Image Compositing and Morphing

COS 426, Fall 2022

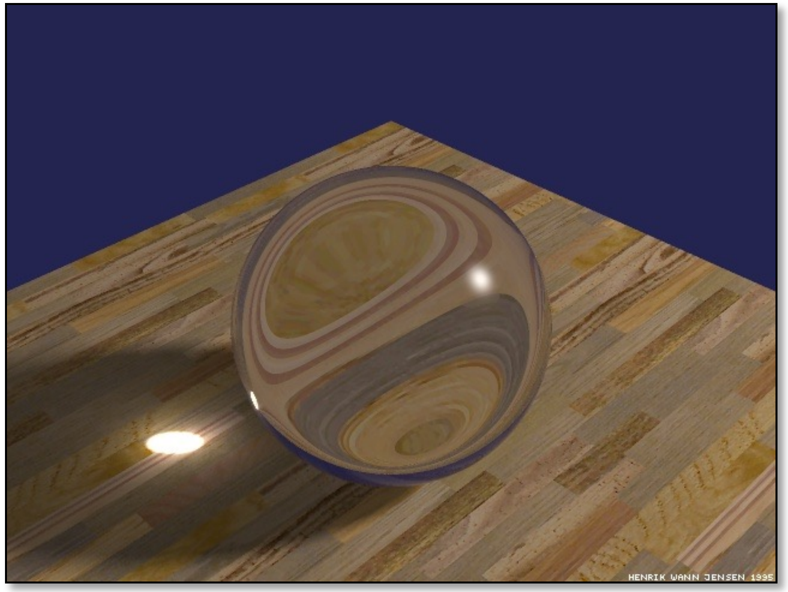
PRINCETON UNIVERSITY

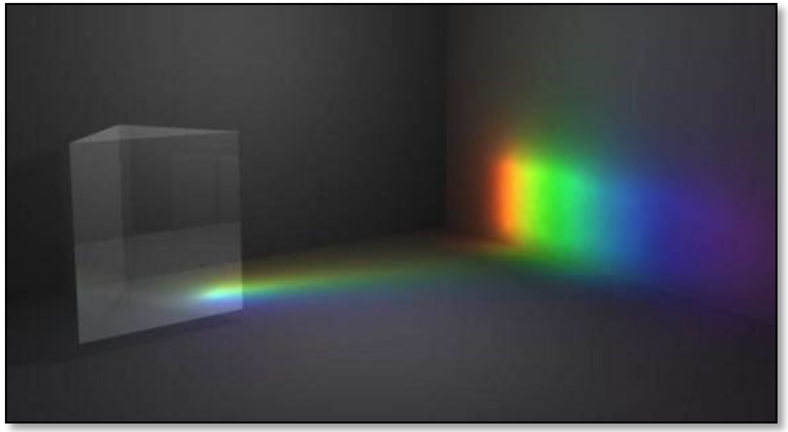
Digital Image Processing

- Changing pixel values
  - Linear: scale, offset, etc.
  - Nonlinear: gamma, saturation, etc.
  - Histogram equalization
- Filtering over neighborhoods
  - Blur & sharpen
  - Detect edges
  - Median
  - Bilateral filter
- Moving image locations
  - Scale
  - Rotate
  - Warp
- Combining images
  - Composite
  - Morph
- Quantization
- Spatial / intensity tradeoff
  - Dithering

Types of Transparency

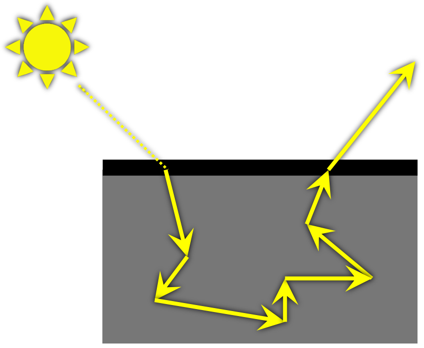
- Refraction
  - Light is bent as it goes through an object
  - Can focus light: caustics
  - Can be color-dependent: dispersion





Types of Transparency

- Refraction
- Subsurface scattering
  - Light leaves at different position than it entered
  - Translucent materials



Types of Transparency

- Refraction
- Subsurface scattering
- Today: compositing
  - Nonrefractive (partial) transparency
  - Separate image into layers with known order
  - ***Pixelwise*** combination: each pixel in each layer can be transparent, opaque, or somewhere in between

Smith & Blinn`84

Example

Jurassic Park (1993)

Image Composition

- Issues:
  - Segmenting image into regions
  - Blending into single image seamlessly

Image Composition

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  - Segmenting image into regions
  - Blending into single image seamlessly

Image Matting

- Chroma keying (blue- or green-screen)
  - Photograph object in front of screen with known color

Rosco Spectrum

Image Matting

- Specify segmentation by hand
  - Purely manual: draw matte every frame
  - Semi-automatic: graph-cut (draw a few strokes)
    Implemented using min-cut algorithm: separate regions along minimal cuts (where edges measure differences between adjacent pixels)

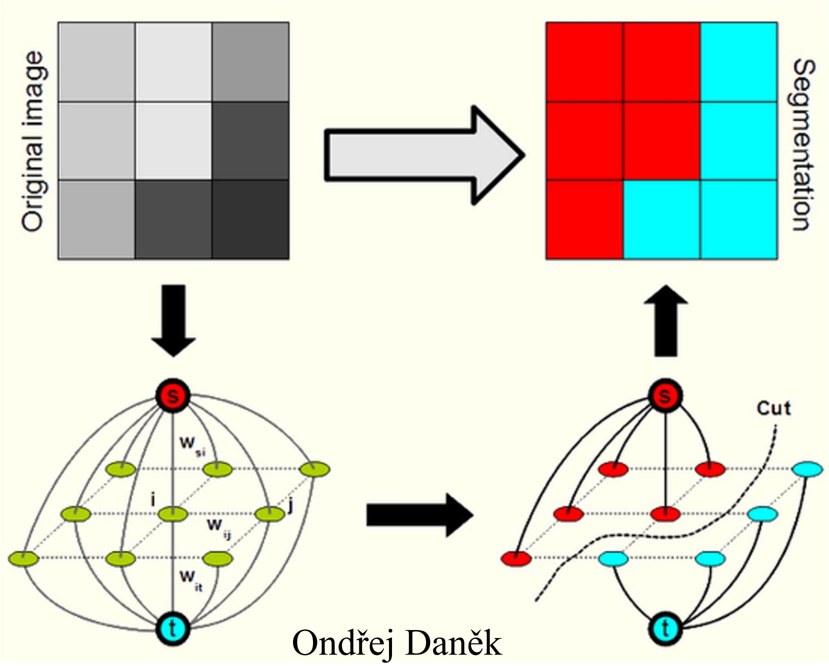
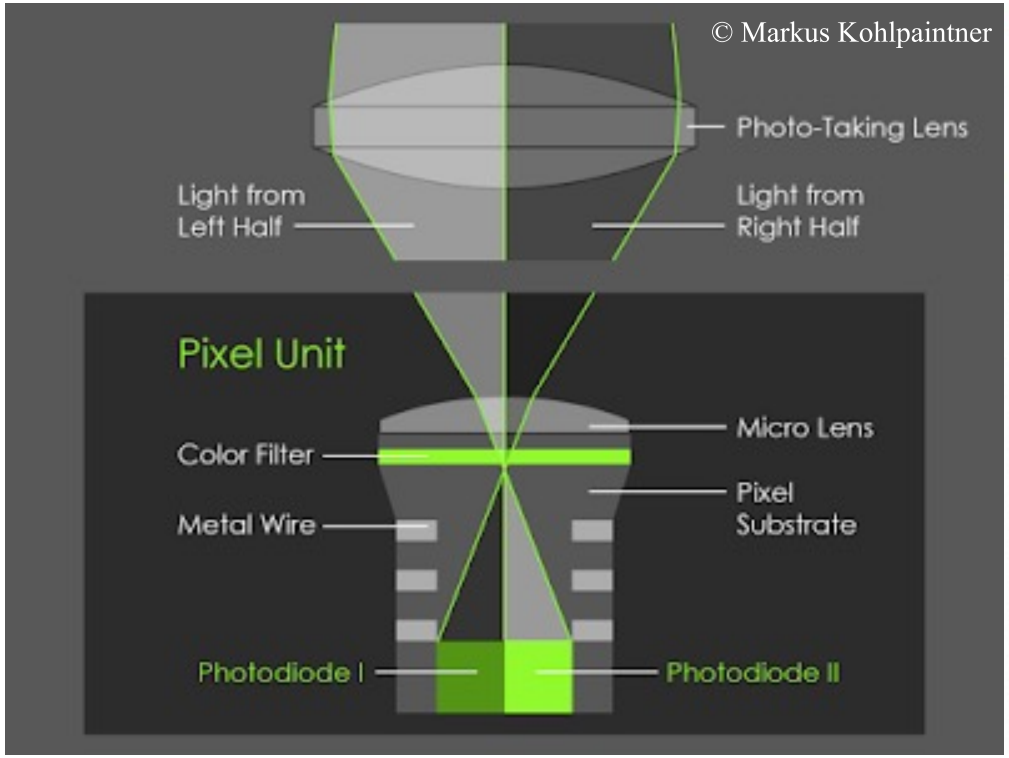
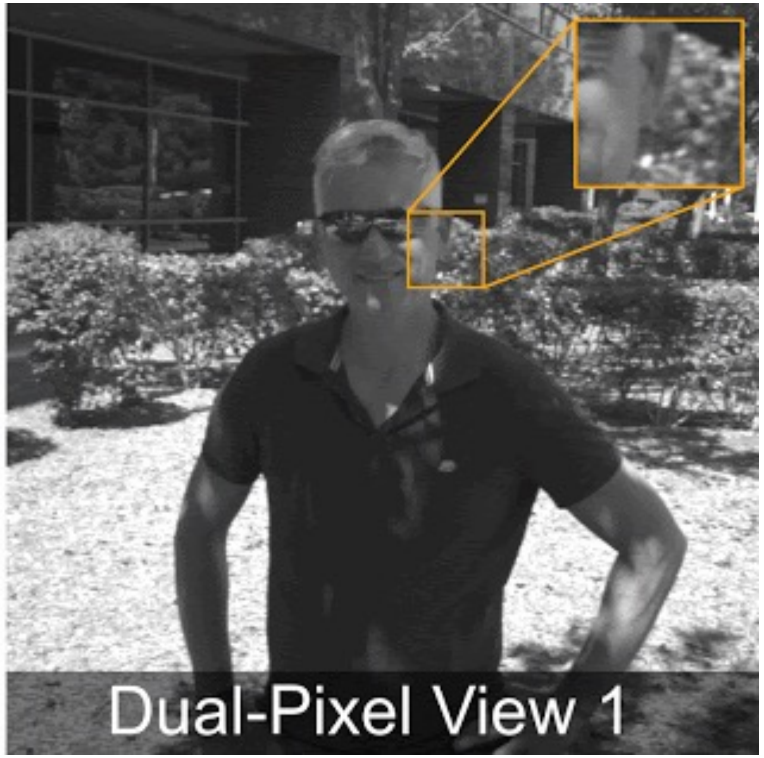


