Autostereoscopic 3D displays: stereoscopic perception without the special glasses

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Overview

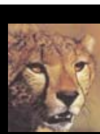
- Why we have two eyes
- History of 3D display technology
- Applications of 3D
- Current technology
- The Cambridge experience

When will 3D replace 2D?

His name was Gaal Dornick and he was just a country boy who had never seen Trantor before. That is, not in real life. He *had* seen it many times on the hyper-video, and occasionally in tremendous three-dimensional newscasts covering an Imperial Coronation or the opening of a Galactic Council.

— *Foundation*, Isaac Asimov, 1951, paragraph 1

Why do we have two eyes?

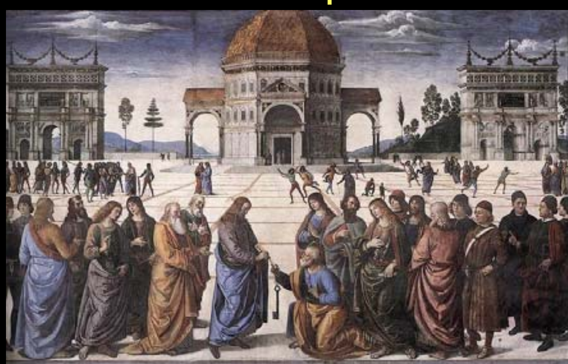


- Redundancy
  - *if one is damaged the other still works*
- Depth perception
  - *allows us to quickly work out the exact location of something*
  - *allows us to quickly work out 3D shape*
- Predator *vs* Prey
  - *predatory creatures have forward facing eyes to give good depth perception and good targeting*
  - *prey creatures have side facing eyes to give good all round vision*

Monocular (2D) *vs* Binocular (3D)

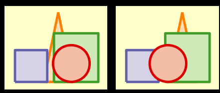
- One eyed people cope as well (almost as well?) as two eyed people
  - ~1% are blind in one eye
  - ~10% are "stereo blind"
    - *can see with both eyes but use only one eye at a time*
  - ~90% see in full stereo
    - *stereo ≡ stereopsis ≈ binocular vision*
- We cope quite happily with 2D media
  - television, cinema, magazines, books, OHP,...
- What extra does binocular vision offer?
  - Fast and accurate depth perception

Monocular depth cues



Why 3D? 3D cues not provided by a 2D image

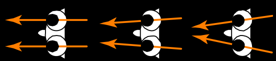
- stereo (binocular) parallax
  - each eye sees a different image



left eye view right eye view

- movement parallax
  - different images are seen when the head is moved

- convergence
  - our eyes converge on the object of interest



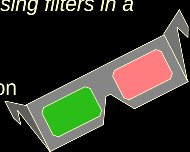
- accommodation (focus)
  - our eyes' lenses focus on the object of interest

3D display — early history

- Stereoscopes
  - Wheatstone 1838
    - *one year before Daguerre made photography viable*
    - *initially hand-drawn stereoscopic pictures*
  - Brewster 1848
    - *very popular throughout the whole Victorian age*
- Uses of stereoscopes
  - amusement
  - surveying
    - *e.g. aerial photography, especially for military purposes*

Applications in entertainment: 3D movies

- Audience wear special glasses
  - anaglyph (red/green)
    - *earliest anaglyph photographs made in 1853*
    - *anaglyph movies require only one projector*
  - polarised
    - *earliest polarisers made in 1934*
    - *polarised movies require either two synchronised projectors or special (rotating) polarising filters in a single projector*
- Very popular in the 1950s
  - trying to counter the rise of the television
- Regaining popularity in IMAX



Getting 3D movies right

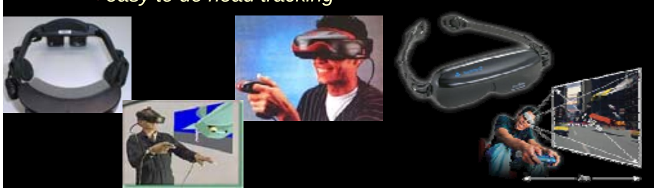
- 3D movies are very convincing if done right
- Extremely easy to do badly
  - audience gets a headache or see no 3D effect at all!
- Whole extra set of production rules required
  - on top of conventional movie production "rules"

Applications in industry

- Used in particular scientific endeavours
  - e.g. microscopy, molecular chemistry, remote manipulation,...
- How useful is 3D?
  - vital?
    - *cannot undertake the work without 3D*
  - plaything?
    - *something to impress the boss, but never used by the real workers*
  - or somewhere in between?
    - *depends on the application*

