Matting and Compositing

www.davehillphoto.com/adventure

Image Manipulation and Computational Photography
CS294-69 Fall 2011

Maneesh Agrawala

[Some slides from James Hays , Derek Hoiem, Alexei Efros and Fredo Durand]

A3 Gradient/Resizing and Warping Due Mon Oct 24

Implement Gradient Domain Techniques or Resizing and Warping

Adequate to implement, best solutions go beyond:

Every technique has some limitations (well written papers usually describe some of them). Develop techniques to address one or more limitations?

Sometimes different papers present different techniques for addressing the same problem Implement competing techniques and compare their strengths and weaknesses.

It may be possible to combine ideas from multiple papers to produce a new hybrid technique that addresses a new problem. Develop a new way to combine the texture synthesis techniques your have read about to solve a new problem.

1 person = 1 paper,

2 people = 1 paper + issue from list above or 2 papers,

3 people = 2 papers + issue from list above

Final Project

Goal: Develop new research idea

Can work in groups of up to 3 people

- Tell us groups by this Thursday (10/27)
- Will assume you are working alone unless told otherwise

Project proposals due 10/31

Proposal presentations 10/31 and 11/2

Final presentations 11/28 and 11/30

Final paper 12/7

How Does Superman Fly?

Super-human powers?

OR

Image matting and compositing?

Dave Hill

http://www.petapixel.com/2011/07/21/dave-hill-photographs-deconstructed/

Motivation: Compositing

Combining multiple images. Typically, paste a foreground object onto a new background

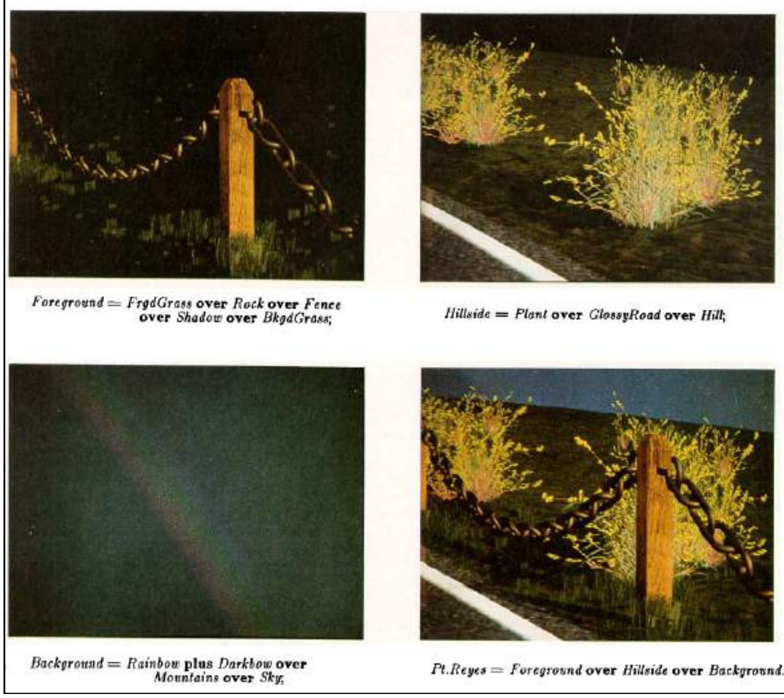
Movie special effect

Multi-pass CG

Combining CG & film

Photo retouching

- Change background
- Fake depth of field
- Page layout: extract objects, magazine covers



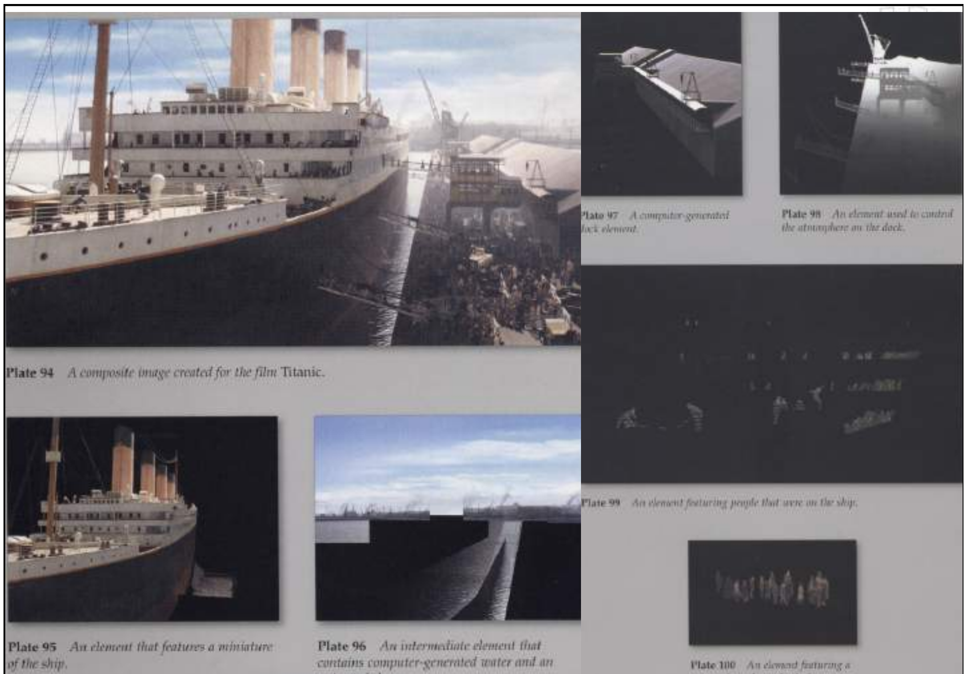
[Porter 84]

