4K – Resolution, Demystified!

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The Origins of 4K

- The name "4K resolution" refers to a horizontal resolution of approximately 4,000 pixels. The use of width to characterize the overall resolution marks a switch from previous television standards such as 480i and 1080p, which categorize media according to its vertical dimension. Using that same convention, 4K UHD would be named 2160p.

- There are two main 4K resolution standards:
  - The **DCI 4K** resolution standard, which has a resolution of 4096 × 2160 pixels (256:135, approximately a 1.9:1 aspect ratio). The DCI 4K standard has twice the horizontal and vertical resolution of DCI 2K.
  - **UHD-1**, or ultra-high-definition television (UHDTV), is the 4K standard for television and computer monitors. UHD-1 is also called 2160p as it has a resolution of 3840 × 2160 (16:9, or approximately a 1.78:1 aspect ratio), which is twice the horizontal and vertical resolution of 1080p, or three times the horizontal and vertical resolution of 720p. UHD-1 is used in consumer television and other media, e.g. video games.

- Many manufacturers may advertise their products as UHD 4K, or simply 4K.
Visual acuity is the sharpness of vision, measured by the ability to discern letters or numbers at a given distance according to a fixed standard eye chart.

- Visual acuity is tested one eye at a time, with the help of a standardized Snellen eye chart.
- Visual acuity is a static measurement, meaning you are sitting still during the testing and the letters or numbers you are viewing also are stationary.
- Visual acuity also is tested under high contrast conditions — typically, the letters or numbers on the eye chart are black, and the background of the chart is white.
Human vision is not made up of pixels, like a digital display device. We see in **degrees**, based on our field of vision.

From the top down, we consider a circle, 360 degrees. Each degree is split up into 60 parts, each part being 1/60 of a degree. These parts are called **arc minutes** (which can be further divided into 60 **arc seconds**).

The angular measure of an object is expressed in **degrees**, **arcminutes**, or **arcseconds**.
Seeing in Degrees

- **Visual acuity accounts for human vision being measured in angles.**
- Our vision subtends (or takes up) a certain number of degrees, which we call the field of vision. This is true for both horizontal and vertical fields of vision.
- Our eyes both face forward (called **binocular vision** and this cuts the circle in half, to 180°.
- Due to anatomy and focus, we see clearly about 124°, with approximately 2° in total focus.
- The remaining amount, which varies from individual to individual, is called **peripheral vision**.
Visual acuity is the smallest object a human eye is capable of resolving, which is 1 minute of arc.

However, the important aspect is to understand the shortest distance by which two lines can be separated and still be visualized as two lines.

If two black lines (on a white background) are separated by a space subtending an angle of less than 1 minute of arc, then the two lines are not seen as separate, but fused together.

When the visual angle between two lines is increased to 1 minute, the lines are seen separately.

\[ \alpha = 5 \text{ arc minutes} \]

\[ d = 20 \text{ ft} \]
Measuring Visual Acuity

- Visual acuity is typically measured using a **Snellen eye chart**.
- The Snellen eye chart is printed with eleven lines of block letters.
- The first line consists of one very large letter, for example E, H, or N.
- Subsequent rows have increasing numbers of letters that decrease in size.
- A person taking the test covers one eye from 20 feet away, and reads aloud the letters of each row, beginning at the top.
- The smallest row that can be read accurately indicates the visual acuity in that specific eye.
Measuring Visual Acuity

- The 8th line, designated **20/20**, is the smallest line that a person with normal acuity can read at a distance of 20 feet.
- Three lines above, the letters have twice the height of those letters on the 20/20 line. If this is the smallest line a person can read, the person's acuity is **20/40**, meaning that this person needs to approach to a distance of 20 feet to read letters that a person with normal acuity could read at 40 feet.
- In an even more approximate manner, this person could be said to have half the normal acuity of 20/20.
- The largest letter on an eye chart often represents an acuity of 20/200, the value that is considered "legally blind" in the US.
Measuring Visual Acuity

- The symbols on an acuity chart are formally known as **optotypes**.
- In the case of the traditional Snellen chart, the optotypes have the appearance of block letters, and are intended to be seen and read as letters.
- They are not, however, letters from any ordinary typographer’s font. They have a particular, simple geometry in which:
  - The thickness of the lines equals the thickness of the white spaces between lines and the thickness of the gap in the letter C
  - The height and width of the optotype is five times the thickness of the line.
Hermann Snellen (the creator of the Snellen eye chart) defined **standard vision** as the ability to recognize one of his optotypes when it subtended 5 minutes of arc.

