Matting and Compositing

Digital Visual Effects, Spring 2009
Yung-Yu Chuang
2009/4/30

Outline

- Traditional matting and compositing
- The matting problem
- Bayesian matting and extensions
- Matting with less user inputs
- Matting with multiple observations
- Beyond the compositing equation*
- Conclusions

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Photomontage

The Two Ways of Life, 1857, Oscar Gustav Rejlander
Printed from the original 32 wet collodion negatives.

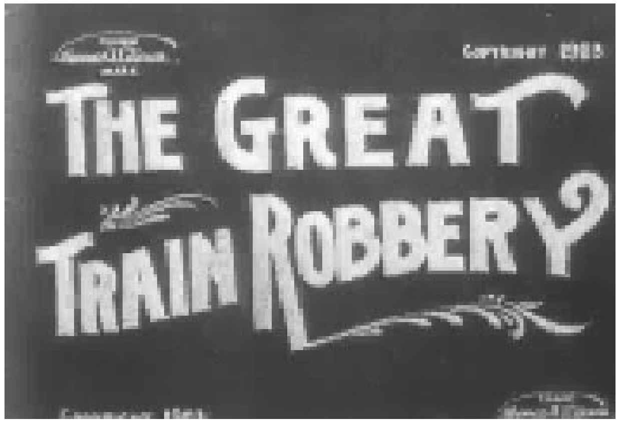
Photographic compositions


Lang Ching-shan

Use of mattes for compositing

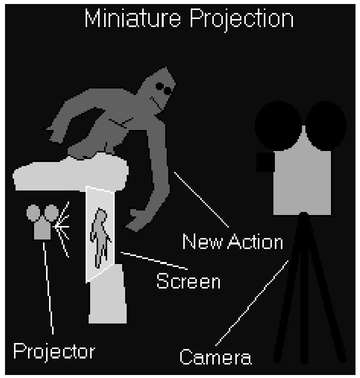
The Great Train Robbery (1903) matte shot

Use of mattes for compositing



The Great Train Robbery (1903) matte shot

Optical compositing



King Kong (1933) Stop-motion + optical compositing

Digital matting and compositing

The lost world (1925)

Miniature, stop-motion

The lost world (1997)

Computer-generated images

Digital matting and composting

King Kong (1933)

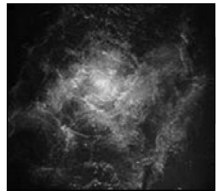
Optical compositing

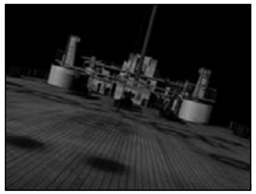
Jurassic Park III (2001)

Blue-screen matting,
digital composition,
digital matte painting

Smith Duff Catmull Porter

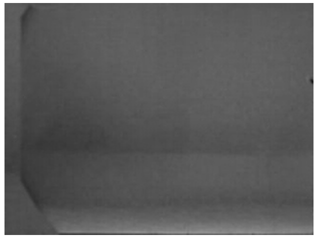
Oscar award, 1996





Titanic

Matting and Compositing

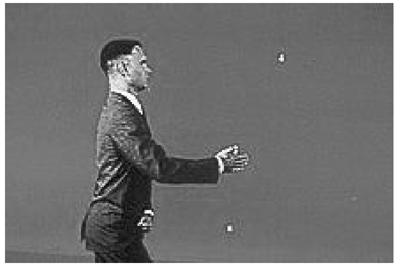


background replacement

background editing

Matting and Compositing

Digital matting: bluescreen matting



Forrest Gump (1994)

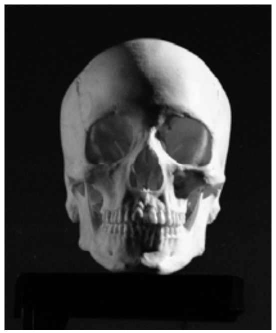
- The most common approach for films.
- Expensive, studio setup.
- Not a simple one-step process.

Color difference method (Ultimatte)

$C=F+\bar{\alpha}B$

Blue-screen photograph

F



Spill suppression
if B>G then B=G

$\bar{\alpha}$

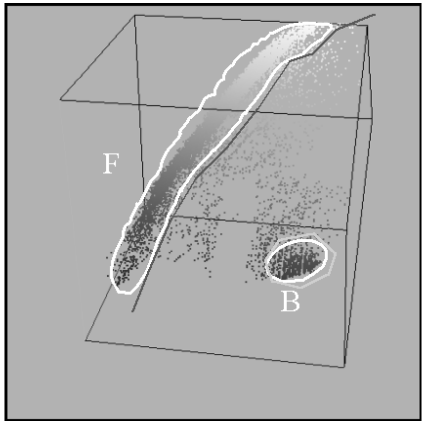
Matte creation
$\bar{\alpha}$=B-max(G,R)

demo with Paint Shop Pro (B=min(B,G))

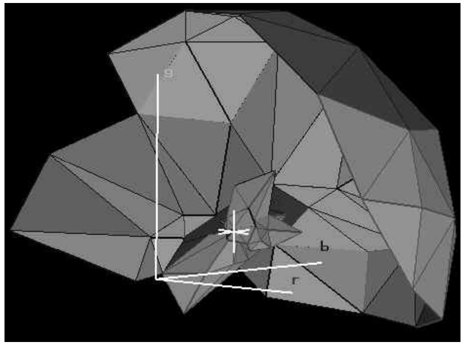
Problems with color difference

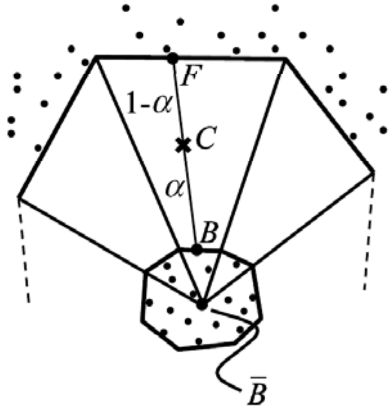
Background color is usually not perfect! (lighting, shadowing…)

Chroma-keying (Primatte)



Chroma-keying (Primatte)





demo

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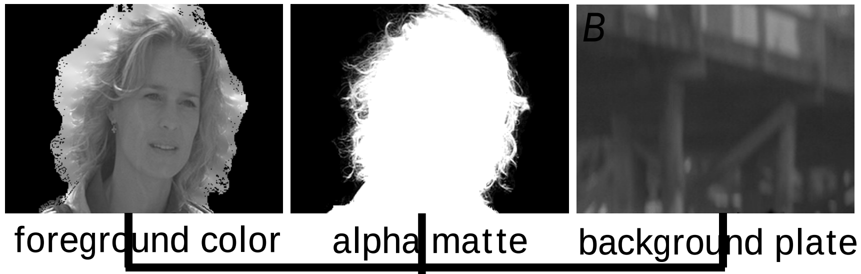
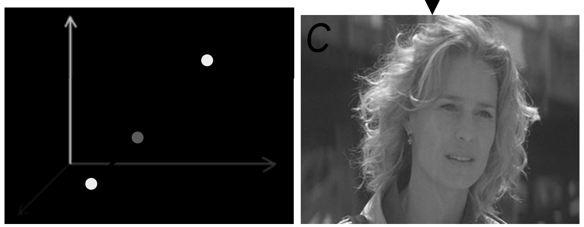
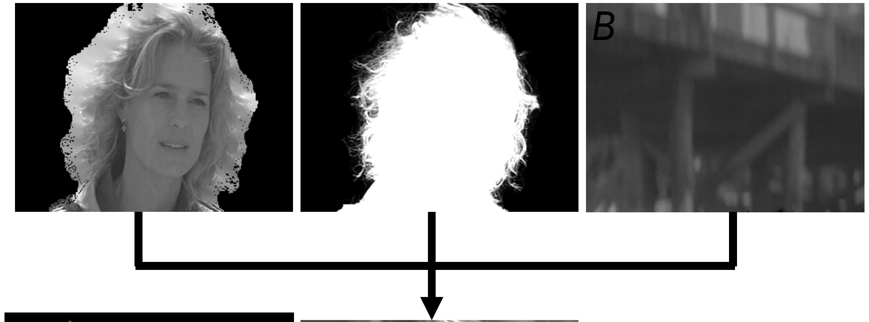


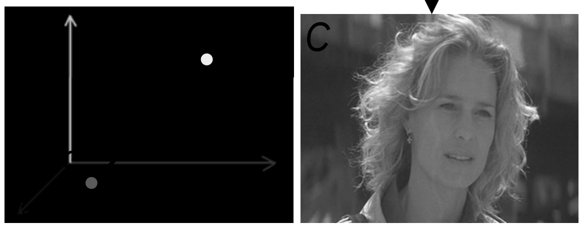


$$C = \alpha F + (1-\alpha)B$$

compositing equation

Compositing

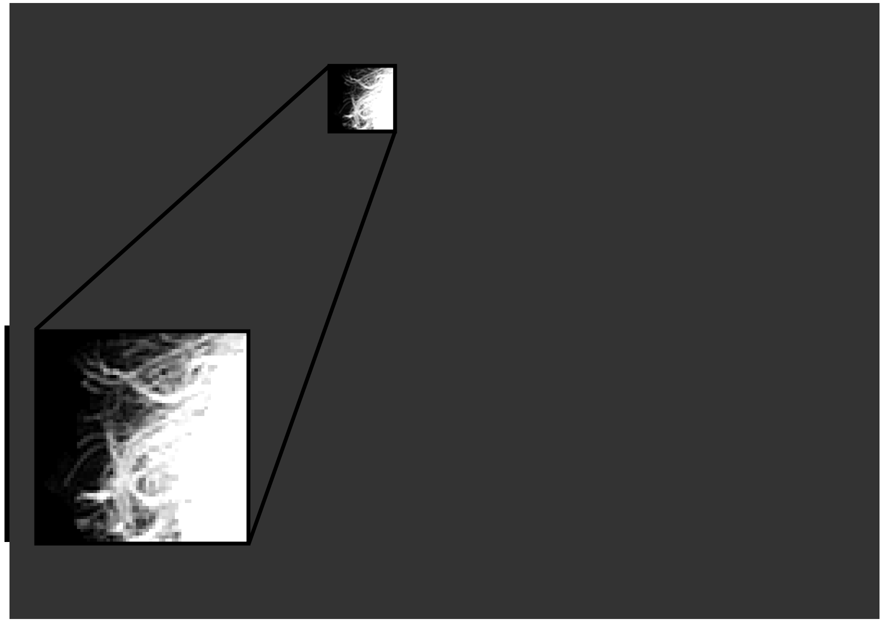


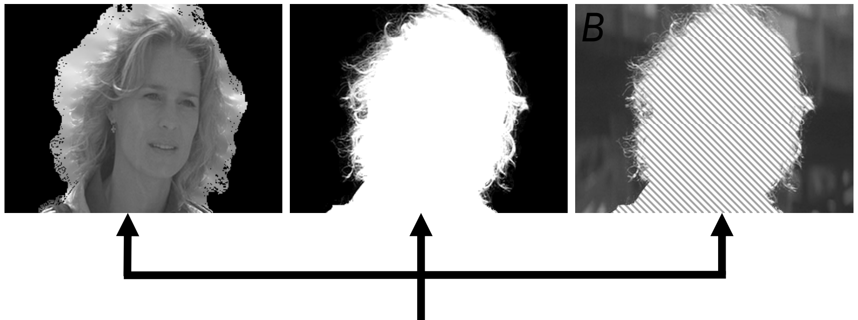


$C = \alpha F + (1-\alpha)B$

compositing
equation

Compositing



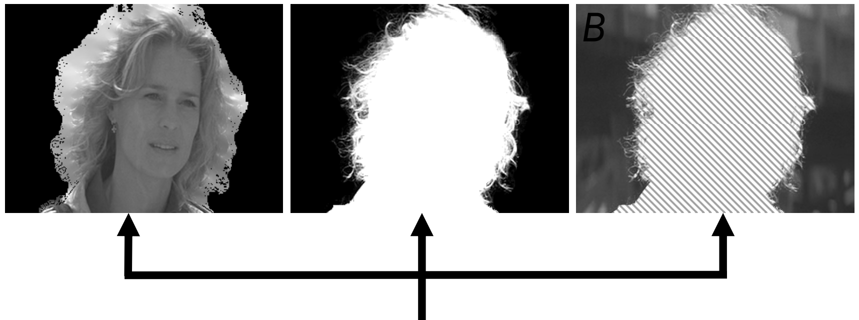


observation

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

compositing
equation

Matting



Three approaches:

1 reduce #unknowns

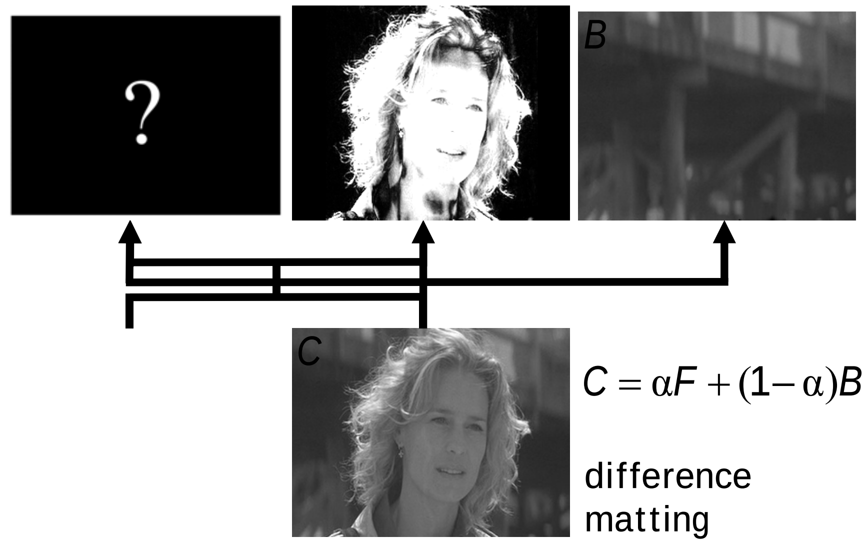
2 add observations

3 add priors

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

compositing
equation

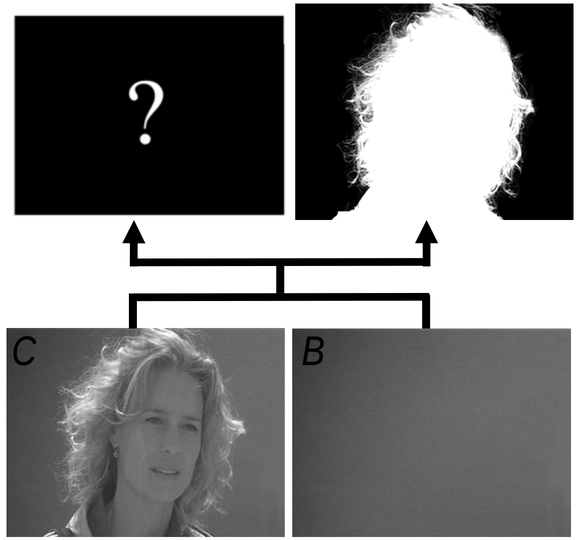
Matting



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

difference matting

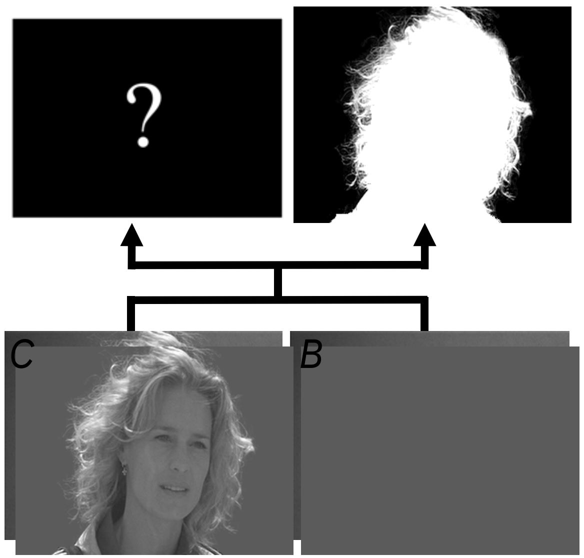
Matting (reduce #unknowns)



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

blue screen matting

Matting (reduce #unknowns)

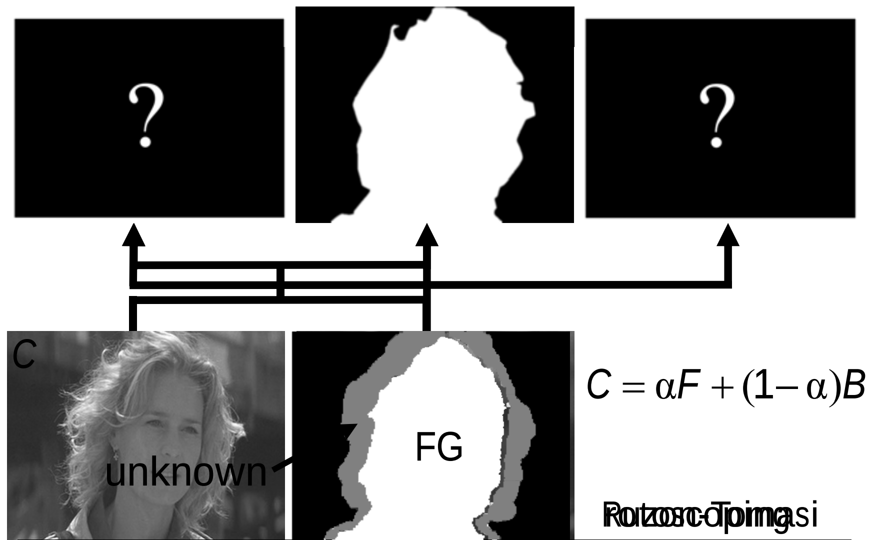


$C = \alpha F + (1-\alpha)B$

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

triangulation

Matting (add observations)



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

Ruzon-Tomasi

Matting (add priors)

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para-
meters

$$z \longrightarrow \boxed{f(z)+\varepsilon} \longrightarrow y$$

observed
signal

$$z^* = \max_z P(z \mid y) = \max_z \frac{P(y \mid z)P(z)}{P(y)} = \max_z L(y \mid z) + L(z)$$

Example:
super-resolution
de-blurring
de-blocking
…

Bayesian framework

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para-
meters

$$z \longrightarrow \boxed{f(z)+\varepsilon} \longrightarrow y$$

observed
signal

$$z^* = \max_z L(y \mid z) + L(z)$$

data
evidence $\dfrac{\|y - f(z)\|^2}{\sigma^2}$

a-priori
knowledge

Bayesian framework

---

posterior probability

likelihood

priors

$$\arg\max_{F,B,\alpha} \boxed{P(F,B,\alpha \mid C)} = \arg\max_{F,B,\alpha} \boxed{P(C \mid F,B,\alpha)}\,\boxed{P(F)\,P(B)\,P(\alpha)} / P(C)$$

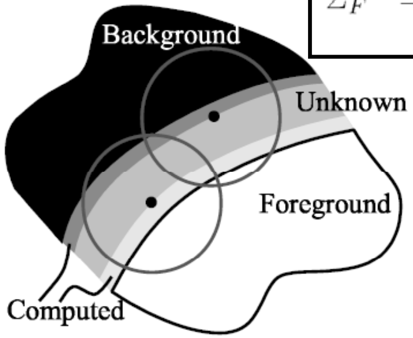
[redacted]

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

Bayesian framework

$$\overline{F} = \frac{1}{W}\sum_{i\in N} w_i F_i$$

$$\Sigma_F = \frac{1}{W}\sum_{i\in N} w_i (F_i - \overline{F})(F_i - \overline{F})^T$$



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

Priors

$$\arg\max_{F,B,\alpha} L(C \mid F, B, \alpha) + L(F) + L(B)$$

$$\begin{aligned}\arg\max_{F,B,\alpha} & -\|C - \alpha F - (1-\alpha)B\|^2/\sigma_C^2 \\ & -(F - \overline{F})^T \Sigma_F^{-1} (F - \overline{F}) / 2 \\ & -(B - \overline{B})^T \Sigma_B^{-1} (B - \overline{B}) / 2\end{aligned}$$

