Principles of 3D Video and

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The leader in video player software

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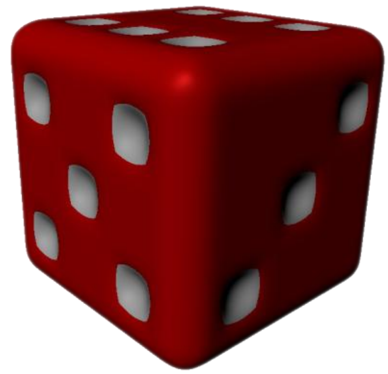
Introduction

This white paper is designed to explain how 3D video works; to help consumers make informed decisions about adopting and enjoying 3D video at home.

What is 3D?

3D is an abbreviation for "three-dimensional." Objects in the real world can be measured in three dimensions; for example, by measuring the length, width, and height of an object. When we look at objects in the real world, we can see the width and height of an object (the two-dimensional view of the object), but we can also *perceive the depth and distance* of the object.



We see the world with our two eyes. Because each eye is in a slightly different location, each sees a slightly different perspective of whatever we are looking at. We don't normally think about these two different views, but if you close one eye at a time, you will see the image that each eye sees. Notice how much different nearby objects appear from the view of each eye.

Although each eye sees a different image, we don't perceive two images. In a process called **stereopsis**, our brain combines the view from each eye into a single picture, and the combined image includes three-dimensional objects and depth perception. The word "stereopsis" is from the Greek words *stereo*, meaning "solid," and *opsis*, meaning "sight." Stereopsis was first described in 1838 by Charles Whetstone, but scientists and artists have been fascinated with three-dimensional perception for many centuries.

While most of the population can see 3D, a small percentage of the population (estimates range from 3 to 15%) suffers from some stereoscopic vision impairment. Depending on the quality of the 3D presentation, this population will see no 3D effect or limited 3D depth perception. There are a number of possible causes for this, from decreased vision in one eye, to the loss of the ability to point both eyes inward towards nearby objects.

Depth Perception

Humans (and most predators) have two eyes in the front of their head. This "binocular vision" improves depth perception, letting a hunter estimate the distance to their prey.

In addition to stereoscopic vision, depth perception also comes from a number of monocular depth cues (depth perception cues that can come from only one eye, or more precisely, that come from the 2D version of the picture that you see). These cues are important to good 3D video, as your brain will expect your stereoscopic perception to closely match your 2D perception of the scene you are viewing.

Monocular cues include:

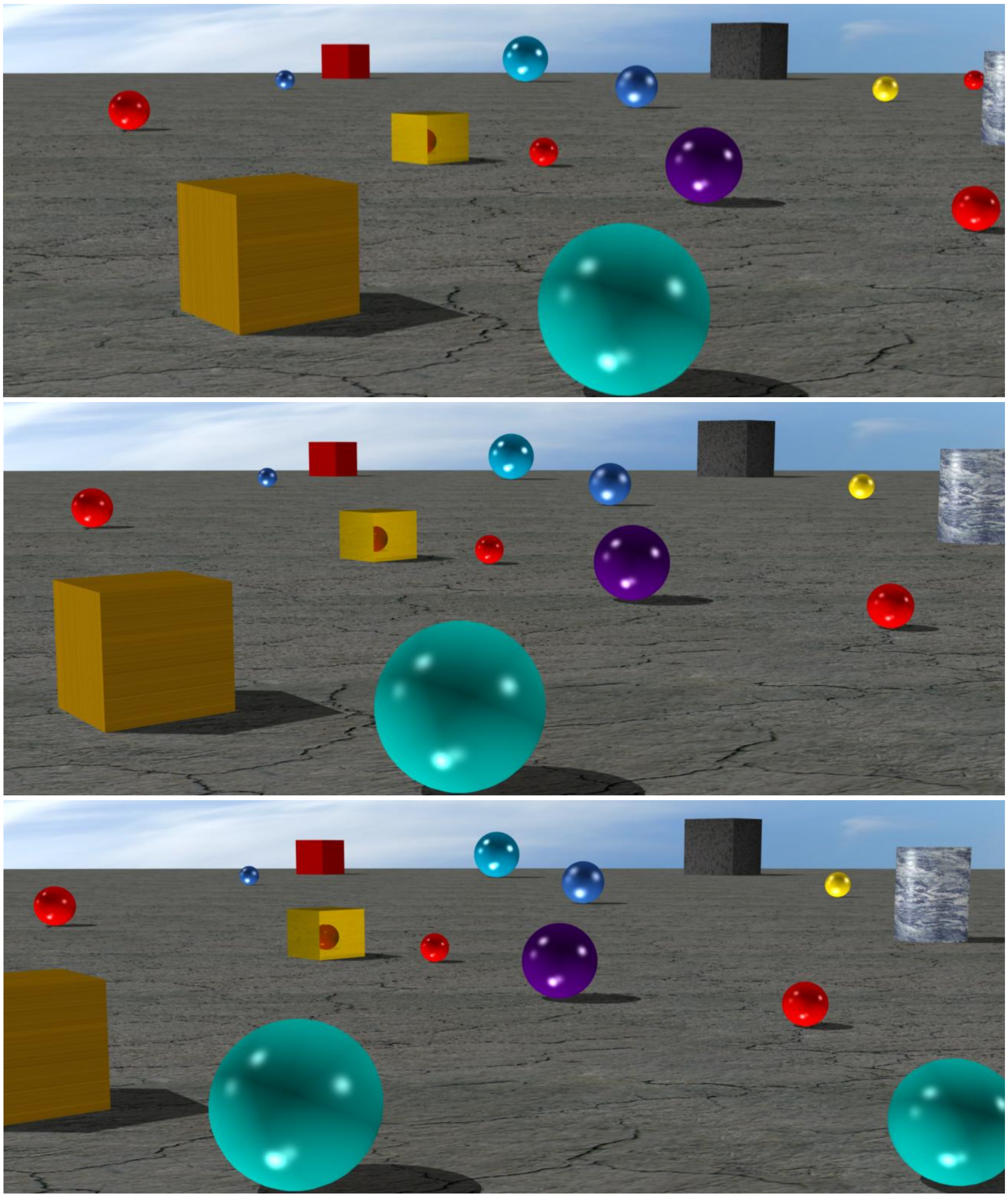
Your memory of the shape and size of different objects-- combined with the relative size of the image you see, lets you perceive the distance to that object. For example, in the photo below, if you are familiar with the size of the bricks that the squirrel is standing on, you can quickly perceive the size of the squirrel, and your distance to the squirrel.

Perspective-- Objects at greater distances appear smaller than near objects. Parallel lines appear to converge as distance increases. This effect is obvious as you stand on a straight road or path and look down the road, or when you look up at a tall building.

Occlusion (interposition)-- If we see two objects, where the first object is blocking part of a second object, we recognize that the first object is closer. In the photo below, you can tell that the tree in the center is closer than the building because it is blocking your ability to see part of the building. Occlusion helps us estimate the relative distance of objects in the photo.

Shadows and Highlights--help us to see objects that are raised above or recessed into a surface. In the photo above, we can see that there are bumps on the tree trunk, thanks to the shadows and highlights.

Parallax-- as we move, we notice that the relative position of nearby objects changes more than far objects. In the photos below, as a virtual camera moves from left to right across a virtual three dimensional scene, you can observe that objects that are closer appear to move (right to left) more than far objects.



Unlike other monocular depth and distance cues, parallax is only observed over time, in moving images. Of course, movies and video are moving images, where parallax will be observed.

Texture gradient-- on surfaces that have a regular pattern, we can judge distance based on the spacing of the pattern. We notice that the spacing of the pattern is wider, and the features are larger on the area that is closer. In the photo above, the pattern formed by the paving stones helps us determine the relative distance of the people and objects that we see. Both the density of the pattern and the perspective that the pattern provides help us sense distance.

Air quality-- far away objects are sometimes obscured by haze or fog, while nearby objects are not.

Accommodation (Focus), and Convergence-- When we look at objects that are close to us in the real world our eyes do two things necessary to see the object clearly. First, our eyes converge inward, so that each eye is aimed at the spot that we want to focus on. Second, to adjust the focus of the lens in our eyes our eye muscles adjust the shape of our eyes in a process called accommodation. The feedback that your eye muscles give your brain as you focus on different objects gives your brain some idea of the distance to each object that you see.

