CPSC 314
04 – BACK TO RENDERING PIPELINE
UGRAD.CS.UBC.CA/~CS314

Textbook: I.1

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Sep 2016

A1

- How is it?
- Remote making its first feeble steps?

- Come to labs
- Learn how to use debugger console

THEORY ASSIGNMENT 1

- Math recap
- Due in a week in class (Sep 23rd)

LAST TIME

- What does the vertex shader do?

LAST TIME

- What does the vertex shader do?
- Fragment shader?

LAST TIME

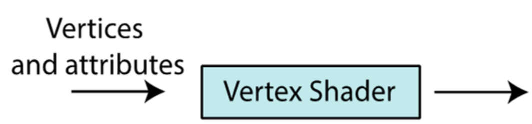
- What does the vertex shader do?
- Fragment shader?

- How to pass some value from JS to Vertex Shader?

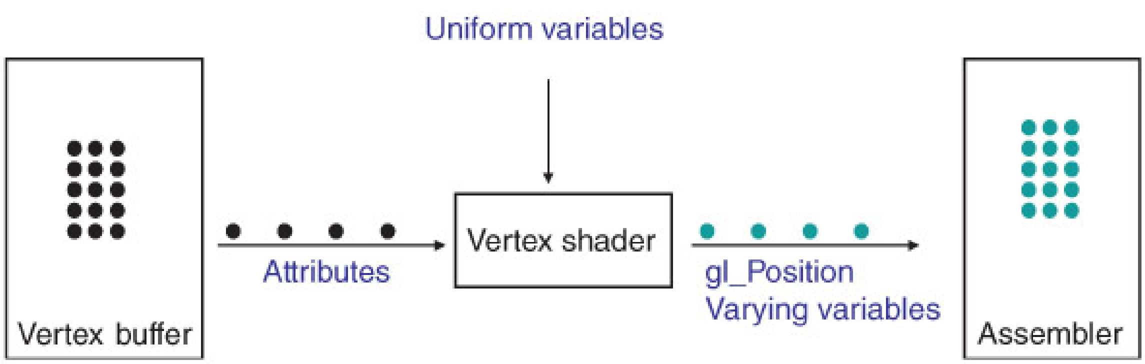
LAST TIME

- What does the vertex shader do?
- Fragment shader?
- How to pass a single value from JS to Vertex Shader?

VERTEX SHADER

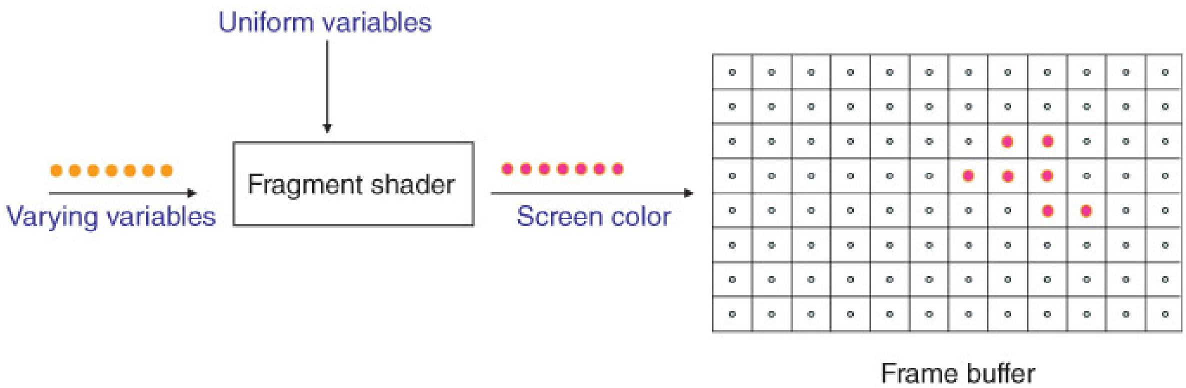


- VS is run for each vertex SEPARATELY



Object coordinates -> WORLD coordinates -> VIEW coordinates

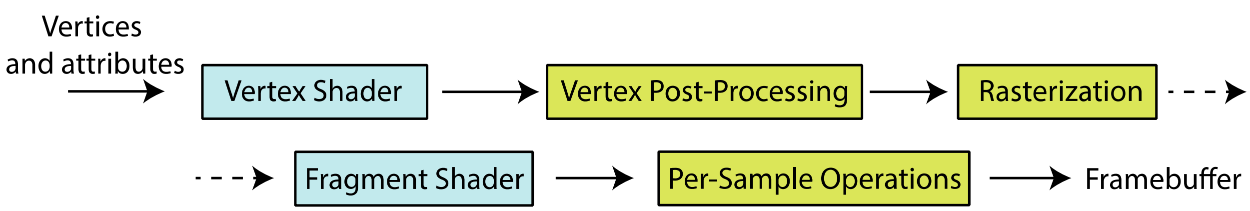
FRAGMENT SHADER



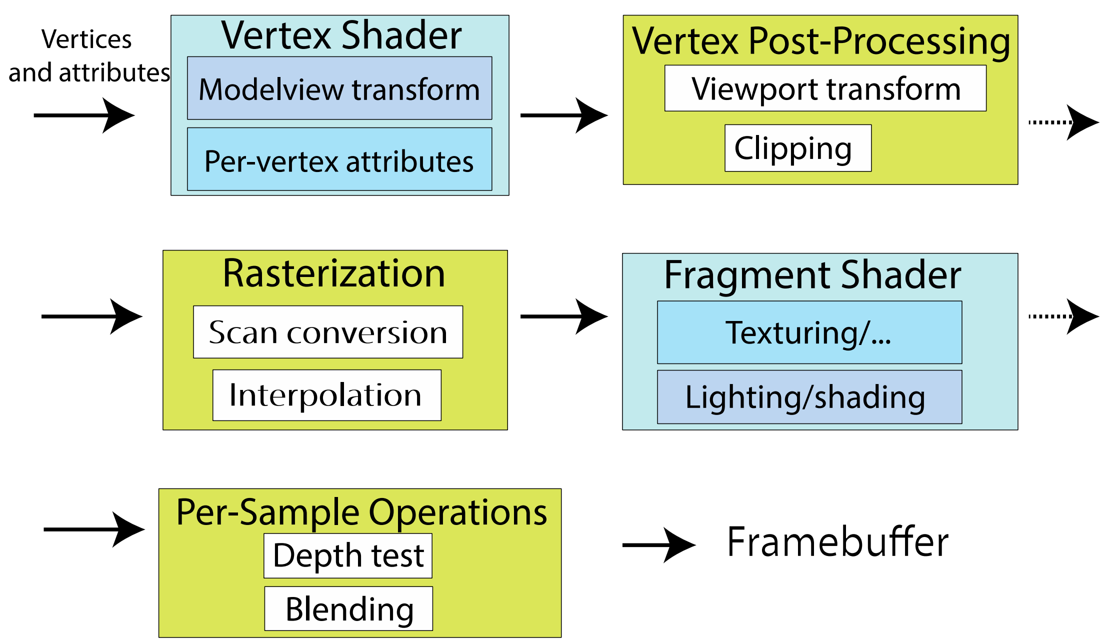
CONCEPTS

- uniform JS + Three.JS → Vertex Shader → Fragment Shader
  - same for all vertices
- varying Vertex Shader → Fragment Shader
  - computed per vertex, automatically interpolated for fragments
- attribute JS + Three.JS → Vertex Shader
  - some values per vertex
  - available only in Vertex Shader