Today's technologies I

- Stereoscopes
  - put your eyes up to the two viewing slots
- Head sets
  - put special helmet (with two displays) on your head
    - *easy to do head tracking*



Today's technologies II

- Glasses
  - need to wear something special
  - three types
    - *anaglyph (simple but produce headaches)*
    - *polarised*
    - *shuttered*

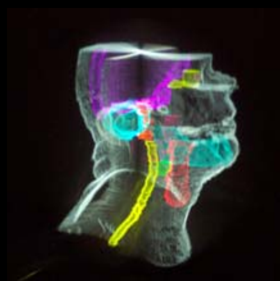
Today's technologies III

- Autostereoscopic
  - no glasses required
  - three types
    - *spatial multiplex (e.g. lenticular or parallax barrier)*
    - *time multiplex (e.g. Cambridge display)*
    - *multi-projector*
  - used in two different ways
    - *two views with head tracking*
      - single viewer
    - *multiple views*
      - many viewers

Today's technologies IV

- Holographic
  - beautiful still holograms are now possible
  - interactive holograms are only experimental (MIT)
- Volumetric
  - drawing in true 3D space
  - various types
    - *spinning plate (e.g. Actuality)*
    - *crystalline (e.g. Er^{3+} doped CaF_2)*
    - *laser plasma display*
    - *vibrating mirror*

Actuality Systems' product (2007)



Applications

- Visualisation
  - of complex three-dimensional structures
    - *scientific & medical*
- Remote manipulation
  - in hazardous environments
    - *copper smelter, underwater, nuclear plant, Mars,...*
- Entertainment
  - video games & simulators
  - movies
  - television(?)

Will 3D replace 2D?

At the end of the road will be found an era in which three-dimensional pictorial presentation will be commonplace and no longer regarded as a scientific curiosity; in which two-dimensional motion pictures, magazine illustrations, radiographs, family 'snaps' and so on are as outmoded as the silent film is to-day.

— *Stereoptics*, Leslie P. Dudley, 1951, preface

Problems with 3D display

- Each of the technologies has its drawbacks
  - all technologies *except* holographic and volumetric
    - *convergence/focus conflict*
  - volumetric
    - *always see through*
  - holographic
    - *limited depth of field*
    - *currently not interactive*
- Does 3D have a sufficient edge over 2D?
  - c.f. colour and black & white
  - c.f. silent movies and talkies

The future of television?

...the author predicts that the next generation of television broadcasting will feature high-resolution (e.g. 2000 lines), wide-screen (1–2m) display giving only illusory depth sensation...
Truly three-dimensional television of very high quality will then follow the wide-screen system, but in the distant future.

— *Three-dimensional imaging techniques*
Takanori Okosi, 1976, p.388

Thoughts & Predictions

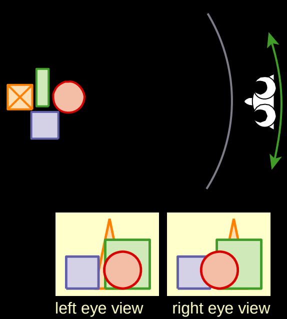
- 3D display has been around for over a century
  - but interactive 3D is new
- 3D displays *do* have niche applications
  - visualisation, remote manipulation, some entertainment
- whether 3D ever replaces 2D is an open question
- 3D will continue to be an interesting research area
  - new types of 3D display will be invented
  - existing types of 3D display will be improved
- much money will be spent
  - but how much will be recouped?

The Cambridge experience: developing an autostereoscopic display

- autostereoscopic
  - a different image to each eye
  - provides:
    - *stereo parallax*
    - *convergence*
    - *movement parallax*
      - if multi-view or head-tracked
  - does not provide:
    - *accommodation*
      - causes eye-strain with particular types of 3D imagery

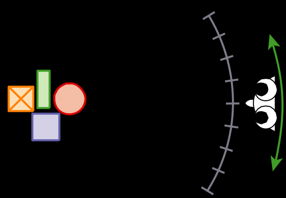
How autostereo works I: stereo perception in the real world

- each eye sees a different image of the world
  - *stereo parallax*
- different images are seen when the head is moved
  - *movement parallax*
- potentially infinite number of different images



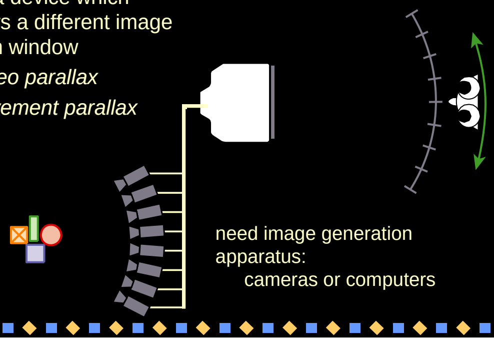
How autostereo works II: a thought experiment

