Notes on Camera Fundamentals

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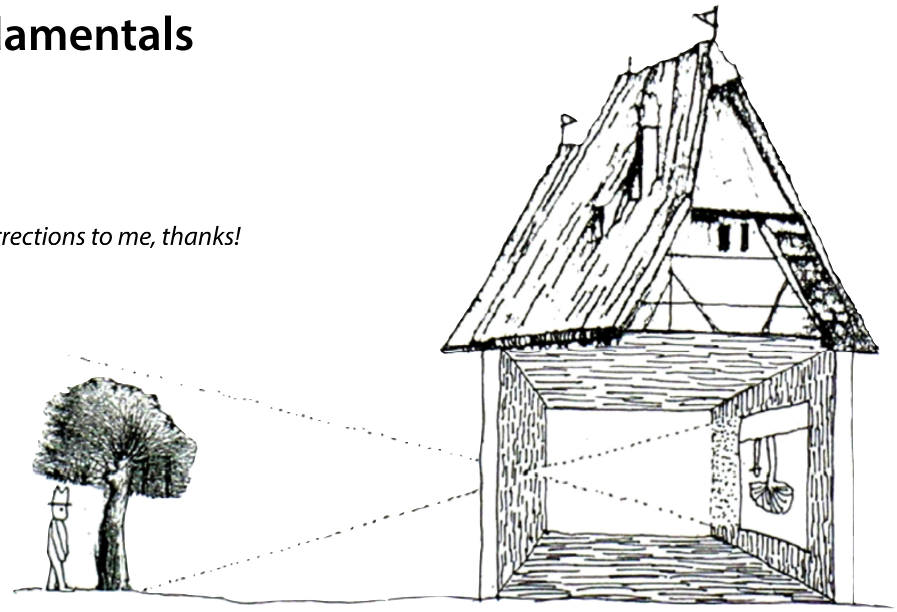
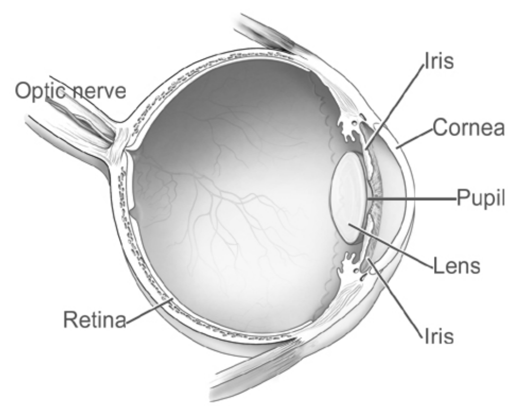
Please send comments, suggestions, and corrections to me, thanks!

Origins



We can trace back the origins of photography to the **camera obscura** (dark chamber). Artists discovered that if you make a small hole in a darkened room it will form on the opposite wall an inverted upside-down image of the scene outside of the room. The image has no exact position of focus (deep-focus).

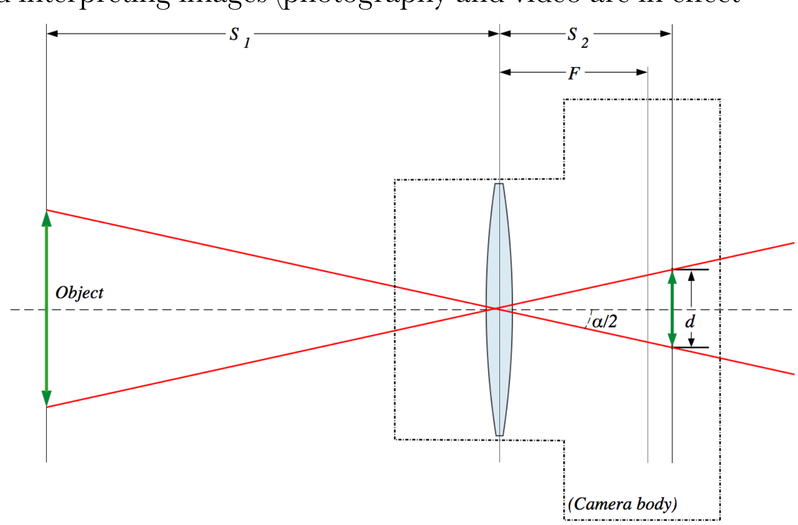
Photography vs. video



A **photograph** is a single image compared to **video** which is a sequence of images that when acquired and subsequently displayed one after another (usually at 30 frames per second) provides the illusion of movement.

