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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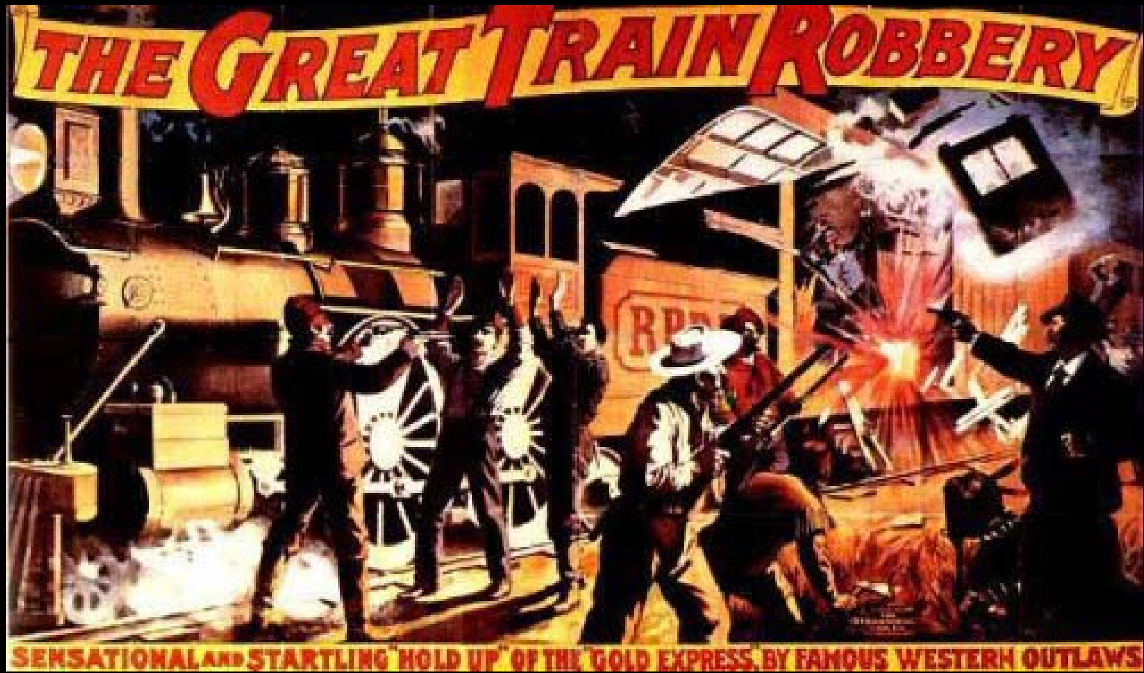
Photomontage

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

Photographic compositions

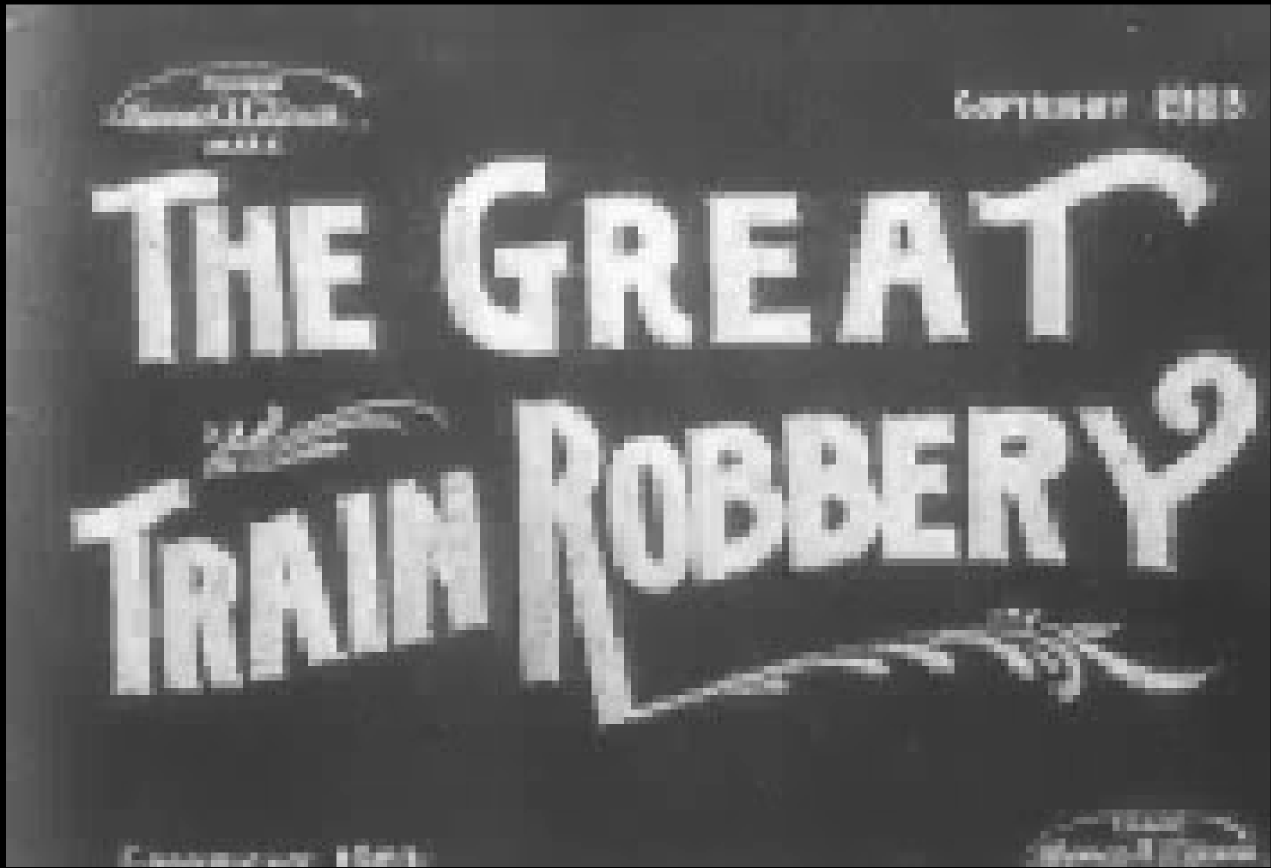
Lang Ching-shan

Use of mattes for compositing



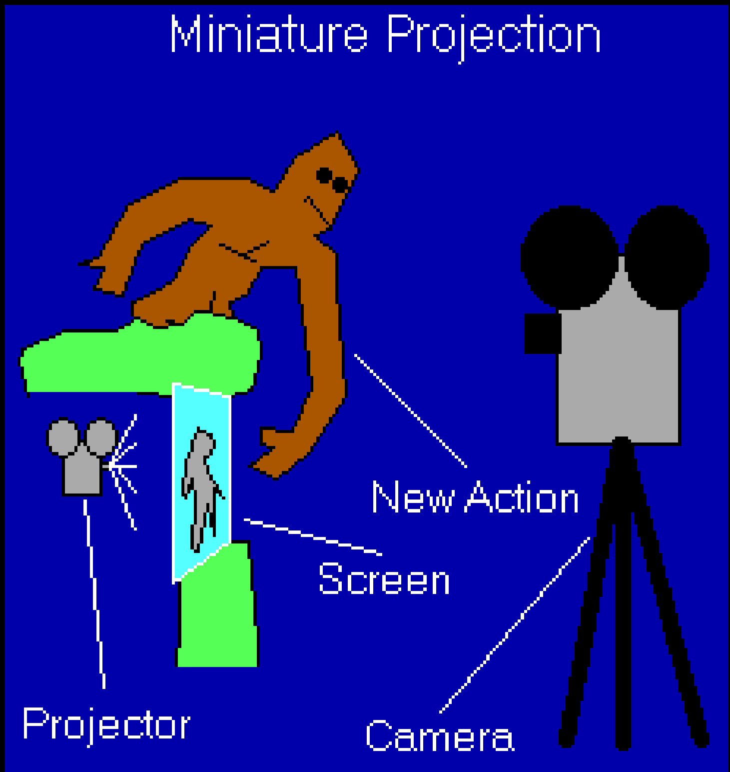
The Great Train Robbery (1903) matte shot

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 composting

King Kong (1933)

Optical compositing

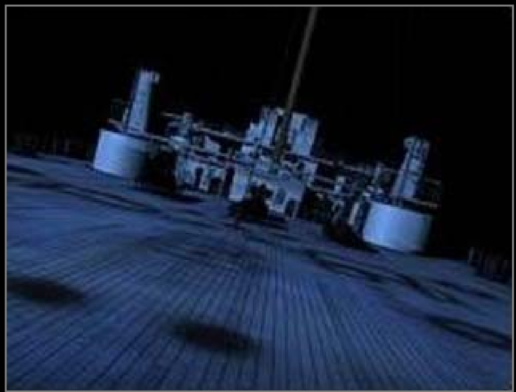
Jurassic Park III (2001)

Blue-screen matting,
digital composition,
digital matte painting

Smith Duff Catmull Porter

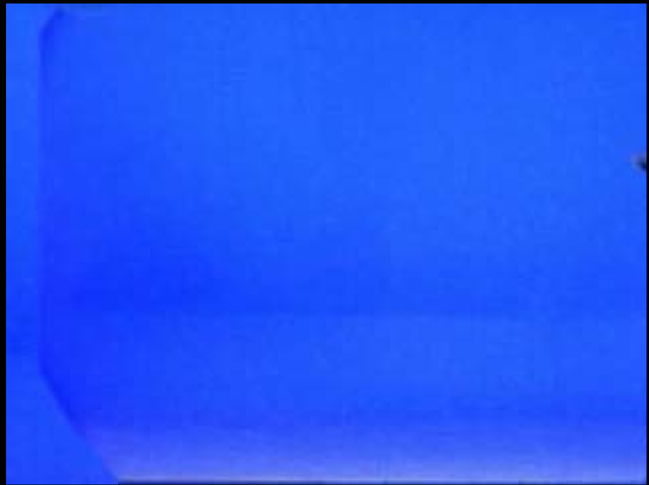
Oscar award, 1996



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

$\bar{\alpha}$

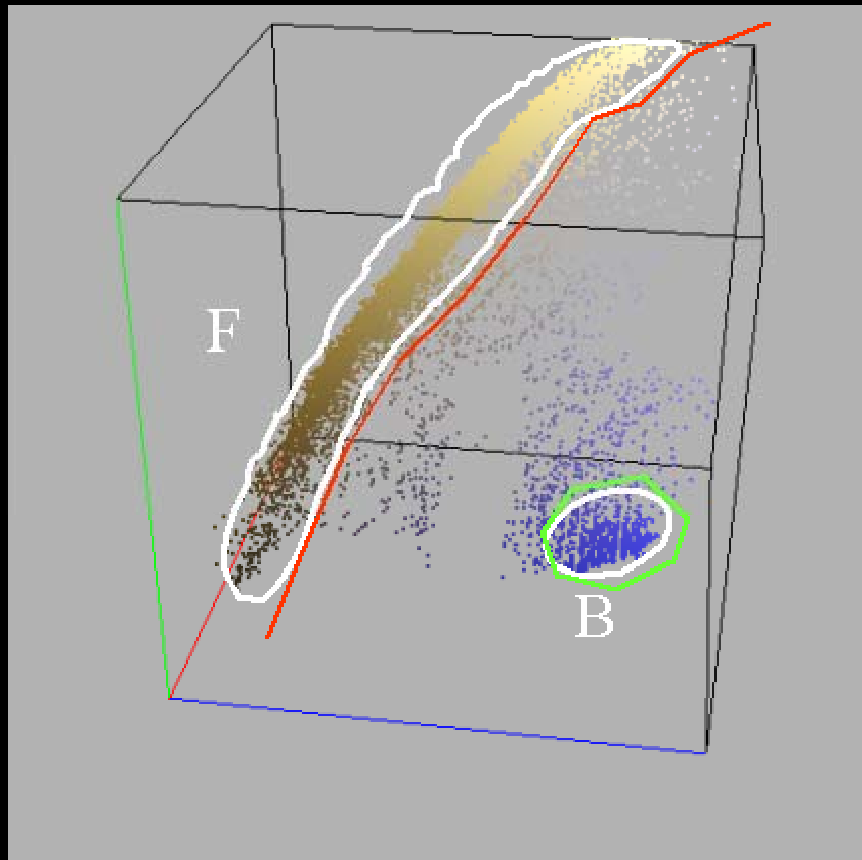
Matte creation
$\bar{\alpha}$=B-max(G,R)

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

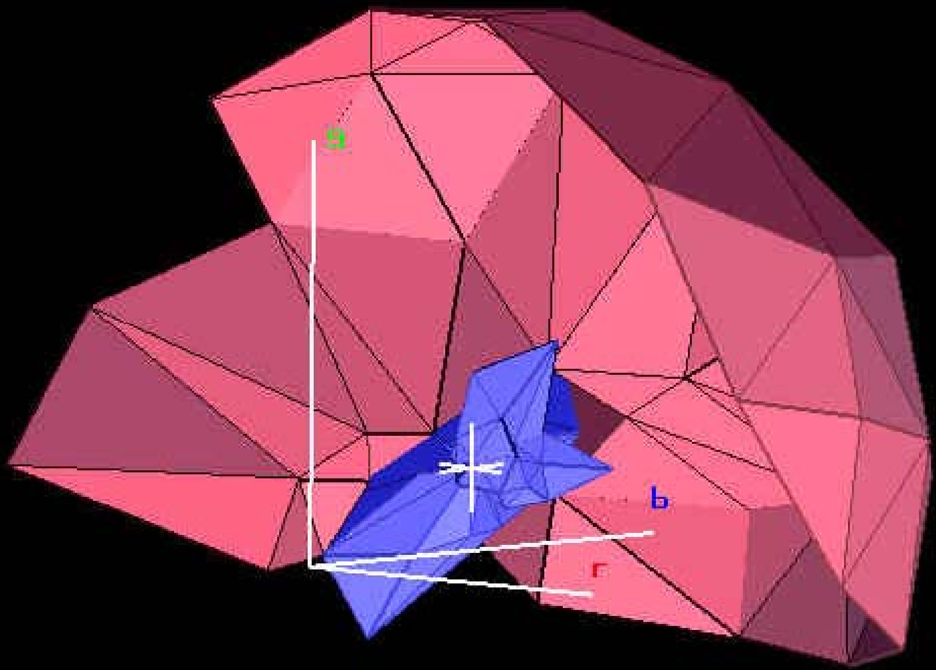
Problems with color difference

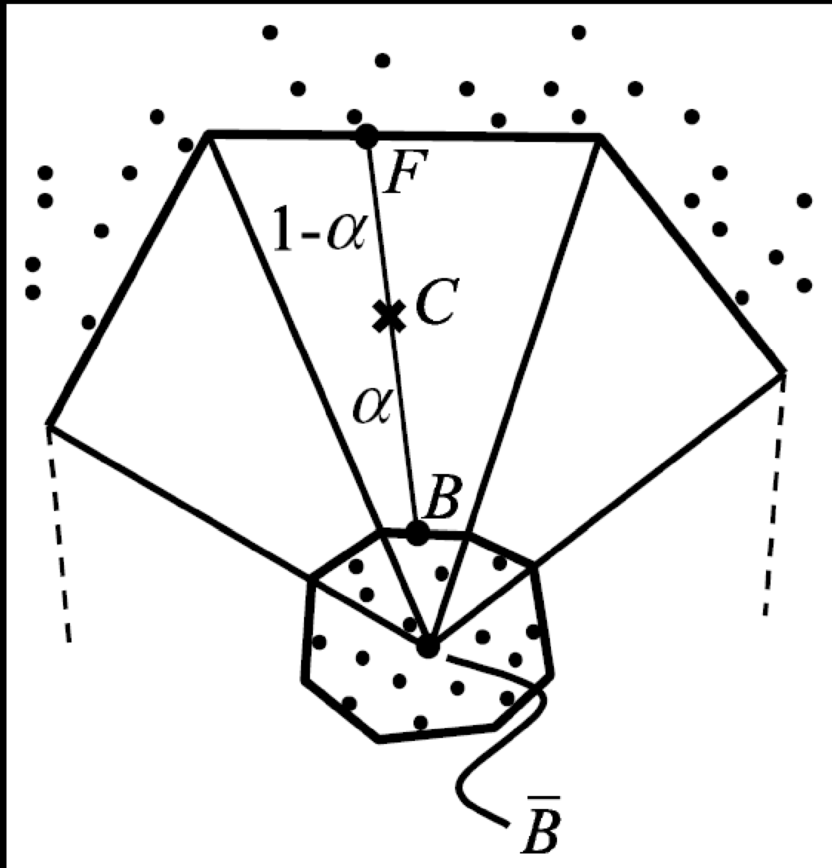
Background color is usually not perfect! (lighting, shadowing...)

Chroma-keying (Primatte)



Chroma-keying (Primatte)





demo

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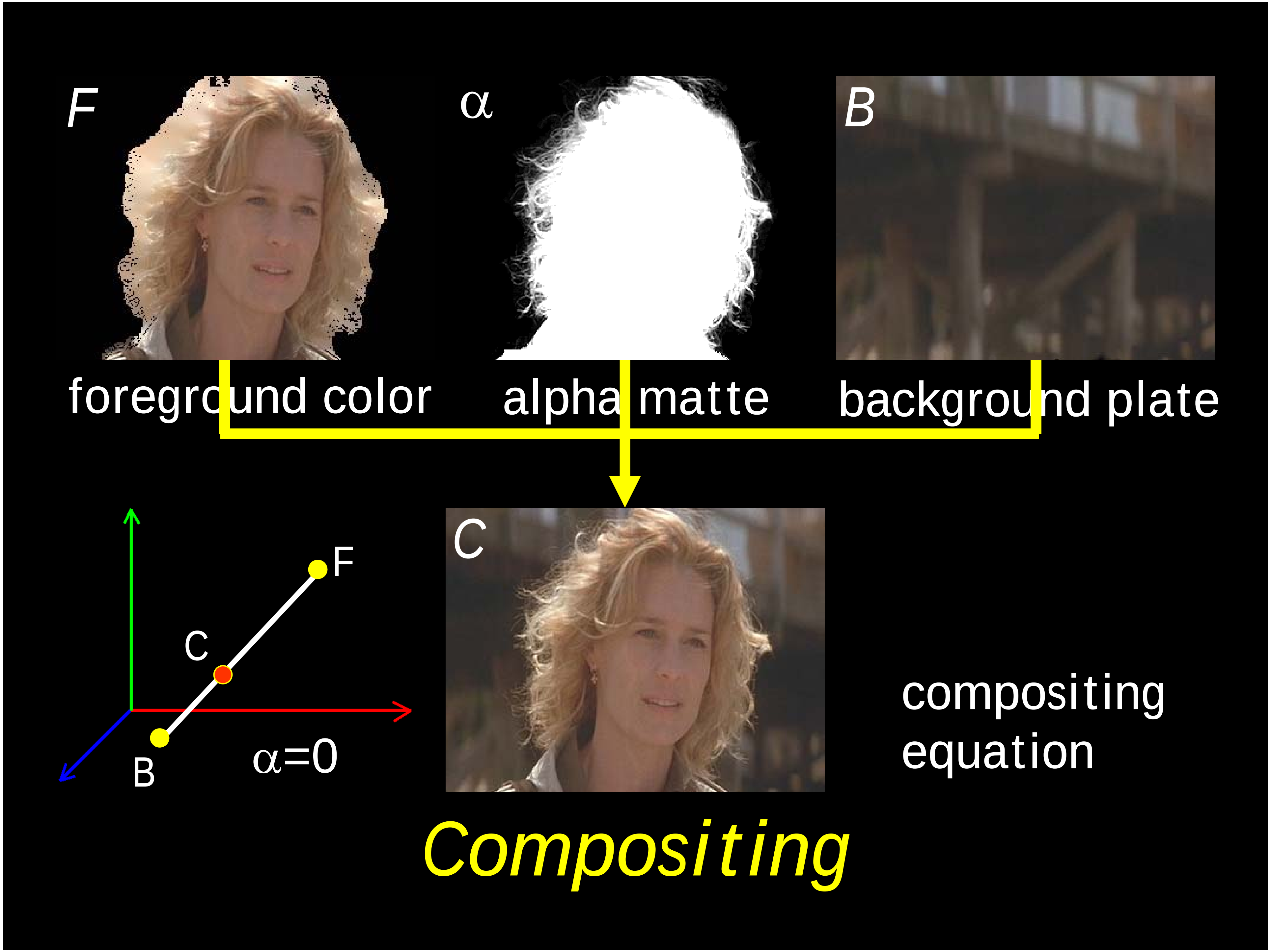
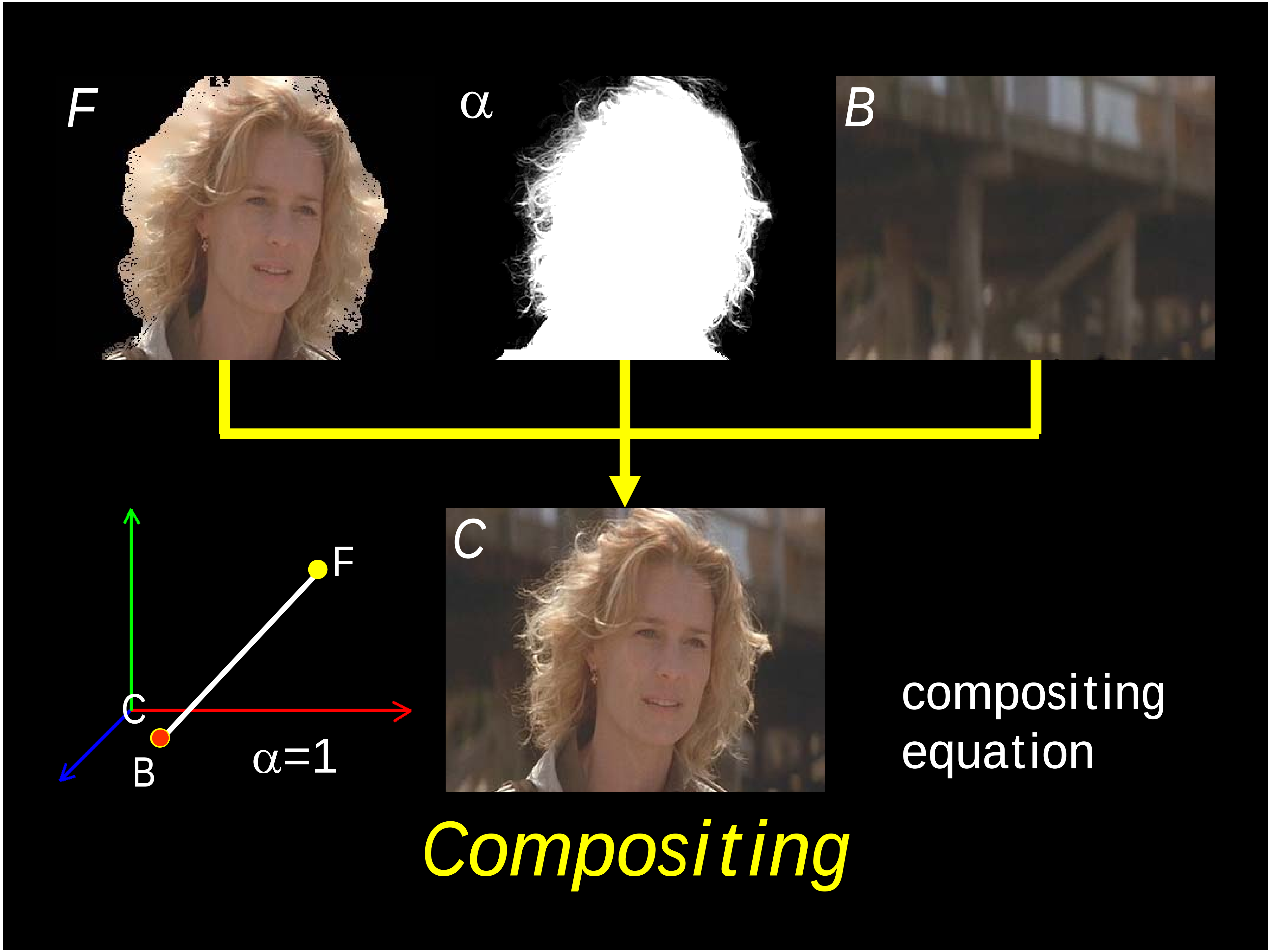
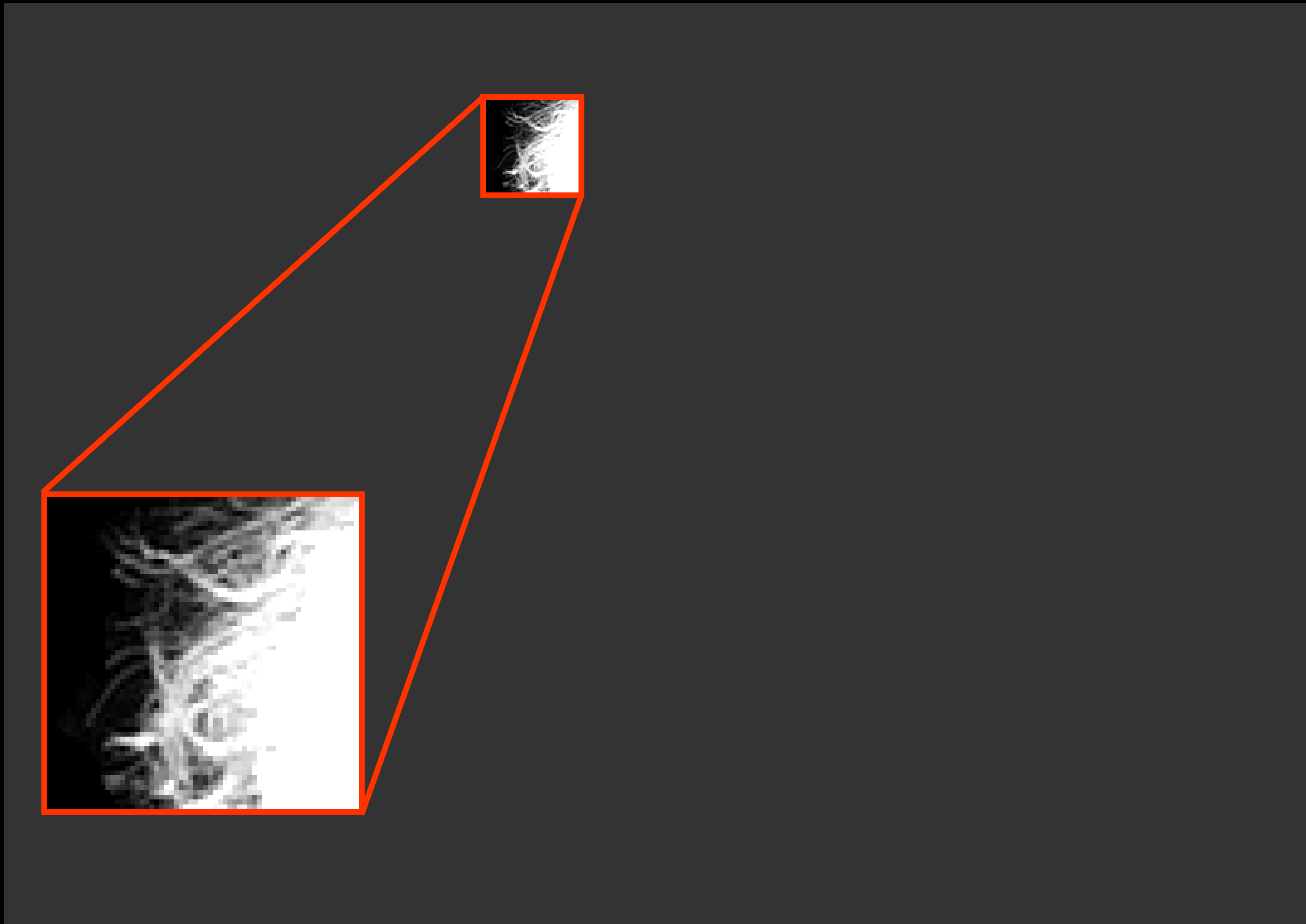
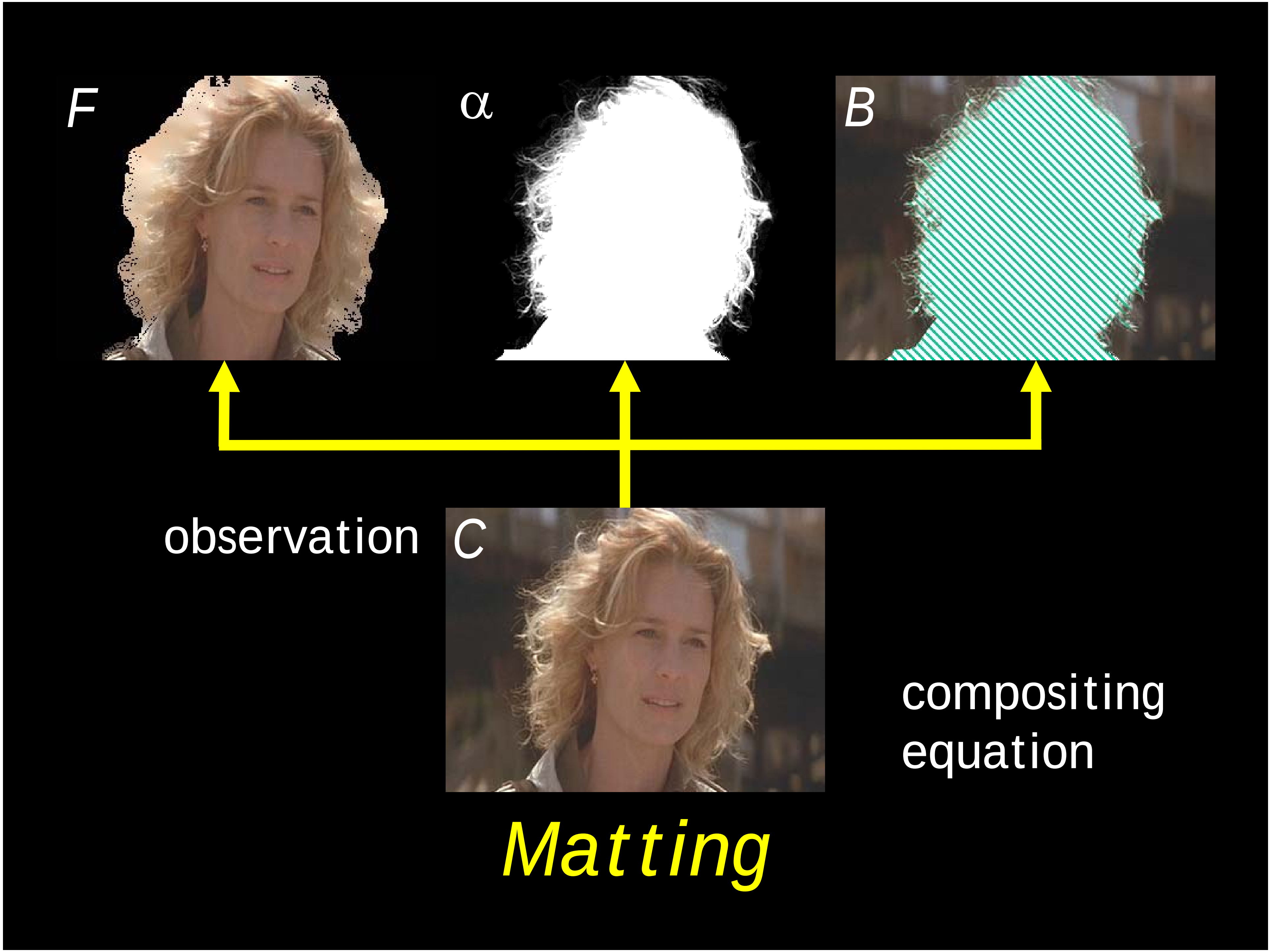
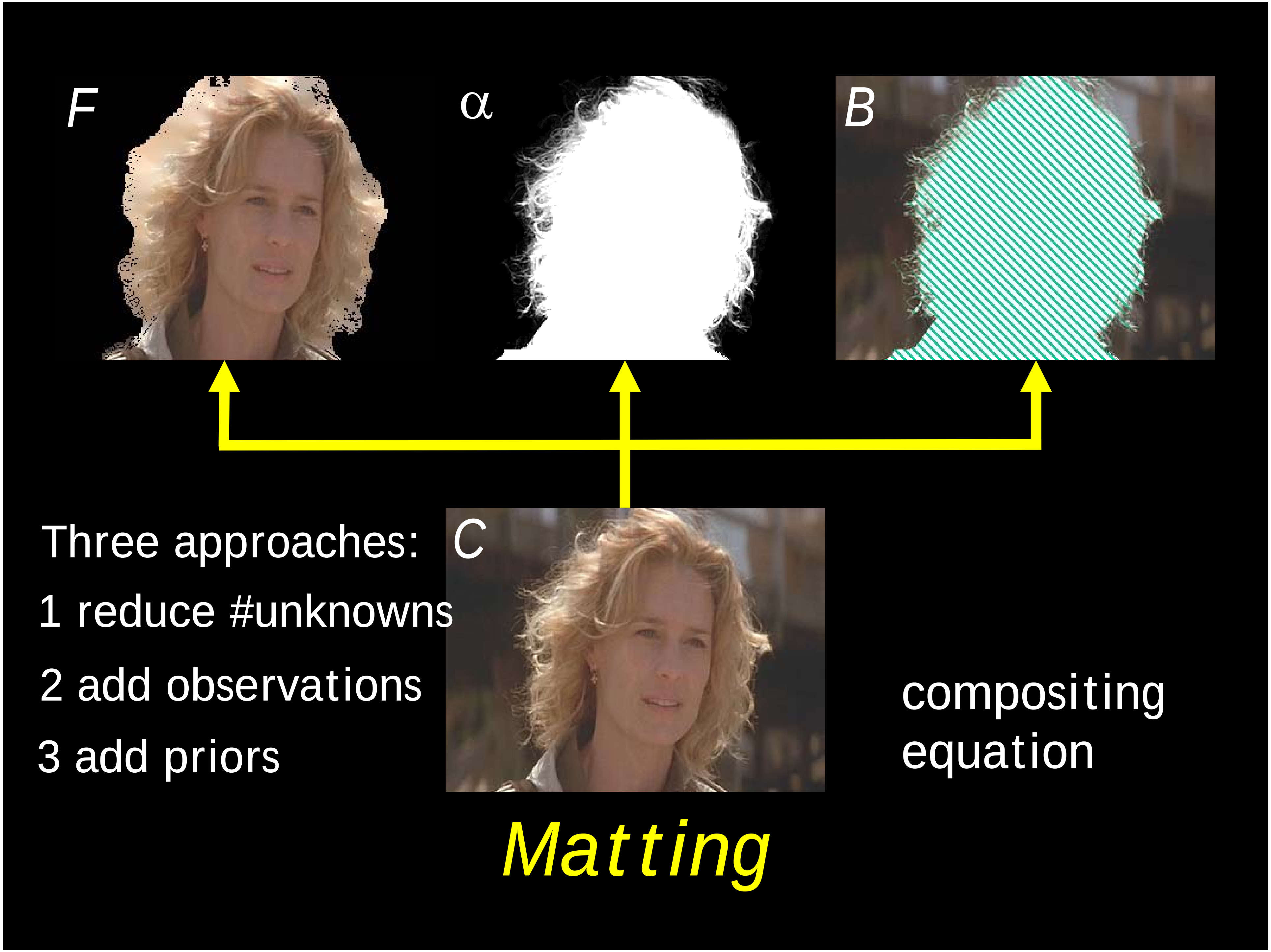


F
α
B
foreground color
alpha matte
background plate
F
C
B
α=0
C
compositing
equation
Compositing

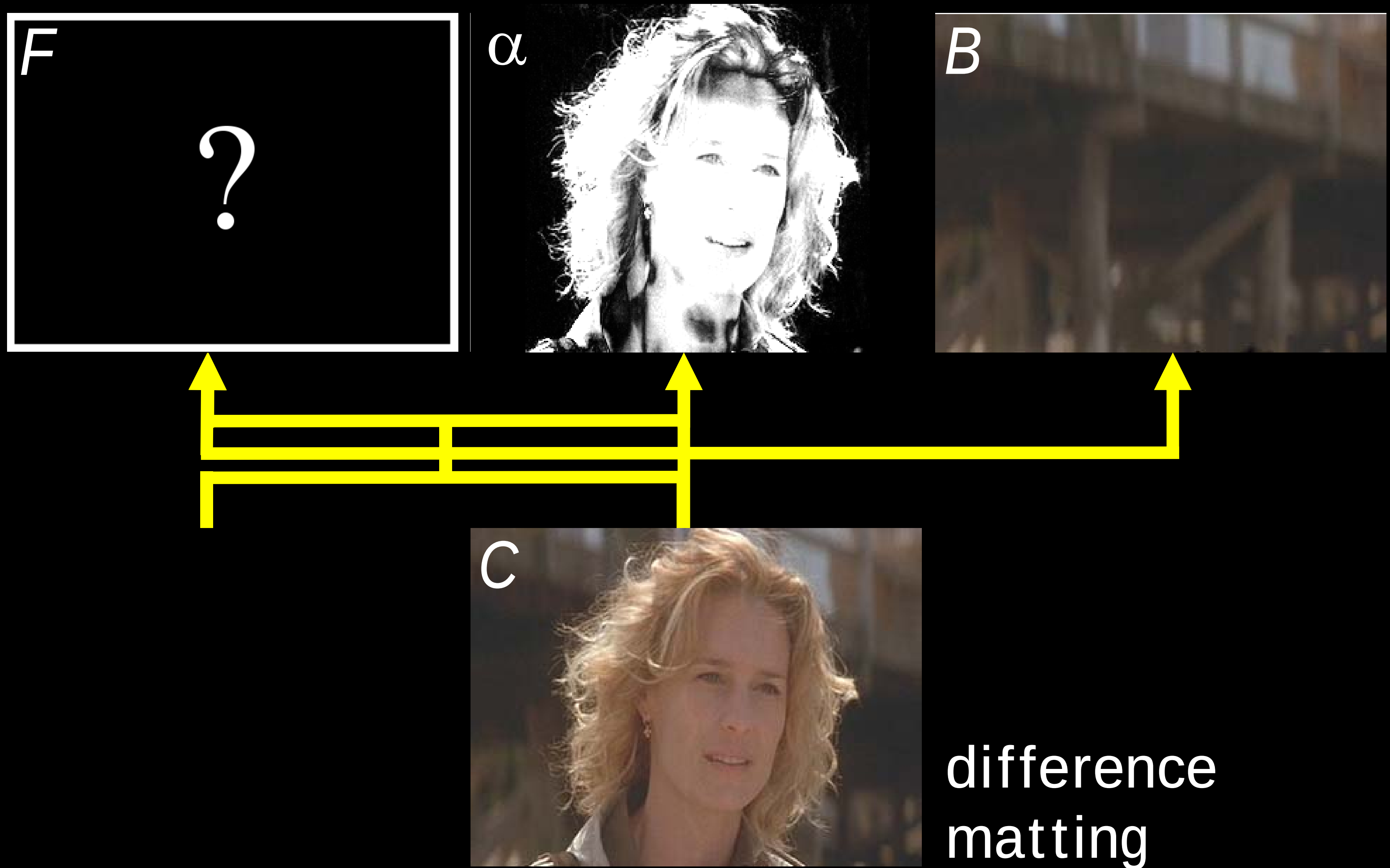

F
α
B
C
F
C
B
α=1
compositing
equation
Compositing



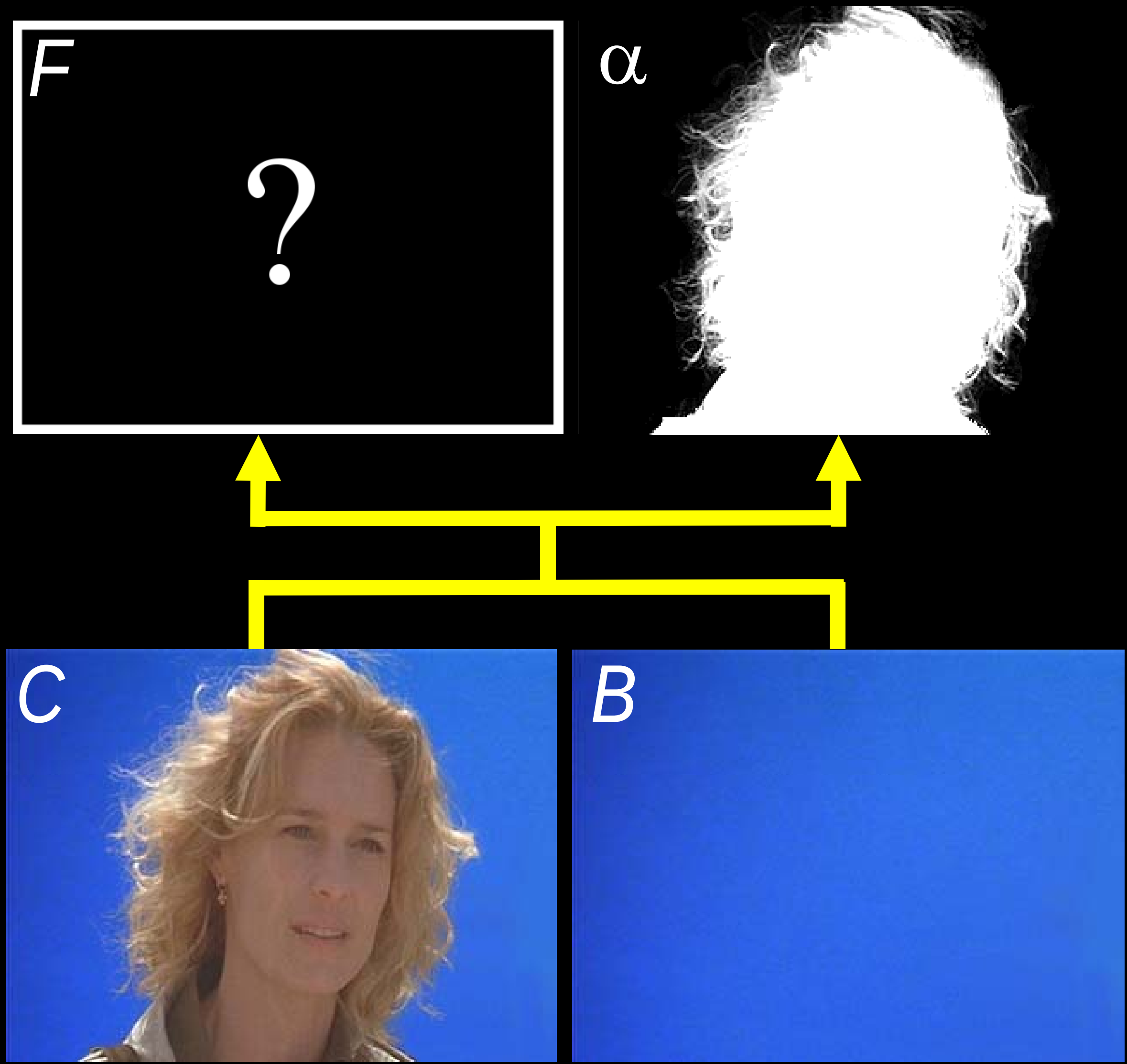

F
α
B
observation
C
compositing
equation
Matting



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

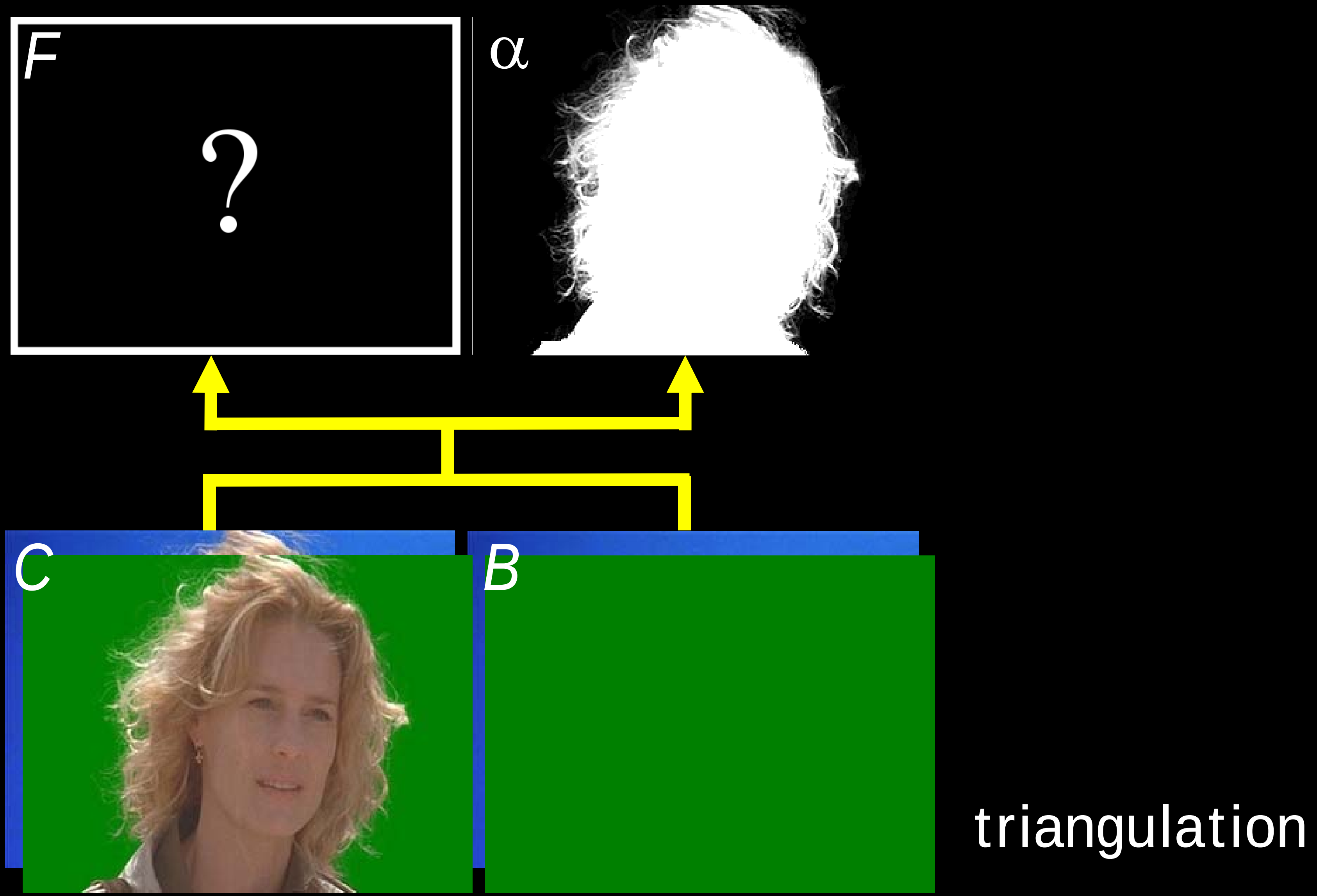


Matting (reduce #unknowns)

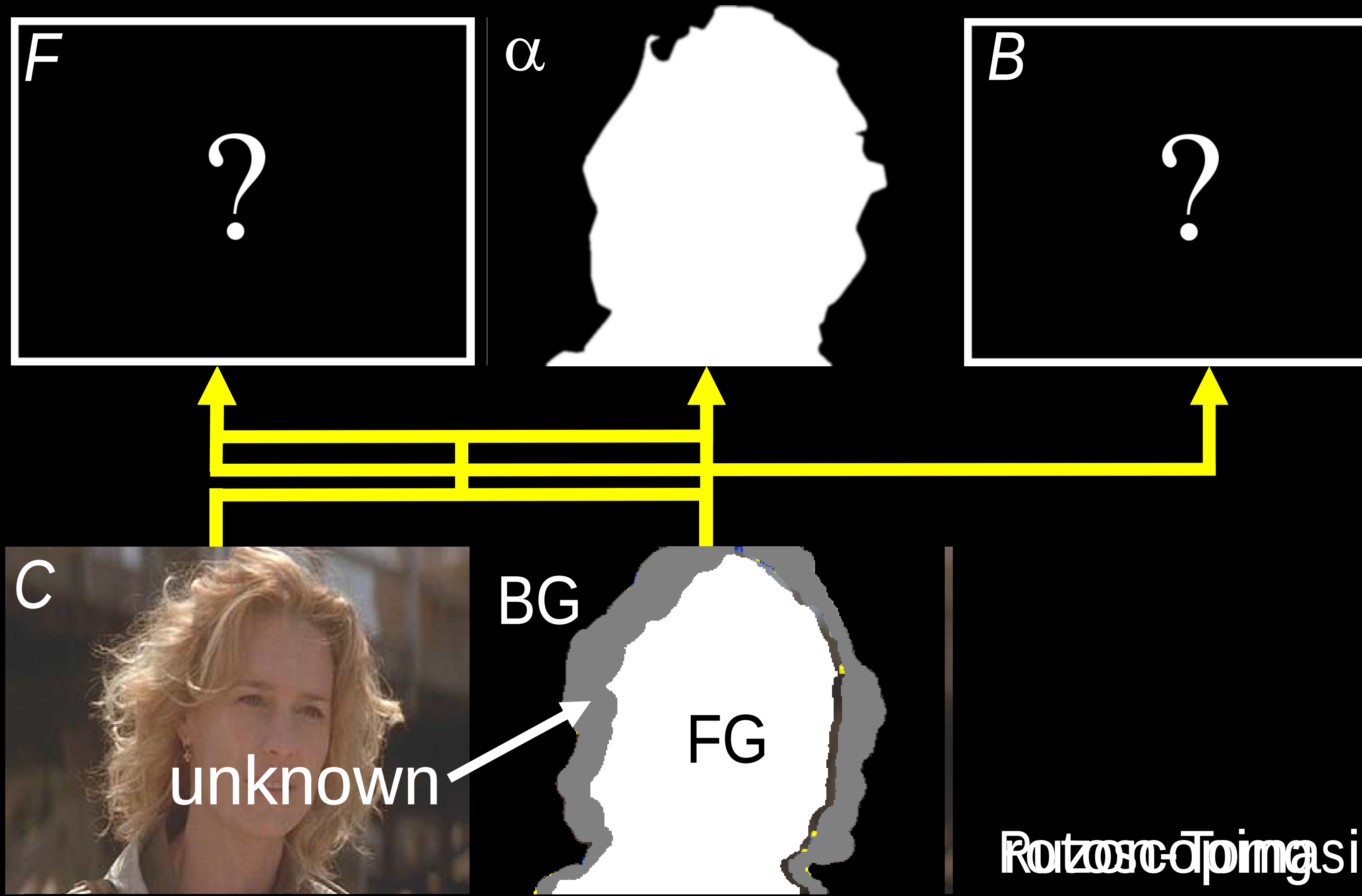


blue screen matting

Matting (reduce #unknowns)



Matting (add observations)



Matting (add priors)

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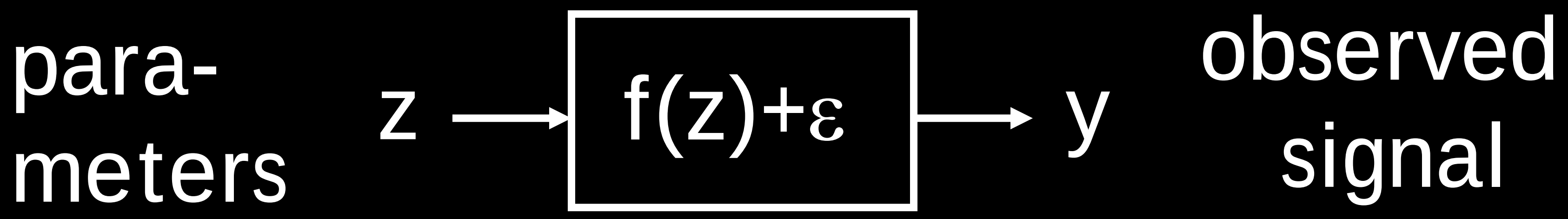
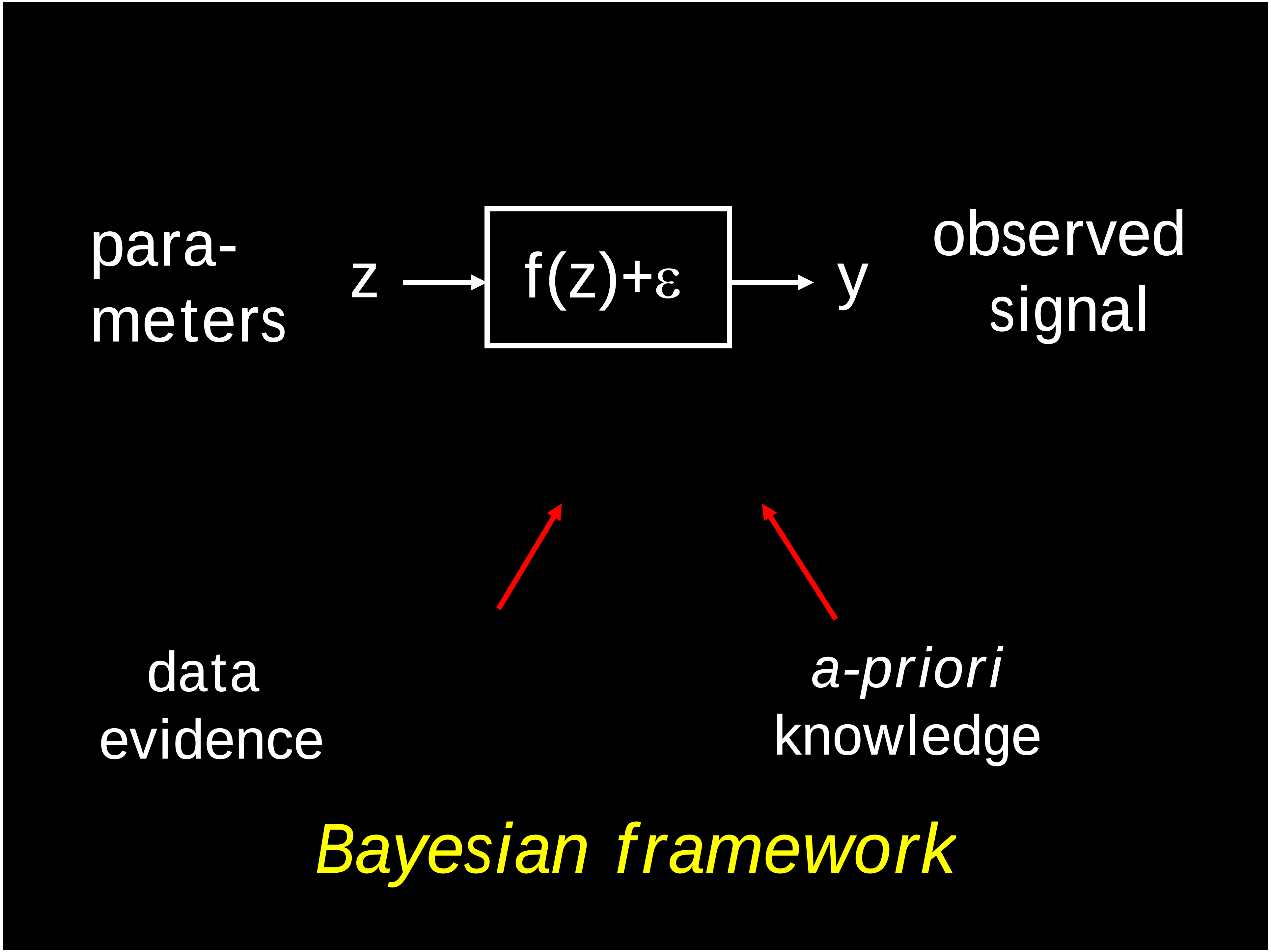


Example:
super-resolution
de-blurring
de-blocking
...

