White Paper

Stereoscopic 3D Technologies

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Introduction

Given the visibility that everything 3D has had during recent months, it is hardly necessary to explain the motivation for a review of 3D TV technologies.

This document does not cover all classes of technologies available for the production and fruition of 3D content. Although a wider overview would be exciting from the point of view of the future developments and instructive with regards to the lessons taught by older solutions, the 3D arena is complex enough without trying to mix all kinds of technologies.

Instead, this report focuses mainly on stereoscopic 3D methods, mentioning other technologies to place them in context. The future trends will develop on the technologies available at this moment in time, so it seems sensible to concentrate on the short term. However, this review tries to highlight the dependencies and relationships between different options available for the deployment of 3D during its 'lifecycle', within the stereoscopic methods.

Although this report does not describe any particularly novel aspect of the technology, it strives to establish the dynamic interplay between the parts. In establishing such relationships between the different phases of the content lifecycle, the aim is to clarify and simplify the issues, by suggesting preferential or mutually exclusive avenues for each option at a given stage of the workflow.

3D Content Lifecycle

The figure below shows the meaning of 3D content 'lifecycle': the content starts its life when it is produced and along the way to being displayed using a 3D-ready device, it may receive a number of formatting changes.

The figure shows a number of possible options in which the 3D content may present itself at each different stage of its life.

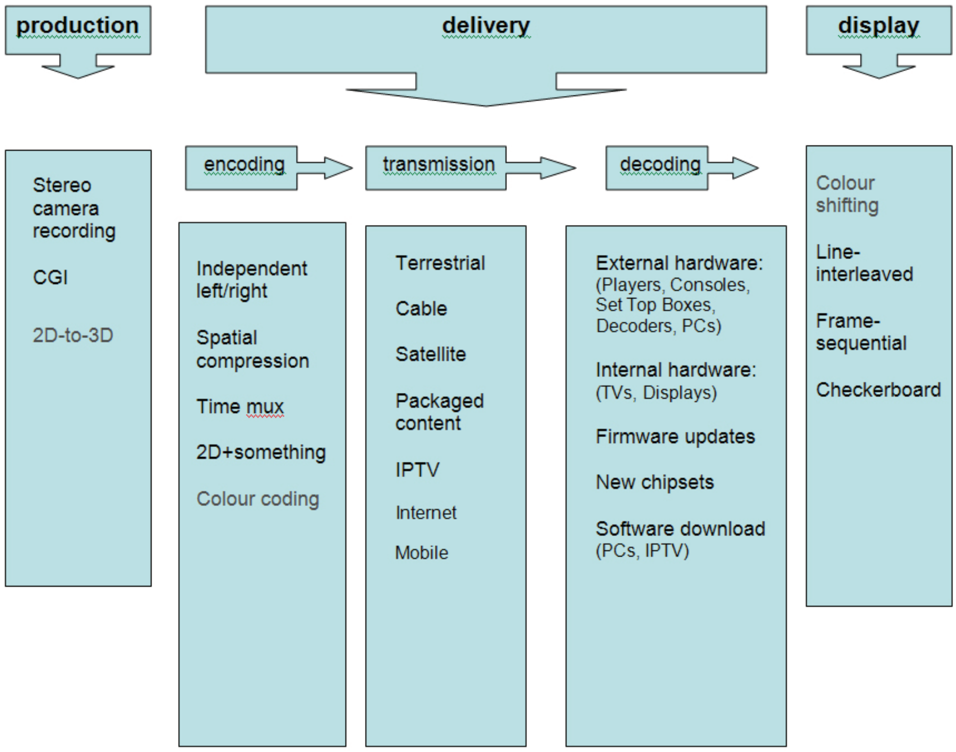

Fig. 1: Possible options for deployment of 3D content at each stage of its lifecycle.

In the following Sections, the aim is to show how one stage influences the next and that the various options do not exist independently, but require particular evaluations in terms of technological and/or business feasibility.

3D Content Production

There are three main approaches to creating 3-D content:

- live camera capture,
- computer generated imagery
- 2D to 3D conversion.

Here one needs to observe that live camera capture may be of a live event or off-line for the production of movies. The former events are obviously more problematic to produce. The conversion from 2D to 3D is of interest, but it is the case of a totally different scenario, which requires very sophisticated image processing.

Live camera capture: recording stereo sequences of images simultaneously.

Live events require the use of stereo cameras. In addition it is possible to obtain depth information using time-of-flight (TOF) cameras, or rangefinders or additional cameras at a set position. Depth maps can also be calculated on a pixel-by-pixel basis in real time or offline, with the data available from the two stereo cameras, or more realistically by using an additional pair of cameras at a greater inter-ocular distance. While all the techniques have their difficulties, the main point is that additional hardware and/ or processing are necessary to generate depth information and to integrate it with the conventional spatial imaging. Therefore at the moment the professional solution is the use of two customised HD cameras mounted on a rig or mirror rig and the most widely available output is an independent pair of co-timed images, giving the left and right view. The table below shows the four providers of professional 3D systems for live acquisition of 3D content.

