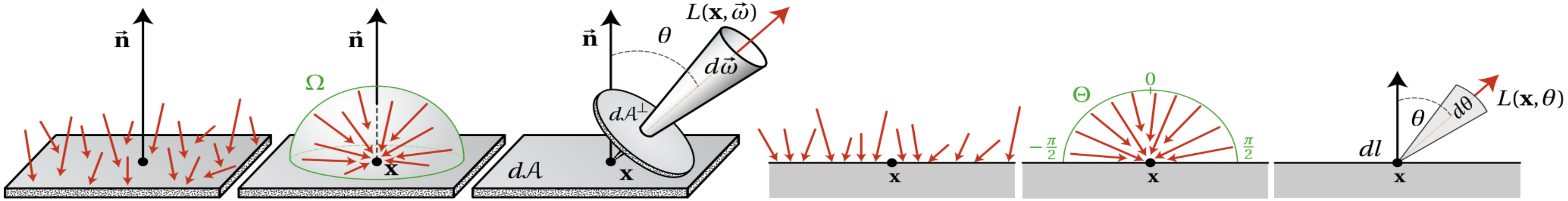
# Advanced Graphics

Lecture 2 additional notes

# Radiometry Terms

- Radiant Flux (Radiant Power)
- Irradiance
- Radiant intensity
- Radiance




(a) 3D Flux (b) 3D Irradiance (c) 3D Radiance (d) 2D Flux (e) 2D Irradiance (f) 2D Radiance

Fig. 1: Comparison of radiometric quantities in 3D (left) and 2D (right). Flux measures the amount of light that hits a finite surface area (3D) or arc-length (2D) from all directions, irradiance integrates the light arriving at a single point over the whole hemisphere (3D) or hemicircle (2D), and radiance expresses the amount of light arriving at or leaving a single point from a differential solid (3D) or plane angle (2D).

Jarosz, W., Schönefeld, V., Kobbelt, L. and Jensen, H. (2012). Theory, analysis and applications of 2D global illumination. *ACM Transactions on Graphics*, 31(5), pp.1-21.

# Radiant Flux

- **Radiant Flux (Radiant Power)** – energy flowing through surface per unit time.
- Defines how quickly energy flows through the surface.
- Measured in *Watts (W) = Joules/second (J/s)*.
- Refers to the *emission* of light.

# Irradiance

- **Irradiance** - the density of radiation incident on a given surface.

- Refers to the *receiving* of light.

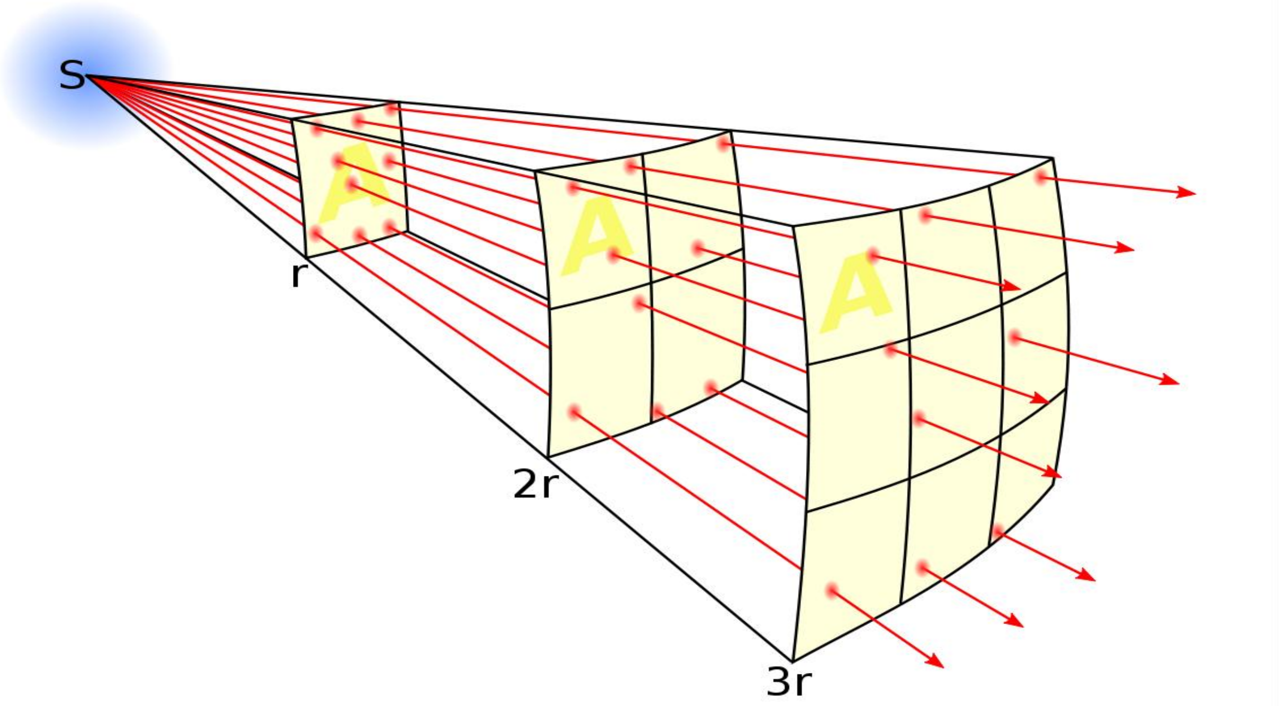
- Units: *Watts per square meter* ($^{W}/_{m^2}$)

# Irradiance

- For example, the area of the surface of the sphere with radius *r* is $4\pi r^2$.
- Therefore, irradiance over its surface is $E = \frac{\Phi}{4\pi r^2}$
- For the spherical disc $E = \frac{\Phi}{\pi r^2}$
- For square surface with side of length A, $E = \frac{\Phi}{A^2}$, etc.

# Inverse-square law

- Irradiance is inversely proportional to the square of the distance from the light source.




