Exposure Correction

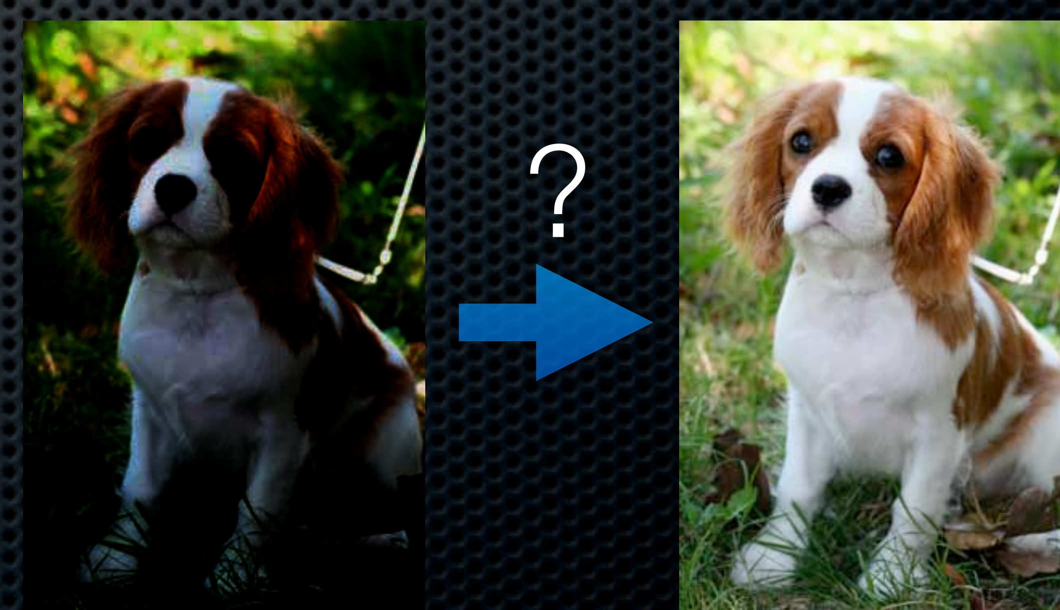
David Capel

Last week,we saw the importance of correct exposure in capturing a good photo

Controlling parameters:

- Shutter speed - *motion blur vs. freeze frame*
- Aperture - *controlling depth of field*
- ISO - *higher sensitivity at expense of noise/grain*

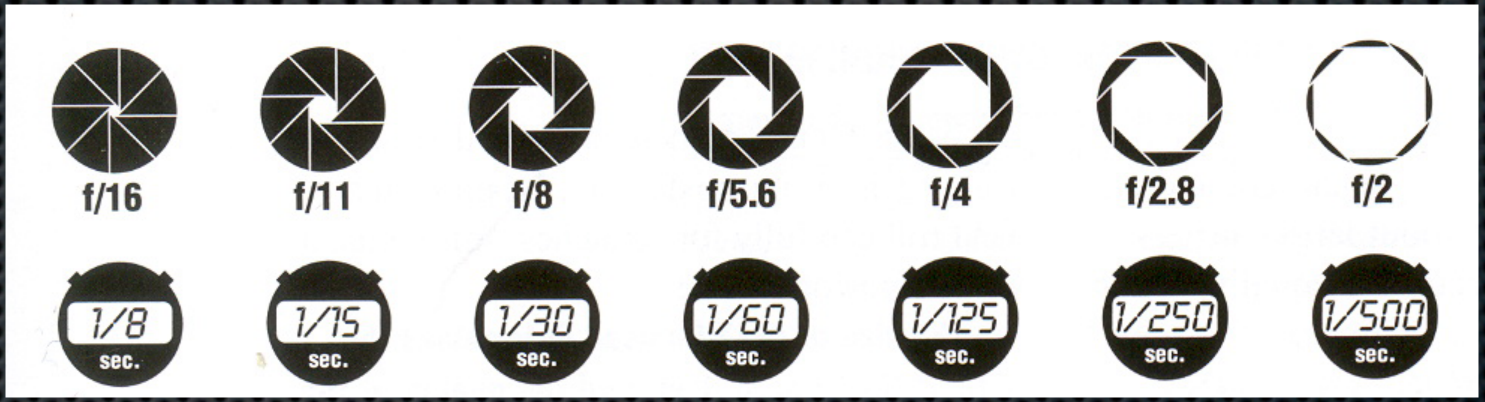
But what if we get it wrong?
Can we fix it later on?



