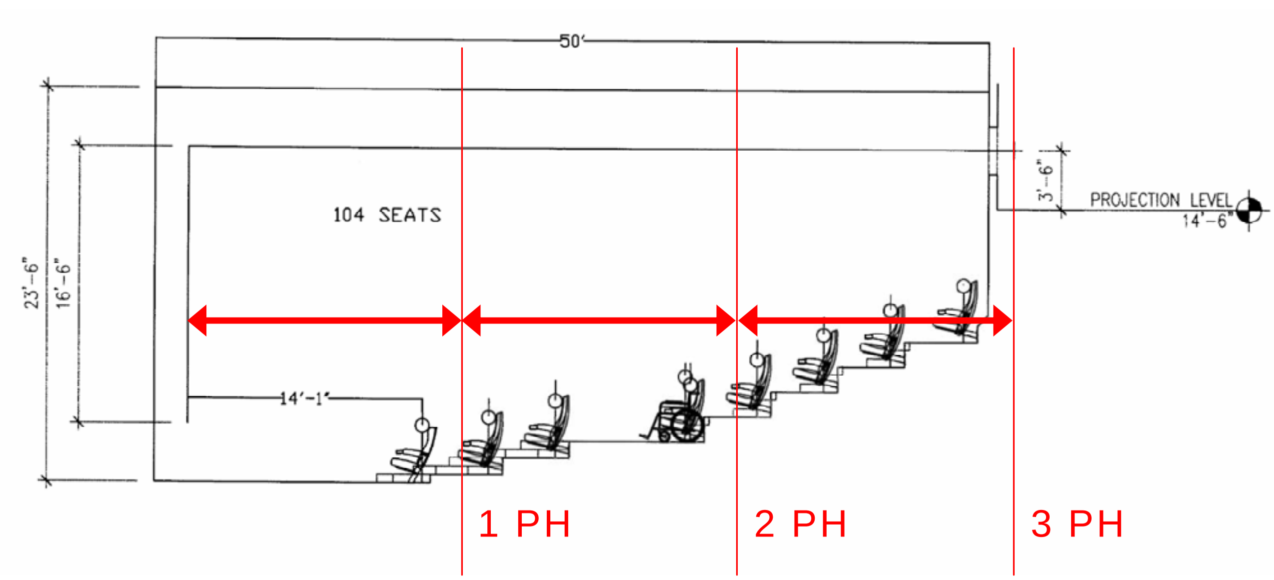
SONY

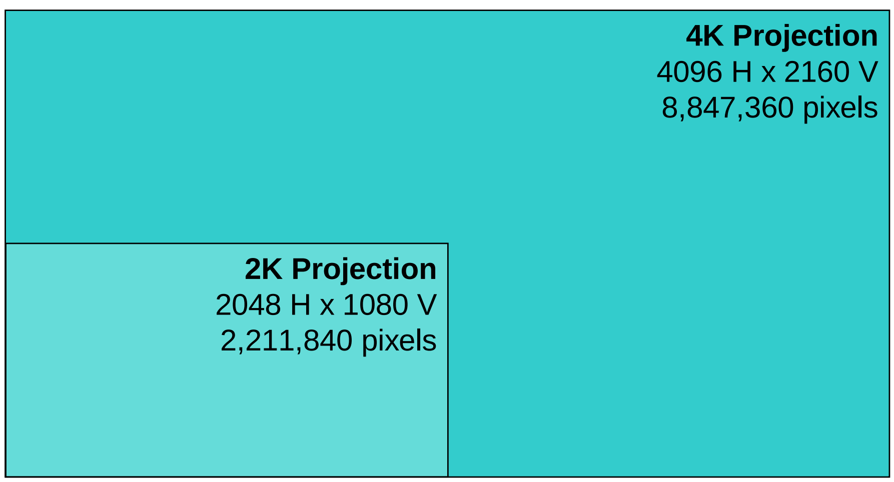
Does 4K really make a difference?

4K digital projection in the theater environment



Introduction

Movie theaters are on the threshold of an historic transformation from film to digital projection. The technology is in place, with broadly accepted specifications and a range of commercially available equipment that supports those specifications. An economic model is also in place, with procedures that enable distributors and exhibitors to share the cost of the digital conversion. One major remaining question is the choice of 2K or 4K digital projection. The choice that theater owners make today will enable—or limit—the quality and flexibility of their presentations for years to come.



4K delivers precisely four times the pixels of 2K.

2K digital cinema provides an image container roughly 2000 pixels across (2048 x 1080 or 2.2 million pixels). 4K digital cinema doubles those dimensions to 4096 x 2160. This equals 8.8 million pixels, exactly four times the count of 2K projection. On paper, 4K is obviously the superior solution. But what about the real world? Will the ticket buying public actually be able to perceive the benefits of 4K resolution in actual theaters?

What you see depends on where you sit

Some have suggested that 4K is only meaningful for very large cinema screens. In fact, screen size isn't the true measure of an audience member's ability to pick out detail. The true measure is the relative distance from that person to the screen, the viewing distance. You can appreciate the role of distance by considering printed material, such as a printout of this document.[1] Most readers will have little trouble identifying individual letters of the text at a distance of 2 feet (0.6 m). At 20 feet (6 m), you'd be doing well to discern the largest headlines. At 200 feet (60 m), you can only see that it is a sheet of paper. At 2000 feet (600 m), you can't even see that.

