Computer Graphics

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http://www.cs.pdx.edu/~fliu/courses/cs447/

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Last time

- Filtering
- Resampling

Today

- Compositing
- NPR
- 3D Graphics Toolkits
  - Transformations

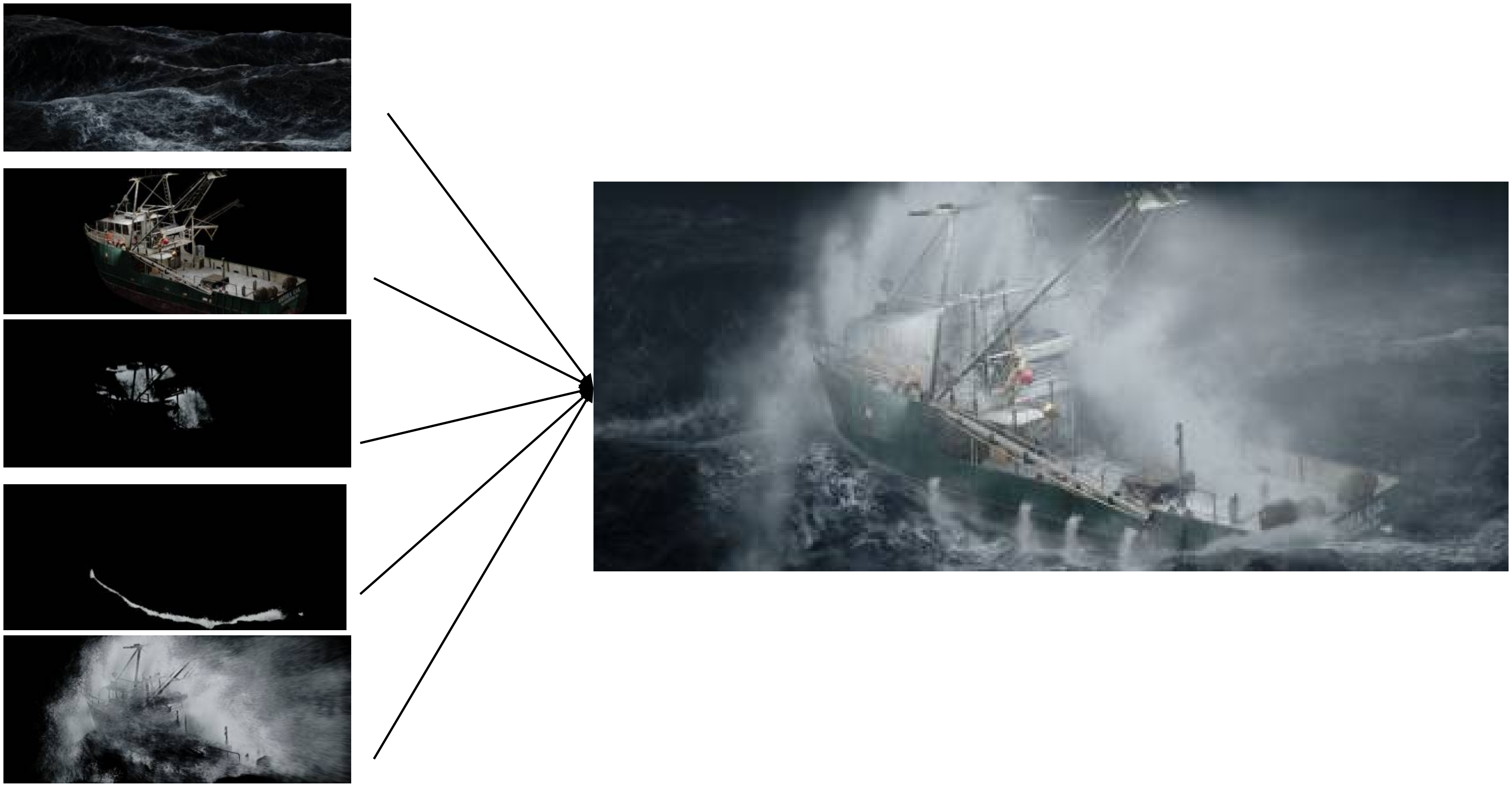
Compositing

- Compositing combines components from two or more images to make a new image
  - Special effects are easier to control when done in isolation
  - Even many all live-action sequences are more safely shot in different layers

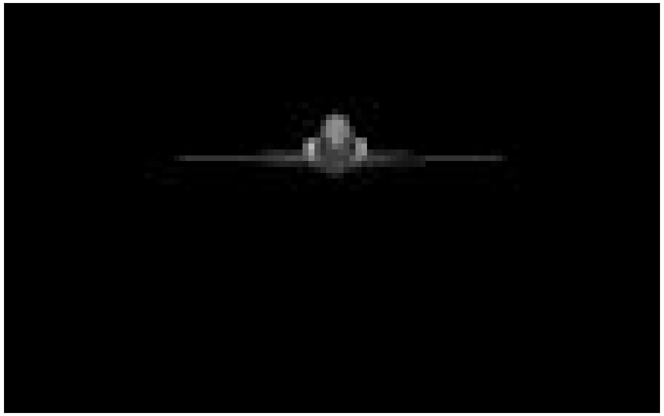
Historically …

- The basis for film special effects
  - Create digital imagery and composite it into live action
  - It was necessary for films (like Star Wars) where models were used
  - It was done with film and masks, and was time consuming and expensive
- Important part of animation – even hand animation
  - Background change more slowly than foregrounds, so composite foreground elements onto constant background
  - It was a major advance in animation – the *multiplane camera* first used in Snow White (1937)

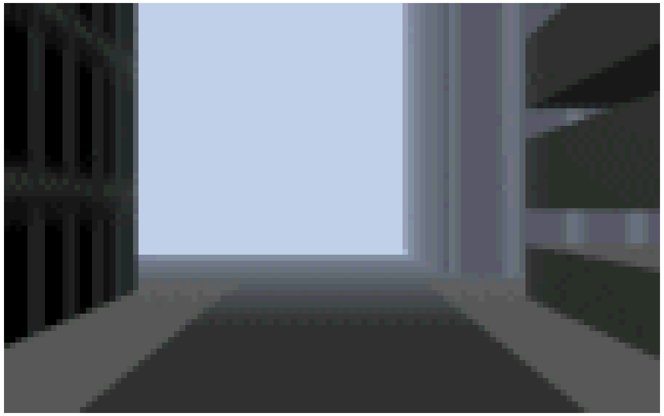
Perfect Storm



Animated Example



over



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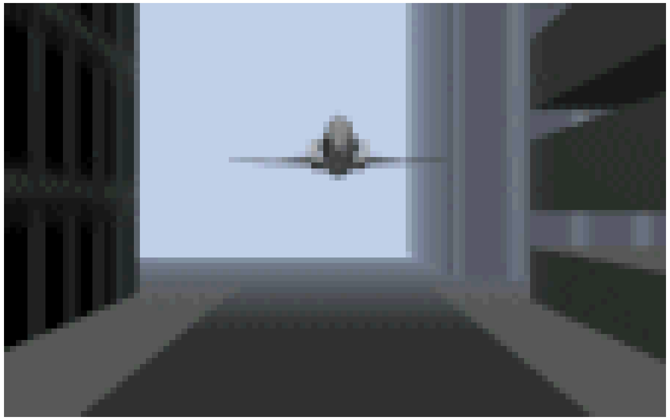


Mattes

- A *matte* is an image that shows which parts of another image are foreground objects
- Term dates from film editing and cartoon production
- How would I use a matte to insert an object into a background?
- How are mattes usually generated for television?

Working with Mattes

- To insert an object into a background
  - Call the image of the object the source
  - Put the background into the destination
  - For all the source pixels, if the matte is white, copy the pixel, otherwise leave it unchanged
- To generate mattes:
  - Use smart selection tools in Photoshop or similar
    - They outline the object and convert the outline to a matte
  - **Blue Screen:** Photograph/film the object in front of a blue background, then consider all the blue pixels in the image to be the background

Compositing

- Compositing is the term for combining images, one over the other
  - Used to put special effects into live action

Alpha

- Basic idea: Encode opacity information in the image
- Add an extra channel, the *alpha* channel, to each image
  - For each pixel, store R, G, B and Alpha
  - alpha = 1 implies full opacity at a pixel
  - alpha = 0 implies completely clear pixels
- There are many interpretations of alpha
  - Is there anything in the image at that point (web graphics)
  - Transparency (real-time OpenGL)
- Images are now in RGBA format, and typically 32 bits per pixel (8 bits for alpha)
- All images in the project are in this format

Pre-Multiplied Alpha

- Instead of storing (R,G,B,α), store $(\alpha R,\alpha G,\alpha B,\alpha)$
- The compositing operations in the next several slides are easier with pre-multiplied alpha
- **To display and do color conversions, must extract RGB by dividing out α**
  - $\alpha=0$ is always black
  - Some loss of precision as α gets small, but generally not a big problem

Compositing Assumptions

- We will combine two images, *f* and *g*, to get a third *composite image*
- Both images are the same size and use the same color representation
- Multiple images can be combined in stages, operating on two at a time

Basic Compositing Operation

- At each pixel, combine the pixel data from *f* and the pixel data from *g* with the equation:

$$c_o = Fc_f + Gc_g$$

- *F* and *G* describe how much of each input image survives, and c_f and c_g are **pre-multiplied pixels**, and **all four channels** are calculated
- **To define a compositing operation, define *F* and *G***

