CS 418: Interactive Computer Graphics

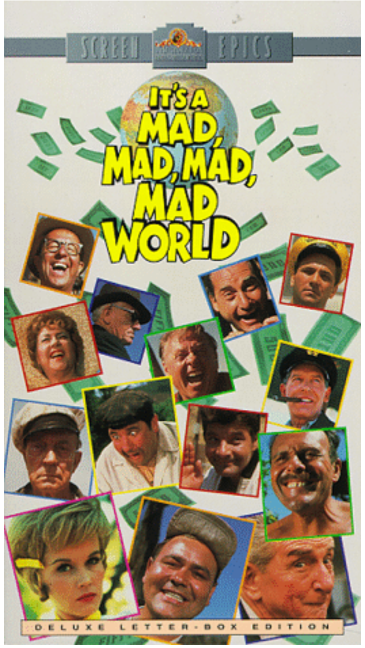
Compositing
&
Blending in WebGL

Eric Shaffer

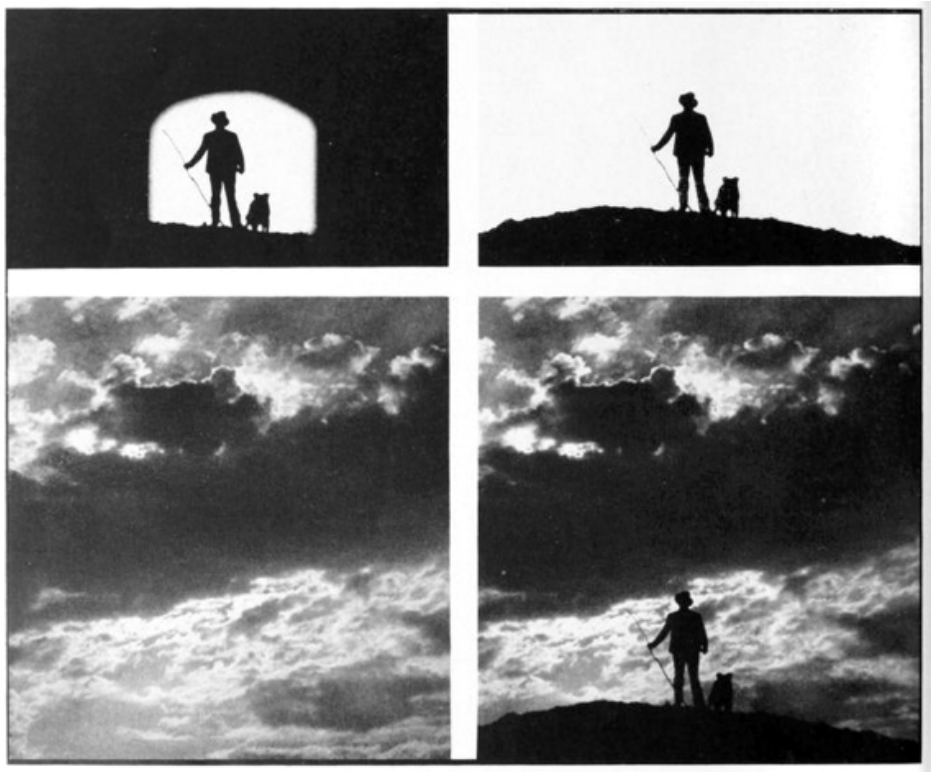
Lynwood Dunn (1904-1998)

- Visual effects pioneer
- Acme-Dunn optical printer

Run film through a projector and re-photograph it
Can zoom in or out, applies filters etc.



Compositing Example



Academy of Motion Picture Arts & Sciences
Scientific and Engineering Award
To Alvy Ray Smith, Tom Duff, Ed Catmull and Thomas Porter for
their Pioneering Inventions in **Digital Image Compositing**.
PRESENTED MARCH 2, 1996

The Over Operator

- Use alpha channel to indicate opacity [Smith]
- Over operator [Porter & Duff S'84]
- *A* over *B*:

$$C_{A \text{ over } B} = \alpha_A C_A + (1 - \alpha_A)\, \alpha_B C_B$$

$$\alpha_{A \text{ over } B} = \alpha_A + (1 - \alpha_A)\, \alpha_B$$

Alternatively (and better?), you can pre-multiply the colors C_A and C_B by the alpha value

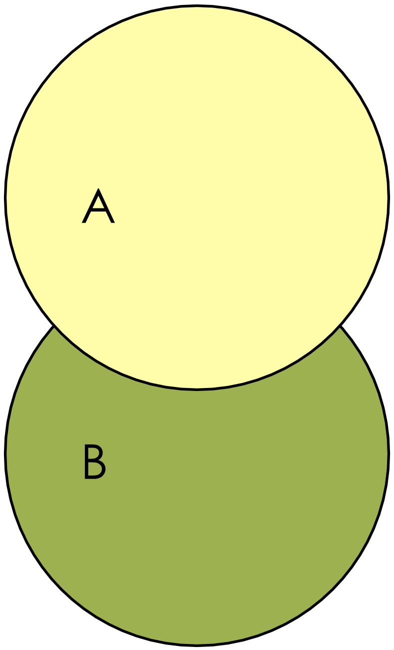
$$C = (\alpha R, \alpha G, \alpha B, \alpha)$$

