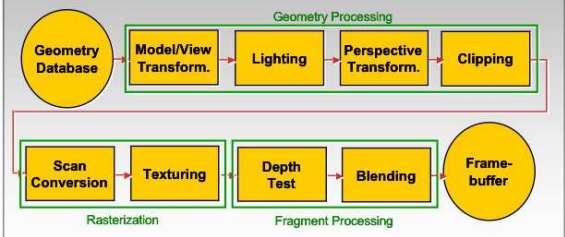
The Rendering Pipeline – A Second Look

Part 1: Geometry Processing

The Rendering Pipeline



Geometry Database

Needs to represent models for

- Geometric primitives
- Relations between different primitives (transformations)
- Object materials
- Light sources
- Camera

Geometric Primitives

Different philosophies:

- Collections of complex shapes
  - *Spheres, cones, cylinders, tori, …*
- One simple type of geometric primitive
  - *Triangles or triangle meshes*
- Small set of complex primitives with adjustable parameters
  - *E.g. "all polynomials of degree 2"*
  - *Splines, NURBS (details in CPSC 424)*
  - *Fractals*

Geometric Primitives

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:*

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

Geometry Database

Implicit Surfaces:

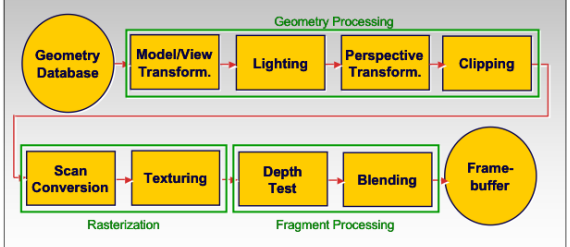
- Surface is defined implicitly via the roots of a function
- E.g:

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

Geometry Database

Triangles and Triangle Meshes:

The Rendering Pipeline



Modeling and Viewing Transformation

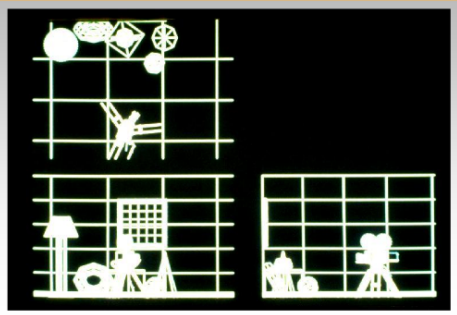
Modeling transformation:

- Map points from *object coordinate system* to *world coordinate system*
- *Same a placing objects*

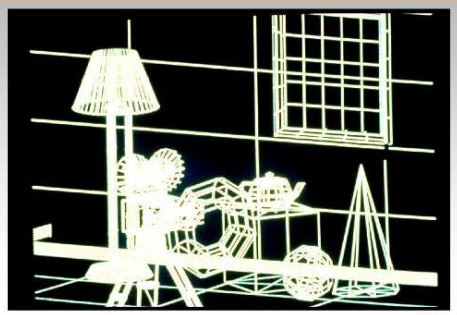
Viewing transformation:

- Map points from *world coordinate system* to *camera* (or *eye*) *coordinate system*
- *Same as placing camera*

Modeling Transformation: Object Placement



Viewing Transformation: Camera Placement



Modeling and Viewing Transformation

Types of transformations:

- *Rotations, scaling, shearing*

- *Translations*

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

Modeling and Viewing Transformation

Linear transformations

- Rotations, scaling, shearing
- Can be expressed as a *3x3* matrix
- E.g. rotation:

$$\begin{pmatrix} x' \\ y' \\ z' \end{pmatrix} = \begin{pmatrix} \cos(\phi) & -\sin(\phi) & 0 \\ \sin(\phi) & \cos(\phi) & 0 \\ 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} x \\ y \\ z \end{pmatrix}$$

Modeling and Viewing Transformation

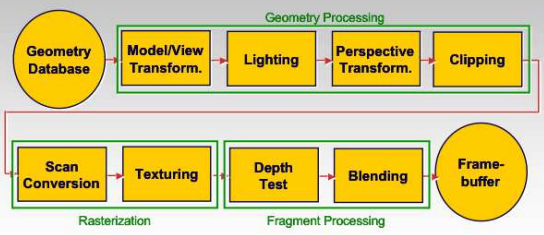
Affine transformations

- Linear transformations + translations
- Can be expressed as a *3x3* matrix + *3* vector
- E.g. rotation + translation:

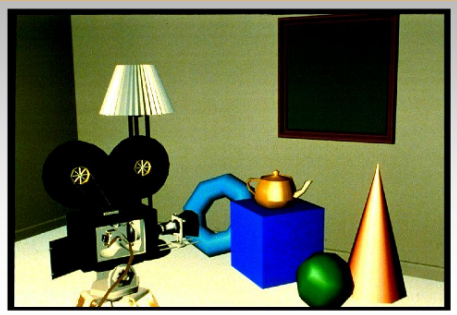
$$\begin{pmatrix} x' \\ y' \\ z' \end{pmatrix} = \begin{pmatrix} \cos(\phi) & -\sin(\phi) & 0 \\ \sin(\phi) & \cos(\phi) & 0 \\ 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} x \\ y \\ z \end{pmatrix} + \begin{pmatrix} t_x \\ t_y \\ t_z \end{pmatrix}$$

- Another representation: *4x4 homogeneous matrix*

The Rendering Pipeline

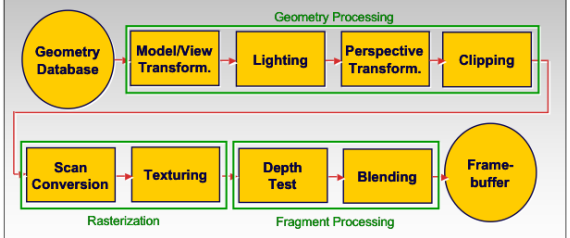


Lighting



Complex Lighting and Shading

The Rendering Pipeline



Perspective Transformation

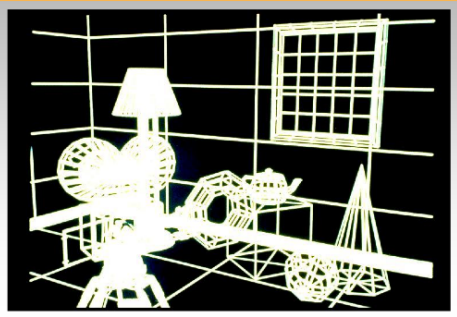
Purpose:

- Project 3D geometry onto a 2D image plane
- Simulates a camera

Camera model:

- Pinhole camera
- Other, more complex camera models also exist in computer graphics, but are less common
  - *Thin lens cameras*
  - *Full simulation of lens geometry*

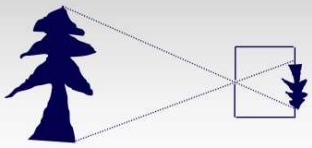
Perspective Projection



Perspective Transformation

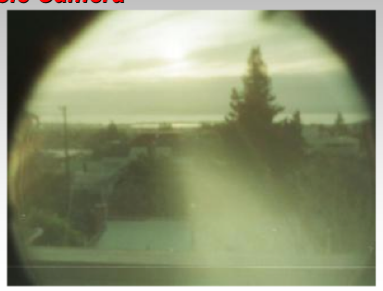
Pinhole Camera:

- Light shining through a tiny hole into a dark room yields upside-down image on wall



Perspective Transformation

Pinhole Camera

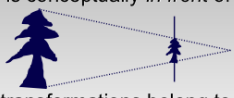


Pinhole Camera - Camera Obscura

Perspective Transformation

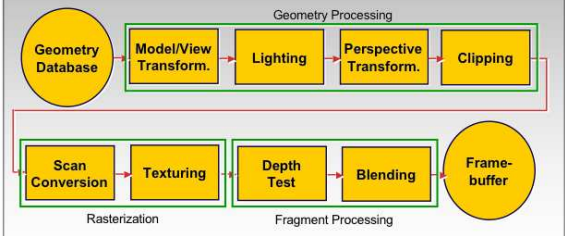
In computer graphics:

- Image plane is conceptually *in front* of the center of projection



- Perspective transformations belong to a class of operations that are called *projective transformations*
- Linear and affine transformations also belong to this class
- *All* projective transformations can be expressed as *4x4* matrix operations