Basic Compositing Operation

- F and G are simple **functions** of the alpha values

$$c_o = F(\alpha_f, \alpha_g)c_f + G(\alpha_f, \alpha_g)c_g$$

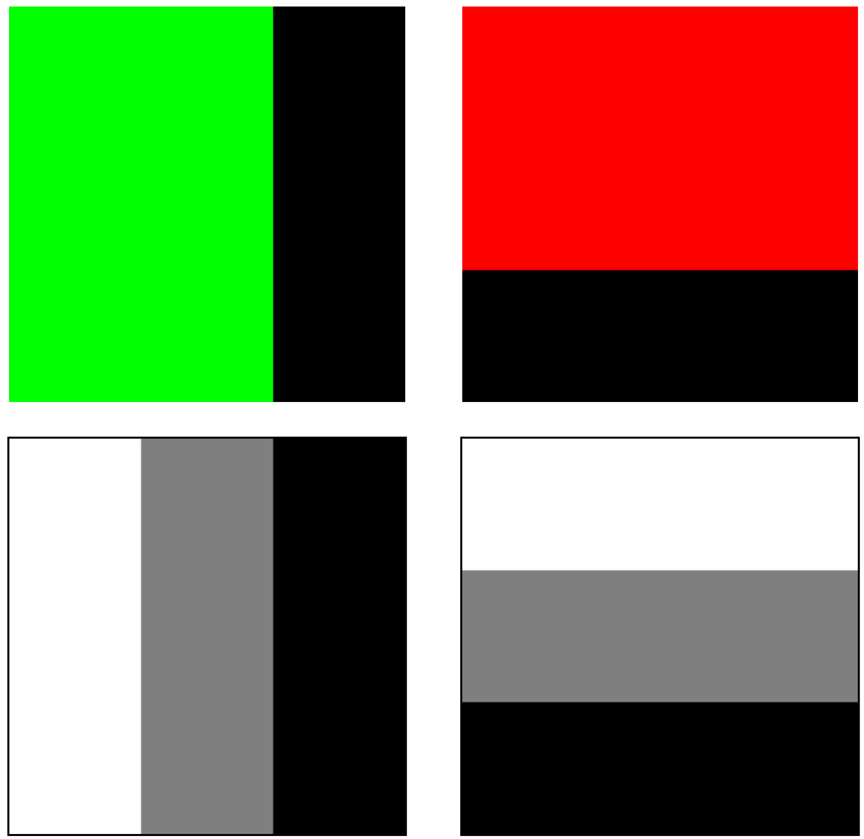
- F and G are chosen (independently)
- Different choices give different operations
- To code it, you can write one compositor and give it 6 numbers (3 for F, 3 for G) to say which function
  - Constant of 0 or 1
  - α_f is multiplied by -1, 0 or 1. Similar for α_g

0	$0,0,0$
1	$1,0,0$
α_f	$0,1,0$
$1-\alpha_f$	$1,-1,0$
α_g	$0,0,1$
$1-\alpha_g$	$1,0,-1$

Sample Images

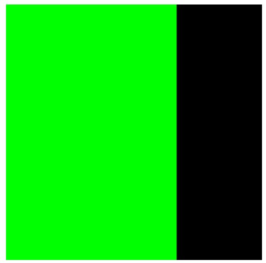
Images

Alphas



Sample Images

Images

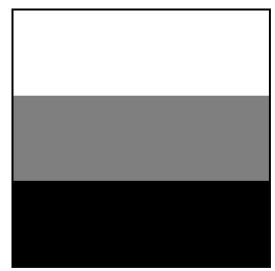


RGB

0,1,0	0,1,0	0, 0, 0
0,1,0	0,1,0	0 ,0, 0
0,1,0	0,1,0	0, 0 ,0

1,0,0	1,0,0	1,0,0
1,0,0	1,0,0	1,0,0
0, 0 ,0	0, 0 ,0	0, 0 ,0

Alphas

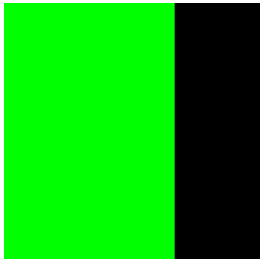


1	0.5	0
1	0.5	0
1	0.5	0

1	1	1
0.5	0.5	0 .5
0	0	0

Sample Images

Images

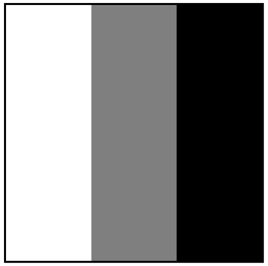


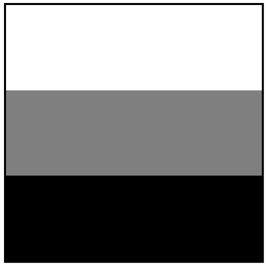
Pre-multiplied RGBA

0,1,0 1	0,0.5,0 0.5	0, 0, 0 0
0,1,0 1	0,0.5,0 0.5	0 ,0, 0 0
0,1,0 1	0,0.5,0 0.5	0, 0 ,0 0

1,0,0 1	1,0,0 1	1,0,0 1
0.5,0,0 0.5	0.5,0,0 0.5	0.5,0,0 0.5
0, 0 ,0 0	0, 0 ,0 0	0, 0 ,0 0

Alphas





"Over" Operator

- Computes composite with the rule that *f* covers *g*

$$F = 1$$

$$G = 1 - \alpha_f$$

$$\Rightarrow \quad c_o = Fc_f + Gc_g = c_f + (1 - \alpha_f)c_g$$

“Over” Operator

$$c_o = Fc_f + Gc_g = c_f + (1 - \alpha_f)c_g$$

f

0,1,0 1	0,0.5,0 0.5	0, 0, 0 0
0,1,0 1	0,0.5,0 0.5	0 ,0, 0 0
0,1,0 1	0,0.5,0 0.5	0, 0 ,0 0

Over

g

1,0,0 1	1,0,0 1	1,0,0 1
0.5,0,0 0.5	0.5,0,0 0.5	0.5,0,0 0.5
0, 0 ,0 0	0, 0 ,0 0	0, 0 ,0 0

result

0,1,0 1	0.5,0.5,0 1	1,0,0 1
0,1,0 1	0.25,0.5,0 0.75	0.5,0,0 0.5
0,1,0 1	0, 0.5 ,0 0.5	0, 0 ,0 0

“Over” Operator: Extract RGB Color

0,1,0 1	0.5,0.5,0 1	1,0,0 1
0,1,0 1	0.25,0.5,0 0.75	0.5,0,0 0.5
0,1,0 1	0, 0.5 ,0 0.5	0, 0 ,0 0

Pre-multiplied RGBA

0,1,0	0.5,0.5,0	1,0,0
0,1,0	1/3,2/3,0	1,0,0
0,1,0	0, 1,0	0, 0 ,0

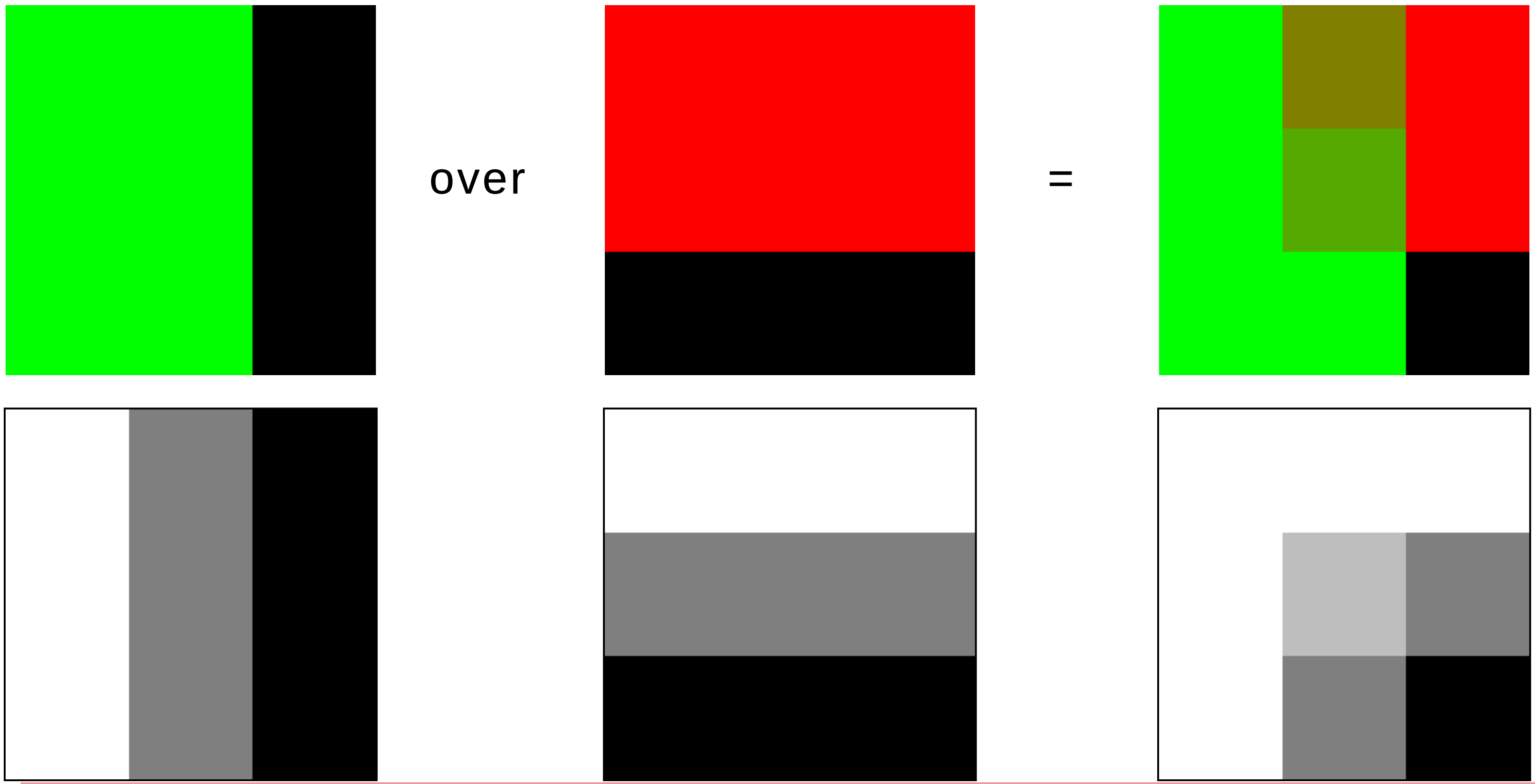
RGB

0,1,0 1	0.5,0.5,0 1	1,0,0 1
0,1,0 1	0.25,0.5,0 0.75	0.5,0,0 0.5
0,1,0 1	0, 0.5 ,0 0.5	0, 0 ,0 0

Alpha

"Over" Operator

- If there's some *f*, get *f*, otherwise get *g*



"Inside" Operator

- Computes composite with the rule that only parts of f that are inside g contribute

$$F = \alpha_g$$

$$G = 0$$

“Inside” Operator

$$c_o = Fc_f + Gc_g = \alpha_g c_f$$

f

0,1,0 1	0,0.5,0 0.5	0, 0, 0 0
0,1,0 1	0,0.5,0 0.5	0 ,0, 0 0
0,1,0 1	0,0.5,0 0.5	0, 0 ,0 0