From Cinefex

Video

http://www.petapixel.com/2011/02/15/amazing-effects-from-popular-tv-shows/

http://www.youtube.com/watch?v=Srt07MIrRRo



From the Art & Science of Digital Compositing

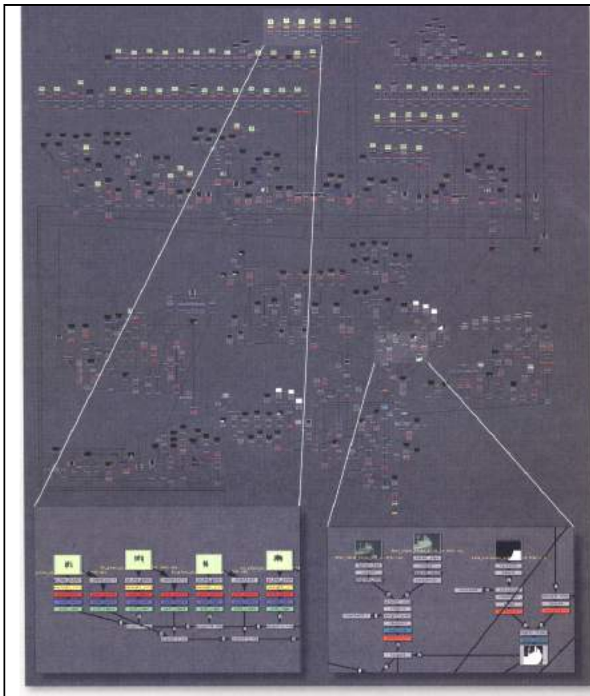


Plate 93 *The script used to create the image shown in Plate 94. Sections are magnified to show detail.*

From the Art & Science of Digital Compositing

Forest Gump

Page Layout, Magazine Covers

Photo Editing

Edit the background independently from foreground

Photo Editing

Edit the background independently from foreground

Technical Issues

Compositing
- How exactly do we handle transparency?

Smart selection
- Facilitate the selection of an object

Matte extraction
- Resolve sub-pixel accuracy, estimate transparency

Smart pasting
- Don't be smart with copy, be smart with paste
- See gradient manipulation

Extension to video
- Where life is always harder

Today

Compositing

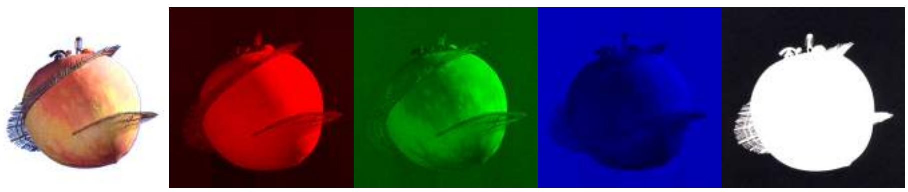
Blue screen matting

Natural image matting

Alpha

α: 1 means opaque, 0 means transparent

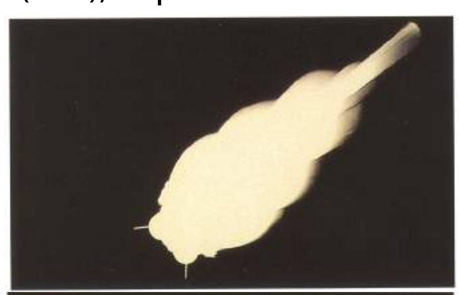
32-bit images: R, G, B, α



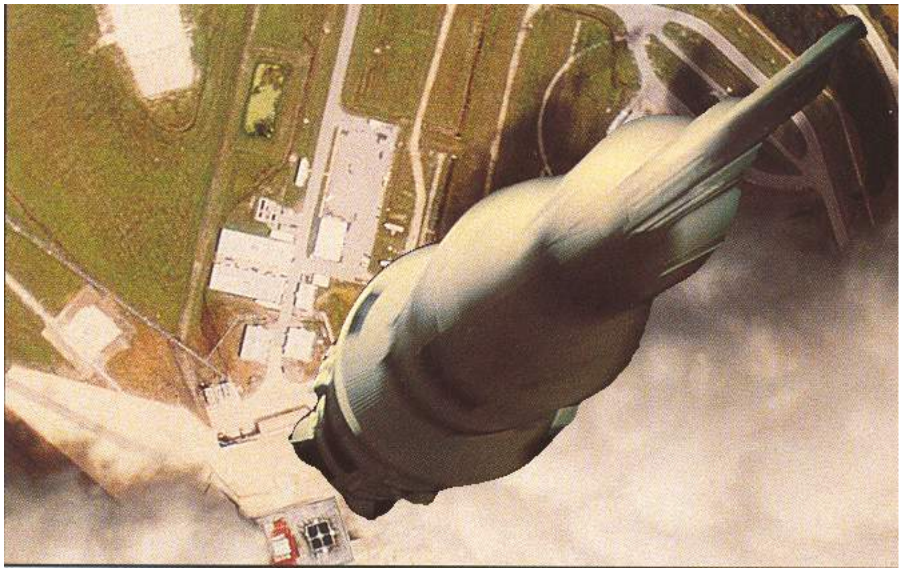
From the Art & Science of Digital Compositing

Why Fractional Alpha?

