WHAT 3D IS AND WHY IT MATTERS

Mark Schubin
SchubinCafe.com

Abstract

The term "3D" is venerable but ambiguous. It can be confusing to viewers, referring to a broad range of technologies, many of them unrelated to depth perception.

Unlike motion, sound, color, and HD, current 3D TV systems do not generally provide more information to viewers, just a sensation of depth, varying with screen size, viewing distance, and pupillary distance of the viewer. Under some conditions and for some viewers 3D can cause visual discomfort.

An understanding of the different meanings and technologies of 3D can help reduce viewer problems and confusion. Future 3D television technologies may be very different.

SEMANTIC AMBIGUITY OF "3D"

3D without Depth Perception

Enter the term "3D circuit" into a search engine, and the first results will likely be related to a Third Circuit court of law. The first non-judicial result might well refer to techniques for stacking transistors or other electronic components.

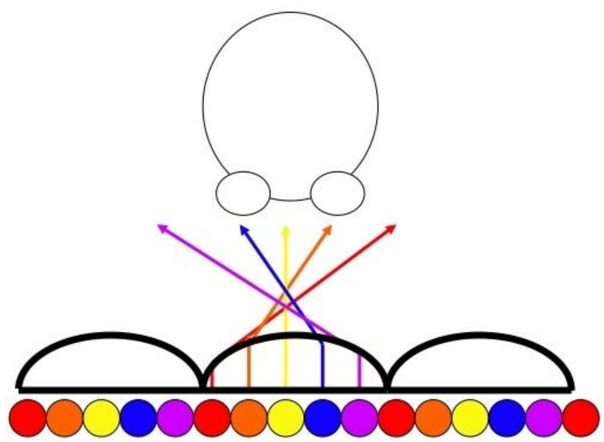
Restricting results to the television field doesn't necessarily help. A major television-set manufacturer still touts its use of 3D comb filtering in its latest digital, flat-panel HDTVs.[1] In that case, the three dimensions are vertical, horizontal, and time.

Three Academy Awards (Scientific & Technical) were presented this year for 3D achievements, but they, too, were unrelated to depth perception. All were awarded for image processing using 3D look-up tables, wherein the three dimensions were axes of color.[2]

Depth of "3D" in Television

Even when the term 3D applies to both depth perception and television, there is a large range of possible meanings. Earlier this year, Study Group 6 of ITU-R (the International Telecommunications Union's Radiocommunication Sector) issued a report "outlining a roadmap for future 3D TV implementation."

Its third-generation future signal format is called "object wave profile," perhaps better known as electronic holography. The second generation is multiview autostereoscopy. Both the second and third generations allow viewers to get different views by shifting their heads (as in "real," non-television vision).



example of multiview autostereoscopy, in this case five-view lenticular (lens-based)[3]

The first-generation signal format in the report is called "plano-stereoscopic." Even that format is assigned four levels based on degree of compatibility with existing displays, existing video frames, and existing signal-distribution standards.[4]

Not even the ITU-R report covers the full range of 3D viewing options. At the high end, for example, there is already full-color, full-motion, high-definition holography, though in its current commercial implementation neither capable of being transmitted live nor of television-program duration.[5]

At the low end, there are 3D-sensation-providing techniques that might be considered less than even plano-stereoscopic, such as the Pulfrich illusion, chromostereopsis, temporal view shifting, and microstereopsis, all of which have been applied to television programming. They will be described later.

Below even those techniques are ordinary television pictures, which, nevertheless, provide multiple depth cues. The terms "3D graphics" and "3D animation," for example, have been applied to digitally generated objects and scenes using such techniques as shading and perspective to create the appearance of depth even in 2D images.

Human Depth Perception Cues

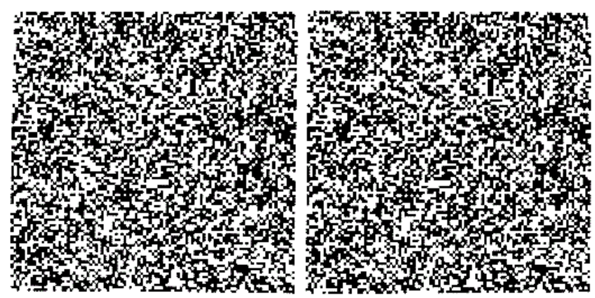
The strongest indicator of depth in human vision at all viewing distances is occlusion or interposition. It is simple to understand. If one object is blocking another, the one being blocked is behind the one doing the blocking. There are many other depth cues, as illustrated in the painting below.

Joachim Patinir, *Charon Crossing the Styx*

Even though it is an early-16th-century painting, reproduced here at a tiny fraction of its size, viewers should have little difficulty distinguishing foreground from background using such cues as occlusion, object size, textural perspective (detail in the vegetation, rocks, and water becoming less distinct towards the background), and aerial perspective (objects in the distance becoming both hazier and bluer). Moving-image media, such as television, offer even more depth cues, including motion parallax (the ability of a camera to "see" around objects as it moves) and temporal size change (e.g., a car getting bigger as it approaches the camera).

The "real" world adds three more cues. One, accommodation, is the focusing of the eyes' lenses on something. The focus muscles send distance feedback to the brain. Another, vergence (or convergence), is the aiming of the eyes. Again, muscular feedback provides a depth cue.

The third cue is called stereopsis or binocular disparity. In viewers with binocular (two-eyed) vision, each eye gets a slightly different view, just as one camera gets two different views at two different moments when it is moving. Stereopsis, however, does not require camera or object motion.



random-dot stereogram

In the absence of any other cue, stereopsis can provide depth information. If the left image above is viewed by the left eye and the other by the right, a square in the center should appear to float above the field of dots.

VIEWING 3D TELEVISION

Revelation vs. Sensation

3D is sometimes characterized as the next step in image media, following such developments as motion, sound, color, and high-definition. From a business standpoint, it very well might be.

At this year's Consumer Electronics Show, Panasonic CTO Eisuke Tsuyuzaki said, "It's a challenging market [for TV-set sales]. We need something to kick us out of this. To me the thing that's going to get us there is 3D."[6]

In terms of viewing experience, however, 3D is different from sound, color, and high definition. Consider this black-&-white still image from 1954.

Without motion, viewers don't know what just happened or is likely to happen. Without sound, they don't know what she's saying (or singing). Without color, they don't really know whether the hair is blonde or blue-tinted white. Without more definition, they can't say whether there is an earring or a trickle of blood. It's clear, however, based on relative sizes, that the face at the lower right is farther away than the main subject.