Over

g

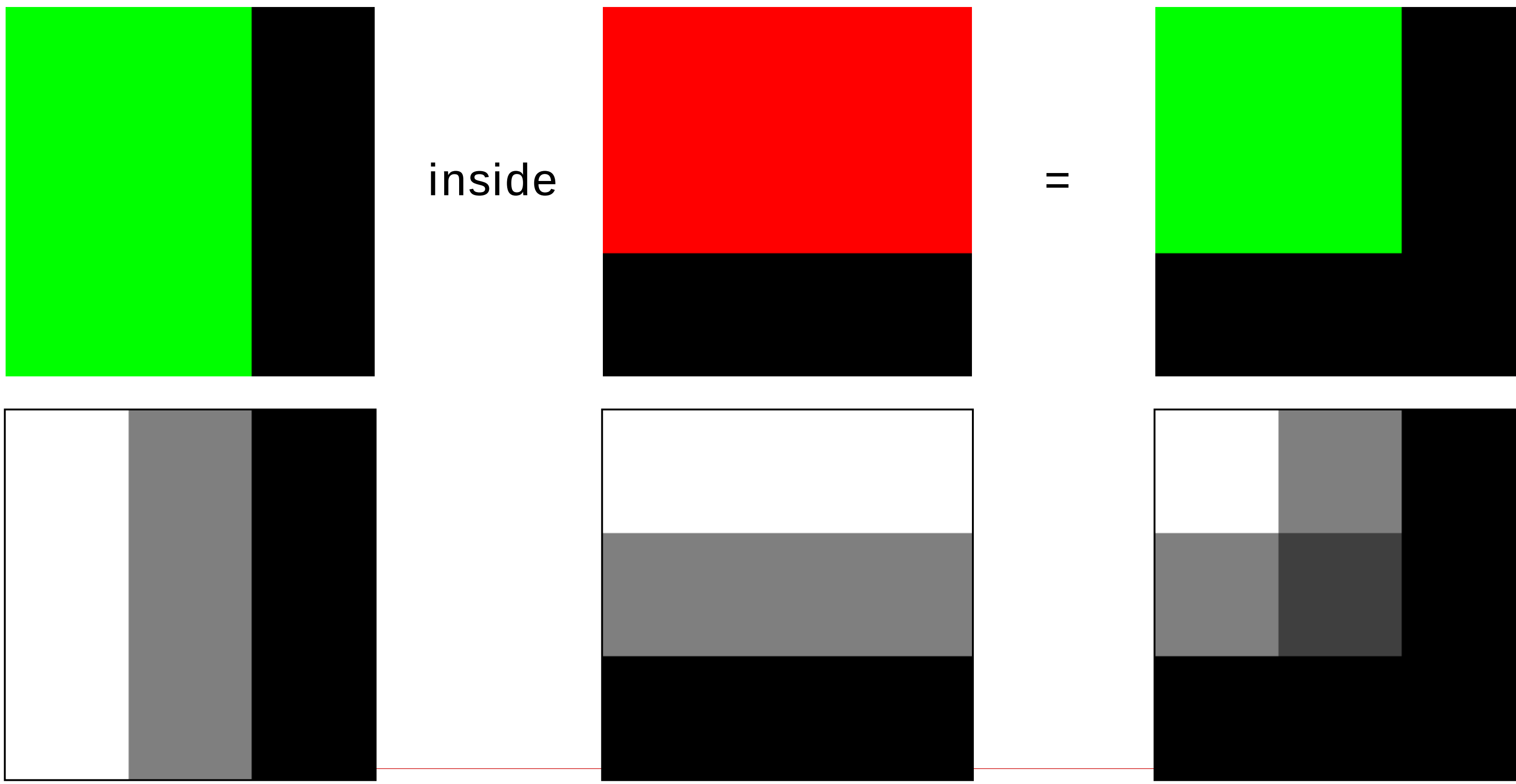
1,0,0 1	1,0,0 1	1,0,0 1
0.5,0,0 0.5	0.5,0,0 0.5	0.5,0,0 0.5
0, 0 ,0 0	0, 0 ,0 0	0, 0 ,0 0

result

0,1,0 1	0,0.5,0 0.5	0,0,0 0
0,0.5,0 0.5	0,0.25,0 0.25	0,0,0 0
0, 0 ,0 0	0, 0 ,0 0	0, 0 ,0 0

“Inside” Operator

- Get *f* to the extent that *g* is there, otherwise nothing



“Outside” Operator

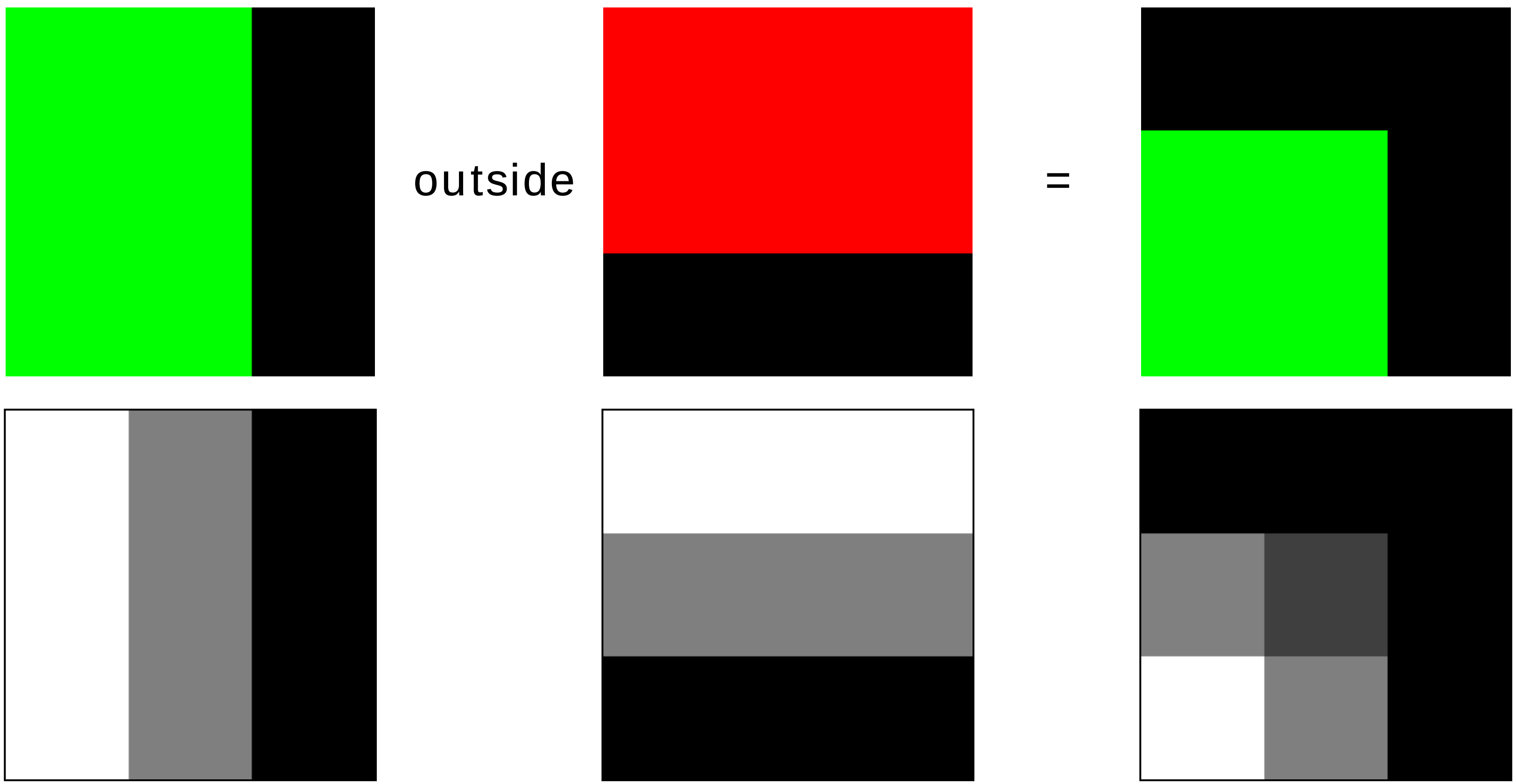
- Computes composite with the rule that only parts of *f* that are outside *g* contribute