Thus the optotype can only be recognized if the person viewing it can discriminate a spatial pattern separated by a visual angle of 1 minute of arc.
Quality of Vision

• Although visual acuity testing determines the relative clarity of eyesight in standardized conditions, it isn't predictive of the quality of vision in all situations.

• For example, it can't predict how well you would see:
  • Objects similar in brightness to their background
  • Colored objects
  • Moving objects

• Three major physical and neurological factors determine visual acuity:
  • How accurately the cornea and lens of the eye focus light onto the retina
  • The sensitivity of the nerves in the retina and vision centers in the brain
  • The ability of the brain to interpret information received from the eyes
Resolution and Pixel Density
What is Resolution?

- Image **resolution** is the amount of detail contained in an image. Higher resolution means more detail is possible.
- Resolution can be measured in various ways:
- For an analog image, resolution quantifies how close lines can be to each other and still be visibly **resolved** (hence the name).
- Resolution units can be tied to physical sizes (e.g. lines per MM, lines per inch, etc.), to the overall size of a picture (lines per picture height, also known simply as lines, TV lines, or TVL), or to angular subtense (how many arc minutes or seconds it subtends, or fills).
- Line pairs are often used instead of lines; a line pair comprises a dark line and an adjacent light line. A resolution of 10 lines per millimeter means 5 dark lines alternating with 5 light lines, or 5 line pairs per millimeter (5 LP/MM).
What is Resolution?

• For a digital display, the **display resolution** is based on the number of distinct **pixels** (short for picture element) in each dimension that the display possesses.

• This is usually quoted as **width x height**, with the units in pixels, for example, 1920x1080 means the width is 1920 pixels and the height is 1080 pixels.

• The sharpness of the image on a display depends on the resolution and the size of the screen.

• The same pixel resolution will be sharper on a smaller screen and gradually lose sharpness on larger screen because the same number of pixels are being spread out over a larger number of inches. This is also known as **pixel density**.
Common Resolutions and Aspect Ratios

* NTSC and PAL/SECAM are analog video standards with no fixed horizontal resolution. The resolutions depicted here for 4:3 aspect ratio assume square pixels, but the actual horizontal resolution (in non-square pixels) ranges from 352 (VHS/Betamax) to 720 (DVD) for both standards.

** Although Digital Cinema System specifies 2K at the depicted resolution (4 pixels per line), in some situations it can assume non-square pixels and go as high as 2048 x 1536. Aspect ratio 17:9 is approximate.
What is Pixel Density?

- **Pixel density** is a critical metric, telling us how many pixels there are in a fixed area of a display.
- This determines the **quality**, **clarity**, and **readability** of the image displayed. It is typically measured as **pixels per inch (PPI)**.
- Manufacturers don’t often specify the PPI of display products, but it is important for comparing the expected picture quality between different display products, or evaluating display size for a given audience position.
- It can be easily calculated if you know a few things about the display. If we have two displays with the same resolution, the smaller one will have the higher pixel density. And if we have displays with the same size, the one with a higher resolution will have the higher pixel density.
- So it's clear that the two parameters that we need in order to calculate the pixel density are **display size** and **resolution**.
Calculating Pixel Density

- We will need to calculate the **diagonal resolution** (in pixels) and then divide it by the **diagonal size** (in inches) of the display.
- The diagonal resolution is the square root of the sum of the squares of the two parts of the resolution (width and length).
- In order to make it sound and look easier to understand we can put this all together into a single formula that you can see below.

\[
\text{Pixel Density} = \frac{\sqrt{\text{width}^2 + \text{height}^2}}{\text{screen size (diagonal)}}
\]
Let’s run through a practical example, step by step using a common display – a computer desktop monitor that is 21.5 inches diagonal with a 1920×1080 resolution.

