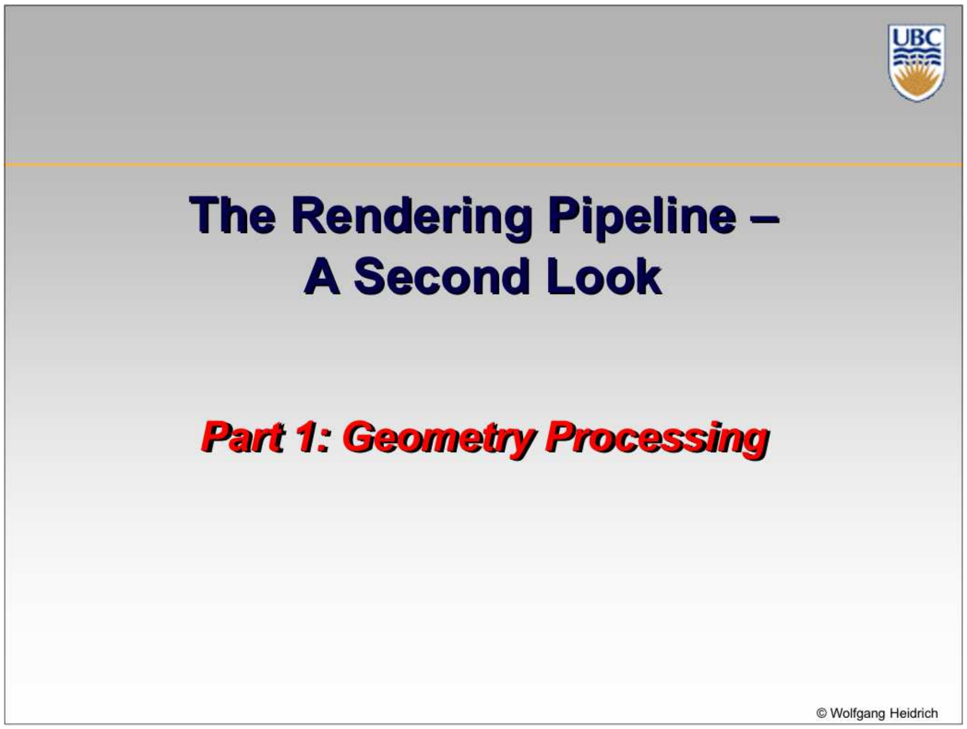
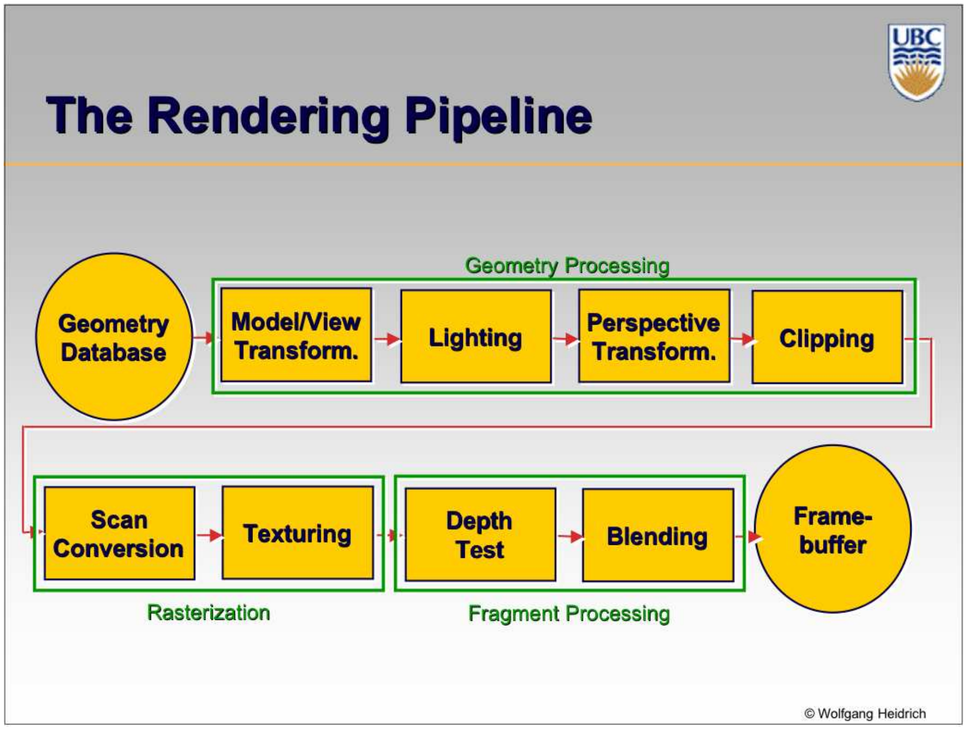


The Rendering Pipeline – A Second Look

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

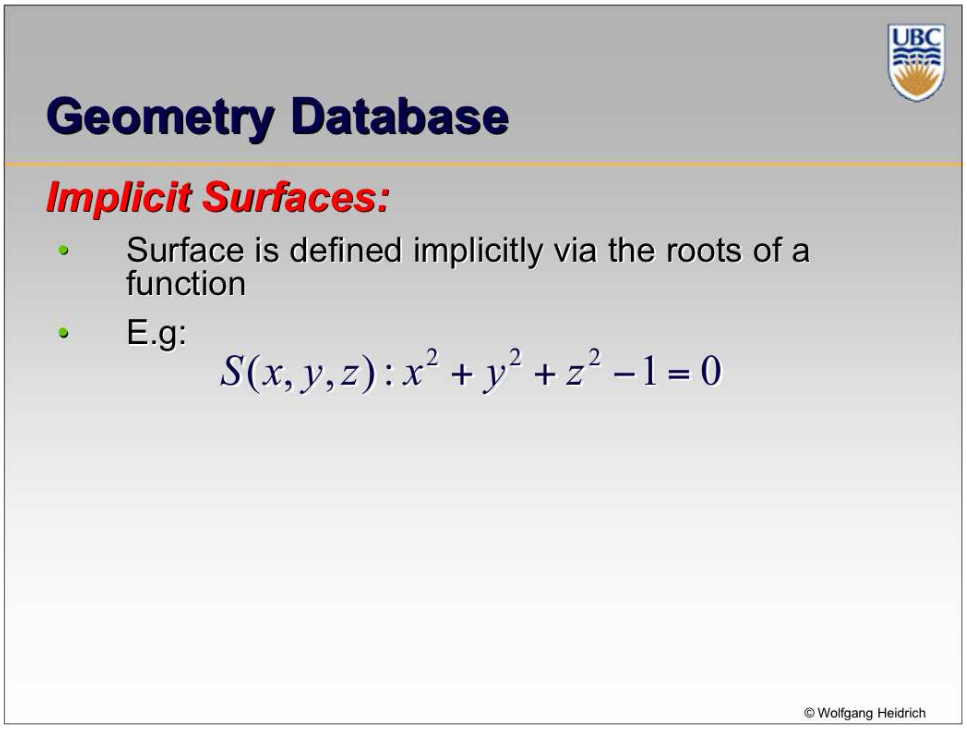
$$C(t) := \begin{pmatrix} \cos(t) \\ \sin(t) \\ t \end{pmatrix}$$

Parametric Functions

Surfaces:

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

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

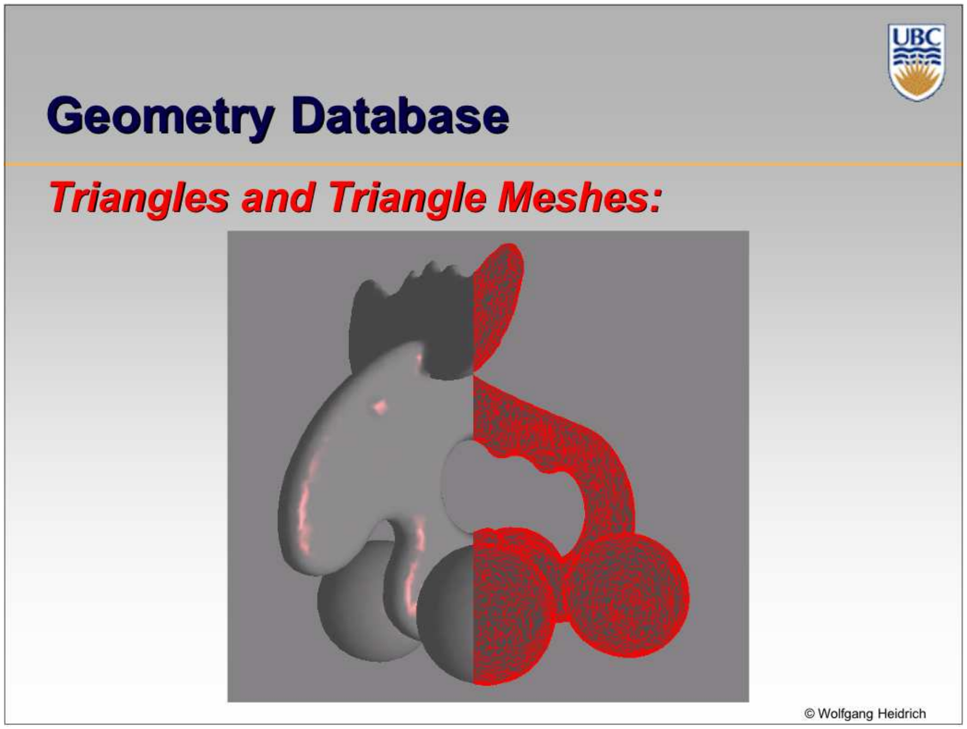


Geometry Database

Implicit Surfaces:

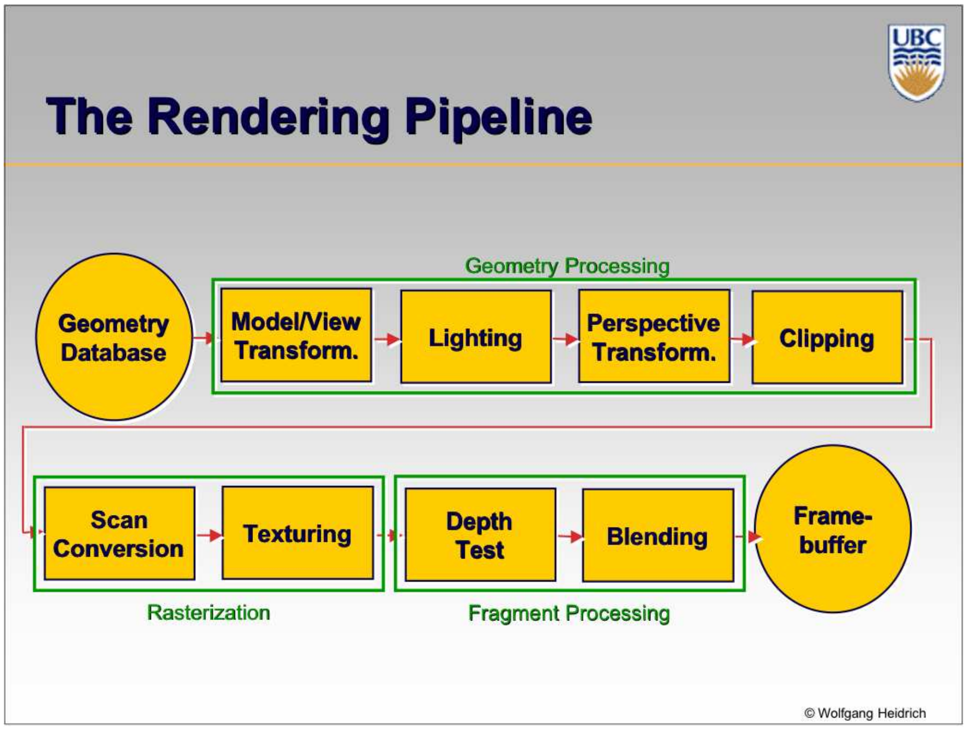
- Surface is defined implicitly via the roots of a function
- E.g:

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



Geometry Database

Triangles and Triangle Meshes:



The Rendering Pipeline

Geometry Processing

Geometry Database

Model/View Transform.