$$F = 1 - \alpha_g$$

$$G = 0$$

“Outside” Operator

- Get *f* to the extent that *g* is **not** there, otherwise nothing



“Atop” Operator

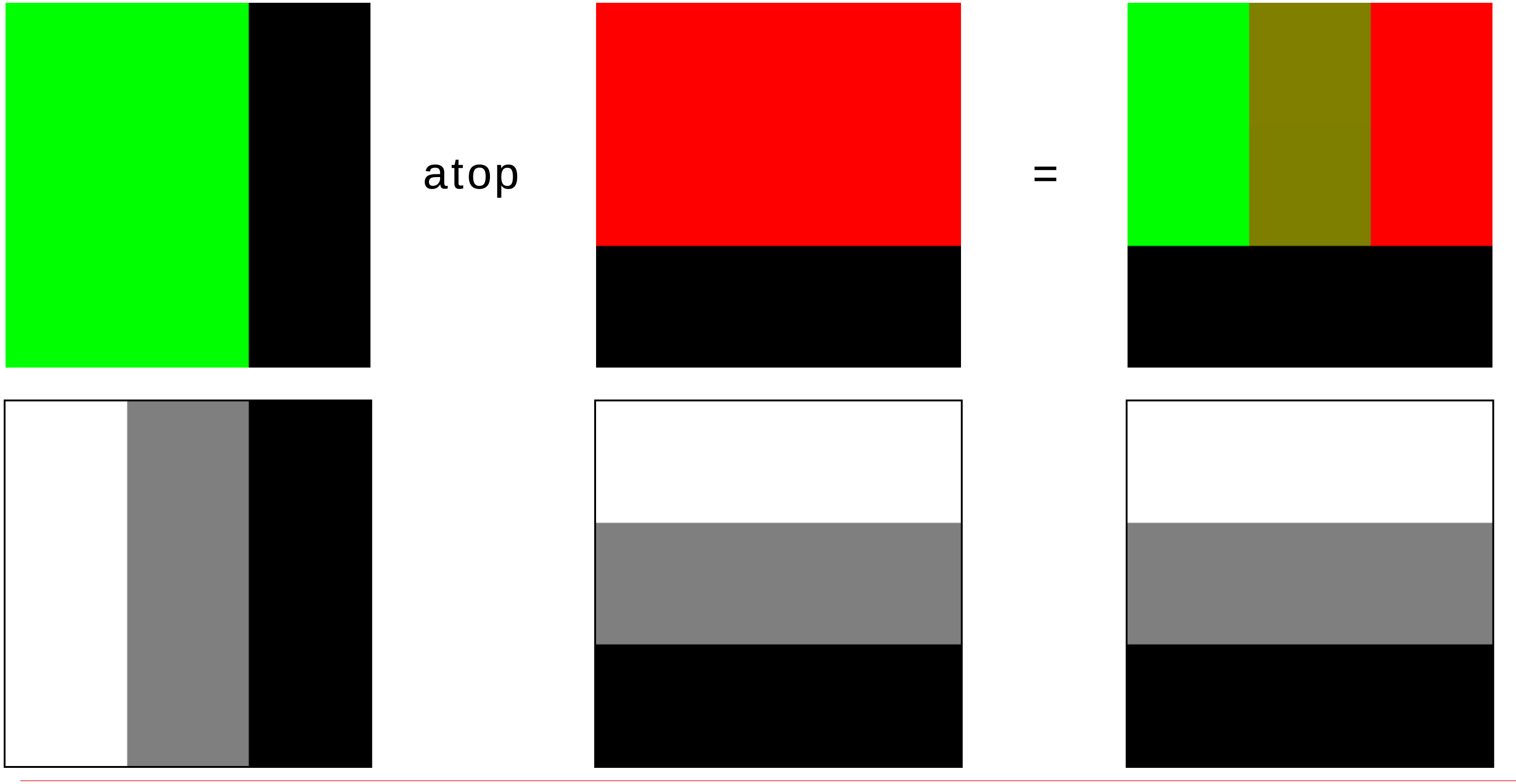
- Computes composite with the *over* rule but restricted to places where there is some *g*

$$F = \alpha_g$$

$$G = 1 - \alpha_f$$

"Atop" Operator

- Get *f* to the extent that *g* is there, otherwise *g*



“Xor” Operator

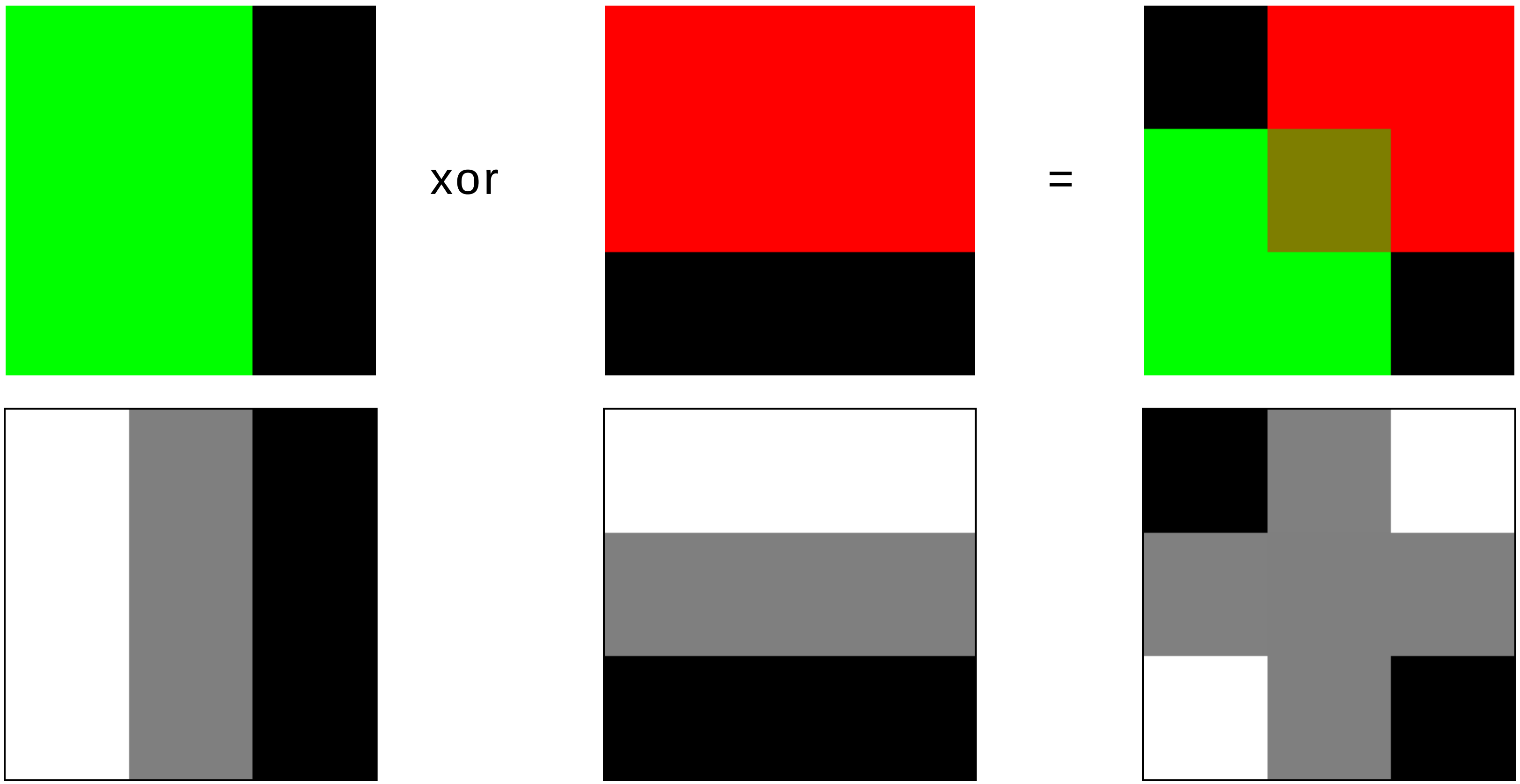
- Computes composite with the rule that *f* contributes where there is no *g*, and *g* contributes where there is no *f*

$$F = 1 - \alpha_g$$

$$G = 1 - \alpha_f$$

“Xor” Operator

- Get *f* to the extent that *g* is not there, and *g* to extent of no *f*



“Clear” Operator

- Computes a clear composite

$$F = 0$$

$$G = 0$$

- Note that (0,0,0,α>0) is a partially opaque black pixel, whereas (0,0,0,0) is fully transparent, and hence has no color

“Set” Operator

- Computes composite by setting it to equal f

$$F = 1$$

$$G = 0$$

- Copies f into the composite

Compositing Operations

- F and G describe how much of each input image survives, and c_f and c_g are **pre-multiplied pixels**, and **all four channels** are calculated

$$c_o = Fc_f + Gc_g$$

Operation	F	G
Over	1	$1-\alpha_f$
Inside	α_g	0
Outside	$1-\alpha_g$	0
Atop	α_g	$1-\alpha_f$
Xor	$1-\alpha_g$	$1-\alpha_f$
Clear	0	0
Set	1	0

Unary Operators

- Darken: Makes an image darker (or lighter) without affecting its opacity

$$darken(f,\phi) \equiv (\phi r_f, \phi g_f, \phi b_f, \alpha_f)$$

- Dissolve: Makes an image transparent without affecting its color

$$dissolve(f,\delta) \equiv (\delta r_f, \delta g_f, \delta b_f, \delta \alpha_f)$$

“PLUS” Operator

- Computes composite by simply adding *f* and *g*, with no overlap rules

$$c_o = c_f + c_g$$

- Useful for defining *cross-dissolve* in terms of compositing:

$$cross(f, g, t) = dissolve(f, t) \ \text{plus} \ dissolve(g, 1-t)$$

Obtaining α Values

- Hand generate (paint a grayscale image)
- Automatically create by segmenting an image into foreground background:
  - Blue-screening is the analog method
    - Remarkably complex to get right
  - "Lasso" is the Photoshop operation
- With synthetic imagery, use a special background color that does not occur in the foreground
  - Brightest blue or green is common

Compositing With Depth

- Can store pixel “depth” instead of alpha
- Then, compositing can truly take into account foreground and background
- Generally only possible with synthetic imagery
  - Image Based Rendering is an area of graphics that, in part, tries to composite photographs taking into account depth

Today

- More Compositing
- Non-photorealistic Rendering (NPR)
- 3D Graphics Toolkits
  - Transformations

Painterly Filters

- Many methods have been proposed to make a photo look like a painting
- Today we look at one: *Painterly-Rendering with Brushes of Multiple Sizes**
- Basic ideas:
  - Build painting one layer at a time, from biggest to smallest brushes
  - At each layer, add detail missing from previous layer

*Aaron Hertzmann. Painterly rendering with curved brush strokes of multiple sizes, SIGGRAPH 1998

Algorithm 1

```
function paint(sourceImage,R_1 ... R_n) // take source and several brush sizes
{
        canvas := a new constant color image
        // paint the canvas with decreasing sized brushes
        for each brush radius R_i, from largest to smallest do
        {
        // Apply Gaussian smoothing with a filter of size const * radius
        // Brush is intended to catch features at this scale
                referenceImage = sourceImage * G(fs R_i)
                // Paint a layer
                paintLayer(canvas, referenceImage, Ri)
        }
        return canvas
}
```

Algorithm 2

```
procedure paintLayer(canvas,referenceImage, R) // Add a layer of strokes
{
    S := a new set of strokes, initially empty
    D := difference(canvas,referenceImage) // euclidean distance at every pixel
        for x=0 to imageWidth stepsize grid do  // step in size that depends on brush radius
            for y=0 to imageHeight stepsize grid do {
            // sum the error near (x,y)
            M := the region (x-grid/2..x+grid/2, y-grid/2..y+grid/2)
                areaError := sum(D_{i,j} for i,j in M) / grid^2
                if (areaError > T) then {
                    // find the largest error point
                    (x1,y1) := max D_{i,j} in M
                    s :=makeStroke(R,x1,y1,referenceImage)
                    add s to S
                }
            }
        paint all strokes in S on the canvas, in random order
}
```

Point Style

- Uses round brushes
- We provide a routine to “paint” round brush strokes into an image for the project

