Basic Principles of

Stereoscopic 3D

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Stereoscopic 3D

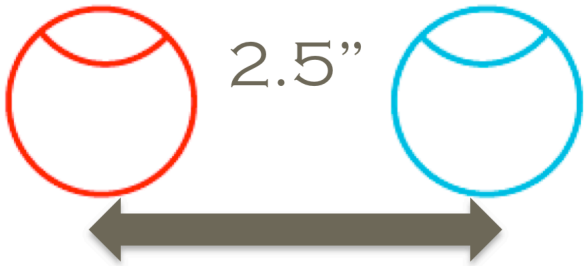
Shooting and transmitting images in Stereoscopic 3D is an attempt to replicate what we see with our own two eyes.

Stereoscopic: Concerned with, or relating to, seeing space three-dimensionally as a result of binocular disparity.
3D: Having height, width and depth

Your eyes are approximately two-and-a-half inches or 6cm apart ('interocular distance'), so they see the same image from slightly different angles and perspectives.
Your brain then combines these two images in order to gauge distance.

This is called binocular vision.

Stereo vision, or 'Stereopsis', is a result of good binocular vision, wherein the separate images from two eyes are successfully combined into one 3D image in the brain.



When shooting a 3D image, two cameras are used to capture separate images of the same object from slightly different angles at one fixed viewpoint.
When played back on a plano-stereoscopic display, the left image is shown only to your left eye and the right image only to your right eye.

Your brain then fuses these two images to give you a perception of depth.

3D in film/television traditionally refers to computer-generated images (CG or CGI) using 3D models. Stereoscopic 3D (S3D) refers to 3D creating the Illusion of depth when viewed on appropriate displays.

S3D Cinematography

A pair of matched cameras, typically spaced at roughly adult eye ‘interocular’ distance (approx 6cm) is used to capture the image.

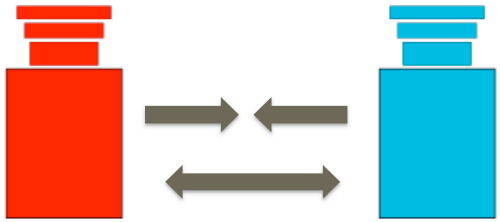
This horizontal offset produces a binocular disparity.

This binocular disparity, together with other information in a scene, including the relative size of objects, occlusion, shadows and relative motion, is processed by the brain to create depth perception.

Interaxial

The distance between the left and right camera is called the ‘interaxial’.

By adjusting the interaxial distance between cameras, we are able to dynamically increase and decrease the depth in a scene.



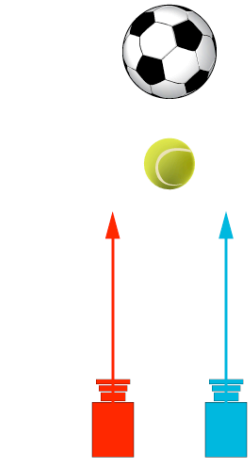
Interaxial

The wider the interaxial,

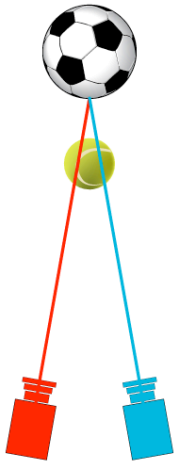
The more depth we capture.

Convergence

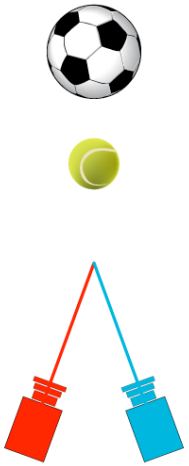
The convergence point determines where the object appears in relation to the screen.
Convergence can be adjusted by toeing-in (an inwardly-angled adjustment) of the cameras or by horizontal image translation (H.I.T) in post-production.



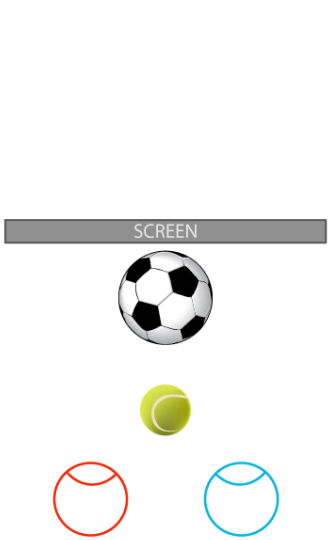
If the two cameras are parallel,



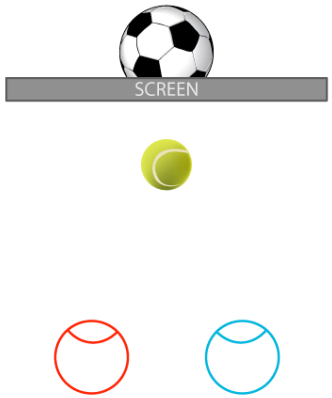
Converge on the object,



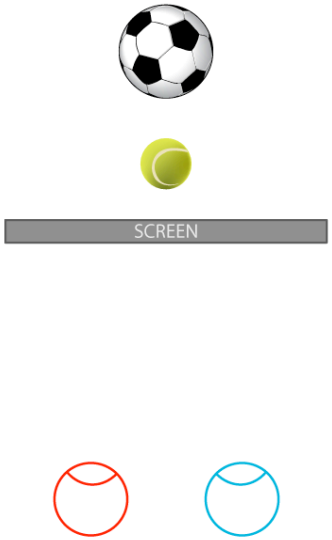
Converge in front of the object,



the 3D picture will be 100%
in front of the screen.