Motion blur, small features (hair), depth of field causes partial occlusion



With Binary Alpha

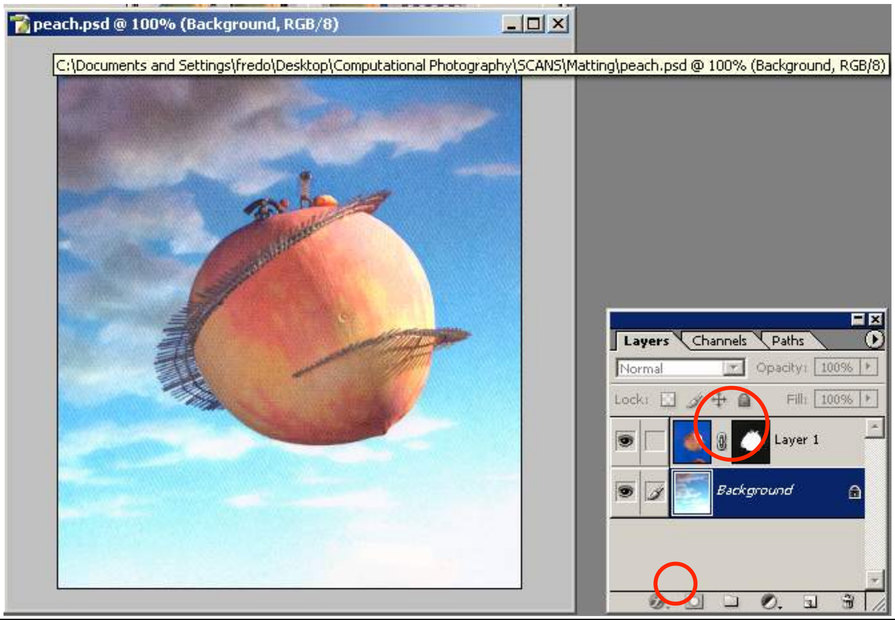


From Digital Domain

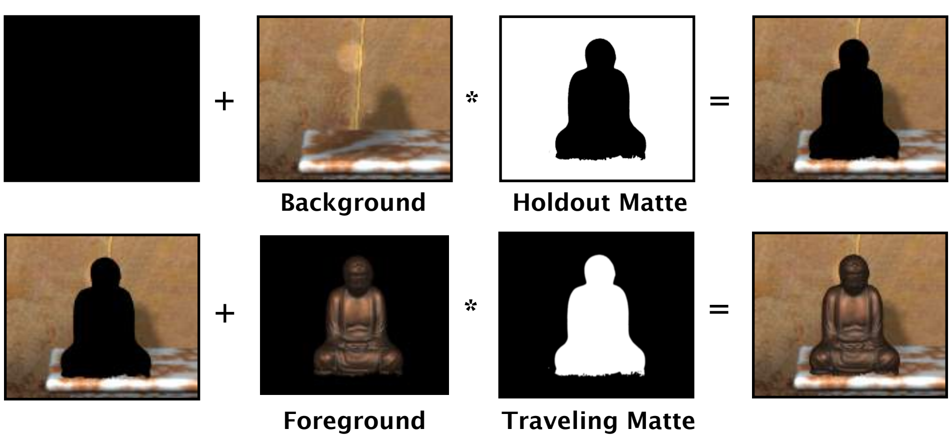
With Fractional Alpha

From Digital Domain

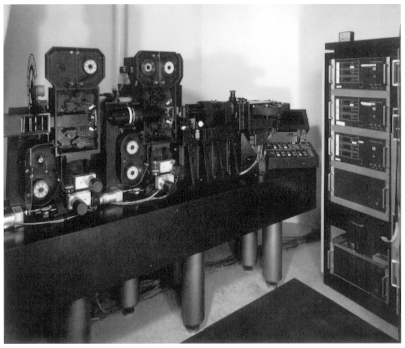
Photoshop Layer Masks



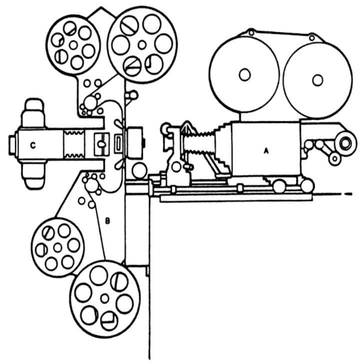
Compositing Two Elements



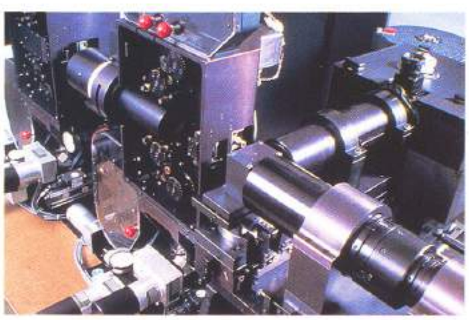
Optical Printing



From: "Industrial Light and Magic," Thomas Smith (p. 181)



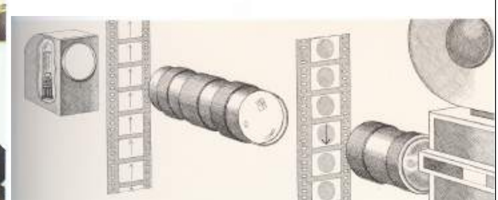
From: "Special Optical Effects," Zoran Perisic



Left: Close-up of the Quad printer, showing projectors (left), beam splitters (center), 4-perf camera (right), and anamorphic lens (lower right). This unit was built by ILM.