Company	Camera type	Depth	Format
Pace	2 X Sony HDC-950 HD 2 X Sony HDC-1500 HD		HDCAM-SR HDCAM-SR
3ality digital	2 X Sony HDC-1500 HD	Yes	HDCAM-SR
Paradise FX	2 X SI-MINI 2K 2 X Red One		CineFom RAW RedCode RAW
P + S Technik	2 X - SI-MINI 2K - RED One - Sony HDW-750, -790, - Sony HDC X3000 - Sony PMW-EX3		CineFom RAW RedCode RAW HDCAM HDCAM XDCAM

Table 1: Professional systems for live 3D content acquisition.

From the information given in the respective companies' websites

[REF-PAC, REF-3AL, REF-PFX, REF-PST], it is assumed that all these systems allow the vertical alignment of the cameras to be adjusted, either electronically or by software, and have provision to change the inter-ocular distance, convergence of the cameras, depth of focus, and other parameters employed by stereographers to achieve their artistic ends. Only 3ality however specifically mentions a number of tools to produce integrated depth information. It is reasonable to assume that the process of content recording includes logging information about depth of objects of reference to allow post-production. However, the kind of dense depth information required to be integrated with the imagery for encoding purposes is an effort of a different scale. Therefore, the kind of output generated by live recording is more easily encoded in left and right independent views and frame compatible mode (see more about it in Section on Encoding).

Format	Bit depth	Resolution	Chroma sampling	Bit rate	File size	Interframe	Compression algorithm
XDCAM HD422	8 bit	1280x720, 1920×1080	4:2:2	50 Mb/s		yes	DCT
XDCAM EX	8 bit	1280x720, 1920×1080, 1440×1080	4:2:0	25-35 Mb/s	190MB/min 262MB/min	yes	DCT
HDCAM	8 bit	1440×1080	3:1:1	144Mb/s		no	DCT
HDCAM-SR	10 bit	1920×1080	4:2:2 4:4:4	440-880 Mb/s		no	DCT
Panavision SSR	10 bit	1920×1080	4:2:2 4:4:4	Up to 3 Gb/s		no	DCT
CineForm RAW(SI-2K)	10 bit	2048×1152	Raw bayer	100-140 Mb/s	900MB/min	no	uncompressed
REDCODE RAW	12 bit	Up to 4096×2304 or 4480×1920	Raw bayer	220-330 Mb/s	1680-2520 MB/min	no	Wavelet
DALSA RAW	16 bit	4096×2048	Raw bayer	~3Gb/s		no	Wavelet

Table 2: Common digital cinematography codec formats
(modified from Digital cinematography-Wikipedia [REF-WiDC])

In January 2010, Panasonic announced the launch of a professional 3D camcorder, whose specifications are given below (taken from Panasonic's own press release [REF-PAN3DCAM]).

Panasonic 3D camcorder specifications

- Product Name: Twin-lens Full HD 3D camcorder (made-to-order)
- Suggested Retail Price for Main Unit: $21,000
- Available: Fall 2010 (made to order)
- Power Consumption: Under 19 W (main unit only)
- Weight: Under 3 kg (main unit only)
- Recording Media: SDHC/SD Memory Card

Computer-generated images (CGIs): creating a stereo pair of views by simulating the presence of two cameras using a CAD program.

Computer-generated content is typically considered the easiest method of stereo generation. The rendering system can render one or more related views depending on the application [REF-WZID]. In this case, all the information about depth, occlusion and transparency is known and readily available in the form of a dense map that may be easily integrated with the digital imagery.

2D to 3D conversion: using monocular depth cues obtained from a 2D sequence to generate the equivalent 3D sequence.

This process requires the segmentation of the 2D image. For each object, it is necessary to calculate (by the use of 2D visual cues) and assign relative depth to each object. It is also necessary to locate occlusion areas and fill them with suitable portions of other objects. The conversion can be either real time or non-real time. Real-time conversion is particularly problematic as segmentation is currently an open field of research in the digital image processing area. This process may create depth and occlusion maps that are suitable for integration with imagery. However, as the depth is assigned to each object and not each pixel, the objects rendered with such technique may appear "flat" and therefore unrealistic. This technique is suitable if one wants to update 2D legacy content to 3D, not really for new content creation and it should not be considered as a form of up-sampling.

As part of the digital cinema workflow, a digital cinema package (DCP) is produced and should be formatted for direct use in cinema, using Dolby or RealD formats.

RealD employs a patented side-by-side format and in January 2010 there have been announced a number of partnerships to use RealD side-by-side proprietary format in 3D enabled TV. Manufacturers announcing collaborations include Sony, Samsung, Toshiba, Panasonic. RealD also produces a so-called 3D pod which transforms side-by-side into a line interleaved or checkerboard pattern. See more in the Section about Displays. Line interleaved is the native format for passive polarised displays, while checkerboard is the native format for DLP displays and has been used for Plasma displays by Samsung and Mitsubishi. Also checkerboard and DLP displays are the favourite combination for cost-effective 3D gaming [REF-AWID].

