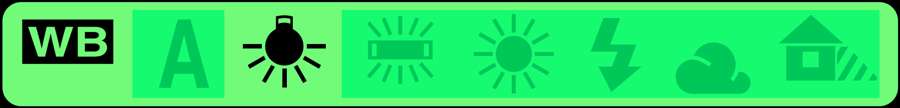
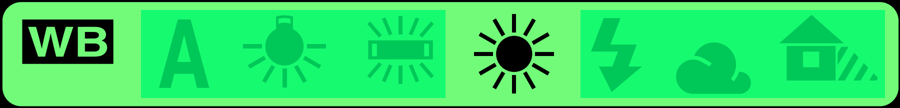
Light Mixture Estimation for Spatially Varying White Balance

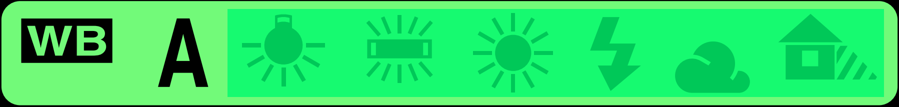
Eugene Hsu
Tom Mertens
Sylvain Paris
Shai Avidan
Frédo Durand


WB

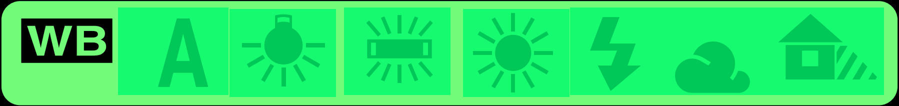

WB
A

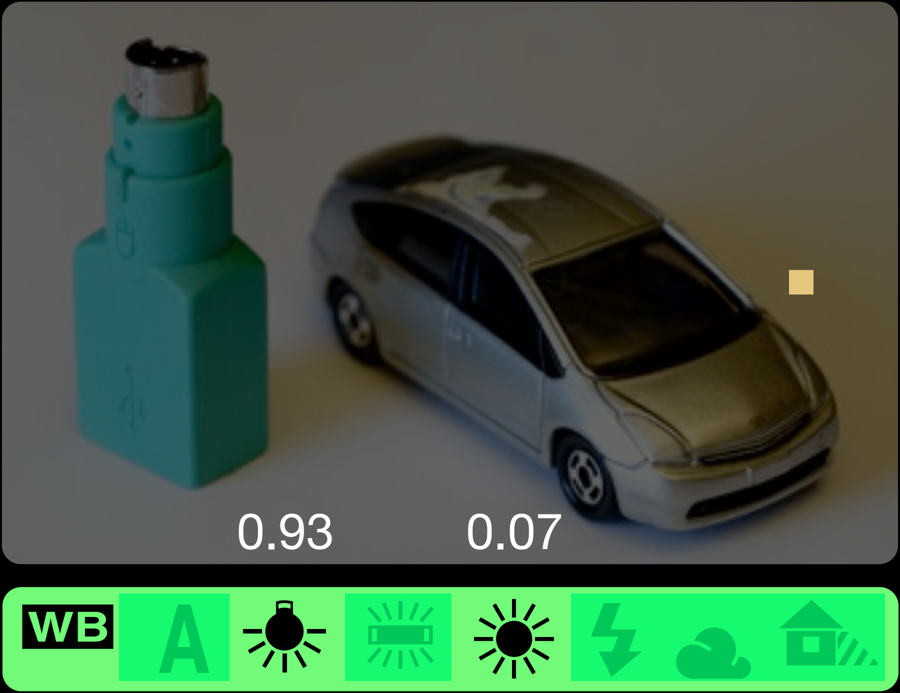

WB

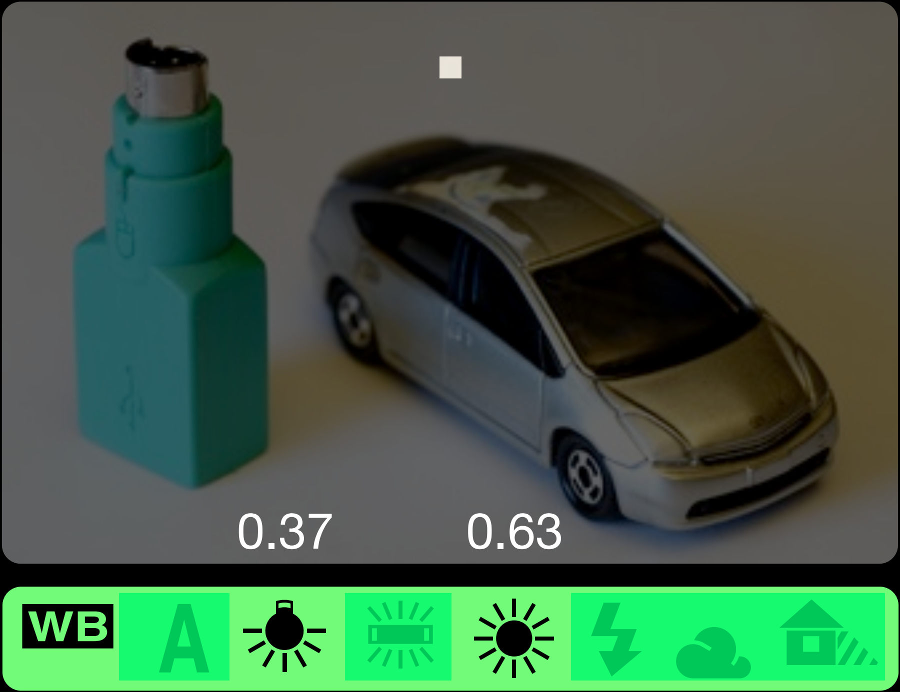

WB
A


WB
A

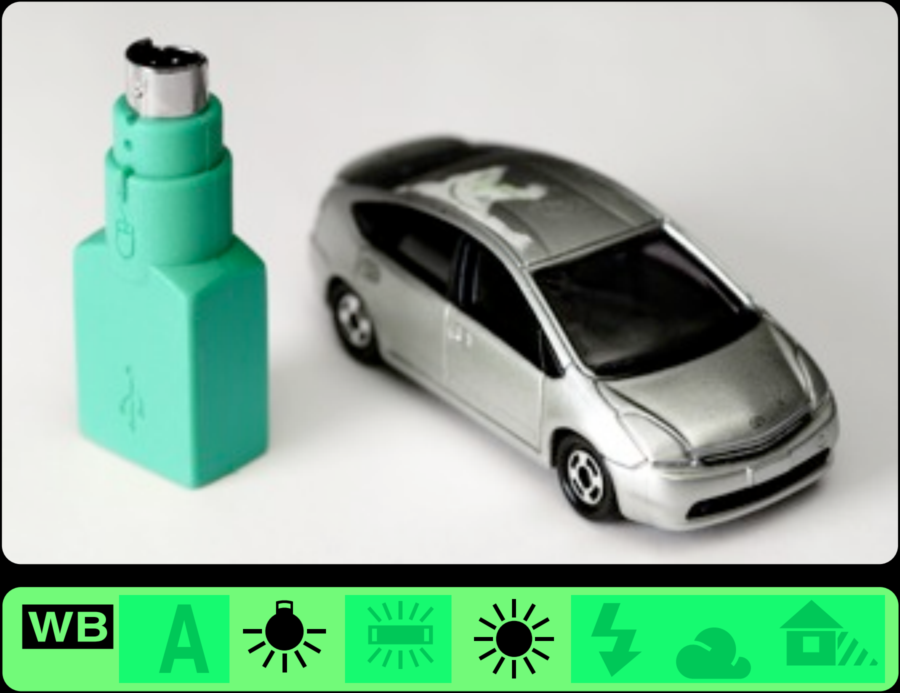

0.02
0.98


WB
A


0.93
0.07
WB


0.37
0.63
WB
A


WB
A


WB
A

Background

Film photographers use color filters during exposure or printing.

Digital cameras simplify this process, but they don't handle mixed lighting.

For mixed lighting, filter each source to emulate single illuminant case.

Barnard [1997]
… smooth lighting

Ebner [2004]
… locally neutral

Kawakami [2005]
… hard shadows

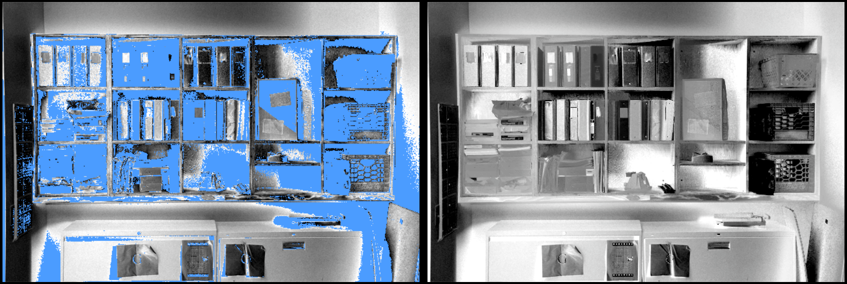
Lischinski [2006]
… user scribbles

Overview

The input is a scene illuminated by two light types given by the user.

We assume that a few material colors dominate [Omer and Werman 2004].

