# Image Warping, Compositing & Morphing

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## Image Processing

- Quantization
  - Uniform Quantization
  - Random dither
  - Ordered dither
  - Floyd-Steinberg dither
- Pixel operations
  - Add random noise
  - Add luminance
  - Add contrast
  - Add saturation
- Filtering
  - Blur
  - Detect edges
- Warping
  - Scale
  - Rotate
  - Warp
- Combining
  - Morph
  - Composite

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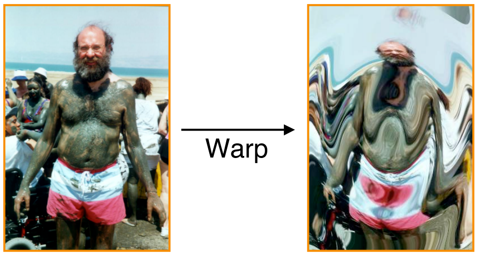
  - Morph
  - Composite

## Image Warping

- Move pixels of image
  - Mapping
  - Resampling



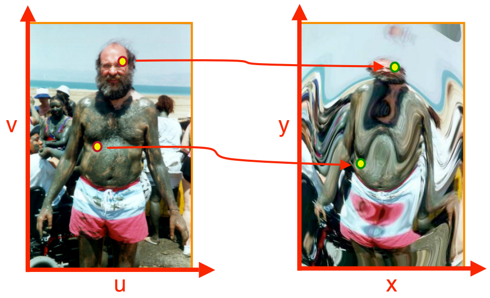
Source image Destination image

## Overview

- Mapping
  - Forward
  - Reverse
- Resampling
  - Point sampling
  - Triangle filter
  - Gaussian filter

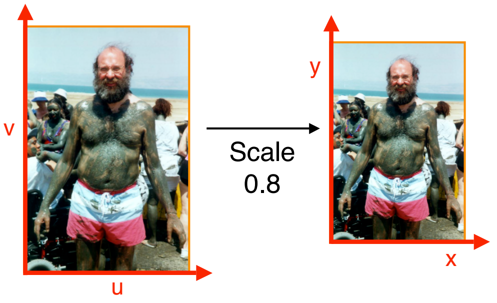
## Mapping

- Define transformation
  - Describe the destination (x,y) for every location (u,v) in the source (or vice-versa, if invertible)



## Example Mappings

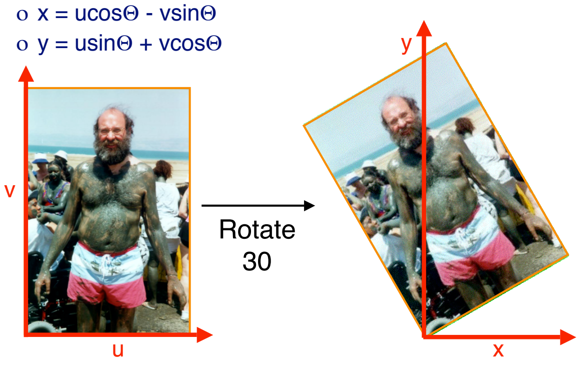
- Scale by *factor*:
  - o x = *factor* * u
  - o y = *factor* * v



Scale
0.8

## Example Mappings

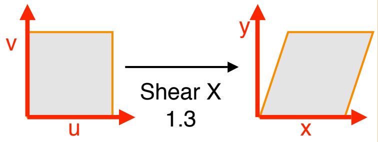
- Rotate by Θ degrees:
  - o x = ucosΘ - vsinΘ
  - o y = usinΘ + vcosΘ



Rotate
30

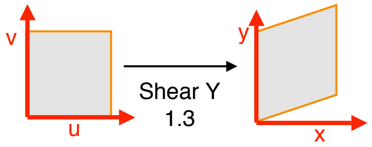
## Example Mappings

- Shear in X by *factor:*
  - o x = u + *factor* * v
  - o y = v



Shear X
1.3

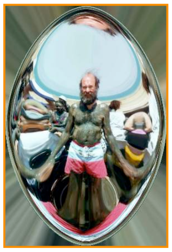
- Shear in Y by *factor:*
  - o x = u
  - o y = v + *factor* * u