Imaging systems

Our imaging systems are modeled after our visual system. Components of an imaging system includes a light sensitive surface (sensor), lens, aperture, shutter, electronic processing, and a means of storage. These are part of a larger apparatus for producing, processing, distributing, and interpreting images (photography and video are in effect constellations of technical and socio-cultural practices).



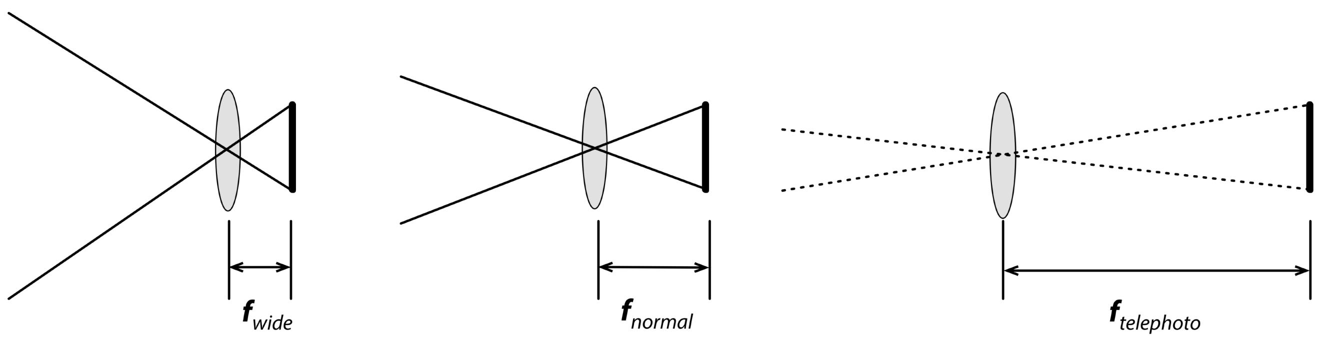
The lens

A pinhole camera allows light rays from an object to pass through a small hole to form an image, however, as you increase the size of the aperture to allow for a brighter image, the image becomes blurry. With a simple convex lens, light rays converge (come together) at the focal point in sharp focus and also allows much more light to pass compared to a pinhole. Contemporary photographic lenses combine a number of convex and concave lens elements to form a compound lens, with each element correcting one more more aberrations in order to produce better images, however, essentially they are doing pretty much the same thing as a simple convex lens as illustrated here.

Focal length

The focal length of a lens is the distance between the optical center of the lens and the image sensor where the subject is in focus, usually stated in millimeters. The focal length of the lens determines:

- field of view (a.k.a. angle of view),
- perspective,
- depth of field, and
- motion blur (as a result of camera movement).



A **normal lens** is a lens with a focal length that provides a perspective and angle of view (conventionally about 40 degrees horizontally) that resembles human vision.

A **wide angle lens** is a lens with a focal length shorter than a normal lens. It provides a wider angle of view with greater depth of field compared to a normal lens and exaggerates perspective such that the apparent distance between objects along the Z axis is expanded in comparison to a normal lens. In addition, there's less noticeable motion blur (as a result of camera movement) when using low shutter speeds compared to a telephoto lens.

A **telephoto lens** is a lens with a focal length longer than a normal lens. It provides a narrower angle of view, shallower depth of field, and compresses the apparent distance between objects along the Z axis in comparison with a normal lens. Because telephoto lenses magnify the scene in comparison to wide angle lenses (the angular velocity of camera movement is greater), camera movement leads to more visible motion when shooting with telephoto lenses compared to wide-angle lenses.

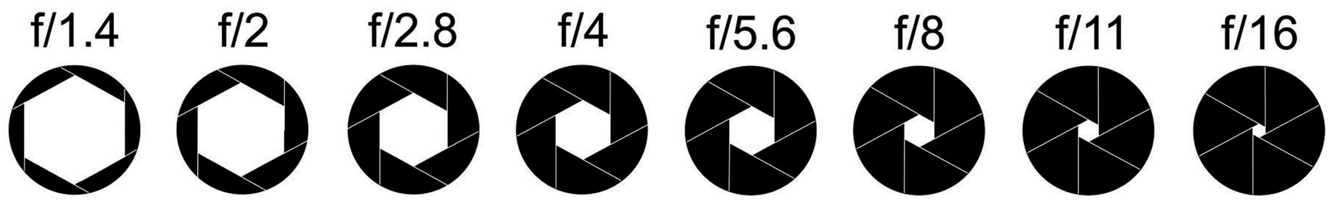
A **prime lens** is a lens with a fixed focal length (e.g. 50mm) while a zoom lens has a variable focal length (e.g. 24-70mm) that can be adjusted by turning the zoom ring on the lens.

