Slide credits: Julio Marco

Sources: CMU 15-463, Dartmouth College CS89/189.

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Sources: CMU 15-463, Dartmouth College CS89/189.

Sources: CMU 15-463, Dartmouth College CS89/189.

Sources: CMU 15-463, Dartmouth College CS89/189.

Wavelength (Color) :: Multi-Sprectral Imaging

And more….

Sources: CMU 15-463, Dartmouth College CS89/189.

color filter array

pipeline

Sources: CMU 15-463, Dartmouth College CS89/189.

3D

2D

Sources: CMU 15-463, Dartmouth College CS89/189.

Sources: CMU 15-463, Dartmouth College CS89/189.

What would an image taken like this look like?

Sources: CMU 15-463, Dartmouth College CS89/189.

Sources: CMU 15-463, Dartmouth College CS89/189.

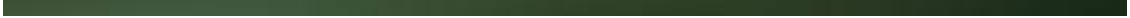
Sources: CMU 15-463, Dartmouth College CS89/189.

Sources: CMU 15-463, Dartmouth College CS89/189.

All scene points contribute to all sensor pixels

What does the image on the sensor look like?

Sources: CMU 15-463, Dartmouth College CS89/189.



All scene points contribute to all sensor pixels

Sources: CMU 15-463, Dartmouth College CS89/189.

Sources: CMU 15-463, Dartmouth College CS89/189.

What would an image taken like this look like?

Sources: CMU 15-463, Dartmouth College CS89/189.

it through

Sources: CMU 15-463, Dartmouth College CS89/189.

it through

Sources: CMU 15-463, Dartmouth College CS89/189.

Each scene point contributes to only one sensor pixel

What does the image on the sensor look like?

Sources: CMU 15-463, Dartmouth College CS89/189.

copy of real-world object
(inverted and scaled)

Sources: CMU 15-463, Dartmouth College CS89/189.

(470 to 390 BC)

Sources: CMU 15-463, Dartmouth College CS89/189.

Sources: CMU 15-463, Dartmouth College CS89/189.

Sources: CMU 15-463, Dartmouth College CS89/189.

focal length f

Sources: CMU 15-463, Dartmouth College CS89/189.

focal length 0.5 f

Sources: CMU 15-463, Dartmouth College CS89/189.

focal length 0.5 f

Sources: CMU 15-463, Dartmouth College CS89/189.

focal length 0.5 f

Sources: CMU 15-463, Dartmouth College CS89/189.

Ideal pinhole has infinitesimally small size

- In practice that is impossible.

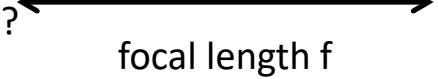
Sources: CMU 15-463, Dartmouth College CS89/189.

Sources: CMU 15-463, Dartmouth College CS89/189.

Sources: CMU 15-463, Dartmouth College CS89/189.

Sources: CMU 15-463, Dartmouth College CS89/189.

- What is the effect of doubling the pinhole diameter?
- What is the effect of doubling the focal length?



Sources: CMU 15-463, Dartmouth College CS89/189.

- 2x pinhole diameter → 4x light
- 2x focal length → ¼x light

focal length f

Sources: CMU 15-463, Dartmouth College CS89/189.

Small (ideal) pinhole:

1. Image is sharp.
2. Signal-to-noise ratio is low.

Sources: CMU 15-463, Dartmouth College CS89/189.

Large pinhole:

1. Image is blurry.
2. Signal-to-noise ratio is high.

Can we get best of both worlds?

Sources: CMU 15-463, Dartmouth College CS89/189.

Lenses map “bundles” of rays from points on the scene to the sensor.

How does this mapping work exactly?

Sources: CMU 15-463, Dartmouth College CS89/189.

Sources: CMU 15-463, Dartmouth College CS89/189.


Sources: CMU 15-463, Dartmouth College CS89/189.

You can see the aperture by removing the lens and looking inside it.

Sources: CMU 15-463, Dartmouth College CS89/189.

https://www.city-academy.com/news/what-is-aperture-in-photography/

Sources: CMU 15-463, Dartmouth College CS89/189.

1. Rays passing through lens center are unaffected.

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2. Parallel rays converge to a single point located on focal plane.

