Matting and Compositing

Digital Visual Effects
Yung-Yu Chuang

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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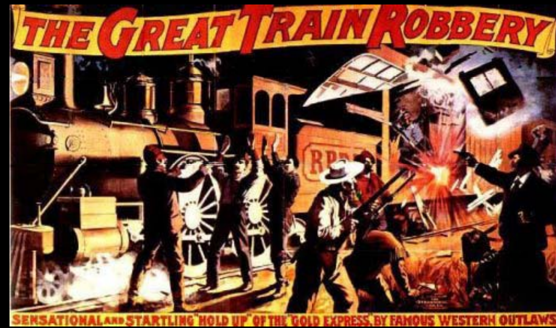
Photomontage

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

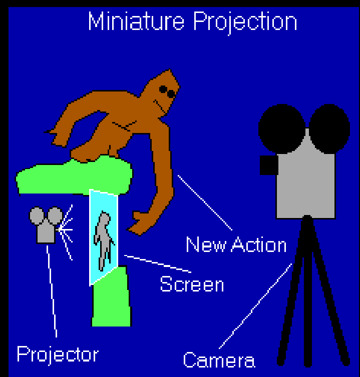


The Great Train Robbery (1903) matte shot

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 compositing

King Kong (1933)

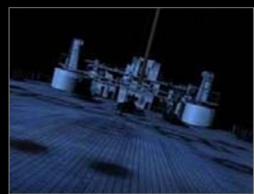
Optical compositing

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)

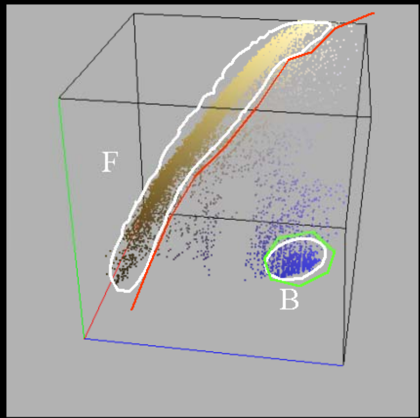
$C=F+\bar{\alpha}B$	F	$\bar{\alpha}$
		
Blue-screen photograph	Spill suppression if B>G then B=G	Matte creation $\bar{\alpha}$=B-max(G,R)

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

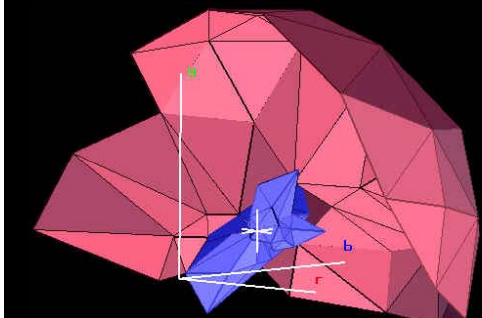
Problems with color difference

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

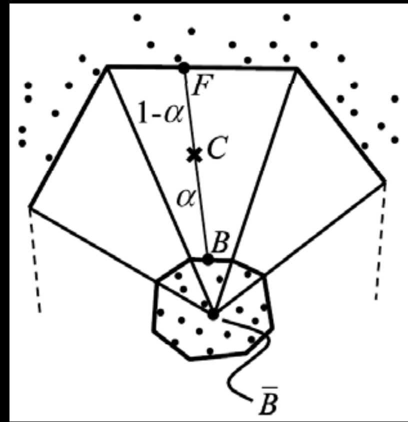
Chroma-keying (Primatte)



Chroma-keying (Primatte)



demo



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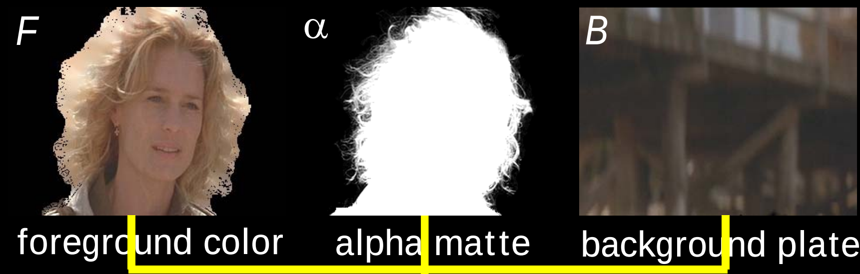
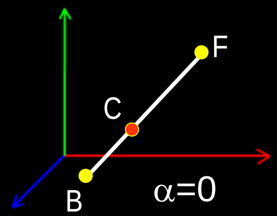
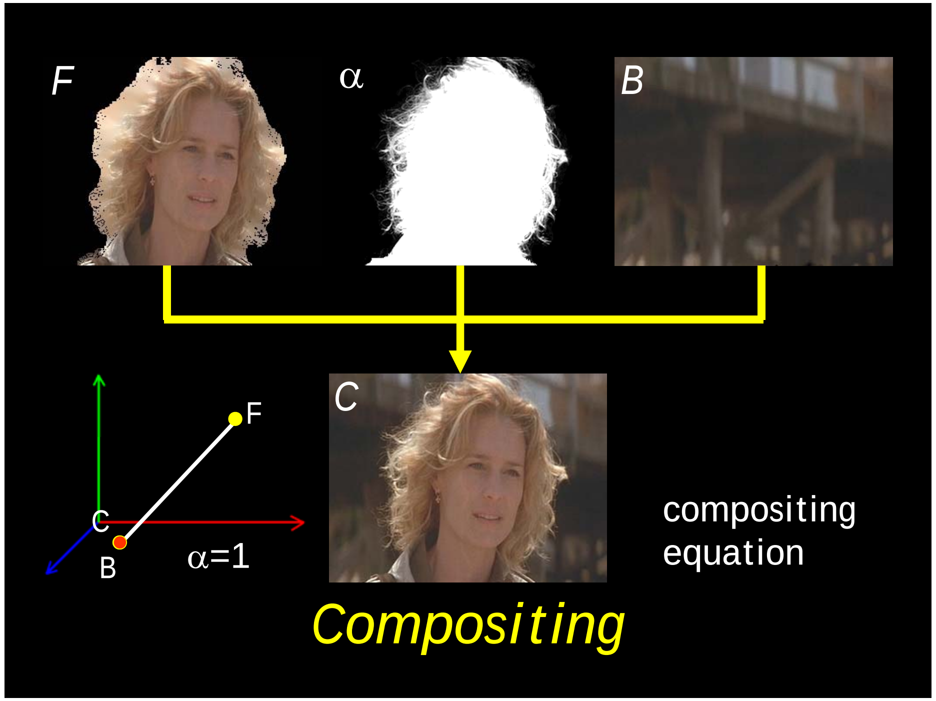
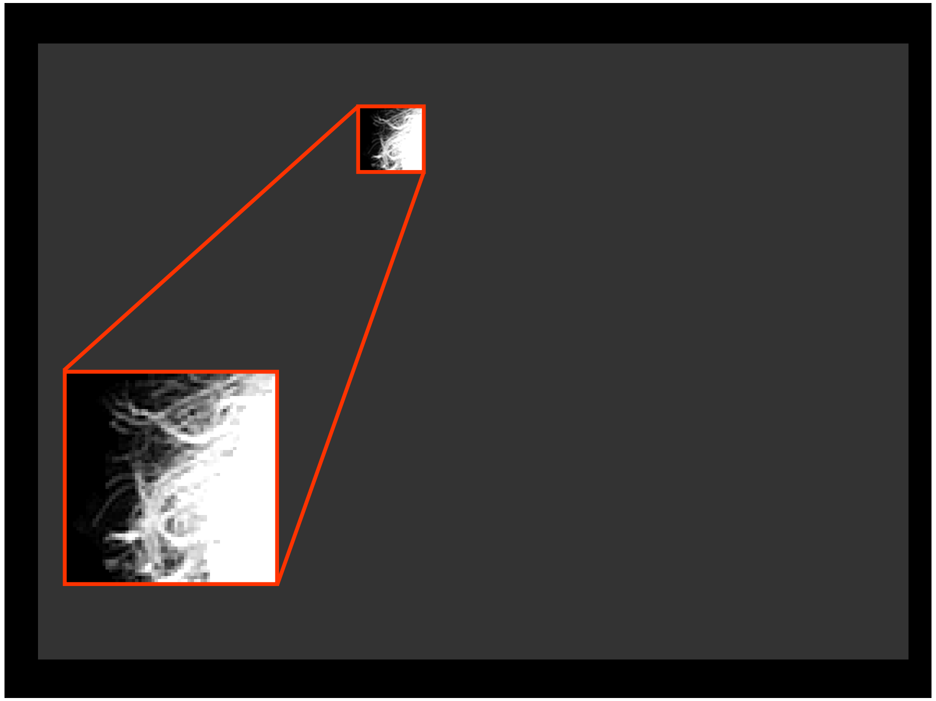


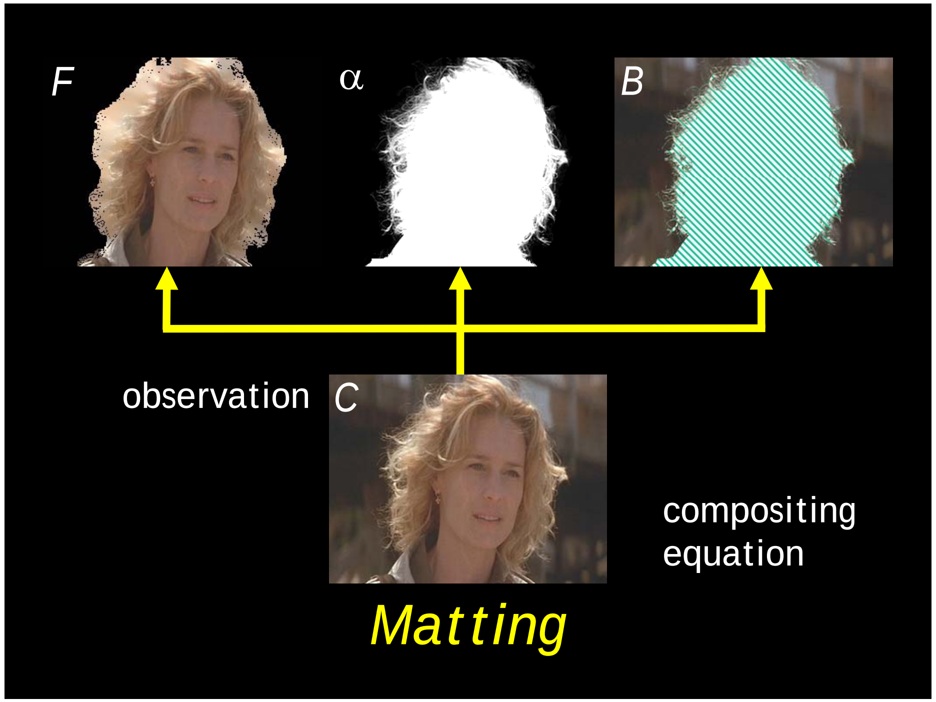


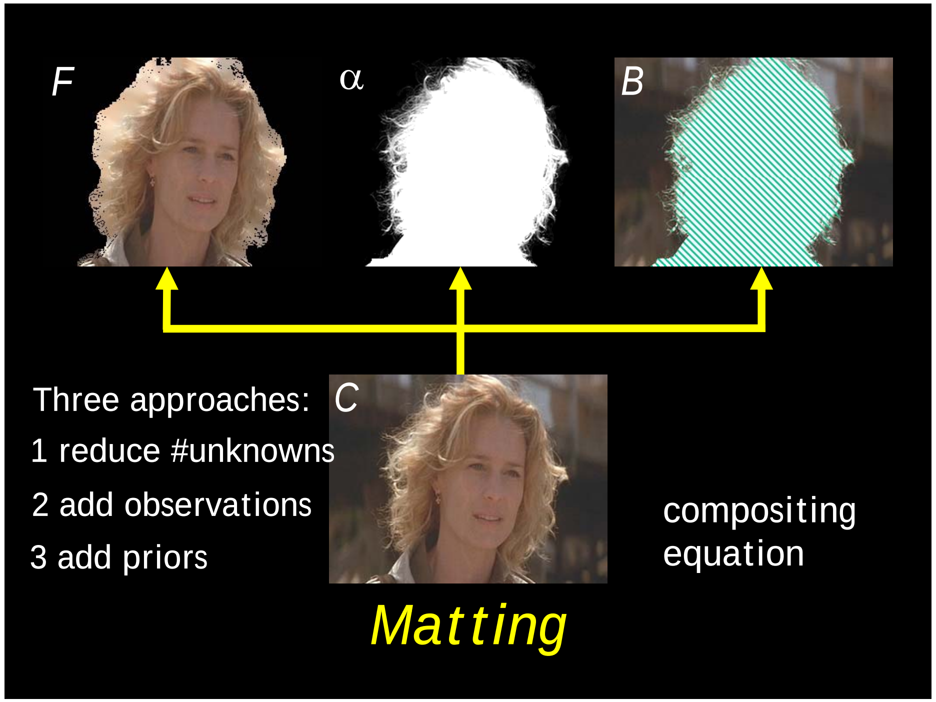
compositing equation

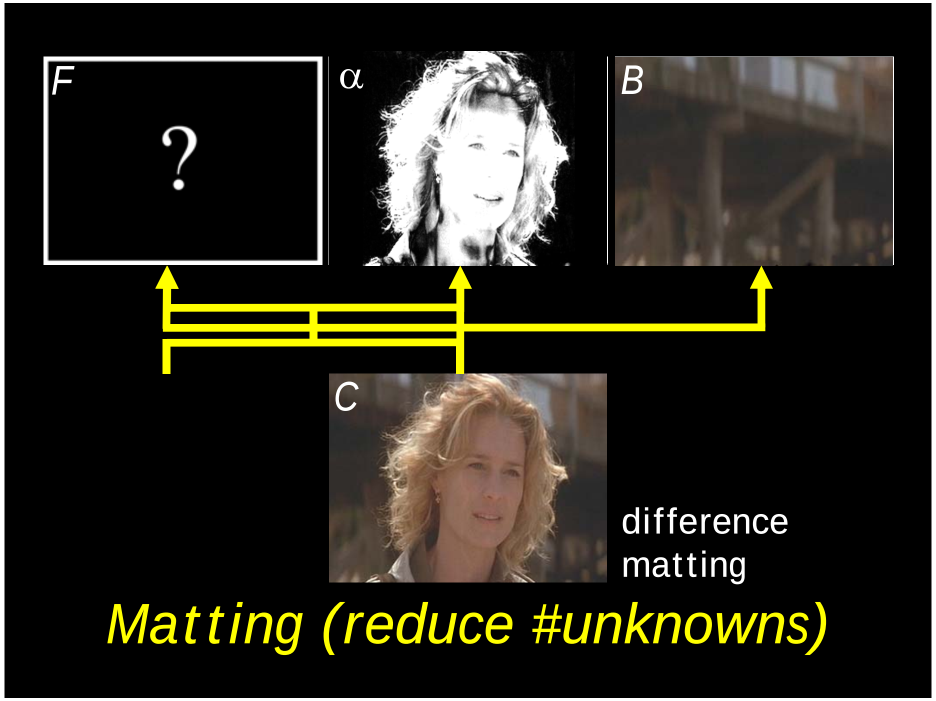
Compositing

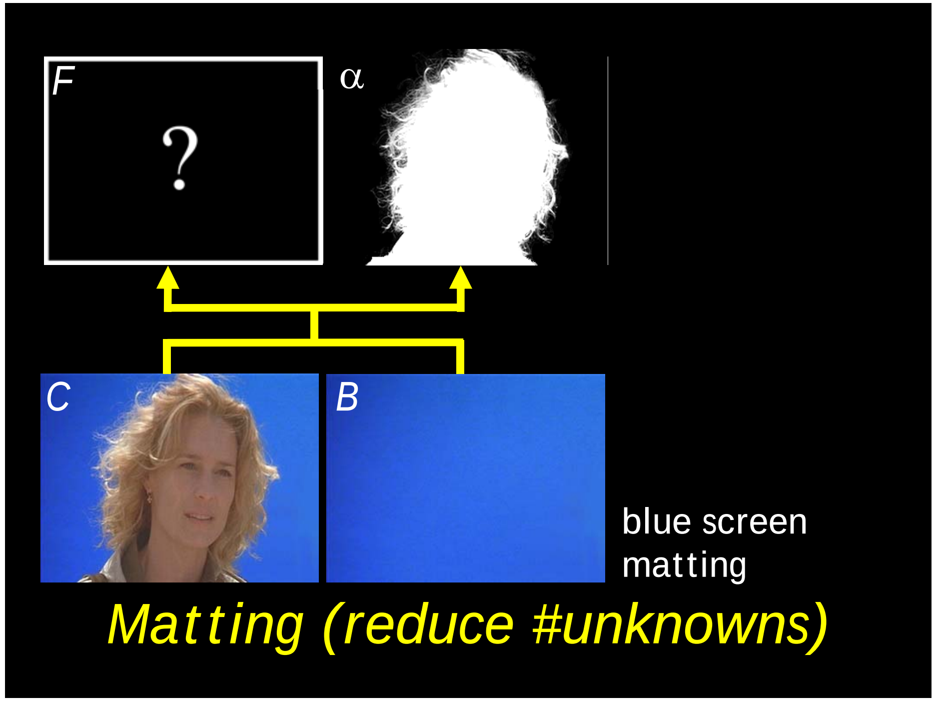

F
α
B
C
F
C
B
α=1
compositing
equation
Compositing

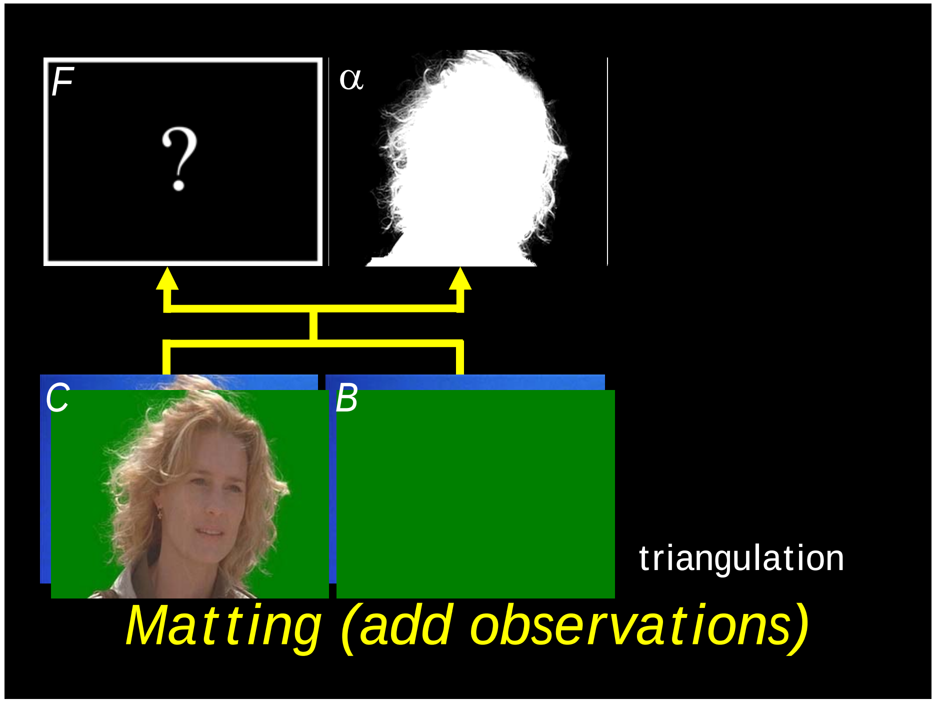


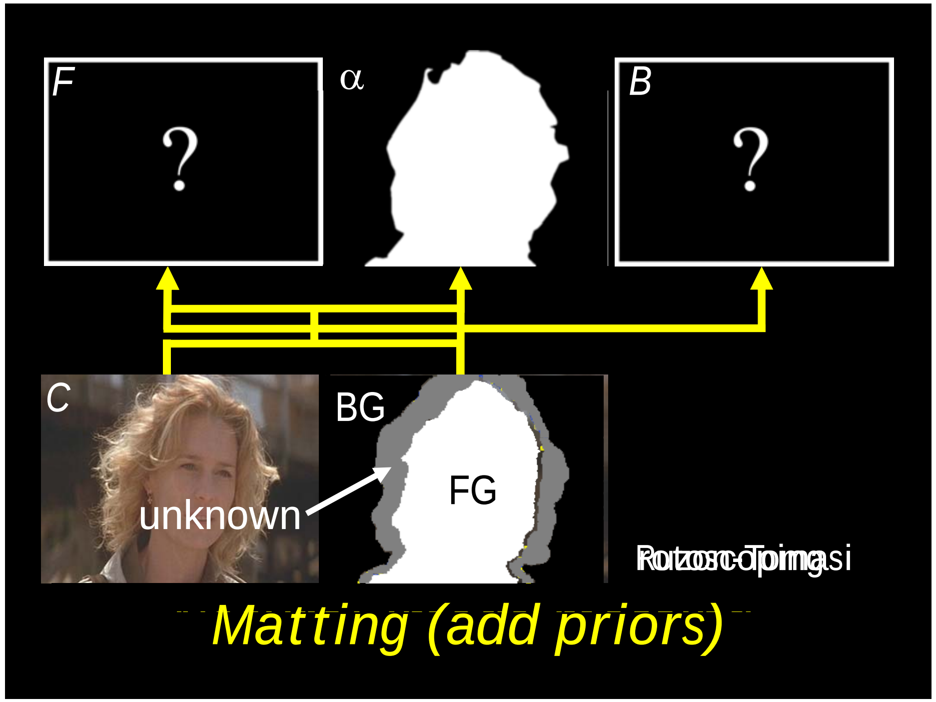

F
α
B
observation
C
compositing
equation
Matting


F
α
B
Three approaches:
1 reduce #unknowns
2 add observations
3 add priors
C
compositing
equation
Matting


F
?
α
B
C
difference
matting
Matting (reduce #unknowns)


F
?
α
C
B
blue screen
matting
Matting (reduce #unknowns)


F
?
α
C
B
triangulation
Matting (add observations)


F
?
α
B
?
C
BG
FG
unknown
Matting (add priors)

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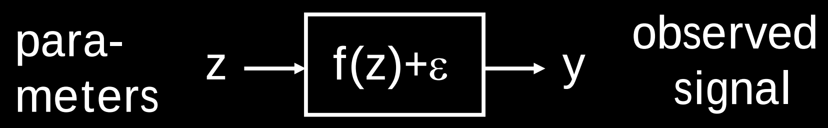
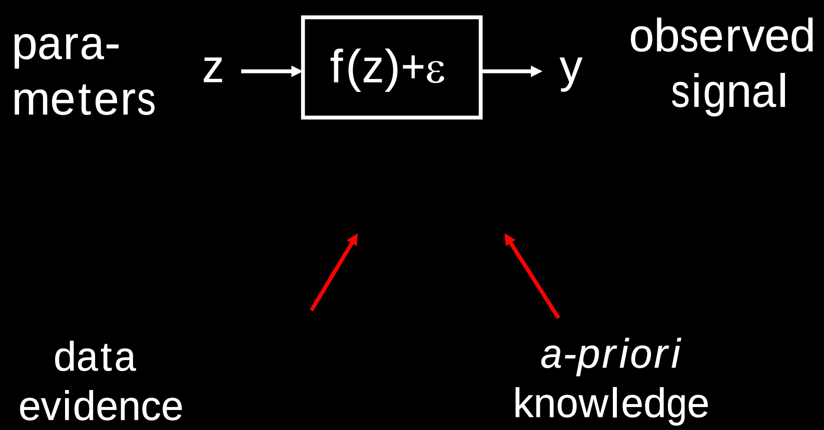


Example:
super-resolution
de-blurring
de-blocking
...

Bayesian framework



Bayesian framework

posterior probability

likelihood

priors

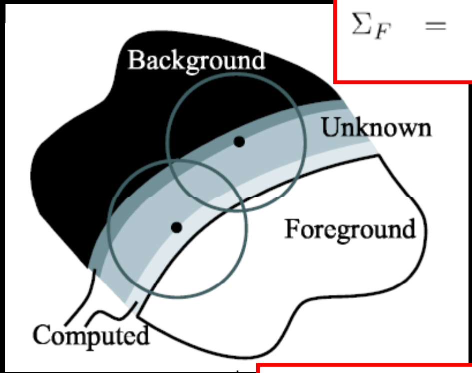
$$\arg\max_{F,B,\alpha} P(F,B,\alpha\,|\,C) = \arg\max_{F,B,\alpha} P(C\,|\,F,B,\alpha)\,P(F)\,P(B)\,P(\alpha)\,/\,P(C)$$