Minimizing motion blur. The rule of thumb for hand-held shooting is that the shutter speed should be greater than the focal length (or the full-frame equivalent focal length for non-full-frame cameras) of the lens, for example, when shooting with a 50mm lens, the shutter speed should be 1/60 or less, however, when shooting with a 200mm telephoto, the shutter speed should be 1/250 of a second or less.

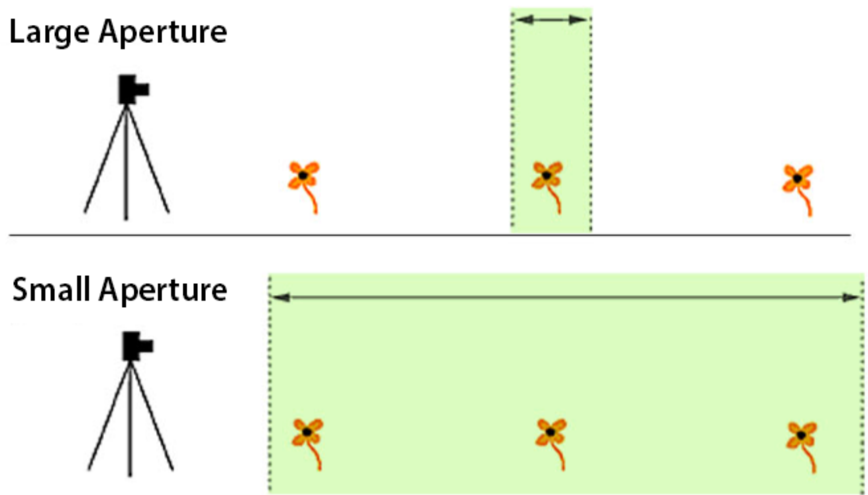
Aperture

The lens aperture (f/stop) has an effect on both exposure and depth of field. Smaller apertures reduce the the amount of light passing through the lens and also results in greater depth of field. Larger apertures permit more light to pass through the lens and also results in less depth of field. The formula used to assign the numbers used to refer to the lens aperture is:

f/stop = focal length / aperture diameter



Each of the steps illustrated above represents one half or twice the light being allowed to pass through the lens, which is referred to as a stop. As the size of the aperture gets smaller the numbers get bigger. These numbers are a factor of the square root of 2. Each represents a full stop difference in exposure. Don't worry if these numbers are confusing, eventually they become second nature.



The aperture also has an effect on depth of field. Large apertures yields shallow depth of field while smaller apertures yield greater depth of field.

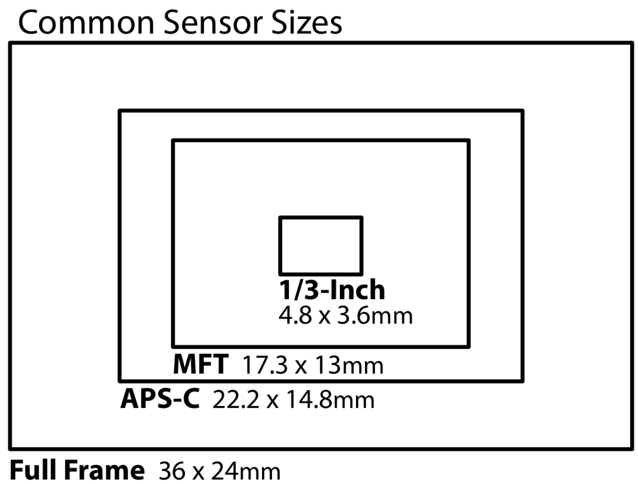
Depth of field is actually a function of three factors: focal length of the lens, the aperture, and the focus setting (see "Hyperfocal distance" later in this document). Wide angle lenses provide deeper depth of field while telephotos provide shallower depth of field.