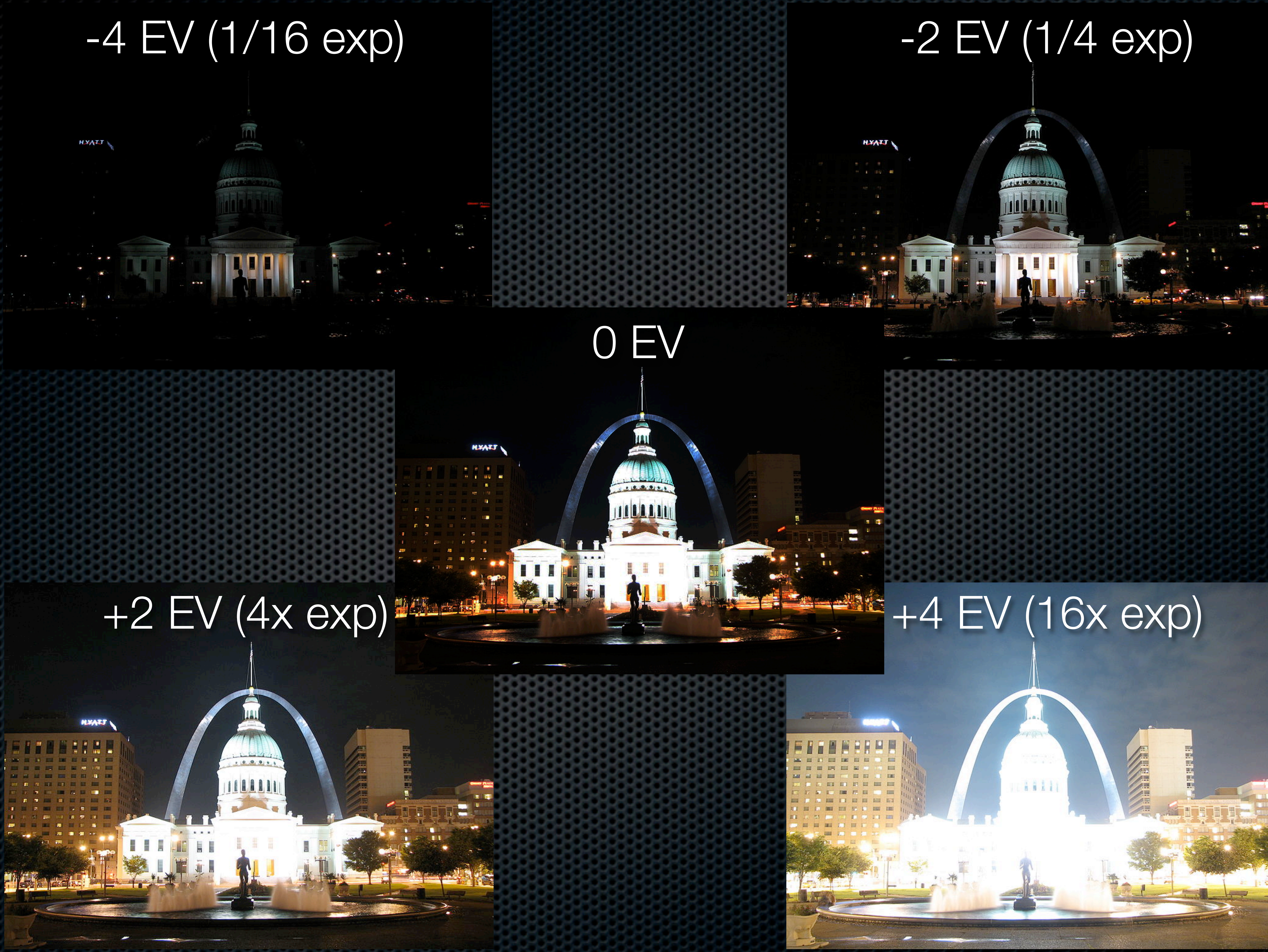
- Recall that **exposure** is partly a measure of total light energy reaching the sensor