Bayesian framework


para-
meters
z
f(z)+ε
y
observed
signal
data
evidence
a-priori
knowledge
Bayesian framework

posterior probability

likelihood

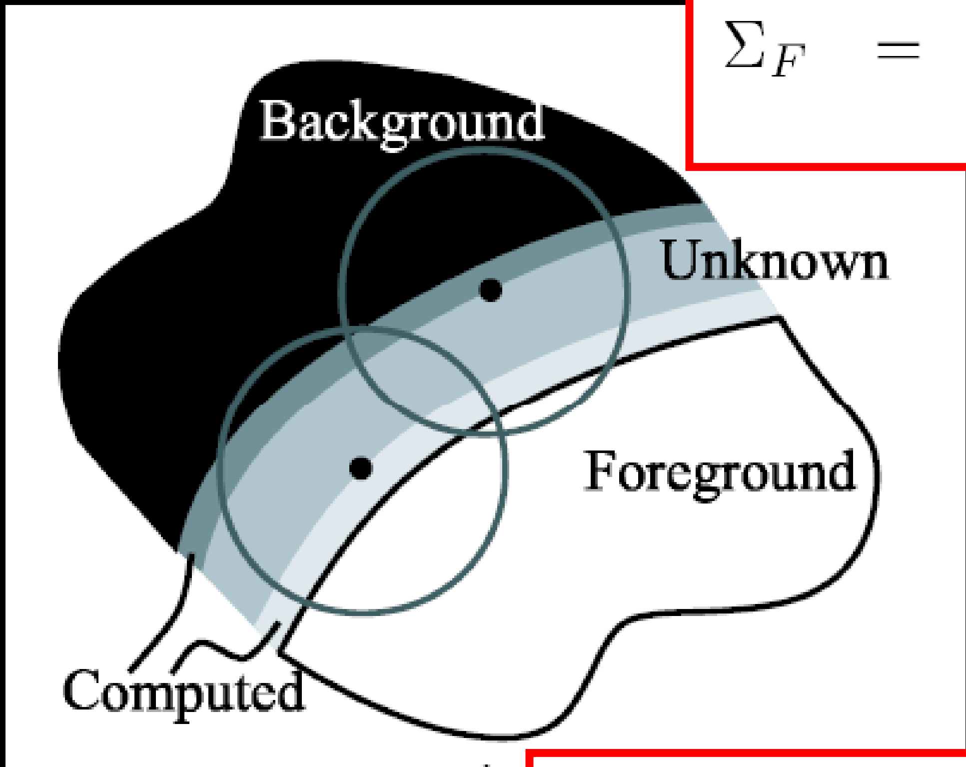
priors

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

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

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

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

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

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

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

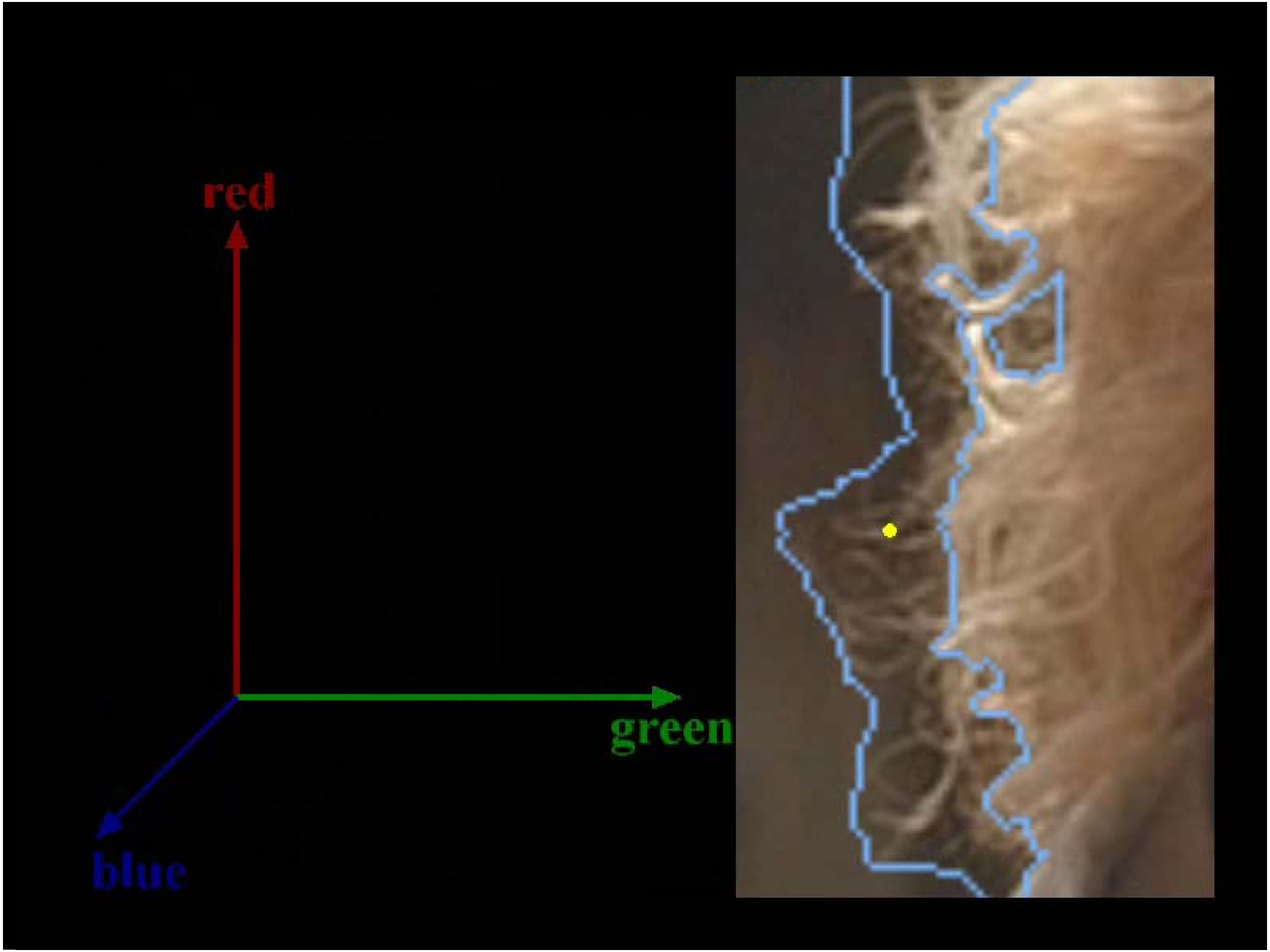
Bayesian image matting

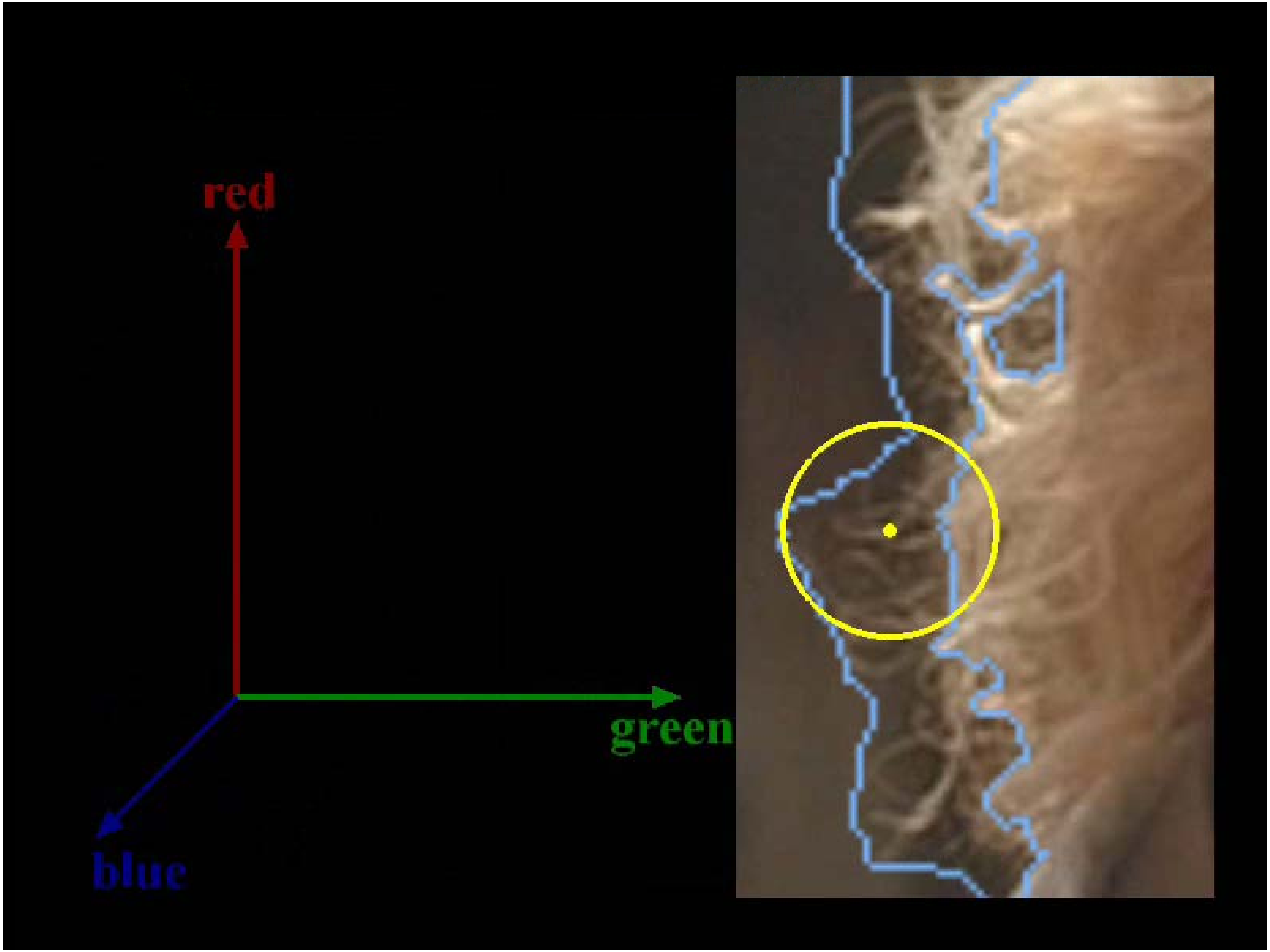
Bayesian image matting

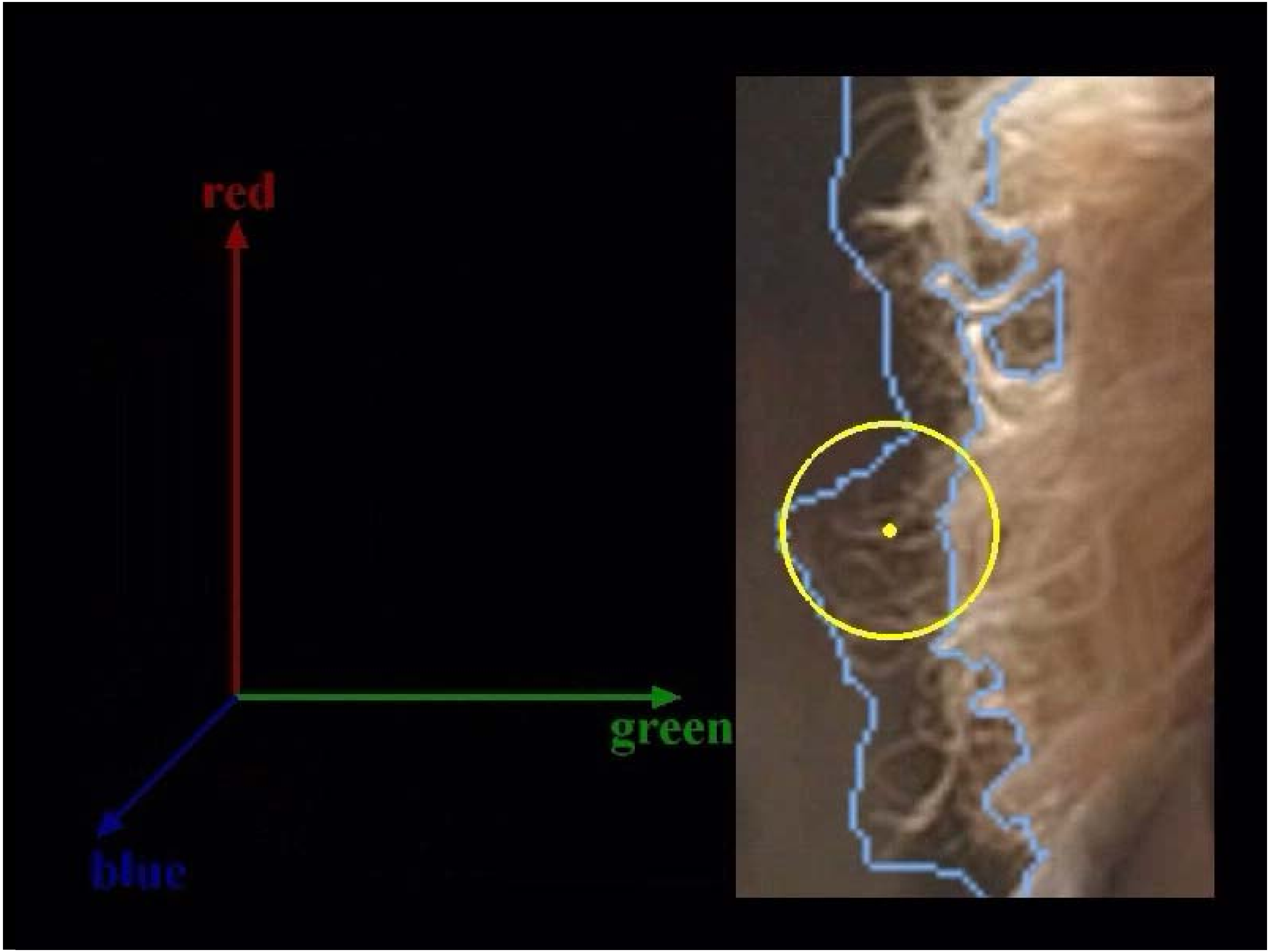
Bayesian image matting

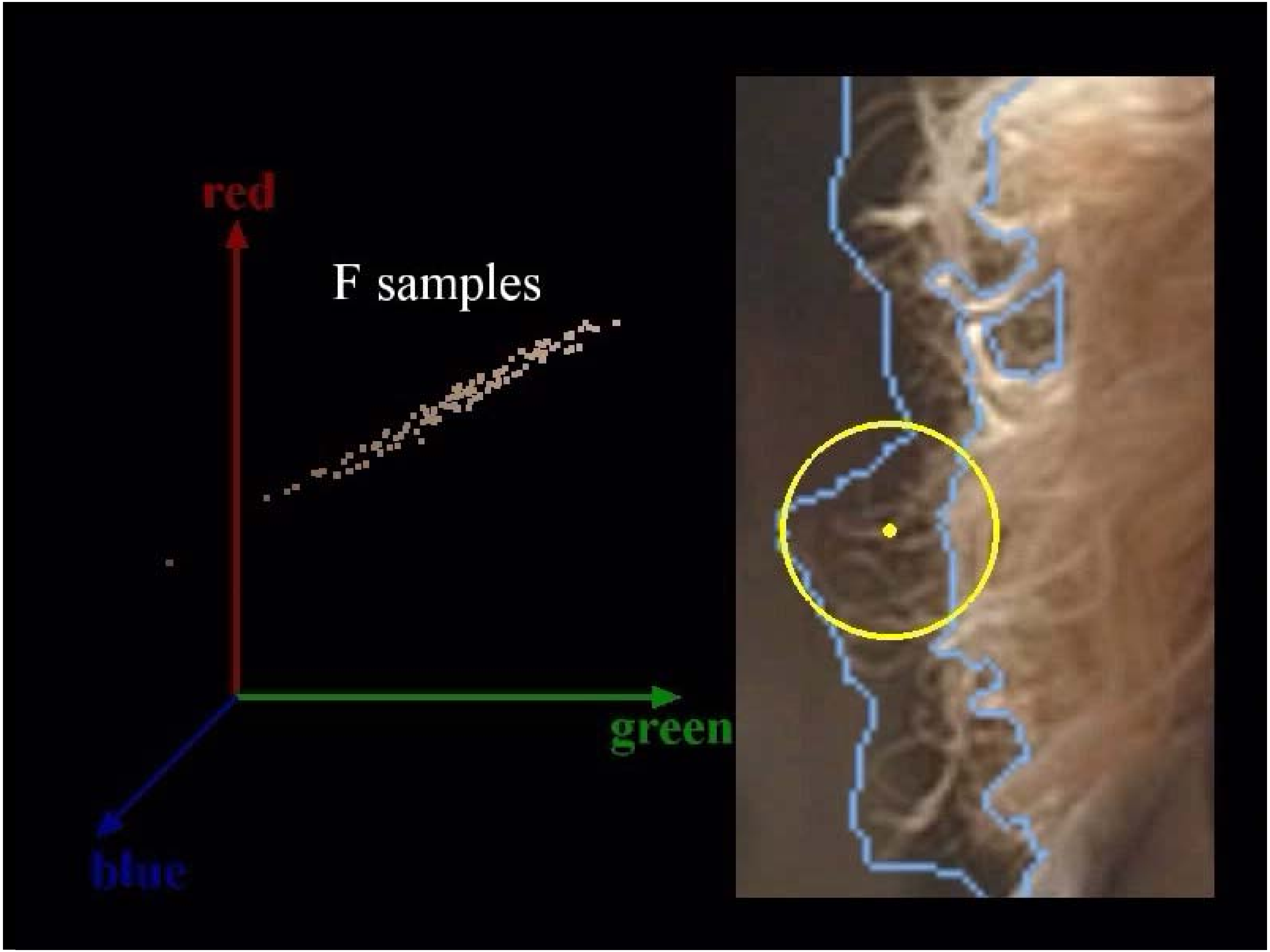
Bayesian image matting

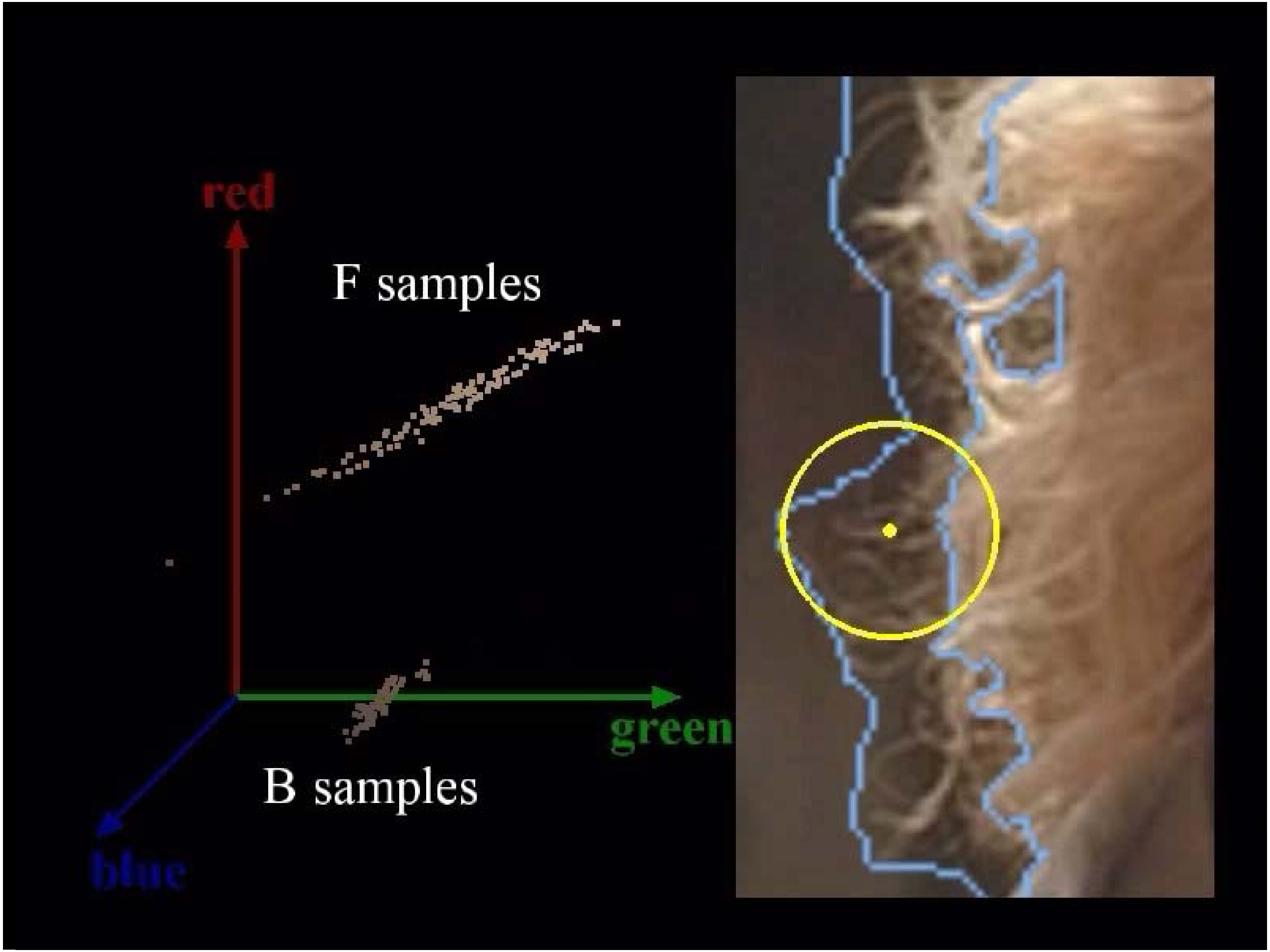
Bayesian image matting

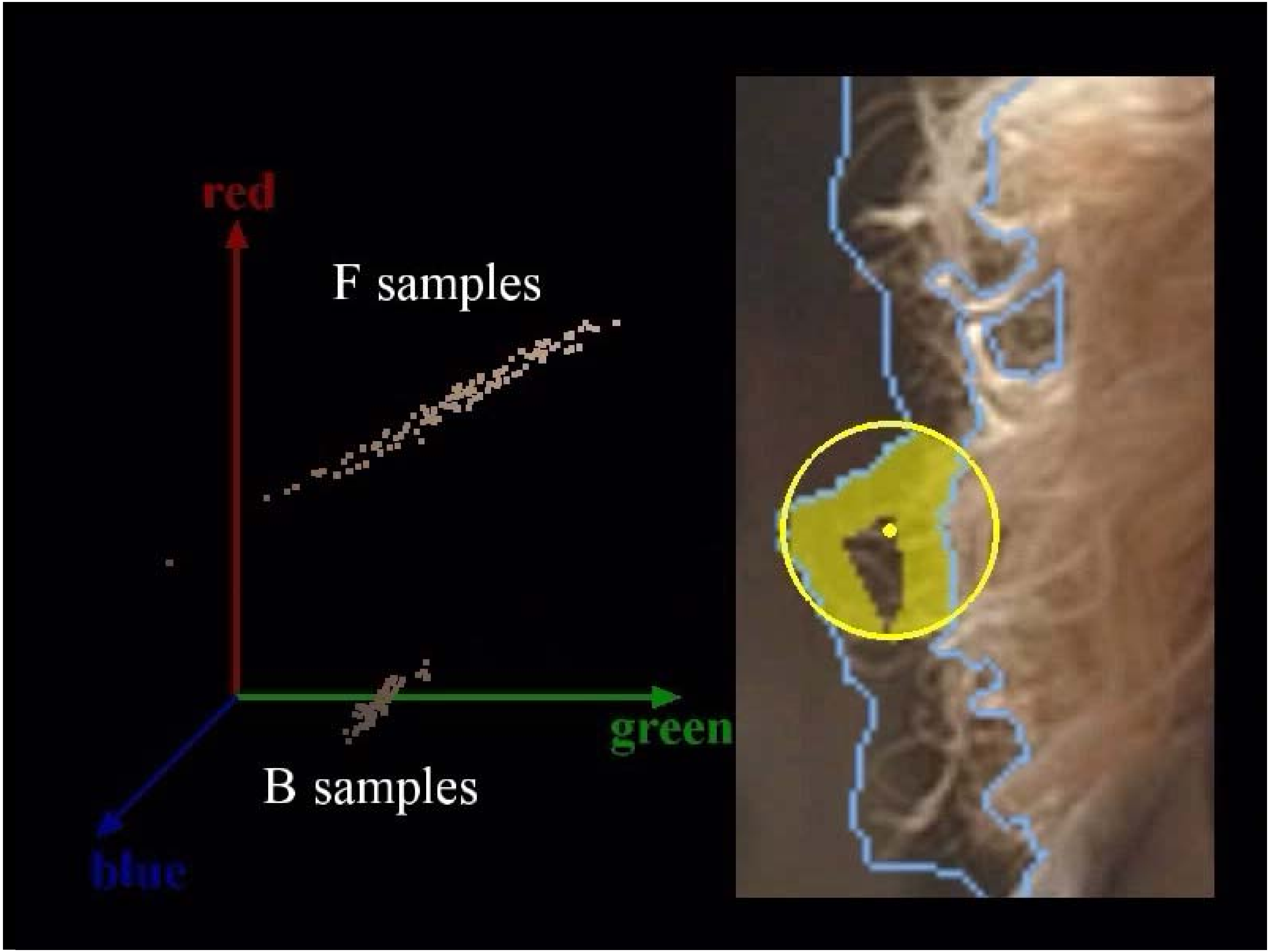

red
green
blue

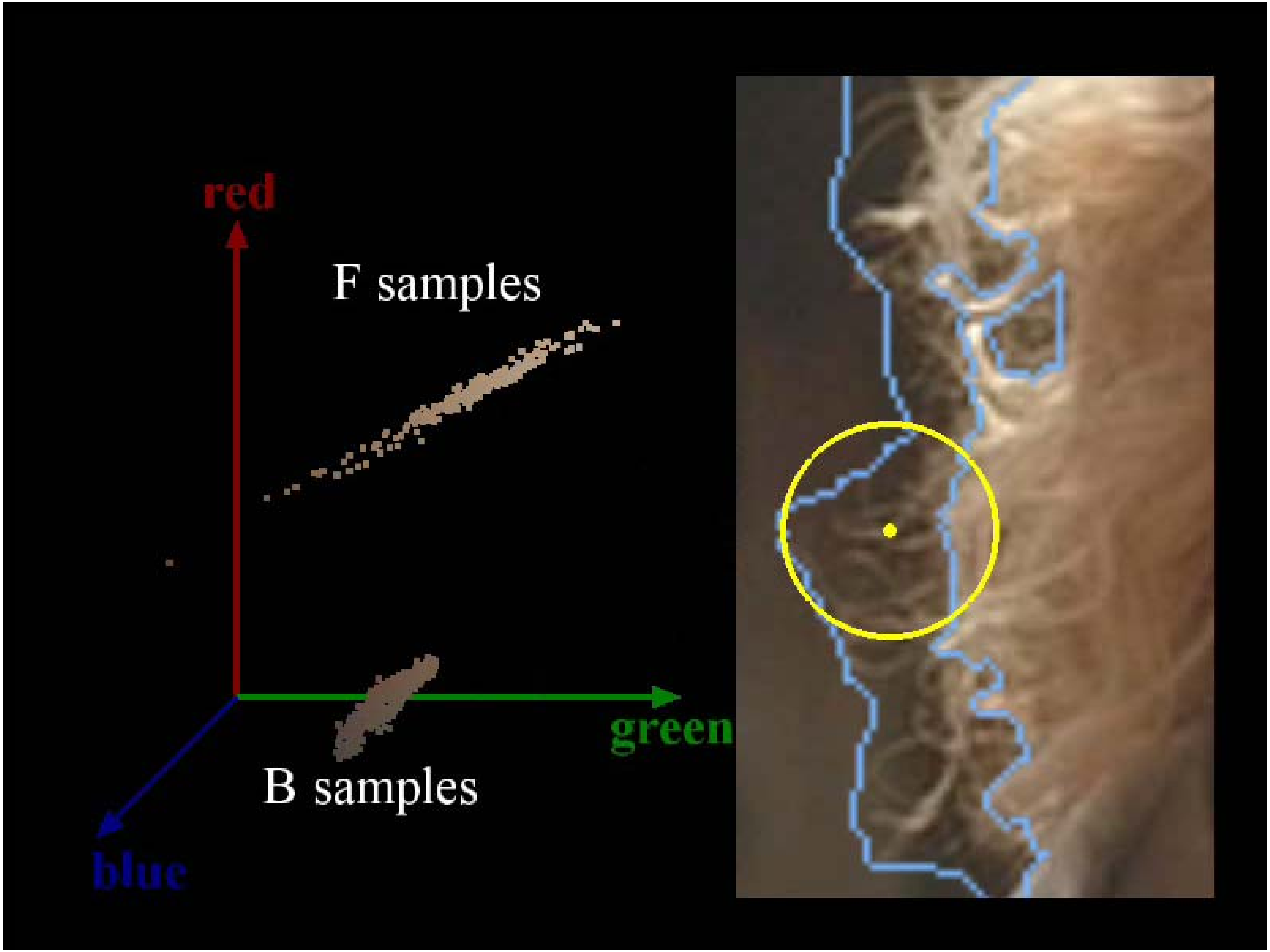

red
green
blue

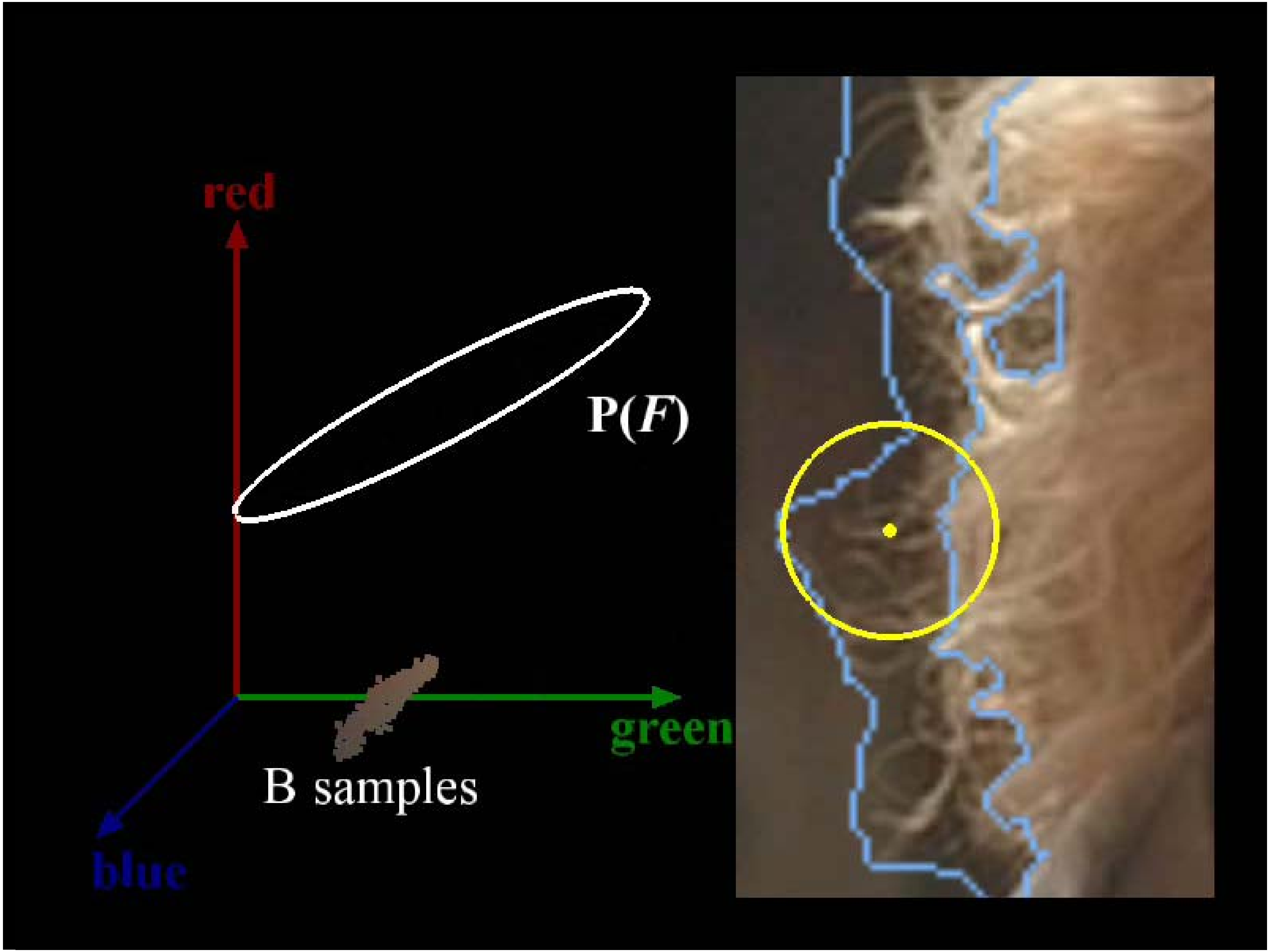

red
green
blue

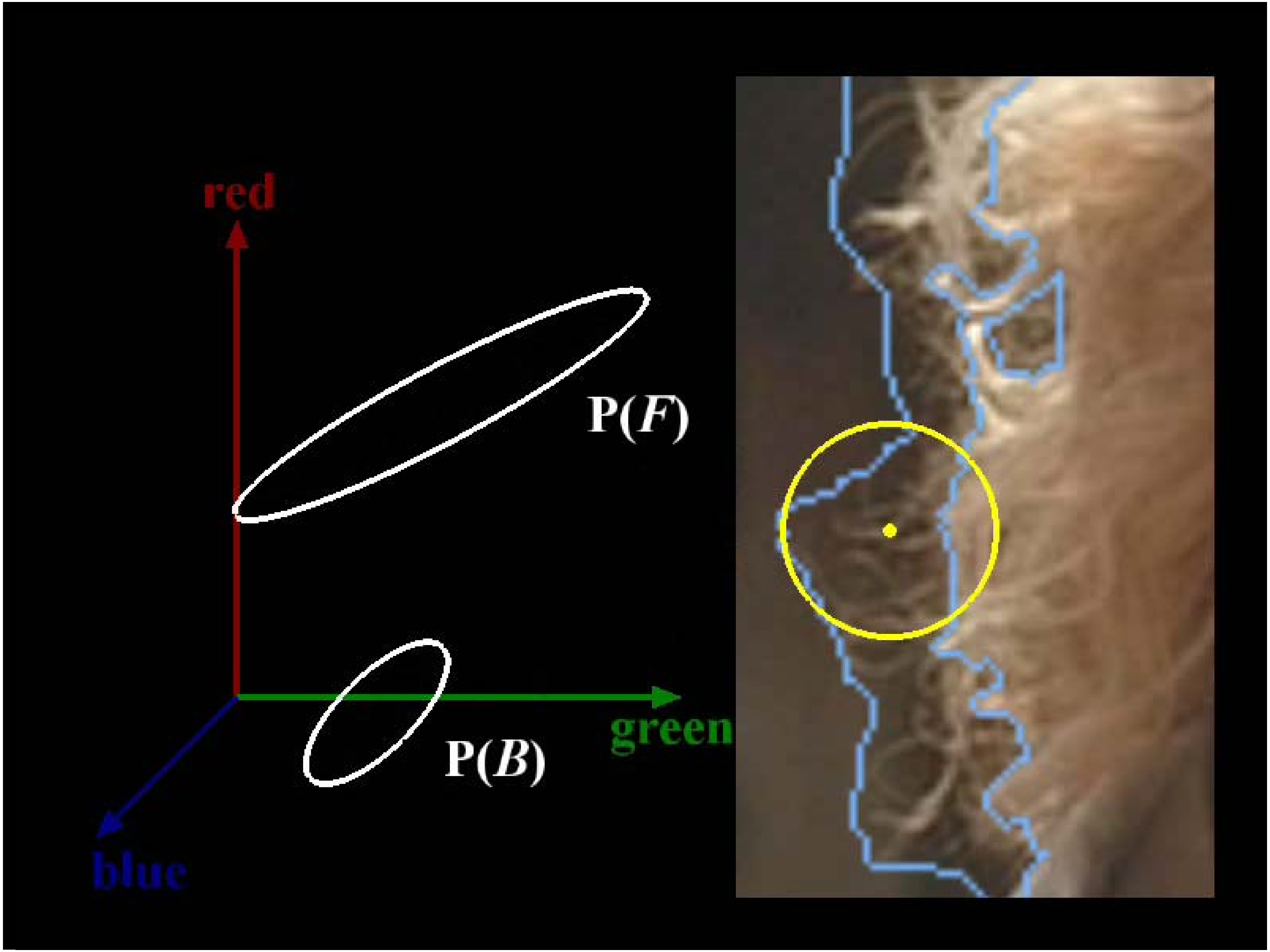

red
F samples
green
blue

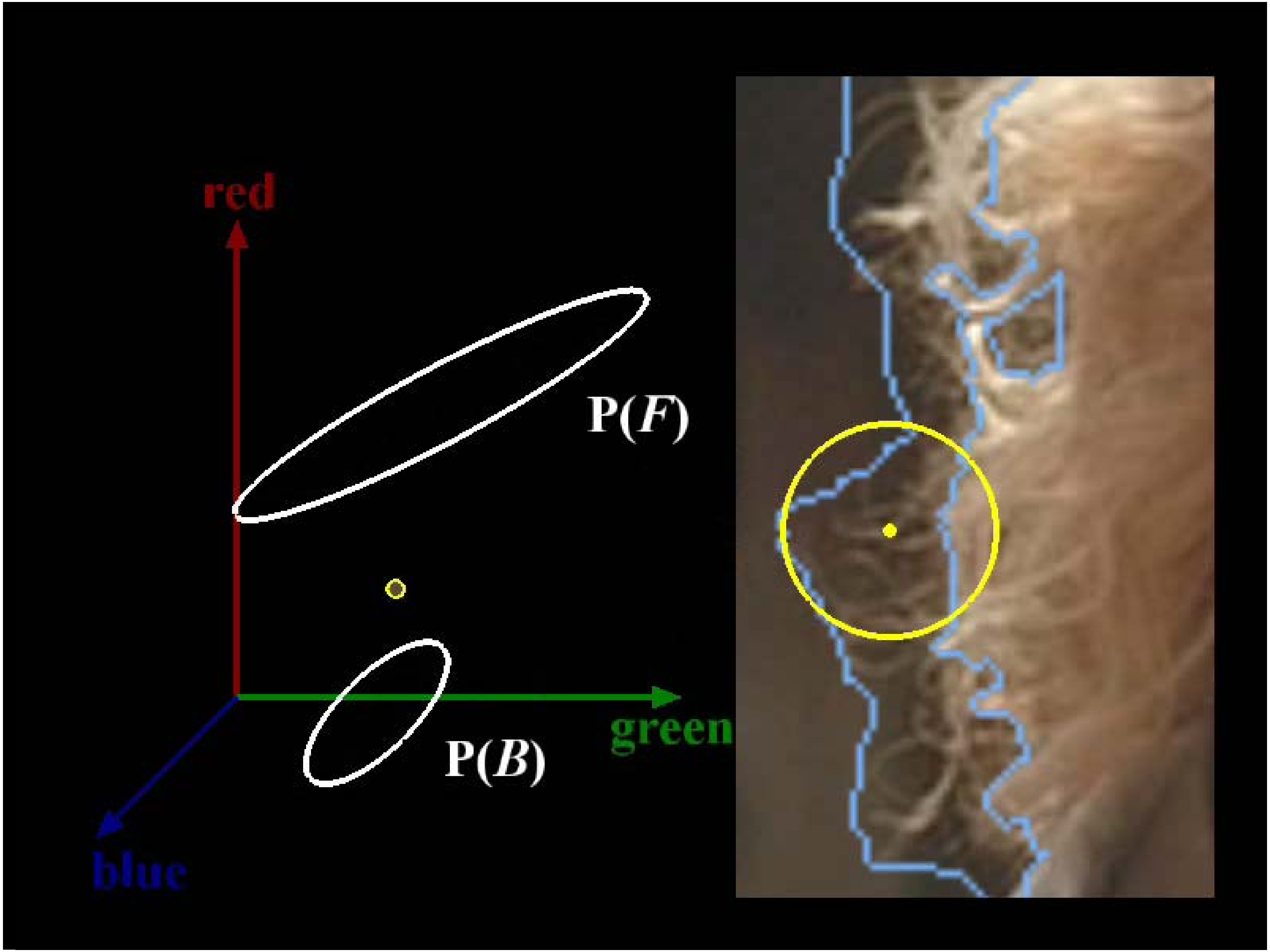

red
F samples
green
B samples
blue

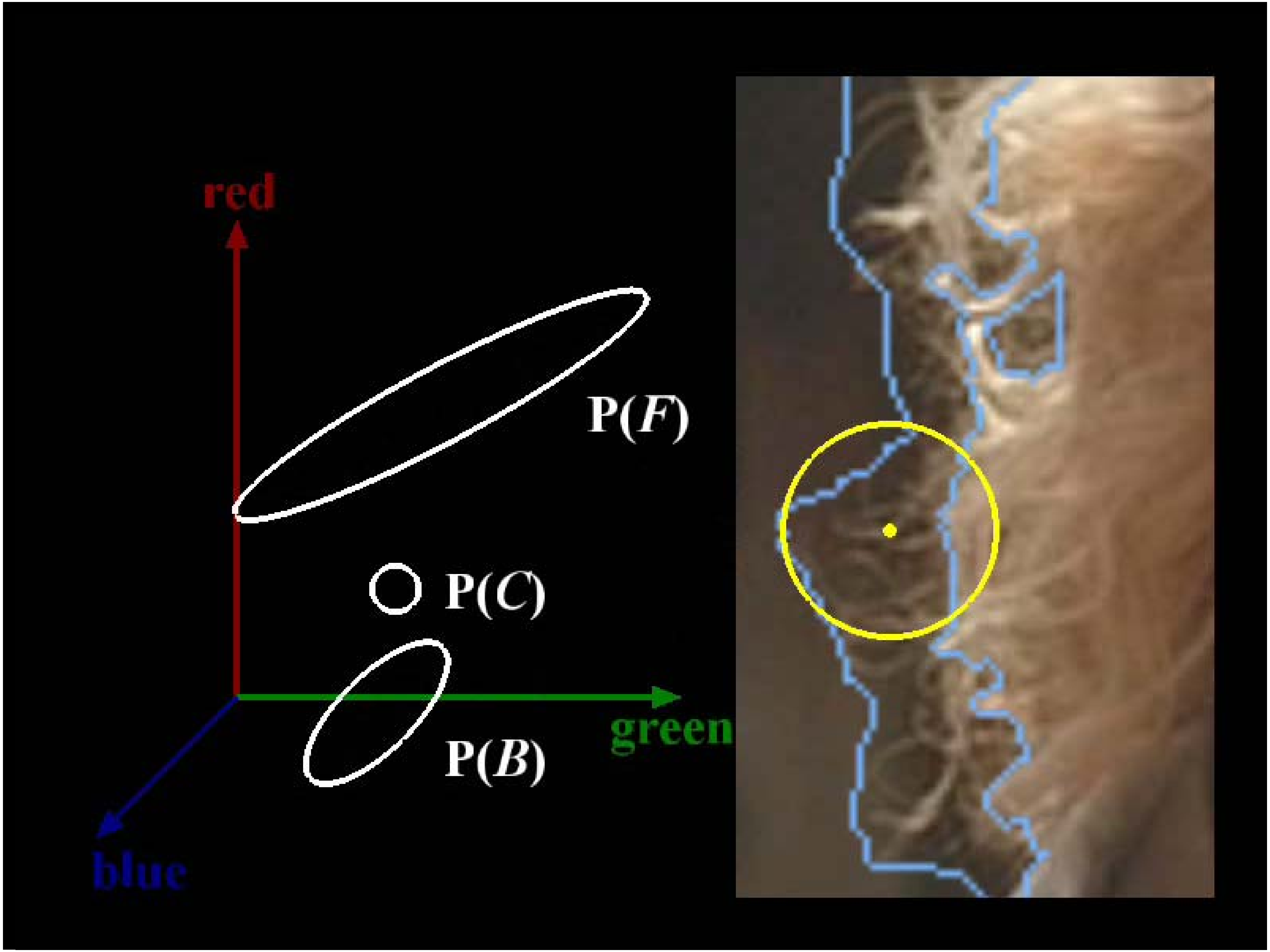

red
F samples
green
B samples
blue

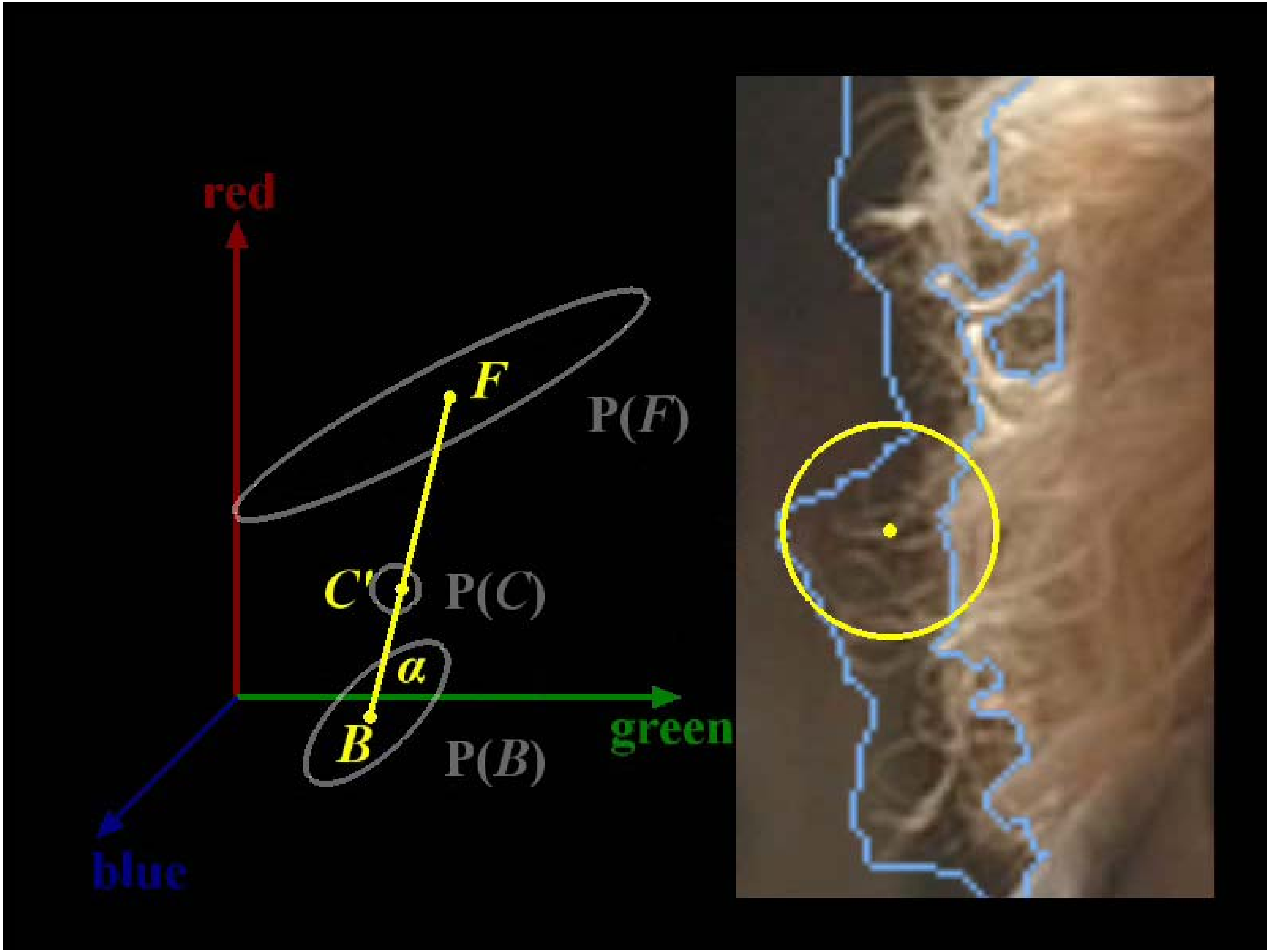

red
F samples
green
B samples
blue


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

alpha

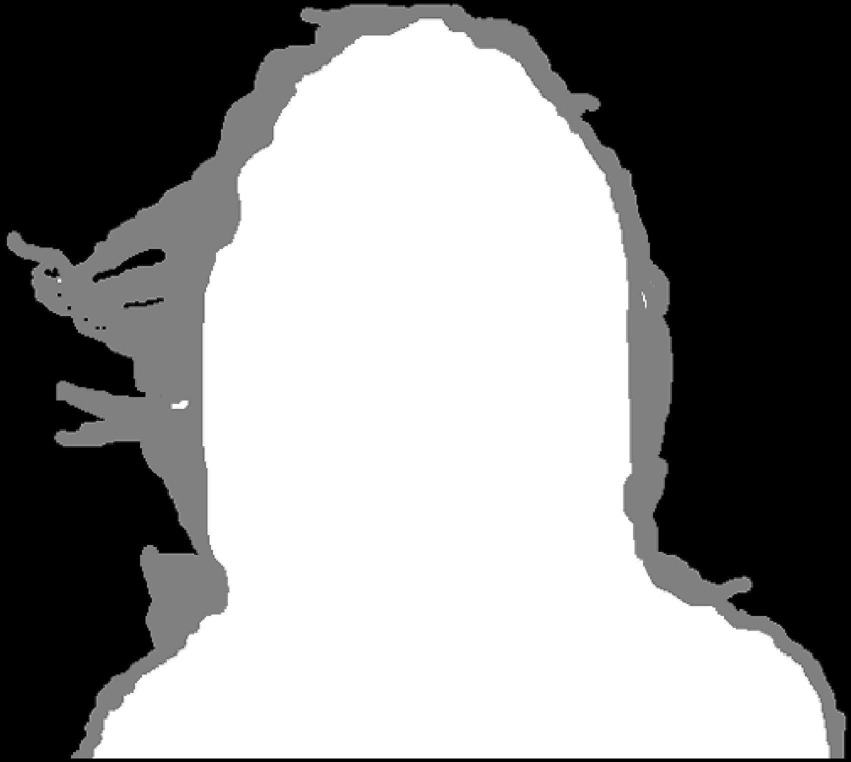
Results

input

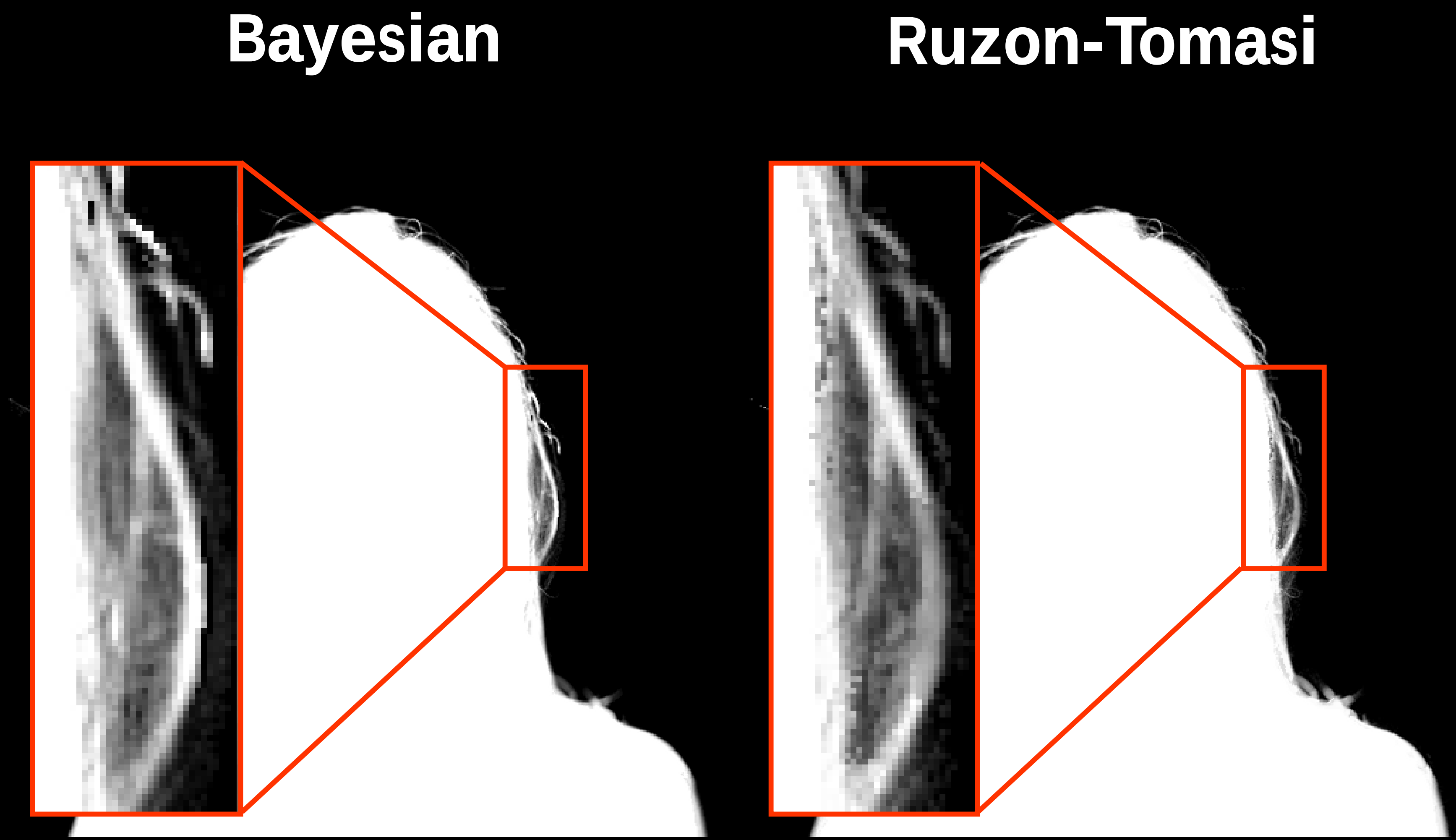
composite

Results

trimap

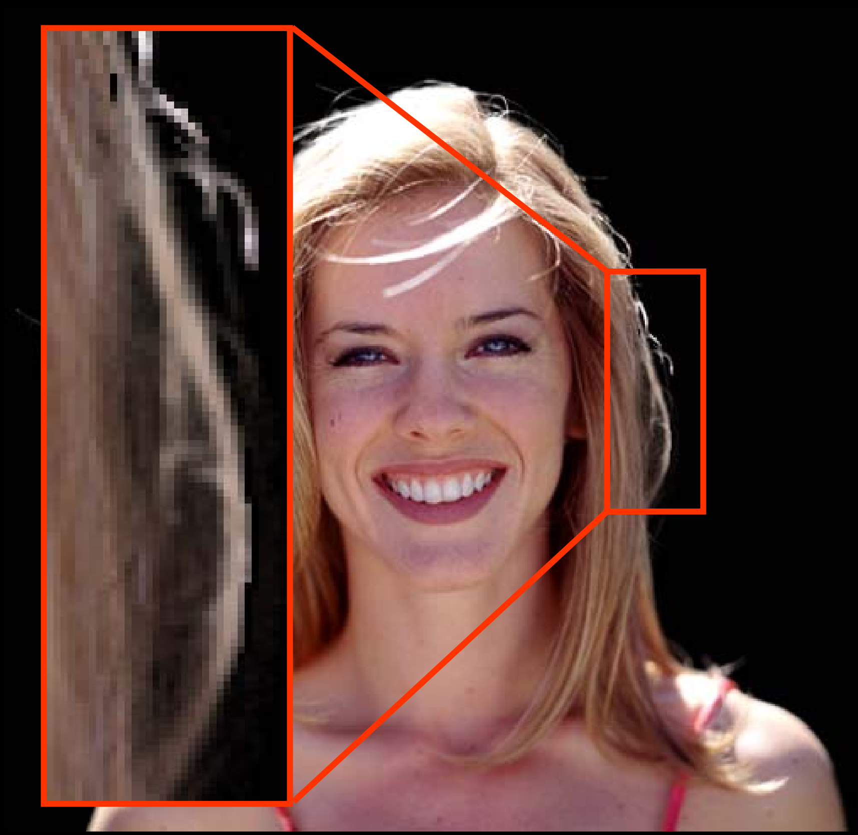


Comparisons

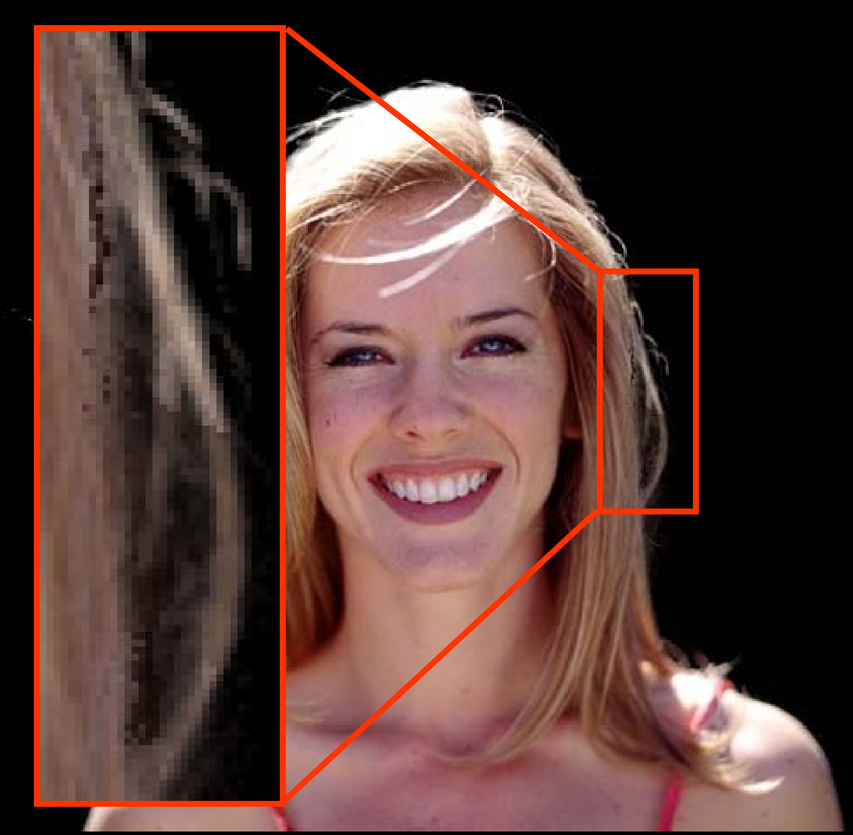


Comparisons

Bayesian



Ruzon-Tomasi



Comparisons

Mishima

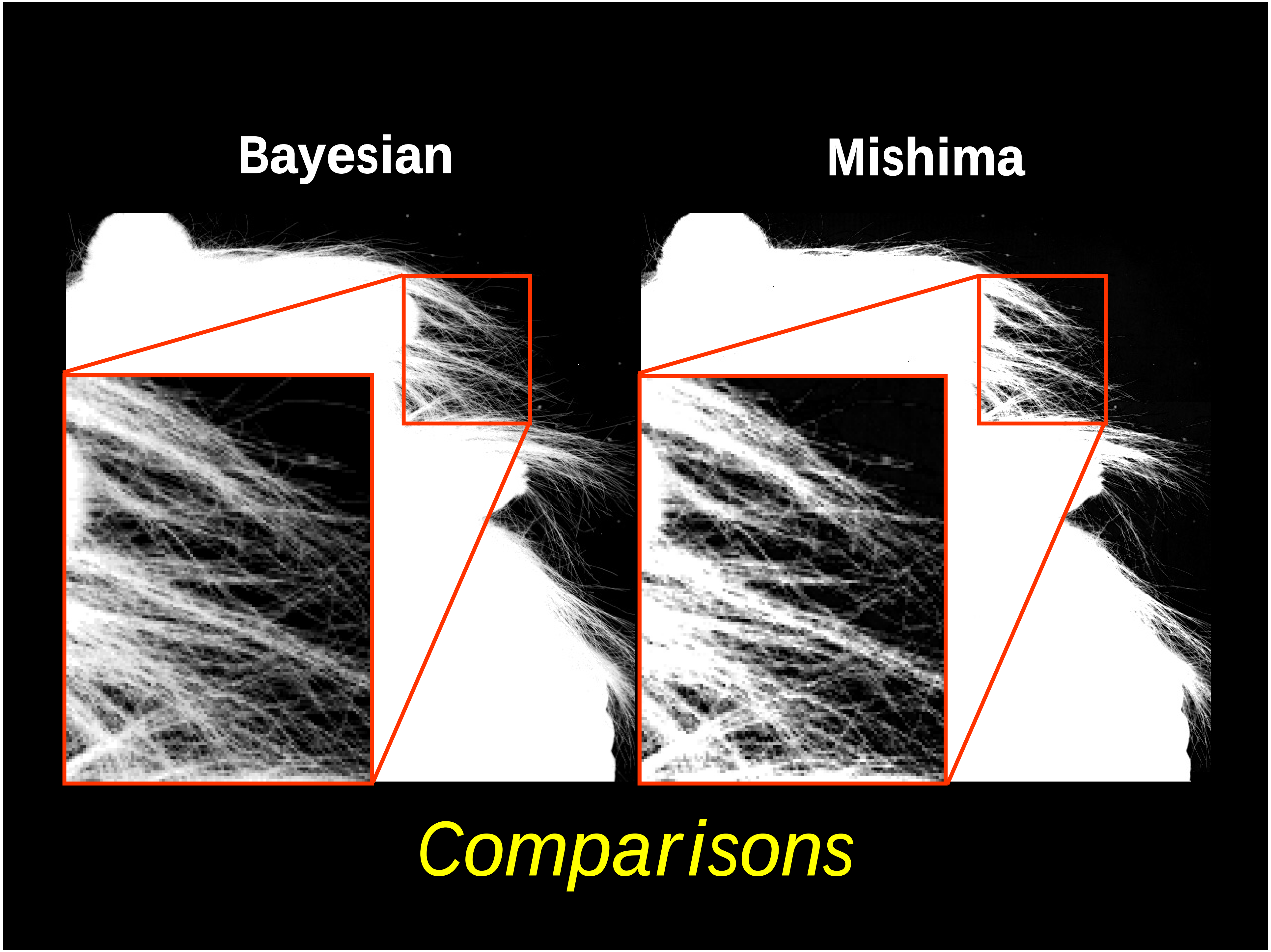
Comparisons

Bayesian

Comparisons

input image

Comparisons


Bayesian
Mishima
Comparisons

Bayesian **Mishima**

Comparisons

input
video

Video matting

input
video

input