The manual control of aperture offers you many creative options and you are encouraged to experiment shooting the same subject at different apertures. With photography this can be accomplished by varying the shutter speed, however, with video, which is usually shot a shutter speed of 1/60th (in order to achieve natural motion blur), it may require the use of Neutral Density (ND) filters to reduce the light entering the lens when shooting outdoors. Most camcorders and cinema cameras have built in ND filters, however, most Mirrorless and D-SLR cameras that double as photo/video cameras do not.

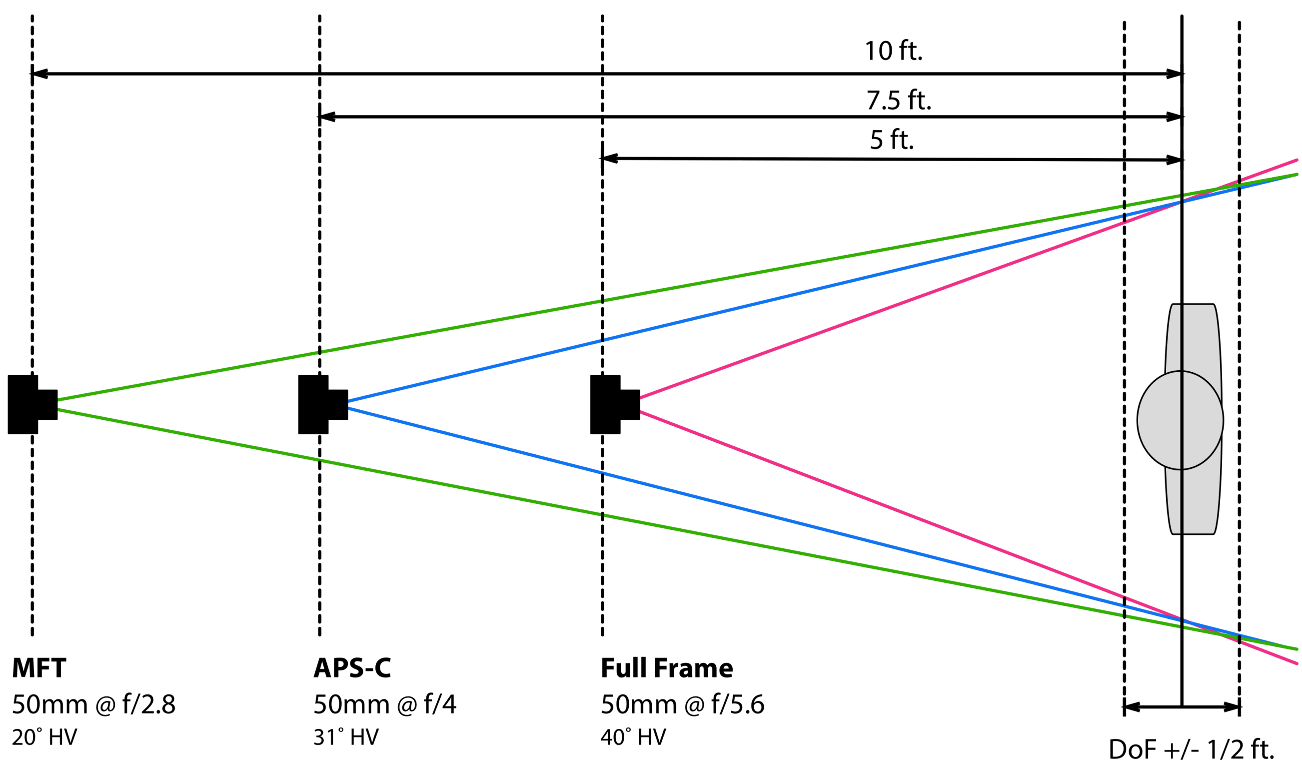
Sensor size

There are many different sensor sizes used in photography and video production ranging from small 1/3-inch sensors which you'll find in cameras like the Panasonic HPX170 to large full-frame sensors like the like you'll find in cameras like the Canon 5D. Full frame sensors get their name because they match the size of a traditional 35mm analogue film frame. Two other common sensor size standards you're likely to come across include APC-C (common among affordable D-SLRs like the Canon Rebel T5i) and Micro-Four Thirds (abbreviated MFT, smaller than APC-C but still reasonably large compared to compact cameras). The Panasonic GH4 is an example of a camera with a MFT sensor.