Bayesian matting

repeat

1. fix alpha

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

2. fix F and B

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

until converge

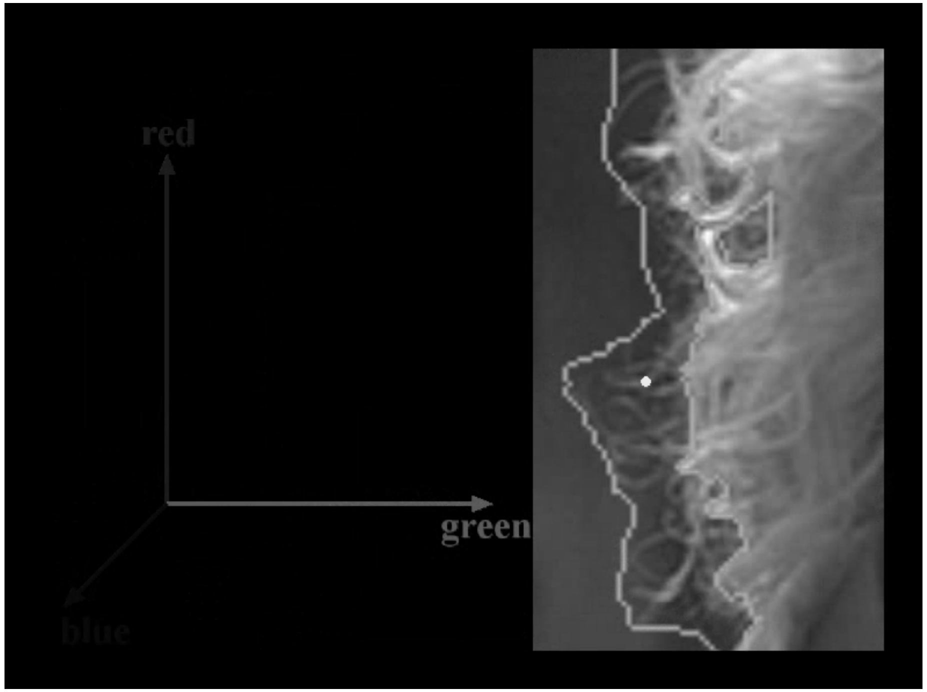
Optimization

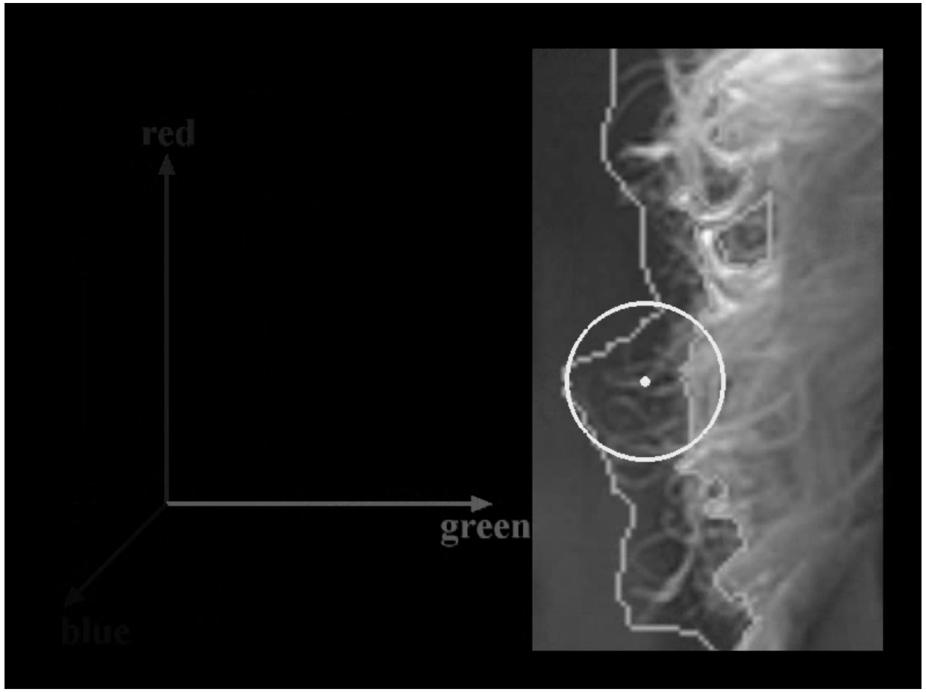
Bayesian image matting

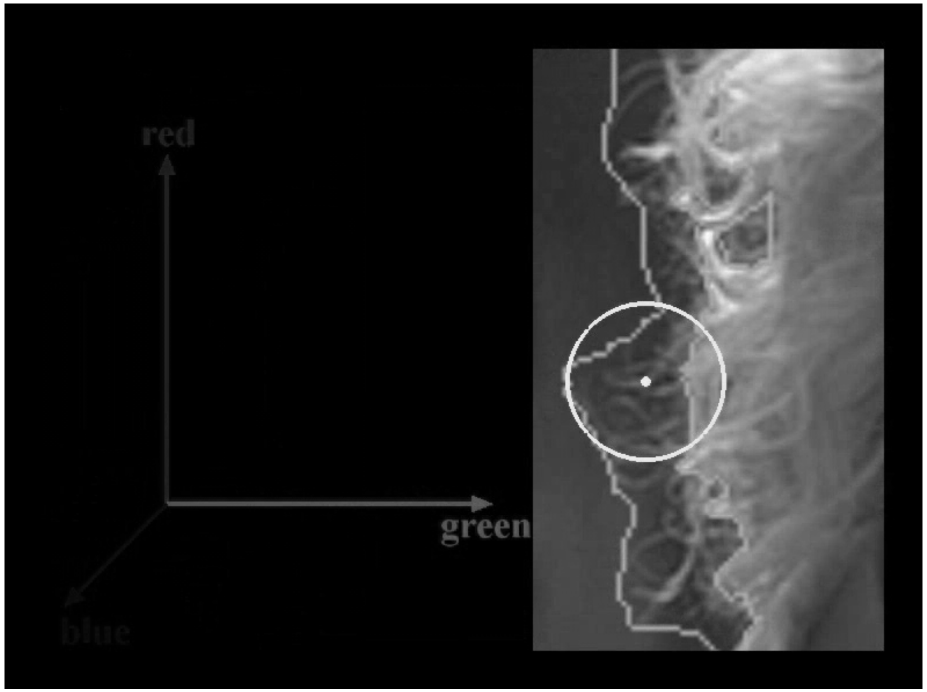
Bayesian image matting

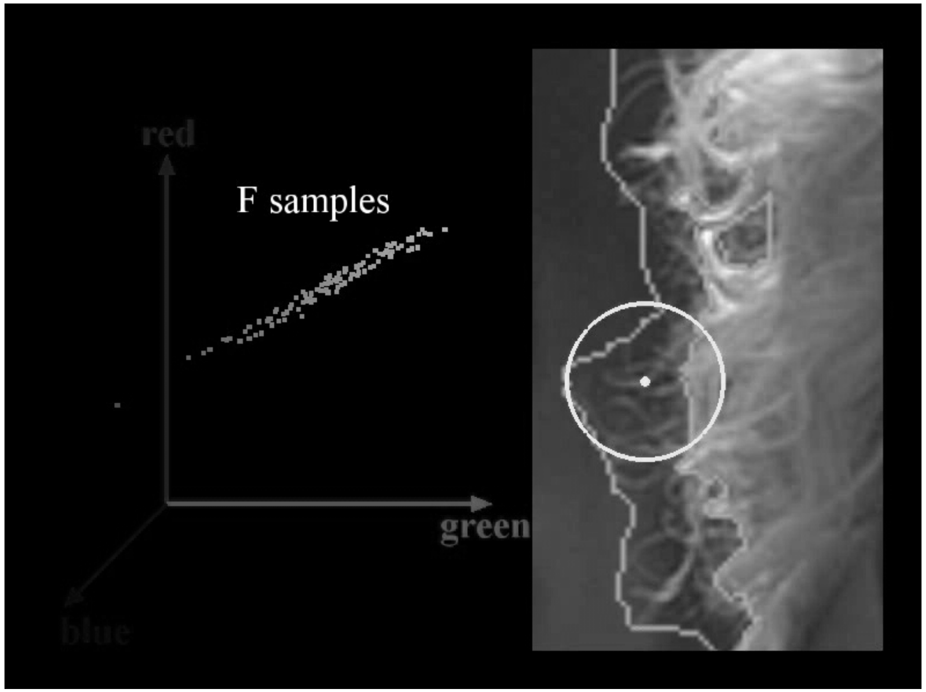
Bayesian image matting

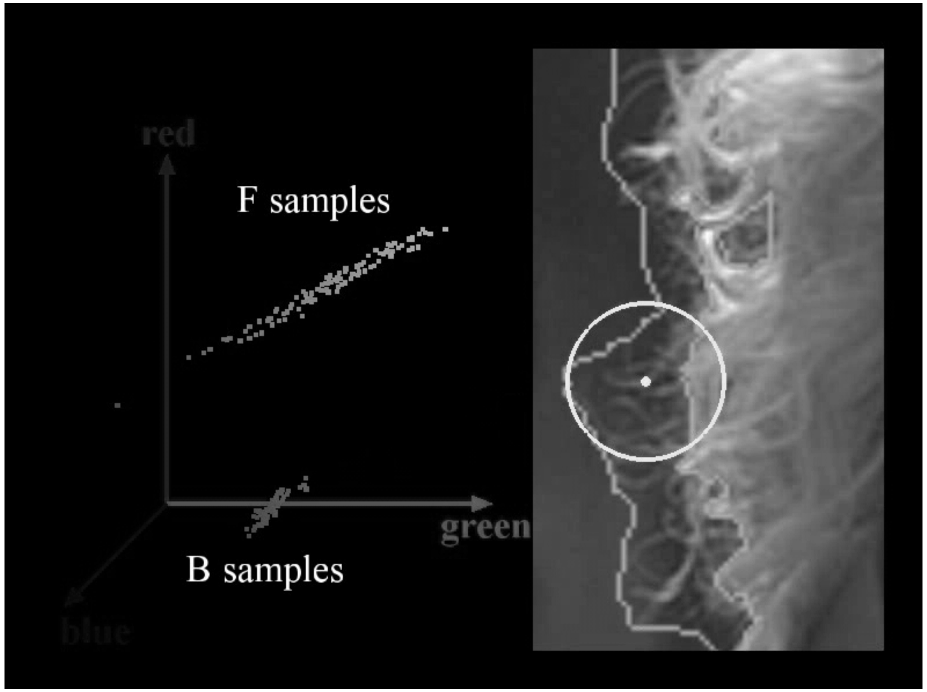
Bayesian image matting

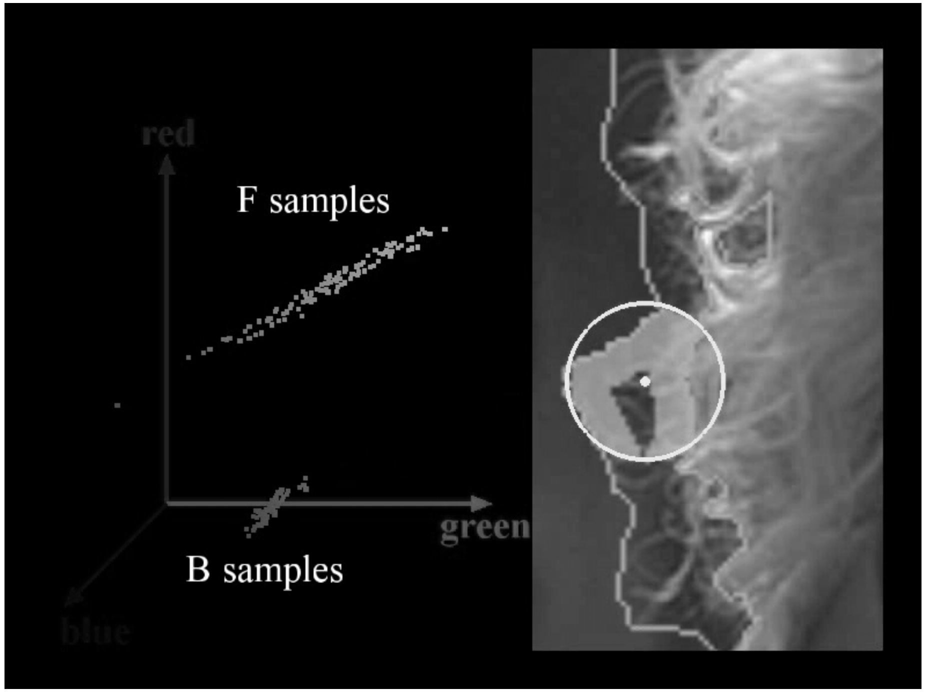

red
green
blue

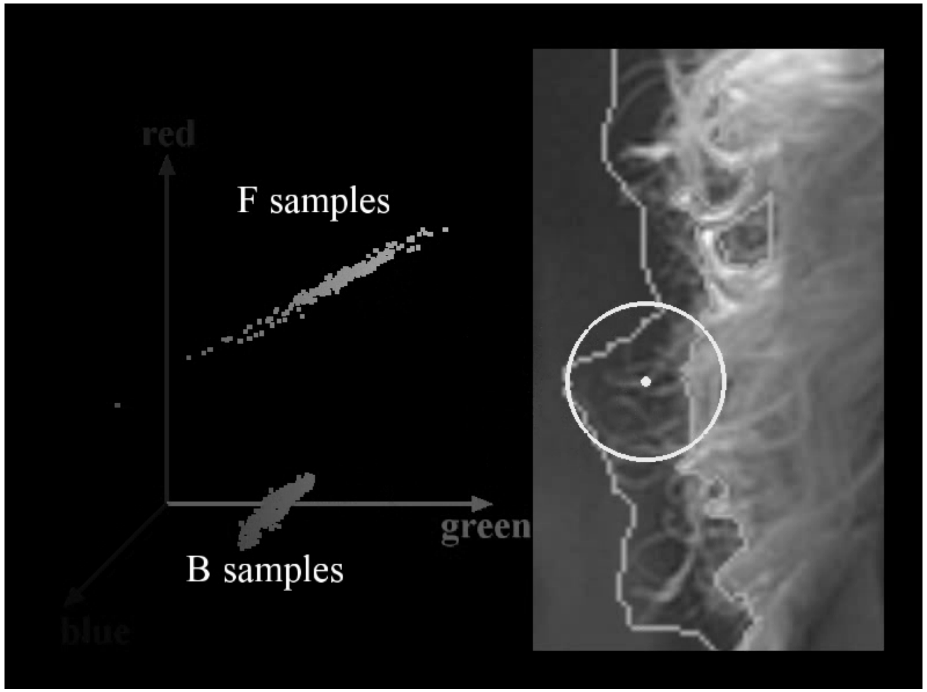

red
green
blue

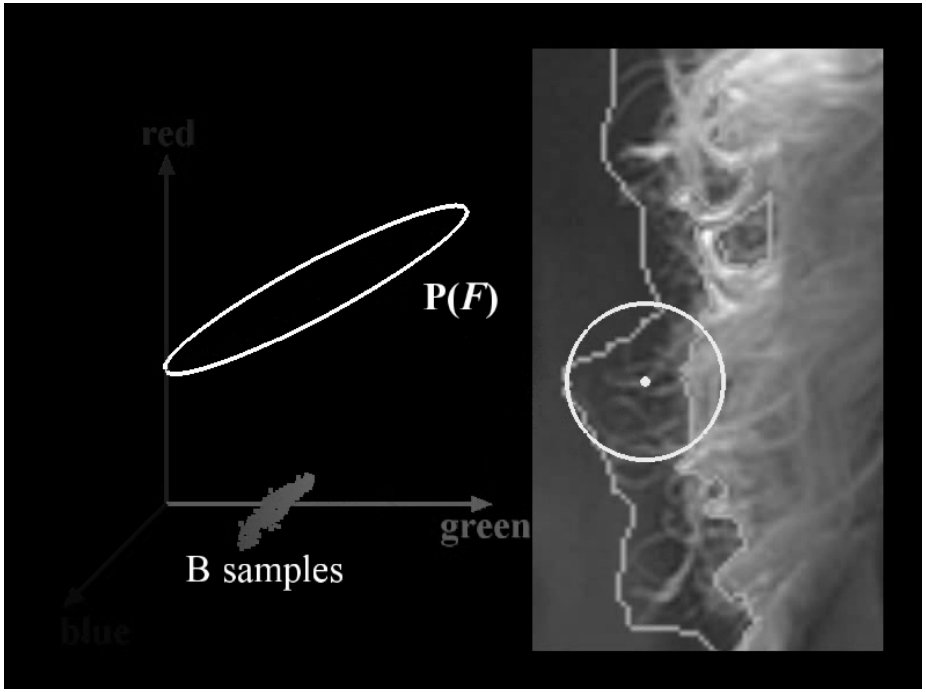

red
green
blue

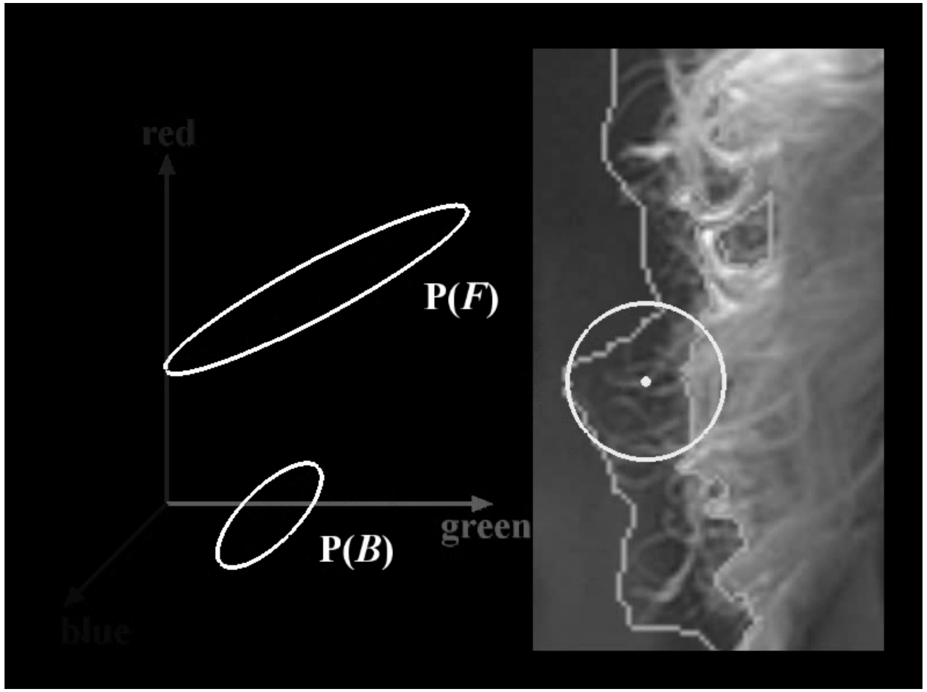

red
F samples
green
blue

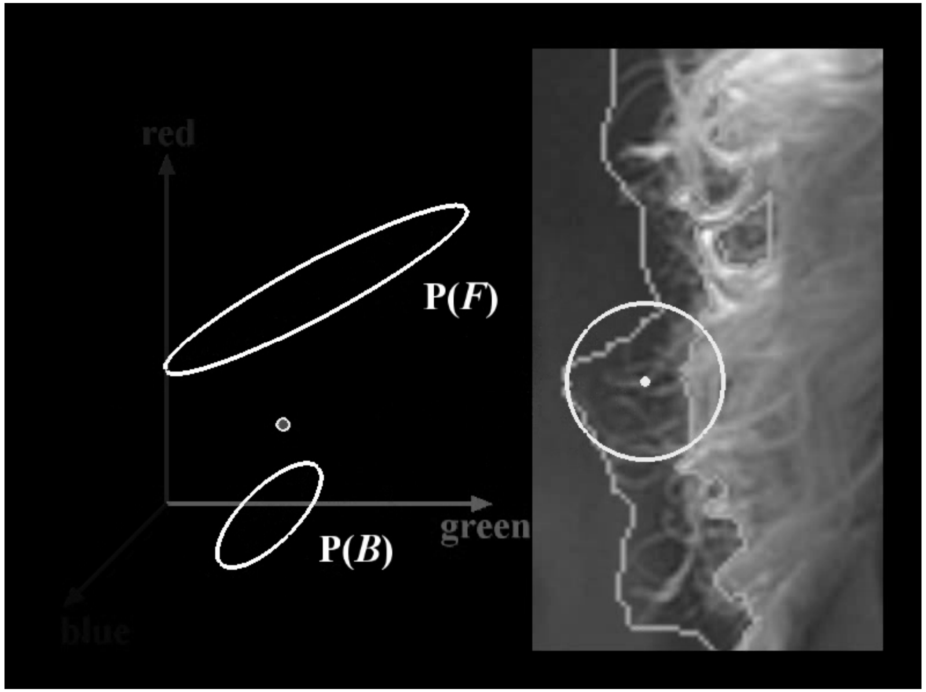

red
F samples
green
B samples
blue

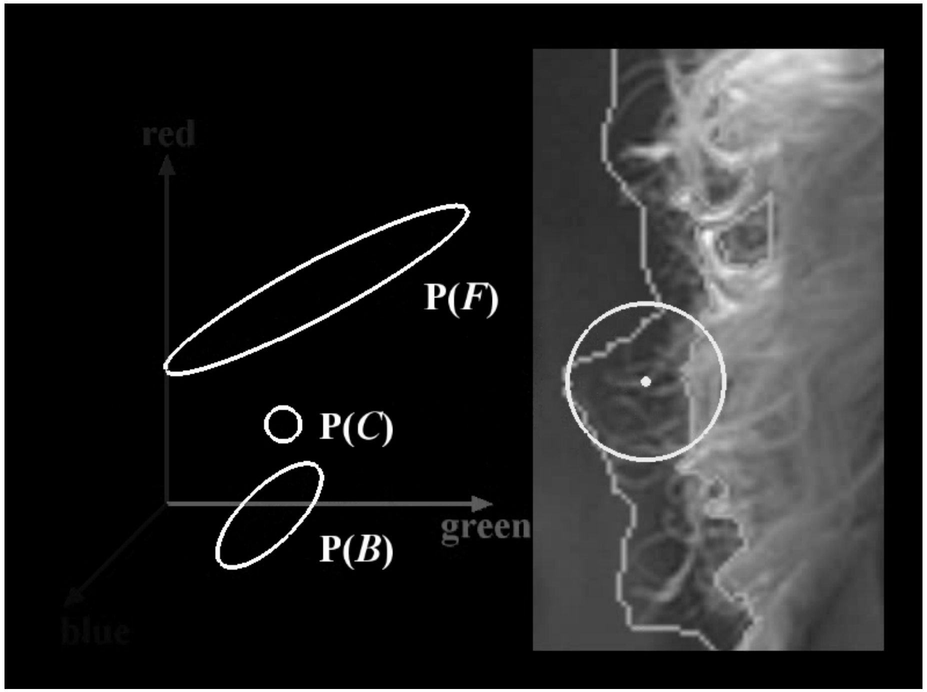

red
F samples
green
B samples
blue

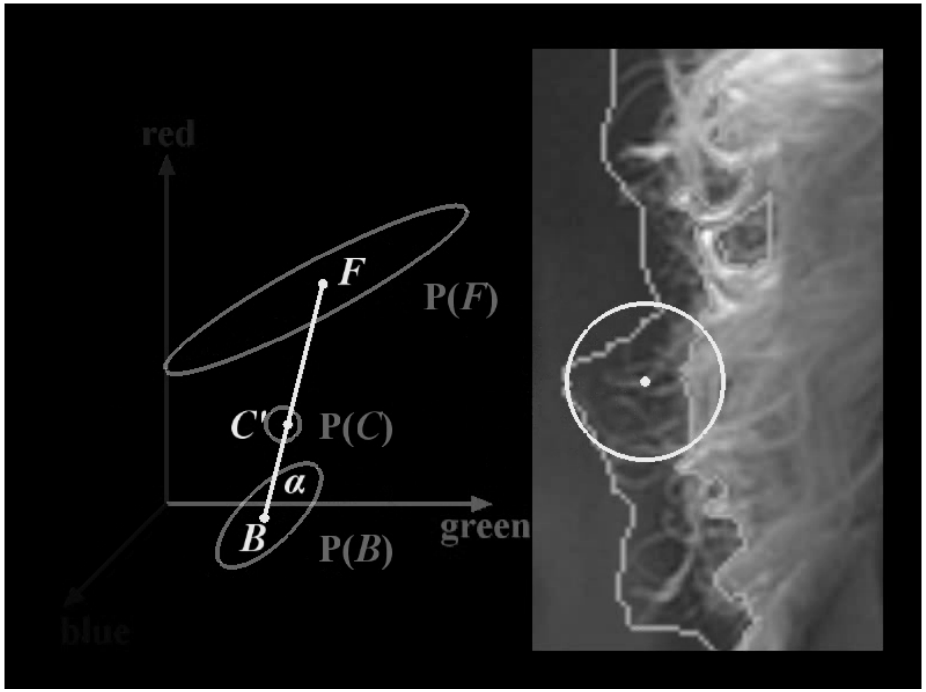

red
F samples
green
B samples
blue


red
P(F)
green
B samples
blue


red
P(F)
P(B)
green
blue

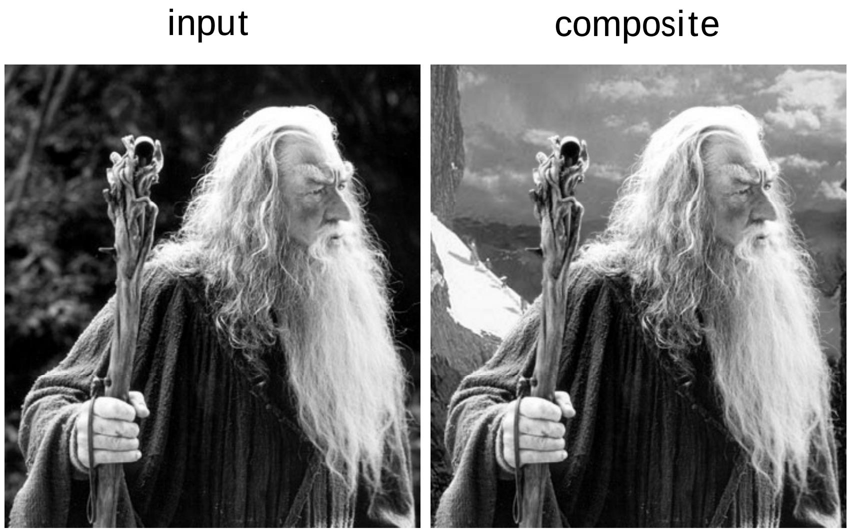

red
P(F)
P(B)
green
blue


red
P(F)
P(C)
P(B)
green
blue

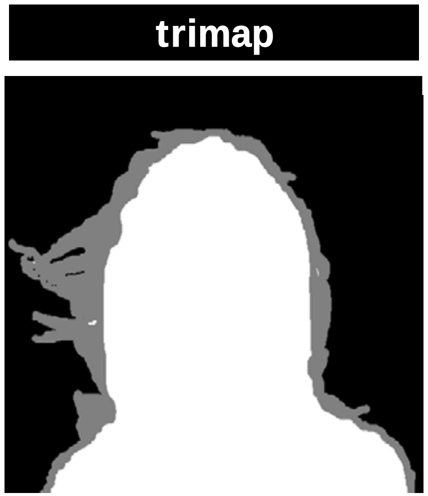

red
F
P(F)
C'
P(C)
α
B
P(B)
green
blue

Demo

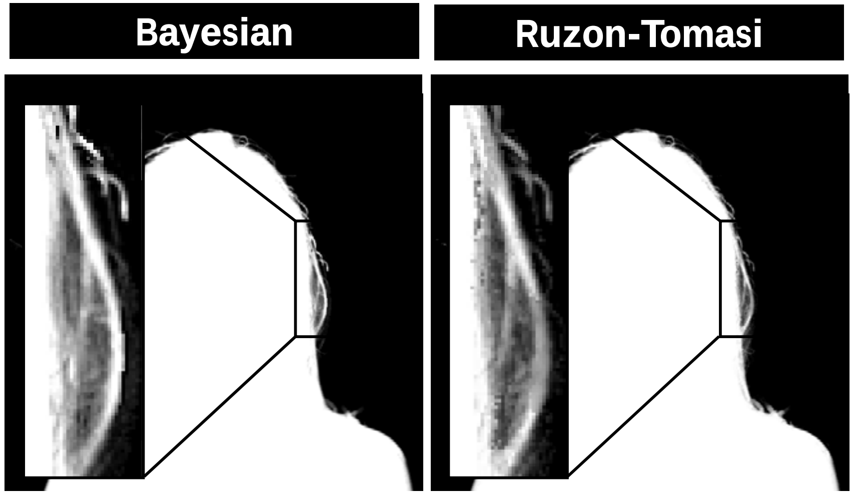
Results



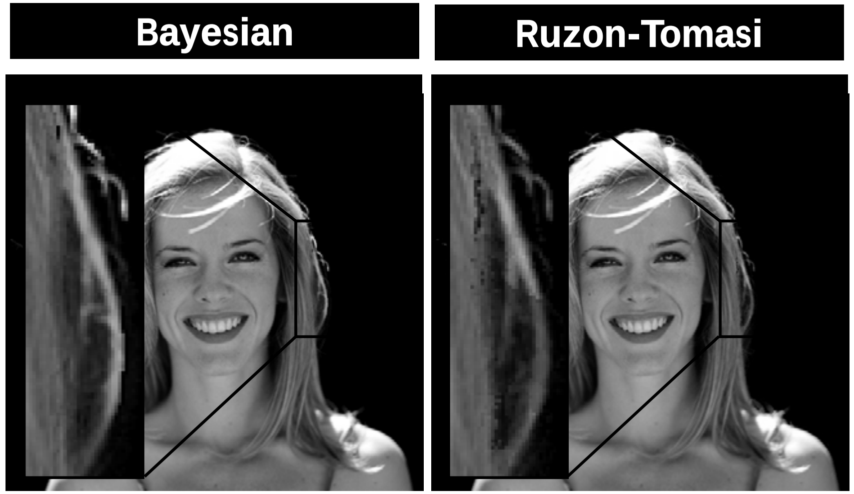
