3D Television (3DTV) Technology, Systems, and Deployment

Rolling Out the Infrastructure for Next-Generation Entertainment

Daniel Minoli

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For Anna, Emma, Emile, Gabby, Gino, and Angela

Contents

Preface

Three-dimensional TV (3DTV) (also called 3D home theater) became commercially available in some markets in 2010, with an expectation for expanded penetration soon thereafter. Many vendor announcements and conferences are now dedicated to the topic. Numerous manufacturers showed 3D displays at the 2009 and 2010 Consumer Electronics Show in the United States, with new hardware expected in upcoming conferences. Many industry consortia now engage in advocacy for this technology. An increasing number of movies are being shot in 3D, and many directors such as James Cameron and Steven Spielberg embrace this upcoming trend.

This text offers an early view of the deployment and rollout of this technology to provide interested planners, researchers, and engineers with an overview of the topic. Stakeholders involved with the rollout of the infrastructure needed to support this service include video engineers, equipment manufacturers, standardization committees, broadcasters, satellite operators, Internet service providers, terrestrial telecommunications carriers, storage companies, content-development entities, design engineers, planners, college professors and students, and venture capitalists, to list a few.

This is the first practical, nonacademic book on the topic. Two other books have appeared on this topic in the recent past, but they are edited collections of fairly theoretical (signal processing, coding, etc.) and other advanced research topics. This book takes a pragmatic, practitioner's view; it is not intended for readers who need theoretical, highly mathematical, or signal-processing-oriented treatment and/or fundamental research. The focus of this text is how to actually deploy the technology. There is a significant quantity of published material in the form of papers, reports, and technical specs that form the basis for this presentation, but the information is presented here in a self-contained, organized, tutorial fashion.

Beyond the basic technological building blocks, 3DTV stakeholders need to consider a system-level view of what it will take to deploy a national infrastructure of 3DTV providers, where such providers are positioned to properly deliver a commercial-grade-quality bundle of multiple 3DTV content channels to premium-paying customers. Although there is a lot of academic interest in various subelements of the overall system, the paying public and the service providers are ultimately concerned with a system-level view of the delivery apparatus.

This text takes such a system-level view. Fundamental visual concepts supporting stereographic perception of 3DTV are reviewed. 3DTV technology and digital video principles are discussed. Elements of an end-to-end 3DTV system are covered. End-user devices are addressed. A press-time overview of the industry is provided by surveying a number of advocacy groups. Compression and transmission technologies are assessed, along with a number of technical details related to 3DTV. Standardization activities, critical to any sort of broad deployment, are identified.

The Author

Daniel Minoli has done extensive work in video engineering, design, and implementation. The results presented in this book are based on work done while at Bellcore/Telcordia, Stevens Institute of Technology, AT&T, and other engineering firms, starting in the early 1990s and continuing to the present. Some of his video work has been documented in his books, such as *IP Multicast with Applications to IPTV and Mobile DVB-H* (Wiley/IEEE Press, 2008), *Video Dialtone Technology: Digital Video over ADSL, HFC, FTTC, and ATM* (McGraw-Hill, 1995), *Distributed Multimedia through Broadband Communication Services* (co-authored; Artech House, 1994), *Digital Video* (four chapters) in *The Telecommunications Handbook* (edited by K. Terplan and P. Morreale, IEEE Press, 2000), and *Distance Learning: Technology and Applications* (Artech House, 1996).

Mr. Minoli has many years of technical, hands-on, and managerial experience in planning, designing, deploying, and operating IP/IPv6, telecom, wireless, and video networks, and data center systems and subsystems for global best-in-class carriers and financial companies. He has worked at financial firms such as AIG, Prudential Securities, and Capital One Financial, and at service provider firms such as Network Analysis Corporation, Bell Telephone Laboratories, ITT, Bell Communications Research (now Telcordia), AT&T, Leading Edge Networks, and SES Engineering, where he is director of terrestrial systems engineering (SES is the largest satellite services company in the world). At SES, in addition to other duties, Mr. Minoli has been responsible for the development and deployment of IPTV systems, terrestrial and mobile IP-based networking services, and IPv6 services over satellite links. He also played a founding role in the launching of two companies through the high-tech incubator Leading Edge Networks Inc., which he ran in the early 2000s: Global Wireless Services, a provider of secure broadband hotspot mobile Internet and hotspot VoIP services, and InfoPort Communications Group, an optical and gigabit Ethernet metropolitan carrier supporting data center/SAN/channel extension and cloud computing network access services. For several years he has been session, tutorial, and now overall technical program chair for the IEEE Enterprise Networking (ENTNET) conference; ENTNET focuses on enterprise networking requirements for financial firms and other corporate institutions.