Many consumer digital cameras on the market have smaller sensors due to a variety of constraints, primarily cost and camera size. The smaller the sensor, the smaller the camera and lens can be. Consider the small camera in your smartphone, it's got a very small sensor and a tiny wide-angle lens. In general, large sensors provide higher quality and are more sensitivite to light. The size of the sensor also influences the perspective and depth of field of the images you take with the camera.



What's a normal lens? The actual focal length of what is considered a wide-angle, normal, and telephoto lens depends on the sensor size. For camera with a full frame sensor a 50mm lens is considered normal. For a camera with an APC-C sensor a normal lens would be around 31mm (not a common focal length for prime lenses). For a camera with a Micro-Four Thirds (MFT) sensor sensor a normal lens would be 25mm.



Why do so many photographers and filmmakers prefer cameras with large sensors? Cameras with large sensors make it easier to produce images with shallow depth-of-field at close camera to subject distances because a normal lens for that format has a longer focal length compared to the focal length of a normal lens on a camera with a smaller image sensor. And since depth of field is determined by the aperture and focal length, the smaller the sensor, the farther away you need to move (along with opening up the aperture) in order to produce the equivalent image in terms of framing and depth of field.

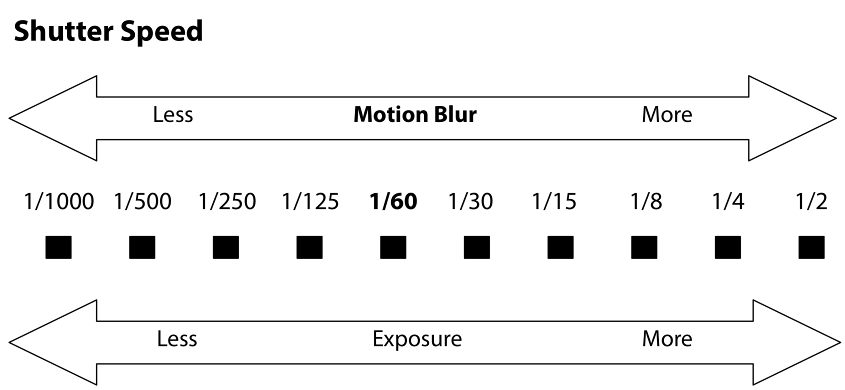
A lot of photographers and filmmakers want to separate subjects from their backgrounds using selective focus while at the same time maintaining a close camera to subject distance, thus their preference for larger sensor cameras. If you wanted to shoot the same image with the exact same field of view and depth of field using cameras with different sensor sizes (let's say MFT, APC-C, and Full Frame) you'd have to do three things:

- Use the same focal length lens, in this example we'll use a 50mm lens (recall that depth of field is a factor of focal length, aperture, and focus point);
- Position the cameras at different camera to subject distances accounting for the angle of view of the 50mm lens on each of the cameras given their sensor size; and
- Set each lens to the aperture that provides the same depth of field (recall depth of field is dependent on focal length, aperture, and focus setting). The comparison chart was created using the depth of field calculator available at http://www.dofmaster.com/dofjs.html. I suggest creating your own version of the chart using the depth of field calculator with your own shooting scenario to get a better feel for this. Eventually you develop an instinct for this.

The smartphone look. It's the size of the sensor and the wide angle lens on smartphones that accounts for their distinctive look in terms of perspective and depth of field compared to videos produced with larger sensor cameras using a normal lens or something close to it. The perspective of a wide angle lens (exaggerating the distance between objects in the Z-axis) is one reason why smartphone selfies look so different than portraits, which are often shot with short telephoto lens and a large sensor camera.

Shutter Speed

Shutter speed has an effect on both exposure (how much light is allowed into the camera) and motion blur. With fast shutter speeds action is "frozen" and objects, even if moving, are crispy sharp. With slow shutters speeds, objects that are moving appear blurry. Motion blur is also caused by camera motion (e.g. doing a swish-pan or simply hand-holding the camera when using a slow shutter speed). The rule of thumb when shooting with a normal lens in still photography is you should use a tripod or other camera support when using shutter speeds below 1/60.



Each step represents one stop difference in exposure (1/2 or double)

With standard video you're exposing the sensor 30 times per second, therefore the standard shutter speed setting is 1/60 of a second, so you'll get some motion blur with any object that moves. It is possible to get a fast-shutter or slow-shutter effect in video, since most cameras have a shutter speed adjustment. Note that the standard shutter speed for video is 1/60th, so you're right at the threshold of needing a tripod and therefore you must may attention to keeping the camera stable to avoid unwanted motion blur. Setting the shutter speed too high in video results in crisp sharp frames that results in a strobing effect.

