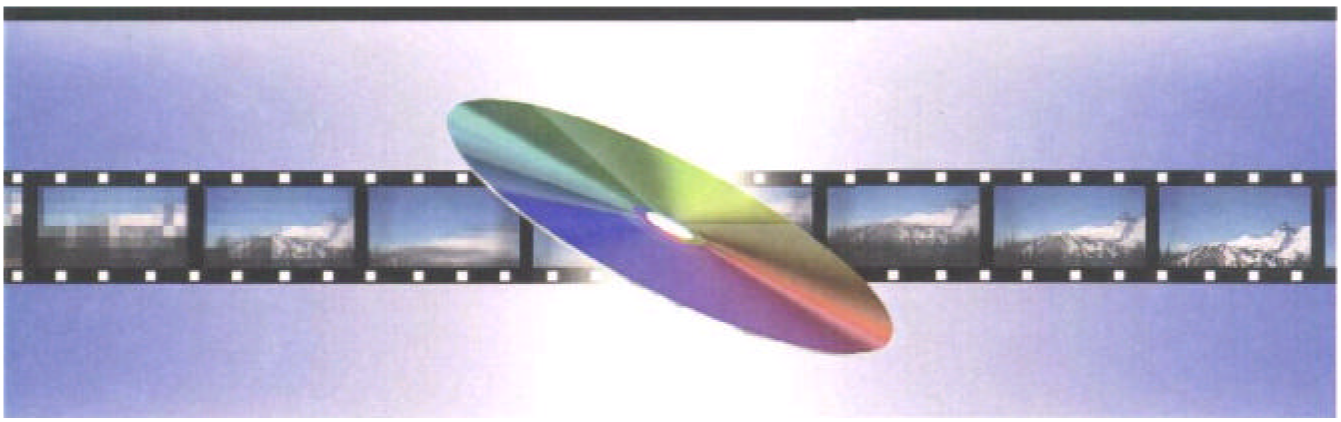
NISTIR 6591

Information Technology Laboratory
Convergent Information
Systems Division
Gaithersburg, Maryland 20899



Digital Cinema 2001
Conference Proceedings

"A New Vision for Movies"

January 11-12, 2001
National Institute of
Standards and Technology
Gaithersburg, MD, USA

Sponsored by:

National Institute of
Standards and Technology
Technology Administration
U.S. Department of Comfnerce

National Information
Standards Organization

NISTIR 6591

Digital Cinema 2001 Conference Proceedings

Charles Fenimore and

Mary Floyd, Editors

U.S. DEPARTMENT OF **COMMERCE**
Technology Administration
Information Technology Laboratory
Convergent Information Systems **Division**
National Institute of Standards
and Technology
Gaithersburg, MD 20899

January 2001

Digital Cinema 2001

Introduction

Charles Fenimore, Program Chair

Welcome to Digital Cinema 2001 Conference and Expo. The last year has seen a wave of new activity surrounding digital cinema. Many movies are being released digitally. There are conferences and shows addressing d-cinema on at least a monthly basis. International standards organizations such as SMPTE and MPEG have studied d-cinema and are beginning to set standards. Significantly, there have been several announcements and demonstrations of new technology supporting digital cinema, including new projectors, high capacity storage, and satellite delivery.

The promise that these evolving technologies can provide higher quality in motion pictures is a compelling new vision for the entertainment production industry, for theater owners, for imaging industries, and for the technology providers. For the *convergence* of information technologies to deliver picture quality in an interoperable and secure system raises significant technical challenges.

Digital Cinema 2001 Conference brings the National Institute of Standards and Technology's expertise in measurements and standards to bear in identifying these challenges. The objectives of the Conference are to:

- Articulate a vision for digital cinema.
- Identify technological and business issues that are barriers to the vision.
- Introduce strategies for breaching the barriers, including needed research, technology development, and standards.

Over the next two days, we will address. The Promise of Digital Cinema: Business Issues; Compression; Standards Issues and Activities; Human Vision; Image Resolution and Color Space; Measurements for Projected Imagery. Compression, and Cameras; and Security and Digital Rights Management. There are several presentations of digital cinema materials as part of the Conference. On Friday afternoon, we will wrap up with a panel discussion on needed areas of work for the future.

There are frequent breaks and a reception on Thursday evening for attendees and their guests. I hope you find these are significant opportunities for informal discussions with the participants.

This Conference is the result of hard work by many people. Members of the Program Committee are Phil Lelyveld and Bob Lambert of Disney, John Wolski of Loews Cineplex. Mike Tinker of Sarnoff, Dave Dawson of the Motion Picture Association of America, Thomas MacCalla of the Entertainment Technology Center, Guy Beakley of SAIC. and John Roberts and Chuck Fenimore of NIST. They have devoted many hours to the planning effort. The industry has generously supported the Conference with digital cinema equipment, In particular, Peter Nicholas of Digital Projection, Doug Darrow of Texas Instruments. Hank Dardy of the Naval Research Laboratory. Jeff Merritt of Panasonic, and John Wolski of Loews have been very supportive. The NIST staff, including Tomara Arrington, Patrice Boulanger, Omar Halmat. Ed Mai, and Teresa Vicente, have provided assistance. Finally, the Conference would not be possible without the the support of the staff and student interns in the Convergent Information Systems Division and without the vision and leadership of Victor McCrary and Xiao Tang.

Digital Cinema 2001

Conference Program

NIST, Gaithersburg, Green Auditorium

Thursday, January 11, 2001

Continental Breakfast (NIST Cafeteria) 7:30 – 8:30 AM

Overview and Business Issues

NIST Greetings

Charles Fenimore, Program Chair, Digital Cinema 2001, *Welcome* 8:30 AM

Karen Brown, Acting Director, NIST 8:35 AM

William Mehuron, Director, Information Technology Lab, NIST 8:50 AM

Overview

Phil Lelyveld,Vice President, Digital Industry Relations, New Technology and New Media, The Walt Disney Company, *Overview of Digital Cinema* 9:00 AM

John Fithian, President, National Association of Theater Owners, *Digital Cinema - Promising Technology, Serious Issues* 9:40 AM

Morning BREAK 10:05 – 10:35 AM

Brad Hunt, Senior Vice President and Chief Technology Officer, Motion Picture Association, *MPA Goals for Digital Cinema* 10:35 AM

Compression and Standards Issues

Digital Cinema Compression

Mike Tinker, Head of Video and Multimedia Applications, Sarnoff Corporation *Into Something Rich and Strange: Prolegomena to a Digital Cinema* 11:00 AM

Steven A. Morley, Vice President Technology, Digital Media Division, QUALCOMM, *Image Compression Designed to Meet Digital Cinema Requirements* 11:25 AM

Gary Demos, President, DemoGraFX, *Quality and Efficiency in Digital Cinema* 11:50 PM

George Scheckel, Vice President, Digital Cinema and Content Production, QuVIS, Inc. *QuVIS' Quality Priority Encoding* 12:15 PM

Questions 12:40 – 1:00 PM

LUNCH — 1:00 – 2:00 PM

Matt Cowan, Principal, Entertainment Technology Consultants
Digital Cinema Clip Demonstration — 2:00 - 2:30 PM

Alan Balutis, Director, Advanced Technology Program, NIST,
Research Partnerships for Innovation — 2:30 PM

Survey of Standards Efforts

Donald C. Mead, Vice President, Digital Electronic Cinema Inc.
MPEG dcinema Profile — 2:50 PM

Robert M. Rast, Vice President, Business Development, Dolby Laboratories
Briefing on SMPTE DC28, Technology Committee on Digital Cinema — 3:10 PM

Stephen Long, Program Manager, Motion Imagery Technology,
National Imagery and Mapping Agency, *Motion Imagery Standards* — 3:30 PM

Afternoon BREAK — 3:50 – 4:15 PM

Human Vision, Image Resolution, and Color

Jeffrey Lubin, Senior Member of Technical Staff, Sarnoff Corporation, *Applications of Human Vision Modeling to Digital Cinema System Design and Testing* — 4:15 PM

Edward F. Kelley, Physicist, NIST,
Impediments to Reproducibility in Display Metrology — 4:40 PM

Michael H. Brill, Sarnoff Corporation,
Encoding of Color Images for Digital Cinema — 5:05 PM

ADJOURN — 5:30 PM

RECEPTION & EXHIBITS — 6:00 – 8:00 PM
Holiday Inn, Gaithersburg

Digital Cinema 2001

Friday, January 12, 2001

Continental Breakfast (NIST Cafeteria)	7:30 – 8:30 AM
Sean Adkins, Vice President, Advanced Technologies, IMAX Corporation, *Cinematic Image Quality - what is it and why does it matter?*	8:30 AM
Thomas MacCalla, Chief Operating Officer, Entertainment Technology Center, *Testing D-cinema at ETC*	9:00 AM

Quality and Measurements for Digital Cinema

Charles Fenimore, Digital Cinema Project, NIST, *Quality Assessment for Digital Cinema: Test materials and Metrics for Compression*	9:20 AM
John M. Libert, Physical Scientist, Flat Panel Display Laboratory, NIST *Video Quality Experts Group: Current Results and Future Directions*	9:40 AM
Morning BREAK	10:00 – 10:30 AM
Paul Breedlove, Digital Cinema Business Development Manager, Texas Instruments Digital Imaging, *DLP Cinema™ Field Demonstration Project: Relationship to Digital Cinema Quality and Measurements*	10:30 AM
Paul A. Boynton, Flat Panel Display Laboratory, NIST *Tools and Diagnostics for Projection Display Metrology*	10:50 AM
John Roberts, Program Manager, Advanced Display Technology Lab, NIST/ITL *DMD Characterization for Digital Cinema*	11:10 AM
Steve Mahrer, Manager, DTV Engineering Liaison, Panasonic BTS *Format Conversion and Image Resolution*	11:30 AM
Steven W. Brown, Physicist, Optical Technology Division, NIST *Calibration of Digital Imaging Systems Using Tunable Laser Sources*	11:50 AM

Digital Rights Management and Storage

William E.Burr, Manager, Secure Technology Group, Computer Security Div., NIST, *Digital Rights Management: How Much Can Cryptography Help?*	12:20 PM
David Sidman, CEO, Content Directions, Inc., *The Digital Object Identifier*	12:40 PM

LUNCH	1:00 – 2:00 PM
Robert Schuler, Vice President, Solutions Group, Savantech, Inc. *Providing Digital Rights Management for Dynamic, Interactive Cinema*	2:00 PM
Michael Miron, Co-Chairman of the Board of Directors and CEO, ContentGuard, Inc. *DRM for the Digital Economy*	2:20 PM
David Cavena, Digital Cinema, IBM Global Services, *The Role of Managed Storage in the Digital Cinema Infrastructure, from Capture to Archive*	2:40 PM
Tom Lipiec, Vice President, Business Development, Video & Audio Entertainment, Constellation-3D, Inc., *Very High Density Storage for D-Cinema*	3:00 PM

Plenary Discussion: Resources for breaching the barriers

Panel drawn from session chairs, keynoters, and selected speakers.	3:20 – 5:00 PM

Adjourn

5:00 PM

Digital Cinema 2001

Exhibitors

Accom, **Inc.** www.accom.com

Constellation 3D www.c-3d.net

DVC Digital Video, Inc. www.digitalvideosystems.com

eMotion, Inc. www.emtion.com

JVC Professional Products Co. www.jvc.com/main.html

Screen Digest www.screendigest.com

National Institute of Standards and Technology www.nist.gov

Karen Brown

Acting Director

NIST

Karen H. Brown is the National Institute of Standards and Technology's deputy director. As a non-regulatory agency of the U.S. Department of Commerce's Technology Administrations, NIST's mission is to strengthen the U.S. Economy and improve the quality of life by working with industry to develop and apply technology, measurements, and standards through a portfolio of four major programs: the Measurement and Standards Laboratories, the Advanced Technology Program, the Manufacturing Extension Partnership and the National Quality Program. As deputy, Brown serves as chief operating officer of NIST, overseeing a $800M annual operating budget and 3,300 on-site staff complemented by 2,000 manufacturing and business specialists serving smaller manufacturers around the country. Brown, who was most recently a Distinguished Engineer at IBM Microelectronics in Hopewell Junction, N.Y., also served (on assignment from IBM) as director of lithography for SEMATECH from 1994-1998.

(continued next page)

Karen Brown, continued...

Brown's 22-year career at IBM concentrated on solving problems in semiconductor lithography and microelectronics. She has a proven track record in management, having successfully met the challenges of moving ideas from the laboratory into manufacturing. Brown also has a keen awareness of the impact of national and international standards on U.S.industry and the economy, having held a variety of standards leadership positions in Semiconductor Equipment and Materials International and helping to bring a semiconductor fabrication line on-board in France.

A native of Schenectady, N.Y., Brown holds a B.A. in chemistry and in history, and a Ph.D. in chemistry from the University of Rochester.

DRAFT 1/10/01 p.m.
Talking Points
NIST Acting Director Karen Brown
Digital Cinema 2001 Conference
January 11, 2001

- Welcome to the National Institute of Standards and Technology, and to one of the first – and hopefully one of the best – conferences of the year. Right up front I want to take note and to thank our cosponsor, the National Information Standards Organization.

- I realize that there were a lot of places around the country where this meeting could have been held – like Hollywood. I assure you that the mayor of Gaithersburg is going to be very excited when he finds out that Hollywood chose to come here.

- You aren't the first and you certainly won't be the last group to come to NIST to discuss a topic that seems far afield from the sort of thing the federal government gets involved with. The good news is that NIST has no – zero – regulatory authority. The better news is that we have lots of experience with technical matters of the sort that face your industry as it looks ahead at the prospects of digital cinema. The best news is that we are an entirely neutral venue for you to share your views.

- I want to explain briefly what NIST is, and our past involvement in the kinds of issues that the movie industry is going to need to tackle if digital cinema is to become a reality.

- Our mission is clear and simple: to strengthen the economy and improve the quality of life by working with industry to develop and apply technology, measurements and standards.

- Our primary customers are U.S. industry and the taxpayers. We don't ever forget that. We are, after all, part of the U.S. Department of Commerce.

- We work through four complementary programs:

1. the NIST laboratories, which specialize in measurements and standards,
2. the Baldrige National Quality Program, which manages the nation's highest award for quality and performance excellence,
3. the Manufacturing Extension Partnership, teaming with centers around the country to provide productivity-improving assistance to small manufacturers, and
4. the Advanced Technology Program, which partners with industry to develop enabling technologies that will benefit the economy broadly.

- When NIST began back in 1901 – yes, it's our centennial year – as the National Bureau of Standards, our focus was on manufacturing, but we always have paid a lot of attention to the service sector.

- And we are no newcomers to the entertainment industry and to the technologies that underlie and provide the infrastructure to allow entertainment media to expand and flourish.

- Let me offer a few examples:

  - NIST was one of the first radio broadcasters in the country, initially transmitting music and speech. And we helped attack the early problem of poor reception. The purpose was research, not entertainment, but the benefits of this technology obviously were broader than anticipated. And let's face it: that's the way it is with most technologies.

  - Another example: NIST's "TvTime," a method for broadcasting time and frequency information on television, was transformed into closed captioning. The technology won us a share of an Emmy Award for outstanding achievement in engineering development in 1980.

  - We've played an enabling role in bringing HDTV to reality. Some of the same NIST lab folks who are here today working on digital cinema and from our Advanced Technology Program will tell you more about that work and our successes to date.

  - Through the NIST Advanced Technology Program, we've even teamed up with one company that is now using math techniques to restore or enhance movies.

- Electronic Books, or Ebooks, were hardly "an item" in the fast-moving information technology markets less than three years ago when we held one of the very first Ebook conferences. In no small part due to our efforts to enable voluntary, open standards, Ebooks are rapidly taking hold. Open standards are vital for Ebooks – and they are just as vital for digital cinema.

- I think we should take note that the entertainment and the information technology/computing sectors are converging rapidly, and they often end up in the form of devices and software that look a lot like office productivity tools. Ebooks likely will look a lot different in a few years, and there's no telling what entertainment applications they will find.

- Clearly, there are lots of opportunities in digital cinema. But here in Washington, that term "opportunities" often as not is a signal that huge challenges loom. Come to think of it, since I spent my career in industry before coming to NIST, that's true in the private sector, too.

- That clearly is the case for digital cinema. I think that the conference organizers have done a great job in recognizing that there are real business AND technical issues that stand in the way of digital cinema. There's no sense in ignoring them. There's a lot of logic in tackling them now, up front. The speakers who follow me will be doing that. For now, I'd like to briefly set the stage.

- We are "awash" in a world of digital content from text to audio, still pictures, and video. And digital cinema is no different -- how the bits are transported, stored, and presented to the viewer or listener is critical.

- Digital cinema represents a convergent technology solution involving software, projection technology, compression, digital data storage, and transmission.

- The technology for showing moving pictures in a theatrical environment is basically unchanged in over 80 years -- we still have film being passed through a gate and shutter and illuminated with a light source.

- But with the systems integration of a number of technologies, digital cinema offers real advantages:

- It costs approximately $2500-$3000 to make a print of the original film for distribution to a theater, and an additional $300-$500 in shipping. This totals roughly $1.2 billion the industry spends on print duplications and shipping.

- That figure could be cut by at least 50% with the simultaneous transmission (by satellite) of a first release movie. Likewise, the digital copy is as good on the 500th showing as the first showing -- while film degrades with each passing through the projector.

- The cost of the digital cinema projector (which is several times higher than film projectors) raises a number of important issues including new business opportunities using digital projection with other digital content. Interoperability is critical if such opportunities are to be realized.

- Because the copy is digital, there is an ability to better protect the cinema from copying -- which because it is digital means that copy protection will need to be more stringent. Thus security and digital rights management becomes a huge issue.

- Other digital cinema specifics relate to the challenges and opportunities of very high quality moving imagery: Digital cinema is unlikely to succeed if it is "just as good as" film. Measuring the quality of moving imagery as it is exhibited on the screen is critical in allowing users to make informed decisions in deploying this new technology. So is the issue of interoperability. There's that word again.

- NIST has a deep involvement in these kinds of measurement issues. Some examples:

- Our Physics Laboratory has developed optical technology that is being used to characterize digital cameras.

- The NIST Electronics and Electrical Engineering Laboratory's work on displays is improving the reliability of measurements.

- Our Information Technology Laboratory is addressing a variety of IT issues including display interfaces, test materials, and security.

- We at NIST recognize the investments the industry has made in developing open standards. That includes:

- Establishment of the Entertainment Technology Center at USC, which is jointly sponsored by the Motion Picture Association, the National Association of Theater Owners, and a number of other industry participants,

- the digital cinema study in the Society of Motion Picture and Television Engineers, and

- the digital cinema compression work in MPEG.

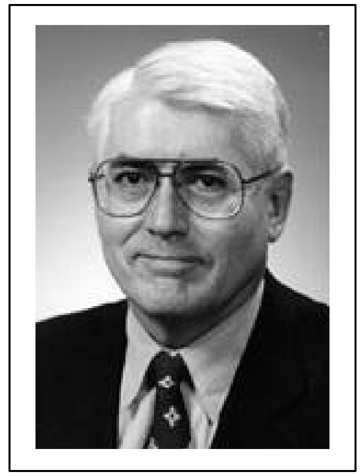
- What about our own investment at NIST? We are comfortable playing a role in digital cinema – if you think there's a place for us and if you can convince us that we are needed to enable this technology to take off and realize its potential.

- Everything we do with our scarce resources must at least have the potential to make a real difference to the economy and quality of life.

- That means that we have to have continuous private sector input and guidance in developing, carrying out, and evaluating our programs.

- This conference, with these participants, is an ideal opportunity for doing just that. We want to make certain that we can contribute in this area, and that our contributions will make a difference--either enabling something to happen that wouldn't otherwise happen or accelerating those advances in a meaningful way.

- I am counting on knowing a lot more about the appropriateness of a NIST role in digital cinema when the curtain falls on this conference. No matter what your conclusions and recommendations, I hope that you have a most productive conference.



William Mehuron

Director, Information Technology Laboratory

NIST

Dr. William O. Mehuron is the Director of the Information Technology Laboratory (ITL) of National Institute of Standards and Technology (NIST), vDepartment of Commerce in Gaithersburg, Maryland. He is also the Chief Information Officer at NIST.

ITL's mission is to strengthen the U.S. economy and improve the quality of life by working with industry to develop information technology. The laboratory works with industry, research, academic and government organizations to develop and demonstrate information technology capabilities that are usable, secure, scalable and interoperate. The laboratory also provides the information technology service (desktop computing, scientific computing and network) capabilities to the entire NIST organization. Detailed information about ITL can be found at http://www.itl.nist.gov/itl.htm.

Dr. Mehuron has held a number of senior management and technical positions in the Federal Government (including civilian, defense and intelligence agencies) and the high technology industry. In these positions, he has been responsible for research, development and acquisition of information systems, sensor and observing systems, and advanced electronic systems. (continued next page)

William Mehuron, continued...

He was with the National Oceanic and Atmospheric Administration (NOAA) from 1995 until 1999 where he served as Director of the NOAA Systems Acquisition Office. He also served as the Acting Deputy Under Secretary (DUS) of NOAA from 1997 until 1998 with line management responsibility for the 12000+ staff NOAA organization. During his tenure with NOAA he directed the development and acquisition of major systems (information systems, satellite and radar systems, and other sensor systems).

Earlier in his government career, Dr. Mehuron was Director for Research and Engineering at the National Security Agency (NSA) where he was responsible for the research, technology, development and systems acquisition programs of NSA. In addition to the in-house activities, he guided a substantial amount of work performed by the industrial base and academia.

In the private sector, Dr. Mehuron has held senior management positions with several advanced technology organizations where he was responsible for research and development efforts in a number of areas including: high-performance work stations, fiber optic networks, network management and security software, computer and communications security products and systems, automated message handling systems, integration of commercial off-the-shelf computer hardware and software, and computer-aided engineering (CAE) design software products and systems.

Dr. Mehuron received a BSEE degree With Distinction from Purdue University. He earned an MSEE and Ph.D. degrees from the University of Pennsylvania. He has also attended the Harvard University Executive Program in National and International Security and an Executive Management Program at the Wharton School of the University of Pennsylvania.

He was awarded the SES Distinguished Rank Award at the National Security Agency for excellence in system acquisition management and leadership. He also received the NSA Exceptional Civilian Service Award for extraordinary performance and exceptional accomplishment, leadership, and personal dedication to the furtherance of the NSA mission.

Dr. Mehuron was awarded the Distinguished Engineering Alumnus award from Purdue University in 1991 for outstanding engineering accomplishment in the military, government and private industry. He is a member of the Institute of Electrical and Electronic Engineers (IEEE).

Information Technology Laboratory (ITL)

"Overview of Digital Cinema"

Phil Lelyveld
Vice President
Digital Industry Relations
The Walt Disney Company

Phil Lelyveld is Vice President of Digital Industry Relations for The Walt Disney Company's New Technology and New Media group. The New Technology and New Media group supports more than 400 business units worldwide. Phil coordinates and participates in Disney's representation at multi-studio and multi-industry forums dealing with the transition from analog to digital; including such new technology initiatives as content protection, DVD, digital cinema, enhanced TV, internet, and HDTV. He also works within Disney to make sure that all of the effected business units are aware of relevant developments, and provides support to individual business units on specific new technology projects. Phil holds an MBA from UCLA , an MS in Geophysics from Stanford, and a BS in Engineering and Music from Tufts.

"Overview of Digital Cinema"

by Phil Lelyveld

This talk will present a high level overview of the major elements of the digital cinema process: content origination, compression, security, transport, storage, playback, exhibition, and back channel. Currently available and anticipated technical options for those elements will be discussed. Digital cinema standards efforts will then be reviewed. The presentation will end with comments on the challenges and possibilities of digital cinema.

Digital Cinema Overview and Issues

Phil Lelyveld
New Technology & New Media
The Walt Disney Company
phil.lelyveld@disney.com

NIST
Digital Cinema 2001
1/11/01

Digital Cinema Overview and Issues

- **Components of Digital Cinema**
- **Standards Efforts**
- **Current Situation**

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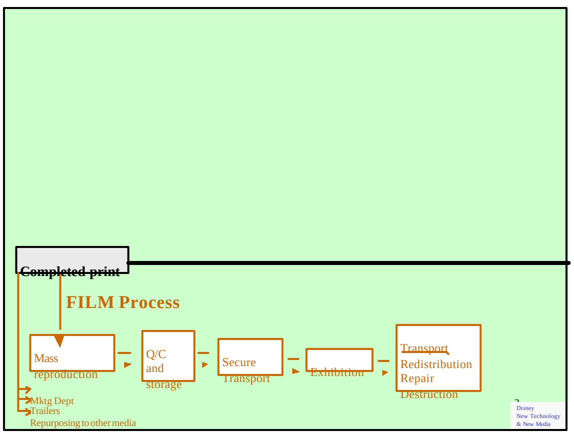
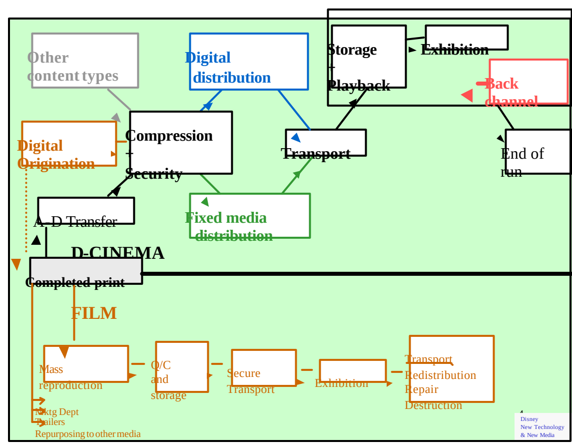
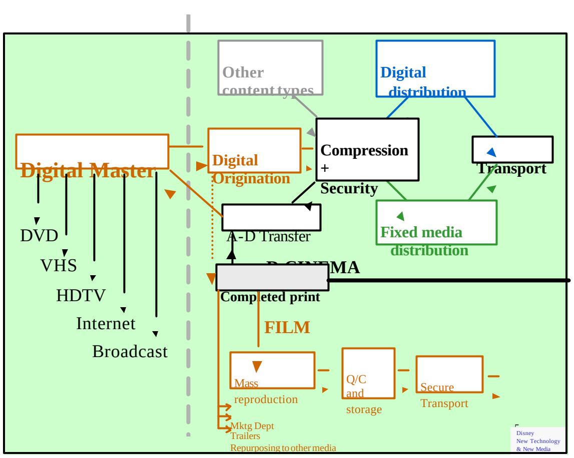
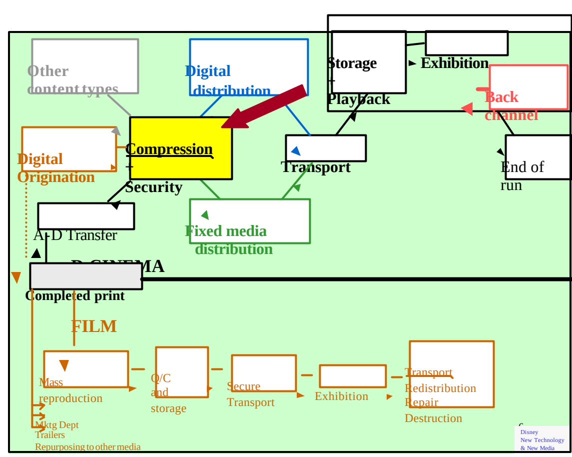








Compression

Wavelet: **stores only the difference from the previous image, based on** a series of **progressively smaller images**, for all but the 'base image'

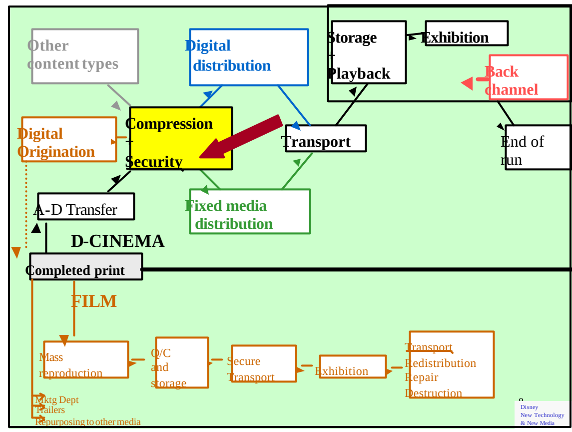
MPEG: uses DCT (discrete cosine transform) **compression of blocks of pixels** to encode complete intra- (or I-) frames, **then interpolates** between I-frames **based on motion or changes** within the block using predicted (or P-) and bi-directional (or B-) frames.