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

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

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

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

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

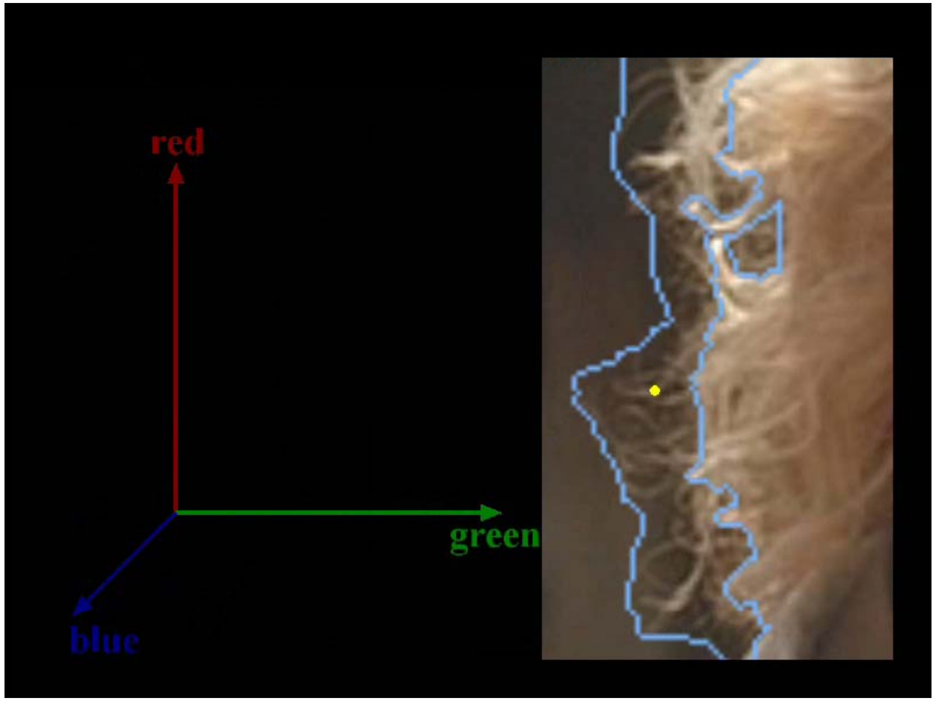
Bayesian image matting

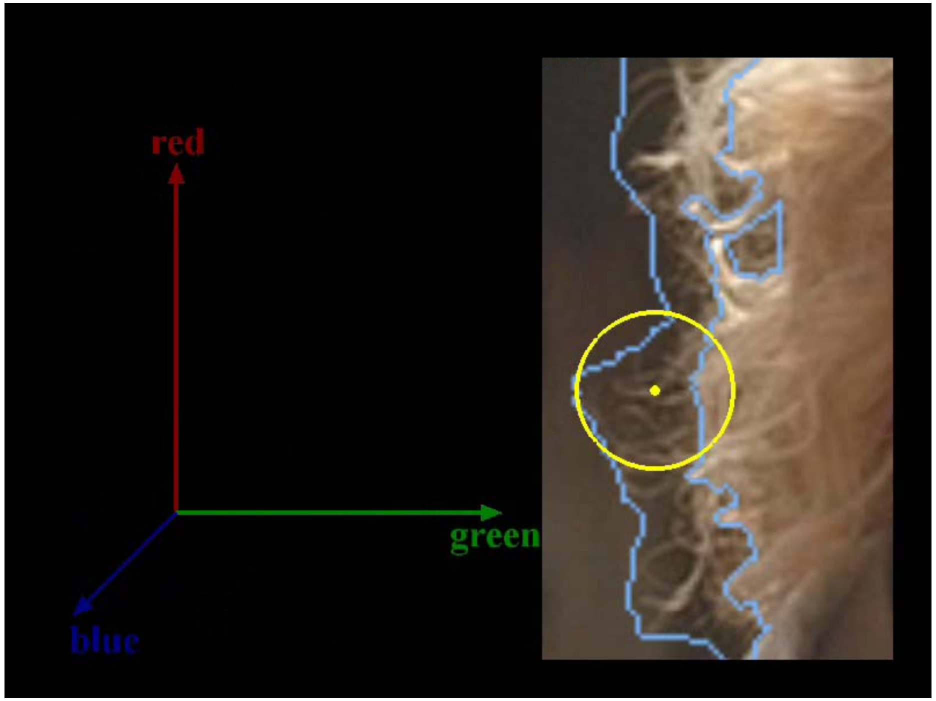
Bayesian image matting

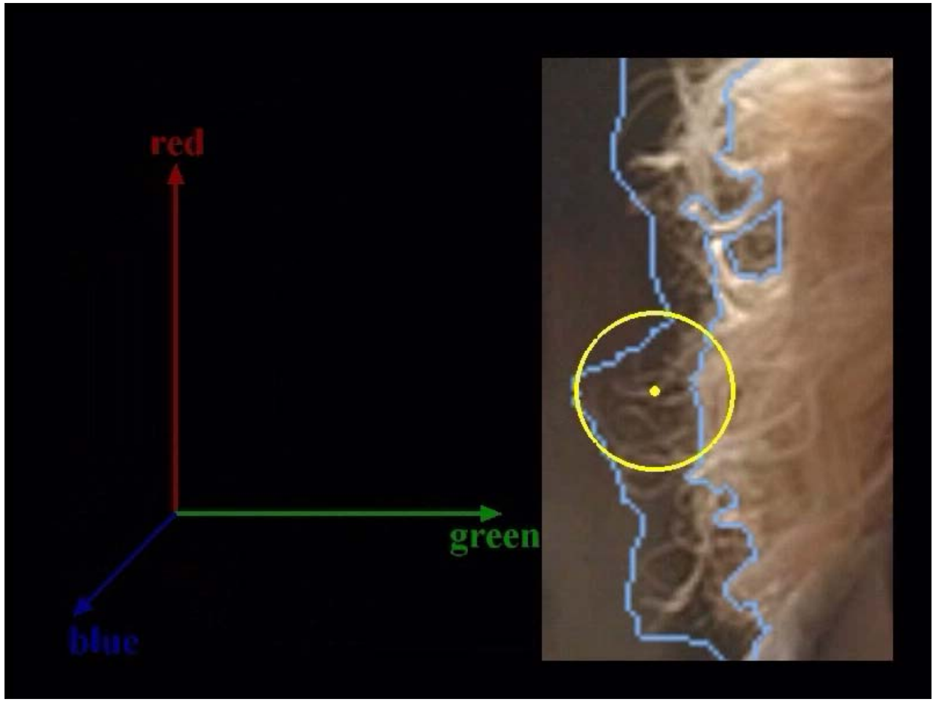
Bayesian image matting

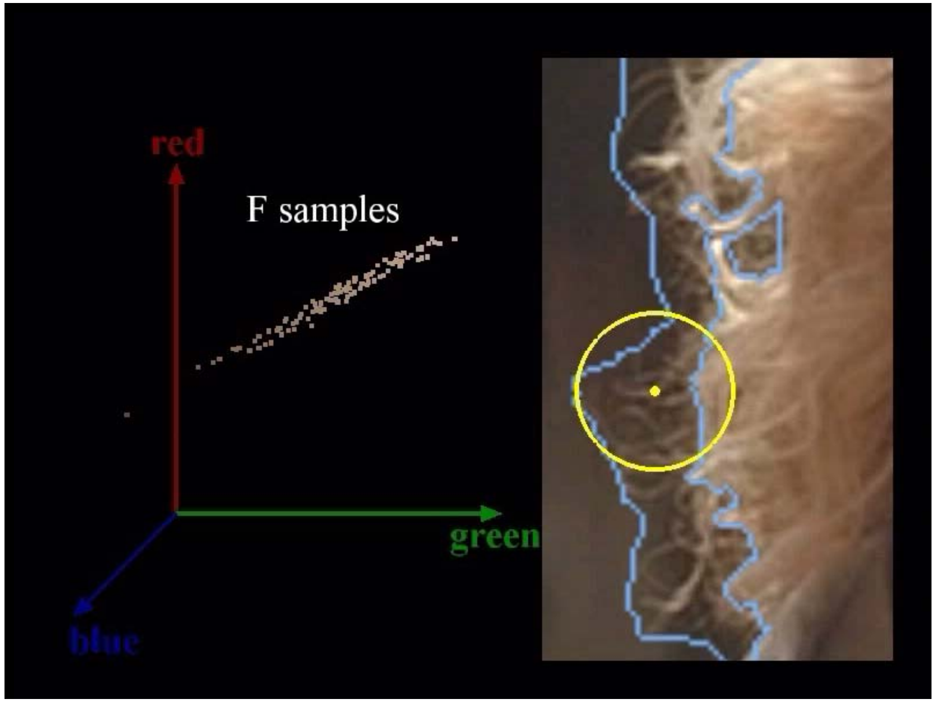
Bayesian image matting

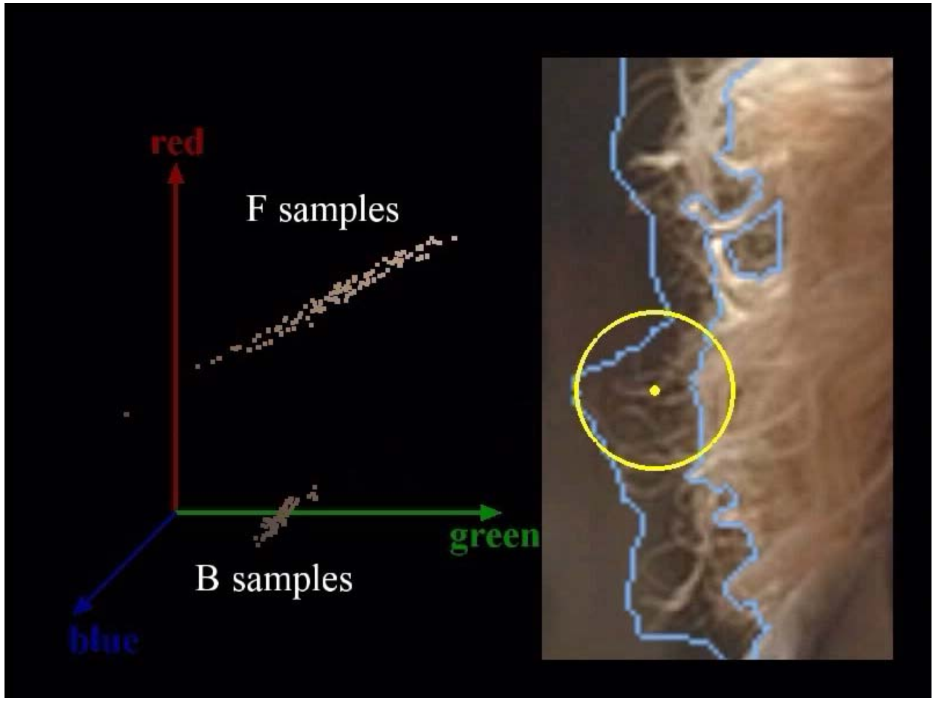
Bayesian image matting

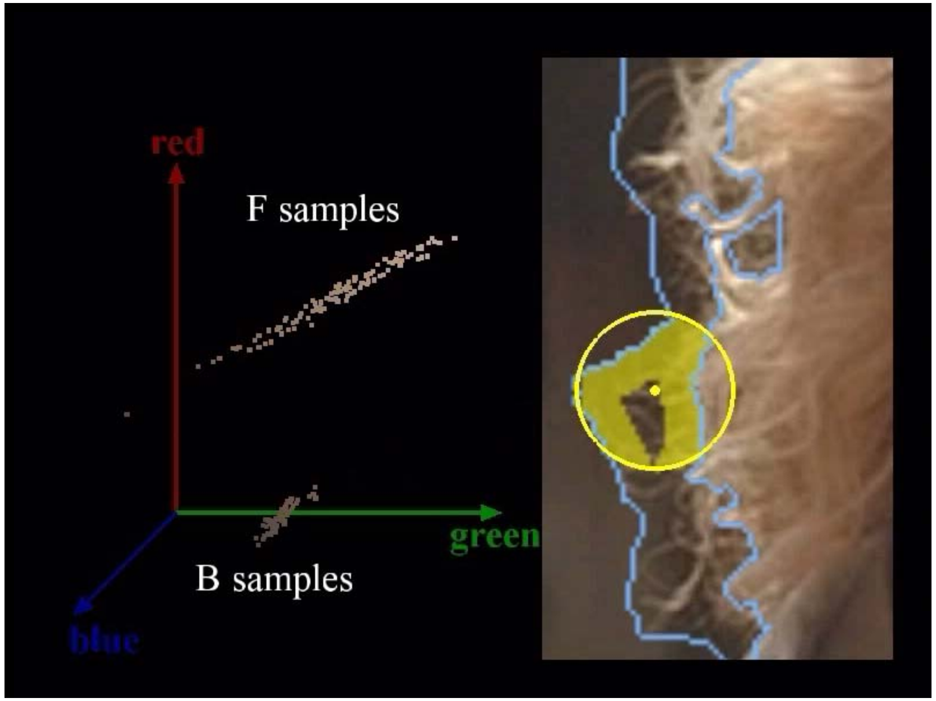

red
green
blue

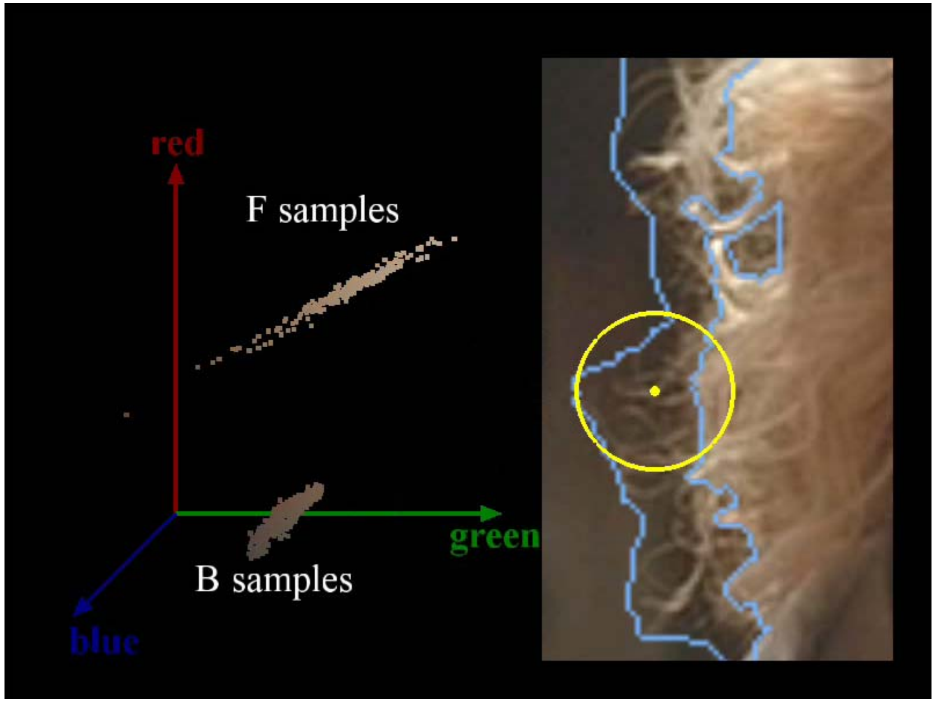

red
green
blue

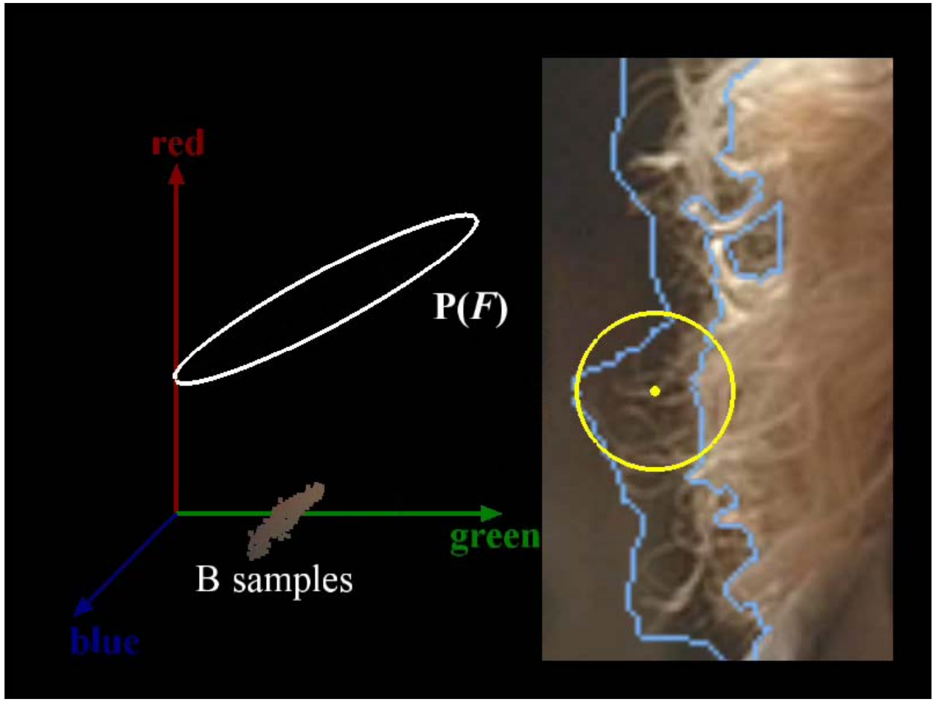

red
green
blue

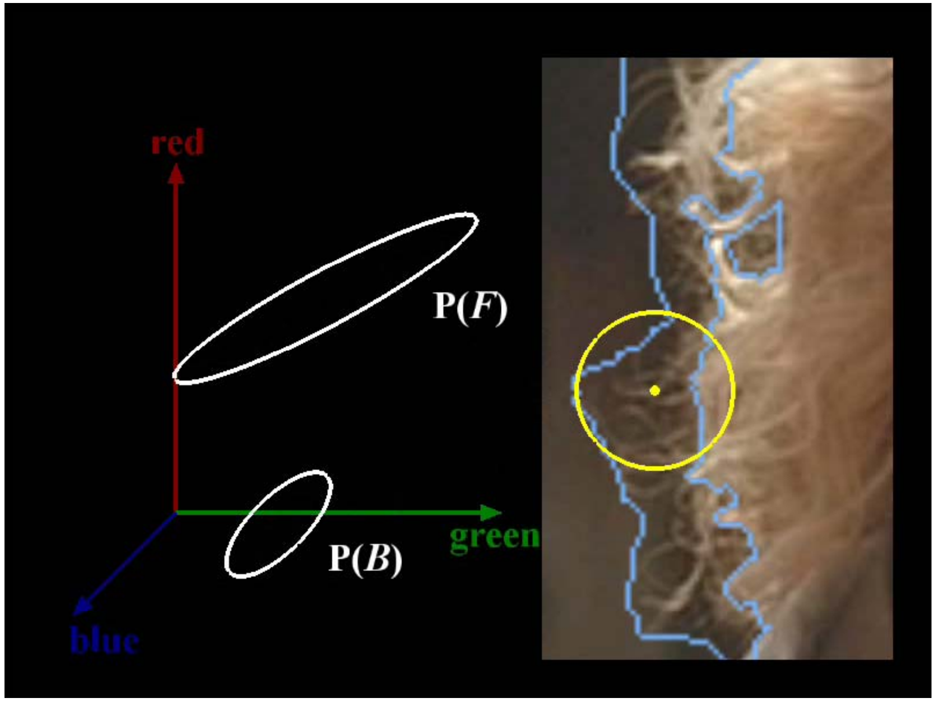

red
F samples
green
blue

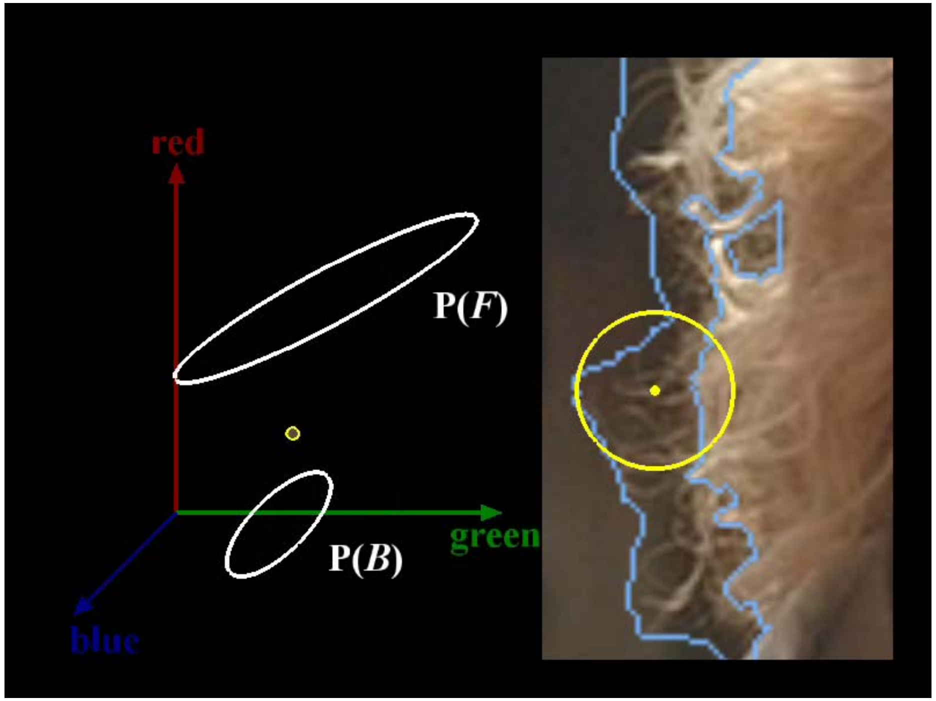

red
F samples
green
B samples
blue

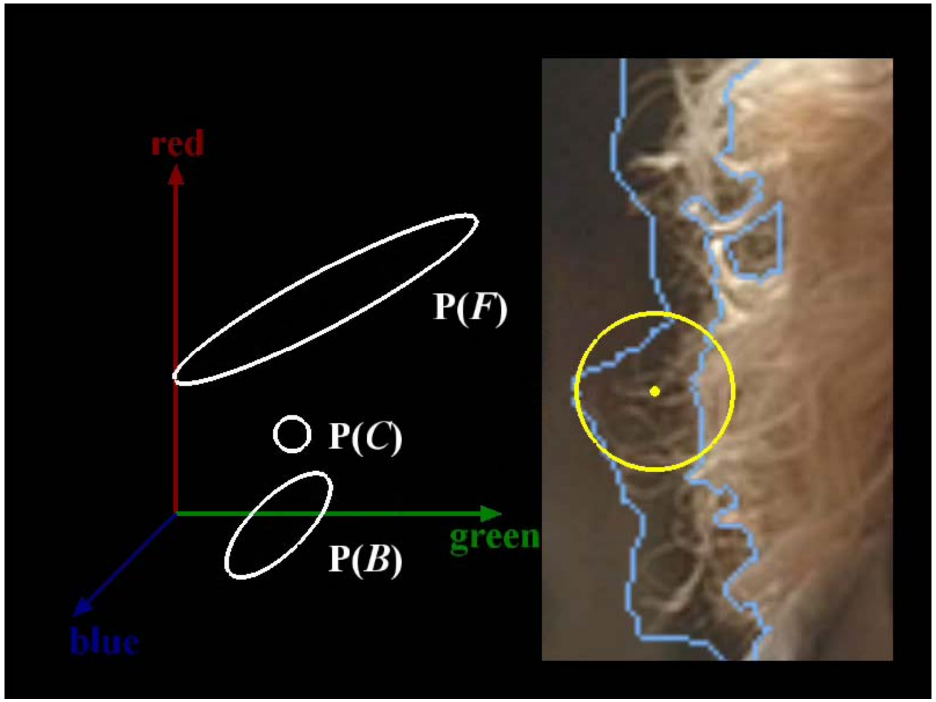

red
F samples
green
B samples
blue

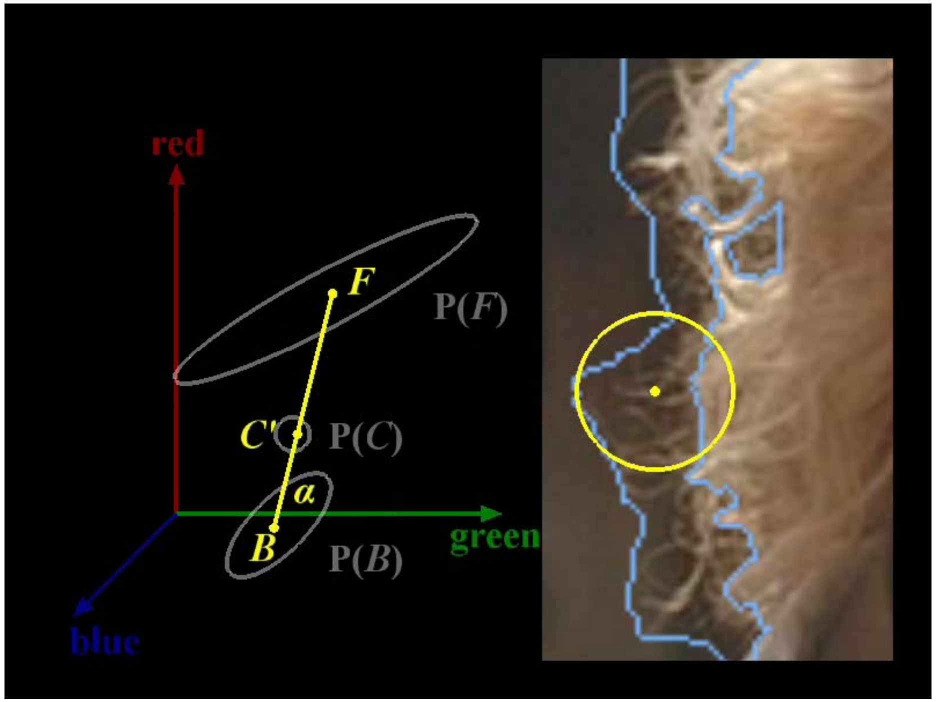

red
F samples
green
B samples
blue


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

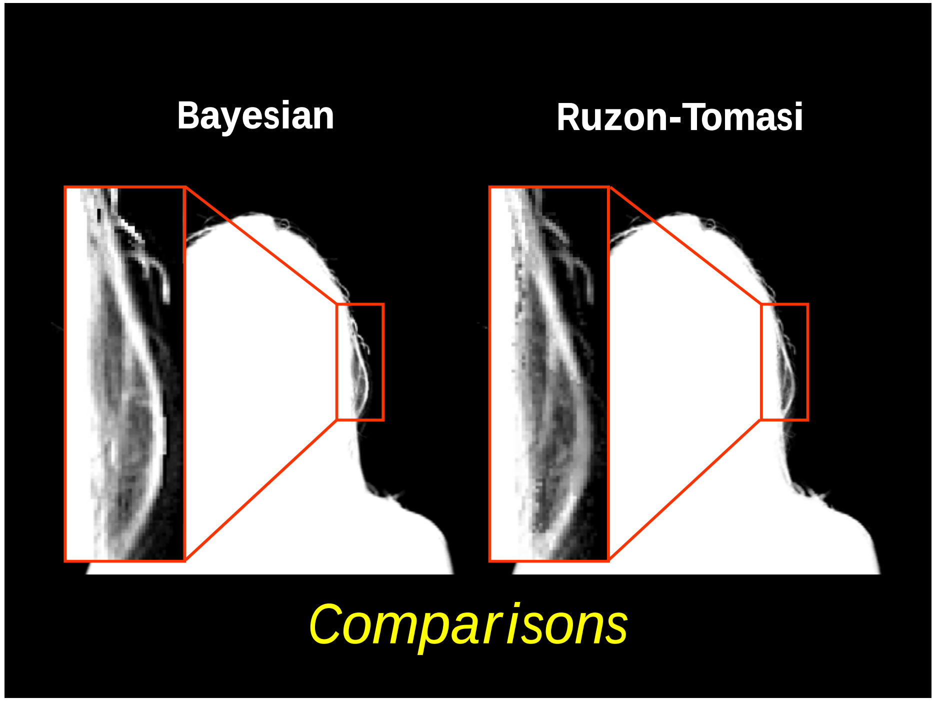

red
F
P(F)
C'
P(C)
α
B
P(B)
green
blue

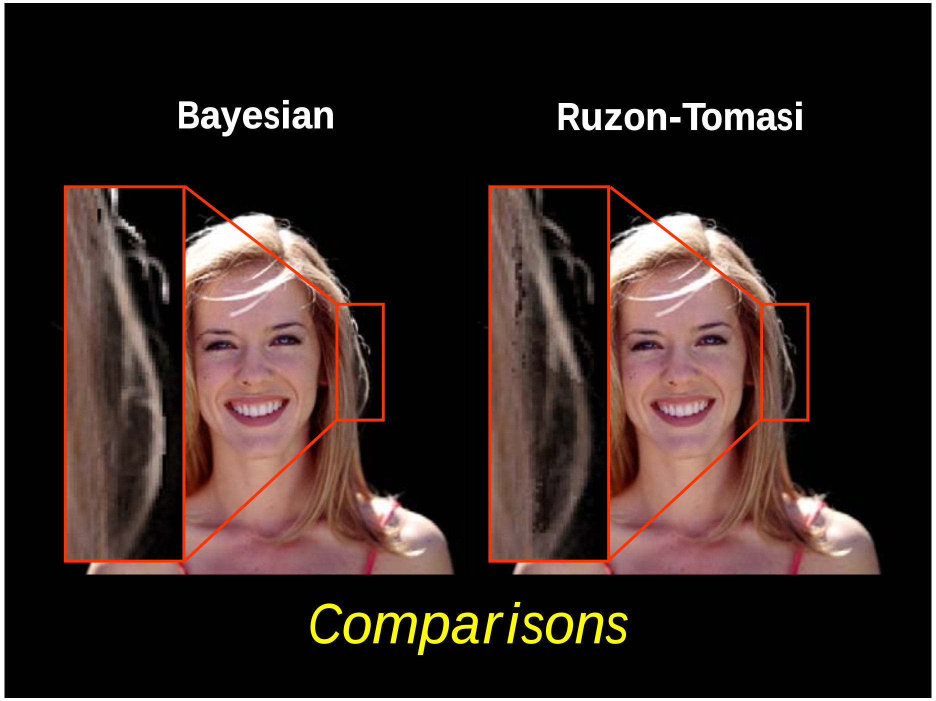
Demo

Results

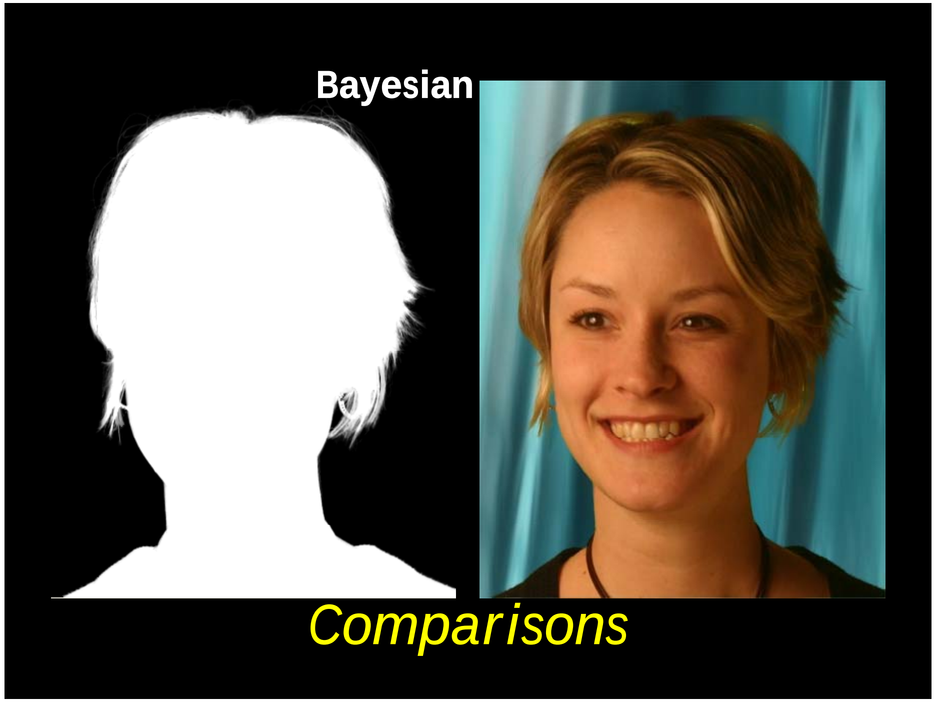
Results

Comparisons


Bayesian
Ruzon-Tomasi
Comparisons

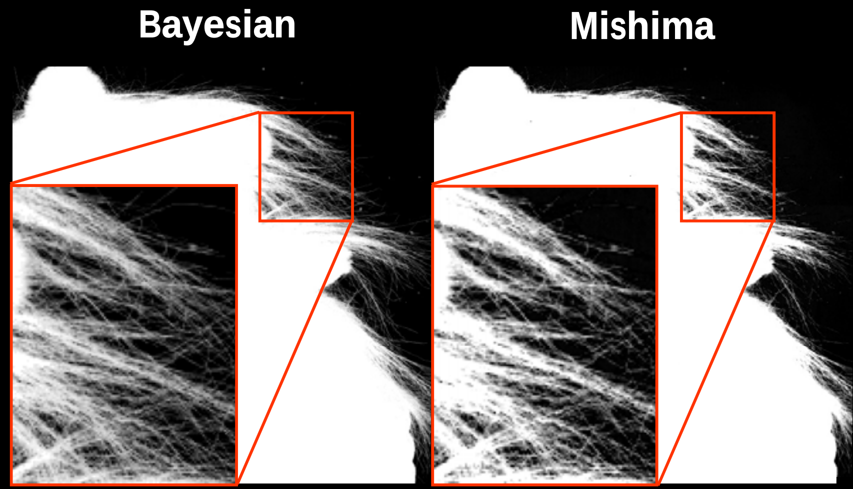

Bayesian
Ruzon-Tomasi
Comparisons


Mishima
Comparisons


Bayesian
Comparisons

input image

Comparisons

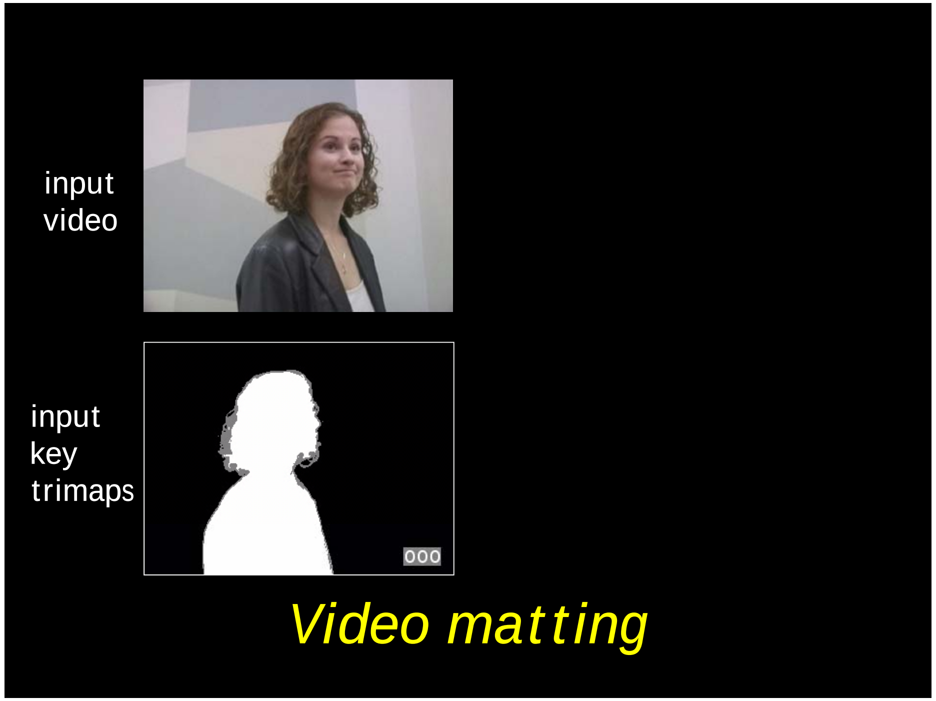


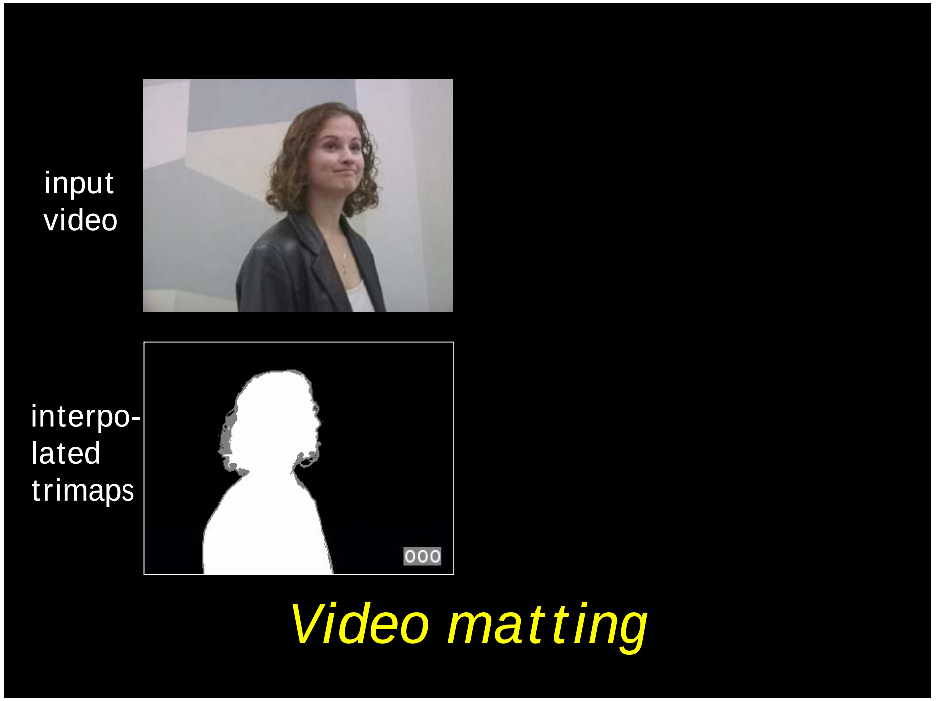
Comparisons

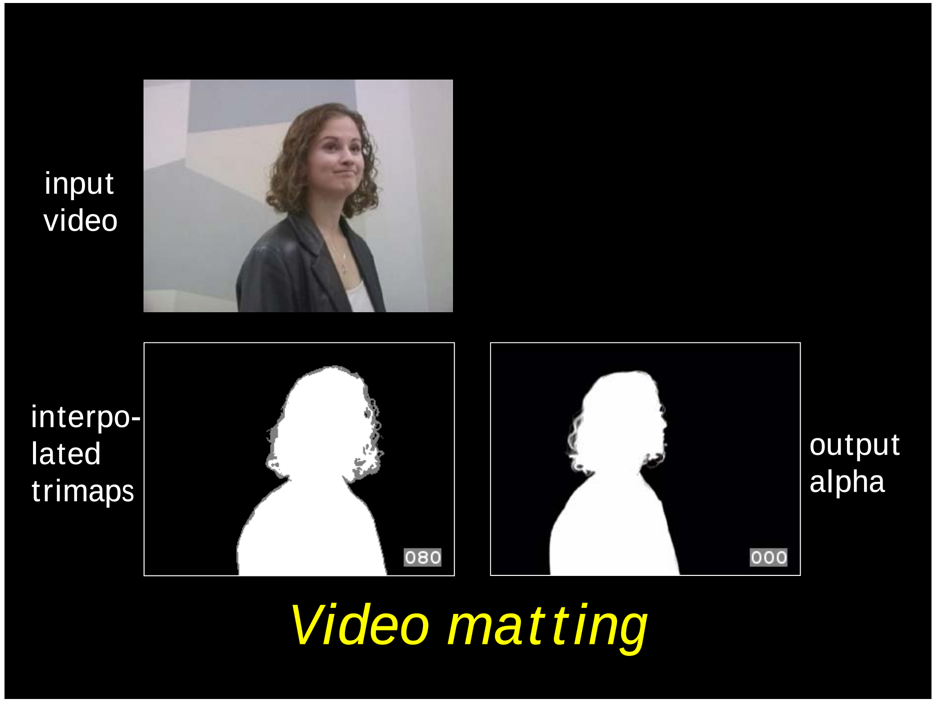
Comparisons

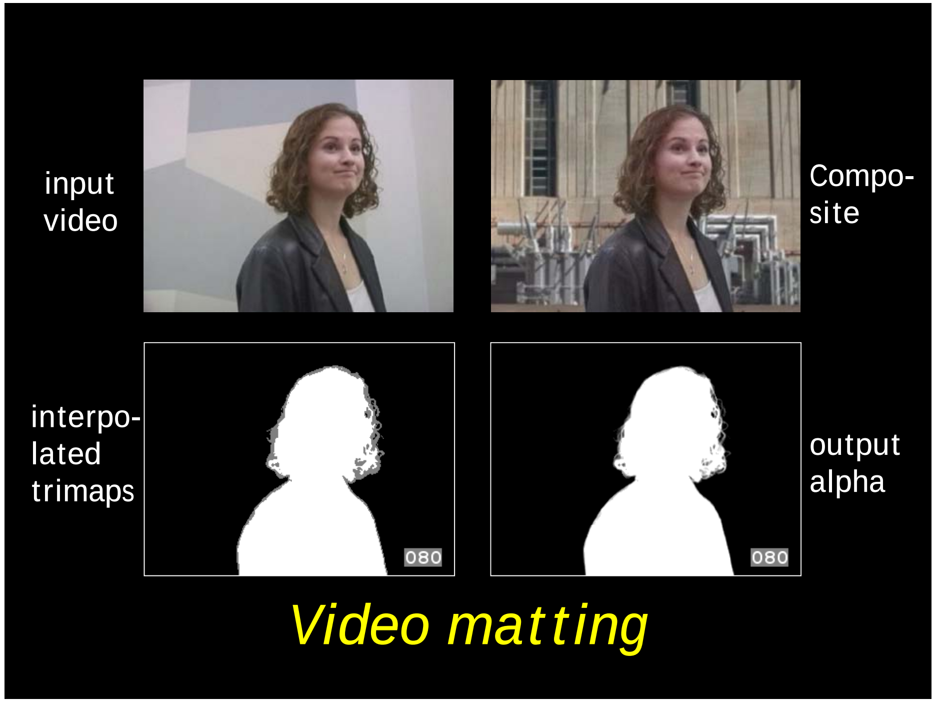
input
video

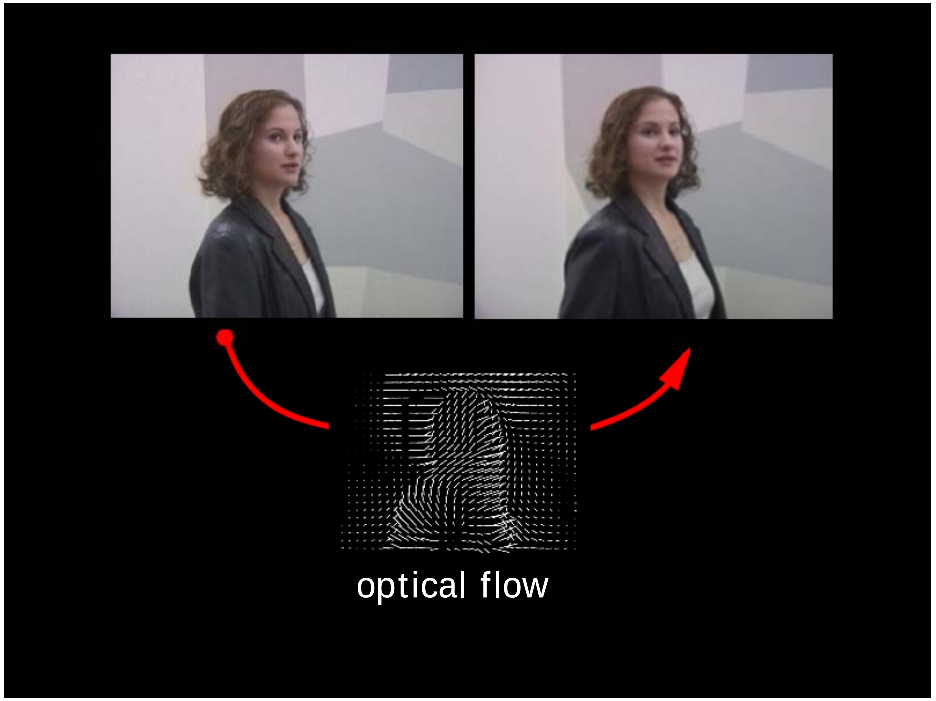
Video matting

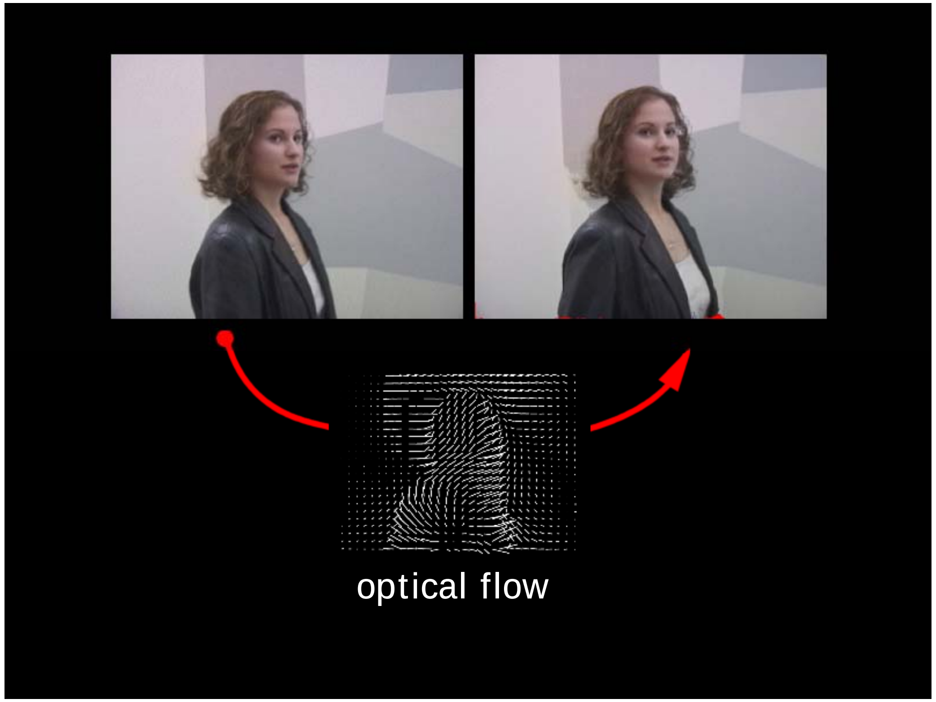

input video
input key trimaps
000
Video matting


input video
interpo-lated trimaps
000
Video matting

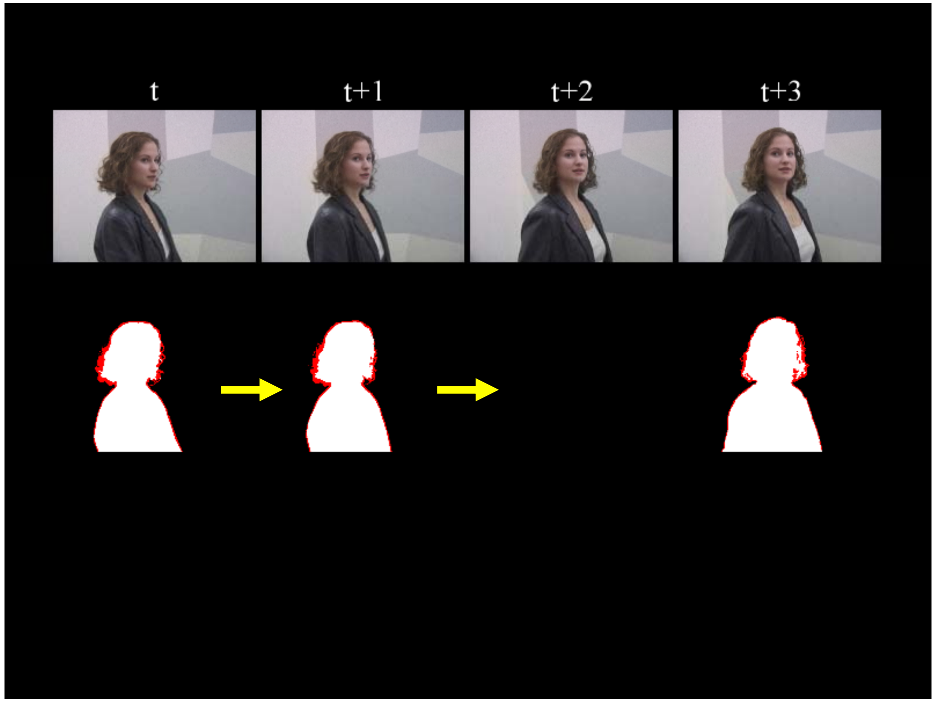

input video
interpo-lated trimaps
080
000
output alpha
Video matting


input video
Compo-site
interpo-lated trimaps
080
output alpha
080
Video matting


optical flow


optical flow


t
t+1
t+2
t+3


t
t+1
t+2
t+3


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

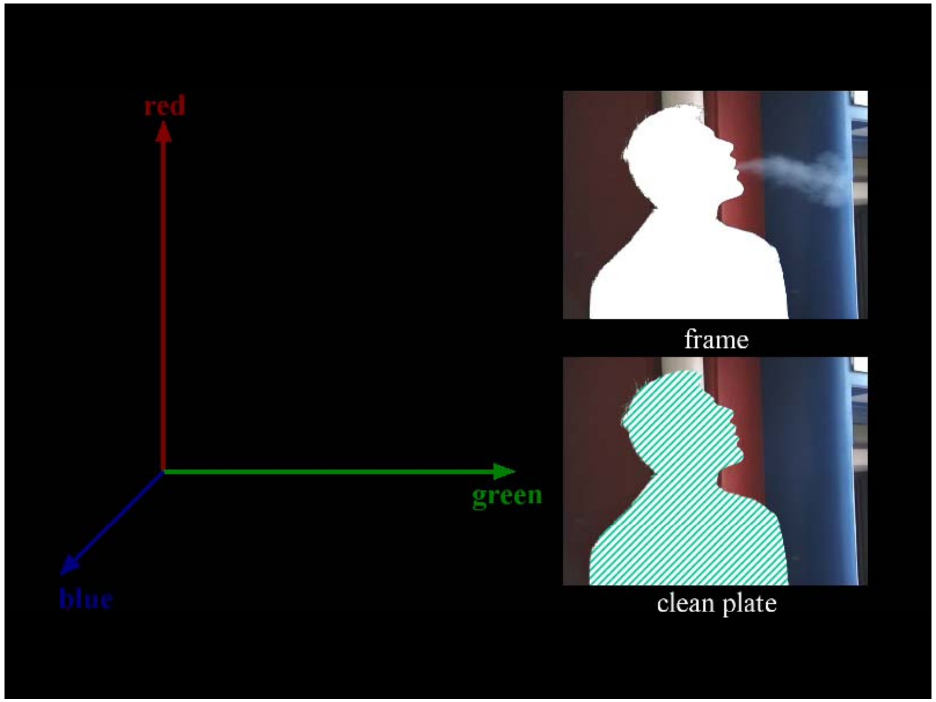
Background estimation

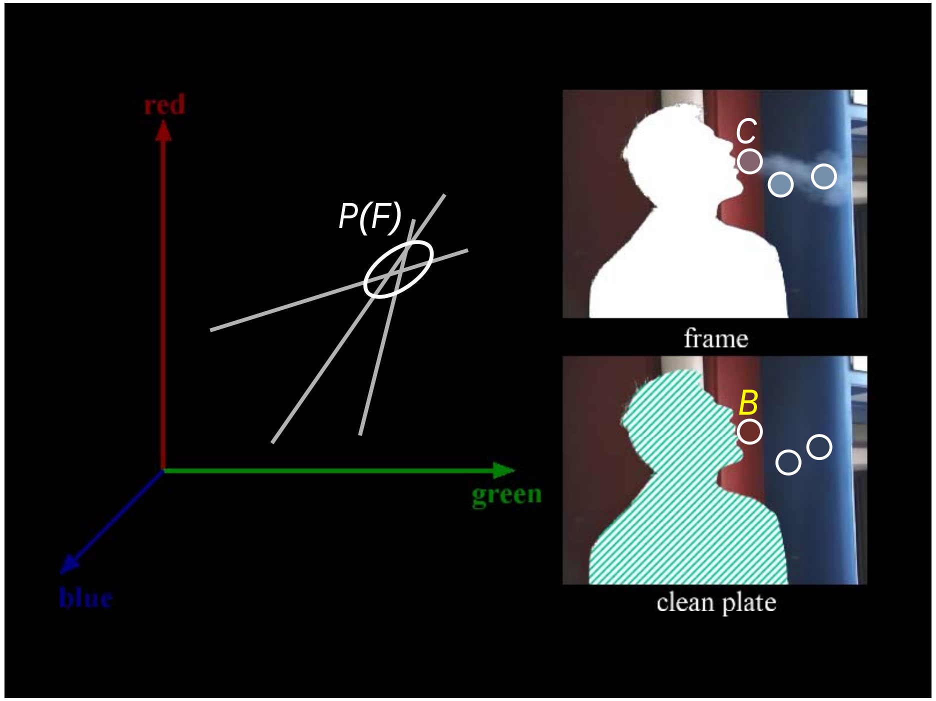
Background estimation


Alpha matte


without
background
with
background
Comparison


input
composite


red
green
blue
frame
clean plate


red
P(F)
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 resulting mattes

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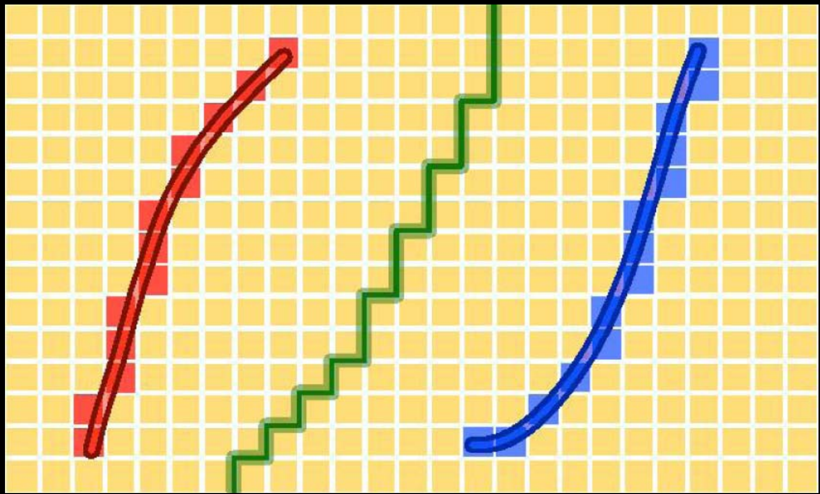