$$\text{exposure} = \frac{\text{shutter speed}}{\text{f-number}^2}$$

- Commonly used steps in f-number and shutter speed correspond to a factor of two change in exposure



- Each factor of two change is called 1 *exposure value* (EV)
- On your camera, changing exposure +/-1EV means changing shutter speed OR aperture by one “stop”


-4 EV (1/16 exp)
-2 EV (1/4 exp)
0 EV
+2 EV (4x exp)
+4 EV (16x exp)

Changing exposure by 1 EV in software ...

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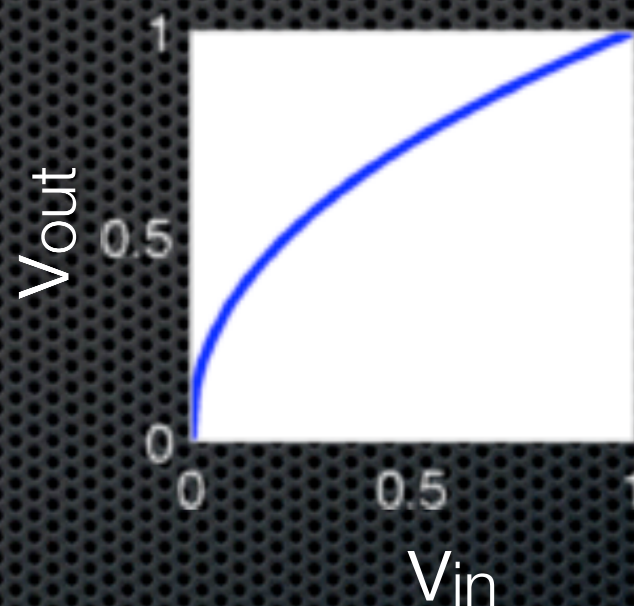
Changing exposure by 1 EV in software ...

- Can't we simply scale the pixel intensity values up or down by a factor of 2?
- **No!** In most digital image and movie formats, pixel values represent "gamma compressed" intensities

linear intensities



$$V_{gamma} = V_{linear}^{1/\gamma}$$

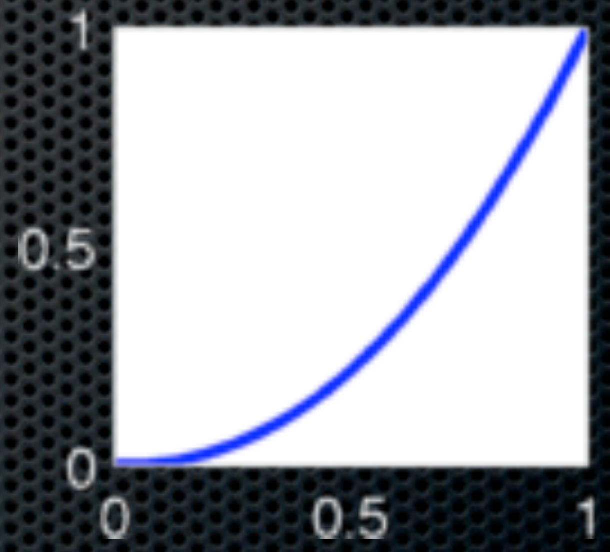
$(\gamma \sim 2.2)$

gamma compressed

Gamma compression

- Originally used to compensate for non-linear behavior of a Cathode Ray Tube (old TV) display:

CRT: Output Intensity = (Input Voltage)$^{2.2}$



- This non-linear relationship is now mimicked by design in modern LCD displays and projectors

(aside: old Mac displays used γ=1.8, but now γ =2.2 is standard)

Changing exposure by 1 EV in software ...