We vote on these dominant material colors and label pixels accordingly.



We then estimate the light mixture and interpolate missing values.

We use the light mixture to achieve spatially varying white balance.

White Balance

$$\begin{bmatrix} I_R \\ I_G \\ I_B \end{bmatrix} = \begin{bmatrix} R_R \\ R_G \\ R_B \end{bmatrix} \bullet \boxed{k \begin{bmatrix} L_R \\ L_G \\ L_B \end{bmatrix}}$$

Observed pixel color is material color multiplied by scaled light color.

$$\begin{bmatrix}W_R\\W_G\\W_B\end{bmatrix} \bullet \begin{bmatrix}I_R\\I_G\\I_B\end{bmatrix} = \begin{bmatrix}R_R\\R_G\\R_B\end{bmatrix} \bullet \boxed{k \begin{bmatrix}L_R\\L_G\\L_B\end{bmatrix}} \div \begin{bmatrix}L_R\\L_G\\L_B\end{bmatrix}$$

Proper white balance is achieved by inverting the light source color.

$$\begin{bmatrix} W_R \\ W_G \\ W_B \end{bmatrix} \bullet \begin{bmatrix} I_R \\ I_G \\ I_B \end{bmatrix} = \begin{bmatrix} R_R \\ R_G \\ R_B \end{bmatrix} \bullet \boxed{k \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix}}$$

Proper white balance is achieved by inverting the light source color.