PIPELINE: MORE DETAILS

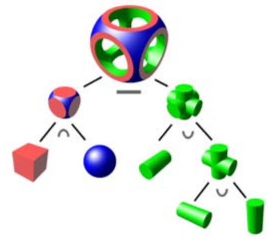


PIPELINE: MORE DETAILS

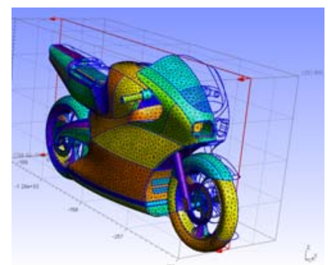


SHAPES: REPRESENTATION OPTIONS

- Volumetric - Boolean algebra with volumetric primitives
  - Spheres, cones, cylinders, tori, …



- Boundary representation – union of surface patches
  - Single basic primitive - Triangle Mesh
  - Higher order surface/curve primitives



SHAPES - CURVES/SURFACES

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

SHAPES: EXPLICIT FUNCTIONS

- Curves:
  - y is a function of x:
  - Only works in 2D

$$y := \sin(x)$$

- Surfaces:
  - z is a function of x and y:
  - Cannot define arbitrary shapes in 3D

$$z := \sin(x) + \cos(y)$$

SHAPES: 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

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

SHAPES: PARAMETRIC FUNCTIONS

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

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

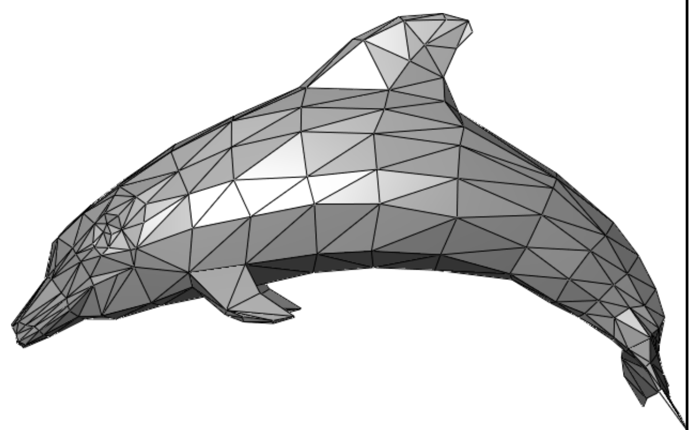
SHAPES: IMPLICIT

- Surface (3D) or Curve (2D) defined by zero set (roots) of function
  - E.g:

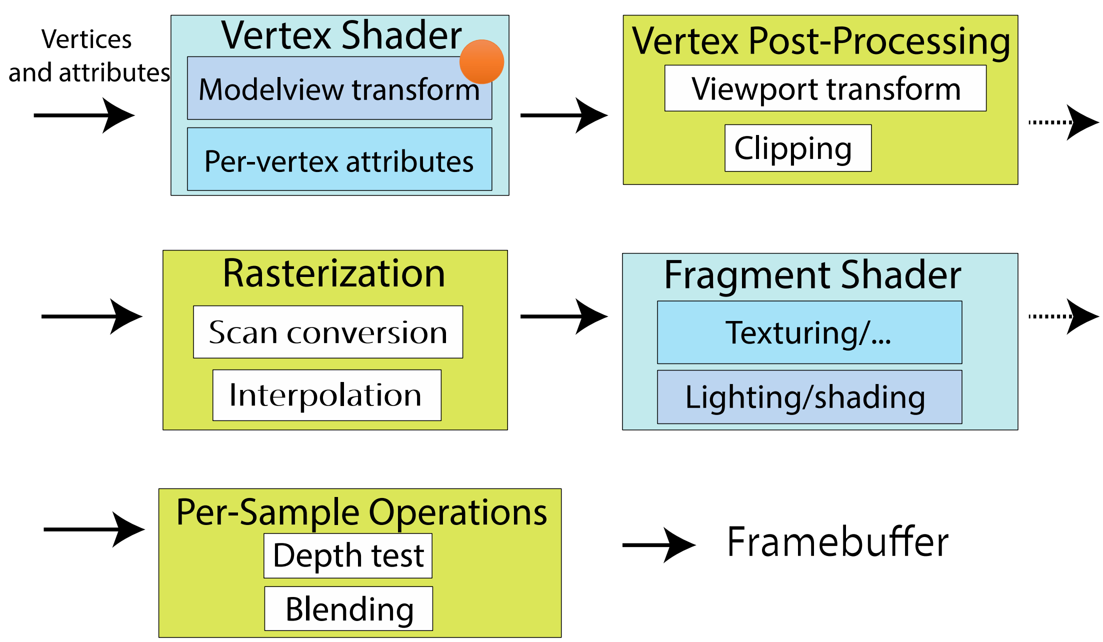
$$S(x, y, z) : x^2 + y^2 + z^2 - 1 = 0$$

