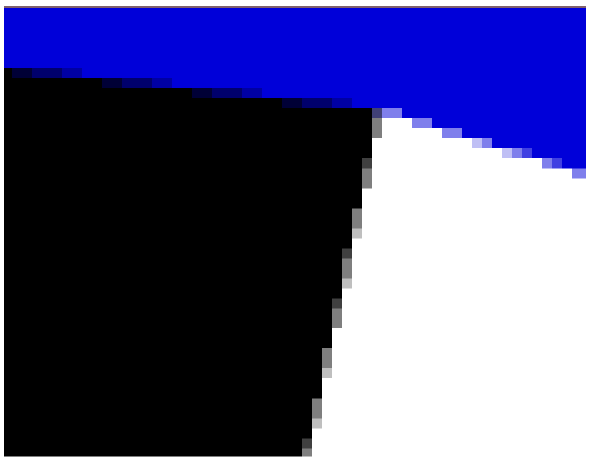
Rasterization

- Turn screen space vertex coordinates into pixels that make up lines and polygons
- A great place for custom electronics
- Anti-aliasing is often built-in

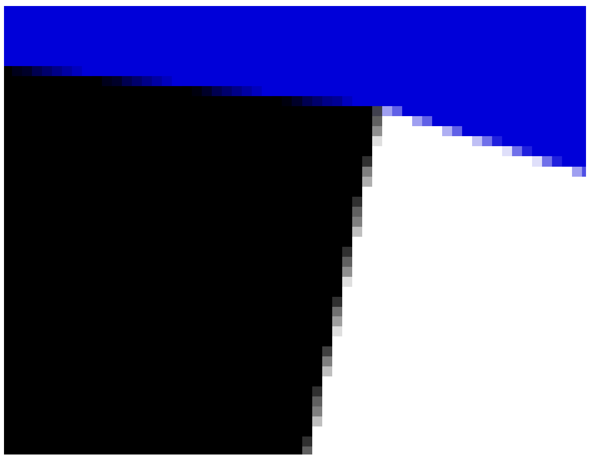


Anti-aliasing is Implemented by Oversampling within Each Pixel

No AA



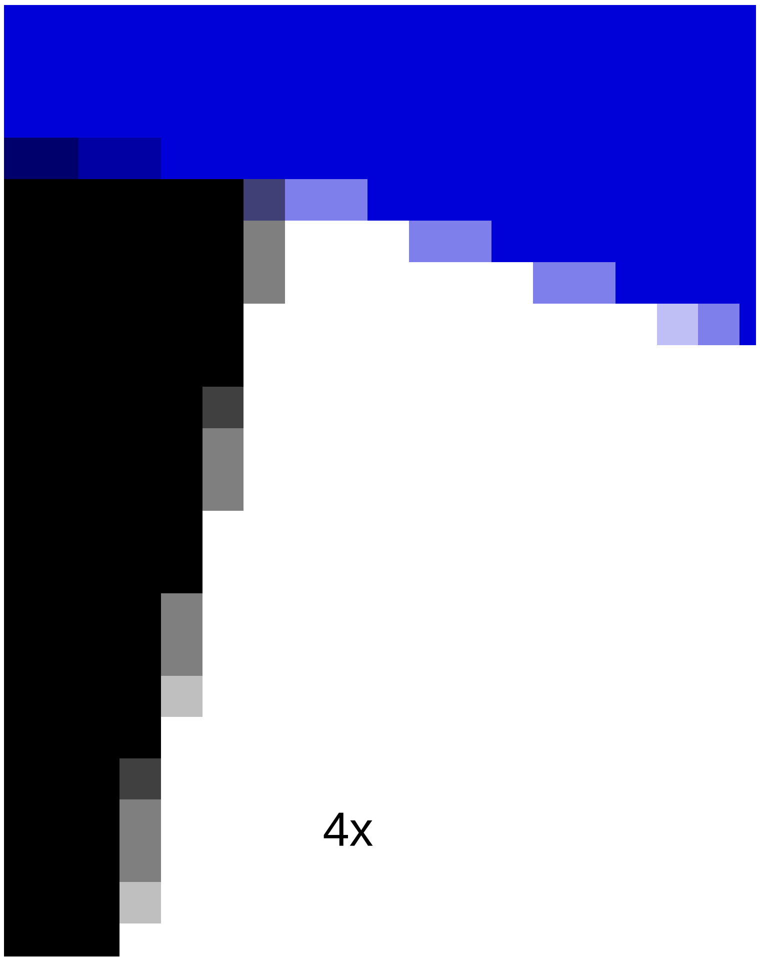
4x

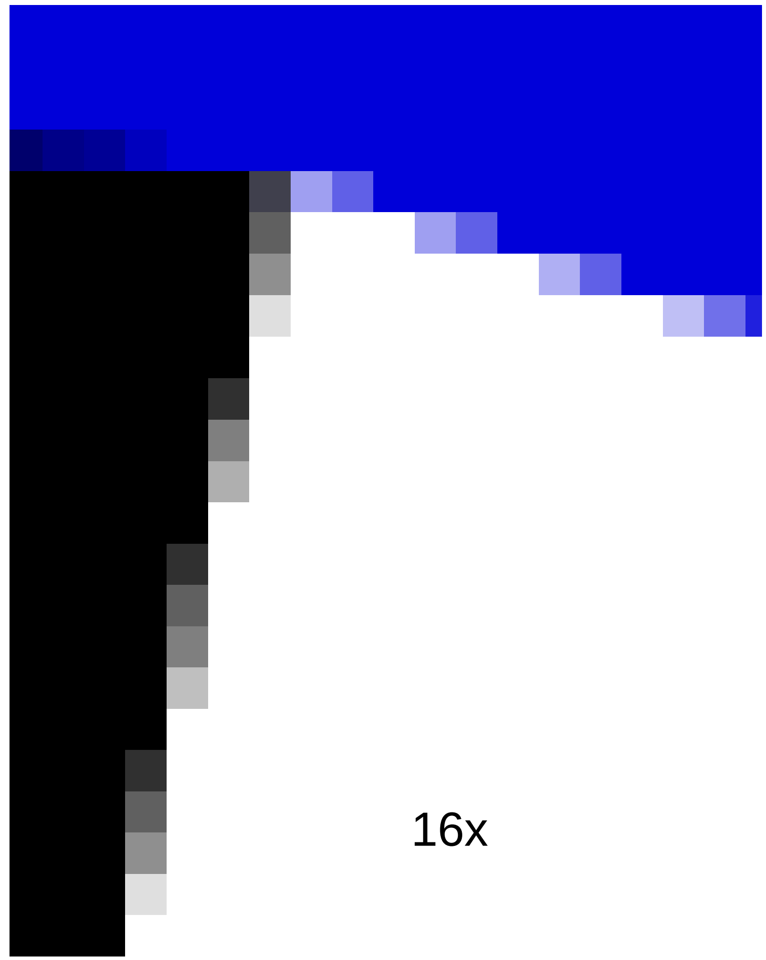


16x

NVIDIA

Anti-aliasing is Implemented by Oversampling within Each Pixel

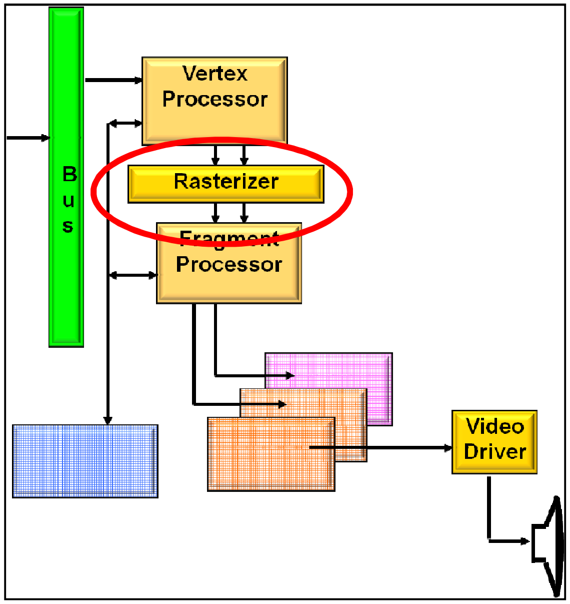




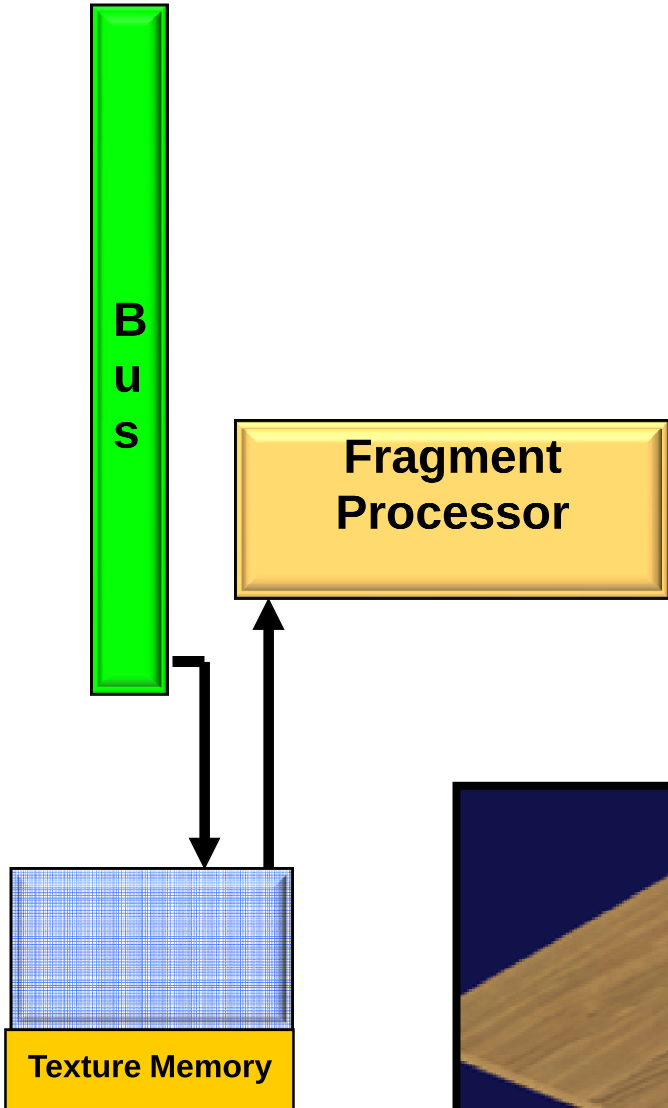
NVIDIA

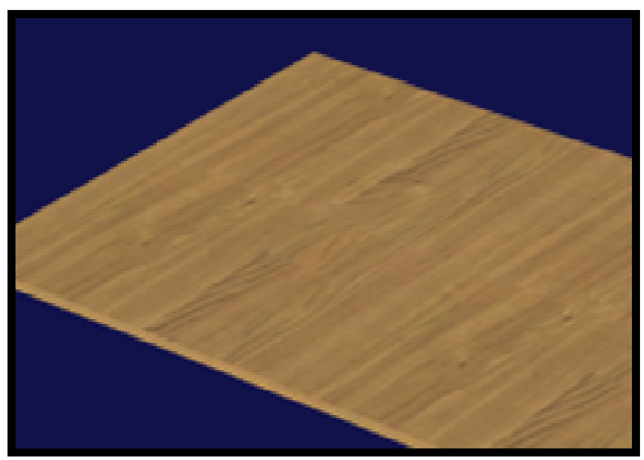
Rasterizers Can Interpolate:

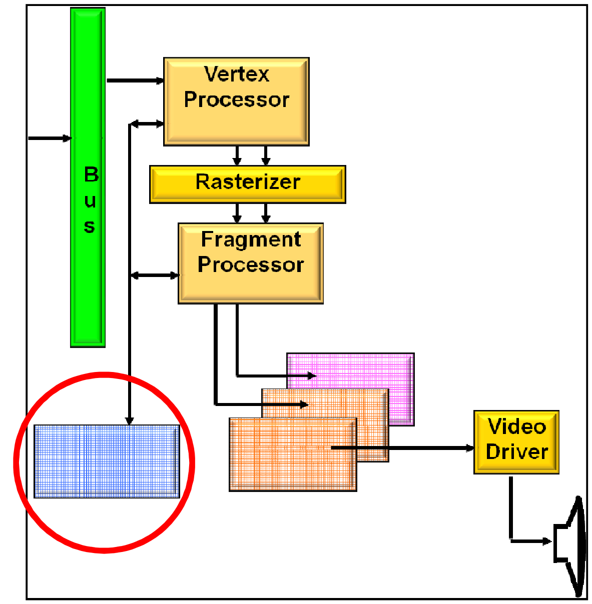
- X and Y
- Red-green-blue values
- Alpha values
- Z values
- Intensities
- Surface normals
- Texture coordinates
- Custom values given by the shaders



Texture Mapping

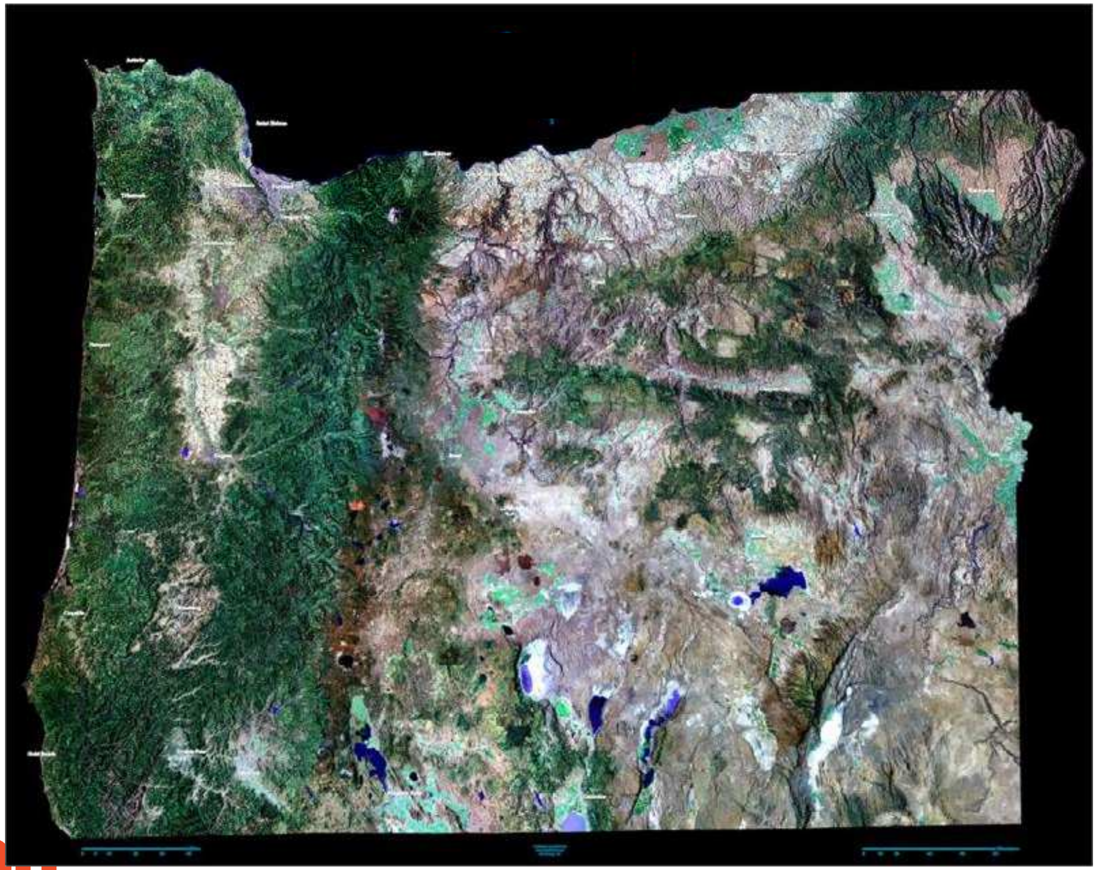




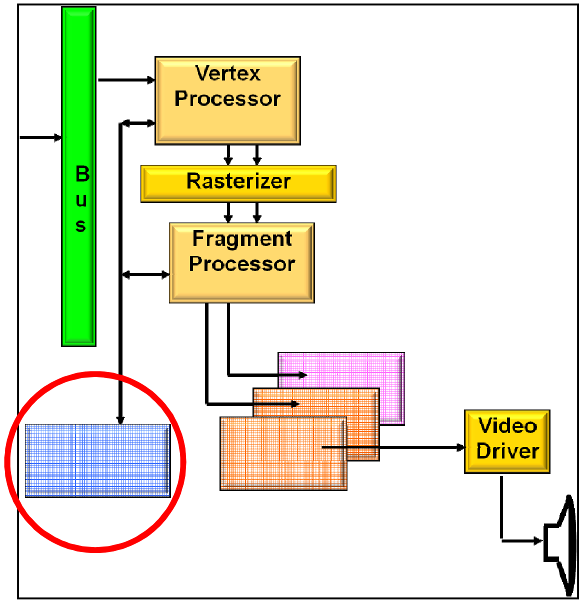


Texture Mapping

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

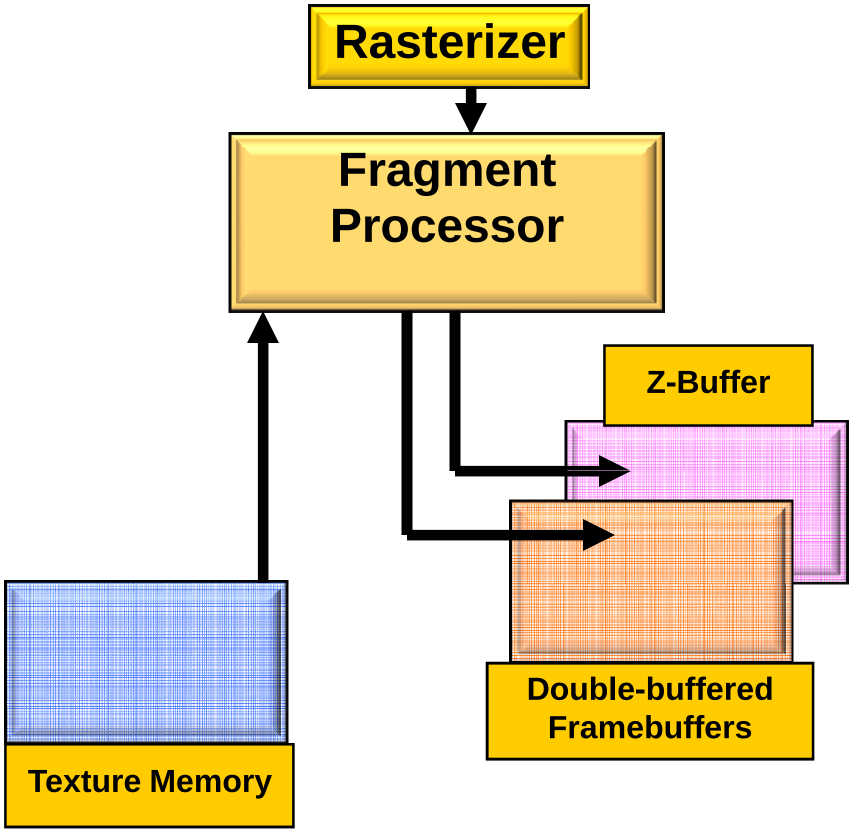


http://2ols.com

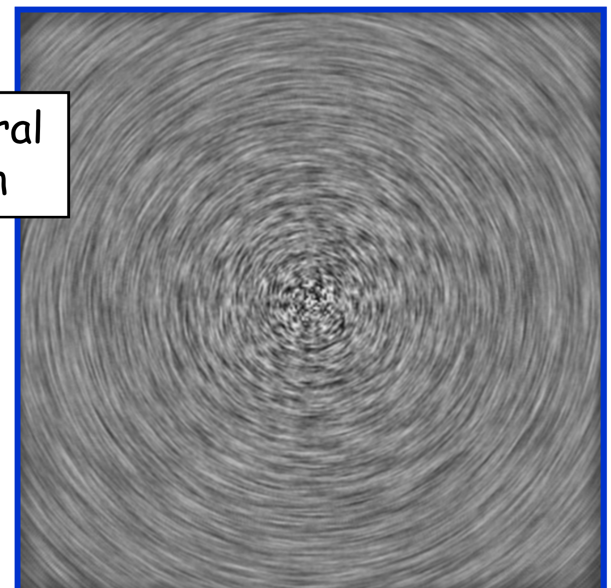


Something Cool:

Write-Your-Own Fragment-Processor Code



Bump Mapping

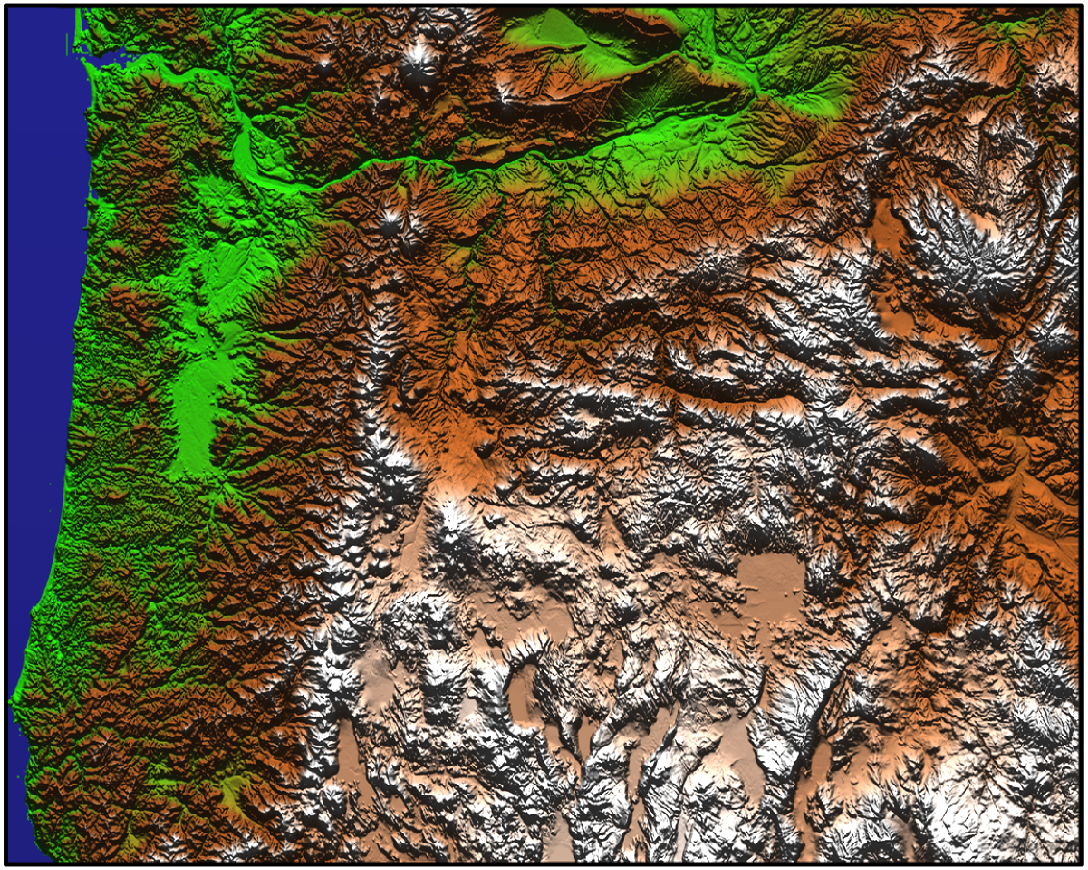


Line Integral Convolution

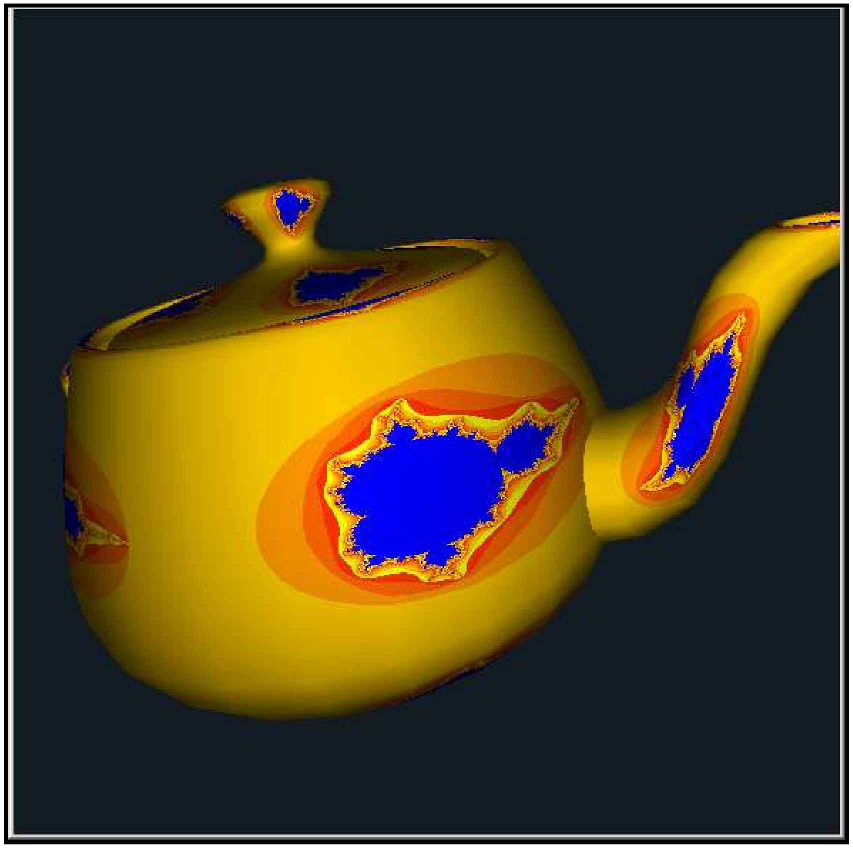
Referred to as:
Pixel Shaders or Fragment Shaders