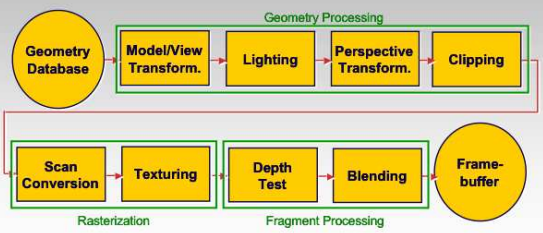
The Rendering Pipeline



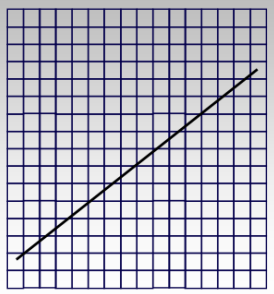
The Rendering Pipeline – A Second Look

Part 2: Rasterization & Fragment Processing

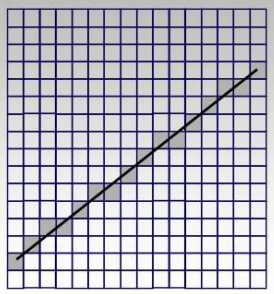
The Rendering Pipeline



Scan Conversion



Scan Conversion

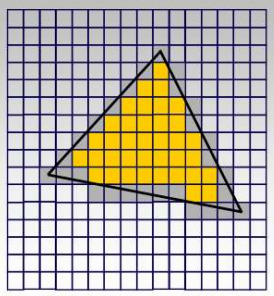


Scan Conversion

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

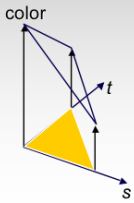
Scan Conversion



Scan Conversion

Color interpolation

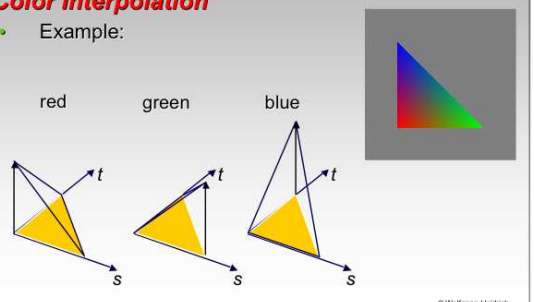
- Linearly interpolate per-pixel color from vertex color values
- Treat every channel of RGB color separately



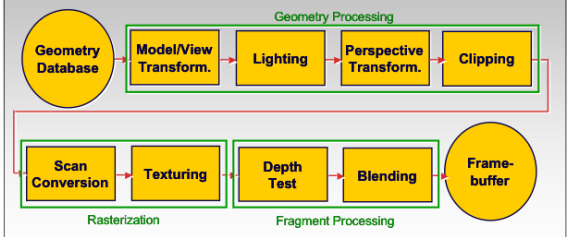
Scan Conversion

Color interpolation

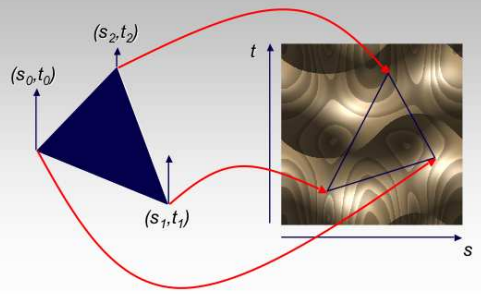
- Example:



The Rendering Pipeline



Texturing



Texture Mapping

Displacement Mapping

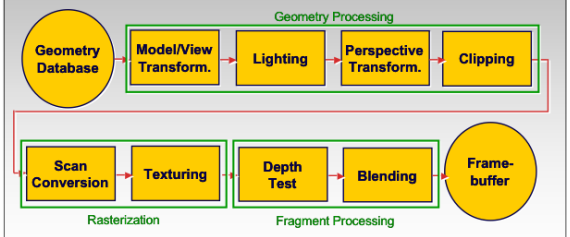
Reflection Mapping

Texturing

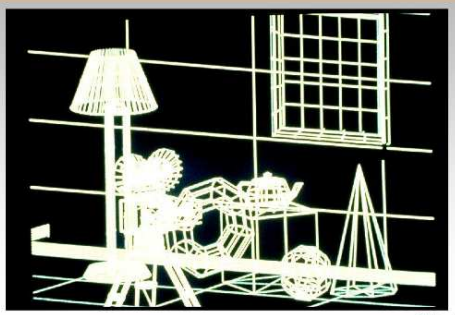
Issues:

- 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)