Unlike motion, sound, color, and high definition, 3D (except for holography, multiview, and similar technologies) does not reveal new information to viewers. It *does* provide a sensation, however, as do such other important moving-image developments as music and directing.

Range of 3D TV Sensations

The report of ITU-R Study Group 6 indicates that "object wave profile" 3D TV, the only form that might approach the "real" world visual sensation of depth, is "technically some 15-20 years away."[4]

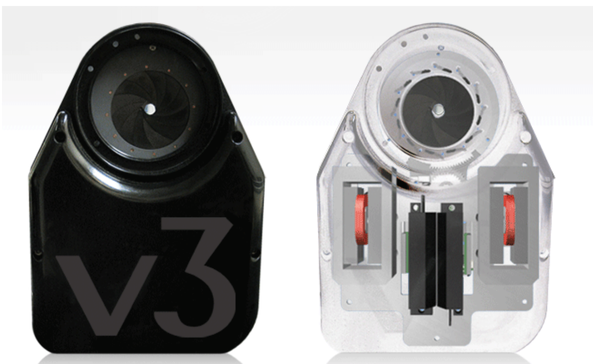
At the 2009 convention of the National Association of Broadcasters (NAB), Japan's National Institute of Information and Communications Technology demonstrated live 3D holography. The image was tiny and crude, had a limited viewing angle, and required a room full of laboratory equipment to produce. Here is a still photo of the image.

Across the aisle, NHK (the Japan Broadcasting Corporation) demonstrated a form of multiview 3D they called "integral" television. It used a multi-lens array in both shooting and display to provide an image that *did* reveal more information as the viewer's head moved.

Unfortunately, the multiple views divide the system resolution. Despite the use of an ultra-high-definition camera (one with 16 times the number of picture elements of so-called "full 1080-line" HDTV), the final image appeared to have less resolution than even a low-grade home VHS videocassette recording. Here is a full-screen image.[7]

At the other end of viewer 3D sensation, below even the ITU-R “first-generation” plano-stereoscopic systems, are view shifting, the Pulfrich illusion, and chromostereopsis. All three can be used with unmodified television distribution systems and displays.

View shifting is a restricted version of motion parallax. If the shift is sufficiently large, and the image is otherwise stationary, it provides a strong sensation of depth. In entertainment-grade moving images, the effect is subdued.[8]

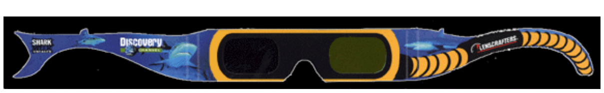


v3 view-shifting lens adaptor

In Pulfrich-illusion 3D, the viewer darkens one eye. Foreground portions of the scene must move in one horizontal direction and background in the opposite. A carousel is ideal Pulfrich material.

According to one theory of how it works, the darkened eye is forced from photopic (retinal cone-based) vision towards scotopic (rod-based). The photochemical reaction in cones is faster than that in rods. The clear eye, therefore, sees what *is*, and the darkened eye sees what *was*, effectively providing a form of motion parallax.

Pulfrich 3D has been used often in television. These glasses are from Discovery *Shark Week* in 3D.[9]



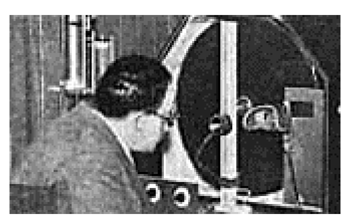
Chromostereopsis is based on the inability of any simple lens to focus different colors at the same point at the same time. Red focuses closer than blue, so a scene in which the foreground is reddish and the background bluish will provide a mild depth sensation.

Just as Pulfrich 3D requires attention to foreground-background choreography, chromostereoscopic 3D requires attention to color placement within a scene. The effect can be enhanced with glasses that shift colors in different directions. Here are red-shifting ChromaDepth glasses used for VH1’s *I Love the 80s* in 3D.[10]

View shifting, the Pulfrich illusion, and chromostereopsis not only utilize ordinary TV sets and distribution systems, but also, even when they use glasses, provide images compatible with viewers not wearing glasses. Other 3D systems (not counting multiview, holography, and so-called volumetric displays) use stereoscopy.

Stereoscopy attempts to duplicate binocular human vision. Separate left-eye and right-eye views are captured (microstereopsis, which will be described later, uses variations of that process).

For presentation to the viewer, some mechanism must be used to direct the appropriate view to the appropriate eye. These range from goggles with built-in screens for each eye, to a broad range of view-controlling glasses, to glasses-free autostereoscopic displays based on visual barriers or lenses. The first 3D TV broadcast, in 1928, used a stereoscope for viewing, as shown below. That forced the viewer into a fixed position, head against the hood.

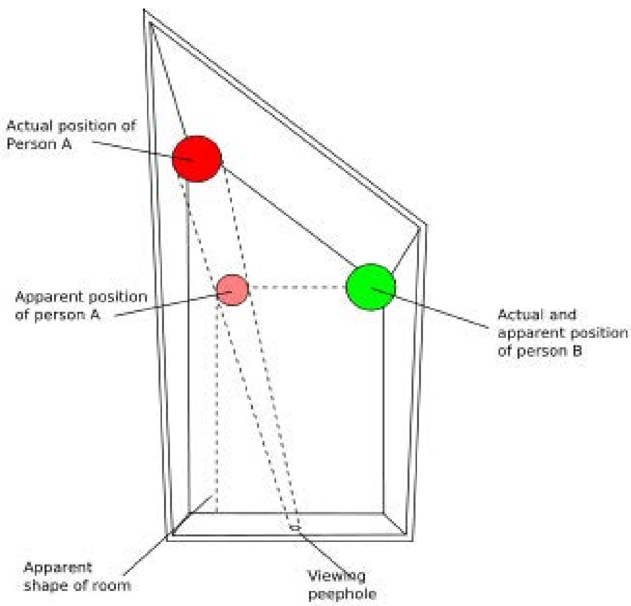


Cue Conflict

In the "real" world, all visual depth cues should work together to provide the same information. In the world of produced imagery, however, they need not.

