



# The Many Ways to Create a 3-D Image

By Chris Chinnock

This article provides some basic information about the ways stereoscopic 3-D images can be displayed for cinema, consumer, or professional applications. While this may sound like a fairly simple exercise, in fact, there are probably dozens of ways to do this. As a result, it is useful to have a reference article that briefly describes the more popular approaches and organizes these approaches to better understand the features and benefits of each. Accompanying this article is a wall chart of stereoscopic 3-D display technologies. This family tree is broken into three branches and outlines the various approaches to creating 3-D. But even the structure of the wall chart was not so straightforward as it can be organized in several ways.

## Fundamental Aspects of Stereoscopic 3-D Images

A stereoscopic 3-D image is created by presenting each eye with an image of a scene as viewed from a slightly different perspective. These two perspectives are designed to mimic what the eye sees, which is a slightly different view of the world. This is called stereopsis and is one key part of human 3-D depth perception.

A 3-D display tries to emulate this natural process by displaying two images, often called the left and right eye images, to provide the two different views of the scene. As with natural vision, the brain then fuses these two 2-D images to create a view that has depth.

Stereoscopic 3-D has a long history, almost as long as the history of photography itself. Sir Charles Wheatstone made the first developments in stereoscopy in 1838. Since then, stereoscopic imaging has been used for still images, movies, and video—perhaps most memorably as the 3-D movies of the 1950s. Of late, there's been considerable “hype” and exaggerated forecasts of the future of stereoscopic 3-D.

Recent significant developments in stereoscopic 3-D display technology have removed many barriers to the wider use of stereoscopic 3-D in television and other products. Digital cinema technology has enabled the rebirth of 3-D movies—a rebirth that has been enthusiastically embraced by the studios, the Hollywood creative community, theater owners, and the viewing public. These successes bode well for the future of 3-D displays.

On the other hand, not all people perceive stereoscopic 3-D in the same way. An estimated 4% to 6% of the population are stereoblind and do not see stereoscopic 3-D. A further estimated 25% to 30% of the population are “stereoanomalous” and do not see 3-D in the same way as the majority of the population. These subsets of the viewing (and buying) public are too large to ignore. One goal of stereoscopic displays is to make them viewable by stereoblind and stereoanomalous individuals without discomfort or confusion. While there isn't much that can be done to overcome stereoblindness, stereoanomaly can be mitigated by properly supporting the stereopsis through the use of additional and appropriate depth or distance cues in the content.

A problem to be avoided in managing content creation is the potential for conflict between convergence and accommodation. Accommodation defines the actual focusing distance of the eyes (typically the distance to the display screen), while convergence deals with the interpretation of depth based on the difference between the two eye views (disparity), which is created during the 3-D filming or post-production process. In short, the eyes always focus on the plane of the display (accommodation) while the convergence of the two eyes is determined by the apparent position of the object in front of or behind the display.

For example, if an object is created to hover 5 ft from the viewer, but the actual TV screen is 10 ft away, a mismatch in accommodation and convergence is created. The eyes want to focus (accommodate) at the TV screen, which is 10 ft away, but the eyes also want to con-

verge on the object that is 5 ft away. They want to converge because our eye muscles know they have to toe in to see objects that are close to us. This mismatch creates eyestrain, which can be particularly severe for objects apparently in front of the display screen. While these objects have a certain “wow” factor, they should be used sparingly to avoid audience fatigue. 3-D content aimed at children, however, may want more “in-your-lap” 3-D effects, so the audience must be considered.

### The Three Branches

The fundamental methods to create a stereoscopic image are shown in the three main branches of the stereoscopic 3-D family tree (see wall chart). These are:

- Co-located Pixels—each pixel for the left and right eye images are superimposed in space at the same time.
- Time Sequential—the left and right eye images are superimposed in space, but *not* at the same time. Each image pair is displayed in sequence, typically from 100 Hz to 144 Hz for each component of the image pairs. This rate is generally fast enough for the eye and brain to fuse these images to create the illusion of stereoscopic 3-D.
- Spatial Separation—the left and right eye images are displayed at the same time, but physically displaced from each other. This means that the odd rows of pixels might display the right eye image while the even rows display the left eye image, for example.

In these branches you will see overlap and redundancy in the use of specific technologies to create each approach. Each of these branches leads to a specific hardware realization.

### Co-Located Pixels

In this approach, the left and right eye images are aligned and displayed at the same time. These images are then separated with passive glasses—either polarized or spectral filter-based.