Scribble-based input

trimap

scribble

Motivation

LazySnapping



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

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

$$d_i^{\mathcal{F}} = \min_n \| C(i) - K_n^{\mathcal{F}} \|$$

n-th mean foreground color

LazySnapping

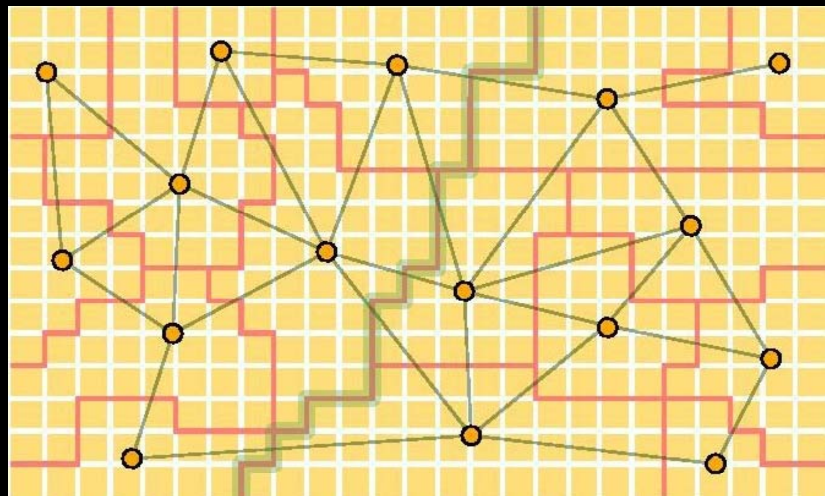
$$E(X) = \sum_{i \in \mathcal{V}} E_1(x_i) + \lambda \sum_{(i,j) \in \mathcal{E}} E_2(x_i, x_j)$$

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

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

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

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

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

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

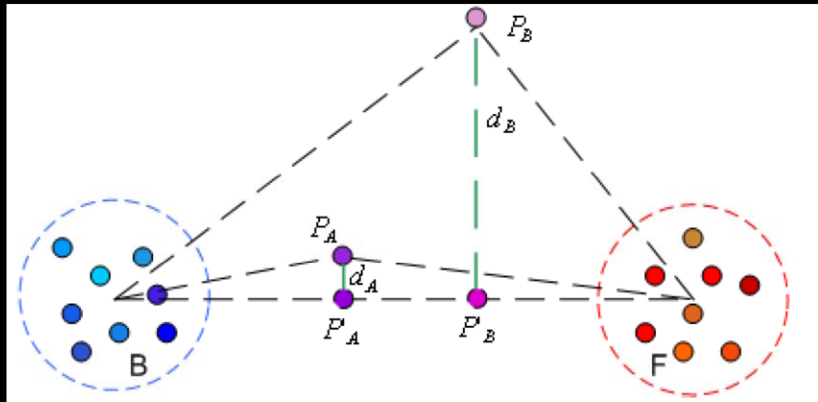
$$\nabla\alpha \approx \frac{1}{F-B}\nabla I$$

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

Poisson matting

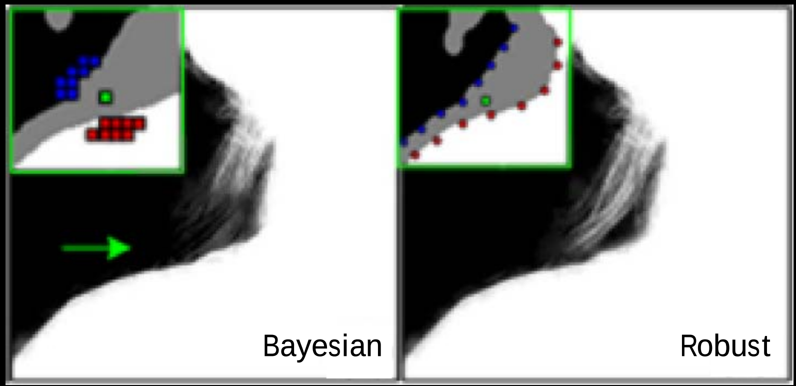
Robust matting

- Jue Wang and Michael Cohen, CVPR 2007



Robust matting

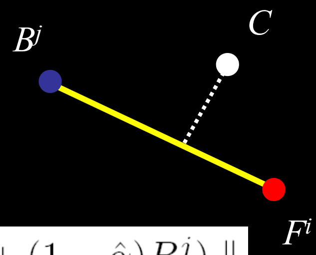
- Instead of fitting models, a non-parametric approach is used



Robust matting

- We must evaluate hypothesized foreground/background pairs

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

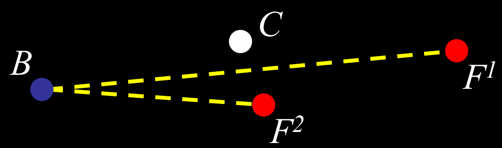


distance ratio

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

Robust matting

- To encourage pure fg/bg pixels, add weights



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

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

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

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

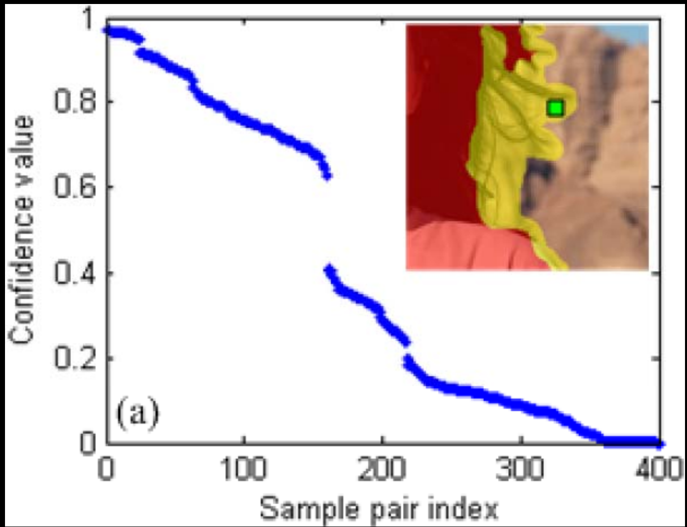
Robust matting

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

confidence

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

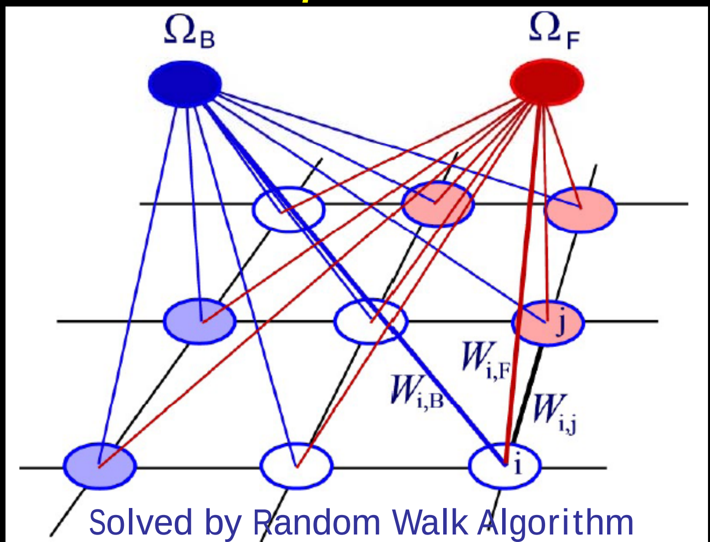
Robust matting



Robust matting

matte confidence

Matte optimization



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)

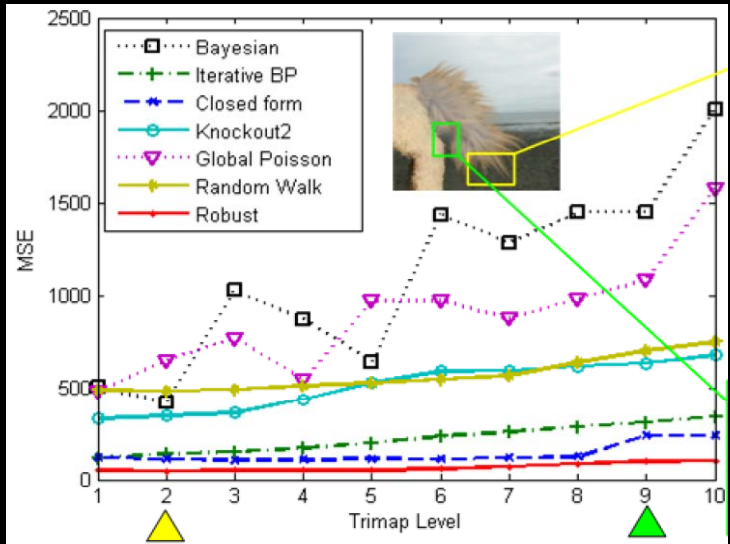
Evaluation

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

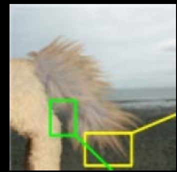
Evaluation

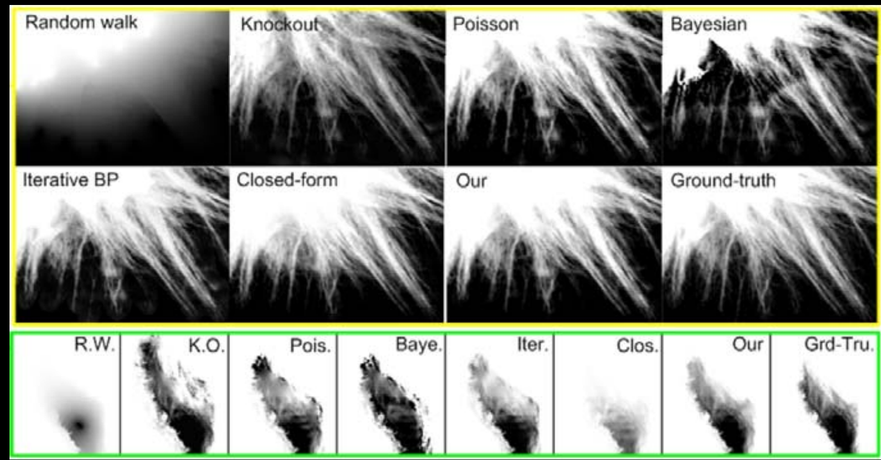
- Mean square error is used as the accuracy metric
- Try 8 trimaps with different accuracy for testing robustness
- 7 methods are tested: Bayesian, Belief propagation, Poisson, Random Walk, KnockOut2, Closed-Form and Robust matting

Quantitative evaluation

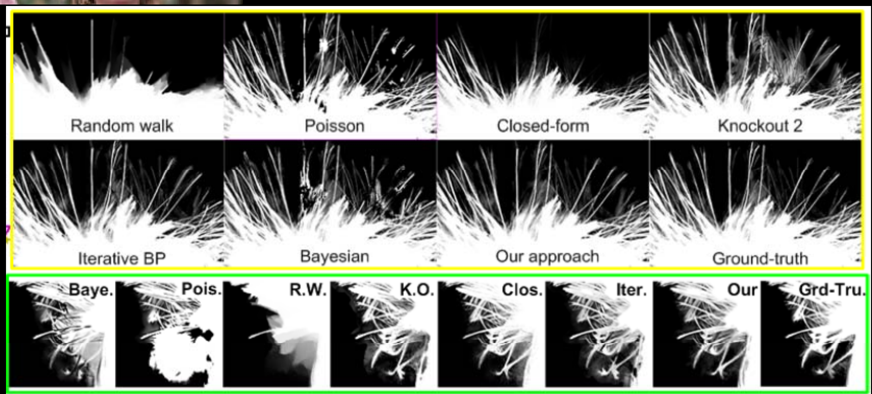


Subjective evaluation





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)