- Irradiance $\propto \frac{1}{r^2}$

https://en.wikipedia.org/wiki/Inverse-square_law

# Inverse-square law

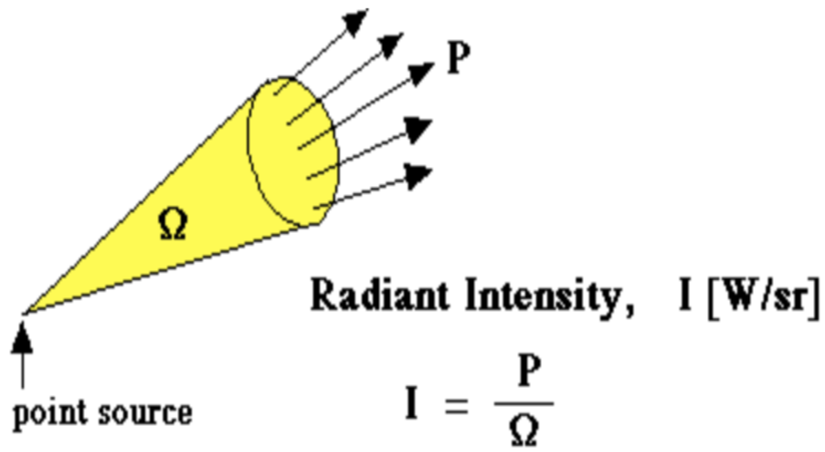
- For example, at distance R = *r* we have irradiance *E* falling on surface of area *A*. When we double the distance such as R = *2r*, the surface of *4*A* receives same irradiance *E*. Therefore, in this case surface of area *A* will receive *E/4* irradiance.

- Darkening of an object happens with $r^2$ fall-off.

- NOTE: The light source needs to be **isotropic** = equally emitting in all directions.

# Radiant intensity

- **Radiant intensity** – radiant flux per unit solid angle.
- Unit: *Watt/steradian* (*W/sr*)
- Theoretical quantity used to describe point light source, which has zero area. No point lights in reality though!
- Useful in computer graphics simulations.



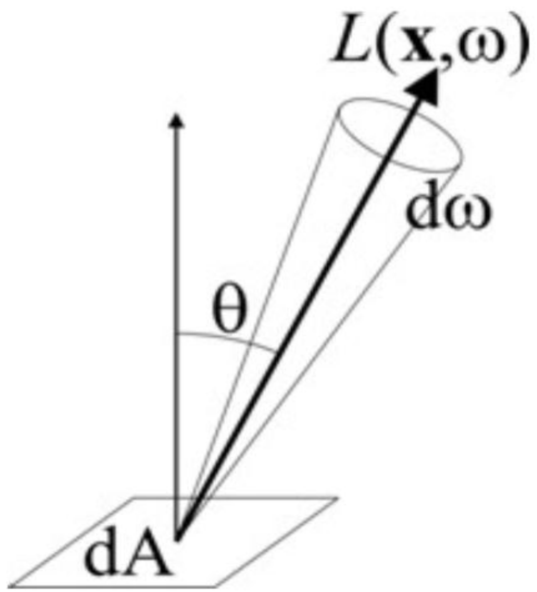

http://omlc.org/classroom/ece532/class1/intensity.html

# Radiance

- **Radiance** – radiant flux per unit area per unit solid angle.

- Units: $W/m^2 sr$

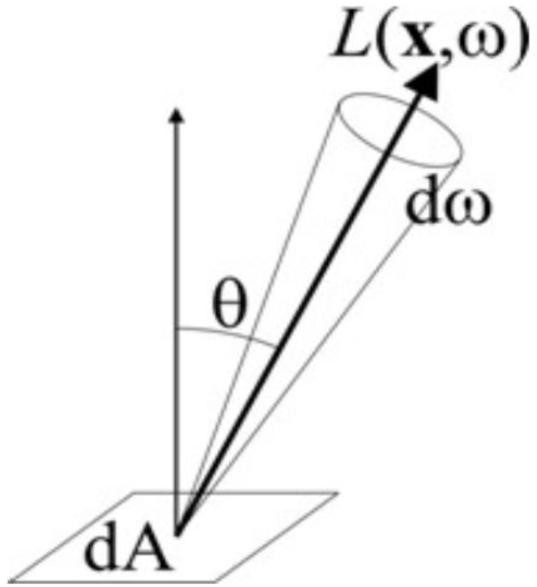
- $L(x,\omega) = \dfrac{d^2\Phi}{dA{*}cos\theta\ d\omega}$, where
  - Φ – radiant flux
  - ω - solid angle
  - A*cosθ – projected area




http://slideplayer.com/slide/9104594/

# Radiance

- Radiance does not change with distance along direction i.e. when moving along $\omega$ in free space.




http://slideplayer.com/slide/9104594/

# Lambert's cosine law

- Irradiance is proportional to cosine of the angle between light direction and surface normal.

- I.e., irradiance falls as light direction gets closer to the surface and rises as the light direction approaches surface normal direction.

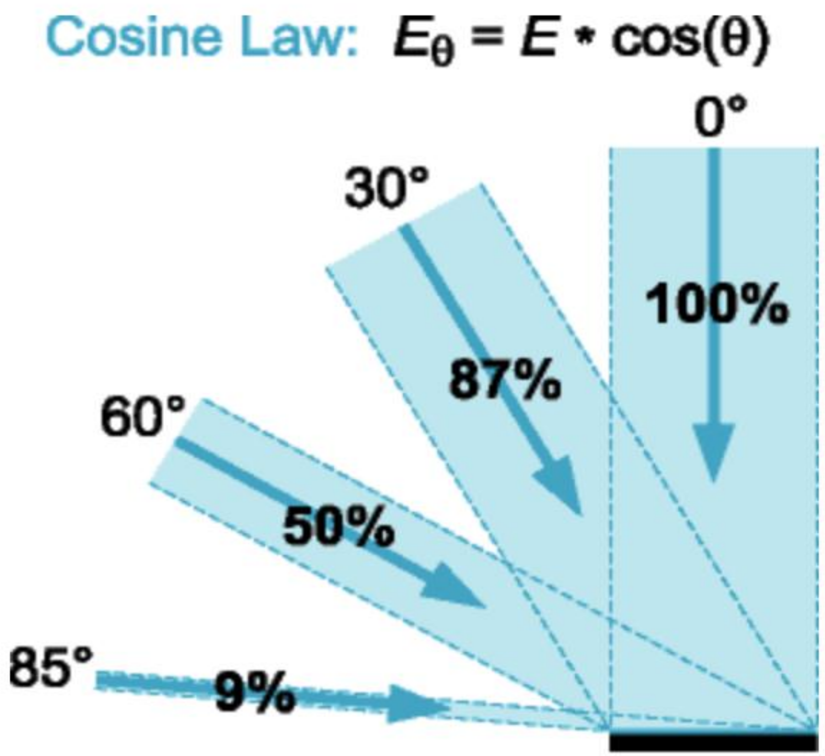


Fig. 6.3 Lambert's cosine law.