- So, first convert pixel values to linear intensity values:

$$V_{linear} = V_{image}^{2.2}$$

- Then apply exposure scaling:

$$V_{linear\_new} = 2^{EV} * V_{linear}$$

- And finally, reapply gamma compression:

$$V_{image\_new} = V_{linear\_new}^{1/2.2}$$

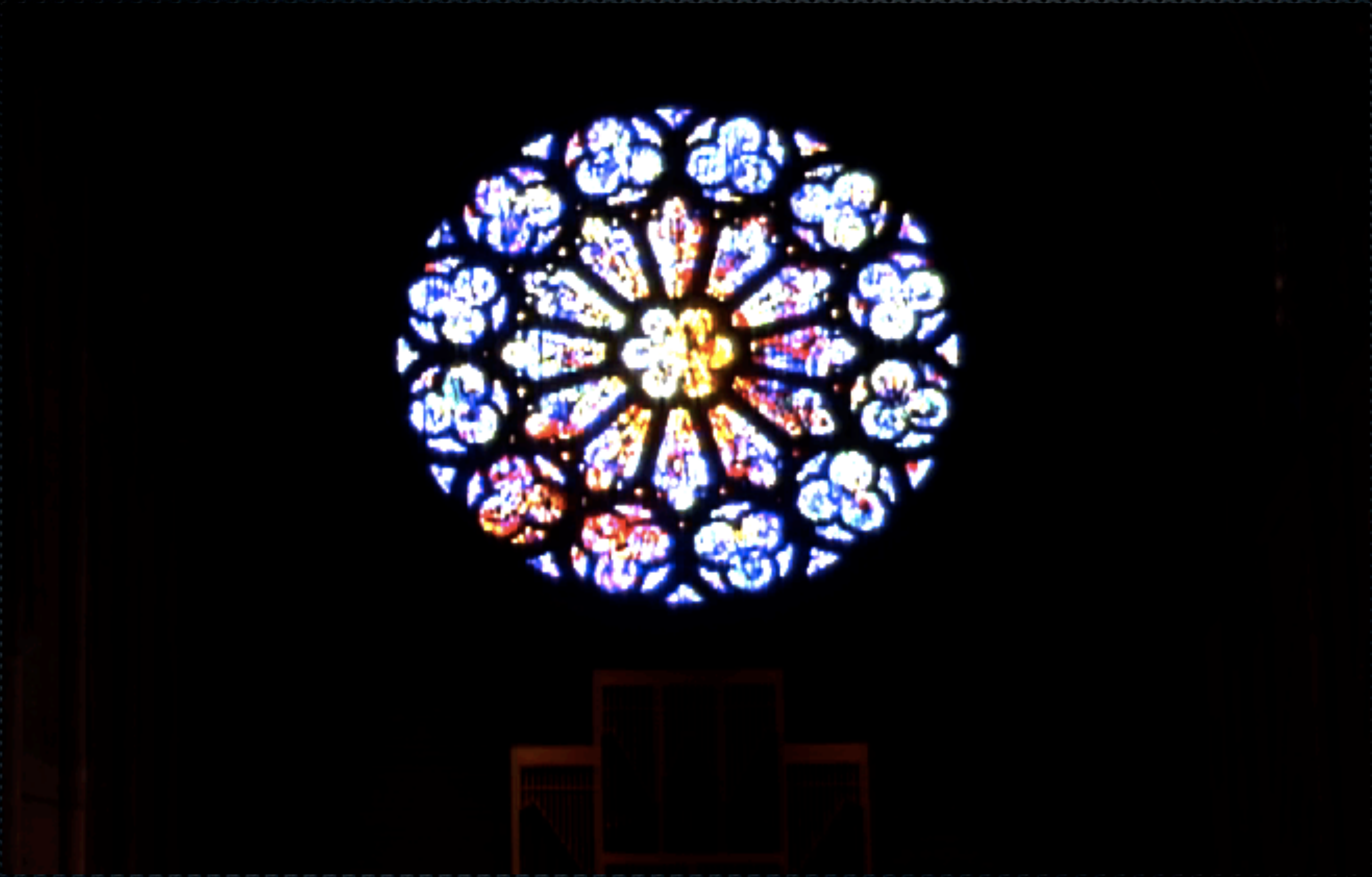
Changing exposure by 1 EV in software ...

