
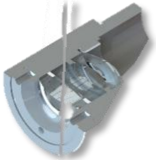



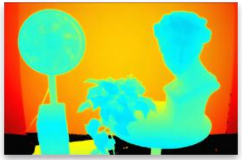

GAMES 204

Computational Imaging

Lecture 09: Imaging Toolbox: Wavefront Analysis and Other Optics

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点昀技术（Point Spread Technology）

Today's Topic

- Wavefront Analysis
  - Point/Line/Edge Spread Function
  - Modulation Transfer Function
  - Wavefront Sensing
- Other Photography Optics
  - Lens Designations.
  - Filters.
  - Prisms.
  - DSLR and Mirrorless Cameras.

Wavefront Analysis

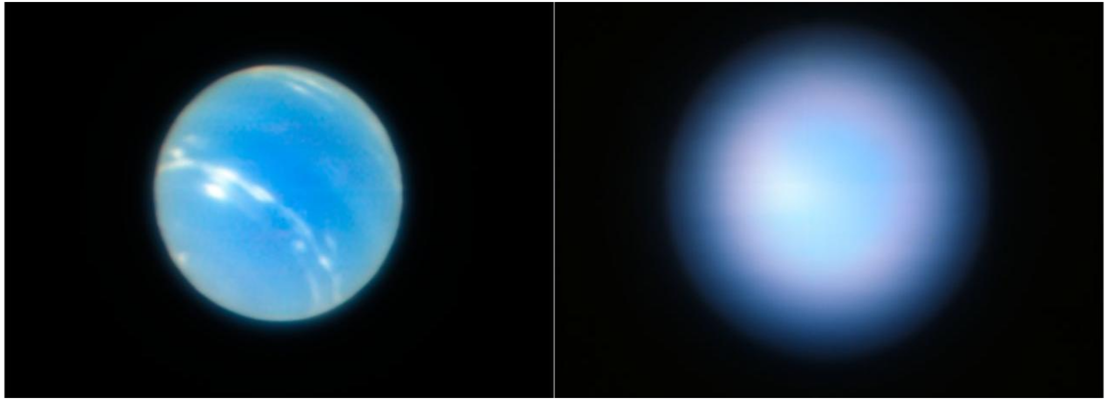
Beyond Sphere and Cylinder . . .

- Higher order aberrations have been traditionally ignored clinically

- Now are routinely considered
  - Post lasik increase in higher order aberrations
  - Can be easily measured
  - Wavefront guided correction available
  - Patient expectations

History of Wavefront Sensing

- DOD in the 1980's to support "star wars"
  - Measure the constantly fluctuating refractive power of the atmosphere to improve accuracy of satellite photos and accuracy of weapons
  - Led to adaptive optics – real time measurements of refractions using "deformable mirrors" that rapidly
  - Astronomers were interested to improve telescope images



Adaptive Optics　　No Adaptive Optics

Credit: www.opt.pacificu.edu; https://www.eso.org/public/images/eso1824b/

Shack-Hartmann Wavefront Sensor

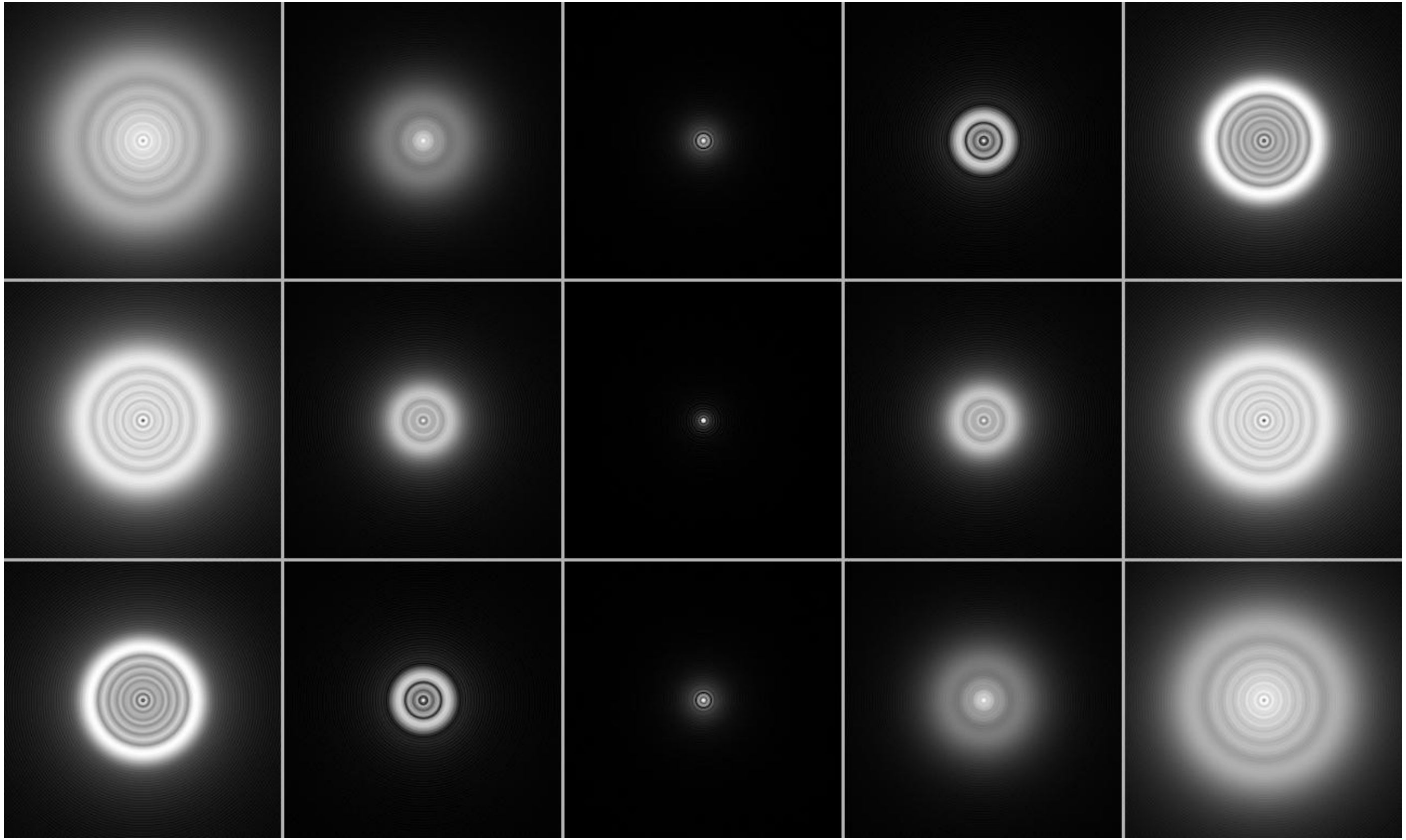
- Hartmann first looked at this a century ago
- Shack elaborated on this in the 1980's working for the US air force
- Liang was the first to use the wavefront sensor to measure the human eye in 1994.
- By the late 1990's commercial development was occurring.