Results



Comparisons



Comparisons



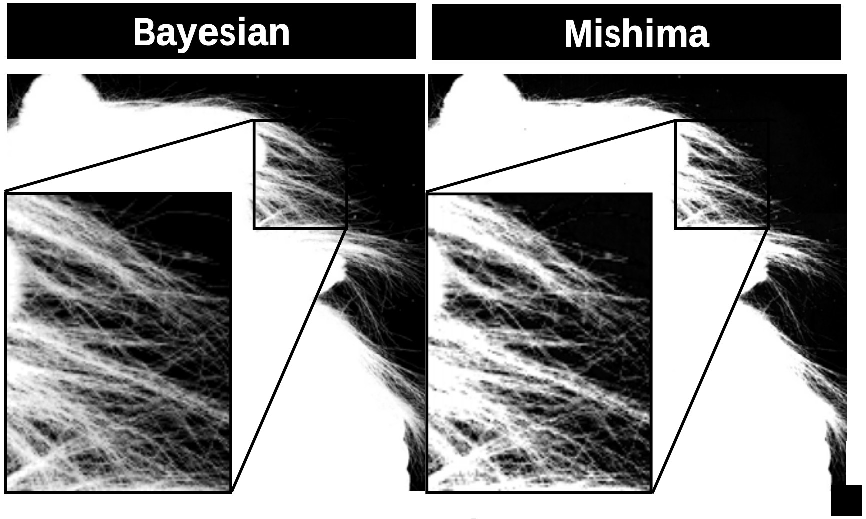
Comparisons

Comparisons

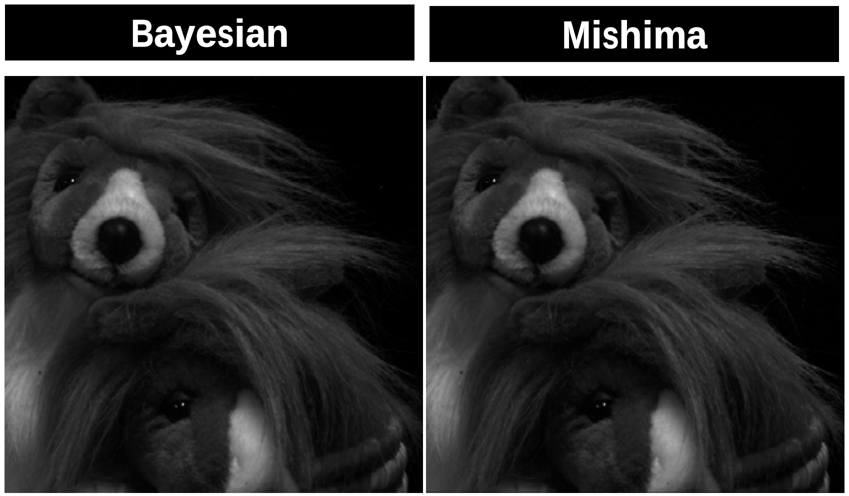
Comparisons

input image

Comparisons



Comparisons



Comparisons

input video

Video matting

input video

input key trimaps

Video matting

input video

interpo-lated trimaps

Video matting

input video

interpo-lated trimaps

output alpha

Video matting

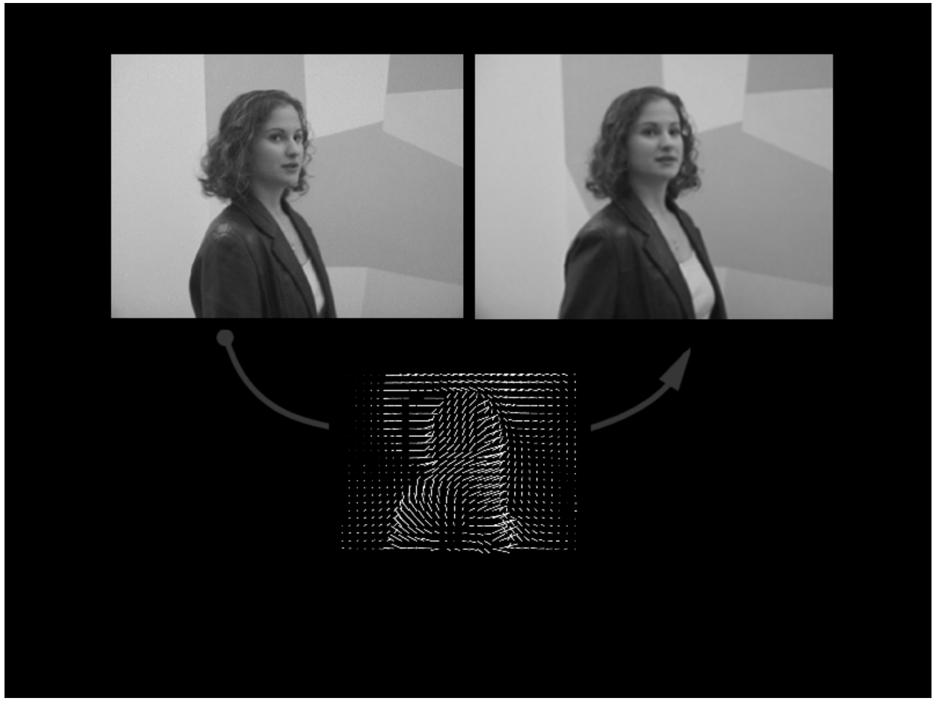
input video

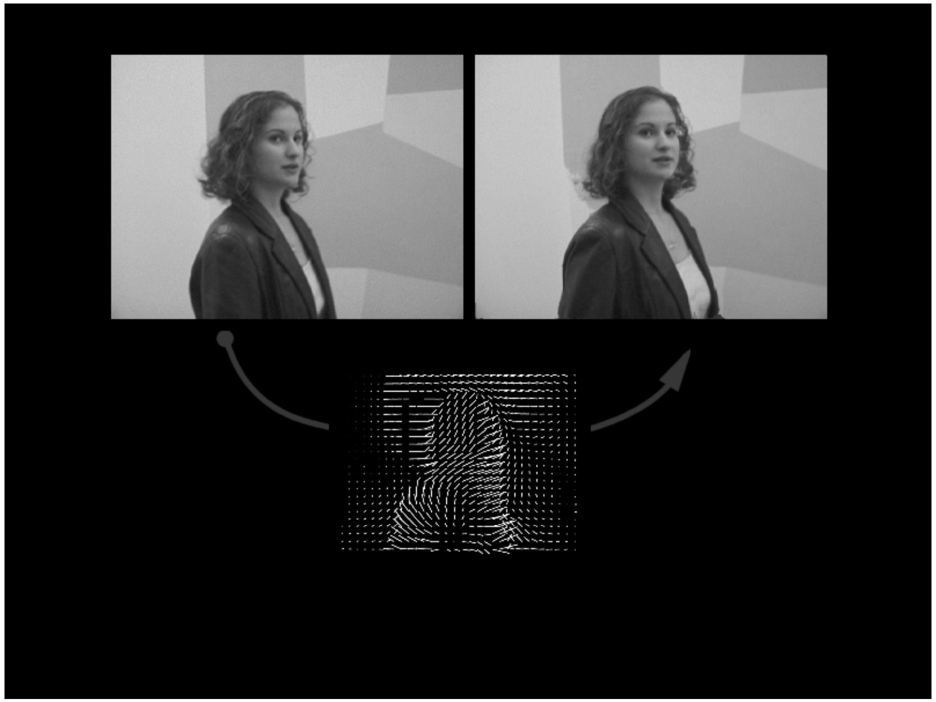
Compo-site

interpo-lated trimaps

output alpha

Video matting





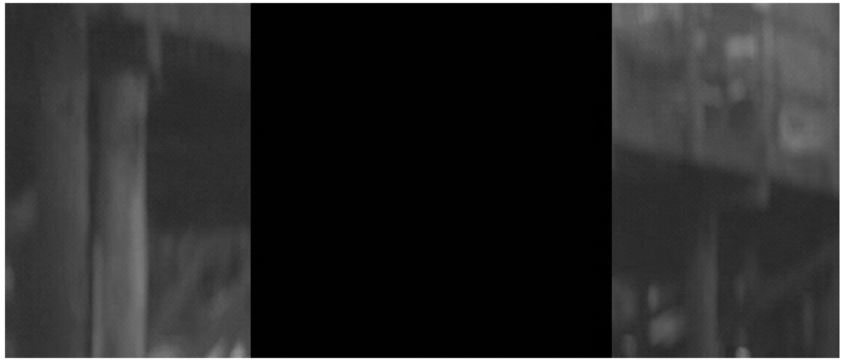

t
t+1
t+2
t+3


t
t+1
t+2
t+3

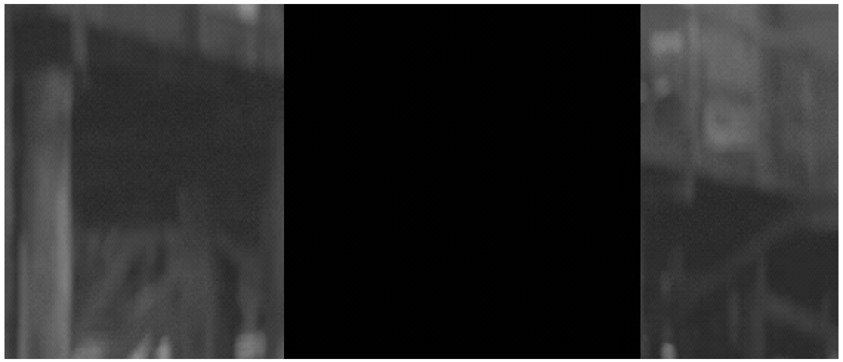

t
t+1
t+2
t+3

Sample composite

Garbage mattes



Garbage mattes



Background estimation

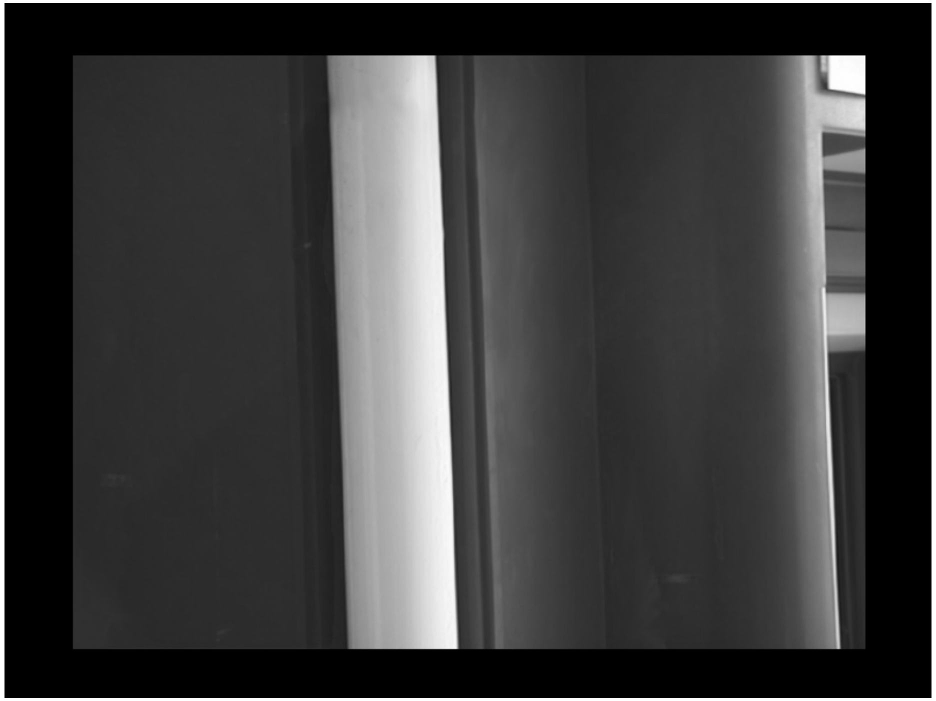
Background estimation

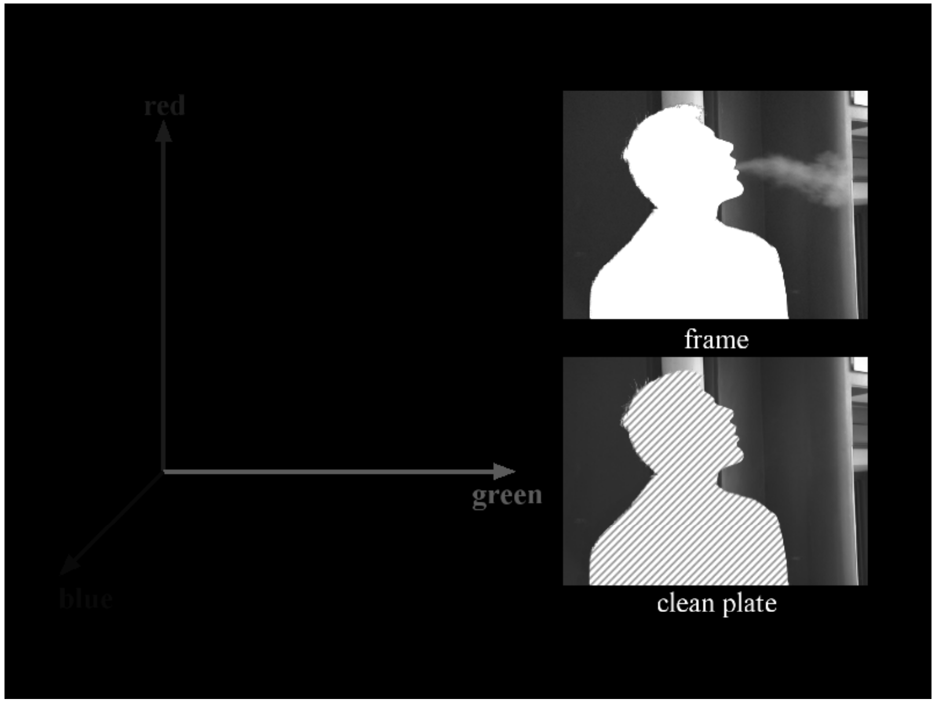
Alpha matte

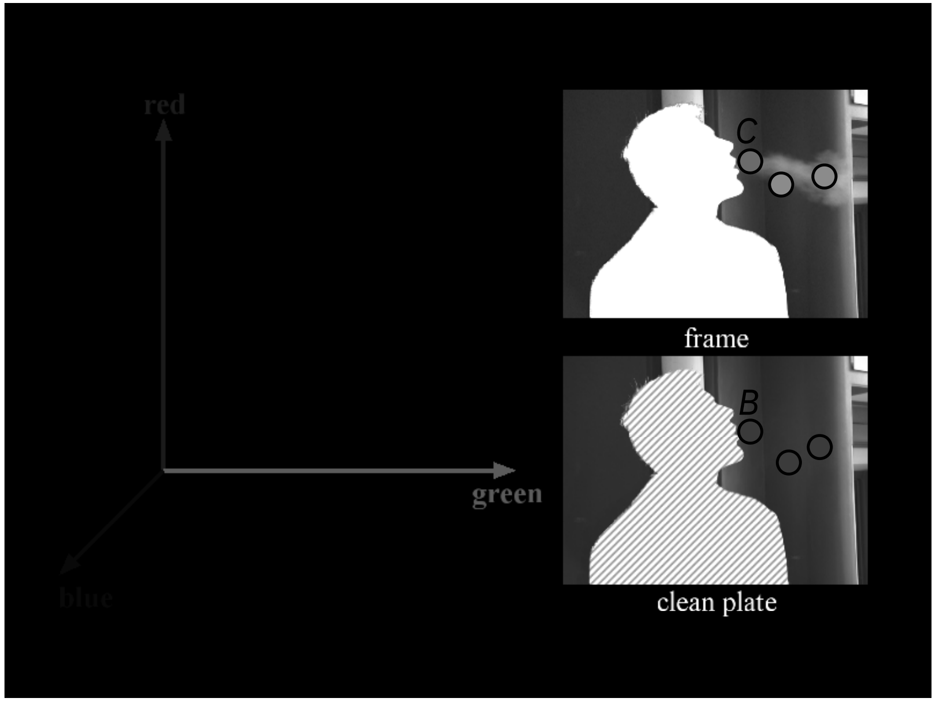
without background

with background

Comparison




red
green
blue
frame
clean plate


red
green
blue
C
frame
B
clean plate

Problems with Bayesian matting

- It requires fine trimaps for good results
- It is tedious to generate fine trimaps
- Its performance rapidly degrades when foreground and background patterns become complex