SHAPES: TRIANGLE MESHES

- Triangle = 3 vertices
- Mesh = {vertices, triangles}
- Example

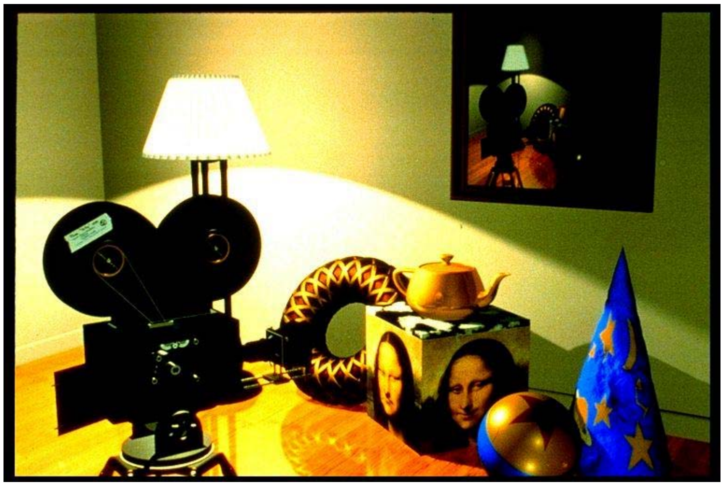


PIPELINE: MORE DETAILS

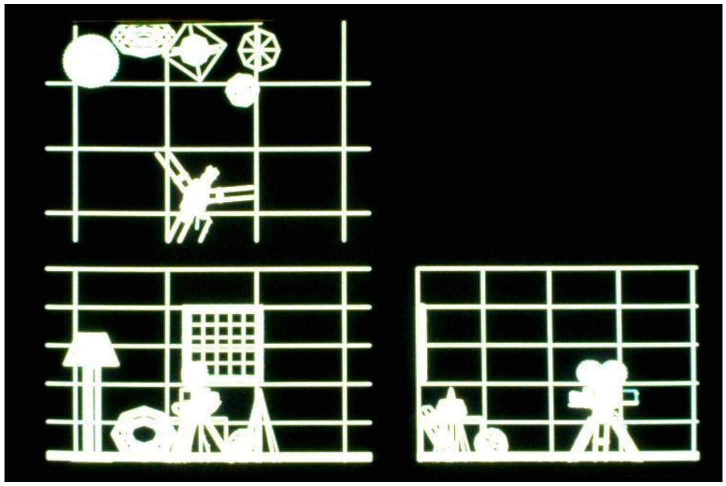


MODELING AND VIEWING TRANSFORMATIONS

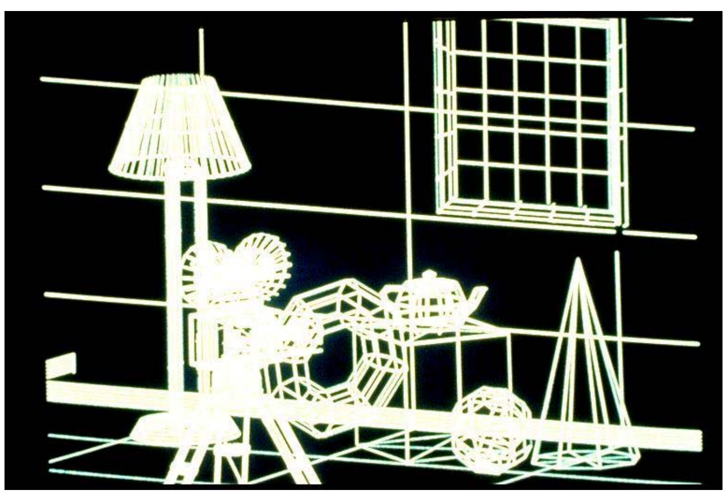
- Placing objects - Modeling transformations
  - Map points from object coordinate system to world coordinate system
- Looking from the camera - Viewing transformation
  - Map points from world coordinate system to camera (or eye) coordinate system



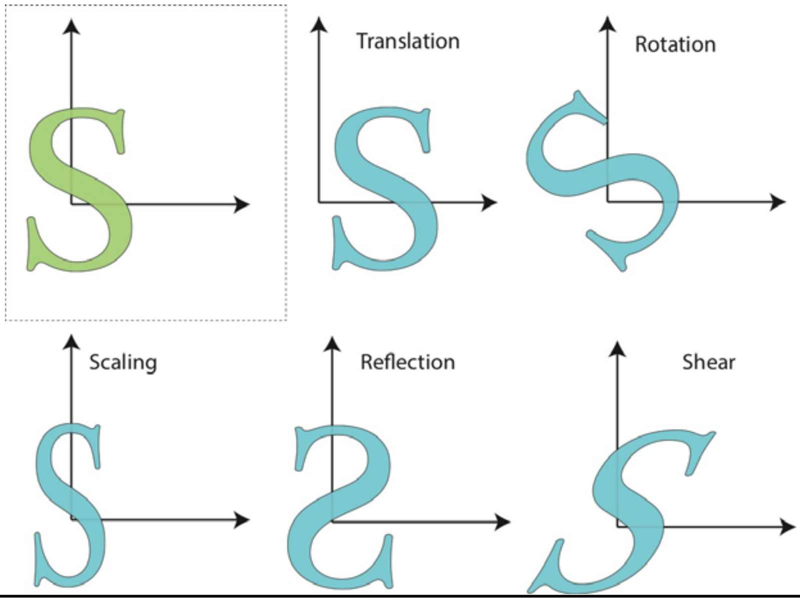
MODELING TRANSFORMATIONS: OBJECT PLACEMENT



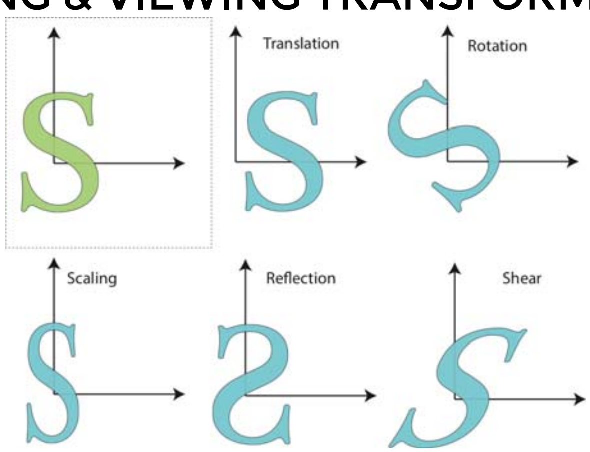
VIEWING TRANSFORMATION: LOOKING FROM A CAMERA



MODELING & VIEWING TRANSFORMATIONS



MODELING & VIEWING TRANSFORMATIONS



- 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:

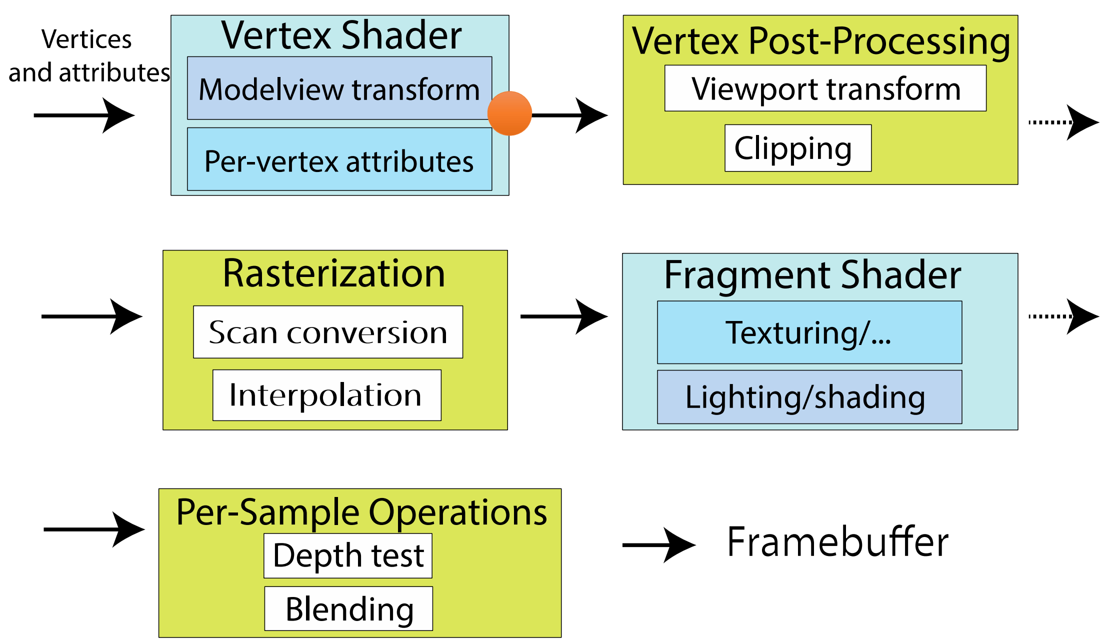
$$\begin{pmatrix} x' \\ y' \\ z' \end{pmatrix} = \begin{pmatrix} 2 & 0 & 0 \\ 0 & 3 & 0 \\ 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} x \\ y \\ z \end{pmatrix} + \begin{pmatrix} t_x \\ t_y \\ t_z \end{pmatrix}$$

  - Another representation: 4x4 homogeneous matrix

MATRICES

- Object coordinates -> World coordinates
  - **Model Matrix**
  - One per object
- World coordinates -> Camera coordinates
  - **View Matrix**
  - One per camera

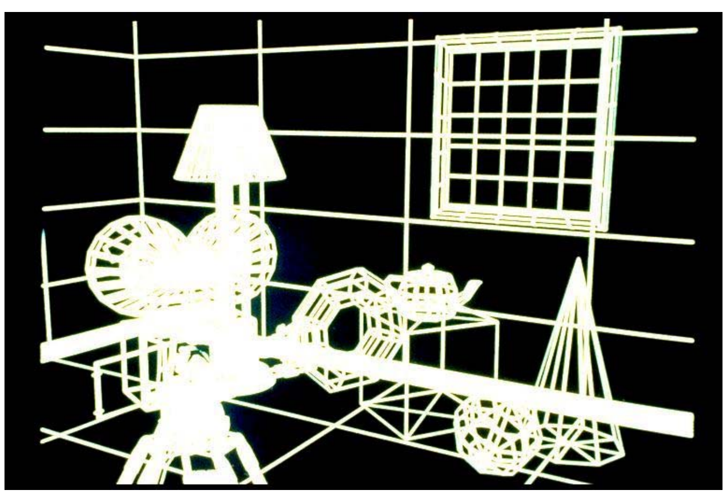
PIPELINE: MORE DETAILS



PERSPECTIVE TRANSFORMATION

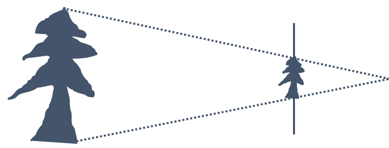
- Purpose:
  - Project 3D geometry to 2D image plane
  - Simulates a camera
- Camera model:
  - Pinhole camera (single view point)
  - More complex camera models exist, but are less common in CG

PERSPECTIVE PROJECTION



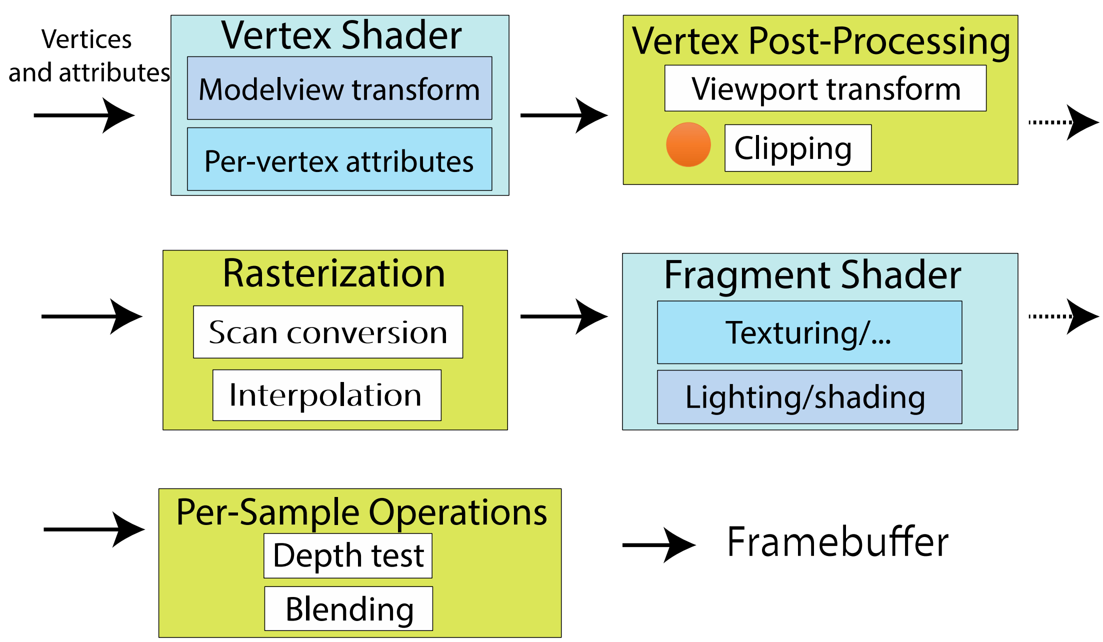
PERSPECTIVE TRANSFORMATION

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



  - Perspective transformation is **one of** projective transformations
  - Linear & affine transformations also belong to this class
  - All projective transformations can be expressed as 4x4 matrix operations