Encoding

One way to distribute the content is to deliver left and right views independently. However, this is not much of an encoding, quite wasteful in terms of bandwidth, packaging, and may be problematic to keep the two views correctly synchronized.

There are four methods for 3D content encoding:

- Spatial compression;
- Temporal interleaving;
- 2D+some form of metadata;
- Colour shifting.

Colour shifting, associated with the anaglyph technique, uses red/green or red/cyan or some other two colour pairing. It is compatible with 2D displays, offers full resolution and glasses are inexpensive, but it is mainly a legacy technology.

Spatial compression: This is useful when trying to deliver a 3D signal over the existing HD video infrastructure. It is also referred as 'frame compatible' as it squeezes the left and the right image into one HD frame. In order to do so it employs some kind of pixel sub-sampling, so the downside is the loss in resolution.

There are two aspects of this approach that need to be considered: the spatial sub-sampling and the frame packaging [REF-SMPTE-WP1].

The proposed spatial sub-sampling schemes are: taking alternate lines, taking alternate columns or sampling diagonally using a quincunx filter.

After the sampling the images are repackaged in side-by-side or over/under format. The quincunx sampling is used and repackaged for transmission because its format is not efficient for direct compression.

The quincunx signal can be used directly in HD interfaces that deal with the co-called checkerboard pattern and this is the signal format of choice for DLP displays.

Time multiplexing: This method presents sequentially left and right images as full resolution frames. Therefore it requires doubling the frame rate and therefore doubling the bandwidth required for a normal 2D HD signal. Compression can use prediction between left and right views, but this tends to be no better than the normal temporal prediction. So the main saving is the reduction of the number of I frames [REF-MW].

2D + something: The idea with this compression technique is to transmit a 2D signal and then some information that allows the reconstruction of a second 2D signal. This would be compatible with existing 2D displays, it may save bandwidth and it is included in MPEG. The most popular types of data suggested in order to supplement the 2D are [REF-TDV, REF-HHI, REF-ZCA]:

- a depth map (2D + depth);
- an optimized disparity map indicated as Delta (2D + D);
- a set of depth, occlusion and transparency maps (2D + DOT).

Other suggestions include supporting multiple view coding as a way to future-proof the encoding standards to the possible adoption of autostereoscopic and holographic displays [REF-HHI]
These are the options considered, however currently there are only two ways of delivering stereoscopic 3D to the home and these are:

Frame compatible: de facto many broadcasters and consumer manufacturers are opting for side-by-side frame packing [REF-RDSBS];

Enhanced Videostream Coding [REF-EVC] which is supported by an MPEG specification [REF-MPEG3D]:

2D+Depth, as specified by ISO/IEC 23002-3 (and also referred to as MPEG-C Part 3), supports the inclusion of depth for generation of an increased number of views. While it has the advantage of being backwards compatible with legacy devices and is agnostic of coding formats, it is only capable of rendering a limited depth range since it does not directly handle occlusions.

Multiview Video Coding (MVC), as specified by ISO/IEC 14496-10 and ITU-T Recommendation H.264, supports the direct coding of multiple views and exploits inter-camera redundancy to reduce the bit rate.

When considering the type of encoding, the deciding factors are [REF-WZDI]:

- The quality of the encoded image;
- The compatibility of the encoded 3D content with current 2D infrastructure and displays;
- The extensibility of the encoded 3D content to (future) multiview displays.

Side-by-side content is the format of choice for cinema packaging [REF-HHI] and it is straightforward to produce and to deliver using the current HD infrastructure. It has the disadvantage that the horizontal resolution of the picture is halved, and considering the final display format, other distortions may be added by the packing into native display format (line-interleaved, checkerboard). This format is also incompatible with 2D displays.

2D+something is probably the best choice for the future, since it is compatible with 2D displays and keeps the resolution of the images. However, as explained in the previous Section, depth information is problematic to extract, unless one uses the 2D+D (optimized difference) method, which features in the current 3D encoder by TDVision [REF-TDV]. At the moment however, the 2D+D is a wasteful format in terms of bandwidth (40 % - 80 % increase in bandwidth compared to a 2D signal, according to [REF-ZCA]).

Transmission

Let us say that a 3D video signal would require a bandwidth of 12Mb/s (this is about the constant bit-rate estimated to be necessary for a 1080p50 currently [REF-ZCA]).
There are a number of transmission platforms where 3D content may be deployed:

- Terrestrial broadcast;
- Cable;
- Satellite;
- Packaged material;
- IPTV;
- Internet download;
- Mobile TV.

Terrestrial broadcast is possibly the most restrictive: there is a limited bandwidth, 6MHz per channel in the US and Japan and 8MHz in Europe, strictly regulated from the point of view of standards, needs to be compatible with both 2D and 3D devices at home and to allow for legacy issues. DVB-T goes up to a little less than 32 Mb/s for a 8MHz channel.