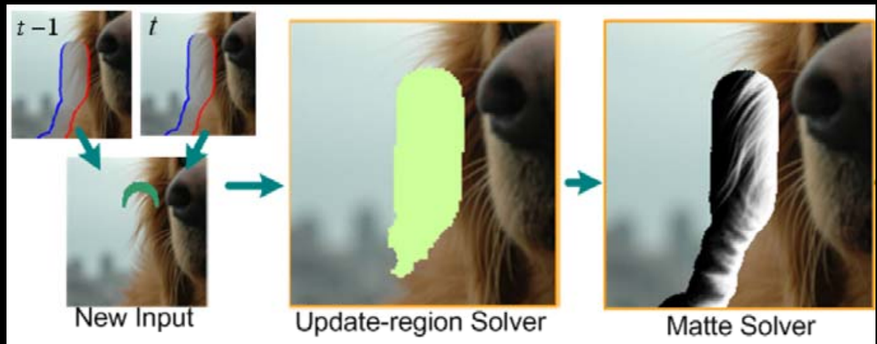
- http://www.alphamatting.com/

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

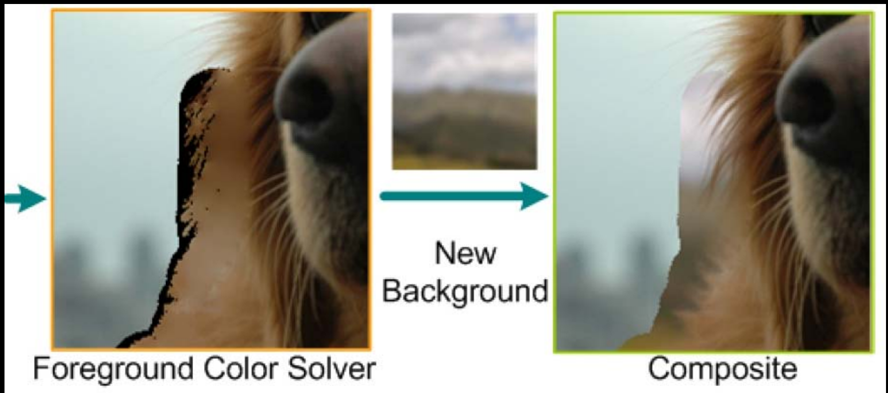
Soft scissor

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

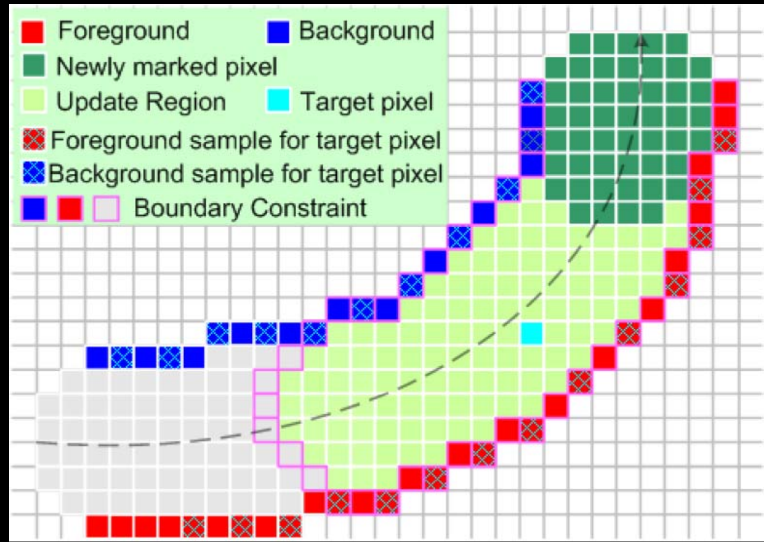
Flowchart



Flowchart



Soft scissor



Demo (Power Mask)

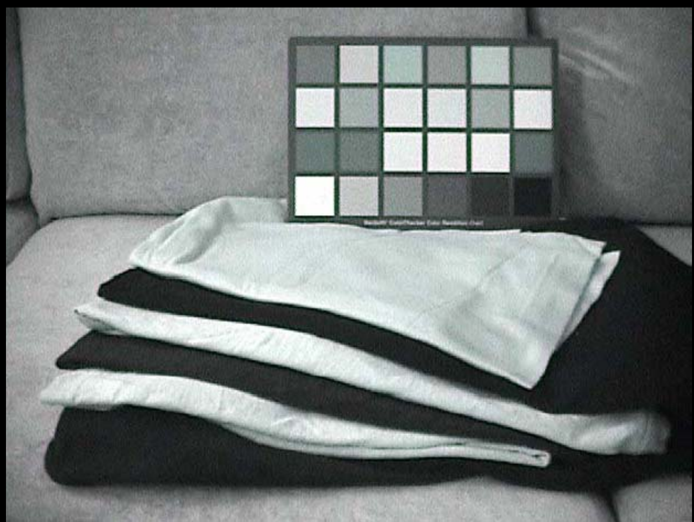
Outline

- 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

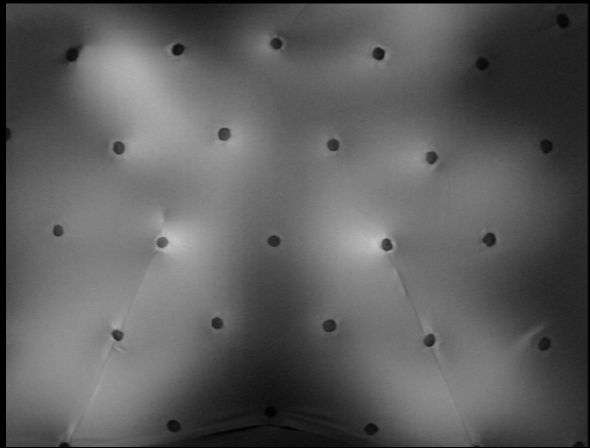
- Invisible lights
  - Polarized lights
  - Infrared
- Thermo-key
- Depth Keying (ZCam)
- Flash matting

Invisible lights (Infared)



Invisible lights (Infared)

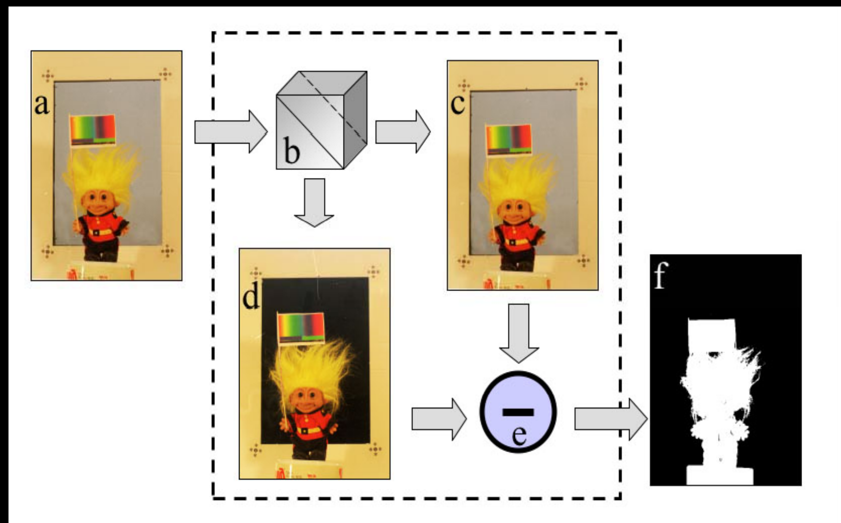
Invisible lights (Infared)



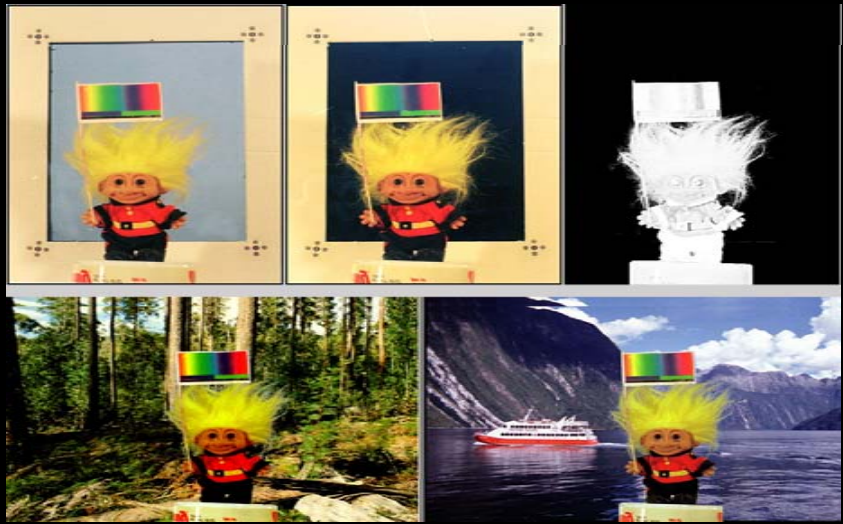
Invisible lights (Infared)

Invisible lights (Infared)

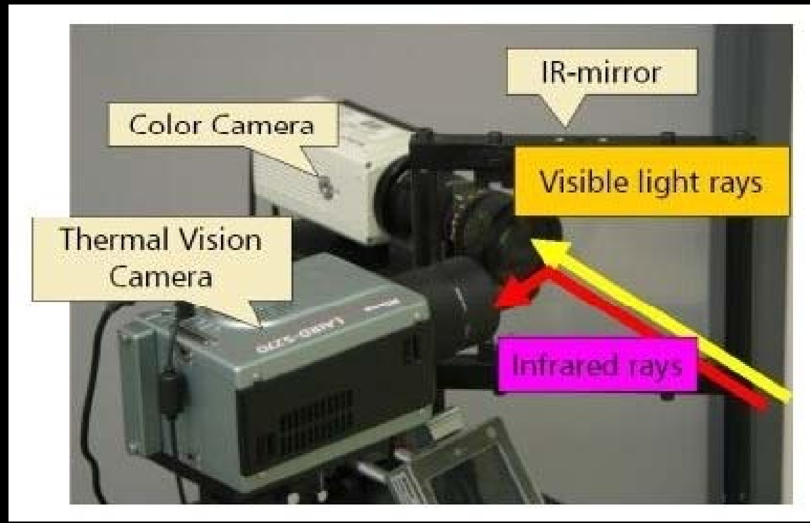
Invisible lights (Infared)



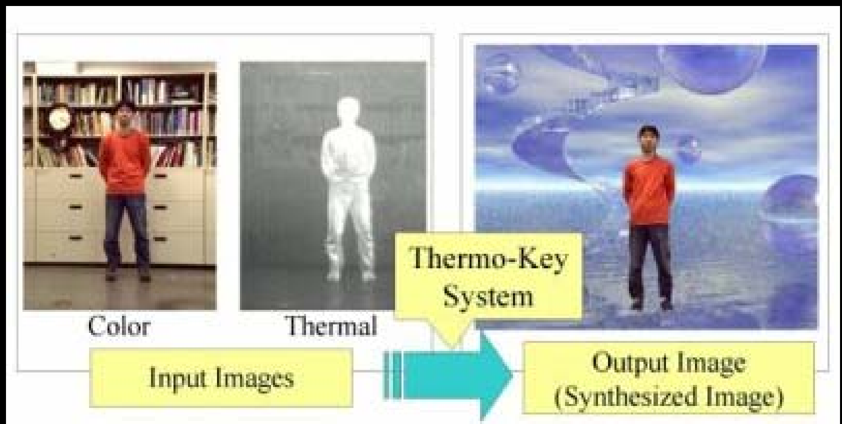
Invisible lights (Polarized)



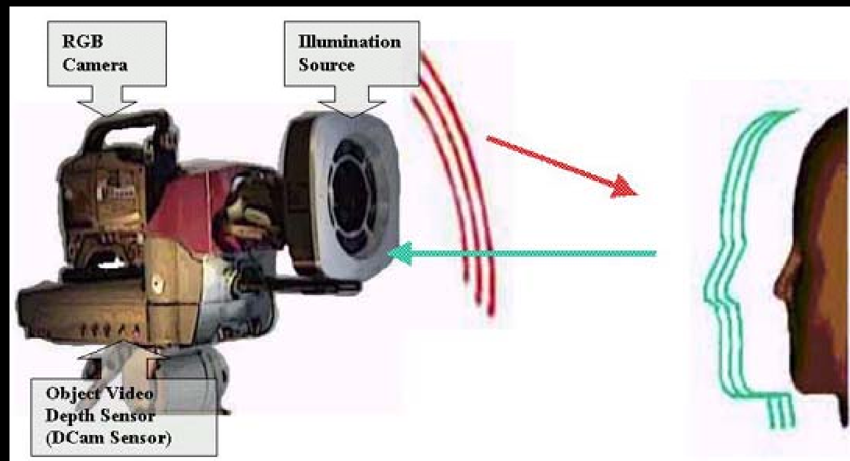
Invisible lights (Polarized)



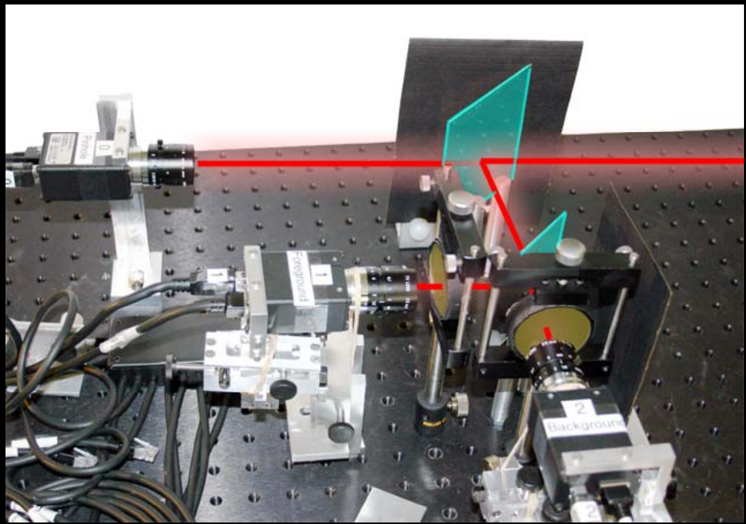
Thermo-Key



Thermo-Key



ZCam



Defocus matting

video

video

Matting with camera arrays

flash no flash matte

Flash matting

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

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.

$$\arg \max_{\alpha, F'} L(\alpha, F' \,|\, I')$$
$$= \arg \max_{\alpha, F'} \{ L(I'|\alpha, F') + L(F') + L(\alpha) \}$$
$$L(I'|\alpha, F') = -||I' - \alpha F'|| / \sigma^2_{I'}$$
$$L(F') = -(F' - \overline{F'})^T \Sigma^{-1}_{F'} (F' - \overline{F'})$$

Flash matting

Foreground flash matting

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

$$\arg \max_{\alpha, F, B, F'} L(\alpha, F, B, F' | I, I')$$
$$= \arg \max_{\alpha, F, B, F'} \{ L(I|\alpha, F, B) + L(I'|\alpha, F') + L(F) + L(B) + L(F') + L(\alpha) \}$$

Joint Bayesian flash matting

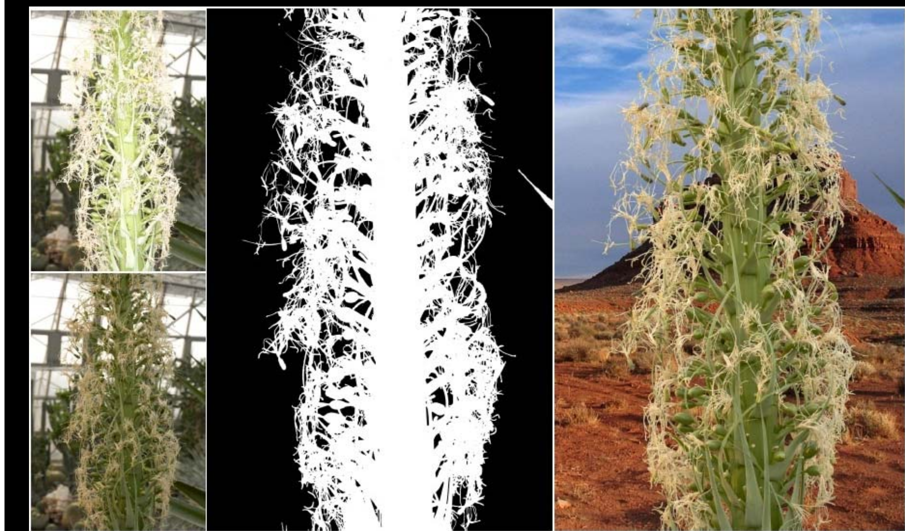
$$\alpha = \frac{\sigma_{I'}^2 (F-B)^T (I-B) + \sigma_I^2 F'^T I'}{\sigma_{I'}^2 (F-B)^T (F-B) + \sigma_I^2 F'^T F'}$$

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

Joint Bayesian flash matting

Comparison

Comparison



Flash matting

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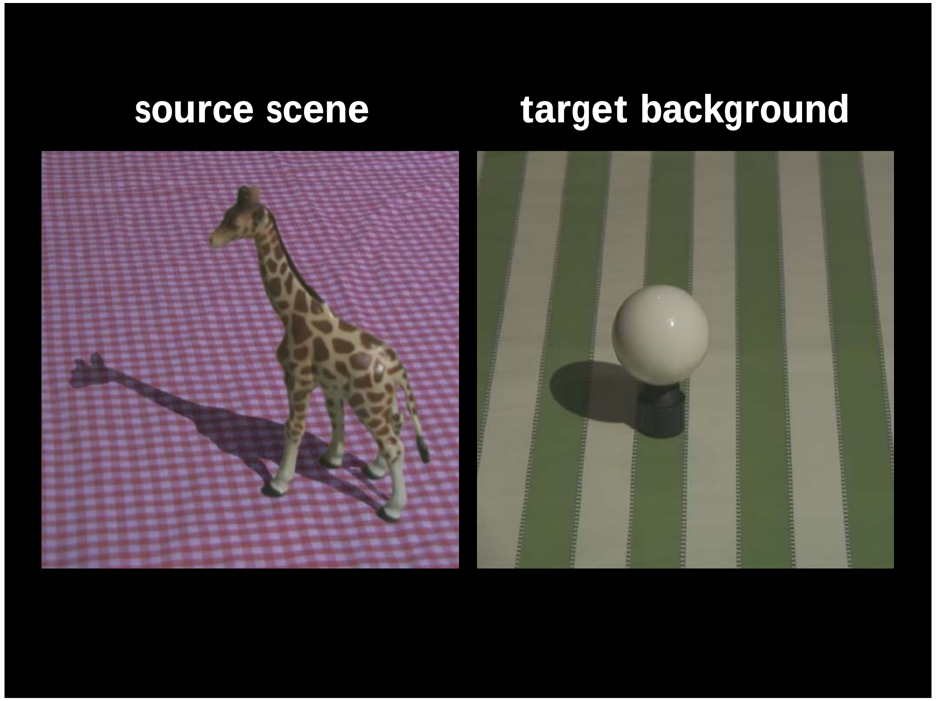
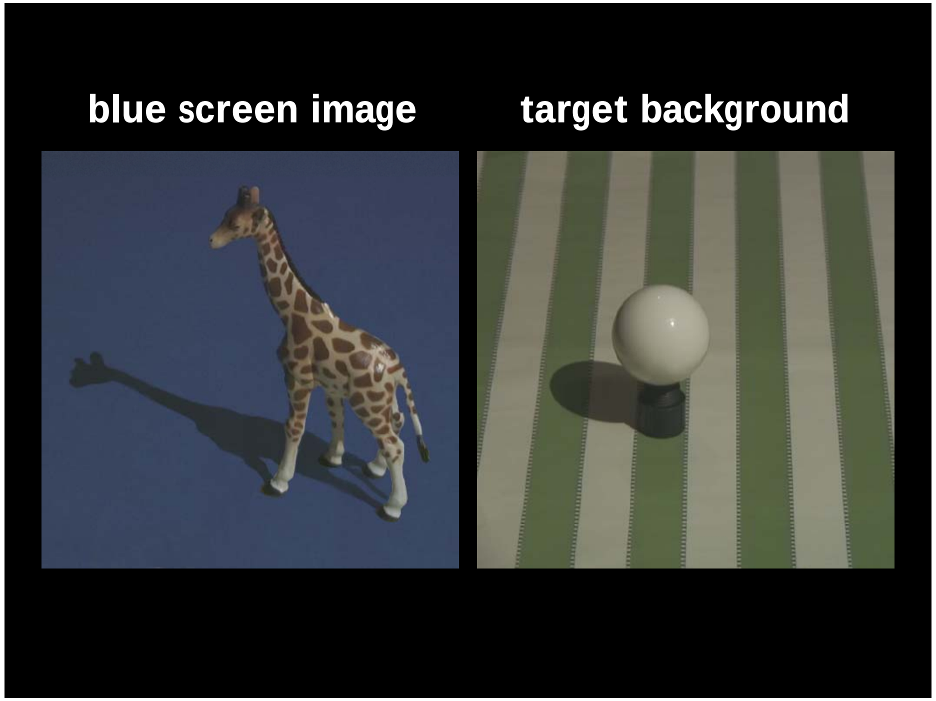
Conclusions

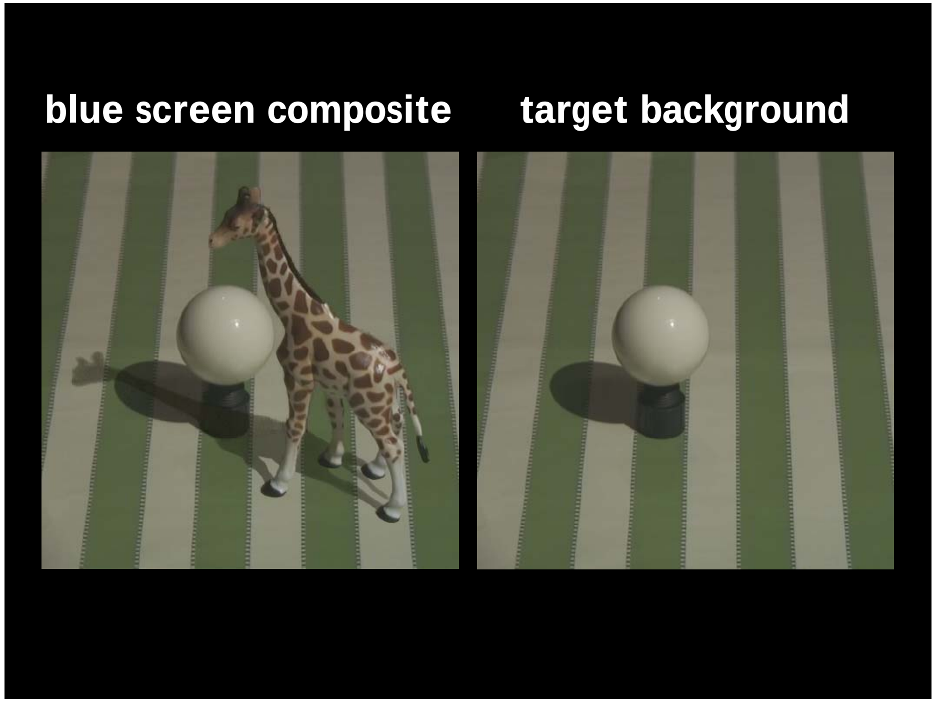
- Matting algorithms improves a lot in these 10 years
- In production, it is still always preferable to shoot against uniform backgrounds
- Algorithms for more complex backgrounds
- Devices or algorithms for automatic matting

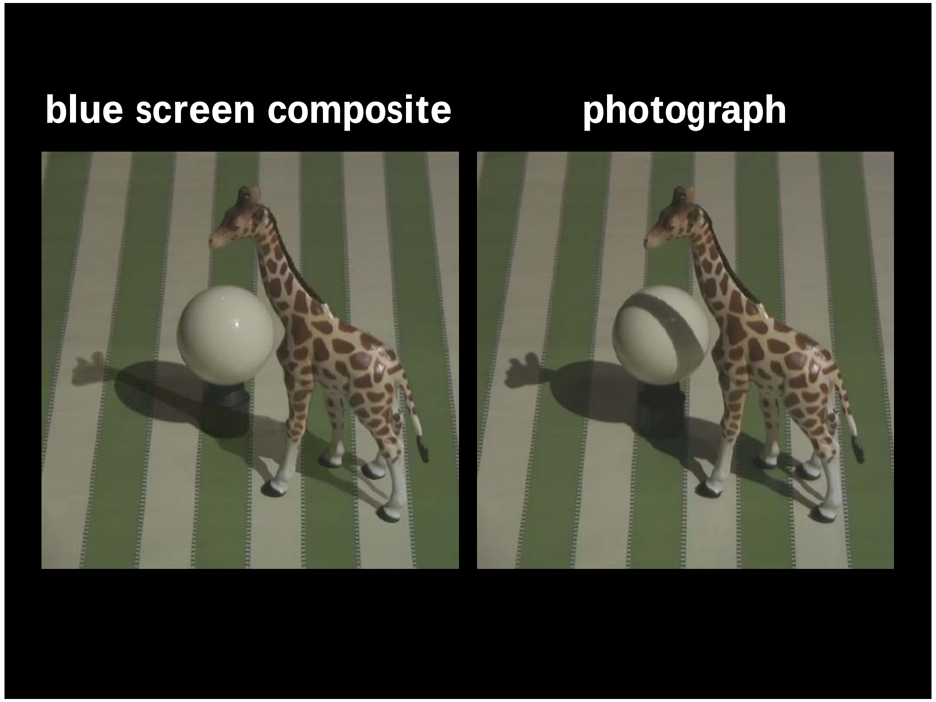
Thanks for your attention!

