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3D Production Guide

This guide will help producers as they plan to create programming for 3D television.

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3D Production Guide

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ONE: Introduction

This guide was written for you, the producers of 3D content for television. Its goal is to help prepare you as you plan for and create a 3D program.

This guide is not a tutorial on the art form of creating 3D images. There are several good books available on the art of stereography. This isn't one of them. This guide is not an equipment catalog. It doesn't contain long lists of cameras, rigs, recorders, lenses, and all of the other things that you will need in order to make a 3D program. The equipment available for producing 3D is constantly changing as the industry evolves. Any attempt to completely catalog all of the options would quickly become dated.

This guide is a tool to help you plan your production. In fact, more than half of the pages in this guide are spent covering the planning that producers need to do before the first frames of video are shot. Producing 3D programs is a complicated business that requires far more planning than producing programs in 2D. There are new crew members and responsibilities, new and complicated equipment, and new post processes to understand. A production's progress can be brought to a standstill at any point by an unwelcome surprise. This guide is intended to help you anticipate those surprises and avoid them.

This guide is broken up into eight sections. Section 1 is this introduction, which you've thankfully taken the time to read. Section 2 deals with all of the aspects of planning a 3D workflow from concept to delivering the masters. Section 3 briefly discusses 2D to 3D conversion and the network's policy and thoughts on that emerging technology. Section 4 talks about production and the tools specific to 3D production. Section 5 covers 3D displays. The display has a big impact on how a 3D production is perceived, and it's important that producers of 3D content understand that impact. Section 6 goes through the common 3D picture errors that cause viewer discomfort and eye fatigue. Section 7 talks about what's new in post production, and Section 8 discusses delivery of the masters. Finally, at the end of this guide is a short glossary. If you run across a term you're not familiar with you'll likely find it there.

We hope that you find this guide to be a useful tool as you plan your 3D production. Producing in a new medium can be intimidating. The transition between HD and 3D can be difficult, but many of our producers have found it to be worth the effort. We hope you will too.

While advance planning should always be a vital part of any professional production process the need to carefully plan well in advance becomes far more critical for 3D productions. When working in 3D there are many opportunities where careful advance planning can prevent costly errors. The common approach of "sorting it out in post" doesn't work in 3D. Many of the problems created by poor planning can't be fixed later in post-production. Proper advance planning will also provide increased efficiency and cost savings in every aspect of the workflow from acquisition to the final program output. In this section of the Guide we take a look at the different components of a typical 3D production workflow and identify some specific challenges that the production company will want to resolve in advance.

Preproduction

Format Planning

The format planning stage of Preproduction is where you have the opportunity to make several critical decisions. These decisions will define the rest of your workflow and will ultimately determine whether it is a smooth process or whether you will fight the consequences of these choices for the rest of the project.

The goal of Format Planning is to determine the HD standard and base frame rate of your project. Once you make that basic decision then you can make equipment and process decisions that support that choice without needing complex workarounds or leaving you with gaps in your workflow.

Frame rate, resolution, and interlaced versus progressive

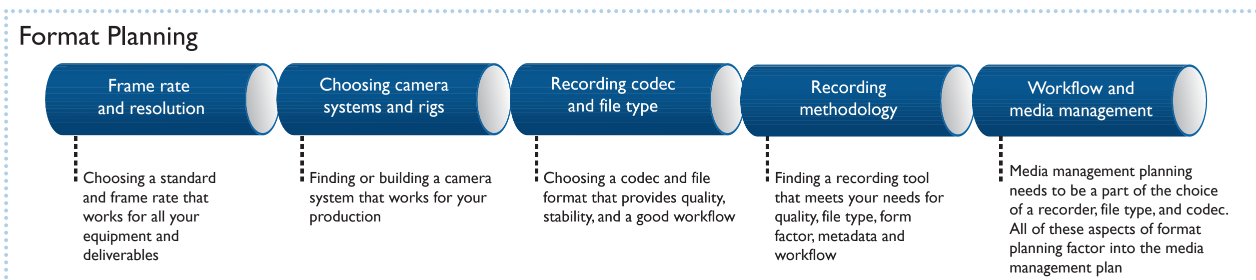
The first step in the planning process should be to determine the HD standard and frame rate that you will use for acquisition. While there may be creative or aesthetic reasons to prefer one frame rate over another it is important (especially in 3D) to understand what your final deliverable format is and the inherent challenges of format conversion for 3D production. (More detail on standards conversion in Section 7)

For example, if you are producing content which will air in the domestic US market that air format will be 1080i 59.94. In this case choosing an acquisition format of 1080p 25 is not your best choice. The conversion process from 1080p 25 to 1080i 59.94 is challenging at best and at worst could introduce disparate artifacts in the different eye views. (See Section 6 for viewer comfort issues) On the other hand choosing an acquisition format of 1080p 23.98 might be a reasonable choice. The 1080p 23.98 format would give you good options for conversion to the US broadcast standards as well as the 50 Hz standards used in many international markets. Before settling on any decision it is a good idea to shoot test footage in the formats under consideration. You can then perform the conversion to the final deliverable standard so you understand the effects of format conversion on the intended look and feel of the material.

Choosing camera systems and rig type

Now that you've determined the best HD format and frame rate it's time to move on to choosing acquisition systems. At this point in planning the workflow there are many decisions that will have a major impact on your choices. For the sake of clarity we'll address each of the major decision points separately.

For stereoscopic (3D) production each acquisition system will need two imaging devices (camera and lens) and a platform (rig) to support them as well as a method to



synchronously record images from the two cameras. There are many possible choices in 3D cameras and rigs. The equipment currently available runs a wide gamut in regards to complexity, size, weight, recording formats, and other features. Start by carefully considering all the possible shooting locations and conditions. Once you have a clear understanding of where you will be shooting and the types of conditions you will encounter you can begin to sort through what types of cameras and rigs will be best suited for each location.

In Section 4 of this Guide you will find a detailed description of the different types of 3D camera platforms (rigs) and examples of the strengths and weaknesses of each. It is imperative to understand the pros and cons of each type of rig prior to making a decision for your production. Frequently equipment decisions are made based on cost or on ease of setup. These considerations should not be the primary drivers. While it may be attractive to reduce costs by purchasing or renting the cheapest rig you can find these savings are easily lost many times over if the rig doesn't meet the needs of your production. Low cost or poorly designed rigs increase production costs through the time wasted trying to work around their inherent weaknesses.

For example, you may be on location and find out the rig is difficult or impossible to align. The rig design may require countless different tools to assemble or make even basic adjustments. You might even find that you simply can't configure the type of rig you're using for the required shot. A stereo rig that is the perfect solution for one scenario may well yield completely unacceptable results in another.

Here are some important points for consideration when selecting a stereo rig:

- Size and weight of the rig.
- Is the shooting scenario relatively static? (Stage or a set) or more dynamic, requiring quick setup and frequent movement?
- Will the rig easily support the size and weight of the intended cameras and lens systems?
- Ease of assembly and setup. (should require few tools, and all adjustable parts properly marked for repeatability)
- Level of support from manufacturer. (Are spares readily and quickly available?)
- Is the rig mechanically able to meet the requirements of the planned shots? (interaxial separation, convergence angle, etc)

There are also important elements to consider when selecting the cameras and lenses to mount on the rig.

First and foremost the cameras must support the format and frame rate that you decided on during the format planning step in your workflow development. At this stage in planning you will need to identify every camera that you may want or need to use for the project. Each of the different cameras should be capable of shooting in the same format and frame rate. If they are not, careful consideration must be given to how you will be able to mix the disparate formats in post, and what the effect will be on the overall look of the footage.

Next you will need to make sure the selected camera and lens package will fit properly on the intended rig. The camera and lens bodies must not interfere with the rig's full range of motion . In a proper fit all cables can be connected without forcing a hard bend or crimp in the cable or connector, and you have the required adjustment range in the camera mount to properly align the two cameras.

Improperly fitted cables on a rig

When choosing a lens system you will need to take in to consideration how you will properly synch the lenses to each other. It is imperative that iris, zoom, and focus are as perfectly matched between the lenses as possible. Even the best matched pair of lenses will have inherent differences that prevent a perfect match. There are a several lens control systems available from manufacturers such as Preston, C-Motion, Element Technica, and Fujinon. Most of these are able to provide a viable solution when paired with the appropriate imaging system (rig, camera, lens, recorder).

Recording codec and file type

As you begin to narrow down your choices on rig and camera systems it is time to consider how you will record. Perhaps your first step might be to determine what will provide the best possible image quality given the selected camera system. Once the image has passed through the camera's imaging block the next opportunity for significant image degradation is at the point of recording. Introducing compression artifacts at this point can have far-reaching consequences which are not typically reversible. At this point you will need to choose the codec and file type that you will use for image acquisition.

A codec is the compression\decompression algorithm used by the recording device to reduce the overall amount of data that needs to be captured and stored.

The file type is the carrier or wrapper format the codec is embedded within.

Some examples of common codecs are:

- AVC-Intra
- H.264/Mpeg4
- DnxHD
- CineForm

Examples of common file types are:

- MXF
- Quicktime (.MOV)
- Mpeg-2

At this stage of planning most of your decisions are interrelated and may have major impacts on the efficiency of your workflow throughout the rest of the project. Ideally you would want to use a codec and file type in acquisition that will be natively supported in your editing system and possibly the 3D sweetening and finishing systems as well. Using a natively supported codec eliminates the need for time-consuming and image-degrading transcodes. If circumstances do not allow for the acquisition format to be supported natively all the way through the workflow then every effort should be made to keep transcoding of the media assets to a minimum. Each successive transcode or format change will add or compound visual artifacts and degrade the quality of the images. While some level of image degradation is tolerable in 2D HD production, image degradation is much less tolerable in 3D as it will likely cause a disparity between the LE and RE images.

Recording methodology

The choice of format, camera, codec, and wrapper all play into the choice of a recording device. Again, there are a wide variety of solutions each with its own strengths and weaknesses. Here it becomes important to ensure the camera systems are perfectly synchronized to each other so the LE and RE cameras are capturing each frame at precisely the same instant in time. Some camera systems have an integrated recording system but in some cases the integrated recorder may not provide an acceptable level of image quality. Most professional cameras also provide a baseband video output (HD-SDI) that can be used to feed an outboard recording system. There are several third party recording systems that are widely used for 3D production. Some, like the Cinedeck , record in somewhat proprietary formats that may not be widely supported in editing systems or that may limit your options for manipulating the footage later in the workflow. Others, like the Convergent Design Nanoflash 3D, may provide a small and lightweight solution well suited for use on a handheld rig.

Ultimately the correct device for your production will be determined by careful consideration of the preferences in codec and wrapper balanced against weight and portability limitations.

And finally, you must consider the selected format and device's ability to capture or generate metadata during acquisition.

Once again, it is critical to systematically plan the entire workflow and to test each step to confirm compatibility before committing to a recording format and recording device.

Workflow and media management

The ultimate goal of the pre-production planning process is to tie the various steps in production and post-production into an efficient workflow while effectively managing the assets generated during production. An efficient and properly designed workflow will pay for the time spent in the planning stages many times over. A poorly considered workflow will just as surely leave you open to any number of unexpected problems and time-consuming workarounds.

A strong media management plan is the heart and soul of any good workflow process. In 3D production you will generate at least double the amount of media assets that a typical 2D production generates. If you are working in file based environment you will want to create backups of each asset, further adding to the amount of media In some cases there may be more than two instances of each asset as you create a field backup, copy to a production server, transcode for editing, copy to archive storage, and so on. These multiple instances can quickly become a burden to keep track of and manage if there is not a well thought out process in place to manage the media. A good process defines what needs to be done each time a file is copied, transcoded, archived, or duplicated. There are several existing systems and software applications which are designed to simplify asset management while providing data security and interoperability with typical editing and archiving tools.

The Cinedeck 3D

The Convergent Design Nanoflash 3D

Metadata Planning

Metadata is quite simply information (data) about other data (media assets). Metadata may provide details about image resolution, bit depth, lens settings, subject matter, or essentially anything else that might be useful to someone using the images at any point after acquisition. In general, rich metadata provides huge opportunities to expedite post production and adds value to the content when it is distributed and archived. The metadata generated for a media asset and how it can be used in archiving and production workflows is really only limited by the user's imagination.

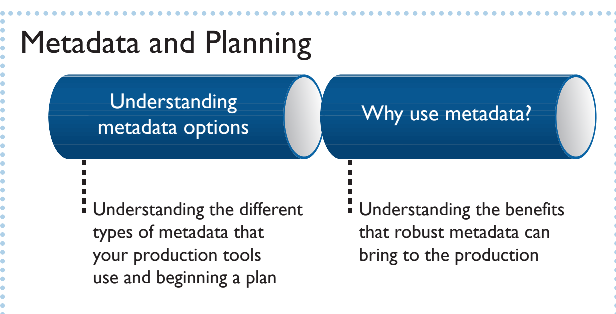
Understanding metadata options

Metadata acquisition can be broken into several different categories:

- Data that is "embedded" with the media (timecode for example)
- Data that is created completely separate from the acquisition system (handwritten notes etc.)
- Data that is created automatically by the acquisition system
- Data that is defined by the user and entered into the acquisition system to embed with the assets

With tape based acquisition systems the only production metadata embedded with an asset is timecode. Any other metadata is created in some external system and it becomes an exercise in media management to keep that metadata associated with the media assets. This type of metadata also has limited use in today's file based world.

File based acquisition brings the opportunity to generate rich metadata within the acquisition system and incorporate that data into the media asset files themselves or as a companion data file that is associated to the media by the metadata fields.



Automatically generated metadata can include most of the critical information about a media asset required for efficient processing and archiving of the asset. A few examples of this type of data are:

- Timecode
- Date
- Camera model and serial number
- Focal length
- Interaxial distance
- Convergence angle
- UMID (or other unique identifier)

User-generated metadata allows the production crew to embed information about the subject matter they record. This metadata can be used for any number of purposes: sorting footage into bins in an NLE, identifying shots the producer liked in the field, or simply identifying the producer and DP on the scene.
A few examples of user defined metadata are:

- Clip ID
- Location
- Camera ID (for multicamera shoots)
- Talent name(s)
- Producer

Metadata can also be "added" to a file based asset after shooting is done. There are existing tools available that provide an interface to edit or append metadata and save it with the original asset. One final thought you need to consider is how you will keep metadata synchronized between multiple instances of the same asset as you deal with backup or archived copies.

Why use metadata?

Many competent production crews frequently point out that they have always done "just fine" without rich metadata in the tape based environment. These crews wonder why they should bother to spend any time or effort acquiring and using rich metadata.

While it is certainly possible to produce quality content without using metadata in the workflow the efficient use of rich metadata presents an opportunity for dramatic time savings and cost reduction. Today's file based acquisition systems make metadata use practical and easily accomplished. In 3D production metadata can become even more critical. Metadata can help the production team identify and correct issues that may not occur in 2D production. These issues might relate to proper camera parity or to understanding what the interaxial distance or convergence angle were for a specific scene. One might say that you could live without electricity or running water too - but is that a good reason to do so?

A Metastory

We didn't start out as believers in metadata. In our first file based production it started as an afterthought. We tried to use some basic camera metadata on the set but soon found ourselves falling back into our old tape based "metadata" system: The AP and her spiral notebook. That first file based production shot dozens of hours of footage on the first shoot. We had three cameras on a four day shoot, and that makes a lot of files to go through. We had set aside a week for our E2 to log and bin all the footage. Unfortunately we misplaced our spiral notebook with all of the log information from the shoot. At the end of the E2's week of logging the editor came in and spent another three days with the producer reorganizing the footage in a fashion that made sense to her.

We knew there had to be a better way. We started by having a group discussion about metadata. The editor, E2, and AP determined in advance how the assets should be organized and sorted to bins. We tested to make sure that clip metadata we added in the field survived the import into our nonlinear editing system. The production team then met to discuss how we would acquire metadata in the field. Our strategy depended on the camera operators remembering to switch metadata profiles when they switched scenes, so we set up a practice day for our production team.

Our next shoot went well. The AP put down her spiral notebook and stayed on top of the whole production team, making sure they kept to the metadata plan. It was amazing how much of a difference it made when we returned from the shoot and started logging and importing footage. Our editing system was able to sort media into bins based on specific metadata fields. Because we had tagged all of our clips with metadata about the scene and the characters we were able to import and organize three days of shoot footage in four hours. The time we saved allowed us to spend more time in the offline edit honing our story.

Operator Training

While familiarity with equipment and process is important in any production like everything else it becomes even more so in 3D. There are a number of new roles in 3D production as well as some unique equipment and adjustments that can make or break your production. Producers need to make sure that they allocate a significant block of time to training for the entire production team.

Communication of the metadata plan

The best place to begin your training is with a clear communication and review of the metadata plan. If carried out properly the metadata plan will help everyone throughout the production process and beyond. Producers should walk everyone through the entire data management plan, and not just on paper. The production team should actually go through the steps of moving media from one device or storage medium to another. The team should import assets into the editing systems for offline and finishing, making sure that metadata carries into these systems as planned, and that the formats chosen will work as you intended. Essentially you need to validate every part of the workflow in advance, taking nothing for granted. Along the way make sure each operator understands what their role is, where metadata needs to be generated, and how it will be protected during file transfers or duplication. This is the opportunity to find gaps or flaws in the initial plan and to determine how to resolve issues so they don't crop up unexpectedly and derail your production. This may also be a time where you find other ways to use metadata to help improve the efficiency of your workflow.

Role of the stereographer

As mentioned previously, 3D production introduces several new roles that are not present in 2D production. Probably the most notable and important of these roles is the stereographer.

The primary role of the stereographer is to supervise all aspects of 3D. They manage the quality of the 3D process in pre-production, production, and post production. In some instances the stereographer will act as supervisor to the 3D production camera crew. In other situations the stereographer will be part of the general camera crew.