Shear Y
1.3

## Other Mappings

- Any function of u and v:
  - o x = $f_x(u,v)$
  - o y = $f_y(u,v)$



Fish-eye

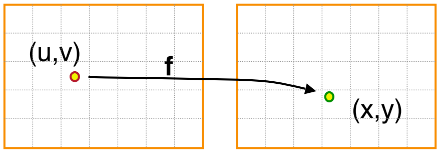
“Swirl”

“Rain”

## Image Warping Implementation I

- Forward mapping:

```
for (int u = 0; u < umax; u++) {
  for (int v = 0; v < vmax; v++) {
    float x = f_x(u,v);
    float y = f_y(u,v);
    dst(x,y) = src(u,v);
  }
}
```

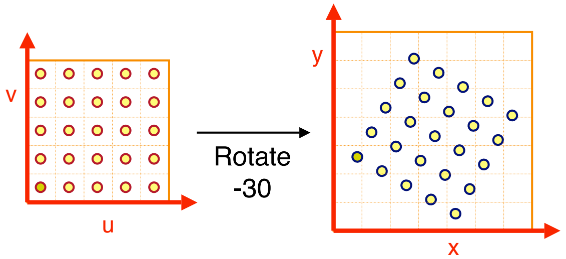


Source image

Destination image

## Forward Mapping

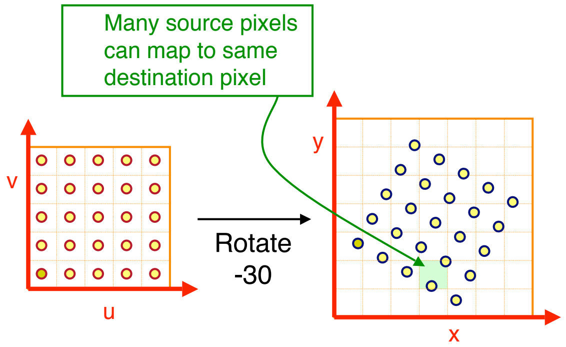
- Iterate over source image



Rotate
-30

## Forward Mapping - NOT

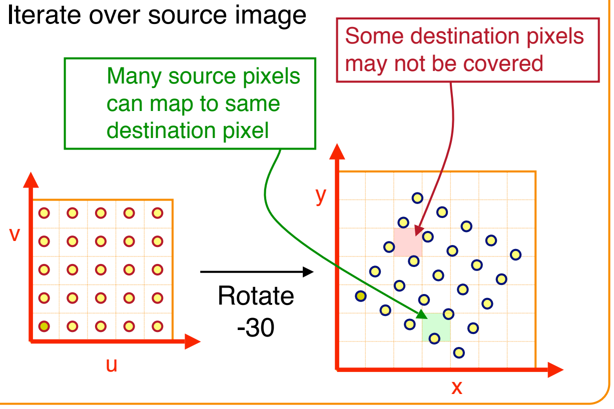
- Iterate over source image



Many source pixels can map to same destination pixel

## Forward Mapping - NOT

- Iterate over source image



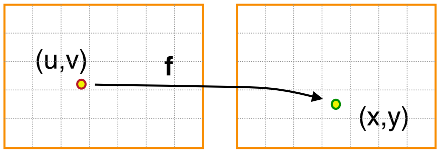
Many source pixels can map to same destination pixel

Some destination pixels may not be covered

## Image Warping Implementation II

- Reverse mapping:

```
for (int x = 0; x < xmax; x++) {
  for (int y = 0; y < ymax; y++) {
    float u = fx-1(x,y);
    float v = fy-1(x,y);
    dst(x,y) = src(u,v);
  }
}
```

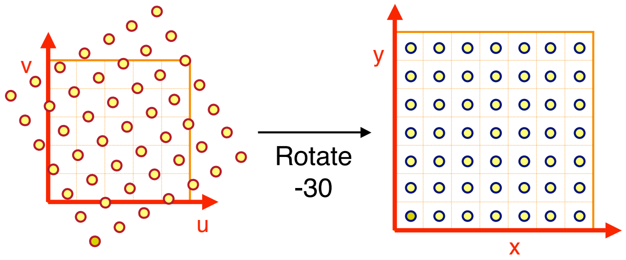


Source image

Destination image

## Reverse Mapping

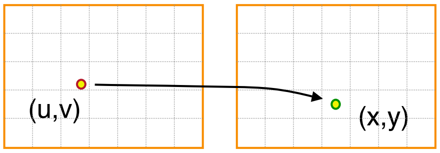
- Iterate over destination image
  - Must resample source
  - May oversample, but much simpler!