With spectral filters, the narrowband and wideband options are available. For the Infitec narrowband approach, the left and right eye filters are placed in front of two separate projectors and the images carefully aligned on the screen. So far, JVC, Sony, and Infitec have demonstrated this approach mostly for professional applications.

The advantage of using broadband filters such as the traditional anaglyph, or the newer ColorCode or Triviz approaches, is that they can be used with almost any 2-D display. The 3-D information, encoded onto the color channels of the 2-D signal, can be transmitted by conventional means and displayed on any 2-D CRT, LCD, PDP or most projection-based systems (the exception is multi-primary projectors or projectors that use a white segment or the BrilliantColor scheme).

Alternatively, as shown in **Fig. 1**, developers or users can use polarization methods with two projectors or two flat

panels (almost always LCDs) to create a 3-D image. In the two-projector configuration, the two projectors are aligned with separate polarizers (circular or linear) placed in front of each projector to correspond to the left or right eye image. IMAX, JVC, Sony, Barco, Christie, NEC, and Panasonic have all shown this type of 3-D system. Systems of this type can and have been assembled from virtually any pair of identical projectors.



Courtesy of M. Brenneholtz

**Figure 1.** Stacked projectors create co-located pixels for 3-D images.

With two flat panels, there are two ways these can be combined. In the stacked approach, the two LCD panels are arranged in series with one in front of the other. These need to be carefully aligned on a sub-pixel basis. The 3-D image is created a little bit differently in this configuration with the back panel controlling the overall luminance of the image and the front panel controlling the polarization state. A standard CCFL backlight unit or a more collimated projection backlight can be used to illuminate the two panels. MacNaughton, iZ3-D, Chi Mei, and Polaris Sensor Technologies all offer products with this configuration.

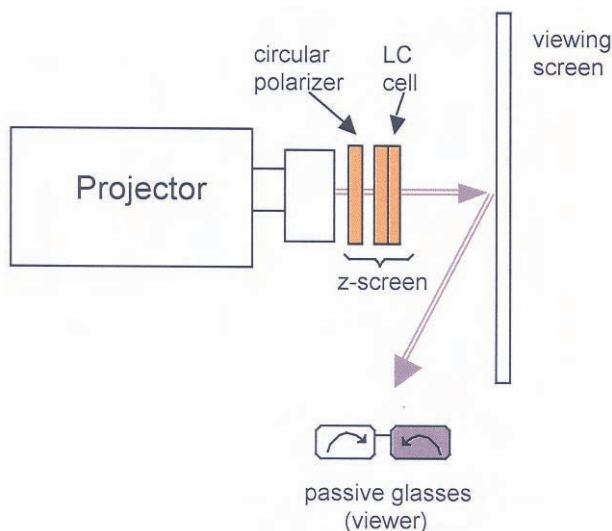
The other way to combine the two images is through the use of a combiner optical element, most usually a large, unpolarized partially reflective element that sits in between the two panels. The arrangement of the two panels and the angle between them vary in the products offered by companies such as Planar, Sevendata, and Omnitec.

### Time Sequential

In the time sequential approach, the left and right eye images are displayed at separate times. The viewer wears active or passive glasses that can separate the images. Ideally, each field is presented for no longer than 8.3 ms (equivalent to a 120 Hz field rate) so that a complete stereoscopic image is presented in 16.7 ms or a 60 Hz rate. In this way, the mind will time-merge these two images to create a 3-D image. Higher rates than these will reduce the visual artifacts produced. For example, 3-D cinema typically uses a 144 Hz field rate, however, some 3-D systems can operate as low as 100 Hz.

If the system designer chooses to use passive glasses, then there are the same two technology choices for creating separate left/right eye images available to the co-located pixels designer. If polarization is used, this can be implemented in either a single projector configuration or a single CRT configuration. In both cases, the left eye image has one polarization state (circular or linear), while the right eye image has the orthogonal state. These are displayed in sequence by the projector or CRT and pass to the correct eye via the passive polarized glasses.

For the projector approach, the most common way to create alternate images with different polarization states is to place a polarization switch (called a z-screen by Real D) after the projection lens of a DLP projector (note for this to work with LCD or LCOS projectors, the red, green, and blue outputs must all be in the same polarization state, which is not always the case). This switch polarizes the images and rotates the polarization, based on a synchronization signal from the projector. This approach, shown in **Fig. 2**, requires the use of a polarization-preserving “silver” screen. Practitioners of this approach use polarization switching technology from Real D Cinema or masterImage, which is implemented on digital cinema projectors from Christie Digital, NEC, and Barco.