Below: ILM's original Quad printer, which was later modified and rebuilt.

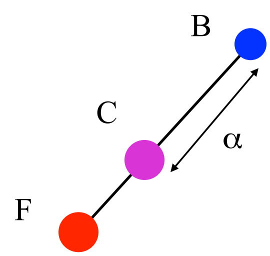
From: "Industrial Light and Magic," Thomas Smith



Compositing

Given the foreground color $F=(R_F, G_F, B_F)$, the background color (R_B, G_B, B_B) and α for each pixel

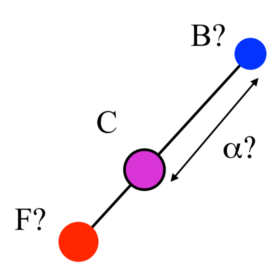
The compositing (aka over) operation is:
$C=\alpha F+(1-\alpha)B$



Matting Problem

Inverse problem:
Assume an image is the over composite of a foreground and a background

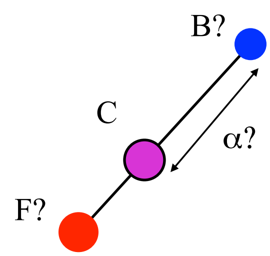
Given an image color C, find F, B and α so that
$C=\alpha F+(1-\alpha)B$



Matting Ambiguity

$C=\alpha F+(1-\alpha)B$

How many unknowns, how many equations?

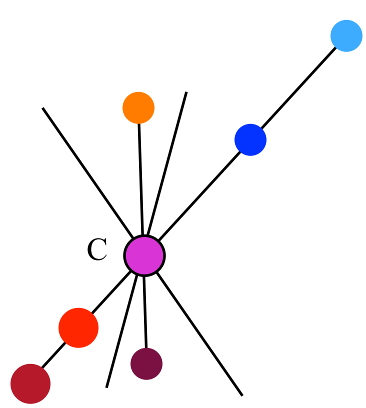


Matting Ambiguity

$C=\alpha F+(1-\alpha)B$

7 unknowns: α and triplets for F and B

3 equations, one per color channel



Matting Ambiguity

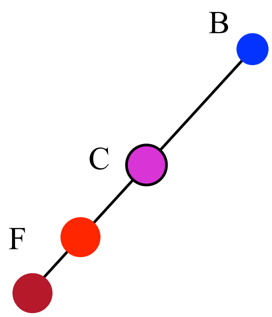
$C = \alpha F + (1-\alpha)B$

7 unknowns: α and triplets for F and B

3 equations, one per color channel

With known background (e.g. blue/green screen):

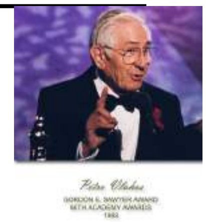
4 unknowns, 3 equations



Questions?

From Cinefex

Traditional Blue Screen Matting



Invented by Petro Vlahos
(Technical Academy Award 1995)

Recently formalized by Smith & Blinn

Initially for film, then video, then digital

Assume that the foreground has no blue

From Cinefex

Traditional Blue Screen Matting

Assume b and g channels of Fg respect $b <= a_2 g$ for $0.5 <= a_2 <= 1.5$

$$\alpha = 1 - a_1(b - a_2 g)$$

- clamped to 0 and 1
- where a_1 and a_2 are user parameters
- constrains Fg g to be linearly related to Fg b

Lots of refinements (see Smith & Blinn's paper)

Blue/Green Screen Matting Issues

Color limitation

- Annoying for blue-eyed people

➔ adapt screen color (in particular green)

Blue/Green spilling

- The background illuminates the foreground, blue/green at silhouettes
- Modify blue/green channel, e.g. set to min (b, a_2g)

Shadows

- How to extract shadows cast on background

Blue/Green Screen Matting Issues

Plate 52 *(b) The element placed into the scene without spill suppression. Note the blue fringes on the subject, particularly in the hair.*

From the Art & Science of Digital Compositing

Blue Spill

http://www.digitalgreenscreen.com/figure3.html

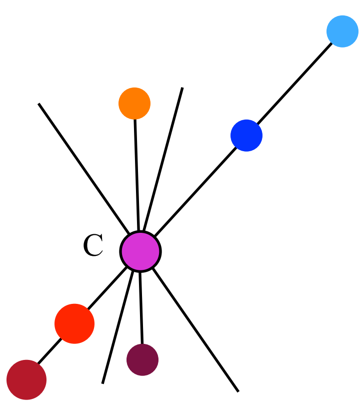
Figure 3. *Firefox Blue Spill Matte Series 1, original shot. Note blue reflected on wing surfaces from bluescreen -- undesirable but unavoidable on such surfaces.*

Recall: Matting Ambiguity

$C = \alpha F + (1-\alpha) B$

7 unknowns: α and triplets for F and B

3 equations, one per color channel



Natural Matting

[Ruzon & Tomasi 2000, Chuang et al. 2001]

Given an input image with arbitrary background

The user specifies a coarse Trimap (specify Fg, Bg and unknown regions)

Estimate F, B, alpha in the unknown region

- We don't care about B, but it's a byproduct/unkown

Now, what tool do we know to estimate something, taking into account all sorts of known probabilities?

input (OK, could be more natural)

trimap

images from Chuang et al

Who's Afraid of Bayes?