Image Matting

- Portrait mode in Google Pixel Phone

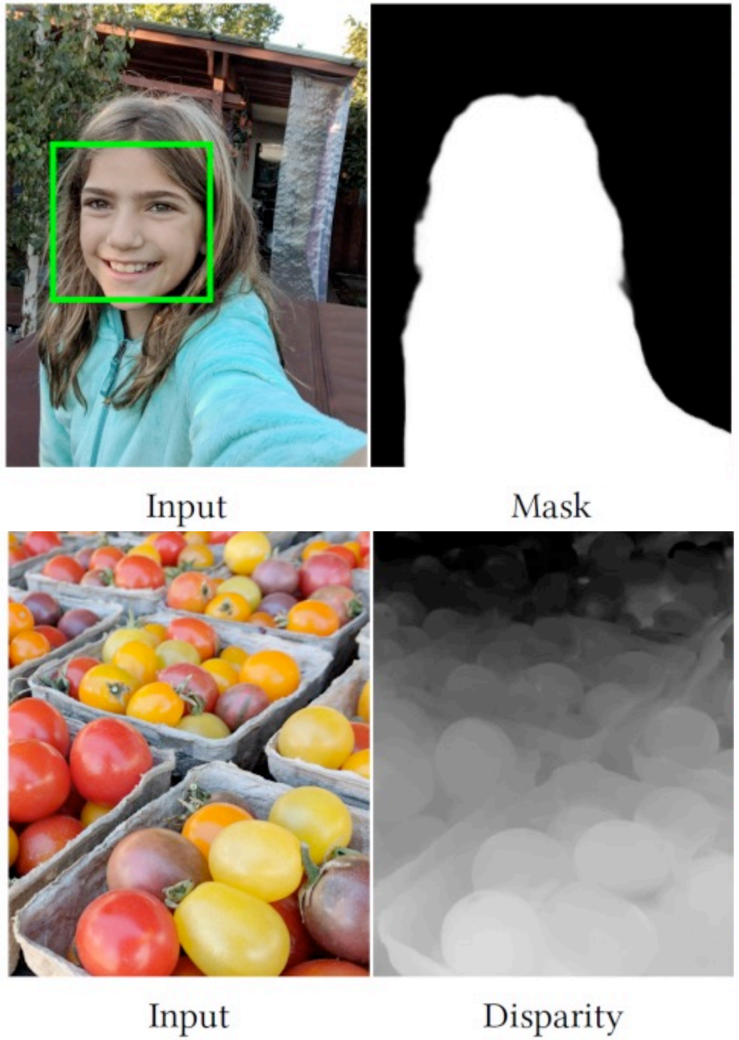




Wadhwa et al., 2018

Image Matting

- Portrait mode blur in Google Pixel Phones



Wadhwa et al., 2018

Image Matting

- Portrait mode blur in Google Pixel Phones

Input Mask Output

Input Disparity Output

Wadhwa et al., 2018

Image Composition

- Issues:
  - Segmenting image into regions
  - Blending into single image seamlessly

Image Blending

- Ingredients
  - Background image
  - Foreground image with blue background
- Method
  - Non-blue foreground pixels overwrite background

Blending with Alpha Channel

- Per-pixel “alpha” channel
  - Controls the linear interpolation between foreground and background pixels when elements are composited

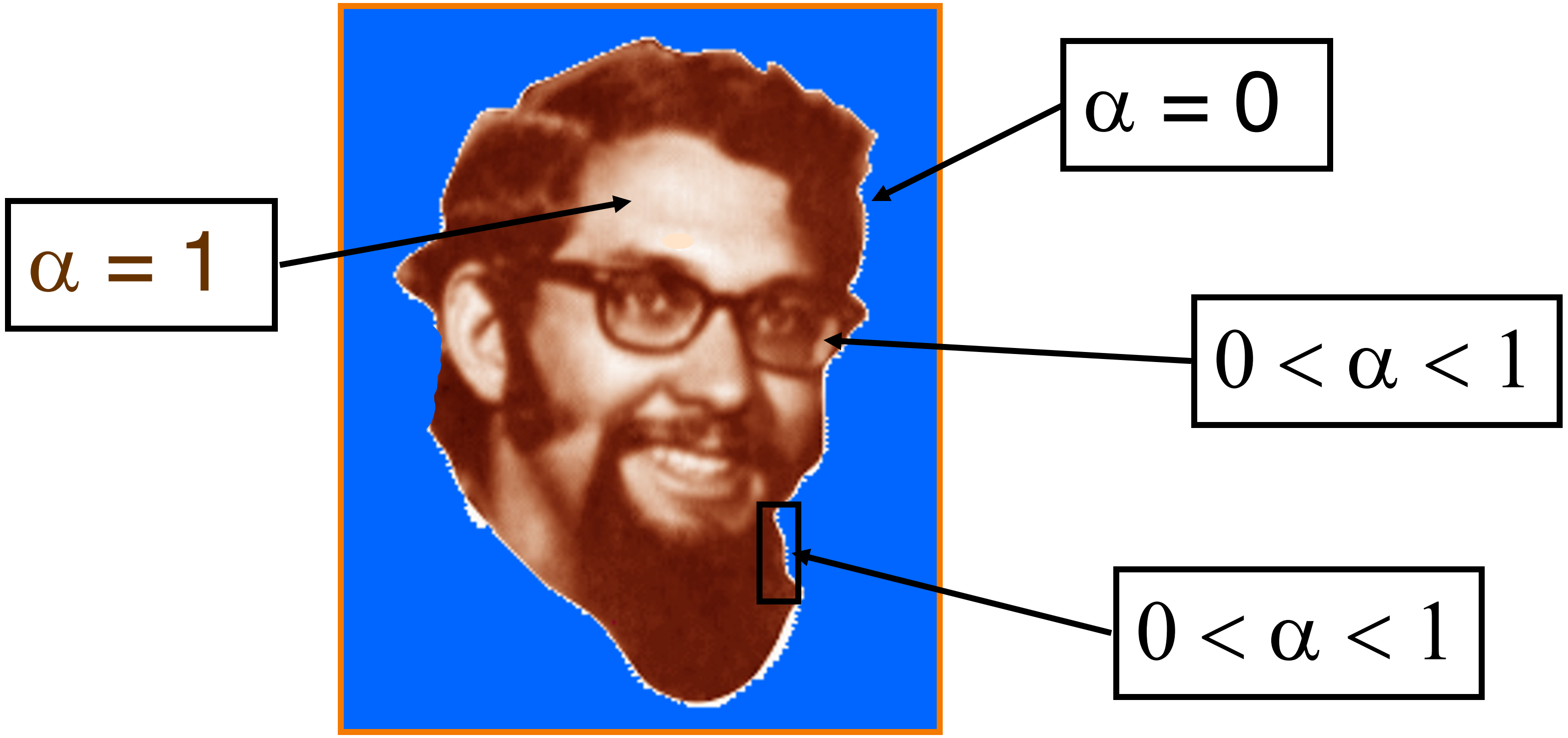
[R,G,B]

↓

[R,G,B,α]

Blending with Alpha Channel

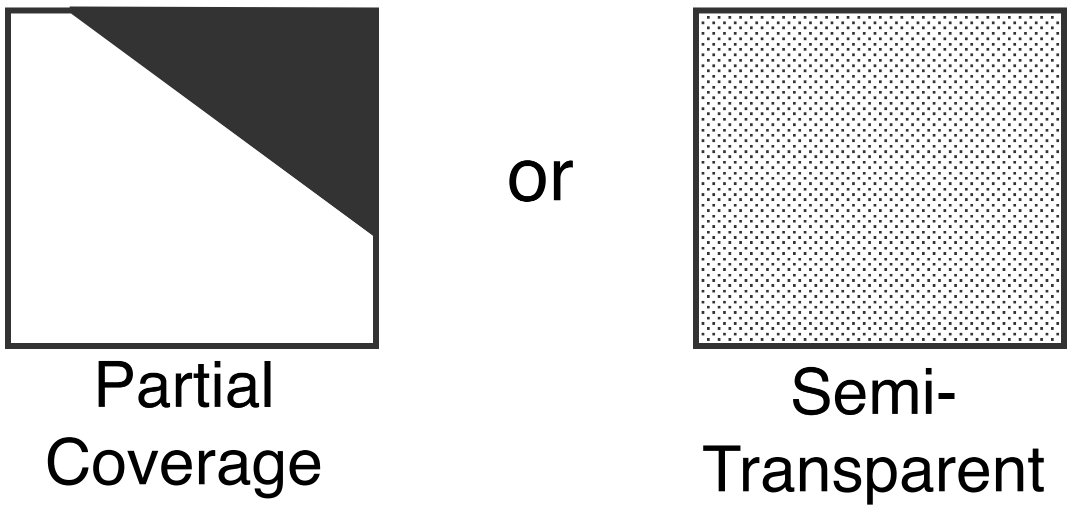
- Per-pixel “alpha” channel
  - Controls the linear interpolation between foreground and background pixels when elements are composited



Alpha Channel

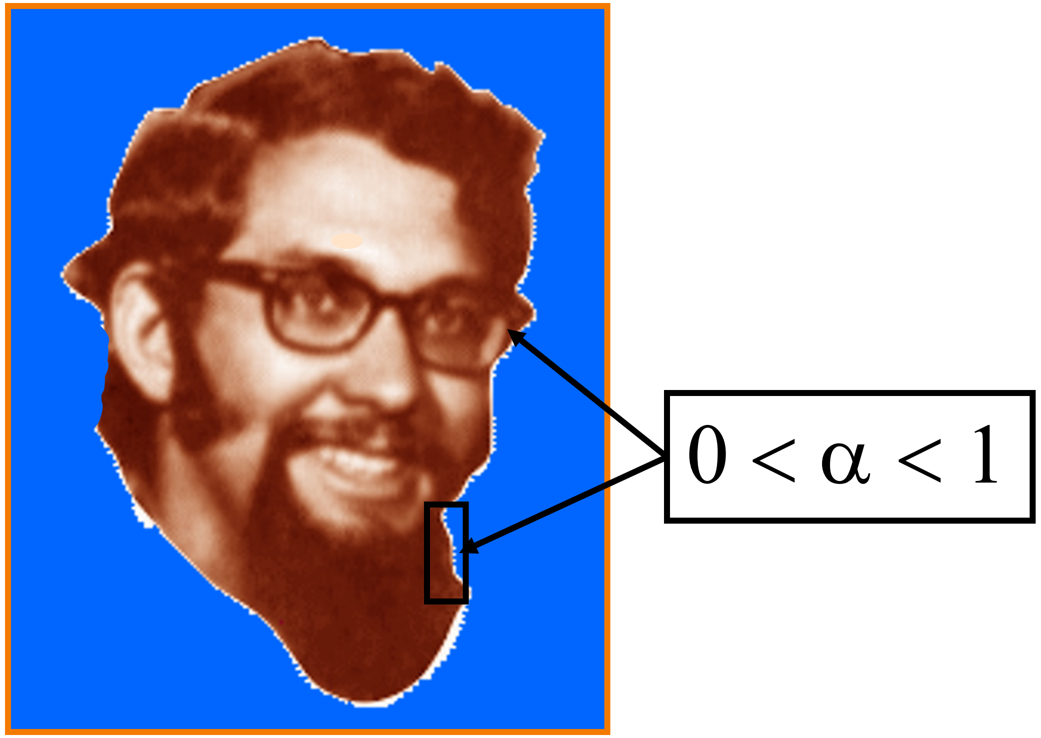
- Encodes pixel coverage information
  - $\alpha = 0$: no coverage (or transparent)
  - $\alpha = 1$: full coverage (or opaque)
  - $0 < \alpha < 1$: partial coverage (or semi-transparent)

- Example: $\alpha = 0.3$



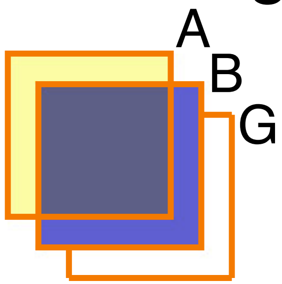
Alpha Blending: "Over" Operator

- If background B is opaque:
  - C = A over B
  - $C = \alpha_A A + (1-\alpha_A)B$
- If background B has its own α:
  - C = A over B
  - $C = \alpha_A A + (1-\alpha_A)\alpha_B B$
  - $\alpha_C = \alpha_A + (1-\alpha_A)\alpha_B$



Compositing Algebra

- Suppose we put A over B over background G

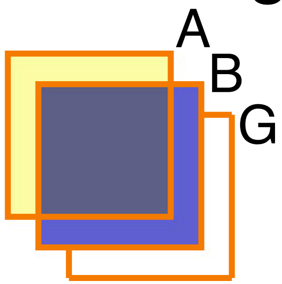


  - How much of B is blocked by A?

$$\alpha_A$$

Compositing Algebra

- Suppose we put A over B over background G



  - How much of B is blocked by A?

$$\alpha_A$$

  - How much of B shows through A?

$$(1-\alpha_A)$$

Compositing Algebra

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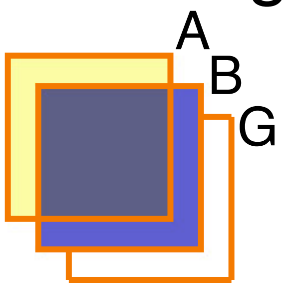


  - How much of B is blocked by A?

$$\alpha_A$$

  - How much of B shows through A?