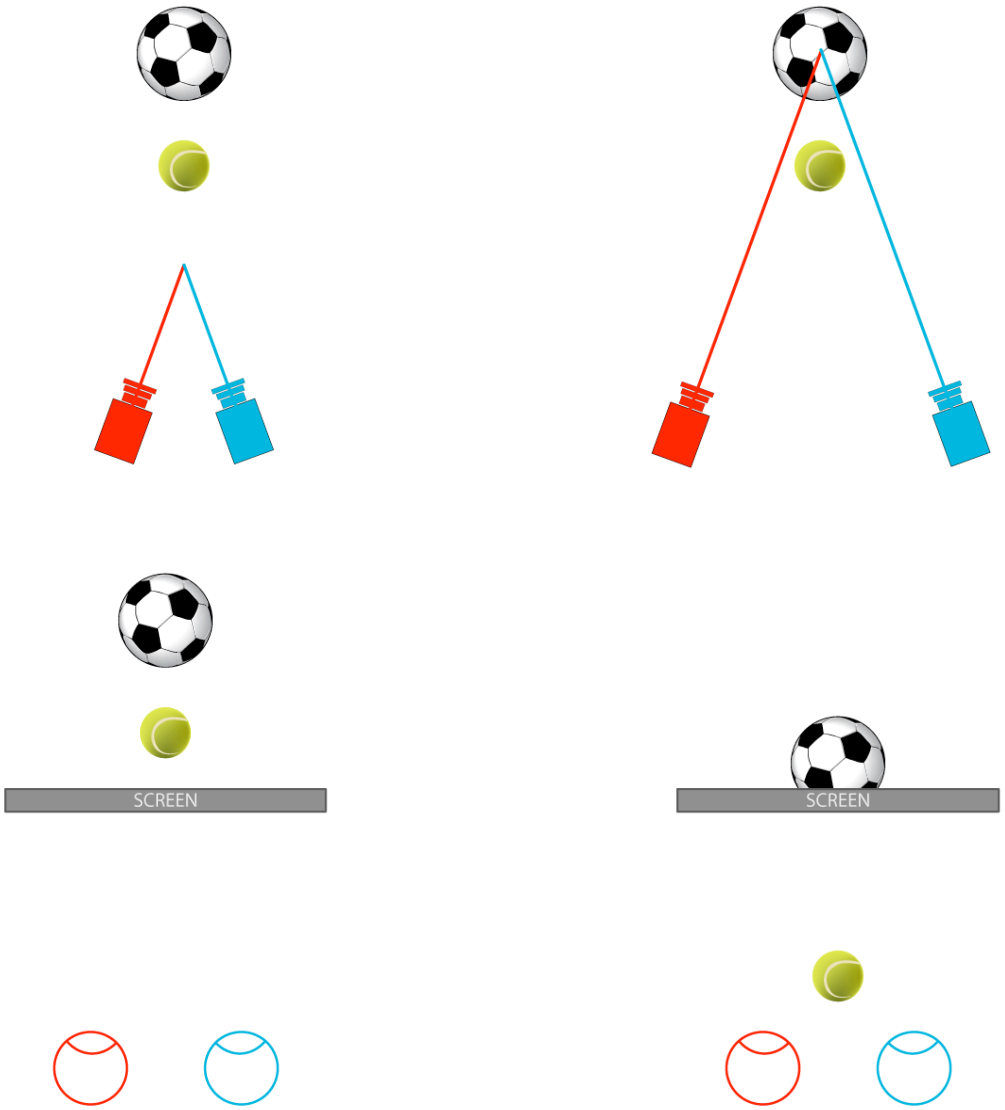
the object appears
at the screen plane.



the object appears
behind the screen.

3D Space

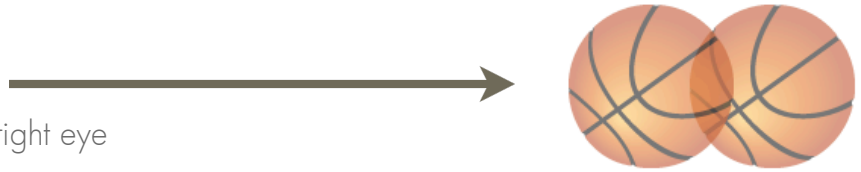
Simultaneously manipulating both the convergence and the interaxial gives control over the depth, and the placement of objects within that 3D space.



Screen Parallax

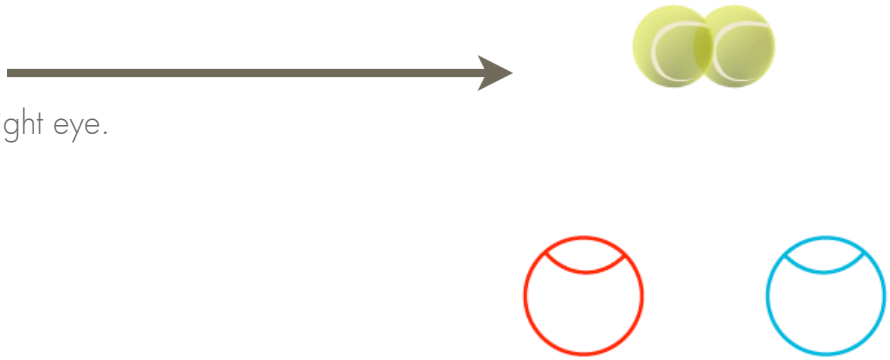
Parallax refers to the separation of the left and right images on the display screen.