Layered MPEG: **in addition to the MPEG** concept, it allows data to be sent at **progressively higher resolutions (layers).**

Fractal: two types

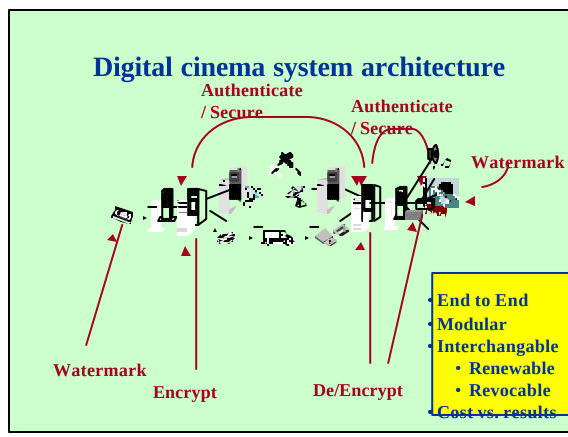
- **Iterated Functions Systems (IFS)** recursively uses contractive functions to produce **ever-finer detail**.
- **Fractal Transform (FT)** is a form of vector quantization (VQ)

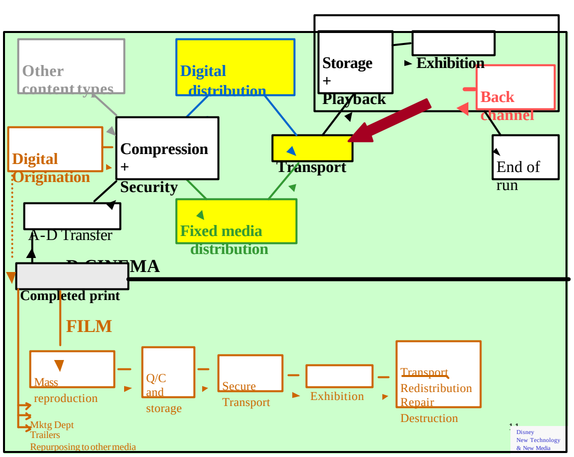
Other

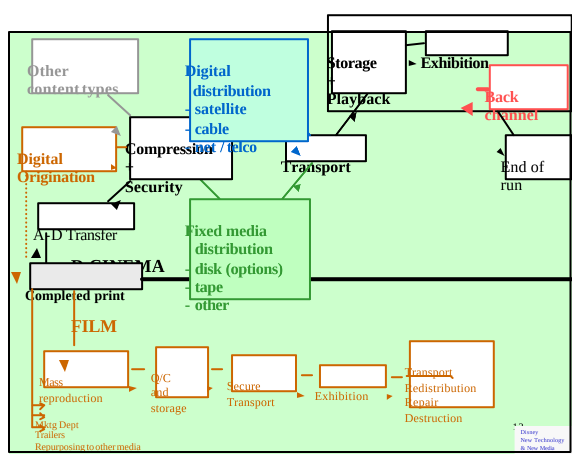


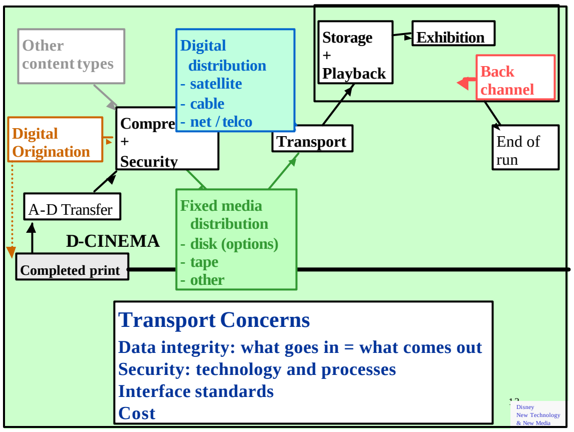
Security

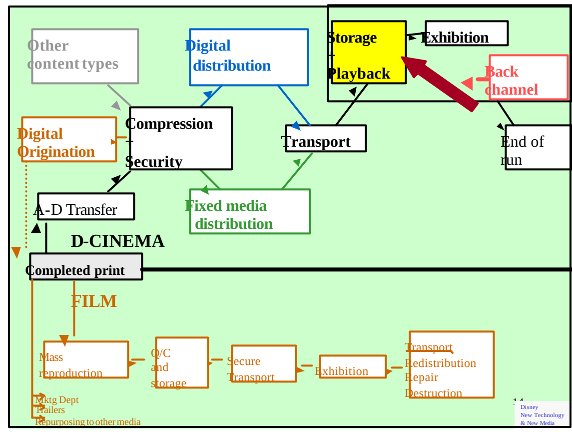
- **Authentication**
  - **verifying parties and content**
- **Encryption**
  - **making the content unusable without authorization**
- **Marking**
  - **watermark vs. fingerprint**
  - **noticeable vs. hidden (steganography)**
- **Physical security**
- **Processes**











Storage & Playback

Example of storage needs

- 3 hour 40 minute movie
- 24 frames per second
- 1080 X 1920 pixels per frame
- 10 bits/pixel

1.97 Terabytes*, uncompressed

- At 23.33 to 1 compression

84.6 Gigabytes* compressed

15

* 8 bits per byte

Storage & Playback

- **Data Rate**
  - Initially, should support typical data rates of 35-90Mbps with visually transparent decompression
- **Reliable**
  - Fail less than 1(?) show per year
- **Secure**
  - Must support delivery of encrypted media
- **Flexible**
  - playlist changes, format changes
- **Backchannel**
  - Diagnostics (playback, audio, and projector)
- **Maintenance and support**
  - Adequate quick-response and product modification support

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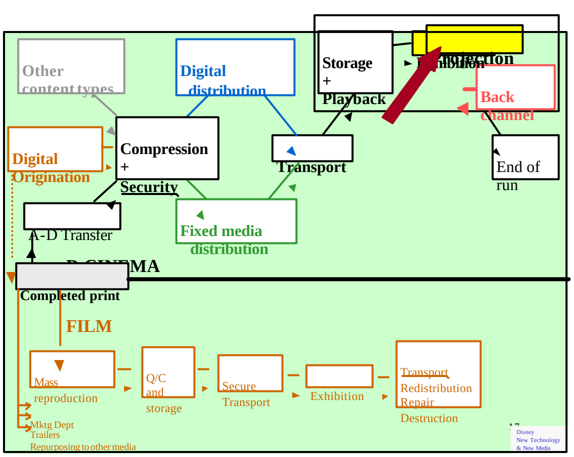

Projection

Multiple projection technologies are desirable

Digital Light Processing (DLP Cinema)

Direct-Drive Image Light Amplifier (D-ILA)

Grating Light Valve

Other

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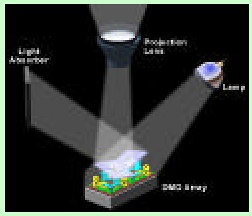
Projection

DLP Cinema

- Based on digital micromirror device technology
- Each micromirror is a pixel
- Micromirrors tilt
- Currently in use
- TI DLP Cinema technology licensed by Christie, Barco, Digital Projection, ….



from Texas Instruments, www.dlpcinema.com

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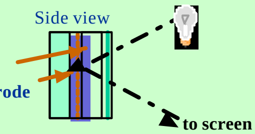
Projection

D-ILA

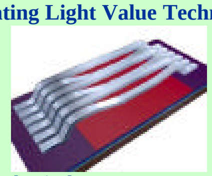


- Based on liquid crystal technology
- Liquid crystal pixels stop/pass light between the light source and the lense - “light valve”
- Theatrical version in development (JVC)

From JVC: http://www.jvc-victor.co.jp/english/pro/dila/feature.html 20

Projection

Grating Light Value Technology



- Micro-electromechanical systems
- A single pixel is made up of multiple ribbon-like structures
- Each ribbon can be moved up or down by electrostatic forces
- The ribbons reflect or refract light
- Theatrical version in development

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From Silicon Light Machines: www.siliconlight.com

Projection

Reflective LCD

(Philips)

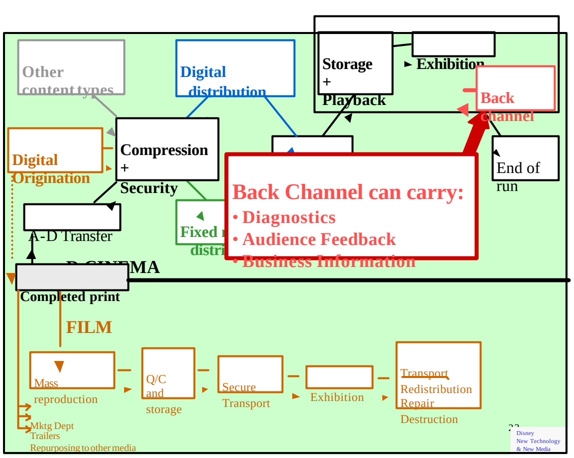
Laser Cathode Ray Tube (L-CRT)

Principia Lightworks (www.principia-optics.com)

Polymorphous Silicon

Other

22



Standards effort

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Standards effort

Brad Hunt

Motion Picture Association
Goals for Digital Cinema

1 Enhanced Theatrical Experience
2 Quality
3 Worldwide Compatibility
4 Open Standards
5 Interoperable
6 Extensible
7 Single Inventory
8 Transport
9 Secure Content Protection
10 Reasonable Cost

Full downloadable word file at: www.mpaa.org/dcinema

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Standards effort

Bob Rast

SMPTE: Society of Motion Picture and Television Engineers
Digital Cinema Study Group - 28.X

DC 28.1 Steering Committee
DC 28.2 Mastering
DC 28.3 Compression
DC 28.4 Conditional Access / Encryption
DC 28.5 Transport / Delivery Systems
DC 28.6 Audio
DC 28.7 Theater Systems
DC 28.8 Projection

Studios, NATO, Cinematographers, Vendors

www.smpte.org, chairman Curt Behlmer, cbehlmer@soundelux.com

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Standards effort

Don Mead

MPEG: Motion Picture Experts Group

Technical specifications for digital cinema files
Testing criteria for digital cinema performance

ISO/IEC JTC 1/SC 29/WG 11 N3758 (Approved October, 2000)
Title: Digital Cinema Requirements

Approved ISO/IEC JTC 1/SC 29/WG 11 N3663 (October, 2000)
Title: Ad Hoc Group on Digital Cinema

www.cselt .it/mpeg/

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Standards effort

Thomas MacCalla

USC ETC (Entertainment Technology Center)

- Studio, industry, and vendor support
- Neutral test facility
- Demonstration sites
  - Hollywood Pacific Theatre
  - CST - France
  - Asia - ?

www.etcenter.org/Body.htm

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Current Situation

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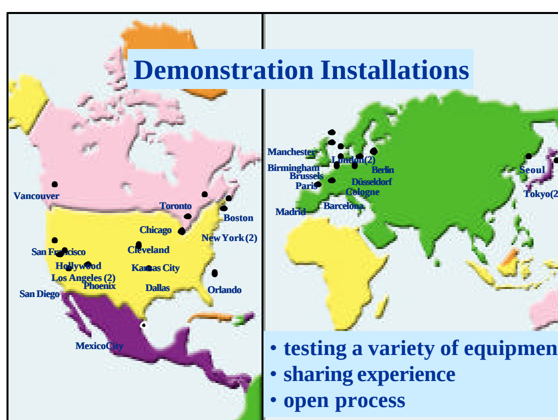
Demonstration Installations



- testing a variety of equipment
- sharing experience
- open process

What movies?

- **Fourteen** movies to date

Star Wars - Episode 1	*Toy Story 2*	*Space Cowboys*
Emperor's New Groove	*Bicentennial Man*	*Fantasia 2000*
The Perfect Storm	*Dinosaur*	*Crimson Rivers*
102 Dalmatians	*Titan AE*	*Bounce*
Mission to Mars		*Tarzan*

- **Distributors:** Disney, Fox, Warner, Miramax, Gaumont
- **Exhibitors:** AMC, Edwards, Cinemark, UCI, GCC, Kinepolis, Warner, Famous Players, Cinemex, Gaumont, Odeon, Toho, others

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What have we learned operationally?

- D-Cinema release preparation is a new science
- Fixed media delivery is practical; other delivery methods work
- Loading/storage/playback technology rapidly evolving
- Projectors are highly reliable, peripherals less so
- Service and support is a key element

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What have we learned from exhibitors and the public?

- 12,500+ performances as of 12/31/00; up time ~99.4%
- Over 1,200,000 patrons - positive response
- Exhibitors are aware the "digital cinema" of the future is already coming to the living room
- Other uses of d-cinema venues are foreseen

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What have we learned creatively?

Issues for this conference

- Subjective reactions vary
- Resolution, color issues: 'trueness' of color imagery, adequacy black levels
- Lots to learn in content creation and preparation
- (in)appropriateness of video or film metrics for digital cinema
- A threshold of quality is essential

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Challenge

Improve the quality and attractiveness of the theatre-going experience *for theatre patrons*

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Thank you

Phil Lelyveld
New Technology & New Media
The Walt Disney Company
phil.lelyveld@disney.com

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"DIGITAL CINEMA— PROMISING TECHNOLOGY, SERIOUS ISSUES"

John Fithian

President

National Association of Theatre Owners

Mr. Fithian is the President of the National Association of Theatre Owners (NATO). Before assuming this position, he represented trade associations, professional athlete unions, communications companies, non-profit organizations, pharmaceutical companies, publishers, and advertising professionals before White House officials and Congress. He also has conducted many press conferences, participated in radio talk shows, and conducted many one-on-one interviews with members of the press. In September of 1998, he was named one of the top forty Washington lawyers under the age of 40 by *Washingtonian* magazine.

Mr. Fithian received a B.A. from William and Mary College in 1984. He earned his law degree from the University of Virginia in 1987.

"DIGITAL CINEMA— PROMISING TECHNOLOGY, SERIOUS ISSUES"

by John Fithian

For motion picture studios, movie theatre operators and their patrons, digital cinema may become the most important technological transition since the advent of sound. Indeed, our industry has operated with the same basic technology for decades. Digital cinema could revolutionize the business by transforming the nature of production, delivery and exhibition; by saving distributors hundreds of millions of dollars annually; and by making it easier for exhibitors to offer alternative content.

None of this will come easy, however. Significant issues and challenges confront the potential transition, not the least of which is the issue of costs. No one knows for sure which technology will prevail, when the transition will occur, nor how it is going to be financed. Nonetheless, the transition will come.

I represent the National Association of Theatre Owners (NATO), the largest trade group in the world for motion picture theatre operators. In the U.S., NATO has over 700 members who operate roughly 25,000 screens. We also have international members. NATO and its members are actively involved in all aspects of the digital cinema debate. NATO members participate in every facet of the Society of Motion Picture and Television Engineers' DC-28 group, which we wholeheartedly endorse. NATO has also helped to form the Digital Cinema Lab at the University of Southern California's Entertainment Technology Center.

In addition to our participation in those industry-wide organizations, NATO also has two internal working groups that study the issue and chart our priorities. One group focuses on the technological issues, while the other is concerned with business.

continued....

I would first like to thank the National Institute of Standards and Technology for convening this important conference, and for inviting me to participate. Second, I would like to make the disclaimer that I am not a digital cinema technology expert. NATO's digital technology consultant, Michael Karagosian, is here with me if any of you have technical questions for us. I am very familiar, however, with the business issues involved. And that is what I would like to discuss today – the business of digital cinema.

For theatre operators, there are many important questions that must be answered before a full-scale roll out of digital cinema will make sense as a business proposition.

1. **For Exhibitors, is the new technology worth the cost?**

In the current environment, a theatre operator can equip a projection booth with a new 35mm film projection unit for about $30,000. That equipment will last for many years, even decades. Digital projection units currently cost several hundred thousand dollars. The best estimate of cost once roll-out begins seems to be about $100,000 at the least. And how long will this equipment last before upgrades are necessary? Two years?

It's very simple math. If anyone expects theatre owners to pay for the transition, they simply don't understand the math. $30,000 over twentyyears, or $100,000 over two. Digital cinema could never drive enough extra traffic through our box offices and to our concession stands to make up the difference.

Some say that equipment costs will come down as the roll-out takes place, just as personal computers or cellular telephones became vastly less expensive over time. Those observers haven't examined the numbers. For a product's cost to decline, there must be economies of scale. Hundreds of millions of consumers world-wide own computers or cell phones. In our world, there are approximately 36,000 movie screens in the U.S., and roughly 120,000 total world-wide. Those numbers do not produce sufficient economies of scale to drive down costs.

continued...

There are potential cost savings for exhibitors. In a fully implemented digital regime, we may need fewer staff and less real estate to operate. Those savings will take years to materialize, however. In the short term, the implementation will actually cost us more staff time and more real estate. We will have to train employees and position digital projection units next to traditional equipment. Only when all product is available in digital format, and when all theatre staff understand the new technologies will our savings occur.

Finally, the present economic challenges facing the exhibition industry exacerbate these costs concerns. With nine major companies in bankruptcy and others fighting to stay alive, paying for popcorn supplies can be challenging enough.

2. For Distributors, is the new technology worth the cost?

Motion picture distribution companies currently spend $1,500 to $3,000 producing a single print of a movie. First-run, wide release pictures need several thousand prints. Once a digital system were in place, costs likelywould not exceed several hundred dollars, if that, to distribute a movie. Simply put, the studios stand to save more than $800 million dollars annually, just in distribution costs. Additional savings will occur in the synergies of producing, editing, and distributing a film all in digital format.

3. Who will control the system and the data?

In the current world, distributors ship films to exhibitors in metal canisters. From that point on, as long as they comply with their contractual obligations, theatre operators control the show. Exhibitors assemble their show elements and determine their screen times. Exhibitors know and interact with their customers. In other words, movie theatre operators operate their business.

In a digital world, data controls. And he who has the digital keys controls the digital data. Theatre owners do not want to be reduced to little more than brick and mortar businesses who build new complexes which the studios then operate remotely.

continued...

4. Will digital cinema offer a better movie-going experience?

Digital cinema is being tested in many locations around the world. Side-by-side demonstrations have been conducted with digital projection next to film. Cinematographers, directors, studio executives, theatre operators and patrons debate the quality of the experience. The technology is improving rapidly, but the jury is still out.

I've heard some commentators say that digital projection is just as good as film. That isn't enough. Why change to an expensive, unproven technology to get an experience that is "just as good" as we have now?

Digital cinema must be better than film, and I believe it can be. Celluloid prints deteriorate over time. As the film runs through projectors over and over, and as the print gets shipped from one exhibitor to the next, the quality of the presentation wanes. Digital cinema will not experience the same effect.

To date, digital cinema has produced positive patron reaction, particularly with animation or action features. But there are still questions about the quality of the digital presentation with real life scenes.

5. Will systems be built toward open, uniform standards that promote competition, worldwide compatibility and interoperability?

A digital system will involve many components built by different manufacturers. The system will have to support different content from different providers. Open, uniform standards must be developed to promote competition, worldwide compatibility and interoperability.

Competition is necessary to avoid monopoly pricing in equipment manufacturing or in digital product delivery. Theatre operators will not agree to a world where all of our product comes through one satellite provider, or one broad-band pipe. Nor will we support a system where any one manufacturer, or any one technology has monopoly control.

continued...

Compatibility is equally important. Exhibitors should be able to play any distributors' movies, and alternative content as well, on one system. We cannot repeat the mistakes made during digital sound implementation, where different systems were necessary to play different product. Interoperability is also important. Different equipment components must be able to work together.

6. Will the system be secure?

Without sophisticated encryption technologies, digital cinema could enable pirates to steal first-run movies for home viewing at the very onset of the theatrical release. Secure transmission must be a priority.

7. Will digital technologies open new business opportunities to exhibitors?

Movie houses need not be just movie houses. From 1990 through 1999, domestic screen count grew from 23,814 to 37,185. The number of movies, however, did not expand at the same rate. Indeed, in the past several years, production has declined.

Granted, there are too many screens in this country and the exhibition industry is suffering as a result. But even as our industry is now reducing screen count, we could still use new product. Digital cinema technologies would make it easier for our members to show musical concerts, sporting events, fine art entertainment, business theatre, religious events, and even educational programming.

Motion pictures will always be our biggest business. But digital cinema may open new doors to essential new revenue streams.

8. Will the digital revolution be open to all potential participants?

I represent more than 700 members. They range from large international circuits, to small one-screen operators in small towns. The digital experience must be open to all potential participants.

Some say that digital cinema will wipe out the small town theatre operator. I disagree. Today, the small town operator is often overlooked by the distributors. My smaller members often cannot get that print they need on the

continued...

first-run break. With digital cinema, the costs to produce that print and ship it across the country or across the world will be virtually eliminated. I believe digital cinema might make it easier for those smaller operators to provide service to their customers. Digital cinema can be good for competition and good for the patrons, but only if managed correctly.

9. Will the industry undertake the planning necessary to effectuate the revolution?

Digital cinema should not be implemented as a private deal between select parties trying to seek quick advantage over their competitors. In the end, they will find that the advantages were ephemeral. In fact, the first companies to roll out digital may find that they have implemented an unproven, costly technology that quickly becomes obsolete, or for which upgrades prove difficult.

Instead, digital cinema should be implemented pursuant to an industry-wide plan. The planning process should involve all distributors and all exhibitors. And the planning needs to take place on two tracks: technical and business.

That's why NATO formed two task forces whereby our membership could have input with selected representatives who would carry exhibition's concerns and goals into the discussions. On the technical side, this construct has born fruit. The SMPTE process is very useful and must continue.

On the business side, however, very little industry-wide planning has taken place. NATO and our members are prepared to undertake this planning immediately. Business planning and standards development can occur simultaneously. There is no reason to wait for the ultimate conclusion of the standard setting process before any business plans are made.

10. Will legal concerns impede industry-wide planning?

I do not believe that the antitrust laws prevent us from engaging in comprehensive planning. We have closely examined this issue and are confident that pro-consumer, pro-competition industry plans, which comport with

continued...

all legal standards, can be achieved and approved in a timely fashion. Some matters must be addressed in the context of individual business deals. But the structure and plans can and must be developed as an industry, in the interest of fair competition and consumer protection.

The technology is promising, but the issues involved are serious. This conference is a great way to advance the ball. Thank you for inviting me to participate.

#

“MPA Goals for Digital Cinema”

Brad Hunt
Senior Vice President &
Chief Technology Officer

Motion Picture Association

Mr. Hunt is currently the Senior Vice President and Chief Technology Officer for the Motion Picture Association. He works closely with the seven major studios that make up the Motion Picture Association in providing guidance on technology issues and policymaking. He chairs internal MPA working groups focused on copy protection, digital cinema, and Internet security issues. He has worked in the motion picture and television industry for over twenty years. His career experiences have included jobs in research and product development, marketing, business development, international sales, and strategic planning in the film, broadcast video, DVD, and post- production service industries. Mr. Hunt has a B.Sc. degree in Chemical Engineering from the Rose-Hulman Institute of Technology and an M.B.A. degree from the William E. Simon Graduate Business School at the University of Rochester. He has served as an Executive Board Member of the Technology Council of the Motion Picture & Television Industry and is a Fellow of the Society of Motion Picture & Television Engineers.

"MPA Goals for Digital Cinema"

by Brad Hunt

The member companies of the Motion Picture Association believe that the introduction of digital cinema represents the greatest opportunity for enhancing the theatrical film experience since the introduction of sound and the advent of color. The conversion from photographic film distribution and display to an all-digital system has the potential of providing real benefits to theater audiences, theater owners, filmmakers, and feature film distributors. But in order for these benefits to be fully realized, digital cinema must be defined, standardized, and implemented in a way that ensures that the benefits accrue to all stakeholders.

The MPA member companies have been involved in public demonstrations of prototype digital cinema systems. We have also held meetings with equipment manufacturers, service suppliers, theater owners, and the creative community to better understand the views of others concerning the implementation of digital cinema. The MPA and its member companies have also participated in the Society of Motion Picture & Television Engineers (SMPTE) Digital Cinema DC28 engineering study groups in the preparation of their reports on considerations in the standardization of digital cinema. Through these activities and the dialogue with other stakeholders, we have developed a list of ten goals that we believe are critical to the successful implementation of a digital cinema system that provides real benefits to all stakeholders. These goals consist of the following:

1. ENHANCED THEATRICAL EXPERIENCE - The introduction of digital cinema must be used by the motion picture industry as an opportunity to significantly enhance the theatrical film experience and thus bring real benefits to theater audiences.
2. QUALITY - The picture and sound quality of digital cinema should represent as accurately as possible the creative intent of the filmmaker. To that end, its quality must exceed the quality of a projected 35mm "answer print" shown under optimum studio screening theater conditions. Any image compression that is used should be visually lossless.
3. WORLDWIDE COMPATIBILITY - The system should be based around global standards so that content can be distributed and played anywhere in the world as can be done today with a 35mm film print.

continued...

4. OPEN STANDARDS - The components and technologies used should be based on open standards that foster competition amongst multiple vendors of equipment and services.
5. INTEROPERABLE - Each of the components of the system should be built around clearly defined standards and interfaces that insure interoperability between different equipment.
6. EXTENSIBLE - The hardware used in the system should be easily upgraded as advances in technology are made. This is especially important in evolving to higher quality levels.
7. SINGLE INVENTORY – Once a consensus on digital cinema standards is reached and implemented, upgrades to the system should be designed so that a single inventory of content can be distributed and compatibly played on all equipment installations.
8. TRANSPORT – The system should accommodate a variety of secure content transport mechanisms, including electronic as well as a physical media delivery.
9. SECURE CONTENT PROTECTION – The system must include a highly secure, end-to-end, conditional access content protection system, including digital rights management and content watermarking, because of the serious harm associated with the theft of digital content at this stage of its distribution life cycle. Playback devices must use on-line authentication with the decrypted content files never accessible in the clear.
10. REASONABLE COST - The system standards and mastering format(s) should be chosen so that the capital equipment and operational costs are reasonable. All required technology licenses should be available on reasonable and non-discriminatory terms.

In addition to documenting these goals, the MPA member companies are preparing a document that more specifically outlines a consensus view of the System and Performance Requirements for Digital Cinema. This document will be posted at a later date on the MPA digital cinema web site located at http://www.mpaa.org/dcinema. Comments on these documents can be directed to the Motion Picture Association's Office of Technology by sending e-mail to: dcinema@mpaa.org.

"''A Practical Testing Approach to Digital Cinema Compression''

Dave Schnuelle

Director of Technology, Digital Cinema, THX Division

Lucasfilm Ltd.

Dave Schnuelle is the Director of Technology, Digital Cinema, for Lucasfilm Ltd., THX Division. He was the Project Supervisor for the Star Wars Episode 1 digital cinema release, and previously was the founder and Principal Engineer of the Lucasfilm THX Digital Mastering Program, a service used by the major motion picture studios to ensure the technical quality of their home video releases. Prior to that Mr. Schnuelle was Chief Engineer of several major post-production facilities in Los Angeles. As an independent consultant, Mr. Schnuelle designed and supervised the construction of Universal Studios High Definition Transfer Facility. Mr. Schnuelle is a co-inventor of several patents on test signals and vertical oversampling in film transfers.

“"A Practical Testing Approach to Digital Cinema Compression"

by Dave Schnuelle

Following the digital cinema release of Star Wars Episode 1 - The Phantom Menace in the summer of 1999, it was apparent that a much higher compression ratio for the program material was needed. The 4:1 ratio used with the Pluto disc recorder was not practical for distribution to multiple sites. Since that time various other compression schemes have been proposed for digital cinema applications. This paper details a practical testing methodology that takes into account the post-production procedures and equipment currently used in preparing digital cinema masters. Subjective "Double-blind A/B" test sessions are conducted separately with expert viewers and with professional film reviewers. Selection of the test material will be discussed, and examples will be shown.

"Into Something Rich and Strange: Prolegomena to a Digital Cinema"

Mike Tinker

Head of Video and Multimedia Applications

Sarnoff Corporation

Mike Tinker has been working in the field of digital image compression since he joined RCA's David Sarnoff Research Center (now Sarnoff Corporation) in 1985. From 1988 to 1993 he worked for Intel Corporation, where he supervised the building of video compression engines, ran a worldwide video compression operation, and was manager of Video Compression Algorithms. During this time he was a delegate to MPEG and served on the Requirements Committee for MPEG2. In 1993, he returned to Sarnoff where he is now the head of Video and Multimedia Applications. For several years, his work has been concentrated on digital cinema. In the past year he has been an active member of the SMPTE Digital Cinema Committee (DC28) and has served as vice-chair of the compression working group of that committee.

"Into Something Rich and Strange: Prolegomena to a Digital Cinema"

by Mike Tinker

Digital cinema is about to happen. But what form it takes is neither predetermined nor rigid. That form will evolve over time; it will certainly be very different five years from now from what it is this year; ten years from now it will be barely recognizable compared to the cinema of today. There are those who believe that d-cinema may be the biggest change in movies since the introduction of color: In fact, it will be a transforming event that will blur the edges between traditional movies and other forms of entertainment. Initially, we will see movies that have been processed and compressed to meet constraints of bandwidth and storage but that are otherwise electronic emulations of the film-based environment. That is where many of us are working today. Eventually, however, evolving digital cinema will open up possibilities far beyond traditional film. Theatres will become a new kind of entertainment center in which traditional linear storytelling in moving pictures will be only one of the possibilities available to patrons. Part of what we must do today is prepare for the coming technologies and the new ways of thinking that will open up the artistic possibilities of the future.

Into Something Rich and Strange: Prolegomena to a Digital Cinema

Mike Tinker
Sarnoff Corporation
1/10/00

Outline

- Prologue
- Today: Getting Started
- Tomorrow: Ensuring Quality
- The Day After Tomorrow: Expanding functionality
- Epilogue

Prologue

- Technology doesn't provide answers.
- Technology facilitates solutions.
- We don't even know the questions yet, . . .
- So we'll get the answers wrong, but . . .
- We can drive to a set of goals.
- In the end, it's about telling stories.

D-Cinema Goals

- Quality
  - Imagery
  - Sound
- Extensibility
  - Flexible
  - Interoperable
  - Compatible
- Security
  - Multi-layered
- Standardization

Today: Getting Started

- New projectors
- New technologies
  - Storage
  - Transmission
- Cost differentiation
  - Film costs are rising
  - Technology costs are falling
- Exciting beginnings

We Want More

- We want an improved experience, but . . .
- Film is great: everybody goes to the movies. But . . .
- It has some drawbacks
  - Deteriorates with time
  - Runs at 24 frames per second
  - Is costly
  - Is inflexible

Tomorrow: Ensuring Quality

- First, emulate the existing technology
  - Horseless carriages
  - Radiotelegraphy
- **Do** make electronic film
- **Don't** make television
  - Different history
  - Different constraints

The Price of Quality

- Forget Storage Costs
  - Compression is necessary for a while, but . . .
  - Storage is moving faster than Moore's law
- Don't worry about bandwidth
  - 100 Mbs transponders
  - Fibre to the world
- Demand highest quality regardless of cost today
- Next year it will cost half as much

Quality: At least as good as film

- RGB
  - Reduced chroma is television
  - KISS: RGB in, RGB out
- Forget "interlaced" and "progressive"
  - Television words
  - Neither compression nor projection uses scanlines
- At least 10-bit log
- At least resolution equal to the best projector
- At least 8 channels of sound

Extensible

- Must be ready for technology improvements
- Must be ready for technology changes
- Must leverage cost curve
  - Old belief: it will cost more next year
  - New reality: it will cost less next year
- Must be interoperable and available world wide
  - Creation compatible with distribution
  - Distribution compatible with local system
  - Local system compatible with projector

Secure

- Layered security
  - Not just one barrier to theft
  - More secure than film
- Encryption: Stop the thief
  - Bitstream encoding
  - Key control
- Watermarking: Catch the thief
  - Insert at all stages
  - Embed the history
- Camcorder foiling: Disable the thief

Standards

- Necessary to achieve goals
  - Remove confusion
  - Sift and winnow technology
  - Bring d-cinema faster
  - Make d-cinema broader
- Promote competition
  - Level playing field
  - Inclusive of all stakeholders
  - Forum for all concerns

The Day After Tomorrow: Expanding Functionality

- It's about telling stories
- It's about making magic
- It's about enhancing the audience's experience
  - Better images and sound
  - New tools for the storyteller

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Incremental Changes: Better Images

- Brighter projectors
- Higher resolutions
- Bigger screens
  - Projectors will get less costly
  - Images will fill more of the audience's field of view
- More frames/second
- 3D without glasses

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Radical Changes: The Magician's New Tools

- Multiple story lines
  - breakdown between linear and non-linear
- "Live" movies
  - breakdown between live and pre-recorded
- Audience participation
  - adaptive entertainment
- Immersion
  - From seeing to experiencing
  - From observing to participating
  - From acted upon to acting in

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Epilogue

Any sufficiently advanced technology
is indistinguishable from magic.
--Arthur C. Clarke

- We must facilitate the magic
- We must enable the magicians
- We must enhance the experience

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Nothing of him that doth fade
But doth suffer a sea-change
Into something rich and strange.
--William Shakespeare

- Movies are suffering a sea-change
- Digital cinema will be:
  - Richer than we can know
  - Stranger than we can imagine
  - An ongoing celebration of the human spirit

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"Image Compression Designed to Meet Digital Cinema Requirements"

Steven A. Morley

Vice President, Technology
Digital Media Division

QUALCOMM

Steven A. Morley is the Vice President, Technology, for QUALCOMM's Digital Media Division. For the past four years, he has been the chief system engineer for QUALCOMM's Digital Cinema system technology. Mr. Morley joined QUALCOMM in 1985 soon after its founding and has lead a number of business and technical development programs involving digital communications and electronics products and systems. Prior to that, Mr. Morley was a Senior Engineering Manager at M/A-Com Linkabit Corporation working in the areas of digital encryption systems and wireless communication networks.

Mr. Morley holds an MSEE degree from Stanford University and a BSEE degree from the University of California, Irvine. He has received several patents in the fields of wireless and satellite communication systems and has published a variety of articles in the fields of electronic security, wireless communications, satellite technology, and digital cinema systems. Mr. Morley is a member of SMPTE and BKSTS.

Digital Cinema 2001 *“A New Vision for the Movies”*

“Image Compression Designed to Meet Digital Cinema Requirements”

by Steven A. Morley

Even in this age of shrinking costs for digital storage and increasingly wide band communication channels, image compression is still a critical component of a digital motion image system, such as digital cinema. An uncompressed two-hour motion picture at today’s image resolution requires more than 1.3 Terabytes of storage and would require nearly three days to transmit at T3 data rates (i.e., 45 Mbps). Using advanced image compression techniques, this storage is reduced to around 40 Gigabytes and can be delivered in “real time” on a 45 Mbps channel. However, existing image compression systems have been developed to support “television quality” performance that will fall short of meeting “cinema quality” when projected on large theatrical screens.

The challenge of an appropriate digital cinema image compression system is to deliver the image quality that filmmakers and audiences are used to seeing in cinema theatres while doing so at data rates that support economical operation of the digital cinema system. Also, the compression system needs to consider tradeoffs in the overall system architecture, such as the security methods and system optimization that are appropriate for digital cinema systems. Finally, the image compression approach must include flexibility for enhancements in the future of digital cinema, such as increased resolution and frame rates.

This presentation will address and itemize the quality considerations that factor in to the selection of an appropriate digital cinema image compression decision. Also, a proposed solution to these requirements will be presented and shown to meet the necessary aspects for a high-quality, cost-effective digital cinema compression system.

January 11-12, 2001
National Institute of Standards & Technology

Image Compression Designed to Meet Digital Cinema Requirements

Steven A. Morley
QUALCOMM Incorporated
San Diego, CA
email: smorley@qualcomm.com

Overview

- The Case for Image Compression in Digital Cinema
- Important Definitions of Characteristics of Digital Images and Compression
- Comparison of Digital Cinema and Digital TV Image Requirements
- Candidate Compression Technologies for Digital Cinema
- Implementation Considerations
- A Practical Solution for Digital Cinema Compression
- Summary

Digital Cinema Is Coming, But "Size Matters"

- An uncompressed digitized movie requires lots of bits
- Ex: for a two-hour movie at cinema resolution:
  - 1920 pixels wide x 1080 pixels wide x 30 bits/pixel x 24 frames/second = 1.5 billion bits per second (approx. 300 times m ore than the data rate of a DVD video)
- 1.3 terabytes (trillions of bytes) for two-hour program (not including audio), (equal to 40 36GB hard disks or 80 maximum density double-sided/double-density DVD's)

Image Compression to the Rescue

- Reduces bit rate for digital representation of an image by taking advantage of:
  - Redundancy within an image frame ("Spatial Redundancy")
  - Redundancy from frame to frame in a motion picture ("Temporal Redundancy")
  - Visual aspects not readily perceptible to the human eye

Compression Rates for Various Applications

- Uncompressed Digitized Film "Original" (at HD resolution) - 1.5 Gbps
- Digital Edit Master - 140-270 Mbps
- Archive - 60-80 Mbps
- ***Digital Cinema Release Master - 35-45 Mbps***
- HDTV Broadcast* - 15-20 Mbps
- High-Quality SDTV* - 4-10 Mbps
- Average-Quality SDTV* - 2-6 Mbps
- Streaming Video - less than 2 Mbps

** includes consideration for conversion to 30Hz*

Compression Savings

- Using digital compression at 45 Mbps, a two-hour movie requires only about 45 GB of storage (including audio)
- This means an entire movie can be stored on a single hard disk or 3 DVD-18 disks

Definition of Image Compression Terms

- ***Compression Ratio:*** Uncompressed bit rate divided by compressed bit rate (e.g., 30:1)
- ***Encoding Rate:*** Typically expressed in "Bits per Pixel" (BPP)
- ***Compressed Bit Rate:*** Data rate (in bits per second) of compressed material

More Compression Terms

- ***Coding Efficiency:*** A metric relating to the compressed bit rate necessary to achieve a certain image quality
- ***Scalability:*** The ability of a compression system to operate at different quality/compression ratio levels

There's "Lossy" and Then There's "Lossy"

- ***Lossless Compression:*** Compression that does not cause any distortion in the digital image
- ***Visually Lossless (or "Transparent") Compression:*** Compression that does not cause any distortion in the electronic image visible to the human eye under normal viewing conditions

"Lossiness" Continued

- ***Lossy Compression:*** Some visual distortion is visible to the human eye under normal viewing conditions
- ***Artifacts:*** Distortions caused by lossy compression

Intraframe vs. Interframe Compression

- ***Intraframe Compression*** processes each frame in a moving image without consideration for any previous or future frames (aka "I-Frame Only")
- ***Interframe Compression*** processes sequences of frames, typically encoding only the differences between frames

Comparing Intraframe and Interframe Compression

- Interframe compression would generally yield better efficiency due to removal of frame-to-frame (temporal) redundancy
- However, interframe compression can also cause motion artifacts under "motion" stress conditions (e.g., scene changes, fast pans, lightning/strobe lights, etc.)