All of these cues provide depth information, even when we view a scene with only one eye. They also help us sense depth when we view standard two-dimensional images. Artists and filmmakers have understood these important visual cues, and have exploited them to add a feeling of realism and depth to paintings, photos, and movies for many years.

Of course, a 2D movie is a flat 2D rendering of a 3D scene. When you watch a 2D movie, your eyes focus on the screen, and they stay focused on the screen (which remains at the same distance) throughout the movie.

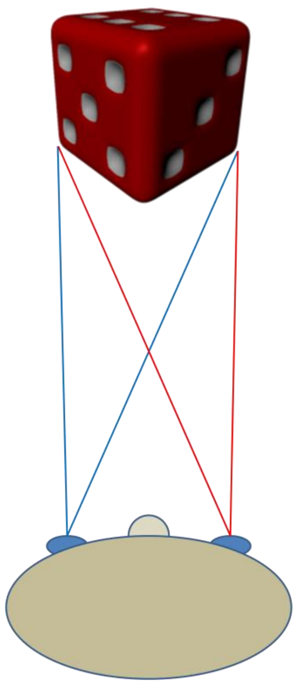
You don't need two eyes to perceive depth, but you do need two eyes to see 3D.

3D movies replicate the images that your eyes would see if you were standing where the 3D camera was when the movie was filmed. Objects and scenery appear to be at different distances, and if all goes according to plan the audience perceives that they are "on location".

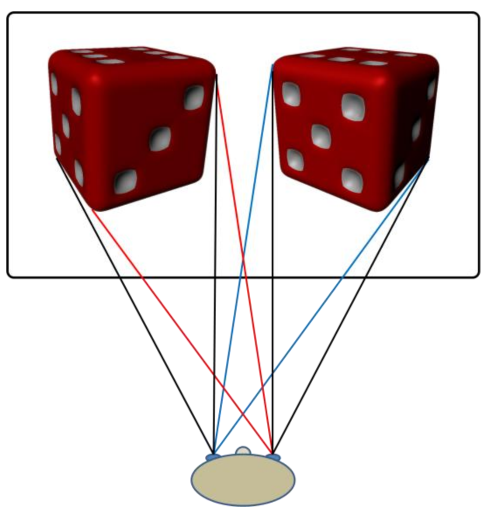
Stereoscopic Vision

In addition to all of the monocular depth cues described above, *most* healthy individuals with sight in both eyes are able to sense depth due to the differences in the images seen by each eye. The two images are processed in the visual cortex of the brain, combined into a single image, combining with all of the monocular depth cues to give a good sense of depth and distance for each object and surface.

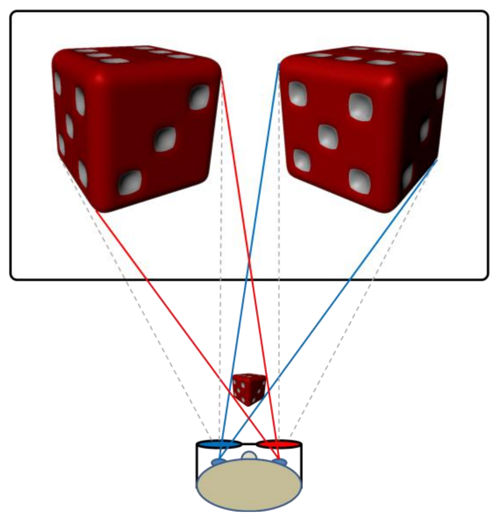
In the real world, each eye sees a different image due to the different position of each eye with respect to nearby objects. 3D video systems are designed to duplicate this real-world experience by providing each eye a unique version of the video.



An observer sees a die. Each eye sees a slightly different view of the die. To capture a 3D picture a 3D camera captures images of the die from the perspective of each eye.



To display the die in 3D the separate images are displayed for each eye. The image for each eye represents a slightly different view of the die. Without 3D glasses the observer will see both images on the display.



3D glasses must be used to insure that each eye only sees the image meant for that eye. When each eye sees the image shot from the correct perspective, the die appears as a 3D object in front of the display.

By displaying a separate image for each eye, a 3D image is created. Objects in a 3D video may appear to be in front of or behind the screen. When the horizontal offset of the left and right-eye images is zero (when the two images converge on the screen), the object will appear to be on the screen (although the apparent distance of the object may be different than the screen distance, due to the focal length of the camera lens and the size of the screen).

Shooting 3D Video

To create the illusion of "being there," and to give our brains the same vision of a scene that we would see if we were seeing the scene with our own eyes, a camera needs to record the scene that each eye would see separately. 3D cameras have two lenses, spaced several inches apart, aligned in parallel. Some 3D cameras use a single camera, and some use two cameras, each with its own lens in a 3D camera rig.

By recording and later displaying a separate image of the scene for each eye, 3D film and video systems can recreate the scene in a way that closely matches what we would see if our eyes were in the same place that the camera was when it recorded the scene.

The average "interocular distance" (spacing of the eyes) is about 2.5 inches. One important variable for 3D camera systems is the interocular distance. The further the spacing of each camera lens, the greater the 3D effect. Cameras set up with an interocular distance of 2.5 inches are said to be configured to be orthostereoscopic. This setup attempts to accurately replicate human vision.

Another important parameter is the *angle of convergence*. 3D camera lenses that are aligned in parallel will result in a picture where all objects appear to be in front of the TV screen (or display). Objects at an infinite distance will appear to be on the screen. To create a stronger 3D effect, camera lenses can be angled (converged) slightly inward. With this setup, objects at the distance where the optical axes of both lenses converge will later appear to be on the screen. Closer objects will appear in front of the screen, and farther objects will appear to be behind the screen. Cameras such as the Panasonic AG3DA1 (shown above) feature lenses that allow for the angle of convergence to be adjusted to align to a distance that the videographer prefers.

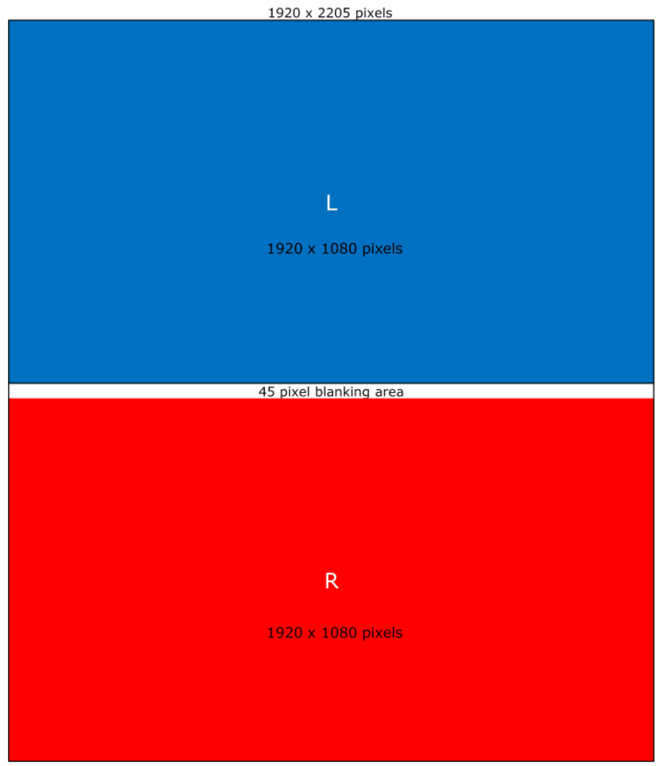
3D animated movies are movies that are created using 3D object modeling software. This genre of movies was pioneered by Pixar with the movie *Toy Story*. Characters and scenery in the movie are generated as three-dimensional models. Of course, these movies are normally rendered to standard two dimensional frames.

Modern computer games are created in a very similar fashion, but they are rendered in real-time as you play the game.

A big advantage of 3D animation is that it can also be rendered and viewed in 3D. To create a 3D version of the movie, the movie is rendered in two separate passes; one for each eye. For the second pass, the studio simply moves the virtual camera perspective 2.5 inches to one side, creating the video for the second eye. Though each frame of video can take hours to render (due to the complexity), the cost of rendering a second perspective of a movie is small compared to the overall cost of creating the movie. For a good movie, the additional cost of creating a 3D version through a second rendering pass is small compared to the benefits.