- There is no direct and local control to the resulted mattes

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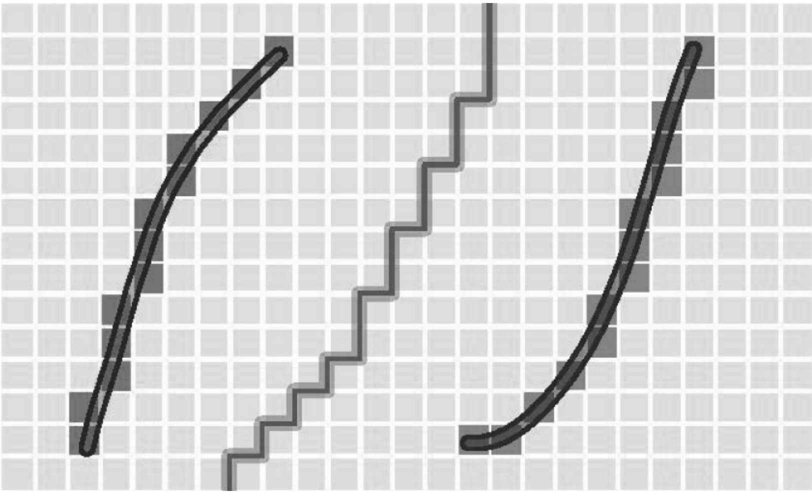
Scribble-based input

trimap

scribble

Motivation

LazySnapping



$$E(X) = \sum_{i\in\mathcal{V}} \boxed{E_1(x_i)} + \lambda \sum_{(i,j)\in\mathcal{E}} E_2(x_i,x_j)$$

$$\begin{array}{llll}
E_1(x_i=1) = 0 & E_1(x_i=0) = \infty & \forall i \in \mathcal{F} \\
E_1(x_i=1) = \infty & E_1(x_i=0) = 0 & \forall i \in \mathcal{B} \\
E_1(x_i=1) = \frac{d_i^{\mathcal{F}}}{d_i^{\mathcal{F}} + d_i^{\mathcal{B}}} & E_1(x_i=0) = \frac{d_i^{\mathcal{B}}}{d_i^{\mathcal{F}} + d_i^{\mathcal{B}}} & \forall i \in \mathcal{U}
\end{array}$$

LazySnapping

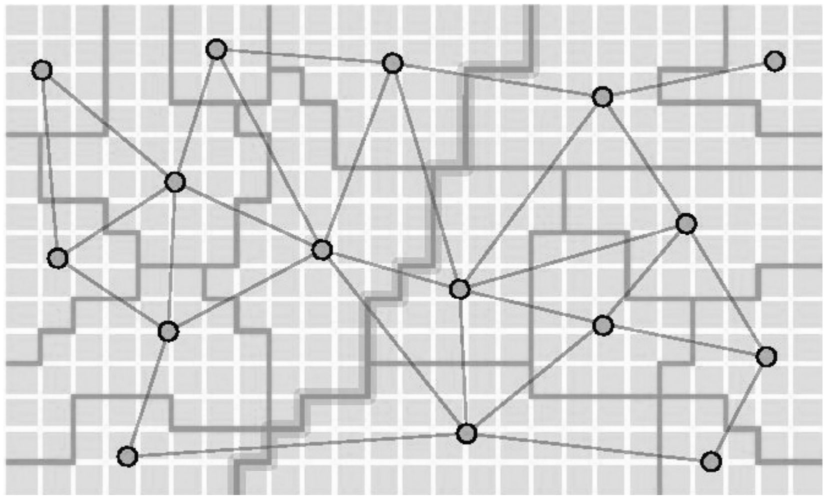
$$E(X) = \sum_{i\in\mathcal{V}} E_1(x_i) + \lambda \sum_{(i,j)\in\mathcal{E}} \boxed{E_2(x_i,x_j)}$$

$$E_2(x_i,x_j) = |x_i - x_j| \cdot g(C_{ij})$$

$$C_{ij} = ||C(i) - C(j)||^2$$

$$g(\varepsilon) = \frac{1}{\varepsilon + 1}$$

LazySnapping



LazySnapping

Matting approaches

- Sampling approaches: solve for each alpha separately by utilizing local fg/bg samples, e.g. Ruzon/Tomasi, Knockout and Bayesian matting.
- Propagation approaches: solve the whole matte together by optimizing, e.g. Poisson, BP, random walker, closed-form and robust matting.

