Congratulations! You passed!

Grade received 100% **Latest Submission Grade** 100% **To pass** 70% or higher

Go to next item Retake the assignment in **7h 59m**

1. The iPhone 6 camera has a CMOS sensor with approx. 3200×2400 pixels. Each pixel is a square with side 1.5 microns. What is the total area of the sensor? **2 / 2 points**

- (selected) $17\ mm^2$
- $25\ mm^2$
- $28\ mm^2$
- $38\ mm^2$

Correct
The total size of the sensor in mm is:
$3200 * 2400 * 0.0015^2 = 17.28\ mm^2 \ \approx 17\ mm^2$

2. The noise models of (a) the scene dependent photon noise and (b) the scene independent readout noise of an image sensor are: **1 / 1 point**

- (a) Gaussian and (b) Poisson.
- (a) Gaussian and (b) Gaussian.
- (selected) (a) Poisson and (b) Gaussian.
- (a) Poisson and (b) Poisson.

Correct
The photon noise represents the randomness of the arrival of photons due to the quantum nature of light. It is modeled as Poisson process. The readout noise is due to electronic noise during the analog-to-digital conversion of pixel voltage. It is modeled as a Gaussian distribution.

3. Imagine you use a camera to take multiple images of a uniformly bright scene. Subsequently, you found out that the probability of the camera sensor receiving no signal $(k = 0)$ at any one pixel is 0.1. What is the mean number of photons arriving at any one pixel of the camera sensor due to photon noise?

2 / 2 points

- ○ 2.6
- ○ 1.7
- ◉ 2.3
- ○ 1.9

Correct

$$P(signal = k) = \frac{\lambda^k \epsilon^{-\lambda}}{k!}$$
$$P(signal = 0) = 0.1 = \frac{\lambda^0 \epsilon^{-\lambda}}{0!}$$
$$\lambda = -ln(0.1)$$
$$\lambda = 2.3$$

4. Consider an *ideal* sensor pixel which has no readout noise. Suppose the pixel captures N intensity values $(I_1, I_2, ..., I_N)$ sequentially while looking at a scene point whose brightness remains constant over time. Let the mean of the intensity values be $(\bar{I} = \frac{1}{N} \sum I_i = 100)$ photons. What is their standard deviation?

3 / 3 points

- ○ 0
- ◉ 10
- ○ 100
- ○ 1000

Correct

Even the measurements taken by an ideal sensor have photon noise due to the randomness of the arrival of photons. The randomness is modeled as a Poisson process, with variance the same as the mean. Therefore, if the mean is 100, the variance is also 100, which means that the standard deviation is $\sqrt{100 = 10}$

5. An analog-to-digital converter (ADC) introduces quantization noise. Recall that

2 / 2 points

the variance of quantization noise is equal to $\frac{\Delta^2}{12}$ where Δ is the size of the quantization step (difference between two successive digital intensity values). What happens to the variance of quantization noise when we replace a 12-bit ADC with a 14-bit ADC?

- ○ Increases 4x
- ○ Increases 16x
- ○ Decreases 4x
- ◉ Decreases 16x

Correct
Adding 1 bit decreases Δ by a factor of 2. When going from 12-bit to 14-bit we add 2 extra bits of resolution. This means Δ decreases by a factor of 4. Since quantization noise depends on Δ^2, the variance decreases by a factor $4^2 = 16$

6.

2 / 2 points

Imagine you oversee the sensor choice for the Hubble Space Telescope. Which sensor would you choose, and which source of noise would you be concerned about? Assume that you have checked before launch that your primary mirror is polished the right way.

- ○ CCD, Fixed Pattern Noise
- ◉ CCD, Dark Current Noise

- ◯ CMOS, Fixed Pattern Noise
- ◯ CMOS, Dark Current Noise

Correct
CCD is more suitable for this task, since the Hubble Space Telescope tries to capture very dim objects with very low noise, and because CCD has greater pixel area, it captures more light and produces a less noisy image. Furthermore, to capture these dim objects, the exposure time tends to be longer (in minutes, as mentioned in the video). Therefore, one needs to care about the dark current noise.

7. **2 / 2 points**

The full moon on a clear night has an apparent magnitude of -12.5.

Astronomers often assign an "**apparent magnitude**" (m) to the brightness of celestial objects. For every 10-fold increase in brightness, the value of m decreases by 2.5. Someone with good vision can spot faint stars with apparent magnitude $m = 2.5$ in the clear night sky. The full moon, also visible with the naked eye, has $m = -12.5$. What is the dynamic range of the human eye for night vision?