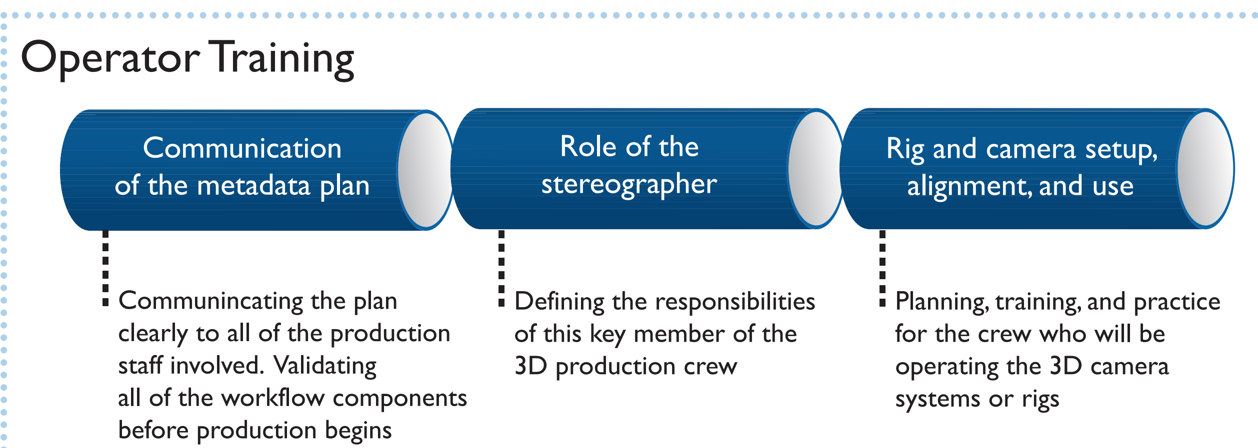
Stereographers must have a strong understanding of all the principles of creating high-quality 3D from both a technical and an aesthetic perspective. One of the key responsibilities of the stereographer is to diagnose problems as they arise and make expert judgment calls as to whether to fix the problem in production or post production. It is also the responsibility of the stereographer to have a firm understanding of the latitude offered to the post production team when certain 3D decisions are made on-set. Expertise with the various tools and techniques for creating and producing 3D is critical. The stereographer must also understand all the issues related to shooting stereo on-set and how those images will translate to the screen of whatever scale is appropriate for the final display of the content.

Stereographer has become a coveted title in 3D production and many unqualified individuals use the title to gain entry into the field. No program currently exists to certify stereographers so a little common sense, caution, and review of previous work is well-advised before hiring the services of anyone in this position.

Rig and camera setup, alignment, and use

Proper rig setup and alignment is more critical to the success of 3D shooting than choice of equipment, crew, stereographer, post system, or even the technical shoot itself. The greatest misconception about 3D shooting is that if something is misaligned or setup incorrectly it can easily be fixed in post. Although certain types of errors can indeed be corrected with the proper post tools most stereo acquisition errors will be extremely time consuming and costly to correct. Some errors are impossible to fix in post.

Before ever going out to shoot the first frames the proper amount of time must be allocated for the production crew to learn how to properly build up, align, and operate the 3D rig. The time required for this will vary depending on the complexity and design of the camera systems chosen for each project. A 3D rig is a complex piece of equipment, as is the process for properly adjusting the rig to capture 3D images that will be comfortable for the end viewer. There is no substitute for advance planning and practice with the selected equipment. Section 4 of this Guide will address some of the more common challenges encountered in rig setup and alignment.



Stereo Planning

Stereo Planning is yet another new process unique to 3D productions. Each project team should decide how 3D will help tell the story. Sometimes capturing a sense of realism, a "you are there" look, is enough. But in most instances, the creative team needs to give some further thought and discussion to ensure the best use of 3D for each specific scene. Stereo planning also plays into many of the points discussed earlier in this section. Productions often choose camera systems before determining how the stereography will help in telling the story. It is best to decide on how a project will use 3D to enhance the storytelling BEFORE choosing the specific camera gear (e.g. capturing a sense of realism, use of stylized look to affect scale, environments where the shoot will take place). These decisions will help the production to choose the 3D camera systems that can best realize the creative vision of the project.

Depth budgets

Creating a depth budget is a similar process to building a storyboard for a program prior to beginning production. Planning a depth budget will likely be most effective if it is done hand in hand with the storyboard or shot planning process. The storyboard shows how shots will be composed and framed. The depth budget identifies how depth will be used in each scene, and how the acquisition tools will be configured to capture that depth. The purpose is to be able to have a smooth flow in the use of depth from one scene to the next. This will help prevent jarring jumps in depth during scene cuts. Rapid jumps in perceived depth are not something that occurs in our natural vision. They can be quite disturbing for some viewers and quickly contribute to eye fatigue and discomfort.

Identifying stereo challenges

As you work through the stereo planning and depth budgeting it is likely that you will come across some situations that present challenges to correctly capturing images in 3D. This could be due to a limitation of the equipment you've selected. For example, a side-by-side (SbS) rig or an integrated camera system's minimum interaxial distance may cause excessive divergence in background objects if used in a close-up interview setting. Challenges like this might dictate that the production will need to use additional camera systems. Other challenges might include working in small spaces, or in extreme low light environments. The goal in this stage of pre-planning is to try to identify the scenarios which will present unique challenges and then determine solutions to overcome them. Anticipating these challenges in the planning stages can prevent you from finding yourself out in the field without the correct tools to capture proper 3D images.

Integrating 2D Materials

It's common to have situations that require the use of a 2D shot or shots in a 3D project. If handled properly using the appropriate techniques there should be few problems with integrating 2D and 3D elements into the program. There are a range of situations that might require using a 2D shot. These could include archival footage use, unsteady handheld shots, or even a shot originally captured using a 3D camera system that has stereo errors the editor cannot correct in post.

Rather than eliminate these shots from the content entirely it is possible to integrate them into the context of the program in 2D. The simplest and often the most effective way to integrate a 2D shot into a 3D project is to put the 2D shot into both the left eye and the right eye. The resulting 2D image will appear at the screen plane when displayed. By adding some convergence to the 2D shot, the shot can be pushed back into positive parallax. The amount of convergence should be determined by the preceding and subsequent shots. By setting the convergence so the 2D image appears at the same depth as the subject of interest in the previous 3D shot the viewer will perceive this as a 3D image. By adjusting the convergence towards the end of the 2D shot to match the incoming 3D shot, the transition between 2D and 3D will be comfortable to the viewer.

Production

Acquisition

Good 3D camera practices require a thorough understanding of the basics of stereography.

This includes an understanding of negative and positive parallax and their effect on the 3D image when properly displayed. The producer's objective should be to avoid creating images that cause discomfort in any way while creating visually pleasing depth within the photography.

Good Camera Practices

The most critical stage of a 3D production is the point of acquisition. Mistakes made here may not be correctable at a later stage. Those mistakes may permanently reduce the quality and comfort of the viewer experience.
At this stage it is imperative to have an experienced stereographer on set who is well versed in stereo image capture. Decisions will be made at this point in regard to focal length, interaxial separation, and convergence angles. The stereographer needs to carefully consider all of these settings to ensure viewer comfort and proper depth continuity between scenes.

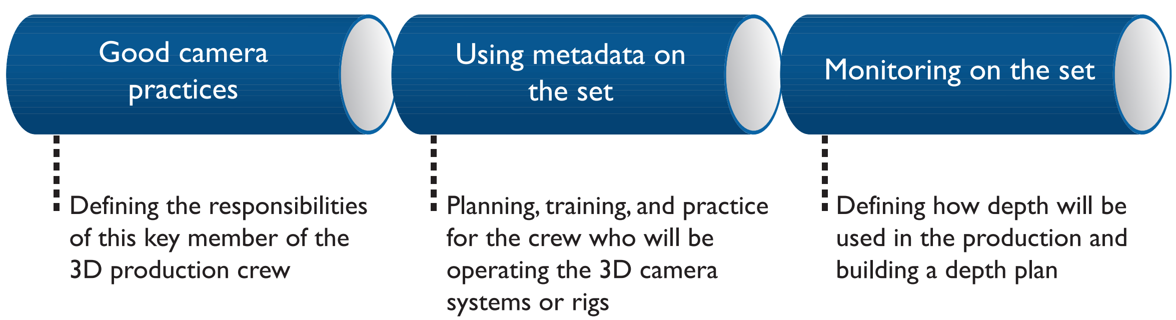
In addition, many of the practices commonly used in 2D production do not lend themselves well to 3D production and are likely to cause viewer discomfort if not avoided. Cinematographers often use shallow depth of field in 2D production to guide the viewer's focus and add a sense of depth. In 3D, shallow depth of field often yields a confusing stereoscopic image. Our visual system does not provide for us to be able to see scenes with a static focal point. When we look at different parts of a scene our eyes focus on what we are looking at. Because of this, the use of shallow depth-of-field shots in 3D productions will often create some visual confusion and may lead to viewer eyestrain. Instead of using depth of field, a better solution in 3D is to use lighting and shadow to direct the eye within the frame.

Fast zooms, pans, and excessive camera shake are also all techniques that viewers can easily tolerate in 2D. In 3D these techniques can be extremely disorienting and will induce vertigo in some viewers. If these techniques are critical to the storytelling it may be best to either take a conservative approach to depth in the shot or to integrate the shot as 2D.

Light artifacts such as specular highlights and flares will typically appear differently in each camera lens. This difference creates a retinal rivalry that can also be extremely uncomfortable for most, if not all, viewers. If these elements are important to the storytelling the use of post-produced effects will provide better control over symmetry in the final images.

Image alignment and image synchronization are new requirements in 3D production and are discussed further in Section 4 of this Guide. Alignment is not just the physical relationship between the two cameras. It includes matching focus, exposure and color between the two eye views.

Planning 3D Acquisition



Using metadata on the set

As discussed previously, the acquisition and use of rich metadata provides endless opportunities for greatly increased workflow efficiency throughout the production and post-production process.

The best place to acquire or generate metadata is at the point of acquisition. This is the only opportunity where all the information that may be useful at a later stage is present. Many of the file based cameras and recording systems have some provision for capturing either camera generated metadata or user generated metadata. However, there are also many 3D acquisition and recording systems that have limited or no ability to capture any useful metadata other than timecode.

If you can't record metadata in the camera it may be necessary to resort to using digital slates at the head of each shot, or even the old-fashioned handwritten notes taken by a production assistant. While this manual approach is less than ideal at least the data will be captured and can be properly associated with the media at a subsequent phase in the production process.

In addition to capturing descriptive information about each shot (location, talent, etc) it is important to capture information about the stereography. This includes information like interaxial distance, focal length, distance to subject, convergence angle and so forth. This information will be important in managing depth budgets in post production. The information becomes invaluable when resolving 3D issues or if a shot needs to be recreated.

Monitoring on the set

It is important for the stereographer and producer to see the 3D images as they acquire them. Unlike 2D productions, there are many things that can go "wrong" in 3D that may go unnoticed if the crew is only monitoring images in 2D. It will also be helpful if the 3D images are reviewed on a display similar in size to the intended end use. For television production this means a minimum of a 42" display. It would be even better to use a display in the 50" to 65" range whenever possible. In a location where it is not feasible to have a large monitor on location the stereographer must have a strong understanding of how disparity will scale as the display size changes. The stereographer should carefully measure positive and negative parallax on the available 3D monitor, and then calculate what this will translate to as the image is scaled up to larger displays.

Monitoring in 3D while actually shooting will give the stereographer the opportunity to ensure that scenes do not contain issues that cannot be resolved in post. Excessive positive or negative parallax, extreme camera misalignment, mismatched exposure or focal points, and excessive window violations can all cause discomfort for the viewer. All of these 3D issues are difficult or impossible to identify when the stereographer is only monitoring in 2D.

Media Management in Production

A good plan for media management has three primary goals:

- **Protection** against the loss of media through hardware failure or process failure
- **Preparing** the media from production for its use in post production
- **Preserving** original camera master materials in their native form for delivery to the network.

A media management plan must address all three of these goals. The plan must also spell out the media management responsibilities of each member of the production staff.

Too often media is mismanaged because managing it properly was "someone else's job." This section of the guide will walk through some of the different steps involved in production media management and many of the decisions that need to be made about this part of the production process.

Managing 3D (stereo) files

One of the key differences in media management for 3D is the added complexity of acquiring images from two different cameras. This increases the amount of media that needs to be managed but also creates the need to correctly identify and manage two separate sets of tapes or files. To further complicate things it is critical that the left eye and right eye views are correctly identified and that the naming conventions used to identify each eye view are maintained throughout the project. 3D cameras and recorders create files in a number of different ways and use a wide range of organizational systems to store those files.

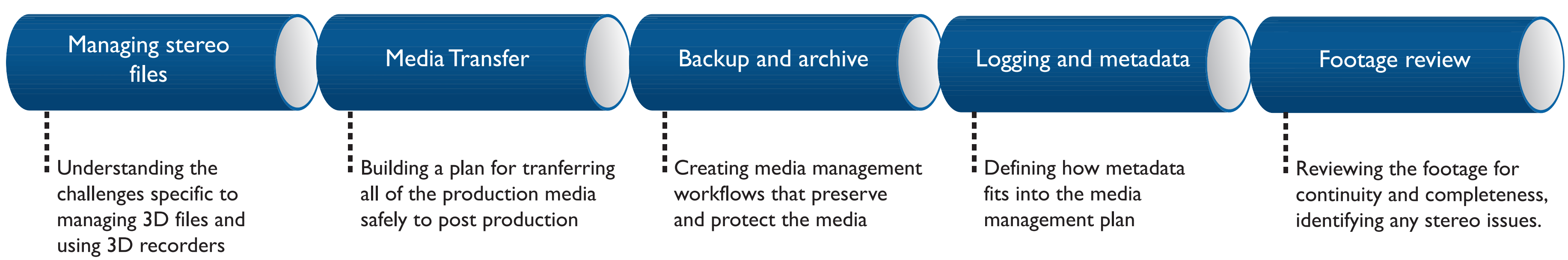
Some systems create a single file that contains both the left eye and right eye media along with common metadata. As an example, the SI2K DDR software uses this approach, putting both views in a single Cineform 3D package. Other systems record a separate file for the left eye and right eye, but store the file on a common piece of physical media. The files are differentiated as left and right eye files based on a naming convention. The 1 Beyond Wrangler 3D Mini SDI uses this type of organization when recording outside of the Cineform 3D codec.

The final type of organization records separate files for the left eye and right eye views and stores the files on separate pieces of physical media. Systems like the Convergent Design Nano 3D and the Panasonic 3DA1 use this organization system.

Understanding how your particular recording system works and building your media management workflow appropriately is essential to 3D production. If your workflow doesn't have a system for sorting and tracking left eye and right eye files it is easy to reverse them. Reversing left eye and right eye views is a common issue in 3D acquisition and post. Unfortunately, it's also one of the 3D problems that can be the most uncomfortable for the viewer. Reversing the eye views will ruin any sense of depth or immersion in a shot, and will confuse and distract the viewer.

An effective plan for managing stereo files must include a strategy for correctly identifying the left eye and right eye assets and then properly maintaining those naming conventions all the way to the final mastering process.

Planning Media Management



Workflow tips for the different organization methods:

Both views at full resolution as a single file

This method of recording organization makes it difficult to reverse the views unless the cameras are reversed. However, it can be easy to reverse the cameras. Check the input configuration on your recorder before shooting to make sure the cameras aren't reversed. Capping the lens or closing the iris of a single camera is an easy way to do this. Assuming that the cameras are properly connected, the file will contain the left eye view and right eye views in the proper orientation.

Two files on a single piece of media

This method of recording organization can be challenging. The recorder needs to be configured so that the left eye and right eye views are clearly identified in the file name. The file name needs to allow for easy sorting, as many post production tools require left eye and right eye files to be paired at import while other systems require that they be stored separately. File name planning and good communication between production and post are essential with this type of organization.

Two files, separate media

This method of recording organization requires good labeling and tracking of the media at all stages of the production process. Systems that use this method keep the two views separate during recording but require careful management to ensure that left eye and right eye media are identified correctly and properly managed as the media is transferred to other physical devices and formats. Some systems can use metadata in the file or different file naming conventions as a method for keeping track of the different eye views. As an example, the Convergent Design Nano3D can be configured so the first two characters of the file name indicate whether the file was recorded on the left eye recorder or the right eye recorder. Other systems, like the Panasonic 3DA1, may not provide for unique file names, but generate metadata to identify the left and right eye images. With any type of recording system it is important to have a well thought out plan for naming physical media, files and folders, and any other media containers in order to properly distinguish between the left eye and right eye assets.

Media transfer

Media transfer is the process of moving the media from one type of storage to another. A good plan for transferring media is essential for any production using file based cameras or recorders. Aside from HDCAM SR dual stream tape, most of the 3D recording choices are file based. Most file based recording systems record the media to flash cards or solid state hard drives (SSD). While these types of storage are both fast and stable, they are also expensive. Due to the high costs using these cards or drives for long term storage quickly becomes impractical. Transferring media to another type of storage allows the expensive flash and solid state media to be reused for acquisition and reduces the amount of this type of storage that the production has to purchase.

A good plan for media transfer has four key attributes:

- The plan requires redundant copies of the media
- It requires that any copy of a media asset be verified against the source using bit for bit verification algorithms.
- It defines a process which will allow anyone working with the media to instantly know the status (e.g. protected, clear to use, safe to format) of the recording media (card, drive, etc)
- The plan is built around devices and interfaces that allow the media to be copied quickly, accurately, and with the least possible amount of labor and human intervention.

Creating redundant copies of the media ensures that the failure of a single drive or data tape won't destroy the only copy of the media. Given the size of hard drives, LTO data tapes, and today's media, a single hard drive or data tape can hold dozens of hours of footage or more. Losing that amount of footage can cause serious damage to a production. Creating redundant copies of the media may seem like a waste of time and money but weighed against the risk of losing several days of production footage it becomes a sound investment.

Verification provides assurance that all copies of the media are valid. Errors do occur in copying. While most data copy processes are reasonably reliable any process that involves moving trillions of bits of data can sometimes result in errors. These errors often are not obvious with a casual look at the file. Comparing file size, file counts, and directory trees between the media copies will not expose data corruption. That's why many manufacturers have come up with software that performs data copying and then verifies the copies using bit for bit verification. The software looks at the source and destination media and ensures that they are an exact match. This level of verification is a critical part of the media transfer plan.