Poisson matting

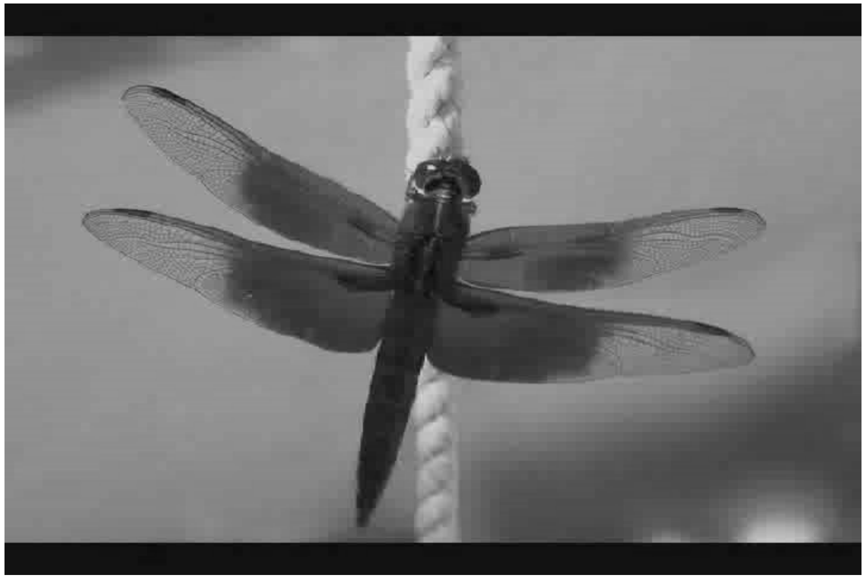
$$I = \alpha F + (1-\alpha)B$$

$$\nabla I = (F-B)\nabla\alpha + \alpha\nabla F + (1-\alpha)\nabla B$$

$$\nabla\alpha \approx \frac{1}{F-B}\nabla I$$

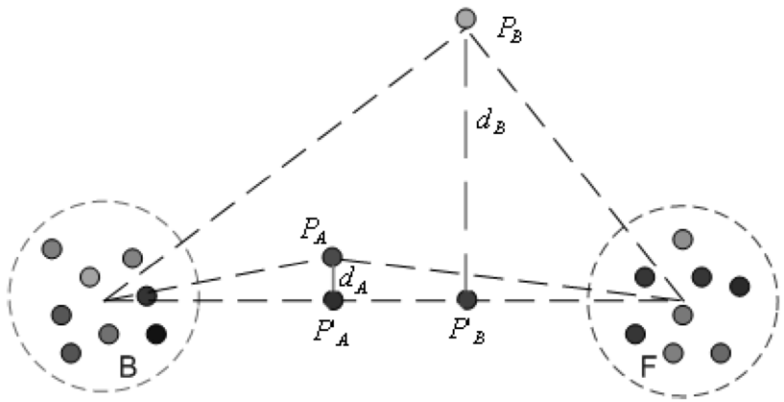
$$\alpha^* = \arg\min_{\alpha} \int\int_{p\in\Omega} ||\nabla\alpha_p - \frac{1}{F_p - B_p}\nabla I_p||^2 dp$$

Poisson matting



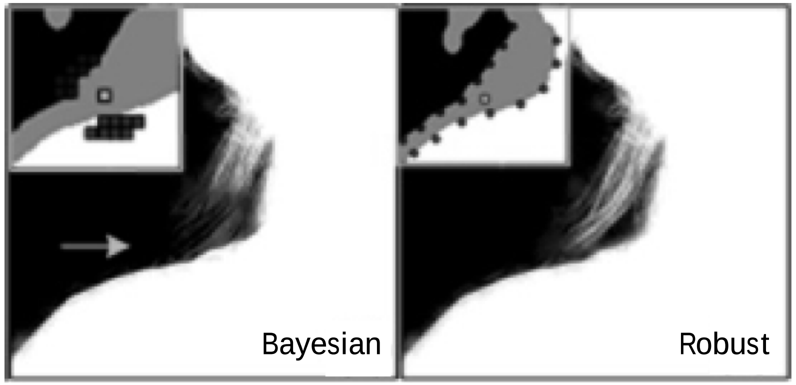
Robust matting

- Jue Wang and Michael Cohen, CVPR 2007



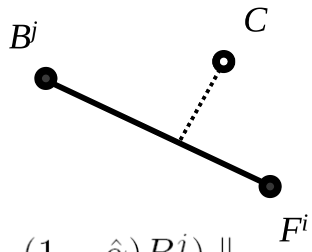
Robust matting

- Instead of fitting models, a non-parametric approach is used



Robust matting

- We must evaluate hypothesized foreground/background pairs



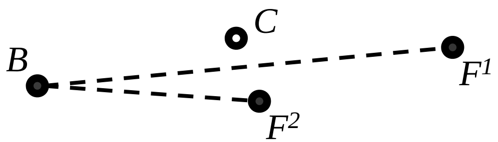
$$\hat{\alpha} = \frac{(C - B^j)(F^i - B^j)}{\| F^i - B^j \|^2}$$

distance ratio

$$R_d(F^i, B^j) = \frac{\| C - (\hat{\alpha} F^i + (1 - \hat{\alpha}) B^j) \|}{\| F^i - B^j \|}$$

Robust matting

- To encourage pure fg/bg pixels, add weights



$$w(F^i) = exp\left\{ - \| F^i - C \|^2 / D_F^2 \right\}$$

$$\min_i(\| F^i - C \|)$$

$$w(B^j) = exp\left\{ - \| B^j - C \|^2 / D_B^2 \right\}$$

$$\min_j(\| B^j - C \|)$$

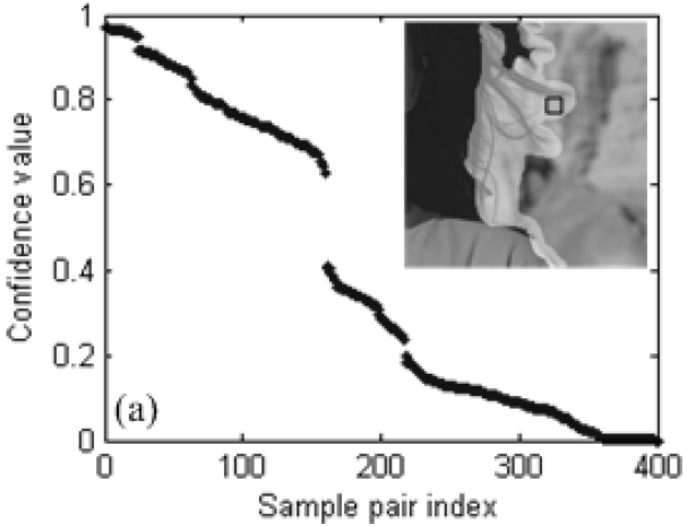
Robust matting

- Combine them together. Pick up the best 3 pairs and average them

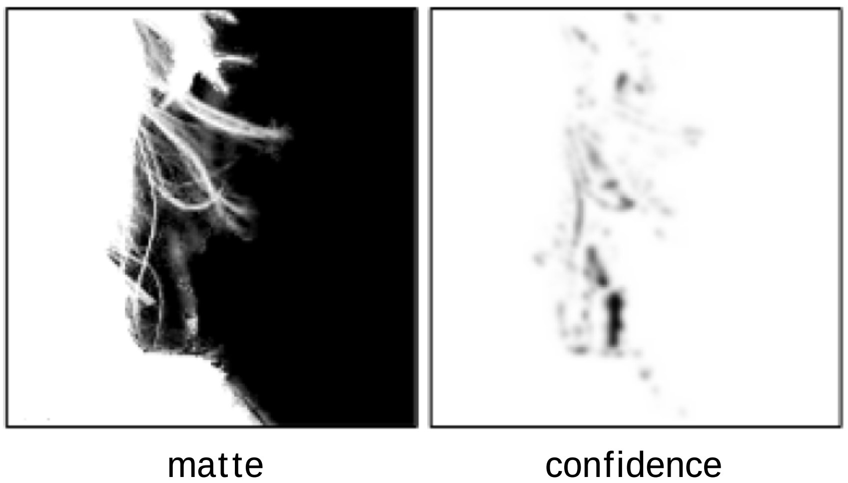
confidence

$$f(F^i, B^j) = exp\left\{ - \frac{R_d(F^i, B^j)^2 \cdot w(F^i) \cdot w(B^j)}{\sigma^2} \right\}$$

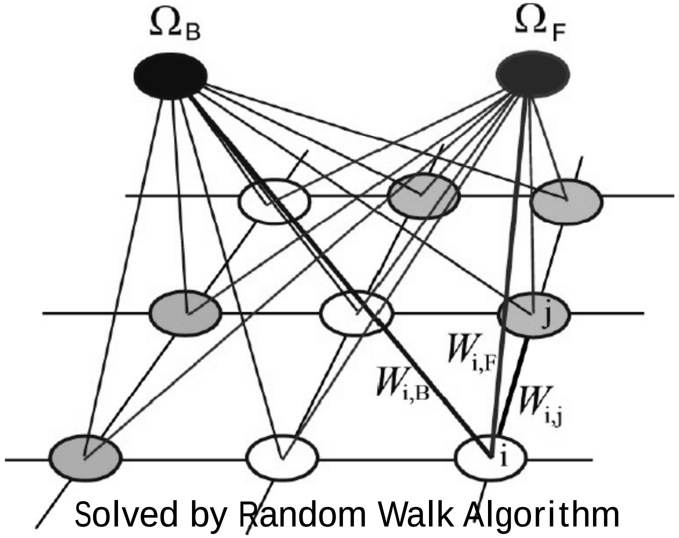
Robust matting



Robust matting



Matte optimization



Solved by Random Walk Algorithm

Matte optimization

data constraints

$$W(i,F) = \gamma \cdot [\hat{f}_i \hat{\alpha}_i + (1-\hat{f}_i)\delta(\hat{\alpha}_i > 0.5)]$$

$$W(i,B) = \gamma \cdot [\hat{f}_i (1-\hat{\alpha}_i) + (1-\hat{f}_i)\delta(\hat{\alpha}_i < 0.5)]$$

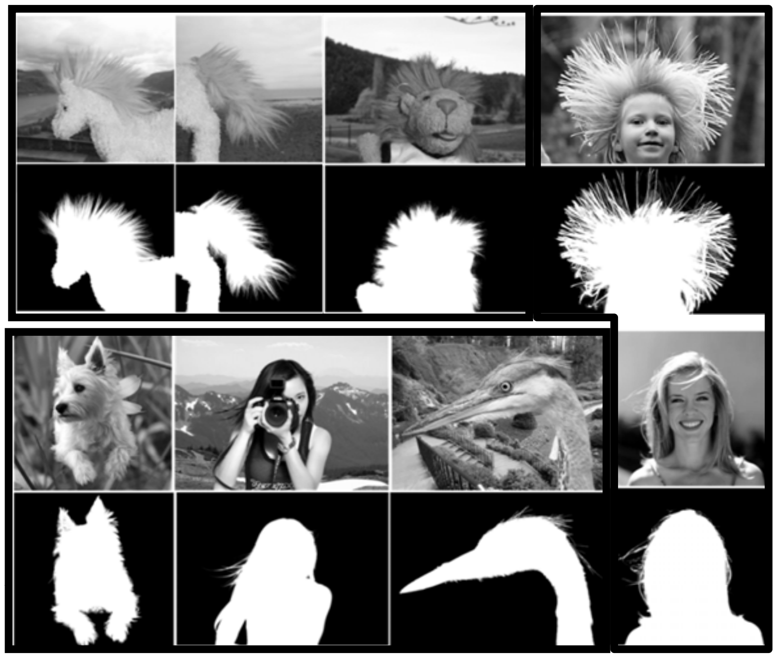
neighborhood constraints

$$W_{ij} = \sum_{k}^{(i,j)\in w_k} \frac{1}{9}(1+(C_i-\mu_k)(\Sigma_k+\frac{\epsilon}{9}I)^{-1}(C_j-\mu_k))$$

Demo (EZ Mask)