Mr. Minoli has also written columns for *ComputerWorld*, *NetworkWorld*, and *Network Computing* (1985–2006). He has taught at New York University (Information Technology Institute), Rutgers University, and Stevens Institute of Technology (1984–2006). He was also a technology analyst at large for Gartner/DataPro (1985–2001); based on extensive hands-on work at financial firms and carriers, he tracked technologies and wrote CTO/CIO-level technical scans in the area of telephony and data systems, including topics on security, disaster recovery, network management, LANs, WANs (ATM and MPLS), wireless (LAN and public hotspot), VoIP, network design/economics, carrier networks (such as metro Ethernet and CWDM/DWDM), and e-commerce. Over the years he has advised venture capitalist firms regarding investments of $150 million in a dozen high-tech companies. He has acted as an expert witness in a successful $11 billion lawsuit regarding a VoIP-based wireless air-to-ground communication system, and has been involved as a technical expert in a number of patent infringement lawsuits (including two lawsuits on digital imaging).

1
Introduction

1.1 Overview

Just as high-definition (HD) content delivery is starting to see deployment around the world, broadcasters and bandwidth providers are being afforded the opportunity to generate new revenues with the delivery of next-generation HD entertainment with three-dimensional (3D) programming. 3D video can be visually dramatic for several genres of entertainment, including but not limited to movies and sporting events. According to recent industry surveys, a majority of people would want to watch 3D to enhance their viewing experience. 3D video has been around for over half a century in the cinematic context, and a number of 3D movies have been produced over the years; viewing of these movies has required the use of inexpensive colored or polarized "glasses." The industry is now looking to move beyond special effects in the theater and bring the technology into the mainstream of movie production and into the home. The goal of this industry is to be able to deliver 3D content over a television system and to use less obstructive (but perhaps more expensive) glasses to enhance the quality of the video experience, or eliminate the glasses altogether.

Three-dimensional TV (3DTV) (also called 3D home theater) became commercially available in a number of markets in 2010. The goal of the service is to replicate the experience achievable in 3D cinematic presentations in a more intimate home setting. A commercial 3DTV system is comprised of the following elements: capture of 3D moving scenes, scene encoding (representation), scene compression, scene transport (or media storage), and scene display. To achieve this, at least three elements are needed: (1) high-quality 3D (stereoscopic) content; (2) appropriate content delivery channels (media, satellite, or terrestrial based); and (3) high-quality home display systems. A number of manufacturers showcased a selection of 3D displays at the 2009 and 2010 Consumer Electronics Show in the United States, and newly developed hardware is expected to be introduced in upcoming trade shows. These products, including #D TV screens, 3D Blu-ray players, 3D projectors, 3D camcorders, and 3D cameras or some subset of them, may be in some consumer homes in 2010 or 2011. Vendors such as IBM, LG, Samsung, Panasonic, Sony, JVC, Mitsubishi, Vizio, Sharp and Philips are active in this space. Samsung and Mitsubishi were already shipping 3D-ready flat-panel TVs in 2008 based on digital light-processing technology from Texas Instruments.

The service was about to debut at press time. In January 2010, ESPN and Discovery Communications announced plans to launch the industry's first 3D television networks. The sports programmer was planning to introduce a 3D network in the summer of 2010, while Discovery is joining forces with Sony and IMAX for a 3D network to launch in 2011. The announcements were seen as representing a potentially game-changing addition to the TV landscape. ESPN states that its new channel—ESPN 3D—was expected to feature at least 85 live sporting events during its first year, starting in June 2010 with the first 2010 FIFA World Cup match South Africa vs. Mexico. Other 3D events were expected to include up to 25 World Cup matches, the 2011 BCS National Championship Game, college basketball and football, and the Summer X Games. "ESPN's commitment to 3D is a win for fans and our business partners. ESPN 3D marries great content with new technology to enhance the fan's viewing experience and puts ESPN at the forefront of the next big advance for TV viewing," stated ESPN representatives during the announcement. ESPN had been testing 3D for more than two years prior to this announcement [SZA201001]. The Master Golf Tournament 2010 was made available in 3D on ESPN, CBS, Cox, and the BBC. Verizon FiOS was planning to offer 3D programming by the end of 2010. BSkyB announced it was starting stereo 3D broadcasts in the United Kingdom in 2010, British Channel 4 was planning to offer a selection of 3D programming at the end of 2009, and other broadcasters and satellite operators are planning to do the same. Sony announced plan to release highlights from the 2010 World Cup on Blu-ray disc (BD); the Blu-ray release of *Titanic*, *Terminator*, and *Avatar* are also expected in 2010. The ability to use polarized or shutter glasses, rather than the traditional red and green glasses, is expected to represent a positive driver to the introduction of the technology in the home. However, the need to use an accessory at all may be somewhat of a hindrance for some; systems that do not require accessories are slightly behind in the development cycle compared with glasses-based systems. A subtending goal of the 3DTV rollout initiative is to provide quality two-dimensional (2D) performance to existing customers accessing but not exploiting the 3D content.