A over *B* w/premultiplied alpha

$$C_{A \text{ over } B} = C_A + (1 - \alpha_A)\, C_B$$

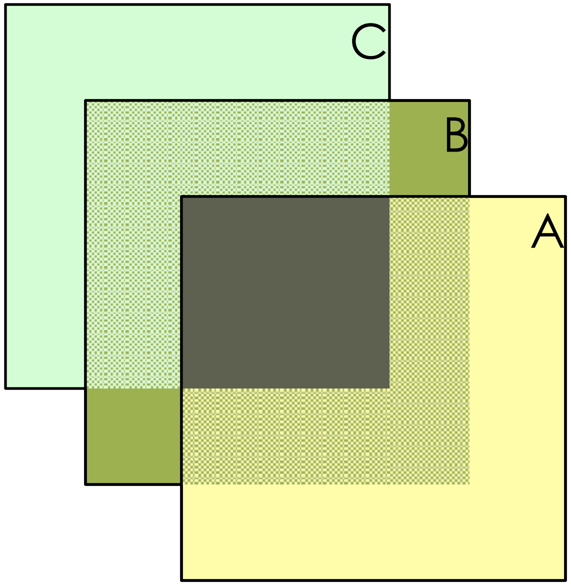
$$\alpha_{A \text{ over } B} = \alpha_A + (1 - \alpha_A)\, \alpha_B$$

Pre-multiplied alpha and Post-multiplied alpha are **not** equivalent. You will usually get similar results, but not in all situations.



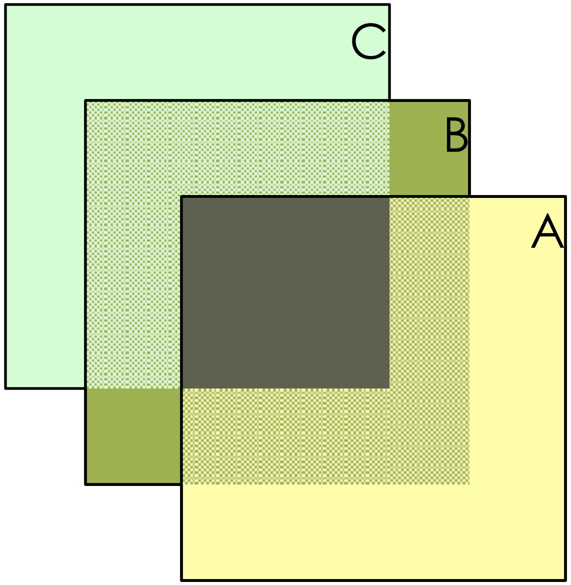
Is Over Associative?

- A over (B over C) = $C_A + (1-\alpha_A)(C_B + (1-\alpha_B)C_C)$



Is Over Associative?

- *A* over (*B* over *C*)
  - $= C_A + (1-\alpha_A)(C_B + (1-\alpha_B)C_C)$
  - $= C_A + (1-\alpha_A)C_B + (1-\alpha_A)(1-\alpha_B)C_C$
  - $= C_{AB} + (1 - \alpha_A - (1-\alpha_A)\alpha_B)C_C$
  - $= C_{AB} + (1-\alpha_{AB})\, C_C$
  - = (*A* over *B*) over *C*
- What about α
  - $= \alpha_A + (1-\alpha_A)\, \alpha_{BC}$
  - $= \alpha_A + (1-\alpha_A)(\alpha_B + (1-\alpha_B)\, \alpha_C)$
  - $= \alpha_A + (1-\alpha_A)\alpha_B + (1-\alpha_A)(1-\alpha_B)\alpha_C$
  - $= \alpha_{AB} + (1-\alpha_{AB})\alpha_C$



Questions….

- Is post-multiplied alpha associative?
- Is the over operator commutative?

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  NO

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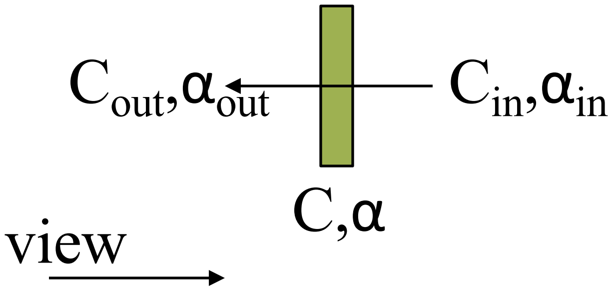
  NO

Accumulating Opacity

- What if you have multiple layers of surfaces to blend?
- Have to work in sorted order

Back to front: Over operator

$C_{out} = C + (1 - \alpha) C_{in}$
$\alpha_{out} = \alpha + (1 - \alpha) \alpha_{in}$



