Pixels and Buffers

CS 432 Interactive Computer Graphics
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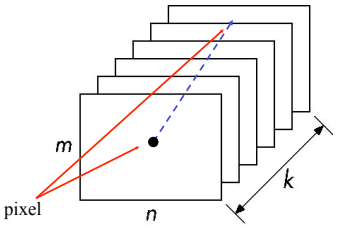
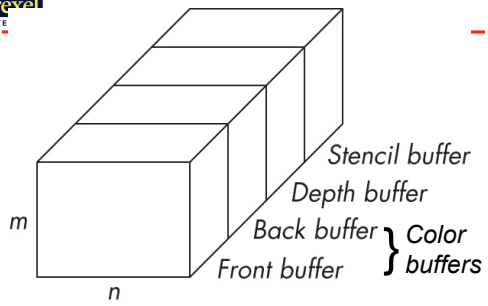
Image Buffer

Define a buffer by its spatial resolution (n x m) and its depth (or precision) k, the number of bits/pixel



OpenGL Frame Buffer

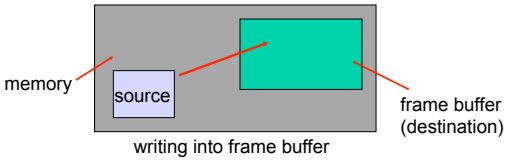


OpenGL Image Buffers

- Color buffers can be displayed
  - Front & Back
  - Auxiliary (off-screen)
  - Stereo
- Depth
- Stencil
  - Holds masks
  - Restricts drawing to portion of screen
- Most RGBA buffers 8 bits per component
- Latest are floating point (IEEE)

Writing in Buffers

- Conceptually, we can consider all of memory as a large two-dimensional array of pixels
- We read and write rectangular block of pixels
  - *Bit block transfer* (*bitblt*) *operations*
- The frame buffer is part of this memory



writing into frame buffer

Clearing Buffers

- A clear (default) value may be set for each buffer
  - `glClearColor()`
  - `glClearDepth()`
  - `glClearDepthf()`
  - `glClearStencil()`

- **`glClear(Glbitfield mask)`**
- Clears the specified buffer

Masking Buffers

- A buffer may be *mask*'ed, i.e. enabled or disabled
- **`glColorMask()`**
- **`glColorMaski()`**
  - Color buffer `i`
- **`glDepthmask()`**
- **`glStencilMask()`**
- **`glStencilMaskSeparate()`**
  - Stencil specific sides (front & back) of triangles

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Fragment Tests and Operations

- After the fragment shader is executed a series of tests and operations are performed on the fragment
- Determine how and whether a fragment color is drawn into the frame buffer

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Fragment Tests and Operations

- Tests and operations are performed in the following order
  - Scissor test
  - Multisample fragment operations
  - Stencil test
  - Depth test
  - Blending
  - Dithering
  - Logical operations
- On/off **`glEnable(), glDisable()`**

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Pixel Tests

- Scissor
  - Only draw in a rectangular portion of screen
  - **`glScissor()`** – Specify rectangle
  - Default rectangle matches window
- Depth
  - Draw based on depth value and comparison function
  - **`glDepthFunc()`** – Specify comparison function
  - Default is **`GL_LESS`**

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Pixel Tests

- Stencil
  - Draw based on values in stencil buffer, if available and enabled
  - Used for drawing into an irregular region of color buffer
  - **`glStencilFunc()`** – Specifies comparison function, reference value and mask
  - **`glStencilOp()`** – Specifies how fragments can modify stencil buffer
  - Used for reflections, capping and stippling

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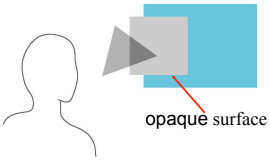
Opacity and Transparency

- Opaque surfaces permit no light to pass through
- Transparent surfaces permit all light to pass
- Translucent surfaces pass some light

translucency = 1 – opacity (α)



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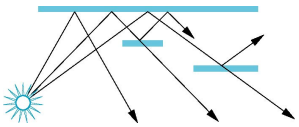
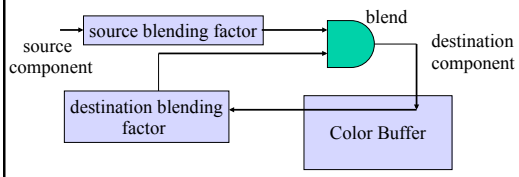
Physical Models