Redundant and verified copies of the media only provide protection if you actually make them and know where they are. Many productions have been sidetracked by accidentally deleting media that they thought was safely copied and archived. To avoid this, it's important to include a system for tracking media in the media management plan. It doesn't have to be overly elaborate, but it needs to be documented and everyone in the production team needs to be aware of it.

Not all methods for copying and verifying media are equal. Some methods can copy a large amount of media safely and quickly with minimal human intervention. Other methods can be slow and require quite a bit of babysitting.

The 1 Beyond Wrangler, a media management appliance

Several manufacturers in the industry have built dedicated appliances that handle the task of copying, verifying, and managing media. These tools tend to be fast, accurate, and require minimal human intervention. They can move data at the maximum speed allowed by the drives, and include automated verification and reporting as part of their features. The more advanced applications are able to create redundant copies from multiple sources concurrently. This is in stark contrast to the most basic form of media copying: the manual drag and drop. Using a laptop's integrated card reader or a USB card reader to copy the media to a USB or Firewire attached hard drive is certainly one of the slowest processes available. It is hampered on both sides by slow bus speeds and interface limitations. The process can be helped along by using software that provides accelerated copying and verification, but it is still inefficient and highly prone to errors.

Backup and archive

Creating redundant copies of the original media is a necessary part of the media management plan, but will also create some additional challenges and complexity. It's important for the media management plan to designate the use of each copy of media. One copy of the media needs to serve as backup protection master. From the time it is created the protection master needs to be set aside from the rest of the media. This copy of the media has two purposes.

- It provides a safe copy of the media that can be restored if the other copies are lost, damaged, destroyed, corrupted, or infected.
- It can serve as the final footage deliverable to the network.

For fully commissioned programs the network requires delivery of the "original camera masters", the footage in its original native form. The protection master can serve as this deliverable, provided that it is preserved in a form that meets the network's standards.

Once multiple copies of the media exist it becomes more difficult to track the changes that are made to the media, especially changes to the file based metadata. Every media management plan is different and will require it's own solution for synchronizing changes to media between the working copies and the backup copies. It is important that the plan address what changes can be made to different copies of the media and how the backup can be used to recover from lost data.

Logging and metadata

In a file based environment metadata is most useful when it is attached to the actual file based footage, as that allows it to be more easily used as the footage makes its way through the rest of production and post production. However, even if it is not possible to attach all of the metadata to the original files, the media management plan needs to address how this information is captured and preserved. The media management stage also provides some opportunities for reviewing footage and adding to the metadata.

Logging can be part of the media management plan as well. While some producers choose to include logging as part of the post production process, logging production information (metadata) in the field can save hours of media sorting later. The media management plan needs to address whether logging is being done in the production environment and how that metadata is attached to the media as the media makes its way towards post production.

Footage Review

Footage review should be part of every media management plan. Footage review involves having the critical members of the production crew review at least a sample of the media before it continues through the production process. This allows the producer to identify issues with impaired footage or missed shots before they become a problem later in production.

3D adds a new level of complexity to the footage review process. Shooting in stereo is difficult and it's easy to make mistakes. It's also easy to lose sight of the creative impact of 3D while trying to make the technology work. The production team should plan to review the day's footage in 3D at the end of each day of shooting. Ideally this review should be done on a full sized 3D monitor. As we've discussed earlier, looking at 3D on small monitors is a different experience than viewing it on a full size monitor.

This review should serve two purposes. First, it should be a review of the creative aspects of 3D. Did the convergence point get set on the right character? Why is that shot so flat? Will the depth of this shot match up with the others in the montage? Second, it should be a second check of the stereo alignment and settings. The team should look out for uncorrectable alignment issues such as tilt misalignments and excessive interaxial distance. The team should plan to reacquire shots that can't be corrected. Every media management plan for 3D needs to include the time and capability to review footage in 3D and on an appropriate size monitor.

Post Production

Post production planning should begin long before the first frame is shot in the field. With all the choices available for frame rates, codecs, metadata, and standards, it's very simple to acquire media in the production phase that creates challenges later. Proper planning and testing of the post production process can minimize these types of challenges.

Media Offload, Prep, and Ingest

This part of the workflow covers the transition from production to post production. At this stage in the plan production has provided media in the form of tapes, drives, or data tape. That media now needs to be prepared so it can be integrated into the editing environment. The effort required in this step of the workflow depends on choices made during acquisition planning. It's possible to create workflows that accomplish this step quickly. If footage is recorded using a codec and wrapper that's natively supported by the chosen editing system then it can be imported into the editing system in a short amount of time. In that scenario it often keeps much of its helpful metadata, making the preparation for the editing process that much easier. Conversely, it's possible to build a workflow that requires a complicated multistep process to get the media ready for editing. Unsupported formats can require multiple steps of transcoding, using valuable time in the edit suite and often losing useful metadata along the way.

Virus scanning

Viruses are a fact of life in our digital age. Even the best and most careful of users can pick up a virus when using a computer that's exposed to the outside world. Viruses can spread from computer to computer quickly inside a network. They can also be spread to computers not on the network when drives and media are exchanged between computers. Their impact can range from a mildly annoying afternoon spent cleaning them to a devastating loss of media and data. For this reason virus protection should be a part of every production workflow that uses digital files. Due to the large load on system resources it is impractical to run virus protection software on a typical edit system. It is necessary to scan drives and media before they enter the editing environment. Virus scans on large volumes of data may take a considerable amount of time which must be accounted for in the workflow process planning.

Media ingest and prep

Ingest, digitizing, capture: whatever you call this process it's a necessary step for getting your media into an editing system. Depending on your choices of editing system, frame rate, footage codec, and footage wrapper, this process can be quick and efficient or time-consuming and tedious.

In the current state of 3D post production it's easy to build workflows that require a long prep time. Some of the editing tools currently available are only able to work with very specific types of files. If the production's footage doesn't match that file type then there's going to be some lengthy transcoding.

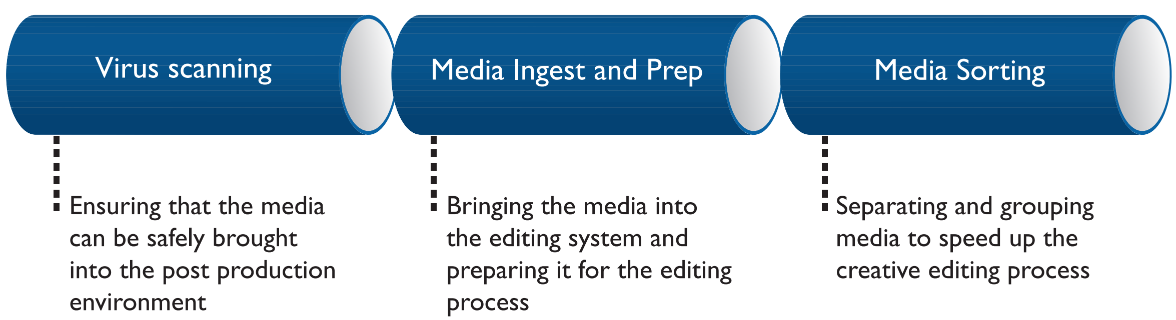
Transcoding has a double impact on a post workflow. First, it takes time. The time it takes can be variable and depends on the system being used to do the transcoding and the complexity and size of both the input and output formats. Second, it can have a major impact on the video quality of the footage. At the very least the footage will suffer some image degradation as it's decoded from its original file format and reencoded in the new format. At worst, transcoding can degrade the footage to the point where it no longer meets minimum image quality requirements, rendering it unusable. Conducting an end to end test of the media preparation workflow is a key part of planning and will also provide insight into how well the media management plan will work.

Working in 3D can present some unique media preparation challenges.

- **Desynchronized recording.** In some recording systems the left eye and right eye recording systems can start and stop at slightly different times. The clips will need to be re-aligned in post as part of the prep stage.
- **Keeping track of the two different eye views.** In some recording systems the default file names for the left eye and right eye clip names don't provide any help in sorting the files.
- **Different clip incrementing between two recorders.** In some recording systems it's easy to get the clip incremental file names desynchronized. This results in the left eye file having a name like L_DSC_0001.MOV while it's right eye partner has the name R_DSC_0002.MOV. This can be a mess to correct in post production.

Again, the key to planning this part of the workflow is to pick a reasonable set of options and test them carefully end to end to discover any pitfalls in the process. It's much better to discover these issues in the planning phase than to discover them after shooting is complete.

Media Offload, Prep, and Ingest



Media sorting

Determining in advance how you will organize media in post production can provide significant opportunities for improved workflow efficiencies. This is especially true if the recording format is capable of carrying descriptive metadata in the file. Productions using file based recording systems should determine a file organization and naming convention prior to shooting.

Choosing an organization and naming convention will allow the crew to use rich metadata as an effective production tool. The file name or file metadata can contain useful information such as the shoot location, shoot date, and subject, as well as the type of footage (interview, B-roll). All of this information can make the post production process more efficient if it is planned in advance (See "A Metastory" back in the "Why use metadata?" section.

A Tale of Two Workflows: Workflow One

Production X shot using two XDCAM EX cameras, recording to a Convergent Design Nanoflash 3D. Footage is 1080i 59.94 MXF files in the MPEG-2 intraframe codec at 140 megabits. A Final Cut Pro 7 system with Neo 3D was used for editing.

The Story

We recorded the XDCAM EX cameras to the Nanoflash 3D to improve the quality of the recording from the camera's native 35 Mb/s format. We also wanted to use the Nanoflash so we wouldn't have to trigger the two cameras separately. Unfortunately we didn't test how the files we recorded in the Nanoflash would work with our Final Cut/Neo post combination. In order to bring footage into Neo the footage needs to be in the Cineform DI codec. Neo includes a program called Remaster that does the transcoding to this format. We recorded the files using the MXF wrapper in the Nanoflash (as opposed to the MOV or AVI wrappers). Unfortunately the Remaster application from Neo couldn't understand these MXF files. We ended up using a separate transcoding application to transcode them to be MOV (Quicktime files). We then had to run the transcode to the Cineform DI codec through Remaster. Once this was done we had to use Cineform to multiplex the individual left eye and right eye files into a single combined file. When this transcode completed we realized that the version of Cineform we were using couldn't handle the interlaced version of our footage. We had to start in Remaster once again, this time using Cineform to deinterlace our footage. Finally, weeks later, we were ready to start working with our footage. At this point I'd question how good our footage really looks after all the transcoding and deinterlacing, but we're stuck with it.

Time Spent Per Hour of Footage: 8 Hours

A Tale of Two Workflows: Workflow Two

Production Y shot using two XDCAM EX cameras, recording to a 1 Beyond Wrangler 3D SDI. Footage recorded at 1080p 29.97 using the Cineform DI (Filmlike 1) codec at 160 Mb/s. A Final Cut Pro 7 system with Neo 3D was used for editing.

The Story

We recorded our XDCAM EX cameras to the external recorder to improve quality and keep the left eye and right eye recordings synchronized. We did some testing using the EX camera's onboard recorders. We couldn't get them to trigger with frame level accuracy, and that caused problems for us when we tried to import them into Remaster. We had to check the sync on each clip, and we decided that would take too much time in our post.
We decided to investigate other recording solutions and found that the 1 Beyond Mini 3D Wrangler was a good solution for us. It required us to adjust our rig a bit to fit the larger recorder, but it allowed us to record both cameras to a combined Cineform DI file on the Wrangler's SSD hard drive. This footage imported into Neo without any further manipulation or transcoding. The Wrangler also let us add some clip level metadata that made it much easier to sort our footage in post. Footage from five days of shooting was loaded up in a day and it looks great.

Time Spent Per Hour of Footage: 0.8 Hours

Editing

Working in 3D brings new challenges and new choices to the editing process. Unlike the transition from SD to HD, the transition from HD to 3D adds new steps to the editing process. It also introduces a world of unfamiliar tools and terms.

Editing has historically been broken into two phases – offline and online editing. The reason for dividing the two phases has changed over the years, as have some of the traditional limitations of offline editing tools. It's now possible to work with HD media in its full resolution during the entire editing process. As computers have become faster and storage has become cheaper the practice of working with footage at low resolutions during creative editing has begun to fade away. However, we still often refer to the first stage of editing as the "offline" process. We also refer to the next step as the "online" process. The offline process focuses on shaping the footage into a coherent story. The online process focuses on "finishing" the media and preparing it for delivery. 3D adds a new step to the process, the step of stereo sweetening. It's arguably part of the "online" process, but it requires special tools and knowledge that go beyond traditional finishing. Defining how each of these editing steps will be completed and the tools used to complete them is an essential part of any production's plan for 3D post production.

Offline

3D adds a new choice to the offline process: to edit in 3D or not? This is a question that every production has to answer as they plan the editing workflow. There are two primary approaches to offline editing for 3D projects.

- 2D only offline
- 3D offline

Each of these approaches has advantages and disadvantages, and neither of them is the "right" approach for every 3D production. The correct choice will depend on the subject matter, the creative vision for 3D within the program, and the editing tools chosen for the process.

The 2D only offline

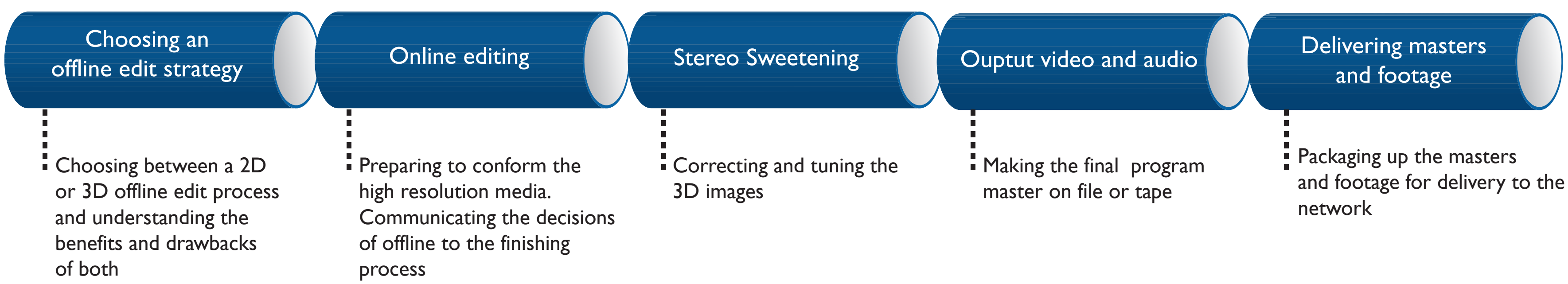
Many productions choose to work in 2D only throughout the offline creative stage of editing. This approach has some distinctive advantages and some major disadvantages.

The key advantage of this approach is simplicity in offline. Media preparation steps are reduced, as only one eye's view needs to be loaded for all the footage. The right eye view can theoretically be loaded only for the shots that are chosen in the finished cut. The offline editors are not distracted from their storytelling craft by challenges with the 3D that will be addressed in online.

The key disadvantage of this approach is that it eliminates viewing in 3D until the end stages of the production. This can lead to some unpleasant surprises when the program is conformed for 3D online. The shots chosen by the creative staff may have 3D alignment issues that can't be resolved (See Section 6). The depth continuity of the program may be nonexistent, with depth jumping around randomly from shot to shot. At the very least, it is unlikely that depth was used as a creative storytelling tool, as the story has been crafted without insight into the depth of any of the shots.

Advantages	Disadvantages
Can use existing 2D editing tools that are already familiar to the editing staff	May require different media preparation steps for the offline and online editing tools, requiring additional effort.
Only one eye's view needs to be captured and prepared for offline	Both eye views are not carefully examined until the online stage. This opens up the possibility that some shots chosen in offline may be unusable in 3D.
Creative editors are not distracted by the 3D	3D is not part of the creative decision making process. There is no thought given to depth as storytelling tool or depth continuity throughout the program. The offline editor may also cut the program using 2D techniques that don't translate well to 3D: rapid cuts, sudden changes in perspective, shaky camera moves, or other features that are likely to cause 3D viewing comfort issues.

Editing, Output, Mastering and Delivery



The 3D offline

Some productions choose to incorporate 3D into every part of the editing process. As with the 2D only approach, this choice comes with advantages and disadvantages.

Advantages	Disadvantages
Allows the offline editor to view and manipulate the 3D. This gives them a better sense of whether shots are comfortable for viewers and whether they can salvage shots with 3D alignment errors.	Often requires that creative editors learn a new tool for viewing and manipulating 3D. Most offline 3D editing systems can't communicate changes in convergence and alignment to the systems typically used for 3D online editing. Requires that the offline editing suites be equipped with 3D monitors and output hardware.
All the media is accessible in 3D, allowing offline editors to choose the best shots	Requires that both eye views of all the footage are prepared and captured into the offline editing system.
3D becomes part of the storytelling process	Creative editors might get distracted by the 3D, bogging down the editorial process.

The biggest advantage of this approach is including 3D as part of the storytelling process. Some of the most successful 3D films and television programs use depth as a tool in the storytelling process, expanding and contracting depth to reflect changes in emotion and energy within the story. When depth isn't part of the storytelling, 3D programs often fall into a "do no harm" model. The depth is there, but it exists only for its own sake. Editors control and manipulate depth during the online editing step, but only change the depth choices if they affect viewer comfort. Including 3D in the offline opens the potential for depth to be a creative tool, as long as the creative editors understand how to use it.

The primary disadvantage of this approach is the increased workload it places on the creative editing process. Media prep takes at least twice as long, as both views of every piece of footage have to be prepared for editing. If the offline editors are using and viewing 3D they typically have to learn a new editing tool or at least a companion application that allows them to view and work with the 3D. The process can become so focused on 3D that some traditional 2D methods of storytelling go by the wayside.