Lighting

Perspective Transform.

Clipping

Scan Conversion

Texturing

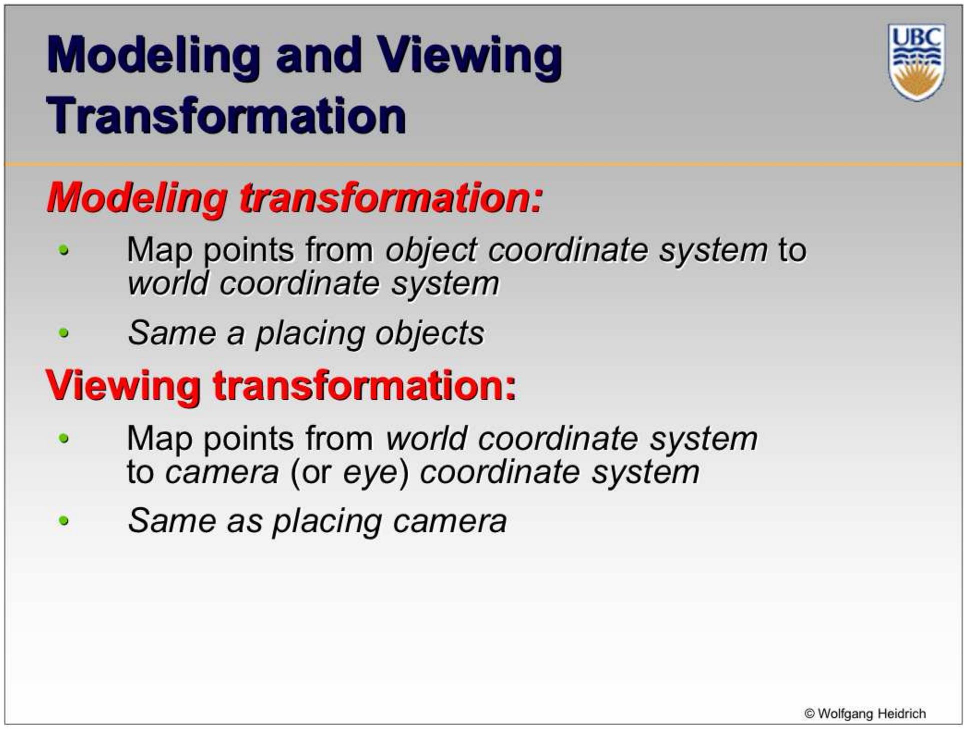
Rasterization

Depth Test

Blending

Fragment Processing

Frame-buffer



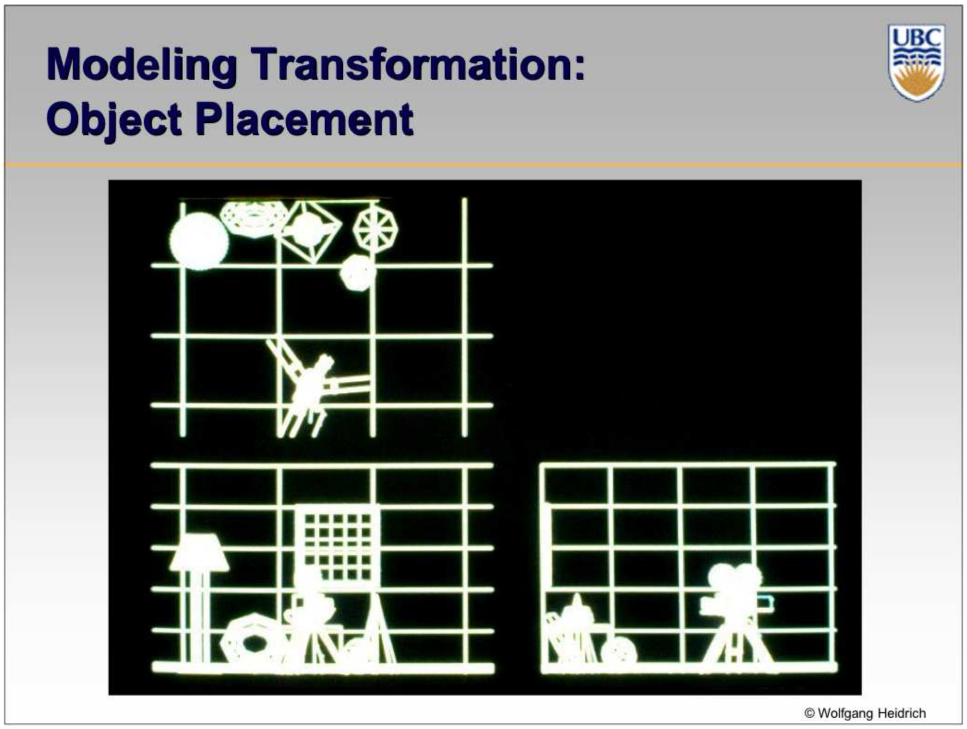
Modeling and Viewing Transformation

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

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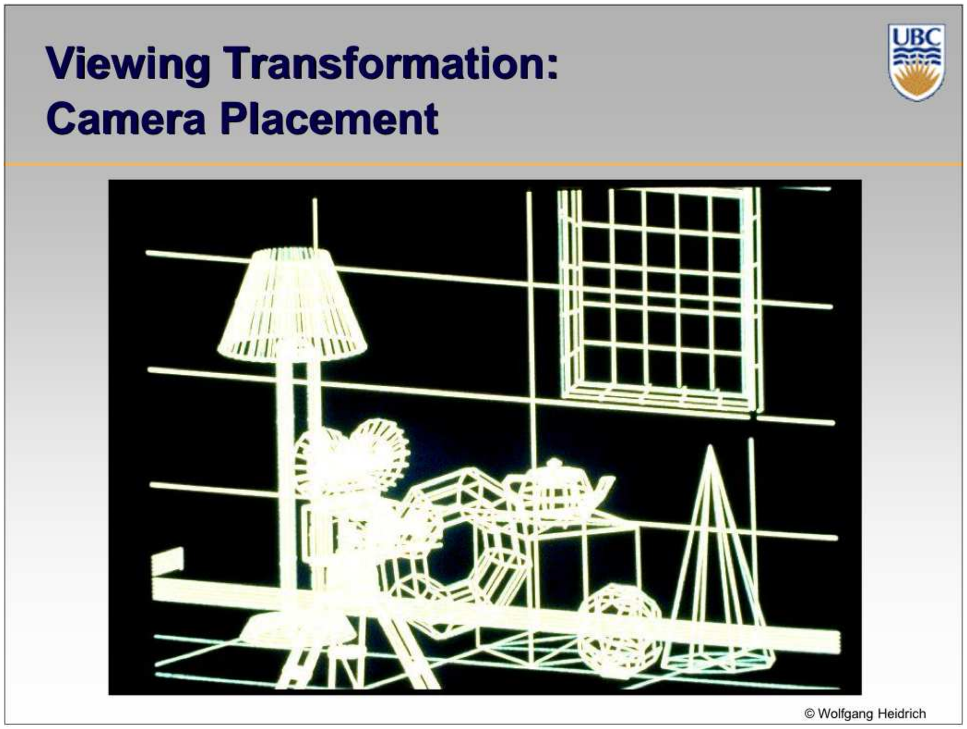

Viewing Transformation: Camera Placement

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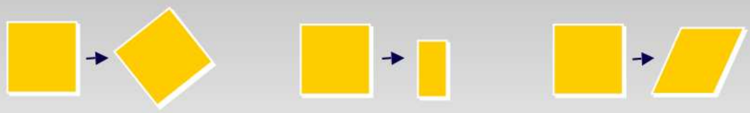
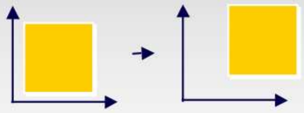
Modeling and Viewing Transformation

Types of transformations:

- *Rotations, scaling, shearing*



- *Translations*



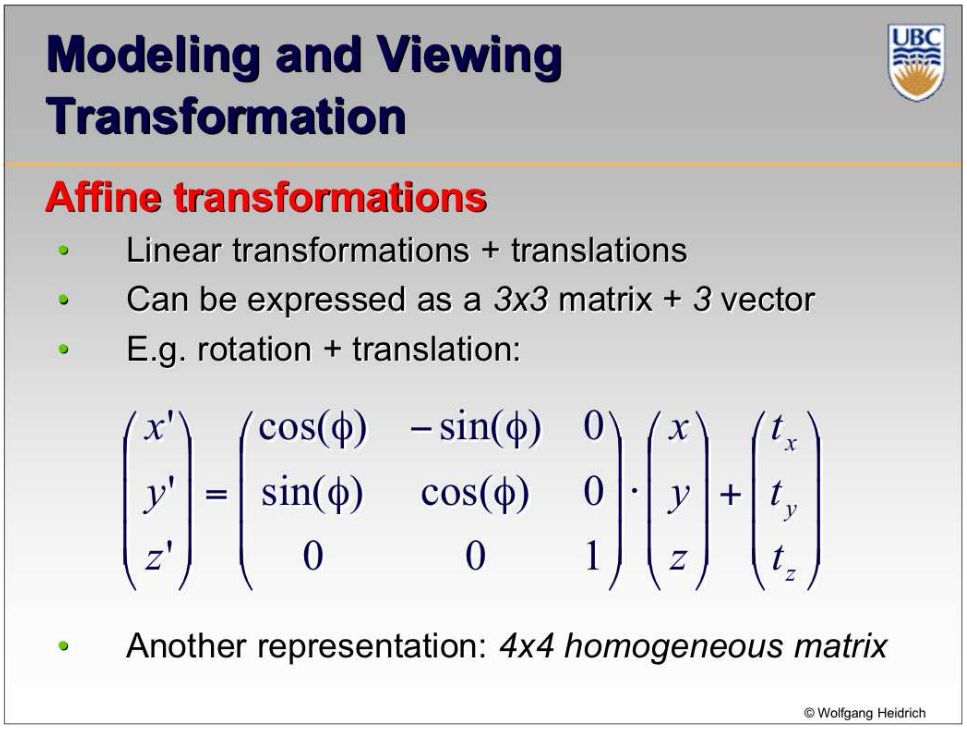
- *Other transformations (not handled by rendering pipeline):*
  - Freeform deformation