key
trimaps

Video matting

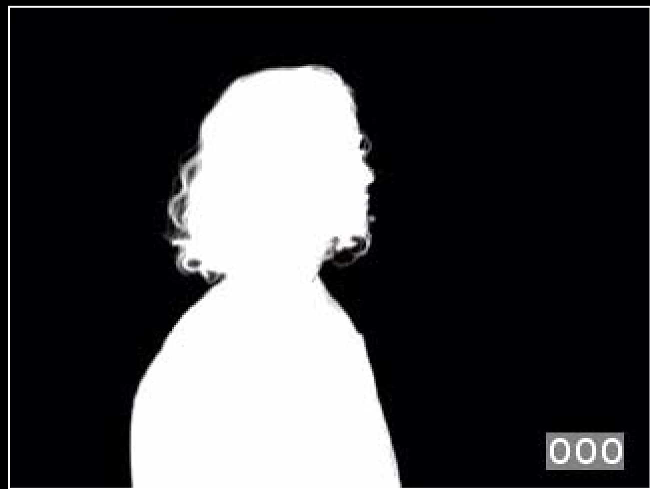
input video

interpo-lated trimaps

Video matting

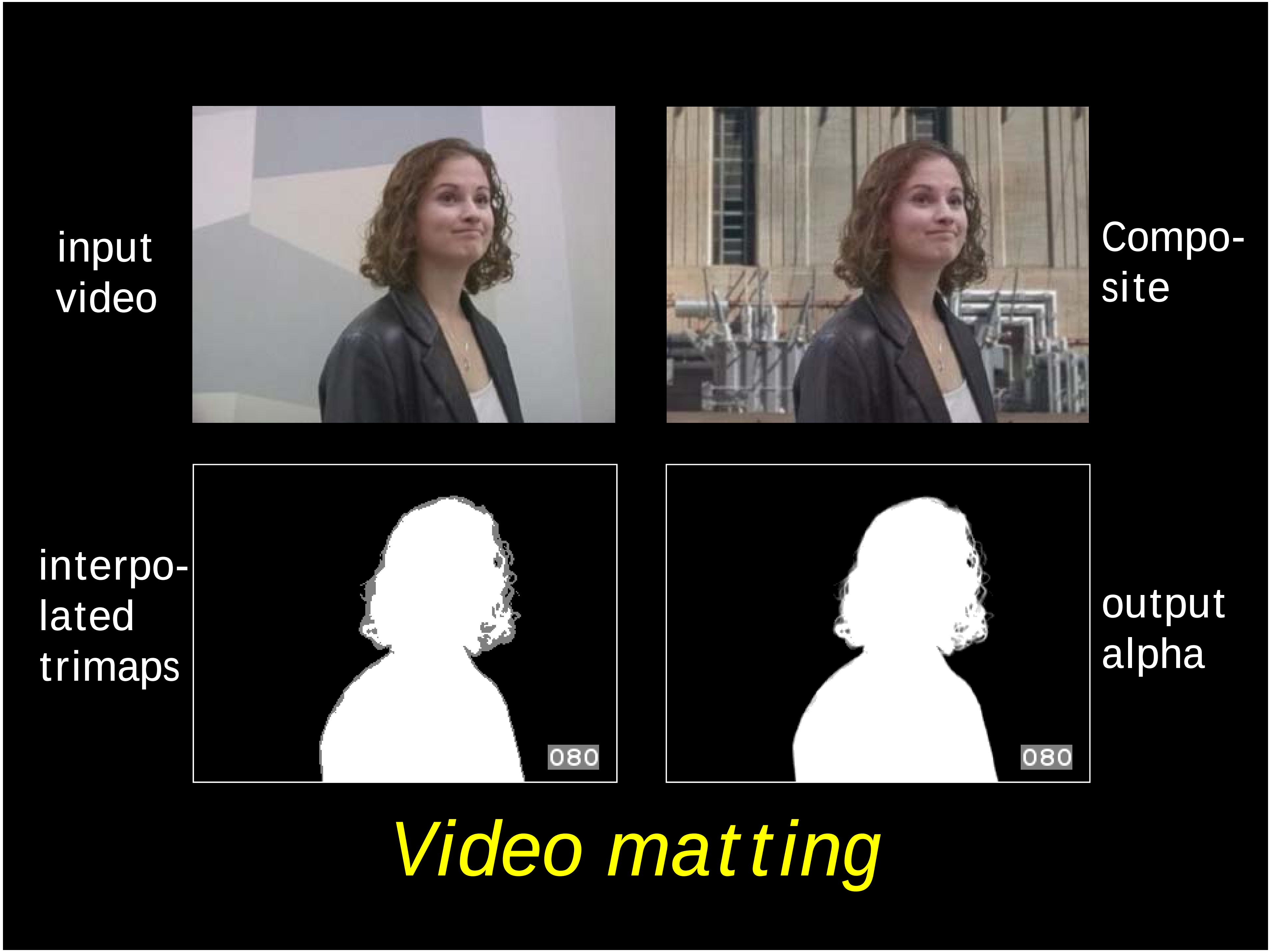
input
video

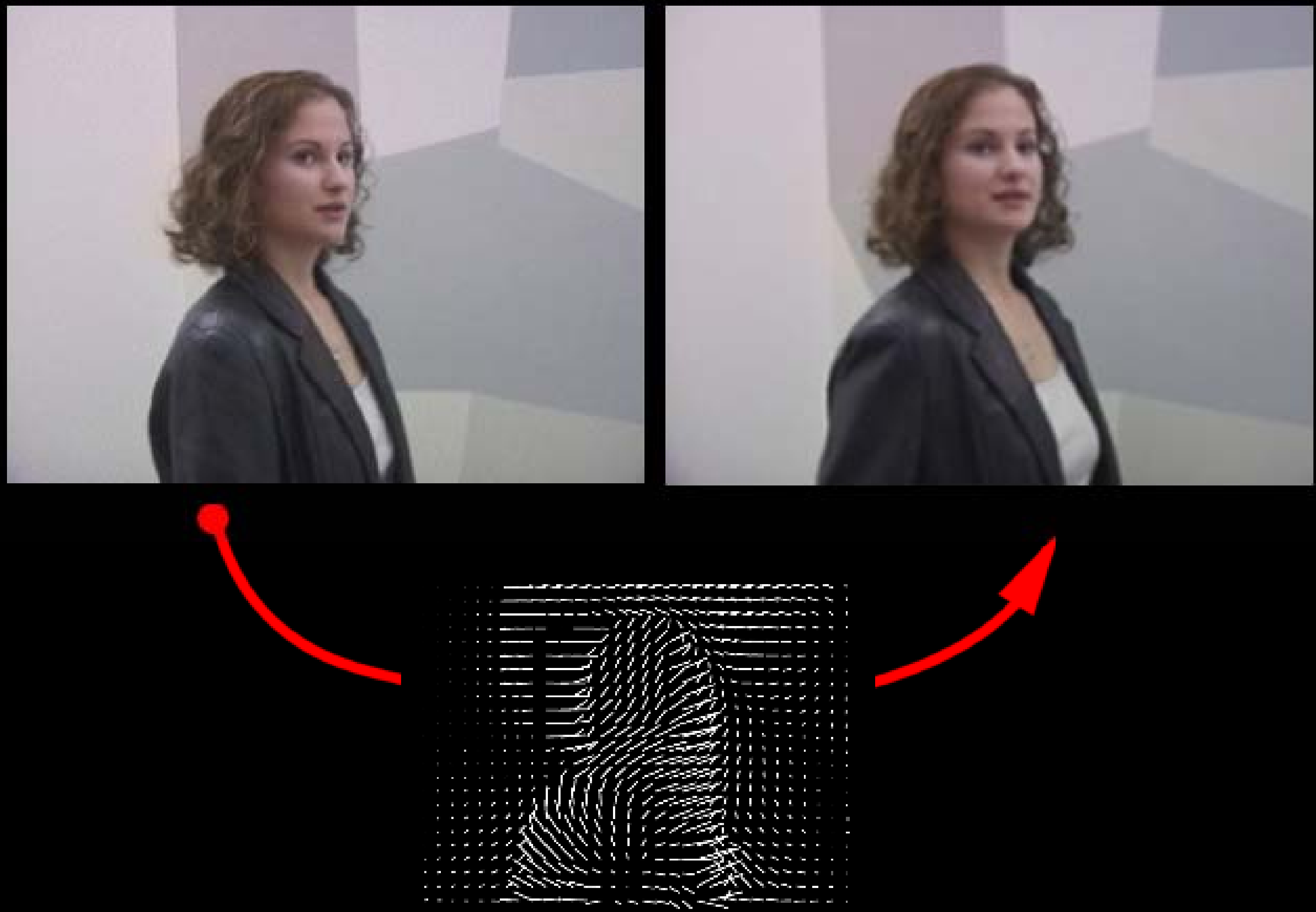
interpo-
lated
trimaps



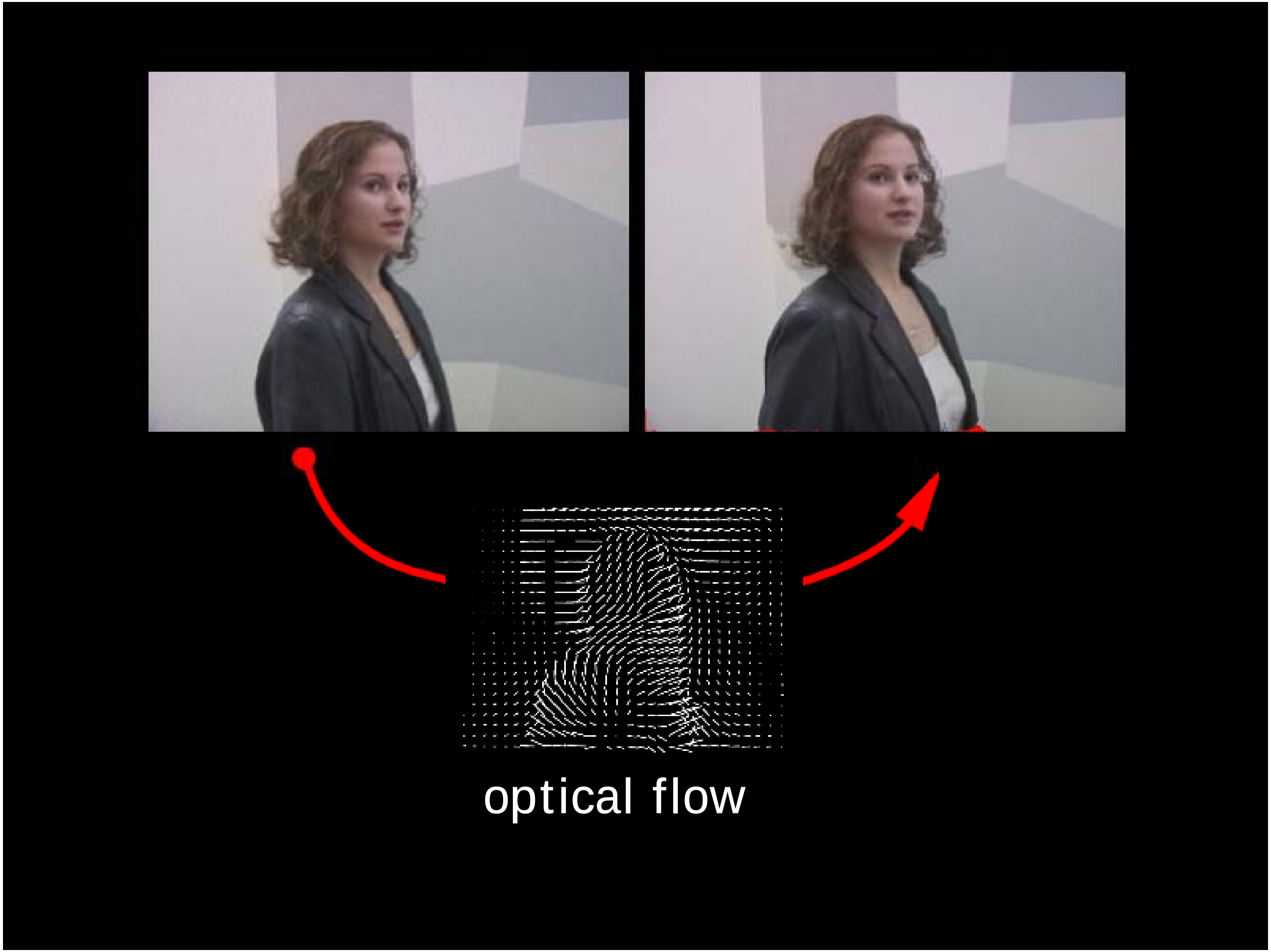
output
alpha

Video matting


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

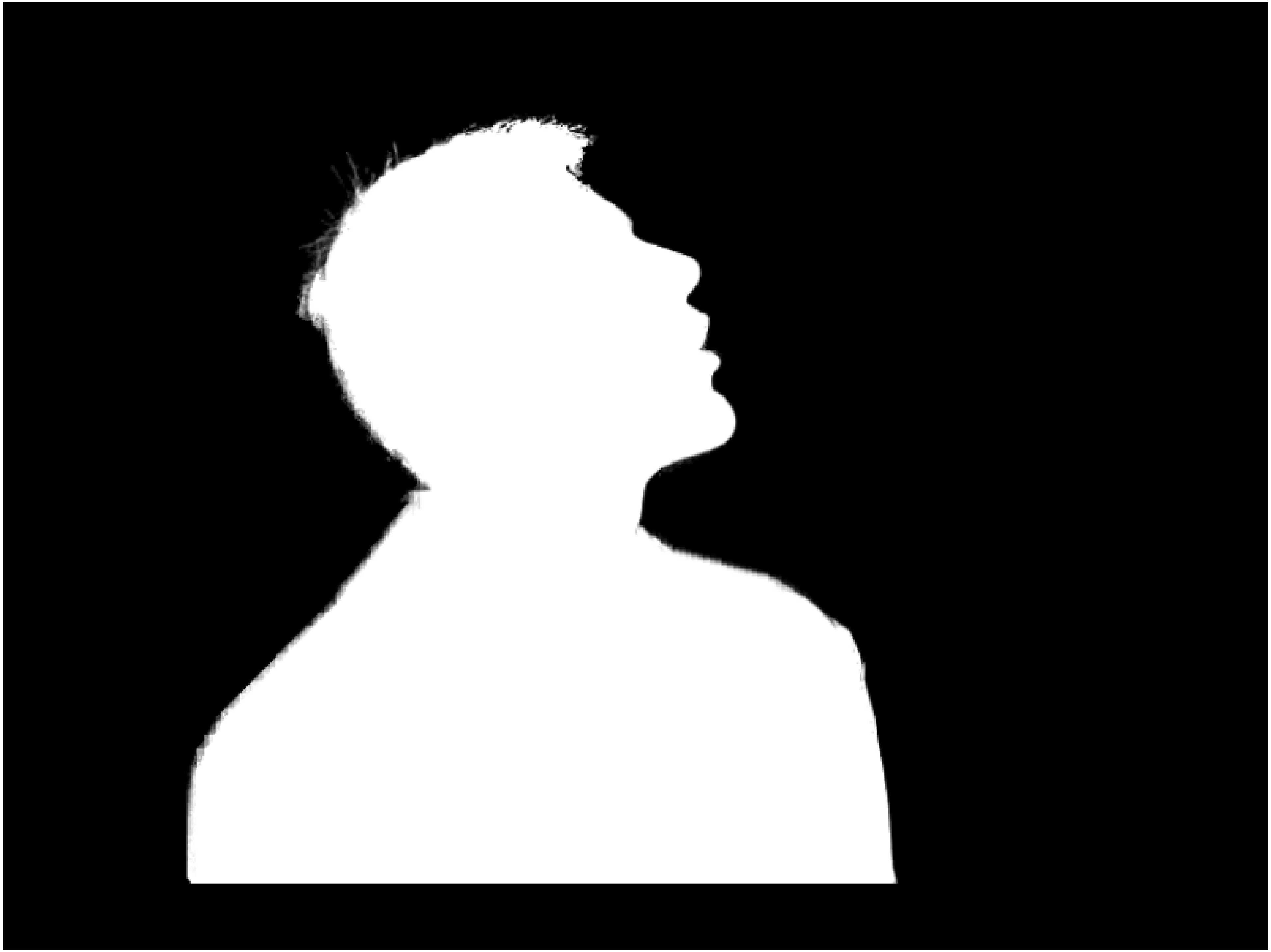
Alpha matte

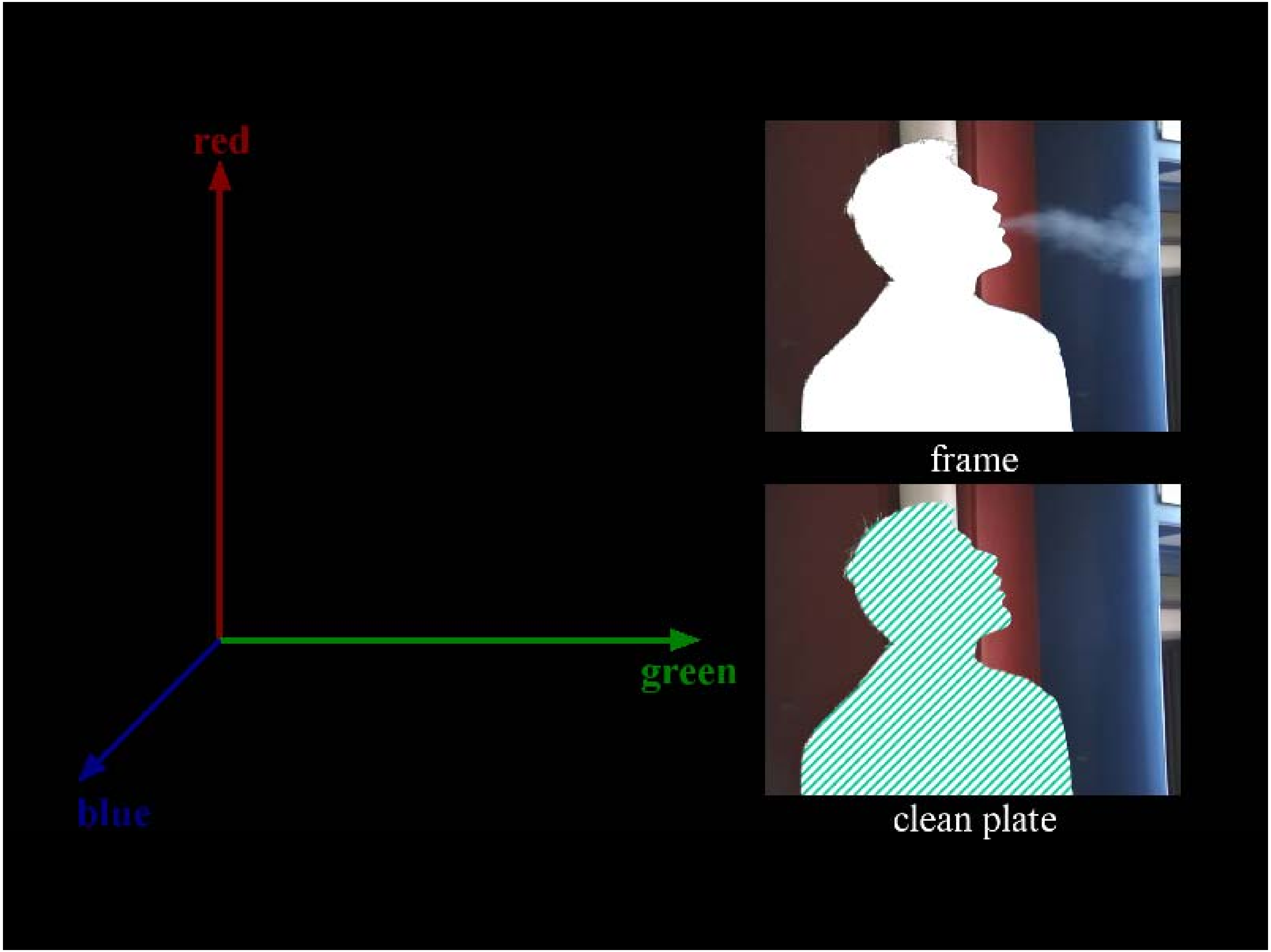
without background

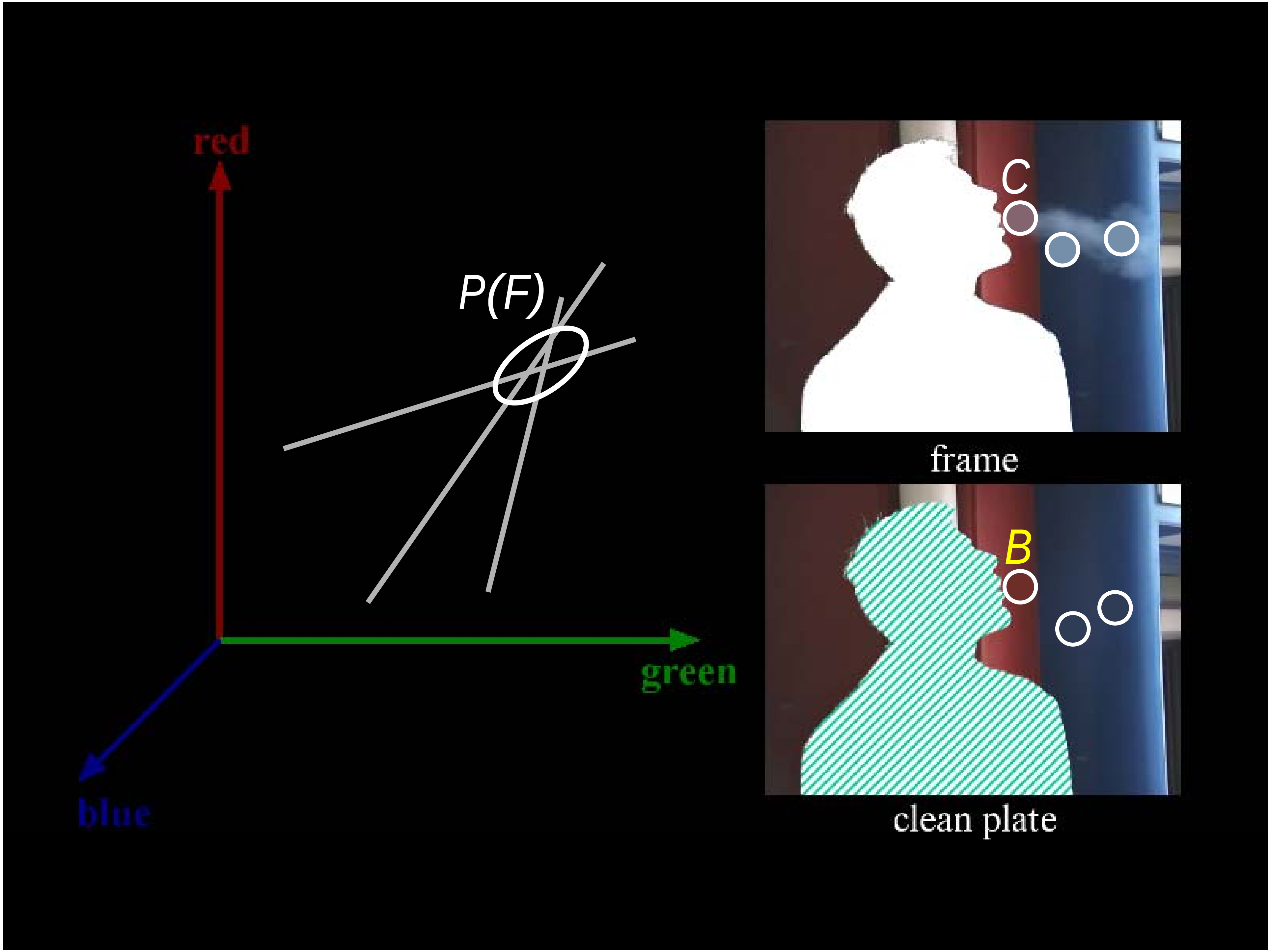
with background

Comparison


input
composite




red
green
blue
frame
clean plate


red
green
blue
P(F)
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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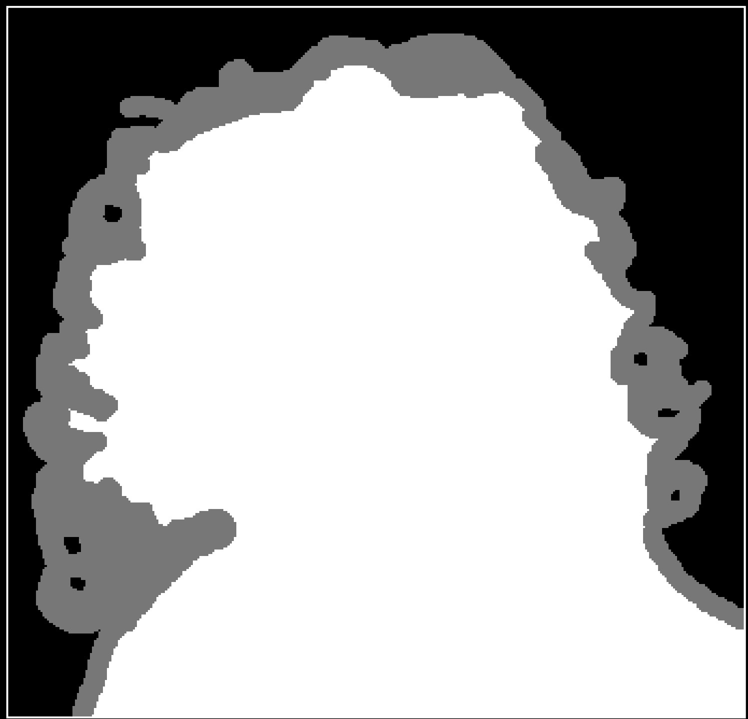
Scribble-based input

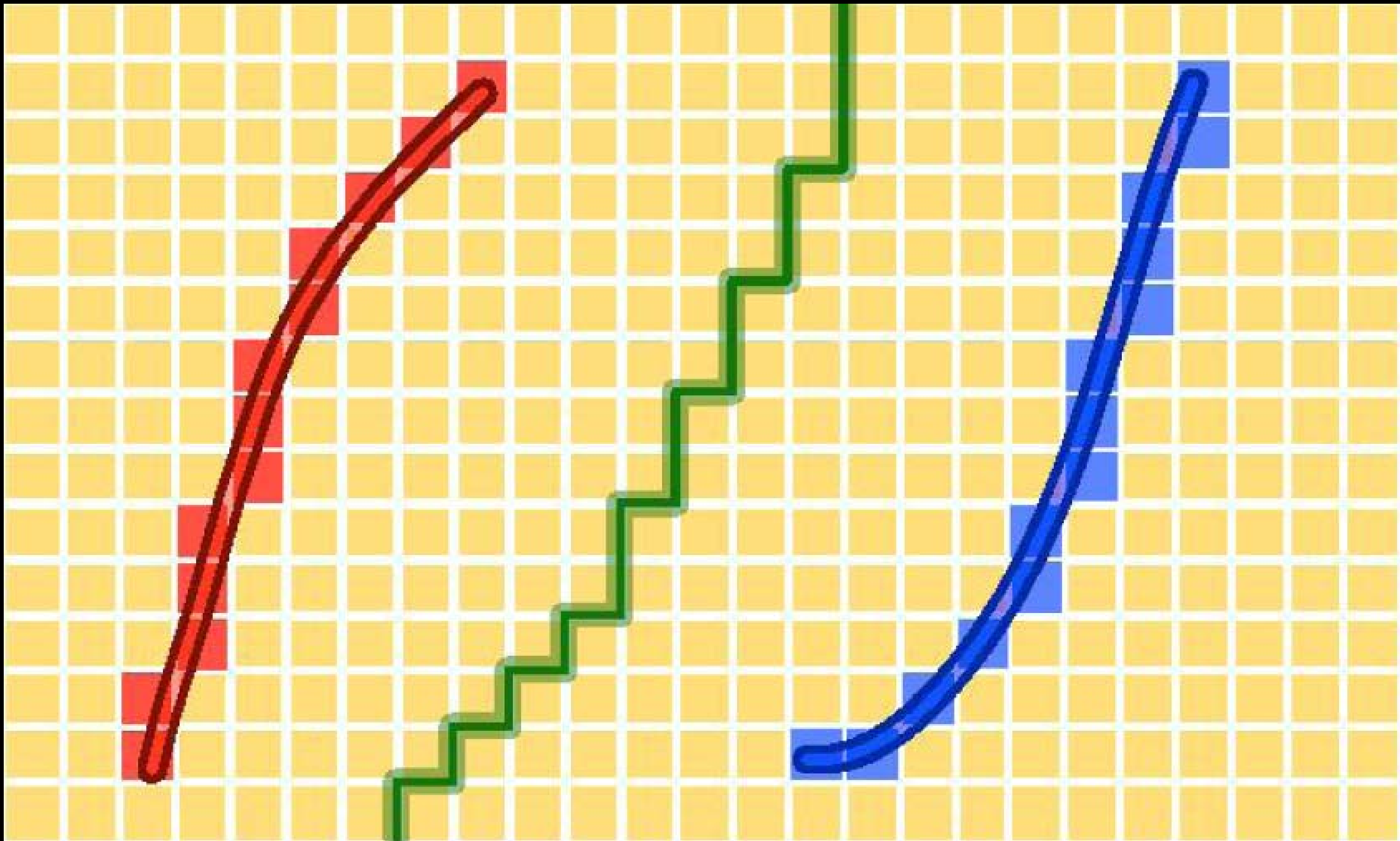


trimap

scribble

Motivation

LazySnapping



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

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

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

n-th mean foreground color

LazySnapping

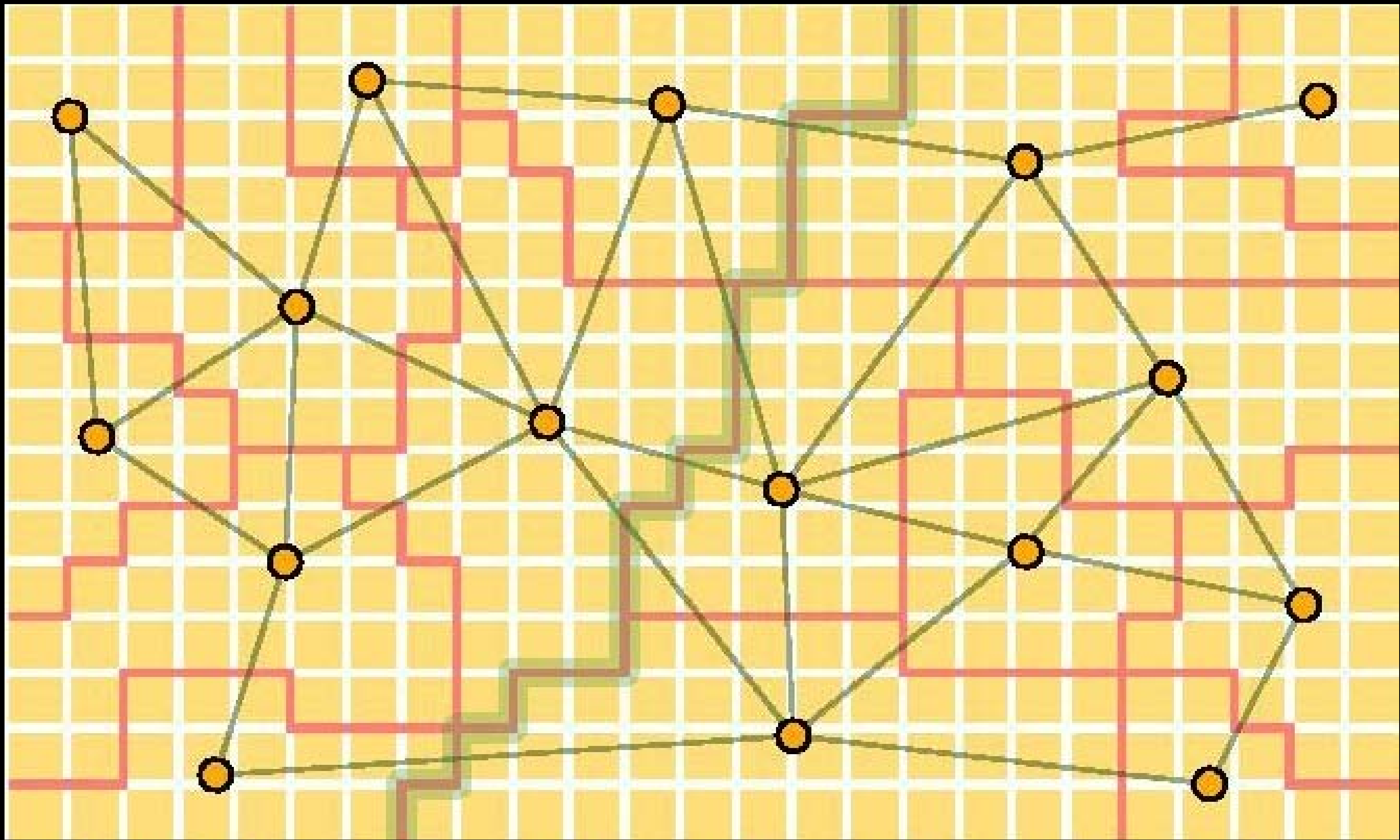
$$E(X) = \sum_{i \in \mathcal{V}} E_1(x_i) + \lambda \sum_{(i,j) \in \mathcal{E}} E_2(x_i, x_j)$$

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

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

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

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

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

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

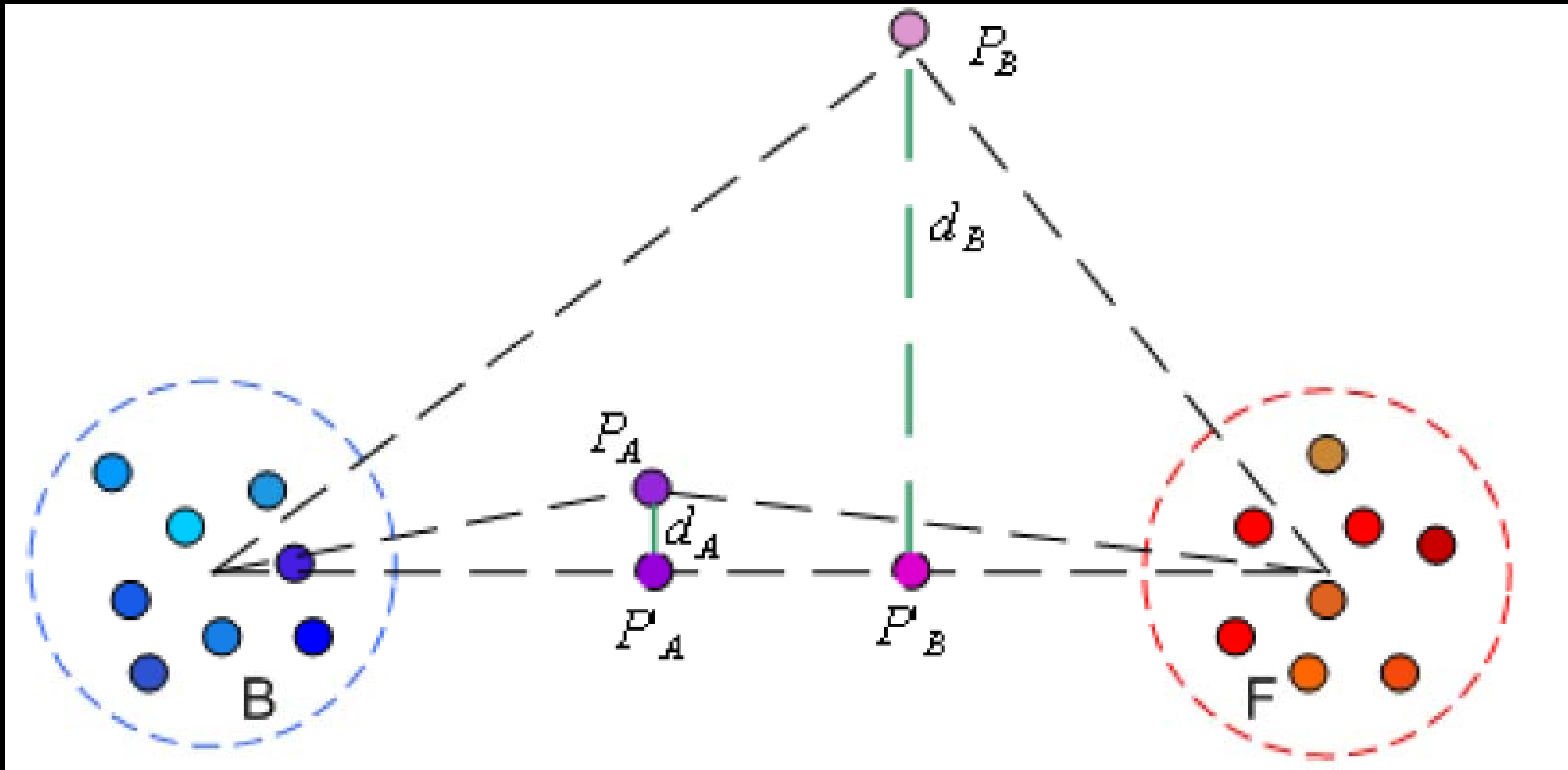
$$\nabla\alpha \approx \frac{1}{F - B}\nabla I$$

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

Poisson matting

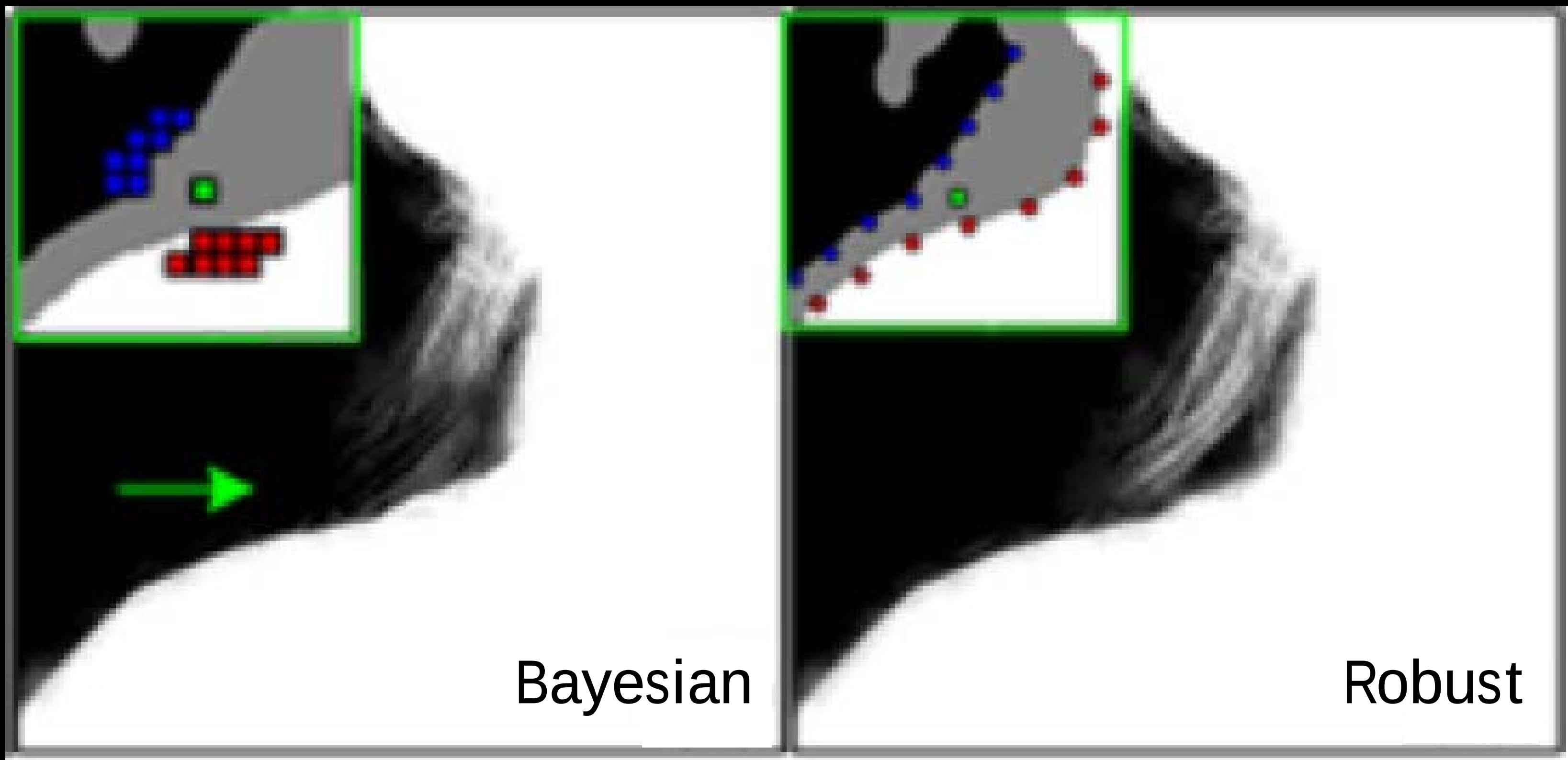
Robust matting

- Jue Wang and Michael Cohen, CVPR 2007



Robust matting

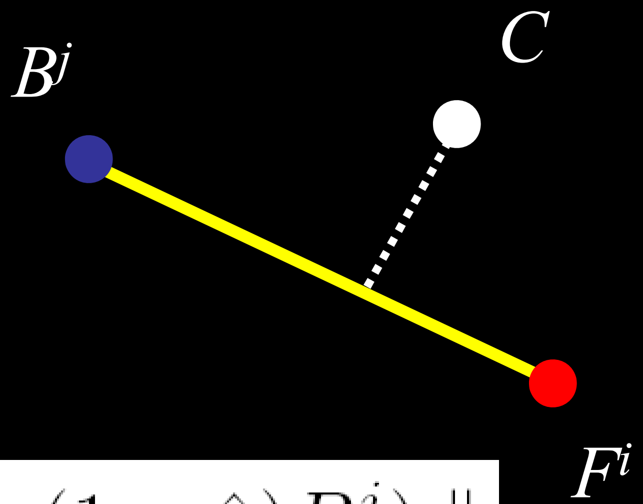
- Instead of fitting models, a non-parametric approach is used