Positive Parallax: Objects appear behind the screen.
The image is shifted to the left for the left eye and to the right for the right eye



Zero Parallax: Objects appear at the screen plane.
The left eye and right eye image are in the same position on the screen.

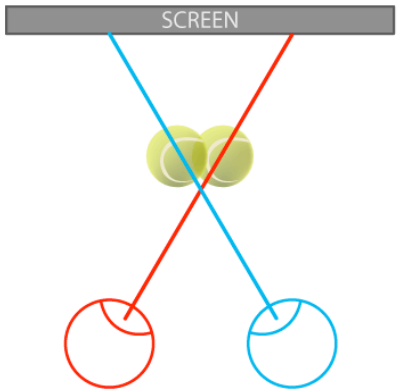
Negative Parallax: Objects appear in front of the screen.
The image is shifted to the right for the left eye and to the left for the right eye.



Accommodation, Convergence & Divergence

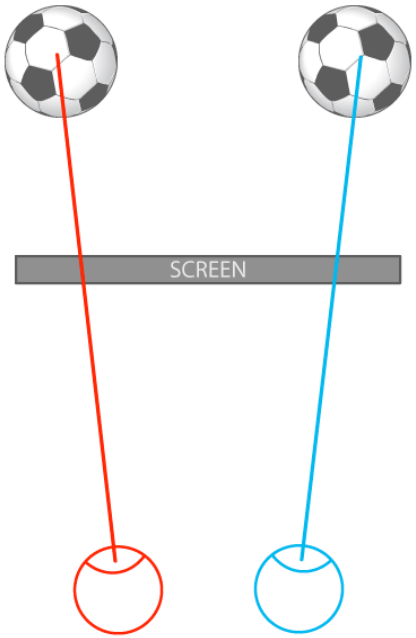
In the real world, our eyes focus (accommodate) and converge at a single point.
When viewing 3D, our eyes always focus on the screen but may converge anywhere along the Z-axis.

Extreme convergence can cause the eyes to turn excessively inward - as a result your audience will not be able to fuse the 3D image.



Infinity Deviation is the amount of background divergence.

If this divergence exceeds the human interocular distance, it can cause the eyes to turn outward, which is both unnatural and extremely uncomfortable – as a result your audience will not be able to fuse the 3D image because of this unnatural eye movement and will quickly experience eye-strain and fatigue..



Depth Budget

Each scene you create has a maximum amount of usable depth within which to create effective 3D.

When objects are placed too far in front of the screen AND too far behind the screen at the same time (too much depth), your audience will not be able to fuse the stereo 3D image.

If your production is to have captions/graphics, this should be taken into account when working out your total depth budget.

This depth budget is calculated as a percentage between the left and right eyes separation in relation to screen width.

Too much depth in a shot (too much interaxial) is very difficult or sometimes impossible to fix in post-production.

Live S3D Broadcast

For Live S3D production, the following technical positions exist:

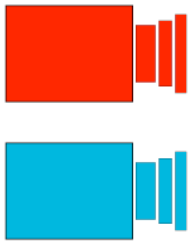
3D Director/Stereographer:
Responsible for creating comfortable 3D among all cameras.
Manages and judges overall 3D quality.
Works closely with match Director.

3D Engineer:
Responsible for all technical issues with 3D, including alignments and synchronization of cameras.

3D/Convergence Puller:
Dynamically adjusts live convergence and interaxial separation.

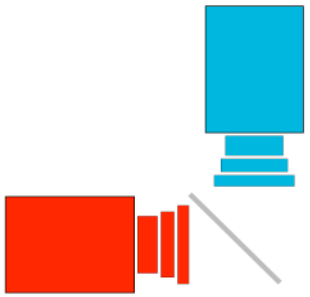
S3D Camera Rigs

Cameras must have matching geometry, exposure, colour balance, focus and synchronized zoom.



Side-by-side/parallel

In a 'side-by-side' rig the cameras are mounted parallel. Due to the physical size of the cameras and lenses, it is difficult to achieve small interaxial separation with a side-by-side rig, so it is mostly suitable for medium and long shots.



Mirror rig/beam splitter

The 'mirror' or 'beam splitter' rig places one camera horizontally, the other vertically. A semi-transparent mirror reflects the scene into the vertical camera while allowing the horizontal camera to see through the mirror. The mirror is fragile, dust prone, reduces light by one f-stop and requires the image shot off the mirror to be flipped. The right eye is generally the image shot off the mirror but this is not always the case. Colour correction of one shot relative to the other may also be required. The interaxial distance on a mirror rig can be as small as you want, even down to zero interaxial, so the mirror rig is very suitable for close shooting.