Rate-based vs. Quality-based Compression

- ***Rate-based Compression*** sets a constant number of compressed bits available per frame
- ***Quality-based Compression*** sets a "required quality" level and let bit rate automatically adjust to meet that quality
- *Quality-based approaches yield better quality at lower average bit rate*

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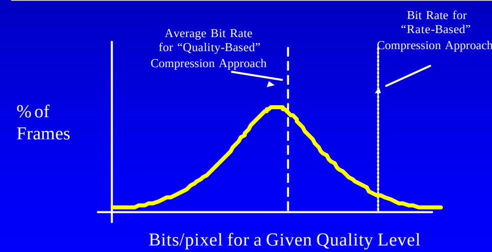
Quality-based vs. Fixed Rate Compression



14

Contrast and Contrast Resolution

- *Contrast* refers to the comparison of the "blackest black" and the "whitest white"
  - Several different methods used to measure this characteristic
- *Contrast Resolution* refers to the number of "shades" possible in each color component
  - Determined by the number of bits used to represent each of the three uncompressed video components and the method of encoding the values ("linear" or "log")
  - Digital television typically uses 8-bit linear encoding, digital cinema will use at least 10-bit linear (log encoding is preferred)

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A Little About Color

- Unlike "film", electronic projection is based on color "addition"
- Traditional representation of a pixel value (i.e., the color and luminance) is with a weighted combination of specific Red, Blue, and Green components (RGB)

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RGB is Not Very "Efficient" for Compression

- There are no perceptual efficiencies in representing a value in RGB
- The human eye is not as sensitive to color detail as it is to luminance detail

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"Luminance/Chrominance" Representation

- The three axes of Red, Blue, and Green can be converted to three axes of "luminance" (commonly referred to as "Y") and two "color difference" chrominance components, such as "I,Q" or "U,V' or "Pr,Pb" or "Cr,Cb"
- When compressing luminance/chrominance representations, typically more attention is paid to accurately representing the luminance values, since the eye is more sensitive to these

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Decimating Chrominance

- Also, chrominance values typically have less information in them to start with, so they compress more efficiently
- And, because the eye is less sensitive to chrominance resolution, in many compression systems 1/2 or 3/4 of the chrominance values are discarded (decimated) before compression

Typical Chrominance Resolution Notation

- *4:4:4* refers to representations with no chrominance decimation
- *4:2:2* refers to representations where half of the chrominance information has been decimated, and
- *4:2:0* refers to representations where 3/4 of the chrominance information has been decimated

Quantifying Visual Quality

- Objective Metrics:
  - Mean Square Error ("MSE")
  - Frequency Weighted MSE
  - PSNR (Peak Signal-to-Noise Ratio)
    - $10\log_{10}\{peak^2/MSE\}$
  - JND (Just Noticeable Differences)
- Subjective
  - Mean Opinion Scores ("MOS")

Status of Image Compression Technology

- Existing "standards-based" compression systems have focused on television applications and have made trade-offs based on that level of quality and the limited bandwidths available
- "Cinema Quality" compression requires different approach
  - Simply "Turning Up the Knob" on the bitrate of existing systems will not provide the necessary quality
- Fortunately, technologies exist that meet the requirements

Digital Cinema Image Compression Requirements

- Compression ratios that support fast transfers of digital cinema programs
- Agile support for various resolutions, frame rates, quality levels
- Support for future upgrading
- Ideally would be a low cost, small size implementation for embedding in projector system

TV vs. Digital Cinema Image Requirements

- Digital TV profiles are based on 8-bit, 4:2:0 or 4:2:2 with resolutions ranging from 720x480 pixels (SDTV) to 1920x1080 pixels (HDTV) with compression ratios of approx. 60:1 to 200:1
- Good digital cinema image quality involves 10-bit (preferably "log") encoding, 4:4:4 ("RGB-like"), with minimal resolution of 1920x1080, expanding to much higher as projection technologies advance, with compression ratios of approx. 35:1 to 50:1

Candidate Digital Cinema Compression Technologies

- Discrete Cosine Transform (DCT) based
- Wavelet based

General Concept of Wavelets

- “Wavelets” are special types of orthogonal signals, similar to sinewaves, that allow efficient frequency-space representation of digitized images
- Wavelet compression “builds up” an approximate representation of the image using successively higher frequencies of wavelets and sub-images within the constraints of the available bit rate

Examples of Wavelet-based Algorithms

- MPEG 4 Still Textures
- JPEG 2000 (Still Images)
- QuBit™ (QuVis)

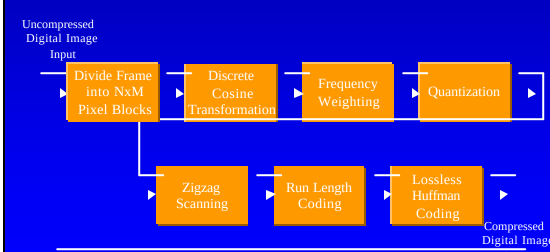
Typical Artifacts Caused by Wavelet Algorithms

- Wavelets result in “soft” or “fuzzy” images with “ wavey” distortion (due to aliasing) when compression ratios get higher

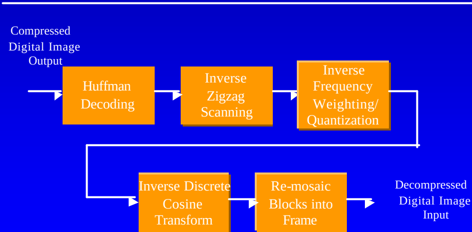
Discrete Cosine Transforms (DCT)

- Most commonly used compression technology for digital motion images today
- Image redundancy is more readily filtered out by first transforming from “pixel domain” to “frequency domain”
- DCT is a “nearly ideal” transform for conversion from pixel domain to frequency representation
- Once in DCT domain, frequency-weighted quantization reduces bit rate with “graceful” layered reduction in image quality

A Typical DCT-Based Compression System



A Typical DCT-Based Decompression System



Examples of DCT-based Algorithms

- JPEG (Intraframe DCT)
- MPEG (1 and 2) (Interframe DCT)
- MPEG4 Video Coding
- Adaptive Block Size DCT (QUALCOMM)

Typical Artifacts Caused by DCT Algorithms

- Blocking Artifacts
- Mosquito Noise
- Motion Artifacts (if using interframe compression)

Enhancing the Basic DCT Approach

- While basic DCT approaches (such as JPEG) are OK, enhancements have been developed to increase efficiency

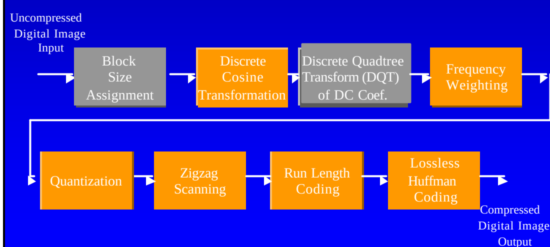
DCT Enhancement: Interframe Coding

- Most popular enhancement is to use "interframe" compression (e.g. MPEG)
  - Encodes the differences from frame to frame
  - Adds additional concern for motion artifacts and synchronization
  - Adds circuit sophistication and processing latency due to additional memory and processing
  - Very difficult to edit

Enhancement Methods: Adaptive Block Size Coding

- Another enhancement uses dynamically variable sized blocks for processing
  - Yields more efficient use of bits by assigning more "attention" to areas of higher detail

"ABSDCT" Compression System



Example of "Adaptive Block Size" DCT Approach

- The Image Frame is Divided into Smaller "Blocks" of Different Sizes for Compression

- Areas with More Detail Get More "Attention" in Smaller Blocks

Advantages to ABSDCT Compression

- Excellent compression quality at reasonable bit rates without requiring inter-frame compression
  - No motion artifacts
- Is a much simpler algorithm than inter-frame methods
  - Decoder or encoder circuits are implemented in a single ASIC chip
  - Searching and editing are straightforward

Advantages to ABSDCT Compression

- Implements "compression without compromise"
  - Works with 10-bit non-linear, up to 4:4:4 sampled images
  - Scalable operation from "ultra-high quality" originals to multiple distribution formats
- Is scalable for various resolutions, aspect ratios, frame rates, compression ratios
  - Format independent operation
- Quality-based compression (not fixed rate)

"Future-Proofness" of an ABSDCT Digital Cinema

- Expanded resolution is supported by multiple decoder devices
  - e.g., A 4kx2k image requires four chips (using today's technology)
  - Still provides low cost, small implementation
- The decoder device is very flexible to work with enhanced encoding
- The ABSDCT algorithm can support layered compression, flexible transcoding and resolution remapping

QUALCOMM's History with Image Compression

- <u>1989</u> - Invented and developed adaptive block methods initially for specialized "higher than hi-def" applications
- <u>1992</u> - Demonstrated realtime compression/decompression hardware implementation
- <u>1995-9</u> - Enhanced ABS algorithm specifically for digital cinema applications and demonstrated cinema quality compression of motion picture clips transmitted over satellite link
- <u>2000</u> - Introduction of single-chip implementation of multi-rate decoder

Implementation Considerations

- Ideally, the digital cinema decoder function should be implemented in a small, low-cost design to allow integration inside digital cinema projector
  - Better Security – no ability to “tap” digital video outside projector
  - Easier System Integration – no need for “video server”, compressed images are input to projector directly from storage
  - Lower Cost -- simpler implementation with fewer parts

QUALCOMM 43

Implementing the ABSDCT Decoder

- Single-chip solution based on standard CMOS technology
- Implements complete ABSDCT decompression on a single chip
- Includes 3-DES decryption of image and sound channels
- Synchronizes image and sound files

QUALCOMM 44

The ABSDCT Decoder Device (cont.)

- Compressed information is input on standard PCI bus format
- Output images provided in standard SMPTE-274 interface
- Output audio supports AES-3 formats (up to 8 channels)
- Interfaces with standard smart card module which stores long-term secret key information

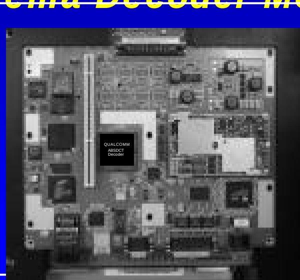
QUALCOMM 45

A Complete ABSDCT Decoder Module

- Interfaces with standard fibre-channel hard disk storage devices
- Performs decryption, decoding, image/sound synch and formatting
- Designed to embed in digital cinema projectors

QUALCOMM 46

QUALCOMM’s Digital Cinema Decoder Module



QUALCOMM 47

Summary

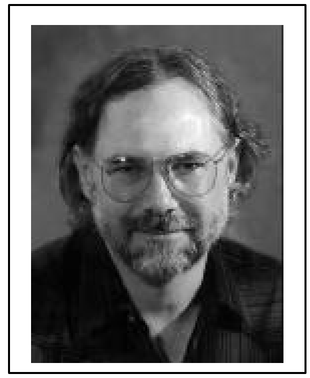
- In order to provide the necessary image quality for digital cinema economically, advanced image compression methods must be used

QUALCOMM 48

Summary (cont.)

- Existing "television-based" image compression systems do not meet cinema quality, but specially designed algorithms such as QUALCOMM's ABSDCT approach do provide the necessary quality at efficient compression ratios
- The ABSDCT algorithm implemented in a single device with built-in encryption, synchronization, and audio processing provides a very effective solution to this key digital cinema technology

"Quality and Efficiency in Digital Cinema"



Gary Demos

President

DemoGraFX

Gary Demos attended California Institute of Technology. In 1975, he joined Information International, where he not only supervised the development of the first Digital Film Printer (for which he received an Academy Scientific and Engineering Award in 1995, and an Academy Technical Achievement Award in 1996), in addition, he helped pioneer the field of computer graphics. In 1981, Gary co-founded Digital Productions and served as the Chief Technical Officer. The company produced photo-realistic images for feature films, television and advertising. Gary and his colleagues received the Academy of Motion Picture Arts and Sciences' Scientific and Engineering Award in 1984 for work on *The Last Starfighter* and *2010*. In 1986, Gary co-founded Whitney/Demos Productions, and in 1988, he founded DemoGraFX, where he serves as President/CEO and Director. Since 1989, Gary has been a prominent strategist in Advanced Television (HDTV) standards, is recognized for his patented Layered Compression System technology, is a member of the Motion Picture Academy's Digital Imaging Technology Subcommittee, is a long-standing member of SMPTE, and is an Associate Member of the American Society of Cinematographers (ASC).

"Quality and Efficiency in Digital Cinema"

by Gary Demos

Digital cinema is best conceived as a system. While projector improvements allowed serious consideration of digital cinema, there have been corresponding breakthoughs in other system elements. These include electronic cameras, disk recorders, telecines, and compression. Compression improvements now show us that high compression ratios can be achieved while maintaining very high visual quality. While the work of DemoGraFX is centered on compression quality, we are very mindful of all elements of the system which captures, processes, compresses, encrypts, stores, transmits, decrypts, decompresses, and displays the image. Such key system attributes as color primaries, non-linear digital pixel representations, and image dynamic range have a significant effect on the quality of the digital cinema system. Current practices in HDTV are sub-optimal for digital cinema. Thus, digital cinema would significantly benefit from new specifications for such system parameters.

Of special consideration is the opportunity to increase the digital cinema frame rate above 24fps while retaining 24fps interoperability. Maximum interoperability with 24fps is achieved utilizing 72fps, while providing improved computer display compatibility as well.

"QuVIS' Quality Priority Encoding"

George D. Scheckel, Jr.

Vice President, Digital Cinema and Content Production

QuVIS, Inc.

George D. Scheckel, Jr., Vice President of Digital Cinema and Content Production of QuVIS, Inc., has more than 21 years of management, marketing and sales/service experience. Scheckel received a BA in General Business from Washburn University and joined Southwestern Bell where, for 18 years, he was responsible for regional sales and telemarketing centers, product management and promotions programs. Positions with Bell include: Area Manager-Regional Staff, Area Manager-Sales/Service Center, Area Manager-Customer Product Promotion Center-Kansas and Area Manager-Accounting Separations Systems.

Prior to joining QuVIS, Scheckel was the Director of Marketing and Sales with Telecommunications Research Associates (TRA), an international telecommunications training company specializing in emerging communications technologies.

As V. P. for QuVIS, Inc. Scheckel has been a key member of the initial management team during company and product development and now focuses on digital cinema activities from the West Coast branch and directs operations to advance QuVIS imaging technology with key studios and post production customers. Since 1996 he has developed relationships with leading companies including Disney, Pixar, DreamWorks, LucasFilms, Warner Brothers, Sony, Miramax, Laser Pacific, and many other industry leaders. He has been a speaker and panelist at trade conferences and expositions and has consulted on QuBit applications worldwide, including cinema, theme park, content production and image distribution.

QuVIS Inc., headquartered in Topeka, Kansas, is the leading provider of digital motion imaging technology. QuVIS provides digital solutions based on quality priority encoding, a real-time recording process that guarantees image quality at user definable levels. QuBit, a high-resolution digital recorder, records, stores and plays back motion images for video and film production, computer animation and television broadcast.

As the heart of the digital cinema production, distribution and playback systems, QuBit is used in pilot D-Cinema applications worldwide. In short, the QuBit is the source for the digital image that replaces film. QuBit has been playing digital motion pictures since November 1999 in more than 30 commercial theaters in North America, Europe and Asia and has been used for the digital screenings of *Toy Story 2, Bicentennial Man, Mission to Mars, Dinosaur, Fantasia 2000, Space Cowboys, The Perfect Storm. 102 Dalmations,* and more. For more information please contact QuVIS, Inc., 2921 SW Wanamaker Drive, Suite 107, Topeka, KS 66614, (785) 272-3656, 800-554-8116 or visit the QuVIS web site at www.quvis.com.

"QuVIS' Quality Priority Encoding"

by George D. Scheckel, Jr.

QuVIS uses a proprietary encoding technology called Quality Priority Encoding. This method of encoding assigns the highest priority to capturing all the information present in the image so that statistical guarantees can be made for the resulting image quality. Using this process the data stream will vary, while the image quality will not. Quality Priority Encoding has its roots in wavelet-based algorithms however a number of key factors and unique processes are deployed in achieving favorable results. What follows is a summary of attributes of QPE that define the approach and differentiate it from other compression approaches.

The QuVIS QPE compression architecture has proven expandability, and was designed to range applications from consumer standard and HD video through resolutions of up to 4 billion image components per second (32 times HD)

The QuVIS QPE system is suitable for archive and critical technical applications, because it can provide quality guarantees, similar to uncompressed systems.

QuVIS, Inc.

Digital Image Technologies

George Scheckel – VP Digital Cinema & Content Production

QuVIS

NIST Overview 1/11/01

Goals for NIST Conference

- Provide background on QuVIS Digital Cinema technology
- Discuss Quality Priority Encoding (QPE)
  - Fundamentals
  - Results
- Value of QPE in an emerging market

QuVIS

NIST Overview 1/11/01

QuVIS Mission Statement

- Provide the highest quality electronic motion image technology at affordable prices that will enable a revolution in the capture, storage, production, transport and display of electronic motion imaging.
- Raise the bar for imaging quality from

"Photons In to Photons Out"!

QuVIS

NIST Overview 1/11/01

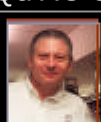
Why Use Compression?

- **Large hard drives store about 3 minutes of uncompressed HDTV. (HD-6MB/frame) More for film……..**
  - **Pixar's Bug's Life was 138,000 frames**
    - **4 Terrabytes @ native data rate of 672 MB/s**
- **Storage, transport, and manipulation of huge amounts of data is neither fast nor simple. It takes time.**

QuVIS

NIST Overview 1/11/01

QuVIS Compression Background



Kenbe Goertzen – QuVIS Pres./CEO/CTO

- Background in defense and industrial digital imaging systems
- Early 90's started working with studios to determine digital image requirements for post production film work and CGI
- Determined traditional algorithms not acceptable because could not statistically *guarantee* an image quality outcome

QuVIS

NIST Overview 1/11/01

QuVIS' Requirements for Film Recording, Mastering and Archival Applications

- Create an electronic alternative to film for motion image recording that:
  - retains *all of the desirable characteristics of film production* including large dynamic ranges
  - could be implemented in an electronic system

Initially, the image recorder was the weakest link in the digital imaging chain

QuVIS

NIST Overview 1/11/01

QuVIS' First Product Using QPE Compression - QuBit

- ***QuBit Motion Image Recorder***
  - ***29+ image formats***
  - ***Real time encoding and decoding***
  - ***Guaranteed image quality***

QuVIS Compression Deployed

- **Themed entertainment**
- **Military/Scientific**
- **Post production**
- Digital Cinema – 31 Pilot sites
  - *14 Studio Feature releases of :*
    - *Toy Story II, Titan AE, Bicentennial Man, Perfect Storm, Space Cowboys, Bounce....*
- Digital Cinema Electronic Screenings

QuVIS "Self Imposed" Compression System Requirements

- Guaranteed Image Quality
- Real time encoding/decoding
- Faster than real time archive and restore
- Flexible formats for Audio and Image
- Easy to integrate with legacy equipment
- Data communications capable
- Software based file format and conversion
- Efficient/cost effective
- Secure

Image Requirements for Cinema

- **Scalable Std Video to ~2Kx1K (curr hdwr)**
  - **QuVIS goal for Cinema 4Kx2K**
- **Min 12 bit / color component for film work**
- **Interlaced, segmented, progressive formats**
- **Various frame rates, color spaces and frame sizes**
- **Guaranteed Image quality**
- **Efficient storage and distribution of data**

QPE: Quality-Priority Encoding

A "whole image approach" to digital motion imaging

Wavelet Based - QPE

- Compression comparisons are inevitable, but historically have different design goals – perceptual, bandwidth ltd.
- Fundamental goal of QPE is different:
  - QPE technical goal is to capture all the relevant information present in the image so that statistical guarantees can be made for the resulting encoded image quality

Wavelet Based - QPE

- Using this approach the data stream will vary but the image quality will not
  - Encoding bandwidth requirements and resulting data rates are source image dependent
- Algorithm elegance and system must accommodate significant peak rates but average data rate is very efficient

QuVIS

QPE General Specifications

Compression	Wavelet based with unique implementation characteristics to achieve image quality goals
	Spatial encoding in current hardware
Bit Depth	36 Bits (12 Bits per Channel) curr hdw
	64 Bits (16Bits/ 4 components in software and ASIC)
Image Resolution	Independent scalable up to 8Kx8K
Formats	Interlaced, Progressive and Segmented

QuVIS

Quality Priority Encoding - Basics

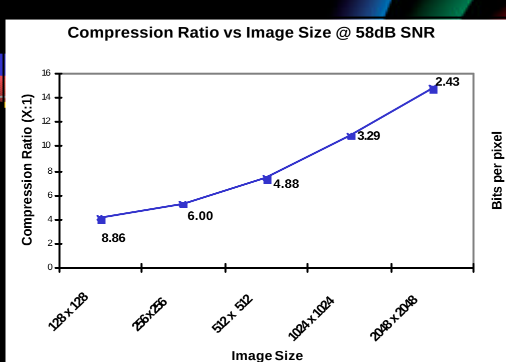
- Select Image Quality – Specify SNR that want to maintain as minimum image quality (36-72 WPSNR)
- Select image format (Currently 29 image formats in QuBit)
  - Now - standard def to 2K x 1K
  - 2001 – standard def to 4K x 2 K
  - Frame rate, progressive, interlaced, segmented frames

QuVIS

Quality Priority Encoding - Basics

- **QPE Processes (Encodes) the Whole Image**
  - **Statistical sampling process: The larger the sample size → the more reliable the prediction of an individual event, i.e. pixel**
  - **Understanding EVERY pixel in an image increases the understanding of the correlation between all pixels and enables more accurate and efficient encoding/decoding**
    - **Results: As image size increases the # of bits per pixel required to represent the image exactly decreases**

QuVIS



Quality Priority Encoding - Basics

- Maintaining the ***original*** image quality is the priority, QPE does not discard any portion of the total image frequency spectrum
  - Preserves entire Modulated Transfer Function for user specified SNR levels
    - As high-frequency information increases (sharp edges, film grain etc) data rate increases accordingly and vice versa
  - Assures that there will not be any occasional artifacts in “busy” sequences

QuVIS

Quality Priority Encoding - Basics

- Over the horizon of a clip/movie average data rate is very efficient because sustained high-frequency information is not “normal”
- Capturing all the frequency information in an image allows us to guarantee the outcome

QuVIS

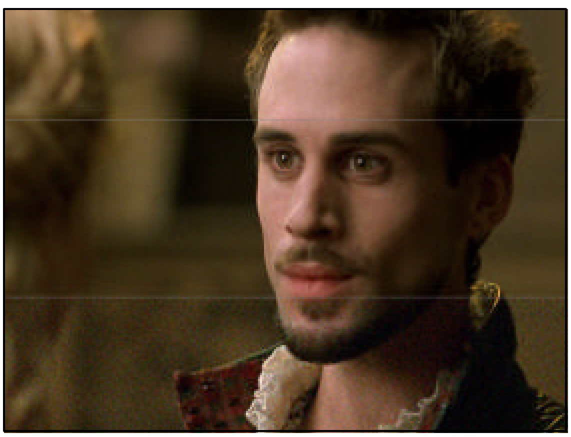
NIST Overview 1/11/01

Quality Priority Encoding - Basics

- QPE is free from coherent artifacts. Error tolerant because errors are distributed through the entire image, not regionalized or visible
- If lower SNR images are acceptable for an application, the image “softens” in a natural manner as SNR is decreased

QuVIS

NIST Overview 1/11/01



NIST Overview 1/11/01

NIST Overview 1/11/01

NIST Overview 1/11/01

Quality Priority Encoding - Basics

- Currently implemented in hardware
  - FPGA's today and ASIC's in process for 2001 deployment
- Real Time encoding and decoding
  - Accommodates production and distribution deadlines, immediate review and in the near future "Live" non-theatrical programs
- Symmetrical – Encoding & Decoding (Same Complexity)
- Algorithms are scaleable. As image size increases no changes required to scale up

QuVIS

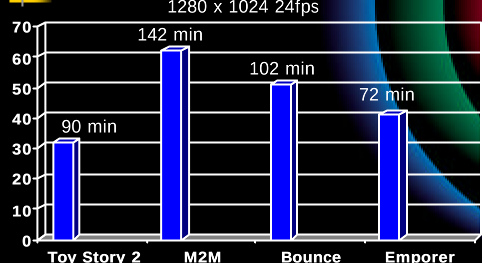
Quality Priority Encoding - Results

- **QPE average bit rate requirements are very low and minimize requirements for:**
  - **Distribution Bandwidth**
    - **Utilize current communications technology**
  - **Server Hard Drives**
  - **Server RAM Buffers**
  - **CPU Processor Requirements**

QuVIS

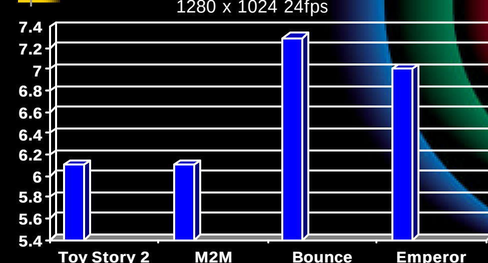
QPE Results - Total GB Data per Movie

1280 x 1024 24fps



QPE Results - Average MB/s

1280 x 1024 24fps

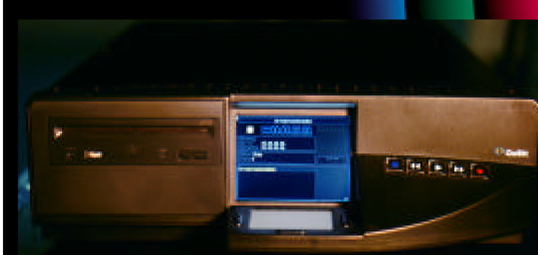


QuVIS compression Summary

- Guaranteed Image Quality
  - User Specify Signal to Noise quality (SNR)
  - Do not discard any of the frequency information
  - Bit rate varies over horizon of a clip - efficient
- Scalable – "any" resolution or frame rate up to 16 bits per color component
- Generationally stable
- Images live in the information domain, store to any digital media, extract with software
- Average data rate is efficient & cost effective

QuVIS

Digital Cinema QuBit with QPE



Contact info

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- 1-800-554-8116

"Digital Cinema Clip Demonstration"

Matt Cowan

Principal

Entertainment Technology Consultants

Matt Cowan is a principal at Entertainment Technology Consultants, where he is involved in digital cinema developments in the areas of projection, systems, and mastering. Entertainment Technology Consultants developed the mastering methodology in current use for mastering feature films for digital release. He has worked extensively with dynamic range and colorimetry of DLP based projectors to achieve the best image performance for the cinema. Entertainment Technology Consultants has mastered extensive test material for digital cinema, and supported the tests and digital mastering for *Star Wars: Episode 1 - The Phantom Menace, Tarzan, Toy Story,* and *Bicentennial Man.*

Mr. Cowan has also worked with industry players and has prepared detailed digital cinema business models that link the traditional cinema business with the new opportunities presented by a digital system.

Mr. Cowan has been an invited speaker and panelist for numerous industry conferences and film festivals, where he has presented papers on digital cinema business, technology, and image quality issues.

Prior to founding Entertainment Technology Consultants, Mr. Cowan was Director of Technology at Electrohome; developing high performance projector platforms aimed at digital cinema applications, and new technology based business initiatives.

Mr. Cowan has a masters degree in Electrical Engineering from the University of Waterloo, and is a member of SMPTE. He has been active in SMPTE technical conferences both as speaker and as session chair, and has participated in a number of industry panels on Digital Cinema. He is currently the Chairman of the SMPTE Digital Cinema Compression Study Group, and a participant in the MPEG ad hoc group on digital cinema.

"Digital Cinema Clip Demonstration"

by Matt Cowan

This presentation will demonstrate a number of digital cinema clips from theatrical releases. These clips were mastered for DLP Cinema™ technology, and have been chosen to illustrate different theatrical intents, and to demonstrate the ability of the digital system to deliver the intent.

The clips were mastered using a Texas Instruments DLP Cinema™ projector as the display target in the digital mastering suite. The clips originate from film and from digital files. For the film material, scanning was performed by C-Reality™ and Spirit™ telecine machines. The digitally generated material was rendered directly to the desired digital format.

The digital clips are stored for this presentation using wavelet based compression in a QuBit™ server manufactured by QuVIS, Inc. Bitrates range from 45 to 60 Mbits/sec, depending on the material. The material is projected in a DLP Cinema™ projector manufactured by Digital Projection, Inc. The projected image is 1280 x 1024 pixels, and uses 1.5:1 and 1.9:1 anamorphic lenses to create the correct aspect ratio for flat and scope material, respectively. Contrast ratio is greater than 1000:1, and the image brightness is 12 foot Lamberts for peak modulated white. The projector's color space is significantly extended beyond conventional SMPTE color gamut to give better yellow-gold, cyan, and green performance. This system is representative of the systems in current use in the digital cinema field trials.

Each clip will be briefly introduced with a discussion of its technical production and its theatrical intent.

"Research Partnerships for Innovation"

Alan Balutis

Director, Advanced Technology Program

NIST

Alan Balutis came to Washington in 1975 as a National Association of Schools of Public Affairs and Administration (NASPAA) Fellow. He worked in a variety of budget, personnel, policy and legislation, and management analysis positions at the then Department of Health, Education and Welfare (HEW) before coming to Commerce in 1979.

Prior to coming to Washington, he served as an Assistant Professor of Political Science at the State University of New York at Buffalo and worked with the New York State Legislature and the National Conference of State Legislatures. He is the author or co-author of four books, over 100 articles, and numerous conference papers on government reorganization, legislative reform, budgeting, and internship programs.

In Commerce, he worked as Director, Office of Systems and Special Projects (1983-84), as Director, Office of Management and Organization (1984-87), as Director for Budget Planning and Organization (1987-94), as Director of Budget, Management and Information (1994-1998), and as Deputy Chief Information Officer (1998-2000). He was named to his current position, Director of the Advanced Technology Program, in April 2000. The Advanced Technology Program (ATP) co-funds with industry high-risk research projects to develop enabling technologies that can form the basis for new and improved products, manufacturing processes and services. It stimulates partnerships among companies of all sizes, universities, and the rest of the R&D enterprise.

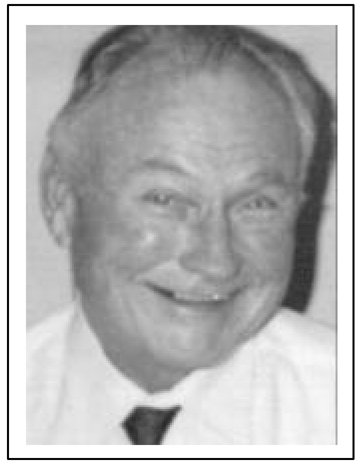
"Research Partnerships for Innovation"

by Alan Balutis

This presentation provides an overview of the Advanced Technology Program (ATP) at the National Institute of Standards and Technology. This exciting program co-funds high-risk, enabling technology development with the potential for broad-based economic benefits. The presentation also provides details on new initiatives and the role of Digital Cinema in the Program.

“MPEG dcinema Profile”

Donald C. Mead
Vice President
Digital Electronic Cinema, Inc.



MPEG, a working group of the International Standards Organization (ISO) has developed 3 Standards (MPEG 1, MPEG 2, and MPEG 4) over the last 12 years and is about to release a fourth (MPEG 7). It has now begun work on a very challenging effort to provide compression standards for very high resolution content.

This paper covers the effort thus far, the requirements, the documents that have been generated, and the " Call for Proposals" that will be released in late January 2001.

Special emphasis will be placed on critical issues of the first round of testing. These include content selection, projectors, screens, and the methodologies of testing.

One of the new items in this proposed standard is that it will include truly lossless coding for archival purposes and "perceptually lossless" coding for distribution.