$$\begin{bmatrix} I_R \\ I_G \\ I_B \end{bmatrix} = \begin{bmatrix} R_R \\ R_G \\ R_B \end{bmatrix} \bullet \boxed{k_1 \begin{bmatrix} L_{1R} \\ L_{1G} \\ L_{1B} \end{bmatrix} + k_2 \begin{bmatrix} L_{2R} \\ L_{2G} \\ L_{2B} \end{bmatrix}}$$

Our technique assumes two lights.

$$\begin{bmatrix} I_R \\ I_G \\ I_B \end{bmatrix} = \begin{bmatrix} R_R \\ R_G \\ R_B \end{bmatrix} \bullet \boxed{k_1 \quad + \quad k_2}$$

The goal of white balance is to show the scene under neutral illumination.

$$\begin{matrix} W_R \\ W_G \\ W_B \end{matrix}$$

$$\alpha = k_1 \div \boxed{k_1 + k_2}$$

Proper white balance is defined by the relative mixture of the lights.

$$\begin{bmatrix} I_R \\ I_G \\ I_B \end{bmatrix} = \begin{bmatrix} R_R \\ R_G \\ R_B \end{bmatrix} \bullet \boxed{k_1 \begin{bmatrix} L_{1R} \\ L_{1G} \\ L_{1B} \end{bmatrix} + k_2 \begin{bmatrix} L_{2R} \\ L_{2G} \\ L_{2B} \end{bmatrix}}$$

$$\alpha = k_1 \div \boxed{k_1 + k_2}$$

Solving for α is underconstrained since the material color is not given.

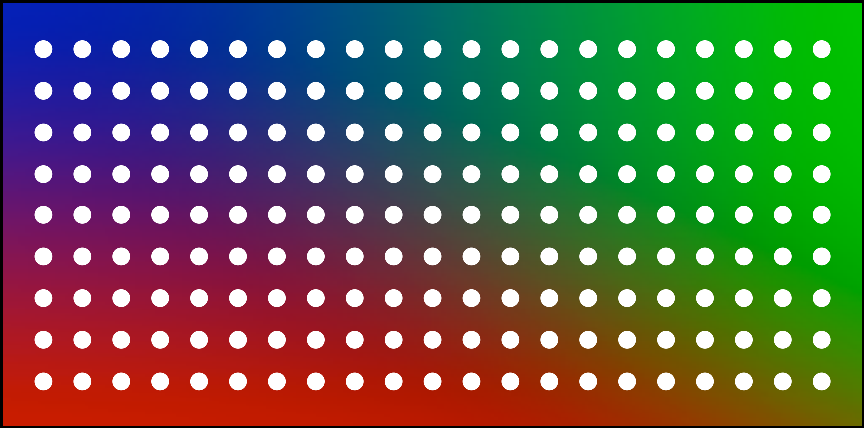
α	α	α	α	α	α	α	α	α	α
α	α	α	α	α	α	α	α	α	α
α	α	α	α	α	α	α	α	α	α
α	α	α	α	α	α	α	α	α	α
α	α	α	α	α	α	α	α	α	α
α	α	α	α	α	α	α	α	α	α
α	α	α	α	α	α	α	α	α	α
α	α	α	α	α	α	α	α	α	α
α	α	α	α	α	α	α	α	α	α
α	α	α	α	α	α	α	α	α	α
α	α	α	α	α	α	α	α	α	α
α	α	α	α	α	α	α	α	α	α

Material Color Estimation

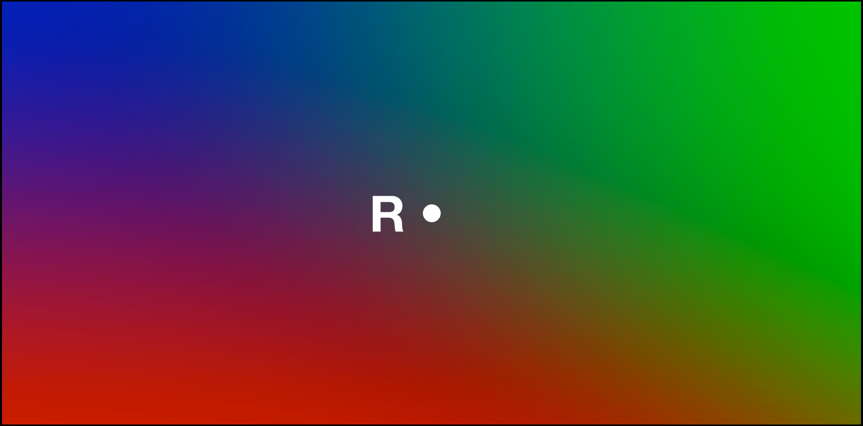

G
G


G
G

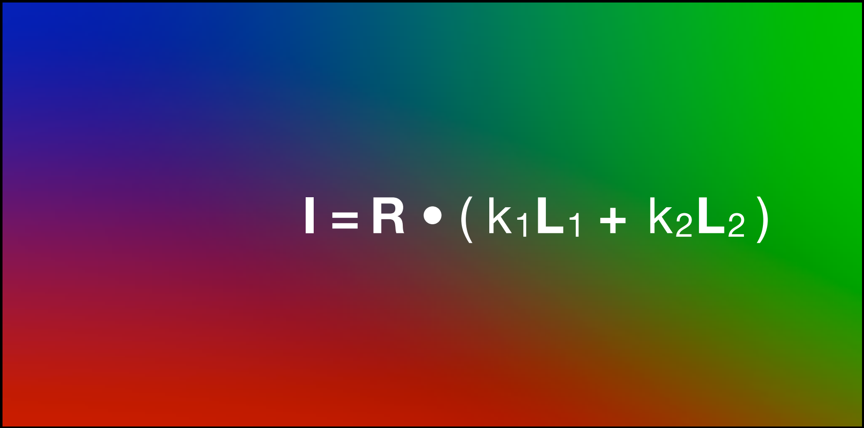

G



Sample material colors and find the one that accounts for the most pixels.