Robust matting

- We must evaluate hypothesized foreground/background pairs

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

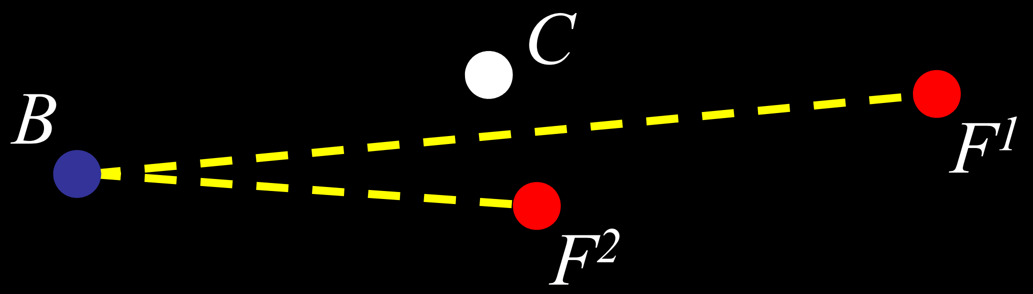


distance ratio

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

Robust matting

- To encourage pure fg/bg pixels, add weights



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

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

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

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

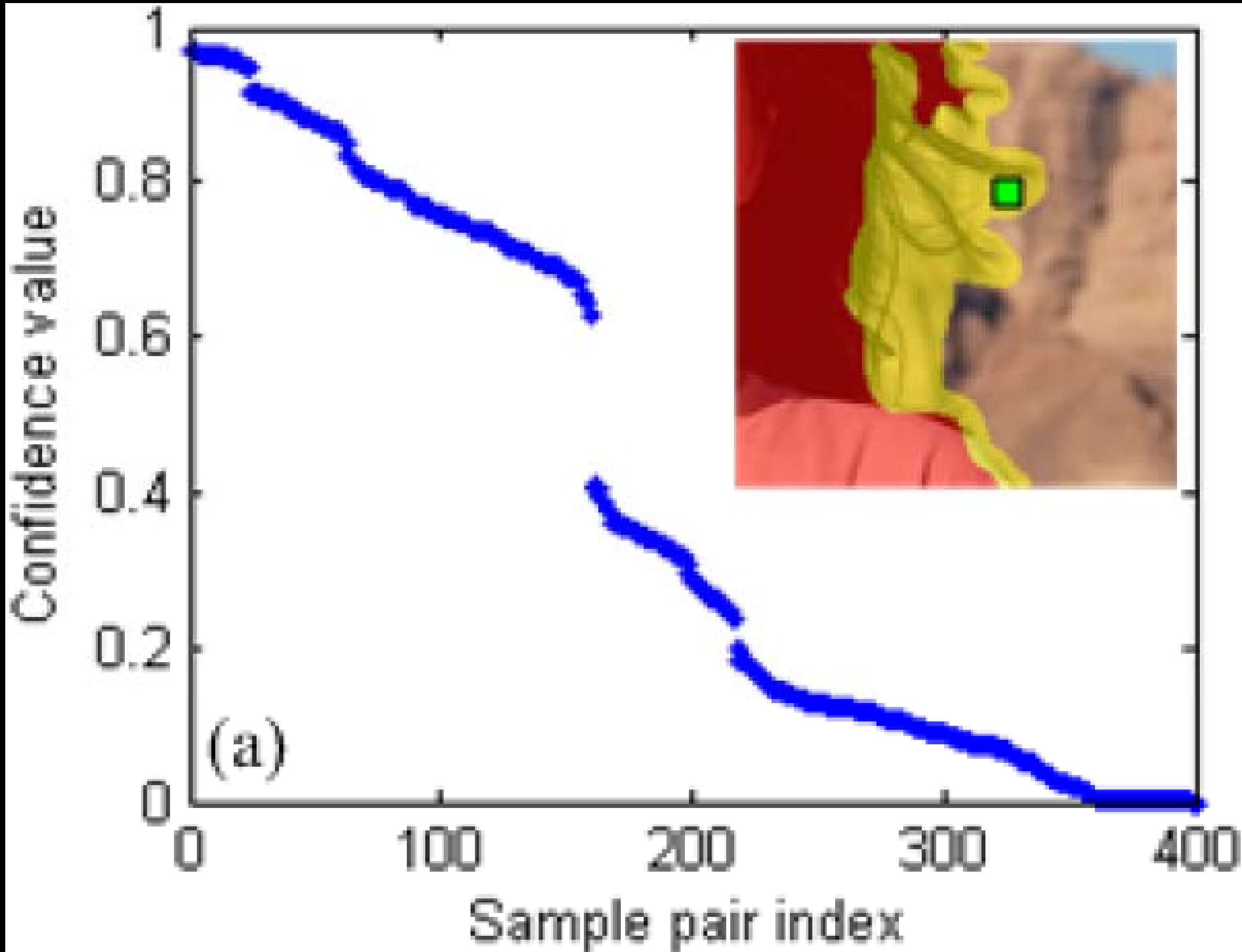
Robust matting

- 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

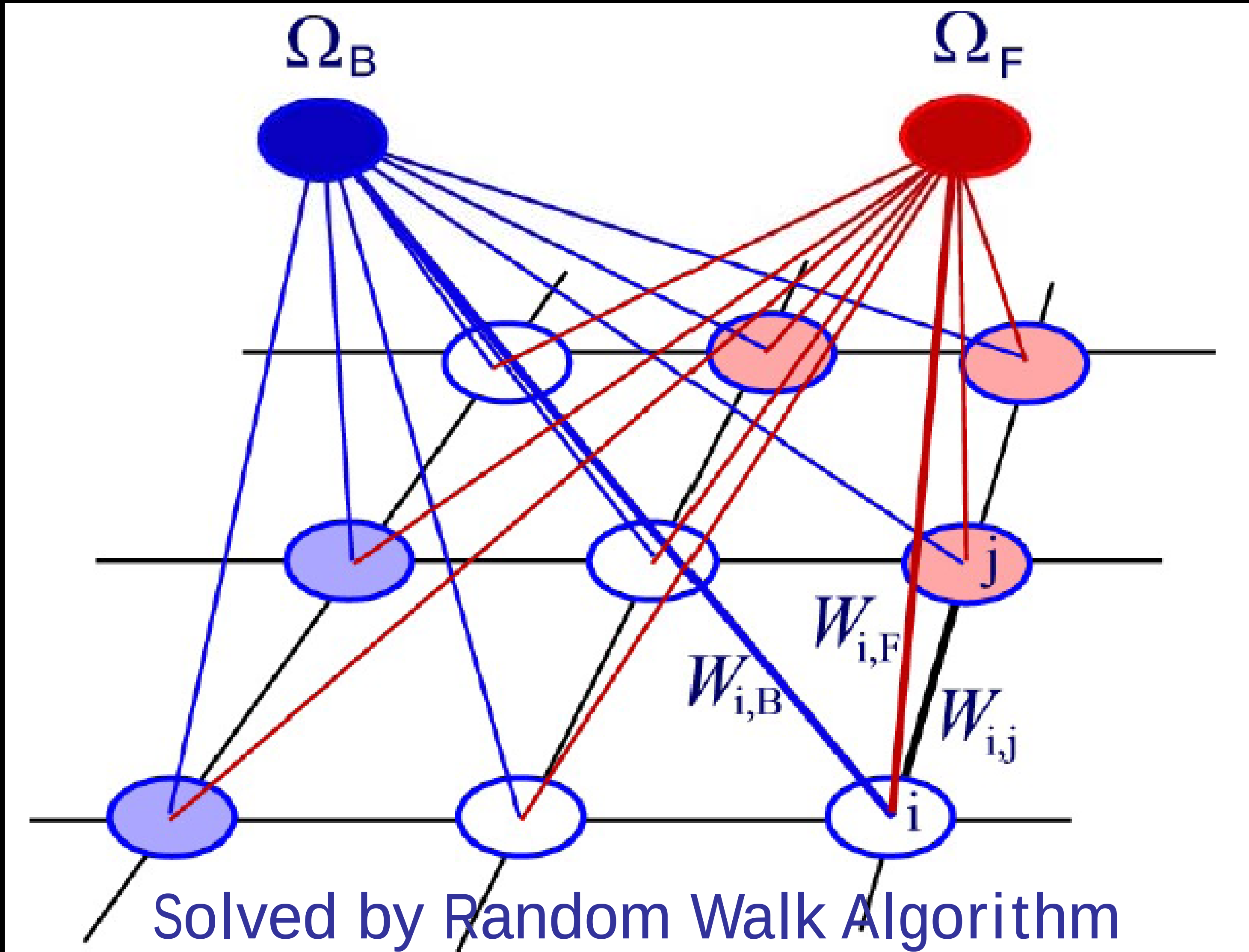


Robust matting

matte

confidence

Matte optimization



Matte optimization

data constraints

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

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

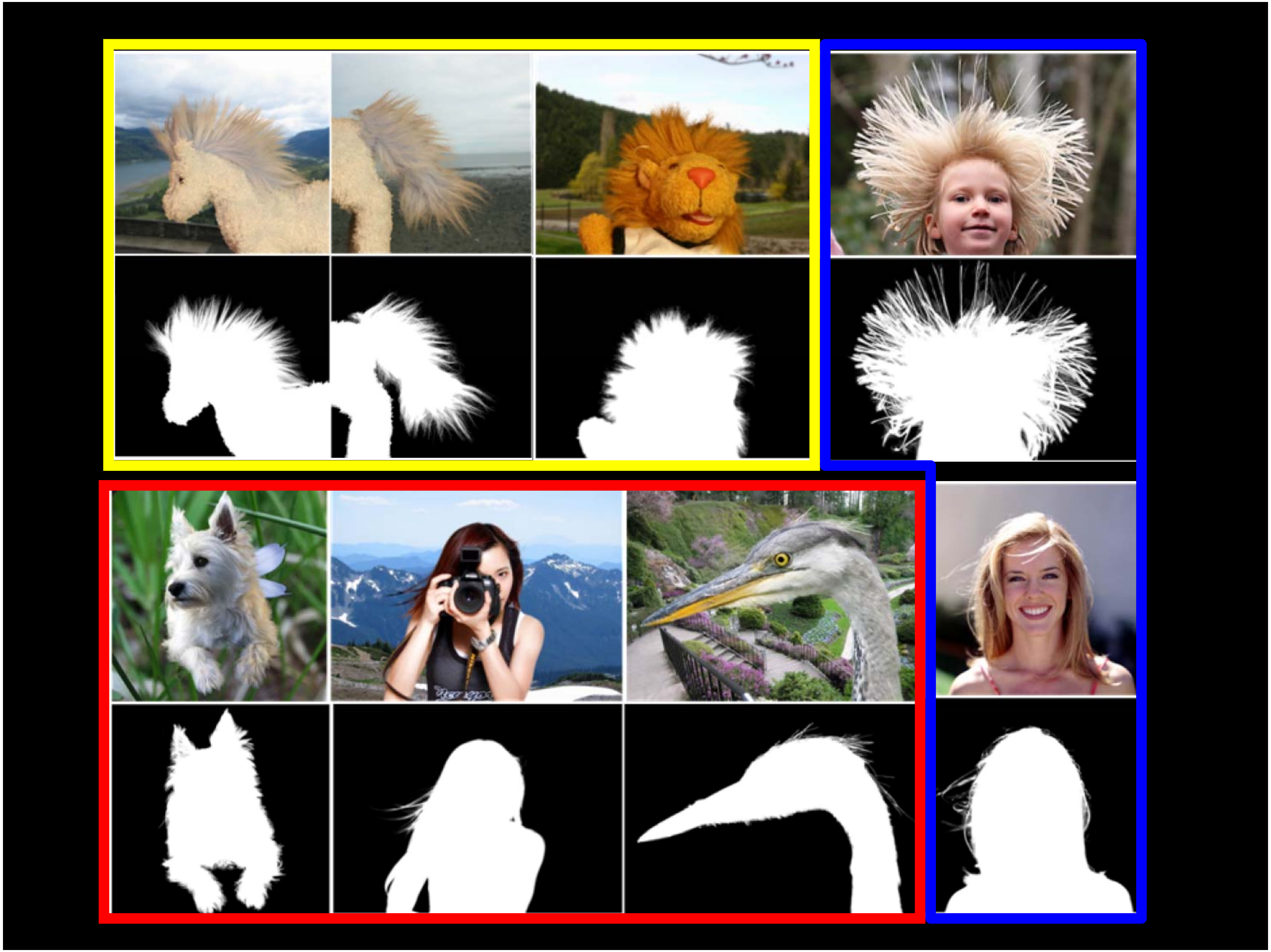
neighborhood constraints

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

Demo (EZ Mask)

Evaluation

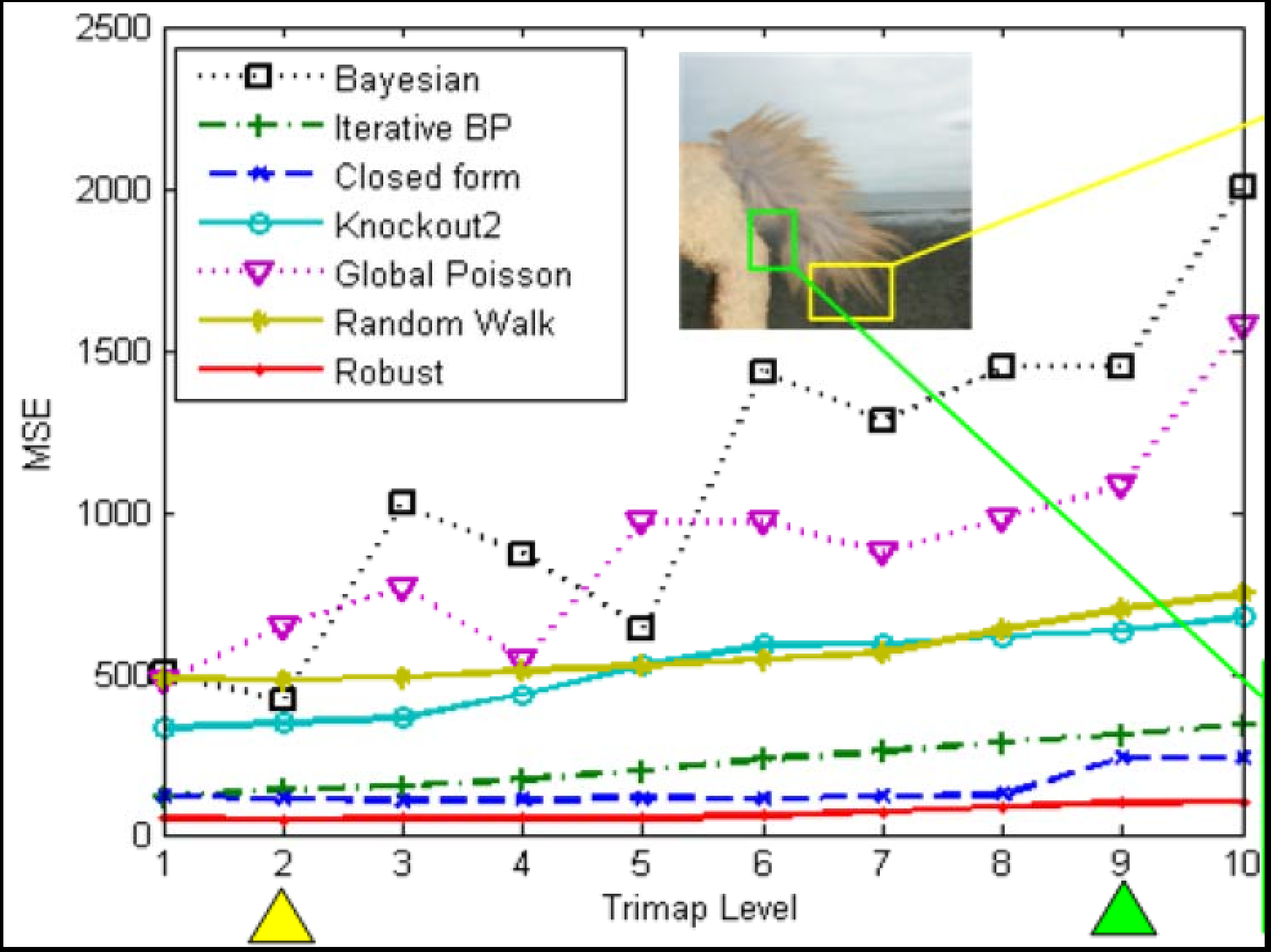
- 8 images collected in 3 different ways
- Each has a “ground truth” matte

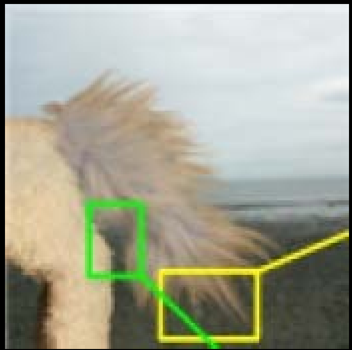


Evaluation

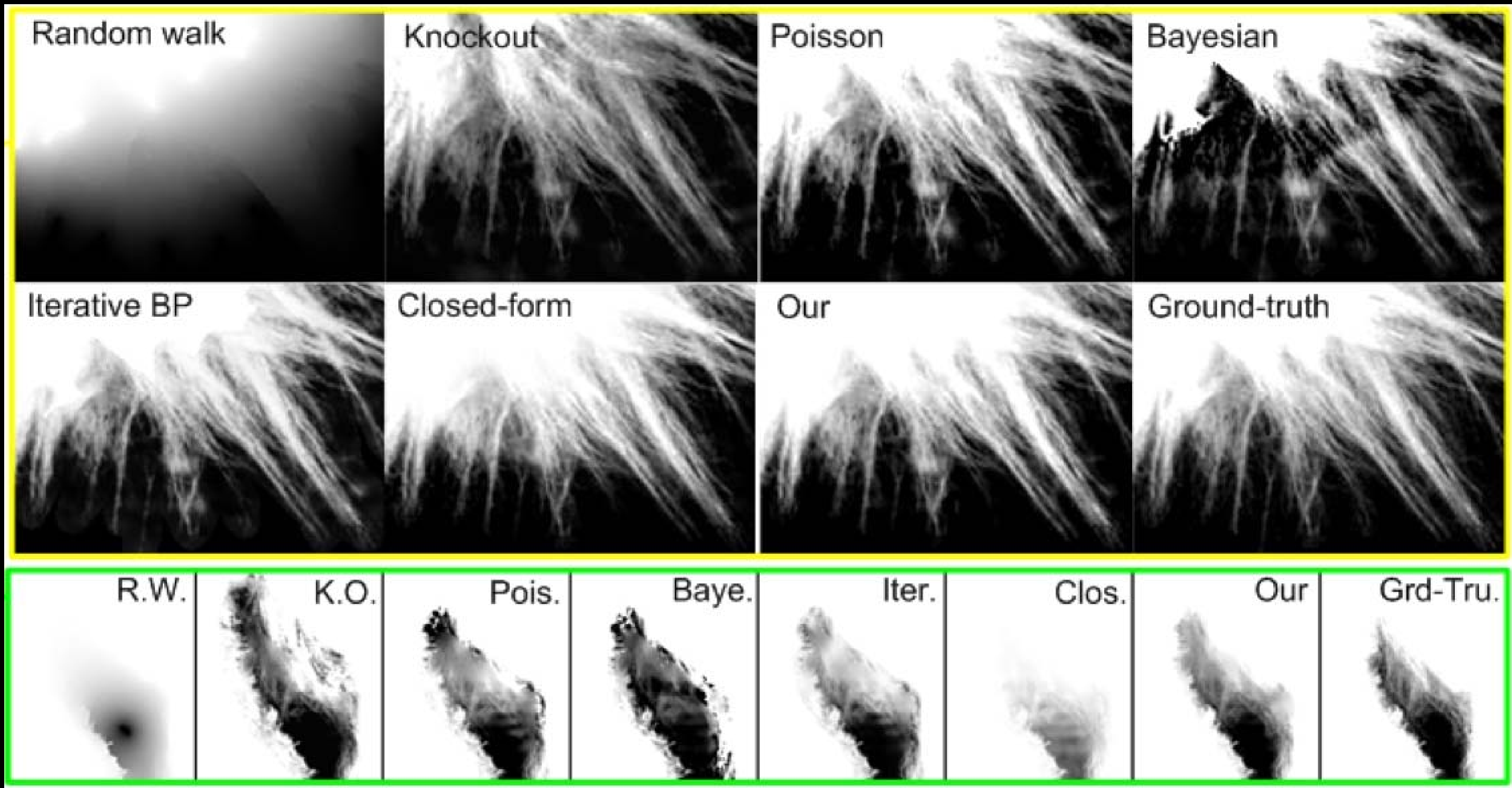
- Mean square error is used as the accuracy metric
- Try 8 trimaps with different accuracy for testing robustness
- 7 methods are tested: Bayesian, Belief propagation, Poisson, Random Walk, KnockOut2, Closed-Form and Robust matting

Quantitative evaluation

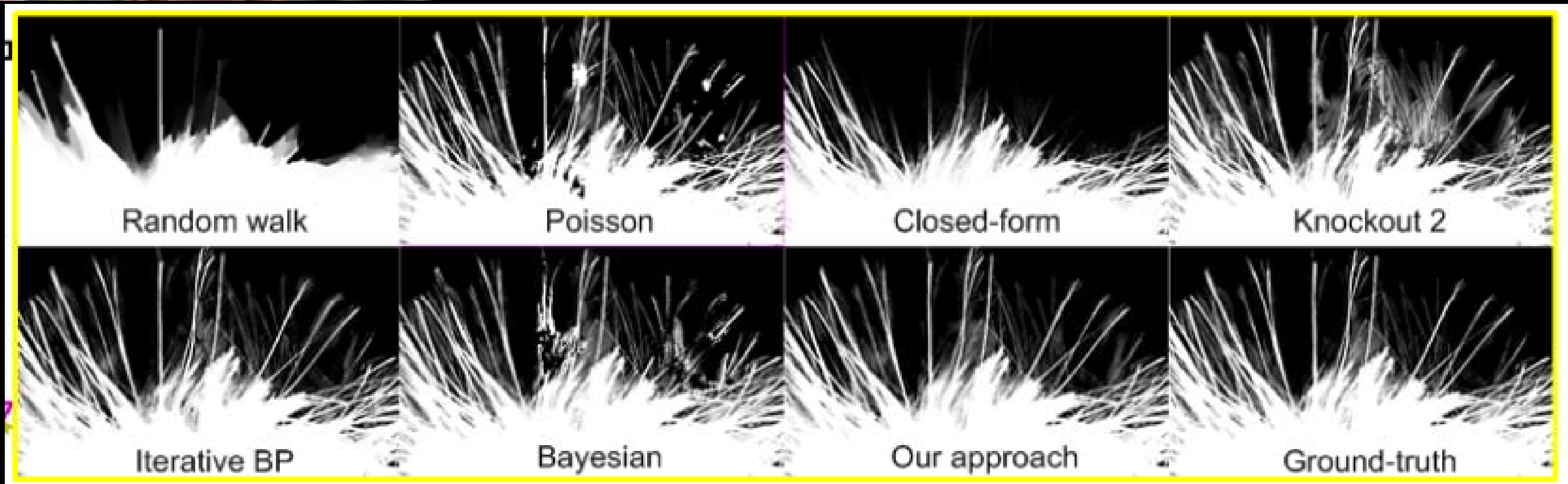


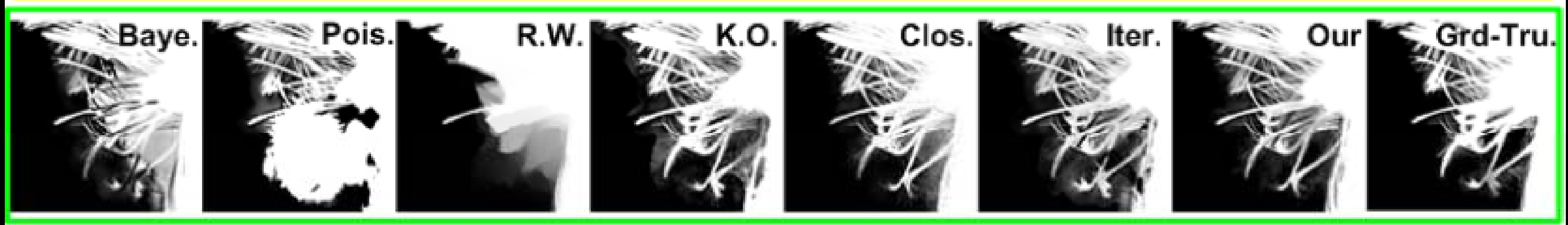


Subjective evaluation



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)

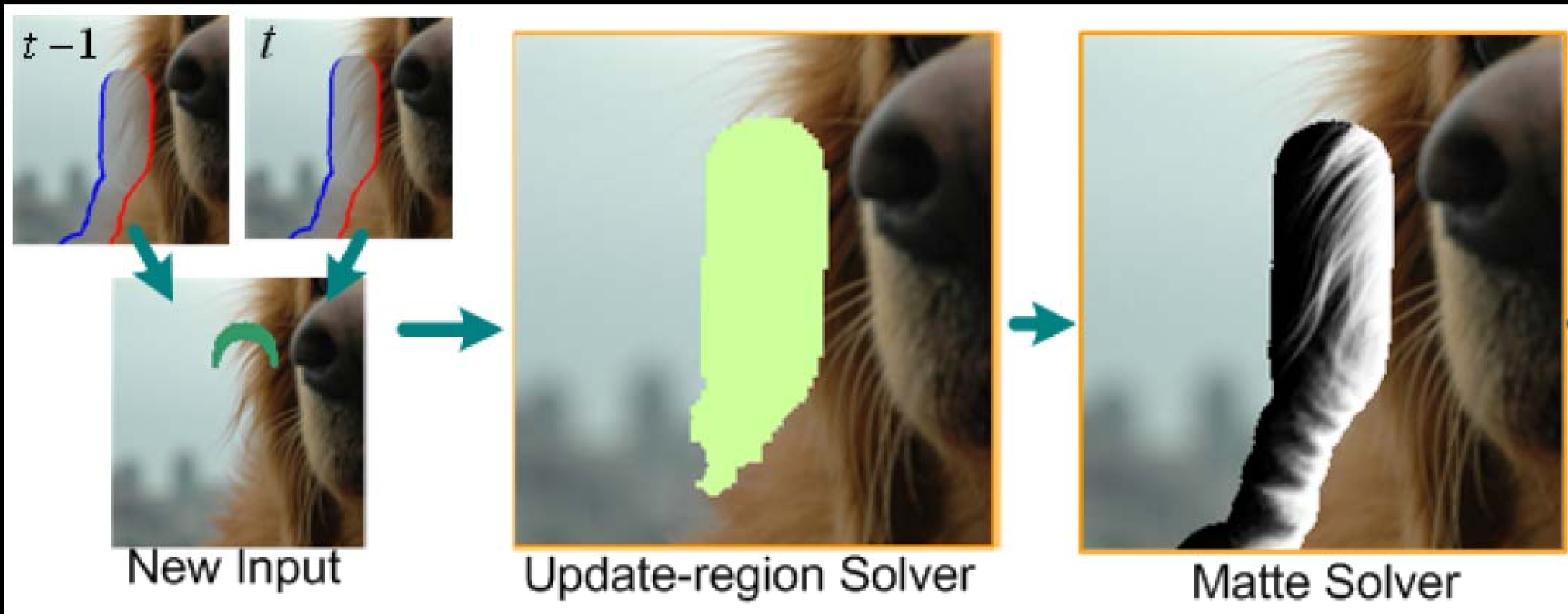
- http://www.alphamatting.com/

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

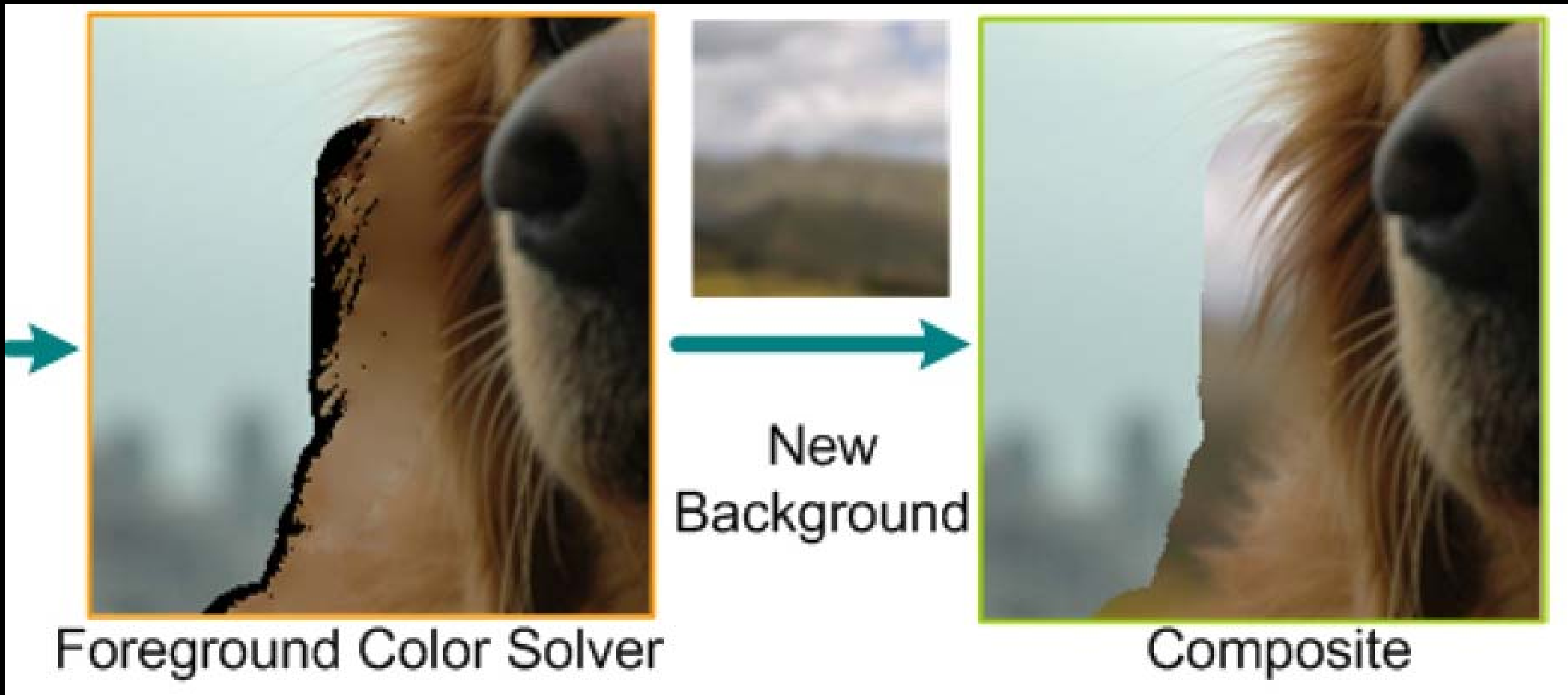
Soft scissor

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

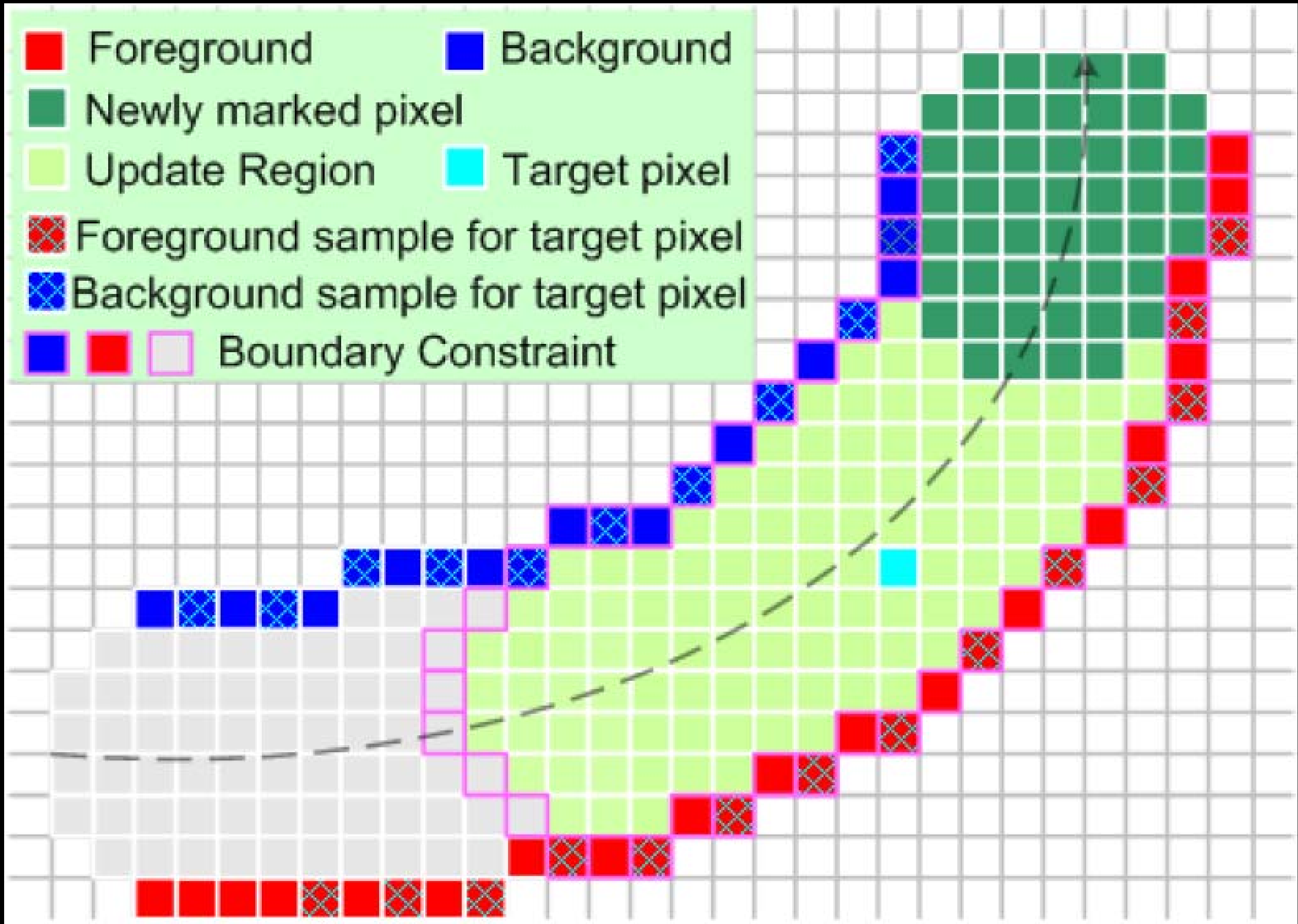
Flowchart



Flowchart



Soft scissor



Demo (Power Mask)

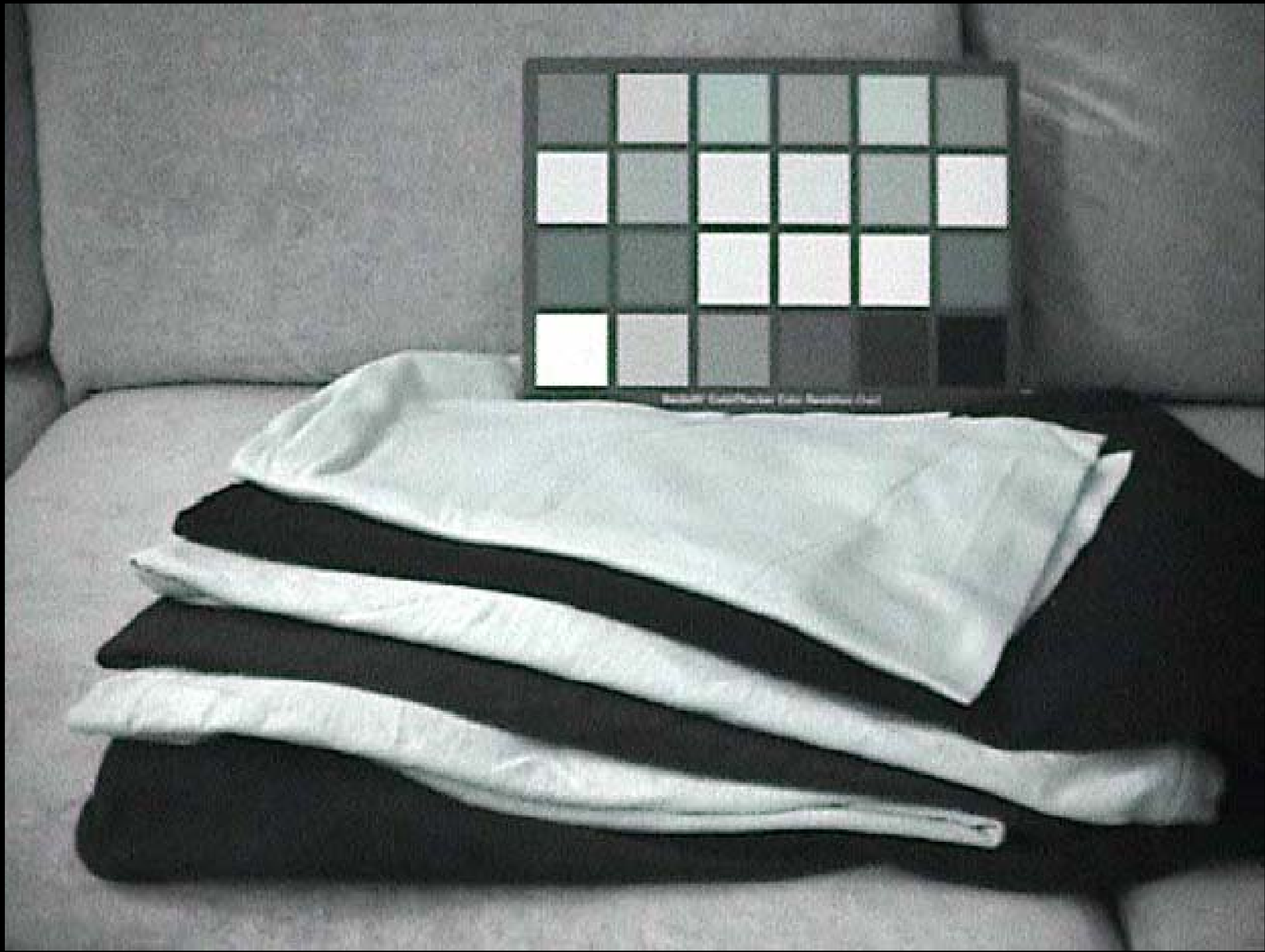
Outline

- 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

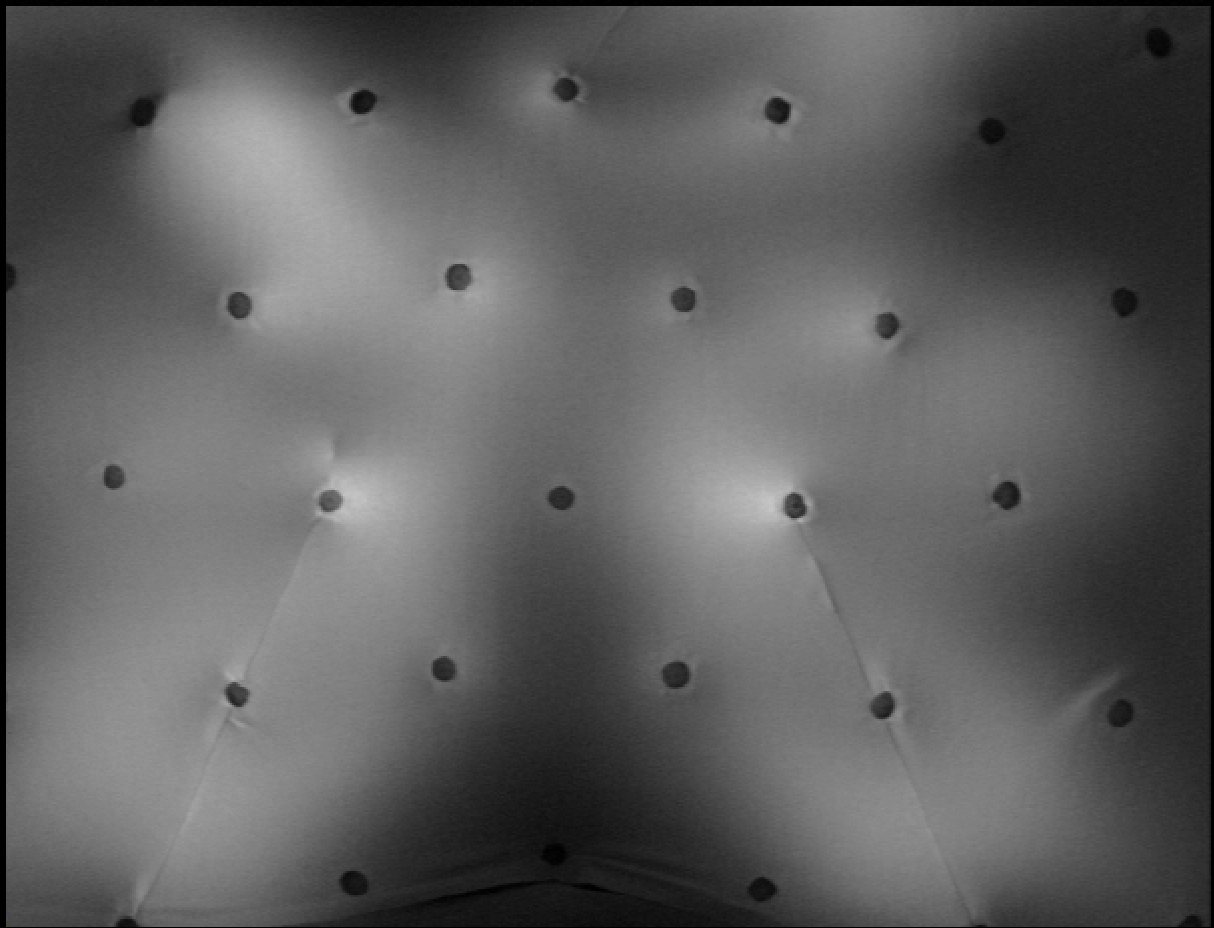
- Invisible lights
  - Polarized lights
  - Infrared
- Thermo-key
- Depth Keying (ZCam)
- Flash matting

Invisible lights (Infared)



Invisible lights (Infared)

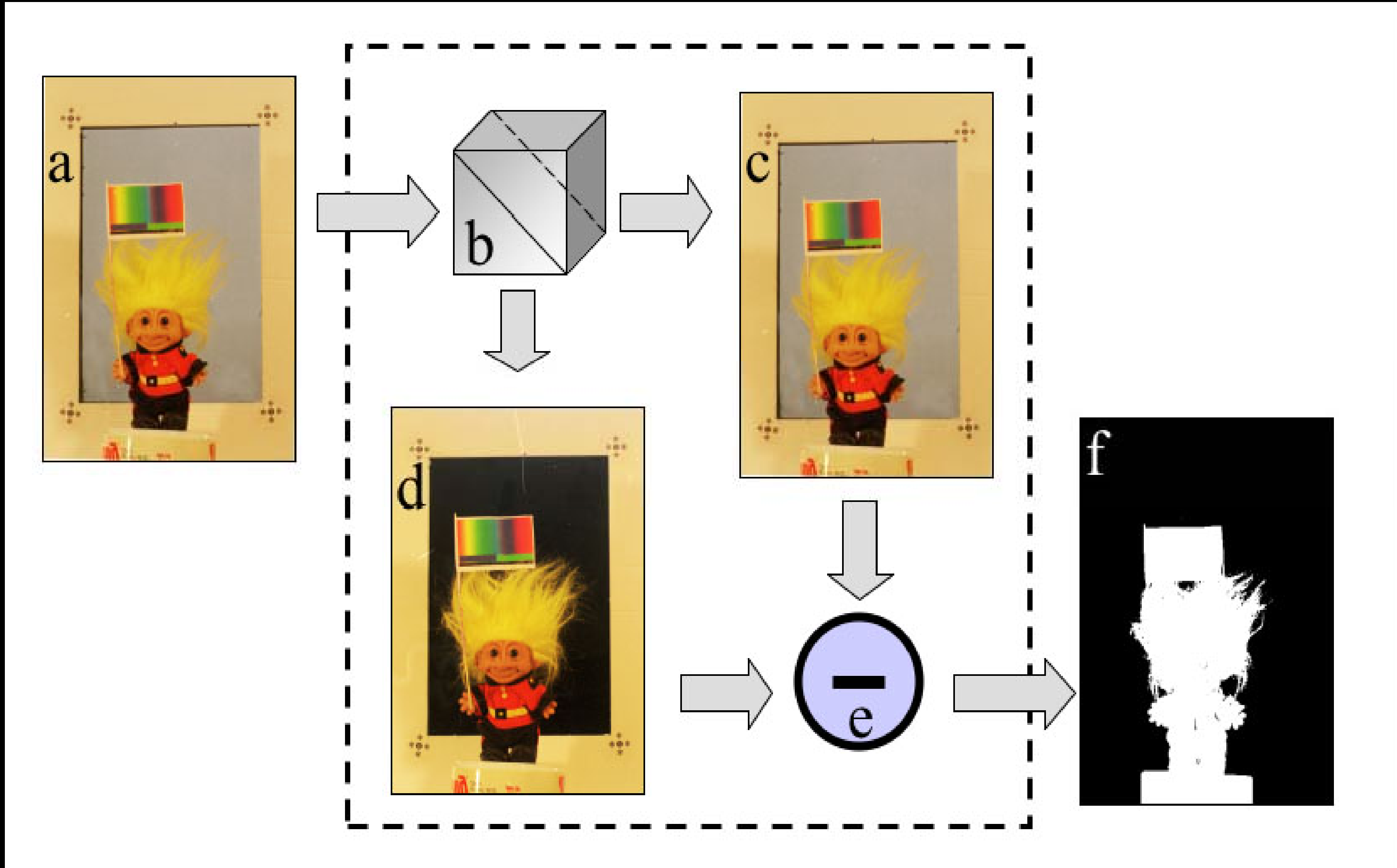
Invisible lights (Infared)



Invisible lights (Infared)

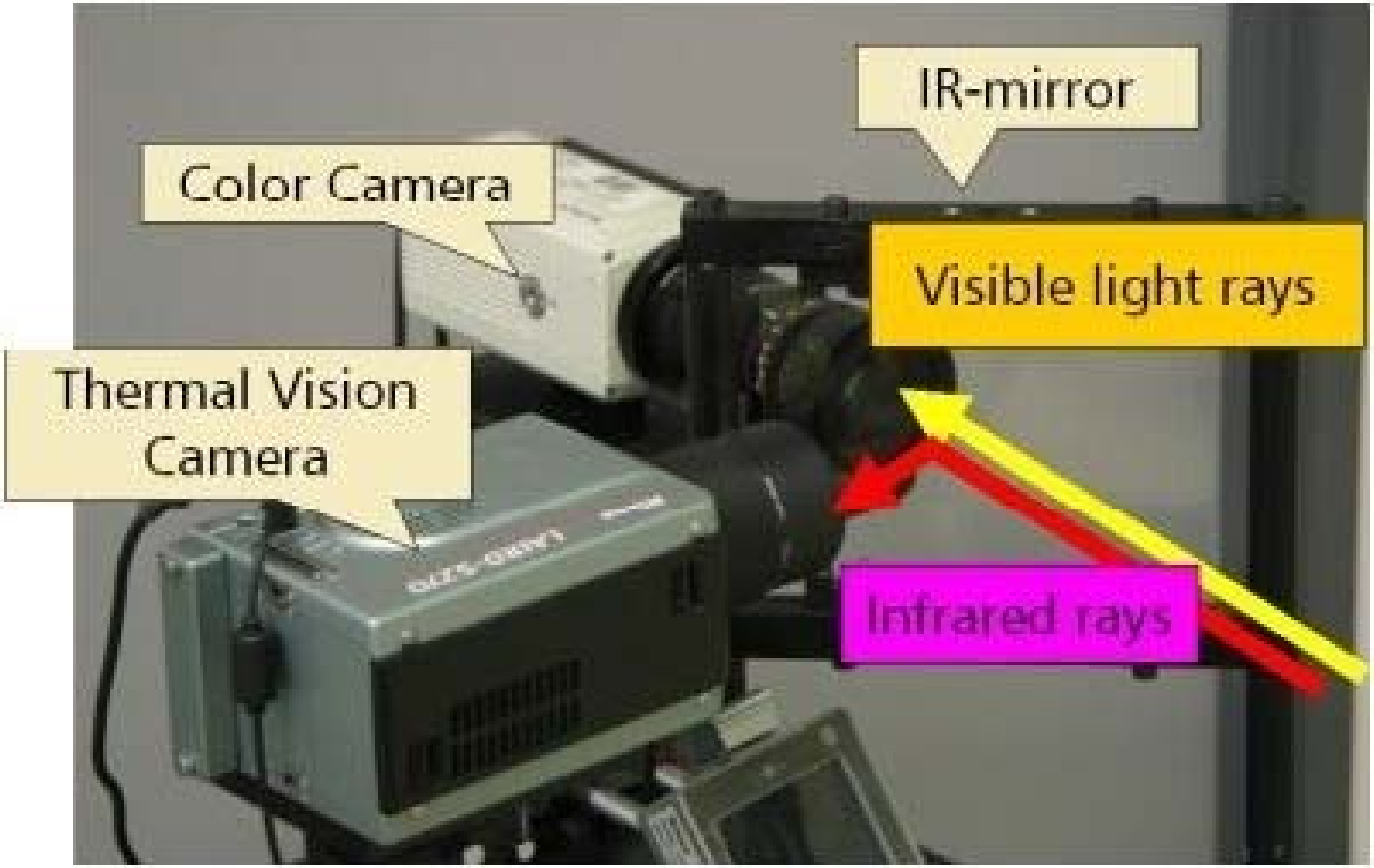
Invisible lights (Infared)

Invisible lights (Infared)

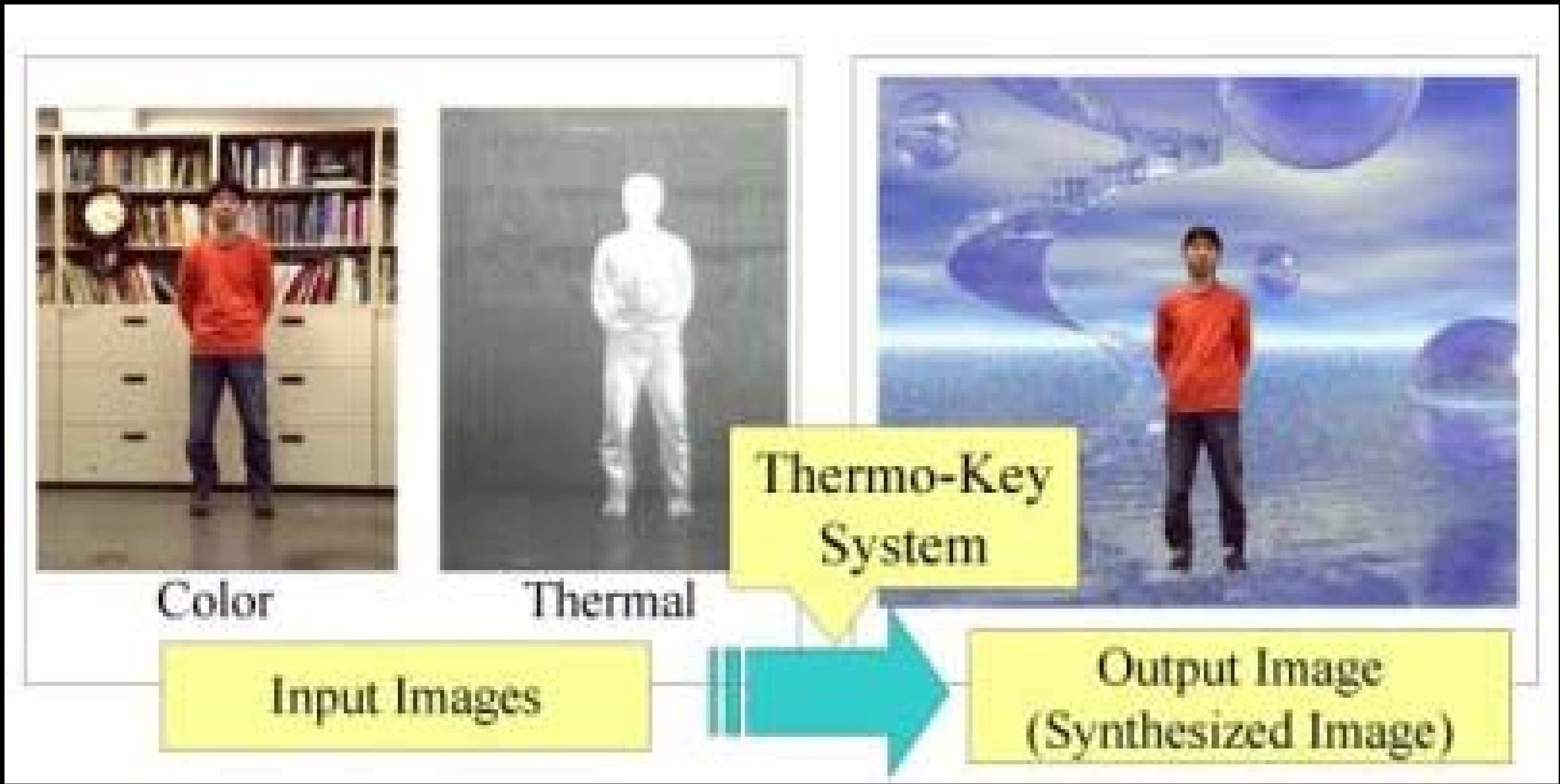


Invisible lights (Polarized)