## Resampling

- Evaluate source image at arbitrary (u,v)

(u,v) does not usually have integer coordinates



Source image

Destination image

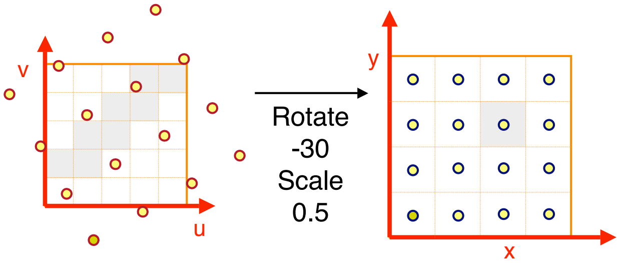
## Overview

- Mapping
  - Forward
  - Reverse
- **Resampling**
  - Point sampling
  - Triangle filter
  - Gaussian filter

## Point Sampling

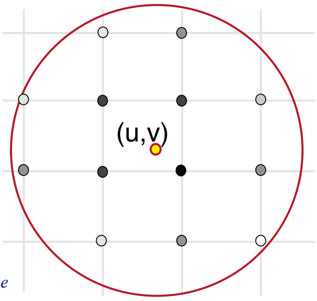
- Take value at closest pixel:
  - int iu = trunc(u+0.5);
  - int iv = trunc(v+0.5);
  - dst(x,y) = src(iu,iv);

This method is simple, but it causes aliasing



## Filtering

- Compute weighted sum of pixel neighborhood
  - Weights are normalized values of kernel function
  - Equivalent to convolution at samples



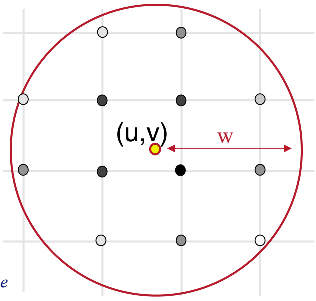
*k(i,j) represented by gray value*

## Filtering

- Compute weighted sum of pixel neighborhood
  - Weights are normalized values of kernel function
  - Equivalent to convolution at samples

```
s = 0;
for (i = -w; i <= w; i++)
  for (j = -w; j <= w; j++)
    s += k(i,j)*I(u+i, v+j);
```