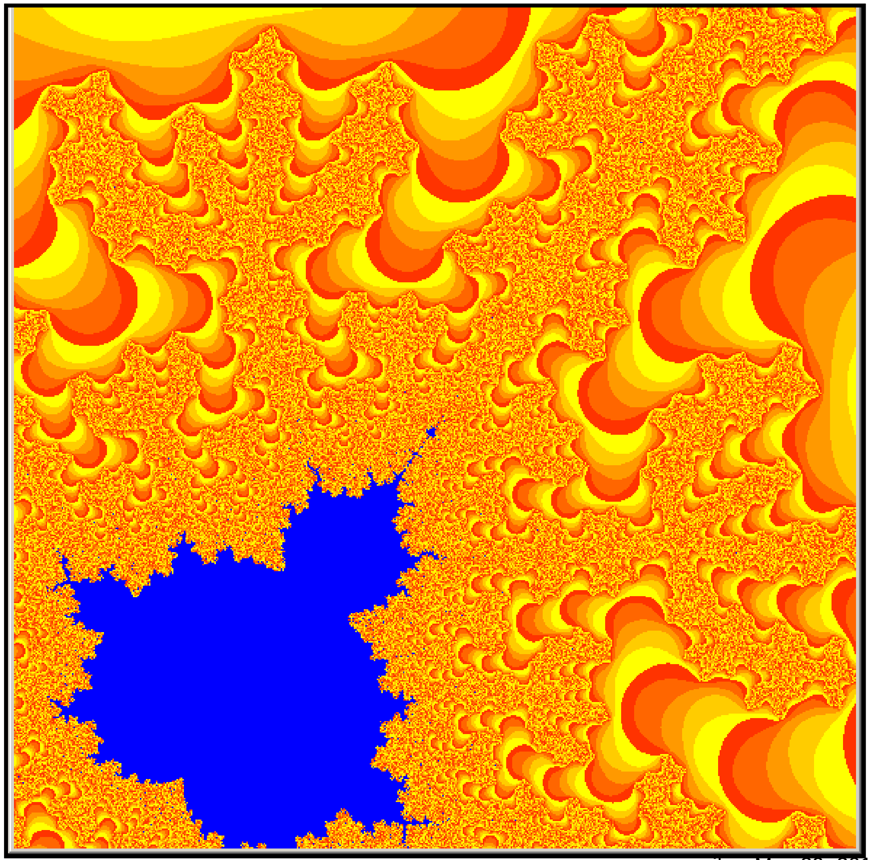
Procedural Texture Mapping

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

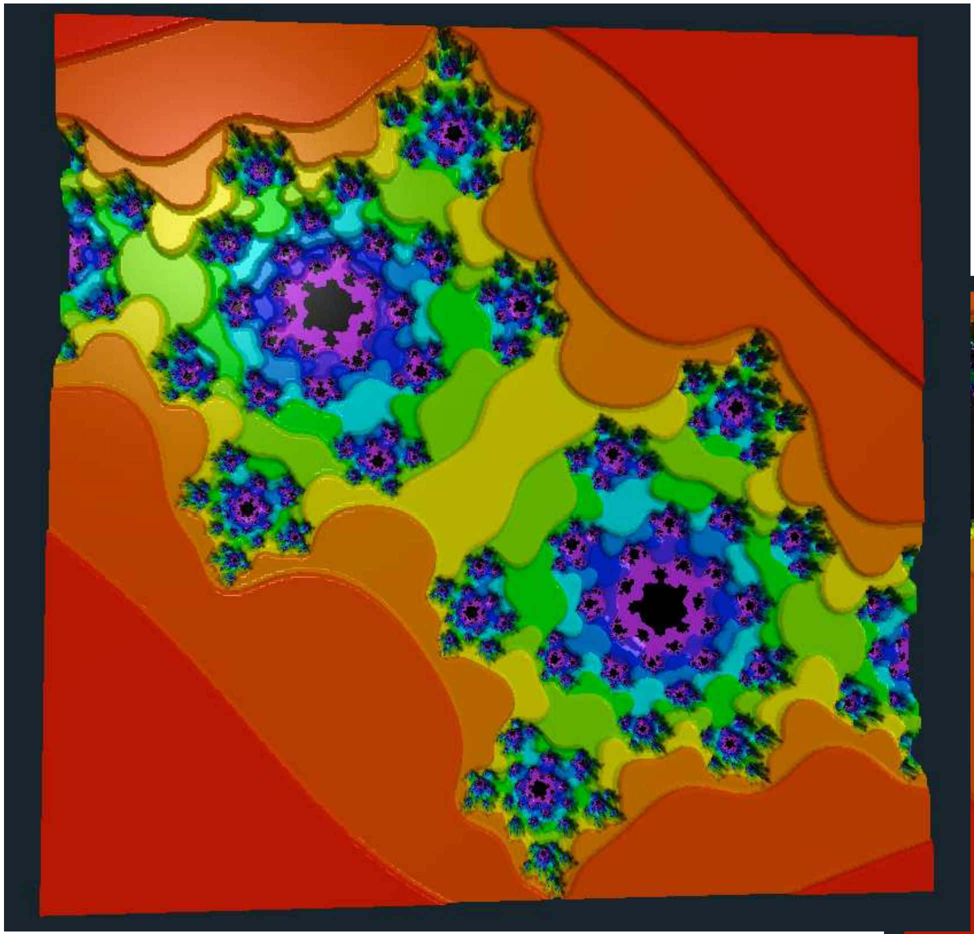


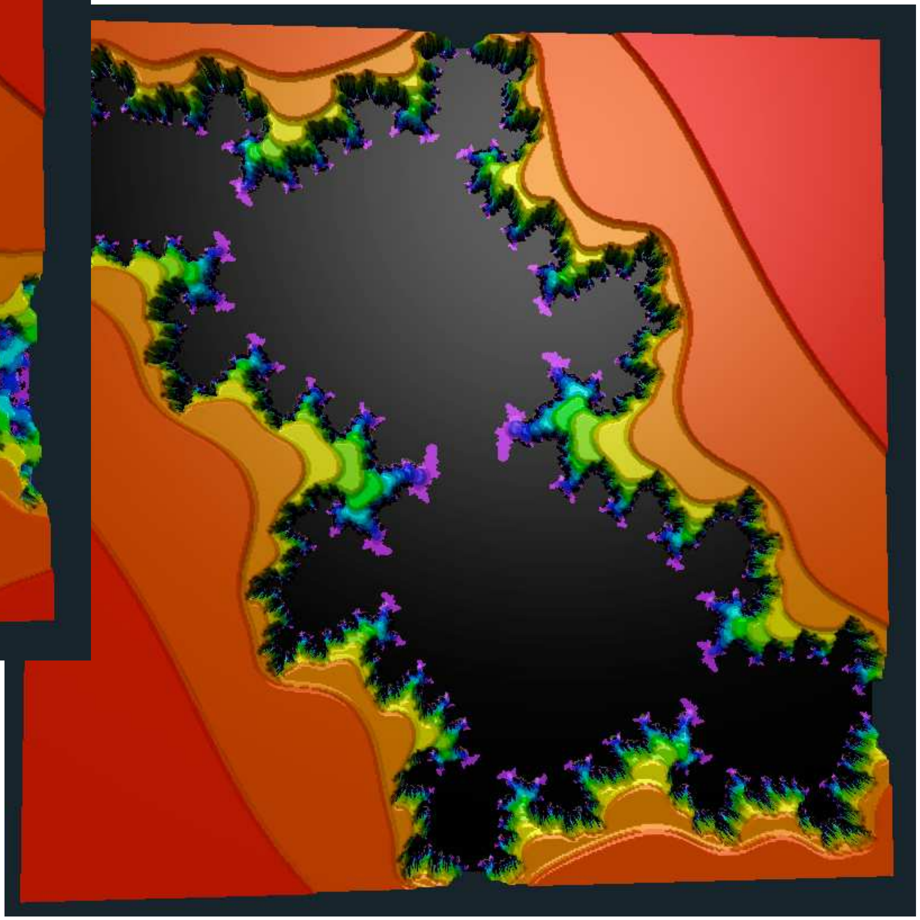
Procedural Textures





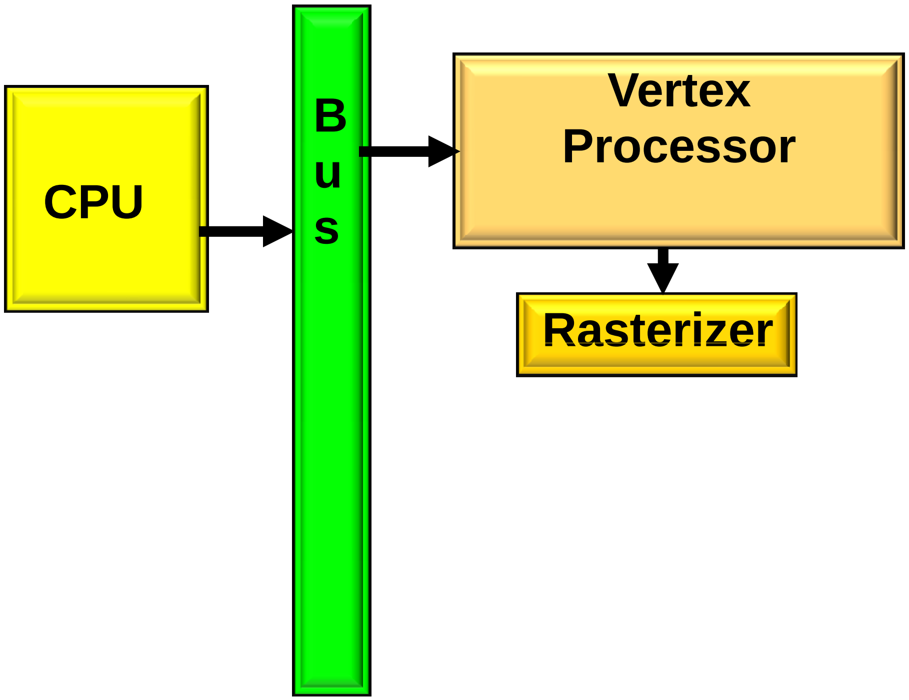
Procedural Textures

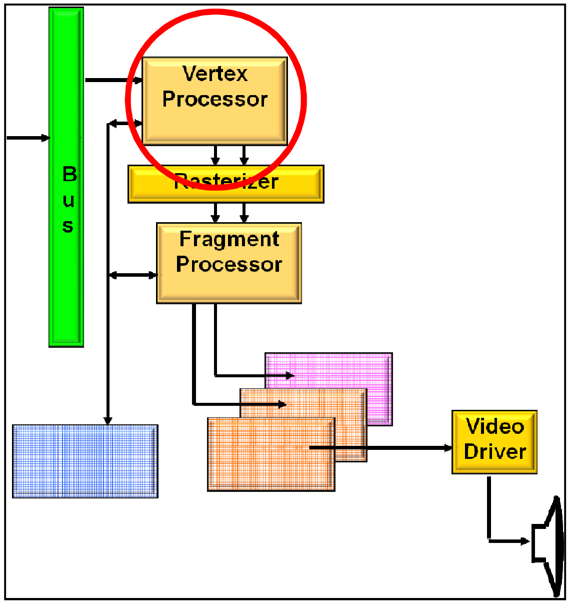




Josie Hunter

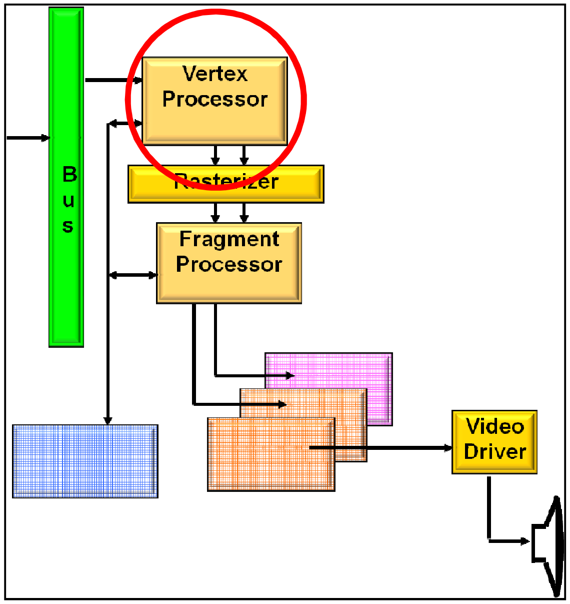
The Vertex Processor





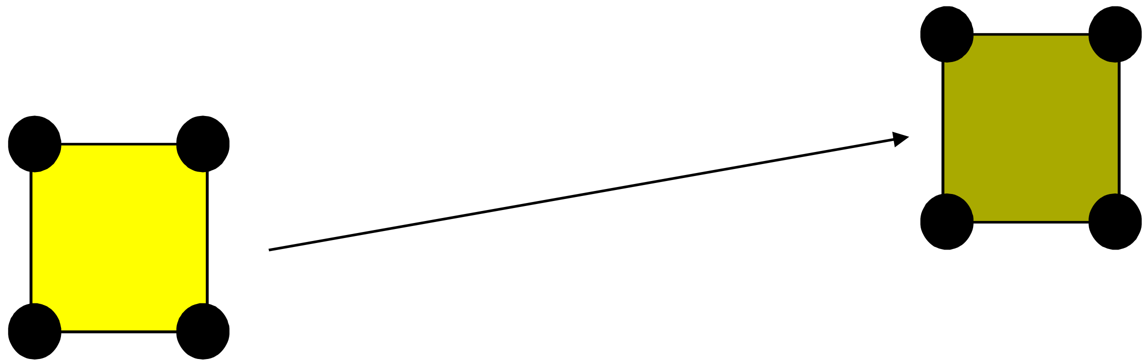
Vertex Processor

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

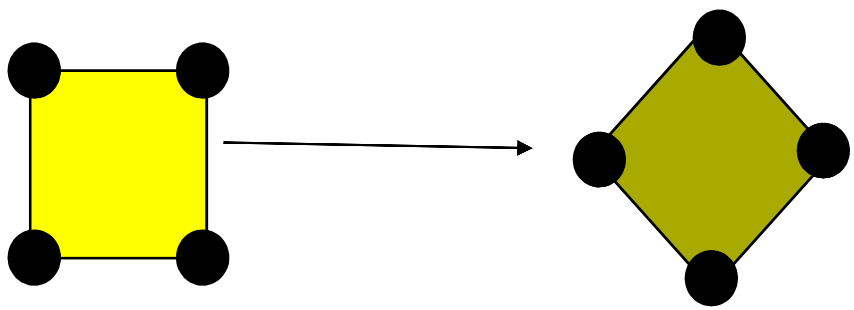


Vertex Processor: Transformations

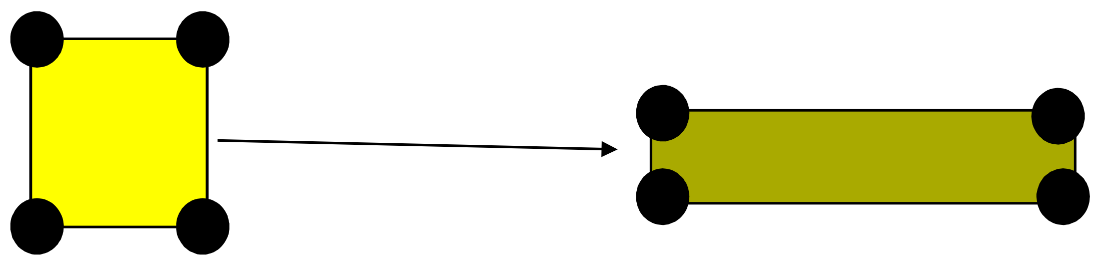
- Used to correctly place objects in the scene
- Translation



- Rotation



- Scaling

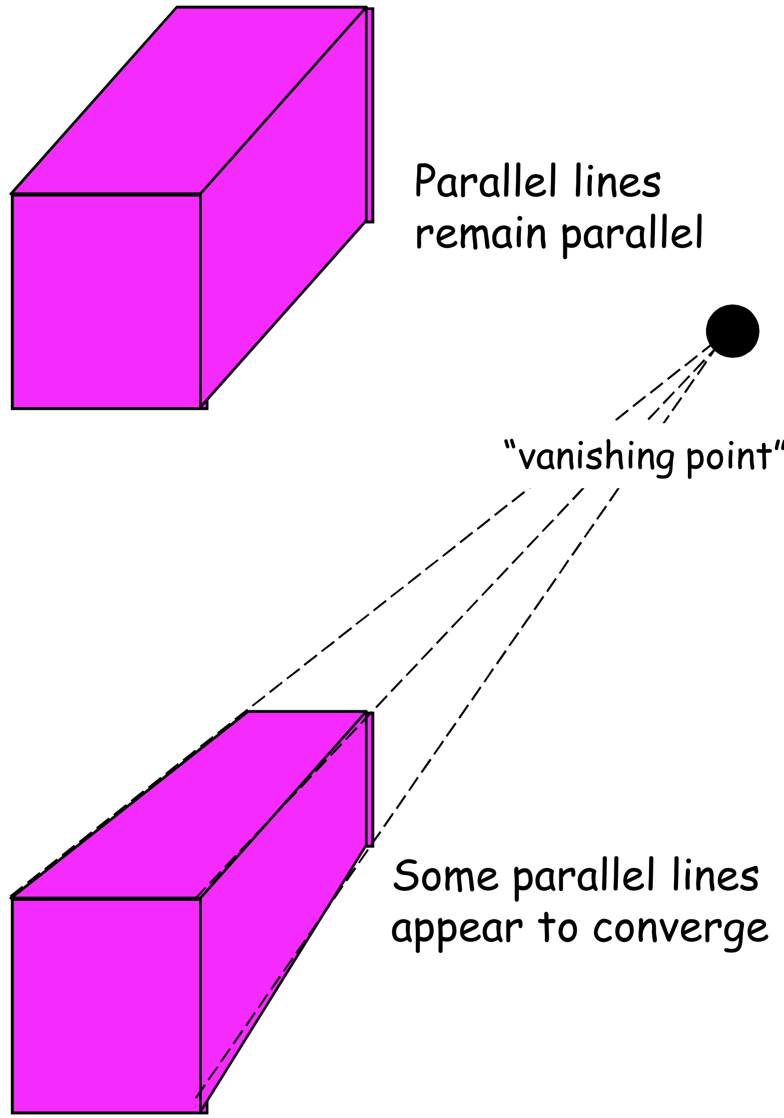


Vertex Processor: Windowing and Clipping

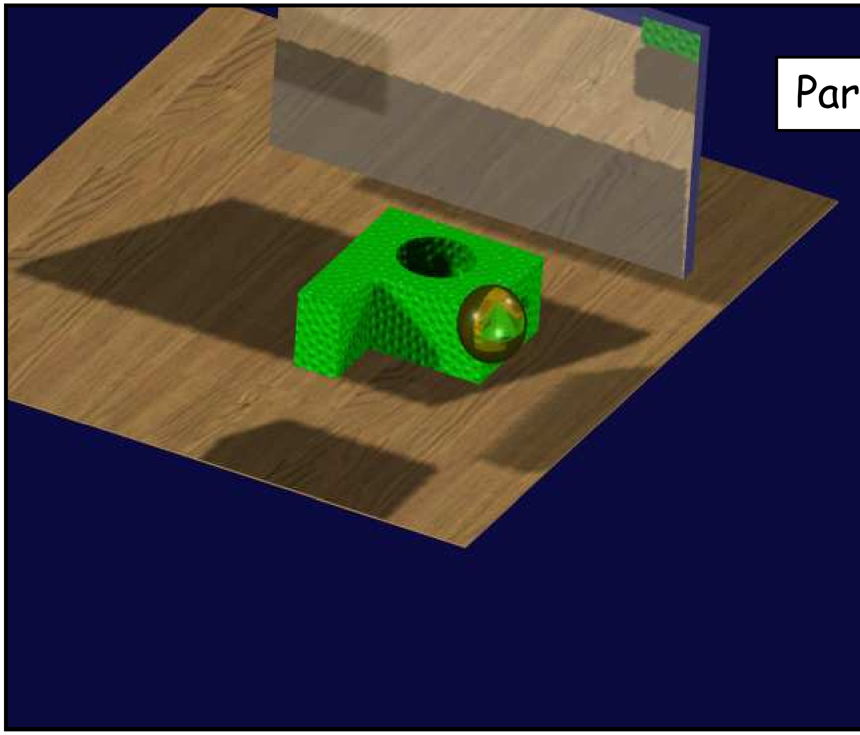
- Declare which portion of the 3D universe you are interested in viewing
- This is called the ***view volume***
- Clip away everything that is outside the viewing volume

Vertex Processor: Projection

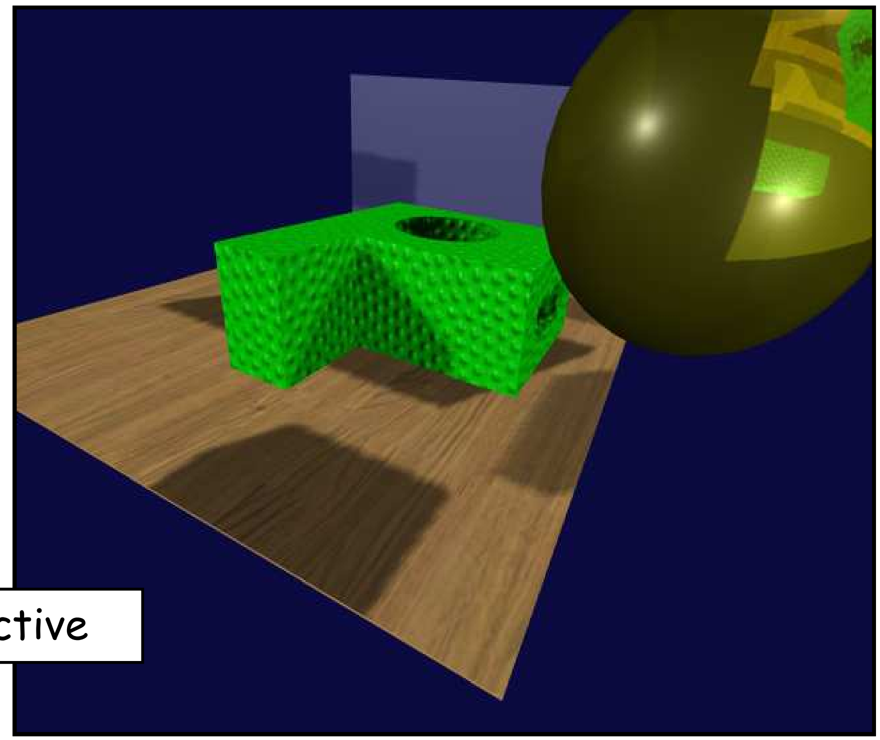
- **Turn 3D coordinates into 2D**
  - ***Parallel projection***
  - ***Perspective projection***