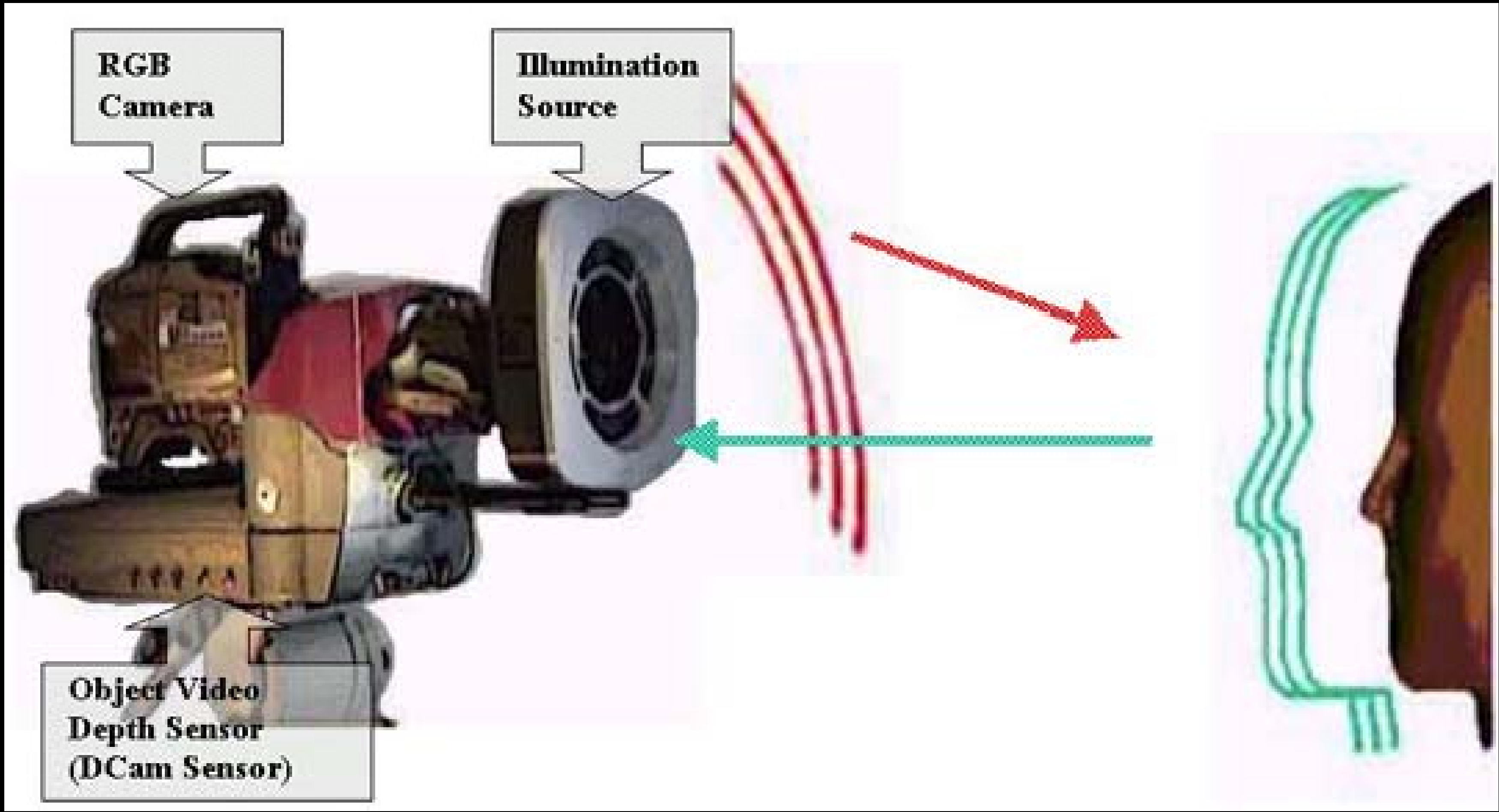
Invisible lights (Polarized)


IR-mirror
Color Camera
Visible light rays
Thermal Vision Camera
Infrared rays

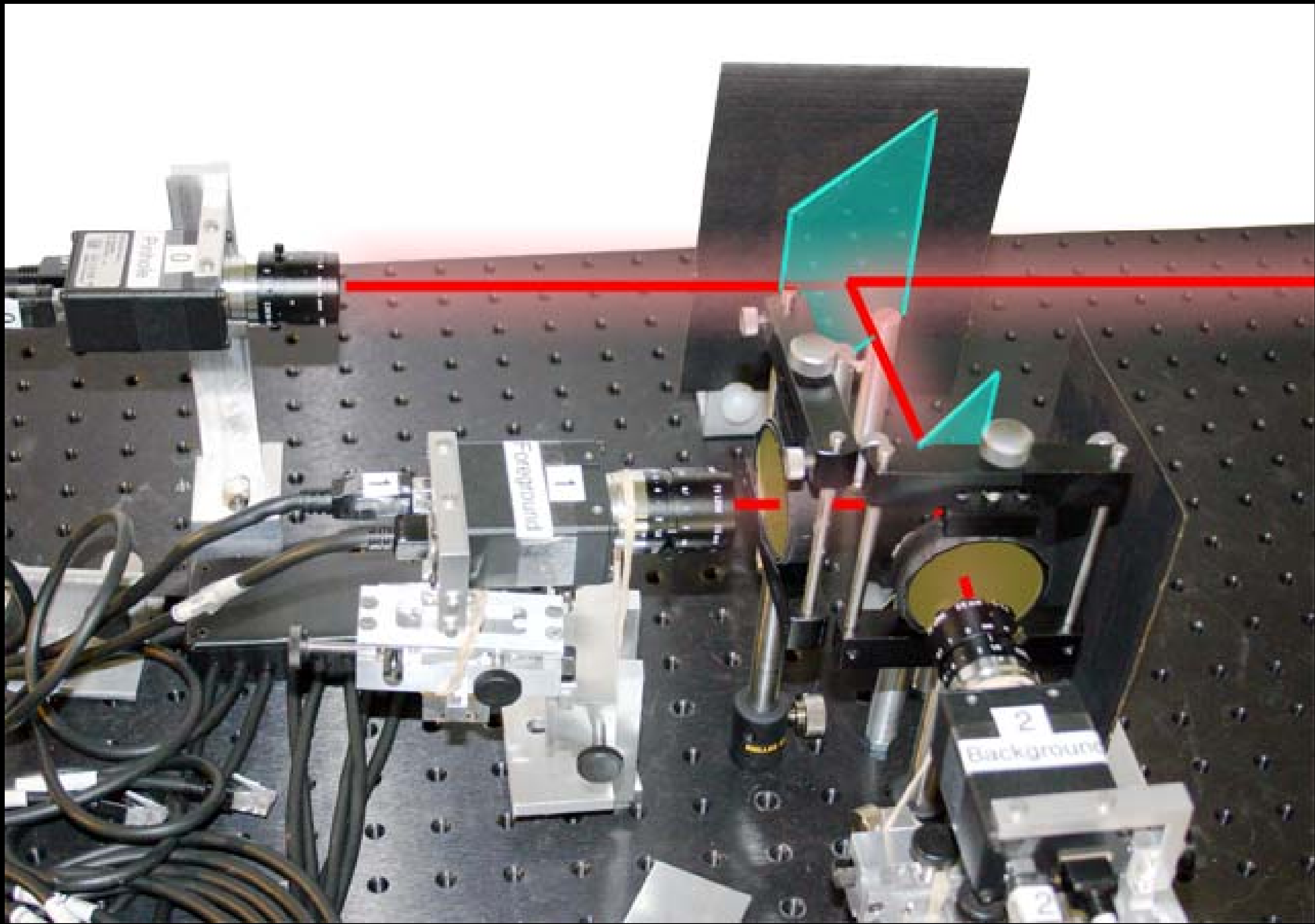
Thermo-Key


Color
Thermal
Thermo-Key System
Input Images
Output Image (Synthesized Image)

Thermo-Key

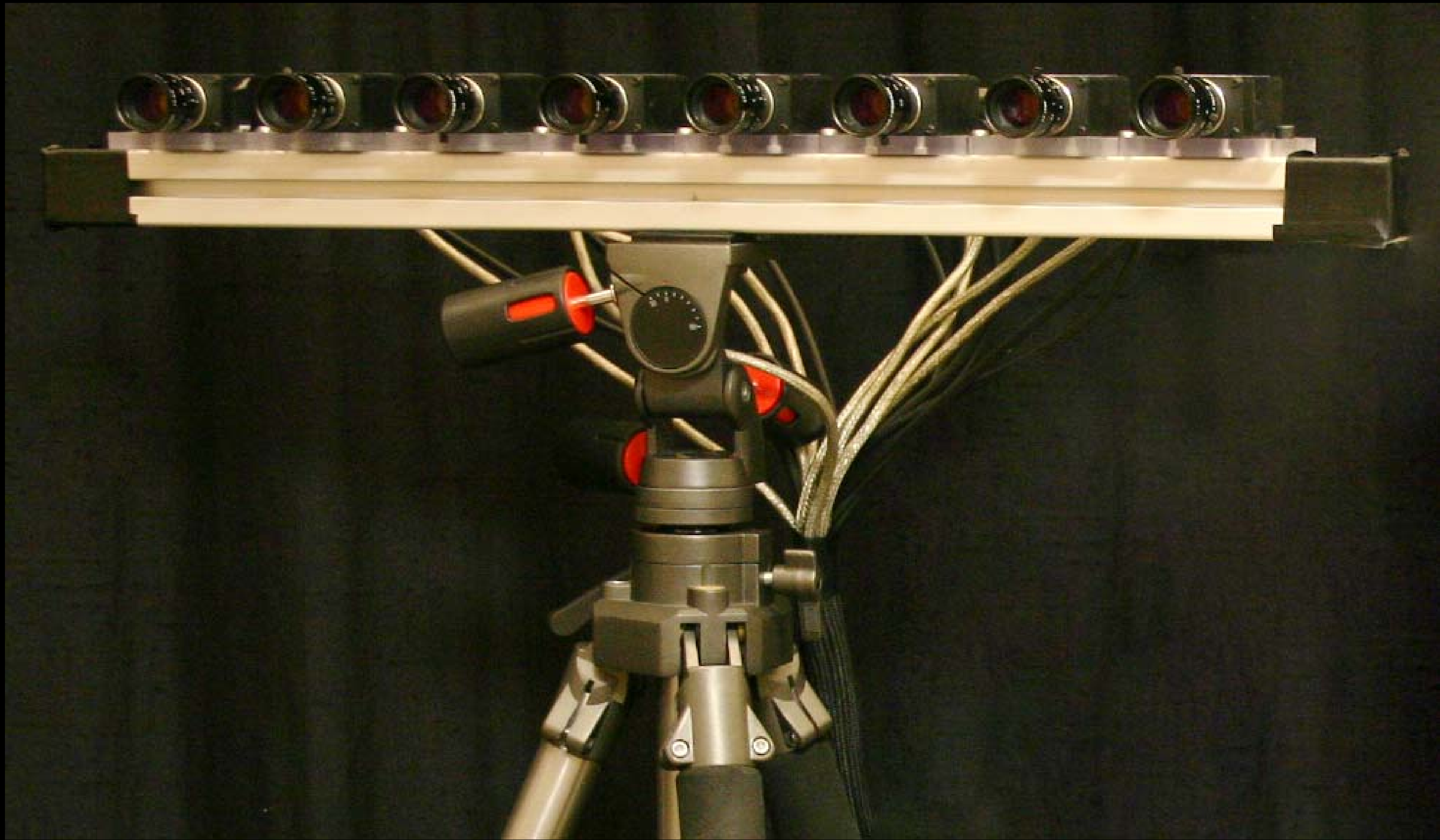

RGB
Camera
Illumination
Source
Object Video
Depth Sensor
(DCam Sensor)

ZCam



Defocus matting

video



video

Matting with camera arrays

flash

no flash

matte

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.

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

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

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

Flash matting

Foreground flash matting

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

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

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

flash

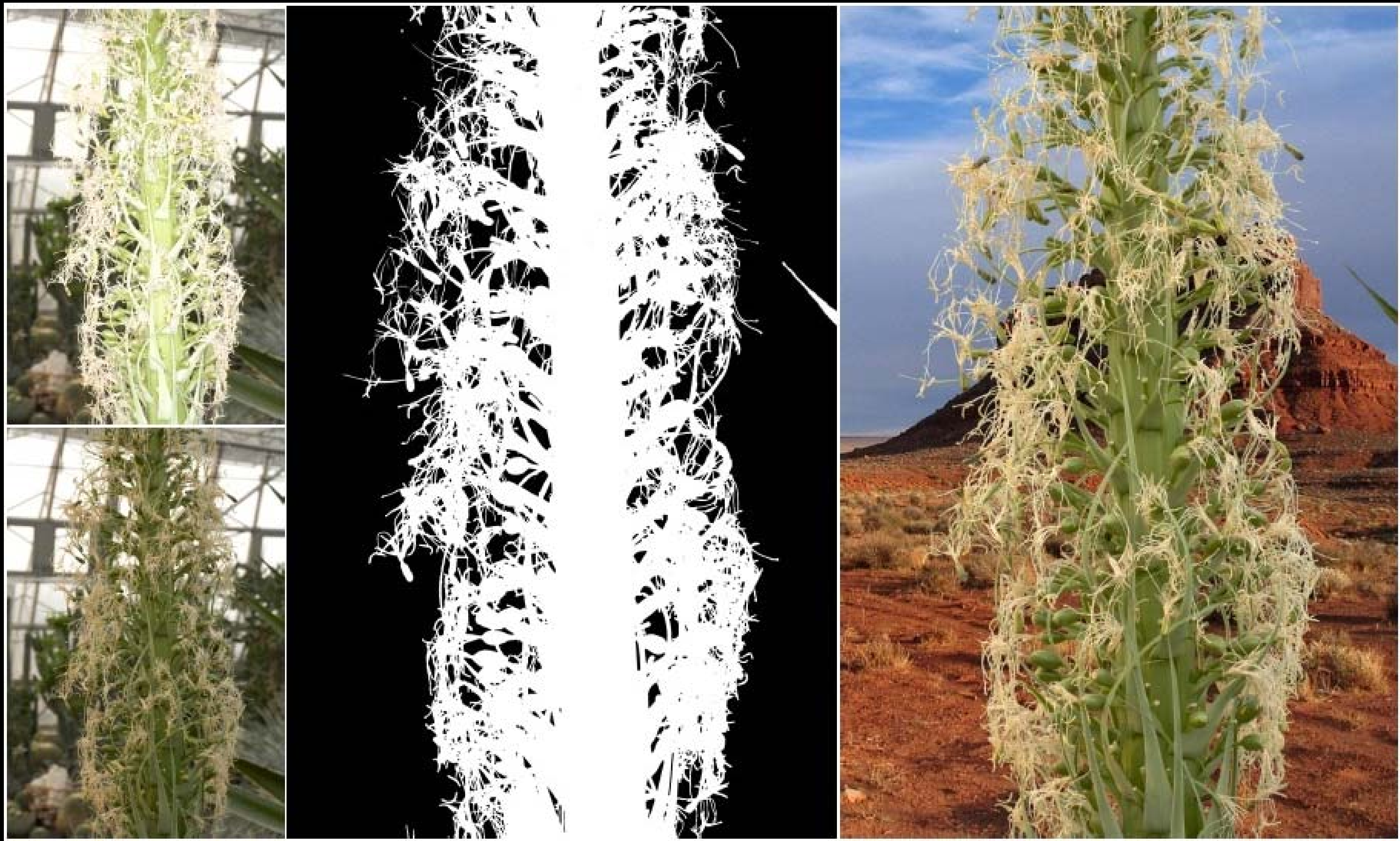
no flash

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

Thanks for your attention!