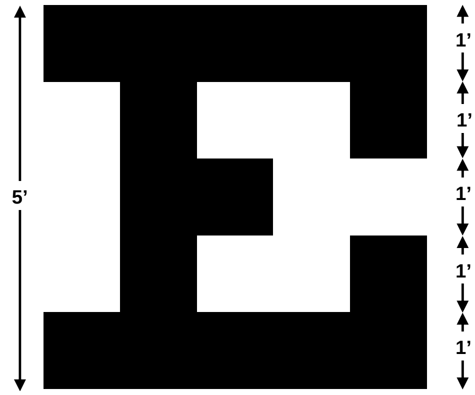
This suggests that for some sufficiently large viewing distance, high definition TV looks no sharper than standard definition. And for some other sufficiently large viewing distance, 4K digital cinema projection will appear no sharper than 2K. But there's a flip side. For audience members who sit close enough to the screen, 2K projection will have visible limitations.

Any comparison between 2K and 4K projection must address three important questions. What is the acuity of human vision? What are the viewing distances in actual, real-world theaters? And how do those distances compare with the distance at which the issues in 2K projection become visible?

What you see depends on your visual acuity

You can change screen sizes. You can change viewing distances. You can change the number of pixels projected. But one thing you cannot change is the visual acuity of the audience. The consensus standard for good vision is a Snellen fraction of 20/20, which is referenced to feet. (Outside the United States, this would be 6/6, referenced to meters.)

But what does 20/20 vision actually mean? It means that the observer at 20 feet can discern letters down to the 20/20 line of an eye chart. These letters are sized to occupy a small fraction of one degree of viewing angle. One degree is equal to sixty subdivisions called "arcminutes." The letters are five arcminutes in height, meaning that 12 of these letters stacked one on top of the other would occupy just one degree of viewing angle. The strokes and voids that form the letters are one arcminute thick.[2] For viewers with 20/20 vision, the smallest observable detail is one arcminute.[3]



A single degree of viewing angle is equal to 60 subdivisions called "arcminutes." Seen from a distance of 20 feet, the letter E on the 20/20 line of an eye chart is just five arcminutes high. Each stroke of the letter (and each void between strokes) is one arcminute wide.

One arcminute of visual acuity means that human observers can discern 60 digital pixels per degree. This is also called 30 dark-to-light cycles per degree or 30 line pairs per degree. This reference for visual acuity has been used by motion imaging engineers for decades.[4]

Some argue that this reference is too conservative. For example, researchers at NHK, the Japanese national broadcaster have reported that viewers can distinguish between pictures that present 156 and 78 cycles per degree. This equates to 312 and 156 pixels per degree respectively—acuity far greater than 20/20 vision would imply.[5] Certainly many audience members have better than normal vision, 20/10 for example.

Others take the opposite approach and recommend a more relaxed reference that corresponds to detail that humans can "clearly" see: 1.03 arcminutes,[6] which equal 58 pixels per degree. Still others have proposed a far more relaxed reference: 44 pixels per degree, said to be the level of detail that humans can "reliably" see.[7] This, the most relaxed reference of all, is the friendliest to 2K digital cinema projection and the least favorable to 4K. Nevertheless, we will make the argument for 4K using this most conservative reference, 44 pixels per degree, as well as the widely accepted standard of 60 pixels per degree.

Needless to say, this discussion of acuity holds true for objects that are sufficiently bright and have sufficiently high contrast. For projected images, it requires that the projectors actually be in focus. It also assumes that the viewer is looking directly at the object, using the "fovea" of the eye, the visual center of the retina where acuity is highest. A more complete analysis might involve screen brightness, viewer contrast sensitivity and angles of eccentricity from the fovea.

Picture Height: the measure of viewing distance

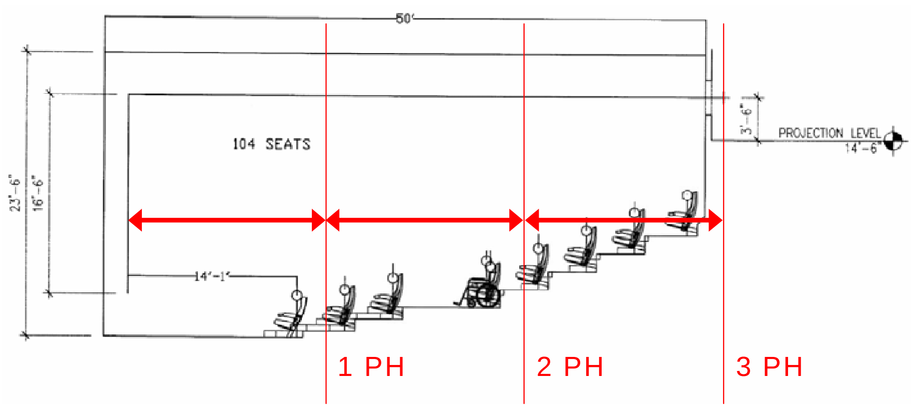
When the standard definition television system was first launched in North America, engineers assumed that viewers would want to sit at a sufficient distance for the individual scanning lines that comprise the picture to blend into a visually seamless whole. In the days before pixels, these engineers figured on 60 horizontal scanning lines per degree. From this, they derived a standard viewing distance of *7.15 Picture Heights (PH)*.

