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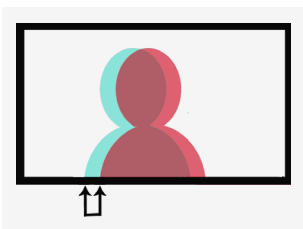
Shannon Benna

Systems and Practices to Produce Stereoscopic Space on Screen

When we as filmmakers, photographers and artists try to create an image, we are bound by the technical constraints of the machines or mediums we use. Through increasingly complex mechanisms or processes, we have been able to reproduce the images we perceive with our eyes more and more realistically. We have also been able to manipulate images to express an imagined aesthetic, intended to convey an artistic vision, an emotion, or a forced perception designed to inspire sympathy/empathy for an unusual perspective. Whether we are discussing black and white, color, still, moving, realistic, fantastical, 2D, or **stereoscopic 3D images**, we must not only consider how the image is technically created, but also how it is delivered to the viewer. An image viewed on a small, personal screen (like a tablet or cell phone) will create a different relationship with the viewer than the same image viewed on a theatrical screen. Likewise, a shared viewing experience in public will create a different response than one experienced via a virtual reality (VR) headset.

As a filmmaker who has worked in both 2D and 3D media, I find that although 3D imaging provides an avenue to recreating the most realistic version of the world that we see every day, it is not always presented in a way that gives the viewer a real-to-life experience. Additionally, stereoscopic 3D can provide a way for an artist to create a fantastical world-view and present an alternate version of reality

to the viewer. I think this is more often the way stereoscopic 3D has been used, however, I don't think it is always because it was the intent of the creator, but due to the way the content is delivered to the viewer. For example, if you create a 3D image that is true-to-life in depth and scale, accurately recreating the way the average person would view another person, or an **orthostereo** image, you must also present it to the viewer in such a way that they are viewing the image from the same position that the camera was capturing it, and without their being aware the image is being projected. Then the viewer would be unaware they were experiencing an optical illusion. Whereas, if an orthoscopic image is projected onto a screen in a theater, the viewer experiences the image as part of an audience, as opposed to as an one-on-one experience, and the image is now larger than life in scale, rendering it no longer realistic, but fantastical. With the advent of modern immersive media we are given the opportunity to place viewers inside of the world of our choosing in a whole new way. Although VR can give us a complete sphere to visit, only with stereoscopic imaging can the environment become truly immersive in the sense of granting the individual a real-life perception opportunity. Via this presentation method we can engage a viewer in an orthoscopic version of an alternate reality, whether it is realism or fantastical, allowing for a whole new way for artists to connect with their audience.



1 Parallax, R/C (all images marked R/C can be viewed stereoscopically with red/cyan anaglyph glasses).

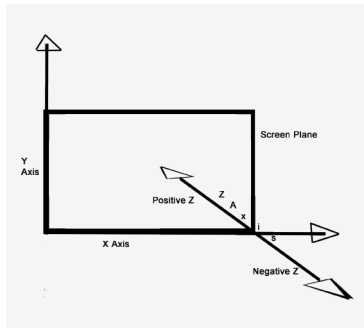
Therefore, to utilize stereoscopic imaging to its fullest capability, we must understand its technical constraints and requirements and we must make a conscious decision about the intended purpose of the images from the beginning. We must not only go through a procedure that ensures the images we create will be viewable as 3D images, and not cause pain or nausea to our viewer, but also choose the right set of tools to capture and deliver our images, accurately expressing our intentions towards reality or fantasy and immersion vs. presentation. Then, once we have chosen our toolset, the subtle adjustments we make to the settings of our tools will convey the emotional and physical sensations we intend, as well as the perspective we present, including the immersive, intimate, spectator and/or voyeuristic quality of the images.

As both a practitioner and an educator of stereoscopic 3D imaging and media production, I believe the key to this and any discipline is communication. Herein lies a bit of a problem, as our terminology is not truly standardized. There are multiple ways to refer to the same effect, error, process, or action, which are not only diversified between production teams or academic institutions, but also between stages of production. The way one speaks of 3D in pre-visualization, development and appreciation is often different than the terminology used in production, or in post-production. There isn't even consistency between editorial, finishing, and conversion, which are all post-production practices. To aid us in this publication, any terms will be typeset in a visually different manner for ease of recognition. There is a glossary of terms and accompanying illustrations to facilitate comprehension as well.

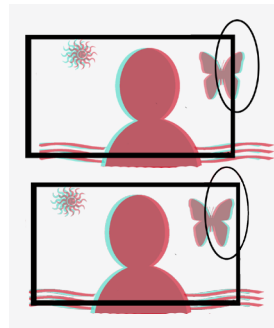
Rules for Creating and Manipulating Stereoscopic Space

To begin, one should understand the basic premise behind stereoscopic imaging. It requires two images, a left and right, representative of and ultimately delivered to each of the viewer's eyes, discretely. As we all see in three dimensions everyday (unless we are part of the 6–12% of the population that suffers **stereo blindness**, or an inability to see in depth) we are pre-equipped with the firmware in our brains to take in these two separate right and left eye images and **fuse** them into an all-encompassing perception of space, complete with volumetric objects living at some distance from us physically. This process is called **stereopsis**, and those who can perceive depth possess **binocular vision**.