Given the standard shutter speed on a video camera is 1/60, this requires very steady hand-held or a camera stabilization device and slow and smooth movement in order to avoid excessive motion blur artifacts.

We've become accustomed to seeing some motion blur in our moving images and it has an influence on how the image is interpreted. Rule of thumb: Fie a normal look your video shutter speed should be double the frame rate. Thus for 30p it should be 1/60. Slower speeds will exaggerate motion blur, while faster speeds will create a strobing effect, more pronounced as the shutter speeds get shorter. The motion blur we're used to seeing in theatrical motion pictures is the result of the frames being exposed at 1/48. When film is shot at 24fps the shutter speed is usually 1/48 (this is because the shutter in a film camera is a rotating disk with a variable angle—180 degrees being standard—so the film is exposed for 1/2 of the time between frames: 1/24 divided by 2 yields 1/48).

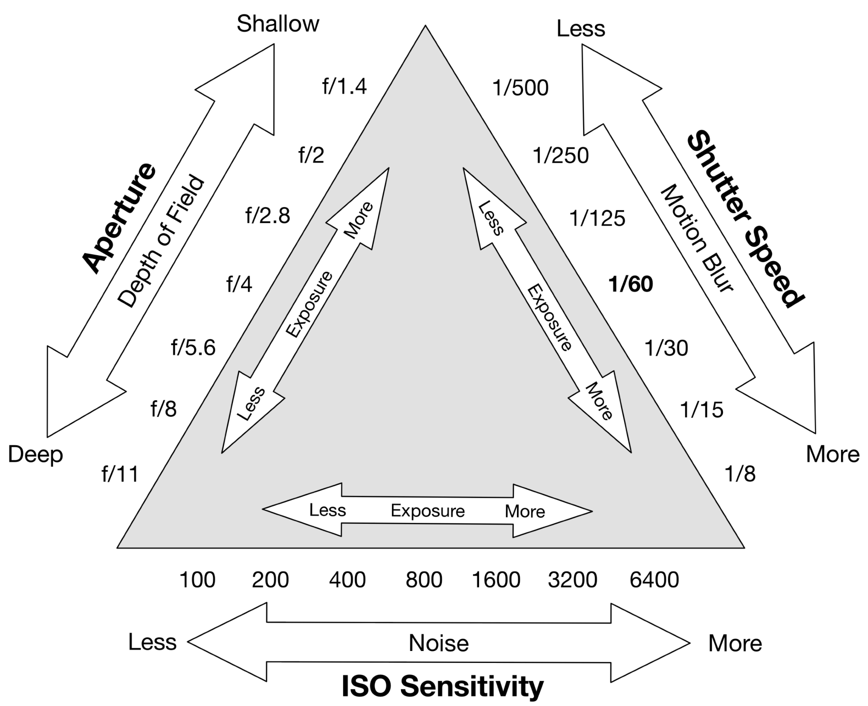
The manual control of shutter speeds can offer you many creative options and you are encouraged to experiment with it.

ISO Sensitivity and Exposure Index

ISO Sensitivity (a.k.a. speed) is a measure of how an image sensor responds to light. The higher the sensitivity, the less light (smaller aperture and/or shorter shutter speed) will be required to capture a properly exposed image. Exposure index (EI) is a camera setting derived from the sensitivity of the imaging system used to determine the camera's exposure in response to a light level measurement. EI and ISO sensitivity are closely related but distinct concepts: EI refers to speed rating assigned to a particular camera and shooting situation in variance to the actual ISO sensitivity of the camera. The EI is an absolute measure of the amount of light that will reach the image sensor.

But we don't need to split hairs, as we're getting started we can think of the ISO setting and the EI as the same thing. The important thing to remember is that increasing the ISO setting on the camera increases the analog gain at the image sensor output prior to digitization (A-to-D conversion), allowing the camera to operate with less light, however, the trade-off is that this increases the level of noise, degrading overall image quality. Current cameras do not produce significant noise until about ISO 1600. High ISO ratings allow us to shoot video under very low light conditions, but there are tradeoffs with added noise at high ISO ratings. The important takeaway is if you're shooting under good lighting conditions or want to open up the aperture more than the camera will let you, adjust the ISO down to 100 to lower the sensitivity to light.