Airy Disc

An Airy disc shows how a point image is degraded by aberration

When wave encounters and obstruction, the direction of the wave changes.
This is called DIFFRACTION

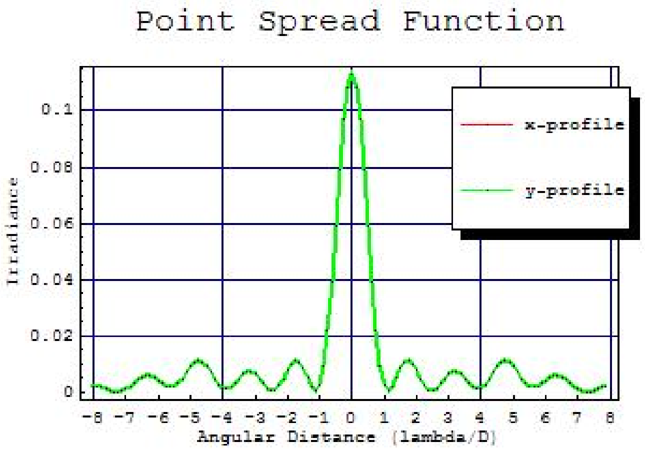
Point Spread Function (PSF)

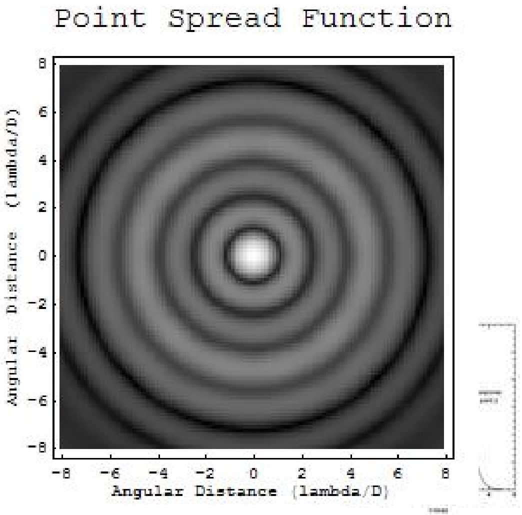


Source:wikipedia

Point Spread Function (PSF)

The image of a perfect point will be at least one point wide.
Normally it's image is brightest in the center and progressively darker away from the center. This image function is the point-spread function.





Point Spread Function (PSF)

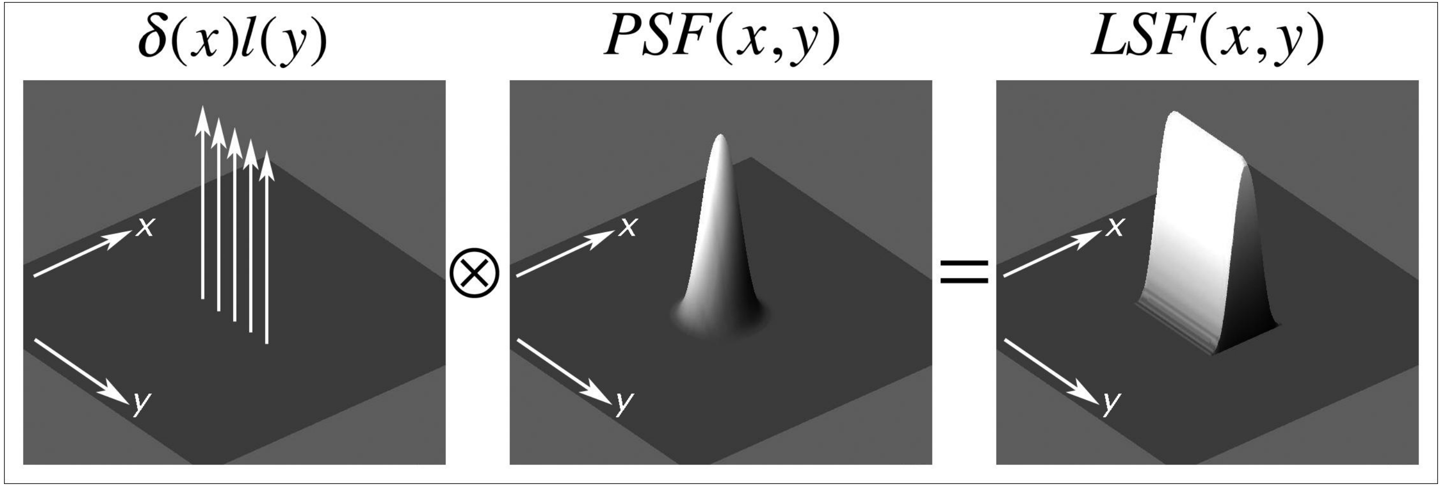
- Used to assess the **spatial resolution** of an imaging system.
- The PSF **need not be symmetrical**, so there may be different spatial resolutions in different directions.
- Note that the PSF is, in most cases, a function with significant variation over the **field of view** and **depth**.

Modulation Transfer Function (MTF)

- Used to assess the overall spatial resolution of an imaging system. MTF is formally defined as the magnitude of the **Fourier transformed point spread function.**
- The concept of the MTF is to portray how much of the contrast at a specific resolution is maintained by the imaging process.

Line Spread Function (LSF)

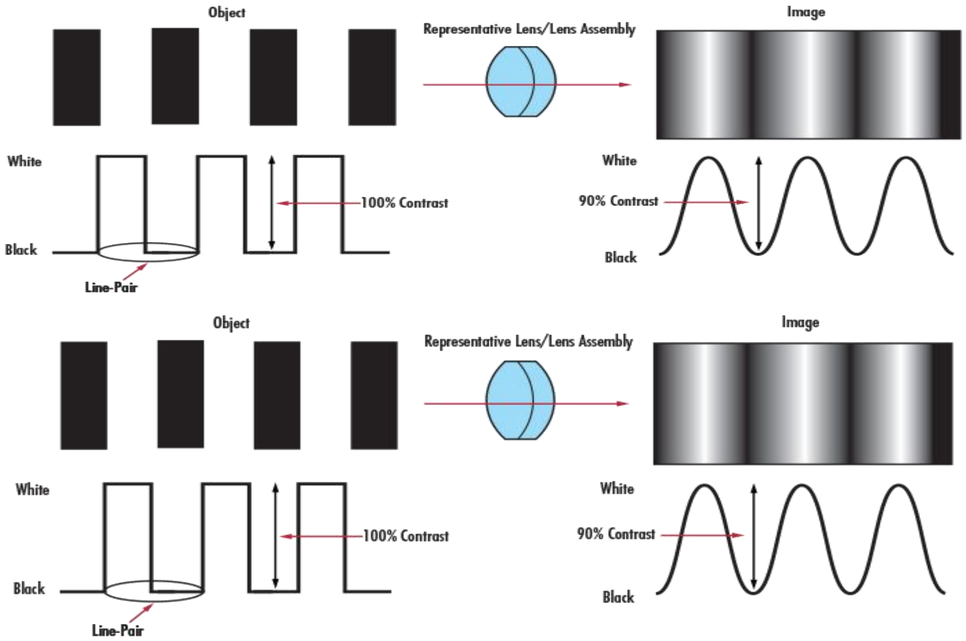
- The LSF is the two-dimensional convolution of the line source with the system PSF.