Shadow matting and composting

source scene

target background

blue screen image

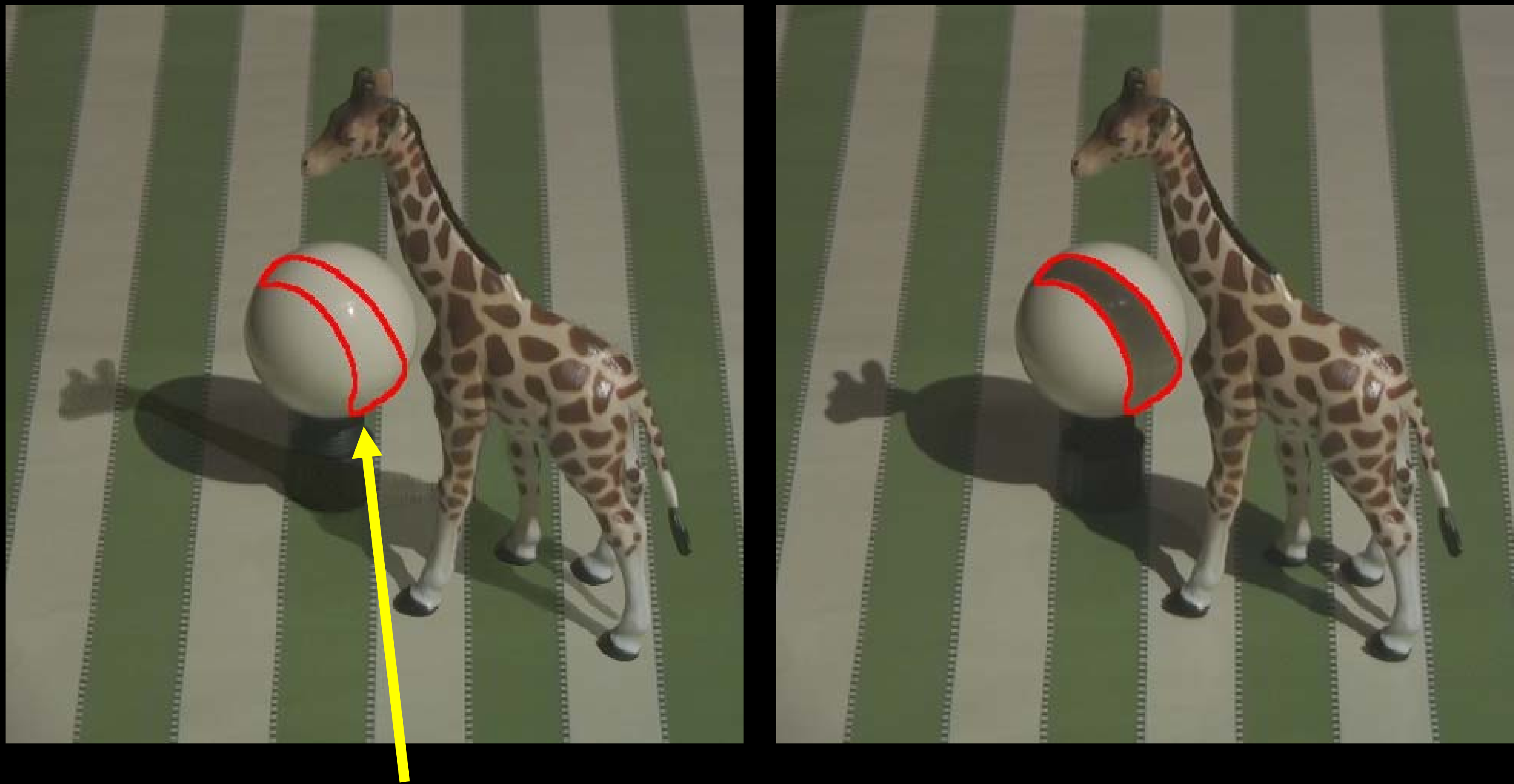
target background

blue screen composite **target background**

blue screen composite

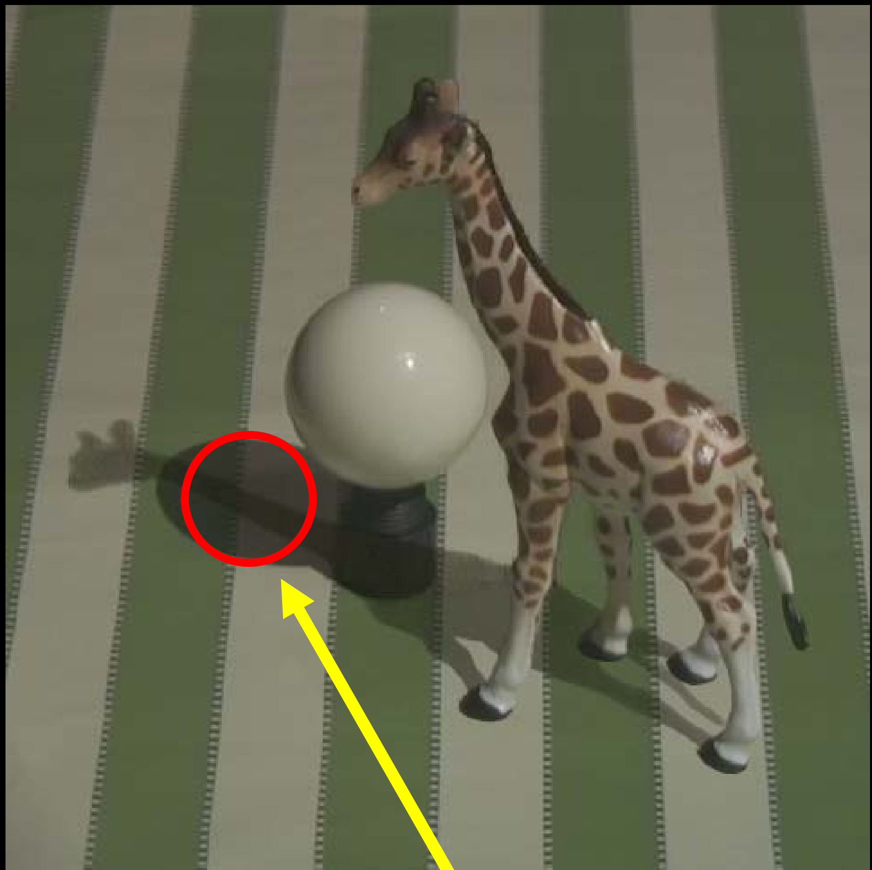
photograph

blue screen composite **photograph**

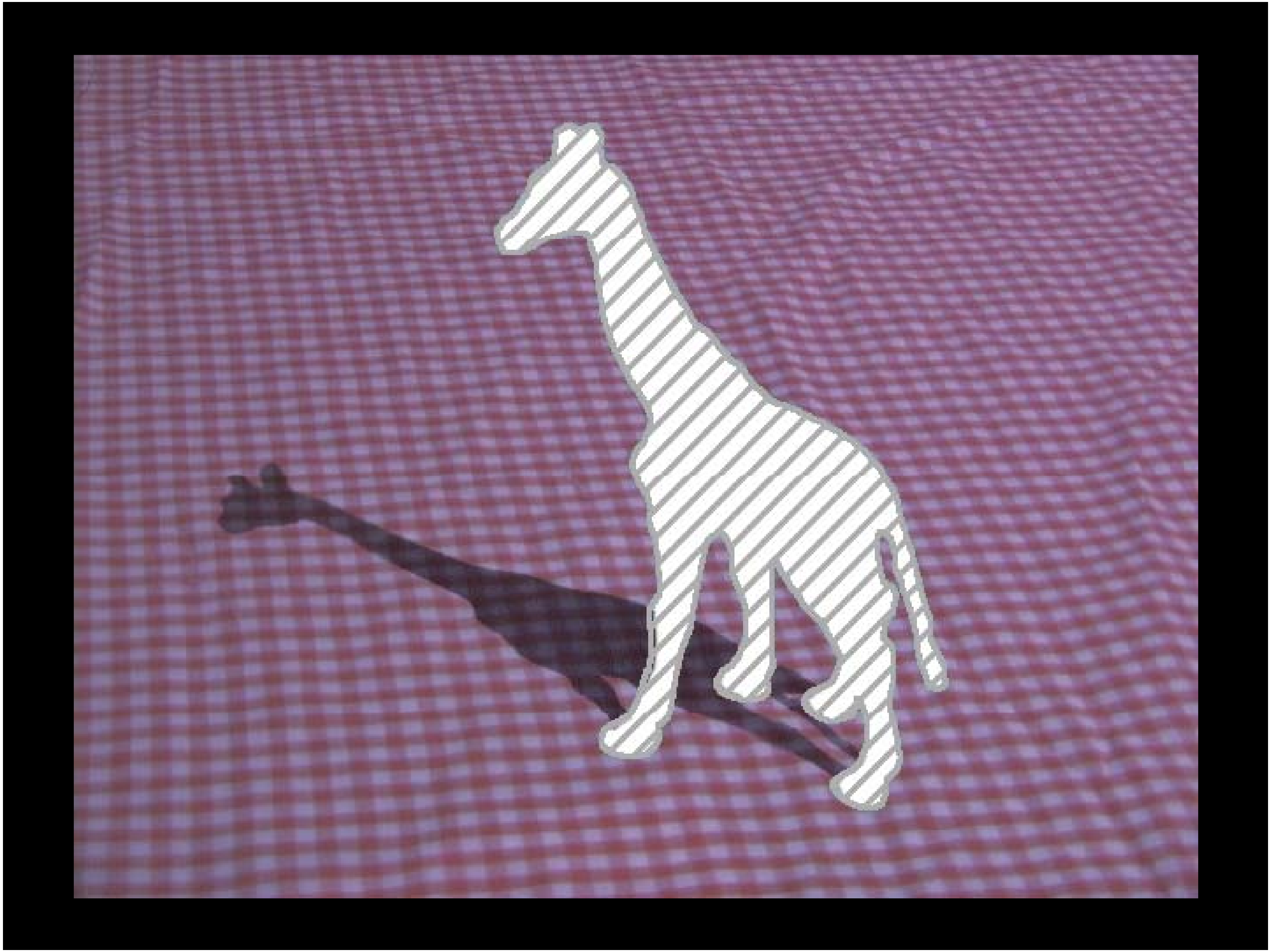


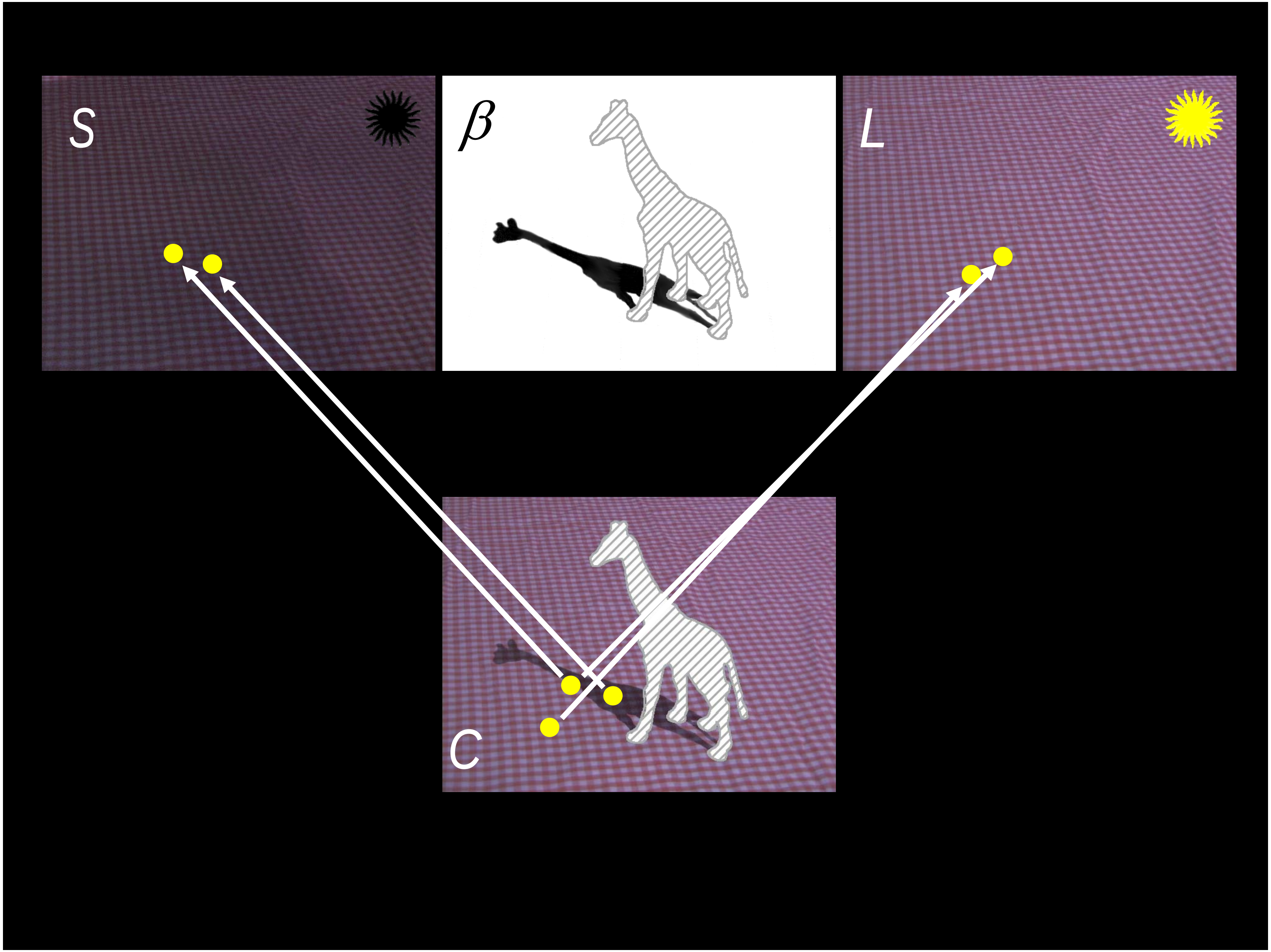
Geometric errors

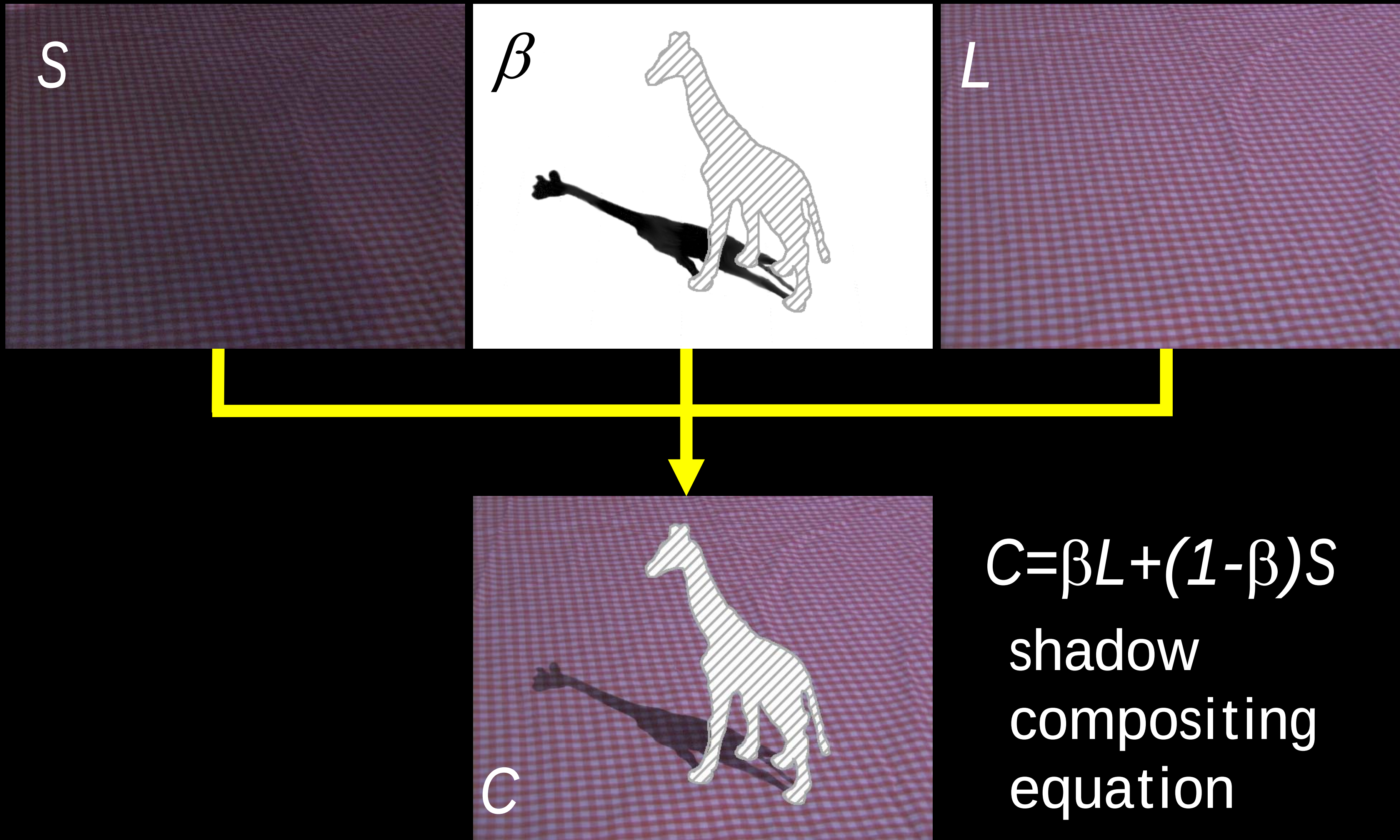
blue screen composite **photograph**



Photometric errors



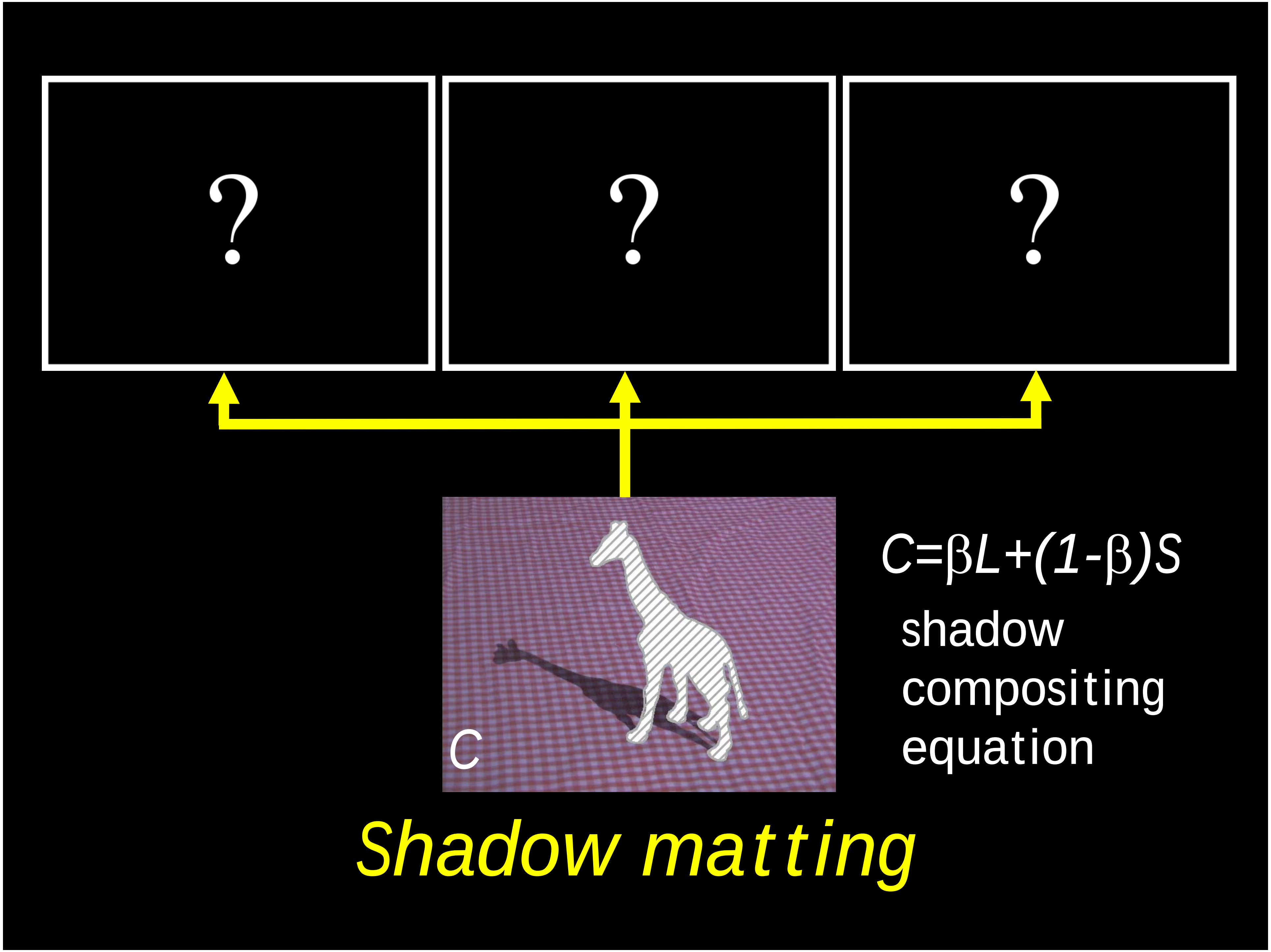

S
β
L
C

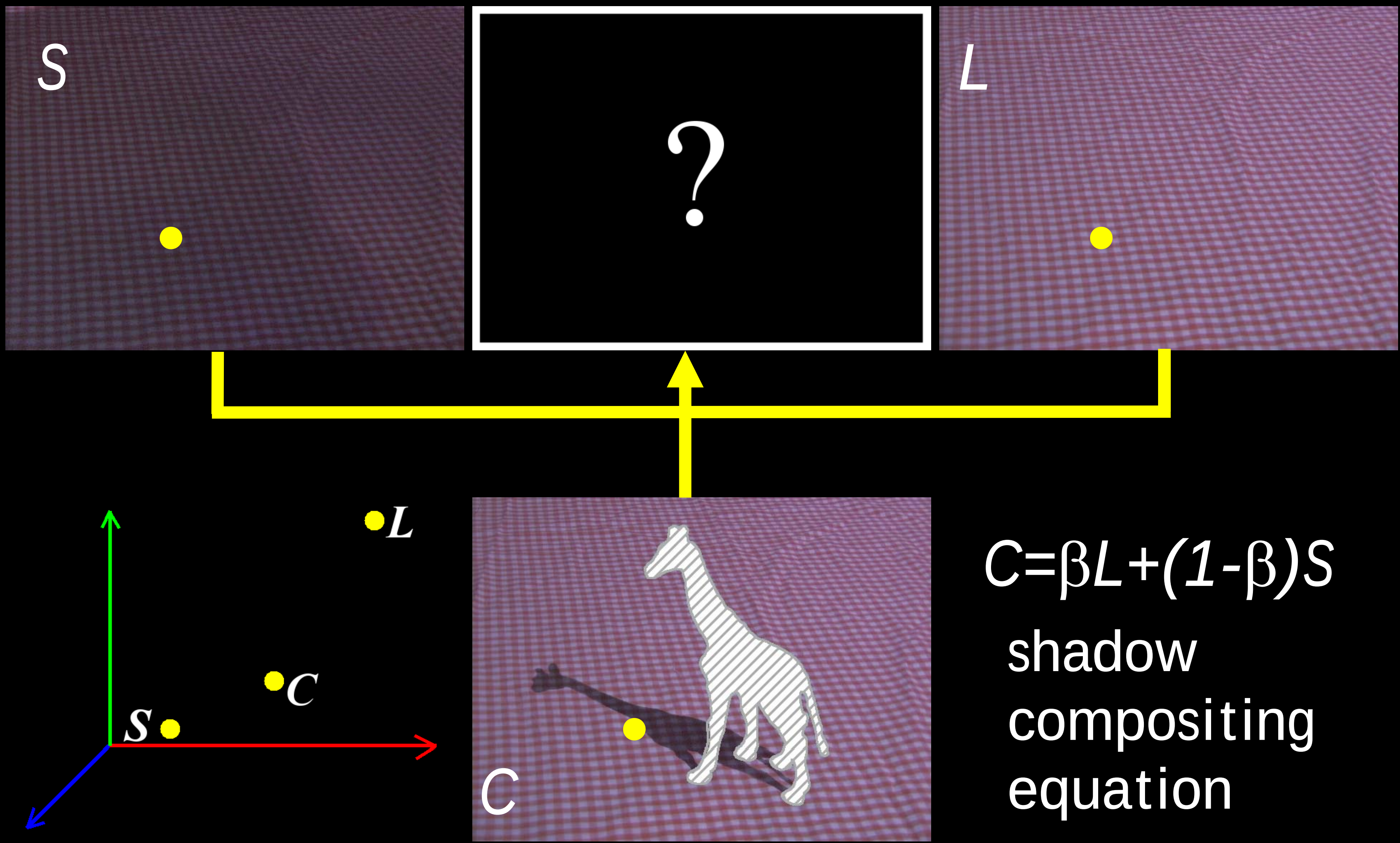


$C = \beta L + (1-\beta) S$

shadow compositing equation

Shadow compositing equation

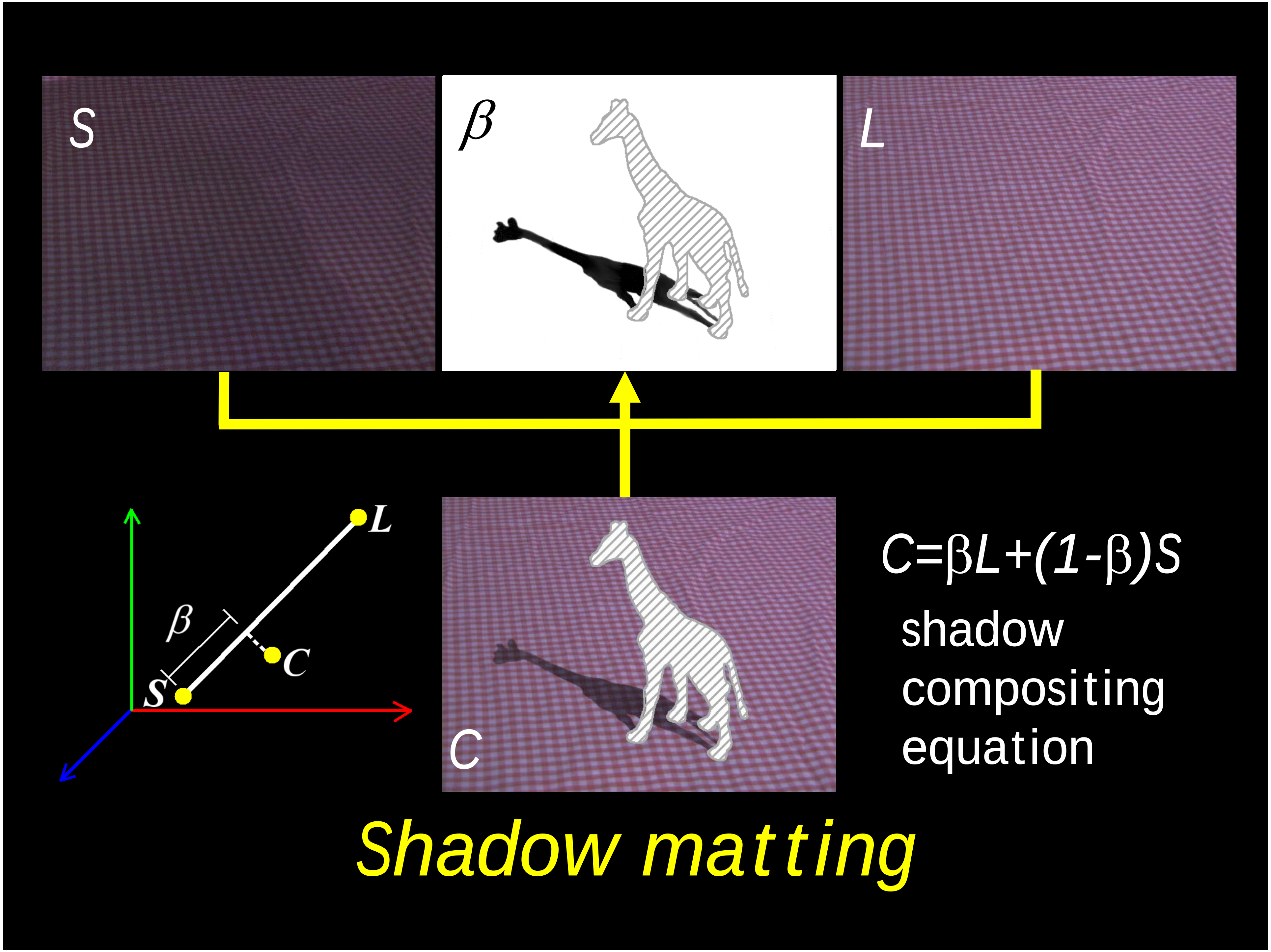

?
?
?
C
C=βL+(1-β)S
shadow compositing equation
Shadow matting

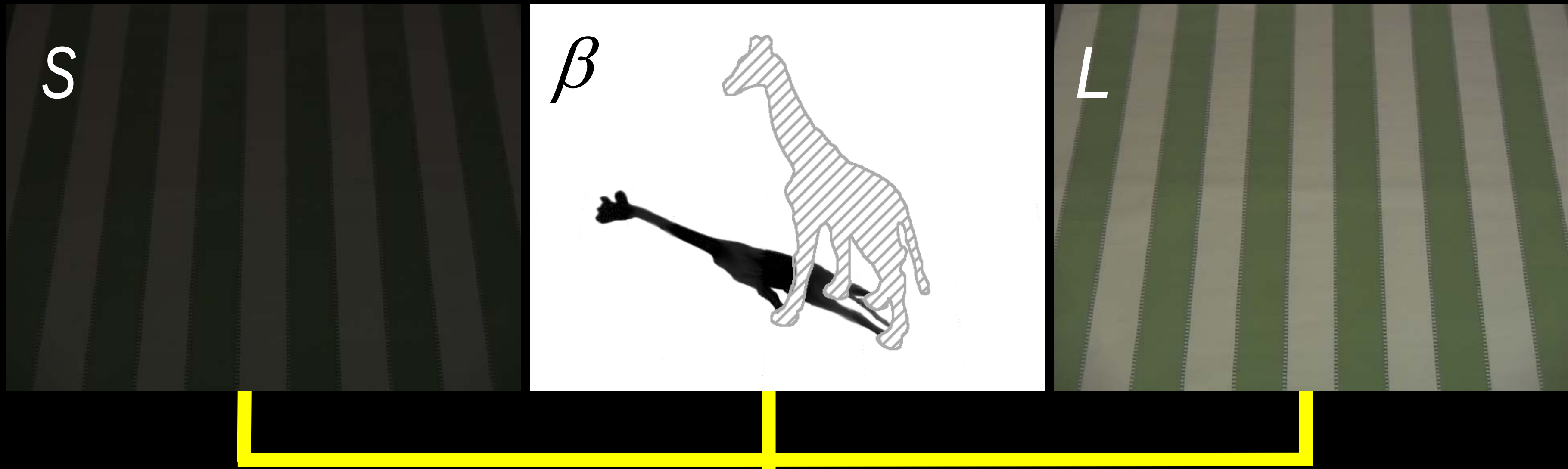


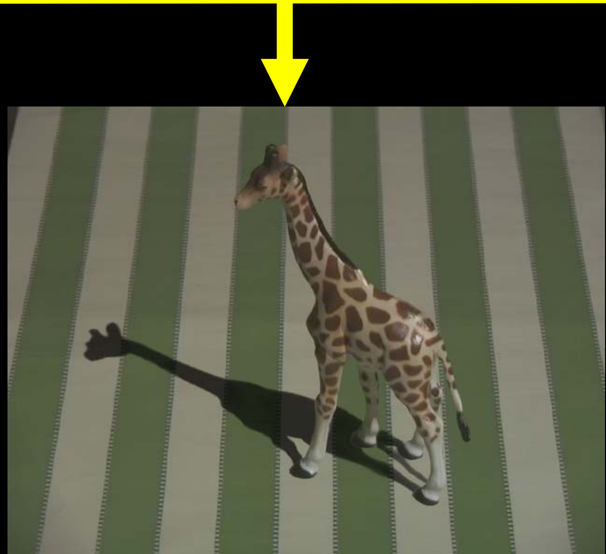
$C=\beta L+(1-\beta)S$

shadow compositing equation

Shadow matting


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

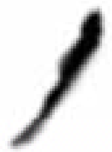


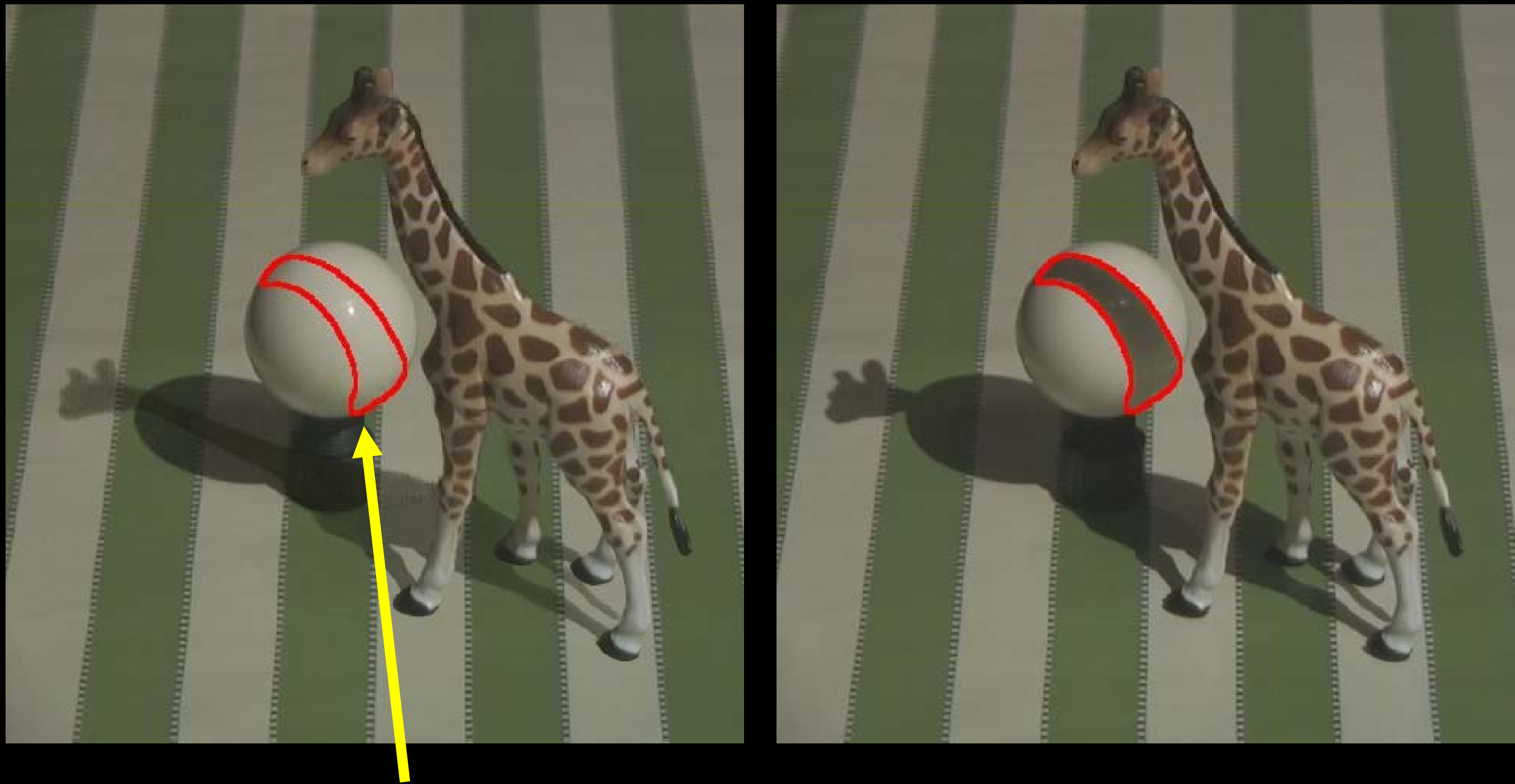


$C=\beta L+(1-\beta)S$

shadow compositing equation

Shadow compositing

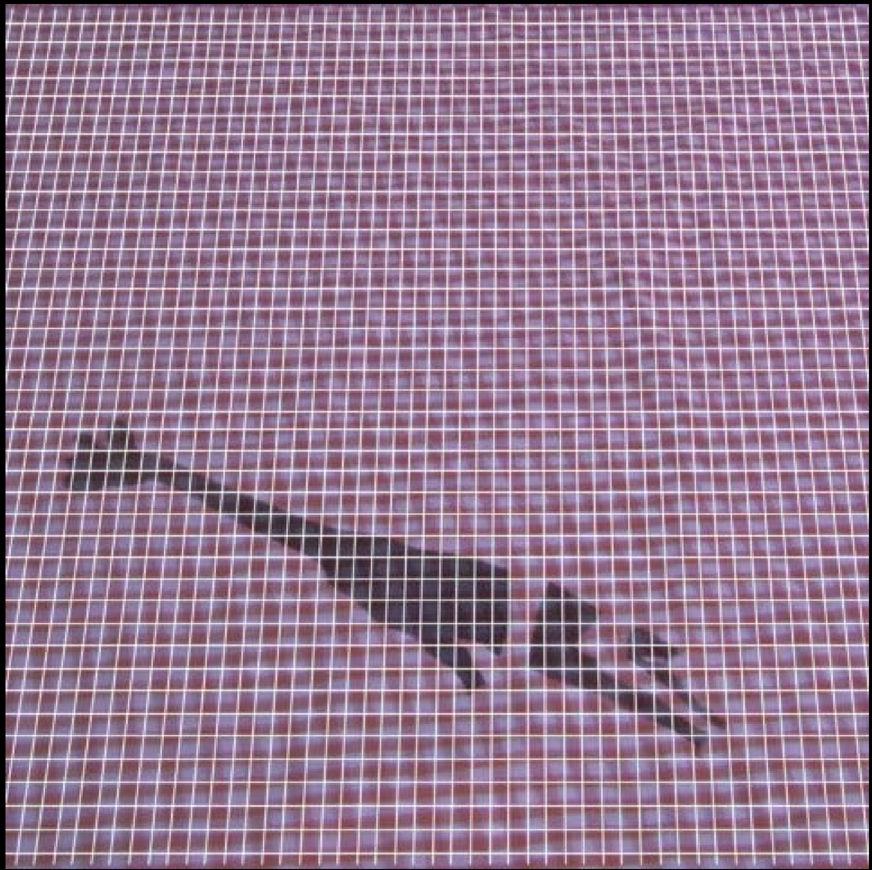




Geometric errors

source scene **target background**

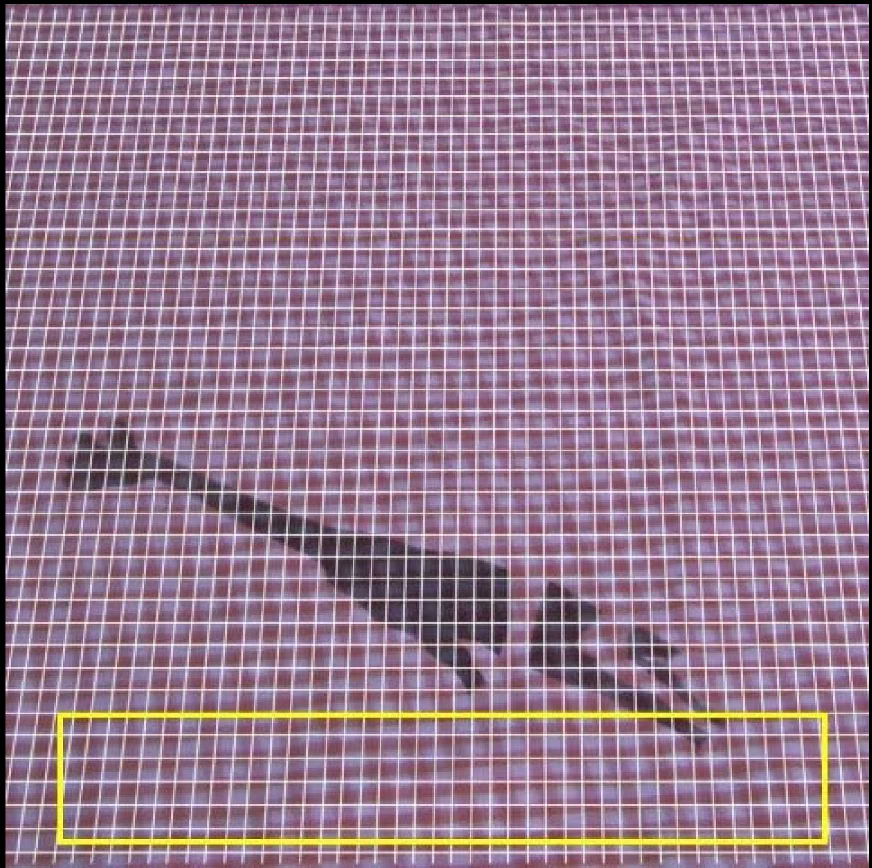
source scene



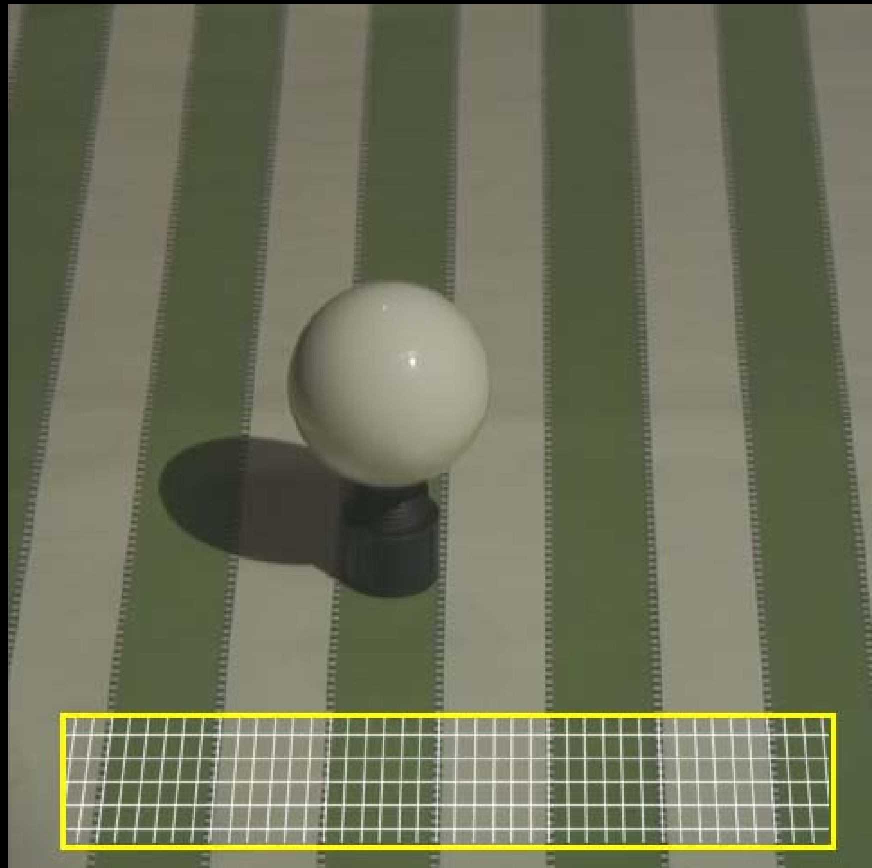
target background

Requirement #1

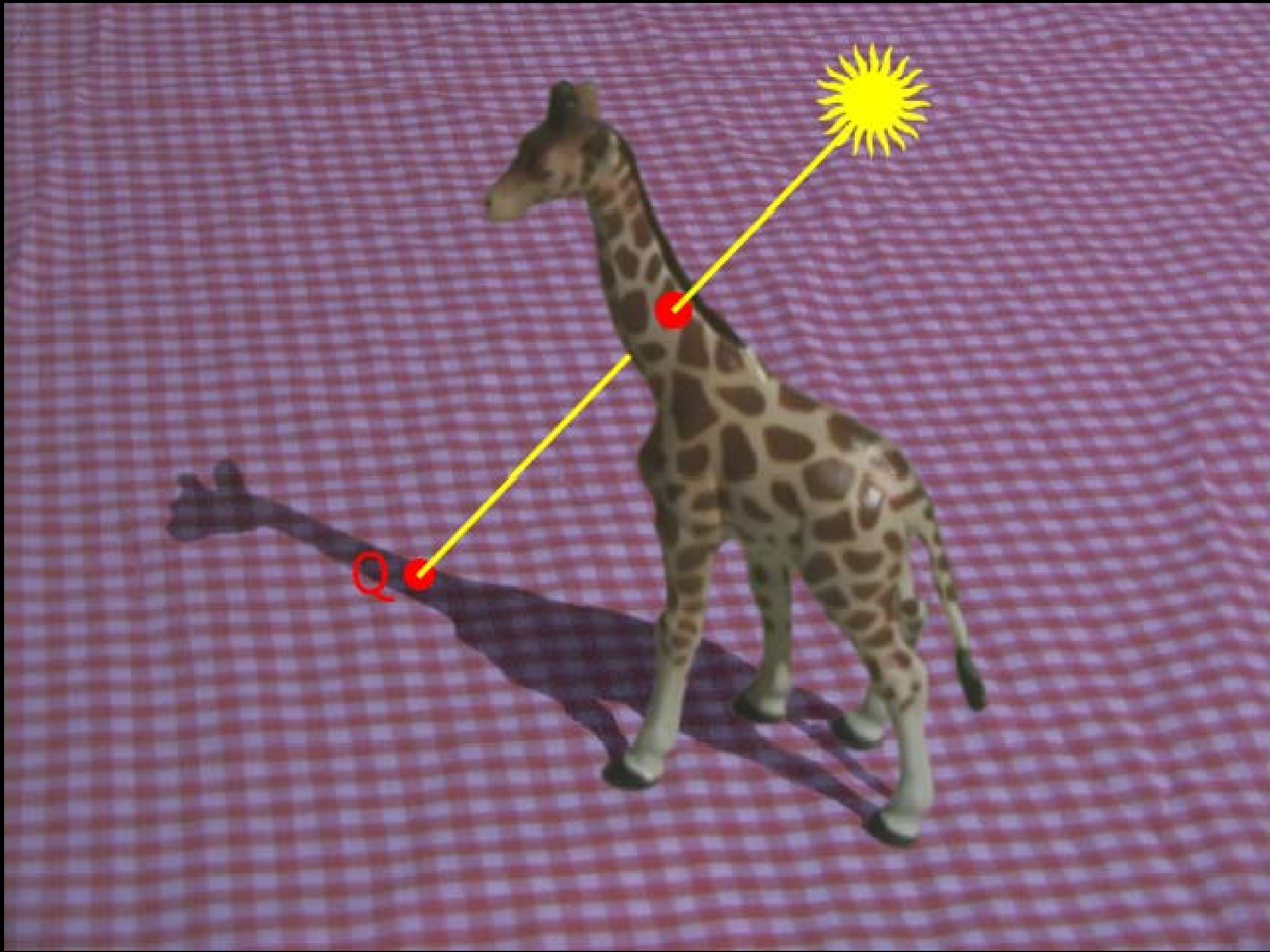
source scene

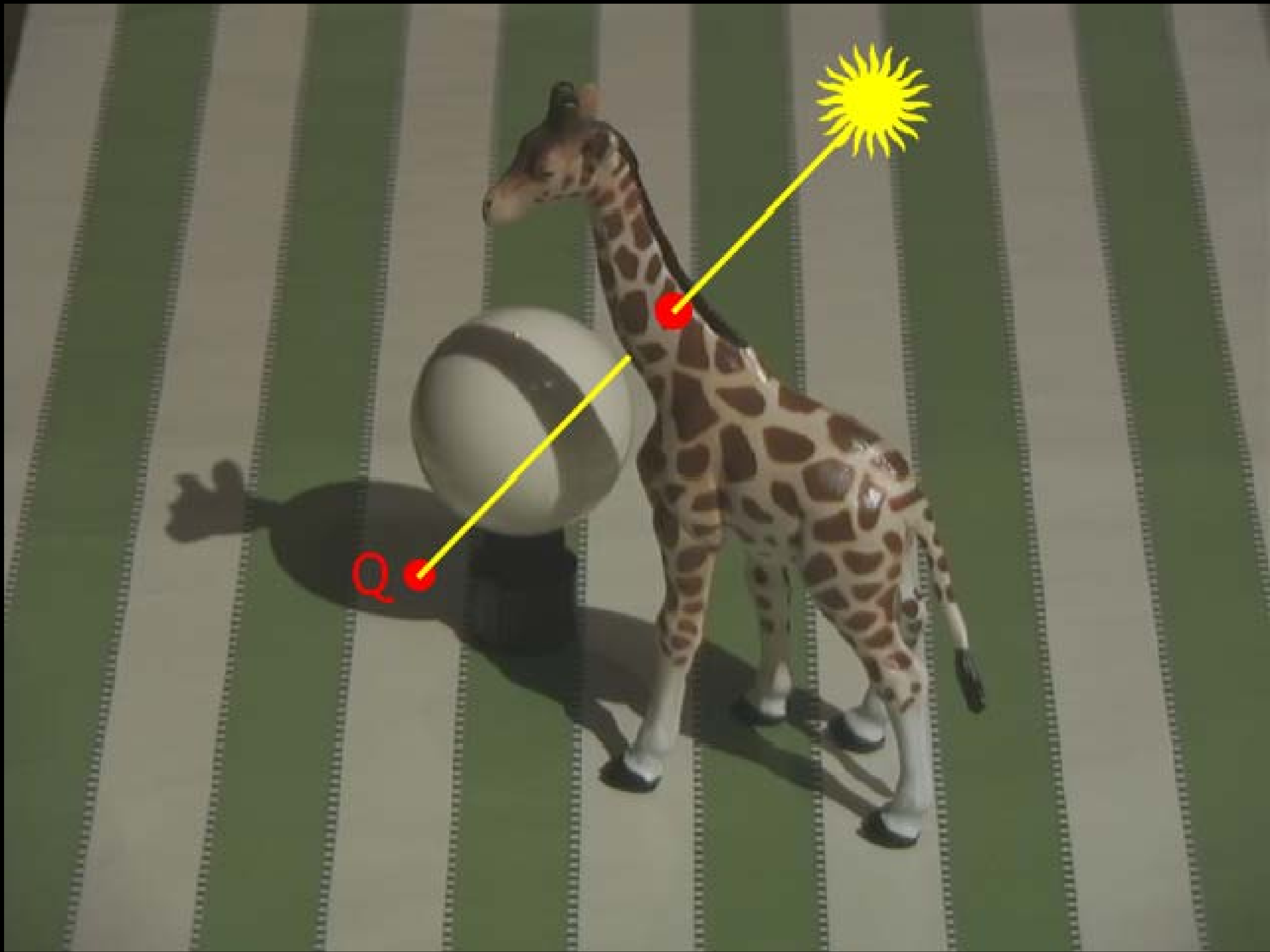


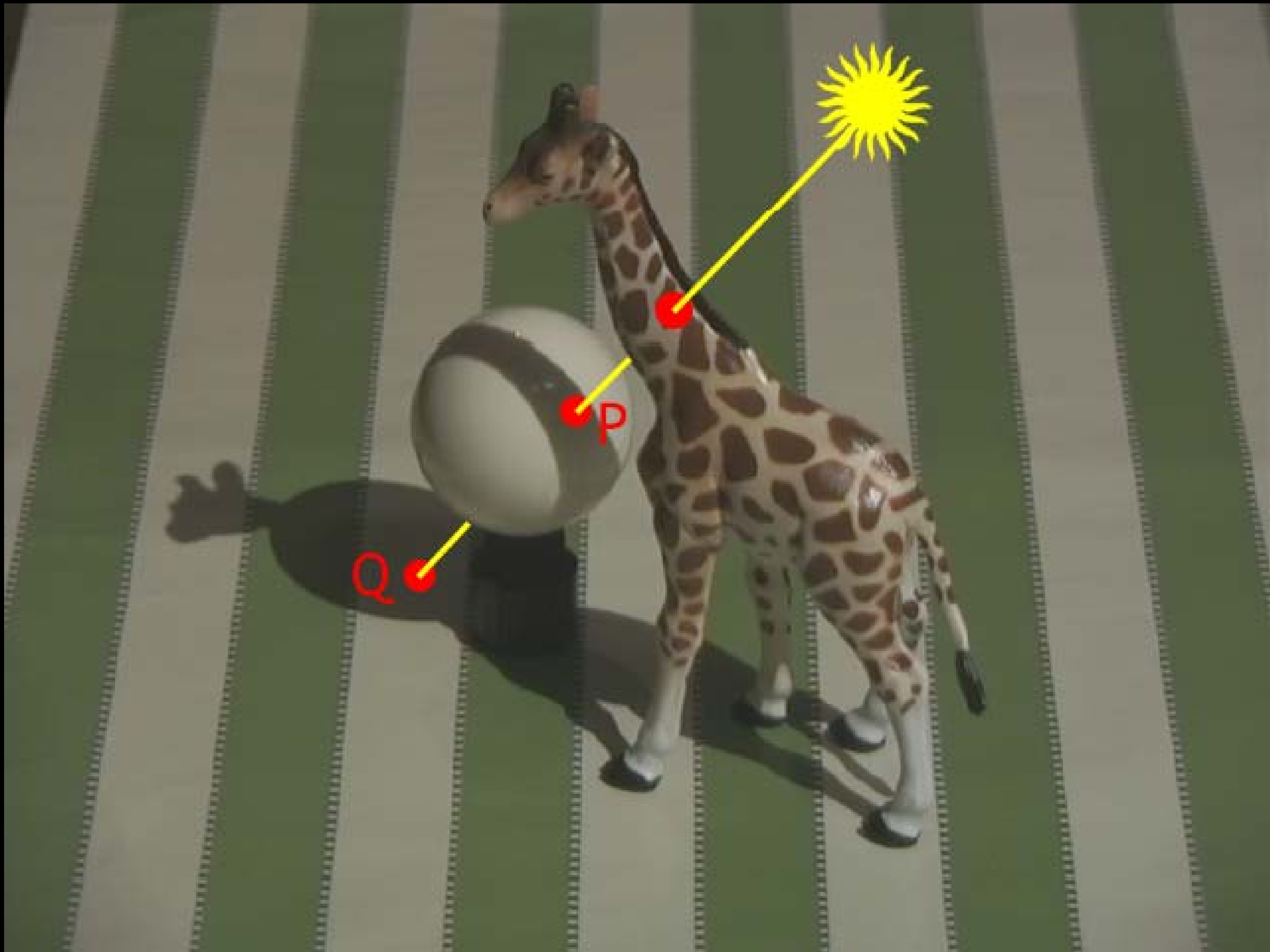
target background

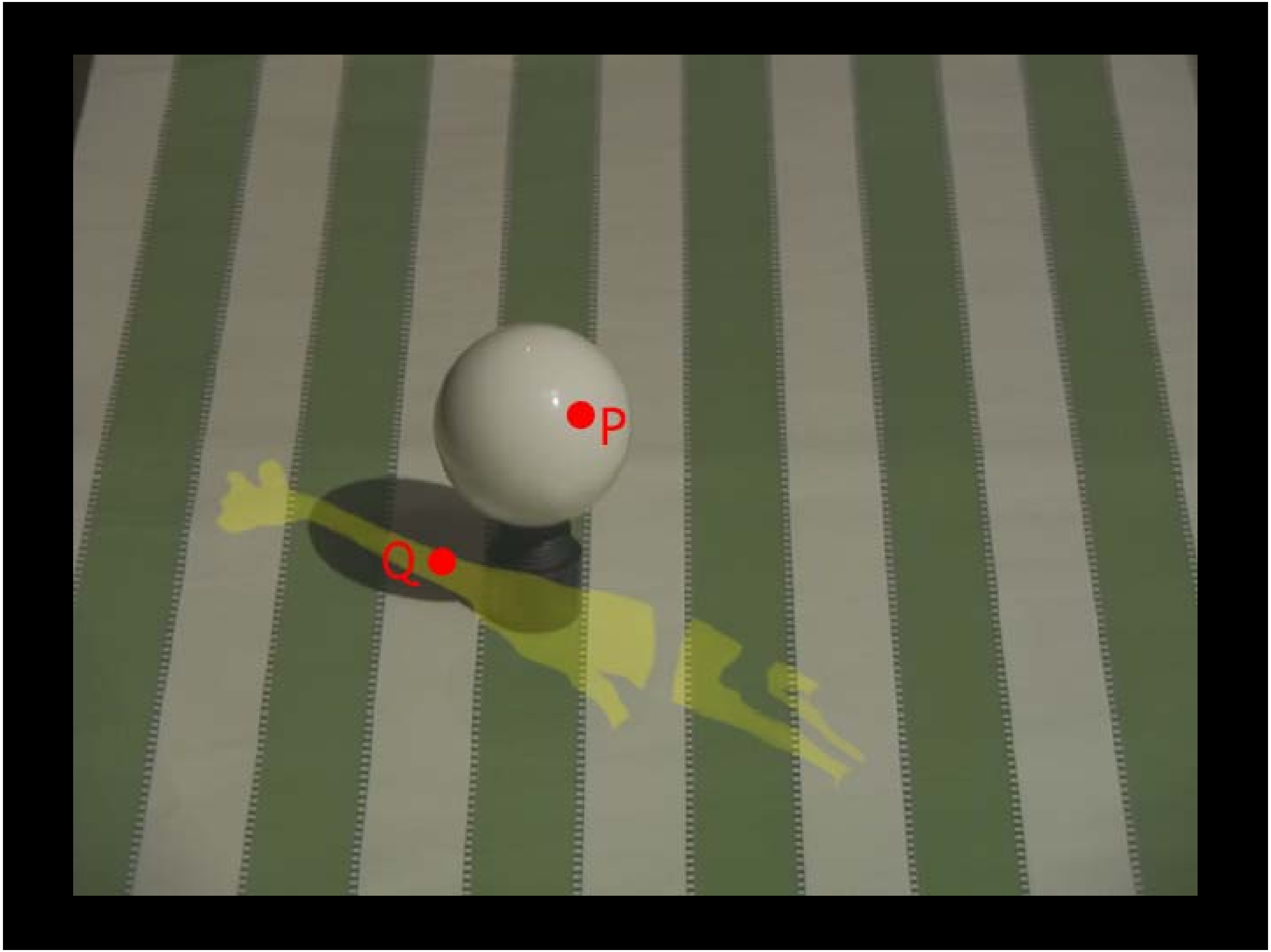


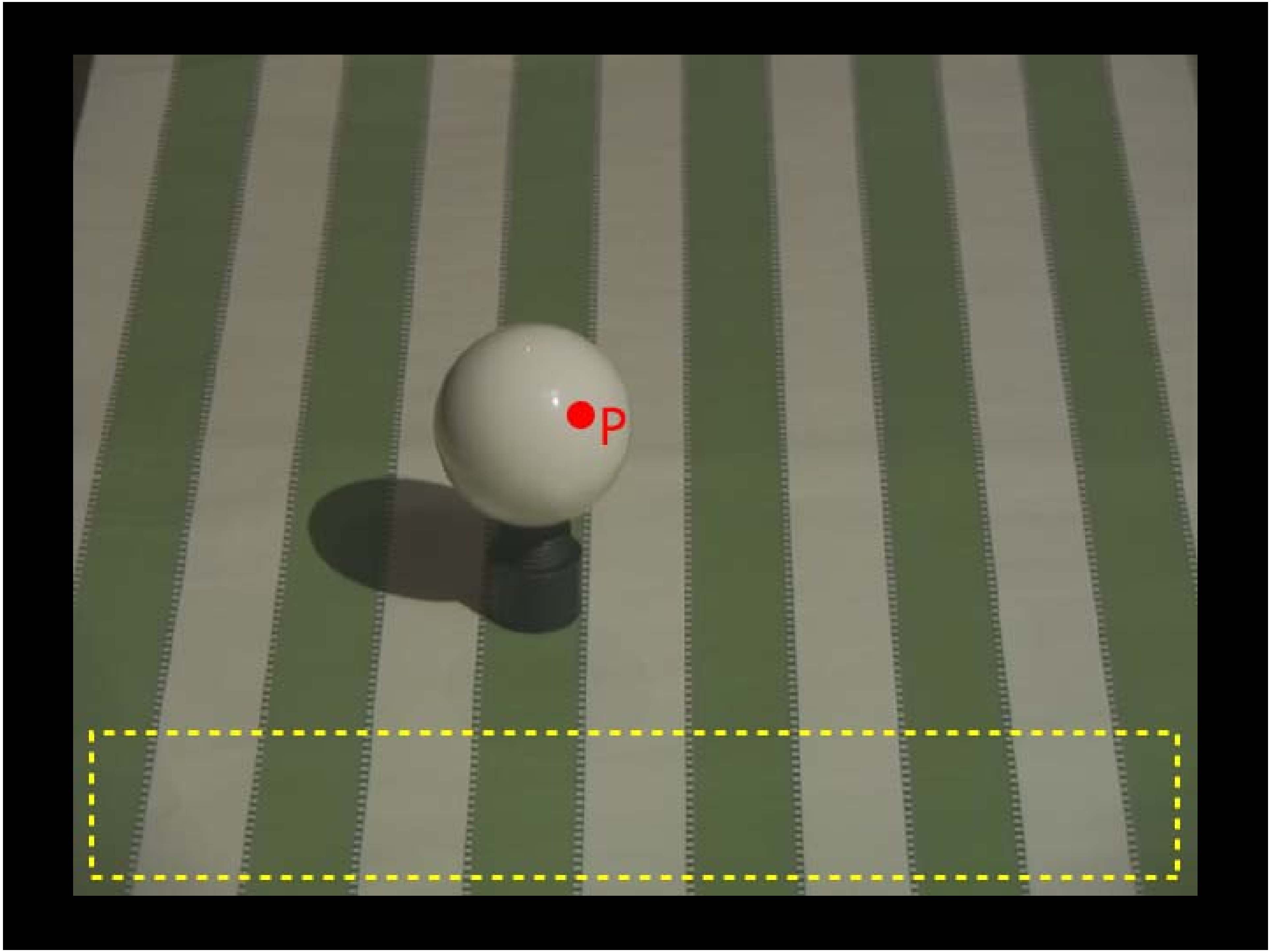
Requirement #2

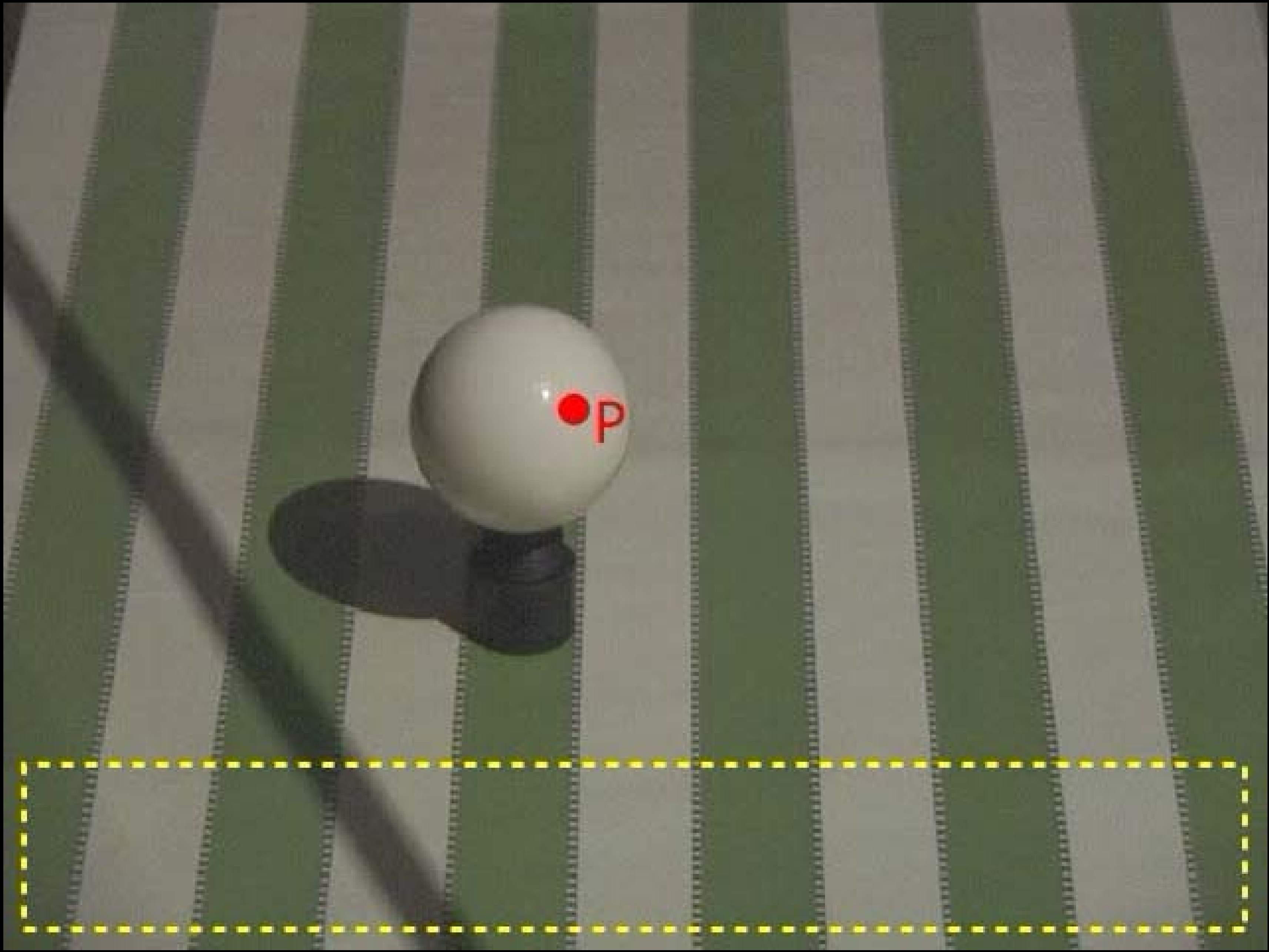

Q

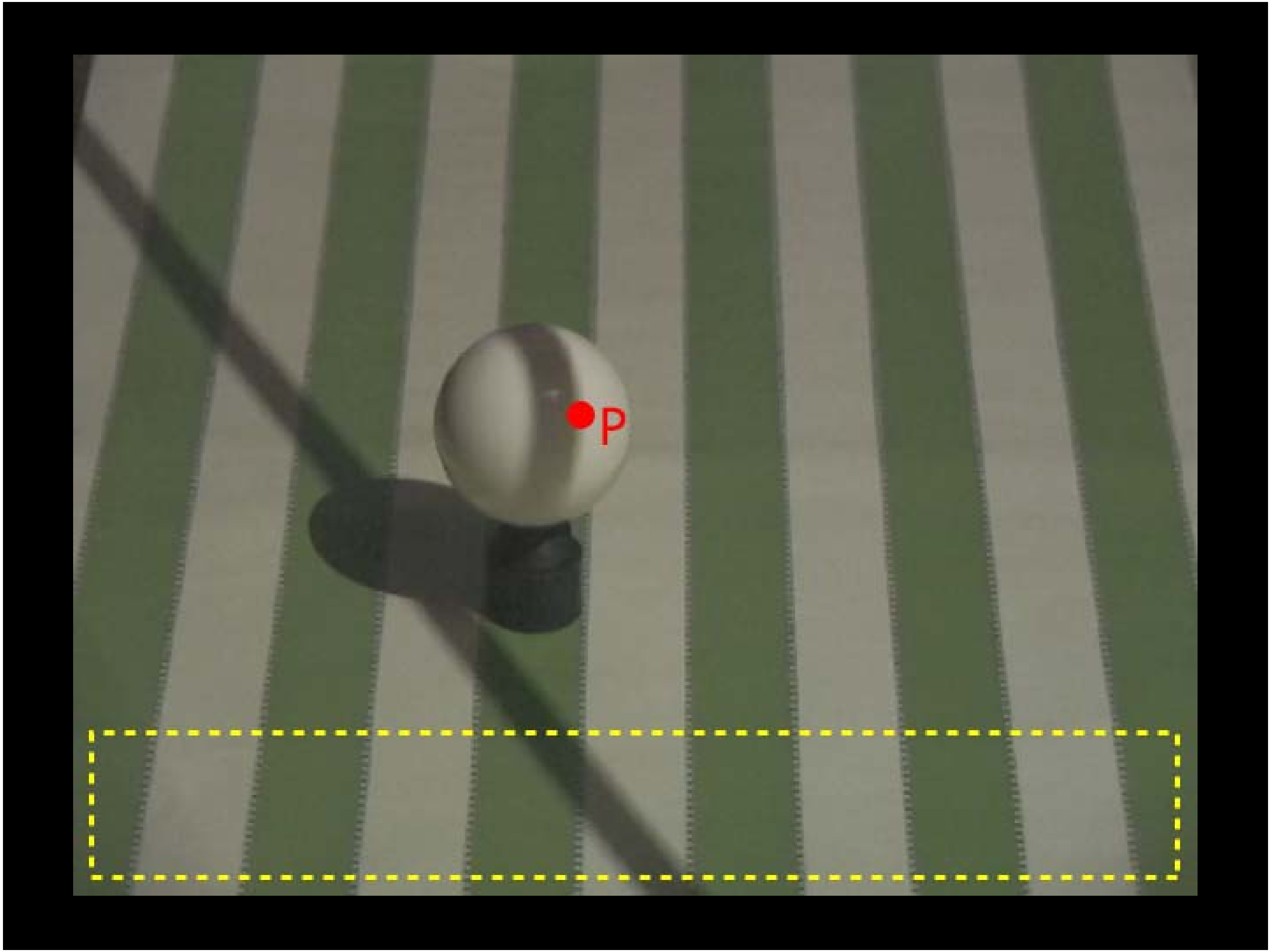

Q

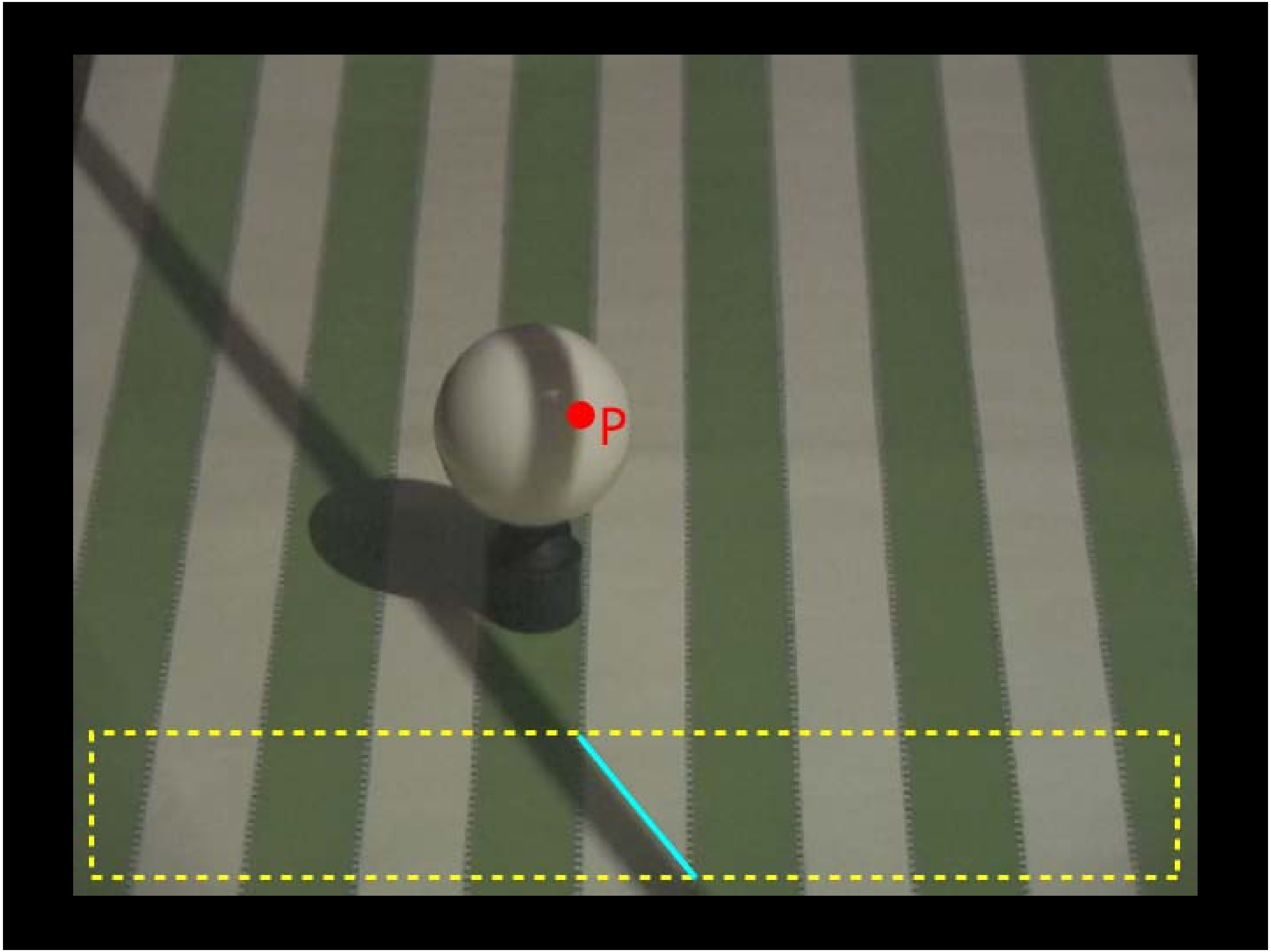

P
Q

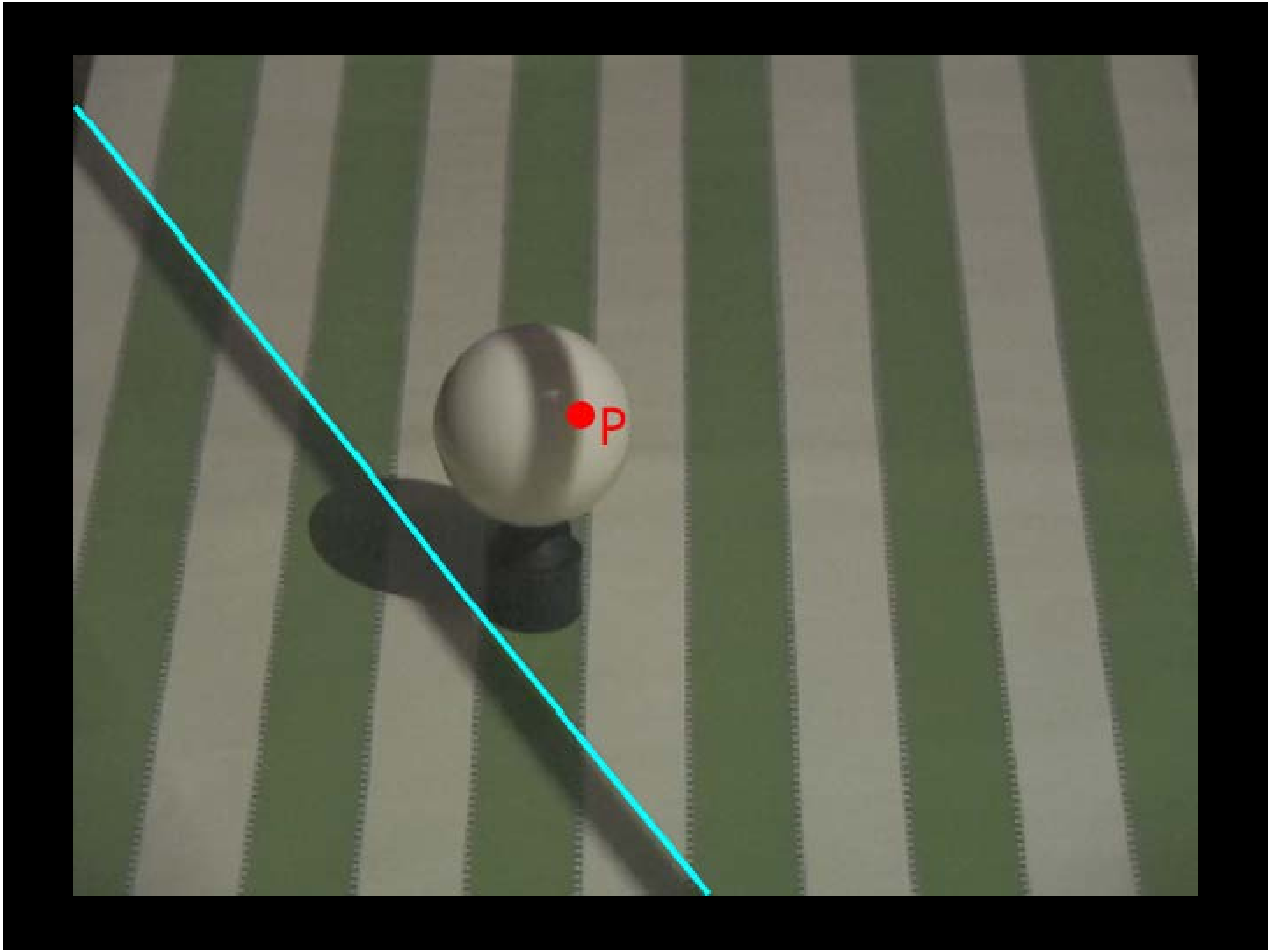

P
Q

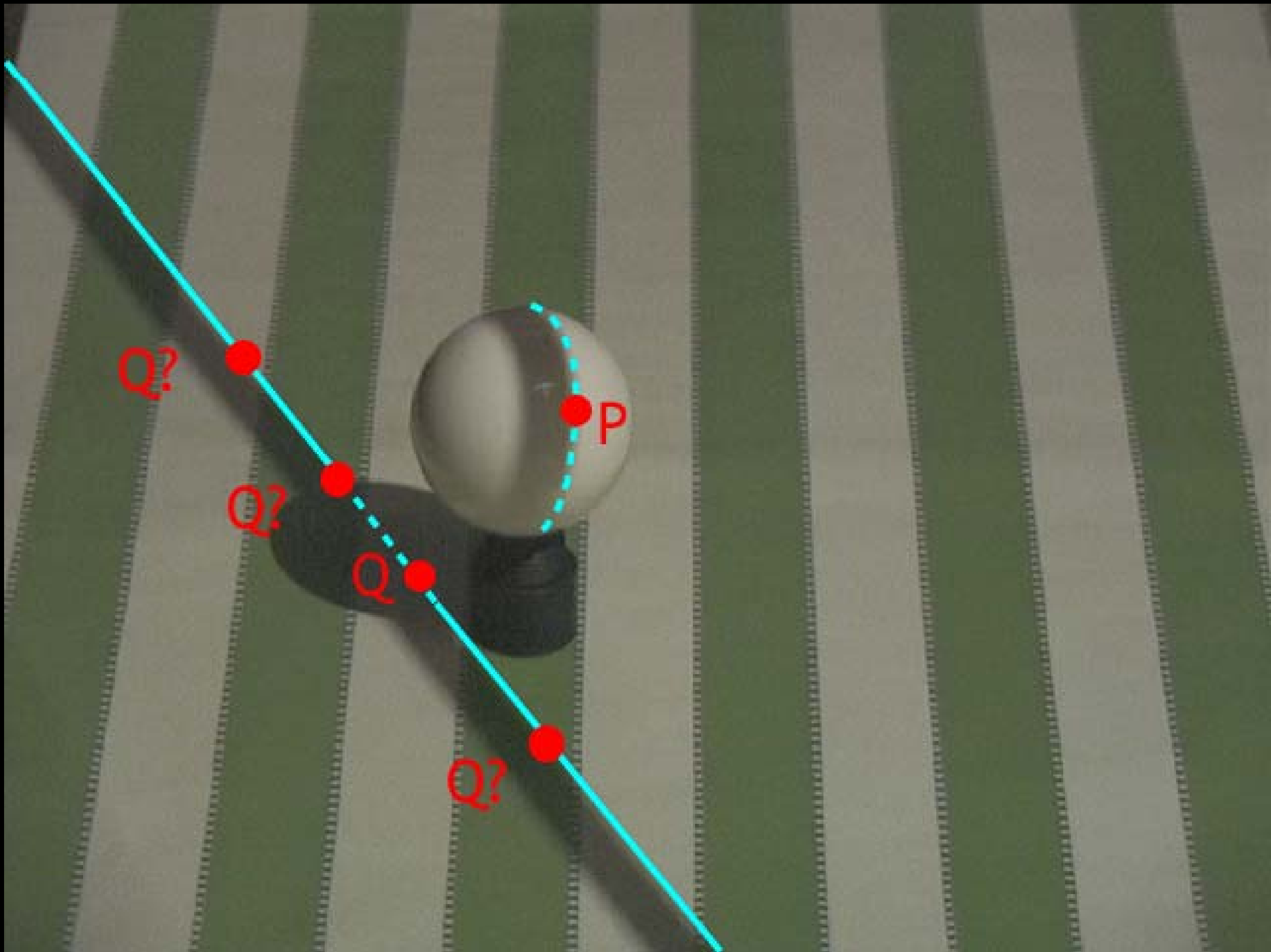

P

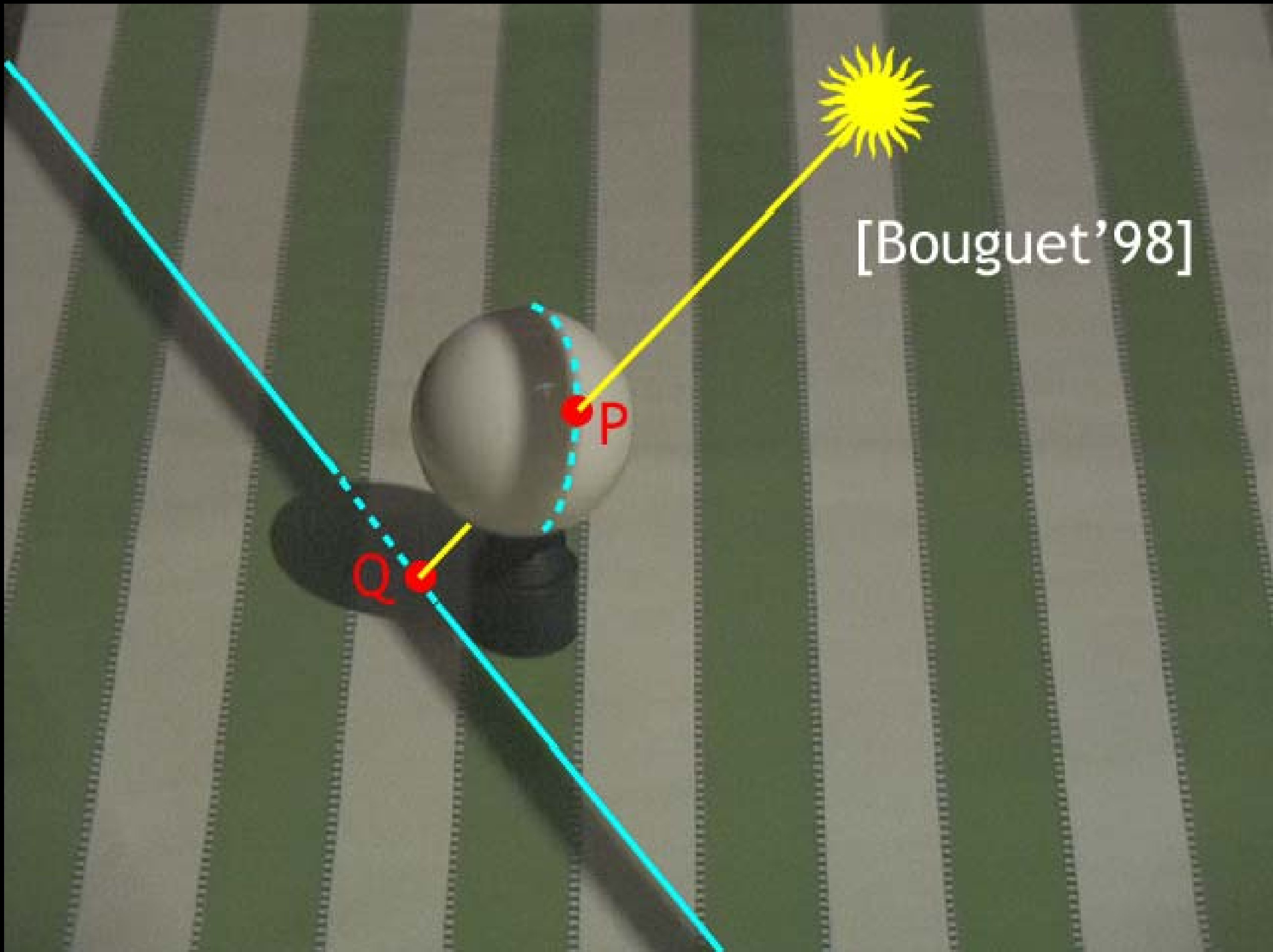

P

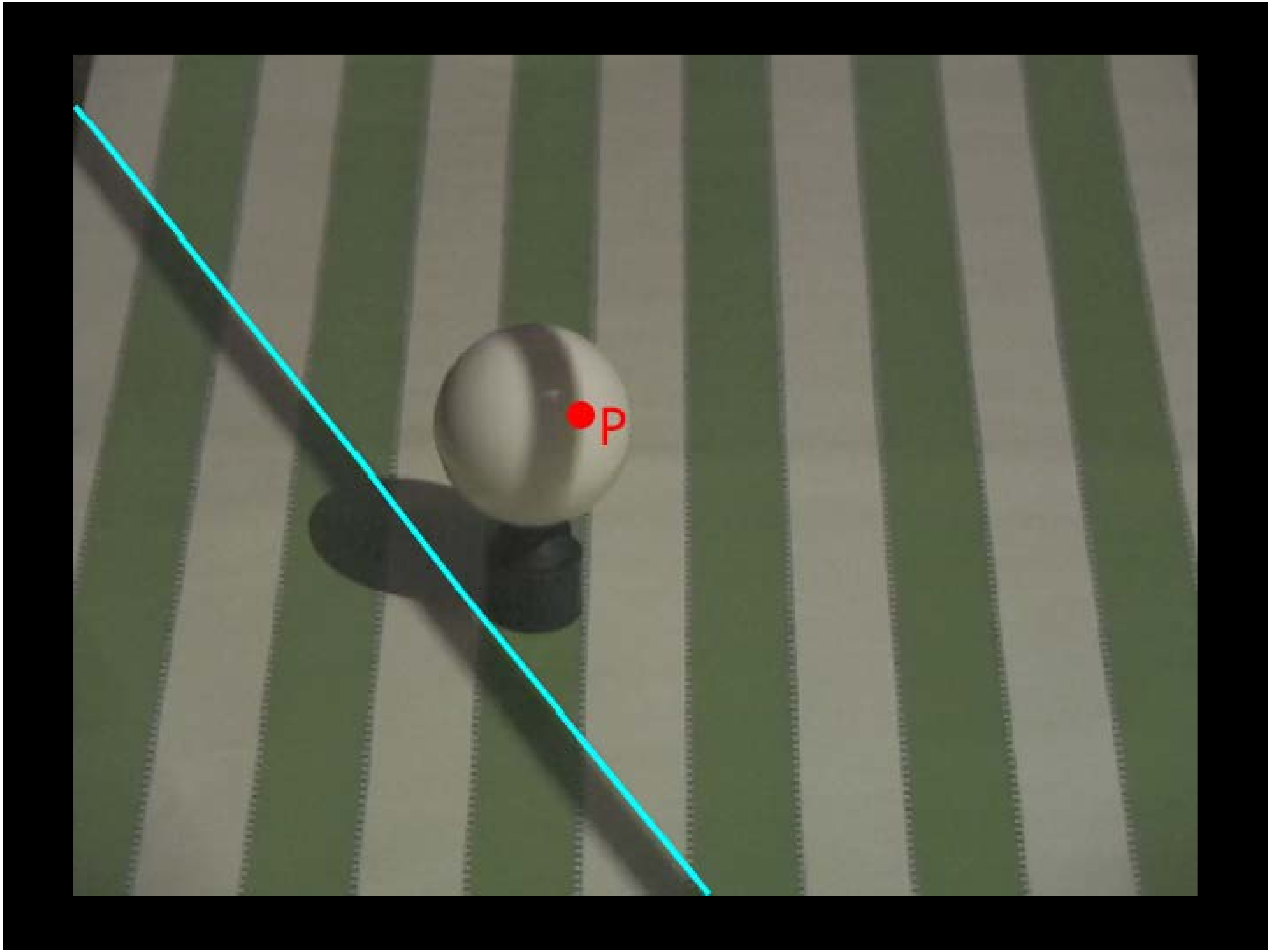

P

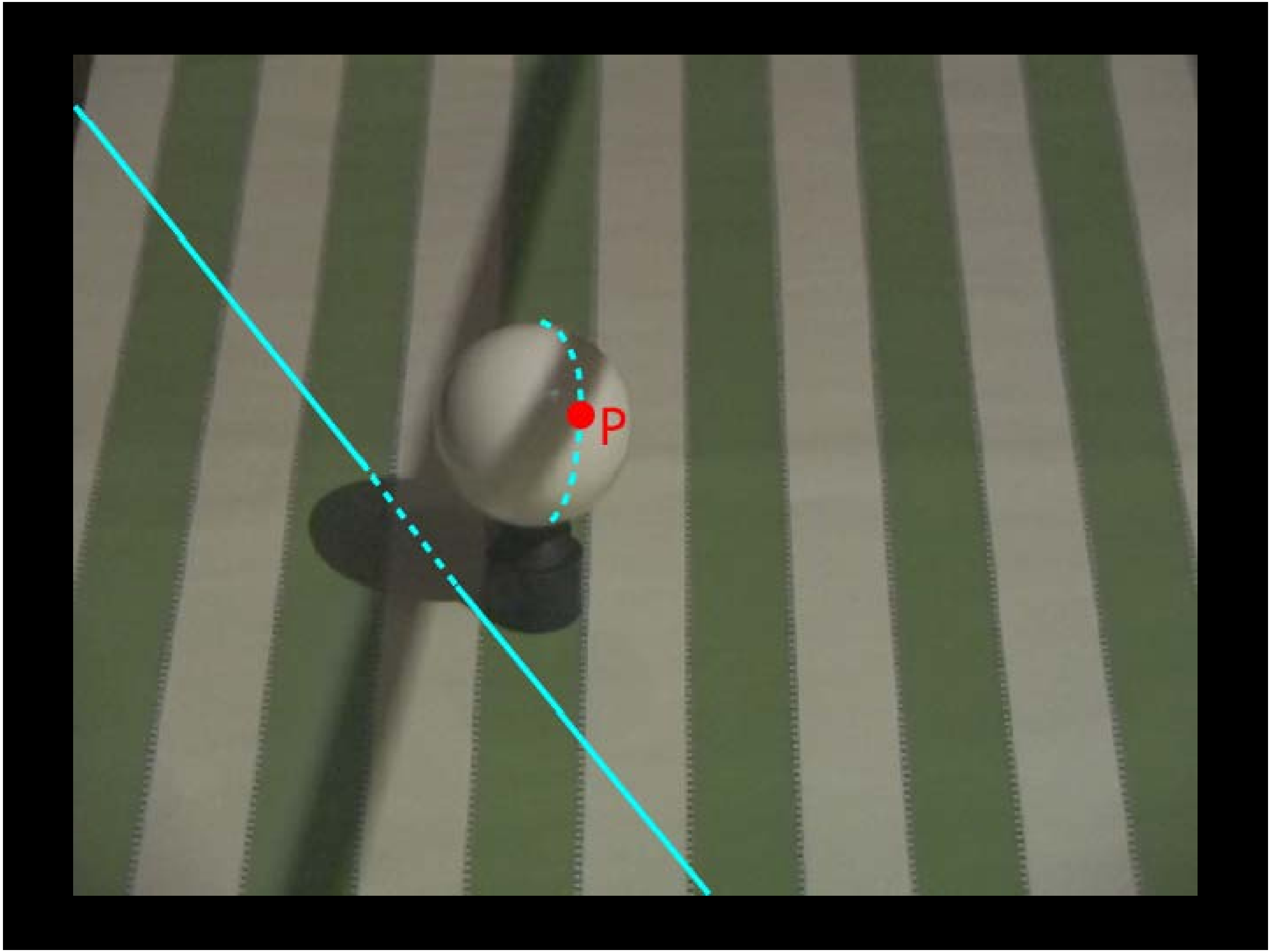

P

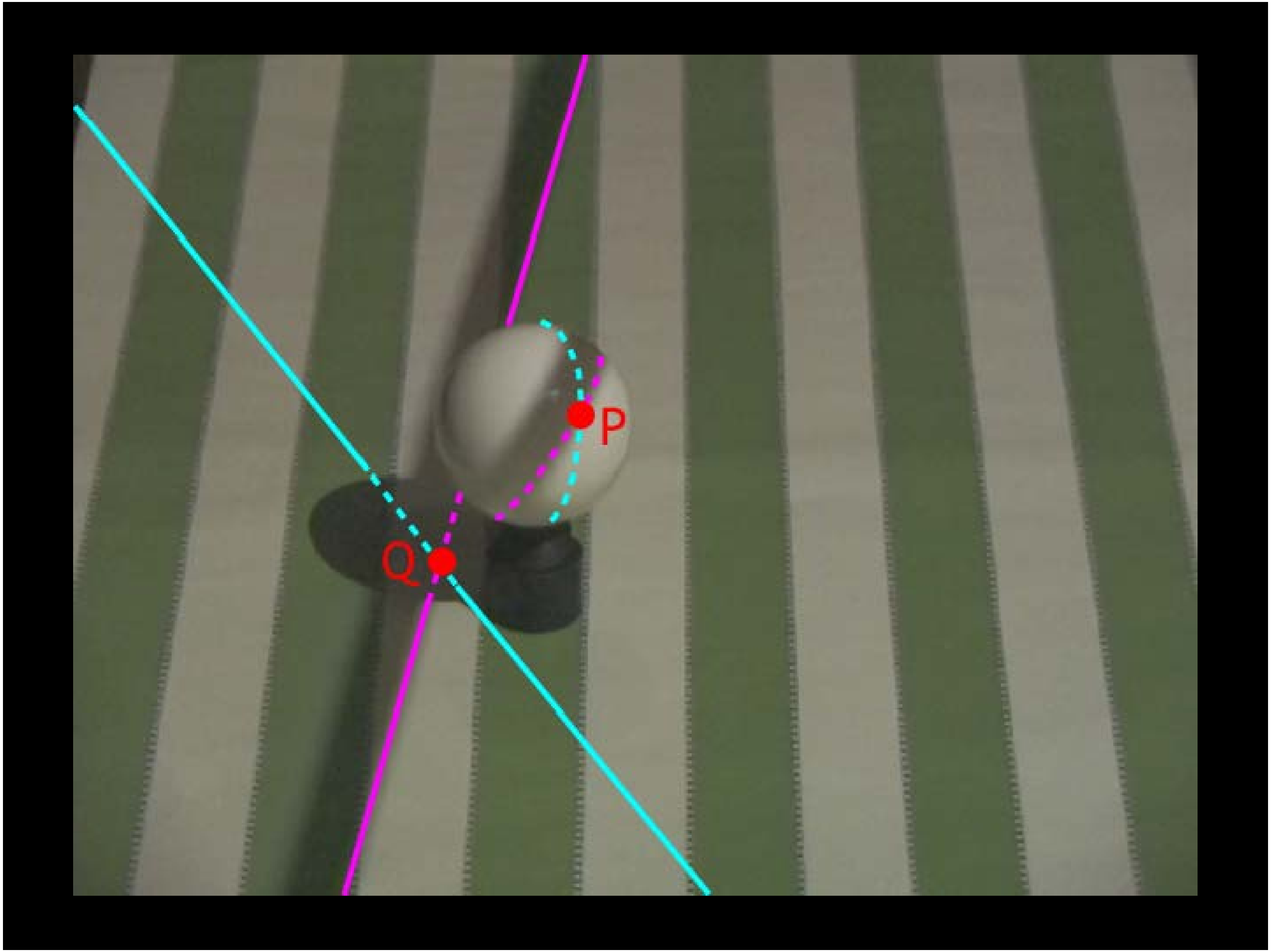

P

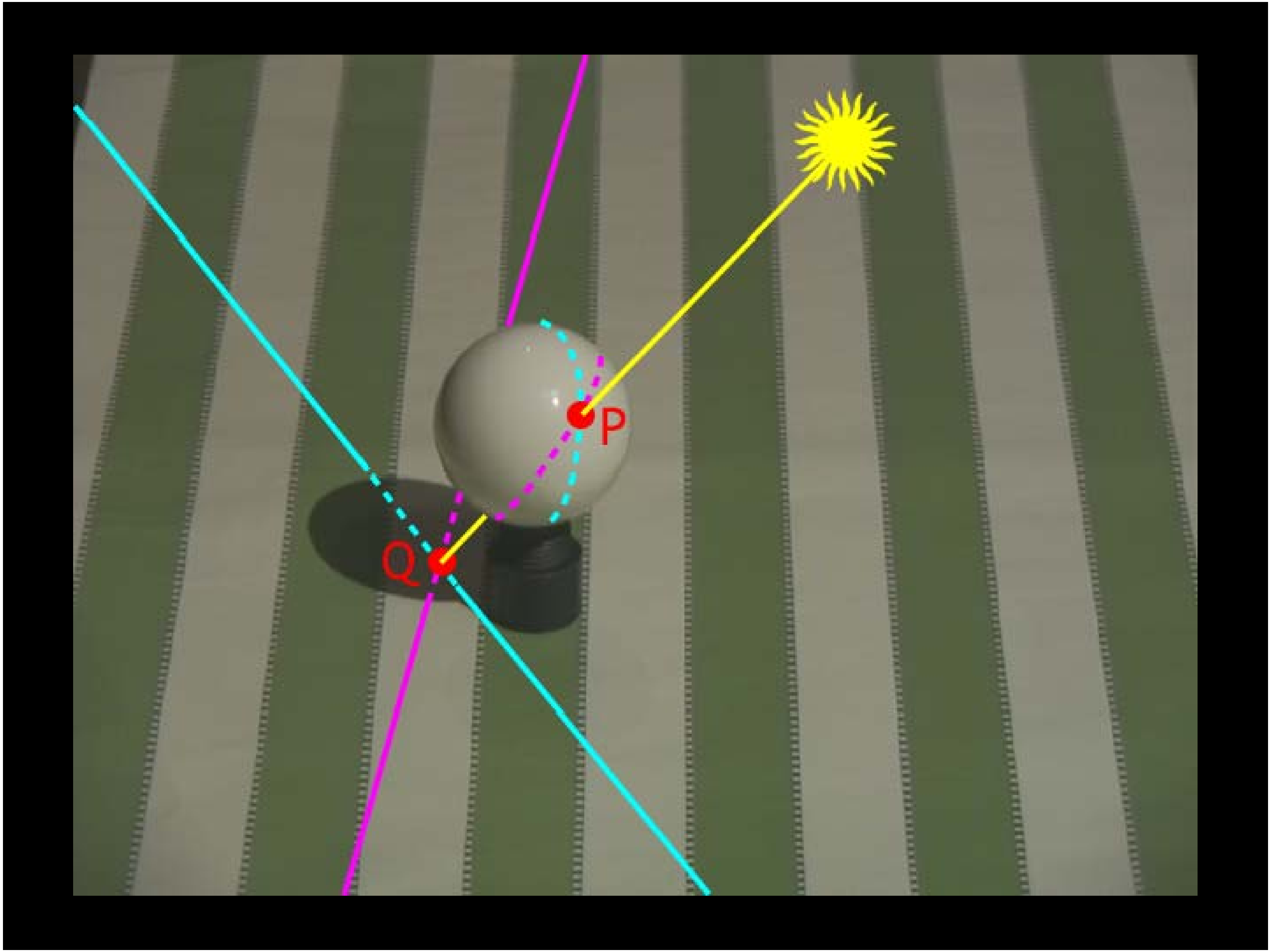

Q?
P
Q?
Q
Q?