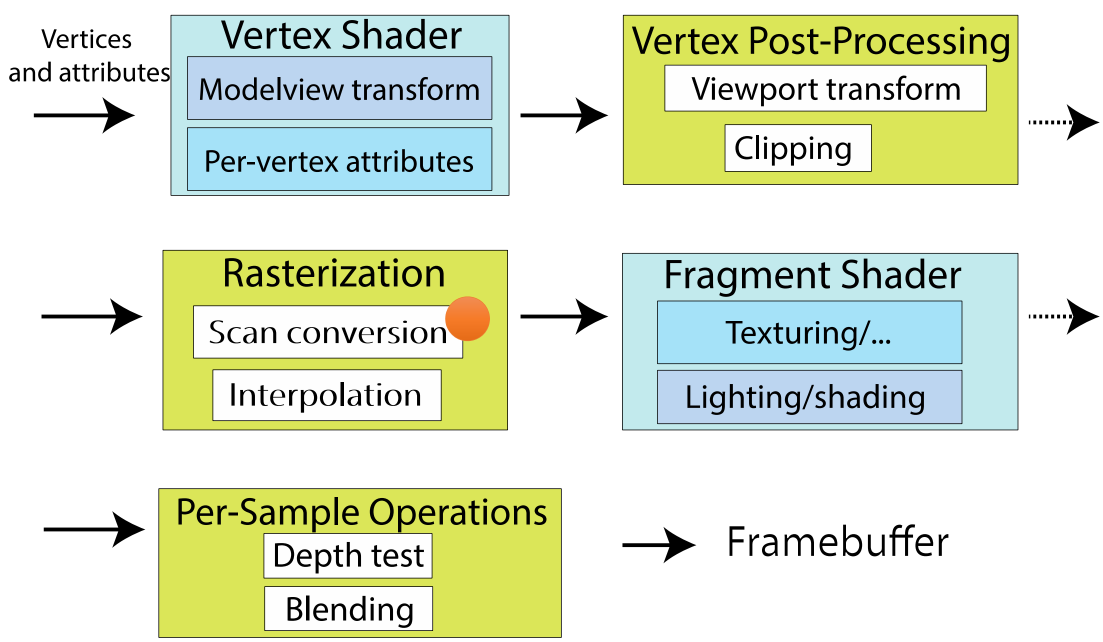
PIPELINE: MORE DETAILS



CLIPPING

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

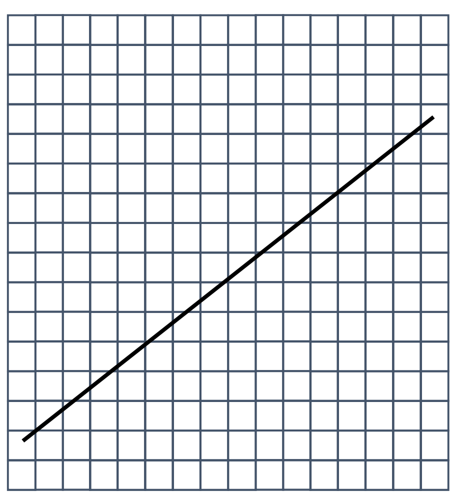
PIPELINE: MORE DETAILS



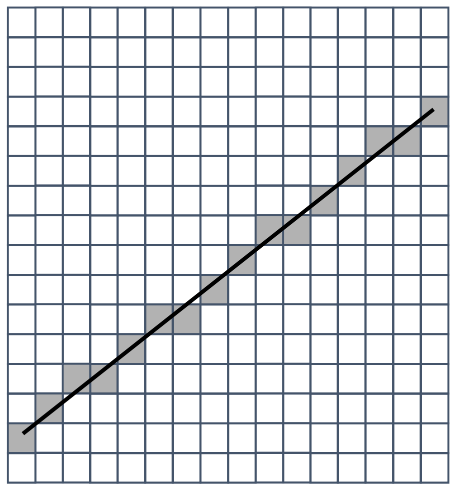
SCAN CONVERSION/RASTERIZATION

- Convert continuous 2D geometry to discrete
- Raster display – discrete grid of elements
- Terminology
  - **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

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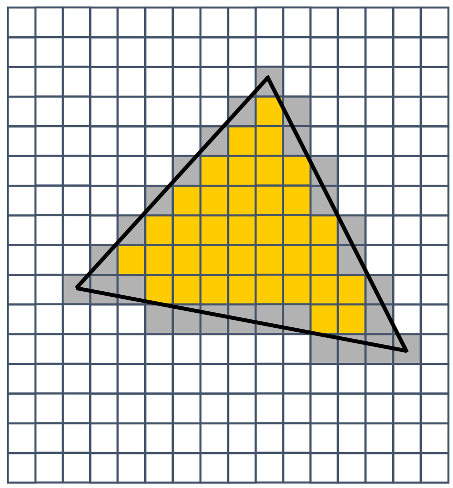
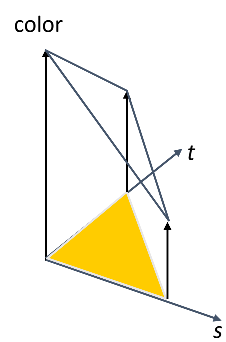