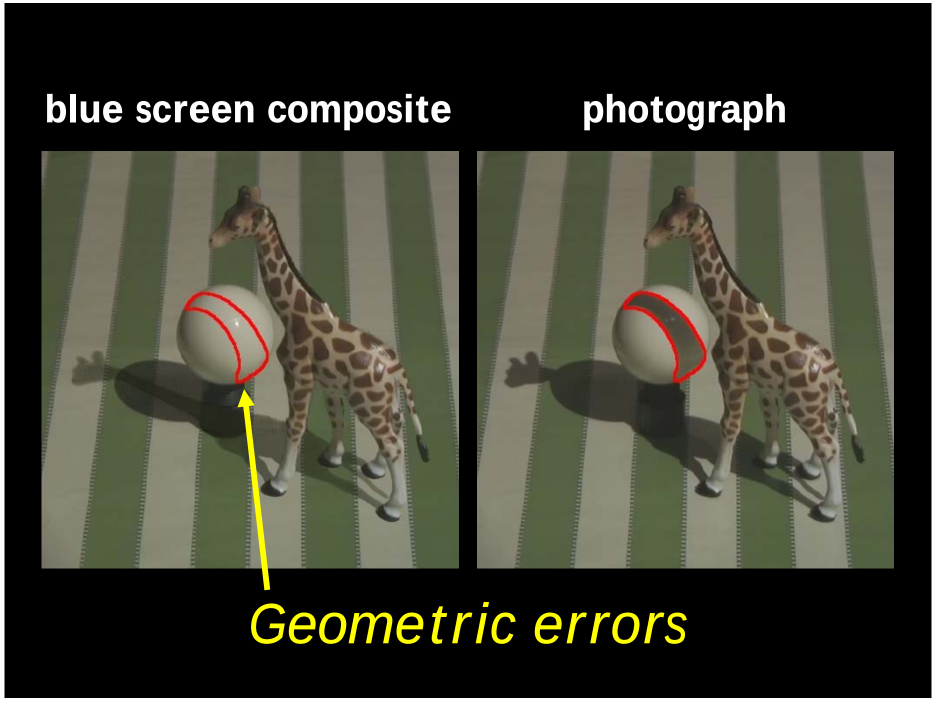
Shadow matting and composting

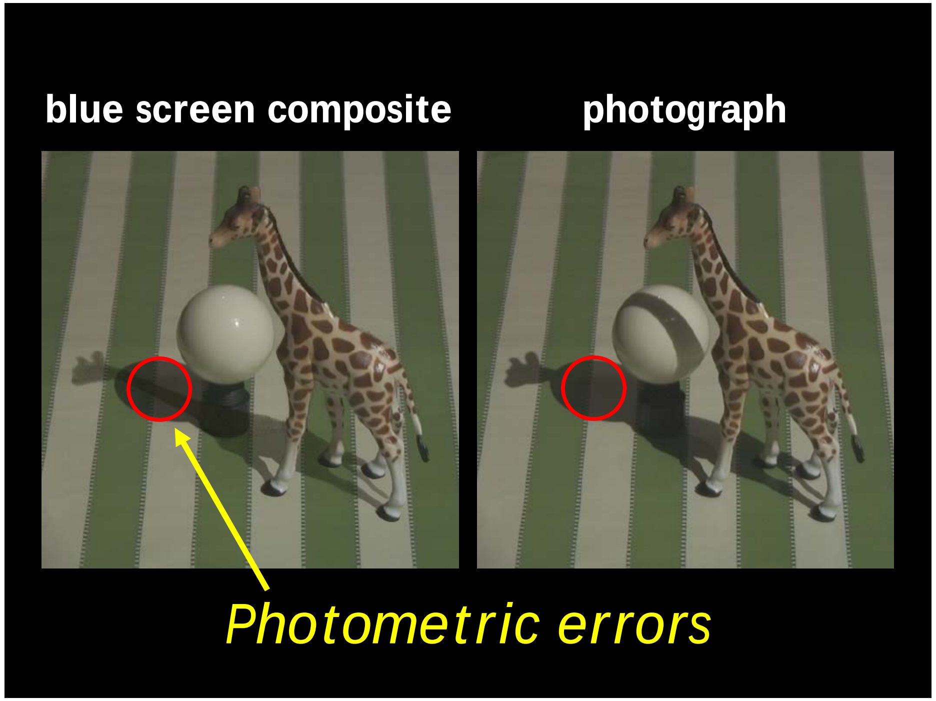

source scene
target background

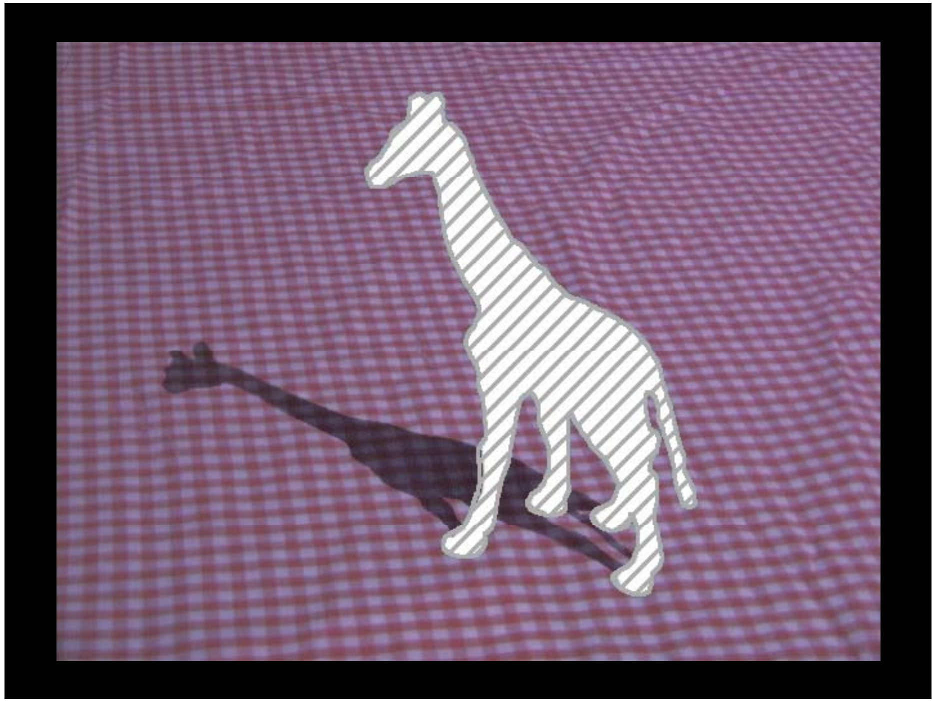

blue screen image
target background

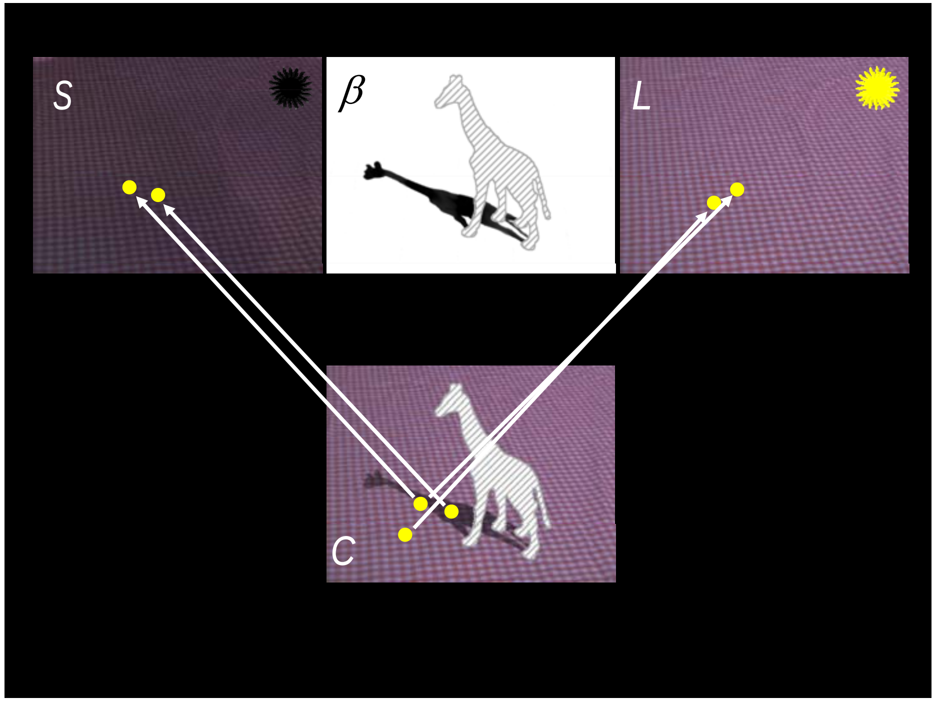

blue screen composite
target background

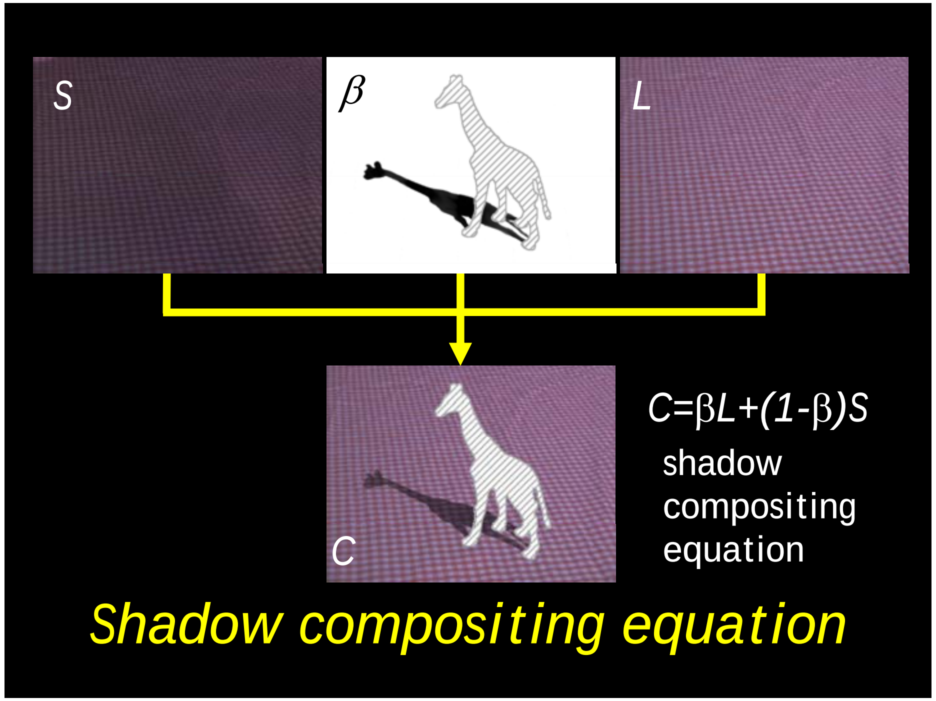

blue screen composite
photograph

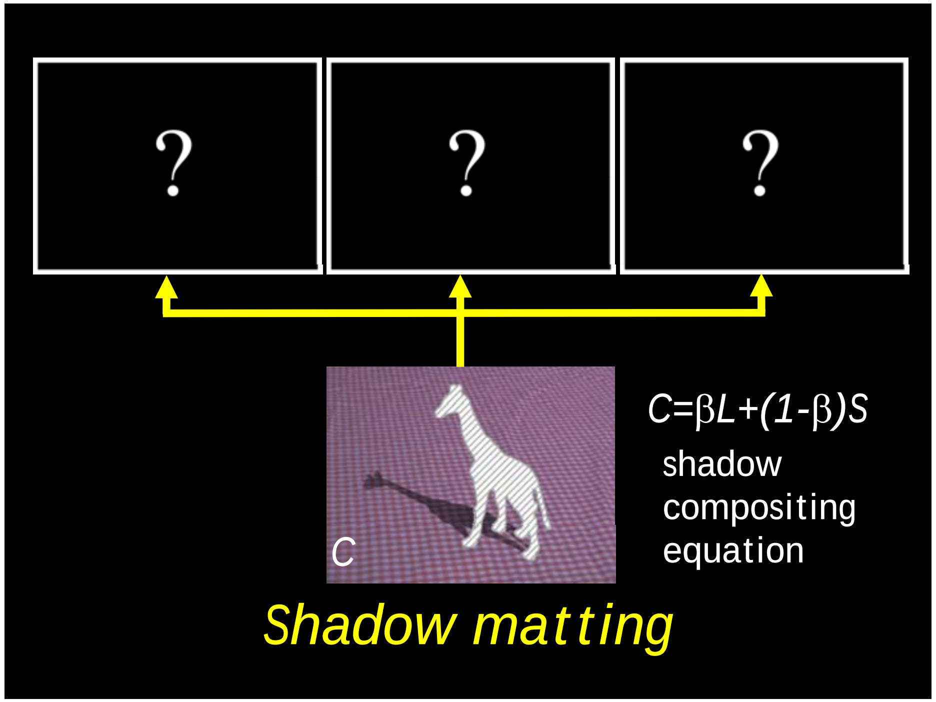

blue screen composite
photograph
Geometric errors

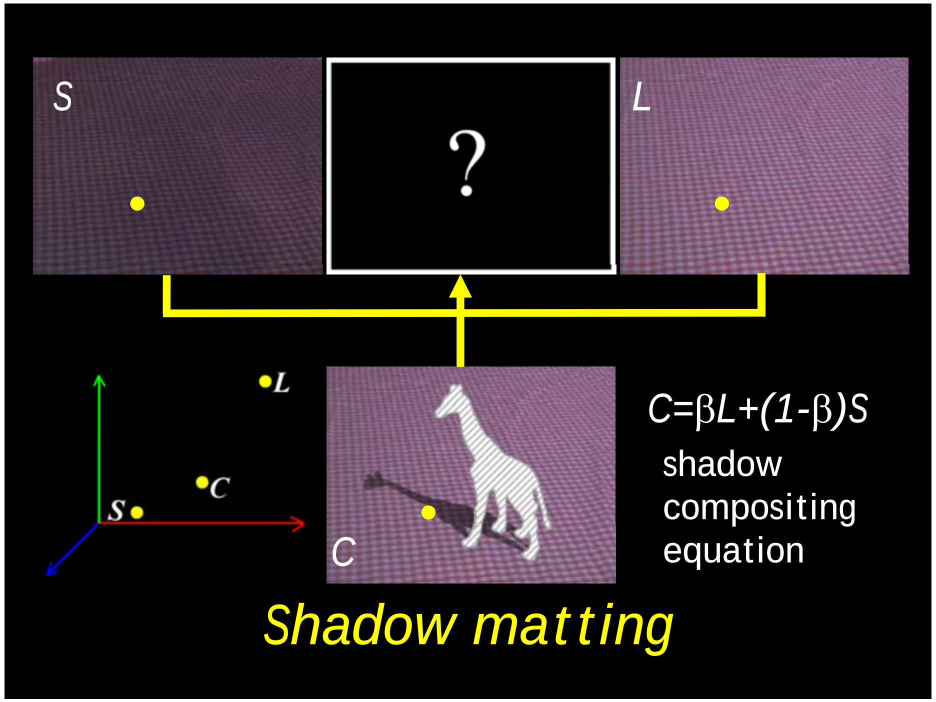

blue screen composite
photograph
Photometric errors

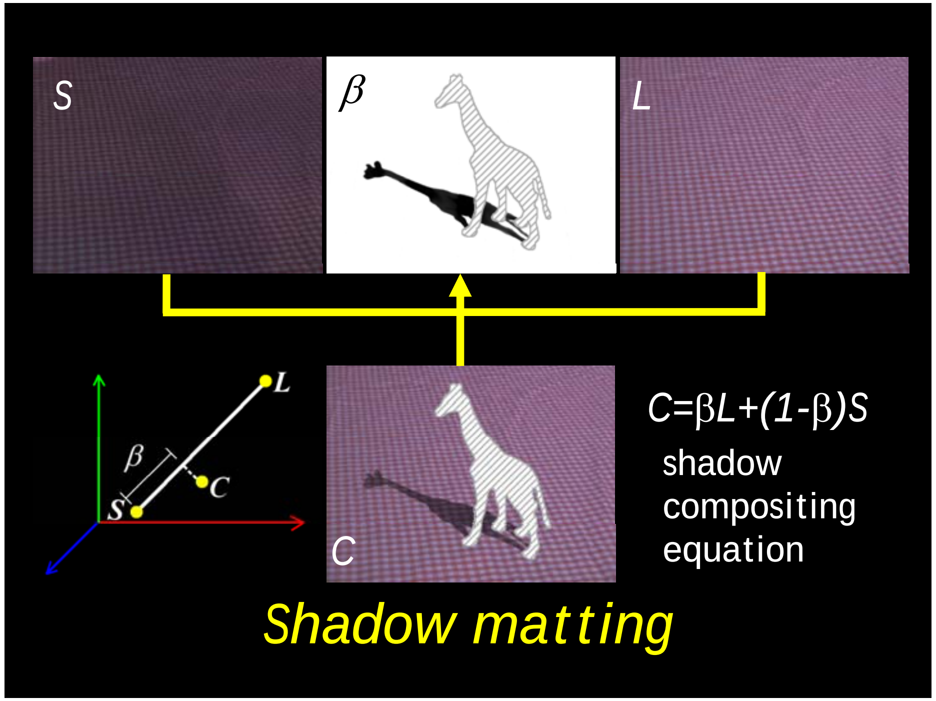


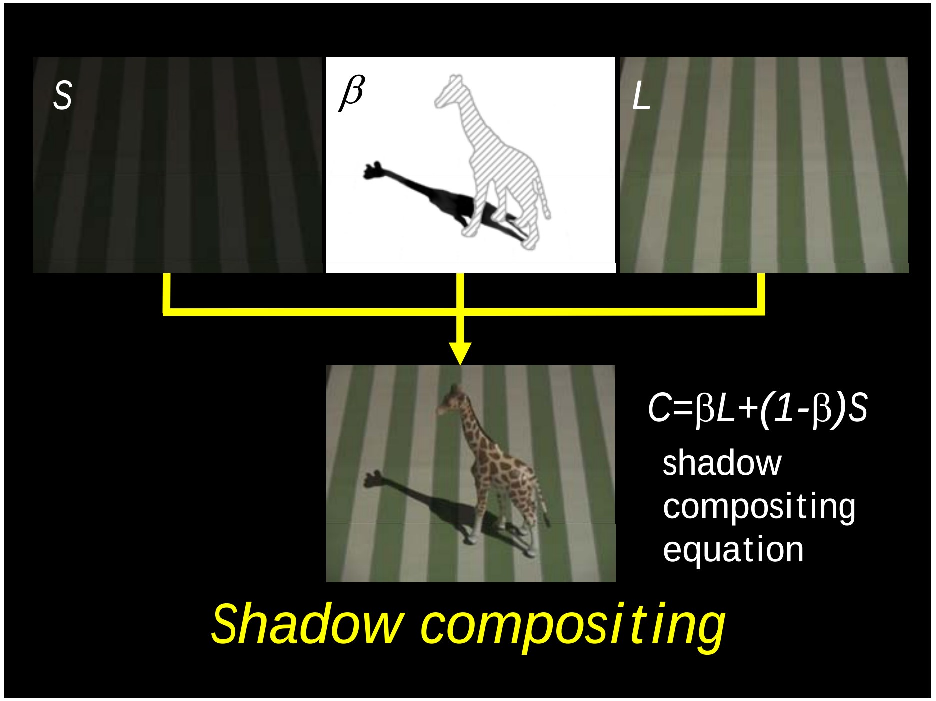

S
β
L
C


S
β
L
C
C=βL+(1-β)S
shadow compositing equation
Shadow compositing equation


?
?
?
C
C=βL+(1-β)S
shadow compositing equation
Shadow matting


S
?
L
L
C
S
C
C=βL+(1-β)S
shadow compositing equation
Shadow matting


S
β
L
C
L
β
C
S
C=βL+(1-β)S
shadow
compositing
equation
Shadow matting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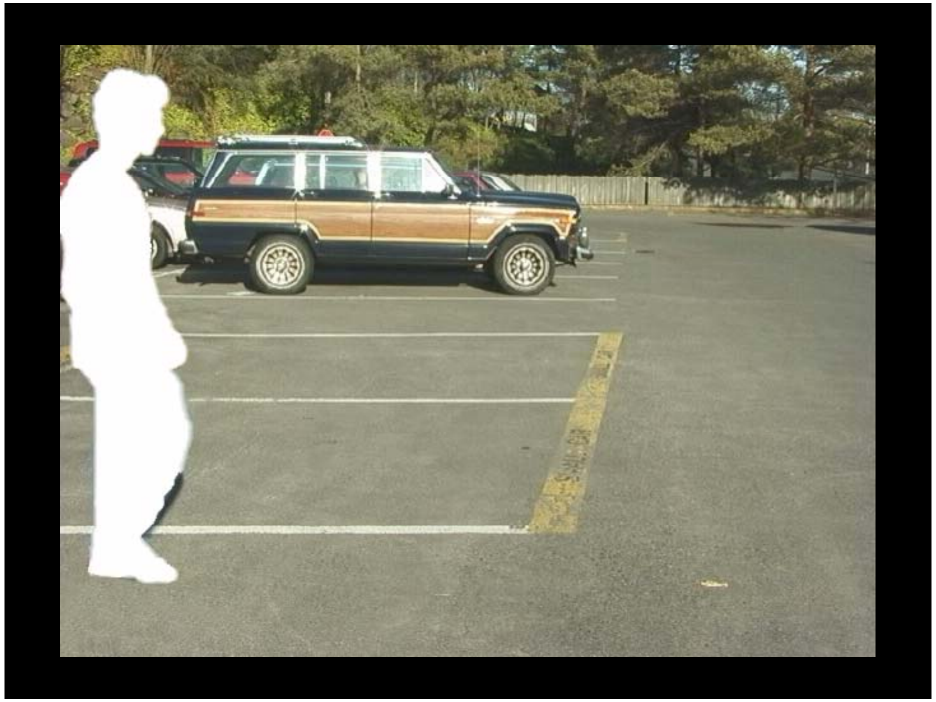
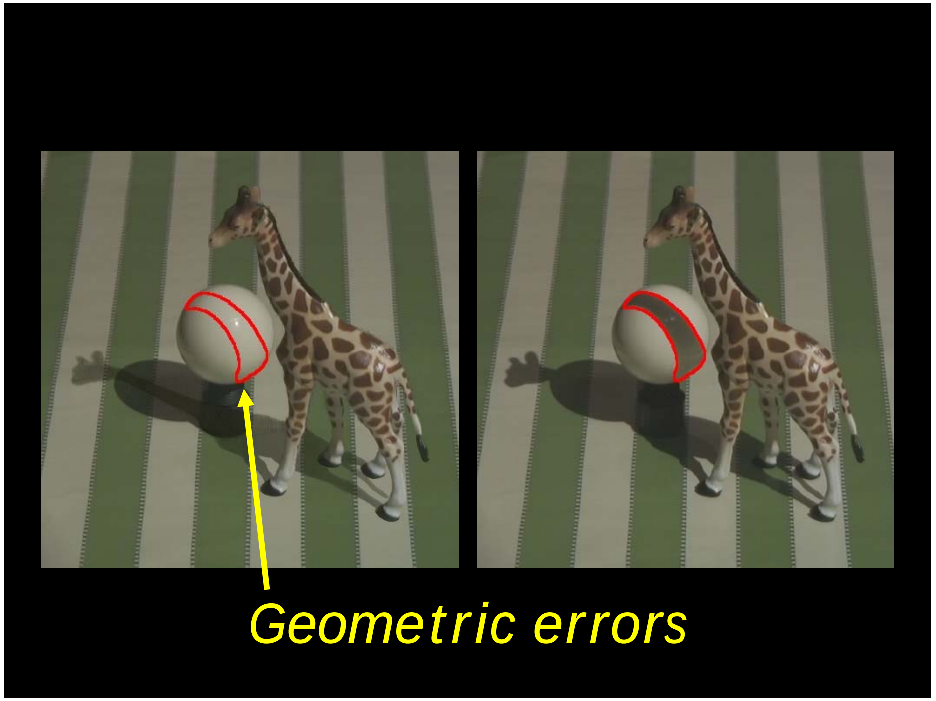
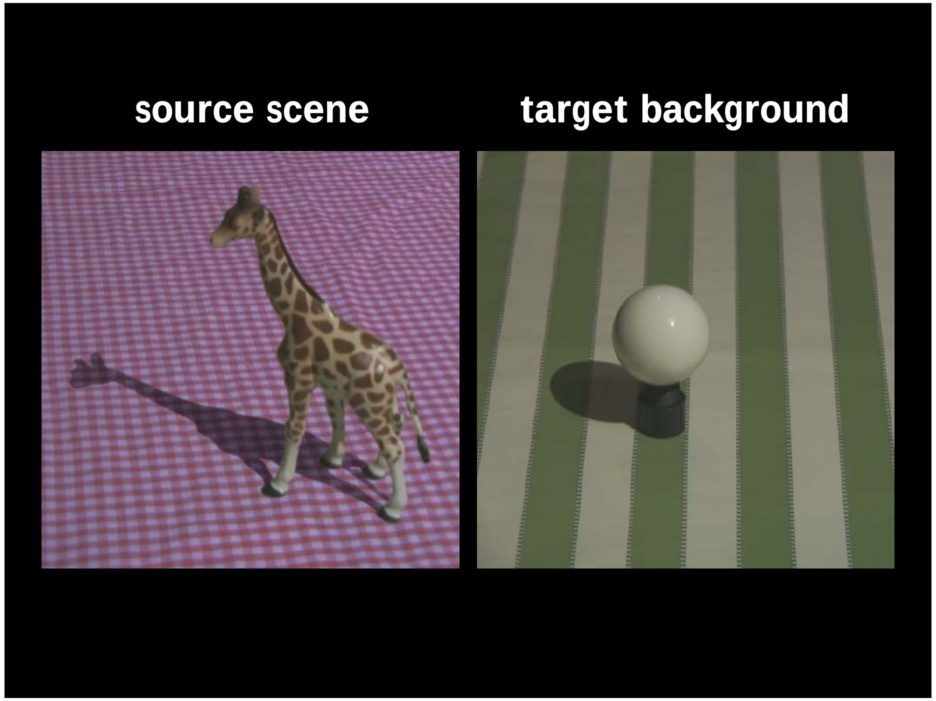
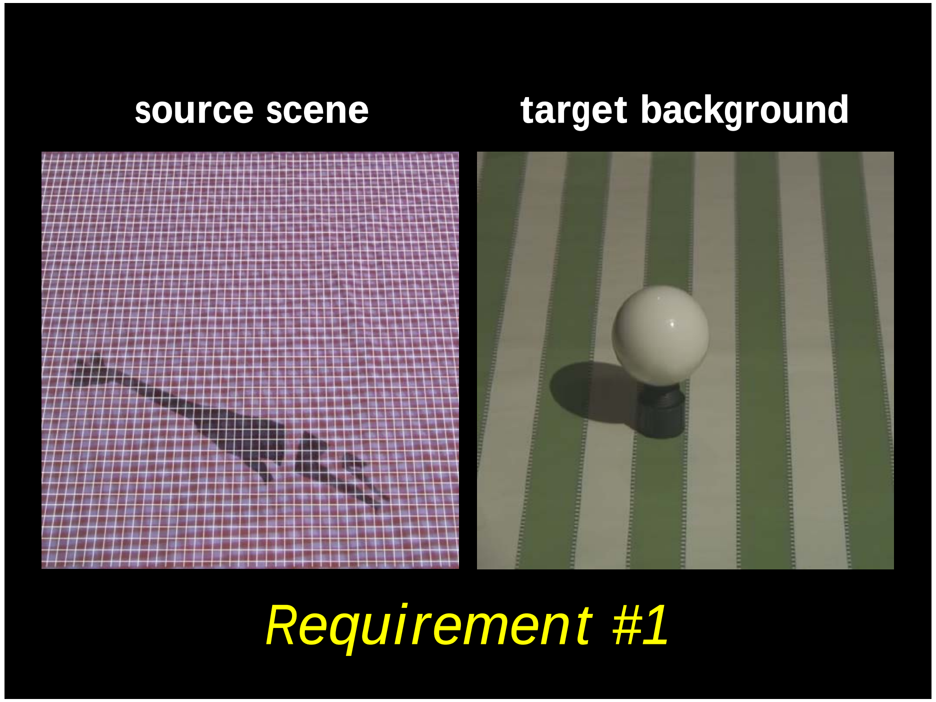
L
C=βL+(1-β)S
shadow
compositing
equation
Shadow compositing

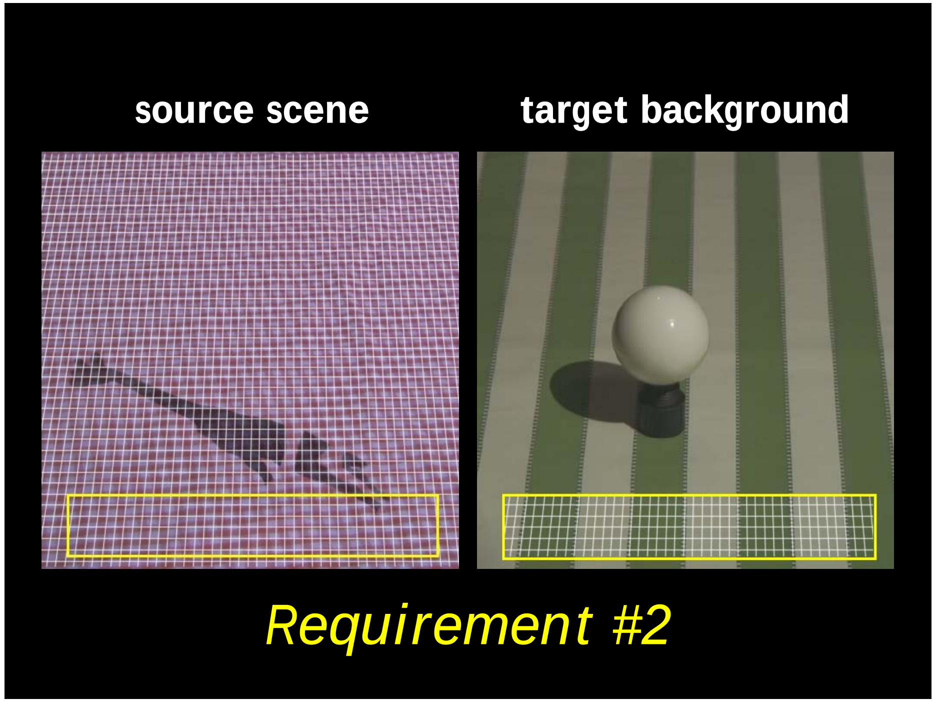


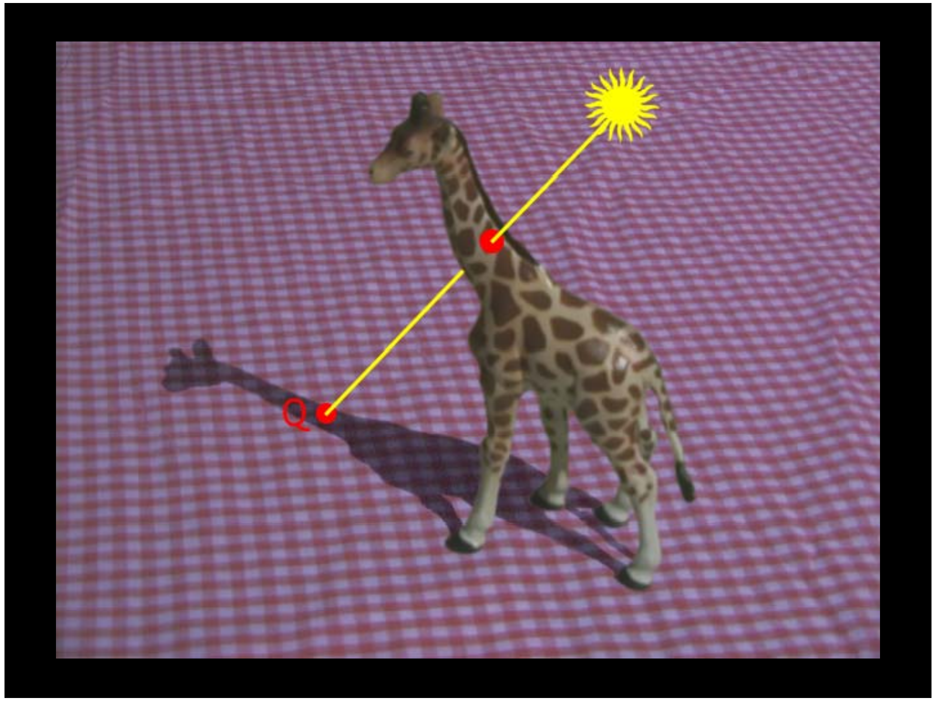


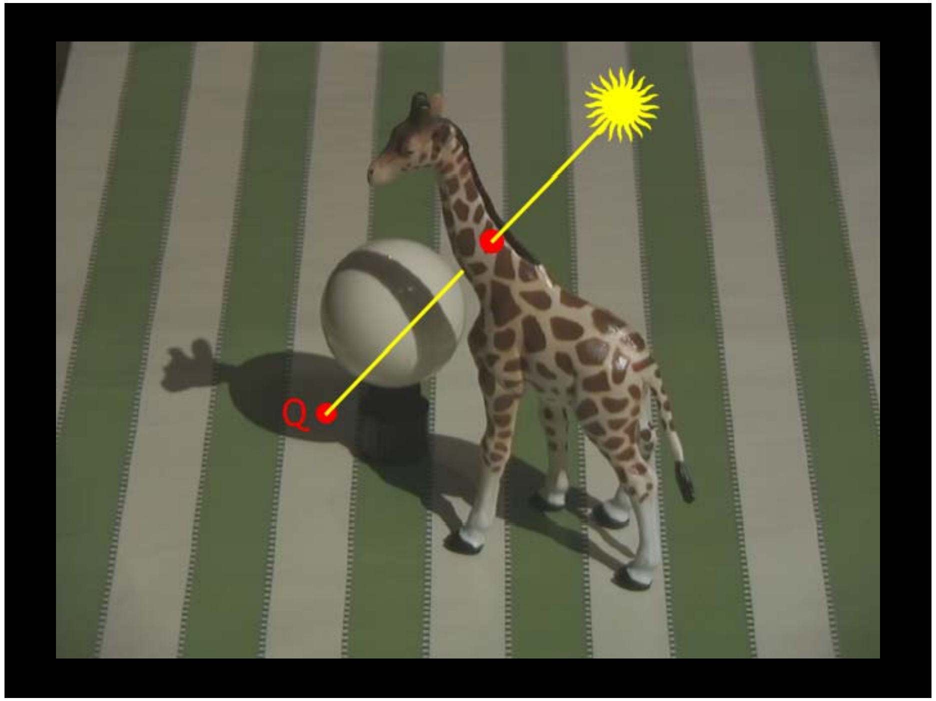


Geometric errors


source scene
target background


source scene
target background
Requirement #1


source scene
target background
Requirement #2


Q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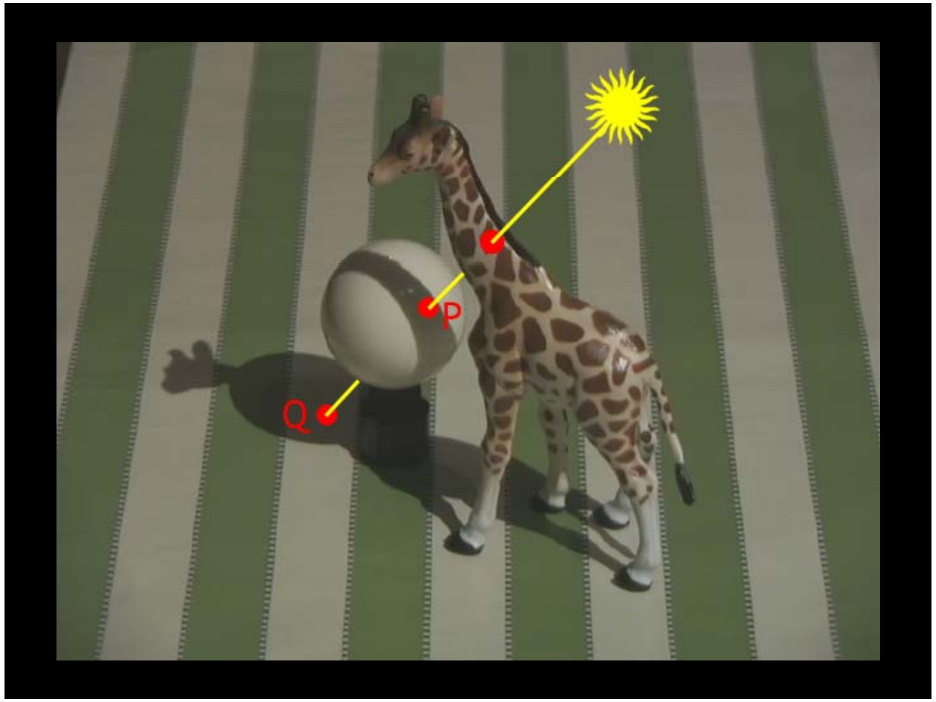
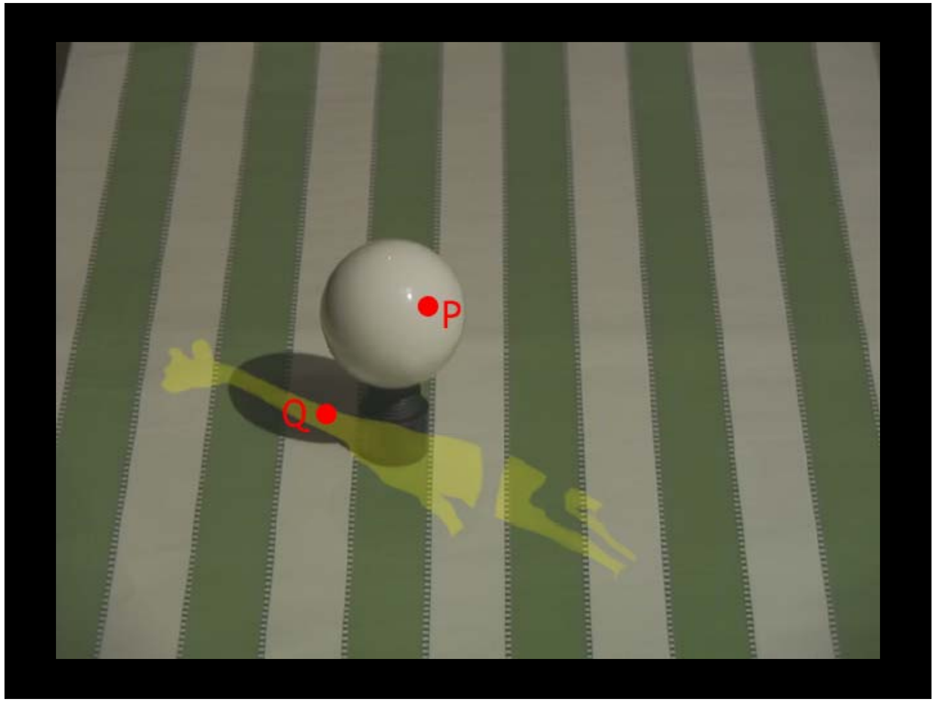