http://www.dfisica.ubi.pt/~hgil/Fotometria/HandBook/ch06.html

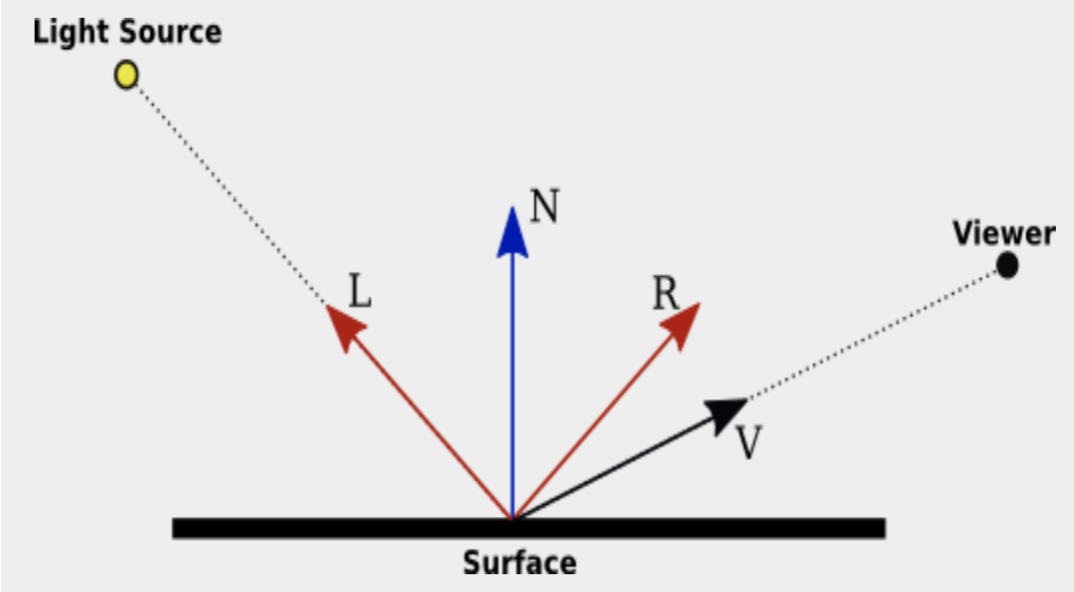
# Radiance

- *Incident* radiance – radiance traveling from a light source.

- *Exitant* radiance – light leaving the surface towards another surface or the camera.

# Radiance

- NOTE: In computer graphics light direction is shown to be originating from the surface and pointing towards light source or camera, as defined by shading equations, although in reality light source emits light.



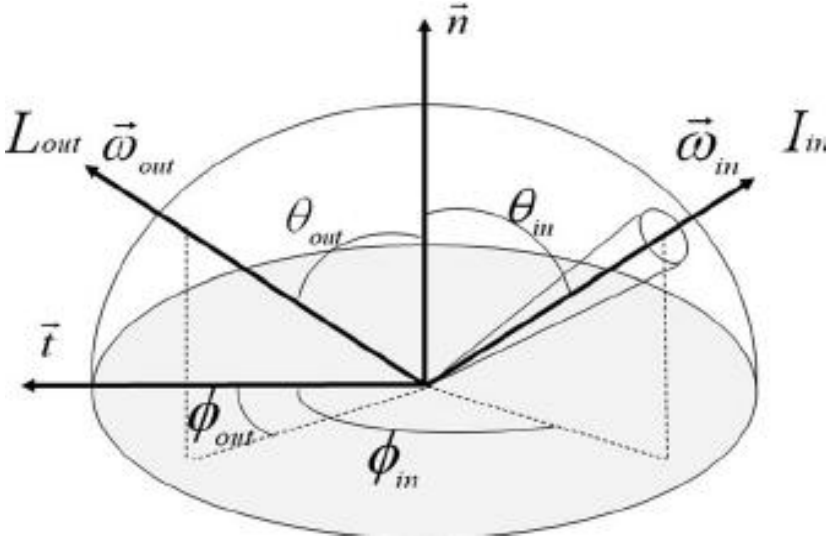

http://math.hws.edu/graphicsbook/c7/s2.html

# Radiance

- In reality **incident radiance ≠ exitant radiance**
- Only possible for perfectly specular surfaces, which do not transmit or absorb incident light, like an ideal mirror, for example.