Studies by Bernard Lechner of RCA in the US and Richard Jackson at Philips Laboratories in Europe determined that actual viewing distance for standard definition TV is around 10 feet (3 meters).[8] The screen size that corresponds to 7.15 Picture Heights at this distance is 28 inches diagonal. This roughly matches the larger CRT sizes of the standard definition era.

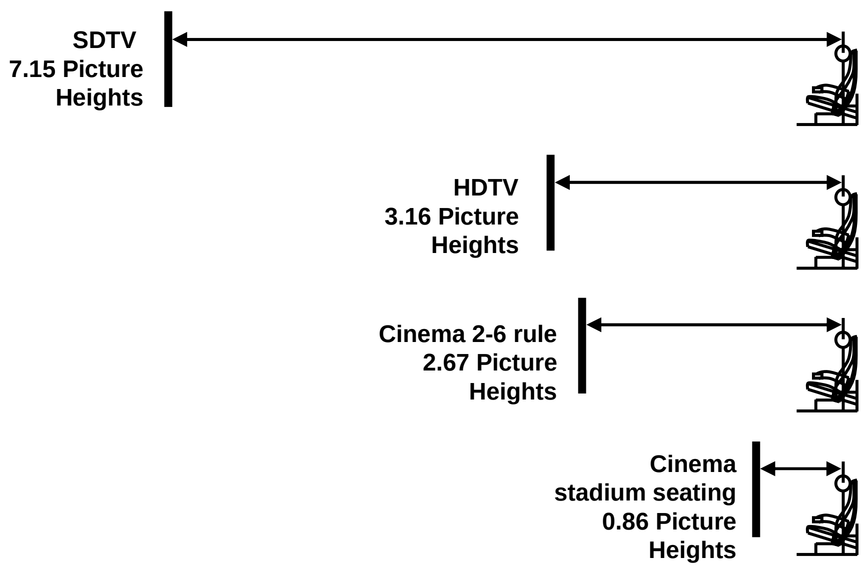
Movie theater design has been influenced by similar calculations. In the 1940s, the Society of Motion-Picture Engineers (SMPE) made a recommendation called the 2-6 rule.[9] It proposed that theater auditoriums be designed with the nearest seats at two times picture width and the farthest at six times picture width. Using the Academy Aperture screen shape of the time, that translates to a minimum viewing distance of *2.67 Picture Heights*.

When high definition television was first proposed, the design goal was to equal the performance of movie theaters. This dictated an increase in TV resolution sufficient to create the illusion of a seamless image at roughly *three Picture Heights*.[10] (The actual figure is 3.16 Picture Heights.) This similarity to the 2.67 specification of old movie theaters is not a coincidence. It is by design.

Since the 1940s, just about everything in movie theaters has been transformed, including auditorium design. Through the 1990s, new theater designs moved to progressively wider-angle projection lenses, which suggests that seats became progressively closer to the screen.[11] By 1994, viewing distances that had once been considered the minimum were now close to the maximum. The renamed Society of Motion Picture and Television Engineers (SMPTE) issued Engineering Guideline EG 18-1994, which recommended that the screen subtend a minimum horizontal angle of 30 degrees for viewers in the back of the room. This corresponds to a distance of *3.45 Picture Heights* (using the contemporary picture proportions of 1.85:1). EG 18-1994 proved to be a snapshot of best practices at the end of the era of sloped-floor auditoriums. It was withdrawn in 2003 as inappropriate for the new era of stadium seating auditoriums, which bring the audience even closer. In stadium seating, the back of the house is about three Picture Heights from the screen while the closest seats are *less than one Picture Height* away.



Architectural elevation of a small "stadium seating" auditorium (104 seats). We have marked viewing distances in Picture Heights (PH). The first row is less than one PH from the screen.



The first three illustrations summarize the designed minimum *viewing distance of various entertainment formats, measured in Picture Heights. The last illustration shows actual practice in our example of stadium seating, which puts the viewer right up against the screen.*

Viewing distance and viewing angle

Any specified viewing distance also enables us to calculate the angle of view that the picture occupies. In the sample 104-seat auditorium, the front row is roughly one Picture Height from the screen while the back row is roughly three Picture Heights. The most desired seats for the most enthusiastic ticket holders are roughly 1.5 Picture Heights from the screen. At this distance, the vertical angle of view is 37°.

How many pixels does a viewer require?

We can multiply this vertical angle of view by the number of pixels per degree to determine the number of vertical pixels required to produce a visibly seamless image for a viewer with good eyesight. The "relaxed" reference of 44 pixels per degree multiplied by 37 degrees vertical equals 1628 pixels vertical.

How does this number compare to 2K? The typical modern movie has a picture width-to-height proportion ("aspect ratio") of 1.85:1. 2K projection accommodates this aspect ratio picture with 1998 pixels horizontal by 1080 pixels vertical. (Different aspect ratios use different accommodations.[12]) The 1080 pixels of 2K projection fall 34% short of the 1628 pixels required to create a seamless picture.