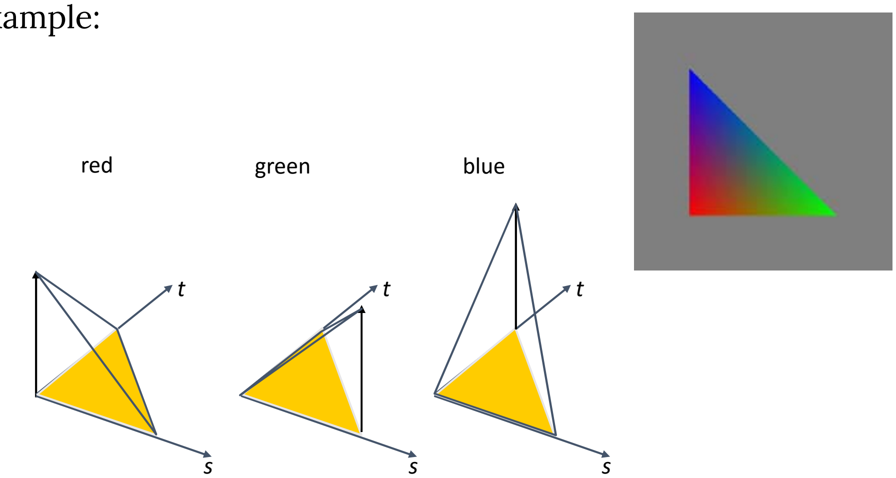
COLOR INTERPOLATION

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

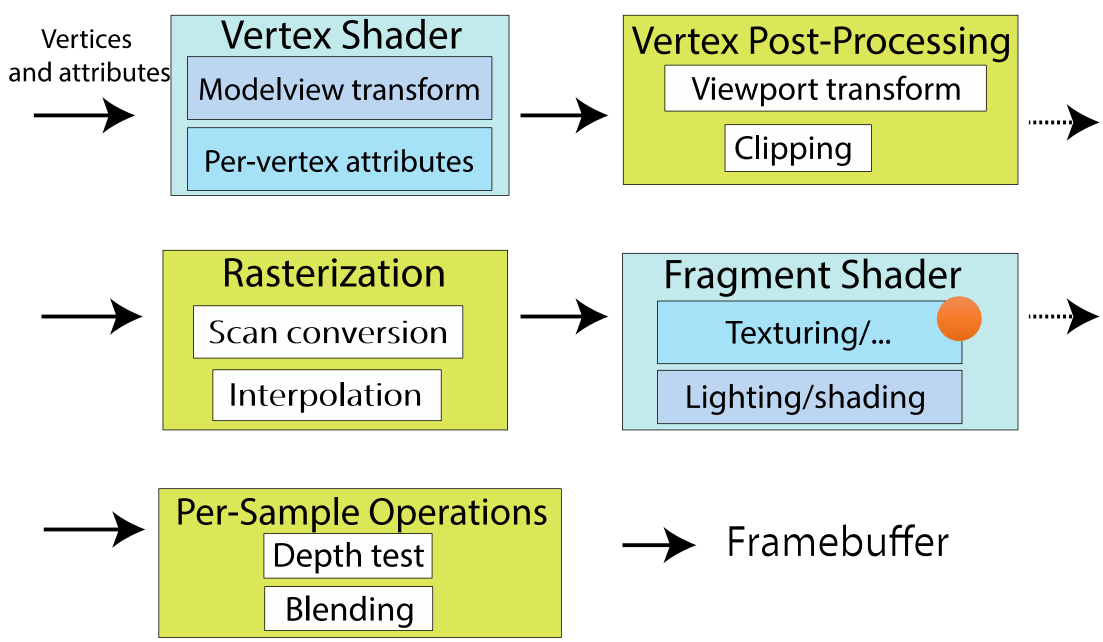


COLOR INTERPOLATION

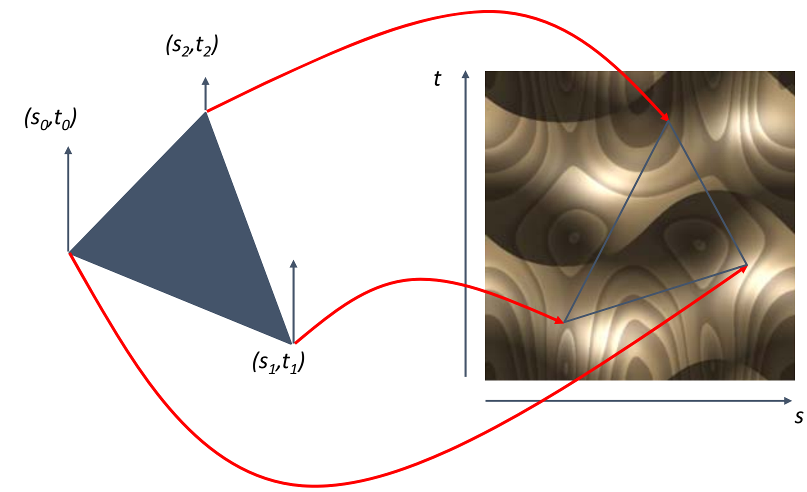
- Example:



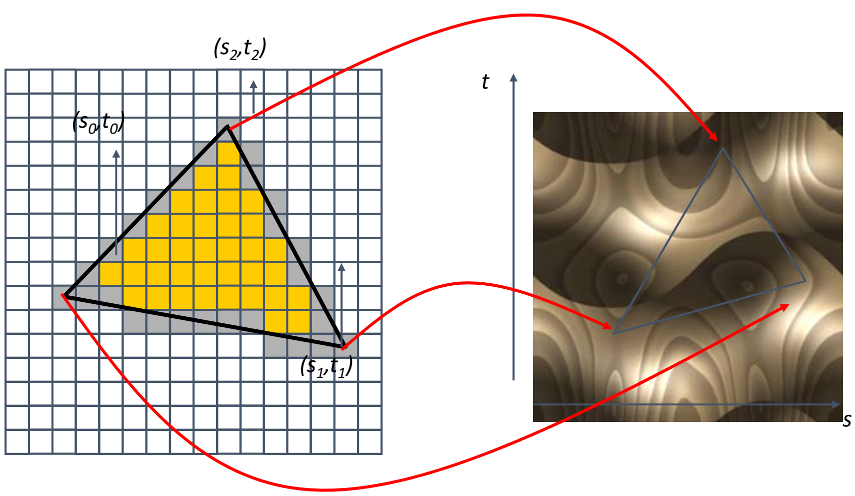
PIPELINE: MORE DETAILS



TEXTURING



TEXTURING



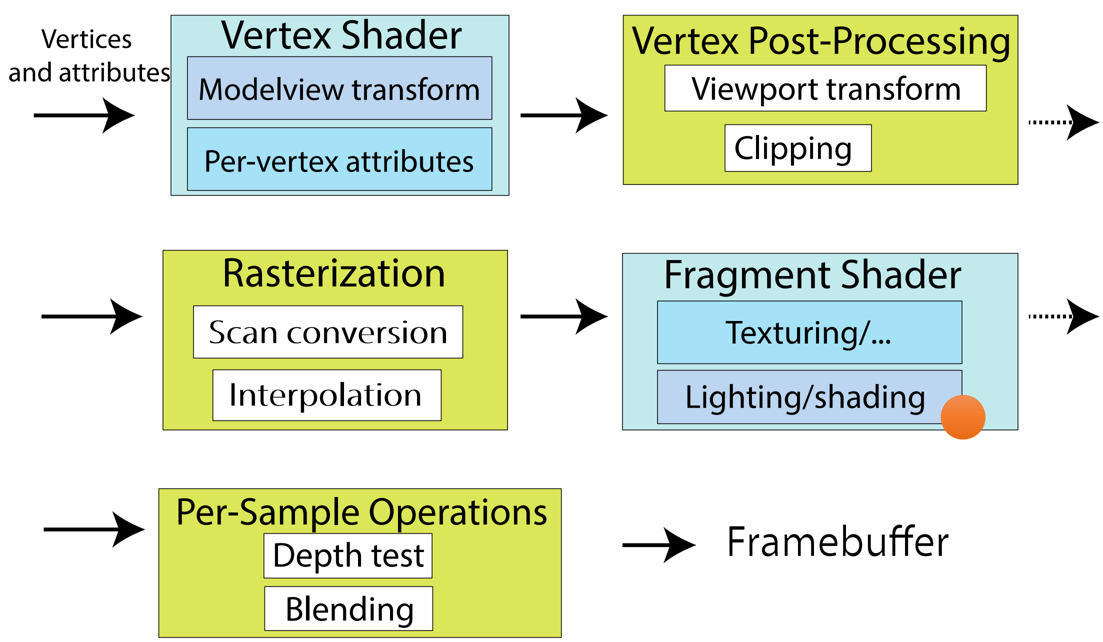
TEXTURE MAPPING

DISPLACEMENT MAPPING

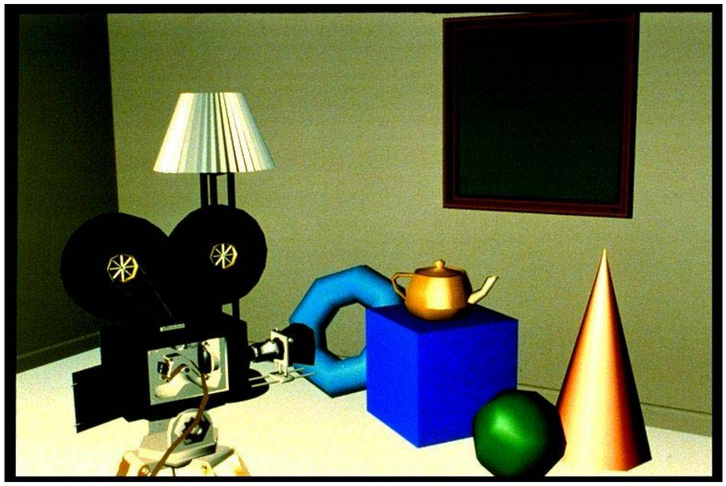
TEXTURING

- 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)