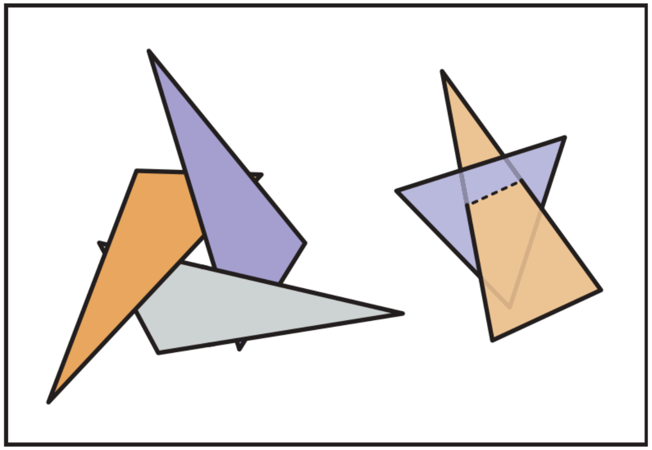
Could also work front to back…

Hidden Surface Removal

- Hidden Surface Removal
  - …don’t render surfaces occluded by surfaces in front of them
- Was a significant area of research in early days of CG
  - …lots of algorithms suggested
- Painter’s Algorithm
  - Render objects in order from back to front
    - i.e. sort your triangles by depth and render deepest first
  - Can anyone imagine any problems with this approach?

Problems with the Painter's Algorithm

- No correct rendering order for
  - intersecting triangle
  - occlusion cycles



- Sorting is slow…too slow for interactivity in complex scenes

Hidden Surface Removal: Z-Buffer

Key Observation: Each pixel displays color of only one triangle, ignores everything behind it

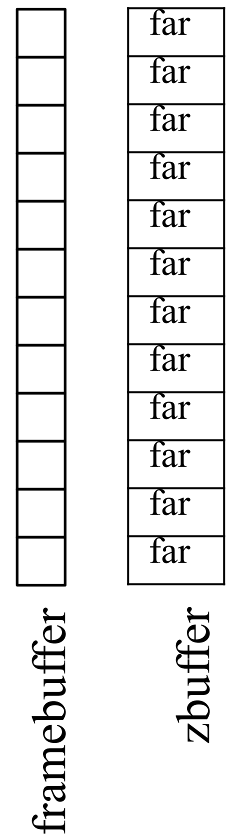
- Don't need to sort triangles, just find for each pixel the closest triangle
- Z-buffer: one fixed or floating point value per pixel
- Algorithm:

For each rasterized fragment (x,y)

If z < zbuffer(x,y) then

framebuffer(x,y) = fragment color

zbuffer(x,y) = z



Frame Buffer: buffer that stores the colors for the pixels we will render

Z-Buffer

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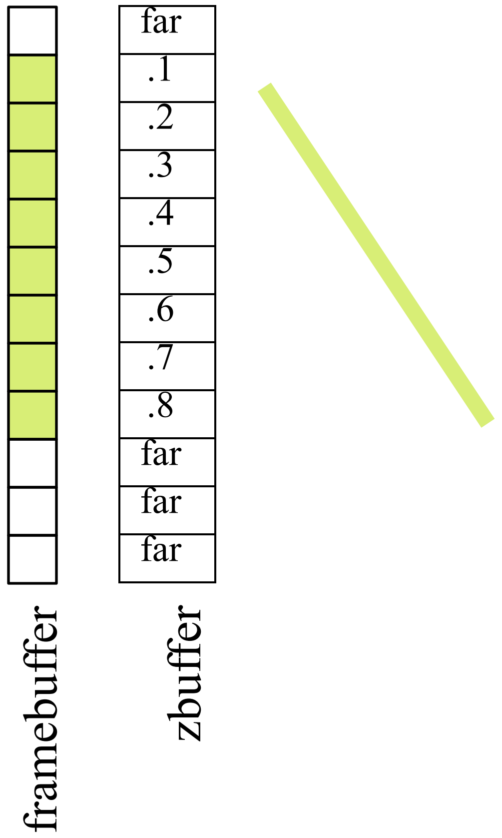