Of course, this 2K shortfall varies according to viewing distance. Sit closer and the shortfall becomes more severe. Sit further and the shortfall will diminish, eventually to zero. The shortfall is also linked to the reference for visual acuity. Using 60 pixels per degree, which corresponds to recognizing the "E" on the 20/20 line of the eye chart, 2K projection can only provide *half* of the required 2220 pixels.[13]

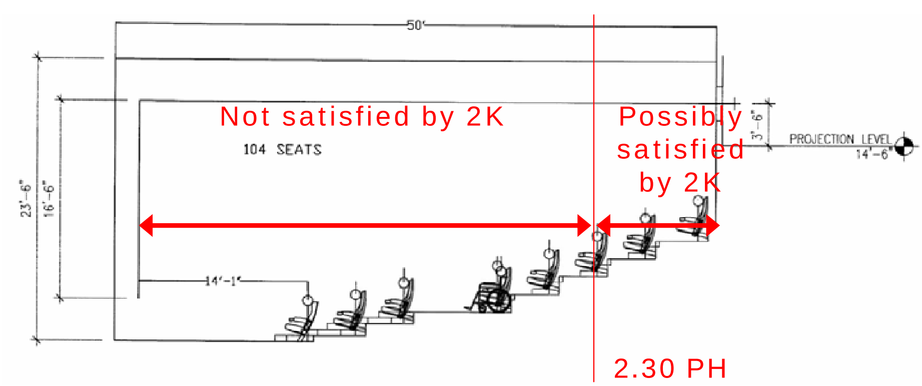
This exaggerated view depicts the effect of stairstep "jaggies" and screen door effect that become visible when you're sitting sufficiently close to a digital projection.

Assuming appropriate content and a 2K projector that's in focus, the 2K shortfall can create a problem for viewers in contemporary stadium seating theaters. At practical viewing distances, the drawbacks of 2K presentation will be visible. These limitations can include the visibility of individual pixels, which can undermine the illusion of reality. Stairstep "jaggies" can add unwanted texture to diagonal lines in the picture. And gaps between pixels can put a fine mesh of black lines across the entire image, as if the picture were viewed through a screen door. (And if a projectionist were to deliberately put a 2K projector out of focus to conceal these artifacts, the picture would lose even more detail.) For many audience members, the benefits of 4K projection will be visible.

Threshold of visibility for 2K pixels

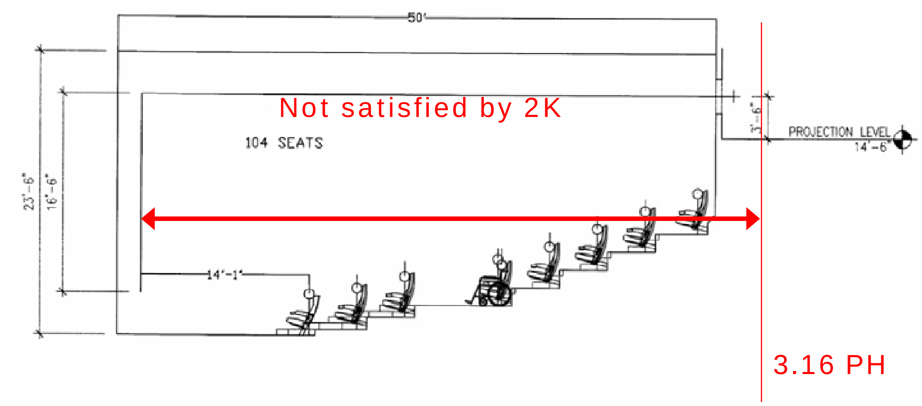
Even though the limitations of 2K are visible from a distance of 1.5 Picture Heights, there still must be some distance at which 2K projection "satisfies" viewers by providing a visibly seamless picture. At this threshold distance, 4K no longer delivers an advantage. At the relaxed reference of 44 pixels per degree, the threshold distance is 2.30 times the Picture Height. Viewers sitting closer than 2.30 Picture Heights can see a benefit to 4K. Viewers sitting farther than 2.30 Picture Heights will see no benefit.

While some have suggested that the benefits of 4K only apply to big screens, consider the small, 104-seat auditorium. If you pace off 2.30 Picture Heights in the sample auditorium, you'll find that audience members in only the last three out of eight rows are at a distance potentially satisfied by 2K projection. Ticket holders in all the other rows, representing 63% of the audience, will not be satisfied by 2K.



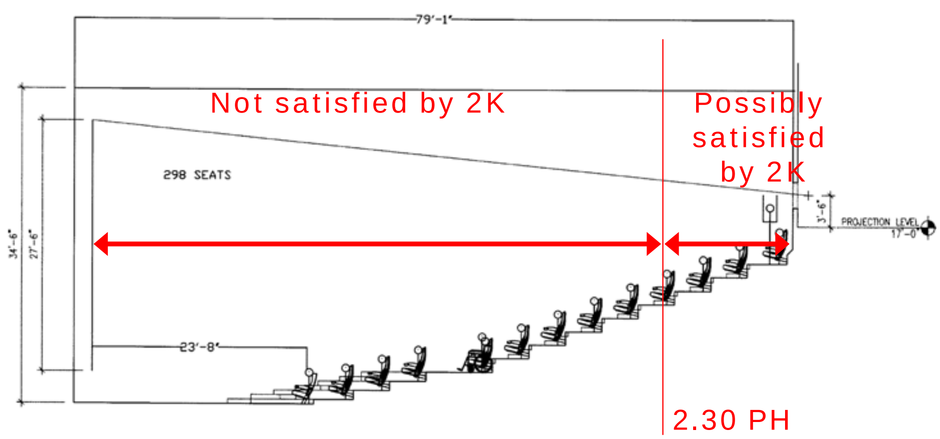
Using the relaxed reference of 44 pixels per degree, 2K projection falls short for 63% of audience members even in this small, 104-seat auditorium.

