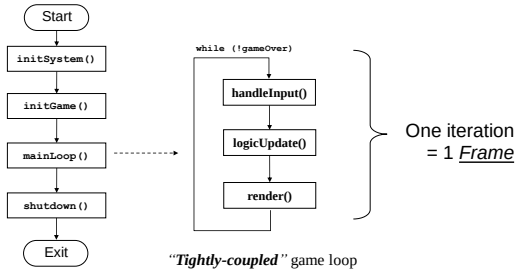
CSc 165
Computer Game Architecture

17 - Additional Topics

Game-Loop Approaches

- Tightly-Coupled
- Fixed frame rate
- Variable-timestep update()
- Gameloop-managed update timing
- Fixed logic rate
- Renderer frame interpolation
- Multi-threading

Review: Game Structure



*"**Tightly-coupled**"* game loop

Tightly-Coupled Approach

Difficulties :

- Different machine speeds produce different game flow effects
- Changes to game logic (e.g. AI) can slow down presentation (frame rate)

Problem source:

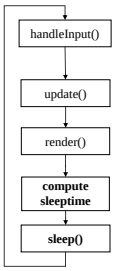
- The two steps have different inherent frequencies
  - `logicUpdate()` frequency should be *fixed*;
  - `render()` frequency should *optimize hardware use*

Conclusion:

- Need to somehow "decouple" the steps

Fixed frame rate

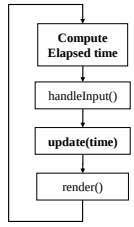
Constant frame – and update – rate (one update per frame)




```
desiredFrameDuration = (1/desiredFPS)*1000000000; //nsec
while (!gameOver)
{  frameStartTime = System.nanoTime();
   handleInput();
   update();
   render();
   frameEndTime = System.nanoTime();
   frameDuration = frameEndTime - frameStartTime;
   while (frameDuration < desiredFrameDuration)
   {  sleepTimeMSec =
         (desiredFrameDuration-frameDuration) / 1000000;
      sleep (sleepTimeMSec);
      frameDuration = System.nanoTime() - frameStartTime;
   }
   yield();  //in case we never sleep
}
```


Variable-timestep updating

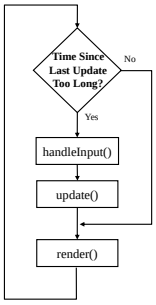
`update()` is responsible for accounting for time variation




```
lastUpdateTime = System.nanoTime();
while (!gameOver)
{  timeNow = System.nanoTime();
   elapsedTime = timeNow - lastUpdateTime;
   lastUpdateTime = timeNow;
   handleInput();
   update(elapsedTime);
   render();
}
```

Gameloop-Managed Timed update

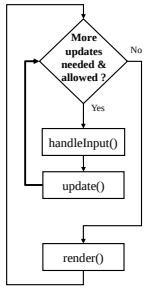
Game-loop accounts for time variation




```
desiredUpdatePeriod = (1/desiredUPS)*1000000000;
lastUpdateTime = System.nanoTime();
while (!gameOver)
{   curTime = System.nanoTime();
    timeSinceLastUpdate = curTime - lastUpdateTime;
    if (timeSinceLastUpdate > desiredUpdatePeriod)
    {   handleInput();
        update();
        lastUpdateTime = System.nanoTime();
    }
    render();
}
```


Fixed logic rate

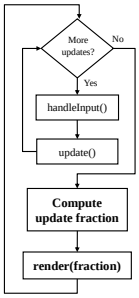
Multiple logic updates between renders as necessary to maintain a fixed logic rate (i.e., to "catch up")




```
updatePeriod = (1/desiredUPS)*1000000000;
startTime = System.nanoTime();
while (!gameOver)
{   currentTime = System.nanoTime();
    timeSinceLastUpdate = currentTime-startTime;
    loopCount = 0;
    while (updateRateTooLow() && loopCount<MAX )
    {       handleInput();
            update();
            startTime += updatePeriod;
            timeSinceLastUpdate = currentTime-startTime;
            loopCount ++ ;
    }
    render();
}
boolean updateRateTooLow()
{   if (timeSinceLastUpdate > updatePeriod)
        return true ;
    else return false ;
}
```