Sometimes a production chooses to blend the best of both the 2D and 3D offline models together into a hybrid approach. The hybrid approach is really a variation of the 3D offline where the producers clearly manage and communicate the expectations for managing depth. The creative editing staff use depth as a storytelling tool, but are not responsible for correcting alignment issues. This approach brings an awareness of 3D into the editorial process, blending the advantages and disadvantages of either of the other approaches.

The hybrid approach's key advantage is its increased awareness of 3D in the offline creative process. Some 3D producers have chosen to make significantly different editing choices in 3D, and the hybrid model allows them to do this easily (See sidebar 2D and 3D delivery case study). Offline editors can be aware of the depth in a shot, but don't try and make stereo corrections or manage alignment. They're just incorporating their knowledge of the shot's depth into the storytelling process and flagging any 3D issues for resolution in the online editing step.

Case Study: Delivering in 2D and 3D

The Program:

A crime re-enactment docu-drama.

The Challenge:

Deliver the network cuts in both 2D and 3D while keeping the program's existing "style."

The Story:

Our program is a crime docu-drama. It's mostly re-enactments and interviews with the actual criminals and the law enforcement officers who ultimately tracked them down. In 2D, our program is driving and fast paced. We cut frequently, mixing in multiple perspectives to provide a sense of intensity. We shoot a lot of angles to do this. Moving the program to 3D required us to rethink our creative direction. When we tried out our editing style using some 3D test footage we found that instead of providing suspense and intensity it provided confusion and nausea. We still had to deliver a 2D program to the network, and they wanted it to stay the way it was, but that approach didn't work for the 3D version. After some testing, we came up with a new approach. We kept some extra cameras on the shoot to cover some of our 2D angles. Rather than using cuts to ramp up the intensity, we placed our 3D rig on a Steadicam and used constant camera movement to raise the suspense level. The result turned out really well. Both the 2D cut and the 3D cut captured our sense of style and pacing, but each was tailored for the appropriate medium. This took extra attention and pre-planning. There were definitely some post production snags, but it all came together in the end.

Choosing Editing Tools

The toolset for 3D editing continues to evolve at a rapid pace. New manufacturers continue to enter the game and longtime players race to develop better tools and features. This section of the guide provides a brief overview of the types of tools that are currently available.

The 3D Plug-ins

The rapid rise of 3D has created a market for 3D plug-ins. These plug-ins add 3D functionality to existing 2D edit systems. They are generally inexpensive, but often have functionality that is far more limited than dedicated 3D editing systems. Some plug-ins require the editor to transcode media to a new format before it can be edited. Other plug-ins require the editor to render all 3D effects before they can be played on the timeline. When you are evaluating a plug-in 3D solution, it's important that you understand the editing workflow needed for your solution.

The Color Corrector / DI System Turned 3D Editor

These systems bring the horsepower of high-end color correction and digital intermediate (DI) film editing to bear on 3D video editing. They are often very expensive but have the fullest toolkits for editing 3D. DI systems often use powerful hardware that allows the editor to manipulate 3D images in real time. Some have advanced tools for correcting 3D geometry and alignment errors. One of the biggest challenges when working with DI tools is finding a way to transfer the editing decisions made in the creative editing process into the DI tool. Some of these tools only use the simple EDL format for importing edit decisions. When you are evaluating a DI or color corrector system for stereo finishing, it's critical to test moving your editing projects into the system.

Integrated 3D Editing Systems

These systems are just beginning to come to market. These systems incorporate 3D tools directly into the nonlinear editing system, allowing for easier integration of 3D materials and an improved workflow. In an ideal world, integrated systems combine the creative flexibility of a traditional editing system with the advanced stereo correction and color correction tools found in the high end color correction and digital intermediate systems. The impact of these systems on stereo editing remains to be seen.

Online editing

The online edit brings all the work that has come before into a nearly finished product. In 3D, this work is often done using high-powered and expensive tools. This makes it even more important to plan ahead and minimize surprises. 3D adds in the new step of stereo sweetening into the online process as well.

Planning for challenges in online editing

3D presents some new challenges even in the "conform" stage of the online edit. Getting the media into the online system can be one of the biggest challenges. Planning for this final movement of media should be part of the media management plan and fully tested before the beginning of acquisition. It's important to understand the acceptable import formats for both the offline and online systems. Some of the common 3D finishing systems accept only a small portion of the codecs and wrappers accepted by typical nonlinear editing systems. It can also be difficult to identify the clips that need to be imported. Many of the 3D online systems can't accept anything more complicated than an EDL when trying to import an editing sequence. The EDL's limitations on characters in source names often truncate file names and make it hard to identify clips. CMX3600 EDLs only allow eight characters in the reel identifier field. Some 3D editing systems allow the import of AAF files or other more advanced sequence exchange systems. It is critical to test that your footage can be imported into the online system and that the offline system and the online system can speak a common language to "discuss" which source tapes or files need to be captured. If the only method of exchange between the two systems involves transcoding and complicated clip renaming schemes, the impact of the extra effort needs to be identified in the post production plan.

Stereo sweetening

Stereo sweetening is the process of adjusting the 3D video for comfort, continuity, and aesthetic impact. It's performed after the online conform is complete. The goal of the process is to create a 3D master that is ready for output and delivery. Stereo sweetening involves three key functions.

- Eye matching for color. Modern science has not yet provided us with two cameras and lenses that are exactly alike, and it certainly hasn't created a beam splitter mirror that doesn't affect the color of the two views differently. Part of stereo sweetening is adjusting the color of one eye to match the other. Failure to match the color of the two views will result in viewer discomfort and display ghosting (more on that in the 3D Comfort and 3D Displays sections). This is a separate step from applying color correction and a "look" to the video. Color correction should be done once both views have been matched to each other.
- Correcting 3D alignment issues. Despite the best efforts of a skilled stereographer and rig technician there may still be alignment issues between the two eye views that need to be corrected (again, more on this in the 3D comfort section). Some alignment errors won't be correctable, so there will need to be a plan for when shots need to be replaced or rendered to 2D.
- Adjusting convergence for comfort and continuity. One of the big tasks in stereo sweetening is adjusting the convergence of the image and choosing the location of the screen plane. If the program was shot with converged cameras the convergence will often need to be tuned to avoid sudden shifts in viewer focus across cuts (see 3D Comfort for more on this). If the program was shot in parallel then it will be necessary to apply convergence for every shot. It's also often necessary to adjust convergence to even out the level of positive and negative parallax in a shot or to avoid stereo window violations.

Mapping out the stereo sweetening process in advance will help the production make best use of time spent in the suite. The tools used for sweetening are often expensive and time wasted in this step of the process can be costly.

Output

The final stages of production are output and delivery. While these stages might seem a long way off during preproduction planning, it's important to make sure the workflows and tools you've put together can create a master that complies with the network standards.

Audio

The network deliverables requires the producer to deliver many different audio tracks with the master. The number of tracks can vary from program to program, as some programs must deliver in 5.1 while others must deliver stereo audio. If the master is being delivered on tapes these audio tracks need to be laid back to those videotapes. The network technical specifications detail the track configuration required for both 5.1 and stereo masters.

Video tape masters are only required to have the full set of audio tracks on the left eye tape. The right eye tape only needs to include a copy of the stereo mix.

Audio Track Configuration for 5.1 Audio Programs

Track	Contents	Description
1	5.1 Mix: Left	Left Channel of Full Mix
2	5.1 Mix: Right	Right Channel of Full Mix
3	5.1 Mix: Center	Center Channel of Full Mix
4	5.1 Mix: LFE (subwoofer)	LFE Channel of Full Mix
5	5.1 Mix: Left Surround	Left Surround Channel of Full Mix
6	5.1 Mix: Right Surround	Right Surround Channel of Full Mix
7	Stereo Mix: Left	Full Mix at equivalent loudness to 5.1 Mix
8	Stereo Mix: Right	Full Mix at equivalent loudness to 5.1 Mix
9	Mix Minus Narration: Left (Music, Effects, clean Interview and foreground dialogue with no Voice Over for non native language speaking contributors)	Undipped for Narration or VO
10	Mix Minus Narration: Right (Music, Effects, clean Interview and foreground dialogue with no Voice Over for non native language speaking contributors)	Undipped for Narration or VO
11	Music and Effects (no narration or dialogue): Left	Undipped for Narration, VO, or Interviews
12	Music and Effects (no narration or dialogue): Right	Undipped for Narration, VO, or Interviews
BWAV	Stereo Music with Sync Pop	Undipped stem at equivalent program volume level
BWAV	Stereo FX/SOT/BG Dialog with Sync Pop	Undipped stem at equivalent program volume level
BWAV	Mono Interview Dialogue with Sync Pop	Undipped stem at equivalent program volume level
BWAV	Mono Narration and VO with Sync Pop	Undipped stem at equivalent program volume level

Audio Track Configuration for Stereo Audio Programs

Track	Contents	Description
1	Stereo Mix: Left	Full Mix at equivalent loudness to 5.1 Mix
2	Stereo Mix: Right	Full Mix at equivalent loudness to 5.1 Mix
3	Mix Minus Narration: Left (Music, Effects, clean Interview and foreground dialogue with no Voice Over for non native language speaking contributors)	Undipped for Narration or VO
4	Mix Minus Narration: Right (Music, Effects, clean Interview and foreground dialogue with no Voice Over for non native language speaking contributors)	Undipped for Narration or VO
5	Stereo Music: Left	Undipped stem at equivalent program volume level
6	Stereo Music: Right	Undipped stem at equivalent program volume level
7	Mono Sound Effects/SOT/BG dialog	Undipped stem at equivalent program volume level
8	Mono Interview & foreground dialog	Undipped stem at equivalent program volume level
9	Mono Narration	Undipped stem at equivalent program volume level

Creating masters

As part of the planning process producers need to decide which type of master to deliver to the network. Once this choice is made it will become part of the program contract. It's important to know that your chosen post solution is capable of making the type of master you need.

The network currently provides two choices for master delivery: tape based delivery on two Sony HDCAM SR tapes or file based delivery of DPX file sequences on external drives. The networks continue to evaluate new options for program delivery and may update this policy to provide more deliverable options in the future. The detailed specifications for these masters are discussed further in Section 8. Not all editing systems and workflows are capable of creating both types of masters. Some editing systems may not be able to lay back all of the audio channels, while others might struggle with maintaining synchronization between the two eyes during a tape output. Some editing systems may have trouble outputting DPX files that comply with the network's technical specifications. The producer must verify the ability of the editing system and workflow to create a valid master as part of the planning process.

Program Delivery

Understanding the network's final delivery requirements is critical during the planning stages of production. As we've discussed earlier, it's important to understand the requirements for the master and to find post production tools and workflows that can create masters that meet those requirements.

It's also important to have a plan for preserving and delivering footage. Most contracts for fully commissioned programs require that producers deliver all of their footage as part of the program's deliverables. If your contract has that requirement then data management and archive become even more important. Section 8 provides further detail on the network requirements for footage and delivery. It is necessary to familiarize yourself with the network policies and the obligations of your contract prior to beginning the project planning phase in order to craft an effective media management plan.

Notes:

THREE:

2D to 3D Conversion

At the time this Guide was authored none of Discovery's networks accept 2D to 3D conversion for the production of any 3D content unless explicitly approved in writing as part of the contractual agreement.

2D to 3D conversion can be a viable technology and may be appropriate to use in certain applications. However the ability to create accurate, believable images as well as the cost and time required for conversion must be understood and considered.

Conversion from 2D to 3D can be used to great advantage when trying to fix all or part of a problematic 3D image. Problems that would be otherwise difficult or impossible to fix can be replaced by 2D to 3D conversion using one of the eye views as a source. When considering the prospect of conversion from 2D to 3D, it is important to first consider using the 2D image within the context of the 3D edit without conversion by using the techniques discussed in Section 2 of this guide.

There are several different processes used in 2D to 3D conversion.

The traditional method uses a labor intensive manual process to identify the depth location of each object within a scene, and then separates the objects into individual layers. This separation and depth location process has to be performed on a frame by frame basis. A team of artists generates a second eye view using copies of the separated objects. The artists also build wireframe models of each object in the scene. The artists combine these models with the separated objects to give the objects a sense of roundness. Finally, the artists paint in any holes in the image created by the separation and repositioning of the objects. When properly executed this process can yield results the average viewer may find indiscernible from natively shot 3D. However, the costs and time required to properly accomplish conversion in this fashion make it an unsuitable method for television production budgets and schedules.

There are also several existing technologies which take a hybrid approach of blending complex depth estimation algorithms with a manual finishing process. Some of these technologies can provide results rivaling the most expensive and time consuming manual processes. In other cases the technologies create conversions with many depth inconsistencies and occlusion errors. As these technologies are further developed it is expected that they will provide viable 2D to 3D conversion solutions for television production.

Finally, there are several different real time hardware based solutions for conversion. These tools use comparatively simple algorithms which try to define objects and their placement in depth relative to the other objects in a 3D scene. While these real time devices can occasionally create a 3D scene with somewhat realistic depth decisions for the most part they will generate sub-standard 3D conversion. They should not be considered as a viable method for 2D to 3D conversion.

Quality control is of utmost importance when dealing with 2D to 3D conversion. Some processes and techniques may be capable of high quality output but even the best process can create 3D images that are not believable.

Notes:

FOUR: 3D Production: Cameras and Tools

Stereoscopic television production presents a number of unique challenges in addition to those of traditional high definition production. The most obvious challenge is the additional equipment required. Until recently producers have created 3D programs using complex and bulky rigs custom built to support a pair of matched cameras. The assembly, calibration, and operation of these rigs is difficult. Users of these rigs often need to fabricate many custom parts and cables to integrate the cameras and lenses needed for each scene. These traditional 3D rigs can also be quite costly. This combination of complexity and cost has prompted many producers who are new to 3D production to experiment with low cost consumer cameras coupled with rudimentary platforms to support the paired cameras and lenses. Unfortunately, this approach is more likely to back producers into a dead end of 3D image errors. These errors may be difficult or impossible to fix at a later stage in the production process.

Fortunately, the needs of this new stereoscopic production community have led to the rapid evolution of new cameras, rigs, recording devices, and many other types of tools intended to simplify 3D production.

As these acquisition systems continue to develop and evolve we can expect to see further improvements in ease of use, overall size and reduced costs.

Even with these improved tools it will continue to be imperative that the entire production team have a comprehensive understanding of the principles of stereoscopy.

Cameras

To select the proper cameras the production team will need to understand some of the requirements unique to stereographic photography.
One of the most important requirements for paired cameras is that they must be perfectly synchronized. If there is any variation in synch the cameras will capture each frame from different points in time. Even the slightest amount of synch error will cause the images to be unusable for 3D production.

In addition to synchronization the production team will also need to consider the size and weight of the cameras as well as their ability to be mounted properly on the rig system which you are intending to use.

Typically the choices of camera and rig platform are intertwined, as each must be well matched to the capabilities or limitations of the other. For example, using a beam splitter rig might require a camera able to flip the image vertically 180 degrees to accommodate the mirror reflection. While this could be done in post that approach would seriously limit your ability to monitor in 3D during acquisition.

Many cameras commonly used on 3D rigs do not have an integrated viewfinder. Using these systems will require that you find a viewing solution for the camera operator that provides sufficient image quality for critical focus and exposure settings.

It's equally important for you to consider the power requirements of the camera systems and which recording methodology will be employed.

Minimum Requirements for Camera Quality

We've already talked about the need for perfect synchronization between 3D cameras and about the unique hardware challenges that frequently occur when you're mounting cameras on 3D rigs. You will also need to consider several other attributes when selecting a 3D camera system.

3D cameras must have a native sensor resolution of at least 1920 x 1080. The distribution methods that networks currently use for 3D content halves that resolution. Using cameras with low resolution will compound the distribution challenges and result in severe image degradation. Cameras also need to have optical clarity and performance that matches the high resolution of the camera's image sensor. Because of their low cost most consumer or prosumer camcorders don't use high quality lenses. Even though these cameras might boast resolutions of 1920 x 1080 in the brochure, their tiny sensors and simple lenses make it unlikely that you'll see anything close to that resolution.

Your 3D cameras also need to be light sensitive enough to work in your intended production environment. Low light sensitivity is an issue with many of the cameras commonly used for 3D production. To make the cameras smaller or closer together the designers use small sensors and small lenses. These smaller lenses and sensors reduce a camera's light sensitivity. In 2D production you may be able to work around a camera's lack of sensitivity by adding gain to the picture. This is not a good option in 3D. Adding gain creates random noise in the picture. Because that noise is random, it's different in each camera. This is called a retinal rivalry - something that is present in one eye but not in the other. Adding gain leaves you with a noisy picture that contains high amount of retinal rivalry which will quickly make viewers uncomfortable.

The small size of consumer cameras makes it tempting for producers to put them on 3D rigs. But between the challenges with synchronization, mounting, resolution, optical quality, and light sensitivity consumer cameras are not a good choice for 3D acquisition.

Choosing the Correct Lens System

If you've chosen cameras that don't have an integrated lens, you will need to select an appropriate lens or perhaps several different lenses to meet the requirements of your project. As with cameras there are a number of choices in lenses, and each has its own set of pros and cons. As you've probably come to expect with stereo 3D production there are many unique requirements that we typically don't consider in normal HD production.
The first of these requirements is that the two lenses are as perfectly matched as possible. Even the best lenses available will have some variation between them. The more complex zoom lenses with multiple moving elements will be more likely to have notable variations between them. This is important as even minor differences in focal length, iris, or focus settings can have a major impact on the stereo image. You can't fix a mismatch in any of these settings without considerable effort and cost - if you can fix it at all.

With variable length zoom lenses you may find there is a considerable amount of variance in the optical center of the lens elements as the lens moves through the zoom range. This can wreak havoc on your ability to align the cameras properly. A shot that is perfectly aligned at one focal length can become misaligned when the focal length is changed. A common practice is to find a range of zoom settings where the lens pair is well matched and then to limit photography to that range in order to maintain proper camera alignment.

There are also cases where using prime lenses will be an appropriate choice. While you must still pay attention to matching a set of prime lenses you eliminate the complexity of maintaining a perfect match throughout the zoom range.