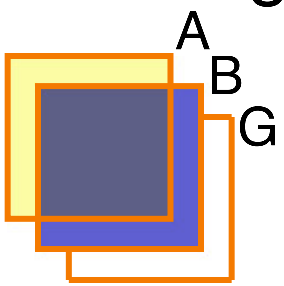
$$(1-\alpha_A)$$

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

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

Compositing Algebra

- Suppose we put A over B over background G



  - Final result?

$$\alpha_A A + (1-\alpha_A)\alpha_B B + (1-\alpha_A)(1-\alpha_B)G$$

$$= \alpha_A A + (1-\alpha_A)\left[\alpha_B B + (1-\alpha_B)G\right]$$

$$= A \text{ over } [B \text{ over } G]$$

Must perform “over” back-to-front: right associative!

Other Compositing Operations

Composition algebra – 12 combinations

$C' = F_A \, \alpha_A \, A + F_B \, \alpha_B \, B$

Operation	F_A	F_B
Clear	0	0
A	1	0
B	0	1

Porter & Duff `84

Other Compositing Operations

Composition algebra – 12 combinations

$C' = F_A \alpha_A A + F_B \alpha_B B$

Operation	F_A	F_B
Clear	0	0
A	1	0
B	0	1
A over B	1	1- α_A
B over A	1- α_B	1

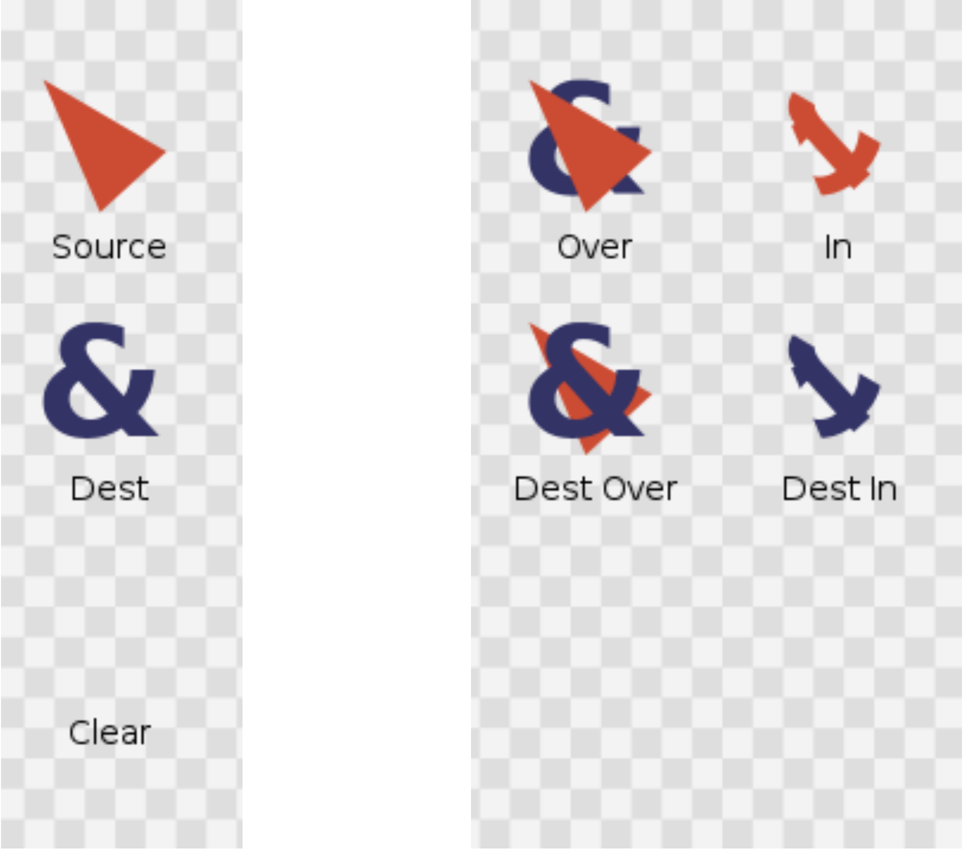
Porter & Duff `84

Other Compositing Operations

Composition algebra – 12 combinations

$C' = F_A \alpha_A A + F_B \alpha_B B$

Operation	F_A	F_B
Clear	0	0
A	1	0
B	0	1
A over B	1	$1-\alpha_A$
B over A	$1-\alpha_B$	1
A in B	α_B	0
B in A	0	α_A



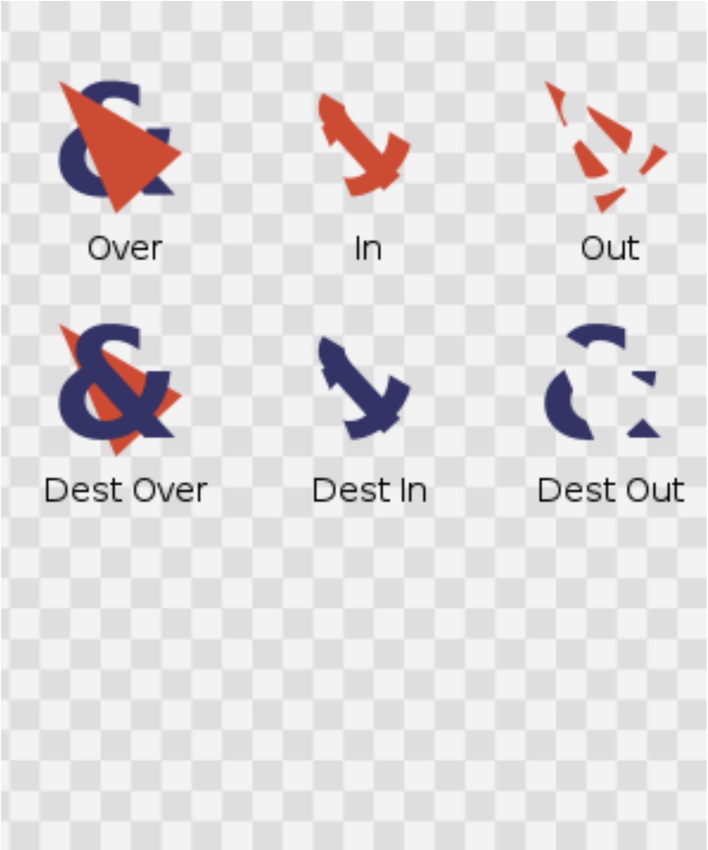
Porter & Duff `84

Other Compositing Operations

Composition algebra – 12 combinations

$$C' = F_A \, \alpha_A \, A + F_B \, \alpha_B \, B$$

Operation	F_A	F_B
Clear	0	0
A	1	0
B	0	1
A over B	1	$1-\alpha_A$
B over A	$1-\alpha_B$	1
A in B	α_B	0
B in A	0	α_A
A out B	$1-\alpha_B$	0
B out A	0	$1-\alpha_A$



Porter & Duff `84

Other Compositing Operations

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$C' = F_A \alpha_A A + F_B \alpha_B B$

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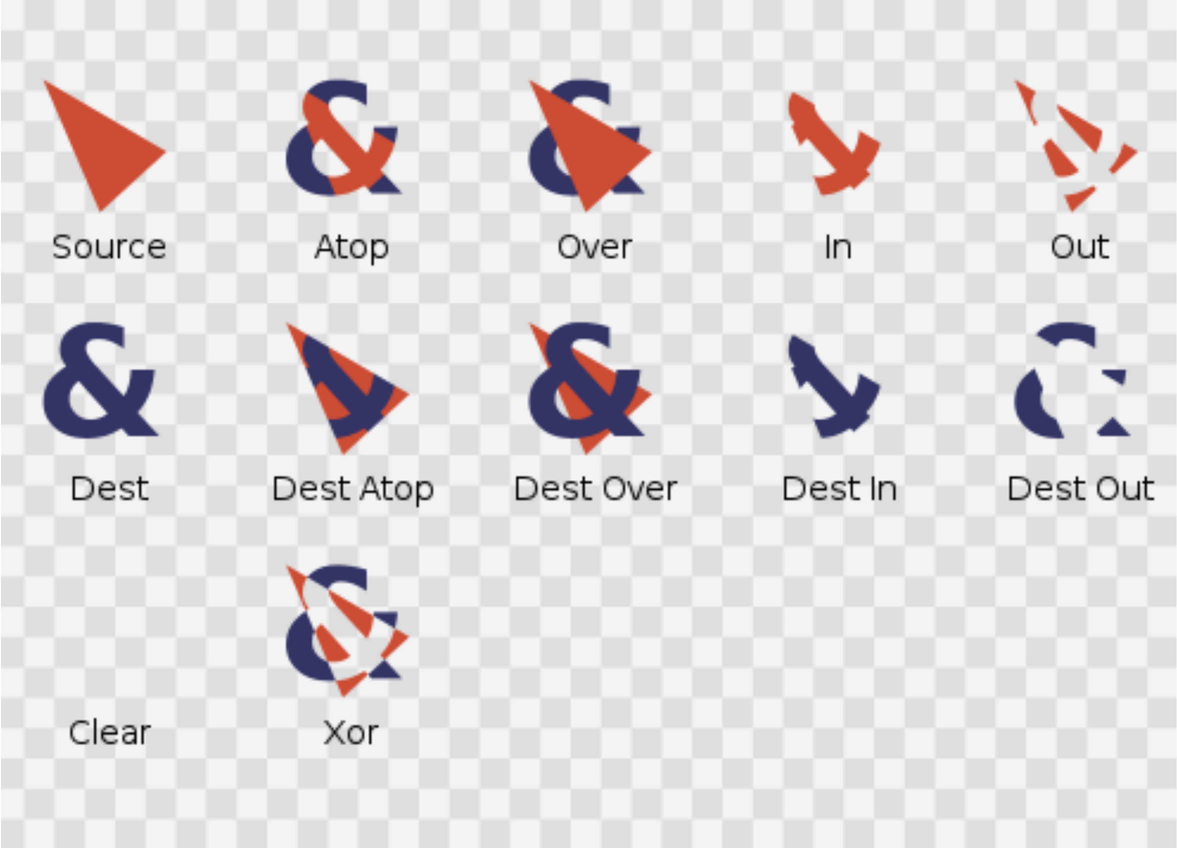
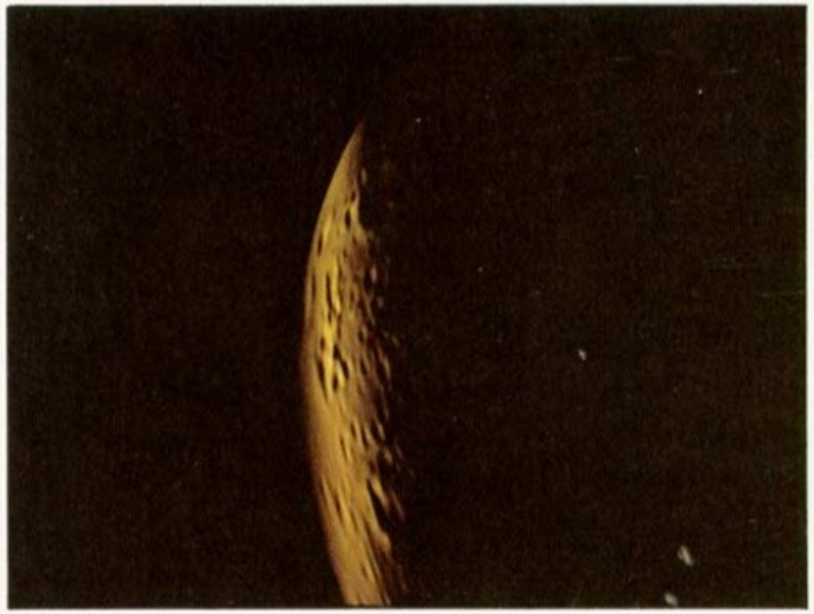
Clear	0	0
A	1	0
B	0	1
A over B	1	$1-\alpha_A$
B over A	$1-\alpha_B$	1
A in B	α_B	0
B in A	0	α_A
A out B	$1-\alpha_B$	0
B out A	0	$1-\alpha_A$
A atop B	α_B	$1-\alpha_A$
B atop A	$1-\alpha_B$	α_A
A xor B	$1-\alpha_B$	$1-\alpha_A$