Modeling and Viewing Transformation

Linear transformations

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

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



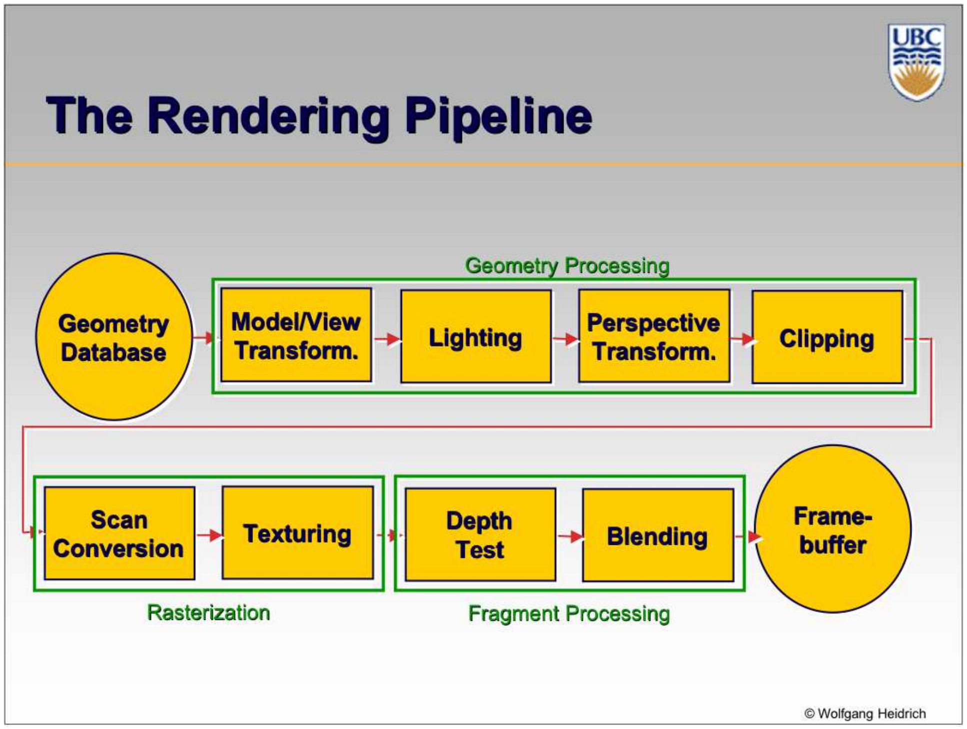
Modeling and Viewing Transformation

Affine transformations

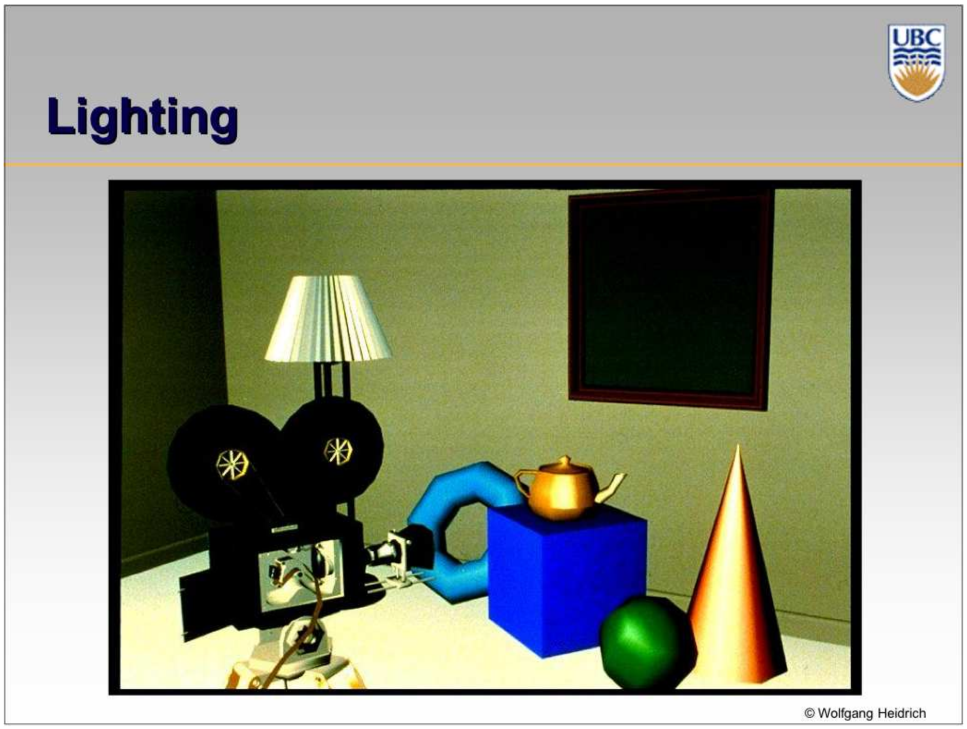
- Linear transformations + translations
- Can be expressed as a *3x3* matrix + *3* vector
- E.g. rotation + translation:

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

- Another representation: *4x4 homogeneous matrix*



The Rendering Pipeline



Lighting

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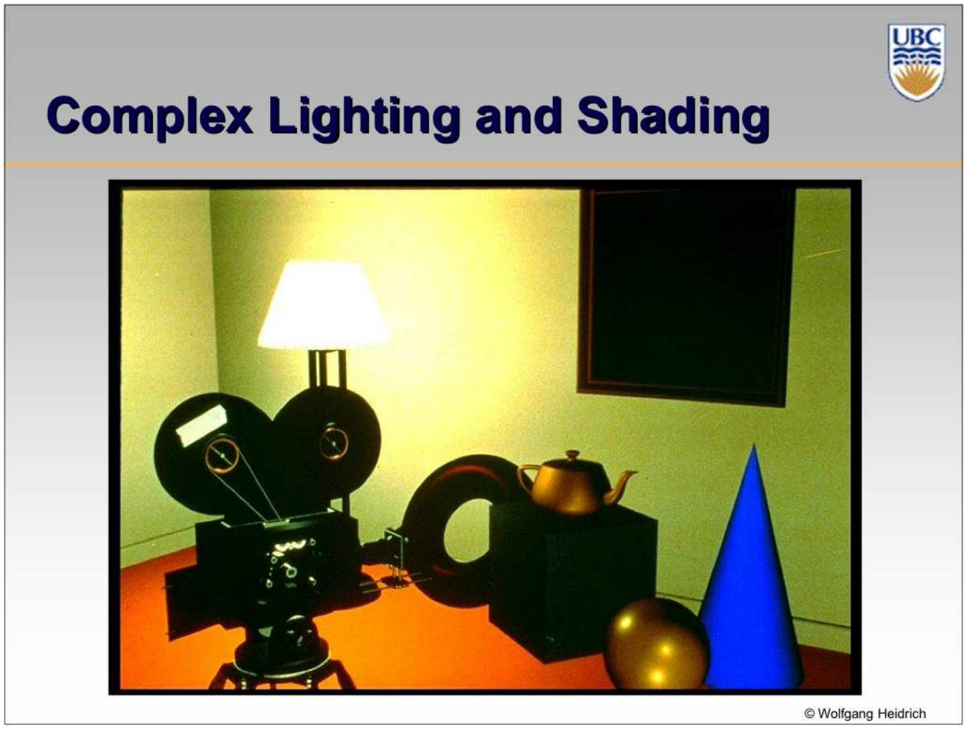

Complex Lighting and Shading

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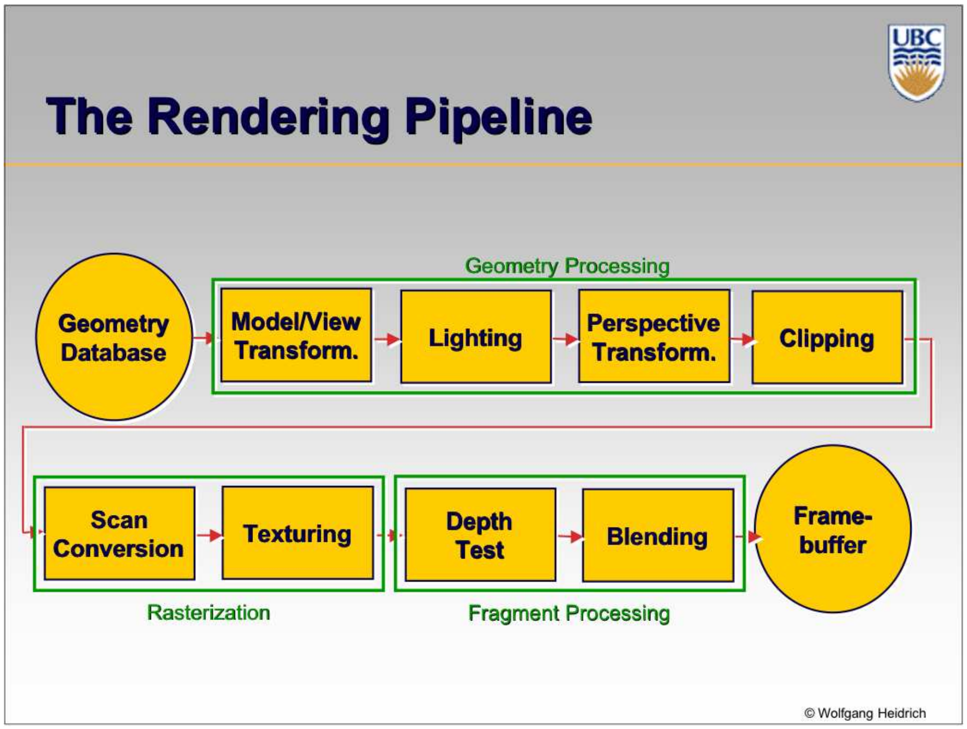


The Rendering Pipeline

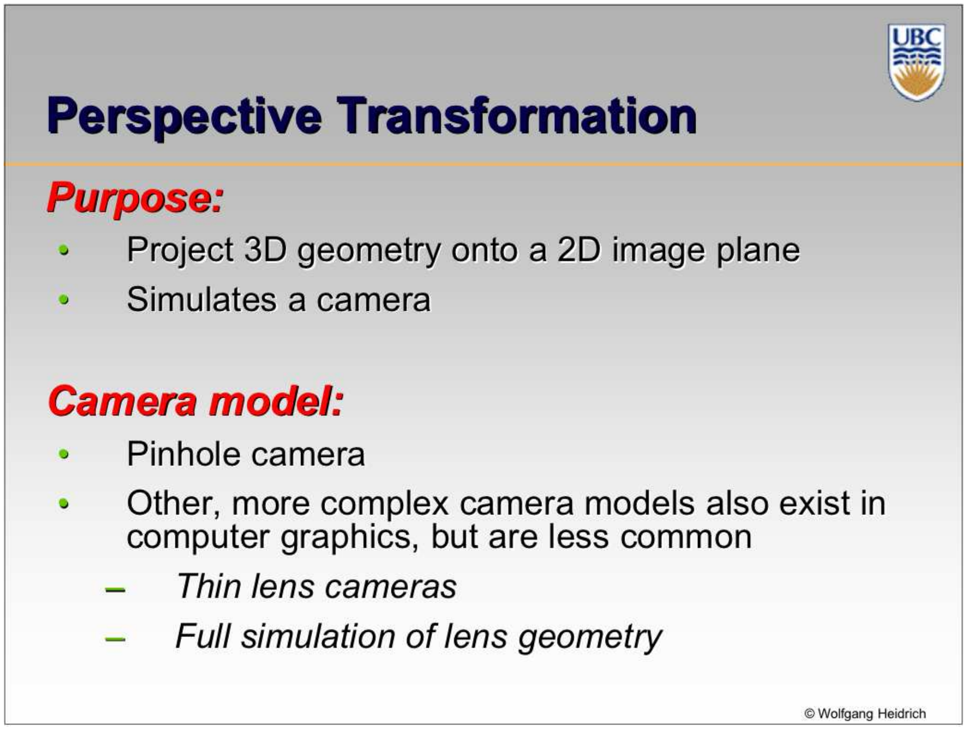
Geometry Processing

Geometry Database → Model/View Transform. → Lighting → Perspective Transform. → Clipping