- Dealing with translucency in a physically correct manner is difficult due to
  - the complexity of the internal interactions of light and matter
  - Using a pipeline renderer



Writing Model for Blending

- Use A component of RGBA (or RGBα) color to store opacity
- During rendering we can expand our writing model to use RGBA values



Blending Equation

- We can define source and destination blending factors for each RGBA component

  $\mathbf{s} = [s_r, s_g, s_b, s_\alpha]$

  $\mathbf{d} = [d_r, d_g, d_b, d_\alpha]$

  Suppose that the source and destination colors are

  $\mathbf{b} = [b_r, b_g, b_b, b_\alpha]$

  $\mathbf{c} = [c_r, c_g, c_b, c_\alpha]$

  Blend as

  $\mathbf{c}' = [b_r s_r + c_r d_r, b_g s_g + c_g d_g, b_b s_b + c_b d_b, b_\alpha s_\alpha + c_\alpha d_\alpha]$

OpenGL Blending

- Must enable blending and set source and destination factors

```
glEnable(GL_BLEND)
glBlendFunc(source_factor,
                destination_factor)
```

- Only certain factors supported
  - `GL_ZERO, GL_ONE`
  - `GL_SRC_ALPHA, GL_ONE_MINUS_SRC_ALPHA`
  - `GL_DST_ALPHA, GL_ONE_MINUS_DST_ALPHA`
  - See Redbook for complete list

Example

- Suppose that we start with the opaque background color $(R_0,G_0,B_0,1)$
  - This color becomes the initial destination color
- We now want to blend in a translucent polygon with color (R_1,G_1,B_1,α_1)
- Select `GL_SRC_ALPHA` and `GL_ONE_MINUS_SRC_ALPHA` as the source and destination blending factors

  $R'_1 = \alpha_1 R_1 + (1 - \alpha_1) R_0$, ……
- Note this formula is correct if polygon is either opaque or transparent

Clamping and Accuracy

- All the components (RGBA) are clamped and stay in the range (0,1)
- However, in a typical system, RGBA values are only stored to 8 bits
  - Can easily loose accuracy if we add many components together
  - Example: add together n images
    - Divide all color components by n to avoid clamping
    - Blend with source factor = 1, destination factor = 1
    - But division by n loses bits

Order Dependency

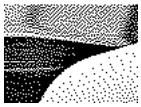
- Is this image correct?
  - Probably not
  - Polygons are rendered in the order they pass down the pipeline
  - Blending functions are order dependent

Opaque and Translucent Polygons

- Suppose that we have a group of polygons some of which are opaque and some translucent
- How do we use hidden-surface removal?
- Opaque polygons block all polygons behind them and affect the depth buffer
- Translucent polygons should not affect depth buffer
  - Render with `glDepthMask(GL_FALSE)` which makes depth buffer read-only
- Sort polygons first to remove order dependency!
- Draw back to front

Dithering and Logical Operations

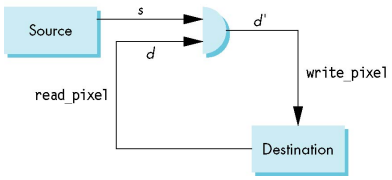
- Dithering
  - On some systems with limited color resolution dithering may be enabled (`GL_DITHER`)
  - System/hardware-dependent



- Final operation combines fragment color with pixel color with a logical operator

Writing Model for Logical Operations

Read destination pixel before writing source



Logical Pixel Operations

Opcode	Resulting Operation
GL_CLEAR	0
GL_SET	1
GL_COPY	s
GL_COPY_INVERTED	~s
GL_NOOP	d
GL_INVERT	~d
GL_AND	s & d
GL_NAND	~(s & d)
GL_OR	s | d
GL_NOR	~(s | d)
GL_XOR	s ^ d
GL_EQUIV	~(s ^ d)
GL_AND_REVERSE	s & ~d
GL_AND_INVERTED	~s & d
GL_OR_REVERSE	s | ~d
GL_OR_INVERTED	~s | d

