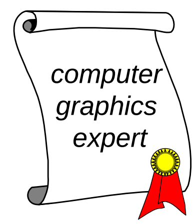
Chapter 2

Basics of Computer Graphics:
Rendering Pipeline/OpenGL

Course Info/Policies (boring stuff):
http:www.ugrad.cs.ubc.ca/~cs314

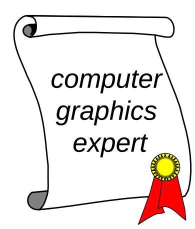
Grading

- Programming Assignments: 40%
- Weekly Mini Home Quizes: 3%
- Participation 2%
  - Classroom
  - Review question composition
- Two Midterms: 25%
  - 12% +13%
- Final Exam: 30%



Grading

- Programming Assignments: 40%
  - 2D Game: Intro to OpenGL (6%) – **out now**
  - 3D Transformations – modeling/animation (11%)
  - Rendering pipeline (11%)
  - Ray tracing (12%)



Grading

- Participation (2%)
  - Classroom: ***Clicker*** responses + classroom involvement
  - Post two weekly review questions
    - Based on material covered each week
    - Submit via DB (private, rev# tag)
      - till Mon 9AM
    - Include: question, multiple choice answers, explanation

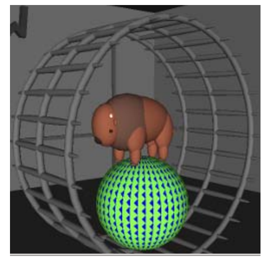
Grading

- Mini Home Quizes: (3%)
  - Online (connect.ubc.ca) quiz each week (from week 2)
  - Released by Tue AM, Due Friday 9AM
  - Multiple choice questions
    - Student/instructor composed
    - If your question selected - double your quiz grade !!!
    - If two selected triple..

Important Dates

- Assignment 1 due: Sep 21
- Assignment 2 due: Oct 12
- Assignment 3 due: Nov 2
- Assignment 4 due: Nov 30

- Midterm 1: Oct 19
- Midterm 2: Nov 9



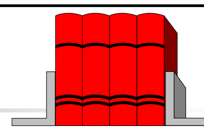
Course Organization

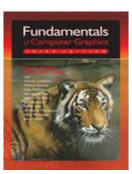
- Programming assignments:
  - C++, Windows or Linux
    - **Tested on department Linux machines**
  - OpenGL graphics library / GLUT for user interface
- **Face to face grading in lab**
  - Opportunity to show all the “cool” extra stuff
  - Test that you do *know* what every piece of your code does
- Hall of fame – coolest projects from 2002 on

Late/Missing Work

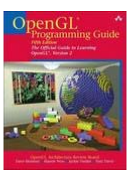
- Programming Assignments:
  - 3 grace days **TOTAL**
    - for unforeseen circumstances
    - strong recommendation: don't use early in term
    - handing in late uses up automatically unless you tell us
- Home Quizes/Review Question Sets
  - Can miss *two* of each
- Exception: severe illness/crisis, as per UBC rules
  - MUST
    - Get approval from me ASAP (in person or email)
    - Turn in proper documentation

Literature (optional)





- Fundamentals of Computer Graphics
  - *Third edition (second is OK too – but note syllabus changes)*
  - Peter Shirley, A.K. Peters



- OpenGL Programming Guide
  - J. Neider, T. Davis and W. Mason, Addison-Wesley

Learning OpenGL

- This is a graphics course using OpenGL
  - not a course **ON** OpenGL
- Upper-level class: learning APIs mostly on your own
  - only minimal lecture coverage
    - basics, some of the tricky bits
  - OpenGL Red Book
  - many tutorial sites on the web
    - http://www.xmission.com/~nate/opengl.html

Plagiarism and Cheating

- Short Summary: Don't cheat
  - Home quizes and programming assignments are individual work
  - Can discuss ideas (including on DB), browse Web
  - But cannot copy code or answers/questions
    - If you REALLY think using a source is OK cite it
- **Must** be able to explain algorithms during face-to-face demo
  - or no credit for that assignment, possible prosecution

Basics of Computer Graphics: Rendering Pipeline

Rendering

Goal:

- Transform (3D) computer models into images
- Photo-realistic (or not)

Interactive rendering:

- Fast, but until recently low quality
- Roughly follows a fixed patterns of operations
  - **Rendering Pipeline**

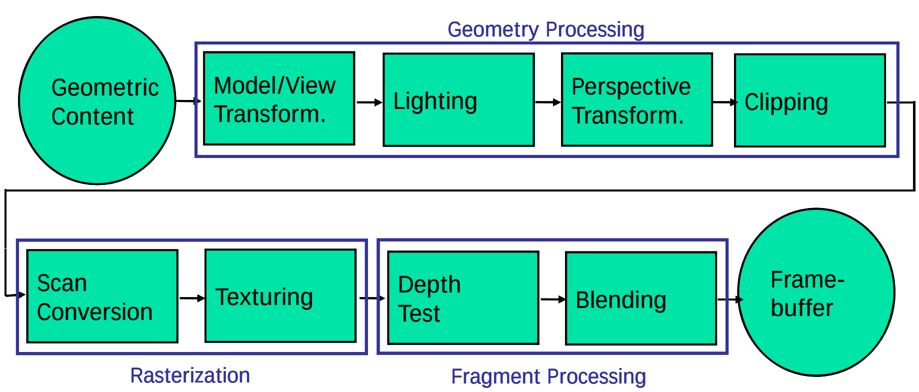
Offline rendering:

- Ray-tracing
- Global illumination

Rendering Tasks (no particular order)

- Project 3D geometry onto image plane
  - Geometric transformations
- Determine which primitives/parts of primitives are visible
  - Hidden surface removal
- Determine which pixels geometric primitive covers
  - Scan conversion
- Compute color of every visible surface point
  - Lighting, shading, texture mapping

The Rendering Pipeline



Rendering Pipeline

- Abstract model of
  - sequence of operations to transform geometric model into digital image
  - graphics hardware workflow
- Underlying API (application programming interface) model for programming graphics hardware
  - OpenGL
  - Direct 3D
- **Actual implementations vary**

Advantages of pipeline structure?