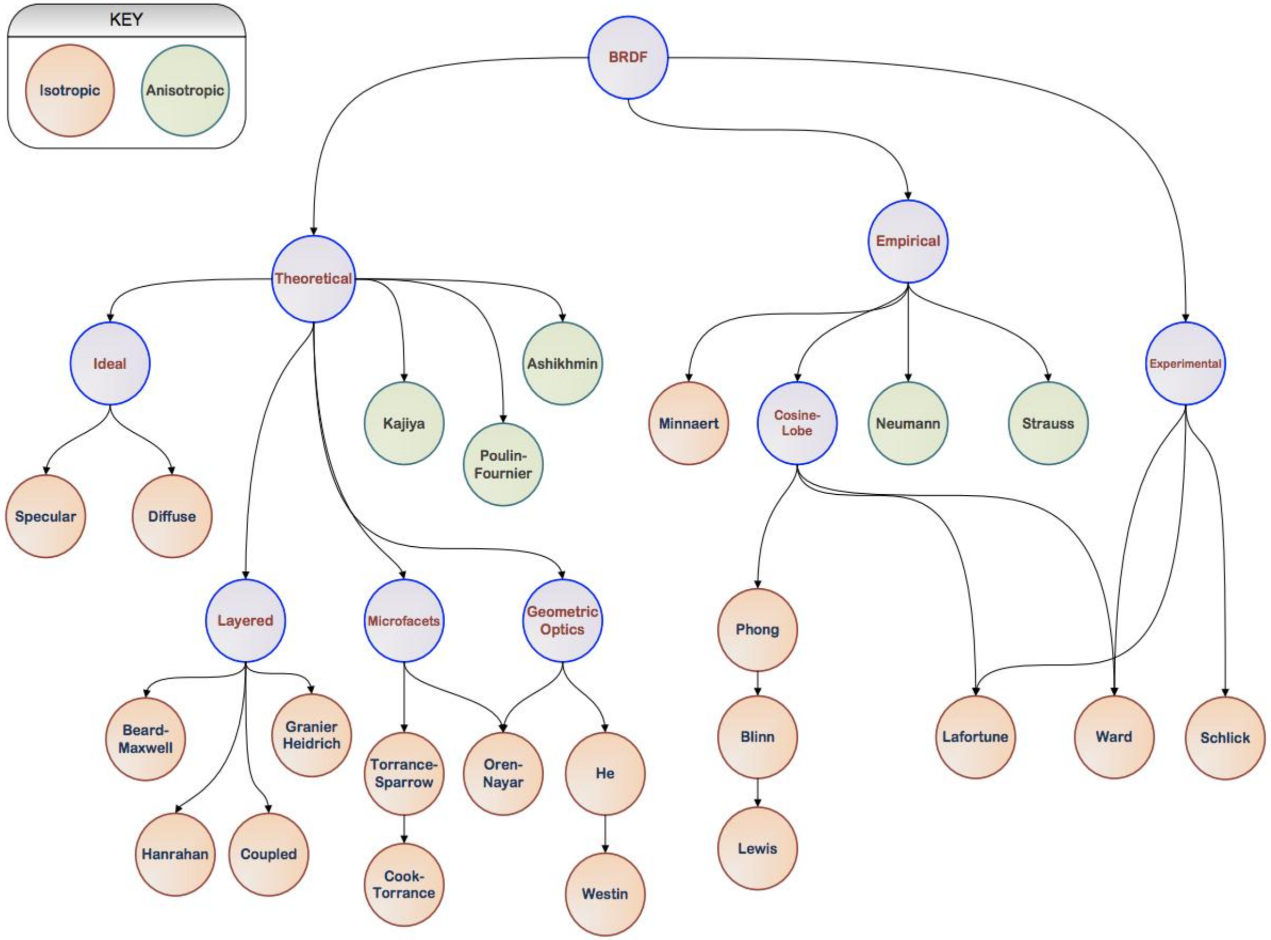
# BRDF

- **BRDF** – ratio of radiance reflected from surface in direction $\omega_{out}$ to the incident irradiance in direction $\omega_{in}$.
- Denoted as $f_r(\omega_i, \omega_o)$.
- Units: *1/steradian* (*1/sr*)
- BRDF for surfaces is defined over the upper hemisphere.




https://www.researchgate.net/figure/252647257_BRDF-Geometry-of-surface-reflection

# Types of BRDFs




http://digibug.ugr.es/bitstream/10481/19751/1/rmontes_LSI-2012-001TR.pdf

# Properties of BRDFs:

1) Non-negativity: $f_r(\omega_i, \omega_o) \geq 0$
2) Energy conservation: $\int_\Omega f_r(\omega_i, \omega_o) \cos\theta_i \, d\omega_i \ \leq 1$ for all $\omega_o$ in $\Omega$, where $\Omega$ is the upper hemisphere of the surface.

- ➢BRDF should not create energy! It can only reflect equal or less energy than the surface receives.
- ➢Note: BRDF can have large values in specific direction but then it must have low value in other directions so that integration over the entire hemisphere does not exceed 1.

3) Reciprocity: $f_r(\omega_i, \omega_o) = \ f_r(\omega_o, \omega_i)$

- ➢Swapping incident and reflected directions does not change BRDF value.

# Radiance Imaging with Cameras

- Consider photograph globally as a measure of radiance and not just pixel values.

- Different setting allow to let more or less light into the lens.

# Typical DSLR camera settings

- Shutter speed
- Aperture
- Gain  (ISO)

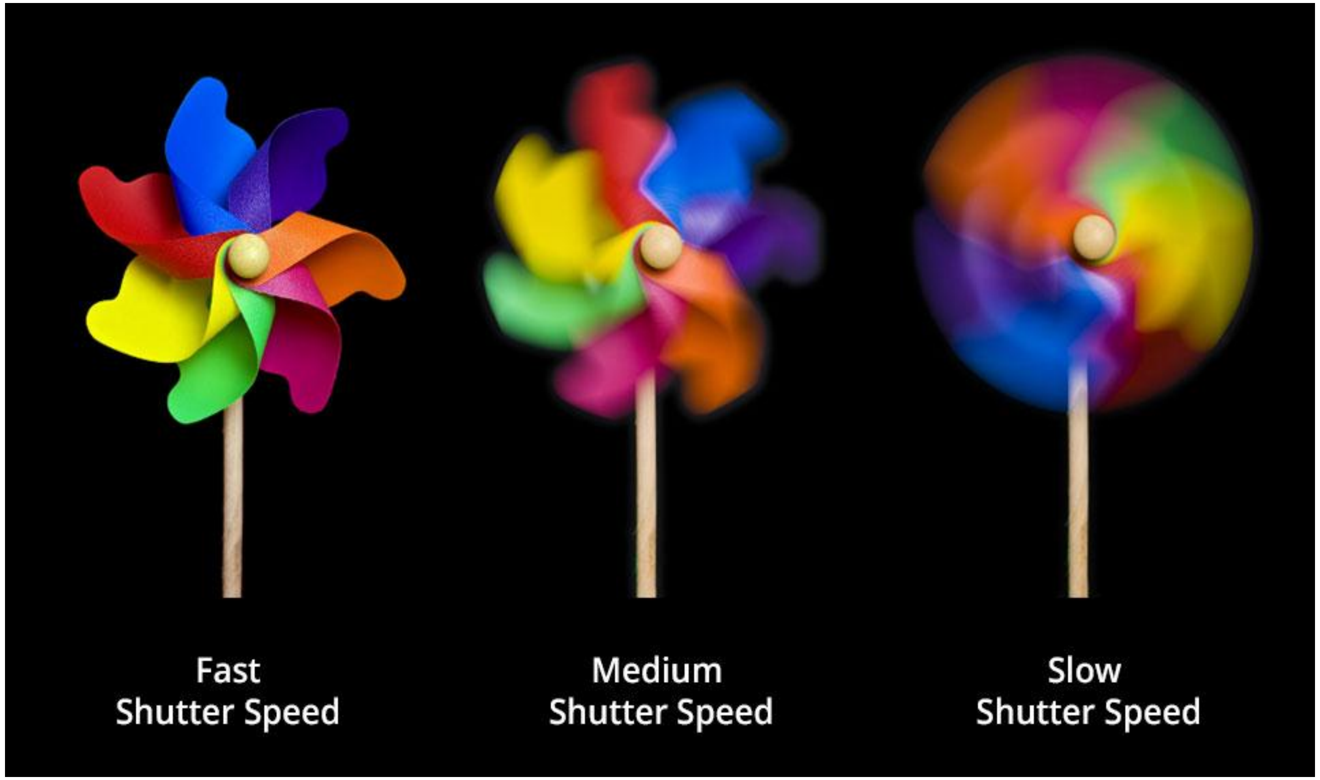
# Shutter speed

- **Shutter speed** – how long the shutter is open to let light in (how long a digital sensor in the camera is exposed to light).

- Measured in fraction of a second.