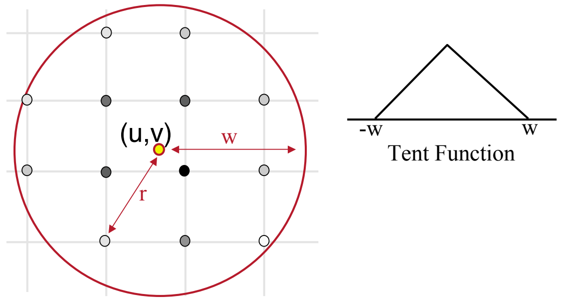
$$\sum k(i,j) = 1$$



*k(i,j) represented by gray value*

## Triangle Filtering

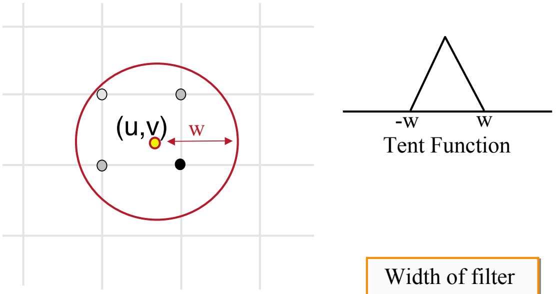
- Kernel is triangle function



Filter Width = 2

## Triangle Filtering

- Kernel is triangle function

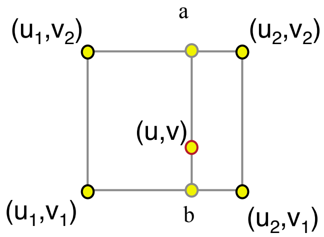


Width of filter affects blurriness

Filter Width = 1

## Triangle Filtering (with width = 1)

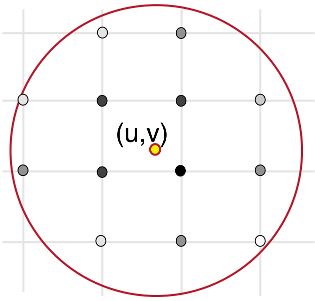
- Bilinearly interpolate four closest pixels
  - a = linear interpolation of src($u_1$,$v_2$) and src($u_2$,$v_2$)
  - b = linear interpolation of src($u_1$,$v_1$) and src($u_2$,$v_1$)
  - dst(x,y) = linear interpolation of “a” and “b”

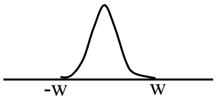


Filter Width = 1

## Gaussian Filtering

- Kernel is Gaussian function



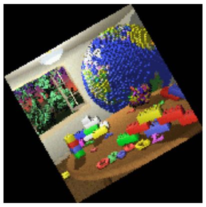


Gaussian Function

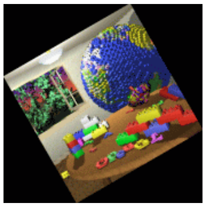
Filter Width = 2

## Filtering Methods Comparison

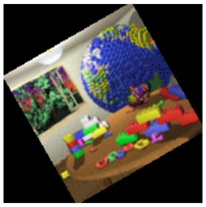
- Trade-offs
    - Aliasing versus blurring
    - Computation speed



Point



Bilinear

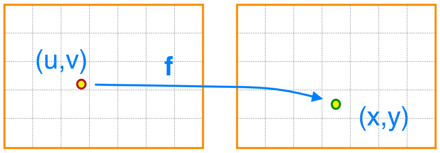


Gaussian

## Image Warping Implementation

- Reverse mapping:

```
for (int x = 0; x < xmax; x++) {
  for (int y = 0; y < ymax; y++) {
    float u = f_x^{-1}(x,y);
    float v = f_y^{-1}(x,y);
    dst(x,y) = resample_src(u,v,w);
  }
}
```



Source image

Destination image

## Image Warping Implementation

- Reverse mapping:

```
for (int x = 0; x < xmax; x++) {
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    dst(x,y) = resample_src(u,v,w);
  }
}
```
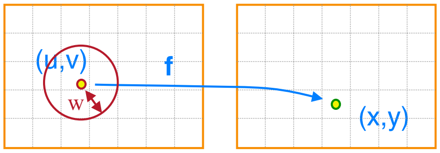



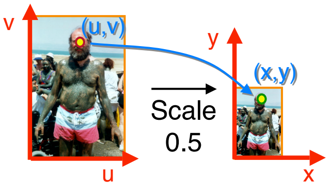
Source image

Destination image

## Example: Scale

- Scale (src, dst, sx, sy):

```
float w ≅ max(1.0/sx,1.0/sy);
for (int x = 0; x < xmax; x++) {
  for (int y = 0; y < ymax; y++) {
    float u = x / sx;
    float v = y / sy;
    dst(x,y) = resample_src(u,v,w);
  }
}
```

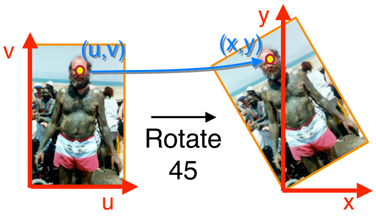


## Example: Rotate

- Rotate (src, dst, theta):

```
for (int x = 0; x < xmax; x++) {
  for (int y = 0; y < ymax; y++) {
    float u = x*cos(-Θ) - y*sin(-Θ);
    float u = x*sin(-Θ) + y*cos(-Θ);
    dst(x,y) = resample_src(u,v,w);
  }
}
```