- divide the viewing zone into a *finite* number of *windows*
- a single image is visible in each window
- still see a different image with each eye
  - *stereo parallax*
- still see different images when the head is moved
  - *movement parallax*



How autostereo works III: multi-view autostereo display

- make a device which displays a different image in each window
  - *stereo parallax*
  - *movement parallax*



need image generation apparatus:
cameras or computers

Technologies for autostereo display

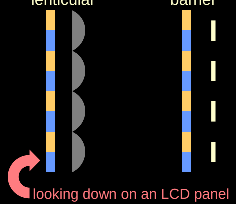
- spatial multiplex
- multi-projector
- time sequential
  - *the original Cambridge displays are of this type*
- hybrids
  - *the new Cambridge displays are a hybrid of time sequential and multi-projector technology*

Spatial multiplex

- divide the horizontal resolution of the display into two or more sets of pixels, each set visible in a particular window
- common ways to do this are:

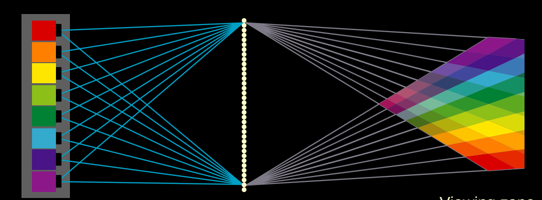
lenticular lenslets
conventionally: up to four views
Philips: up to seven views
Stereographics: up to nine views

parallax barriers
realistically: only two views



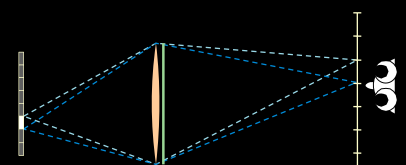
Multi-projector display

- one projector for each view
  - *expensive*
- can provide a large number (tens) of views



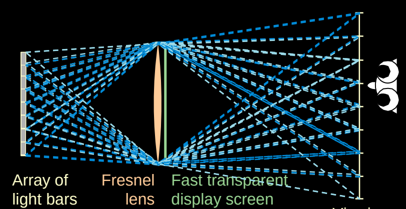
Time sequential display: theoretical implementation I

- a fast transparent display screen is illuminated by a light bar through a lens, causing the image to be visible in only one of the viewing zones



Time sequential display: theoretical implementation II

- synchronising the display with the changing of the light bar causes a different image to be visible in each zone

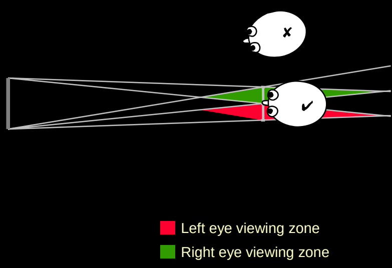


Types of autostereo display

- two view
  - *without head tracking*
    - need to keep the head perfectly still
  - *with head tracking*
    - for a single viewer
- multiple view
  - *need at least six views to make it usable by a single viewer*
  - *need more views for multi-viewer use*

Two view display: method I

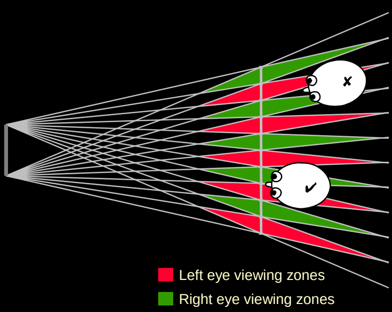
- a two view display which provides just two views is usable by a single viewer
- without head tracking, the viewer must keep his head in exactly the right position



Two view display: method II

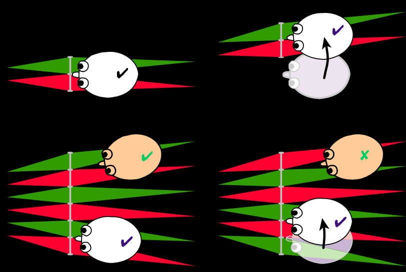
- a two view display using parallax barrier or lenticular technology provides multiple viewing areas

