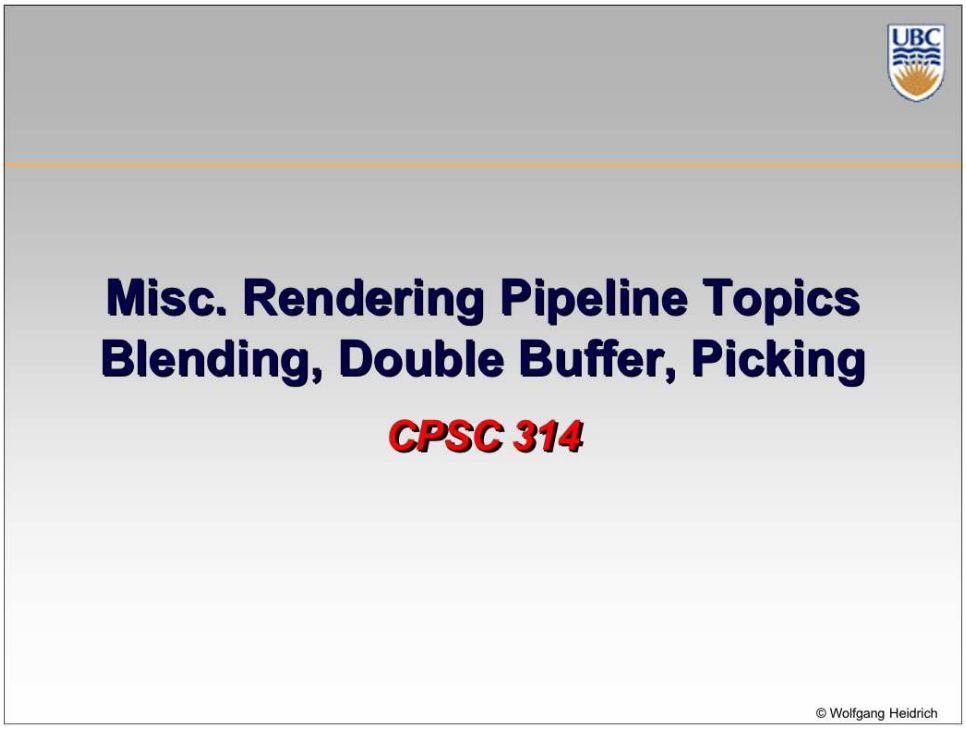
Misc. Rendering Pipeline Topics
Blending, Double Buffer, Picking
CPSC 314
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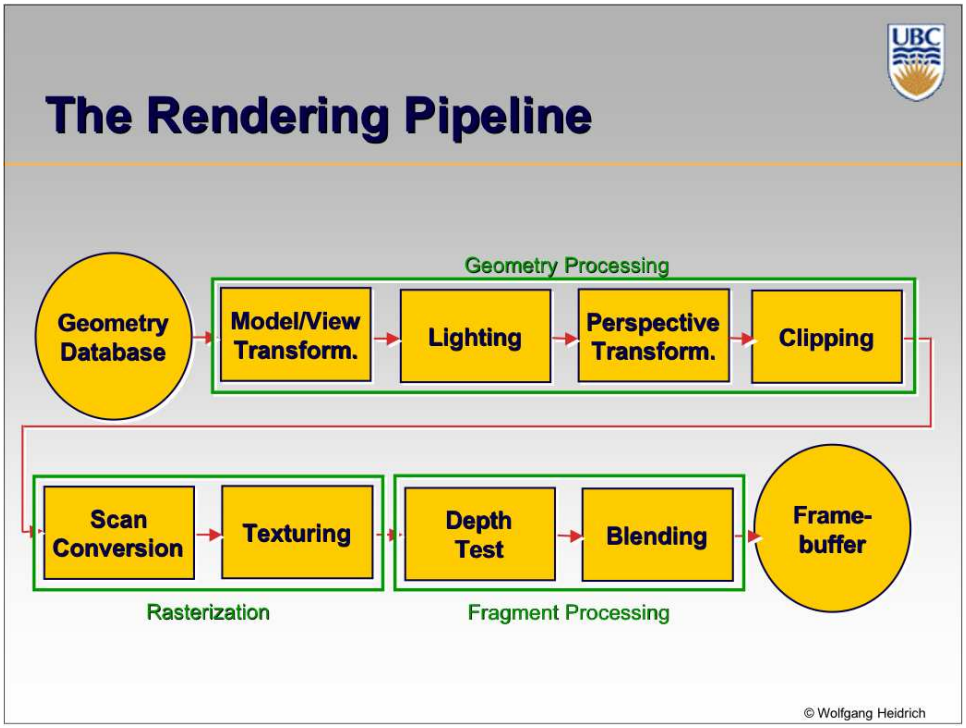
The Rendering Pipeline
Geometry Processing
Geometry Database
Model/View Transform.
Lighting
Perspective Transform.
Clipping
Scan Conversion
Texturing
Depth Test
Blending
Frame-buffer
Rasterization
Fragment Processing
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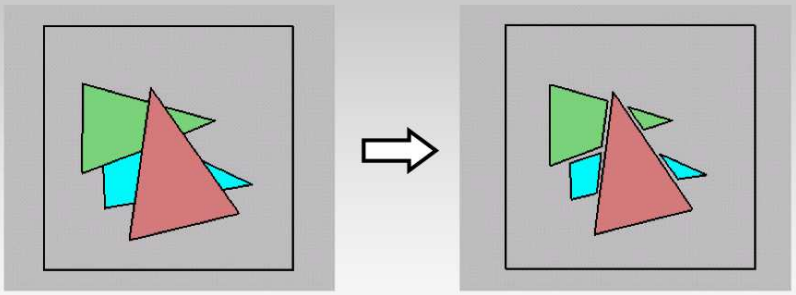
Depth Test / Hidden Surface Removal

- For most interesting scenes, some polygons overlap



- To render the correct image, we need to determine which polygons occlude which

Hidden Surface Removal

Object Space Methods:

- Work in 3D before scan conversion
  - *E.g. Painter's algorithm*
- Usually independent of resolution
  - *Important to maintain independence of output device (screen/printer etc.)*

Image Space Methods:

- Work on per-pixel/per fragment basis after scan conversion
- Z-Buffer/Depth Buffer
- Much faster, but resolution dependent

The Z-Buffer Algorithm

Augment color framebuffer with Z-buffer

- Also called depth buffer
- Stores z value at each pixel
- At frame beginning, initialize all pixel depths to ∞
- When scan converting: interpolate depth (z) across polygon
- Check z-buffer before storing pixel color in framebuffer and storing depth in z-buffer
- don't write pixel if its z value is more distant than the z value already stored there

Z-Buffer

Store (r,g,b,z) for each pixel

- typically 8+8+8+24 bits, can be more

```
for all i,j {
 Depth[i,j] = MAX_DEPTH
 Image[i,j] = BACKGROUND_COLOUR
}
for all polygons P {
  for all pixels in P {
    if (Z_pixel < Depth[i,j]) {
      Image[i,j] = C_pixel
      Depth[i,j] = Z_pixel
    }
  }
}
```

Depth Test Precision

- Reminder: projective transformation maps eye-space z to generic z-range (NDC)
- Simple example:

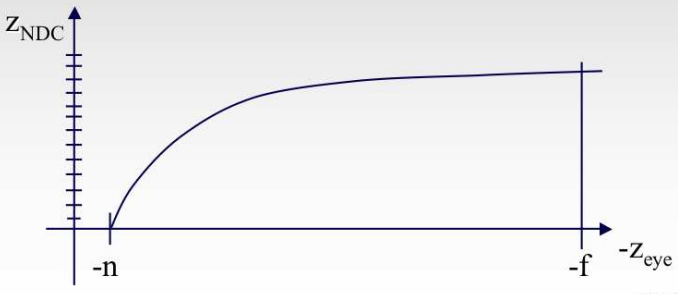
$$T\left(\begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}\right) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & a & b \\ 0 & 0 & -1 & 0 \end{bmatrix} \cdot \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