Encoding and delivering 3D video content

The highest-quality method to encode and deliver a 3D video program is to store and deliver it as a dual-stream synchronized video program, with one full-quality video stream for each eye. This is how Blu-ray 3D works, storing the video for each eye as a full "Blu-ray quality" video program.

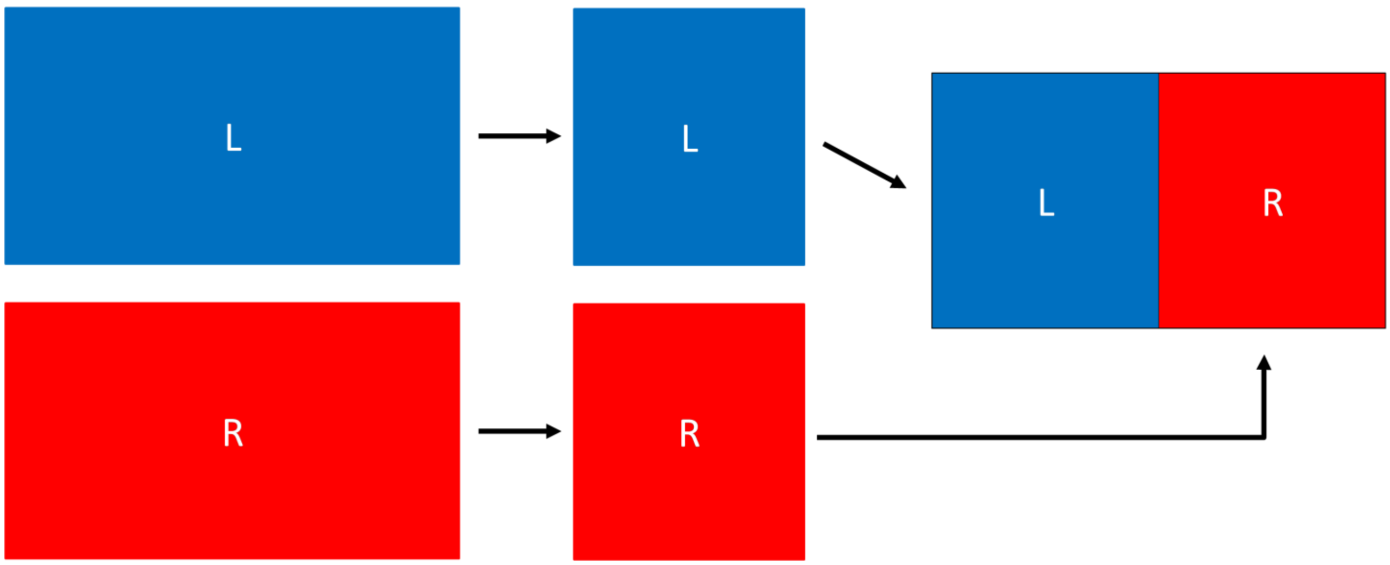


The HDMI 1.4 specification provides for 3D stereoscopic video to be delivered in several different ways, including over/under-formatted frames that are 1920 pixels wide, and 2205 pixels high. The frame for the left eye and right eye are delivered together to assure that synchronization is always maintained, even if the signal is momentarily lost and then restored.

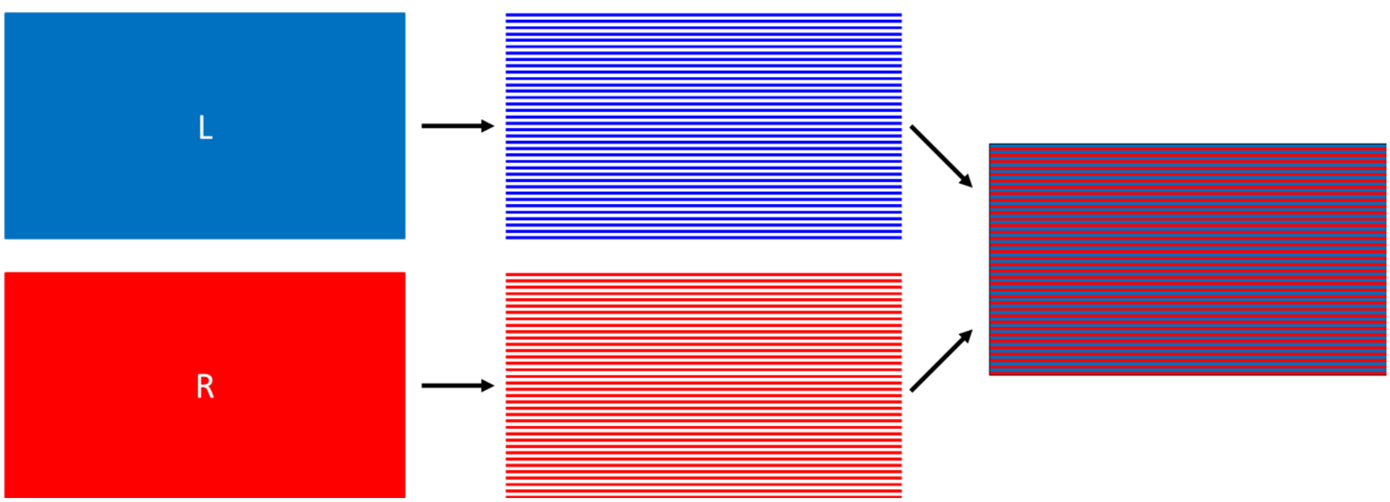
Compressed 3D encoding

For compatibility with existing equipment and video standards, 3D video content can be compressed to fit in a standard video signal. There are several ways that this can be done.

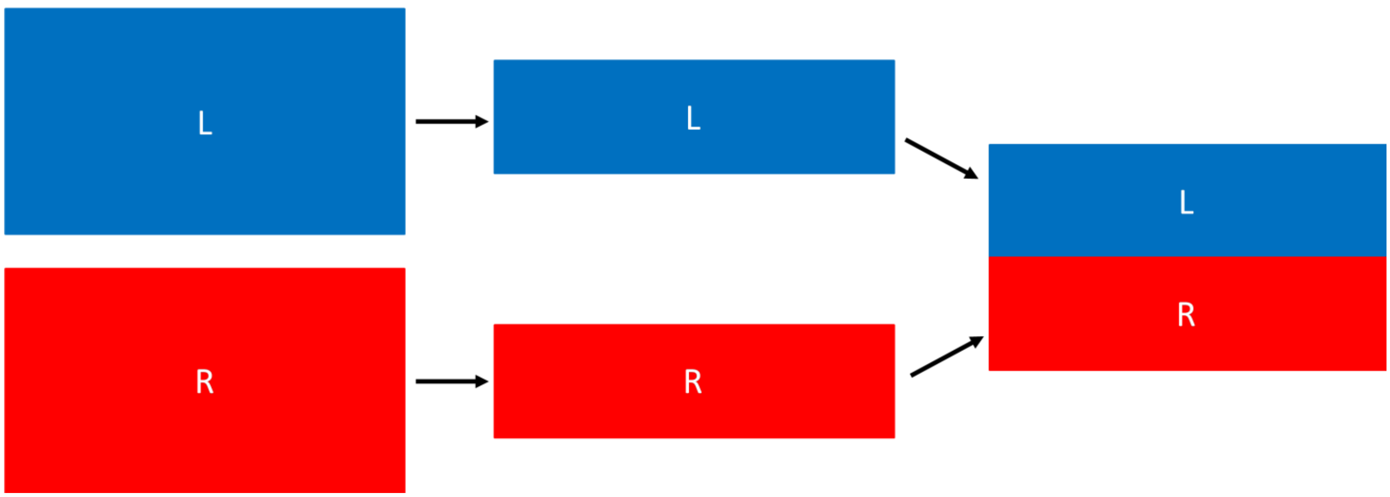
Side by Side encodes the video for each eye in half of a standard video frame (with the right eye picture on the right side of the frame). Thus, the video for each eye is stored with half of the horizontal resolution (960 x 1080 pixels in a standard 1080p video frame).



Interlaced stores the video for each eye in alternate horizontal lines. The odd lines store the picture for one eye, while the even lines store the picture for the other eye. The picture for each eye has full horizontal resolution, but half of the normal vertical resolution (1920x540 in a 1080p video frame).