-1EV
(0.5x intensity)

Original

+1EV
(2x intensity)

What if our image is really over/under exposed?



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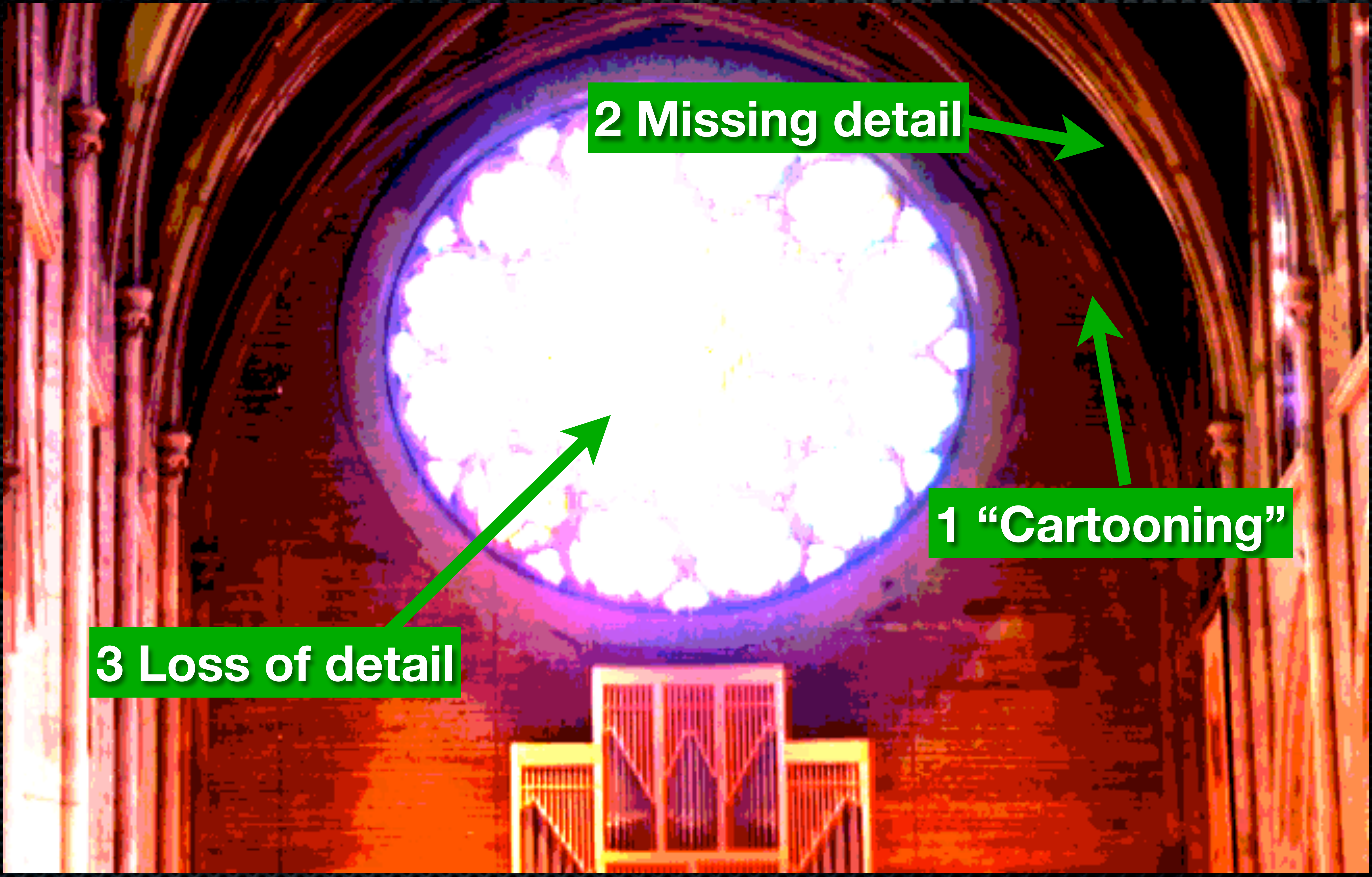
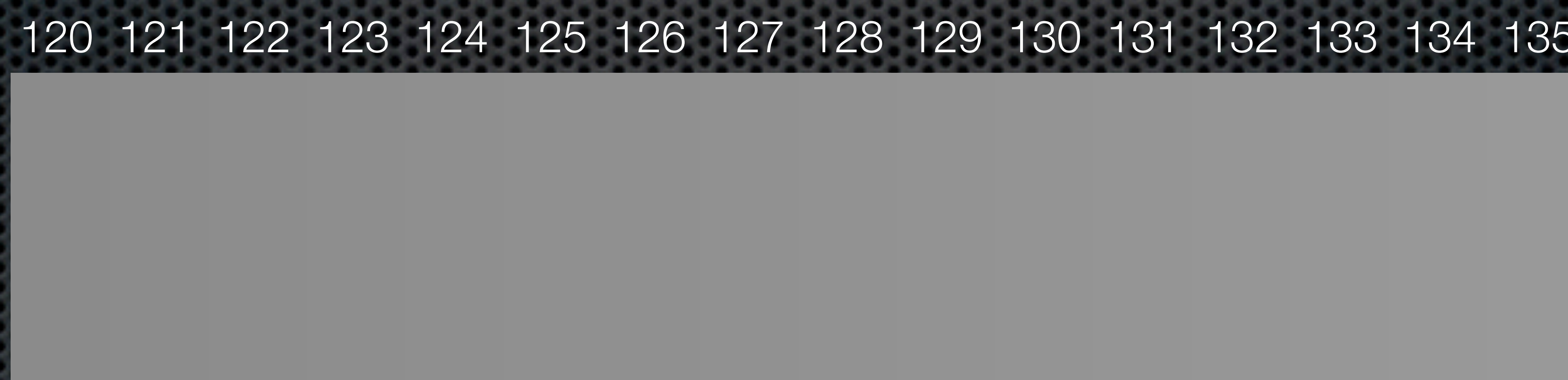