The next challenge is keeping the lens adjustments perfectly synchronized while shooting. There are several stereo controller systems currently available from vendors like C-Motion, Preston, and Element Technica. You can couple these controllers with micro drive motors and geared rings on the lenses. Once the control system is calibrated it can adjust both lenses synchronously. A stereo 3D lens control system needs to be able to control a minimum of six axes simultaneously. There are some systems available that can control eight axes, combining the rig interaxial and convergence controls in the same handset as the lens controls. Lens control systems can be tricky to assemble and calibrate. As with any other part of a 3D acquisition system there needs to be significant time allocated for the crew to test and train.

Most 3D lens systems are designed to operate both lenses with a single controller.

Choosing 3D Production Tools

Rigs vs. Single Body Systems

At a high level there are basically two different types of 3D camera systems. The most traditional involves mounting two matched cameras and lenses to a platform (rig) that provides adjustments for geometrically aligning the cameras optical paths and changing their interaxial distance and convergence angle. There are two basic types of stereo rigs: the side by side rig and the beam splitter rig. We'll discuss the difference and appropriate uses for each in the next section.

The other type of system is commonly referred to as an integrated single body 3D camera. These systems incorporate both cameras and their lenses into a single camera body with an integrated recorder. This provides the user with a complete system in a package not much different in size and weight than a typical HD camcorder. Integrated stereo camera systems may have many advantages over traditional rigs. They tend to be a bit more rugged and less prone to alignment issues and are easier to maintain. They can usually be operated by a single person. However, they do have some important practical limitations. First and foremost single body systems cameras are a variation of the side by side rig but without the ability to adjust the interaxial distance. This puts some rather serious restrictions on the distance between the camera and the subject and limits the focal lengths that can be used while still capturing effective 3D images. Integrated systems are often suitable for medium distance shots but fall short if the subject gets too close or too far from the camera. It is easy to create unusable stereo images if you use a fixed interaxial camera inappropriately.

Self-contained, single body stereo systems will likely become the system of choice for many classes of shooting in the same way the camcorder has become the standard for news, documentary, and live events. Though single body systems currently have many limitations, we will soon see more and better examples of self-contained stereo systems that will challenge the rig-based systems for market share.

Mounting cameras on a rig typically will provide more flexibility in setting the interaxial distance between the two cameras. This flexibility allows rigs to create comfortable 3D images in a wider range of scenes. However, this flexibility comes at a cost. Stereo camera rigs are pretty much all some level of science project. Building a 3D rig requires you to integrate bits and parts from a number of different manufacturers. And it's likely that you will need to have some custom parts built for you. As a result traditional stereo rig systems often cost two or three times more than integrated single-body systems and in some cases much more than that.

Side by Side vs. Beam Splitter Rigs

Side by Side (SbS) camera rigs are the simplest type of 3D rig. They consist of two cameras bolted on a plate next to each other, typically with adjustments for interaxial distance and convergence angle. SbS rigs tend to be relatively simple to assemble and operate, can be inexpensive, and are usually fairly robust, lending themselves to use in challenging environments or locations. The primary concern with SBS rigs is their limited minimum interaxial distance, or how close together the two cameras can be mounted. This limit is determined by the size and shape of the camera body, lens, and accessories. In general, side by side rigs cannot have an interaxial distance smaller than the diameter of the camera lens. This distance is rarely less than 65 mm when using reasonable quality HD lenses. Having a larger interaxial distance will make the 3D images shot with the rig appear deeper and can miniaturize objects if used with the wrong focal length or object distance from camera.

A large side by side rig in action. This rig supports wide interaxial distances for shooting from a distance. Image courtesy of ZGC.

A small side by side rig designed to support the small Cunima cameras. The small camera bodies and lenses allow this rig to have a smaller minimum interaxial distance. Image courtesy of Stereoscope.

A mobile beam splitter rig designed to be used with a Steadicam. Image courtesy of ZGC.

A studio beam splitter rig designed for tripod or dolly use. Image courtesy of Stereoscope.

As the interaxial distance gets larger it gets harder to control the amount of parallax in the 3D image. The amount of parallax can easily become excessive, causing hyper-convergence or divergence. Excessive parallax is a primary cause of viewer discomfort such as headaches, eyestrain, and nausea.

Another challenge when using SbS rigs is that in most applications only one of the cameras is moved when adjusting convergence angle. This can create image keystoning in one eye view that will need to be corrected in post to properly align the images in both eye views.

SbS rigs can be useful for creating depth in scenes which are beyond the normal range of human depth perception. Humans only perceive depth at distances of less than 45-50 meters. Side by side rigs that allow for wide interaxial separation can create 3D images that show depth well beyond that distance. However, the use of SbS rigs can come at the cost of having a limited range of overall scene depth in which the camera rig is effective.

For scenes with close up objects or a large range of distance from foreground to background, a beam splitter rig would be a better choice.

Beam Splitter rigs place two cameras at right angles to each other with a high quality "beam splitter" mirror placed at a 45 degree angle between them. The term "beam splitter" refers to a mirror that is 50% transmissive and 50% reflective. This means that a beam of light directed at the mirror will be split equally, with half the light passing through the mirror and the other half reflected away from it. With a pair of cameras mounted at right angles to one another and a beam splitter mirror aligned between them at 45 degrees, one camera will "see" through the mirror and the other will "see" the reflection from the mirror. When the cameras are properly aligned in this configuration it is possible for both cameras to capture images with exactly the same point of view. Because of this a beam splitter rig has no limits on minimum interaxial distance.

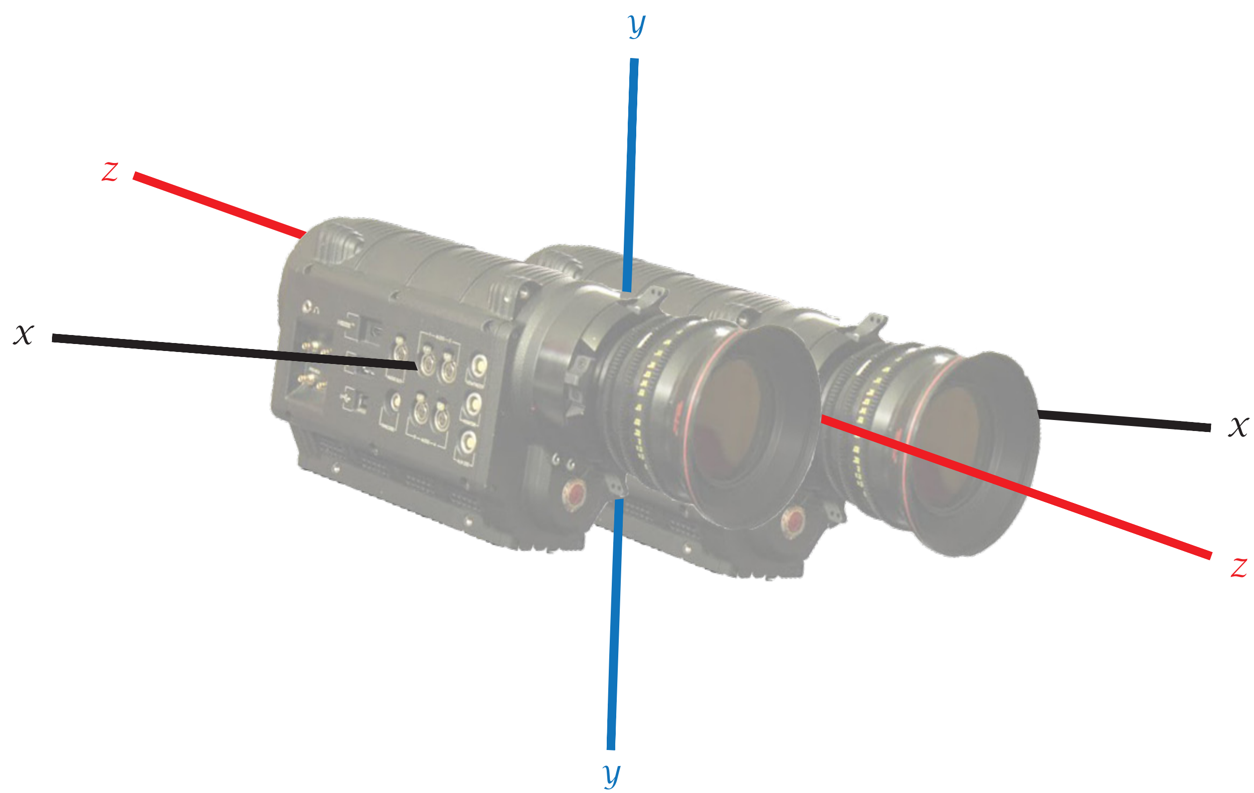
Beam splitter rigs do have limits on maximum interaxial distance. On this type of rig the maximum interaxial distance is limited by the width of the mirror. This rarely exceeds six inches, and in most cases would be more in the range of four inches. This increased interaxial range allows the operator to configure a beam splitter properly for any 3D shot that may be required.

This flexibility comes with significant limitations. Beam splitter rigs are considerably larger and more cumbersome to operate than a SbS rig. The mirror is delicate and easily damaged. They also tend to collect dust, fingerprints and other contaminants that can ruin shots. The mirror also reduces the amount of light reaching the camera by about one stop. Finally, the mirror housing limits the usable field of view on wide angle shots and makes the use of filters impractical.

Ultimately the choice of rig type will be determined by a number of factors including cost, portability, crew experience, and any physical restrictions at the shooting location.

Common 3D Production Issues

Proper rig setup and alignment is more critical to successful 3D shooting than choice of equipment, crew, stereographer, post system, or even the technical requirements of the shoot itself. The greatest misconception about stereo production is that if something is not aligned or set up correctly it can easily be fixed in post. Although some types of problems are simple to correct using good post tools, many other problems are expensive, time-consuming, or impossible to fix.



Rigs Alignment and Adjustment

In order to provide a usable platform 3D camera rigs need to have certain commonalities. All rigs must be able to mount a pair of cameras and lenses. Each rig must also provide the ability to move and rotate the cameras independently along the X, Y and Z axes. Moving the cameras along the X axis changes the interaxial separation. Rotation on the X axis is used to ensure the optical path along the Z axis is parallel for both cameras. Moving the cameras along the Y axis is used to align the cameras horizontally while changing the rotation on the Y axis adjusts the convergence angle.

Camera movement along the Z axis is used to place both camera sensors at precisely the same distance from the subject. Rotation on the Z axis is used to ensure that the edges of the image frames are perfectly parallel in both cameras.

Aligning the rig involves using the four adjustments not related to interaxial distance or the convergence angle. The rig operator uses these adjustments to bring both cameras into perfect vertical and horizontal alignment. In a perfectly aligned rig the cameras are at the same height and the same distance from the subject. There must not be any differences in rotation along either the X or Z axes. Besides supporting the cameras 3D rigs must also be able to support mechanisms to synchronize and adjust focus, aperture and zoom on the lenses.

Calibrating and aligning a stereo rig can be a complex and tedious process. The process is made even more complex when using low cost or poorly designed equipment. Each system has its own unique requirements for the setup and alignment process. Detailed step-by-step descriptions of how to align specific 3D rigs is outside the scope of this document. However, the alignment process for all rigs should have some basic commonalities. First and foremost you need to make sure that the lenses are properly matched, backfocused, and synchronized. Then you can begin to physically align the cameras on the rig. When aligning cameras it is extremely helpful for the operator to see the views of the two cameras simultaneously. Many specialized 3D monitors provide multiple views that help with alignment. Overlays, anaglyph modes, difference maps, and checkerboard views can all be useful for aligning cameras.

Alignment is easiest to do using stereo alignment charts set up at varying distances from the rig. The first step is to make sure the camera sensors are precisely the same distance from the charts (along the Z axis). Once both cameras are at the same starting point you can begin working through the process of image alignment along the X, Y, and Z axes.

One of the more common alignment errors occurs when the optical path for the LE and RE cameras is not perfectly parallel along the Z axis. This creates a condition known as a tilt misalignment. In this condition the images appear to be vertically aligned at one point along the Z axis, however objects at different points along the Z axis will progressively diverge from vertical alignment the further they are from the single point of alignment. This is an important error to be aware of and to avoid as it cannot be corrected in the post-production process.

Some important features to look for in rig design include accurately marked scales at all adjustment points and rigs that require the least amount of different tools for assembly and adjustment. Well-designed rigs will also give appropriate consideration to locations for mounting the various accessories needed operate the cameras, lenses, and recorders. The best rigs are not necessarily the most complex. A well designed system minimizes moving parts and limits adjustments to only those absolutely required for proper camera alignment

Managing Depth in Production

During production it is important to monitor depth and convergence on a scene by scene basis. Managing the camera and rig settings appropriately will help to ensure that you follow the planned depth budget and create 3D that will not cause viewer discomfort.

While there are several methods for monitoring 3D during acquisition, by far the best method is simply to have an appropriate size monitor available and review shot setups in advance. There will be some situations where having a large 3D monitor at the point of acquisition is simply not an option. In these situations there is no alternative other than to spend time with the exact camera, lens, and rig that will be used in the field. During this testing you need to shoot multiple setups with objects and backgrounds at distances similar to what is expected in the field. Carefully record the camera settings and analyze the resulting imagery. The stereographer and camera operator both must have a clear understanding of how each specific acquisition system will work in all the foreseeable shots. The primary goal of this process is the capture of 3D images with comfortable levels of parallax during production. It is important to understand that content which has comfortable depth when viewed on a small screen may not be comfortable to view on a larger screen due to increased parallax caused by magnification of the image. This is not an issue that can be fixed in post-production. Using small portable monitors in the field as the only means of verifying depth and convergence leaves you dangerously susceptible to this issue.

Along with managing viewer comfort it is important aesthetically to ensure that the perceived depth in a sequence match from scene to scene except when the stereographer chooses to vary the depth as a creative tool. However, this should be something that was addressed in the pre-production planning stages when defining the depth budget.

Interaxial distance determines the overall amount of depth within a scene. The convergence angle determines where objects in the scene fall relative to the screen plane. Constantly shifting the convergence point during a shot to follow the subject of interest in the frame is not recommended. It is better to allow the subject of interest to move forward and backwards relative to the screen plane much like we would experience in the real world with our own eyes. This will create a more natural looking image. Convergence can be changed both in-camera as well as in post-production. Typically convergence is set during acquisition and the fine-tuned during post-production. The edited sequence of shots provides the proper context for adjusting any depth imbalances between shots.

FIVE: 3D Displays and Monitoring

It's important for producers of 3D content to understand the technology behind the 3D displays currently being sold to consumers. At the time this guide was written, the consumer electronics industry is beginning to release their second generation of 3DTVs. While technology continues to evolve, manufacturers are currently using a few different technologies for 3D displays. Each of these technologies has its own strengths and limitations. To effectively produce content for these displays producers of 3D content must be aware of the different types of displays and how each display technology impacts the viewer's experience.

Common Display Types

There are four types of 3D displays currently being sold for the home:

- Direct view displays using active shutter glasses for view separation (Active Glasses)
- Direct view displays using patterned film and passive glasses for view separation (Passive Glasses)
- Projection systems using active shutter glasses for view separation (Active Glasses Projection)
- Projection systems using alternate polarization and passive glasses (Passive Glasses Projection)

The direct view displays (LCDs/LEDs and Plasma) are by far the most common. At the time this guide was written the active glasses displays have most of the market share, although passive glasses displays are on the rise. Projection displays represent a much smaller portion of the home market, as these displays are being sold mainly to home theater enthusiasts.

Active Glasses Displays

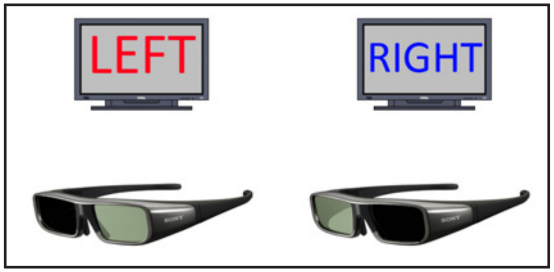
Almost all the consumer electronics manufacturers sell displays that use electronic shutter glasses for view separation. This type of 3DTV is the most economical to build, as most of the cost of the "3D" component in this type of display is in the glasses.

Active glasses displays work by taking advantage of the high picture refresh rates in modern LCD/LED and plasma displays. Many modern LCD/LED panels have refresh rates of 240 or 480 Hz (number of times per second the image is refreshed on screen) to allow for better motion smoothness and less smearing when watching 2D HD pictures. Some plasma displays are also capable of high refresh rates, with many displays capable of rates of 600 Hz or higher.

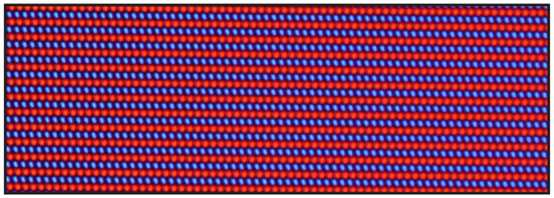
When the display is in 3D mode it uses the fast picture refresh rate to rapidly alternate between the two eye views. This rapid succession of left eye and right eye pictures is matched up with a pair of electronic glasses worn by the viewer. These glasses have thin LCD films over each of the lenses. The display communicates with the glasses using either infrared or radio commands. When the display is showing the image for the left eye, it tells the glasses to darken the LCD film on the right lens, allowing only the left eye to see what's on the display. When the display is showing the right eye image the opposite happens. The glasses get the message to darken the left lens, preventing it from seeing the image intended for the right eye. This allows each eye to only see its intended image, creating the 3D experience. The display switches so quickly between the left and right eye images that the viewer perceives them being displayed at the same time.

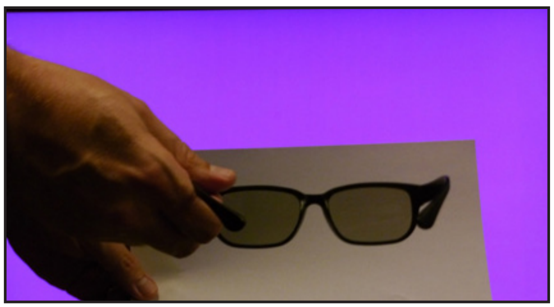
Active glasses displays have some major advantages and disadvantages. First among their advantages is their ability to show each eye's view at the full resolution of the display. They often have a wide viewing angle, allowing viewers to sit in almost any position relative to the television and still get a good 3D experience. Some first generation sets require the tilt of the viewer's head to be absolutely parallel with the display in order to get the best 3D experience.