Porter & Duff `84

Image Composition Example

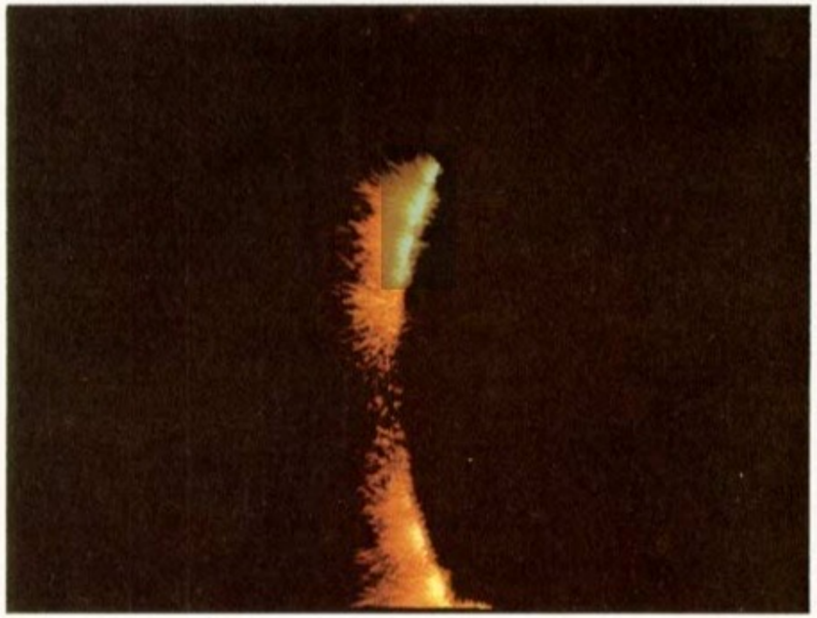
Stars



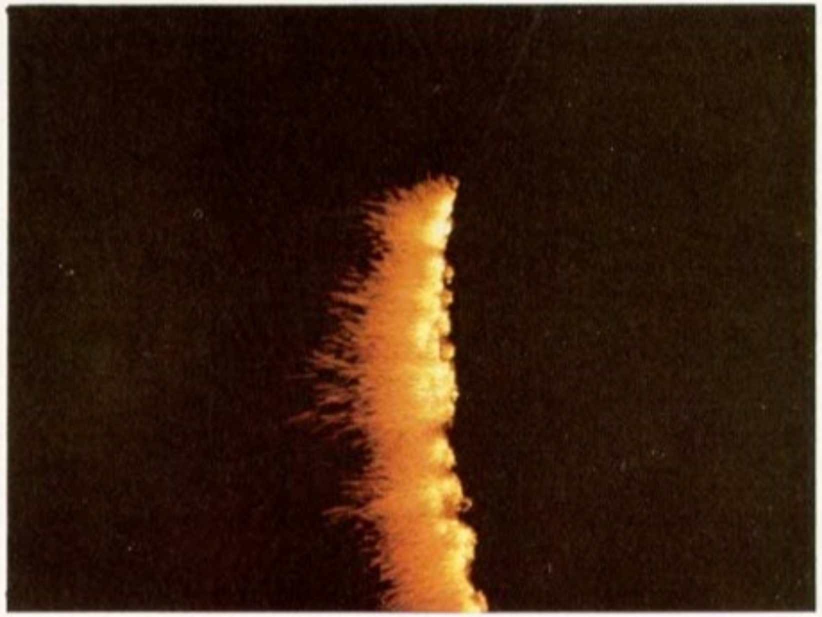
Planet

Porter & Duff `84

Image Composition Example



BFire

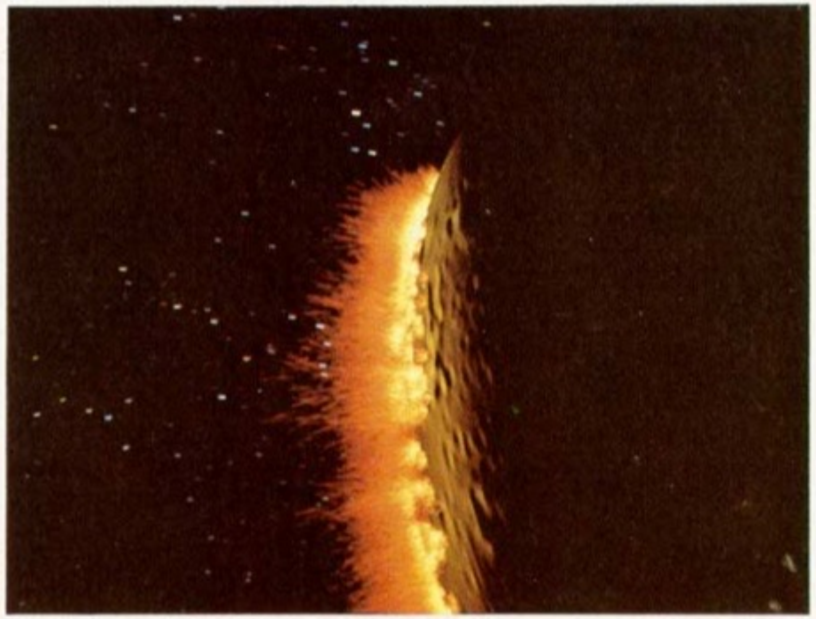


FFire

Porter & Duff `84

Image Composition Example

BFire **out** Planet



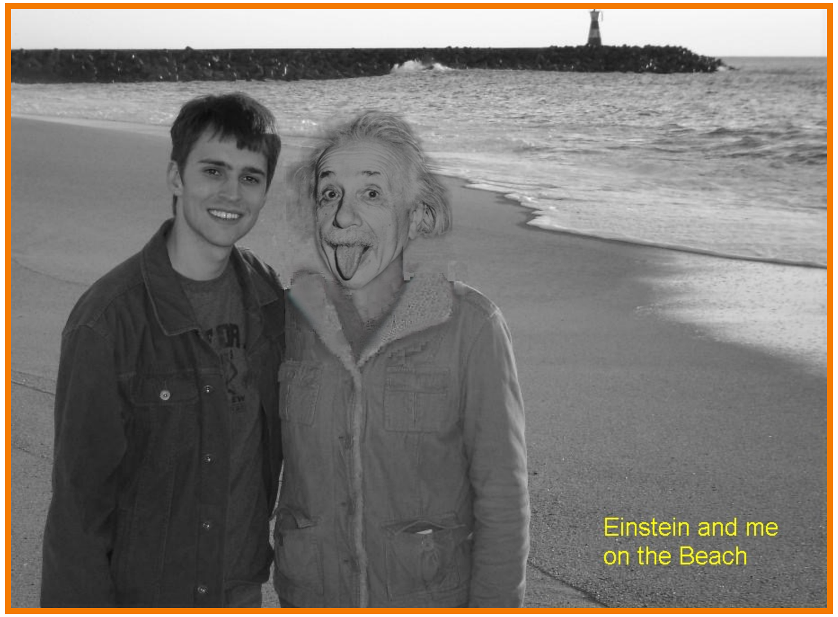
Composite

Porter & Duff `84

Image Composition Example

“Genesis” sequence from Star Trek II: The Wrath of Khan

COS426 Examples



Darin Sleiter

Kenrick Kin

Poisson Image Blending

Beyond simple compositing

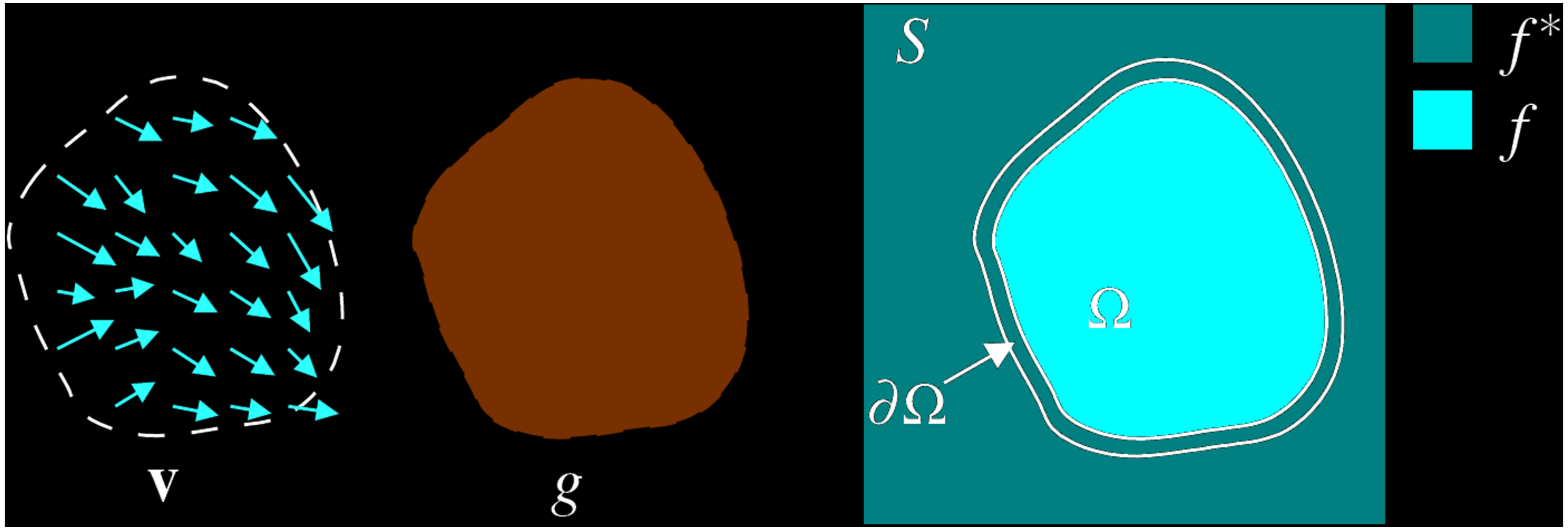
- Solve for image samples that follow gradients of source subject to boundary conditions imposed by dest