In recent years there has been high growth in the area of 3D cinema: In 2006, 330 3D screens were installed in the United States, in 2007 this number increased to 768, and in 2008 it doubled. By 2011 more than 4,300 3D screens are expected [3DM200901]. Worldwide, the number of 3D cinema screens was more than 1,300 at the end of 2007 and was predicted to grow to over 6,000 by 2009 [BAR200901]. The Consumer Electronics Association (CEA) estimates that about 2.2 million 3D TV sets will be sold in 2010, and that more than 25 percent of sets sold in 2013 will be 3D enabled. Early adopters in the United States make up about 5 million households that could adopt 3D TV within three years; after that, about 20 million additional homes could sign up for 3D "pretty quickly," before the technology then goes mass market in about five to ten years [SZA201001].

A number of Hollywood studios have announced major productions in 3D and an increasing number of movies are now being shot in 3D; *all* future Pixar movies are reportedly being shot in 3D and many directors (including James Cameron and Steven Spielberg) are reportedly embracing this trend [SOB200901]. Hollywood studios had several new 3D titles ready in the summer of 2010. The Blu-ray Disc Association (BDA) announced in late 2009 specifications for creating full 1080p 3D Blu-ray disc content, and the first 3D-enabled Blu-ray players made its debut at the Consumer Electronics Show in January 2010.

A joint 2008 consumer study of the CEA and the Entertainment and Technology Center at the University of Southern California concluded that 3D technology is now positioned "to become a major force in future in-home entertainment." According to the study, an estimated 41 million U.S. adults have seen a 3D movie in theaters in the past 12 months, and nearly 40 percent (of the consumers polled) said they would prefer to watch a movie in 3D than watching that same movie in 2D [TAR200901].

There is now a renewed industry interest in the 3DTV research primarily due to the advances in low-cost 3D display technologies. Propitiously, there is also interest in this topic by the standards-making organizations. The Moving Picture Experts Group (MPEG) of the International Organization for Standardization/International Electrotechnical Commission (ISO/IEC) is working on coding formats for 3D video and has already completed some of them. As far back as 2003, the 3D Consortium (3DC) with 70 partner organizations was formed in Japan and more recently, a number of new activities have been started, including the 3D@Home Consortium, the Society of Motion Picture and Television Engineers (SMPTE) 3D Home Entertainment Task Force, the Rapporteur Group on 3DTV of ITU-R Study Group 6, and the TM-3D-SM group of the Digital Video Broadcast Project (DVB). At face value, it would appear at press time that the European community is ahead of the rest of the world at the system-research/system-design level, while the Japanese/Korean manufacturers are taking the lead at the TV display-production level, and from a commercial service delivery the United States appears to be ahead.