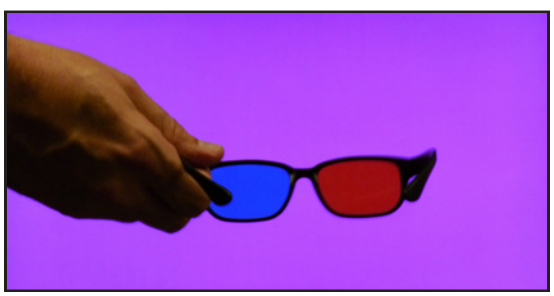
Active sets have two big disadvantages. The first is the active glasses themselves. Because the glasses contain electronics and batteries they are often heavier and bulkier than typical eyewear like prescription eyeglasses or sunglasses. This can make it uncomfortable for viewers to wear the glasses for a long period of time. It also makes viewing difficult for viewers who already wear prescription



Active shutter glass synchronization.


This is a close up view of a passive micropolarized display showing a blue field in the left eye and a red field in the right. When you look at the display closely, you see the alternating lines of red and blue. When you look at it from a distance it appears purple.


The glasses for passive micropolarized displays use clear polarizing filters. The purple screen beyond the glasses is the same image shown above, where the left eye image is a blue field and the right eye image is a red field.


This is what you would see through the glasses when looking at the image shown above. The left eye lens "sees" the blue, the right "sees" the red.

eyeglasses, as the 3D glasses need to be worn over the top of their eyeglasses. The rapid cycling of the glasses can also cause visible flickering in rooms that use fluorescent lighting. The glasses also require power, and they either need to be plugged in to charge or have their batteries changed on a regular basis. The second generation of some manufacturer's active glasses attempts to correct some of these comfort issues. These new glasses decrease the weight of the eyewear and move the heavier parts of the electronics away from the eyes and nose, instead placing them over the ears.

The second disadvantage of active displays is increased crosstalk, or ghosting. Crosstalk is the leaking of one of the 3D eye views into the other. Viewers see it as a distracting "ghost" image in the 3D picture, so it is often called ghosting. Ghosting can cause viewer fatigue and annoyance. Unfortunately, the types of 3D images that cause ghosting vary from display to display. There are some conditions that consistently cause ghosting across most displays.

Any producer creating content for these 3D displays should avoid creating 3D images that have the following conditions.

- **Excessive parallax:** the more difference there is between the left and right eye views, the more visible ghosting will be. Parallax is essential to creating the 3D experience, but excessive parallax contributes to ghosting.
- **Colorimetric mismatch between the eye views:** Poor color alignment between the eye views will cause ghosting on most sets. Some of the manufacturer's active glasses sets are especially sensitive to this condition.
- **High contrast objects:** Objects that contrast sharply with the background behind them are more likely to pick up ghosting artifacts.

Passive Glasses Displays

Some of the consumer electronics manufacturers have sensed the consumer frustration with active glasses and have begun making displays that use passive glasses to create the 3D effect. Passive glasses displays have been widely used in the professional market for several years. Most passive glasses displays require a special film to be built into the display panel. The film is expensive and can add significantly to the cost of the display.

Passive glasses displays use a combination of polarizing filters to separate the two eye views. The first set of filters is in the polarizing film placed on the front of the display panel. The polarizing film has a pattern that polarizes alternating lines of the display screen in opposite orientations. The television processes 3D pictures so that the left eye view goes to one set of lines and the right eye view goes to the adjacent, opposite polarized set of lines. When this polarized display is viewed through glasses with polarized filters, the left and right eye views are received only by the appropriate eye.

The single greatest advantage of passive glasses displays is the glasses themselves. The glasses can be made cheaply and are lightweight. Using passive glasses technology it's even possible to make prescription 3D glasses, allowing viewers to wear a single set of lenses when watching 3D. Unfortunately this convenience comes at a cost. The current generation of passive glasses displays has some disadvantages. In order to get the best experience viewers need to view the display from a limited range of vertical viewing angles. Outside of this range viewers will begin to experience increasing levels of crosstalk and other artifacts.

Another disadvantage is reduced resolution. Current passive glasses displays halve the resolution of the displayed picture, as half the lines are used for displaying each eye view.

Projection Systems

Projection systems make up a small part of the home market. Like the direct view displays they can use either active glasses or passive glasses. Active glasses projection systems receive a synchronizing signal from the projector that causes the darkened eye to alternate, just like an active glasses direct view display. Passive glasses projection systems typically alternate the polarization of each frame and display the eye views in sequence, just like an active glasses display does. The passive eyewear filters the images, sending the correct view to each eye.

Future Displays

Technology continues to move forward. The consumer electronics industry has shown demonstrations of large glasses free (autostereoscopic) displays. However, it's unlikely that practical autostereoscopic displays will be brought to the market before 2015. Some manufacturers are also investigating hybrid set designs that will allow for full resolution display while using passive glasses. These hybrid designs use active polarizing film placed over top of the screen. This technology will likely come to the market in 2012 or 2013.

The Impact of Displays on Stereo Viewing and Perception

When producers create content in 2D the size of the typical home viewing set is probably their last concern. We've grown used to creating content that can be shown on iPhones and movie screens, and the home user's display is less and less of a concern. In 3D the size of the home user's display must be a primary consideration. Understanding how your material is going to be viewed is essential to creating good 3D content that viewers can watch comfortably. Apart from the advantages and disadvantages of specific display technologies, two other viewing factors have a major impact on how viewers perceive 3D content. These factors are display size and viewing distance.

All 3D content needs to be targeted towards a small range of display sizes. For 3D television content, that target should reflect the size of the 3DTVs in the marketplace. Most 3D displays currently being sold are between 40 and 80 inches (diagonal) in size. You'll find some larger (mostly projection screens) and some smaller, but most the consumer displays in the market fall into this size range. Display size has a major impact on viewing comfort in 3D due to its scaling effect on parallax. As the display size increases, the parallax (differences) between the left eye and right eye images also increase.

Parallax is discussed in far more depth in Section 6. For this discussion, understand that parallax determines the relative strength of the 3D effect and that there are limits to how much viewers can tolerate comfortably. The 3D production community has not come to a definitive agreement on what these limits are. Part of the challenge is that the tolerance for parallax varies significantly between individuals. The production community does agree on a few things. First, the community generally agrees parallax that causes the viewer's eyes to diverge should be avoided. As the average interocular spacing for adults is around 2.5 inches, images that create parallax values of more than 2.5 inches should be avoided. As shown in the table above, that point of divergence is different for displays of different sizes. Therefore it's critical that producers of 3D content view their programming on a range of displays that are typical of sizes in the home market. It's also critical that producers set up their depth budgets with these display sizes in mind, building 3D that is both comfortable and engaging for the home viewer.

Table 5.2

Display size impact on parallax

Display Size	Horizontal Pixels Per Inch	Horizontal Percent of Screen Per Inch	Max Pixels of Parallax in 2.5 Inches
40 inches	55	3%	138
60 inches	37	2%	93
80 inches	27	1.5%	68
35 feet (420 inches)	5	0.26%	13
Formula	1920 pixels / screen width in inches) Screen width for 16:9 screens = screen diagonal x 0.872	100 / Screen width in inches	1920 pixels / screen width in inches x 2.5 inches

Another key viewing factor is viewer distance. The perception of 3D volume changes as the viewer moves closer or further from the screen. Recent studies done by the vision science community have also shown that viewer's tolerance for 3D parallax also changes as the viewer moves relative to the screen ("The zone of comfort: Predicting visual discomfort with stereo displays", Shibata et al 2011). The Shibata study suggested that viewers positioned at typical television viewing distances (around seven to ten feet from the display) were more comfortable with higher levels of negative (out of the screen) parallax than positive (into the screen) parallax (Shibata, et al 2011 pg 21). For these reasons, producers should also create their content while viewing it at distances that mirror the home environment as much as possible. For the average viewer this distance is normally three to five screen heights away from the display, depending on the size of the display.

Notes:

SIX: Creating Comfortable 3D

It's possible to make 2D shows that people don't want to watch, but it's nearly impossible to create 2D shows that cause viewers serious discomfort. Unfortunately the same is not true for 3D. Because the very concept of 3DTV is built on making the human vision system do things it wouldn't ordinarily do it's easy to cause eye strain, discomfort, or headaches. There are many things that we know contribute to a viewer's comfort or discomfort when watching 3D, and there are likely many more factors that we don't yet understand. The vision science community is still studying the effects of 3DTV viewing. Much of their research so far has told us that viewer's perceptions of 3D vary quite a bit from person to person. 3D images that are uncomfortable for one viewer to watch may be perfectly comfortable for another.

We do know that viewers don't get all of their information about depth from the difference between the images from their left and right eyes. That depth cue, which scientists call "stereopsis," is only one of many depth cues that people use to determine where objects are in relation to themselves. Other cues like occlusion, perspective, size, and motion provide just as much or more information to the viewer's brain about how objects fit into the world around them. Making comfortable 3D requires that we use stereopsis as a complement to these other depth cues, not as a conflicting distraction. It's easy enough to accidentally create a brain-bending M.C. Escher puzzle out of a 3D shot if other depth cues are not taken into consideration.

The best way for producers to minimize viewer discomfort is to understand the various 3D challenges and errors that are known to cause it. This next section of the guide walks through many of those errors.

View Alignment

Physical misalignment of the two eye views is one of the 3D errors that we know causes discomfort in viewers. View misalignment forces the viewer's brain to work harder to maintain the 3D illusion, and that will ultimately cause discomfort. We can separate view alignment issues into several different categories.

- **Focus mismatch**
  This is caused when one of the two cameras has a different focal setting than the other. At best this error can cause an overall softness in the image and in some cases may cause a disturbing retinal rivalry for some viewers.

- **Field of view mismatch**
  In this type of alignment error the left eye and right eye images are not framed exactly the same. This is typically caused when one camera lens has a different zoom setting than the other. This will almost always result in discomfort for viewers, and can cause extreme discomfort if the mismatch is significant.

- **Geometric alignment**
  There are three types of geometric misalignment that commonly occur during 3D acquisition. One camera can be placed slightly higher or lower than the other camera but is otherwise properly aligned. This creates a vertical misalignment. The second common alignment error occurs when the edges of the images are not parallel. This is called a rotational misalignment. Finally, the cameras can be pointed in slightly different directions on the X axis. This creates a tilt misalignment. Vertical and rotational misalignments can generally be fixed in post production. Tilt misalignments are impossible to fix. All three of these alignment errors cause viewer discomfort. Some viewers are more sensitive to alignment errors than others, so it's important to get the alignment as close to perfect as possible. It is important for the crew to get alignment correct during shooting, as cleaning up alignment errors in post is expensive and time consuming.

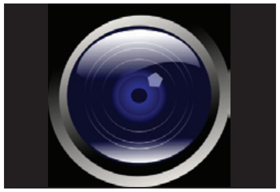
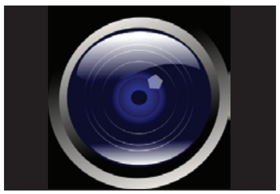
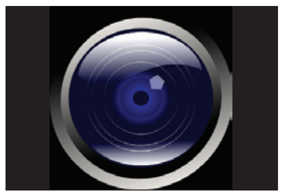
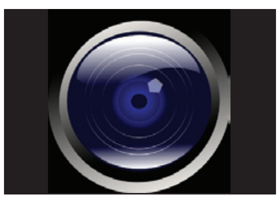
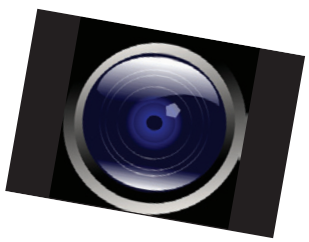
<table>
<tr><th></th><th>Camera A</th><th>Camera B</th><th>Camera A Image</th><th>Camera B Image</th><th>Overlay Image</th></tr>
<tr><td rowspan="2">Field of View Mismatch</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="5">When using lenses with a variable focal length is is possible to create a field of view mismatch. In the graphic above we see that the B camera lens is at a wider focal length than the A camera lens. This results in objects appearing smaller in the B camera. Field of view mismatches can be tricky to diagnose, as create mismatched edges on all sides of an object.</td></tr>
<tr><td rowspan="2">Vertical Misalignment</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="5">In a vertical misalignment one camera is at a different height than the other camera. This results in the the higher camera seeing a slightly lowered version of the image. The resulting 3D image has a vertical misalignment. In a simple vertical misalignment all objects in the frame have the same vertical offset regardless of how far they are from the camera. In our "overlay" view we see that while the A camera and B camera images are vertically offset the offset is the same for the foreground cylclist and the background dog walker.</td></tr>
<tr><td rowspan="2">Rotational Misalignment</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="5">In a rotational misalignment one of the cameras is skewed on the vertical axis. This causes the picture of that camera to rotate relative to the other camera. In our "overlay" view we see that both the foreground cyclist and the background dog walker are rotated in the B camera view.</td></tr>
<tr><td rowspan="2">Tilt Misalignment</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="5">A tilt misalignment occurs when the sight lines of the two cameras are not parallel on the horizontal axis. In the graphic above the B camera is tilted upward. This results in an inconsistent vertical misalignment in the picture. In our "overlay" view we see that the vertical alignment offset is not the same for the foreground and background objects. The image of the foreground cyclist is higher in the B camera, while the image of the background dog walker is lower. Tilt misalignments are impossible to fix completely.</td></tr>
</table>

Image synchronization

It should go without saying that the images from the left eye and right eye have to be synchronized in time. However, this is actually one of the more common 3D alignment errors. It occurs when cameras are not precisely synchronized to each other using reference signals. The synchronization between two cameras is usually referred to as genlock, and it must be present in all 3D acquisition systems. If a 3D acquisition system is not genlocked the cameras will capture each frame at slightly different points in time. This will create a highly uncomfortable 3D error that no amount of post production can correct. It's also easy to temporally misalign the eye views when using external recorders. Sometimes the eye views can start recording a frame or two apart from each other. This type of image synchronization error can be corrected in post production.

Colorimetric Alignment

Color variations are inherent to lenses, mirrors, and cameras. With a single camera, color artifacts are usually subtle to the point of being below the threshold of detection for most viewers. However, when two cameras, lenses, and perhaps a beam splitter mirror are brought together even subtle differences between the camera systems can become obvious. Like all differences between the two eye views, color differences can be distracting or uncomfortable for viewers. They can also cause ghosting on some consumer 3D displays. The editor and stereograher must correct these color discrepancies to avoid causing viewer discomfort.

Defining Convergence, Parallax, and Interaxial

As discussed in the introduction, this guide is not intended to be a tutorial on stereography. However, it's important that everyone involved with the creation of 3D content understand the impact that basic stereography principals can have on the comfort of 3D viewers. The key to the basics of 3D comfort lies in three concepts: convergence, interaxial distance, and parallax.

Convergence of the two eye views is part of human stereo vision. Our eyes rotate inward as they both aim at the object we're trying to look at. In stereography the convergence angle of the cameras determines where objects in the scene fall along the Z axis relative to the screen plane. It's important to understand that changing convergence doesn't affect the amount of total depth in a scene. Changing convergence modifies how much of the scene lies in front of or behind the screen plane. Convergence can be changed during shooting by rotating the cameras on the Y axis. It can also be changed in postproduction by moving the left eye and right eye images horizontally. This technique of changing convergence is referred to as "horizontal image translation." Many in the 3D production community have argued the merits of changing convergence during shooting or only during post production. For some, it has become an argument with almost religious fervor. Both approaches have benefits and drawbacks. But whenever you do it, at some point convergence must be set in order for viewers to comfortably watch.

Parallax is the term used to describe the difference between the left eye and right eye views. Some stereographers also use the term "disparity" to describe this difference. On 3D displays the amount and type of parallax an object has determines where that object appears to fall along the Z (depth) axis. If an object is located at the screen plane than the left eye and right eye view of that object are the same. Therefore an object at the screen plane has zero parallax.

Objects that appear in front of the screen plane have negative parallax. The left eye's image is actually to the right of the right eye's image and vice versa. Objects that appear to be behind the screen have positive parallax. The left eye's image is to the left of the right eye's image. Objects that have positive parallax equal to the distance between the viewer's eyes (their interocular distance) will appear to be in the infinite distance. When we look at objects in the far distance in real life the lines of sight between our eyes are parallel. If a stereographer shoots a scene with the lines of sight of the two cameras parallel, (that is, with no convergence set during shooting), and no changes are made in post, then all of the objects in the 3D scene that are closer than the infinite distance will have negative parallax and appear to be in front of the screen. It's not possible to comfortably view 3D content on television size displays with the cameras set parallel. In order to do so a viewer would need to convince their brain that the screen plane is in the infinite distance. That's difficult to do for a television that's sitting seven feet from you.

While convergence determines where the screen plane falls in the depth of a scene, interaxial distance determines how much depth there is. Interaxial distance is the distance between the center of the two lenses in a 3D camera or rig. Increasing this distance increases the depth in a 3D image. The reason that stereographers need to change the interaxial distance isn't apparent to everyone at first glance. After all, we never change the distance between our eyes and we manage to see 3D just fine. The reason is that our eyes have a constant field of view and a constant relative display size. Our eyes can't zoom in to magnify an image but camera lenses certainly can. In order to deal with these magnification issues the stereographer needs to change the interaxial distance between the two cameras to keep the image from becoming distorted or uncomfortable. If the interaxial distance is fixed it limits how close or far away from the camera objects can be before they start causing uncomfortable levels of parallax.