This means that:
- **Display diagonal** = 21.5 inch
- **Width** = 1920
- **Height** = 1080

Calculate diagonal resolution:
- **Diagonal resolution** = square root of \((1920^2 + 1080^2)\)
- **Diagonal resolution** = square root of \((3686400 + 1166400)\)
- **Diagonal resolution** = square root of 4852800
- **Diagonal resolution** = 2203 (rounded)

Calculate pixel density:
- **Pixel density** = diagonal resolution / display size
- **Pixel density** = 2203 / 21.5
- **Pixel density** = 103 PPI (rounded)
What About “Retina Displays”? 

- **Retina** is Apple's trademark for a display with enough resolution that the human eye is unable to distinguish between pixels at a typical viewing distance.

- As Steve Jobs said: "It turns out there’s a magic number, right around 300 pixels per inch, that when you hold something around to 10 to 12 inches away from your eyes, is the limit of the human retina to differentiate the pixels."

- **Given enough viewing distance, all displays eventually become “Retina.”**
What About “Retina Displays”?

- Instead, there are two factors that create a Retina Display screen: pixel density and the distance from which the screen is normally viewed.

- **Pixel Density** as we know, refers to how tightly packed the screen's pixels are. The greater the density, the smoother the images. This is based on a combination of the device's resolution and its physical size.

- **Viewing Distance** refers to how far away users generally hold a device from their eyes. This matters, because the definition of a Retina Display is one where the pixels cannot be seen by a human eye. A display viewed from much closer up, or that is much larger, needs a greater pixel density in order for visual acuity to account for the user not seeing the pixels.
Pixel Density VS. Viewing Distance

Optimal viewing distances to see benefits of High Resolution TV/Monitors

- Full HD, Quad HD, 4K and above, all appear to be equivalent at these distances
- 1920x1080 (Full HD)
- 2560x1440 (Quad HD)
- 3840x2160 (4K UHD)
- 7680x4320 (8K UHD)

Screen Size - Diagonal (inches)

Viewing Distance (feet)

Optimal distance
- 1080p (Full HD)
- 1440p (QHD)
- 2160p (4k UHD)
- 4320p (8k UHD)
Understanding Native and Pixel Shift 4K
Some LCoS manufacturers (such as Canon) have gone beyond e-shift 4K and now produce native 4K 3 LCoS imaging devices (with all the benefits that LCoS provides).

These 4K LCoS possess all 8.3 million pixels required to create a native DCI (4096x2160) or UHD-1 (3840 x 2160) image without any interpolation or simulation of pixels.
What is Pixel Shift 4K?

- **Pixel shift** (or e-shift) technology uses the physical imaging technology inside a projector, to approximate 4K UHD resolution from a lower resolution device.
- Though pixel shift technology does not actually produce a true 4K picture, it does substantially boost the apparent resolution of the picture well beyond 1080P FHD, and it can do so at a lower cost than native 4K projectors.
- Until native 4K projectors drop to the price level of standard 1080p, there will definitely be a place in the market for pixel shift technology.
Though there are technical differences in pixel shifting from various LCD manufacturers, all 3LCD and 3LCoS pixel shift systems are similar.

An image is projected onto the screen with an initial scan in native 1920x1080 format. On the next refresh of the chips, the light is refracted to cause the projected image to be slightly offset by half a pixel to the right and upward.

The optical system alternates back and forth, alternating between its native position and its offset position so rapidly that the eye can't detect the process.
Pixel Shift – 3LCD and 3LCoS

- Video processing blends the two images together, for a smooth transition and reducing any artifacts. The end result is a picture that looks much sharper than standard 1080P.

- This pixel shift technique effectively doubles the number of addressable pixels that the projector can use to define the image, from about 2.1 million in standard HD 1080p to about 4.15 million.

- By comparison, there are about 8.3 million addressable pixels on a native 4K chip.
Pixel Shift – Single Chip DLP

- A 4K DLP chip starts with a higher resolution than 1080P devices. It has a total of 2716x1528 mirrors.
- With proprietary video processing it is capable of having a single mirror (pixel) perform as two discrete pixels on screen.
- This delivers double the number of pixels in each refresh compared to e-shift 4K projectors.
- The total number of addressable pixels in this process is \((2716 \times 1528) \times 2 = 8.3\) million, or the same as a native 4K signal.
Q&A
For More Information

If you would like more information, please contact Brawn Consulting:

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Thank you!