Here again, our conclusion is inextricably linked to the reference for visual acuity. If we use the more stringent reference of 60 pixels per degree—the standard invoked for decades in the design of motion imaging systems—then 2K fares considerably worse. The distance at which the 4K advantage can no longer be seen increases to 3.16 Picture Heights. (This is the same threshold distance as HDTV, which provides the same 1080 vertical pixels as 2K.) In the theater, this is beyond the back wall of the auditorium. Using this reference, 100% of audience members with good vision will be dissatisfied by 2K.

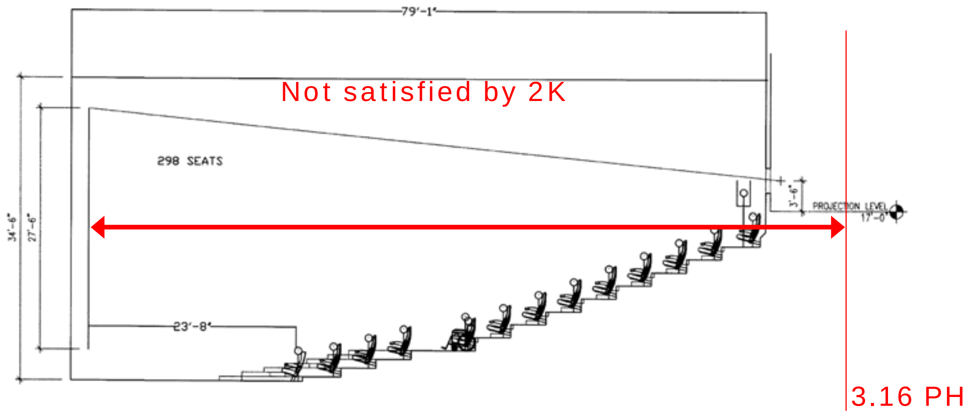


Using the more stringent reference of 60 pixels per degree, no audience members will be satisfied by 2K projection.

This analysis of a small auditorium disproves the theory that 4K is only relevant for big screens. In addition, a similar analysis of a large auditorium (298 seats) yields nearly identical results. As long as audience members are sitting closer than the threshold of visibility, the 4K advantage is equally meaningful on screens big or small.



Threshold distance at 44 pixels per degree, superimposed on a larger, 298-seat auditorium.



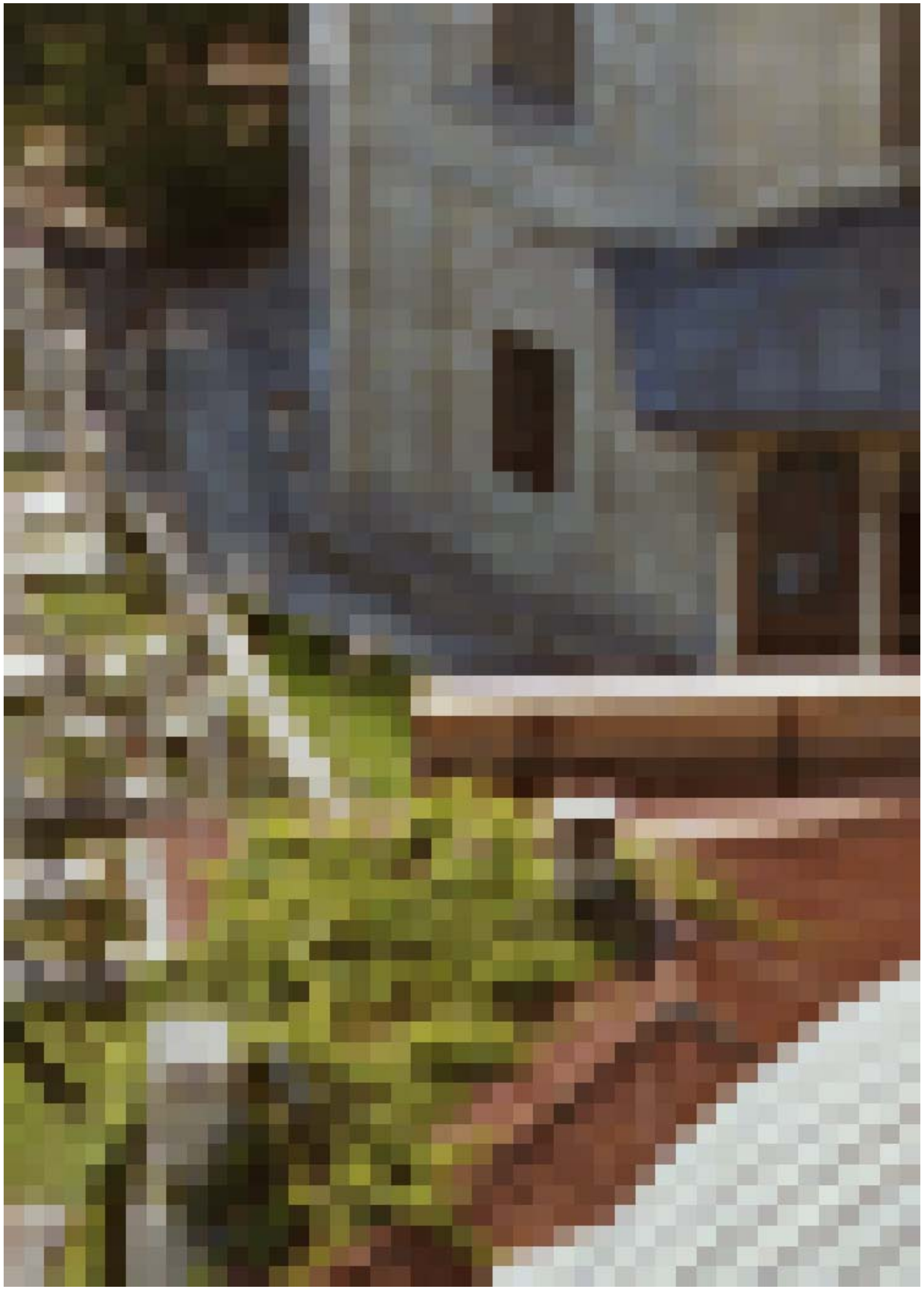
Threshold distance at 60 pixels per degree, 298-seat auditorium.