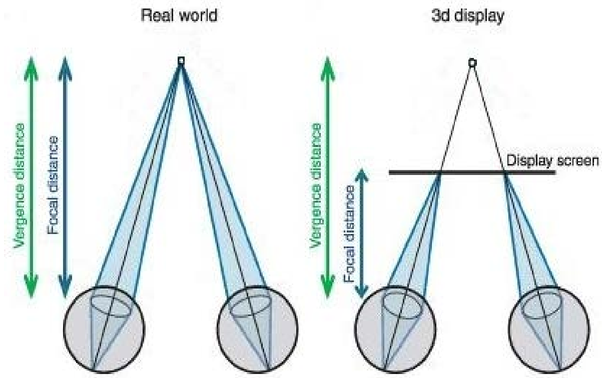
Sometimes cue conflict is used intentionally to provide a desired effect. The Ames-room illusion, for example, uses a distorted version of a normal room so that the parallel-line perspective cue fails.

In an Ames room, surfaces that appear to be parallel, like the walls, floor, and ceiling, are not. The illusion was used intentionally in the *Lord of the Rings* movies to make certain characters appear smaller than others. An Ames-room plan is shown below.[11]



Sometimes, however, there can be undesirable cue conflicts. In "real" world vision, for example, accommodation and vergence should always provide the same muscular depth feedback. In stereoscopic 3D, eyes always focus on the screen, but vergence may be at, behind, or in front of the screen,

The illustration at the top of the next column indicates the conflict. At the left is the "real" world; at the right is a 3D screen. In this case, the stereoscopic convergence point is located behind the screen.[12]



The vergence-accommodation cue conflict has been proven to cause discomfort under certain viewing conditions. At theatrical viewing distances, it is generally not a problem unless the stereoscopic convergence point is very far in front of the screen. At close TV-viewing distances, however, a convergence point far behind the screen might cause discomfort.[12]

A different cue conflict is shown below, this time between two of the most powerful cues, occlusion and close-range stereopsis. In the upper pair of images, the text is difficult to read when viewed stereoscopically, because its positioned 3D depth is behind the snowball it is occluding. In the lower pair, the text depth has been moved to the front, and it is easier to read.[13]

THE OTHER THREE DIMENSIONS OF 3D

Pupillary Distance

If the goal of shooting stereoscopic 3D is to capture the disparate views of binocular human vision, it is important for the stereographer to have a sense of how disparate those views normally are. It is not necessary to duplicate them precisely. As in other image media, it might be desirable to exaggerate or diminish an effect.

Although there are many human-vision depth cues, they don't all have the same influence at different distances. Stereopsis, or binocular parallax, is an extremely strong cue, second only to occlusion at very close distances, where the space between the pupils of the eyes is significant. As distance increases, stereopsis diminishes, disappearing completely at a few hundred meters.[14, 15]

When the left- and right-eye images are captured with lenses spaced beyond the appropriate distance, the result is "hyperstereo;" stereopsis is extended to greater distances, but the viewer experiences a sensation of diminished depth, as though looking at a doll house or through the eyes of a giant. "Hypostereo" is the opposite.

A stereographer can choose an appropriate view-separation distance based on lens magnification and human pupillary distance, PD, the distance between the centers of the pupils of our eyes. Unfortunately, there is no single PD. According to one researcher, the "range of 45-80 mm is *likely* to include (almost) all adults, and the minimum… for children (down to five years old) is around 40 mm" [emphasis added].[16] Variation in human pupillary distance is the reason binoculars have adjustable hinges.

Thus, stereography based on a 40 mm PD might seem like hypostereo to an adult viewer with a larger PD. Conversely, something shot based on an adult PD might seem like hyperstereo to a young child viewing the same screen.

Screen Size

When looking at an infinite distance, both eyes of a viewer with normal vision will point straight ahead. The vergence angle will be zero. In human vision, furthermore, "infinity" can be considered to be as close as ">20 ft."[17]

A stereographer can measure a viewer's PD, shoot accordingly, and arrange to have the content presented to a viewer with objects at infinity separated by the PD on any screen that is wide enough. Unfortunately, there is a great range of screen sizes.

The largest cinema-auditorium screens are more than 100 feet wide. The smallest screens (exclusive of built-in-screen goggles) on which some people watch entertainment programming are probably on mobile phones, just about an inch wide. In between are television screens ranging from a few to 152 inches in diagonal.

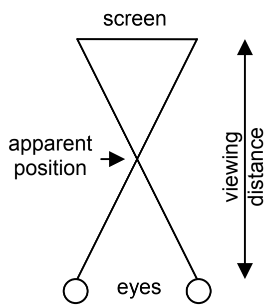
Display adjustment of stereo disparity based on screen size is not yet the case in television sets. A conflict between PD-based stereopsis and screen-size-based convergence, therefore, is likely.

Infinity eye-view disparity set to 40 mm on a 100-foot screen will become 0.93 mm on a 32-inch-diagonal 16:9 TV screen. For a viewer with the author's 68-mm PD, viewing the screen from the nominal-viewing Lechner Distance of nine feet, the vergence-based feedback depth for infinity will be just over nine feet, barely behind the screen.

Conversely, an infinity separation set for a small screen can scale up on larger screens beyond the viewer's PD. That calls for the eyes to *di*verge rather than *con*verge, an unnatural condition.

Viewing Distance

In the example above, it was necessary to specify PD, screen size, and viewing distance, because vergence angles are based on all three. It is easiest to illustrate the effect with negative parallax, the condition in which a point in the right-eye's image is to the left of the left eye's image.



As shown above, if the negative parallax equals the viewer's PD, then the vergence point will be exactly halfway between the screen and the viewer. Of course, that distance will vary with the viewer's distance to the screen.

A viewer watching at a distance of four feet will get vergence feedback indicating that the point is two feet in front of the screen. A viewer with the same PD watching the same screen at a distance of 12 feet will get vergence feedback indicating that the same point is six feet in front of the screen.

VIEW-CONTROL MECHANISMS

Fixed Position

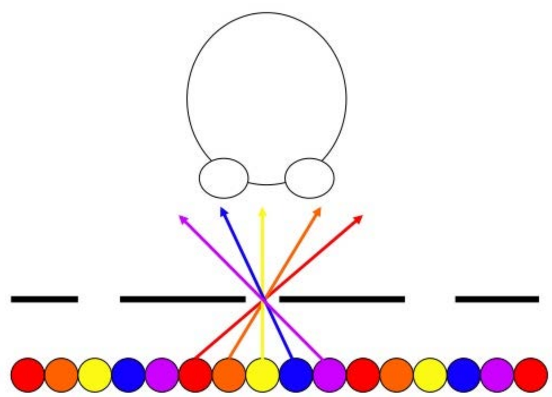
Again, the first 3D TV broadcast, in 1928, used a stereoscope to control which view got to which eye. The viewer's head was placed against the stereoscope hood. Prismatic lenses directed each eye to its appropriate view and increased the accommodation distance to reduce the possibility of vergence-accommodation conflict, and adjustments could be made for different viewer PDs.