Shooting Parallel or Converged

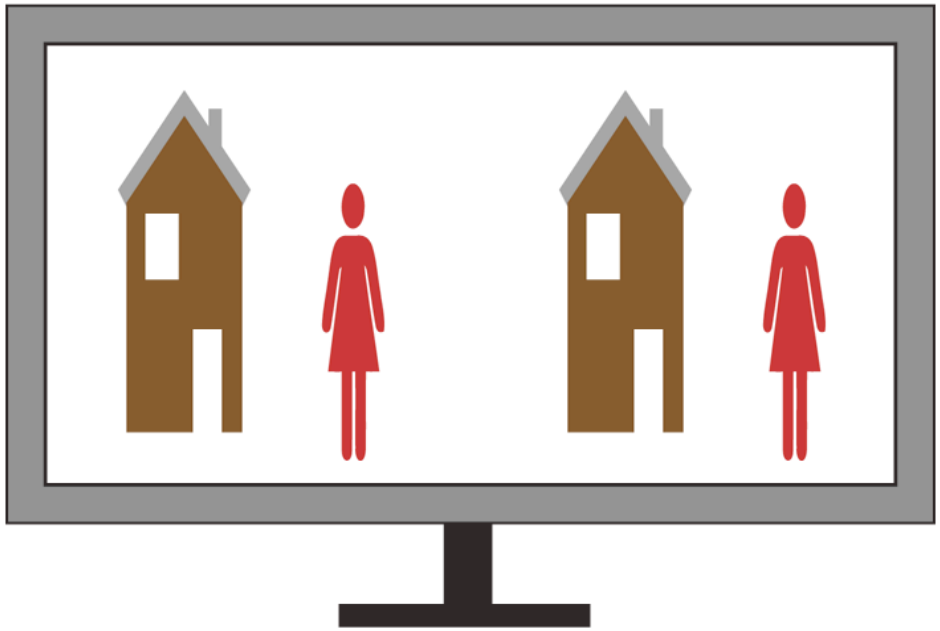
Shooting parallel refers to acquiring stereo images without camera toe-in. All convergence adjustments are made in post-production.
(Not to be confused with a side-by-side parallel camera rig)

When shooting parallel, the zero parallax point will be at infinity, giving every object negative parallax (all objects appear in front of the screen). Extra time will be needed in post-production to adjust the convergence. Setting the cameras at normal human interocular distance can be tricky for close ups.

When shooting with toe-in convergence, there is a chance of 'keystoning', which is noticeable geometric distortions in the four corners of the combined images due to their slightly differing perspective views of the same scene (see S3D errors). If the cameras have excessive toe-in convergence there is a risk of background deviation making the 3D image very uncomfortable to view and impossible to fuse. Toe-in is useful in situations when the objects in the scene are very close to the camera.

Viewing 3D

For transmission, Sky combines the left eye and right eye images into a single video stream by squeezing them horizontally in the side-by-side (SBS) format.



This is then expanded out by the viewing device.

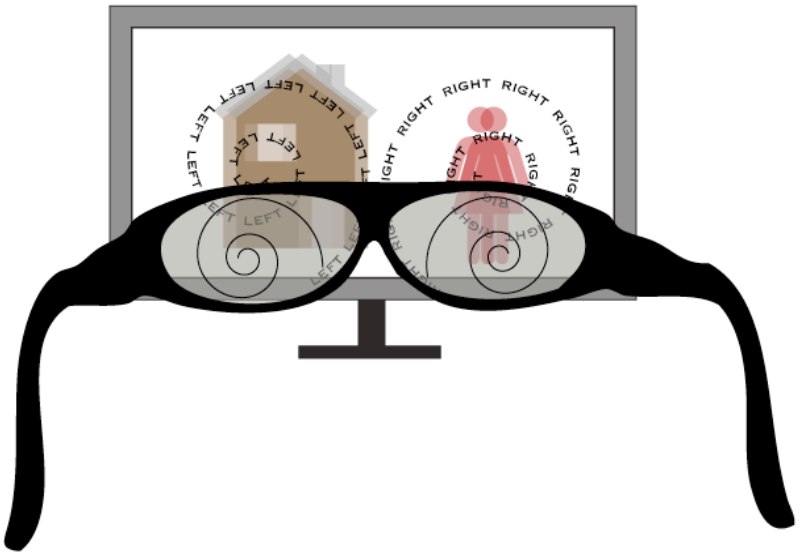
S3D Glasses

Circular Polarisation (Passive glasses)

Each image is circularly polarised by the display and shown together – the left eye is polarised clockwise and the right eye is polarised anticlockwise. The glasses also have a circular polarising filter for each eye - the left lens filters or blocks out the right eye image and the right lens filters or blocks out the left eye image.

They are referred to as 'passive' because the glasses do not require any power to operate them.

Passive glasses are very cheap to manufacture and buy.



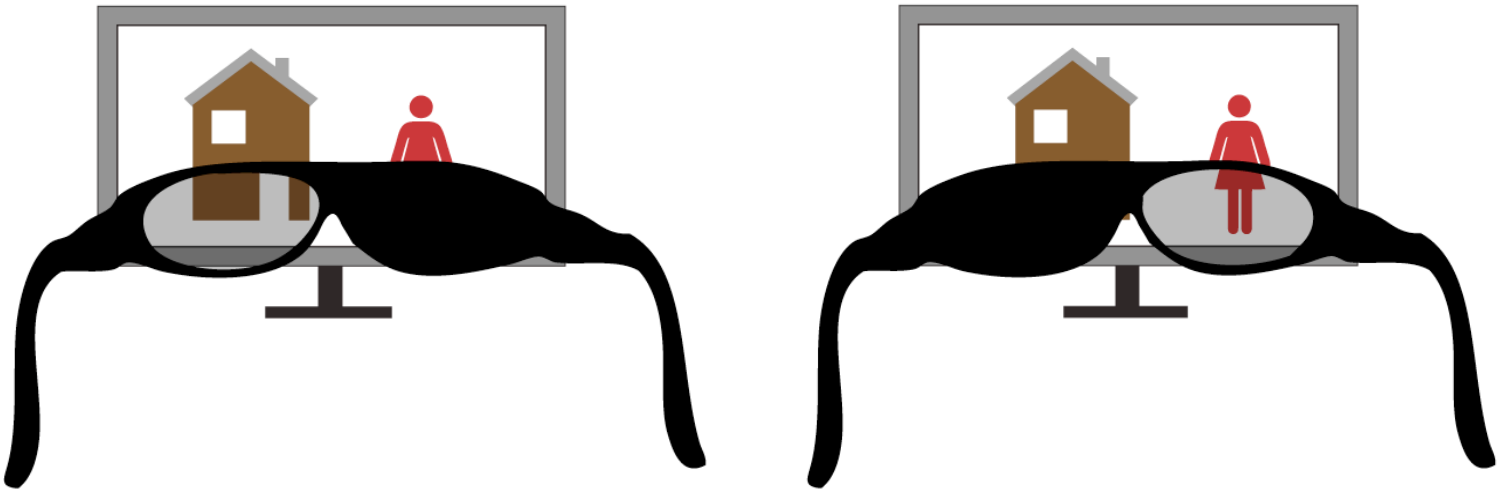
S3D Glasses

Shutter (Active glasses)