Problem 1 : Intensity Quantization

- Most images are stored with 8-bits of intensity resolution in each RGB channel, i.e only $2^8 = 256$ possible values
- However, brightness change between adjacent values is barely noticeable to human viewers



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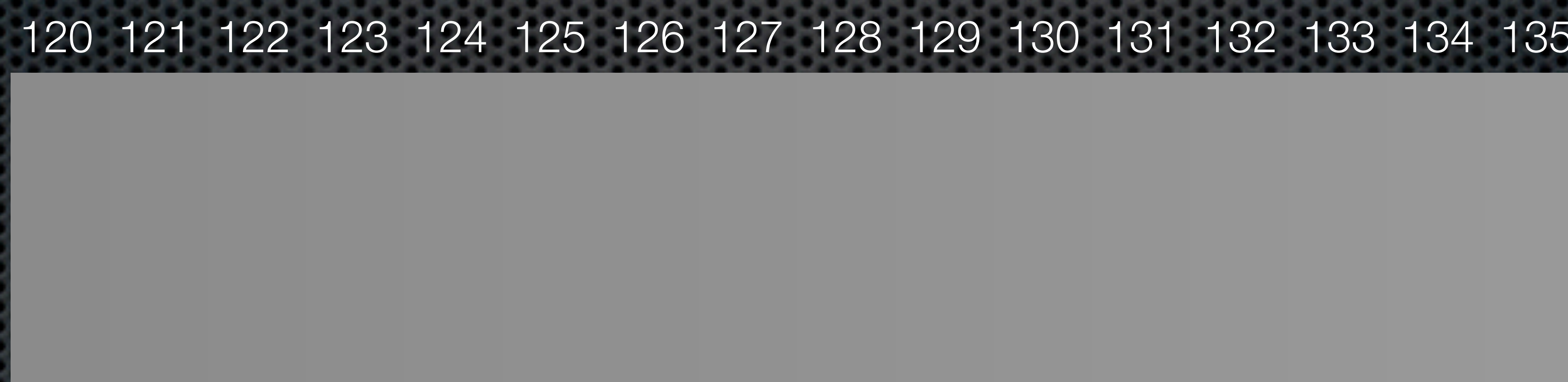
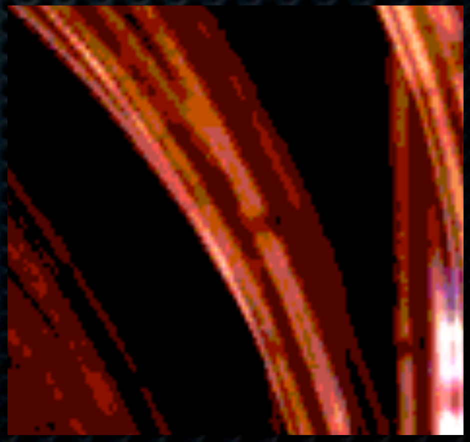
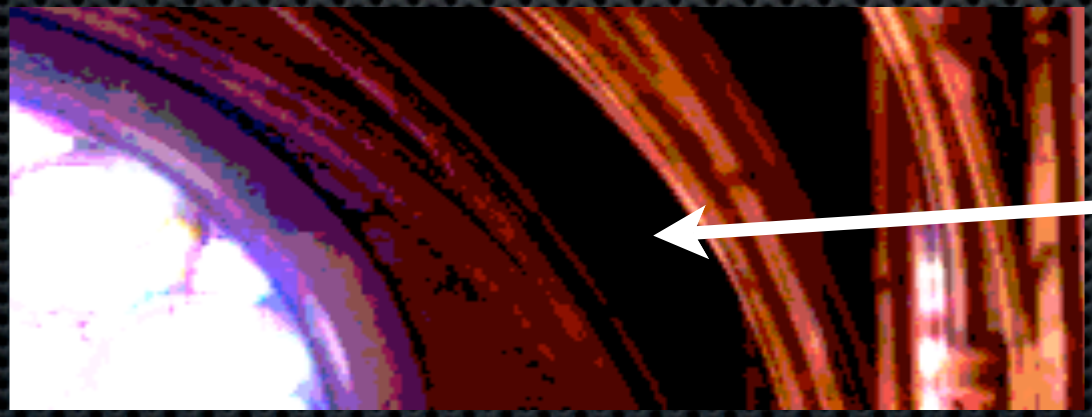


.. until we apply a large gain : steps become clearly visible!



Problem 2 : Sensor dynamic range

- Ratio of max/min intensities that can be recorded by the camera sensor in a single image
- Intensities outside this range are recorded as pure black or pure white
    - Typical CCD sensor ~ 1000:1 (~10 EV)
    - Human eye ~ 10000:1 to 100000:1 (~13-16 EV)



Intensities below sensor range

Exaggerated example ...