- Logical separation of different components, modularity
- Easy to parallelize:
  - Earlier stages can already work on new data while later stages still work with previous data
  - Similar to pipelining in modern CPUs
  - But much more aggressive parallelization possible (special purpose hardware!)
  - Important for hardware implementations!
- Only local knowledge of the scene is necessary

Disadvantages?

- Limited flexibility
- Some algorithms would require different ordering of pipeline stages
  - Hard to achieve while still preserving compatibility
- Only local knowledge of scene is available
  - Shadows
  - Global illumination

(Tentative) Lecture Syllabus

- Introduction + Rendering Pipeline (week 1/2)
- Transformations (week 2/3)
- Scan Conversion (week 4/5)
- Clipping (week 5)
- Hidden Surface Removal (week 6/7)
- Review & Midterm (week 7)
  - Midterm: Oct 19
- Lighting Models (week 8)
- Texture mapping (week 9/10)
- Review & Midterm (week 10)
  - Midterm: Nov 9
- Ray Tracing (week 11)
- Shadows (week 11/12)
- Modeling (content creation) (week 12/13)
- Review (last lecture)

Rendering Pipeline Implementation: OpenGL/GLut

OpenGL

- API for graphics hardware
  - Started in 1989 by Kurt Akeley
- Designed to exploit graphics hardware
- Implemented on many different platforms

- **Pipeline processing**
  - **Event driven**
  - **Communication via state setting**

GLUT: OpenGL Utility Toolkit

- **Event driven !!!**

```
int main(int argc, char **argv)
{
     // Initialize GLUT and open a window.
    glutInit(&argc, argv);
    glutInitDisplayMode(GLUT_RGB | GLUT_DOUBLE);
    glutInitWindowSize(800, 600);
    glutCreateWindow(argv[0]);

    // Register a bunch of callbacks for GLUT events.
    glutDisplayFunc(display);
    glutReshapeFunc(reshape);

    // Pass control to GLUT.
    glutMainLoop();

    return 0;
}
```

Event-Driven Programming

- Main loop not under your control
  - vs. procedural
- Control flow through event callbacks
  - redraw the window now
  - key was pressed
  - mouse moved
- Callback functions called from main loop **when events occur**
  - mouse/keyboard, redrawing...

Graphics State (global variables)

- Set state once, remains until overwritten
  - glColor3f(1.0, 1.0, 0.0) → set color to yellow
  - glSetClearColor(0.0, 0.0, 0.2) → dark blue bg
  - glEnable(LIGHT0) → turn on light
  - glEnable(GL_DEPTH_TEST) → hidden surf.

OpenGL/GLUT Example

```
void display(void) {// Called when need to redraw screen.
        // Clear the buffer we will draw into.
       glClearColor(0, 0, 0, 1);
       glClear(GL_COLOR_BUFFER_BIT);

       // Initialize the modelview matrix.
       glMatrixMode(GL_MODELVIEW);
       glLoadIdentity();

       // Draw STUFF

       // Make the buffer we just drew into visible.
       glutSwapBuffers();
}
```

GLUT Example

```
int main(int argc, char *argv[]) {
   .....
    // Schedule the first animation callback ASAP.
    glutTimerFunc(0, animate, 0);
    // Pass control to GLUT.
    glutMainLoop();
    return 0;
}
void animate(int last_frame = 0) {
   // Do stuff
    // Schedule the next frame.
    int current_time = glutGet(GLUT_ELAPSED_TIME);
    int next_frame = last_frame + 1000 / 30;
    glutTimerFunc(MAX(0, next_frame - current_time),
   animate, current_time);
}
```

GLUT Input Events

```
  // you supply these kind of functions
void reshape(int w, int h);
void keyboard(unsigned char key, int x, int y);
void mouse(int but, int state, int x, int y);

  // register them with glut
glutReshapeFunc(reshape);
glutKeyboardFunc(keyboard);
glutMouseFunc(mouse);
```

GLUT and GLU primitives

```
gluSphere(...)
gluCylinder(...)

glutSolidSphere(GLdouble radius, GLint slices, GLint stacks)
glutWireSphere(...)

glutSolidCube(GLdouble size)
glutWireCube(...)

glutSolidTorus(...)
glutWireTorus(...)

glutSolidTeapot(...)
glutWireTeapot(...)
```

- Note:
  - Have limited set of parameters
  - Control via global transformations (see a1 template)
  - **Need to save/restore setting**

GLUT and GLU primitives

- Example (from a1):

```
void Pad::draw() {
    glColor3f(1, 1, 1);
    glPushMatrix(); → Save previous state
    glTranslatef(x_, y_, 0);
    glScalef(width_, height_, 1);
    glNormal3f(0, 0, 1);
    glBegin(GL_QUADS);
    glVertex3f(-0.5, -0.5, 0);
    glVertex3f(-0.5, 0.5, 0);
    glVertex3f(0.5, 0.5, 0);
    glVertex3f(0.5, -0.5, 0);
    glEnd();
    glPopMatrix(); → Restore previous state
}
```

GLUT and GLU primitives

- Basic Transformations:

```
// Different basic transformations
glTranslatef(…);
glRotatef(…);
glScalef(…);
```

Your tasks for the weekend

- Piazza Discussion Group:
  - Register
  - Post review questions by Mon 9AM
    - Use private option, rev1 tag

- Assignment 1
  - Test programming environment on lab computers/Set laptop environment (optional)
  - Should have all the necessary background after this class

Your tasks for the weekend

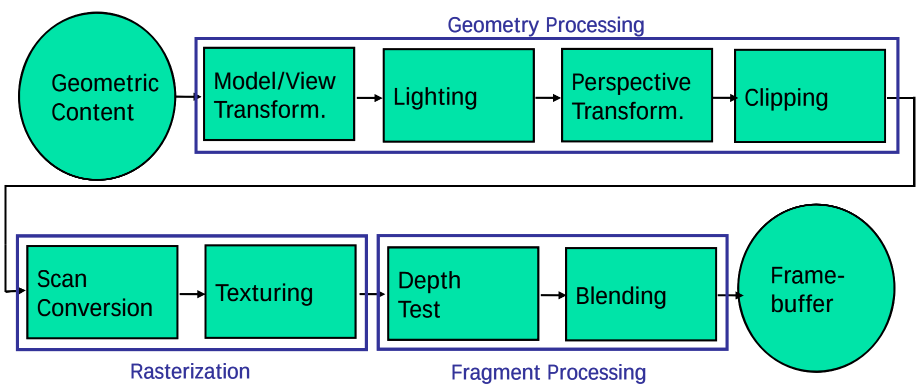
- Sign and Submit Plagiarism Form
  - http://www.ugrad.cs.ubc.ca/~cs314/Vsep2012/plag.html
- Optional reading (Shirley: Introduction to CG)
  - Math refresher: Chapters 2, 4
    - **Lots of math coming in the next few weeks**
  - Background on graphics: Chapter 1

Assignment 1

- Experience OpenGL & GLUT
- Have FUN
- Description:
  http://www.ugrad.cs.ubc.ca/~cs314/Vsep2012/a1/a1.pdf
- Deadline: Sep 21

Rendering Pipeline in (More) Detail

The Rendering Pipeline



3D Content

- Needs to represent models for
  - Shapes (objects)
  - Relations between different shapes
  - Object materials
  - Light sources
  - Camera

Shapes

- Different philosophies:
  - Volumetric
    - Boolean algebra with volumetric primitives
      - Spheres, cones, cylinders, tori, …
  - Boundary representation
    - Single basic primitive
      - Triangles or triangle meshes, points, lines
    - Higher order surface primitives with adjustable parameters
      - E.g. “all polynomials of degree 2”
      - Splines, NURBS (details in CPSC 424)
      - Implicits

Curves/Surfaces

- Mathematical representations:
  - Explicit functions
  - Parametric functions
  - Implicit functions

Explicit Functions

- Curves:
  - y is a function of x: $y := \sin(x)$
  - Only works in 2D
- Surfaces:
  - z is a function of x and y: $z := \sin(x) + \cos(y)$
  - Cannot define arbitrary shapes in 3D

Parametric Functions

- Curves:
  - 2D: x and y are functions of a parameter value t
  - 3D: x, y, and z are functions of a parameter value t

$$C(t) := \begin{pmatrix} \cos(t) \\ \sin(t) \\ t \end{pmatrix}$$

Parametric Functions

- Surfaces:
  - Surface S is defined as a function of parameter values s, t
  - Names of parameters can be different to match intuition:

$$S(\phi,\theta) := \begin{pmatrix} \cos(\phi)\cos(\theta) \\ \sin(\phi)\cos(\theta) \\ \sin(\theta) \end{pmatrix}$$

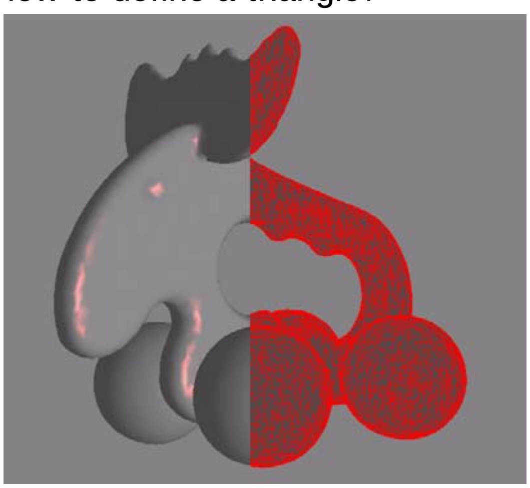
Shapes

- Implicit Surfaces:
  - Surface defined by zero set (roots) of function
  - E.g:

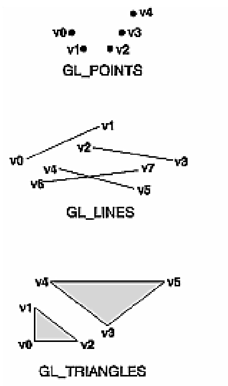
$$S(x, y, z): x^2 + y^2 + z^2 - 1 = 0$$

Shapes

- Triangles and Triangle Meshes:
  - How to define a triangle?



Open GL: (Some) Shape Primitives



glPointSize(float size);
glLineWidth(float width);
glColor3f(float r, float g, float b);
....

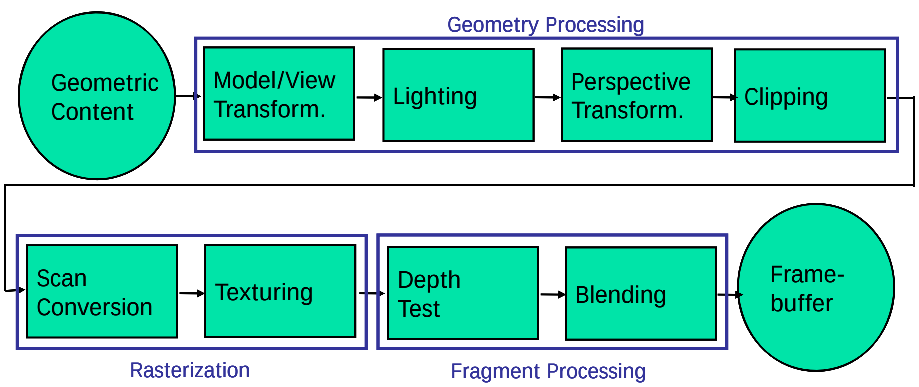
- TRIANGLE...

```
glColor3f(0,1,0);
glBegin( GL_TRIANGLES );
  glVertex3f( 0.0f, 0.5f, 0.0f );
  glVertex3f( -0.5f, -0.5f, 0.0f );
  glVertex3f( 0.5f, -0.5f, 0.0f );
glEnd();
```

OpenGL – Shape Primitives

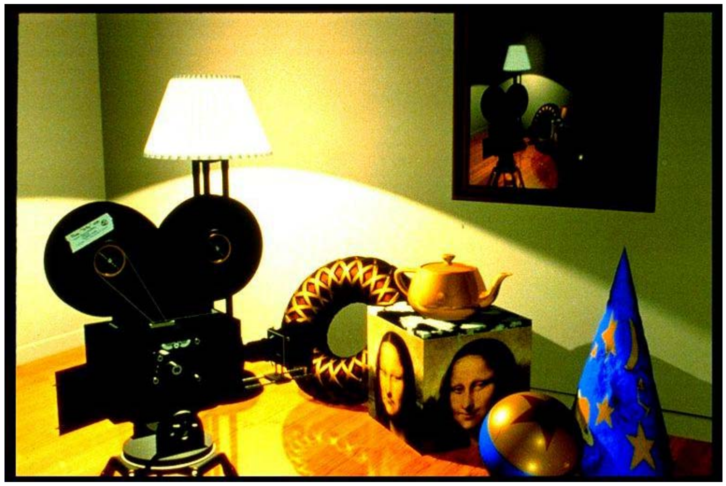
- How to interpret geometry
  - glBegin(<*mode of geometric primitives*>)
  - *mode* = GL_TRIANGLE, GL_POLYGON, etc.
- Feed vertices
  - glVertex3f(-1.0, 0.0, -1.0)
  - glVertex3f(1.0, 0.0, -1.0)
  - glVertex3f(0.0, 1.0, -1.0)
- Done
  - glEnd()

The Rendering Pipeline

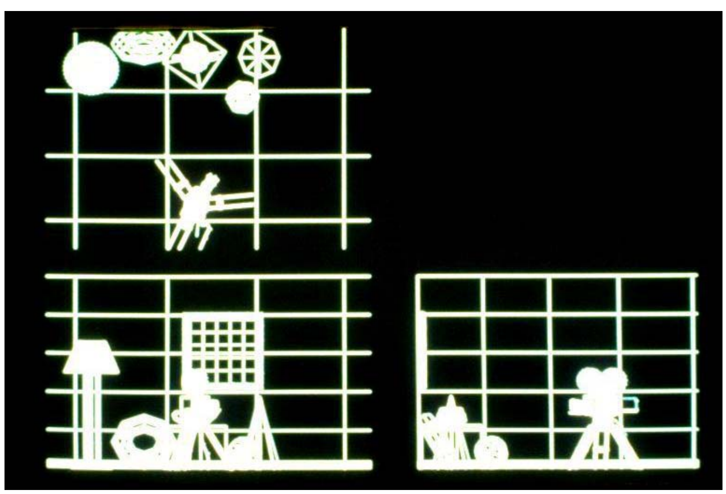


Modeling and Viewing Transformations

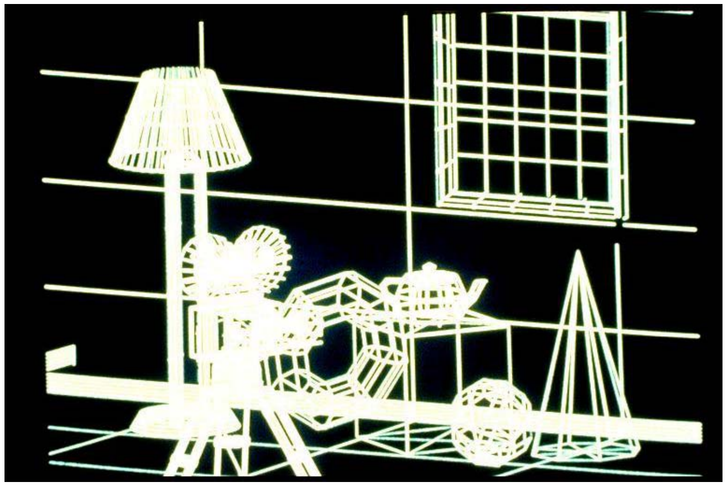
- Placing objects - Modeling transformations
  - Map points from object coordinate system to world coordinate system
- Placing camera - Viewing transformation
  - Map points from world coordinate system to camera (or eye) coordinate system



Modeling Transformations: Object Placement

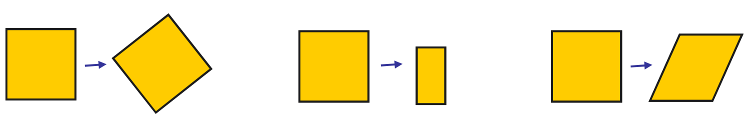


Viewing Transformation: Camera Placement

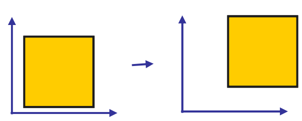


Modeling & Viewing Transformations

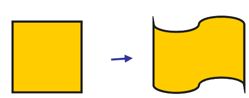
- Types of transformations:
  - Rotations, scaling, shearing



  - Translations



  - Other transformations (not handled by rendering pipeline):
    - Freeform deformation



Modeling & Viewing Transformation

- Linear transformations
  - Rotations, scaling, shearing
  - Can be expressed as 3x3 matrix
  - E.g. scaling (non uniform):

$$\begin{pmatrix} x' \\ y' \\ z' \end{pmatrix} = \begin{pmatrix} 2 & 0 & 0 \\ 0 & 3 & 0 \\ 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} x \\ y \\ z \end{pmatrix}$$

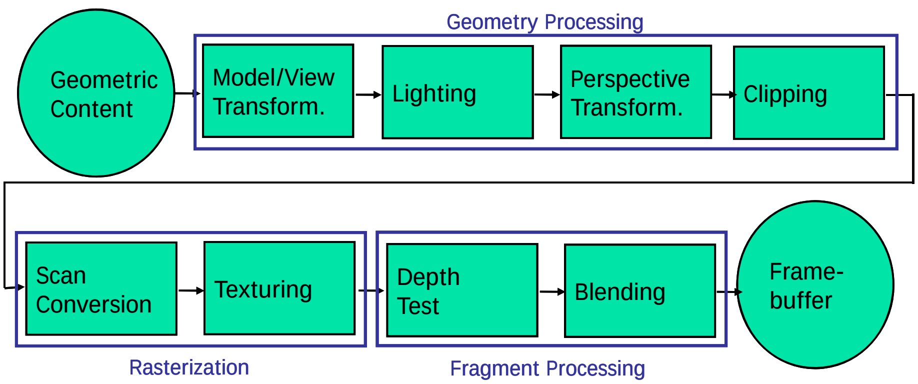
Modeling & Viewing Transformation

- Affine transformations
  - Linear transformations + translations
  - Can be expressed as 3x3 matrix + 3 vector
  - E.g. scale+ translation:

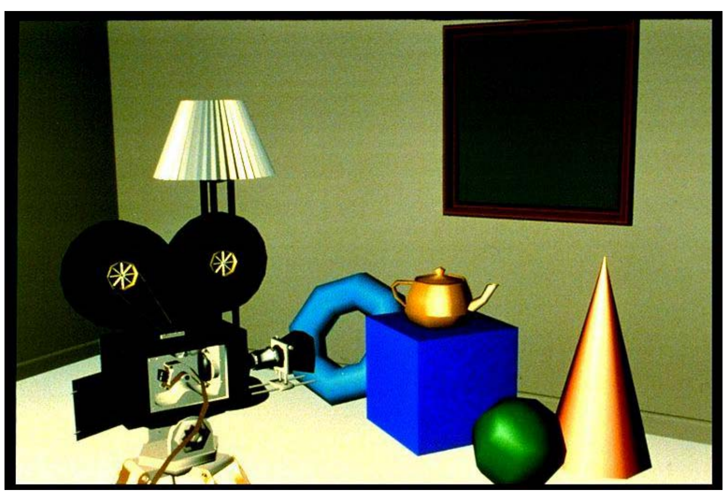
$$\begin{pmatrix} x' \\ y' \\ z' \end{pmatrix} = \begin{pmatrix} 2 & 0 & 0 \\ 0 & 3 & 0 \\ 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} x \\ y \\ z \end{pmatrix} + \begin{pmatrix} t_x \\ t_y \\ t_z \end{pmatrix}$$

  - Another representation: 4x4 homogeneous matrix

The Rendering Pipeline

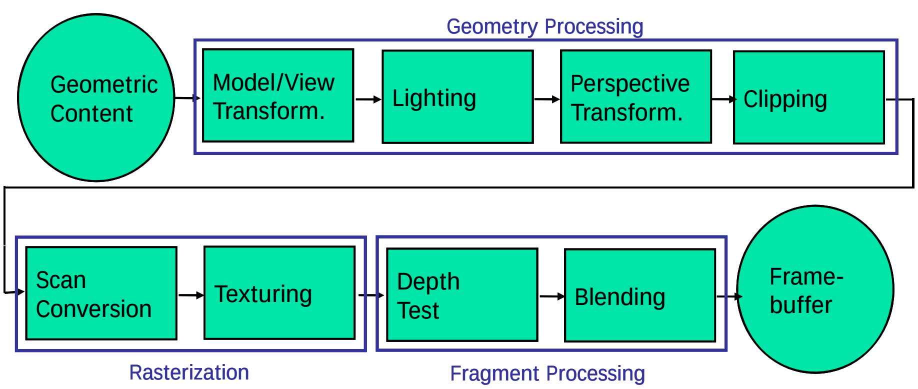


Lighting



Complex Lighting and Shading

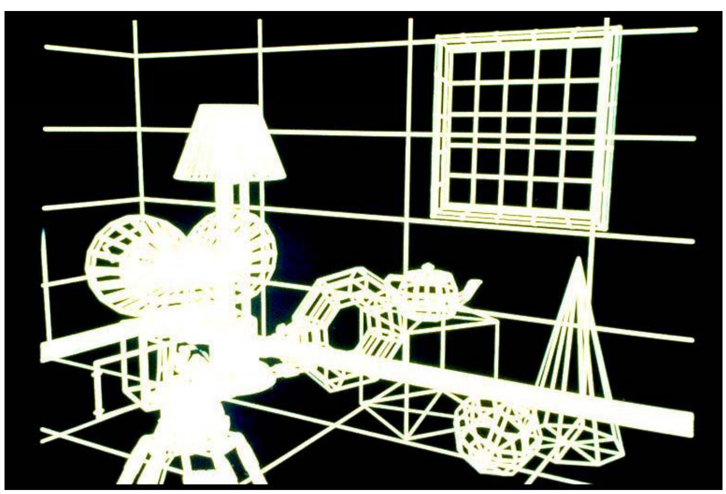
The Rendering Pipeline



Perspective Transformation

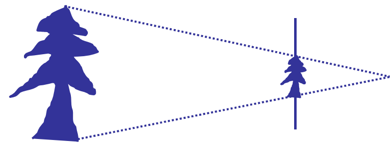
- Purpose:
  - Project 3D geometry to 2D image plane
  - Simulates a camera
- Camera model:
  - Pinhole camera (single view point)
  - Other, more complex camera models also exist in computer graphics, but are less common
    - Thin lens cameras
    - Full simulation of lens geometry

Perspective Projection



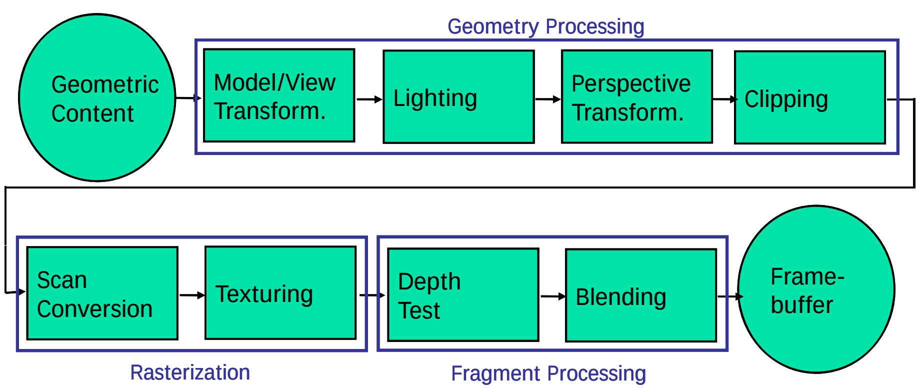
Perspective Transformation

- In computer graphics:
  - Image plane conceptually in front of center of projection



  - Perspective transformations – subset of projective transformations
  - Linear & affine transformations also belong to this class
  - All projective transformations can be expressed as 4x4 matrix operations

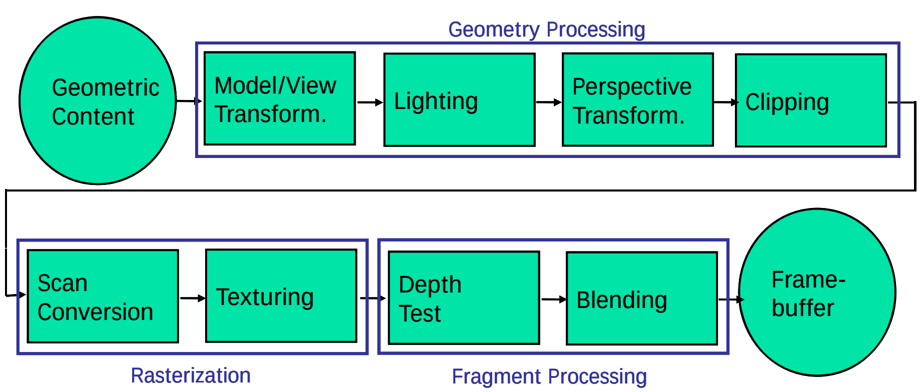
The Rendering Pipeline



Clipping

- Removing invisible geometry
  - Geometry outside viewing frustum
  - Plus too far or too near one

The Rendering Pipeline

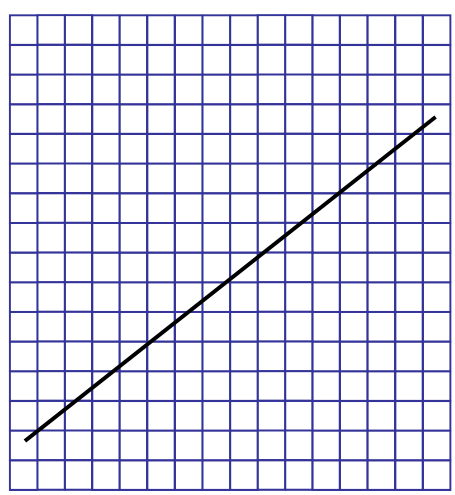


Scan Conversion/Rasterization

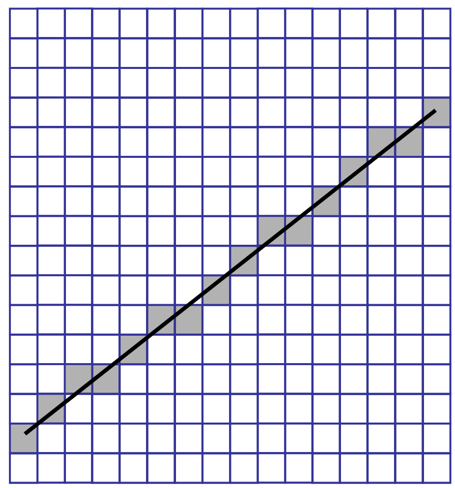
- Convert continuous 2D geometry to discrete
- Raster display – discrete grid of elements
- Terminology
  - **Pixel:** basic element on device

  - **Resolution:** number of rows & columns in device
    - Measured in
      - Absolute values (1K x 1K)
      - Density values (300 dots per inch)
  - **Screen Space:** Discrete 2D Cartesian coordinate system of the screen pixels

Scan Conversion



Scan Conversion

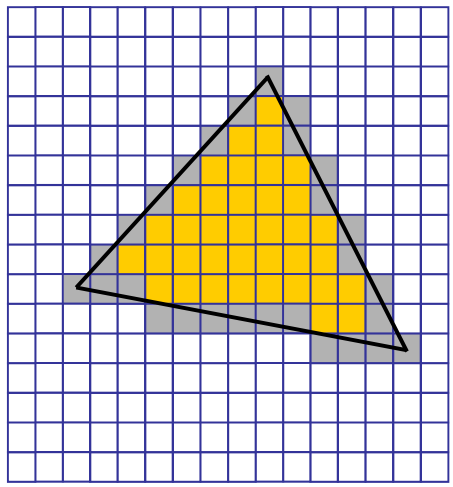


Scan Conversion

- Problem:
  - Line is infinitely thin, but image has finite resolution
  - Results in steps rather than a smooth line
    - Jaggies
    - Aliasing
  - One of the fundamental problems in computer graphics

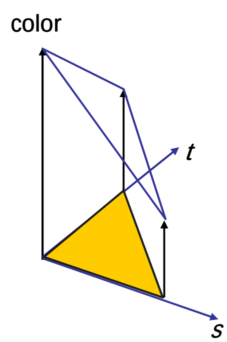
Scan Conversion

-



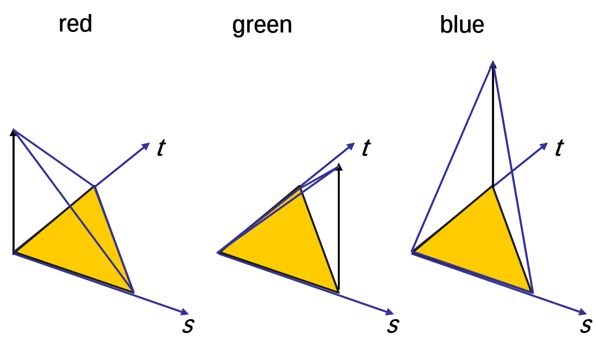
Scan Conversion

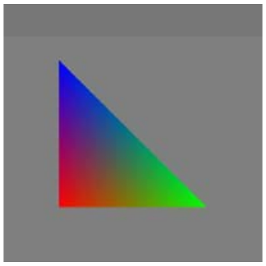
- Color interpolation
  - Linearly interpolate per-pixel color from vertex color values
  - Treat every channel of RGB color separately



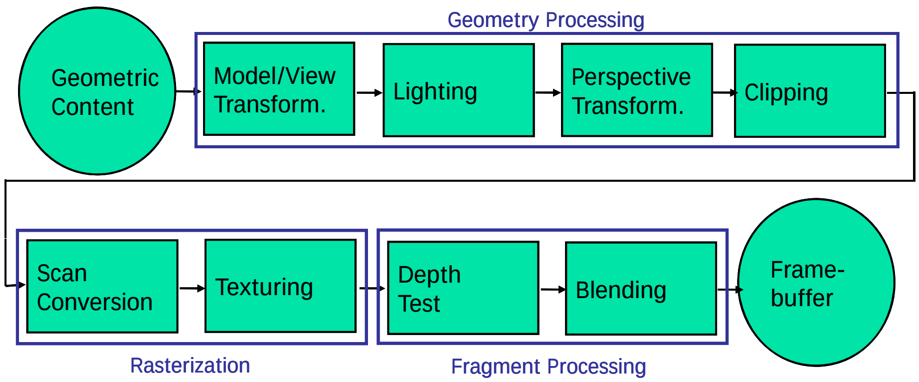
Scan Conversion

- Color interpolation
  - Example:

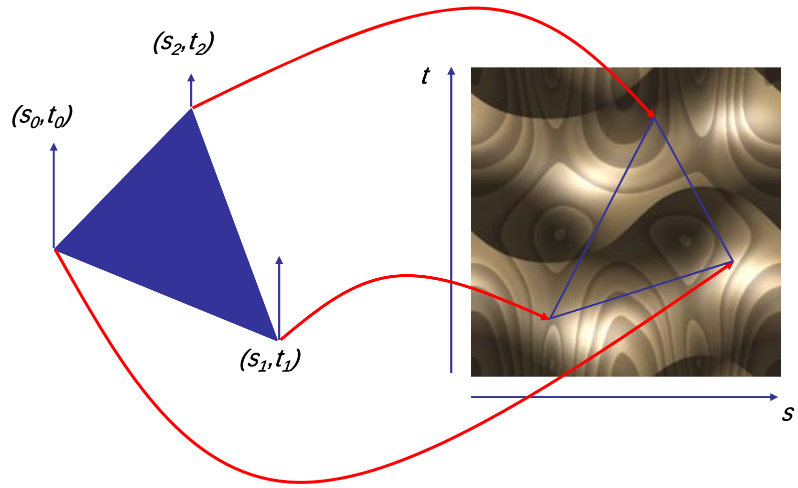




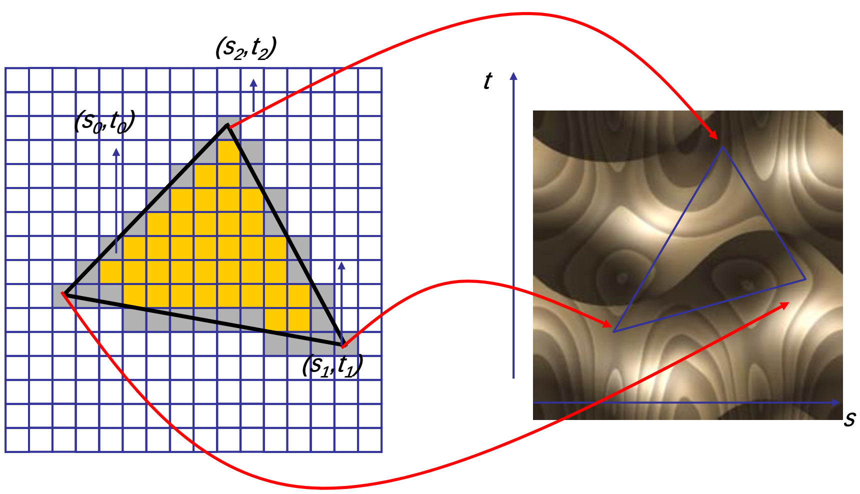
The Rendering Pipeline



Texturing

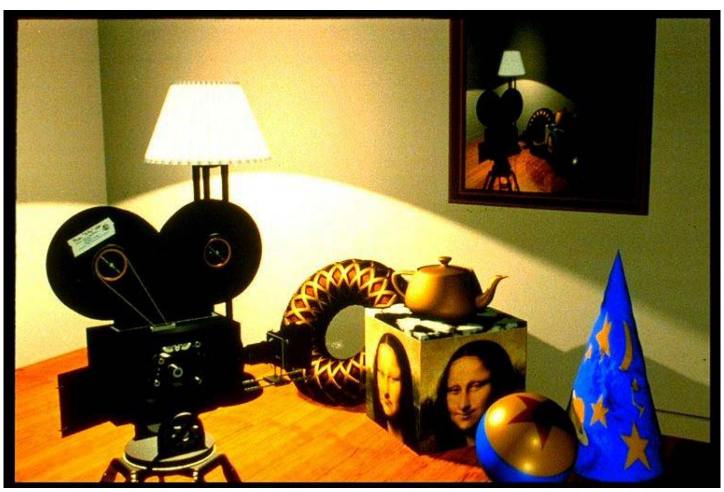


Texturing



Texture Mapping

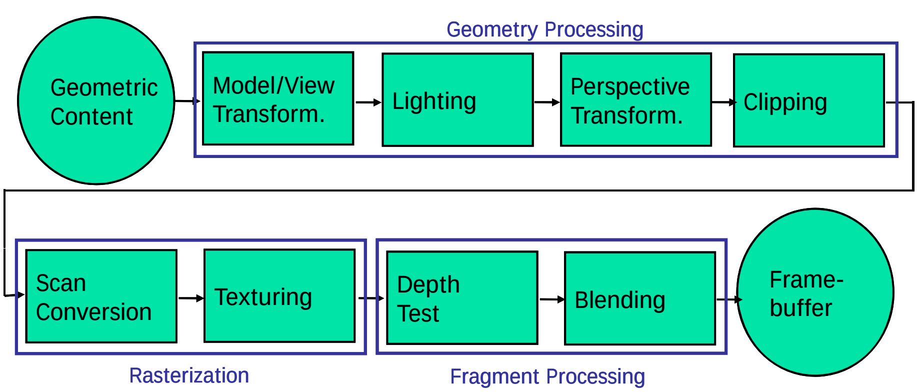
Displacement Mapping



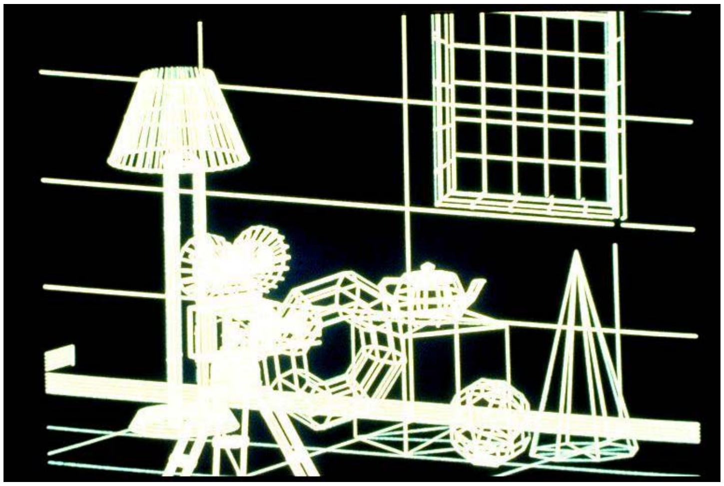
Texturing

- Issues:
  - Computing 3D/2D map (low distortion)
  - How to map pixel from texture (texels) to screen pixels
    - Texture can appear widely distorted in rendering
    - Magnification / minification of textures
  - Filtering of textures
  - Preventing aliasing (anti-aliasing)

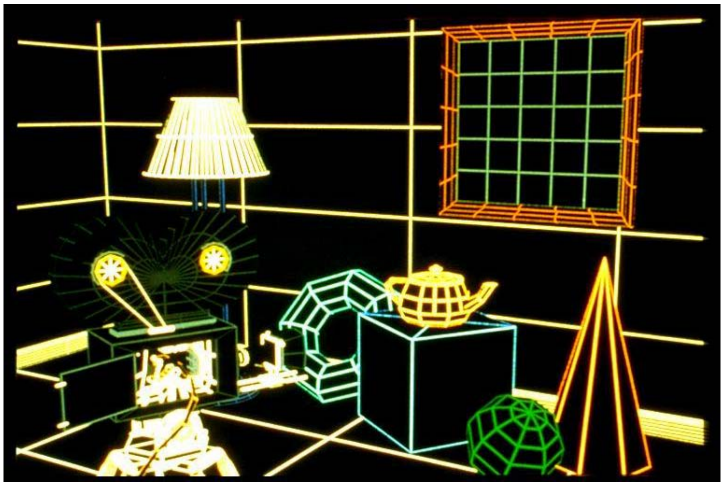
The Rendering Pipeline



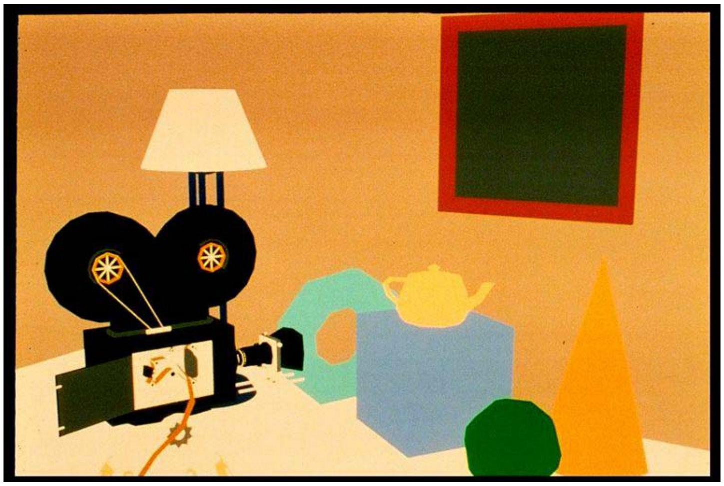
Without Hidden Line Removal



Hidden Line Removal



Hidden Surface Removal

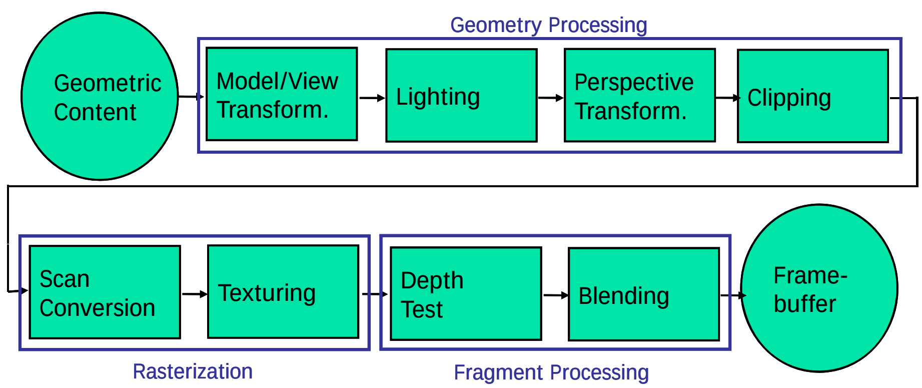


Depth Test /Hidden Surface Removal

- Remove invisible geometry
  - Parts that are hidden behind other geometry
- Possible Implementations:
  - Per-fragment decision
    - Depth buffer
  - Object space decision
    - Clipping polygons against each other
    - Sorting polygons by distance from camera

Depth Test /Hidden Surface Removal

The Rendering Pipeline



Blending

- Blending:
  - Final image: write fragments to pixels
  - Draw from farthest to nearest
  - No blending – replace previous color
  - Blending: combine new & old values with some arithmetic operations
- Frame Buffer : video memory on graphics board that holds resulting image & used to display it

Not Handled: Reflection/Shadows

Basics of Computer Graphics: Rendering Pipeline