- Thus:

$$z_{NDC} = \frac{a \cdot z_{eye} + b}{z_{eye}} = a + \frac{b}{z_{eye}}$$

Depth Test Precision

- Therefore, depth-buffer essentially stores 1/z, rather than z!
- Issue with integer depth buffers
  - *High precision for near objects*
  - *Low precision for far objects*



Object Space Algorithms

Determine visibility on object or polygon level

- Using camera coordinates

Resolution independent

- Explicitly compute visible portions of polygons

Early in pipeline

- After clipping

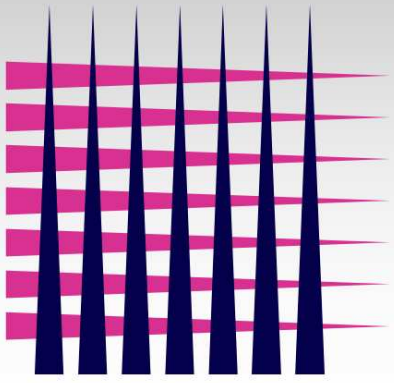
Requires depth-sorting

- Painter's algorithm
- BSP trees

Object Space Visibility Algorithms

What is the minimum worst-case cost of computing the fragments for a scene composed of *n* polygons?

Answer:
$O(n^2)$

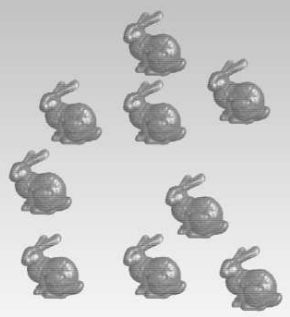


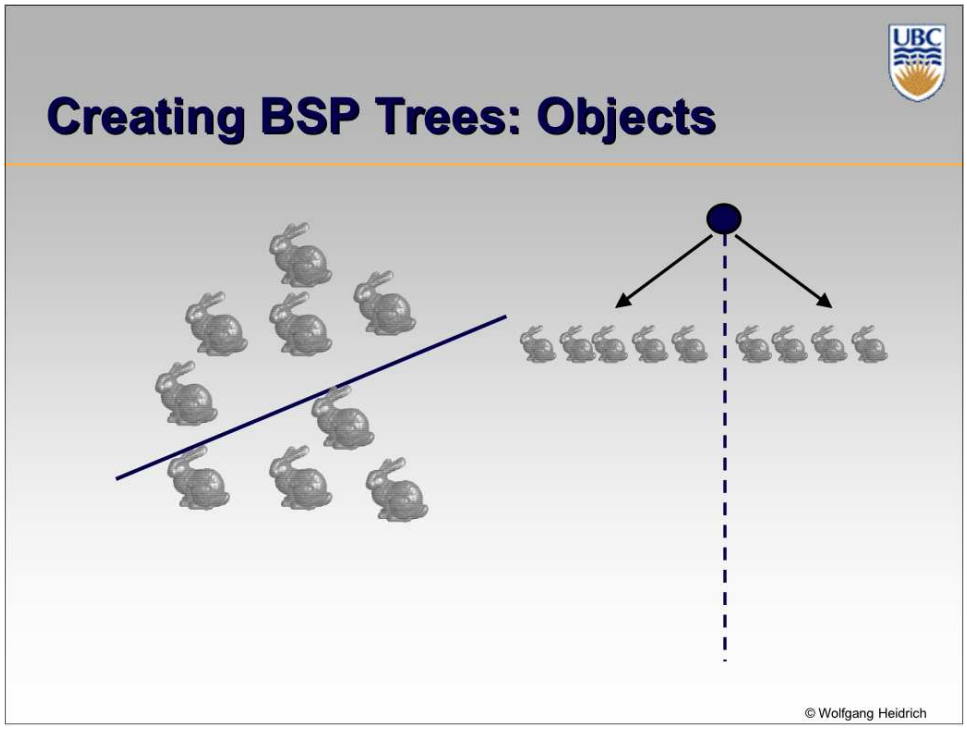
Binary Space Partition Trees (1979)

BSP Tree: partition space with binary tree of planes

- Idea: divide space recursively into half-spaces by choosing splitting planes that separate objects in scene
- Preprocessing: create binary tree of planes
- Runtime: correctly traversing this tree enumerates objects from back to front