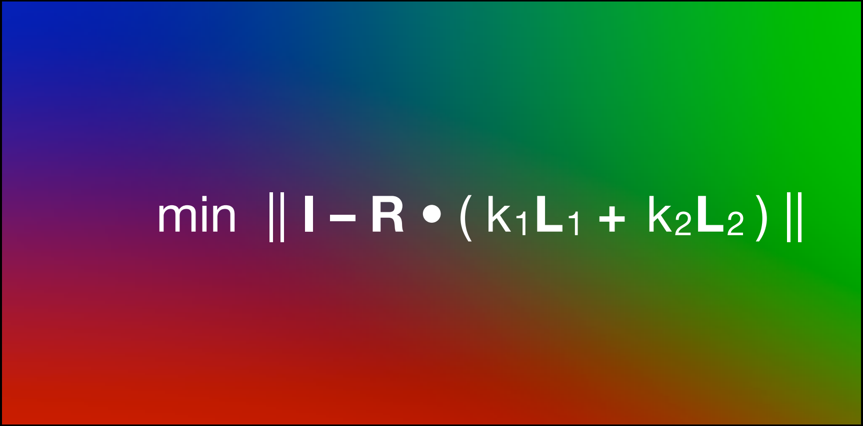


Given a candidate material color …



$$\mathbf{I} = \mathbf{R} \bullet (\, k_1\mathbf{L}_1 + k_2\mathbf{L}_2 \,)$$

… how it could appear in the image?



$$\min \; \| \mathbf{I} - \mathbf{R} \bullet (k_1 \mathbf{L}_1 + k_2 \mathbf{L}_2) \|$$

… what could be that material color?

$$t \geq \min \| \mathbf{I} - \mathbf{R} \bullet (k_1 \mathbf{L}_1 + k_2 \mathbf{L}_2) \|$$

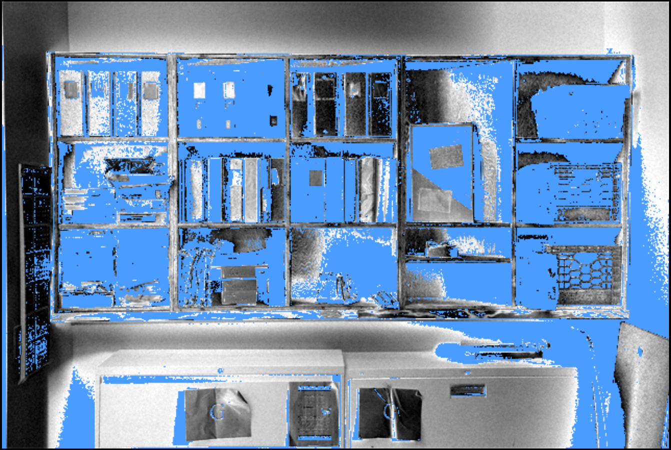
If this expression holds, we say that the pixel votes for the material color.


G
G

48%

48%
16%

48%
16%



Mixture Interpolation

$$\begin{bmatrix} I_R \\ I_G \\ I_B \end{bmatrix} = \begin{bmatrix} R_R \\ R_G \\ R_B \end{bmatrix} \bullet \boxed{ \begin{bmatrix} k_1 \end{bmatrix} \begin{bmatrix} L_{1R} \\ L_{1G} \\ L_{1B} \end{bmatrix} + \begin{bmatrix} k_2 \end{bmatrix} \begin{bmatrix} L_{2R} \\ L_{2G} \\ L_{2B} \end{bmatrix} }$$

… assume that $\mathbf{L_{1B}}$ and $\mathbf{L_{2B}}$ are 1.

… divide out the blue channels.

$$\begin{bmatrix} I_{R \div B} \\ I_{G \div B} \end{bmatrix} = \begin{bmatrix} R_{R \div B} \\ R_{G \div B} \end{bmatrix} \bullet \boxed{ \begin{bmatrix} \alpha \end{bmatrix} \begin{bmatrix} L_{1R \div B} \\ L_{1G \div B} \end{bmatrix} + \begin{bmatrix} 1-\alpha \end{bmatrix} \begin{bmatrix} L_{2R \div B} \\ L_{2G \div B} \end{bmatrix} }$$

$$\begin{bmatrix} I_{R \div B} \\ I_{G \div B} \end{bmatrix} = \begin{bmatrix} R_{R \div B} \\ R_{G \div B} \end{bmatrix} \bullet \boxed{\alpha \begin{bmatrix} L_{1 R \div B} \\ L_{1 G \div B} \end{bmatrix} + (1-\alpha) \begin{bmatrix} L_{2 R \div B} \\ L_{2 G \div B} \end{bmatrix}}$$