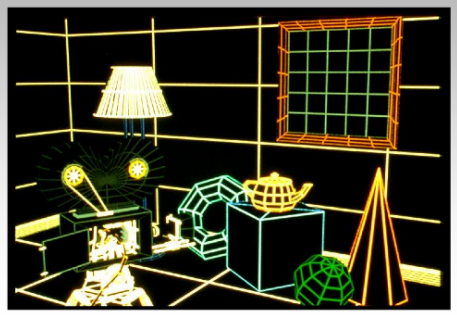
The Rendering Pipeline



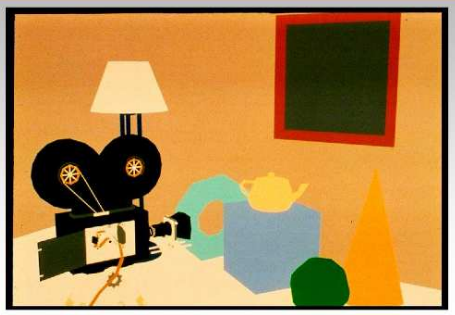
Without Hidden Line Removal



Hidden Line Removal



Hidden Surface Removal



Depth Test / Hidden Surface Removal

Remove invisible geometry

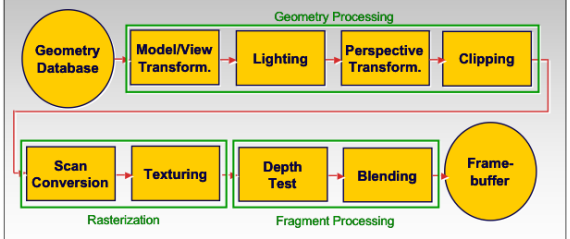
- Parts that are hidden behind other geometry

Possible Implementations:

- Per-fragment decision
  - *Depth buffer*
- Object space decision
  - *Clipping polygons against each other*
  - *Sorting polygons by distance from camera*

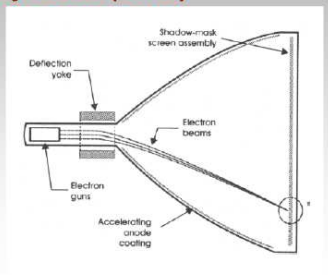
Depth Test / Hidden Surface Removal

The Rendering Pipeline



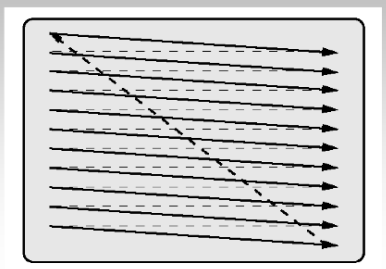
Display Technology

Cathod Ray Tubes (CRTs)



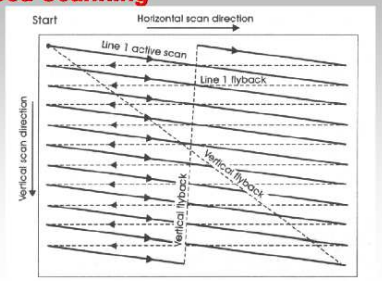
Display Technology

Raster Scan Electron Beam



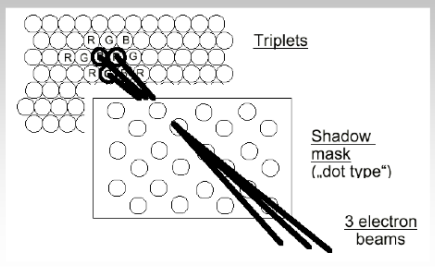
Display Technology

Interlaced Scanning



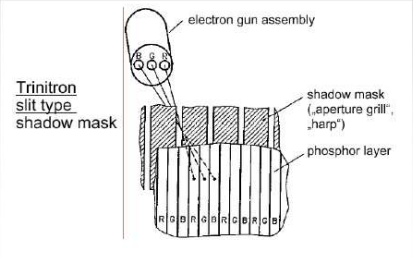
Display Technology

Color CRTs



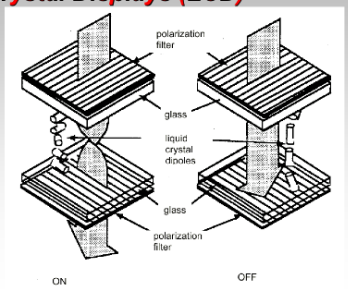
Display Technology

Trinitron CRTs



Display Technology

Liquid Crystal Displays (LCD)



Coming Up…

Thursday, Sep 13:

- Geometric Transformations (Affine)

Tuesday, Sep 18:

- Geometric Transformations (Perspective)