→ Scan Conversion → Texturing → Depth Test → Blending → Frame-buffer

Rasterization

Fragment Processing



Perspective Transformation

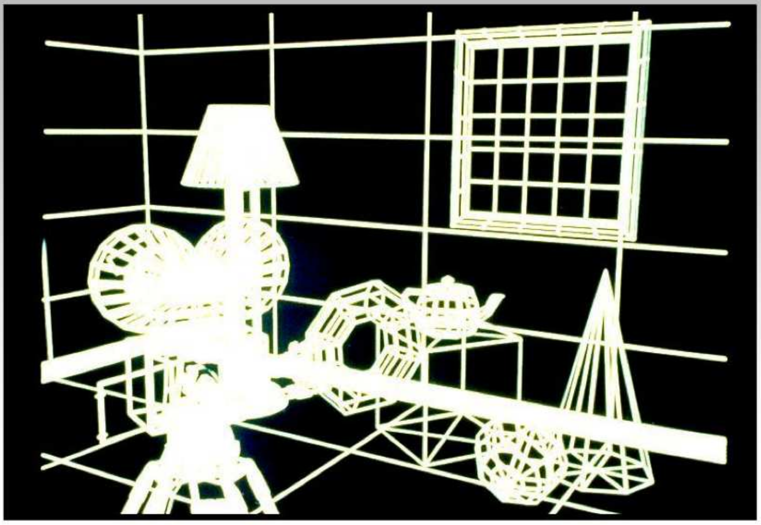
Purpose:

- 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



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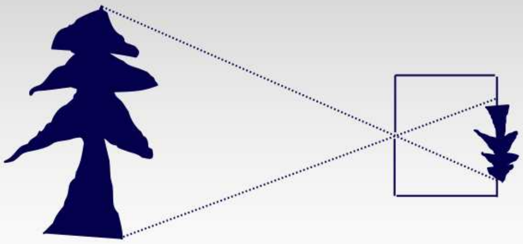
Perspective Transformation

Pinhole Camera:

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



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Perspective Transformation

Pinhole Camera

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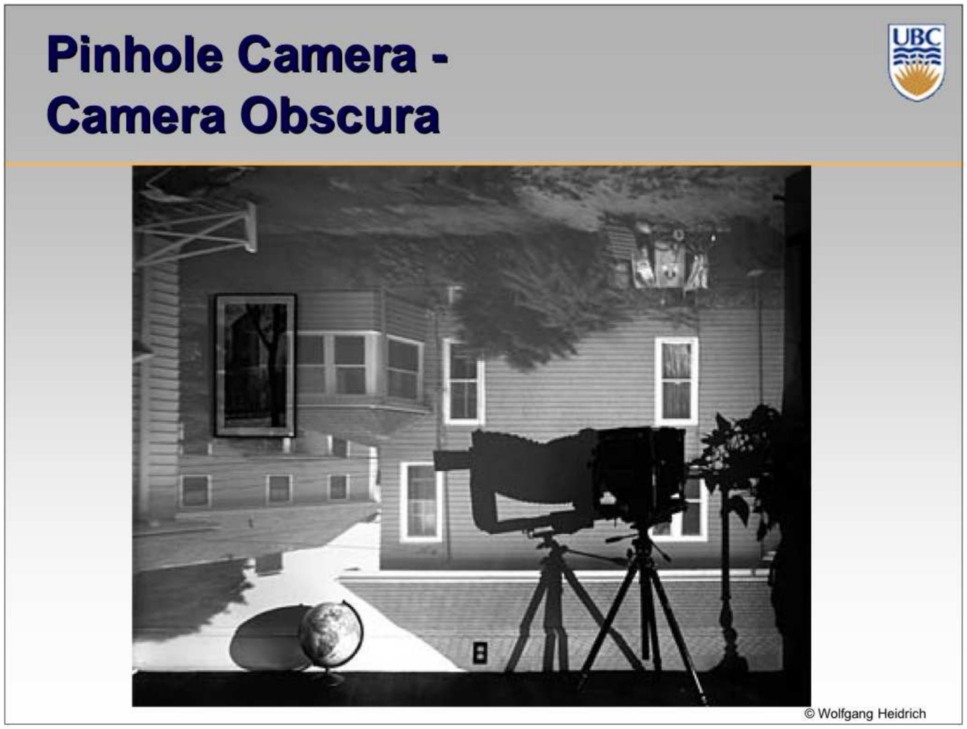

Pinhole Camera - Camera Obscura

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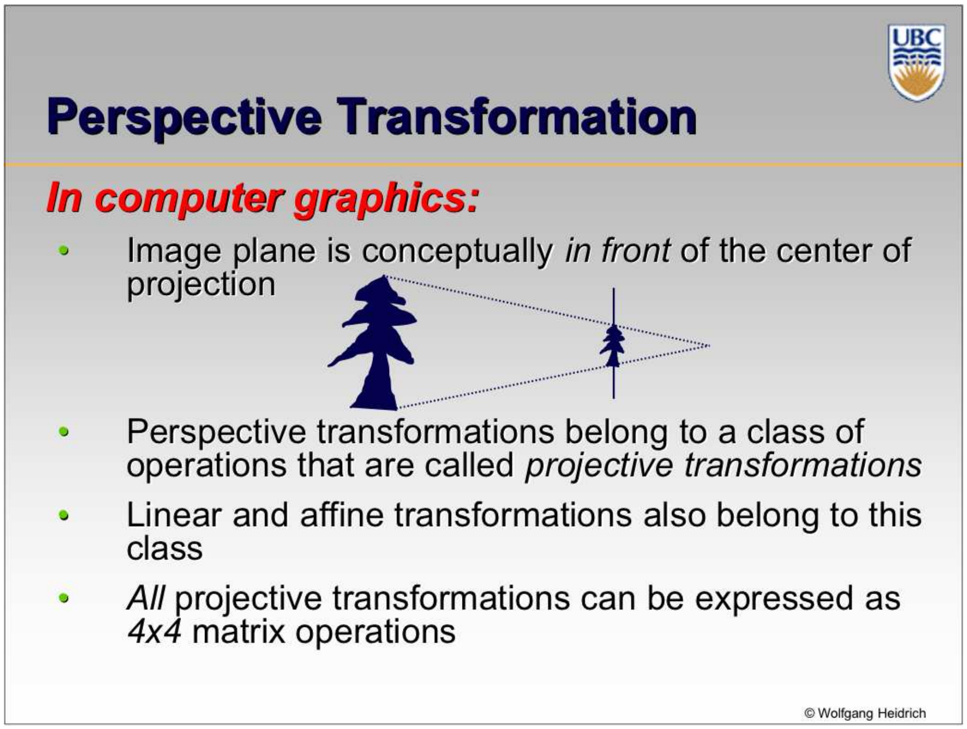

Perspective Transformation

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

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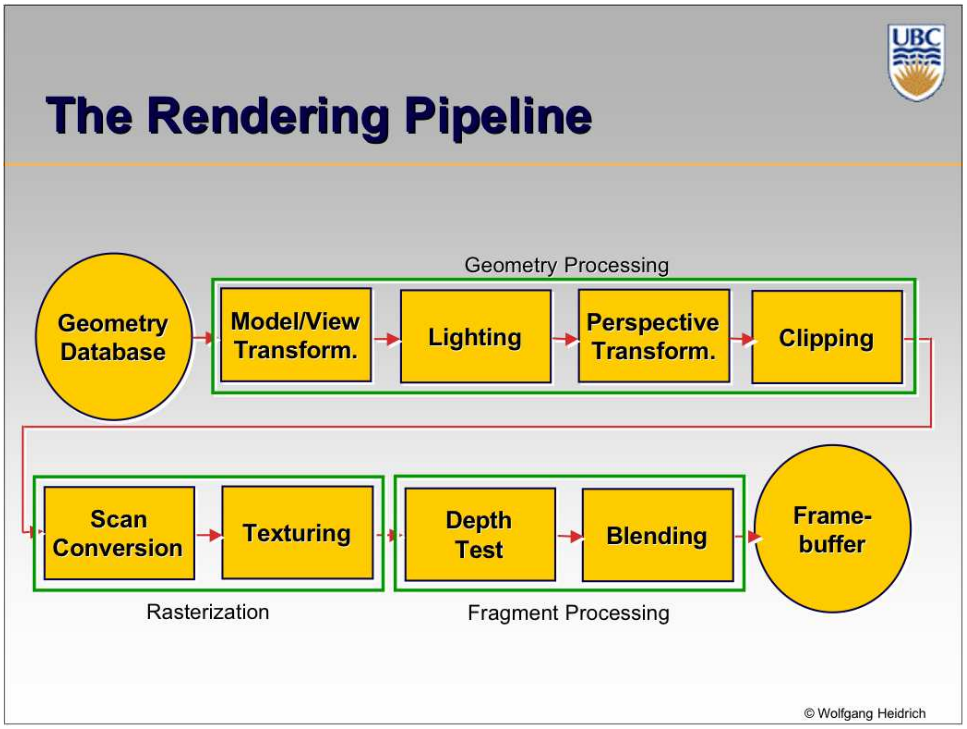

The Rendering Pipeline

Geometry Database

Geometry Processing: Model/View Transform. → Lighting → Perspective Transform. → Clipping