P
Q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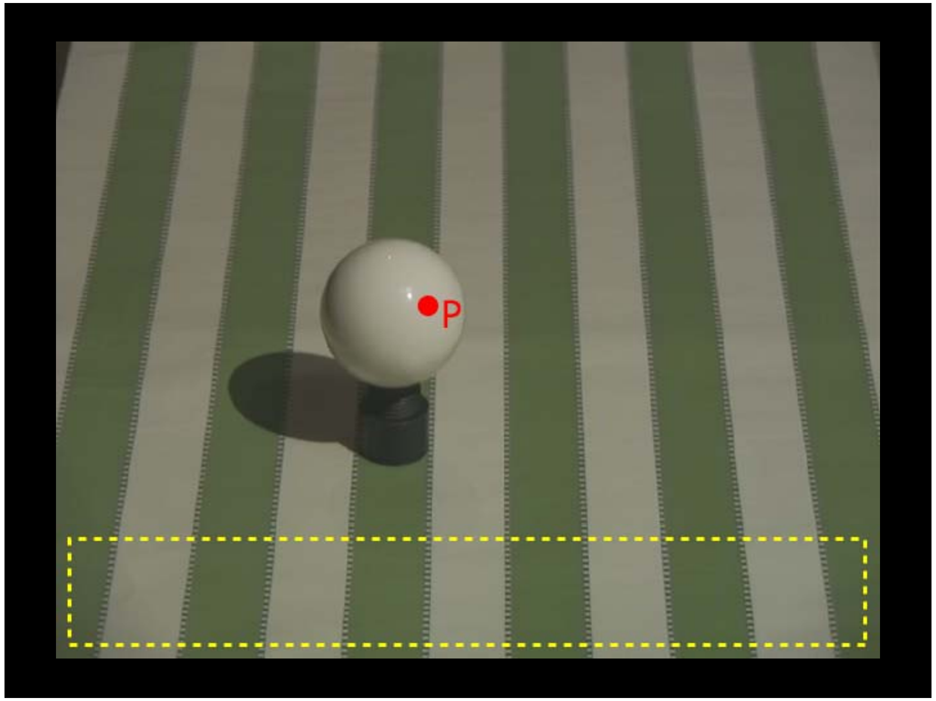
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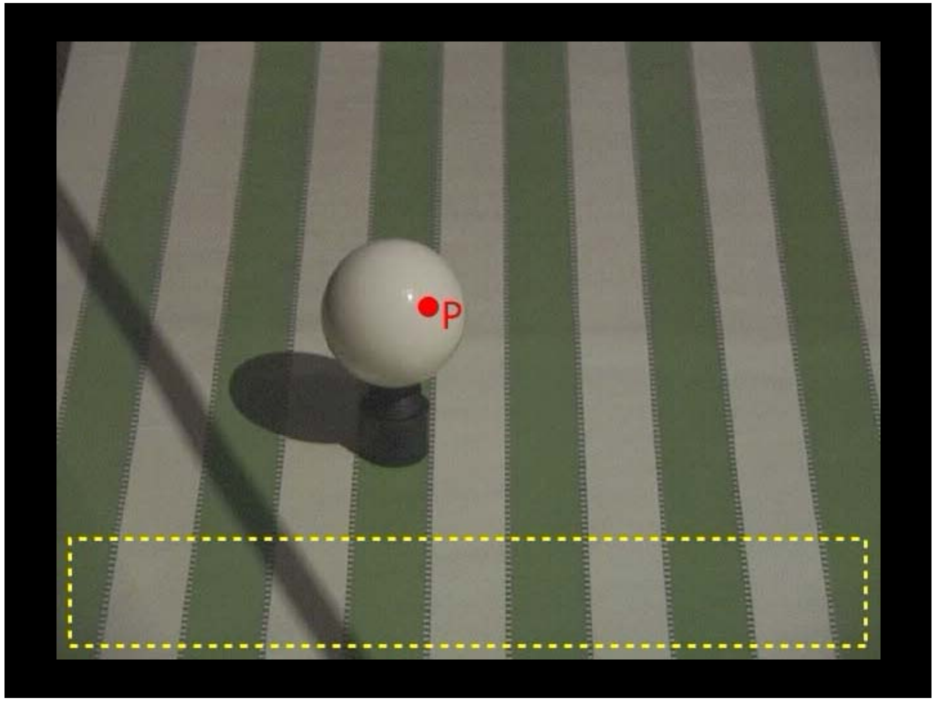
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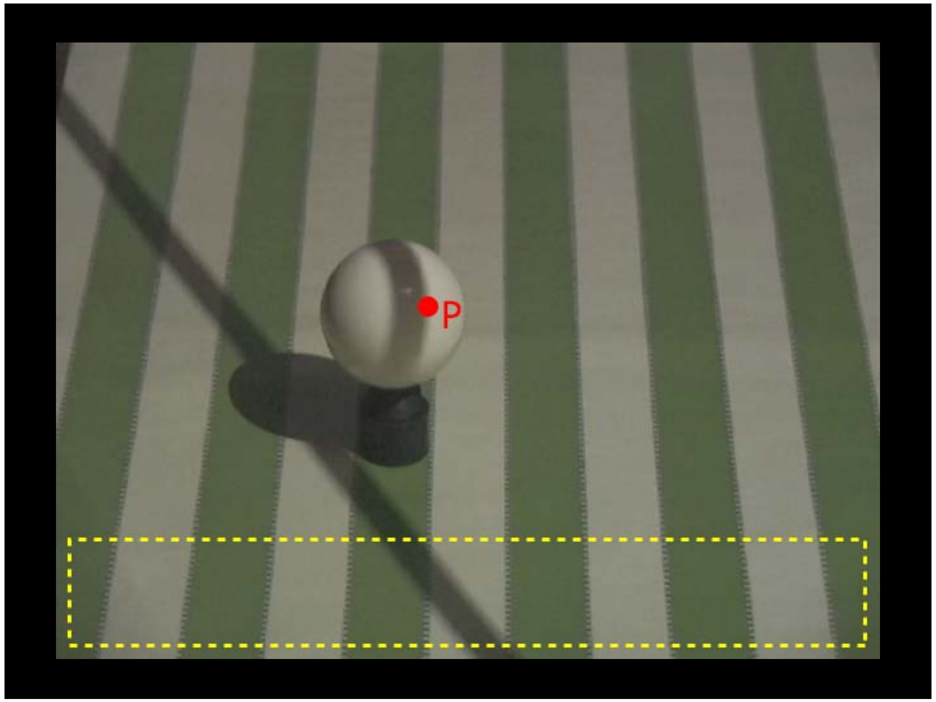
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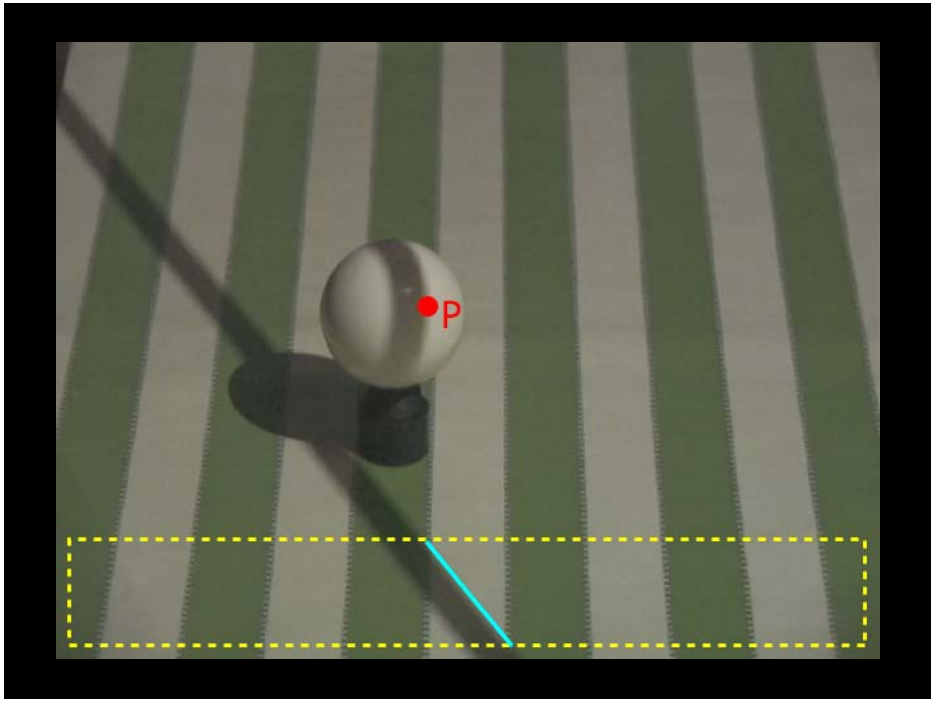
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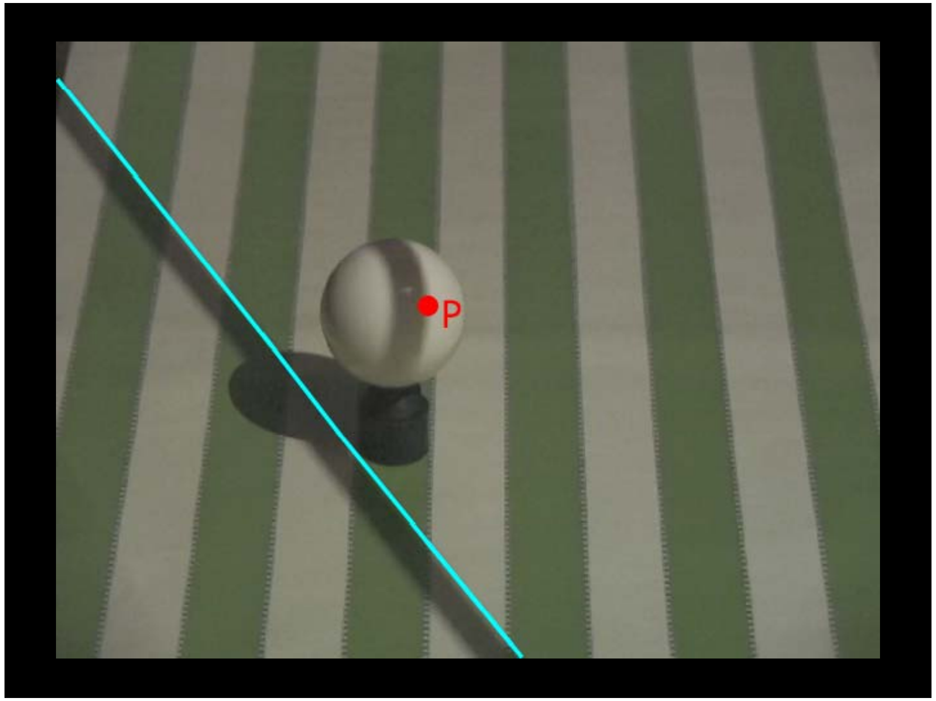
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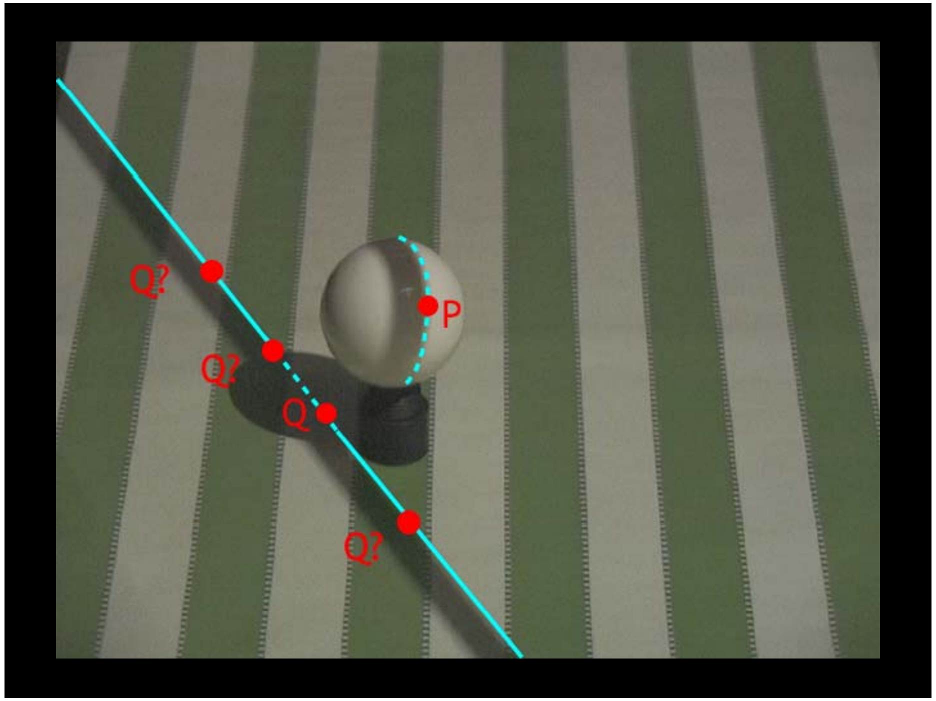
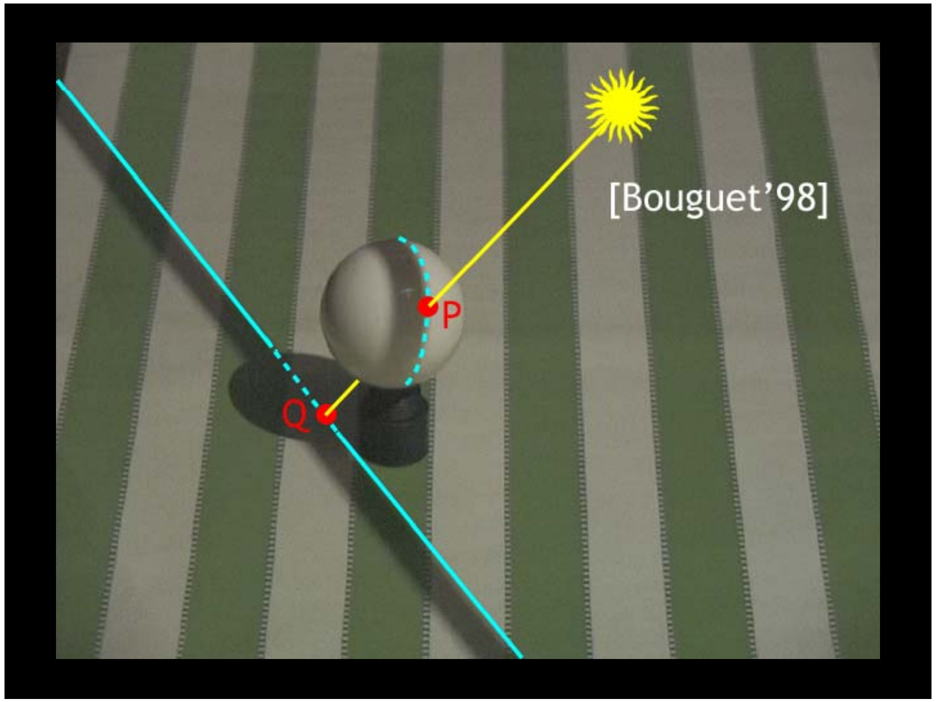
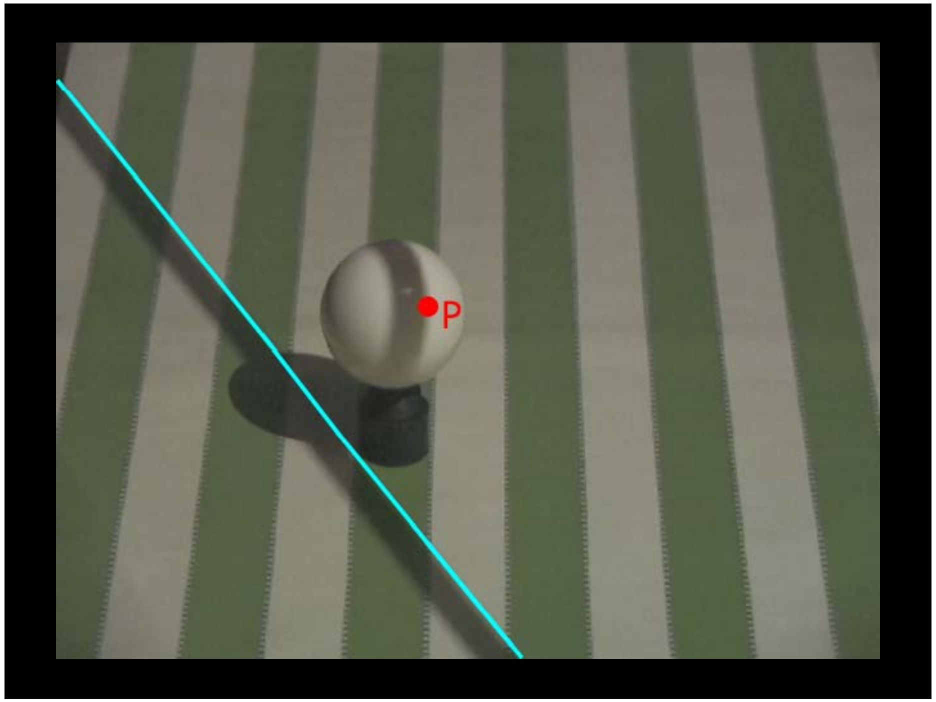

Q?
Q?
Q
Q?
P


[Bouguet'98]
P
Q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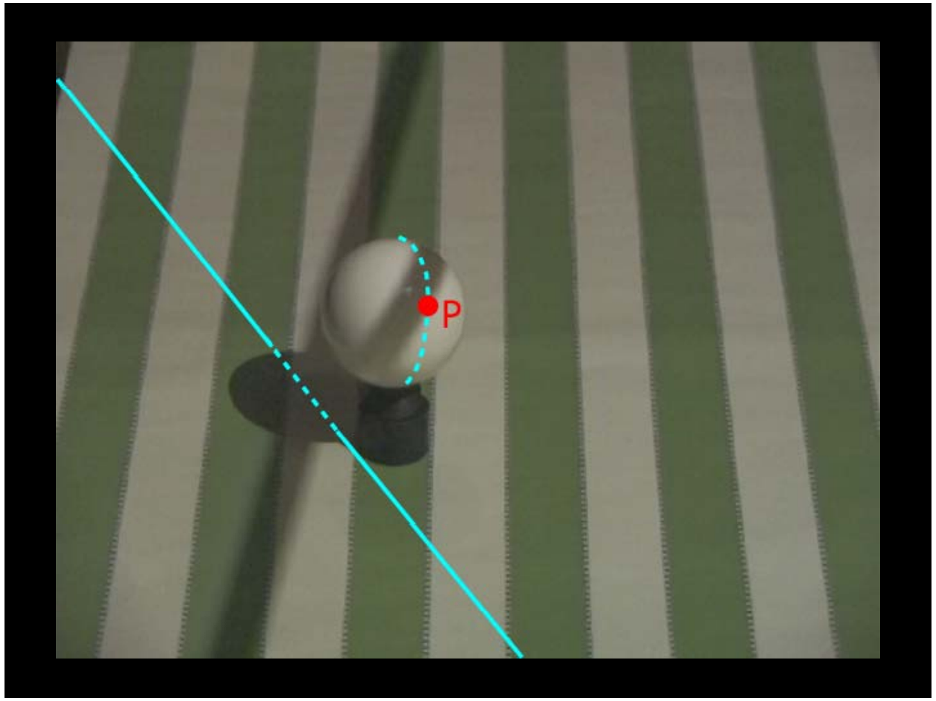
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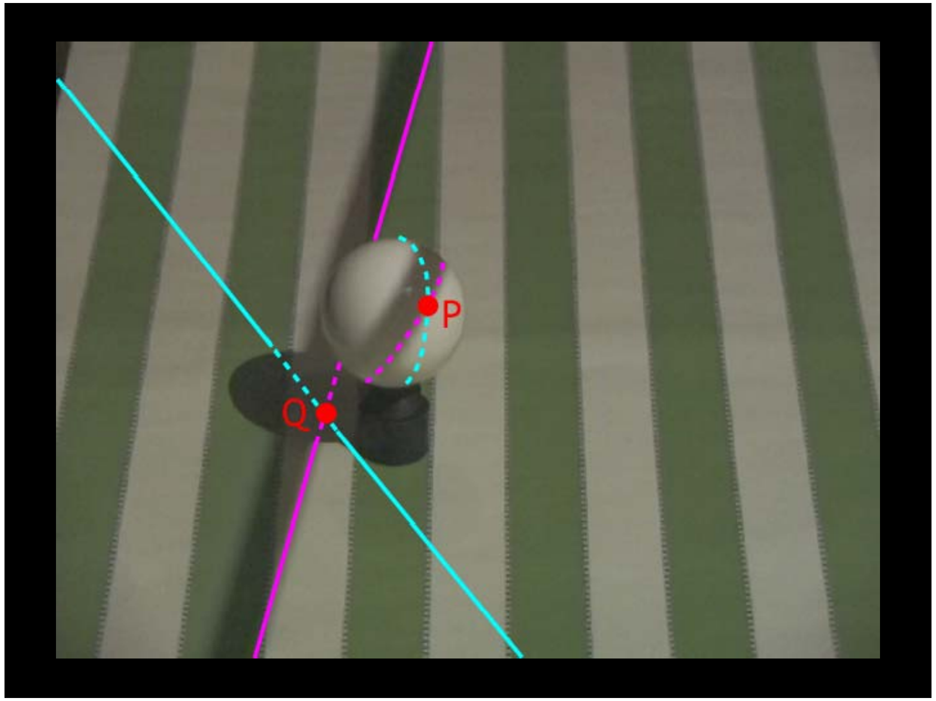
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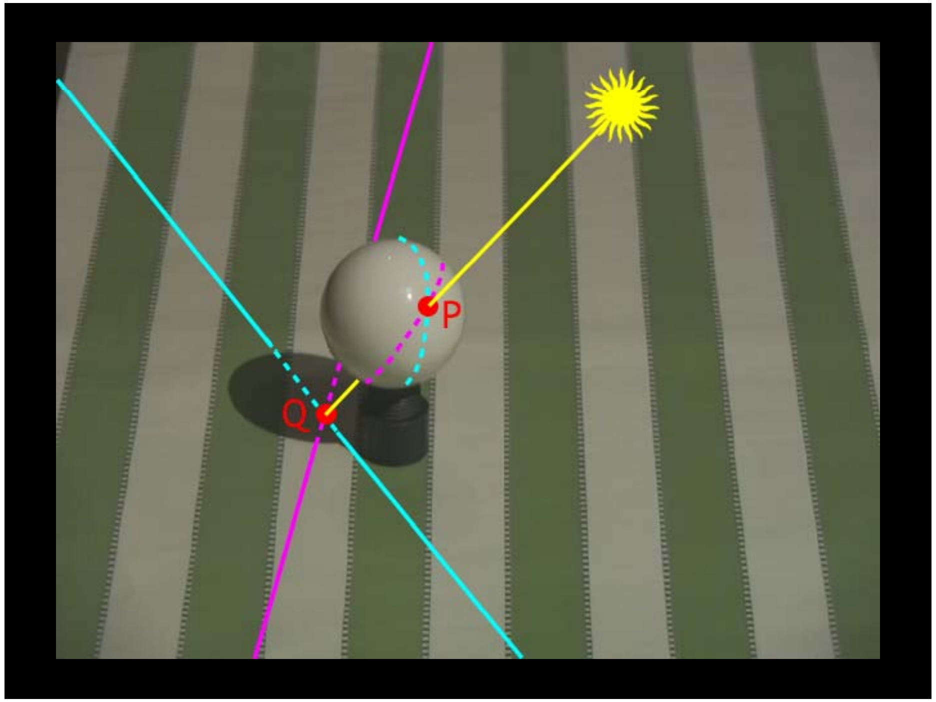
Q