Interpolated frames

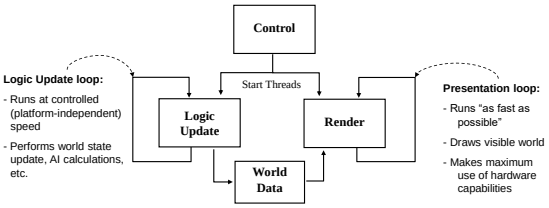
- **`render()`** assists in accounting for time variation (e.g. by smoothing animations)




```
desiredUpdatePeriod = (1/desiredUPS)*1000000000;
startTime = System.nanoTime();
while (!gameOver)
{   currentTime = System.nanoTime();
    timeSinceLastUpdate = currentTime-startTime;

    //...loop here to do multiple updates as before...

    //check if update loop hit MAX
    if ( updateRateTooLow())
    {   //yes, loop hit MAX; advance start time to
        //  within 'period' of current time
        startTime = currentTime-desiredUpdatePeriod;
    }

    percentWithinUpdatePeriod = min ( 1.0,
            ((currentTime-startTime)/desiredUpdatePeriod));

    render(percentWithinUpdatePeriod);
}
```


Multi-threaded Approach

Separate threads for **`Update()`** and **`Render()`**



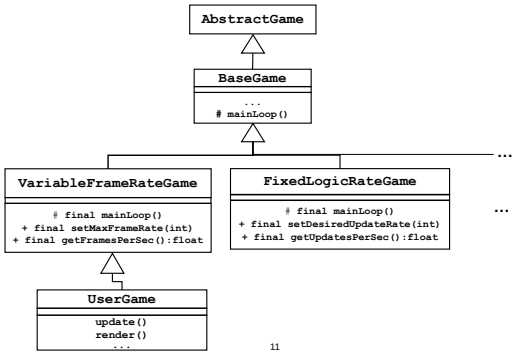
Logic Update loop:

- Runs at controlled (platform-independent) speed
- Performs world state update, AI calculations, etc.

Presentation loop:

- Runs "as fast as possible"
- Draws visible world
- Makes maximum use of hardware capabilities

Game Engine Timing Support



Normal Mapping

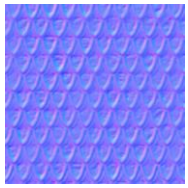
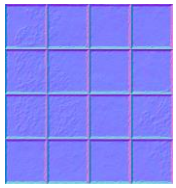
The (X,Y,Z) values of the normal can be stored as (R,G,B) values in an image file called a normal map.

Converting normal (-1...+1) to RGB (0...1) is easy:

$$R = (N_X + 1)/2$$
$$G = (N_Y + 1)/2$$
$$B = (N_Z + 1)/2$$

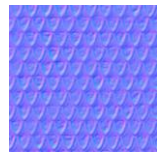
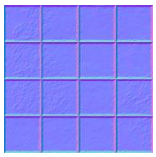
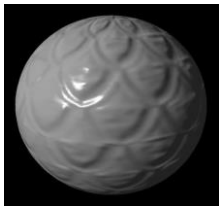
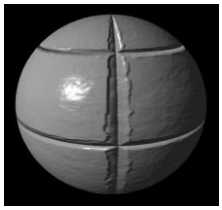
The normal map can then be stored in a texture!

Example normal maps:

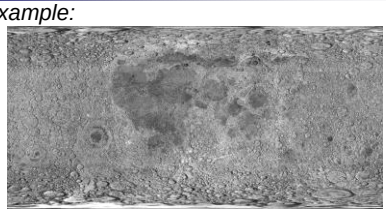
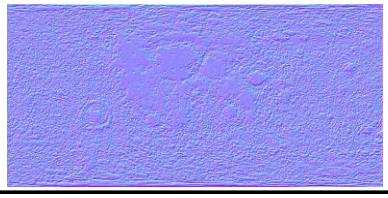



Values in normal maps are usually stored as offsets from vertical relative to the plane tangent to the surface, with the Z (or B) coordinate set to 1.0. This is why normal maps appear "bluish".