The modern equivalent is video goggles, wherein each eye gets its own screen, with an adjustable lens system to provide a significant accommodation distance. An example, the Vuzix Wrap 920, is shown below.

It is intended to provide the sensation of a 67-inch screen viewed from a ten-foot distance and has a suggested price of about $350.[18] An upcoming model is to include stereoscopic cameras for "augmented reality."

Autostereoscopic Systems

Autostereoscopic displays use lens-based (lenticular, illustrated previously) or barrier technology (shown below) to direct the eye views. If more than two views are used, there is leeway in viewer position, and shifting the head can reveal new information, as in the "real" world.[3]



parallax-barrier multiview autostereoscopic display

Unfortunately, the overall display resolution must be divided by the number of views presented. That's why the image on the NHK "integral" television display appears so crude despite utilizing ultra-high-definition equipment.

Having just two views reduces the resolution problem. Unfortunately, it also makes the viewing "sweet spot" narrower.

As can be seen from the diagram on the previous page, successful view control in autostereoscopic displays is also affected by viewing distance and deviation from the orthogonal axis. Relatively large autostereoscopic displays viewed at relatively short distances can make tracking of objects across the screen difficult.

Glasses

Not counting the special glasses for Pulfrich (one lens darkened) and chromostereoscopy (color spread), glasses for 3D viewing may be divided into four categories, each with sub-categories. They are: view-directive, polarized, color-filtered, and shuttering.

When *Business Week* magazine ran the headline "3-D Invades TV" in 1953, the glasses being used were view directive, with prisms to direct the eyes to side-by-side views on a TV screen. They are shown below on the left. Next to them are modern prismatic glasses for side-by-side viewing.[19]

In side-by-side displays, viewers without glasses can choose to watch just one of the images, perhaps covering the other to avoid distraction. When the right-eye view is to the left of the left-eye view, viewers without glasses may also occasionally cross their eyes to fuse the two into a 3D image.

One problem with side-by-side displays is that they have a vertically oriented aspect ratio. The trend in television has been towards ever wider aspect ratios, with two manufacturers offering 21:9 screens.[13]

An alternative, therefore, has been over-under displays of the two images. On a 4:3-aspect-ratio TV screen, each image would have the shape of the widest-screen movies. Again, prismatic glasses have been used, as shown at left below.[20] Cross-eyed viewing without glasses, however, is impossible.

In both side-by-side and over-under displays viewed through prismatic glasses, there is a restricted "sweet-spot" viewing distance. Inexpensive, adjustable-distance mirror-based prototype glasses have been demonstrated (above right), but they have not yet been manufactured.

Polarized glasses are used in systems with matching display polarizers. As an example, if the left eye's view is polarized horizontally and the right eye's view is polarized vertically, then, if a viewer wears matching glasses, only horizontally polarized light will reach the left eye, and only vertically polarized light will reach the right.

When polarized images are projected, it is necessary for the screen not to depolarize the light. Non-depolarizing screens are sometimes called "silver" screens. In practice, linearly polarized glasses are usually polarized along 45- and 135-degree axes.

With the left-eye and right-eye images superimposed on the screen, any light of the wrong polarization that reaches a viewer's eye (optical crosstalk) might be perceived as a ghost. Many factors affect ghosting, including the polarization materials used, their alignment, and scene content (a white object in one eye's view spatially coincident with a black field in the other eye's view is an extreme example). Ghost-reduction systems can be used.[21]

In addition to linear polarizers, there are also circular polarizers. The alignment of circular polarizers is not critical in the manufacture of glasses. On the display side, it's also possible to use a switchable optical delay to reverse the direction of circular polarization on a temporal basis (e.g., alternate video field or frame).

Ghosting can also be wavelength dependent (many circular-polarizing filters do not cancel shorter wavelengths like blues as well as do linear polarizers) and affected by the angle of the viewer's head and the glasses on it. Appropriate 3D viewing requires upright viewers, not heads on shoulders.

Linear polarizers provide a self-correction function to viewers; as they see double images, they align their heads to reduce them. Circularly polarized glasses do not provide that indication of head misalignment.

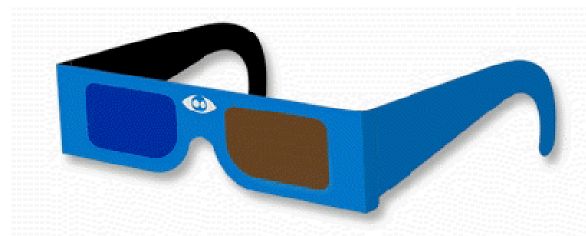
Glasses with colored filters, such as those shown above, have been used for 3D for so long that they are called "anaglyph" (literally three-dimensional carving). Even inexpensive color filters have very distinct pass bands (that allow certain colors through) and stop bands (that prevent colors from getting through).[22]

When the filters were used for black-&-white movies, therefore, with matching filters on the projection side, there was little ghosting. Unfortunately, color television displays do not match the colored filters as well, resulting in increased ghosting.

Anaglyph technology may be used with existing TV sets and distribution systems. Besides ghosting, however, there have been other issues associated with anaglyph glasses, including poor color rendition and brightness mismatch between the eyes. There is also the chromostereoscopic issue of red accommodation being different from blue.

For those reasons (and others), there are many different anaglyph color combinations. A green-magenta pair, such as the one shown below, reduces the brightness mismatch.[23]

Magnification is sometimes used to adjust red accommodation. A dark amber-blue pair, such as the one shown below, is said to offer better color rendition.[24]



Colored and polarized filters cause reduced transmission of light to the eyes due to both the glasses and the filters used on the screen or in projection. In cinemas, where light levels are lower than those of TV screens even in unfiltered projection, the transmission reduction is sufficient to cause a noticeable color-desaturation effect. It has been mentioned in reviews that consider both 2D and 3D versions of the same 3D movies.[25]

One form of color-filter glasses is *not* referred to as anaglyph. It uses interference-filter technology to create something that might be considered an optical comb filter. Each eye gets red, green, and blue primary colors, but the color primaries for one eye do not match those for the other. Thus far, the system, glasses shown below, has been used only with projection displays.[26]

All of the previous 3D glasses – view-directive, polarized, and color-filtered – are electronically passive, and the anaglyph and polarized versions can be made very inexpensively. The last type, shuttering (eclipse) glasses, are electronically active.