Results

Original

Biggest brush

Medium brush added

Finest brush added

Where to now…

- We are now done with images
- We will spend several weeks on the mechanics of 3D graphics
  - Coordinate systems and Viewing
  - Clipping
  - Drawing lines and polygons
  - Lighting and shading

Graphics Toolkits

- Graphics toolkits typically take care of the details of producing images from geometry
- Input (via API functions):
  - Where the objects are located and what they look like
  - Where the camera is and how it behaves
  - Parameters for controlling the rendering
- Functions (via API):
  - Perform well defined operations based on the input environment
- Output: Pixel data in a *framebuffer* – an image in a special part of memory
  - Data can be put on the screen
  - Data can be read back for processing (part of toolkit)

OpenGL

- OpenGL is an open standard graphics toolkit
  - Derived from SGI's GL toolkit
- Provides a range of functions for modeling, rendering and manipulating the framebuffer
- What makes a good toolkit?
- Alternatives: Direct3D, Java3D - more complex and less well supported

A Good Toolkit…

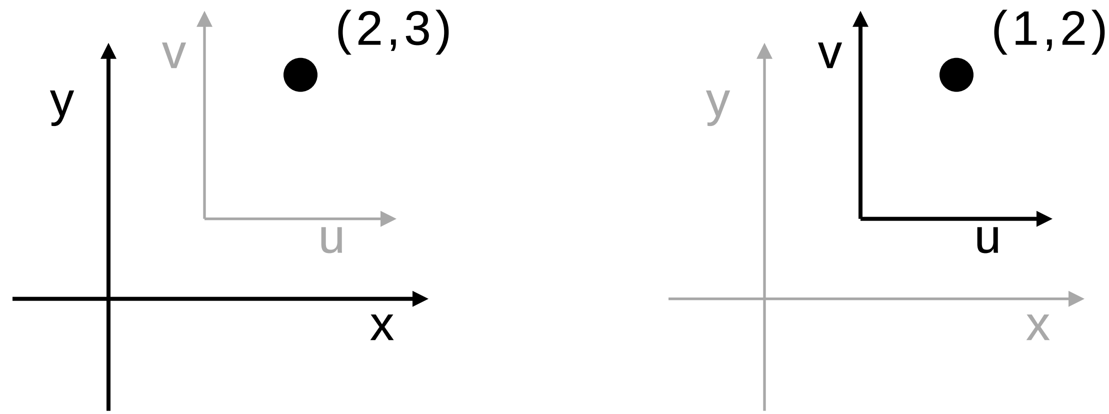
- Everything is a trade-off
- Functionality
  - Compact: a minimal set of commands
  - Orthogonal: commands do different things and can be combined in a consistent way
  - Speed
- Ease-of-Use and Documentation
- Portability
- Extensibility
- Standards and ownership
- Not an exhaustive list …

Coordinate Systems

- The use of *coordinate systems* is fundamental to computer graphics
- Coordinate systems are used to describe the locations of points in space, and directions in space
- Multiple coordinate systems make graphics algorithms easier to understand and implement

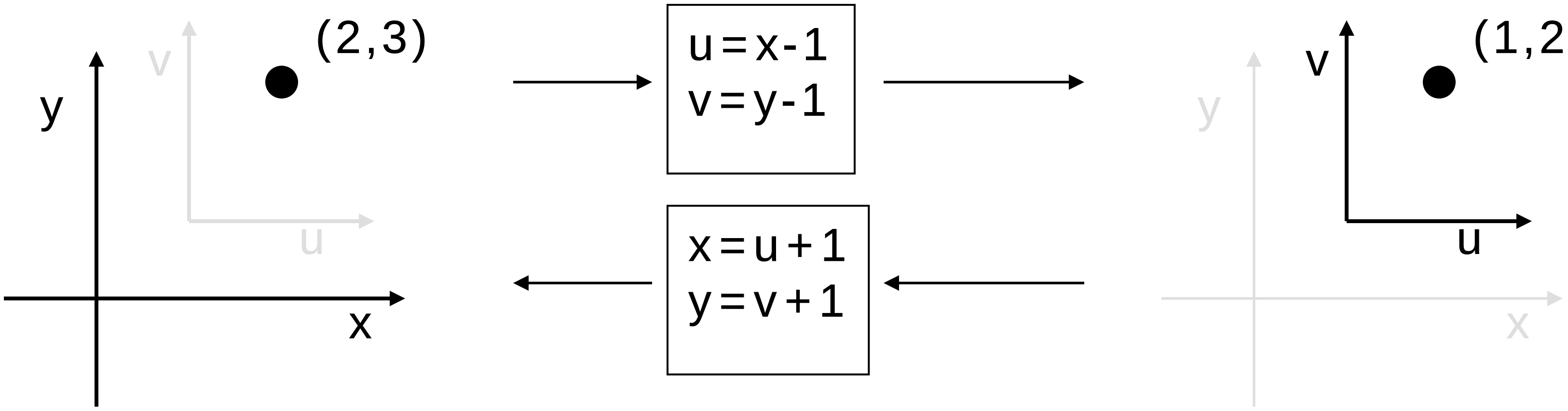
Coordinate Systems (2)

- Different coordinate systems represent the same point in different ways



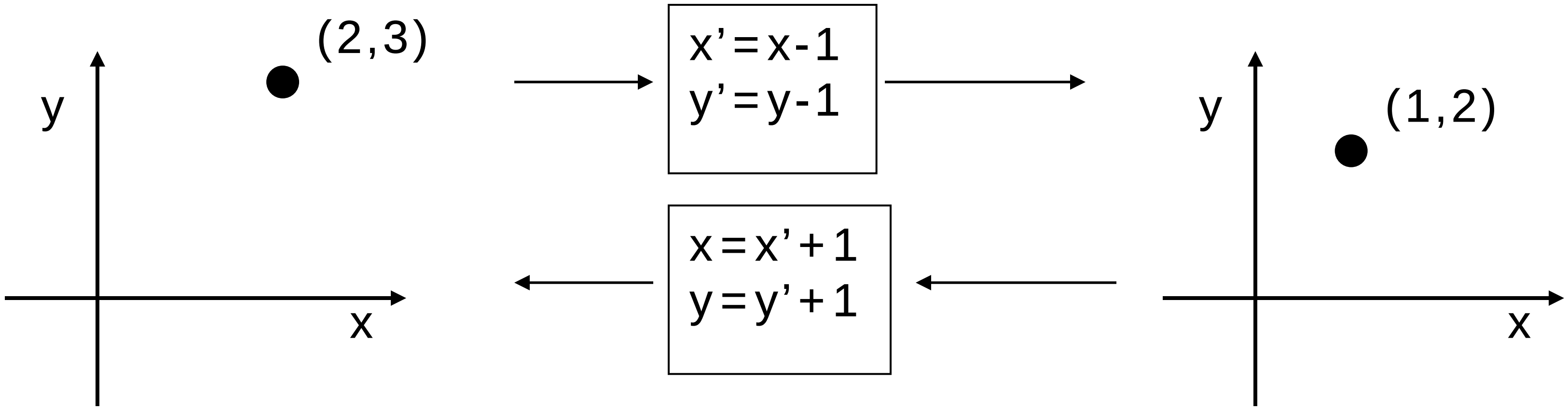
Transformations

- Transformations convert points between coordinate systems



Transformations (Alternate Interpretation)

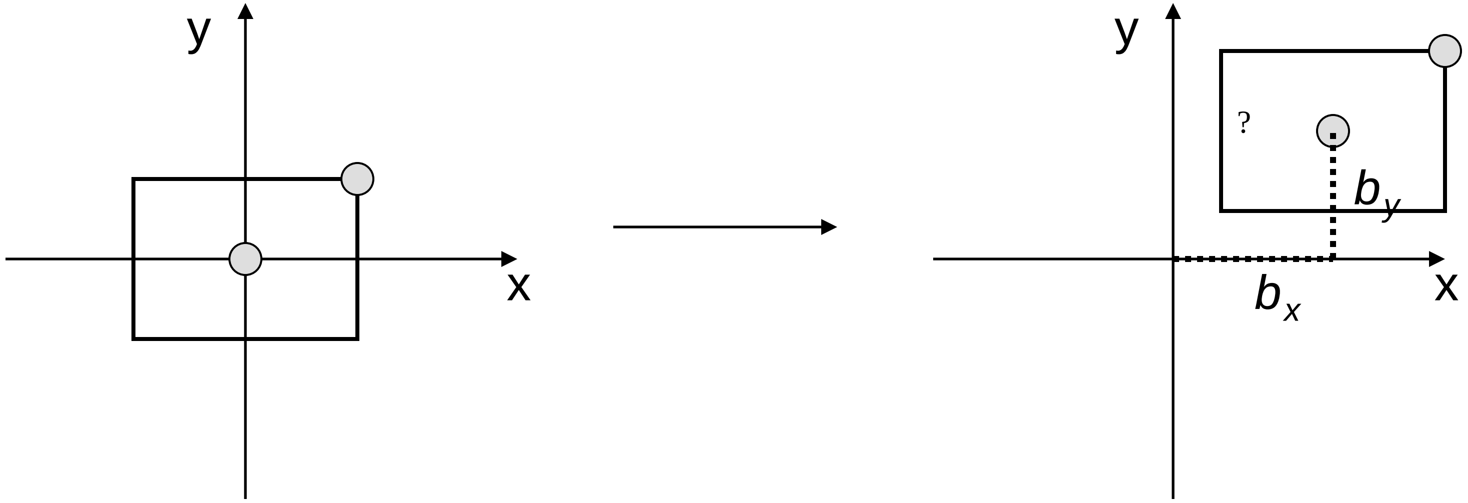
- Transformations modify an object's shape and location in one coordinate system



- The previous interpretation is better for some problems, this one is better for others