Digital Electronic Cinema Inc.(DECI)

MPEG & dcinema
Donald C. Mead
11 Jan 2001

Digital Electronic Cinema Inc.(DECI)

MPEG Background

- MPEG is a subdivision of the International Standards Organization(ISO) Formally, ISO/IEC SC29 WG11
- Started in 1988 under Convenorship of Dr. Leonardo Chiariglione
- MPEG has developed the MPEG 1, MPEG 2, & MPEG 4 standards. A fourth standard, MPEG 7 will be finalized shortly

Digital Electronic Cinema Inc.(DECI)

MPEG Process

- Develop Requirements
- Public Call for Proposal
- Evaluate proposals and develop Verification Model
- Refine Verification Model through Core Experiment Process
- "Design Freeze" with Committee Draft

Digital Electronic Cinema Inc.(DECI)

dcinema Profile Chronology

- Dec 99 -Top level requirements presented to MPEG
- Feb 00 - Unanimous U. S. National Body resolution to MPEG requesting development of a dcinema profile
- Mar 00 - ad hoc group formed to develop requirements
- July 00 - 4 Output documents / ahg re-established
- Oct 00 - ahg under Test Group / 2 output documents
- Dec 00 - Special Meeting of ahg to develop Test

Digital Electronic Cinema Inc.(DECI)

Requirements Summary

- Must have algorithms for both lossless(archive) and perceptually lossless(distribution)
- Must support input images up to 16 million pixels
- Must support pixel intensity up to 16 bits per color
- Must support simple transcoding from lossless to lower resolution
- Must support both constant and variable bit rate coding

Digital Electronic Cinema Inc.(DECI)

Key Test Issues

- Content
- Test Methodology - sequential or side-by side viewing, for example
- Screen- perforated or not, power or not, reflectivity
- Projector - lack of a high resolution projector requires compromise
- Anamorphic properties or not

Digital Electronic Cinema Inc.(DECI)

Schedule

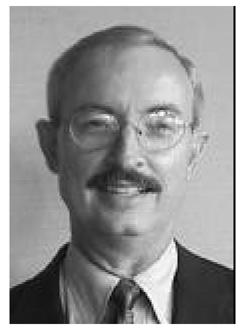
- ☹ **Jan 01 - Release Call for Proposals**
- ☹ **Feb 01 - Reservations Due and Test Content Available**
- ☹ **June 01 - Proposals Due and Shoot out**
- ☹ **July 01 - Verification Model 1**
- ☹ **Jan 02 - Committee Draft(CD)**

"Briefing on SMPTE DC28, Technology Committee on Digital Cinema"

Robert M. Rast

Vice President, Business Development

Dolby Laboratories



Bob Rast is responsible for business development at Dolby Laboratories, San Francisco. Development projects include digital cinema (d-cinema), music delivery, and expanding usage of Dolby technology in computers and games.

Bob joined Dolby in September 1998 to lead Dolby's efforts in digital cinema. He is vice chairman of the SMPTE Technology Committee on Digital Cinema (DC28). He also continues as an industry leader in digital television (DTV), and is a member of the executive committee of the ATSC (Advanced Television Systems Committee).

Previously, Rast was Vice President, Technical Business Development, for General Instrument, where he focused on HDTV and coordinated GI's participation in digital television standards setting. Following GI's historic proposal for an all-digital HDTV system, in 1990, Rast led the effort to make GI's system the U.S. broadcast standard. When the remaining four competing systems merged and became the Digital HDTV Grand Alliance in 1993, Bob became one of its leaders. The Grand Alliance system is the basis for the DTV broadcast system now being deployed in the U.S. and other countries, and which included Dolby Digital™ surround sound.

Before General Instrument, Rast spent seven years with American Television & Communications (ATC), the cable TV division of Time, Inc. A senior vice president, he was responsible for business and technology development.

Prior to ATC, Bob was with RCA for eleven years. At RCA's Consumer Electronics Division he was an engineering manager responsible for design and development of digital products. At RCA Laboratories, he was Group Head, TV Systems Technology Research.

Rast holds 13 patents. He was a co-recipient, in 1980, of the RCA David Sarnoff Team Award for Outstanding Technical Achievement. In 1997, he accepted, on behalf of General Instrument, an engineering Emmy awarded to the Grand Alliance member companies for contributions to the broadcast DTV standard. He was named to the DTV Honor Roll by Broadcasting and Cable magazine, and is a member of the Academy of Digital Television Pioneers. His contributions to HDTV and the Grand Alliance are described in New York Times writer Joel Brinkley's 1997 book, Defining Vision.

Mr. Rast holds a BSEE degree from the University of Maryland, and attended graduate school at the University of Pennsylvania.

"Briefing on SMPTE DC28, Technology Committee on Digital Cinema"

by Robert M. Rast

SMPTE is the host organization for a digital cinema standards activity for the motion picture industry. The committee formed early in 2000. Throughout the year numerous meetings on its study groups were held. Mr. Rast, vice chairman of DC28, will provide a briefing on DC28, its progress, and the outlook.

Status Report: D-Cinema Technology Committee (DC 28)

ITEA Seminars

Los Angeles

January 2001

Why Standards?

- Need to Ensure
  - Interoperability
  - Compatibility
  - Performance
  - Extensibility
- Desired by Many, Demanded by
  - Content Owners
  - Exhibitors

Why SMPTE?

- Neutral Cross-Industry Technical Forum
- Established Track Record
- SMPTE provides a host function, to help the industry figure out D-Cinema
- The SMPTE end product will be standards, but the early assessment phase is broader

DC 28 Technology Committee

- Due Process Committee
  - Can Write Standards, But Has Not Yet Done So
  - Has Fairly Strict Guidelines & Procedures
- Management
  - Curt Behlmer - Chair
  - Bob Rast – Vice Chair
  - Mark Hyman – Secretary

Committee Scope

- DC 28 includes
  - Mastering
  - Distribution (transport)
  - Exhibition
- DC 28 does not include
  - Capture
  - Production

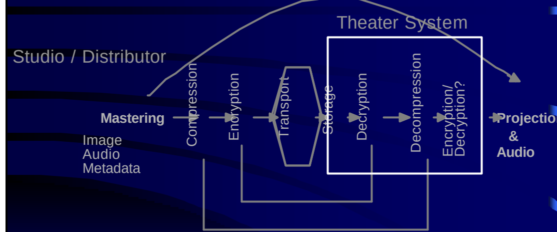
DC 28 Mission Statement

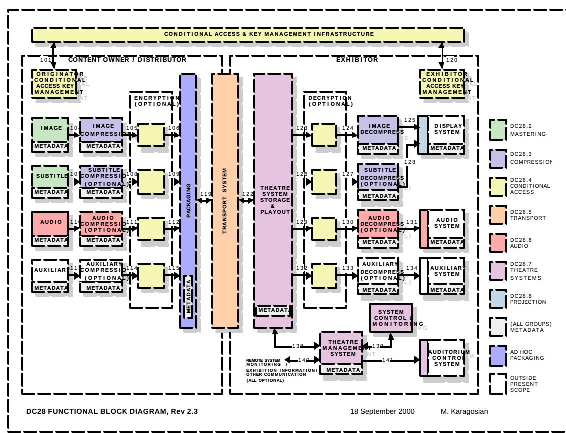
- Provide Industry Technical Forum for D-Cinema
- Identify Key Systems & Technology Issues
- Develop a Recommended Approach to Standards
- Identify, Establish and Coordinate Necessary Groups to Achieve Overall Objectives
- (Future) Write the SMPTE Standards

Study Groups

- Considering that
  - SMPTE is a host for the industry
  - The initial need is broader than just SMPTE standards
- We created study groups initially
  - Not due process working groups
  - Broader charter, but don't write standards
  - Can evolve to working groups, write standards

D-Cinema System





Study Groups at January 2001

28.1	Steering/Systems	*Curt Behlmer*
28.2	Mastering	*Jerry Pierce*
28.3	Compression	*Matt Cowan*
28.4	Conditional Access	*Harrison/McMannis*
28.5	Transport	*Storozum/Garsha*
28.6	Audio	*Gary Margolis*
28.7	Theater Systems	*John Wolski*
28.8	Projection	*Al Barton*

Ad Hoc Groups

- Two formed to date
- Colorimetry *Fred Van Roessel*
  - Previously Worked with P3
  - Mastering & Projection Coordination
- Packaging *Chuck Garsha*
  - Recently formed
  - Affects a number of groups
  - Likely to become a study or working group

Liaison with Industry Organizations

- Representation
  - NATO
  - MPAA
  - ITEA
  - USC / ETC
  - ICIA
  - AES
  - MPEG
- Outreach
  - ASC
  - Cinematographer's Guild
  - DGA
  - AMPAS
  - International

Status Report

- Three Meetings of Technology Committee to Date
- 12 Months of Work
- Study Groups Continuing to Meet Monthly
- Significant Effort
  - Over 250 people, 100 Companies
- Outreach Effort Continues

Interim Report

- Each Study Group Now Completing Interim Reports
  - Key Issues, Considerations and Recommendations
- To be integrated into a DC 28 interim report
  - Overview, System Assessment & Glossary
  - Available now on-line
- Currently an internal management document
  - Expect holes and substantial variability
- Expect to publish summary in February 2001 SMPTE Journal

Outlook

- DC 28 is Necessary, But Not Sufficient
- Working Groups in Near Future
- Beyond SMPTE
  - Market Trials
  - Performance Testing (e.g., USC / ETC)
- DC 28 to Document Conclusions

How Do You Get Involved ?

- Statement of Participation
  http://www.smpte.org/engr/sop.html
  (Reference DC28)
- Email Reflector
  http://smpte.vwh.net/cgi-bin/majordomo
- FTP Site
  ftp://smpte.vwh.net

Resources

- Meeting Calendar
  ftp://smpte.vwh.net/pub/dc28/DC28.0-Technology_Committee/Meeting_Calendar
- Interim Reports (early November)
  ftp://smpte.vwh.net/pub/dc28/DC28.0-Technology_Committee/Interim_Report

SMPTE

D-Cinema Technology Committee (DC 28)

Study Group Reports

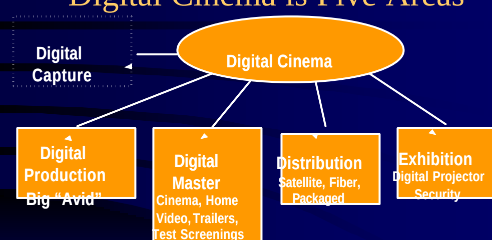
- Mastering (DC28.2)
  - Jerry Pierce & Howard Lukk
- Compression (DC28.3)
  - Matt Cowan
- Conditional Access / Encryption (DC28.4)
  - Chuck Harrison, Bill McMannis & Michael Karagosian
- Theater Systems (DC28.7)
  - John Wolski & Michael Karagosian

Study Group Reports

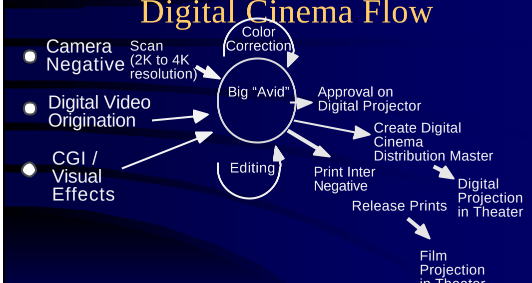
- Transport / Delivery Systems (DC28.5)
  - Dick Stumpf & Chuck Garsha
- Audio (DC28.6)
  - Tom Scott & Garry Margolis
- Projection (DC28.8)
  - Al Barton

SMPTE DC28.2 Mastering Committee

Digital Cinema is Five Areas



Digital Cinema Flow



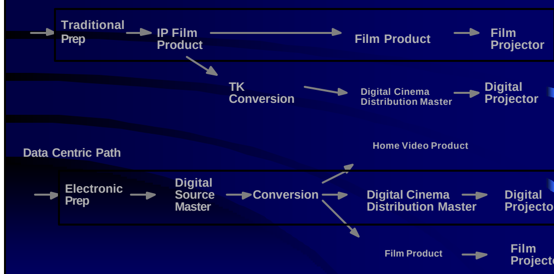
Mastering Committee

- First step in conversion to D-Cinema Presentation
- Will impact future way we make a movie (digital version at same time as film version)
- Evolutionary design of flow
- Goal is to set the standards for delivery to theater without interfering with the creative way we make a movie

Goals of Mastering

- Digital presentation should do no harm. All versions of D-Cinema should be equivalent or better experience to projected film
- The standard should have functionality of film (plays anywhere in the world)
- Should not be limited to 35mm film temporal restrictions (24fps) but able to convey other experiences, if desired
- A better and more consistent experience for the consumer
- More tools for the filmmaker in making stories

Mastering Flows



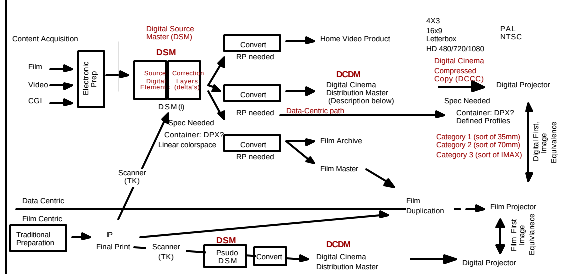
The (Tentative) Answer

DCDM *Distribution* Master (not the editing master)

	Vertical	Horizontal (2.39:1)	1.85 Horizontal	Bit Rate		Mega-PELS
DCDM 10D	2048	4928	3808	8.7	Gb/sec	10.1
DCDM 5.5D	1536	3680	2848	4.9	Gb/sec	5.7
DCDM 2.5D	1024	2464	1920	2.2	Gb/sec	2.5

Square PELS 10 bit log color, New color primaries, white point 5500, 4:4:4, Frame rates 24P, 48P, (60P), (72P), Fixed vertical variable width

FUTURE MASTERING AND DISTRIBUTION FLOWS



DC28.3 Compression Study Group

Matt Cowan, Chairman

Objectives

- To define image compression requirements
- To determine how to specify requirements
- To identify standards and recommended practices
- To examine how to test image compression quality

Process

- Meet approx. monthly
- About 100 participants
  - core group of 20
- Prepared report summarizing study group activities
- Preparing to enter Working Group phase

Compression Requirements

- Visually Lossless
- Forward - Backward compatible
- Economic
- Open standard
- High efficiency
- Compatible with other system elements
  - encryption, watermarking,

Achieved:

- Requirements
- General test issues
- Needed Standards and RP's identified

To be Completed:

- Comprehensive testing program

Difficulties in Study Group

- Compression is I/P intensive
  - Current players have large investments in I/P
  - Unwillingness to share I/P in working group phase
- Unable to penetrate the "heart" of compression issues

Recommendations

- Finish test program under study group
- Enter working group for writing compression standard
  - Gives ability to call for technology proposals

SMPTE STUDY GROUP DC28.4 CONDITIONAL ACCESS & ENCRYPTION

Chuck Harrison	<chuck_harrison@iname.com>	Co-Chair
Bill McMannis	<bmcmannis@gqti.com>	Co-Chair
Phil Lelyveld	<phil.lelyveld@disney.com>	Secretary

Contact co-chair to participate

Monthly meetings at AMPTP

Biweekly conference call

DC28.4 E-mail reflector

INTRODUCTION & SCOPE

Title: - DC28.4 Study Group on Conditional Access & Encryption

Reality: - Content Protection (encryption/decryption)
- Conditional Access
- Key Management
- Watermarking & Fingerprinting
- Audit Trail
- And a bit more

OUR INPUTS

- Studios – individually and through MPAA
- Theatre Owners
- Distribution
- Equipment manufacturers
- Security experts

REQUIREMENTS EXPRESSED TO US

Content Owners
- End-to-end security
- Renewability, upgradeability
- Traceability for anti-piracy enforcement
- Precise control of authorized use (per rental agreements)
- Worldwide compatibility
- Single inventory

Exhibitors
- Reliability & Maintainability
- Ease of use
- Flexibility in scheduling
- Multivendor interoperability
- Field reconfigurability

Everyone
- Affordable
- Early rollout

SECURITY "BAG OF TRICKS"

- Encryption algorithms for content
  AES (Rijndael), 3DES, others
- Authentication techniques
  - for people, communications, and equipment
  - may use public key certificates
- Key management
  Exchange or generate keys, secure from eavesdroppers
- Systems may be on-line or off-line
  - online: private networks, modem, internet
  - offline: smartcards, crypto tokens, disks, etc.

SOME WORK ITEMS

- Audit system for usage tracking
  - ensures every showing is logged
  - completely separate fromboxoffice systems
- Standard way to specify "authorized use" conditions
- Watermarking (forensic)
  - trace distribution path and time/place of piracy
  - DCinema performance goals are very demanding
- Security within the theatre
  - must defend against possible "hackers" in booth
  - no exposed plaintext
  - tamper response: equipment "self defense"
  - maintainability without introducing security holes

DC28.4 SUMMARY

- It can be done, but needs careful execution.
  - Full-performance watermarking may be delayed.
- We have developed a fairly complete set of requirements.
  - Refinements will continue.
- Some proven cryptographic tools are available.
- We need additional input from Digital Cinema equipment designers and security experts in order to continue.
- Working Group should convene early 2001. We want participation from all sectors of the business.

STUDY GROUP DC28.4
CONDITIONAL ACCESS

This Presentation Can Be Found In The Conditional Access/Presentations Folder
ftp://smpte.vwh.net/pub/dc28/

DC28.5 Study Group
On
Transport & Delivery Systems

Richard Stumpf

DC28.5 Study Group On Transport & Delivery Systems

Purpose:

1. Receive content files from Compression/Encryption processes
2. Provide for a variety of transport mechanisms
   - Physical Media
   - Satellite
   - Terrestrial Networks
3. Provide common interfaces at input and output transport link

DC28.5 Study Group On Transport & Delivery Systems

- Group held 10 monthly meetings since January 2000
- Total membership – 77
- Co Chairs – Chuck Garsha , Dick Stumpf
- Secretary – Ira Lichtman

DC28.5 Study Group On Transport & Delivery Systems

Study Group Investigated:

- Current practice in film and digital cinema distribution
- Suitable digital transport methods, physical media, terrestrial & satellite
- Transport link input and output gateway coordination
- Ways to provide common interface at input and output of transport link

DC28.5 Study Group On Transport & Delivery Systems

Key Findings

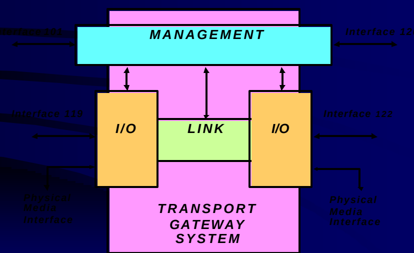
- Digital cinema demands on transport are unique in terms of
  - Payload capacity
  - Multicast requirement
  - Time sensitivity
  - Transparency/robustness
- Adhere to OSI Model to meet industry demands for openness & interoperability
- Provide for management of conditional access, transport configuration & management data

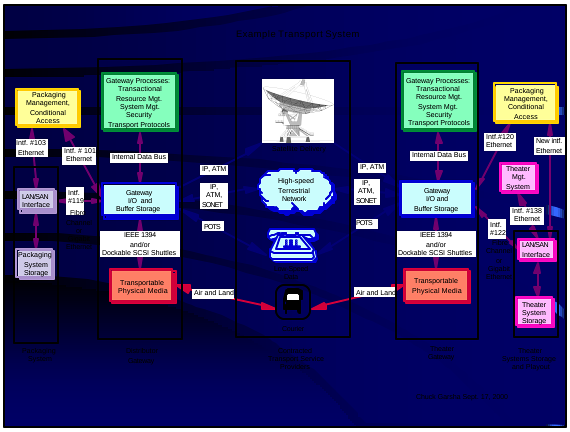
DC28.5 Study Group
On
Transport & Delivery Systems

Key Findings

- ❑ A conversion facility or “Gateway” is recommended at input and output of the transport link
  - Conform content, ancillary & supervisory data to range of transports links
  - Perform transcoding and multiplexing to conform to needs of various types of links

DC28.5 Study Group
On
Transport & Delivery Systems





DC28.5 Study Group
On
Transport & Delivery Systems

Key Findings

- ❑ The need was defined for a Packaging Working Group to:
  - Recommend a unified approach to organizing and cross-referencing the various types on content, ancillary and management data
  - Make recommendations on structure of wrapper or container for DC distribution
  - Form Working Group to standardize interfaces between Digital Cinema Packaging, Transport & Theater Systems

Digital-Cinema Transport
SMPTE Study Group (DC28.6) Audio
Interim Report

Tom Scott, *ednet, inc.*

SMPTE

Digital Cinema Background:

- **Transition from Analog to Digital well under way in 2000**
- **Digital Sound already in theatres**

D-Cinema System Audio Assumptions

- **File Based System**
- **Transport methodology is immaterial**
- **Local storage in theatres**
- **Audio and image are separate files**
- **Live event streaming is not central to Digital Cinema**
- **Legacy material must be accommodated**

Digital Sound on Film

- **As linear as film**
- **Analog backup on the film**
- **Several different formats have evolved**
- **Copies must be individually produced, transported, warehoused, recycled...**

Digital Cinema Sound

- **A file or collection of files**
- **Synchronized to Image by Theatre System**
- **Spliceable to make up show**
- **Able to carry additional tracks**
  - **Commentary, Hearing Impaired**

DCDM Audio

- Twelve channel capacity
- 24 bits at 48 kHz sampling
- Mappable to individual theatre speaker setup

Compression in Current Systems

- **Required in current systems because of film resolution and playback technology**
- **Does not improve quality**
- **Considered by most a burdensome complexity**

Compression in Digital Cinema

- **Do we still *need* compression?**
- **May be required during transition years**
- **ITUR 5 transparency must be achieved**

Encryption and Watermarking

- **Required to protect intellectual property**
- **ITUR 5 rating must be observed**

Theatre Playback

- Twelve channel capacity
- 5.1 channel minimum delivery to speakers
- Channel to speaker routing via metadata

New Capabilities for Digital Cinema Sound

- **Multiple versions (languages and ratings) as allowed by content owner**
- **Additional “tracks” for Hearing Impaired**
- **Commentary for Visually Impaired**

Recommendations for Working Groups

- **DCDM Master Standards**
- **Digital Cinema Audio Quality Issues**
- **Digital Cinema Audio Systems Issues**
- **Digital Cinema Packaging Issues**

SMPTE DIGITAL CINEMA DC28.7 THEATRE SYSTEMS STUDY GROUP

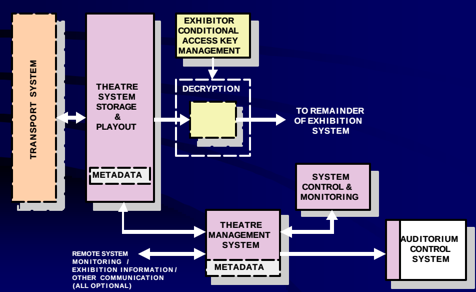
John Wolski	Chairman
Michael Karagosian	Vice-Chairman
Kevin Wines	Secretary

INTRODUCTION & SCOPE

Scope: Operational Issues
Maintenance Issues
Interoperability / Scalability / Extensibility

Meet: Typically Once Monthly
20 - 30 Attendees

BLOCK DIAGRAM



SYSTEM ELEMENTS

- Storage / Playback
  - Transport Communication
  - Interface to Physical Media
  - File Storage
  - Playback (Streaming Data)

SYSTEM ELEMENTS

- Theatre Management System
  - Operator Identification
  - Assembly of Shows
  - Automation Console
  - Control & Monitoring Console

SYSTEM ELEMENTS

- Control & Monitoring
  - Status & Fault Monitoring
  - Component and Automation Controls
  - Remote Monitoring
  - Confidence Monitoring
  - Metadata

KEY FINDINGS

- Standard Networks and Busses
  - Interoperability / Scalability / Extensibility
  - Support for both IP and Streaming Data (examples:)
    - IEEE 1394a/b
    - FibreChannel

KEY FINDINGS

- Standard Protocols
  - SNMP for control and monitoring
- Use OSI when describing transports
  - "EIA 232" is not good enough

KEY FINDINGS

- Standard method for assembling shows
  - Metadata flags can point to splice points and automation events

MOVING FORWARD

- Recommend 4 New Working Groups:
  - Application Protocols Working Group
  - Data Transport Working Group
  - DC Metadata Working Group
  - Data Packaging Working Group

MOVING FORWARD

- Continue Theatre Systems Study Group
  - Interface to the Exhibition Community

SMPTE DIGITAL CINEMA DC28.7 THEATRE SYSTEMS STUDY GROUP

This Presentation Can Be Found In The Theatre Systems/Documents Folder
ftp://smpte.vwh.net/pub/dc28/

DC28.8 Digital Cinema Projection S G

Chair: Al Barton

Vice-Chair: Dave Lund

Secretary: Dave Schnuelle

ftp://smpte.vwh.net/pub/dc28/DC28.8-projection

dc28-projection-list@smpte.vwh.net

DC28.8 Digital Cinema Projection S G

- SG meets once a month*
- SG has been meeting since January 2000
- SG attendance averages 20~30 people
- SG members include: exhibition, manufacturers, studios, etc.

*except October

DC28.8 Digital Cinema Projection S G

- Two main discussion areas:
  - Projection Systems
    - Interfaces
    - Security
    - Minimum specifications
  - Projected Image
    - Minimum specifications

DC28.8 Digital Cinema Projection S G

- Projection System Interfaces
  - There must be a common interface for the DCDM
    - Must also support direct interface with mastering for QC and QA
  - The implementation of this interface must not preclude interfaces for Live Events, Computer Presentations, Video Conferencing, PPV, etc.

DC28.8 Digital Cinema Projection S G

- Projection System Security
  - Must be "tamper proof"
  - Must allow for maintenance
  - Must allow for fingerprinting
  - Must allow for CA deployment
  - Might need to allow for decode an decryption processing inside the console

DC28.8 Digital Cinema Projection S G

- Projection System Minimum Specifications
  - Must have 2K x 1K or greater imager
  - Must handle 24Hz frame rate
  - Must map to colorimetry used for mastering
  - Must reproduce image with no visible degradation if scaling is used

DC28.8 Digital Cinema Projection S G

- Projected Image Minimum Specifications
  - Minimum of 12ftL on screen
  - Minimum geometric distortion
  - Minimum viewing distance
  - Maximum uniformity deviation
    - Brightness
    - Color
  - Minimum contrast ratio

DC28.8 Digital Cinema Projection S G

- Items still under discussion:
  - White Point - D55 vs. D65
  - Test and measurement methods
  - How to handle subtitles

DC28.8
Digital Cinema Projection S G

- SG is now ready to move to a WG
  - Write standards for DC projection
  - Write recommended practices for implementation of today's technologies
- Need input from ALL aspects of the industry

"Applications of Human Vision Modeling to Digital Cinema System Design and Testing"

Jeffrey Lubin

Senior Member of the Technical Staff

Sarnoff Corporation

Jeffrey Lubin received a Ph.D. in Psychology at the University of Pennsylvania, and is currently a Senior Member of the Technical Staff at the Sarnoff Corporation, where he is the lead scientist in a group that develops and applies human vision models to various problems in electronic display. Dr. Lubin holds numerous patents in both human vision modeling and image processing, and is the principal investigator behind the Sarnoff JNDMetrix™ family of image quality metric algorithms that were recently awarded a technical Emmy from the National Academy of Television Arts and Sciences.

Digital Cinema 2001

"A New Vision for the Movies"

"Applications of Human Vision Modeling to Digital Cinema System Design and Testing"

by Jeffrey Lubin

Quantitative modeling of a human observer's ability to detect differences between two image sequences can provide useful performance information for the design and testing of digital cinema systems and components. In this talk, the basic elements of a human visual discrimination model will be reviewed, and specific applications in digital cinema will be discussed. In particular, the applications of visual modeling to "perceptually lossless" digital compression will be described.

January 11-12, 2001

National Institute of Standards & Technology

"Impediments to Reproducibility in Display Metrology"

Edward F. Kelley

Physicist

NIST

Graduating from University of Idaho in 1970 in physics, he entered graduate school at Montana State University finishing in 1977 with a Ph.D. in experimental atomic physics. He started in a post-doctoral position at NIST (formerly the National Bureau of Standards) in high-voltage impulse measurements using the electro-optical Kerr effect. He continued on at NIST as a staff member for approximately 11 years investigating liquid dielectric breakdown and high-voltage pulse-measurement techniques. In 1988, he received the R&D 100 award for an Image Preserving Optical Delay designed for observing the initiation of random phenomena such as partial discharges. After having returned to Idaho to get a taste of private consultation and university teaching, he returned to NIST and is now the Project Leader of the Display Metrology Project and oversees the Flat Panel Display Laboratory at NIST to assist industry in developing display metrology and measurement standards to quantify display quality.

Digital Cinema 2001 *“A New Vision for the Movies”*

“Impediments to Reproducibility in Display Metrology”

by Edward F. Kelley

Most people are surprised to learn of the complexities of measuring the performance of electronic displays. Serious errors are encountered in even seemingly simple measurements if we blithely measure displays without being aware of the pitfalls. We discuss the nefarious veiling glare, the measurement of resolution, the remarkable complications found in reflection measurements, and other surprises that affect reproducibility of the measurements.

January 11-12, 2001

National Institute of Standards & Technology

IMPEDIMENTS TO REPRODUCIBILITY IN DISPLAY METROLOGY

Digital Cinema 2001

January 11-12, 2001
NIST

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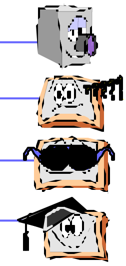
Gaithersburg, MD 20899-8114

IMPEDIMENTS TO REPRODUCIBILITY IN DISPLAY METROLOGY

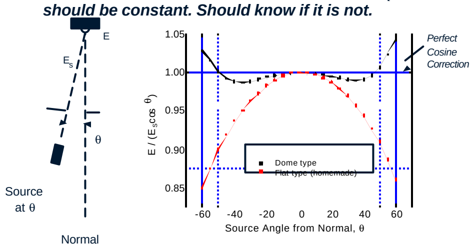
- Display Metrology
  - *Devices & Deployment*
  - *Measurements & Diagnostics*
  - *Reflection Metrology*
  - *Tips & Things*



Devices & Deployment, Cont.

- Illuminance Meter — Cosine Corrected?

  For small source at q, illuminance goes as cosq.
  If illuminance meter is cosine corrected, E/cosq should be constant. Should know if it is not.

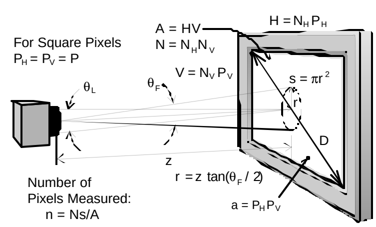


Example ONLY! Don't lift these data and use elsewhere.

Devices & Deployment, Cont.

- Subtense of Detector & Region Measured

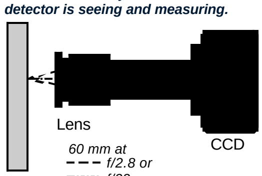
  Be aware of rays of light contributing to the signal. Some displays have a viewing-angle sensitivity, and we can inadvertently measure what our eyes don't see.

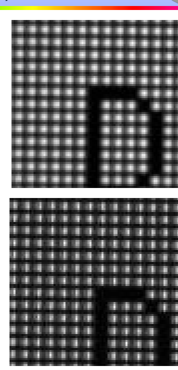


Devices & Deployment, Cont.

- Subtense of Lens a Factor

  Top photo at f/2.8 gathers light from many directions. Bottom photo at f/32 is more the way the eye sees things. (Lens f# = f/D=focal-length/diameter: At f/2.8 f=60 mm lens has D=21 mm whereas at f/32 D=1.9 mm.) Diagram is approximately to scale. We must be concerned about just what the detector is seeing and measuring.

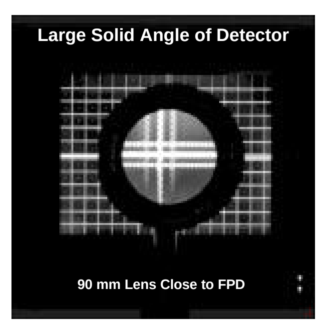




Devices & Deployment, Cont.

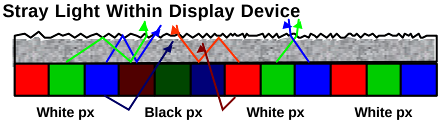
Subtense of Lens a Factor , Cont.

Note how much lighter the black pixels are at the top compared to the bottom or central regions.



Stray Light Management

Stray Light Within Display Device

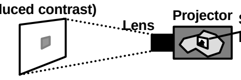


- FPDs — front surface near pixels permits strong diffusing surface with some resulting internal scattering and reflections.
- CRTs — front surface significantly separated from pixels provides more reflection plus internal scattering and beam halation behind pixel surface.

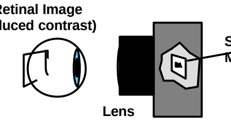
Stray Light Management, Cont.

Stray Light Within Display Device, Cont.