Creating BSP Trees: Objects

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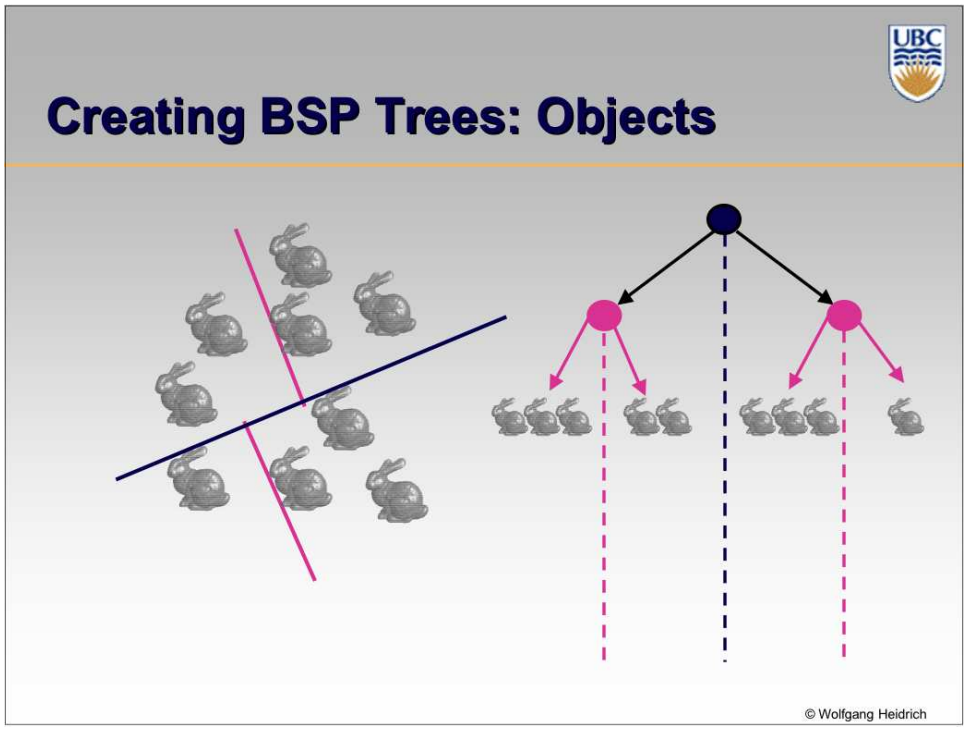
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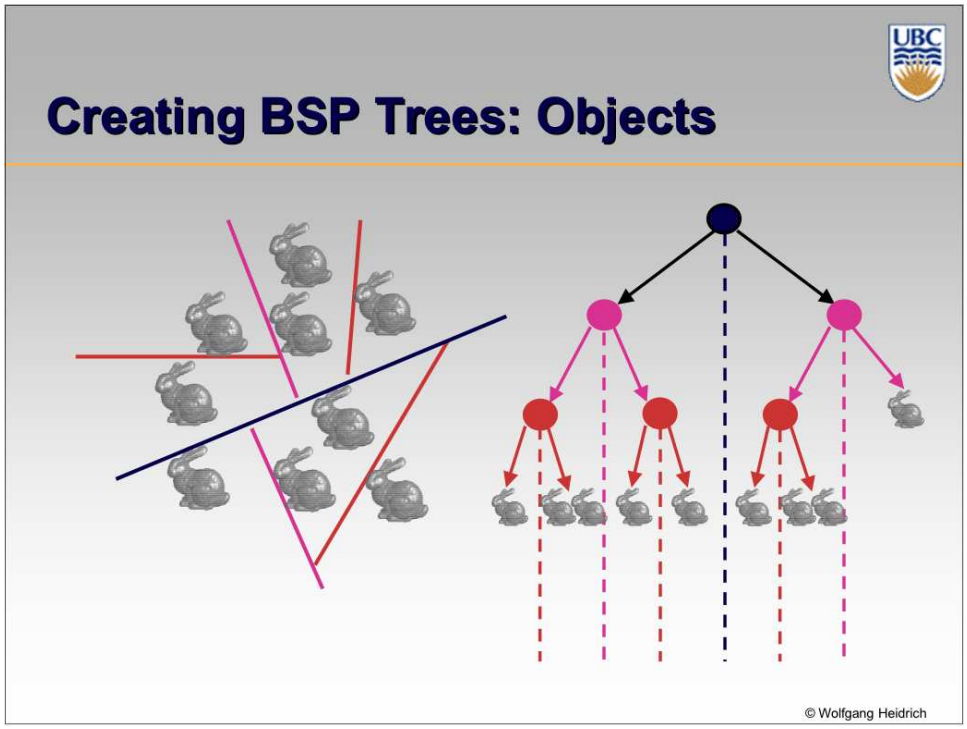
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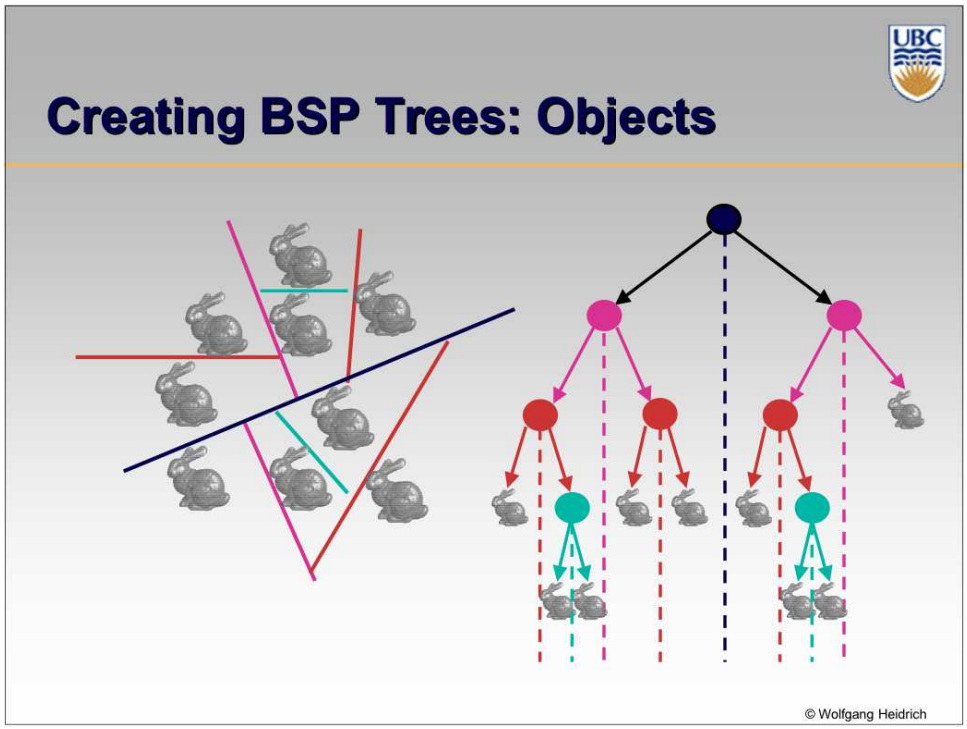
Creating BSP Trees: Objects
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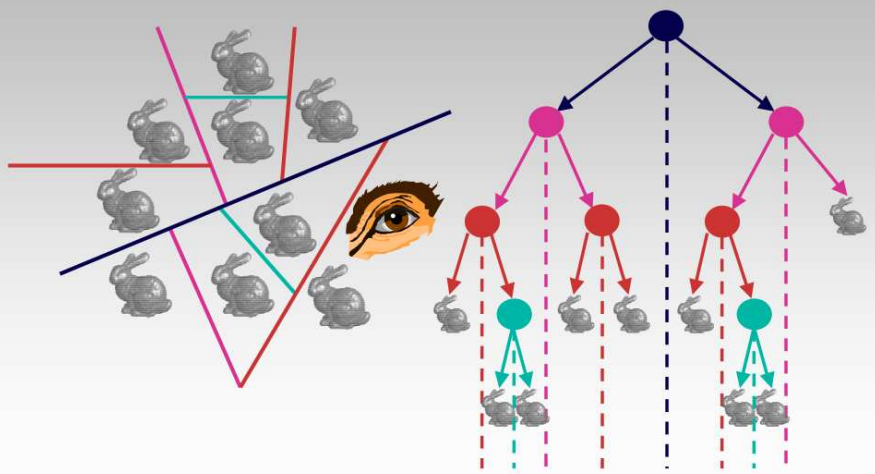
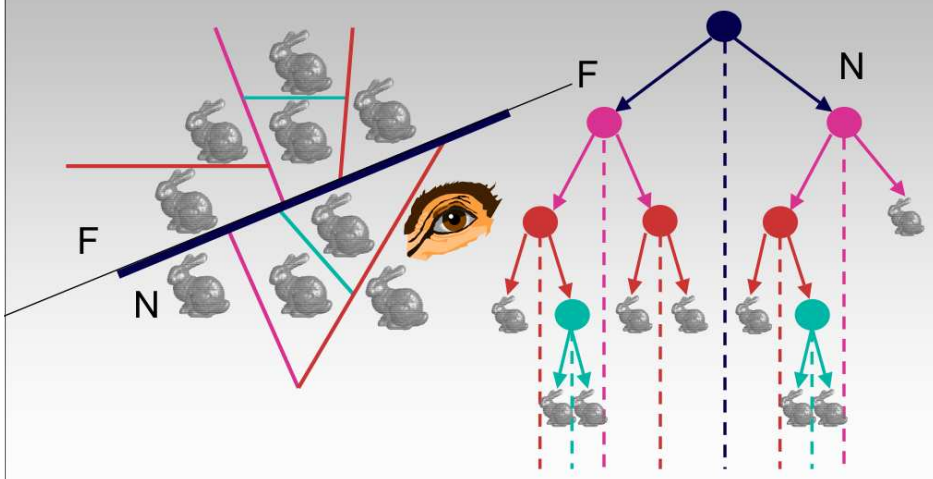
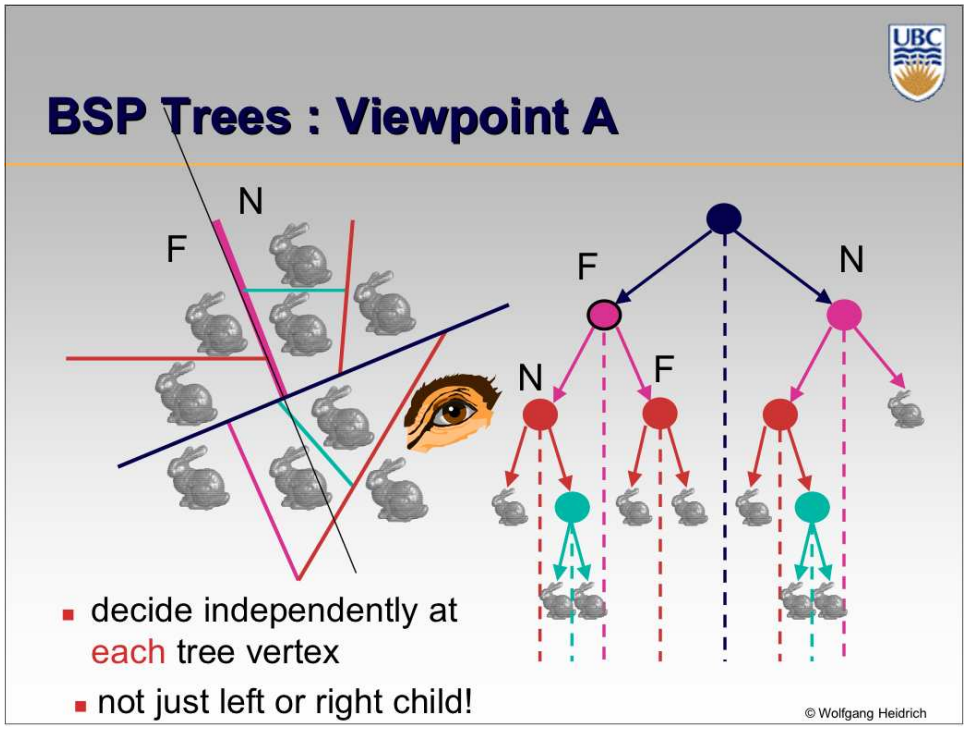
BSP Trees : Viewpoint A