Source:carlesmitja

Modulation Transfer Function (MTF)

➢ How can the degradation of an optical system be evaluated?



Perfect Line Edges Before (Left) and After (Right) Passing through a Low Resolution Imaging Lens

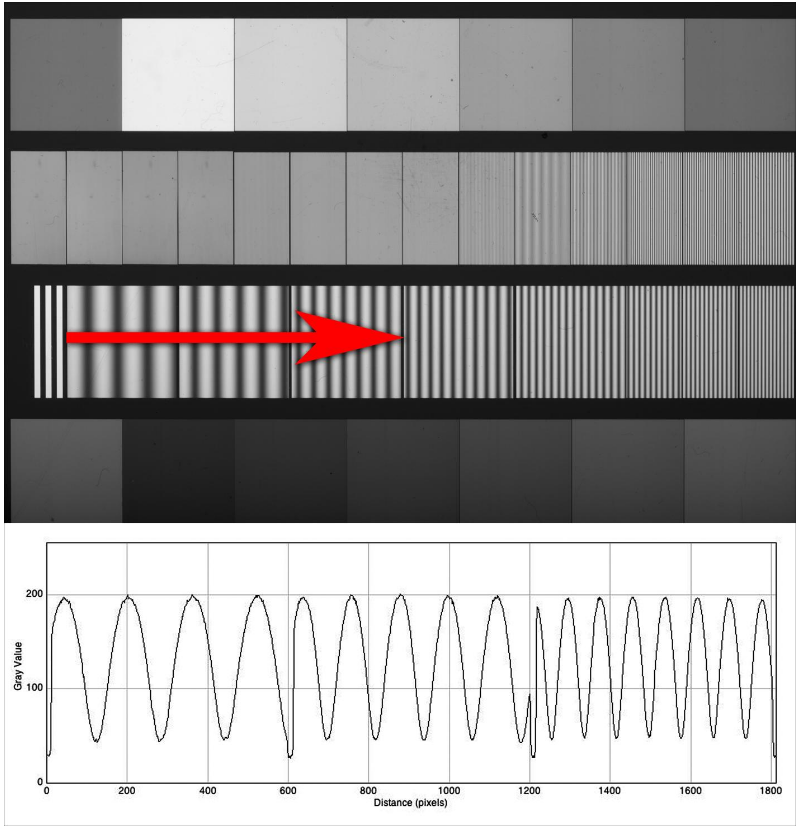
$$M\text{ (Modulation)} = \%\text{ Contrast} = (I_{max} - I_{min}) \,/\, (I_{max} + I_{min})$$

Source:edmundoptics

Modulation Transfer Function (MTF)

- Square wave grating of specific frequency and contrast is passed through an optical system. The MODULATION can then be measured

- MTF= M_{in}/M_{out}

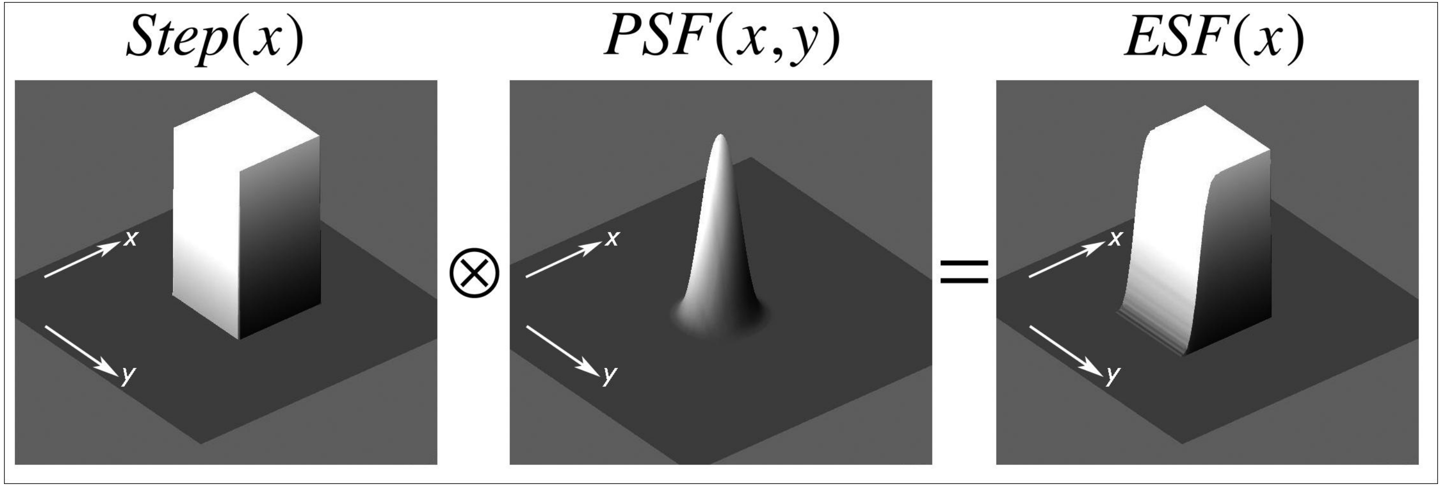


sinusoidal grating

Source:carlesmitja

Edge Spread Function (ESF)

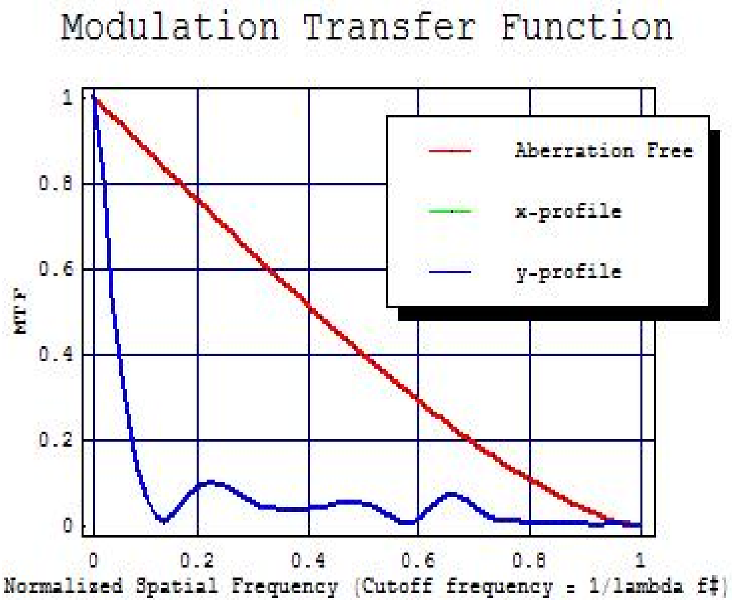
- The ESF the two-dimensional convolution of the edge source or step function with the system PSF.