- Projection Displays: Projection lens veiling glare



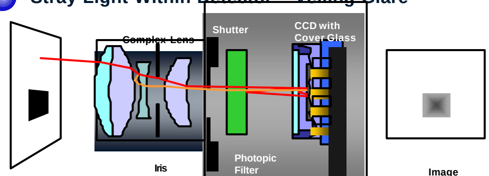
- HMDs: Relay lens veiling glare



STRAY LIGHT INTRINSIC TO DISPLAY
We can't do anything about it, but we want to measure it accurately.

Stray Light Management, Cont.

Stray Light Within Detector – Veiling Glare



Reflection off of internal lens structure

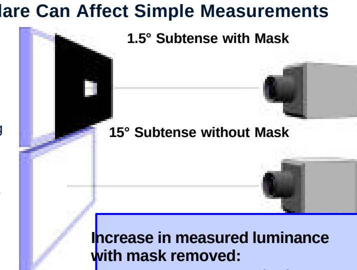
Reflection between lens surfaces

Avoiding Veiling Glare

Veiling Glare Can Affect Simple Measurements

Measurement of Full-Screen White

Comparison of two identical luminances having different angular sizes. Same screen with & without mask (1.5° or 15° angular diameter of white area from lens of detector)



Increase in measured luminance with mask removed:

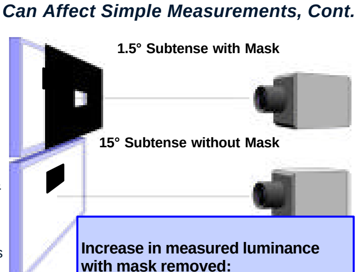
Instrument #1 0.4 %
Instrument #2 1.3 %
Instrument #3 4.8 %

Avoiding Veiling Glare, Cont.

Veiling Glare Can Affect Simple Measurements, Cont.

Measurement of Black Rectangle on White

This shows how important it is to anticipate veiling glare in the detection system. Same screen with & without mask (1.5° mask hole, 15° angular diameter of white area from lens of detector)

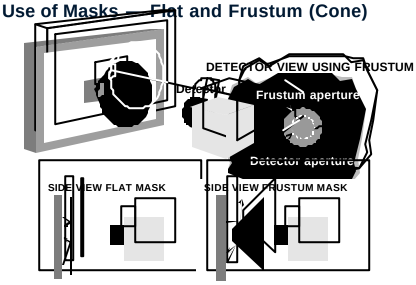


Increase in measured luminance with mask removed:

Instrument #1 50 %
Instrument #2 325 %
Instrument #3 1200 %

Avoiding Veiling Glare, Cont.

Use of Masks — Flat and Frustum (Cone)

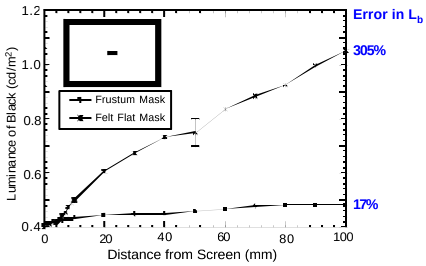


Avoiding Veiling Glare, Cont.

Frustum Mask Compared to Flat Mask

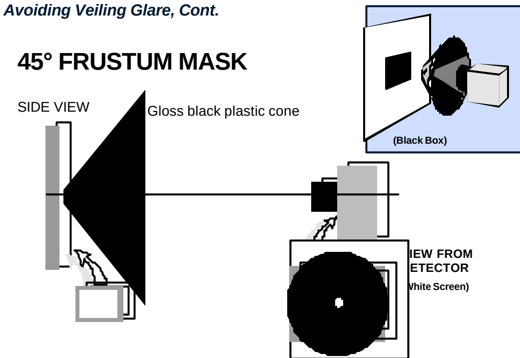
Only if the flat mask is placed very near or on the surface of the FPD screen can it compare with the frustum mask. (CRTs have thick glass faceplates.)

Flat mask near or on screen may cause heating.



Avoiding Veiling Glare, Cont.

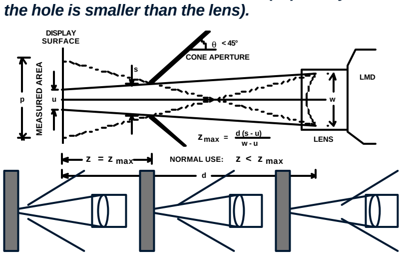
45° FRUSTUM MASK



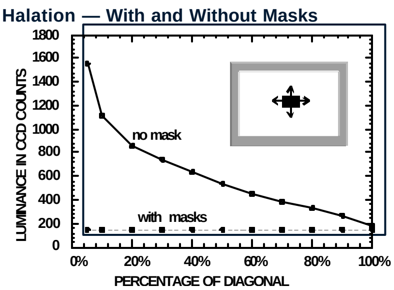
Avoiding Veiling Glare, Cont.

Avoid Vignette (vin-yet´) from Mask

Keep in mind that if the mask is too close to the lens it can interfere with the measurement (especially when the hole is smaller than the lens).

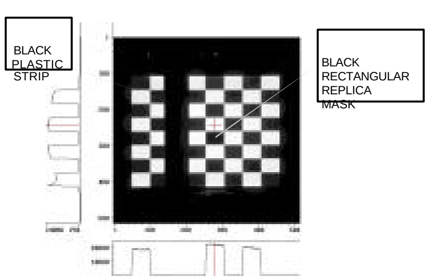


Avoiding Veiling Glare, Cont.



Small Area Measurements

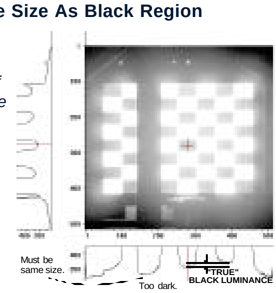
Replica Masks



Small Area Measurements, Cont.

Replicas, Same Size As Black Region

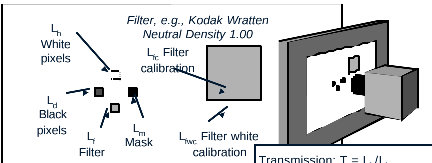
- *Replica masks must be close to (±10 %) the size of the black area to be measured.*
- *It is often a good idea to check your measurements using a NDF (neutral density filter) replica mask (at same T).*



Measurements and Diagnostics, Cont.

Small Area Measurements, Cont.

Replica Mask with Diagnostic Filter Mask



Corrected white: $L_w = L_h - L_m$

Corrected black: $L_b = L_d - L_m$

Transmission: $T = L_{fc}/L_{fwc}$ (filter material has temperature dependence). *Use cone mask to measure luminances here in a uniform part of screen.*

Check: Does $(L_f - L_m)/L_w = T$???

If so, measurement is probably good. (At least a lot better than if we didn't do anything!)

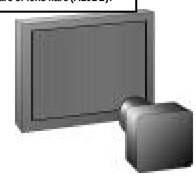
Measurements and Diagnostics, Cont.

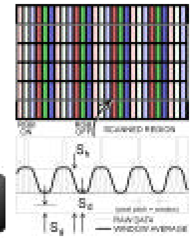
Resolution Measurements

From VESA (Video Electronics Standards Association) FPDM (Flat Panel Display Measurements Standard) Ver. 1.0—Combination of 303-2 and 303-7

303-2 N x N GRILLE LUMINANCE AND CONTRAST

Warning
This measurement can be grossly inaccurate unless proper accounting (and/or correction) is made for veiling glare or lens flare (A101-2).

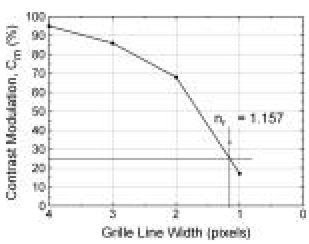


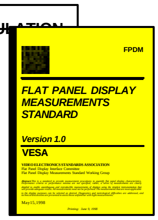


Measurements and Diagnostics, Cont.

Resolution Measurements, Cont.

303-7 RESOLUTION FROM CONTRAST MODULATION





www.vesa.org

$$C_m = \frac{L_w - L_b}{L_w + L_b}$$

$$\text{Resolution} = \frac{\#\ \text{arraypixels}}{n_r}$$

Measurements and Diagnostics, Cont.

Array Detector Problems

Photopic Response

Sensitivity to IR can seriously corrupt what was intended to be a luminance measurement.

Flat-Field Correction

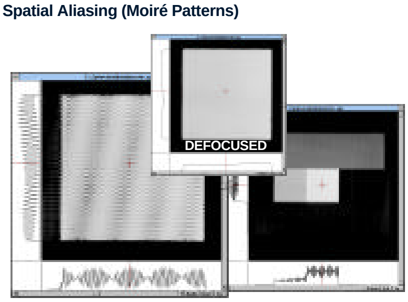
Nonuniformity partially corrected by FFC. FFC may change with lens and object configurations.

We are assuming a background subtraction is performed before the FFC. The FFC can change for the type of lens used, the f-stop, the focus, the size of the light-area measured and its distance, etc. Very difficult to accurately create because a truly uniform source of sufficient size is hard to obtain and because the correction needed can change so much with conditions. Be careful. What will serve as a FFC for one configuration may not for another!!

Measurements and Diagnostics, Cont.

Array Detector Problems, Cont.

Spatial Aliasing (Moiré Patterns)

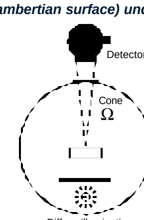


Canonical Reflection Terminology

Reflectance Factor, R:

Ratio of the reflected flux from the material within a specified cone to the flux that would be reflected from a perfect (reflecting) diffuser (perfectly white Lambertian surface) under the same specified illumination:

$$R = \left(\frac{\Phi_{\text{material}}}{\Phi_{\text{perfect diffuser}}} \right)_{\text{Cone}} \Bigg|_{\text{For Specified Illumination Conditions}}$$



Cone shown: Ω = 0.0379 sr for 12.6° apex (6.3° inclination angle from normal)

Special cases:

Luminance Factor β: $\Omega \to 0, \quad R \to \beta$

Reflectance ρ: $\Omega \to 2\pi, \quad R \to \rho$

Reference: CIE Publication #46 & #44

Example only, many other configurations possible.

Canonical Reflection Terminology, Cont.

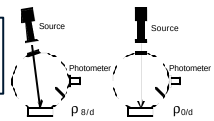
Reflectance, Diffuse Reflectance ρ :

Ratio of the (entire, $\Omega = 2\pi$) reflected flux to the incident flux:

$$\rho = \frac{\Phi_r}{\Phi_i}$$

Note notation: source/detector

Specify angle or use "d" for diffuse.

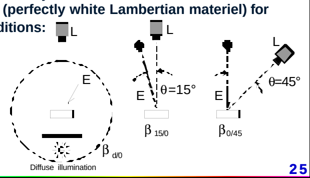


Luminance Factor β :

Ratio of the luminance of the object to that of the luminance of a perfect reflecting diffuser (perfectly white Lambertian materiel) for identical illumination conditions:

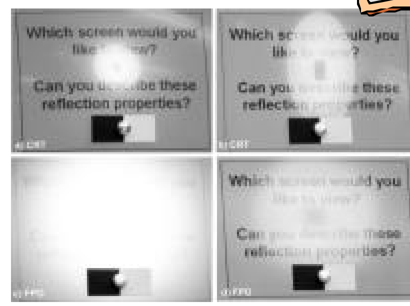
$$\beta = \frac{L}{E/\pi}$$

Note: luminance coefficient: $q = \beta / \pi$



NIST 25

Reflection Measurements



NIST 26

Reflection Measurements, Cont.

Oversimplified Models — Possible Ambiguity

- *"Diffuse" (Lambertian) component assumption:*

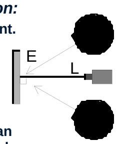
  Display surface measured as if it were matte paint.

  β = luminance factor, q = luminance coefficient,

  E = illuminance, L = observed luminance.

  $$L = qE = \frac{\beta}{\pi}E$$

  Strictly speaking this equation is for a Lambertian material: "diffuse" means scattered out of specular direction and is <u>not</u> limited to Lambertian materials.



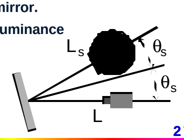
- *Specular component assumption:*

  Display surface treated as if it were a mirror.

  ρ_s = specular reflectance, L_s = source luminance

  $$L = \rho_s L_s$$

This can be performed with a large source (15°) and a small source (1°)



NIST 27

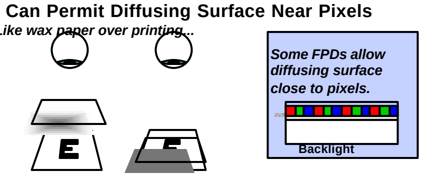
Reflection Measurements, Cont.

Oversimplified Model: Easy to Measure, Robust, IF OK

Unfortunately, many FPDs are not well characterized by just these two components — oversimplified model.

FPDs Can Permit Diffusing Surface Near Pixels

Like wax paper over printing...



Intelligibility depends upon distance of strong diffusion layer from surface containing information

Problem: Simple Models Inadequate for All Surfaces

Neither Lambertian nor specular models may work!

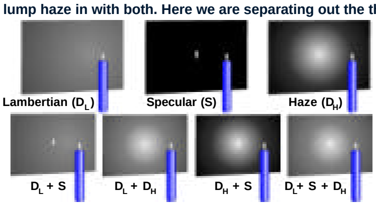
NIST 28

Reflection Measurements, Cont.

Three Component Reflection Model

- ***Specular, Lambertian, Haze***

  Most think in terms of specular (mirror like) and diffuse (Lambertian-like) and lump haze in with both. Here we are separating out the three.



- ***Haze:*** ***Intermediate state between specular and Lambertian.***

  Displays can exhibit any of the three components and any of the three components in combination.

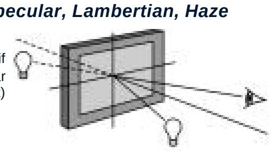
NIST 29

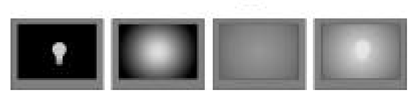
Reflection Measurements, Cont.

Three Component Reflection Model

Specular, Lambertian, Haze

Virtual Image (if there is a specular component)



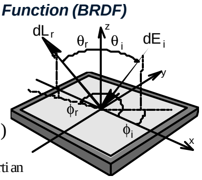


NIST 30

Reflection Measurements, Cont.

BRDF — Three Components:

- ***Bidirectional Reflectance Distribution Function (BRDF)***
- ***A generalization of L = qE: dL = B dE.***
- ***Diffuse has two components:***
  Lambertian & Haze
- ***Haze provides the gain of the screen***



$$dL_r(\theta_r,\phi_r) = B(\theta_i,\phi_i,\theta_r,\phi_r;\lambda,p)dE_i(\theta_i,\phi_i)$$

$$B = S + D_L + D_H \begin{cases} D_L = q = \beta/\pi \Rightarrow \text{Lambertian} \\ S = 2\rho_s d(\sin^2\theta_r - \sin^2\theta_i)d(\phi_r - \phi_i \pm \pi) \Rightarrow \text{Specular} \\ D_H = H(\theta_i,\phi_i,\theta_r,\phi_r) \Rightarrow \text{Haze} \end{cases}$$

$$L_r(\theta_r,\phi_r) = qE + \rho_s L_s(\theta_r,\phi_r \pm \pi) + \int_0^{2\pi}\int_0^{\pi/2} H(\theta_i,\phi_i,\theta_r,\phi_r)L_i(\theta_i,\phi_i)\cos(\theta_i)d\Omega.$$

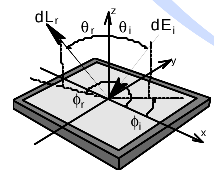
dE, element of illuminance

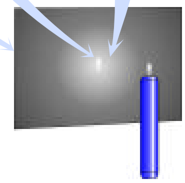
Reflection Measurements, Cont.

Observed Luminance = *Lambertian Component* + *Specular Component* + *Haze Component*

$$L_r(\theta_r,\phi_r) = qE + \rho_s L_s(\theta_r,\phi_r \pm \pi) + \int_0^{2\pi}\int_0^{\pi/2} H(\theta_i,\phi_i,\theta_r,\phi_r)L_i(\theta_i,\phi_i)\cos(\theta_i)d\Omega.$$

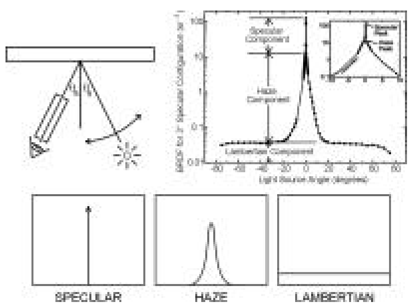
Background gray **Distinct image** **Fuzzy ball**





Reflection Measurements, Cont.

Three components in BRDF often seen in CRTs

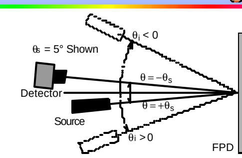


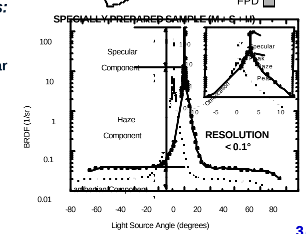
Reflection Measurements, Cont.

Simple BRDF

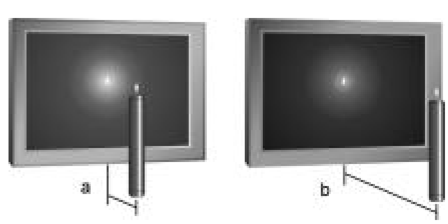
- ***Extremes:***
  - **Lambertian (flat)**
  - **Specular (spike)**
  - **Haze is in between.**
- ***Haze characteristics:***
  - **Proportional to illuminance**
  - **Directed in specular direction**

NOTE: 3 to 5 orders of magnitude possible (or more!—your eye has no trouble seeing this range!)





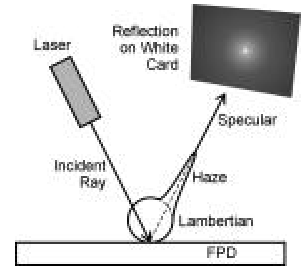
Reflection Measurements, Cont.



Like the Lambertian component, the haze is proportional to the illuminance; but like the specular component, it follows the specular direction.

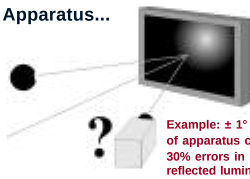
Reflection Measurements, Cont.

Reflection of laser beam onto white card gives the BRDF projected onto a plane.



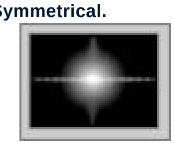
Reflection Measurements, Cont.

- **With Haze, Measurements Can Be Sensitive to the Geometry of the Apparatus...**
  - *LMD distance*
  - *Lens diameter*
  - *Focus*
  - *Source size*
  - *Source distance*
  - *...?*



Example: ± 1° misalignment of apparatus can result in 30% errors in measured reflected luminance.

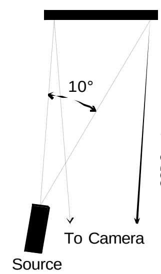
- **Haze Reflection Need Not Be Symmetrical.**
  Star patterns and spikes further complicate a full characterization of reflection, accomplished only via a complete BRDF.

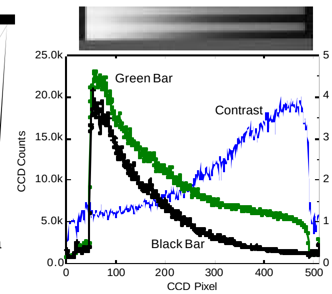


NIST

Reflection Measurements, Cont.

Haze exhibits angular sensitivity to position of source.
What contrast do we want???



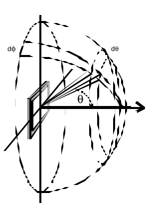


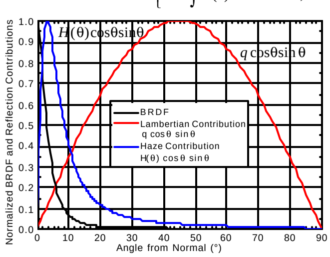
NIST

Reflection Measurements, Cont.

What is the reflection contribution (as a function of angle) from the Lambertian component compared to the haze component for a ring of light about the normal from a uniform luminance hemisphere?

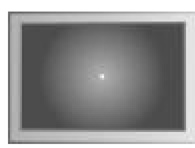
$$L_R = \iint BL\cos\theta\sin\theta\, d\theta\, d\phi = \begin{cases} 2\pi q L\int \cos\theta\sin\theta\, d\theta, & \text{Lambertian} \\ 2\pi L\int H(\theta)\cos\theta\sin\theta\, d\theta, & \text{Haze} \end{cases}$$



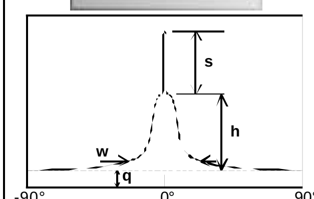


NIST

Reflection Measurements, Cont.



In the most general case, when there is a Lambertian, specular, and haze component, there are at least four parameters that are needed to specify the reflection characteristics since haze has a peak and a width (at the very least).

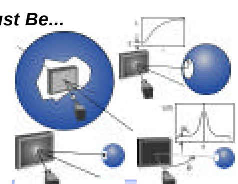


If we only make two simple measurements or three, the problem is underdetermined and an infinite number of displays can measure the same and look different to the eye!

NIST

Reflection Measurements, Cont.

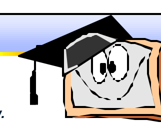
- **Proposed Simple Measurement Schemes:**
  Acceptable Methods Must Be...
  - **Robust:** Results not subject to small apparatus imperfections or irregularities or choice of equipment
  - **Reproducible:** Same results obtained with same displays around the world
  - **Unambiguous:** Apparatus configuration and requirements clearly presented and all important concerns made obvious



OBJECTIVE: To find the minimum set of measurements to adequately quantify reflection performance for a variety of applications.

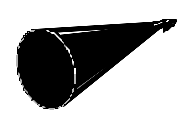
NIST

Tips and Things



- **Cone Light Trap**
  - ***Small, an absolute black, put in field of view.***
  - ***Large, trap to absorb reflections off screen.***
  - ***Make from gloss-black plastic.***
  - ***Turn tip around or fold back on itself so there won't be a reflective cup at the end.***

If you can't find black plastic sheets that are very black (manufacturing quality varies), you might try painting a thin plastic sheet with a good high-gloss black oil-base paint from a quality paint company.

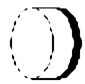


NIST

Tips and Things, Cont.

White Reflectance Standard

- ***Possible to obtain types that can be refurbished in your lab (e.g., 220 to 240 grit water-proof emery paper using circular-linear combined motion under running water).***
- ***Make sure it is sufficiently thick (some need to be 10 mm depth or more, whatever the manufacturer states is necessary). A 50 mm diameter disk may be required.***
- ***Over 99% reflectance (e.g. $r_{6/d}$), quasi-Lambertian… BUT watch out!!! … What kind of reflectance is this 99% value???***



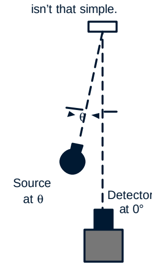
CAUTION: ***These may not be Lambertian.*** *The reflectance (e.g., of 0.99) is obtained under specific conditions of illumination and reflected-light measurement (e.g., $\rho_{6/d}$ illumination 6° from normal and measurement of diffuse reflected flux in a hemisphere). The reflectance will not necessarily be the same for all angles and all configurations!!! If you need to use it for a certain configuration (other than the configuration for which it was calibrated) then it must be calibrated for that special configuration. We cannot necessarily use the 99% value for just any configuration we want (blindly hoping that it will be OK). An illuminance meter might be better.*

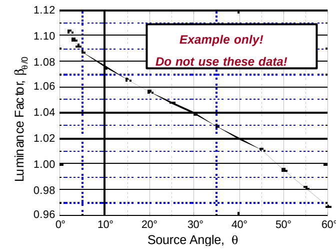
Tips and Things, Cont.

Luminance Factor of White Standard Example

Example ONLY; don't use these results for your own purposes!!!

This shows that you cannot plop one of these in your apparatus, measure its luminance, assume a luminance factor of 0.99 and calculate the illuminance—it just isn't that simple.



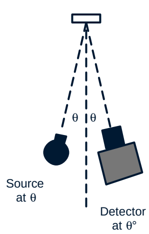


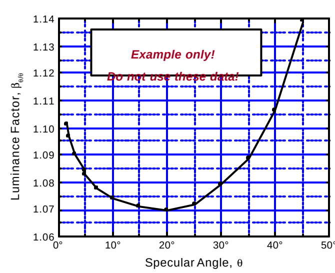
Tips and Things, Cont.

Luminance Factor of White Standard Example

Example ONLY; don't use these results for your own purposes!!!

Specular configuration $\beta_{\theta/\theta}$ has very different characteristics from $\beta_{\theta/0}$ configuration.

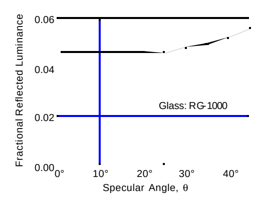


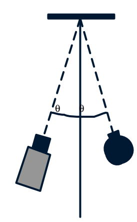


Tips and Things, Cont.

Black glass

Useful for making measurements of source in specular reflection configuration. Note slight angle dependence of specular reflectance.



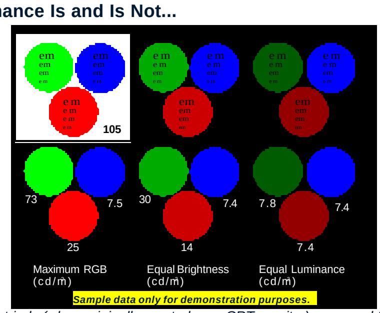


Sample data only for demonstration purposes.

Tips and Things, Cont.

What Luminance Is and Is Not…

The luminance metric attempts to match the spatio-temporal response of the eye. Two colors of equal luminance may not be perceived as having the same brightness, especially since brightness can depend upon ambient conditions.



The center triads (when originally created on a CRT monitor) appeared to have the same brightness. The right triads were adjusted to have the same luminance as the blue dot (all blue dots should be the same).

Tips and Things, Cont.

Measurement Uncertainty & Repeatability, Cont.

Display Measurement Assessment Transfer Standard — DMATS (dee´-mats)

Collaboration with the Optical Technology Division of NIST's Physics Lab (Drs. Yoshi Ohno and Steve Brown)

- ***WHAT IT IS: A uniformly backlit target assembly that exploits the capability of the measuring instrumentation in participating laboratories.***
- ***HOW IT WORKS: NIST measures, participating lab measures what it wants to, NIST re-measures, results shared with lab (NOT a calibration!).***
- ***RESULTS: Anonymous comparison shows what industry can expect in making straightforward measurements of displays.***

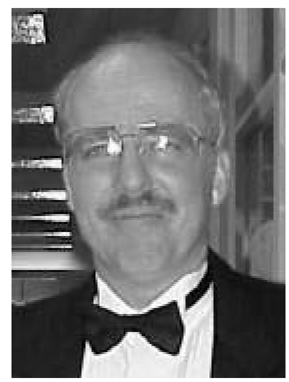
IMPEDIMENTS TO REPRODUCIBILITY IN DISPLAY METROLOGY

Edward F. Kelley, 301-975-3842, kelley@nist.gov

"Encoding of Color Images for Digital Cinema"

Michael H. Brill

Sarnoff Corporation



Dr. Brill is presently developing models and metrics for vision-based display standards, and also colorimetric standards for digital cinema. He developed the color part of Sarnoff's JNDmetrix vision model, for which he holds four patents, and also has written parts of VESA's standard on flat-panel display metrology. In earlier work, he designed and implemented simulation of nerve-fiber electrical behavior; designed and implemented performance-prediction models for sonar systems; designed algorithms for automatic recognition of human speech. He has reviewed technical papers for more than 15 journals, and has published more than 50 refereed technical articles. For work on the mathematical basis of machine and human color constancy, he received the 1996 Macbeth Award from the Inter-Society Color Council (ISCC). Also, he has published articles in color reproduction, color rendering, and other topics in computational colorimetry. In addition, he has contributed extensively to the use of geometric and photometric invariants in machine vision. Dr. Brill has chaired or co-chaired three conferences with SPIE, and also co-chaired the 1995 ISCC Pan-Chromatic Conference in Williamsburg, VA. He was a member of the Board of Directors of the ISCC from 1992-1995, and was President of the ISCC from 1998 to 2000. He is on the Editorial Board of *Color Research and Application*, and is an Associate Editor of *Physics Essays*.

"Encoding of Color Images for Digital Cinema"

by Michael H. Brill

The goal of digital cinema is to replace film distribution of movies by a softcopy alternative, but to ensure that the image quality in the movie theater is at least as good as it was for film. Therefore, insofar as it is possible, the colors presented on film should be copied faithfully into the projected digital images. There are two classes of problems inherent in film-to-digital transfer: managing the color (between scanned inter-positives and projected images), and encoding the digital signal for transmission once the color-management problems have been resolved. The present paper deals with the second of these issues, and summarizes the work of the SMPTE Digital-Cinema Ad Hoc Committee on Colorimetry (chaired by Fred Van Roessel). In particular, there has been a recommendation to encode digital-cinema images at 10-bit precision through the logarithm of three chosen extra-spectral primaries. This expedient avoids wasting code values, either due to their being outside the spectrum locus or due to their being indiscriminable from each other. Although some difficulties might be envisioned with the blue primary (which has a negative luminance), analysis reveals that these difficulties will not emerge in practice.