Cable: This platform is relatively less restricted in terms of bandwidth; it is well regulated, but already has a business model that could be used for deployment of 3D, in terms of Video on Demand. So cable platforms could opt for 3D-only channels, with a set-top box to decode and present the material, and 2D compatible channels. DVB-C has channels of 2MHz, 4MHz, 6MHz, 8MHz and 10MHz going up to 64 Mb/s.

Satellite: Telecommunications satellites house between 24 and 32 transponders, with bandwidths between 27 and 50 MHz. Typically each satellite transponder has a bandwidth of 36 MHz. The business models to deliver 3D content are also similar. The difference is that the satellite platform is not restricted by external regulations. DVB-S2 goes up to a little less than 46 Mb/s.

Packaged material: This can be media such as Blu-ray or DVD. This medium may contain movies or games. It is expected that packaged media such as Blu-ray discs will be the main platform for 3D home entertainment. The Blu-ray disc format has large disc storage space (25/50 GB). The video decoding can support up to a 40-Mb/s data rate and the 1080p format.

The Blu-ray 3D specifications have been finalised in December 2009. The disc capacity and bit rates Blu-ray Disc provides enable us to deliver 3D in Full HD 1080p high definition resolution. The Blu-ray 3D specification also allows PS3 game consoles to play back Blu-ray 3D content in 3D. Additionally, the specification supports playback of 2D discs in forthcoming 3D players and can enable 2D playback of Blu-ray 3D discs on the large installed base of Blu-ray Disc existing players.

The Blu-ray 3D specification calls for encoding 3D video using the Multiview Video Coding (MVC) codec, an extension to the ITU-T H.264 Advanced Video Coding (AVC) codec currently supported by all Blu-ray Disc players. MPEG4-MVC compresses both left and right eye views with a typical 50 % overhead compared to equivalent 2D content, and can provide full 1080p resolution backward compatibility. Source: Blu-ray Disc Association [REF-BDA].

IPTV: IPTV is a service provided through a telecommunications infrastructure. IPTV covers both live TV as well as stored video (video on demand, or VOD). The playback of IPTV requires either a PC or a set-top box connected to a TV. Video content is typically compressed using either an MPEG-2 or an MPEG-4 codec and then sent in an MPEG transport stream delivered via IP multicast in the case of live TV or via IP unicast in the case of video on demand. IP multicast is a method in which information can be sent to multiple computers at the same time. The (MPEG-4) H.264 codec is increasingly used to replace the older MPEG-2 codec [REF-WiIPTV].

Internet download: Internet TV generally refers to streams sent over IP networks (normally the Internet) from outside the network that connects to the user's premises. An Internet TV provider has no control over the final delivery and so broadcasts on a "best effort" basis. Compared to IPTV, Internet TV is a quick-to-market and relatively low investment service and relies on existing infrastructure [REF-WiIPTV].

Mobile TV: Mobile TV and cell phones can also provide 3D content using single-view autostereoscopic screens. They use a different format from broadcast quality video. Bandwidths are currently very limited for video services [REF-WZDI].

As far as television is concerned, the most likely platforms for delivery of 3D content are satellite and cable, maybe a hybrid satellite/cable IPTV service (if they take off). Satellite and cable platforms have the advantage of having the available bandwidth to cope with 3D content. They do not have the need to worry about 2D compatibility, since they have the flexibility to dedicate channels only to 3D TV or to operate an on-demand service. As subscription services, their business model is already oriented to premium customers. Free-to-view services have the additional restriction of regulation, not least with regard to eye strain, which is a major issue for regulators.

Terrestrial broadcast has very limited bandwidth and especially free-to-view operators have the paramount need to ensure compatibility with 2D technology and content.

IPTV models have not established themselves and 3D mobile TV will use completely different technology and compression schemes, so these platforms are less interesting at the moment. The case of the Internet is curious because Internet download could be an easy way to update software and firmware or even content to be viewed somewhere else. Also if the content is to be seen on the computer screen, possibly the public will have lower expectations and it could be the medium to experiment with different solutions.

For 3D, the expectations of the consumers in terms of cinematic experience, availability of 3D content in Blu-ray and DVD packages and the availability of 3D games seem likely to drive the request for 3D compatible displays and then a willingness to view 3D television as well.

The expectation of the public in terms of quality experienced through DVD has driven the requirement for HDTV. Now, even though the transition from SD to HD has taken decades, by now enough of the public is familiar with the visual quality of HDTV, at least by the usage of packaged material. Once the step from SD to HD is made for this kind of audience, the transition to 3DTV may be considered the natural progression and a small incremental step to be embraced (provided the price is right, i.e. not much more than HDTV).