BSP Trees : Viewpoint A




BSP Trees : Viewpoint A
N
F
F
N
N
F
decide independently at each tree vertex
not just left or right child!
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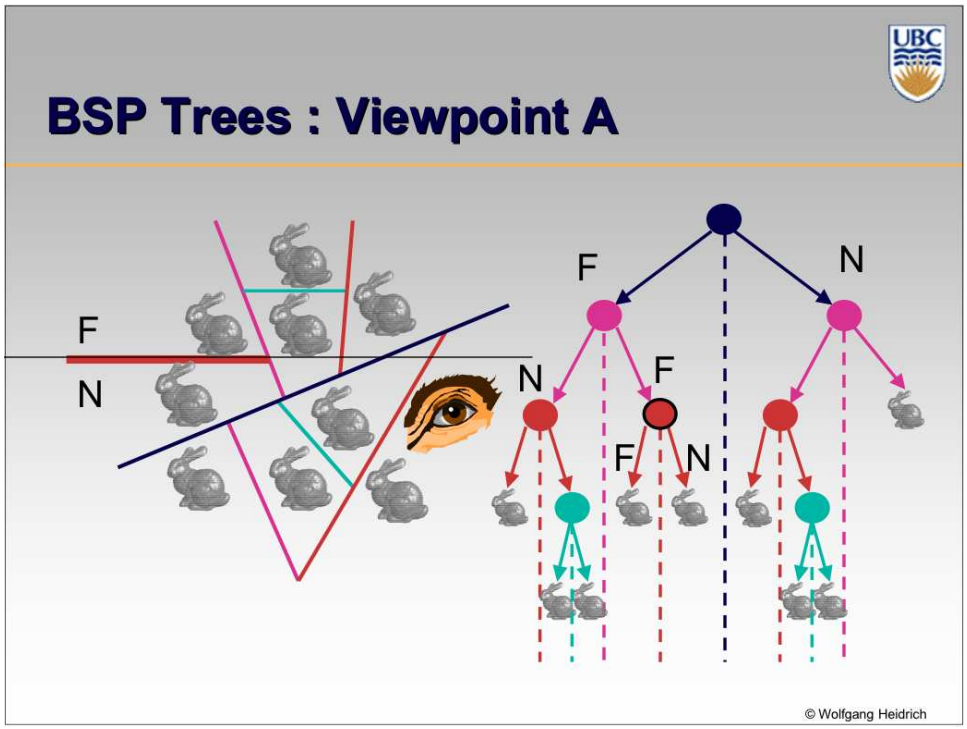
BSP Trees : Viewpoint A
F
N
F
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F
N
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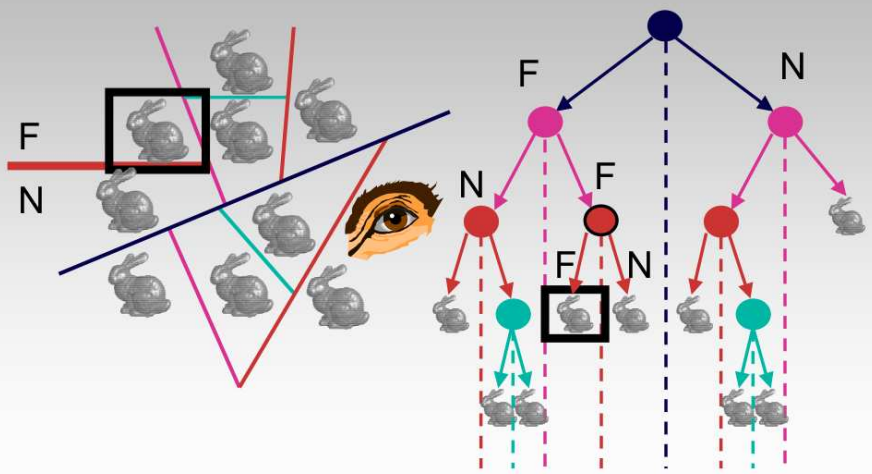
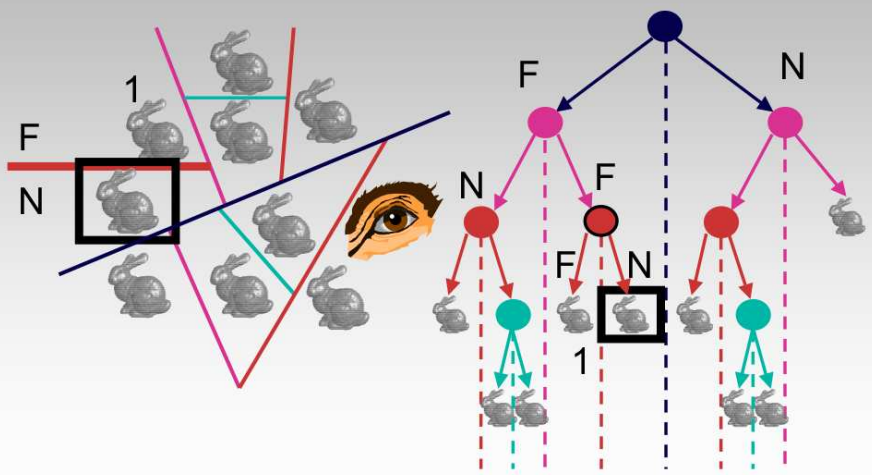
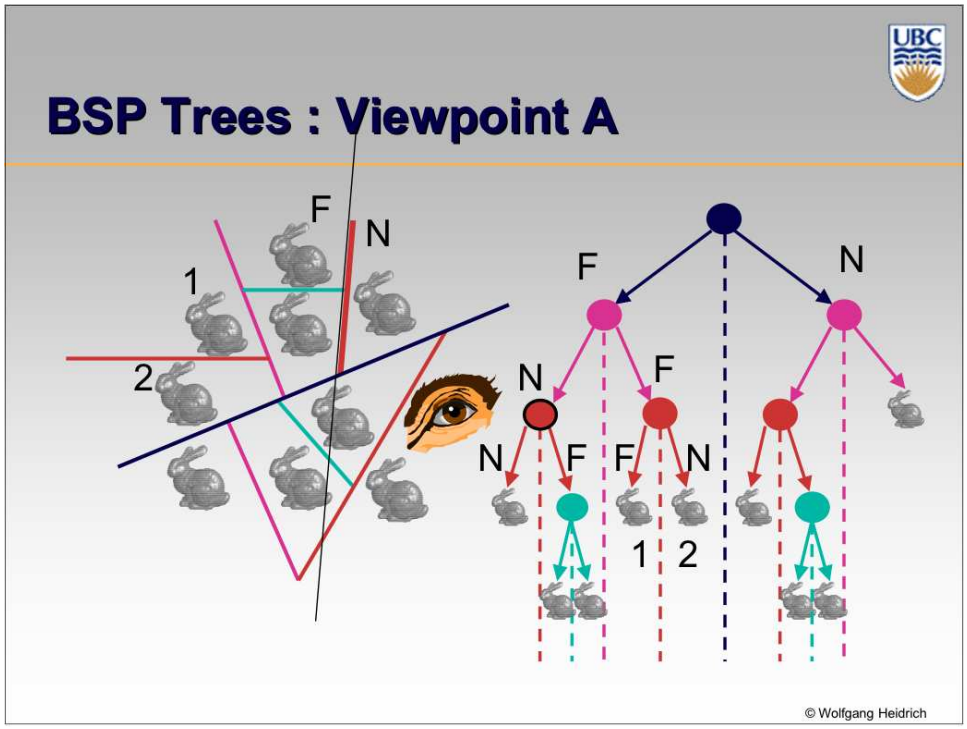
BSP Trees : Viewpoint A



