3D FOR THE 21ST CENTURY: THE TSUKUBA EXPO AND BEYOND

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Interest in 3D has never been greater. The amount of research and development on 3D photographic, motion picture and television systems is staggering. Over 1000 patent applications have been filed in these areas in the last ten years. There are also hundreds of technical papers and many unpublished projects.

I have worked with numerous systems for 3D video and 3D graphics over the last 20 years and have years developed and marketed many products. In order to give some historical perspective I'll start with an account of my 1985 visit to Exposition 85 in Tsukuba, Japan, I spent a month in Japan visiting with 3D researchers and attending the many 3D exhibits at the Tsukuba Science Exposition. The exposition was one of the major film and video events of the century, with a good chunk of its 2 1/2 billion dollar cost devoted to state of the art audiovisual systems in more than 25 pavilions. There was the world's largest IMAX screen, Cinema-U (a Japanese version of IMAX), OMNIMAX (a dome projection version of IMAX using fisheye lenses) in 3D, numerous 5, 8 and 10 perforation 70mm systems - several with fisheye lens projection onto domes and one in 3D, single, double and triple 8 perforation 35mm systems, live high definition (1125 line) TV viewed on HDTV sets and HDTV video projectors (and played on HDTV video discs and VTR's), and giant outdoor video screens culminating in Sony's 30 meter diagonal Jumbotron (also presented in 3D).

Included in the 3D feast at the exposition were four 3D movie systems, two 3DTV systems (one without glasses), a 3D slide show, a Pulfrich demonstration (synthetic 3D created by a dark filter in front of one eye), about 100 holograms of every type, size and quality (the Russian's were best), and 3D slide sets, lenticular prints and embossed holograms for purchase. Most of the technology, from a robot that read music and played the piano to the world's largest tomato plant, was developed in Japan in the two years before the exposition, but most of the 3D hardware and software was the result of collaboration between California and Japan. It was the chance of a lifetime to compare practically all of the state of the art 2D and 3D motion picture and video systems, tweaked to perfection and running 12 hours a day, seven days a week. After describing the systems at Tsukuba, I will survey some of the recent work elsewhere in the world and suggest likely developments during the next decade.

In spite of the tremendous efforts expended on the giant screen 2D systems, audience reaction made it clear that 3D was far more impressive. The most popular exhibit, for which people stood in line for as much as five hours, was the 3D OMNIMAX film at the Fujitsu pavilion. This anaglyph film (red-blue glasses were worn) was created entirely with computer graphics. Having worked with numerous systems for 3D photography, film and television on a daily basis for 20 years, I regard anaglyphs as suitable for 3D only when there is no alternative. This was unfortunately true for the OMNIMAX format at the time since the extreme fisheye camera and projection lenses would need special designs for dual systems. The twin camera and projection system for IMAX did not appear until 1986 at Exposition 86 and double OMNIMAX debuted at Exposition 90 in Osaka, Japan. Polarization does not work well with the curved dome screen of OMNIMAX. So, an alternative was to return to the 100 year old eclipse or field sequential technology and equip each member of the audience with LCD shutter goggles synchronized with the alternating left and right images from the projector. This yields a fine image and eliminates some of the problems associated with polarizers. This is identical to the technique now common for 3D television and computer graphics. Though, first introduced in Japan in 1990 the first U.S. IMAX theater to use LCD shutter glasses opened in New York City in 1995.

The motivation for the giant screen formats IMAX (flat screen) and OMNIMAX (dome screen) is to fill all or most of our visual field with a high resolution, steady image and thus create a very powerful impact. Of course, we can fill our visual field by sitting in the front row of an ordinary theater, but the graininess and jitter of the image and the need to focus so close defeat this. These problems are solved in IMAX and OMNIMAX by the giant size of the negative and by custom engineered cameras and projectors. It is even more desirable to eliminate the screen edges in 3D since these may clip off part of the left or right eye images, creating conflicting depth cues and a tendency to pull objects to the plane of the screen. Panoramic 3D systems for photography, motion pictures and video had been designed before, but this was the first time since Cinerama in the 50's that such systems had been widely presented to the general public.

The 3D OMNIMAX film "The Universe-We Are Born Of The Stars" was created on Fujitsu M380 and Links I supercomputers by teams of programmers from Fujitsu, Toyo Links Corp. and Dr. Nelson Max of California's Lawrence Livermore Labs. The program had to take into account the distortion of the fisheye lens and calculated about 2.2 million pixels (1500 by 2000 or 1728 by 1280) for each frame and each eye. Even with a computer performing 1.5 million calculations per second, a single 50 second trip through an ice crystal required 70 hours of computing time. Two problems with OMNIMAX are the distortions of the fisheye lenses and the obtrusiveness of the screen surface. But the generation of the images with computer graphics and a black background largely eliminated these and, in spite of the always bothersome red and blue filters in the glasses, the effect was stunning. It was some of the most impressive 3D I'd seen up to that time. The viewing angles were given as 180 degrees horizontal and 125 vertical, but this depended on where one sat, with the angles being greatest and the effect best in the lower seats. This was especially true since most of the action took place in the lower partion of the screen, forcing most viewers to look down, bringing the audience and the screen edge back into the picture. This mistake was also made in the IMAX and other pavilions. Another mistake, shared by most of the systems was excessive image motion, which makes 2D annoying and 3D unwatchable. Other problems were the usual 3D nemeses of horizontal parallax and jump cuts between large and small parallax values. Some shots had up to 3 feet of parallax between the left and right eye images. This creates eyestrain, and, as the rest of the film demonstrated, was unnecessary for superb effects. My recent trip to Korea to see the three different giant IMAX 3D films in Taejon shows that these continue to be problems with all IMAX Corp. films right to the present time (1996).