Vertex Processor: Projection

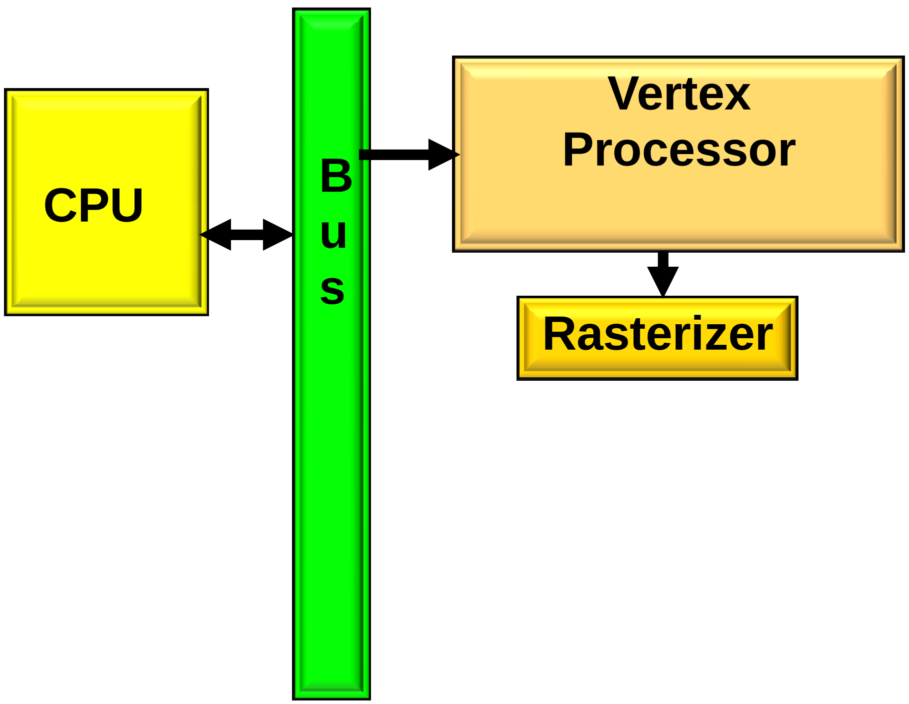


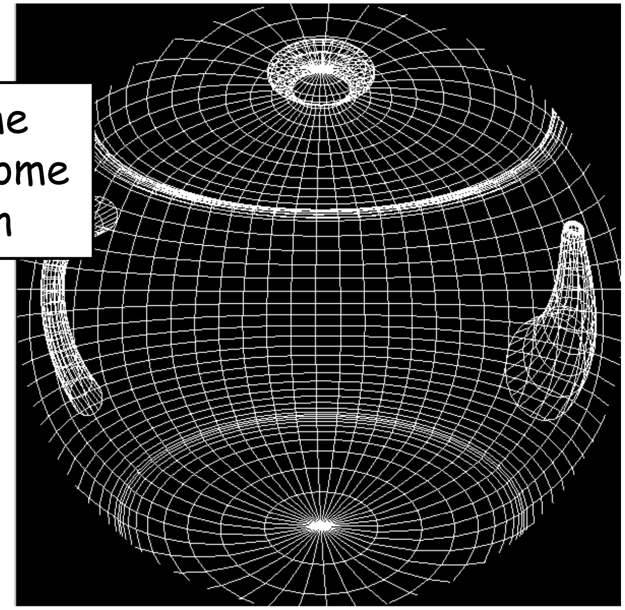
Parallel



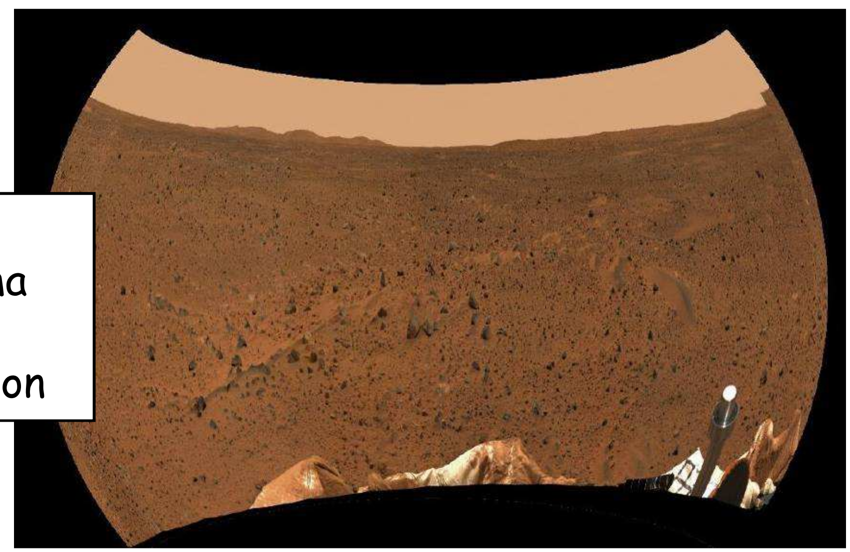
Perspective

Something Cool:
Write-Your-Own Vertex Code





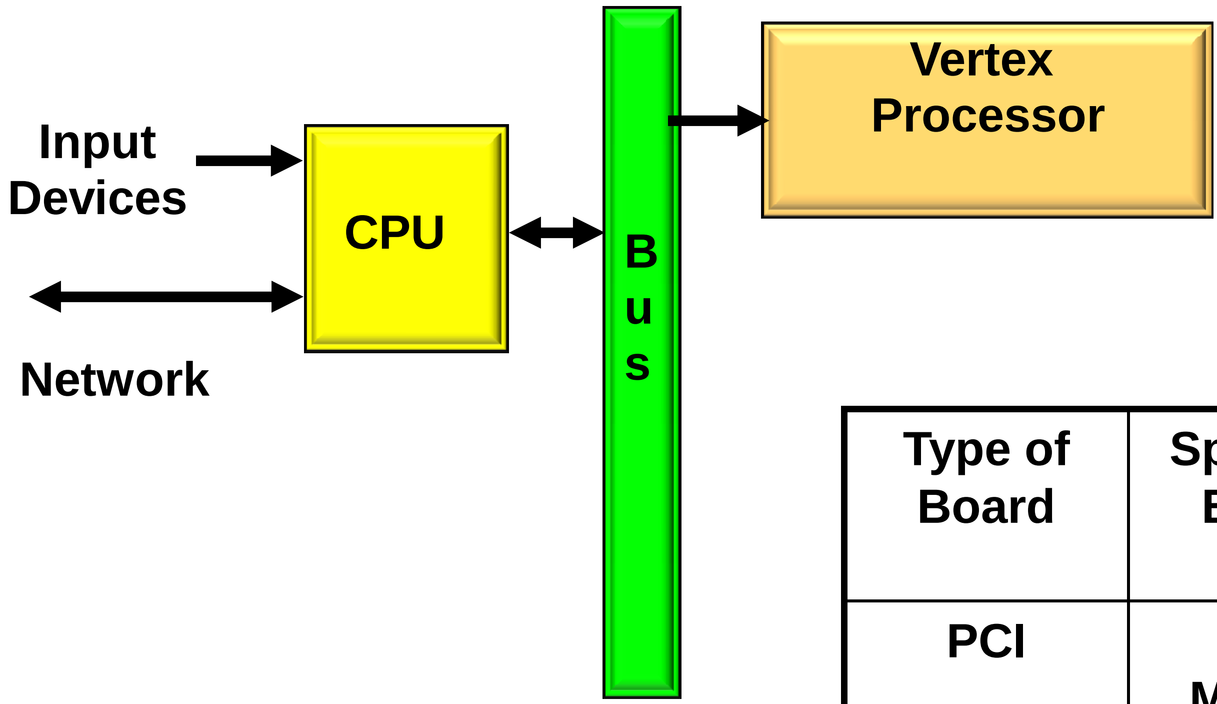
Wireframe Teapot Dome Projection



Mars Panorama Dome Projection

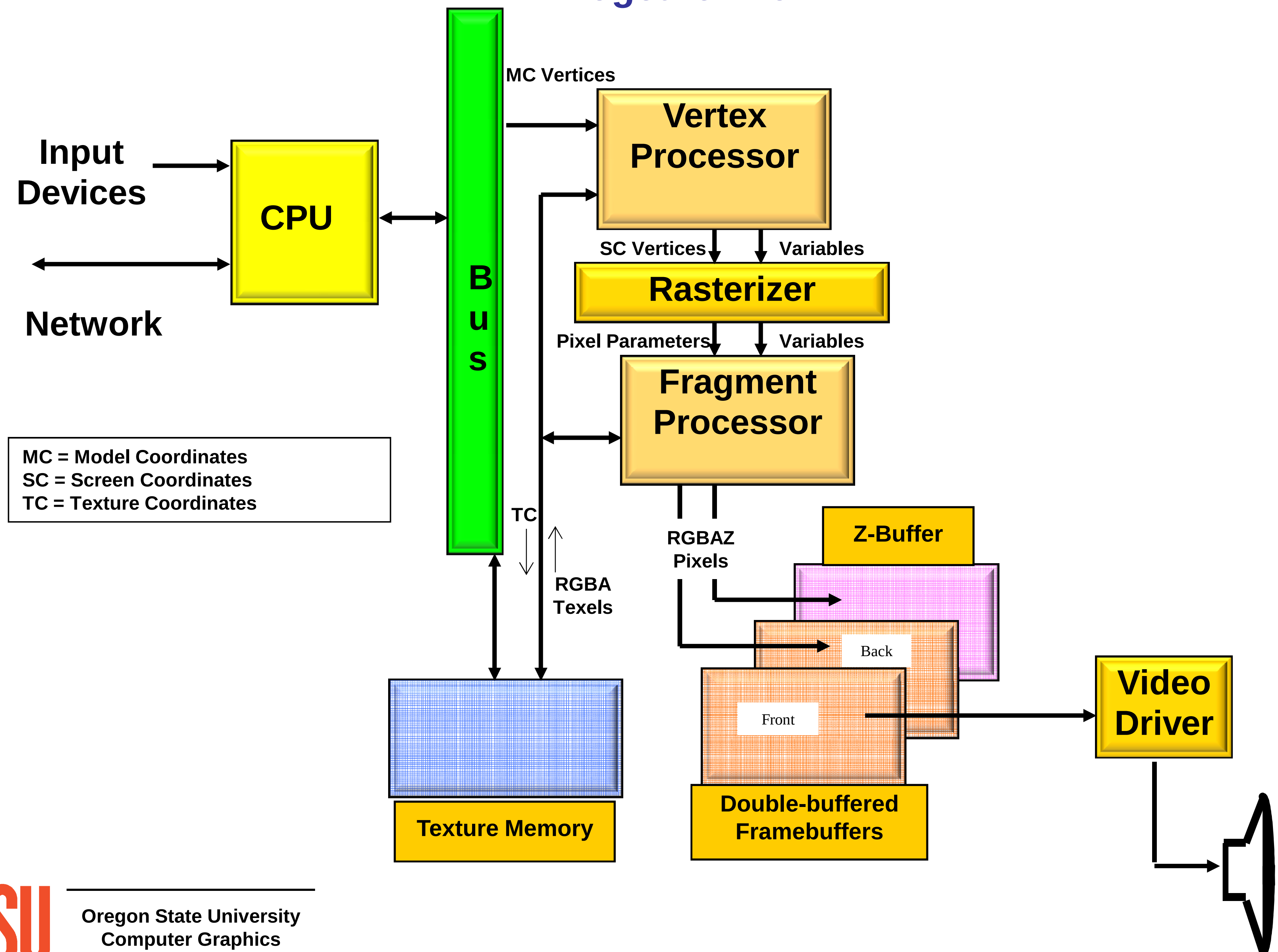
Referred to as:
Vertex Shaders

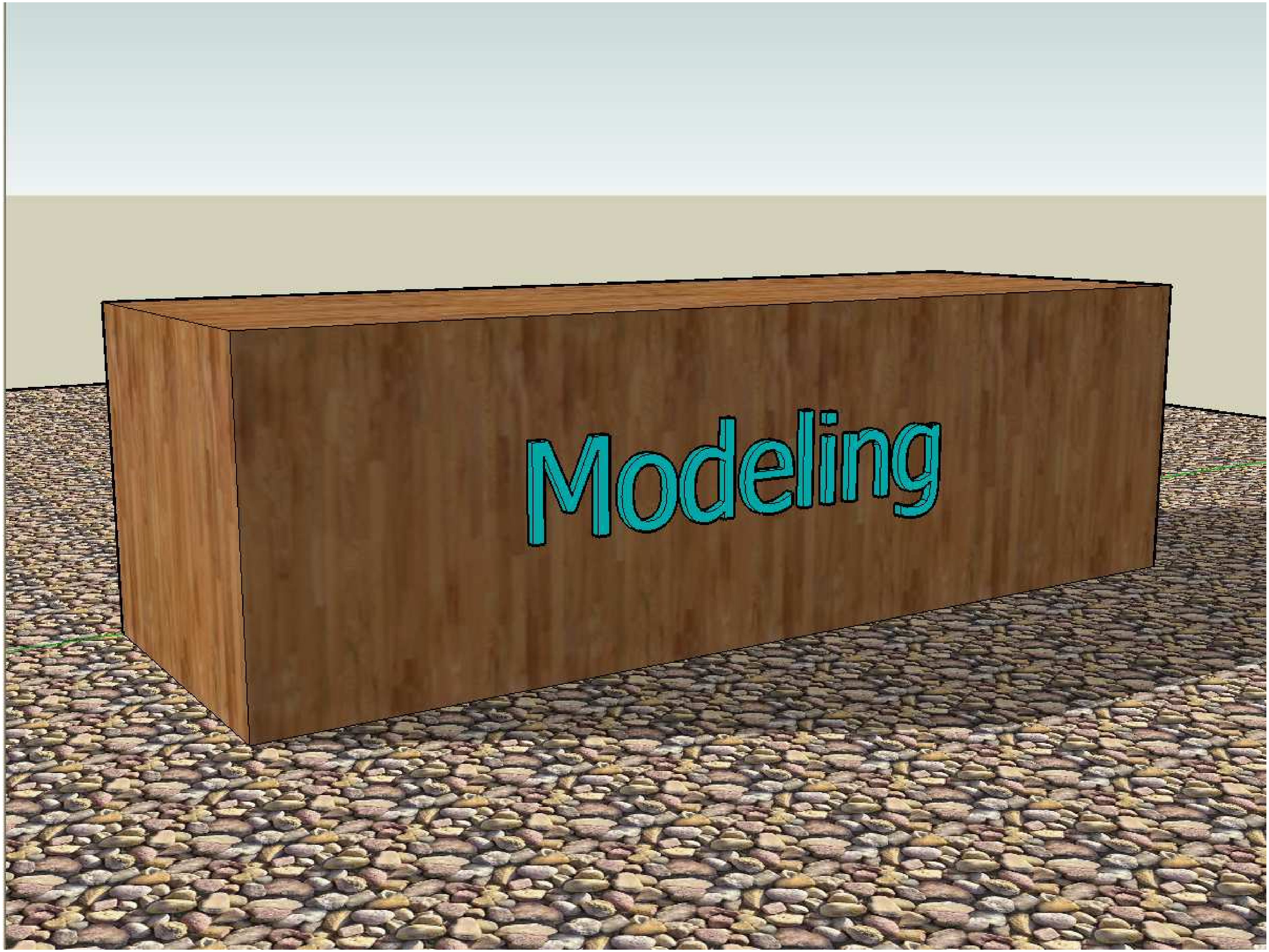
The CPU and Bus



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 !




Modeling

What is a Model?

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

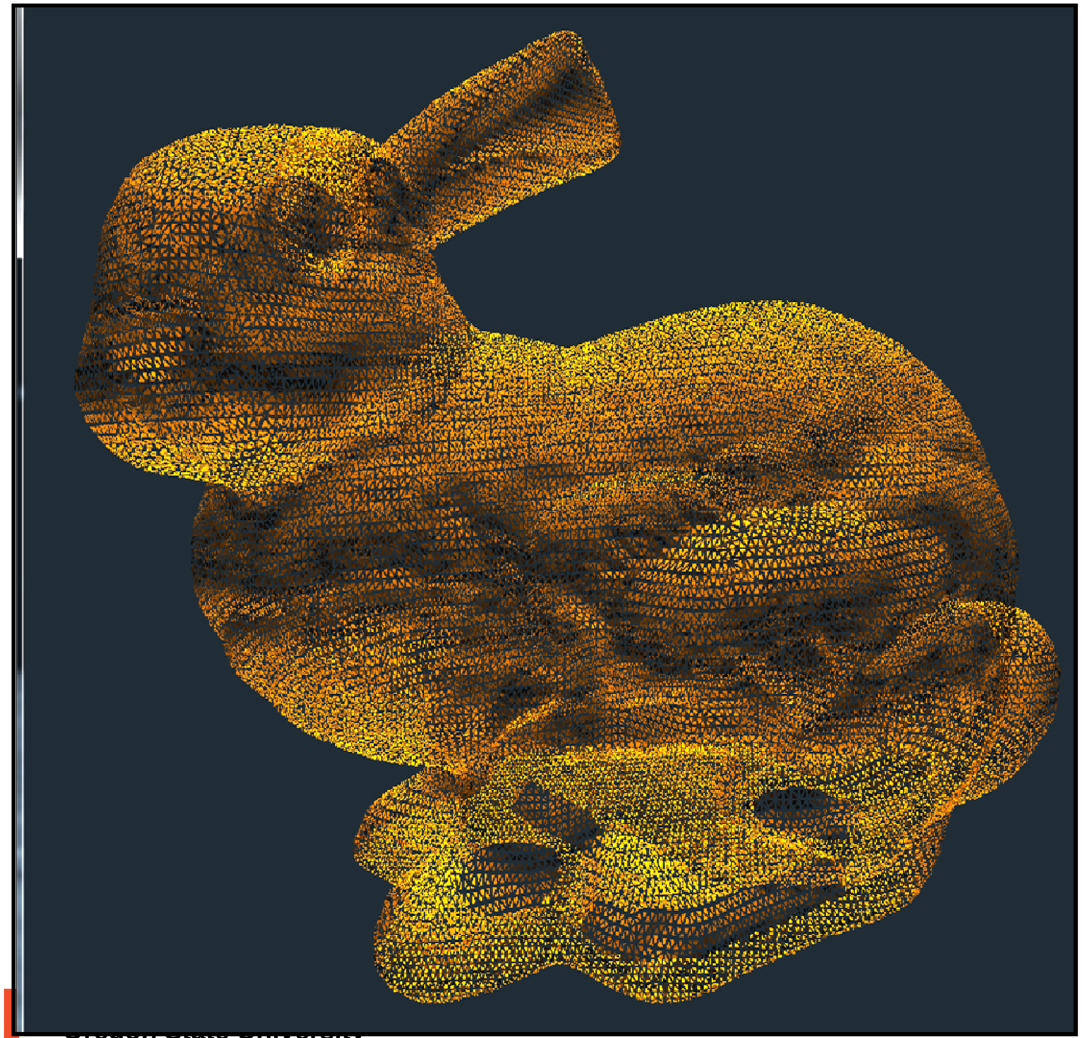
In computer graphics applications, what do we want to ask about B?

- 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

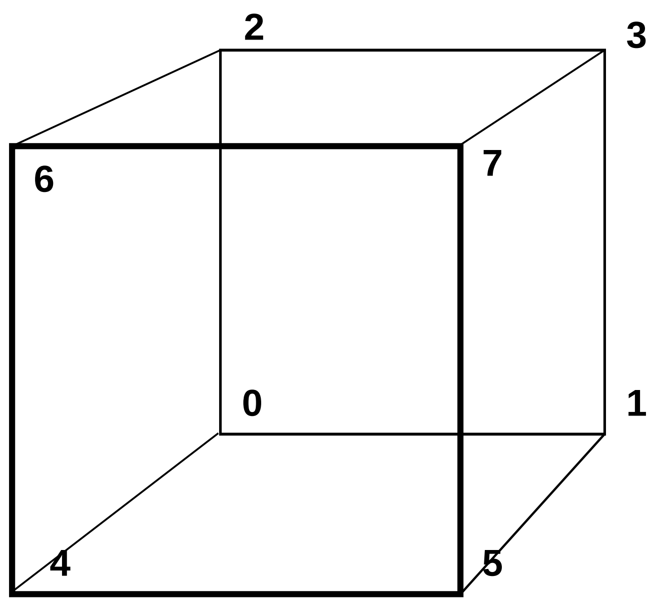
Explicitly Listing Geometry and Topology

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

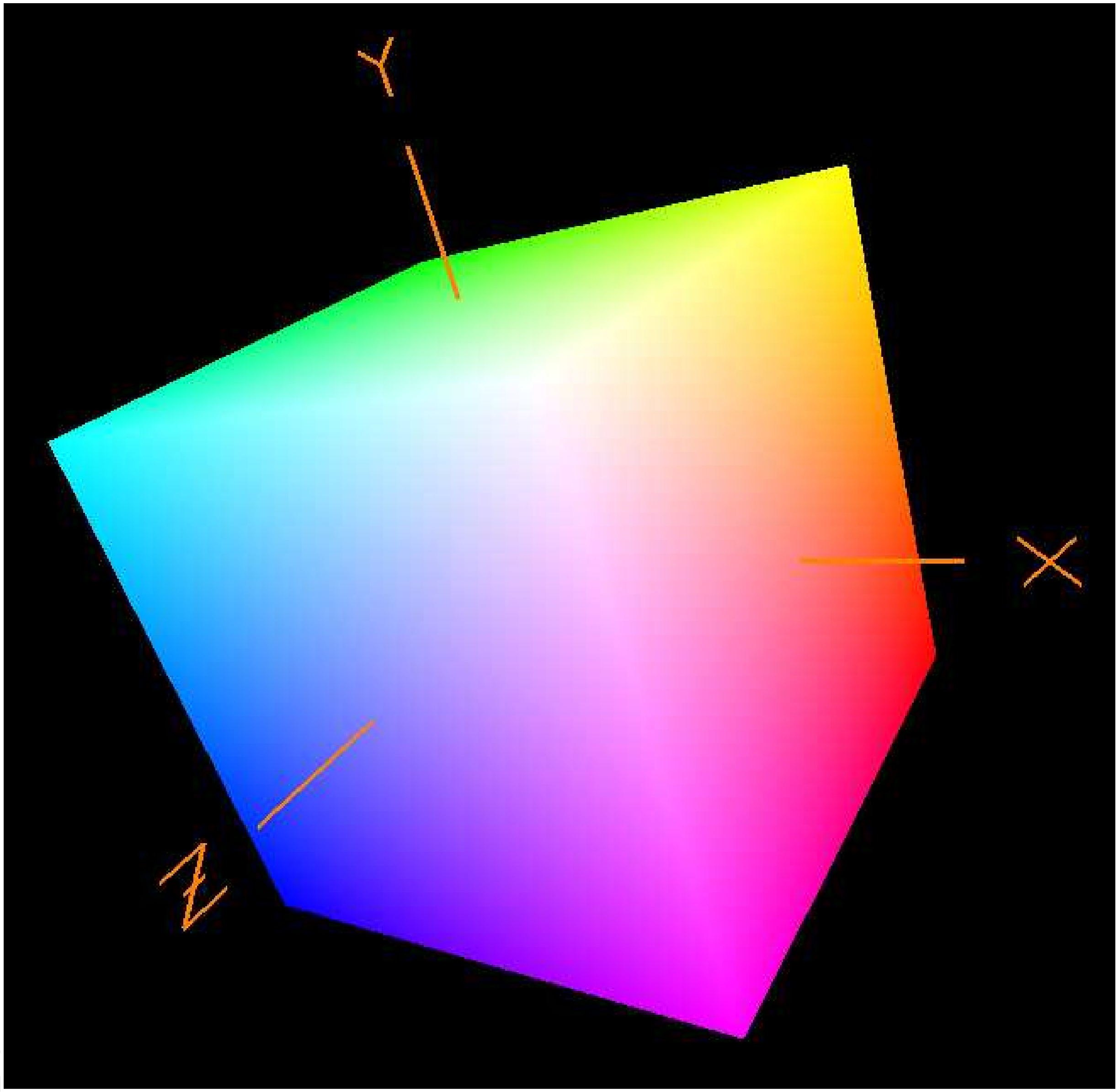



```
static GLfloat CubeVertices[ ][3] =
{
        { -1., -1., -1. },
        {  1., -1., -1. },
        { -1.,  1., -1. },
        {  1.,  1., -1. },
        { -1., -1.,  1. },
        {  1., -1.,  1. },
        { -1.,  1.,  1. },
        {  1.,  1.,  1. }
};
```

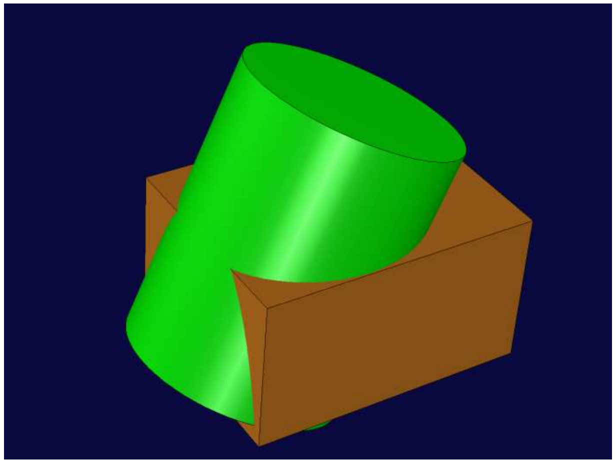
```
static GLfloat CubeColors[ ][3] =
{
        { 0., 0., 0. },
        { 1., 0., 0. },
        { 0., 1., 0. },
        { 1., 1., 0. },
        { 0., 0., 1. },
        { 1., 0., 1. },
        { 0., 1., 1. },
        { 1., 1., 1. },
};
```

```
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 }
};
```