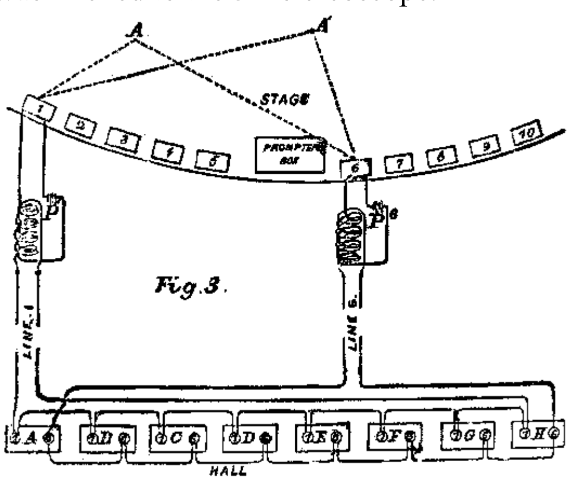
They alternately block the view of one eye and then the other in synchronization with the presentation of the alternating views on the display screen. They may be wired to the display or use a wireless (infra-red or radio-frequency) sync system. Wireless active glasses must use batteries for the shutters.

In consumer TV sets, shuttering depends not only on the flashing speed of the glasses but also on the refresh rate and optical characteristics of the display. A review of this year's first 3D TV sets shows differences in ghosting based on display technology.[27]

MICROSTEREOPSIS

Evolution of Stereo Sound

In 1881, at the International Electricity Congress, a demonstration of what we would today call stereo sound was conducted. Pairs of microphones at the lip of the Paris Opera stage, as shown below, fed pairs of telephone receivers in listening rooms. The process was then called "binauricular auduition," but it was likened to the 3D stereoscope.[28]



Crowds (among them author Victor Hugo) were impressed by the ability of stereo sound to provide localization of sound. There was a "Wow" factor.

Early stereo sound in the electronic era also used widely separated microphones and speakers. The result, sometimes called "ping-pong stereo" (when sounds were heard first coming from one speaker and then from the other), also provided an exciting, if unnatural, source-localization sensation.

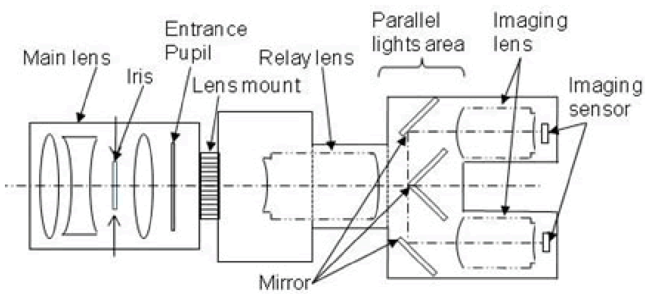
Now that stereo sound is common, it is often acquired through "single-source" techniques (more closely spaced microphones). They deliver less of a "Wow" factor but what is often considered a more natural sound. A tiny stereo microphone is shown below, larger than actual size.[29]

"Kinder Gentler Stereo"[30]

As noted previously, conflict between 3D vergence and accommodation can cause viewer discomfort, and a mismatch between separation during image acquisition and viewer vergence on the same material can change the perceived depth of the 3D sensation. Is there an alternative?

One proposal has been called "microstereopsis." [30] It is based on the principle that binocular human vision is extremely sensitive to stereoscopic disparity – under some conditions down to a fraction of one arcsecond (an arcsecond is 1/3600 of a degree of arc).[31]

A sensation of depth, therefore, can be conveyed with very little separation between left- and right-eye views. When displayed, the image is, furthermore, generally accepted by viewers without glasses as normal 2D.



One manufacturer showed a single-lens (but dual image sensors) 3D video camera based on microstereopsis (above) at the CEATEC show in Japan last October, and 3D pictures from it were demonstrated at the 2009 Consumer Electronics Show.[32] There have been other versions used (with single sets of image sensors) at least as early as the 1970s for television broadcasts.[33]

THE BUSINESS OF 3D TV

The Current Push for 3D TV

Consumers have used 3D technology at least since the publication of the invention of the stereoscope in 1838.[34] All of the view-control technologies mentioned previously (directive, polarized, colored, and shuttering) were developed and used for the display of 3D images before the end of the 19th century.[35] The origins of stereoscopic cinema also date back to the 19th century,[36] and those of stereoscopic television to 1928, almost the first television broadcast.[37] Why, then, does there seem to be a push only now for 3D TV?

A historical search would show that there has actually been development work on 3D TV almost continuously. A 1930 book discusses “several possible methods of accomplishing Stereoscopic Television.”[38] A 1938 RCA patent covered 3D TV.[39] Live 3D TV was demonstrated at a 1950 meeting of the Institute of Radio Engineers. *The New York Times* ran a story on April 22, 1980 headlined “3-D TV Thrives Outside the U.S.” about work in Australia, Italy, Japan, Mexico and at the ITU.[40] Below are images of 3D video cameras from 1989 (left) and 2001.[41]

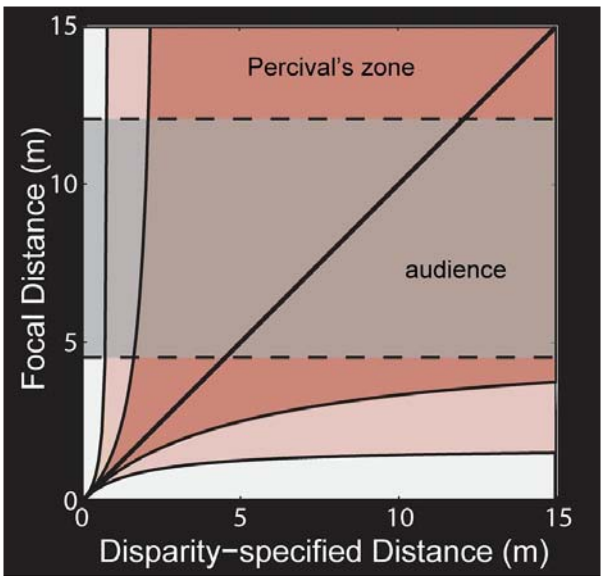
There *are* some new developments in the field, however, suggesting that the current era of 3D TV might be different from previous ones. The current highest grossing movie of all time, for example, is a 3D production.[42]

Solid-state imagers and memories allow tiny side-by-side 3D cameras and camcorders, as shown below.[43] Digital processing allows correction of optical distortions and other 3D shooting problems. Advances in display technology make inexpensive 3D TV sets possible, and the redundancy of the two views in stereoscopic imagery suggests low additional bit-rate for 3D signal distribution.