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Sources: CMU 15-463, Dartmouth College CS89/189.

object distance D focal length f

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object distance D focal length f

object distance D focal length f

object distance D focal length f

object distance D focal length f

Sources: CMU 15-463, Dartmouth College CS89/189.

object distance D focal length f

object distance D focal length f

object distance D focal length f

object distance D focal length f

object distance D focal length f

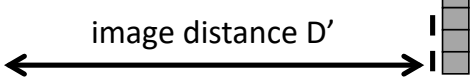
object distance D focal length f

Focusing property: object distance D focal length f

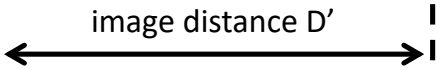
1. Rays emitted from a point on one side converge to a point on the other side.

Sources: CMU 15-463, Dartmouth College CS89/189.

Sources: CMU 15-463, Dartmouth College CS89/189.

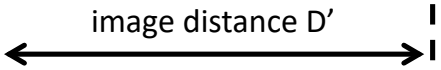


Sources: CMU 15-463, Dartmouth College CS89/189.



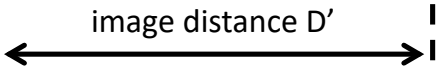
Sources: CMU 15-463, Dartmouth College CS89/189.

Use similar triangles



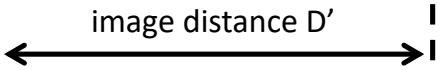
Sources: CMU 15-463, Dartmouth College CS89/189.

Use similar triangles



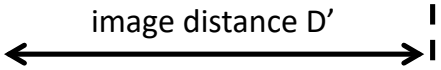
Sources: CMU 15-463, Dartmouth College CS89/189.

Use similar triangles



Sources: CMU 15-463, Dartmouth College CS89/189.

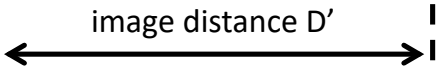
Use similar triangles



Sources: CMU 15-463, Dartmouth College CS89/189.

Use similar triangles

- We call **m = y / y' the magnification factor**



Sources: CMU 15-463, Dartmouth College CS89/189.

Do we lose anything by using a lens?

Sources: CMU 15-463, Dartmouth College CS89/189.

focal length f

digital sensor

Sources: CMU 15-463, Dartmouth College CS89/189.

focal length f

digital sensor

We get a blurry image. This is called defocus.

- Defocus never happens with a pinhole camera.

Sources: CMU 15-463, Dartmouth College CS89/189.

Sources: CMU 15-463, Dartmouth College CS89/189.

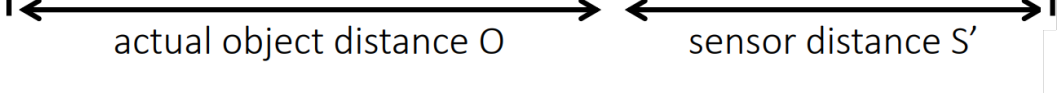
$$\frac{1}{D'} + \frac{1}{D} = \frac{1}{f}$$

Unless our scene is just one plane, part of it will always be out of focus.

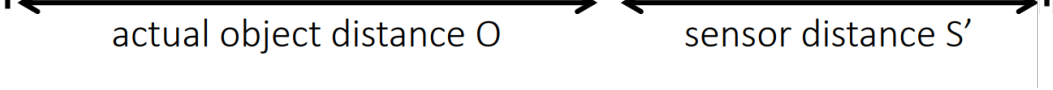
Myopia

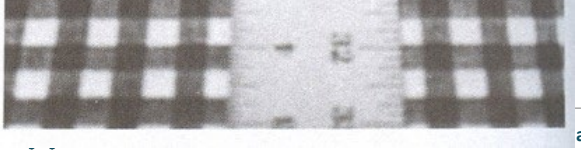
Astigmatism

Sources: CMU 15-463, Dartmouth College CS89/189.



Sources: CMU 15-463, Dartmouth College CS89/189.


actual object distance O
sensor distance S’



Sources: CMU 15-463, Dartmouth College CS89/189.

Sources: CMU 15-463, Dartmouth College CS89/189.

- focus

focus

- What happens to plane in focus?

move lens further away from sensor

Sources: CMU 15-463, Dartmouth College CS89/189.

focus

- Focal plane moves closer

move lens further away from sensor

Sources: CMU 15-463, Dartmouth College CS89/189.

Sources: CMU 15-463, Dartmouth College CS89/189.