Seeing the 4K difference for yourself

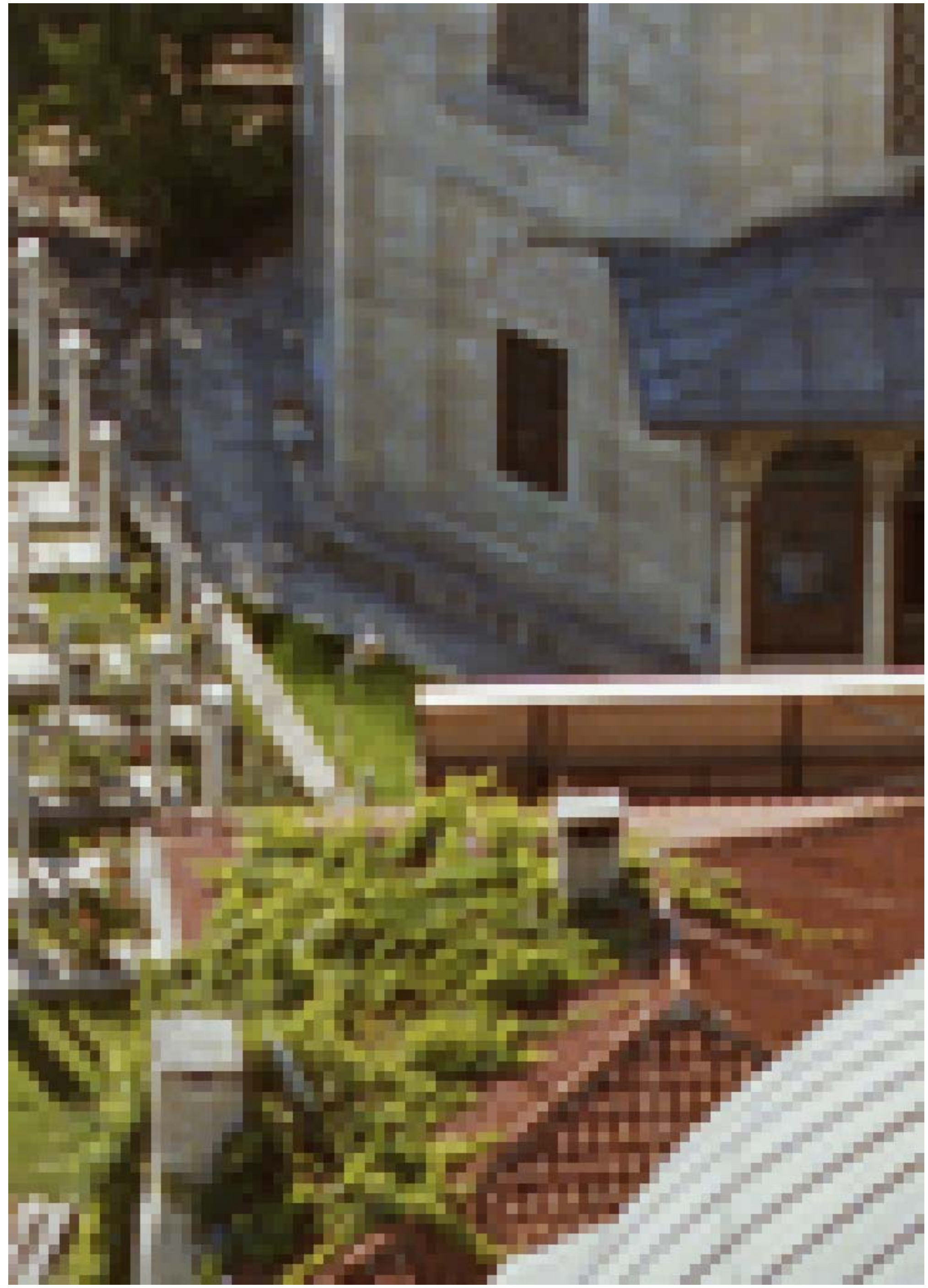
It is possible to simulate the difference between 2K and 4K projection. The following page provides side-by-side images[14] for your evaluation. View a color printout of this page from 8 feet, 7 inches (2.6 meters) to simulate first row seats at 0.86 Picture Heights. From close viewing, you can easily see the difference between the two images, especially in the windows and archways. As you would expect, the further back you move, the less distinct the differences become.