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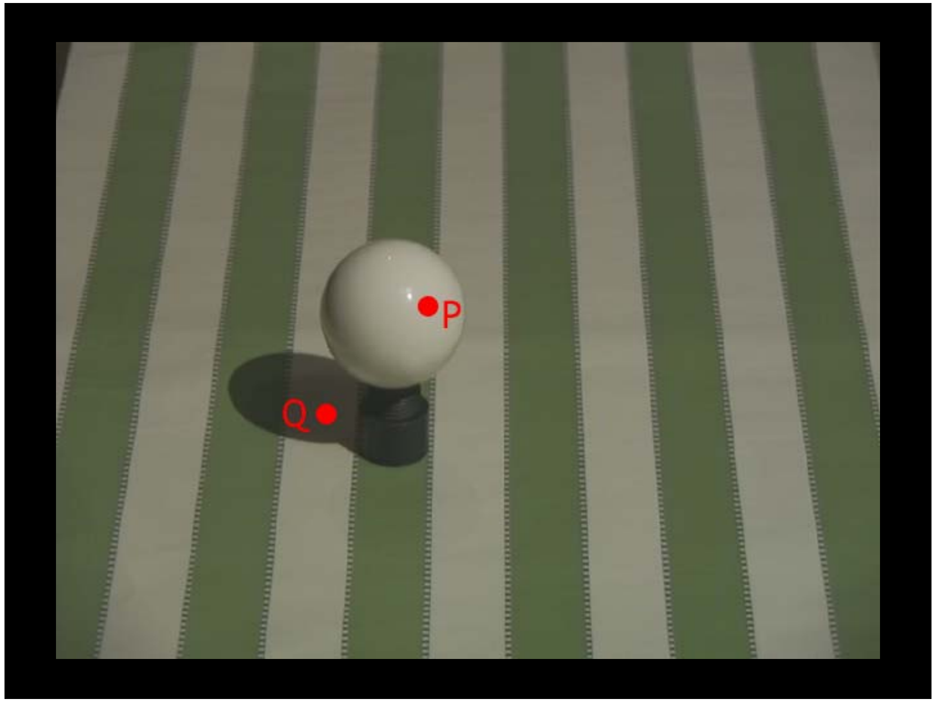
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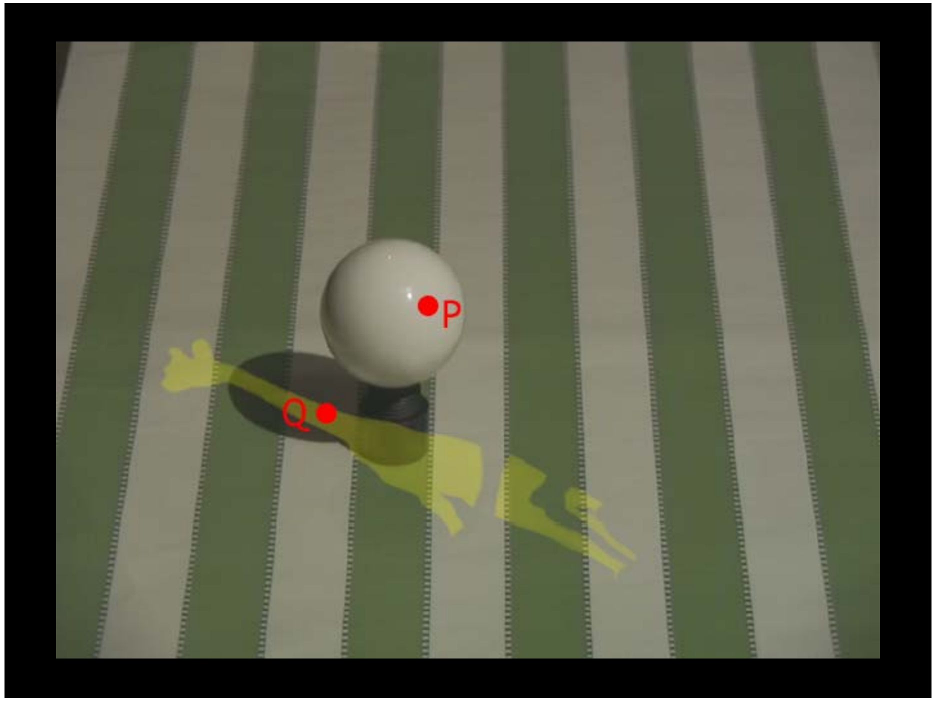
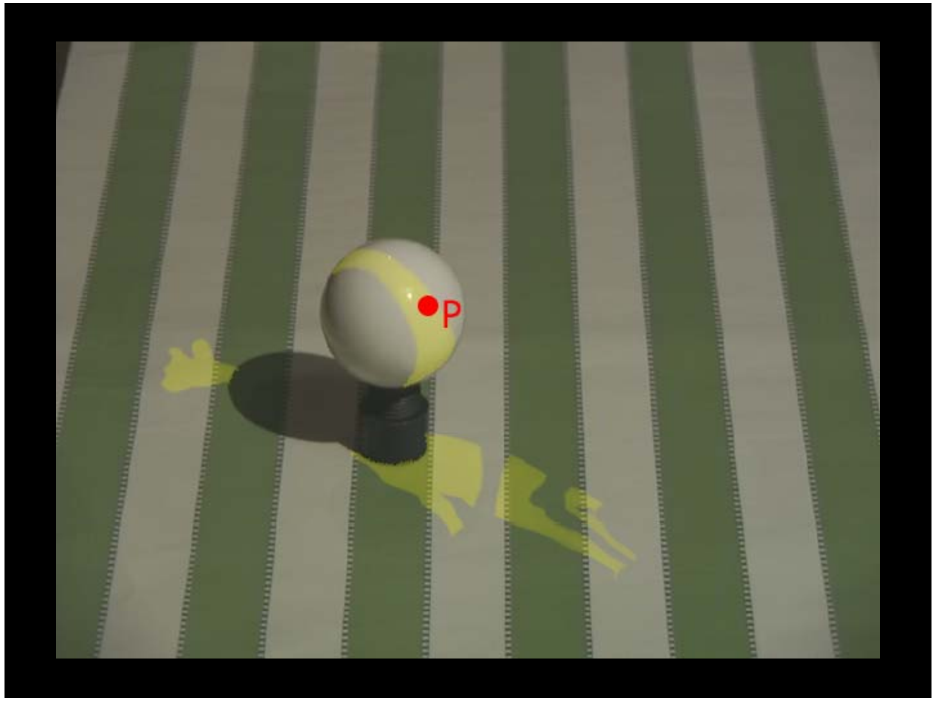
Q


P
Q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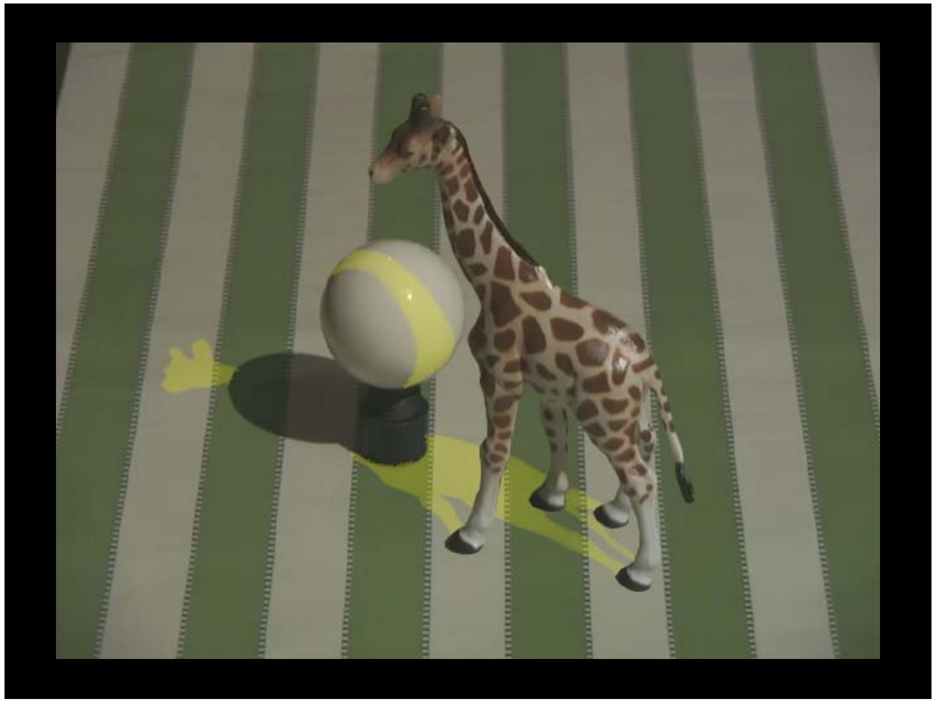
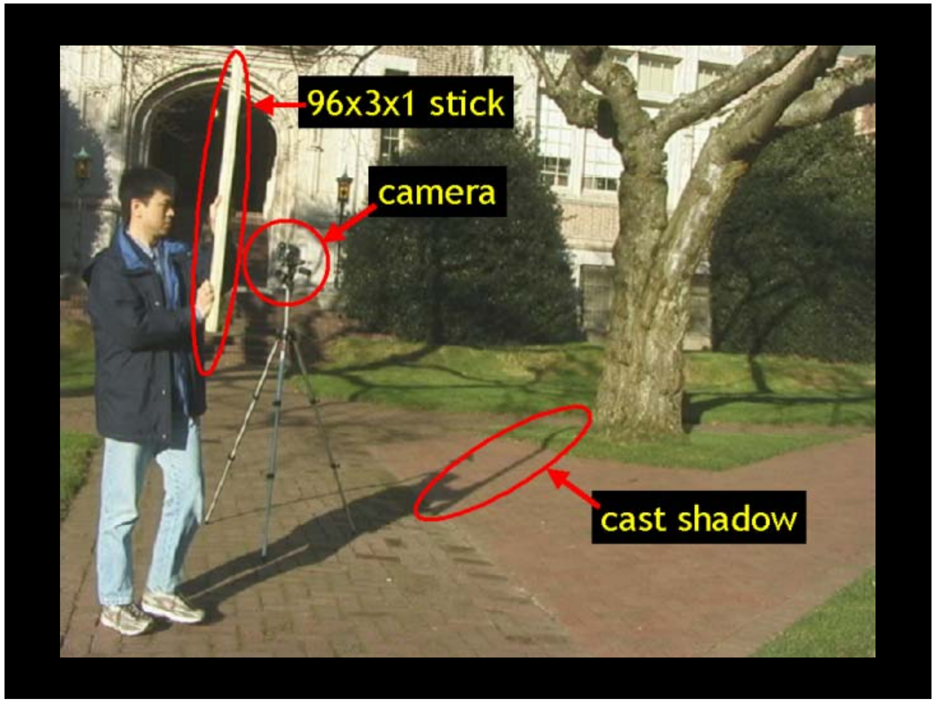
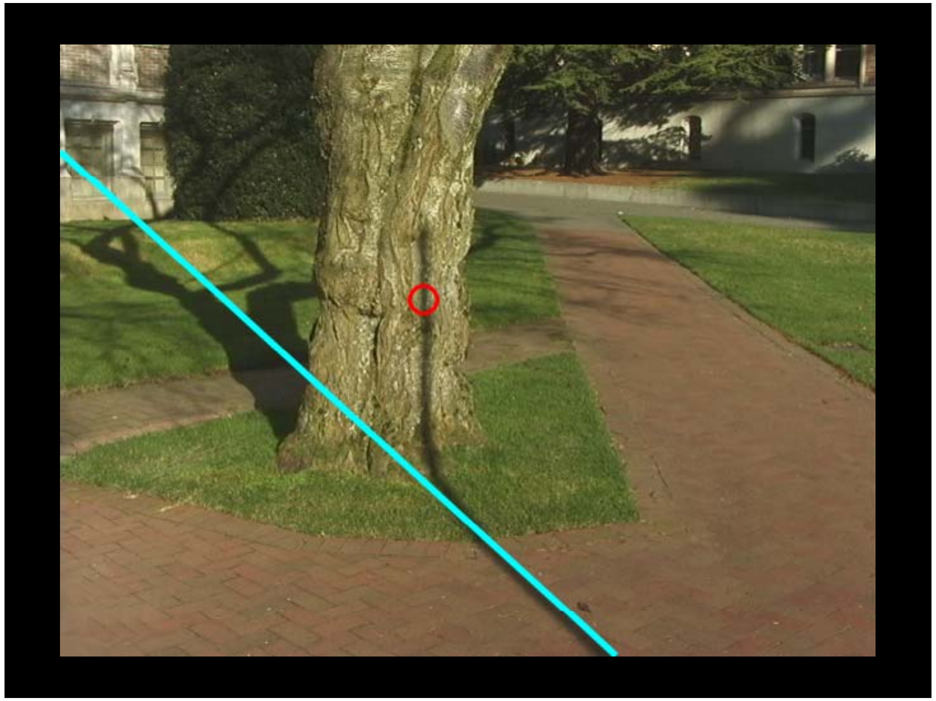
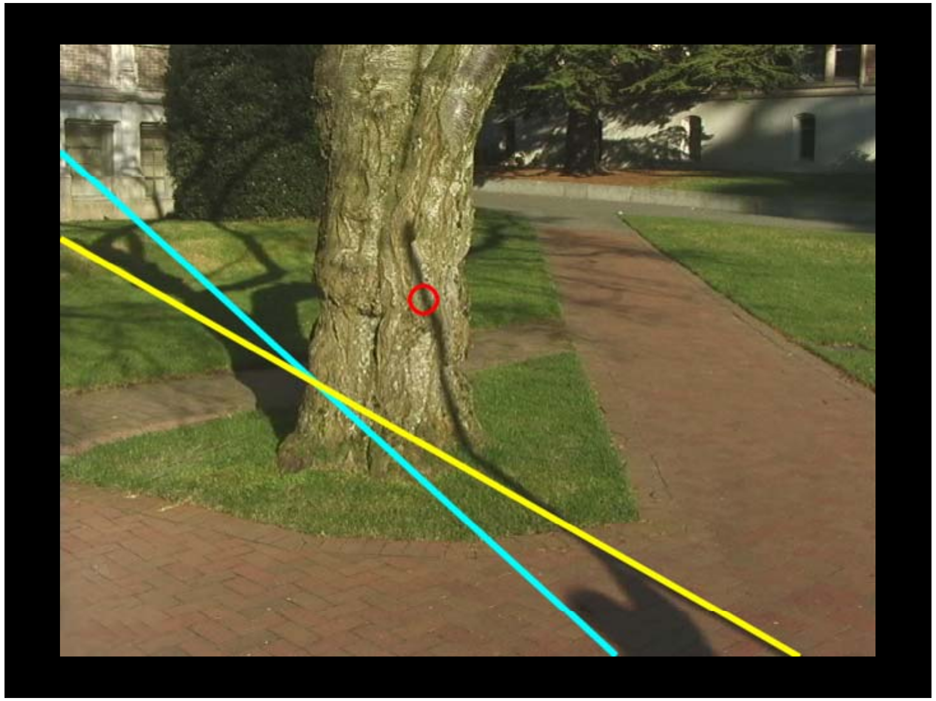
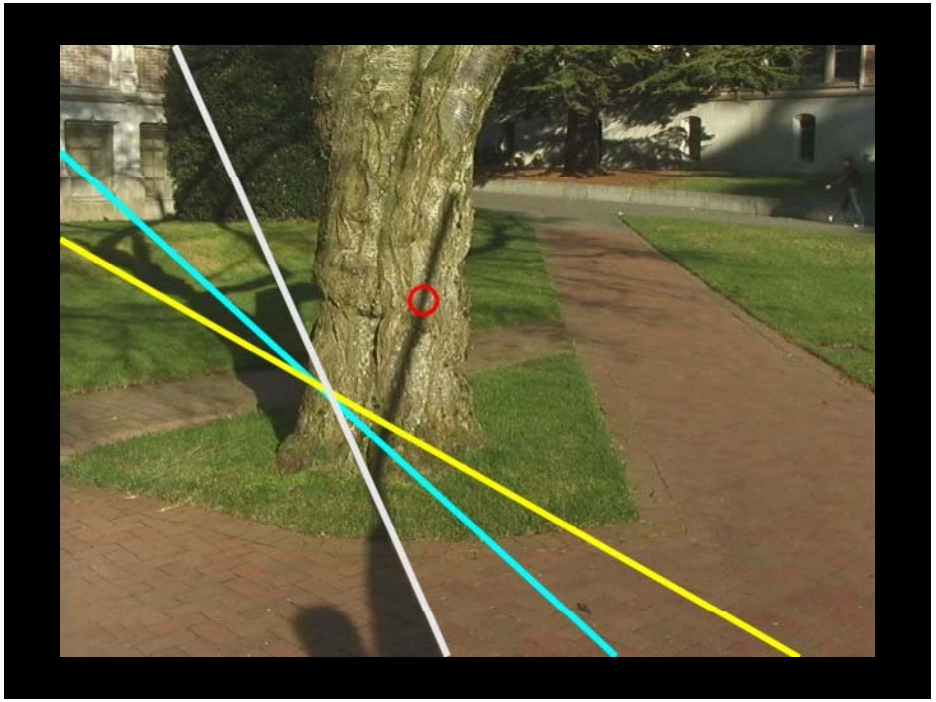
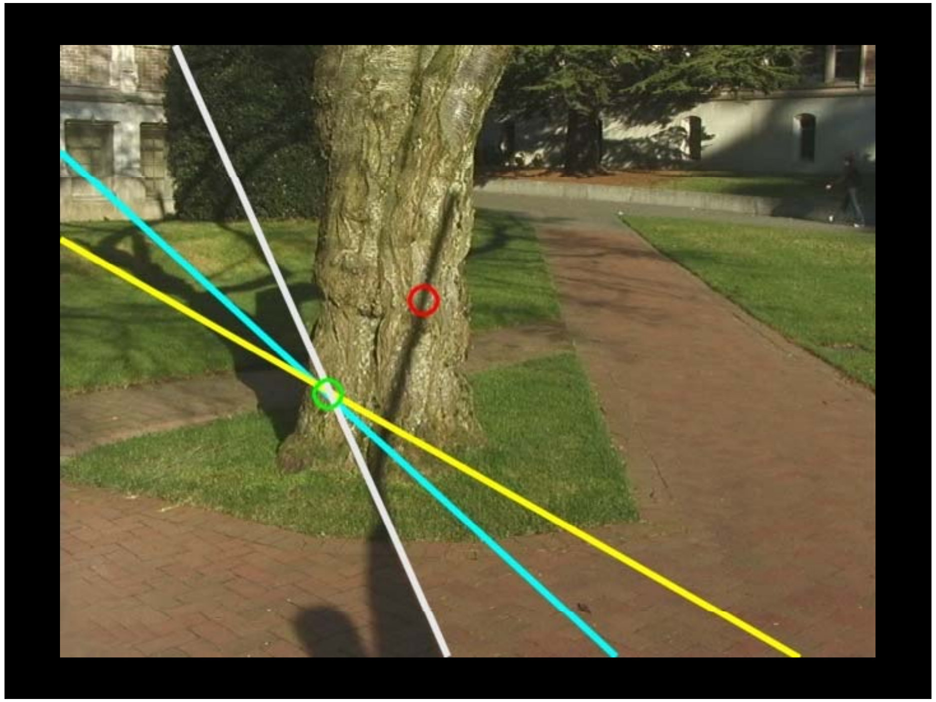
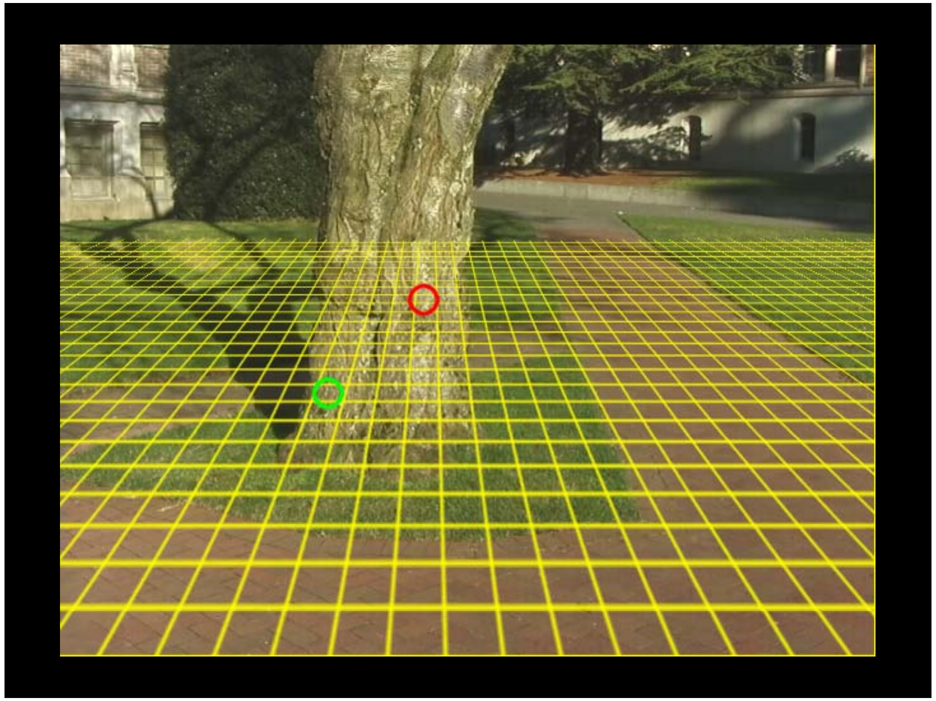
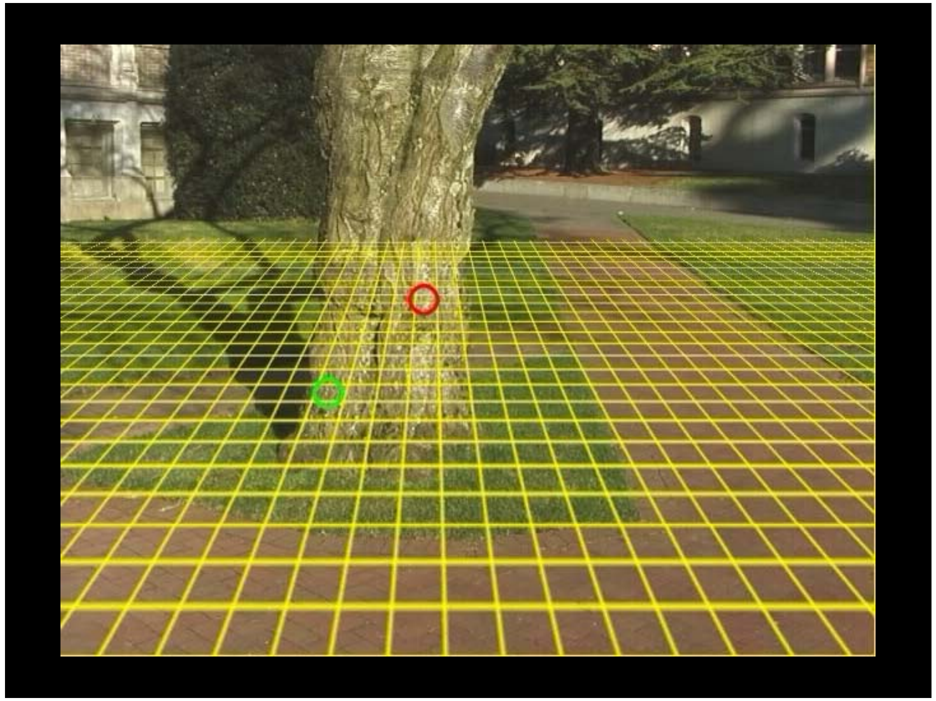


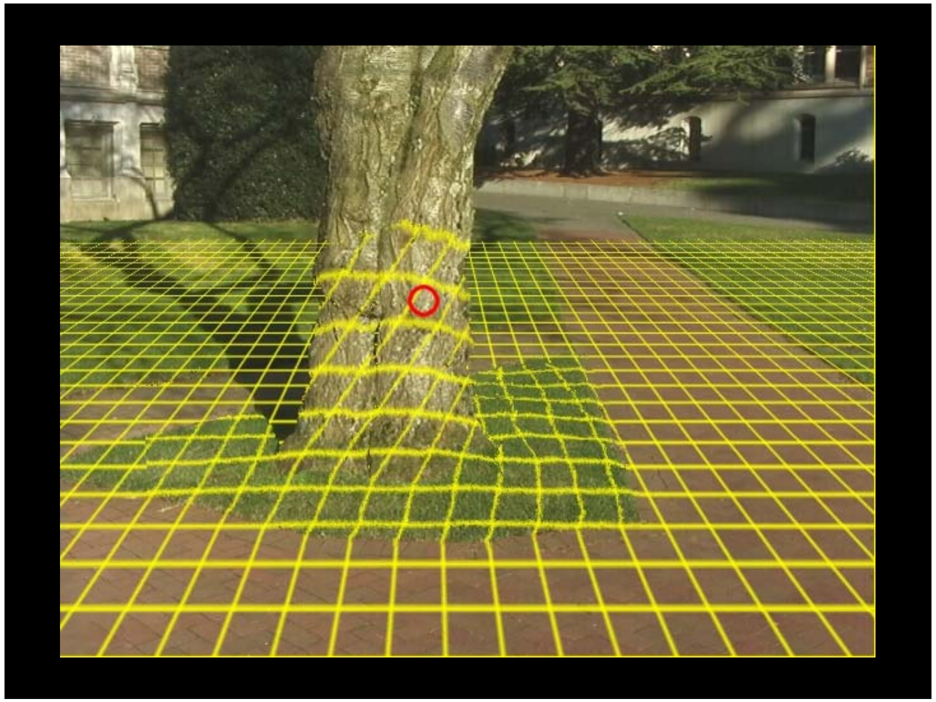

96x3x1 stick
camera
cast shadow

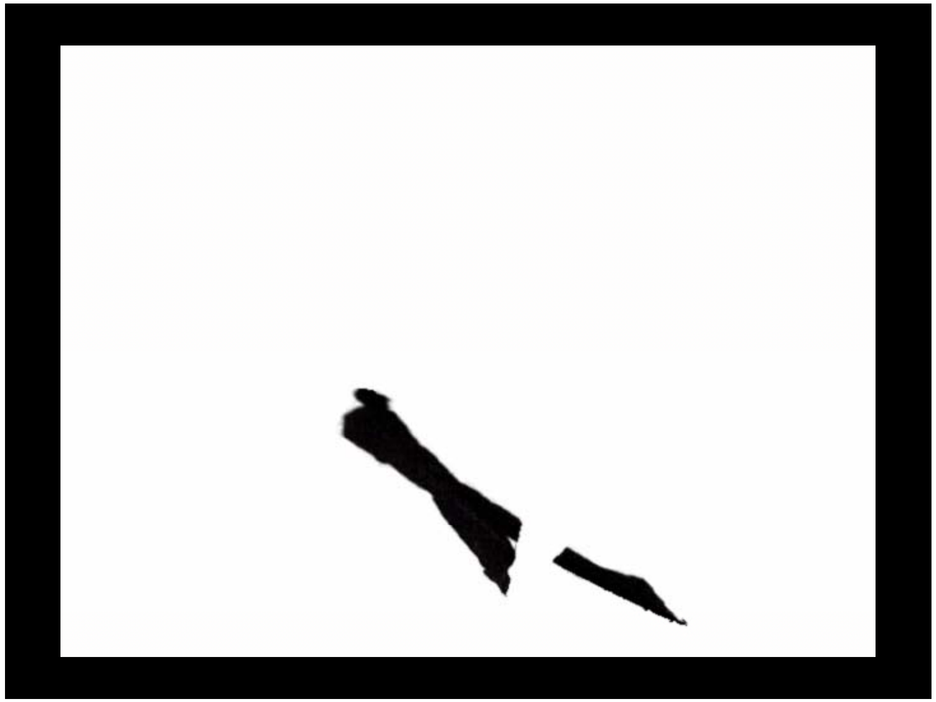


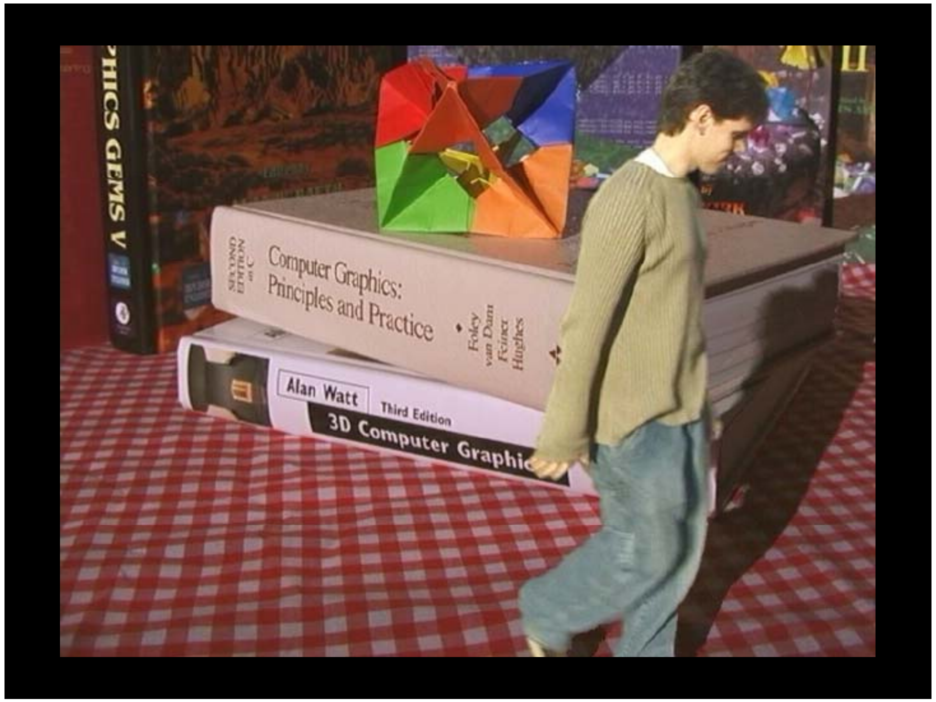






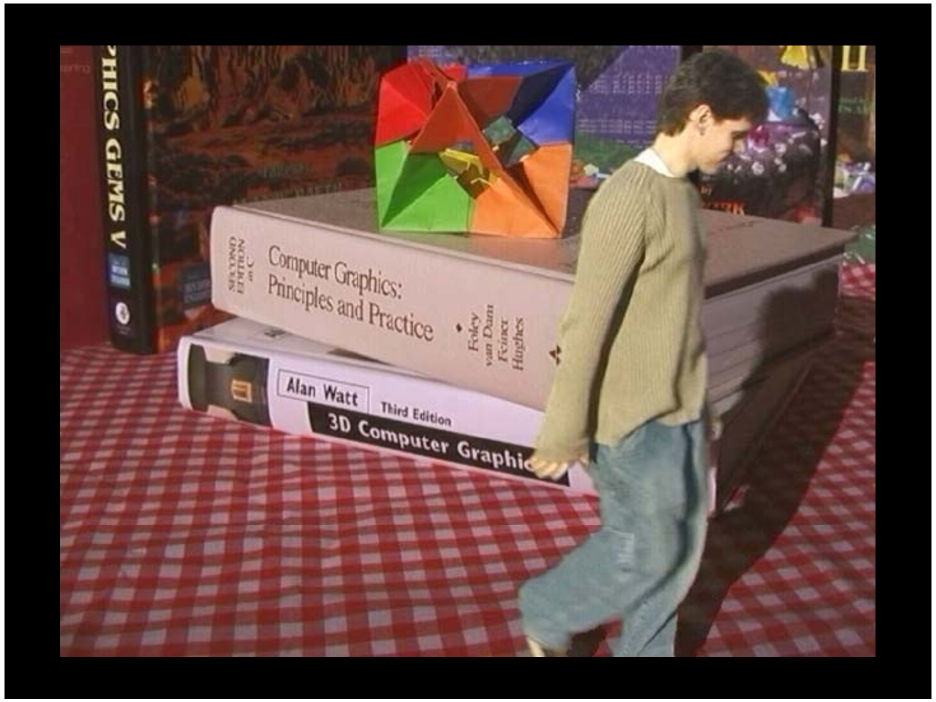









Computer Graphics:
Principles and Practice
Foley
van Dam
Feiner
Hughes
Alan Watt
Third Edition


Computer Graphics:
Principles and Practice
Foley
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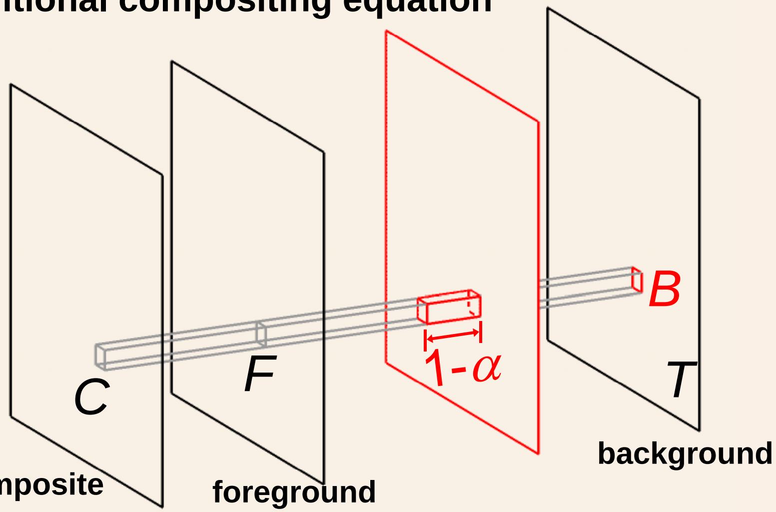
Feiner
Hughes
Alan Watt
Third Edition

Environment matting

blue screen matting

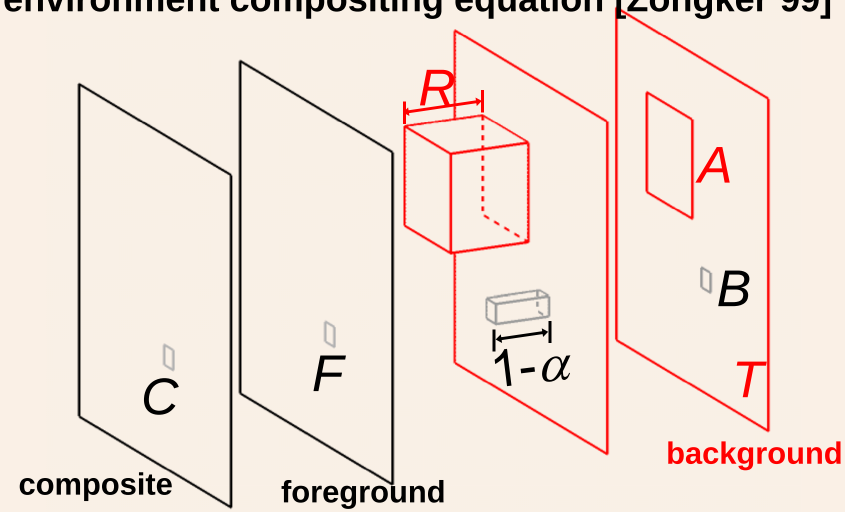
photograph

traditional compositing equation



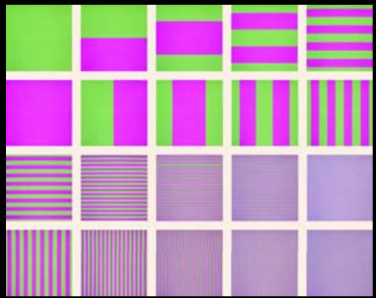
$$C = F + (1-\alpha)B$$

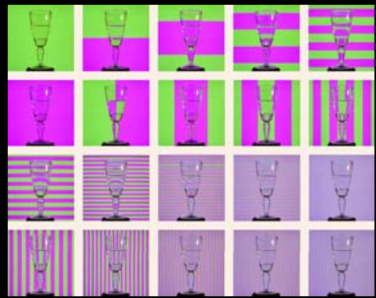
environment compositing equation [Zongker'99]



$$C = F + (1-\alpha)B + R\mathcal{M}(T,A)$$

O(k) images





Environment matting [Zongker'99]

Zongker et al.

photograph

Problem: color dispersion

Zongker et al.