Stereo means "having depth, or three dimensions"; stereo vision is the process whereby two eye views are combined in the brain to create the visual perception of a single three-dimensional image. There are two commercial-grade approaches to 3DTV: the use of *stereoscopic* TV displays, which requires special glasses to watch 3D movies, and the use of *autostereoscopic* TV displays, which show 3D images in such a manner that the user can enjoy the viewing experience without special accessories [ONU200701]. Short-term commercial 3DTV deployments, and the focus of this book, are on stereoscopic 3D (S3D) imaging and movie technology. (Autostereoscopic technology may be appropriate for mobile 3D phones and there are several initiatives to explore these applications and this 3D phone-display technology.) S3D (also known as stereoscopy or stereoscopic imagery) uses the characteristics of human binocular vision to create the illusion of depth, making objects appear to be in front of or behind the screen. The technique relies on presenting the right and left eyes with two slightly different images which the brain automatically blends into a single view. Subtle right–left dissimilarities in the images create the perception of depth and can be manipulated to creative advantage [AUT200801]. It should be noted up front that holographic* 3DTV with high-quality optical replica of artifacts, objects, and people appearing to float in space or standing on a tabletop-like display, where viewers are able to look or walk around the images to see them from different angles, is not within practical technical, content mastering, or commercial reach at this time for home TV reception, although there are proponents. Besides applications in cinema (and emerging TV usage), 3D viewing technology has been used for a number of years by players of video games by utilizing head-mounted displays that provide a fully immersive experience.

The basic technical challenges to provide a routinely available, commercial 3DTV service relate to the reliable/inexpensive capture, representation (encoding, compression), transmission, display, synchronization, and storage of elementary streams (ES) that comprise the content (ESs contain audio information, video information, or data—such as closed caption electronic program guides—that is formatted into a packetized stream).

The physiological reason for the human sense of depth has been understood for over 100 years. Based on that understanding, a number of techniques for recreating depth for the viewer of photographic or video content have been developed. Fundamentally the technique known as "stereoscopy" has been advanced, where two pictures or scenes are shot, one for each eye, and each eye is presented with its proper picture or scene, in one fashion or another. We note here that neither 3D stereoscopic viewing nor 3DTV is "brand new" per se: Stereoscopic 3D viewing techniques are almost as old as their 2D counterparts. Soon after the invention of movies in the 1900s, stereoscopic images were periodically shown at public theaters. The world's first stereoscopic motion picture and camera were made by William Friese-Green in 1893 [STA200801]. The means to achieve stereoscopic display has migrated over the years from anaglyth to polarization; anaglyth is a basic and inexpensive method of 3D transmission that relies on inexpensive colored glasses, but its drawback is the relatively

* The concept of a hologram is built on the pattern of light formed by interference between two crossing light rays: a "signal" (or "object") beam that restores information that was recorded inside photosensitive storage media, and a "reference" beam. The three-dimensional picture formed by this light configuration is called a hologram [HTH200701].

low quality. This technical progression eventually led to the routine display of 3D in theaters, where stereoscopic movies now are shown fairly regularly. In Europe and Japan anaglyphic TV broadcasts (for example, with two-channel, phase alternate line [PAL] demonstrations) were trialed in 1983, 1985, and 1987). To mention a few more recent initiatives, an experimental stereoscopic 3D-HDTV system was documented in 1999 by the NHK* Science & Technical Research Laboratories (NHK-STRL). Also, there was a Korean broadcasting experiment in 3D-HDTV with the broadcast of 2002 FIFA World Cup. In 2009 there was a satellite transmission in Europe of a live music performance that was captured, transmitted, and projected on prototype models of stereoscopic 3DTVs, and there was also a satellite transmission of a live opera performance from a French opera house to electronic cinema sites throughout France [BAT200901].

A considerable amount of research has taken place during the past 30-plus years on 3D graphics and imaging;† most of the research has focused on photographic techniques, computer graphics, 3D movies, and holography. More recently and with the advent of HDTV, research is starting to emerge on the use of HDTV techniques to deliver stereographic content directly to the home. With regard to actual commercial deployment of home 3DTV services at this time or in the near future, a key development has been the relatively recent introduction of HD services that provide a more realistic experience by increasing spatial resolution and widening the viewing angle. 3DTV focuses on a sensation of depth; psychological studies have been undertaken in the past couple of decades, validating that a wide screen is necessary to achieve adequate 3D experiences—hence the genesis of stereoscopic HDTV services, that is to say 3DTV as we know it today.

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* NHK stands for Nippon Hoso Kyokai, which translates to Japan Broadcasting Corporation.

† The field of imaging, including 3D imaging, relates more to the static or quasi-static capture/representation (encoding, compression)/transmission/display/storage of content)—for example, photographs, medical images, CAD/CAM drawings—especially for high-resolution applications. This topic is not covered here. The interested reader may consult, among other texts, D. Minoli, Imaging in Corporate Environments, Technology, and Communications, McGraw-Hill, 1994.