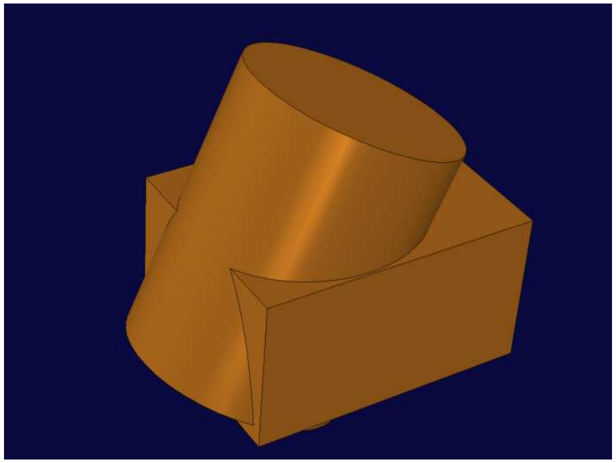
Cube Example



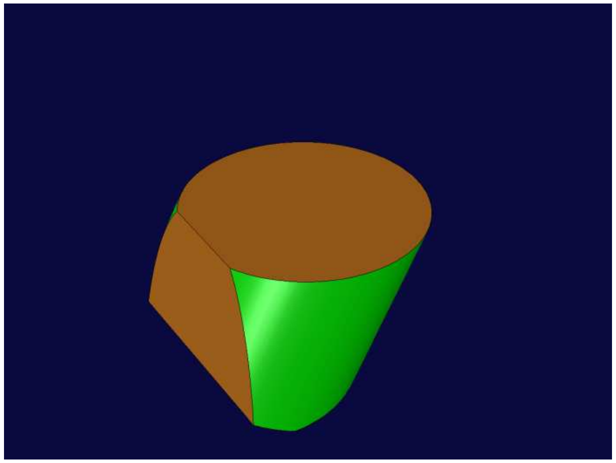
Solid Modeling Using Boolean Operators



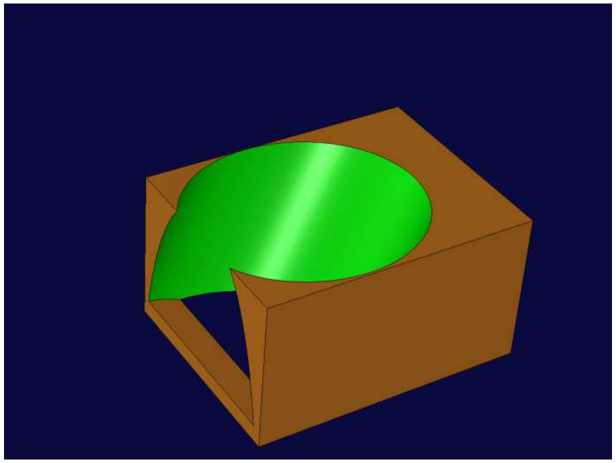
Two Overlapping Solids



Union

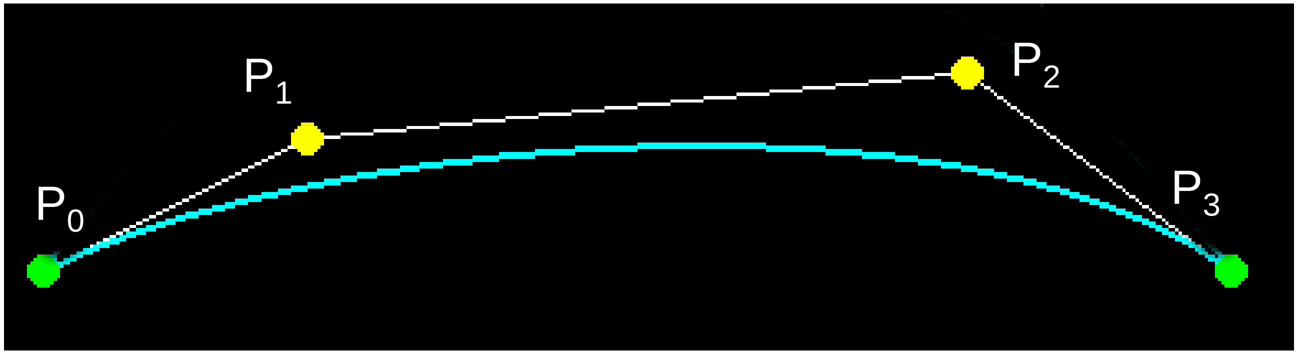


Intersection



Difference

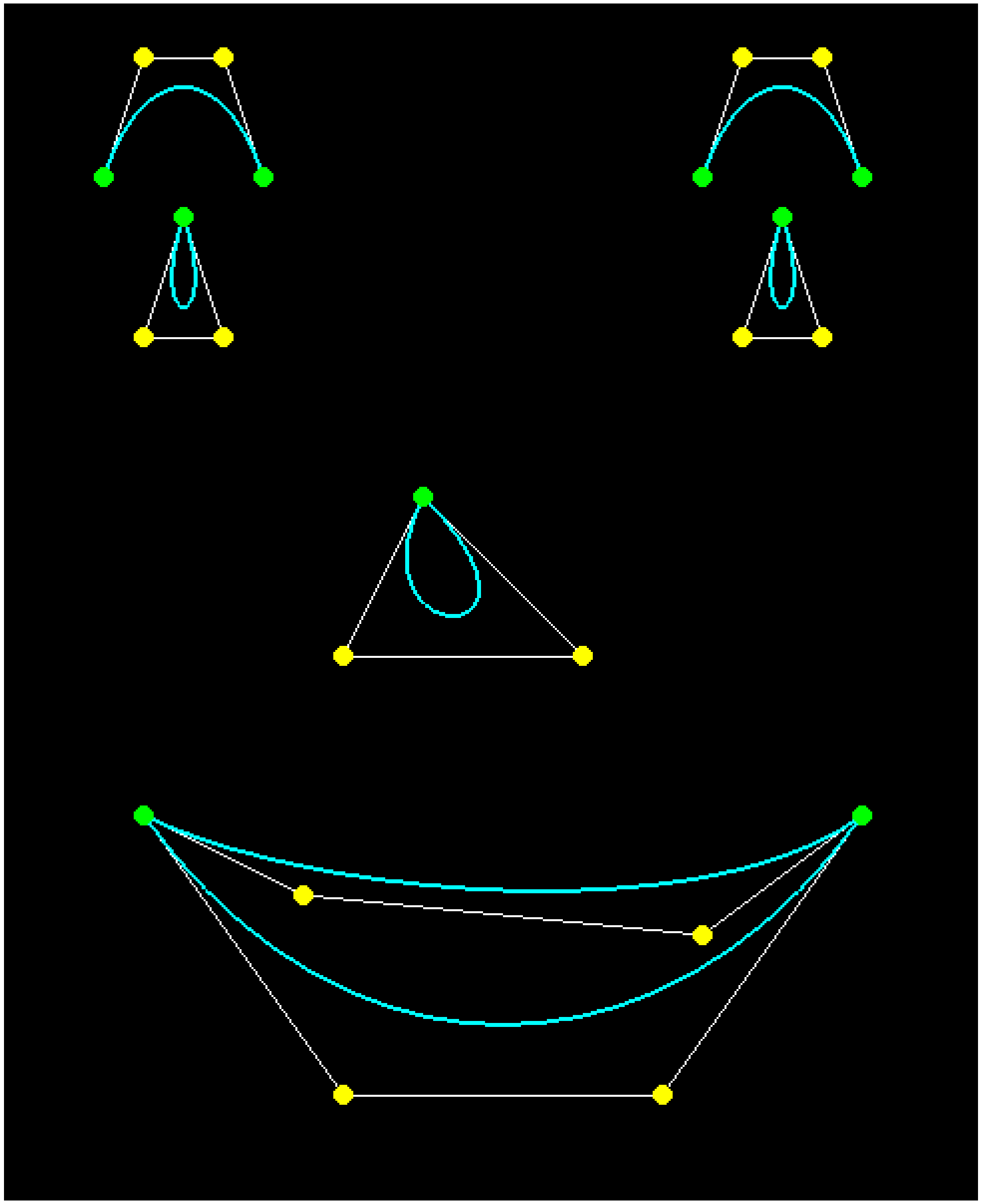
Curve Sculpting – Bezier Curve Sculpting



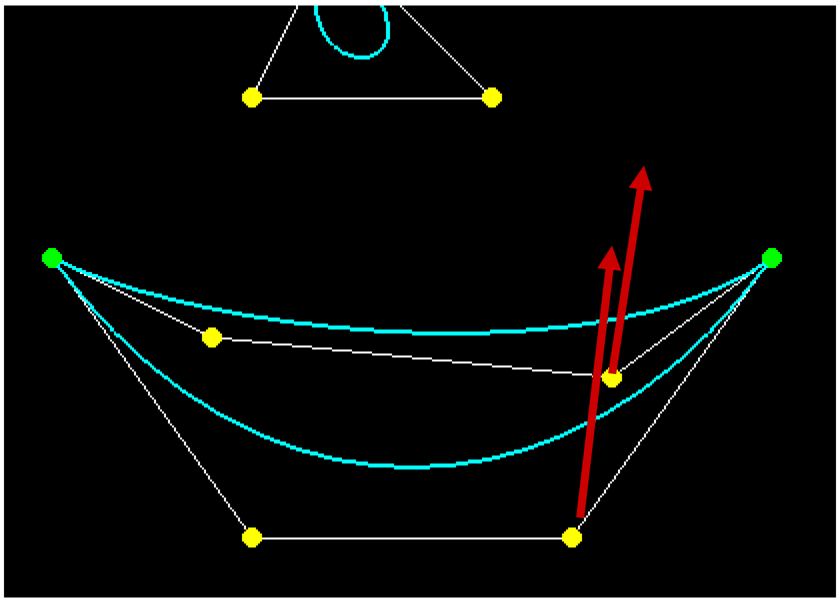
$$P(t) = (1-t)^3 P_0 + 3t(1-t)^2 P_1 + 3t^2(1-t)P_2 + t^3 P_3$$

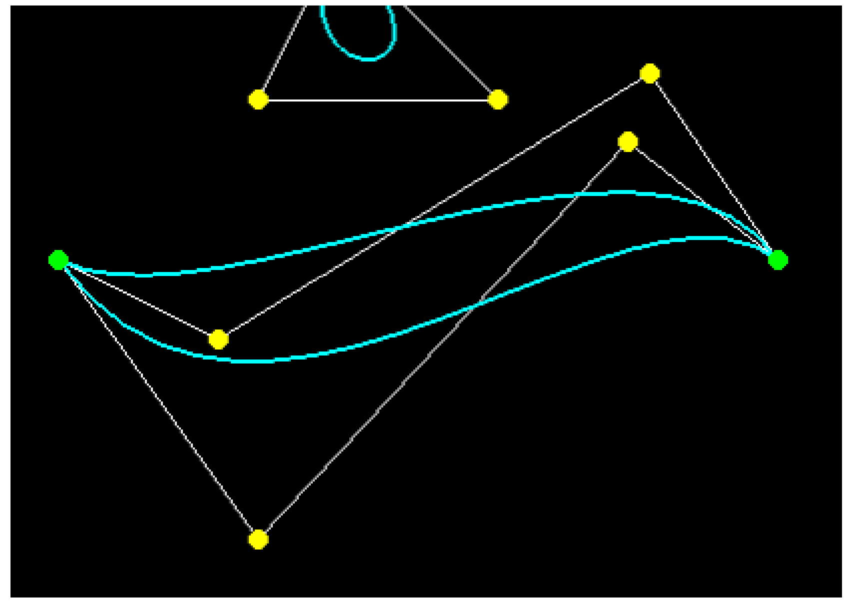
$$0. \le t \le 1.$$

Curve Sculpting – Bezier Curve Sculpting Example

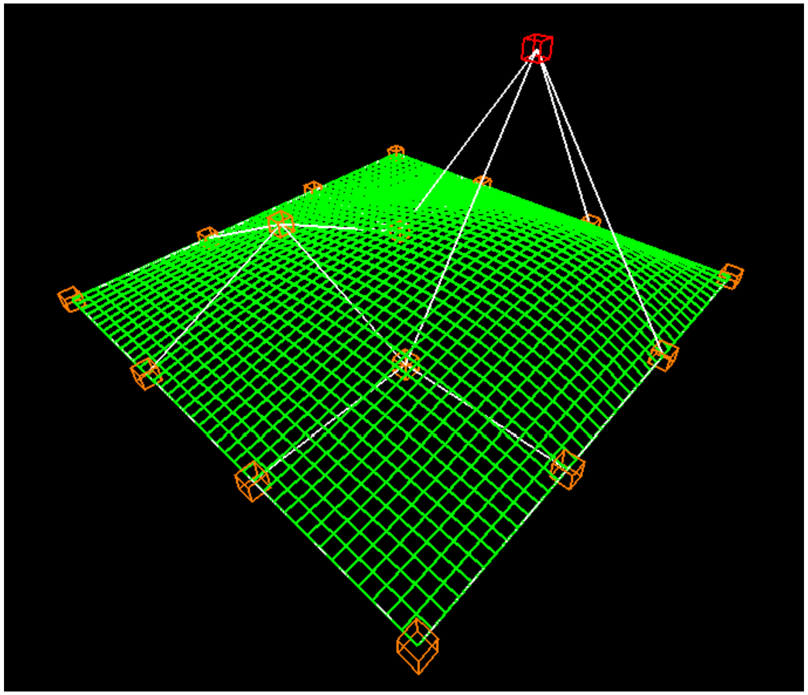


Curve Sculpting – Bezier Curve Sculpting Example

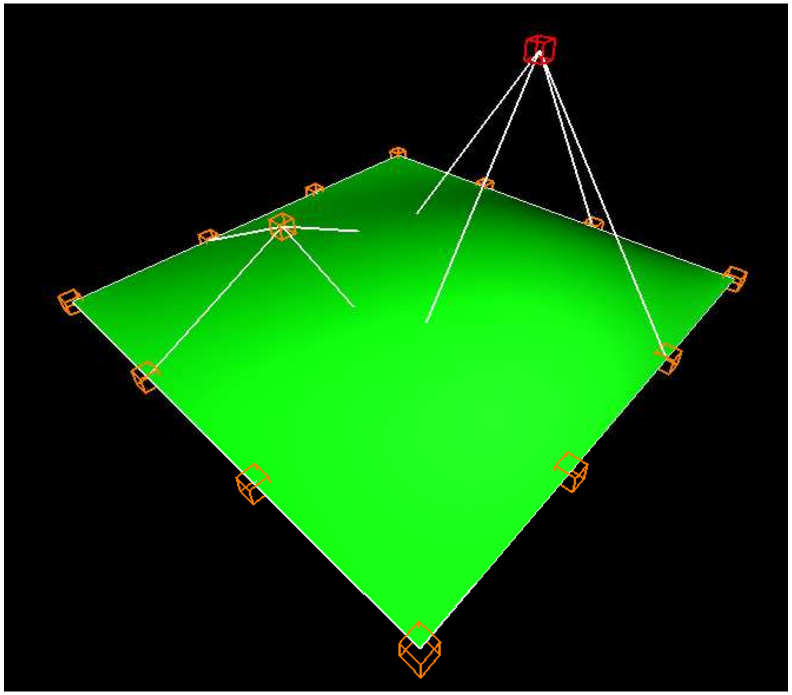




Surface Sculpting

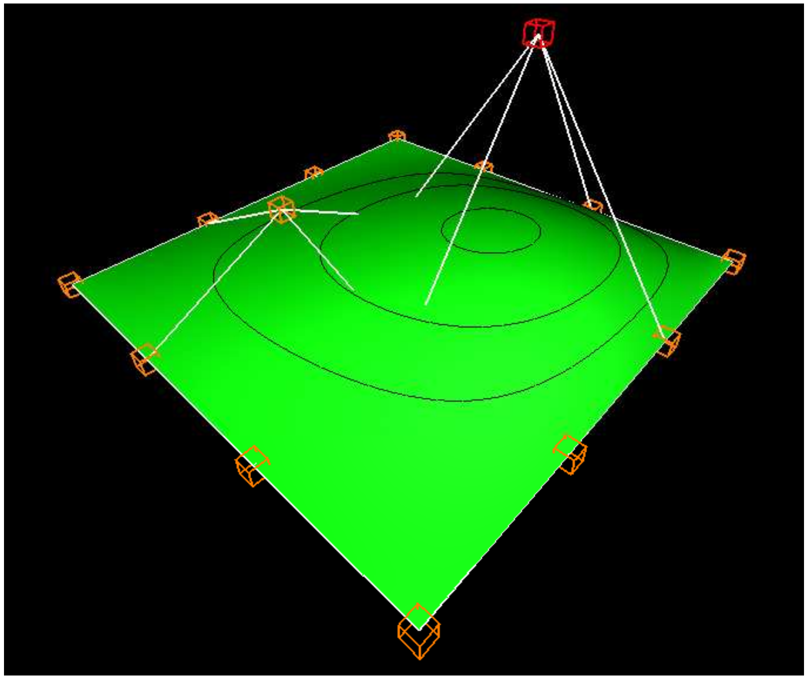


Wireframe

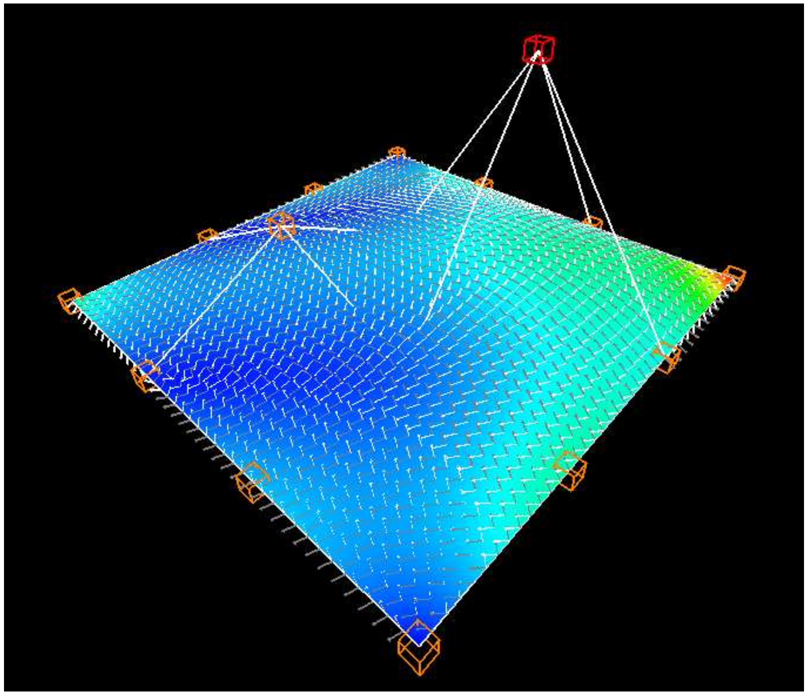


Surface

Surface Equations can also be used for Analysis

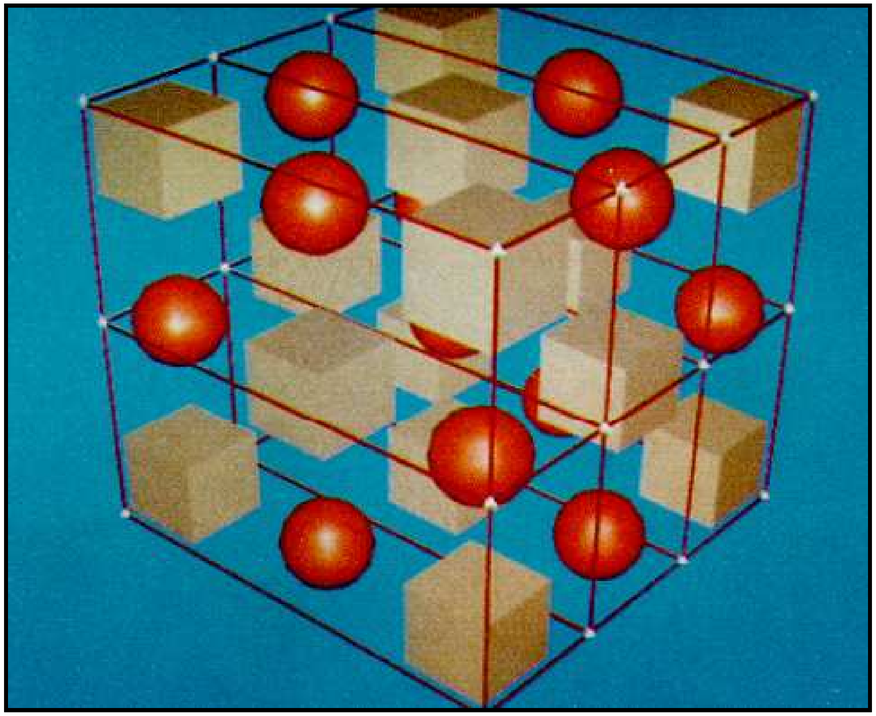


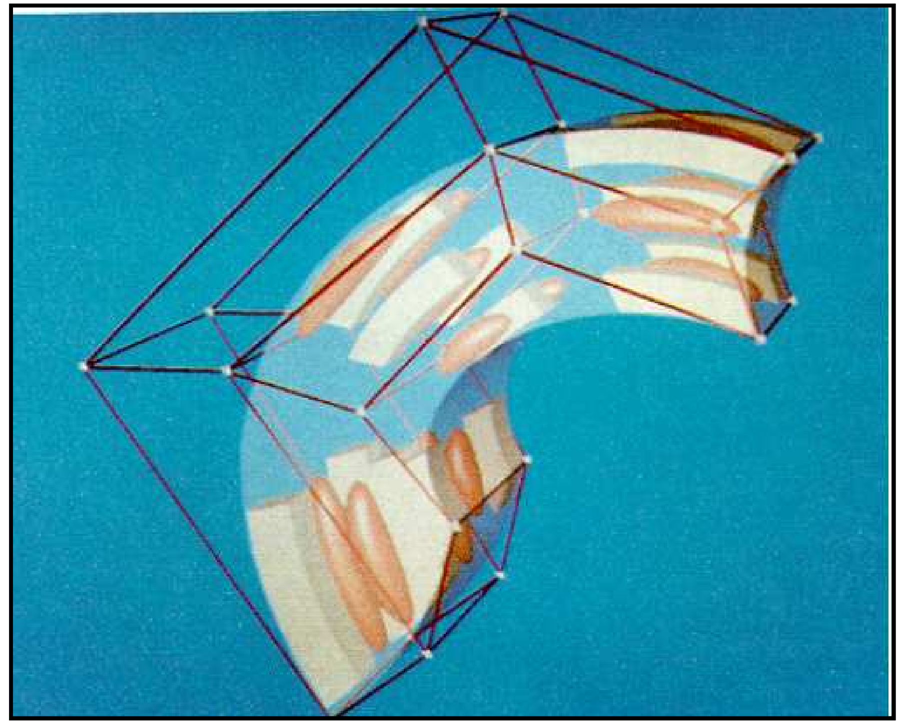
With Contour Lines



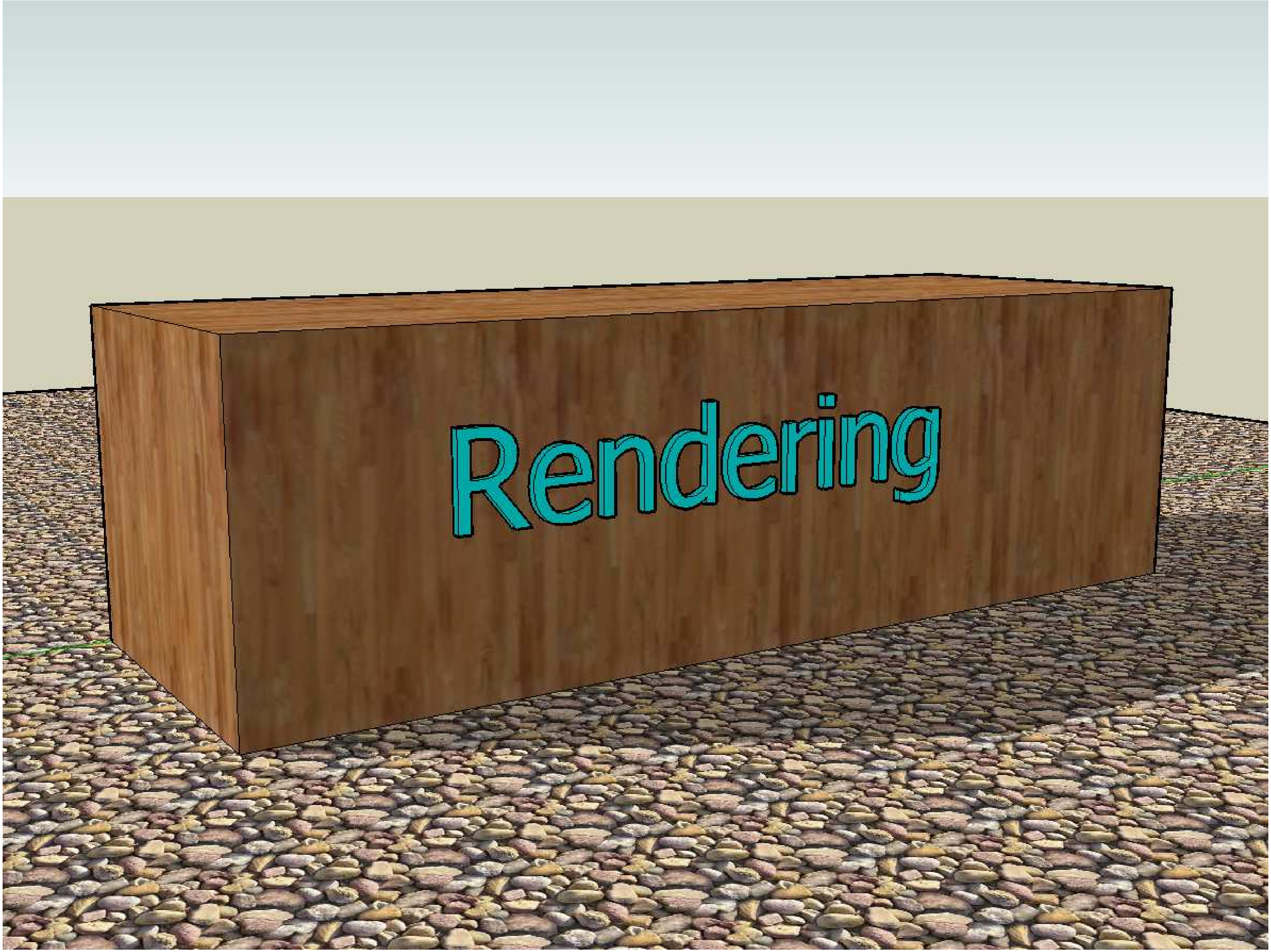
Showing Curvature

Volume Sculpting





Sederberg and Parry

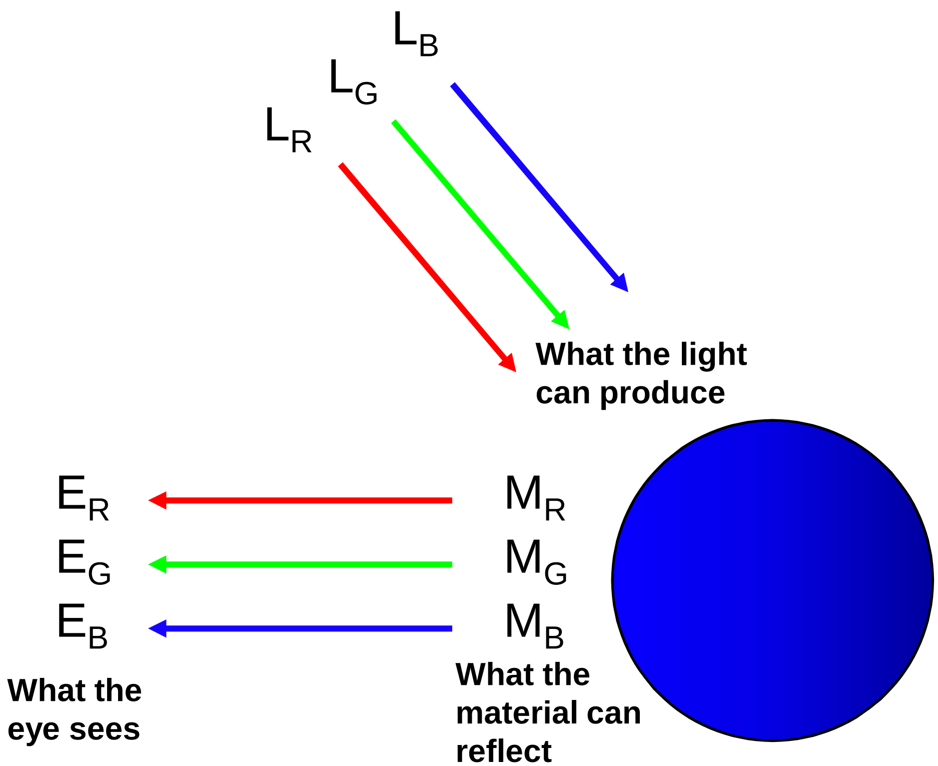

Rendering

Rendering

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

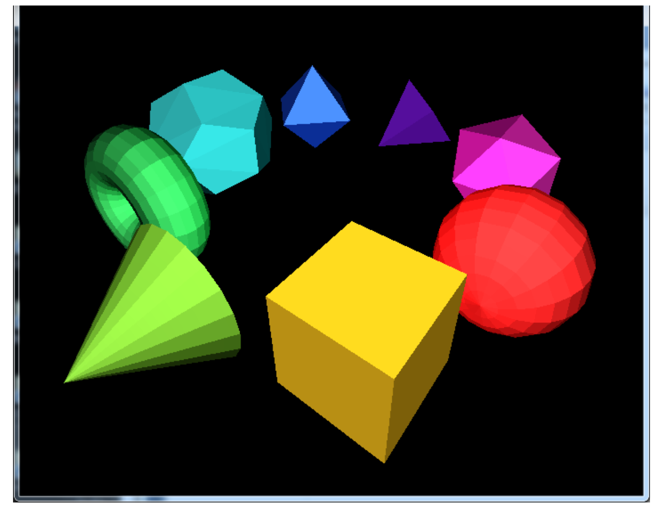
- How realistic do I want this image to be?
- How much compute time do I have to create this image?
- Do I need to take into account lighting?
- Does the illumination need to be global or will local do?
- Do I need to take into account shadows?
- Do I need to take into account reflection and refraction?

