Image Warping, Compositing & Morphing

Adam Finkelstein
Princeton University
COS 426, Spring 2003

Image Processing

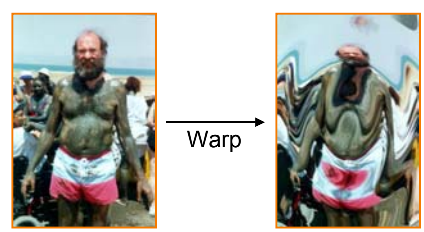
- Quantization
  - Uniform Quantization
  - Random dither
  - Ordered dither
  - Floyd-Steinberg dither
- Pixel operations
  - Add random noise
  - Add luminance
  - Add contrast
  - Add saturation
- Filtering
  - Blur
  - Detect edges
- Warping
  - Scale
  - Rotate
  - Warp
- Combining
  - Composite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

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

Image Warping

- Move pixels of image
  - Mapping
  - Resampling



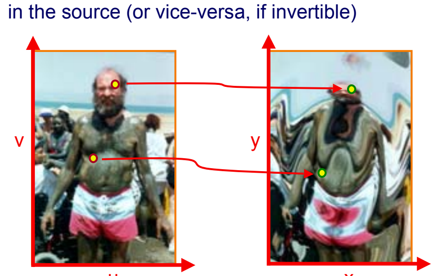
Source image   Destination image

Overview

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

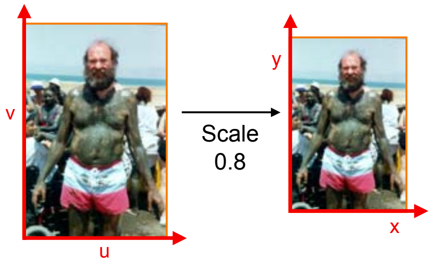
Mapping

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



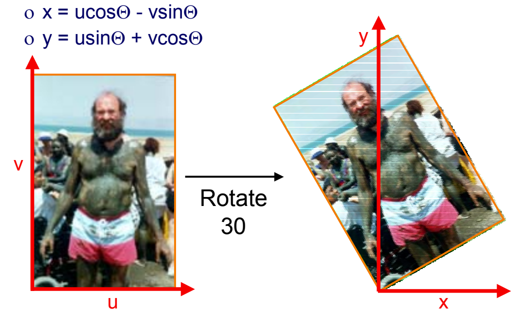
Example Mappings

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



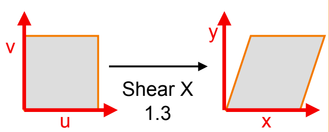
Example Mappings

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

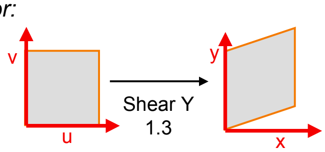


Example Mappings

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



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



Other Mappings

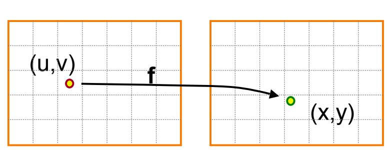
- Any function of u and v:
  - x = f_x(u,v)
  - y = f_y(u,v)

Fish-eye "Swirl" "Rain"

Image Warping Implementation I

- Forward mapping:

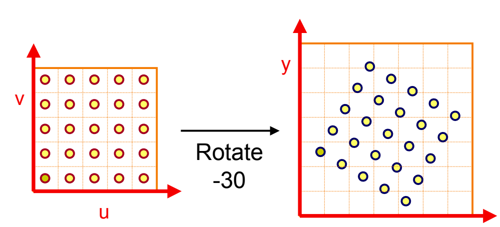
```
for (int u = 0; u < umax; u++) {
  for (int v = 0; v < vmax; v++) {
    float x = fx(u,v);
    float y = fy(u,v);
    dst(x,y) = src(u,v);
  }
}
```



Source image Destination image

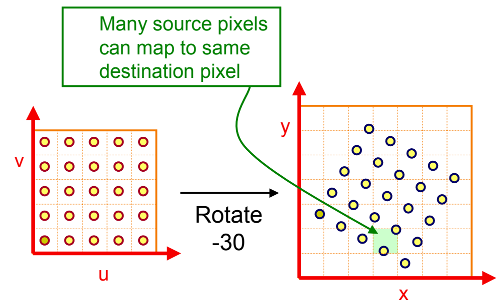
Forward Mapping

- Iterate over source image



Forward Mapping - NOT

- Iterate over source image



Forward Mapping - NOT

- Iterate over source image

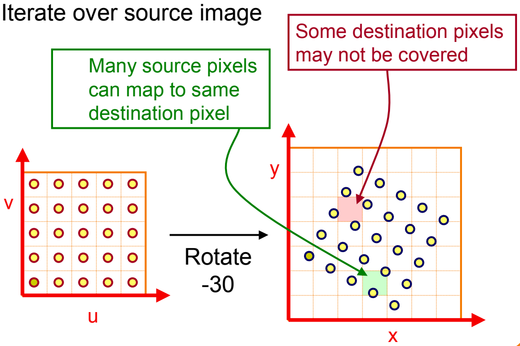
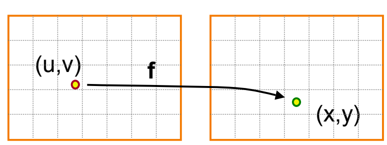


Image Warping Implementation II

- Reverse mapping:

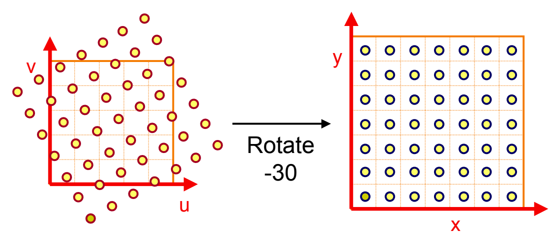
```
for (int x = 0; x < xmax; x++) {
  for (int y = 0; y < ymax; y++) {
    float u = fx^-1(x,y);
    float v = fy^-1(x,y);
    dst(x,y) = src(u,v);
  }
}
```



Source image Destination image

Reverse Mapping

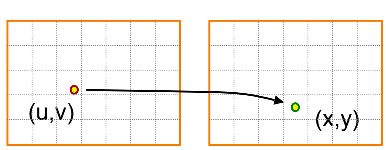
- Iterate over destination image
  - Must resample source
  - May oversample, but much simpler!



Resampling

- Evaluate source image at arbitrary (u,v)

(u,v) does not usually have integer coordinates



Source image Destination image

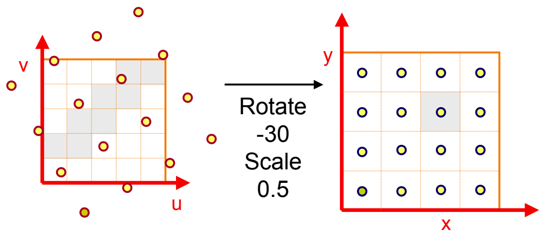
Overview

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

Point Sampling

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

This method is simple, but it causes aliasing



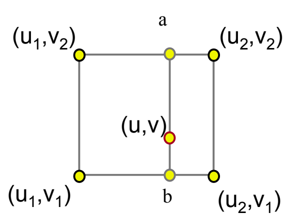
Triangle Filtering

- Convolve with triangle filter

Figure 2.4 Wolberg

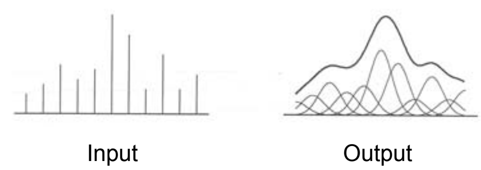
Triangle Filtering

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



Gaussian Filtering

- Convolve with Gaussian filter

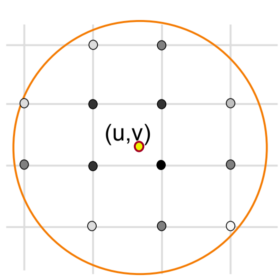


Width of Gaussian kernel affects bluriness

Figure 2.4 Wolberg

Gaussian Filtering

- Compute weighted sum of pixel neighborhood:
  - o Weights are normalized values of Gaussian function



Filtering Methods Comparison

- Trade-offs
  - o Aliasing versus blurring
  - o Computation speed

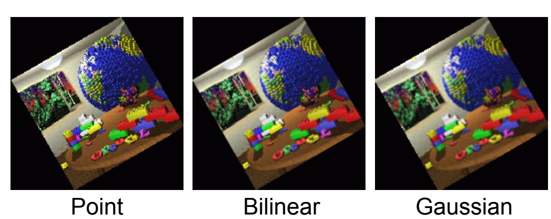
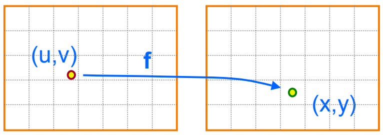


Image Warping Implementation

- 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) = resample_src(u,v,w);
  }
}
```

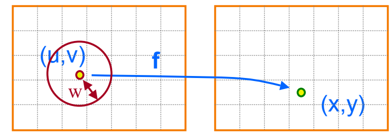


Source image   Destination image

Image Warping Implementation

- 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) = resample_src(u,v,w);
  }
}
```

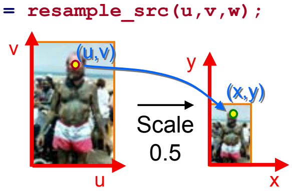


Source image   Destination image

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);
  }
}
```



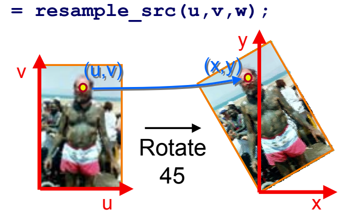
Example: Rotate

- 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);
  }
}
```

$x = u\cos\Theta - v\sin\Theta$

$y = u\sin\Theta + v\cos\Theta$



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);
  }
}
```

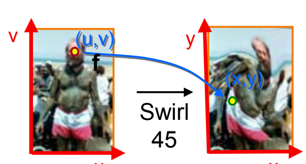


Image Processing

- 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

Overview: combining images

- 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

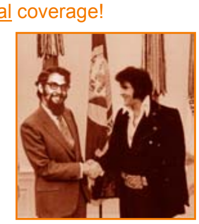
- Separate an image into "elements"
  - Render independently
  - Composite together
- Applications
  - Cel animation
  - Chroma-keying
  - Blue-screen matting

Dobkin meets the King

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

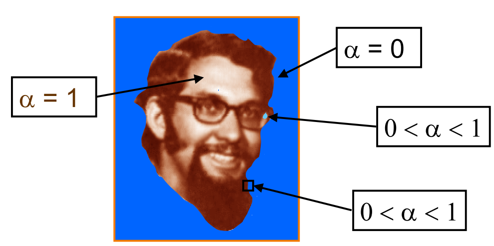
Partial Coverage

or

Semi-Transparent

Compositing with Alpha

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



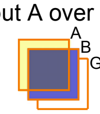
Pixels with Alpha

- Alpha channel convention:
  - o (r, g, b, α) represents a pixel that is α covered by the color C = (r/α, g/α, b/α)
    - » Color comonents are premultiplied by α
    - » Can display (r,g,b) values directly
    - » Closure in composition algebra
- What is the meaning of the following?
  - o (0, 1, 0, 1) = ?
  - o (0, 1/2, 0, 1) Full green, full coverage
  - o (0, 1/2, 0, 1/2) Half green, full coverage
  - o (0, 1/2, 0, 0) = ? Full green, half coverage

No coverage

Semi-Transparent Objects

- Suppose we put A over B over background G



  - o How much of B is blocked by A?

α_A

  - o How much of B shows through A

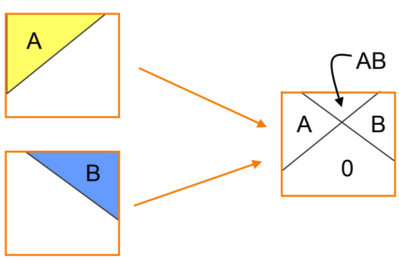
$(1-\alpha_A)$

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

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

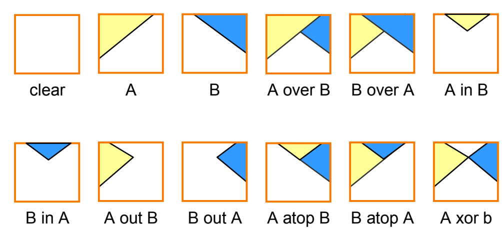
Opaque Objects

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



Composition Algebra

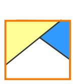
- 12 reasonable combinations



Porter & Duff `84

Example: C = A Over B

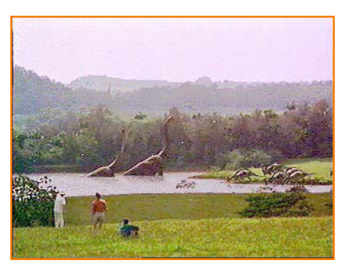
- For colors that are not premultiplied:
  - o $C = \alpha_A A + (1-\alpha_A)\,\alpha_B B$
  - o $\alpha = \alpha_A + (1-\alpha_A)\,\alpha_B$
- For colors that are premultiplied:
  - o $C' = A' + (1-\alpha_A)\,B'$
  - o $\alpha = \alpha_A + (1-\alpha_A)\,\alpha_B$



A over B

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

Image Composition Example



Jurassic Park

Overview

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

Image Morphing

- Animate transition between two images

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

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

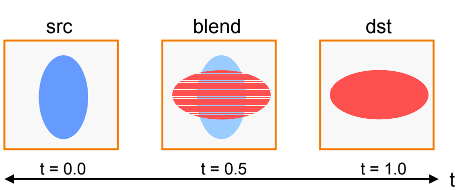


Image Morphing

- Combines warping and cross-dissolving

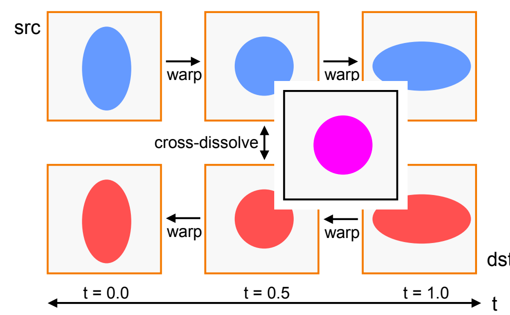
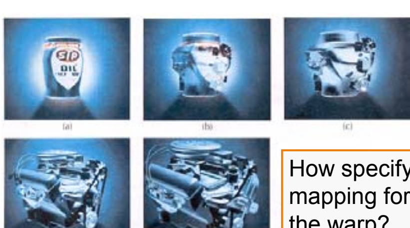


Image Morphing

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

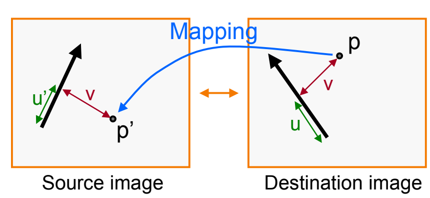


How specify mapping for the warp?

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?



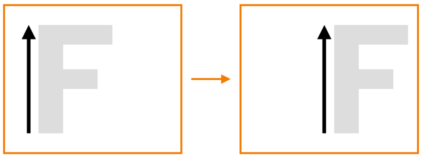
u is a fraction

v is a length (in pixels)

Beier & Neeley SIGGRAPH 92

Warping with One Line Pair

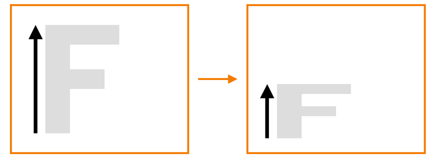
- What happens to the "F"?



Translation!

Warping with One Line Pair

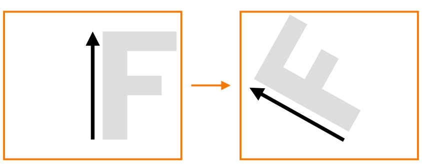
- What happens to the "F"?



Scale!

Warping with One Line Pair

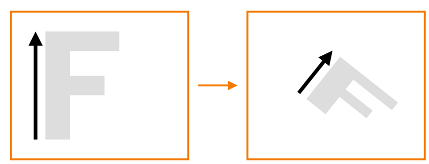
- What happens to the "F"?



Rotation!

Warping with One Line Pair

- What happens to the "F"?

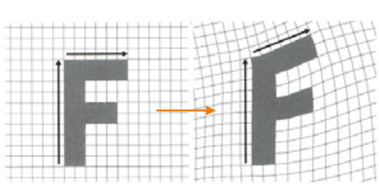


In general, similarity transformations

What types of transformations can't be specified?

Warping with Multiple Line Pairs

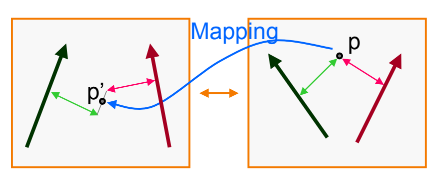
- Use weighted combination of points defined by each pair of corresponding lines



Beier & Neeley, Figure 4

Warping with Multiple Line Pairs

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



Source image   Destination image

p' is a weighted average

Weighting Effect of Each Line Pair

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

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

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

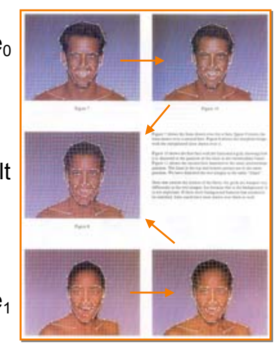
```
WarpImage(Image, L'[…], L[…])
begin
    foreach destination pixel p do
        psum = (0,0)
        wsum = 0
        foreach line L[i] in destination do
            p'[i] = p transformed by (L[i],L'[i])
            psum = psum + p'[i] * weight[i]
            wsum += weight[i]
        end
       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

Morphing Pseudocode

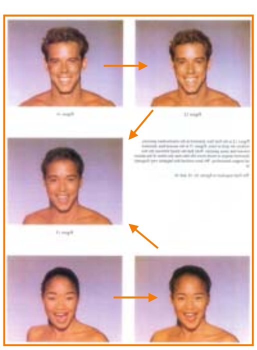
```
GenerateAnimation(Image_0, L_0[…], Image_1, L_1[…])
begin
    foreach intermediate frame time t do
        for i = 1 to number of line pairs do
            L[i] = line t-th of the way from L_0 [i] to L_1 [i]
        end
        Warp_0 = WarpImage(Image_0, L_0, L)
        Warp_1 = WarpImage(Image_1, L_1, L)
        foreach pixel p in FinalImage do
            Result(p) = (1-t) Warp_0 + t Warp_1

    end
end
```

Beier & Neeley Example



Beier & Neeley Example



CS426 Examples

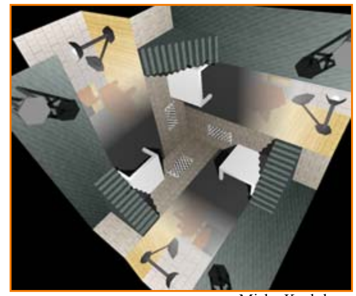
CS426 Class, Fall98

Robert Osada, Fall00

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



Misha Kazhdan,
CS426, Fall99