Bit Writing Modes

- Source and destination bits are combined bitwise
- 16 possible functions (one per column in table)

XOR mode

- Recall from Chapter 3 that we can use XOR by enabling logic operations and selecting the XOR write mode
- XOR is especially useful for swapping blocks of memory such as menus that are stored off screen

If S represents screen and M represents a menu the sequence

$S \leftarrow S \oplus M$
$M \leftarrow S \oplus M$
$S \leftarrow S \oplus M$

swaps the S and M

x	y		
1010 ⊕	0011	=	1001 → x
1001 ⊕	0011	=	1010 → y
1001 ⊕	1010	=	0011 → x
0011	1010		

Buffer Selection

- OpenGL can read from any of the buffers (front, back, depth, stencil)
- Default to the back buffer
- Change with **`glReadBuffer`**
- Note that format of the pixels in the frame buffer is different from that of processor memory and these two types of memory reside in different places
  - Need packing and unpacking
  - Reading can be slow
- Drawing through texture functions

OpenGL Pixel Functions

```
glReadPixels(x,y,width,height,format,type,myimage)
```

start pixel in frame buffer; size; type of pixels; type of image; pointer to processor memory

```
GLubyte myimage[512][512][3];
glReadPixels(0,0, 512, 512, GL_RGB,
      GL_UNSIGNED_BYTE, myimage);
```


Formats & Types

- `GL_RGB`
- `GL_RGBA`
- `GL_RED`
- `GL_GREEN`
- `GL_BLUE`
- `GL_ALPHA`
- `GL_DEPTH_COMPONENT`
- `GL_LUMINANCE`
- `GL_LUMINANCE_ALPHA`
- `GL_COLOR_INDEX`
- `GL_STENCIL_INDEX`

- `GL_UNSIGNED_BYTE`
- `GL_BYTE`
- `GL_BITMAP`
- `GL_UNSIGNED_SHORT`
- `GL_SHORT`
- `GL_UNSIGNED_INT`
- `GL_INT`
- `GL_FLOAT`
- `GL_UNSIGNED_BYTE_3_3_2`
- `GL_UNSIGNED_INT_8_8_8_8`
- etc.

Deprecated Functionality

- glDrawPixels
- glCopyPixels
- glBitMap
- Replace by use of texture functionality, glBltFrameBuffer, frame buffer objects

Render to Texture

- GPUs now include a large amount of texture memory that we can write into
- Advantage: fast (not under control of window system)
- Using frame buffer objects (FBOs) we can render into texture memory instead of the frame buffer and then read from this memory
  - Image processing
  - GPGPU

Frame Buffer Objects

- Frame buffer useful for off-screen rendering, moving data between buffers and updating texture maps
- Attach renderbuffers to minimize data copies and optimize performance
- The window-system-provided buffers can never be associated with a framebuffer object

Frame Buffer Object

- `glGenFramebuffers()` – Allocate unused framebuffer object ids
- `glBindFramebuffer()` – Allocate storage for framebuffer and specifies read/write status
- Frame buffer parameters normally determined by its attachments

Renderbuffers

- Does memory management of formatted image data
- `glGenRenderbuffers()` – Allocate unused renderbuffer ids
- `glBindRenderbuffer()` – Sets state info to defaults and allows state info to be modified
- `glRenderbufferStorage()` – Allocate storage and specify image format

Attaching a Renderbuffer

- `glFramebufferRenderbuffer()` – Attaches a renderbuffer to a framebuffer. Specifies buffer type
- Type can be color, depth or stencil

Moving Pixels Around

- `glDrawBuffer()` – Specifies color buffer enabled for writing/clearing
- `glReadBuffer()` – Specifies color buffer enabled for source of reading
- `glBlitFramebuffer()` – Copies pixels from one buffer to another
- `glReadPixels()` – Copies pixels from the “read” buffer into an array

- Go to RenderBuffer.txt
- This is example 4.11 in the Red Book, 8th edition

Buffer Applications

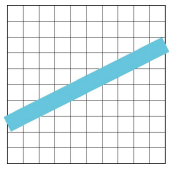
Anti-aliasing

- Aliasing – artifacts produced from inadequate sampling
  - Jagged edges
  - Missing thin objects/features

