Computer Graphics for Large-Scale Immersive Theaters

SIGGRAPH 2001

EXPLORE INTERACTION AND DIGITAL IMAGES

Computer Graphics
for Large Scale Immersive Theaters

Course Notes for Siggraph 2001

Course Organizer

Ed Lantz
Spitz, Inc.

Presenters

Ed Lantz
Spitz, Inc.

Ben Shedd
Princeton University

Brad Thompson
Spitz, Inc.

Carter Emmart
Hayden Planetarium

Martin Ratcliffe
Exploration Place

Abstract

Large-scale video projection of immersive environments is revolutionizing planetaria and dome theaters worldwide. Using multiple edge-blended video projectors, these systems provide ultra wide field-of-view, high-resolution images on dome screens. Numerous planetaria have recently installed immersive video systems, and dozens more are planned in addition to corporate showrooms, tourist destination theaters, and other immersive video applications. This course surveys large-scale immersive video systems offered by major manufacturers, and showcases several new installations and their productions. Industry leaders provide a comprehensive look at both real-time and pre-rendered production techniques.

Presenter Biographies

Ed Lantz - Product Development Manager, Spitz, Inc.

Ed Lantz is Product Development Manager for Spitz, Inc. He leads the development of advanced immersive visualization systems, supporting hardware and software. Ed pioneered Spitz's Immersive Visualization Environment products including the ImmersaVision™ video format, and the ElectricHorizon™ and ElectricSky™ theaters. He has published several articles on domed theaters, and regularly presents at the International Planetarium Society conference. He was guest editor for the May 1997 issue of ACM's *Computer Graphics*, chaired a SIGGRAPH 96 panel on virtual reality and organized a SIGGRAPH 95 course on hemispheric graphics production. In a former life he led optical signal processing research for SIGINT and ELINT applications. Ed holds a Bachelors and Masters in Electronics Engineering from Tennessee Tech University.

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Ben Shedd – Department of Computer Science, Princeton University, Shedd Productions

Academy Award winning filmmaker Ben Shedd has been a professional film & video director/producer/writer for 29 years. He has produced and directed 29 films, co-writing 18 of these productions. Since 1985, Ben has been designing, directing, and producing giant screen IMAX® & OMNIMAX science films, including SEASONS, TROPICAL RAINFOREST, the FORT WORTH FLYOVER II Signature Film, and DANCING IN THE SKY. His films have received forty international awards and are distributed worldwide. He holds a Master of Arts degree in Cinema from the University of Southern California, and a Bachelor of Arts degree in Radio/Television/Film from the San Francisco State University.

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Carter Emmart - Visualization Director, Hayden Planetarium in the Rose Center for Earth and Space, American Museum of Natural History

Carter Emmart has been a scientific illustrator and visualizer for 20 years. While with the NASA Ames Research Center he edited and illustrated the book "Strategies for Mars: A Guide to Human Exploration", that assess the state of issues regarding human missions to the planet Mars. As contractor to the Smithsonian Air and Space Museum, he fabricated a model exhibit of a piloted Mars transit spacecraft. He joined the National Center for Atmospheric Research from 1993-98 where he served as visualization specialist for the GENESIS Earth system modeling project and worked with various media, including IMAX large format film. Carter has a diverse background in conceptualization and visualization of future space exploration, Earth-system simulation, and astronomical phenomena. He is currently directing the visualization efforts of the Digital Galaxy Project, where models of the cosmos are turned into images that fill the 68-foot dome at the newly rebuilt Hayden Planetarium in New York. Carter holds a bachelor of arts in Geophysics from the University of Colorado.

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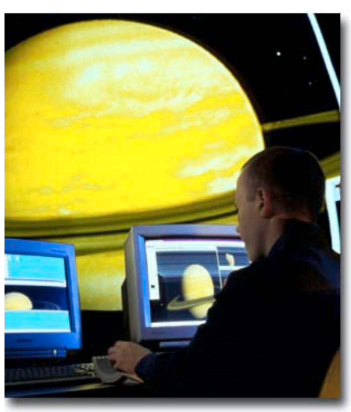
Brad Thompson - Lead Animator, Spitz, Inc.

Brad Thompson is a 3D computer graphics animator with a degree in Imaging and Digital Arts from the University of Maryland, Baltimore County. Brad has worked extensively with 3D animation tools including Softimage, Alias Power Animator, 3D Studio Max, World Builder, Truespace and others on platforms ranging from SGI to Windows NT to Macintosh. Brad is also an accomplished 2D compositing artist. He is currently responsible for production of immersive video content in Spitz's ImmersaVision™ format. His work has led to the development of specialized techniques for creating and rendering images for the dome environment.



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Martin Ratcliffe - Director, Theaters & Media Services, Exploration Place

Martin Ratcliffe is Director of the Boeing CyberDome at Exploration Place. He began his planetarium career at Armagh Planetarium, Northern Ireland, where video projection in a planetarium was introduced in 1985 and electronic interactive shows were first developed for Planetariums in 1986. Following six years directing shows at the Buhl Planetarium, Carnegie Science Center, Pittsburgh, he became Director of the world's second StarRider theater, part of a $62-million facility called Exploration Place in Wichita, Kansas. In addition to directing production of shows in this new medium of real-time interactivity for domed theaters, Martin contributes a monthly column to Astronomy magazine, films total solar eclipses of the Sun for television, and has consulted on a number of television documentary series for shown on Discovery and The Learning Channel in the USA and Channel Four in the UK (Wonders of the Universe, Encyclopedia Galactica). He holds a Bachelor of Science degree in Astronomy from University College, London, England, and is President of the International Planetarium Society (2001-2002).

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Credits and Notices

The presentors would like to thank the many organizations who have contributed to or assisted with this publication, including Afshad Mistri at SGI, the Boeing CyberDome, Elumens Corp., Evans & Sutherland, the LodeStar Planetarium of Albuquerque, NM, Michael Bruno of Spitz, the National Space Centre of Leicester, UK, Zenturio Group of London, and all of our respective institutions.

The organizer would also like to thank his friends and co-workers for their support during the preparation of this document, and apologizes for any oversights or omissions. Every attempt was made to provide a balanced treatment of this field without vendor preference.

Course Syllabus

8:30 - *Introduction to Large-Scale Immersive Theaters* (E. Lantz)
Provides historical context for immersive graphics including large-format film and video projection. Introduction to spherical video projection systems, applications, and installations.

9:15 - *Principles of Immersive Imagery* (B. Shedd)
A discussion of practical ways to design effective imagery and insure content continuity for immersive dome screens. Develops a philosophy of immersive imagery by comparing and contrasting small framed images with giant immersive projections, and provides a toolbox of approaches to produce for these new screen spaces.

10:00 - Break

10:15 - *Spherical Image Generation and Projection* (E. Lantz)
Review of various methods for getting video onto the sphere, with emphasis on multi-projector edge-blended displays. Looks at popular spherical mapping and edge-blending methodologies, including software and real-time hardware approaches. Also covers image generation and playback using video servers and real-time, multi-pipe image generators.

11:00 - *Immersive Rendering Basics* (B. Thompson)
Discusses the basic technical and conceptual challenges encountered in rendering animations for spherical screens, and presents some of the methods that our industry has invented to deal with them. Technical hurdles include the absence of monitors to view spherical graphics, the need to adapt flat-view-plane rendering tools for spherical screens, and the need for massive amounts of storage space and rendering power to deal with the large-format spherical frame resolutions. Conceptual hurdles are substantial because spherical animation challenges a flat-screen cinematic language that's been subconsciously programmed into us from the first days of motion picture and video.

12:00 – Lunch

1:30 - *Immersive Rendering Basics*, *cont.* (B. Thompson)

2:00 - *Tools and Techniques for Realtime Dome Production and Education* – (C. Emmart) The Hayden Planetarium arguably has the world's most powerful group visualization system in the world. Powered by a 7-pipe SGI Onyx, the Hayden system can project both real-time graphics and pre-rendered shows. System details are presented and show production techniques are discussed, along with recommendations for future directions and research opportunities.

3:00 - Break

3:15 - *Real-Time Interactive Show Production for the Boeing Cyber Dome* (M. Ratcliffe)
Presents details of real-time interactive shows that have been developed on the Evans and Sutherland StarRider™ system for the Boeing CyberDome theater – a 170-seat domed theater that allows each audience member to interactively control various aspects of a CG models via a 5-button key pad attached to each seat. Audience members can take the role of white blood cells fighting a bacterial infection, pilots on board a Martian-bound aircraft, or as controllers of continental plates as they drift around the Earth. Requirements for meaningful interactive scenarios are discussed.

4:15 - *Immersive Rendering Demonstrations* (Various)
Presents compelling examples of the latest cutting-edge animations rendered for full-dome video systems and discussion of rendering techniques and artistic challenges. Some of the latest immersive production tools are also demonstrated.

4:45 – *Wrap-Up and Q&A* (E. Lantz)

Table of Contents

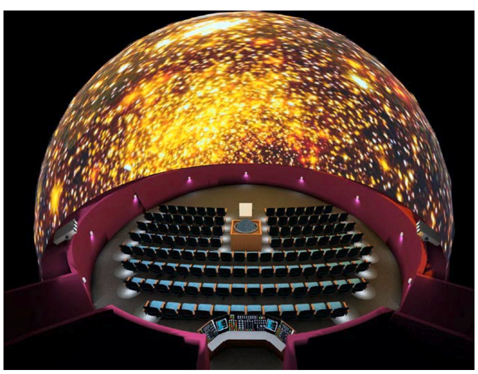
Introduction to Large-Scale Immersive Theaters

Ed Lantz
Brad Thompson

Entertainment technologies strive to deliver memorable, compelling experiences to large populations. Cinema represents an efficient, reproducible medium for the delivery of such experiences. Historic improvements in cinema technologies have centered on making the image larger, brighter, or higher in resolution. Higher brightness and resolution provides a more realistic image, while a larger image provides a greater visual impact or sense of presence. More recent improvements in cinema technologies center on digital cinema, the use of digital graphics projectors to replace the century-old film-based technologies.

The "Holy Grail" of visual display is to deliver an eye-limited resolution image with a wide instantaneous field-of-view such that the entire retina is excited to its full capacity. Video-based systems that strive in this direction include the CAVE® [Cruz-Neira 93], head-mounted displays [Kaiser 95], and various wrap-around video projection systems such as the Reality Center [Traill 97]. Such systems typically accommodate a single user or small collaborative group. Historic large-scale immersive environments include painted panoramas [Gernsheim 68], multi-projector systems such as Circlevision and Cinerama [Hart 00], and more recently, large format film theaters including omni theaters using hemispheric projection screens [Shaw 83] and dome-based training simulators [Fisher 87].

From these roots, a new generation of visual displays have emerged in the last 5 years that are large-scale video-based "digital dome" immersive theaters [Lantz 96]. These are digital graphics environments that provide a visually (and aurally) immersive display accommodating tens to hundreds of people. Such systems are first appearing within planetaria and other special venue domed screen attractions. Indeed, the 2,700 planetaria worldwide, totaling an annual attendance of nearly 90 million visitors, represent a substantial market for this emerging medium [Loch Ness 00]. Unlike film theaters, these modern video-based environments allow visitors to "plug in" to digital information space, including live telepresence events, realtime computer simulations and games, and the latest happenings in the global digital village.



Digital Dome Theater

To date 33 digital dome theaters have either opened their doors or soon will, mostly as planetaria (Table 1). As the number of theaters grows, so will the demand for quality show programming and events. While large-format cinematography can provide some material for these facilities, 2D and 3D computer graphics rendering and compositing techniques makes up the vast majority of programming material to date. This course is intended as a primer for animators and other computer graphics professionals wanting to enter this emerging field.

Technical Challenges. The demand for simultaneous high-resolution and ultra-wide field-of-view provides a formidable challenge for even the most advanced graphics generation and display systems. For instance, the projection of eye-limited resolution onto a hemispheric screen demands over 200 million pixels – two orders of magnitude greater than the new 1080i high-definition television standard. This is far beyond current display system performance. However, acceptable display quality is achievable with as few as 4 million pixels under certain circumstances, and large-scale systems exceeding 8 million pixels are readily available. Interestingly, the immersive imagery provides a strong sense of presence even without 3D stereoscopic effects.

High-resolution systems utilize multiple edge-blended graphics projectors to achieve a single wide field image. These projectors must focus over a region of the spherical screen, and the image must overlap

Table 1 – Large Scale Immersive Video-Based Theaters Planned or Now Open*

Facility Name	Location	Vendors	Opening Year
Hayden Planetarium	New York, NY	Trimension/SGI	2000
Adler Planetarium	Chicago, Illinois	Evans & Sutherland	1999
Exploration Place	Wichita, Kansas	Evans & Sutherland	2000
	Shenzhen, China	Evans & Sutherland	2001
Madame Tussaud's	New York, NY	Evans & Sutherland	2000
	Montpellier, France	Evans & Sutherland	2001
Burke Baker Planetarium	Houston, Texas	Sky-Skan, Inc.	1999
LodeStar Planetarium	Albuquerque, NM	Sky-Skan, Inc.	2000
Carnegie Museum of Natural History's Earth Theater	Pittsburgh, PA	Sky-Skan, Inc.	2000
	Seville, Spain	Sky-Skan, Inc.	2001
GaiaSphere	Athens, Greece	Sky-Skan, Inc.	2001
	Lucerne, Switzerland	Sky-Skan, Inc.	2001
	Baton Rouge, LA	Sky-Skan, Inc.	2002
	Cleveland, Ohio	Sky-Skan, Inc.	2003
Smithsonian Air and Space	Washington DC	Sky-Skan, Inc.	2004
Minamimakimura Village Local Culture Exchange Center	Nagano, Japan	Goto Optical	1997
	Fujigawa, Japan	Goto Optical	open
	Matsue, Japan	Goto Optical	open
National Fusion Research Institute	Kyoto Prefecture, Japan	Goto Optical	2001
Northern Lights Centre	Watson Lake, Yukon	Spitz, Inc.	1997
Science City at Union Station	Kansas City, Missouri	Spitz, Inc.	2000
Orange Imaginarium	Bristol, UK	Spitz, Inc.	2000
Volkswagen Autostadt	Wolfsburg, Germany	Spitz/Furneaux Stewart/Seimens	2000
National Space Centre	Leicester, UK	Spitz, Inc.	2001
Bibliotheca Alexandria	Alexandria, Egypt	Spitz, Inc.	2001
Rauch Planetarium	Louisville, KY	Spitz, Inc.	2001
Samford University	Birmingham, AL	Spitz, Inc.	2001
Glasgow Science Centre	Glasgow, UK	Spitz, Inc.	2001
Volkswagen Gläserne Manufaktur	Dresden, Germany	Spitz/BRC	2001
ElectricHorizon Theater	Ketchikan, Alaska	Spitz, Inc.	2002
Clay Center for the Arts & Sciences	Charleston, WV	Spitz, Inc.	2002
Denver Museum of Nature and Science	Denver, Colorado	SGI/Zeiss/Schneider	2003
Griffith Planetarium	Los Angeles, CA	uncommitted	2004

* based on best available marketing information – no claims of accuracy are implied

adjacent projectors for seamless blending. The projectors must have precise geometric positioning to allow accurate image overlay in the edge-blend regions. And all projectors must be similarly color corrected to provide a true seamless effect. Current systems meet these difficult requirements with varying degrees of success using off-the-shelf projectors intended for flat-screen projection.

Computer graphics for spherical projection must be rendered onto a view sphere as opposed to the current view plane paradigm. Alternately, multiple flat plane renders can be stitched using 2D image-processing algorithms to from a complete view sphere. The resulting spherical images are brought together in post-production with live-action, titles, stock footage and other composited elements to build a complete edited program. The resulting spherical master frames must be split out into individual channels, spherically warped, properly masked for edge blending and stored on separate digital data recorder channels for synchronous playback.

Alternately, realtime computer graphics can provide multiple simultaneous rendering pipelines for full hemispheric display of high-resolution images to provide an immersive, fully interactive group experience. Show producers for such systems are challenged to effectively involve the audience in meaningful interaction [Chiwy 00], and must also pioneer new storytelling and show production techniques.

Artistic Challenges. Given an immersive audio/visual delivery system and the requisite production tools, the next challenge is to make good use of the medium. We are bombarded by cinema and television every day. It visually communicates with us though a language that has evolved over the past century. It's a language that many of us have been conditioned to receive and understand since birth. The language developed and is continuing to develop though the tireless efforts of hundreds of thousands of filmmakers and videographers striving to learn how to best exploit the frame for the purpose of telling the story that they want to tell.

The underlying technologies that power immersive theater are outgrowths of the same technology that power television and cinema. The artist's goal of communicating a story to the viewer has not changed. What has changed is that the frame has been taken away. The frame has always been part of the cinematographer's language. It has been used as a device to direct the viewer's attention, define a space, convey emotion, or even obscure something from the viewer's gaze [Shedd 97]. Now that the frame is gone, how do we do these things? Artists have to learn to adapt the language to this new medium. When we give up the frame, we gain the power to truly immerse our audience in the story space. The audience is no longer an outside observer viewing the action through a "window on the world". Now we can push the viewer right up to and through that window so that they can experience what they might actually experience if they were a passive, or in the case of real-time theaters, an active participant in the story.

Because immersive experiences fill the retina, such images excite the opto-vestibular response caused by optic flow across the retina [Lappe 99]. This can lead to an exciting experience or cybersickness, depending upon the person and the production. Immersing someone in a rapidly changing space can disorient him or her. As artists and storytellers, we have to develop an understanding of the power that we wield. New storytelling paradigms have to be invented to deal with the wide field of view, frameless images.

Conclusions. With large-scale immersive theaters we are seeing the birth of a new medium. Because the medium is spherical, it has an aesthetic lure that is difficult to describe. Because the medium is video graphics, it is less expensive and more accessible than film and thus more open to independent producers. Because the medium is digital, it is open to rapid or real-time display of electronic information. And because the medium is immersive, it touches us on a deeper level, both psychologically and physiologically. As we learn to fully utilize this powerful medium, as the related display and production technologies mature, and as our ability to rapidly generate increasingly complex images grows, we expect to see growing interest in this format and eventually, widespread use of immersive displays in education, leisure and home entertainment.

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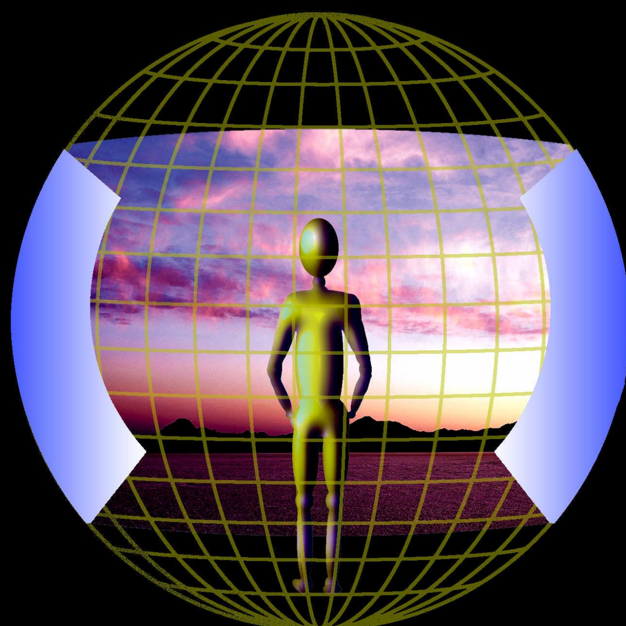
SIGGRAPH 2001
EXPLORE INTERACTION AND DIGITAL IMAGES

Computer Graphics for Large-Scale Immersive Theaters

Course #31



8:30 am - 5:00 pm

Course Organizer

Ed Lantz - Spitz, Inc.

Computer Graphics for Large-Scale Immersive Theaters

Presentors

- **Ed Lantz** - Spitz, Inc.
- **Ben Shedd** - Princeton University, Shedd Productions
- **Brad Thompson** - Spitz, Inc.
- **Carter Emmart** - American Museum of Natural History
- **Martin Ratcliffe** - Exploration Place

SIGGRAPH 2001 EXPLORE INTERACTION AND DIGITAL IMAGES

Syllabus - Course #31

a.m.	8:30	Introduction (Lantz)
	9:15	Principles of Immersive Imagery (Shedd)
	10:00	Break
	10:15	Spherical Image Gen. and Projection (Lantz)
	11:00	Immersive Rendering Basics I (Thompson)
p.m.	12:00	Lunch
	1:30	Immersive Rendering Basics II (Thompson)
	2:00	New York's Hayden Planetarium (Emmart)
	3:00	Break
	3:15	Boeing Cyber Dome (Ratcliffe)
	4:00	Immersive Rendering Demonstrations

Computer Graphics for Large-Scale Immersive Theaters

Introduction

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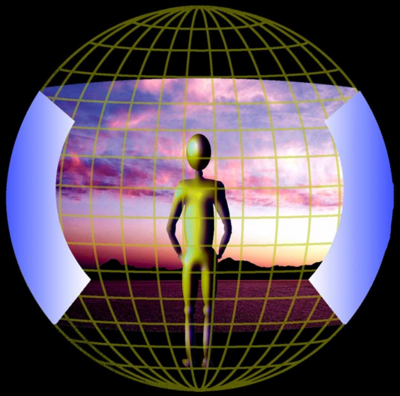
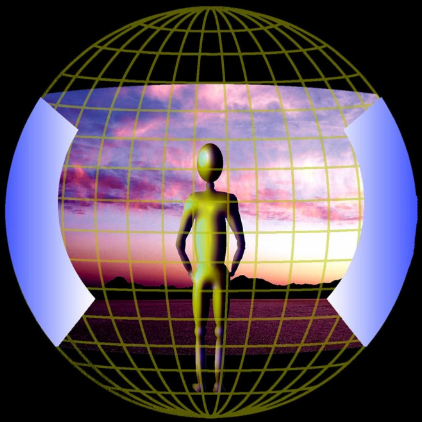


SIGGRAPH 2001
EXPLORE INTERACTION AND DIGITAL IMAGES

The Quest for Visual Immersion
A Brief History...

30,000 B.C.E.



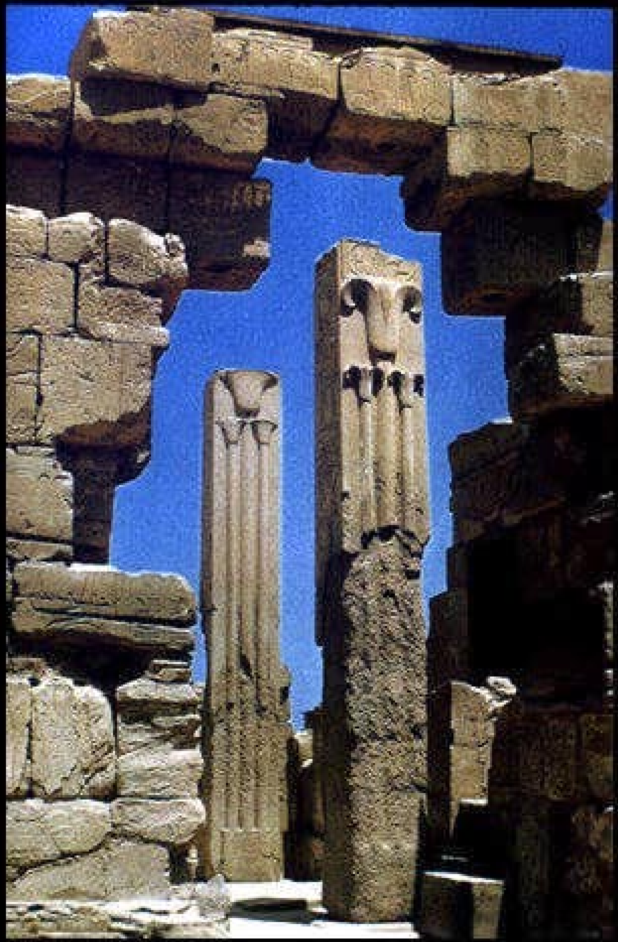
2001 A.D.

Visual Communication was used by prehistoric humans over 30,0000 years ago as evidenced by cave paintings Chauvet, Verona and others…

These caves were immersive environments…

…Were they perhaps prehistoric "cathedrals" designed to invoke a sense of awe?

Ancient Architects created Massive Immersive Environments...



Temple of Amon, Egypt
1500 B.C.

Photos Courtesy Prof. Hugh Lester, Tulane University

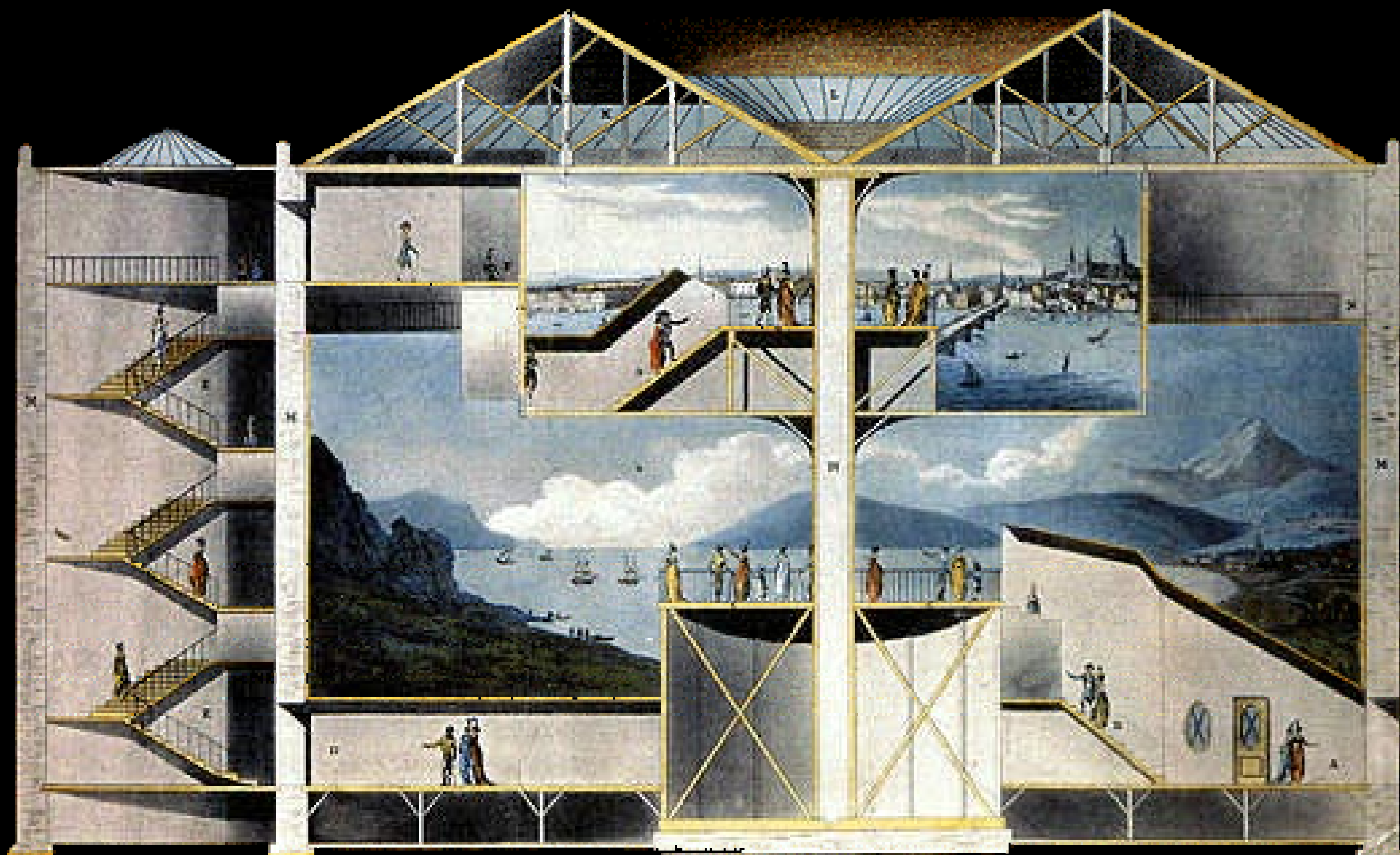
Renaissance Artists Created Ornate Immersive Spaces in the 16th Century…

Sistine Chapel

St. Peter's Cathedral

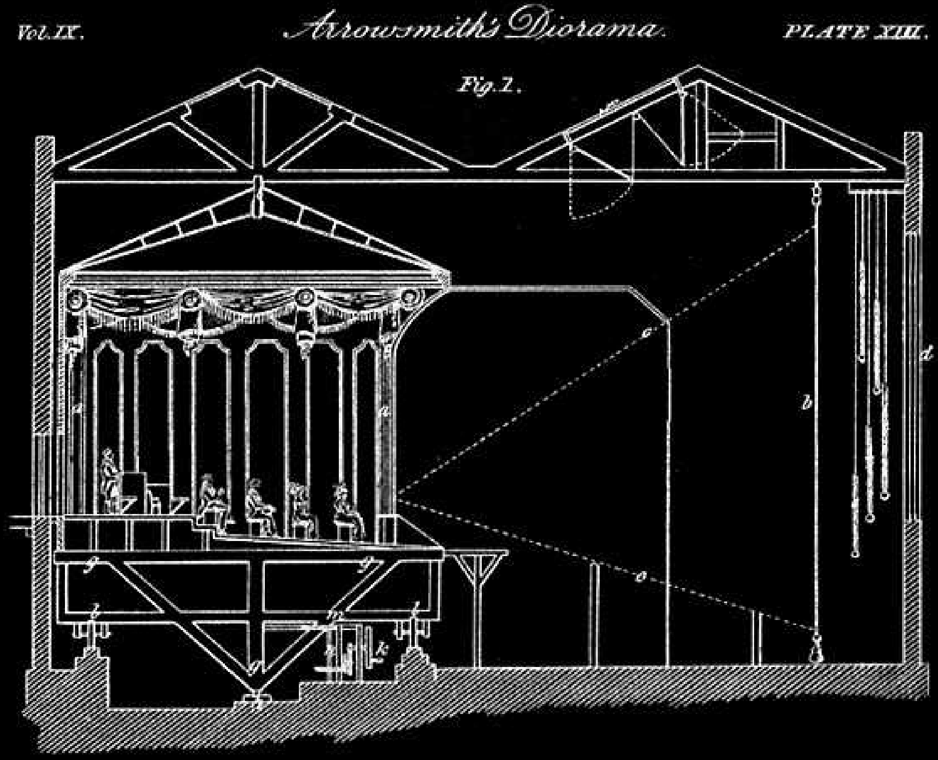
Photos Courtesy Prof. Hugh Lester, Tulane University

Scottish Painter Robert Barker Exhibited 18 m Diameter Panoramic Paintings in Edinburgh in 1788. Larger Panoramas followed...



Robert Mitchell, *Barkers Panorama at Leicester Square*, courtesy The British Museum, London

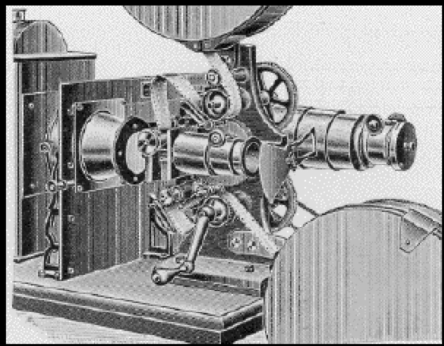
Daguerreand OthersCreated Diorama Theaters Using Large Paintings in the Early 19th Century…

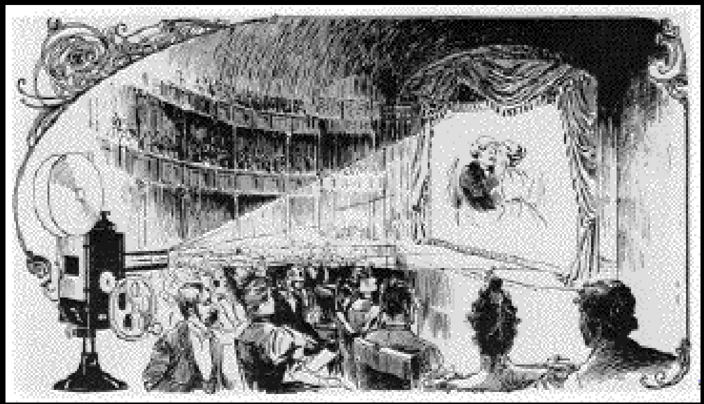


Arrowsmith's Diorama Patent

L. J. M. Daguerre, 1826

Early 20th Century..Film Emerges as Powerful, Dynamic Storytelling Medium





Lumière Cinématographe et. al 1895

Images Courtesy Stephen Herbert, PROJECTION BOX : http://easyweb.easynet.co.uk/~s-herbert/ProjectionBox.htm

Film Evolves into Widescreen and more Immersive Formats...

1897 Raoul Brimion-Sanson's "Cineorama" - France

10 Projectors on 30m Diameter Screen...

1939 Fred Waller's "Cinerama" - NY World's Fair

11 Synchronized Projectors - reduced to 3 in 1952

1953 20th Century Fox's Cinemascope

2.35:1 Anamorphic with Surround Sound

1955 Mike Todd's Todd-AO

5-perf, 70mm, 30fps format

1970 Imax Corp's IMAX

15-perf 70-mm horizontal film format

See MEGASYSTEMS Large Format Film History - www.870.com/lfhis.htm

American Widescreen Museum http://www.widescreenmuseum.com/widescreen/intro.htm

Immersive Spherical Formats Also Evolve…

1926 Carl Zeiss's "Model 1" Planetarium - Munich
World's first modern planetarium

1946 Armand Spitz's "Model A" Planetarium - Philadelphia
Planetaria for the Masses

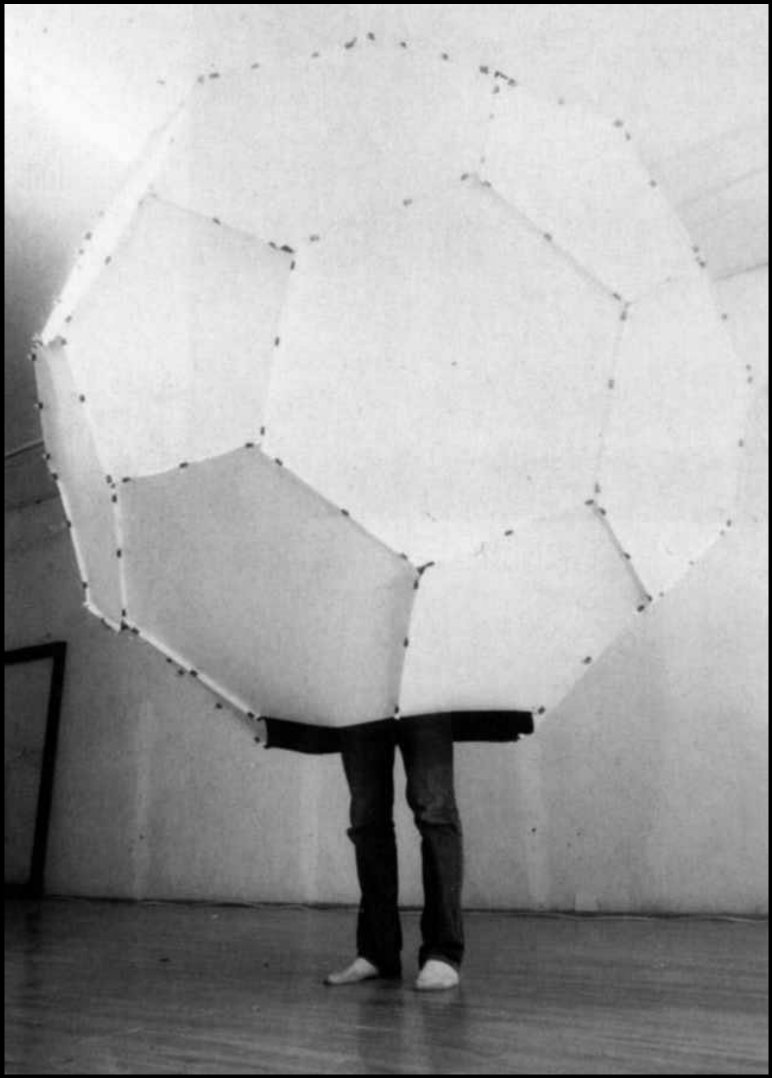
1962 World's Fair introduces "Spacarium" - Seattle, WA
35mm fisheye cinema

1972 Imax's IMAX Dome (Omnimax) - San Diego
5-perf, 70mm, 30fps format

1983 Evan's & Sutherland's Digistar
Hemispheric vector graphics video projector

…Culminating in the Ultimate Immersive Experience...

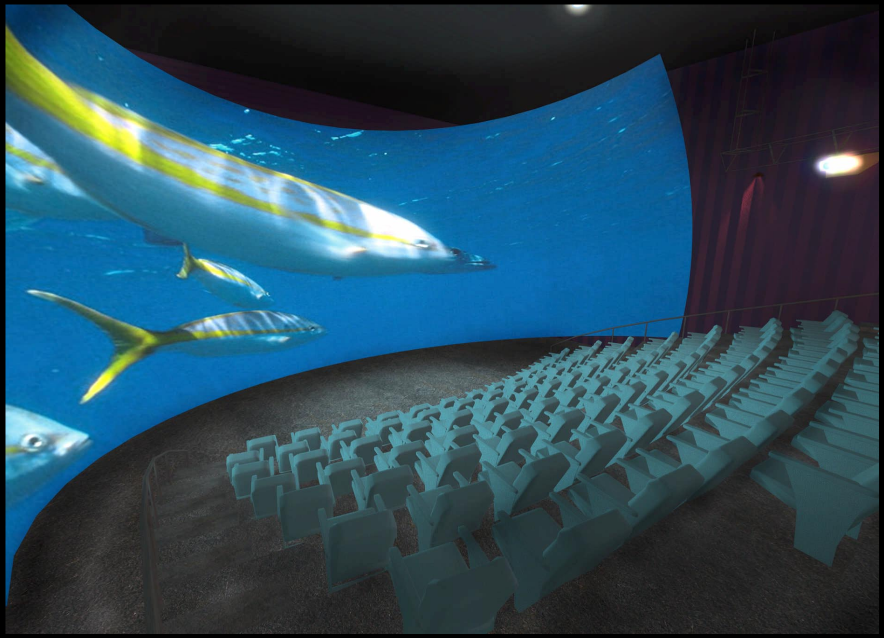
Spherorama



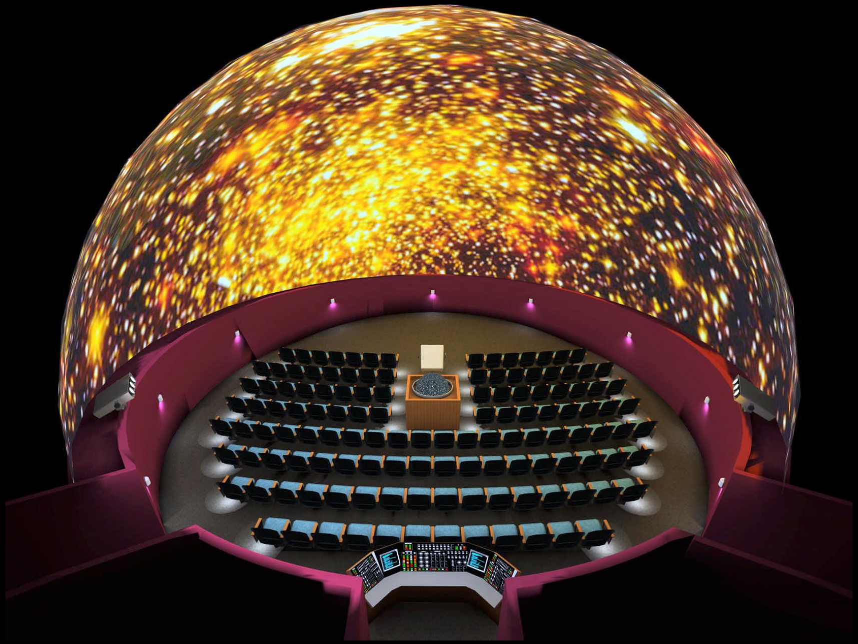
Courtesy Michael Miranda, *Spherorama*, 1991

Truncated icosahedron with B&W photographic prints from custom pinhole camera...

Large Scale Immersive Theaters



Partial Dome Theater



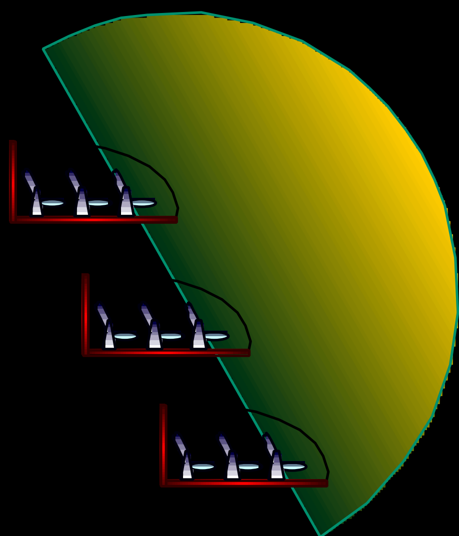
Full Dome Theater

Visual Immersion

Walk-In Immersive Display - Visual Display with Simultaneous High Resolution and Wide Field-of- View

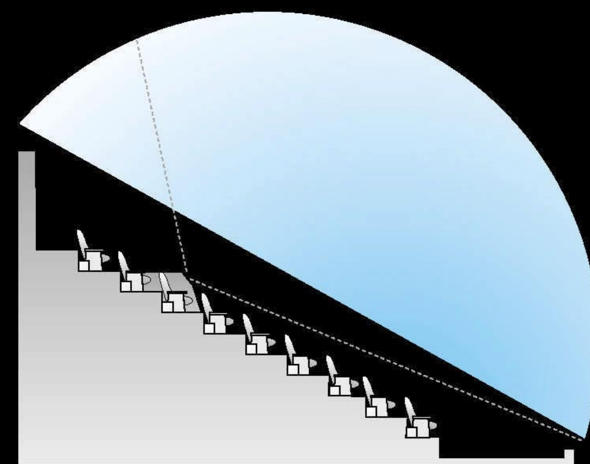
- Creates a Sense of Presence within a Virtual Environment
- Invokes Opto-Vestibular Response in Brain
  - Thrill-ride or cybersickness possible
- Horizontal FOV >140°, Vertical FOV >40°

Large Scale Immersive Theaters

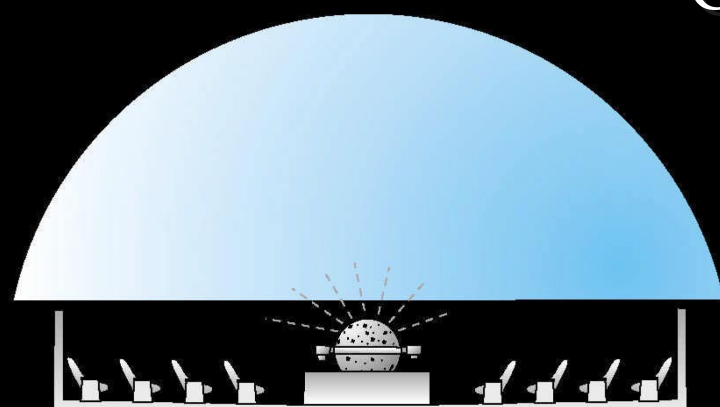


Simulator Rides

Primary Applications

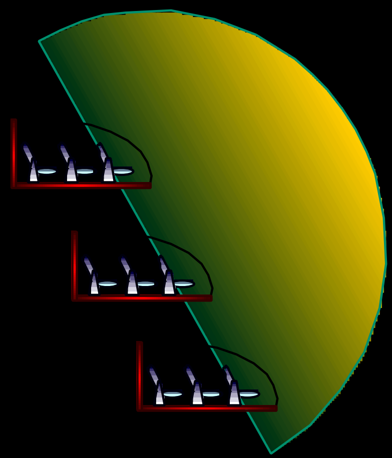


Omni Large-Format Film Theatres



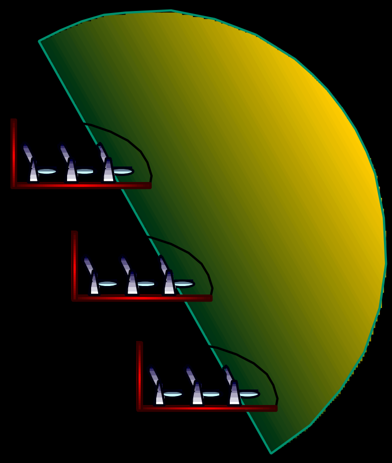
Planetaria

Simulator Rides



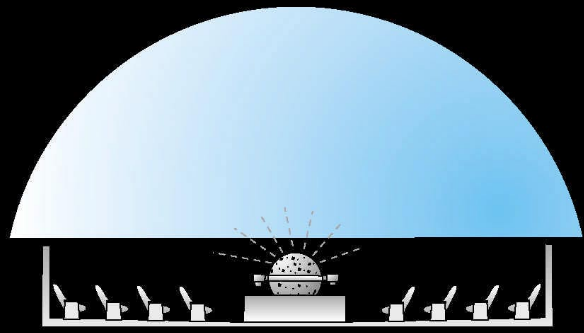
- Partial and Full-Dome Systems
- Specialty Film for Maximum Realism
  - Large-format film
  - High frame rates
  - 3D Stereoscopic Systems
- Motion Platform
- Spatial Sound
- Multi-Sensory Effects
  - Wind, rain, snow, fog, vibration

Simulator Rides



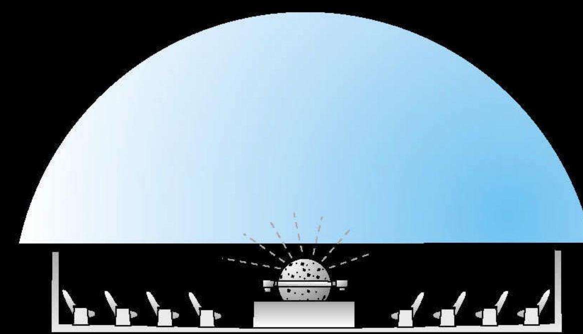
- Applications
  - Theme parks & LBE
  - Museums, science centers
  - Micro-attractions, arcades
- Example Installations
  - Race for Atlantis - Caesars, Las Vegas
  - Star Trek the Experience - Hilton, Las Vegas
  - Back to the Future - Universal Studios
  - California Dreaming - Disneyland

Planetaria



- Hemispheric Projection Screen
- Starfield Projector
  - High-resolution astronomical simulation
- Hemispheric Slide Projection
- Narrow Field Video
- Laser Graphics
- Combination Large-Format Film, Planetarium
- Total Annual Attendance Worldwide: 87,400,000

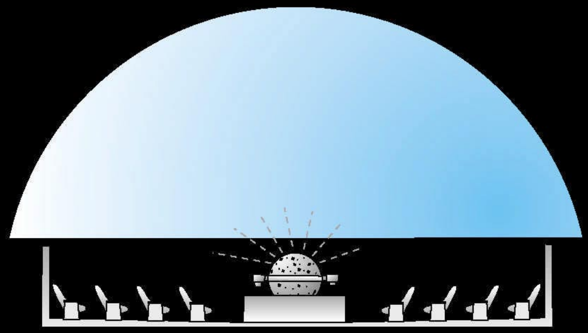
Planetarium Facts*



Planetarium Classification	Worldwide # of Theaters	% of Total
School/District	999	36%
University/College	397	14%
Museum/Science Center	375	14%
Observatory/Other	201	7%
Unclassified	782	28%
TOTAL	2754	

* Courtesy The LNP Planetarium Compendium, Loch Ness Productions, 2000

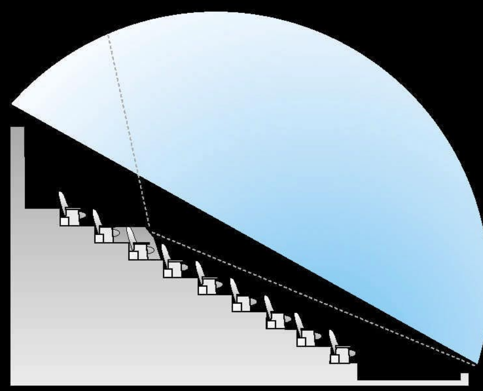
Planetarium Facts*



Dome Size (m)	# of Theaters	# Tilted Domes
3 - 6	766	2
6 - 9	696	3
9 - 12	463	9
12 - 15	191	23
15 - 18	98	17
18 - 21	102	34
21 - 27	80	40
Portable	774	

* Courtesy The LNP Planetarium Compendium, Loch Ness Productions, 2000

Omni Film Theaters



- Hemispheric Projection Screen
  - Tilted 30° typically
- Large-Format Film
  - 15-perf, 70mm (original IMAX® format)
  - 8-perf, 70mm
- Dome Diameters from 15m to 28m+
- 254 LF Theaters Worldwide - Half are Domes*
- 175 Large-Format Films Released*

* From White Oak Associates, Inc. Inventory of Large Format Theaters, 1998 edition

Large Scale "Digital Dome" Theaters

- Full Dome or Partial Dome Video Projection
- Multiple Edge-Blended Projectors
- 26 Existing/Planned Theaters by 5 Manufacturers
- Most Use Pre-Rendered, Pre-Recorded Shows
  - Digital video server technologies
  - Hi-resolution systems emerging
- Several Theaters Pioneering Realtime Interactivity
- Most are Planetaria - Others Include Corporate Theaters, Visitor Centers, and Theme Parks

Digital Dome Manufacturers

- Evans & Sutherland - Salt Lake City, UT
- GOTO Optical - Japan
- Spitz, Inc. - Chadds Ford, PA
- Sky-Skan - Nashua, NH
- Trimension, Inc. - Burgess Hill, UK

Digital planetarium system also announced by:

- Silicon Graphics/Zeiss/Schneider

Digital Dome Theaters...

- AMNH/Hayden Planetarium - New York City
- Bibliotheca Alexandria - Alexandria, Egypt
- Burke Baker Planetarium - Houston, Texas
- Exploration Place - Wichita, Kansas
- National Space Centre - Leicester, UK
- LodeStar Planetarium - Albuquerque, NM
- Madame Tussaud's - New York City
- Northern Lights Centre - Watson Lake, Yukon
- Volkswagen's Autostadt - Wolfsburg, Germany

Compelling Spherical Icons...

Volkswagen Autostadt
Wolfsburg, Germany

Bibliotheca Alexandria
Alexandria, Egypt

Powerful Immersive Environments…

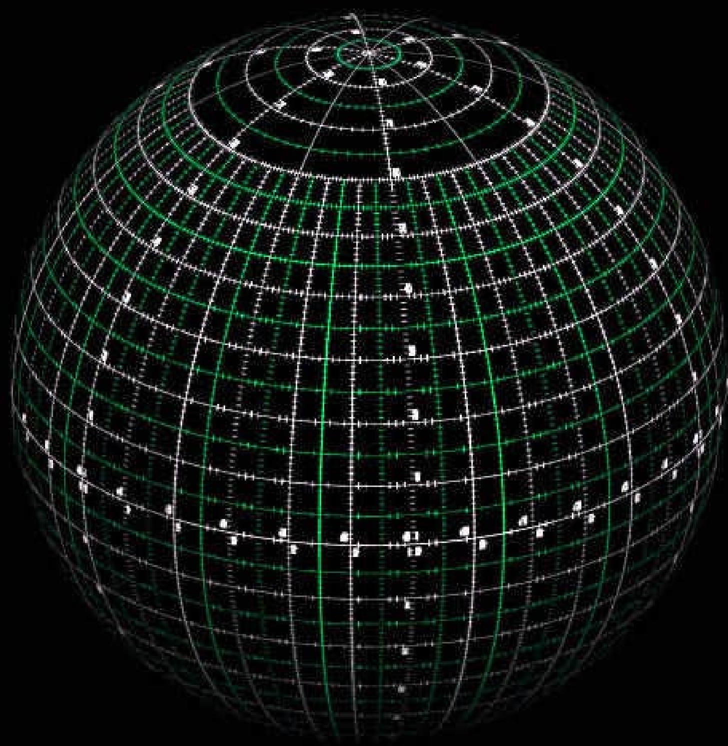
LodeStar Planetarium
Albuquerque, NM

Volkswagen Autostadt
Wolfsburg, Germany

Engaging Content...

The Birth of a New Medium...

Immersing the World



Special Thanks to:

Spitz, Inc.

Evans & Sutherland

National Space Centre, Leicester, UK

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Computer Graphics for Large-Scale Immersive Theaters

Principles of Immersive Imagery

Ben Shedd

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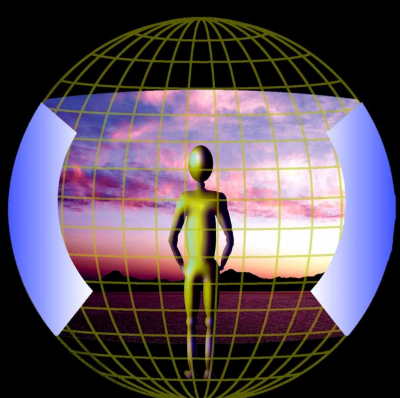

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Immersion: What's different?

We - the audience - are inside the images in immersive theaters.

Immersion: What’s different?

The immersive image is viewed without a frame. It’s frameless.

The immersion experience is on the audience's side of screen, not up on the screen.

- Immersive images mean we can move our head, which gives us place feedback.
- We need to provide ways to focus and point attention, and we need to plan when the focus is being left open.

Dome screen - planetarium seating

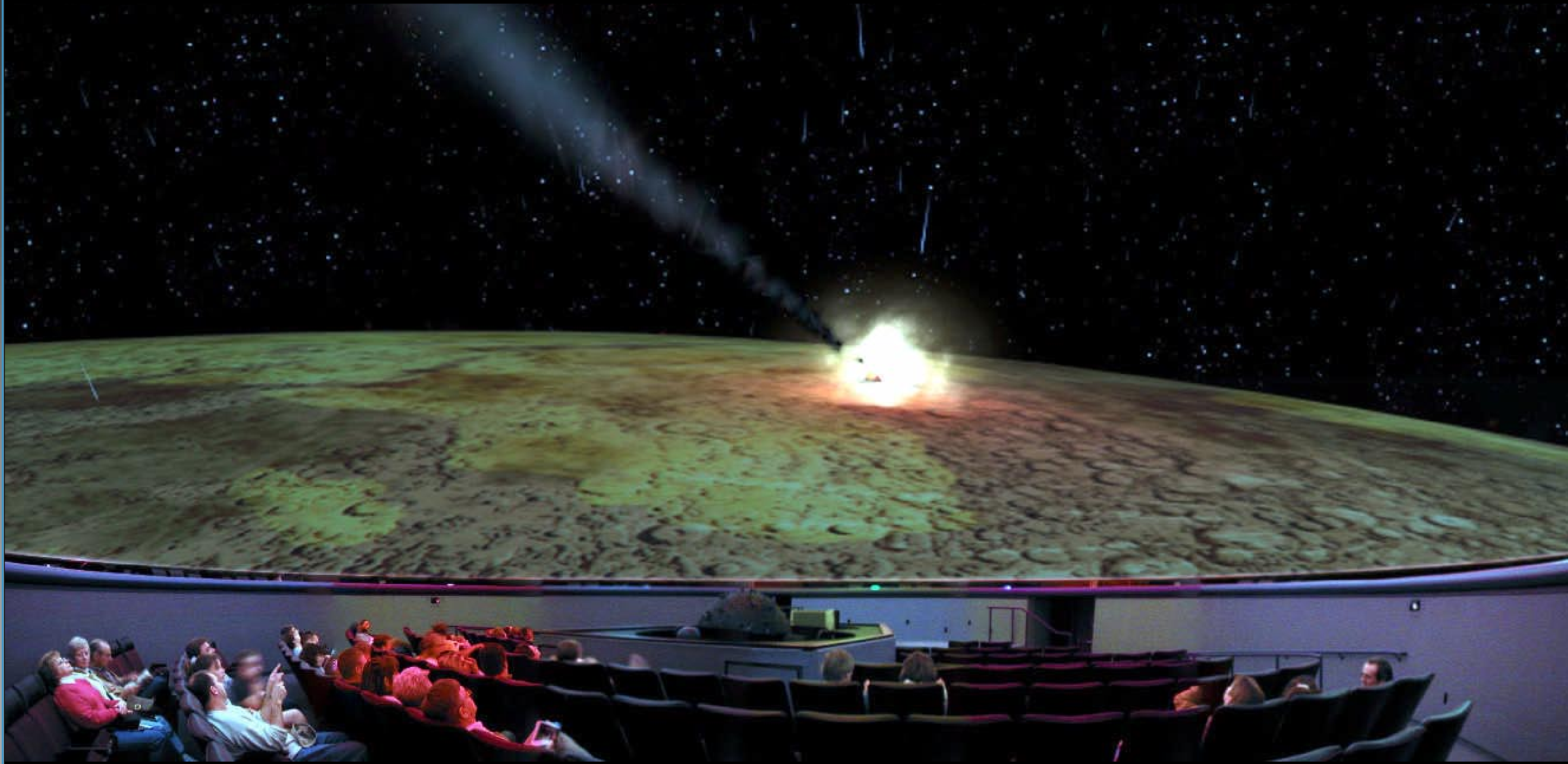

Image Courtesy: Spitz, Inc

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Dome screen - stadium seating

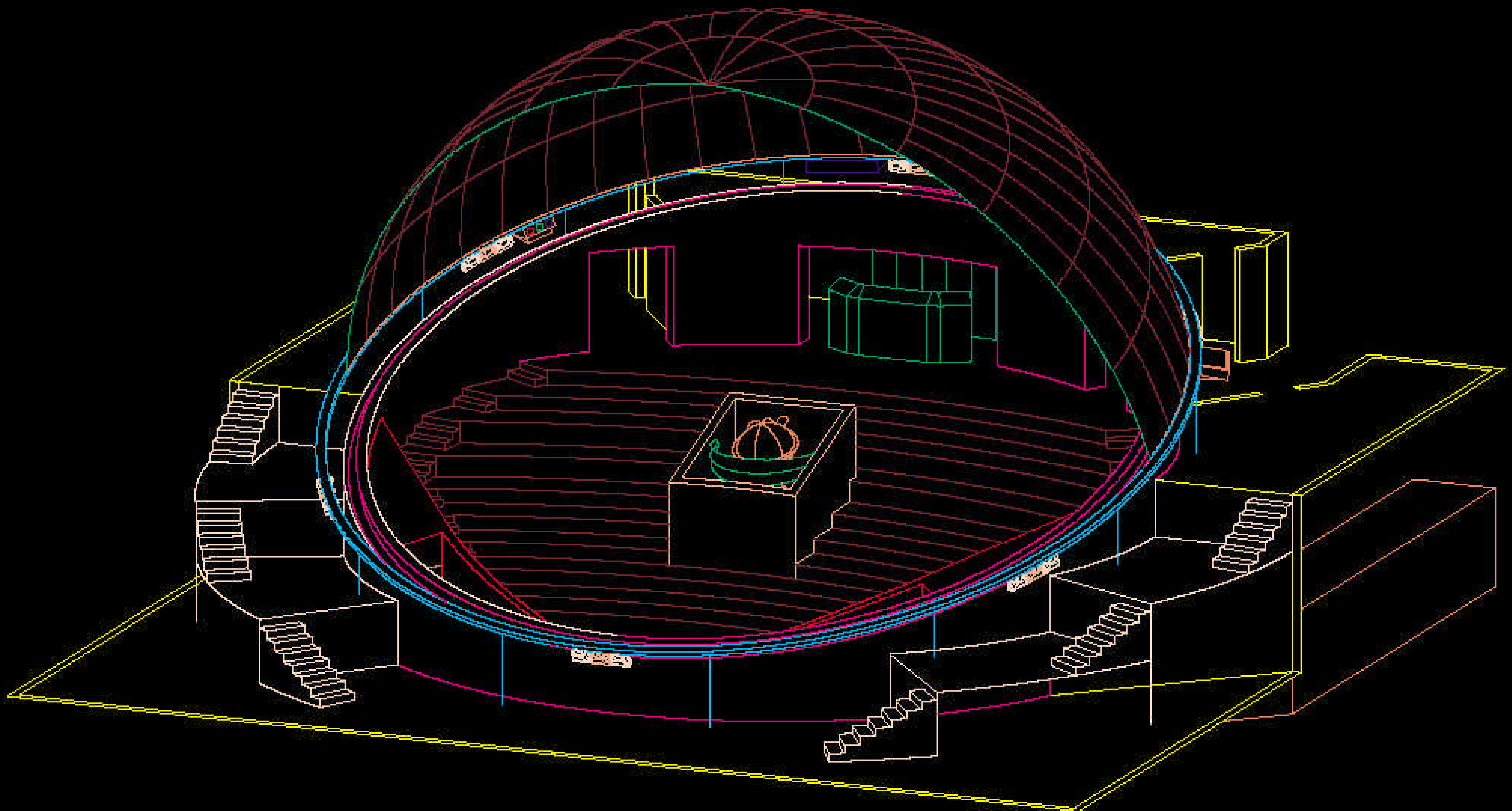

Image Courtesy: Spitz, Inc

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Inside the image….
Immersive productions are frameless!

My experience discovering Framelessness.

- Making a dome film… and discovering the difference…
- Thinking about the current visual language based on the frame.
- Rethinking the immersive visual space.

The audience's view in immersion is first-person experience, not a second-hand event.

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Looking back to look forward.

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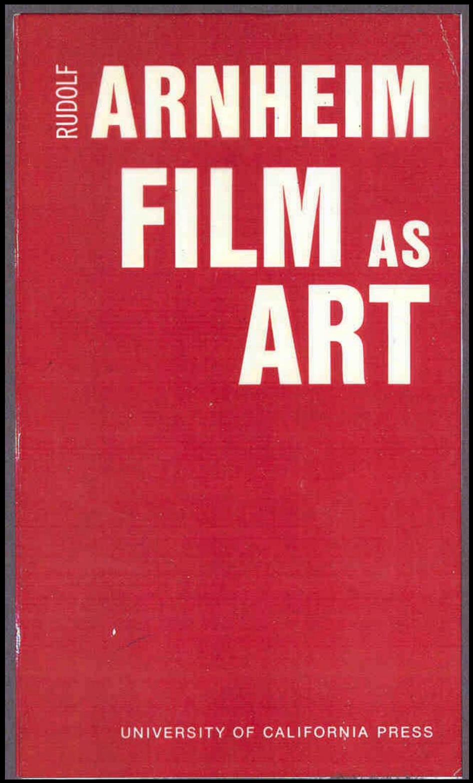
Film As Art

by Rudolf Arnheim

University of California Press



First published in the 1930's

Ben Shedd
Principles of Immersive Design

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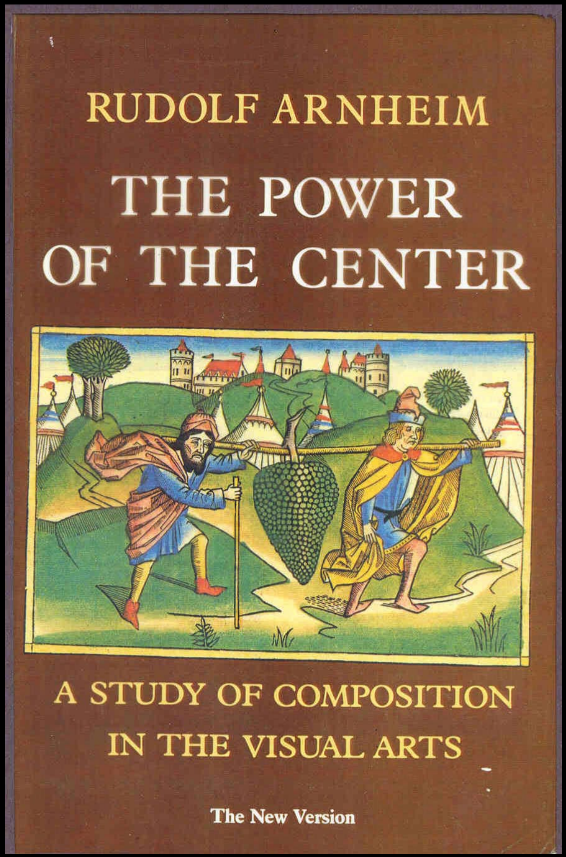
The Power of the Center

A Study of Composition in the Visual Arts

by Rudolf Arnheim

University of California Press



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The frame of an image has been a key design element throughout history.

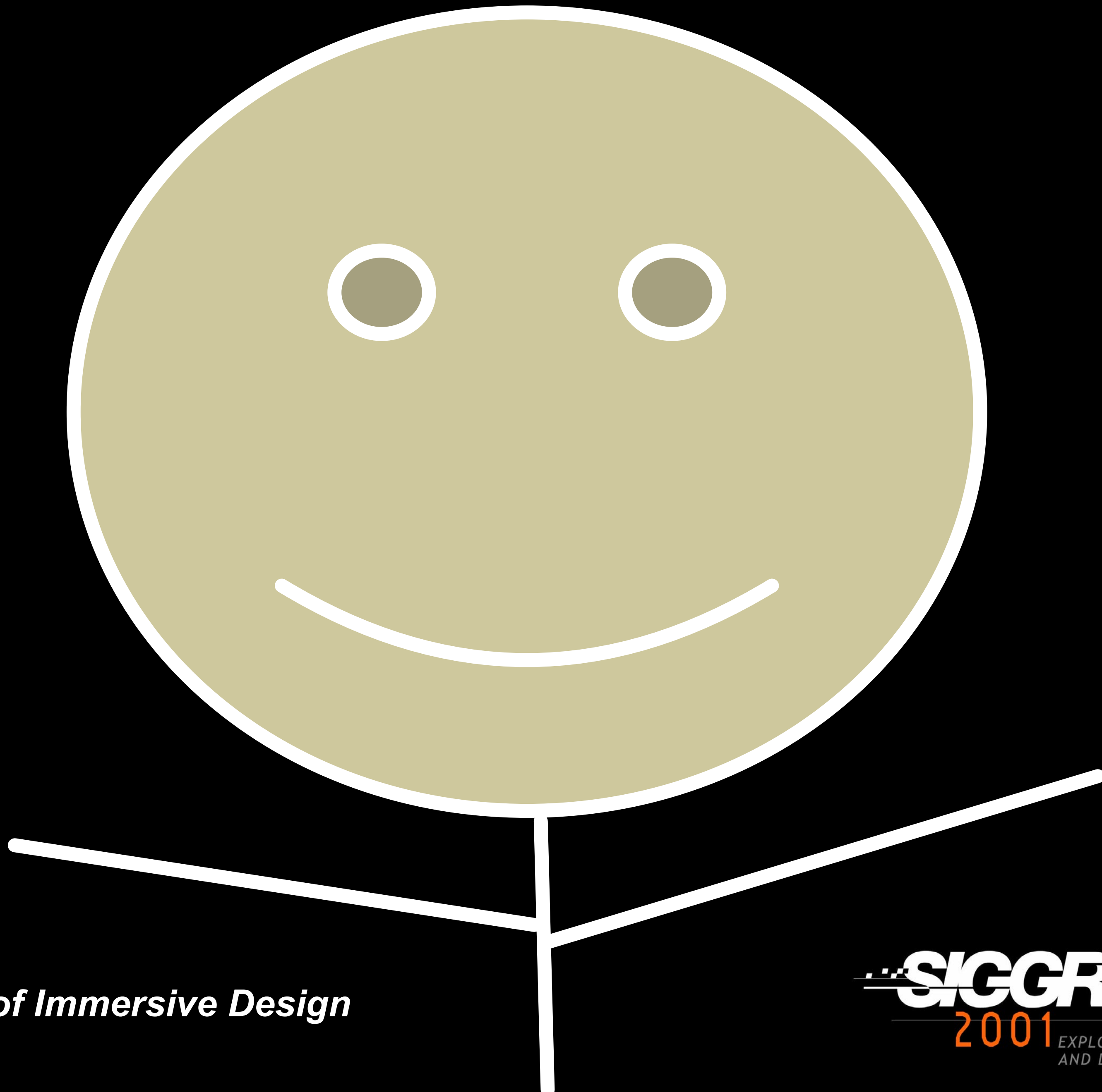
Everywhere we look, we see framed images, without seeing the frame.

- **Reference: Rudolf Arnheim, *The Power of The Center* -** University of California Press 1988

Exploding the Frame

Images in frames are so common that we don’t notice the frame nor how key it is to the composition nor the amount of the image which we are creating in our imagination.

Here’s a very familiar example …..



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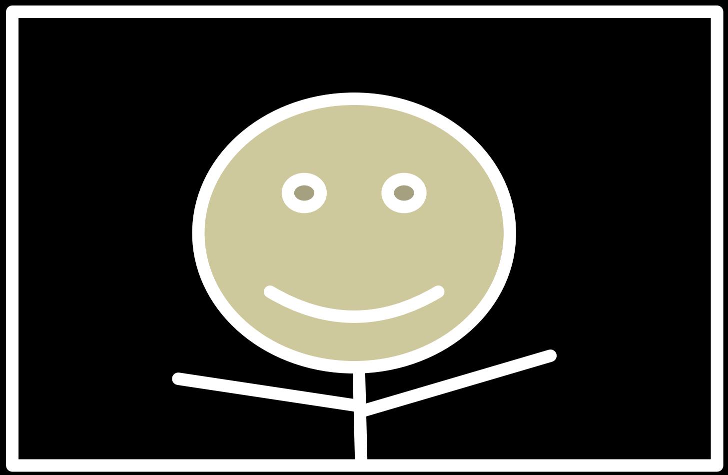

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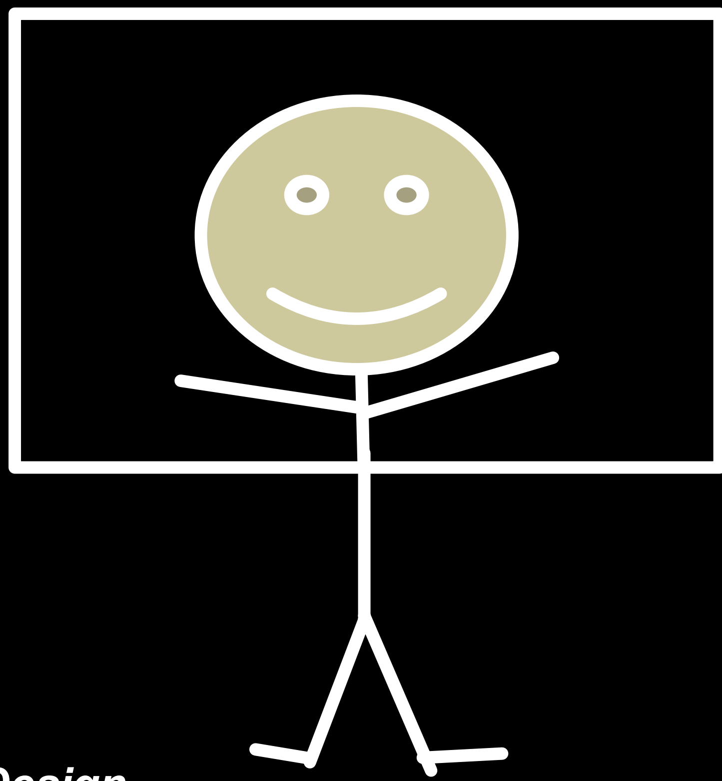

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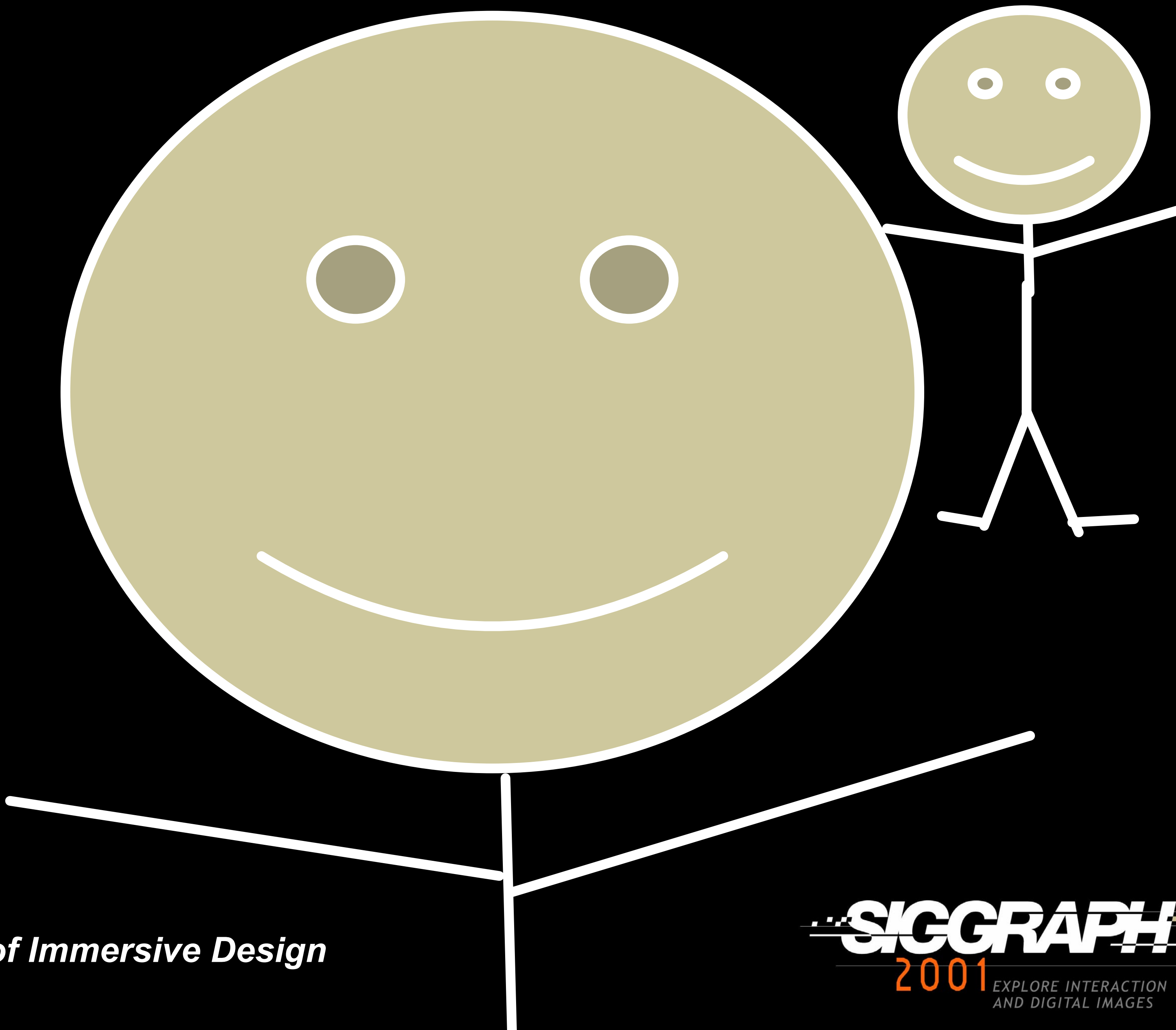

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EXPLORE INTERACTION AND DIGITAL IMAGES

Size matters.
SIZE MATTERS!

- No Frame on images means no frame of reference for scale.
- With no frame, the audience is “growing and shrinking” in relation to the images in the immersive experience.

Dome screen tarium seating

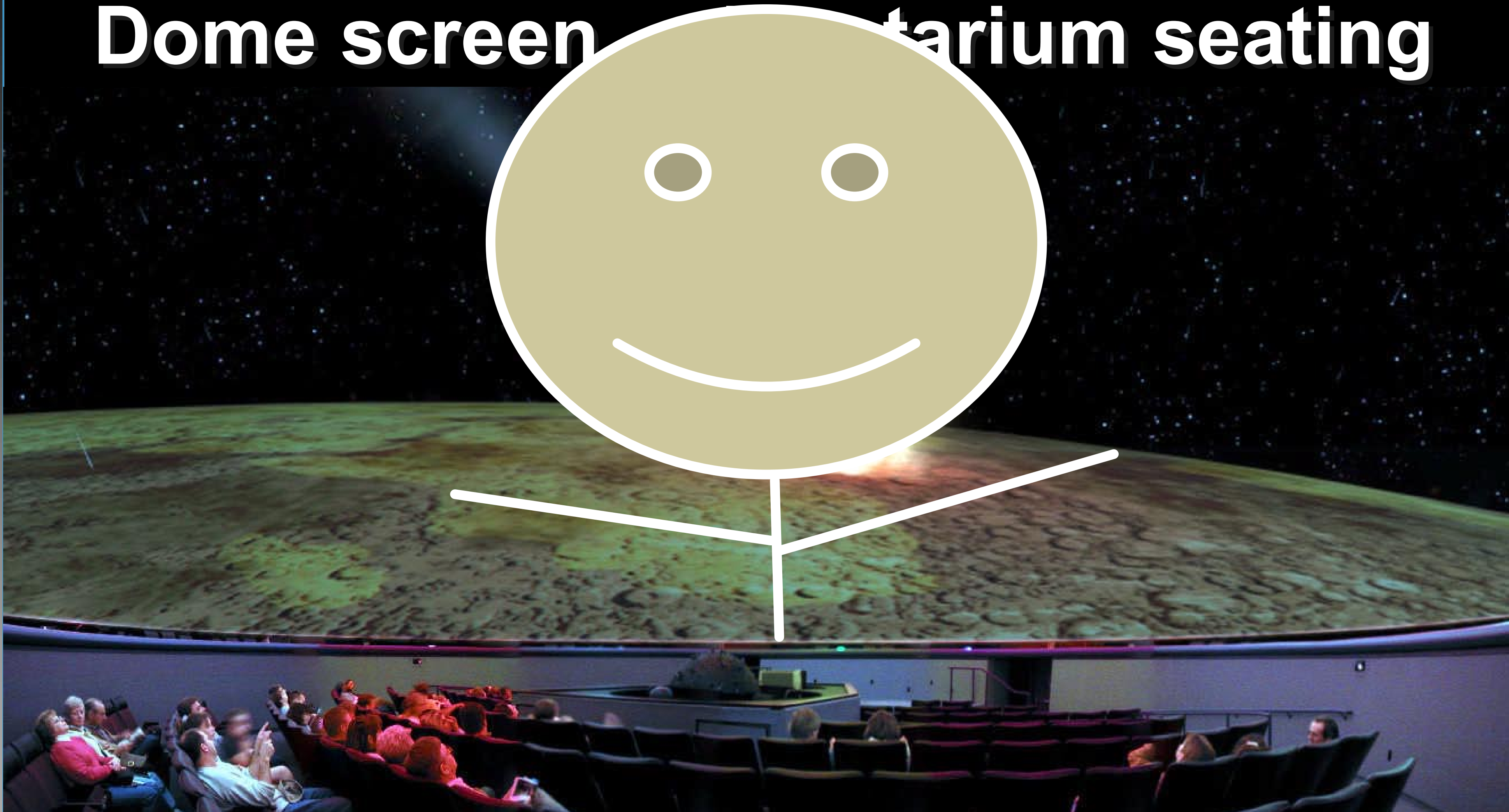


Image Courtesy: Spitz, Inc

Immersion: What's different?

The immersive image is viewed without a frame. It's frameless.

This image has a frame.

In fact, it has two frames.

Immersion: What's different?

The immersive image is viewed without a frame. It's frameless.

This image has a frame.

In fact, it has two frames.

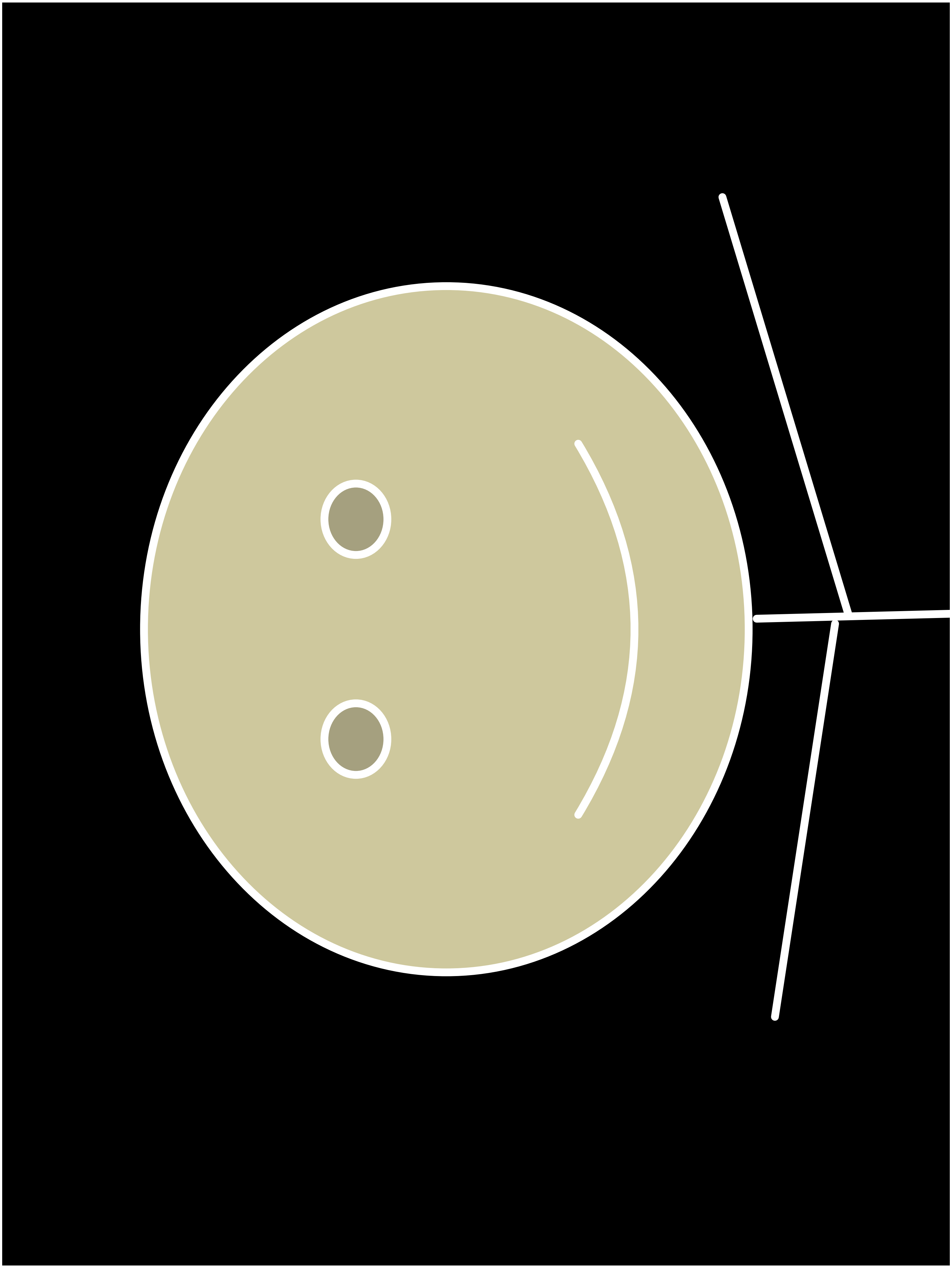
Immersion: What's different?

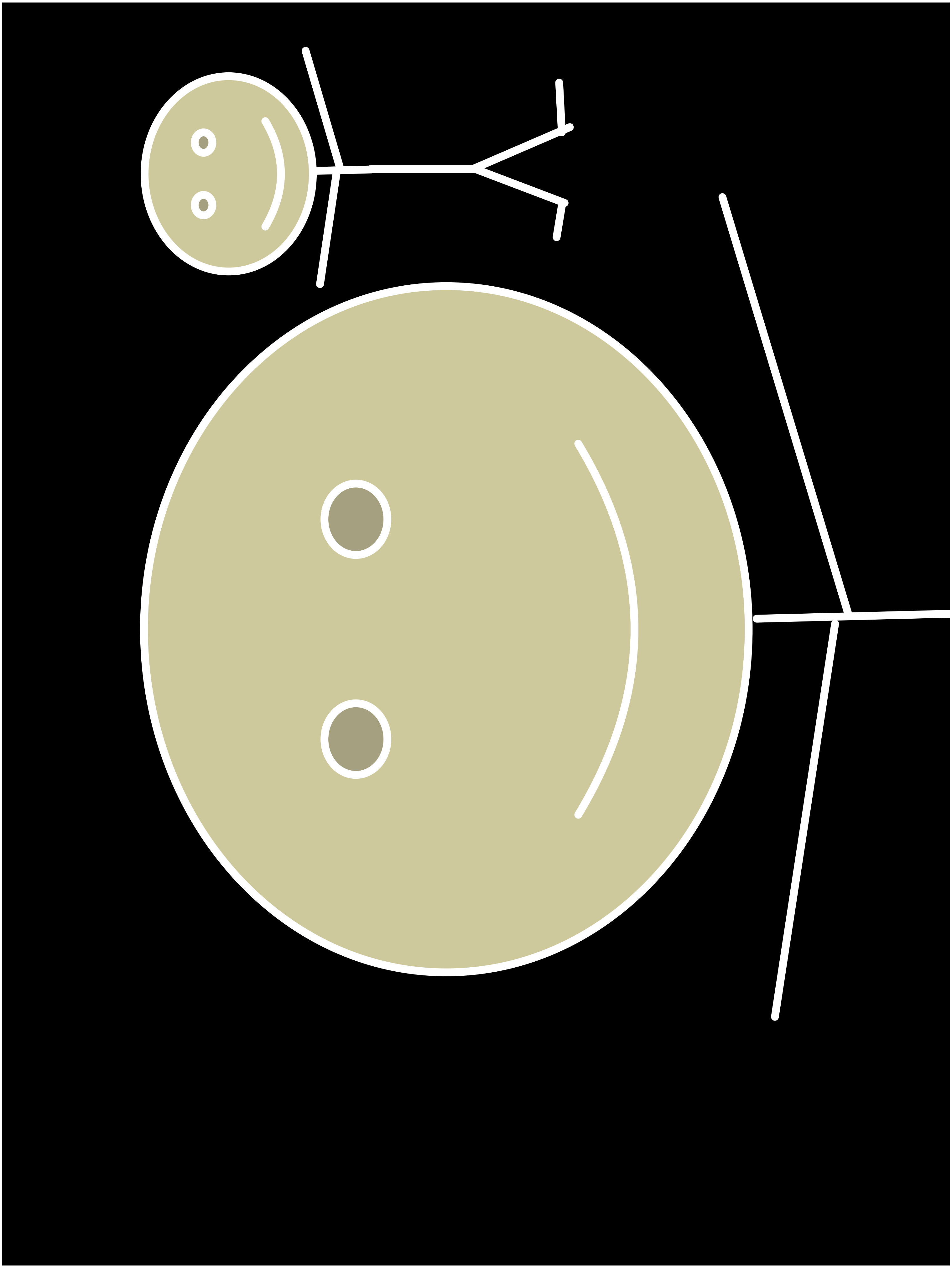
The immersive image is viewed without a frame. It's frameless.

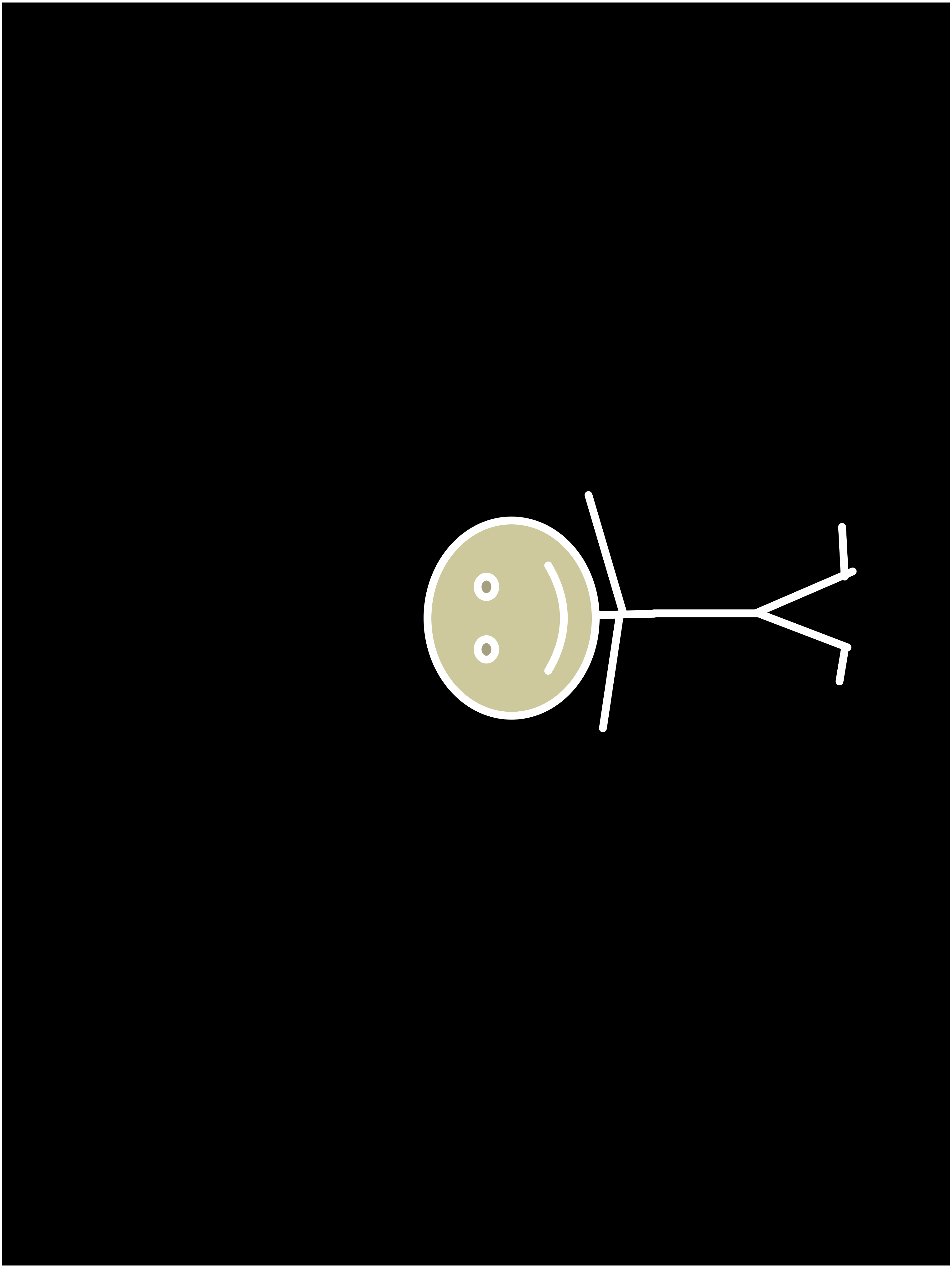
This image has a frame.

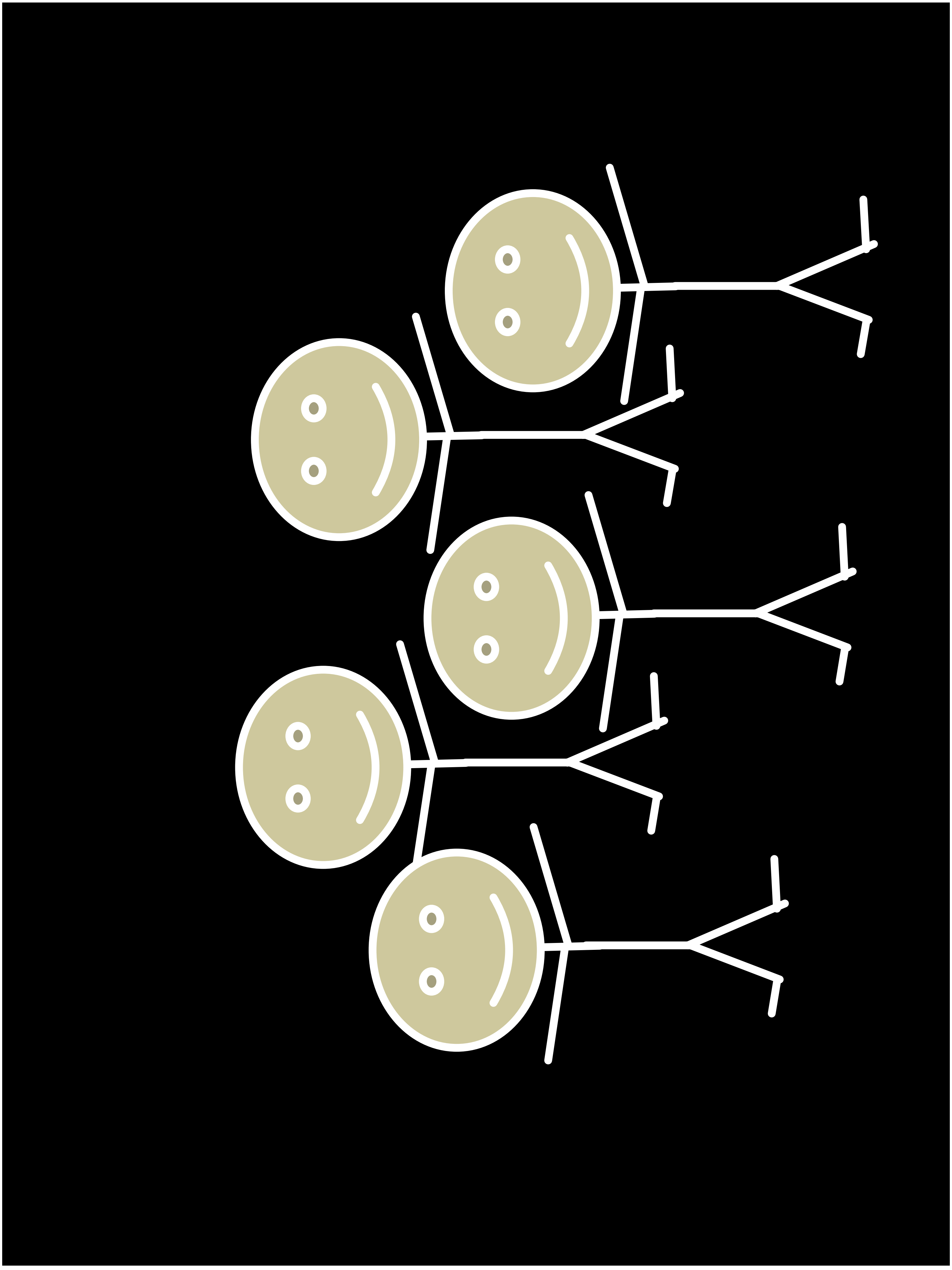
In fact, it has two frames.

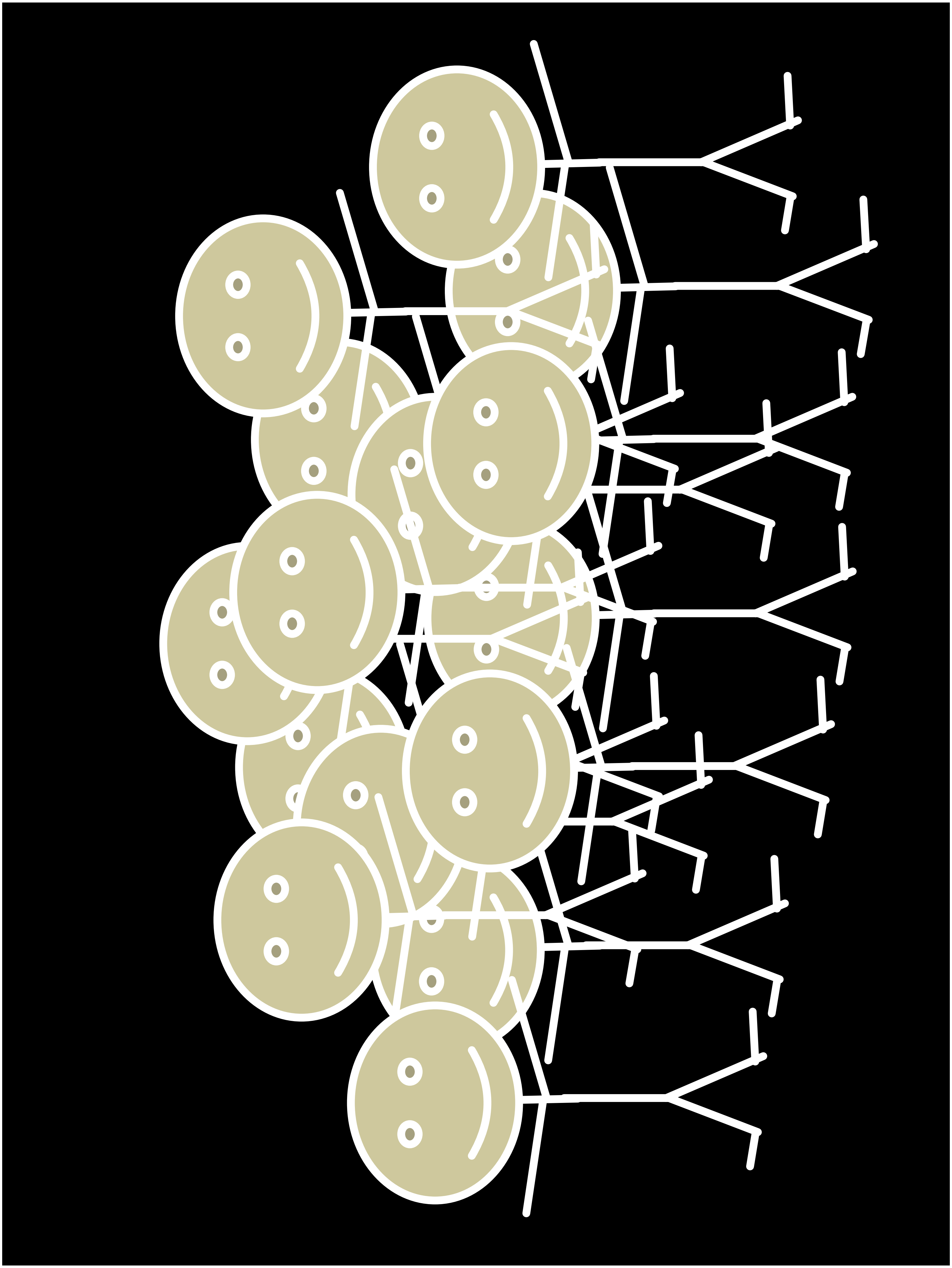
Now it only has the projector frame frame.











[redacted]

Ben Shedd
Principles of Immersive Design

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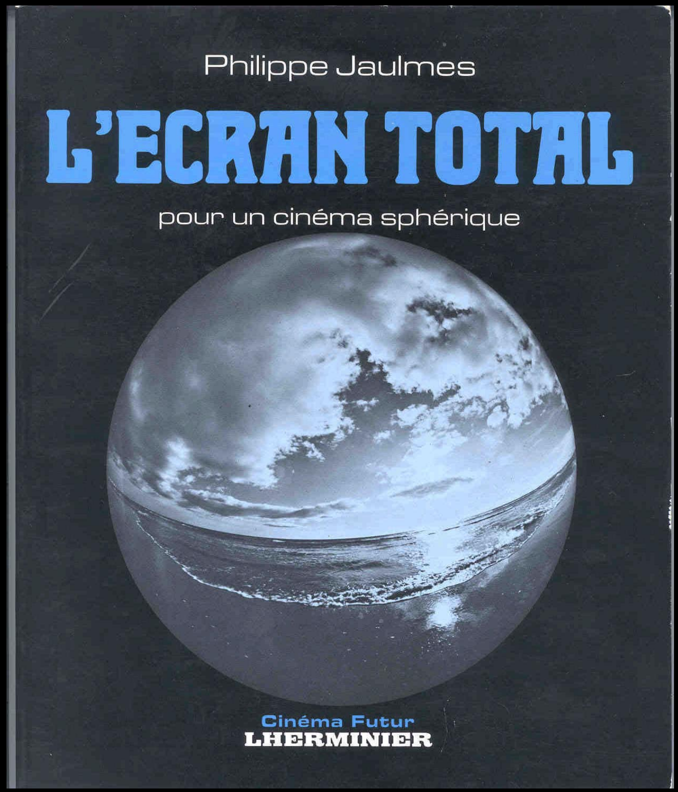
L'ECRAN TOTAL

pour un cinéma sphérique

by Philippe Jaulmes

Cinema Futur



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Immersion/Framelessness: What are the implications?

“You are there”

“It is here”

“We are together”

Concepts from:
At the Heart of the Matter: The Study of Presence
by Matthew Lombard and Theresa Ditton

Immersion/Framelessness: What are the implications?

"We are moving"

"We are growing and shrinking"

"We are the main character in the story"

Concepts from:
Exploding The Frame
by Ben Shedd

Immersion:
A TOOLBOX FOR EFFECTIVE PRODUCTION

Ben Shedd
Principles of Immersive Design

SIGGRAPH 2001
EXPLORE INTERACTION AND DIGITAL IMAGES

The audience has no clue of the projection technology.

Many immersive projection systems are multi-projector, tiled systems.

- **The audience will not understand unintentional frames projected within the immersive space.**
- **Reference: Rudolf Arnheim, *Motion - 1934, Film As Art*.** University of California Press 1957

Most all of the production tools have frames.

The common working tools:

- The storyboard images have frames.
- The cameras have frames.
- The desktop computer design and editing machines have frames.

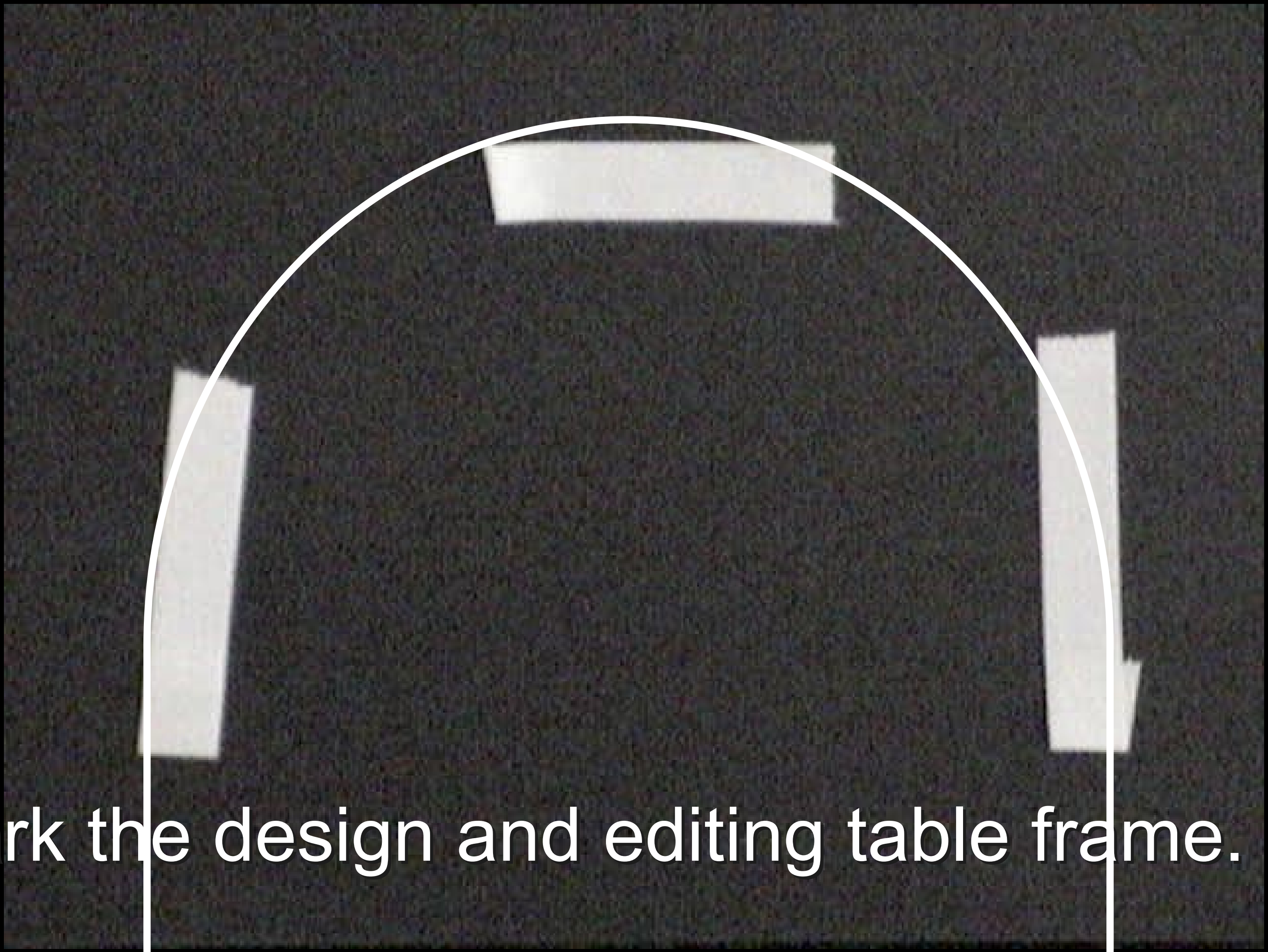
The Audience is immersed inside the image and inside the frame.

The challenge: All the production tools show images inside a frame, 180° opposite to how the audience will experience the immersion events.

- Make or find a fisheye viewfinder.
- Mark the design and editing table frame.

The Audience is immersed inside the image and inside the frame.

- Make or find a fisheye viewfinder.



- Mark the design and editing table frame.

The Audience is immersed inside the image and inside the frame.

The challenge - part 2: All of us are habituated to seeing images inside frames. Expert production crews are experts at *using* frames.

- How to explode the creative parameters for the crew? How to immerse the crew?
- Get in the theater as often as possible.

The Audience is moving.

The challenge: With no frame, any image movement is perceived as audience movement in the opposite direction.

- Track start and stop movements in a shot.
- Track the sense of movement from shot to shot. How does the audience move?

The Audience is growing and shrinking.

The challenge: With no frame of reference, the sensation of size change is a direct experience for the audience.

- Pace for this cognitive sensation.
- Design the action as events on the audience's side of the screen.

The Audience is directly experiencing the scale of things.

The challenge: With no frame, any image is perceived as a one to one experience.

- Track the scale of objects within an image.
- Track the scale represented from image to image. How does the audience track it?

Movement needs continuity.

It is a first person experience for the audience.

- The audience seems to be moving.
- The theater seems to be moving.
- Movement within images must tie together as they are strung together.

Scale needs continuity.

It is a first person experience for the audience.

- The audience seems to be growing and shrinking.
- Scale within images and between images must tie together as they play out.

The images appear on a curved screen.

The challenge: You can't get around the fact that the screen surface is curved and the image is annealed onto that surface.

- Optimize in circular patterns from center.
- Optimize for majority of seats. How does the audience track it?

Photo depth of field sharpness decreases with increase in image size.

The challenge: For photographic images, the amount of apparent focus in the depth of field is inversely proportional to the size of the screen.

- Use lens charts to determine fine focus.
- See the image projected on the full screen.

Continuity provided by music and sound.

The challenge: Music written to frameless images can be very amusical.

- The sound is not 50%/50% with picture, but the whole is an 100% experience.
- Musical patterns can provide wonderful anticipation and release. Edit to music.

Write final narration to the pictures.

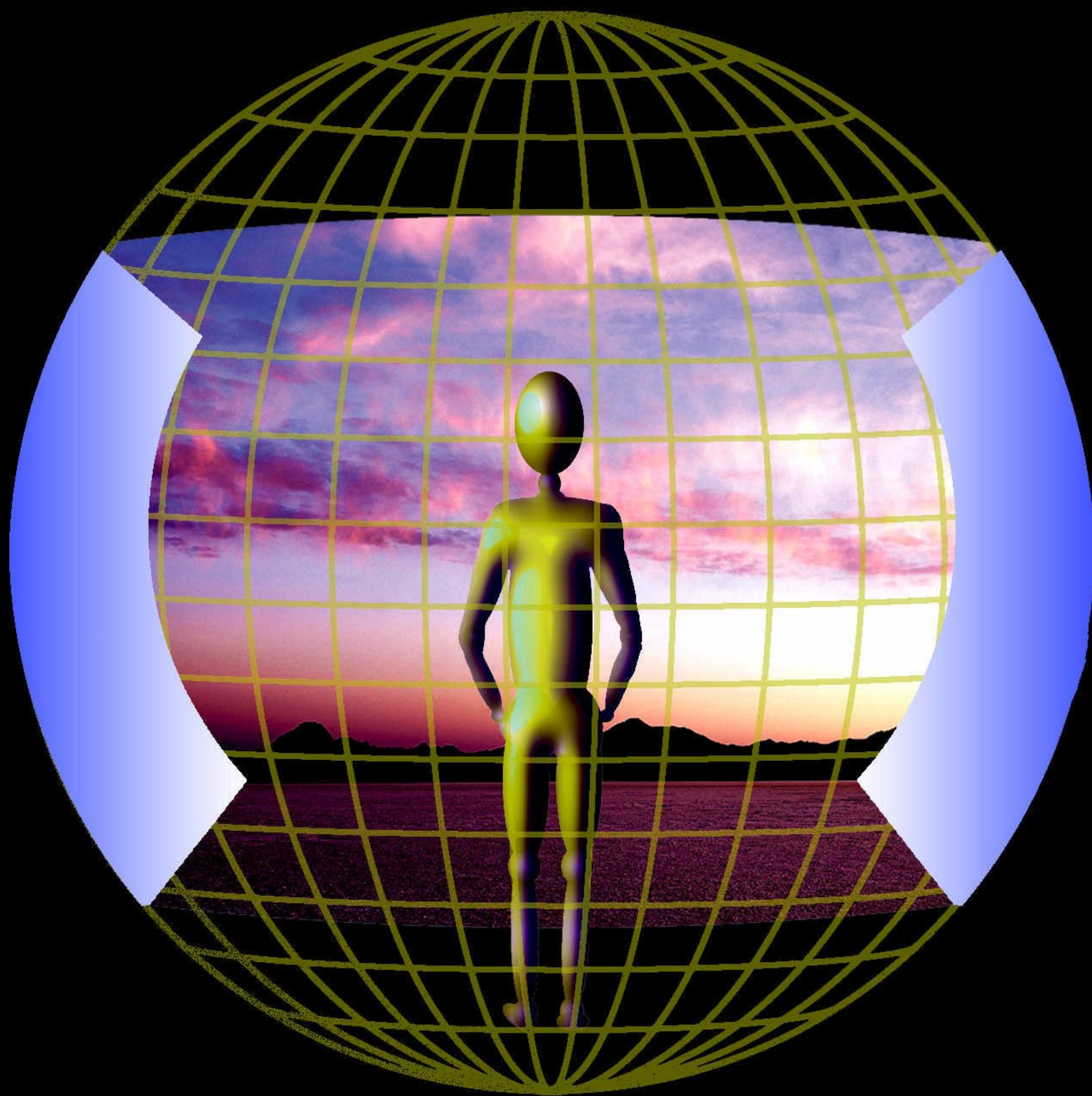
- See what the audience is seeing and write directly from what we are seeing.
- Let the audience have time to observe and experience for ourselves. It's a visceral experience. *Give the audience time to feel*.

The screen is essentially a huge black space, a vast "negative space."

- It is not necessary to fill the whole screen all the time.
- The shift in image size against black provides another tool for provoking and promoting AWE in the viewers.
- Open and close the screen size deliberately.

The audience's view in immersion is first-person experience, not a second-hand event.

We are immersed within the experience. The immersive experience is viewed without a frame. It's frameless.



Ben Shedd
Principles of Immersive Design

SIGGRAPH 2001 EXPLORE INTERACTION AND DIGITAL IMAGES

References: Essays on Immersive Design By Ben Shedd

Exploding The Frame

http://www.cs.princeton.edu/~benshedd/ExplodingtheFrame.htm

Designing for the Dome

http://members.aol.com/sheddprod2/papers.html#the%20Dome

Designing Effective Giant Screen Films

http://members.aol.com/sheddprod2/papers.html#Designing

References: Books and Papers

The Power of the Center by Rudolf Arnheim
University of California Press 1988

Film As Art by Rudolf Arnheim
University of California Press 1957

L'ECRAN TOTAL pour un cinéma sphérique by Philippe Jaulmes. Cinema Futur Paris Lherminier 1981

At the Heart of the Matter: The Study of Presence by Matthew Lombard & Theresa Ditton
http://www.ascusc.org/jcmc/vol3/issue2/lombard.html

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American Cinematographer Manual. Charles G. Clarke ASC and Walter Strenge ASC, Editors;, American Society of Cinematographers, Hollywood, CA 4th Ed. c. 1973.

References: Books and Papers

Building and Using A Scalable Display Wall System

Authors: Kai Li, Han Chen, Yuqun Chen, Douglas W. Clark, Perry Cook, Stefanos Damianakis, Georg Essl, Adam Finkelstein, Thomas Funkhouser, Timothy Housel, Allison Klein, Zhiyan Liu, Emil Praun, Rudrajit Samanta, Ben Shedd, Jaswinder Pal Singh, George Tzanetakis,and Jiannan Zheng.

IEEE Computer Graphics & Applications, Vol. 20, No. 4, July/August 2000

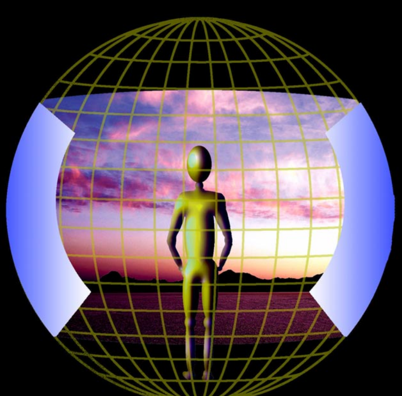
Immersive displays: *Exploding The Frame*

- This frameless research was supported by an Alden B. Dow Creativity Center Residential Fellowship, a grant from the Science Museum of Minnesota, and a conference grant from the National Science Foundation.
- Ben Shedd is a Senior Research Scholar & Lecturer in the Department of Computer Science, Princeton University, and owner of Shedd Productions, Inc.

Computer Graphics for Large-Scale Immersive Theaters

Spherical Image Generation and Projection

Ed Lantz
Product Development Manager
Spitz, Inc.
elantz@spitzinc.com



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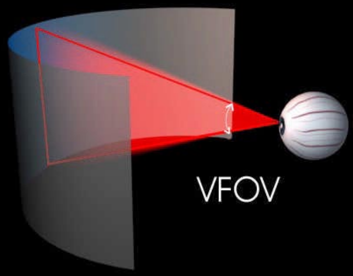
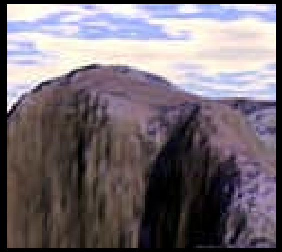
Immersive Display Image Metrics

- Field of View



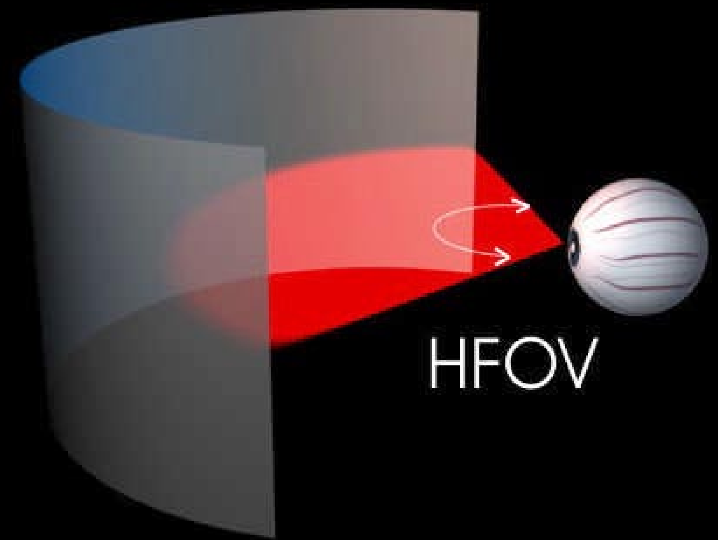
- Brightness

- Resolution



Field of View

- Total horizontal and vertical image angle in spherical coordinates with respect to viewer's eyepoint-or- spherical screen origin



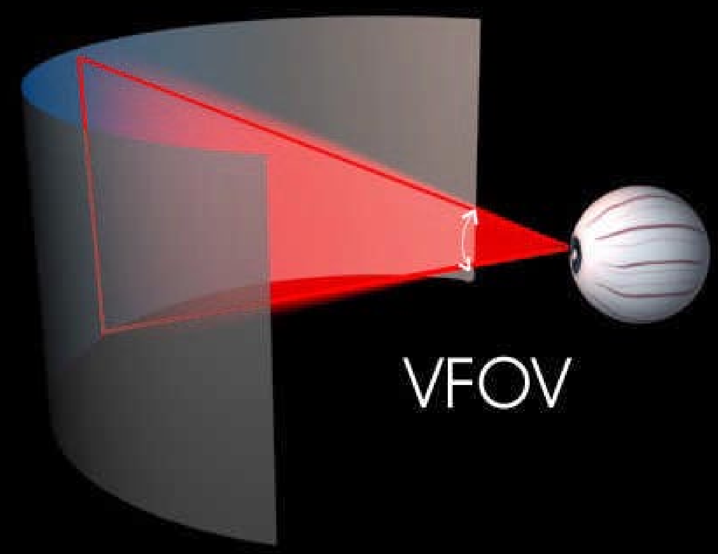


Image Brightness

Video Projector Brightness » Lumens

brightest video projector is 12,000 Lumens

Theater Brightness » Foot Lamberts

SMPTE standard for film is 16 ftL

1 Foot Lambert = 1 Lumen over 1 Sq. Ft.

for Lambertian Screen with 100% Reflectivity

Image Resolution

Acuity of Eye = 1 arcminute/line pair

1 arcminute= 1/60 degrees = 0.017°

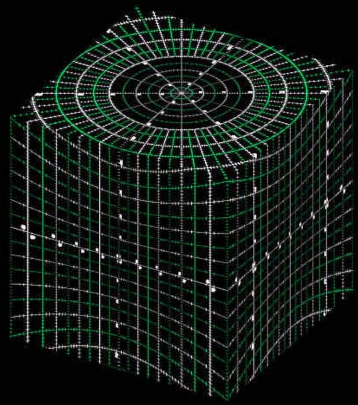
Ideally it takes 2 pixels to represent a resolvable line pair

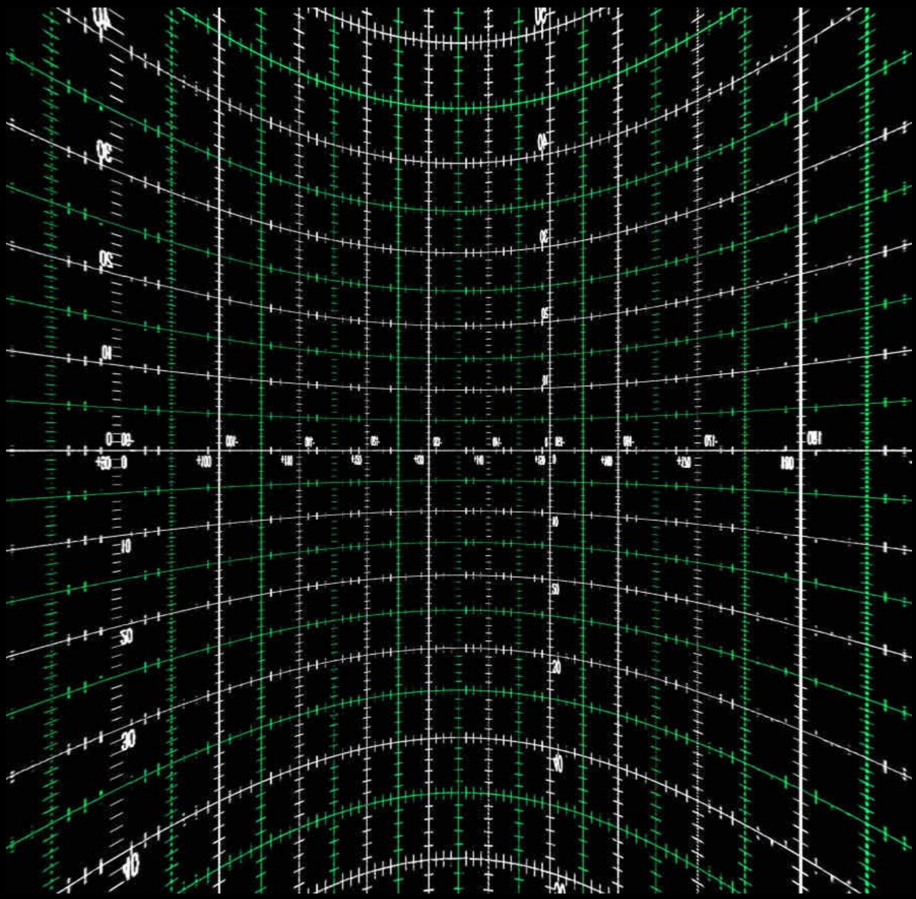
# of Resolvable line pairs < # pixels/2

Why a Sphere?

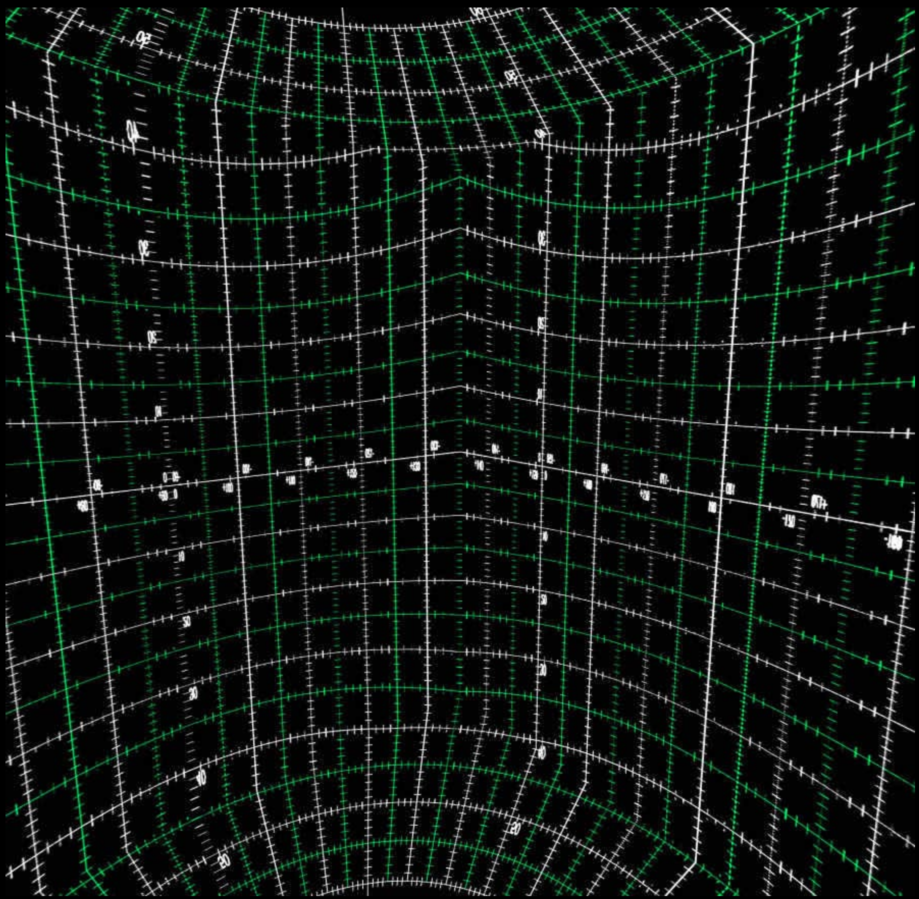
- Greater Immersivity than Flat Screen
  - Flat screen theoretically limited to 180°
  - Sphere easily provides 360° horizontal FOV
- Graceful Degradation of Off-Axis Perspective
  - Rectilinear displays introduce artifacts i.e. CAVE™

Cubic Distortion



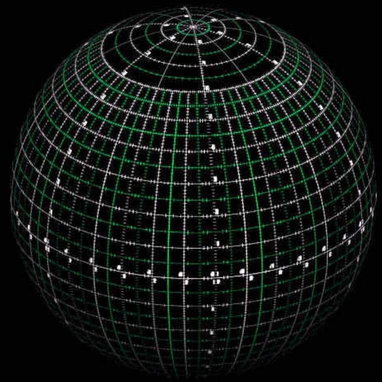


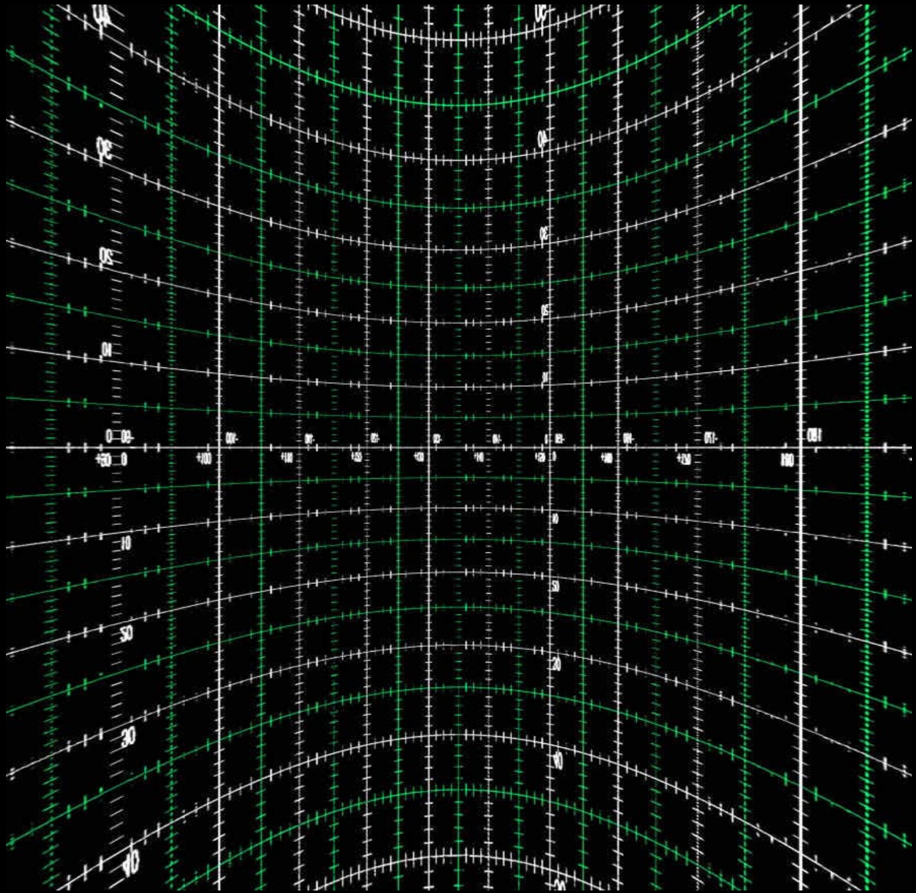
Ideal Viewpoint



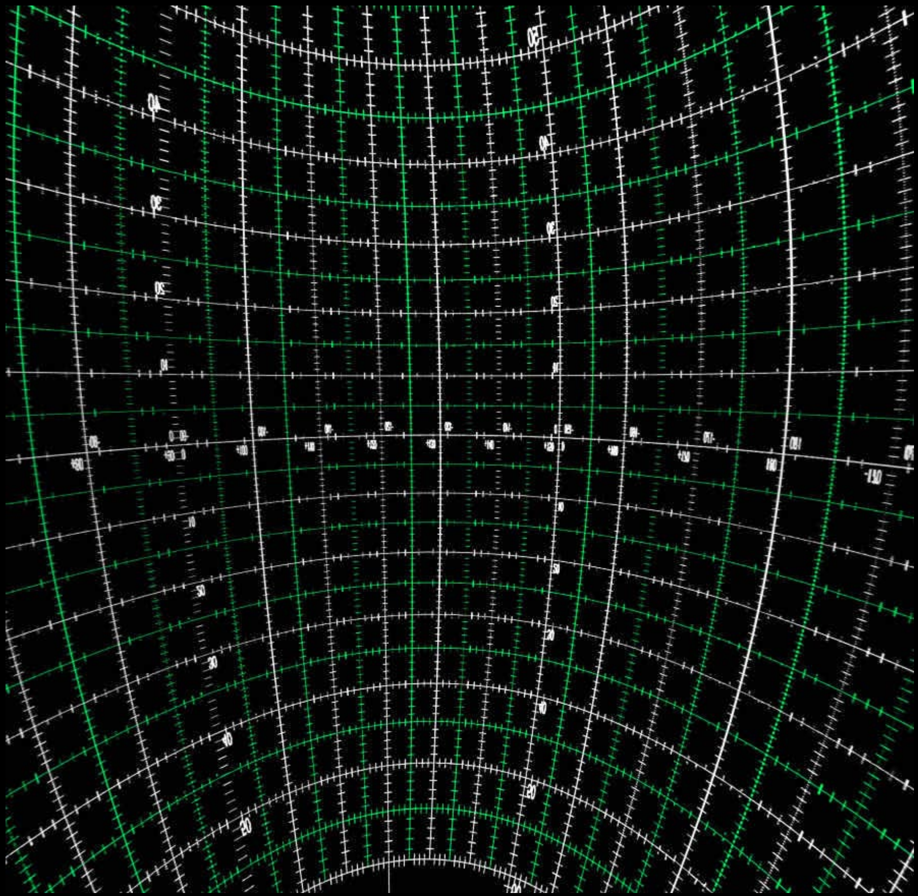
Offset Viewpoint

Spherical Distortion





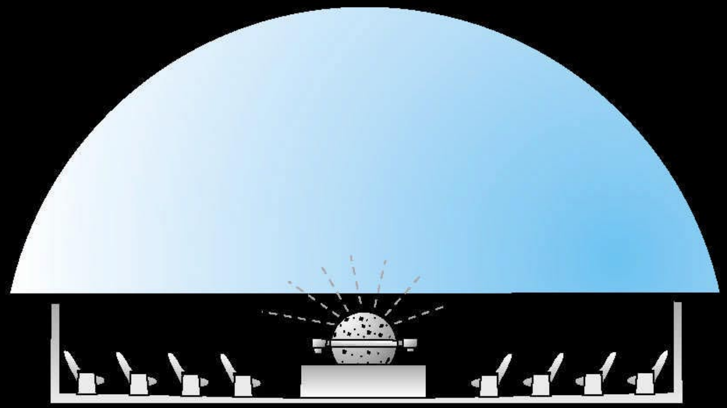
Ideal Viewpoint

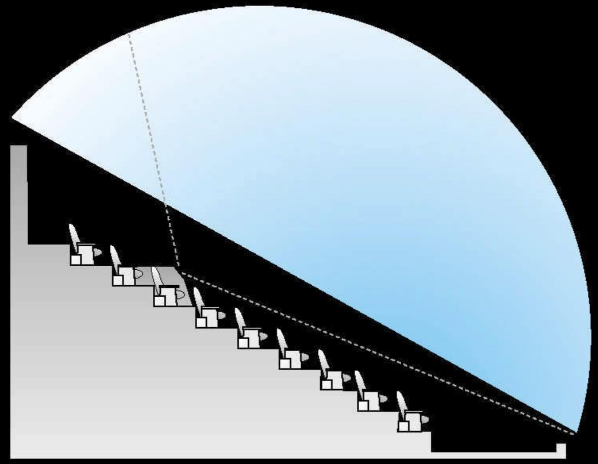


Offset Viewpoint

Theater Design

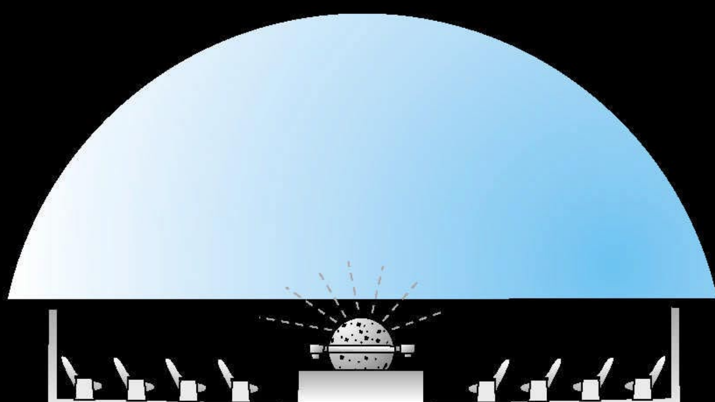
- Dome Tilt
  - Level dome requires reclined seating
  - Tilted dome + stadium seating brings dome screen into viewer's field of view

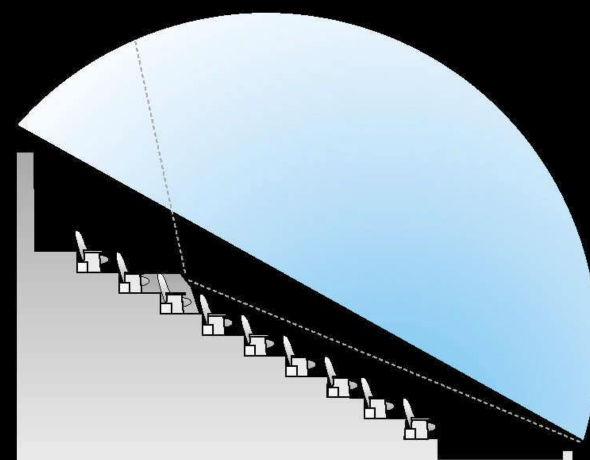




Theater Design

- Seating Configurations
  - Unidirectional seating provides single point of focus
  - Concentric seating popular in old planetarium designs and special applications





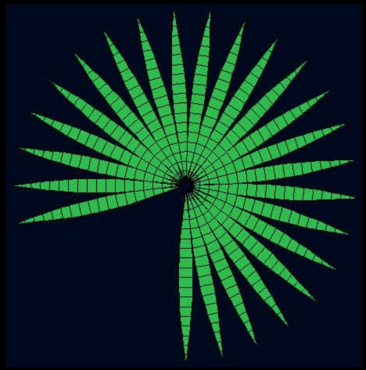
Theater Design Goal:

When the lights go out...

The theater disappears!

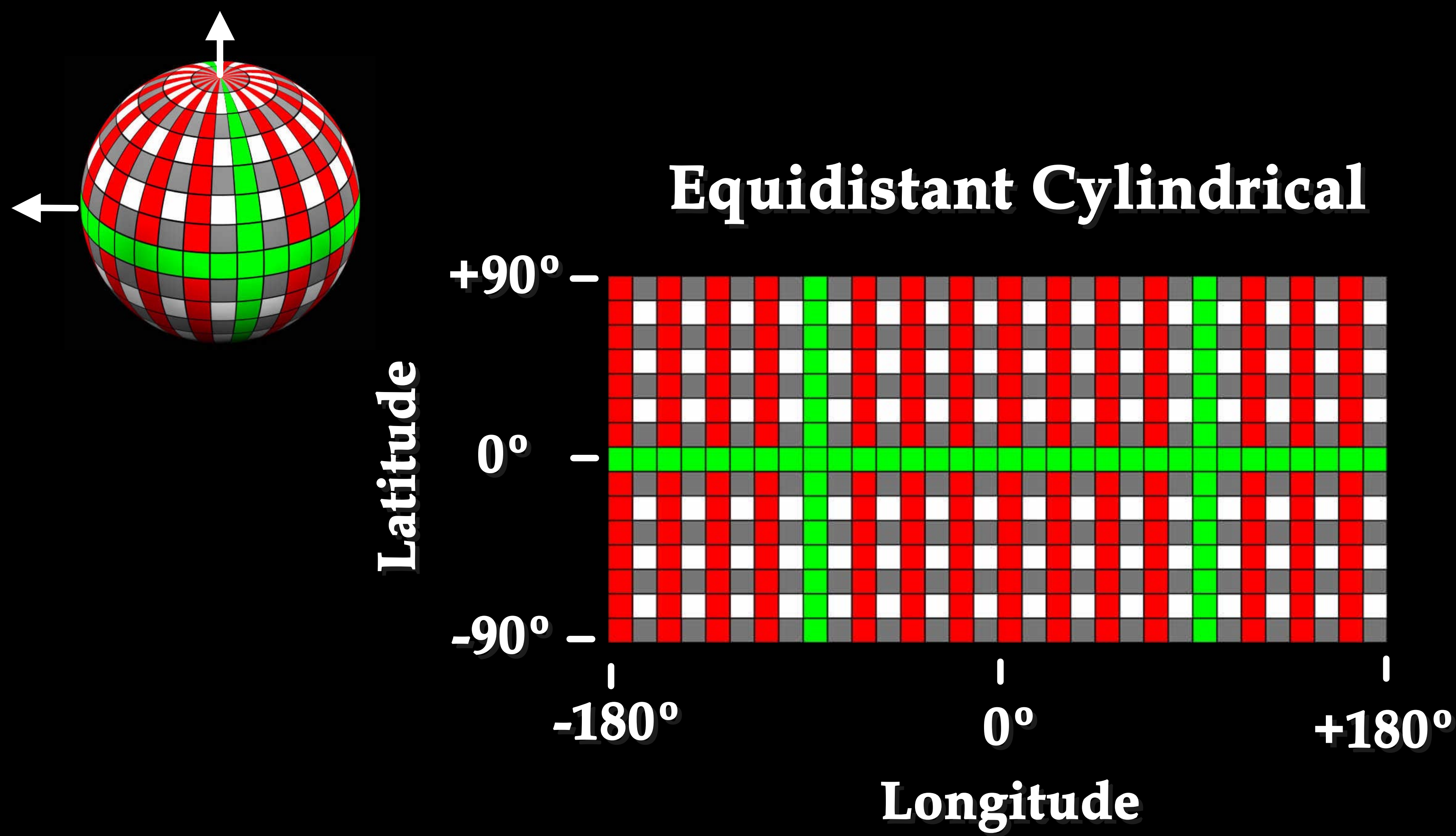
Minimize all “reality intrusions”

Skinning a Sphere

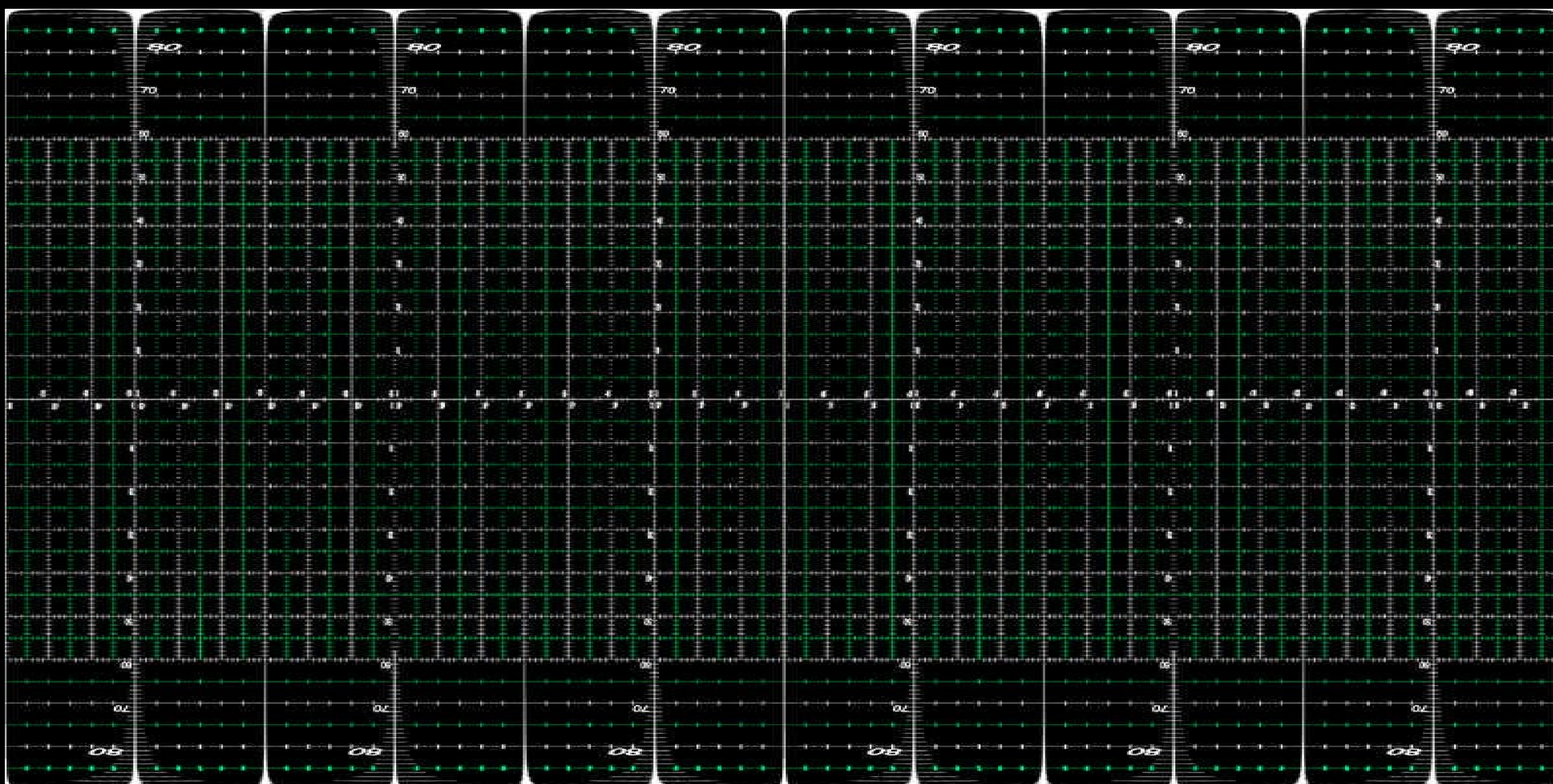


- Spherical Mastering Format (Immersoid)
  - Single large frame representing entire sphere
  - Master format for archiving, distribution, etc.
  - Independent of particular projection geometry
  - Defined only by resolution and field-of-view
- Spherical Projection Format (Sub Frames)
  - Multi-pipe format that matches projection geometry
  - Sub frames individually warped and blended

Spherical Mastering Format

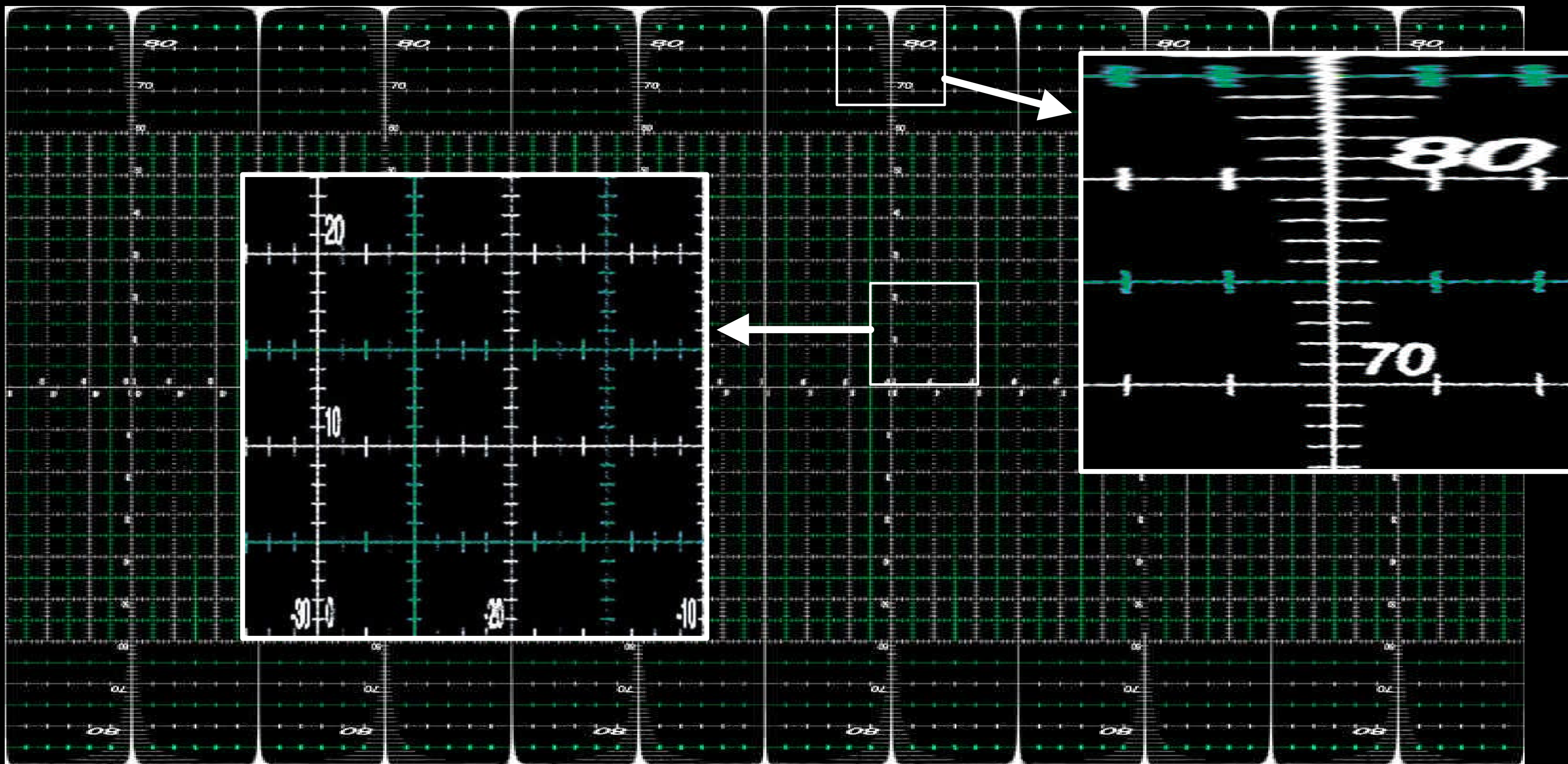


Equidistant Cylindrical Master

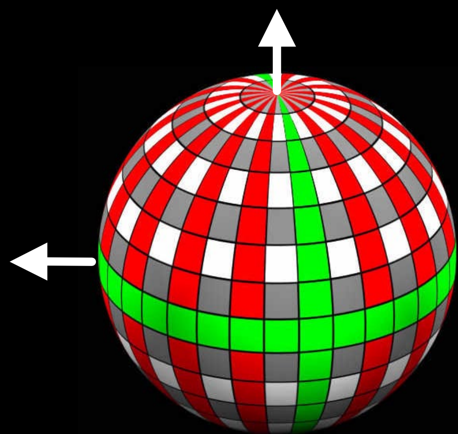


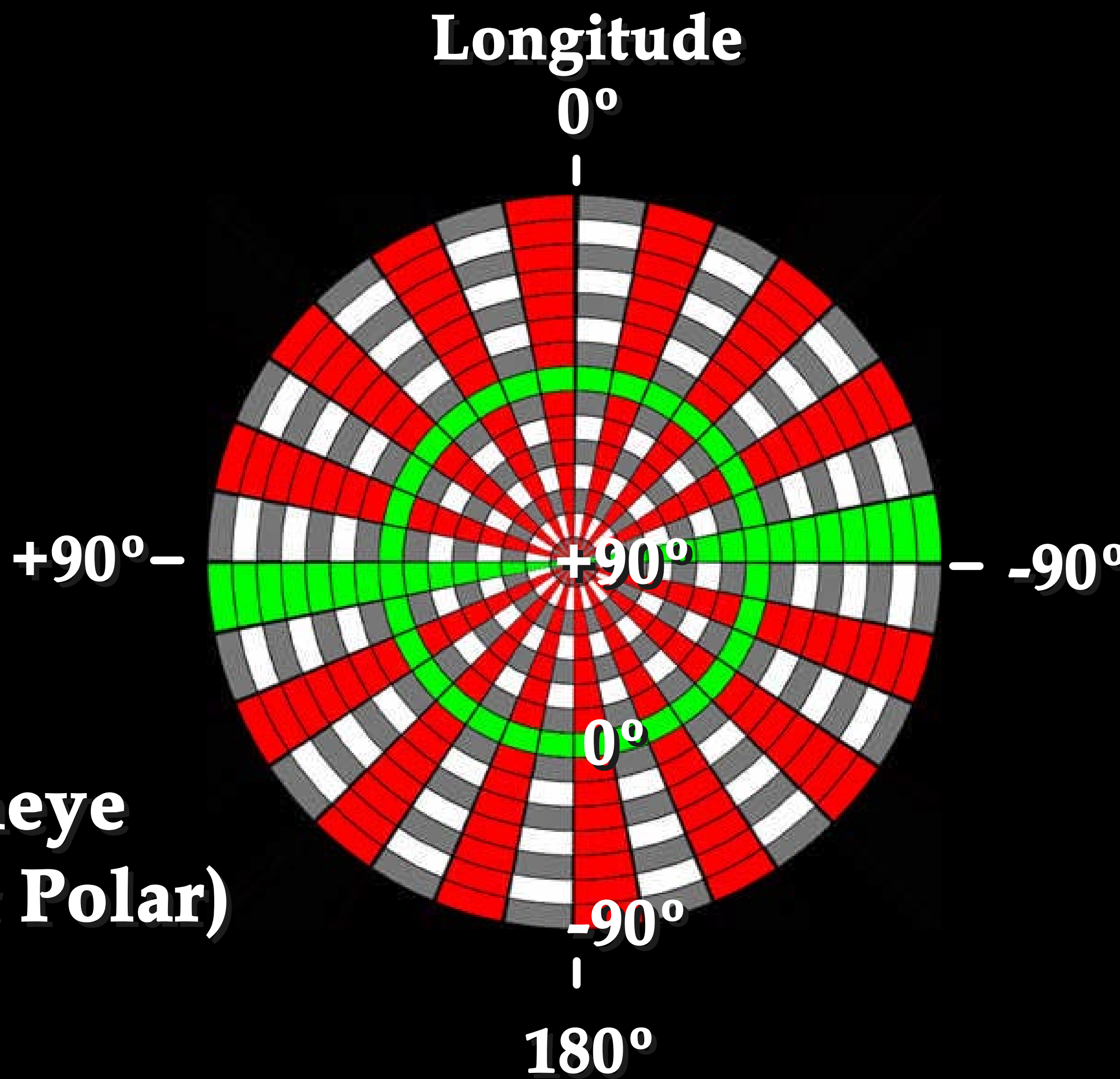
Entire Edge Maps to Single Pixel at Pole

Equidistant Cylindrical Master



Spherical Mastering Format

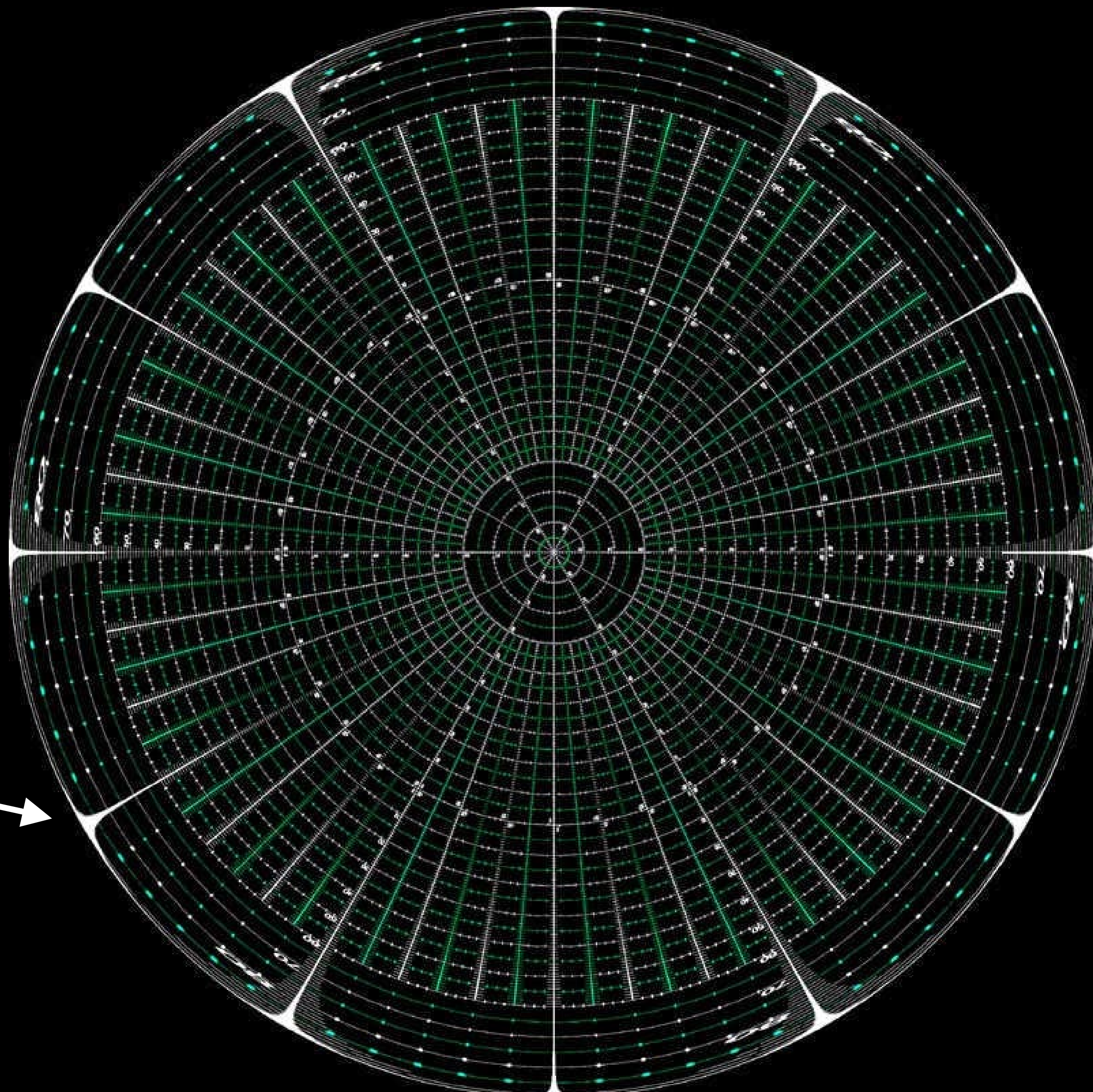




Polar Fisheye
(Equidistant Polar)

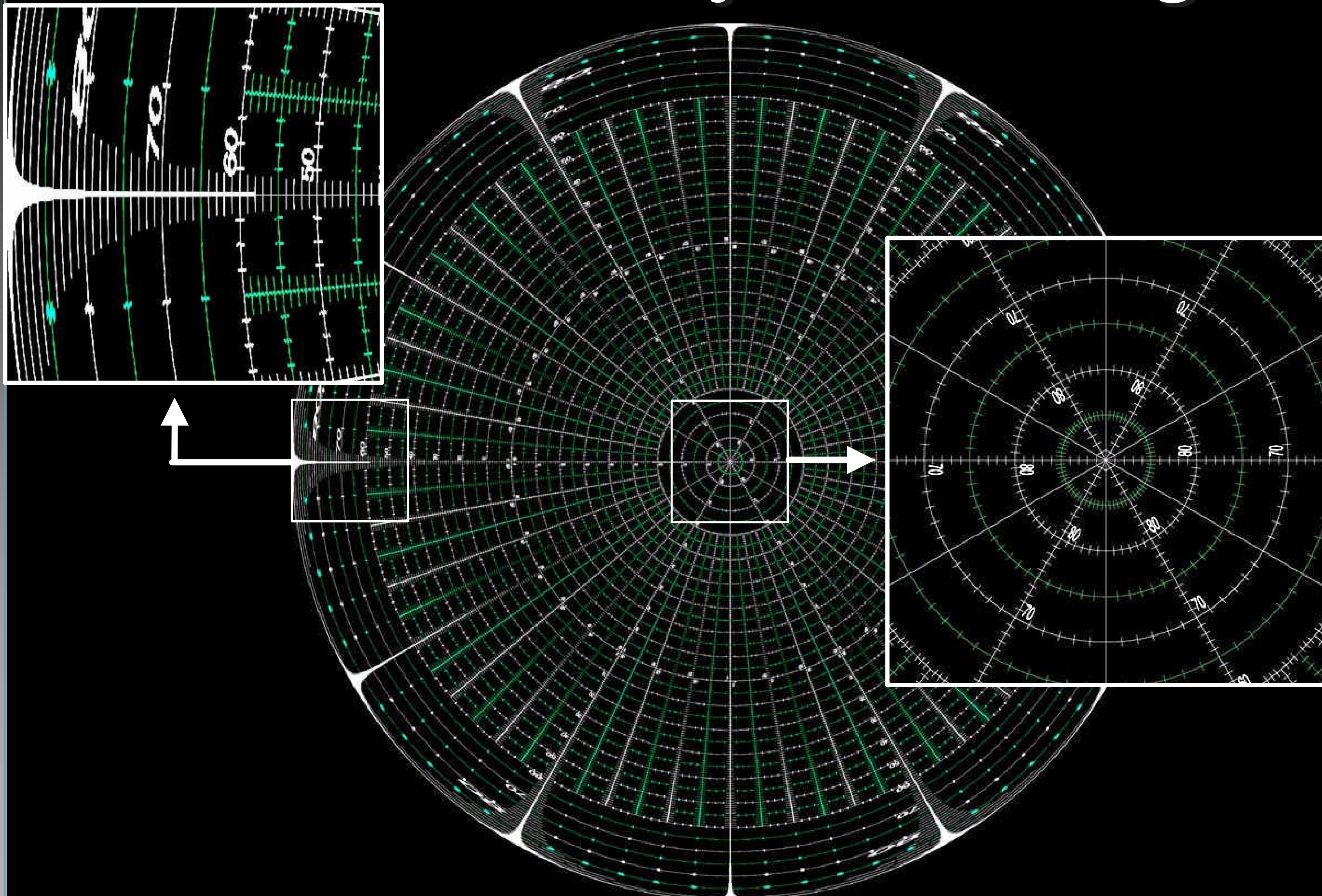
Polar Fisheye Mastering

Entire Outside Edge Maps to Single Pixel at South Pole

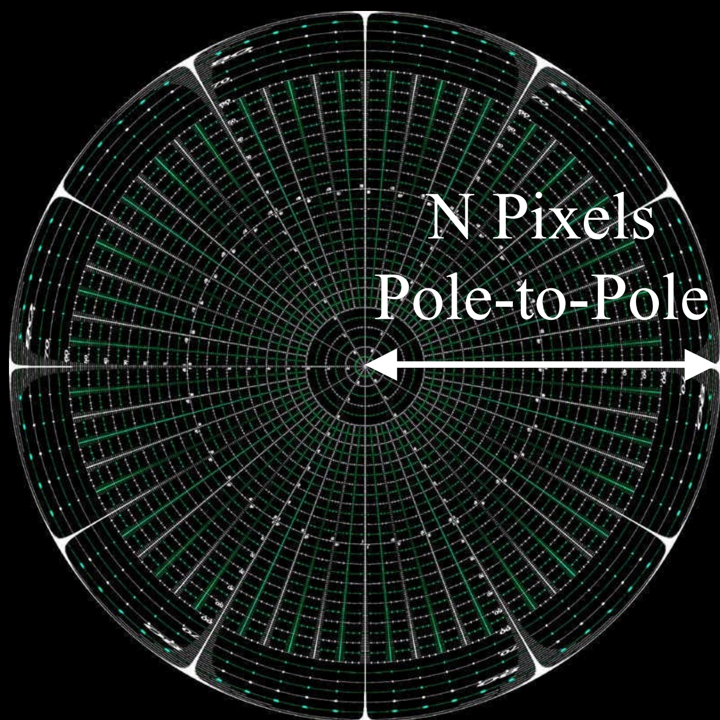


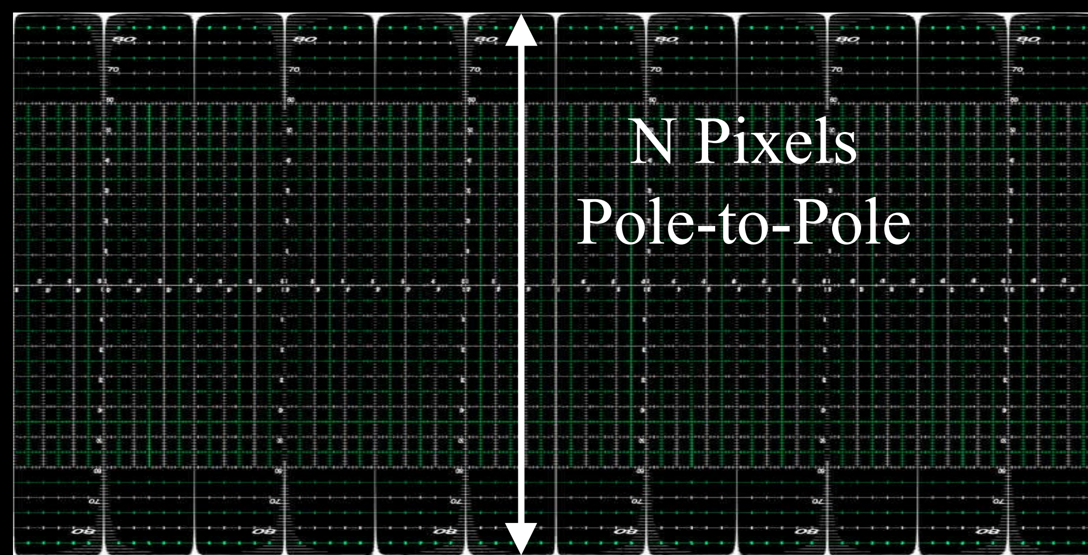
Polar Image Fills 78.5% of Square Frame

Polar Fisheye Mastering



Polar versus Cylindrical Mastering

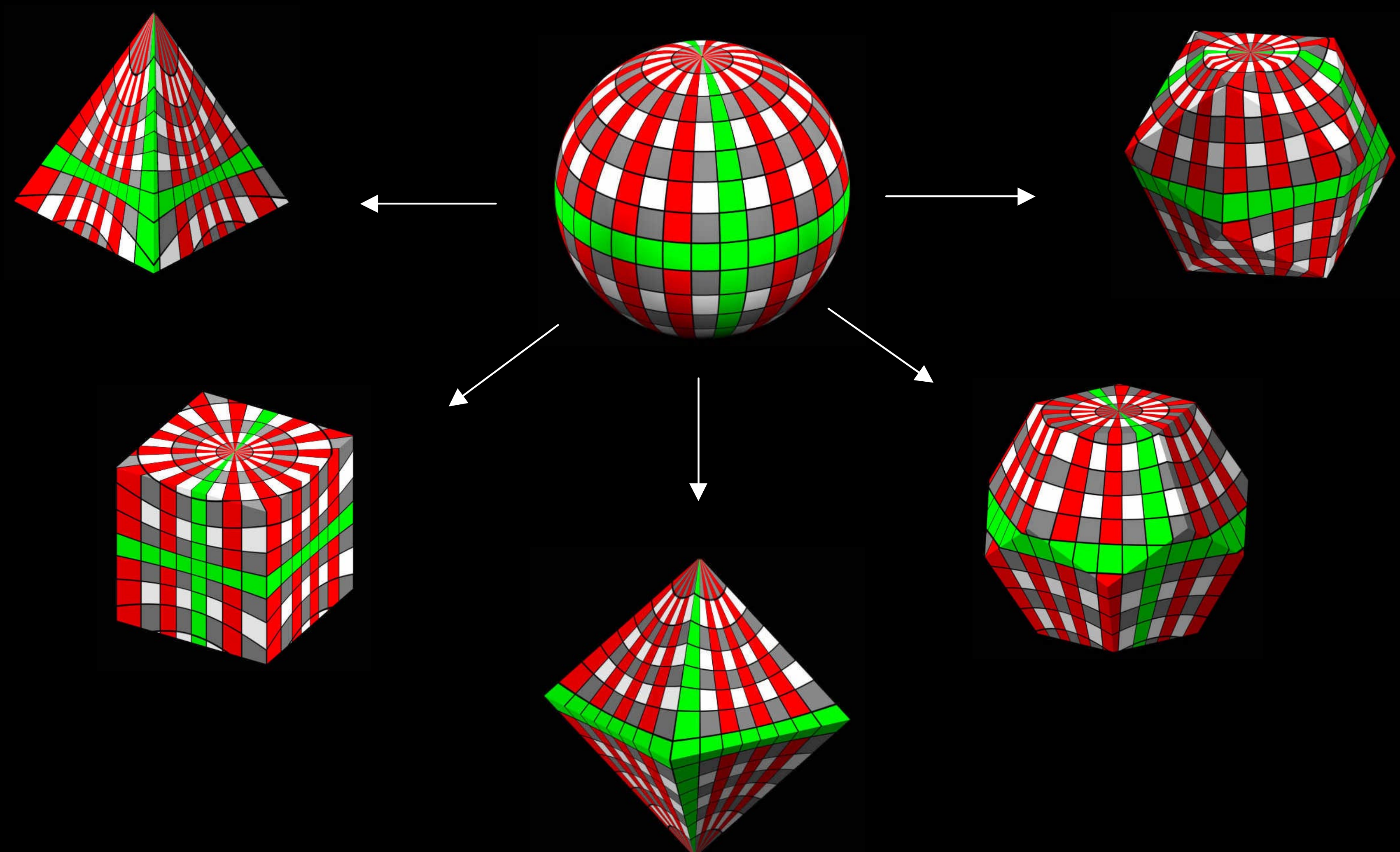




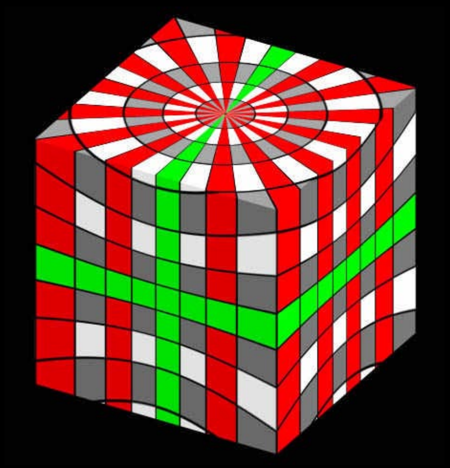
File Size = $4N^2$

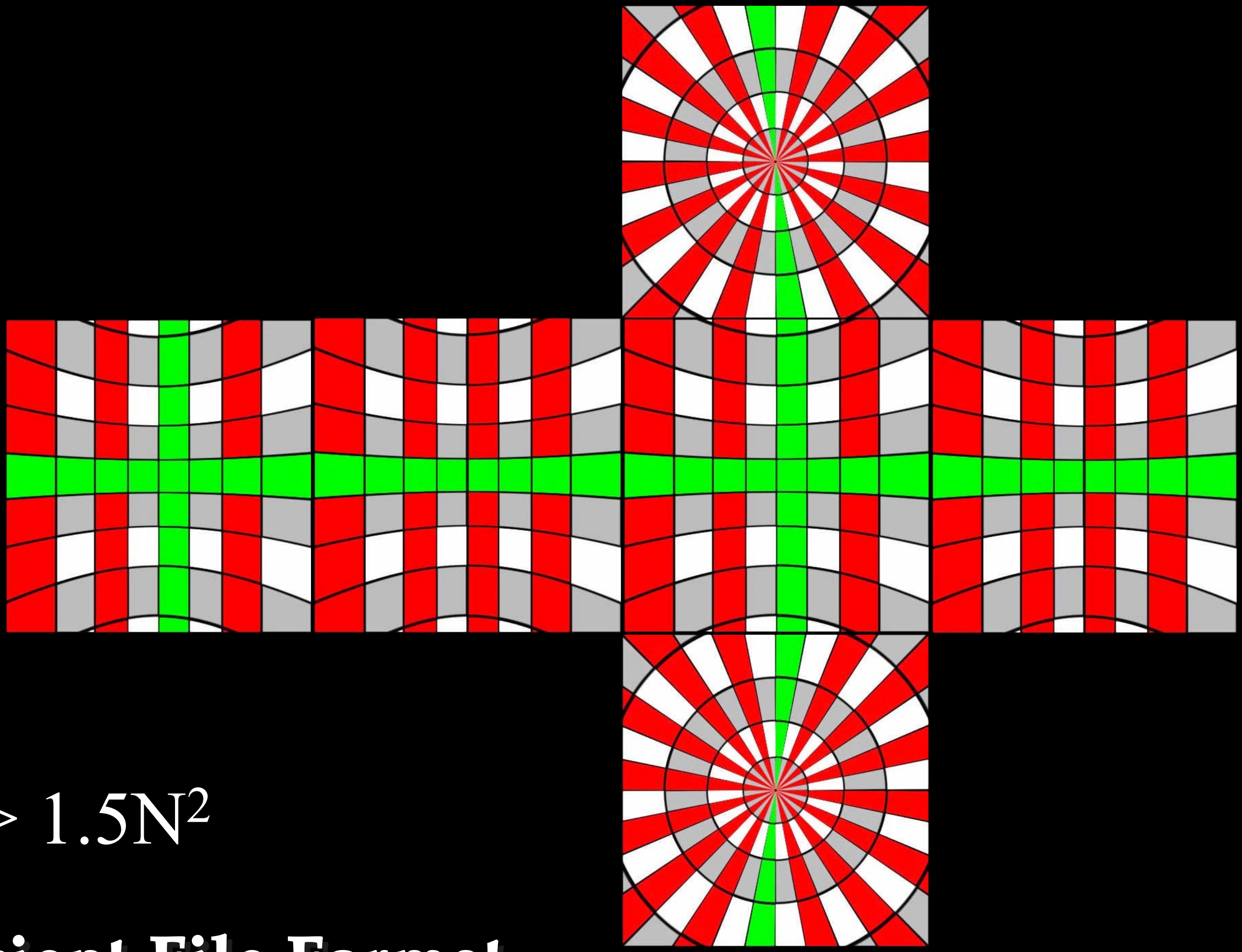
File Size = $2N^2$

Skinning a Sphere with Platonic Solids



Skinning a Sphere - Cubic Mapping



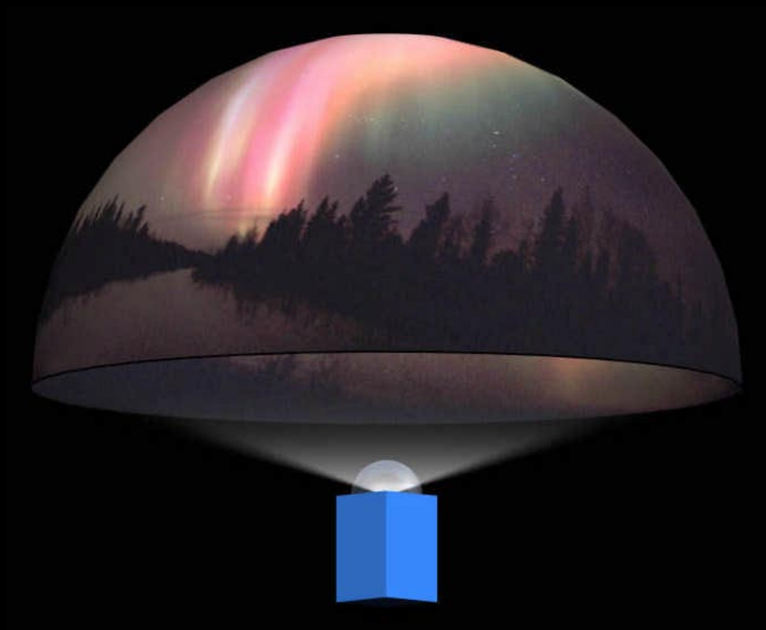


File Size > $1.5N^2$

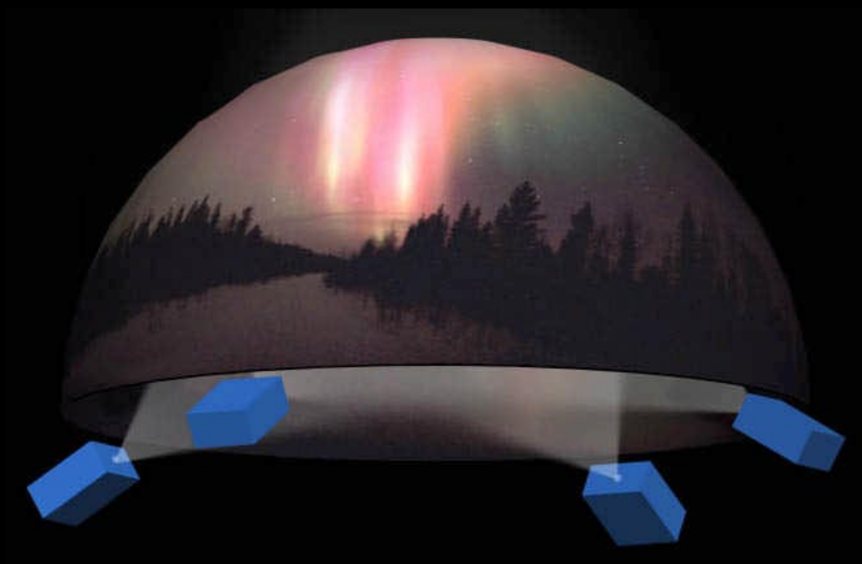
Advantage - Efficient File Format

Disadvantage - Images are Discontinuous

Spherical Projection Formats



Single Projector
(Fisheye)



Arrayed/Mosaicked
Projectors
(Edge-Blended)

Fisheye Projection

Polar Fisheye Source Image

- Simple Configuration
- Limited Hemispheric Resolution (1024x1024 pixels)
- Requires Obtrusive Projector Inside Theater Space

Fisheye Projection Applications

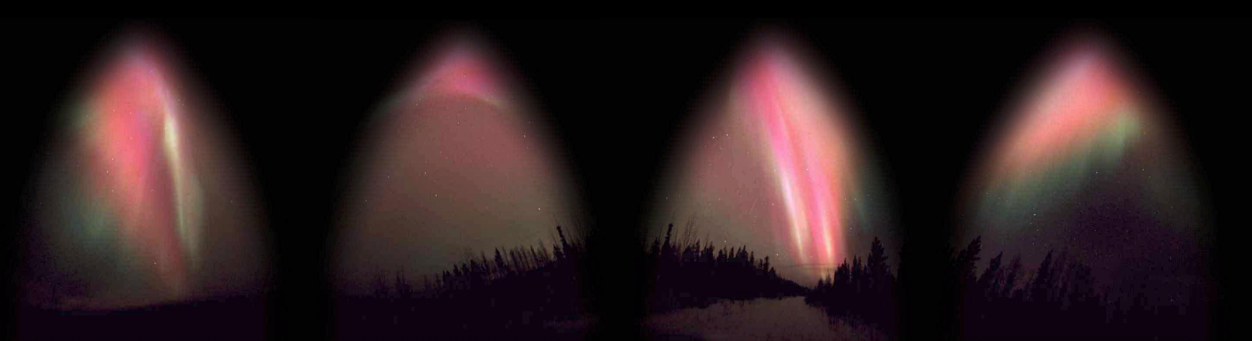
Elumens VisionStation™ Series

- Ideal Dome Production Monitors!
- Screen Diameters from 1.6m to 5m
- Resolution of 1365x1024 pixels… And Growing

Image Courtesy Elumens Corp.

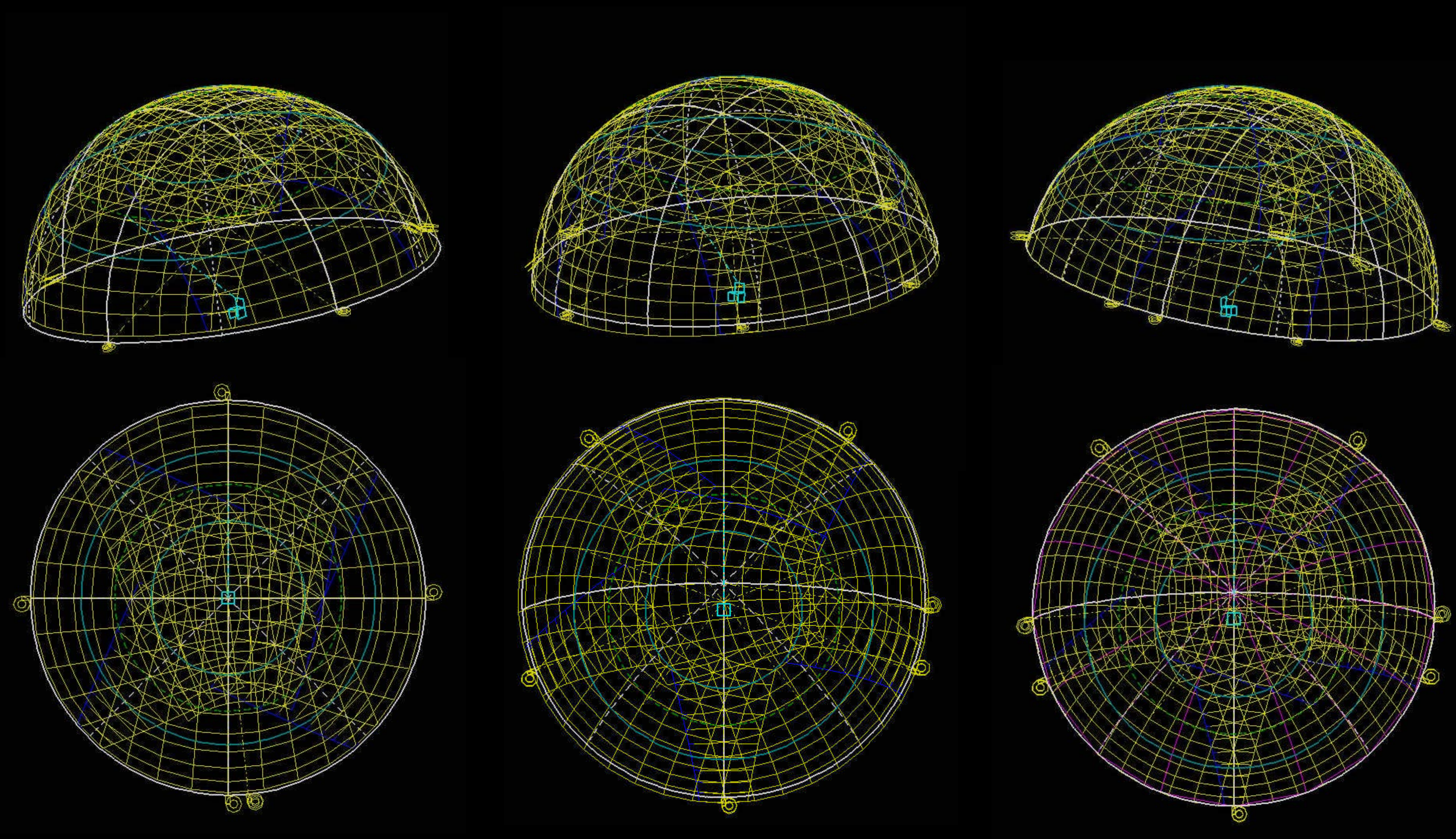
Mosaicked Projection

Polar Source is Split Into Sub-Frames and Edge-Blended



Sub Frame 1   Sub Frame 2   Sub Frame 3   Sub Frame 4

Many Projection Geometries



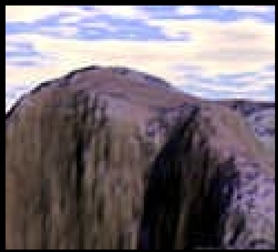
Five Projectors Six Projectors Seven Projectors

MosaickingProvides Simultaneous High Resolution, Wide FOV

Wide FOV,LoRes

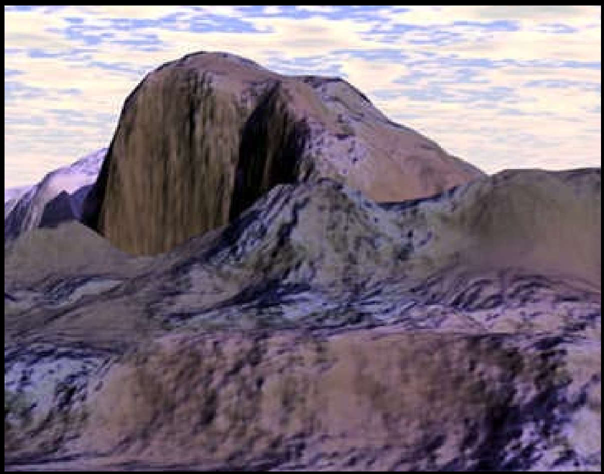
Single Channel

Narrow FOV HiRes



Single Channel

Wide FOV,HiRes

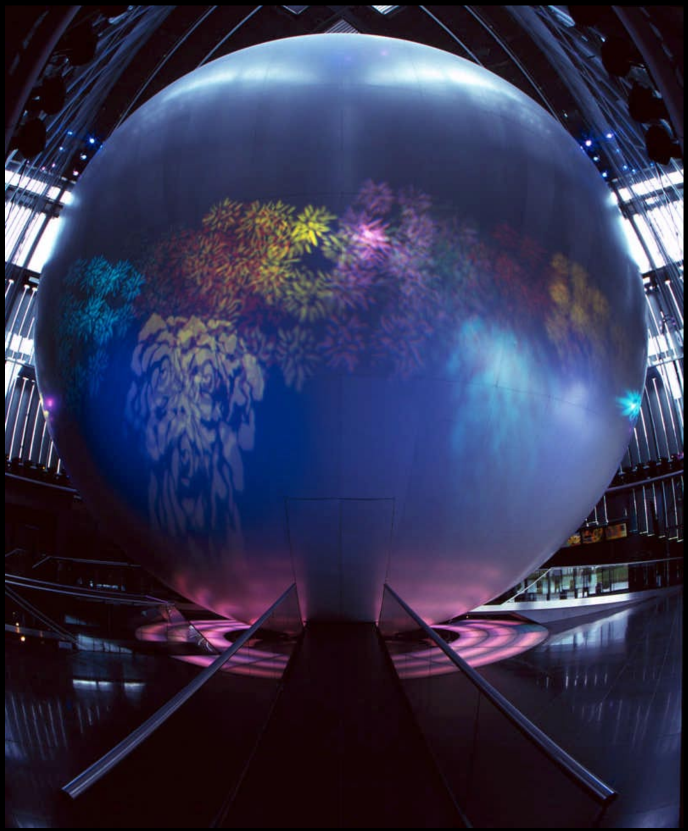


N Channels Mosaicked

MosaickingPros and Cons

- "Limitless" Resolution over Chosen FOV
- Greater Brightness for Given Projector Type
- Master Image Must Be Parsed, Warped, Blended
- Multiple Projectors to Align, Color Balance
- Multiple Video Channels or Image Generator Pipes
- Obviously More Complex and Costly… But
- Cinematic Quality Image over Hemisphere

VolkswagenAutostadt
Hemispheric Digital Cinema



3.5 Ft.L. @ 4 million pixels using 4x Barco DLP

Edge Blending and Spherical Mapping Techniques

- Pre-Rendered Blends and Mapping
  - Post-production processing of sub-frames
  - No special playback hardware
- Realtime Blends and Mapping
  - Allows realtime display of CGI, video sources, etc.
  - Dome becomes large virtual desktop!

Pre-Rendered Edge Blends and Spherical Mapping

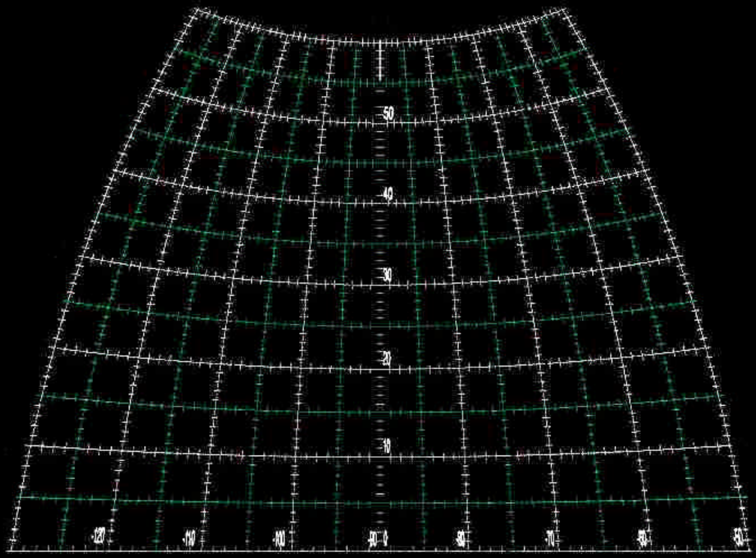
- 2D image processing with DigiDome™ or PolyDome™
- Ad-hoc process using 3D renderer
- On-site "tweaking" possible prior to processing
- All immersive content must be post-processed
  - Live spherical images not possible

Realtime Edge Blends

- Requires Edge-Blend Hardware
  - Panoram's Panomaker™
  - SEOS's DigiBlend™
  - Integral to Barco, Sony, 3D-Perception projectors
- Control Over Blend Regions
- Separate Interactive Control of R,G,B Blends
- Night/Day Gamma Mapping

Realtime Spherical Mapping

- Input Flat Plane, Polar, or Equidistant Source
- Realtime Digital Warping
  - SEOS's Mercator™
  - 3D Perception
- Projector Geometry Control
  - Requires CRT projectors
  - Geometry adjustments (keystone, bow, etc.)
  - Orthogonal adjustments (bilinear interpolation, etc.)

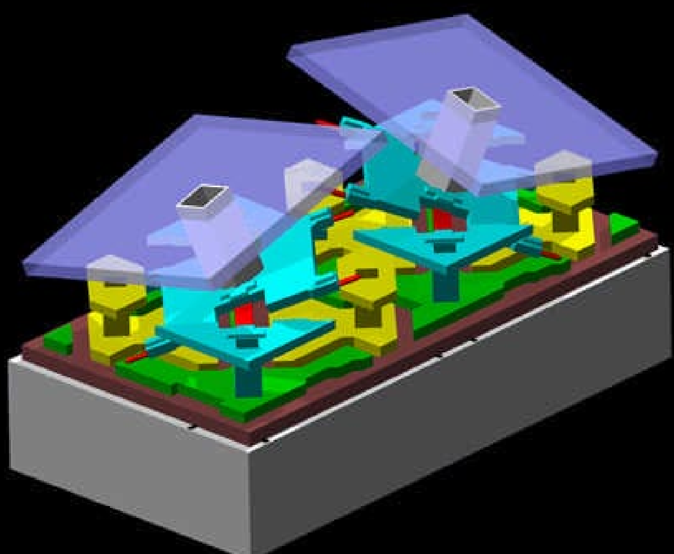


Video Projector Technologies

- LCoS/D-ILA - Liquid Crystal on Silicon
- LCD - Transmissive Liquid Crystal Display
- CRT - Cathode Ray Tube
- Calligraphic CRT
- DLP - Digital Light Processor
- Laser Projection - Various Technologies

DLP Projectors

- MEMS Mirrors on Silicon Substrate
- High Contrast >1000:1
- Good Resolution 1280x1024
- Very High Brightness 12,000 Lumens



Images Courtesy Texas Instruments

LCoS Projectors

- Liquid Crystal on Silicon Substrate
- Excellent Pixel Fill Factor - No “Screen Door” Effect
- High Contrast - up to 1000:1
- High Brightness - up to 7000 Lumens
- QXGA Resolution - 2048x1536 pixels

Image Courtesy JVC Corp.

CRT Projectors

- Analog Technology - Continuous Image (no pixels)
- Highest Resolution - 2500x2000 Addressable Pixels
- Analog Image is Subject to Drift
- Very Low Brightness - 270/1200 Lumens for 9" CRT
- Ultra High Frame Sequential Contrast - 10^6:1
- The ONLY Projector that Fades to True Black!

Image Courtesy Christie, Inc.

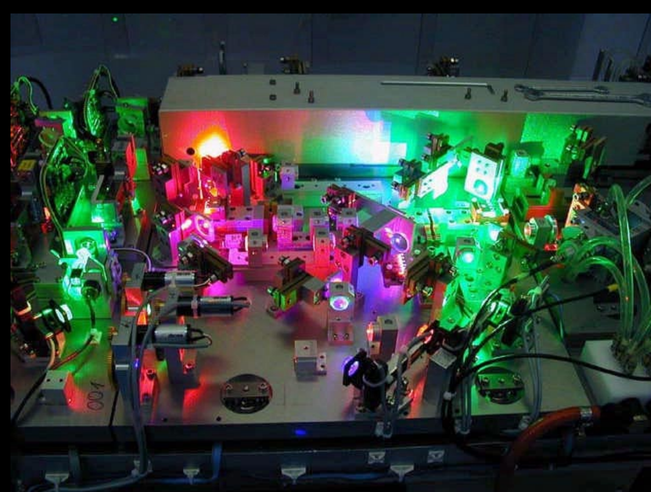
Calligraphic CRT Projectors

- Light Points and Lines Only
- Points are 1/3 the Diameter of Raster Pixels
- Combination of Raster/Calligraphic Available
- Digistar™ is Full Dome Calligraphic Star Projector

Digistar Images Courtesy Evans & Sutherland, Inc.

Laser Projectors

- Promises High Resolution, Very High Contrast
- New Semiconductor-Based Solid-State Lasers
- Several Competing Systems Emerging
- SGI/ZEISS/Schneider Projector Optimized for Dome Projection


Images Courtesy Silicon Graphics, Inc.

Image Generation: Feeding the Dome

- Pre-Rendered Video/Graphics
  - Digital Graphics Playback Resolutions up to 1600x1200, Video Resolutions up to 1920x1080i
  - Pre-rendering provides superior image quality
- Realtime Graphics
  - Provides user interactivity
  - Rendering speeds rapidly increasing
- Live Video Feeds
  - Immersive Cameras
  - Videoconferencing
  - Interactive performance

Playback of Pre-Rendered Graphics

- Standard Video Formats
  - CCIR-601 Format (720x486)
    - Requires expensive video line interpolators
  - HD 1920x1080i
    - 16:9 format not well suited to dome geometry
- Graphics Formats
  - 1280x1024 provides good resolution
  - 1600x1200 provides excellent resolution
- Multichannel Graphics/Video Servers
  - RAID technologies
  - Storage capacity in multi TB
  - Graphics compression available

Realtime Image Generation

- Dome Systems Pioneered in Training Simulators
- Immersive Visualization & VR Workspaces
  - CAVE™, Reality Center, etc. - group interactivity

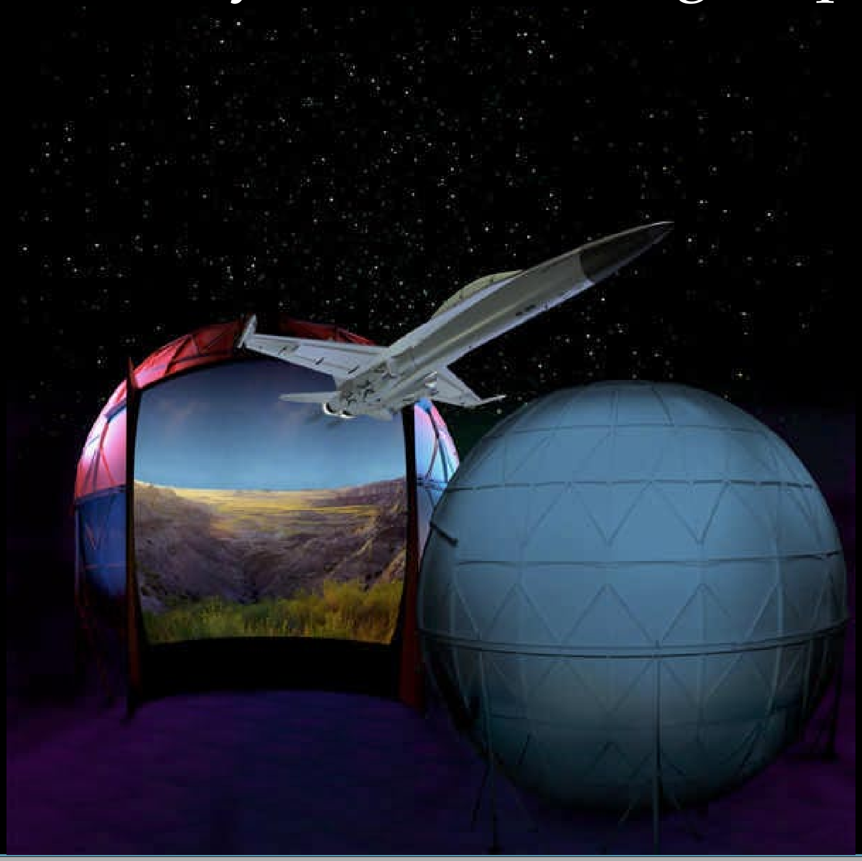


Image Courtesy Spitz, Inc.

Realtime Image Generation

Networked PC's:
(MetaVR VRSG, SGIGraphics Cluster™)

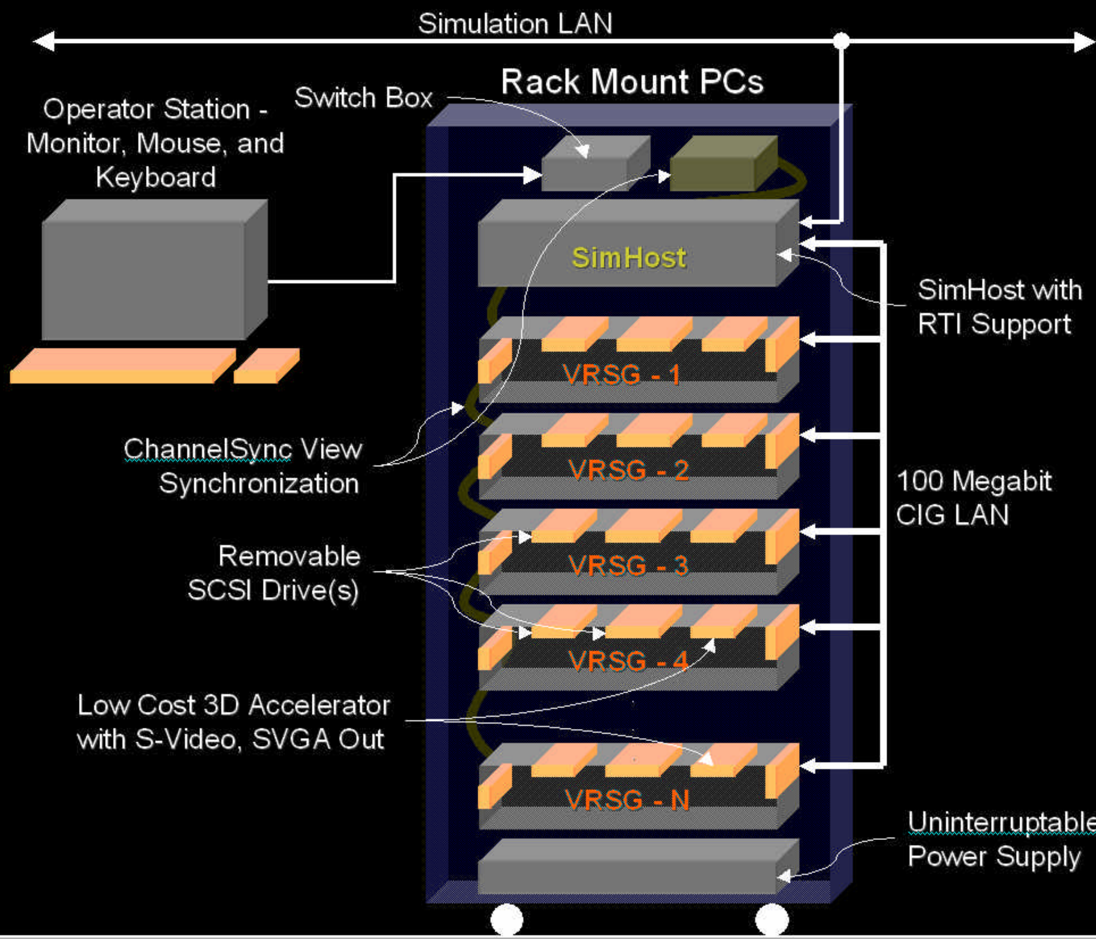


Image Courtesy MetaVR

Realtime Image Generation

GeForce3-based graphics cards (NVIDIA):

- 1 Billion Bilinear Filtered, Multi-Textured Pixels/second
- 64Mb of DDR Memory
- GPU capable of 800 Billion Operations per Second
- Transform, Clip and Light 31 M Triangles per Second
- Full Scene Anti-Aliasing up to 1280x1024
- Maximum Texture Map Size 2048x2048-pixels

Realtime Image Generation

Mainframe Solutions Still Offer Highest Performance

Image Courtesy Silicon Graphics, Inc.

Live Action on the Sphere...

Immersive Media's Dodecahedral Camera

Image Courtesy Immersive Media Company

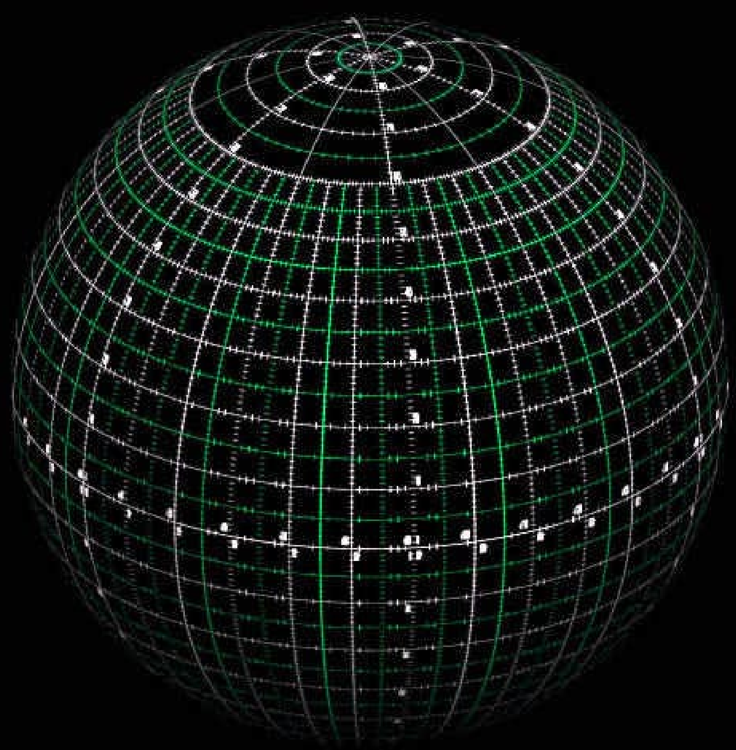
For more links: www.cis.upenn.edu/~kostas/omni.html

Telepresence

CMU's Nomad Robot Tested by NASA Ames in Atacama Desert... Live Audience Telepresence

http://www.cs.cmu.edu/afs/cs/project/lri-13/www/atacama-trek/

Immersing the World



Special Thanks to:

Elumens Corp.

Evans & Sutherland

MetaVR

Silicon Graphics Corp.

Spitz, Inc.

SIGGRAPH 2001 EXPLORE INTERACTION AND DIGITAL IMAGES

Computer Graphics for Large-Scale Immersive Theaters

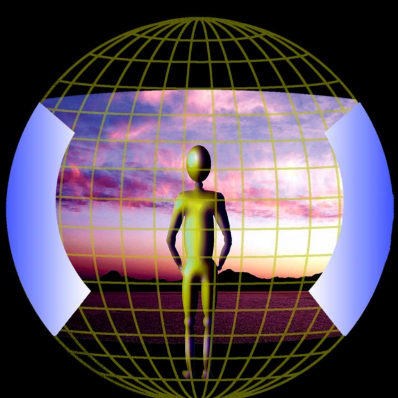
Immersive Rendering Basics

Brad Thompson

Lead Animator

Spitz, Inc.

bthompson@spitzinc.com



SIGGRAPH 2001
EXPLORE INTERACTION AND DIGITAL IMAGES

Aesthetic Considerations: Understanding the space

- Completely fills FOV
- Increased sense of speed
- Puts viewer *in* the space
- Mix of cinema and simulation

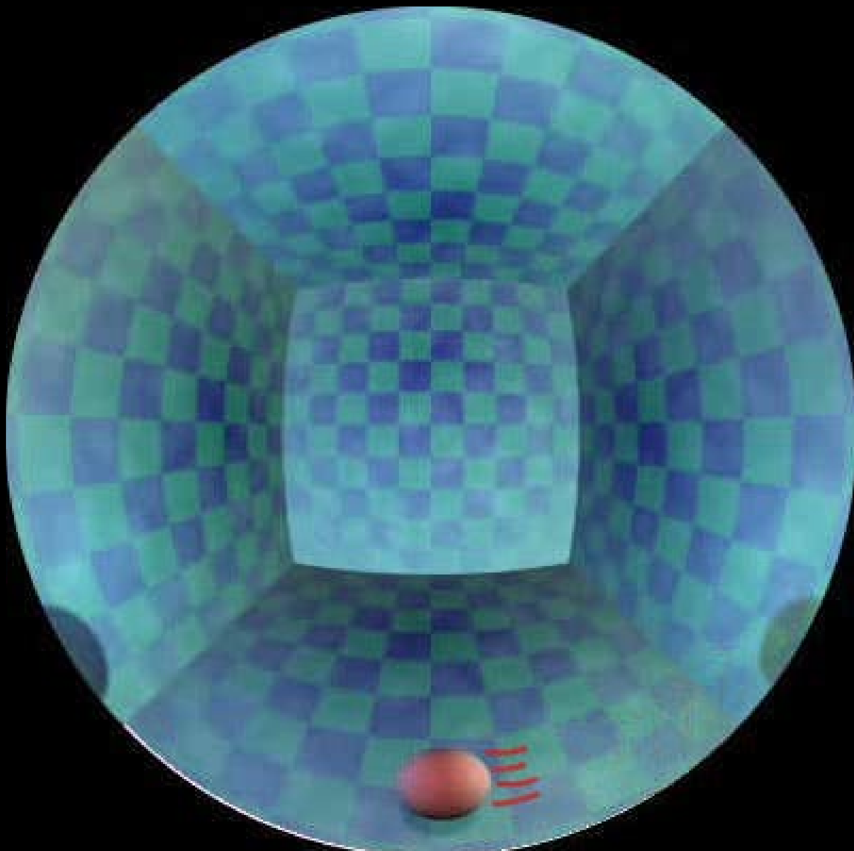
Size and Detail Requirements

- 4K frame = 16 million pixels
- High resolution combined with huge FOV = more detail required
- Appropriate detail level is very difficult to judge on SD or even HD monitors.

Frame Rate

- 30fps progressive scan is minimal
- 30fps interlaced scan gives smoother motion but is less flexible and requires rendering at 60 full fps anyway for full hemisphere formats.
- 60fps progressive scan may be desirable for fast moving scenes, or small moving objects.

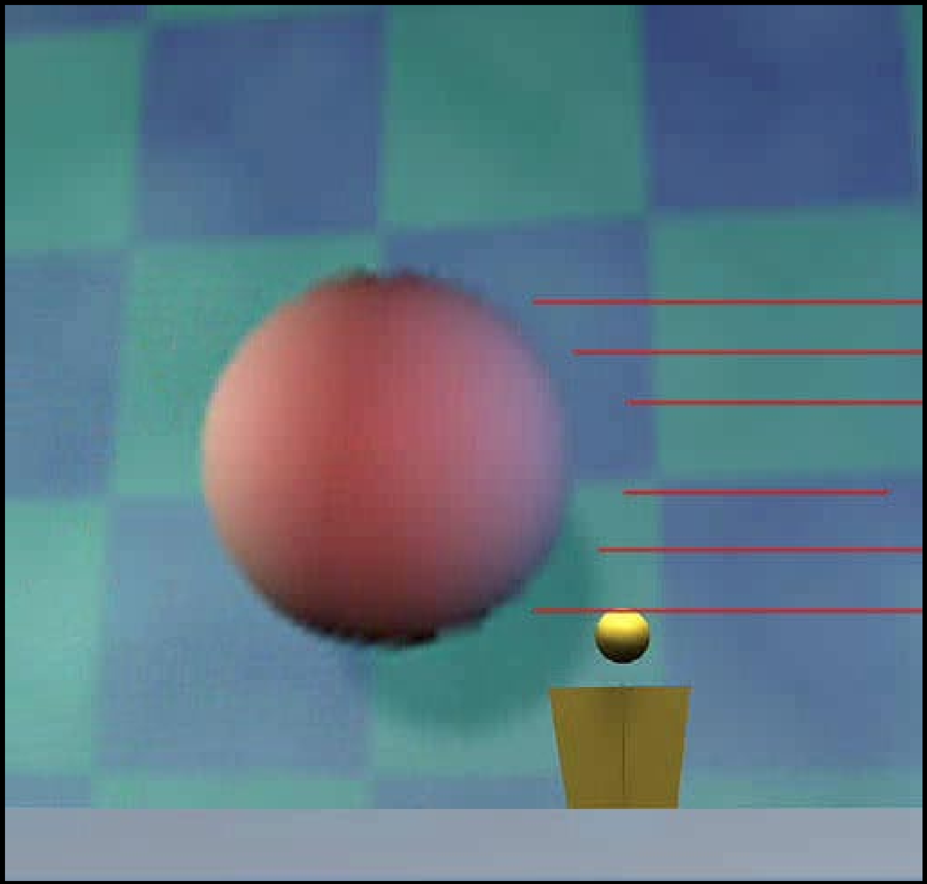
Apparent Motion Increase



Immersive Master Frame

- Motion that looks OK on your monitor can be overwhelming in the theater.
- Can cause "cybersickness"
- There is no substitute for viewing your animation in the dome!

Apparent Motion Increase



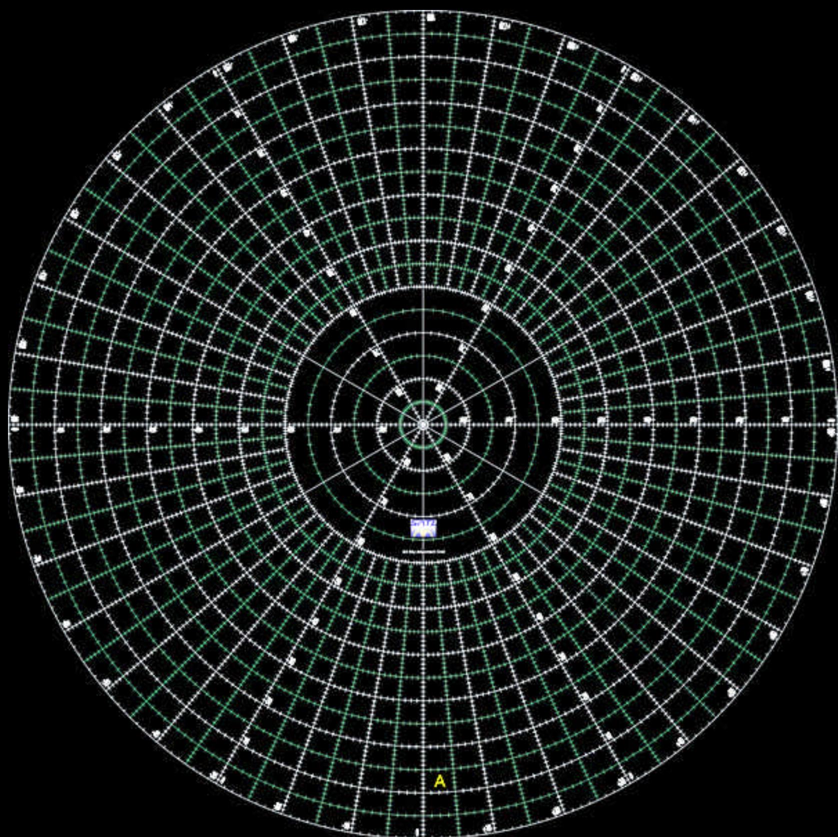
Same image as seen from a seat in the theater.

- Motion that looks OK on your monitor can be overwhelming in the theater.
- Can cause "cybersickness"
- There is no substitute for viewing your animation in the dome!

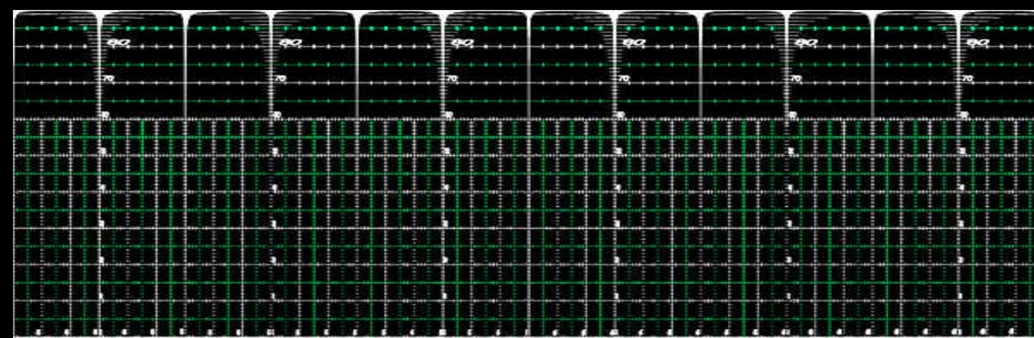
Technical Considerations

3D Rendering for Immersive Environments

How to Represent a Spherical Image

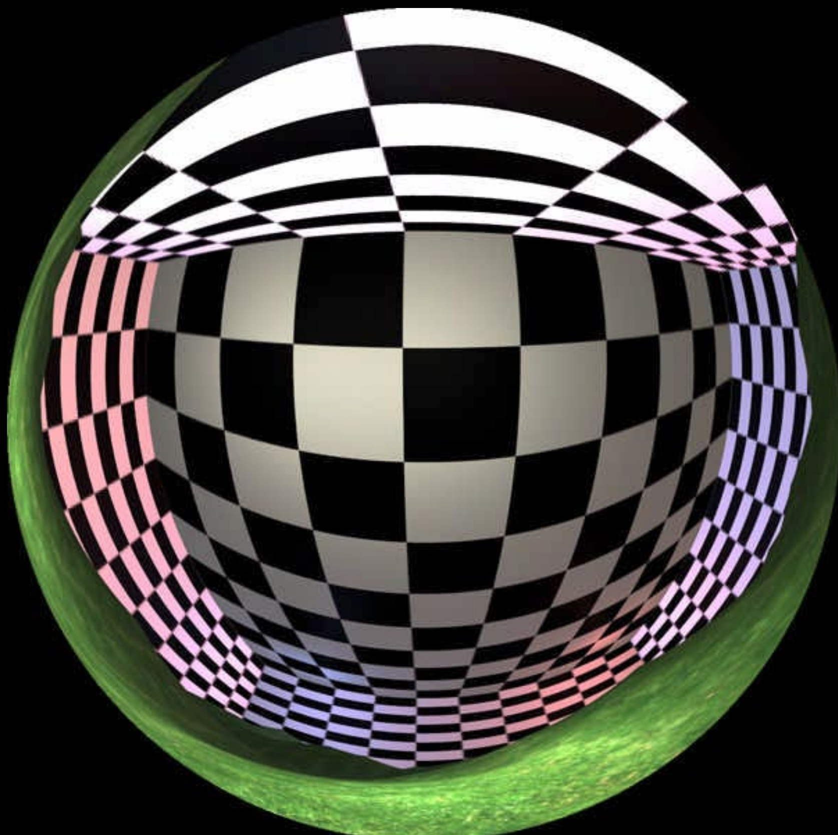


Polar projection

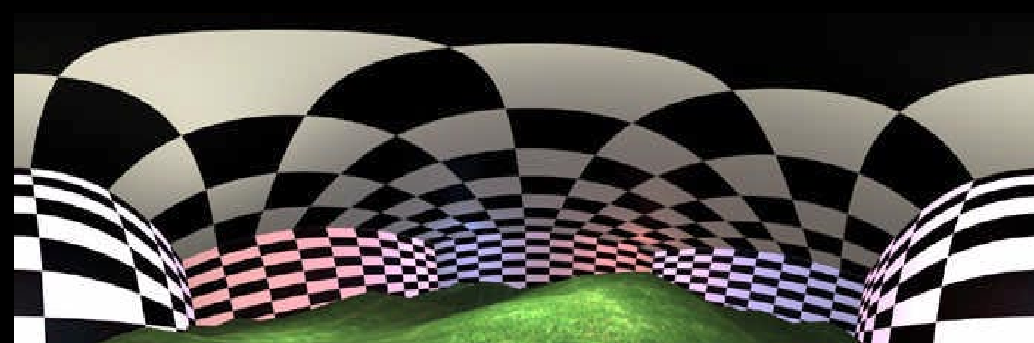


Equidistant cylindrical projection

How to Represent a Spherical Image

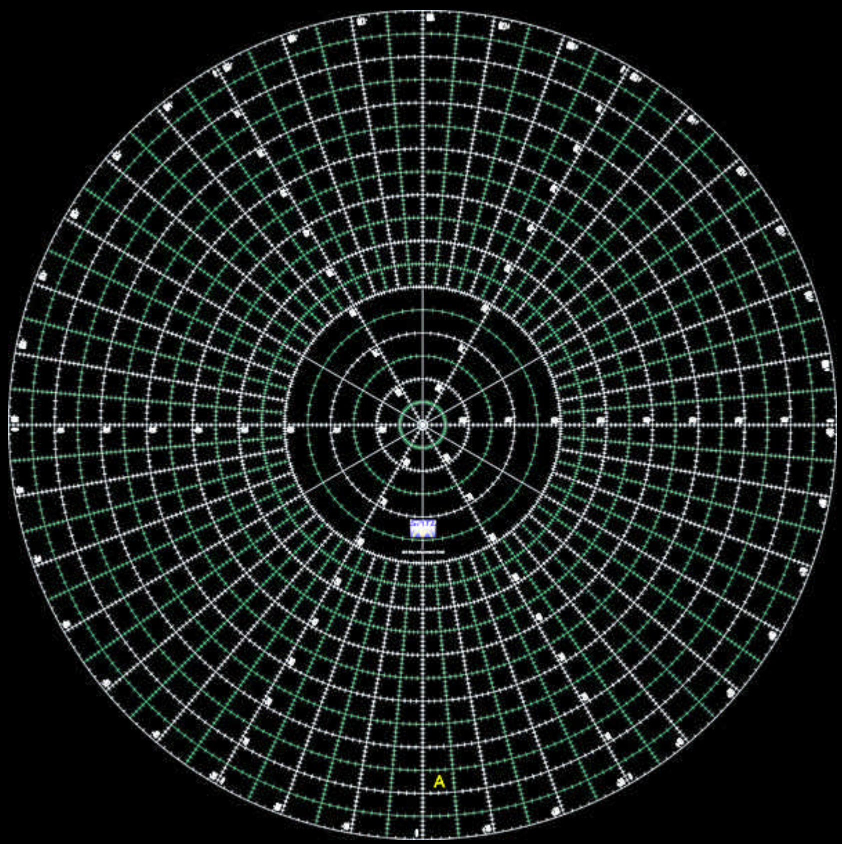


Polar projection



Equidistant cylindrical projection

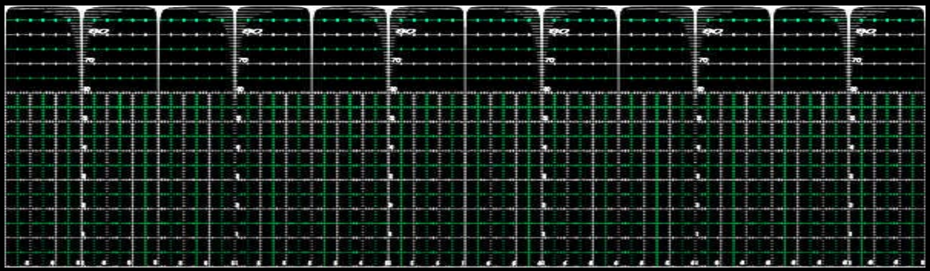
How to Represent a Spherical Image



Polar projection

- Placement of objects on dome is easily understood
- Polar distortion makes image comprehension challenging
- Non-linearity makes post animation challenging

How to Represent a Spherical Image



Equidistant cylindrical

projection

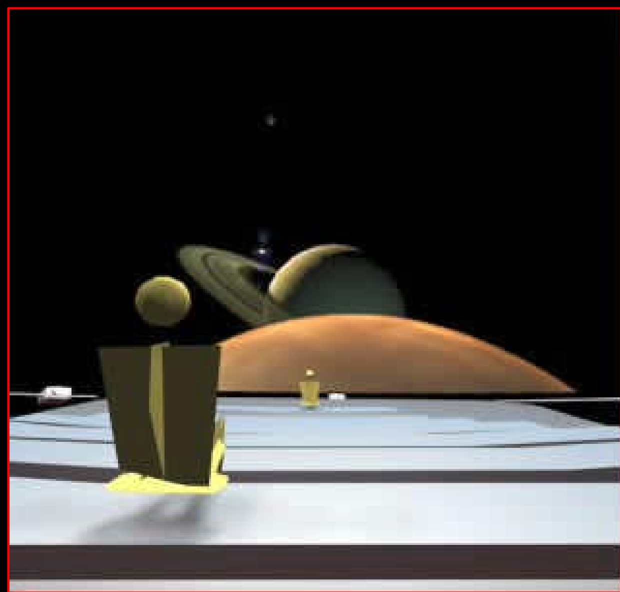
- More difficult to understand placement of objects on dome

- Less distortion of the lower panorama, but more at the top

- Post animation is easier unless objects cross the zenith

How to Represent a Spherical Image

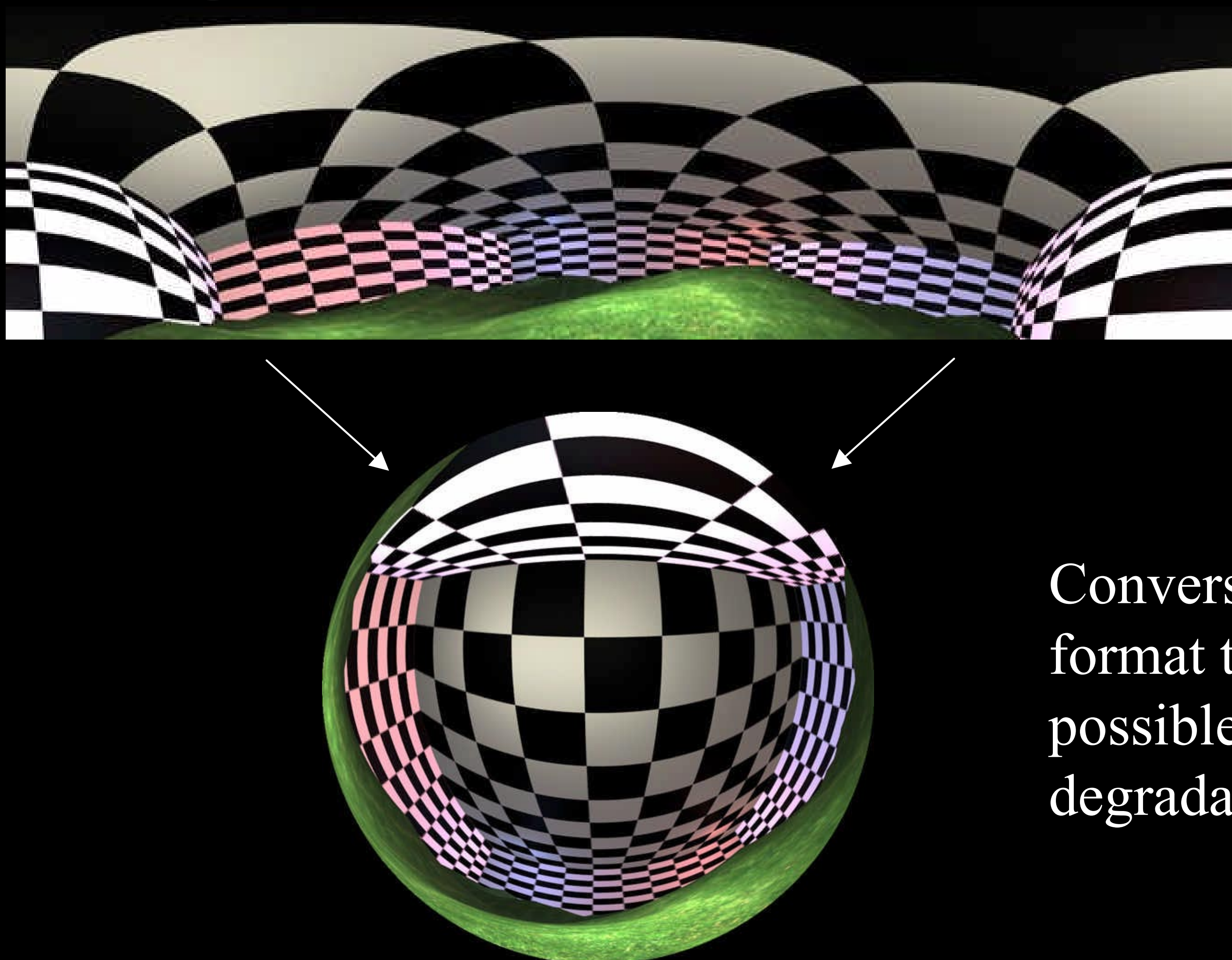
Theater view



Polar view

Cylindrical panorama view

How to Represent a Spherical Image

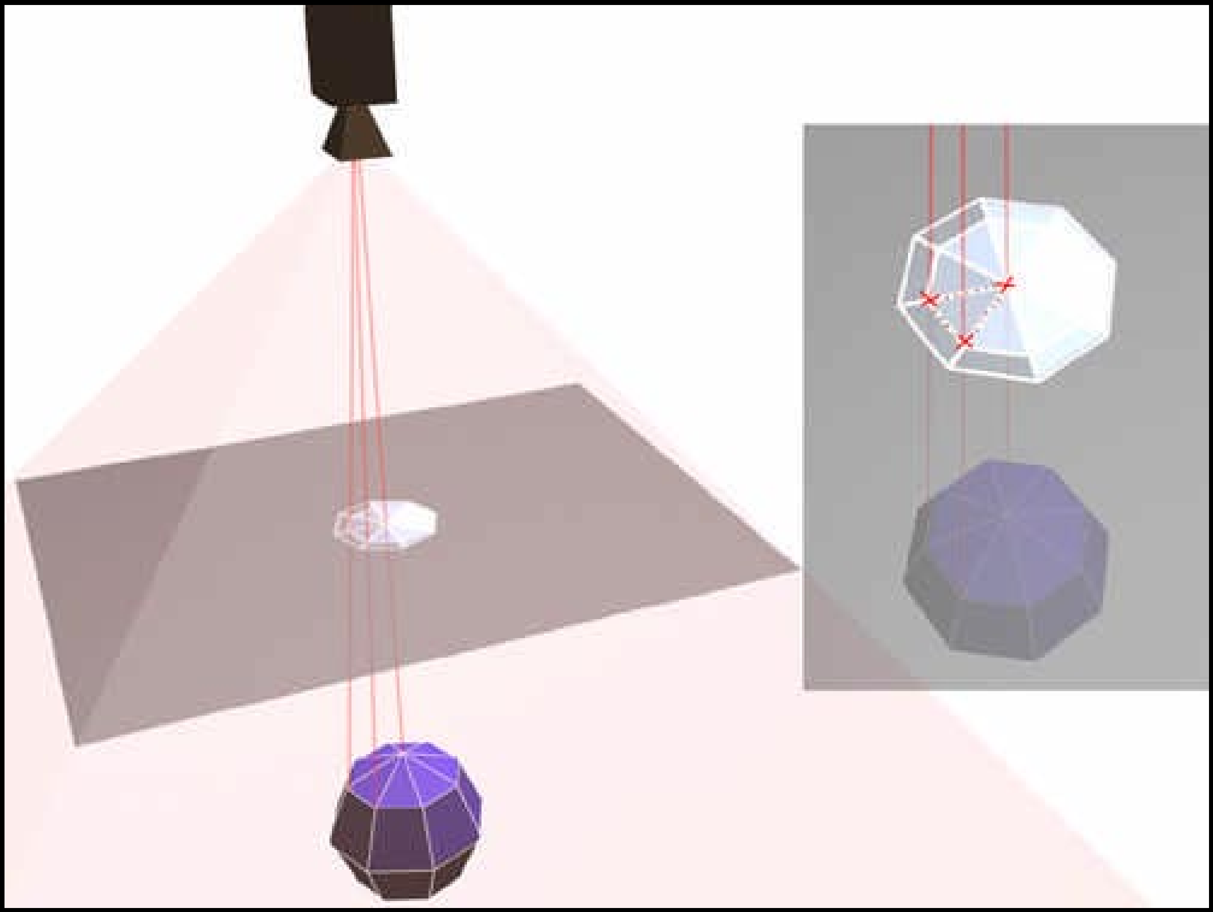


Conversion from one format to another is possible with minor degradation.

Rendering Spherically

- Most 3D software can only render parallel or perspective projections
- These rendering algorithms are highly optimized and efficient
- More general transformations can get more and more expensive as they are composed. This doesn’t happen with 4x4 matrices
- Easier to create alternative camera projections within a raytracer.

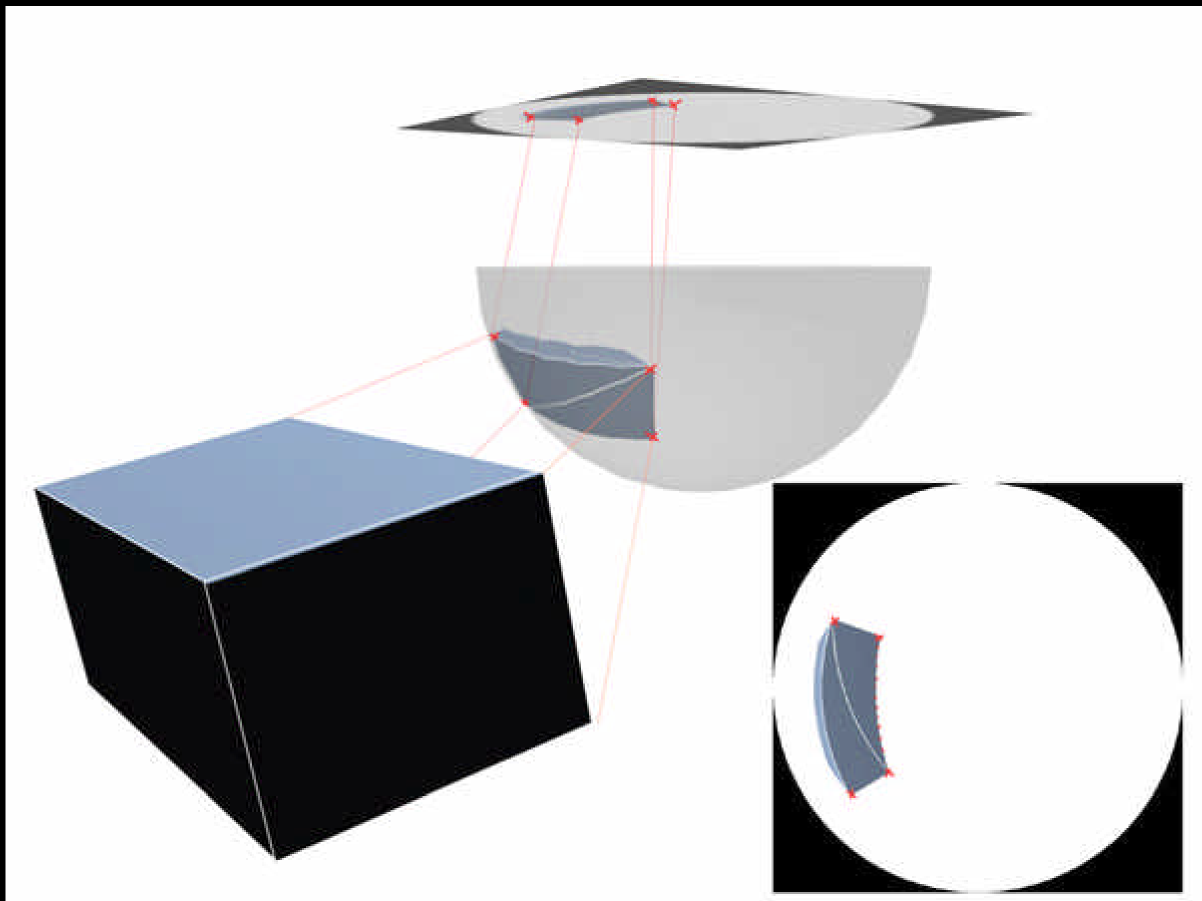
Rendering Spherically



Perspective Projection

Flat plane projections carry polygons to polygons.

Rendering Spherically



More general projections do not work this way.

Polar (fisheye) projection

Two Practical Approaches to Rendering of Spherical Imagery

- Use a renderer capable of alternative projections , i.e. fisheye
  - Limited range of renderer choices...
- Use standard flat plane renderer with hemicube
  - Wide range of choices, along with new limitations

Alternative Projections

- Cebas's RayMax or Spitz's customized variant ImmersaMax are specifically optimized for this
- Mental Ray and BMRT are capable, but less elegant
- POVray has some capabilities as well
- Many new rendering packages on the horizon claim to support this feature

Alternative Projections

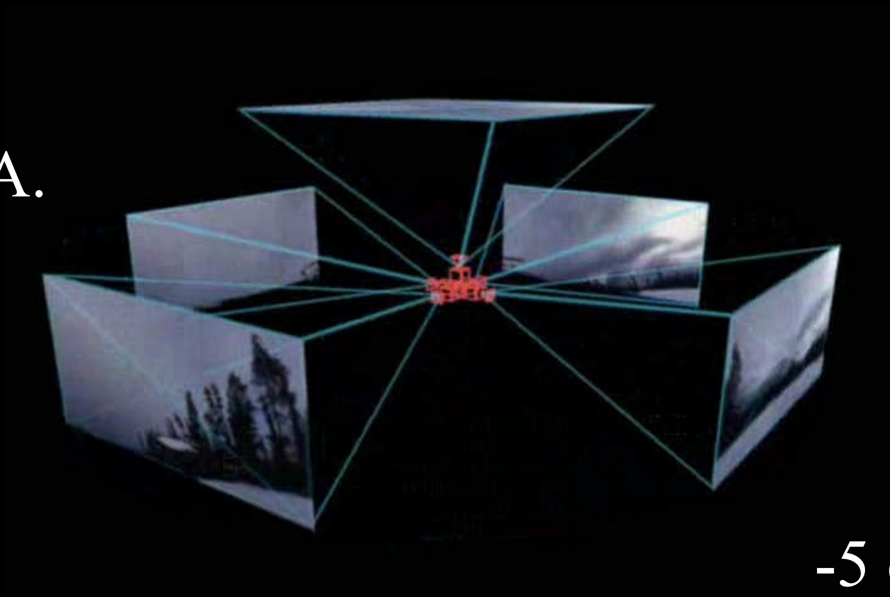
- Image quality is generally higher because no post warping is involved
- Immediate feedback. No post processing required
- Efficiency. Resulting renders are nearly projection ready

Alternative Projections

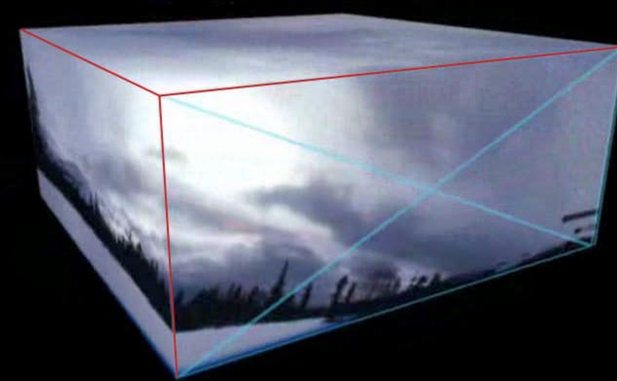
- Smaller storage requirements since finished frames are returned… no need to store "partials"
- Textures and effects that rely on the camera normal usually work better with this method
- Integrated 3D post effects like glows or flares don't show seaming artifacts

HemicubeSolution

A.



B.



- -5 cameras
- -90deg FOV
- -Post process required

C.

D.

HemicubeSolution

- Universality. Any rendering engine that can render perspective projections can be used
- Faster rendering speed, depending on scene
- Cubic map implemented in Apple's Quicktime 5
- Partials are not warped and can more easily be re-purposed for flat screens
- Conceptually familiar to many 3D artists because it's similar to a "cubic environment map"

HemicubeProblems

Hemicubeseaming dangers:

- Texture effects that rely on camera normal
- Particles that rely on camera normal (facing particles)

HemicubeProblems

Hemicubeseaming dangers:

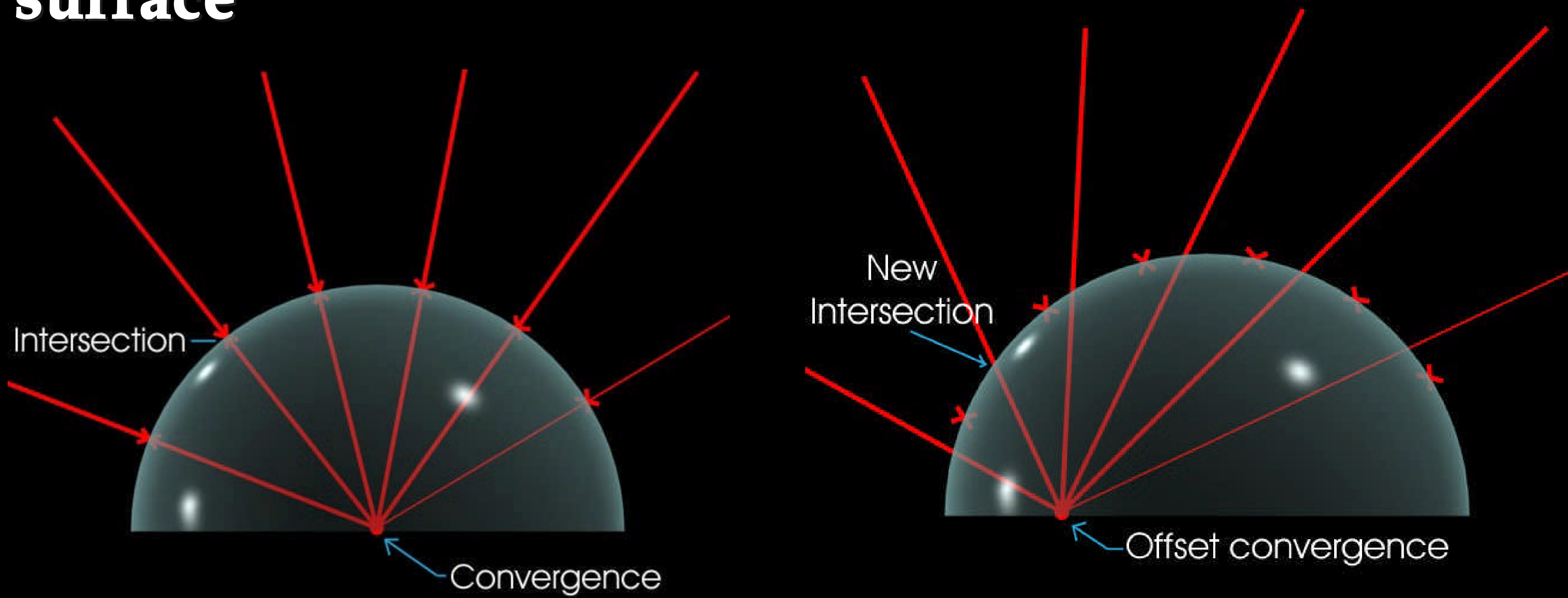
- Post glows based on an object channel
- Lens flares

Eyepoint Offset

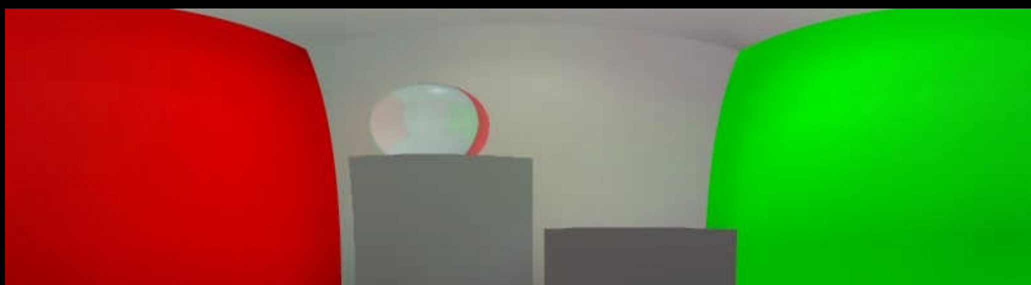
- Geometry only looks absolutely correct from one position in the dome, typically dome center.
- In many applications, there are no seats at this position in the theater.
- An eyepoint offset function can be applied so that geometry looks correct from other seats.
- Can be implemented in both 3D and 2D processes.

Eyepoint Offset

Focal convergence moved away from the projection surface



EyepointOffset



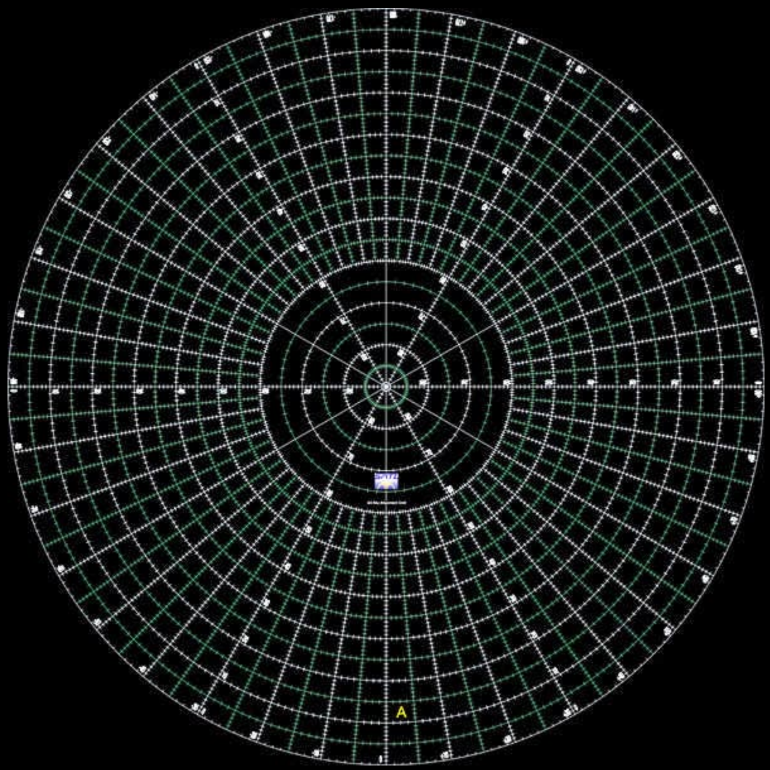
Eye point shifted 50% toward rear of dome

Eye point at dome center

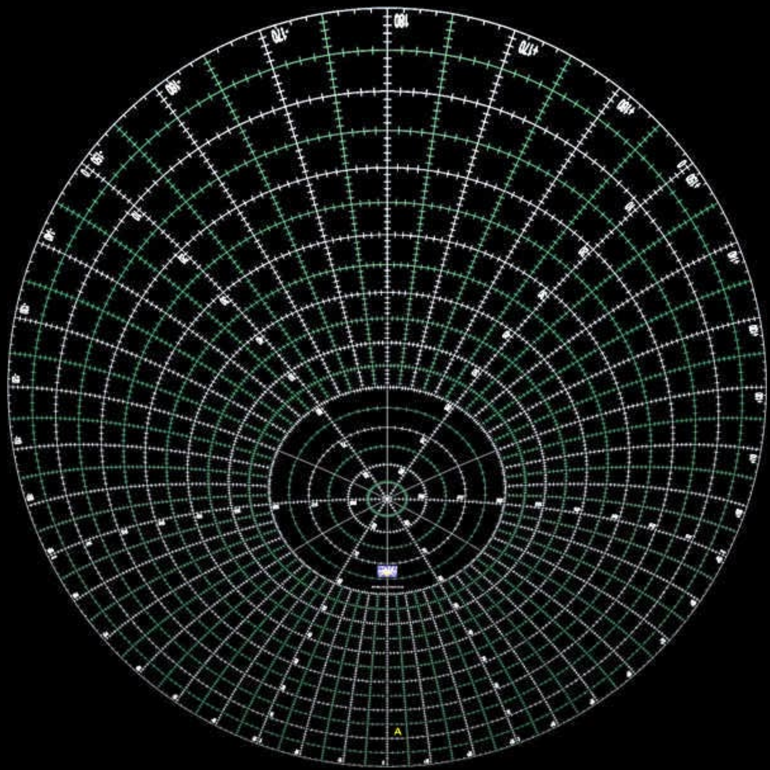
Eye point shifted 50% toward front of dome

Equidistant cylindrical imagery

EyepointOffset

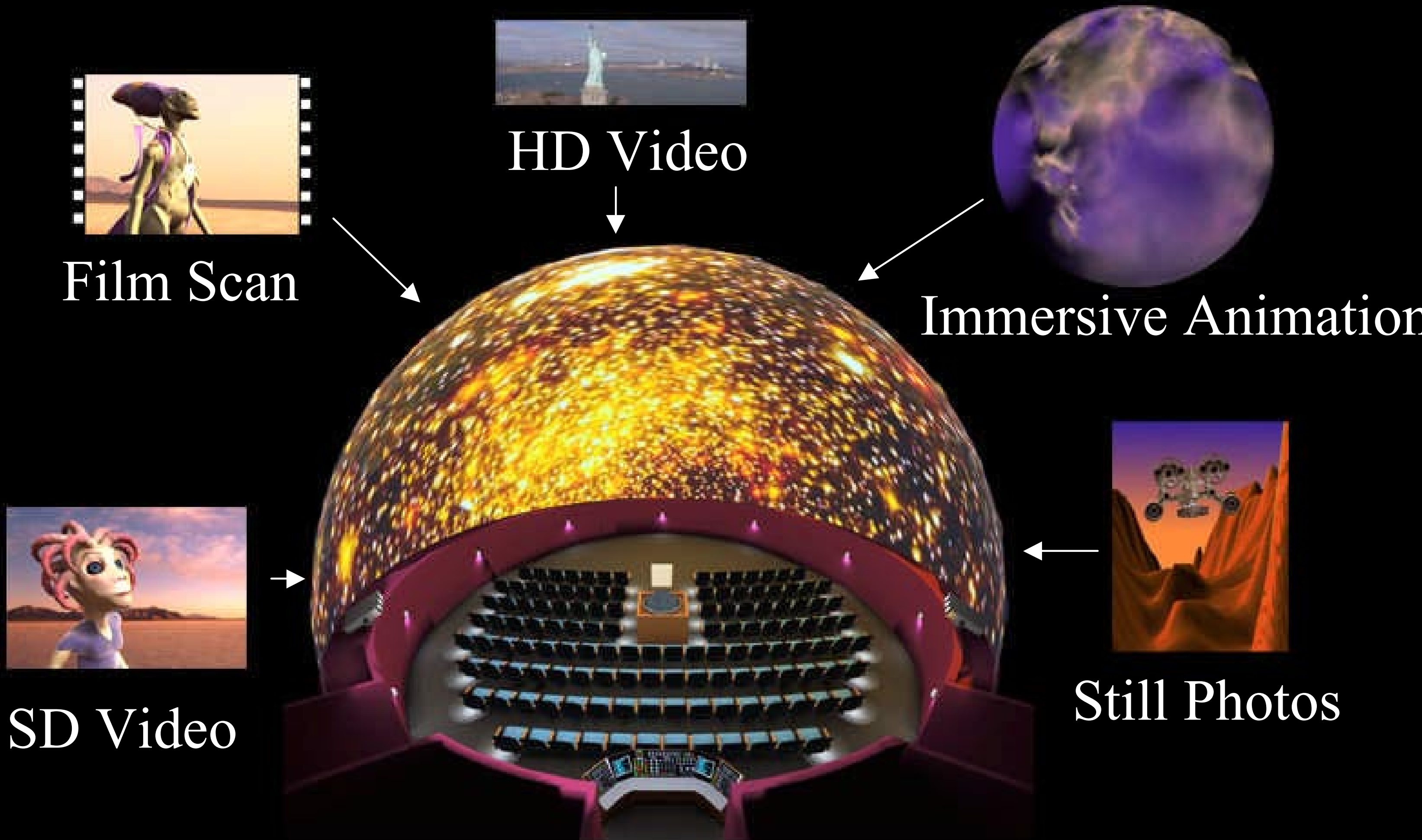


Polar mapping



Eyepoint shifted forward

2D Processing



2D Processing

- Adjusting, compositing, adding to imagery that is already in a spherical format
- Reformatting standard “flat plane” imagery
- Preparing spherical material for projection
- 2D warping is faster than 3D equivalent

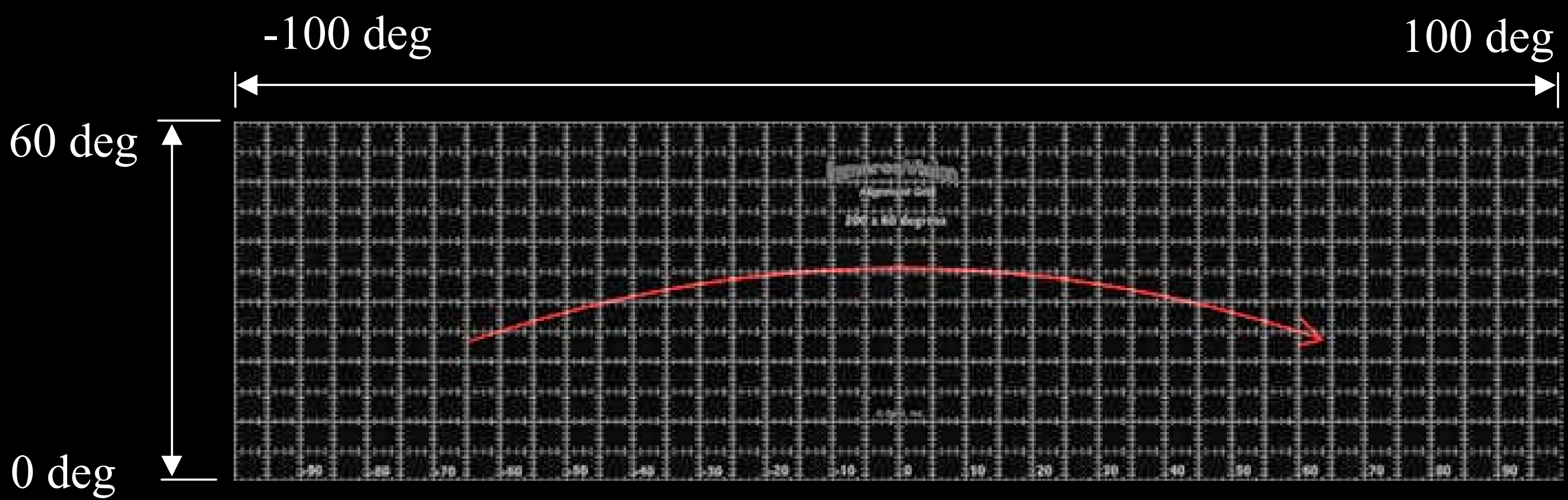
2D Processing

- **Adjusting, compositing, adding to imagery that is already in a spherical format**
  - For many operations, any off-the-shelf, resolution independent compositing/fx package can be used.
  - Uniform image adjustments like color or gamma correction don't require software to be aware of unique format.

2D Processing

- **Adding motion effects may require special handling**
  - Generally, geometry correction isn’t needed if the effect is small in the frame and doesn’t run into a high distortion zone.
  - Effects that cover a large portion of the dome will require geometry correction
  - Animation trajectories are affected by the unique format.

2D Processing

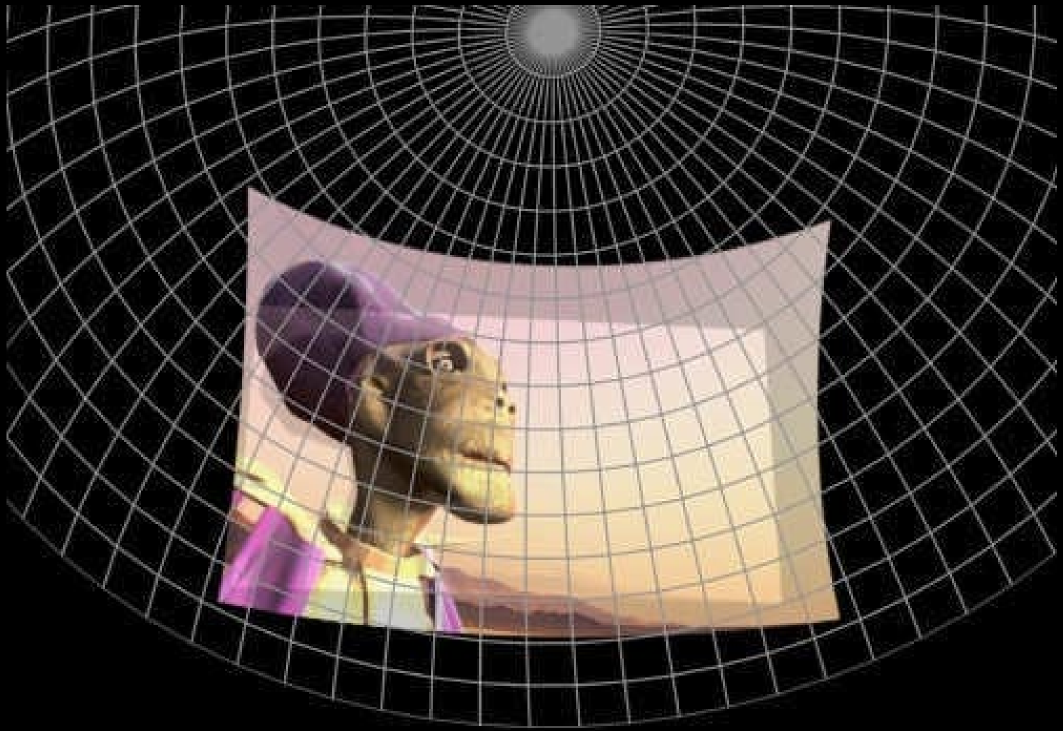


Trajectory of an object moving in a visually straight line through an equidistant cylindrical mapping

2D Processing

Reformatting standard imagery

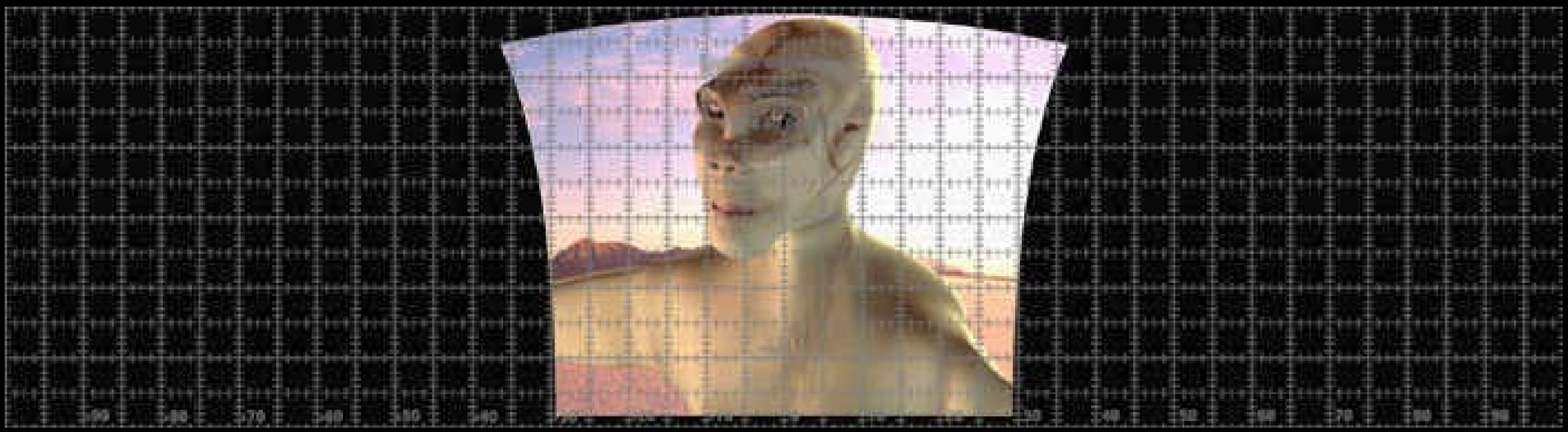
- Processing required to reformat standard “flat” imagery to work on the dome.



2D Processing

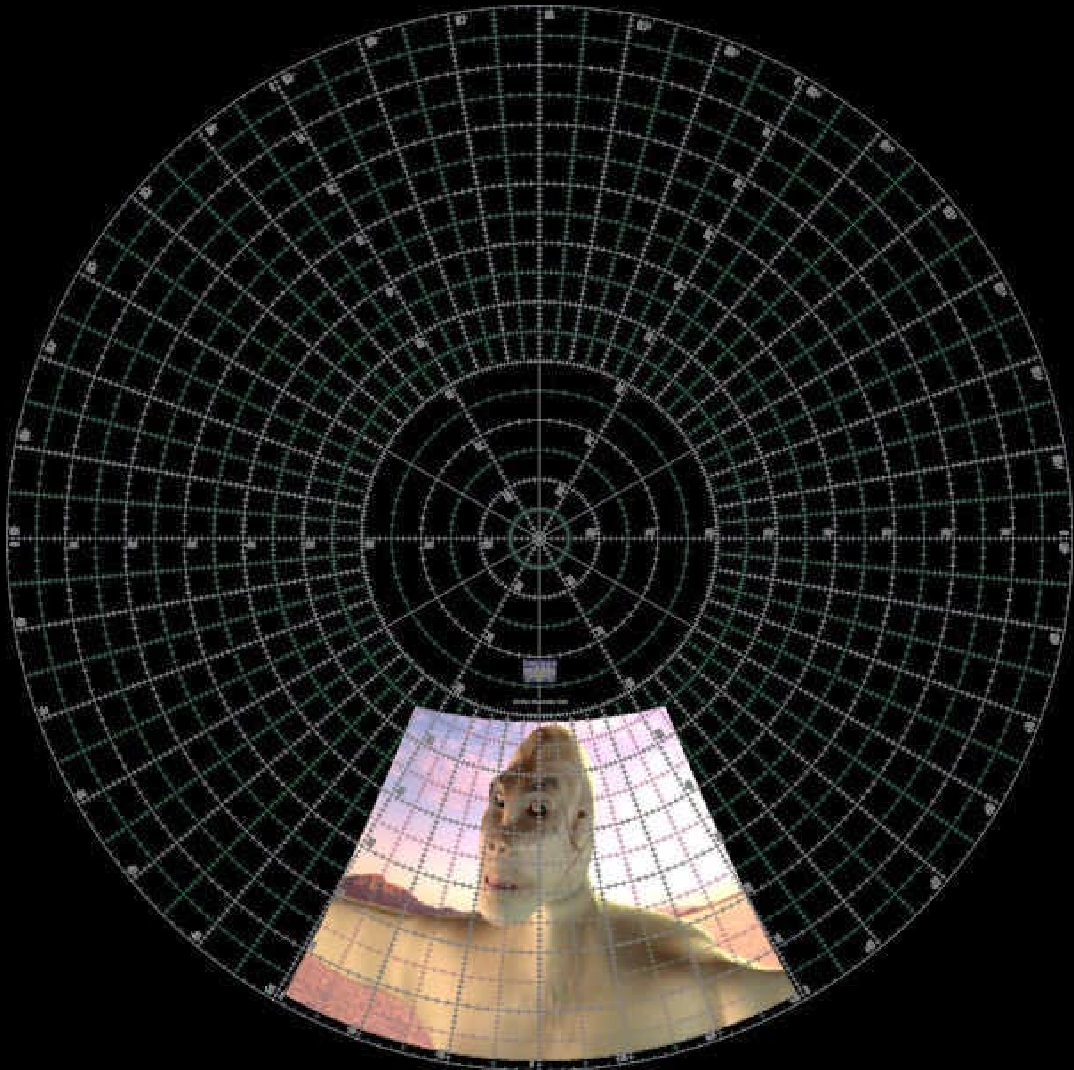
Reformatting standard imagery

- "Billboard" filter creates a virtual flat plane
- Plane can be positioned anywhere on dome
- Theoretical 180 degree limit to horizontal FOV



2D Processing

Source video



Billboard processed video

2D Processing

Conglomerator™ tool

- Constantly evolving, multi-function, stand-alone, batch image warping tool written by Spitz, Inc.
- Mapping conversions, hemicube stitching, image cropping
- Simple GUI or command line execution for scripting.

2D Processing

Panorama stitching tools:

- Several commercial stitching tools are currently available for sale or for free (see references)
- Panoramic photography can be easily formatted for direct display on the dome.
- Can be useful as photographic sets for animation or Paul Debevec HDRI style light sources.

Editing and Finishing

Most immersive projection systems rely on multiple edge-blended projectors

- Master frames must be broken out into separate video streams for each projector
- These separate streams are then played back synchronously under the control of a theater automation system.

Editing and Finishing

2 ways of editing various clips into a full show

- Split master frames first, create edit from low resolution proxies, then conform each projector stream to the edit
- Edit first, perhaps on low resolution proxies first, then conform the full resolution master frames to the edit. Splitting into projector streams is done to the final edited master sequence

Editing and Finishing

Split first method

- Reduced storage requirements since you can work with encoded video.
- Off-the-shelf editing software can be used because the resolutions are standard
- Faster processing due to smaller frames and less disk I/0

Editing and Finishing

Edit first method

- Advantage is that you end up with a full resolution "master" edit that can be more easily converted for playback in different formats and theater projection configurations, and is easier to preview.
- Much greater working storage requirements
- Requires resolution independent editor
- Slower

Storage Requirements

Most common resolutions for "Master" frames are 8 or 10 bits per color channel at:

- 1800x486 Panoramic/partial dome
- 1024x1024 Single lens SXGA projection
- 2200x2200 SD full dome projection
- 2800x2800 HD full dome
- 4000x4000 Ultra HD full dome

Storage Requirements

Worst case calculation:

- 4000x4000 = 16,000,000 pixels per image
- 30bits of color info per pixel = 480,000,000 bits per image or about 60 megabytes.
- at 60fps = 3,600 megabytes per second
- 20 minute show = 4,320,000 megabytes
- double storage for editing = over 8.5tb

Storage Requirements

Of course these requirements can be reduced by:

- using 8 bit per channel color depth
- using lossless compression on frames (RLE)
- dropping to 30 fps
- using “split first” editing method
- good planning and understanding of process

Real-Time Rendering on the Dome

- Technology pioneered in the simulator market.
- Use in theaters for entertainment and education is new
- Several theaters currently in operation that are using this technology
- Incredible future potential.

Real-Time Rendering on the Dome

Real-Time Rendering Issues:

- Image quality limited by hardware speed
- Motion magnification makes lower frame rates unacceptable
- Artifacts are magnified because of wide FOV
- Motion magnification may cause "cybersickness" if control is not smooth

Real-Time Rendering on the Dome

Real-Time Rendering Issues:

- Advanced rendering techniques not yet available in real-time systems
- How do you have the whole audience interact in a meaningful way?

Real-Time Rendering on the Dome

Benefits and Potentials:

- Immersion plus interactivity may mean a deeper experience for the viewer
- Increased level of participation
- Increased willingness to suspend disbelief

Real-Time Rendering on the Dome

Benefits and Potentials:

- Could serve as pre-viz tool for animators
- Instant gratification with animation tests
- Fosters experimentation
- Theater could double as a visualization tool for scientists or engineers

Thinking Toward the Future

Production tool advancements:

- Hope to see arbitrary/programmable camera projections available in more off-the-shelf 2D and 3D packages and rendering engines
- Real-time preview of alternate camera projections in 3D packages for more WYSIWYG and less "render and pray"

Thinking Toward the Future

Production tool advancements:

- More robust editing solutions that fit the needs of immersive video producers
- Truly resolution independent digital editor capable of working in real-time, using low resolution proxies for offline conforming of either full resolution clips or projector sub-frames

Thinking Toward the Future

Better visualization tools:

- Not every animation house has a dome theater to view dailies
- A QTVR-like dome movie previewing software would help those without a dome be able to visualize what their images will look like prior to projection

Thinking Toward the Future

Better visualization tools:

- A cheaper single lens projector/portable dome system that could be purchased or rented by a production facility for low cost viewing of dailies
- Generally easier to use, less “academic” interfaces for our tools

Thinking Toward the Future

More invisible integration between software and theater hardware

- Standardized/unified interfaces for all the tools from production through theater automation
- Better hardware abstraction so that you don't need to "know the rack" to make a show

Thinking Toward the Future

Standardization of theater systems:

- This will allow easy content sharing between theaters
- Easy, less expensive distribution for immersive producers. Theaters themselves should not need to do any production work.
- Opens a larger market for content providers.

References:

Rendering:

Hemispherical video production:
http://astronomy.swin.edu.au/pbourke/projection/skyvision/

Spherical Rendering info:
http://wwwcs.unc.edu/~zimmons/cs238/maps/environment.html

A Realistic camera model for CG:
http://graphics.Stanford.EDU/papers/camera/

Full Dome Video planetarium production: http://wwwplanispherecom/

Makers of RayMax and FinalRender: http://wwwcebas.com

Makers of Mental Ray renderer: http://wwwmentalimages.com

Makers of BMRT: wwwexluna.com

POV-Ray raytracer: http://wwwpovray.org/

SIGGRAPH 2001 EXPLORE INTERACTION AND DIGITAL IMAGES

References:

Rendering:

Paul Debevec's HDRI lighting page:
http://www.debevec.org/Research/HDR/

Chris Subagio's dome light tool: http://www.3dluvr.com/subagio/domelight/HDRdome.html

Image based rendering of realistic lens systems:
http://www9.informatik.uni-erlangen.de/eng/research/rendering/lensmodel/

Cubic environment mapping: http://www.iqtvra.org/DeFish/fisheye.html

SIGGRAPH 2001 EXPLORE INTERACTION AND DIGITAL IMAGES

References:

Image processing:

Panorama tools: http://www.fh-furtwangen.de/~dersch/

Realvis multi image stitching tools: http://www.realviz.com

Guide to panorama stitching software: http://www.panoguide.com/

International Quicktime VR assoc.: http://www.iqtvra.org/

Spherical imagery aquisition:

Panoscan: http://www.panoscan.com

http://www.fpvideo.com/index_p.html

Discussion Groups:

Full-dome Video Discussion Group:
http://groups.yahoo.com/group/fulldome

SIGGRAPH 2001 EXPLORE INTERACTION AND DIGITAL IMAGES

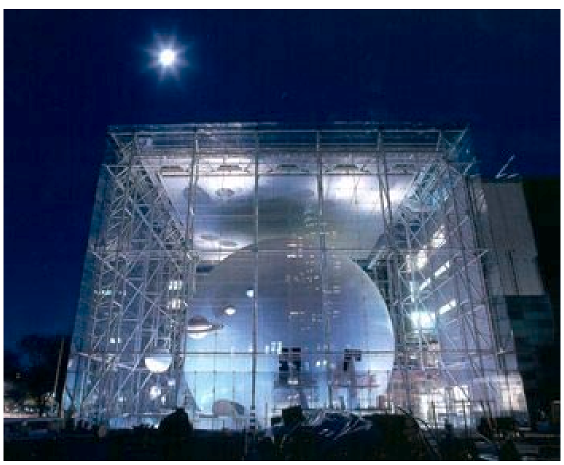
Tools and techniques for real-time dome production and education

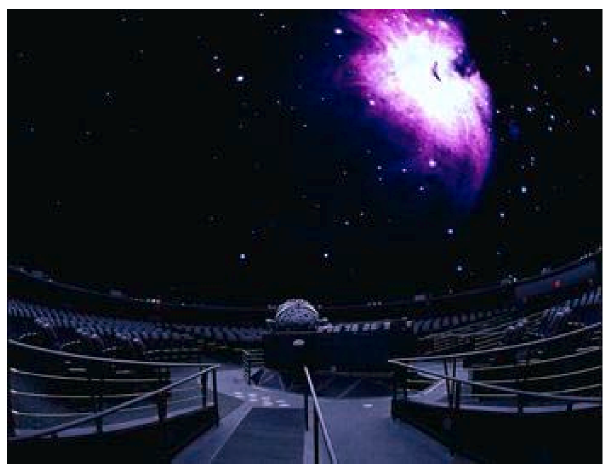
Carter Emmart
Director of Astronomical Visualization
The new Hayden Planetarium at the Rose Center for Earth and Space
American Museum of Natural History
carter@amnh.org

Introduction

New York City's Hayden planetarium originally opened in 1935 with a Zeiss Model II planetarium projector. In 1997 it was shut down for renovation. The new Hayden Planetarium opened last year and has been hailed as the most advanced large-scale immersive theater in the world. In addition to a 7-projector full dome video system and 7-pipe SGI Onyx2®, the new Hayden also has the latest Zeiss Mark IX star projector. The 429-seat hemispheric theater is housed inside an 87 ft. diameter sphere.

This presentation reviews the real-time hardware and software tools employed at the new Hayden, and discusses techniques learned from the application of these advanced tools in the production of educational programs.





Photos © D.Finnin/AMNH

Clockwise from top left, the Hayden Sphere at night, planetarium interior with Zeiss Mark IX projecting 9,100 stars, and having fun in the Cullman Hall of the Universe.

Real-time tools for the Hayden Planetarium

I. Hardware

Two SGI Onyx2 IR-2 graphics computers:

A. For Dome: In addition to running real-time applications, this machine runs stored show movies from disc arrays, performs as a rendering engine, and does astrophysics simulations:

Seven graphics pipelines, 28 processors, 16GB ram, 90GB internal drives, 2TB external storage on Ciprico-7000's

B. For production testing, real-time, rendering, HD video editing, and astrophysics simulation:

Three graphics pipes, 12 processors, 6GB ram, 45GB internal drives, 550GB external Ciprico raid arrays for HD video editing, and 270GB external Ciprico raids for development work.

Three SGI Octane's

Ten SGI O2's

II. Software

A. C-Galaxy, Aechelon Technology Inc.

Real-time, Performer based software co-developed by AMNH and Aechelon to visualize a digital model of our Milky Way galaxy. This development was part of the NASA sponsored foundation project for education at AMNH called the Digital Galaxy Project.

Display of 25,000 charted stars from the European Space Agency's Hipparcos Star Catalog blended seamlessly with one billion stars mapping out the extent of the Milky Way from an astrophysical statistical model. Additional non stellar objects as alpha texture maps also supported. Constellation line connectivity and additional support graphics available with real-time edit capability.

Three basic modes of scale available, including Solar

System, interstellar and external Milky Way viewing.

B. Everest, PEAK

Real-time production software primarily used for broadcast media.

Used at AMNH in daily production of electronic signage and constantly updated science bulletins. Supports high definition Earth Event Wall projection and Astro Bulletins multi screen power wall.

Seven synchronized channel version for dome used for support graphics in productions and presentations. Rapid diagrammatic prototyping and modeling is fast and easy in dome environment or from desktop workstations.

High definition and digital video inputs can be run through Everest for manipulation in virtual worlds for dome or fed out to bulletins.

C. Virtual Director, National Center for Supercomputing Applications

Interactive, remote collaborative, flight path scripting and scientific visualization display software.

Developed for use in NCSA's Cave immersive display, this software was configured to also work in dome to support show production. Collaboration between AMNH and NCSA is through the National Computational Science Alliance's Grand Challenge Cosmology Consortium. This collaboration has allowed us to co-develop models and applications that run in this environment as well as on a desktop/laptop version of the display set called Partiview which spans multiple platforms.

Scalability of visual data display from Virtual Director in our dome on down to multiple platform Partiview on desk and laptops allows maximum flexibility for educational use as well as production effort. Results will be demonstrated in class.

Collaborative potential allows remote viewing and manipulation between multiple sites and platforms.

Examples of models from different data sets will be shown, and include the AMNH model of the Milky Way made up purely of observed data, and University of Hawaii astronomer, Brent Tully's atlas of galaxies beyond the Milky Way.

III. Remote tools

National Center for Supercomputing Applications' Cave:

In production, models can be shared between AMNH and NCSA, where either site can create and edit flight paths through either static or animated data sets and simulations.

Desktop and laptop Partiview:

Data and support graphics can be set up and edited remotely in NCSA's Partiview for study. This preparation is the ground work for what can then be loaded into the dome display via Virtual Director. Flexibility of this kind means that one can study certain problems prior to dome scheduling.

Remote collaborative function means that multiple institutions, domes, caves, power walls, and smaller scale multiplatform end users can share in simultaneous viewing of real-time exploration of data sets, and sessions or paths can be archived for later reference. Educational potential of this is just beginning to be examined.

Techniques learned with real-time capability

Various results of this discussion will be demonstrated in class and at the CAL after the course.

Our goal is to simulate various astronomical phenomena. Subtle and constant motion elucidates the third dimensional nature of many of these astronomical environments and objects. This is perhaps the most important key to being able to interpret form from what is inherently an abstract realm given the alien environment it represents in comparison to the world we ordinarily confront.

Motion control in real-time allows for careful study of how best to examine structures within models displayed. Immediate feedback of manipulation saves iteration time of non real-time set ups. One gets to "live with" the environments and gains a familiarity from a basis of presence. For example, using Maya preview renderings, we had thirty three study moves on the Orion Nebula before we were satisfied with results. This technique predated our use of Virtual

Director, NCSA's interactive flight path scripting software. Now a much more intuitive process to craft camera moves in the dome environment can be accomplished.

From scripted camera moves in real time, software renderings to higher orders of quality and techniques such as volumetric rendering can then be used to create non real-time movies for playback. After our Orion move was approved, it was then carefully volume rendered with the San Diego Supercomputer Center's MPIRE renderer by Dave Nadeau and Jon Genetti.

Other scenes from our premier show "Passport to the Universe" were Choreographed and polished by Bob Patterson, Donna Cox and Stuart Levy in the NCSA cave. Traversal of the Tully galaxy atlas and Jeremiah P. Ostriker's simulation of large scale structure of the universe was crafted in the cave and then approved in dome.

Real-time adjustment of visibility and relationships of objects and appearance is key in the dome given its unique display environment. Projection display issues such as cross reflectivity and color saturation are best adjusted interactively in dome when possible. This is a great time saver as well.

The abilities to control astronomical models in real-time and interactively adjust the display of data groups and their appearance is an obvious path toward teaching the relationships and meanings of the models. Perhaps the best way to educate visitors about these concepts is to demonstrate them interactively as if they were there in front of the audience. We find that interactivity in the manner of "tour guide" is perhaps the best use of the real-time capability for educating.

Links

GALACTIC MPIRE: Flying through the Digital Galaxy
http://mpire.sdsc.edu/hayden99.html

Rose Center for Earth and Space
http://www.amnh.org/rose/

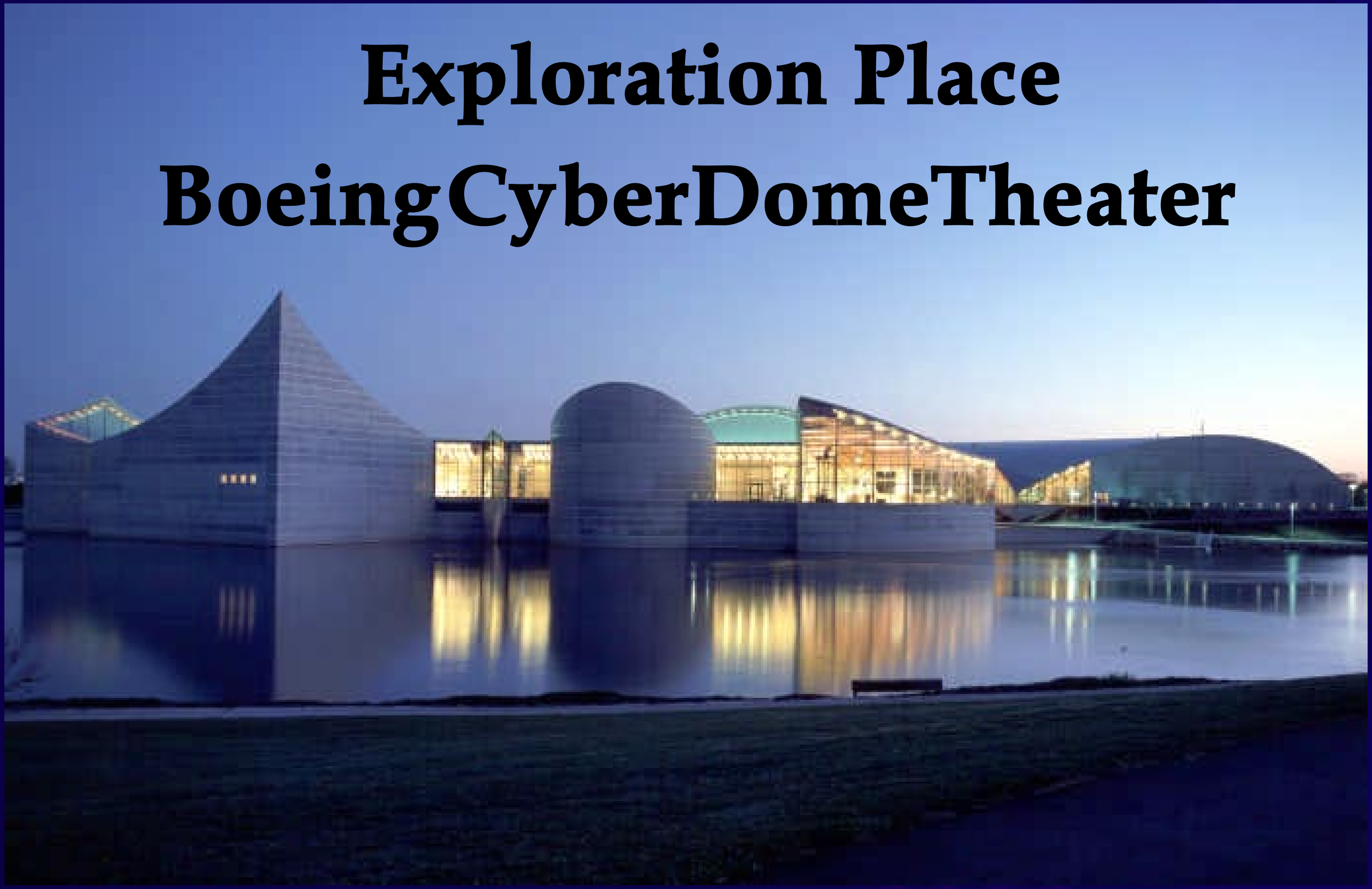
National Center for Supercomputing Applications (NCSA)
http://www.ncsa.uiuc.edu/

Grand Challenge Cosmology Consortium
http://zeus.ncsa.uiuc.edu:8080/GC3Home.html

San Diego Supercomputing Center
http://www.sdsc.edu/

A Voyage to Orion: This view of the stars, gas, and dust clouds at the center of the Orion Nebula is an example of the images produced using the MPIRE Galaxy Renderer. The image is based on a 3-D model and color-corrected images by C. R. O'Dell and Zheng Wen of Rice University.

RealtimeInteractive Show Production



ExplorAtion PLACE

Boeing CyberDome Theater

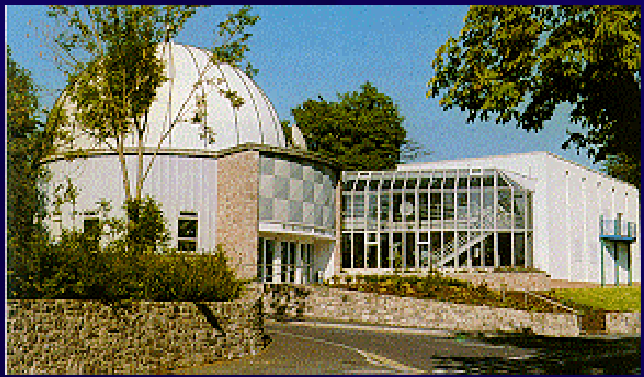
Interactive Domed Theater Overview

- **Armagh Planetarium, N. Ireland – 1985**
- **Buhl Planetarium, Pittsburgh, PA – 1991**
- **Boeing CyberDome, Wichita, KS – 2000**

- Multimedia domed theaters (video, star projection, slides, surround sound audio)
- 3-5 button interactive handsets on each seat
- Polling, voting, branching decisions, direct control or "flying" interaction (CyberDome).

Armagh Planetarium
N. Ireland, 1985

- First use of video projection in a planetarium.
- 100 seats
- 3-button polling interactive driving 4 video disk players.
- MSX multimedia automation
- Video brightness and contrast tweaked by hand
- Branched programming – audience chose what topic to see next.



ExplorAtion PLACE

Boeing CyberDome Theater

Buhl Planetarium
Pittsburgh, PA, 1991

- 2nd Interactive Planetarium in U.S.
- 150 seats
- 3-button seat mounted interactive units
- Branch Programming w/ SPICE Runshow
- Digistar
- SPICE Automation
- Tight multimedia/interactive integration

Boeing CyberDome Theater
Wichita, Kansas, 2000

- 60-Foot Diameter Dome
- 170 Interactive Seats
- 30-Degree Tilt
- 4-Projector StarRider
- Digistar II
- Separate Video Field
- All-Sky Slide System

Exploration Place

Boeing CyberDome Theater

Boeing CyberDome Theater
Wichita, Kansas, 2000

- 2nd E&S StarRider
- Real-time rendering engine
- Full dome real-time mass interaction

Exploration PLACE

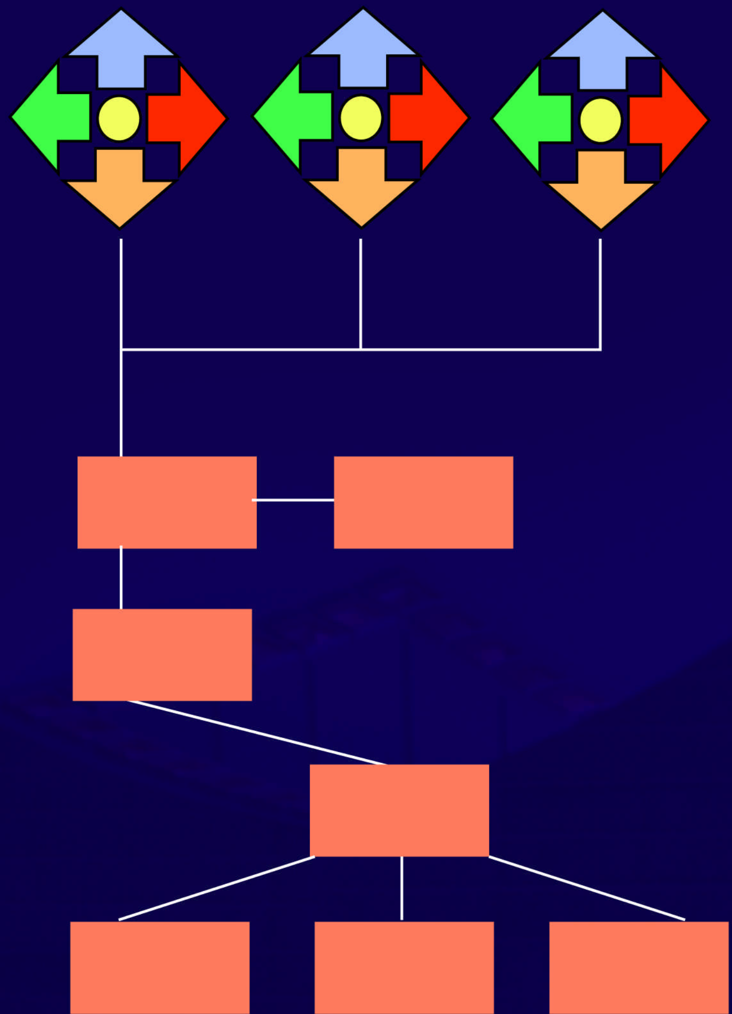
Boeing CyberDome Theater

Interactive Overview

Types ofInteractives

- Polling – Getting audience feedback using questions
- Branching – Audience choose show content
- Q&A – Content quizzing, testing and trivia
- Realtime – Actual control over graphic elements and cameras.

Interactive Signal Flow



5-BUTTON INTERACTIVE HANDSETS

TARRAGON UNITS

STARRIDER HOST

E&S IMAGE GENERATOR

SEOS VIDEO OUTPUT

Exploration PLACE

Boeing CyberDome Theater

Boeing CyberDome Theater Interactive Overview

- Mars Landing – from *CyberExplorer*
  - Audience collectively lands on Mars
- Cell Wars – from *CyberExplorer*
  - Audience destroys bacterial infection
- Continental Drift – from *CyberExplorer*
  - Rearrange the continents to create a new earth.

Boeing CyberDome Theater Interactive Overview

- Stellar Parallax – from *Crack the Cosmic Code*
  - Guess stellar distances from their parallax movement
- Speed of Light Trivia – from *Crack the Cosmic Code*
  - Just how fast is light?
- Crab Nebula/Black Hole Fly – from *Crack the Cosmic Code*
  - Navigate through these star remnants in search of clues

Boeing CyberDome Theater Interactive Overview

- Spectral Analysis – from *Crack the Cosmic Code*
  - Use the Hubble Space Telescope to get an object's spectrum and tell how its moving

Mars Landing Interactive

Goal: to safely land a futuristic Mars glider on “Lowell Base” on Mars.

Audience input is averaged and resultant send to image generator to control glider

More audience equals more success

Exploration PLACE

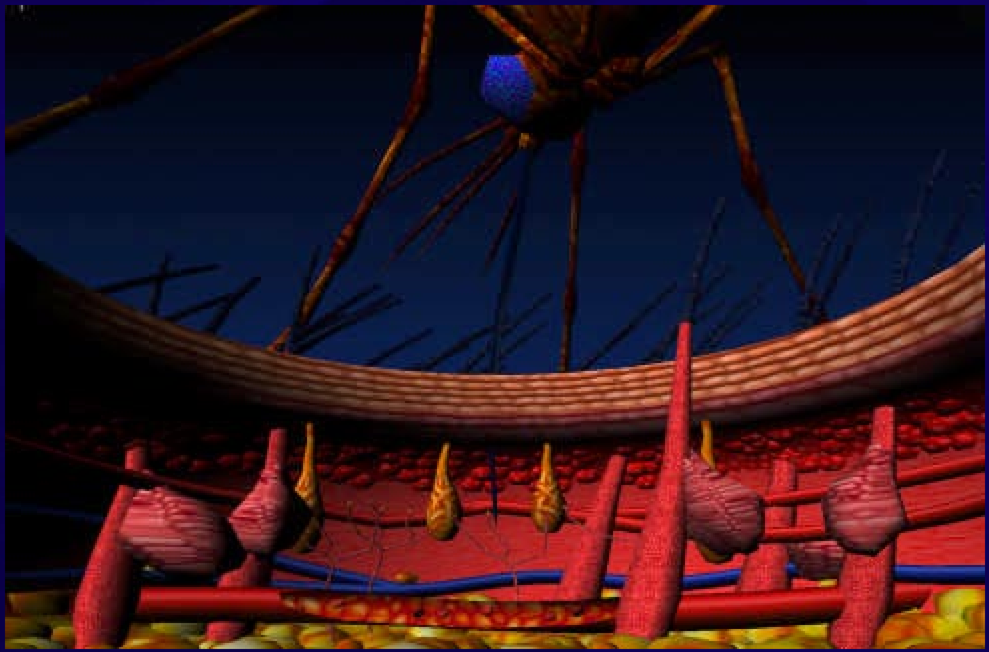
Boeing CyberDome Theater

Cell Wars Interactive

Goal: After splitting up into teams, each team's white blood cell must maneuver and destroy a bacterial infection.

Each team's input is averaged, and the resultant sent to the image generator.

Less players per team equal more success



ExplorAtion PLACE

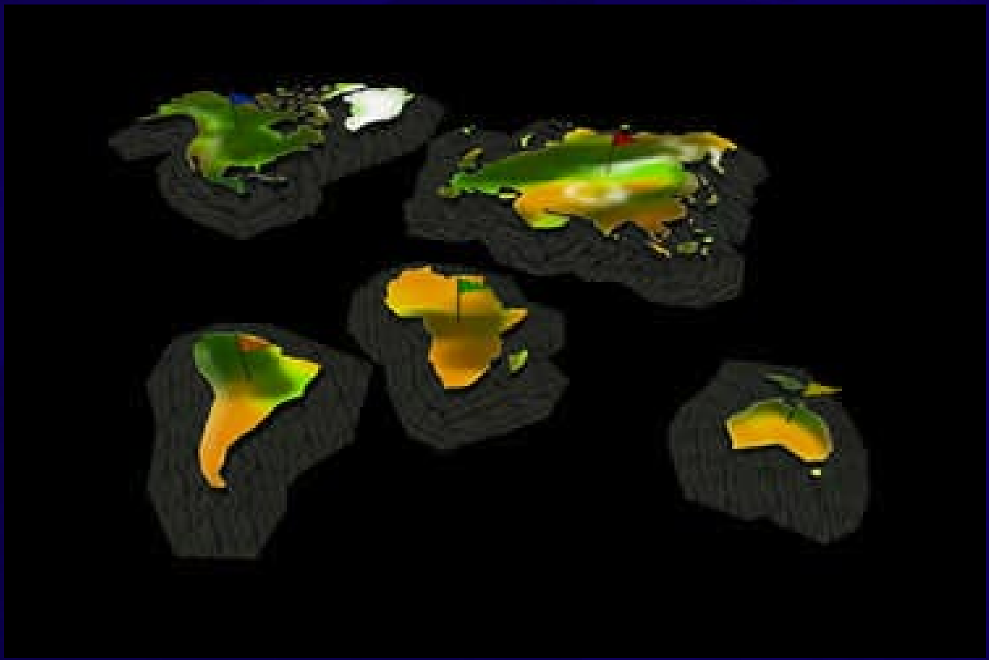
Boeing CyberDome Theater

Continental Drift Interactive

Goal: After splitting up into teams, each team is assigned a continental plate to move around the face of past and future Earth.

Each team's input is averaged, and the resultant sent to the image generator.

Result compared to common reference point – an Earth map.



ExplorAtion PLACE

Boeing CyberDome Theater

Stellar Parallax Interactive

Goal: After splitting up into teams, each team is assigned a continental plate to move around the face of past and future Earth.

Each team's input is averaged, and the resultant sent to the image generator.

Result compared to common reference point – an Earth map.

ExplorAtion PLACE

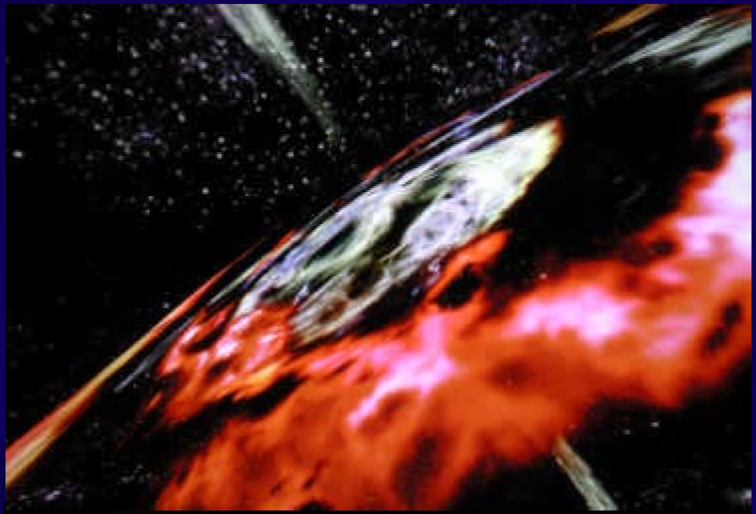
Boeing CyberDome Theater

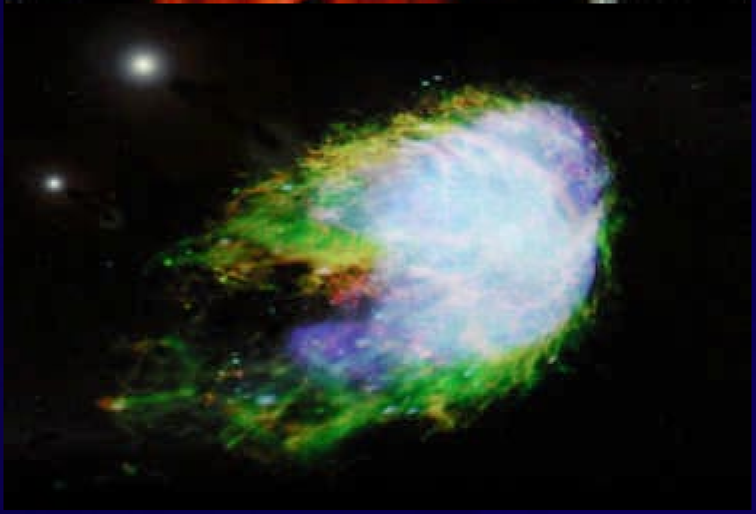
Crab Nebula/Black Hole Flights

Goal: The audience is in control of the theater as they search for a pulsar in the crab nebula. Later, they try and escape the gravity of a black hole.

Audience input is averaged and resultant sent to image generator to control flight path.

Mysteries await as the audience searches and explores on their own.





Exploration PLACE

Boeing CyberDome Theater

Speed of Light Trivia Interactive

Goal: The speed of light is fast – but the Universe around us is large. A series of questions let the audience guess at how long light takes to travel to various parts of our solar system.

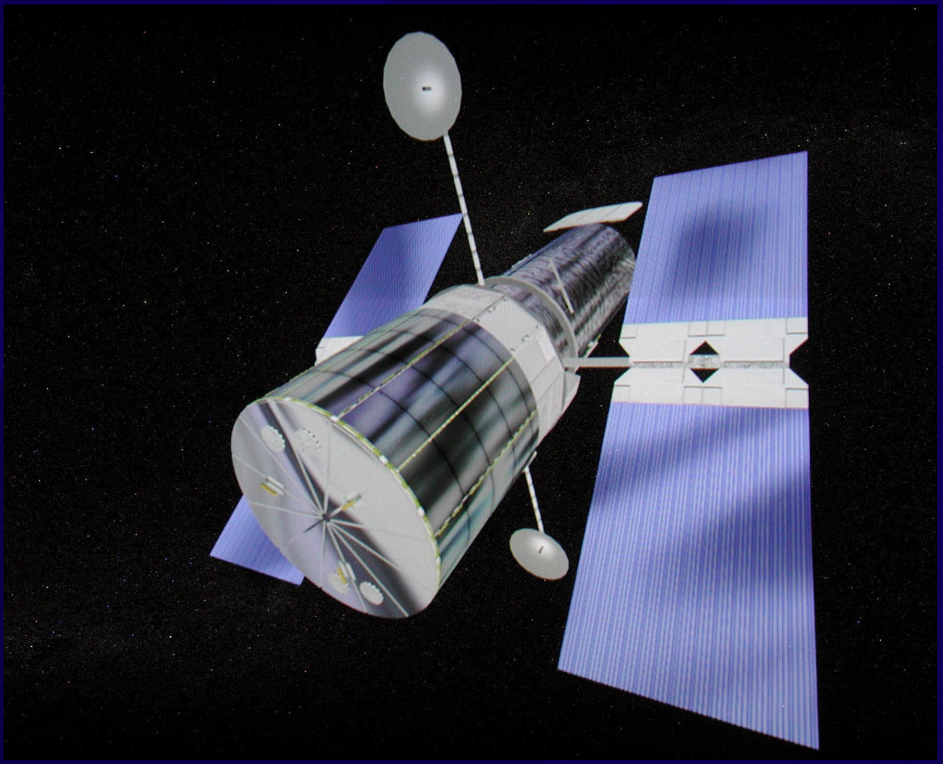
The audience votes for their answer. Score is kept and shown through a seating chart of the theater.

Spectrum Analysis Interactive

Goal: Using a virtual space telescope, the audience analyzes spectra from different objects. Are they moving toward us, away from us, or are they spinning?

The audience votes for their answer. Score is kept and shown through a seating chart of the theater.

Reinforces the basic concept of red and blue shift in astronomy.

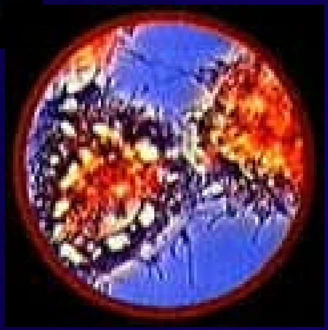


Exploration PLACE

Boeing CyberDome Theater

Other Notable Interactive Shows
Journey Inside the Living Cell, 1994

- Simple realtime interactive rendering of video on dome.
- Audience collectively maneuvers cells around body.
- CINEMATRIX Interactive Entertainment System® wireless interactive paddles with image recognition camera.



Exploration Place

Boeing CyberDome Theater

The Future of Realtime Interactive Show Production

- Create meaningful interactive experiences for visitor
- Graphic and projection quality will improve
- Production tools will get more artist friendly

IMMERSIVE THEATER RESOURCES

This Bibliography is provided for those wishing to research spherical display history, applications and related technologies. Following the alphabetical listing, sources are listed according to category. These sources span many disciplines, including planetaria, cinema, motion simulation, psychophysics and cognitive science, military systems, virtual reality and computer graphics. We have also added a listS of related web links, professional societies and vendors. We hope you find it useful.

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TRADE ORGANIZATIONS

Giant Screen Theater Association (GSTA)

The Giant Screen Theater Association is a network of organizations and individuals that are involved with or interested in the large-format screen industry. TheGSTA was founded in 1977 by four educational institutions that housed 15 perforation/70mm projection equipment. The goal of the GSTA was to foster information exchange and to work collaboratively on film production. The organization is incorporated as a nonprofit group. The GSTA has grown steadily since 1977 and currently has 81regular members, 60 developing members, and 204 associate members, representing 31countries. In addition to the 15 perforation /70mm theaters, GSTA also welcomes 8 perforation/70mm and 10 perforation /70mm theaters as Theater Members. The organization is not directly involved in film production, although individual members and groups of members have produced large-format films.

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American Widescreen Museum
http://www.widescreenmuseum.com/widescreen/intro.htm

Cybersphere Spherical Projection System
http://www.ndirect.co.uk/~vr-systems/sphere1.htm

Full Dome Video Planetaria Discussion Group
http://groups.yahoo.com/group/fulldome

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GRASP Lab Omnidirectional Vision Home Page
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National Space Centre, Leicester, UK
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Fax: +1 603 882 6522
USA Toll Free: 1-800-880-8500

office@skyskan.com
http://www.skyskan.com
Manufacturer of special effects, immersive video and audio systems, and computer controls.

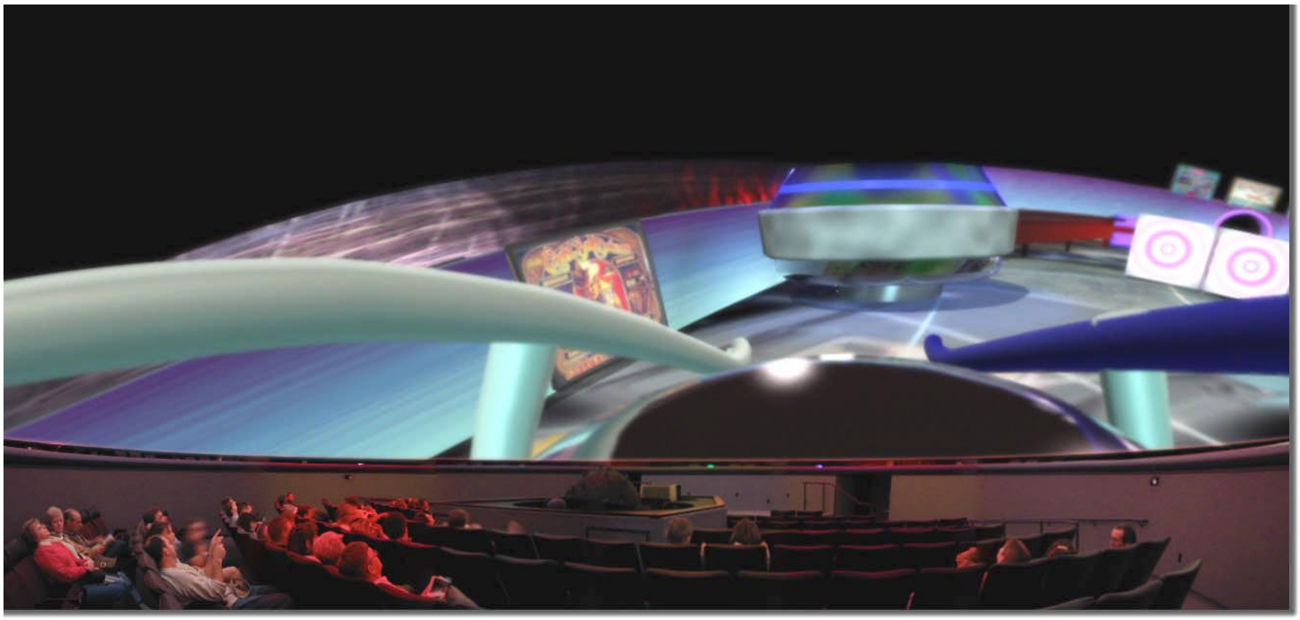
Spitz Inc
U.S. Route 1
Chadds Ford, PA 19317
Tel: (610) 459-5200
Fax: (610) 459-3830
Spitz@spitzinc.com
http://www.spitzinc.com/
Planetaria, premium dome screens, turn-key immersive theatres, and immersive content production and distribution.

TAN Projektionstechnologie GmbH
http://www.tan.de
Immersive and stereoscopic display products.

Trimension Systems, LTD
Whittle House, Marchants Way
Burgess Hill, West Sussex
RH15 8QY
Tel: +44 (0) 1444 480130
Fax: +44 (0) 1444 250777
http://www.trimension-inc.com
Numerous immersive projection and stereoscopic system products. SGI partner for Reality Centers.

Carl Zeiss Jena GmbH
Planetarium Division
Carl-Zeiss-Promenade 10
07745 Jena
Tel: (0049) 3641 642283
Fax: (0049) 3641 643023
planetarium@zeiss.de
http://www.zeiss.de/de/planetarium/home_e.nsf/
Manufacturer of planetarium instruments and dome video systems.

Computer Graphics for Large-Scale Immersive Theaters



Immersive Production Showcase

Prepared by:

Mike Bruno
Spitz, Inc.

SIGGRAPH 2001 EXPLORE INTERACTION AND DIGITAL IMAGES

Production Showcase

Table of Contents

Production Showcase

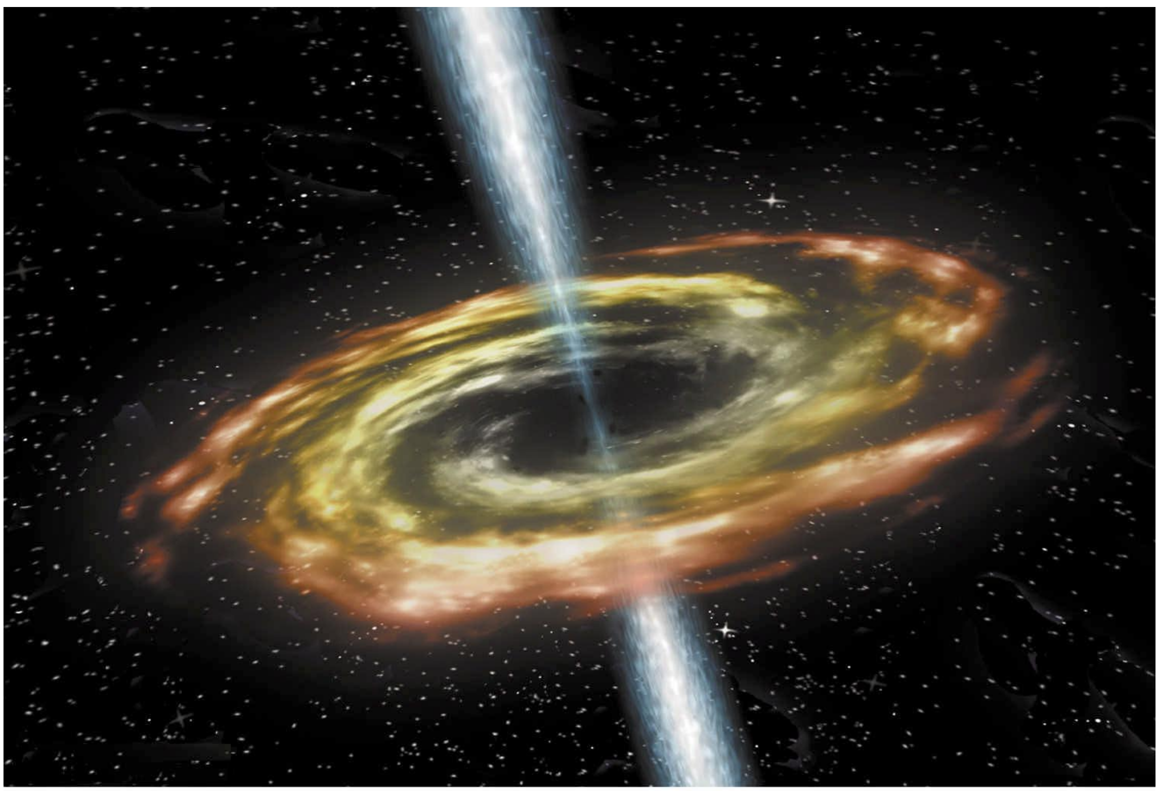
Title of Project:	***Journey to Infinity***
Production Company:	Evans and Sutherland
Running Time:	Approximately 40 minutes
Description of Work:	In "*Journey to Infinity*", our search for the secrets of life in the universe begins with a space shuttle flight around planet Earth, and continues as we take an interactive journey through our solar system. Travelling down to the surface of Mars to find the Pathfinder, exploring the oceans under the frozen surface of Europa, witnessing the death and birth of stars, and unlocking the secrets of mankind's essential connection with the universe. Through the use of cutting edge graphics technology from Evans & Sutherland, the audience is allowed to interact with various portions of the show in ways that were previously impossible, adding a whole new dimension to entertaining and educating large groups of people in a completely immersive environment.

Credits:	Executive Producer - Stan Walker
	Producer - Rick Hinton
	Director - Terence Murtagh
	Narrator - Corey Burton
	Written - Terence Murtagh
	Audio Design & Music Composer - Jack Wall
	Technical Producer - Jason Rice
	Modeling & Animation
	    Evans & Sutherland - Tom Weighill, Brian Sullivan
	    Visual Reality - Greg Mildenhall
	    Axiom Design - Tony Jones, Ken Olsen
	    Digital Artworks - Eric Morgansen
	    Mondo Media - Eric Chadwick, Kelly Kleider
	Digistar II Programming - Aaron McEuen, Kevin Scott, Chris Anderson

Production Tools Used:	3DSMax, MultiGen Creator, Adobe Photoshop, ACDSee, ProTools, Evans & Sutherland ShowMaker , Evans & Sutherland REALimage PC Technology, Evans & Sutherland ESIG Image Generator, Evans & Sutherland Digistar II Programming Language.

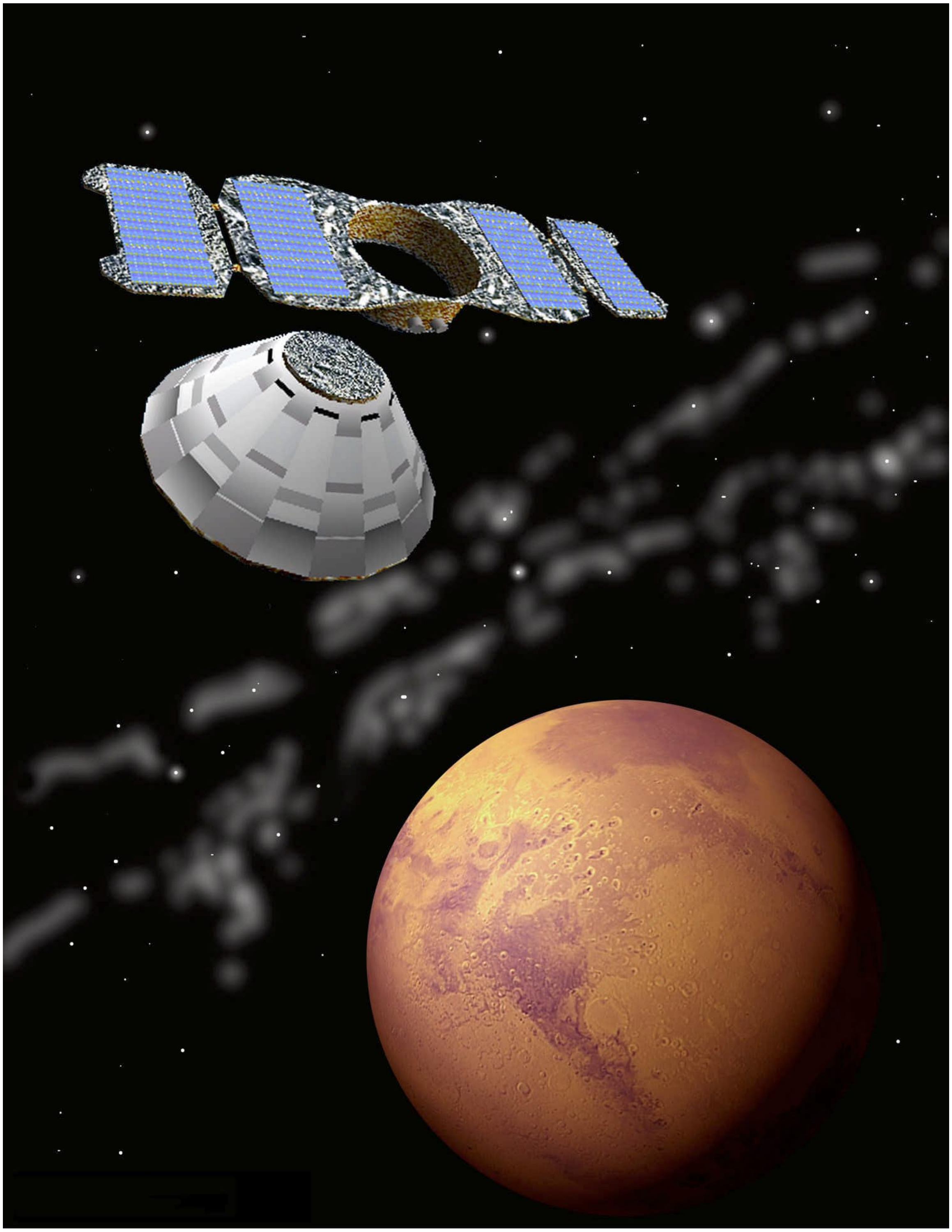
Production Challenges/ Creative Solutions: This was the first show created for StarRider Interactive, so it had to break new ground and define an effective production process. In the process we discovered effective ways to create real-time models and environments, interactive sequences, and camera movements and compositions that worked in an all-dome format.

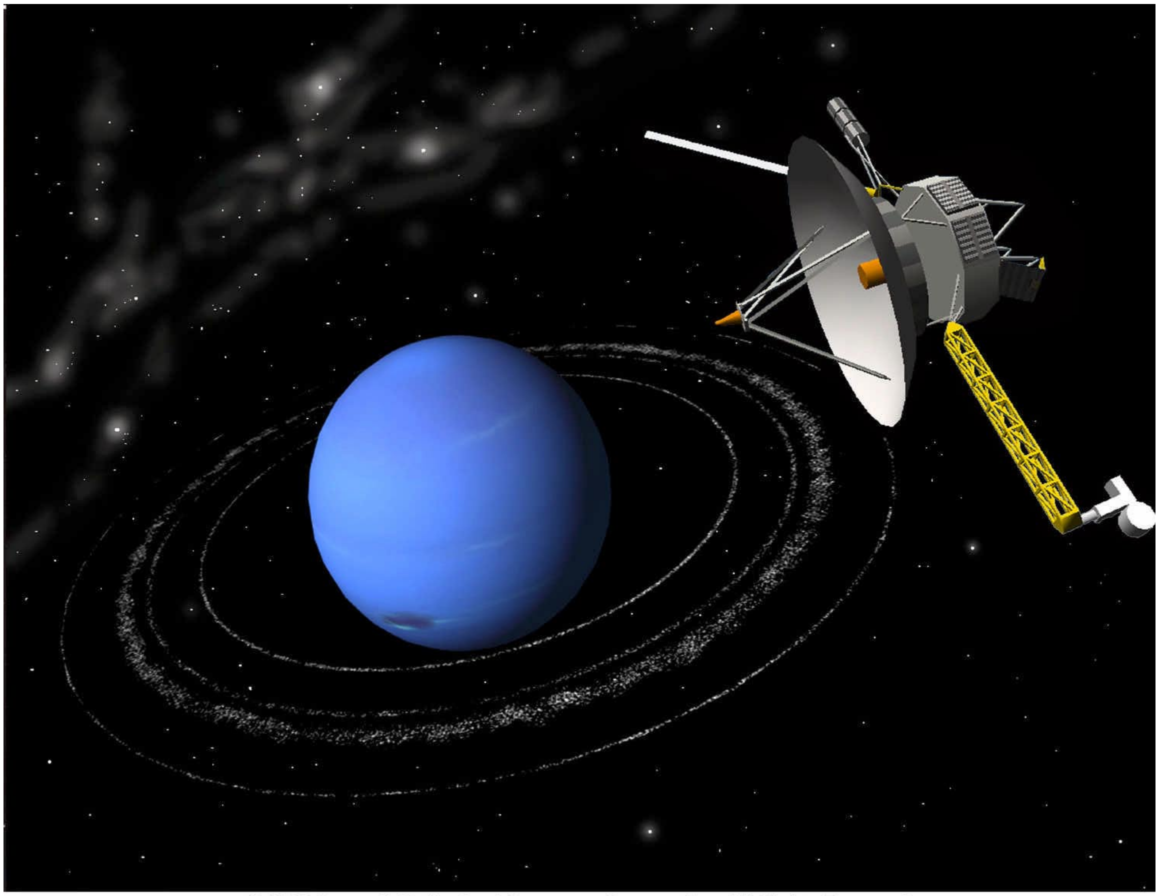
Sample Images:



Production Showcase

Production Showcase

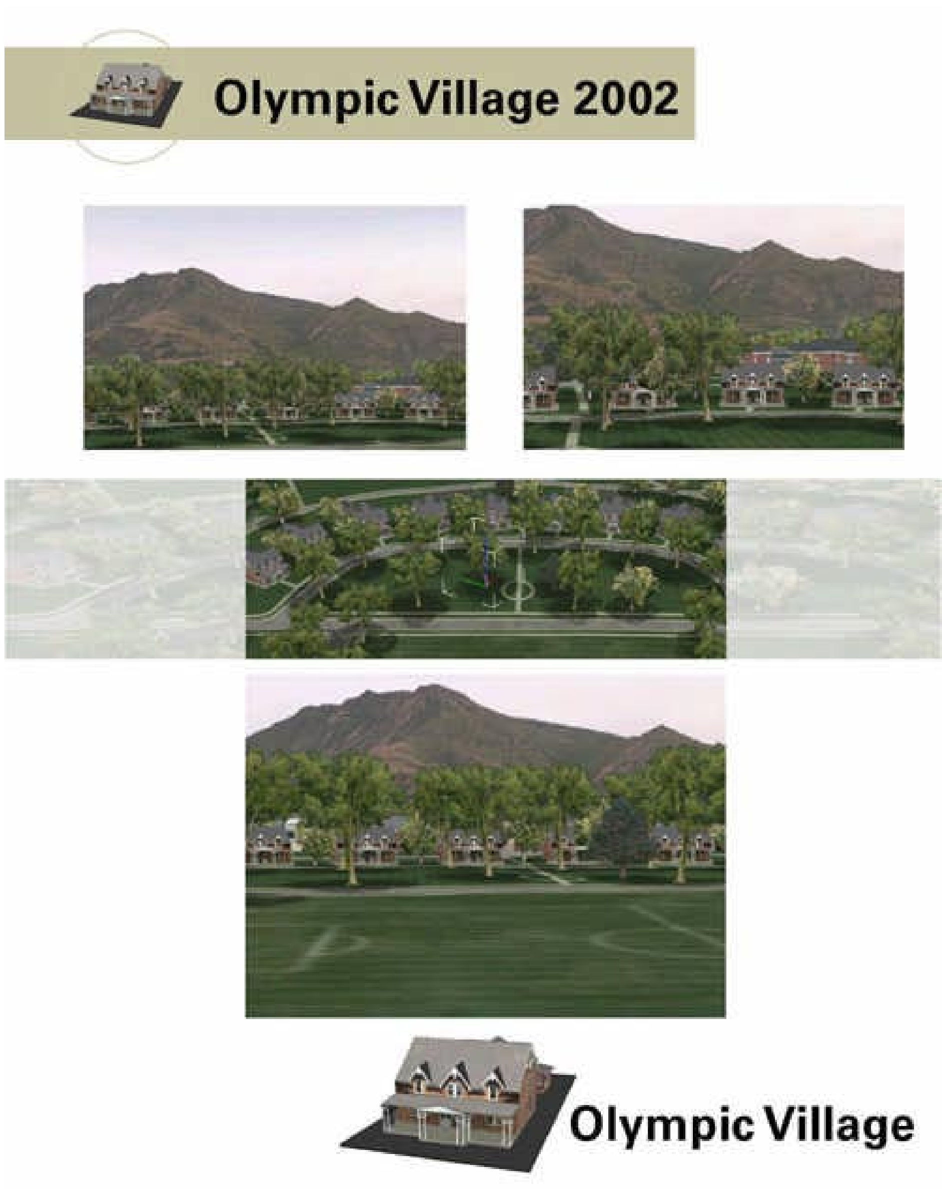




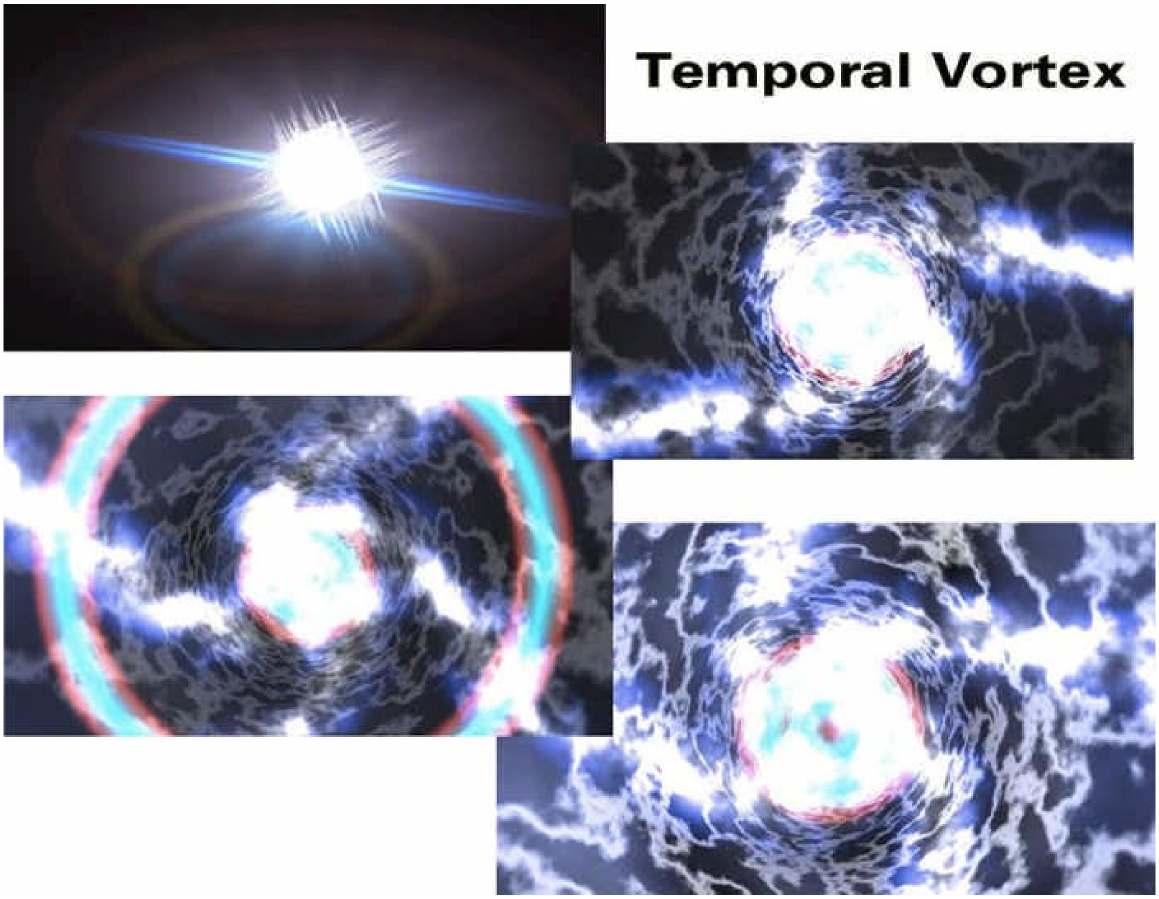
Production Showcase

Title of Project:	***We Take You There***
Production Company:	Evans and Sutherland
Running Time:	Approximately 8 minutes
Description of Work:	"*We Take You There*" was the first all-dome video show produced in the StarRider SV format. This 8-minute time-travel adventure, produced exclusively for SIGGRAPH '99, takes audiences on a high-speed tour through time and space. From Salt Lake's Winter Olympic Village in 2002, to NASA's restricted air space in Florida, to 2 billion years ago in nearby space, to a breathtaking journey inside a human eye, this exciting show was the first to demonstrate the power of an all-dome immersive video experience. The production also included a pre-show sequence displayed on a more traditional medium (flat screen television).
Credits:	Producers - Michael Daut, Debra Walker Writer/Director - Michael Daut Art/Animation Director - Don Davis Music/Sound Design - Jack Wall Animators - Don Davis, Craig Stickler, Kevin Beaulieu, Pattie Dawson
Production Tools Used:	3DSMax, Adobe Photoshop, Adobe After Effects, Maya, Electric Image, SkyStitcher, SkyVision Renderer, ProTools, Evans & Sutherland REALimage technology, ACDSee, NameWiz, Knoll Renamer, Evans & Sutherland's RapidSite.
Production Challenges/ Creative Solutions:	Being the first complete show developed in the all-dome StarRider SV format, there were several challenges and a bit of a learning curve. One of the unique aspects of this show, was the conversion of the high-resolution real-time images produced by the Evans & Sutherland image generators to a linear video format.

Sample Images:


Olympic Village 2002
Olympic Village

Production Showcase



Production Showcase

Title of Project: ***Cyber Explorer***

Production Company: Evans and Sutherland

Running Time: Approximately 40 minutes

Description of Work: Travel through the mysteries of outer space and the wonders of inner space in "Cyber Explorer", a one of a kind adventure that will take you on a fantastic voyage into places never before seen by human eyes. Pilot a fixed wing glider and touch down on the surface of Mars as you visit the first human colony on Mars. Then shrink down to microscopic size and fight a bacterial infection inside the human arm. Next, you'll travel to the center of the earth and explore the geologic and seismic forces at work deep within our planet. And you'll soar through the reaches of space, encountering some of the most beautiful destinations in our galaxy and in the universe itself.

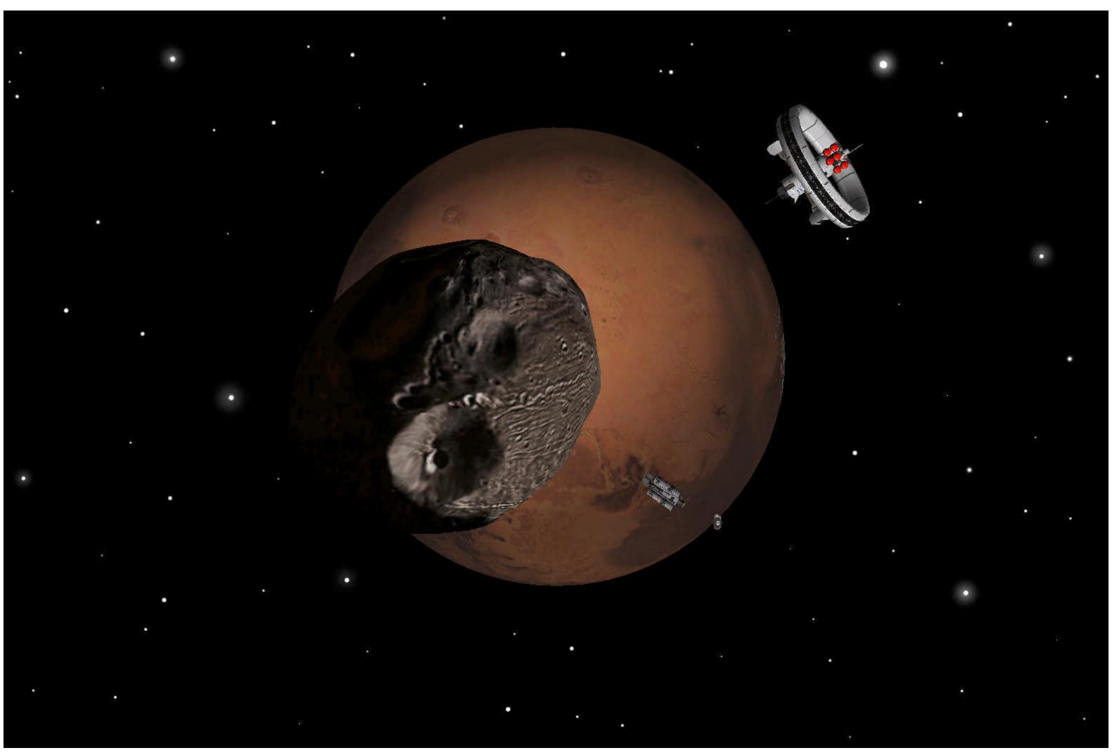
Credits:

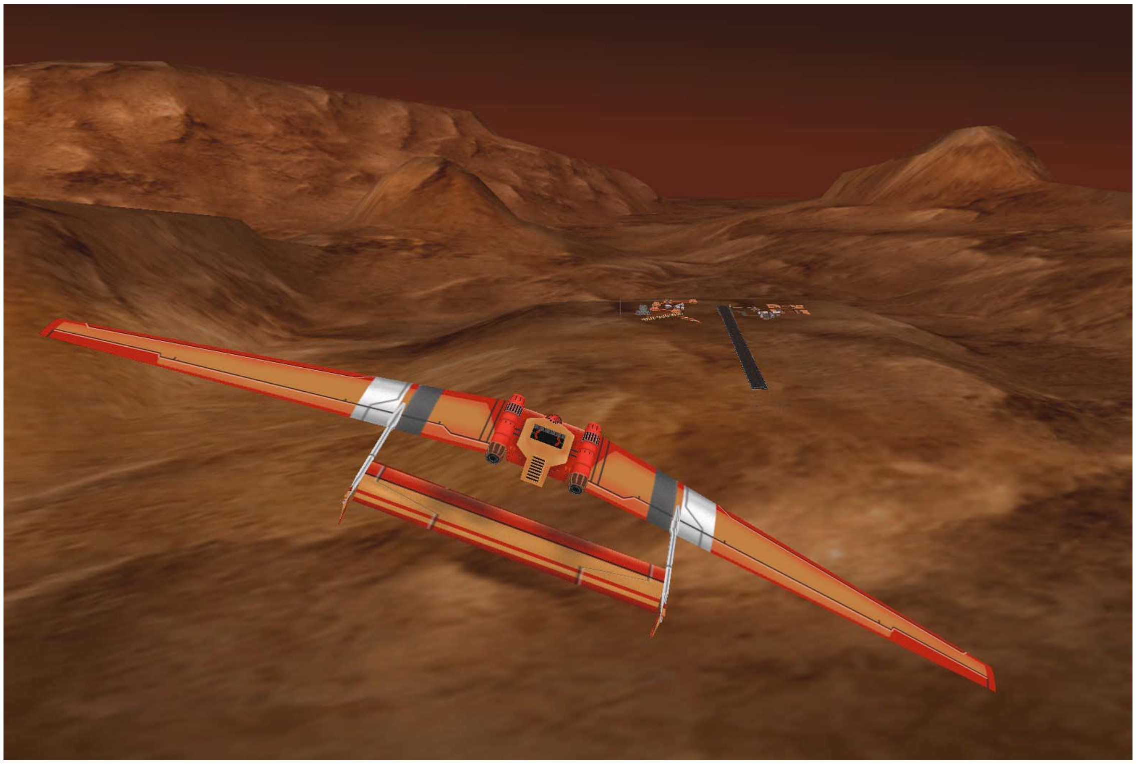
Executive Producer - Terence Murtagh
Producer - Michael Daut
Show Concept - Martin Ratcliffe
Written - Terence Murtagh, Martin Ratcliffe
Graphics – Brice Broaddus, Ken Carlson, Don Davis, Simon Edgar, David Miller, Brian Sullivan
Digistar Sequences - Aaron McEuen, Kevin Scott
Show Programming - JT Taylor, Ken Carlson
Interactive Sequences - Lynn Buchanan
Music - Jack Wall

Production Tools Used: 3DSMax, MultiGen Creator, Adobe Photoshop, ACDSee, ProTools, Evans & Sutherland ShowMaker, Evans & Sutherland Real Image PC Technology, Evans & Sutherland ESIG Image Generator, Evans & Sutherland Digistar II Programming Language.

Production Challenges/ Creative Solutions: With Cyber Explorer, we raised the bar with the entire production. There were more models, more complicated shots, more sophisticated Digistar II integration, and more interactive sequences. These elements had to be incorporated into a show that had four distinct sections. We effectively tied each section together and delivered a show that amazes and astounds audiences.

Sample Images:

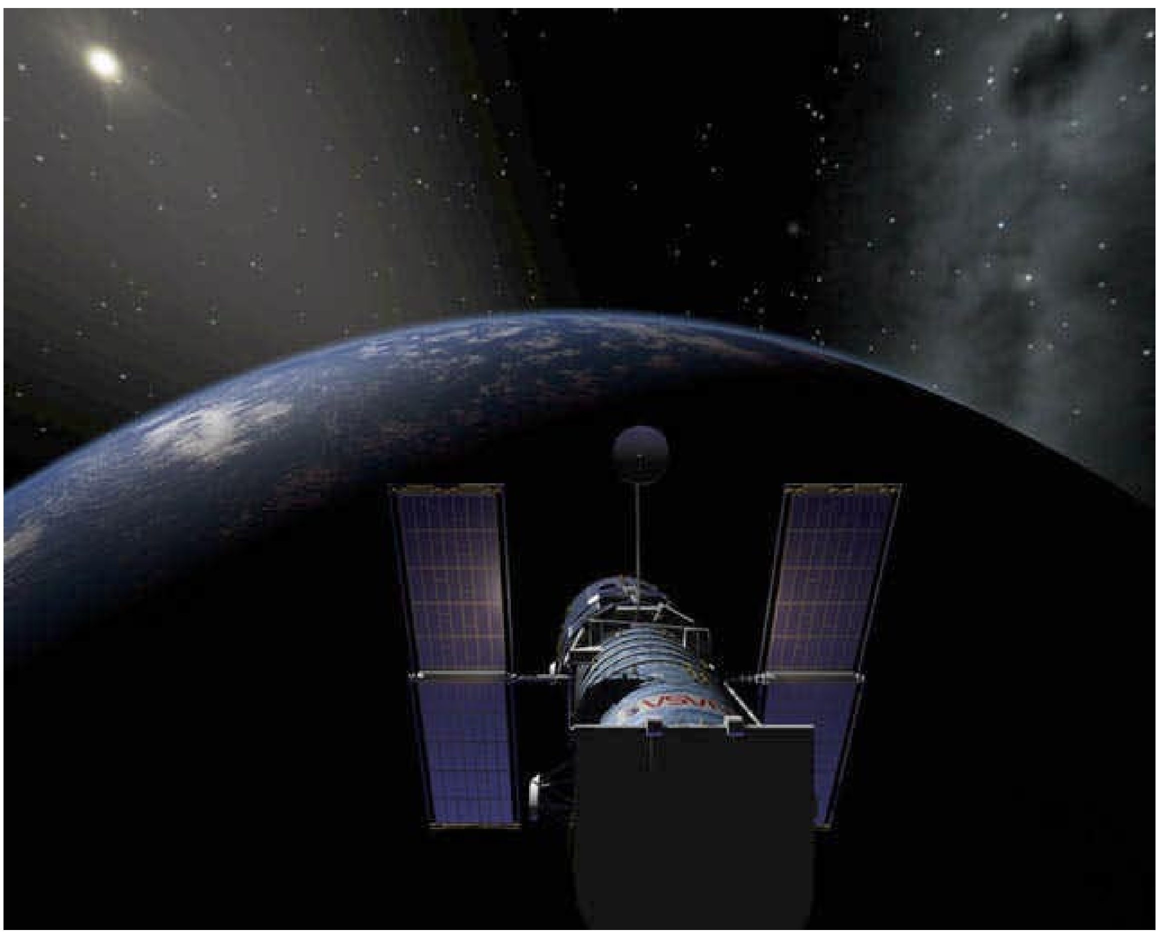




Production Showcase

Title of Project:	***Wonders of the Universe***
Production Company:	Evans and Sutherland
Running Time:	Approximately 22 minutes
Description of Work:	"Wonders of the Universe" is the first complete presentation to be made in digital, 360–degree immersive video format designed specifically for licensing to domed theaters. Using data from telescopes and observatories around the world, and in space, we created this unique experience in a totally digital medium. Peer deep into space through the eyes of the orbiting Hubble Space Telescope and travel back billions of years in time to witness the birth of the universe. On this breathtaking excursion you'll witness the formation of galaxies and explore some of the most wondrous nebulae and astronomical structures yet discovered. As your travels continue, you'll fly deep into our own Milky Way galaxy and return home to Earth on a spectacular tour through the solar system.
Credits:	Executive Producers - Terence Murtagh, Kirk Johnson Producer/Director - Michael Daut Writer - Terence Murtagh Art/Animation Director - Don Davis Narrator - Corey Burton Music/Sound Design - Andrew Yoshiro Lead Animator- Don Davis
Production Tools Used:	Electric Image, Adobe Photoshop, Adobe After Effects, ACDSee, NameWiz, Knoll Renamer, SkyStitcher, SkyVision Hi-Def Renderer.
Production Challenges/ Creative Solutions:	With "Wonders", we created the first full-length astronomical show in which we again defined the visual grammar of all-dome visuals. The challenge was to keep the visual story moving at the appropriate pace to keep the audience captivated for almost 25 minutes. The end result is a breathtaking show that has quickly become the benchmark for all-dome astronomy shows.

Sample Images:



Production Showcase

Title of Project:	***It Happened in New York***
Production Company:	Evans and Sutherland
Running Time:	Approximately 15 minutes
Description of Work:	*"It Happened in New York*", the second gate attraction at Madame Tussaud's New York, is the most complex CGI/live-action film ever undertaken. This all-dome-video, time-travel adventure combines live action photography with computer generated images and actual historical footage of some of New York's most famous faces including Babe Ruth, Ed Sullivan, Elvis Presley etc. For the production there were more than 700 buildings created, 4 miles of New York City streets created and 61,000 extras photographed and created.

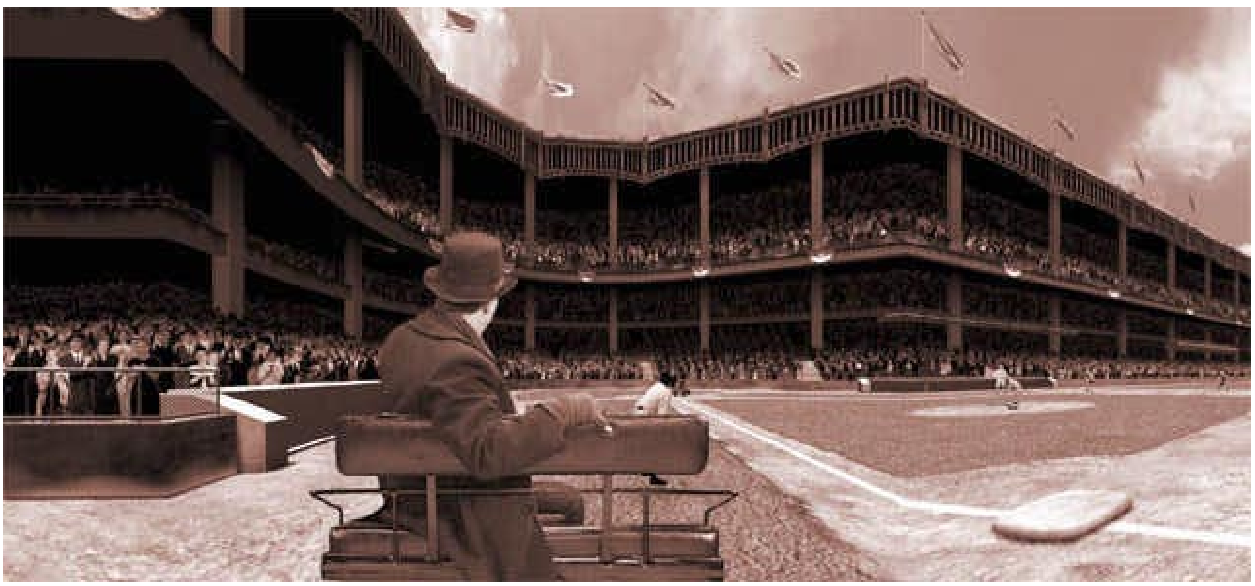
Credits:	Executive Producer - Tony Peluso, Kirk Johnson
	Creative Directors - Ross Cibella, Rick Hinton, Michael Daut
	Producers - Rick Hinton, Michael Daut
	Writers - Patrick Barry, Rick Hinton
	Production Manager - Jay Kirk
	Music - Michael Crain
	CGI Production -
	    Director - Vince Pedulla
	    Technical Director - Ed Gross
	    Animation - Dan Cruz
	    3D Modelers - Jason Diaz, Eric Ortiz
	Live Action Production -
	    Producer - Heidi Welker
	    Director - Jack Tinsley
	    Line Producer - Steve Montrowl
	    Camera Operator - Jim Adams
	    Engineers - Quyen Le, Andrew Theocharopoulos

Production Tools Used:	Maya, 3DSMax, MultiGen Creator, Adobe Photoshop, Adobe After Effects, BOXX Render Farm, Avid Media Illusion, Avid Media Composer, Evans & Sutherland REALimage Technology, ProTools, ACDSee, NameWiz, DeBabelizer, SkyStitcher, SkyVision Hi-Def Renderer, Motion Control, HDTV Video Cameras, Soundstages at Universal Studios

Production Challenges/ Creative Solutions:

The greatest production challenge was the integration of live action footage, including principal actors and thousands of extras, and historical footage of celebrities, into the CGI backgrounds. The sheer enormity of the project in terms of the number of models created for the show, the amount of extras composited in the scenes, and the thousands of hours of rendering was intimidating to say the least. The result is a one-of-a-kind show that audiences in New York have been enjoying time and time again.

Sample Images:

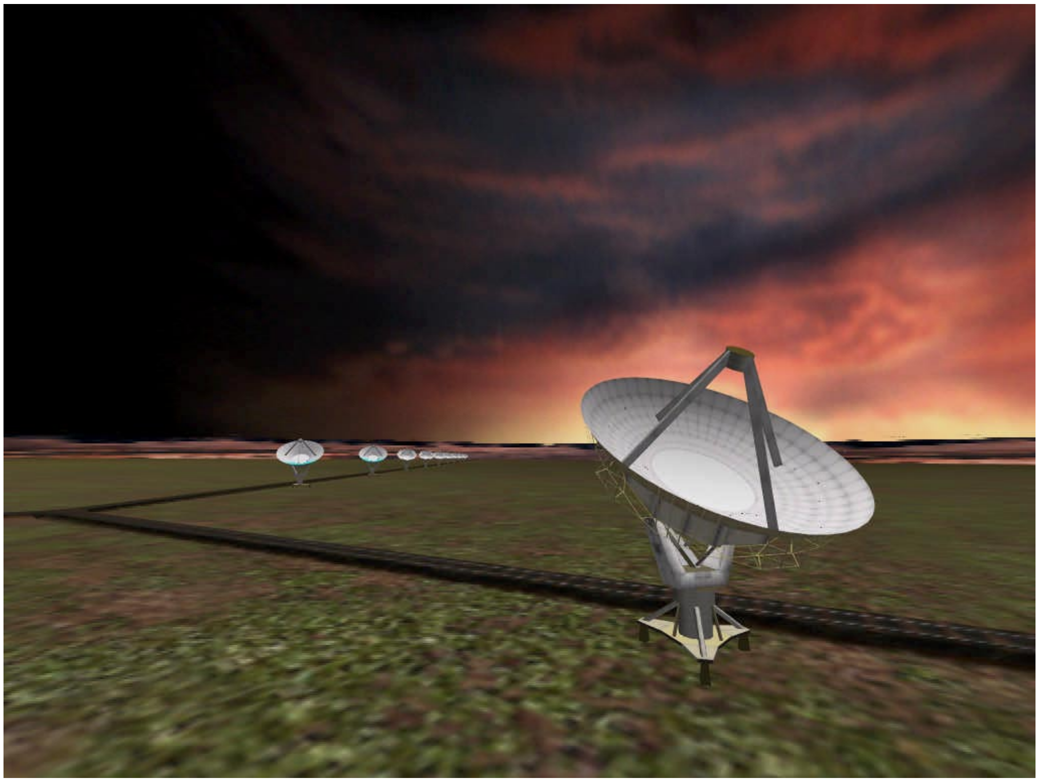


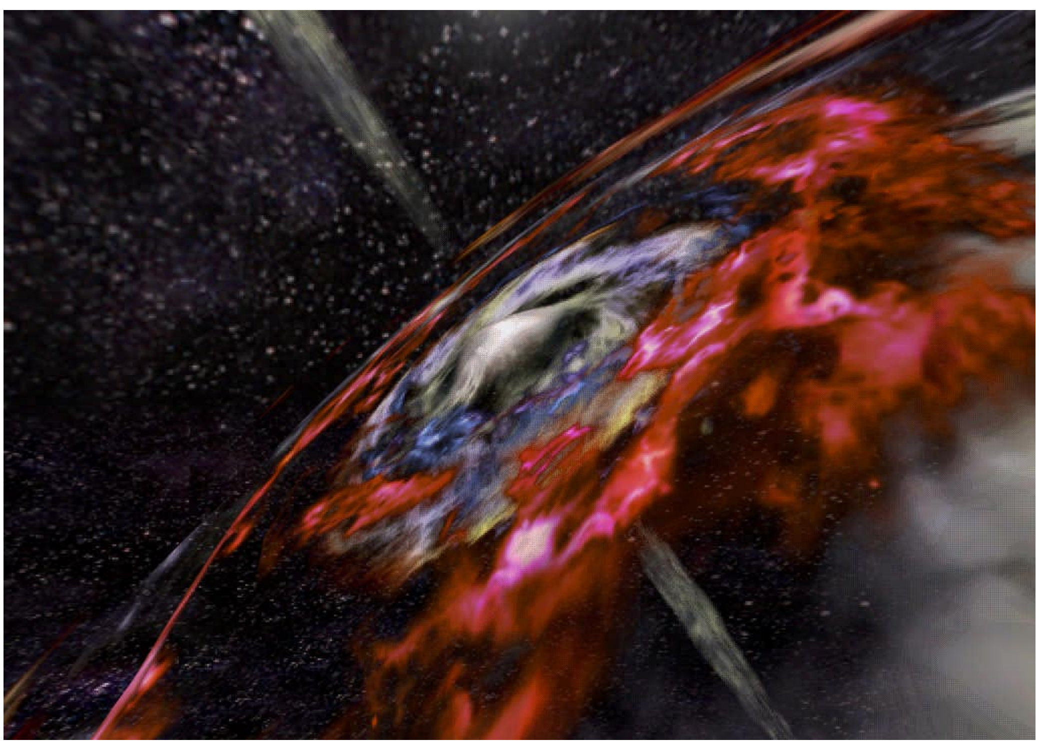
Production Showcase

Production Showcase

Title of Project:	***Crack the Cosmic Code***
Production Company:	Evans and Sutherland
Running Time:	Approximately 40 minutes
Description of Work:	"Crack the Cosmic Code" starts out in Chaco Canyon, NM and a 1000 year-old Native American rock drawing of a crescent moon, what appears to be a star, and a human handprint. Is this a mysterious clue to some ancient astronomical event? What does this rock drawing have in common with a telescope constructed in the mid-nineteenth century in Ireland, with the Very Large Array of radio telescopes in modern day New Mexico, and to the Hubble Space Telescope orbiting Earth? And how are they related to the Crab Nebula? On our journey of discovery, we look for clues by measuring stars' distances from Earth, learn about space and time with the light year, unlock the secret code hidden in a spectrum, and travel inside a black hole. Audiences will investigate the secrets of the universe in this interactive all-dome adventure.
Credits:	Executive Producer - Terence Murtagh Producer - Michael Daut Exploration Place Exec. Producer - Martin Ratcliffe Written by - Terence Murtagh, Martin Ratcliffe Graphics – Ken Carlson, Marty Sisam, Don Davis, Davin Flateau, Don Pence, Brian Sullivan Digistar Sequences - Aaron McEuen, Kevin Scott Show Programming - Ken Carlson Interactive Sequences - Lynn Buchanan Music – Jack Wall
Production Tools Used:	3DSMax, MultiGen Creator, Adobe Photoshop, ACDSee, ProTools, Evans & Sutherland ShowMaker , Evans & Sutherland Real Image PC Technology, Evans & Sutherland ESIG Image Generator, Evans & Sutherland Digistar II Programming Language.
Production Challenges/ Creative Solutions:	As with every new show, the challenge is to top previous successes, and with "Crack the Cosmic Code" we did just that. The CGI is more realistic; the camera moves are more dramatic; the interactive segments are more entertaining; and the overall show is the strongest interactive experience we've produced to date.

Sample Images:





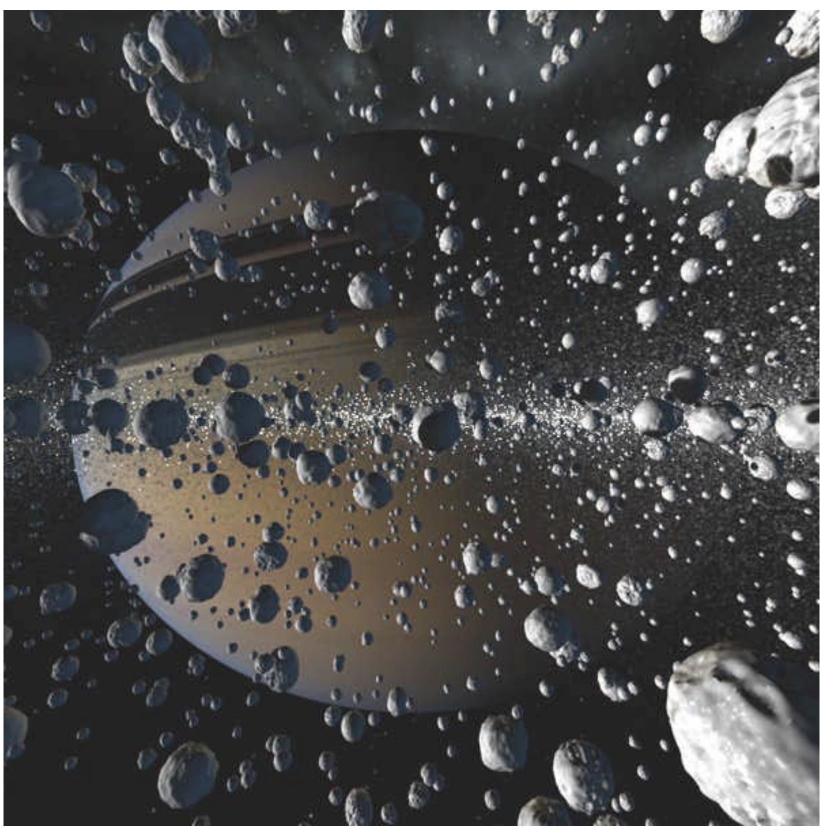
Production Showcase

Title of Project:	***Body Works***
Production Company:	Evans and Sutherland
Running Time:	Approximately 40 minutes
Description of Work:	“Body Works” lets you experience how our bodies work from the inside as you embark on an interactive voyage of discovery. Explore the intricacies of sight as you take the controls and make an eye see. Discover how sound is transformed as it enters your ear and becomes signals that can be interpreted by your brain. Pump blood through the circulatory system as you make the heart beat in perfect rhythm. These and many other adventures will be found as you explore just how the human body works.
Credits:	Executive Producer - Terence Murtagh Producer - Michael Daut Exploration Place Exec. Producer - Martin Ratcliffe Writer - Terence Murtagh Graphics - Ken Carlson, Davin Flateau, Don Pence, Marty Sisam Digistar Sequences - Aaron McEuen, Kevin Scott Show Programming - Ken Carlson Interactive Sequences - Lynn Buchanan Music – Andrew Yoshiro
Production Tools Used:	3DSMax, MultiGen Creator, Adobe Photoshop, ACDSee, ProTools, Evans & Sutherland ShowMaker , Evans & Sutherland Real Image PC Technology, Evans & Sutherland ESIG Image Generator, Evans & Sutherland Digistar II Programming Language.
Production Challenges/ Creative Solutions:	In “Body Works” we are taking the interactive experience to a new level. In multiple interactive segments, audience members will learn about how our senses work, how our brain controls our muscles, and how our blood circulates throughout our body. The inherent challenge is to make this learning experience fast-paced and fun for audiences of all ages. We are also designing the script so that the interactives all flow out of the key moments in the story.

Production Showcase

Title of Project:	***New Horizons***
Production Company:	Evans and Sutherland
Running Time:	Approximately 22 minutes
Description of Work:	From breathtaking landscapes to violent volcanic eruptions to the sheer beauty of Saturn's rings, "New Horizons" immerses audiences in an unforgettable all-dome-video experience. Explore the planets and moons of the solar system in a majestic journey through our celestial neighborhood. For the first time, audiences will travel down to the surface of all the planets, and experience what life would be like from those brave new worlds. Our journey begins as we follow a comet as it travels through interplanetary space. On each of our exotic ports of call, real data and images from modern space probes is transformed into stunning 360° photo-realistic 3D animation.
Credits:	Executive Producers - Terence Murtagh, Narrateo Ltd. Producer/Director - Michael Daut Writer - Terence Murtagh Art/Animation Director - Don Davis Music/Sound Design - Andrew Yoshiro
Production Tools Used:	Electric Image, Adobe Photoshop, Adobe After Effects, ACDSee, NameWiz, Knoll Renamer, SkyStitcher, SkyVision Hi-Def Renderer.
Production Challenges/ Creative Solutions:	"New Horizons" builds on the success of "Wonders" by adding sweeping landscapes on the surfaces of the planets and moons in our solar system. The shots are more complex; the camera moves are more sophisticated; and the show is more fast-paced.

Sample Images:



Production Showcase

Title of Project:	***Body Tours***
Production Company:	Evans and Sutherland
Running Time:	Approximately 15 minutes
Description of Work:	At the Center of Miniaturized Medicine in the year 2125, you'll shrink down to the size of a microbe and get injected into a patient who is suffering an infection from a mysterious virus. Produced in cooperation with the University of Utah Medical School, this high-speed immersive adventure is not only exciting, but educational as well. Travelling from the base of the eye to the interior of the heart, you'll explore exotic ports of call in CMM Probe Alpha with its robotic outboard scout vehicle. As you piece together the clues the virus has left behind, you'll race against time to save the patient on your roller-coaster ride through the body. Laser battles, genetic weapons, and lots of surprises along the way, make this a show audiences will want to experience again and again
Credits:	Executive Producers - Terence Murtagh, Kirk Johnson Writer/Producer/Director - Michael Daut Co-Producer - Tom Casey Art/Animation Director - Tom Casey Music/Sound Design - Jack Wall Animators - Tom Nypaver, Desiree Roy
Production Tools Used:	Maya, Maya Paint FX, Adobe Photoshop, Adobe After Effects, Sky Stitcher, SkyVision Hi-Def Renderer, DeBabelizer, ACDSee, NameWiz, ProTools.
Production Challenges/ Creative Solutions:	How do you shoot an adventure "movie" for all-dome video? That is the groundbreaking challenge of "Body Tours." Instead of keeping the audience at a fixed eye point at the center of the immersive space, we're editing between multiple camera setups within each scene, and using film-style editing to tell the visual story. This project promises to be one of the most exciting adventures ever produced in StarRider SV.

Sample Images:

Production Showcase

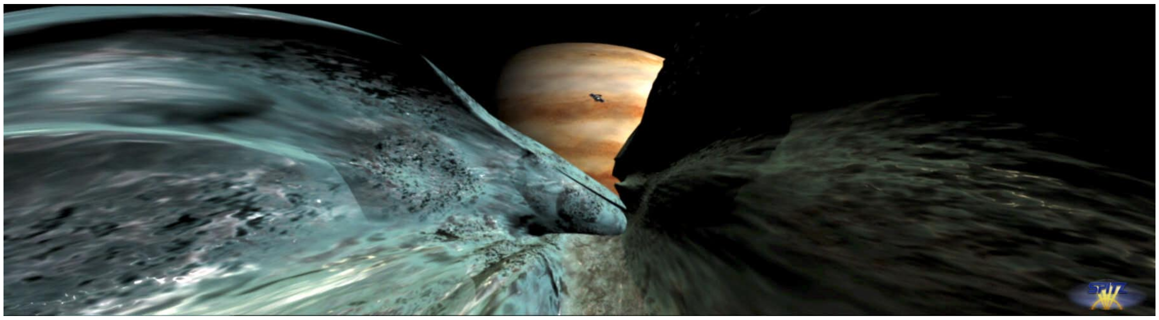
Title of Project:	***Introducing…ElectricSky™***
Production Company:	Spitz, Inc./Ballentyne Brumble Communications
Running Time:	Approximately 15 minutes
Description of Work:	A 15-minute immersive video production to launch Spitz's new ElectricSky dome video theater. Included a wide variety of material, ranging from original 3D CGI to wide-angle film formats like Omnimax 15/70 and VistaVision, to still imagery composited with 2D and 3D effects, to HD video. All visuals were produced or converted for projection in Spitz's ImmersaVision 200 format, with a 200°horizontal by 60°vertical field-of-view.
Credits:	Executive Producer: Mike Bruno Producer/Director: John Ballentyne Animation: Brad Thompson, Ted Artz, Andrew Gardiner, Jeff Glass, Sean Eno, ARC, Pixel Liberation Front, Walter Barrows, Tony Butterfield Music: John Avarese Technical Direction: Ed Lantz Film Scans: Imagica Omnimax Footage: Courtesy of Graphic Films HD Video: Rebo Group
Production Tools Used:	3DSMAX, Maya, Maya Paint FX, Adobe Photoshop, Adobe After Effects, DeBabelizer, ProTools, Scitex StrataSphere.
Production Challenges/ Creative Solutions:	This project (1996) was a pioneering effort that demonstrated the potential of Spitz's new ImmersaVision video format. The main challenges were to produce a show for a spherical display environment using existing off-the-shelf hardware and software primarily designed for flat-screen applications. Our success led to the development of a series of immersive 2D and 3D plug-ins and stand-alone image processing applications that we use on a daily basis today.

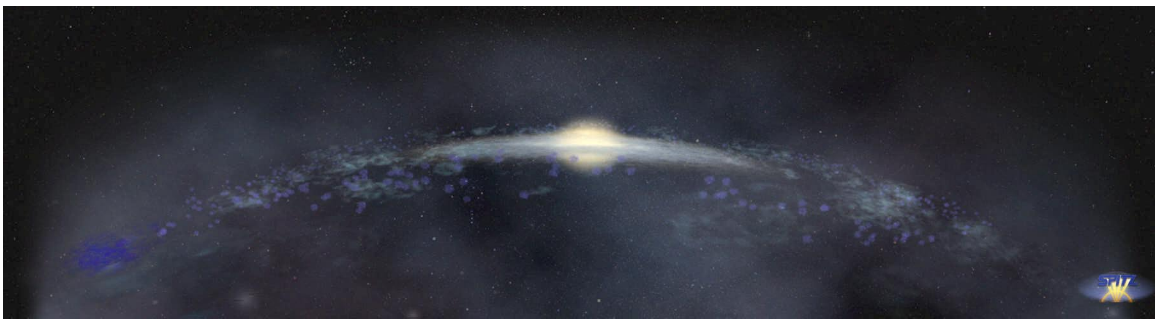
Sample Images:

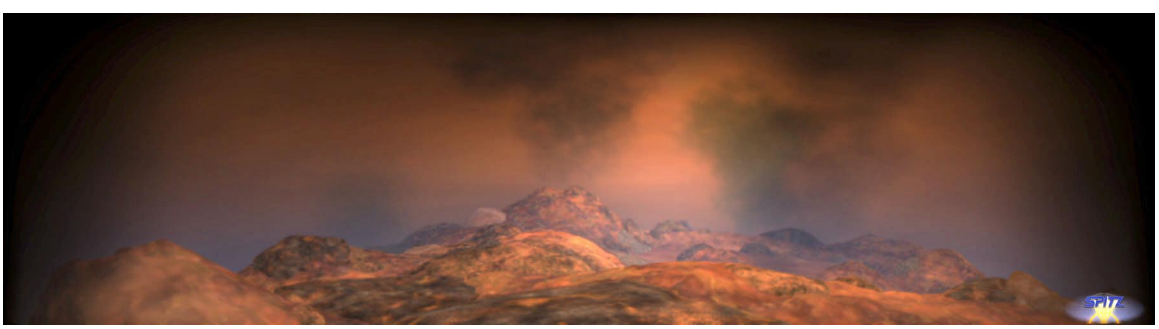
Production Showcase

Title of Project:	***Oasis In Space***
Production Company:	Spitz, Inc.
Running Time:	Approximately 25 minutes
Description of Work:	*Oasis In Space* is the first in a series of immersive video programs for Spitz's ElectricSky theaters to be entirely produced using original 3D computer animation. *Oasis In Space* takes you on a startling and beautiful journey through our Solar System and beyond in search of water and water worlds like Earth. Incorporating the latest results of astronomical research and exploration, including recent data from robot explorers, the program offers a new perspective on a substance of obvious importance to our planet. With a proven, audience-tested story, visually immersive imagery and an original surround-sound musical score, the program will inform, delight and entertain viewers of all ages.
Credits:	Producer – Mike Bruno Writers – Robert Burnston, Mike Bruno Art/Animation Design and Direction – Brad Thompson Music/Sound Design – John Avarese Animators – Amalgamation House, Theo A. Artz, Bill Carr, Sherry Roark, Brad Thompson Narrator – Peter Thomas, John Culshaw
Production Tools Used:	3DSMAX, ImmersaMax, Conglomerator, Billboard Filter, Maya, Maya Paint FX, Adobe Photoshop, Adobe After Effects, DeBabelizer, ProTools, Adobe Premiere RT, PolyDome.
Production Challenges/ Creative Solutions:	*Oasis In Space* was the first immersive sky show to be produced for Spitz's new ElectricSky™ dome video theater system, so it had to showcase the product and appeal to a wide audience. Production challenges included optimizing long render times, working with particles and volumetrics in a spherical format, editing non-standard (1800x486 pixel) video. Solutions included network rendering, off-the-shelf software tools supplemented with custom software plug-ins.

Sample Images:







Production Showcase

Title of Project: ***PopMania!***

Production Company: Spitz, Inc.

Running Time: Approximately 24 minutes

Description of Work: *PopMania*! combines panoramic video, lasers, 3D computer animation and surround sound to immerse viewers in a world of 20th century fads, fashions and follies. From the Charleston to the Macarena, from the hula-hoop to Pokemon, from the beehive to the Mohawk, *PopMania*! takes a nostalgic look at the trends that have shaped the face of the past 100 years. Set to popular music, this toe-tapping show is a must-see for fans of pop culture.

Credits:

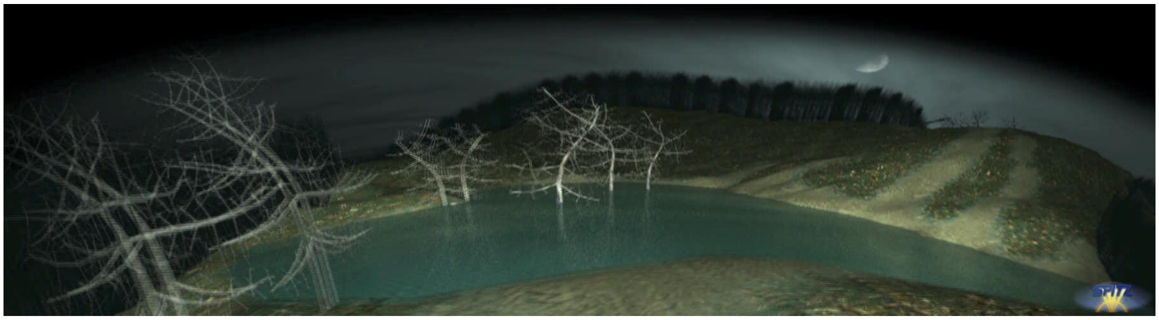
Producers - Mike Bruno, Dustin Sparks
Associate Producer - Andrew Birgensmith
Director - John Ballentyne
Art Direction - Theo A. Artz
Animation Design and Production - Brad Thompson, Amalgamation House, Pat Finley, Andrew Gardner, Bill Carr
Music and Soundtrack Production - John Avarese
Video Editing - Chris Kenworthy
Writer - Bernard Falkoff
PopMania! Theme Song
  Lyrics - Mike Judy
  Music - Bret Kull
Video Post-Production - Brad Thompson, Cubist Post & Effects
Laser Graphics Sequences -
  Production Manager - Willie Castro
  Producer - Andy Hagerman
  Artists - Willie Castro
  Digitizers - David Lawter, Todd Misell, Priscilla Bernardo
Music Rights Clearance and Licensing - Clearance Quest
Production Management - Ballentyne Brumble Communications, Spitz, Inc.
Technical Direction - Ed Lantz
Video Field Production - Barry Berg, Dianne Brumble
Digital Photography - Spitz, Inc.
Production Assistants - Cheryl Adack, Vera Camillo , Gretchen Perry , Emily Shuster, Anne Smythe , Fran Swiger, Donna Tinney

Archival Research - Dianne Brumble, Gretchen Perry
Archival Images - WPA Film Library, Historic Films, ABCNEWS VideoSource, Oddball Film and Video, National Archive and Records Administration, Corbis Images, PhotoDisc, NASA

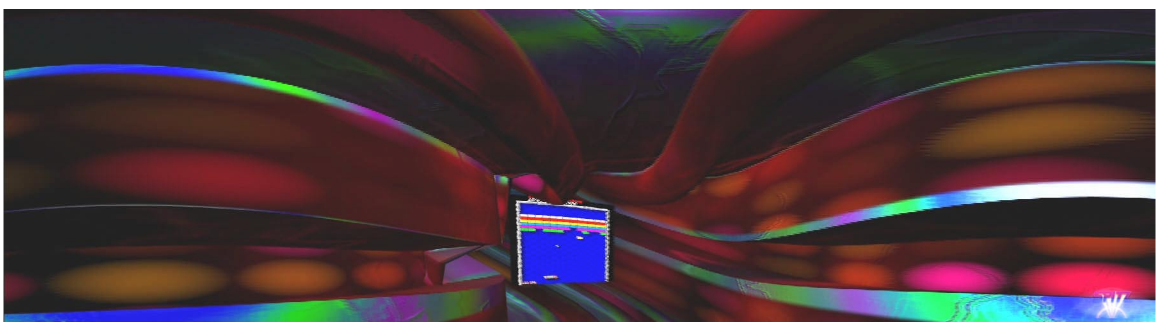
Production Tools Used: 3DSMAX, ImmersaMax, Conglomerator, Billboard Filter, Maya, Maya Paint FX, Adobe Photoshop, Adobe After Effects, DeBabelizer, ProTools, Scitex StrataSphere, Scitex VideoCube, Adobe Premiere RT, PolyDome.

Production Challenges/ Creative Solutions: *PopMania!* was produced as an “evening entertainment” attraction for the Science City, a new hands-on science museum in Kansas City, MO. We faced lots of challenges in producing this show, ranging from technical issues to how to affordably license 25 popular songs and more than 40 minutes of archival film and video. One of the more interesting artistic challenges was to seamlessly integrate lots of footage that was originally designed for viewing on a flat screen into the fabric of an immersive dome “experience” show. Equally challenging was communicating our creative vision to a client 1000 miles away who was unfamiliar with the dome environment. We tried websites, preview videotapes, but in the end, we learned that there’s no substitute for presenting show concepts in the actual playback environment. Last but not least, we had to cover 100 years in about 24 minutes – no easy feat!

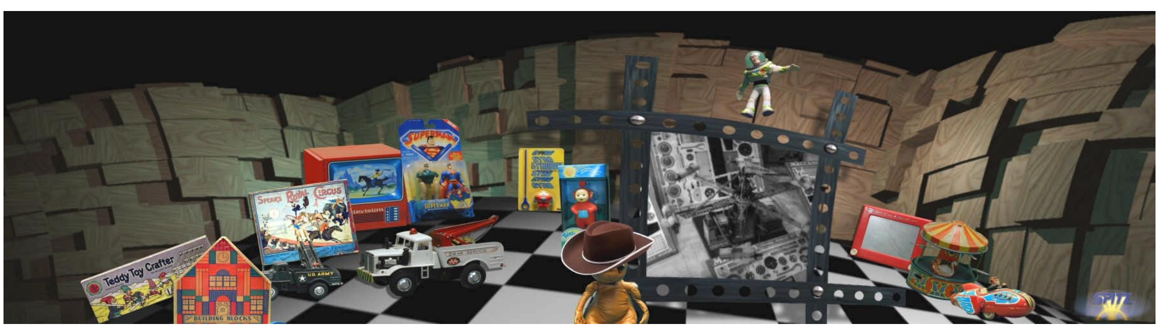
Sample Images:




LAST FOR CALL
REFRESHMENT
TIME




STRANGE

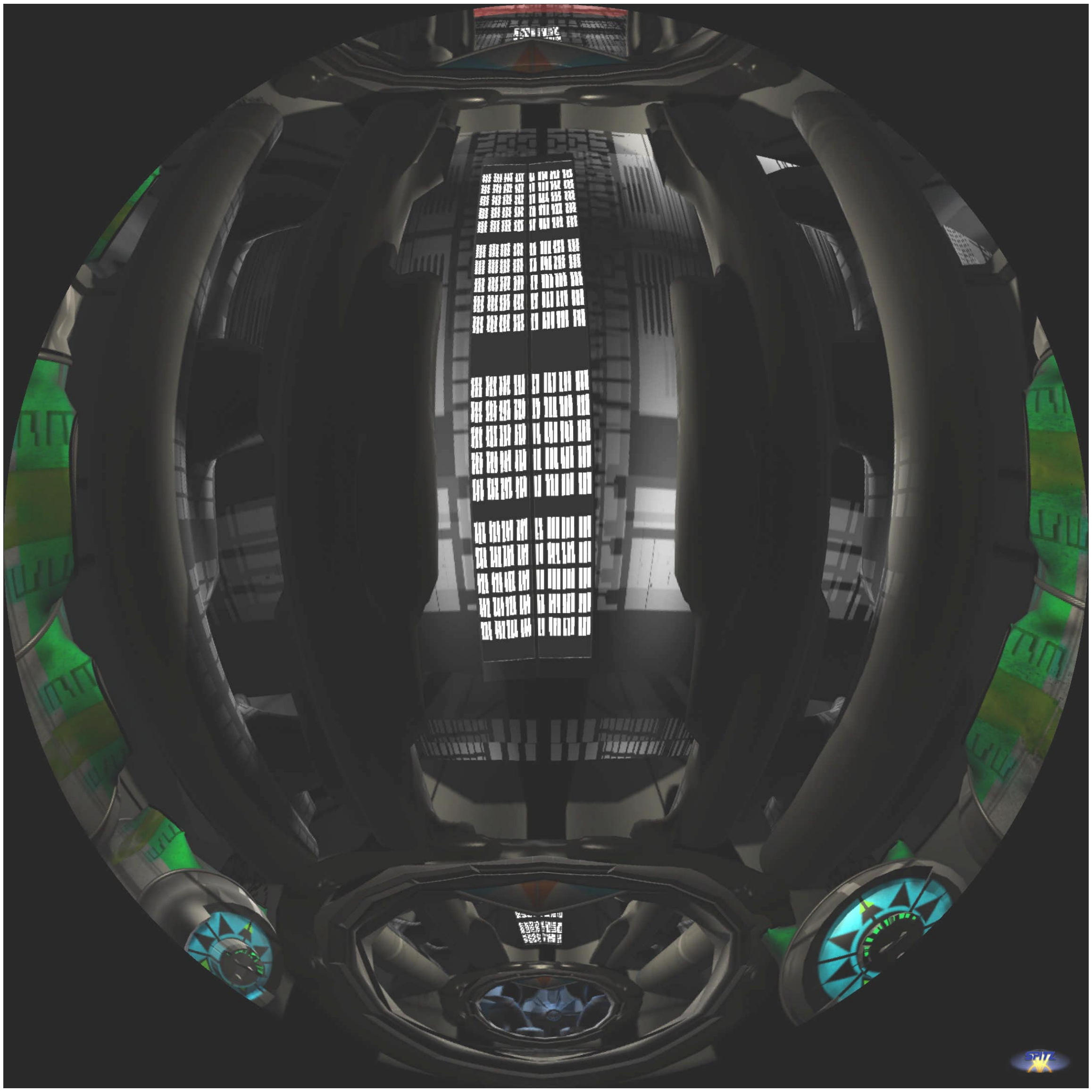

Teddy Toy Crafter

Production Showcase

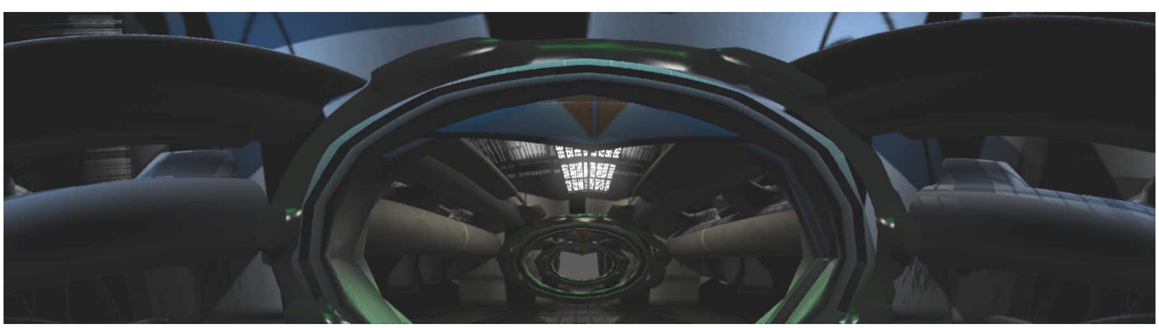
SIGGRAPH 2001 EXPLORE INTERACTION AND DIGITAL IMAGES

Title of Project:	***Dark Star Adventure (working title)***
Production Company:	Spitz, Inc.
Running Time:	Approximately 30 minutes
Description of Work:	*Dark Star*, a Spitz character-animated feature about black holes and other cosmic curiosities, is currently in production. Join our young protagonist Subrah and her robot helper Sweeps as they make a harrowing escape from a dying planet and embark on an action-packed adventure through the cosmos, including a memorable trip through a wormhole. An original sci-fi story with an educational twist for kids of all ages.
Credits:	Producer – Mike Bruno Writer – John Stoke Art/Animation Design and Direction – Brad Thompson Animation Storyboards – Willie Castro Music/Sound Design – John Avarese Animators – Bill Carr, Brad Thompson, Wes Thompson Character Voices – TBD
Production Tools Used:	3DSMAX, ImmersaMax, Conglomerator, Billboard Filter, Maya, Maya Paint FX, Adobe Photoshop, Adobe After Effects, DeBabelizer, ProTools, Adobe Premiere RT, PolyDome.
Production Challenges/ Creative Solutions:	*Dark Star* takes immersive video production to an entirely different level with the use of 3D animated characters and cinematic storytelling techniques. We are faced with multiple challenges: expressing a character's emotions without the use of extreme close-ups, presenting dialogue without cutting back and forth between different POV's, developing fluid camera moves that are not disturbing to the viewer. Our goal is to move beyond the documentary style with which we are all familiar and to develop content that kids will drag their parents to see.

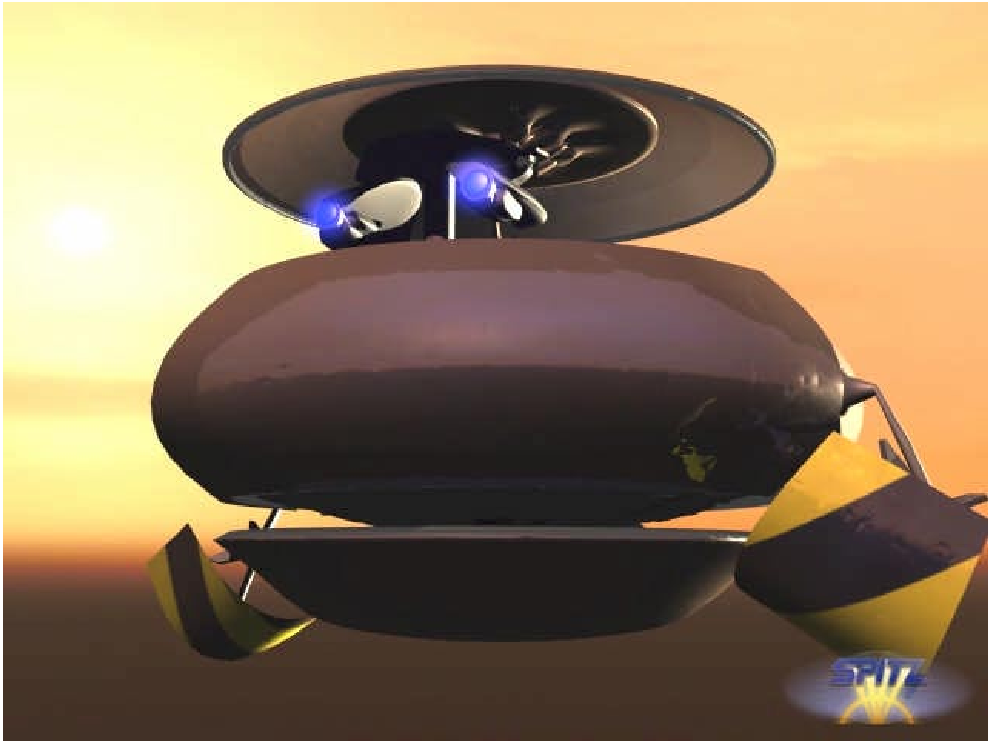
Sample Images:

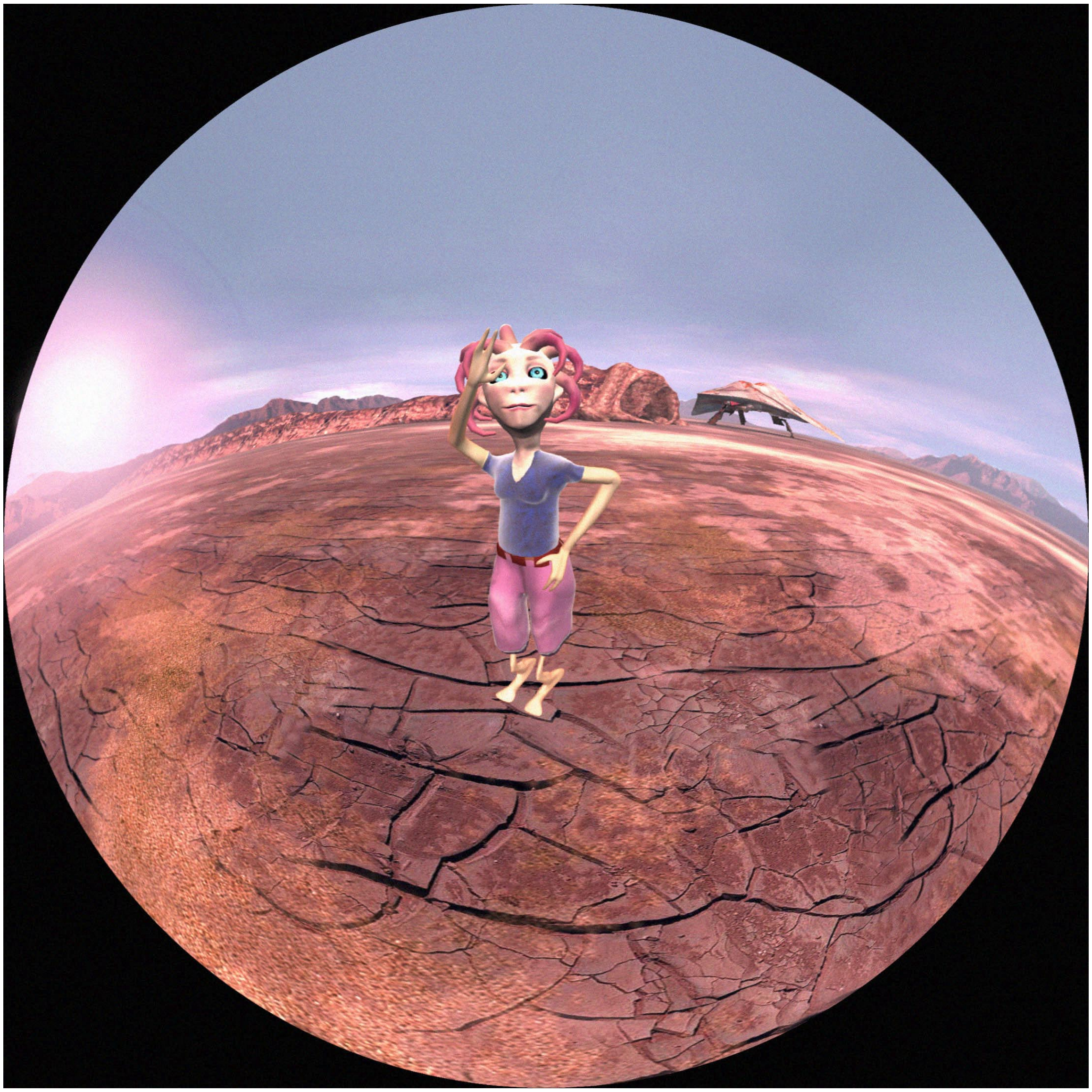


ImmersaVision 360 master image (polar format) – inside the engine room



ImmersaVision 200 master image (panoramic format) – inside the engine room



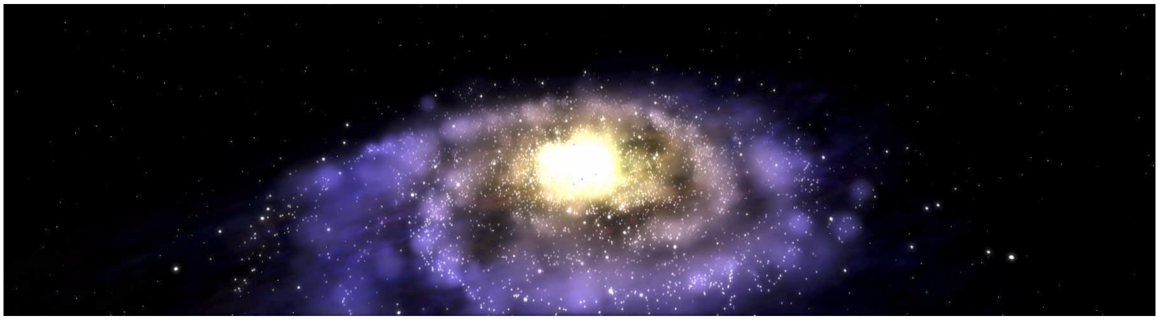


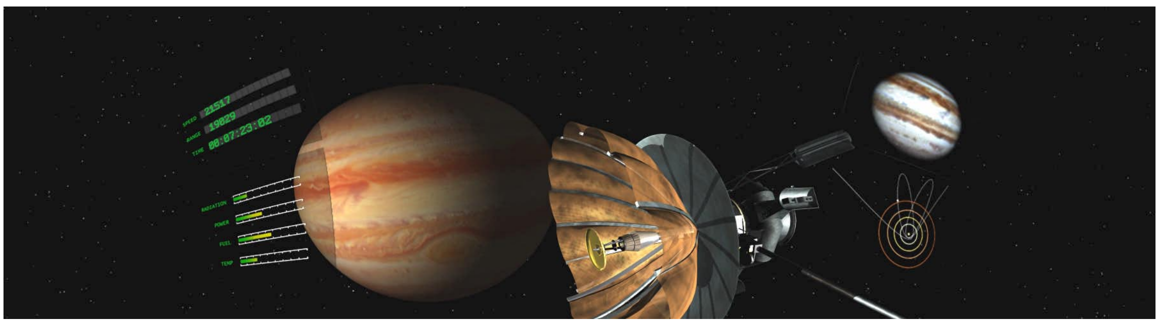
Production Showcase

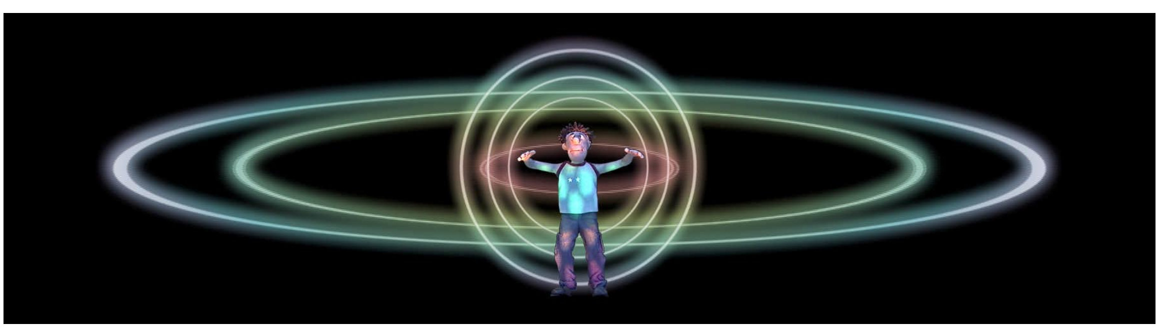
Title of Project:	***BIG***
Production Company:	National Space Centre, Leicester, UK
Running Time:	Approximately 20 minutes
Description of Work:	*BIG* is a public program that explores the size and scale of our universe. Unlike any sky show you have ever seen, *BIG* combines a light-hearted storytelling style with immersive 3D computer animation, stop-motion characters and a surround-sound musical score to bring a really big subject down to earth. Designed for family audiences.
Credits:	Executive Producer – Alex Barnett Producer/Director – Annette Sotheran Original Concept - George Reed Writers – Alex Barnett, George Reed, Chas Walton Narration - Sir Richard Attenborough Lead Animator - Andy Gregory Animation and Compositing - Max Crow Stop Motion - Roger Jones, Annette Sotheran Soundtrack - Music Pip Greasley Sound Design - Will Penny Sound Production - SoniXploras Technical Director - George Barnett Production Assistant - Helen Osbourn Directorial Assistance - Andy Gregory, Roger Jones Laser Graphics - Dave Oxenreider
Production Tools Used:	3D Studio Max 3.1, ImmersaMax, After Effects 4.1, Real Motion Blur, Pro-Optic Suite, Premier 5.1 RT, Photoshop 5.5, Billboard Filter, DPS Velocity and Reality
Production Challenges/ Creative Solutions:	Team previously experienced in TV. Main challenge was adapting from TV format to Spitz's ImmersaVision dome video format both creatively and technically.

Production Showcase

Sample Images:





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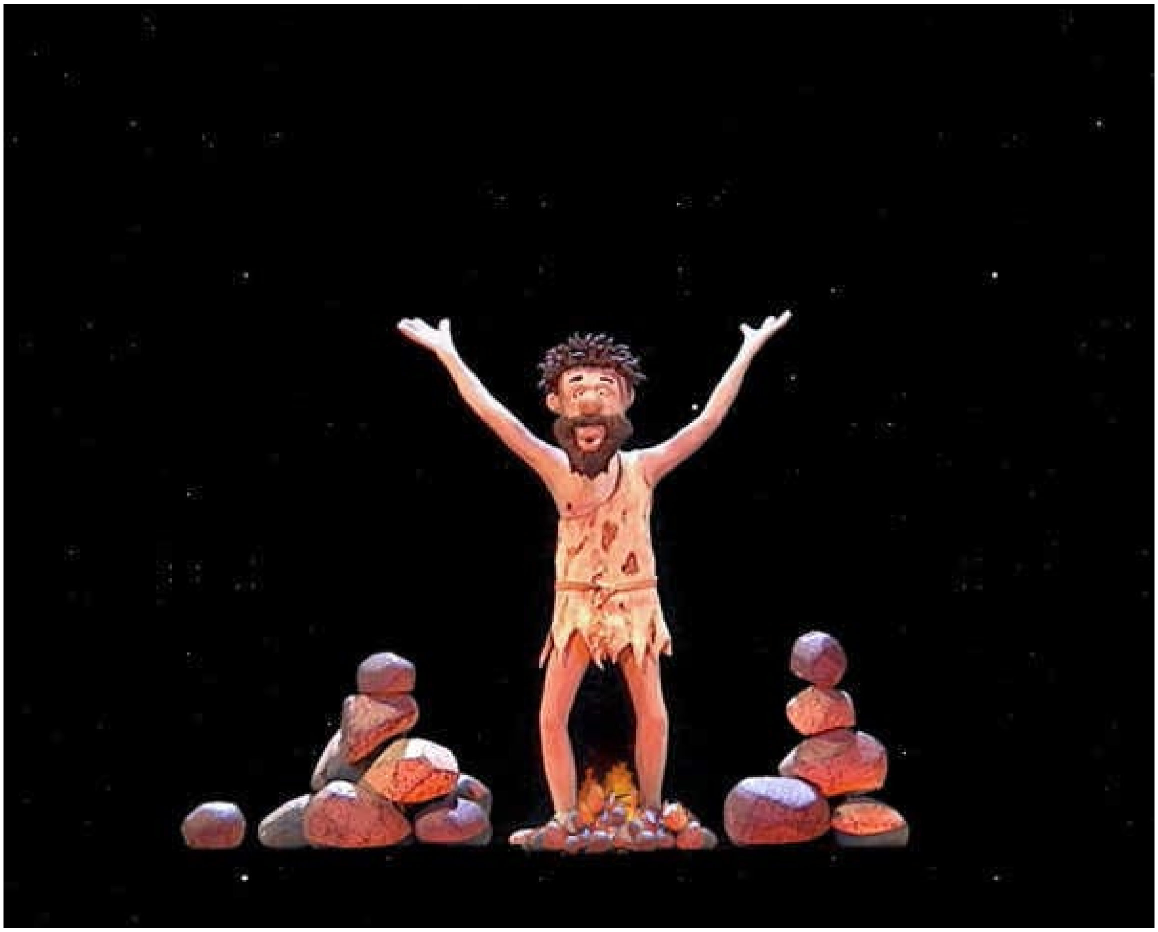
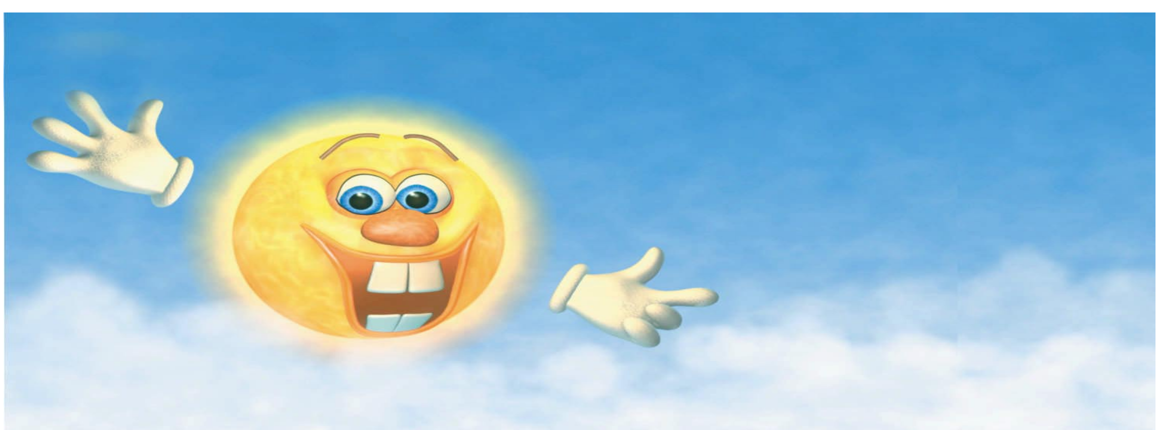


Title of Project:	***Sunshine***
Production Company:	National Space Centre, Leicester, UK
Running Time:	Approximately 20 minutes
Description of Work:	*Sunshine* is a highly interactive, immersive video show for young children under the age of 5-years old. Sunshine, a loveable cartoon Sun, doesn't care if the children get loud or excited; in fact, he wants them to look around, raise their hands, sing and play along with his tricks. In the process, the children are introduced to the colors of the day sky and the other suns of the night sky. Produced in Spitz's ImmersaVision 200 panoramic video format.
Credits:	Executive Producer - Alex Barnett Animator/Director - Roger Jones Producer - Annette Sotheran Script - George Reed Soundtrack - Pip Greasley Technical Director - George Barnett
Production Tools Used:	3D Studio Max 3.1, ImmersaMax, After Effects 4.1, Real Motion Blur, Pro-optic suite, Premier 5.1 RT, Photoshop 5.5, Billboard Filter, DPS Velocity and Reality, Spitz InterAct Audience Response System
Production Challenges/ Creative Solutions:	Team previously experienced in TV. Main challenge was adapting from TV format to Spitz's ImmersaVision dome video format both creatively and technically. Real-time interactive component also a factor.

Sample Images:



Title of Project: ***My Very Easy Method, Night & Day, Starz!***

Production Company: National Space Centre, Leicester, UK

Description of Works: *My Very Easy Method…*is an audience response program based on the mnemonic for learning the names of the planets in order from the sun. The students are challengingly transported from planet to planet to be immersed in special and spectacularly different environments, often with an element of humor.

Night & Day, a show for younger children, presents the concepts of night and day as a relative position problem between the observer's position on a spinning earth and the position of the Sun. The program starts with the simple concept that by turning and reflected motion, the student can make objects appear to move. The concept is reinforced with a game of Simon Says between a loveable animated cartoon sun and the audience. This is a fun program that requires a "teacher presenter" and participation from the classroom teacher.

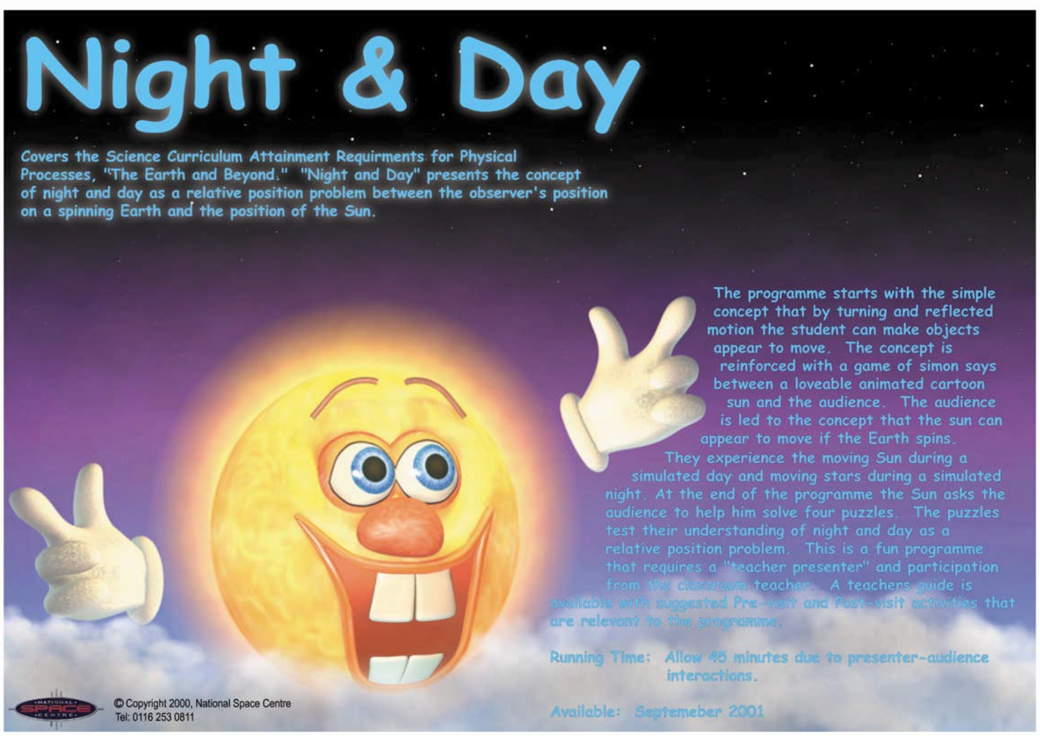
Starz! is a school show that follows the lifetime of three different masses of stars and explains their evolution over long time-scales in terms of thermonuclear reactions and opposing forces. The program includes the birth and death of stars and such exotic objects as supernova explosions, neutron stars and black holes. At the end of the program the audience discovers that they are born of the stars.

All programs are produced in the ImmersaVision 200 panoramic dome video format for Spitz's ElectricSky system and include original 3D animation, 5.1 surround soundtracks, laser graphics and other visual effects.

Production Tools Used: 3D Studio Max 3.1, ImmersaMax, After Effects 4.1, Real Motion Blur, Pro-Optics Suite, Premier 5.1 RT, Photoshop 5.5, Billboard Filter, DPS Velocity and Reality, Spitz InterAct Audience Response System

Notes: The above programs are "school shows" designed to complement the UK science curriculum for elementary school students. They are currently in production and are scheduled for completion in late 2001.

Sample Images:




STARZ!
Covers the Science Curriculum Attainments Requirements for Physical Processes, "The Earth and Beyond." "STARZ!" follows the lifetime of three different masses of stars and explains their evolution over long time-scales in terms of thermonuclear reactions and opposing forces. The programme includes the birth and death of stars and such exotic subjects as supernova explosions, neutron stars and black holes. At the end of the program the audience discovers that they are born of the stars.
Optional demonstrations and student interactive questions are used throughout the programme. Information is provided for an optional winter sky tour to point out examples of the appearance and positions of objects that are part of the programme.
Running time: 40 minutes
Available: November 2001
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Tel: 0116 253 0811

Production Showcase

Title of Project:	***Wonderful Journey***
Production Company:	Zenturio Group Ltd.
Running Time:	Approximately 7 minutes
Description of Work:	Sponsorship film made for Orange Telecommunications PLC to be shown in an ElectricSky theatre built by Spitz,Inc. A film about communication made for a younger audience to enjoy. We start in outer space, descending through a "word storm" atmosphere to different situations around the world, guided by an orange balloon.
Credits:	Executive Producer: Andy Neumann Producers: David Turchi, Jennifer Lane, Siobhan Lyons Director: Jason Glenister Post-production: Bruce Steele / Glassworks Ltd Music: Kris Jenkins
Production Tools Used:	Soft Image, Flame
Production Challenges/ Creative Solutions:	Live action shot on 35mm on location in South Africa, incorporated with CGI starfield and balloon effects, formatted for ImmersaVision 200 dome video format.

Sample Images:

Title of Project:	***Every Day a Little Better***
Production Company:	Zenturio Group Ltd.
Running Time:	Approximately 7 minutes
Description of Work:	Made for the Volkswagen 360º dome theatre specially built for the Autostadt in Germany. Relates the story of two sisters and their respective struggles towards perfection: one to be a concert violinist, the other an ice-skater.
Credits:	Executive Producer: Andy Neumann Producer: David Turchi Director: Tom Ackerman Post-Production: Bruce Steele / Glassworks Ltd Music: Merv de Peyer
Production Tools Used:	Soft Image, Flame
Production Challenges/ Creative Solutions:	Live action footage shot on 35mm and Vistavision on location in South Africa, Italy and Prague using fish-eye lenses, incorporated with stills plates and CGI to create a fully 360º immersive viewing experience.

Sample Images:

Production Showcase

Title of Project: ***Eye of the Eagle***

Production Company: Boston Productions

Running Time: Approximately 25 minutes

Description of Work: Eye of the Eagle is an immersive high-definition video production for a tourist destination theater in Ketchikan, Alaska. The production follows a young couple as they search for their Tlingit spiritual roots while adventuring through southeast Alaska. The program is presented in a Spitz ElectricHorizon™ video theater, which has a spherical video screen with a 200°horizontal by 60°vertical field-of-view.

Credits:
Directed by - Bob Noll
Written by - Davie Hunsaker
Produced by - Paul Van Wart
Director of Photography - Andy Sobkovich
Editor - Chet Kaplan
Music by - Jeanine Cowen
Casting by - Heike Brandstatter and Coreen Mayrs, C.S.A.
Visual Effects Coordinator - David Hedley

Production Tools Used: Sony HDW400, Avid Media Composer, Jileo Uncompressed HD Non-Linear System

Production Challenges/ Creative Solutions: The greatest challenge was working in a format where everything (all equipment and people) are in frame. Where do you hide your lights?

Sample Images:

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Report of the IPS Technical Committee

Full-Dome Video Systems

Kevin Scott
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Richard McColman
Morehead Planetarium
Chapel Hill, North Carolina, USA

One of the primary charters for the IPS Technical Committee is to review the range of competing full-dome video systems that have recently become available, develop some sort of evaluation metric, and attempt to define a set of standards that would help manufacturers address compatibility issues for content production and presentation. To that end, we are beginning the process of looking at the major systems, each in detail. In this quarter's column we'll give a comprehensive overview of the major technologies involved, discuss two prevailing architectures, and review a few of the major systems.

Technology Overview

Let us begin by saying that one could easily write much more on this subject than we have space for here, and that this overview is simply a brief introduction to some of the technologies and terms that may appear in a discussion of full-dome video systems. Also please keep in mind that we, the members of the IPS Technical Committee, are not equipment vendors. We are looking at these systems as potential customers in light of our collective expertise. Furthermore, the IPS Technical Committee will not attempt to recommend one system or another. Our main focus is to disseminate information and to encourage the major vendors to create interoperable systems.

There are several companies that provide full-dome video systems in a variety of formats. Some of the major vendors include:

ElectricSky™ – Spitz, Inc.
Virtuarium – GOTO Optical Mfg., Co.
V-Dome – Trimension, Inc.
VisionDome™ – Alternate Realities Co.
StarRider™ – Evans & Sutherland
SkyVision – Sky-Skan, Inc.

The actual physical setup varies from system to system, although there are some similarities. Most of the options use multiple video projectors and some form of edge-blending technology to create a seamless video image over the entire surface of a planetarium dome. Only Alternate Realities offers a single-lens system for smaller theaters. To generate images, some systems use a graphics super computer and others use off-the-shelf hardware and software solutions. Finally, there is a wide range of control and automation mechanisms, audience response sub-systems, and production philosophies.

There are two primary architectures in all-dome video systems: real-time and offline (also known as "pre-rendered"). Real-time systems use massive amounts of processing power to generate every image "on-the-fly." Offline systems render video out to a storage medium (hard disk, tape, laserdisc) and then play back as needed. Each architecture has its own merits, but the larger question of which type of system a theater might choose is probably more philosophical or financial in nature, rather than technical.

Real-time architectures have their roots in high-end flight simulator displays. Historically, these Image Generators (IGs) were specifically designed to recreate out-of-cockpit views for pilots, ground warfare, and other military training scenarios. Modern IGs provide a more general-purpose approach to graphics and can now reproduce wider range of content.

Production with real-time systems involves creating 3D graphics models for every object in your "show." These models are then given texture and color, and are placed in a three-dimensional space – the "world." Over time, objects can move from one place to another, change in size and shape, and fly in and out of the audience's view. In the spirit of flight simulators, the audience's viewpoint can also change over time, allowing for tremendous production freedom and graphic realism.

Real-time systems compute images as fast as they can – hopefully producing images at more than 30 frames-per-second (fps). Depending on the complexity of the show sequence, real-time frame rates may vary, resulting in motion that can be very smooth in some places and jerky in others. With careful production, though, these systems can produce consistent, smooth motion.

Since real-time architectures generate images on-the-fly, they work very well in interactive environments. For example, with StarRider™ from Evans & Sutherland, it is possible to "fly" the theater with a single joystick, much like one would fly a flight-simulator. Another important feature of real-time image generation is the ability to manipulate program content on the dome without having to refer to some sort of "preview" or having to wait for animation sequences to render on a separate computer. On the other hand, real-time systems are somewhat limited in the complexity of the scenes that they can produce, and they require very technically skilled modelers to create objects that will be shown in a program. Further discussion of the merits and challenges of various systems will be addressed within individual product evaluations.

Offline (pre-rendered) architectures stem from recent advancements in digital video production and non-linear editing systems. Desktop video production and animation has become very popular in the last several years. Today's systems can provide full professional level capability at a fraction of the cost of yesterday's studio gear. Witness television programs like *Star Trek* and *Babylon 5*, along with blockbuster movies like *Armageddon* and *Independence Day*; each of these productions used PC-based animation and video editing systems to create visual effects.

Production with offline systems is similar to real-time. Objects are modeled and textures are applied. One tremendous difference, however, is the complexity of the models that can be used, at the expense of time. An offline model can be as detailed as you like, but you have to wait for the computer to render each image. One advantage is that slow-time animation systems tend to be more advanced (both in terms of interface and features) than the current crop of real-time production software.

After selecting models and designing the animated sequences that will make up your program, an additional step must be employed to generate images for the dome. In a multi-projector situation, frames of animation must be divided up, directed to the appropriate projector, and synchronized with all of the other content. This process is handled differently in each of the primarily offline solutions evaluated here.

Near-real-time is another term that may be applied to some pre-rendered systems. Given that all of your show content is prepared and placed in random access storage (e.g. hard disk or laserdisc), it is then considered to be online content. From there, individual frames can be displayed at will, or in sequence, at almost any frame rate. In this sense, pre-rendered content can mimic some of the functionality of a real-time system.

Finally, there is a need to address standards between systems. Currently, each vendor has a unique projector configuration, development platform and imaging hardware. Some vendors support industry standard tools like 3D Studio Max for modeling and animation, and After Effects for compositing, although the final media format is different for each system. That is, content created for one system can't easily be used by another. This is especially true when moving from real-time to offline or vice versa.

Perhaps a first step is to encourage vendors to agree on a common projector configuration. Then we can concentrate on common media formats and production standards. One example of vendors working together was demonstrated at the most recent IPS conference in London where Sky-Skan and Evans & Sutherland used the same projectors to showcase SkyVision and StarRider. While each vendor's content was very different, at least they were somewhat compatible at the projector level. This kind of cooperation is beneficial to both vendors and planetariums by expanding the library of available content that can be presented in a theater.

Once there is a potential for projection compatibility it is necessary to address the source material and production differences between real-time and pre-rendered systems. As an example, we'll work through a prototypical visual sequence and highlight a few of the production considerations for both architectures. Our storyboard snippet begins with the planet Saturn appearing on the limb of our dome and zooming up to rest at front and center. After pausing for a moment, we move towards the planet, dip through its rings and fly on to Titan.

In a real-time environment, one would start by creating a sphere to represent the planet Saturn and a disk for its rings. This combination would probably be modeled several times, each with a different level of detail (LOD). Because real-time systems are limited in the amount of detail that can be displayed in any one channel, (one channel = one projector) it is often necessary to create simplified models to represent the object when viewed from a distance. While zooming in towards the planet, we'd start with the simplest model and transition between the others as it got closer. The key is to develop models with the minimum number of polygons necessary to achieve the desired effect.

Texturing the planet's surface isn't much of a challenge – one can find very accurate texture maps that will work nicely. The rings are a bit more difficult. Designing a 2D texture for the rings as viewed at a distance is not trivial, but designing a series of textures to make the rings three-dimensional when we move through them is downright hard. Unfortunately, a real-time system could not possibly handle a model of every individual clump of material in the rings – and most real-time systems don't support particle animation (an algorithmic method for generating lots of tiny objects without having to explicitly model every single one). In this case you'll most likely use a collection of flat polygons with custom texture and transparency maps.

Once all the models are complete and textured, they must be translated into the desired image generator format and downloaded to the IG and to a show-control workstation. Once everything is "installed", then comes the task of positioning models and preparing flight paths for both the objects and/or the view camera. Those details are very system-specific and are beyond the scope of this article. In any case, once everything is roughly positioned and timed, you're ready to finalize the sequence and move on.

To replicate this same scene in an offline environment, you again start with basic models and textures. This time you don't have to worry about level-of-detail models and polygon counts (though these techniques can save you some rendering time). There are also a number of "special effects" that you can add in the offline system not currently available with real-time. For example, you might develop a complex particle system to represent the rings where all of the individual particles are moving independently and realistically with the proper gravitational effects. You might also add layering effects to the planetary surface to simulate cloud layers. All these effects add rendering time, but they also add a stunning amount of realism to the finished sequence. Finally, the tools for creating object paths and camera paths are far superior to most real-time show production software. Furthermore, in most cases you can do all of your modeling, animation, and rendering in one software package, on one computer. Real-time often requires you to work with separate modeling, animation, and control packages, and several different computer systems.

As you read through the following product reviews, keep in mind that the technological issues of all-dome video are just one small part of the equation.

Regardless of which system you may prefer from a technical standpoint, there may be larger, more difficult questions to pose:

- Can I afford it?
- Will it help further the goals of my planetarium?
- Will it help me reach my audience more effectively?

You should also consider the time and money you'll spend on maintenance and production. Another important consideration is whether you have the creative and technical talent on your staff to effectively use the system, or if you prefer to use external production houses and private consultants. Any full-dome video system will more than likely require at least two, perhaps three full-time employees with very specific skill sets. The potential for these systems is great, but they require a significant resource commitment.

SkyVision Product Review

This review does not constitute a recommendation nor endorsement for any product or company.

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Evaluation Setup:

Cabletron, a large hardware vendor in the networking business, hired Sky-Skan, through a series of subcontractors, to produce and operate a demonstration program for Cabletron at the recent Networld & Interop show in Atlanta, Georgia USA. The program was given in a small 27-ft (8.2m) vacuum dome produced by ProDome (Antti Jannes & Co. in Finland). In addition, there was a Digistar II instrument, several moving-mirror incandescent fixtures, and an infra-red sound system. As an aside, the seats were from an automobile manufacturer and were very comfortable! Sky-Skan also demonstrates SkyVision in their 30-ft (9.1m) dome in Nashua.

SkyVision currently consists of six Barco video projectors (with outboard line quadruplers) for imaging on the dome. Five projectors form a continuous horizon image, and the sixth projector forms a "cap" that fills in the zenith. Each projector was mounted underneath the springline of the dome. SkyVision, as assembled in Atlanta, used Barco 801s projectors running at approximately 80% brightness. Sky-Skan also offers a high definition system called SkyVision HR. Using the same configuration, this system makes use of six Barco 1209s projectors. The digital video workstations that feed the projectors have an initial on-line video playback capacity of approximately 25 minutes and the native resolution for each frame of video is 1726 x 1296 pixels. This yields an image resolution approaching that of an IMAX frame across the dome.

All of the projectors are accessed through the SPICE automation system and each can function as a stand-alone unit along with providing SkyVision output. This makes the system extremely flexible when it comes time to incorporate more traditional video sources (e.g. laserdisc, DVD, and tape formats) into a program.

Producing the images were six PC compatible computers, each with a compressed video output card. In addition, the "zenith" computer also had a SMPTE timecode generator, and an additional card that delivered eight channels of digital audio for the show's soundtrack. Each machine also had a removable storage unit with a 9GB hard disk.

SPICE automation controls the SkyVision system, allowing programmers to search for and play from individual frames of video, and to play segments by name. The six-computer configuration is fairly flexible, and may change in subsequent revisions of the system. One advantage of keeping all six computers is that when it comes time to render new footage, you can have six processors working on the job.

In its current configuration, SkyVision supports two hours of online storage. That's two hours of full-dome imagery without changing disk drives. There are other storage options that can provide up to eight hours of online video if needed. Since the system uses removable technology, it is just as easy to swap in a new set of drives for additional content. In any case, SkyVision content storage is very flexible.

SkyVision supports interactivity through Sky-Skan's proprietary hardware/software combination, along with some creative pre-production. Since all of the content is pre-rendered and stored to hard disk, multi-path programs (where the audience chooses various topical segments during the course of the show) are quite simple to execute. In fact, when compared to laserdisc, hard disk based video can offer faster search times and more flexible control over playback. More advanced forms of interactivity are also possible, though it may require some extra effort during pre-production to assemble all the content in a meaningful way.

The production process for SkyVision is relatively straightforward; the magic is in the software. Sky-Skan has produced a clever production tool that can take a computer image file and dice it up such that it can be displayed as a whole by the SkyVision projectors. You can use almost any image, though to achieve full-dome video you will probably use a fish-eye lens (either real or virtual) to generate an appropriate hemispherical representation of the subject.

Perhaps the two most common ways of producing SkyVision images are via animation and compositing. When creating animated sequences, the renderer is set up with a virtual camera that mimics a fish-eye lens. This compensates for the distortion that occurs when projecting onto a hemispherical screen. The detail of an animated sequence is limited only by time and the sophistication of your rendering software. It is also possible to use video and film footage shot in more familiar rectangular formats. Using a compositing tool (e.g. Adobe After Effects) one can stretch and position footage for use with SkyVision.

Note that since the date of this review, Sky-Skan has made progress on streamlining the SkyVision production process and has integrated additional content development tools.

SkyVision Strengths & Criticisms

Probably the most important technical considerations to address are image quality, content production, and maintenance. The full-dome image generated by SkyVision is surprisingly good, but varies with content. With proper alignment, the seams between projectors are nearly invisible. Depending on the image being projected, sometimes the seams are not detectable at all. Projector alignment will drift with time, though, and will likely require regular adjustments to maintain the best image. High-detail, natural footage such as Earth-bound panoramas seem to be more forgiving than some animated sequences when it comes to detecting misalignments. Edge blending between the five horizon projectors is excellent. Edge blending inconsistencies between the zenith projector and the others is much more noticeable. As with any multi-projector system, the "soccer ball" effect is unavoidable when viewing large, bright, low-detail areas such as a daytime summer sky. (Keep in mind that this review was conducted in an inflatable dome, and it is nearly impossible to accurately align multiple projectors in such an environment — actual installations provide much better results.) Given a bit more time, the engineers at Sky-Skan say they can tune the image blending algorithms to minimize the visual impact. Content is perhaps the largest factor in evaluating image quality. Some material looks absolutely wonderful on SkyVision, while other sources highlight its weak points. Our guess is that this effect has as much to do with psychology and the human visual system as it does with the technical aspects of multi-image projection.

Some planetarians who have used large format video projectors may feel a bit underwhelmed by the brightness offered by CRT based systems, especially in larger domes. Thankfully, this isn't so much of a problem when using an all-dome video system by itself. That is, when the eye can't compare between a smaller, brighter projector and a larger, more dim image, the perceived contrast ratio is very high and the image appears to be quite acceptable. For mission critical applications, the image brightness issue can be overcome by doubling the number of projectors, effectively having two projectors per frame and having an instant backup for the theater.

It may occur that while producing an animated sequence for SkyVision, you spend all night rendering only to put the result up on the dome and find that it's not acceptable, for whatever reason. Careful planing and pre-production can minimize these troubles, but it's still a fact of life. To help alleviate this problem, one might do some production work in the dome itself, using one of the SkyVision projectors as a preview monitor. Then it is possible to adjust colors, intensity, detail, alignment, etc. such that it looks best when viewed on the dome, rather than on a computer screen.

Perhaps the greatest strength of SkyVision is the ability to produce detailed, Hollywoodstyle imagery with well known tools. Granted, the time required to render complex scenes is substantial, but it's the realism that modern audiences demand. Another strength of SkyVision is that it takes a software approach to solving projection geometry and overlap issues. This lowers the cost to the end user because software is easy to reproduce and upgrade and does not rely on more expensive proprietary "black box" hardware.

SkyVision is offered in full and partial dome configurations.

The first SkyVision installation was unveiled at the Houston Museum of Natural History's Burke Baker Planetarium on December 11, 1998.

StarRider Product Review

This review does not constitute a recommendation nor endorsement for any product or company.

StarRider™
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Evaluation setup:

The Evans & Sutherland Digital Theater division has constructed a demonstration and development theater at their headquarters in Salt Lake City, Utah. This theater features a 36-ft (11m) variable tilt Astro-Tec dome, Sky-Skan automation and sound reinforcement, a Digistar II digital planetarium, and a full dome StarRider projection system.

StarRider is currently based on the ESIG (Evans & Sutherland Image Generator) and the PRODAS display system from SEOS. PRODAS consists of six specially modified Barco CRT video projectors and a proprietary edge blending system to create a seamless dome image. The projectors are arrayed in a five-segment panorama with a sixth projector filling in at the zenith. (This configuration is very similar to SkyVision, with some differences in projector placement.) StarRider projectors normally reside in a cove space or projection gallery such that the front lenses sit just beneath the dome springline. PRODAS comes with a rather elaborate remote control panel that is used to administer all aspects of projector setup and operation. Unfortunately, the unit is not immediately compatible with any automation system; that functionality may arrive shortly.

With the addition of a video source switcher, StarRider can accommodate other input sources (e.g. laserdisc, DVD, SkyVision, and tape formats). Using these alternate sources and some creative animation techniques, it is theoretically possible to create non-real-time content for playback on StarRider. It is also possible to turn off the edge-blending hardware. In effect, this makes each projector behave as a "normal" Barco and provides six discreet channels of video.

The graphics muscle behind StarRider is the Evans & Sutherland line of image generators. As previously mentioned, the current version of StarRider ships with the ESIG — a proven technology that is used extensively in other E&S simulator product lines. StarRider is also available with the new Harmony and Ensemble image generators, both from E&S. Ensemble will come in at the lowest price point, using custom PC-based graphics technology. Harmony will offer the highest performance and image quality. Harmony uses several proprietary graphics engines to generate the six simultaneous video streams that drive StarRider. The IG is based on a number of custom chip designs and runs under a specially designed real-time operating system which results in unmatched performance. Harmony supports a number of breakthrough graphics technologies such as texture sharpening, real-time Phong shading, and a multisample depth buffer. Suffice it to say that Harmony is a very complex piece of engineering that is still in its infancy. I strongly recommend that you explore the E&S website if you're interested in these and other technical details of Harmony.

FuseBox is the software product that controls the Harmony IG and integrates the entire StarRider system. FuseBox is a show production and show control tool that brings together models, textures, and other assets, into a visual scripting environment. Show elements respond to system and user definable events (e.g. time cues), and "paths" help define object motion. In addition, FuseBox is the hub of StarRider's interactive capabilities. StarRider uses flight sticks and an armrest keypad for audience participation. FuseBox is a rapidly evolving tool that is being tuned to the program development needs of StarRider. Its learning curve is steep, but therein lies its power.

StarRider audio is handled by SawPro which is a commercial multitrack audio editor and playback system. SawPro can support up to 32 tracks of simultaneous audio playback provided that you have enough sound cards in your host computer (a Pentium class system with at least 128Mb RAM). SawPro is the SMPTE show source for StarRider and is triggered by FuseBox via MIDI. In case you're wondering, a 20 minute show with six audio channels requires about 650Mb of disk space if the material is stored at CD quality (44.1KHz sample rate, 16 bit resolution). As with most hard disk based audio systems, there is no wait for tape rewinding and the system can instantaneously jump to any place in the soundtrack – quite a boon during production.

The production process for StarRider is somewhat complex. Each task, in and of itself, is not overly difficult, but each has its own separate challenges. To begin, all of the visuals in a show must be modeled and textured. The modeling process can be done with tools like 3dStudio Max and MultiGen. The challenge is to create models that will work well in a real-time architecture. Perhaps the most important point is that models should have low polygon counts. In the process of creating textures, one must consider how colors will change when viewed on a large screen display, the effects of transparency, along with the physical size and image complexity of the texture. There are substantial differences when modeling for offline or real-time systems.

Once all the assets are generated, the next step is to begin organizing and developing the show in FuseBox. Models are positioned and oriented in the virtual world, given flight paths and other attributes, and events are timed to match appropriate script and score cues. During the course of production, one must keep in mind the capabilities of the real-time IG. In order to maintain image frame rates, a limited amount of detail may be present in each of StarRider's six video channels.

StarRider Strengths & Criticisms

StarRider shares most of the basic technical challenges found in multi-projector all-dome video systems; image quality, content production, and maintenance. StarRider's image quality is a function of content, production technique, and projector tuning. Visuals must be well modeled, strategically placed, and motion must be scripted with care. Harmony and the other E&S IGs are relatively forgiving technologies, but they do have limits when it comes to the complexity and placement of StarRider visuals. Specifically, there is a limit on the amount of detail that can be displayed in any one channel of the IG (recall that StarRider is a six-channel system — one channel per projector.) Furthermore, aligning and color matching the StarRider projectors is a challenging process. In order to maintain the best image, the projectors will most likely require bi-weekly adjustments. It is important to note that when the system is properly tuned, the resulting image is seamless and very pleasing to the eye.

Developing StarRider content requires a staff of creative and skilled professionals. The terminology and technical challenges of real-time are daunting. There's also a steep learning curve when it comes to the highly specialized software used to create and control models. Thankfully, one can use popular software like 3D Studio Max to create models, but one must use FuseBox to manipulate them within the context of a show. Still, the very best StarRider shows will be produced by those who have a firm grasp of real-time modeling concepts.

Perhaps StarRider's greatest technical achievement is truly interactive production and presentation. Interactively placing and moving visual elements on the dome is a relatively new production model and one that offers a tremendous amount of creative freedom. Furthermore, the real-time processing of StarRider allows one to develop audience interfaces that are unique and robust.

StarRider is normally sold as a complete package with dome, projectors, Digistar II digital planetarium, sound system, interactive hardware, effects, automation, and software. StarRider and Digistar II work well together on the dome, but they are wholly separate development environments. E&S currently offers full and partial dome StarRider systems.

The first StarRider installation was unveiled at Chicago's Adler Planetarium on December 4, 1998.

ElectricSky Product Review

This review does not constitute a recommendation nor endorsement for any product or company.

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Evaluation setup:

Spitz has several demonstration domes at its headquarters in Chadds Ford, Pennsylvania. ElectricSky™ is currently housed in their 40-ft (12.2m) dome (10 degree tilt). The theater also showcases a Spitz planetarium instrument, Spitz's new ATM-4 automation system, and a full complement of all-sky and special effects projectors.

ElectricSky is offered in several configurations. To be more correct, ElectricSky is a member of a family of products called ImmersaVision™, an immersive multimedia theater system developed by Spitz. All-dome (immersive) video is just one aspect of ImmersaVision. Currently, the most extensively supported suite of products include ElectricHorizon and ElectricSky. For this review, we are taking a look at Electric Sky as configured with three projectors providing a 200 x 60 degree field-of-view. Spitz also offers a four-projector system (panorama with top-cap) and a seven projector full-dome array. ElectricSky uses newly-developed Electrohome dome projectors with advanced geometry correction and edge blending technologies from Panoram.

The entire system is integrated within the ATM-4 automation software, allowing random video source selection, routing, and output format. ElectricSky provides support for CRV, laserdisc, DVD, tape, digital disk recorders, and workstation source material. ATM-4 also automates the edge blending hardware such that blended and non-blended source can be displayed within the same program.

Spitz developed a 10 minute demonstration program to showcase the ImmersaVision format. The first performance was delivered from a trio of CRV discs, and the second from DVDs. Without a side-by-side comparison, it's difficult to see any differences between the two source formats; both were of excellent quality. Spitz is also exploring hard disk based storage options with an eye toward an integrated media server. Recording source material to a CRV disk is relatively simple, but the disks hold less than a half hour of video per side. On the other hand, DVDs hold much more content but are currently somewhat expensive to create. Keep in mind that almost any video playback format can be used and the folks at Spitz seem to be generally flexible in supporting customer-preferred equipment.

Audio can originate directly from the playback devices or from a separate digital tape or disk recorder. ElectricSky uses the 5.1 surround sound standard from either encoded source or discreet channels. The ElectricSky specification outlines a complete theater treatment for sound reproduction, including speaker types, placement, and reinforcement hardware.

ATM-4 automation controls all aspects of ElectricSky through a new Windows interface. ImmersaVision content is treated as a single playback system with a standard set of control options. In addition, ATM-4 supports interactivity via proprietary hardware (audience responders) and integrated software control. Like any other pre-rendered architecture, interactive and multi-path programs require a bit of pre-production effort. Any time the audience is given a choice, two or more separate bits of content must be generated and stored for real-time retrieval during the program.

The production process for the ImmersaVision format is greatly simplified through the use of a number of custom utilities and plug-ins that work with off-the-shelf production tools like AfterEffects, and Photoshop. In addition, Spitz has developed a special plug-in for the popular program 3D Studio Max, called ImmersaMax, used to generate CG content for ImmersaVision.

ImmersaVision content can originate from a number of different source material formats including film, video (HD and NTSC), panoramic and hemispherical video and film, computer graphics, and still images. In each case, a producer can chose the form of spherical correction, if any, that needs to be applied to the source material to ensure that it is displayed correctly on the dome. Spitz is the only manufacturer that offers the ability to set an eyepoint when correcting materials for display on a dome. That is, every other system assumes that the viewer is seated in the very center of the theater, which is usually the location of the planetarium instrument. With Spitz's utilities, you can create a view that is better suited to your particular theater layout.

Because ElectricSky uses hardware edge blending there are a number of other image sources that can be considered. For example, you can connect a desktop PC/Macintosh to the system, displaying the computer desktop across three full projectors. ElectricSky can also be driven by multi-channel visualization systems (from Silicon Graphics, Intergraph, HP, etc.), and other real-time image sources. This is a tremendous advantage during production because you can test source material without having to split it up into three separate frames and then apply soft edges for display. In the case of ElectricSky, just open a window containing an image with the correct aspect ratio and you're done! One might also imagine playing video games on this enormous display, or perhaps seeing every cell in a large spreadsheet. The possibilities are quite exciting.

ElectricSky Strengths & Criticisms

Spitz's video panorama and ImmersaVision projection format are more than a collection of software and hardware. In developing these technologies, Spitz spent a great deal of time researching large-format immersive displays. What they've come up with is an extremely flexible system that can accommodate a diverse range of source material and a production and presentation philosophy that is based on the science of visualization. Of all the systems reviewed thus far, Spitz has demonstrated the greatest amount of technical flexibility and product forethought.

Spitz blends their video projectors with a 25% overlap, which is a bit more than the other manufacturers use. This larger overlap seems to have a positive effect on the resulting image, giving the very best color blending, and absolutely seamless geometry blending. Spitz also uses a circular top-cap, reducing the edge-blend artifacts that can be quite harsh in a pentagonal cap (a la SkyVision and StarRider).

Like SkyVision, ElectricSky production uses mostly off-the-shelf tools and popular software packages for the manipulation and generation of content. Spitz, however, has developed additional custom utilities that allow an illustrator or animator to use virtually *any* software package for content creation, even if that software doesn't support spherical rendering or custom image warping! The other tremendous advantage to ElectricSky is the ability to preview content on the dome without having to split images and pre-blend. In fact, you can use ElectricSky as a working desktop and produce images right on the dome.

Spitz is currently focused on the three-projector ImmersaVision format, with a sound philosophy and research to back up their development efforts. They are working to build more support for their full-dome video product, though Spitz did not demonstrate full-dome capability during the review. There's no doubt that a tremendous amount of content can be effectively displayed within the ImmersaVision format. A planetarium, though, implies a complete hemisphere and sometimes it's necessary to exploit the full dome for maximum effect. Bear in mind that full-dome configurations can be much more expensive, and they require more complex production techniques. There is a clear trade-off and a planetarium's choice may depend on cost, support, production and maintenance issues. Formats like ImmersaVision provide a cleaner, more uniform image than full-dome, are easier to maintain and operate, and provide a very dramatic effect when used well. It's not an easy decision.

The first ElectricSky theater was unveiled at the Northern Lights Centre in April of 1997. The Northern Lights Centre is located in Watson Lake, Yukon Territory, Canada.

VisionDome Product Overview

This overview does not constitute a recommendation nor endorsement for any product or company.

VisionDome™
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VisionDome is a system for projecting full-color, full-motion graphics, created and manipulated in a 3-D computer environment. The technology is most similar to that of StarRider, but instead of using several video projectors to cover the dome, VisionDome uses a single projector and fish-eye lens to achieve a full-dome image. VisionDome is a real-time architecture that shares many of StarRider's strengths and content development challenges.

Alternate Realities Corporation is located in North Carolina's Research Triangle Park, nestled between the cities of Raleigh, Durham, and Chapel Hill. Morehead Planetarium proved to be a convenient, yet challenging test for their system in an actual, working planetarium theater. (Until that time they had limited their activities to using the technology in a small, demonstration dome as a stand-alone system.) Besides the challenges of positioning the projector off-center, such a demonstration would test the ability of the system to project images over a much greater distance. Both the VisionDome and Morehead staffs were initially skeptical about how well the system's images would hold up projecting onto a 20.7-meter (68-foot) dome, but felt, nonetheless, that the challenge would be informative in evaluating VisionDome's capabilities and limitations.

After a couple of preliminary visits to evaluate the Morehead theater environment, and to arrange for an adequate electrical power feed, the VisionDome team arrived to conduct their test. Their equipment included a 3-D graphics workstation and image processor; a high-intensity, high-resolution video/graphics projector; a specially-designed optical assembly for the 180-degree projection; and a large, makeshift wooden stand for the projector.

On "test day", equipment setup was completed within only a couple of hours of arrival. The large projector had been placed on its stand, the long optical pipe — complete with integral fisheye lens — was mated and aligned to the projector, and the graphics workstation and processor was up and running. A few moments later, the first VisionDome images were being drawn. A variety of different images were displayed during the test, including fractal-style images, a graphical Space Shuttle launch, and a DNA double helix, among others.

The initial results were encouraging with a number of images that showed a surprising degree of sharpness and clarity. Motion of the manipulated "objects" was relatively smooth, with very little jerkiness evident. Objects were projected with a variety of background colors, but the best results were obtained when objects were placed against a black background.

Of course, it was assumed that there would be difficulties associated with the Morehead test. Some of the images displayed during the test were quite "soft" in appearance. The VisionDome people said this was because they were testing image-sequences of a variety of resolutions. It was obvious that only the higher-resolution images would be applicable for all-dome use. There was some distortion visible in the images, taking the form of the image appearing to rest atop a curved void of black extending about 75 degrees in azimuth and about 10-15 degrees in altitude at the void's apex. The VisionDome folks attributed this effect to an incorrect mechanical adjustment between the projector and the lens pipe. They explained that this would be easily correctable by re-machining the shim-plates between the two components. However, the good news was that the distortion that would normally be encountered by projecting images off-center is easily corrected by loading a computer algorithm into the graphics processor.

The main limitation seen during the test was Morehead's large dome-size, which lowered the brightness, contrast, and overall color-saturation of the images. In addition, Morehead's white, high-reflectance dome further reduced the overall contrast of many images — particularly those incorporating non-black backgrounds — because of "cross-bounce". (This is a phenomenon familiar to all-dome film people, and is why such theaters have gray domes to reduce the overall reflectance, and thus, the cross-bounce effect.) Both the VisionDome and Morehead personnel suspected that lowered brightness, contrast, and color would be negative factors in the test, but were, nonetheless, pleasantly surprised that the images "held up" as well as they did. However, because of these limitations, VisionDome, as currently configured, is not optimized for large-dome applications. And given the need for lowered dome reflectance, the system is probably best suited for domes roughly 12-meters (40-feet), and smaller.

VisionDome Strengths & Criticisms

As with most of the systems under review, content for VisionDome is a primary concern. VisionDome's graphics workstation and application software appeared to be quite functional. However, since there is currently little in the way of appropriate ready-to-go graphical sequences for the system — particularly those which are astronomical in nature — the burden appears to rest primarily on the shoulders of the end-user. Facilities considering VisionDome or any other similar graphical system for the planetarium must consider the issue of content availability. With a trend toward smaller staffs in planetariums these days, many facilities may be hard-pressed to create original images for use in programs, given the staff-time and expertise needed to generate even the simplest 3-D objects and manipulated sequences. To that end, Mr. Galluppi and the engineers at ARC are interested in approaching the planetarium community as a potential market and looking for artists/designers to develop visual content.

The Morehead demonstration should be looked at as a worst-case scenario. Not only was the dome extremely large, but the system was tested with an older generation of video projector. Newer projectors from the same manufacturer can produce brighter, sharper images at higher resolutions. The greatest potential for VisionDome is in smaller theaters where the image can be most effectively used.

Alignment and color balancing with VisionDome is greatly simplified since there is only one projector and one lens. There are no bright spots, overlap areas, or other alignment headaches to deal with. While the system is not maintenance-free, it is much less expensive to own and operate.

An ideal partnership would probably be to install a VisionDome system into a college or university planetarium where staff and students could make use of it as a visualization platform and showcase for student graphics work. VisionDome is available in a number of configurations and price-points.

Questions and comments regarding these reviews should be made directly to the respective vendor or to the IPS Technical Committee:

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Large-Scale Immersive Displays in Entertainment and Education

Ed Lantz
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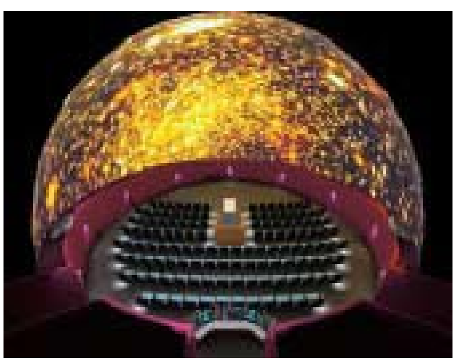
Abstract. Large-scale immersive displays have an established history in planetaria and large-format film theaters. Video-based immersive theaters are now emerging, and promise to revolutionize group entertainment and education as the computational power and software applications become available to fully exploit these environments.

Requirements for an effective visual display are developed. Limitations of commercial projection and image generation technologies are discussed and improvements are suggested. Trade-offs between flat, cylindrical, and spherical projection screens are discussed. Recent work is presented in group telepresence and interactive VR Cinema. Ongoing issues include group interactivity paradigms, show production tools, and the need for research establishments to disseminate compelling source material to public venues. Research topics are suggested in Human Factors, Virtual Reality, Computer Graphics and Display Engineering.

Entertainment and Education

Large-scale immersive displays have been in use since the first Zeiss planetarium in 1926. The popular IMAX® Dome format, first demonstrated in 1973, utilizes 70mm film with roughly 5000x4000 line resolution on a dome screen. Simulator rides utilize 35mm or 70mm film projected onto partial dome screens. Over 2500 dome theaters are now in place worldwide.

Immersive displays utilizing wrap-around screens are well suited for public presentations as they require no special viewing skills, unlike other VR technologies such as head-mounted displays [1]. Emerging video-based immersive theaters are capable of providing real-time experiences for large groups including guided tours through popular virtual environments, virtual sports, group telepresence and interactive simulations[2].



Immersive video “digital dome” theater

Entertainment and informal education applications result in display requirements which differ from visualization systems research or collaborative design. Such applications include traditional planetaria, science centers, aquariums, zoos, corporate theaters, visitor centers, location-based entertainment and community special-venue theaters. Emphasis is placed on the overall quality of visitor experience. The entire theater is intergral to visitor experience, of which the information display is but one element. General theater design considerations include the following.

- Transparency - The theater is designed to “disappear” during the presentation by using dark and non-obtrusive finishings. Projection systems and computer equipment are hidden from view and acoustically isolated. Visual cues associated with the projection surface are minimized (i.e. seamless projection screen).

- Comfort - Seating is arranged to assure good sight lines and comfortable viewing for extended periods.

- Geometry - Since an entire group cannot simultaneously occupy the ideal eye-point of an immersive display, a projection geometry must be adopted which has a graceful degredation in orthoscopy as the viewer moves off-axis. Geometry should be “acceptable” from all paid seats.

• Interactive Ergonomics - Whatever method is used for group interaction with the immersive experience must be easy to learn, simple to use and accessible to a wide range of skill levels.

• Audio - Theatrical surround audio is common to all modern theaters and is key to a compelling experience.

• Realiability and Maintainability - Theaters must operate cost effectively. This requires minimizing down-time and equipment maintenance costs.

• Throughput - Special venue theaters require ample seating and virtually no visitor training for an enjoyable experience. Emphasis is on providing sufficient visitor throughput to recover capital and operating costs. Immersive displays such as the CAVE™ do not provide an attractive economic model due to their low throughput, high cost and specialized staff requirements.

Immersive Projection Screens

Consider the field-of-view (FOV) produced by a flat projection screen. The FOV is proportional to twice the arctangent of the screen height or width. As the screen is made larger (or the viewing distance reduced), the FOV apporaches a limit of 180 degrees. The next progression is to a cylindrical screen with a vertical rotational axis. An image projected onto a cylindrical screen provides a full 360 degree horizontal FOV. Vertical FOV, however, remains limited to 180 degrees even for an infinitely tall screen.

Another approach for attaining a wide field-of-view is to utilize a polygonal screen configuration such as a cube or dodecaherdon. However, polygonal screens such as the CAVE, which employs a cubic configuration, do not provide a graceful degredation in orthoscopy as the viewer moves off-axis. The discontinuities inherent in polygonal screens have therefore limited their use to a small number of special venue theaters.

Dome screens offer a wide FOV with the possibility of nearly full visual immersion. High-quality dome screens are readily available ranging from 3 meters to over 27 meters in diameter. Dome screen projection surfaces are typically formed by compound-curved, perforated, powder-coated aluminum panels. The perforated projection surface allows airflow from HVAC to penetrate the screen and also affords a degree of acoustic transparency. Ambient sound can therefore penetrate the screen and be absorbed rather than reflected (and focused) back into the theater space. Also, loudspeakers can be freely placed behind a perforated screen.

Screen diameter is often driven by the required seating capacity. More seats can be placed in a given dome if a greater compromise in visitor experience (i.e.greater geometric distortion) is tolerated. In general, smaller domes (<10 meters) provide undesirable visual cues that one is viewing a screen surface. This is probably due to a combination of visual accommodation (focusing) and binocular disparity (stereopsis) for varying screen distances as occurs with eye motion. Any imperfections in the dome surface, such as visable seams or perforations, also contribute to a loss of realism. Small simulator domes avoid this by placing the viewer(s) within a small viewing volume near dome center and using a solid screen surface with specially finished seams.

Surface reflectivity is a critical issue with curved-screen theater design. Image contrast can be degraded due to the “integrating sphere” effect caused by light scattered from a projected image back onto another portion of the curved screen. A bright image can therefore “wash out” the entire screen if the screen reflectivity is too high. Two solutions exist for this effect. Some dome simulator systems employ screen “gain,” an increased specular reflectivity with respect to a Lambertian surface which scatters light equally in all directions [3]. This narrows the range of angles reflected from an image to cover the primary “viewing volume,” the volume containing the viewer’s head, and not the screen itself. Drawbacks to this approach include difficulty edge-blending multiple projectors and a reduced seating area. Screen gain has successfully been employed in training simulators and 3D simulator rides such as Imax’s *Race for Atlantis* in Las Vegas. The polarization-preserving properties of a high-gain screen surface make it crutial for polarized 3D projections [4].

Another method for increasing contrast is to reduce the screen reflectivity using a neutral-density powder-coat. Since scattered light requires at least two screen reflections to reach the viewer’s eye, the scattered component is proportional to the square of the reflectivity R, which is always less than one.

The image brightness itself is subject to a single reflection and is attenuated by R. Contrast is therefore improved at the expense of overall image brightness. It is useful to note that the exact degredation of contrast due to cross-scattering depends on the nature of the image being projected. The percieved contrast of a projected starfield, for instance, is not appreciably improved by lowering reflectivity much below 0.5 (50%). However, domes made for film projection often employ dome reflectivities of 0.3 or less.

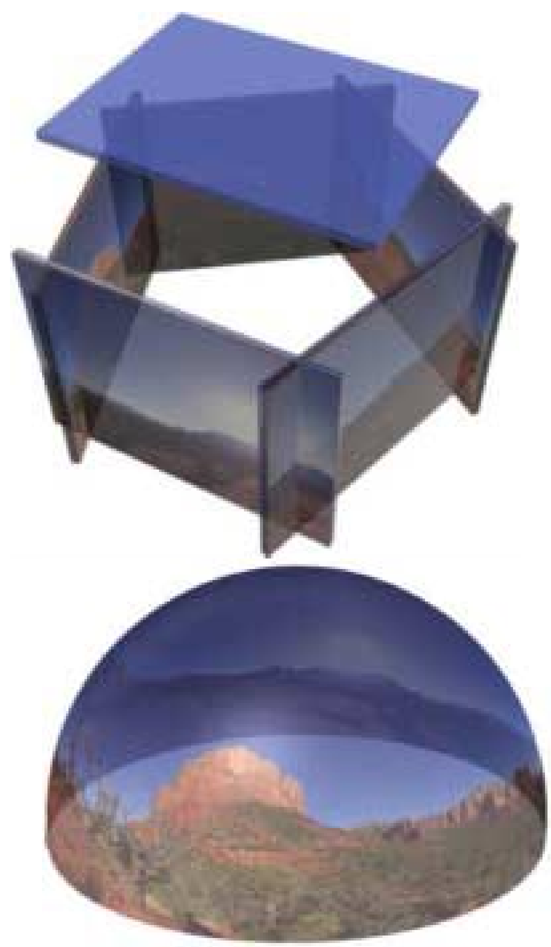
Projection Techniques

The projection of extreme wide field-of-view (FOV) images is problematic. It requires, for instance, over 400 million pixels to cover a hemisphere with eye-limited (1 arcmin) resolution [5]. In contrast, the 1080i high-definition video format provides only 2 million pixels. A more practical approach would be to require the equivalent resolution of a 72 dpi monitor viewed at 0.6 meters (2 feet), which is 4 arcminutes under ideal conditions. The 4 arcminute requirement reduces the hemispheric coverage to 30 million pixels, still out of reach for any single projector. Even the popular IMAX® Dome format, which is not a full hemisphere, provides perhaps 12-20 million pixels for a stationary image [6].

A modern 9-inch CRT video projector can provide up to 2500x2000 addressable pixels, resulting in a 5 million pixel image. Higher resolutions will be possible with the new 12-inch projectors. However, physical limits will soon be reached on signal bandwidth and optical resolution. Arrayed projection avoids these limits by using multiple arrayed (mosaicked) video projectors which are edge-blended (stitched) to seamlessly reconstruct the original high-resolution source [7]. Extreme high-resolution displays are possible using this technique.

The success of arrayed projection depends in part on the technique used to edge-blend adjacent images. Soft-edge masking can be performed quite easily using an alpha-channel. However the monochrome alpha-channel affords no custom control of individual color layers. In practice, the gamma response of each projected color is slightly different requiring different edge-blend settings on each color component for optimal performance. Separate red, blue and green edge-blend masks must be created interactively for each installation and maintained as the projection source ages. Outboard electronics with a dedicated user interface are typically employed in such applications [8].

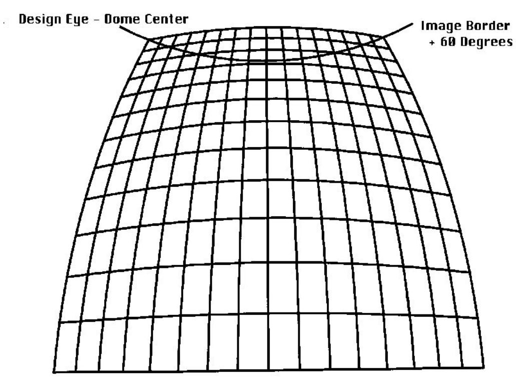
Projector deviations from ideal gamma performance can limit achievable edge-blend quality. The blue phosphor in CRT projectors, for instance, has a gamma response which deviates significantly from other phospors and requires linearization circuitry. If a color saturates, for instance, the edge-blend for a bright image will require different settings than for a dim image. Precice gamma correction is not a high priority for projector manufacturers. Neither is matching the color balance and gamma response between two projectors. Creating an acceptable edge-blend is currently more of an art than a science due to a lack of control over these factors. The commercialization of arrayed projection systems will ultimately require auto-calibration features for edge-blending and projector geometry.



Six rendered views are mapped and blended onto dome

Geometric mapping is required to transform a two-dimensional view-plane raster image into a spherical or cylindrical section. Accurate image mapping is a critical issue for arrayed dome projection, as an effective edge-blend requires pixel-accurate overlap of adjacent frames over a compound curved projection surface. Any mismatch between frames creates a degredation in resolution performance within the edge-blends.

Two common techniques for mapping are image warping in the image generator and raser warping in the video projector. CRT projectors have geometry correction circuits which are incredibly flexible. Fixed-panel projectors such as the DLP or LCD are not capable of image mapping and therefore place extra demand on the image generator.



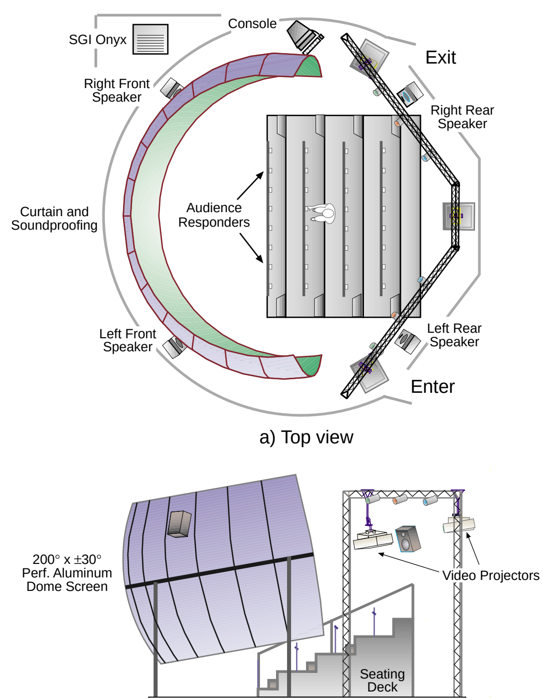
Typical image mapping

An interesting trade-off exists in system design. The edge-blend width typically ranges from 1-25% of the frame width. A wider edge-blend region increases the eye's tolerance to adjacent projector color mismatch due to the gradual color change. At the same time, however, the wider blend area is more demanding on projector alignment over a larger area and requires more redundant pixels to be rendered per channel.

Display brightness and contrast performance are also critical factors for an effective presentation. The eye's sensitivity to color degrades with decreasing image brightness. CRT projectors, while they offer the greatest flexibility in geometric mapping and scan rates, are the lowest brightness of all projector types. A typical 9-inch CRT projector provides a brightness of 240 lumens while a high-end light-valve projector currently tops out at around 6000 lumens - 25 times brighter at only five times the cost. High contrast is required to produce effective edge-blends under dark-frame conditions and to project over stars in planetaria. Unfortunately, either brightness or contrast are presently limited by available display technologies. It will be some years before video can match the quality of large-format film [9].

Recent Work

Several companies have recently announced large-scale immersive video-based theaters for real-time 3D presentations. The first public installation was the Spitz ElectricHorizon™ VR Theater, a temporary experimental theater tested last year in Pittsburg's Carnegie Science Center [10]. This theater seats 32 persons on an inclined seating deck and includes 3-button responder units for audience interactivity. The screen is a 200° horizontal by 60° vertical FOV partial dome with an 8.5 meters diameter. The image is produced by three edge-blended Electrohome Marquee™ 9500 projectors. Image generation is provided by a single-pipe Onyx® Infinite Reality feeding three SVGA video channels.



a) Top view

b) Side view

The opening show, ROBOTIX Mars Mission, was developed by Carnegie Mellon's SIMLAB and funded by Learning Curve Toys of Chicago, IL. The show depicts a mission to the planet Mars based on Learning Curve's ROBOTIX toys and

NASA Mars data sets. This project revealed numerous challenges to be overcome in the commercialization of IPT for entertainment and education. While compelling, the quality of a video-based display projecting real-time 3D images simply cannot match the image quality and photorealism that people have come to expect from special effects in film. The success of these theaters will hinge on the creative use of audience interactivity to differentiate them from similar film-based theaters.

A second project last July converted the ElectricHorizon theater into a telepresence command station for Nomad, a robotic explorer. Nomad was designed by Carnegie Mellon's Robotics Institute and tested in Chile's Atacama Desert in conjunction with NASA Ames. A live

Realtime panoramic image from Nomad robot at Carnegie Science Center

feed from Nomad's "panospheric" camera was displayed in real time for audiences at the science center. The camera provided a 360° FOV image which was remapped onto the immersive display by the Onyx. Although the frame rate was slow, since the remapping occurred in real time the audience was able to smoothly rotate the camera view using their responder buttons.

Passive video playback systems avoid some of the pitfalls and expense of experimental real-time 3D-based theaters. Last year Spitz installed their first ElectricSky™ theater in the town of Watson Lake within Canada's Yukon Territory. The Northern Lights Centre is a unique multi-use, multi-format special venue theater which employs a partial dome panorama similar to the ElectricHorizon format. Feature shows are pre-rendered from 3D computer graphics, film and video, heavily composited in post production, and played back from three line-interpolated NTSC sources. Other activities at the Centre include licensed DVD films, video game

ElectricSky video panorama

tournaments, and laser shows. While this system does not employ high-end real-time 3D image generation, it is easily upgraded for this capability. Numerous such theaters will be installed in coming years, both with and without real-time capabilities, and will provide a new venue for anyone producing visually compelling virtual environments and immersive content.

Content Development

Much of the content for virtual environments is produced by the commercial simulator and academic communities. The cost of developing a large volume of immersive experiences is too much for any one corporate entity to bear. If these new theaters are to thrive it will be a collaborative effort. There needs to be a pathway for the dissemination of interesting and informative models and simulations into these public venues.

A satisfying theatrical experience hinges on the presentation of a compelling show or interactive experience. Regardless of how novel and informative graphic content may seem, if it is not woven into an interesting story it will probably fall flat. For this reason it is important to involve media professionals in any serious attempt to develop entertaining shows for IPT systems. Early projects will help define successful show production models and storytelling conventions for immersive programming.

Our experience has taught us that the rules for IPT presentations go well beyond those of conventional media. The possibility of inducing motion sickness, for instance, requires close attention [11]. While simulator rides exploit this effect, their duration is seldom more than several minutes. If the desire is to convey information, immersive visuals might in fact prove to be a distraction in some cases.

Another important issue in the commercialization of IPT is the development of user-friendly content production tools. Numerous tools exist for digital film and video production along with armies of trained professionals. Visual simulation is a highly specialized field with only a handful of experts and specialized software. This is changing, however, with the advent of real-time 3D computer games. Immersive multimedia productions will likely hybridize tools from the film and video, visual simulation and 3D video game industries. An immersive production environment would ideally be capable of handling any input format including live action film or video, HDTV, and pre-rendered animations.

One issue that remains open is the best means for involving the audience within an interactive, immersive experience. Pushbutton responders leave a lot to be desired. Group “majority rules” interactive experiences are not nearly as compelling as one-on-one video games. Even multidimensional controls such as joysticks do not provide a personal involvement in show outcome. Early systems will likely employ a trained navigator or “tour guide” to control the viewpoint for the audience.

Research Topics

Large-scale immersive video-based theaters are finding applications in numerous special venues including planetaria. As the installed base of theaters increases, the need for compelling content and product developments will increase as will available funding. University research is expected to play a major role in the commercialization of IPT. Therefore this paper concludes with suggestions for IPT research.

IPT opens the doors for unique work in Human Factors Engineering and Psychophysics. The wide instantaneous field-of-view provided by IPT can be used to study the opto-vestibular response and other phenomena relying on peripheral vision [12]. The concept of presence may have to be revisited. If Information Visualization scientists better understood how the brain processes wide-field imagery then the increased visual bandwidth of IPT could be more fully exploited for information communication and navigation.

It is important to characterize edge-blend performance based on factors such as gamma linearity and gamma matching between projectors, color balance, and geometric alignment. It is difficult to develop specifications for projector gamma linearity without knowing the sensitivity of the eye to deviations in linearity for an edge-blended image. Robust test patterns for display performance testing are required. It would also be useful to evaluate various projector types for fundamental limitations in key areas important to edge-blending such as gamma linearity and color balance.

A major stumbling block is the lack of innovation in group interactive paradigms and hardware interfaces. Perhaps the most interesting work being done in this area is by Rob Fisher of the Studio for Creative Inquiry at Carnegie Mellon in conjunction with Cinematrix. Rob is creating a new research facility for the purpose of studying the educational effectiveness of group interactive technology. Topics include portraits of audience behavior designed to reveal features like emergent behavior, group dynamics, nearest neighbor effects, and changes in response time.

Immersive theaters will never succeed without a constant stream of compelling content. Quality content is needed now to demonstrate the viability of these theaters and to jump-start the market.

Renaissance painter Leonardo da Vinci considered natural perspective to be spherical [13]. Currently images are rendered as view planes and then warped or mapped to a cylinder or sphere. Practically every rendering engine in existence is based on planar perspective projection. It would be interesting to examine the possibility of a spherical rendering engine. Such a renderer would operate in polar coordinates and would require an efficient means of mapping multi-resolution images to a sphere [14,15].

[1] Ed Lantz, Steve Bryson, David Zeltzer, Mark Bolas, Bertrand de La Chapelle, and David Bennett, “The Future of VR: Head Mounted Displays versus Spatially Immersive Displays,” *Computer Graphics*, Annual Conference Proceedings Series, pp. 485-486, 1996.

[2] Ed Lantz, "Future Directions in Visual Display Systems," *Computer Graphics*, 31(2), pp. 38-45, 1997

[3] Shen Ing, "High Gain Screen Technology," *Image VI Conference Proceedings*, pp. 41-52, July 1992

[4] Kevin Arthur, Kamal Hassan, and Hugh Murray, "Modelling Brightness, Contrast and 3D Coincidence in Dome Screen Theaters," 134th SMPTE Technical Conference Proceedings, pp. 1-14, November 1992

[5] Hemispheric pixel mapping estimate assumes the image originates from an equidistant polar format with equal-area pixels spanning the diameter (representing 180°). For 1 arcminute resolution, pixel size is 0.5 arcminutes (assuming ideal Nyquist sampling), requiring a 21,600 pixel diameter polar file size. Resulting frame contains 466,560 total pixels with 400,500 active pixels.

[6] Achievable resolution of film-based systems depends on a variety of factors including film stock, exposure, and camera/projector optics. Between 50 and 150 line-pairs per millimeter are typical resolution values for film stock.

[7] Theo Mayer, "New Options and Considerations for Creating Enhanced Viewing Experiences," *Computer Graphics*, 31(2), pp. 32-34, 1997

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[9] Laurence J. Thorpe, "HDTV and Film - Issues of Video Signal Dynamic Range," *SMPTE Journal*, pp. 780-795, October 1991

[10] Ed Lantz and Jon Shaw, "Spatially Immersive Displays for Group Information Visualization," *Workshop on New Paradigms in Information Visualization and Manipulation* (NPIV'96), in conjunction with CIKM 96, pp. 37-40, October 1996.

[11] Thomas B. Sheridan and Thomas A. Furness III, ed., various articles in "Spotlight on Simulator Sickness", *Presence*, Vol. 1, No. 3, 1992.

[12] Gunnar Johansson and Erik Börjesson, "Toward a New Theory of Vision: Studies in Wide-Angle Space Perception," *Ecological Psychology*, 1, pp. 301-331, 1989.

[13] R. Patteson Kelso, "Perspective Projection: Artificial and Natural," *Engineering Design Graphics Journal*, Vol. 56, No. 3, pp. 27-35, 1992.

[14] W. Fetter and C. Wittenberg, "A Progression of Wide-Angle Display Developments by Computer Graphics," *Displays*, Vol. 5, No. 2, pp. 65-83, 1984

[15] Gyorgy Fekete, "Rendering and Managing Spherical Data With Sphere Quadtrees," *IEEE Visualization '90 Proceedings*, pp. 176-186, 1990

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Future Directions in Visual Display Systems

Ed Lantz
Spitz, Inc.

Introduction

Visual displays have evolved in several parallel application areas including television, computer monitors, graphics monitors, portable displays, projection displays and most recently, immersive displays. Film, too, has matured as the highest resolution display medium available. One might mistakenly proclaim that today's visual displays produce an image quality which nearly matches that of our perception. The truth is that primitive cave petroglyphs viewed in firelight far exceed the visual capacity of any modern imaging and display system. Our visual displays only represent a small piece of what our eyes perceive to be reality.

Consider the visual content in a highly ornate architectural space such as the Sistine Chapel. One is immersed within great columns, arches and a ceiling covered with Michelangelo's paintings containing hundreds of human figures. One could argue that this space is a vast immersive display system designed to invoke a sense of awe and communicate a biblical world view. The environment is static, but viewing it involves a great deal of eye, head and body motion. Even our best large-format film displays are at a loss to reproduce the range of colors, dynamic range of intensities, field of view and level of detail present in such a space.

Visual displays are arguably becoming our primary means of information delivery. Their design can profoundly affect how we daily communicate and interact with information. As image capture, generation and display technologies advance, we will see visual systems improve in both realism and level of immersion. Arrayed display systems are already providing a leap in simultaneous wide field of view and high resolution. These advances are fundamentally changing the way in which information can be represented by increasing information bandwidth and enabling a deeper engagement of our visual senses.

Social Impact

Despite their inability to thoroughly feed our hungry senses, advances in display technologies, coupled with advances in high speed networking and computing, are having major impacts on society. Never before have so many ideas, philosophies, images and data been accessible to so many people worldwide.

Those of us in medium- and high-income nations are becoming increasingly empowered to express ourselves through visual media. A home video can now be shot, edited and distributed to other family members to be viewed on their television set, or digitized and uploaded onto a web page. Visual media technologies are growing less expensive and will eventually reach all corners of the earth and all levels of society. Humanity's ability to personally record, manipulate, generate, distribute and display graphic material is rapidly increasing.

Unlike television, personal media production and networking are bi-directional and tremendously empowering. Many have likened the effect to neurons connecting to form an organism, a kind of global consciousness. Some futurists, such as Interval Research's Marc Davis, even suggest that readily accessible "garage cinema" will produce a monumental change in how we communicate. He predicts an eventual shift from glottographic (vocal-based) communication to semasiographic (meaning-based) communication through images and image sequences [8]. Others are quick to point out the pitfalls of image-based communication [14]. The growing field of information visualization is perhaps the first formalized step towards semasiographic communication [5].

Visual Display as Human Machine Interface

Visual displays were born out of a desire to capture, transmit and display real-world imagery. Computers now employ visual displays as human machine interfaces (HMIs). Achieving a better representation of real-world imagery drives display technology in essentially the same direction as achieving a better HMI. That is because both applications require an interface which exploits natural vision perception, whether it is real-world imagery or a spatial representation of data such as a graphical user interface (GUI).

Consider the visual display as a wideband HMI. The eye takes in gigabits of information per second using over 100 million photoreceptors. This information is compressed down to just a few Mbps in the retina and sent to the visual cortex [26] and other brain centers which control orientation and motor control [11]. On the other side of the interface, a computer is whirring with billions of operations per second. The object, it would seem, is to provide the highest bandwidth interface between brain and computer. To an engineer, the optimal hardware solution seems obvious: total retinal stimulation. Don't let a single nerve ending in either eye go to waste.

Much of our cognitive information is derived from a small portion of our visual field of view (FOV). The fovial region of the eye, less than 2 degrees of our total FOV, contains most of our photoreceptors (see Figure 1). Consider the broadcast television display. Viewed from a comfortable distance it spans 10-15 degrees of our FOV with 152,000 effective pixels of information [17].

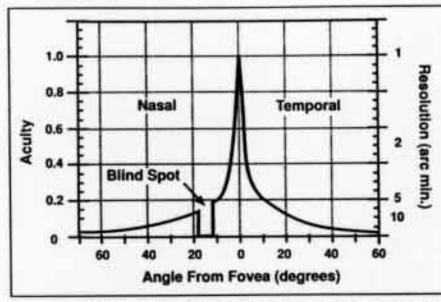

Figure 1: Distribution of visual acuity across the retina [31].

It doesn't take a cognitive scientist to see that there is more to our visual perception than is stimulated by staring at a television. For instance, eye and head motion allow us to take in significantly more information, providing a cognitive "view sphere" of our surroundings [9]. Cognitive maps arise when we navigate through a space providing us with a continuous stream of view spheres. Head displacement and navigation also create optic flow and motion parallax which is sensed by our peripheral vision and used by our sensory-motor system to judge motion. Motion sickness is likely an example of visual motion cues conflicting with vestibular and kinesthetic cues [32].

Ideally we want a display which can stimulate all of our retina while allowing freedom of eye rotation, head rotation and physical displacement. Enter the head-mounted display (HMD) pioneered by Ivan Sutherland in the late 1960s [34]. This revolutionary display is coupled to the user's head. A geometrically correct computer generated image is displayed as a function of head rotation and displacement. The HMD has matured with numerous commercially available models ranging from inexpensive video game units to million-dollar helmet-mounted simulator display systems for military training [21].

Why Doesn't Everyone Use an HMD?

If the HMD is the ultimate display device, then why doesn't everyone use one? To start with, there is relatively little content available in an immersive (3D computer graphics or immersive video) format. Full-motion immersive video imaging has only recently emerged [36, 2, 27]. Synthetic 3D imagery can be generated and displayed in real time, but virtual environment (VE) technology is in its infancy. There is much to learn about representing information and telling compelling stories in three-dimensional interactive space [29]. Also, the greatest hindrance with VE technology is the high cost of a quality image generator (IG) and associated VE production. These limitations are disappearing, however, with falling computer costs and increasing graphics power.

We then have the problems associated with the displays themselves. Only very expensive HMD's can simultaneously display high resolution and wide field of view. Most of these units are CRT-based which means they are quite large and encumbering. HMDs are also limited to a single user per graphics channel. Other remaining problems include multi-user hygiene and user fatigue due to improperly adjusted optics, conflicting accommodation and vergence cues and image latency. Also, features such as opacity (the blocking out of external reality) can actually be a hindrance in real-world applications that include co-workers and ringing phones.

Head-coupled displays such as the Boom™ or Push™, pioneered by Fakespace, are common alternatives to the classic HMD [4]. See-through HMD designs, as pioneered by Virtual i-O and others, are also gaining popularity. These displays are vital to augmented reality which overlays the real world with related information [3], and will likely be popular with future wearable computers.

Another promising HMD technology is the Virtual Retinal Display (VRD) currently being refined by University of Washington's Human Interface Technology Lab. The VRD scans an image directly onto the viewer's retina resulting in images with high brightness, resolution and contrast. Still in development, the current implementation is bulky due to the optical scanner, and has a narrow exit pupil making it difficult to align one's eye to the display [22]. However, this technology could ultimately offer a low cost, high-resolution, high-brightness stereo display in a package the size of conventional eyeglasses.

The HMD is theoretically the ultimate display device. In reality, HMD technology requires greater refinement if it is to be a widespread household or office tool. Nevertheless HMDs have already found niches in applications such as entertainment, training and visualization. HMD technology is steadily improving thanks to a number of innovative and responsible manufacturers. At last count there were more than 40 HMD models offered by 23 manufacturers [12]. It is reasonable to believe that these niches will expand as HMD and computer-generated imagery (CGI) technologies mature.

Desktop Immersion: Larger Monitors?

The HMD and talk of creating a "virtual reality" popularized the concept of visual immersion. By filling our field of view with CGI, perhaps we could simulate reality well enough to be believable, or at least well enough to foster a "willing suspension of disbelief." VR developers see the HMD as the ultimate visual display since it would allow total freedom of head rotation, physical mobility and direct hand-eye interaction within a virtual environment. But consider a modern office environment, boardroom or small theater where none of these interface requirements are paramount. High-resolution monitors are already used for stereoscopic viewing using eye-sequential glasses [10]. *Why not simply make a larger monitor to cover more of our retina and forget the VR interface?*

In fact, workstation monitors have been driven to higher and higher resolutions by the needs of CAD, graphic arts, image processing and other specialized fields. Monitors that display 1280x1024 pixels are now routine, 1600x1200 is readily available, and 2048x1536 is available, but expensive. Monitors with 2048x2048 or 2560x2048 pixels currently represent the upper limit of display resolution [30].

Two important factors in immersive display design are resolution and field of view. Image fidelity requires high resolution, measured in resolvable dots or effective pixels. Immersion requires wide FOV. Increasing FOV while maintaining high resolution requires an increase in effective pixels.

The average human eye can resolve approximately one line-pair per arc-minute under the best viewing conditions. Viewed at a distance of 61 cm (2 feet), this represents an acuity of about 300 dots-per-inch (dpi). A 61 cm (24-inch) diagonal monitor would therefore require about 5700 horizontal dots to display eye-limited resolution. Most color monitors have 72 dpi. Therefore, a factor-of-four resolution increase is ultimately possible without making the monitor any larger. Present CRT shadow mask technology limits the spatial resolution to about 88 dpi in advanced displays [30]. Fortunately, we do not require eye-limited resolution to make an effective display.

A 61 cm (24-inch) monitor subtends about 43 degrees horizontal FOV when viewed at two feet. The horizontal FOV for both eyes is an approximate ellipse that is 130 degrees vertical by 200 degrees horizontal (see Figure 2) [31]. Add head motion and our horizontal field extends to over 270 degrees. It is easy to see how little a monitor fills our visual field. Even if we made our monitor infinitely large, it would only fill a 180 degree FOV. I call this the IMAX® limit — the FOV of a very large flat view plane.

Let's say, however, we wrap our monitor around us in the form of a cylinder to fill a 200 degree FOV while maintaining typical monitor resolution. With a 24-inch viewing distance and 72 dpi resolution we would ideally require 6032 horizontal dots. If our cylindrical display also covered 130 degrees vertical it would be over eight feet tall and have 7400 effective vertical pixels! Our immersive display would require an image generator that drives about 45 million effective pixels on a cylindrical surface with a 2.7 GHz video bandwidth. Today's best CRT monitors only have 5.2 million pixels and 300 MHz bandwidth.

This simple exercise demonstrates the difficulty of creating an immersive display with simultaneous wide FOV and high resolution. Enter human factors engineering. Since we are surface dwellers, our visual cognition has evolved to be much more sensitive to motion in the horizontal plane. Limiting the vertical FOV to 60 degrees gives us a vertical screen height of 28 inches with 2000 vertical resolvable dots. Our visual compromise yields a more feasible desktop display, but still requires 12 million pixels and 720 MHz bandwidth.

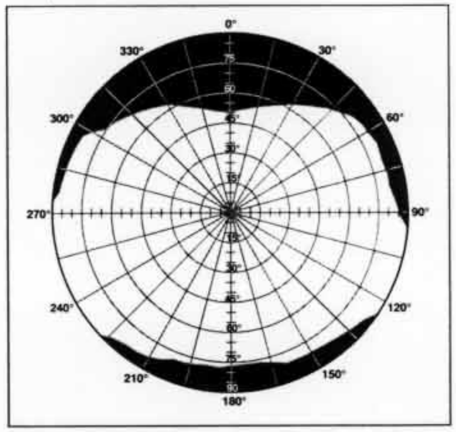

Figure 2: Visual field of view (FOV) for both eyes [31].

Arrayed Projection Displays

Our cylindrical monitor requires a 6032x2000 resolvable dot display. We also found that the largest CRT displays have only 2560x2048 addressable pixels. If we are to display a seamless, high-resolution, wide FOV image with today's technology, another approach must be adopted. Such a display is possible using arrayed projection techniques developed originally for training simulator displays. Multiple projected images are overlapped and "edge-blended" using optical or electronic means. Arrayed projection (also called mosaicking or tiling) is used to create high-resolution video displays on both flat and curved screen surfaces (see Figure 3) [25].

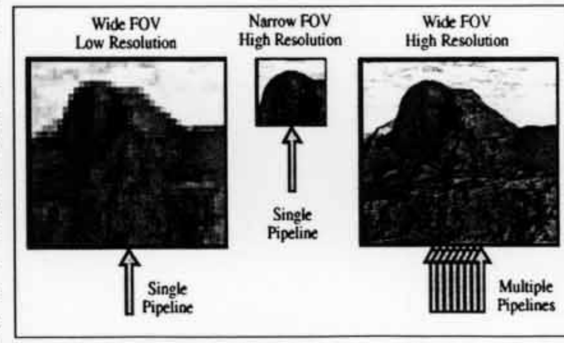

Figure 3: Arrayed projection allows parallel video channels to provide both wide FOV and high resolution.

The importance of arrayed projection will grow with the demand for higher resolutions. This is because the laws of physics will ultimately limit the electrical bandwidth obtainable from a single video stream. Parallelism in video streams is inevitable. Multiport video capability is now common even on desktop computers. Multiple graphics rendering pipelines are available on higher-end supercomputers. Lacking are affordable arrayed projection systems to exploit this existing capability, and the software to drive them. Companies such as Panoram, Seos and Spitz are making great strides in these areas, but greater support from computer manufacturers will be required to produce an integrated arrayed desktop environment

Stationary Immersive Displays: VR for the Masses

The cylindrical monitor described above belongs to a class of displays sometimes called walk-in immersive, panoramic, cab, simulator, spatially immersive or stationary immersive displays (SIDs), as shown in Figure 4 [24, 23]. SIDs

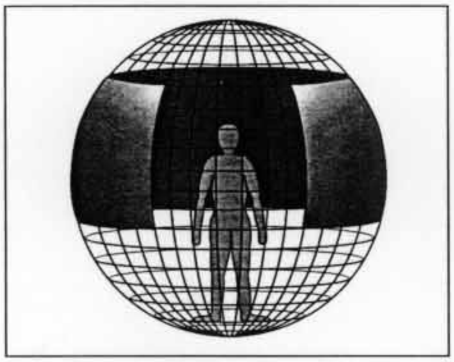

Figure 4: Stationary immersive display concept.

have a long history of use, dating back to Robert Barker's large panoramic paintings in the late 16th century. Panoramic cinematography was demonstrated as early as 1900 [33]. Planetaria have used hemispheric dome screens for astronomical simulation for over 70 years [1]. Cinerama, a 146 degree FOV film projection format, flourished in the 1950s [6]. The 1962 world's fair in Seattle introduced modern 35mm hemispheric film, followed by IMAX® 70mm large screen in 1970 and IMAX® Dome (Omnimax) in 1973. Dome video projection is now commonly used in vehicle simulators [13]. Elaborate systems for tactical military aircraft training include eye-tracking coupled to steerable high-resolution area-of-interest inset displays [31].

A recent SID is the CAVE, first demonstrated at SIGGRAPH 92 by the University of Illinois, Chicago [7]. The CAVE projects high-resolution stereoscopic video, refreshed at 120 Hz, onto three walls and the floor of a cubic space. The result is an immersive display with far greater resolution than an HMD. The CAVE is an interactive virtual environment (VE) system, allowing the user some degree of mobility while dynamically adjusting the rendered image perspective to the user's eyepoint. Unfortunately, direct hand-eye interaction with the VE is problematic since the user's eyes cannot simultaneously focus on screen and hand. This is generally not a hindrance, as hand controllers are easily used to interact with the VE.

More recent examples of SIDs include Silicon Graphics' Reality Centre, the brainchild of David Hughes of the Reading, England branch. A similar system was installed at SGI's Mountain View headquarters where it is better known as the Visionarium [18]. The Visionarium is an eight meter diameter partial dome screen providing 160 degree horizontal FOV and 40 degree vertical FOV. It is based on SEOS's PRODAS simulator technology and is driven by a three-pipeline SGI Onyx®. A portable Visionarium system, the GVR120, is manufactured by Panoram Technologies, Inc. (see Figure 5). Also driven in real-time by an Onyx, the GVR120 has a 120 to 160 degree FOV and utilizes a portable five meter diameter cylindrical screen with three Ampro 3600 projectors. These systems are finding favor with plant and automobile designers who can realize large cost savings by finding design flaws prior to construction.

A larger SID system for edutainment is the ElectricHorizon™ VR Theater manufactured by Spitz, Inc. (see Figure 6) [23]. This theater seats 32 persons on an inclined seating deck and includes three-button audience responder units for interactivity. The screen is an ultra-wide 200 degree horizontal by 60 degree vertical FOV and is 8.5 meters in diameter. The image is produced by three edge-blended Electrohome Marquee™ projectors. ElectricHorizon opened in January 1997 at Pittsburgh's Carnegie Science Center as a traveling exhibit. The opening show, ROBOTIX Mars Mission, was developed by Carnegie Mellon's SIMLAB and funded by Learning Curve Toys of Chicago, Ill. The show depicts a mission to the planet Mars based on Learning Curve's ROBOTIX toys and NASA Mars data sets.

The Flostation by Flogiston Corp. is a single-user SID (see Figure 7). This device uses a single hemispheric rear-projection screen onto which spherically corrected video is projected to provide full visual immersion in look-ahead mode.

Figure 5: GVR120 Portable Visionarium by Panoram Technologies, Inc.

Originally developed under a NASA contract, the unit includes a Personal Motion Platform chair to simulate the neutral body posture and motion experienced in microgravity.

Even larger SIDs are now available for planetaria and dome theaters. Three products on the market now include Spitz's ElectricSky™, Evans & Sutherland's StarRider™ and Goto Optical's Virtuarium™ (see Figure 8). These "digital dome theaters" can navigate visitors through the virtual environment of their choice. Audience interactivity is provided by individual chair-mounted or handheld responders or an interactive human "navigator." In one envisioned scenario, the navigator is a sports announcer who guides the passive audience's view of a real-time game between two teams engaged in VE "cyber-sports." Team members use HMDs and other specialized interface devices far too encumbering for a general audience. Such systems are the dawn of "VR for the masses."

Armchair VR

We return to the argument that many real-world display applications could use the visual immersion of a CAVE, but do not require the expensive VR interface paradigm of head-tracking

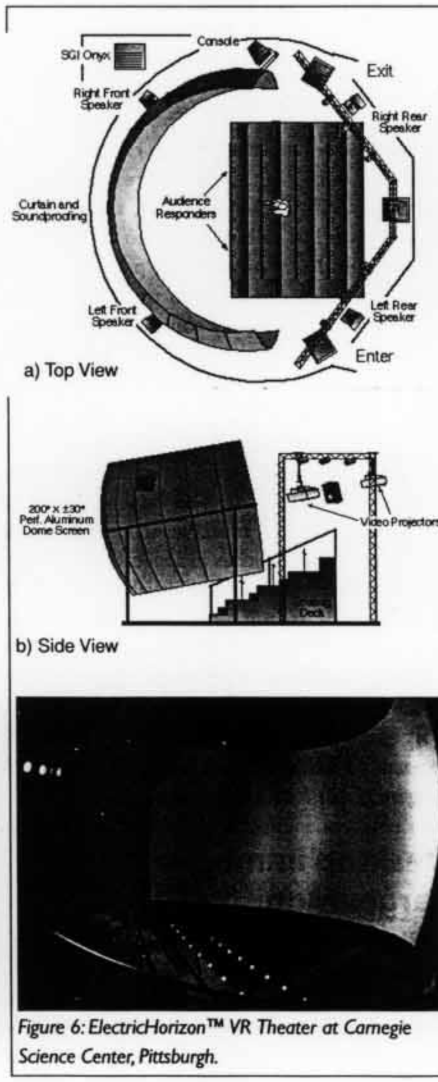

Figure 6: ElectricHorizon™ VR Theater at Carnegie Science Center, Pittsburgh.

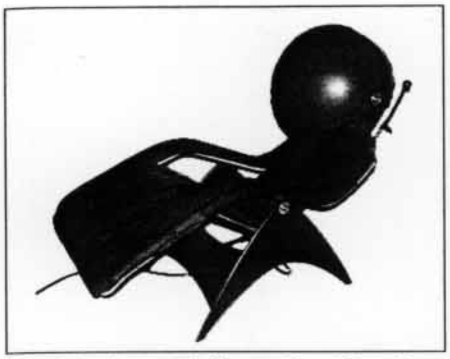

Figure 7: The Flostation by Flogiston Corp. of Austin, Texas.

Figure 8: Digital dome theaters will bring virtual environments to the masses.

and data gloves. Enter a compromise in VE interface which I call Armchair VR. Using a wide FOV SID, the user remains comfortably seated and navigates the virtual space using common hand controllers or even a mouse. The effect is one of being seated in the control bridge of a large robot or exoskeleton that can be manipulated by hand controls. Such a system could even employ a separate monitor on the robot control panel for status and information display. This is similar in principle to "cab" displays used in location-based entertainment such as the BattleTech Center in Chicago [16] and various other simulator rides.

We are comfortable with cab-type environments. They are unencumbering and allow collaborative interaction. Driving a car is perhaps the most common example. Some head motion is required, but most of our time is spent looking forward and exercising our peripheral vision. Imagine trying to drive a car with all the windows painted black except for a small monitor-sized aperture on your windshield. VR systems attempting to utilize a single monitor or projection screen with stereoscopic viewing share this difficulty. Armchair VR attempts to do away with the cab and create the illusion of floating in space.

In Armchair VR, eye motion is supported by the display FOV but extensive head rotation is not. This may seem at first to be a hindrance to creating a sense of presence, the goal of most VEs. However, those who are fielding HMD systems in public venues are finding that visitors often do not exploit the range of head motion available to them [29]. Experiments in a 360 degree classroom with swivel chairs yielded similar results [28]. It seems that, in our television-based society, people prefer to sit back and be passively entertained without the effort of head and body motion.

Single-user Armchair VR systems could employ the 200 degree x 60 degree cylindrical monitor display envisioned above. Larger projected video displays could seat tens or even hundreds of viewers. The use of cylindrical or dome displays allows off-axis viewing with a minimum of distortion. Unlike the rectilinear CAVE display, curved-screen displays exhibit a graceful degradation in orthoscopy as the viewer is displaced from the ideal view point. Unfortunately, most CGI rendering engines are still stuck in the "flat-plane" mentality. Images must first be rendered onto a view-plane then geometrically processed either in software or hardware for curved-surface projection. Perspective projection and rendering onto a generalized view-surface would open the door to single-pass, ultra-wide FOV rendering for spherical or cylindrical projection.

Many who are pioneering VR applications in industrial, marketing, visualization, education, entertainment and research markets believe that SID is the future display of choice for a broad range of VR-like applications. Non-VR applications requiring visualization, data navigation or even word processing will likely benefit from the increased field of view as well. SIDs can readily display pre-rendered or live-action imagery without the need of a computer. One could envision a time when all home entertainment systems include a wrap-around screen.

Virtual Model Displays

Another class of displays are emerging from "Fishtank VR," the use of desktop monitors to display virtual environments [35]. Virtual Model Displays (VMDs), as dubbed by Bryson and Bolas at last year's SIGGRAPH panel [24], are limited FOV displays best suited for displaying 3D objects or models. In VEs, one is sometimes concerned more with a particular object or model than an immersive space. For instance, in a medical simulation, one might be more interested in representing the virtual patient alone. There is no need to render ceiling, walls, floor, etc. In addition to increased modeling time and system performance requirements, representing an immersive VE in such cases can actually distract the user from performing the desired task and from collaborating with others. Total engagement of the user's visual senses, with associated risk of "simulator sickness," is not always justified.

Examples of VMDs include the Electronic Visualization Laboratories' ImmersaDesk™, GMD's Responsive Workbench and Fakespace's Immersive Workbench. While these displays can and are used to display navigable VEs, they are ideally suited for manipulation and display of 3D models and other limited FOV content that is unaffected by a display frame. Other VMDs include volumetric and globe-type displays.

Film Still Rules

As far as image brightness, resolution, dynamic range and color saturation are concerned, film still rules supreme. Large-frame formats such as 8-70 (8 perforation tall image on 70 mm frame) or 15-70 (Imax's horizontal 15 perforation format) are difficult to compete with using conventional video projection. IMAX® 3D™ is perhaps the crowning achievement of imaging and display systems [15]. Film's shortcomings, however, are its expense and lack of interactivity. Video is a much less expensive, faster turn-around production medium. Information can be downloaded from a web site daily and dropped into a show or be displayed in real time. Also, video allows real-time multi-user interactivity using, for instance, the Cinematrix™ system demonstrated at SIGGRAPH 91 and 94. The distribution of film is also a major expense. Video cinema will utilize wideband networked communications to distribute video movies.

It is not a matter of whether video projection will replace film, but a matter of when. Rapidly maturing technologies such as TI's digital micromirror device (DMD), light valve projectors and laser video projectors are already closing in on 35mm film. Video projectors are steadily improving in brightness, contrast and resolution, and can now be arrayed for increased resolution. Video does not exhibit film artifacts such as dust, scratches, image jitter or image fade. Video can also be stored in digitized format which does not have the lifetime limitations of film, and which can be duplicated indefinitely without additional image degradation. Emerging video formats using progressive scan are free of the motion and edge-crawl artifacts found in interlaced NTSC and PAL. Even as "bad" as it is, existing video formats can be line-doubled or quadrupled with motion processing and detail enhancement. Such processing, popular with home theater aficionados, allows a high resolution projector to produce a stunning image easily mistaken for film.

The End of the Flat Screen?

As performance increases and prices drop, wrap-around SIDs, VMDs and HMDs promise to revolutionize many segments of the display industry. However, as with all alluring technological advances, we must question their true utility. For instance, what good is visual immersion and creating a sense of presence? We know that displays which fill our peripheral vision are more engaging to our sensory-motor systems. Does this improve cognitive learning and comprehension? Surprisingly, the answer to this question remains open, even when it comes to some visual simulators [36].

To maximize cognition, visual information should be presented in a simple and understandable form. Just because we *can* display information in an immersive, stereoscopic format does not mean that we *should*. As a sensory interface, interactive, immersive formats offer greater information bandwidth. I suspect that, over time, information visualization researchers will discover how to exploit that bandwidth.

From an artistic standpoint, SIDs and HMDs offer the creative mind a larger canvas on which to paint. Even renaissance painter Leonardo da Vinci considered natural perspective to be spherical [20], as do some modern cognitive scientists [19]. Immersive visuals are highly compelling and psychologically engaging. As these systems become more affordable and widely available, animators will prefer to see their work displayed before an audience on ultra-wide screen immersive displays or HMDs as opposed to a television or monitor. Artistically we are entering an era of immersive, frameless graphics.

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Visual Display System Resources

Following are some selected resources for further information on visual display systems.

Books

- The *Handbook of Display Technology* offers an excellent overview of recent display technologies and their historical origins.
  Handbook of Display Technology
  Joseph A. Castellano
  Academic Press, Inc.
  New York (1992)
  ISBN 0-12-163420-5
  http://www.apcatalog.com/cgi-bin/ap
- Jon Peddie's *High-Resolution Graphics Display Systems* is a profusely illustrated and comprehensive guide to graphics displays.
  High-Resolution Graphics Display Systems
  Jon Peddie
  Windcrest/McGraw-Hill
  New York (1994)
  ISBN 0-8306-4292-7
- *Display Engineering* provides the theoretical basis of visual system technology, design and ergonomics.
  Display Engineering
  D. Bosman, Ed.
  Elsevier Science Publishers
  Amsterdam, New York (1989)
  ISBN 0-444-87319-8
- *Head-Mounted Displays: Designing for the User*, recently published by Melzer and Moffitt of Kaiser Electro-Optics, addresses the "wide array of human centered disciplines required for the design of head-mounted virtual reality, industrial and military display systems."
  Head-Mounted Displays: Designing for the User
  James E. Melzer and Kirk W. Moffitt
  McGraw-Hill
  New York (1997)
  ISBN 0-07-041819-5
  http://www.mcgraw-hill.com
- *Communication in the Age of Virtual Reality* compiles well-written articles on the display hardware, software, storytelling and social implications of this new communications medium.
  Communication in the Age of Virtual Reality
  Frank Biocca and Mark R. Levy, Eds.
  Lawrence Erlbaum Assoc.
  Hillsdale, NJ and Hove, UK (1995)
  ISBN 0-8058-1550-3
- *Virtual Environments and Advanced Interface Design* includes several comprehensive chapters on advanced visual display design and applications.
  Virtual Environments and Advanced Interface Design
  Woodrow Barfield and Thomas Furness III, Ed.
  Oxford University Press
  New York, Oxford (1995)
  ISBN 0-19-507555-2
  http://www.comlab.ox.ac.uk/archive/publishers/oup.html
- *Virtual Reality: through the new looking glass* contains an excellent overview of the progression of immersive display technology.
  Virtual Reality: through the new looking glass, 2nd. Ed.
  Ken Pimentel and Kevin Teixeira
  McGraw-Hill
  New York (1995)
  ISBN 0-07-050168-8
  http://www.mcgraw-hill.com

Publications

- *CyberEdge Journal* — VR technologies' premier industry magazine.
  http://www.cyberedge.com
- *HDTV Newsletter Online* — For the latest in HDTV news.
  http://web-star.com/hdtv/hdtvnews.html
- *PRESENCE: Teleoperators and Virtual Environments* — MIT journal with technical papers on VR and immersive display technologies.
  http://www-mitpress.mit.edu/jrnls-catalog/presence.html
- *Real Time Graphics* — Newsletter of virtual environment technologies and markets.
  http://www.cgsd.com
- *inquiry.com* — Web site with 11 GB of free access technical information for information technology professionals.
  http://www.inquiry.com

Manufacturers

- Alternate Realities — Vision Dome™ hemispheric display.
  http://www.virtual-reality.com/arc.html
- Dimensional Media Associates, Inc. — Manufactures the High Definition Volumetric Display (HDVD™) and the HoloGlobe.
  http://www.3dmedia.com
- Evans & Sutherland — Dome theater displays including Digistar® and StarRider™.
  http://www.es.com
- Fakespace Labs — Stereoscopic displays including BOOM™, PUSH™ and Immersive Workbench.
  http://www.fakespace
- Flogiston Corp. — Developed the Flostation, a unique single-user immersive display.
  http://www.flogiston.com
- In-Vision, Inc. — High-resolution immersive displays including Virtual Binoculars.
  sales@nvis.com
- Kaiser Electro-Optics — Advanced high-resolution, wide-angle head-mounted displays.
  http://www.cts.com/browse/keo
- Liquid Image Corp. — Manufacturer of wearable displays.
  http://liquidimage.ca/vr
- Panoram Technologies, Inc. — Portable Visionarium and video edge blending solutions.
  http://www.panoramtech.com
- Pyramid Systems, Inc. — Advanced visualization displays including ImmersaDesk™ and CAVE™.
  http://www/pyramidsystems.com/
- SEOS Displays Ltd. — Visionarium and simulator displays.
  seos@fastnet.co.uk
- Silicon Graphics, Inc. — Includes the Visionarium SID-type display.
  http://www.sgi.com/Products/visionarium/
- Spitz, Inc. — ImmersaVision™ immersive visualization environments.
  http://www.spitzinc.com
- Virtual i-O — Affordable HMDs including Virtual i-glasses™ and see-through HMDs.
  http://www.vio.com/

continued on the following page

Visual Display System Resources
(continued)

Organizations/Conferences

- ICIA — For projection video technologies check out the International Communications Industries Association, sponsor of the INFOCOMM International® conferences and the annual Projection Shoot-Out®.
  http://www.icia.org/
- The Image Society — Annual IMAGE Conference is the stomping grounds of many high-end visual simulation gurus.
  http://www.public.asu.edu/~image/Image.html
- I/ITSEC — Interservice/Industry Training Systems and Education Conference — The largest annual military simulation and training conference.
  http://www.iitsec.org/
- SPIE — Society of Photo-Optical Instrumentation Engineers — Hosts numerous conferences and publishes the largest body of literature available on optics, imaging and photonics. Proceedings on Stereoscopic Displays and VR Systems is a must.
  http://www.spie.org
- SID — Society for Information Display — Hosts an annual conference which is the display engineer's paradise.
  http://www.display.org/sid
- SMPTE — Society of Motion Picture and Television Engineers — Numerous publications, conferences and standards development for film and video.
  http://www.smpte.org/

Universities

- HITLab — The Web site of University of Washington's Human Interface Technology Laboratory is always chock full of resources on immersive technologies. Be sure to check out the directory */sciw/visual-faq.html* for the visual display industry guide.
  http://www.hitl.washington.edu
- Iowa Center for Emerging Manufacturing Technology — Research in CAVE headed by Dr. Carolina Cruz-Neira.
  http://www.icemt.iastate.edu
- NCSA — National Center for Supercomputing Applications at the University of Illinois at Urbana-Champaign. Numerous research programs in high-performance visualization.
  http://www.ncsa.uiuc.edu
- SIMLAB — Developed VR experience *ROBOTIX Mars Mission* at Pittsburgh's Carnegie Science Center for Spitz's ElectricHorizon™ theater.
  http://topaz.rec.ri.cmu.edu
- Stanford Computer Science — Co-developer of the Responsive Workbench.
  http://aperture.stanford.edu/
- University of North Carolina/Chapel Hill — Research projects in immersive visualization.
  http://www.cs.unc.edu/~fuchs/

New Options And Considerations for Creating Enhanced Viewing Experiences

Theo Mayer
Panoram Technologies

The Day the Standards Died

Once upon a time, life was simple. Electronic display meant television. OK, OK so even when life was simple there were two main standards — NTSC (affectionately known as "Never The Same Color Twice," or better known as the U.S. standard) and PAL, the standard for much of Europe.

With the entire user base and the whole broadcast infrastructure hanging on them, changing or improving the television standards was a far from trivial task. Attempts at doing so included such Herculean developments efforts as Sony's HDVS bid for the high definition television standard.

Then along came the computer with its new user bases, self contained infrastructures and inherent capability to format its output to various standards. At first there seemed to be no correlation between the television formats and the endless and growing series of computer output standards. Only the display board, monitor and test equipment manufacturers needed to respond to the ever increasing variety of formats.

But then it got worse!

At the high end, workstations and engineering computers crept into higher and higher resolutions. At the low end, multimedia created an acceptance of grainy, steppy little "postage stamp movies" as acceptable imaging.

Now we are in the situation where both ends keep creeping in both directions!

On the low end, multimedia is moving toward full screen, full motion video, while the Internet continues to increase the use and acceptance of steppy little animated postage stamps. In the evolving middle, television sets are used to surf the net with Net TV, while computers are used as TV sets, and Japanese television manufacturers like Sony and NEC are jumping into the PC market. Finally, on the high end, workstation and graphics systems have evolved texture mapped, photo realistic, extreme high resolution, real-time outputs with full motion video resolution images incorporated directly within the systems.

Changing display formats has become as fluid as changing a setting on a drop down menu or even resizing a window. At what resolution? Who knows! You choose. At what standard? Who knows! We have even stopped naming them.

I propose to you, dear readers, that we unanimously declare the idea of display standards as DEAD!

Perhaps a less dramatic, positive and much more politically correct way of stating the above is to assert that "Today, display output formats are totally scalable." This has a profound affect on the makers of all types of display devices — they need to incorporate today's inherent media scalability into their hardware's technical capabilities.

Consequently, if there are no more standard technical formats to center on, perhaps we need to center on "experiential formats."

The Experience

We experience visual media in a variety of ways for a variety of reasons with each form and format having a different reason and "viewing experience." Playing with this idea, I have divided the viewing experience into four distinct categories — The Postage Stamp Experience, The Television Experience, The Theatrical Experience and The Immersive Experience.

The Postage Stamp Experience

The only excuse for postage stamp movies is that we can't do better given bandwidth limited conditions. And no matter how cool it seemed when you first saw movies playing on your computer screen, we only put up with the rotten quality because we have no choice but to do so. The *only* really cool part is that it happens at all!

On the other hand, I recently enjoyed a visit from a very progressive Australian production company called Go Man Go. Rather than popping a VHS into the VCR to show their reel, they pulled out their Macintosh laptop and proceeded to present their capabilities using a multimedia presentation they had on their hard disc. They were showing me their high end, high resolution, high quality work in a basically low res, partial screen, steppy video, multimedia, laptop display format.

And it worked! I pondered this for quite a while. How was it, that I experienced and bought into their media "quality" by viewing such a low quality format? I concluded (very happily) that *design quality* rides above all display qualities as an experience! Their presentation was so well designed, I automatically accepted that the images would naturally be fabulous given the bandwidth of reality!

The Television Experience

The television experience is ubiquitous. In that regard, it forms a baseline and standard for all our visual media experience. Interestingly enough, it shares certain similarities to the postage stamp experience. The television image is typically only a "hot spot" within our field of vision. That is not very different from a "hot spot" within the field of a screen. In any case, with the "television experience" we take in the entire image, as well as some of the surrounding environment, in one "visual gulp." Our mind zooms into the area of interest filtering out the surround.

And it works! We get totally sucked in. I have also pondered this for quite a while. With virtually no content qualities to speak of — how can the television experience suck in so many people for three to five hours a day? What kind of statement is this on human nature?

How about this for rationalization....it's related to thousands of years of our species staring into campfires! Perhaps "theoretical proposition" would be a more positive and politically correct way to put it. I invite you to follow the television/campfire analogy.

While every fire moves and changes in a seemingly unique way it's *actually* always pretty much the same show. The fire fills only a small part of your field of view, yet you are still totally sucked into it. The fire has about the same amount of relevant theme or message as a typical television show! In fact, the next time you flip through your 100 to 500 channels and decide it's boring, try building a fire (Caution: DO NOT try this if not properly equipped with a fireplace!). You may soon realize that like much of television, a fire is actually quite violent. And of course, they are both nice to snack in front of!

Think of the rich heritage of a family of "stone couch potatoes" wrapped in their furs, starring into the fire for three to five hours every night. Mom stitching hides, dad chewing the fat, while 2.5 offspring flip channels by throwing little bugs and stuff into the flames. (This analysis does not, however, explain soap operas or Montel Williams!)

The Theatrical Experience

The next step up the experience ladder is the theatrical experience. It is ever so much more emotionally involving! It can thrill you, touch you, even scare you and generally overwhelm you. The "big screen" has certainly survived the nearly half century onslaught of television! It is oft theorized that it is the "larger group" experience that differentiates the theatrical experience from the television experience. I tend to disagree.

I think the emotional viewing enhancement of the theatrical experience has to do with the size of the "field of view." To cross over to the theatrical experience the picture must be large enough, and "in your face" so that it not only exceeds being a "hot spot" in your field of view, but you actually begin to use *eye scan* motion to experience the image. I propose that the excitement happens because you have to move your eyes to keep up with the action.

And it works! As you might have guessed by now, I have pondered this for quite a while and think I can find a plausible rationale for why it is so engaging by again examining millennia of evolution. Simply put, any *dynamic* event or object large enough to require eye scan motion to absorb, is potentially and literally quite engaging. Imagine how engaging and all consuming that campfire would seem to the StoneCouch family if it had grown big enough so that they had to use "eye scan" motion to view it all! See what I mean?

The Immersive Experience

There *is* a step beyond the theatrical experience that is potentially even more involving, and that is the immersive experience. Such an experience can be defined as being where mere eye scan motion is not enough and the image becomes so all-encompassing that the viewer begins to engage *head scan* motion. When the scope and resolution of the imagery becomes large enough, the viewer can leave the center of focus, and turn both their head and attention to discover and study details of the scene and contextual environment. This is a *very* powerful media experience and leads to terms such as "virtual reality."

My most memorable experience of this was in an Omnimax theater during a special guest preview of the film *The Dream is Alive* — a circa 1984 IMAX film about the U.S. Space Shuttle. Much of the film was actually shot on board the shuttle by the astronauts. I was invited to see the rough footage before it was edited. The shots were all raw takes. One of the astronauts was in the theater and narrated the shots as they ran. The images played on a dome surface that covered at least 180 degrees of my field of view all around. Because the shots were long and the images were of extreme high resolution, I soon found myself viewing the images in totally new ways. My interest would drift from the center of focus to explore a little turn buckle on a wire in the shuttle's cargo bay. I chose where and when I would turn my head to explore some aspect of the scene. It was exhilarating. It was almost like *being* up in space looking over the shuttle cargo bay. It was the best media experience of my life!

A year later I saw the released film. It was well cut with an exciting pace which I keep up with. The grand musical score played in rich six channel surround sound. The deeply sentimental script was narrated by the rich and venerable tones of Walter Cronkite. And it was a total bore compared to the raw footage experience!!

A few years later I attended the second of the TED (Technology in Entertainment & Design) conferences in Monterey, California. The TED conferences were ecclectic gatherings. I was sitting next to Steve Wozniak, with Steward Brand and Nicholas Negroponte a few rows up, while this gentle-souled, long haired guy on stage, Jaron Lanier, was talking about putting helmets on his head, and wearing data gloves while manifesting as a lobster in the new concept called virtual reality. This was the first I had heard of it! For show and tell, Jaron brought one of these systems with him and we were all invited to come try it.

As I emerged from my first "trip in," slightly nauseous from the lag between my head motion and the system response, a mild headache from the heavy helmet, eyes a little blurry from the "not quite correct" 3D and miserable resolution, I was certain that I had experienced something profound. If one could only combine the "immersivity," unencumbered freedom and extreme resolution of the Omnimax film experience with the interactivity potentials of the VR helmet experience.

It could work! I have pondered this for quite a while, and in fact, have dedicated much of the energy of an entire company to providing the means of melding those two immersive experiences. Our solution is to use groups of video projectors which are arrayed together to create single, seamless, scalable resolution electronic images.

Technical Details

The array of video projectors are laid out adjacent to one another. Each projector in the array provides another piece of the total picture with the aggregate image being larger, brighter and higher in resolution than would be possible using a single electronic projector. To maximize the potential of this requires addressing several issues including:

- Image generation technologies.
- Image storage/retrieval technologies.
- Image integration technologies such as Video Panoram.

Image Generation

In the early days of exploring arrayed video projection technology, the original images were shot in high resolution film. The film frames were transferred to video (NTSC) in three overlapping segments. Each segment was stored on a separate laser disc. The synchronized laser discs were played back while the Video Panoram edge blending processor seamlessly stitched the images back together. The result was a photo realistic (film images) electronic display that had a very wide, theatrical (too big for one visual gulp) aspect ratio of 3.33 to 1 and a horizontal playback resolution of 1600 pixels as opposed to the NTSC's standard of 640.

Computer graphics are much more straightforward to generate. One simply works at an output resolution that matches the desired results. For example, it is a simple matter to set the scalable graphic resolution of the Mac image to 1600x480 pixels. Using a program like Adobe AfterEffects, you can

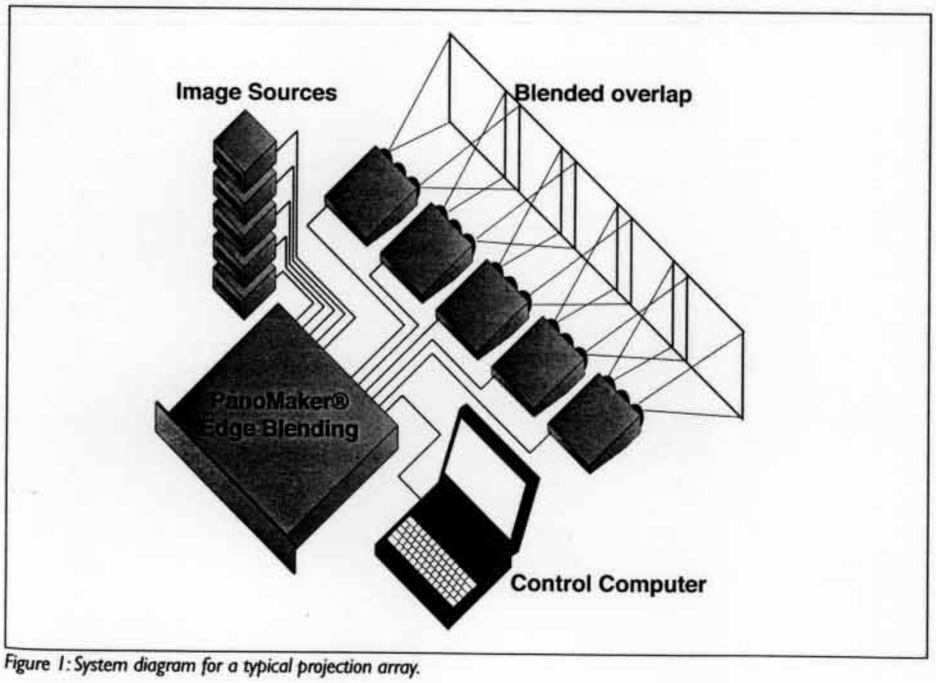

Figure 1: System diagram for a typical projection array.

design scenes, perform animations and set up image compositing to render at 1600x480 pixels. (Unfortunately the Macintosh OS's "monitors" control panel only allows you to set up adjacent outputs, rather than overlapping ones. This means you have to go through some additional steps and machinations to get a seamless multi-channel output from the Mac and precludes "real-time" outputs unless you program your own Init or version of the monitors control panel.)

On the new SGI Onyx2 platform, however, the scalability of the multichannel output buffers is ideally suited for seamless projector arrays. With an Onyx2 and a three projector Video Panoram projection array, a real-time display output of 3200x1024 pixels at 60 frames per second is simply one of the standard (there is that word again) output formats. Yet this format delivers a 3,276,800 pixels display resolution. Compare this to a standard 640x480 (307,200 pixels) video output or even a high-res workstation's 1280x1024 (1,310,720 pixels) resolution.

Image Storage and Playback

Given that we now we have the ability to generate extremely high resolution images, what are the choices for higher resolution playback, besides a 1600x480 (768,000 pixel) NTSC based system? The answer turns out to be "not many" — HDTV playback systems such as Sony's HDVS laser discs are cumbersome, expensive, not broadly available or supported and by reputation, not highly reliable.

There is good news on the horizon, however. There are up and coming, disc based, video recording technologies whose inventors have realized that there are no more standards, and have instead adopted scalable digital visual record/playback architectures. We are still a couple of years away, but progress is being made.

Projection geometries can be very flexible — especially if the image creators have the ability to easily format their output to the selected projection geometry. Projection geometry is somewhat more complex than simple scalability since in some cases, the images need to be "mapped" onto complex surfaces like domes. This can become challenging and may require a whole new series of production skills, especially if a variety of sources need to be integrated into a unique projection geometry or onto unique projection surfaces.

Further discussion on this topic is beyond the scope of this article, but meanwhile, here are some numbers for more standard applications.

The first example is a video (NTSC) based three projector arrayed geometry and a high resolution SGI Onyx 3200x1024 type display. Each array assumes a 25 percent overlap for the seamless edge blending. This is not a fixed ratio, but a nice safe overlap region to ensure high quality and reliably seamless results.

For the multi-projector video resolution display, the overall display resolution is set to 1600x480. The first output channel is fed the left most 640x480 pixels. The second output channel starts at horizontal pixel 480 and goes to pixel 1120. The right most channel receives horizontal pixels 960 to 1600.

For the 3200x1024 type display, the first output channel is fed the left most 1280x1024 pixels. The second output channel starts at horizontal pixel 960 and goes to pixel 2240. The right most channel receives horizontal pixels 1920 to 3200.

Image Integration

The Video Panoram seamless edge blending technology is only part of the solution for integrating the projector array back into a single composite image.

Maintaining each projector's mechanical alignment automatically is a technology that is being approached by the projector manufacturers as well as by Panoram Technologies. Between us, we are not far away from the automation of this task.

Perhaps a more important challenge is the setting and maintaining a perfect color balance between the projectors. Automated color matching and maintenance capability for multi-projector arrays will appear in 1997.

Summary

Electronic visual media is becoming a highly scalable experience ranging from low res, low frame rate, partial screen postage stamp experiences to mega resolution, totally interactive immersive experiences. The television and theatrical media experiences provide the ubiquitous middle ground.

On the high end, advances in visual super computing, upcoming scalable image storage systems and reliable arrayed projection technologies hold the promise of electronically projected displays that can be created of almost any size, geometry and undreamed of resolutions.

The future looks big, bright and very high rez!

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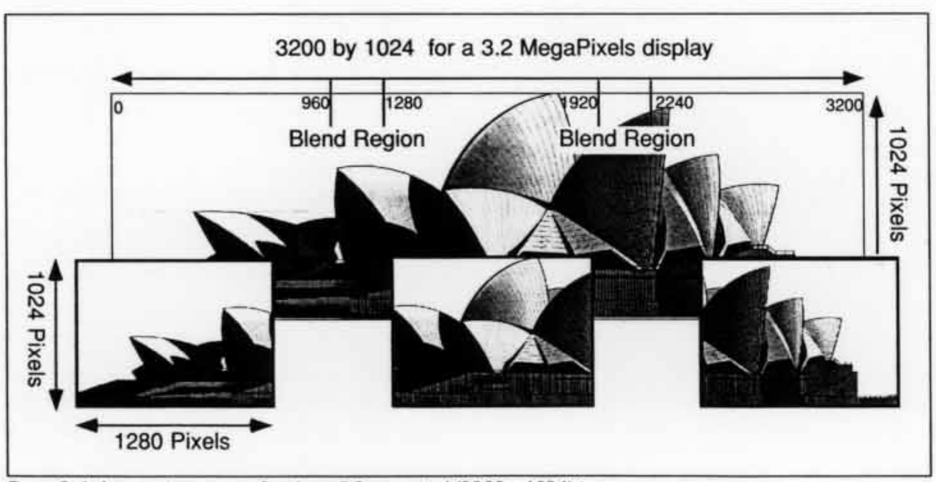

Figure 2: A three projector array forming a 3.2 megapixel (3200 x 1024) image.

A Dodecahedral Approach to Immersive Imaging and Display

David McCutchen
Immersive Media Co.

Real life, as we experience it every day, does not take place in a window or a box. We experience sights and sounds all around us, as part of a spherical field of view. If we turn, we will see another part of our environment (a word which comes from the Old French for "that which is around you"). We are immersed in our experience of the world.

The dream of reproducing or creating such an all-encompassing scene is the goal of immersive imaging. The idea of immersive imaging is as old as planetariums, and as new as the latest in virtual reality. Today immersion is receiving more attention than ever, because it represents the ultimate form of image production and display, one which will undoubtedly be part of the media used in the next century.

Yet until now, movies and television have been based on rectangular images, projected on screens or displayed on video monitors. Even the growth of computer graphics has followed this limitation. If we find a way to easily base our imaging and display on a sphere, then the creation of true immersive imaging will be on the way to becoming a reality. Recent advances in many fields of imaging technology are increasing the resolution and performance of cameras, projectors and computer imagers. But the size and extent of a spherical screen is far beyond the limits of any single imaging system. If a way can be found to meet the challenge of the spherical screen, then we can dare to dream about the creation of apparently real projected worlds, using photography, computer imaging or a combination of both for special effects.

The Search for a Standard

The evolution of the new spherical immersive medium is already following the patterns found in the origins of other forms of entertainment media, including motion pictures and television. After an initial period of experimentation, the search begins for a standard format which will embody the new medium in a form that will deliver the experience to the widest possible audience, while not restricting the requirements of producers and manufacturers. Once the format and its ground rules are settled upon, the true growth of the medium can begin.

The choice of a standard format for spherical immersive imaging is needed now. Some of the criteria for an immersive format should be how well it solves the problem of creating a spherical immersive display, including the recording of environments in motion, and whether it represents simplicity, flexibility and expandability for the future. There are two main forms of image display to be included in such a standard: dome theaters and what is commonly called virtual reality. The first deals with an image of up to a hemisphere, while the other can include an essentially complete spherical image.

Previous attempts to expand to immersive, "wrap-around" views have been based on wide-angle or panoramic images, either single wide images such as Cinemascope, or widescreen side by side composite images such as Cinerama or Circlevision. These and other panoramic formats are based on a cylindrical approach, where the images can be thought of as being projected on the sides of a cylinder surrounding the viewer, rather than a sphere. Apple's Quicktime VR (QTVR) [1] also uses this cylindrical approach, with one or more images taken in succession in a scanning fashion along a horizontal plane, to be blended together to create an overall view from which a region of interest can be extracted. Using the cylinder may simplify the compositing and viewing process, but does not address the fundamental fact that the world appears to us as a sphere rather than a cylinder. It also ignores the top and bottom areas of the spherical field of view, which could be well worth seeing. The images produced by QTVR are also still, and lack the motion and bustle characteristic of a real environment.

Still image spheres can also be created, such as in Omniview's PhotoBubbles, where two hemispherical fisheye images are fused together, and a roving region of interest can be extracted from within the composite image to give the effect of looking around. While this is a better approach to addressing the special requirements of a sphere, these images still lack motion.

To achieve the best possible results, there are several fundamental reasons in favor of subdividing the sphere to create the overall immersive image out of separate parts. These reasons become even more important if we conceive of this immersive imaging system as being electronically based, such as in video. Having a video-based immersive imaging system puts it squarely in the path of present and future developments that are making video the universal medium of image exchange everywhere, and allows for recording of scenes in motion, and even live transmission of them from place to place.

A spherical image represents an extremely large amount of information. It quickly becomes apparent that present video standards are inadequate for recording such a wide field of view in a single image with acceptable results. There are simply not enough pixels. For example, if a single hemispherical "fish-eye" view is recorded in a 640x480 image (making a circle 480 pixels across, surrounded by black), a rectangular view extracted from it, representing a 50 degree diagonal field of view, would represent roughly only 133x80 pixels. If higher resolution specialty cameras are used, the problem becomes finding the proper recording, editing and transmission equipment, and contending with massive bandwidth bottlenecks. Even present video standards are already straining the limits of inexpensive transmission systems such as telephony and the Internet.

An Ultimate System

The size of the challenge can be shown by the bandwidth requirements for an immersive imaging system with enough resolution to present a completely real-looking image in a dome theater. For a video-based system, such a convincing level of resolution for dome projection cannot be expected from any single-projector or single-camera systems in the near future. The resolution of cameras and projectors is expected to increase, but not up to the levels demanded by such an enormous screen. However, there is an alternate approach to compositing images to build up the required resolution and performance and provide the key to an immersive imaging standard.

The ultimate imaging and display system would recreate the field of view and resolution of the human eye. As detailed by Seth Shostak [3], an ideal imaging system would require a three-quarters hemisphere field of view, three-channel 17-bit color for a dynamic range of 50 dB or 100,000:1, two channel stereopsis, a frame rate of 60 Hz, and a resolution of 0.5 arcmin, yielding an image measuring roughly 36,000x28,000 pixels, and a bandwidth of over 750 GB/sec. Given the continuation of current trends in data storage and in microprocessor power, Shostak projects that such an ultimate system could possibly be realized sometime between the years 2010 and 2020.

Compositing is the Key

Compound imaging systems can reach this goal much sooner by the use of multiple elements. The advantages of this parallel-stream approach are already being shown by parallel processing in computers. Multiple projectors can display a higher resolution overall image in a dome than any single projector. If image generators compatible with these projectors are used, then a very large, truly immersive image can be built up.

The extension of this approach to what is called virtual reality addresses the need for a viewer to look down below the horizon in every direction, which is impossible in a dome, thereby getting the feeling of being in a full environment. The generation of regions of interest (ROI) from within full-surround scenes is already being done with computer-imaging based VR systems. If such ROI's were being extracted from within photographed scenes produced by a spherical camera system, the result would be a new kind of photographic virtual reality.

Since real life happens in every direction, in a sphere surrounding the viewer, the best solution is based on the sphere. The key is in finding a standard method of creating, organizing and compositing these images together on a spherical surface. The best system would divide the sphere into simple, standardized segments, all with equal size, shapes, edges and angles. These segments would then be used for dictating the design of the cameras, projectors and other image generators to be used. The segments should be suitable for hemispheric projection such as in a dome, whether flat or tilted, and also be capable of being multiplied to build up a full-surround spherical image.

Skinning the Sphere

The answer is as old as Plato, and as new as Buckminster Fuller. Of the various methods of subdividing the sphere, geodesics are well-known for their simplicity and elegance. And within geodesics are the five Platonic solids as the ultimate standardized methods of dividing the sphere, with each having segments of exactly the same shape and size, with equal edges, sides and corner angles. Such ultimate simplicity and standardization of components has long-term advantages in simplifying everything from image processing procedures for computers to manufacturing procedures for hardware. These five Platonic solids are the four-sided tetrahedron, the six-sided hexahedron or cube, the eight-side octahedron, the 12-sided dodecahedron and the 20-sided icosahedron.

Of these five ultimate spherical divisions, the dodecahedron, made up of 12 pentagons, is the best choice (See Figure 1). The use of the dodecahedron is the basis of RoundAbout™ immersive video [2] , which is currently being developed and used by the Immersive Media Company.

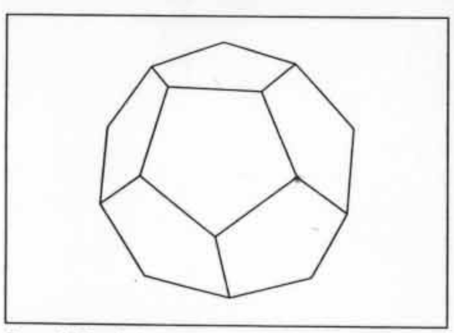

Figure 1: The dodecahedron.

The Power of the Pentagon

The dodecahedron's pentagons are closer to a circle in shape than the triangles found in the tetrahedron, octahedron and icosahedron, or the squares found in the cube. This has optical advantages, because the circular shape of the pentagon is better suited for lenses, which create images that are actually circular. Light passing through a typical lens creates a circular lens image, even if it is cropped to a rectangle before the image is recorded. Within this cropped image, the quality of the image is typically greater towards the center, in a "quality circle" which is defined as the circle that touches the top and bottom edges of the cropped frame.

In RoundAbout immersive video, the essential dodecahedral pentagon is extracted from within this quality circle, and the center of the pentagon is the same as the center of the image (see Figure 2). In terms of field of view, the width of the quality circle is 74.75 degrees, or roughly 75 degrees. This is within the range of available off-the shelf wide-angle camera lenses for most types of cameras. The extra image area outside of the pentagon, extending to the corners of the typical 4:3 aspect ratio video image, is almost equal in area to the pentagon itself. This extra image can be considered as an extension from each pentagon edge, and is useful in blending together the edges of adjacent pentagons for a more continuous composite image.

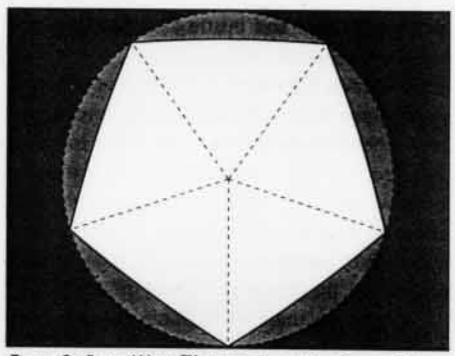

Figure 2: RoundAbout™ immersive video frame with pentagon (orientation for images above the horizon).

Cameras built to this standard (see Figure 3) can photograph environments in motion in every direction, with a width of view that depends on the number of cameras being used and recorded. For example, with Immersive Media's forthcoming Dodeca 1000 RoundAbout immersive video camera the maximum is 11 cameras in a modular array, reserving one segment for the camera mount, to record a nearly spherical image. Even this maximum number of cameras forms a configuration that is quite small, because of the miniaturization of the CCD video components. All of the video signals from the various cameras are genlocked together, with special linked exposure and color balance features, and a shared SMPTE time code signal accompanies each of the video streams produced by the various cameras for postproduction synchronization. Outputs from each camera include analog component, Y/C and Composite NTSC video. Recording of the video streams is done on regular videotape, using whatever video recorder format the producer may desire. For maximum quality with minimum weight, ultra-small DVC recorders such as the Sony DCR-PC7 or the JVC BR-DV10 offer a promising approach. This is especially important when doing portable handheld shots, if the entire recording apparatus must be carried around, and the weight and size of the multiple recorders becomes a factor.

Figure 3: The prototype RoundAbout immersive video camera uses 11 video imagers in a compact array.

Displaying the Image

Using six recorded pentagons together creates a hemisphere, with a zigzag bottom edge that can be cropped and filled to a straight line. Passing the six video streams to six video projectors, with one for the top and five for the sides, will create a full video image for a dome, with an overall resolution much greater than any single projector could produce (see Figure 4). Cropping and compositing for such a multi-

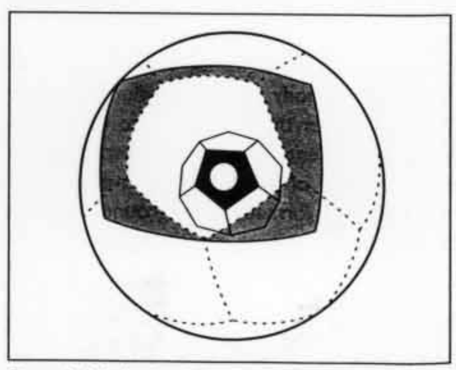

Figure 4: A dodecahedral division of a spherical field of view, showing a video projection of one pentagonal facet.

part projected image can be accomplished by existing devices such as Panoram Technologies' Panomaker™ III for automated projector matching and blending.

Such a video dome is capable of displaying not only the photographed images produced by the camera, but also any other images that obey the RoundAbout format. Computer-generated images, for example, could be mixed with the photographic images, to give a sense of heightened reality, or substituted for the photographed images altogether.

Producing this subdivided image through computer-generated means alone may yield advantages of interactivity for the audience, but will require a substantial investment in hardware. Feeding the projectors with prerecorded video, on the other hand, requires much lower cost, and allows a simple, standardized playback platform for the distribution of prerecorded shows to a network of venues.

The size of the playback dome is variable, depending in large part on the capabilities of the projectors. The best results involve video domes that are a similar size to the many planetaria that can be found worldwide. The construction of new, video-based dome theaters can also be done for a substantially smaller cost than the larger, large-format film theaters. The use of video has other advantages, such as the live telecast of immersive images from point to point.

Because the dodecahedral standard is modular, it allows for different numbers of segments to be used for different playback situations. Three pentagons together is ideal for filling a shallow dome, and four pentagons is roughly equal to the field of view of an Omnimax image. The addition of more views, to create a more total spherical image, takes the prerecorded image beyond domes into even more exotic forms of playback, with increased resolution and realism that comes from their use of multiple sections. In practice, it is often good in the field to record eight pentagons, forming a picture that includes the six views of a horizontal hemisphere, plus two views below the horizon. A program produced in this way can be displayed at least two different ways in two different domes. Using the uppermost group of six pentagons will illuminate a conventional horizontal or slightly tilted dome. Optionally, using another group of six, including the two lower views instead of two at the back of the first hemisphere, will form an image in the form of a hemisphere tilted 63.4 degrees, for a more frontal immersive effect. Recording nine pentagons allows another form of grouping to show even more below the horizon. Eleven pentagons is the practical limit of camera recording, and represents a nearly spherical image. The field of view is so wide that care must be taken to keep the cameraman and the equipment out of the picture (unless, for reasons of *cinema verité*, you want to see them!).

Making use of the extra field of view and bandwidth in these total images leads to even more exotic forms of spherical image display, which can be thought of as an inside-out and an outside-in approach to the recorded spherical image. An example of this outside-in approach is represented by Immersive Media's spherical television screen called the Teleball™, an eight foot diameter globe that is illuminated by a set of dodecahedral images produced by an ultra-compact modular global image projector. The effect is similar to looking at a reflection in a giant shiny silver ball, except that the "reflection" is actually a recording of a spherical image taken somewhere else. This device uses the same video feeds as a dome theater projection, with the addition of the extra ones below the horizon.

Other Display Methods

Another method from Immersive Media for using all of the segments in a spherical image is the Wheel™, a full-bandwidth, omnidirectional live photographic personal viewing system for immersive telecasts. This PC-based image-processing subsystem uses an HMD or another form of steerable monitor to direct the extraction of a region of interest from within a multichannel feed representing the various segments of the immersive image. Earlier experiments done in conjunction with Warp California demonstrated the first uses of RoundAbout imaging for the production of a photographic form of virtual reality, and the feel of being surrounded by the look and sound of another real place.

Because the geodesic geometry of the dodecahedron is so widely understood, the production of images compatible with the RoundAbout format can come from a wide variety of sources, by converting them using spherical mapping techniques. The conversion between the Platonic solids is especially straightforward, so cube-based imaging systems, for instance, can use the RoundAbout standard to apply their images to dome theater projection.

As image processing software becomes even more sophisticated, the conversion between spherical formats can be eased, and the whole field of immersive imaging can grow. Images produced in RoundAbout immersive video can be converted for display in panoramic systems such as Silicon Graphics' Reality Center and Visionarium, Panoram Technologies' GVR120 and Spitz Inc.'s ElectricHorizon™ VR Theater, by extracting the relevant sections of the pentagons. Other dome formats such as Goto Optical's Virtuarium™, Spitz's ElectricSky™ and Evans and Sutherland's StarRider™ can benefit from full-dome photography in addition to computer-generated images. "Feeding the sphere" with dodecahedral images, both directly and indirectly, has the potential to create new forms of immersive entertainment, and aid the growth of other aspects of a new immersive imaging industry.

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ElectricSky™ Immersive Multimedia Theater

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Abstract

A new vision is emerging for planetaria. We soon will be able to graphically control the entire surface of a dome screen, in real-time, with high-resolution images from a variety of sources - synthetic, remotely sensed, filmed, hand painted or drawn, videotaped and photographed. This new video technology transforms the planetarium into a general-purpose immersive visualization environment or "digital dome." Digital domes breathe new life into planetaria and empower planetarians to educate and inspire in a way that no competing medium can. Spitz's ElectricSky™ theater, the first of these new facilities, is a proven multi-use, multi-format theater. ElectricSky supports a variety of community-based activities including corporate galas, video game tournaments, movie theater presentations, concerts, multi-media/web presentations, interactive 3D programming and laser shows in addition to traditional planetarium presentations. Digital dome theaters will enable planetaria to disseminate the latest scientific discoveries to a sophisticated, media-savvy public.

Back to the Basics

There is an ongoing debate regarding the utility of planetaria in today's world. Astronomical images are adequately presented and discussed in television documentaries. Films such as the Star Wars and Star Trek series have entertained millions with futuristic visions of deep space. Desktop computers running inexpensive software simulate the celestial sphere with pinpoint accuracy. And stunning panoramas of Mars are downloaded by millions directly from NASA's website. Aside from philanthropy, how do we justify the cost of building and maintaining a modern planetarium?

To help answer this we revisited the original purpose of a dome theater: to simulate spatial presence. A spherical image provides the greatest visual field-of-view of all projection surfaces, nearly filling the viewer's retina[1]. Such images have a powerful psychological impact on our sense of space and balance, the opto-vestibular response. Images mapped onto a dome surface therefore induce the greatest "sense of presence" of all presentation media. Planetarians have recognized this for many years, resulting in a plethora of full-dome special effect devices to exploit immersivity by "working the dome."

Film formats can cover a dome with all-sky images. No such format has been available for video, however. Video is directly compatible with electronic information and graphics formats and has a fast production turn-around time making it ideal for planetarium applications.

ImmersaVision™ Video Panorama

Spitz has pioneered a new format for dome video production called ImmersaVision™. ImmersaVision is a universal, open and evolutionary format for full-motion spherical video productions. Its simplest and most robust embodiment is ImmersaVision 10:3, a partial-dome cylindrical panoramic format. As shown below, ImmersaVision 10:3 maps a rectangular frame with a 10:3 aspect ratio onto a spherical section which is 200 degrees horizontal by 60 degrees vertical. Prior to projection the panorama is broken into three overlapped sub-frames. Standard D1 video (CCIR-601) sub-frames (720x486 pixels) results in a 1800x486 pixel frame. Each sub-frame is soft-edge masked and spherically warped so they blend seamlessly on the dome to reconstruct the original panoramic frame. With digital video playback and processing, the result is a visually compelling, full-color wrap-around video image - an exciting new medium!

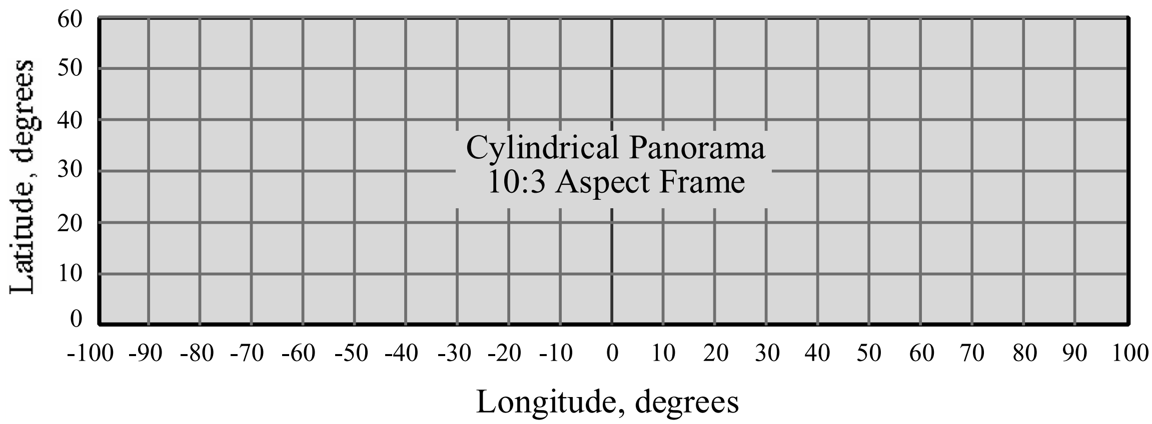
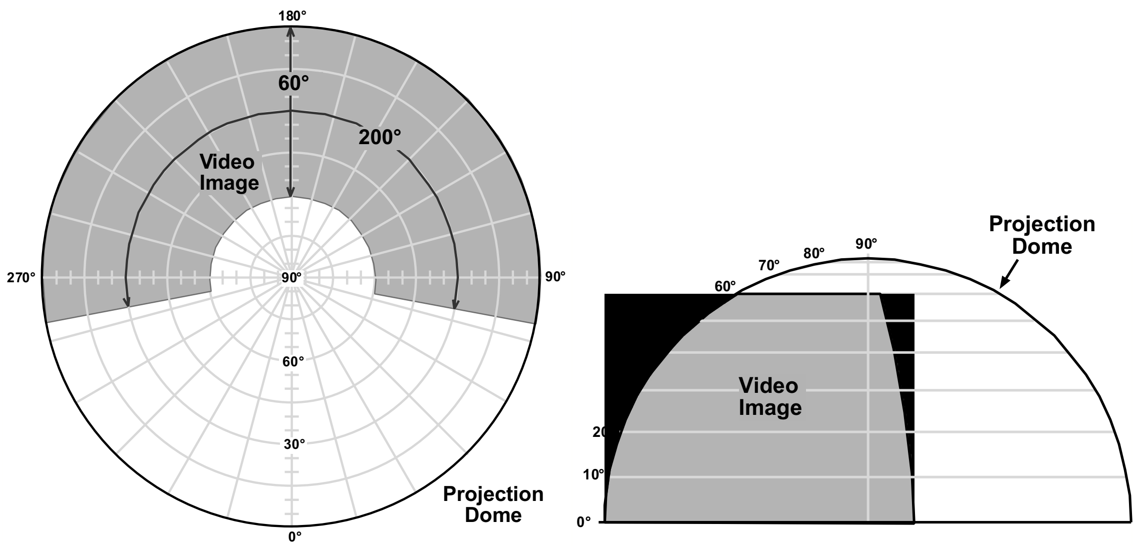


Fig. 1 - Cylindrical equidistant mapping for ImmersaVision 10:3



Top View

Side View

Fig. 2 - Dome Coverage of ImmersaVision Video Panorama

Two techniques are available for performing the edge-blending and spherical warping. The first and most obvious approach mimics the process used for all-sky multi-image projections. We call it pre-rendered edge-blending and mapping, or pre-blending. Each video frame is digitized, and using a custom Photoshop plug-in, an edge-blend mask is applied to the image. The plug-in also applies spherical warping according to the particular dome geometry. Pre-blending requires show customization to a particular projector type and dome geometry for best results.

The second technique is used in most flight simulators which employ CRT projectors. Edge-blending is applied in real-time using an electronic video edge-blend processor[2]. Spherical mapping is also applied in real-time using a special CRT dome video projector which allows extreme geometric correction. The result is a better edge-blend and a more flexible, general purpose system. The edge-blend is better because it is adjusted interactively to achieve the ideal blend for a given theater configuration. As CRTs age, the edge-blends can be maintained to look their best. And because the edge-blending and mapping occur in real-time, the additional expense of pre-blending is avoided. This also allows a real-time image to be projected across the entire panorama, such as a computer desktop or a panoramic video camera. This feature is crucial for a true multi-use facility.

Spitz is presently recommending pre-rendered systems for theaters with smaller budgets who are more concerned with playback-only operation. Systems using real-time blending can easily accept pre-blended material and can actually switch modes under automation. Shows which are produced using the ImmersaVision format can be adapted to either system. This is because ImmersaVision is a spherical format which is independent of projection means.

Higher resolutions are easily obtained up to the maximum projector bandwidth and scan frequency (2500x2000 addressable pixels for CRT graphics projectors). Greater dome coverage is possible by adding more projectors, allowing up to a full hemispheric video display.

ElectricSky™ Theater

Spitz has combined the ImmersaVision Video Panorama with all-sky multi-image, a standard star projector, dome laser projection and standard digital audio (5.1 format) to create a powerful immersive multimedia theater format called ElectricSky. The first ElectricSky theater was sold to the Town of Watson Lake in the Canada's Yukon Territory. In its first year of operation, Watson Lake's *Northern Lights Centre* has become on of the Yukon's largest tourist attractions. Offerings include feature shows on the Northern Lights, laser shows from Laser Fantasy, feature films from DVD, and Saturday morning video game tournaments on the dome. Multi-use capability has contributed to the success of this remotely located theater.

Fig. 3 - ElectricSky Theater

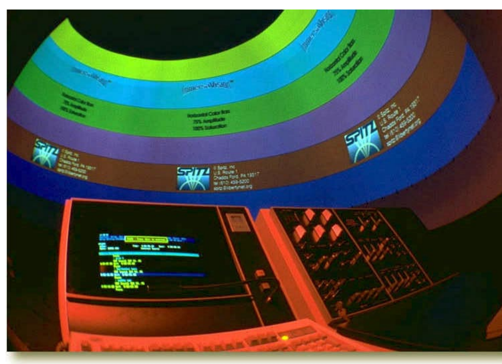


Fig. 4 - ImmersaVision Video Panorama

The philosophy behind ElectricSky is to exploit video and laser projections and eliminate many of the less reliable planetarium special effects and slide projectors. Multi-image is reduced to a set of all-skys and three dissolve pairs. Multi-image panoramas are eliminated by using video for moving panoramas and by digitally mapping still panoramas to the all-sky projectors. This consolidation of planetarium equipment results in a more reliable theater and more transportable shows. An extensive astronomical graphics library and feature productions, developed in-house by Spitz animators and others, will facilitate the use of panoramic video.

The use of all-sky slides and a star projector provides a full-dome effect which supplements the partial dome video. And Spitz's new Windows 98-based Theater Control System provides a single, elegant user interface. The result is a streamlined and well documented theater format which is much more user-friendly and accessible to local media professionals. Shows produced in ElectricSky format are easily transported to other ElectricSky theaters, resulting in near plug-and-play operation.

Show Production

Perhaps the most exciting thing about the ImmersaVision format is the ease with which original graphic material can be produced. Graphics are created using a wide variety of source material, and post-produced and edited using standard desktop computers. Shows are downloaded digitally and played back under automation using synchronized digital players. Source material can be generated from 3D computer graphics using software such as Lightwave, 3D Studio Max, Softimage or Alias/Wavefront. Traditional painted panoramas can be scanned and used as compositing backgrounds. Slit-scan panoramic photographs also make excellent source material. Still artwork is brought to life in video using camera pans, tilts, zooms and other special effects. Compositing is a powerful tool allowing many simple, inexpensive graphics effects to be layered to produce a visually rich and compelling sequence.

To facilitate ElectricSky show production, Spitz is developing a family of ImmersaVision software plug-ins for the Adobe software suite. These software tools empower users of Photoshop, After-Effects, DeBabelyzer and other desktop graphics applications to produce quality ElectricSky shows. Effects include geometric transformations and spherical special effects which are essential to dome video productions.

Asset management of digital video is handled by the theater control system. Since shows reside on hard drives, new show material can be downloaded automatically from FTP sites overnight and drop-replaced into the show. The capability to rapidly display timely scientific data and late-breaking NASA images differentiates the video-based theater from film formats.

Real-Time Computer Graphics

ElectricSky is also capable of Real-time interactive 3D presentations. Spitz has demonstrated such a system using their ElectricHorizon™ Virtual Reality Theater[3]. ElectricHorizon is powered by a Silicon Graphics Onyx® Infinite Reality™ computer, and uses three edge-blended Electrohome Marquee® projectors to produce a panoramic video display on a 28 foot diameter partial-dome screen. A seating deck includes 32 interactive audience responders each containing 3 lighted pushbuttons which are read by the Onyx computer. ElectricHorizon was first demonstrated as a temporary theater installed last year at Pittsburgh's Carnegie Science Center.

ElectricHorizon show programming included *Virtual Pompeii*, an interactive walkthrough of Pompeii in 79 A.D., and *Robotix Mars Mission*, a VR Cinema experience funded by Learning Curve Toys. Both programs were developed by Carnegie Mellon University's SIMLAB.

Fig. 5 - Group Telepresence

ElectricHorizon was also a group telepresence test site for NASA's Atacama Desert Trek. Carnegie Mellon's Robotics Institute tested their Nomad rover last year in Chile's Atacama Desert, in cooperation with NASA Ames. Equipped with a unique "panospheric" camera, Nomad beamed back real-time panoramic images to the Carnegie Science Center which were displayed to audiences in the ElectricHorizon theater. Using the push-button responders, the audience could rotate the panoramic image by a full 360 degrees. This demonstration of real-time telepresence in a group environment paves the way for future planetaria to accept live panoramic feeds from planetary rovers. Red Whittaker, director of the Robotics Institute, believes that immersive displays will play a key role in future robotic missions to Mars and other planets.

Basing a theater entirely on real time 3D graphics capability, while exciting and full of potential, is still unproved. Pre-rendered shows rely on time-tested show production models developed for film and video. Pre-rendered material can exploit a wide variety of inexpensive desktop video production techniques including compositing, live-action and offline rendering. Since computer graphics do not have to be rendered in a fraction of a second, photorealistic rendering techniques such as ray tracing are possible. Real-time 3D programming requires an entirely new show production model requiring expensive, high-end computers, specialized simulation programming and new innovations in audience interactivity. While we welcome the chance to provide real-time 3D systems to planetaria, such systems should be considered experimental in nature and approached with caution.

The Future Is Bright

We expect ElectricSky to quickly become a new standard in planetaria worldwide. The introduction of an immersive computer graphics display into the planetarium will elevate planetaria to a greater level of quality, utility and respect. The new potentials opened by such a theater are far-reaching. Immersive video will attract the art, computer science, and astronomy departments of local universities, colleges and high-schools to participate in show production. Laser light shows will be propelled to new heights by the incorporation of full-color video imagery. Planetaria within schools will have the opportunity to work synergistically with other departments outside of astronomy or physics who will want to share the dome. Spitz is working to provide a pipeline of scientific data from government agencies and research institutions for use in ElectricSky theaters.

In summary, digital dome technology is now a viable alternative for planetaria and dome theaters. The added capabilities may hold the key to the future success of planetaria - both as a vehicle for scientific outreach and a self-sustaining, profitable special-venue attraction.

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VR in immersive and interactive theatres : the bridge between movie and video-game experiences.

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Abstract.

In 1994, an immersive and interactive room was revealed for the first time to the general public : this was the opening of the very first RealityCentre®, located in the offices of sgi UK. The room is a facility accommodating 50 people, where exclusively interactive content is performed on a panoramic screen with a 160° field of view.

The RealityCentre® in sgi UK

*The **immersion** is perfect : from wherever you look at it, there is a seamless image, you are in it!*

*The **interaction** is there : an operator leads you through realistic and fantasy worlds.*

*You are in a **theatre**, you are not alone, it is a social experience, but... the frustration comes from the fascination : there is only one operator who "plays" with it... you'd like to try, but unfortunately, you're not a VIP.*

The goal of this presentation is therefore to demonstrate, through concrete examples, how it is possible to provide rich interaction to a large audience, creating a new type of entertainment : the bridge between video-games and movie theatre experiences.

Group Interaction.

Group interaction, a factor of dissemination :

Since 1993, when we started our developments in interactive VR experiences, our company, ***de pinxi***, has been providing immersion on large screens, with the participation of an audience instead of a single operator.

The participation of the *full audience* is for us an important step in the popularisation of large- scale interactive experiences : a larger public will create the need for larger projects, and richer content.
This is why we see group interaction systems as the way to move interactive experiences from the status of "demos/attractions" to the status of *edutainment* "productions".

Interaction strategies :

The idea is to use interactive techniques, pretty similar to the one deployed in flight simulation, to create new, social and active *edutainment* content. The imagery is generated on **sgi** graphics computers, modified each $1/60^{th}$ of second, according to the actions of all the operators making up the audience.

Different control strategies can be applied, one after another, or together, depending on the scenario of the interactive experience.

Full audience interaction **:** uses the whole group of operators ; the action of the audience is the weighted result of all the input devices, the audience can be considered as a 'big analogue joystick', this is typically used for navigation. A clear feedback of the current trend of the audience appears on the large screen.

Team interaction : this strategy is based on dividing the audience into teams, to enable competition or collaboration missions. This contributes to an unrivalled atmosphere in the room : the teams, made up of 5-10 people, become one force, and the members progressively tend to synchronise their actions ! Team scoring or feedback appears clearly on the large common display.

Personal action : each individual is provided with an input device driving a clear unique symbol on the display ; this symbol enables him/her to accomplish actions, such as : interrogate, select or collect objects in the virtual environment, open doors, raise buildings, clear obstacles, choose directions, start AV-media playing and special effects, etc… A personal feedback is provided on the display integrated in the seat of each member of the audience : requested information, individual scoring, any help and advice to continue with the experience.

To assess the main objective of field operation (in a museum or a theme park), we develop strategies so that they avoid dependence on the number of *spect-Actors* in the audience.

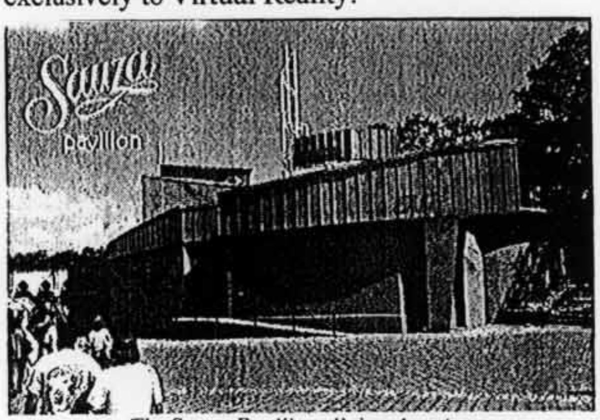
These concepts have been integrated into a software and hardware combination, called ***argoGroup***™. It consists of:

- a software core, ***ArgoKernel***™, the *de pinxi* real-time engine;
- a set of electronic control units, including input devices and personal displays, built into each operator's seat.

Group interaction for leisure - Case-studies.

Case 1 : Sauza Pavilion in Reino Aventura. (theme park in Mexico city)

The experience : The newest attraction launched at Reino Aventura is a pavilion dedicated exclusively to Virtual Reality.



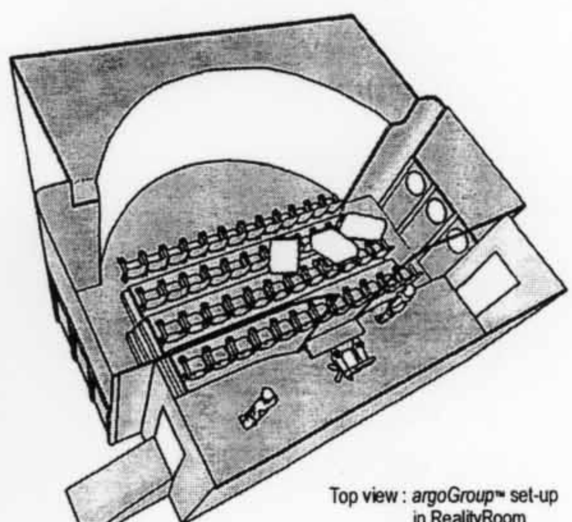
The Sauza Pavilion, Reino Aventura.

For its client Sauza (world leader in the production of Tequila), *de pinxi* has created the key attraction of the pavilion, allowing an entire audience of 36 members to interact *together* with the virtual world under exploration.

Inside the Pavilion, the immersive and interactive theatre.

The audience is divided into teams, each with different missions, sometimes competing, sometimes co-operating. Among their numerous tasks, they have to open passages, to navigate through risky terrain, to destroy obstacles and, above all, to rebuild Mexico's main natural and heritage sites : Teotihuacan, the Canyon del Cobre, Zocalo, the Night of the Dead…

The infrastructure : The room consists in a "RealityRoom" built by **Trimension** : this is a panoramic room where a system of 3 high-definition video-projectors creates a 160° open picture (the human field of vision) over a diameter of 8 metres, in stereoscopic mode .



Top view : *argoGroup*™ set-up in RealityRoom

The engine of the show is an Onyx2 IR2 machine from **sgi**, making it possible to reach very high display resolutions (typically 4000 X 1000 pixels), and to visit unrivalled rich virtual worlds at a steady frame rate. Furthermore, the outstanding *antialiasing* removes any computer image artefacts from the displays : it is mandatory for such large screen set-ups.

Operating : as a complete attraction in a theme park, the pavilion is provided with a pre-show area (creating the atmosphere of the experience) and with a training zone : the members of the audience are able to practise during the waiting time, they are also briefed according to their personal mission in the group.

The show is automated, and a single operator is enough to ensure proper performance. The capacity of this particular room reaches 3,000 visitors a day.

Case 2 : Laval Virtual 99 & Siggraph99 (temporary set-ups).

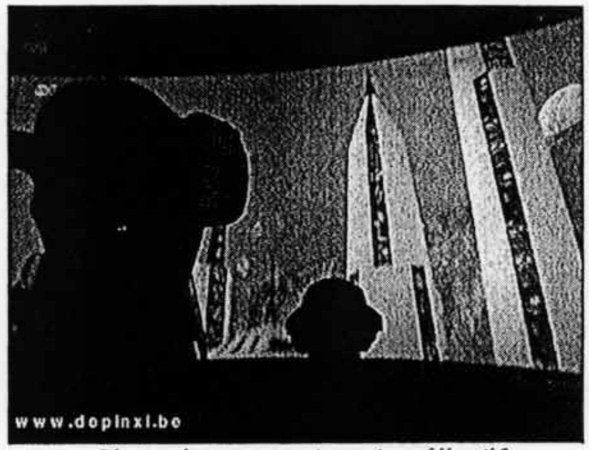
The *argoGroup*™ system has also been developed in a portable version.

To operate in temporary configurations, where training time has to be reduced, and the efficiency of "players" maximised, we simplify the interaction strategies by reducing the number of roles in the interactive quest. On the other hand, we raise the collaborative aspect of the show : teams are larger, and they are encouraged or advised by a performing actor.

To facilitate the audience's control, we have chosen familiar input devices, like popular game pads without personal display.

The experience : "Kaotik2, the Mask of Time", is an interactive show blending the dynamism of a game with the thrill of a big- screen ride.

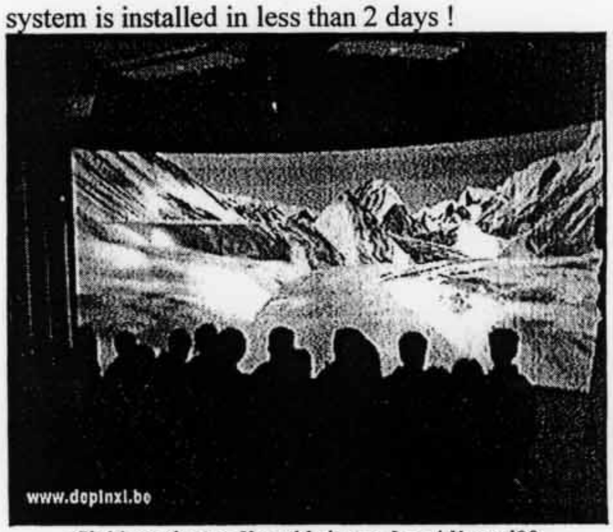
The roles are assigned sequentially to each team, to enable all members of the audience to rate their skills on each possible task : avoiding obstacles, collecting objects and eliminating enemies.



Playing the stereoscopic version of Kaotik2.

An incredible atmosphere fills the immersive theatre immediately : people collaborate with people they have never met before, they really synchronise their actions to become a coherent team.

The infrastructure : The room consists of a portable "RealityRoom" from **Trimension**, or a portable "RealityCenter" from **Barco** : with the same characteristics as the fixed locations ; the system is installed in less than 2 days !



Children playing Kaotik2 during Laval Virtual99.

New developments : educational content.

Group interaction was successfully tested, deployed and now operates in theme park and trade-fair environments.

We have started to go further, offering interactive content for groups, to fulfil the requirements of museums and educational applications.

To open large scale (truly) interactive experiences to educational content, we found three main directions to follow.

Enhancing personal feedback :

By enhancing the personal feedback system, we were able to combine the unrivalled feeling of an immersive social experience with the educational level of a multimedia "classical" cd-rom.

The activity of the audience ensures a better delivery of the educational message : members of the audience discover the message by themselves, choose their own topics of interest.

Ease of operation :

We have developed a high level of automation for the group interaction system : this provides practical solutions for museum operation.
The system doesn't necessarily require an operator to run it : it can be started up once a day, in "waiting mode" (an auto-pilot system), and be sensitive to the audience entering the theatre. As soon as an attendee takes his place, it enables full audience interaction mode.

A conference mode is provided for guided tours (groups of visitors such as schoolchildren with their teacher).

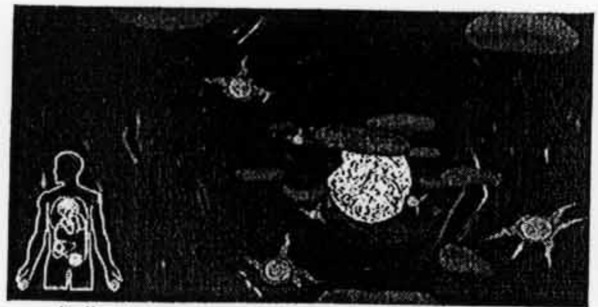
Digital media, no format constraints :

We have made special efforts in developing "non-format-oriented" content : the digital media free the operator from any concerns about format ; the content is played from a computer, and therefore is able to be adapted to unrestricted projection set-ups : flat screen, panoramic screen , planetarium, in monoscopic or stereoscopic modes, etc...

Thanks to its digital nature, the interactive content can seamlessly integrate traditional media (film sequences, still pictures, diagrams, etc...) to create an overall spectacle.

Examples to come :

The first educational title to be released in this direction, is the Human Body Voyage, an enhanced version of a title already developed by *de pinxi* for the Sciences Exploration Centre, a museum located in Cairo.



Following a group of cells in the circulatory system.

Two new educational applications are under development : one is related to historical content, the second to fine arts. Check our web pages for more information in the coming weeks.

Conclusion.

Group interaction is not only possible, but also offers an important added value, as a social and educational experience.

Group interaction is a key feature in popularising truly interactive large-scale experiences, making the bridge between multimedia (interaction) and movie (social immersion).

Large scale interactive experiences will reshape the way we think of entertainment for the future and will offer a new, unrivalled power of attraction for the operators that will deploy them.

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Interactive collaborative media environments

D M Traill, J M Bowskill and P J Lawrence

Virtual reality (VR) provides a revolutionary interface between man and machine. However, present display and interface peripherals limit the potential of virtual environments within many activities or scenarios. Mainstream immersive VR is centred on head mounted display (HMD) based solutions in which the user is isolated from their surrounding environment. The occlusion of real world interaction within such systems imposes unnatural social and physical constraints on the user. Media environments can be classified as one form of enhanced reality based around immersive physical spaces intensified for effective collaborative activities. Current research is directed at three forms of enhanced spaces — immersive projected displays, interactive video environments, and immersive desktop environments. While HMD and desktop VR facilitates many collaborative tasks, the synthesis of real and virtual realities within a life-size environment offers distinct advantages within other applications. This paper introduces the concepts behind media environments, reviews current research and presents applications being explored at BT Laboratories.

1. Introduction

Humans have an unrivalled ability for assimilating, understanding and communicating information. This ability when applied to computing is often handicapped by the interface through which we communicate with the information beyond, the ubiquitous interface being the keyboard and mouse. Technology is only a solution if the interface is intuitive and closely aligned with the physical and social demands of the human task. Virtual reality (VR) represents a leap in interface technology in which the user is immersed in a graphical and auditory machine representation of a natural (or sometimes abstract) environment.

With the popular present-day perception of VR being reserved almost exclusively for single users playing games and/or simulations, the wider potential for VR within, for example, industry, commerce and health, is being overlooked. This traditional viewpoint of VR is being challenged by the work of numerous researchers around the world working at the leading edge of visualisation/application techniques. VR techniques can be employed within tasks demanding collaboration between individuals or groups of people, where the immersive reality is provided by an interactive physical environment, rather than using head-mounted technologies. The range of display technologies currently being used for VR is diverse (Fig 1), and a number of 'partial immersion' interfaces are now being developed which will facilitate new ways of working effectively using VR.

Ubiquitous solutions will be based on 3-D graphical interfaces combined with continuous presence video and spatialised audio [1]. The synthesis of many such techniques is being explored within 'media environments' that are networked for collaborative applications.

The discussion covers the reasons why media environments are being developed, with emphasis on the research covering immersive and desktop systems.

2. Virtual environments

Both modern business, and society in general, is underpinned by a need for effective communications. As humans, we are equipped with complex biological mechanisms which allow us to communicate within an equally complex social etiquette. For many decades telephone technology has been able to satisfy our basic need to communicate within ever expanding communities and organisations. However, demands and expectations change and remote collaboration with larger communities of people, discussing diverse forms of information, requires new technologies and solutions, in order to communicate effectively.

Kalawsky [2] defines virtual environments as synthetic sensory experiences that communicate physical and abstract components to a participant. An illustration of the interrelationships in a virtual environment is given in Fig 2, a partitioned virtual environment. The shaded region shows a fully interactive virtual environment embodying visual, auditory and touch environments; this region is commonly termed 'virtual reality'. The ability for technology to stimulate most of our senses including vision, hearing and

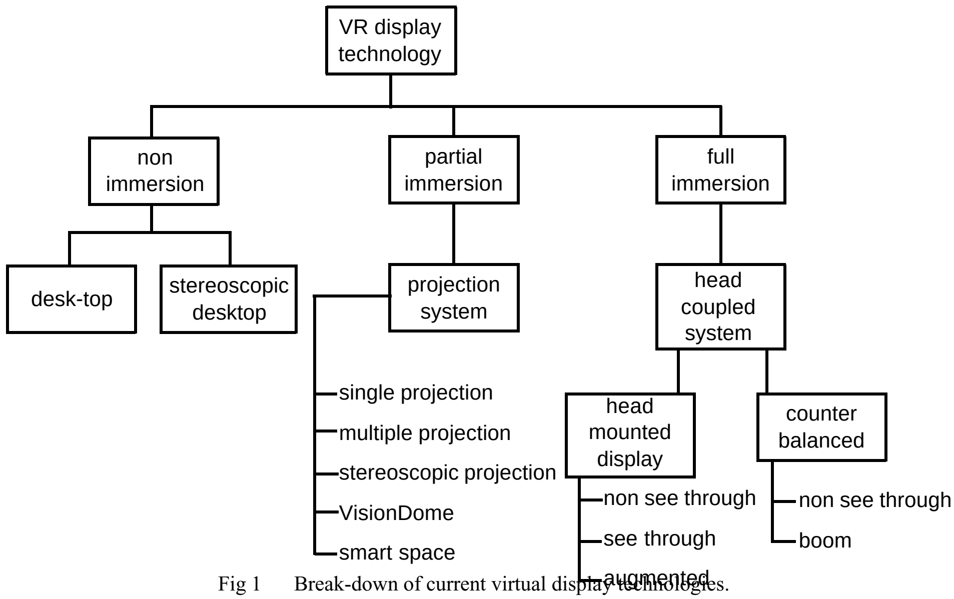

Fig 1 Break-down of current virtual display technologies.

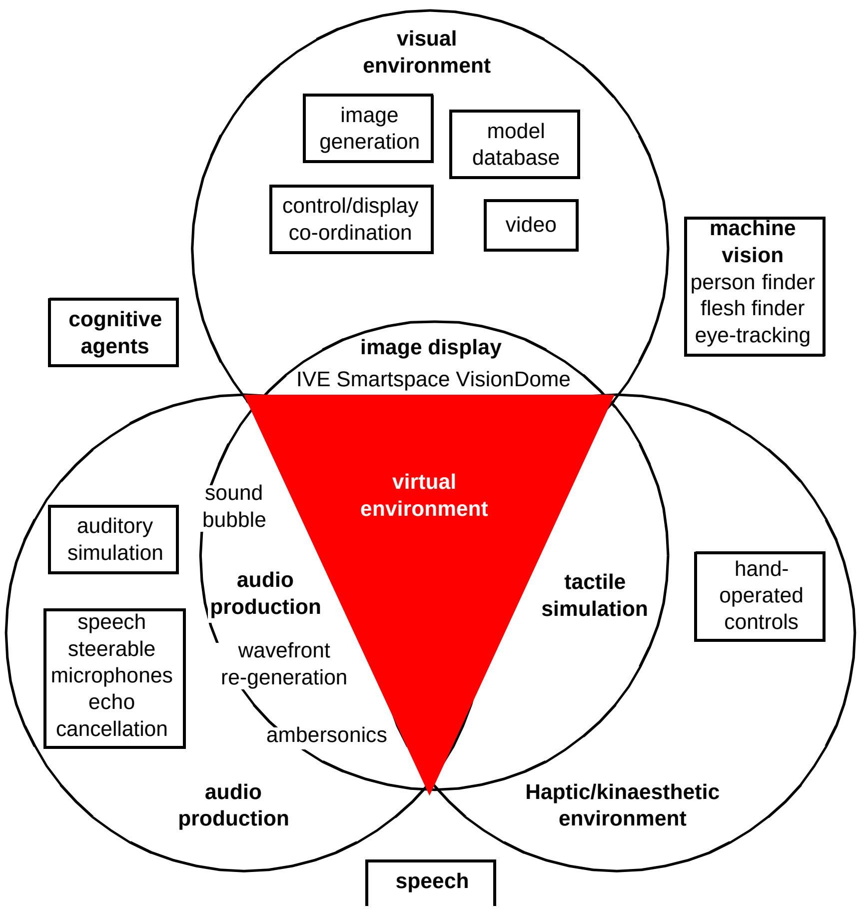

Fig 2 Partitioned virtual environment.

touch, enables human immersion in artificial virtual environments.

In terms of collaborative working, virtual environments can produce the mutual sense of presence that is an important trait within any collaborative activity. Shared virtual environments such as MASSIVE [3] allow users to meet and communicate in different worlds. However, present display and interface peripherals limit the potential of virtual environments within many activities or scenarios. Mainstream immersive VR is centred on head mounted display (HMD) based solutions in which the user is isolated from their surrounding environment. The occlusion of real world interaction within such systems imposes unnatural social and physical constraints on the user. Consider the difficulty in reacting to interruptions such as the telephone or carrying out 'normal' background activities such as note taking. Desktop VR breaks the user from the immersive environment and thus detracts from many applications in which interaction or 'life scale' is important. Being in a world and looking into a world are two distinct experiences.

3. Media environments

The media environments [4] project at BT is looking at ways of creating more natural immersive spaces. Media environments are spaces in which the physical world is enhanced with 2-D or 3-D computer graphics, which can be complemented with spatialised audio. These elements when combined produce an immersive experience within a more natural human environment. An office, for example, could include back projected or flat screen technologies to create areas in which virtual artefacts can be manipulated using gestures.

Many human tasks are based on groups of people collaborating and not just on individuals. Activities, such as design reviews, rely on collaboration between people not all of whom are physically remote. Therefore, spaces in which people can meet, discuss ideas in person and be immersed in a wider collaborative activity, offer significant benefit to many interactive situations. Telepresence technology is biased towards spatially distributed individuals with, typically, one user workstation per location. This can be characterised as 'networked personal immersion'. Successful solutions to many tasks rely on technology which supports not only interaction between sites but also allows each point of presence to be inhabited by more than one person, i.e. 'networked group immersion'. The areas of enhanced reality, interactive video environments, desktop immersion and group immersion represent complementary examples of media environments and technologies, the integration of which forms the basis of current research.

3.1 Enhancing Reality

While much effort is being focused on the realisation of virtual worlds, a potentially important grouping of technologies is emerging. There is an intermediate stage between the worlds of fact and fiction, a form of 'enhanced reality' [5]. In an enhanced reality environment the user sees, and interacts with, a view of reality that has been modified to augment the operator's perception and handling of the associated task. The key to this technology is the idea of visual annotation, whereby video images of an operator's surroundings are enhanced by computer generated graphics.

The conventional view of a VR environment is one in which the participant is totally immersed in, and able to interact with, a completely synthetic world. Such a world may mimic the properties of some real-world environment, either existing or fictional; however, it can also exceed the spatial bounds of physical laws ordinarily governing reality. Virtual reality has been developed from a convergence of video technology and computer hardware; the underpinning being computer graphics. Enhanced reality, in contrast, represents a convergence of the aims and technology of virtual reality with the domains of image processing and machine vision. Underpinning is provided by image processing techniques, the extraction of information from the real scene, as opposed to the graphical construction of a virtual scene. An aim which enhanced reality supports is the notion of intelligence amplification as envisaged by Brookes [6] in which the technology augments the decision-making criteria of human operators by enhancing their visual perception. For a discussion on the forms of graphical annotation and reality enhancement refer to Bowskill et al [7].

Milgram and Kishino developed a taxonomy of mixed, or enhanced, reality in an attempt to define the concept of a 'virtuality continuum' between real and virtual environments [8], as represented in Fig 3. Milgram also emphasises that the next generation telecommunications environment must provide an " *ideal virtual space with [sufficient] reality essential for communication* ". Both 'virtual space' and 'reality' are available within the same visual display environment. Real environments are defined as environments consisting solely of 'real objects' and include, for example, what is observed via a conventional video display of a real-world scene. Virtual environments consist solely of 'virtual objects' an example of which would be a conventional computer graphic simulation. The most straightforward way to view a mixed reality environment is one in which real world and virtual world objects are presented together within a single display. As indicated in Fig 3, this is anywhere between the extrema of the virtuality continuum.

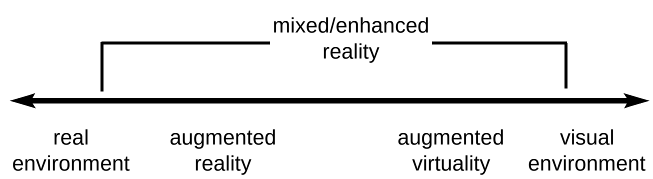

Fig 3 The Milgram 'virtuality continuum'.

VR is inherently suitable for modelling and interacting with abstract environments, which are beyond our present capabilities. However, in applications in which a real environment must be modelled in order to create an acceptable level of immersive realism then some form of an enhanced reality is called for. After all, why generate a computer model of reality when reality is all around? Is it not more appropriate to annotate reality with enhancements to improve the task in which the user is engaged? For collaborative virtual environments (CVE) the nature of the interface space is determined by the user's real world constraints and the social constraints of the task in which they are involved. For example, surgeons could benefit from being able to participate in collaborative visualisation and diagnosis sessions. However, the physical constraints of their working environment would dictate an augmented reality interface to the CVE in which the virtual participants could be seen to co-exist within the real environment. If immersion in a single real or virtual space is prohibited then perhaps some form of 'metaworld' is required in which participation with a number of real and virtual spaces or users is possible.

Enhanced reality can also include audio rendering, adding spatialised audio to objects to act as navigation aids, to aid the performance of a task. Audio cues are already used as alert tones on personal computers, but with advances in spatialised, and 'rendered' audio, auditory feedback will become increasingly feasible. In an enhanced space these can act as a navigational guide either when the visual scene may be occluded or as an audio icon for additional directional information.

3.2 Interactive video environment (IVE)

While exploring the unique artistic potential of the computer, Myron Krueger can be credited with many significant experiments in which the possibilities of mixing video, computer graphics, and gesture/position sensing technologies were demonstrated. These are reviewed by Krueger [9]. METAPLAY (circa 1970) first demonstrated a 'responsive environment', as Krueger termed it, in which a participant viewed and interacted with a back-projected image of themselves annotated with computer graphics. Although initially graphics were generated and mediated by a remote human facilitator, the evolution of this system extended the role and capabilities of computer-based mediation. VIDEOPLACE, an open-ended laboratory in which image processing is used to identify user attributes, has been under development since 1975 as a form of 'shared video space'. Krueger perceived the potential as a telecommunications medium to be significant, as illustrated by the following quote: *"Even in its fetal stage, VIDEOPLACE is far more flexible than the telephone is after one hundred years of development"* [10].

MIT Media Lab, in collaboration with BT Laboratories, developed ALIVE (Artificial Life Interactive Video Environment) [11], a system in which a human can interact with a virtual agent within an unconstrained environment. The system is based on a magic mirror metaphor, as is VIDEOPLACE, in which a person in the ALIVE space sees their own image as in a mirror. Real-time video of the user in the reflected world is augmented with 'Silas' the dog, an autonomous computer animated graphic (virtual agent). This is displayed on a back-projected screen, which forms one wall within the room in which the user is standing.

Interaction between real and virtual participants of the reflected world is facilitated via the 'Pfinder' vision-based tracking system [12]. This extracts the user's head, hand, and foot positions, as well as the gesture information, from the real-time video. Pfinder's gesture tags and feature positions are used by the artificial character to make decisions about how to interact or respond to the user. Pfinder also allows graphics to be placed correctly in the 3-D environment, such that video of the person must be able to occlude, or be occluded by, the graphics. A subsequent application of the Pfinder system has been to enable body position and poise of a user to directly control navigation within the SURVIVE (Simulated Urban Recreational Violence IVE) 3-D virtual game environment. This system demonstrates the ability to use gesture recognition to interact with the computer without using a keyboard or mouse.

The potential also exists for IVE systems to create convincing shared virtual spaces and this has been demonstrated in the form of a collaborative conferencing tool [13]. In this a remote participant can be viewed as an annotated figure (avatar) within the user's local environment, as illustrated in Fig 4. Information about the users, via Pfinder, is shared between geographically separate locations. At the remote end, information about the user's head, hand, and feet position is used to drive a video avatar that represents, or perhaps purposely misrepresents, the user in the scene. Such an approach is inherently scalable, with the potential for large numbers of people to collaborate and communicate in a single shared space. Firstly, network bandwidth is efficient, as it is possible to create convincing telepresence without transmitting video to the remote site. An IVE conference between MIT and the Human Interaction Centre at BT Laboratories has, for example, been demonstrated via a 64 kbit/s ISDN network connection.

The visual perception of a synthesis of real and life size virtual artefacts, with corresponding auditory cues from a spatialised audio system, creates an effective form of telepresence and offers great potential for teleconferencing and CVE activities. A practical advantage is the suitability for IVEs to be integrated within 'real world' spaces, for example, meeting rooms or lecture theatres. A metaphor which current research is exploring is the 'morphic table', as termed by the authors. A real table is complemented with an adjoining display, allowing the physical surface to extend into a virtual environment as illustrated within Fig 5. In terms of the future development of IVE-based interfaces to collaborative spaces, two primary areas of activity can be identified — multi-participant support (including appropriate mechanisms for interaction and control arbitration), and comprehensive mechanisms for annotating and interacting with imported virtual artefacts.

Fig 4 ALIVE, including a real person, a virtual avatar and Silas the virtual dog (agent).

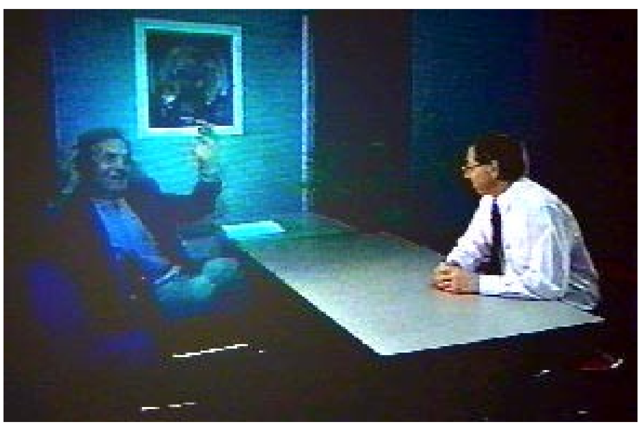

Fig 5 Morphic table.

3.3 Desktop immersion

All computer users are familiar with the non-immersive desktop interface. Desktop immersion has been largely restricted to HMD peripherals. For example, Kalawsky identifies Desktop VR as *"CAD systems with the added advantage of some form of animation, so that ... objects can be dynamically controlled"* and introduces immersive virtual environments as *"systems that employ a helmet-mounted display or a BOOM-like display to present a visually coupled image"* [2]. Interacting with a CVE via a non-immersive desktop interface can be adequate if the surrounding physical environment accommodates the user. However, it has been observed that a 'degree of presence' problem exists when users become distracted by local events within their physical space, leaving their virtual embodiment unoccupied [3]. In this respect increased desktop immersion, while maintaining a degree of real world awareness, is desirable.

Two approaches exist for desktop immersion, either create a personal 'enhanced reality desk space' using a look through display or create a physical desk built around advanced interface technologies. An example of the former enhanced reality is provided by 'Windows on the world' [14]. Perhaps it is obvious to suggest that wherever we use a personal computer interactively within a task there may be times when the display would be better placed **within** our view than on a monitor **in** our view. In 'Windows on the world' the user wears a look-through display, which is tracked, and the display indexes into an X windows 'virtual desktop' bitmap. As the user moves, the display is updated to a different part of the X windows workspace. This effectively places the user inside a display space that is mapped on to part of a surrounding virtual sphere. Application windows can either be displayed at fixed positions within the virtual desk space, fixed within the user's field of view or attached to real world objects. Not only can annotations be attached to stationary objects but, if the object is tracked, the annotation window can be made to follow objects as they move.

BT SmartSpace is an example of a physical advanced interface — a novel integration of technologies, which gives the user enhanced visual and auditory immersion. SmartSpace, as shown in Fig 6, is designed as a chair-based workstation, which is able to replace the conventional combination of a desk, and associated personal computer. The current SmartSpace prototype provides a user interface to a performance personal computer, which is mounted remotely from the chair and connected via an umbilical cable. Visual display is provided by two distinct areas. The primary display and control surface is a high resolution (XGA) Pixel Vision touch screen which is mounted above the user's lap, a position which is highly intuitive. A screen-based keyboard, or OCR software, allows text to be entered. A secondary display is provided by a wrap around screen, which extends in an arc 120 degrees within the user's field of view. The screen is a laminate of glass and liquid crystal which is voltage switchable, allowing the normally transparent 'window' to be made opaque when the display is projected. Projection is provided by two video projectors mounted in the headrest.

The sense of visual immersion produced by such a wide screen is complemented via a transaural audio system, as described by Hollier et al [1], which allows sound sources to be positioned relative to the user. Interaction within applications can be via a conventional tracker ball, touch-screen mouse emulation, 3-D space mouse, or voice. While user trials have largely still to be undertaken the SmartSpace prototype has been demonstrated for high quality (life-size, eye-to-eye) video-conferencing, video telepresence (with physical chair movements driving the position of a remote camera) and the navigation of virtual environments.

Fig 6 The BT SmartSpace.

3.4 *VisionDome* ™

As described previously most telepresence technologies are aimed at single users and ignore the fact that tasks are often undertaken by groups of people. The 'VisionDome™,[1] [15], developed by Alternate Realities Corporation (ARC), attempts to address this problem by creating an immersive environment for a group of people. The main advantage of the dome is that viewers do not have to wear inhibiting hardware.

BT has been collaborating with ARC for the last two years on the development of the VisionDome. Much of the work has concentrated on gaining a greater understanding of how to create applications that give the viewer a sense of immersion. Current research is concentrating on how this type of environment can be used to provide an 'enhanced' videoconferencing environment. The large screen enables live video images and real-time computer graphics to be displayed at the same time. This will enable face-to-face videoconferencing with the users being able to view and manipulate a shared computer-generated model.

[1] VisionDome is a registered trademark of Alternate Realities Corporation.

Technical background

The idea of viewing images within a dome is not new. Cyclorama panoramic paintings were first created in the 1700s, to depict historic events and modern planetariums were opened in the 1920s. The VisionDome attempts to take this one step further by giving the audience the ability to interact with a 3D world, creating a walk-in VR experience.

The VisionDome, as illustrated in Fig 7, is a hemispherical projected digital display system. A central projector unit projects on to the tilted hemisphere of the dome creating a 360° by 180° image. The projector uses a hemispherical lens that matches the curvature of the dome surface. When coupled with spherical rendered images the projected scene appears undistorted to the viewer. The system is capable of projecting real-time computer-generated graphics, high-definition TV (HDTV) video images, and live video camera images. The advantage of the dome is that it gives the participants the experience of life-size 3-D models without having to wear inhibiting hardware. Linked with compelling audio, the audience can be temporarily transported into a virtual world.

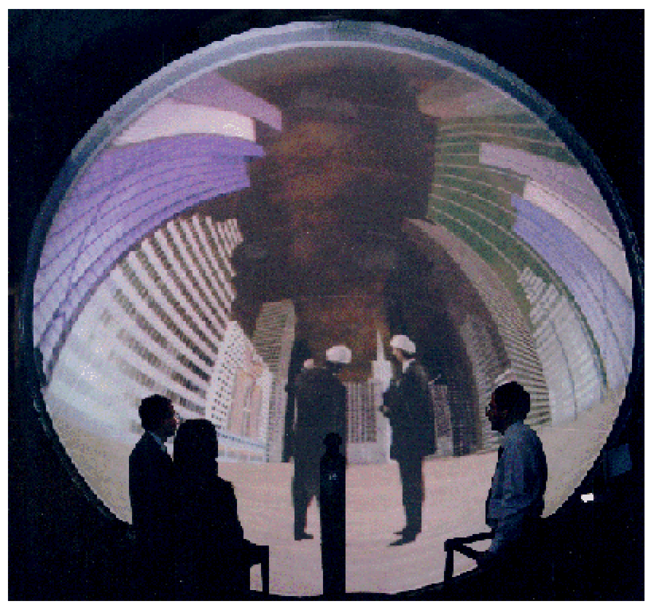

Fig 7 Demonstration of an architectural review meeting inside the VisionDome.

User immersion is achieved by projecting an image that is greater than the viewer's field of view. In doing so the viewer loses their normal depth queues, such as framing of the image by the edge of the screen, and, if the content is correct, can see beyond the surface of the screen. This illusion gives the sense of 3-D to the objects projected on to the screen. The dome itself allows freedom of angular motion (head motion), so that the viewer can turn their head slightly, up and down or left and right and still have their field of view occupied by the image [16].

Content creation

Little support currently exists for spherical rendering and hemispherical projection. Projecting a flat plane results in the image being ‘stretched’ across the surface and this appears distorted and unnatural to the eye. To create the correct spherical perspective that matches our spatial perception images have to be distorted before projection.

For this development, content has been created using 3-D computer animation tools. Each frame of a scene is rendered as sequential images. These images are transferred on to videotape that can then be played back on the dome. To give sufficient resolution on the VisionDome such that the image does not appear blurred, HDTV equipment is used. HDTV has a resolution of 1920 vertical by 1035 horizontal lines giving an aspect ratio of 16:9. The VisionDome screen is effectively a circle with an aspect ratio of 1:1. Spherical images are created, as in Fig 8, for the dome with an aspect ratio of 1035 by 1035 lines.

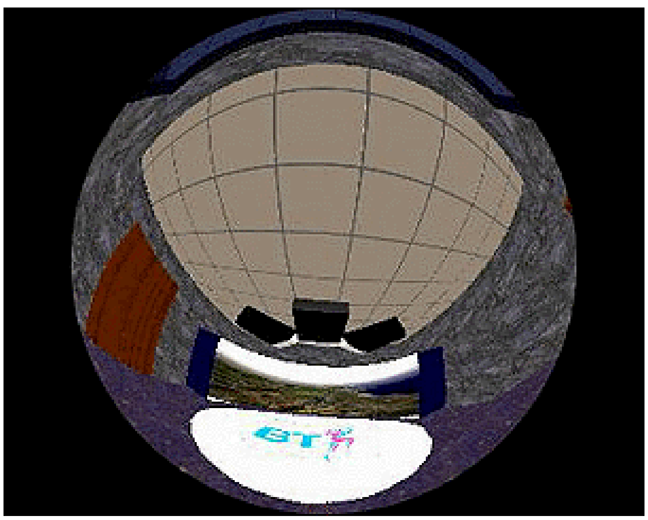

Fig 8 Spherical image.

To create the spherical image an ‘anamorphic’ lens is placed in front of the camera. The anamorphic lens allows a greater field of view to be captured in a single frame. To create the anamorphic lens in a 3-D computer animation package, a reflective hemisphere matching the shape of the projection lens is placed in front of the virtual camera. Using a technique called ray tracing the hemisphere reflects the scene into the camera. Ray tracing is computationally intensive — coupled with HDTV resolution, single images can take several hours to render. The three-minute animation shown at Innovation 97 at BT Laboratories took approximately four months to render on two Silicon Graphics (SGi) high-end workstations.

Real-time graphics enables the audience to interact with an application giving a pseudo-virtual environment. The graphics are distorted before viewing on the VisionDome, by using a 3-D transform on the vertices in the model. This transform has the same result as an anamorphic distortion. ARC have produced a modified OpenGL library for an SGi workstation that performs the transformations. OpenGL is SGi’s standard graphical library, which is utilised by a number of current VR applications, which could therefore be used on the dome.

The second main problem with the real-time graphics is referred to as ‘object subdivision’. This causes distortion of large objects that have a low number of vertex points. Consider the simple example in Fig 9, where a straight line is to be transformed. In the left image just the end-points have been transformed, with the result that when the straight line is rendered on to the dome it will be badly distorted. The longer the line, the worse the distortion becomes. To correct this distortion, the object can be broken up into smaller shapes ensuring a more faithful transformation of each component part. This is shown for the straight line in the right image.

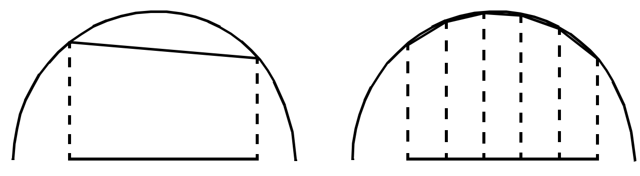

Fig 9 Distortion of large objects (left) and with object sub-division (right).

Distorting the graphics in software results in a degradation in performance of the machine. This has limited the complexity of real-time models on the VisionDome. Current developments by ARC have concentrated on optimising their libraries to utilise the parallel processing available of an SGi workstation.

As these types of projection systems become more common, content creation will become easier, with support for spherical projection being moved from software into hardware.

4. Virtual collaborative working

Effective collaboration in a computer-mediated environment demands an intuitive interface with the ability of having a sense of perceptive coupling with members of the shared environment [17]. The technologies described above open up the possibility for collaborative working. Semi-immersive display systems enable several video windows to be displayed at the same time, giving face-to-face video-conferencing with the ability to visualise data. However, in multi-user environments such as the VisionDome issues over mediation and control between local participants need to be addressed.

Creating an effective human interface to ever-increasing volumes of complex information is a critical challenge. People will be able to interact with data in a way that is natural and implicit, without needing special procedures or tools, thus generating the need for computers to understand and naturally interact with emotion [18].

Creating the right environments and infrastructure for these possibilities to be realised will take the integration of features from a number of technologies, forming a broad-band network infrastructure supporting transfer of data from a number of different sources — live video, video servers, and data servers.

Ranges of activities have been envisaged that may be carried out in such environments. Imagine, for example, a shared space [19] in which:

- the public, planners and politicians could walk through a proposed urban development, experiencing the environmental impact,
- engineers from around the globe could meet to review a virtual product design, exploring options in form and function,
- military commanders or commercial managers could be immersed in scenarios and information, collaborating on complex, time-critical decisions,
- scientists could travel through their data, interacting in real-time with the underlying instruments or experiments,
- students could be transported in time and space, collaborating with tutors and colleagues in an unfamiliar environment.

Undoubtedly collaborative spaces offer significant opportunities in product design, development and testing to display life-size images with an appropriate sense of perspective. Developers could use the environment linked to real-time computer-generated graphics to develop and understand new products. By projecting live or pre-recorded video into the space, particularly into a dome or large wrap-around screen, a compelling sense of immersion within the environment can be created. Telepresence applications could include remote real-time projection of sporting events and concerts, immersive videoconferencing, and re-creation of remote or environmentally hostile locations.

Virtual environments will have a significant impact on both education and entertainment. But these two areas may well migrate together into 'edutainment'. Children could visit anywhere on earth; the present, the past and maybe even representations of the future. A class could be immersed in an informative and entertaining manner that they would be unlikely to forget. Not only would the events or images be viewed at the correct scale, but such environments offer the interaction essential to effective learning.

4.1 *Differences between HMDs and projected display systems*

Head-mounted displays give a high degree of immersion within a virtual environment, but are only accessible to a single user. An immersive spatialised display is for a group of people experiencing the same information at the same time while having some feeling of immersion. A major advantage of a projected immersive display is that it can be more convenient and easier to use.

A simple analogy would be the difference between a motorbike and a car. The motorbike offers a single viewer an exhilarating experience through a limited view of the world, i.e. their helmet visor. The car can contain several people with a single driver, who is responsible for the direction, etc. Each person in the car has a large viewing area, the windscreen, which can be obscured by others. One does not need any specialised training to be a passenger in a car, whereas a complete novice cannot be expected to get on to a bike and be able to drive it safely or effectively. It could be argued that the car is safer and more comfortable, whereas a motorbike is more exhilarating and closer to the elements, giving better feedback to the user.

4.2 *Network Futures*

Underpinning collaborative virtual environments is the interconnecting network. The network has to support both connectionless data traffic and connection-oriented speech and video. At BT Laboratories an experimental network, 'The Futures Test Bed' [20], has enabled the testing of collaborative environments unhindered by bandwidth constraints.

Other advances in network technology [21] have seen the development of asymmetric connections over copper wire. Asymmetric connections enable a high bandwidth connection in one direction with lower bandwidth control information being sent in the other. This type of connection is suitable for video-on-demand applications and may be appropriate for CVEs with a virtual world rendered on a central server distributed to remote users. Asymmetric digital subscriber loop (ADSL) technology is expected to deliver approximately an 8-Mbit/s channel. A hybrid version VADSL using copper/fibre connection is predicted to offer channels in the range of 25 Mbit/s to 51 Mbit/s.

5. Conclusions

This paper has introduced and defined media environments, a collection of interfaces in which real and virtual spaces are mixed. Media environments can be classified as one form of enhanced reality, based around immersive physical spaces enhanced for effective collaborative activities. Current research is directed at three forms of enhanced spaces — immersive projected displays, interactive video environments, and immersive desktop. While HMD and desktop VR facilitates many collaborative tasks, the synthesis of real and virtual realities within a life-size environment offers distinct advantages within other applications. The rationale is to develop immersive environments, such as the VisionDome or IVE, which support more than a single user. Developments to date indicate that media environments provide an effective interactive interface within teleconferencing and collaborative visualisations. In the future it is envisaged that networked media environments will allow remote groups of people, and individuals, to communicate in many novel and intuitive ways.

Acknowledgements

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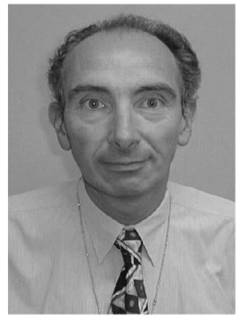

Peter Lawrence joined BT as an apprentice, gaining an HNC in Electronic Engineering. At BT Laboratories he worked on the development of filtering systems and digital multiplexing equipment for a trunk waveguide system. Subsequently he developed multiparty audioconferencing systems for both private and dial-up circuits. Following this, he worked on a mains-borne communications system for remote control of equipment, and then led the development of a network transmission performance analyser for measuring the speech quality of telephone connections. In 1990 he became head of a team developing speech performance instrumentation such as a digital telephone tester and a remote noise recorder. He now manages the Media Environments project looking predominantly at various aspects of virtual environments. He is an associate member of the IEE.

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SPHERICAL IMAGE REPRESENTATION AND DISPLAY: A NEW PARADIGM FOR COMPUTER GRAPHICS

Ed Lantz

Our visual senses are flooded with graphical representations of both real and imaginary scenes. Graphical representation has progressed from early petroglyphs to artwork, printed media, photography, cinema, television, and most recently, computer graphics and networked communications. These media are a major source of visual stimulation for our edification and enjoyment. There exists one common denominator with virtually all popular forms of graphical representation: They are displayed on a flat view plane. As Michael Naimark points out in his Realspace Imaging taxonomy, monoscopic imaging of a flat plane is the equivalent of looking through a viewing window with a single stationary eye [Naimark 91]. Since we cannot poke our head through the window, we are limited to a field of view of less than 180°. Despite the problems associated with representing three-dimensional space on a plane [Barbour 91] we have been driven by the limitations of our technologies.

Throughout history, there have been those who recognized the shortcomings of planar projection. Leonardo Da Vinci considered classical perspective projection to be "artificial," while the projection which best produces the image as beheld by the eye he called "Natural Perspective Projection." [Kelso 92] Da Vinci's Natural Perspective is simply the projection of the environment on to a spherical surface, with the view point fixed at the spherical origin. Unfortunately, the realization of spherical projection required the difficult task of producing graphics on a spherical surface.

With the more recent focus on immersive graphical representations, spherical perspective is being revisited. In fact, spherical representation is being touted by some cognitive scientists as a more robust model for spatial reasoning [del Pobil 93]. Applications of the spherical reference system in AI and robotics include navigation, collision detection, and the determination of three dimensional object characteristics including orientation, distance and size. The spherical paradigm is finding applications in graphical representation as evidenced by Apple's new QuickTime-VR™, Warp California's Virtual Television (VTV), and Artificial Reality's Vision Dome™. Spherical projection is also becoming more viable. Vehicle simulators routinely use domed projection surfaces, as do planetariums, omni film theaters, and most recently, entertainment simulators.

Unfortunately, the technology does not yet exist to fully immerse our visual senses within an interactive spherical viewing space which matches the visual resolution of the eye. In fact, were such a display technology to exist, today's best supercomputers would be hard pressed to render the required 300-400 million pixels at 120 frames per second needed to match our visual acuity with flicker-free stereoscopic imagery [Brown 92]. With 24-bit color, that would amount to nearly one trillion bits per second effective data rate. But the technology does exist, within certain constraints, to fool the eye into believing that one is immersed within just such a space. The purpose of this course is to present techniques for creating the illusion of presence within a domed environment.

FLAT SCREEN VIEWING

Television. Consider the visual experience of watching a television. We intellectually know that we are viewing a relatively small flat screen with limited resolution and other artifacts. No attempt is made to convince viewers that the images are actually present in their living room. A 66 cm (26-inch diagonal) television viewed at two meters only occupies an 11x15 degree field of view. This is just enough to stimulate the sensitive foveal region of the eye – provided our eyes remain fixed on the CRT. For an NTSC signal, the image formed on our retina has a resolution no better than three arc-minutes per line-pair, falling short of the one arc-minute average resolution of 20:20 vision.

Despite this, our imaginations are so engaged by the characters represented by this matrix of luminescent phosphor dots that we suspend our awareness of the medium and become captivated by the story line. Perceiving cartoon animations as “real” requires even more imagination, which our minds willingly provide. Even a narrative alone, as in old-time radio storytelling, is capable of invoking visualization and strong emotional identification. It seems that our minds are hungry for guided scenarios onto which we can project imaginary dramas. This strong need for identification with characters and a plot distracts our judgment of the medium itself [Allen 93].

Cinema. Cinema provides us with larger, clearer images. However, we rarely are provided with the illusion of true presence. At the cinema we are quite aware that we are sitting in a theater watching illusionary projections. The image of a car speeding towards us does not frighten us *per se*. There are too many cues which provide us with medium awareness, including editing technique (hard cuts, etc.), frame rate artifacts, scratches and dirt on the film, and the theater setting itself. But for the purpose of storytelling, at least, we only require a good narrative with recognizable characters with which we can identify [Smith 94]. A sense of presence is not required for emotional engagement.

Stereoscopic Displays. The introduction of stereoscopic 3D effects to cinema brought us closer to a sense of presence. Binocular depth cueing allows us to better depict volume, and is particularly effective for reproducing slow moving objects within close visual range (<10m). However, other artifacts are introduced which induce a high degree of medium awareness. While binocular disparity is exploited, no method of 3D projection effectively utilizes vergence as a depth cue. Our eyes therefore remain focused at a fixed distance. Tilting the head causes a loss of convergence. These and other factors produce eye strain in many such systems when viewed for extended periods, especially in earlier versions. Also, the 3D glasses themselves are somewhat cumbersome and limit the field of view.

These problems aside, we are still faced with a projection screen with finite extent. The screen edges often “give away” the 3D effect, giving us a visual cue that our eyes are not converged on the screen. Even head-mounted displays utilize a flat view plane. Also, the LCD devices used in HMD’s have poor optical resolution. While there is considerable research being performed to advance this and other shortcomings of HMD's, it will be a while before HMD's can produce a believable sense of presence.

Large Screen Cinema. Several 70mm film formats have taken hold over the years which offer greater image resolution than the standard 35mm formats. This permits a theater configuration with a larger field of view projection screen. For instance, in an IMAX® film theater, an eight-story high screen can occupy over 70° of our visual field. With steeply-pitched seating, the theater largely disappears and we are treated to greater visual immersion. Without stationary visual cues provided by the ambient setting of a theater (floors, walls, ceiling, other patrons), our minds are free to really believe that we are on a roller coaster, or flying over the Grand Canyon.

In fact, many large screen effects are not appreciably enhanced by stereoscopic displays. Stereopsis looses importance as a depth cue for rapidly moving objects [Murray 94], or for objects with a distance of approximately 17 meters [Rolfe 86]. Motion parallax visible in moving scenery takes the place of motion parallax due to head motion. Viewers are forced to move their head and eyes to track objects across the large field of view, giving a greater sense of presence. Also, the phenomenon of optic flow across the peripheral vision reinforces motion cues.

Rectilinear Immersion. Even a flat screen of infinite extent only provides a 180° field of view. To create greater immersion, it is a natural extension to surround the viewer with more than one screen. A recent example is the CAVE, first demonstrated at SIGGRAPH 92 by the University of Illinois, Chicago [Cruz-Neira 93]. The cave essentially uses a cube as an approximation of a sphere. High-resolution stereoscopic video, refreshed at 120 Hz, is projected onto three walls and the floor of a cubic space. Since the primary user wears a head-tracker, the planar perspective transformations are adjusted in realtime to achieve orthoscopic image reconstruction. This minimizes image discontinuities at the corners where projection surfaces meet, at least for the one person wearing the head tracker. The result is an immersive display with far greater resolution than a head-mounted display. The CAVE has become a viable VR research tool, as evidenced by its popularity at SIGGRAPH 94.

HEMISPHERIC DISPLAYS

A domed environment is the ultimate in immersive, walk-in displays [Heilig 55]. A spherical projection surface is free of discontinuities and can potentially surround the viewer with a 360° field of view. In theaters where viewers are seated unidirectionally, a hemispheric projection surface approaches full retinal stimulation, allowing for appreciable eye and head motion. Presently there are three areas of technology which must be advanced to implement an interactive, domed projection theater: projection systems, image generation hardware and software, and domed screens.

Projection Systems. To fill a hemisphere with eye-limited resolution would require about 200 million pixels. Even the world's largest film format (15-perf, 70mm) used by IMAX® DOME cannot approach the required 14,000 lines of resolution. However, the impact of full immersion seems to make up for the lack of spatial resolution. While the IMAX® format does provide the highest resolution near-hemispheric full-motion graphics presently available, film is not an interactive medium. Audience feedback devices have recently been demonstrated which would allow an entire theater to become engaged in real-time interaction with the show content. The future will demand the real-time flexibility afforded by video projection.

Spherical video projection is presently employed in vehicle simulators. For instance, a tactical flight simulator system demonstrated at the Air Force's Human Resources Laboratory in Arizona utilizes six General Electric light-valve video projectors which are mosaicked together on a dome [Reno 89]. This system demonstrated an average of 7 arc minutes per line pair resolution over a hyperhemispherical high-gain surface. Since the limiting resolution of the eye is about 1 arc minute, a higher resolution Area of Interest (AOI) projector is servo linked to a head tracker on the pilots helmet, providing a high-resolution image inset against the background. This and similar systems, while expensive, have demonstrated the feasibility of full-dome video imagery.

Image Generation. Flight simulator systems require, by necessity, realtime interactive 3D graphics engines, or Image Generators (IG's). For domed simulators, wide-angle background images demand multiple IG channels. Each channel must be rendered using the appropriate view angle, warped for off-axis spherical projection, and soft-edge masked for seamless mosaicking. These real-time requirements are quite demanding of current IG engines. While IG hardware continues to advance at a rapid pace, software algorithms must also be developed for spherical perspective transformation, rendering, and projector mapping.

Many new perceptual effects are possible with a true spherical perspective transformation. For instance, the view point can be pulled from the center of the view sphere to create the spherical equivalent of a zoom lens. However, published research in spherical perspective and rendering algorithms seems to have ended about ten years ago [Fetter 84]. The paradigm shift from the view plane to the view sphere, along with the associated hardware and software developments, will likely be a slow process.

Domed Screens. Consider what happens when a projected image scatters off the diffuse surface of a hemispheric screen. Assuming Lambertian scattering, some of the reflected light strikes the floor, walls, and seating area while the rest lands back on the dome. Scattered light striking the dome is free to reflect multiple times, subject to some attenuation upon each successive reflection. This cross-dome scatter can seriously degrade the contrast of domed projections by "washing out" the darker areas of an image.

In domed theaters, present methods of dealing with cross-dome scatter involve reducing the screen reflectivity with spectrally neutral gray paint. Since cross-scattered light is subject to two (or more) reflections, it suffers greater attenuation in proportion to the perceived image which is attenuated by the surface reflectivity only once. Image contrast ratio due to scattered light can be expressed as

$$Cr = \frac{Li-Ls}{Ls}$$

where Li is the image luminance and Ls is the luminance of the scattered light. Decreasing reflectivity R causes higher order reflection terms within Ls to drop more rapidly than the first order image reflection Li, resulting in improved contrast (i.e. $Li \propto R$, $Ls \propto \sum R^n$ for $n \geq 2$). In practice, the improvement of Cr for a lower R will depend heavily on the location and features of the projected images, with larger image sizes generally benefiting more. This is why omni film theaters use much lower reflectivities than planetariums [Skolnick 95].

The obvious disadvantage of this approach is that the image luminance Li is reduced in proportion to R. We trade off image brightness for increased contrast, since there are obvious limits to how bright an image can be made. Omni film theaters are often faced with a choice between a picture which is bright and washed out or gray and dynamic. Omni filmmakers have learned to compensate for the media by avoiding scenes with large areas of high brightness or poor contrast.

Another solution exists for increasing contrast of domed projections. Simulator systems employ screens with a specular reflectance component in addition to diffuse reflectance. The greater the specular lobe, the greater the screen "gain" relative to a Lambertian surface. For a domed screen, the result is that more light is scattered towards the center of the theater, and less is scattered back onto the dome. In tactical aircraft simulators, the pilot is confined to a small volume near the geometric center of the dome. This allows very high dome gains to be used. However, in a theater, a reduction in viewing volume means less seating area - usually not a good idea. Also, domes with gain complicate multi-projector mosaicking since image intensity is a function of projection angle and viewing position [Skolnick 94]. IMAX® has experimented with small screen gains in their IMAX SOLIDO® theaters with reportedly good success [Arthur 92]. However, without further developments, image contrast of domed projection will never match that of flat screen projection.

PLANETARIA

In 1926 the first planetarium opened to the public in Munich, Germany. A brainstorm of Carl Zeiss' engineering team, these domed theaters were designed for one purpose - to recreate the night sky. Early planetariums were expensive monuments built to honor their wealthy philanthropists. After the space race began in the late 1950's, more affordable planetaria were constructed all over the U.S. as educational classrooms for astronomy and space science.

Today's planetarium/classrooms are finding it difficult to compete for educational funding. Astronomy education is performed very effectively using classroom computers, many of which can be purchased for the cost of a planetarium. A new generation of planetaria are emerging which are pioneering non-traditional use of the planetarium as an immersive, multi-sensory theater for entertainment and "edutainment."

Advanced Planetaria. These modern planetarium theaters represent the most complex and elaborate public-access graphic display systems in use today [Rider 94]. Advanced planetaria are hemispheric theaters which utilize a multitude of projection devices, including raster video, hemispheric calligraphic video, laser graphics, large-format film, multi-image, and specialized opto-mechanical projectors. When skillfully applied, the strengths of each projection system is exploited to create the illusion of presence. Within certain limitations, individual projection sources can be orchestrated as if they were a single, high resolution projection source.

Production of graphics for hemispheric theaters is more demanding than for film or video alone. Factors such as geometric distortion, cross-dome scatter, projector mosaicking (or tiling), and limited projection field-of-view must be considered. Accurate representation of planetary motion, and the seamless integration of many separate projection devices and graphics formats presents many technical challenges in real-time synchronization and control, and image registration.

Planetaria vs. Simulators and Omni Theaters. Planetaria have certain advantages over other users of domed environments including vehicle simulators and omni film theaters. Simulators are required to produce graphics which are generated in realtime, necessitating powerful graphics engines with lower quality rendering. The latest planetarium video projection systems utilize component level laser video disc technology such as the Sony CRV™ format with interpolation line doubling for playback. Images can therefore be rendered in non-realtime with much greater detail, but still retain some interactive qualities due to the rapid laser disc access times. Also, simulators require user inputs to be directly linked to physical models which determine and limit image characteristics such as the motion path. Planetarium shows are carefully scripted in advance, allowing the layering of complex effects sequences. These sequences or show segments can still be triggered in realtime, or used to enhance lower resolution realtime computer graphics projections.

Both simulators and omni theaters attempt to reproduce daytime outdoor scenery which causes the greatest contrast washout due to cross-dome scatter. Much of the imagery in planetariums is projected against a black background, often with stars. The low ambient light environment prevents screen washout, provides a greater illusion of depth, and tends to hide any seams or imperfections in the projection surface as well as hiding the theater itself. Also, the visual acuity of the eye is reduced at low luminance levels, thereby reducing the impact of limited projector resolution. Since objects are projected against black, insetting an image from a high-resolution, small field of view projection source is easily accomplished. Add motion control to this limited FOV projector and you have the ability to translate the image completely around the dome. This technique is used in simulators to project targets, but requires realtime masking of the background image to inset the higher resolution target image. Only the brightest stars in a planetarium will "punch through" a crisp video image, eliminating the need for masking in many cases.

Lessons from Planetaria. Planetaria have 70 years of experience in hemispheric projection techniques. They have taught us how to control and synchronize many complex projection systems to produce high apparent resolution over a domed screen. The most believable graphical representation of reality is probably found in the planetarium starfield. Modern optomechanical star projectors produce a visual resolution over the dome which can exceed the resolution of the eye with up to 28,000 stars. Planetaria have also brought us dazzling laser light shows, and Evans & Sutherland's Digistar®, the world's first hemispheric computer graphics projector.

Planetaria also teach us what not to do in a dome. Hemispheric theaters should be designed to minimize visual cues that remind us that we are in a theater. This includes the elimination of visible seams in the dome surface, noise from projection equipment, obtrusive star projectors and control consoles (which once *were* a special effect in themselves), and brightly colored furnishings. Many contemporary planetaria continue to demonstrate false visual cues which invoke medium awareness. These include raster lines, switching noise, and tape dropouts in video images, visibility of projector dark frames, free-floating images clipped by the projector frame, intense image flicker, poor image focus, and image motion control artifacts such as jitter and backlash. In all fairness to planetarians, myself included, it is often costly and time consuming to achieve the perfect illusion of presence.

APPLICATIONS IN VIRTUAL REALITY

The success of virtual reality hinges on techniques which produce a greater sense of visual immersion. Spatial reasoning requires the creation and maintenance of cognitive maps, or a spatial awareness of the environment [del Pobil 93]. We refine these cognitive maps as we navigate through our virtual environment and manipulate objects therein. Navigation or travel over terrain involves a phenomenon called optical flow by flight simulation researchers [Richards 82]. Optic flow is the movement of objects or terrain past our central fovial vision and out to the edges of our peripheral vision. It has been found that peripheral optic flow is crucial for high performance in visually demanding tasks such as tactical aircraft combat [Rolfe 86]. Wide-angle displays are therefore important in creating the sense of presence and spatial awareness sought after by VR developers.

Walk-In Immersive Displays. Head-mounted displays (HMD's) are a welcome departure from ordinary planar graphical representation, although they still rely on orthostereoscopic reproduction using flat LCD panels. Very wide field-of-view HMD's are currently in development [Kaiser 95]. However, walk-in immersive displays offer several advantages over HMD technologies including group viewing and interaction, wide field of view, and high resolution without restrictive headgear. This was recognized by the developers of the CAVE [Cruz-Neira 93] who opted for immersion with the more mature flat screen technology. However, images reproduced on a domed screen provide a spherical perspective which best matches our spatial perception. Within the VR community, spherical displays are still largely ignored due to their lack of resolution and expense. However, future spherical projection displays could become the norm for common VR systems.

In fact, one such system is now being introduced into the marketplace. Artificial Reality, a spin-off from the North Carolina Supercomputing Center, has just introduced the Vision Dome, a hemispheric alternative to the flat screen monitor [Bennett 95]. Initially designed for small to medium-sized domes (< 8 meters), their system accepts output from a computer workstation, PC, or standard video and processes it for projection on a tilted hemispheric screen. The single-projector light-valve display is full color, raster-based and is capable of stereoscopic projection. Real-world applications envisioned for Vision Dome include network management, marketing, museums, and air traffic control displays. With further advancements in video display technology, spherical image generation hardware and software, and domed screens, such systems could dominate the VR marketplace.

USING THE ILLUSION OF PRESENCE

Most of the efforts in VR and display systems revolve around the technology for creating a greater illusion of presence. Let us assume that we have a display system capable of creating the visual illusion of presence. What does it offer us that cannot be provided by existing mediums?

Recall the earlier discussion on television. Television could be described as linear narrative-based storytelling supplemented with fovial stimulation. The narrative seems to take precedence, while the limited visual element is used to enhance the narrative, set the scenes, and control the focus of our attention. Viewing television involves visual and kinesthetic passivity. We also remain comfortably detached from the action, with the obvious awareness that we are watching a television.

<u>Presence</u> <u>Demands</u> <u>Work</u>. Unlike television, immersive displays require active viewing, demanding content-dependent head and eye movement. Viewer fatigue is common in omni film theaters and planetariums, which explains why these programs are around one half hour in

length. VR systems induce even greater fatigue and require extensive kinesthetic involvement. Immersive displays also make it more difficult to remain safely detached. We are more likely to respond to a stimuli as if it is actually present. We therefore are subject to a greater level of stress, including involuntary fear, the sense of falling, and motion sickness. The producer thus has greater command over the participant's attention and psychological experience.

Visual Storytelling. Immersive displays will bring us visual-based storytelling supplemented with narrative. As pointed out by Mort Heilig, this is more in proportion to our natural perception (70% visual, 20% auditory, 5% olfactory, 4% tactile and 1% taste) [Heilig 55]. Visual-based storytelling will allow the creation of many new storytelling devices which are not yet possible or sufficiently effective with present visual systems. For instance, many people engage in dangerous sports and activities because of the thrill it produces. Perhaps these experiences can be recreated with sufficient visual realism to invoke the same physiological response. Also, VR systems driven by artificial intelligence technology will allow interaction with cognitive-emotional agents to create drama [Bates 92].

Consider our inner experience of thoughts, emotions, and sensations. Our subjective experience is very personal and difficult to convey semantically. This is the domain of poets, who paint images and feelings with words. But our inner experience remains largely visual. Artists can convey through visual media inner realities which cannot be spoken. Traditionally, films which contain only the artistic element, without narrative, do not hold the viewer's attention for long and are not popular. However, the illusion of immersion in an artistic environment with matching aural/musical stimulation could create a moving experience which transcends narrative. Laser light shows and music videos are perhaps the precursors of this new art form.

Another possible storytelling device is to depict archetypes representing the character's inner conflict or imagination. In other words, we would crawl into the character's head. The immersive display allows room for the simultaneous depiction of our external reality and our inner archetypes, memories, and internal imaging.

SUMMARY

Technology is emerging which will allow computer graphics to fully exploit the spherical perspective and display paradigm. The course notes which follow present the latest techniques for the generation and display of spherical graphics within existing hemispheric environments including planetaria, omni theaters, and simulators. Topics include the evolution of hemispheric theaters, technical overview of domed projection systems and environments, spherical perspective projections, and the use of hemispheric multi-image, film, video, and laser graphics to create the illusion of presence

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The Challenges of Creating Immersive Audio in Large Scale Virtual Environments

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Abstract

Three-dimensional film projection has been providing semi-immersive visual experiences to audiences for many years, and has been improving steadily since its inception. Video and graphic rendering technology is advancing at a rapid pace, allowing for higher quality virtual reality imaging and presentations. Has audio been able to advance at the same pace as its visual counterparts? Can today's audio production techniques and playback systems accurately reproduce immersive audio environments? Are these systems viable for a large-scale audience? This paper will examine the challenges of producing and recreating immersive audio for large-scale virtual environments.

0. Introduction

immer' sive *adj.* to be of a nature to cause one (person) to be immersed, entirely absorbed, involved deeply…

We hear in three dimensions. It's easy to confirm that we do because we can hear sounds all around our head and at varying distances. It's also easy to confirm that the perception of the three-dimensional (spatial) aspects of sound has been essential to our survival. Consider what could happen to you if you were crossing a busy street and your ears could not judge where the cars were coming from. Unless you had eyes all the way around your head you could be in trouble.

However, is the ability to hear sound in three dimensions essential for producing a viable virtual environment? Most people would argue yes; that to produce a good virtual environment you should try to replicate reality not only in the visual experience but in the aural experience as well. The irony of this is that most entertainment venues that advertise themselves as a virtual environment do not utilize three-dimensional sound systems. Let's take a look at the reasons why this might be.

1. Providing true three-dimensional audio to a large audience can be almost impossible and at the very least, expensive.

2. People have come to accept stereo and surround audio systems as being "immersive". There is no need to provide any other type of audio system.

3. Most people have never heard a three-dimensional audio system and do not know (or care) what they are missing.

It is important to note that once most people have listened to a good three-dimensional audio system, they are amazed at how much it can improve the overall entertainment experience.

Before we get into examining what is "immersive audio" or "three-dimensional" audio, what works and what does not, let's look at the basic audio systems.

1. The Basics

Since we are studying three-dimensional audio, we will review the basic audio systems in terms of geometrical dimensions.

Monophonic: The most basic of the audio systems is monophonic (mono). Mono is simply a single channel of audio information played back through a single loudspeaker. This type of system only provides the listener with a single "point" or "point source" of information with no spatial characteristics. {Fig. 1}

Stereophonic: Stereophonic (stereo) is not just adding a loudspeaker to a monophonic system. (That would be considered two-channel mono.) Stereo is actually recording an audio signal or "event" with two microphones, creating two channels of information, and playing them back through two loudspeakers. The distance between the two microphones while recording and the two loudspeakers during playback gives the sound spatial characteristics. The typical stereophonic playback system, with left and right loudspeakers, provides the listener with spatial information spread along a line in front of them. Stereo can therefore be considered a single dimension "sound scape". {Fig. 2}

Surround Sound: Surround sound systems take stereo a step further by producing multiple, single dimension "sound scapes". This is accomplished by taking both mono and stereo audio signals and playing them back through multiple loudspeakers. The typical surround sound system consists of left, center, right, left & right side and sometimes rear loudspeakers. Where stereo can be considered as a line of sound in front of the listener, surround can be considered a square of sound around them. To consider this in terms of dimensions, surround sound is a two-dimensional "sound scape". {Fig. 3}

Binaural: Binaural literally means "two ears" and describes how we hear, hopefully with both ears. Binaural recording and playback methods involve recording a pair of audio signals that represent as closely as possible the signals that would be present at the ears of a listener. This goal is often accomplished by placing small microphones at the ear positions of a mannequin's head. The mannequin head is then placed where a listener would stand or sit. Upon playback, the pair of recorded signals are delivered individually to the listener's ears, usually through headphones. In this way, the binaural recording and headphone playback replicate what we would have heard had we been standing or sitting where the mannequin was. Since we hear in three dimensions, a binaural recording and playback is considered a three-dimensional "sound scape". {Fig. 4}

Current audio systems tend to use one or a combination of the audio systems described above. They are the building blocks of almost all audio systems.

2. What Audio Systems Are Currently Being Used and How Effective Are They?

The most common of the so-called "immersive" playback systems are:

- Surround Sound
- "Non-standard" Surround Sound
- Binaural
- Combination Binaural / Surround Sound

In this section we will take a closer look at how each of these systems work and just how effective they are at immersing a large-scale audience in sound.

Surround Sound: As stated above, surround sound is a combination of mono and stereo audio signals played back through the traditional left, center, right, left and right surround loudspeaker arrangement.

Surround sound audio in a typical movie theater is created by a sound engineer who takes single audio "tracks" and mixes them together into a soundtrack while listening to it play back through a surround sound system. This mixing process is usually completed while the sound engineer is sitting in the theater itself. In essence, the sound engineer is making himself a part of the audience and is mixing the soundtrack in a way that he believes the audience will be most effectively "surrounded" by sound.

The problem with this technique is that the sound engineer mixes the audio while sitting in one seat, usually in the middle of the seating area. The soundtrack will sound best only in that seat and the few seats immediately around it, an area that is commonly called the "sweet spot".

Considering that surround sound is a two-dimensional square of sound that has been optimized for only one seat in the theater, it is not very effective in creating an immersive audio environment for the entire audience. In fact, if you ever sit in the back corner of a theater you will realize that you are missing quite a bit of the sound track because your ears will mostly be hearing the loudspeaker closest to you. {Fig. 5}

We also have to keep in mind that any loudspeaker-based system is dependent on room acoustics. If a room is not carefully designed from an architectural and acoustic stand point, the surround effect can fall apart completely.

Non-Standard Surround Sound: Non-standard surround sound is referred to as such because it utilizes more loudspeaker placements than the typical five-loudspeaker surround sound system.

A non-standard surround system will usually add rear and/or ceiling loudspeakers to the already existing left, right, center, left and right surround loudspeaker arrangement. The hope is that the rear and ceiling loudspeakers will add a more immersive quality to the standard surround system. What actually happens is that the audience can now hear audio above and behind them but only if they are sitting in the select seats which allow them to do so.

All the problems that exist with standard surround sound are present in a non-standard system. The only real benefit to this type of system is that it can support special visual or "atmospheric" effects that occur behind or above the audience. Even this can only be considered a benefit if the show's creator does not mind the audience being distracted away from the action occurring in front of them.

Binaural: Binaural systems, as mentioned earlier, utilize a mannequin head for recording and headphones for playback.

Much like surround sound, binaural recordings are sometimes created in the theater or other environment in which they will played back. Typically the binaural mannequin head is placed in one seat (usually in the center) while its microphones capture audio events as they occur around it. Though the recording will be three-dimensional in nature, it will only seem convincing when listened to from the seat the mannequin head was sitting in.

Binaural recordings can also be created artificially in a studio using a computer. The computer can take prerecorded audio and simulate the way in which a mannequin head would have recorded it.

Both ways of creating binaural recordings have potential problems in providing audio along with a visual presentation to a large audience.

Imagine sitting in the middle of a theater while a projected image of a giant flying insect is placed in the middle of a screen. While this image is being projected, the sound of a giant flying insect is being played back through your headphones and it sounds as if it is coming from right in front of your nose. Now, if you are sitting to the far right of the screen, the projected image will be seen to your left but the sound will still be coming from immediately in front of you. The location of the visuals and sound will not match. {Fig. 6}

Another downfall to binaural recordings is that since they are typically played back through headphones, the sound will follow the turning of your head. In the case of the projected insect, if you turn your head to the right the insect will still sound as if it is coming from in front of you even though the image will remain on the screen.

Finally, one of the biggest drawbacks in a headphone based audio system is the headphone itself. In a mass audience entertainment complex they are expensive to maintain and replace.

Combination Binaural / Surround Sound System: This type of system, as its name implies, utilizes both binaural and surround sound playback systems simultaneously. {Fig. 7}

Of all the different audio system configurations, a combination system can provide the most realistic three-dimensional audio environment for a large audience. By carefully choosing which sounds come from the surround loudspeakers and which ones are reproduced via headphones, most of the obstacles experienced in a separate surround or binaural system are alleviated. For example, only the sounds that are supposed to move with the head would be placed in the headphones and those sounds that need to be linked to a static visual (such as a film screen) will come from an associated loudspeaker. The use of the headphones can help mask the fact that a member of the audience is not sitting in the "sweet spot."

An interesting phenomenon that can be produced from a combination system is the ability to produce sound moving from one dimension to another. A sound can move around the room, via the surround loudspeaker system. Then the sound can move from the loudspeakers to the headphones and back again, producing a depth to the sound or a to-and-fro movement.

This system is not perfect in that there are still the "sweet spot" and acoustic issues associated with the surround portion of the system. In addition, the audio tracks must be mixed and placed in the loudspeakers and headphones with surgical precision to produce the maximum effect. With this type of system there are also the headphone maintenance and replacement issues. This is especially true due to the fact that small, open ear headsets (such as those provided with portable stereo systems) must be used to allow sound from the loudspeakers to enter the ear.

All of the systems discussed in this paper so far are useful in terms of producing audio for various types of entertainment venues. However, we can see that they may not be effective in producing the truly immersive audio we should expect in a virtual environment, especially for a large audience.

Should we give up hope of ever being in a large entertainment venue with 200 of our closest friends, enjoying a 3-D system that immerses us in sound? Well, yes and no…

3. Hope For the Future (?)

I hesitate to use the words "new technology," it's almost an oxymoron. By the time we hear of some new technology it can actually be quite old. So, as I proceed into this next section, keep in mind that some of the technology being discussed has been researched for the last 20 years. For that reason I will carefully use the words "newer technology".

Newer technology is available that can alleviate some of the problems encountered in the audio systems currently being used. However, before we design or redesign entertainment venues to include these newer technologies we have to understand what their limitations are.

There are quite a few newer 3-D audio systems that are being researched and developed at this time, but for the sake of brevity we will look briefly at the two most prevalent (and I believe most promising) technologies. These are:

- Crosstalk Cancellation
- Dynamic Head Tracking Systems

Crosstalk Cancellation: To understand how a crosstalk cancellation system works we must first understand what crosstalk is and why we need to cancel it.

When we listen to a three-dimensional recording, such a binaural, it is played back over headphones to allow the left and right audio information to be precisely placed at the listeners' ears. Remember, the reason why binaural systems are considered three-dimensional is because the sound is recorded and played back directly at the ear, just as we would naturally hear it.

We discussed earlier the problems when using headphones; the sound can sometimes become disassociated with the visual presentation. This is not a desirable effect when the sound is supposed to be associated with a static visual such as a movie screen. We know that using loudspeakers allows the sound to be placed with the visual (screen) and that they are immune from head turning issues. What we need is a means to listen to binaural recordings over loudspeakers.

When listening to two loudspeakers there is a certain amount of audio information that travels from the left loudspeaker into the right ear and the right loudspeaker into the left ear. The sound from the left and right loudspeakers are literally "crossing" over into the right and left ears. Hence the name "crosstalk". There is no crosstalk when using headphones because it is impossible to get the sound from the left headphone into the right ear. {Fig. 8}

In a loudspeaker-based system, a three-dimensional audio signal would be distorted due to crosstalk incurred when the left and right information are no longer being delivered solely to the ear where it is supposed to go.

How then, can we deliver the correct three-dimensional audio signal to the correct ear using loudspeakers? If we know where the loudspeakers and the listener are located and the relationship between them, we can then calculate the distance the crosstalk signals travel (left audio signal traveling to the right ear and the right audio signal traveling to the left ear). We would then add the inverse of these crosstalk signals with the crosstalk signals themselves to cancel them out (remember from math class $-1 + 1 = 0$). This process is carried out by a device called a crosstalk canceler. {Fig. 9}

The drawback to using a crosstalk cancellation system is that the crosstalk calculations are based on the distance between the loudspeakers and only one listening position. Once again we have the problem of an audio system with a distinct sweet spot. Can this sweet spot be made large enough to hold a theater full of people? No. Each listener would have to have their own set of loudspeakers and a crosstalk canceler with calculations based on their location. With all these loudspeakers in a room it would be a cacophony! There is some hope though. Several companies are working on systems that will allow a small group of listeners the ability to sit in the sweet spot created by two or more loudspeakers.

Dynamic Head Tracking Systems: Dynamic head tracking is utilized with headphone based systems. As its name implies, a head tracking system "tracks" or follows the movement of the head.

To understand why we need a head tracking system, let's revisit our problem with headphones. They are great for recreating three-dimensional audio, but if you turn your head you will lose the relationship between a visual element and its associated audio.

A dynamic head tracking system allows a listener to turn their head and will adjust the "position" of the audio to compensate. We'll examine what comprises a dynamic head tracking system to better understand how it works.

A head tracking system is made up of a transmitter, a receiver, and a computer. The transmitter is a small device that is attached to the top of a pair of headphones. This transmitter sends out signals (data) to the receiver which, in turn relays these signals onto the computer. Within the computer is a software program and a series of digital signal processors which can determine the position of the listener's head based on the information sent from the transmitter. The computer then "repositions" the audio and sends it back to the headphones. {Fig 10}

As an example, we'll take another look at our flying insect from earlier in the paper. We had a problem with the sound of the flying insect following our head as we turned it, although the projected image of the flying insect remained on the screen. If we are using a head tracking system, when we turn our head to the right, the new head position is sent to the computer. The computer will then pan (move) the audio towards the left ear so that the location of the flying insect sound will remain constant. As you continue to turn your head left and right or nod up and down, the computer will continue to reposition the sound in your headphones so that it will always be perceived as coming from a constant location. {Fig. 11}

A binaural recording played back through a set of headphones with a dynamic head tracking system is about as close to replicating natural hearing as our current technology will allow us.

As with most audio systems though, it is not perfect. First of all, head tracking systems are very expensive, especially when you consider that you need one system per listener. Secondly, like all other computer-based systems, there is a certain amount of time lag created while the computer goes through a set of computations. This time lag is most noticeable when you are comparing a computer-simulated phenomenon to an actual physical phenomenon. Think about when you turn your head; what you hear will change immediately. With a dynamic head tracking system, when you turn your head it will take a certain amount of time for the computer to calculate your new position and give you feedback. This amount of time can be quite noticeable and very distracting.

4.0 Conclusions

There is a great deal more to explain about all of the systems mentioned in this paper, but I wanted to present the basic ideas without getting caught up in all the math and science. This paper has posed many of the challenges to reproducing immersive audio for a large-scale audience. What I hope has been revealed are some of the possible solutions to these challenges. I also hope that at least some of this paper is useful to you when considering what type of audio system to use.

Entertainment venues should always strive to stay on the cutting edge of technology in order to remain competitive. In that pursuit though, the limitations of technology must be acknowledged and understood for it to be used properly and successfully. The technologies being developed for three-dimensional audio provide us with exciting new possibilities for entertainment projects. These technologies should not be overlooked by anyone who hopes to remain competitive in the world of entertainment.

I would like to end this paper with a few parting thoughts and points to ponder.

- You will need to determine early on whether the audio (and visual) system will be helping to create a virtual environment or to recreate an actual environment.
- The audience will be more "forgiving" of audio reproduction in a virtual environment, especially one that is not trying to simulate reality. This is due to the lack of prior cues, or

memories, from which the audience has to compare it with.

- When recreating an actual environment, the audience will be more critical of the audio system. They will expect to hear information coming from not just all directions, but in all directions with exact placement.

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Biography

Linda Gedemer's interest in audio started with a love of music. As a child, she attended the Academy for Performing and Visual Arts in Chicago, Illinois where she studied classical piano and bassoon. After noticing that their daughter had dismantled and rebuilt most of the electronic devices in their house, Linda's parents suggested that she study engineering. With her parent's encouragement Linda decided to combine her love of music with that of electronics. She attended the University of Miami in Florida where she obtained a degree in Music Engineering Technology. Her professional career in the field of audiovisual system engineering has included projects for such prominent companies as Walt Disney Imagineering. Through her work at Disney and as an independent consultant, Linda has designed sophisticated media systems for many of the world's best-known exposition sites, museums, performance arenas, and theme parks. Linda is now a Senior Audiovisual Consultant with Arup Audio Visual, part of the international engineering firm of Ove Arup and Partners.

Figure 1
Monophonic: "Point" of Sound.

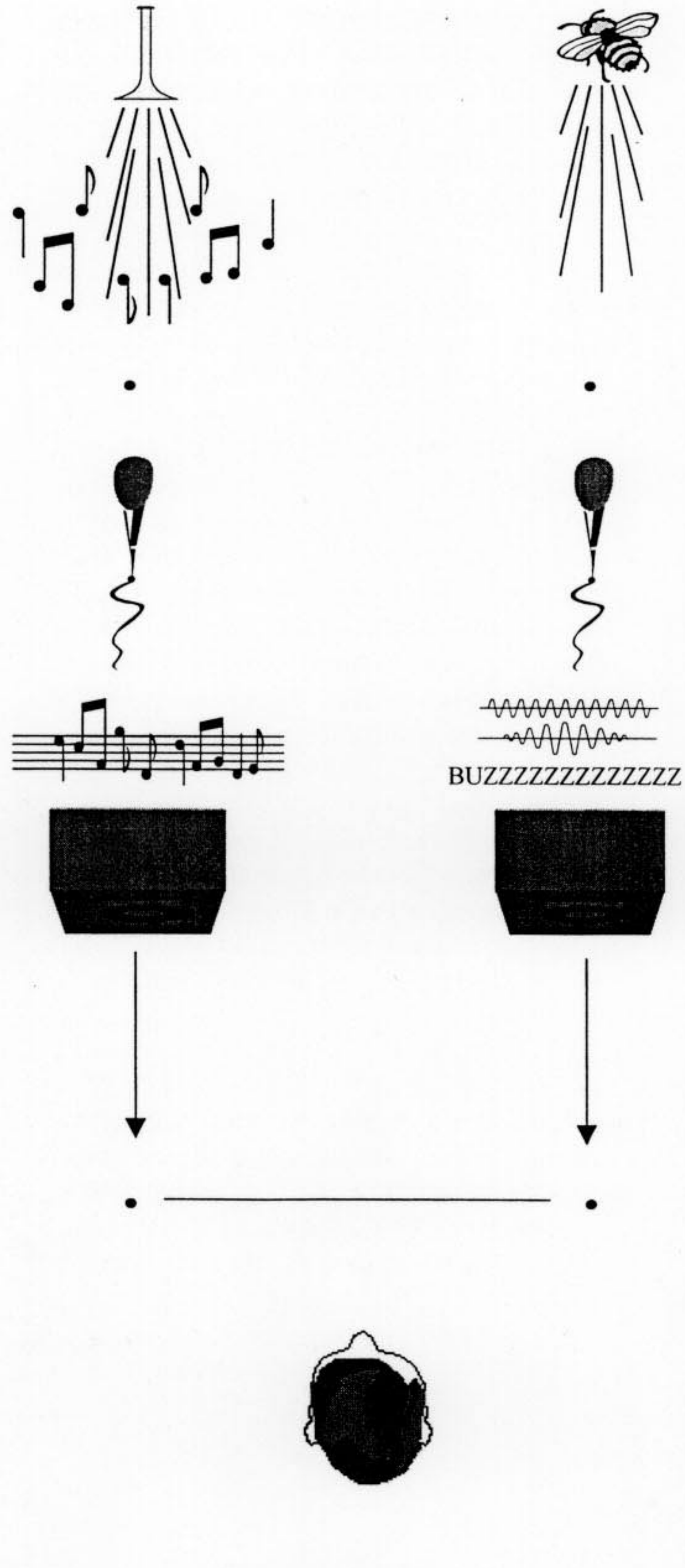

Figure 2
Stereophonic: "Line" of Sound.

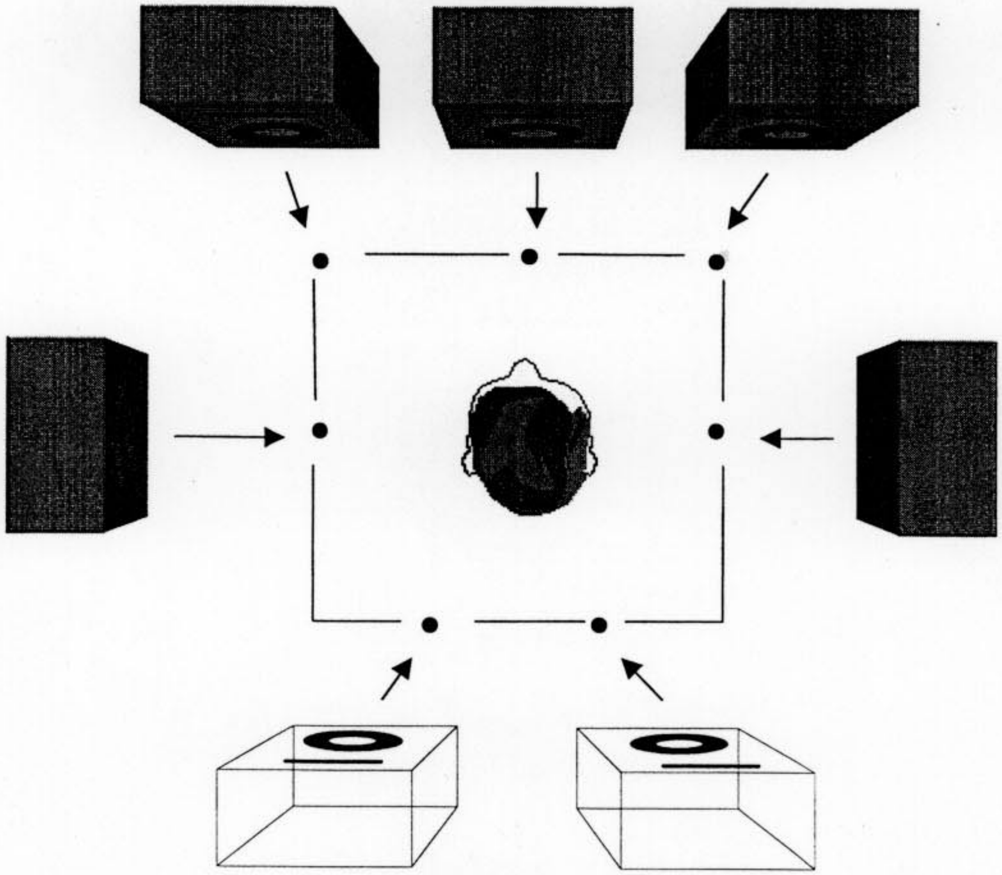

Figure 3
Surround Sound: "Square" of Sound.

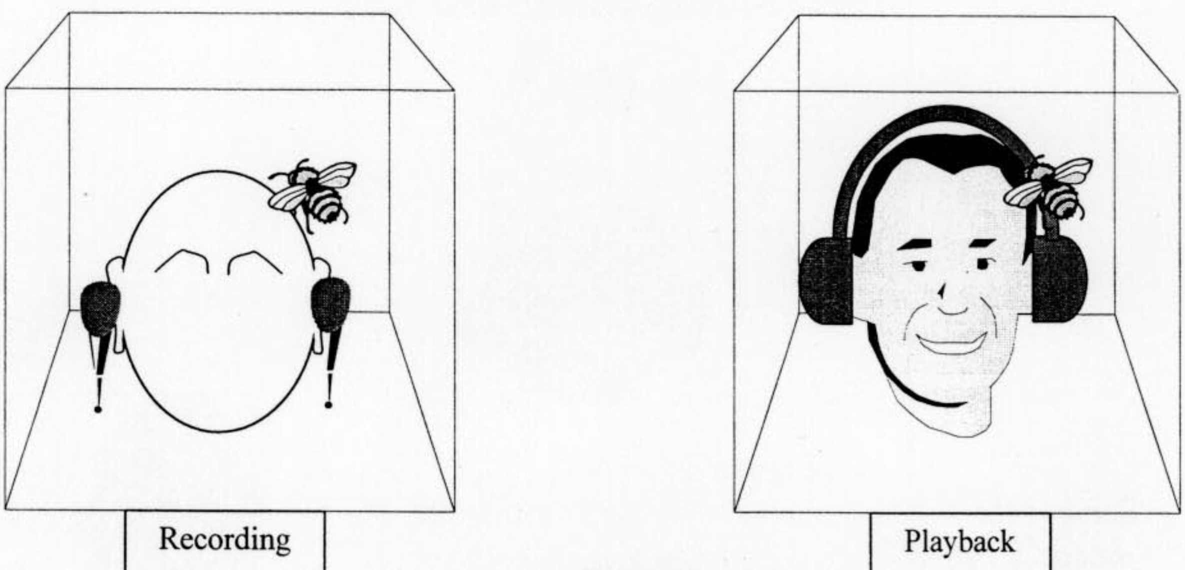

Figure 4
Binaural: Three-Dimensional Sound.

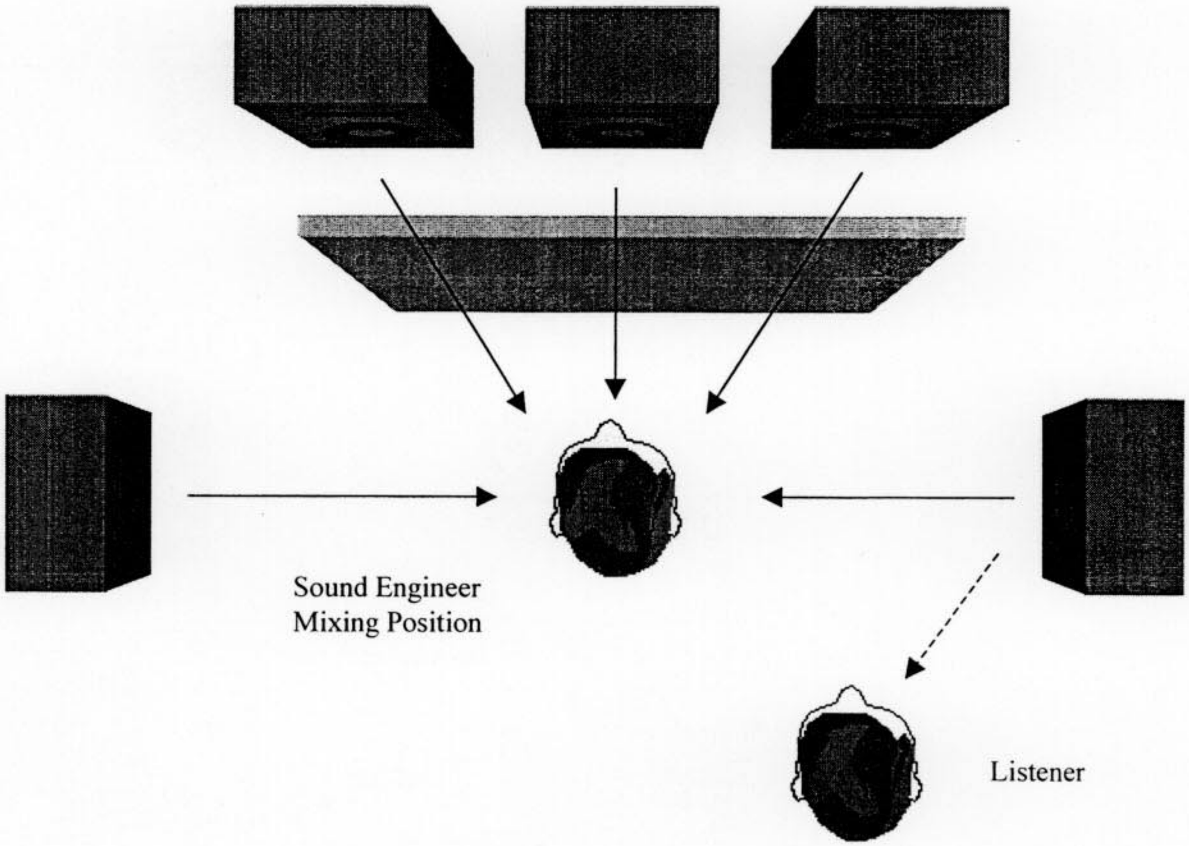

Figure 5
Surround Sound Loudspeaker Layout showing the Sound Engineer's Mixing Position. Notice the potential problem area for a listener.

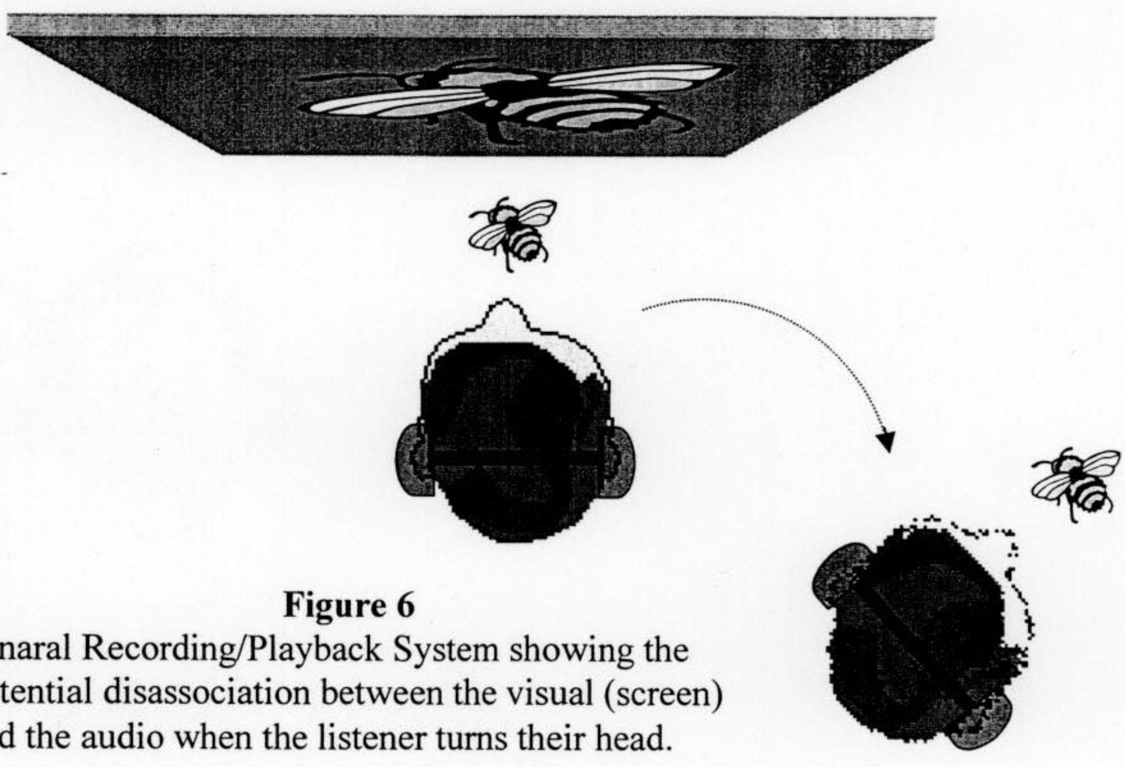

Figure 6
Binaral Recording/Playback System showing the potential disassociation between the visual (screen) and the audio when the listener turns their head.

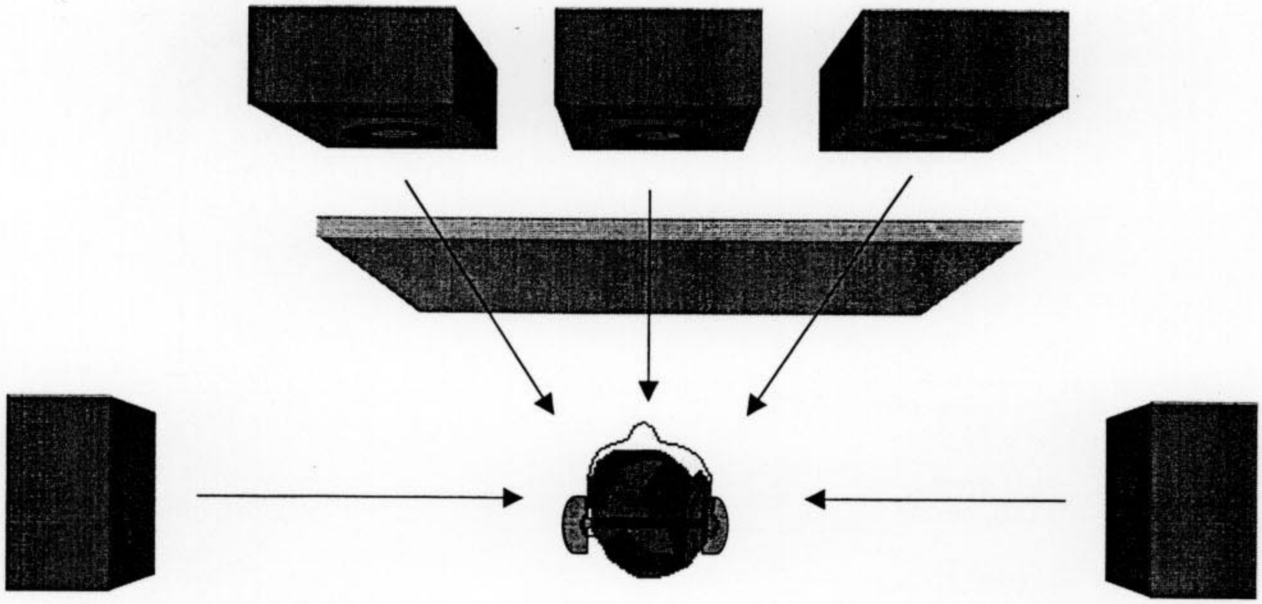

Figure 7
Typical Combination Binaural/Surround Sound System.

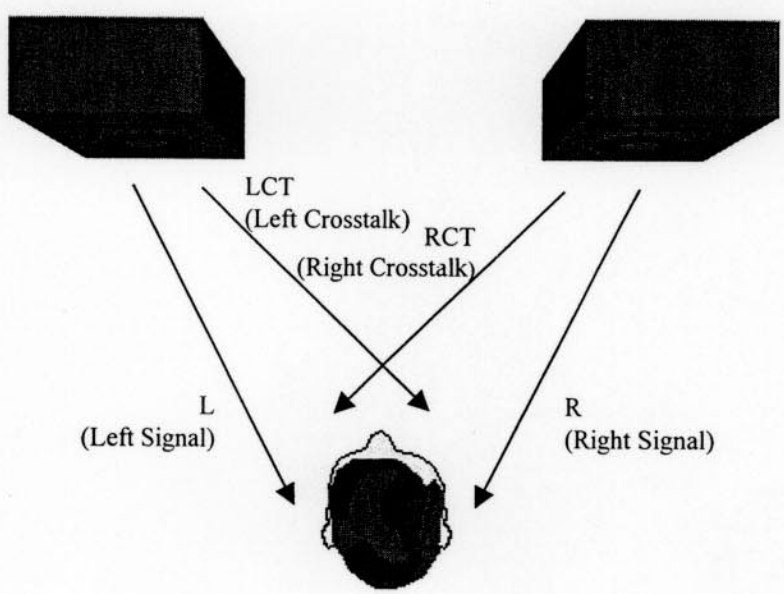

Figure 8
Diagram of Loudspeaker Crosstalk.

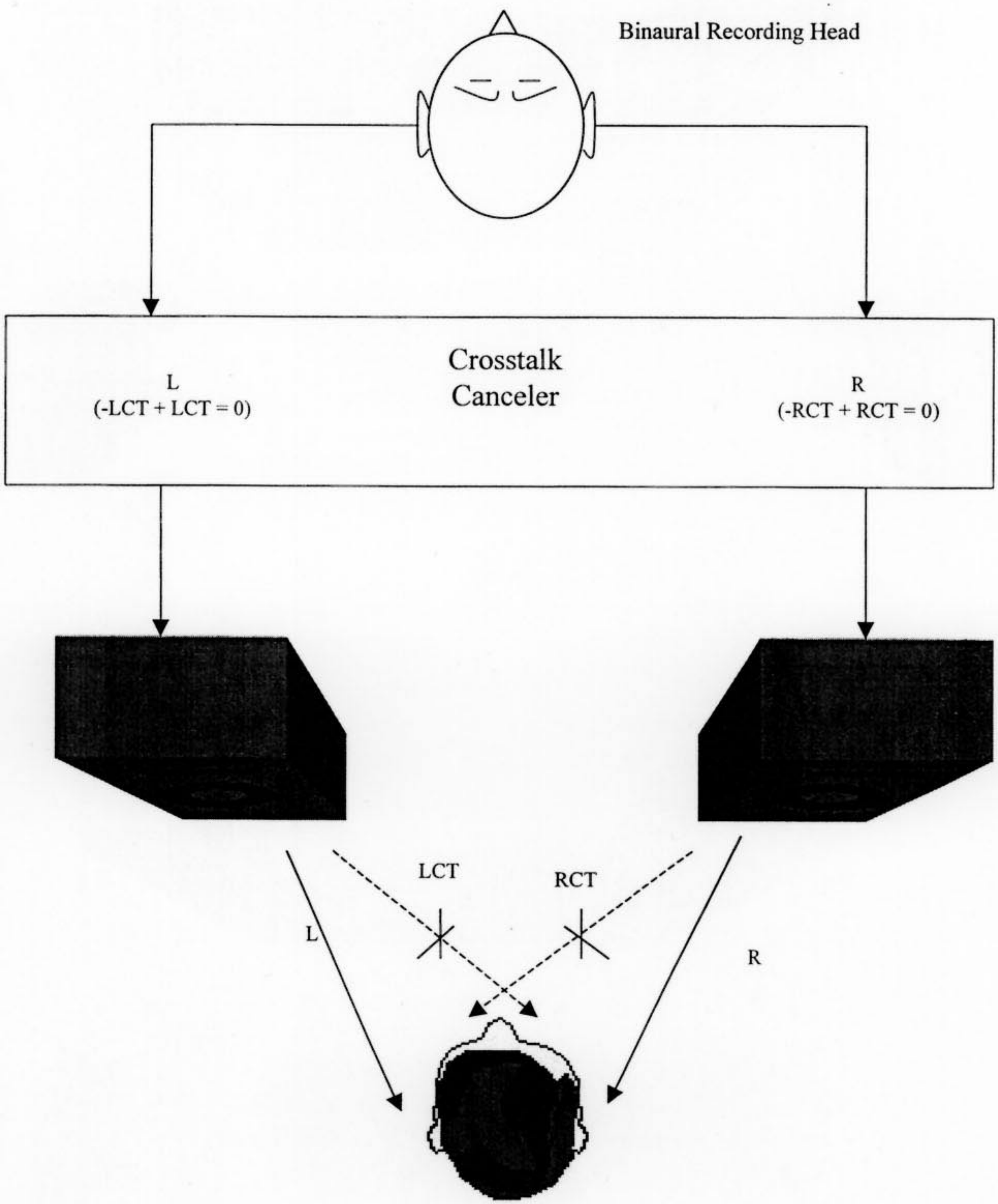

Figure 9
Using a Crosstalk Canceler to alleviate loudspeaker crosstalk.