Over/Under is a format that encodes the picture for each eye with half the vertical resolution stacked on top of each other in a single video frame. The picture for the left eye is stored in the upper half of the frame, and the right eye is stored in the lower half. As with the **Interlaced** format, the picture for each eye has full horizontal resolution, but half of the normal vertical resolution (1920x540 pixels for a 1080p video frame).



Displaying 3D Video

A stereoscopic 3D video contains two time-aligned video channels; one for each eye. To view 3D video, the display technology and the 3D glasses must assure that the left eye sees only the video meant for the left eye, and so on for the right eye. There are a number of different technologies that are designed to accomplish this, and each technology has its own benefits, drawbacks, and costs.

Anaglyphic 3D

Mention 3D video and the image that comes to mind for many people is that of the familiar 3D glasses, with one red and one blue lens. These glasses use the *anaglyphic* method of displaying a 3D image.

Anaglyph 3D Glasses

Anaglyph Image

Anaglyph images are created by using color filters to remove a portion of the visible color spectrum from the image meant for each eye. When viewed through the color filters in the 3D glasses, each eye only sees the image that contains the portion of the color spectrum not filtered out by the lens. The benefit of the anaglyphic method is that no special display is needed; any standard 2D display or TV can display an Anaglyphic 3D image. The drawback of anaglyphic 3D is obvious; the overall image quality suffers as a large portion of the color spectrum is filtered out of the image for each eye.

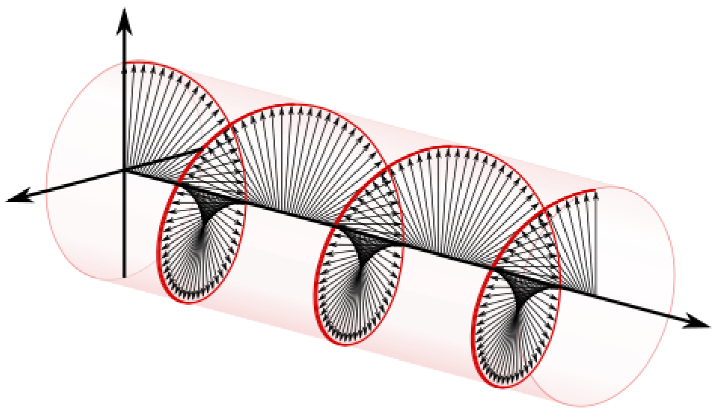
3D Displays

A 3D display must be able to display two separate video images on the same screen. There are several methods that are used to accomplish this. Each display method must be paired with the corresponding 3D glasses technology designed to assure that each eye only sees the video meant for that eye.

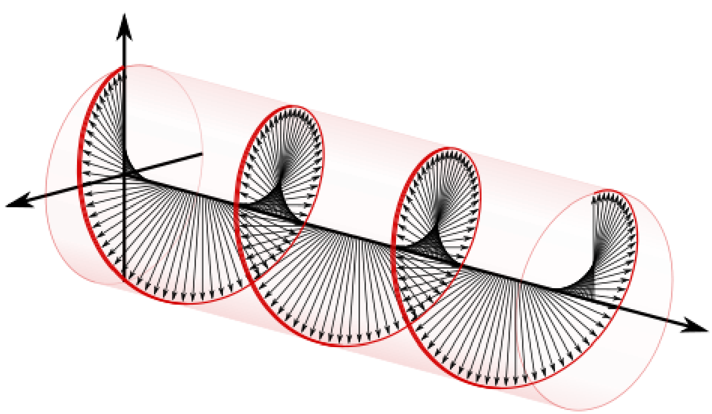
Polarized displays + Polarized Glasses

Modern TVs and displays emit light from each pixel, in some combination of red, green and blue wavelengths. The light emitted by a TV or display can be filtered, such that all of the light coming from a row of pixels has the same electromagnetic orientation. Though the light travels in a straight line from the display pixel to your eye, it may be filtered so that it has one of two circular polarization states (left-hand, or right-hand).

For example, imagine that a beam of light is traveling along the center of the spiral graphic below. The arrows pointing outward from the axis of the direction of travel represent the changing direction of the orientation of the electric field of the light beam [though we don't think of light in the same way we think of radio waves, light is another type of electromagnetic wave]. If you align the thumb of your **left** hand along the center axis of the spiral graph below (the direction of travel of the light), you will be able to close your fingers into a fist in the direction that the electric field rotates around this beam of light. Light with this circularly polarization is said to be **left-handed**.



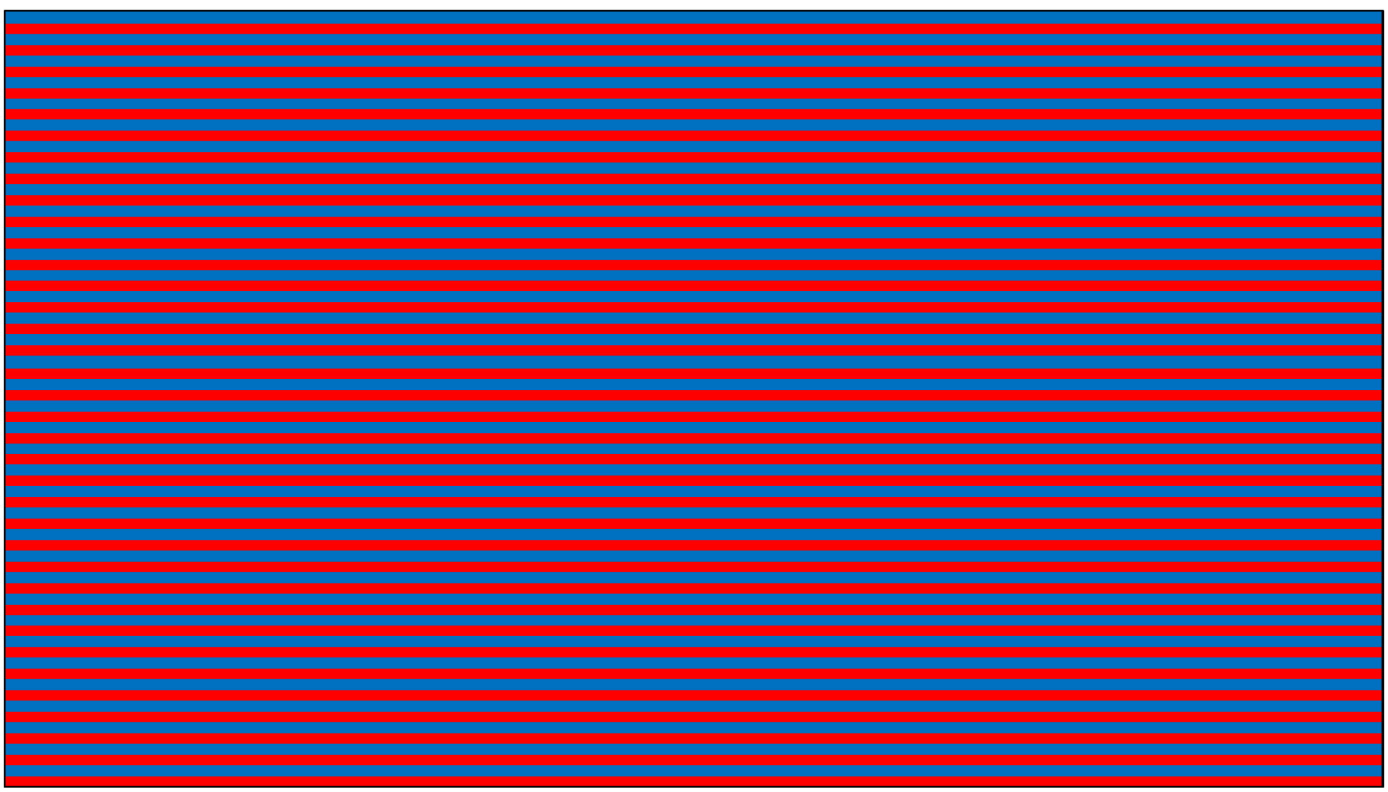
The graphic below shows the direction that the electric field rotates around a beam of circularly polarized light with **right-handed** orientation**.**

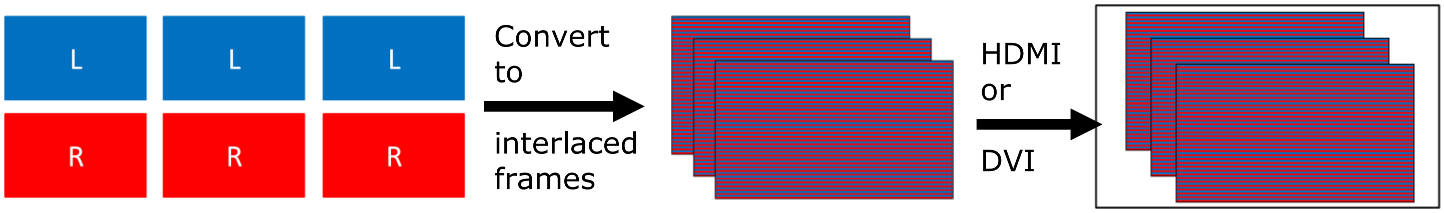


Circularly polarized light with one orientation can pass through a polarizing filter with the same orientation, but will be blocked by polarizing filter with the opposite orientation. In this way, half of the pixels of a 3D display can be used to display the video for one eye, while the other half display the picture for the other eye.