**Figure 2.** Real D 3-D cinema approach.

direct-view CRT can also be used for desktop settings. Here, a large pi-cell is placed over the CRT screen. This does the same thing: polarizes the image and changes the polarization orientation on alternate frames using a sync signal from the CRT. Practitioners here include MacNaughton and Real D Scientific, among others. These systems are used by professionals and consumers, but the rapid decline in CRTs makes this an obsolete approach.

The other way to create a time sequential image is with spectral filters—either narrowband or broadband types used with a single projector display. In the narrowband or Infitec approach, the filter set is placed in front of or inside the projector on a rotating wheel. The rotation is synchronized to the left and right eye images, with users wearing matched

filter sets. A standard screen can be used with this set-up. Dolby uses this approach for its cinema installation.

Broadband filters can also be used with a projector, but the only practical approach is the one proposed by Eclipse 3-D. For this approach, the DLP projector would need to include a narrowband yellow filter in addition to the red, green, and blue filters on the color wheel. This approach may find limited success since it provides neither the image quality of other time sequential approaches nor the backward-compatibility advantages of other broadband anaglyphic approaches.

The other major branch in the Time Sequential approach is to use active glasses. For this approach, the output of the display is mostly unchanged, except that the left and right eye images are displayed at 120 Hz or faster. The active glasses block one eye and are transparent for the other eye, then switch to show the other eye image. A synchronization signal is needed to trigger the shutter glasses to show the left/right eye image at the correct time. This is most commonly done by an IR transmitter broadcasting a sync pulse to all the active glasses in the room.

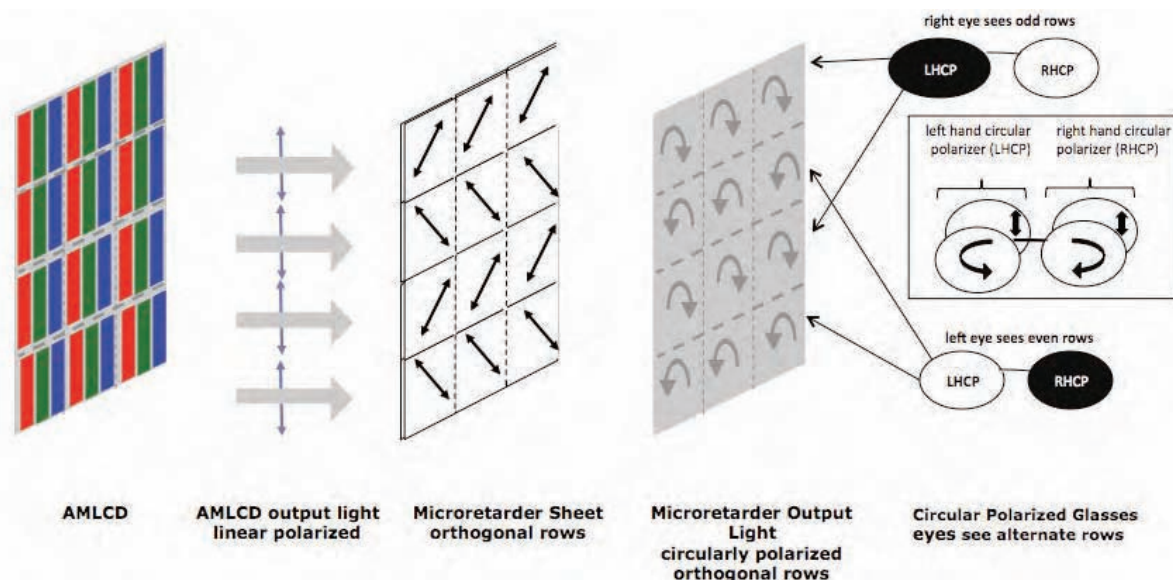
In projectors, the most common consumer implementation is the DLP-based rear-projection TV. Both Samsung and Mitsubishi currently offer a number of models capable of displaying 3-D images. For the professional market, InFocus and DepthQ offer a single front-projection solution, while XpanD offers an active glasses solution for digital cinema and alternative content.

Samsung has also developed several new PDPs that can show 3-D content in a time sequential manner with active glasses. These are scheduled to begin shipping in the spring of 2008 for consumer and professional use. CRTs operating at 120 Hz that can be used with active glasses have been around for some time. This technology is becoming increasingly hard to find, however. Consumer 3-D TV content is available using the NTSC interlace pattern to provide left and right eye images. This produces a 30 Hz image to each eye and unacceptable flicker for long-term viewing. The decline of CRTs in the consumer space is making this approach obsolete as well.