- Anti-aliasing – removing artifacts via super-sampling, filtering, blurring, smoothing
- OpenGL offers a number of ways to perform anti-aliasing

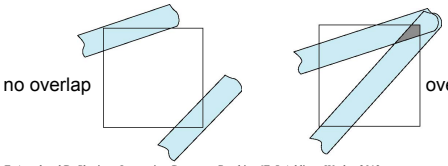
Line Aliasing

- Ideal raster line is one pixel wide
- All line segments, other than vertical and horizontal segments, partially cover pixels
- Simple algorithms color only whole pixels
- Lead to the "jaggies" or aliasing
- Similar issue for polygons



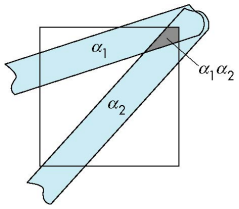
Antialiasing

- Color a pixel by adding in a fraction of the fragment's color
  - Fraction depends on percentage of pixel covered by object
  - Fraction depends on whether there is overlap

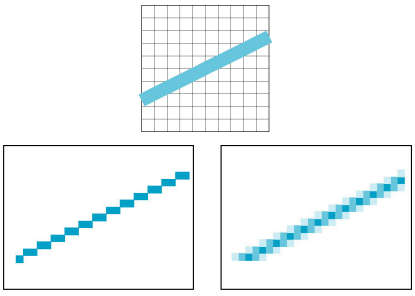


Area Averaging

- Use average area $\alpha_1+\alpha_2-\alpha_1\alpha_2$ as blending factor



Area Averaging



OpenGL Antialiasing

- Can enable separately for points, lines, or polygons

```
glEnable(GL_POINT_SMOOTH);
glEnable(GL_LINE_SMOOTH);
glEnable(GL_POLYGON_SMOOTH);
```

- Assigns fractional alpha values along edges
- Based on pixel coverage

```
glEnable(GL_BLEND);
glBlendFunc(GL_SRC_ALPHA,
                    GL_ONE_MINUS_SRC_ALPHA);
```


Multisampling

- If available and enabled(**`GL_MULTISAMPLE`**) multiple *samples* are generated per pixel
- Each *sample* - color, depth and stencil value
- If fragment shader is called for each *sample*, shader must be *sample*-aware
  - **`sample in vec4 color`**
  - **`gl_SamplePosition`**
- All samples are combined to produce the color, depth and stencil value for pixel
- If available, slows performance

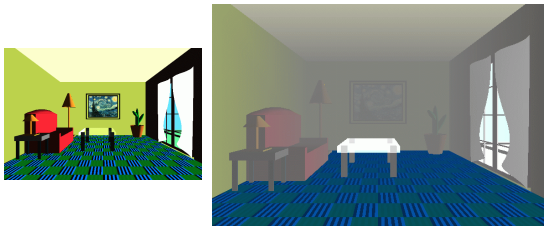
Fog

- We can blend with a fixed color and have the blending factors depend on depth
  - Simulates a fog effect
- Blend source color C_s and fog color C_f by

$$C_s' = f\,C_s + (1\text{-}f)\,C_f$$

- f is the *fog factor*
  - Exponential
  - Gaussian
  - Linear (depth cueing)
- Hard-coded fog deprecated but can recreate

Fog Effect



http://www.engin.swarthmore.edu/~jshin1

Picking

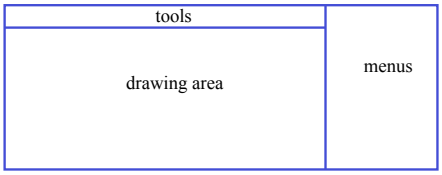
- Identify a user-defined object on the display
- In principle, it should be simple because the mouse gives the position and we should be able to determine to which object(s) a position corresponds
- Practical difficulties
  - Pipeline architecture is feed forward, hard to go from screen back to world
  - Complicated by screen being 2D, world is 3D
  - How close do we have to come to object to say we selected it?