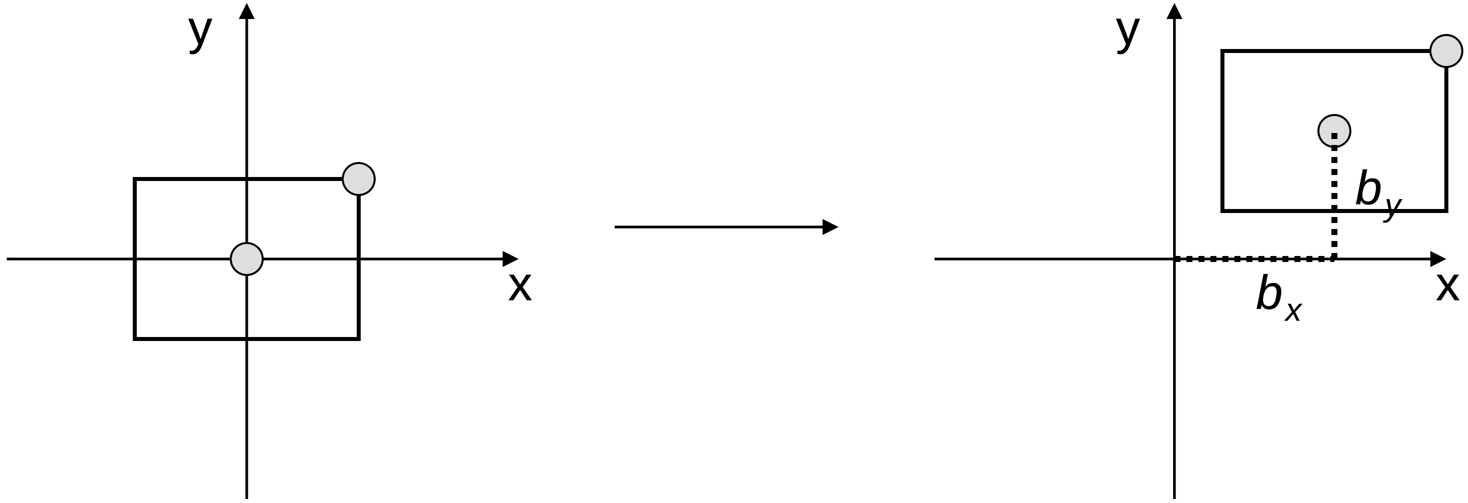
2D Translation

- Moves an object $$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} ? & ? \\ ? & ? \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} + \begin{bmatrix} ? \\ ? \end{bmatrix}$$



2D Translation

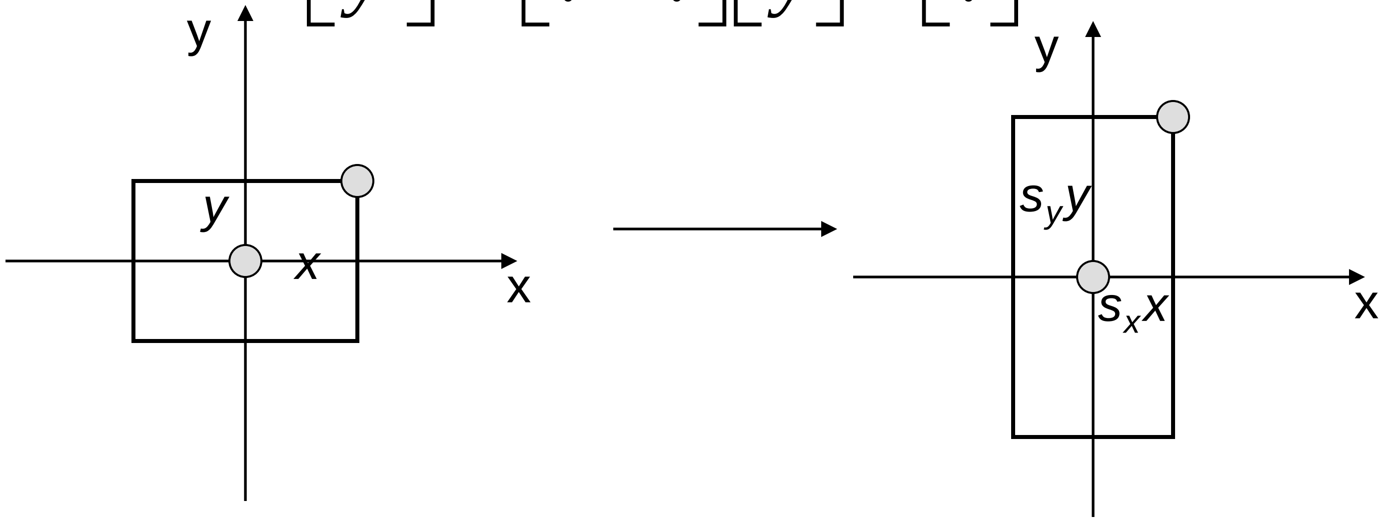
- Moves an object $\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} + \begin{bmatrix} b_x \\ b_y \end{bmatrix}$



2D Scaling

- Resizes an object in each dimension

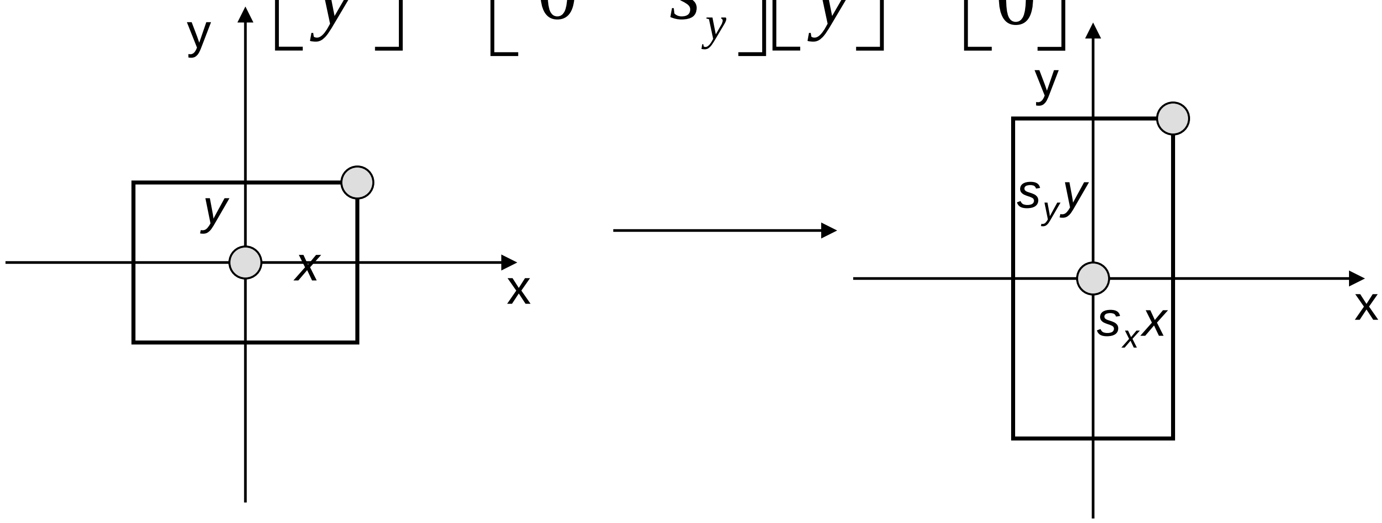
$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} ? & ? \\ ? & ? \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} + \begin{bmatrix} ? \\ ? \end{bmatrix}$$



2D Scaling

- Resizes an object in each dimension

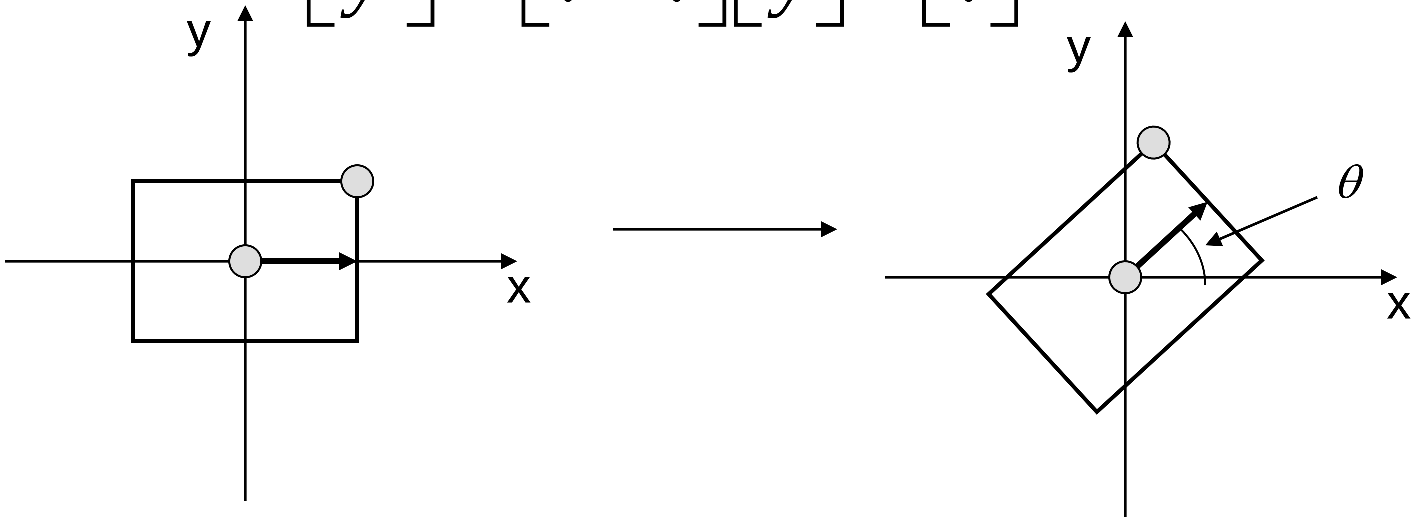
$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} s_x & 0 \\ 0 & s_y \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$