Bayesian Inference

You observe y and want to infer x that generated this y

Example: y:student wears Berkeley T-shirt
x: school the student from

Bayesian approach:

define P(x|y) for each possible x to generate given observation y

Example: P(being Stanford student | given is wearing Berkeley shirt)
P(being Berkeley student | given is wearing Berkeley shirt)
P(being SF State student | given is wearing Berkeley shirt)

Usually, pick answer with highest probability

Bayes Theorem

$$P(x|y) = P(y|x)\, P(x) \,/\, P(y)$$

The parameters you want to estimate

What you observe

Likelihood function

Prior probability

Constant w.r.t. parameters x.

P(being Stanford student | given is wearing Berkeley shirt)

= P(wears an Berkeley shirt | given being a Stanford student) P(being a Stanford student) / P(wearing an Berkeley T shirt)

Bayes Theorem: Semi Proof

Think in terms of numbers

- and count in two different ways, starting with full # of x and full # of y

#student Stanford students wearing Berkeley shirt

= #Stanford student

x Percentage(Stanford student to wear Berkeley shirt)

= #student wearing Berkeley shirt

x Percentage(Berkeley shirt wearers from Stanford)

That is

$P(x)P(y|x)=P(y)P(x|y)$

and thus $P(x|y) = P(y|x)\ P(x) \ /\ P(y)$

Bayes theorem

$$P(x|y) = P(y|x)\ P(x) \ /\ P(y)$$

The parameters you want to estimate

What you observe

Likelihood function

Prior probability

Constant w.r.t. parameters x. (usually ignore)

P(Berkeley shirt | Stanford)= 1%	P(Stanford) = 20%
P(Berkeley shirt | Berkeley) =100%	P(Berkeley) = 20%
P(Berkeley shirt | SF State) =40%	P(SF State) = 60%

Therefore, if you see someone with an Berkeley shirt, a safe bet is to assume they are from which school?

Stanford "score": 0.0020

Berkeley "score": 0.2000

$\boxed{\text{SF State "score": 0.2400}}$

Bayes Theorem for Matting

$$P(x|y) = P(y|x)\ P(x)\ /\ P(y)$$

The parameters you want to estimate

What you observe

Likelihood function

Prior probability

Constant w.r.t. parameters x.

Matting and Bayes

What do we observe?

$$P(x|y) = P(y|x)\ P(x)\ /\ P(y)$$

The parameters you want to estimate

What you observe

Likelihood function

Prior probability

Constant w.r.t. parameters x.

Matting and Bayes

What do we observe?

- Color C at a pixel

$$P(x|C) = P(C|x)\ P(x)\ /\ P(C)$$

The parameters you want to estimate

Color you observe

Likelihood function

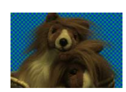
Prior probability

Constant w.r.t. parameters x.

Matting and Bayes

What do we observe: Color C

What are we looking for?



$$P(x|C) = P(C|x)\ P(x)\ /\ P(C)$$

The parameters you want to estimate

Color you observe

Likelihood function

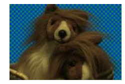
Prior probability

Constant w.r.t. parameters x.

Matting and Bayes

What do we observe: Color C

What are we looking for: F, B, α



$$P(F,B,\alpha|C) = P(C|F,B,\alpha)\, P(F,B,\alpha) \,/\, P(C)$$

Foreground, background, transparency you want to estimate

Color you observe

Likelihood function

Prior probability

Constant w.r.t. parameters x.

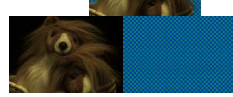
Matting and Bayes

What do we observe: Color C

What are we looking for: F, B, α

Likelihood probability?

- Given F, B and Alpha, probability that we observe C



$$P(F,B,\alpha|C) = P(C|F,B,\alpha)\, P(F,B,\alpha) \,/\, P(C)$$

Foreground, background, transparency you want to estimate

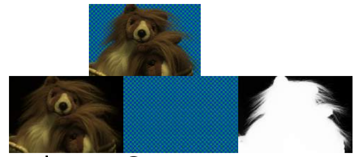
Color you observe

Likelihood function

Prior probability

Constant w.r.t. parameters x.

Matting and Bayes



What do we observe: Color C

What are we looking for: F, B, α

Likelihood probability?

- Given F, B and Alpha, probability that we observe C
- If measurements are perfect, probability is non-zero only if $C=\alpha F+(1-\alpha)B$
- But assume Gaussian noise with variance σ_C

$$P(F,B,\alpha|C) = P(C|F,B,\alpha)\ P(F,B,\alpha)\ /\ P(C)$$

Foreground, background, transparency you want to estimate

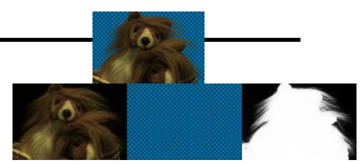
Color you observe

Likelihood function

Prior probability

Constant w.r.t. parameters x.