Encoding of Color Images for Digital Cinema

Michael H. Brill
mbrill@sarnoff.com

11 Jan 2001

Overview

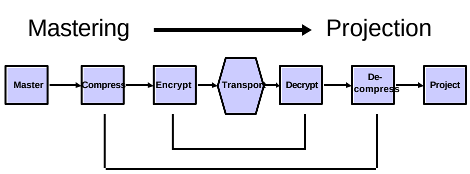
I. Goal of digital cinema: Replace film distribution by softcopy distribution
(Digital Cinema Distribution Master--DCDM)

II. Must maintain or exceed film visual quality, e.g.:
   a. Copy colors faithfully
   b. Minimize artifacts like quantization
   c. Be compatible with present, future projection technology.
   d. Be bit-efficient
   e. Be computationally efficient at distribution time (I.e., just prior to compression)

Place of Digital Master (DCDM)

(From F. Van Roessel, Panasonic)

Digital Cinema Flow Diagram

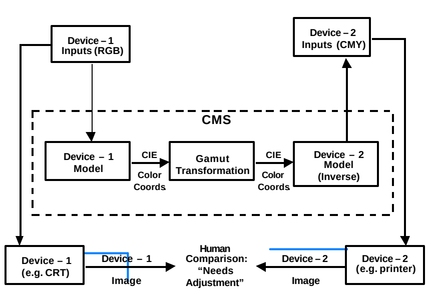


Task: Film-to-Digital Color Transfer

- Manage color between scanned inter-positive and projected images:
  - Electronic cinema must be visually indistinguishable from its film-based predecessor.
- Encode digital signal for distribution (e.g., choose color primaries, white, nonlinearity on each primary). *Subject of this talk*
- Compress digital signal (e.g., by MPEG)

Generic Color Management

……

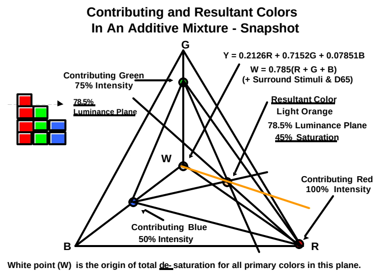


SMPTE Ad Hoc Group on Colorimetry

- Formed 8 Feb 2000:
  - Chair: Fred Van Roessel, Panasonic.
- Responds to request of DC 28.2 (Mastering) and DC 28.8 (Projection) Study Groups
- So far, addressed selection of color primaries, white point, signal representation
- Docs at ftp://smpte.vwh.net/pub/dc28

Additive Color Mixture

(from John Silva, Modern Digital Systems)

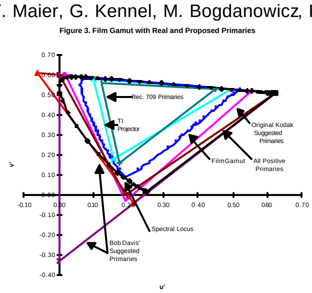


Ways to Waste Code Values

- Values are unproducible (e.g., outside spectrum locus)
- Values are indistinguishable (e.g., small absolute steps at high luminance)

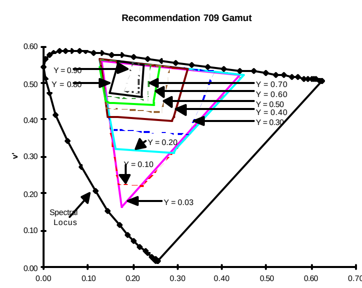
Candidate Color Primaries

u' = 4x / (-2x + 12y + 3) and v' = 9y / (-2x + 12y + 3)
(from T. Maier, G. Kennel, M. Bogdanowicz, Kodak)



3D Gamut of RGB cube

(from T. Maier, G. Kennel, M. Bogdanowicz, Kodak)

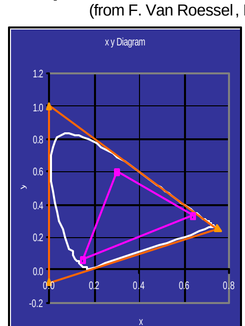


Choice of Color Primaries

- Red (x = 0.75, y = 0.25)
- Green (x = 0, y = 1)
- Blue (x = 0, y = -0.08)
- Rationale: minimum of unused codes (5 % for linear codes)
- Note 1: Primaries are extra-spectral (to represent as + integers, no - sign)
- Note 2: Blue has negative luminance

Proposed DCDM Primaries

(from F. Van Roessel, Panasonic)



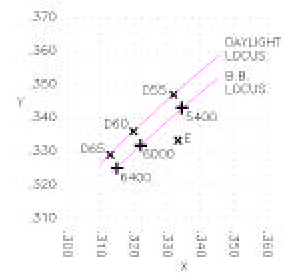
	x	y
Red	0.750	0.250
Green	0.000	1.000
Blue	0.000	-0.080

White Point

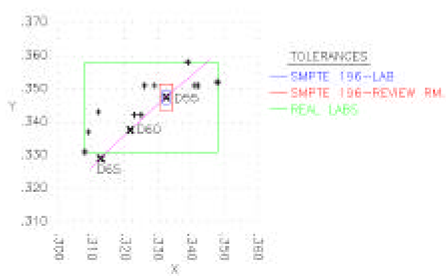
- Needed to convert CIEXYZ to RGB of DCDM, and also to projector primaries
- Standard white point doesn't limit cinematographer's choice
- No recommendations of white point could be made: Film studios use 5500K. Theaters use 6500K (a bit more efficient).
- Mastering & Projection Groups will have to decide

White Point Specification

(D. Richards, 3 Dec 1999)



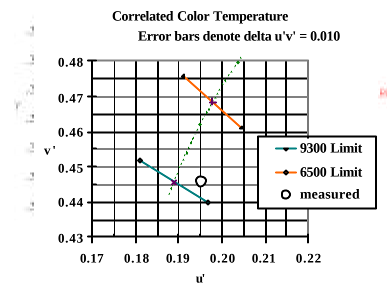
White Point Error Bound



White Point Error Bound

u' = 4x / (-2x + 12y + 3) and v' = 9y / (-2x + 12y + 3)

Uniform-Chromaticity *(T limits nominal here)*

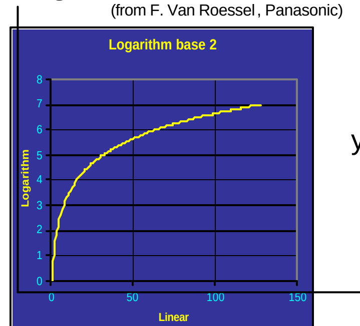


Signal Representation

- Mastering, Compression SGs agreed that best interface to compression is full-bandwidth RGB
- Log transfer functions on R, G, B; no linear portion at low-luminance end; 10 or 12-bit word; 10 bits yield ~ 4 decades D.R. [code r = (1 + d)^n, where d ~0.01]
- Log to base 2 could simplify hardware, software. (Variable luminance modifier in metadata if needed)

Logarithm Transfer Function

(from F. Van Roessel, Panasonic)



$y=\log_2(x)$

Implementation of base-2 Log

(from F. Van Roessel, Panasonic)

12 bit base-2 Logarithm

XXXX.XXXXXXXX

4-bit exponent n, 8-bit mantissa m

Represents $2^n * 2^{m/256}$

Contrast Range: 65536:1

Smallest Increment: $2^{1/256} - 1 = 0.27\%$

Problem with Negative-Luminance Blue Primary?

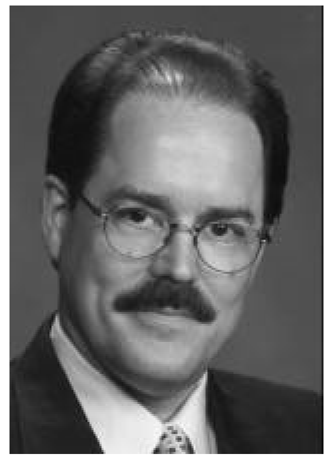
- Log makes larger steps at higher B values
- Higher B values drive luminance lower
- Thus there might be larger luminance steps at lower luminance--Conspicuous contouring artifacts possible
- Scenario: deep blue sky from a spacecraft
- Resolution: There is not enough luminance decrement to incur even a CIELAB unit of artifact.

Future Work of Ad Hoc DC Colorimetry

- Generate R, G, B signals with the proposed primaries by a telecine
- Deliberately limit DCDM color gamut, to be more compatible with actual projectors.
- Convert from DCDM color space to the various projector color spaces
- Convert from full bandwidth RGB space to luminance&chrominance for compression.
- More info: Fred Van Roessel <VanRoesselF@panasonic.com>

"Cinematic Image Quality - what is it and why does it matter?"

Sean Adkins
Vice President,
Advanced Technologies
IMAX Corporation



Mr. Adkins is the Vice President, Advanced Technologies with Imax Corporation where he heads the research and development activities of the company and its subsidiaries. Mr. Adkins has 6 U.S. patents issued or applied for in the area of entertainment technology. Mr. Adkins has been designing and developing technology for the entertainment industry for over 22 years. Mr. Adkins is a member of the Society of Motion Picture and Television Engineers, the International Society for Optical Engineering(SPIE), and the International Alliance of Theatrical Stage Employees. In1988 he co-founded the Canadian Centre for Image andSound Research, a non-profit Society that performed research in new technologies for the arts.

"Cinematic Image Quality - what is it and why does it matter?"

by Sean Adkins

The coming transition to digital cinema projection naturally raises questions about the impact that digital technologies will have on the quality of the projected image and the nature of the cinema experience. In this brief address the speaker will discuss the technical, aesthetic and business elements of the cinema, highlighting the ways in which projected image quality affects each of these elements. In particular the discussion will consider the effect that digital technology will have on each of the stakeholders in the cinema experience, from the artists to the audience.

1

Digital Cinema Conference 2001

Cinematic Image Quality
-what is it and why does it matter?

Sean Adkins
Vice President,
Advanced Technology
IMAX Corporation

2

Introduction

- What is cinematic image quality?
- Who cares about cinematic image quality?
- What are the cinematic image quality issues that we confront as we introduce digital cinema?

3

What is Cinematic Image Quality?

- More than just numbers
- It is a language developed through a partnership of art and technology
- Cinematic images are visually and culturally distinct

4

Who Cares About Cinematic Image Quality?

- The Audience
- The Producers
  - creative people
  - business people
- The Equipment Manufacturers
- The Postproduction Service Providers
- The Exhibitors

5

The Role of Standards

- Standards for film based cinema

6

7

What is Standardized?

- Neither the imager or the display
- Not the resolution, dynamic range, color quality or fidelity
- Consider film standards in comparison to television standards

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8

What are the Issues of Cinematic Image Quality?

- Protect the uniqueness
- Support continued evolution
- Standardize the right things
- Preserve the legacy
- Try for better, not just good enough

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9

Concerning the Stakeholders

To the Audience:

- Don't confuse novelty with innovation
- This will become a one way trip
- Ask that the legacy be preserved
- Insist that change brings genuine improvements
- You need a healthy industry to have good cinematic experiences

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10

Concerning the Stakeholders

To the Creative Team:

- Consider your technical choices carefully
- Look for the opportunities in new technology
- Be demanding
- Ask for a balance between short term and long term

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11

Concerning the Stakeholders

To the Manufacturers:

- Include the creative team
- Remember the value of a unique cinema
- Think of the future
- Think about a system design that makes things better
- Don't kill off film too soon

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12

Concerning the Stakeholders

To the Postproduction Industry:

- This will start as a parallel process
- Think hard about quality
- Think of the future

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13
Concerning the Stakeholders
To the Exhibitors:
Value the distinctiveness of the cinematic experience
Consider a renewal in your approach to quality
Market technical excellence
Insist on realistic expectations and a comprehensive infrastructure
Text copyright 2001 IMAX Corporation,
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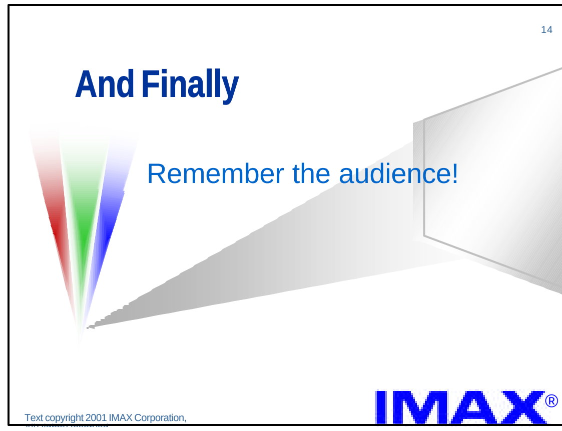
14
And Finally
Remember the audience!
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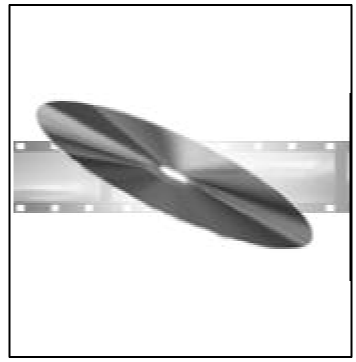
"Benchmarking Key Attributes of Digital Cinema"



Thomas MacCalla, Jr.

Chief Operating Officer

Entertainment Technology Center

Thomas MacCalla has a multi-disciplined point of view on entertainment technology. He combines computer science and telecommunications disciplines with an understanding of picture and sound technologies. His role as Chief Operating Officer (COO) of the Entertainment Technology Center (ETC) at the University of Southern California (USC) has immersed him in technologies directed at solving many entertainment industry challenges.

His current focus is on: Digital Cinema, Virtual Stage, Entertainment on Demand (EOD), Immersive Simulation, and HDTV. Last March, ETC launched a **Digital Cinema Lab**, in conjunction with MPA, NATO, ITEA and SMPTE. The purpose of the lab is to provide benchmarks for attributes of film and video, needed to move the industry forward.

Thomas' past ETC activities include:

-- 1995- the first live demonstration of wide area digital transport, for entertainment production, to an audience of over 500 entertainment professionals.

-- 1997- the first wide area broadband security test of production content recognized by the *State of California Trade and Commerce Agency*.

continued...

-- 1998- the first live 8 node wide area demonstration of digital dailies integrating various speeds (400 kbps to 155 mbps) using terrestrial, wireless and satellite transport simulcast to three Hollywood Studios (Warner Brothers, Sony Pictures, and Universal Studios).
-- 1999- Advanced DVD testing for the Copy Protection Technical Working Group.

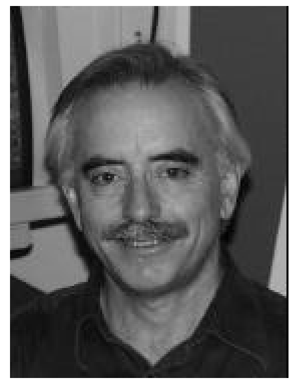
Thomas' previous experience includes his:
-- MBA in 1978, from the *University of California at Los Angeles*, with triple majors in Marketing, Finance and International Business
-- Work at *Xerox*, four years, during *Xerox's* development of Ethernet, micro-computing, and artificial intelligence. He held positions in System Design and Marketing.
-- Work at Pacific Bell for Fourteen years starting just before the breakup of *AT&T*. He was the first Director of Entertainment Technology at *Pacific Bell*. During his tenure, he was instrumental in several innovative developments including:
  - o Pacific Bell's first digital implementation to voice networks
  - o Pacific Bell's first implementation of advanced video services for production and post-production
  - o Pacific Bell's first commercial implementation of ATM at OC3 (155 mbps) and OC-12 (622 mbps) for use of CGI effects and animation transport.

"Quality Assessment for Digital Cinema: Test Materials and Metrics for Compression"

Charles Fenimore

Digital Cinema Project

NIST



Charles Fenimore currently leads NIST's Digital Cinema Project in the Convergent Information Technology Division. For several years he has been involved in quality assessment for digital video and digital cinema and has developed test imagery and test metrics for moving picture compression. For the last two years he has chaired the SMPTE Group on TV Assessment Materials which has collected subjective assessment materials for distribution by SMPTE. He has also contributed to the development of test methods for the Video Quality Experts Group (VQEG).

Fenimore has been a mathematician at NIST for 16 years. In addition to his work on imagery, he has developed models for non-linear characteristics of fluid and electrical flows. He holds a B.S. in Math from Union College and a Ph.D., also in Math, from Berkeley.

"Quality Assessment for Digital Cinema: Test Materials and Metrics for Compression"

by Charles Fenimore

Compression is one of several enabling technologies for digital cinema. The digital cinema imagery which is projected onto a screen may have passed through several stages in a chain of processing. Assessing one component (such as compression) in this complex system requires that other components of the system be qualified or controlled. This includes:

- the content of the cinema to be used,
- format conversions which are applied,
- the characteristics of the display, including its measured resolution or sharpness, brightness, contrast, and dynamic response,
- the environment for viewing, and
- the visual acuity of the viewing panel in the case of subjective testing.

Both objective and subjective test materials are essential in this process. The experience gained in developing materials for digital video give direction to the process of finding and developing materials which are useful in assessing digital cinema.

Quality Assessment for Digital Cinema: Test Materials & Metrics for Compression

Charles Fenimore
Convergent Information Systems Division, NIST

Digital Cinema 2001 Conference
January 12, 2001

NIST

Quality Assessment

- Tests - subjective and objective
- Display matters in compression tests - strategy for complex systems
- Video and cinema: materials and metrics
- Conclusions

NIST

Quality measurement in video

- Compression in digital cinema.
- Subjective testing is the gold standard, objective testing is a useful adjunct
- Selection of test materials
- Qualification of the test system
- Test methods smorgasbord: ITU-R Rec 500

NIST

Goals of Testing

- Characterize for a range of typical materials
  OR
  Stress the system, to see where it breaks
- Compression or decompression testing.
- Threshold vs. Wide Range Tests.

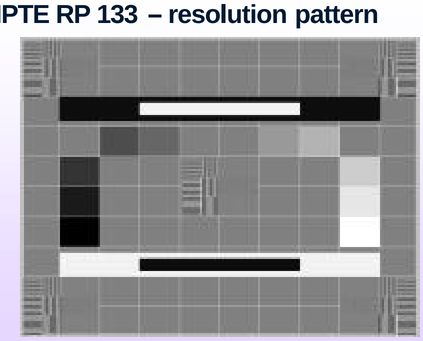
NIST

Qualifying the system

- Resolution and sharpness.
  Spot-size: trade flicker for resolution
- Motion rendition and flicker, image stability
- Dynamic range, tone
- Brightness and contrast
- Visual acuity of the viewers

NIST

SMPTE RP 133 – resolution pattern



NIST

Selection of subjective test materials

Desired attributes include a range of:

- *resolution and detail patterns,*
- *image and camera motion,*
- *luminance,*
- *color saturation and hue,*
- *skin tones,*
- *noise,* and
- *graphics and titles.*

A sense of presence, reality, and depth.

NIST

Skin Tones

NIST

Selection of subjective test materials

Experience provides surprises in coding difficulty.

Range of image detail, motion, color and luminance.

Criticality: a computable measure of image detail and motion in electronic imagery.

NIST

Surprisingly tough to compress

NIST

Synthetic test patterns

Used in engineering evaluation of imaging systems.

SMPTE color bars, Philips

SMPTE Rec. 133 Resolution Chart.

Sarnoff, AT&T, many other contributors

NIST spinning wheel (blocking) and moving spirals (mosquito noise) patterns.

NIST

Conclusions

Subjective and objective metrics & materials are valuable for imaging system evaluation.

Properly designed d-cinema testing:

- *Know who are users, what are needs and goals.*
- *Translate user needs to engineering requirements (subjective and objective criteria, resolution and sharpness, color characteristics),*
- *Specify measurement protocol to test requirements: metrics and materials.*

NIST

Digital Cinema 2001

"A New Vision for the Movies"

"Video Quality Experts Group: Current Results and Future Directions"

John M. Libert
Physical Scientist,
Flat Panel Display Laboratory
NIST

John M. Libert received his B. S. degree in Experimental Psychology and his M S. in Quantitative Geology from the University of Maryland in 1970 and 1981, respectively. His early work included geophysical data analysis and remote sensing via multi-spectral imagery and synthetic aperture radar. He later worked in the areas of signal and image analysis, including development of computational vision models for image motion perception and stereopsis. In 1997, he joined the Electronics and Electrical Engineering Laboratory of the National Institute of Standards and Technology where he conducted research in digital video image quality measurement. He now continues his work in the Flat Panel Display Laboratory of NIST's Display Metrology Project where he is developing a transfer standard for the assessment of electronic display measurement methods and instruments.

"Video Quality Experts Group: Current Results and Future Directions"

by John Libert

Subjective assessment methods have been used reliably for many years to evaluate video quality. They continue to provide the most reliable assessments compared to objective methods. Some issues that arise with subjective assessment include the cost of conducting the evaluations and the fact that these methods cannot easily be used to monitor video quality in real time. Furthermore, traditional, analog objective methods, while still necessary, are not sufficient to measure the quality of digitally compressed video systems. Thus, there is a need to develop new objective methods utilizing the characteristics of the human visual system. While several new objective methods have been developed, there is to date no internationally standardized method.

The Video Quality Experts Group (VQEG) was formed in October 1997 to address video quality issues. The group is composed of experts from various backgrounds and affiliations, including participants from several internationally recognized organizations working in the field of video quality assessment. The majority of participants are active in the International Telecommunications Union (ITU) and VQEG combines the expertise and resources found in several ITU Study Groups to work towards a common goal. The first task undertaken by VQEG was to provide a validation of objective video quality measurement methods leading to Recommendations in both the Telecommunications (ITU-T) and Radiocommunication (ITU-R) sectors of the ITU. To this end, VQEG designed and executed a test program to compare subjective video quality evaluations to the predictions of a number of proposed objective measurement methods for video quality in the bit rate range of 768 kb/s to 50 Mb/s. The results of this test show that there is no objective measurement system that is currently able to replace subjective testing. Depending on the metric used for evaluation, the performance of eight or nine models was found to be statistically equivalent, leading to the conclusion that no single model outperforms the others in all cases. The greatest achievement of this first validation effort is the unique data set assembled to help future development of objective models.

VIDEO QUALITY EXPERTS GROUP: VALIDATION OF OBJECTIVE MODELS OF VIDEO QUALITY ASSESSMENT

John M. Libert
NIST
12 January 2001

(john.libert@nist.gov)

Study Objectives

- To execute a highly controlled study to validate state-of-the-art "double-ended"* digital video quality models against subjective quality ratings of source video processed in a variety of ways.
- Recommend model(s) to ITU study groups for measurement standards.

(* source sequence available for comparison)

WEB: http://www-ext.crc.ca/vqeg/
Reflector: ituvidq@its.bldrdoc.gov

Subjective Testing

- Over 26,000 subjective opinion scores were generated
  - 20 different source sequences processed by…
  - 16 different video systems and evaluated by…
  - eight independent subjective testing laboratories

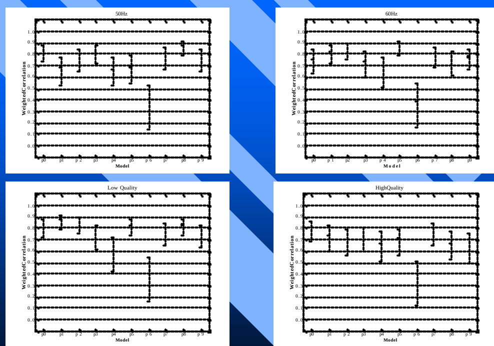
- 50 Hz & 60 Hz materials
- "High Quality" (3 Mb/s to 50 Mb/s)
- "Low Quality" (768 kb/s to 4.5 Mb/s)
- Double Stimulus Continuous Quality Scale (DSCQS) method used
- Security Maintained
  - Source sequences selected by independent group and
  - unknown to model proponents prior to submittal of code

Objective Testing

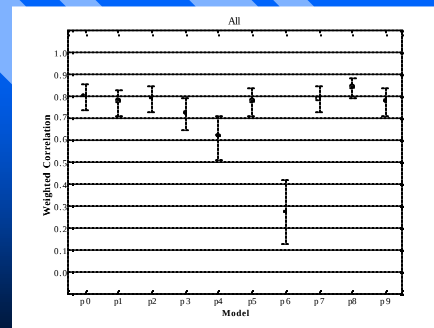
- 10 computational vision models proposed
- Peak Signal To Noise Ratio (PSNR) used as reference objective model
- Models verified independently on subset of sequences
- Data reduced and analyzed by NIST

Results

- 8 of 10 models performed at levels not statistically differentiable from one another.
- Model performance not statistically different from that of PSNR
- Comparatively high correlation among subjective ratings.



Correlation coefficients with 95% confidence intervals.



Conclusions

- VQEG unable to recommend a model as a substitute for subjective testing.
- PSNR result surprising, but spurious?
  - Precise registration + comparatively high quality
  - Single set of viewing conditions

Continuing Work

- All models have been further refined using large volume of test material generated by the study ➔ legacy of VQEG?
- VQEG on to testing “reduced reference”* models

*comparison of processed with some “feature” representation of source

Digital Cinema 2001

"A New Vision for the Movies"

"DLP Cinema™ Field Demonstration Project: Relationship to Digital Cinema Quality and Measurements"

Paul S. Breedlove

Digital Cinema Business Development Manager

Texas Instruments Digital Imaging

Paul S. Breedlove, Digital Cinema Business Development Manager at Texas Instruments (TI) Digital Imaging, has spent the last four years working with the movie industry to adapt TI's DLP™ technology to meet industry requirements. Previously, Paul worked in TI's Calculator Division where he invented the popular *Speak & Spell*™ talking learning aid, receiving the prestigious IEEE Masaru Ibuka Consumer Electronics Award in 1993. Paul has also managed TI's Personal Computer engineering department and served as Worldwide Computer Strategy manager for TI's Semiconductor Division

Paul holds five patents and is a member of IEEE and SMPTE.

"DLP Cinema™ Field Demonstration Project: Relationship to Digital Cinema Quality and Measurements"

by Paul Breedlove

For the past year, Texas Instruments (TI) has worked with Technicolor, movie studios, exhibitors, and other manufacturers to conduct field demonstrations of digital cinema in 31 locations located in North America, Europe, Japan, and Asia. The results of these demonstrations have provided many insights into the image quality, standards, and supporting measurement technology needed for digital cinema.

Color stability, contrast ratio stability, and field reliability were tested and evaluated for possible inclusion in standards. Color gamut, bit depth requirements, and other areas of possible impact on quality and standards will be discussed. TI's views on some possible standards will be presented.

DLP Cinema™ Field Demonstration Project: Relationship to Digital Cinema Quality and Measurements

Paul Breedlove

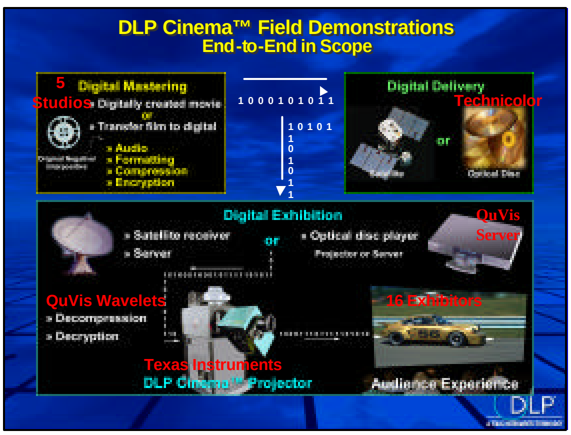
DLP Cinema Business Development Manager
Texas Instruments
Digital Imaging
Plano, Texas

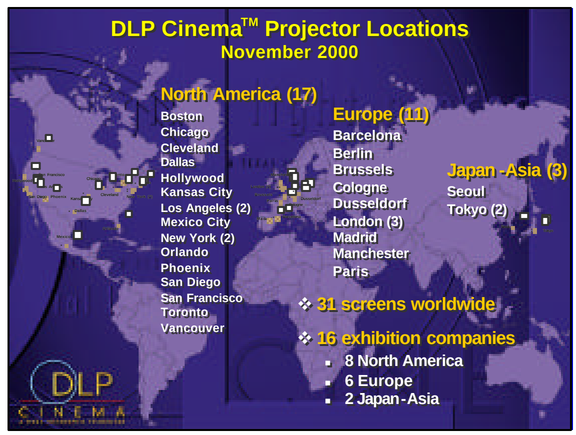
NIST Digital Cinema Conference

January 11 - January 12, 2001

Digital Cinema Projector
Projection Applications and General Requirements

	Digital Cinema Projector	Large-venue Projectors
Viewing Environment	Darkened theater	Well-lit large room
Source	Feature films, trailers	Video & graphics
Brightness	>10,000 lumens	Varies with product
Contrast ratio	>1000:1 Sequential	~450:1 Sequential
Color	Wide color gamut similar to film, more than TV	TV
“Look”	Film look	TV look
Frame rate	24 frames per second like film	Variable frame rates, for video & graphics





DLP Cinema™ Field Demonstrations
Studio Results

14 Digital Movies from 5 Studios		Date	International
Star Wars: Episode I	Fox/LucasFilm	June 1999	
Tarzan	Disney	July 1999	
Toy Story 2	Disney	November 1999	Y
Bicentennial Man	Disney	December 1999	
Mission to Mars	Disney	March 2000	Y
Dinosaur	Disney	May 2000	Y
Fantasia 2000	Disney	June 2000	Y
Titan AE	Fox	June 2000	
The Perfect Storm	Warner Bros’	July 2000	Y
Space Cowboys	Warner Bros’	August 2000	Y
The Crimson River	Gaumont (France)	September 2000	Y
Bounce	Miramax	November 2000	
102 Dalmations	Disney	November 2000	Y
Emperor’s New Groove	Disney	December 2000	Y

DLP Cinema™ Field Demonstration
Exhibitor Results

- Attendance thru 10/31/2000: >1,100,000 people
- Performance Metrics
  - Total shows / Hours 11,800 / 34,000
  - Total Projector Installed Time: 1032 weeks
  - Total Usage: 431 weeks

DLP Cinema™ Field Demonstration
Technical Results - System Reliability

	N. America	Europe	Japan-Asia	Total
Shows	8200	2600	1000	11,800
Shows Lost	53	45	11	109
% Lost	0.6%	1.7%	1.1%	0.9%

- Film projector reliability: 0.25% shows lost
- Digital demonstration lost show causes
  - System failure other than projector
  - Movie delivered late
  - Operation error
- No lost shows due to DLP Cinema projector

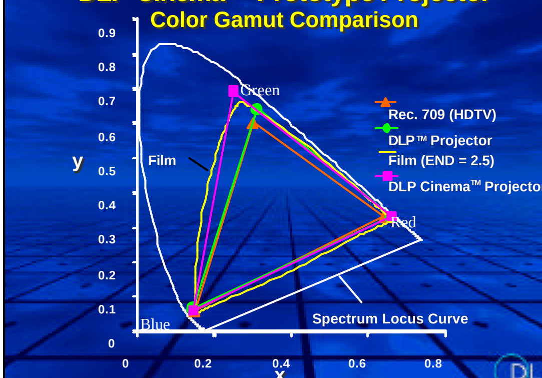
DLP Cinema™ Prototype Projector Set-up in Each Location

- Resolution: 1280 ´ 1024 pixels (1.25:1)
- Film formats: 1.85:1 & 2.39:1 (anamorphic lenses)
- Display frame rate: 24 fps (like film)
- Luminance: 12 ftL (=16ftL open gate film proj.)
- Brightness: up to 10,000+ lumens (6KW lamp)
- Screen size: > 60 ft. depending on screen gain
- Contrast ratio: >1000:1 full-on/full-off
- Effective bit depth: 14 bits/component - linear
- Color temperature: 6500° Kelvin
- Color gamut: Equivalent to film, > HDTV

DLP Cinema™ Technology Important Image Quality Attributes

- Digital fidelity
  - Same colors on every screen
  - Colors determined by the precise division of time.
  - No lag or motion smearing as in LCD light valves.
- Digital stability
  - No change in colors with time.
  - No change in contrast ratio with time.
  - No image damage due to use.
  - Quick setup and low maintenance.
- Projection booth compatibility
  - Inline light path (like film projector).
  - Compact

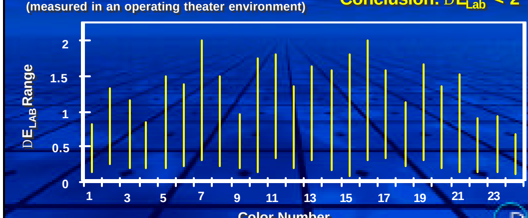
DLP Cinema™ Prototype Projector
Color Gamut Comparison



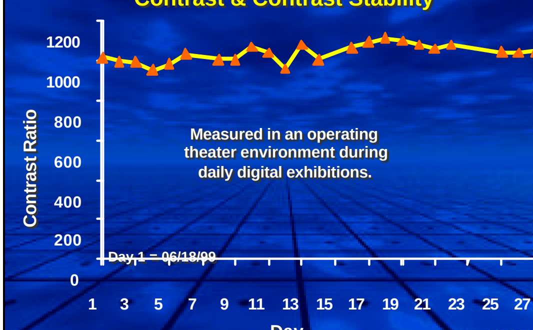
DLP Cinema™ Prototype Projector
Color Stability in L*A*B* (LAB) Color Space

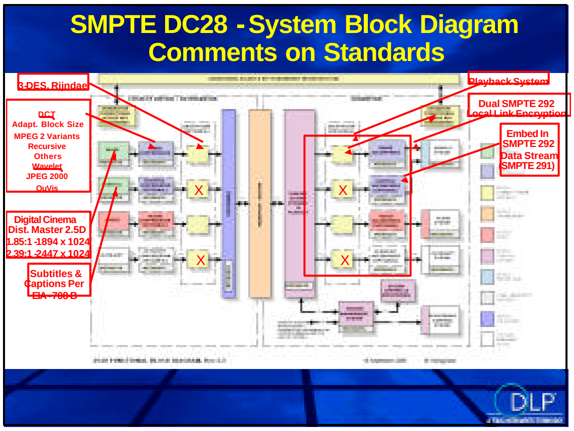
ΔE_{Lab} (or jnd) = daily meas. - the average over 20 days (measured in an operating theater environment)

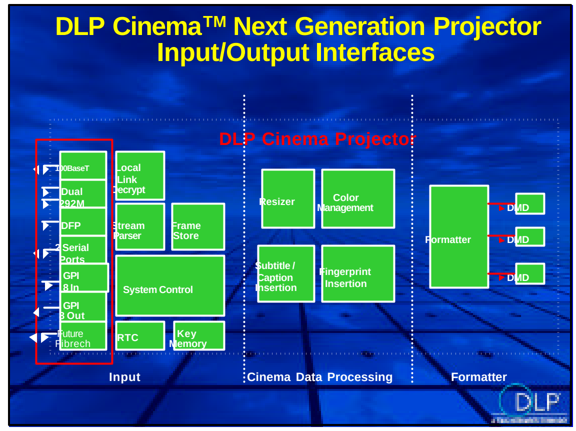
Conclusion: $\Delta E_{Lab} < 2$

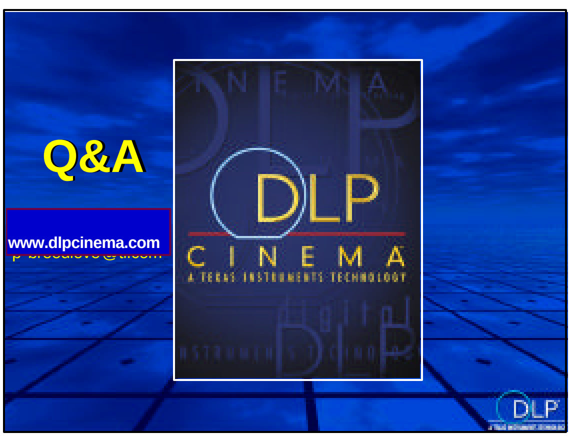


DLP Cinema™ Prototype Projector
Contrast & Contrast Stability




SMPTE DC28 - System Block Diagram
Comments on Standards
3-DES, Rijndael
DCT
Adapt. Block Size
MPEG 2 Variants
Recursive
Others
Wavelet
JPEG 2000
Digital Cinema
Dist. Master 2.5D
1.85:1 -1894 x 1024
2.39:1 -2447 x 1024
Subtitles &
Captions Per
EIA -708-B
Playback System
Dual SMPTE 292
Local Link Encryption
Embed In
SMPTE 292
Data Stream
(SMPTE 291)
DLP


DLP Cinema™ Next Generation Projector
Input/Output Interfaces
DLP Cinema Projector
100BaseT
Dual
292M
DFP
Serial
Ports
GPI
8 In
GPI
8 Out
Future
Fibrech
Local
Link
Decrypt
Stream
Parser
Frame
Store
System Control
RTC
Key
Memory
Resizer
Color
Management
Subtitle /
Caption
Insertion
Fingerprint
Insertion
Formatter
DMD
DMD
DMD
Input
Cinema Data Processing
Formatter
DLP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"Tools and Diagnostics for Projection Display Metrology"

P. A. Boynton

Flat Panel Display Laboratory

NIST

Mr. Boynton received his BSEE at Northwestern University. He has been at the National Institute of Standards and Technology (NIST) for nearly twenty years. He presently works in the Flat Panel Display Laboratory, where he performs research in the evaluation and development of electronic display measurements, standards and procedures. He serves on several standards committees, including ANSI/PIMA, ISO, and VESA.