BSP Trees : Viewpoint A




BSP Trees : Viewpoint A
F
N
1
2
F
N
N
F
N
F
F
N
1
2
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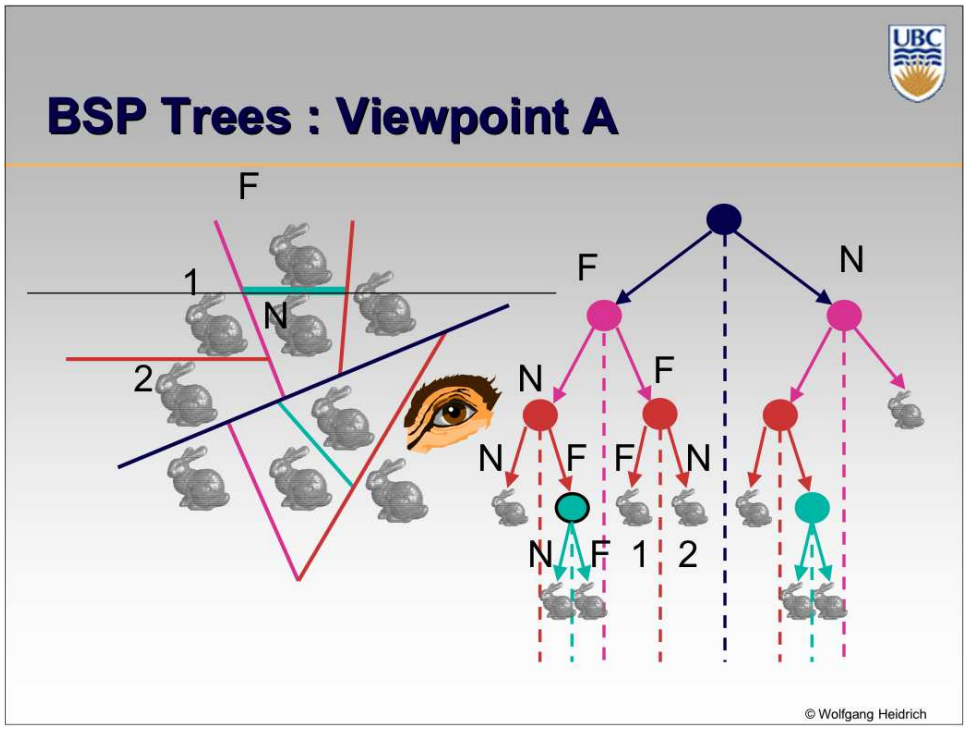
BSP Trees : Viewpoint A
F
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F
1
2
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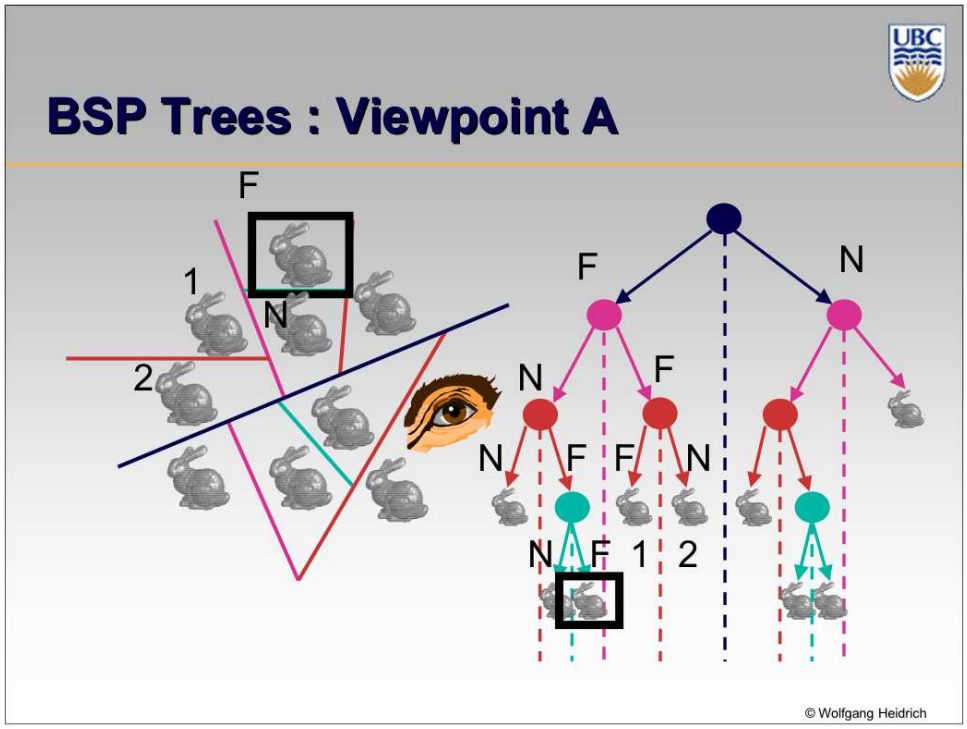
BSP Trees : Viewpoint A
F
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1
2
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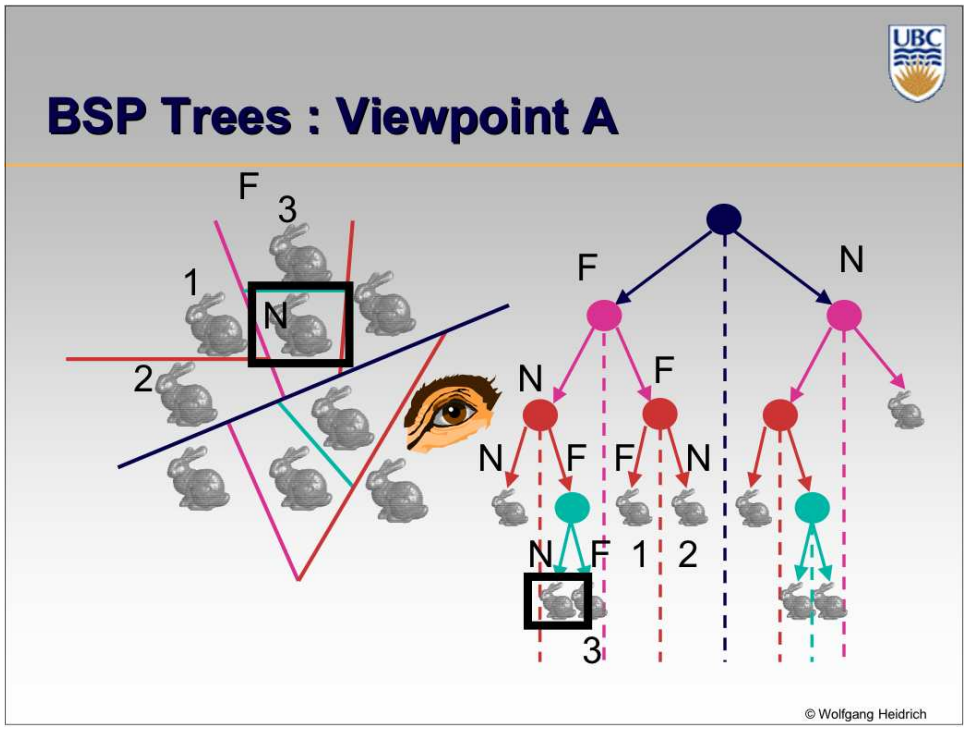
BSP Trees : Viewpoint A
F
3
1
N
2
F
N
N
F
N
F
F
N
N
F
1
2
3
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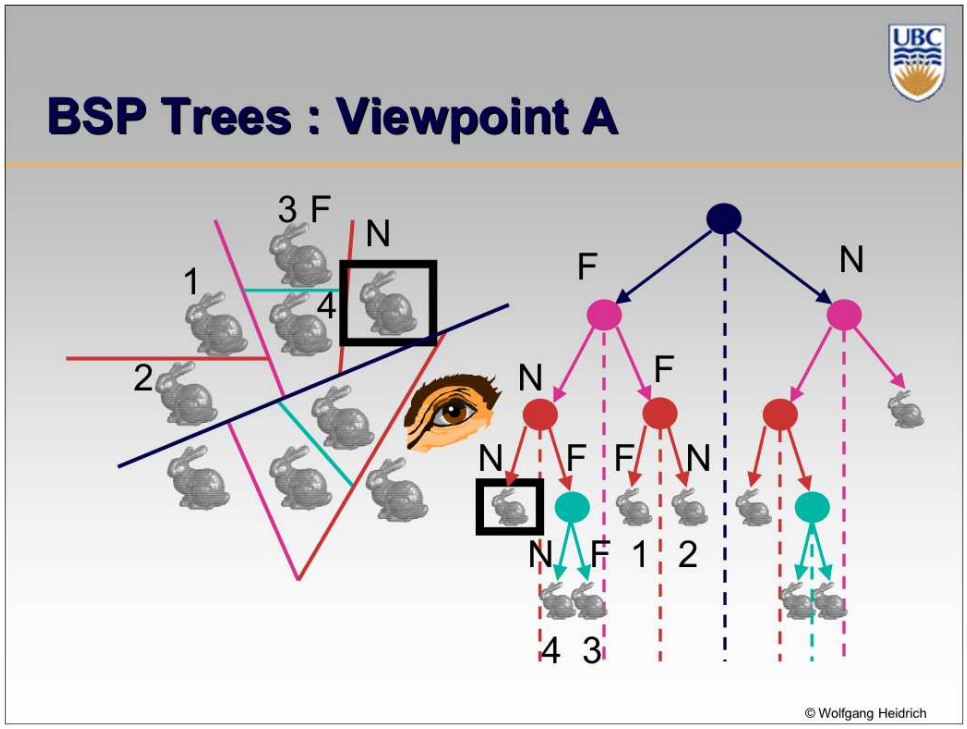
BSP Trees : Viewpoint A
3 F
N
1
4