The two video views required for 3DTV can be compressed using standard video compression techniques in what is called a simulcast transmission approach to 3DTV. However, more effective compression is sought. Moving Picture Expert Group 2 (MPEG-2) encoding is widely used in digital TV applications today and H.264/MPEG-4 Advanced Video Coding (AVC) is expected to be the leading video technology standard for digital video in the near future. Extensions have been developed recently to H.264/MPEG-4 AVC and other related standards to support 3DTV; other standardization work is underway. The compression gains and quality of 3DTV will vary depending on the video coding standard used. While inter-view prediction will likely improve the compression efficiency compared to simulcasting (transmitting the two views), new approaches, such as asymmetric view coding, are necessary to reduce bandwidth requirements for 3DTV [CHR200601].

Clearly 3DTV will require more bandwidth of regular programming, perhaps even twice the bandwidth; some newer schemes such as "video+depth" may require only 25 percent more bandwidth compared to 2D, but these schemes are not the leading candidate technologies for actual deployment in the next two to three years. Techniques now being advanced involve side-by-side juxtaposition of left/right frames where the two images are reformatted and compressed (at the price of reduced resolution) to fit into a standard (HD) channel. If HDTV programming is broadcast at high quality—say, 12–15 Mbps using MPEG-4 encoding—3DTV will require 24–30 Mbps when the simulcast approach is used.* This data rate does not fit a standard over-the-air digital TV (DTV) channel of 19.2 Mbps, and will also be a challenge for non-fiber-to-the-home (non-FTTH) broadband Internet connections. However, one expects to see the emergence of bandwidth reduction techniques, as alluded to above. On the other hand, direct-to-home (DTH) satellite providers, terrestrial fiber-optic providers, and some cable TV firms should have adequate bandwidth to support the service. For example, the use of digital video broadcast, satellite second generation (DVB-S2) allows a transponder to carry 75

* Some HDTV content may be delivered at lower rates by same operators, say 8 Mbps; this rate, however, may not be adequate for sporting HDTV channels and may be marginal for 3D TV at 1080p/60Hz per eye.

Mbps of content with modulation using an 8-point constellation and twice that much with a 16-point constellation.* However, the tradeoff would be (if we use the raw HD bandwidth just described as a point of reference) that a DVB-S2 transponder that would otherwise carry 25 channels of standard definition video or six to eight channels of HD video would now only carry two to three 3DTV channels. For this reason, the simulcast approach is not being seriously considered at this time; the reduced resolution side-by-side approach is preferred in the short term.

Consumer electronics original equipment manufacturers (OEMs), content owners, service providers, retailers, and consumers are the stakeholders in this new 3DTV service deployment. As is the case with any new technology, industry economics and business models play a key role in the early stage of deployment. There are also many technical and design questions that need to be answered before widespread 3DTV deployment can take place; these are related to post-production 3D mastering, delivery options, and home TV screens. Mastering of images for 3DTV will likely require 1920x1080 pixel resolution at 60 frames per second and per eye. At this juncture neither the mastering technology nor the end-to-end transmission systems are standardized. Several manufactures are aiming at the 3DTV market, but each has advocated, so far, a different approach. As a minimum there has to be standardization for image formatting of the source materials; content can then be delivered by content distributors over a number of (or all) distribution channels: from physical media to terrestrial, satellite, cable, and other streaming services. A milestone was reached in 2009, in the view of some, when SMPTE defined the basic requirements for a stereoscopic 3D Home Master standard. In general, there is interest in developing a backwards-compatible and flexible broadcast 3DTV system.

Figure 1.1 depicts a basic 3DTV system. As can be inferred from the figure, an end-to-end upgrade of the current environment is

* The Digital Video Broadcasting Project (DVB) is an industry-led consortium of over 250 broadcasters, manufacturers, network operators, software developers, regulatory bodies, and others in over 35 countries committed to designing open technical standards for the global delivery of digital television and data services. Services using DVB standards are available on every continent with more than 500 million DVB receivers deployed.