2D Rotation

- Rotate counter-clockwise about the origin by an angle θ

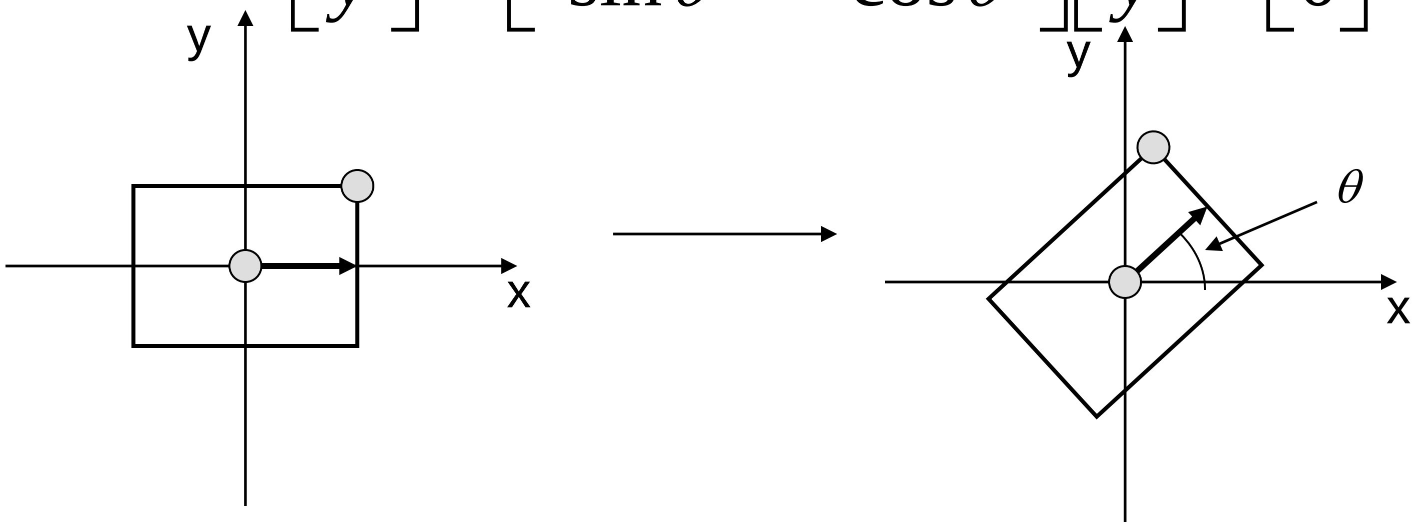
$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} ? & ? \\ ? & ? \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} + \begin{bmatrix} ? \\ ? \end{bmatrix}$$



2D Rotation

- Rotate counter-clockwise about the origin by an angle θ

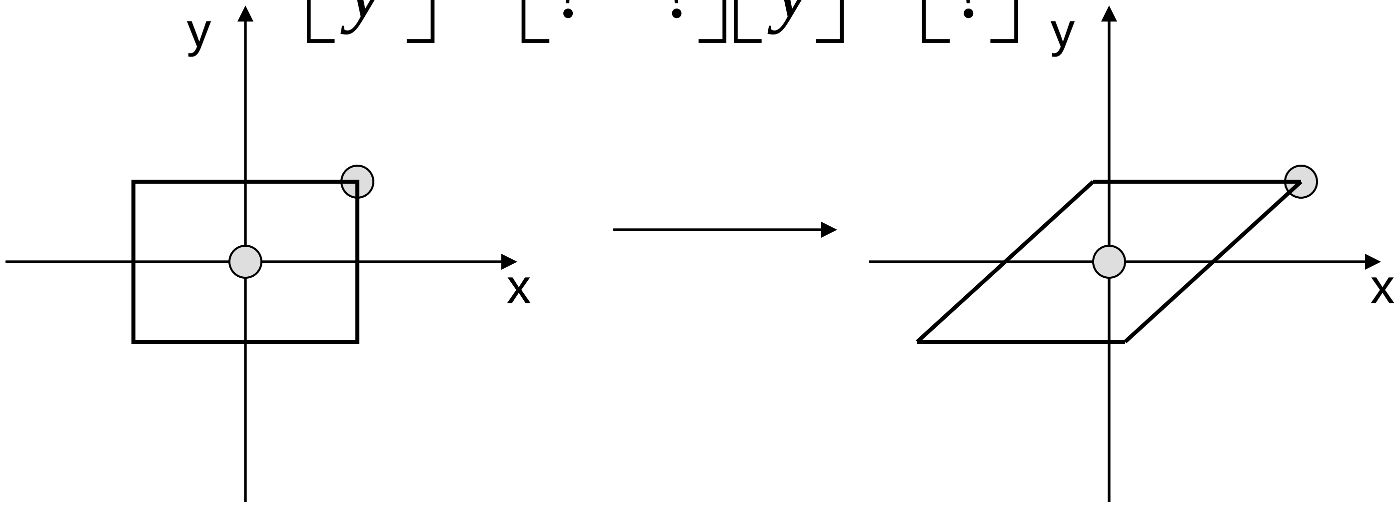
$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$



X-Axis Shear

- Shear along x axis (What is the matrix for y axis shear?)

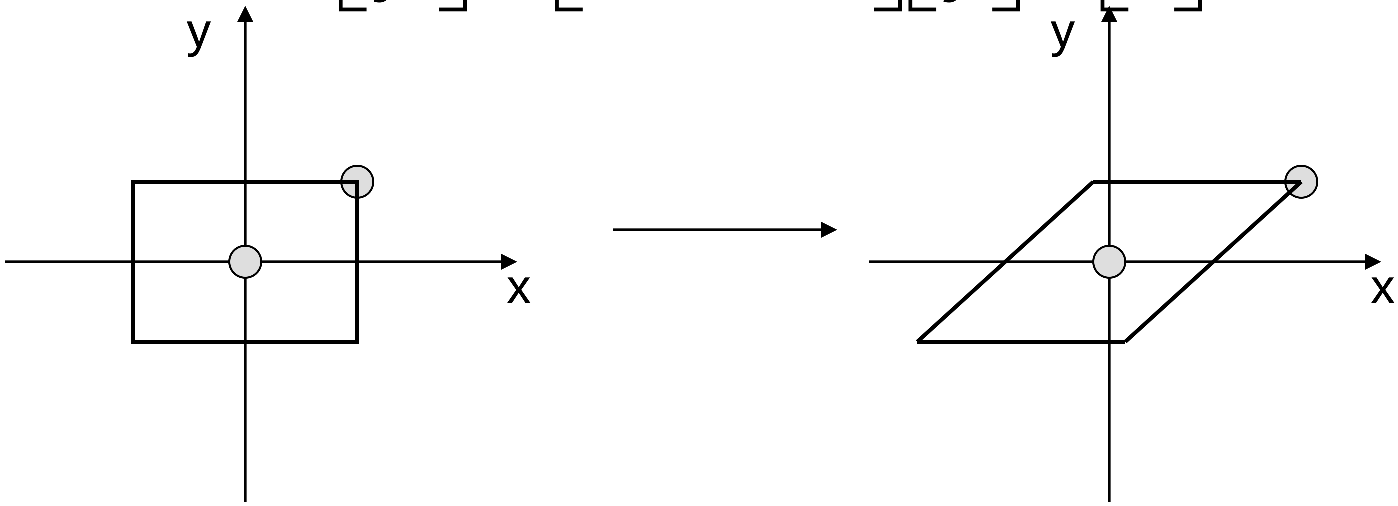
$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} ? & ? \\ ? & ? \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} + \begin{bmatrix} ? \\ ? \end{bmatrix}$$



X-Axis Shear

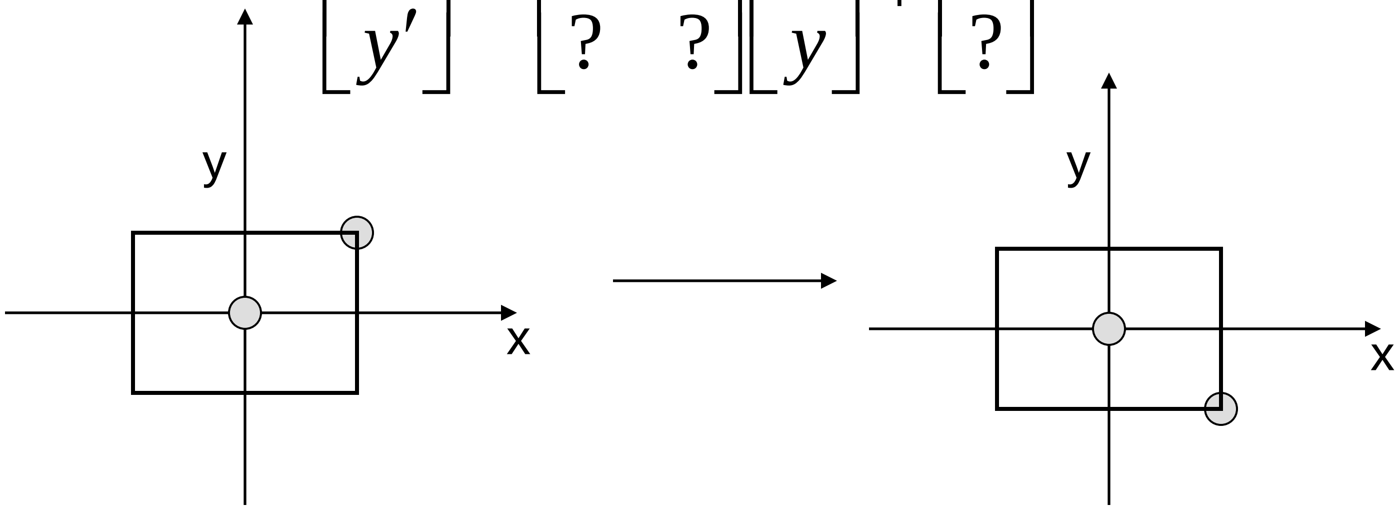
- Shear along x axis (What is the matrix for y axis shear?)