# Effects of shutter speed variation

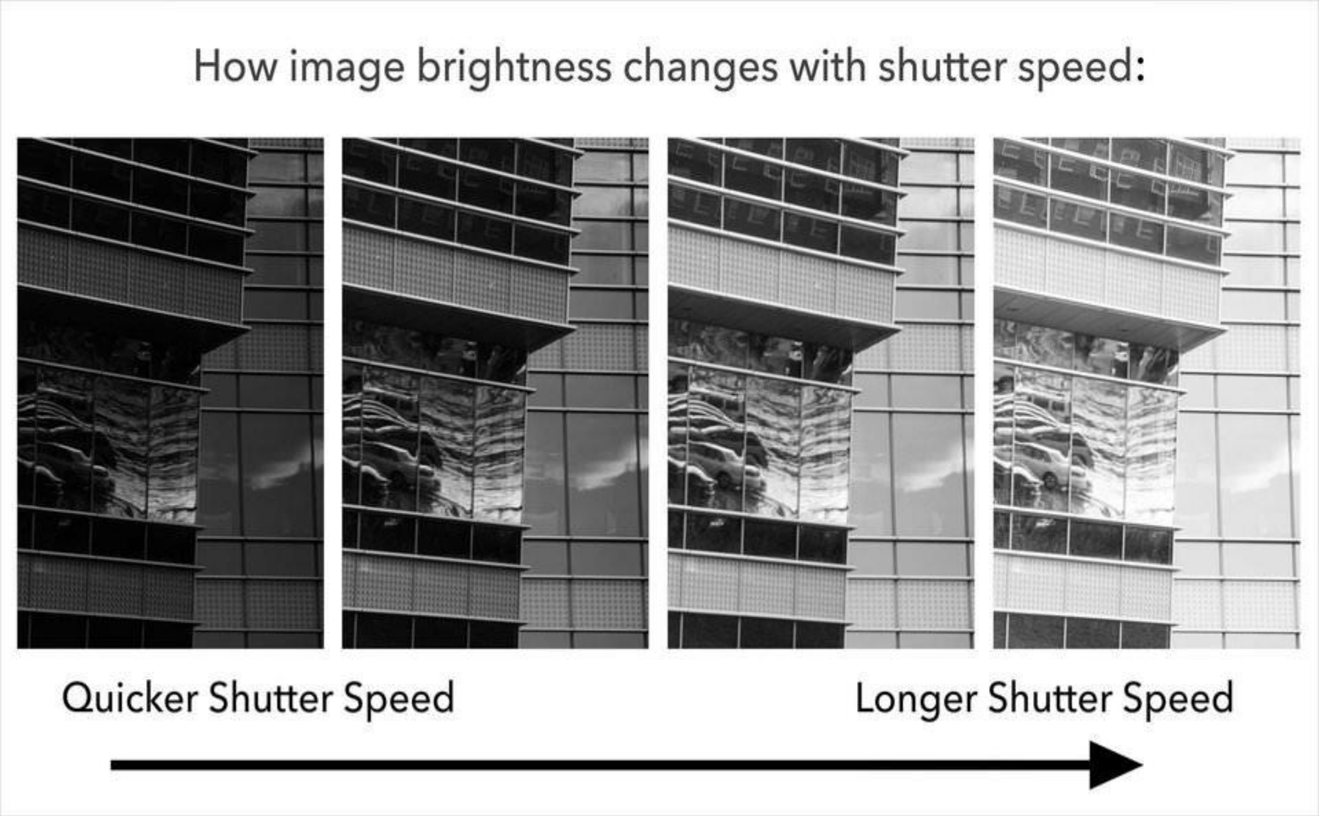
- Motion freeze




http://photoalevel.blogspot.co.uk/2016/09/camera-settings.html

# Effects of shutter speed variation

- Change in brightness




https://photographylife.com/what-is-shutter-speed-in-photography

# Aperture

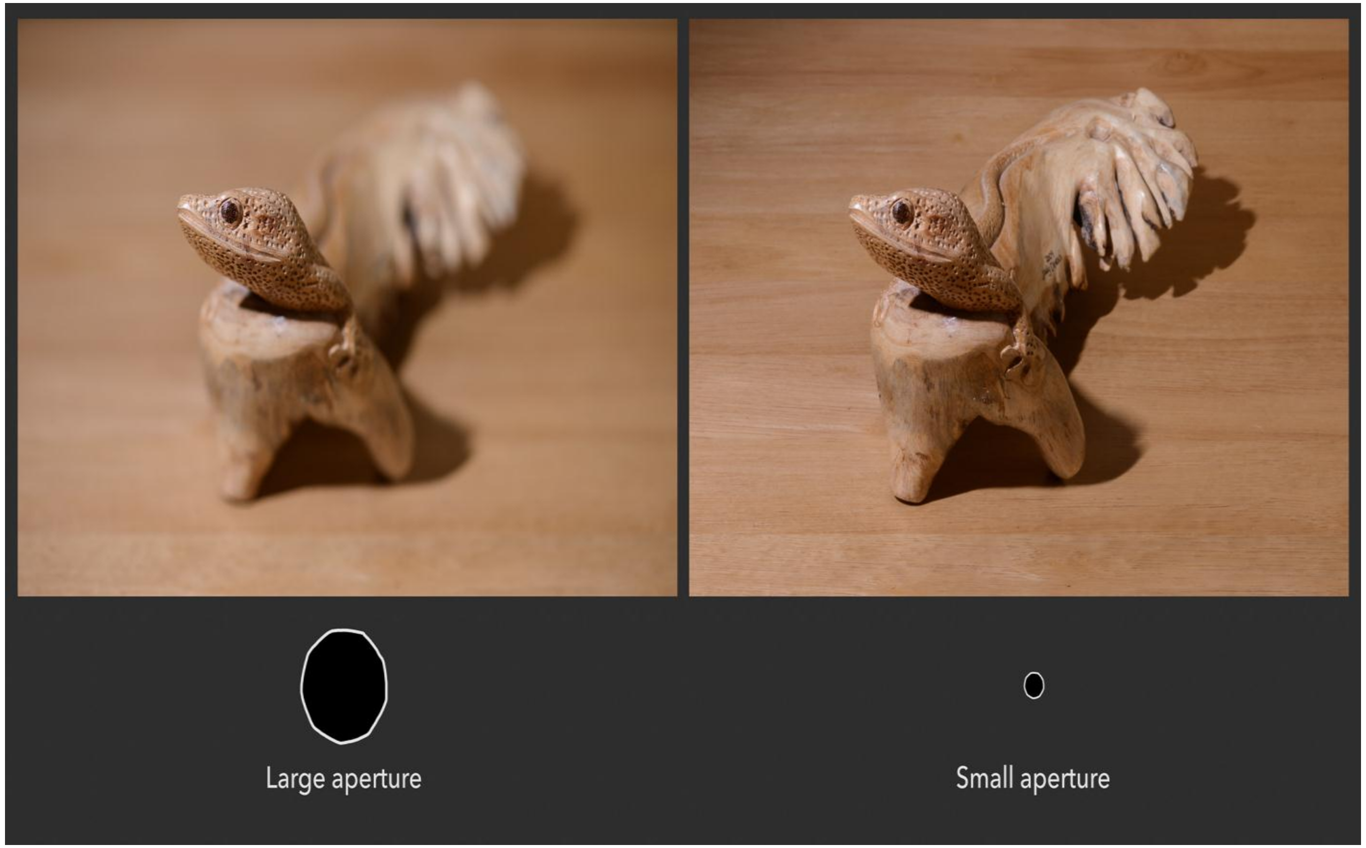
- The opening in a lens, through which light travels to enter the camera.