Matting and Bayes



What do we observe: Color C

What are we looking for: F, B, α

Likelihood probability: Compositing equation + Gaussian noise with variance σ_C

Prior probability:

- How likely is the foreground to have color F? the background to have color B? transparency to be α?

$$P(F,B,\alpha|C) = P(C|F,B,\alpha)\ P(F,B,\alpha)\ /\ P(C)$$

Foreground, background, transparency you want to estimate

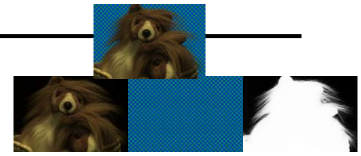
Color you observe

Likelihood function

Prior probability

Constant w.r.t. parameters x.

Matting and Bayes



What do we observe: Color C

What are we looking for: F, B, α

Likelihood probability: Compositing equation + Gaussian noise with variance σ_C

Prior probability: Build a probability distribution from the known regions given by the trimap

- This is the heart of Bayesian matting

$$P(F,B,\alpha|C) = P(C|F,B,\alpha)\ P(F,B,\alpha)\ /\ P(C)$$

Foreground, background, transparency you want to estimate

Color you observe

Likelihood function

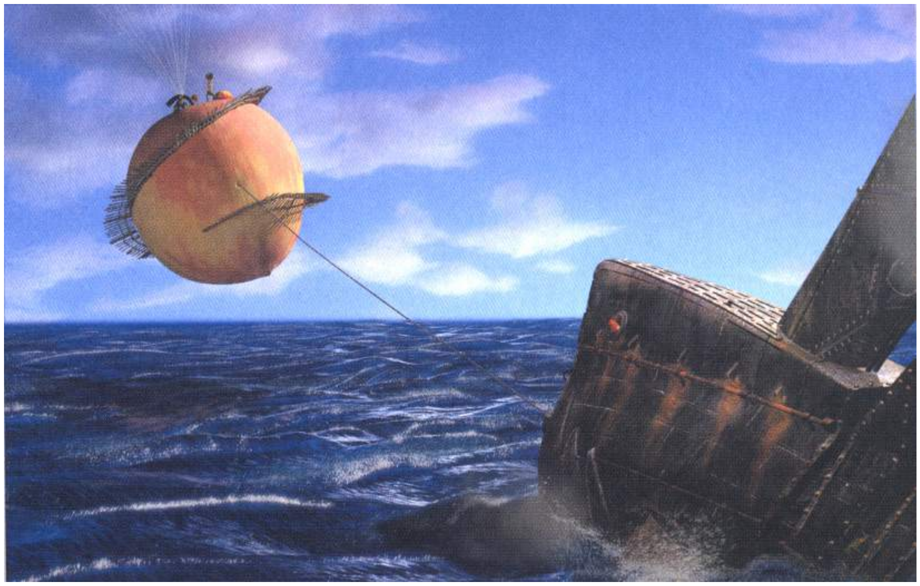
Prior probability

Constant w.r.t. parameters x.

Note

The noise in the measurement argument is partially propaganda. A deeper reason to add a Gaussian around the measurement is to make the problem more tractable by smoothing the probability/optimization energy

Questions?



From the Art & Science of Digital Compositing

Let's Derive

Assume F, B and α are independent

$$P(F,B,\alpha|C) = P(C|F,B,\alpha)\ P(F,B,\alpha)\ /\ P(C)$$
$$= P(C|F,B,\alpha)\ P(F)\ P(B)\ P(\alpha)/P(C)$$

But multiplications are hard!

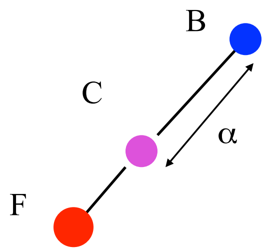
Make life easy, work with log probabilities

L means log P here:

$$L(F,B,\alpha|C) = L(C|F,B,\alpha) + L(F) + L(B) + L(\alpha) - L(C)$$

And ignore L(C) because it is constant

Log Likelihood: L(C|F,B,α)

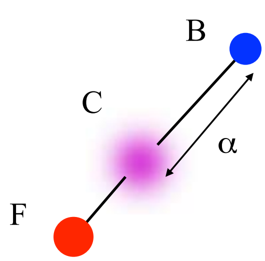


Log Likelihood: L(C|F,B,α)

Gaussian noise model: $e^{\frac{-\text{color difference}^2}{\sigma_C^2}}$

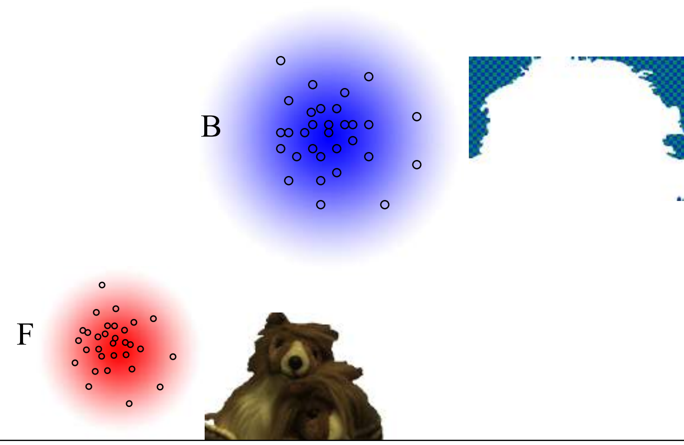
Take the log:

L(C|F,B,α)= $- \|C - \alpha F - (1-\alpha) B\|^2 / \sigma^2_C$



Prior Probabilities L(F) & L(B)