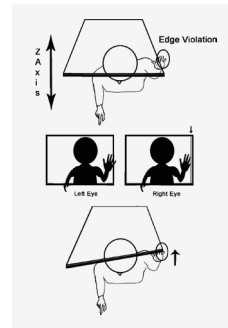
The amount of separation between the eyes is known as **inter-ocular [IO]** separation, while the distance between the imaging sensors is known as the **inter-axial [IA]** distance. These terms are often used interchangeably and are measured in a variety of different units: inches, centimeters, percentage of screen size, and pixels. Although it may seem extreme, we *are* concerned with pixel accurate measurements, as this can mean the difference between an image that is comfortable to view, and *too deep* for the average person to fuse. Through stereoscopic imaging we are able to *trompe l'œil* or fool the eye into believing these two images, captured from two slightly different perspectives are actually a three dimensional object, landscape or world. The wider the separation between the same object in each of the images when overlaid, or **parallax** (fig. 1), determines the amount of depth in the image. Too much parallax can render the image unresolvable, as the eyes would be forced to **diverge** or strain towards the periphery in order to attempt to fuse the stereo pair into a single image.



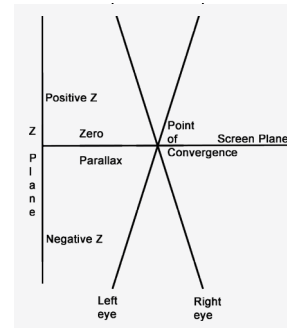
2 Z-Space.



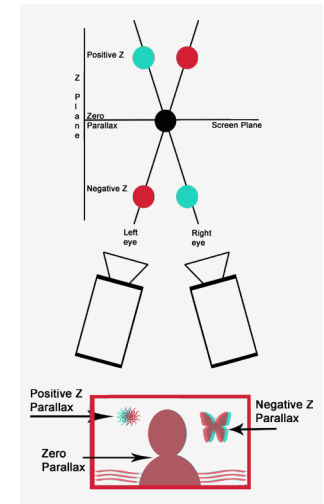
3 Edge violation above, correct framing below, R/C.



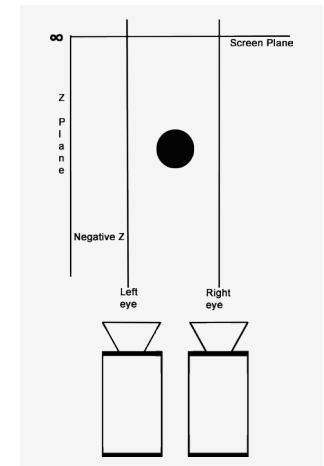
4 Floating window correction.



5 Convergence in stereo-space.



6 Parallax separation in 3D image, R/C.



7 Shooting Parallel.

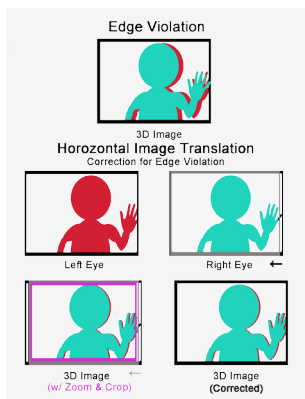
Along with being able to control the amount of depth in a stereoscopic image, we are also able to choose where objects are placed in relation to the screen plane, or where they are placed along the Z axis (fig. 2). Objects behind the screen plane are in **positive Z space**, while objects that are in front of the screen, or float into the audience's space are in **negative Z space**. It is often difficult to perceive the actual screen plane, and in some cases, especially VR presentation, the screen plane does not truly exist. We do use the concept of the screen plane to describe **zero parallax**, for ease of discussion, especially while creating images and using traditional on-set monitors.

If an object is intended to be positioned in negative Z space, it must not be clipped off in any unnatural fashion but be imaged as a whole. If part of the object exists off screen it must also be in positive Z space. If the object/subject is both partially off screen *and* in negative Z space, the effect is called an **edge violation** (fig. 3) and causes confusion in the brain. A person or thing *cannot* be simultaneously outside of a window and inside at the same time without being angled.