- Expressed as a fraction of focal length.

- The larger the division number, the smaller the aperture.

# Effects of changing aperture

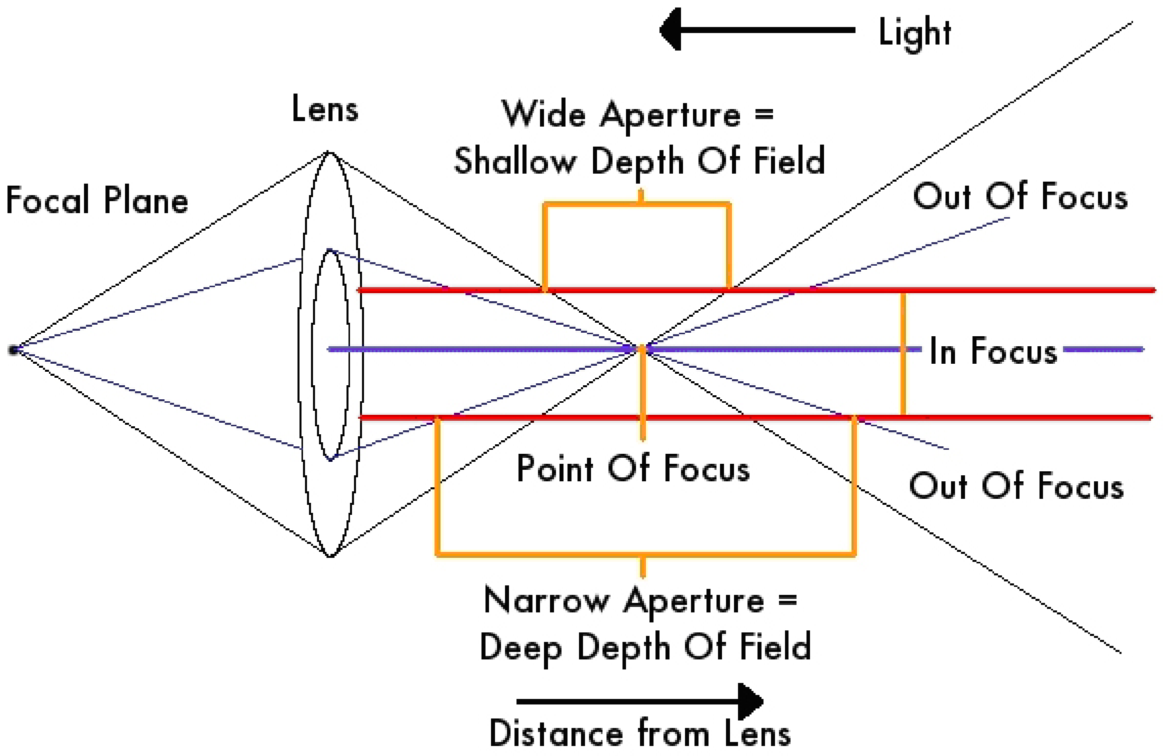
- Depth of Field




https://photographylife.com/what-is-aperture-in-photography

# Depth of Field (DoF)

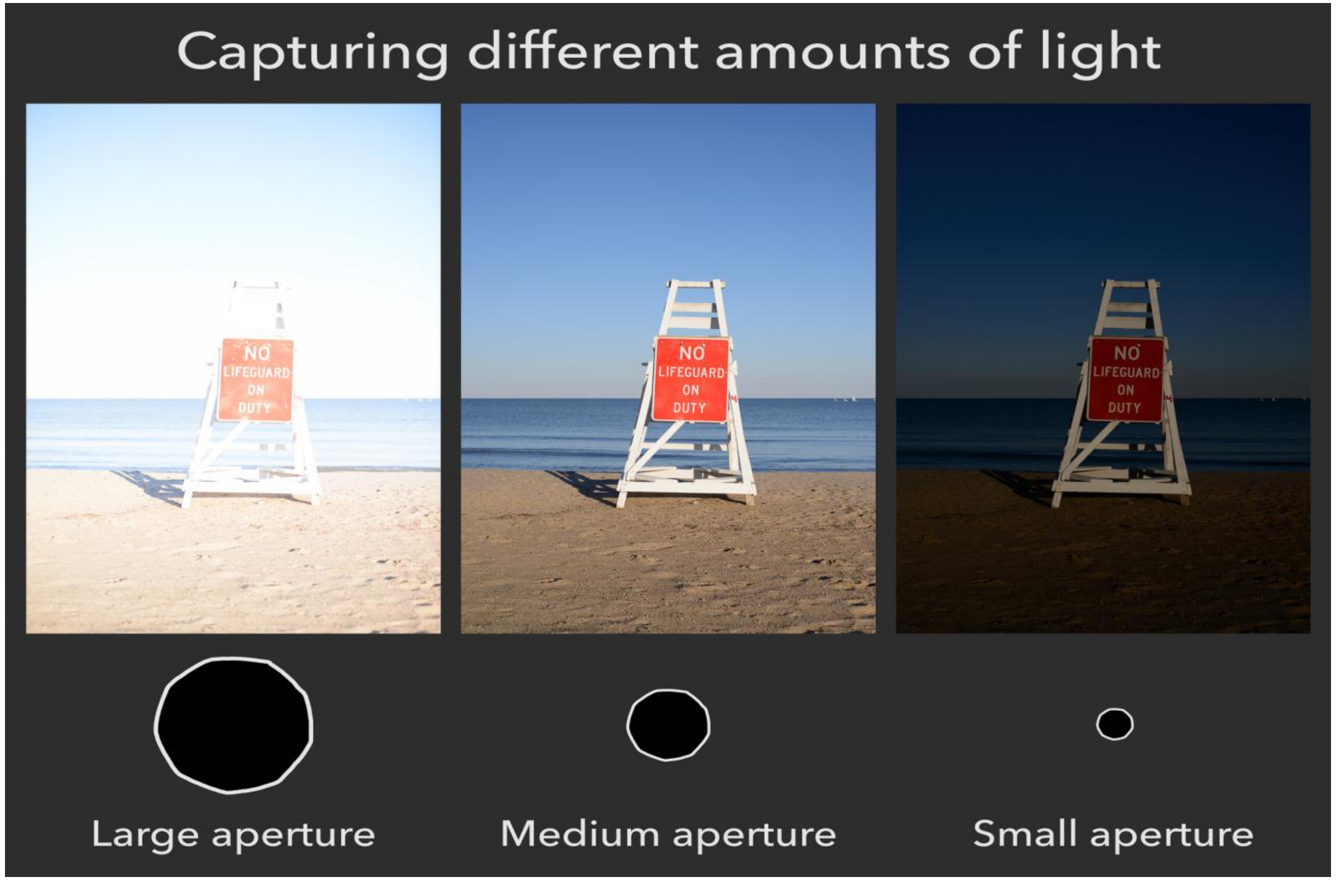
- For narrow aperture rays intersect at more acute angle than for large aperture.
- DoF is defined by the distance between rays crossing the *circle of confusion* (in red).
- Smaller distance (i.e. smaller DoF) for wide aperture, larger for small aperture.