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} 1 & sh_x \\ 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$



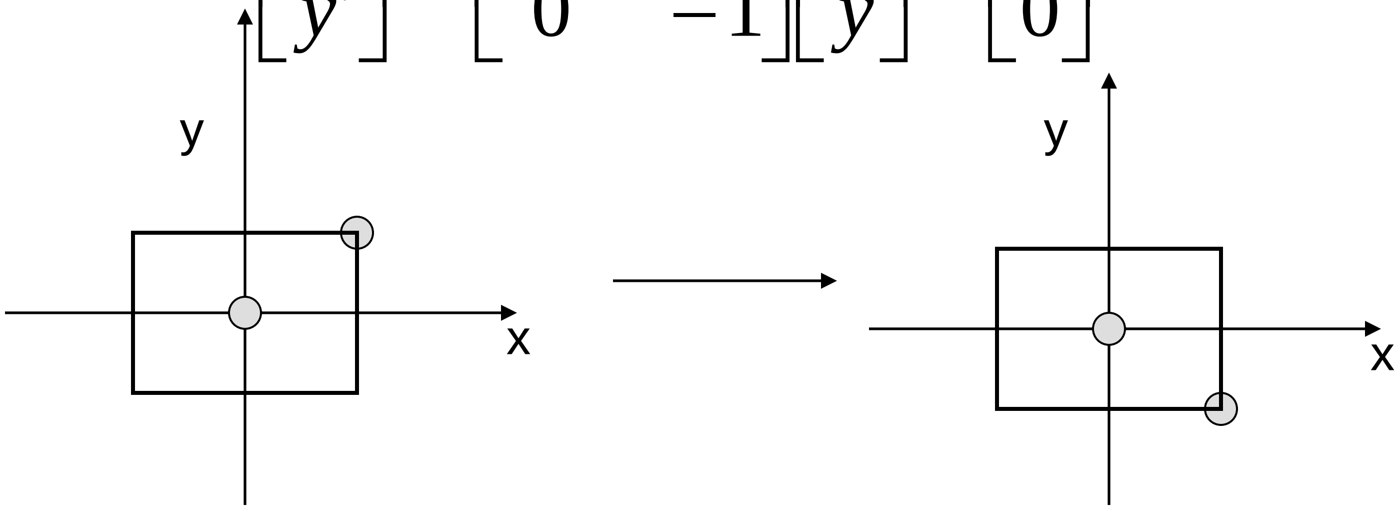
Reflect About X Axis

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} ? & ? \\ ? & ? \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} + \begin{bmatrix} ? \\ ? \end{bmatrix}$$



Reflect About X Axis

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$



2D Affine Transformations

- An *affine transformation* is one that can be written in the form:

$$x' = a_{xx}x + a_{xy}y + b_x$$
$$y' = a_{yx}x + a_{yy}y + b_y$$

or

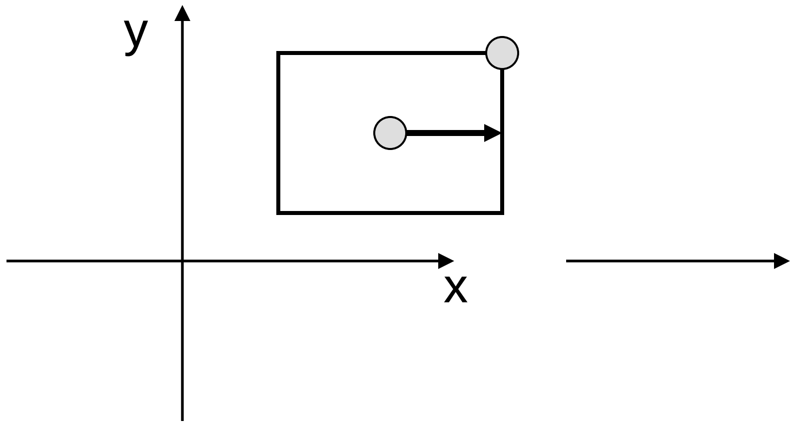
$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} a_{xx} & a_{xy} \\ a_{yx} & a_{yy} \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} + \begin{bmatrix} b_x \\ b_y \end{bmatrix}$$

Composition of Affine Transforms

- Any affine transformation can be composed as a sequence of simple transformations:
  - Translation
  - Scaling (possibly with negative values)
  - Rotation

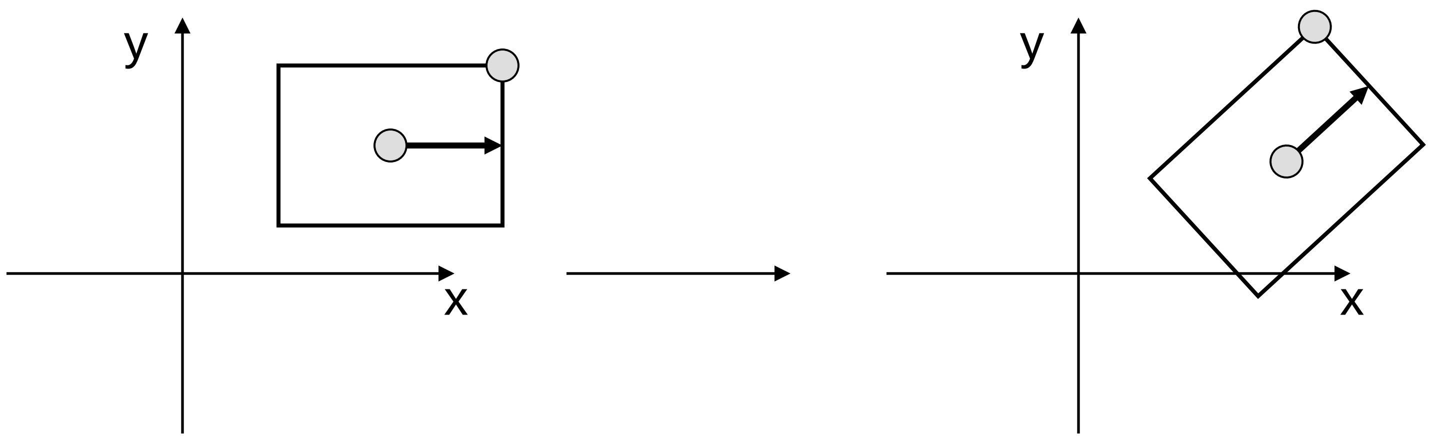
Rotating About An Arbitrary Point

- What happens when you rotate an object about an arbitrary point that is not the origin?



Rotating About An Arbitrary Point

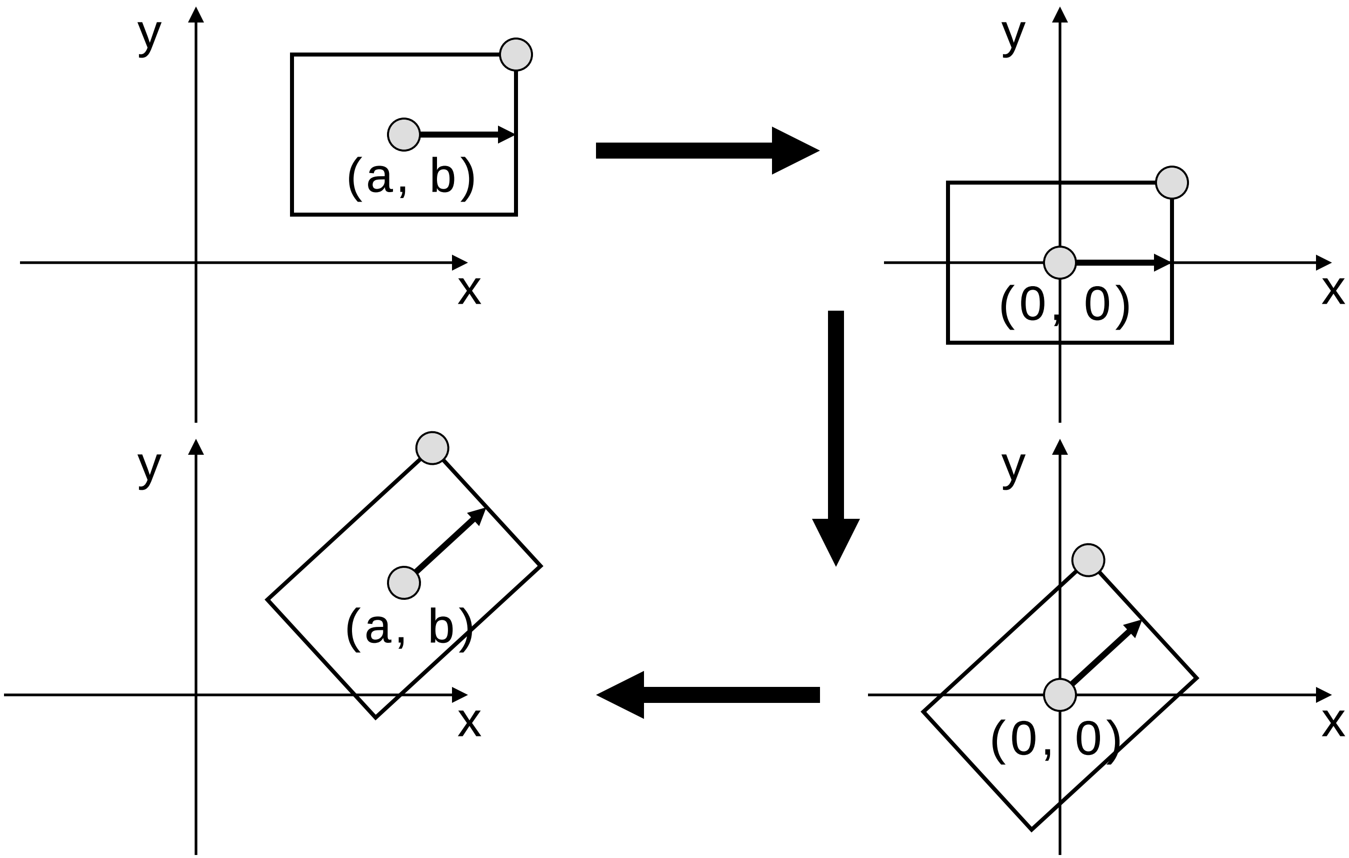
- What happens when you rotate an object about an arbitrary point that is not the origin?



How Do We Compute It?

- How do we rotate an about an arbitrary point?
  - Hint: we know how to rotate about the origin of a coordinate system

Rotating About An Arbitrary Point



Rotating About An Arbitrary Point

- Say you wish to rotate about the point (a,b)
- You know how to rotate about $(0,0)$
- Translate so that (a,b) is at $(0,0)$
  - $x'=x-a,\ y'=y-b$
- Rotate
  - $x''=(x-a)\cos\theta-(y-b)\sin\theta,\ y''=(x-a)\sin\theta+(y-b)\cos\theta$
- Translate back again
  - $x_f=x''+a,\ y_f=y''+b$

Rotating About An Arbitrary Point

- Say R is the rotation matrix to apply, and p is the point about which to rotate
- Translation to Origin: $\boldsymbol{x}' = \boldsymbol{x} - \boldsymbol{p}$
- Rotation: $\boldsymbol{x}'' = \boldsymbol{R}\boldsymbol{x}' = \boldsymbol{R}(\boldsymbol{x} - \boldsymbol{p}) = \boldsymbol{R}\boldsymbol{x} - \boldsymbol{R}\boldsymbol{p}$
- Translate back: $\mathbf{x}''' = \mathbf{x}'' + \mathbf{p} = \mathbf{R}\mathbf{x} + \left(-\mathbf{R}\mathbf{p} + \mathbf{p}\right)$
- The translation component of the composite transformation involves the rotation matrix. What a mess!

Next Time

- Composing transformations
- 3D Transformations
- Viewing
-