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F
N
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F
N
F
F
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1
2
4
3
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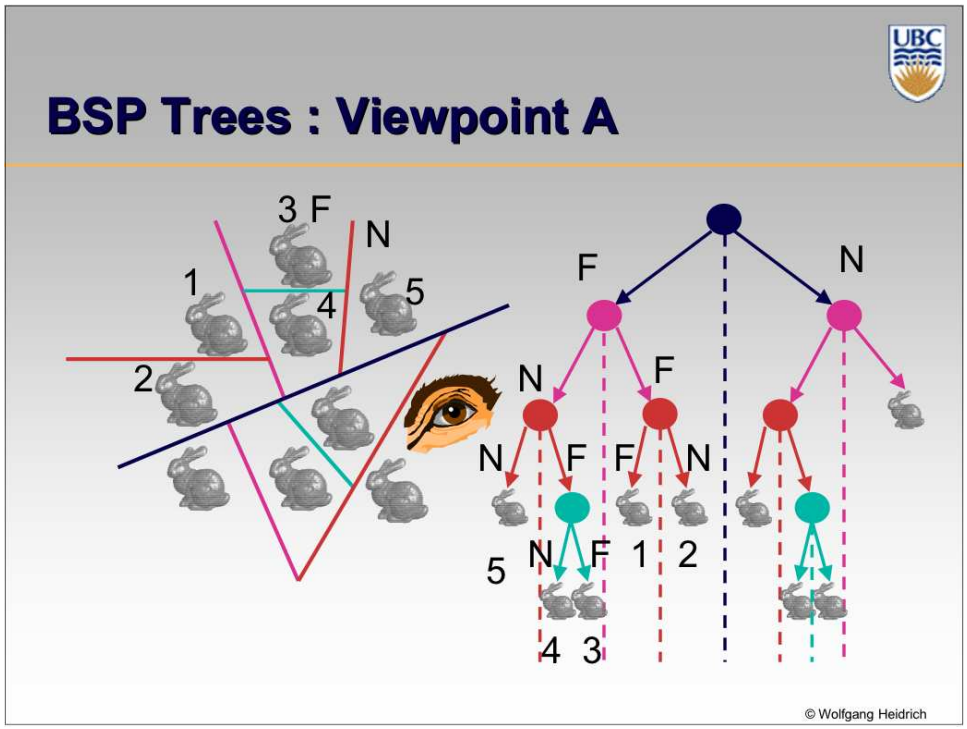
BSP Trees : Viewpoint A
3 F
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4
5
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F
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F
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N
5
N
F
1
2
4
3
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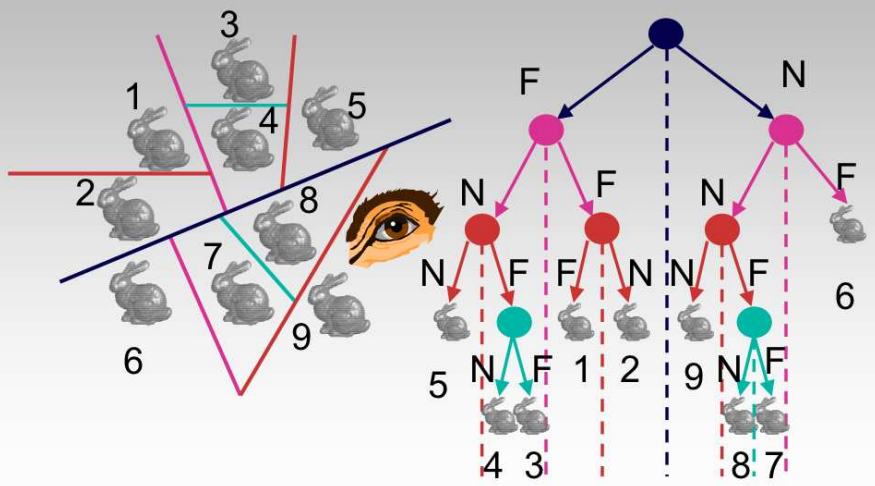
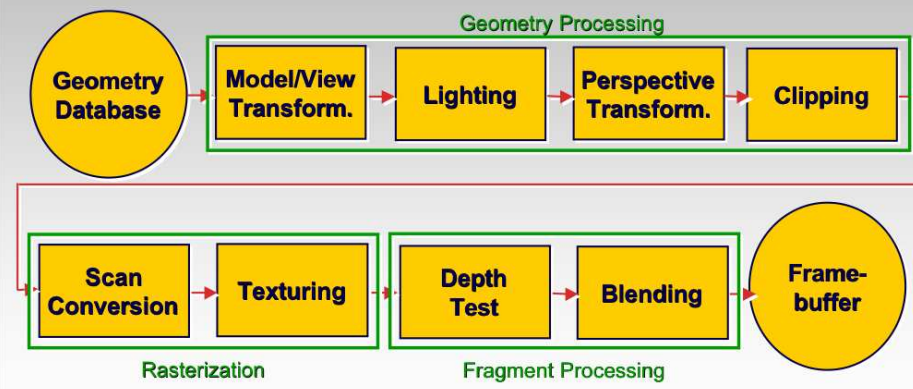
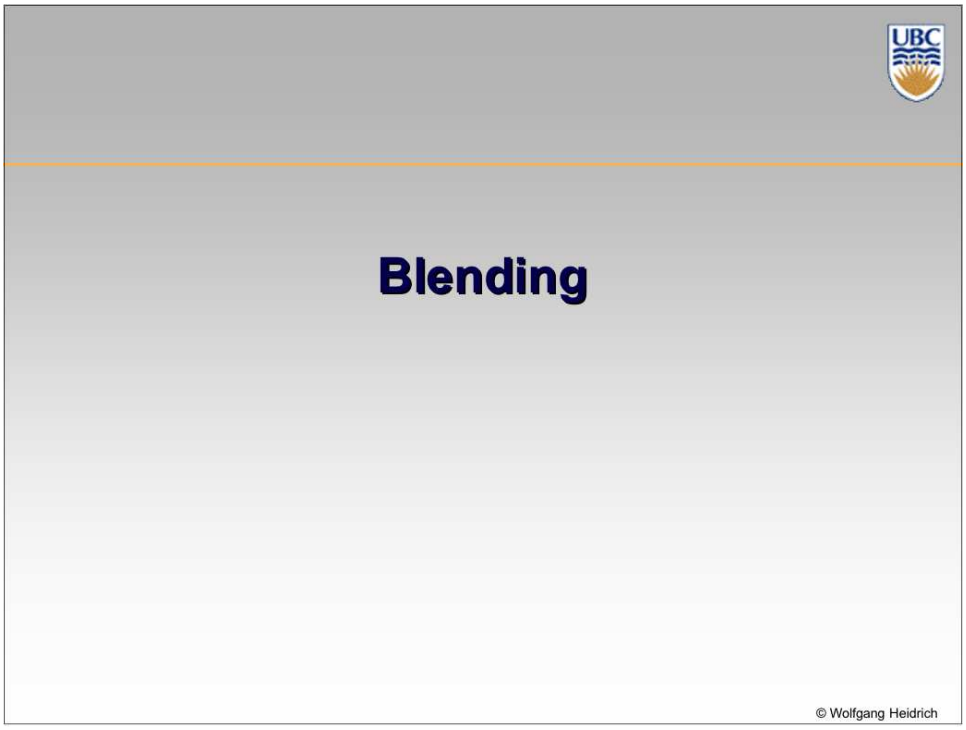
BSP Trees : Viewpoint A