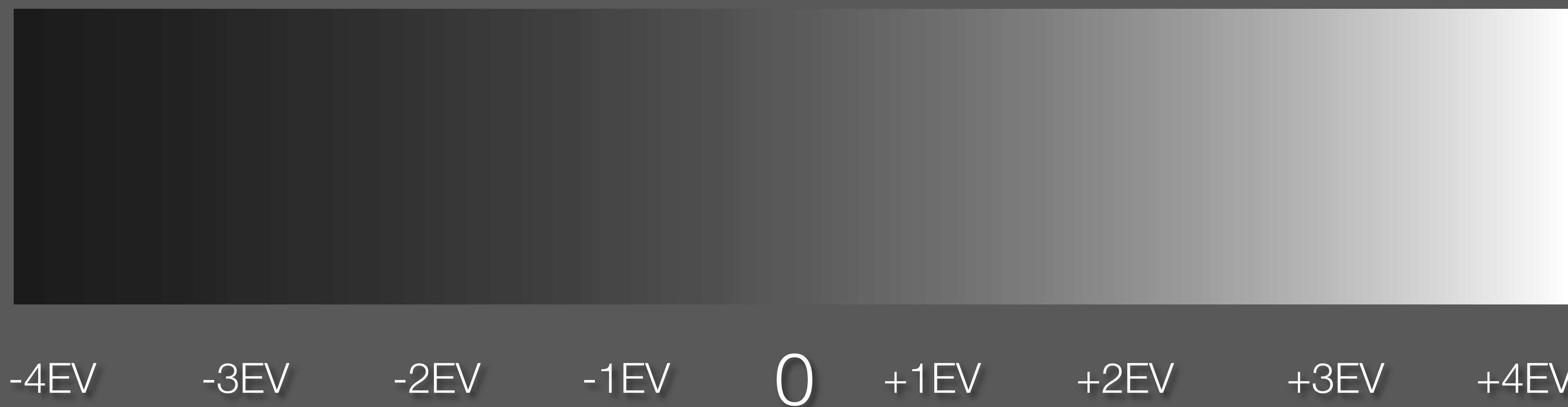
“True” image arriving at sensor
dynamic range = 8 EV
256:1

Recorded image
dynamic range = 6 EV
64:1

Problem 3 : Display dynamic range

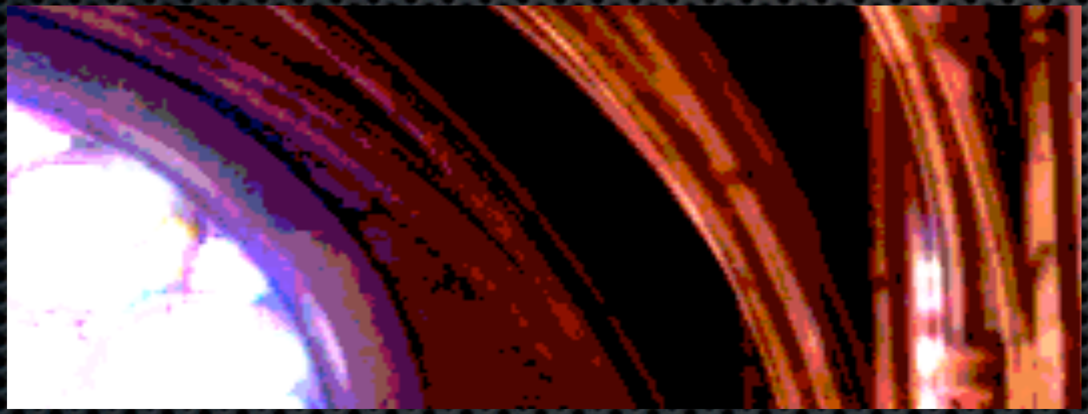
- Real displays can't render "infinitely" dark or bright
- Dynamic range = Ratio of max/min intensities that can be reproduced by the display device
- Intensity variations outside this range are lost
  - Sunlit scene ~ 100000:1 (15-16 EV)
  - LCD display ~ 500:1 to 1000:1 (9-10 EV)
  - Black-and-white newspaper print ~ 10:1 (3.5 EV)

Dynamic range of this projector?



Solution: High Dynamic Range Imaging

- HDR images captured a larger dynamic range
  - e.g. 10-16 EV (1024:1 to 65536:1)
- ... with finer quantization of intensities
  - e.g 16-bit or 32-bit per pixel per color channel



Exposure adjusted 8-bit image

Exposure adjusted HDR image