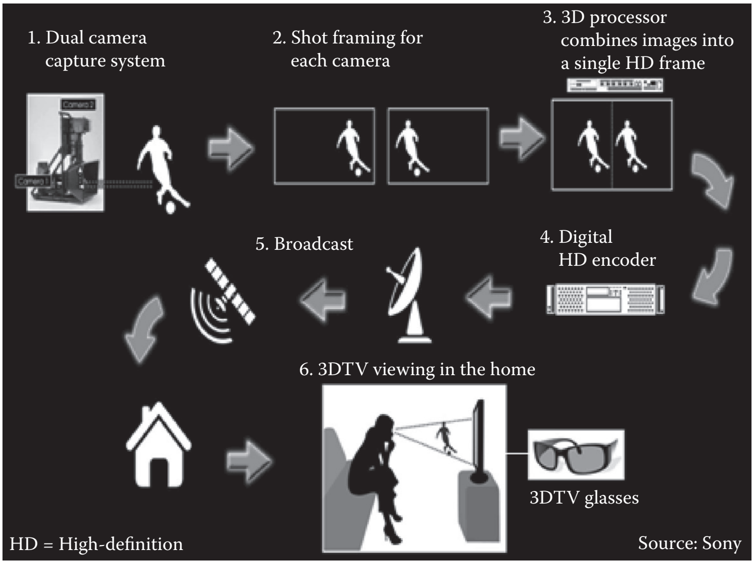

Figure 1.1 Basic 3DTV system.

needed in order to be able to support the 3DTV service. This includes image (content) capture, signal processing and encoding, transmission, and screen rendering. A 3DTV signal can be seen as a container that carries two content streams (two TV programs): one for the right eye and one for the left eye.* For full resolution acquisition where each stream is captured at 24 frames per second (fps), this clearly means that each second of content will have 48 frames. For 60p (progressive) HD acquisition, each signal will be captured at 60 fps, generating a combined stream of 120 fps. This type of stereogram allows images to be printed, projected, or viewed on a TV or computer screen to provide 3D perception; the two images are superimposed but are separated, such that each eye sees only the desired image. An early approach to 3D is via an anaglyth, namely, with the use of colored filters and viewing spectacles (commonly red and cyan, or red and green—to the naked eye, the encoded 3D image looks overlapping, doubled, and blurry); usually, the image for the left eye is printed in red ink and the right-eye image is printed in green ink [3DA201001]. Note that this early anaglyph technique produces an experience that is inferior to

* Another approach is to carry some data (say, 2D content for one eye) plus a channel of metadata to generate the 3D signal.

the cinematic 3D experience in a theater. Most of the current 3DTV displays for televisions (and cinema) require wearing either polarized or shuttered glasses. TV displays likely will need about $100 in new silicon to support 3DTV. Products offering autostereoscopic imaging without the need of special glasses are emerging; for example, a line of 3D televisions initially planned to be brought to market by Philips used very small lenses placed over the red, blue, and green pixel points that make up the television screen. The lenses cause each individual pixel to project light at one of a series of nine angles projecting from the display [ISS199901].

As noted, technical advances—or at the very least, system upgrades—are required along the entire chain of Figure 1.1. To illustrate this point, advances are being made for content capture; for example, Sony recently introduced a single-lens camera that is able to capture 3D images. The majority of existing 3D setups use two-camera systems to record images tailored specifically for the left and right eyes of the viewer. The new Sony camera takes a single image that is split by mirrors and recorded on two sensors, resulting in a "smoother" picture. With this program acquisition, viewers are able to watch the 3D images using special polarized glasses; without these glasses, they will just see normal 2D television. End-to-end interoperability, from content creation to the home user, is critical to the success of this nascent service. Furthermore, quality of the delivered video will depend upon appropriate quality support of each element in the chain: if any one link in the chain is deficient in some fashion, then the overall quality will suffer accordingly. In the short term, 3D content of choice may be available at home from a Blu-ray disc player or a PC file; in the longer term, the content will be available at the set-top box (STB), this being fed from a terrestrial cable TV system, a satellite DTH link, a broadband Internet connection, or, eventually, also from terrestrial over-the-air broadcasting.

To generate quality 3D content, the creator needs to control the *depth* and *parallax* of the scene, among other parameters. Depth perception is the ability to see in 3D to allow the viewer to judge the relative distances of objects; depth range is a term that applies to stereoscopic images created with cameras. Parallax is the apparent change in the position of an object when viewed from different points—namely, the visual differences in a scene when viewed from different points. A 3D display (screen) needs to generate some sort of parallax that, in turn, creates a stereoscopic sense. There are a number of ways to create 3D content, including (1) computer-generated imagery (CGI), (2) stereo cameras, and (3) 2D-to-3D conversions. CGI techniques are currently the most technically advanced, with well-developed methodologies and tools to create movies, games, and other graphical applications, and the majority of cinematic 3D content is comprised of animated movies created with CGI. Camera-based 3D is more challenging. A two-camera approach is the norm at this time; another approach is to use a 2D camera in conjunction with a depth-mapping system. With the two-camera approach, the two cameras are assembled with the same spatial separation to mimic how the eye may perceive a scene. The technical issues relate to focus/focal length, specifically keeping in mind that these have to be matched precisely to avoid differences in vertical and horizontal alignment and/or rotational differences (lens calibration and motion control must be added to the camera lenses). Conversion of 2D material is the least desirable but perhaps it is the approach that could generate the largest amount of content in the short term. Some note that it is "easy to create 3D content, but it is hard to create good 3D content" [CHI200901].