Fundamentals of Computer Graphics Lighting

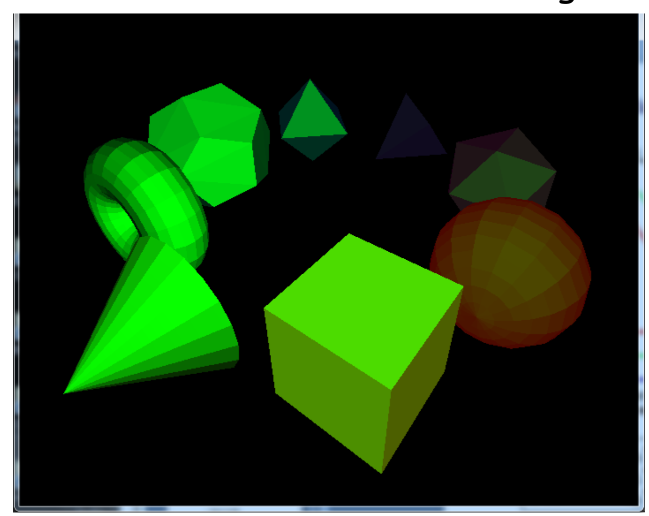


$$E_R = L_R * M_R$$
$$E_G = L_G * M_G$$
$$E_B = L_B * M_B$$

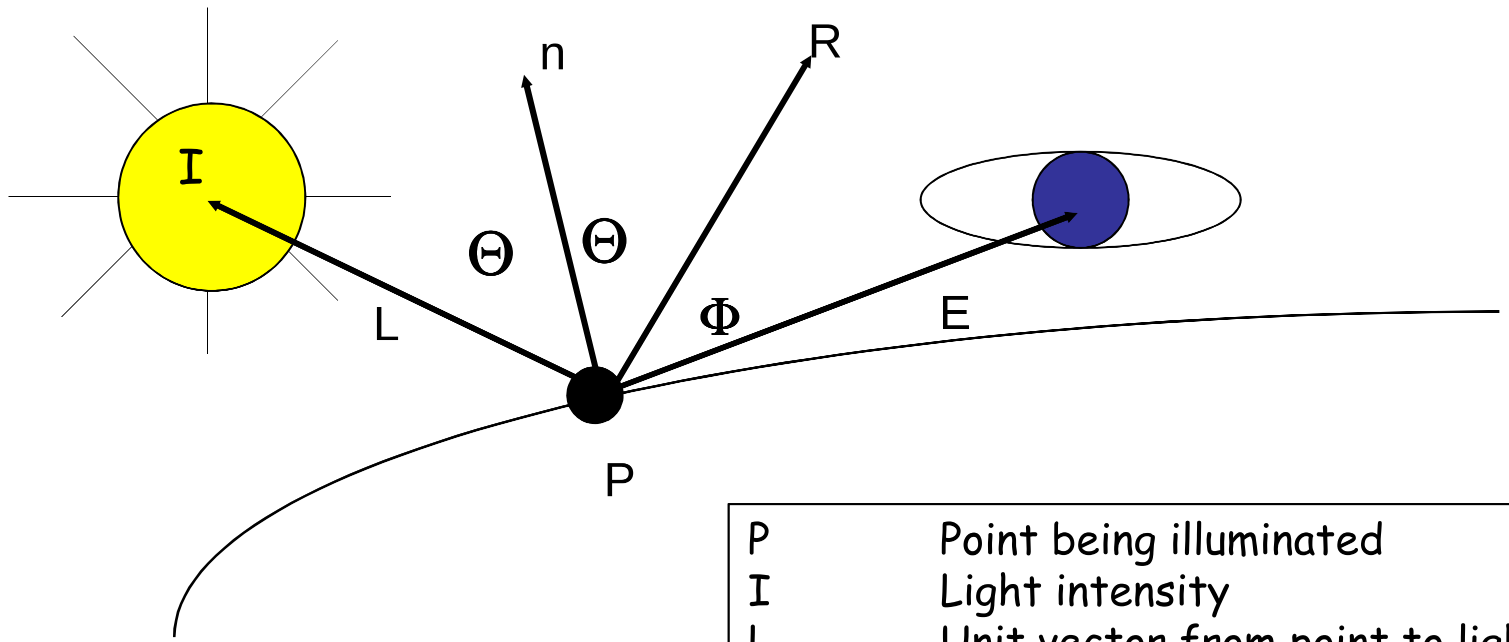
White Light



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

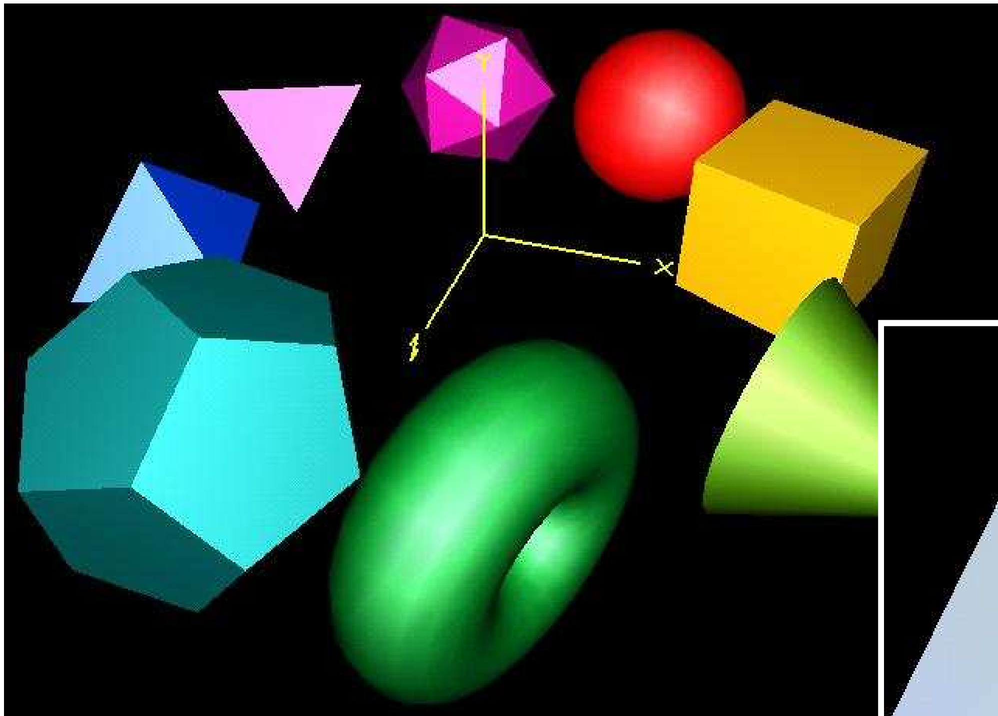
Three Elements of Computer Graphics Lighting

+

+

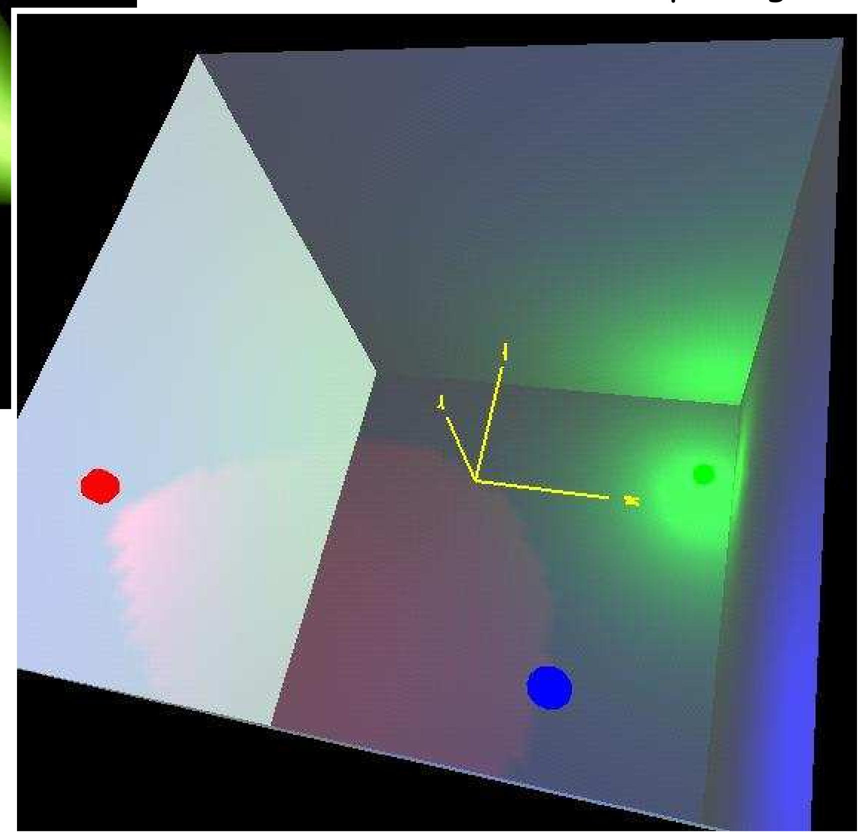
=

Lighting Examples



Omnidirectional Point Light

Spot Lights

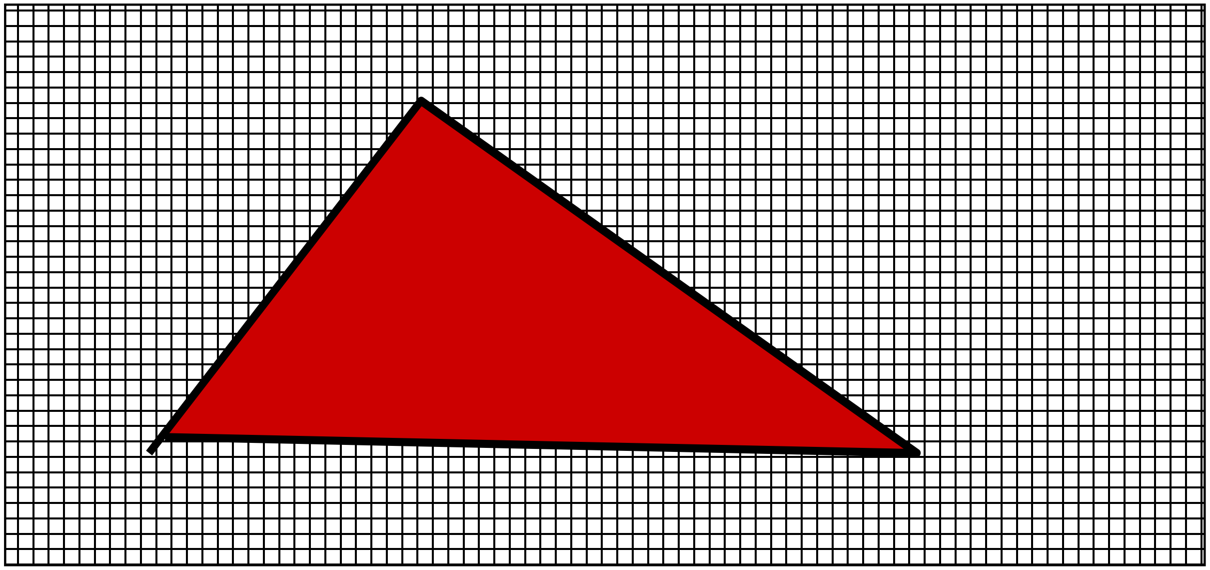


Two Types of Rendering

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

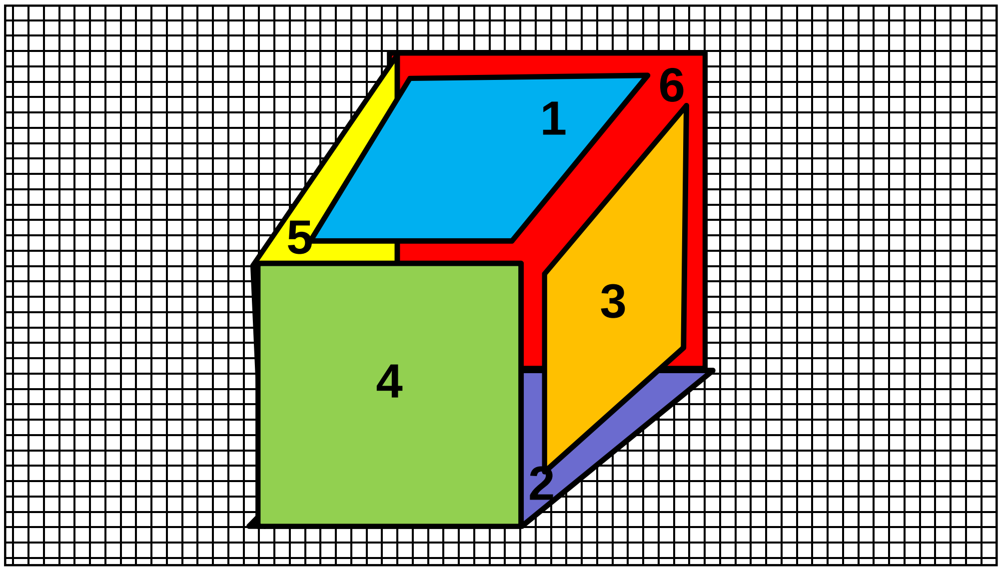
Starts at the Object

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

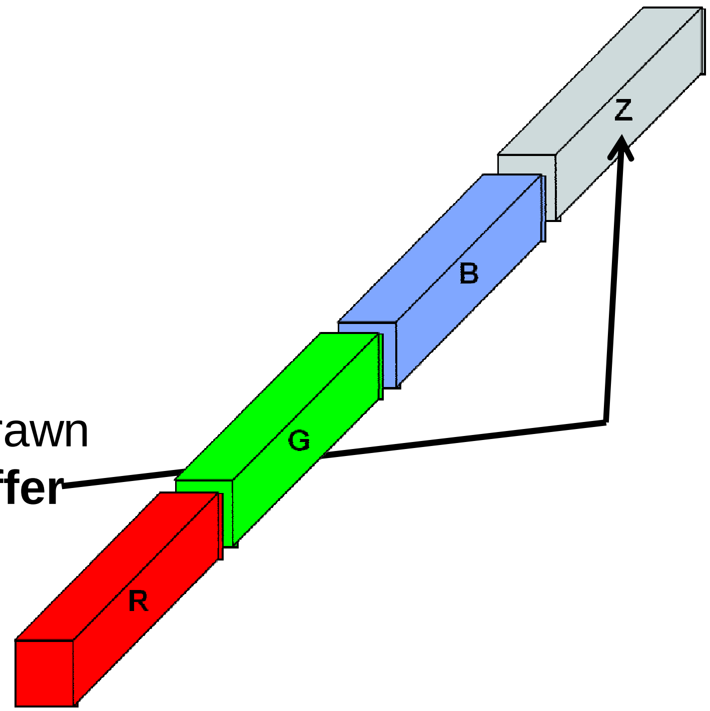


How do things in front look like they are *really* in front?

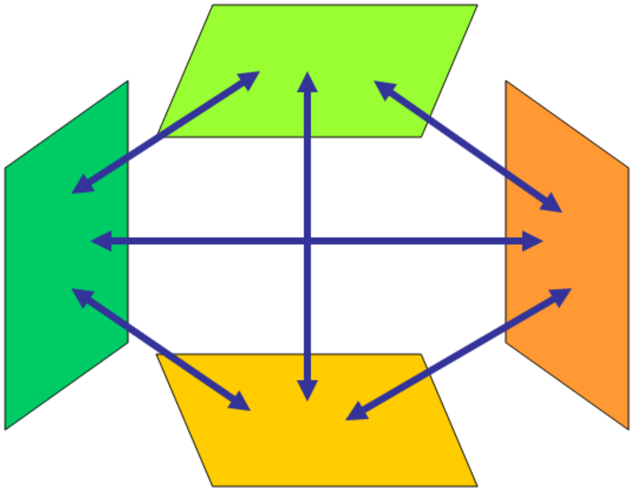
Your application might draw the polygons in 1-2-3-4-5-6 order, but 1, 3, and 4 still need to look like they were drawn last:



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*

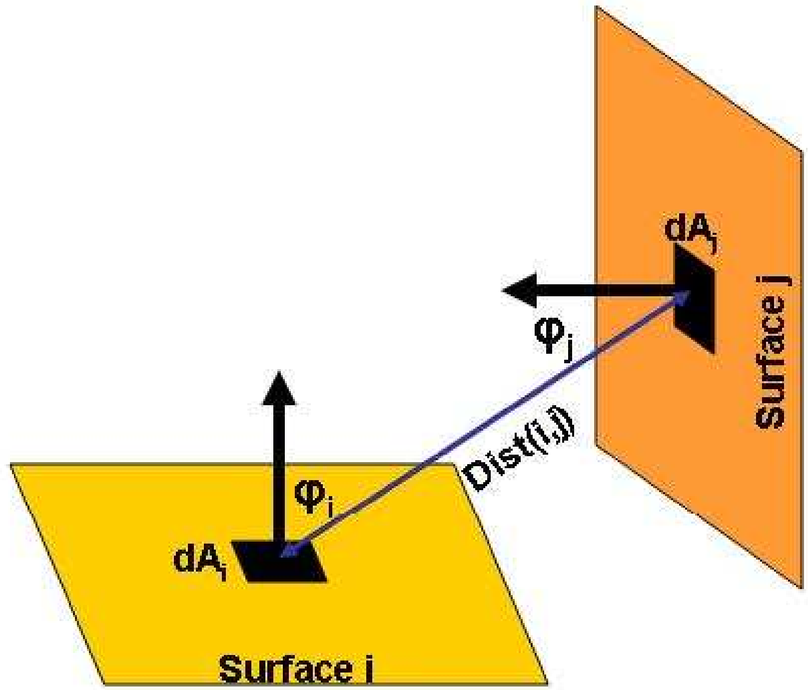
A_i is the area of surface element *i*

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



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

The Radiosity Matrix Equation

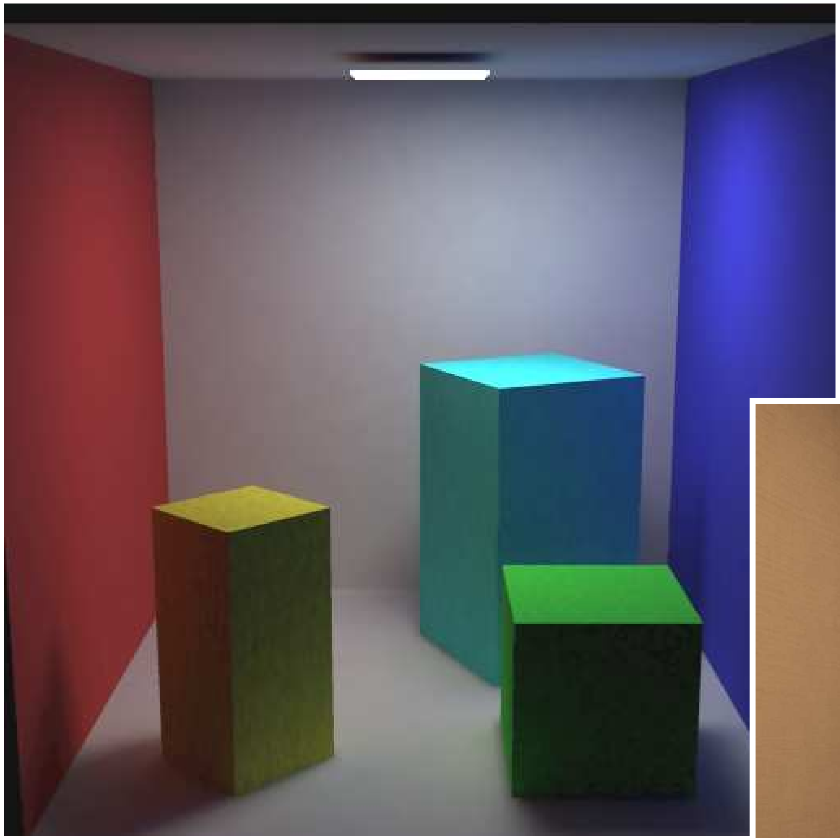
Expand $B_i A_i = E_i A_i + \rho_i \sum_j B_j A_j F_{j \to i}$

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

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

This is a lot of equations!