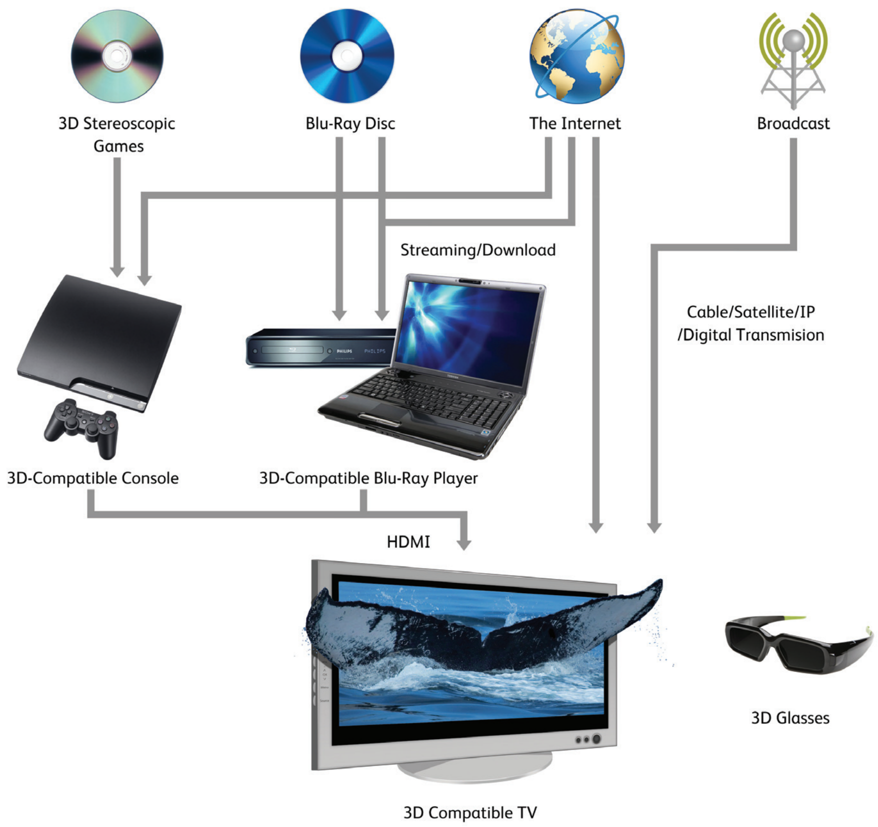

Figure 2: Possible platforms for delivery of 3D content and their possible interplay

Decoding

There are several options for decoding implementation and they depend on the encoding, the delivery platform chosen and the display of choice. The following is a list of options as presented by a transcoder manufacturer [REF-TDV]:

- External hardware (SetTop Boxes, Blu-ray players, DVD players,
- gaming consoles, decoders)
- Internal hardware (inside the TV or inside the Decoder)
- Firmware update to existing devices (Chipsets / STB / Decoders)
- New hardware (updated chipsets)
- Software update/download (PC, IPTV)

Whatever the combination of encoding/platform/display employed, one common feature of all these systems is the HDMI interface. The HDMI 1.4 specifications are available to adopters since May 2009. From Silicon Image press presentations HDMI 1.4 features an increased maximum resolution to 4K × 2K (3840×2160p at 24Hz/25Hz/30Hz and 4096×2160p at 24Hz, which is a resolution used in digital cinemas); an HDMI Ethernet Channel, which allows for a 100 Mb/s Ethernet connection between the two HDMI connected devices; and introduces 3D Over HDMI with support for several stereoscopic 3D formats including field alternate, frame alternate, frame packing (RealD side-by-side, checkerboard [REF-WiHDMI]), line alternate, side-by-side half, side-by-side full, 2D + depth, and 2D + depth + graphics + graphics depth, with top/bottom half and full formats to be added in January 2010. HDMI 1.4 requires that 3D displays support the frame packing 3D formats at either 720p50 and 1080p24 or 720p60 and 1080p24 [REF-HDMILC].

3D Display Technology

The technology used to simulate the depth presence in a scene influences the type of display used to provide the 3D content.
3D display technologies include:

- Anaglyph,
- Stereoscopy,
- Auto-stereoscopy,
- Holography,
- Volumetric displays.

Anaglyph technology has had great visibility in the past and in recent months, in the UK at least [REF-Ch4]. Interestingly, even in the 1950s anaglyph technology was the choice only for a small proportion of productions [REF-PSIET]. Therefore, this review does not discuss anaglyph, since it is unacceptable in terms of quality of the image and important only for quick demonstration and historical perspective.

Multiple-view displays and all the related technology are certainly exciting and most probably the ideal way to enjoy 3D content, once they translate their objectives into workable practice. However they are at the research and experimental stage at the moment and the current optimistic view is that some sort of glasses-free device will be available in the next 10 years [REF-ZCA]. This leaves stereoscopic displays to be the choice at present.

Stereoscopic displays require the viewer to wear 3D glasses, which can be passive polarised glasses or active shutter glasses. Therefore one could classify the technology as passive stereoscopic and active stereoscopic.