It is possible, therefore, that, from a technology standpoint, and, perhaps, even in terms of consumer desire, the time has finally come for 3D TV to achieve significant household penetration. As noted, however, the push by TV-set manufacturers is being driven by not those but a desire to overcome the poor sales in "a challenging market."[6]

Audience Issues

Although some of the current push for 3D TV might be based on the success of some 3D movies in cinemas, 3D in movie theaters is very different from 3D in the home. First, there is viewing distance.



As can be seen from the diagram above, a cinema audience falls within Percival's zone of comfort (dark area) for all conditions except vergence ("disparity-specified") distances extremely close to the viewer. A home audience falls outside the zone, however, at many vergence distances, especially at close viewing ranges ("focal distances").[12]

It's conceivable that, as viewers become accustomed to 3D imagery, their visual systems will tolerate greater vergence-accommodation conflict. Human perception has certainly been trained in other areas. Listeners to Edison's "tone tests" (beginning in 1915), for example, were reportedly unable to distinguish the sounds of phonograph recordings from those of live singers either in concert halls or at close range.[44]

There are many other differences between cinema and TV audiences. Glasses are provided for all 3D cinema viewers. Home viewers must obtain their own.

Inexpensive anaglyph glasses might be provided free to viewers by advertisers, but newer 3D TVs often use active shutter glasses. They allow the set manufacturer to offer 3D capability at low cost (needing just an emitter for the synchronizing signal), but they are an expensive addition for viewers, some currently priced at over $150 per pair.[45]

Even if consumers purchase a number sufficient for all members of a household, that doesn't cover guests, and – at the moment, at least – there is no guarantee that glasses that work on one TV will work on another, so guests can't even bring their own. Standards might eliminate that issue, but there is still one of battery life, currently on the order of *weekly* U.S. household TV-viewing time.[45]

There are also viewers with stereo-visual impairments. Some, for example those blind in one eye, might not perceive 3D effects but can enjoy one eye's view when wearing 3D glasses. Others, however, cannot seem to tolerate 3D images even when wearing 3D glasses.[46] Those viewers can usually self-select non-3D cinema auditoriums in which to view movies also available in 3D versions. At home, alone, such viewers should also be able to view 2D versions of 3D shows (assuming appropriate signal-distribution methods).

If the majority of a group opts to watch 3D, however, those 2D-only viewers cannot watch at all. An option might be 2D glasses, delivering the same view to both eyes.[47] In the case of active shutter glasses, however, such an option might reduce the image frequency to the point where flicker is visible (also a problem for viewers blind in one eye).

Some other differences of home viewing from cinema include multitasking, which might be difficult when wearing 3D glasses, channel-changing between 2D and 3D imagery, and closed captions. As noted, graphics obscuring 3D images must be placed in front of whatever is being obscured.

There might also be viewers who simply do not like 3D. According to a 2009 report, “Approximately 20% of the people who attended a 3D movie did not like it, citing eye fatigue, the eyeglasses and other issues,” and “About 5% of people are ’stereoblind’ and cannot see in relief.”[48]

Distribution Issues

Even within any given image format and frame rate, there are multiple mechanisms for distributing 3D. In the uncompressed domain, these include the side-by-side and over-under systems described previously (in both shrunken and anamorphic versions), field alternation between eye views, frame alternation between eye views, side-by-side with image rotation (in multiple forms), quincunx (alternating-square checkerboard patterns, e.g., left-eye on the red squares and right-eye on the black), dual feed, and left-eye view plus depth information (there is also a variant: left-eye view plus depth information plus graphics information).

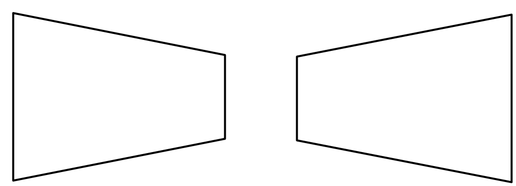
Each has advantages and disadvantages. The disadvantages can include reductions in spatial and temporal resolution. Despite what seems to be a confusing array of formats, however, relatively inexpensive converters are already available. HDMI Licensing has established a small number of mandatory 3D formats in HDMI 1.4a and allows others.[49]

In the compressed (bit-rate-reduced) domain (e.g, MPEG-2, MPEG-4 AVC, etc.), the tremendous redundancy between the left- and right-eye views would be expected to reduce the overhead of the second eye’s view well below 100%. Some test results seem to confirm that expectation. Others, however, do not.[50] Some work on finding optimum compression parameters might be required.

Production and Post Production

Post-production processing for 3D includes format conversion, convergence correction, view matching, and 2D-to-3D conversion. Remarkably, even the chromostereoscopic concept of reddish foregrounds and bluish backgrounds, alone, has been used with some success in automatic 2D-to-3D conversion.[51]

There is a debate among stereographers about the value of convergence during shooting. Still-picture 3D cameras typically have not used convergence so as to avoid the image distortion shown below. Digital image processing, however, can correct the problem.



exaggerated view of convergence-based image distortion of rectangular frames

Based on the reduced effects of both stereopsis and vergence angle with increased distance, 3D cameras (or dual-camera rigs) are often placed closer to scenes being shot than are conventional 2D cameras. Many involved in the acquisition of 3D TV imagery also note that 3D seems to require fewer cameras and less cutting between camera positions than does 2D. The need for even a different sound mix for 3D production has been discussed.[52]

Remarkably, the same was said of HDTV in its early days.[53] It might well be the case.

Unfortunately, as the history of HDTV sports and entertainment production shows, 3D-only television programming is unlikely after the experimental period ends. Whereas sports were once picked up in dual productions, one optimized for HD and the other for standard-definition (SD), today a single production serves both audiences with the faster cutting and greater number of cameras of SD production, and with consideration of its narrower screen as well. 3D productions will likely, similarly, have to serve 2D audiences.

Although sources vary, it appears that U.S. household penetration of HDTV sets only recently exceeded 50%, and, even within those households, not all TV sets are HDTV and not all HDTV sets are used to receive HDTV programming.[54] In 3D, not only is the technology much younger, but vision issues might also prevent some viewers from *ever* purchasing a 3D set. Content programmers will be faced with a largely 2D television audience for many years.