Rasterization: Scan Conversion → Texturing

Fragment Processing: Depth Test → Blending

Frame-buffer

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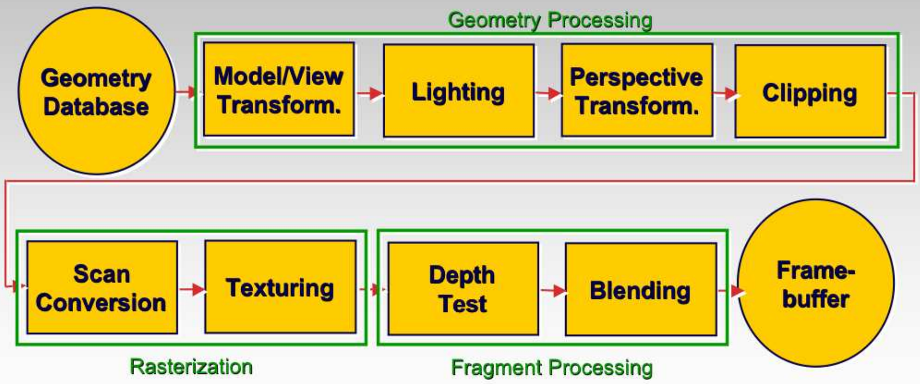
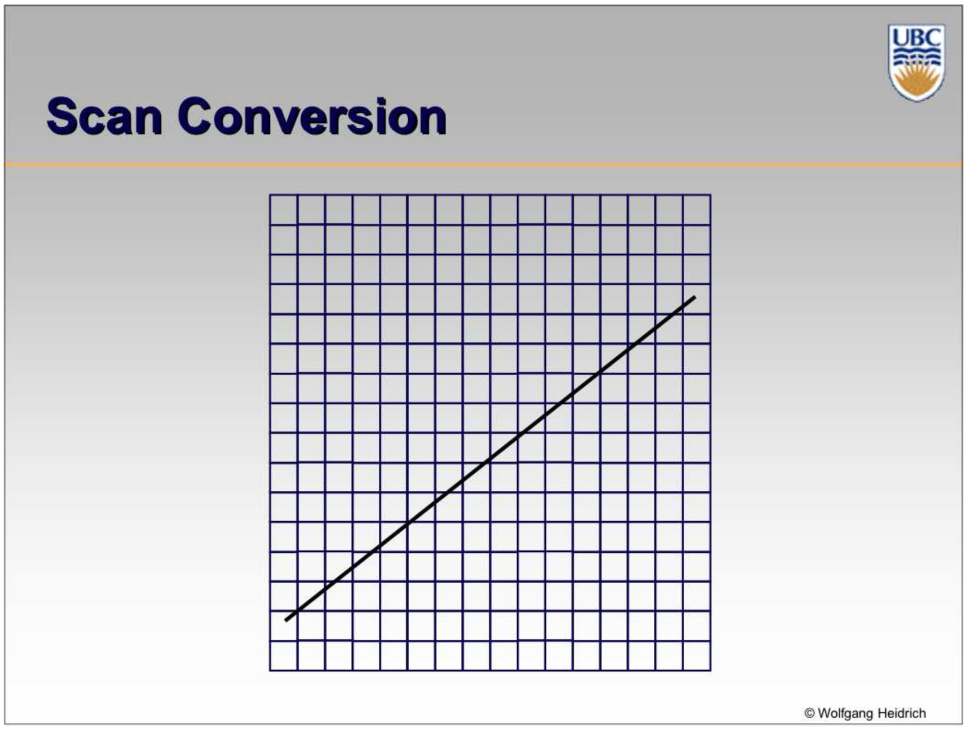
The Rendering Pipeline – A Second Look

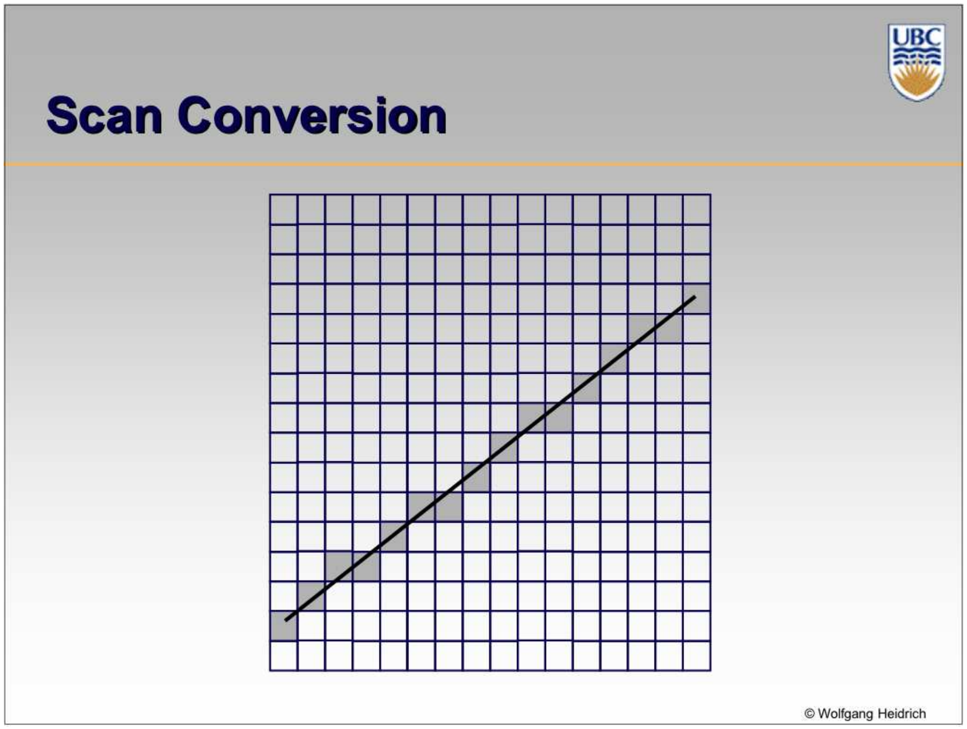
Part 2: Rasterization & Fragment Processing

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

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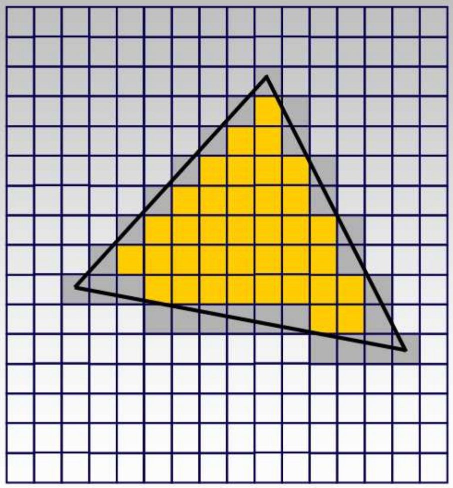
Scan Conversion



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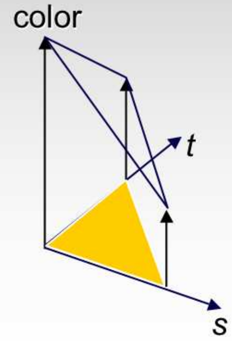
Scan Conversion

Color interpolation

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



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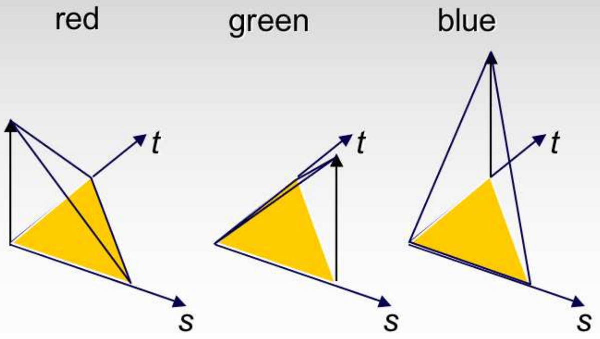
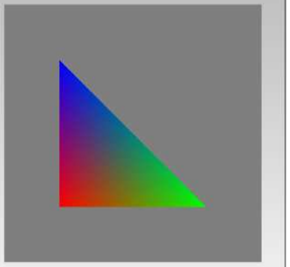
Scan Conversion

Color interpolation

- Example:





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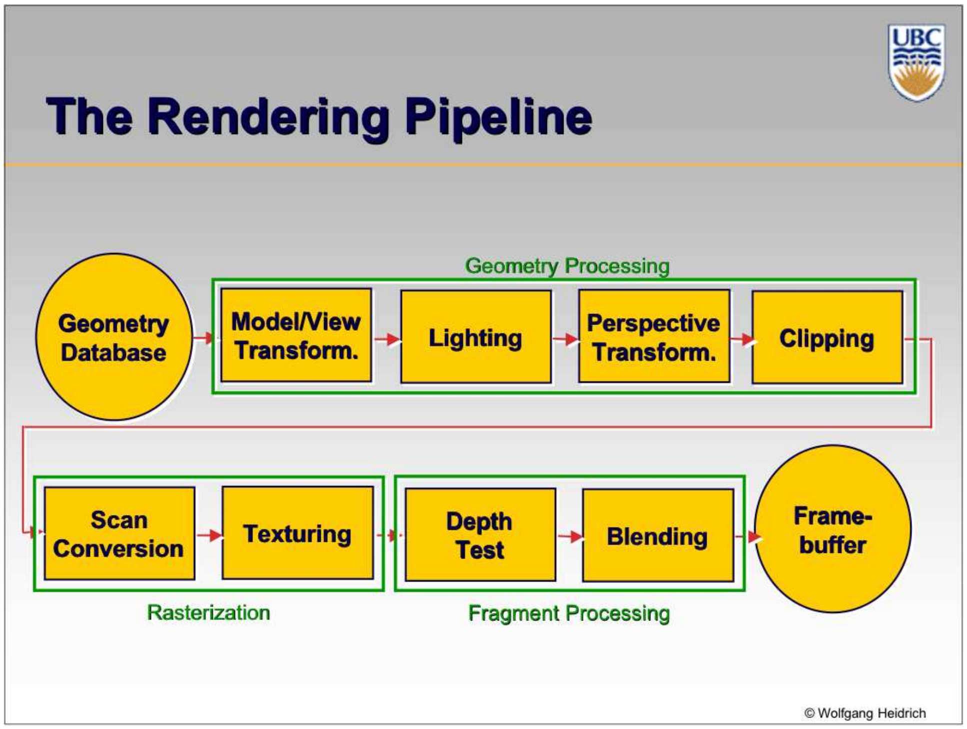

The Rendering Pipeline

Geometry Database → Geometry Processing: Model/View Transform. → Lighting → Perspective Transform. → Clipping → Rasterization: Scan Conversion → Texturing → Fragment Processing: Depth Test → Blending → Frame-buffer

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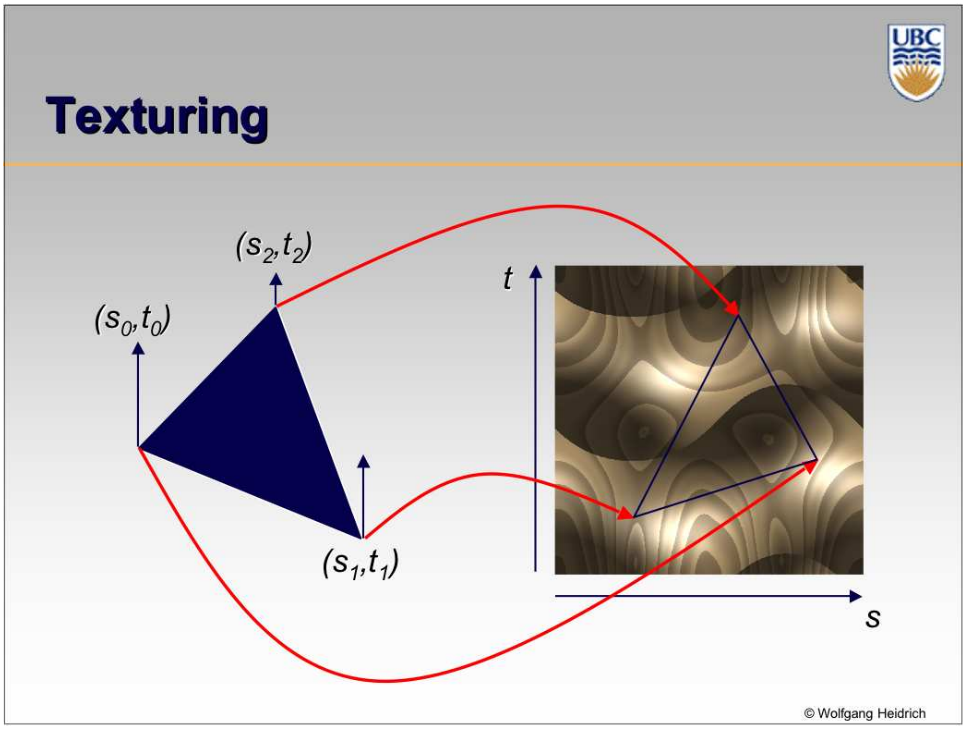