- ↑ Focal length ↓ Field of view

drawbacks related with the shape of the lens: barrel distortion, perspective distortion, vignetting…

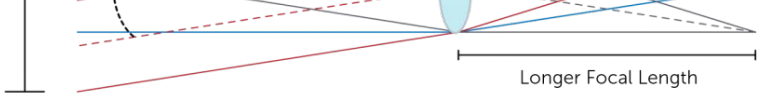
Sources: CMU 15-463, Dartmouth College CS89/189.

Sources: CMU 15-463, Dartmouth College CS89/189.

- What happens to field of view as we focus closer?

move lens further away from sensor

- What happens to field of view as we focus closer? → It becomes smaller.



Sources: CMU 15-463, Dartmouth College CS89/189.

- What happens to field of view when we reduce sensor size? → It decreases.

Sources: CMU 15-463, Dartmouth College CS89/189.

color filter array

pipeline

Sources: CMU 15-463, Dartmouth College CS89/189.

Sources: CMU 15-463, Dartmouth College CS89/189.

Sources: CMU 15-463, Dartmouth College CS89/189.

… until the camera shutter closes. Then, they convert stored photons to intensity values.

Sources: CMU 15-463, Dartmouth College CS89/189.

- Not the only important optical performance metric!

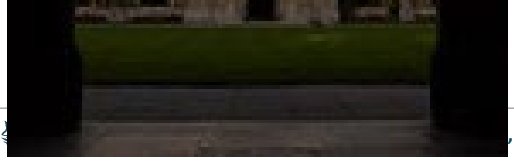
number of photons

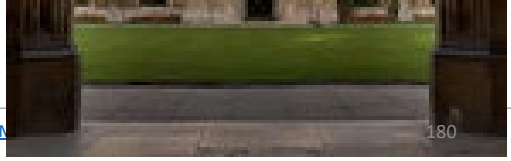
Sources: CMU 15-463, Dartmouth College CS89/189.

over exposure
(non-linearity due
to sensor saturation)

number of photons

Sources: CMU 15-463, Dartmouth College CS89/189.



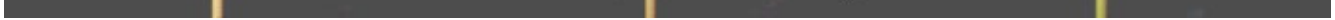


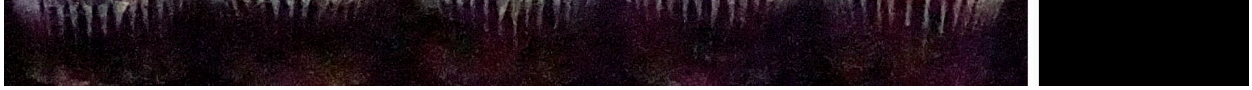
Sources: CMU 15-463, Dartmouth College CS89/189.

Sources: CMU 15-463, Dartmouth College CS89/189.

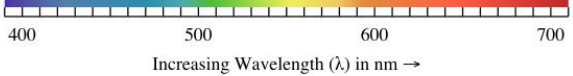
on the top statue

creep into focus





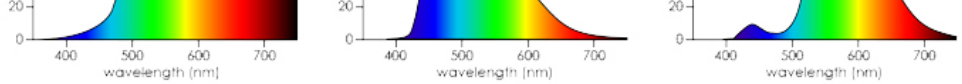
Sources: CMU 15-463, Dartmouth College CS89/189.



range of these wavelengths.

Sources: CMU 15-463, Dartmouth College CS89/189.

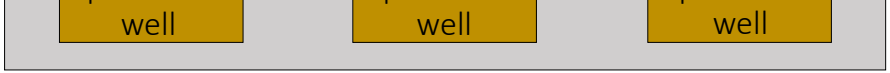
distributions “white”.



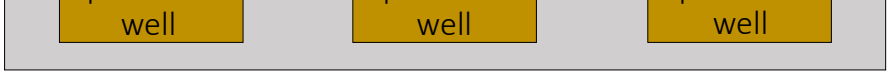
Sources: CMU 15-463, Dartmouth College CS89/189.

Weighted combination of light's SPD: light contributes more at wavelengths where the sensor has higher sensitivity.

Sources: CMU 15-463, Dartmouth College CS89/189.

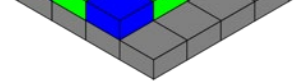


Sources: CMU 15-463, Dartmouth College CS89/189.