Passive stereoscopic displays or stereoscopic polarizing displays:
Such displays use different (linear or circular) light polarization to present the left and the right view to a viewer who wears passive polarized glasses: the left lens is polarized according to the polarization of the left view and vice-versa for the right lens and view.

The stereoscopic polarizing display employs an optical filter applied to the surface of an LCD display. The filter most commonly used today is Xpol, which is an extension of the micro-polarization filter µPol [REF-AWDI].

The polarization filter covers the display with alternate polarization horizontal lines, creating the 3D equivalent of an interlaced picture by assigning pixels for left and right eyes to alternate lines. This means that full HD (1920x1080) content is presented in half vertical resolution per eye. This is therefore also termed as 'Half HD' 3D TV.

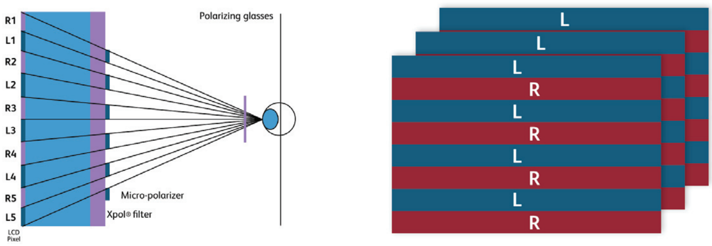

Fig. 3: Stereoscopic polarizing displays and line(row)-interleaved format.

Active stereoscopic displays or frame sequential displays:
Stereoscopic frame sequential displays use active (liquid-crystal) shutter glasses and a higher frame rate (120Hz is commonly proposed for this kind of display) display to present alternating images for the left and the right eye. A full HD image is displayed to each eye. This 3D method is also referred to as the time-sequential technique. The active glasses are synchronised to block the left and right eyes alternately as the right and left views are presented at a frame rate double that of the corresponding 2D signal.