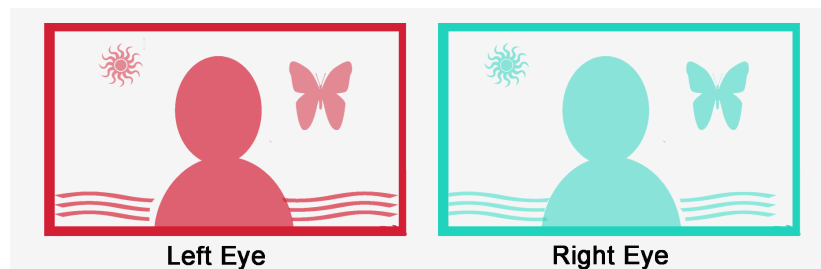
We can angle the screen plane to accommodate this creative choice by employing a **floating window** (fig. 4), or a black mask that is applied to the side of one eye to bevel that side of the screen plane backwards in space. This technique is used exclusively in a traditional presentation method, in VR there is no *off-screen*, and thus no **stereo window** to consider.

Objects that appear at the screen plane are at zero parallax and are considered to be the point of **convergence**. The point of convergence is the point at which our eyes cross when we naturally observe the world (fig. 5), or where the two imaging devices' lines of sight cross when capturing images. If we choose to set convergence during the initial imaging stage, we are said to be shooting **converged** and we set a degree of rotation that the cameras will turn in towards each other for each shot to decide where objects/subjects will be positioned along the Z axis (fig. 6).

It is not necessary to converge the lines of sight when initially imaging. If we do not, it will give the effect that all of the image appears in negative Z space and is referred to as shooting **parallel** (fig. 7). Using this method, all of the image



8 Horizontal Image Translation correction for edge violation, R/C.



9 Stereo Pair, R/C.

can be pushed out into the audience's space, all the time, like in an IMAX 3D film. When shooting parallel, the point of convergence can also be chosen during the post-production process. However, there will be a loss of resolution and an alteration of framing to compensate for the change in overlap of the images when zooming in and cropping the image to eliminate superfluous edges. An adjustment to where the images overlap and where the subsequent point of convergence exists, is called a **Horizontal Image Translation**, or H.I.T. (fig. 8).

Stereoscopic Imaging Toolsets

Below are brief descriptions of five ways to capture stereoscopic images, using either one or two cameras. The choice of toolset will ultimately be decided by physical restrictions, as well as by the desired effect of the images to be captured.

Any of these toolsets can be used in a parallel or converged configuration, dependent upon the intended immersive or invasive quality of the content, and the chosen delivery format(s). Projects shot and delivered in parallel will only be viewable on a Giant Screen, where the viewer is relieved from looking at all of the screen at the same time



10 Monoscopic / 2D Image, R/C.

and can choose to fuse smaller portions of the image selectively. If the content is also going to be available on home theater or TV screens, the images will all have to be adjusted to push some of the image back into positive z space, so there is not too much parallax separation present in all parts of the screen to be fused at one time.

Single Camera Methods

2D-3D conversion: Images captured with a single camera then post-production processed to create second eye view. This process can be very useful when **native capture** (stereoscopic imaging as produced using a naturally occurring **stereo pair** (fig. 9) or left & right eye images) is not practical, i.e., when physical size, scale diversity, or camera/rig mounting and/or operating space is very restricted. Although conversion can be expensive and time consuming, it can also be very helpful when creating fantastical scenarios, as the creation of a second eye image from the existing **monoscopic** (2D), or single eye image (fig. 10) can utilize more than one inter-axial setting at a time, creating more complex geometry than is achievable when using physical cameras in a physical environment.

Stop motion/stepper motor: Two images captured by a single camera/lens, in succession, but after shifting perspective between the first and second images. The amount of shift between images is equivalent to the inter-axial distance. The subject must remain static during the acquisition of both images intended for a single stereo pair, and the camera must only shift along the X axis. The stereo pairs are then strung together in an image sequence and played back at speed, each stereo pair equal to one frame in *frames per second*.

Dual Lens/Camera Methods

Single-body/dual-lens camera systems: There are a variety of stereoscopic 3D video/digital cinema camera options ranging in size, weight, image compression method and quality, but with fixed inter-axial distance and permanent lens choices. These devices allow for less setup and no alignment necessary or possible (some aberrance in hardware may require post-production geometry and/or color correction). Dependent upon the inter-axial distance, the cameras innately restrict the amount of depth an image can have, as the distance from subject and/or the furthest background point is limited to avoid excessive parallax. They do grant extreme freedom and mobility for the content creator, although they limit creative flexibility. These solutions are ideal for ENG (Electronic News Gathering), Reality and documentary situations, where time and crew/equipment space is limited. One must camera test to assure the fixed inter-axial does not prohibit the necessary distance from the subject to create both ideal framing and intimacy/immersive effect, as well as viewable 3D images.