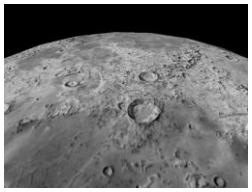
The surface tangent plane is defined by mutually-perpendicular tangent and bi-tangent vectors (both perpendicular to the normal).

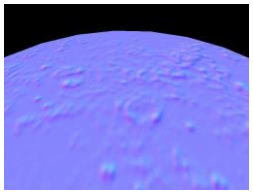
Moon example:

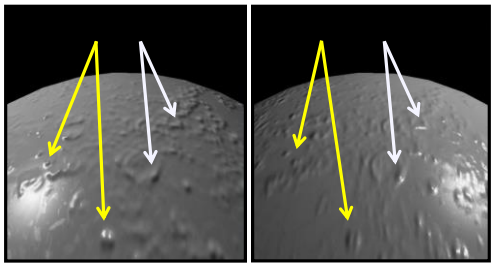
Sphere with moon texture map:



Sphere textured with corresponding normal map:

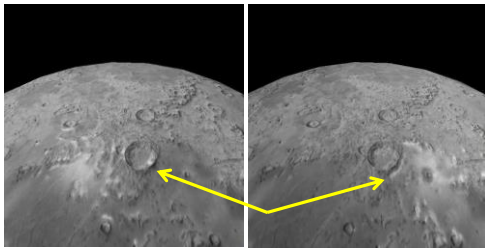


Normal map lighting effects on moon:



Note the changes in specular highlights at the indicated locations.

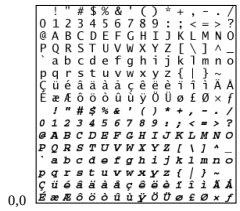
Combining texture map and lighting with normal map -- effect on moon:

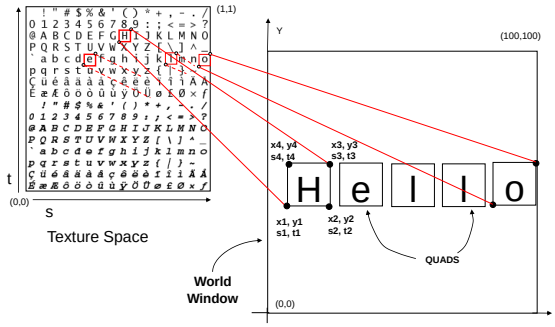


Texture-Mapped Fonts

Create a texture map image containing font characters:

- "texture map" each desired character to a single polygon
- Build output image strings from texture-mapped polygons





Texture-Mapped Fonts (cont.)

Drawbacks:

- Requires an external application to create the font texture
- Scaling can affect font appearance
- Difficult to implement proportionally-spaced fonts
- Uses up a texture unit

see the Wikibook "Modern OpenGL Tutorial Text Rendering 01"

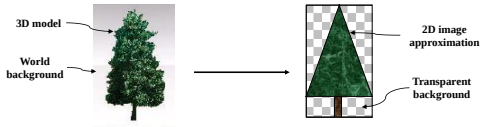
Billboards

Basic approach:

- Replace a complex 3D model with a 2D image
- Maintain image orientation toward camera

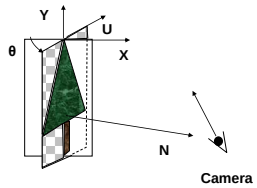
Works well when

- Model is sufficiently "far away"
- Model tends to have "axial symmetry"



Basic steps:

- Create flat object with 2D texture-mapped image
- Translate object to tree location in world
- Rotate object so that it points to the camera