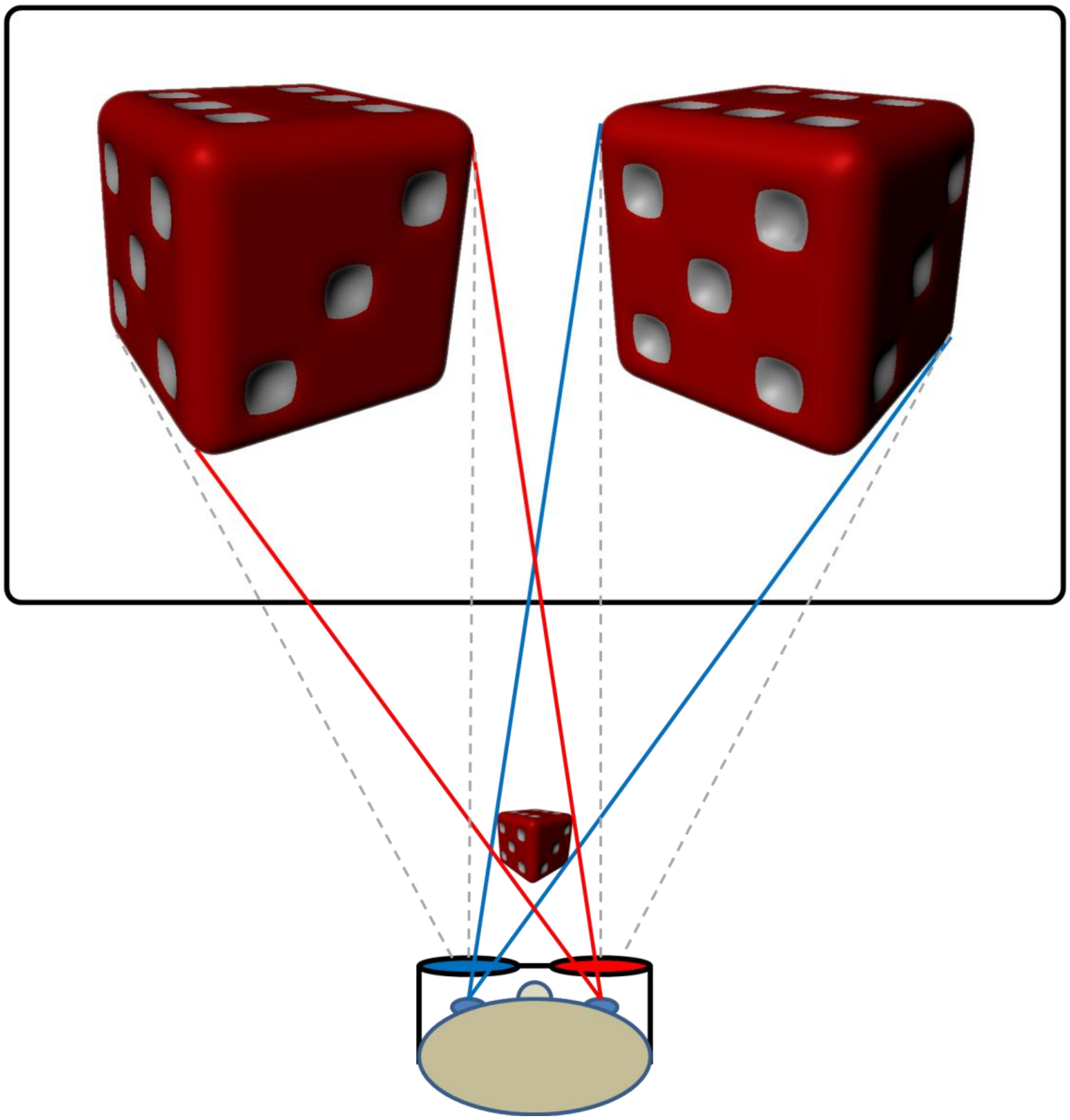
3D Displays can be manufactured with polarization filters which are aligned with the rows of pixels on the display. This allows half the pixels on the display to be dedicated to displaying the picture for one eye, and the other half of the pixels for the other eye. Note that the effective resolution provided by a polarized display to each eye is half of the full display resolution.

Row interleave polarized 3D display
Odd horizontal rows of pixels are used for one eye, even rows for the other eye.
[Red and Blue are used to indicate left and right eye images]





To play back a stereoscopic 3D video program, such as a Blu-ray 3D on a Polarized display, the left and right video frames are converted to interlaced video frames. The display is designed to show odd rows of pixels to one eye, and even rows of pixels to the other eye.



With polarized 3D glasses, each eye will only see the part of the image meant for that eye. In the image above, red and blue indicate the different circular polarization on the lens for each eye. Though two images appear on the display at the same time, with the 3D glasses each eye only sees the image meant for that eye. The human visual system combines the image into a single 3D image.

Polarized displays are one of the least expensive ways to display a 3D video, and polarized glasses are inexpensive. However, polarized displays aren't always able to filter the light perfectly, such that 100% of the light meant for each eye has the correct orientation. Similarly, polarized 3D glasses aren't always able to block 100% of the light that is meant for the other eye. This problem, where one signal bleeds into another signal traveling along the same transmission path is known generically as "cross-talk". For 3D display systems, cross-talk leads to double images (fuzzy, unsharp images). The image quality of a 3D polarized display decreases noticeably if the viewer is not directly in front of (perpendicular to) the display.

Frame Sequential (Alternate Frame) display and Active Shutter Glasses

Some of the latest generation 3D displays, televisions and projectors are capable of displaying 3D video with separate left- and right-eye pictures in an alternating sequence. To avoid flicker, a refresh rate of 120 Hz or higher is used. A 120 Hz 3D monitor displays a full resolution frame for one eye for a 120^{th} of a second, followed by a full resolution frame for the other eye for the next 120^{th} of a second. Each eye will see 60 frames per second, but for less than half the time that the video is playing.

Note that a frame sequential display does not need to be modified with a polarizing filter. It only needs to be able to display frames at a rate high enough to avoid the appearance of flicker (generally, 60 Hz or higher for each eye is required to avoid noticeable flicker). As polarizing filters can affect the overall image quality, frame sequential displays, TVs and projectors will typically have better image quality than polarized displays (for both 3D content and normal 2D content).