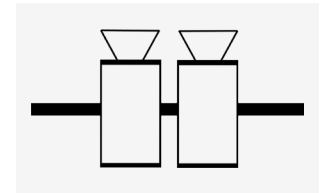
If the fixed inter-axial distance is too wide, the camera will not be able to approach near enough to the subject to

get a close-up shot and will leave the audience feeling an emotional separation from the topic. Also, it could create too large of a parallax separation in the background elements, causing a divergence among viewers. This effect becomes exaggerated in an immersive delivery method, such as the cinema or a VR set-up.

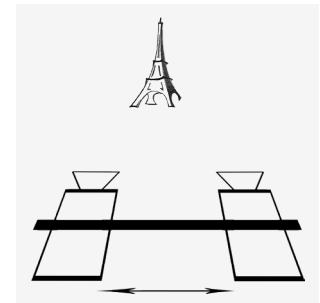
Light levels that will be standard for the subject matter must also be considered as some camera systems handle low light better than others. If a lack of light is innate in the subject, one should be aware that a greater than usual amount of light is recommended for stereoscopic image viewing, as there is light loss when projecting through **polarizing** or color filters, and the viewer is wearing 3D glasses. Dim images can cause eye-strain, and low lumen projection in theaters has been the cause of much 3D media criticism and distaste. Additionally, lighting techniques for 3D production are more demanding, as accenting individual areas along the Z axis create **depth cues**, or planes of light for the viewer to distinguish, creating a richer depth environment.

Side-by-side rig (fig. 11): Dual camera configuration utilizing a simple bar with both cameras oriented next to one another. This is convenient for shooting larger, spectacle style subjects with an increased potential inter-axial distance but limits cameras from getting any closer to one another than the physical body and or lenses will allow.

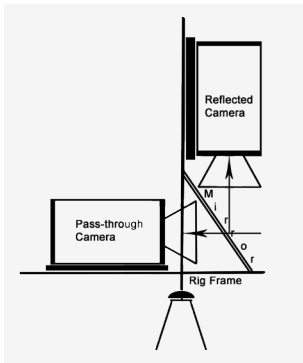
Shooting with an exaggerated inter-axial setting can create an effect called **hyperstereo** (fig. 12), which allows us to perceive depth in environments or objects that are very large or further away than we are able to observe depth in naturally. Due to the average inter-ocular separation of human eyes (about 6.3–7.6 cm or 2.5–3 inches) we are restricted from observing depth in anything more distant than 18.3–30.5 m or 60–100 feet away.



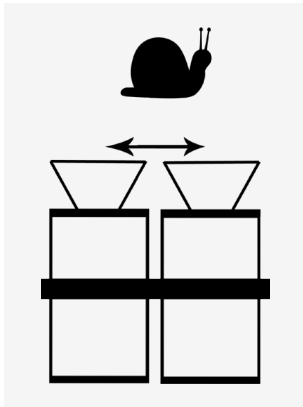
11 Side-by-side rig.



12 Hyperstereo.



13 Beamsplitter rig.



14 Hypostereo.

While this process is ideal to allow the viewer to see depth in grand vistas, large objects, architectural structures or natural wonders, when used to perceive depth in normal sized objects that are a great distance from the camera, an effect called **miniaturization** can occur. This effect makes objects and people seem very small, like toys, or as if the viewer were a giant. This can be used creatively to simulate a fantastical scenario, rather than to observe sporting events etc. from a distance, as miniaturization will pull the viewer out of the experience and remind them they are watching something artificially produced.

Beamsplitter rig (fig. 13): Dual camera configuration utilizing a mounting bracket with mirror to reflect the desired image into one camera lens (**reflected camera**), while the second camera looks through the mirror to capture (**pass-through camera**), allowing for a far narrower inter-axial separation than the physical cameras would be able to achieve if mounted next to each other. There is significant light loss due to the mirror in the rig, about 1.5 to 2 stops decrease, so lighting conditions must be of significant consideration when choosing to shoot with a beamsplitter.

Shooting with a narrower inter-axial separation than our average inter-ocular separation of 2.5 inches will allow for use of extreme/close-up shots, which are a standard part of cinematic storytelling when we want to convey focus or attention to a specific object or to intensify the emotional connection with the subject. It is not a realistic situation, as we rarely put our faces very close to an object or person when we are paying attention to a particular thing but is useful as a cue to the audience that something important is happening.

The narrowness of the inter-axial setting must be used with care, because although it can help us to get closer to a subject, an effect called **hypostereo** (fig. 14) can result, in

which one can perceive the world as if one were very small. This effect can be used creatively to immerse the viewer into the world on a microscale, like documenting insects, surgical procedures, electronics construction or granting the viewer a first-person POV as the inhabitant of a fantasy world of tiny people like in Jonathan Swift's *Gulliver's Travels* (Benjamin Motte, 1726).

Once we are able to communicate verbally about our intentions and desires concerning the stereoscopic images we wish to produce, we can begin to choose the toolset, pipeline and workflow that will help us to achieve these aims.

Stereoscopic Imaging Systems Set-Up and Variables

No matter what camera or rig is chosen for the job, there are a consistent set of parameters that must be adhered to in order to ensure the two images that are produced are useable. The two images must be exactly matched in every way, except for their slight difference in vantage point along the X axis. Any discrepancy between the images is called **retinal rivalry** (fig. 15), as it can cause eye strain, because the viewer will be seeing something in one eye but not seeing it in the other. Each of the following items listed must be precisely matched and aligned to achieve a perfect stereo pair. It is useful to label each piece from the cameras, lenses, and media cards to cables card to cables etc. as *Left* and *Right*. Further, one should maintain use of each item in the same position consistently as it alleviates confusion and allows for easier troubleshooting if a problem arises. One basic guideline is to eliminate potential variables at every opportunity.

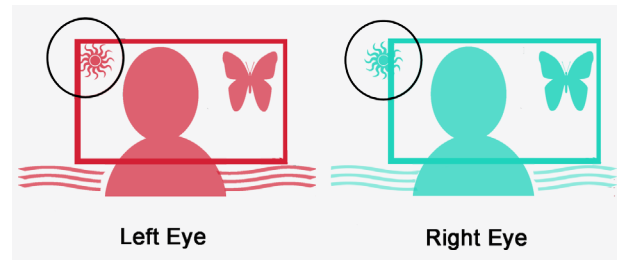
Cameras should be the same make, brand, and have the same firmware version. They should ultimately be able to genlock. The frame rate and shutter speed/shutter angle set-

tings should be the same on both cameras. Exposure and color temperature should also match as closely as possible, but note that the mirror will cause a color and light shift in one camera. Final exposure and color balancing will need to be done in post-production.

Lenses should be a matched pair (as close as possible), lens mapping helps with aberrations in the physical elements, and using wider lenses is preferred to long lenses as zooming compresses space, which manifests in 3D images as **cardboarding**, or the flattening of objects so they appear like cardboard cutouts. Prime lenses (lenses with only 1 focal length) are most preferable, although for speed in production, wider zoom lenses (lenses with multiple focal lengths, but not to exceed 50 mm ideally) can be used as vari(able)-prime lenses, allowing one to have multiple focal length choices without having to change the lenses on the rig and re-align every time. In order to perform the initial alignment, zoom lenses must be set to the same actual focal length. Although the lens marking may denote a particular focal length, the optical reality of 50 mm being exactly the same on different lenses is very improbable. A visual confirmation of zoom scale must be checked.

The back of the lenses should be the same distance from the sensor when attaching them to their respective cameras. Not all lenses are adjustable, but most professional digital cinema cameras do have the option to adjust back focal distance. Also be sure to focus both cameras to properly align them.

FIZ motor calibration is essential if we desire to have dynamic framing or to zoom in or out during a scene in 3D imaging. These motor systems are used in 2D production to control Focus, Iris, and Zoom of the lenses remotely. The same motor systems can be used during stereoscopic production, but two sets will be needed (one for each camera). They will need to be calibrated to work in unison if they are



15 Retinal rivalry, R/C.

to match the images in a stereo pair. A third FIZ control can be used on some beamsplitter rigs to motorize the adjustments for inter-axial and convergence.

Filters may be used but must be matched in density and orientation. The most commonly used filter is a quarter wave retarder, placed in front of the mirror in the beamsplitter. This protects against polarization issues, which result from shooting reflective surfaces from slightly different angles. As the reflection will look different in the left and right eye, when viewed as a stereo image, strobing will occur and take the viewer out of the moment or cause eye-strain. This effect can be used creatively but should be intentional.

Timecode is important for both imaging and post-production practices. Some cameras generate their own timecode, while others must be fed timecode. This provides not only a point-of-reference for post-production to find specific events within footage, but also allows for multiple camera shoots to have a common standard. It also provides a regulated cadence by which the cameras may be synced.

Genlock is a process by which two cameras may be linked together. Regardless of the shutter speed chosen, the cameras must open and close shutter at the exact same time. Genlock guarantees the two cameras will maintain



16 Anaglyph 3D Image, R/C.

their sync with each other, so that the left and right cameras capture the exact same frame without any discrepancies being introduced by the shutter angle. If not there will be temporal differences and the images will be unusable. Also, if a camera system is not genlocked but both cameras are started at the same time, the shuttering tends to drift out of sync over time.

There are a few configurations one might apply to the cameras being linked, but in stereoscopic imaging, we tend to use the *master/slave* configuration. This allows changes on one camera (master) to automatically be applied to the other camera (slave), so we are certain the settings are always the same on both cameras and eliminate user error.

Keeping cameras in sync is not just concerned with shuttering, but also with scanning. Film cameras capture images by the opening and closing the physical aperture, allowing light to pass through the iris and strike the film, leaving an impression. Digital cameras have two types of shutters available: A **global shutter**, which behaves like a film camera and takes one massive impression each time the camera shutters, or a **rolling shutter**, which basically acts like a scanner or copy machine, scans the lines of resolution in succession starting at the upper left hand corner and ending with the lower right corner. When using cameras with a rolling shutter, the scan progression must be in sync as well. This is what we are referring to when we describe the cameras as being in phase. There are some additional issues when using rolling shutter cameras including dealing with fast motion. One arises when the first part of the image is scanned before the last part of the image, thus causing motion artifacts. Additionally, one or both cameras on the rig are sometimes mounted in inverted positions (because of mounting necessity), so the cameras may actually be scanning in the opposite direction.

When an inversion of image occurs, whether it is because one of the cameras on a beamsplitter is recording a reflected image and it appears backwards, or because the camera is mounted upside down, that image must be flipped and/or flopped to allow for alignment and monitoring during production. **Flip/flop** can be done in camera (if the option is available on the camera) or at the monitoring level. It does not matter which stage it is done at, but it must be done at some point, either during initial image capture, or during the post-production process.

Some specialty monitors exist for onset 3D monitoring and make the process much easier. They usually have multiple modes that are helpful during alignment, and when setting inter-axial & convergence. They range in size from 5 inches (which would be used for onboard camera monitoring for the operator) to large TV size, which would be used by the stereographer when setting the depth in each scene or by the director to view and compose shots and on set action or playback and review. They can be fully polarized stereoscopic monitors (that use polarized lens glasses) or an **anaglyph** (fig. 16) display (which utilize the red/cyan glasses). Polarizing filters orient the left and right eye images' light waves to only pass through their correlating glasses' eye. This same technology is used in theaters and on 3D TVs.

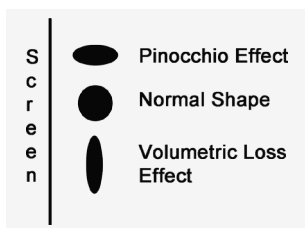
There are also some pass-through devices that will output a 3D image in a variety of formats, although anaglyph images are able to be viewed on any standard monitor or computer screen. Some form of 3D monitoring is essential for at least the alignment stage, and is highly recommended during production, although with the use of complex calculations, inter-axial and convergence can be set without it. This will definitely increase on-set production time and will often increase the required amount of post-production corrections.

Alignment Settings on Beamsplitter Rigs and in Post-Production Correction

Alignment is one of the most important aspects of 3D imaging, as it can be the difference between communicating an emotional message via an image on screen and having a meaningful experience lost in translation due to a technical aberration that prevents it being viewed comfortably. As there are so many variables in these imaging systems, and the adjustments that effect the outcome are so minute, the following procedure is very helpful in establishing sound geometry for image capture. Because we are working in three-dimensional space, any defects will create alignment issues, and render the images un-viewable. Although some corrections can be made during the post process, some aspects are permanent and thus must be matched as closely as possible before imaging.

The following are the basic points of alignment and/or geometry correction:

1. **Mounting:** When mounting the cameras onto the rig, they must be square and level, meaning the camera must be exactly perpendicular to the mirror at a 90 degree angle and when a bubble level is placed on top of the camera rig it should be level to the ground.
2. **Horizontal:** During the alignment, set the horizontal separation between the cameras to zero (zero rig); this will produce the exact same image in both eyes, essentially creating a 2D image. Once the images are exactly the same, as you proceed through the process of alignment, your images will be geometrically matched, and the rig will be properly aligned for stereoscopic imaging.
3. **Scale:** The images must be at the same scale in order to match geometrically. Therefore, when mounting the cameras on the beamsplitter rig, the lenses should be equidistant from the mirror and zoomed to the same focal length (optically). Also, the images output from the cameras should be in focus, as it is nearly impossible to ascertain pixel accurate alignment in an out of focus image.
4. **Vertical alignment:** This setting is sometimes controlled by adjusting the height of the camera. If this is the case, the potential for pitch and roll issues arises. To combat this, many rig designers place the vertical alignment adjustment at the mirror.
5. **Pitch:** This is the measurement of the height of the front or back of the physical camera body as mounted to the rig. As some internal sensors are not always physically squarely seated in the camera, adjustment of pitch can help to correct for this geometrical issue. However, it is very easy to use this to compensate for misalignments created via another variable and thus make the geometry incorrect in either the background or foreground. Ideally one should be able to zoom from one end of the lens to the other without losing alignment, but as lenses have physical weight, they can shift center of gravity when on one end or the other, so one must align for the object of interest on a shot by shot basis.
6. **Roll:** This is a measure of the camera body's flush mounting to the rig as well but is concerned with the tilt left or right.
7. **Rotation:** As one camera either hangs down or points upward into the mirror, the camera can have a tendency to pivot on the mounting plate.



17 Distortion effects.

Process of Formulating Depth in Images on Screen

After properly aligning the beamsplitter rig, we are ready to begin capturing stereoscopic images. We need to make a series of creative choices to decide how to set the inter-axial and convergence (if we are shooting converged). There are many methods that involve complex processes of measuring and mathematical computation. However, a simple method for creating natural and comfortable 3D is called the Natural Depth Method, developed by stereoscopic filmmakers Alan & Josephine Derobe. This process creates stereoscopic images by choosing a natural convergence point for the viewer to focus on, then balancing the amount of parallax separation between the negative and positive Z spaces. The procedure is as follows:

1. Set IA to roughly 2.5 inches.
2. Set the convergence on the object/subject you want to be at the screen plane.
3. Check the parallax of the nearest object/subject, at the closest point it will pass in front of the rig, to make sure it is not too diverged to be fused.
4. Check the parallax of the furthest object or background for excessive disparity. (If the background is out of focus, there can be more forgiveness, as the audience will not be attempting to fuse a blurry image.)
5. Decrease the IA to adjust for acceptable amount of parallax in both.
6. Re-converge.
7. Repeat until entire image is comfortable to view.
8. Finally, when parallax is within acceptable **depth budget** (allowed amount of separation, usually mea-

sured in percentage of screen size, as dictated by creative design or distribution channel):

9. Check for distortion within the subject/object of interest.
10. If there is too much IA + convergence, objects will distort, elongating along Z axis, creating a *Pinocchio effect* (fig. 17).
11. If there is too little IA + convergence, object will distort elongating along X axis, either flattening the image, or rendering a lack of volume or roundness (fig. 17).

Controlling Parallax for various Delivery Formats

A larger size of screen proportionally increases the amount of depth a given parallax separation will display. There are often several versions of a 3D product that have been re-converged for each distribution channel. For example, media intended to be viewed on a cell phone, personal tablet or small monitor will have greater parallax separation than the version distributed for movie theater projection. Conversely, projects designed for Giant Screen Cinema (IMAX) will be unviewable on a smaller screen. Most feature movies/documentaries are routinely reconverged before being released for home theater consumption.

Creative Design in Producing Stereoscopic Images

When designing a piece of stereoscopic media one must take into consideration the demands of production, as per the physical elements (scale of subject, size of environment, size of budget, desired pace of production, un/predictive nature of subject matter), but also the way the eye receives infor-

mation and the time it takes the brain to process the stereoscopic images into a three-dimensional environment. Often to ease this process, we will divorce from traditional cinematic practice and embrace a cinematic theatre approach. This means longer takes of action in which we move within space as if the camera is a character/anthropomorphized, rather than executing the traditional set-ups (establishing shot, two-shot, over the shoulder, coverage, etc.). This allows for a more natural viewing experience, as if we were there, as opposed to being reminded that we are viewing a captured image. This serves us well in both orthoscopic imaging as well as fantastical settings and helps the viewer to stay immersed in the scene.

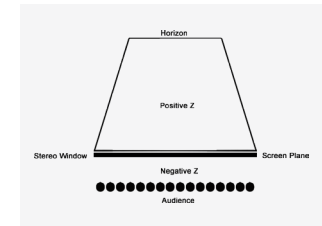
If we do adhere to traditional set ups, it is advisable to use longer shots and cut less often when editing, as it takes the brain several seconds to fuse a new shot. One should also attempt to transition from one shot to the next while having the point of interest at the same position along the Z axis, at least at the end of one shot and the beginning of the next. The convergence point, or placement along the Z axis can be dynamic, softly easing the viewer from one shot to the next. Once the images have been fused, the subject can visually move freely within the stereo space, and in and/or out of the **stereo window** (fig. 18), into positive or negative Z space.

The use of more or less depth as well as placement of objects/subjects along the Z axis can render many diverse psychological effects on the viewer. There is no set of defined rules by which one can construct specific reactions. On the production side we discover them as the stereoscopic medium is explored. Dynamic inter-axial and/or convergence can be used to draw a viewer into the image or to push objects away from the viewer, creating a sense of dramatic/emotional tension, or loss. Objects/subjects that are pushed into negative Z space can be used as a gimmick, to

throw something into the viewer's face or to create a sense of intrusion into the audience's space, while placement of an objects/subject in positive Z space can create a sense of voyeurism. Increased depth in a scene, with the subject in the distance, can make a viewer feel as though the space is vast and provide a sense of occhiolism, while increased depth with the subject and environment filling up the scene can create a sense of claustrophobia. A diminished depth when observing a subject or their environment can provide a sense that something is lacking in that person's life, while realistic volume and depth can create a sense of well being and richness in the subject's life. The freedom of the camera to move within the three-dimensional space can create a sense of weightlessness or buoyancy, while a static or locked-off shot can provide the physical sensation of restriction or captivity. The only true way to learn these tricks is to watch as much stereoscopic content as possible, both with glasses on and off. When an emotional reaction is noted, look at the image without glasses to ascertain the parallax and convergence setting. Also, there is nothing like practicing and experimenting to help one grasp the subtle art that is **stereography** or designing depth for expression on screen.

Figures

1-18: Shannon Benna.



18 Stereo window in display environment.

Glossary of Stereoscopic 3D Terms

2D–3D conversion Postproduction process by which a second eye view is generated from a single eye image.

3D image A volumetric image consisting of a left and right eye view, delivered discretely to each of the viewer's eyes, and perceived to have depth. Also called **stereoscopic 3D**.

Alignment The matching of geometric elements/configuration when assembling a stereoscopic imaging system, or the postproduction process of correcting geometric mismatches in image pairs.

Anaglyph A method of displaying stereo images that utilizes contrasting color images & filtering glasses to discretely deliver left and right images to their respective eyes.

Beamsplitter rig Dual camera configuration utilizing a mounting bracket with mirror to reflect the desired image into one camera lens (reflected camera), while the second camera looks through the mirror to capture (pass-through camera).

Binocular vision The ability to perceive depth while viewing with two eyes.

Cardboarding An effect in stereoscopic imaging that comes from shooting an object/subject at great distance while zoomed in using telephoto lenses.

Converged a method of stereoscopic imaging where the cameras will turn in towards each other a specified degree of rotation for each shot. This decides where objects/subjects live along the Z axis.

Convergence The point at which our eyes cross when we naturally observe the world, or where two imaging devices' lines of sight cross.

Depth cues Points of interest along the Z axis, accenting layers of depth in space.

Depth budget The sanctioned amount of overall parallax separation in a 3D image, as dictated by creative design or the distribution channel.

Diverge The effort to fuse two images by straining towards the periphery.

Edge violation An object/subject that is both partially off screen and in negative Z space.

FIZ Motorization & controls for the focus, iris, and zoom of a lens.

Flip/flop The vertical/horizontal re-orientation of an image. (There is not a standardized direction = term.)

Floating window A black mask that is applied to the side of one eye to bevel that side of the screen plane backwards in space.

Fuse The physical process of combination of separate images in the brain, creating a single image, complete with volumetric objects living in space at some distance from us physically.

Global shutter Digital imaging shutter that captures all of the image at once, like a traditional film aperture.

Horizontal Image Translation (H.I.T.) Post-production process where the convergence point is changed in a shot, by shifting one or both of the images left or right in relation to one another.

Hyperstereo A method of stereoscopic imaging using exaggerated inter-axial settings, intended

to give depth to objects at a great distance.

- Hypostereo** A method of stereoscopic imaging using very narrow inter-axial settings, allowing for extreme close-up or macro images of very small objects/subjects.
- Inter-Axial (IA)** The distance between the nodal centers of acquisition point on digital imaging sensors.
- Inter-Ocular (IO)** The amount of separation between the pupils of the eyes.
- Miniaturization** A side effect of shooting hyperstereo, where objects appear to be miniaturized.
- Monoscopic** A single eye or 2D/flat image.
- Native capture** Stereoscopic imaging using 2 cameras or lenses to create a left and right eye image.
- Negative Z space** In front of the screen plane/stereo window.
- Orthostereo** A realistic depth image, reproducing the natural scale and volume of an object/subject.
- Parallax** The separation between the same object in the left and

right images of a stereo pair when the images are overlaid.

- Parallel** A method of stereoscopic imaging where the cameras do not tow in towards one another, placing the screen plane at infinity.
- Pass-through camera** The camera that looks through the mirror of a beamsplitter to capture an image. Also called the Direct Camera.
- Polarized** A method of displaying stereo images that utilizes special filters to orient the left and right eye images' light waves. Electrons from the left eye light waves are spun to the left, while electrons from the right eye light waves are spun to the right. Left and right polarizing filters are worn in front of the viewer's eyes, which only allow the correlating light waves to pass through.
- Positive Z space** Behind the screen plane/stereo window.
- Reflected camera** The camera that captures the image reflected in the mirror of a beamsplitter.
- Retinal rivalry** When all or part of an object appears in one eye of a stereo pair, but not in the other.

- Rolling shutter** A digital imaging shutter that scans lines of resolution starting with the upper right corner and finishing in the lower left.
- Side-by-side rig** Dual camera configuration utilizing a simple bar with both cameras oriented next to one another.
- Stereo blindness** An inability to perceive depth, when viewing with two eyes.
- Stereo pair** A left and right eye image that when viewed create a 3D image.
- Stereo window** The screen plane boundary between the negative and positive portions of the Z axis.
- Stereography** The creative art and technical science of creating stereoscopic 3D images.
- Stereopsis** The perception of depth by fusing two images into one volumetric image.
- Z axis** Towards or away from the audience.
- Zero parallax** At the screen plane.