## Spatial Separation

There are two main paths to create a 3-D display using the spatial separation technique. The use of passive glasses using polarization to separate the left/right eye images is embodied in a technology called X-pol or micro-pol. As shown in **Fig. 3**, a standard LCD panel is modified to add another sheet on the front of the screen. This sheet contains rows of polarizers (typically circular, but they could be linear) that alternate their orientation on adjacent rows. The pitch of this line of polarizers needs to be matched to the pitch of the LCD rows.

To create a 3-D image, the left image is placed on even rows and the right eye image placed on odd rows. Viewers wearing passive glasses then see the correct set of rows in each eye. This offers a 3-D image where each eye sees half the vertical



Courtesy of M. Kalmanash

Figure 3. Micropolarizer-based 3-D AMLCD architecture.

resolution of the normal 2-D display. For video material, the brain fuses the left and right eye images so the resolution reduction is minimal. In systems displaying small-font text, half the pixels in a character go to one eye and the other half go to the other eye, which make these systems not acceptable for long-term use for some professional applications. Pavonine, Zalman, Hyundai, and SpectronIQ 3-D all offer products from monitor to TV size.

The other major approach is called autostereoscopic, which means no glasses are required. Autostereoscopic systems are based on the system creating two or more views of the scene and displaying each view into a discrete set of angles. When the head is properly located in a "sweet spot" viewing zone of the display, the left eye perceives one view and the right eye perceives the adjacent view, with the two views creating a stereoscopic pair. Typically, there are multiple viewing zones, allowing more than one person to use the display. An autostereoscopic display must present at least two views and common displays present between 5 and 9 views, with some displays having up to 25 or more views. Each of these views is slightly different from the others and represents the scene as seen from a slightly different angle. The primary set of viewing zones is in a horizontal fan near the axis of the display. Secondary zones are further off axis, but these secondary zones often have reduced image quality. There are two common autostereoscopic approaches in use today: parallax barriers and lenticular arrays.

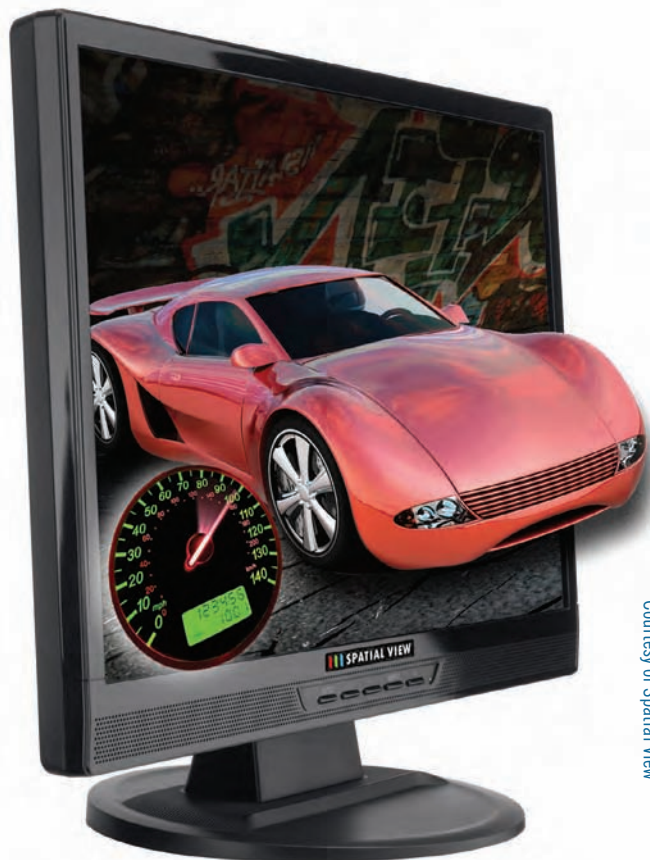
In the parallax barrier approach, the idea is to create a barrier by adding a second sheet in between the backlight and the LCD panel, or in front of the LCD. This barrier consists of vertical slots, much like a picket fence. A viewer looking through this picket fence would see only a subset of the vertical columns in the LCD panel, and the left and right eye would see different sets of columns. Thus, by encoding the left eye view on one set of columns (perhaps odd columns) and the right eye view on the other columns (even), a two-view autostereoscopic image is created at a certain distance

from the display. To see the correct 3-D image, the viewer must hold his head in one of the "sweet spots" of the display where the left eye sees the left image and the right eye sees the right image.