Digital Cinema 2001
“A New Vision for the Movies”

“Tools and Diagnostics for Projection Display Metrology”

by P.A. Boynton

Electronic projection display specifications are often based on measurements made in ideal darkroom conditions and assume ideal measurement instrumentation. However, not everyone has access to such a facility, and not always will the light-measuring devices necessarily provide accurate information. In many environments, ambient light from other sources in the room illuminates the screen. This includes room lights directly illuminating the screen and the reflection of these light sources off of walls, floors, furniture, and other objects. Additionally, back-reflections arising from the image on the projection screen must be considered. These stray light components contribute to the measured values and give rise to inaccurate measurement of the projector light output

Measurement instrumentation face challenges as well. Light from outside the measurement field can reflect off the lens surfaces of the light-measuring devices, creating a veiling glare that corrupts the measurement. Projectors using a high-energy scanning beam to render the image may pose difficulties for some instruments to accurately measure. Likewise, saturated colors may be difficult to measure with some spectroradiometers and especially colorimeters.

Thus, these and other conditions may make the task of adequately comparing and evaluating different projection systems difficult. We can better verify whether the projector is operating according to its specifications or compare its performance with other projectors by compensating for stray light and testing the measurement instrumentation. Simple tools and diagnostics will be discussed that address some of these concerns.

January 11-12, 2001
National Institute of Standards & Technology

Tools and Diagnostics for Projection Display Metrology

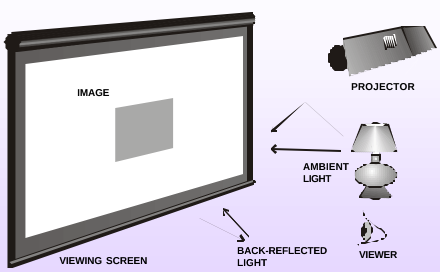
Paul A. Boynton

Flat Panel Display Laboratory
National Institute of Standards and Technology
Gaithersburg, MD 20899

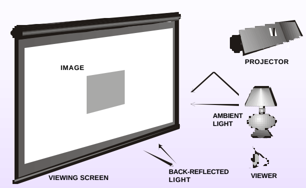
BASIC CONCERNS

- What are the effects of stray light?
- How does the scanning beam of flying spot displays affect the LMD?
- What are the effects of saturated colors?

FRONT-PROJECTION DISPLAY MEASUREMENTS AND STRAY LIGHT

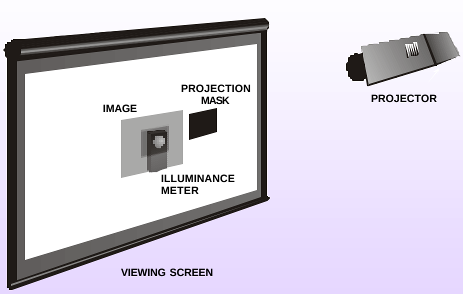


EFFECT OF STRAY LIGHT ON ILLUMINANCE MEASUREMENTS

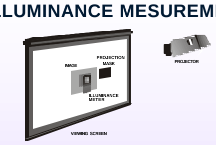


Case	Condition	Illuminance of black rectangle (lux)
Case 1	reflective surface removed	2.32
Case 2	reflective surface in close proximity	2.78
Case 3	ambient light entering room	8.45

PROJECTION MASK



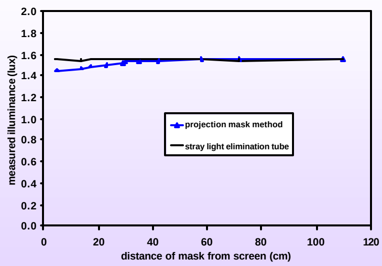
EFFECT OF PROJECTION MASK ON ILLUMINANCE MESUREMENTS



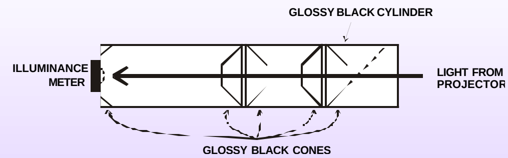
Case	Condition	Illuminance of black rectangle (lux)
Case 1	reflective surface removed	2.32
Case 2	reflective surface in close proximity	2.78
Case 3	ambient light entering room	8.45

	Measurement with projection mask (lux)	Corrected measurement (lux)
Case 1	0.76	1.56
Case 2	1.24	1.54
Case 3	6.88	1.57

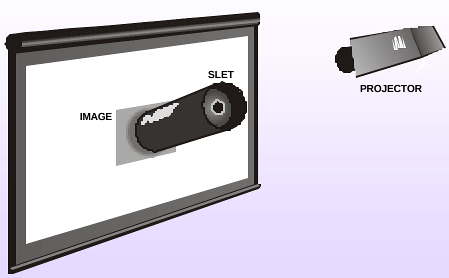
EFFECT OF MASK DISTANCE FROM SCREEN



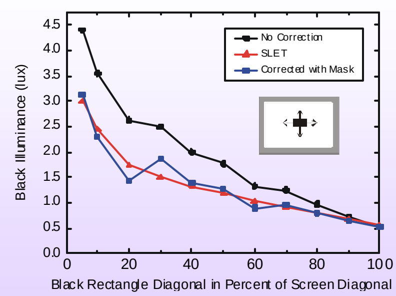
STRAY LIGHT ELIMINATION TUBE (SLET)



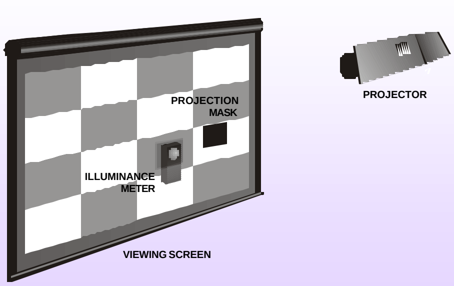
USING THE SLET



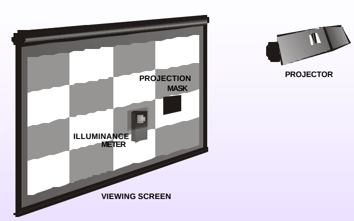
EFFECT OF STRAY LIGHT COMPENSATION



MEASURING CONTRAST RATIO

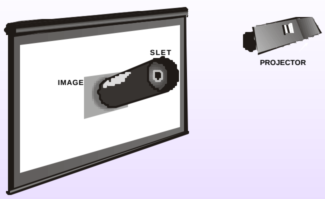


MEASURING CONTRAST RATIO



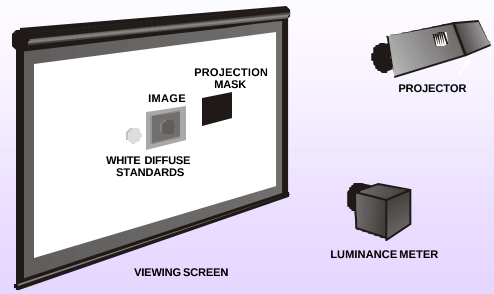
method	average white illuminance (lux)	average black illuminance (lux)	contrast ratio C_R
no mask used	97.0	1.37	71:1
projection mask used	97.0	0.90	107:1

EFFECT OF ROOM LIGHTS WHEN USING THE SLET

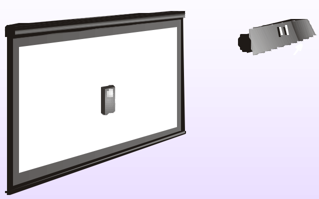


method	Measured illuminance with no SLET (lux)	Measured illuminance with SLET (lux)	deviation
room lights off	2.33	1.55	50%
room lights on	266	1.56	16951%

MEASURING LUMINANCE



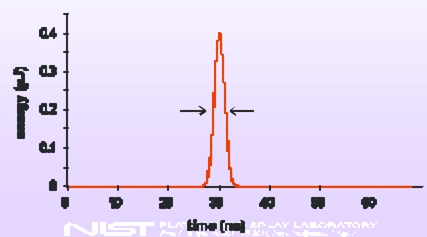
FLYING-SPOT DISPLAYS



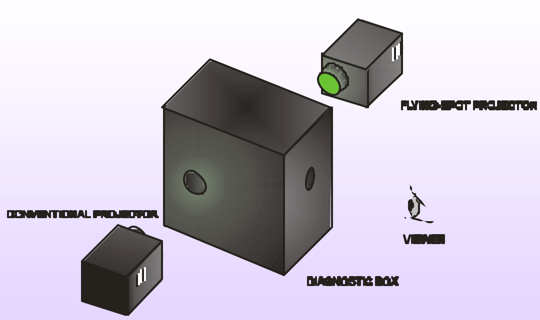
Concern has been expressed that many LMDs cannot properly measure many properties of flying-spot displays.

MEASUREMENT CONCERNS

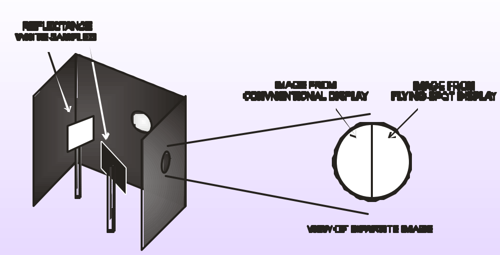
- Pulses are too narrow (integration error)
- Pulses contain too much energy (saturation error)



FLYING-SPOT DIAGNOSTICS

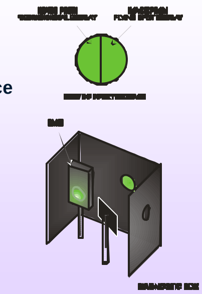


BREAKOUT OF DIAGNOSTIC BOX



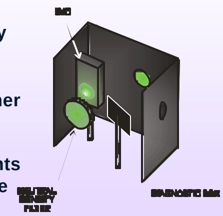
TESTING THE LMDs

- Adjust sources to match in luminance and color
- Measure luminance or illumiance with the LMD
- If the measurements of the two sources are close, then your instrument is not affected



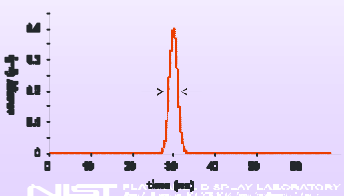
TESTING THE LMDs

- If not, then measure the sources with an ND filter in place.
- If both sources are reduced by the same amount, then this would point to a possible integration error, or some other cause
- If the ratio of the measurements differ, then this would indicate a possible saturation error

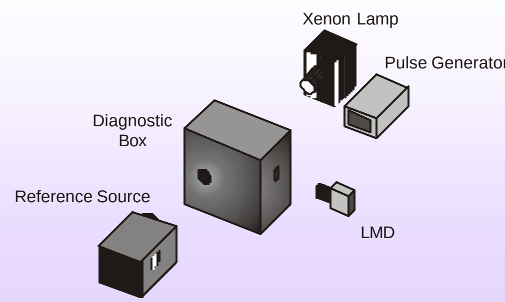


"SIMULATE" FLYING SPOT

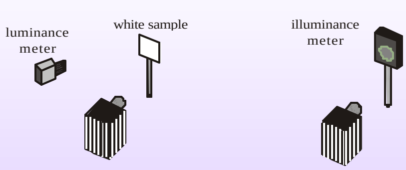
- 5 - 40 ns pulse width
- 200 nJ per pulse
- 60 Hz repetition rate



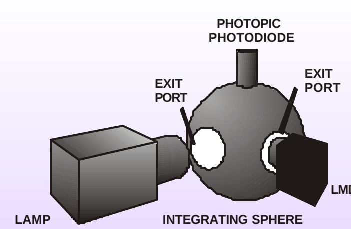
DIAGNOSTIC WITH A PULSED SOURCE

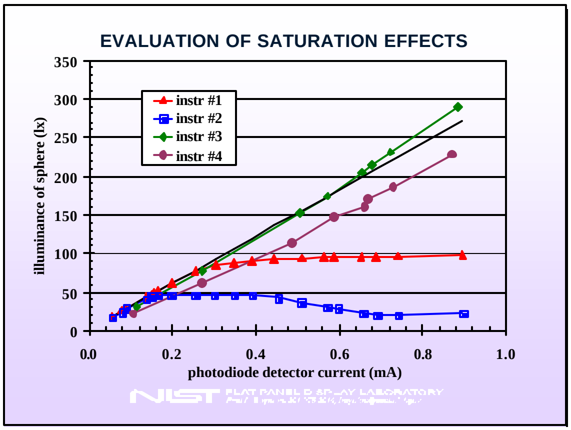


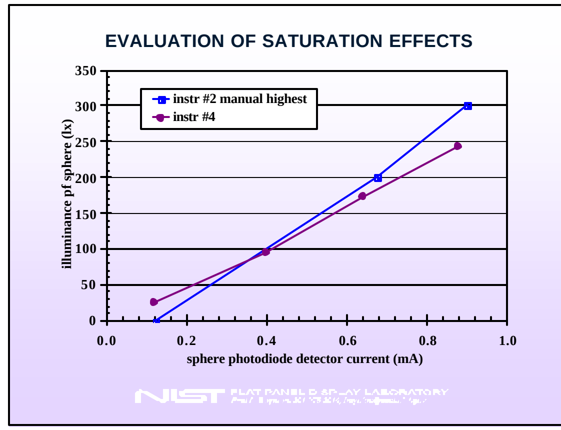
ALTERNATIVE METHOD

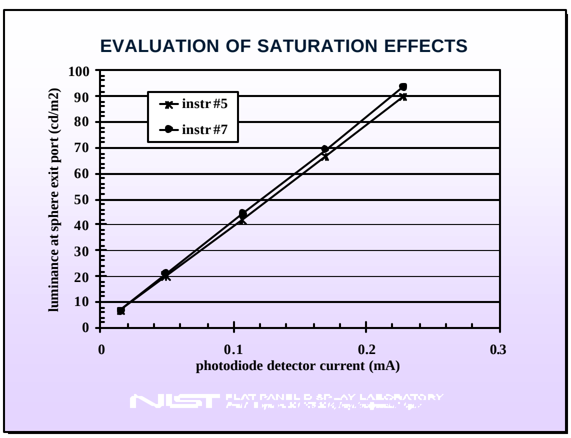


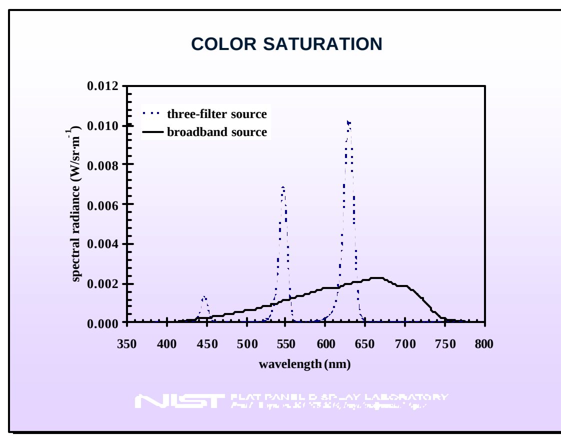
ALTERNATIVE METHOD

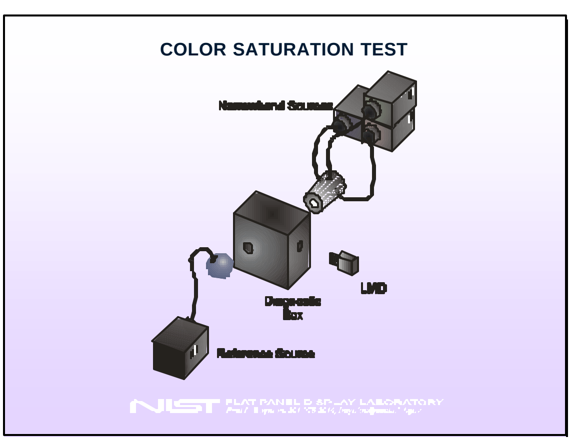


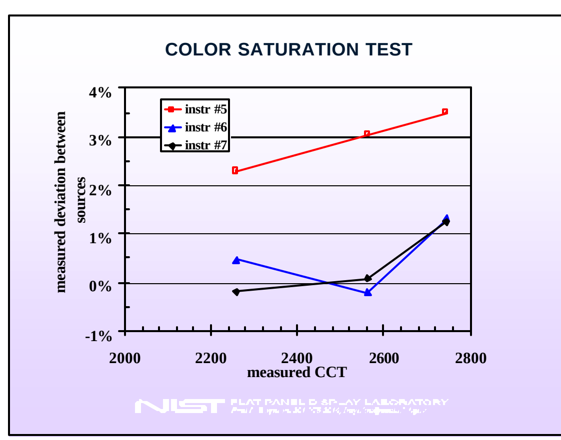

EVALUATION OF SATURATION EFFECTS
illuminance of sphere (lx)
photodiode detector current (mA)
instr #1
instr #2
instr #3
instr #4
0
50
100
150
200
250
300
350
0.0
0.2
0.4
0.6
0.8
1.0


EVALUATION OF SATURATION EFFECTS
illuminance pf sphere (lx)
sphere photodiode detector current (mA)
instr #2 manual highest
instr #4
0
50
100
150
200
250
300
350
0.0
0.2
0.4
0.6
0.8
1.0


EVALUATION OF SATURATION EFFECTS
luminance at sphere exit port (cd/m2)
photodiode detector current (mA)
instr #5
instr #7
0
10
20
30
40
50
60
70
80
90
100
0
0.1
0.2
0.3


COLOR SATURATION
spectral radiance (W/sr·m-1)
wavelength (nm)
three-filter source
broadband source
0.000
0.002
0.004
0.006
0.008
0.010
0.012
350
400
450
500
550
600
650
700
750
800


COLOR SATURATION TEST
LMD


COLOR SATURATION TEST
measured deviation between sources
measured CCT
instr #5
instr #6
instr #7
-1%
0%
1%
2%
3%
4%
2000
2200
2400
2600
2800

COLOR SATURATION TEST

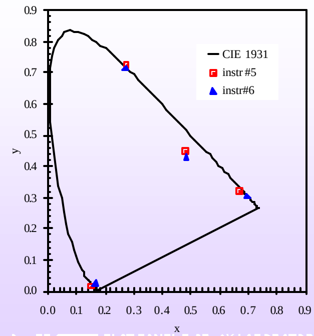
Verification of the additivity of luminances for various LMDs

LMD	Red source luminance (cd/m²)	Green source luminance (cd/m²)	Blue source luminance (cd/m²)	Sum of luminances (cd/m²)	Combined sources (cd/m²)	Difference
#5	46.1	76.3	0.44	122.8	123	0.13%
#6	48.94	81.54	.7040	131.18	131.2	0.01%
#7	46.86	77.72	.457	154.04	125.4	0.29%

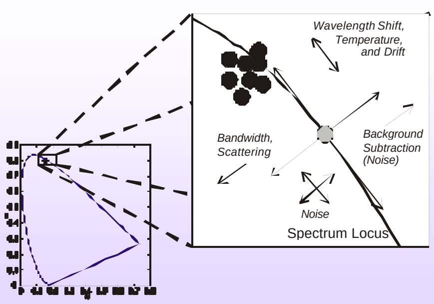
Verification of the additivity of tristimulus values for various LMDs

source	X	Y	Z
red source	111.71	48.94	0.18
green source	31.00	81.54	1.48
blue source	4.89	0.70	23.85
sum of red, green, and blue	147.60	131.18	25.50
combined source	148.14	131.20	25.97
difference	0.37%	.01%	1.81%

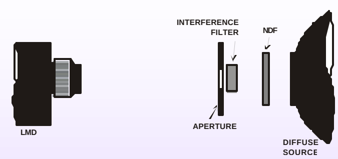
COLOR SATURATION TEST

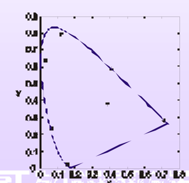


COLOR SATURATION TEST



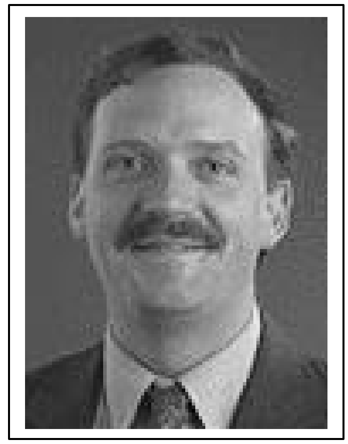
COLOR SATURATION





"DMD Characterization for Digital Cinema"

John Roberts
Program Manager,
Advanced Display Technology Systems Lab
NIST/ITL



John Roberts is Program Manager for the Advanced Display Technology Systems lab, within the Convergent Information Systems Division of the Information Technology Laboratory at the National Institute of Standards and Technology (NIST).

This lab is dedicated toward research on the role of displays (including, but not limited to visual displays) as the human-machine interface in information technology systems. Current projects include development of new display characterization techniques, investigation of stereo display requirements and electronic book readers, and development of new Braille display technology for E-books and other information devices.

John has conducted display research since 1993, and participates in the display-related technical committees of the Video Electronics Standards Association (VESA).

"DMD Characterization for Digital Cinema"

by John Roberts

DMD (micromirror) projectors can provide high resolution, fast response time, and a large number of colors and brightness levels (grayscales). These properties make DMD highly suitable for digital cinema projection systems. However, as with any display technology, a detailed knowledge of system operation can be helpful in optimizing performance. DMD characterization techniques being developed at NIST will be useful for digital cinema, both in production and in installation/diagnosis of projection systems.

DMD Characterization for Digital Cinema

John Roberts
Tracy Comstock
NIST

DMD Projection Systems

- High resolution
- Many colors and brightness levels (grayscales) - improves realism
- Fast response time, high frame rate
- Good for Digital Cinema, *however...*
- As with all displays, knowledge of display operation is needed for optimum performance!

Optimizing Display System Performance

- Make best use of grayscale/color generation methods used by the display
- Avoid "pathological cases" that degrade image quality
- Evaluate a model for given classes of application - interaction of input signals, internal control algorithm
- Check a specific display for correct operation

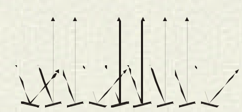
Basic DMD Operation

Micromirrors machined into a megapixel array

Light is reflected through projection optics, or into a light trap

Switching time tens of microseconds

Pixels are binary (fully on or fully off)



Generation of Colors/Grayscales

- Pixels are always "on" or "off" - no inherent grayscales
- Grayscales are generated by temporal modulation and spatial modulation
- Colors (red, green, blue) shown sequentially, or using multiple DMDs

Temporal Modulation

- Fast mirror switching permits many brightness levels
- Binary coded pulse widths for switching control within frame
- "Bit splitting" - rearrange sequence of binary time steps to reduce visible artifacts such as flashes

Spatial Modulation

- Patterns of pixels produce variations in visible grayscale
  - Effective resolution is reduced
- Used with temporal modulation for more grayscales, fewer visible artifacts

The Need for DMD Characterization

- Operational details not always available to the customer
- Manufacturer may not be aware of detailed needs for a specific application
- Diagnosis when problems arise

Method of Observation

- High speed screen image capture
  - Continuous, or periodic
  - Triggered, or free-running
- Selected test images (animations)

Experimental Setup

- Test images with known properties
- Repeated image capture, timing offset wrt frame rate
- Reconstructed animation shows mirror timing

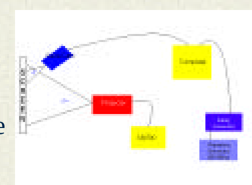
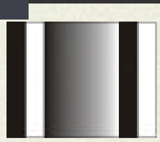
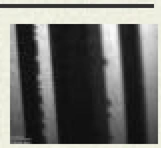


Image Examples



TEST PATTERN



OBSERVED IMAGE

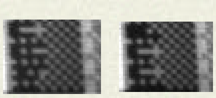
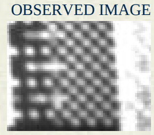


IMAGE TIMING: TWO CONSECUTIVE IMAGES



COMBINED RESULT

Designing Test Images

- Horizontal, vertical gradients to look for potential critical grayscales
- Blocks with known grayscales to observe spatial, temporal modulation
- Add visual tags to assist optical triggering (e.g. full-red block appears in red field only)
- Video tests: either rapid sequential capture camera, or short-cycle repeating animations

Pathological Cases

- Temporal
  - Flicker observed at certain gray levels
  - Color breakup, geometric distortions
  - Possible workaround: remap some colors, use spatial modulation
- Spatial
  - Regular patterns (in graphics, halftoning) interfering with modulation pattern
  - Workarounds: avoid deliberate use, filter

Application for Digital Cinema

- Content creators: Test material for suitability with selected displays
- Theater owners: portable device and test suite for checking installed projectors
- Possible future development: extended video sequences, with mathematical analysis of captured images

Summary

- Selected test patterns and high-speed image capture can be used to observe DMD operation and detect problems
- DMD characterization can be useful for digital cinema, both in production and in testing installed systems

Acknowledgements

- Xiao Tang, Victor McCrary, other ITL/NIST management
- Charles Fenimore - Digital Cinema
- Edward Kelley - display characterization
- Richard Gale and Peter van Kessel, Texas Instruments

"The Use of Format Conversion in Digital Cinema"

Steve Mahrer

Manager, DTV Engineering Liaison

Panasonic Broadcast & Television Systems Company

Stephen (Steve) Mahrer is Manager DTV Engineering Liaison, within the Strategic Technical Liaison group of Panasonic's Broadcast & Television Systems Company. Prior to this position he held positions within Panasonic of Engineering Manager, Digital VTR Engineering Manger and Olympic Project Manager. Responsibilities include Digital VTR Engineering / DTV Engineering Liaison for Panasonic's products, including D-3, D-5, D-5 HD, DVCPRO and DVCPRO HD formats.

Prior to joining Panasonic, Steve was for six years a Principle Staff Engineer with NBC's Technical Development Laboratory, 30 Rockefeller Plaza, New York. A broad range of projects were handled including work on Advanced Television, equipment evaluation, Engineering Support for the 1988 Seoul Olympics, and the custom design of an embedded digital video data signaling system that was later awarded a US patent.

Mahrer joined NBC from RCA Broadcast Systems, after being transferred to the US from RCA's European manufacturing base, RCA (Jersey) Ltd. in 1984. Work at RCA concentrated on CCD camera design and product support for RCA's existing PAL/SECAM equipment, much of which was extensively customized by RCA (Jersey) Ltd. for the European market. Mahrer's background represents over twenty six years of design and engineering on both camera and VTR products, systems and product support. He has also "survived" three Olympic Games.

“The Use of Format Conversion in Digital Cinema”

by Steve Mahrer

With the introduction of DTV, digital format conversion has become a well accepted process in video production, distribution and presentation. It has been utilized in both high-end professional applications and leading edge consumer products. Depending on the constraints of the application, the quality can vary in a number of aspects. Due to the large viewing angle of digital cinema presentations, compromises in image quality are typically magnified rather than masked. We will consider the effect that format conversion processes have on the quality of the final displayed images. This will include a discussion of the limitations of current techniques for both spatial and temporal conversions. Both electronic video and scanned filmed sources will be considered. A demonstration will be given to illustrate the type of artifacts and distortions that can be produced in this process.

"Calibration of Digital Imaging Systems Using Tunable Laser Sources"

Steven W. Brown

Physicist, Optical Technology Division

NIST

Dr. Brown received a BS degree in Physics from the College of William and Mary and a PhD in Applied Physics from the University of Michigan. After receiving his PhD, Brown was an NRC postdoctoral researcher at the Naval Research Laboratory in Washington, DC, where he worked on detailed studies of the optical properties of nanostructures. He joined the Optical Sensor Group within the Optical Technology Division at NIST in 1997. His current interests include colorimetry, display metrology, and optical remote sensing, along with the development of calibration techniques for digital imaging systems.

"Calibration of Digital Imaging Systems Using Tunable Laser Sources"

by Steven W. Brown

Accurate evaluation of the colorimetric performance of digital cameras is critical for accurate color reproduction in digital cinema. Digital imaging systems, such as digital cameras, are often calibrated against incandescent sources that have a broad, featureless spectrum. When these instruments subsequently observe a scene, unforeseen errors in color measurements can occur because of the very different spectral distribution of the calibration source from the measured scene. These colorimetric errors can in turn adversely impact accurate color reproduction in digital cinema.

To address this issue, we have developed a laser-based facility for Spectral Irradiance and Radiance Responsivity Calibrations using Uniform Sources (SIRCUS) for the radiometric, photometric and colorimetric calibration of digital imaging systems such as CCD cameras. In this facility, tunable lasers are directed into an integrating sphere (IS), producing a uniform, monochromatic, Lambertian source. We describe the calibration of a monochrome CCD camera equipped with a removable photopic filter. Details of the facility and the calibration approach will be presented. During the radiometric calibration, the pixel-to-pixel uniformity, linearity, and absolute spectral responsivity were determined over the visible spectral range (400 nm to 800 nm).

"Digital Rights Management: How Much Can Cryptography Help?"

William E. Burr

Manager,
SecureTechnology Group

Computer Security Division
NIST

Bill Burr is the manager of the NIST Security Technology (SecTech) Group, a member of the Advanced Encryption Standard (AES) team and Chairman of the Federal Public Key Infrastructure Technical Working Group, and one of the inventors of the Bridge CA concept. The SecTech Group is responsible for Federal Information Processing Standards for cryptography. Mr. Burr has worked at NIST for 22 years in Information Technology Standards, was the Chairman of the Small Computer System Interface (SCSI) standards committee in the 1980s and has been working on computer security, public key infrastructure and cryptography for about a decade.

"Digital Rights Management: How Much Can Cryptography Help?"

by William E. Burr

Cryptography offers powerful techniques for data protection in "classical" communications applications. Claims are often made that some new "technology" will enable or make electronic publishing "safe." This talk sounds a cautionary note, at least for large scale, controlled distribution of digital content to millions of consumers or subscribers. The essential difference is that both the sender and the receiver are trusted parties in a communications protocol (an attacker is a third party), but in DRM applications the consumer who receives the data is the likely attacker. This is a much more difficult problem. Cryptography may also offer small comfort to traditional intellectual property rights holders in the face of changing ethics and notions of property rights, and evolving business models, all of which are driven by new digital technologies.

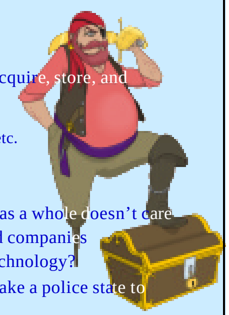
Digital Rights Management: How Much Can Cryptography Help?

Bill Burr
william.burr@nist.gov

Digital Cinema 2001

January 12, 2000

My Daughter the "Pirate"



- College freshman
  - Biggest use for her laptop is to acquire, store, and manage MP3s, and burn CDs
    - Napster, Knutella, MP3.com, etc.
    - not a hacker, but good at Napster, etc.
    - CD burner is required equipment
- Copyright pirate?
  - University doesn't care, society as a whole doesn't care
  - Little public sympathy for record companies
  - Can IP rights fly in the face of technology?
  - Given the technology, would it take a police state to stop the "piracy?"

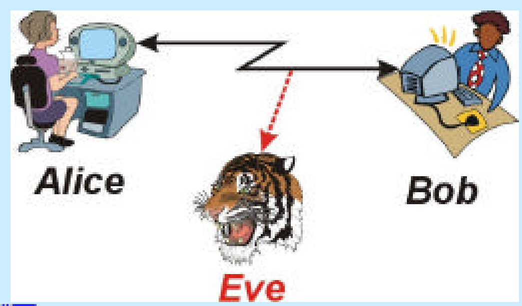
2

DRM Problem

- Rights holders want to have their cake and eat it too
  - Easy to copy digital document
    - low publishing costs
    - but the copy is as good as original, and anybody can make it
  - Advantages of digital/network distribution
    - low cost, convenience
  - May want to charge per use
    - whatever happened to original sale doctrine?
- Can encryption protect digital documents from unauthorized access?
  - But allow sales and distribution of creative works

3

Classical Encryption Model



4

Classical Encryption Model

- Alice and Bob want to communicate in secrecy so they encrypt their traffic
- Eve, an eavesdropper, intercepts all Alice's and Bob's traffic, and knows their encryption algorithm, but not their key.
- Eve still can't tell anything about the contents of Alice's and Bob's communication

5

Classical Encryption Model

- We have this problem fairly well solved
  - Strong symmetric key encryption such as AES
  - Public-key key exchange and strong authentication
  - Many protocols such as S/MIME. SSL, TLS, IPSEC, etc.
- Direct cryptanalytic attacks are impractical if Alice and Bob protect their keys

6

DRM Cryptographic Problem

- Don't want Bob to make "unauthorized" copies
  - Enforce this cryptographically somehow
- Forget Eve, ***we don't trust Bob***
  - Bob can always copy the encrypted file
    - DVD CSS does nothing to prevent copying of DVD
  - But Bob has use of the key or he couldn't use the document at all
    - Bob doesn't have to actually "break" the cryptography itself to get at the plaintext
  - May be millions of Bobs
- A big-time key management/protection problem

NIST

Key Management

- Even with hardware, key management is tough
- Don't want any key that can compromise more than one thing
  - With DVD there are lots of keys, any one of which effectively decrypts everything
  - Millions of keys?
  - Change keys frequently?
  - On-line?
- Complexity
- Can you fit rigorous key management into an attractive product and business model?