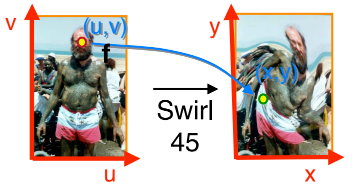
x = ucosΘ - vsinΘ
y = usinΘ + vcosΘ



## Example: Fun

- Swirl (src, dst, theta):

```
for (int x = 0; x < xmax; x++) {
  for (int y = 0; y < ymax; y++) {
    float u = rot(dist(x,xcenter)*theta);
    float v = rot(dist(y,ycenter)*theta);
    dst(x,y) = resample_src(u,v,w);
  }
}
```



## Image Processing

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## Overview: combining images

- Image morphing
  - Specifying correspondences
  - Warping
  - Blending
- Image compositing
  - Blue-screen mattes
  - Alpha channel
  - Porter-Duff compositing algebra

## Overview: combining images

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  - Specifying correspondences
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  - Porter-Duff compositing algebra

## Image Morphing

- Animate transition between two images

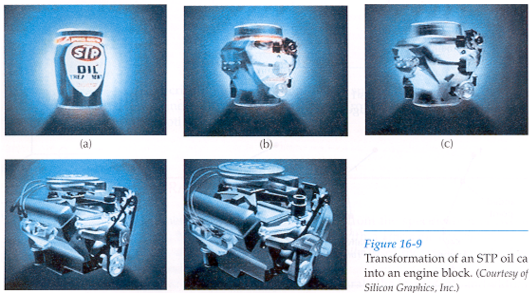


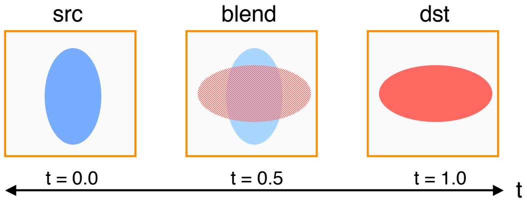
*Figure 16-9*
Transformation of an STP oil ca
into an engine block. (*Courtesy of*
*Silicon Graphics, Inc.*)

H&B Figure 16.9

## Cross-Dissolving

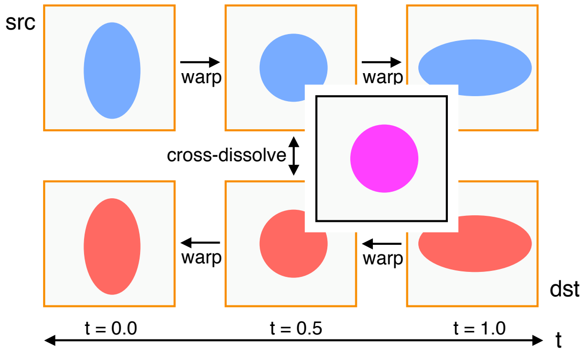
- Blend images with “over” operator
  - alpha of bottom image is 1.0
  - alpha of top image varies from 0.0 to 1.0

$$\text{blend}(i,j) = (1-t)\ \text{src}(i,j) + t\ \text{dst}(i,j) \quad (0 \le t \le 1)$$



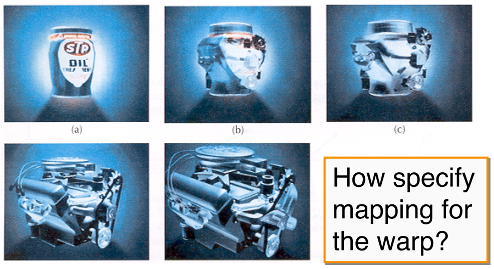
## Image Morphing

- Combines warping and cross-dissolving



## Image Morphing

- The warping step is the hard one
  - Aim to align features in images

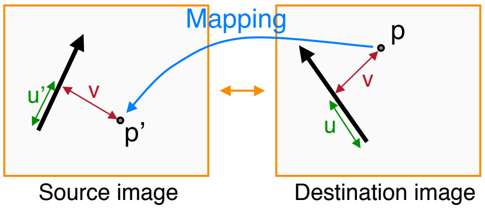


How specify mapping for the warp?

H&B Figure 16.9

## Feature-Based Warping

- Beier & Neeley use pairs of lines to specify warp
  - Given p in dst image, where is p' in source image?