A multiview autostereoscopic display allows several people to see the 3-D image if each holds his head in one of the multiple zones that fan out horizontally. Two of the negatives of the parallax barrier approach are the narrow viewing zones and the rough transitions between adjacent zones. Another disadvantage of the approach is the reduced display brightness, which goes roughly as  $1/N$  or  $2/N$  where  $N$  is the number of zones. Horizontal resolution with vertical slots in the parallax barrier is also reduced by a factor of between  $1/N$  and  $2/N$ , but time multiplexing of these images can reduce this loss. Companies like Spatial View (Fig. 4), NewSight, and Tridality offer such displays.

These same displays can be further optimized to create a single-user, two-view display. To do this, additional head or eye tracking hardware and software is used. By knowing where the user's head or eyes are in relation to the 3-D display, the content or the parallax barrier can be adjusted so the viewing zone follows the motion of the viewer's head. Pavonine, Dimension Technologies, and Tridality offer two-view, parallax barrier-type autostereoscopic displays. One disadvantage of this approach is that a head-tracked system is strictly a single-user system. For a second viewer, the viewing zone moves unpredictably, based on the motion of the primary user's head.

The other popular approach for autostereoscopic 3-D displays is to use a lenticular array in place of the parallax barrier. This is a sheet of long cylindrical lenses that are placed in front of the LCD panel. It functions like the parallax barrier in that the lenses direct multiple views of the scene into multiple viewing zones. Lenticular designs are beginning to dominate over parallax barrier designs because they do not have the  $1/N$  luminance decrease problem, although they have the same resolution and viewing zone problems as



Courtesy of Spatial View

**Figure 4.** Typical 3-D monitor.

systems with parallax barriers. Because of this, lenticular autostereoscopic displays with up to 25 zones have been demonstrated. Some companies, such as Philips, one of the leading proponents of the technology, angle the lenticular array to split the loss of resolution between horizontal direction and vertical directions. While the total resolution loss in pixel count is the same as with parallax barriers, the image produced can now be balanced in horizontal and vertical resolution.

With no head or eye tracking, companies like LG Electronics, NEC, Samsung, Philips 3-D, and Alioscopy now, or will soon, offer commercial products that offer multiview capabilities.

To create a more optimized two-view autostereoscopic display, using LCD technology, SeeFront, working with Spatial View, offers an eye-tracked lenticular approach.

Besides all of the stereoscopic methods described so far, there are additional ways to create a 3-D display without glasses. This includes volumetric displays, where a physical volume of space is filled with voxels (volume pixels), holographic displays, and other variations on the lenticular or barrier approaches. These will not be detailed, as they are still developmental and/or one-of-a-kind demonstrations.

Use of a glasses-free technology is the long-term goal of TV makers, but today most activity in autostereoscopic displays is focused on commercial applications such as digital signage or other attention-getting applications in casinos or

corporate lobbies. The reduction in resolution with an autostereoscopic display, plus the limitations on head position make this approach not acceptable for HDTV at this time. Volumetric displays, in addition to being far too expensive for consumer TV, have poor resolution, color depth, and contrast. These compromises are also not considered acceptable for 3-D HDTV.

## Summary

3-D displays have been used in many professional applications for many years, but the resurgence of 3-D movies and the emergence of a 3-D TV market have many people very excited. Some see 3-D TV as the next natural evolutionary wave. However, the hurdles that remain are significant and include the creation of more 3-D content and an efficient way to deliver this content to consumers' homes—ideally using the existing 2-D HDTV infrastructure. These issues may take years to resolve, but as 3-D-enabled TV sets continue to be rolled out, the good news is that when the content and delivery mechanisms are ready, many people may actually have a TV that can display this 3-D content.

## The Author

**Chris Chinnock** is president of Insight Media, a company he started in 1998. Insight Media provides technology, market, and product intelligence through monthly and yearly reports, special reports, custom consulting, and conferences. Chinnock takes an active role in all of these activities and is particularly active in strategic-level consulting projects. Insight Media has a roster of over 800 companies that subscribe to various services, including custom consulting, on a worldwide basis. Chinnock holds a BS degree in electrical engineering (BSEE) from the University of Colorado. Before the formation of Insight Media, Chinnock worked in a variety of engineering, management, and business development positions at companies such as MIT Lincoln Labs, Honeywell Electro-Optics, GE AstroSpace, and Barnes Engineering.