From a content-creation/editing perspective, first-iteration approaches of having "stuff fly into the face of the viewer" are now being replaced with early-stage "viewer in the scene" immersion content that might be classified as being closer to virtual reality (VR). Future developments may include the creation of rich, continuous, multi-individual virtual environments, interactive immersive animation environments, immersive VR,* telepresence, mixed reality (MR)/augmented reality (AR), and other synthetic sensory environments that as a group we call real virtuality (RV), but the commercialization of these advances may be a decade off or more.

However, the reader and/or viewer should not mistake (or compare) CGI-created "viewer in the scene" material, popular in cinematic 3D movies, with simple 3D perception: The former is very engaging, compelling, and intensive while the latter basically provides a more

* Telepresence refers to the process of interacting with a remote real world while immersive virtual reality refers to the process of interacting with a digital world [ALR200901].

natural and realistic view of the content. Seeing a soccer or golf game in 3D will not be as dramatic as a scene in the Avatar movie—other sporting events such as wrestling or boxing may perhaps provide a more vivid 3D experience if the cameras are right in the ring.

1.2 Background and Opportunities

There are ardent proponents of the technology and its commercial opportunity, while others take a more cautious view. This section provides an array of industry snapshots to give the reader a sense of where the service and technology stands.

The technology is being presented this way by proponents:

> [T]he next killer application for the home entertainment industry—3DTV … will drive new revenue opportunities for content creators and distributors by enabling 3D feature films and other programming to be played on their home television and computer displays—regardless of delivery channels. [SMP200901]

Others offer observations such as these:

> The recent popularity of 3D movies in North America has fueled the global 3D boom, and consortiums related to 3D including 3D@Home in North America, 3D4YOU in Europe, 3DFIC in Korea and C3D in China were established and commitment to lead the 3D industry started. [3DC200901]
>
> 3DTV augments the traditional TV technology by showing the viewer not only sequences of 2D images but streams of three-dimensional scene representations. To the viewer at home this will mean a completely new media experience. He will perceive the displayed events in a more immersive way, and he may even get the chance to choose his own viewpoint to watch the displayed events. In the future, 3D movies will become a standard and provide enhanced interactivity options, e.g., by allowing the user to navigate through the scenes. [3DT200701]
>
> Throughout [2009], moviegoers have shown an overwhelming preference for 3D when presented with the option to see a theatrical release in either 3D or 2D. We believe this demand for 3D content will carry over into the home now that we have, in Blu-ray Disc, a medium that

can deliver a quality Full HD 3D experience to the living room. … In 2009 we saw Blu-ray firmly establish itself as the most rapidly adopted packaged media format ever introduced. We think the broad and rapid acceptance Blu-ray disc already enjoys with consumers will be a factor in accelerating the uptake of 3D in the home. In the meantime, existing players and libraries can continue to be fully enjoyed as consumers consider extending into 3D home entertainment. [SHI200901]

The recent box office success of "Avatar," which recently passed $1 billion worldwide and is set to become the #2 movie of all time behind director James Cameron's own "Titanic," has helped prove the 3D format can draw a stunning number of viewers. [SZA201001]

As early as in the 1920s, John Logie Baird, one of the TV pioneers, dreamed of developing high-quality, three-dimensional (3D) color TV, as only such a system would provide the most natural viewing experience. Today, eighty years later, the first black-and-white television prototypes have evolved into high-definition digital color TV, but the hurdle of 3D still remains to be overtaken. New hope arises from recent advances in a number of key technologies, with the following developments being of particular importance: (a) the introduction and increasing propagation of digital TV in Europe, Asia and the United States; (b) the latest achievements in the area of single- and multiview autostereoscopic 3D display technologies; (c) the increased interest in the investigation of the human-factors requirements for high-quality 3DTV systems. [Author's note: Many of these issues are still valid.] [FEH200401]