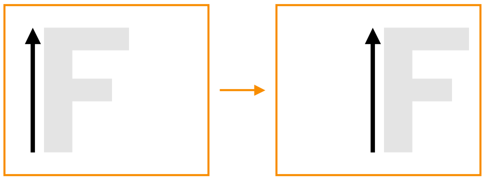
u is a fraction

v is a length (in pixels)

Beier & Neeley
SIGGRAPH 92

## Warping with One Line Pair

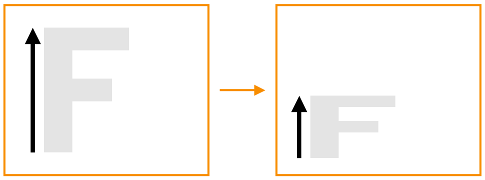
- What happens to the "F"?



Translation!

## Warping with One Line Pair

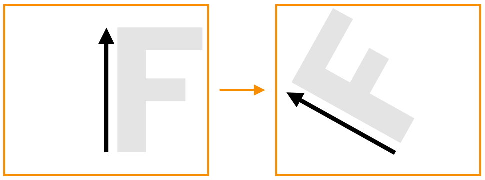
- What happens to the "F"?



Scale!

## Warping with One Line Pair

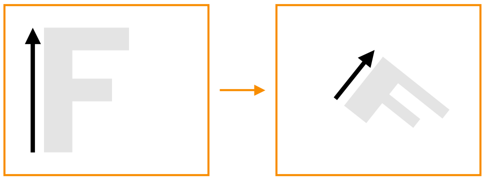
- What happens to the "F"?



Rotation!

## Warping with One Line Pair

- What happens to the “F”?

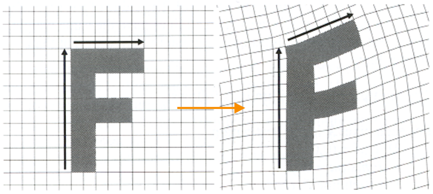


In general, similarity transformations

*What types of transformations can’t be specified?*

## Warping with Multiple Line Pairs

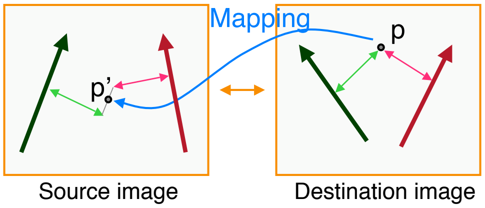
- Use weighted combination of points defined by each pair of corresponding lines



Beier & Neeley, Figure 4

## Warping with Multiple Line Pairs

- Use weighted combination of points defined by each pair of corresponding lines



p’ is a weighted average

## Weighting Effect of Each Line Pair

- To weight the contribution of each line pair, Beier & Neeley use:

$$\boxed{weight[i] = \left( \frac{length[i]^p}{a + dist[i]} \right)^b}$$

Where:

- *length[i]* is the length of L[i]
- *dist[i]* is the distance from X to L[i]
- *a, b, p* are constants that control the warp

## Warping Pseudocode

```
WarpImage(Image, L’[…], L[…])
begin
    foreach destination pixel p do
        psum = (0,0)
        wsum = 0
        foreach line L[i] in destination do
            p’[i] = p transformed by (L[i],L’[i])
            psum = psum + p’[i] * weight[i]
            wsum += weight[i]
        end
        p’ = psum / wsum
        Result(p) = Image(p’)
    end
end
```

## Morphing Pseudocode

```
GenerateAnimation(Image$_0$, L$_0$[…], Image$_1$, L$_1$[…])
begin
    foreach intermediate frame time t do
        for i = 1 to number of line pairs do
            L[i] = line t-th of the way from L$_0$ [i] to L$_1$ [i]
        end
        Warp$_0$ = WarpImage(Image$_0$, L$_0$, L)
        Warp$_1$ = WarpImage(Image$_1$, L$_1$, L)
        foreach pixel p in FinalImage do
            Result(p) = (1-t) Warp$_0$ + t Warp$_1$

    end
end
```

## Beier & Neeley Example

Image$_0$

Warp$_0$

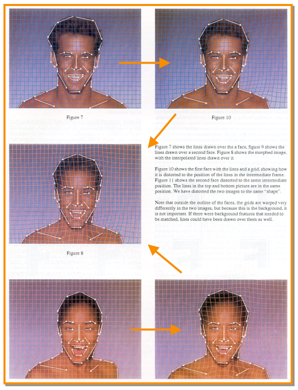


Figure 7

Figure 10

Figure 7 shows the lines drawn over the a face, figure 9 shows the lines drawn over a second face. Figure 8 shows the morphed image, with the interpolated lines drawn over it.