Radiosity Examples



AR Toolkit

Autodesk

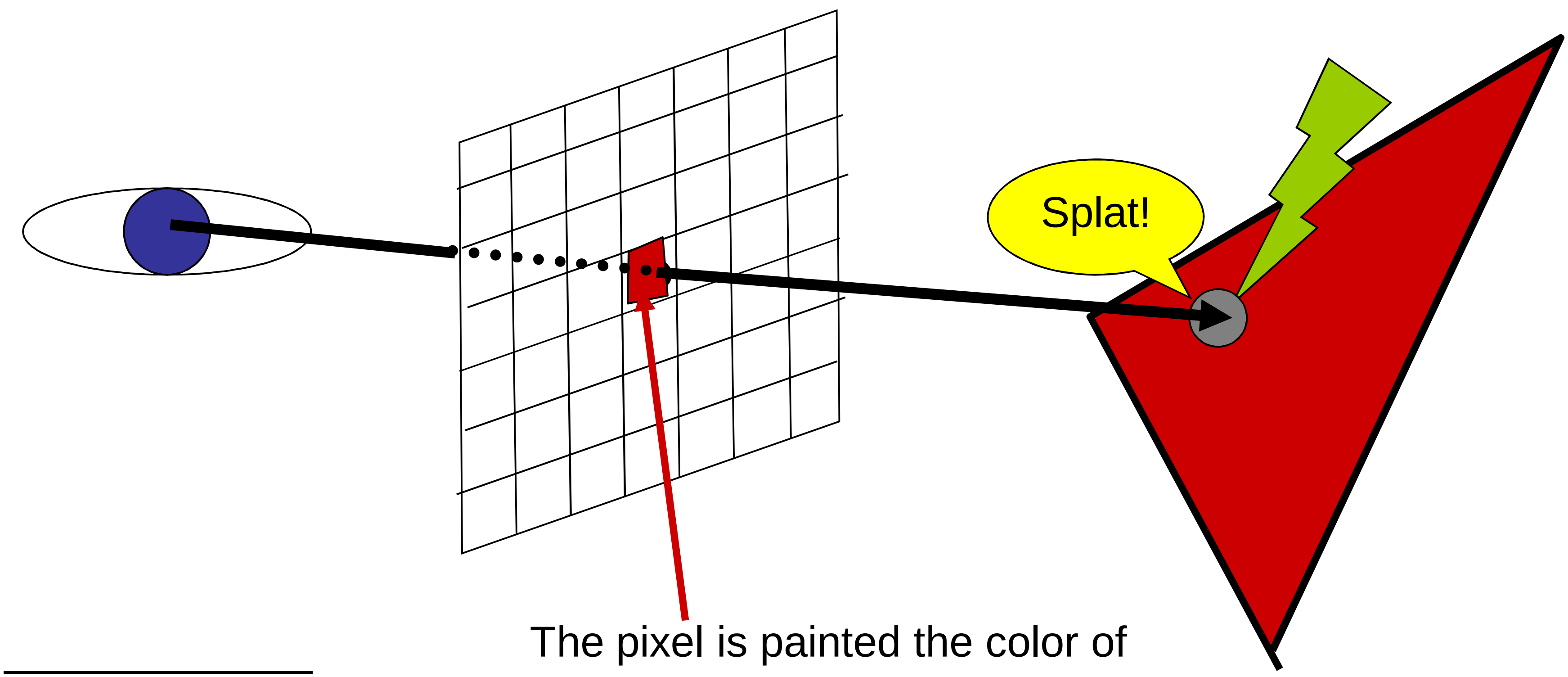
Radiosity Examples

Cornell University

Cornell University

Starts at the Eye

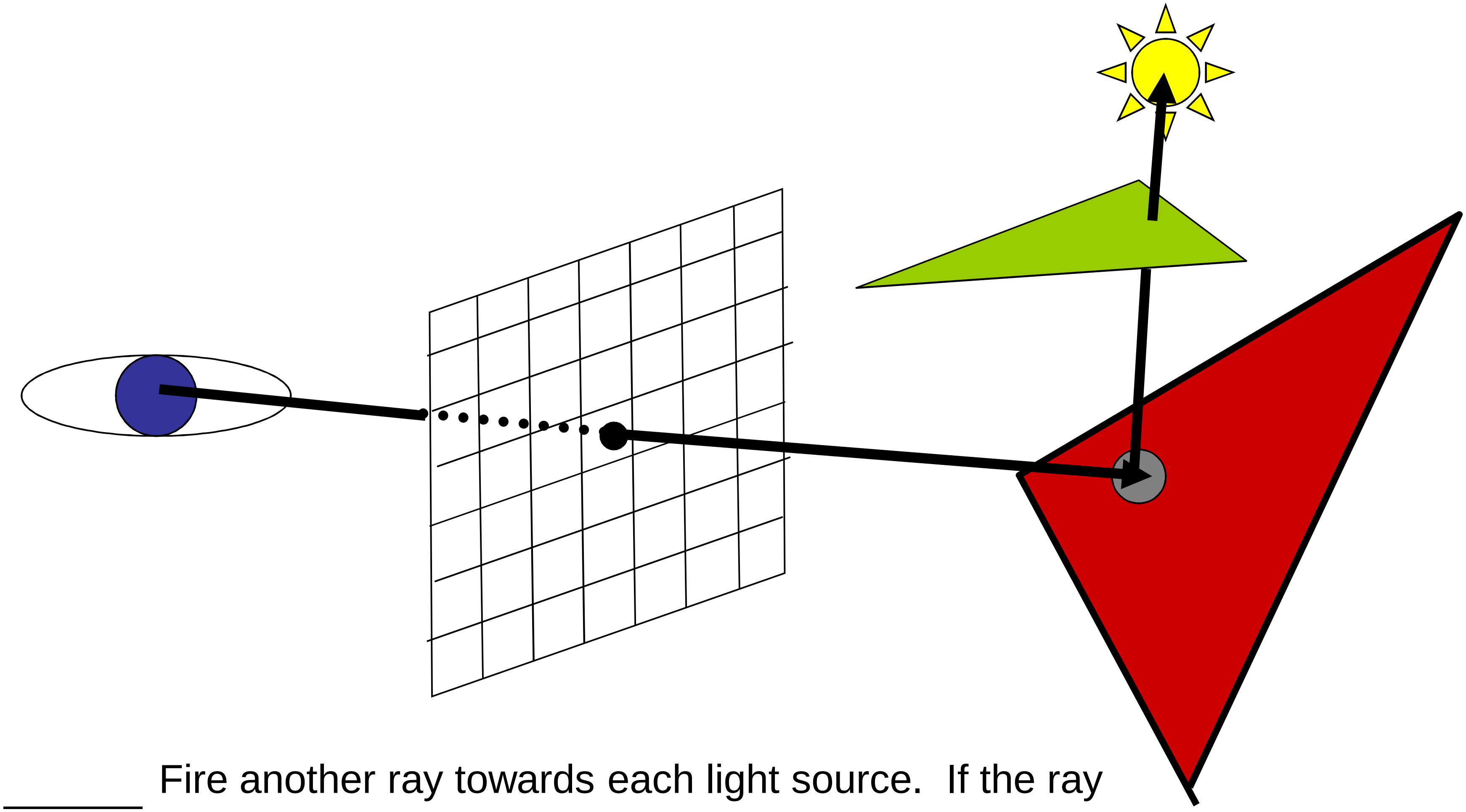
The most common approach in this category is ray-tracing:



The pixel is painted the color of the nearest object that is hit.

Starts at the Eye

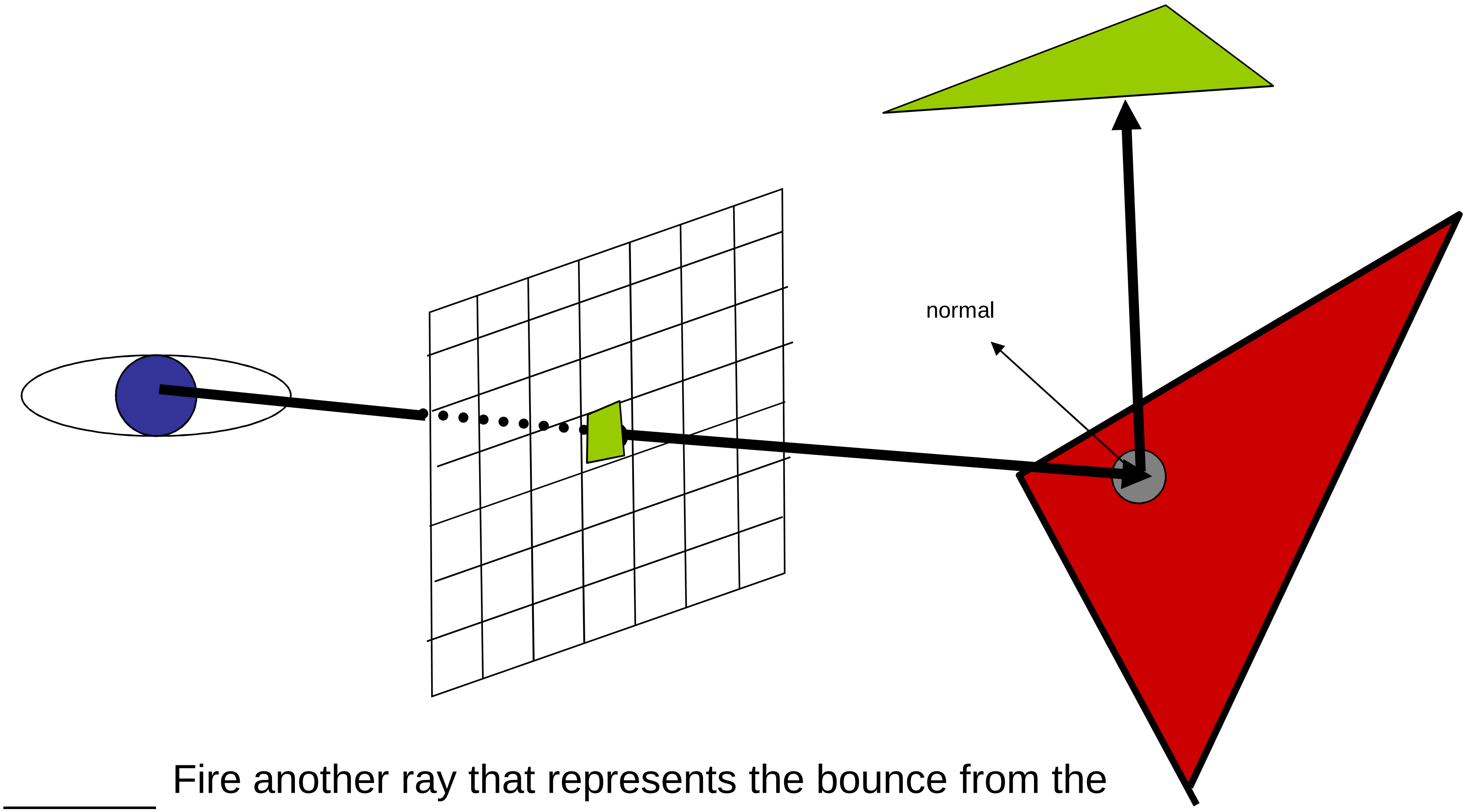
It's also easy to see if this point lies in a shadow:



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

Starts at the Eye

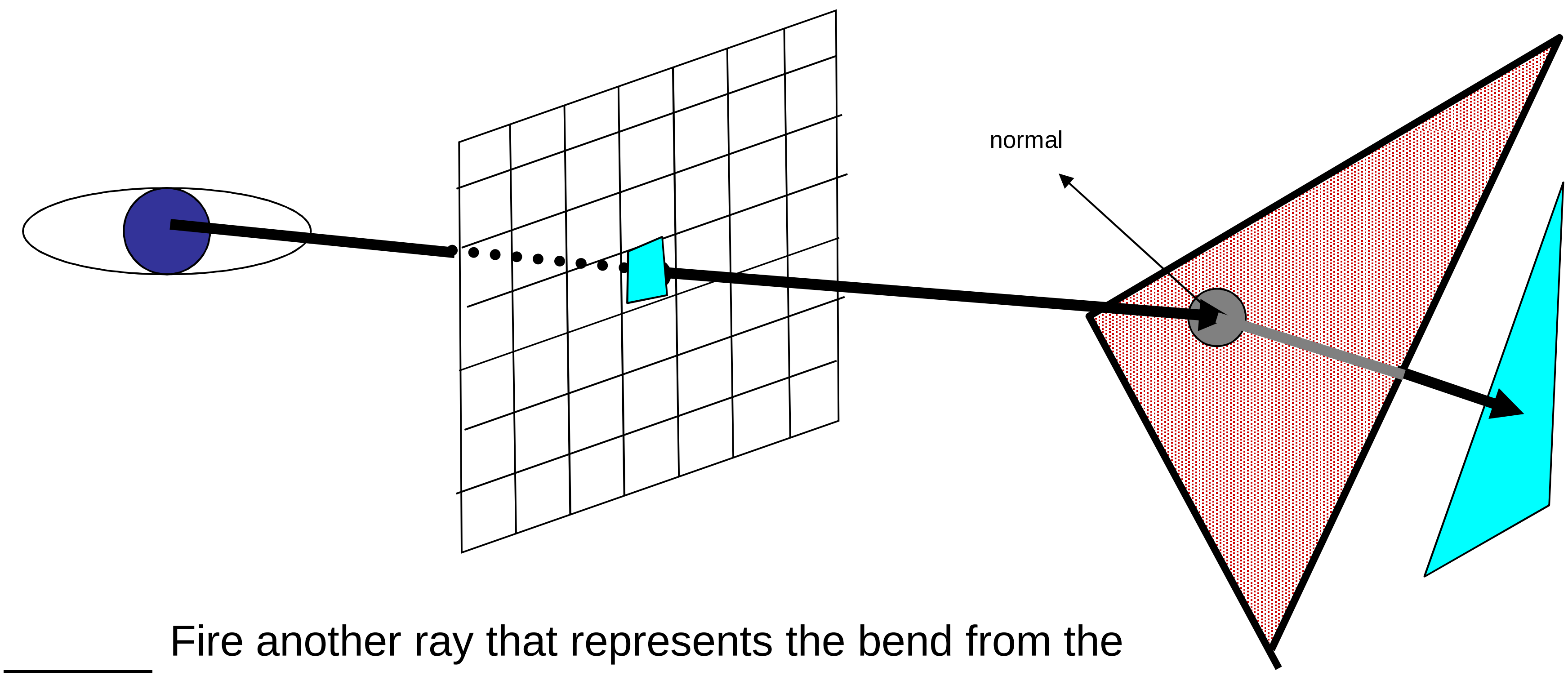
It's also easy to handle reflection



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

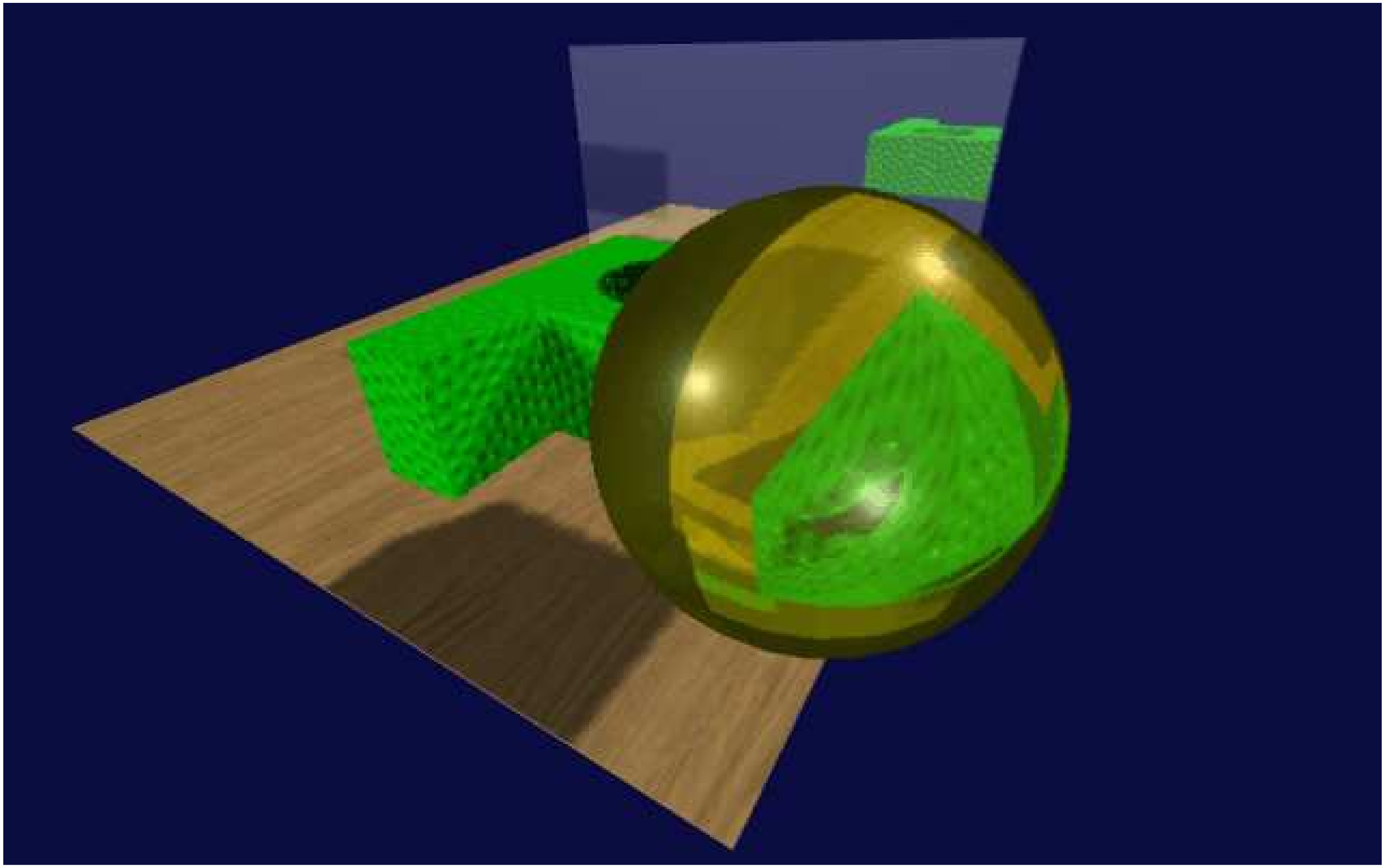
Starts at the Eye

It's also easy to handle refraction

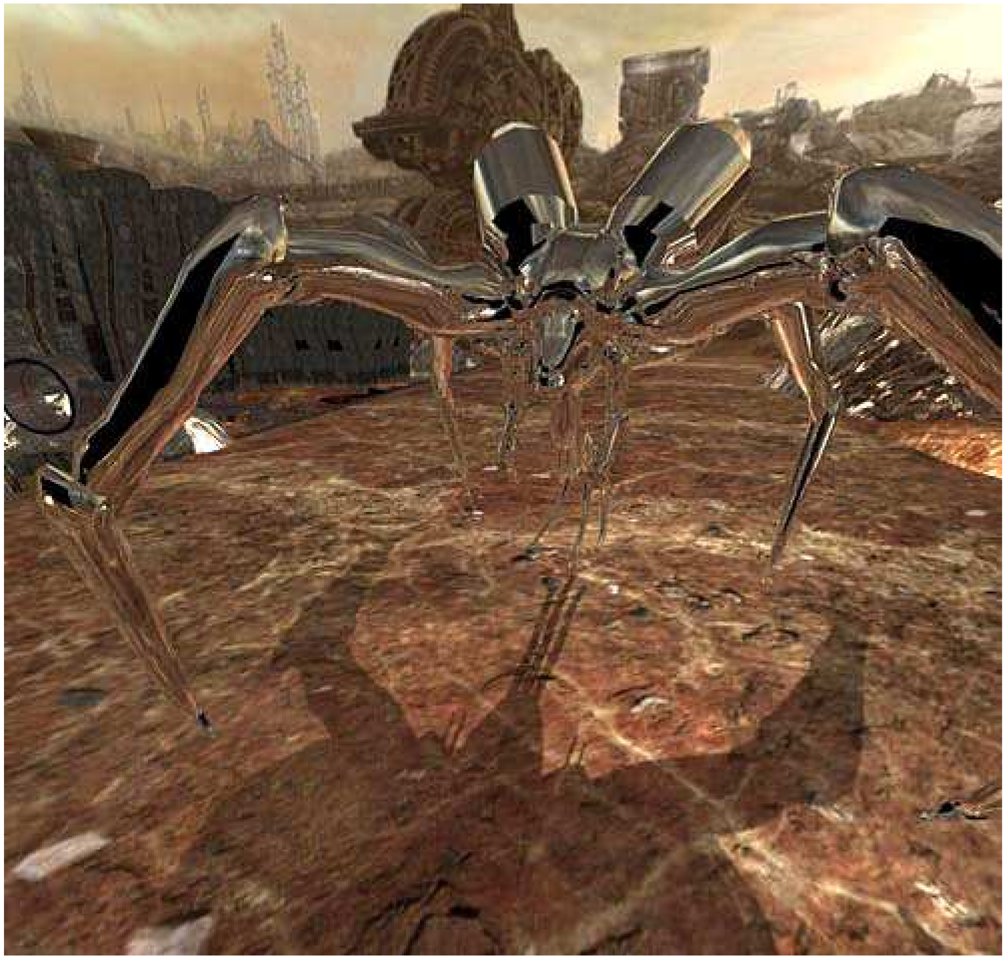


Fire another ray that represents the bend from the refraction. Paint the pixel the color that this ray sees.

Ray Tracing Examples



Ray Tracing Examples



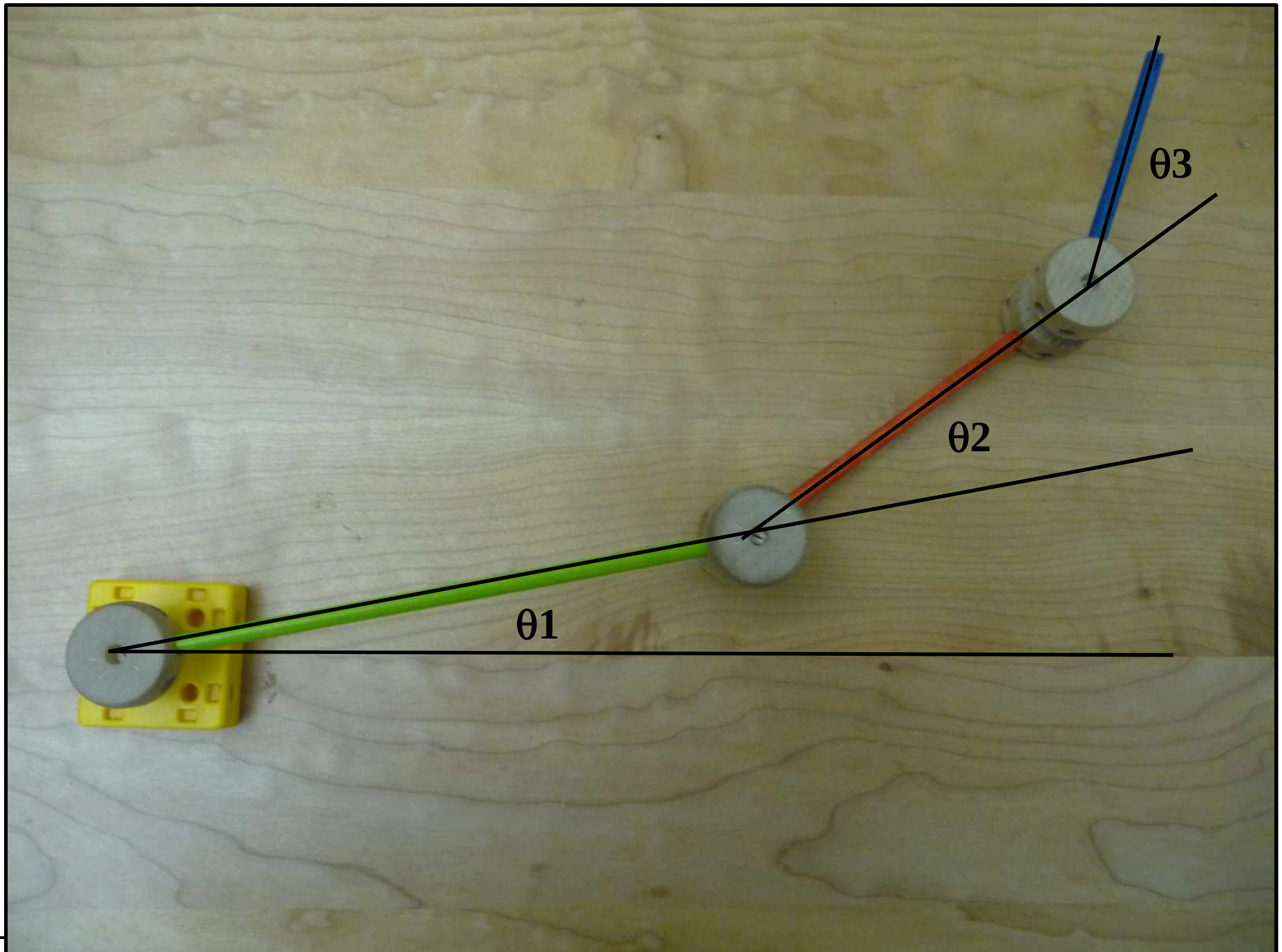
Quake 4 Ray-Tracing Project

Ray Tracing Examples

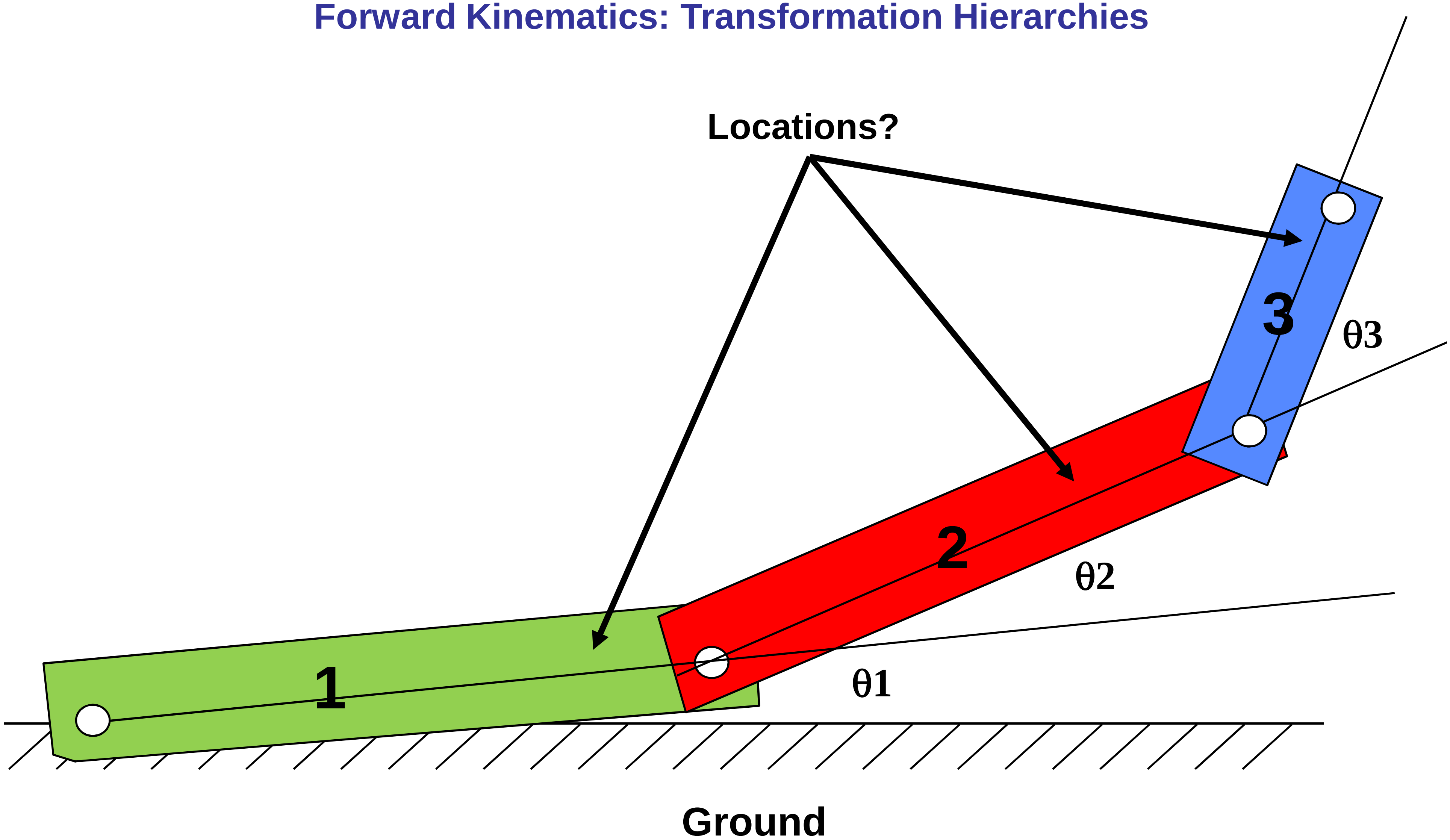
IBM's Cell Interactive Ray-tracer


Animation

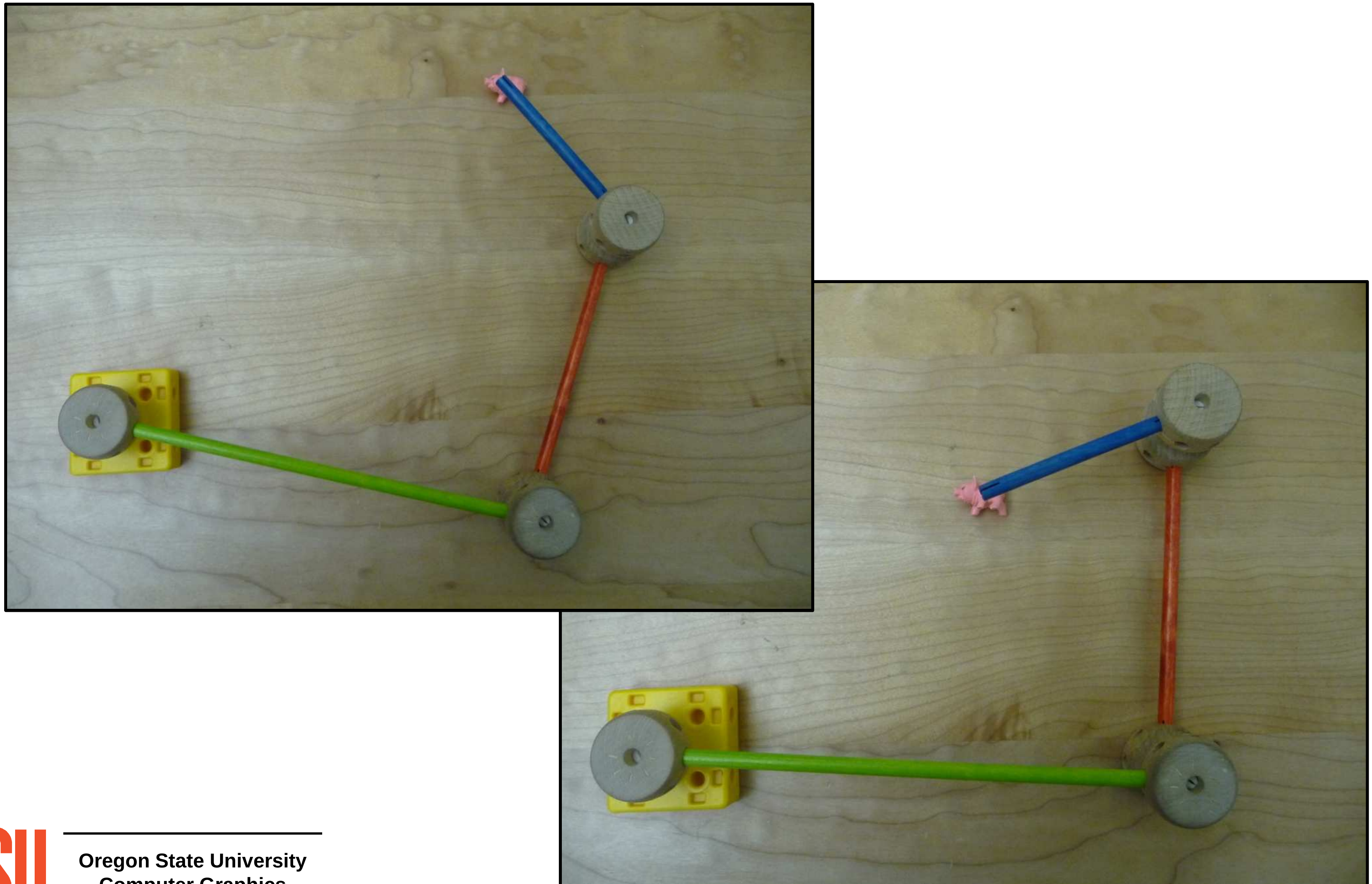
Forward Kinematics:
Change Parameters – Things Move
(All Children Understand This)



Forward Kinematics: Transformation Hierarchies



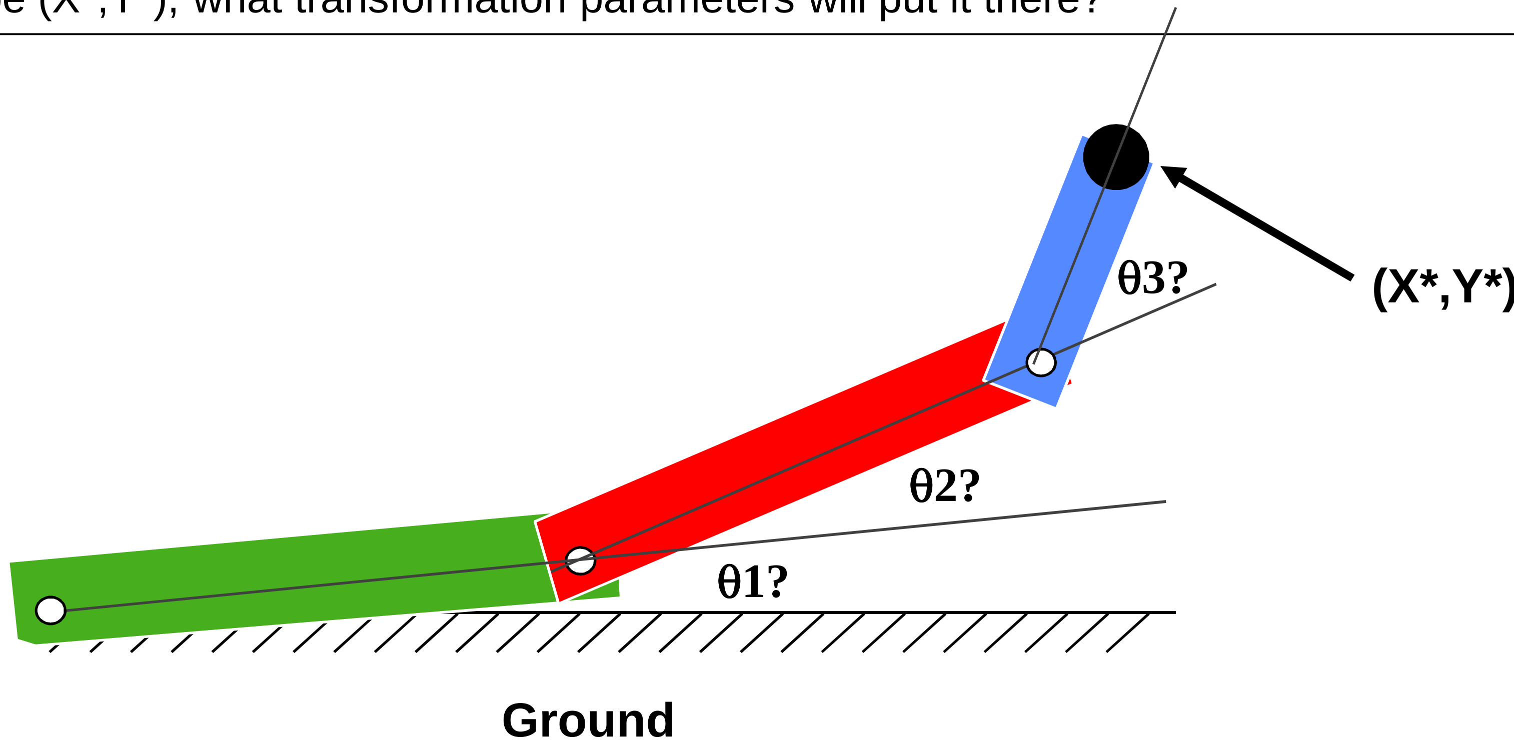
Inverse Kinematics (IK): Things Need to Move – What Parameters Will Make Them Do That?



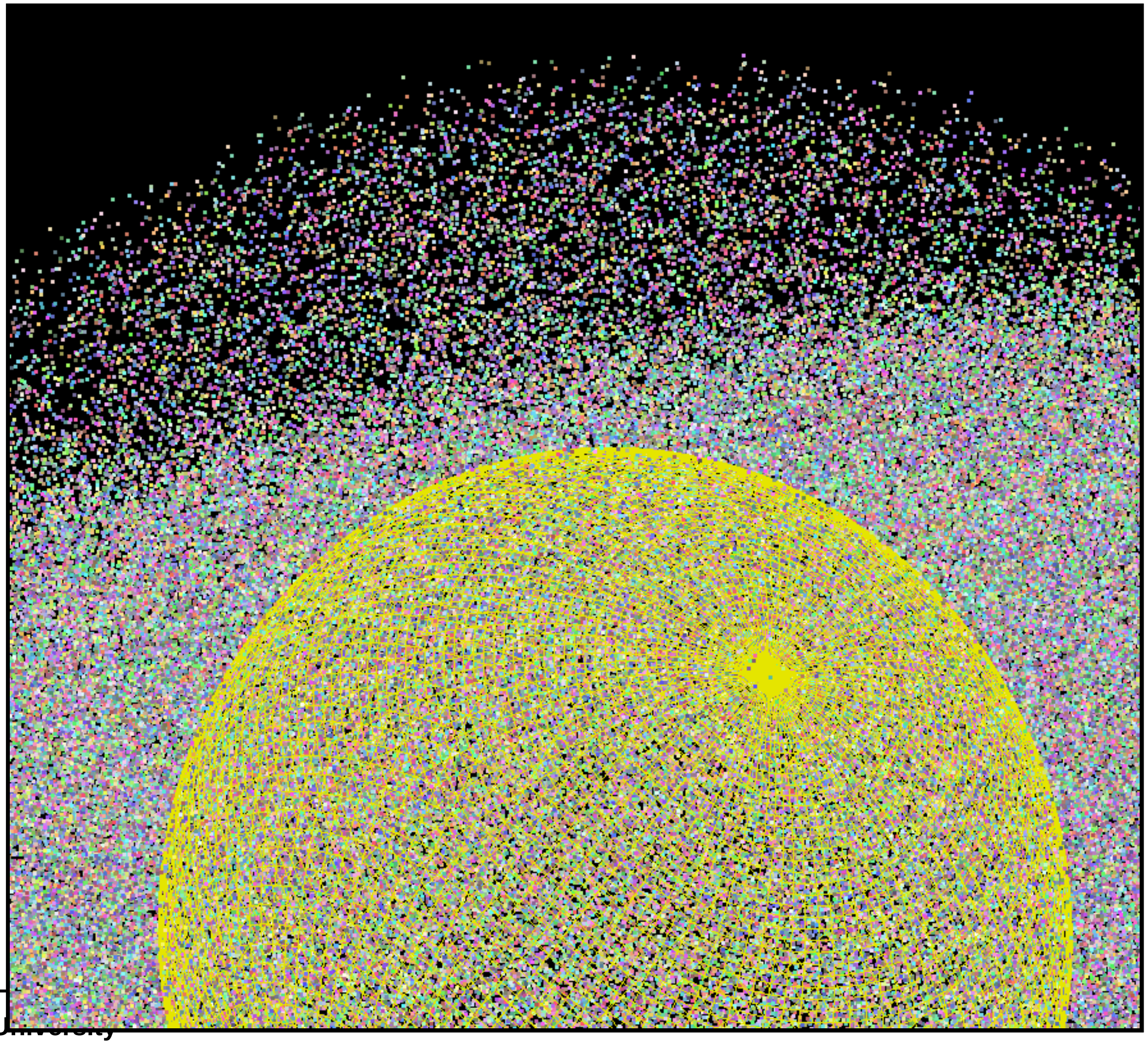
Inverse Kinematics

Forward Kinematics solves the problem "if I know the link transformation parameters, where are the links?".

Inverse Kinematics (IK) solves the problem "If I know where I want the end of the chain to be (X*,Y*), what transformation parameters will put it there?"

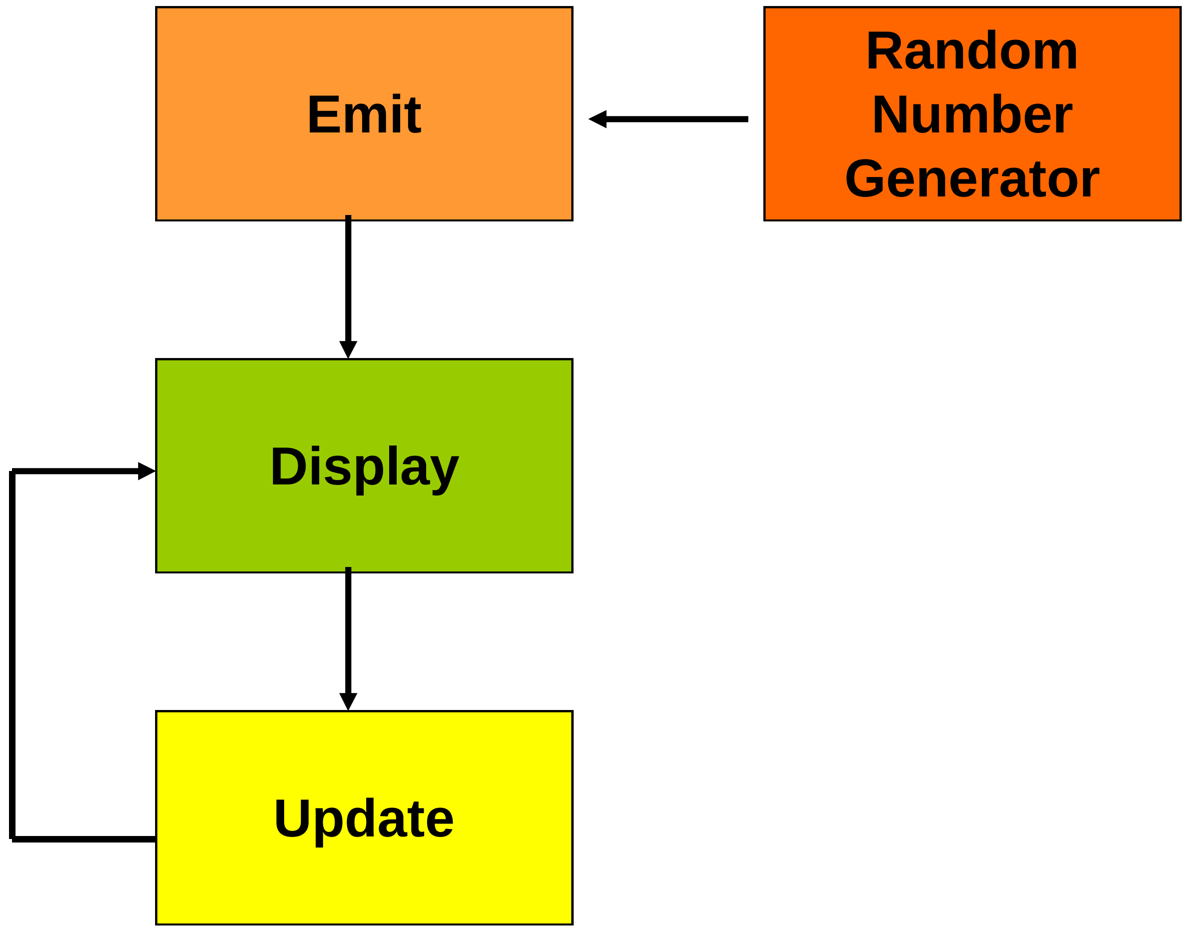


Particle Systems:
A Cross Between Modeling and Animation?

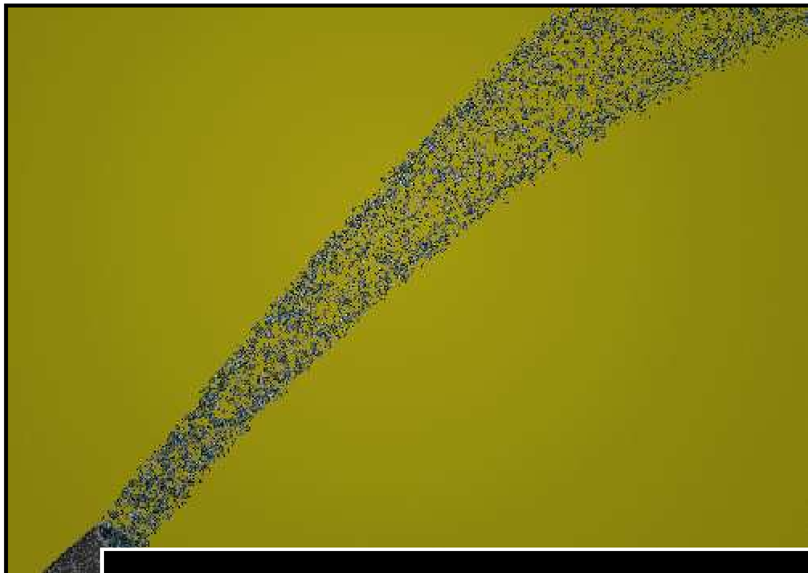


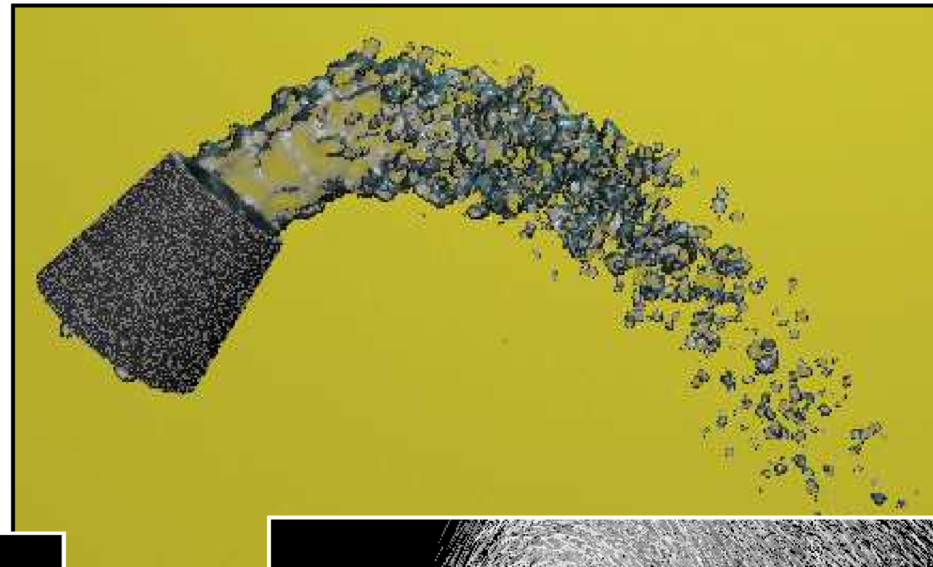
Particle Systems:
A Cross Between Modeling and Animation?

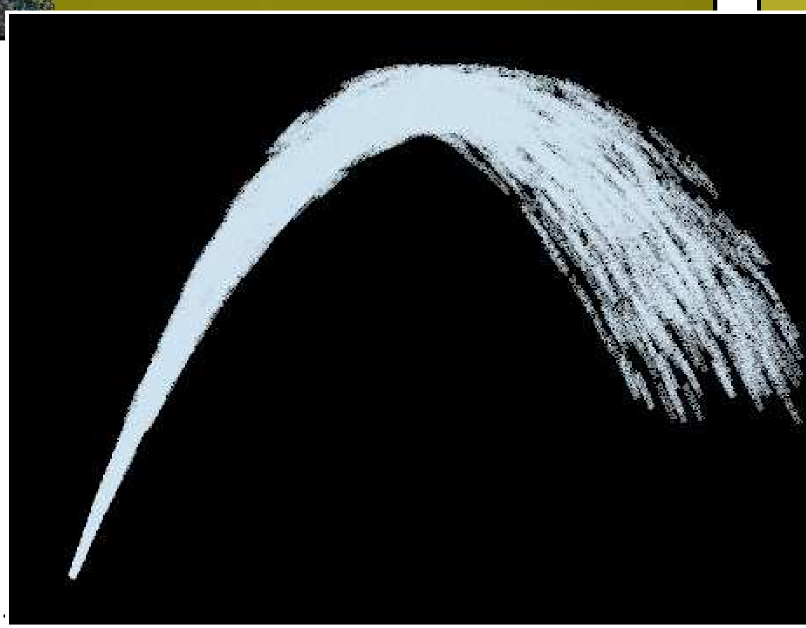
The basic process is:

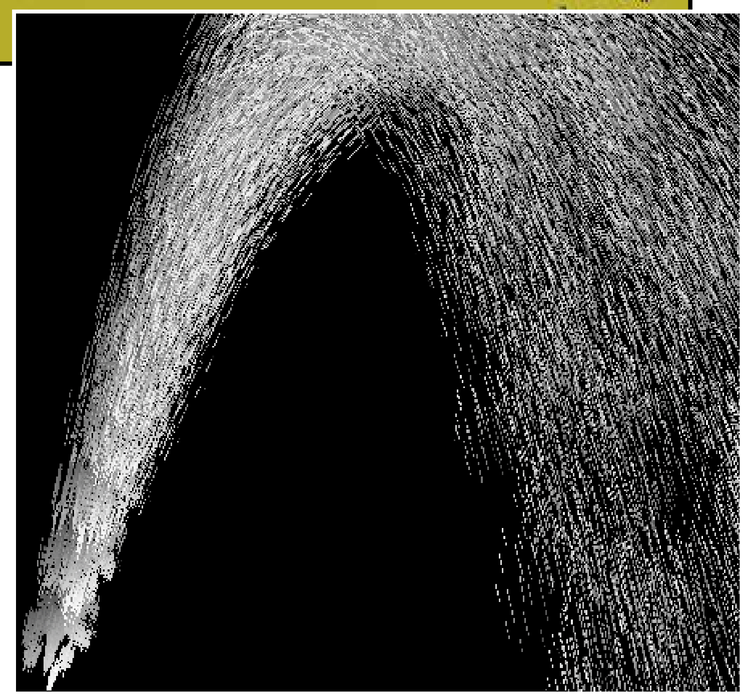


Particle Systems Examples



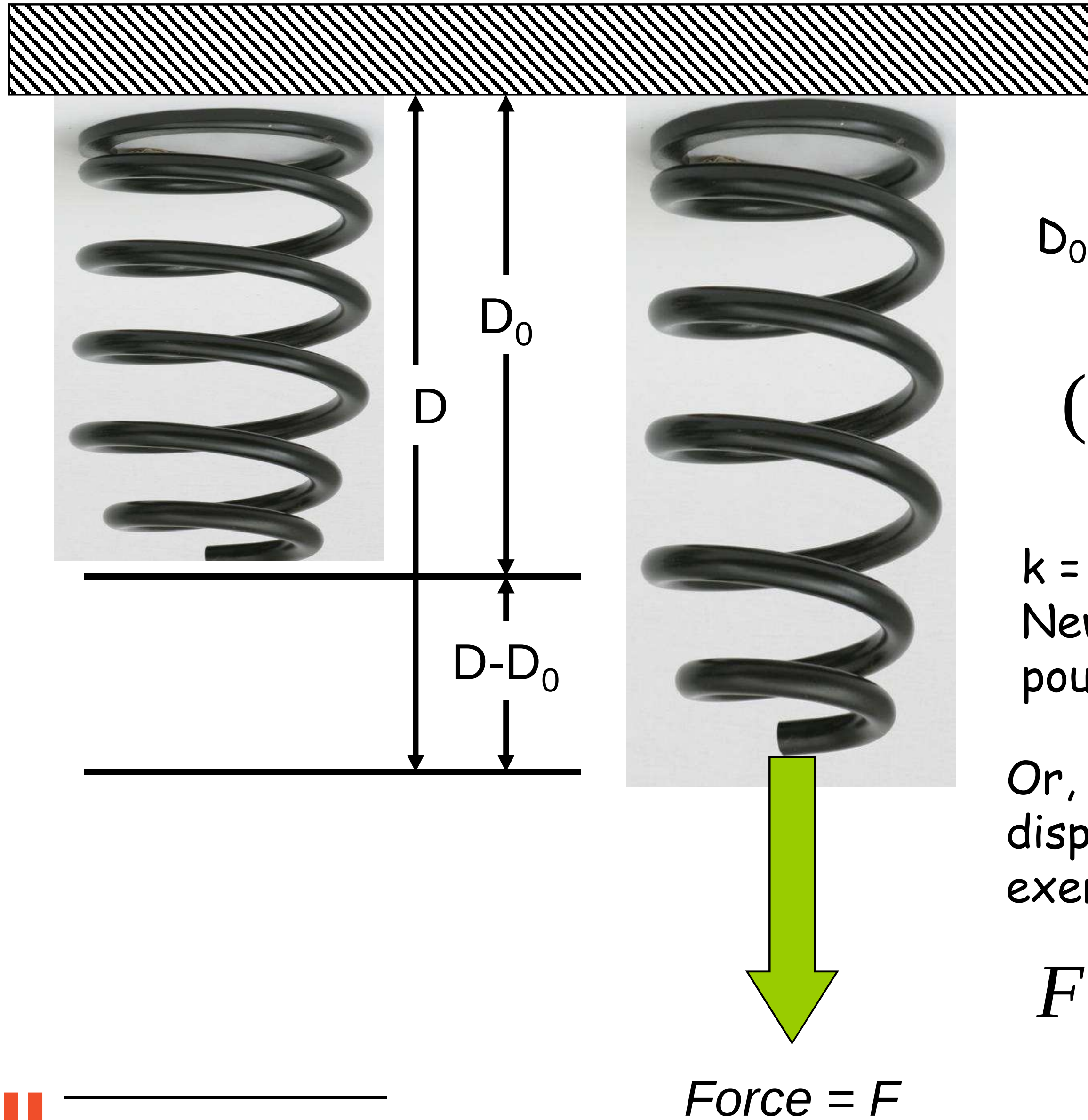






Chuck Evans

Animating using Physics



D_0 = unloaded spring length

$$(D - D_0) = \frac{F}{k}$$

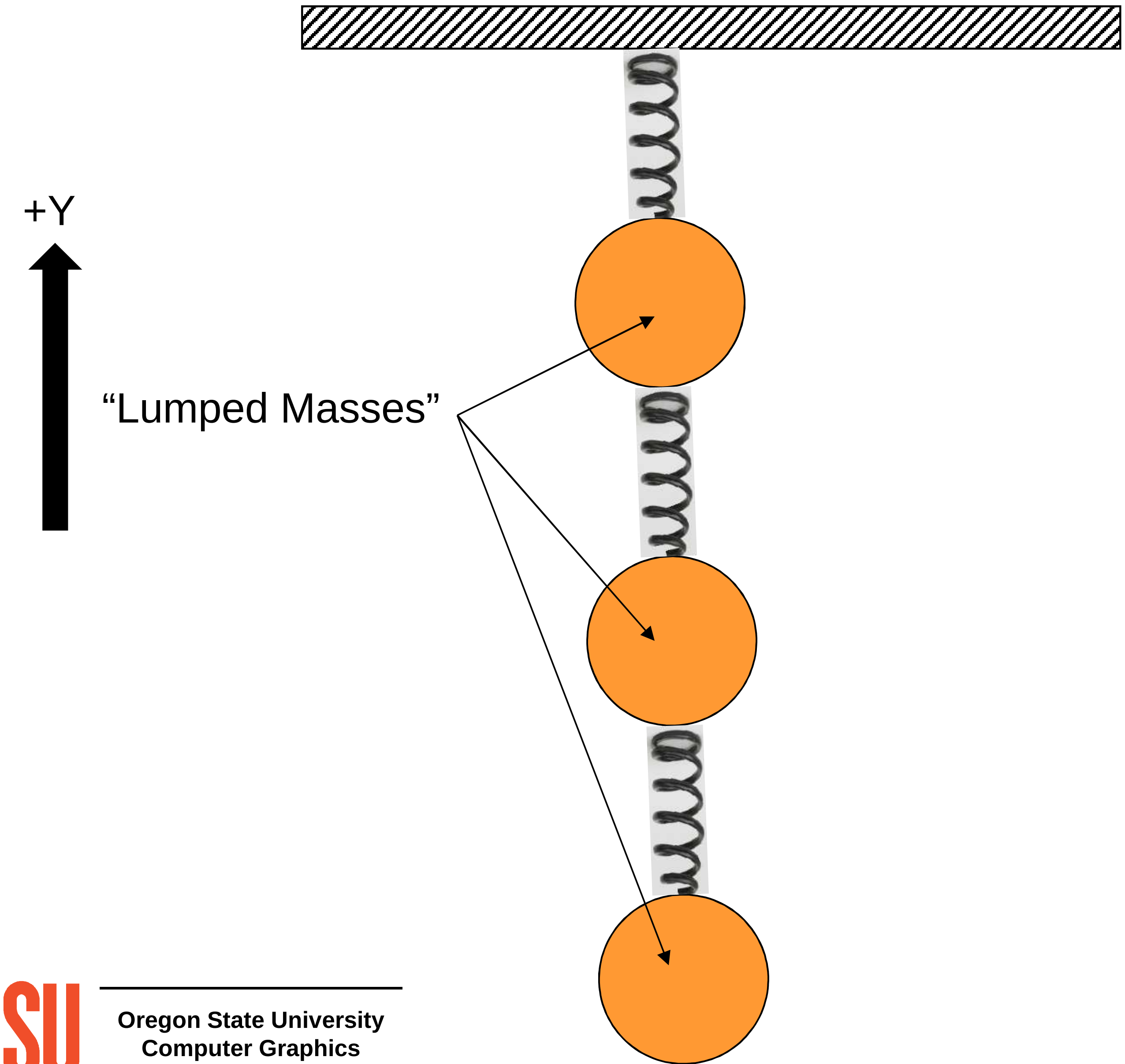
k = ***spring stiffness*** in Newtons/meter or pounds/inch

Or, if you know the displacement, the force exerted by the spring is:

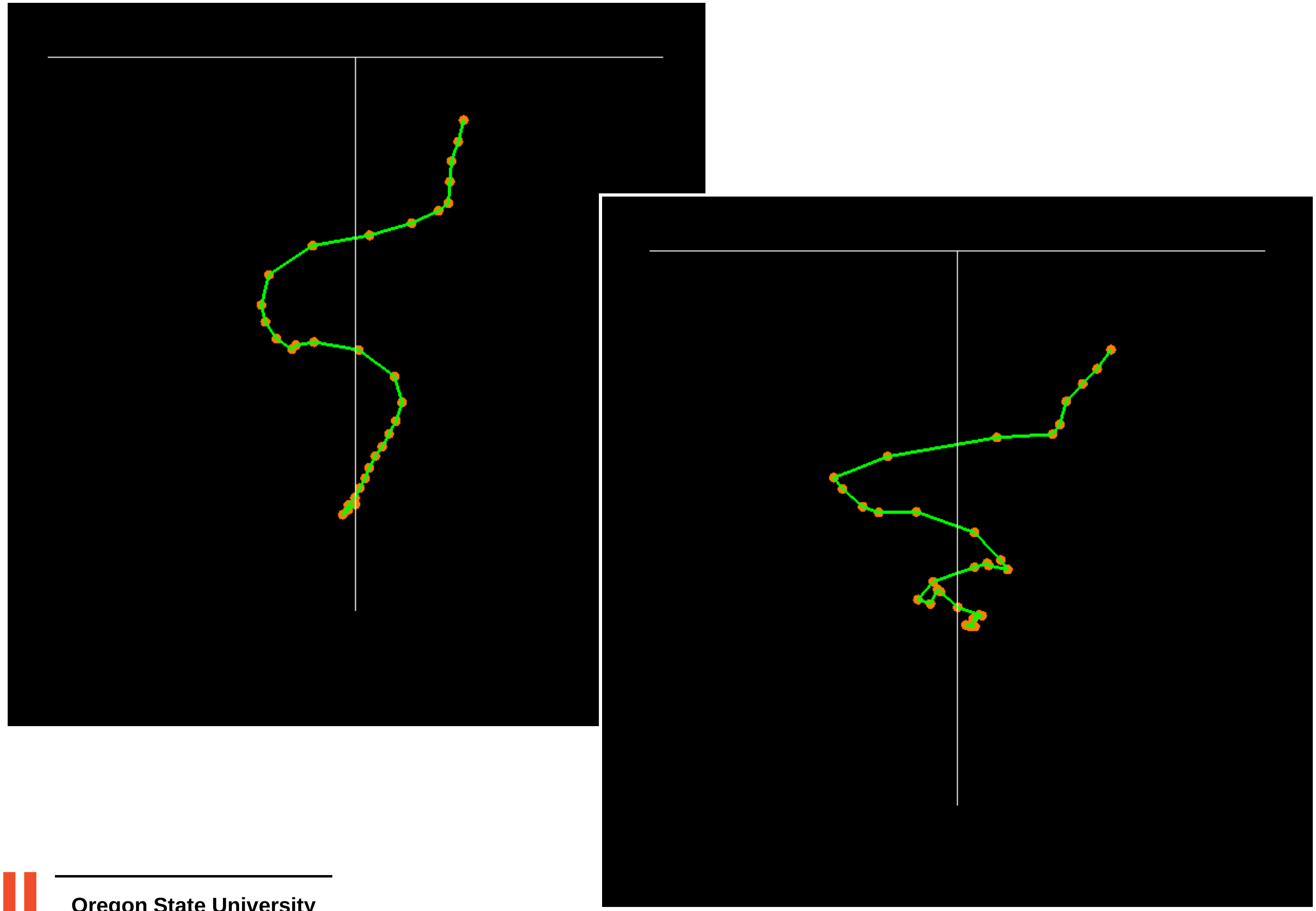
$$F = k(D - D_0)$$

This is known as Hooke's law

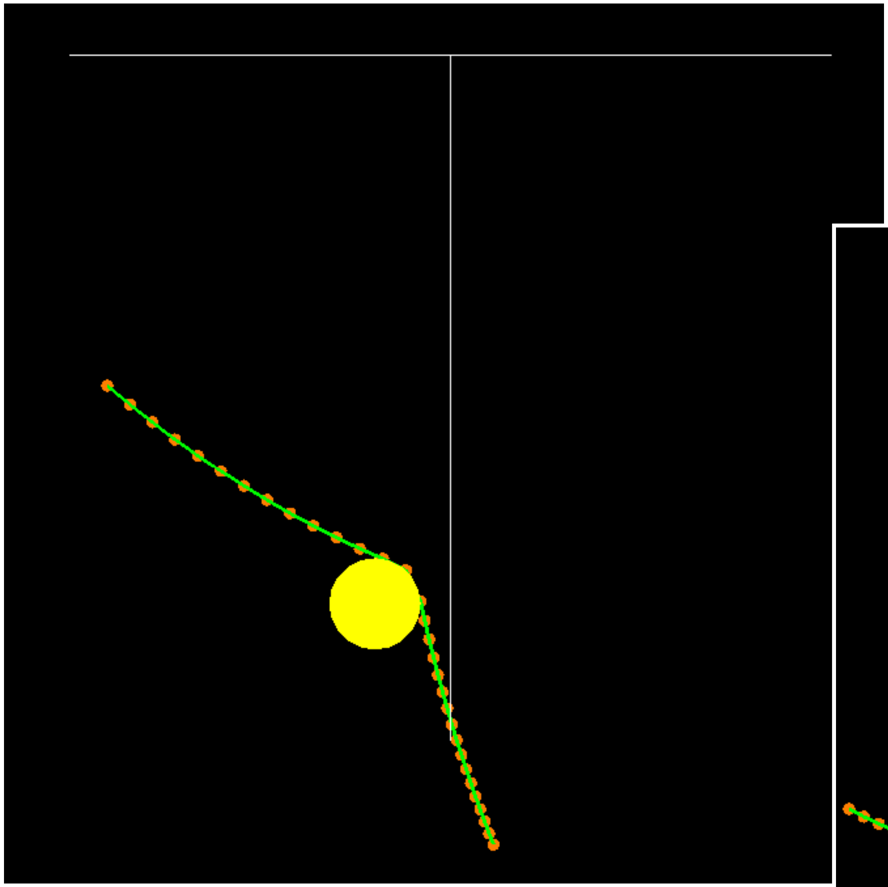
Animating using the Physics of a Mesh of Springs

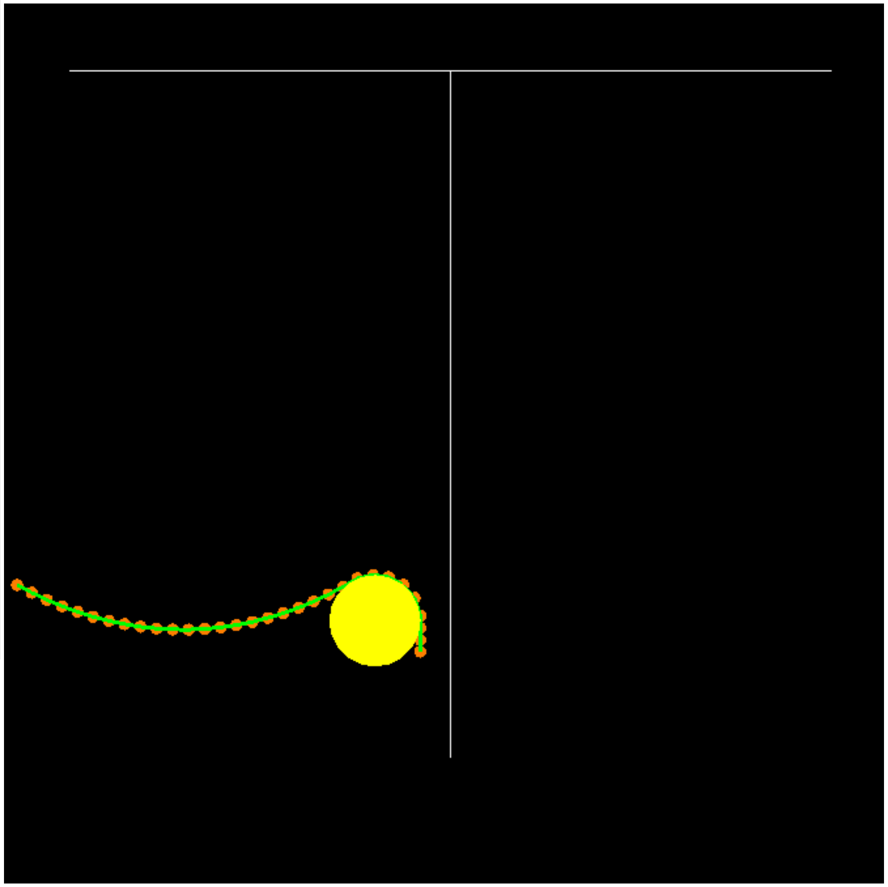


Simulating a Bouncy String

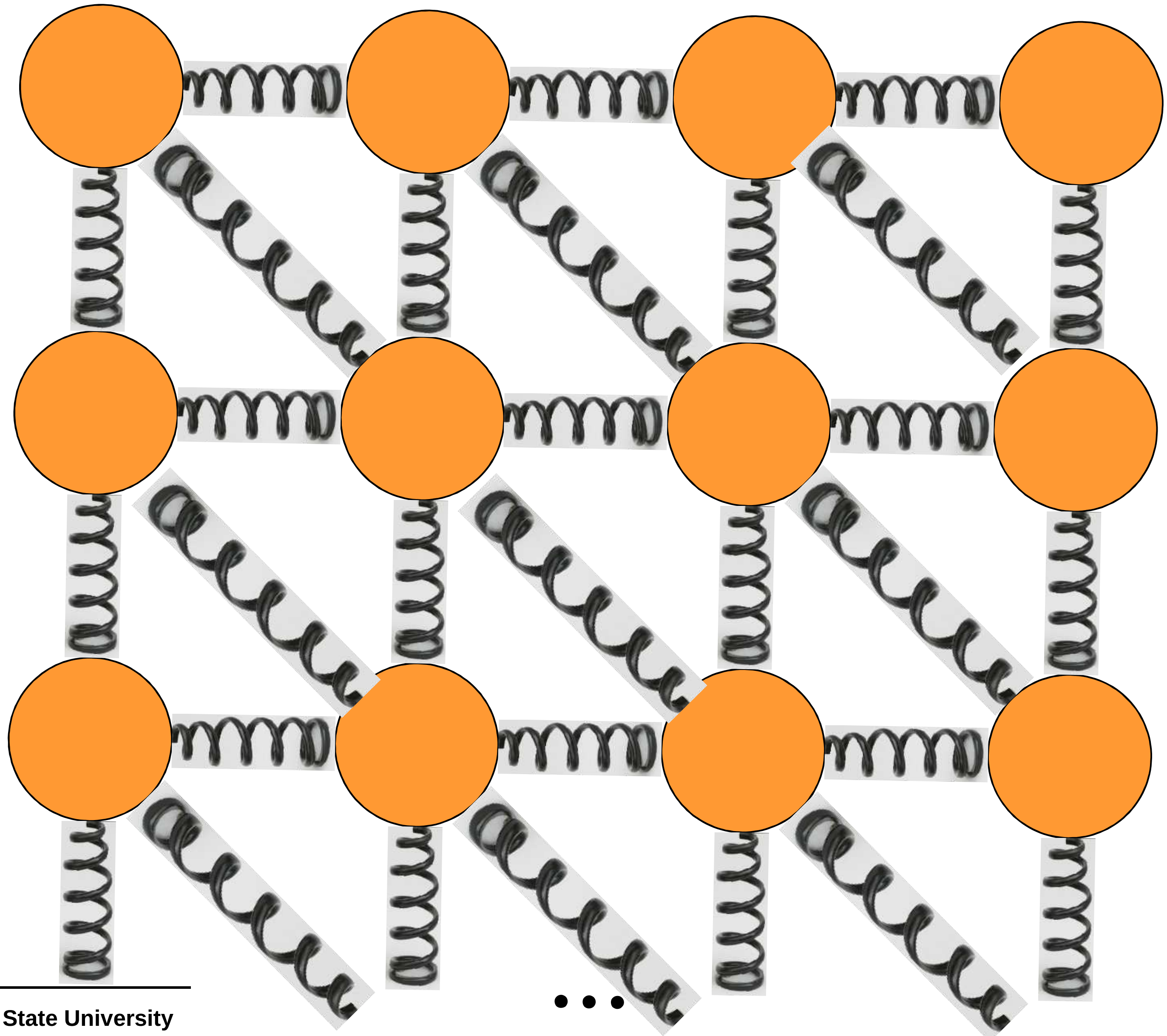


Placing a Physical Barrier in the Scene

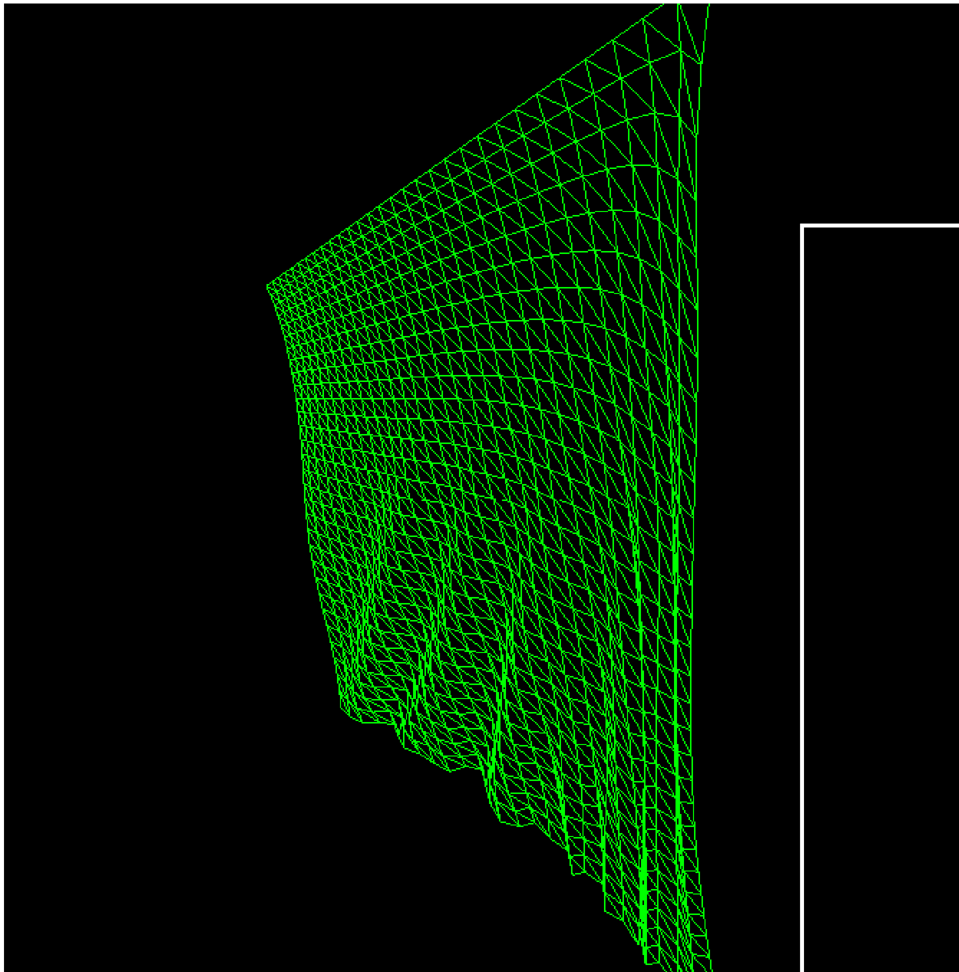


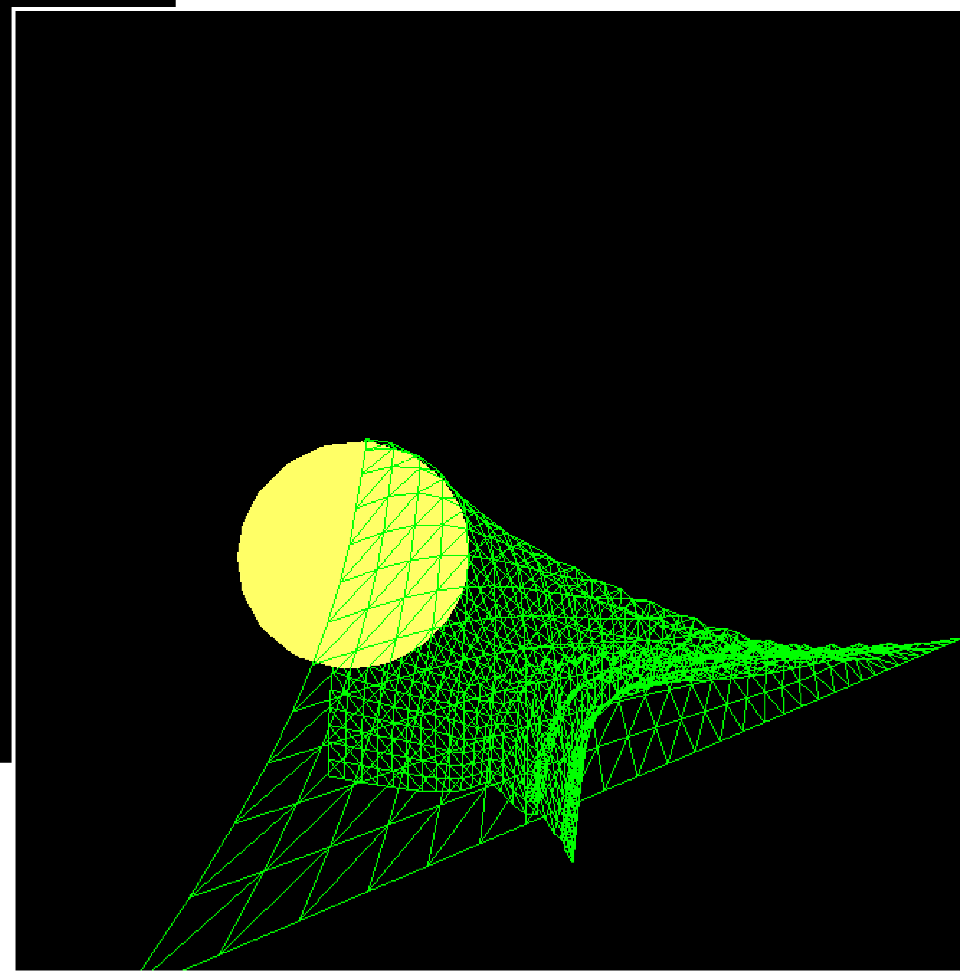


Animating Cloth



Cloth Examples





Cloth Examples





David Breen, Donald House, Michael Wozny: *Predicting the Drape of Woven Cloth Using Interacting Particles*

Cloth Examples

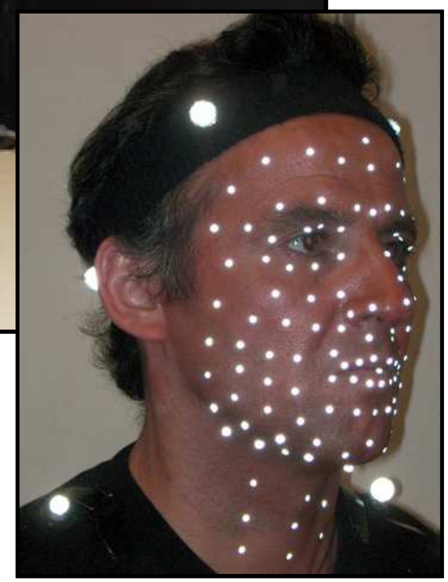
MiraLab, University of Geneva

Motion Capture

NaturalPoint

Polhemus

Polhemus



MocapLab


Finding Additional
Information

Where to Find More Information about Computer Graphics and Related Topics

Mike Bailey
Oregon State University

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`http://www.siggraph.org/publications/bibliography`

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(`http://www.computer.org`, 714-821-8380)

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

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

SIGHPC ....ACM Special Interest Group on High-Performance Computing
`http://sighpc.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

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. Upcoming Conferences

ACM SIGGRAPH:
2012: Los Angeles, CA – August 5-9
2013: Anaheim, CA – July 21-25
2014: Vancouver, BC – August 10-14
http://www.siggraph.org/s2012
http://www.siggraph.org/s2013
http://www.siggraph.org/s2014

ACM SIGGRAPH Asia:
2012: Singapore – November 28-December 1
http://www.siggraph.org/asia2012

ACM SIGCHI:
2013: Paris, France – April 27 - May 2
http://www.sigchi.org

SC: International Conference for High Performance Computing, Networking, Storage, and Analysis:
2012: Salt Lake City, UT -- November 10-16
http://www.supercomputing.org

IEEE Visualization:
2012: Seattle, WA – October 14-19
http://visweek.org

Eurographics
2013: Girona, Spain – May 6-10
http://eg2013.udg.edu/

Game Developers Conference:
2013: San Francisco, CA – March 25 - 29
http://www.gdconf.com

E3Expo
2012: Los Angeles, CA – June 7-9

http://www.e3expo.com

PAX (Penny Arcade Expo)
2012: Seattle, WA– August 31 – September 2
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):
2013: Las Vegas, NV – April 6-11
http://www.nab.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