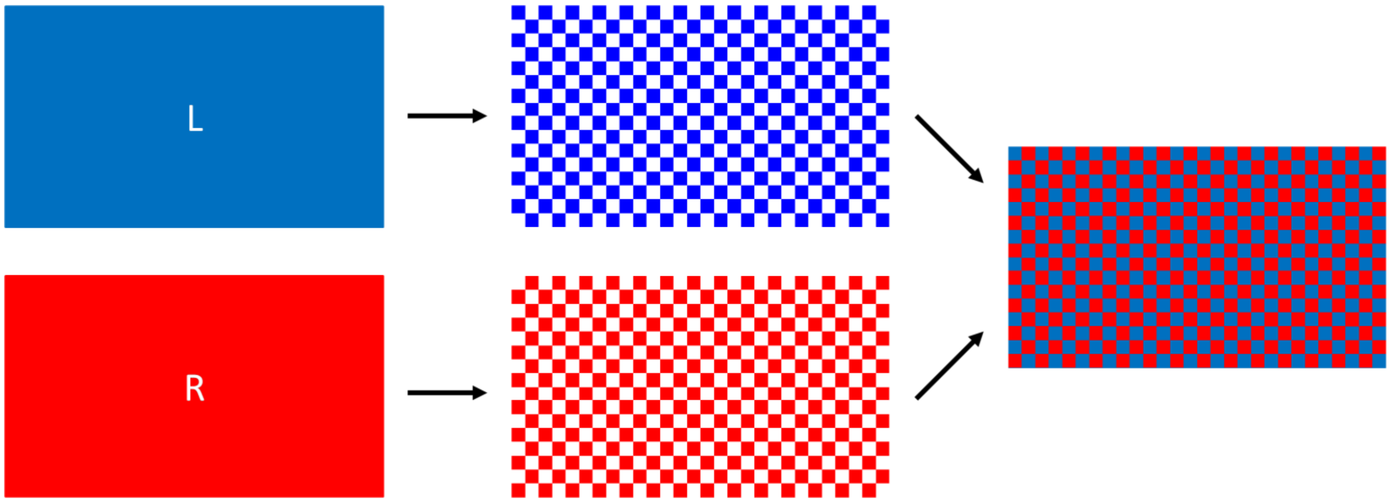
Frame sequential displays (also known as alternate frame displays) are often paired with liquid crystal (LC) "active shutter" glasses for viewing 3D content. Active Shutter glasses, such as Nvidia's 3D Vision glasses, use liquid crystal lenses in front of each eye. The glasses receive an infrared synchronization signal from a base station. This signal is used to synchronize the glasses to the display, such that the left eye is blocked when a frame of video is being displayed for the right eye, and vice versa. Note that there is a "blanking interval" during the transition from one frame to the next where the active shutter glasses block both eyes.

Active shutter glasses provide a number of benefits, including;

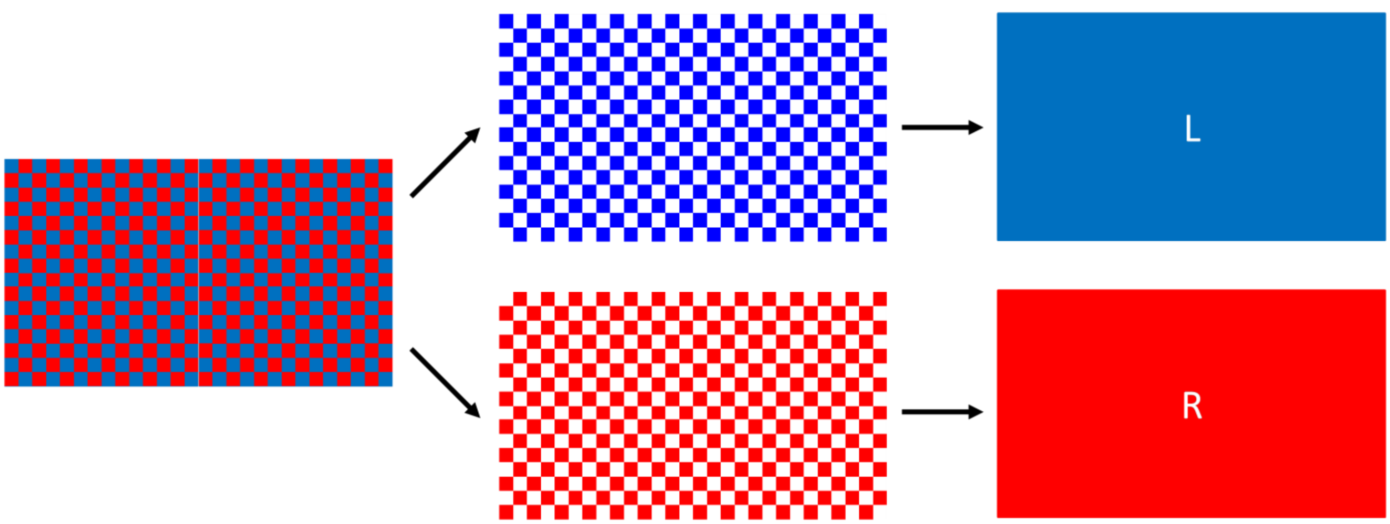
- Full resolution is possible. Because frames are displayed sequentially, each frame is able to use the full resolution of the display. Active shutter glasses are capable of providing a picture quality that has twice the pixel resolution of 3D displays that rely on polarized glasses.
- Extremely low crosstalk. As each frame is displayed, the lens in front of the corresponding eye is given an electrical signal that makes the lens transparent. When the glasses are tuned for and synchronized perfectly to the display, each eye will see very little of the image meant for the other eye. This results in a very sharp and clear 3D picture.
- LC shutter glasses are not sensitive to your head position and viewing angle, whereas polarized glasses suffer from image quality problems if you are not positioned directly along the center of the direction that the display is facing.

DLP 3D Television

Texas Instruments licenses Digital Light Processing (DLP) technology to both Mitsubishi and Samsung, and both manufacturers offer 3D televisions and projectors based on rear-projection DLP technology. These TVs are designed to accept a 3D video signal where the picture for the left and right eyes is downsampled in a grid pattern known as “checkerboard.” This allows a 3D signal to be delivered to the TV in a standard (non-3D) video signal format through a standard HDMI 1.3 connection (though the real resolution of each video frame is half of the original signal resolution).



The DLP TV decodes the incoming checkerboard encoded frames, separating the correct pixels for the left and right video frames, then upsampling each frame to the full TV resolution. As with other compressed 3D formats, half of the original picture resolution is lost in this process.



DLP 3D televisions use active shutter glasses to display 3D programs as 120 Hz sequential frames.

Note that while DLP televisions and projectors may be advertised as "3D-Ready," until models are available that support a full–resolution, dual-stream 3D video signal through HDMI 1.4, consumers should check to see if their chosen set-top Blu-ray 3D player can supporting their DLP TV by outputting a checkboard video signal. If not, the consumer will need to purchase a 3D-to-checkboard adapter (Mitsubishi offers a 3DC-1000 adapter).

Autostereoscopic displays

Autostereoscopic displays are capable of displaying a 3D image without the use of 3D glasses. These displays use lenses that are designed to insure that each eye sees the video signal meant for that eye. There are several manufacturers working to produce and market autostereoscopic displays. While autostereoscopic displays promise 3D video without the need for glasses, consumers should consider both the 2D and 3D video quality, compared with other display solutions before selecting a display.

Head-Mounted Displays

A head-mounted display is like a pair of glasses containing small displays in place of the lenses. With a head mounted display, a separate display is used for each image.

Unfortunately, consumer-grade head mounted displays today are not capable of displaying a high definition video signal.

Blu-ray 3D

Blu-ray 3D is a new movie format developed by the member companies of the Blu-ray Disc Association (BDA). Blu-ray 3D movies are expected to be released in early 2010, providing an extremely high-quality format for enjoying 3D movies at home.

The physical format for Blu-ray 3D is identical to all other forms of Blu-ray disc. The logical format is based on the current Blu-ray audio/video format, but has been extended to provide for stereo 3D video and 3D menus. Earlier Blu-ray players will not be able to play Blu-ray 3D titles. While set-top Blu-ray players will need to be replaced, PC Blu-ray player software can be upgraded. Blu-ray 3D player software will require a Blu-ray drive that is capable of 2x or faster read speeds. Fortunately, all but the first generation of BD-ROM and BD-R drives are 2x or faster.

Blu-ray players capable of playing Blu-ray 3D are backward compatible, supporting standard (two-dimensional) Blu-ray movies. In addition, the Blu-ray 3D format allows for Blu-ray 3D titles to be created in such a way that they can be played by a legacy Blu-ray player as a standard 2D Blu-ray movie. Blu-ray 3D players can be configured to operate in either 2D or 3D (stereoscopic) mode, allowing consumers to upgrade their player and disc collection before they upgrade their TV or display to 3D.