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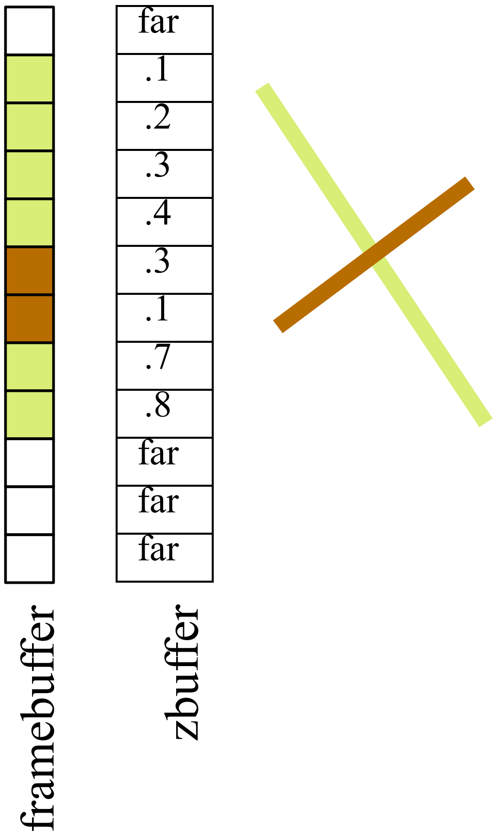
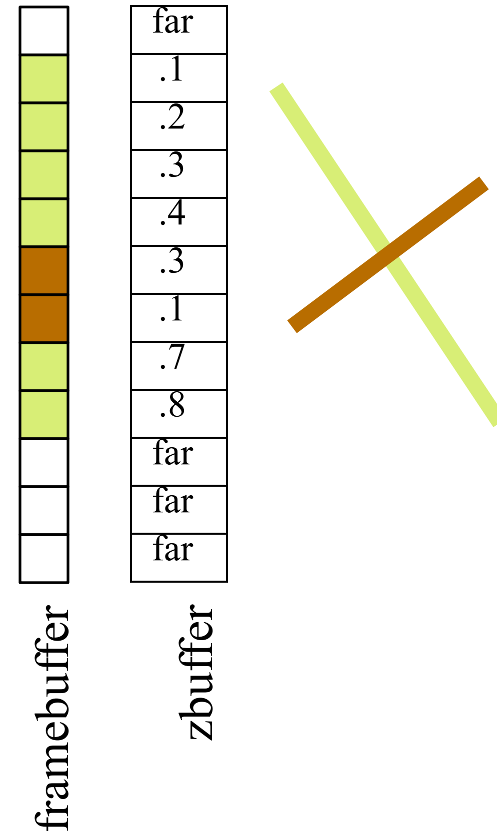


Z-Buffer

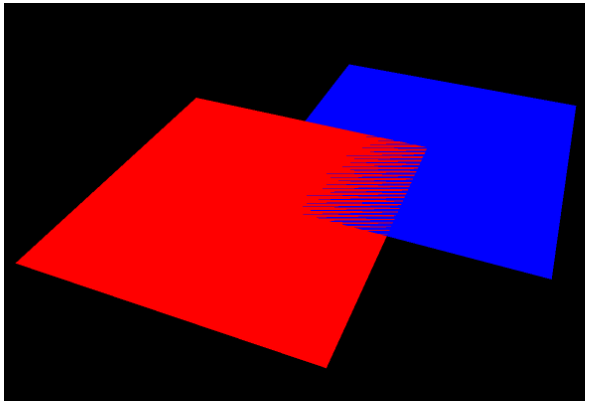
- Get fragment z-values by interpolating z-values at vertices during rasterization
- True perspective projection destroys z-values, setting them all to *–d*
- The perspective distortion we use preserves at least the ordering of z-values



Precision Issues with Z-Buffering

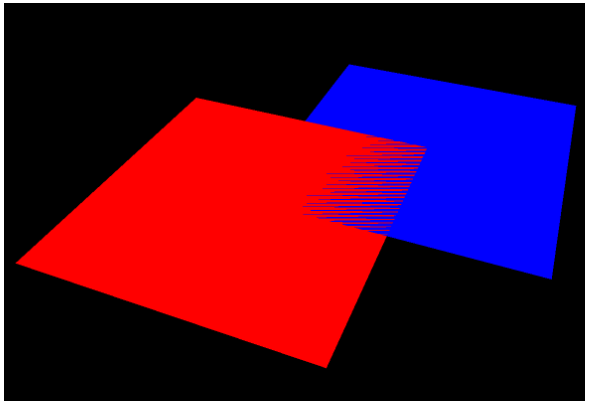
- In practice, depths values are typically converted to non-negative integers when stored in the z-buffer.
  - Comparison operation needs to be fast…
- Imagine having depth values of {0,1,…,B-1}
  - 0 → near clipping plane distance
  - B-1 → far clipping plane distance
- Depths occur discretely in "buckets"
  - Each bucket covers a range of length $\Delta z = \frac{f-n}{B}$
- If we use b bits for the z-buffer values, $B = 2^b$
  - You usually can't change the value b
  - To maximize z-buffer effectiveness, **need to minimize f-n**

Z-Fighting



How can you fix z-fighting?