PIPELINE: MORE DETAILS

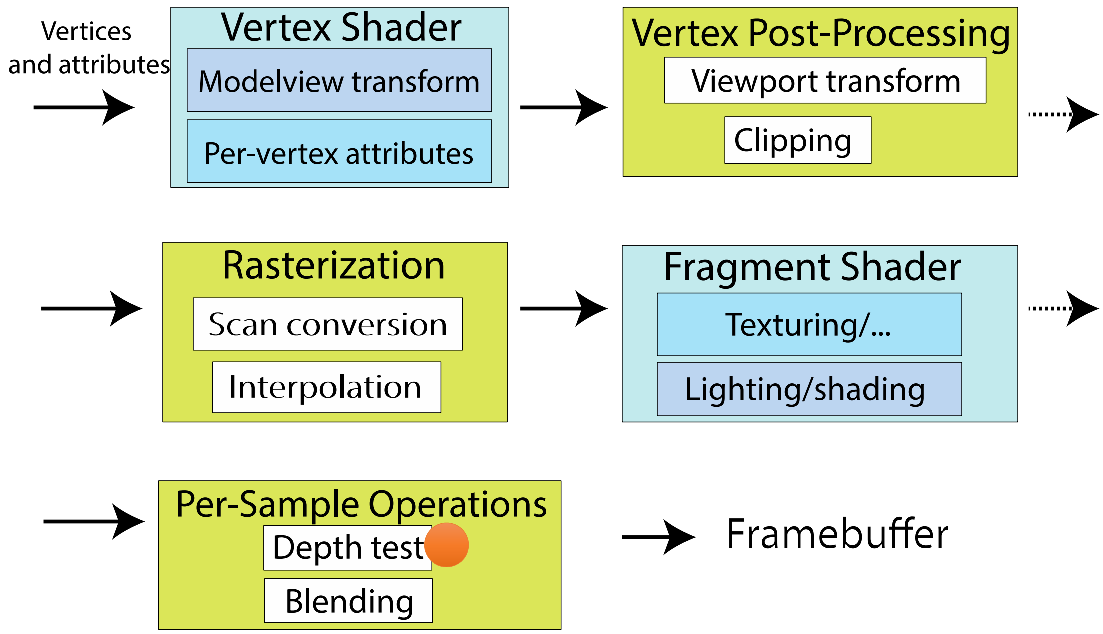


LIGHTING

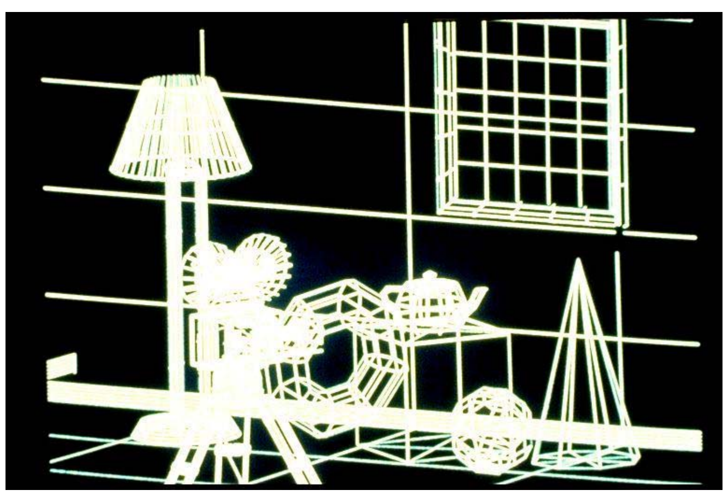


COMPLEX LIGHTING AND SHADING

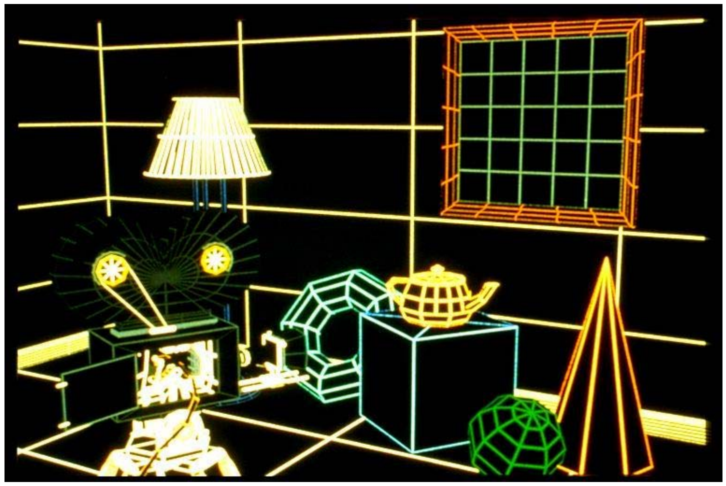
PIPELINE: MORE DETAILS



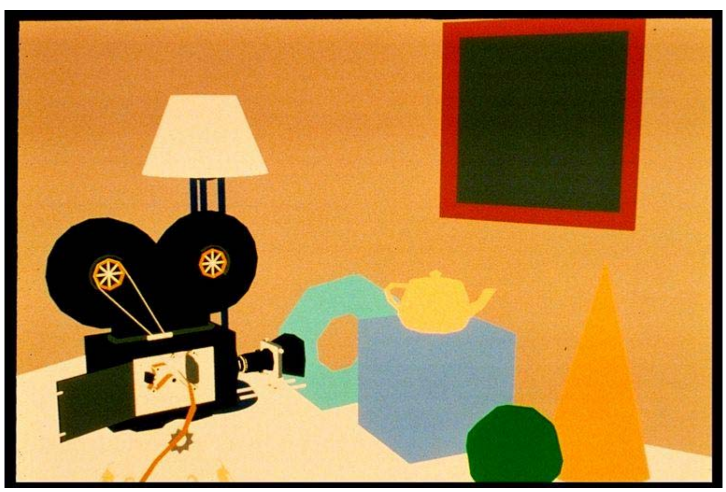
WITHOUT HIDDEN LINE REMOVAL



HIDDEN LINE REMOVAL



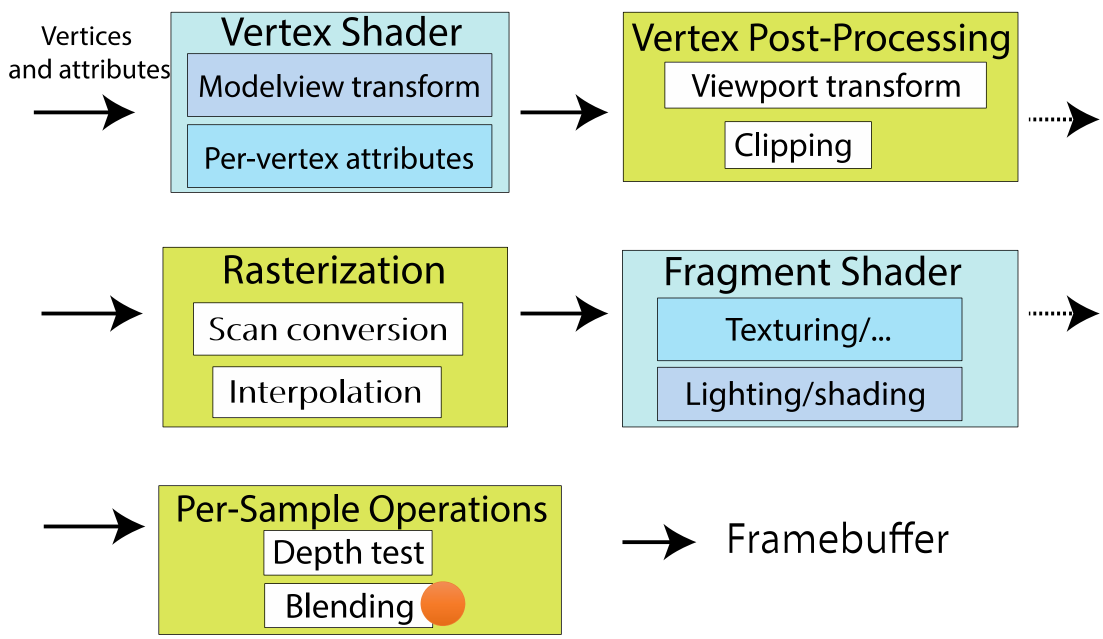
HIDDEN SURFACE REMOVAL



DEPTH TEST /HIDDEN SURFACE REMOVAL

- Remove invisible geometry
  - Parts that are hidden behind other geometry
- Possible Implementations:
  - Pixel level decision
    - Depth buffer
  - Object space decision
    - E.g. intersection order for ray tracing

PIPELINE: MORE DETAILS



BLENDING

- Blending:
  - Fragments -> 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

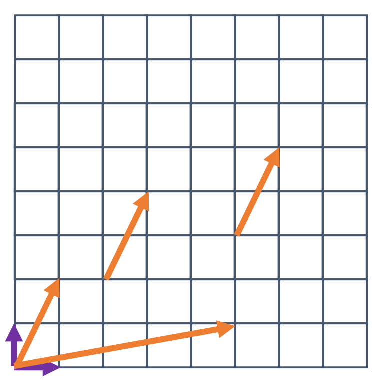
REFLECTION/SHADOWS

</PIPELINE>