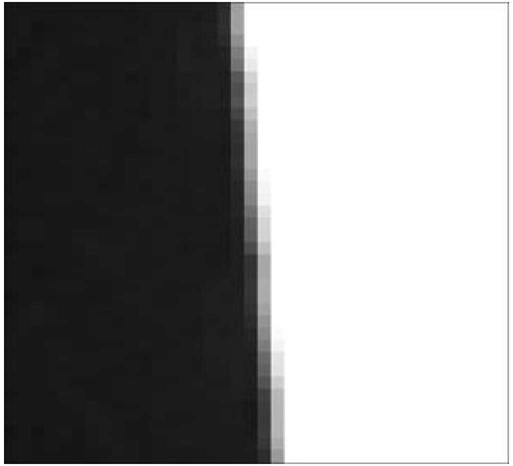
Modulation Transfer Function (MTF)

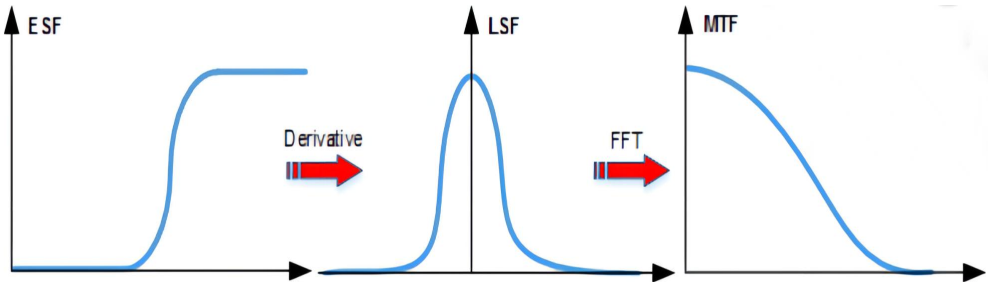
- In the optimal case, the MTF value is 1 meaning that object and image contrast are identical.

- MTF usually starts with a value 1 at 0 spatial frequency which represents a homogeneous background. It then drops in a system-specific manner down to zero. By using the MTF, two systems can readily be compared: At each spatial frequency (or 1/resolution) that system with the higher MTF maintains better contrast.



Slanted Edge Method for MTF





An actual edge image showing the periodicity pattern caused by the slanted position of the test target image over the sampling grid of sensor.

Wavefront Analysis (Wavescan)

- Light is has both **particle** and **wave** characteristics
- Wavefront analysis describes the **wave behavior** of light
- Actual image displacement of the point source from foveola as it passes through the optical system of the eye compared to the ideal image.

Custom Lasik（Wavefront-LASIK）

Wavescan uses the principles of MTF

- Custom can correct for
  - Myopia or hyperopia
  - Astigmatism
  - Spherical Aberration
  - Coma

- Custom does not correct for
  - Chromatic aberration
  - Diffraction

https://www.youtube.com/watch?v=y-UpTLMEkEM

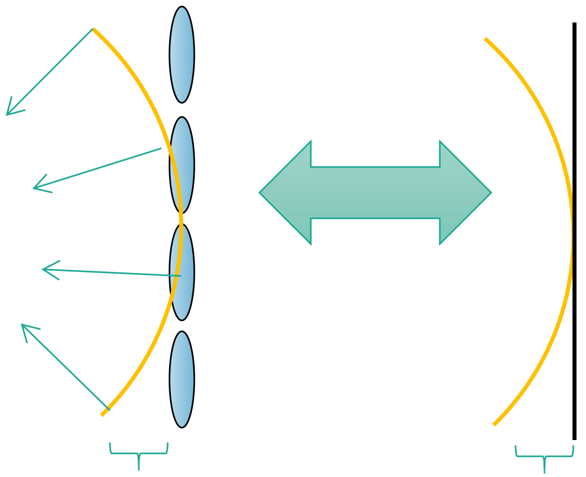
Hartmann-Shack Aberrommetry

- Analyze light that emerges or is reflected from the retina and passes through the optical system of the eye.

- Produces a "fingerprint" of the aberrations for an individual eye.

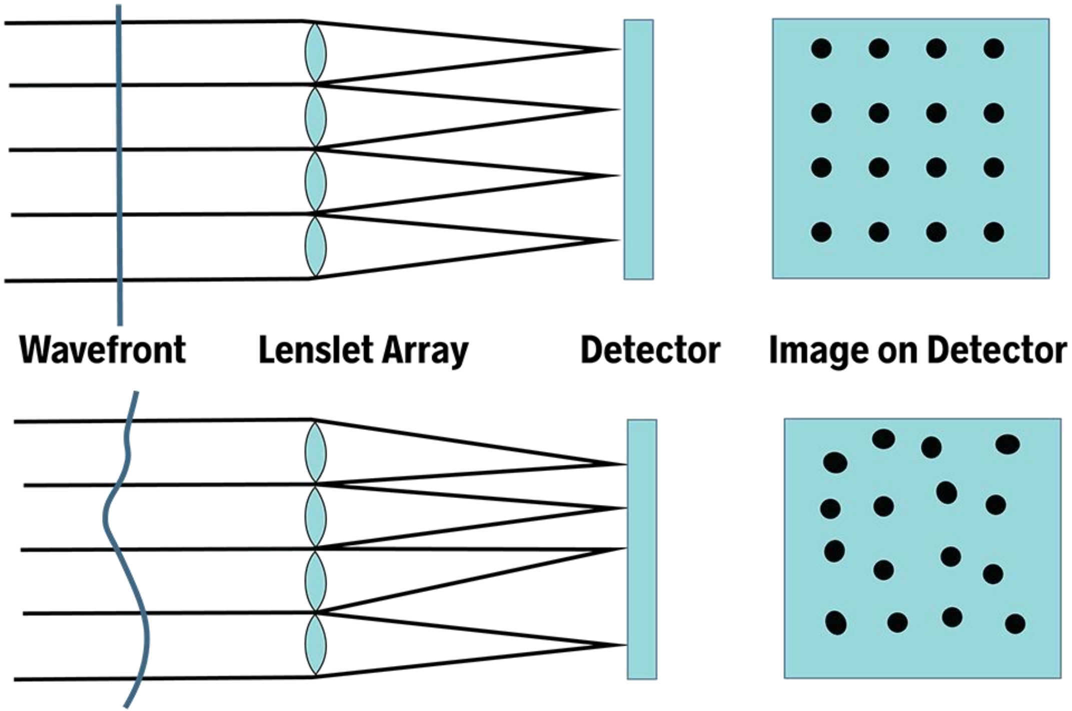
Wavefront Analysis

The distance between the wavefront surface and a reference plane



Wavefront exiting the eye.
Distance from the reference plane
is measured at many points.