Two Approaches

- Rectangular maps
  - Easy to implement for many applications
  - Divide screen into rectangular regions
- Use back or some other buffer to store object ids as the objects are rendered

Using Regions of the Screen

- Many applications use a simple rectangular arrangement of the screen
  - Example: paint/CAD program

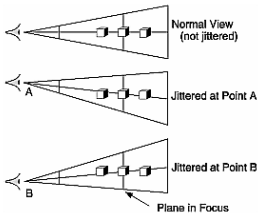


Using another buffer and colors for picking

- Can assign a unique color to each object
- Then render the scene to an alternate color buffer (other than the front/back buffer) so the results of the rendering are not visible
- Then get the mouse position and use `glReadPixels()` to read the color in the alternate buffer at the position of the mouse
- The returned color gives the id of the picked object

Interactive Depth-of-Field

- Jitter camera
- Each frustum has common plane "in focus"
- Accumulate & blend images



Interactive Depth-of-Field

Reflections

- One of the most noticeable effect of inter-object lighting
- Direct calculation of the physics (ray tracing) is too expensive
- Our focus is to capture the most significant reflection while minimizing the overhead via rendering the "virtual object"

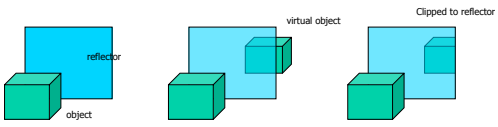


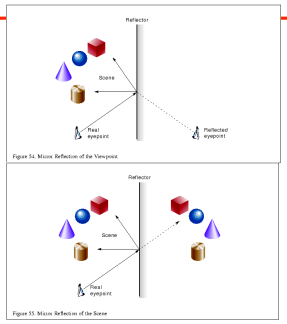
Image vs. Object Space Methods

- Image space methods: create a texture from a view of the reflected objects and apply it to the reflector
  - Advantage: does not depend on the object geometry
  - Disadvantage: sampling issue and also only an approximation (environment mapping as an example)
- Object space methods: create the actual geometry of the object to be reflected and render it to the reflector
  - Disadvantage: accuracy of the geometry
  - Advantage: more accurate reflection (for nearby objects)
- Both methods need to create the virtual objects

Planar Reflections

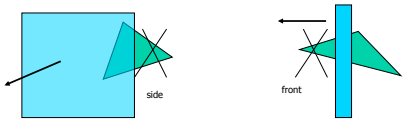
- The most common reflection – flat mirror, floor, wall, etc
- Creating virtual objects (or reflected objects) is much easier
- A view independent operation – only consider the relative position of the object and the reflector
- The virtual object is created by transforming the object across the reflector plan

Planar Reflections



Render the Reflected Geometry

- An important task: clip the reflected geometry so it is only visible on the reflector surface
  - Beyond the reflector boundaries and in front of reflector



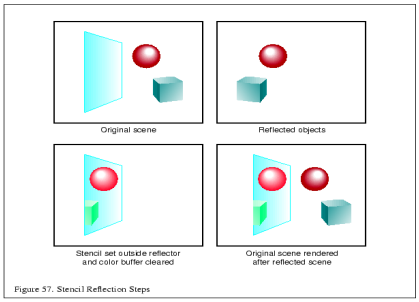
Clipping using the stencil

- The key is you only want the reflected geometry to appear on the reflector surface
- Use stencil buffer:
  - Clear the stencil buffer
  - Render the reflector and set the stencil
  - Render the reflected geometry only where the stencil pixels have been set
- The above algorithm uses the stencil buffer to control where to draw the reflection

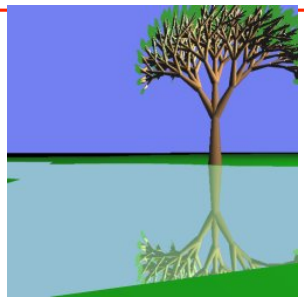
Clipping using the stencil

- Another method: render the reflected object first, and then render the reflector to set the stencil buffer, then clear the color buffer everywhere except where the stencil is set
- This method is to use the stencil buffer to control where to erase the incorrect reflection
- Advantage: when it is faster to use stencil to control clearing the scene than drawing the entire scene with stencil tests

The stencil erase algorithm



Reflection Effect



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Other Applications

- Compositing
- Image Filtering (convolution)
- Motion effects