Texturing

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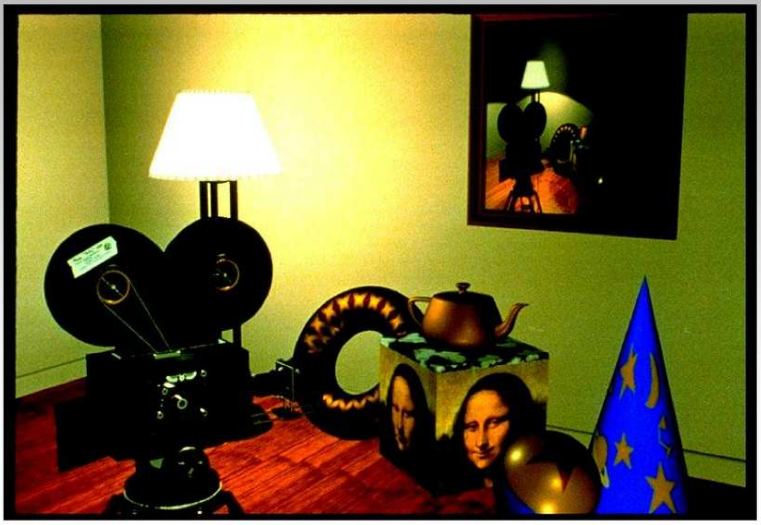
Texture Mapping



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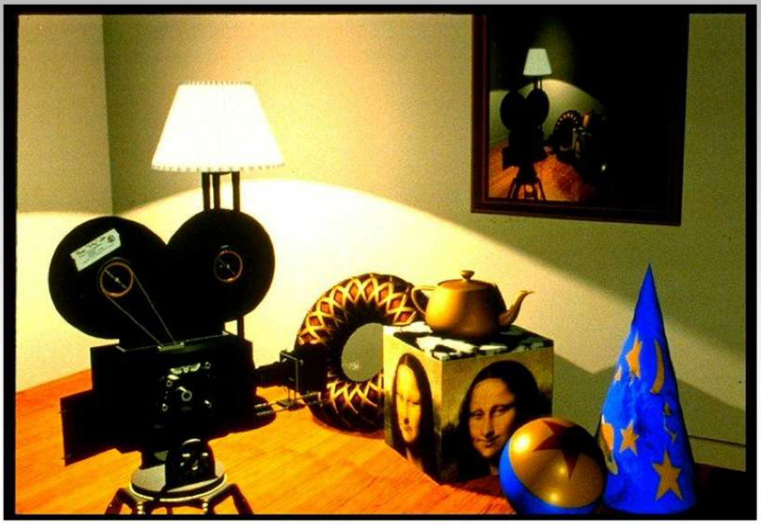
Displacement Mapping



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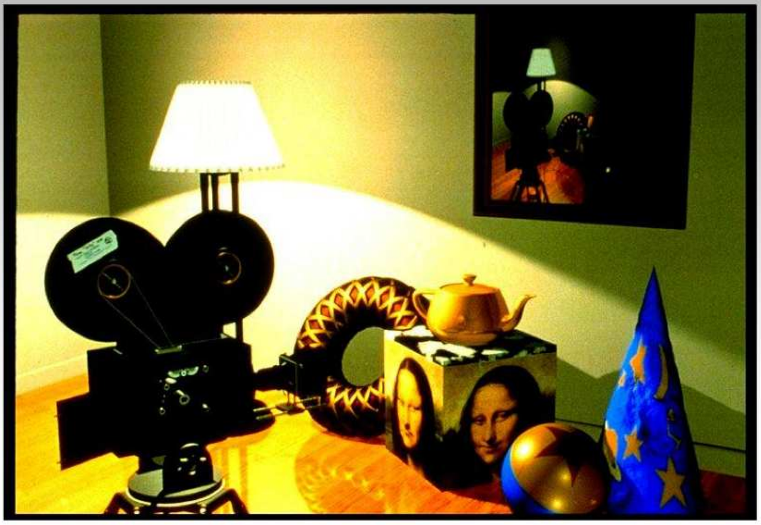
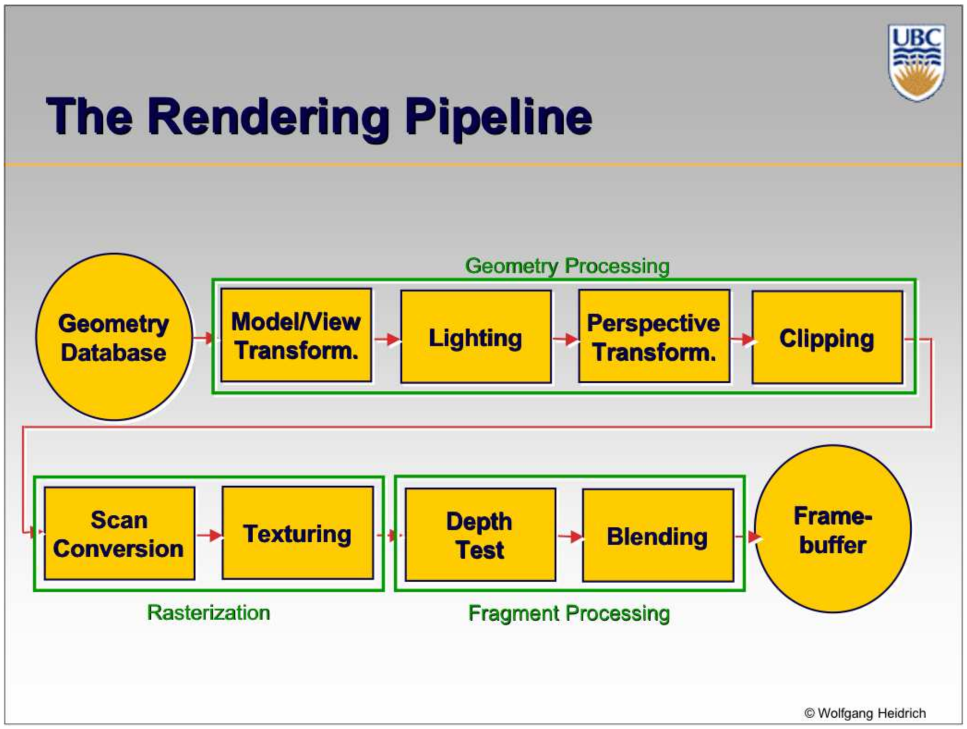
Reflection Mapping



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

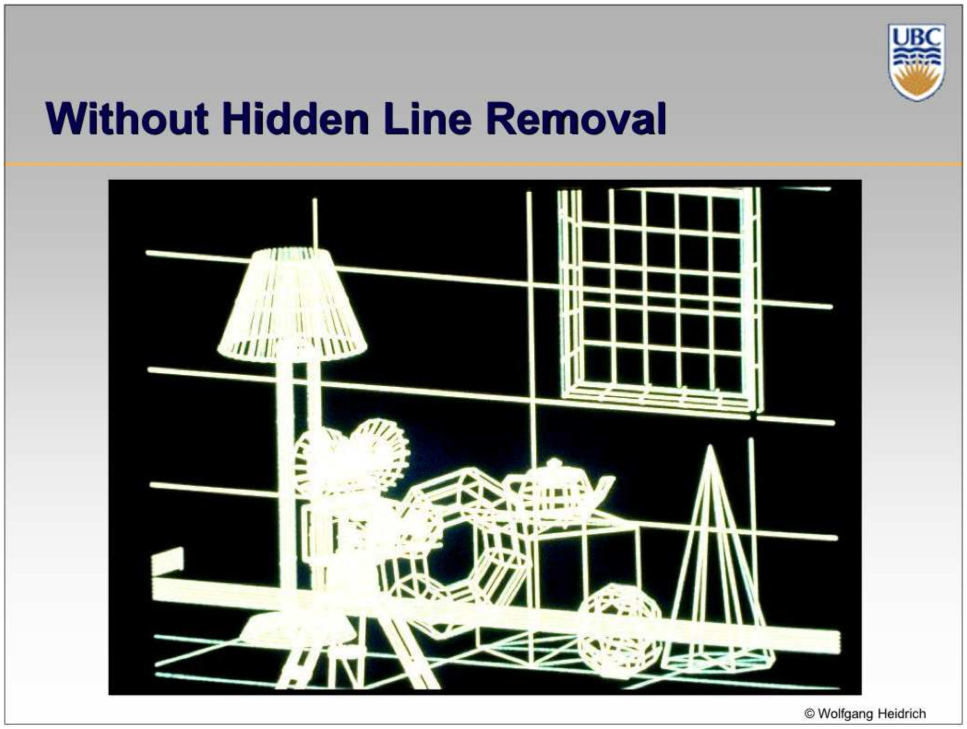
Geometry Processing

Geometry Database → Model/View Transform. → Lighting → Perspective Transform. → Clipping

→ Scan Conversion → Texturing → Depth Test → Blending → Frame-buffer

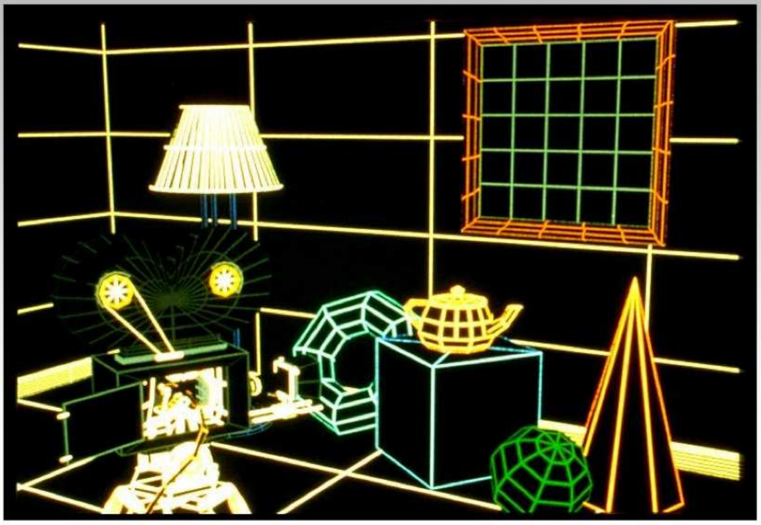
Rasterization

Fragment Processing



Without Hidden Line Removal

Hidden Line Removal



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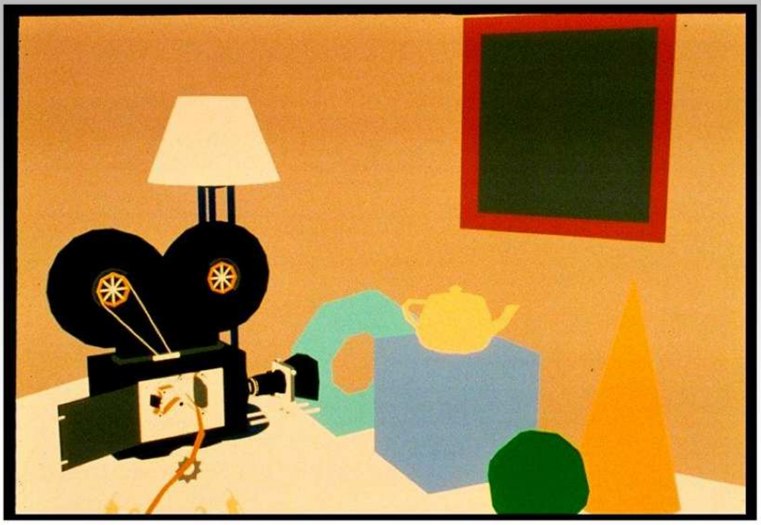
Hidden Surface Removal