Active glasses contain LCD lenses that alternately 'black-out' each eye depending on whether the right or left image is being displayed on the screen. The shuttering occurs in complete synchronisation with the images, and happens so rapidly that you don't notice the shutter-effect.

They are referred to as 'active' because they require a battery to operate the synchronisation sensor and LCD lenses.

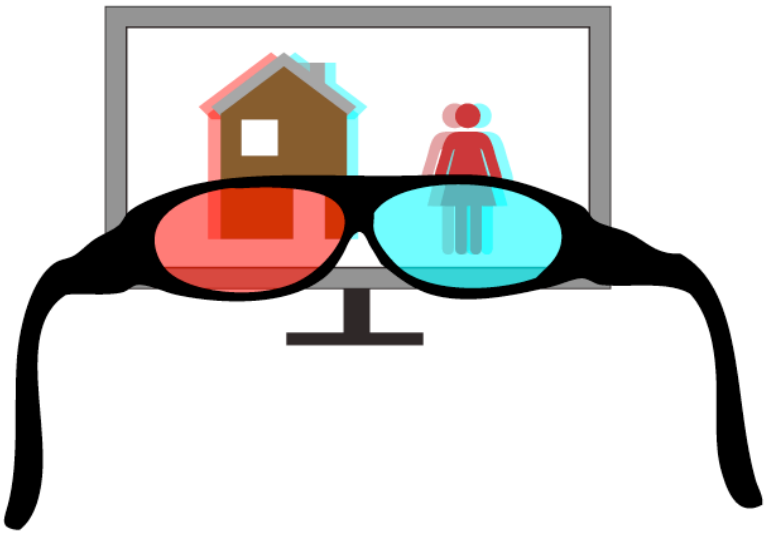
Active shutter glasses are relatively expensive to manufacture and buy.



S3D Glasses

Anaglyph

The two images are individually coloured (typically red and cyan) and then superimposed as a single image. Through the use of similarly coloured filters in the glasses, each eye sees only its correct image.



Post-production

Stereoscopic acquisition is currently by dual-stream HDCAM-SR or on two separate HDCAM/HDCAMSR tapes (One for each eye).

3D projects mean double the recorded material, double the required disc space for storage, and double the rendering time for any stereoscopic adjustments made in post-production.

Editing

The ideal editing system will ingest, edit, correct errors and play out dual-stream stereoscopic video in real-time.

Due to artefacts from the mirror (typically in the right eye when shooting with a mirror rig) the left eye image is generally considered the master image, and is usually used when making 2D from 3D material.

Generally, the pace of 3D edits should be slower. This allows the viewer time to converge on various parts of each shot.

3D objects have a perceived size. In positive parallax (far away), a large airliner or cruise ship appears real.
In negative parallax (inside the room), it appears to be a scale model.

Cuts between shots with strong negative to strong positive parallax, or vice-versa, can be very uncomfortable and quickly become visually tiring.

A depth grade ensuring depth continuity (avoiding depth jump-cuts) will probably be required to ensure comfortable 3D.

To alter the depth position of a shot to make a cut comfortable, the convergence point can be adjusted by shifting the horizontal distance between the two images in a stereo pair. This is called horizontal image translation (H.I.T).

An active depth cut is where you can dynamically adjust the convergence point to match the depth position of the outgoing and incoming shots.

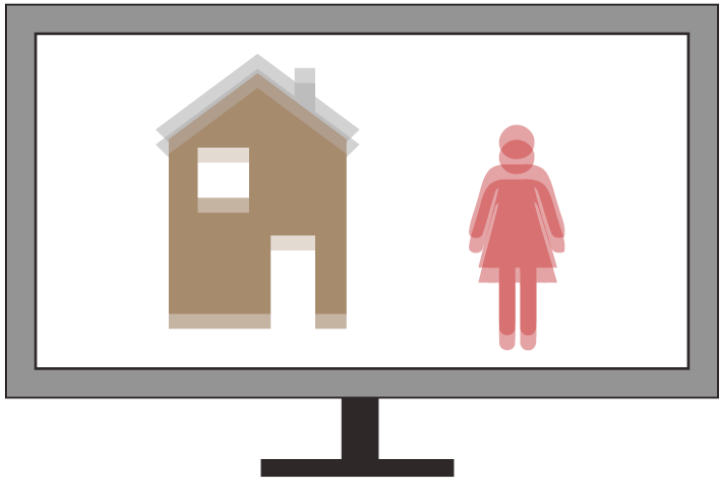
In post-production, correction of common 3D errors and matching colour grading between the two images may also be required.

Various display tools can aid correction, such as: ‘anaglyph’, ‘onion skin’ and ‘difference’ views.