Blu-ray 3D movie titles will contain two full Blu-ray quality video streams, one for each eye. Decoding a Blu-ray 3D is comparable to decoding two standard Blu-ray movies at the same time. While it would be reasonable to expect that the video file size and bit rate would double (since the number of decoded frames doubles), there are some efficiencies in a 3D video that can be taken advantage of. Since each eye is seeing a slightly different perspective of the same scene, there are many similarities in the frames of video for the left and right eyes. The video encoding experts in the Motion Picture Experts Group (MPEG) have taken advantage of this fact to reduce the overall bit rate and file sizes for stereoscopic 3D. A new video codec was developed, based on the Advanced Video Codec (AVC, also known as H.264), called Multi-View Codec (MVC). Blu-ray 3D uses MVC video encoding, which provides for very high picture quality with an overhead (vs. standard Blu-ray) of 50%. While the peak bit rate for standard Blu-ray movies is 40 Mbits/second, the peak bit rate for Blu-ray 3D is 60 Mbits/second.

Blu-ray 3D MVC is encoded as a primary video stream (for one eye, or for 2D playback) and a dependent video stream for the other eye. The dependent video stream references the objects in each frame of the primary video stream, encoding only the differences.

Blu-ray 3D has enhanced graphics capabilities, allowing for 3D menus and subtitles positioned in 3D video. Menu and subtitle graphics and text can be defined to appear on a plane that is offset from the screen. This plane can be defined to be either closer to or farther away from the viewer. This depth offset is accomplished by shifting the text or graphics horizontally by an equal and opposite amount over the video stream for each eye.

Upgrading to Blu-ray 3D

To enjoy Blu-ray 3D titles, consumers must upgrade their PC or their home theater system. There are several components that are needed;

- A 3D-capable display (TV, desktop display, or notebook PC display)
- 3D glasses compatible with your display
- A PC with Blu-ray 3D player software, or a (set-top) Blu-ray 3D player

To choose the right solution, there are some important things to consider for each of these components.

Blu-ray 3D TVs or Displays

The Blu-ray 3D format does not specify the 3D display technology. This allows consumers to choose the 3D display technology that best meets their needs. At the high-end, consumers will likely select true 120 Hz frame-sequential displays that use LC active shutter glasses. Less expensive systems can be configured using polarizing displays and glasses.

Blu-ray 3D Players

Blu-ray 3D players can be implemented on a PC using Blu-ray player software, or as a dedicated hardware solution, otherwise known as a set-top Blu-ray player. Sony PlayStation 3 (PS3) game consoles are expected to get a firmware upgrade in the summer of 2010, providing support for Blu-ray 3D.

Set-top Blu-ray 3D Players

Several set-top Blu-ray 3D players have been announced; and some are already available.

Blu-ray 3D on a PC

Another way to enjoy Blu-ray 3D is to purchase Blu-ray 3D player software, such as CyberLink PowerDVD 10 Ultra. PCs can be connected to a 3D-compatible display, and later, to a 3D-capable TV. In other words, a PC with Blu-ray player software is a fully-functional Blu-ray player, capable of all of the same functions as a set-top Blu-ray player. A Blu-ray 3D-capable PC offers many capabilities that fixed function hardware devices don't:

- Enjoy 3D Games--over 400 game titles can be played in 3D
- Access and enjoy Internet video from *any* Web site, including 3D video
- Play 2D and 3D video files from almost any source (DV, HDV, AVCHD, AVI, WMV, MOV, etc.)
- View 2D and 3D photos
- Support for cable or satellite TV content through solutions such as DirecTV2PC
- Support for premium, protected video (Amazon, iTunes, etc.)
- Video enhancement, such as Cyberlink TrueTheater HD, TrueTheater Motion, and TrueTheater Lighting
- Access and play music, video, or browse photos on your home entertainment system
- Use other 3D software, such as CAD, 3D animation, or 3D solid object modeling software

Blu-ray 3D capability will be available in every PC form factor, including;

- Notebook PCs (with true 120 Hz sequential-frame displays)
- Desktop PCs and displays
- Home Theater PCs

Important considerations for 3D Video

Should I upgrade my TV, or my PC?

Ultimately, you'll want to watch movies on the largest screen that you can afford. Several 3D TV models are available today, and more will be available later this year.

This year, 3D TVs are going to be relatively expensive. Typically, the replacement cycle for TVs is between 5 and 10 years. Consumers who have recently purchased a new large-screen TV may be reluctant to upgrade to a new 3D TV right away. It is likely that consumers will add 3D capability at some point in the future when they otherwise choose to upgrade or replace their TV. Of course, this decision depends on many factors, such as the availability of Blu-ray 3D titles, 3D TV channels, and other 3D video content.

Replacement cycles for notebook PCs, and upgrade cycles for desktop PCs are much faster. Enthusiasts may upgrade their desktop PCs every year. It will be easy to add 3D video decoding and display capability when upgrading or replacing a PC. For these reasons, we think that the installed base of 3D video-capable PCs will vastly outnumber 3D capable TVs in the next few years.

Decoding Blu-ray 3D on a PC

While quad-core CPUs can support software decoding of 3D Blu-ray, the optimal solution includes a graphics card or integrated graphics capable of decoding Blu-ray 3D in the GPU. The latest generation graphics processors, including Nvidia's GeForce GT240, GT340, GT330, GT320, GTX470, GTX480 graphics cards and GeForce 300M series mobile graphics, and systems with Intel Core processors with Intel HD graphics (Core i3, Core i5, and Core i7 mobile) support dual HD video stream decoding. Blu-ray 3D video decoding solutions can be expected for ATI Radeon 5000 series graphics in the future.

Blu-ray player software utilizes these modern graphics processors to decode Blu-ray 3D MVC, resulting in very low CPU utilization and flawless video performance.

Connecting a PC display

Full-quality 120 Hz frame sequential 3D video is only supported through a dual-DVI connector (for Nvidia 3D Vision-compatible displays), or (soon) through a High Speed HDMI cable to a HDMI 1.4-compliant display.

HDMI 1.4 specifies support for a number of 3D video signal formats, including full-frame dual-stream 3D, where both the left and right video frames are packed into a single stereo frame, with the left eye picture on top of the right. HDMI 1.4

stereoscopic frame packing supports 1080p at 24 frames per second, or 720p resolution at 50 or 60 frames per second.

HDMI 1.4 also defines 3D signals compressed into standard 2D video formats, including side-by-side and over/under.

Polarized displays can be connected to a PC using standard DVI or HDMI 1.3 connections.

Connecting to a 3D TV
Full-quality 120 Hz frame-sequential 3D video (such as Blu-ray 3D) is only supported through a High Speed HDMI cable to a HDMI 1.4-compliant TV.

Nvidia has announced that some 3D Vision-compatible graphics cards and systems will be software upgradeable to provide HDMI 1.4 stereoscopic output through a forthcoming 3DTV Play software update. This driver update will allow compatible GeForce graphics cards to provide a full stereoscopic 3D signal to 3D HDTVs.

AMD and Intel are also expected to support HDMI 1.4 compatible stereoscopic 3D video output in the future.

Active Shutter Glasses
To avoid flicker, active shutter glasses operate at 120 frames per second or faster. Active shutter glasses only work with TVs and displays capable of displaying 3D at 120 Hz or faster.

Active Shutter Glasses also require a transmitter. The transmitter receives a synchronization signal from the TV (through a VESA connector), or from the PC (through a USB connection).

Generally, there is no cross-platform standard for active shutter glasses across all of the available TV and PC display manufacturers. Consumers will need to buy the model of 3D glasses that is designed for their TV or display. One exception to this rule is Nvidia's 3D Vision system, which is licensed to a number of PC and PC display manufacturers, including Acer, Asus, Alienware, LG and Samsung. For 3D TVs, consumers will need to buy their 3D glasses from the same manufacturer to assure compatibility (Sony, Panasonic, Samsung, etc.).

120 Hz TVs
Many TVs sold in the past few years have advertised 120 Hz or faster refresh rates. However, these TVs are not designed to accept a 120 Hz video signal. They can only accept a standard (50 or 60 Hz) television video signal.

Through a process called "inverse telecine," these TVs are able to extract the original 24p movie signal from a video signal, create new intermediate frames, and display the movie at five times the original 24p frequency. This is done to eliminate the uneven motion (called "motion judder") that can result from displaying a movie shot at 24 frames per second on a display with a refresh rate of 60 Hz.