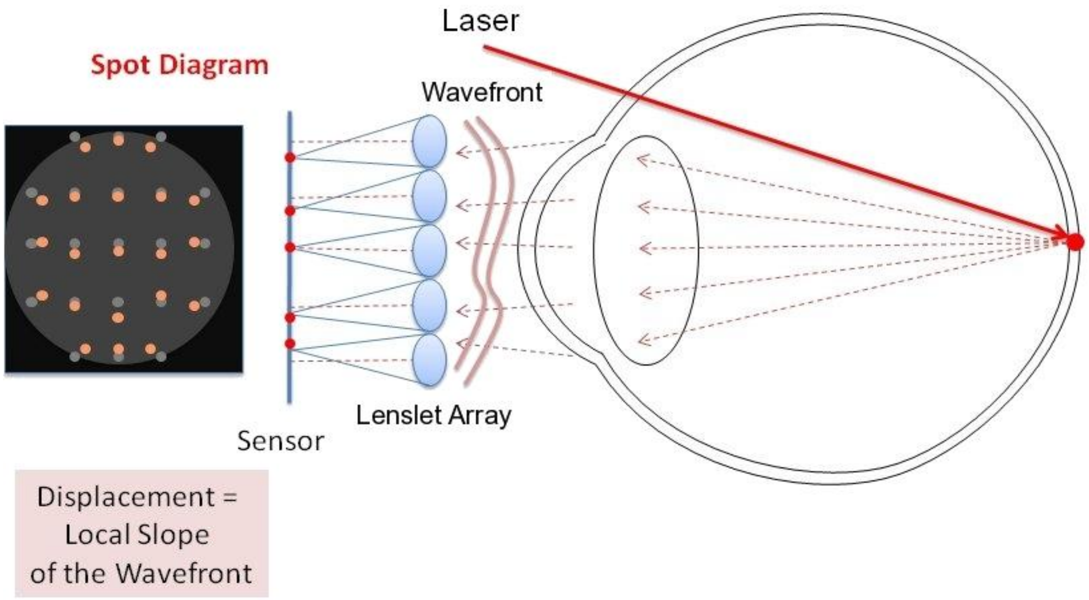
Wavefront Analysis



Shack–Hartmann sensors are used in astronomy to measure telescopes and in medicine to characterize eyes for corneal treatment of complex refractive errors

https://www.opticsforhire.com/blog/rms-wavefront-error-explained/

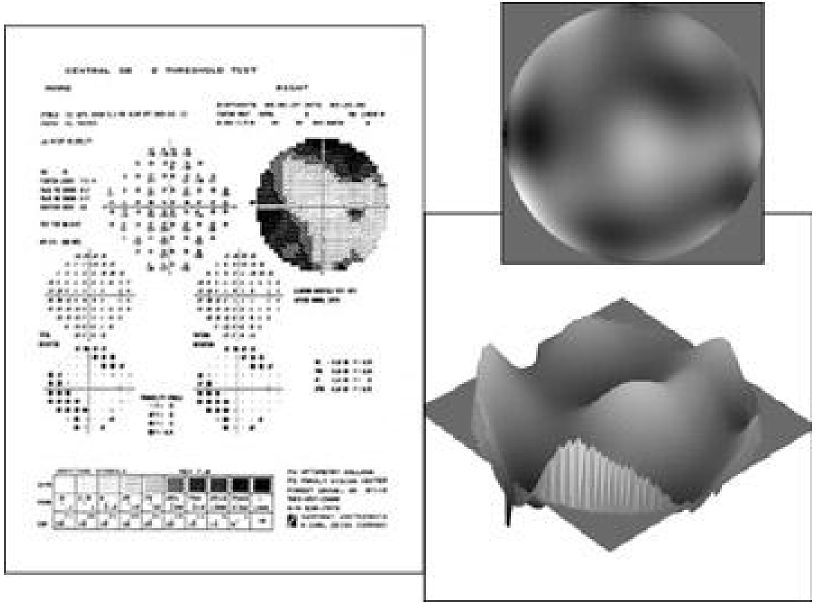
Hartmann Shack Aberrometer



Lenslet Array divides the broad beam of light into many sub-beams for measurement.

Each lenslet focuses onto the Video sensor. We analyze the position of each spot.

Wavefront Analysis

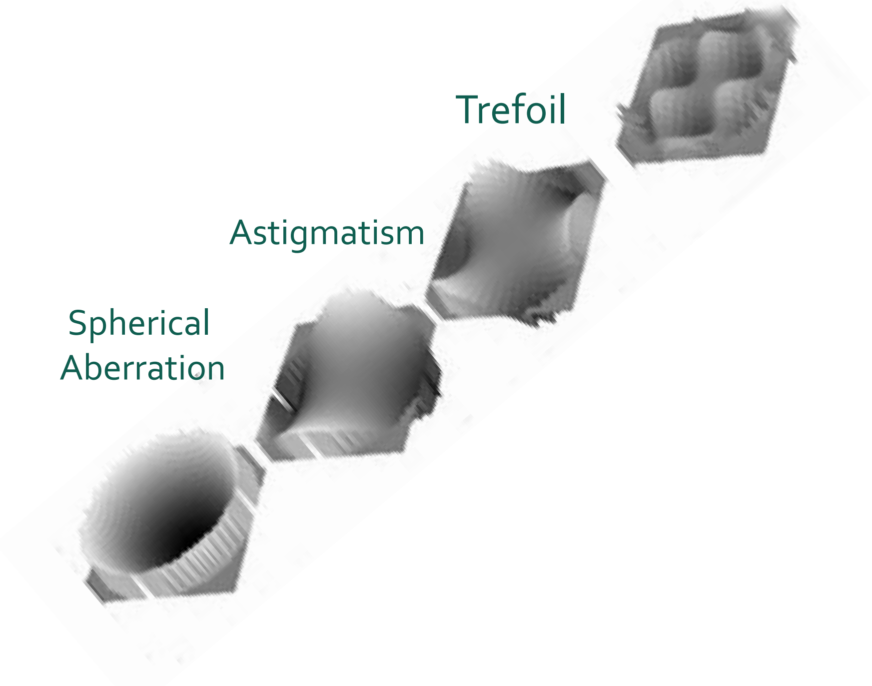


Quadrafoil

Trefoil

Astigmatism

Spherical Aberration



Sometimes it is easier to visualize the wavefront in a 3D surface plot

Wavefront Analysis – *Root Mean Square*

- Measure of the deviation of an actual image from an ideal image of the source point object

- RMS of ideal system is 0

- RMS of human eye increases from 0.1mm(<40 years old) to 0.25mm (>60 years old).

- Standard LASIK increases RMS especially for large pupils.

Lens Designations

Wide-Angle Lenses

Ultra-wide lenses can get impractically wide…

Fish-eye lens: can produce (near) hemispherical field of view.

Telephoto Lenses

Lenses with focal length 85 mm or larger.

Technically speaking, “telephoto” refers to a specific lens design, not a focal length range. But that design is mostly useful for long focal lengths, so it has also come to mean any lens with such a focal length.