S3D Errors

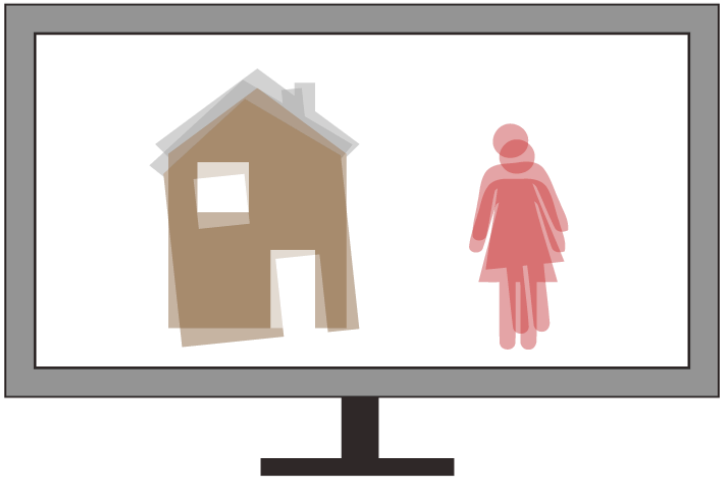
Vertical misalignment

With a vertical misalignment, our eyes have to move vertically apart to fuse the image. This is an unnatural movement for our eyes and can be very uncomfortable.



Rotational error

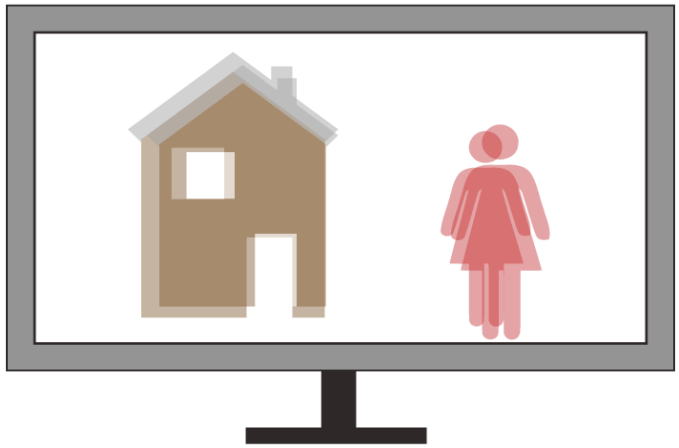
Camera misalignments can also be in the form of rotation errors (pitch, yaw and roll). These are generally most apparent on the four edges of the image.



S3D Errors

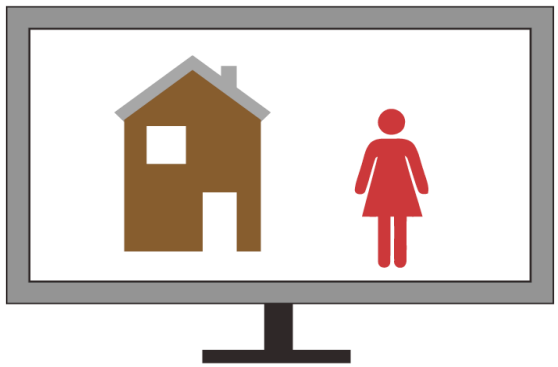
Zoom mismatch

If the cameras are at different focal lengths, it results in a zoom/size mismatch between the left and right eye images. Zooms also have to be synchronized throughout their zoom ranges.

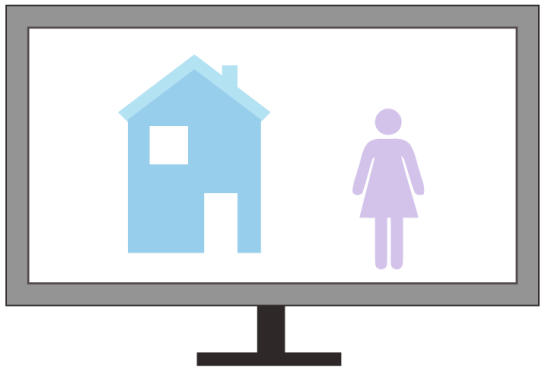


Colour difference

The cameras exposure and colour balance should be the same.



Left eye



Right eye

S3D Errors

Retinal rivalry

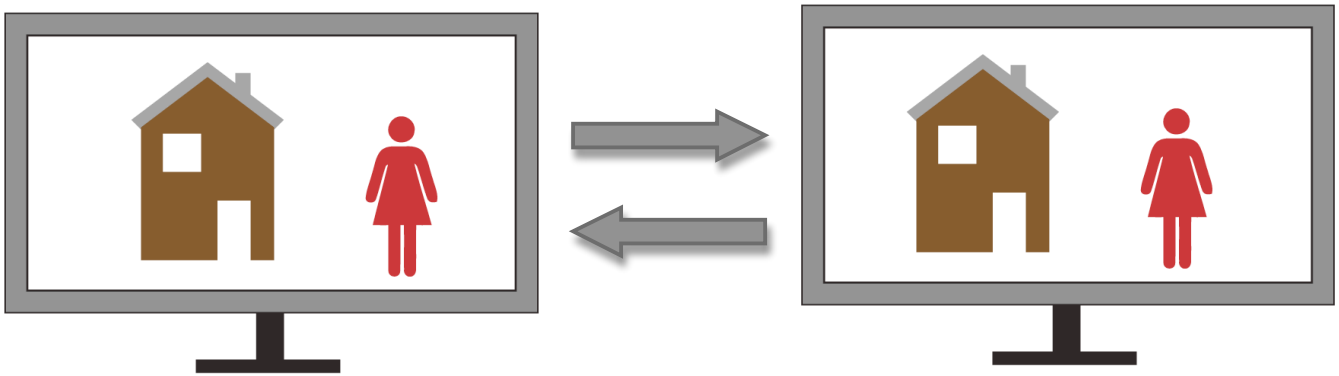
When something appears only in one eye, the viewer cannot reconcile the images.
This can occur in the form of reflections, glints, lens flares & motion artefacts.
Close one eye, then the other, to see the differences between the eyes.