The Rendering Pipeline




Blending
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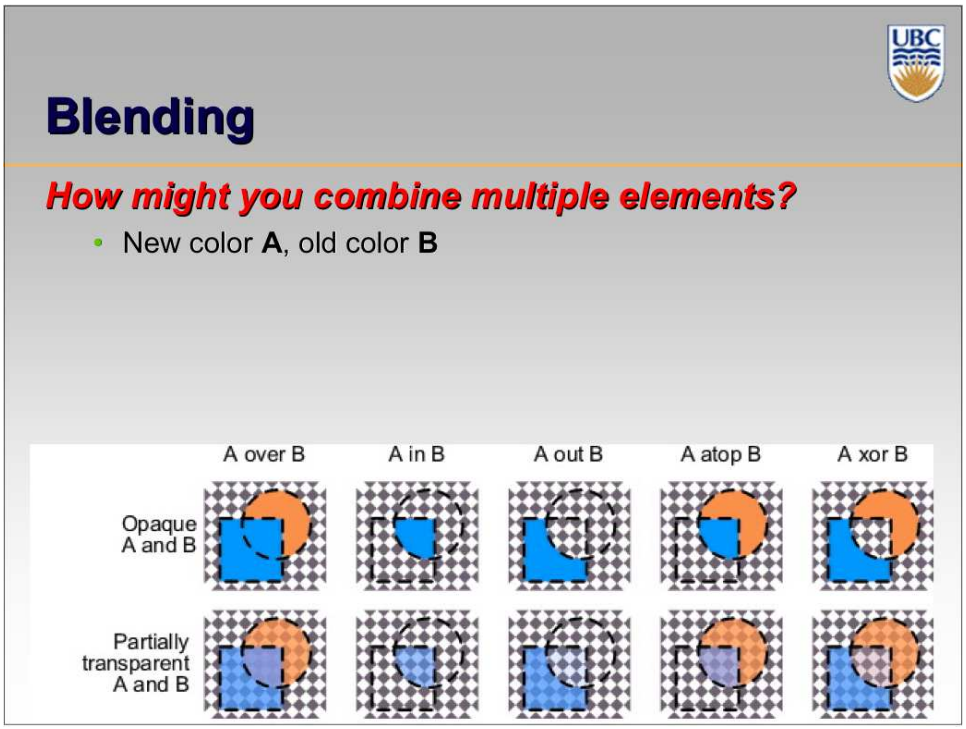

Blending
How might you combine multiple elements?
New color A, old color B
A over B
A in B
A out B
A atop B
A xor B
Opaque A and B
Partially transparent A and B

Premultiplying Colors

Specify opacity with alpha channel: (r,g,b,α)

- α=1: opaque, α=.5: translucent, α=0: transparent

A over B

- **C** = α**A** + (1-α)**B**

But what if B is also partially transparent?

- **C** = α**A** + (1-α) β**B** = α**A** + β**B** - α β**B**
- γ = β + (1-β)α = β + α – αβ
  - *3 multiplies, different equations for alpha vs. RGB*

Premultiplying by alpha

- **C'** = γ **C, B'** = β**B, A'** = α**A**
- **C'** = **B'** + **A'** - α**B'**
- γ = β + α – αβ
  - *1 multiply to find C, same equations for alpha and RGB*

OpenGL Blending

In OpenGL:

- Enable blending
  - *glEnable(GL_BLEND)*
- Specify alpha channel for colors
  - *glColor4f(r, g, b, alpha)*
- Specify blending function
  - *E.g: glBlendFunc(GL_SRC_ALPHA, GL_ONE_MINUS_SRC_ALPH)*
    - C= alpha_new*Cnew + (1-alpha_new)*Cold

OpenGL Blending

Caveats:

- Note: alpha blending is an order-dependent operation!
  - *It matters which object is drawn first AND*
  - *Which surface is in front*
- For 3D scenes, this makes it necessary to keep track of rendering order explicitly
  - *Possibly also viewpoint-dependent!*
    - E.g. always draw “back” surface first
- Also note: interaction with z-buffer

Double Buffer

Double Buffering

Framebuffer:

- Piece of memory where the final image is written
- Problem:
  - *The display needs to read the contents, cyclically, while the GPU is already working on the next frame*
  - *Could result in display of partially rendered images on screen*
- Solution:
  - *Have TWO buffers*
    - One is currently displayed (front buffer)
    - One is rendered into for the next frame (back buffer)

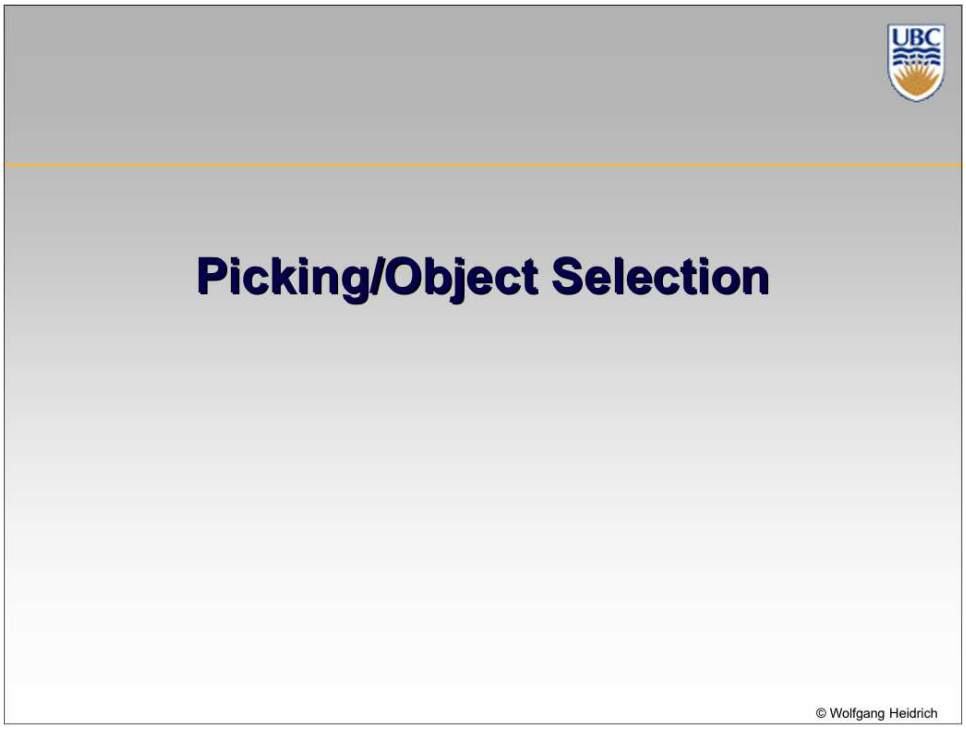
Double Buffering

Front/back buffer:

- Each buffer has both color channels and a depth channel
  - *Important for advanced rendering algorithms*
  - *Doubles memory requirements!*

Switching buffers:

- At end of rendering one frame, simply exchange the pointers to the front and back buffer
- GLUT toolkit: glutSwapBuffers() function
  - *Different functions under windows/X11 if not using GLUT*



Interactive Object Selection

Move cursor over object, click

- How to decide what is below?

Ambiguity

- Many 3D world objects map to same 2D point

Common approaches

- Manual ray intersection
- Bounding extents
- Selection region with hit list (OpenGL support)

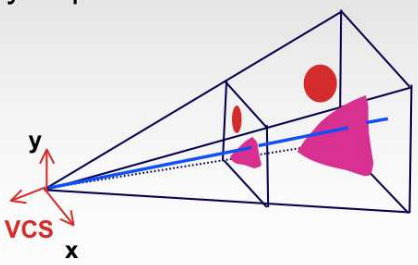
Manual Ray Intersection

Do all computation at application level

- Map selection point to a ray
- Intersect ray with all objects in scene.

Advantages

- No library dependence



Manual Ray Intersection

Do all computation at application level

- Map selection point to a ray
- Intersect ray with all objects in scene.

Advantages

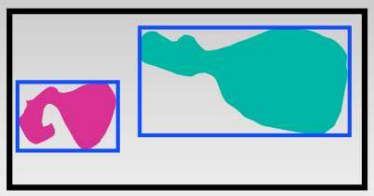
- No library dependence

Disadvantages

- Difficult to program
- Slow: work to do depends on total number and complexity of objects in scene

Bounding Extents

Keep track of axis-aligned bounding rectangles



Advantages

- Conceptually simple
- Easy to keep track of boxes in world space

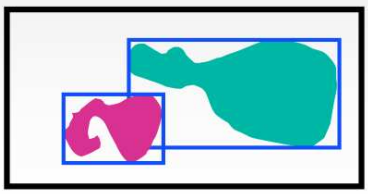
Bounding Extents

Disadvantages

- Low precision
- Must keep track of object-rectangle relationship

Extensions

- Do more sophisticated bound bookkeeping
  - *First level: box check. second level: object check*



OpenGL Picking

"Render" image in picking mode

- Pixels are never written to framebuffer
- Only store IDs of objects that would have been drawn

Procedure

- Set unique ID for each pickable object
- Call the regular sequence of glBegin/glVertex/glEnd commands
  - *If possible, skip glColor, glNormal, glTexCoord etc. for performance*

Select/Hit

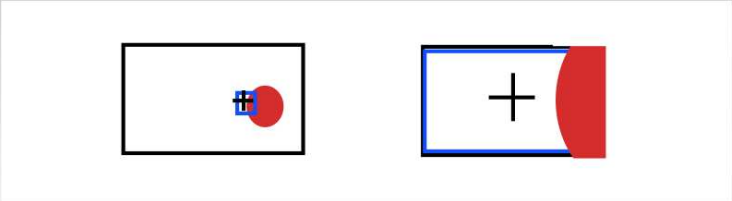
OpenGL support

- Use small region around cursor for viewport
- Assign per-object integer keys (names)
- Redraw in special mode
- Store hit list of objects in region
- Examine hit list

Viewport

Small rectangle around cursor

- Change coord sys so fills viewport



Why rectangle instead of point?

- People aren't great at positioning mouse
  - *Fitts's Law: time to acquire a target is function of the distance to and size of the target*
- Allow several pixels of slop

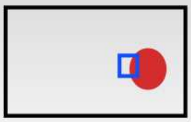
Viewport

Tricky to compute

- Invert viewport matrix, set up new orthogonal projection

Simple utility command

- gluPickMatrix(x,y,w,h,viewport)
  - *x,y: cursor point*
  - *w,h: sensitivity/slop (in pixels)*
- Push old setup first, so can pop it later



Render Modes

glRenderMode(mode)

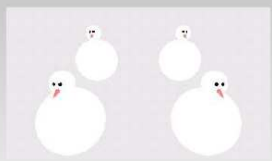
- GL_RENDER: normal color buffer
  - *default*
- GL_SELECT: selection mode for picking
- (GL_FEEDBACK: report objects drawn)

Name Stack

- "names" are just integers
  glInitNames()
- flat list
  glLoadName(name)
- or hierarchy supported by stack
  glPushName(name), glPopName
  - *Can have multiple names per object*
  - *Helpful for identifying objects in a hierarchy*

Hierarchical Names Example

```
for(int i = 0; i < 2; i++) {
  glPushName(i);
  for(int j = 0; j < 2; j++) {
    glPushMatrix();
    glPushName(j);
    glTranslatef(i*10.0,0,j * 10.0);
      glPushName(HEAD);
      glCallList(snowManHeadDL);
      glLoadName(BODY);
      glCallList(snowManBodyDL);
      glPopName();
    glPopName();
    glPopMatrix();
  }
  glPopName();
}
```



http://www.lighthouse3d.com/opengl/picking/

Hit List

- glSelectBuffer(int buffersize, GLuint *buffer)
  - *Where to store hit list data*
- If object overlaps with pick region, create **hit record**
- Hit record
  - *Number of names on stack*
  - *Minimum and minimum depth of object vertices*
    - Depth lies in the z-buffer range [0,1]
    - Multiplied by 2^32 -1 then rounded to nearest int
  - *Contents of name stack (bottom entry first)*

Using OpenGL Picking

Example code:

```
int numHitEntries;
GLuint buffer[1000];
glSelectBuffer( 1000, buffer );
glRenderMode( GL_SELECT );
drawStuff(); // includes name stack calls
numHitEntries= glRenderMode( GL_RENDER );
// now analyze numHitEntries different hit records
// in the selection buffer
...
```


Integrated vs. Separate Pick Function

Integrate: use same function to draw and pick

- Simpler to code
- Name stack commands ignored in render mode

Separate: customize functions for each

- Potentially more efficient
- Can avoid drawing unpickable objects

Select/Hit

Advantages

- Faster
  - *OpenGL support means hardware accel*
  - *Only do clipping work, no shading or rasterization*
- Flexible precision
  - *Size of region controllable*
- Flexible architecture
  - *Custom code possible, e.g. guaranteed frame rate*

Disadvantages

- More complex

Coming Up…

Tuesday:

- Texture Mapping

Thursday:

- Sampling