Prime vs Zoom Lenses

focus ring: changes focus distance

single focal length

available focal length range

focus ring: changes focus distance

zoom ring: changes focal length

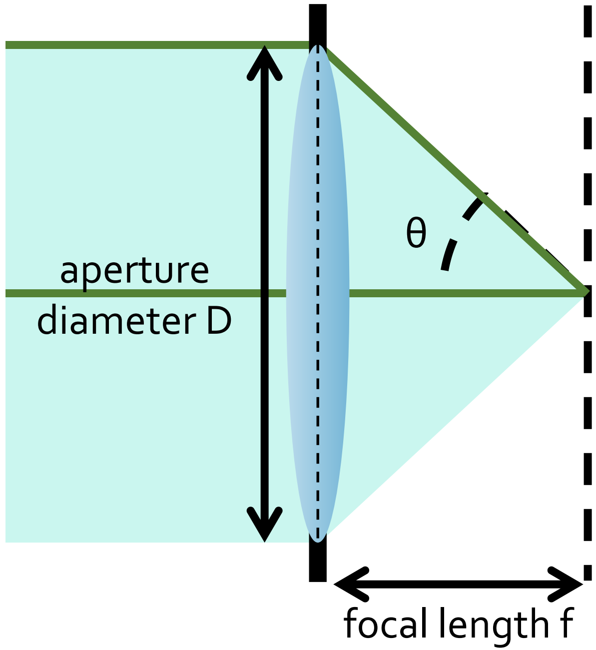
Prime lens: fixed focal length

Zoom lens: variable focal length

Why use prime lenses and not always use the more versatile zoom lenses?

Zoom lenses have **larger aberrations** due to the need to cover multiple focal lengths.

Numerical aperture and f-number



Numerical aperture (NA): sine of half-angle of entering light cone.

- Varies with focus settings, we consider NA at infinity focus.
- A larger NA means a larger aperture.

$$\mathrm{NA} \equiv \sin\theta$$

F-number (f/): ratio of focal length and aperture diameter.

- Independent of focus setting (at least for ideal lenses).
- A larger f/ means a smaller aperture.

$$\mathrm{f/} \equiv \frac{f}{D}$$

How are the two related under paraxial approximation?

$$\mathrm{NA} = \sin\theta \approx \tan\theta = \frac{D}{2f} = \frac{1}{2\mathrm{f/}}$$

Aperture Size

Most lenses have variable aperture size.

- F-number notation: "f/1.4" means $f/\ \ = 1.4$.
- Usually aperture sizes available at steps of one-half or one-third stops.
- Older lenses have separate manual aperture ring.
- Modern lenses control the aperture through a dial on the camera body ("gelded" lenses).

f/1.4 f/2.8 f/4 f/8 f/16

Note: A "stop" is a change in camera settings that changes amount of light by a factor of 2.

- If the current aperture is at f/4, what is the f-number one stop up and one stop down?

Lens Speed

- A *fast* lens is one that has a **large *maximum aperture***, or a small *minimum f-number*.
- The "speed" of a lens is its minimum f-number.

Why does this zoom lens has more than one lens speeds?

- The max aperture size varies as the focal length (zoom) varies.

Fastest Possible Lenses

What is the speed of the fastest possible lens?

- From paraxial approximation, fastest lens is f/0.5.
- In consumer photography, fastest lenses are f/0.9 – f/0.95.

Leica Noctilux 50mm f/0.95 (price tag: > $10,000)
Fast lenses tend to be bulky and expensive.

Zeiss 50 mm f / 0.7 Planar lens
Originally developed for NASA's Apollo missions.

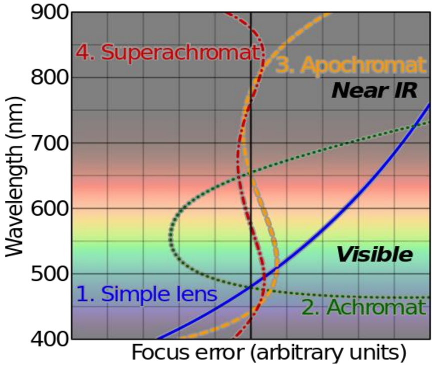
Other Lens Designations

Macro lens: very large magnifications (typically at least 1:1).

- Lens body allows effective lens plane to be placed far away from sensor.
- Macro photography: extremely close-up photography.

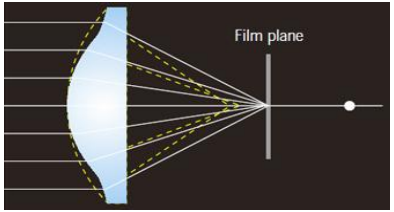
Achromatic or apochromatic lens: corrected for chromatic aberration.

- Achromatic: two wavelengths have same focus.
- Apochromatic (better): three wavelengths have same focus.
- Often done by inserting elements made from low-dispersion glass.
- Expensive.



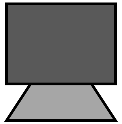
Aspherical lens: reduces aberrations.

- Expensive, often only 1-2 elements in a compound lens are aspherical.

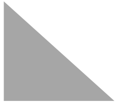


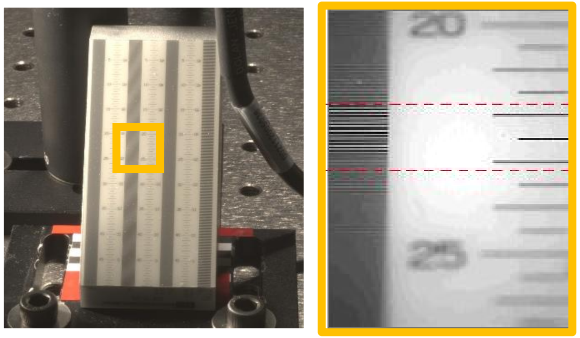
Other Lens Designations

hyperspectral camera



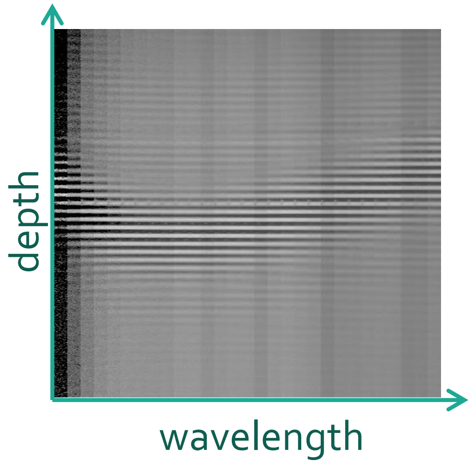
depth-of-field target

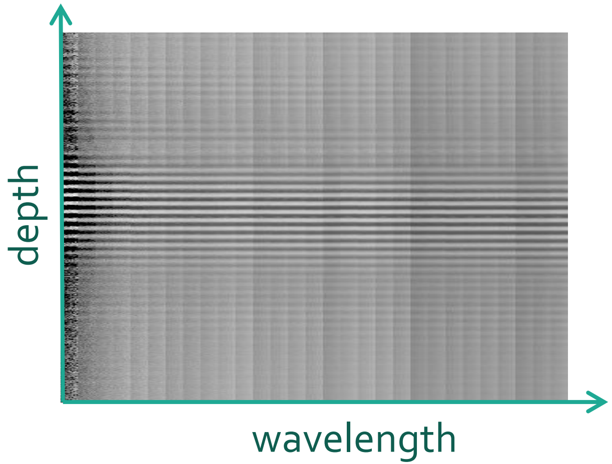




standard lens ($500)

apochromatic lens ($5000)