sources destinations cloning seamless cloning

Poisson Image Blending

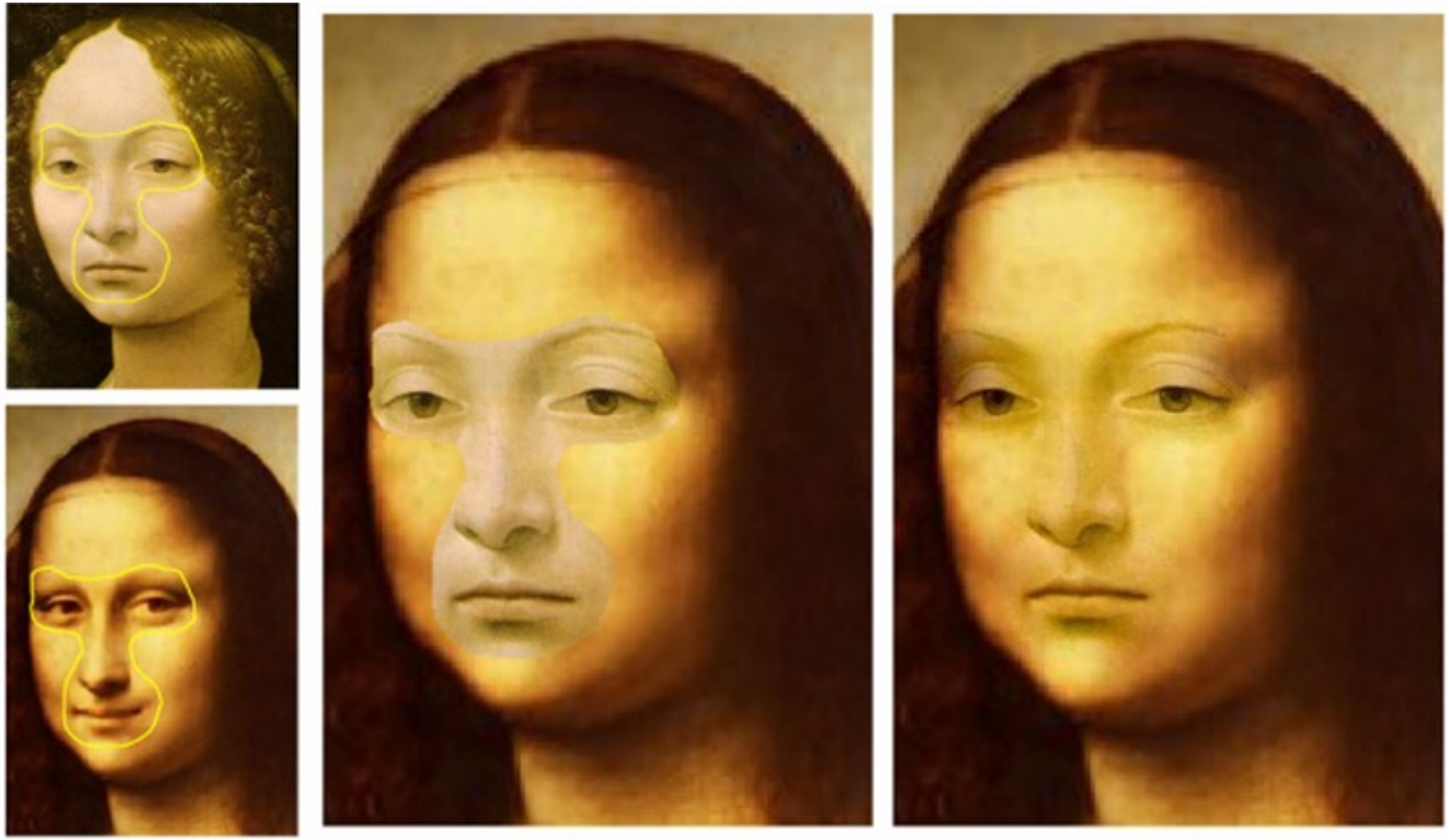
Beyond simple compositing

- Solve for image samples that follow gradients of source subject to boundary conditions imposed by dest



$$\min_f \iint_\Omega |\nabla f - \mathbf{v}|^2 \text{ with } f|_{\partial\Omega} = f^*|_{\partial\Omega}$$

Poisson Image Blending



source/destination cloning seamless cloning

Digital Image Processing

- Changing pixel values
  - Linear: scale, offset, etc.
  - Nonlinear: gamma, saturation, etc.
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- Filtering over neighborhoods
  - Blur & sharpen
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  - Median
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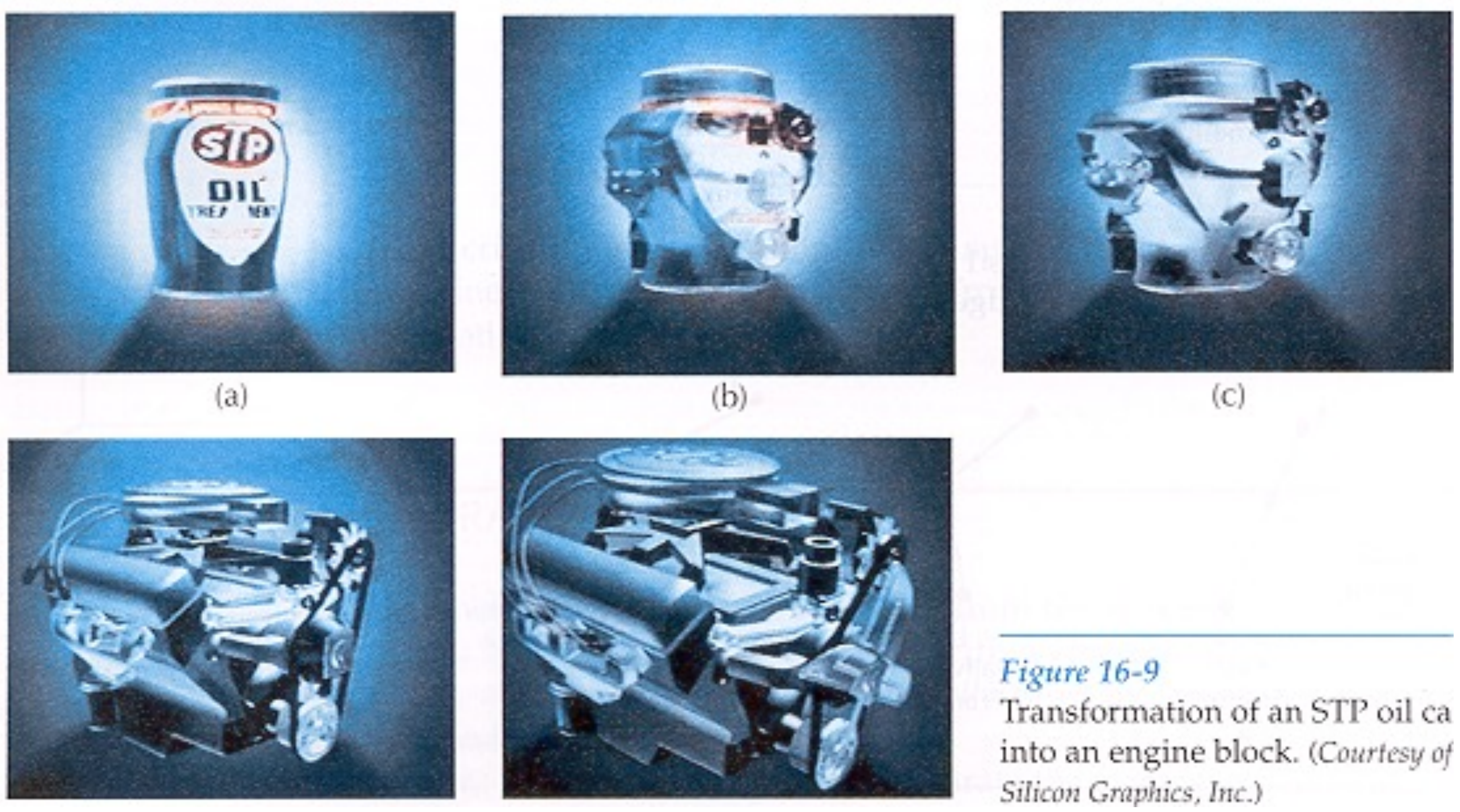
- Spatial / intensity tradeoff
  - Dithering

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 1.0 to 0.0

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

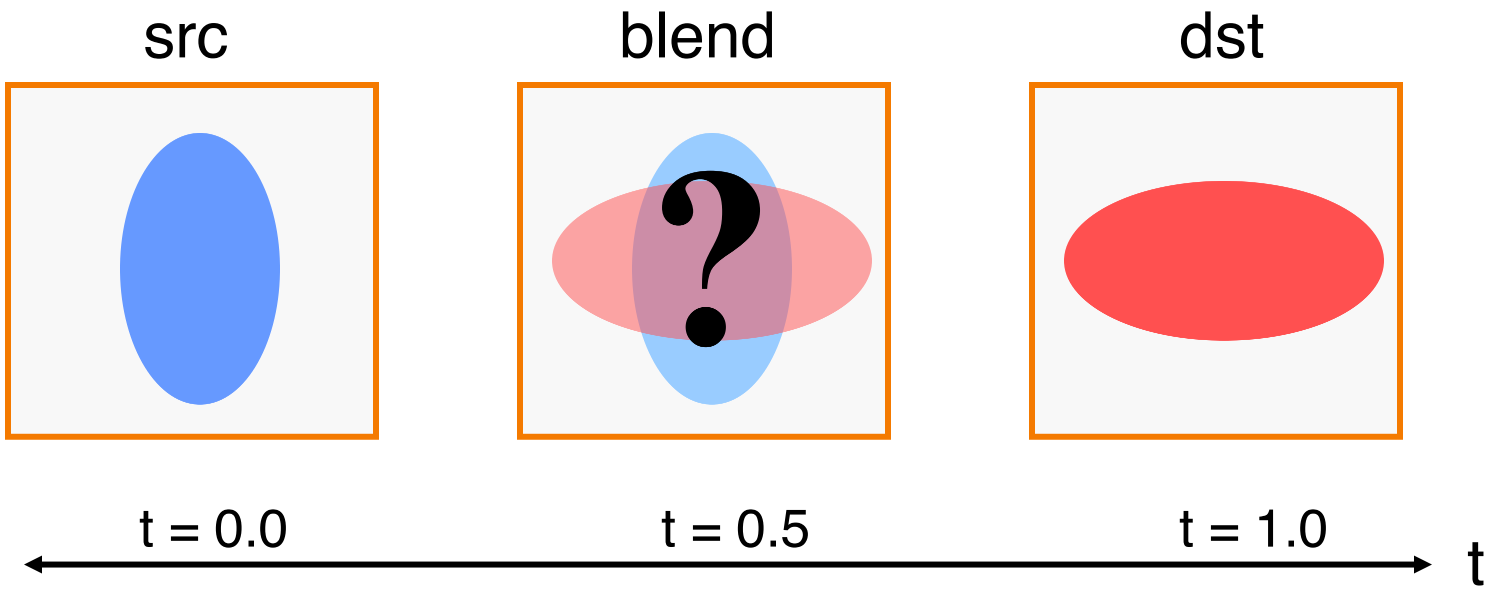
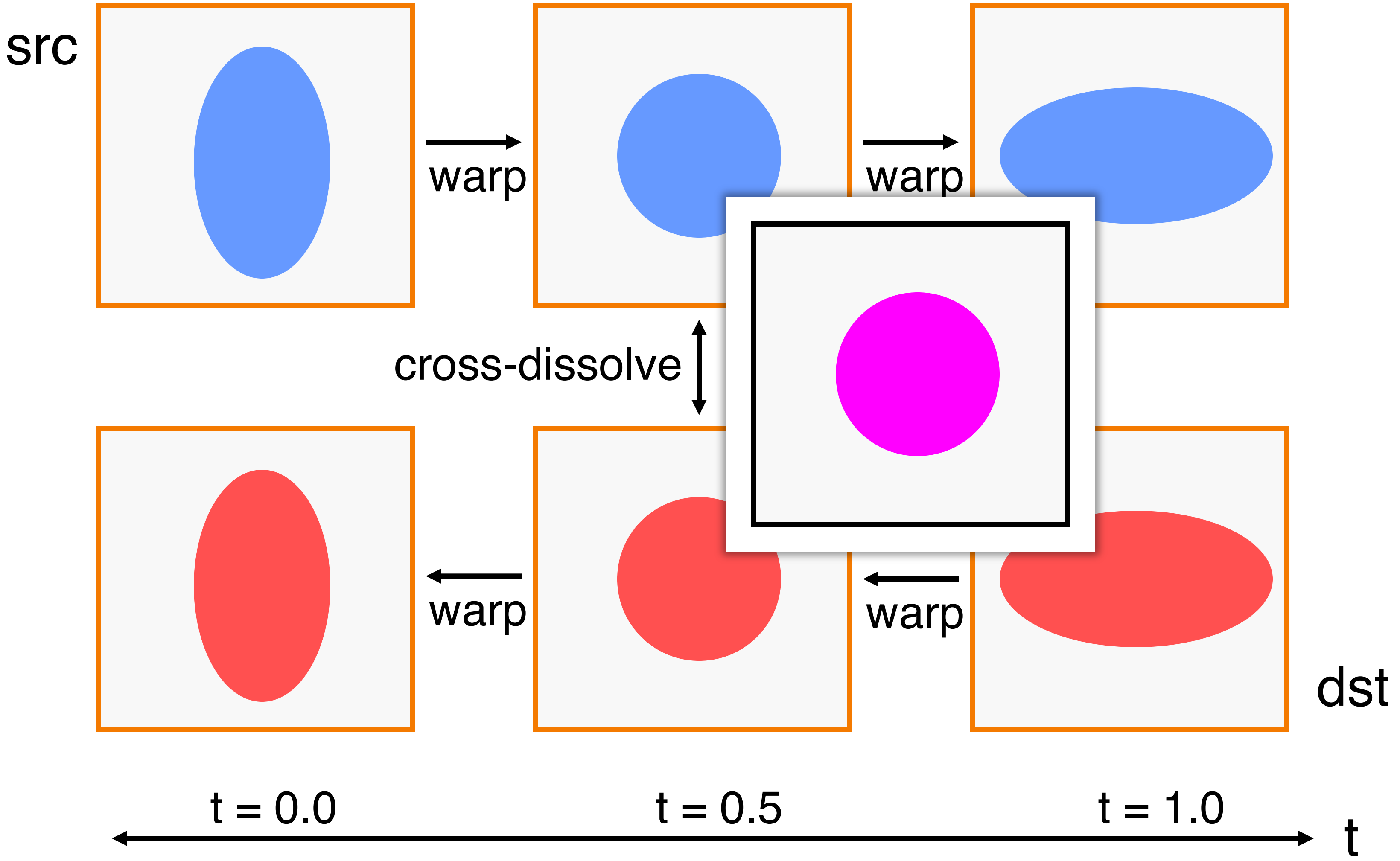
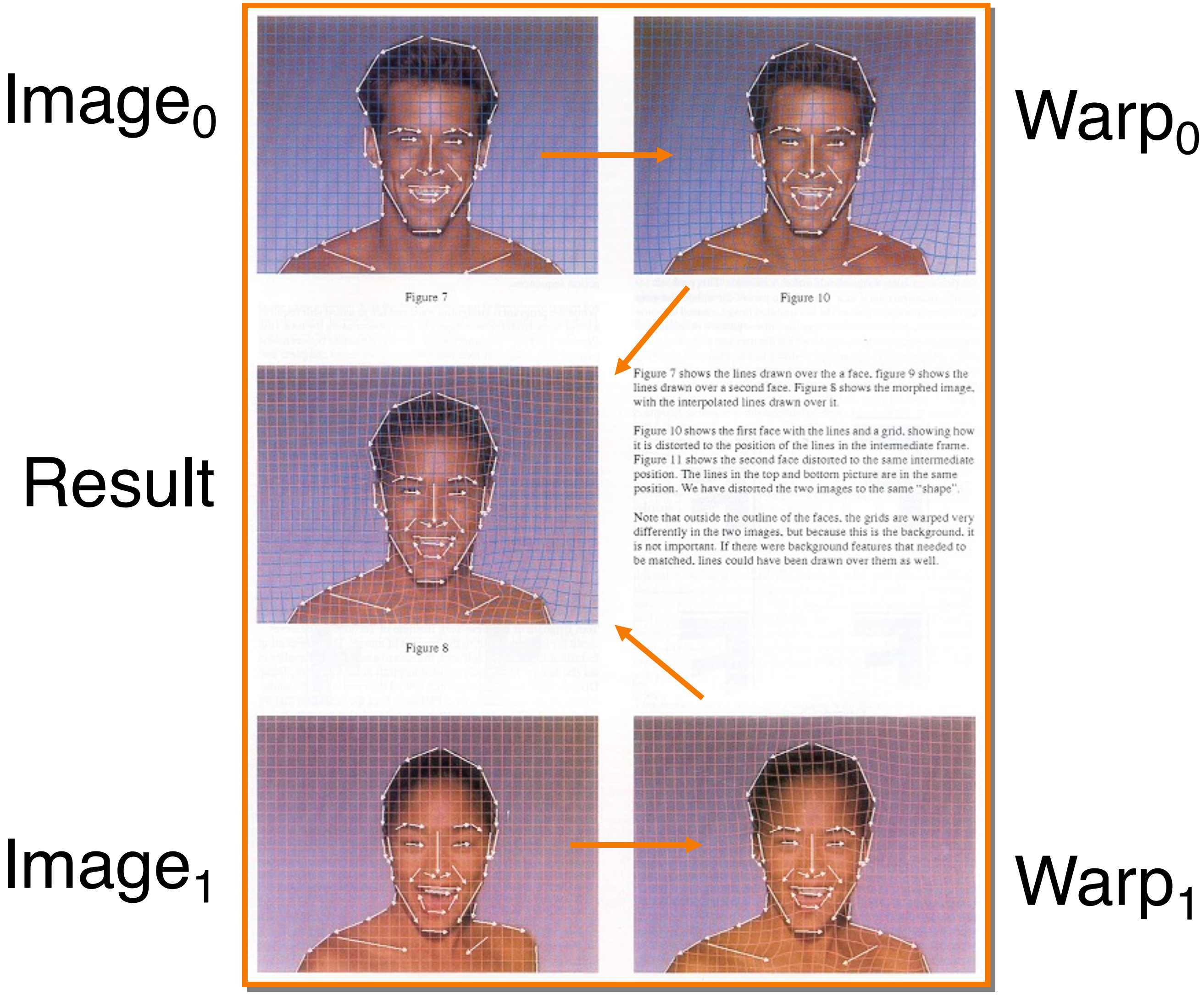


Image Morphing

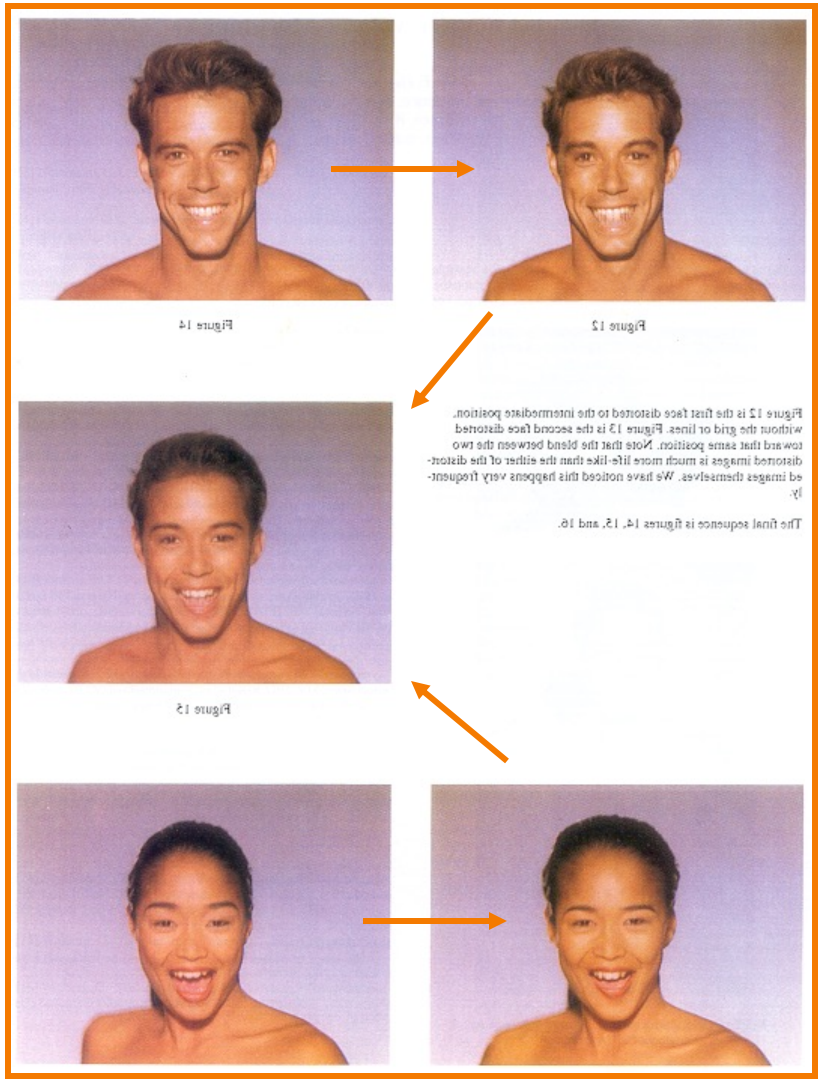
- Combines warping and cross-dissolving



Beier & Neeley Example



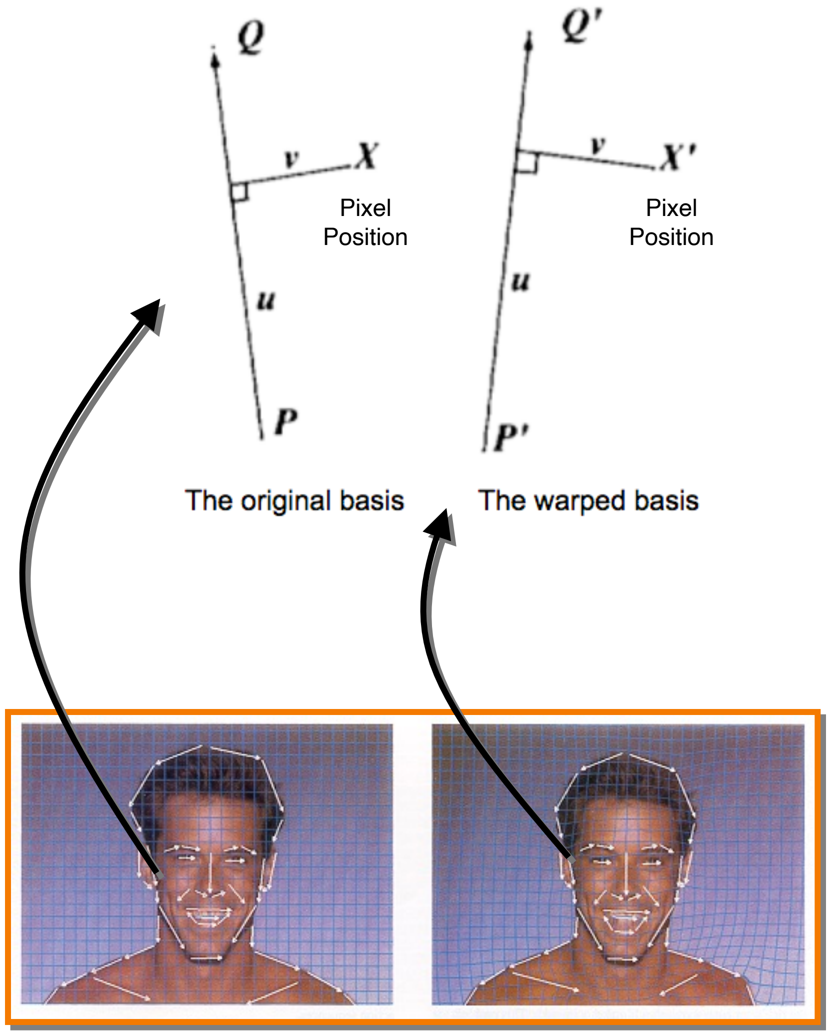
Beier & Neeley Example



Beier & Neeley Example

Black or White, Michael Jackson (1991)

Warping Pixel Locations



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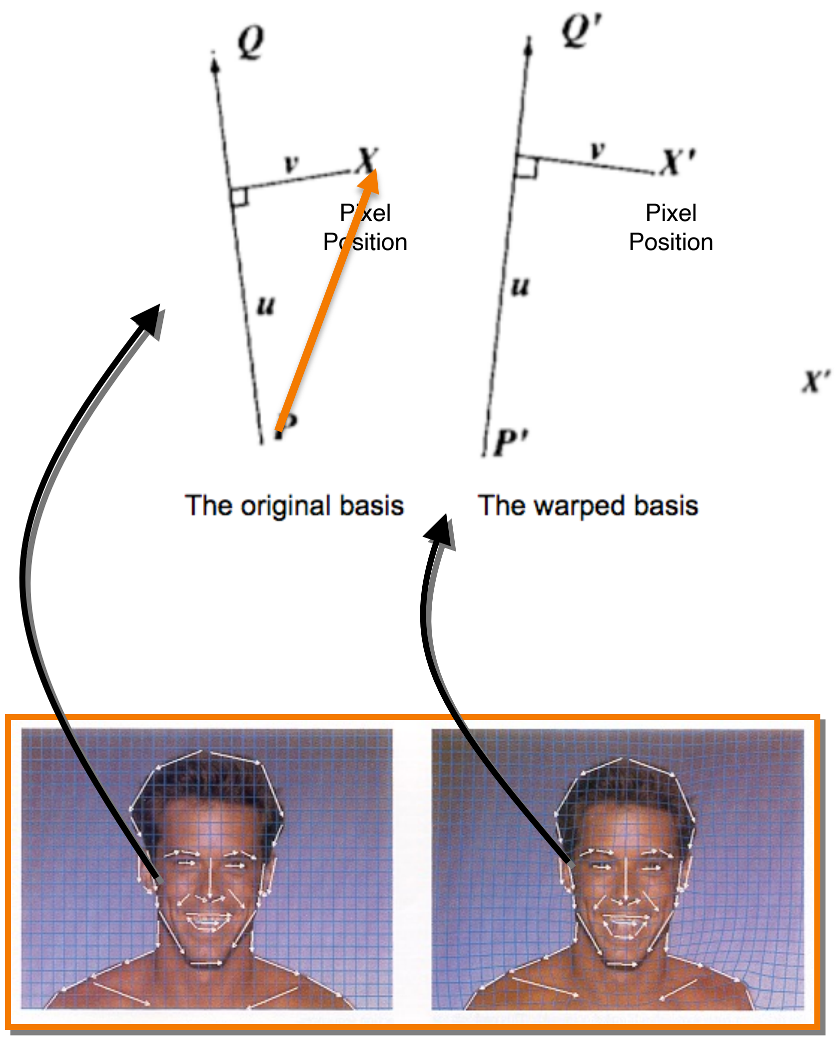
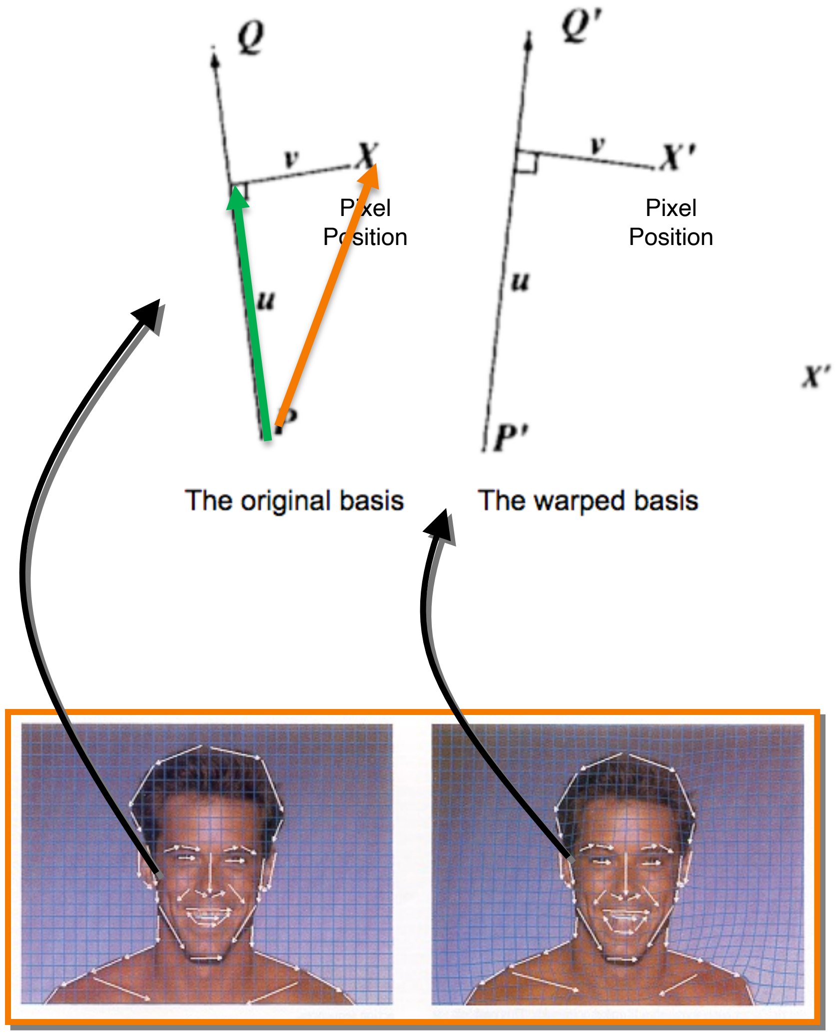


$$u = \frac{(X - P) \cdot (Q - P)}{\| Q - P \|^2}$$

$$v = \frac{(X - P) \cdot Perpendicular(Q - P)}{\| Q - P \|}$$

$$X' = P' + u \cdot (Q' - P') + \frac{v \cdot Perpendicular(Q' - P')}{\| Q' - P' \|}$$

Warping Pixel Locations



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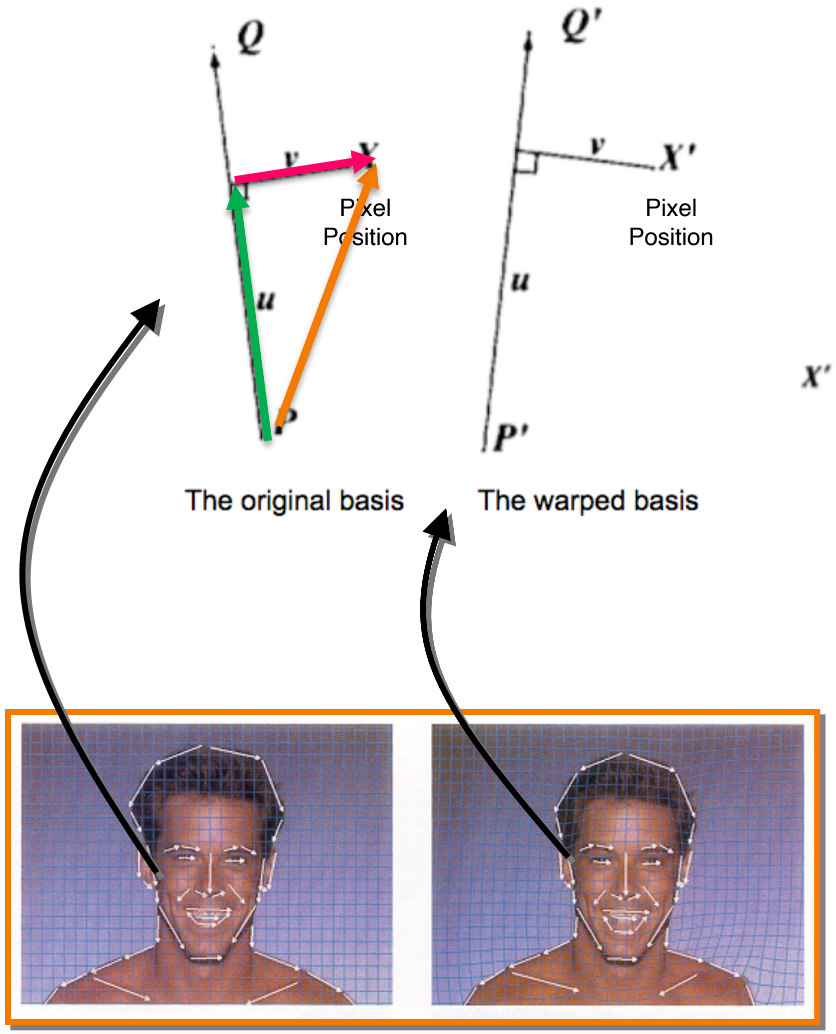

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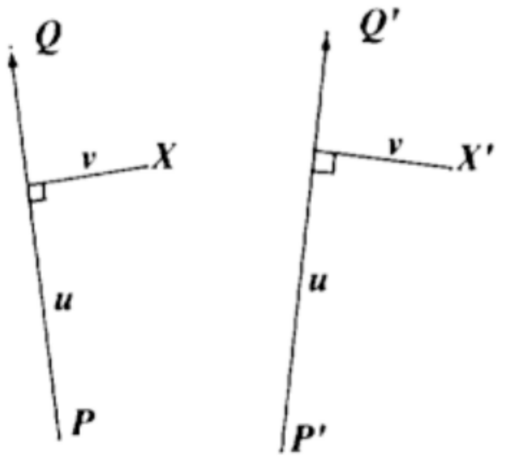
Warping Pixel Locations



The original basis The warped basis

$$u = \frac{(X-P)\cdot(Q-P)}{\|Q-P\|^2}$$

$$v = \frac{(X-P)\cdot Perpendicular(Q-P)}{\|Q-P\|}$$

$$X' = P' + u\cdot(Q'-P') + \frac{v\cdot Perpendicular(Q'-P')}{\|Q'-P'\|}$$

This generates one warp per line, each of which is a simple rotation and non-uniform scale (scaling is only done along the axis of the line). These warps must then be averaged to get the final warp. In the original paper, the weights for the average are tuned with the formula below. The *dist* variable is the distance of the point from the line segment, and the *length* variable is the length of the line segment.

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

The equations give several parameters to tune, and I got the best results when $a = 0.001$, $b = 2$, and $p = 0$. Ignoring the length of the line segments (by setting p to zero) gave better results than when the length was taken in to account. I used seven contours with 28 line segments to represent the features of each face.

Nice implementation notes from Evan Wallace, Brown University
http://cs.brown.edu/courses/csci1950-g/results/proj5/edwallac/

Warping Pseudocode

```
WarpImage(Image, L_src[…], L_dst[…])
begin
    foreach destination pixel p_dst do
        psum = (0,0)
        wsum = 0
        foreach line L_dst[i] do
            p_src[i] = p_dst transformed by (L_dst[i],L_src[i])
            psum = psum + p_src[i] * weight[i]
            wsum += weight[i]
        end
        p_src = psum / wsum
        Result(p_dst) = Resample(p_src)
    end
end
```

Morphing Pseudocode

```
GenerateAnimation(Image0, L0[…], Image1, L1[…])
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 L0[i] to L1[i]
        end
        Warp0 = WarpImage(Image0, L0, L)
        Warp1 = WarpImage(Image1, L1, L)
        foreach pixel p in FinalImage do
            Result(p) = (1-t) Warp0 + t Warp1
        end
    end
end
```

COS426 Example

Amy Ousterhout

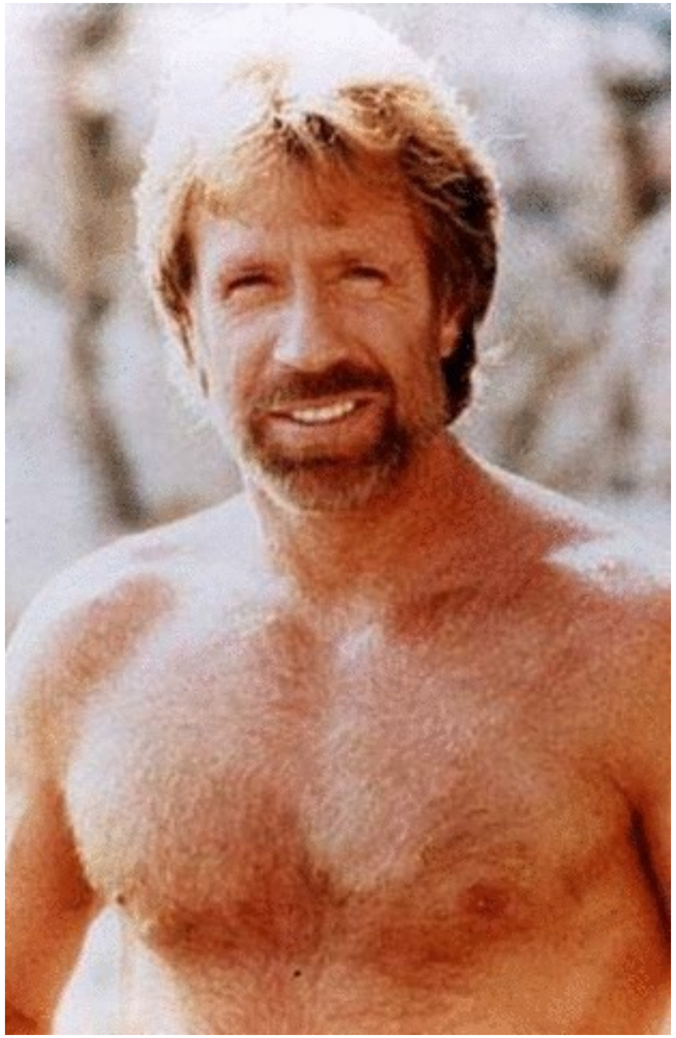
COS426 Examples

ckctwo

Jon Beyer

COS426 Examples

Sam Payne



Matt Matl

Image Composition Applications

- "Computational photography": new photographic effects that inherently use multiple images + computation
- Example: stitching images into a *panorama*

[Michael Cohen]

Image Composition Applications

- Photo montage

[Michael Cohen]

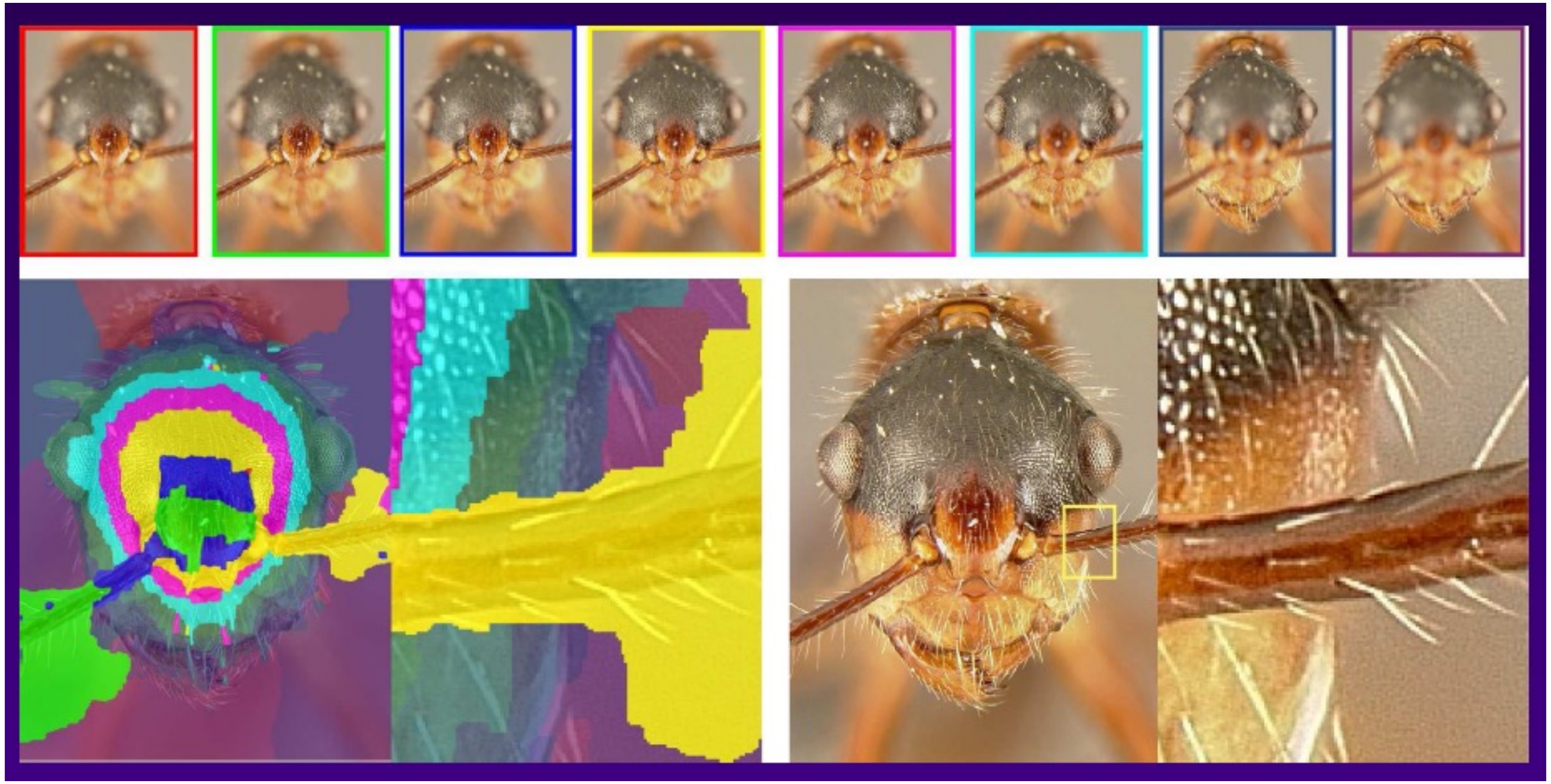
Image Composition Applications

- Stoboscopic images

[Michael Cohen]

Image Composition Applications

- Extended depth-of-field



[Michael Cohen]

Scene Completion Using Millions of Photographs

James Hays and Alexei A. Efros

SIGGRAPH 2007

Slides by J. Hays and A. Efros

Hays et al. SIGGRAPH 07

Hays et al. SIGGRAPH 07

Hays et al. SIGGRAPH 07

Image Completion

Hays et al. SIGGRAPH 07

Image Completion

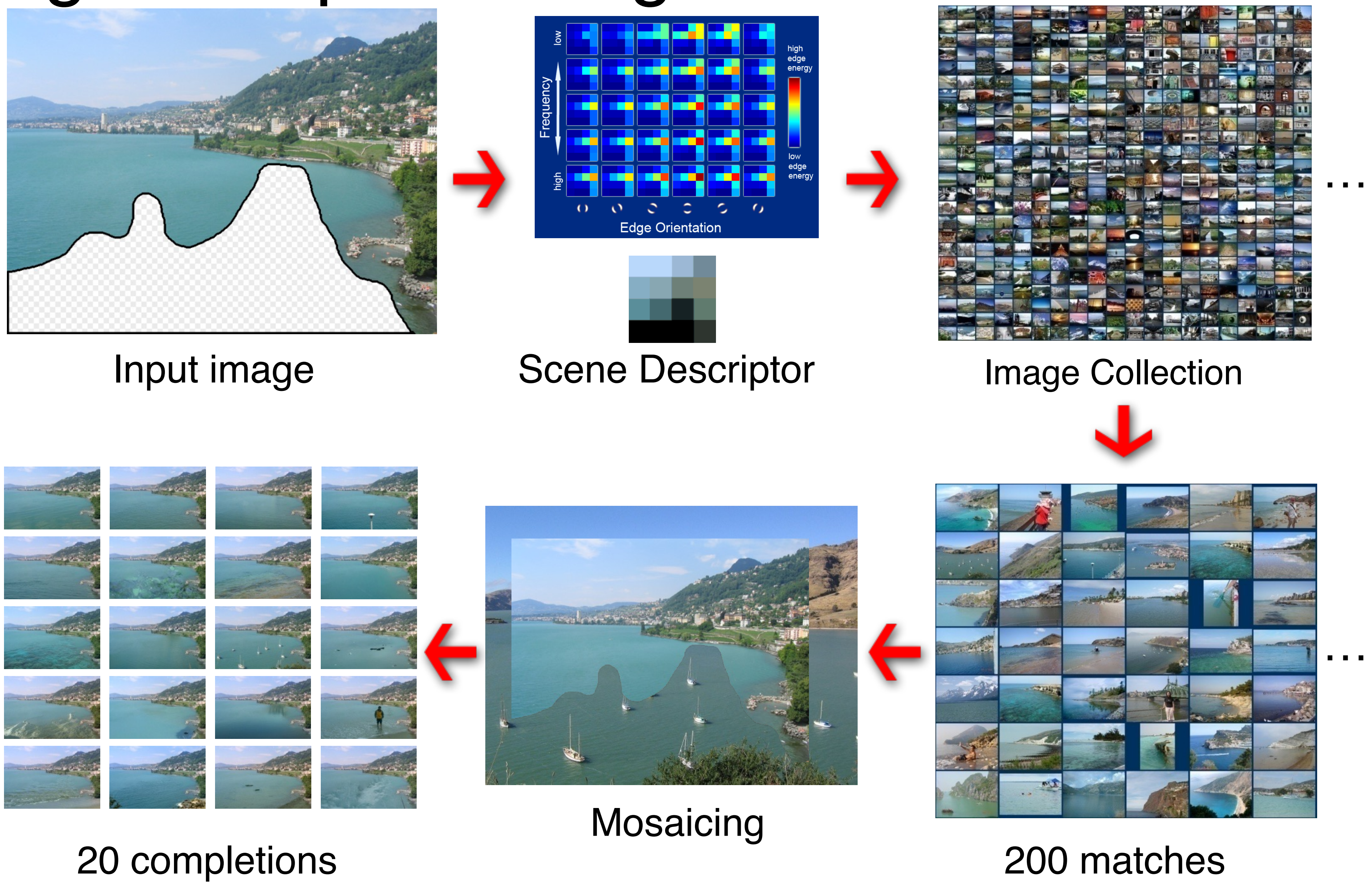
2.3 Million unique images from Flickr

Hays et al. SIGGRAPH 07

Scene Completion Result

Hays et al. SIGGRAPH 07

Image Completion Algorithm



Hays et al. SIGGRAPH 07

Hays et al. SIGGRAPH 07

Hays et al. SIGGRAPH 07

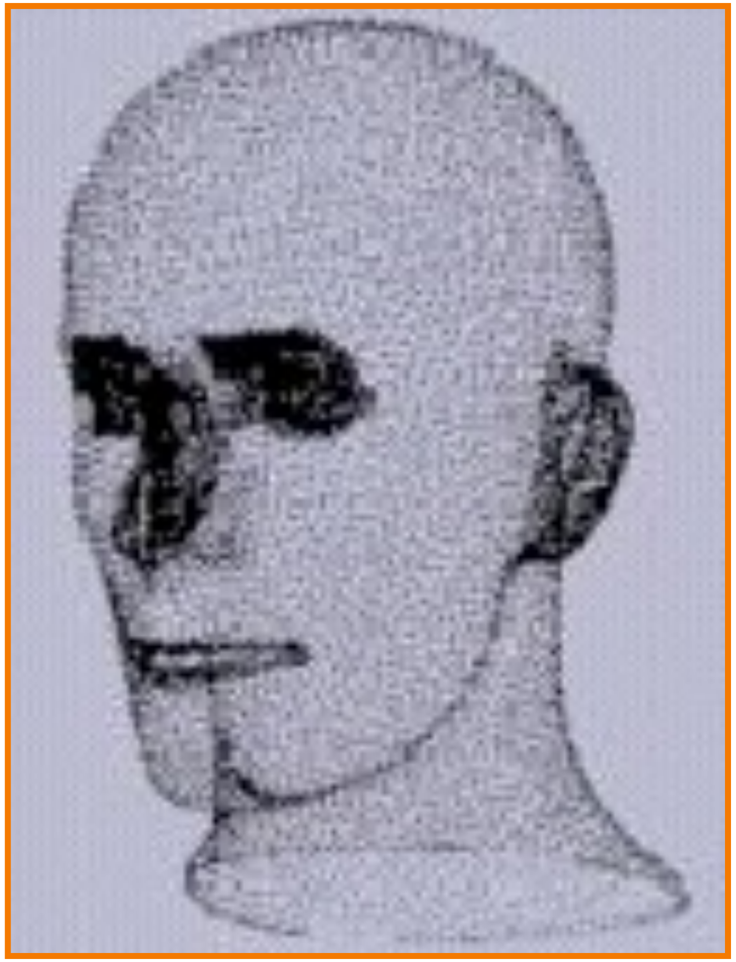
Hays et al. SIGGRAPH 07

Hays et al. SIGGRAPH 07

Summary

- Image compositing
  - Alpha channel
  - Porter-Duff compositing algebra
- Image morphing
  - Warping
  - Compositing
- Compositing in Computational Photography

Next Time: 3D Modeling



Hoppe