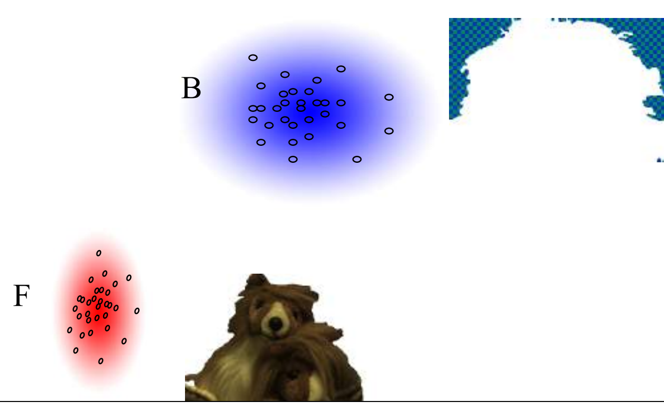
Gaussians based on pixel color from known regions



Prior Probabilities L(F) & L(B)

Gaussians based on pixel color from known regions

- Can be anisotropic Gaussians
- Compute the means $\bar{F}$ and $\bar{B}$ and covariance Σ_F, Σ_B



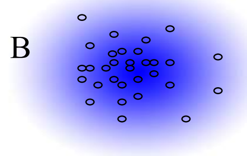
Prior Probabilities L(F) & L(B)

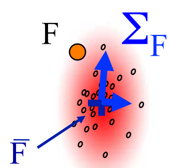
Gaussians based on pixel color from known regions

$$\bar{F} = \frac{1}{N_F}\sum F_i \qquad \Sigma_F = \frac{1}{N_F}\sum (F_i - \bar{F})(F_i - \bar{F})^T$$

$$L(F) = -(F - \bar{F})^T \Sigma_F^{-1} (F - \bar{F})/2$$

Same for B





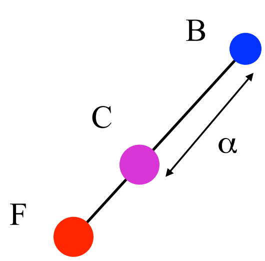
Prior Probabilities L(α)

What about alpha?

Well, we don't really know anything

Keep L(α) constant; essentially ignore it

- But see coherence matting for a prior on α



Bayesian Matting Equation

Maximize L(C|F,B,α) + L(F) +L(B)+L(α)

$$L(C|F,B,\alpha) = - \|C - \alpha F - (1-\alpha) B\|2 / \sigma^2_C$$

$$L(F) = -(F - \bar{F})^T \Sigma_F^{-1} (F - \bar{F})/2$$
$$L(B) = -(B - \bar{B})^T \Sigma_B^{-1} (B - \bar{B})/2$$

Unfortunately, not a quadratic equation because of the product (1-α) B

➔ iteratively solve for F,B and for α

For α Constant

Derive L(C|F,B,α) + L(F) +L(B)+L(α) wrt F & B, and set to zero gives

$$\begin{bmatrix} \Sigma_F^{-1} + I\alpha^2/\sigma_C^2 & I\alpha(1-\alpha)/\sigma_C^2 \\ I\alpha(1-\alpha)/\sigma_C^2 & \Sigma_B^{-1} + I(1-\alpha)^2/\sigma_C^2 \end{bmatrix} \begin{bmatrix} F \\ B \end{bmatrix} = \begin{bmatrix} \Sigma_F^{-1}\overline{F} + C\alpha/\sigma_C^2 \\ \Sigma_B^{-1}\overline{B} + C(1-\alpha)/\sigma_C^2 \end{bmatrix},$$

For F & B constant

Derive L(C|F,B,α) + L(F) +L(B)+L(α) wrt α, and set to zero gives

$$\alpha = \frac{(C - B) \cdot (F - B)}{\|F - B\|^2}$$

Recap: Bayesian Matting

The user specifies a trimap

Compute Gaussian distributions $\bar{F}$, Σ_F and $\bar{B}$, Σ_B for foreground and background regions

Iterate

- Keep α constant, solve for F & B (for each pixel)
- Keep F & B constant, solve for α((for each pixel)

Note that pixels are treated independently

Additional Gimmicks

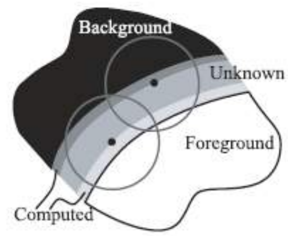
Use multiple Gaussians

- Cluster the pixels into multiple groups
- Fit a Gaussian to each cluster
- Solve for all the pairs of F & B Gaussians
- Keep the highest likelihood