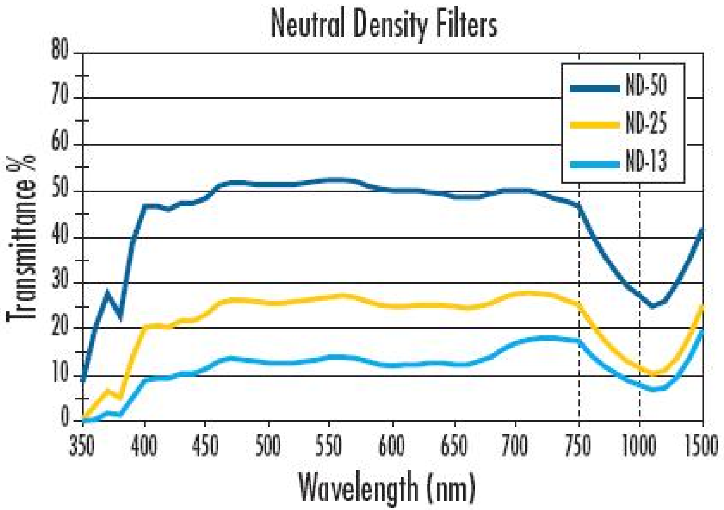


Filters

Neutral Density (ND) Filters

Alternative way to control exposure:

- (Approximately) spectrally flat from 400-700 nm.
- Homogeneous glass that blocks by absorption or by reflection

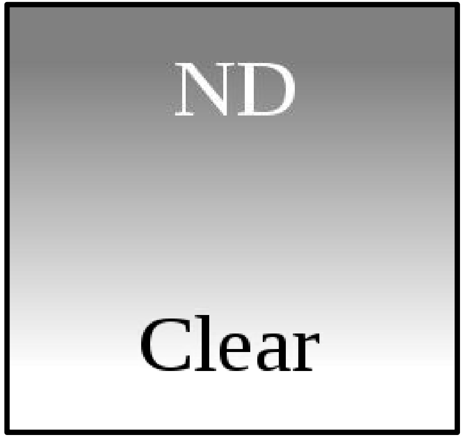


Often characterized by *optical density* (OD):

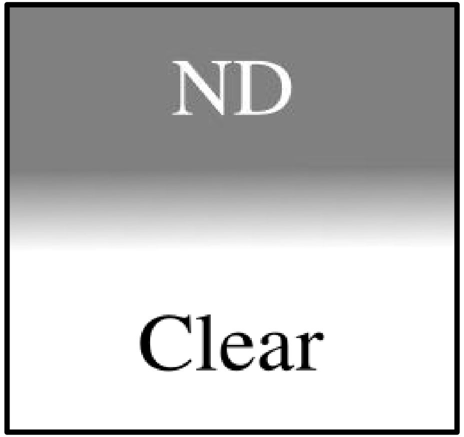
- Transmittance = $10^{-\text{optical density}} * 100$.
- Optical density is additive as you stack together ND filters.

Graduated Neutral-Density Filters

Variable optical density, from too high to too low/zero.



soft edge



hard edge

What are these filters useful for?

Graduated Neutral-Density Filters

Useful in scenes with parts of very different brightness.

- Common scenario: Sky – horizon – ground.

Polarizing Filters (or Polarizers)

Most commonly circular polarizers.

- Same principle as polarizing sunglasses.

What are these filters useful for?

Polarizing Filters (or Polarizers)

Reduce sky light

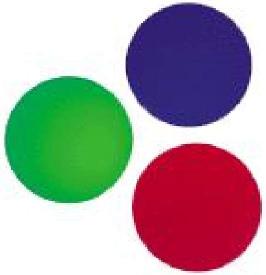
Reduce haze

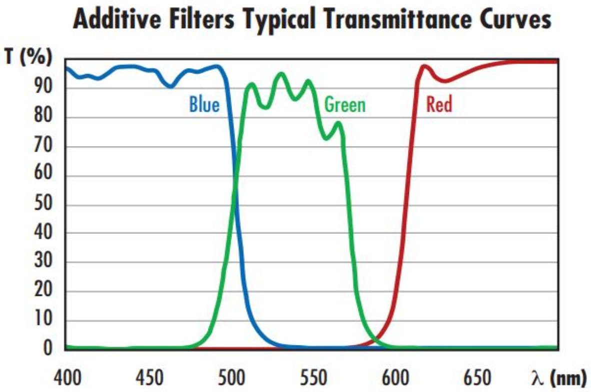
Polarizing Filters (or Polarizers)

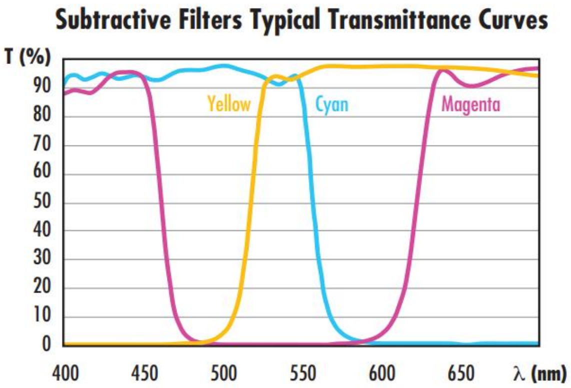
Reduce direct reflections

Spectral (color) Filters

Mostly used for scientific applications or under very special lighting settings.







Source:edmundoptics

Filter Size

The filter size you need to use is determined by the lens you are using.

- You can find the filter size marking in the front of the lens.
- You can avoid having to buy dozens of filters by using step-up and step-down rings.

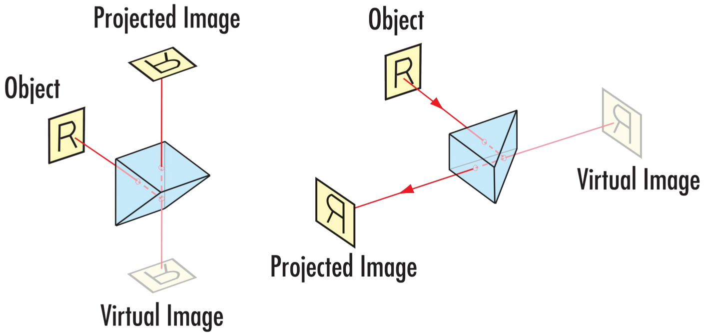
filter size marking

Prisms

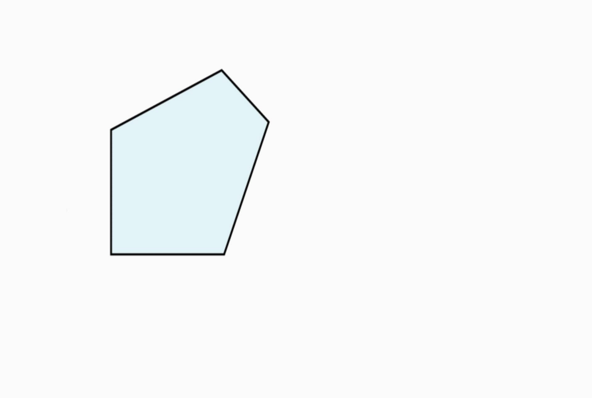
Prisms

Many different types of prisms that produce different types of reflections.