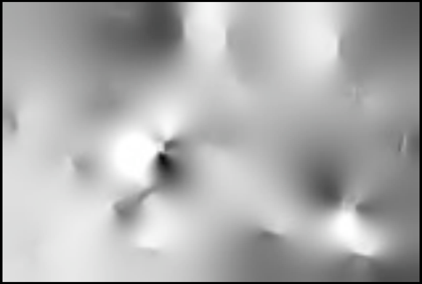
T ook xactly lik age ma g!

$$\begin{bmatrix} I_{R\div B} \\ I_{G\div B} \end{bmatrix} = \begin{bmatrix} R_{R\div B} \\ R_{G\div B} \end{bmatrix} \bullet \boxed{\alpha \begin{bmatrix} L_{1R\div B} \\ L_{1G\div B} \end{bmatrix} + 1-\alpha \begin{bmatrix} L_{2R\div B} \\ L_{2G\div B} \end{bmatrix}}$$

We perform interpolation using the matting Laplacian [Levin et al. 2006].

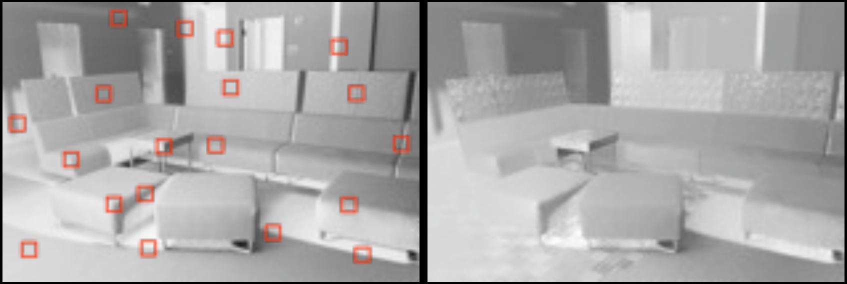
This scene was shot using multiple exposures, so we have ground truth.

We constrain the points in the red squares and interpolate the rest.

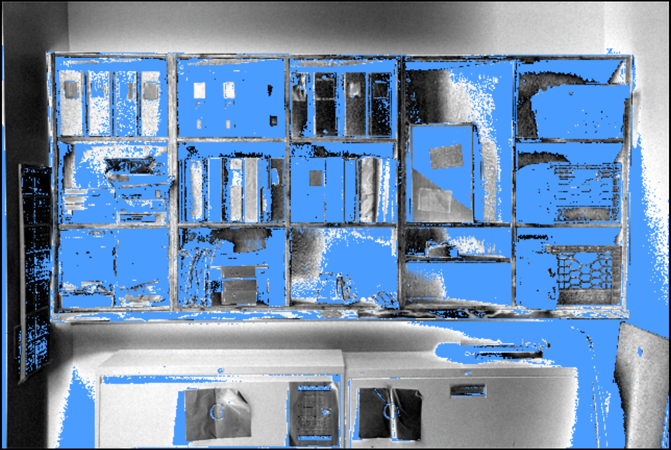
 

Smooth interpolation is pretty bad.

Edge-aware interpolation is also bad.



Matting Laplacian is much better.




G
G

Results

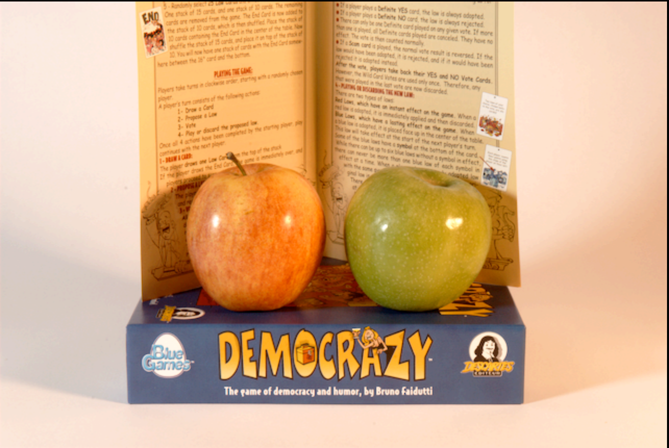
The following results use synthetic inputs from multiple exposures to allow ground truth evaluations.