To Simulate	View from (feet)	View from (meters)
Digital cinema from 0.86 Picture Heights	8 feet 7 inches	2.6 meters
Digital cinema from 1.0 Picture Height	10 feet	3.0 meters
Digital cinema from 2.0 Picture Heights	20 feet	6.0 meters
Digital cinema from 3.0 Picture Heights	30 feet	9.0 meters

Of course, this demonstration is only a rough approximation of what happens in a darkened theater.



2K Simulation



4K Simulation

4K and consumer research

Focus group research confirms that real-world theater-goers can see the 4K difference. Movies were presented to a theater audience in both 2K and 4K, without identifying which was which—and without saying anything about the technical differences between the pictures. Audience members were not told to expect a resolution difference in these "unaided" tests. Even under these demanding circumstances, respondents consistently gave 4K higher marks for every aspect of picture quality. Respondents also gave 4K higher scores than 2K on every measure of expected consumer behavior including, "This is something I would tell my friends about," "This is worth paying more for," and "I would go out of my way to go to a theater that offered this type of picture quality."[15]

4K projection and the 4K content pipeline

In many ways, 4K movies have arrived in force. Today movies are routinely made available to theaters as 4K digital cinema packages (DCPs). Most of these are originally shot on 35mm film.

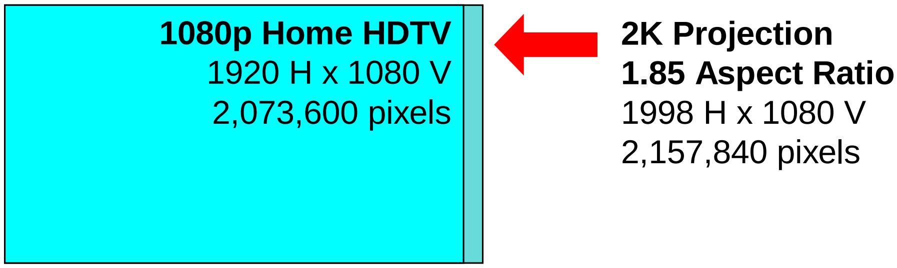
Some purists might argue that to fully exploit the capabilities of 4K projection, the ideal starting point would be 4K digital cinematography. Here again, 4K is making great strides. Current digital cameras achieve resolution up to 3K. Several companies are now racing to introduce the first digital cinema cameras to attain full 4K resolution. Recent history leads us to expect digitally-originated full 4K movies soon.

After all, digital cinema production technology gets more sophisticated every day. And in just a few short years, digital cinematography has made heroic strides in resolution, color and contrast handling. Given the unceasing progress of digital technology, it is inevitable that digitally-originated full 4K productions will become common early in the operating life of 2K digital cinema projectors.

Toward more immersive entertainment

Until the 1950s, cinema was overwhelmingly in black-and-white, with monophonic sound and the squarish 1.333:1 aspect ratio. The advent of television forced the cinema to adopt more immersive modes of presentation, including color, widescreen "scope" pictures, stereo sound, and eventually digital surround sound.

One by one, each of these cinema advances has been matched by home entertainment. Television adopted color (starting in the 1950s), stereo sound (1980s), widescreen presentation and digital surround sound (1990s). Today, increasingly affordable 1080p high definition televisions challenge the cinema with resolution that is in some ways comparable to 35mm film and is almost exactly equal to 2K resolution. With 1.85 aspect ratio content, 2K has exactly the same number of vertical pixels as HDTV, and just 4.1% more horizontal pixels.



When projecting 1.85 aspect ratio content, 2K provides only 4.1% more pixels than HDTV showing 1.78 aspect ratio content.

Simply stated, 2K is insufficient to position the cinema as clearly superior to HDTV. Visible pixels, jagged outlines and screen door effect won't work when your audiences can enjoy superb pictures of nearly identical resolution at home. And whatever value 2K may have in the short term, it will certainly be undercut as the studios increasingly roll out 4K releases. Investment in 2K digital cinema projection is in effect a bet against 4K, which has experienced rapidly growing support among exhibitors, studios and digital cinema equipment companies.

Like color, widescreen, stereo and surround sound before it, 4K is another giant advantage in the ongoing competition between the theater experience and electronic entertainment in the home. 4K makes a visible difference on screens big and small. For 3D movies, 4K projects left-eye and right-eye information simultaneously, eliminating the limitations of triple-flash presentation. 4K projection is scalable, accommodating 4K, 2K, HD and other digital content. In fact, the smaller pixels of 4K projection and contemporary signal processing actually improve the presentation of 2K material.[16] The choice between 2K and 4K is a choice between limiting yourself with a short-term solution and maximizing your return for years to come.

To find out more and to see 4K and 2K head-to-head in a suitable environment, register online today at www.sony.com/digitalcinema.

# # #

Glossary.

20/20. The Snellen Fraction that represents standard visual acuity. 20/20 vision corresponds to 60 pixels per degree and 30 line pairs per degree.

2-6 rule. A 1940s-vintage engineering recommendation for movie theaters that specified a viewing distance of 2 to 6 times the picture width, equal to 2.67 to 8 times the picture height.