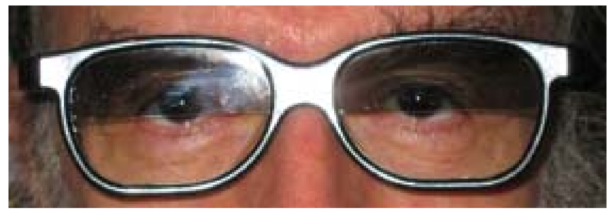
Advancing technology, however, might make possible the use of "virtual-camera" technology for 3D acquisition. Virtual cameras have been used for years. A number of physical cameras capture information about a space and everything within it. Processors can then create a virtual camera that can effectively "shoot" from any position within the space – even "moving" during a shot. The same technique can be applied to stereoscopic virtual cameras.[55] It can also be used to create the multiple views of a multiview autostereoscopic display.

The Little Things

Cameras, lenses, post-production equipment, distribution equipment, and displays might seem to cover all of 3D, but there is more. In addition to major 3D equipment, there are many minor elements required for the complete 3D chain.

Stereoscopic test and monitoring equipment is just becoming available. Stereoscopic viewfinders, due to their very close focal distances, can be difficult to use (and, due to the difficulty of implementing some stereoscopic display technologies, many 3D viewfinders use anaglyph glasses).

A cable manufacturer has just introduced 3D coax (color-coded bound coax pairs). A mobile production facility engineer found a need to create 3D half glasses (shown below) so that crews could look up at 3D displays but also down at dimly lit control surfaces.[56]



Should electronic program guides be in 3D? Should displays scale stereoscopic disparity according to screen size? Despite its 82-year history, 3D TV remains a young field, with discoveries still being made.

THE BOTTOM LINE

TV set manufacturers might make money from selling 3D TV sets. Glasses makers might make money from selling glasses. Movie producers, distributors, and exhibitors might make money from 3D, though even that is not guaranteed.[57]

As for the rest of the industry, although experiments generate both useful information and publicity, it's not yet clear whether 3D will increase revenue, slow a decrease in revenue, or simply cost money. And viewers exposed to multiple 3D technologies might get confused.

Some recent 3D events carried on cable systems have used anaglyph (in different color-pair formats), Pulfrich, and color-shifting glasses, all with images viewable on ordinary TV sets. Newer 3D events are being carried as side-by-side images intended to be converted to something else by special 3D

TVs. Glasses that work for one form of 3DTV won't necessarily work for another, yet even movie-theater glasses have been tried for such home television 3D material as the Michael Jackson tribute in this year's Grammy Awards broadcast.[58]

Gary Shapiro, president and CEO of the Consumer Electronics Association (CEA), addressed the current 3D TV situation in his column in the March/April edition of *Vision*, a CEA publication. "It is early and many challenges must be overcome. We must agree on standards so consumers can invest in glasses. We must understand that those with eye issues, monovision or susceptibility to motion sickness may not appreciate 3D. We need to qualify consumers and set their expectations to avoid 3DTV returns. We need to understand the benefits and any potential harm from 3D viewing."

Shapiro wrote, "3DTV will be a hit." He asked the industry, however, to "back away from irrational exuberance…." "Otherwise," he continued, "we risk launching a new feature that will not meet lofty expectations."[59]

REFERENCES

1. Haier HLC32B, http://bit.ly/aFDsve
2. Academy of Motion Picture Arts & Sciences, 2010 SciTech Awards, http://bit.ly/8EIVtH
3. Diagram from Thomas Edwards, FOX Network Engineering & Operations, "Approaches to Non-glasses-based 3D displays," presented at SMPTE 2009 Tech Conference, Hollywood
4. ITU-R Study Group 6 Report, 14 January, http://bit.ly/8ynsKJ
5. RabbitHoles, http://www.rabbitholes.com/
6. *Multichannel News,* January 7, 2010, http://bit.ly/7HAXHq
7. NHK integral television, http://bit.ly/cnFrno
8. v3 Depth Enhanced Imaging, http://www.inv3.com/index.html
9. American Paper Optics Pulfrich, http://bit.ly/cJ0uMr
10. American Paper Optics ChromaDepth, http://bit.ly/bwIsgP
11. A short video explaining and illustrating the Ames-room illusion may be found here: http://bit.ly/19JEA0; it might be worth noting that stereoscopic image capture is incompatible with this illusion.
12. Martin S. Banks, Vision Science Program, University of California - Berkeley, "User Issues in 3D TV & Cinema," presented at the 2010 HPA Tech Retreat, Rancho Mirage, California; much of the information is also available in David M. Hoffman, Ahna R. Girshick, Kurt Akeley, and Martin S. Banks, "Vergence-accommodation conflicts hinder visual performance and cause visual fatigue," *Journal of Vision,* vol. 8, no. 3, http://bit.ly/dAQWm7
13. Jeroen Stessen, Philips Consumer Lifestyle Advanced Technology Lab, Eindhoven, Netherlands, From "21:9 TV," presented at the 2010 HPA Tech Retreat, Rancho Mirage, California
14. Shojiro Nagata, "How to reinforce perception of depth in single two-dimensional pictures," *Pictorial communication in virtual and real environments,* Taylor & Francis, 1991
15. James E. Cutting & Peter M. Vishton, "Perceiving layout and knowing distance: The integration, relative potency and contextual use of different information about depth," *Perception of Space and Motion,* Academic Press, 1995, http://bit.ly/cCo3w9
16. Neil A. Dodgson, "Variation and extrema of human interpupillary distance," *Proc. SPIE,* 2004, vol. 5291, no. 36, http://bit.ly/brHuaH
17. Eugene M. Helveston, editor-in-chief, "Refractive and Refractive Accommodative Esotropia," *The Strabismus Minute,* vol. 2, no. 24, http://bit.ly/bXpBkZ
18. Vuzix Wrap 920, http://bit.ly/ioDRD
19. 1953 prism glasses image from James Butterfield; Prisma-Chrome glasses from Anachrome, http://bit.ly/8N8idR
20. LeaVision prismatic viewers from KMQ, http://bit.ly/ckeiKz; LeaVision mirrored prototype
21. Inition paper on polarization extinction and stereoscopic ghosting, http://bit.ly/8WWN5g
22. Andrew J. Woods & Tegan Rourke, "Ghosting in Anaglyphic Stereoscopic Images," http://bit.ly/atYYIE; Louis Ducos du Hauron applied the name "anaglyphe" to a color-based view-control stereoscopic system in 1893 (more in reference 35)
23. American Paper Optics TrioScopics, http://bit.ly/9VNHbD
24. Glasses shown are American Paper Optics ColorCode, http://bit.ly/dwfIH6; some versions of 3D Magic's SpaceSpex appear to be similar, http://bit.ly/aE3oBU
25. Review of *Up* by James Berardinelli, for example, http://bit.ly/gCNEG
26. Dolby 3D, http://bit.ly/2d4SXN
27. "Big Differences in 3D TVs," ConsumerReports.org, http://bit.ly/cOmi0J