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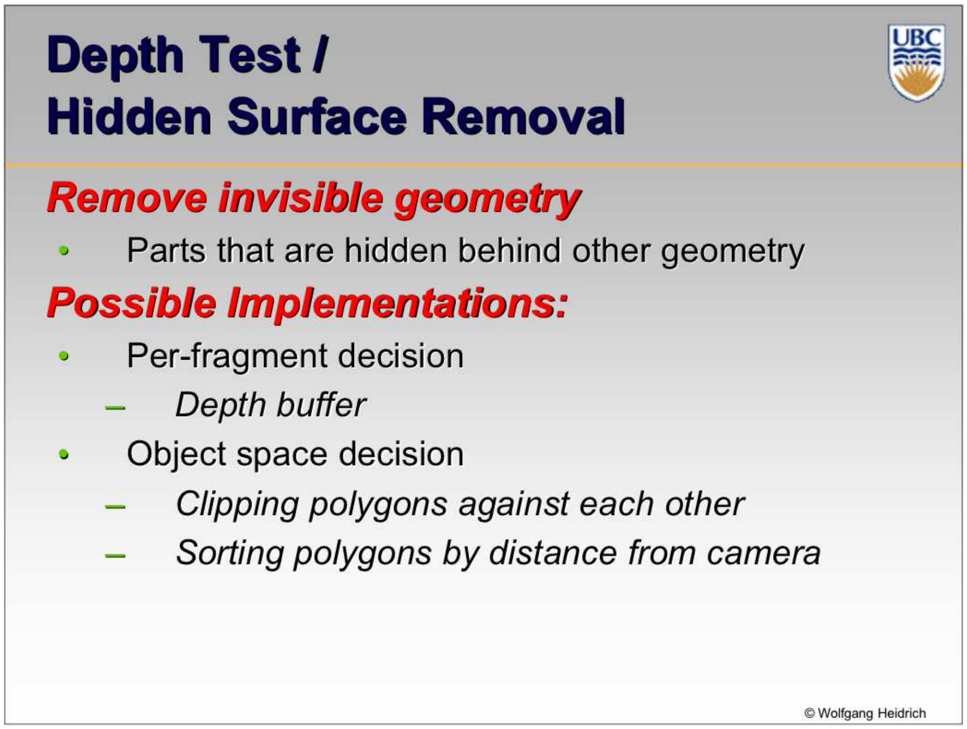


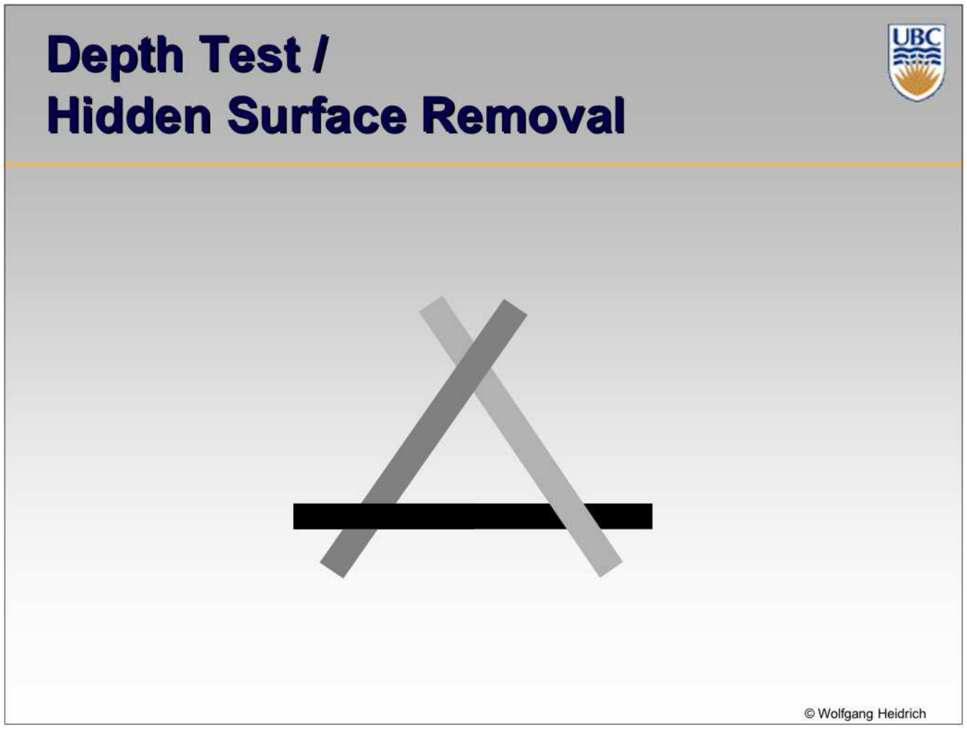
Depth Test / Hidden Surface Removal

Remove invisible geometry

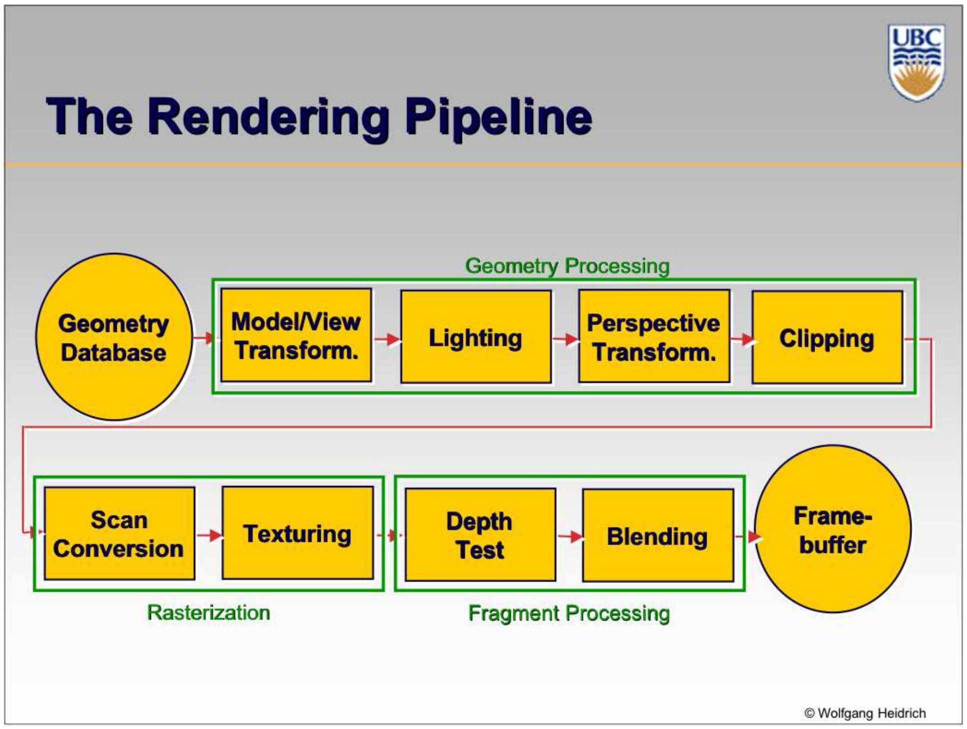
- Parts that are hidden behind other geometry

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

Geometry Processing

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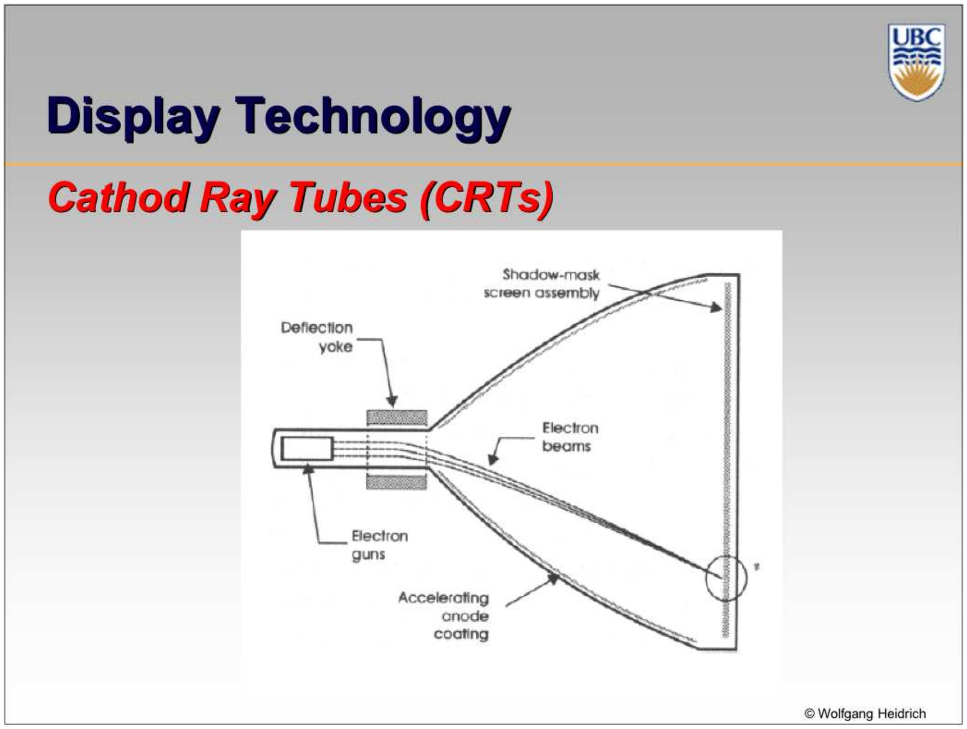
Rasterization