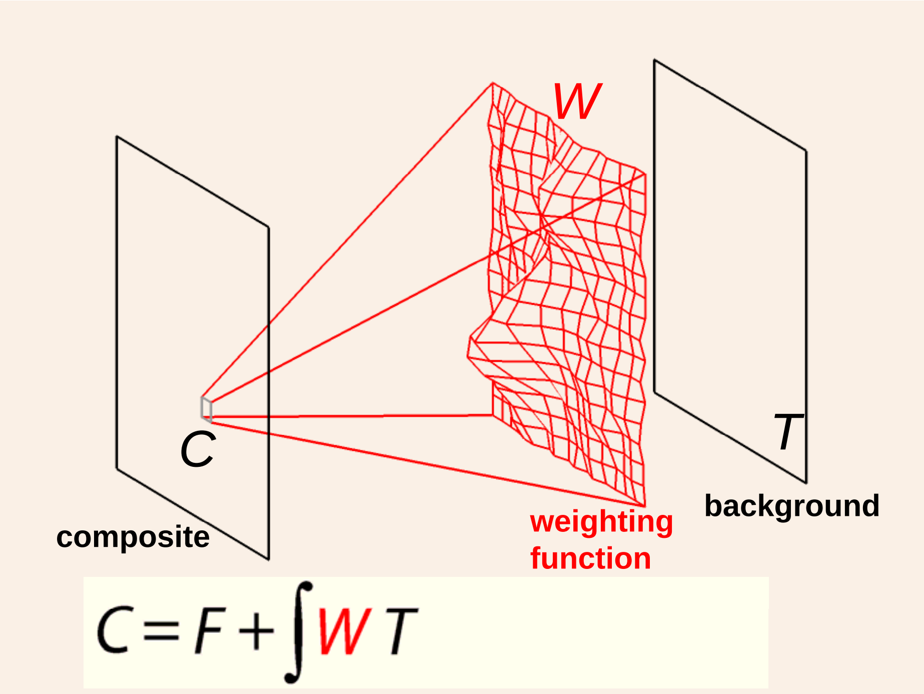
photograph

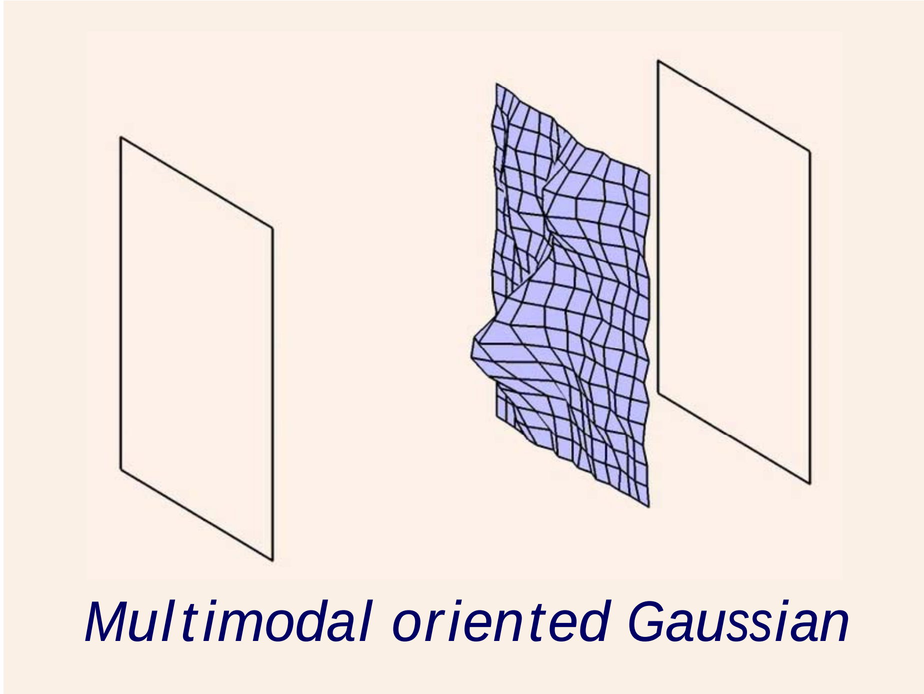
Problem: glossy surface

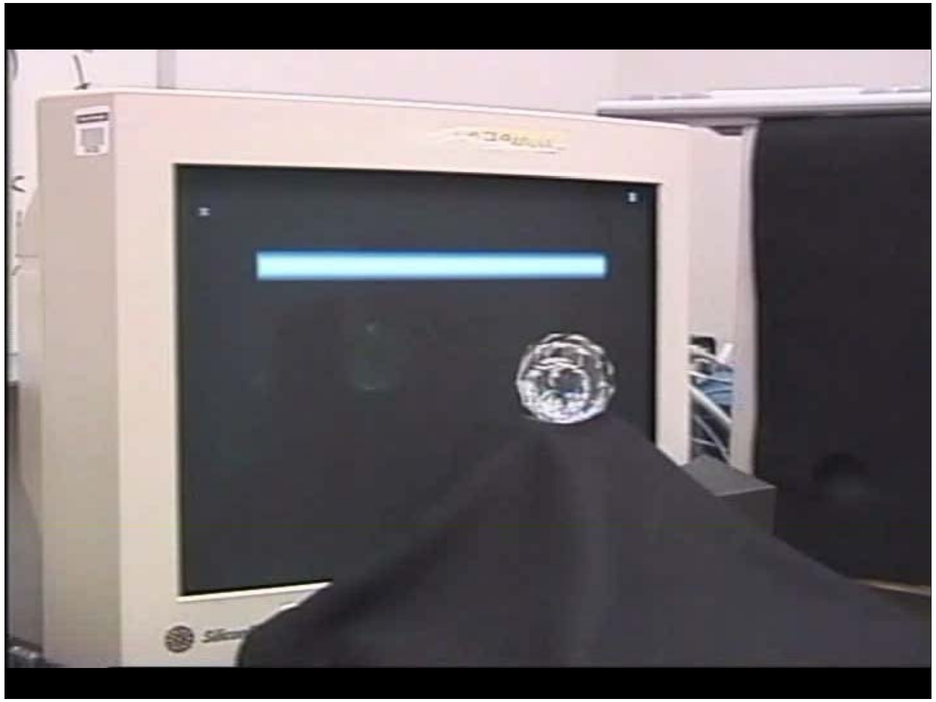
Zongker et al.

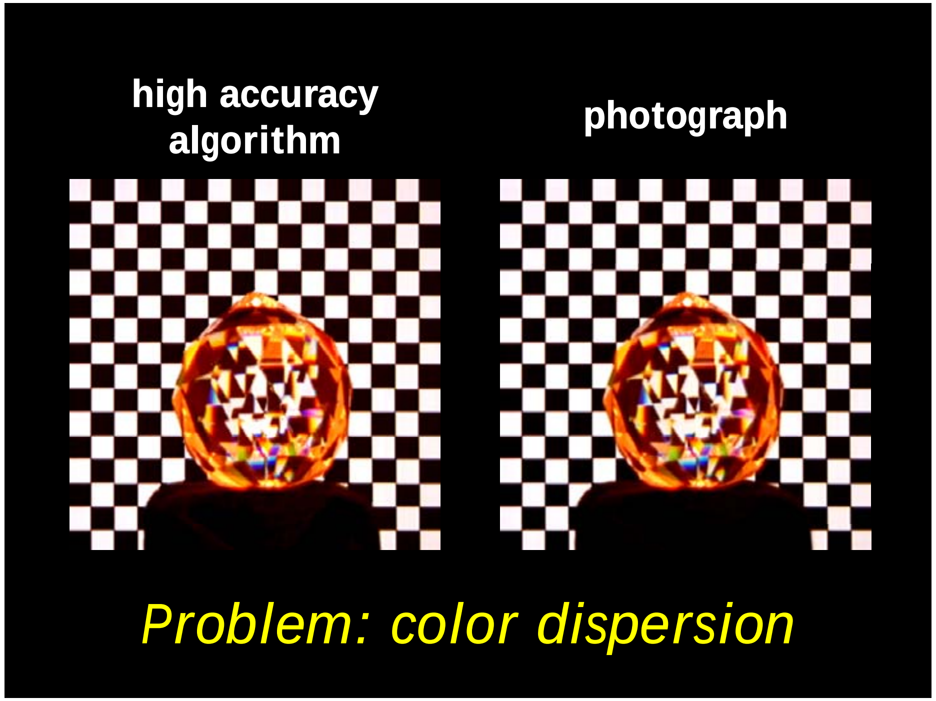
photograph

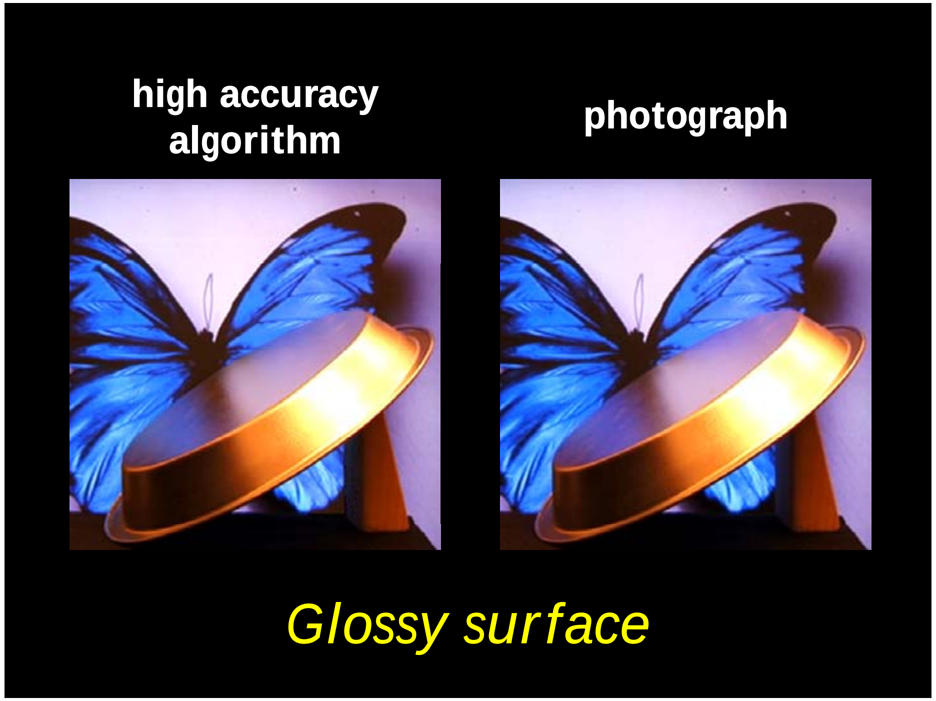
Problem: multiple mappings

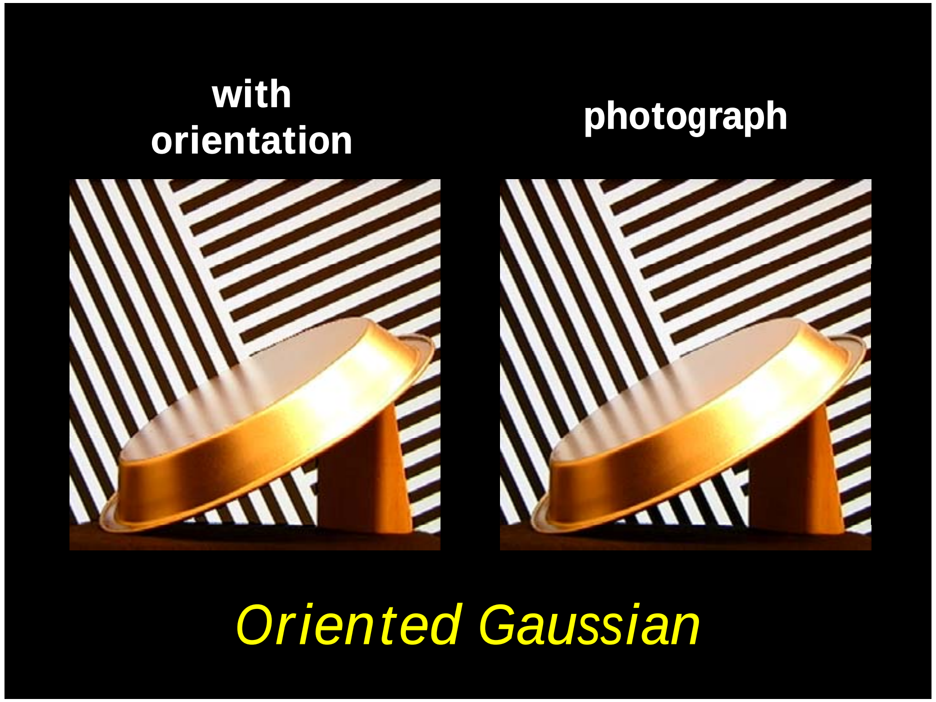

W
C
T
composite
weighting
function
background
$C = F + \int W T$

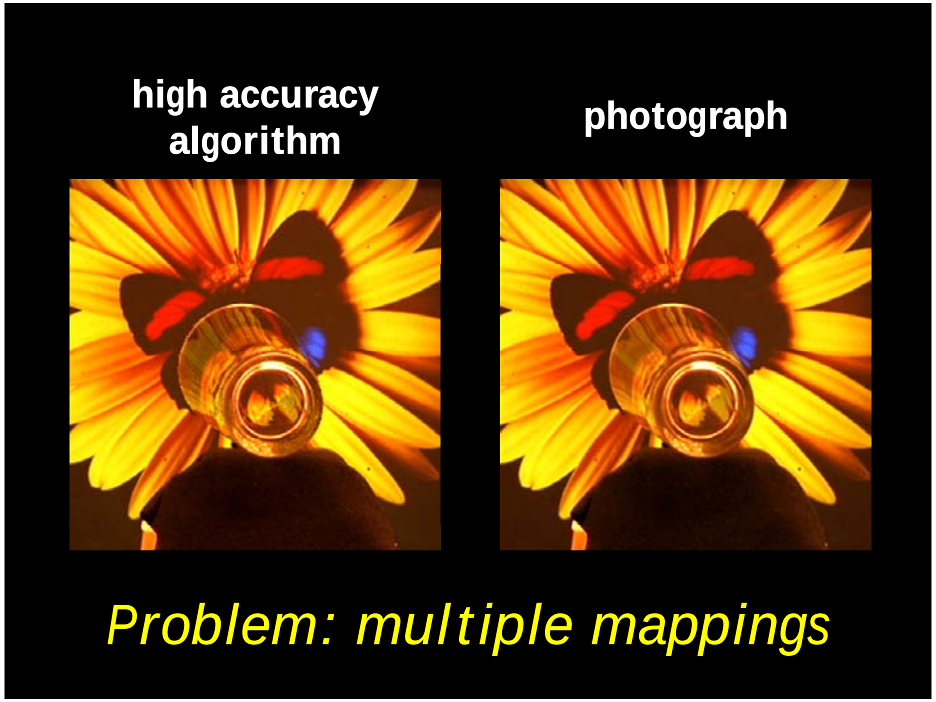

Multimodal oriented Gaussian



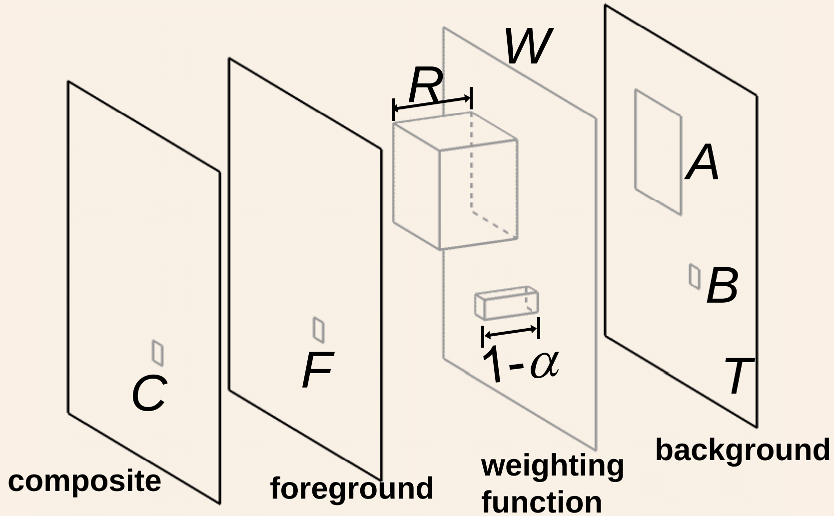

high accuracy algorithm
photograph
Problem: color dispersion


high accuracy algorithm
photograph
Glossy surface


with orientation
photograph
Oriented Gaussian


high accuracy algorithm
photograph
Problem: multiple mappings

$$C = F + (1-\alpha)B + R\mathcal{M}(T,A)$$



$$C = F + (1-\alpha)B + R\mathcal{M}(T,A)$$

3 3 1 3 4

3 observations
11 variables

- A, R
- α
- F

$$C = R\mathcal{M}(T,A)$$

3 3 4

3 observations
7 variables

- A, R
- α
- F

$$C = \rho \mathcal{M}(T, A)$$

3 1 4

3 observations
5 variables

- $A, R \longrightarrow A, \rho$ (colorless)
- α
- F

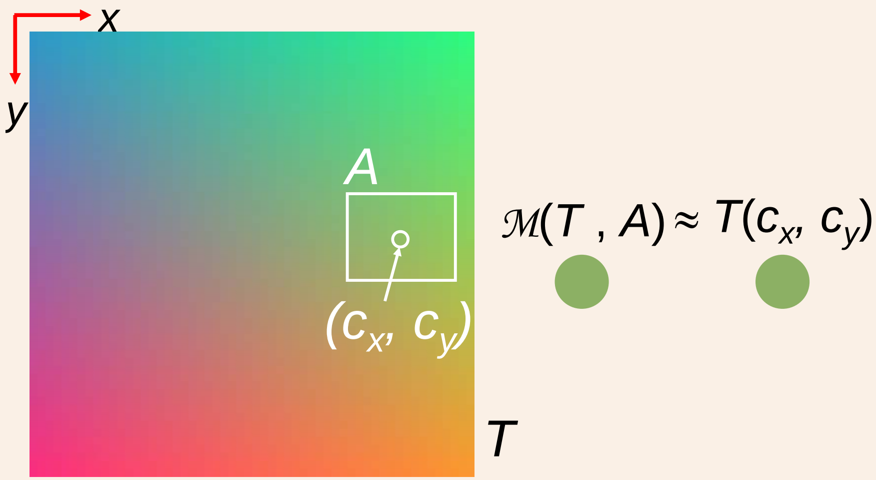
$$C = \rho\, T(c_x, c_y)$$

3 1 1 1

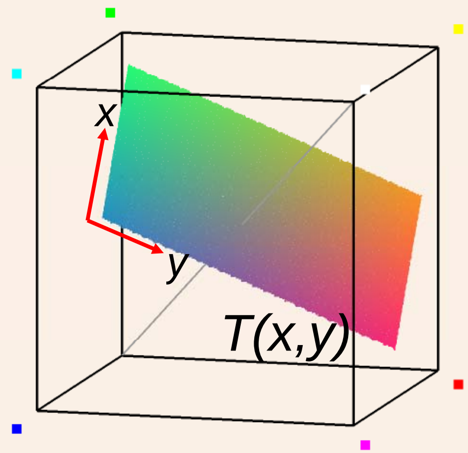
3 observations
3 variables

- $A, R \longrightarrow A, \rho \longrightarrow c_x, c_y, \rho$ (colorless → specularly refractive)
- α
- F

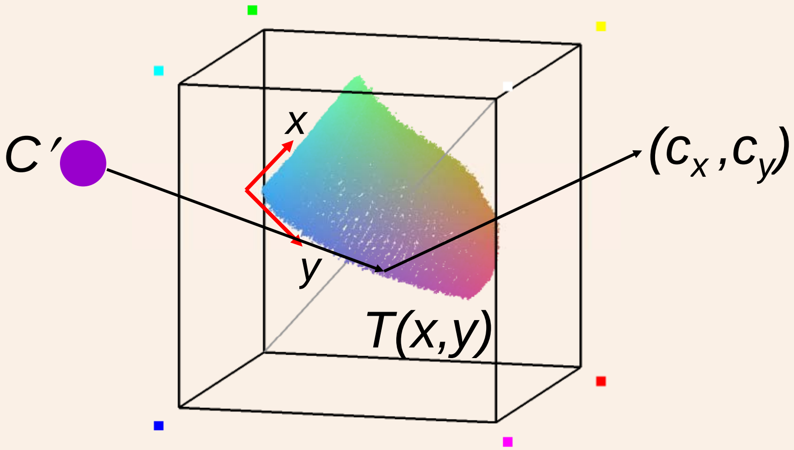
Stimulus function



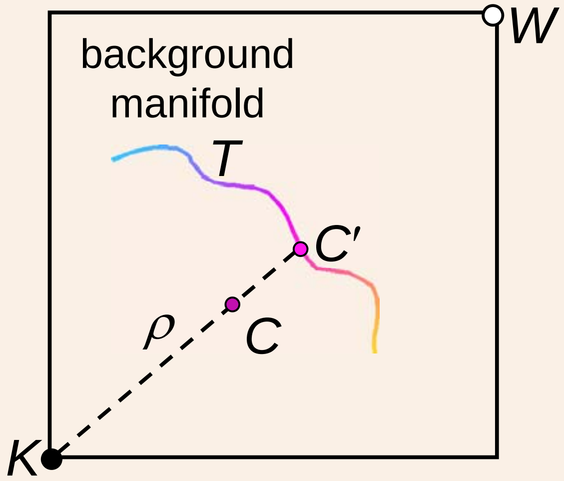
Ideal plane in RGB cube



Calibrated manifold in RGB cube



Estimate c_x, c_y and ρ



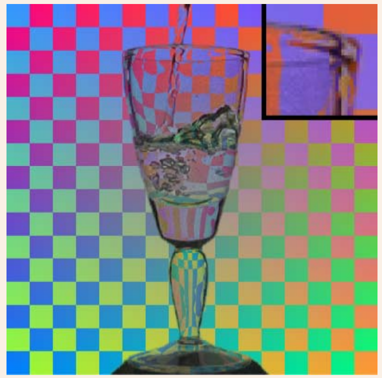
$$C' \to (c_x, c_y)$$

$$\rho = \frac{\|KC\|}{\|KC'\|}$$

Problem: noisy matte

Edge-preserving filtering

without filtering



with filtering

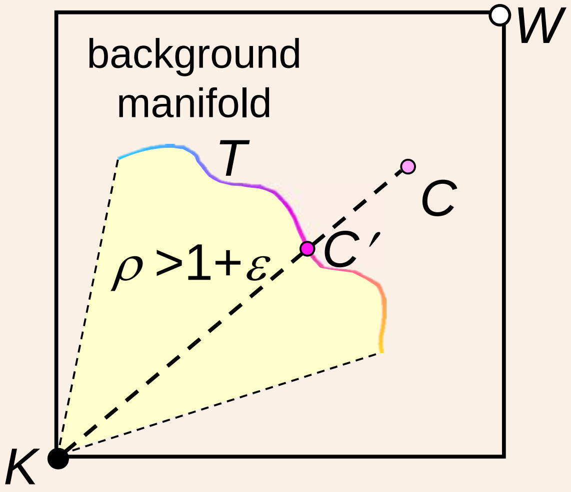
Input image

Difference thresholding

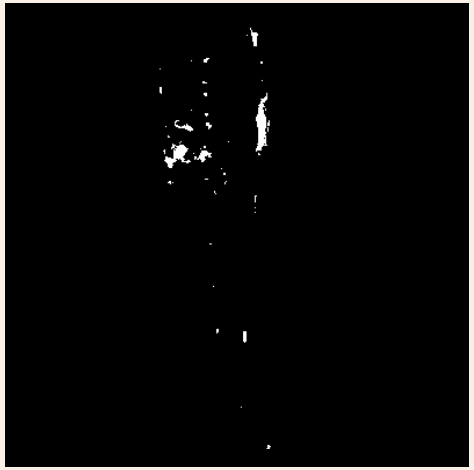
Morphological operation

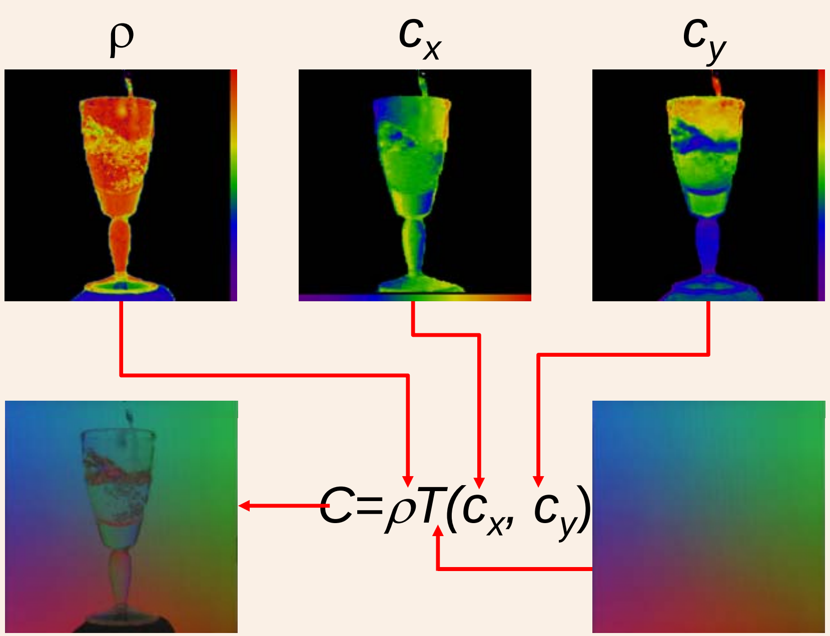
Feathering

Heuristics for specular highlights

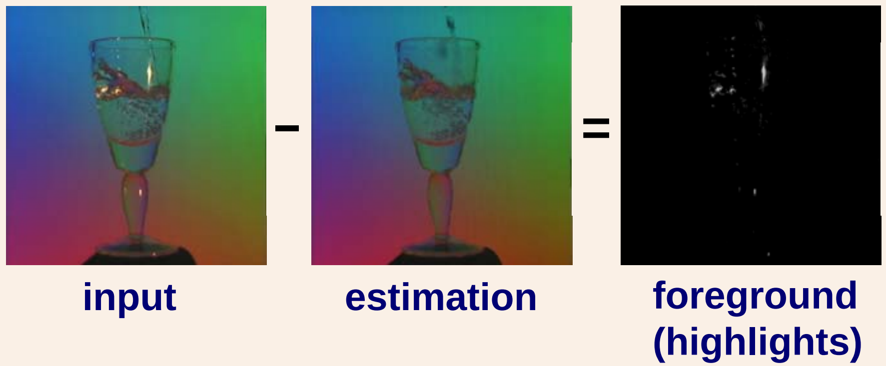


Heuristics for specular highlights





Heuristics for specular highlights



Composite with highlights

	compositing model	matting method
color blending		blue-screen Bayesian
shadow		Shadow matting
refraction reflection		High-accuracy env. matting