https://www.liveinternet.ru/users/i196irina/rubric/4047202/?aid_refresh=yes

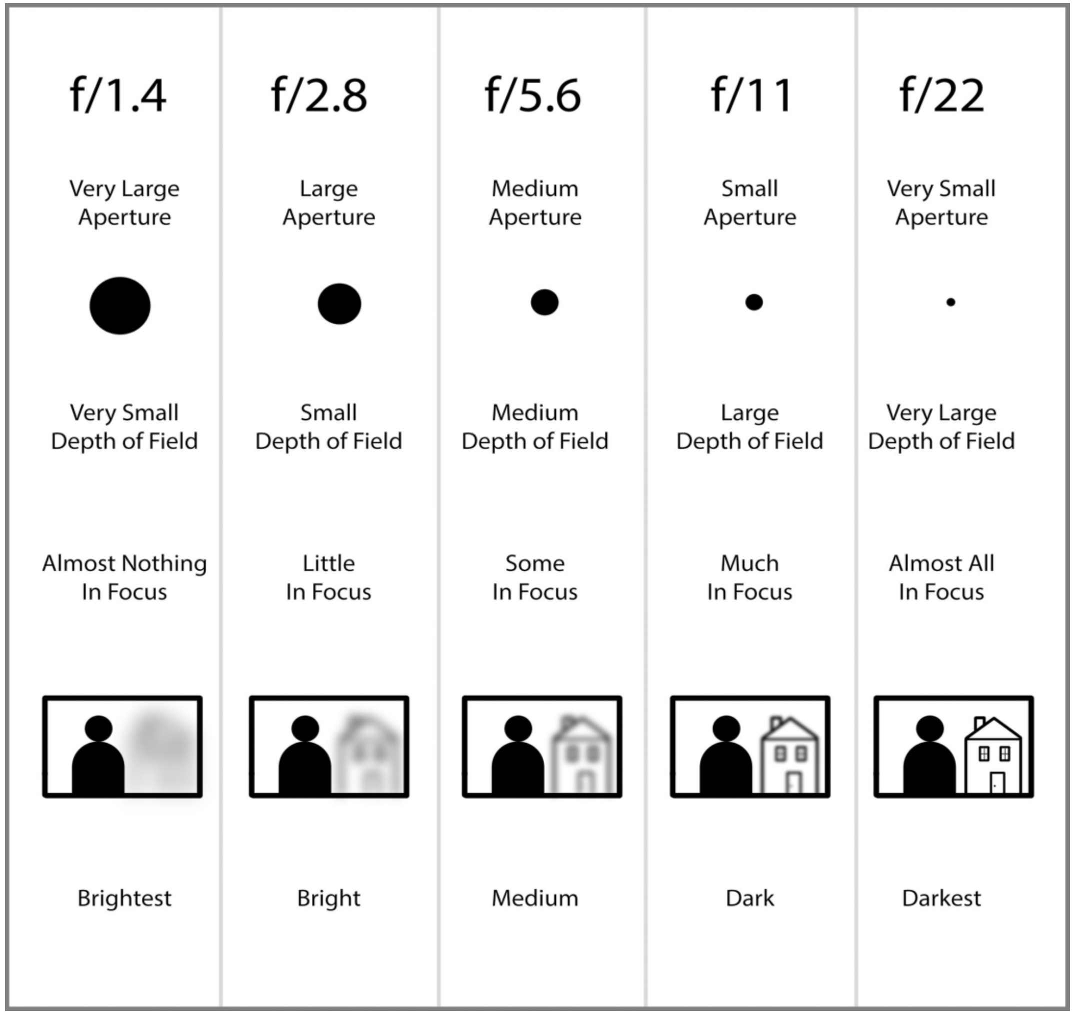
# Effects of changing aperture

- Exposure




https://photographylife.com/what-is-aperture-in-photography

# Aperture summary




https://photographylife.com/lens-aperture-chart

# Aperture

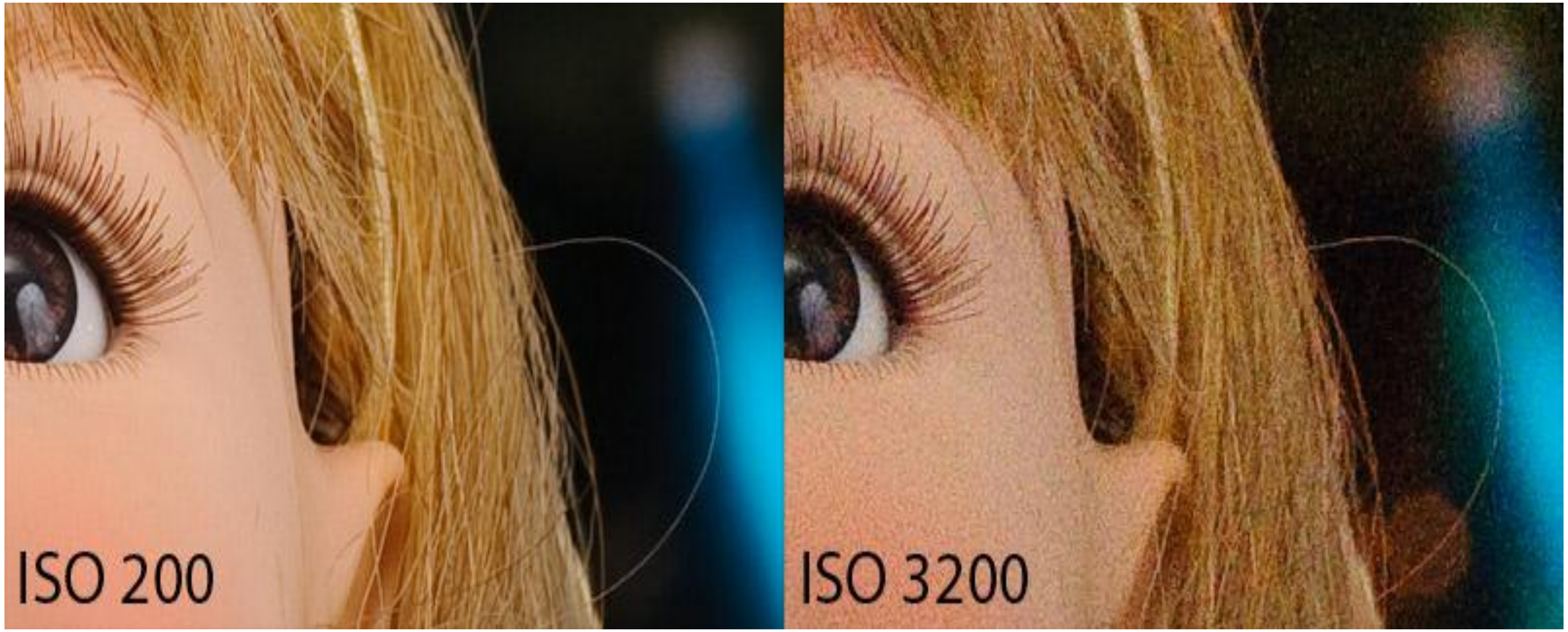
- More info at https://photographylife.com/landscapes/everything-aperture-does-to-your-photos