Evaluation

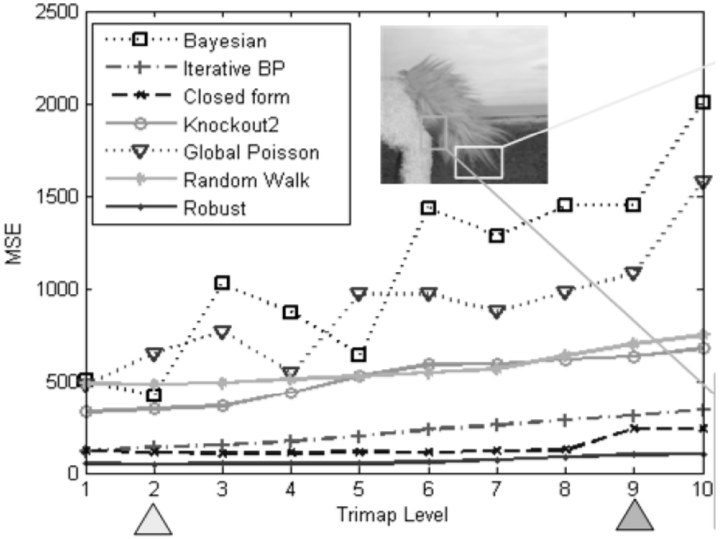
- 8 images collected in 3 different ways
- Each has a “ground truth” matte



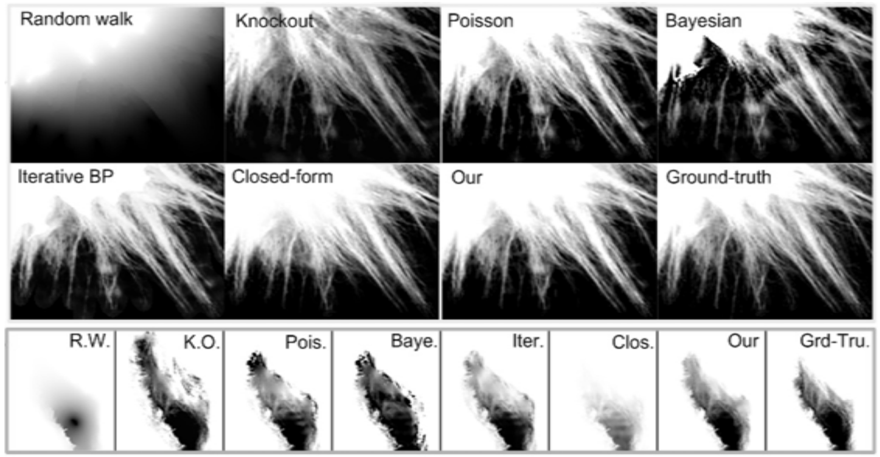
Evaluation

- Mean square error is used as the accuracy metric
- Try 8 trimaps with different accuracy for testing robustness
- 7 methods are tested: Bayesian, Belief propagation, Poisson, Random Walk, KnockOut2, Closed-Form and Robust matting

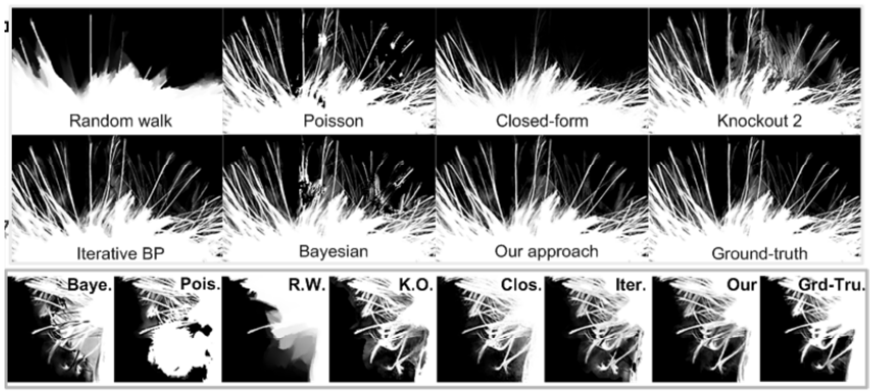
Quantitative evaluation



Subjective evaluation



Subjective evaluation



Ranks of these algorithms

	accuracy	robustness
Poisson	**6.9**	**6.8**
Random walk	**6.0**	**4.4**
Knockout2	**4.5**	**4.5**
Bayesian	**3.9**	**6.0**
Belief Propagation	**3.3**	**3.1**
Close-form	**2.6**	**2.0**
Robust matting	**1.0**	**1.3**

Summary

- Propagation-based methods are more robust
- Sampling-based methods often generate more accurate mattes than propagation-based ones with fine trimaps
- Robust matting combines strengths of both

New evaluation (CVPR 2009)

- http://www.alphamatting.com/

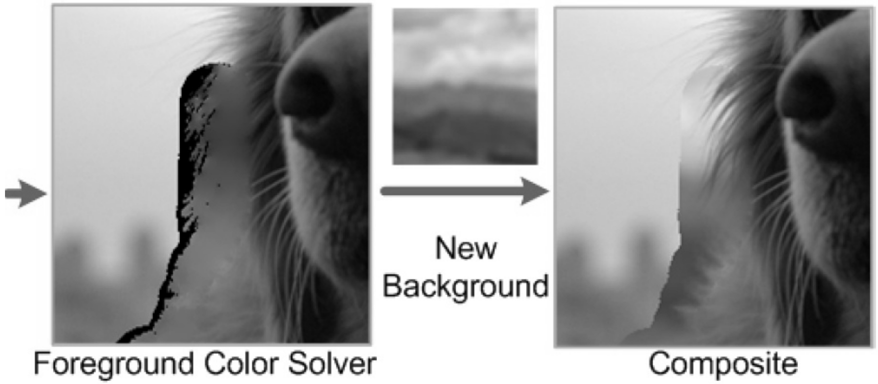
Method	SAD	MSE	Grad.	Conn.
Closed-form [13]	**1.3**	**1.4**	**1.5**	2.0
Robust matting [23]	1.9	1.8	1.7	3.4
Random walk [8]	3.3	3.2	3.5	**1.3**
Easy matting [9]	4.0	4.4	4.2	3.7
Bayesian matting [6]	4.5	4.3	4.3	5.0
Poisson matting [20]	5.9	5.9	6.0	5.6

Soft scissor

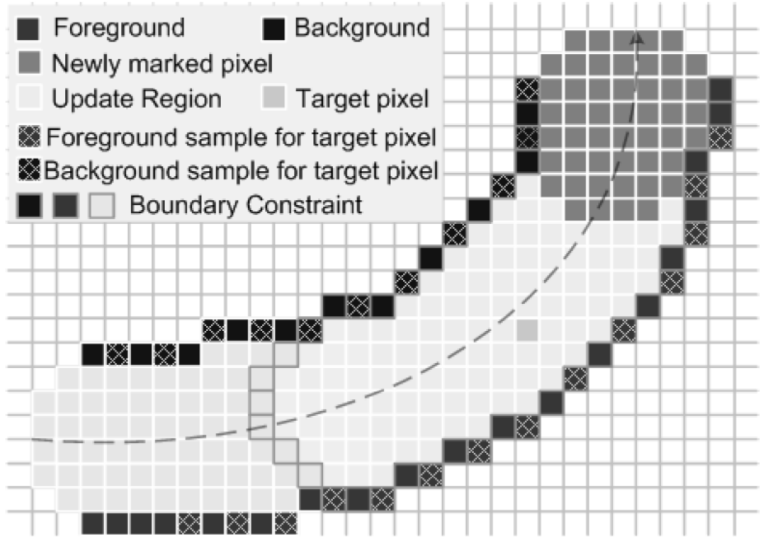
- Jue Wang et. al., SIGGRAPH 2007
- Users interact in a similar way to intelligent scissors

Flowchart

Flowchart



Soft scissor



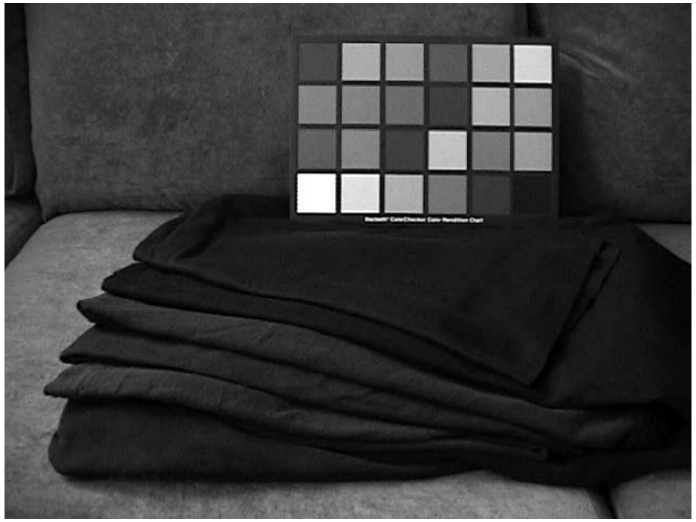
Demo (Power Mask)

Outline

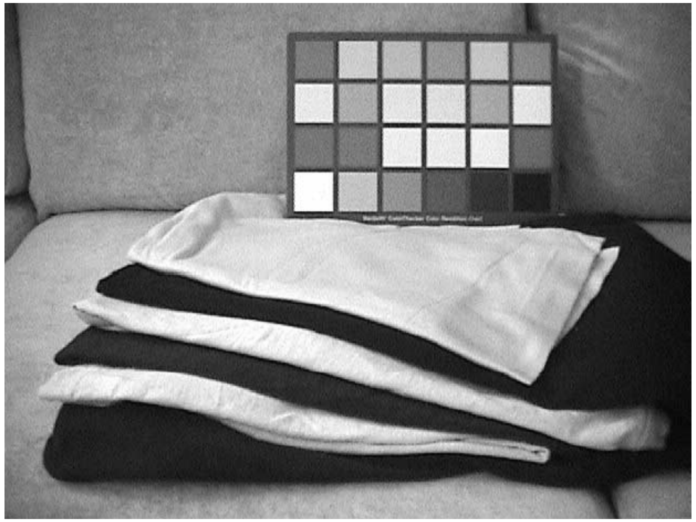
- Traditional matting and compositing
- The matting problem
- Bayesian matting and extensions
- Matting with less user inputs
- Matting with multiple observations
- Beyond the compositing equation*
- Conclusions

Matting with multiple observations

- Invisible lights
  - Polarized lights
  - Infrared
- Thermo-key
- Depth Keying (ZCam)
- Flash matting

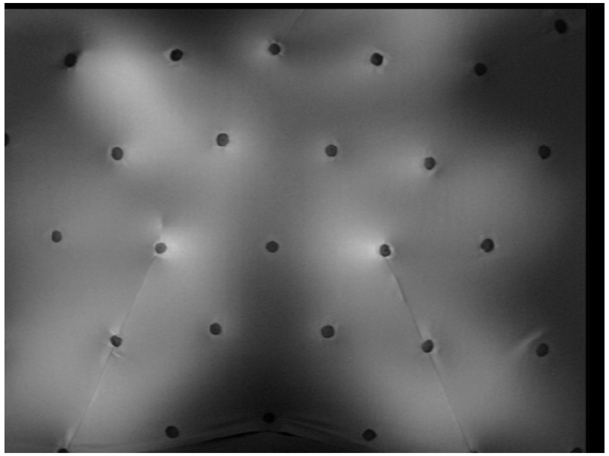


Invisible lights (Infared)



Invisible lights (Infared)

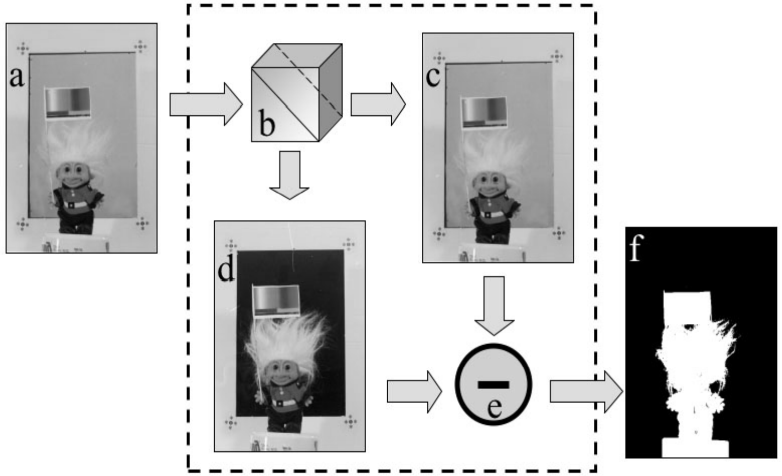
Invisible lights (Infared)



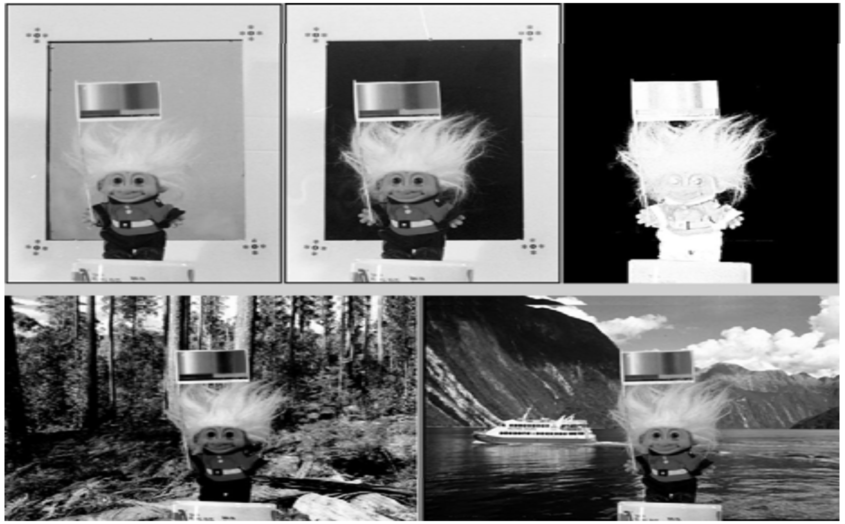
Invisible lights (Infared)

Invisible lights (Infared)