Z-Fighting

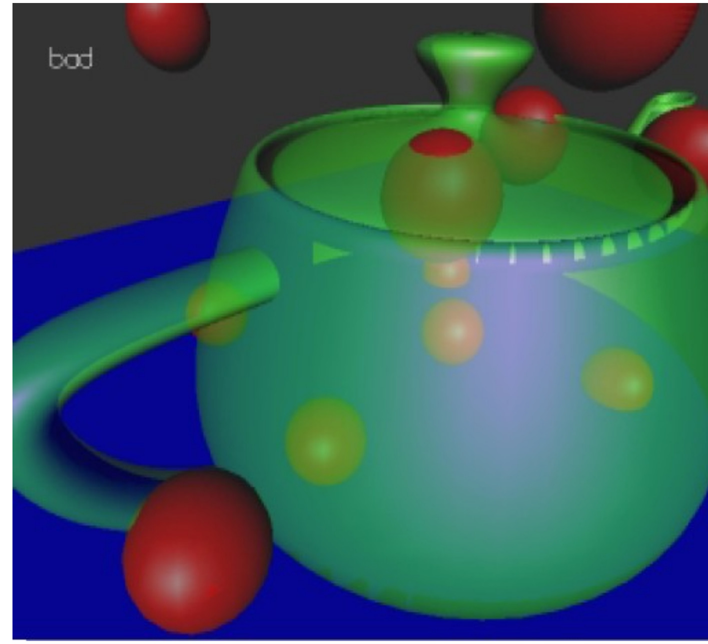


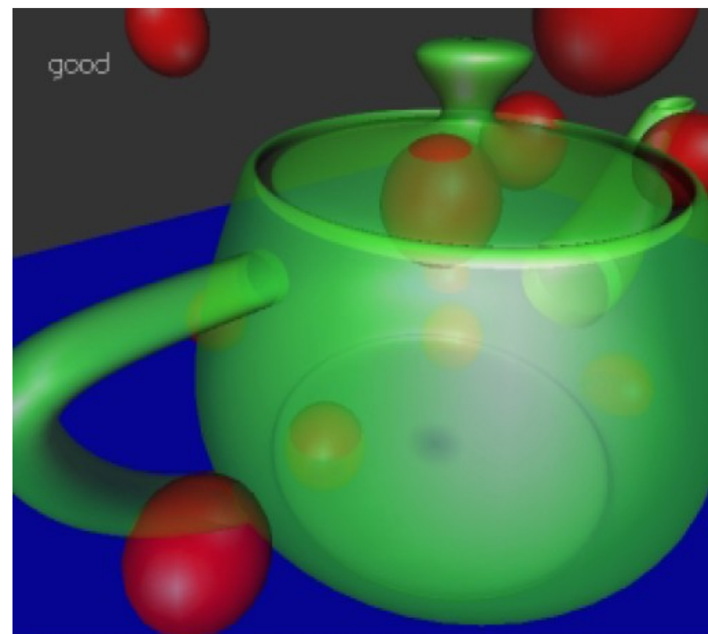
How can you fix z-fighting?

1. Move co-planar polygons slightly away from each other
2. Move near and far clipping planes as close together as you can

Order Independent Transparency

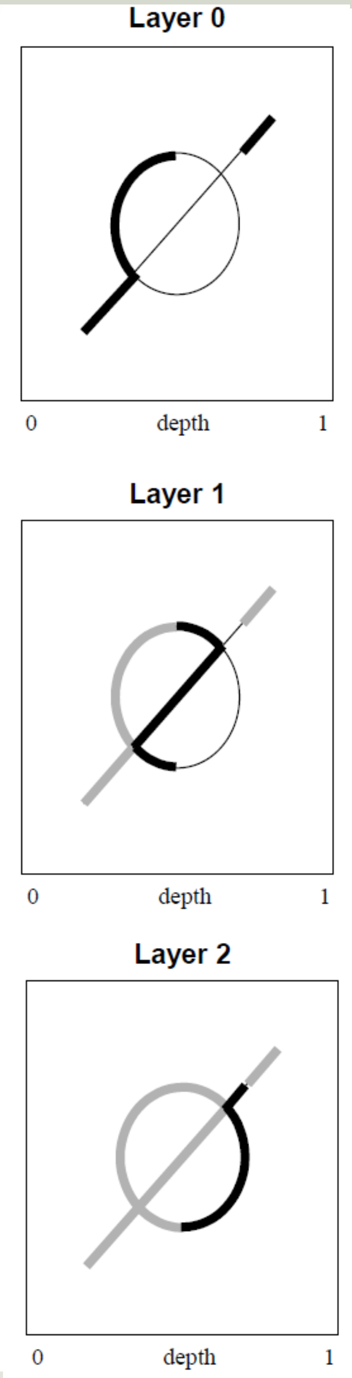
- Alpha blending works for sorted rendering
  - Front to back
  - Back to front
- Doesn't work for out-of-order
  - Front, back, middle
- Could need to keep track separately of the front part and the back part
- Could keep a linked list at each pixel
  - A-buffer (Carpenter)
  - Not practical for hardware