Right Angle Prism



Penta Prism



Any use of pentaprisms in photography?

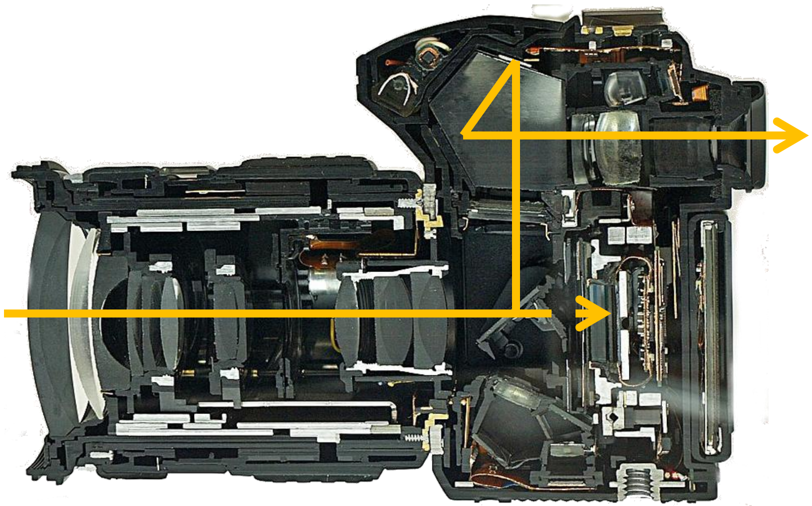
Source:edmundoptics

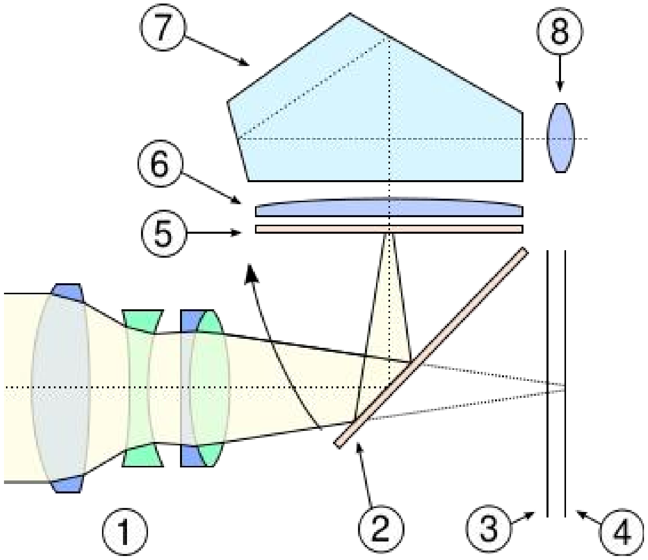
DSLR and Mirrorless Camera

Single Lens Reflex (SLR) Cameras

Mechanism to provide direct view through the lens (TTL).

- Any downsides?



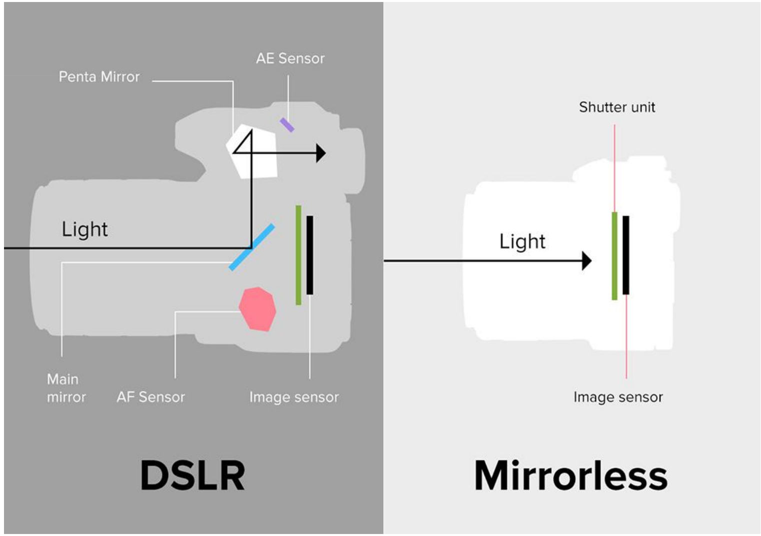


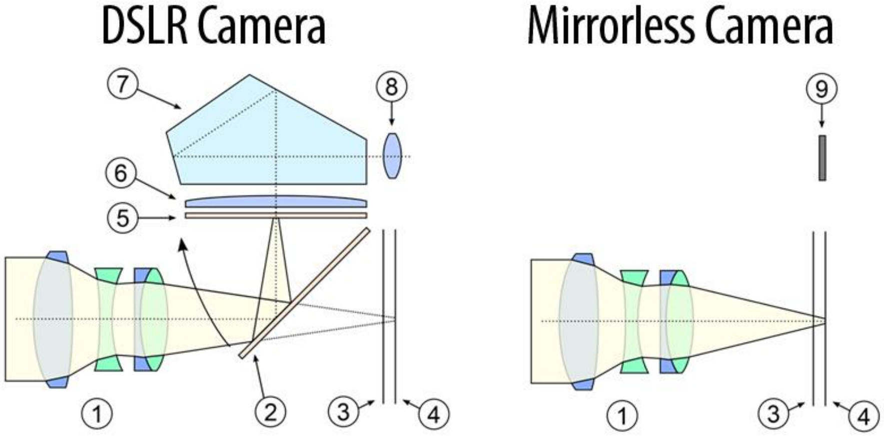
1 - Front-mount Lens
2 - Reflex Mirror at 45 degree angle
3 - Focal Plane Shutter
4 - Film or Sensor
5 - Focusing Screen
6 - Condenser Lens
7 - Optical Glass Pentaprism (or Pentamirror)
8 - Eyepiece (a.k.a. viewfinder)

SLR Versus Mirrorless

Mirrorless cameras used to be mostly point-and-shoot, but are quickly becoming the dominant choice for high-end photography.

- ➢ What are some pros and cons of mirrorless compared to SLR?





1 - Front-mount Lens
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Source:Canon

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Thank You!

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点昀技术（Point Spread Technology）