The Exposure Triangle (Photography)



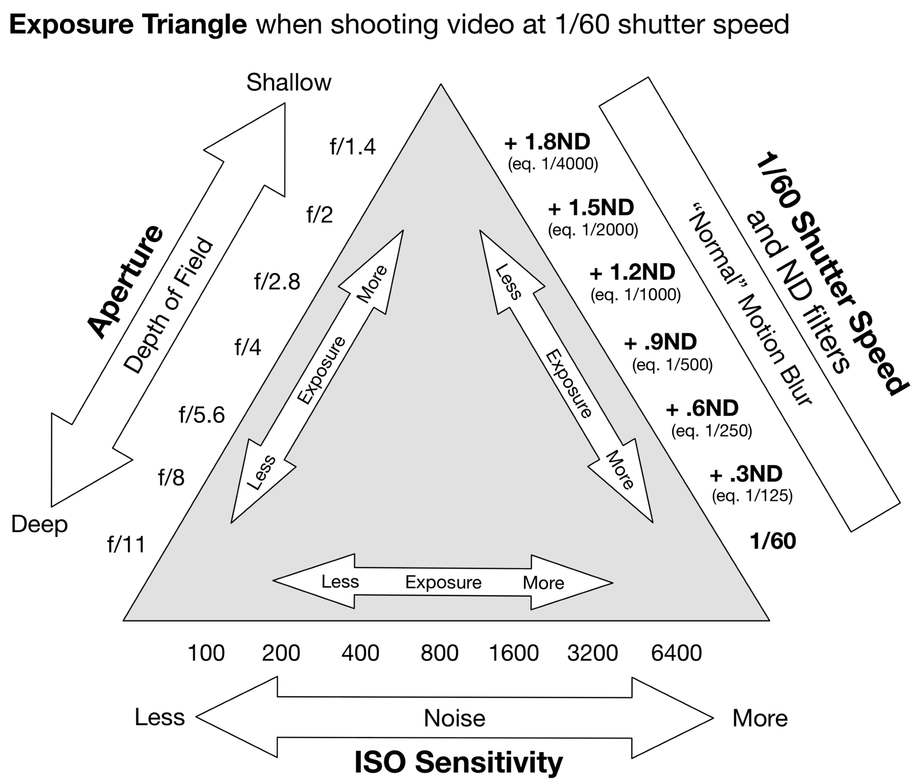
Exposure triangle for photography

Three settings—**ISO sensitivity**, **shutter speed**, and **lens aperture** — determines the total amount of light reaching the image sensor. As you change these settings to achieve proper exposure, you are also changing other aspects of the image:

- As you adjust shutter speed, you are also changing the amount of **motion blur**.
- As you adjust the aperture, you're also changing the **depth of field**.
- As you adjust the ISO sensitivity you are changing the level of **noise** in the image.

When using your camera on automatic exposure more there's one more adjustment to consider: Exposure Compensation. This allows you to "overexpose" or "underexpose" your image, usually in 1/3 stop increments. This provides you some level of creative control when using automatic exposure.

Exposure triangle when shooting video at 30p



When we're shooting 30p video we usually set the shutter speed to 1/60 in order to have "normal" motion blur in the image. Normal is relative, and varying the shutter speed can be used for a specific effect, higher shutter speed yield crisp, sharp frames with a stutter, while lower shutter speeds result in blur, especially with camera movement or moving objects. When we shoot with 1/60 as the shutter speed, we have a fixed shutter., so how do we vary the exposure so that we can shoot with large apertures in bright sunlight? In this situation we can use ND filters (or a Variable ND filter). This allows us to reduce the exposure while keeping the shutter speed at 1/60 of a second. This results in a revised exposure triangle shown here.

- As you add or subtract ND (or adjust a Variable ND filter), you are changing the amount of **exposure** without changing the motion blur of the 1/60 shutter speed.
- As you adjust the aperture, you're also changing the **depth of field**.
- As you adjust the ISO sensitivity you are changing the level of **noise** in the image.

When using your camera on automatic exposure more there's one more adjustment to consider: Exposure Compensation. This allows you to "overexpose" or "underexpose" your image, usually in 1/3 stop increments. This provides you some level of creative control when using automatic exposure.