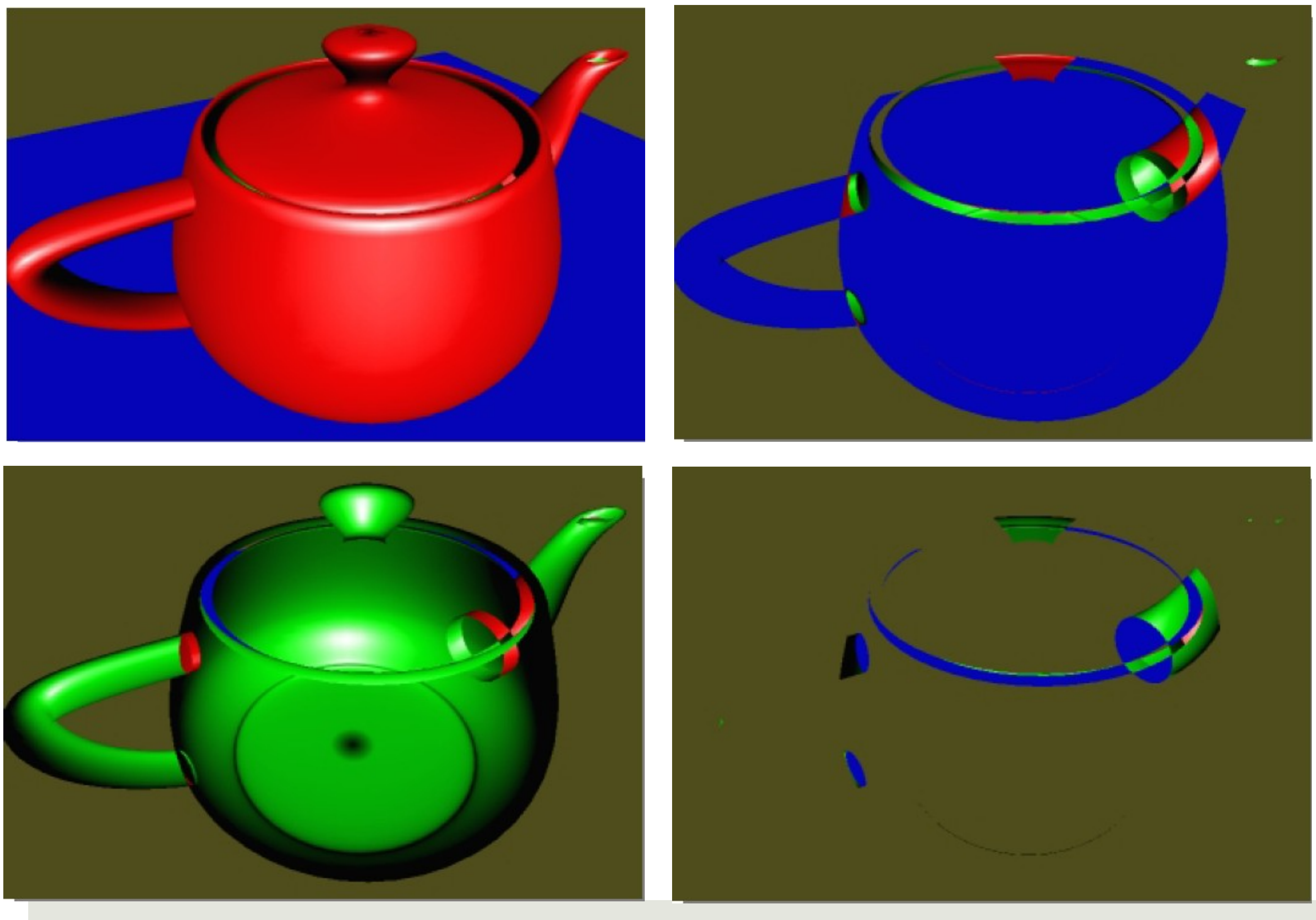


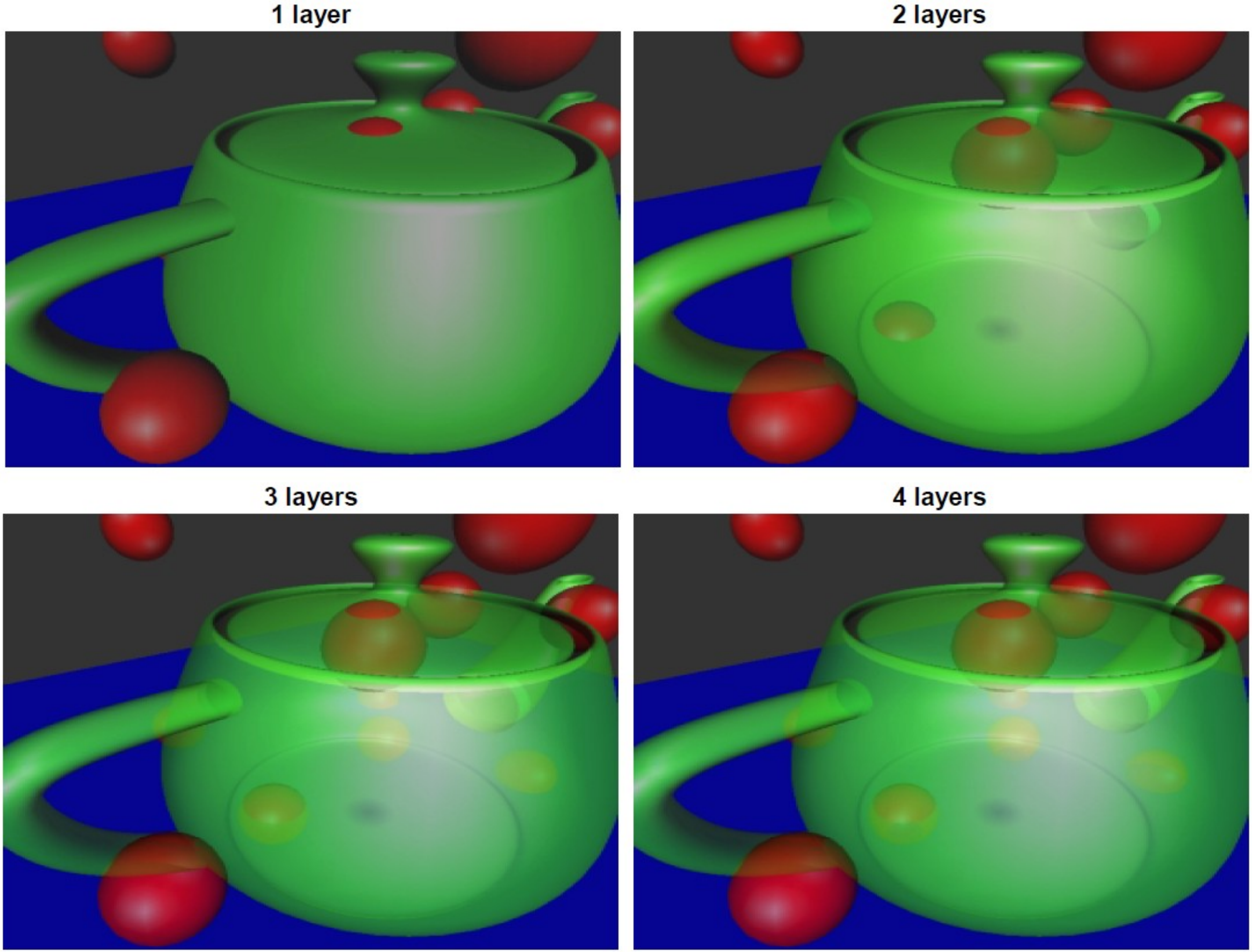
Depth Peeling

- Cass Everett, NVIDIA Tech Rep, 2001
- Needs 2 z-buffers (previous, current)
- One rendering pass per layer
- Fragment written to frame buffer if
  - Farther than previous z-buffer
  - Closer than current z-buffer
- After each pass, current z-buffer written to previous z-buffer
- Surviving fragment composited "under" displayed fragment

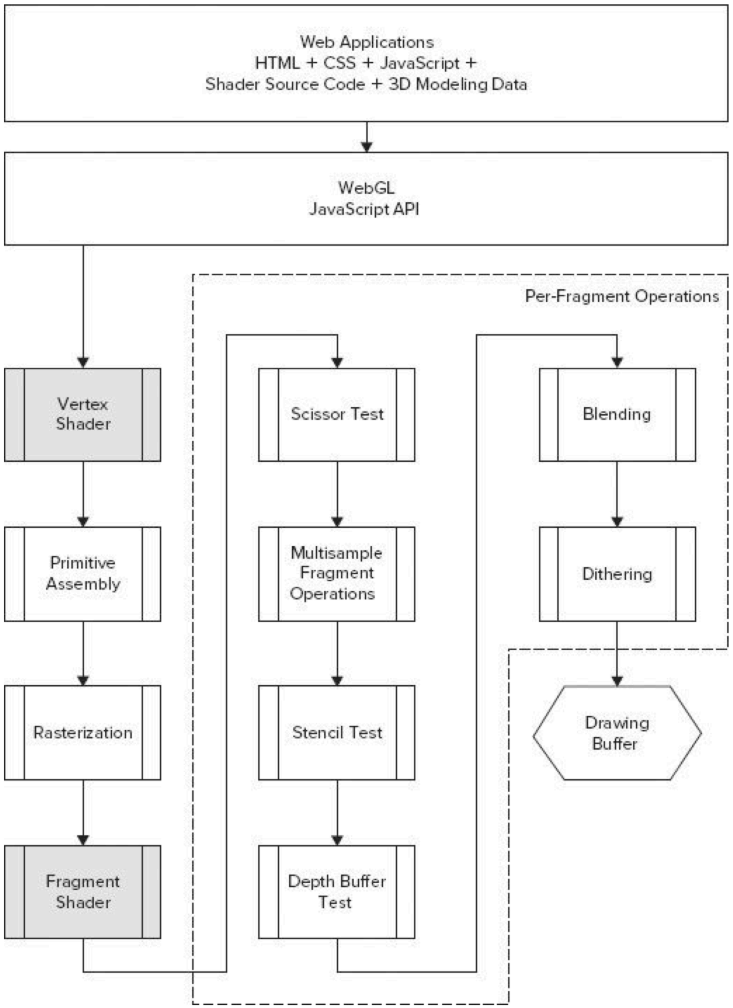


Depth Peels – Which Layer is Which?




1 layer
2 layers
3 layers
4 layers

WebGL Pipeline



Scissor Test:
cull pixels outside of a rectangular area

Multisample:
anti-aliasing operation

Stencil Test:
uses a stencil buffer to mask pixels
can be used in shadow generation

Depth Buffer Test:
hidden surface removal

Blending:
compositing using alpha channel

WebGL Hidden Surface Removal

```
gl.enable(gl.DEPTH_TEST);    // use depth test for hidden surface remove
gl.depthFunc(gl.LESS);       //this is the default
gl.clear(gl.DEPTH_BUFFER_BIT); // clear depth values form previous frame
```

Hidden surface removal uses the depth buffer (z-buffer)

Happens after the fragment shader

Blending

```
//enable blending

gl.Enable(gl.BLEND)



//to set up the parameters of the generic blending equation
//call ONE of the functions below

gl.blendFunc(GLenum sfactor, GLenum dfactor);

//OR

gl.blendFuncSeparate(GLenum srcRGB, GLenum dstRGB,
                     GLenum srcAlpha,
                      GLenum dstAlpha);
```

WebGL lets you specify the factors and operations in the generic blending equation:

$$color_{final} = factor_{source} \times color_{source} \textbf{ op } factor_{dest} \times color_{dest}$$

Blending

$$\text{color}_{\text{final}} = \text{factor}_{\text{source}} \times \text{color}_{\text{source}}\ \textbf{op}\ \text{factor}_{\text{dest}} \times \text{color}_{\text{dest}}$$

FUNCTION	RGB BLEND FACTORS	ALPHA BLEND FACTOR
gl.ZERO	(0, 0, 0)	0
gl.ONE	(1, 1, 1)	1
gl.SRC_COLOR	(R_s, G_s, B_s)	A_s
gl.ONE_MINUS_SRC_COLOR	$(1, 1, 1) - (R_s, G_s, B_s)$	$1 - A_s$
gl.DST_COLOR	(R_d, G_d, B_d)	A_d
gl.ONE_MINUS_DST_COLOR	$(1, 1, 1) - (R_d, G_d, B_d)$	$1 - A_d$
gl.SRC_ALPHA	(A_s, A_s, A_s)	A_s
gl.ONE_MINUS_SRC_ALPHA	$(1, 1, 1) - (A_s, A_s, A_s)$	$1 - A_s$
gl.DST_ALPHA	(A_d, A_d, A_d)	Ad
gl.ONE_MINUS_DST_ALPHA	$(1, 1, 1) - (A_d, A_d, A_d)$	$1 - A_d$
gl.CONSTANT_COLOR	(R_c, G_c, B_c)	A_c
gl.ONE_MINUS_CONSTANT_COLOR	$(1, 1, 1) - (R_c, G_c, B_c)$	$1 - A_c$
gl.CONSTANT_ALPHA	(A_c, A_c, A_c)	A_c
gl.ONE_MINUS_CONSTANT_ALPHA	$(1, 1, 1) - (A_c, A_c, A_c)$	$1 - A_c$
gl.SRC_ALPHA_SATURATE	(f, f, f)	1

Changing the Blending Operator

```
gl.blendEquation(Glenum mode);
```

Lets you specify the blending operation.
Addition is the default.

```
//colorfinal = factorsource × colorsource + factordest × colordest
gl.blendEquation(GL_FUNC_ADD);

//colorfinal = factorsource × colorsource − factordest × colordest
gl.blendEquation(GL_FUNC_SUBTRACT);

//colorfinal = factordest × colordest − factorsource × colorsource
gl.blendEquation(GL_FUNC_REVERSE_SUBTRACT);
```

Blending

```
gl.blendFunc(GLenum sfactor, GLenum dfactor);
```

Lets you specify the blending function for both the RGB and Alpha values for both the source and destination

```
gl.blendFunc(gl.SRC_ALPHA,  gl.ONE_MINUS_SRC_ALPHA);
```

Will implement the over operator we saw previously

You can use it to generate semi-transparent imagery

It's the most commonly used formulation

Pre-multiplied Alpha

- Non-pre-multiplied alpha example: (1.0, 0.0, 0.0, 0.5)
- Pre-multiplied alpha example: (0.5, 0.0, 0.0, 0.5)
- For blending use:

```
gl.blendFunc(gl.ONE,  gl.ONE_MINUS_SRC_ALPHA);
```

- PNG images use non-pre-multipled alpha
  - in case you are loading colors from an image
- You can choose to work either way…

Blending and Drawing Order

```
// 1. Enable depth testing, make sure the depth buffer is writable
//    and disable blending before you draw your opaque objects.
gl.enable(gl.DEPTH_TEST);
gl.depthMask(true);
gl.disable(gl.BLEND);

// 2. Draw your opaque objects in any order (preferably sorted on
state)
// 3. Keep depth testing enabled, but make depth buffer read-only
//    and enable blending
gl.depthMask(false);
gl.enable(gl.BLEND);

// 4. Draw your semi-transparent objects back-to-front
// 5. If you have UI that you want to draw on top of your
//    regular scene, you can finally disable depth testing
gl.disable(gl.DEPTH_TEST);

// 6. Draw any UI you want to be on top of everything else
```

Anyuru, Andreas
Professional WebGL Programming: Developing 3D Graphics for the Web

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