2K. A Digital Cinema distribution and projection system that uses an image container of 2048 pixels horizontal by 1080 pixels vertical. 2K projectors can show either 2K or 4K content.

4K. A Digital Cinema distribution and projection system that uses an image container of 4096 pixels horizontal by 2160 pixels vertical. 4K projectors can show either 2K or 4K content.

Arcminute. A measure of angle equal to 1/60 degree.

Aspect ratio. The ratio of picture width to picture height. In movies, this can vary from title to title.

Aspect ratio accommodation. The method of exhibiting movies of varying aspect ratios on a digital projector with a fixed aspect ratio. For example, while 2K projectors have 2048 x 1080 pixels, movies with an aspect ratio of 1.85 are accommodated at 1998 x 1080 pixels.

DCI. Digital Cinema Initiatives, LLC, the body responsible for recommending technical specifications for Digital Cinema distribution, encryption and projection. The DCI specification supports both 2K and 4K distribution and projection.

Fovea. The visual center of the retina, where the eye is most sensitive to detail.

HDTV. High Definition Television, a family of TV broadcast and display formats up to a maximum of 1920 pixels horizontal by 1080 pixels vertical.

Jaggies. In digital projection, stairstep effects that are especially visible at the diagonal edges of on-screen objects. Can be annoying for audience members sitting close to the screen.

Line pairs. Adjacent black and white lines of a given thickness, used in resolution test charts. Visual acuity can be stated in line pairs per degree.

K. In computer-speak, two to the tenth power or 1,024. In digital film scanning, the width of the image is described as 2K (2048) or 4K (4096) pixels.

Picture height. A measure of relative viewing distance that enables comparison among screens of different sizes.

Pixel. Short for "picture element," the smallest independently described area of a digital image. Pixels can be physical, as on a camera image sensor or projector. They can also be logical, as data in a digital image file.

Screen door effect. In digital projection, a grid of black vertical and horizontal lines between pixels that can be annoying for audience members sitting close to the screen.

SDTV. Standard Definition Television. In the United States, this corresponds to a digital image of 720 pixels horizontal by 480 pixels vertical.

Snellen Fraction. The eye doctor's measure of visual acuity. Standard acuity is 20/20 in the United States, referenced to feet. Internationally, it's 6/6, referenced to meters.

Stadium seating. The modern auditorium design that pushes the audience far closer to the screen than the classic 2-6 rule.

Triple flash. A system that enables 3D to be shown from a single 2K projector. This can cause unwanted visual artifacts as the projector's display devices rapidly alternate between right-eye and left-eye information.

Viewing angle. The angle occupied by a given screen at a given viewing location. Viewing angles increase as the audience sits closer.

Viewing distance. The distance from the screen to a given viewer. To simplify comparisons of different screen sizes, this is often stated in terms of Picture Height (PH).

Visual acuity. Sensitivity of the eye to detail. While most commonly stated as a Snellen Fraction, such as 20/20, it can also be expressed in pixels per degree or line pairs per degree.

1. Schubin, Mark, "High and Why," Digital TV, October 2004
2. http://webvision.med.utah.edu/KallSpatial.html
3. There are exceptions. Stars visible to the naked eye represent powerful contrast against the night sky and can be smaller than one arcminute in diameter. Humans are also an order of magnitude more sensitive to misalignment (vernier acuity).
4. Robin, Michael and Poulin, Michel, "Digital Television Fundamentals," 1998, pages 3-4
5. Schubin, Mark, "The Future of Videography (All in One Place)," Videography, July 2008.
6. Kiening, Hans, "4K+ Systems: Theory Basics for Motion Picture Imaging," SMPTE Motion Imaging Journal, April 2008
7. Schubin, Mark, "High and Why," Digital TV, October 2004
8. Schubin, Mark, "HDTV: Myths and Math," Videography, August 2004
9. The New Encyclopedia Britannica, 15th edition, Macropedia vol 34, page 430
10. Hoffner, Randy, "HDTV and the Resolving Power of the Eye," TV Technology, January 5, 2005
11. Allen, Ioan, "Screen Size: The Impact on Picture and Sound," SMPTE Journal, May 1999
12. Digital Cinema Initiatives LLC, "Digital Cinema System Specification 1.2;" March 7, 2008
13. For similar calculations, see Kiening, Hans, op. cit.
14. The 2K and 4K simulation images were shot on 65mm film, then scanned on an ARRI Scanner at 4K resolution. The images were down-res'ed 3:1 (for 4K simulation) and 6:1 (for 2K simulation), using lancos3 filter (in linear space). The images were cropped to 90x126 pixels (4K) and 45x63 pixels (2K), then converted to PNG format at 750 x 1050 pixels (5x7 inches at 150 DPI) using nearest (box) filter. The results were then inserted into a Word document at 100% size.
15. Study conducted by Parker Marketing Research at a Sony Pictures Entertainment screening room on March 3-4, 2009.
16. The combination of Sony's Intelligent Smoothing algorithm and the 4K SXRD™ (Silicon X-tal Reflective Display) imager enhances edges and transitions to levels that can not be obtained by a 2K system. The algorithm interpolates three additional pixels for every pixel in the incoming 2K image, then accurately maps image edges and transitions over the additional three pixels. Diagonals, edges and transitions that cross pixel edges are smoother and sharper than would be displayed on a lower-resolution system.

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www.sony.com/digitalcinema 2nd Edition; May 3, 2010