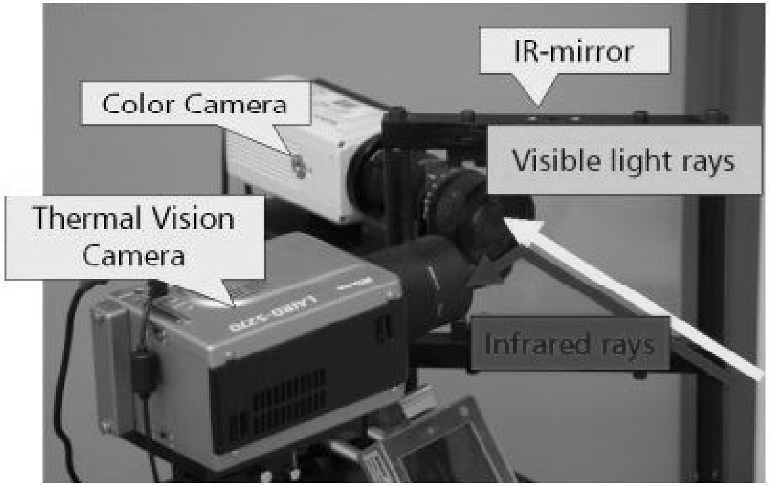
Invisible lights (Infared)



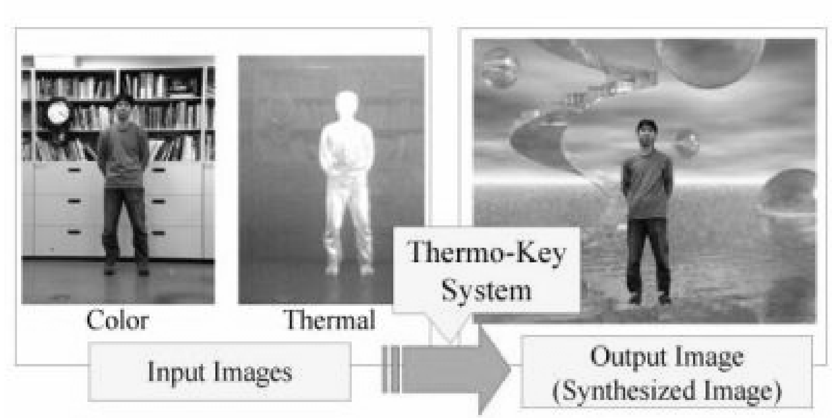
Invisible lights (Polarized)



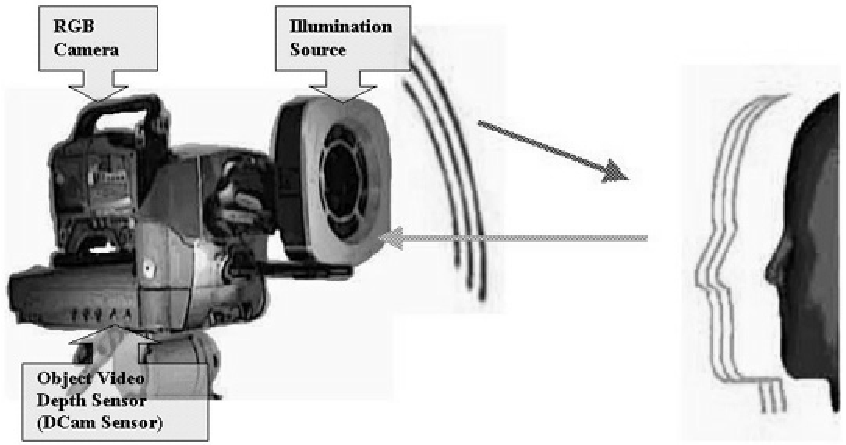
Invisible lights (Polarized)



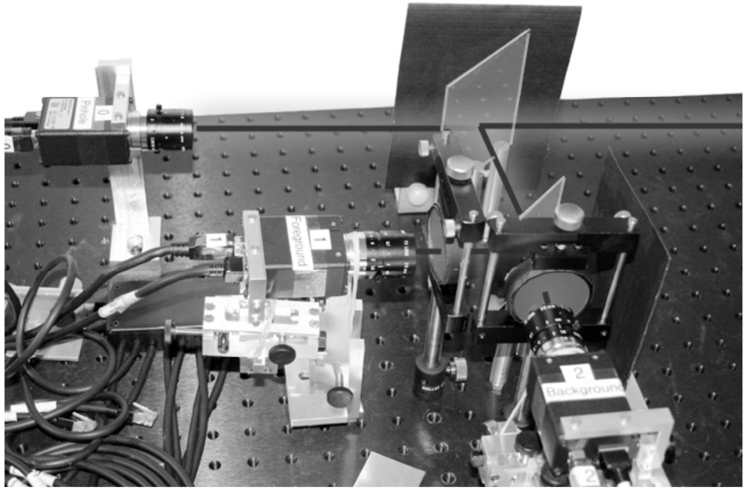
Thermo-Key



Thermo-Key

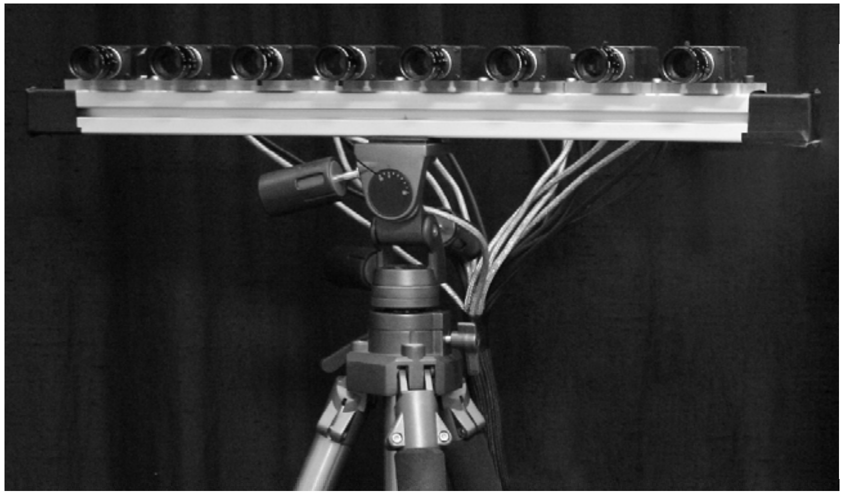


ZCam



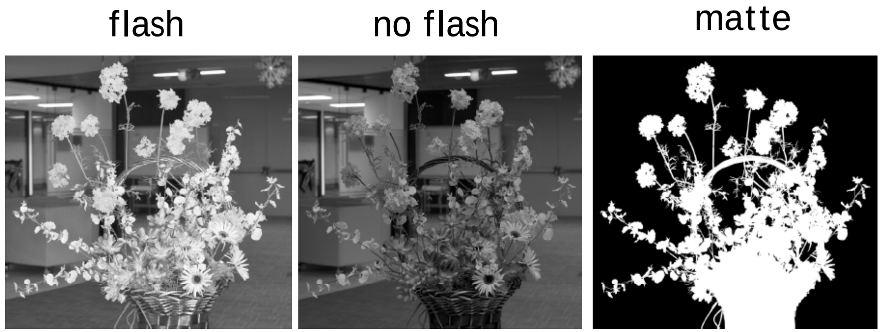
Defocus matting

video



video

Matting with camera arrays



Flash matting

$$
\begin{aligned}
I &= \alpha F + (1-\alpha)B, \\
I^f &= \alpha F^f + (1-\alpha)B^f,
\end{aligned}
$$

Background is much further than foreground and receives almost no flash light $B^f \approx B$

$$
I^f = \alpha F^f + (1-\alpha)B
$$

Flash matting

Foreground flash matting equation

$$
I' = I^f - I = \alpha(F^f - F) = \alpha F'
$$

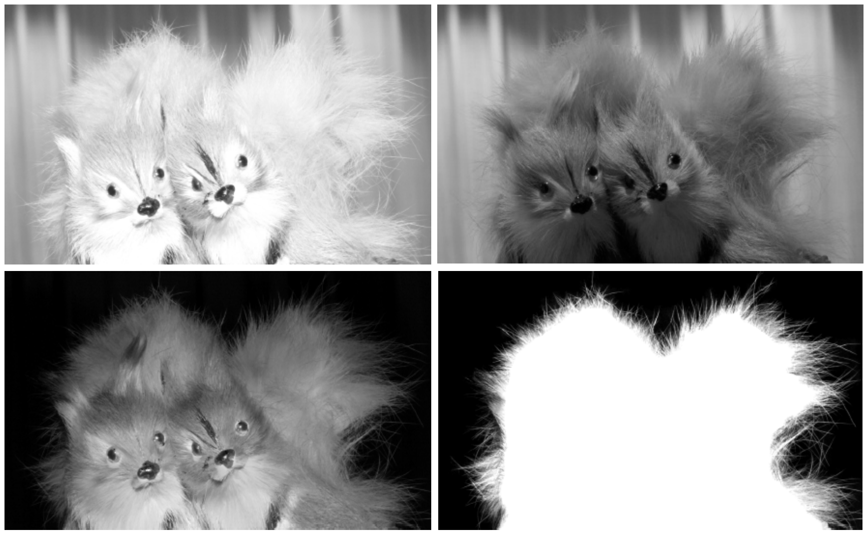
Generate a trimap and directly apply Bayesian matting.

$$
\begin{aligned}
&\arg \max_{\alpha, F'} \; L(\alpha, F' \,|\, I') \\
&= \arg \max_{\alpha, F'} \; \{L(I'|\alpha, F') + L(F') + L(\alpha)\}
\end{aligned}
$$

$$
L(I'|\alpha, F') = -||I' - \alpha F'||/\sigma_{I'}^2
$$

$$
L(F') = -(F' - \overline{F'})^T \Sigma_{F'}^{-1} (F' - \overline{F'})
$$

Flash matting



Foreground flash matting

$$
I = \alpha F + (1-\alpha)B
$$
$$
I' = \alpha F'
$$

$$
\begin{aligned}
&\arg \max_{\alpha, F, B, F'} \; L(\alpha, F, B, F' | I, I') \\
&= \arg \max_{\alpha, F, B, F'} \{L(I|\alpha, F, B) + L(I'|\alpha, F') + \\
&\qquad L(F) + L(B) + L(F') + L(\alpha)\}
\end{aligned}
$$

Joint Bayesian flash matting

$$\alpha = \frac{\sigma_{I'}^2 (F-B)^T (I-B) + \sigma_I^2 F'^T I'}{\sigma_{I'}^2 (F-B)^T (F-B) + \sigma_I^2 F'^T F'}$$

$$\begin{bmatrix} \Sigma_F^{-1} + \mathbf{I}\alpha^2/\sigma_I^2 & \mathbf{I}\alpha(1-\alpha)\sigma_I^2 & \mathbf{0} \\ \mathbf{I}\alpha(1-\alpha)\sigma_I^2 & \Sigma_B^{-1} + \mathbf{I}\alpha^2/\sigma_I^2 & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \Sigma_{F'}^{-1} + \mathbf{I}\alpha^2/\sigma_{I'}^2 \end{bmatrix} \begin{bmatrix} F \\ B \\ F' \end{bmatrix}$$

$$= \begin{bmatrix} \Sigma_F^{-1}\overline{F} + I\alpha/\sigma_I^2 \\ \Sigma_B^{-1}\overline{B} + I(1-\alpha)/\sigma_I^2 \\ \Sigma_{F'}^{-1}\overline{F'} + I'\alpha/\sigma_{I'}^2 \end{bmatrix},$$

Joint Bayesian flash matting

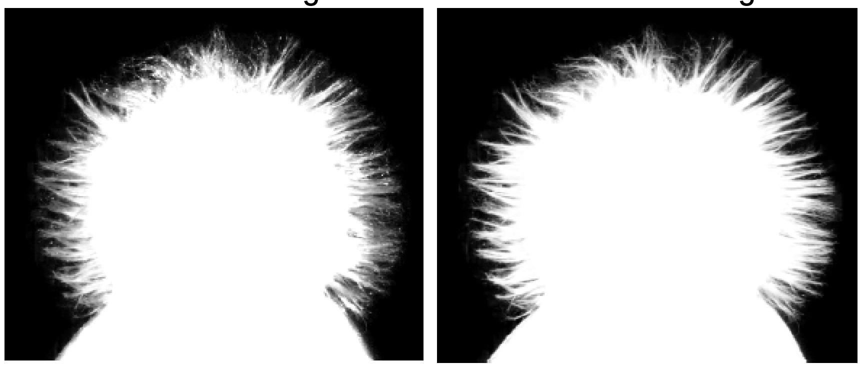
flash

no flash

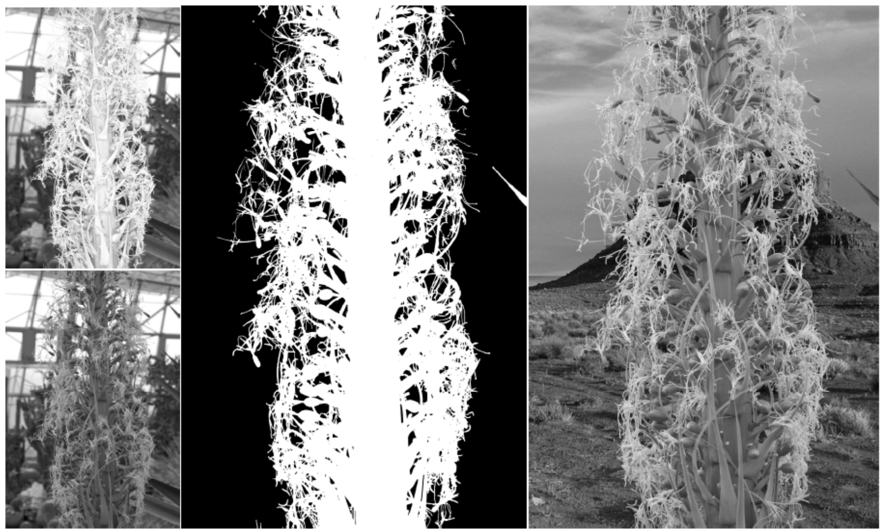
Comparison

foreground flash matting

ioint Bayesian flash matting



Comparison



Flash matting

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Conclusions

- Matting algorithms improves a lot in these 10 years
- In production, it is still always preferable to shoot against uniform backgrounds
- Algorithms for more complex backgrounds
- Devices or algorithms for automatic matting