# Gain (ISO)

- sensitivity of a camera to environment light.
- ISO setting allows to electronically boost energy received by the sensor.
- Can increase ISO when there is not enough light in the surroundings.

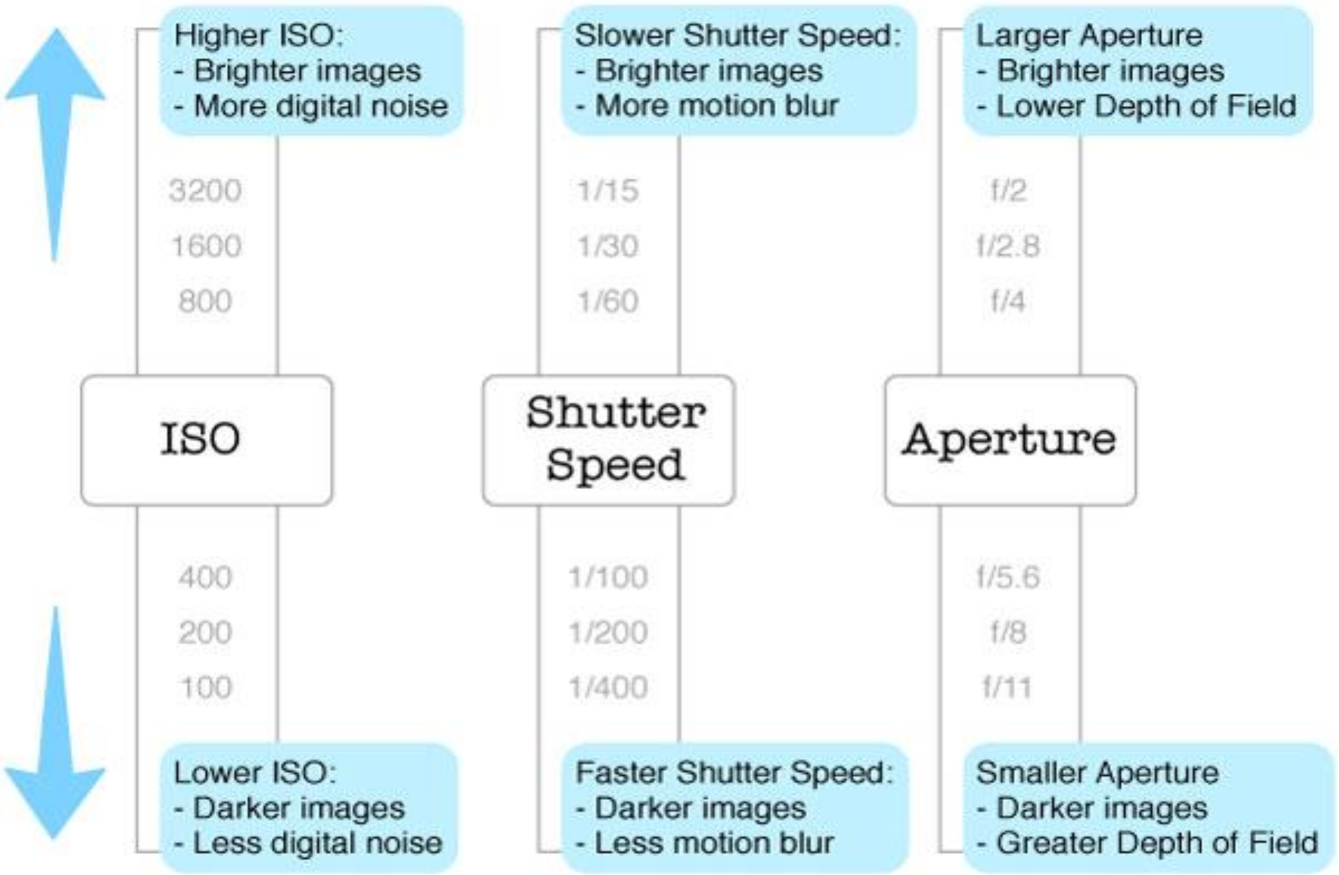
# Gain (ISO)

- However, larger ISO leads to higher image noise!




https://photographylife.com/what-is-iso-in-photography

# Summary




http://www.photocritic.org/articles/equivalent-exposures

# ND filter

- ND (neutral density) filters – use when there is too much light in the surroundings (e.g. sunny weather) to avoid saturated photos.

https://en.wikipedia.org/wiki/Neutral-density_filter

# High Dynamic Range (HDR)

- Real world has significant dynamic range of radiance.

- Use camera settings to adjust camera towards environment. Human eye operates in a similar way adapting to bright and dark environment.

- Impossible to capture high dynamic range with a single photograph. To collect true radiance information need to apply HDR imaging. i.e. take multiple photographs (exposure stack) with different settings, collect ranges of radiance and then fuse images into one called HDR image

# Gamma correction

- Typical exposure fusions assume linearly captured data, which implies it can also be combined linearly.
- Monitors have non-linear gamma curve, they tend to depress pixel intensities while projecting images on the screen. Hence, pixel intensities are multiplied by g*amma* parameter before display.
- Gamma is different for every individual device, but typically has value of 2.2.
- If a monitor displays pixel values implicitly raised by *gamma,* we need to raise intensities to the power 1/*gamma* to produce linear response on the screen. The process refers to gamma correction.