without head-tracking there is a 50% chance of a pseudoscopic view



Two views with head tracking

- method I
  - *physically move the zones*
- method II
  - *swap the zones*

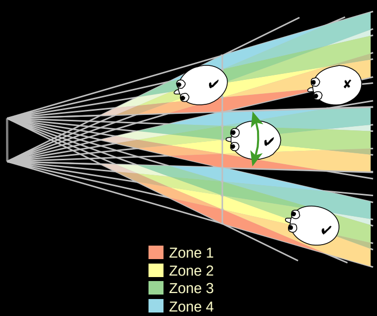


both methods only work for a single viewer

Multiple views I: a four view display

- a four view display allows:
  - *some head movement*
  - *less chance of pseudoscopic viewing*

it is possible to repeat lobes, to accommodate multiple viewers



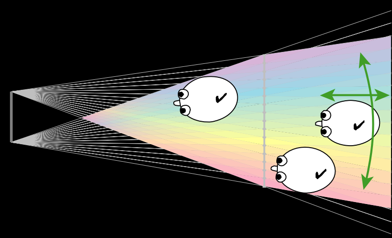
Multiple views II: a sixteen view display

- a large number of views

multiple viewers

ease of head movement
  left/right
  forwards/back

no need to track the viewers' heads

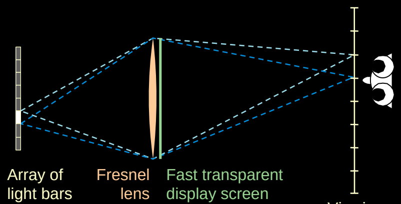


Multiple view *vs* head tracking

- multiple view
  - can accommodate multiple viewers
  - no need to track the viewers' heads
  - requires the generation of all of those multiple views
- head tracked, two view
  - can only accommodate a single viewer
  - must track the viewer's head
    - *a completely separate problem to the display technology*
  - only need to generate two views

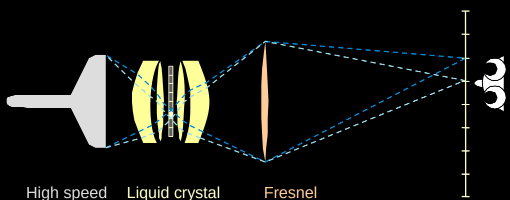
Time sequential display: theoretical implementation - review

- a fast transparent display screen is illuminated by a light bar through a lens, causing the image to be visible in only one of the viewing zones



Time sequential display: practicable implementation

- replace the fast transparent display screen with a fast (1kHz) CRT and a dynamic optical system



Where we were in 1995…

- **10" display (1992), upgraded to colour (1993)**
- **25" display (1995)**
- **Live video input (1995)**
- **Tests with 3D input devices**

Cambridge autostereo display: a time sequential device

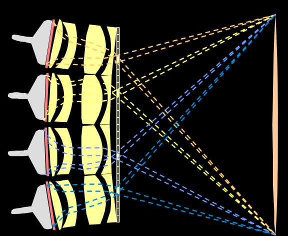
- original development 1986–91, 16 view monochrome, 320x240
- by 1995 could do 6 view colour, 320x240
- recent advances have pushed to the limits of CRT technology to achieve the following rates:

Resolution	(pixels)	512x384	640x480
Number of views	monochrome	21	15
Number of views	colour	7	5
Field rate	(Hz)	1260	900
Line rate	(kHz)	320	280
Pixel rate	(MHz)	250	270

Problem: we wanted to increase the number of colour views beyond what is possible with a single CRT

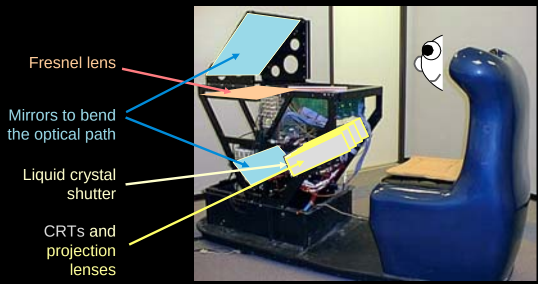
Solution I: 25", multi-projector, time sequential, 28 view display [1997]

- the shutter is placed in front of the projection lens array
- multiple projection lenses are abutted
  - *each produces seven colour views*
  - *28 full colour views in total*



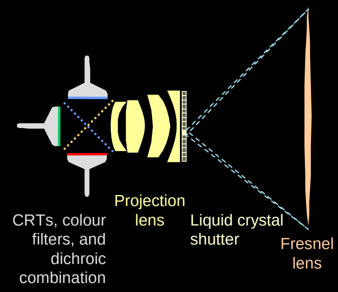
Dynamic colour filtering for colour sequential operation

Solution I: the finished device — a 25" Cambridge autostereo display



Solution II: 50", parallel colour, time sequential, 15 view display [1998]