Parallax and Comfort

Parallax is a key factor in 3D viewing comfort. Too much parallax will cause viewer discomfort. Too little parallax will leave a 3D image looking flat and shallow. Parallax also scales relative to the size of the display. No matter how big a display we're watching our eyes are still 2.5 inches apart. Content with parallax values that a viewer would find comfortable on a 40 inch screen could cause significant discomfort when viewed on a 100 inch screen. The 3D production community has not yet come to an agreement on standards for parallax. The difference in display sizes, viewing distance, individual variation, and the challenges of accurately measuring parallax have contributed to this lack of standards. The impact of display size and viewing distance are discussed in detail in Section 5 of this guide.

Individual variation is a major challenge for producers when they are evaluating parallax. The amount of positive and negative parallax that viewers can tolerate varies significantly between individuals. For this reason it's never a good idea to have a single person determine the parallax settings for a 3D production.

At the time this guide was written, tools for automatically measuring parallax are still in the early stages. Several manufacturers have tools in the market. Some of these tools are useful. A few of them may be accurate. But all of them have some limitations. Automated 3D measurement tools measure parallax by trying to match up pixels between the left eye and right eye views. What comes naturally to our human vision system is a major mathematical challenge for these measurement tools, and they frequently provide inaccurate results. At this point, while 3D measurement tools are a helpful guide, it's best for the 3D content producer to rely on their eyes, the eyes of another, and a ruler to determine the level and comfort of on-screen parallax.

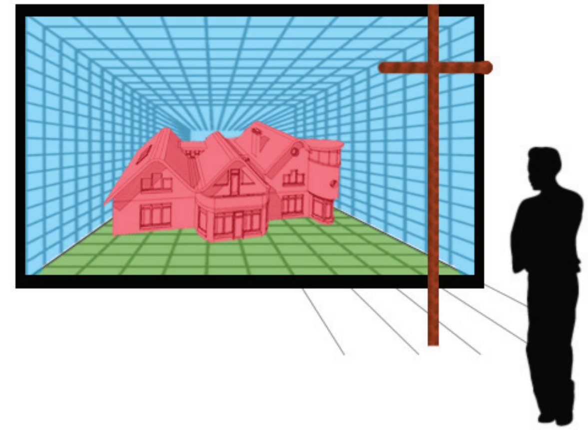
Stereo Window Violations

Our minds perceive 3D displays as a window into a separate 3D world. Objects can be on our side of the glass or on the far side of the glass. When an object is on the far side of the window (in positive parallax), our brain accepts that the object can be cut off by the edges of the window. When objects are on the near side of the window (in negative parallax) our brains don't accept that they can be cut off by the window's edges. We call this 3D error a stereo window violation.

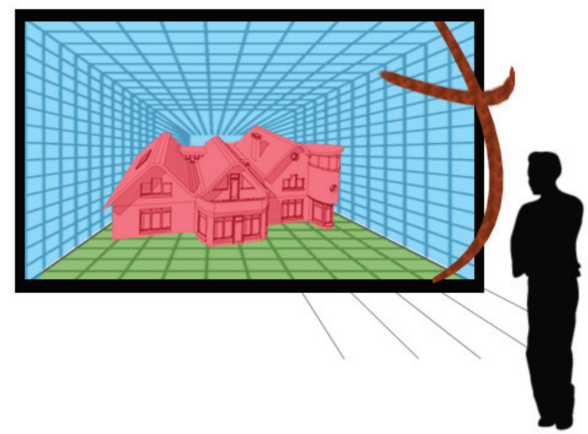
Objects that are in negative parallax should not touch the boundaries of the screen. As an object comes further into negative space it needs to be closer to the center of the screen. When an object in negative space touches the screen's edge it creates a retinal rivalry. One of our eyes can see part of the object while the other eye can't. These retinal rivalries are instantly distracting to viewers and can cause discomfort. At the very least they cause a breakdown in the 3D effect.

Window violations can occur with any screen edge. The most distracting occur on the left and right edges of the screen. Window violations on the top and bottom of the screen are typically less distracting but can ruin the 3D effect and change how viewers perceive the depth in a scene.

Imagine a 3D scene that contains a telephone pole and a house. The house is just behind the screen plane. The telephone pole is well in front of the house and is in the negative space in our 3D scene. However, our shot framing cuts off the top and bottom of the telephone pole. A viewer of our 3D scene will perceive that the telephone pole is at the screen plane, just in front of the house. The top and bottom window violation locks the telephone pole to the screen plane. To some viewers, the pole may appear to be bowing outward towards the negative space.



A perspective drawing of our 3D scene, with the telephone pole out in front of the screen plane in negative parallax



Because the telephone pole is cut off by the screen edges on the top and bottom it appears stuck at the screen plane. Some viewers may perceive the pole as bowing out of the screen and becoming distorted

In general, window violations on the left and right edges cause the most discomfort, but all window violations should be evaluated for how they impact the perception of the 3D scene.

Vergence

Even 3D images that are perfectly aligned and color balanced can cause discomfort for some viewers. A phenomenon that the vision science community calls "vergence/accommodation conflict" can be a common cause of eye strain and discomfort. Watching 3DTV forces our eyes and brain to do things they wouldn't normally do. In the real world our vision system uses two functions, vergence and accommodation, to allow us to see everything in the world, both in focus, and at a proper depth. Vergence is the term for our eye's ability to rotate in opposite directions around a vertical axis. This allows us to converge the lines of sight from both eyes on a specific object. Accommodation is the term for our ability to change the shape of our eye to bring objects into focus. In normal situations these ocular "adjustments" are always tied together. Our eyes converge and focus on the same object, and those two functions define what we're "looking at."

When we're looking at an object on a 3D display, our eyes will converge on the point in space where an object seems to appear. Our eyes will converge on that object whether it appears to be in front of or behind the screen of the display. However, in order to keep the object in focus our eyes have to focus on the screen of the display, as that is where the actual image of the object exists. This de-coupling of vergence and accommodation can reduces viewer's ability to fuse some objects and frequently causes viewer discomfort and fatigue. Every cut or transition forces the viewer's eyes to make the vergence and accommodation adjustment, and that has been shown to cause discomfort in some people. The recent study done by the University of California, Berkeley ("The zone of comfort: Predicting visual discomfort with stereo displays", Shibata et al 2011) found that at typical television viewing distances this can cause more discomfort than at cinema viewing distances. Producers of 3D content can minimize this discomfort by following some simple guidelines.

Vergence and Parallax Shifting Across Cuts

As discussed earlier in the guide, some producers shoot 3D programs in parallel and have all convergence set in post production, and some shoot with the cameras converged. Even programs that are shot with the cameras converged will require the producer to change convergence in post. Since it's difficult to anticipate which shots may be placed next to each other in the editing process, even a well-planned shoot will require some changes to convergence in post to avoid large jumps in convergence across cuts.

To minimize the discomfort caused by the vergence/accommodation conflict discussed earlier, the producer needs to place shots together in a way that minimizes the vergence changes and refocusing of the eyes from one shot to the next. To do this the editor or stereographer needs to match the convergence point of the outgoing shot's subject of interest to the incoming shot's subject of interest as much as possible. This will prevent the viewer's eyes from having to make significant adjustments during the shot change. For example, the subject of interest in a shot appears to be six feet behind the screen (in positive parallax). This shot is followed by a shot where the subject of interest is four feet in front of the screen (in negative parallax). Without adjustments, the viewer's eyes will experience the vergence/accommodation conflict as they find the objects at their proper depth and then shift their focus back to the plane of the screen at the cut.

If large shifts in the convergence are necessary across cuts the editor can use a "convergence dissolve" to minimize the discomfort. By animating the convergence within a few frames of the cut the editor can change convergence in the outgoing shot to bring the subject of interest to a distance of (for example) one foot inside the screen while changing the convergence of the incoming shot to the same point as the outgoing shot so that these objects briefly appear at the same depth from the viewer. After the cut, the editor changes the incoming shot's convergence to return the subject of interest to its original setting. The editor can gradually change the convergence over the span of just a few frames, depending upon the nature of the adjustment being made. By making this subtle change in post-production we can reduce the possibility of inducing eye strain and fatigue in the viewers.

Occlusion and Text Placement

Occlusion, or one object blocking the view of another, is our strongest depth cue. If our view of a tree is blocked by a fence post, the fence post MUST be between us and the tree. Nothing in the real world violates this visual rule. However, it's all too easy to violate it when making 3D content. Violating the occlusion depth cue is a sure way to distract and confuse your viewer.

Text and Graphic Object Placement

Placing text or graphic objects in stereo content requires more care and attention than placing those objects in 2D. In 2D, text and graphics only need to be placed in a horizontal (X) and vertical (Y) position. Some placements have become so well established that they are described by their position on the screen. In the television production community a graphic identifying the person on screen is commonly called a "lower third," as that's where it is almost always placed on the screen. In 3D, the content producer also needs to place text and graphics somewhere in depth, giving them a Z position in addition to their X and Y position. The Z placement of the graphic or text has a major impact on 3D comfort.

Depth Placement

The first rule for placing text or graphics is not to violate the occlusion depth cue. If a graphic is placed on top of an object in the 3D image it MUST also be closer to the viewer in Z space than the object it is occluding. At first there seems to be a simple solution for always obeying this rule: always put the text way out in front of the screen, and nothing will possibly come in front of it, right? That solution has challenges of its own. Text and graphics elements should appear to be just "in front" of any video objects immediately surrounding them. For example, if objects in the video content have a slight positive disparity (meaning that they are perceived to be just "behind" the screen) then it would be ideal for the editor or stereographer to place graphic or text objects right at the screen plane (zero parallax between L/R images).

Text objects at the screen plane have the added benefit of eliminating possible ghosting effects that occur when stereo graphics and text are presented on some direct view displays.

Dynamic Depth Placement

Viewers expect that stereo video objects will move in Z space. When viewers see objects located near the X and Y position of graphics or text, the stereographer or editor should dynamically position graphic elements to remain just in front of the surrounding objects. If the object the graphics are covering comes forward, the graphics would need to come forward with it. This gets challenging when a graphic stays on screen during a shot change. The graphic may have to be repositioned to avoid occlusion conflicts in the new shot. If the editor or stereographer has to change the disparity of the text or graphic from shot to shot they should ease the transition so that the viewer will have less trouble fusing the stereo images.

The Color and Contrast of Text and Graphics

Typical 2D content often contains yellow or white text with luminance values above 50%. These levels may not be the best choice for text on today's 3D displays. As discussed in Section 5, many of today's 3D displays are prone to ghosting. High contrast text with high luminance values and certain color palettes can cause ghosting on 3d consumer displays. This artifact makes it difficult for the viewer to fuse the images and contributes to discomfort and eye strain.

SEVEN: Tips for 3D Post Production

Even with the best planning, training, and checking, 3D shots still can go wrong. It then becomes the job of the editor and stereographer to correct these shots during the stereo sweetening phase of post production. This next section of the guide provides advice on how to correct 3D shots in post.

3D Shot Correction

Geometric Alignment Errors

Alignment errors are one of the more common 3D shot problems that make their way to post production. 3D rigs are complex and temperamental and it's easy for even a trained crew to get a few shots out of alignment. Some alignment errors are relatively simple to correct in post. Vertical or rotational alignments can be corrected using the DVE tools in the editor. Most 3D editing systems have tools that do this easily, and some even have tools that correct simple alignment errors automatically. Compound alignment errors can be harder to diagnose and fix. It's easy enough to look at the two images and see a straight vertical misalignment. It's much harder to diagnose the problem when that vertical alignment is mixed with a slight field of view misalignment and some rotation. Most 3D editing systems have visualization tools that make these alignment errors more visible. Difference maps, anaglyph views, checkerboard views, and wiggle modes can all make alignment errors easier to see and diagnose. If you're having a hard time diagnosing an alignment problem, start with viewing the shot in a wiggle mode if the editing system has this feature. The wiggle mode quickly alternates between showing the left eye and right eye view. It generally makes it easier for your eyes to quickly see the difference between two shots. Be careful about relying on automated tools to diagnose alignment issues. The best automated 3D measurement tools can sometimes detect and identify simple alignment issues but often fail to properly diagnose complex alignment problems.

A few types of geometric alignment errors can't be corrected. Vertical tilt misalignment can't be corrected, as the vertical misalignment is inconsistent throughout the shot. Adjusting the vertical alignment for one object will throw objects in front of or behind that object out of alignment. If the tilt misalignment is severe the shot may need to be placed in the sequence as 2D or replaced. Focus misalignments are also impossible to fix. One eye is typically in clear focus while the other eye is out of focus. Adjusting the sharp eye to match the bad eye is possible, but undesirable. Sharpening the blurry eye doesn't usually work. Again, the best option here is probably to replace the shot.

Colorimetric Alignment Errors

Color correcting one eye view to match the other is a necessary part of the stereo sweetening process.The inherent differences between cameras and lenses always apply some color shifting. Beam splitter mirrors also tend to apply a hue to at least one of the eyes. Most producers start the stereo sweetening process by doing a base grade to bring the two eye views back into relative color alignment.

Other types of colorimetric alignment errors can also occur. Exposure mismatches are common when using cameras that don't have properly synchronized iris controls. These are typically easy to fix unless one of the eyes is overexposed to the point of clipping. Clipped highlights can't be recreated. Typically shots with clipped highlights or lowlights need to be rendered as 2D or replaced.

Window Violations

Stereo window violations can be distracting to viewers (See Section 6 for a definition). Not all window violations are equal. Window violations that touch only the top or bottom of the frame may not be an issue. When a window violation is distracting or uncomfortable it needs to be removed from the program. There are three basic techniques for correcting window violations. The illustration on the next page shows each of these three techniques.

The first is to change the convergence point in the shot so that the offending object comes behind the screen plane. This may not be an option, as moving the convergence point forward will increase the parallax of all of the objects in the positive space. This may cause excessive positive parallax and divergence.

	Left Eye Right Eye	Overlay	Notes
Original Image with Violation			The man's shoulder coming into the shot on the left edge creates a window violation. The shoulder is in negative parallax (in front of the screen plane), but is being cut off by the left screen edge. This creates a retinal rivalry, as more of the shoulder is visible in the left eye than in the right eye. Retinal rivalries are distracting and uncomfortable for viewers.
Adjust Convergence			One approach to correcting the window violation is to change the shot's convergence point in post. If we change the convergence so that the man's shoulder is now at the screen plane (no ghost in the overlay image) we no longer have the window violation and its distracting retinal rivalry. But by changing the convergence point and moving it towards the viewer we've increased the amount of positive parallax in the picture. Look at the difference in parallax on the telephone pole. Making large changes to convergence may increase parallax to points where it becomes uncomfortable for viewers.
Crop out Violation			Another approach to correcting the window violation is to crop both the left and right eye images to remove the offending object. In this example we've cropped out the man's shoulder and blown up both the left and right eye's images to fill the screen. The images have become somewhat softer due to the increase in size, but there is no longer a window violation in the shot. While cropping and blowing up shots also increases parallax, in this case it increased it less than changing the convergence. Again, look at the difference in the parallax on the telephone pole in the center of the shot.
Floating Window			The final approach to correcting the window violation is to use a floating window. The floating window technique adds a black bar to the eye view that is showing more of the offending object. The black bar crops out the area of retinal rivalry, making the same amount of the object visible in both eyes. In our example here we've added the black bar to the left edge of the left eye view, removing the part of the man's shoulder that was creating the retinal rivalry. While the floating window is effective in the cinema, the brighter viewing environment of the home makes it less effective on 3DTVs.

The second choice is to reframe the shot to cut out the offending object. If the object is close to the edge, blowing the shot up slightly can cut it out of the picture entirely. The downside of this approach is the loss of resolution from the zoom and the magnifying effect that zooming will have on the amount of parallax in the shot. If the shot already had borderline high amounts of positive or negative parallax, applying a digital zoom may push those parallax levels into the uncomfortable range.

The final and least preferable choice is to add floating windows to the picture. Floating windows are a common technique in 3D editing for the cinema. They don't work as well on television displays. A floating window cuts off the offending object in one eye by placing a black bar on one edge of the picture. This makes it seem like the screen plane is at an angle to the viewer. In the theater, where audiences watch 3D in near total darkness, this technique is almost imperceptible. On television displays the effect is far less subtle and may be just as distracting as the window violation. If none of these approaches work, the shot will need to be replaced or rendered to 2D.

Standards and Frame Rate Conversion

3D standards conversion is not simple or easy. We've come to take standards and frame rate conversion for granted in SD and HD production. In the past few years the technology has come to the point where good standards conversion technology has made standards conversion artifacts are imperceptible to most viewers.

The necessity of keeping every frame of the two eye views perfectly synchronized makes standards conversion far more difficult in 3D. The typical frame blending and repeating that is a normal part of standards conversion can create painful retinal rivalries if the blending and repeating frames don't occur at the same time in each eye. At the time this guide was written 3D standards conversion can only be done using a small set of highly specialized tools. Because of this, producers of 3D content should avoid building workflows that rely on format conversion.

Notes:

The networks have provided 3D producers with two options for delivering program masters. Producers can deliver on HDCAM SR tapes or deliver digitally using DPX file sequences.

DPX File Delivery

The DPX format is the current option for file based delivery. The DPX file format is commonly used for master delivery by the digital cinema industry. Each DPX file contains a single frame of video. DPX files are grouped together into sequentially numbered series of thousands of frames. A 43 minute program in the 1080p 23.98 standard contains around 62,000 DPX files for each eye. The DPX standard has many different file parameters that allow flexibility across a wide range of content types. Those parameters need to be set to specific values for the files to work properly for the network.

The network's current policy requires that productions deliver DPX files on hard drives. The drives must be formatted as FAT32 or NTFS. Some operating systems limit the number of files that can be put in a single directory of a FAT 32 volume. On most versions of Windows that limit falls far short of the 62,000 files needed to deliver a single eye view of a program. For Microsoft Windows systems the NTFS file system is a better choice for drive formatting. The network requires the drives to be self contained. Bare drives or individual drives out of a multi-drive enclosure won't work. The drive also needs to have a Firewire interface. All power and interface cords need to be included in the packaging with the drive. You need to ship drives in protective containers to prevent physical damage to the drive.