Use local Gaussians

- Not on the full image

Solve from outside-in

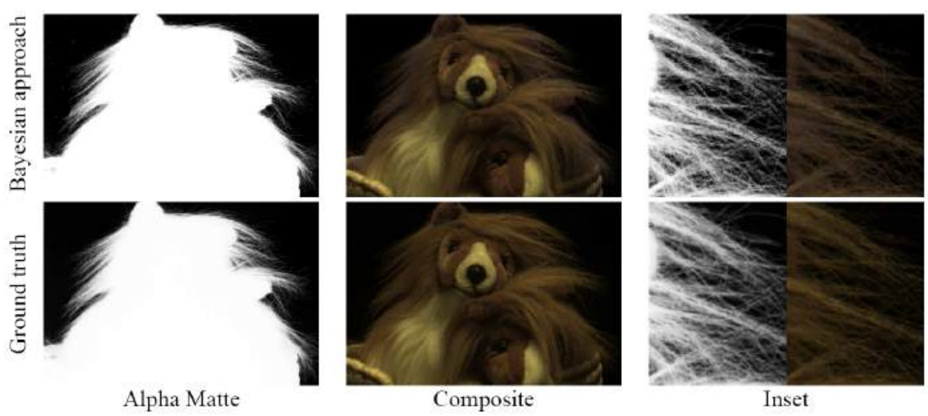


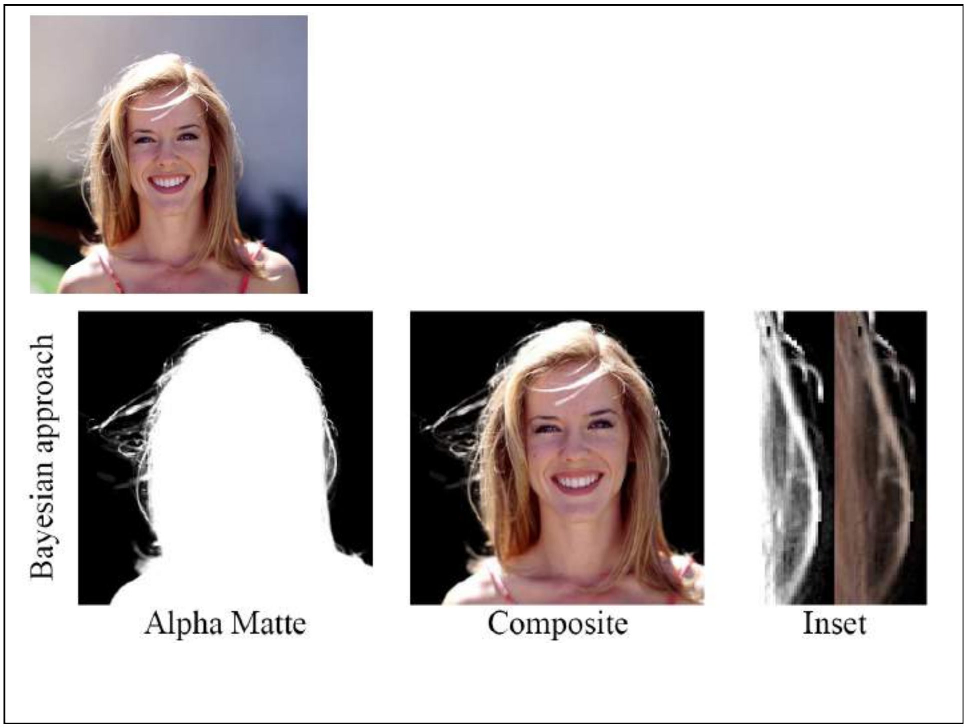
See Chuang et al.'s paper

http://grail.cs.washington.edu/projects/digital matting/

Results

From Chuang et al. 2001

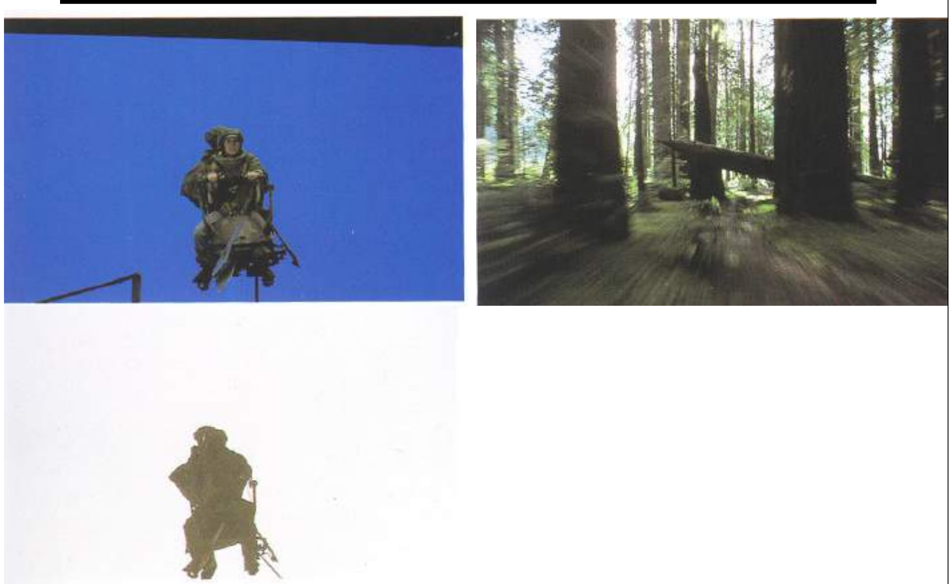



Bayesian approach
Alpha Matte
Composite
Inset


Alpha Matte
Composite
Inset

[Chuang 01]

Questions?



From Industrial Light & Magic, Smith

Extensions: Video

Interpolate trimap between frames

Exploit the fact that background might become visible

http://grail.cs.washington.edu/projects/digital-matting/video-matting/

Video Matting of Complex Scenes

Yung-Yu Chuang[1] Aseem Agarwala[1] Brian Curless[1] David Salesin[1,2] Richard Szeliski[2]

[1]University of Washington [2]Microsoft Research