Input

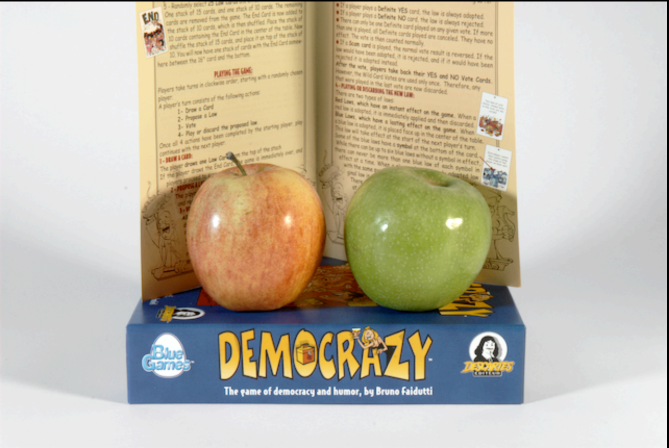
Output

Ground Truth

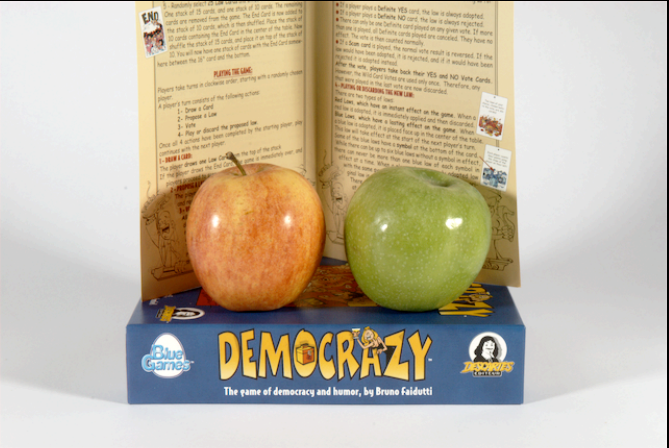
Output


DEMOCRAZY
The game of democracy and humor, by Bruno Faidutti
Blue Games

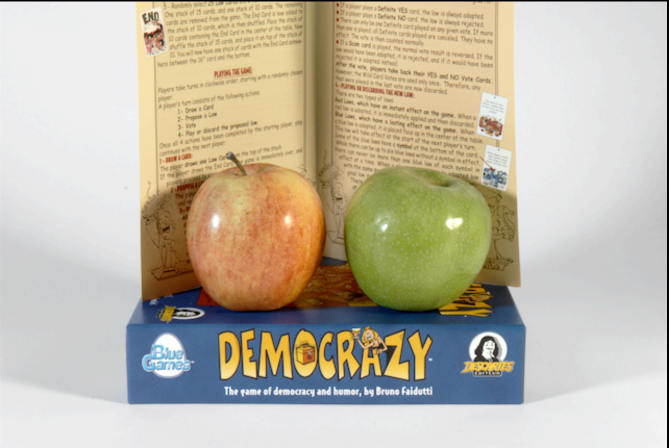
Input


Blue Games
DEMOCRAZY
The game of democracy and humor, by Bruno Faidutti

Output



Ground Truth


DEMOCRAZY
The game of democracy and humor, by Bruno Faidutti

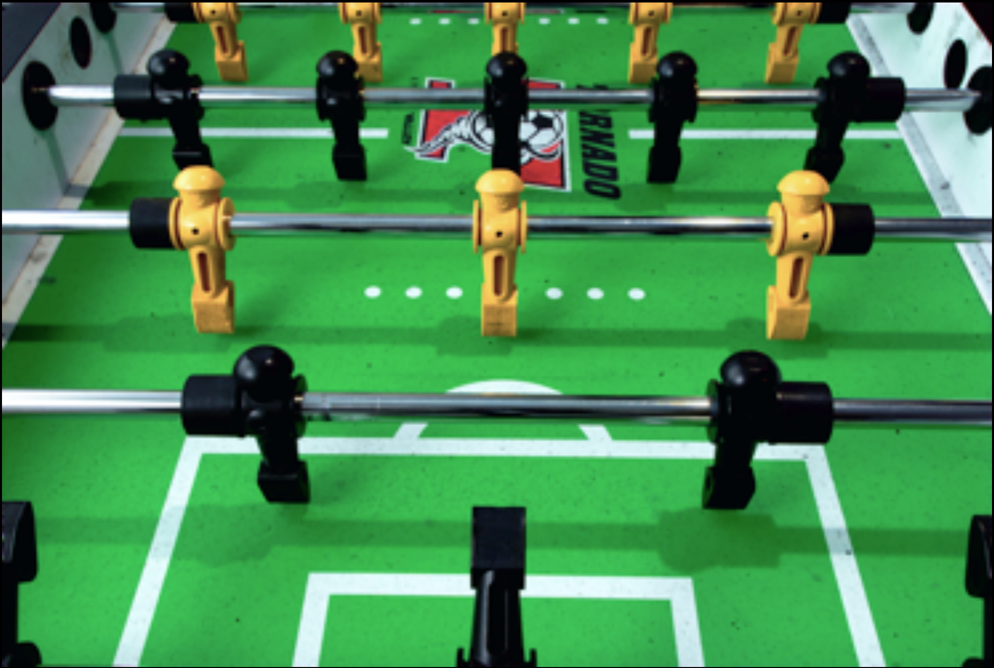
Output

The following results are from single exposures with real mixed lighting.

Input

Output

Input



Output

Input

Output

Input

Output


HOLGA
120N
OPTICAL LENS
1:8 f=60mm
ILFORD
FP4 PLUS
ISO 125/22°
120

Input


ILFORD
FP4 PLUS
ISO 125/22°
120
HOLGA
120N
OPTICAL LENS
1:8 f=60mm

Output

Input

Output

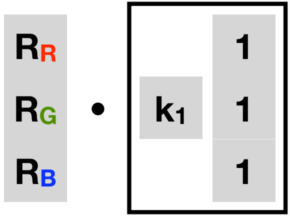
Relighting

$$\begin{bmatrix} R_R \\ R_G \\ R_B \end{bmatrix} \bullet \boxed{k_1 \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} + k_2 \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix}}$$

From the white balanced image, separate the lighting contributions.

$$\begin{bmatrix} R_R \\ R_G \\ R_B \end{bmatrix} \bullet \boxed{k_1 \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} + k_2 \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix}} \bullet \alpha \div \boxed{k_1 + k_2}$$

Multiply the white balanced image by α for the first contribution.



Multiply the white balanced image by α for the first contribution.

$$\begin{bmatrix} R_R \\ R_G \\ R_B \end{bmatrix} \bullet \boxed{\begin{matrix} & 1 \\ k_1 & 1 \\ & 1 \end{matrix}} \qquad \begin{bmatrix} R_R \\ R_G \\ R_B \end{bmatrix} \bullet \boxed{\begin{matrix} & 1 \\ k_2 & 1 \\ & 1 \end{matrix}}$$

Multiply the white balanced image by 1–α for the second contribution.

$$\begin{bmatrix} R_R \\ R_G \\ R_B \end{bmatrix} \bullet \boxed{k_1 \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix}} \bullet \begin{bmatrix} L_{1R} \\ L_{1G} \\ L_{1B} \end{bmatrix} + \begin{bmatrix} R_R \\ R_G \\ R_B \end{bmatrix} \bullet \boxed{k_2 \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix}} \bullet \begin{bmatrix} L_{2R} \\ L_{2G} \\ L_{2B} \end{bmatrix}$$

We can choose new lights and add the images to get the desired effect.

Input

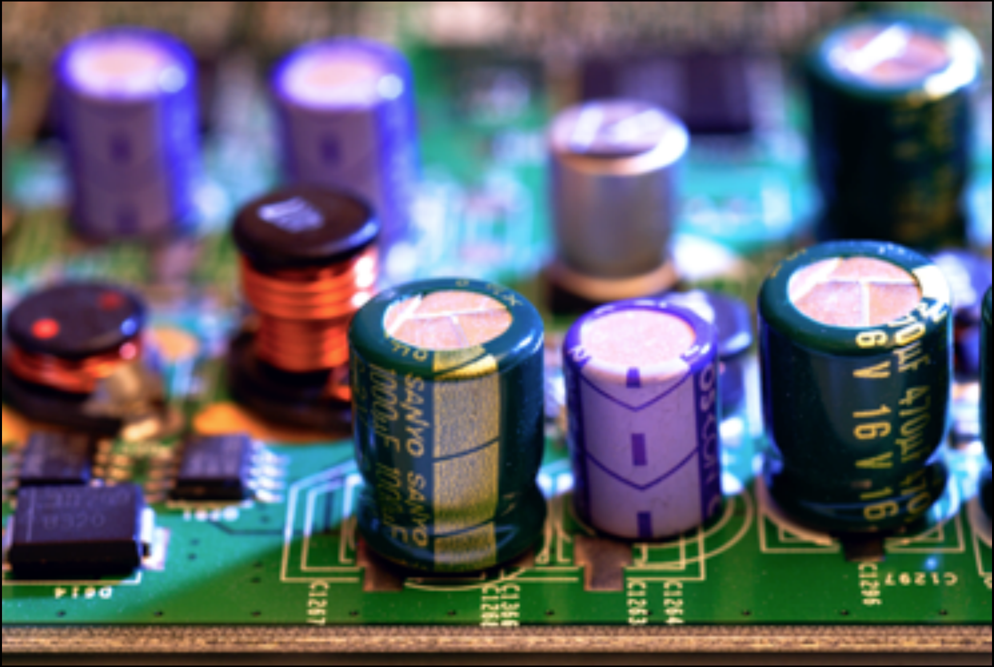
Output

Output

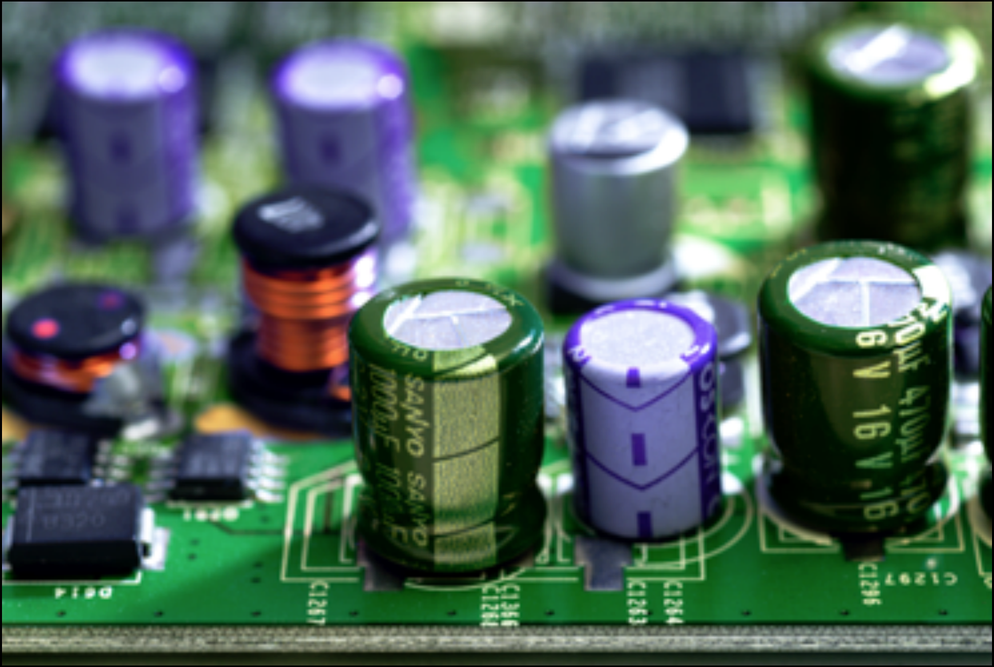
Input

Output

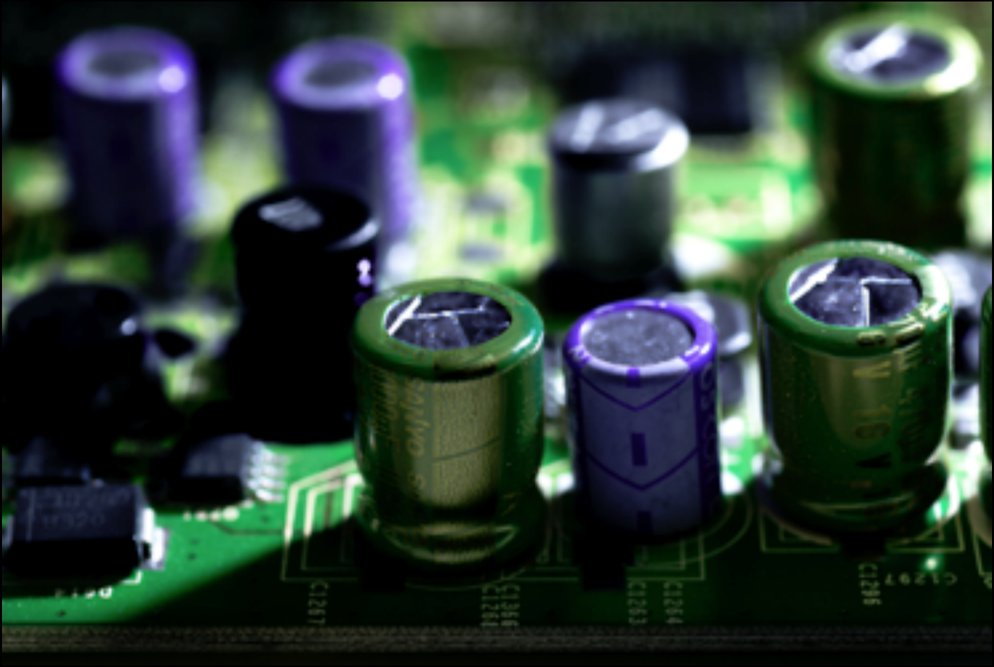
Output



Input



Output



Output

Discussion

There are two types of light in the scene which the user must identify …

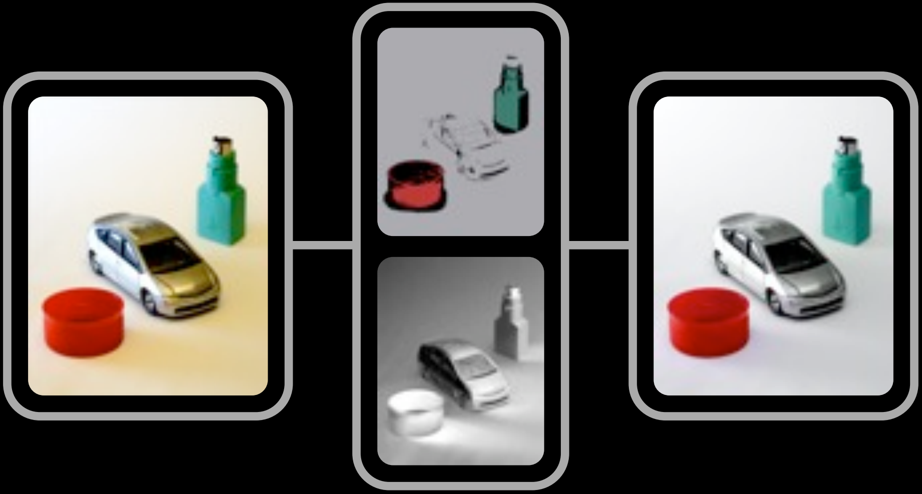
… can we automate identification?

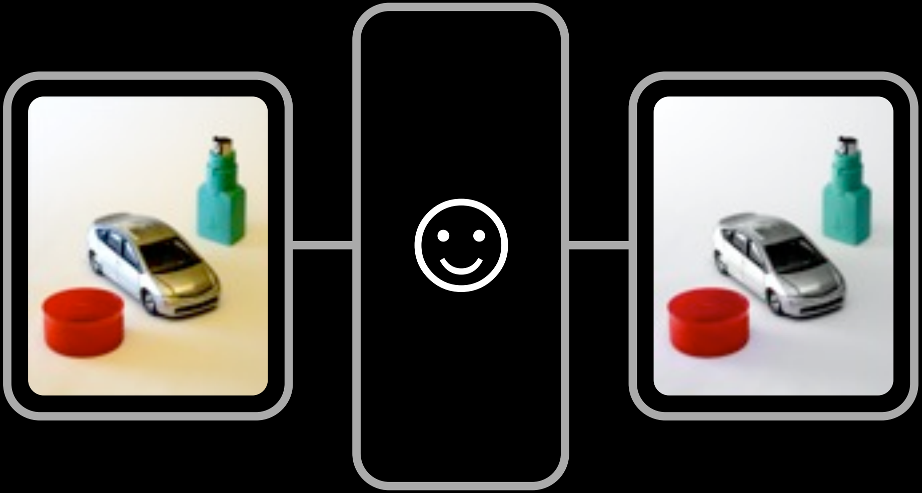
… why not allow more light types?

The scene is dominated by a small set of material colors …

The scene is dominated by a
small set of material colors …

… which must appear under
different mixtures of light.





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