3DTV is one of the "hottest" subjects today in broadcasting. The combination of the audience's "wow" factor and the potential to launch completely new services makes it an attractive subject for both consumer and professional. There have already been broadcasts of a conventional display-compatible system, and the first HDTV channel compatible broadcasts are scheduled to start in Europe in the Spring of 2010. [DVB201001]

Hollywood studios are eager to find new ways to gain revenues from an increasing number of 3D titles they are developing for the cinema. Engineers have explored ideas for 3D on television for years, and 3DTV demos have long been a staple of major exhibitions for consumer electronics giants. But the latest moves indicate big industry organizations may think the time is right to plough the road for tomorrow's mainstream products. [MER200801]

> Of all the new High Definition Multimedia Interface (HDMI) Version 1.4 features, 3D is getting the most interest from the broadcasters. … Everybody is lined up behind 3D, so it will be a big launch next year [2010]. [MER200901]
>
> 3D media is clearly the wave of the future! [ANA200901]
>
> 3D multimedia applications are receiving increasing attention from researchers in academia and in industry. This is in part due to new developments in display technologies, which are providing high quality immersive experiences for prices within the range of consumers. 3D video has become a strong candidate for the next upgrade to multimedia applications, following the introduction of HD video. [HEW200901]

But others offer observations such as these:

> 3DTV is coming to a living room near you. But will the technology spur a consumer spending spree like digital and high-definition TV did before it? Or will 3D end up being the next big flop? One thing is clear: TV manufacturers need something new to get people buying TVs. [REA200901]
>
> In a wide range of demos, companies will claim at the Consumer Electronics Show in January 2010 that stereoscopic 3D is ready for the home. In fact, engineers face plenty of work hammering out the standards and silicon for 3DTV products, most of which will ship for the holiday 2010 season. [MER200901]

At a recent (2009) CEA Industry Forum, the focus has been on consumer electronics retail trends (such as changes in channel dynamics), 3DTV technology, green technology, and social media. CEA takes the tentative position that:

> 3DTV technology is demonstrating clear success at movie theatres and will gradually evolve into other facets of consumers' viewing habits; 3D TV is similar to HDTV in that consumers are more likely to want it once they have truly experienced it. But the industry needs to have reasonable expectations for 3DTV. It is gaining momentum but may not hit critical mass for several years. [CEA200901]

The ITU noted recently that:

> It has proven somewhat difficult to create a 3D system that does not cause "eye fatigue" after a certain time. Most current-generation higher resolution systems also need special eyeglasses, which can be

> inconvenient. Apart from eye-fatigue, systems developed so far can also have limitations such as constrained viewing positions. Multiple viewpoint television systems are intended to alleviate this. Stereoscopic systems also allow only limited "production grammar." … One should not under-estimate the difficulty, or the imagination and creativity required, to create a near "ideal" 3DTV system that the public could enjoy in a relaxed way, and for a long period of time. [ITU200801]
>
> Creating a 3D television system that can be viewed in comfort poses great challenges. We can—and should—examine "stereoscopic systems" to see how well we can make them work, and how we can arrange compatibility with normal television channels. It may be possible to achieve compatible 3D television systems which can be watched comfortably for the length of a program. But at the same time, we need to continue the fundamental research into [holography] to make possible 3D television which really is equivalent to "being there." [DOS200801]

Practitioners also note that:

> The production pipeline for 2D television has developed into a mature and well-understood process over many years. Scenes are recorded with cameras from single-view points, captured image streams are post-processed, transferred to receivers, and displayed on planar screens. In contrast, the production process for 3D television requires a fundamental rethinking of the underlying technology. Scenes have to be recorded with multiple imaging devices that may be augmented with additional sensor technology to capture the three-dimensional nature of real scenes. In addition, the data format used in 3D television is a lot more complex. Rather than normal video streams, time-varying computational models of the recorded scenes are required that comprise of descriptions of the scenes' shape, motion, and multiview appearance. The reconstruction of these models from the multiview sensor data is one of the major challenges that we face today. Finally, the captured scene descriptions have to be shown to the viewer in three-dimensions which requires completely new display technology. [ROS200801]

When the 3DTV goal is stated as follows, it is clear that this is an unattainable milestone at least for the next decade or so. Something more pragmatic is in order, as described in this text, at least for the next two to five years, to mid-decade: