

Go 3D or Not?

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Shooting 3D may sound easy but after small research, more and more problems are revealed.. Problem with this is that everything you read will try to explain you how to shoot 3D in the viewpoint of shooting it perfectly. For this reason I was very frustrated after starting my research as it seemed worthless to even try with compromised equipment. It is good to remember that 3D has been done before the digital and computer controlled rigs were available. It may have not been perfect, but now even the cheapest equipment will give you digital workflow that wasn't available before. I believe 3D can be done even independently although it may not be as good as in commercial productions. How good it is will be defined by your skills and limited by the equipment you can afford.

Basic requirement for seeing 3D is two eyes, each seeing the world from slightly different angle. The basic requirement for shooting 3D is two images, one for each eye. They can be shot by using 3D cameras or specialized rigs with two synced cameras as usually is the case in the professional world. To avoid headaches the images must not have any disparities, which include rotation, vertical shift, keystoneing, focus, size, color and brightness. All these problems may be corrected by properly calibrating the cameras. Additional conflicts occur when the objects front of the screen are cut by the screen. This can be avoided by planning the shoot well or in post-production by pulling the edge of the screen to front of the violating object.

Interaxial is used to define the overall depth. This is the parallax range of the shot. This depth is then baked in and can't be modified in the post. Only thing we can do in post is to move everything in the scene either closer or farther by doing horizontal image translation. This can also be done when shooting by angulating the cameras.

KEYWORDS:

3D, S3D, stereoscopy, cinematography, filmmaking

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1 INTRODUCTION

Shooting 3D is sometimes referred as S3D indicating Stereo 3D. S3D movies are not to be confused with animations done using 3D modeling such as Toy Story. Stereoscopic shooting means that traditional cinema's each camera is replaced by a pair of cameras to create two images, one for each eye. When these two images are viewed stereoscopically, the brain fuses them together creating the illusion of depth, turning the screen into a window where landscape extends beyond the screen and the objects may fly into the room.

Shooting 3D may sound easy to many after the above description. Reality is far more complex. Even small differences in the camera positioning, angling, zooming and focusing can cause huge discomfort to the viewer. On top of that there are limitations on how our eyes work, they converge but they don't diverge. Initial camera calibration requires time and it has to be repeated when lenses are changed. The values of the camera positioning need to be adjusted with nanometer precision

ideally with computer-controlled rigs to produce perfect images. Shooting 3D will also force filmmakers to rethink some of the classical composition and storytelling rules so that they can tell the story in 3D without causing audience to feel nauseated.

In this thesis I will cover the basic concepts of shooting 3D, supported by example 3D pictures produced with a 3D laboratory program allowing to test out theories. You will need red-cyan anaglyph glasses to view these images in 3D. In addition you will see some illustration explaining the concepts. I will go through the basic questions arisen to me when thinking about building my own 3D rig. How to build a rig is not included in this thesis since I haven't done one, but hopefully you would know enough to start your journey to 3D after reading this thesis. I'll not go on to the workflows of editing in 3D but I'll introduce some of the post-production methods that need to be used to ensure pleasurable viewing experience for the audience.

2 BRIEF HISTORY OF 3D



Audience watching 3D movie with glasses on.¹

Although stereoscopic imaging has been around pretty much since the invention of photography, the 3D movies have experienced three dawns. You may remember seeing photos from 50s where the audience is wearing anaglyph red-cyan glasses in the theaters. 3D movies were shot with traditional multi-camera techniques, which were soon phased out by far simpler single camera widescreen color movies in regular 2D

front. In theaters playing the 3D movies required two perfectly matched projectors running in sync. Sync and alignment problems on the screening could have left audience dizzy even though everything in the actual production may had been done to acceptable level in standards of 3D. 3D did a short come back in 80s. This also failed to turn 3D into a norm such as movies with sound or color had done before.

If you ask a random person what's going to happen with 3D now, there's good chance that he'd answer that it's going to die out soon because it happened before. However there's a big difference between the 3D before and now. Digital shooting and projection techniques with computer precise control and image analyzers have made the shooting of perfect 3D finally possible. The amount of 3D movies being shot and theaters capable of screening them is on a rapid rise. 3D is a way for studios to generate extra income from tickets as seeing the 3D version is more expensive than the regular version. Although it's now possible to view the 3D movies at home, it's still a quite rare luxury. This means that 3D movies can still offer an unique experience in theaters. Larger screen size also gives 3D totally

different feeling since bigger screens allow more content to be placed front of the screen.

3D seems to be dividing opinions quite harshly to people either liking or disliking it. Common opinion amongst the people disliking 3D is that the objects look like cardboard cutouts. We need to note that there's lots of difference in quality between the stereoscopy of 3D movies, some have been shot well some have not. Some of the movies advertised as 3D movies have been converted from 2D to 3D using cheap methods. These methods of course produce bad results. This doesn't mean that all the converted 2D originals are bad 3D since with more expensive methods the conversions can be done very well.

3D is not for everyone. 3-15% of the people are not able to see 3D at all or they have difficulties to fuse the images together correctly. This means that even though everything would be perfect in shooting and screening, you would still have small unreachable audience. People with problems fusing the images are experiencing more headaches as their eyes and brains are working harder to build up the fused 3D image.

We have now gone from analog to digital acquisition and projection, from anaglyph to passive and active glasses, we even have autostereoscopic displays that allow viewers to see 3D without glasses at all. No matter what method is used to view 3D movies, the 3D effect will be "fake" with stereoscopic acquisition. If you move your head, the effect will angle itself with you. You will not be able to see behind the objects like you'd see in the real life. But for movies this is as real as it gets until hologram technology will take on.

3 CAN IT BE DONE... CHEAPLY?

When I first started researching 3D cinematography I was dreaming about building my own rig and shooting a short movie later. This excitement quickly turned into frustration... perfect 3D is so complex. Can it be done at home? Before we jump in to the theory I will first introduce the main dilemmas I faced. If you don't fully understand the problems or terminology below, don't worry, they will be covered in later chapters.

You need to find a way to sync the cameras. This may not be needed in still like shots but if there's movement, was it camera's or object's, the perfect sync is a must. To fuse 3D images properly there can only be horizontal shift between two images as your eyes are horizontal too. Any time difference will be interpreted as disparities between left and right image by your brain. A very simple example would be a bouncing ball. If the cameras are not in sync, the vertical position of the ball is different between the images. You will try to fuse something together that can't be fused and this will give you a headache. So the first problem is that you need to get the cameras to run in sync.

Easiest, cheapest and most obvious solution for 3D rig is side by side. You can simply take a piece of wood and attach two cameras on to it. If you lack the skills to do even that you can experiment by placing two cameras on to the table side by side. Problem is that the size of actual cameras usually makes it impossible to get the distance between the cameras, the interaxial, down to acceptable range. Larger the interaxial, stronger the 3D effect will be. Of course if the effect is too big you will not be able to fuse images and you will see ghosting.

Monitoring is also a big problem. Without ability to monitor the shots in 3D you will have no way to calibrate your cameras or to know if your calculations for shooting each shot are correct. If you got yourself a 3D monitor or managed to build some other way to preview the signal from two cameras at the same time in 3D, what will you do if you need to see the shot again? If you shoot with two normal cameras which both store the footage separately on their own memory cards you would also need to be able to sync this footage when playing it back.

Then comes the screen size. In 3D this will set some limits to your movie and define how much of the action can be behind the screen and vice versa. Ideally you would know the viewing format when you shoot it so that you may optimize the 3D for that media. It feels awfully lot to ask from someone just starting.

Even if I went out to shoot something with a 3D rig that I built myself, would it ever be good enough? If thinking about employment, would I be able to learn things I'd need to know in big productions? The price tag of the equipment used in professional world is so high that hobbyist can only dream about winning in lottery. Is the experience from your DIY rig worth anything in the world where groups of specialists are needed to operate everything properly? Discouraged enough? Ok, lets get started with the theory and finding those answers.

4 SEEING DEPTH AND 3D

4.1 NON-STEREOSCOPIC DEPTH CUES

Before we go into stereoscopic vision, it is good to know that there are also non-stereoscopic depth cues that can help people to perceive 3D. When we moved from black and white movies to color movies we gained new information that actually made watching the movies easier. We no longer had to leave guessing of the colors to our brains. Moving to 3D is quite opposite to adding the colors. Our brains have to work more now to fuse the images. Naturally any information that can help us on that is more than welcome.

Perspective lines that escape towards a point in the distance help us to perceive relative size of the objects. Even in small spaces it is often useful to shoot so that we get some perspective to avoid shot looking flat.

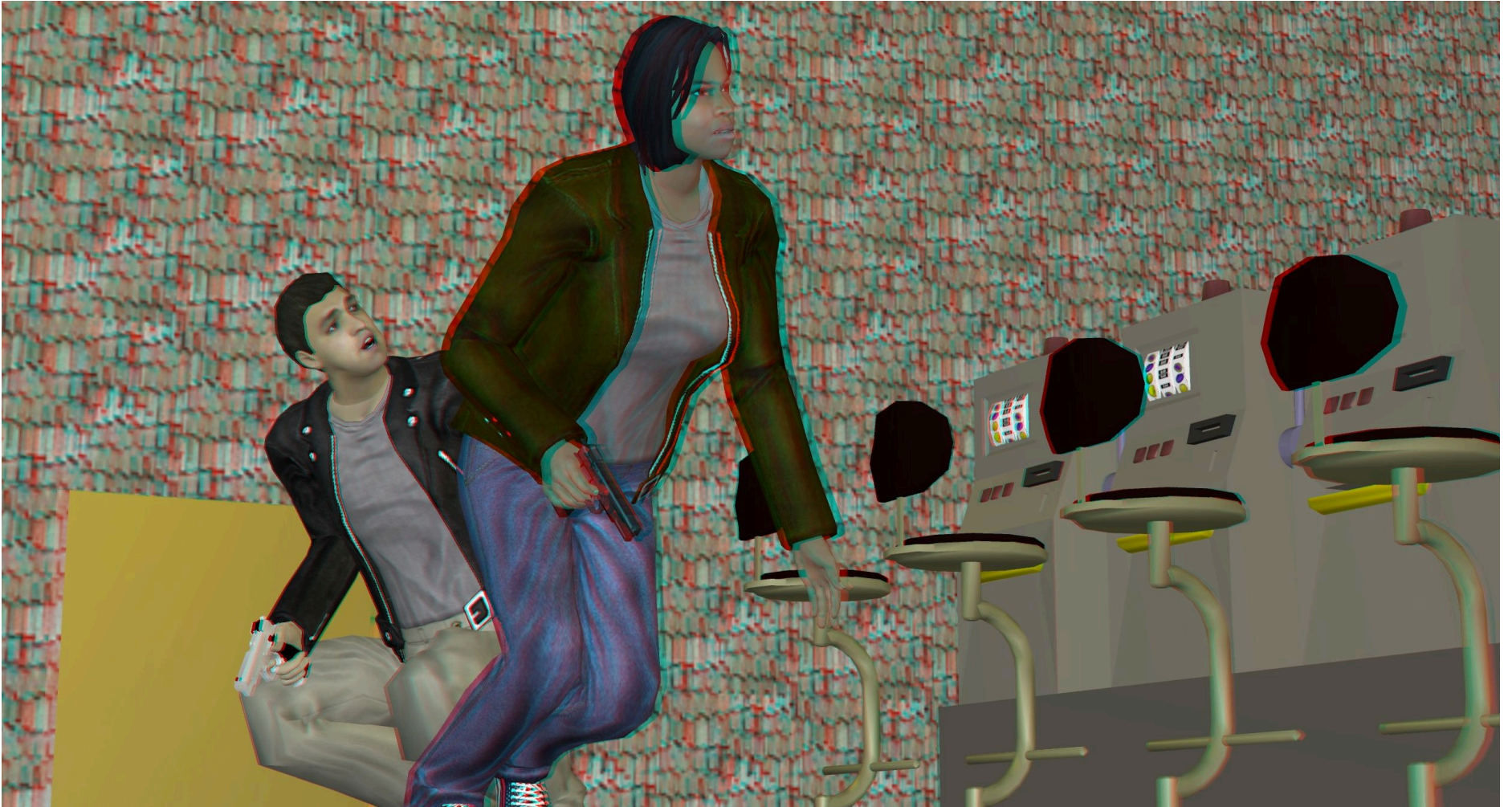
Light and shadows have been used traditionally in movies to create feeling of depth in the images. Lights and shadows give roundness to faces or forms to any other objects. Foreground objects tell us that they are closer by casting shadows to

background objects and shadows themselves form perspective lines. *(See the 3D images on next two pages for how the shadows affect the feeling of depth in shots.)*

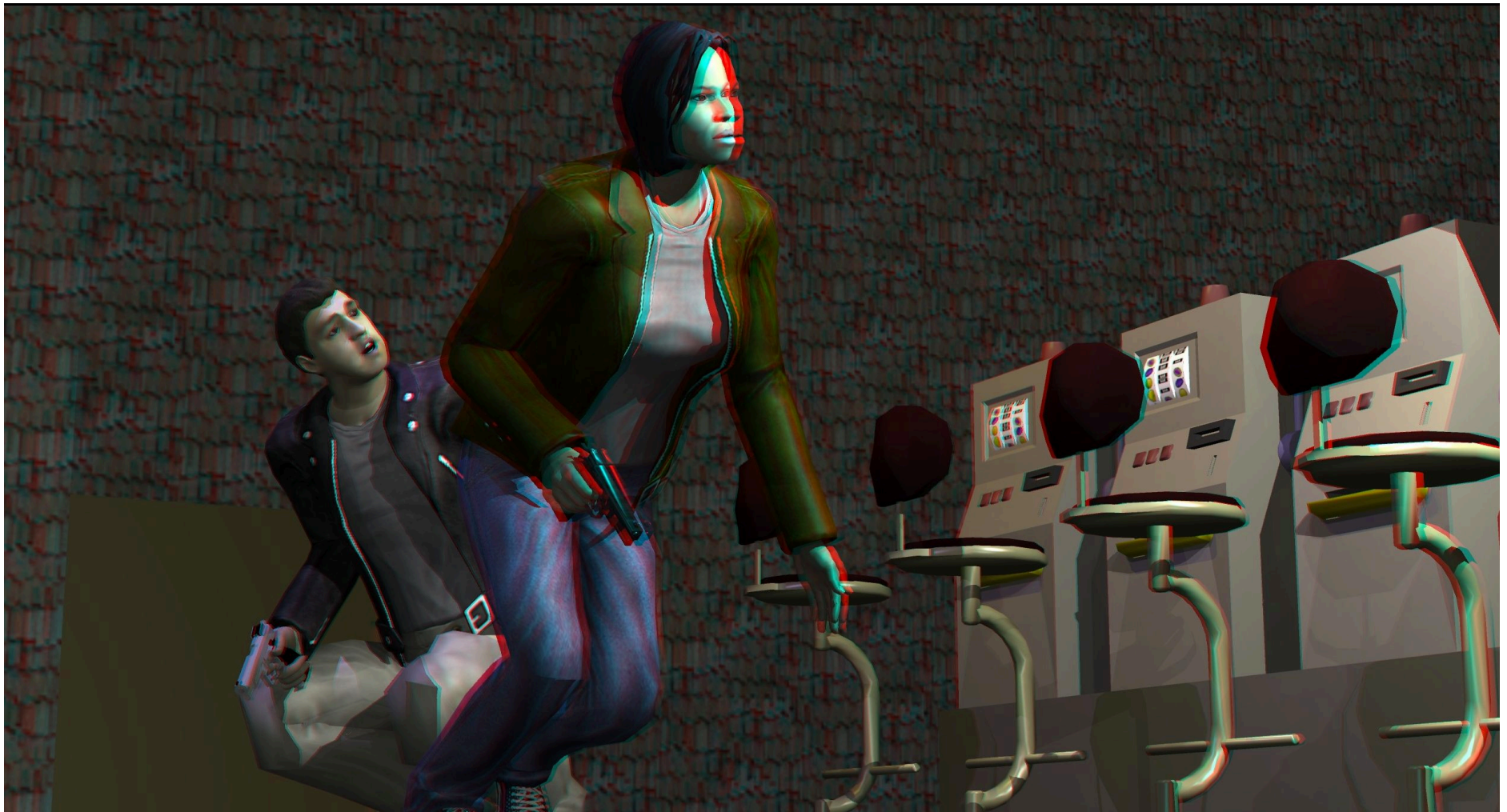
Similarly to the shadows falling to the background objects we may have foreground objects masking far objects. Although this can help perceive depth, in 3D we have to be careful with these foreground objects because they may cause stereo window violations. This happens if an object that appears to be at front of the screen is cut half at the edge of the screen. It's a conflict where an object seems to be masked by something that is behind it in depth. This phenomenon will be explained later.

If we have movement in the frame, was it objects' or the camera's, we notice the objects close to us are moving faster. This difference in movement speeds helps us to perceive the objects distance to us and in relation to each other.

When some objects start to disappear into a fog we know the objects are farther. Even without a fog, the far objects simply show less texture detail allowing our brains to understand that they are farther away.



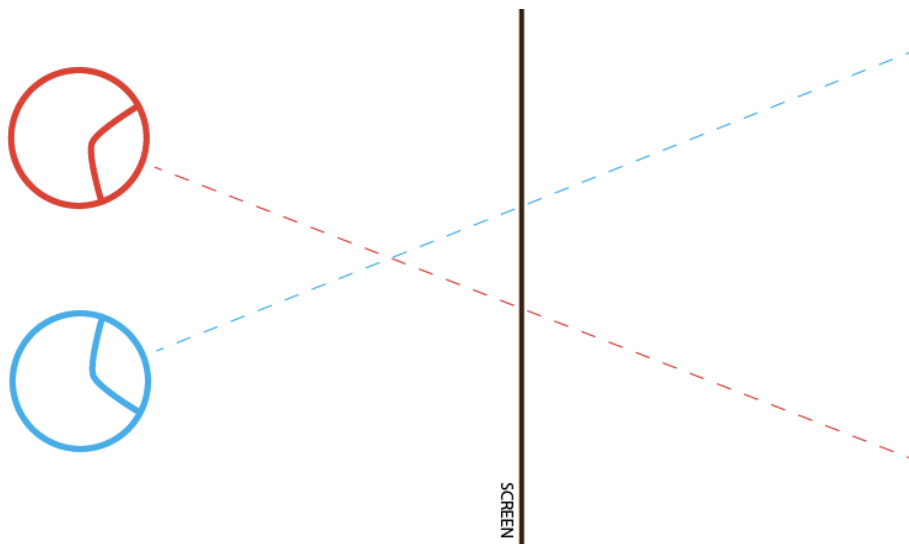
Eventhough the image has a 3D effect it still feels rather flat due to the lack of shadows.



The image has exactly the same 3D parameters with the previous image but the shadows give better shapes to the objects. The object differentiation is also better as the objects cast shadows over each other. This enhances our 3D experience.

4.2 STEREOSCOPIC VISION

In 3D depth perception requires your eyes to turn inwards, converge. This is exactly what happens when we view the objects in the real world too. When the objects are far away the eyes are parallel and closer the objects are more the eyes need to face inwards. People with only one working eye will not be able to see 3D. So as having two cameras is the minimum requirement for shooting stereo 3D, having two working eyes is the minimum for viewing the 3D movies.

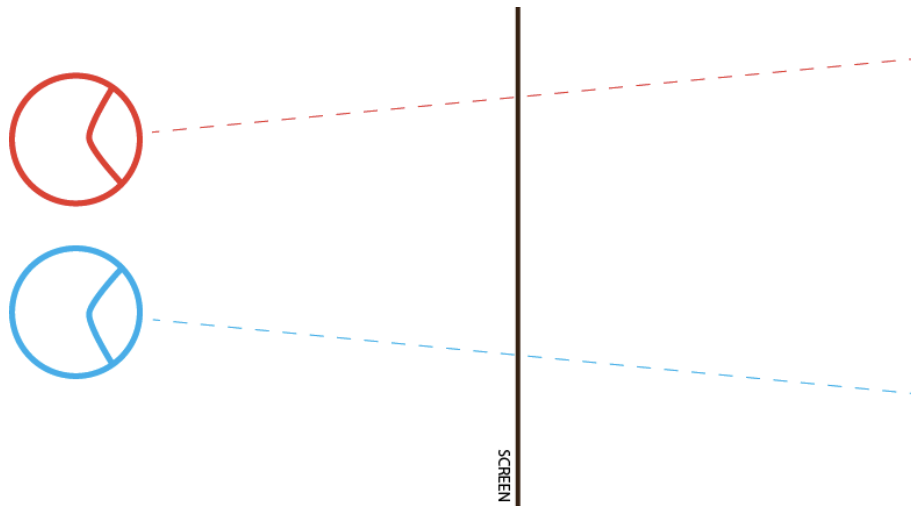


Eyes converge to the close objects. Closer the objects are, more eyes will converge.

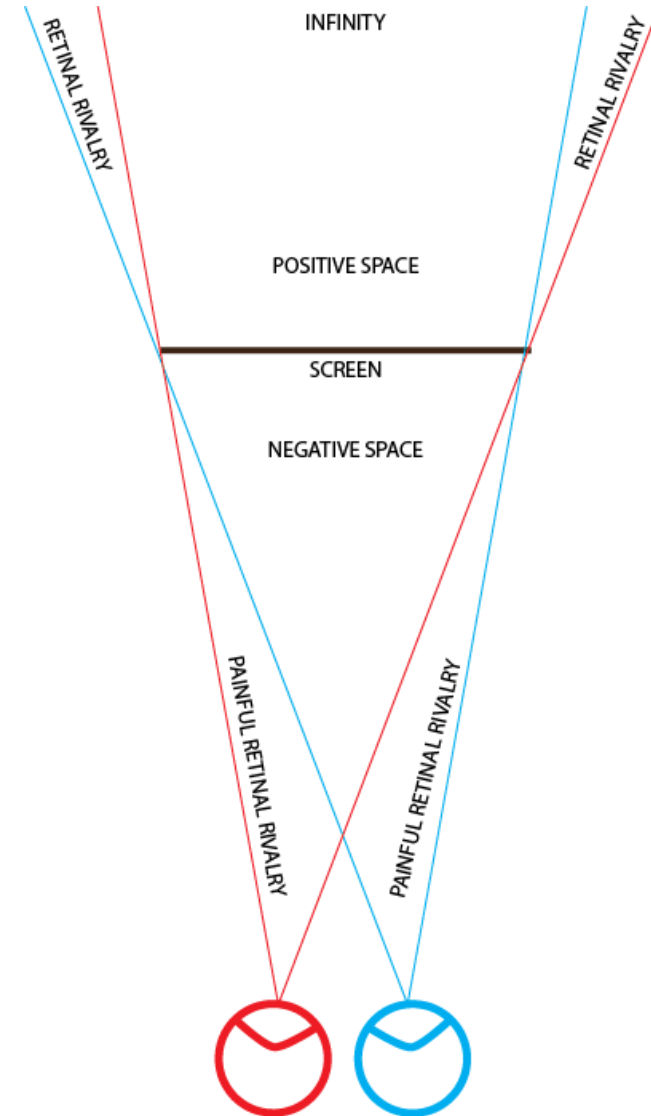
Place your hand straight in front of you and lift up one finger. While focusing on the finger bring it closer to your face and you will feel how your eyes start to converge. All this time your brain is fusing the images from both eyes together. Fusion is automatic reflex and you can be sure about this because you always only see one image in your field of view, despite the fact that you have two eyes. You'll see the difference between the images if you place your other hand front of one of your eyes. Now move it back and forth between the eyes, consecutively always covering one them. Your finger's position changes horizontally. Closer the finger is, bigger the change in it's position. This difference is called parallax and it's different to each object in our scene depending on their distance from the camera.

Keep moving your finger and at some point you will not be able to focus on it any more. It becomes soft and you start to see things as a double. When the object is close enough the difference on what your eyes see becomes too big, the brain will not be able to fuse the image anymore. If you keep trying, your eyes will become tired and will start to hurt. Since our eyes have this limitation even in real life, you can be assured that this limits us also when shooting 3D images.

Where the eyes converge to close objects for fusing 3D they can't turn outwards, they can't diverge. The average distance between adult's eyes is 6.5cm. If you shoot and post-produce your 3D carelessly, your left and right images may end up having bigger difference than 6.5cm in the far objects. You have to always make sure that this difference, the far parallax, won't exceed 6.5cm on the screen.



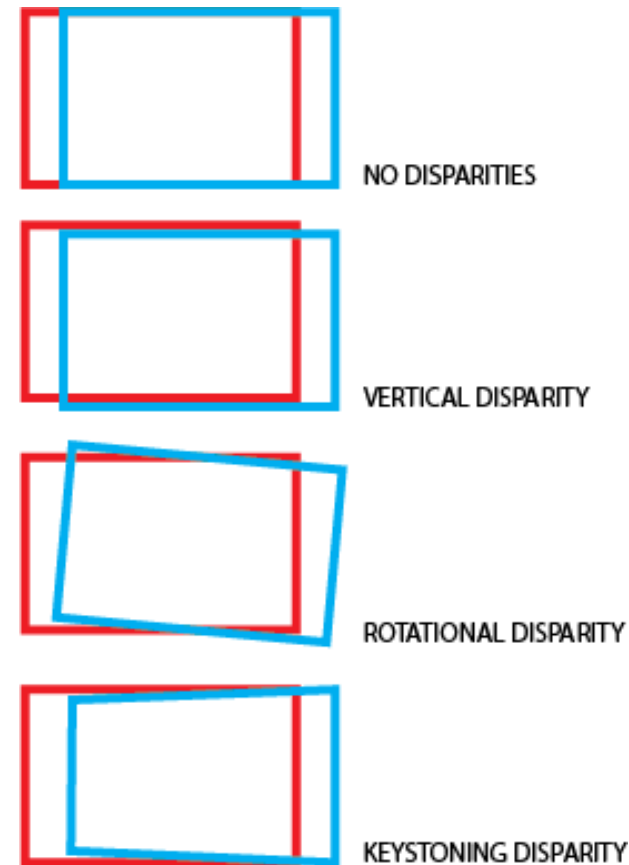
Diverging eyes will cause headache.



Retinal rivalry areas. Also worth noting is that closer we are to the screen plane in placement of the objects, easier the 3D will be to see.

Our virtual screen will still be limited by the triangle between the eye and the edges of the screen. If we see an object only with one of our eyes then this will cause retinal rivalry as it won't have a matching pair to be fused with in the other eye. We are quite used to this when foreground object masks the background object, which in theaters is similar to having the object behind the screen plane being cut by the edge of the screen. If the object is at the front and visible only with one eye this will cause strong retinal rivalry by causing a stereo window violation. Stereo window violations will be explained later.

All the disparities between left and right image will cause retinal rivalry. Eyes are supposed to see the same thing from slightly different perspective. Therefore, all other except horizontal differences will cause conflicts. This will then cause eyestrain and headache. These rivalries can be anything from vertical to roll, from colors to brightness, from keystone effects to lens flares. Naturally we must eliminate all disparities.



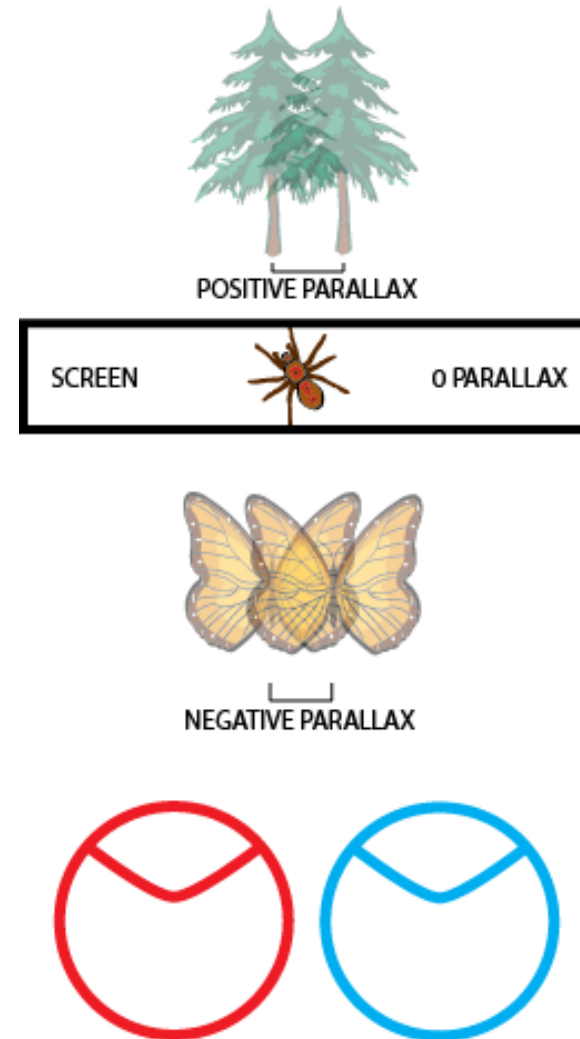
Examples of different disparities between left and right image.

5 3D IMAGE CHARACTERISTICS AND PRESENTATION PROBLEMS

5.1 PARALLAX AND FAR PARALLAX

Parallax is the difference in horizontal positioning of the object between the left and the right image. It also tells us where this object is placed in depth. In an anaglyph image you can easily see this difference between the edges of different colors. Parallax is measured in percentages of the width of the whole image. A 2% parallax is 38.4 pixels on an image that has width of 1920 pixels. Objects with 0% parallax appear at the screen plane, objects with a negative parallax are floating at the front of the screen and the objects with positive parallax are behind the screen plane. The space behind the screen is called positive space and the space front of it is called negative space.

Objects that have the parallax of 6.5cm will appear as the farthest object in the scene. It's called the artificial horizon. The parallax of the most distant object in the scene is called "far parallax".



Parallax is the horizontal difference of the each object between the left and right eye.

Far parallax doesn't need to be as long as 6.5cm. It can be smaller which simply indicates that everything in the scene is closer, but it can't be larger because that would require eyes to diverge. What this parallax is in percentages depends on your screen size. Bigger the screen, smaller the far parallax has to be.

5.2 PARALLAX RANGE - THE TOTAL 3D DEPTH

Parallax range is the difference between the far parallax and the parallax of the nearest object. It gives the shot its total depth. Increasing parallax range increases the total depth of the shot making the 3D effect stronger. For example, if the farthest object is at 1% parallax and the closest object is at -2% parallax, then the parallax range for the shot is 3%. Hollywood is quite conservative with the parallax ranges: often just 1.5% or 2%. Naturally there are exceptions for example in the occasional shots where the object flies towards the audience. If you shoot with 2-3% parallax range it can be adjusted to work with any screen size. If you are not sure what range to use, it's better to go for smaller range. With a smaller parallax range it is easier for viewers to fuse the images and you can get away with small disparities. However, if whole movie is shot with a

very small parallax range the audience will feel cheated. Where is the 3D, why aren't the things flying out from the screen? Therefore depth of a movie should be scripted so that audience can have both intense 3D effects that they came to see and the times to rest their eyes.

The far parallax is limited by the point where eyes would need to diverge, but how do we know the maximum parallax for the close objects? I have no clear answer on this as some people will lose their ability to fuse earlier than others. One thing is for sure, the fusing will get harder as the parallax range grows and it will cause more and more eye strain. Parallax range of 3% is already considered a strong 3D, especially on the big screens where most of the effect is at front of the screen. With a parallax range of 6% most of the people can't fuse images anymore. So probably the momentarily maximum is somewhere around 3-5% depending on the fusing ability of the viewers. If you go to the extremes, don't stay there too long.

There's another problem with big parallaxes: ghosting will start to appear. Ghosting is the leakage of the image from one eye to another that looks like a weaker transparent double image. It will cause the audience to disconnect with the movie as it feels

like technical malfunction that reminds them that they are just watching a movie.

The total depth of each shot is baked in into the shot the moment it is shot. It can't be changed afterwards by normal methods such as post-production shift. It would require a 2D-to-3D conversion to create a new image for one of the eyes. The total depth is defined at the moment of shooting by the interaxial, the distance between cameras. Another thing affecting the total depth is the camera's relative distance to the objects. These will be covered later in it's own chapter.

(See the 3D images at the end of this chapter for different parallaxes and parallax ranges.)

5.3 SCREEN SIZE

To ensure that our far parallax doesn't cause the eyes to diverge we have to calculate far parallax for each screen size. The needed far parallax is the average eyes' interocular divided by the screen size. For a 10m screen: $6.5\text{cm} / 1000\text{cm} = 0.0065$. This gives us a far parallax of 0.65%.

If you have 1% parallax for the farthest objects and you show it on a 6.5m screen your image is ok because 1% of 6.5m is 6.5cm. However, if you show your movie on a 13m screen

without modifying it the parallax of 1% is 13cm. As a result your eyes will not be able to fuse the image fully and this will cause the objects exceeding the 6.5cm parallax to be doubled.

When you shoot your movie you should consider where it's going to be shown so that you can maximize the 3D for that screen size. It's easy if you know there's only going to be one viewing format. If you will have many viewing formats you need to make a version of the film for each screen size. To adapt your film for the different screen sizes requires you to do a post-production shift aka H.I.T, horizontal image translation. The post-production shift will move everything in the scene either closer or farther. It will be explained later.

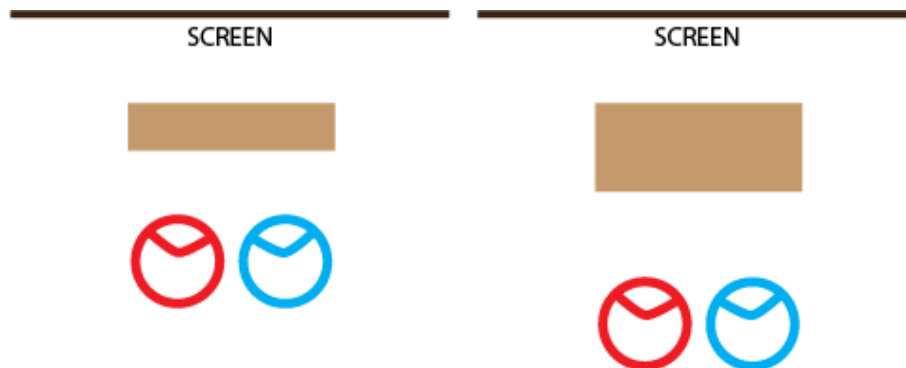
The bigger the screen is, more the objects will appear in the front of the screen. This happens because we need to avoid viewers eyes from diverging so as the screen size grows, smaller the allowed far parallax becomes. On the other hand on small screens the negative parallax is more limited and it is better to place most of the objects behind the screen. The common far parallaxes for different screens are:

- 2% for small screens
- 1% for 6.5m screens
- 0.5% for 13m screens

0.25% for IMAX

5.4 SCREEN DISTANCE

Object's perceived distance from the viewer depends on viewer's distance to the screen. Object with negative parallax equal to the eye separation will cause the object to appear at the half way between the viewer and the screen. Doubling the parallax will cause the objects to be perceived at 1/3 of the distance from viewer to the screen. If viewer is very close to the screen, the perceived distance is small which makes the image feel fat. When the viewer moves farther the 3D will seem to stretch more out of the screen. This means the 3D movie will be seen differently depending where the viewer sits.



As the viewer moves farther from the screen the objects stretch more towards him.

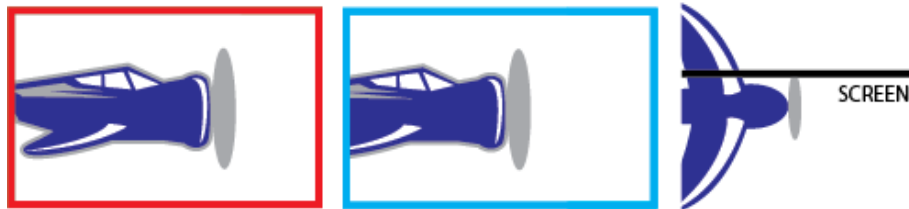
5.5 FLOATING STEREOSCOPIC WINDOW AND STEREO WINDOW VIOLATIONS

In traditional cinema the screen is the screen, it's static and flat, always in the same place. With 3D the screen turns into a window extending beyond the screen and flying into the theater. Same way the screen plane becomes dynamic and we can push it behind the physical screen or bring it into the theater. We can even lean the screen to any direction. The window will change according to the shot and it may be dynamically moved even during the shot.

To explain stereo window violations, it's better to use an example. Imagine a doorframe or corner of a house, someone behind the wall pushes his head out and takes a peak at us. We only see the parts of him that are not masked by the wall. Now think about the edge of a movie screen, character outside of the frame pushes his head into the frame to take a peak at us. If this character is behind the screen plane, this feels completely natural to us. We see the edge of the screen as a wall that's blocking our view. If the character would be incorrectly placed at the front of the screen plane we'll run into a serious problems. It looks as if the character was cut in half by an object that is

actually behind the character. This is one of the most painful mistakes in 3D.

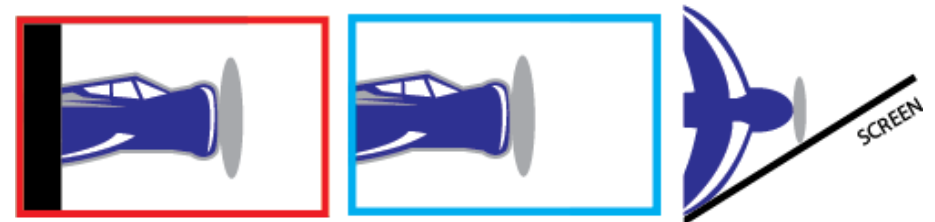
(See the 3D images at the end of this chapter for a violation example and corrected version.)



The plane entering the frame is in stereo window violation as it is front of the screen, but still cut in half by the screen.

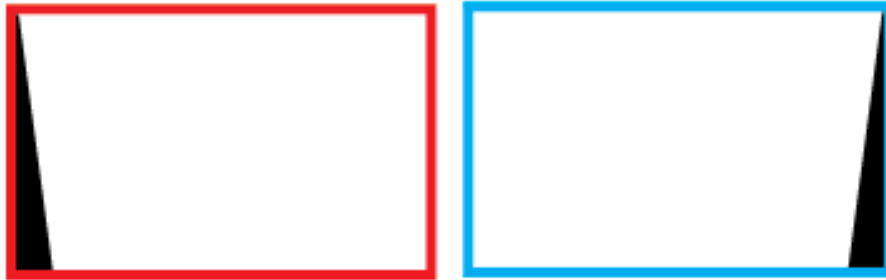
Luckily for us the floating stereoscopic window method will allow us to correct this conflict. Floating stereoscopic window is achieved by masking the sides of the shots with black bars. If you mask both images from the same side you simply reduce the frame size, but when you mask just one of the images you will move the edge of the screen. If you mask the left image's left side you will pull the left side of the window towards you. If you also mask the right side of the right image then the whole window moves closer. If you mask the left side of the right image and right side of the left image you will push the window farther. Pushing is quite rare where pulling is used to solve the

stereo window violations. In the case of someone entering the frame from the left in stereo window violation, you want to mask the left image's left side to pull the left side of the window closer. How much you need to mask? If the character that is at front of the screen enters the picture from the left side he will first appear in the left image, but later he will appear on the right image. From each left frame we need to mask out the part of the character that doesn't show on the right image.



Part of the left image that doesn't exist in right image is masked. This moves the edge of the screen to the front of the object.

Masking the window doesn't need to be vertically symmetrical. If needed, we can pull any of the corners independently. Using this method on both of the top or bottom corners we can move either the top or the bottom of the screen in depth. If we need to, we can just move one of the corners or any combination of them. With dynamic window the screen becomes a floating paper that we can bend and turn as we wish.

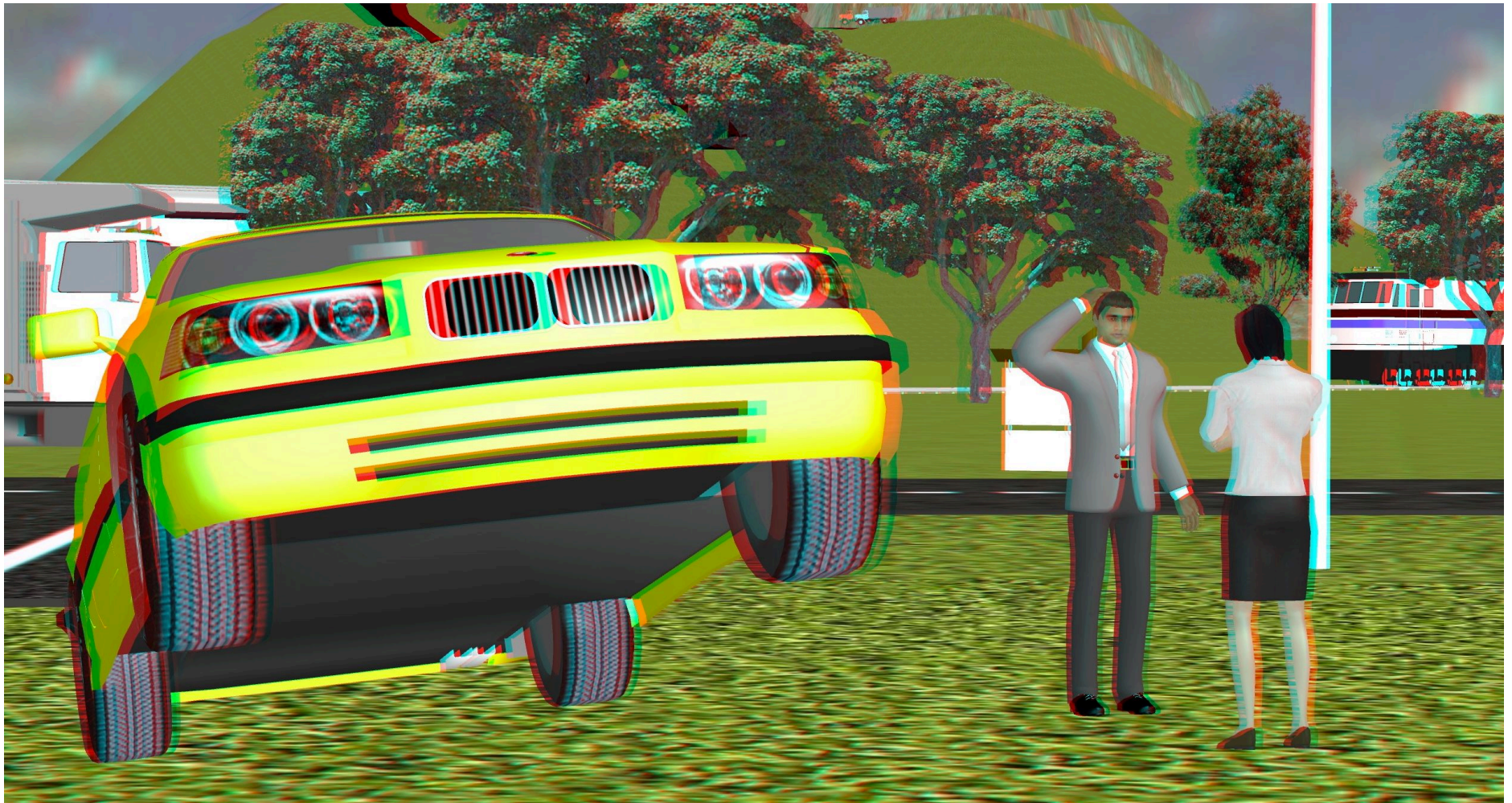


Masking is not vertically symmetrical. Pictured masking will cause the bottom edge to be pulled towards the viewer. It can be used for example in the situations where the camera placed at low level has lots of ground in the shot that is violating the stereo window.

Most people will not mind about small violations if they happen in the top or bottom of the screen, later being the least intrusive because when we talk with the people we are used to seeing their heads, not the lower part of their bodies. If the violating object is dark, close in color to the black of the edge, the violation becomes harder to notice. So sometimes throwing a simple vignette effect to the side of violation will help.

To spot the violation our brain needs approximately 0.5 seconds. If the object is really close to us and enters or exits the frame fully within that time, it will not have time to cause us retinal rivalry.

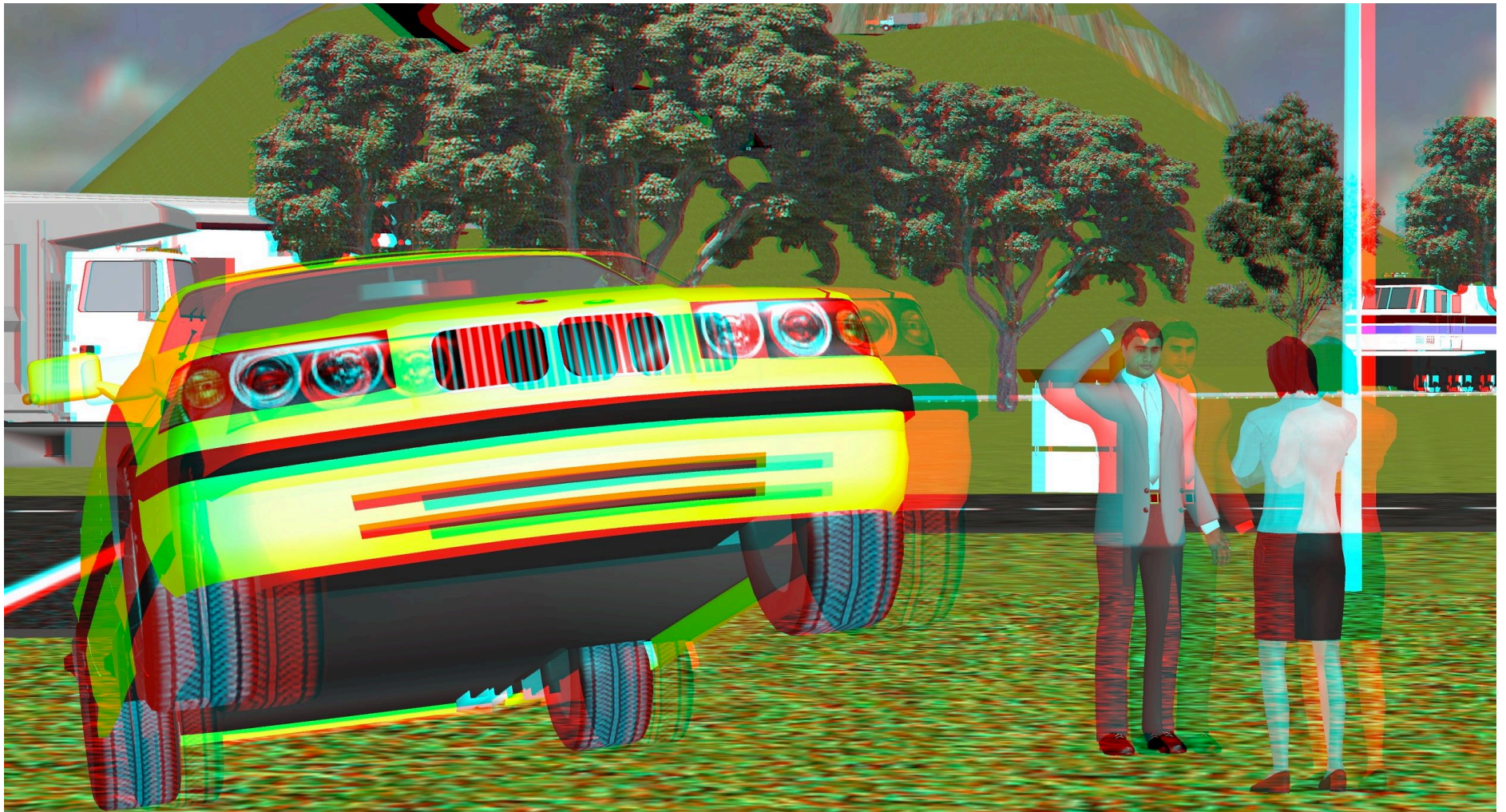
Floating stereoscopic windows also allow us to better match the depth of consecutive shots to avoid depth jump cuts. Technique is called dynamic depth matching. It'll ease the viewer to fuse the incoming shots by leading their eyes to the right depth just before the actual cut happens. Basically the depth of the outgoing shot is moved to match the depth of the incoming shot.



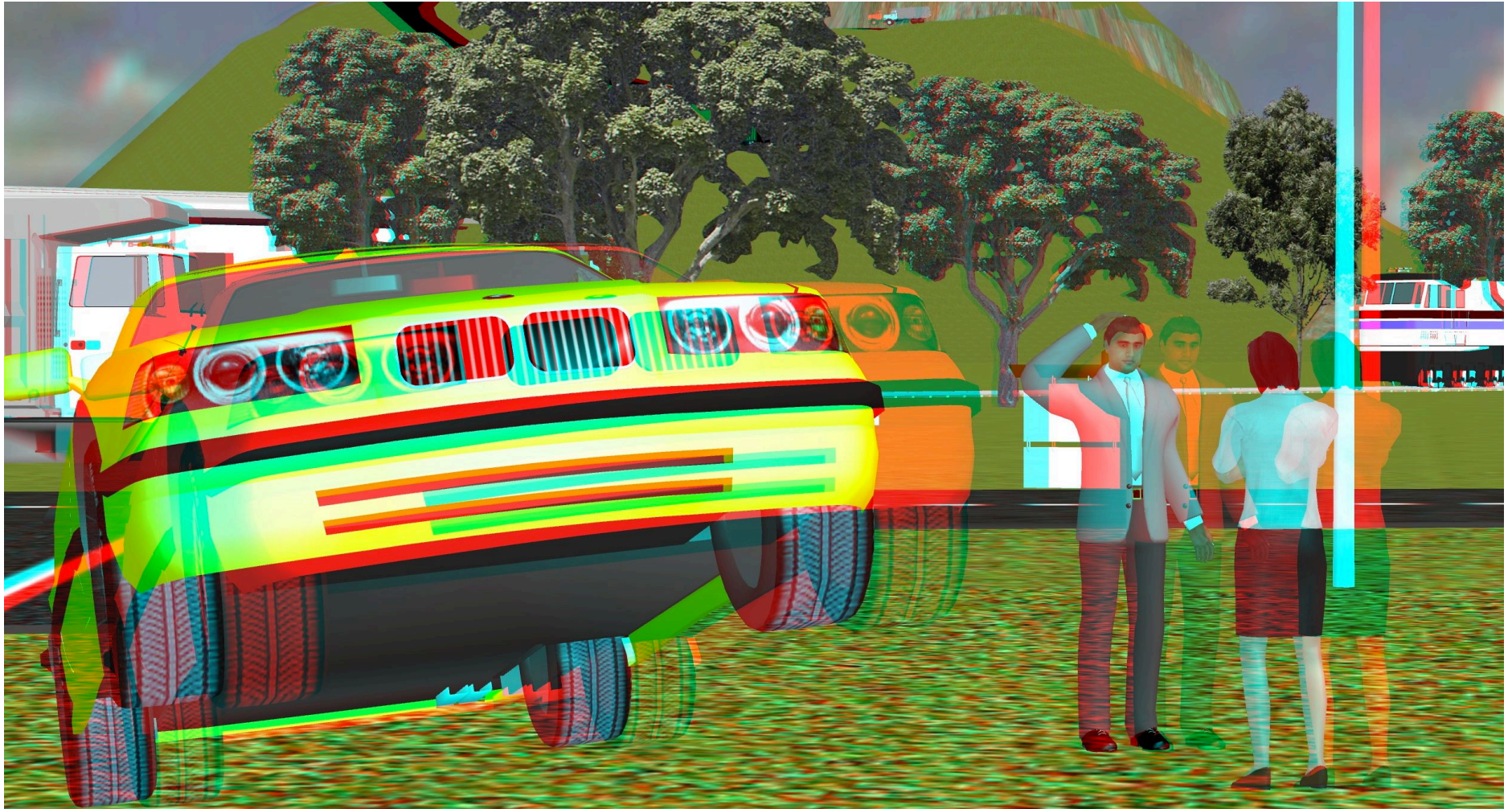
NORMAL 3D EFFECT. The closest object at -1.3% (the car grill), the far parallax at +1.0% (background). This image has rather safe parallax range of 2.3%.



STRONG 3D EFFECT. The closest object at -3.2% (the car grill), the far parallax at +1.0% (background). This image has already really strong stereo effect with parallax range of 4.2%



EXTREME 3D EFFECT. The closest object at -4.6% (the car grill), the far parallax at +1.0% (background). This image has extreme parallax range, many viewers will not be able to fuse it.



TOO STRONG 3D EFFECT. The closest object at -7.0% (the car grill), the far parallax at +1.0% (background). For demonstration purposes this picture has even more extreme parallax range compared to the previous one.



TOO LARGE FAR PARALLAX. The closest object at 0% (the car grill), the far parallax at +9.7% (background). The far parallax is way too large.



STEREO WINDOW VIOLATION. The closest object at -2.0% (the car grill), the far parallax at 0%, the car is at stereo window violation as it is front of the screen but still being cut by the edges making the picture uncomfortable to watch. Our brains will try to push everything behind the screen because of this conflict.



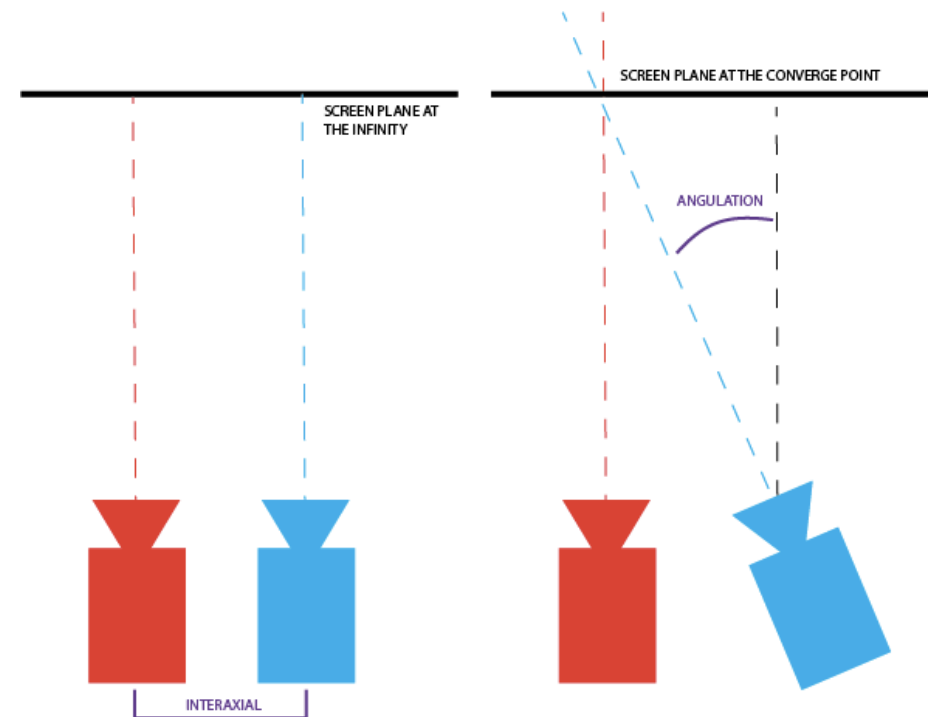
STEREO WINDOW VIOLATION CORRECTED. Everything pushed back 2% with H.I.T. The closest object at 0% (the car grill), the far parallax at 2%, the car is no longer at stereo window violation. Overall depth of the image is still the same with 2% parallax range.

6 SHOOTING PARAMETERS

6.1 INTERAXIAL

Interaxial, sometimes referred to as interocular, is the distance between the axes of the lenses. Farther the cameras are from each other, larger the interaxial. Interaxial is used to control the total amount of depth in the shot. Larger the interaxial, more there's depth in the shot. We measure this with parallax range, the difference in depth between the farthest and the closest object. If an object is very close to the camera, an even small interaxial can produce big parallax. If the interaxial is fixed, our only way to control the total depth in the shot is to move everything in the set either closer or farther in relation to the camera. Choosing correct interaxial is very important as it will bake the total depth into the shot. There's no easy way to change it after shooting.

We relate the reality with our average interocular distance 6.5cm. When we shoot 3D movies we have the option of choosing our interaxial which is often smaller than the interocular of our eyes. Larger interaxial can be used to shoot wide scenes and big objects that would otherwise seem too flat



Interaxial is the the difference between cameras. Angulation is the angle how much the camera differs from the parallel angle.

and produce disappointing 3D for the audience. We should still be careful on how much depth we give to the shot since seeing the big objects with strong 3D will cause these objects to look small. It can make a whole city look like miniature model. This happens because we are not used to seeing big objects normally without moving farther away... and farther the objects

are, flatter they appear. Similarly if we use really short interaxial to shoot small objects very close to the camera, these objects will then feel bigger.

(See the 3D images at the end of this chapter for how the interaxial and object's distance from camera affect the amount of 3D.)

6.2 ANGULATION (CAMERA CONVERGENCE):

Angulation aka camera convergence is the angle of how much the cameras are turning inwards. The angulation range is usually from 0 degrees to 2 degrees, later is already very strong. For practical purposes usually only one camera is turned: to achieve 1 degree angulation you turn one of the cameras 1 degree inwards, not both cameras 0.5 degrees inward. With angulation 0 degrees the cameras are parallel. When shooting parallel the far objects are going to be on the screen level by default. This means that everything else will be at front of the screen in the negative space reaching towards the viewer.

The place where the lenses' axes converge will be the screen plane. Objects on screen plane appear exactly on the screen, not behind, not front of it. Angulating doesn't affect the total depth, but it simply moves everything in the scene either closer

or farther. Angulating cameras will introduce keystone effect. Small keystone effects do not matter but more you angulate, more keystone will appear and you may need to correct in post by pulling the corners of the image to change its perspective. Naturally this will cause some of the resolution to be lost.



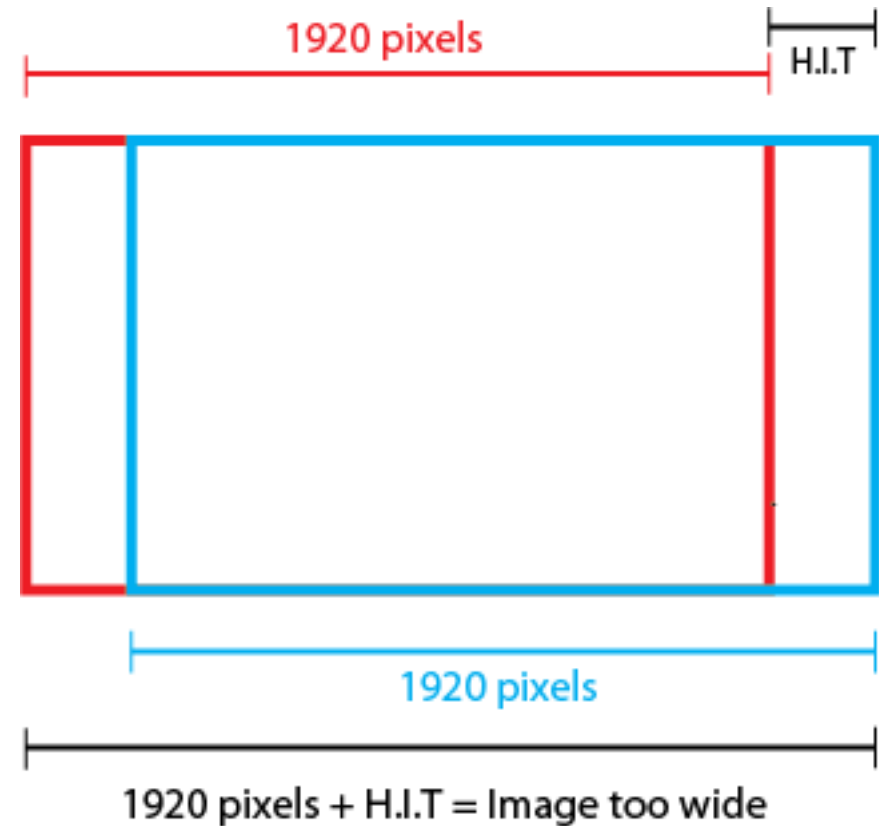
Exaggerated example of keystone causing the objects in the frame to have all kinds of disparities.

6.3 POST-PRODUCTION SHIFT AKA HORIZONTAL IMAGE TRANSLATION

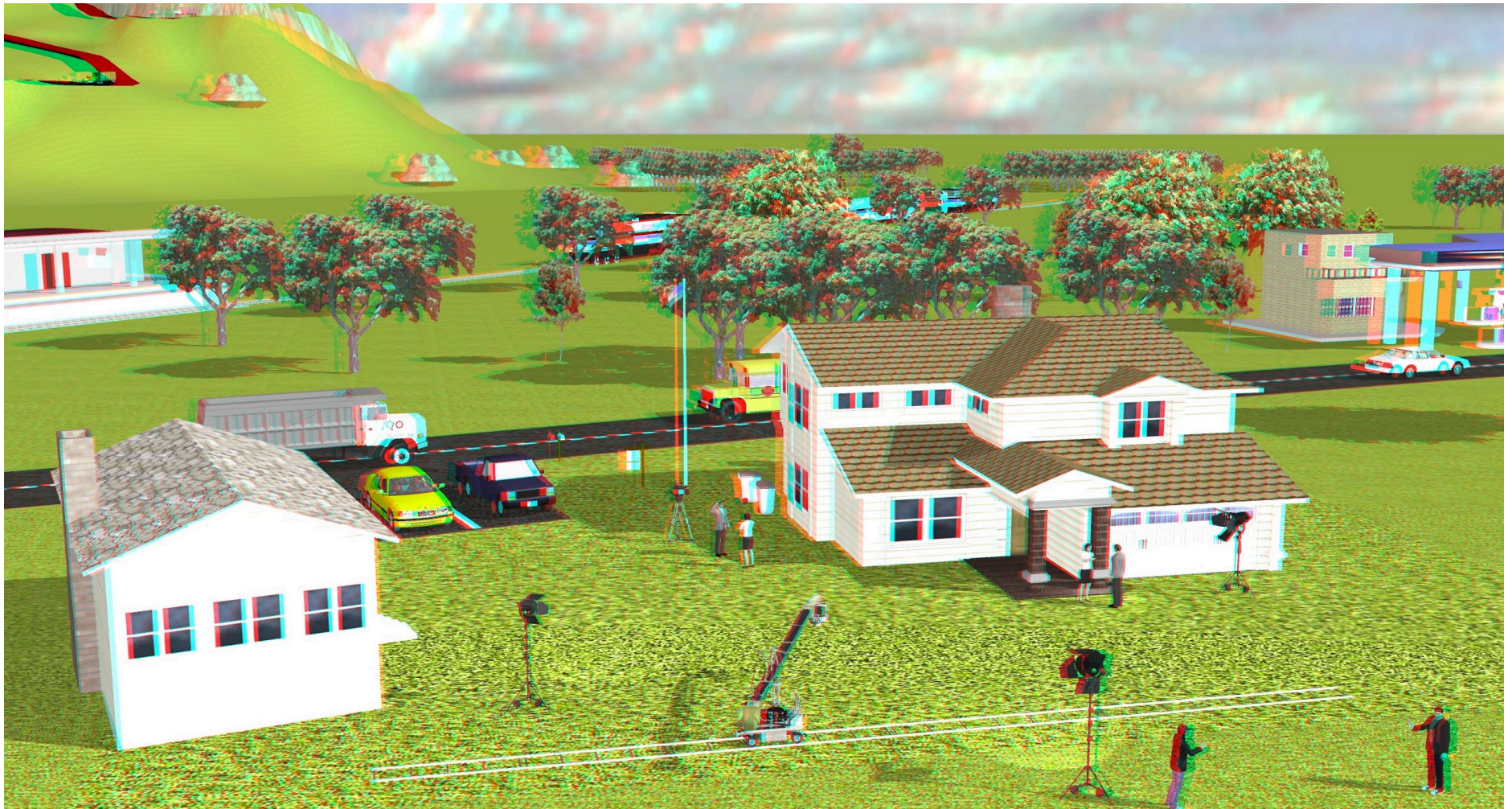
Post-production shift aka horizontal image translation (H.I.T) is more of a post-production parameter as you already may have

figured out from its name. However, if you have stereo compositing monitor in use when shooting, you can set the post-production shift there and see the image corrected immediately. This way the post-production shift becomes one of the shooting parameters. If you are going to shoot parallel (without angulating your cameras) then post-production shift is your only way to move the screen plane and therefore necessary parameter.

Without post-production shift our two images overlap each other fully. Post-production shift moves the left and right images farther apart from each other. This means that the area on both sides of the screens where we have just one image (not two overlapping images) appears and becomes bigger as we apply more correction. This leads to “over shooting” as our footage’s width is now exceeding the format’s limits. For the final product we will need to crop and zoom the image, which causes us to lose some of the resolution. Just like angulation, the post-production shift will not affect the total depth of the image.



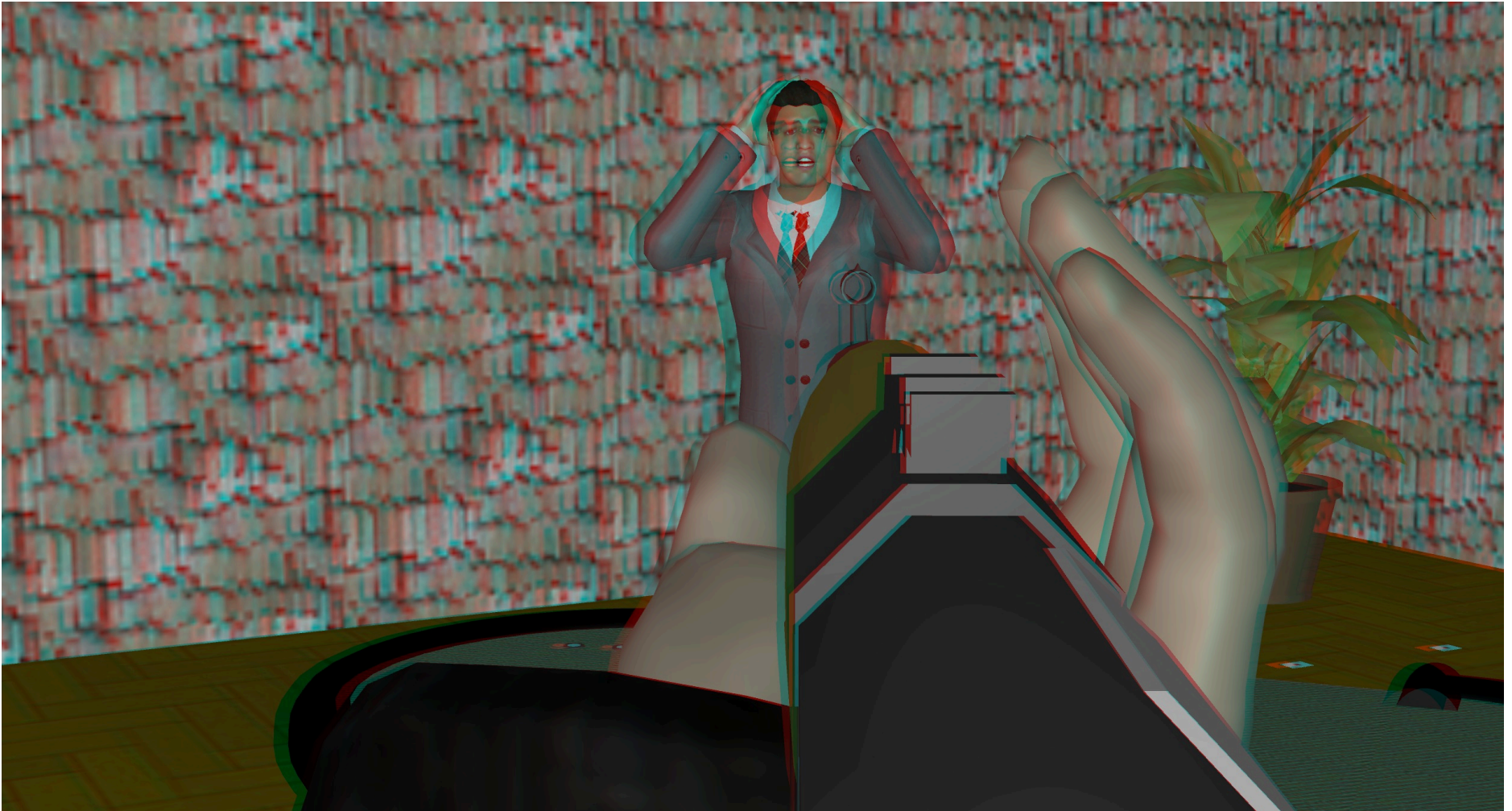
Horizontal image translation leads to the image being too wide compared to the original format as each of the images has already been shot with the maximum width of the format.



MINITURIZATION. Long interaxial when shooting large scenes can lead to miniturization of objects as we are not used to seeing them with strong 3D effect in real life.



SMALL INTERAXIAL WITH OBJECTS FARTHER. With a very small interaxial of 29mm this image produces quite disapointing 3D effect. The closest object at 0% and far parallax 1%



SMALL INTERAXIAL WITH AN OBJECT CLOSE TO THE CAMERA. The interaxial is only 1mm, even smaller than in previous image but since the rifle is really close to the camera even this small interaxial can produce a parallax in it. The closest object at - 0.15, far parallax 1%.

7 GEARING UP FOR THE SHOOT

7.1 REQUIREMENTS, OPTIONS AND LIMITATIONS

Because our stereoscopic vision works by fusing the images from both eyes together the basic requirement for shooting 3D is that we shoot two images, one for each eye. We either need a 3D camera or two cameras placed on a rig to simulate our eyes. Of course with the rig solution we are not limited to simulating the distance between our eyes but we may want to place the cameras closer or farther away from each other depending on what we shoot.

If you shoot with small handheld 3D camera, you will lose all the control on the depth. Professional 3D cameras have converge control but that only equals on doing the post production shift later. You are still limited to the offered interaxial which defines the overall depth of the scene. Without interaxial control only way to control depth is by moving camera closer or farther.



Sony 3D camera with adjustable convergence.²

For some cameras you may find a specialized 3D lenses. Basically they mount similarly to normal lens, or are extension to the normal lens, but they divide the image into two. Problem with this solution is not only losing the control of converge and interaxial but also halving the horizontal resolution. Horizontal resolution is the most important resolution for the 3D as 3D effect is formed from the horizontal parallaxes.

If you want to control everything, which I'm sure you do, you need to have a 3D rig with two cameras. The specialized rigs and other equipment used now has pretty much been developed by the hobbyist who started shooting 3D with their DIY rigs. Eventually these rigs turned from mechanical to motorized, electronic and finally fully computer controlled. Motors were added to make the changes on the fly or remotely if accessing camera was hard, for example if it was placed on the end of a crane. These motors then could be linked to work in sync with each other and finally sophisticated image analyzers could control the rig automatically fixing the possible errors and mismatches. On these rigs the adjustments include:

- Interaxial, the distance between the two cameras. Larger the interaxial in relation to the subject, stronger the 3D effect is.
- Angulation, the angle of the two cameras in relation to the each other. This is used to either bring everything closer or pushing it back, it is useful to define where the screen plane is.
- Yaw and tilt is used to compensate lens differences when zooming. On zoom lenses the axis shifts around when zooming and each lens have their own unique shift. This

control is calibrated to automatically compensate for the shift of each lens on its different focal lengths.

- Roll, the angle of cameras in relation to horizon. It's used to adjust rotation.
- Synchronized focusing motors for both lenses ensuring that they are focused to exactly the same spot.
- Synchronized zooming motors for both lenses ensuring that the focal length is exactly the same.

In perfect 3D there are no disparities but if you shoot it with your DIY rig or even professional mechanical rig, adjusting it to the nanometer precision is practically impossible. You can find comfort in the fact that small disparities can be tolerated, but even these maximums are really small:

- Vertical less than 0.8%
- Rotation less than 0.8%
- Zoom less than 1.2%

Naturally you don't want to be close to these limits. Some of the disparities may be corrected in the post by moving or rotating the images in relation to each other but you will lose some of the resolution or introduce new disparities as you can't adjust the image on subpixel level. I have no number for allowed

difference for focus, but since the most of the 3D is shot with a long depth of field, the effect of focus disparities become almost meaningless. Of course if you choose to shoot your 3D movie with shallow depth of field or you use it as a special storytelling tool to indicate something, you better get the focus exactly right on both cameras.

If you go with two cameras your first task is to get them to run in sync. Professional cameras offer the gen-lock option to sync the cameras and to keep them on sync. However normal gen-lock may not be accurate enough. Best option is to have external sync pulse generator that is connected to the both cameras' gen-lock in port. On cheaper cameras you have a LANC remote controller port. If you modify a LANC controller to start two cameras with one press then you should have pretty accurate synchronization. However, this sync will run out as the time passes. If the sync is spot on in the beginning given that the solution you used to start the cameras was accurate, your sync should stay good for at least minute or so. You need to experiment to see how long you can roll before time shift starts to cause disparities. Naturally you need to test first if your solution is accurate to begin with.

Current trend of S16 sized sensor RAW cameras are new interesting wave in cinematography this year. This is also an interesting new twist when talking about 3D. These cameras are smaller in size and the longer D.O.F is actually a benefit. There's already few placed at the \$3000 range coming out later this year. While they are not perfect for 3D they are still better than many earlier options and at least they are cheap. At least the camera from Blackmagic Cinema Camera has a HD-SDI out making the usage of external recorder possible without converters on the way. Currently this is the road that I think I'll take when building my set. However first I have to do some experiments to see how important having a gen-lock truly is as these cameras don't seem to offer that option either. There is a interesting camera called Flare 2KSDI coming out for about \$7000 that due to the small width could get quite far even in side-by-side rig..

If you are using DSLRs you may try starting the video shooting on each camera, then take a picture using a modified remote control that is linked to both cameras, then do the clap. You need to sync the footage in editing according to the clap but taking the synchronized photo while still shooting the video should have matched the sensor readout to the same phase. This should work at least on Canons¹⁰, while all cameras may

not allow taking a photo while shooting the video as I noticed is the case with Sony NEX-5N. NEX-5N is promising for 3D because of its ability to shoot 50p but it's lacking a way to start the video remotely. Possible way around this could be opening the shell and hard wiring the sensors under the REC-button as this method works at least for shutter release.¹¹ Canon on the other hand has USB-controllers such as Okii on the market that allow the starting of the video recording.⁸ However, due to Canon's protocol you can't simply use one of these controllers with two cables but have to actually modify two controllers to work in sync.

Unless the cameras' especially have a 3D feature that uses the image stabilizers to compensate for the zoom axis shift (Canon XF105), you need to disable it. Image stabilizers, if working independently, may choose to stabilize the images differently and that will cause disparities between the images.

7.2 SIDE-BY-SIDE VS. BEAMSPLITTER MIRROR

Choosing the correct rig for you cameras comes down to simple question of needed interaxial. Side-by-Side rigs are limited by the cameras physical size and they usually have interaxial larger than 13cm. With really small cameras such as SI-2K it is

possible to get closer. Since interaxial defines the total depth of the shot by larger interaxial causing more depth, the side-by-side rigs are usually only usable on wide shots or shooting objects far away.



*Filmfactory's Side-by-side rig.*⁵

If you are stuck using side-by-side rig you would need to move the actors farther away from the camera to compensate for long interaxial. This may be alright outside or in a studio with movable walls but many times you simply won't have that luxury. The simple solution would at first seem to be flipping one

the cameras upside down to get them closer but unlike film, which is exposed full frame at a time, many digital cameras use sensors that are exposed line after line, the infamous rolling shutter. If you shoot out of the moving car window you will notice the lampposts or trees leaning backwards as these objects change place between exposing the first and last line of the sensor. If you flip one of the cameras upside down this rolling shutter will cause the objects to lean to different directions, creating retinal rivalry.



Shot with one of the cameras flipped upside down, the rolling shutter causes the moving objects to lean different directions.

Many times the needed interaxials are really small, requiring even the lenses to overlap with each other. No side-by-side solution could offer that. I started to think that only way to shoot 3D would be usage of a beamsplitter rig aka mirror rig. Mirror rig gets it's name from having a mirror that is 50% reflective and 50% transmissive which splits the beam in to two parts. It's

similar solution with a teleprompter. Small interaxial of mirror rig will allow you to bring the lenses closer or even fully overlap each other which is very handy for calibration. Remember that when you attach the cameras to a mirror rig you need match the rolling shutter by placing the cameras so that they read the scene in same direction.



*Filmfactory's Mirror rig aka beamsplitter rig.*⁵

Mirror rigs have their problems too. They are bulky and rigging the cameras can take a long time. Mirrors gather lots of dust and they break easily. You will also lose one stop of the available light on each camera because the mirror splits the arriving light 50-50 for both of the cameras. Due to the nature of the light, the colors will shift and the reflection/transparency will cause differences in brightness between the left and right images. Polarization also occurs on reflected image. These differences need to be balanced out as well as possible by placing filters front of the cameras. It is probably impossible to get it perfectly right without correcting in post.

Cheapest mirror rig I've found for sale is DIY kit from 3Deyes and it goes for \$1500. If you want to build your own mirror rig through your own trial and error the most expensive part probably is the mirror itself. You need to make sure that it is as close 50-50 split as possible and it needs to be surface coated. Surface coated means that the reflective part is on the top of the glass, not under it. Normal household mirrors are not surface coated: If you place your finger on the mirror you will see a small space between the tip of the finger and reflected tip of the finger. On surface coated mirrors there's no space between. If you use normal non-surface coated mirror, the glass

itself will reflect small amount of light giving creating a secondary ghost image next to the real one.

7.3 LENS CHOICES

When shooting 3D lens choices are wider than when shooting traditional cinema. There are two main reasons:

- 1) Long lenses compress depth and therefore kill the roundness, which in extreme cases make the objects look like cardboard cutouts. (*See the example 3D images at the end of this chapter for effects of different focal lengths.*)
- 2) Long lenses produce shallower depth of field. In 3D our eyes want the ability to focus anywhere in the image. See chapter 8.1 for more information.

21mm is the normal focal length for s35 movie camera with 1.85 aspect ratio. This produces the 53 degree field of view. This so called normal focal length produces the image exactly as we see it in our eyes.

As mentioned earlier, zoom lenses have axis shift when zoomed and it is impossible to find a pair that would shift same way. This shift means that if you place a dot on the middle of the frame and zoom in, this dot will move to different directions

depending on the focal length, it will not stay in the absolute center. On professional computer controlled rigs, where the shift can be compensated by small adjustments to yaw or tilt AND the zooms can be synchronized to be at the exactly same focal length, the zoom lenses are preferred as changing the lens requires recalibration of the rig. If you are shooting with manual rig you better use fixed lenses or zoom lenses only at their widest and longest end to avoid differences in focal length. If you change the focal length in manual rig you better recalibrate your rig.

7.4 MONITORING

Monitoring is highly recommended to avoid bitter failures that become visible only in the post when you put the images together. Stereo compositing monitor builds a stereo image from the outputs of two cameras allowing you to see the image exactly as it would look when it's ready. The monitors also have different aides to help you set up your cameras visually, they may show depth difference maps or reference lines to help you count the parallax.



Aides on stereo compositing monitor: Lines indicating 1% parallax help us to visually count the parallaxes from the screen (above). Lines indicating 2% parallaxes combined with depth map visually showing the differences (below).

Monitor will also allow you to set the post production shift on the field for previewing purposes. It can then be written down on the slate so that the editor will later know how to configure that shot. Preview image may be an anaglyph image that can be viewed with an anaglyph glasses or use more expensive active or passive glasses system that give you accurate colors unlike anaglyphs. Stereo compositing monitors are quite expensive, Transvideo's (monitors that according to Alexandre Saudinos are the best) starting from 7000 euros. Panasonic has sub-\$4000 monitor but it lacks some of the features that good compositing monitor should have.

Cheaper DIY solution would be to buy normal 3DTV and stereo HD-SDI to HDMI converter. Basically the converter takes in the left and right channel each on its own HD-SDI connector and pushes out a single HDMI signal with embedded 3D that normal 3D displays can understand. Then you count the parallax from the screen using a ruler or piece of paper cut on to the 1% width of the screen. If you shoot with cameras without HD-SDI out you would first have to convert the signals from HDMI to HD-SDI unless you are able to find converter that accepts HDMI as inputs.



AJA HD-SDI to HDMI converter capable of embedding the two channels to a single 3D-HDMI signal.³

Monitoring is also available through dedicated computer software which many times do lot more than just monitor the signal as they may have different kind of image analyzers built-in. They may even be able to automatically control the motorized high end rigs. However, these programs are made for niche market and therefore are quite expensive. Dashwood's Stereo 3D CAT has free version but to get the anaglyph viewing mode you need \$1249.⁶

7.5 RECORDING

Unless you have 3D camera you will have to sync the footage from two cameras together in post as both of the cameras can only record their own footage. There are external recorders that are capable of handling two feeds and recording them in stereo format. These recorders just like the monitors are very expensive, starting from around \$6000.

Good thing about recorders is that they solve the issue of needing to playback the footage from two cameras in perfect sync. Since the footage is recorded to one place it can also be played in perfect sync by press of a single button. To solve the playback problem otherwise I can only come up with few untested ways: If your cameras have remote control with play option you may be able to use one remote to start playing on both of the cameras; if you have 3d monitor with processed anaglyph output you could record a copy of the shot to a normal external recorder and review the shot from there in hardcoded anaglyph. Of course this recording would be totally useless to any other purposes as we want to keep the channels separate so that they may be re-encoded later to any of the available 3D viewing formats.



Blackmagic's 3D in/out box allowing us to input two separate video signals to a computer. These signals can then be analyzed as 3D with the help of dedicated program.⁴



Gemini RAW recorder with native 3D support. Just released, not available yet.⁹



3D WITH SHORT FOCAL LENGTH. The short focal length of 24mm gives more roundness and depth to the image.



3D WITH LONG FOCAL LENGTH. With the focal length of 130mm the roundness of objects and the space has been compressed.

8 SHOOTING 3D

8.1 PREPARATION

3D should be scripted so that movie has variation in the strength of the 3D, giving audiences enough 3D effect so that they don't feel disappointed but still allowing their eyes to rest. Of course 3D as an effect should be used a way to tell a story, not just for the sake of the 3D as a gimmick.

Storyboarding becomes more important because you need to know how the depth is going to be cut. Too much jumping in the depth will strain the viewer as it always takes time to get used to the depth of the new image. If the depth matches on the point of the cut, then the transition is easy for the viewer.

Storyboarding will also help you to detect possible stereo window violations. You may need to compose shots differently than in traditional cinema, for example you may want to leave some headroom to avoid them being cut in a way that would cause stereo window violations. When drawing storyboards you can use a thicker pen for foreground objects, a normal one for screen plane and a thin pen for behind the screen. This way the depth is easily readable to everyone who sees the storyboards.

The cheap DSLR video has made the shallow depth of field an ongoing trend in the independent movies. When you think of how to tell your story in 3D you may want to consider if shallow D.O.F gives that instant cinema feeling anymore. Out of focus areas give less depth information because of the lost detail. In addition to artistic style the shallow depth of field is used to control what the viewer should be focusing. In 2D it feels normal but in 3D it feels little unnatural. In 3D viewer needs more freedom to let the eyes wander. Even if the cameras had been converged to certain point, 3D effect will work if the viewer chooses to focus at something else. *(See the 3D images at the end of this chapter for the effects of D.O.F.)*

You will need lots of light because most likely you will shoot with really small apertures for long depth of field. If you shoot with a mirror rig you will lose an extra stop of light. Avoid creating high contrasts because they will easily create ghosting. The areas most vulnerable to the high contrast are the left and right edges of the screen. Another reason to avoid high contrasts is that if you burn out white and crush the blacks there will be no detail to produce parallax on these areas. *(See the 3D images at the end of this chapter for the effects of contrast.)*

Since the 3D effect is based on the differences between left and right image, if you have no details you also will have no depth. If you shoot an empty white wall, even if you exposed it correctly it would still be an empty white wall. You should always choose surfaces that have some detail like decorative patterns or visible material texture. If you have a flat empty wall, you can't renovate and you are tied to that location, you better hang some pictures or posters on to the wall so that it will have some depth cues. *(See the 3D images at the end of this chapter for the effects of no detail surfaces)*

Fake backgrounds such as paintings will not work in 3D as they have no depth. Everything in the painting will appear exactly at the distance of that painting.

8.2 CAMERA CALIBRATION

Camera Calibration has to be done before you start shooting, change a lens or if there are any other changes except interaxial or angulation on the rig. If you don't calibrate your cameras you will have many different kind of disparities between left and right images that could have been avoided. Disparities will cause retinal rivalry and then give the viewer a headache.

To calibrate a side-by-side rig you need to have two calibration sheets. You place them on an even separated by the distance of your interaxial. This way, although the cameras are pointing at the different sheets, the both cameras should have exactly the same kind of patterns on their viewfinders. Then you adjust the rig with the help of compositing monitor so that the patterns on the sheets are perfectly overlapping.

Calibrating a mirror rig is easier. You will simply set the interaxial to zero to have both of the lenses overlap each other. Then while looking at the compositing monitor you to set the cameras so that the both cameras are seeing exactly the same image. You don't even need a calibration sheet although you might get more accurate results with one.

Because of the mirror we may find other problems in the brightness and color. For brightness you need to use filters as you need to have same parameters on the both cameras. If you have to adjust in camera, try adjusting gain. Although gain patterns will not match, it is still more tolerable disparity than changing the aperture or shutter speed would cause. Don't simply choose the same preset white balance for both cameras, but take a custom one for both separately. It will allow the cameras to correct internally some of the differences caused by

the mirror. If you need to make more adjustments, use the transmissive camera as a reference since the reflective camera receives more “damaged” light.

After calibration is done, shoot some calibration footage for later reference.

8.3 SETTING UP THE CAMERA

There are two methods to shoot 3D: Parallel and converged cameras. You need to choose which method you would like to use. The workflows are pretty much the same except on the way, how we choose where our far parallax is. In parallel shooting we use post-production shift and in converged shooting we angulate cameras. Before you start to shoot, make sure the cameras are calibrated to avoid disparities between the images.

Before you start adjusting the cameras you should decide where do you want the background be. This will give you the far parallax percentage that you need when you do the adjustments. Other thing you need to decide is that how much total depth you want this shot to have. This will be your parallax range. If you don't know or understand what you want, try

building the shot with far parallax of 1% and parallax range of 2% or 3%.

I will first cover a pretty idiot proof two step method for setting the camera up. Idiot proof means that after setting your cameras you should have acceptable stereo images that won't hurt the audience's eyes. If that's not enough there's more theory coming afterwards.

8.3.1 TWO STEP METHOD TO SETUP THE CAMERAS

1) ADJUSTING THE FAR PARALLAX

Set the cameras parallel with a small interaxial. If shooting parallel the background is at the screen plane with the far parallax of 0%, everything else is front of the screen with negative parallax. If you are in small space and a wall blocks your view to the infinity the wall will also appear at the front of the screen and you need to check from your monitor what's the parallax of that wall.

Push the background to the chosen far parallax, usually 1% for objects at infinity. You can do this either by selecting a post-production shift from the monitor (shooting parallel) or

angulating the cameras (shooting converged) until you have the chosen far parallax.

2) ADJUSTING THE INTERAXIAL

Choose which of the two methods you want to use: Closest object method or Screen plane method. Both will produce the same result but will allow you to concentrate on different things when doing the adjustments. You probably know best which one in any given shot is more important to you: where the closest object is or where the screen plane is.

A) CLOSEST OBJECT METHOD

With the closest object method you can control exactly how much you want the 3D effect to reach out towards the viewer. The visual method requires a monitor capable of showing the differences between right and left image. Ideally it would display a reference line between each 1%.

VISUALLY

Choose the wanted near parallax according to your parallax range. If the far parallax is 1% and the wanted range is 3% then the near parallax would be -2%. While looking at the nearest object's parallax on the monitor, move the cameras until the parallax is correct.

MATHEMATICALLY

Send your assistants with a measure tape to stand in both sides of the frame at the distance of the closest object. Measure the frame width. If the frame width at this point is 2m and the wanted parallax range is 3% then the interaxial is 3% of the 2m (200cm) which is 6cm.

B) SCREEN PLANE METHOD

If you need to control where the screen plane is (this is the point with parallax 0%), you may want to set the interaxial using the screen plane method.

VISUALLY

Look at the monitor and check the differences between left and right image. Find the point where there's no difference. If you change the interaxial now you will notice how the point moves.

MATHEMATICALLY

If you have no 3D monitor you can use specialized stereo 3D calculators to check the rig settings. These calculators are available for computers and smartphones.

CHECK THE FAR PARALLAX AFTER INTERAXIAL

Check the background again to make sure it is still at the point where you placed it at the step 1. If the background has moved, set the far parallax again according to the step 1.

You have set the interaxial and your far parallax is also where it should be? That's it! You are ready to shoot.

8.3.2 THE 1/30 RULE

The 1/30 rule is a thumb rule that states that the interaxial should be 1/30th of the distance from the camera to the closest object. You can use it as a starting point if you don't know what to do. If the closest object is at 1.2m then the interaxial should be 4cm. This works well in outside shots with the background at infinity, cameras being parallel and the expected screen size less than 165cm, which in the world of TVs is 65". When shooting big screen feature films this 1/30 rule becomes more conservative. You can use 1/60th of the closest object's distance or even less. If you are not sure, you better choose shorter interaxial at first and then go up from there according to the results you see on your compositing monitor.

If you use the 1/30 rule you will first choose the interaxial according the rule, then you push the background behind the screen by selecting the post-production shift or angulating the

cameras with the help of your compositing monitor. If the total depth is too shallow, the 3D effect seems to be too weak then you can increase the interaxial and after that push the back background again. You can repeat this until you are happy the image you see.

8.3.3 CALCULATING THE EXACT INTERAXIAL

So the 1/30 rule is not enough? Don't worry there's a way to calculate the exact interaxial. You can do the calculations with specialized stereo calculators but incase you don't have one, or you just enjoy doing math, I'll explain the whole formula.

Send your assistants with a measure tape to the both sides of your frame at distance of the closest object. Measure the frame width. Then have them do the same thing at the distance of the farthest object. Insert the values with the wanted parallax range to the formula:

$$I = P / ((1 / Wc) - (1 / Wf))$$

I is the interaxial.

P is the wanted parallax range.

Wc is the width of the frame at the closest object's distance.

Wf is the width of the frame at the farthest visible object's distance.

Above formula is good if we are inside, in small spaces or have something large close by that blocks our view to the infinity. If the farthest object is at the infinity or very far away it will not be very convenient (or even possible) to measure the frame width at that distance. In these situations **Wf** will be very long and therefore $1/Wf$ will approach the zero. This means you'll only need to measure the frame at distance of the closest object and it simplifies the formula to:

$$I = P \times Wc$$

So now that you have your interaxial you need to check from your monitor where the objects are and push back the far parallax to the wanted value, for example 1%, using the monitor. If you aimed for the 3% parallax range, you measured the frame and calculated the interaxial correctly your close objects should now have -2% parallax which you can also see from the monitor using the 3D compositing aides.



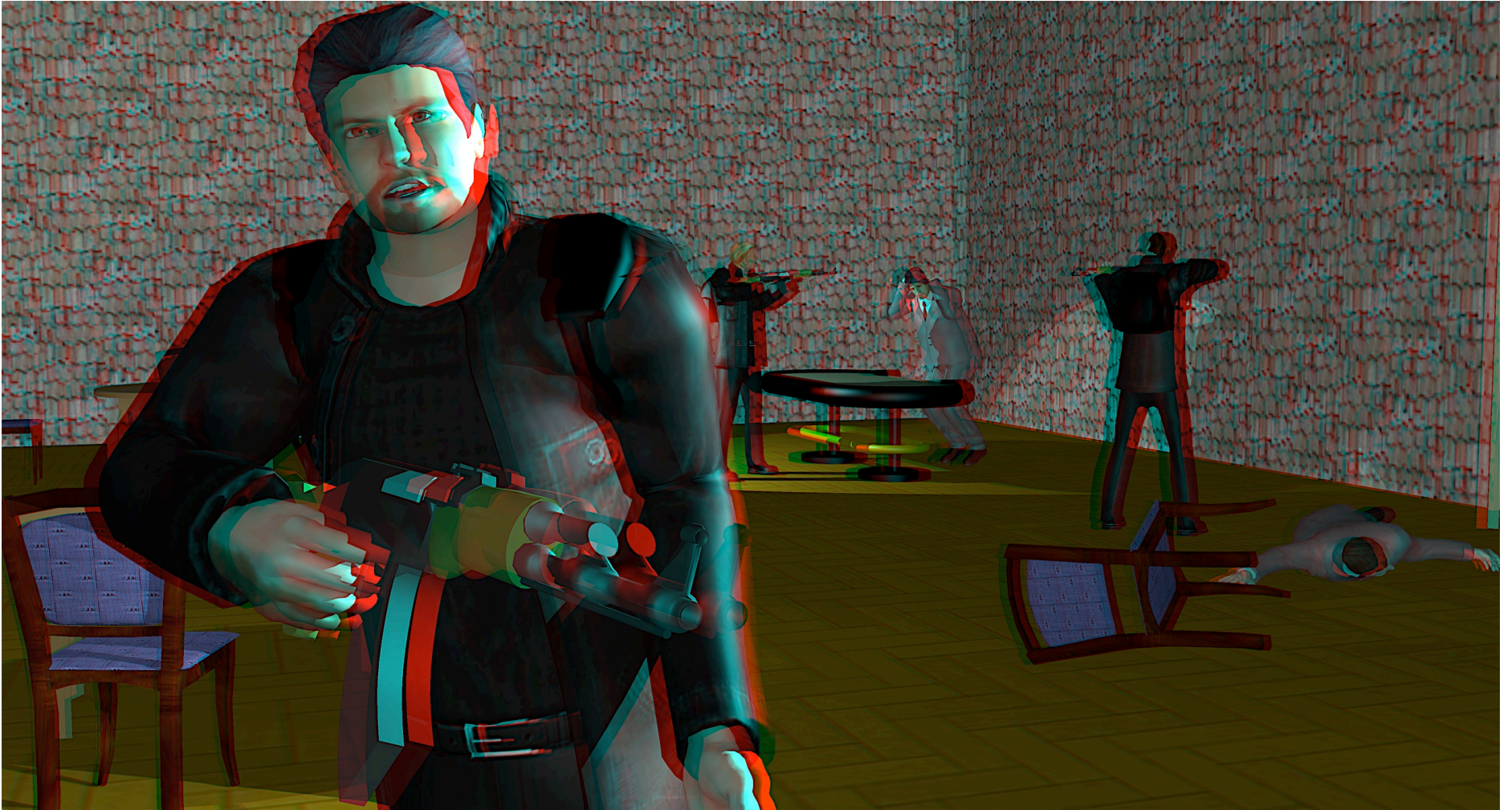
NO BACKGROUND DETAIL. No background detail makes the background to have no exact depth. We have no clues for placing it at its correct position.



BACKGROUND DETAIL. The background is still at same place with the previous shot. Because it has detail we are able to place it at its correct depth.



SHALLOW D.O.F. Shallow depth of field locks our vision to the face of the villain. You may find this bit unnatural.



LONG D.O.F. Everything being in focus allows our eyes to converge anywhere in the picture.



HIGH CONTRAST GHOSTING. Extreme example of high contrast causing ghosting effect.



NORMAL CONTRAST. The image having less contrast is easier to fuse. You may still experience ghosting especially near the dark areas. Since this is anaglyph image it is vulnerable to color mismatches: the amount of ghosting also depends the colors of your glasses compared to the setting of your monitor/printer.

9 POST-PRODUCTION TIPS

Editing pace should be slower to allow the eyes to adjust. Larger the parallax, slower you need to edit. Remember that parallax range can't be changed in post so it is what you shot with. You can only move this range back and forward with post-production shift.

For consecutive shots with radical change in the depth or parallax of the main object, you can move the floating stereoscopic window or adjust the horizontal image translation dynamically at the ends of each shot to make that shot match the incoming shot better.

Do the horizontal image translation correctly in comparison to the screen size where the movie is going to be shown. If there are multiple end delivery formats you need to do a version for each of them.

Correct the possible disparities by adjusting the rotation, size, vertical position, corner points (for keystone) and colors.

Correct the possible stereo window violations using the floating stereoscopic windows.

If you add effects, they need to be volumetric. If you use flat effect layers that work perfectly in traditional, in 3D these effects will look like cardboard cutouts.

Compression will weaken the 3D effect and also creates mismatching compression artifacts. It's better to present your 3D movies in as big resolution as possible.

10 SUMMARY AND CONCLUSIONS

In 3D everything seems to affect everything and therefore planning becomes even more important. It's easy to explain what 3D is, but mastering it is hard. This is why the 3D is so treacherous to do. Of course I can't comment on this personally as I haven't yet shot 3D but after finishing this research I'm certainly one step closer to do so and I no longer feel as discouraged as I felt when I started my research.

One of the big questions for me was that if I shoot some 3D on my own, would it be any good when applying for professional work on this field? In early days of 3D it was shot with less than perfect equipment so it is safe to say it can be done. Even the less sophisticated equipment of today is digital, which makes shooting 3D easier than it ever was when still shooting on film. If I can learn to shoot good 3D with "bad" equipment, I'm sure I can shoot good 3D with good equipment too. Of course it might require some additional studying to know how this equipment works, but in big productions the equipment comes with technicians. In the end to get hired is based on one's merits, if you do something great, other people see it and they like it, you are more likely to find work. The same applies for 3D, but with 3D you don't have as much competition yet as you have in

traditional side, which is now more crowded than ever thanks to Youtube and \$400 DSLRs turning anyone to a cameraman.

It is said that many traditional cinema's professionals have to re-learn everything when they move to 3D. Things that used to be good storytelling or good cinematography may not be that in 3D. It's always harder to forget something done for years than simply fill an empty canvas. However, I don't think anyone is going to be hired as a cinematographer for 3D movie simply because they know 3D. It will only get them the stereographer's position where the cinematographer is still the director of photography. Of course this will change when we start to have cinematographers who can do 3D. More the stereographers teach others on their craft, quicker they run out of their own jobs.

Then comes the problem of the gear? Is it too expensive? Is it too hard to build something that would get the job done? While most of the equipment is quite expensive and complicated it's getting more integrated and cheaper. Cheaper prices will make the equipment more accessible while the integration will make it easier to use.

To learn the craft you need to buy or build a mirror rig. I'm saying a mirror rig because side-by-side rig doesn't really allow the cameras to have small enough interaxial for most of the situations. If you build the mirror rig yourself, use basic DSLRs and you are willing to trust your calculations without ability to monitor 3D while shooting you can probably get started with just \$2000 or even less. With regular 3DTV used for monitoring you still need the converter to fuse the signal, but compared to the price of real compositing monitor it's still very cheap. Of course more money you spend, more convenient the shooting becomes as more and more of the problems will be solved from achieving and holding the synchronization to separate 3D recorders allowing you to save lots of time in post manually combining the left and right image. With \$20000 you can already get quite good manual setup with dedicated 3D recorder taking the big part of the budget. If you can learn the basics with your \$2000 rig, hook up some paying customers for 3D projects then moving up to \$20000 setup is not so distant anymore.

So after all this, I'd say that 3D could be done on independent level. But since it would be done with manual rig you won't be able do all those fancy dolly and crane shots that would require

adjusting the camera parameters on the fly. The base level of how good 3D you can shoot will be defined by your skills and limited by the equipment you can afford.

Are you able to shoot 3D just by reading this thesis? Probably not as I think if I were given the equipment now, it would take its time to put the theory to the practice. However, I think the information given here should enable you to practice to shoot 3D. If you are interested in 3D you should definitely read more about it and if you choose to build your own 3D rig you need to do your own research depending on what your budget and your needs are.

SOURCE MATERIAL

All the theory gathered and combined from (unless otherwise stated):

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All diagrams by Tuomas Hakala (as based on the theory)

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