Fragment Processing

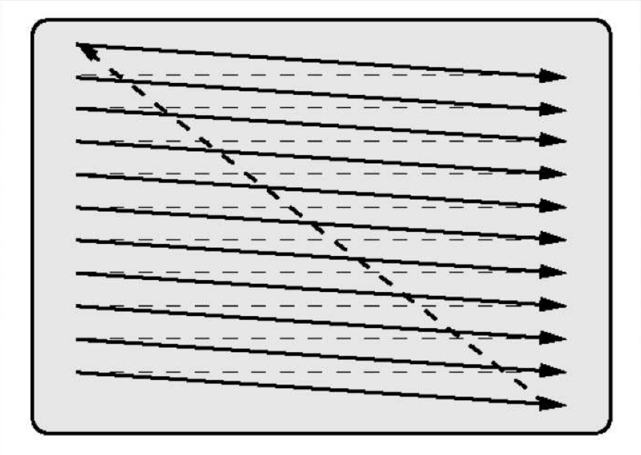


Display Technology

Cathod Ray Tubes (CRTs)

Display Technology

Raster Scan Electron Beam



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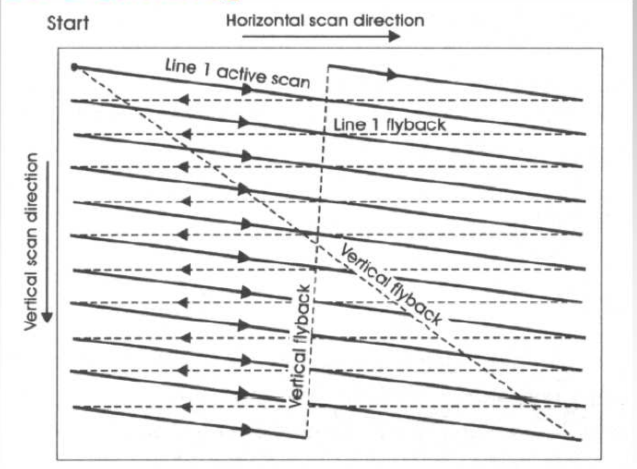
Display Technology

Interlaced Scanning



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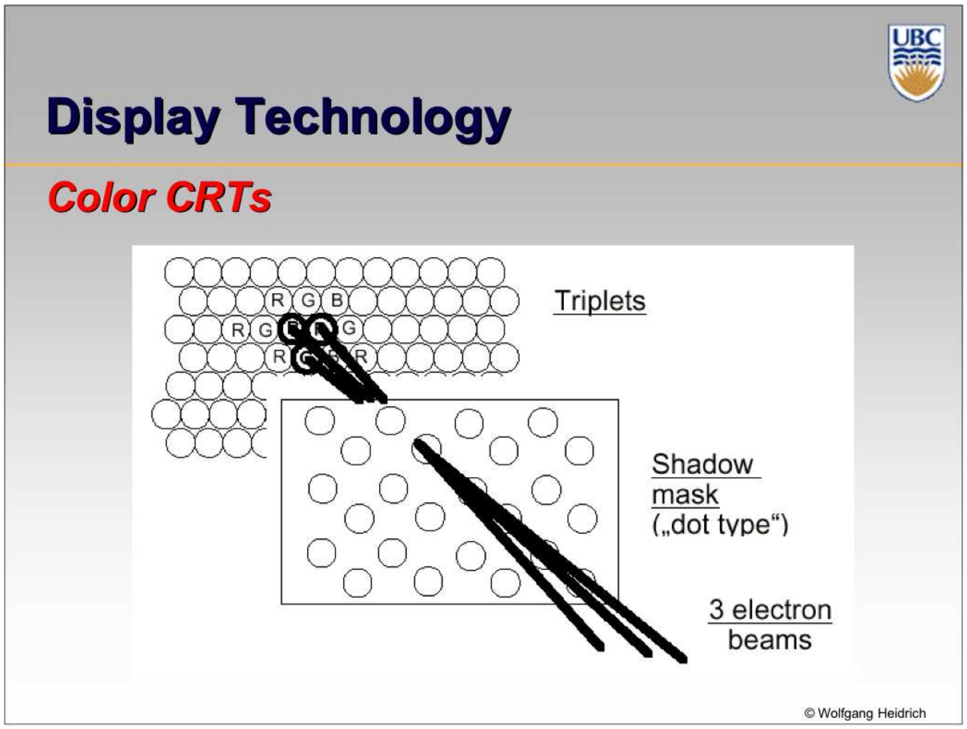

Display Technology

Color CRTs

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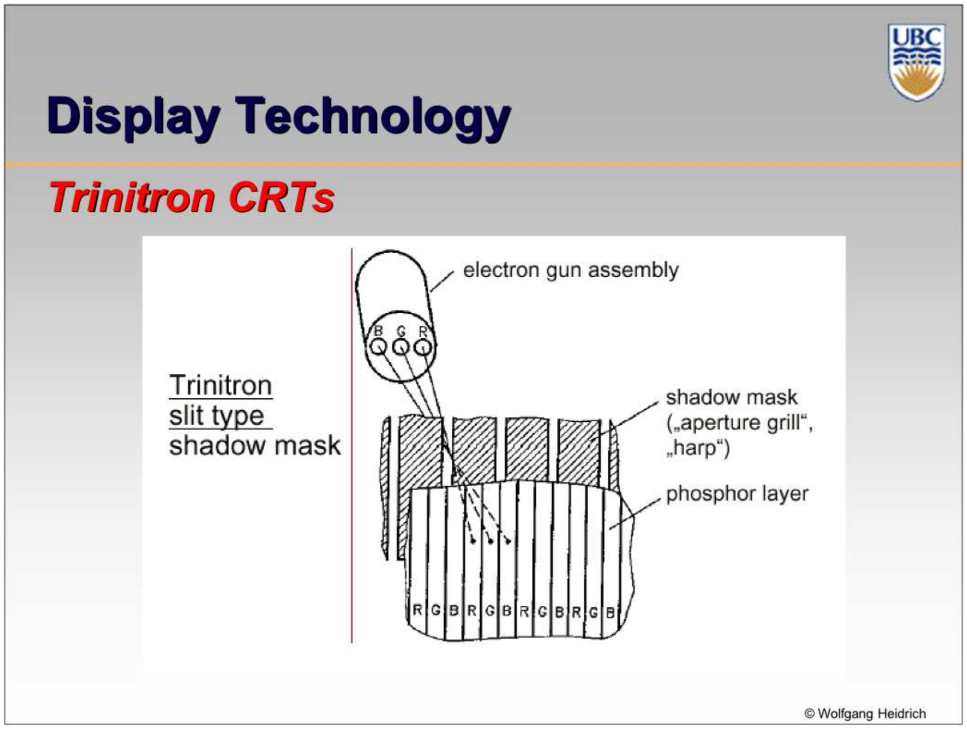

Display Technology

Trinitron CRTs

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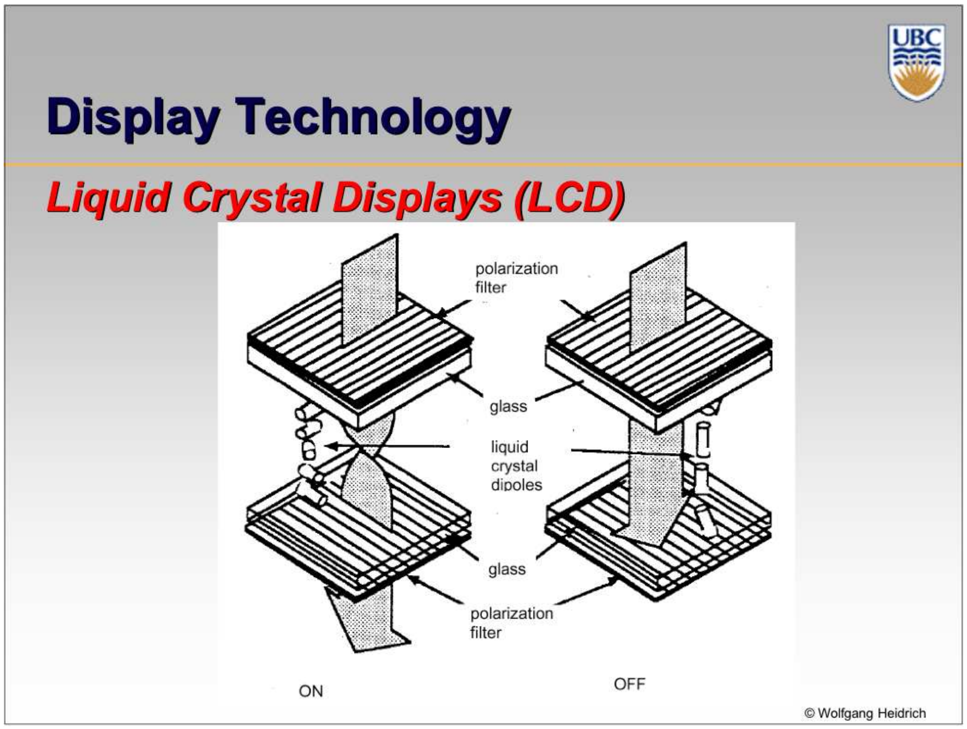

Display Technology

Liquid Crystal Displays (LCD)

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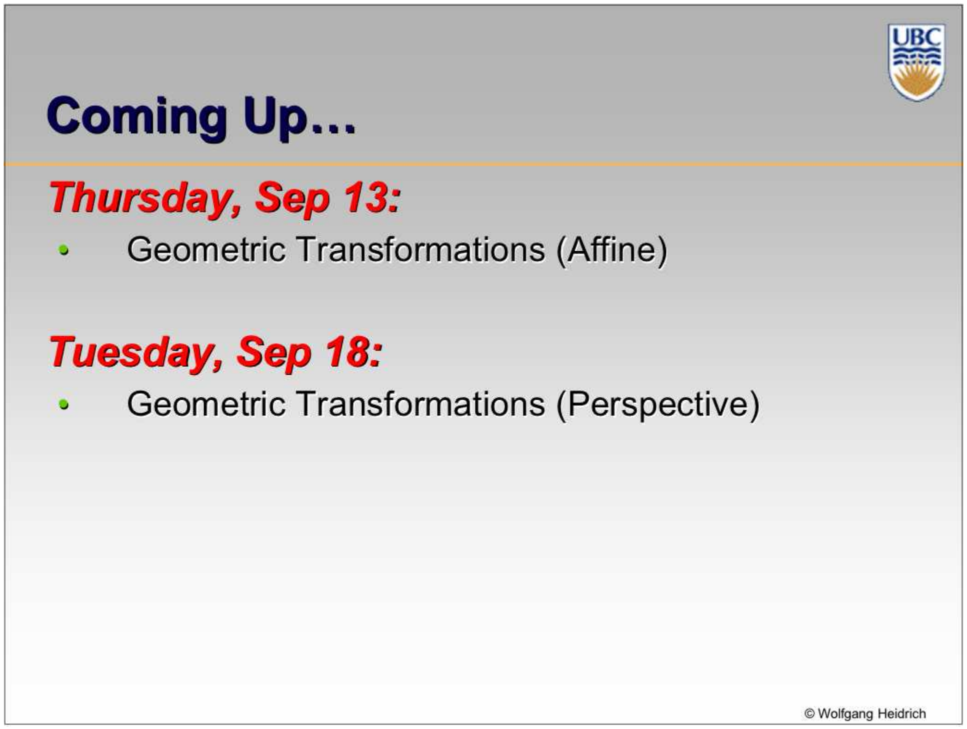

Coming Up…

Thursday, Sep 13:

- Geometric Transformations (Affine)

Tuesday, Sep 18:

- Geometric Transformations (Perspective)

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