28. "The Telephone at the Paris Opera," *Scientific American,* December 31, 1881, http://earlyradiohistory.us/1881opr.htm
29. Olympus ME-51S stereo microphone
30. Mel Siegel, Yoshikazu Tobinada, and Takeo Akiya, "Kinder Gentler Stereo," *Proc. SPIE Stereoscopic Displays and Virtual Reality Systems VI,* January 1999, http://bit.ly/cjxCqy, and Mel Siegel and Shojiro Nagata, "Just Enough Reality: Comfortable 3D Viewing via Microstereopsis," *IEEE Transactions on circuits and systems for video technology,* 2000, vol. 10, no 3, http://bit.ly/aPazme
31. Ian P. Howard and Brian J. Rogers, *Binocular Vision and Stereopsis*, Oxford University Press, 1995
32. Sony 240-fps single-lens stereoscopic camera demonstration, http://bit.ly/9kof6D
33. Jimmie D. Songer, Jr., U.S. patent 3,712,199, issued January 23, 1973, http://bit.ly/9pGpXF; a similar system, with horizontal-slit iris, was used by Digital Optical Technology Systems for television broadcasts in Europe and Australia and was exhibited at "The Future of Film Technology" in New York, Jan. 1980.
34. Charles Wheatstone, "Contributions to the Physiology of Vision. Part the First. On some remarkable, and hitherto unobserved, Phenomena of Binocular Vision," *Philosophical Transactions of the Royal Society,* vol. 128, 1838, http://bit.ly/d0hWDY
35. Franz Paul Liesegang, translated by Hermann Hecht, *Dates & Sources: a contribution to the history of the art of projection and to cinematography*, The Magic Lantern Society of Great Britain, 1986
36. H. Mark Gosser, *Selected Attempts at Stereoscopic Moving Pictures and Their Relationship to the Development of Motion Picture Technology, 1852-1903,* Arno Press, 1977, http://bit.ly/co1HRp
37. R.F. Tiltman, "How 'Stereoscopic' Television Is Shown," *Radio News,* Nov. 1928, http://bit.ly/dbSagH
38. Thomas W. Benson, *Fundamentals of Television*, Mancall Publishing, 1930
39. Vladimir K. Zworykin, U.S. patent 2,107,464, February 8, 1938, http://bit.ly/9CPr8B
40. *The New York Times*, http://www.nytimes.com/
41. Ikegami LK-33, http://bit.ly/apydTH, and Canon 3D lens for XL1 camcorder, http://bit.ly/a0IqNj
42. *Avatar,* http://bit.ly/4EeQSs; the 2nd highest grossing movie of all time is the same director's non-3D *Titanic,* however, and no other 3D movie has yet entered the top-10.
43. Lux Media Plan LP-1 stereoscopic camera with 2/3-inch-format imagers, shown at IBC 2009 with the author's forefinger in front
44. "The History of the Edison Disc Phonograph," Library of Congress, http://bit.ly/boiVuU
45. Pete Putman, ROAM Consulting, "3D in the Home: Trends and Products," presented at the 2010 HPA Tech Retreat, Rancho Mirage, California
46. Rafe Needleman, "TV industry turns blind eye to non-3D viewers," CNet News, January 15, http://bit.ly/6Patze
47. Mark Schubin, "2D (not 3D) Glasses," *Schubin Café,* Feb. 3, 2010, http://bit.ly/9Kxd2F
48. "Eyes wide open: 3D tipping points loom," PricewaterhouseCoopers, http://bit.ly/d2vHNI
49. The 3D portion of the HDMI 1.4a specification is available for free download here: http://bit.ly/cectlV.
50. Peter Symes, SMPTE, "3D in the Home: Standards for 3D," presented at the 2010 SportsTechLA, USC; video coverage of the presentation may be found under the title "3D and SMPTE" here: http://bit.ly/cRe4QK.
51. "CRC-CSDM: Colour-based Surrogate Depth Maps for real-time 2D to 3D conversion," IBC 2009, http://bit.ly/caarb0
52. "TV jumps on 3D bandwagon for live sport," *Variety*, March 25, 2010, http://bit.ly/cVS3N6
53. European Eureka Project, for example, [HDTV] "requires fewer cameras," http://bit.ly/bXybaE
54. Leichtman Research, *HDTV 2009: Consumer Awareness, Interest and Ownership,* November 30, 2009, http://bit.ly/6SblPN; at roughly the same time (late 2009), Leichtman put U.S. household HDTV penetration at 46%, Magid at 43%, the Consumer Electronics Association at 63%, and Opinion Research Corporation at 62%, http://bit.ly/dADhJB
55. Oliver Grau and Vinoba Vinayagamoorthy, "Stereoscopic 3D sports content without stereo rigs," BBC Research & Development White Paper 180, originally published in the *Proceedings of IBC 2009,* http://bit.ly/cIrJMk
56. Belden 1694D; 3D "bifocals" by Richie Wirth, Jr., engineer-in-charge of All-Mobile Video's Titan
57. Although the 3D movie *Avatar* is the highest grossing movie of all time, another 2009 3D movie, *Call of the Wild 3D*, which opened on June 12, grossed just $28,682 domestically through March 29 of this year, http://bit.ly/cImyvV
58. Deborah McAdams, "Grammys Get Big Numbers," *Television Broadcast*, Feb. 1, 2010, http://www.televisionbroadcast.com/article/94056
59. Gary Shapiro, "Is 3DTV Over-Hyped?" Shapiro's Spectrum on the Consumer Electronics Horizon, *Vision,* March/April 2010, http://bit.ly/cfhJQQ

AUTHOR

Multiple-Emmy-Award-winning SMPTE Fellow Mark Schubin is an independent technology consultant based in New York. He is the chief information server at http://SchubinCafe.com.