Figure 10 shows the first face with the lines and a grid, showing how it is distorted to the position of the lines in the intermediate frame. Figure 11 shows the second face distorted to the same intermediate position. The lines in the top and bottom picture are in the same position. We have distorted the two images to the same "shape".

Note that outside the outline of the faces, the grids are warped very differently in the two images, but because this is the background, it is not important. If there were background features that needed to be matched, lines could have been drawn over them as well.

Figure 8

Result

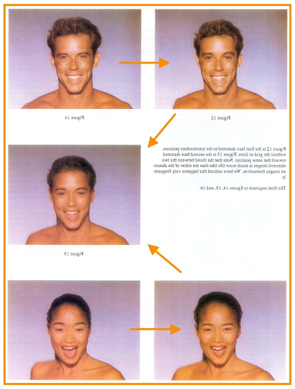
Image$_1$

Warp$_1$

## Beier & Neeley Example

Image$_0$

Warp$_0$



Result

Image$_1$

Warp$_1$

## Overview

- Image compositing
  - Blue-screen mattes
  - Alpha channel
  - Porter-Duff compositing algebra
- Image morphing
  - Specifying correspondences
  - Warping
  - Blending

## Even CG folks Can Win an Oscar

Smith Duff Catmull Porter

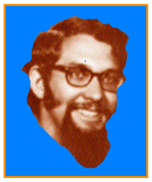
## Image Compositing

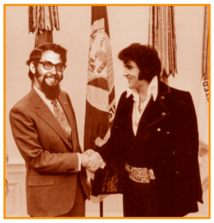
- Separate an image into "elements"
  - Render independently
  - Composite together
- Applications
  - Cel animation
  - Chroma-keying
  - Blue-screen matting

## Blue-Screen Matting

- Composite foreground and background images
  - Create background image
  - Create foreground image with blue background
  - Insert non-blue foreground pixels into background

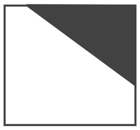
Problem: no partial coverage!



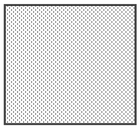


## Alpha Channel

- Encodes pixel coverage information
  - o $\alpha = 0$: no coverage (or transparent)
  - o $\alpha = 1$: full coverage (or opaque)
  - o $0 < \alpha < 1$: partial coverage (or semi-transparent)
- Example: $\alpha = 0.3$

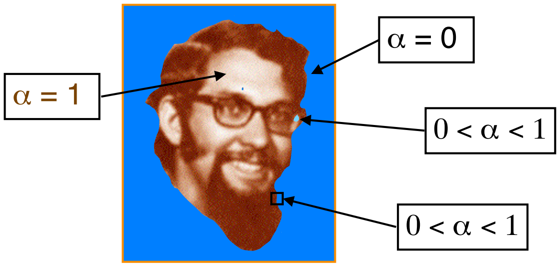

Partial Coverage

or


Semi-Transparent

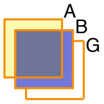
## Compositing with Alpha

Controls the linear interpolation of foreground and background pixels when elements are composited.



## Semi-Transparent Objects

- Suppose we put A over B over background G



  - o How much of B is blocked by A?

$\alpha_A$

  - o How much of B shows through A

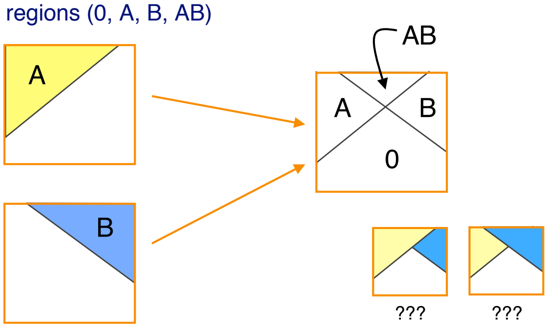
$(1-\alpha_A)$

  - o How much of G shows through both A and B?