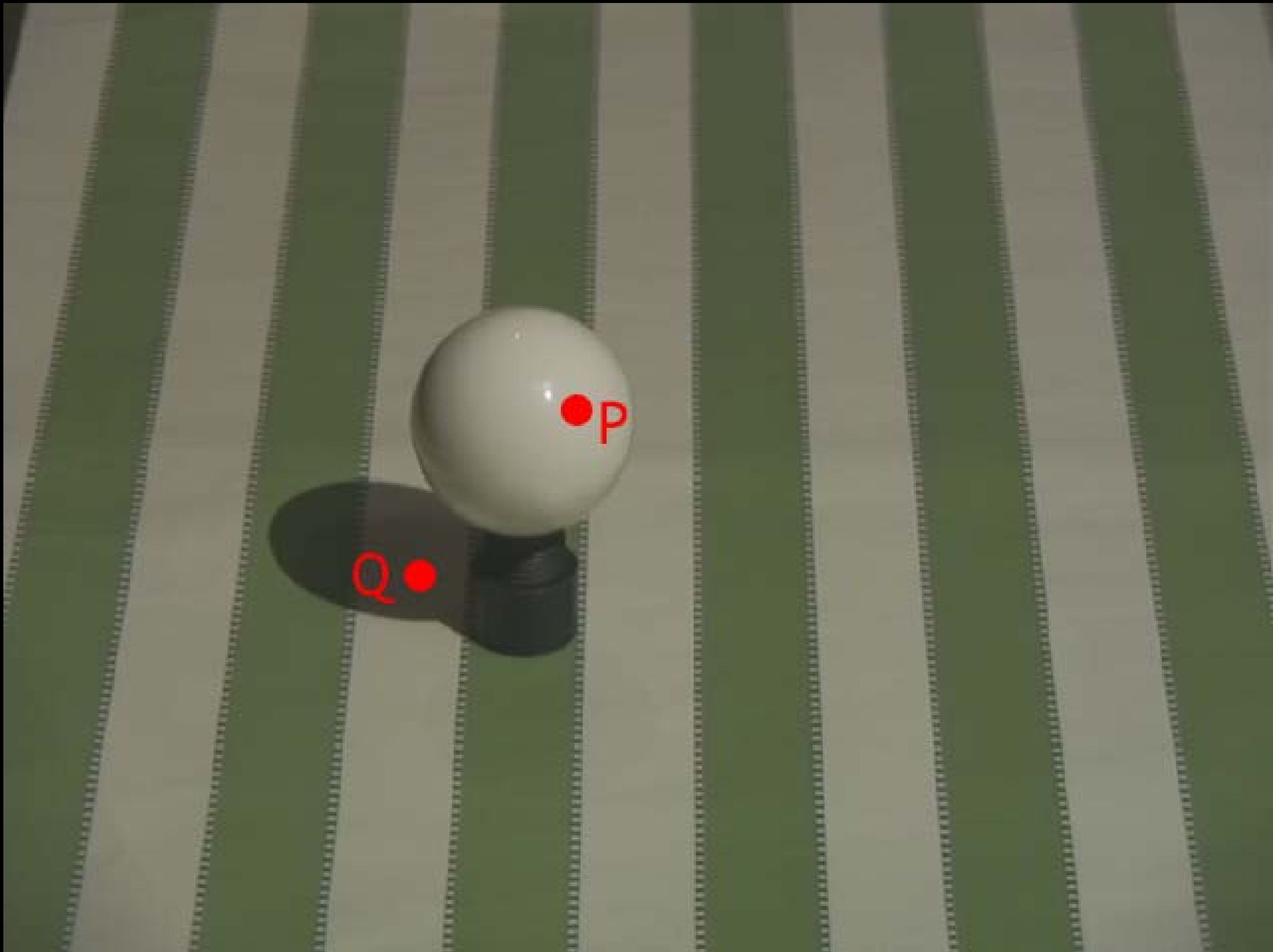

[Bouguet'98]
P
Q


P

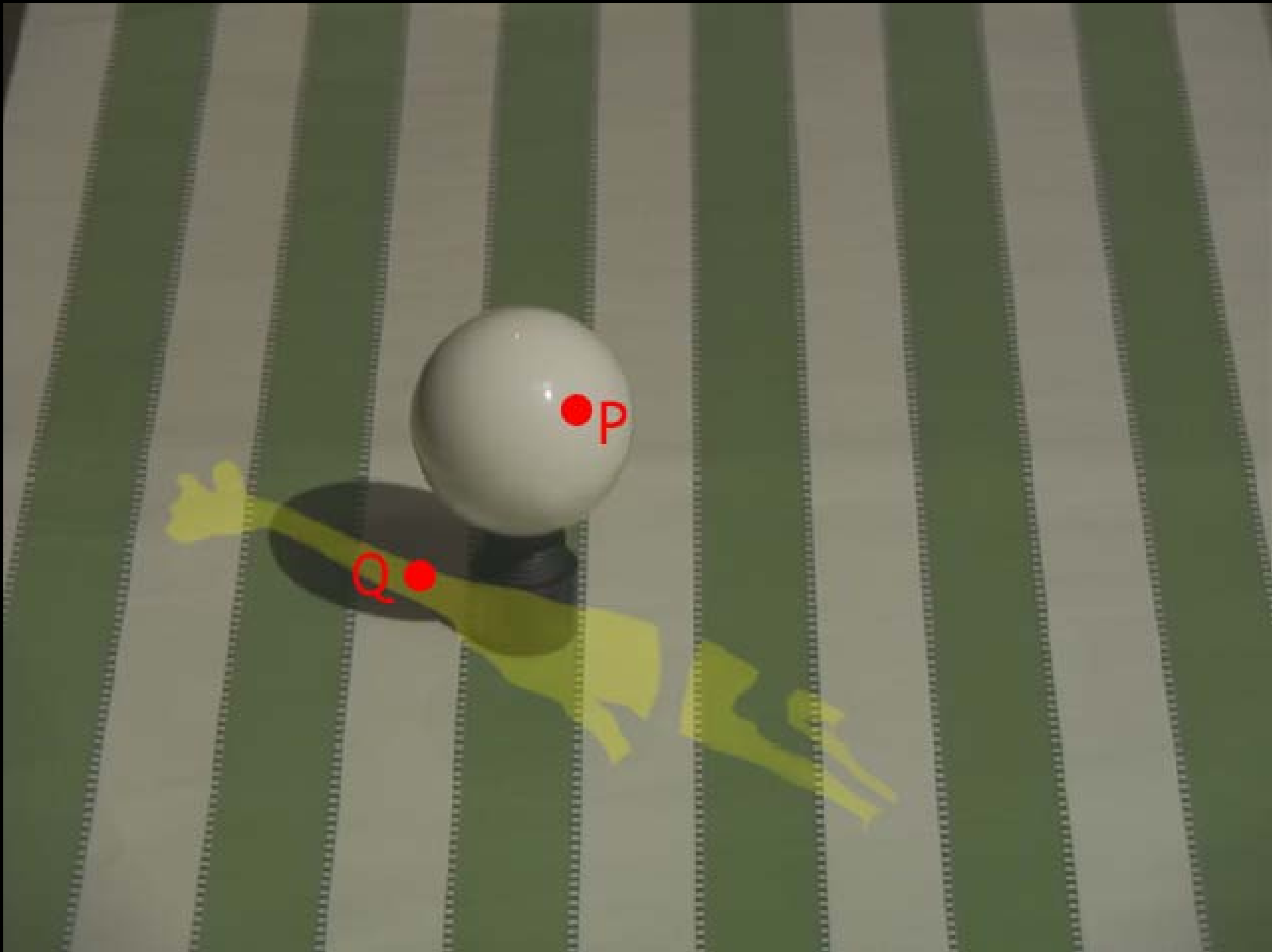

P

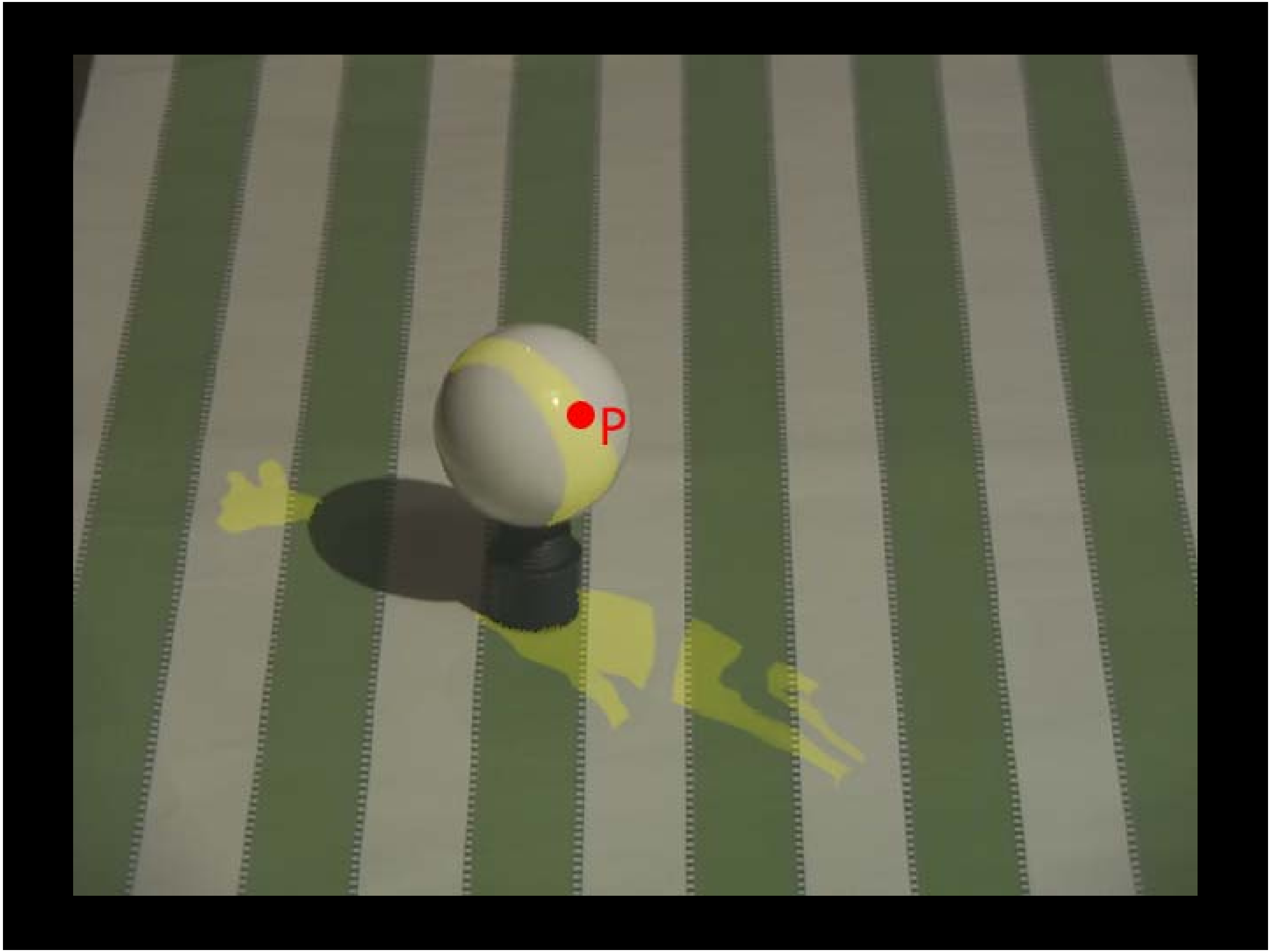

Q
P


P
Q

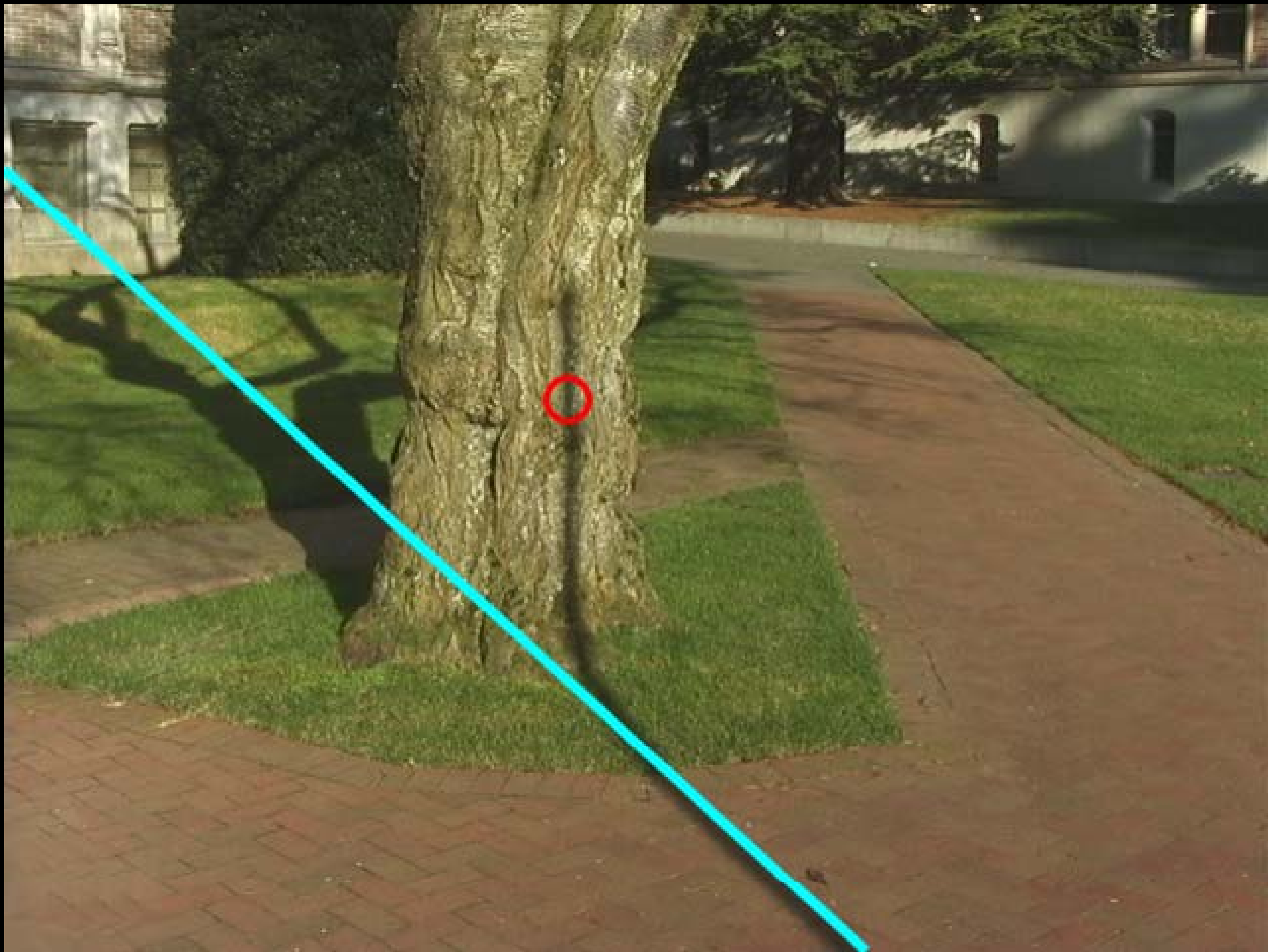


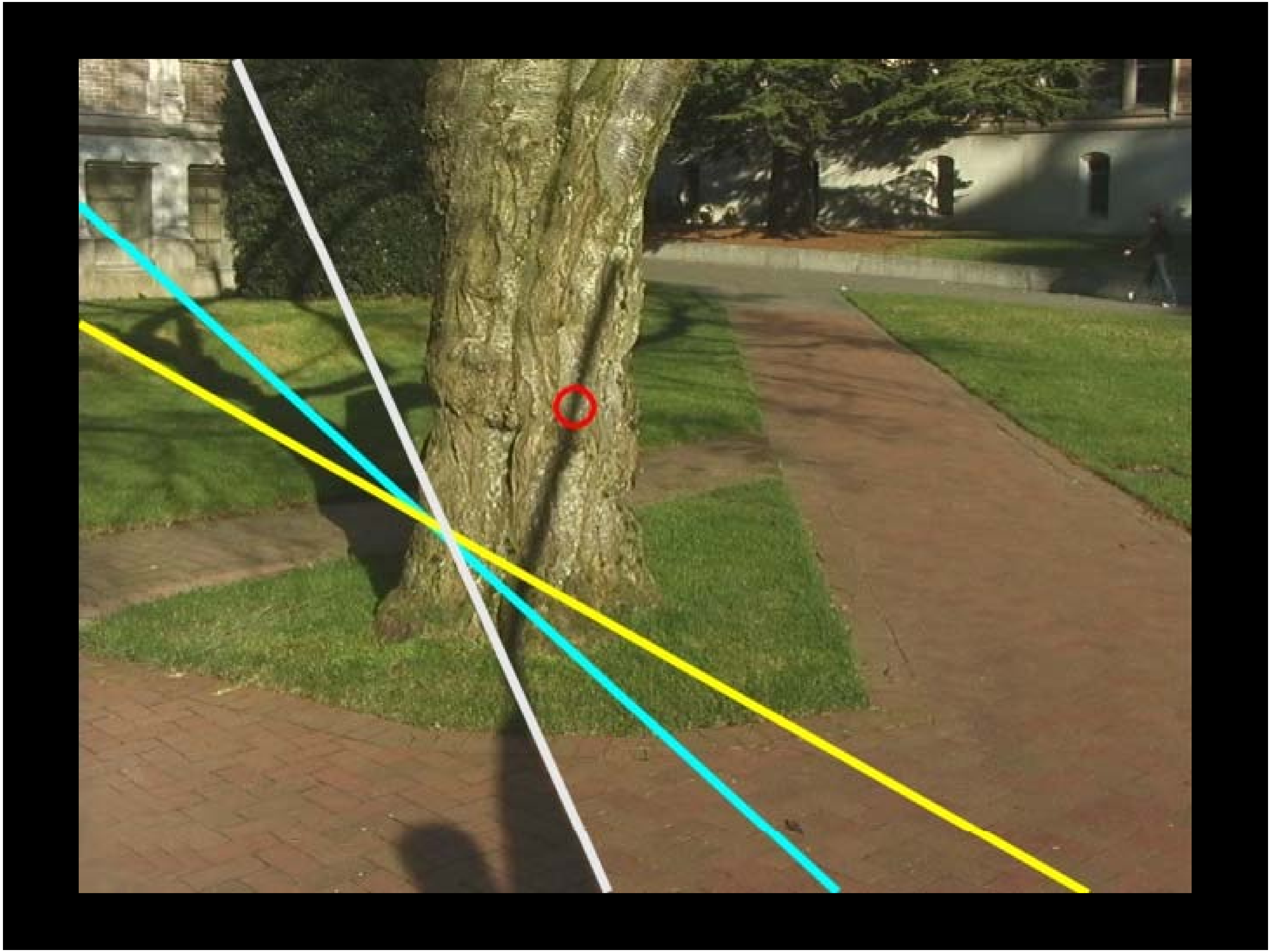
P
Q

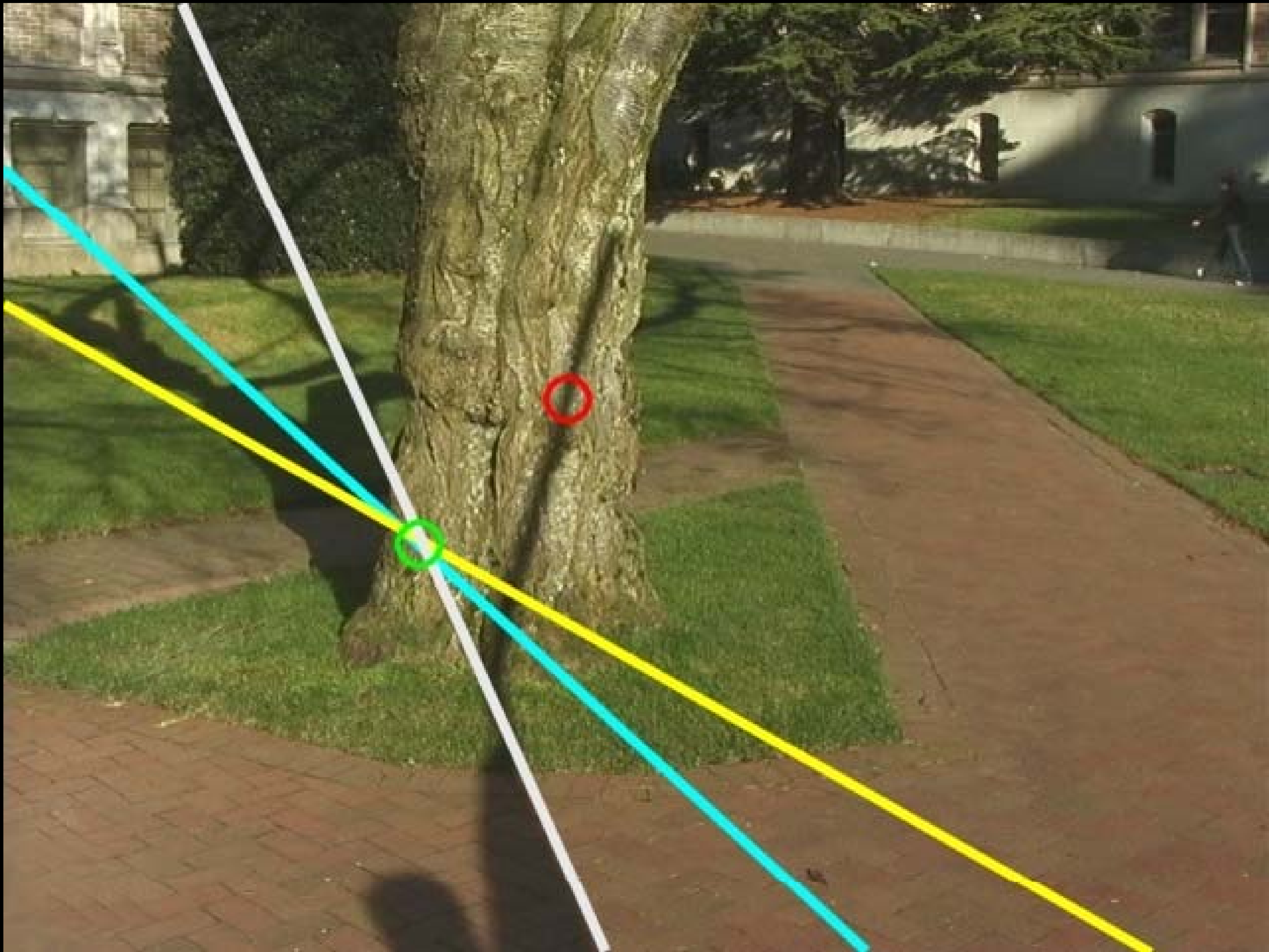

P
Q

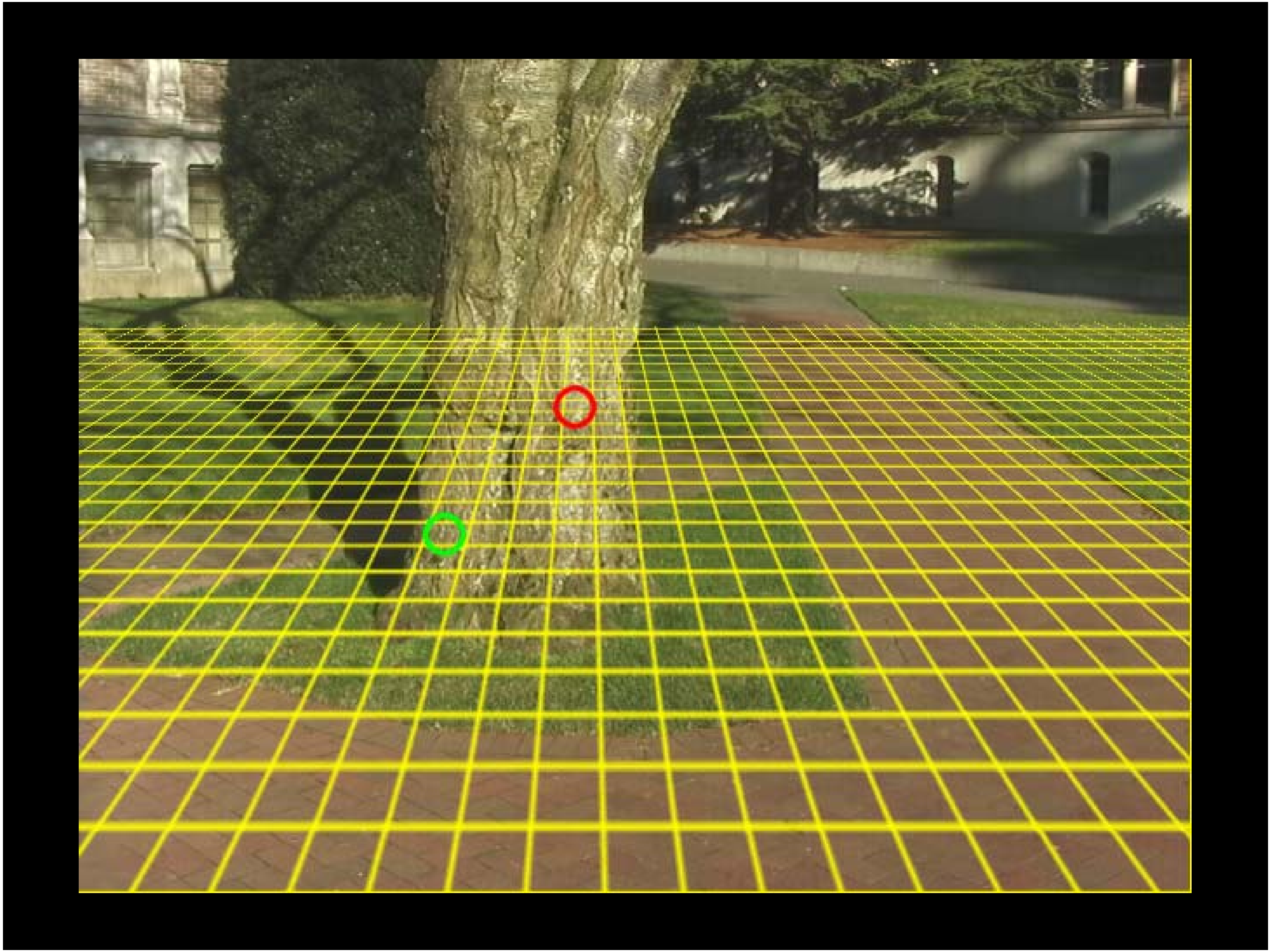

P

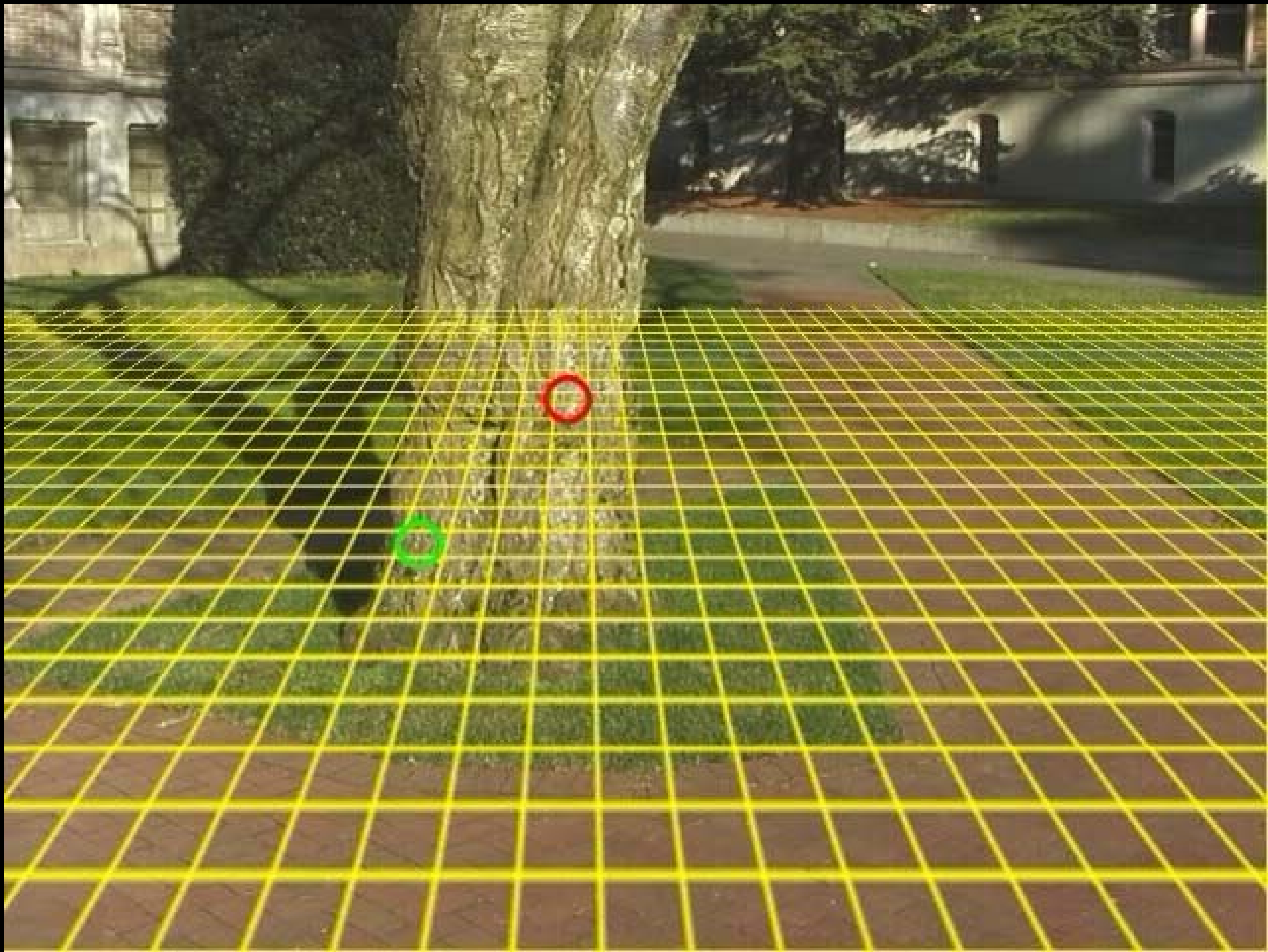

96x3x1 stick
camera
cast shadow

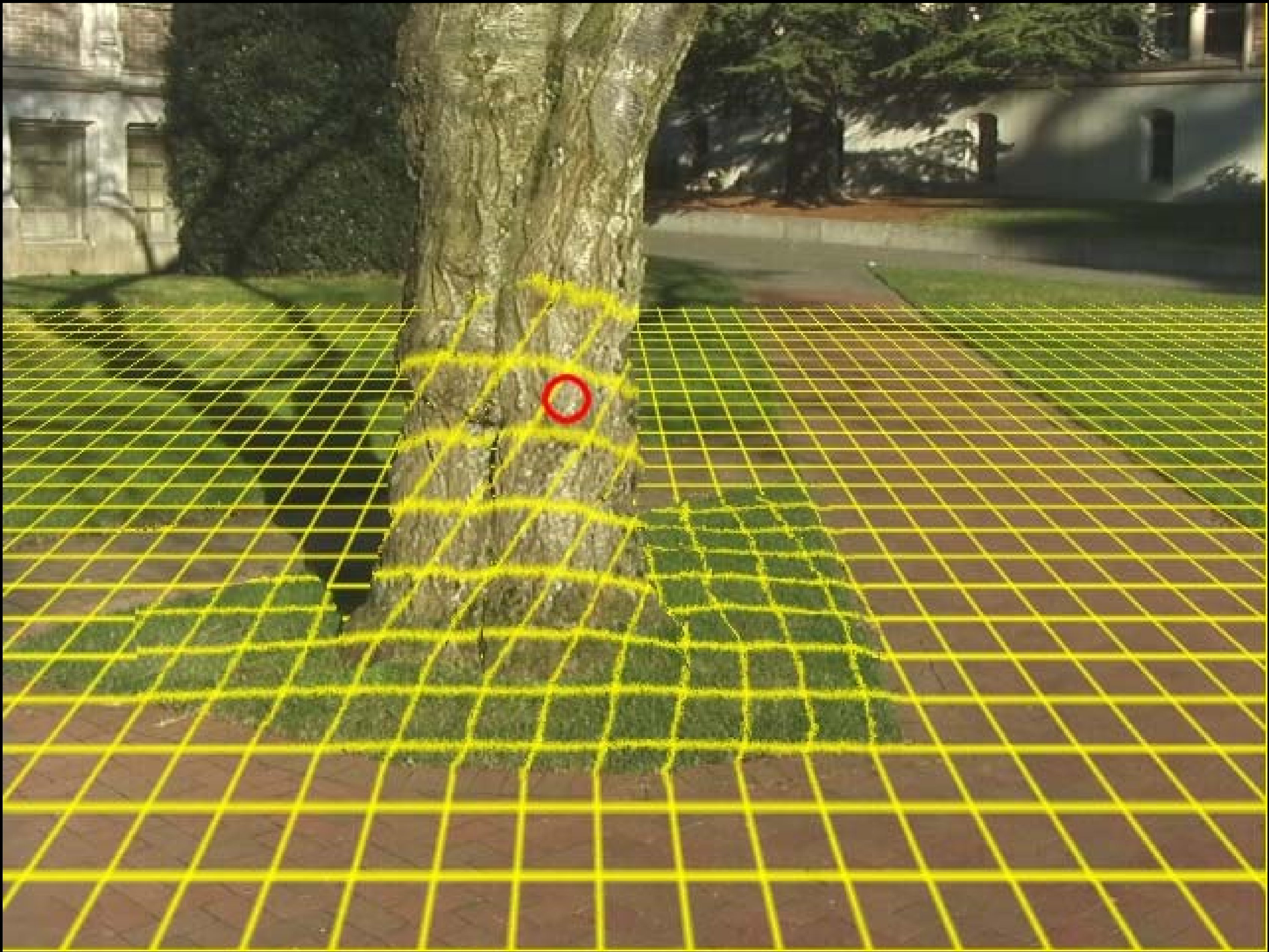


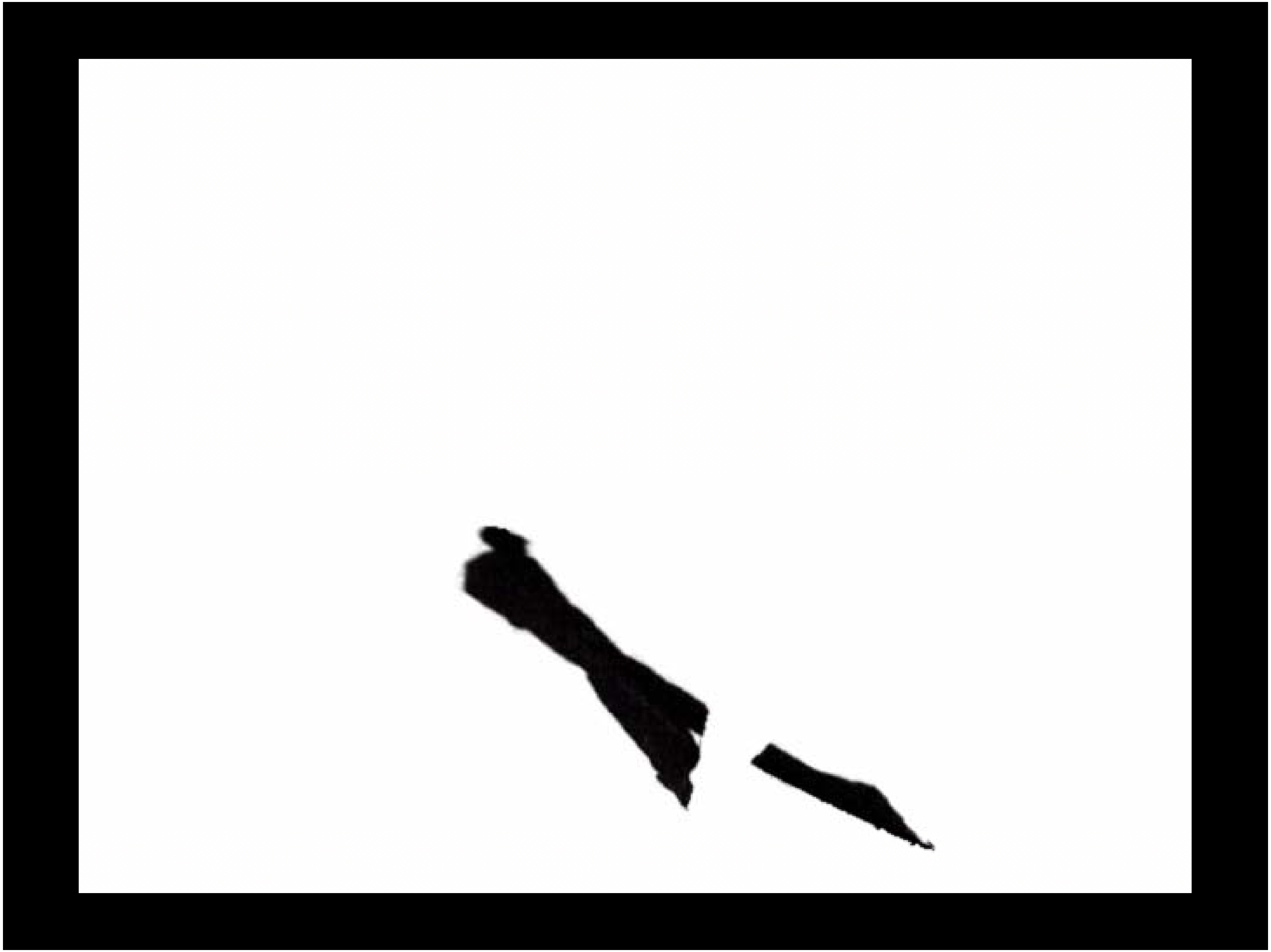


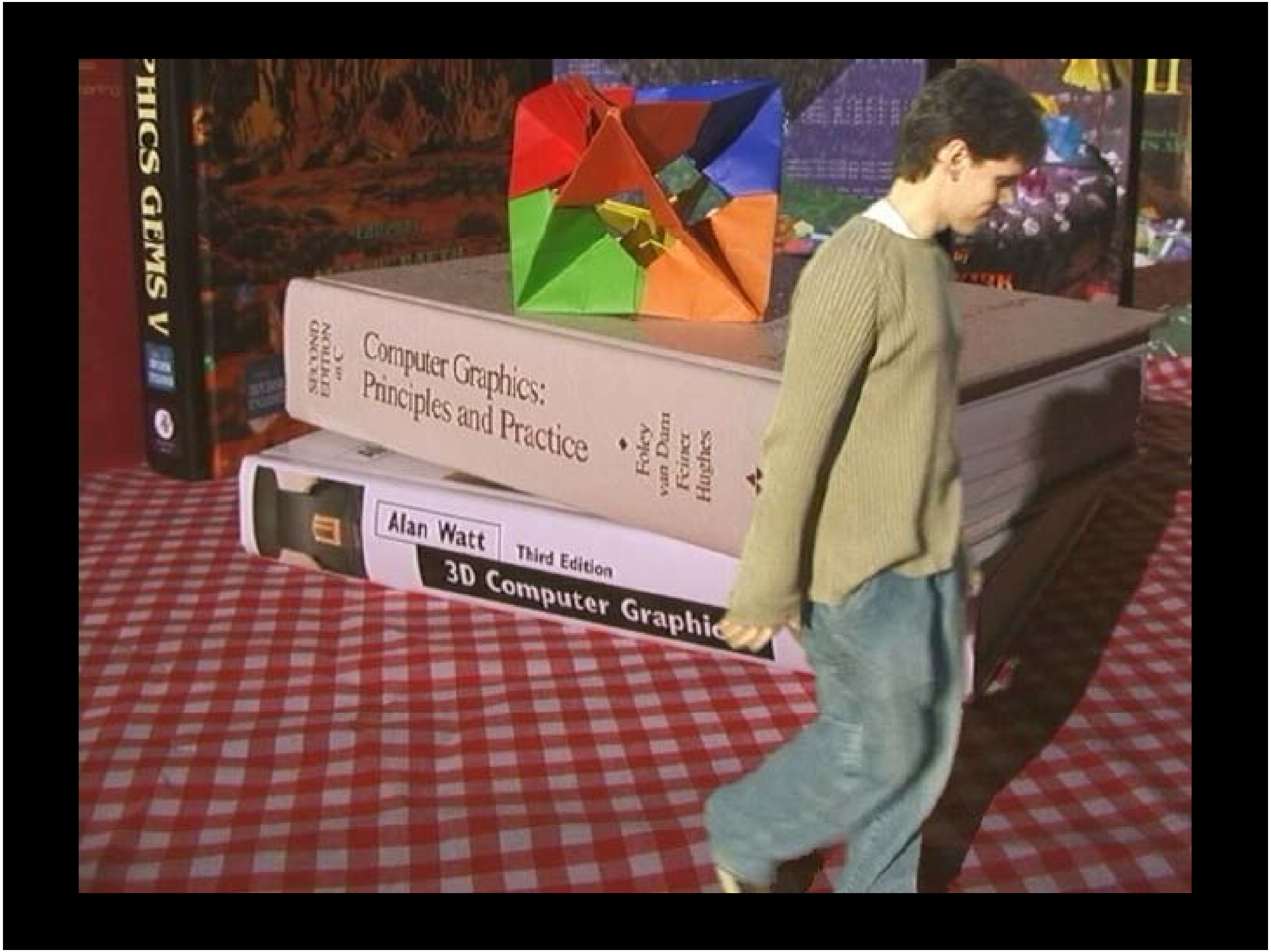


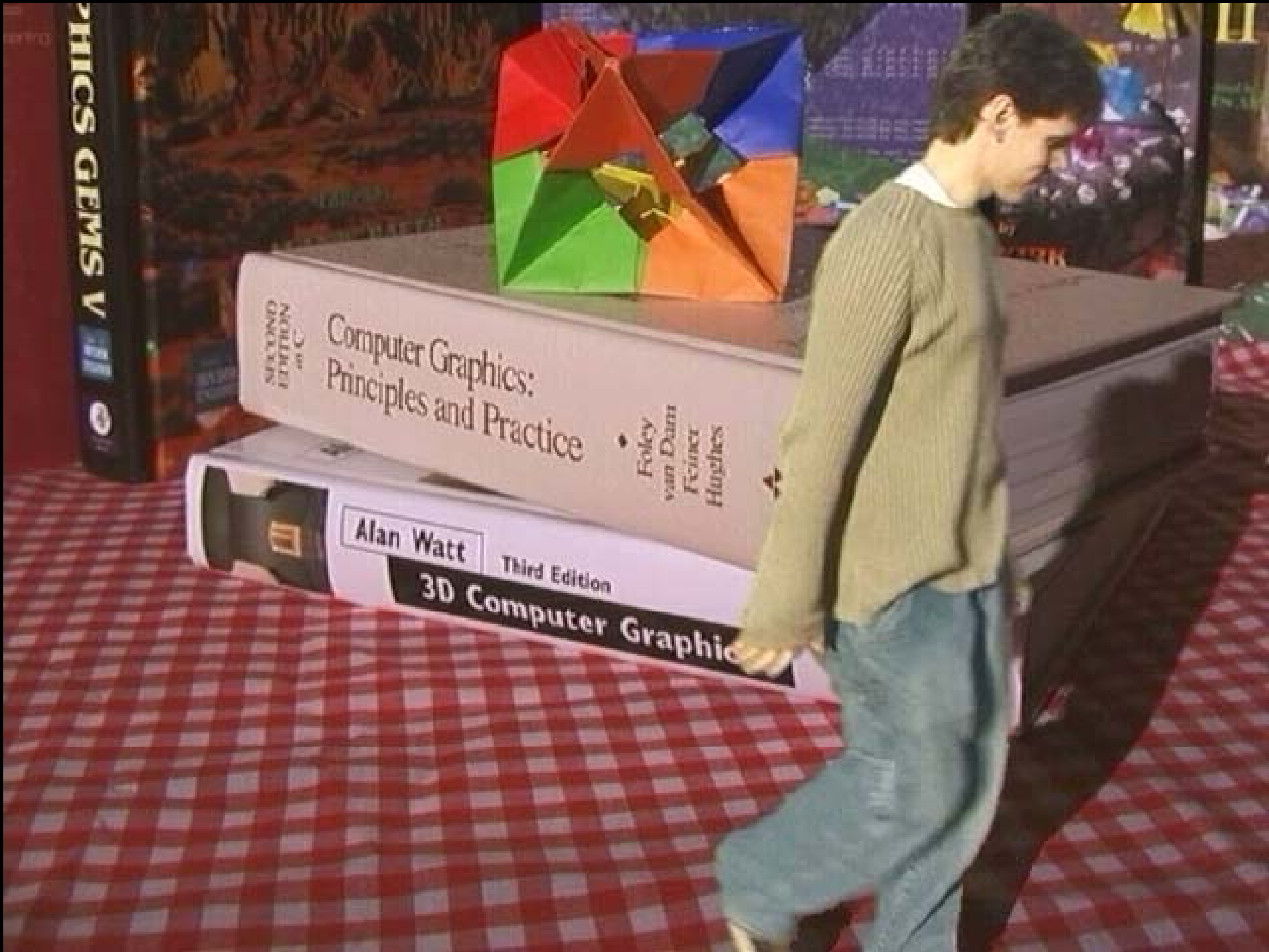









GEMS V
Computer Graphics:
Principles and Practice
Foley
van Dam
Feiner
Hughes
Alan Watt
Third Edition