To display 120 Hz sequential-frame 3D, a TV or display must be designed to accept and display 120 frames of video per second. These legacy "120 Hz" TVs are not designed to display stereoscopic content, or support 3D active shutter glasses.

Brightness
Because they block alternate pixels, rows, or frames of video from each eye (depending on the type of 3D display you have chosen), less than half the light from a 3D display system reaches your eyes.

To minimize crosstalk on frame sequential display systems, active shutter glasses block both eyes during the transition period between the display of each video frame. For all of these reasons, it is helpful to choose a 3D display with high brightness levels.

It is also important to avoid any reflections on the screen of your TV or display, as these reflections will be seen at a fixed depth (the distance from your eye to the display), making it a bit harder for your eyes to naturally focus on whatever you are interested in.

Due to both concerns, (brightness and reflections) you will find that 3D video is best viewed in a dark room.

Accommodation Disparity
Although objects may appear to be in front of or behind the display, they are not really there. Because the image is really coming from a flat screen, to see the 3D video clearly the muscles in your eyes must keep your eye lens focused to the distance of the screen. The fact that the 3D video is really only in focus on a flat plane creates a disparity between one visual cue (accommodation) and the other visual cues.

When your eyes try to focus on 3D objects that appear to be close to you, your eyes will naturally converge inward while trying to accommodate for viewing a nearby object. Unlike the real world, all objects in a 3D video will only be in focus on the display. If you try to focus on objects that appear to be right in front of your nose you will be disappointed as you instead lose focus.

Fortunately, it seems that most people are able to adjust to this disparity without much difficulty, letting them relax and enjoy a 3D video without losing focus.

Blur Disparity

In the real world our eyes focus on the objects that we are looking at. Objects that are nearer or farther appear out of focus. Because a 3D video is presented on a flat screen, the blur gradient that we experience in the real world will not be seen in a 3D video. If the 3D video is shot with a wide depth of field, the majority of the scene will be in focus, allowing the audience to see any part of the scene clearly when they focus on the screen.

If the Director or Cinematographer chooses to use a narrow depth of field, scenes may be shot with the subject in focus and other areas out of focus. While this technique can approximate the blur gradient we experience in the real world, it has the drawback of causing objects that we would normally be able to focus on to be out of focus, and impossible to focus on.

Blur disparity is an unavoidable issue, regardless of how a 3D video is shot or rendered. Studies have suggested that blur disparity and accommodation disparity tend to provide a cue to the brain that although it is seeing a stereoscopic view of a three dimensional scene (real or computer generated), the actual 3D video presentation is on a flat screen.

Eye Strain

We naturally view our world in 3D, and so a good 3D production makes it easy to suspend the disbelief that we are not actually "on scene", live and in-person. However, the viewer will naturally try to focus to different distances depending on the apparent distance of subjects and scenery in the 3D video. When you not only scan your eyes from side to side, but focus in and out, your eye muscles get a bigger workout than you would get from watching a video in 2D. Once you are able to adjust to the brave new world of 3D video, you will find yourself relaxing and enjoying, instead of trying to actively focus on objects near and far.

Motion Sickness

Motion sickness is normally caused by a disagreement in your brain between what you see and the motion that you feel (by your inner ear, which gives you your sense of balance). Motion sickness can *also* be caused by a disagreement within the visual system of your brain. If a 3D video is shot, displayed, or viewed poorly, the 3D depth perception of the objects in the scene may conflict with the 2D depth information that we perceive. These conflicts can cause the viewer to suffer similar symptoms to common motion sickness (fatigue, headache, dizziness, or in the worst case, nausea).

3D producers know how to minimize the potential for problems by:

- keeping subjects in the 3D comfort zone, at roughly the distance of the convergence point of the camera (at least most of the time)
- avoiding focusing on objects that are extremely close to the camera (your eye will try to focus on the object as it if is close to you, when your eye needs to focus to the distance of the display)
- avoiding zooming in and out (which changes the scale of the 3D space)
- avoiding excessive camera motion (for example, flying through a jungle; the audience has suspended the disbelief that they are watching a movie, and now the subconscious part of their brains are more prone to be concerned when their eyes are telling them that they are flying through the jungle but the sense of balance from their ears is telling them that they are sitting still)
- keeping near subjects away from the edge of the frame (where the picture for one eye could leave the frame)
- being sure that all content is 3D (producers cannot use flat 2D backgrounds or effects in a 3D production)
- minimizing the use of a narrow depth of field (causing parts of the scene to be out of focus – causing problems for viewers who attempt to focus on these objects)

Fortunately, experienced 3D producers know how to avoid these problems.

Consumers can minimize the potential for problems by:

- choosing a high-quality 3D display and 3D glasses solution (minimizing ghost images caused by crosstalk)
- minimizing reflections on their TV or display (reflections are 2D)
- Viewing 3D content from the center of the direction that the display is facing (or from the center of a 3D theater – keeping the relative distance of all parts of the scene centered and in proportion)

An audio analogy

3D video is similar in many ways to surround sound. Just as surround sound adds depth, placing you in the middle of the performance, 3D video places you, the viewer, in the action.

Just as we see the world with two eyes, we hear the world with two ears. Binaural hearing lets us sense the direction that sounds are coming from. Your brain processes the sounds detected by both of your ears. Without thinking, your brain will sense the difference in the time that the sound arrives at each ear, and the difference in the volume of the sound that each ear detected and you will have a sense for the direction that the sound came from. Our three-dimensional vision is similar to our three-dimensional hearing. We don't have to think about the differences in the picture that each eye sees; we just *sense* the relative distance of everything we see.

When sound recording was first developed, each recording contained only a single channel of audio. Monaural recordings were later improved with two-channel stereo recordings. Two channels of audio provide an added dimension with respect to the apparent location of the source of each sound that is mixed into the recording. This "sound stage" allows recording engineers to arrange the relative position of instruments in a band, from left to right. When played back through a stereo amplifier and stereo speakers, the listener can hear a difference in relative volume coming from each speaker, and the relative timing of the sound for each instrument or voice. These differences give our brains an audible clue that helps us sense where the sound is coming from.

With a stereo recording, all of the sound appears to come from one general direction: the direction of the speakers. This is fine for reproducing music, as we are used to music coming from the direction we are facing when we attend a live music performance. Movies producers want their audience to feel that they are at the location that the movie is happening (in the room, or at the scene). To give the audience the feel of "being there", multi-channel surround sound was developed.

Just as surround sound systems provide a more immersive experience, 3D video adds an important third dimension to movies and television.

Done well, 3D video provides an experience that feels real and natural. Clearly, audiences are excited by the experience, and they have shown a strong preference for seeing 3D movies in 3D cinemas.

About the Author

Tom Vaughan is the Director of Business Development for CyberLink, developers of the leading Blu-ray player software, PowerDVD. He is responsible for marketing, strategic relationships, and new business development in the US. When the DVD format first emerged, Tom was responsible for developing the DVD authoring and mastering processes, managing the production of some of the first commercial DVDs in the US. Tom holds a B.S. in Electrical and Computer Engineering and an M.B.A. from Drexel University.

About CyberLink

CyberLink Corp is the leader and pioneer in enabling digital multimedia on PCs and consumer electronics through innovative video player software, video editing software, webcam, photo management and connected home solutions. Backed by a group of high-caliber software engineers, CyberLink has developed a strong portfolio of software intellectual property. CyberLink has built a solid reputation for delivering high-quality, interoperable, and fast time-to-market solutions that keep our OEM partners on the leading edge. Our business partners include leaders in the PC industry: optical drive manufacturers, graphics-card makers, and all of the leading PC manufacturers.

Today, CyberLink's software solutions include: complete applications for Blu-ray Disc, digital home entertainment, TV-on-PC and human resource development. With customers spanning from multi-national corporations to small/medium-sized businesses, and from power users to home users, CyberLink has enjoyed rapid and consistent growth leading to a record breaking IPO in 2000 on the Taiwan Over The Counter Exchange (OTC: 5203). Currently, CyberLink is listed on the Taiwan Stock Exchange (ticker symbol: 5203.TW). CyberLink's worldwide headquarters is located in Taipei. To keep up with market demands, CyberLink has operations in North America, Europe and the Asia Pacific region, including Japan.

For more information, please visit CyberLink's website at www.cyberlink.com.