Photo/video cameras vs. smartphones

What really differentiates digital cameras is the size and quality of the image sensor and the lenses you can use with them. Generally, the bigger the sensor, the better the pictures, especially in lower light conditions. Professional D-SLR cameras have bigger sensor than a smartphone and thus capture finer detail with lower noise at low light levels. They also support interchangeable lenses for more flexibility.

Hyperfocal distance

The hyperfocal distance is the focus setting at a particular aperture that produces the greatest depth of field. It depends on the same three factors that determine depth of field:

- **Aperture**: A wider depth of field means that you can focus closer and still keep the background sharp. The smaller the aperture, the closer the hyperfocal distance will be, and
- **Focal length**: The smaller the focal length (the wider the angle of view), the closer the hyperfocal distance, and
- **Sensor size**: The larger the sensor, the closer the hyperfocal distance will be.

If you set the lens focus to the hyperfocal distance, your depth of field will extend from half of the hyperfocal distance to infinity—providing you with much deeper depth of field than simply focusing on infinity.

Determining the hyperfocal distance can help you make sure you have the right parts of your image in focus. It is mostly useful for landscape work where you are often concerned with keeping distant elements sharp and it's hard to confirm focus on a small LCD even with the magnification feature. In these cases the following these hyperfocal distance charts should help you set the optimal focus. With experience you'll develop a feel for the proper settings and where you want to focus. The charts on this page were calculated using the Depth of Field calculator at http://www.dofmaster.com/dofjs.html.

White Balance

White light is actually a mixture of multiple colors across the visible spectrum. A camera records the intensities of the additive primaries (red, green, and blue) with the goal of rendering colors (especially neutral colors and skin tones) correctly. White balance changes the overall mixture of these primaries in an image. Our eyes and brain are very good at determining what is white under different lighting conditions, however, photography and video cameras are not, even with auto white balance (AWB) set.

Incorrect white balance usually leads to a color cast in an image, usually excessive blue outdoors or excessively orange or green indoor. Cameras can be white balanced by pointing the camera to a white surface under the current illumination and setting the white balance following the instructions in the manual. Cameras usually have several presets including daylight (5500K) and tungsten (3200K).

Attention to white balance is important because if the red channel is overexposed (as will happen if you shoot with the camera set to daylight under tungsten lighting conditions) or the blue channel is overexposed (as will happen if you shoot with the camera set to tungsten under daylight lighting conditions), you can't correct the color in post, since critical information has been lost!

Video frame rates

The standard cinema frame rate around the world is 24p. The NTSC (US) video standard is 30p and the PAL (Europe) video standard is 25p. 25p has an identical look aesthetically to the cinema standard of 24p. 30p has a smooth video-like look, therefore, many filmmakers prefer to shoot in either 24p or 25p.

To shoot 25p is necessary in some circumstances, especially in PAL regions of the world when a shutter speed other than 1/50 is used. Certain lighting systems running on a 50hz power current will cause a flickering image with 24p material. Shutter speeds other than 1/50 or 1/100 such as 1/30, 1/60, 1/80 or 1/200 make the problem worse.

Locking the shutter speed to 1/50 in 24p mode prevents most of the flickering from occurring and you can set very precise frame rates using the Syncho Scan feature if your camera supports it.

Creatively speaking, 1/48 or 1/50 are the most aesthetically pleasing shutter speed for many shooting situations if you want motion blur to match footage conventional film footage which provides the "film look."

If you wish to reduce motion blur at higher shutter speeds such as 1/80 or 1/200 for example, match the frame rate of video to your region - 25p for PAL (UK, Europe, China) and 30p for NTSC (Japan, US).

When we say "24p" or "25p" the 'p' stands for progressive. With progressive video a full frame is shown at once as opposed to interlacing which uses scan-lines on alternating frames to show the image. Interlaced video as it is called was the analogue broadcast video standard for a long time but it is now obsolete. Shooting1080i is an outdated practice and and takes away from the film look of 24p.

Do not shoot in the1080i mode with your camera if you want optimal image quality.

When we say "30p" or "24p" the number refers to the frame rate. Frame rate is specified in frames per second (FPS). 24p has a noticeable 'even judder' which contributes to the film look and was the cinema acquisition standard for a long time before film was replaced with digital imaging. Today filmmakers choose between 24p or 25p for a film look or 30p and 60p for a smoother, more "live" look typical of home video, live sports or broadcast television.