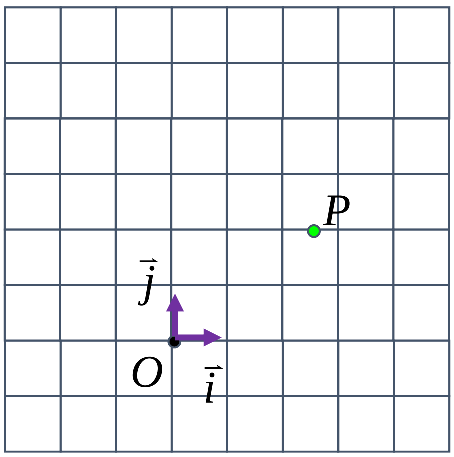
- Questions?

COORDINATE SYSTEMS

- Coordinate system = Origin + Basis Vectors



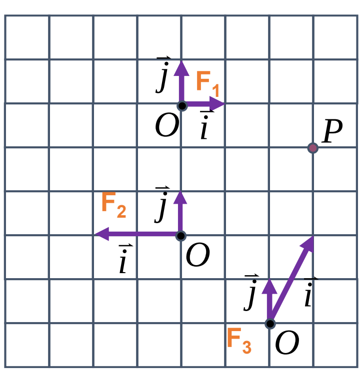
COORDINATE SYSTEMS



$$P = O + x\vec{i} + y\vec{j}$$

equivalent: $P = (x, y)$

COORDINATE SYSTEMS



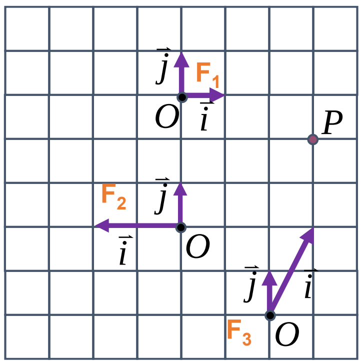
$$P = O + x\vec{i} + y\vec{j}$$

F_1

F_2

F_3

COORDINATE SYSTEMS



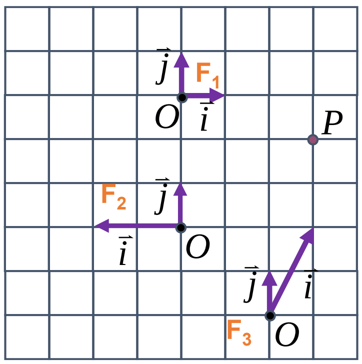
$$P = O + x\vec{i} + y\vec{j}$$

F_1 **P(3,-1)**

F_2

F_3

COORDINATE SYSTEMS



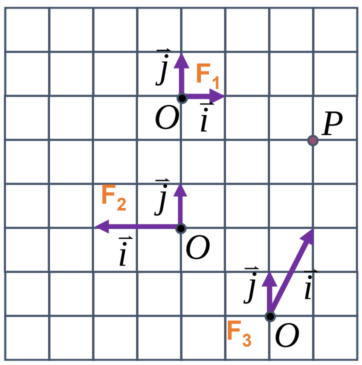
$$P = O + x\vec{i} + y\vec{j}$$

F_1 **P(3,-1)**

F_2 **P(-1.5,2)**

F_3

COORDINATE SYSTEMS



$$P = O + x\vec{i} + y\vec{j}$$

F_1 **P(3,-1)**

F_2 **P(-1.5,2)**

F_3 **P(1,2)**

BONUS (WARM-UP)

- For a given vector and a coordinate frame, are vector's coordinates unique? Why? Are they always defined?