- use parallel colour (three CRTs) rather than sequential colour filtering
- in practice, we replace the Fresnel lens by a 50" spherical mirror



50" autostereoscopic display

50 inch display: specification I

based on marketing research for aerospace and entertainment applications

- good resolution
  - at least VGA (640×480) resolution
  - a good number of views
    - *wide eye box (>300mm)*
    - *three views between a viewer's eyes (~22mm wide zones)*
- large screen
  - potential users believe that a large screen is essential
  - quantified as "50 inch diagonal"

50 inch display: specification II

- full colour
  - potential users believe that monochrome is too limiting
- two viewers
  - allow two users to perceive either the same or different 3D images whilst maintaining close proximity to provide for maximum interaction
  - quantified as providing two viewing lobes separated sufficiently to allow two users to be close to one another without restricting each other's personal space

Resolution

- CRT drive electronics run at 285 kHz line rate, ~230 MHz pixel clock
- this allows 15 monochrome views at VGA resolution
  - ~3.5 µs line time including ~0.7 µs flyback time
  - ~1.1 ms field time including ~0.3 ms flyback time (240 visible lines per field)

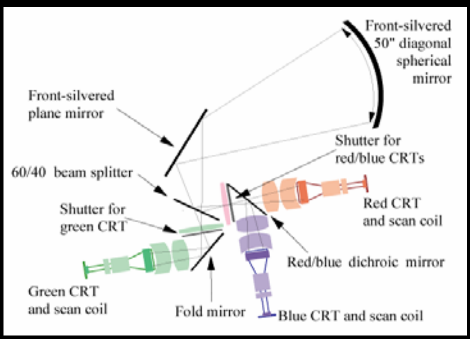
Full colour I: the previous solution

- previous versions of the Cambridge display have used sequential colour
  - shadow mask based colour CRTs are not capable of the required luminance
  - avoids the challenge of aligning three separate colour CRTs
  - has the disadvantage that it divides the number of views by three
- in this case it would reduce the number of views from 15 to 5
  - 5 is too small a number of views to be usable

Full colour II: the new display

- the new display uses three monochrome CRTs
  - the three images are combined by a dichroic (red/blue) mirror and a 60/40 beam splitter
    - *dichroic to combine red and blue allows us to put the transition band in the green part of the spectrum, so very little light loss and no variation in transmitted light with variation of incident angle*
    - *60/40 beam splitter is used because the green CRT has a considerably brighter phosphor than either the red or the blue CRT*
  - independent control of each CRT's picture shape correction allows for precise alignment of the three colours

Optical design



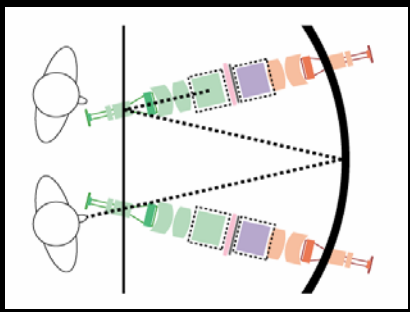
Large screen

- previous versions have used a Fresnel lens as the front optical element
  - Fresnel lenses are flat
  - but they scatter ambient light, causing unwanted specular reflections
- the new display uses a front silvered, concave, spherical section
  - sophisticated CRT picture shape correction allows for correction of the distortions caused by the curved mirror

Two viewing lobes I

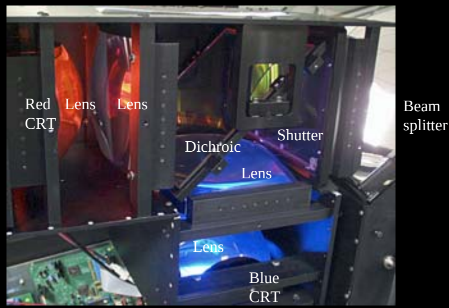
- use two independent three-CRT subsystems
- each images onto the same curved mirror, via a large flat mirror
- provides two viewing lobes separated by about a metre

Two viewing lobes ≡ two display systems



Construction: overall

Construction: optical details



The display in operation...

...and on the screen

Summary of the 50" display's development

- a successful re-engineering of the Cambridge time-multiplexed concept
- the result:
  - a 15 view, 50 inch, colour autostereoscopic display
  - with two viewing lobes
  - viewable under normal lighting conditions

Summary & looking ahead...

- why autostereo?
  - *3D without glasses*
- multiple view *or* head tracked?
  - *both will find uses in particular applications*
- applications?
  - *visualisation of complex 3D structures*
  - *remote manipulation*
  - *entertainment*
- will 3D ever find a use beyond these niche markets?
  - *an open question...*