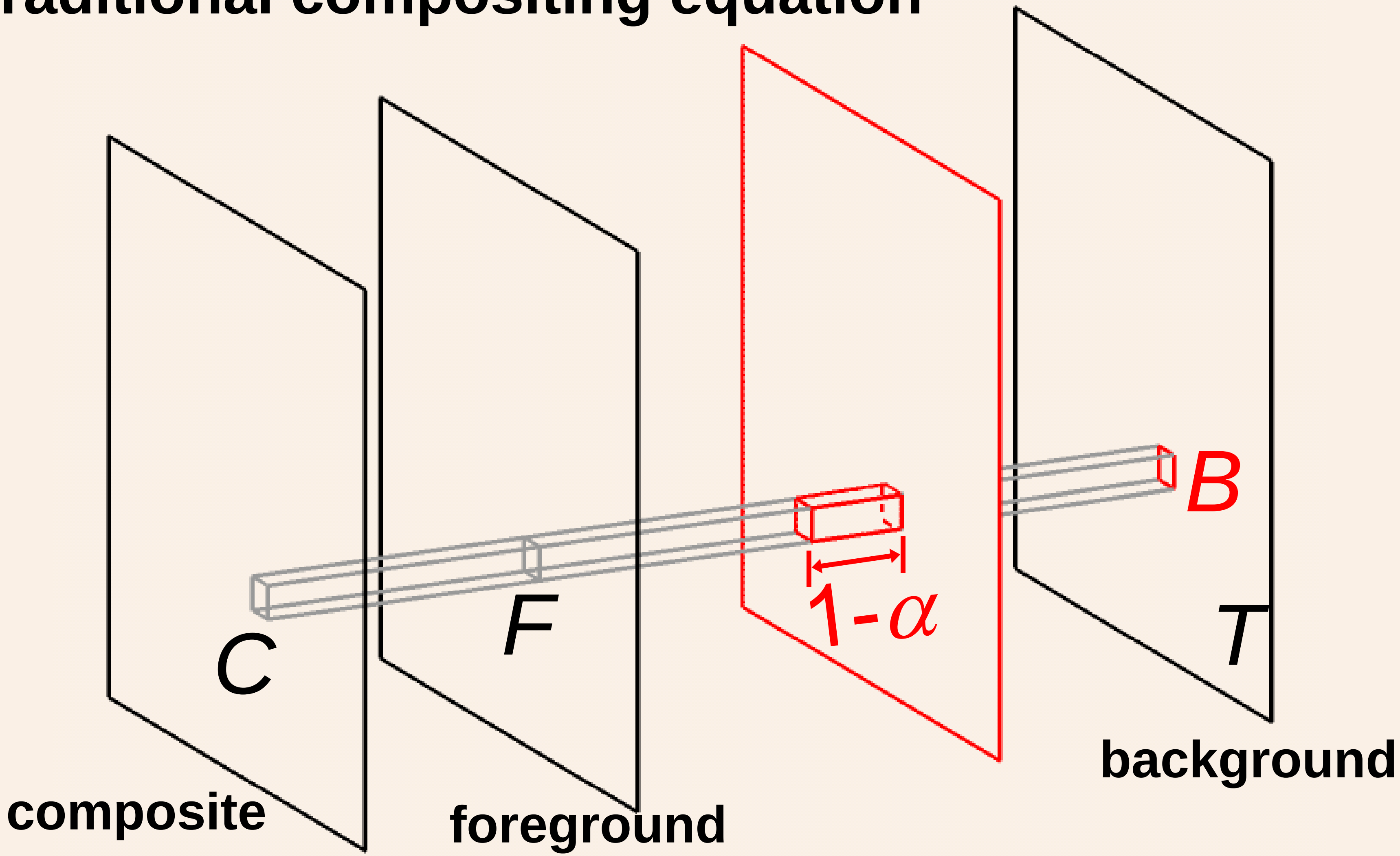

PHICS GEMS V
SECOND EDITION in C
Computer Graphics:
Principles and Practice
Foley
van Dam
Feiner
Hughes
Alan Watt
Third Edition
3D Computer Graphic

Environment matting

blue screen matting

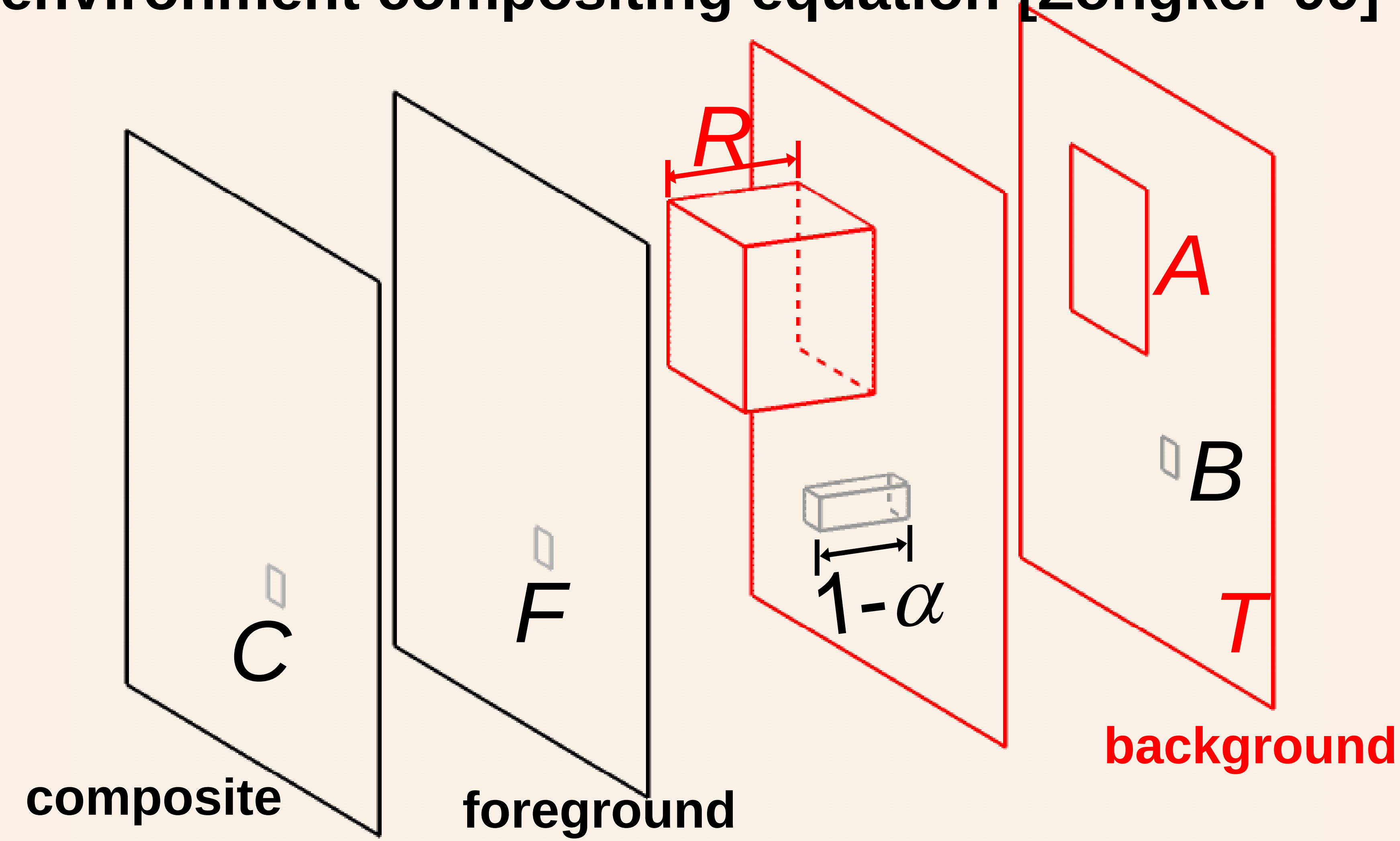
photograph

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

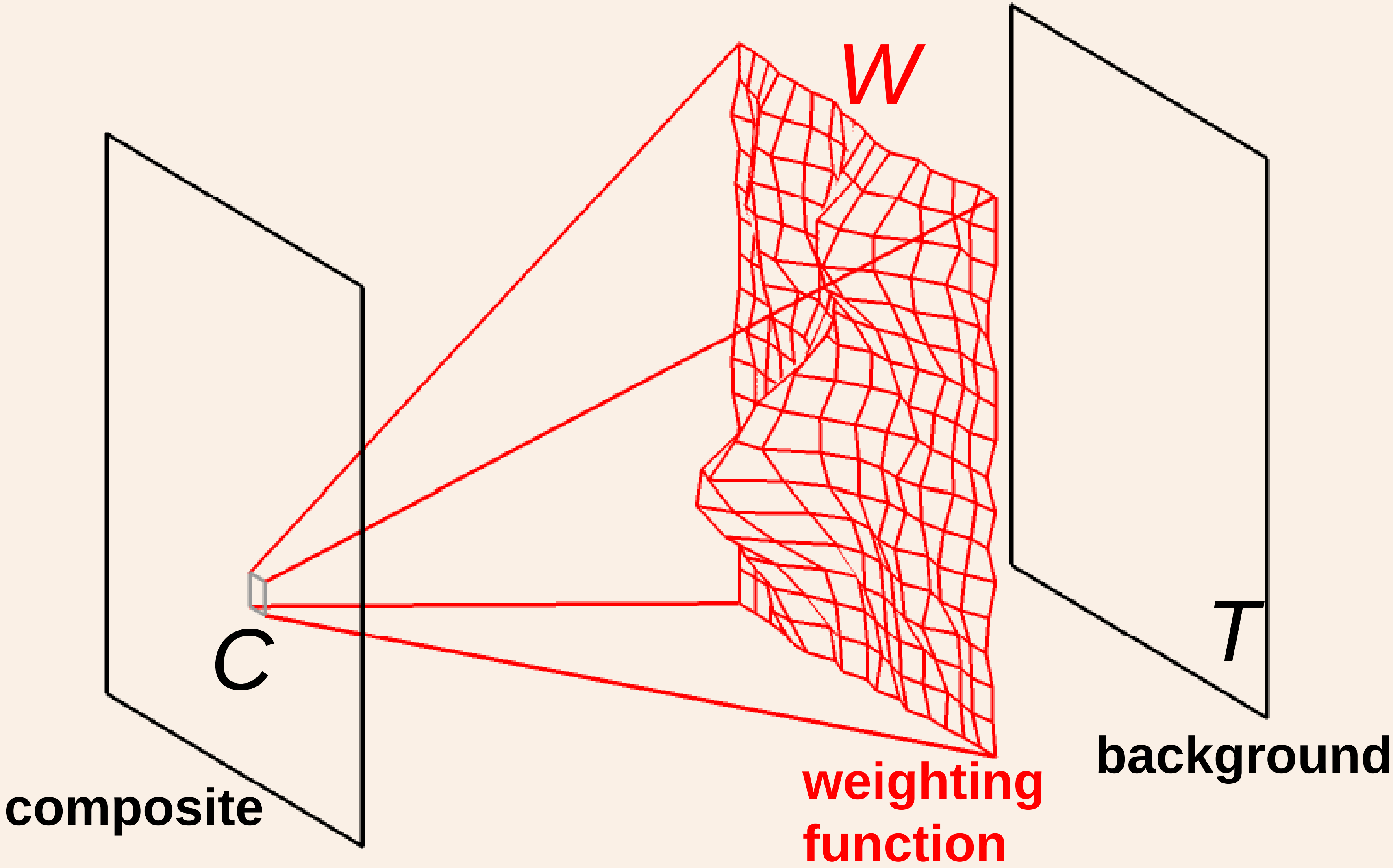
Zongker et al. **photograph**

Problem: glossy surface

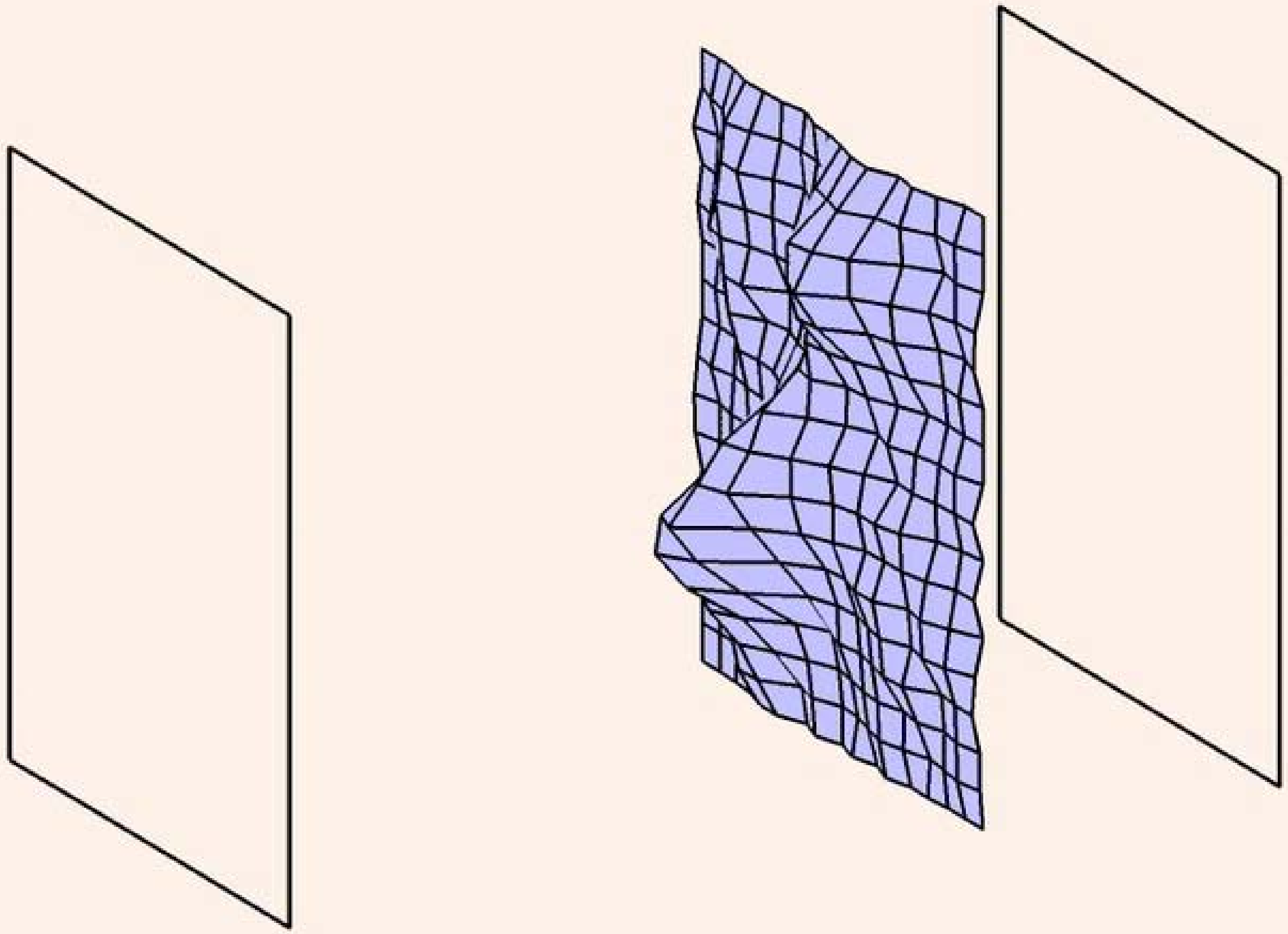
Zongker et al.

photograph

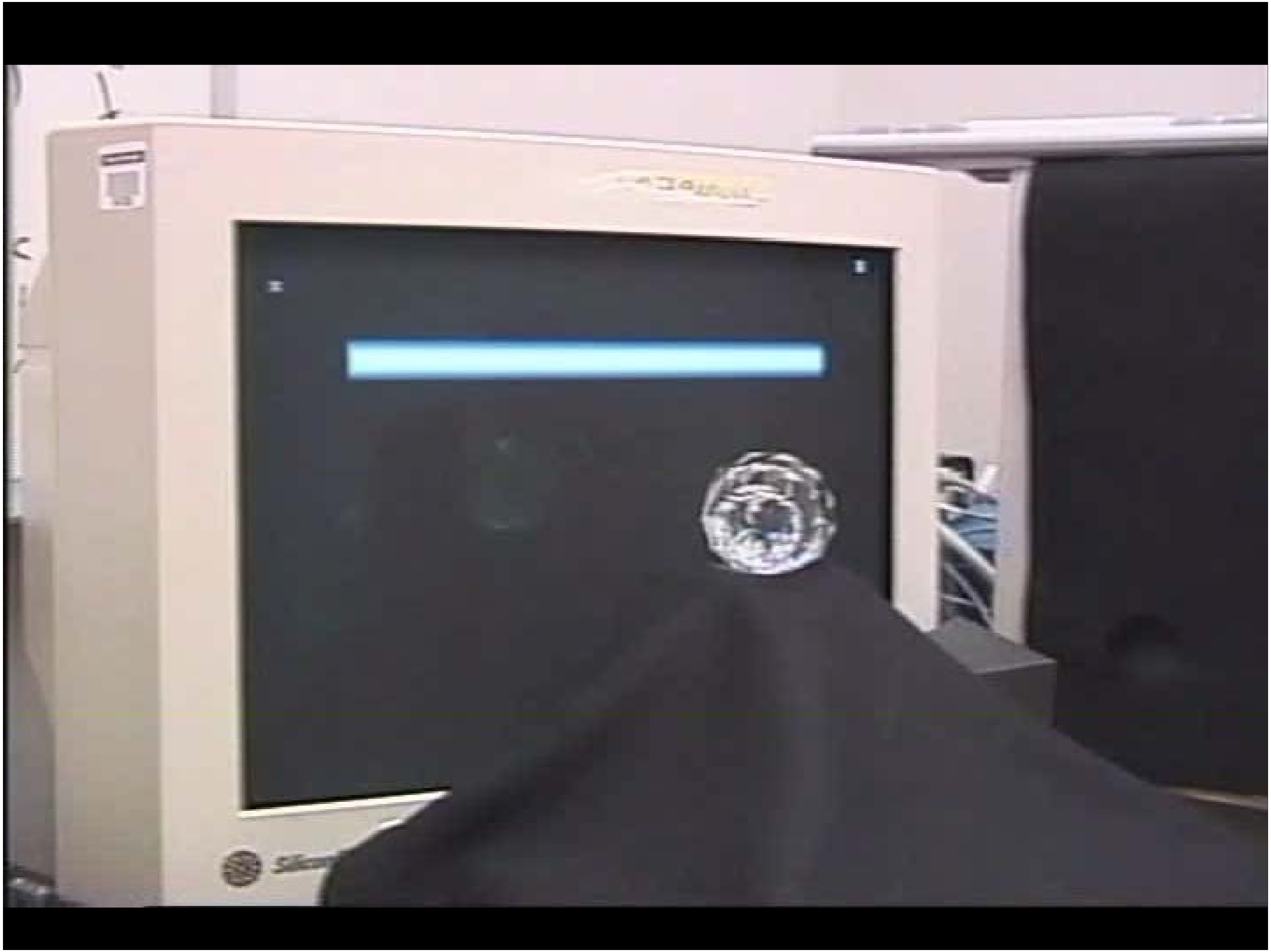
Problem: multiple mappings



$$C = F + \int W\,T$$



Multimodal oriented Gaussian



high accuracy algorithm

photograph

Problem: color dispersion

high accuracy algorithm

photograph

Glossy surface

with orientation

photograph

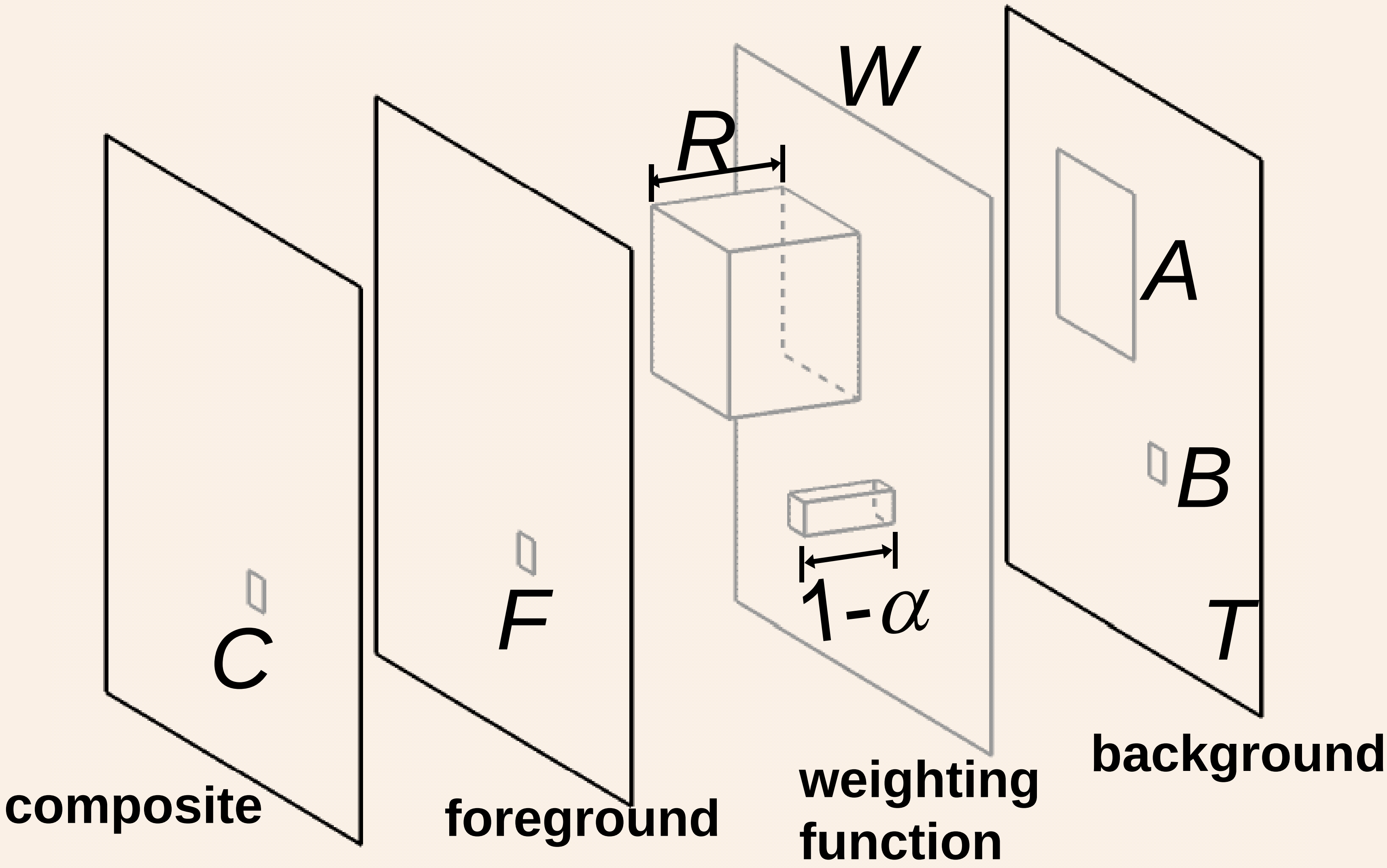
Oriented Gaussian

high accuracy algorithm

photograph

Problem: multiple mappings

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



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

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 ⟶ A, ρ
- α colorless
- F

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

3 1 1 1

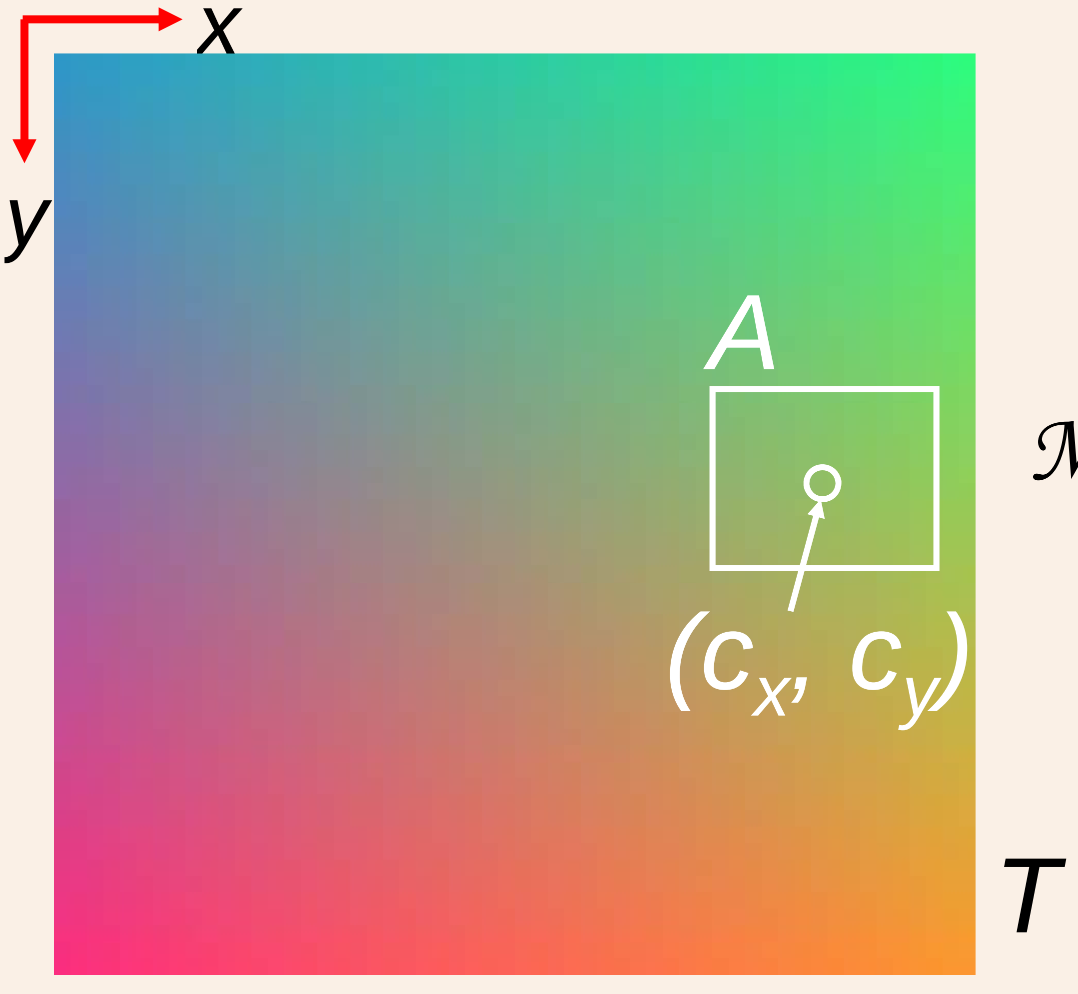
3 observations

3 variables

- $A, R \longrightarrow A, \rho \longrightarrow c_x, c_y, \rho$

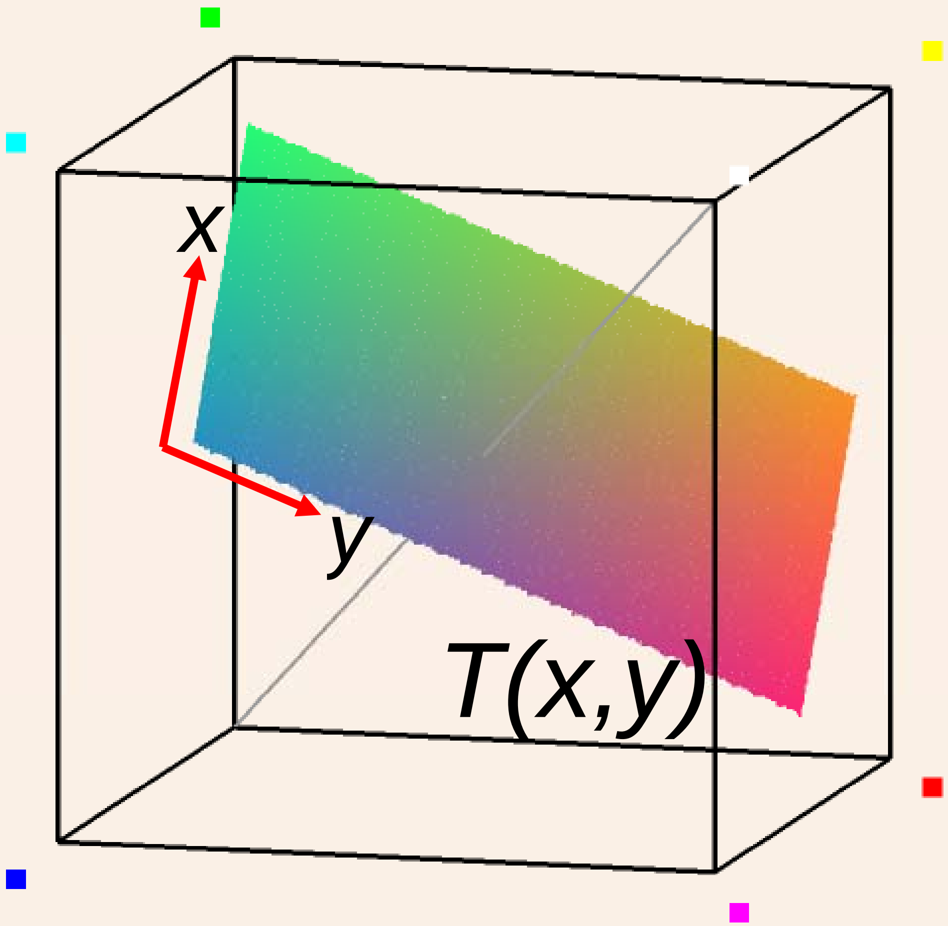
  colorless specularly refractive
- α
- F

Stimulus function

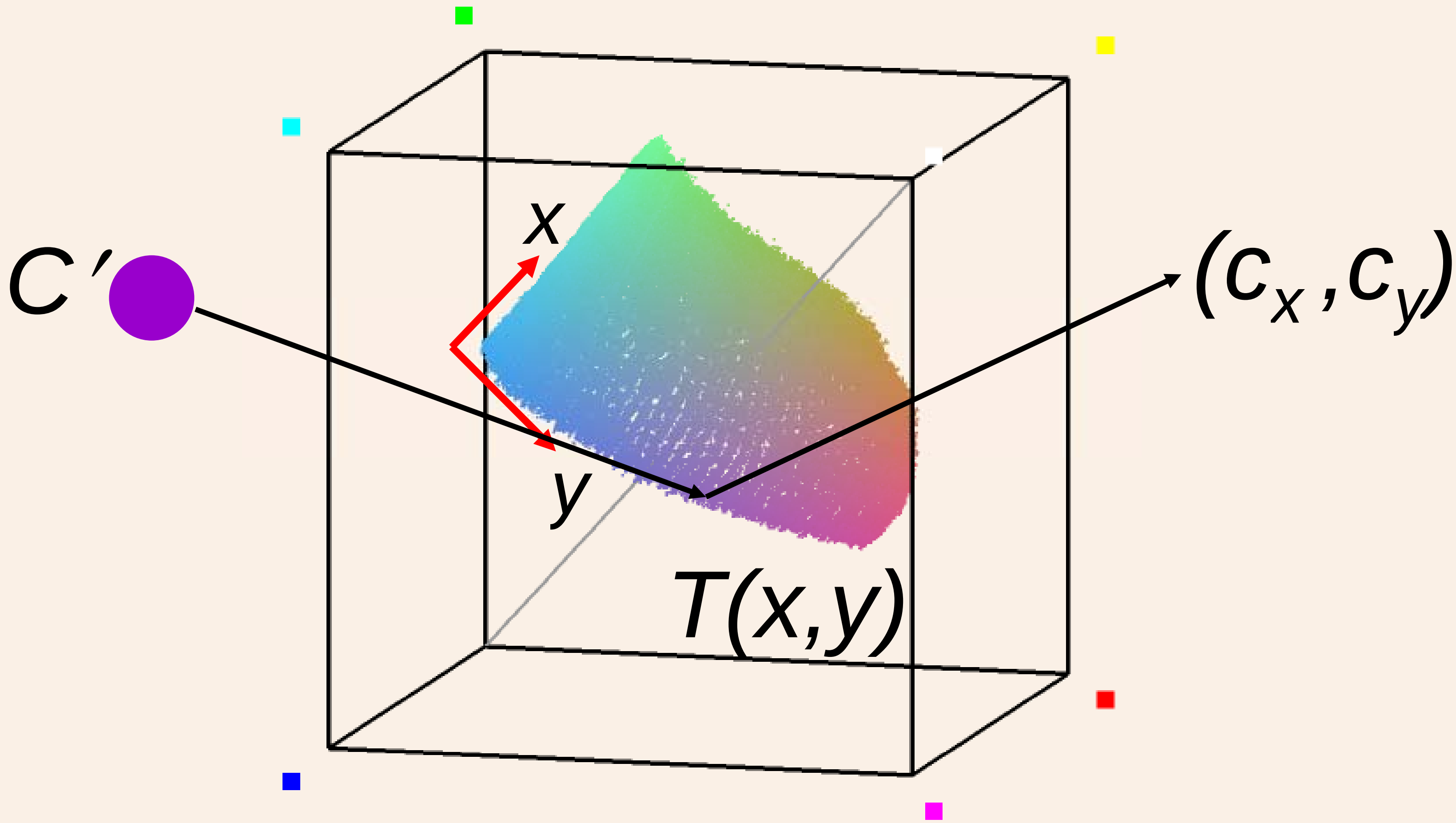


$$\mathcal{M}(T, A) \approx T(c_x, c_y)$$

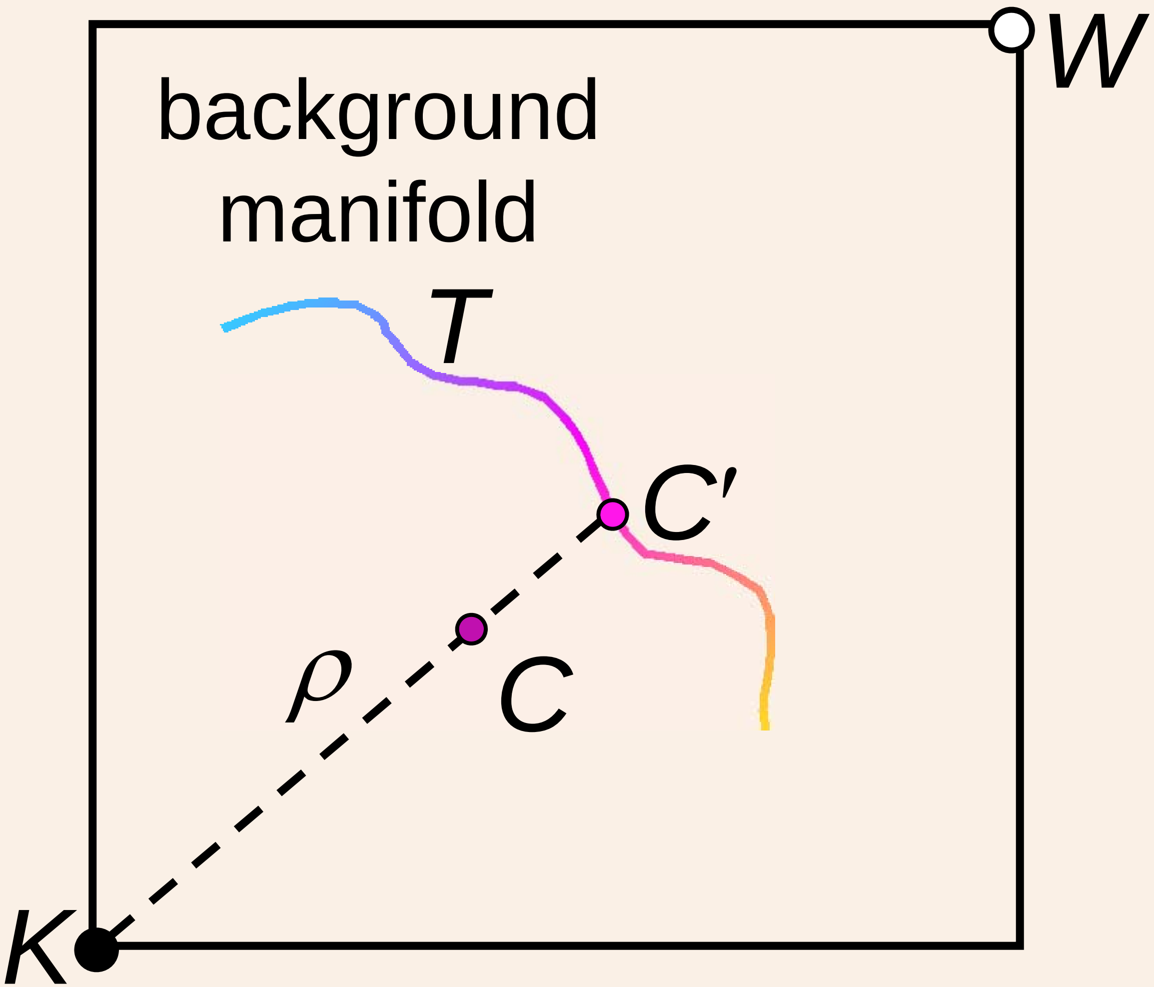
Ideal plane in RGB cube



Calibrated manifold in RGB cube



Estimate c_x , c_y *and* ρ



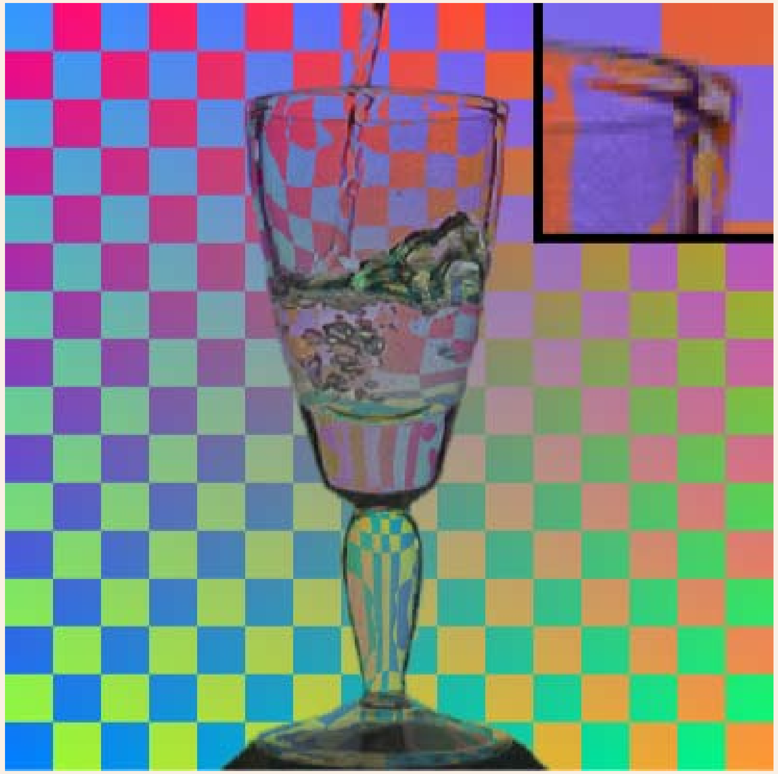
$$C' \rightarrow (c_x, c_y)$$

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

Problem: noisy matte

Edge-preserving filtering

without filtering

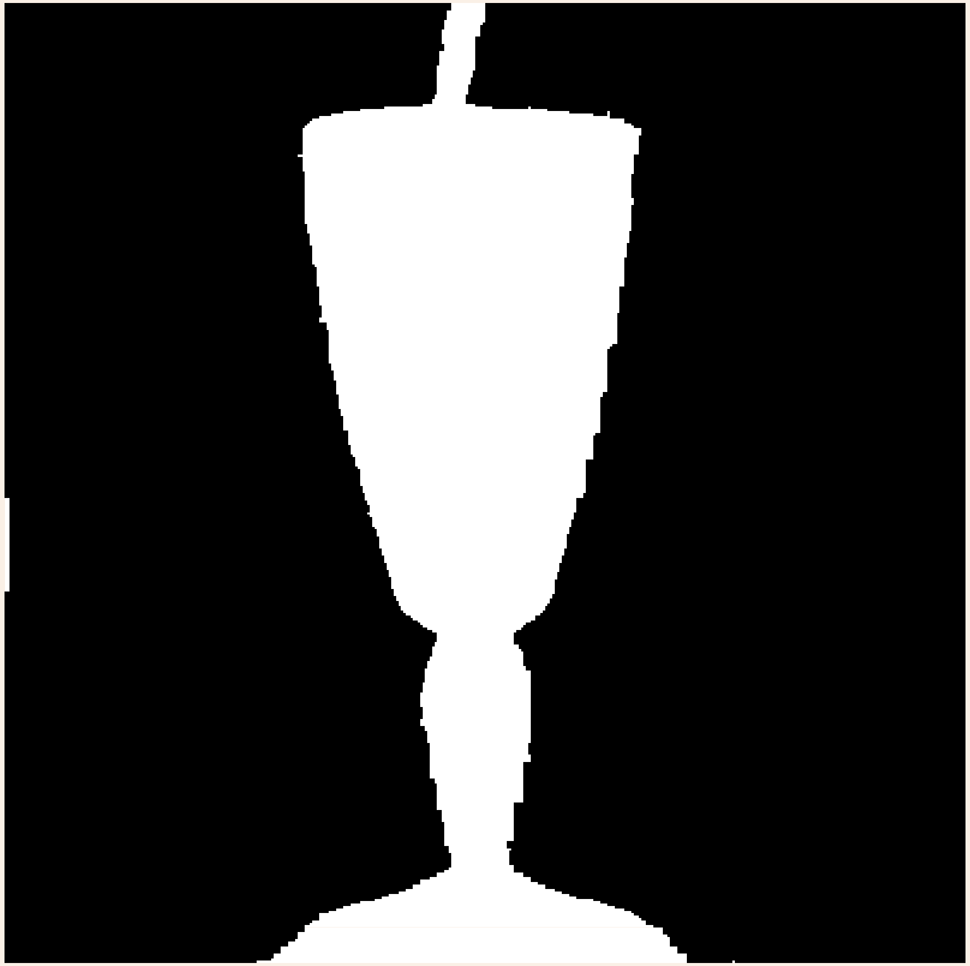


with filtering

Input image

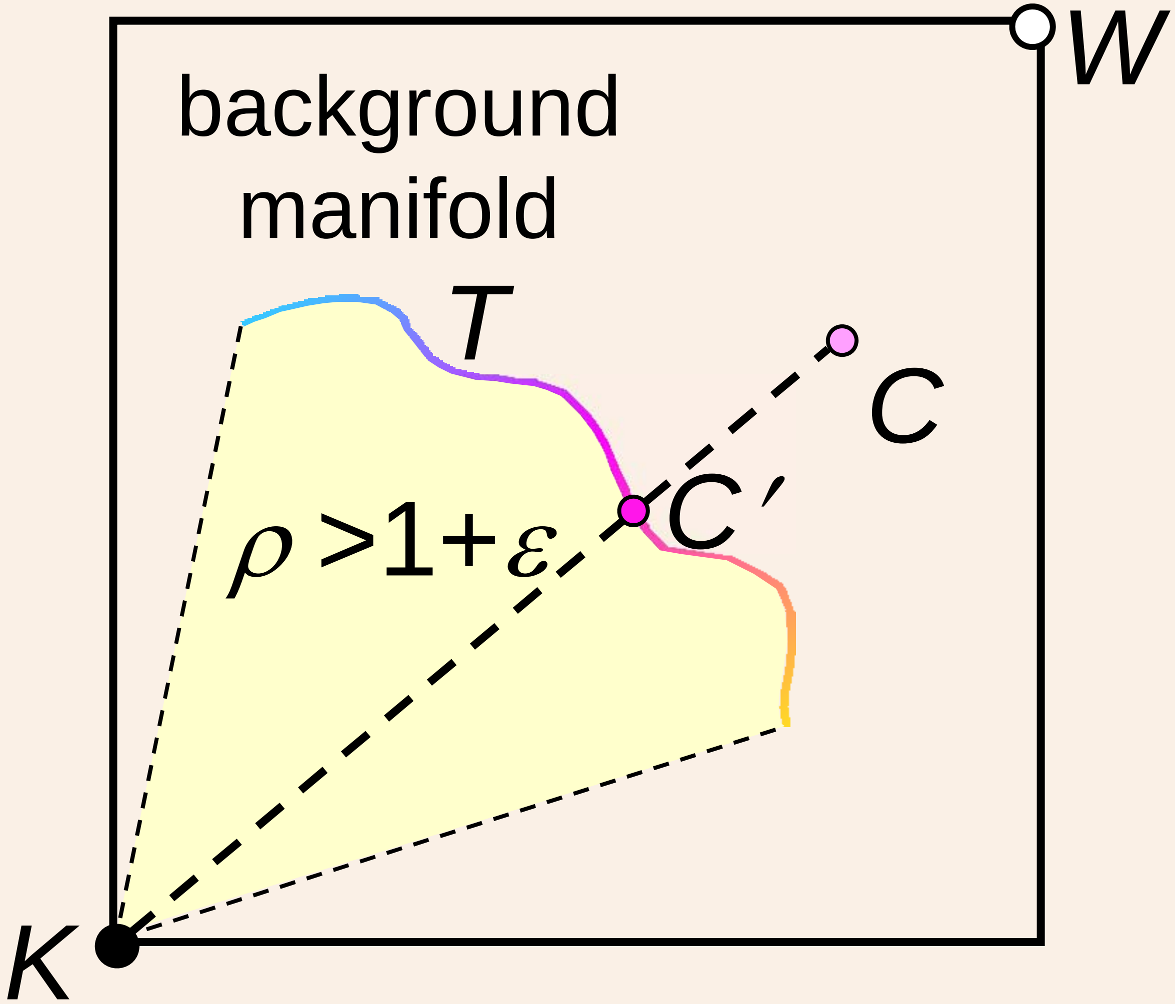
Difference thresholding

Morphological operation

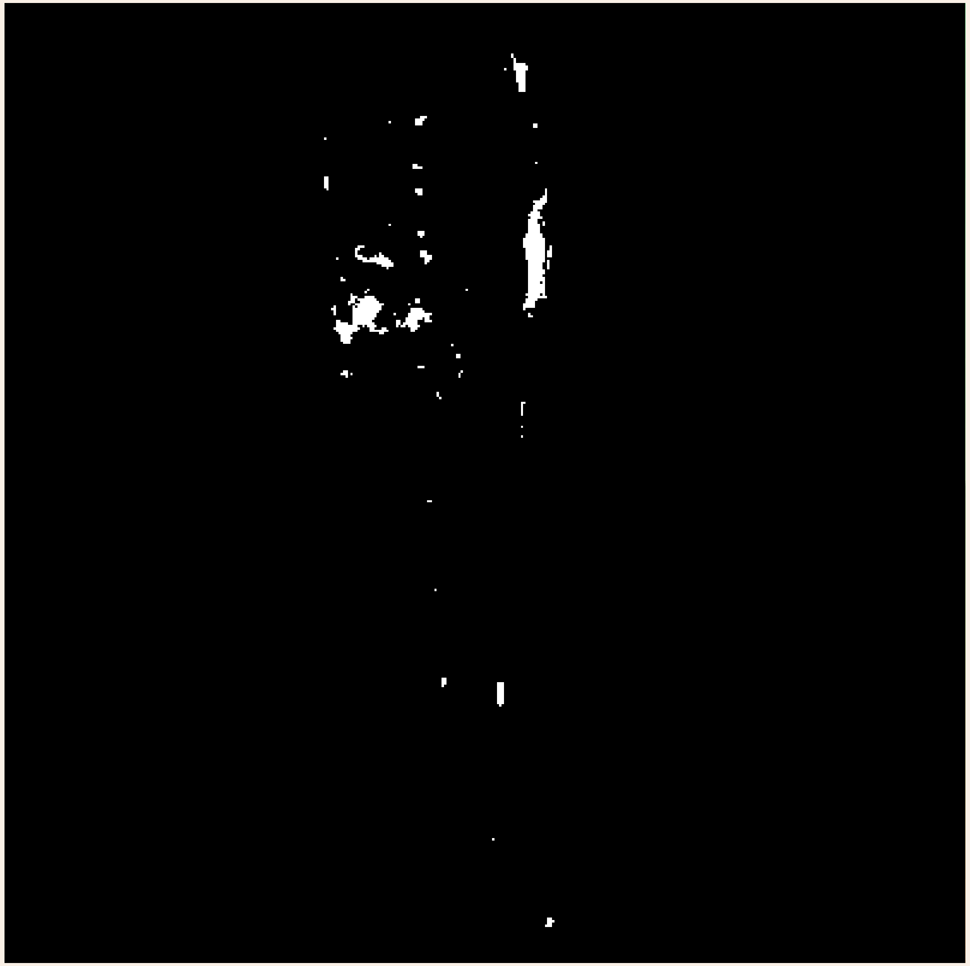


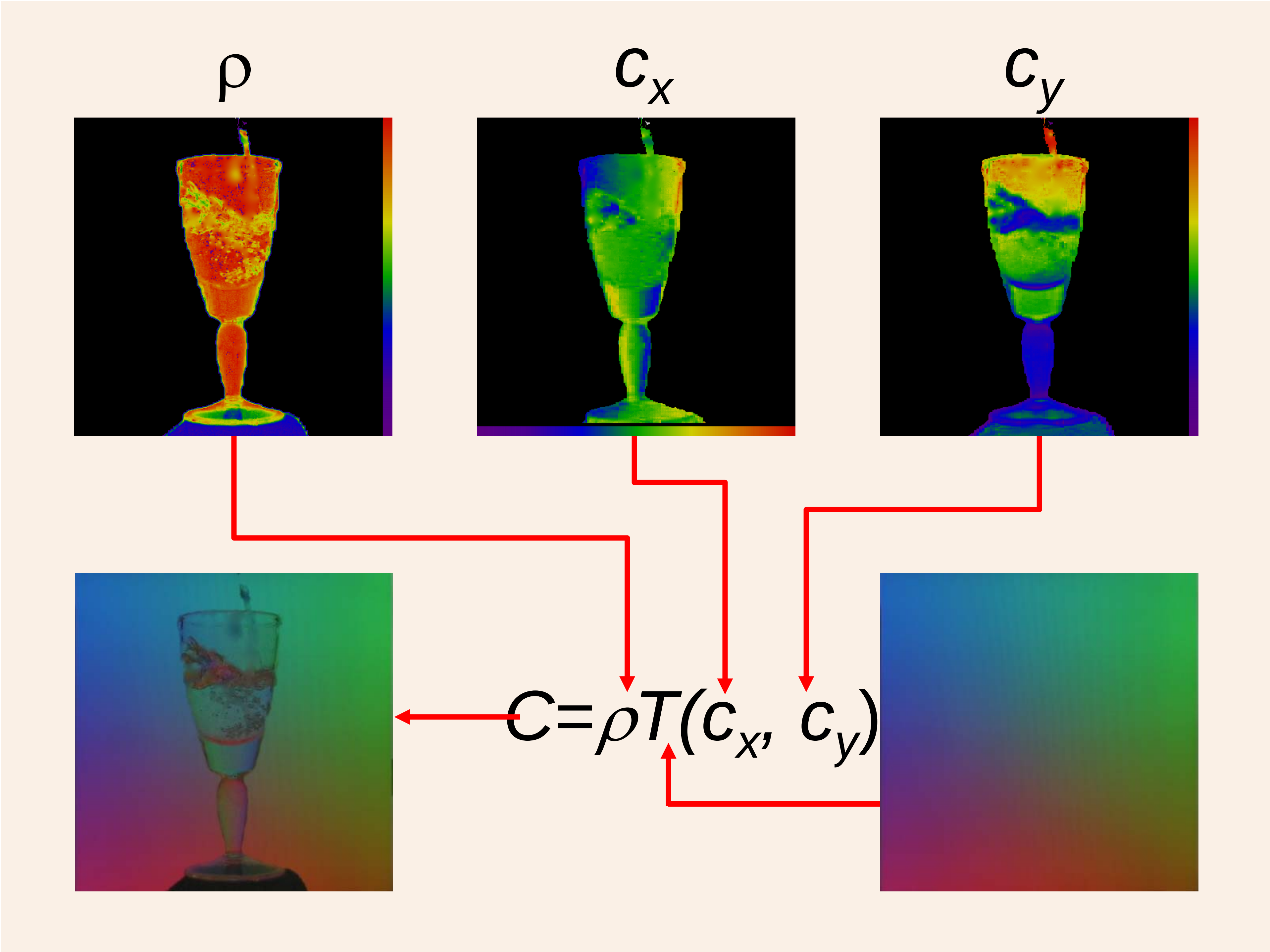
Feathering

Heuristics for specular highlights



Heuristics for specular highlights




ρ
c_x
c_y
$C=\rho T(c_x, c_y)$

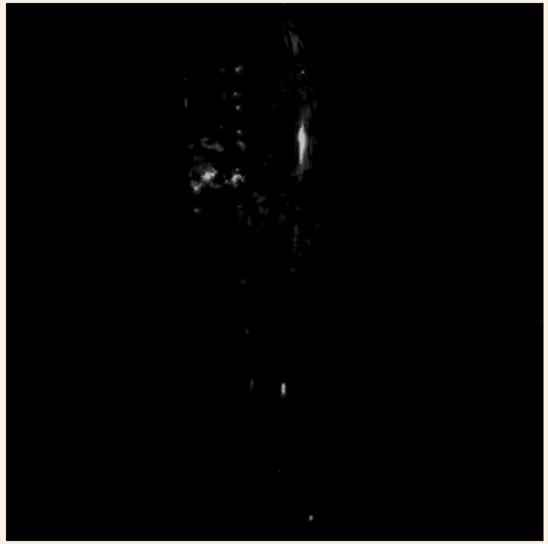
Heuristics for specular highlights

input

–

estimation

=



foreground (highlights)

Composite with highlights


3369 52264

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