X = {1,0,0}
N = Camera – Loc
Y = V = {0,1,0}
U = V ⊗ N
Θ = X • U

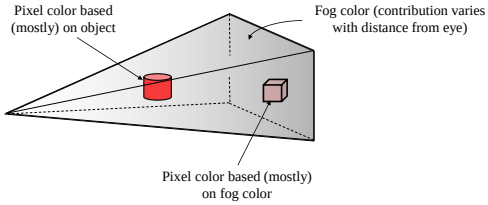
Atmospheric Effects - Fog

A useful effect: blend pixel color with another color (e.g. gray) based on *distance from eye.*

"Fog" is not just for simulating fog, but also for enhancing the sense of 3D depth for the viewer.

There are simple models, as well as sophisticated models that include light scattering effects.

Fog (simple approach)



a more comprehensive model:

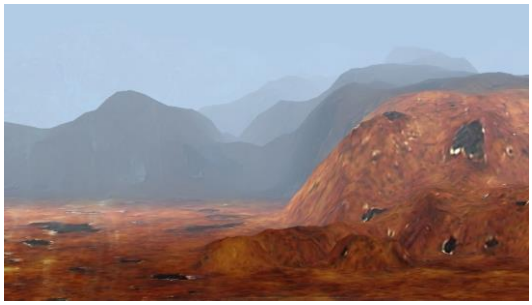
Extinction – *rate of decay from image color to black*

Inscattering – *rate of change from image color to fog color*

$f_e = e^{-zx}$

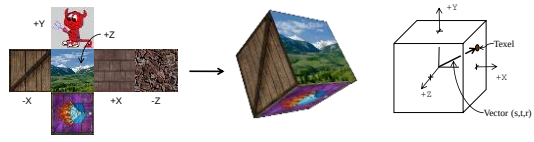
$f_i = e^{-zs}$

z = distance from eye to object,
x = extinction coefficient,
s = inscattering coefficient



Atmospheric Effects – Environment Mapping

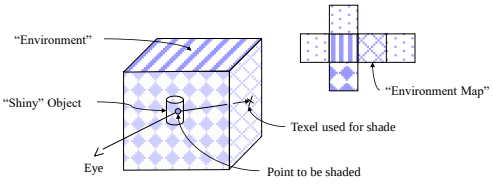
- OpenGL cubemap =
  a *single* texture object with *six* 2D faces
- Texture coords (s,t,r) = vector from the *cube center*

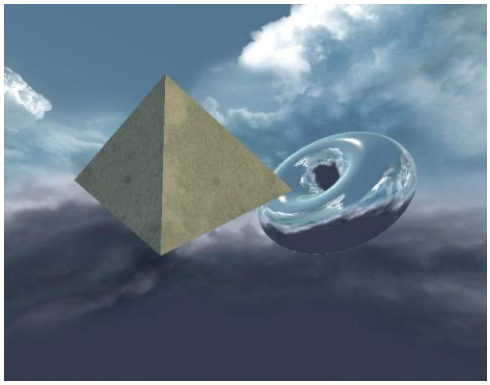


using OpenGL cubemaps makes
"environment mapping" easier

Environment Mapping

- Useful technique for rendering "mirror" objects
- Create texture cube map describing the "environment"
- Shade object points by following "reflection" of eye vector (to surface normal) into the map





3D Textures

- 2D Texture Images are "painted on"
  … and sometimes they look like it
- Desired: make it look like an object is "made out of" some material

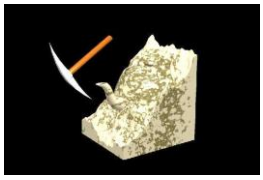
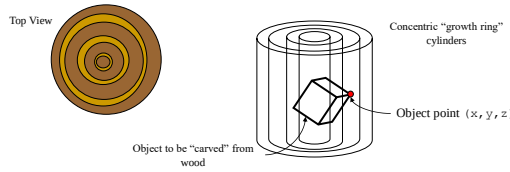


Image source: ACM SIGGRAPH Education Slide Set, R. Wolfe, DePaul Univ.

3D Texture Example: Wood-grain

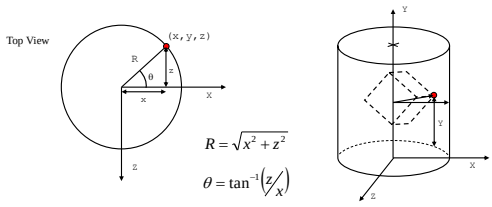
Wood grain is caused by *tree rings*



Needed: a function `f(x,y,z)` mapping an object location into the "wood space" – i.e. obtaining the "wood color"

wood-grain example (cont.)

Computing cylindrical location for `(x,y,z)` object point

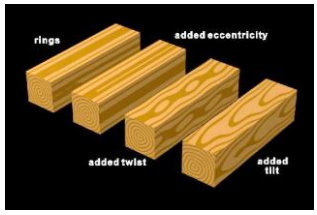


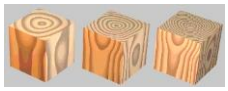
$$R = \sqrt{x^2 + z^2}$$

$$\theta = \tan^{-1}\left(z/x\right)$$

$$H = y$$

wood-grain sample results





Variations in ring density

Variations in Ring Width

Image source: ACM SIGGRAPH Education Slide Set, R. Wolfe, DePaul Univ.

Perlin Noise

Ken Perlin (NYU), 1985

- "Classic Noise" (1985)
  - Gradient noise using cubic Hermite interpolation
- "Improved Noise" (2001)
  - Gradient noise using quintic interpolation and precomputed gradients
- "Simplex Noise" (2005)
  - Hardware implementation

Computer Graphics V19 No.3, July 1989

AMPAS Oscar, 1997

"Randomness" is important in many 3D textures:

- Natural materials (wood, marble, granite …)
- Man-made materials (stucco, asphalt, cement …)
- Natural phenomena (clouds, fire, smoke, wind effects …)
- Model imperfections (rust, dirt, smudges, dents …)
- Pattern and motion imperfections (bumps, wobbles, jitters…)

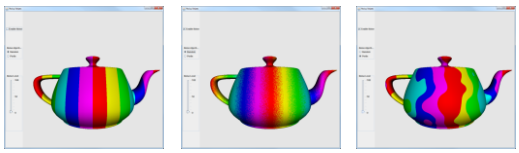
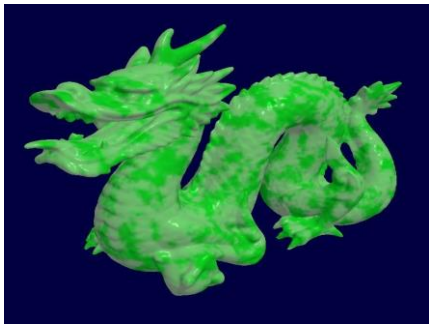


Image source: ACM SIGGRAPH Education Slide Set, R. Wolfe, DePaul Univ.

Example – "Jade"



Atmospheric Effects - Clouds

Clouds are complex:

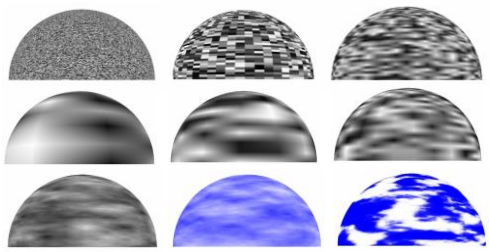
- scatter and reflect light in diverse ways
- drift and morph over time

There are simple models, as well as sophisticated models that include light scattering effects.

Simple models often use 3D textures and Perlin noise.

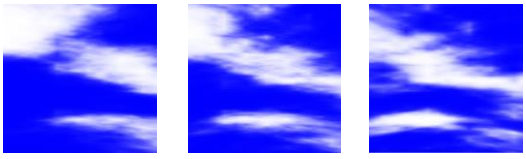
Atmospheric Effects - Clouds

Mixing 3D noise at different levels of precision:



Atmospheric Effects - Clouds

3D texture allows efficient "morphing" by slowly changing the Z parameter when accessing texture map:

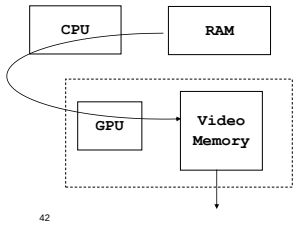


"Immediate-Mode" Graphics

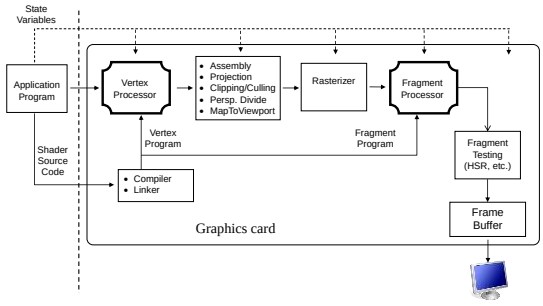
CPU transfers RAM data over main bus

- Time consuming
- Bus Contention

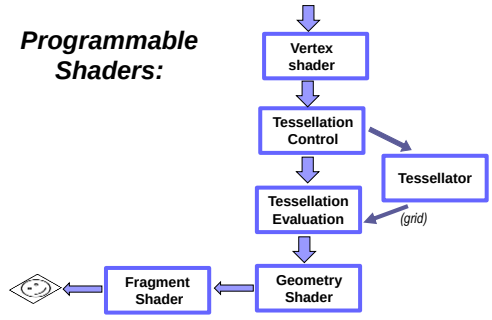
```
glBegin(GL_TRIANGLES);
   glColor3f (1.0, 0.0, 0.0);
   glVertex3f(0.0, 0.0, 0.0);
   glColor3f (0.0, 1.0, 0.0);
   glVertex3f(1.0, 0.0, 0.0);
   glColor3f (0.0, 0.0, 1.0);
   glVertex3f(1.0, 1.0, 0.0);
glEnd();
```



The *PROGRAMMABLE* Graphics Pipeline



Programmable Shaders:

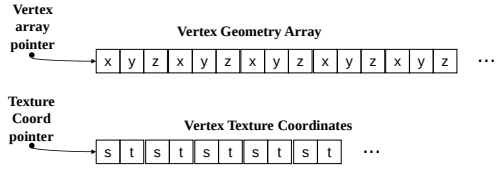


Hardware ("Shader") Programming

High-level languages:

- **HLSL** ("High-Level Shading Language")
  - Proprietary (Microsoft)
  - Powerful
  - Specific to DirectX
- **Cg** ("C for graphics")
  - Proprietary (nVidia)
  - Supports both DirectX and OpenGL APIs (more complex)
- **GLSL** ("OpenGL Shading Language")
  - Open standard
  - Compiles to all common vendor chips
  - Can run "on top of" DirectX, or directly on hardware

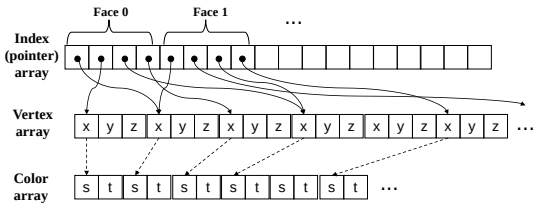
Vertex Arrays



Steps to use Vertex Arrays:

- Enable use of each array type (geometry, tex, etc.)
- Point to each array to be used
- Load each array with data (geometry, tex, etc.)
- Specify what to draw, and from where, in the arrays

Indexed Vertex Arrays



Vertex Buffer Objects (VBOs)

- Map an "application buffer" *directly to high-speed video memory (such as DRAM)*
- Buffers can include *"vertex arrays"*
- Methods like **`glDrawArrays()`** operate on video memory data

see CSc-155…