The Japanese Industrial giant, Sumitomo Corporation, was represented by the Sumitomo pavilion '3D Fantasium' which presented the double 65mm camera, double 70mm projector StereoSpace system of Dr. Richard Vetter on a computer designed screen. The theater had a computer controlled seven channel sound system with 29 speakers in 6 patterns which rolled the sound around the theater to accompany the visuals. The short film was a charming children's fantasy, with stunning impact and enthusiastic audiences all four times I saw it. Nevertheless, the film showed all the vexing problems of even the most carefully engineered and used double camera and projector systems. There was up to 6 inches of image jitter and weave and consequently, portions of the right and left eye images, which should have been coinciding (homologous points), were, at any instant, as much as a foot apart vertically and/or horizontally. This undoubtedly causes eyestrain and detracts from the stereoscopic effect, but is characteristic of every double 3D system I've ever seen (except video systems). Asymmetrical illumination of the two images was minimal, but a slight red tinge to the right eye image-presumably due to uneven print timing-was sometimes noticeable. I've found that keeping two cameras aligned and in focus is a nightmare and the lack of focus in one eye in some shots and the vertical parallax in many shots bore this out. Overall, these problems were modest and I'm sure keeping this giant double camera rig under control required heroic efforts. The use of excessive horizontal parallax in many shots was unfortunate, but extremely common in most commercial 3D films and videos.

The double system, twin cameras and projectors, certainly has some advantages-it is easier to get a bright image, the lenses are often faster (gather more light) than single camera 3D lenses, the negative area is doubled, and there may be less image distortion. Its disadvantages are also clear: tremendous filming restrictions with these giant, delicately aligned rigs; numerous opportunities at all stages for binocular asymmetries, and far more trouble and cost shooting, editing, printing, doing effects, distributing and projecting.

Since the system used by Disney for their "Magic Journey" show and in more recent years for "Captain Eo", Muppet Vision" and "Honey I Shrunk The Audience" in the USA, Europe and Japan is basically the same as the United Artists system, with two 65mm cameras and two 70mm projectors, I viewed the film at Tokyo Disneyland several times. I was prepared for a bad experience when I viewed the slide show in the lobby. Some 40 stereo slide viewers were mounted on the wall, but their optical quality was the worst I have ever seen, and six of the slides were presented pseudoscopically (right eye gets left eye picture). The lobby of `Magic Journey' at DisneyWorld in Florida in 1989 had lovely big 3D lenticular prints of Disney characters by Grayson Marshall.

In overall quality, the Disney and U.A. systems were similar, but the U.A. system had a larger, brighter image and was more impressive. The Disney film had some slight asymmetrical illumination and vertical parallax in some shots and both films had excessive horizontal parallax in many shots. The most impressive show at Tokyo Disneyland was Matsushita's revolving theater in which robots and film displayed scenes from Japanese history. I have also seen `Magic Journey' at Disneyland in California and at DisneyWorld in Florida but it has now been replaced. In Florida, they used to show an old Donald Duck 3D cartoon before the main film. There was excessive horizontal parallax in nearly every shot of `Magic Journey' and vertical parallax in some. There is also the usual jitter and weave of the two images that one expects from double systems. Those visiting the Epcot center at DisneyWorld should not miss the `Backstage Magic' show at Communicore East, which uses a large mirror to create a lovely illusion of a tiny woman walking through Disney's massive computer center. Another exhibit not to be missed is the `American Adventure' theater in which robots acting out US history leave many people with tears in their eyes.

In the early 80's, Disney created a 360 degree surround movie system using multiple cameras and projectors which they call `Circlevision'. There are two of these at EPCOT, one in the China pavilion, and one in the French pavilion. Similar systems have been created many times, and there are independently designed 360 degree theaters operating in Moscow and Lausanne. In addition to these, I have seen other 360 degree film, slide and video systems at Tsukuba, Vancouver and elsewhere and I find all of them a waste of time and money. The nonmatching edges between the images and their relative jitter and weave are very annoying. Also, since one can only see about 120 degrees, what's the point of a surround system? In addition, everyone has to stand, which is tiresome and restricts the film length. For much less money and effort, you can make a good 2D or 30 display that is much easier to look at and can be viewed sitting down.

Also on view until 1994 at EPCOT and Disneyland was Captain Eo, a film made with the dual 65mm camera rig engineered by Steve Hines of Hines Labs, Glendale, California. Minute for minute, it is the most expensive film ever made and, with the combined talents of George Lucas, Francis Coppola and the Disney organization, it should have been fantastic. Unfortunately, it is a $25 million failure. The nicest part of the film is the 3D star field which covers the screen and its surroundings before the film starts. It is created with optical fibers which transmit polarized light to tiny holes, but it lasts only a few seconds. The 3D ranges from tolerable to terrible with many shots having excessive horizontal parallax (which causes images to stick out of the screen and tends to produce eyestrain). Many shots also have vertical parallax-a vertical displacement between the right and left images-which should never exist and which also produces eyestrain. At Disneyland, the two prints were mismatched, making the film's star, Michael Jackson, look red thru one eye and green thru the other, though this problem was not present when I saw the film at EPCOT in DisneyWorld. Asymmetrical illumination of the right and left images, in which the corresponding area of the right and left images have different brightness, is always a problem with double projector 3D films and contributed to the eyestrain. Excessive movement of the subject or camera and cutting between shots with large parallax differences were other problems. All these errors make stereo fusion difficult, especially for those sitting in the front half of the theater.

Why does it matter where you sit? Suppose the right and left images are separated by two and a half inches on the screen with the right image to the left. Since, our eyes are separated by about the same distance, this will make their line of sight cross halfway to the screen and the image will stick out into the theater. A person a hundred feet from the screen will be crossing their eyes fifty feet away while focused on the screen more or less at infinity, which is relatively comfortable. But, someone twenty feet from the screen will be focused at twenty feet and crossing their eyes only ten feet away-a good recipe for eyestrain. Some of shots in Captain Eo have the images displaced by four feet, which causes extreme eyestrain.

`When looking out a window, the right and left edges of the images are slightly different for the two eyes and when 30 image pairs are created, they must have the same relationships on the screen that they would if you were looking out a real window. If errors are made, there will be an annoying flicker, blur or shimmer at the right and left edges of the screen. This problem is present in some shots in Captain EO. This can be eliminated by appropriate masking during filming, printing or projection.