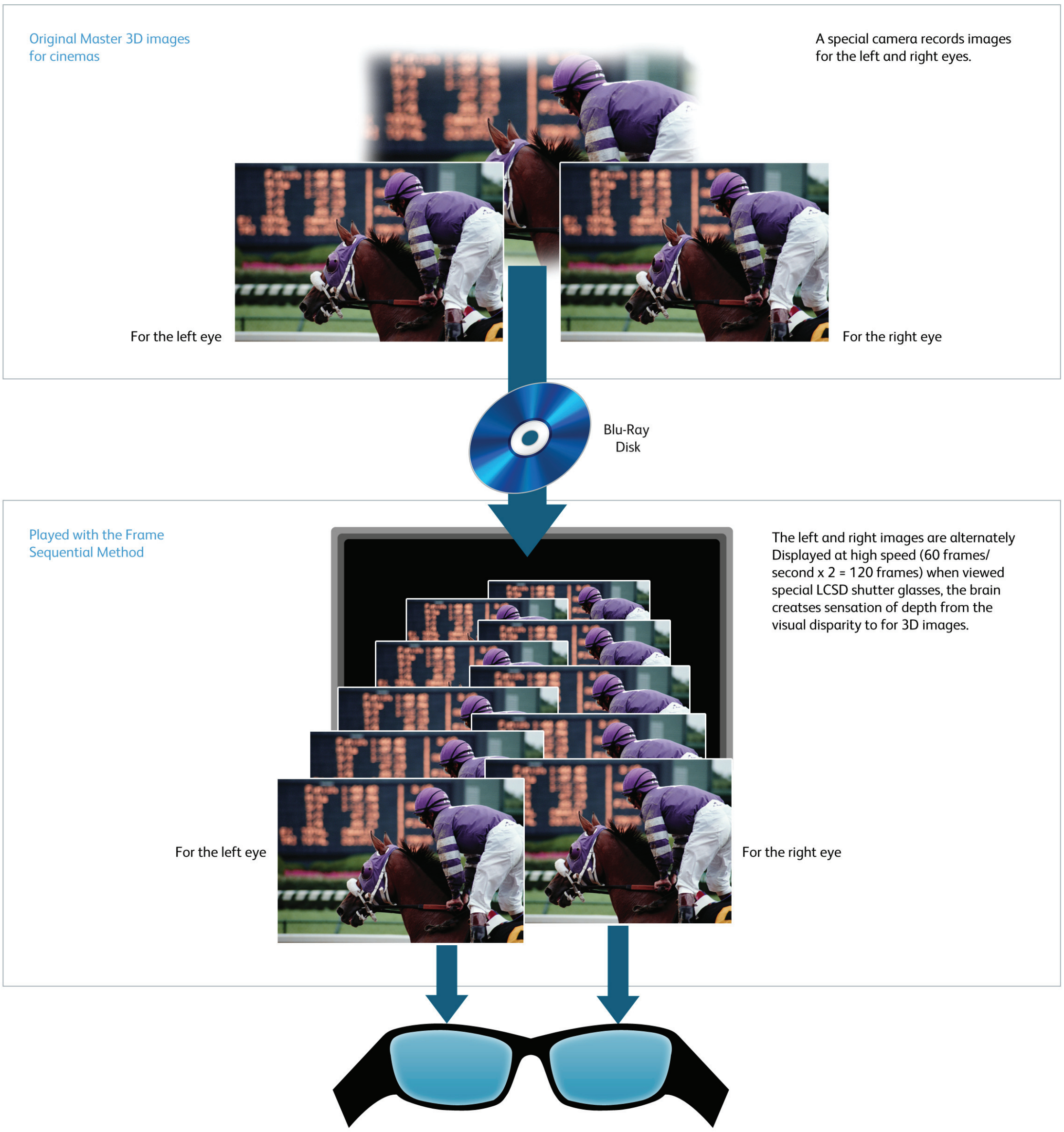

Fig 4: Frame sequential system to deliver Full HD 3D.

The time-sequential technique and active shutter glasses are also used with DLP displays, but in this case the left and right input signals are multiplexed into a single checkerboard pattern that occupies a single frame bandwidth, but with half resolution. DLP displays are a medium of choice for gamers in 3D. DLP technology is particularly suited to frame sequential methods since it has a fast switching time (up to 30 µsec [REF-TI])

There are actually only a handful of native 3D formats, which are linked to the display technology used; these formats are:

- Row-interleaved
- Full frame sequential
- Checkerboard.

These formats are linked to the display technology used as summarised in the table below. Row-interleaved is very practical for polarised displays as the filters to block the different views are physically arranged in alternate horizontal lines. Checkerboard is the required native input format for DLP displays (these displays also use a particular combination of techniques since the left and right views are combined in one frame by the checkerboard pattern, but then the left and right views are displayed in a time sequential way, using active glasses and a higher frame rate, 120Hz).

3D method	Glasses	Display type	Native format	Resolution	Pros	Cons
Polarized stereoscopic	Passive - polarized	LCD	Line-interleaved	Half HD – ½ Hor.	Inexpensive glasses	Expensive filter coating on display
Frame sequential stereoscopic	Active - shutter	LCD Plasma	Frame interleaved 120Hz	Full HD	Unmodified HD monitor can be used	Expensive glasses + need to recharge
Wobulated stereoscopic	Active - shutter	DLP	Checkerboard 120Hz	½ Hor ½ Vert.	Inexpensive displays, fast switching times	Additional set-top to mux signal into checkerboard

Table 3: Overview of relationships between stereoscopic techniques and stereoscopic display technical specifications.