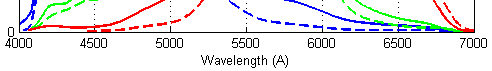


Sources: CMU 15-463, Dartmouth College CS89/189.

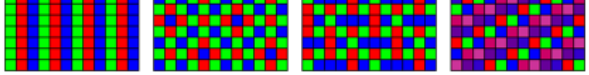
Why more green pixels?



Generally do not match human LMS.



Sources: CMU 15-463, Dartmouth Co $f(\lambda)$ 189.



CFA? What criteria would you consider?

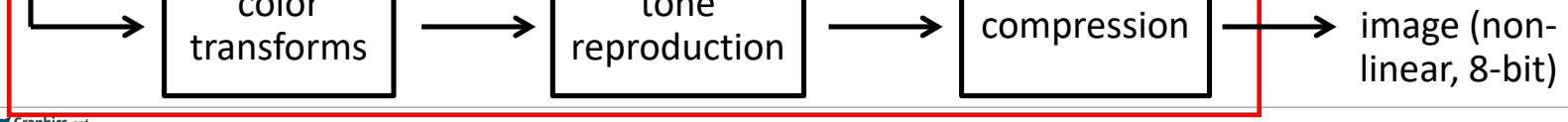
Sources: CMU 15-463, Dartmouth College CS89/189.

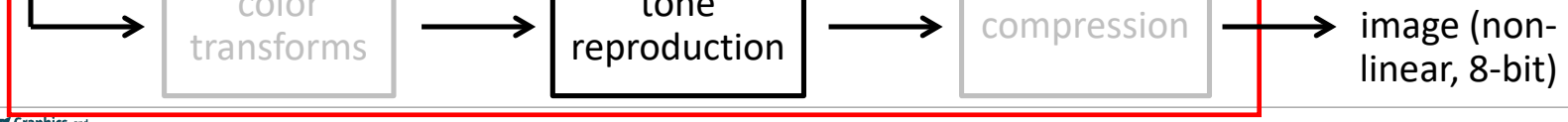
color filter array

pipeline

Sources: CMU 15-463, Dartmouth College CS89/189.

Sources: CMU 15-463, Dartmouth College CS89/189.


color transforms
tone reproduction
compression
image (non-linear, 8-bit)


color transforms
tone reproduction
compression
image (non-linear, 8-bit)

[Slide credit: Todd Zickler]

different whites

image captured under fluorescent

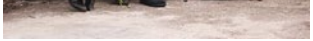


image white-balanced to daylight

Sources: CMU 15-463, Dartmouth College CS89/189.

	1000 - 2000 K	Candle Flame

Sources: CMU 15-463, Dartmouth College CS89/189.

Sources: CMU 15-463, Dartmouth College CS89/189.

where k controls the exposure

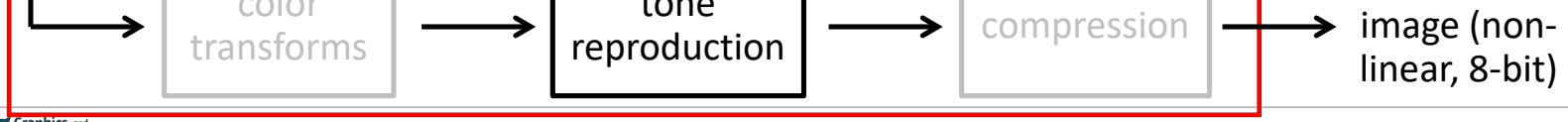
Sources: CMU 15-463, Dartmouth College CS89/189.

Sources: CMU 15-463, Dartmouth College CS89/189.

white-balanced RGB → $\begin{bmatrix} G' \\ B' \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & G_{max}/B_{max} \end{bmatrix} \begin{bmatrix} G \\ B \end{bmatrix}$ ← sensor RGB

input image grey world white world

Sources: CMU 15-463, Dartmouth College CS89/189.

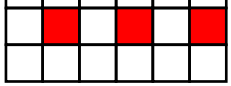


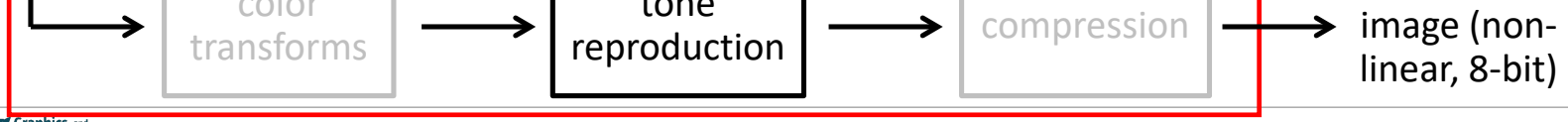
Sources: CMU 15-463, Dartmouth College CS89/189.