In addition, the whole film had a muddy look due to the lighting and was done deliberately to give the film it's sinister feel. It was full of monsters, threats and violence and there was even a sign in the lobby warning that children might be frightened! This was not the only exhibit with warnings about frightening children and one wonders what is going on in Disney's upper echelons that they feel the need to release monsters from the male id to frighten children. As a final insult, the disco soundtrack was earsplitting, though it was quieter at EPCOT. Only the haunting memory of "Comin' at Ya!", "Sea Dreams", the Hitachi film at Tsukuba, the TamaTech film and several IMAX efforts, stops me from naming this the worst piece of 3D filmmaking in recent times.

All 3D projects need to hire a couple of good stereoscopists from day one. This was by far the most expensive 3D project and it's scandalous that they didn't do it right. One sign of the primitive state of 3D films is that they are shot and edited flat(2D). Several years ago, I coinvented and patented a 3D television system that can be used for viewing 3D films in 3D while they are shot and edited and it has been used on commercial 3D movies. It was supplied by StereoGraphics Corporation, a company I cofounded. So, why didn't George and Francis use it for Captain Eo? In fact, they did use it for one day but decided they had everything under control and didn't need it further. As the results show, they needed lots more help. It's almost always this way on 3D projects people may know next to nothing about 3D, but as soon as someone waves money, they are Instant 3D experts and the project winds up a disaster or far less effective than it could be.

The Hitachi pavilion at Tsukuba had a short 3D computer graphics film produced by Digital Productions in California. I expected problems when I saw that the rear seats were about 50 feet from the screen and even from there 1 was only able to see 3D about one fourth of the time due to excessive parallax, excessive rate of change of parallax and excessive angle of rotation between the left and right images. The fine lines in some shots had nearly disappeared due to loss of resolution during transfer and the final live sequence had bad vertical parallax. It is interesting to note that the previous state of the art in stereoscopic computer graphics(the famous paper airplane sequence created by Abel and Associates for Matsushita's 3D TV system in 1982)- had all of the same errors. The fourth time I saw this film I sat in the front seats with Allen Lo, creator of the Nimslo 30 camera. We agreed that from this position, there was no detectable 3D. A different version of the film was later shown in the US and, with smaller screens and more distant seating, the 30 should have been better. On mounting a stereo pair from this film for still viewing, I could see that the extreme rotations employed to create the stereo pair made fusion difficult even when horizontal displacement problems were eliminated. This five minute film probably cost a million dollars and could have been vastly improved by spending a few thousand dollars to have a good stereoscopist looking over the programmer's shoulder.

If a standard 2D film had such bad focus that Humphrey Bogart looked like Lauren Bacall or, if the color balance were off enough to make Mel Gibson's skin the color of your front lawn, nobody would tolerate it. But practically every 3D film and video contains errors of parallax, asymmetrical illumination etc. that do just as much damage to the 3D effect and nobody associated with it's production seems to notice. Everybody needs more experience with 3D and the only way to get it fast is to hire an expertstereoscopist.

The primary function of the stereoscopist is not the manipulation of abstruse equations, but the pointing out of obvious errors such as binocular asymmetries, excessive parallax, fast changes of parallax etc. If competent stereoscopists were used during the making of the 3D films and tapes for Tsukuba, the producers, editors and directors must have ignored them. The total expended on 3D hardware and software at Tsukuba must have exceeded $30 million and a few thousand dollars for 3D consultants could have made the films so much better. There are many 3D still photographers available who have more experience with 3D than almost anyone in the motion picture or television industry.

The errors I point out may seem minor but it is clear they do bother people and detract greatly from the experience. I talked with about 100 people at the exposition and all were very enthusiastic about 3D, but often complained about a lack of sharpness. In fact, all the films were in good focus, and they were really complaining about the errors in the production and projection. All the films at the exposition were short and feature length films would greatly increase the viewing problems since all the defects add together and cumulate with time to create discomfort.

The biggest problems with 3D are not technical but human. Project directors rarely have any experience with 3D and some who do have produced films that are virtual catalogs of stereoscopic errors. They seldom take into account how much 3D perception varies from person to person and how much it can change with learning. In 1985 I put on a big 3D show at the FutureWorld Exposition in San Francisco, California. Some 3,000 members of the public had a chance to view 3D displays, such as Lowell Noble's hyperscope and Bob Collender's Stereoptiplexer, that even most 3D experts have never seen. Some could see the 3D instantly, but others took up to a minute to fuse the images and others couldn't see the 3D at all. It is possible to intersperse 2D and 3D footage in feature length films to allow the audience to 'rest their eyes' and this could also make filming easier and cheaper.

A problem with all systems using passive polarizing (or active LCD shuttering) glasses is the slight ghosting or crosstalk, due to a lack of complete blocking of the other eye's image even when the polarizers in the goggles are perforationectly aligned with those in the projectors. When people tilt their heads from the vertical, the alignment is lost and ghosting increases when linear polarizers are used. Circular polarizers are not sensitive to head tipping, but their ghosting is slightly greater. Polarizers with lower ghosting exist, but they also have lower light transmission and higher cost. Linear polarizers are fine if photography and projection are properly done. One of the problems with large amounts of horizontal parallax is the opportunity for serious ghosting, especially when there are light objects on dark backgrounds or vice versa.

It would be useful to have established engineering parameters for 3D movie and television systems but the vast data available from psychophysics are mostly useless since they are rarely gathered under conditions relevant to home TV or theatrical viewing. Single camera systems have the major advantage that most of the problems can be engineered out when the lenses are manufactured, but a well engineered vertical double camera rig with easy variability of convergence and interaxial and large negative size has much to commend it and can be printed on a single strip for projection or recorded on a single videotape. Perhaps the best double camera control has been designed by Steve Hines of HinesLab in Glendale, California and used by Disney. Because of low resolution and need for electronic manipulation of images, double camera (or at least double imaging chip) systems are probably preferable for video.

In spite of the use of large values of negative parallax (right eye image as much as ten feet to the left of the left eye image) the image, meant to appear very close to the viewer, often appeared to be at or even behind the plane of the screen. The most convincing placement of objects out in the audience occurred when there were other depth cues such as perspective (e.g., a ladder sticking out of the screen), or when there was no other cue for placing an object in space except a small parallax. This latter situation occurred in the Sumitomo film with a yellow cube on a dark background and in most of the FujitsuOmnimax Film.

The Streel Pavilion presented a 70mm 3D film produced in the new '10 perforation 65' system created by Chris Condon of Stereovision International in Burbank, California. A Flight Research camera, modified for 10 perforationoration pulldown by Jacob Monroy, was fitted with Condon's newly designed and patented lens to give, in 65 mm, the wide aspect ratio over and under 3D format that is standard in 35 mm. A Kinotone projector was modified for 10 perforation pulldown and fitted with a custom Toshiba triple lamp xenon lamphouse. Projection through a Stereovision lens was steady and bright with no vertical parallax (one advantage of the single band system). There was a slight asymmetrical illumination, partly due to cameras and partly to projection. Some shots showed excessive horizontal parallax (useless since the image appeared to be at the screen) and a few were unfusible. The color and contrast were not always optimal, probably due to the use of some 35 mm blowup footage and to some subjects, such as gloomy factory interiors. Lack of sufficient lighting with consequent use of large apertures is a common problem with 3D and may have been responsible for the slight lack of sharpness in some shots. Overall, the film was quite effective, with some stunning special effects and enthusiastic audiences.

Douglas Trumbull's Showscan theater at the Toshiba pavilion was especially interesting since it has been promoted as a substitute for 3D. It was easy to tell this was not true with eyes closed just by listening to the audience's restrained reaction. There was a powerful sensation of depth in some closeups and in an electron microscope shot and the sharpness was impressive. This is to be expected from a system which shoots 65 mm film at 60 frames per second. Clearly, the next step for Showscan is 3D and this was done at Exposition 1992 in Seville, Spain. The side by side anamorphic 65 mm 3D lens, which Condon manufactured at my suggestion, should work perforationectly with Showscan and the result would be superior (ease of use, quality, cost) to any other 3D format requiring special cameras and projectors.

The 1985 3D feature length animated film ‘Starchaser’ is quite interesting to compare with the Tsukuba films. The action is placed almost entirely behind the plane of the screen by giving everything a slight positive parallax. This means the right eye image is to the right of the left eye image as opposed to the negative parallax used when images are meant to protude into the audience space. With positive parallax the eyes are both focused and converged essentially at infinity, making the film easy to view for prolonged times. Since the distance between our eyes is about two and a half inches, objects with two and a half inches of positive parallax will be seen with eyes parallel and will tend to appear at infinity. Objects with smaller amounts of positive parallax will appear to be between infinity and the screen, while those with large amounts of positive parallax will tend to appear behind those with two and a half inches. The problem with giving objects more than two and one half inches of positive parallax is that 3D fusion will require the eyes to diverge or toe out, something they never do normally, and a potential source of eyestrain. Divergences inevitably crop up with live 3D shooting with objects located some distance behind the point of convergence of the two optical axes of the lenses, but in animated images, divergence is completely unnecessary and I can’t imagine why they felt compelled to put divergent backgrounds in this film. Many of the resulting shots were hard to fuse.

When working on the 3D film ‘Rottweiler’ a few years ago, I spent a lot of time doing calculations in order to avoid divergences of more than a degree or so (calculated for the average spectator in the average seat), but I now think that most of the time the attention is so completely focused on the principal subjects that there is seldom time to make the attempt to fuse other objects and their parallax is often of no consequence. Also, objects not near the principal subjects are often out of focus, particularly with the slower lenses of single camera systems, which will have less depth of field when they are used at large apertures due to inadequate lighting. Most filmmakers seem to have ignored parallax of near and far objects and have gotten away with it for these reasons. It is often unnecessary to do any calculations. For Condon’s over/under lenses, a glance at the viewfinder calibrations gives the acceptable depth range. The same is true for double camera systems if a 3D video viewfinder is used.

It is usually maintained in the literature that divergence should be kept to less than one or two degrees. "Starchaser" often has two feet of positive parallax in the background. For a person 80 feet from the screen, this creates less than one degree of divergence, but for those 20 feet away, the divergence is three degrees. Even three degrees did not seem to cause much discomfort, but, as with excessive negative parallaxes, they are clearly unnecessary. Adjacent shots with two feet of positive parallax and with zero positive parallax in the furthest plane did not seem to have different depth. They often pulled convergence (changed parallax during a shot) very effectively, as was probably first done on many shots in ‘Rottweiler’.

Another fault of ‘Starchaser’ is the rapid panning. The 3D animation is generally good with four distinct planes in most shots, but the absence of perspective in the figures makes them flat rather than round and detracts greatly from the film. If any further 3D cel animation is to be done, it should make use of a 3D drawing machine which can create stereo pairs with true perspective. Such machines have been known for over 100 years, but no use of them has been made in commercial animation. In Japan, I visited Vladimir Tamari who has designed and built such a machine. With suitable improvements, it could do a 3D animated film (or 3D comics) far better, faster and cheaper. However, the age of cel animation is clearly drawing to a close and one can foresee virtually all animation in 2D or 3D being done by computer in the very near future.

The 35 mm over/under 3D films using the Stereovision camera and projection lenses for Niigata and Nagano science museums were excellent and once again demonstrated that a single camera, single projector system can produce superb results for a fraction of the cost and trouble of double systems. However, the Japanese single camera, single projector system at the Tama Tec park near Tokyo was a disaster. It had nearly every error possible, including 10 feet of parallax when the furthest seat was only 40 feet from the screen.

In 1970, the Russians brought their lenticular autostereoscopic (no glasses for viewers) motion picture system to Japan and I had hoped to see the new holographic motion picture system developed by Komar and his coworkers at NIKFI in Moscow. This system uses large format cameras and holographic film synchronized with a pulsed laser and a holographic screen for projection. The system was not at Tsukuba, and when I visited Moscow the next year, I found that all work on the system had stopped. The only substantial remaining effort in holographic motion pictures was that of Smigielski and Albe in France. Since then there have been efforts by about 20 different groups with significant progress but still no commercial system.

The INS pavilion at Tsukuba contained two other types of 3D displays - a Pulfrich pendulum and a graphics display using electrooptic shutters. When a neutral density filter is placed over one eye a pendulum appears to swing in an ellipse. Named after its 19th century discoverer, this effect also works when objects on a video screen are moved horizontally at different speeds and has been the basis for video games and TV series. I was probably the sole observer of the world's largest Pulfrich display. One evening at Tsukuba the last image on the 100 foot diagonal Sony Jumbotron was a rotating flower vase. I quickly tore a pair of polarizing glasses in half and made a suitable filter for seeing the 60 foot tall 3D image.

The giant video screens from Sony, Matsushita and Mitsubishi could also be used for 3D presentations by covering their surface with alternating strips of sheet polarizer, interdigitating a stereo pair from two VCR's or cameras and viewing with polarizing glasses. This was done with the Jumbotron during the final days of the exposition.

There was a well concealed 3D slide show in the Electrogulliver pavilion at Tsukuba. Only about 30,000 of the exposition's 15 million visitors could see it due to space limitations. People wore giant polarizing glasses for a short dual projector 35 mm slide show. Some of the slides were very difficult to look at since they had stereo insets which contained conflicting depth cues.

A 3D slide set was available for purchase, but had mostly long distance shots of buildings and there were also some unexciting lenticular 3D photos from Toppan Corp. Far superior lenticular photos up to 16 by 20 inches have been produced by Douglas Winnek of Carmel Valley, California and others in the US and Europe. Multiplex, transmission and reflection holograms were abundant, with the large multiplex in the Polaroid exhibit and the fantastic reflection holograms from the Russia being best.

In multiplex holography, multiple 2D views are made on film, tape or computer, and a very narrow (ca. 1 mm), tall (ca. 200 mm) hologram made of each frame. When many of these are printed side by side, a holographic stereogram results. I believe that the sharpest, brightest and most complex multiplex holograms are those of Sharon McCormack, who ran San Francisco's School of Holography and now works in White Salmon, Washington. She has developed special techniques for a holographic movie lasting 5 minutes and viewable by 20 people. Standard 2D footage can be converted to a holomovie.

Both lenticular photos and holograms can provide superb publicity for 3D or 2D shows, and the recent achievement in both formats of high quality mass production guarantees their frequent use in future advertising.

3D FILM SYSTEMS USED IN JAPAN DURING THE 1980's

System	Site	Camera Lens	Projection
United Artists	Tsukuba	Standard 65mm	two 70mm
Stereovision 10Perf 65	Tsukuba	Stereovision 10Perf 65	Stereovision 10Perf 70
Stereovision 35	Tsukuba	none (graphics)	Stereovision
Stereovision 35	Niigata	Stereovision 35	Stereovision
Stereovision 35	Nagano	Stereovision 35	Stereovision
Omnimax	Tsukuba	none (graphics)	Omnimax
Disney	Disneyland	Standard	two 70mm
Cinemagic	TamaTec	Cinemagic	Cinemagic
Stereovision 35	Hokkaido	Stereovision 35	Stereovision

Matsushita engineers created an autostereoscopic (no glasses) 3DTV system for the national Panasonic pavilion at the exposition. The general concept behind it has been understood for over 50 years and has been applied to video systems many times. Probably the most successful system in terms of quality and simplicity was that of California inventor Maurice Tripp, who built a 13 inch diagonal lenticular TV with a fiber optic faceplate about 1976. The Matsushita system used five video cameras, five synchronized recorders and five three inch color video projection tubes for playback. An array of lenses and semisilvered mirrors relayed the images to a double lenticular screen. It was not possible to see an unblurred picture and I found the 3D effect modest. Tripp's system seems to have had a far superior image and used only one camera and recorder.

In recent years, completely new approaches have been developed for autostereoscopic movies and TV. I'll mention a few of the active US inventors. Homer Tilton has developed a moving parallax barrier device called a 'parallactiscope' which he described in a recent book. Lowell Noble of SOCS, Santa Clara, California, has improved the parallactiscope and added lenses to project the image into space in his 'stereohyperscope'. Kirby Meacham of Ohio has prototyped a simple mechanical parallax barrier system. Clarence Adler, also of Ohio, has prototyped a device with mirrors and lenticular screens. Marvin Pund of Missouri has a system intended for a single viewer which incorporates a headtracker. George Plotz of Massachusetts has a concave mirror system that has been marketed in simple form by the American company Edmund Scientific for several decades. This ashtray shaped device makes a coin placed at it's bottom appear to float several inches in the air. Bernard Ciangola of New Jersey created a 3D image with a large rotating lens. Lowell Harris has produced a refined version of the varifocal mirror system marketed briefly by Genisco Corporation and Weingart Incorporated of Fort Wayne, Indiana, has shown an autostereoscopic 'Stereo-Optic Imager' which uses dual crt's and there are several dozen new autostereo patents every year.

The most promising display for those who want any size screen and any type of imagery may be the Stereoptiplexer created by Robert Collender of Glendale California. It is suitable for movies, TV and graphics and his prototype demonstrates that his unique patented principle works. It projects multiple images rapidly over a curved screen and has the interesting property that it can often produce excellent 3D from 2D footage. He has described it in the SPIE volumes on 3D imaging and in patents.

In the near future, it should also be possible to do a type of image processing similar to the inbetweening common in computer animation system, so that 2D films and tapes can be converted to 3D. I visited professors Agui and Nakajima at the Tokyo Institute of Technology in 1985 and saw a striking example of the creation of 3D pairs from 2D originals of a marble statue. Many are working along similar lines and, while it may be well into the next century before programs and computing speed are advanced enough to convert 2D material to completely satisfactory 3D, it can be done well enough now to be useful and entertaining. Software which makes 3D models from 2 or more photos is available from several companies and most CAD and graphics programs will incorporate this capability in the near future. This will provide a tremendous stimulus to the development and use of 3D displays since the entire body of flat and stereo photos, video, drawings, painting, films and computer graphics will then be available as a stereo database. Sanyo marketed an IC in 1995 which synthesizes 3D from 2D using time delay and motion estimation. However, using this technique alone requires the existence of rapid horizontal motion and tends to produce viewer discomfort after a few minutes. 3DTV Corporation has a technique for real time conversion of 2D to 3D which works even on still images and is more comfortable to view. Video tapes and CD's with films converted to 3D using this technique will appear in 1996

It is a relatively simple matter to modulate a multicolor laser with a video signal and project video on a large screen with stunning colors. The Health and Sports pavilion at the exposition contained a small videolaser and Japan's NHK prototyped an 1125 line laser video system in 1976. Cavendish Labs of England and Visulux Corp. of Santa Clara, California have sold many such systems to industrial clients and Lowell Noble (of SOCS) and Tom Rust (of Lazerus Corp., Berkeley, California) have independently projected polarized 3DTV with their own laser video systems in the 1980's. Noble reduced the size of his laser to 0.5 by 10 inches and wanted to develop a home laser TV system. It's source could be a high definition compact video disc system. With almost infinite depth of focus, superb color saturation and the potential for 5000 or more lines of resolution, such systems merely await development money to pose a serious challenge to lens projection of film and video. The American companies, Proximax Laser and Power Corporation, began in 1995 to develop a projection system with solid state micro lasers that may overcome the problems of size, cost, power consumption, need for water cooling and unreliability.

Some advantages that video has over film are the easy combination of several signals (e.g., graphics overlay) in real time and the ease of doing image processing. In 1986, I saw the Visulux system given some simple real time processing(edge enhancement) by Ed Sandburg and laser projected on a six meter diagonal screen. Interference patterns were eliminated by vibrating the screen. The image was fantastic and most people would have thought they were seeing 35 mm film. Even experts would have thought they were seeing a special high definition TV system, but it was a standard broadcast. It is often said that video lacks the resolution of film and invalid comparisons are made between the available pixels in a frame of video and that of a frame of 35 mm film. However it must be kept in mind that average theatrical 35 mm projection probably does not exceed 700 lines resolution due to image jitter and weave and that even Imax probably has less than 1,000. Disney eliminated about 75% of the jitter in their double 70 mm 3D system by using pin registered projectors. If film is to maintain its edge over video, it will need better engineering of cameras, printers, projectors, and film registration systems.

3D AT THE VANCOUVER EXPOSITION 86

The year after the Tsukuba exposition there was another world exposition in Vancouver, Canada. There were a number 3D theaters, the most spectacular of which was the first use of the double camera, double projector IMAX system in the CN theater in the Canada pavilion. The 3D was truly stunning and this was unquestionably the finest projected image in the world. Nevertheless, nearly all the errors to be expected from double camera, double projector systems were present in most shots. The worst error was the excessive horizontal parallax (up to six feet) in nearly every shot. Sometimes I was able to fuse this, as in one lovely shot of a teddy bear hanging in front of my face, but eyestrain was troublesome even for my constantly excercised visual system from the last row, and I pity those who sat in the front. The next most serious problem was the vertical parallax present in every shot and varying from two inches up to two feet. The shot to shot variation showed that about a third of this was due to misaligned projectors and the rest to misaligned cameras. Some shots showed that the cameras were skewed since there was more vertical parallax of distant objects than of close ones. All these errors could have been eliminated or greatly reduced during shooting if a 3D video viewfinder had been used or during optical printing or by carefully aligning projectors. It is amazing that those in charge of this project did not do this.

The jitter and weave of each image was about one inch, so the maximum error in the placement of homologous points was about two inches. Asymmetrical illumination was minimal with slight vignetting (darkening) or the right edge of the left eye image. The film was well shot, but, like everything I have seen in the IMAX and OMNIMAX format, it had negligible story line and the cameras were often panned or jerked around too fast. In the OMNIMAX theater at the exposition the audience was even cautioned to look away if they became sick and many (including me) found this necessary. The brief 3D computer graphics sequence worked well, though it was a decade behind the state of the art. Fortunately, the CN theater is a permanent installation, so they are presumably showing a better made 3D film now. A sensible way to do 3D with IMAX and OMNIMAX is with a single camera, single projector side by side anamorphic lens. Jacobsen in Europe and Condon in the US have built such lenses for 70 mm.

The Ontario pavilion had a double 70 mm 3D system. There were memorable shots of flying geese and a train, but about half the time there were 2D shots, 2D panel inserts, or old stereographs, which just wasted time. About two inches of weave and an irritating asymmetrical illumination flicker were present. This flicker, in which irregular patches of one eye image are darker than corresponding patches for the other eye, is usually present in dual systems (e.g., in the otherwise excellent "Muppet Vision" dual 70mm 3D film playing at Disney World in 1995) and sometimes in single systems (e.g., in parts of the Russian 3D film at the exposition). Presumably, this is due to asymmetries of film, processing, printing or projection. In some shots horizontal parallax was excessive, but overall it was sensibly kept to a minimum with objects placed in or behind the plane of the screen. Vertical jitter and vertical parallax were barely noticeable and there was only slight asymmetrical illumination. Four or five well illuminated outdoor shots were stunning.

The third 3D movie system at the exposition was the 20 year old Russian Stereo 70 system. Having seen half a dozen excellently shot and projected films in this side by side square format single camera 70 mm system in Moscow a few months earlier, I was prepared for a treat.

Unfortunately, the lenses which fill the screens in the 26 specially designed 3D theaters in the U.S.S.R. filled only about a third of the screen in Vancouver and there was no masking. Two nonmatching blurry edges were visible on each side, the right eye image was slightly out of focus, and the print (a nature film) had irregular patchy exposure. The color film is clearly not up to western standards, though the fresh prints I saw in Moscow were much better. As in the Moscow films, there was a slight vertical parallax in some shots, but the very intelligent use of convergence, with nearly all objects in or behind the plane of the screen, coupled with the even illumination and lack of random displacement of homologous points that plague double systems, made the film a delight to watch and free of eyestrain.

Douglas Trumbull's 60 frames per second 70mm Showscan system appeared at the British Columbia pavilion. In brightly lit scenes, when lenses were stopped down for good depth of field, and when motion parallax was also present (as in a shot of racing cowboys) the illusion of 3D was very convincing. This system cries out for a side by side anamorphic 3D lens. A dual 65mm camera, dual 70mm projector 3D Showscan system appeared at Expo '92 in Seville, Spain, but it did not strike me as substantially more impressive than the many dual 70mm, 24 frame per second, films I have seen.

POSSIBLE LARGE SCREEN 3D CAMERA AND PROJECTION SYSTEMS

System	Cost of Hardware	Cost of Prints, etc...	Binocular Asymmetries	Camera Size and Weight	Negative Size
Single 35mm Over/Under	1	1	1	1	1
Single 65mm Anamorphic	3	3	1	2	3
10 Perf 65mm	4	4	1	2	6
Double 35mm	4	4	2	3	2
Showscan 65mm Anamorphic	5	4	1	2	7.5
Single IMAX Anamorphic	12	12	1	3	10
Double 65mm	8	10	2	4	6
Double Showscan	8	10	2	4	ca. 15
Double IMAX	20	20	2	6	20
Laser	20	all	1	all	all
Stereoptiplexer	20	all	1	all	all
Holographic	20	10	1	all	all
1125 Line Video	20	10	2	4	all
StereoPlate	1	1	1	1	1
SpaceStation	1	1	1	1	1
SpaceBox	1	1	1	1	1

Relative costs and, to some extent, asymmetries are arbitrary since all systems are subject to continual modification and some are yet to be built. Many other systems are also possible including side by side anamorphic versions of 8 perforation 35mm (Vistavision) and of the 8, 10 and 15 perforation 65mm systems created for the Tsukuba Exposition. All values are relative to the 35mm single camera, single projector system. The following three devices are produced by 3DTV Corp. of San Rafael, CA. StereoPlate is an active LCD plate that converts CRT video projectors for 3D viewing. The SpaceStation is a demultiplexing device that permits a single field sequential video stream to feed twin video projectors. The SpaceBox is a controller for dual video disc players or dual digital video discs.

Video Projection Systems by Image Quality

Ranking	Type of Video Projection System
1	2 projectors with smart linedoublers and dual laser discs, dual digital video discs or dual video tapes
2	2 projectors with dual laser discs, dual digital video discs or dual video tapes
3	2 projectors with smart linedoublers and SpaceStation Model 4
4	2 projectors with SpaceStation Model 4 in VGA mode
5	2 projectors with SpaceStation Model 4 in NTSC or PAL mode
6	1 projector at 100Hz or 120Hz with linedoubler and StereoPlate
7	1 projector at 100Hz or 120Hz with StereoPlate or active glasses
8	1 projector at 50Hz or 60Hz with linedoubler or the SpaceView lcd projector
9	1 projector at 50Hz or 60Hz with RGB input
10	1 projector at 50Hz or 60Hz with YC input
11	1 projector at 50Hz or 60Hz with composite input

PANORAMIC 3D MOVIES

The desire to create a more powerful effect by eliminating the screen edges has been one of the driving forces in film technology since it's earliest days. Virtually all 35 mm films now have an aspect ratio of 2:1 or more and Panavision, with it's 2.35:1 is nearly universal in US production. The OMNIMAX dome theaters, with more than 180 degrees horizontal and more than 90 vertical viewing angles, effectively eliminate screen edges for most spectators when the filmmakers remember to place the object of attention in the center of screen. OMNIMAX was first done in 3D at the 1985 Japanese exposition with red-blue anaglyph, and IMAX at the 1986 Canada exposition with a double camera, double projector system. A single camera, single projector panoramic 3D system was introduced a few years ago with the Super Cinema 3D system. The camera and projection optics for this system were designed by Walter Meier and Jan Jacobsen for Meier's Vergnugungsbetreibe A.G. of Zurich, Switzerland. Jacobsen previously designed the side by side anamorphic 70 mm 3D lens used for the seldom seen German 3D erotic film 'Love in 3D'. Meier also design and built collapsible dome screens and created a PVC based aluminum paint which retains its reflective properties after repeated folding. This system has been widely used in Europe with some 50 domes being used by circuses and fairs and several appeared in the U.S.A. "Boomerang", one of the films made with this system, was shown at a permanent installation at Branston, Missouri, USA. The screen, however, is rectangular and only slightly curved. There is also a permanent installation at Seoul Land in Korea.

Super Cinema 3D uses standard 70 mm cameras and projectors with the side by side anamorphic stereo optics and a special 8,000 watt xenon lamp house. The 3D film covers about 180 degrees horizontal and 90 vertical and is accompanied by 6 track stereo sound. Audiences of up to 1,000 stand to watch one of about a dozen, 12 minute films currently available. A permanent dome has also been created near Milan, Italy with a 100 foot diameter which cost about $300,000 including projector and films. This system is a natural for all the world's planetariums.

The films seem to have problems with vertical parallax and excessive horizontal parallax. Those who can read French may consult issues 16, 28,30, and 33 of the bulletin of the Societe Suisse de Stereoscopie.

The US representative is J. Whittington & Assoc. of Springfield, Missouri (417-883-5376). In Europe contact Meier in Zurich (0041-1737-2055).

3D TELEVISION AT THE EMMEN ZOO

When I visited Holland in 1986, I went to see a 3DTV system at a zoo. About a two hour drive from Amsterdam, the town of Emmen contains a lovely zoo that had one of the few 3D TV systems in the world that is on continual display to the general public. In fact, the only other one I knew of was an identical system at the Philips science museum in Eindhoven. The images were recorded with a pair of broadcast quality cameras on a pair of synchronized one inch tapes. The cameras are at right angles with one shooting thru and the other off a semisilvered mirror. The edited tapes are transfered to videodiscs and played on a pair of custom synchronized Philips videodisc units into a pair of 23 inch color monitors, mounted at right angles with polarizers and a semisilvered mirror to superimpose the images. An audience of about twenty people viewed the images with polarized glasses. Rudiger Sand, of the IRT in Munich worked on this system and has published articles on it in German journals an in English in the SMPTE journal.

The general concept of this system is an old one and has been used many times but rarely has there been such a wide range of technical resources available. I had seen the same 3D program shown at the zoo in Sand's lab in Munich on a pair of Barco videoprojectors which had slightly modified optics and a reversed color sequence of the 3 tubes to optimize the image. I was delighted to find that great care had been taken and binocular asymmetries were barely detectable. Convergence had been very conservative and objects were nearly always behind the plane of the screen. After seeing so many multimillion dollar projects with sloppy technique, this was a joy to behold.

Unfortunately, the 3D glasses sold at the zoo were used and the lenses were covered with fingerprints which badly blurred the image. This is one of the greatest problems with all 3D systems - the public doesn't know to clean the lenses and nobody tells them. Probably half of all the viewers saw mildly to severely blurred images. Since only about a dozen people can get a good view, there were two 3D setups. Both exhibited many of the problems of the dual channel approach, with scratched mirrors that cause asymmetrical blemishes in light scenes. The mirrors were full of dust and fingerprints and a small boy ran his hand down the mirror at the end of the show. Clearly, an antireflection coated glass or plastic barrier is necessary.

Ghosting in high contrast scenes was moderately annoying, but reflections from the mirror were more troublesome, especially in bright scenes. A black velvet surround should help. About one and 1/2 cm of the top and 1 cm of the bottom of the right and left images did not match. This was quite bothersome and could easily be eliminated by masking. On one of the set ups the right image was lacking sufficient contrast and color saturation and the pairs of both setups were different in hue, saturation and contrast. The larger image of videoprojectors can be seen by at least 50 people, has no mirror problems and is considerably more impressive. Also, the cost of one dual projector setup should be comparable to two of the mirror setups.

In spite of these problems, the system is well done and the audiences were receptive. I'd love to see these images put on 1125 line videodiscs and projected on a 10 meter screen with a pair of Eidophor's 1125 line projectors!

Images are in the "3D For the 21st Century" section of the 3D-Rom!!!

Left and right frames from the double IMAX 3D film at the Vancouver exposition. The state of the art in imaging technology for those who can afford it.

A frame from the OMNIMAX film in the Fujitsu pavilion at Tsukuba. Undoubtedly the finest 3D computer graphics to that time it subsequently showed in OMNIMAX theaters around the world. It could be remastered from the original tapes and projected with polarized systems.

National Panasonics 1125 HDTV system in the background with interactive consoles for viewers in the foreground at Tsukuba Exposition 1985.

Left: frames from the Nagano City Science Museum film. Right: frames from the 3D computer film created by Digital Productions for the Hitachi pavilion at Tsukuba. The fine quality of the Stereovision lens is obvious when the Nagano frames are viewed in a stereoscope, as is the excessive hoizontal displacement and image rotation of the Hitachi film.

A 3D pair shot with a Nimslo closeup 3D camera off the screen of the Matsushita autostereoscopic 3DTV at Tsukuba. The pair is taken from the two outside Nimslo lenses which have about the same separation as our eyes and the blurriness shows that it was not possible to get a sharp image from any position.

The 1985 Matsushita 3DTV system at Exposition 1985. This autostereoscopic system used the latest technology but was not terribly impressive.

Maurice Tripp of Skia Corp. in California in 1978 with an early lens for his fiber optic lenticular video system. Probably the most successful autostereoscopic TV system at that time; he planned to use it as a display for his autostereoscopic x-ray system. He later found he could get good results with ordinary wide angle lenses.

Douglas Winnek received his first patent on autostereoscopic movies in 1932 and was still active in the early 1990's.

A stereo pair from the Steel Pavilion Film at the Tsukuba exposition. It gave excellent results for the first use of ChrisCondon's '10 perforation 65' system.

Test footage from the new side by side anamorphic 65mm 3D lens designed and built by Chris Condon of Stereovision International in 1981. Completely compatible with all 2D 65mm technology, the system should see wide use.

The illusory 3D cube on Sumitomo's 3D Fantasium Theater. Dr. Richard Vetter's double 70mm StereoSpace system delighted audiences inside.

Chris Condon of Stereovision International with his side by side anamorphic 65mm 3D lens. It gives excellent image quality with a single unmodified camera and projector and could be used on Trumbull's Showscan system or scaled up for IMAX.

Victoria Condon with the Stereovision Intl. '10 Pert 65' camera and lens used for the Steel Pavilion film at the Tsukuba Exposition. A custom '10 Perforation 65' projector and a Stereovision projection lens completed the system.

Stereovision Intl. 35mm lens being used by Gakken personnel for the shooting of a Nagano City Science Museum film. This lens is an industry standard and had been used to shoot three films for permanent installations in Japan by 1986.

The Cinema U projector in the Shueisha pavilion at the Tsukuba exposition is similar to IMAX with sideways 15 perforation 70mm, but lacks the smooth film transport of IMAX. With a scaled up version of Condon's side by side anamorphic lens, IMAX would make a fantastic single camera, single projector 3D system.

Sharon McCormack incorporated live action and computer graphics in her holomovie 'Time Man'. I believe she produces the highest quality multiplex holograms in the world.

The arrangement of mirrors and lenses in US inventor Clarence Adler's autostereoscopic system. Projected panoramagrams of this type have been patented at least a hundred times by many inventors beginning with Ives some 60 years ago. Modem technology makes such systems practical.

Robert Collender with a model of his Stereoptiplexer theater -- perhaps the leading contender for 3D movies and TV without glasses.

A diagram of one of Kirby Meacham's dynamic parallax barrier systems for 3D without glasses. Tilton's parallactiscope is similar and Noble's stereohyperscope scans the slits electrooptically.

Large screen film formats. Left center: 35mm over/under industry standard with a 35mm side by side square format and a 35mm side by side anamorphic to it's right. Below that is a single frame from a 35mm anaglyphic print originally shot in double 35mm black and white. Below that is a 35mm side by side anamorphic test print originally shot in double 35mm color. At the right is 70mm side by side anamorphic test footage shot with Condon's lens. Below this is a 70mm side by side square release print of originally shot in 35mm side by side square format. At the bottom right are 70mm over/under frames from the Steel Pavilion Film at the Tsukuba Exposition shot with Condon's '10 perforation 65' lens. For comparison, are shown some 2D formats. At center left is 1 and 1/2 frames from the 35mm 8 perforationoration sideways format (Vistavision) used in several Tsukuba Exposition 1985 Pavillions. At the bottom left are 1 and 1/2 frames from the 70mm 15 perforation. sideways format used by IMAX and Cinema U at Tsukuba. At the top are a 6 by 6 (120mm) still camera slide and a 6 by 10 (120mm) still transparency.

Separation of the two stereoscopic views for left and right. Polarizing filters in front of the projector lenses and corresponding filter glasses cause the left eye to only see the upper projection triplet and the right eye to see the lower one. The projectors use plane polarizers because of their inherent advantages, but circular polarized systems, allowing more freedom of head movement, are also possible.

The reversed sequence of the projector tube array in the second row compensates, in the resultant picture, for the typical color shading.