$(1-\alpha_A)(1-\alpha_B)$

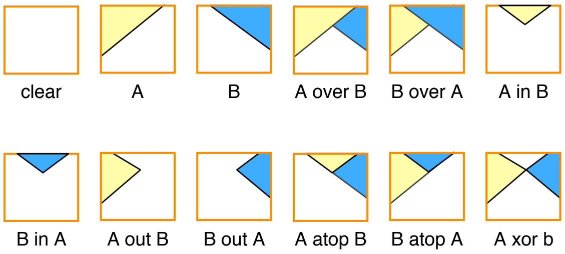
## Opaque Objects

- How do we combine 2 partially covered pixels?
  - o 3 possible colors (0, A, B)
  - o 4 regions (0, A, B, AB)



## Composition Algebra

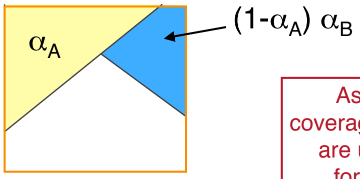
- 12 reasonable combinations



Porter & Duff `84

## Example: C = A Over B

- Consider the areas covered:
  - o $C = \alpha_A A + (1-\alpha_A)\,\alpha_B B$
  - o $\alpha = \alpha_A + (1-\alpha_A)\,\alpha_B$

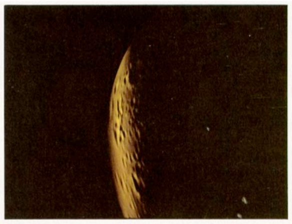


A over B

Assumption: coverages of A and B are uncorrelated for each pixel

## Image Composition Example

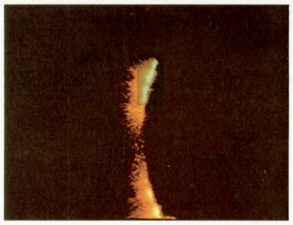
Stars



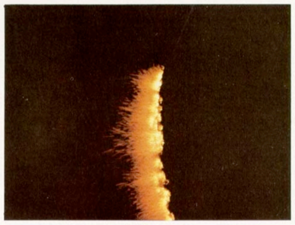
Planet

[Porter&Duff *Computer Graphics* 18:3 1984]

## Image Composition Example



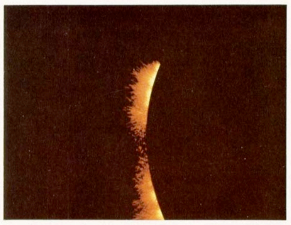
BFire



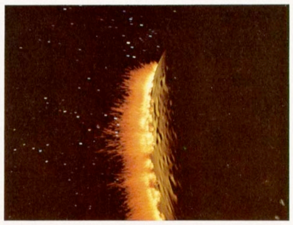
FFire

[Porter&Duff *Computer Graphics* 18:3 1984]

## Image Composition Example



BFire **out** Planet



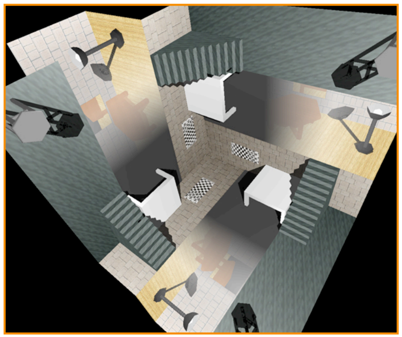
Composite

[Porter&Duff *Computer Graphics* 18:3 1984]

## Image Processing

- Quantization
  - Uniform Quantization
  - Random dither
  - Ordered dither
  - Floyd-Steinberg dither
- Pixel operations
  - Add random noise
  - Add luminance
  - Add contrast
  - Add saturation
- Filtering
  - Blur
  - Detect edges
- Warping
  - Scale
  - Rotate
  - Warp
- Combining
  - Composite
  - Morph

## Next Time: 3D Rendering



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