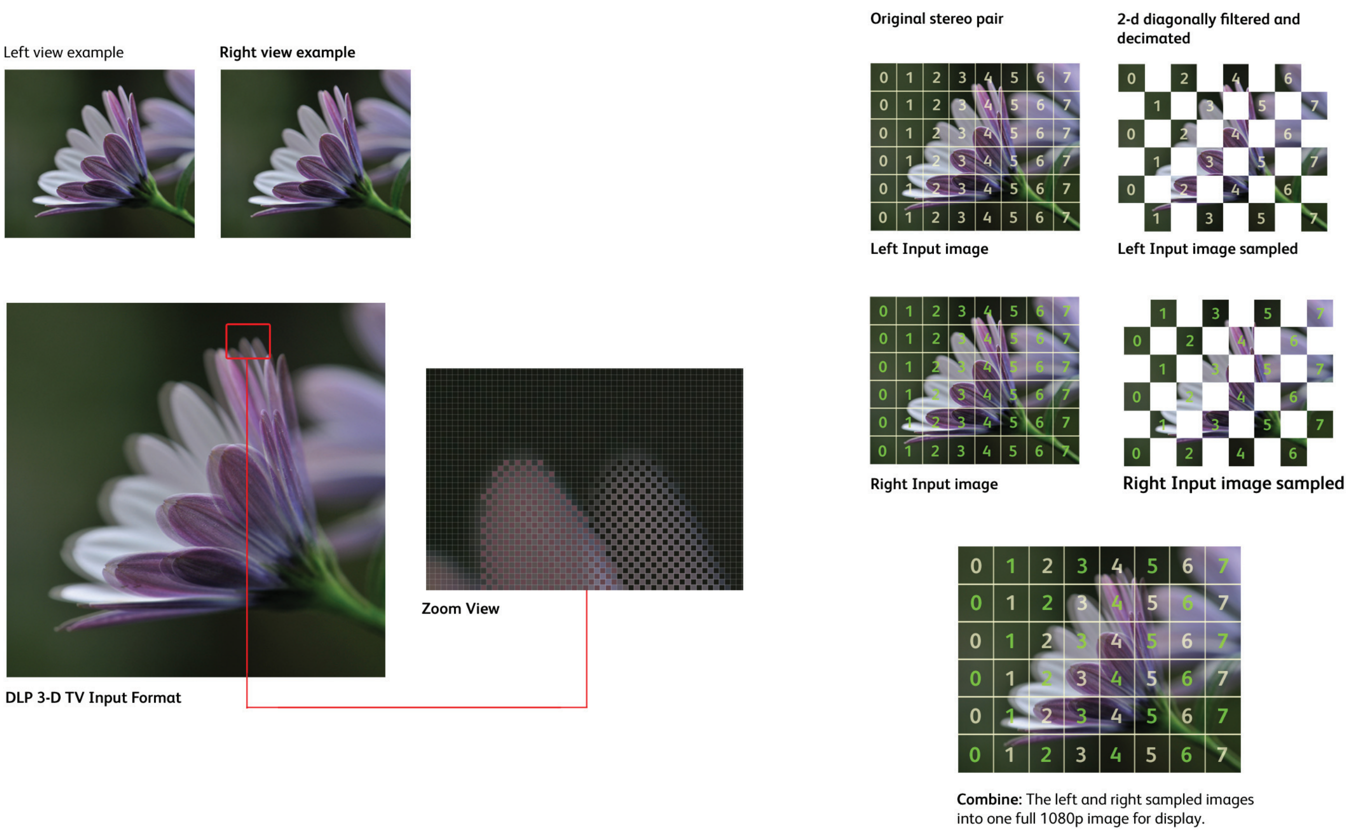

Fig. 5: DLP Checkerboard Input.

3D Plasma displays were originally introduced by Samsung and Mitsubishi and used a spatially sub-sampled input in the form of checkerboard, row-interleaved or column-interleaved [REF-AWDI]. However, the plasma display presented at CES by Panasonic is a full HD 3D display which uses a frame-sequential technique at 120Hz and this is probably the future trend for Plasma displays in 3D.

	Passive	Active	LCD	Plasma	DLP
Sony		X	X		
Panasonic		X		X	
Samsung		X	X	X	X
Toshiba		X	X		
Hyundai	X		X		
LG	X		X		
JVC	X		X		
Mitsubishi					X

Table 4: Consumer electronic manufacturers' choices of 3D technology.

	Passive	Manufacturer	Active	Manufacturer
LCD	X	Hyundai, JVC, LG	X	Sony, Toshiba, Samsung
Plasma			X	Panasonic, Samsung
DLP			X	Samsung, Mitsubishi

Table 5: Specialisation of manufacturers on any particular 3D technology.

Developing Trends

RealD: The RealD Format is a proprietary version of a side-by-side 3D format that uses a unique set of technologies to multiplex a left-eye and right-eye 3D image stream into a single channel. The RealD Format is capable of delivering high definition 3D content to any 3D-enabled display type using today's HD infrastructure across cable, satellite, packaged media and the internet (H.264, Windows Media and MPEG2 compatible).

RealD has announced agreements with Sony, JVC, Samsung, Toshiba and Panasonic and with DIRECTV, stereoscopic RealD Format into Sony's BRAVIA LCD high definition TVs and other upcoming consumer products, as well as with JVC for its LCD monitors, Samsung for its line-up of 3D TVs, Toshiba for its REGZA LCD TVs and Panasonic for the company's Full HD 3D VIERA TVs. These RealD-enabled 3D TVs will have out-of-the-box capability to display content delivered in the RealD Format utilizing today's HD infrastructure and existing HD set-top boxes from RealD partners including DIRECTV.

Sensio: Sensio has agreements to provide their proprietary side-by-side format to the display manufacturers Vizio and ViewSonic. SENSIO 3D is compatible with existing standard DVD and Blu-ray players as well as games consoles including Xbox and Playstation 3 and is the format of choice for the creation of high profile 3D gaming experiences.

BSkyB: BSkyB tested the 3D service across its existing infrastructure and claims it can be received by the current generation of Sky HD set-top boxes. BSkyB will use 3ality Digital's specialized "3flex" camera rigs and image processors to produce much of the 3D content it plans to broadcast. BSkyB will use a side-by-side format.

Side-by-side is key for Sky because it allows the broadcaster to use the existing Sky HD receivers.

PACE: PACE owns a 43-foot production truck and last year created a 53-foot unit, Supershooter 3D, in a joint venture with NEP.. ESPN has used PACE to provide 3D production technology for its new 3D channel that launches in June,

Other: In Korea, CJ HelloVision and HCN plan to start 3D broadcasting trials in the second half of the year 2010. Discovery Channel and ESPN have announced the launch of 3D services as well.

Encoding	Leadership	Consumer Manufacturer	Delivery Network
RealD	Digital Cinema	Sony, Panasonic, JVC, Samsung, Toshiba	DirecTV
Sensio	Gaming	Vizio, ViewSonic Hyundai	

Table 7: 3D formats may emerge as de facto standards.

Network	Content	Format	Other collaborations
BSkyB	3ality	Side-by-Side	
ESPN	PACE	Left and Right independent	NEP
Discovery Communication	Sony IMAX	RealD Side-by-Side	IMAX

Table 8: Activity among broadcasters to provide 3D TV.

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