- ◯ 60 dB
- ◯ 80 dB

- 100 dB
- (selected) 120 dB

Correct

Going from -12.5 to 2.5 is a difference of 15 units of magnitude. Each increase of 2.5 is a 10x decrease in brightness. To cover 15 units, we need 10^6 fold increase in brightness when going from the dimmest visible star to a bright full moon. This gives the human eye a dynamic range of $20\ log\left(\frac{I_{max}}{I_{min}}\right) = 120dB$

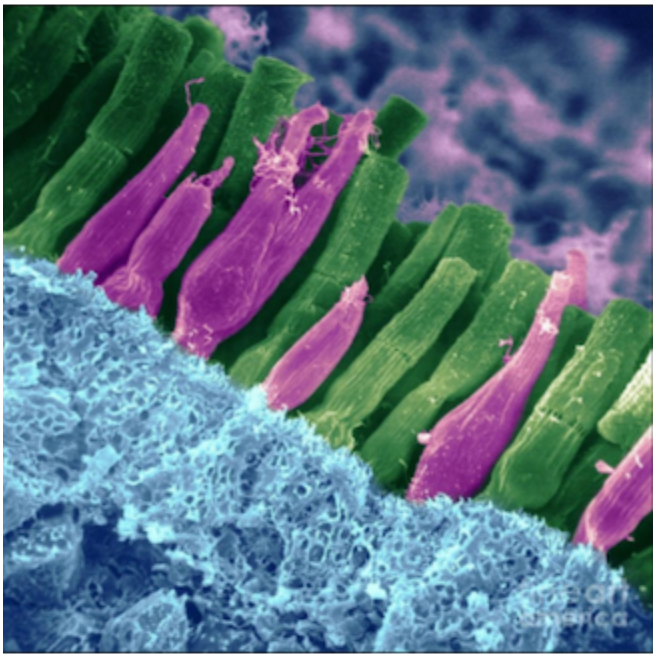
8. You bought a new camera with twice as high dynamic range (in dB) as your old camera. Let $B_{max,old}$ denote the maximum photon energy that can be read by your old camera. If both cameras detect the same baseline minimum photon energy of 1, what is the maximum photon energy that can be read by your new camera?

3 / 3 points

- $B_{max,old}$
- (selected) $B^2_{max,old}$
- $B^4_{max,old}$
- $B^{16}_{max,old}$

Correct

$dynamic\ range_{new} = 20 * log\left(\frac{B_{max,new}}{B_{min}}\right)$
$dynamic\ range_{new} = 2 * dynamic\ range_{old}$
$20 * log\left(\frac{B_{max,new}}{B_{min}}\right) = 2 * 20 * log\left(\frac{B_{max,old}}{B_{min}}\right)$
$log\left(B_{max,new}\right) = log\left(B^2_{max,old}\right)$
$B_{max,new} = B^2_{max,old}$
So, the new camera can capture $B^2_{max,old}$ times maximum possible photon energy.

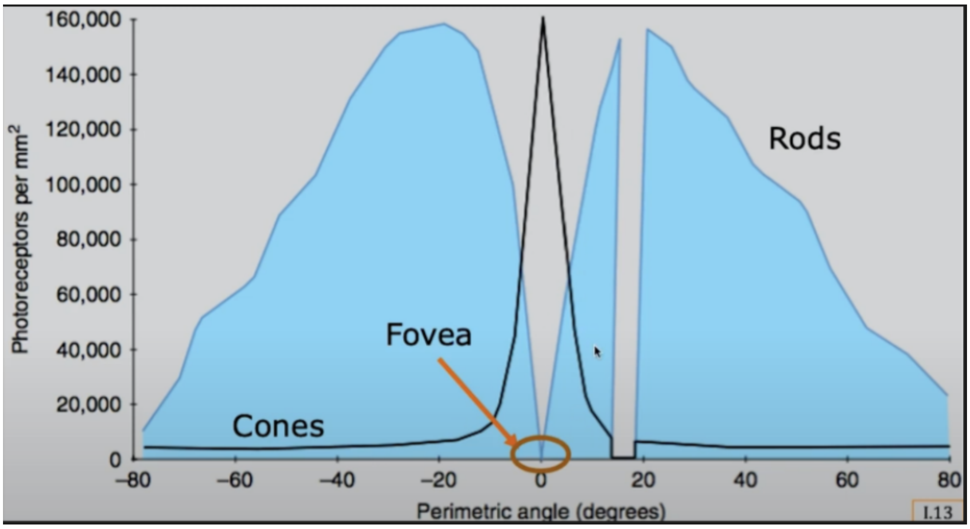
9. 

1 / 1 point

Are there more or fewer cones than rods? Where is each located with respect to the fovea?

- ○ Fewer cones than rods; rods concentrated at the fovea, cones away from the fovea
- ◉ Fewer cones than rods; cones concentrated at the fovea, rods away from the fovea
- ○ Fewer rods than cones, rods concentrated at the fovea, cones away from the fovea
- ○ Fewer rods than cones; cones concentrated at the fovea, rods away from the fovea

Correct



There are on average ~120M rods and ~7M cones. For the location of each with respect to the fovea, please see the figure above.

10. Which of the following statements is false?

2 / 2 points

- ○ Combining the pictures with multiple exposures in multi-shot HDR compresses the differences in brighter areas, while exaggerating the differences in darker areas.
- ◉ Measured brightness, like image brightness, always increases linearly as exposure increases.
- ○ Gamma curves can be reconstructed by comparing measured brightness against known color reflectance.
- ○ Manufacturers use Gamma curves to further compensate for limited dynamic range for example by making darker values more distinct and brighter values more similar.

Correct

While image brightness increases linearly with increased exposure, measured brightness tends to be non-linearly related to image brightness and thus to exposure. This relationship is depicted by a camera response function.