The network also requires data verification for programs delivering on drives. When you're copying thousands of relatively small files from one drive to another it's easy for files to be corrupted or missed. Data verification helps to prevent these errors. The network requires that drives be verified using an MD5 checksum. The MD5 checksum is a data management tool that looks at a file's contents and generates a 128-bit value for that file. If the file's contents change, the MD5 value would also change. Producers are required to include MD5 checksum files on the drive along with the DPX sequences. Running MD5 checksums on 124,000 files can take a considerable amount of time, but it verifies that the copying process has not introduced errors or data corruption.

Table 8.1
DPX File Parameters

DPX Parameter	Network Requirement	Comments
Image Size	1920 x 1080	
Colorimetric Specification	Code 6: ITU-R 709-4	This setting tells the importing system what gamma and color space were used to create the file. Setting it improperly causes other systems to map the colors and luminance levels improperly.
Bit Depth	10 bits (integer)	While some in the cinema community use 16 bit DPX files for exchange, 10 bit files are more than adequate for television content.
Byte Order	Big Endian	A file's "endianness" describes the order the bytes are written in. Big endian files have their most significant byte written first, while little endian files start with their least significant byte.
Timecode	Valid SMPTE timecode header for each frame	DPX files can carry timecode, with each individual DPX file given a separate timecode value.
Pixel Aspect Ratio	1:1 (square)	

HDCAM SR Tapes

Producers can also deliver masters on HDCAM SR tapes. The network requires two tapes: one for the left eye view and one for the right eye view. The tapes must be recorded in the single channel 4:2:2 mode. The network requires that tapes have matching timecode.

The HDCAM SR format has the capability to record both eye views on a single tape while running the tape at double speed. SR tapes recorded in that format are often referred to as "dual stream" tapes. At the time this guide was written dual stream tapes were not an accepted delivery format for the networks.

Footage

The producer is responsible for delivering footage to the network in its native form. If the program was shot using tape based systems then the producer can provide the original tapes. When a program is shot using file based recording systems those files must be delivered in their native format. Cameras and external recorders usually capture file based footage to fast and reusable flash based storage. Delivering flash cards or solid state drives (SSDs) to the network would be impractical.

Producers should follow some simple guidelines when delivering file based footage to the network. First, the producer should deliver the media on an external Firewire drive. Just as with the delivery of electronic program masters, the drive must be provided in a protective case along with all needed interface and power cords. Second, the footage files should be preserved just as they came out of the camera or recorder. If the footage was originally recorded on flash memory that was formatted as a FAT32 volume the hard drive that the producer uses for delivery should also be formatted as FAT32. If the original footage was recorded in a specific folder format and hierarchy then that format and hierarchy must also be maintained. Many post production workflows require the footage to be transcoded to another format for editing. Even if that is the case, the network delivery policy requires the producer to deliver the files in their native form, not the transcoded product file.

NINE: Glossary

The 3D@Home Consortium created this glossary of terms commonly used when discussing 3D images. The glossary is used in this guide with the permission of the Consortium.

Aberration – An imperfect image formed by an optical system.

Accommodation – The physiological process that alters the shape of the lens of the eye and thereby the optical power of the eye so as to form a clear image of an object at both near and far distances.

Accommodation-Convergence Reflex – The physiological link that causes the eyes to change focus as they change convergence Accommodation-Convergence Rivalry – A discrepancy between accommodation and convergence depth cues in which one of the depth cue impacts perception to a greater extent than the other.

Artifact (Artefact) – A visual or perceptual defect introduced during capture, post-processing, compression, transmission, rendering, or display.

Barrel Distortion – An optical aberration caused by decreased magnification at increasing distance from the optical axis. Also known as a Fisheye Effect.

Binocular Artifact – A visible defect that is perceptible when using both eyes but imperceptible when using a single eye.

Binocular Depth Cue – A depth cue that involves both eyes. Binocular parallax and convergence are binocular depth cues.

Binocular Parallax – The phenomenon in which the position of an object appears to change when viewed by the left eye alone and then the right eye alone, or vice versa, when the head is stationary.

Blockiness – Regularly spaced vertical and horizontal visual discontinuities, typically observed in content that was highly compressed using block DCT-based codecs such as MPEG2 and MPEG4/AVC.

Blur – Loss of visual detail and sharpness of edges, typically the result of optical blur, reduced resolution, noise filtering, or deblocking filters used in MPEG4/AVC.

Brain Shear – As defined by James Cameron: "The brain's inability to reconcile the images received by the left and right eyes into a coherent stereo image, which causes it to send corrective messages to the eye muscles, which try to compensate but can't fix the problems baked into the image on the screen, creating an uncomfortable feedback loop and physical fatigue of eye muscles, which causes the eye muscles to scream at the brain, at which point the brain decides to fuse the image the hard way, internally, which may take several seconds or not be possible at all –- all of which leads to headache and sometimes nausea."

Cardboard Effect – The condition in which objects appear as if cut out of cardboard and lack individual solidity. Usually the result of inadequate depth resolution arising from, for example, a mismatch between the focal length of the taking lens, the stereo base and/or the focal length of the viewing system.

Chroma Mismatch – A situation in which the chromatic composition of an object(s) in the left-eye image is not the same as that of the right-eye image. See also Color Mismatch.

Chrominance Mismatch – A situation in which the color, hue, or saturation of an object or scenes in the left-eye view is different than in the right-eye view.

Cognitive Dissonance – An uncomfortable mental state brought on by contradictory perceptions or ideas. According to the theory of cognitive dissonance, people will be motivated to act in a way that reduces or eliminates the sources of contradictory perceptions.

Color Mismatch – A situation in which the color of an object(s) in the left-eye image is not the same as that of the right-eye image. See also Chroma Mismatch.

Compressed Depth Artifact – Any visible artifact that results from the digital compression of a depth map.

Convergence – The ability of both eyes to turn inwards together. This enables both eyes to be looking at the exact same point in space. This skill is essential to being able to pay adequate attention at near to be able to read. Not only is convergence essential to maintaining attention and single vision, it is vital to be able to maintain convergence comfortably for long periods of time. For good binocular skills it is also to be able to look further away. This is called divergence. Sustained ability to make rapid convergence and divergence movements are vital skills for learning.

Crosstalk – Incomplete isolation of the left and right image channels so that one leaks (leakage) or bleeds into the other. Looks like a double exposure. Crosstalk is a physical entity and can be objectively measured, whereas ghosting is a subjective term. See ghosting.

Depth Budget – The maximum amount of depth consistent with comfortable stereoscopic fusion. The depth budget depends on the size of the display and location of the viewer.

Depth Change Stress – A physiological and perceptual condition that results from frequent, abrupt, or extreme depth cue changes such as might occur at scene changes or ad insertion points.

Depth Conflict – A visual artifact in which depth cues are incongruent, which can give rise to the percept that an object resides both in front of and behind another object simultaneously. This artifact may be seen more frequently in poorly coded graphic overlays.

Depth Cue – Any of a number of visual characteristics that create a sense of depth in natural environments and in stereoscopic representations. Depth cues can be monocular, such as occlusion, or binocular, such as convergence. Depth cues include: occlusion, motion parallax, binocular parallax, linear perspective, atmospheric perspective, relative size, shadowing, accommodation, and binocular disparity.

Depth Cue Rivalry – A situation in which two or more depth cues are in conflict by suggesting different apparent depths for the same object or region of an image. Depth cue rivalry may sometimes be observed in connection with graphic overlays.

Depth Discontinuity – An abrupt and crisply delineated change in apparent depth that creates a sense of distinct objects.

Depth Distortion – Any artifact that creates a sense of false depth.

Depth Map – A set of values that provide data related to the depth of each pixel or region in a stereoscopic image. Depth Map is often confused with Disparity Map or Difference Map, both of which provide other kinds of data.

Depth Script – A scene-by-scene stereographic plan used in the creation of content.

Difference Map – A set of values that provide data on the pixel-by-pixel difference between a left-eye image and a right-eye image. Difference Map is often confused with Disparity Map or Depth Map, both of which provide other kinds of data.

Diopter – Unit of measurement of the optical power of a lens or curved mirror. Equal to the reciprocal of the focal length.

Diplopia – 'Double vision'. In stereo viewing, a condition where the left and right homologues in a stereogram remain separate instead of being fused into a single image.

Discrepancy – A noticeable mismatch between the left- and right-eye images.

Disparity Map – A set of values that provide data related to the pixel-by-pixel disparity between homologous features in a left-eye and right-eye image. Disparity Map is often confused with Depth Map or Difference Map, both of which provide other kinds of data.

Disparity – The distance between conjugate points on overlaid retinas, sometimes called retinal disparity. The corresponding term for the display screen is parallax.

Display Artifact – A visible defect that results from the physics or signal processing of the display apparatus.

Distortion – In general usage, any change in the shape of an image that causes it to differ in appearance from the ideal or perfect form. In stereo, usually applied to an exaggeration or reduction of the front-to-back dimension.

Divergence – The converse of convergence. The situation in which the optical axis of the left and right eyes move outward away from parallel. Divergence is most likely to be associated with objects placed at extreme distance in the Z axis.

Dwarfism – See Lilliputism.

Edge Distortion – Any visible artifact that creates an unnatural appearing edge or boundary typically caused by optical mismatch or compression artifacts.

Edge Violation – A visual artifact that can arise when part of an object near the edge of the display is represented in the left-eye image but is not represented in the right-eye image or vice versa.

Extrastereoscopic Cues – Those depth cues that are appreciated by a person using only one eye, also called Monocular Cues. They include occlusion, interposition, geometric perspective, motion parallax, aerial perspective, relative size, shading, and textural gradient.

False Depth – A visual artifact in which an object or part of an object appears to be at a depth that is in unnatural given the context of the scene. This artifact may be more common in 2D-to-3D conversions.

Fisheye Effect – see Barrel Distortion.

Fixation Point Conflict – A situation in which a scene or image has numerous objects, graphics, and focal points that cause a viewers gaze to flit and wander excessively.

Floating Window – A set of cropping masks applied asymmetrically to the left- and right-eye images to avoid window violations and give the appearance of a virtual window at a depth other than the screen depth.

Focal-Length Mismatch – characterized by a radial interference pattern when L-R images are viewed overlaid. This can be a vexing source of brain shear.

Focus Mismatch – An optical or signal processing artifact in which the focus of the left- and right-eye images are not the same.

Focus-Fixation Mismatch – A situation in which a viewer's visual attention is drawn to an object or feature that is out of focus, typically as the result of the use of a narrow depth of field in a stereoscopic image.

Fusion – The merging (by the action of the brain) of the two separate views of a stereo pair into a single three-dimensional (or Cyclopean) image.

Geometric Distortion – Any visible artifact in which apparent magnification varies spatially within an image. Common geometric distortions include barrel and pincushion distortion.

Ghosting – A condition of incomplete stereoscopic fusion that results in the perception of a double image. See also Crosstalk, which is an objective physical phenomenon as opposed to ghosting which is a subjective phenomenon.

Giantism – Jargon term for the impression of enlarged size of objects in a stereo image due to the use of a stereo base separation less than normal for the focal length of the taking lens(es). See also hypostereo.

Horizontal Image Translation (HIT) – The horizontal shifting of the two image fields to change the value of the parallax of corresponding points.

Horopter – The surface in space that contains all points whose images stimulate corresponding retinal points; i.e., that all have zero disparity. (Lambooij, et al., 2009).

HVS – acronym for Human Visual System.

Hyperstereoscopic – Use of a longer than normal stereo base in order to achieve the effect of enhanced stereo depth and reduced scale of a scene; it produces an effect known as Lilliputism because of the miniaturization of the subject matter which appears as a result. Often used in order to reveal depth discrimination in architectural and geological features. The converse of hypostereo.

Hypostereoscopic – Using a baseline that is less than the distance between the left and right eyes when taking the pictures. This exaggerates the size of the objects, making them look larger than life. It produces an effect known as Giantism. The converse of hyperstereo. A good use for this would be 3D photographs of small objects; one could make a train set look life size.
Inversion – The visual effect achieved when the planes of depth in a stereograph are seen in reverse order; e.g., when the left-hand image is seen by the right eye, and vice-versa. Often referred to as pseudostereo.

Lilliputism – Jargon term for the miniature model appearance resulting from using a wider-than-normal stereo base in hyperstereography.

Linear Perspective – An image formation phenomenon and perceptual depth cue in which, for example, lines that are parallel in 3-dimensional physical space appear to converge.

Luma Mismatch – A situation in which the luma of an object(s) in the left-eye image is not the same as that of the right-eye image.

Misalignment – In stereo usage, a condition where one eye's view is rotated, tilted, raised, or lowered relative to the view of the other eye. Misalignments contribute to viewer discomfort.

Monocular Artifact - A visible defect that can be detected solely using either the left or right eye.

Monocular Blur – Image softness or lack or resolution that is limited to either the left- or right-eye view such as may occur as the result of asymmetric or multi-resolution coding.

Monocular Depth Cue – See Extrastereoscopic Cues.

Motion Parallax – The visual phenomenon and perceptual depth cue in which the relative position of foreground and background objects change as a function of distance from the viewer when the viewer's head moves.

Negative Parallax – A situation in which a feature in the left-eye image is to the right of the corresponding feature in the right-eye image, which causes the eyes to converge to a point in front of the display, which causes the feature to appear to be in theater space.

Occlusion – The image formation phenomenon and depth cue in which nearer objects block all or part of more distant objects.

Orthostereoscopic – An image capture system that mimics the binocular geometry of human vision, including interocular distance.

Panum's Fusional Area – The small area around the horopter where sensoric fusion takes place. (Lambooij, et al., 2009).
Parallax – The change in the apparent location of an object or features as viewing position changes. See also Binocular Parallax and Motion Parallax.

Percival's Zone of Comfort – An optometric rule of thumb for the viewing of stereo stimuli; it is the approximate range of vergence and accommodation responses for which the viewer can fuse images without discomfort. (Banks, et al., 2008).

Perspective – see Linear Perspective

Perspective-Stereopsis Rivalry – Any inconsistency between binocular depth cues and perspective that can lead to ambiguous interpretation of depth.

Positive Parallax – A situation in which a feature in the left-eye image is to the left of the corresponding feature in the right-eye image, which causes the eyes to converge to a point behind the display, which causes the feature to appear to be in screen space.

Psuedostereo – The effect produced when the left view image and the right view image are reversed. This condition causes a conflict between depth and perspective image.

Psuedoscopic – The presentation of three-dimensional images in inverse order, so that the farthest object is seen as closest and vice-versa: more correctly referred to as inversion. Achieved (either accidentally or deliberately, for effect) when the left and right images are transposed for viewing.

Puppet Theater Effect – A phenomenon in which objects appear smaller than their familiar size, caused by conflict between the binocular cues, perspective cues, and prior knowledge of the sizes of familiar objects.

Retinal Rivalry – The simultaneous transmission of incompatible images to each eye.

Reverse 3D – see Pseudostereo.

Rotation – Misalignment of the images caused by the cameras not being level on the X axis. This results in the left eye and right images not being parallel.

Shear Distortion – The phenomenon by which the relative positions of objects in a stereoscopic image appear to change with the change in the viewer's position.

Size Distortion – see puppet theater effect, gigantism, and lilluptism.

Stereo Acute – The ability to perceive stereoscopic depth cues. Inability to perceive stereoscopic depth cues is known as Stereoblindness.

Stereoblindness – The inability to perceive stereoscopic depth cues. Common causes of stereoblindness include strabismus and amblyopia. Normal stereoscopic vision is also known as Stereo Acute.

Stereoscopic Latency – The amount of time between the presentation of a stereoscopic stimulus and the perception of depth by a typical viewer.

Strabismus – A disorder in which the eyes do not line up in the same direction when focusing. As a result, the two eyes fail to focus on the same image thereby compromising or completely eliminating binocular depth perception. Strabismus is a leading cause of amblyopia, also known as "lazy eye," which is the loss on one eye's ability to see detail.

Stutter – Irregular pauses or repeated pictures that result in non-smooth motion.

Sweet Spot – The viewing distance and position that produces the optimal stereoscopic experience free from excessive convergence, cross talk, ghosting, psuedostereo, or other artifacts.

Synchronization Error – A situation in which the left- and right-eye images or frames are not presented simultaneously.

Temporal Mismatch – see Synchronization Error.

Vergence-Accommodation Linkage – see Accommodation-Convergence Reflex.

Vergence-Accommodation Conflict – see Accommodation-Convergence Rivalry.

View Discrepancy –The situation in which the left-eye image contains visible details or features that are not present in the right-eye image, or vice versa. Reflections are a common source of View Discrepancy.

Vertical Disparity – The situation is which the corresponding points the left- and right-eye images are not coincident along the vertical dimension.

Viewer Discomfort – A feeling of unease or fatigue that can sometime result during stereoscopic viewing. Several causes of viewer discomfort have been proposed, including: rapid changes in accommodation and convergence; depth cue conflicts; and unnatural blur. (See Banks, et al., 2008 and Lambooij, et al., 2008).

Viewer Fatigue – A condition of eye strain and/or reduced ability to achieve binocular fusion that can sometimes result during stereoscopic viewing. Several causes of viewer fatigue have been proposed, including: rapid changes in accommodation and convergence; depth cue conflicts; and unnatural blur. (See Banks, et al., 2008 and Lambooij, et al., 2008).

Window Violation – A depth cue conflict that can arise when part of an object is cut off by the edge of the display. In the case in which the object has a disparity that would make it appear to be in front of the screen, the part of the object that is cut off by the edge of the display may also be interpreted as occlusion by the viewer: i.e., the disparity and occlusion depth cues would be in conflict. Window violations can be addressed by use of Floating Windows.

Zero Parallax – A situation in which a feature in the left-eye image is in the same place as the corresponding feature in the right-eye image, which causes the eyes to converge to a point on the display, which causes the feature to appear to be at the same depth as the display.

Zone of Clear Single Binocular Vision – The set of vergence and focal distances for which a typical viewer can see a sharply focused image; i.e., it is the set of those distances for which vergence and accommodation can be adjusted sufficiently well. (Banks, et al., 2008).

Zone of Comfortable Viewing – see Percival's Zone of Comfort.

Zoom Mismatch – see Focal-Length Mismatch.

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