Sources: CMU 15-463, Dartmouth College CS89/189.

- Edge-aware interpolation.

Sources: CMU 15-463, Dartmouth College CS89/189.





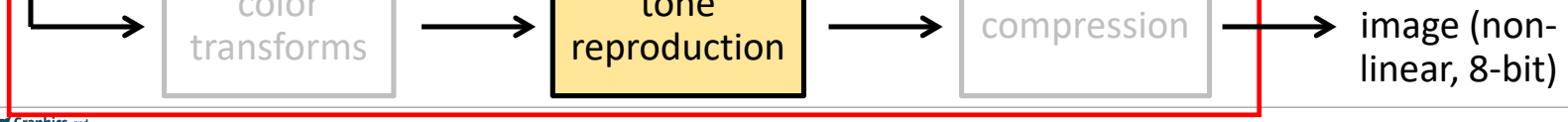
Sources: CMU 15-463, Dartmouth College CS89/189.


Sources: CMU 15-463, Dartmouth College CS89/189.

Bright scene and large pixels: photon shot noise is the main noise source.

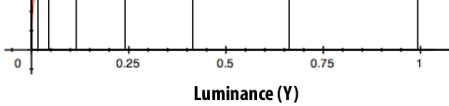
Sources: CMU 15-463, Dartmouth College CS89/189.

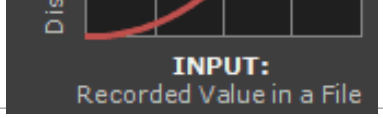

5
1
2
3
4
5
6
7
8
9

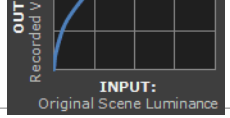

color transforms
tone reproduction
compression
image (non-linear, 8-bit)

Sources: CMU 15-463, Dartmouth College CS89/189.

Sources: CMU 15-463, Dartmouth College CS89/189.

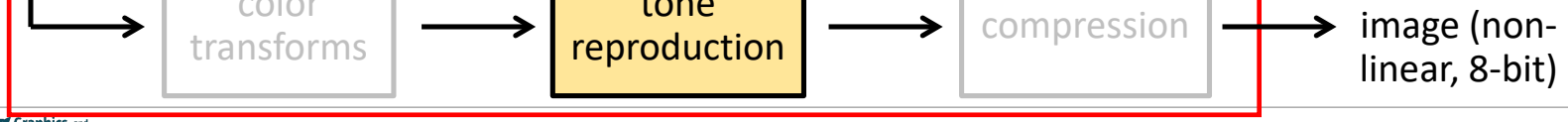

0
0.25
0.5
0.75
1
Luminance (Y)


INPUT:
Recorded Value in a File



- Add inverse display transform here.
- This transform is the tone reproduction or gamma encoding.

before gamma after gamma



Sources: CMU 15-463, Dartmouth College CS89/189.

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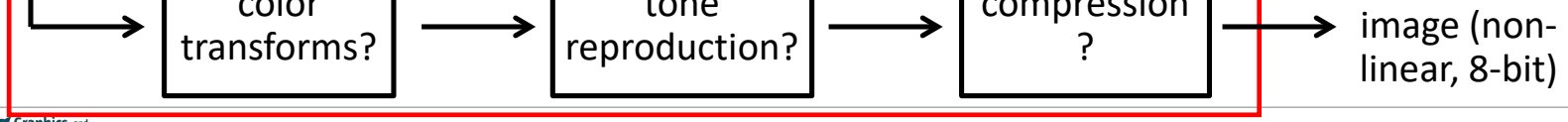

Sources: CMU 15-463, Dartmouth College CS89/189.

Sources: CMU 15-463, Dartmouth College CS89/189.

- Chakrabarti et al., "Probabilistic Derendering of Camera Tone-mapped Images," PAMI 2014.
  Discusses how to (attempt to) derender an image that has already gone through the image processing pipeline of some (partially calibrated) camera.