Left eye

Right eye

Psuedoscopic

Also known as false, inverted or reversed stereo. Your left and right eyes / images have been reversed.
Flip your glasses upside-down to check.



Right eye

Left eye

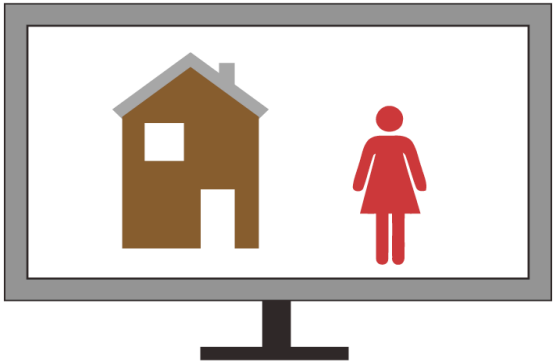
S3D Errors

Ghosting/Crosstalk

Caused by signal leakage (crosstalk) between the two eyes when an image intended for the left eye appears partially in the right eye or vice versa. This is most noticeable on high contrast images.

Focus wander

Most small camera rig errors can be corrected in post-production. Focus errors cannot be corrected.



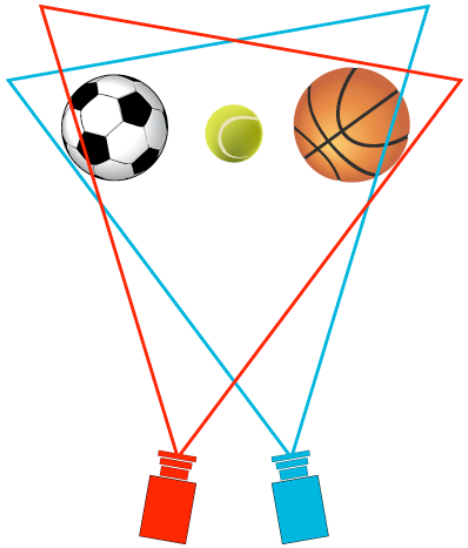
Left eye

Right eye

S3D Errors

Keystoning

'Keystoning' is an effect which happens when toed-in camera convergence causes geometric distortions in the four corners of the combined images. Techniques like corner-pinning can be used to help correct these errors in post-production.



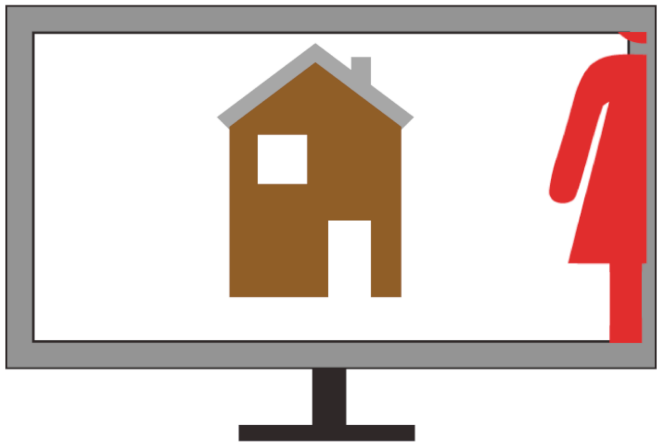
Left eye

Right eye

S3D Errors

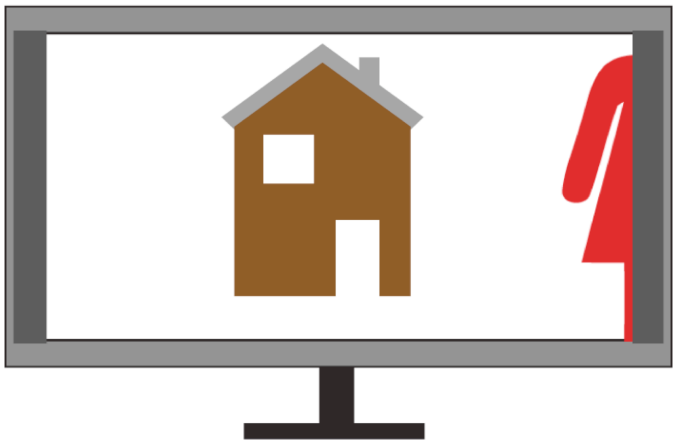
Edge violation

If the action comes out of the screen (negative parallax) and the objects are cut off by the screen edges, this causes an edge violation.
The image appears to be in front of the screen, yet is cut off by the screen frame, so it simultaneously appears to be behind the screen. This causes a 'conflict of cues'.



Floating Stereoscopic Window

To fix an edge violation involves applying a crop mask on the left of the left image, and on the right of the right image, which gives the illusion of the screen surround being on top of the image.



Stereo 3D Terminology

2D
Having width and height.
3D
Having width, height, and depth.
Accommodation
The automatic adjustment in the focal length of the eye to permit focus of objects at varying distances.
Active Shutter glasses
Contain LCD lenses that alternately 'black-out' each eye syncronised to the screen so the correct image is presented to the correct eye.
Anaglyph
A type of stereoscopy in which the two pictures are individually coloured and then superimposed as a single image.
Autostereo Display
Viewing display which allows the viewer the illusion of depth without the aid of special glasses.
Binocular Vision
The use of both eyes together.
Breaking the Frame/ Breaking the Stereoscopic Window
See Edge Violation.
Card boarding
Usually the result when the interocular distance of the viewer exceeds the interaxial distance, giving a cardboard cut-out effect.
Checkerboard
A display format where the left and right eye images are combined into a single checkerboard image.
Circular polarisation
A form of polarised light in which the light travels in a corkscrew.
Convergence (eyes)
The inward rotation of the eyes to focus on an object at close range.
Convergence (stereography)
Sets the scenes depth position in relation to the screen by either toeing-in the cameras or in post-production by a horizontal image translation (H.I.T).
Convergence puller
Person who dynamically adjusts the convergence and interaxial of the cameras.
Crosstalk
See Ghosting.
Depth Budget
The maximum positive and negative parallax to allow for comfortable 3D viewing, expressed as a percentage of screen width.
Depth Grading
A post-production process where the convergence point (and thus the position of the object in perceived 3D space) is adjusted by a horizontal image translation (H.I.T) of the left and right eye images.
Depth Script
A script setting out the depth budget of individual shots throughout a production.
Divergence (eyes)
The opposite of convergence – both unnatural and uncomfortable.

Stereo 3D Terminology

Edge Violation
Also called 'breaking the stereoscopic window' or 'breaking the frame'. If the action comes out of the screen (negative parallax) and the objects are cut off by the screen edges, this causes an edge violation. Contradictory depth cues are sent to the viewer. One cue is saying that the action is in front of the screen and another is saying that the action is behind it.

Floating Window
This involves applying a crop mask on the left of the left image, and on the right of the right image, which gives the illusion of the screen surround being on top of the image, which eliminates the edge of screen depth cue conflicts

Ghosting
Caused by signal leakage (crosstalk) between the two eyes when an image intended for the left eye appears partially in the right eye (or vice versa).

Gigantism
See Hypostereo.

Horizontal Image Translation (H.I.T)
The horizontal shifting of the left and right eye images to change the value of the parallax of corresponding points. This moves the convergence point so you can alter the on screen depth position of your scene.

Hyperstereo
By using a camera interaxial larger than the average human interocular of 2.5" the resulting images display objects that when viewed appear smaller than they are in reality. Subjectively this makes the audience feel like a giant looking at tiny objects which is called 'miniaturization'.

Hypostereo
By using camera interaxial smaller than the average human interocular of 2.5" the resulting images display objects that when viewed appear larger than they are in reality. Subjectively this makes the audience feel like an insect looking at giant objects which is called 'gigantism'.

Infinity Deviation
If the positive parallax deviation goes beyond the human interocular distance, it becomes impossible to fuse the 3D. This can lead to eyestrain and headaches.

Interaxial distance
The distance between the camera lenses' axes.

Interocular distance
The distance between the eyes' axes (or pupils).

Keystoning
The result when toed in camera convergence causes geometric distortions in the four corners of the combined images due to their slightly differing perspective views of the same scene.

Lenticular display
A method of displaying stereoscopic images without the aid of glasses.

Linear polarisation
A form of polarised light in which the light travels vertically and horizontally.

Miniaturization
See Hyperstereo.

Near/Far Misery
The effect when objects are placed too far in front of the screen and too far behind the screen at the same time. Your audience will not be able to fuse the stereo image.

Over-Under
A display format that combines the left and right eye images into a single image by squeezing the two together vertically.

Stereo 3D Terminology

Parallax
This refers to the separation of the left and right images on the display screen.
Positive Parallax puts objects behind the screen, Zero Parallax puts objects on the screen plane and Negative Parallax puts objects in front of the screen.

Parallax budget
See Depth Budget.

Passive Polarised 3D glasses
These are 3D spectacles made with polarizing filters. They are used alongside a view screen that preserves the polarized light. Referred to as passive because the glasses do not require any power to operate them.

Plano-Stereoscopic
This is a projected stereoscopic image made up from two planar images.

Pseudoscopic
Pseudo stereo, inversion inverted stereo or reversed stereo. The effect that will be produced when the left and right eye images are reversed.

Retinal Rivalry
When something appears only in one eye, the viewer cannot reconcile the images. This can occur in the form of reflections, glints, lens flares & motion artefacts.

Side By Side (SBS)
A display format that combines the left and right eye images into a single image by squeezing the two together horizontally.

Stereo blind
Stereo blind is a term which is used to describe people that cannot fuse two images into one with depth.

Stereo Free Viewing
The ability to view a stereo 3D image without the use of any viewing aid. This can be achieved by either parallel or cross-eyed viewing of a stereo image pair.

Stereographer
Person responsible for comfortable and effective Stereoscopic 3D for the intended final deliverable.

Stereo Image Processor (SIP)
Diagnostic, evaluation and correction tool used for calibrating focus, zoom, colour etc. Provides graphic overlays and metadata to help analyze and control the stereo alignment.

Stereo infinity
The farthest distance at which we can perceive something closer than infinity. Usually regarded at 200 meters.

Stereoplexing (Stereoscopic multiplexing)
The technique to incorporate the left and right images into a single information channel without an increase in bandwidth.

Stereopsis
The result of good binocular vision, wherein the separate images from two eyes are successfully combined into one 3D image in the brain.

Stereoscopic
Concerned with, or relating to seeing space three-dimensionally as a result of binocular disparity.

Toeing-in
An inwardly angled adjustment of the cameras used for adjusting convergence.

Further Reading

3D Movie Making: Stereoscopic Digital Cinema from Script to Screen
By Bernard Mendiburu
Published by: Focal Press

Foundations of the Stereoscopic Cinema
By Lenny Lipton
Download from: www.stereoscopic.org/library/index.html

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