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Things that don't Work Well

- Strong cryptography in a weak system
- Security by obscurity
- Hacker challenges

NIST

Strong Crypto in a Weak System

- Attacker attacks the weakest link
  - A $500 lock in a $50 door is a waste of money
- Crypto algorithm is almost never the weakest link
  - Plaintext is often exposed
  - It may suffice to copy the ciphertext
  - How do you protect the keys?
    - DVD uses a weak algorithm, and then gives away the key so you don't even have to break the algorithm
- AES encryption is very strong, but by itself it doesn't solve the real problem

NIST

Obscurity Doesn't Work

- Security by obscurity won't work long
  - Any widely used consumer system will be known in detail by too many people, and will be reverse engineered in time even if the secrets were otherwise kept, Circumvention of Technological Protection Measures legislation notwithstanding
    - "Keeping the algorithm secret isn't much of an impediment to analysis, anyway – it only takes a couple of days to reverse-engineer the cryptographic algorithm from executable code…The system for DVD encryption took a weak algorithm and made it weaker." - Bruce Schneier
- If you have to keep anything more than a few keys secret, you're usually dead meat.

NIST

Hacker Challenges

- Offer a prize to anyone who can "hack" some protection scheme
  - if nobody wins the prize the scheme must be good
- Just doesn't work
  - Can only prove that protection is broken
  - Never enough time
  - Can rarely harness the best talent
    - not enough reward to be worthwhile
  - There is more fame and profit from waiting until the technology is deployed and then exploiting or announcing the hack.

NIST

Things that may Work a bit Better

- Steganography/watermarks
- Hardware protection
- Genuine open competition

Steganography

- Steganography hides a message in something else (e.g. a "watermark" in a digital video)
  - typically would identify the original source
  - might include a serial number
- Requires very tight controls to be useful
  - Records of every original sale
  - Every original must be a little different if you're to trace the "leak"
  - How can it work to protect mass distribution to millions of viewers?
- Can sometimes be defeated technically

Hardware Protection

- Use a semiconductor chip that won't give the key directly to Bob, and ensures he pays.
- Helps reduce IP piracy, but
  - Consumer product protection can't cost much
    - The key is there and it can be extracted in time
      - Bob can activate the key, but
        - » to do it right, one key should never "give away the store"
  - The plaintext digital copy still exists during playback
    - a probe in the right place recovers what the pirate wants
      - integrating everything on one chip with very high resolution lithography makes probing harder
  - High quality analog can be redigitized
- Who can ignore the software player market?

Open Competition

- Worked with AES
  - NIST invited submissions from anybody
  - Analysis of algorithms by crypto community
    - got expertise money could never buy
  - NIST picked winner
- Could we do something similar with DRM?
  - Basically a tougher problem
  - Wouldn't solve larger business/social problems
  - Takes a long time
  - Who could run it?

Copyright

- Statute of Anne, in 1710
  - Beginning of modern copyright law
  - Limited term of protection
  - Limited rights: print, publish, sell
    - original sale doctrine
  - Earlier laws gave copyrights to printers
  - Nominally gave rights to authors, but
    - printers controlled presses and as a practical matter still controlled copyrights
      - many authors, few printers, big investment for presses
    - today perception is publishers, record companies and movie studios primary copyright beneficiaries
      - authors and performers often get a small part of total revenues

Copyrights & Technology

- Copyrights were a reaction to the printing press
  - No need for copyright when copies were made by hand
- Copyright law evolves with technology
  - *Folsom v. Marsh* - 1841, fair use
  - 1909 Copyright Act - Player Piano, mechanical royalties
  - Betamax Case - 1984
  - Home Audio Recording Act - 1992
  - Digital Millennium Copyright Act - 1999
    - ISP Liability
    - Circumvention of Technological Protection Measures
      - can this even slow down software hacks?
      - how much will it slow down hardware hacks?
  - *RIAA v. Diamond Multimedia* - 1999

A Changing World

- Old
  - Production, publication, marketing and distribution are expensive, favoring large industrial corporations
  - Most of the costs have to do with production and publication, distribution and marketing, not creativity.
- New
  - Digital technology and the Internet make production, publication, distribution and even marketing less expensive and capital intensive
  - Disintermediation is more or less the name of the E-commerce game
  - Sometimes you have to "eat your children"

NIST

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Conclusion

- Cryptography does some things very well, but
- A *small* part of a DRM solution, no answer to:
  - The digital challenge to manufacturing and distribution
  - Disintermediation
  - Evolving hacker friendly social attitudes
- Can often "hack around" strong cryptography in consumer applications
- A good business model for DRM is needed
- Cryptographic hardware protection can at least slow down unauthorized access
  - Combined with appropriate pricing & business models this may be enough

NIST

20

"The Digital Object Identifier"

David Sidman

CEO

Content Directions, Inc.

Prior to founding Content Directions, Inc. in August 2000, David Sidman was Director of New Publishing Technologies at John Wiley & Sons, a leading global publisher of print and electronic products. His responsibilities included positioning Wiley as a successful electronic publisher through a combination of strategy development, internal projects enabling organic growth, and external acquisitions/ investments. His accomplishments included establishing the online sales channel for print products (both through relationships with online bookstores and through Wiley's own Web Catalog), developing an internal R&D program which has incubated many of Wiley's electronic products, and initiating/managing projects to develop the back-office production and e-commerce systems needed to support online publishing. At the industry level, in cooperation with other publishers and the AAP, he has founded and/or driven many key initiatives such as the Digital Object Identifier (DOI), as well as various standards involving Metadata, E-Books, Digital Rights Management, etc.

Prior to Wiley, Mr. Sidman was Director of Strategic Technologies for Moody's Investors Service, IT Director for the International Capital Markets Division of Barclays Bank, and held various other positions involving Wall Street and the Information Industry, both on the customer side and the information provider side. He is a graduate of Harvard University.

"The Digital Object Identifier"

by David Sidman

The Digital Object Identifier (DOI) was developed 4 years ago to enable e-commerce and protect copyright for all online content industries, although it was first implemented in the scientific publishing community where 61 of the largest international Scientific Journal publishers have already tagged over 2 million articles with DOIs and are using it to cross-link the world's primary-science literature. Based on technology developed by the principal inventor of the Internet, Dr. Robert Kahn, and implemented within the scientific/university community which was also the early adopter for the Internet itself (and later the Web), the DOI is now ready for adoption across all other content industries: film, video, photography, music, etc. The DOI does not replace other numbering systems for content (SMPTE, etc.); instead it empowers them with an Internet-based, DNS-like routing system which guarantees a permanent link from the identifying number to the actual content, and which facilitates transactions of all kinds: syndication, distribution, e-commerce, revenue tracking, digital rights management, etc. David Sidman will provide an overview of the DOI and explain its business benefits for Digital Cinema.

The Digital Object Identifier

David Sidman
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dsidman@contentdirections.com

NIST/NISO "Digital Cinema" Conference
January 12, 2001

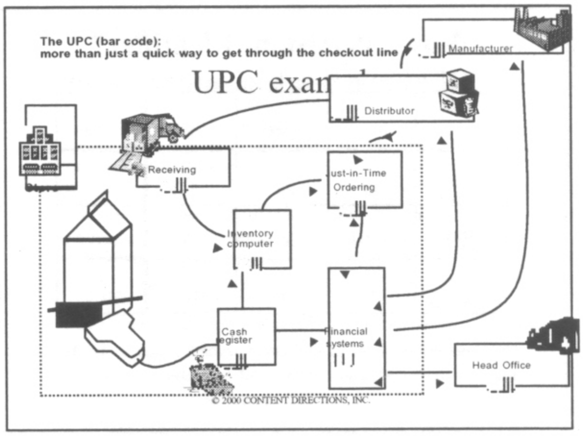
What is the DOI?

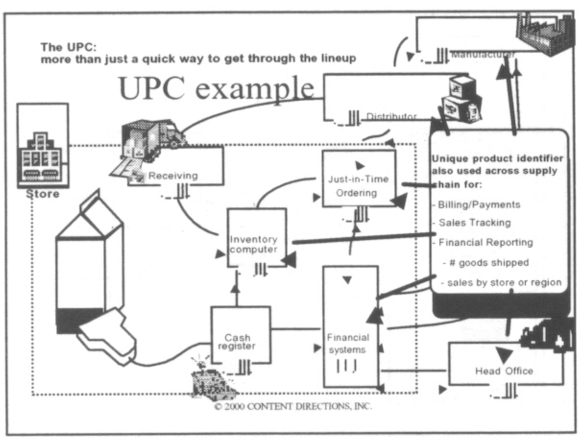
- "The DOI is the UPC (Bar Code) for objects of intellectual property on the Internet." Two aspects:
  1. **Uniquely identifies content** - therefore enables computers to execute transactions of all kinds: Buy, Sell, Syndicate, Track, Compute Royalties, Clear Rights, Enforce Copyright, Grant Permissions…
  2. **Provides a Stable, Persistent Link to the Content Itself** (or to the Owner's website)
- Initiated (1996) in order to:
  a) create an e-commerce market for intellectual property online
  b) protect copyright in that market (otherwise no one gets paid)

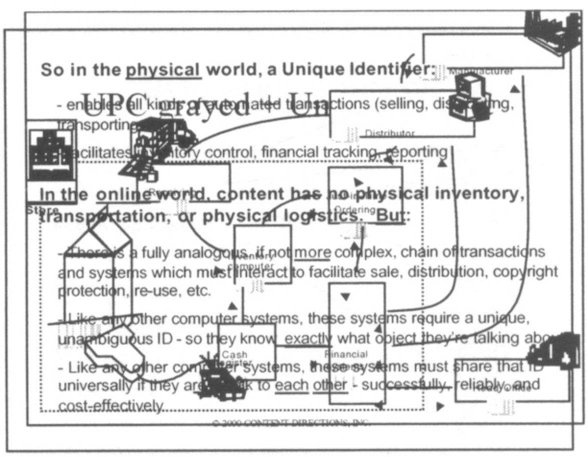
#1 - Unique Content ID

- Any type of content: text, music, film, video, photographs, software…
- Any level of granularity: whole book, individual chapters, illustrations, data sets, tables, music tracks, versions (e.g. dif. resolutions)…
- Compatible with (superset of) any & all other numbering schemes (ISBN, ISSN, ISWC, UPC…)
- Once assigned, never changes ("A DOI is Forever")
- Why is a unique ID so important for transactions?

(UPC/Bar Code example…)





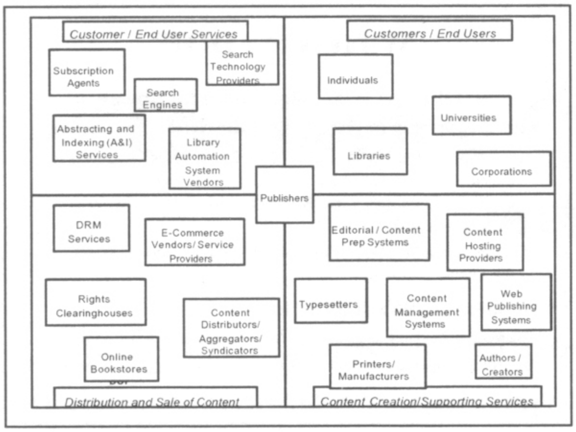


So in the physical world, a Unique Identifier:

- enables all kinds of automated transactions (selling, distributing, transporting…)
- facilitates inventory control, financial tracking, reporting

In the online world, content has no physical inventory, transportation, or physical logistics. But:

- There is a fully analogous, if not more complex, chain of transactions and systems which must interact to facilitate sale, distribution, copyright protection, re-use, etc.
- Like any other computer systems, these systems require a unique, unambiguous ID - so they know exactly what object they're talking about
- Like any other computer systems, these systems must share that ID universally if they are to talk to each other - successfully, reliably, and cost-effectively.



#2 - Persistent Identifier

- DOI never changes, but URL does: Content Owner maintains the correct URL pointer in a directory
- Directory is similar to Domain Name System (DNS): single directory logically, but distributed physically
- If maintained faithfully, a DOI link survives:
  - moving the content to a different server
  - Content Owner's sale of that content unit/product line
  - acquisition of Content Owner by another company

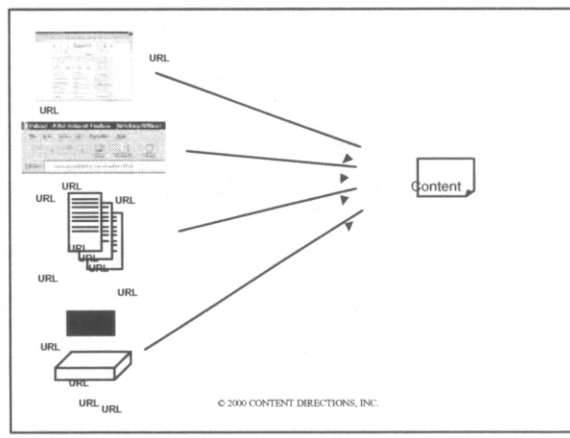
Why a Persistent Identifier?

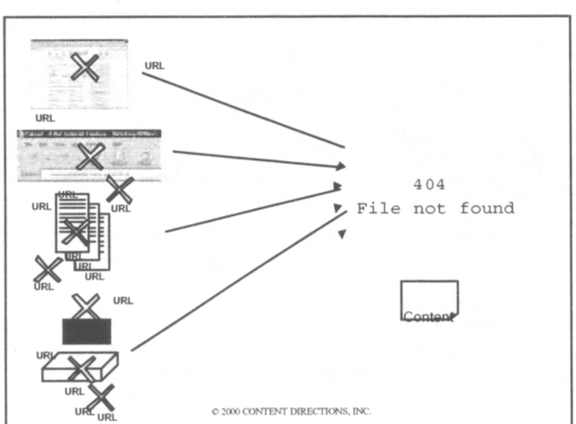
URLs are not sufficiently reliable

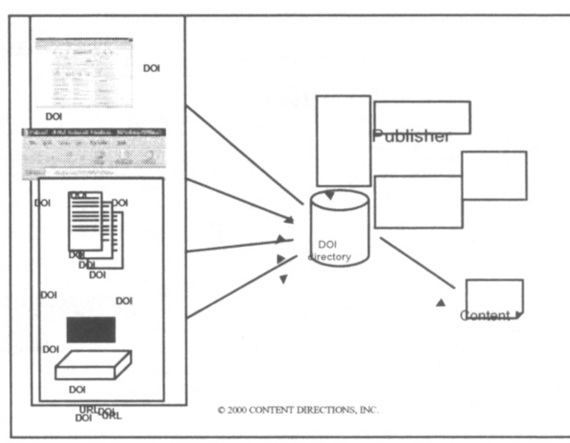
	http	gopher	ftp	Total
Number of journals	33	26	2	
URLs listed	81	36	29	148
% functional	67%	28%	31%	50%

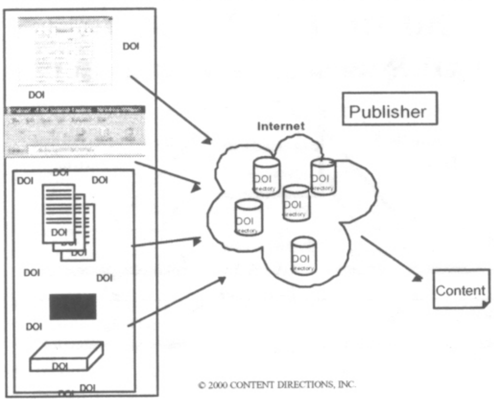
Data from Ford& Harter, College and Research Libraries, July 1998

Brewster Kahle (1997): half life of a URL = 44 days









Underlying Technology for DOI

- "Handle System"
- Robust, scalable, live & working since 1997
- Developed by CNRI (Corporation for Nat'l Research Initiatives - non-profit research org)
- Run by Dr. Robert Kahn, one of principal inventors of the Internet
- CNRI runs, coordinates, or supports many Internet standards bodies: IETF, IAB, etc.

Publishing Industry Support

- **Association of American Publishers** (project was initiated by the AAP Enabling Technologies Committee, 1996)
- **International Publishers Assocation** (IPA endorsed its launch at the Frankfurt Book Fair 1997)
- **STM International** (also endorsed the launch, and has given special support because the STM market was the first to go online)
- **Many individual publishers**, esp. STM Journals

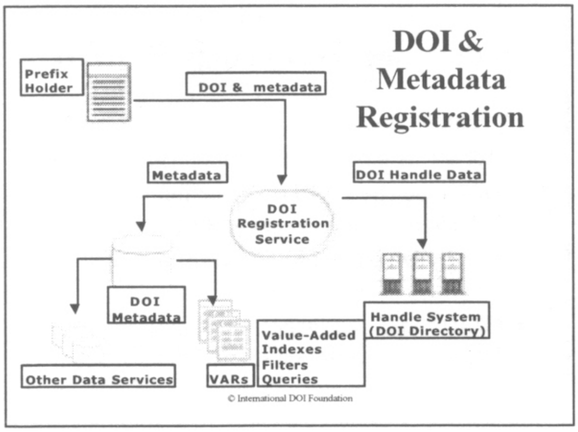
Current State of Deployment

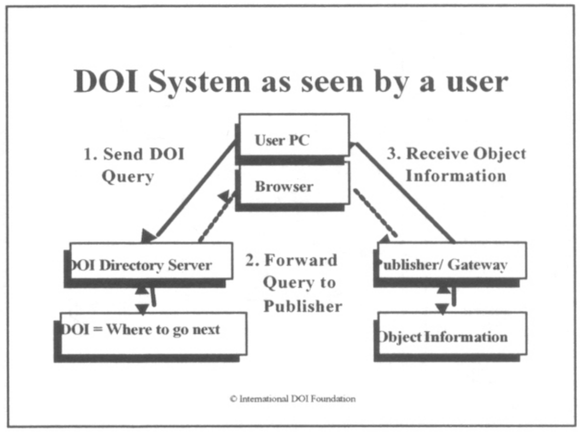
- Scientific Journals
  - 61 of the largest international journal publishers funding permanent non-profit DOI tagging operation ("CrossRef")
  - 2 million DOIs registered to date
  - "Killer app:" Cross-linking the world's scientific journal literature, based on a common "DOI Lookup" database
- eBooks
  - Stephen King moves 500,000 eBook copies in 24 hours
  - Wake-up call to Trade Publishers: 1) there is a market, but 2) the content had better be copyright-protected...
  - AAP/Andersen Consulting "eBook Standards" initiative about to declare DOI the identifier of choice for eBooks
- Other Content Industries (Music, Video, Photography, Software...)
- 3rd Party Support from Technology Vendors & Others
  - Digital Rights Management (DRM)
  - Content Management Systems (CMS)
  - "Infomediaries"

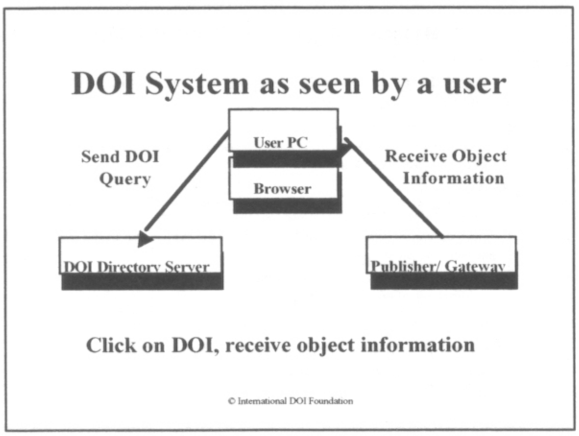
How the DOI System Works

DOI number format

- **10.1065/abc123defg**
- **10** = DOI **10.1065** = Handle prefix
- **abc123defg** = Handle suffix
  - item identifier
  - any format
  - naming authority (publisher)
- in use, a DOI is an opaque string (a "dumb number" - a good thing)







What does DOI do for Digital Cinema? Improves 3 areas:

1. **Post-Production** (content development)
   - No organized Digital Workflow today
   - Many parties work on different aspects
   - Can't easily "modularize" or manage the content itself
2. **Distribution**
   - "Last Mile" problem for hi-bandwidth content requires extraordinary control of distribution logistics
3. **Commerce, Syndication, Rights Management**
   - Don't get Napstered
   - <u>Profit</u> from the efficiencies of digital distribution

Special Focus: DRM (Digital Rights Management)

DRM is More than Anti-Piracy

- Allows the Studio to specify all the things that can be done with the content downstream:
  - Sample/Preview
  - View fully, but with limitations (see below)
  - Forward
  - Re-sell
  - Syndicate
- Can also specify:
  - How many times
  - For how long a period
  - For what price
  - To whom (forwarding)
- Not just negative (locking content up), but also affirmative (new ways to sell, great mktg potential)

Super-distribution:
The "Holy Grail" of DRM

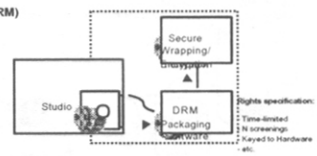
- Turn customers themselves into points of additional distribution
- The most targeted, effective selling imaginable (friend to friend; knows tastes/interests; more pre-qualified than the best sales lead, targeted banner ad, or bookstore display)
- Turns pass-along from an act of piracy into an additional sale
- Instead of undermining revenue, multiplies revenue

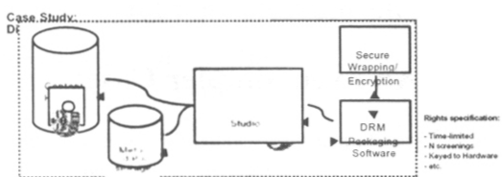
How does the DOI assist DRM?

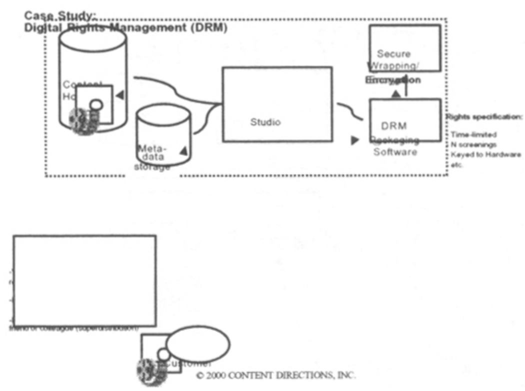
- DOI is "necessary, but not sufficient"
- DRM vendors must support it
  - but they will, because it will make their products work much better, and will facilitate a more seamless and friction-free end user experience
  - Also, they all use internal content IDs anyway - but they only work internally; they'd be glad to use a universal ID, assigned at the source by the Content Owner
- Mostly, everyone is waiting for the Content Producers to assign DOIs to their content

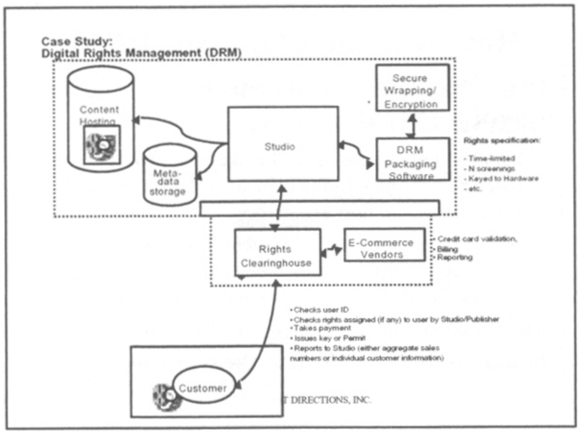
How DOI works with DRM...

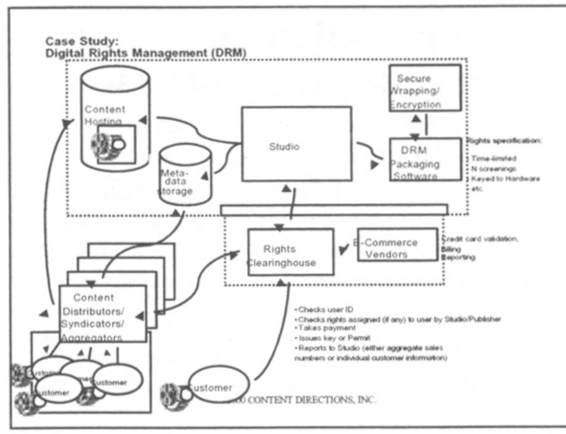
Case Study:
Digital Rights Management (DRM)

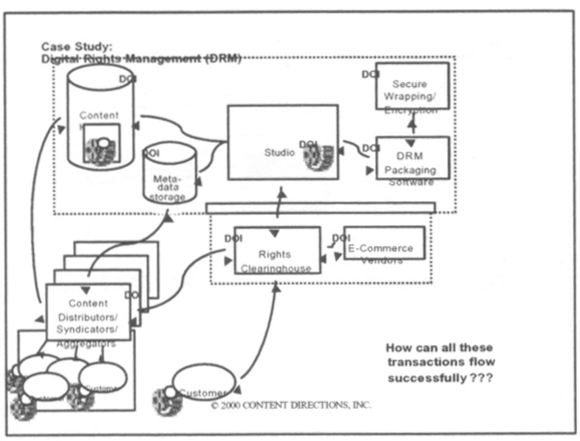


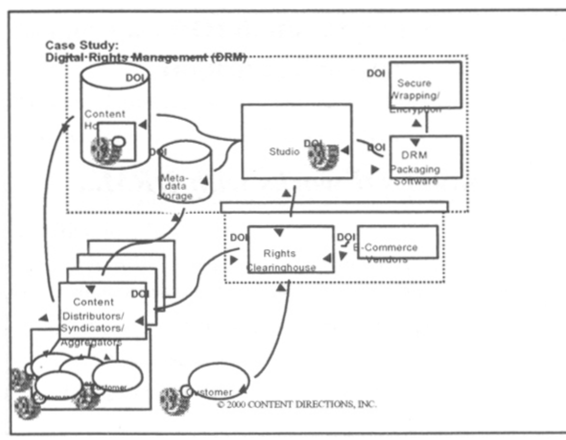


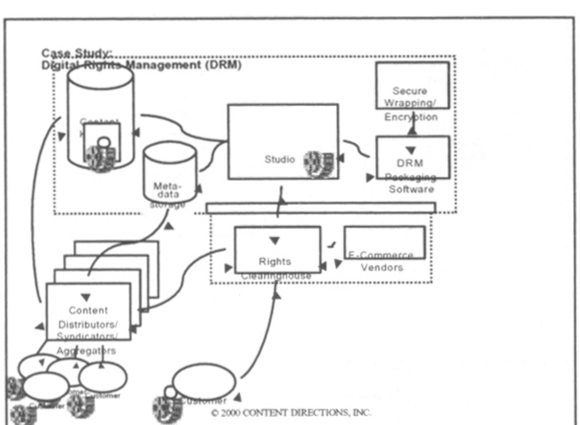








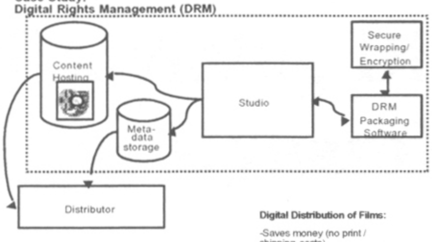




An Even Simpler Case:

Digital Distribution to Theaters...

Case Study:
Digital Rights Management (DRM)



Digital Distribution of Films:

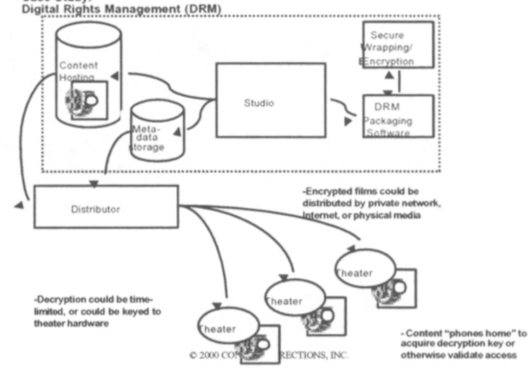
-Saves money (no print / shipping costs)

-Speeds Delivery

-Increases Flexibility (include new theaters, widen release)

-Potentially increases studio control over content

Case Study:
Digital Rights Management (DRM)



Market Opportunity

- 54% of all Internet users indicate a willingness to buy content
  - Jupiter Communications, Aug 1999
- $40 billion digital commerce market opportunity by 2003
  - SIMBA, Jan 1999
- $185 billion market today for online intellectual property, growing to $275 billion by 2003
  - J.P. Morgan, November 1999
- $200 billion in media content already sold in the U.S. in 1999
  - Veronis, Suhler & Associates, Information Industry Report, 1999

How can Content Directions help?...

Strategy and Business Case
- Education
  Overviews or intensive workshops tailored to Executives and/or Staff.
- Business Case
  Identify increased revenues, cost savings, and implementation costs

Business Planning
- "State-of-Readiness" assessment of:
  Post-Production workflow; IT systems;
  E-commerce systems; Back-office systems
- Develop DOI-based product strategy
- Develop implementation recommendations

Implementation Planning
- Metadata assessment
- Detailed cost-benefit analysis
- Define implementation project

Implementation
- CDI will act as project manager and general contractor
  - Custom development or off-the-shelf package integration (Post-Production Systems, Asset Mgmt, Digital Rights Mgmt, E-Commerce...)

Post-Implementation Value-Added Services
- CDI will develop or consult on developing company- or industry-specific value-added applications. E.g.:
  - Automation of relationships with syndicators/distributors
  - Advanced DRM solutions
  - "Multiple-resolution" applications

Further information

- International DOI Foundation (IDF):
  http://www.doi.org
- Corporation for Nat'l Research Initiatives (CNRI):
  http://www.cnri.reston.va.us
- CrossRef Consortium (scientific journal publishers)
  http://www.crossref.org
- Content Directions, Inc. (coming soon):
  http://www.contentdirections.com

Thank you!

David Sidman
CEO
CONTENT DIRECTIONS, INC.
"The DOI Experts"

Content Directions

CONTENT DIRECTIONS, INC.
558 9th Street
Brooklyn, New York 11215
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"Providing Digital Rights Management for Dynamic, Interactive Cinema"

Robert Schuler

Vice President, Solutions Group

Savantech, Inc.

Robert heads up the professional services for Savantech, serving the content industry to provide solutions that enable digital delivery and monetization of digital content and rights. Prior to Savantech, he was a senior member of the engineering team for Xerox Rights Management where he helped to architect and design Xerox's Digital Rights Management technologies, yielding patent-pending works and contributing to emerging standards. Robert's broad DRM experience comes from his professional engagements on major accounts in the Publishing, Music, Movie, Government and Corporate markets for digital content. Robert holds a bachelor of science degree in computer science from the University of Southern California.

Digital Cinema 2001

"A New Vision for the Movies"

"Providing Digital Rights Management for Dynamic, Interactive Cinema"

by Robert Schuler

The range of obstacles set before the purveyors of content to successfully exploit digital distribution is evident. Clogged pipelines are choked for sufficient bandwidth. The dearth of essential automated systems within content companies, including Digital Asset Management and IP Management, inhibits the efficient and scaleable utilization of digital content. Incompatible, competing and immature content interchange formats, software applications and industry standards leave confusion and apprehension. Piracy, fueled by the popularity of file sharing tools, threatens ownership of content. Legacy systems for rights and royalty management fall short of comprehending the issues raised by digital distribution or to support newer business models. Whether for business-to-business distribution or direct to consumer sales, a wide range of issues must be addressed to provide meaningful digital rights management to exploit the dynamic and interactive content opportunities available.

January 11-12, 2001
National Institute of Standards & Technology

Providing DRM for Dynamic, Interactive Cinema

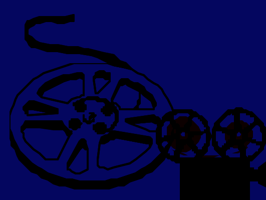
Robert Schuler
Savantech, Inc.

Overview

What is New Media?

DRM solutions for New Media

New Media



"New" Media

What's "New" about "New Media"?

"New"
- Distribution method changes
- Value Chain changes
- Service Providers change
- Technology changes

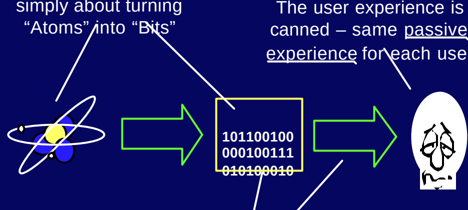
Media
- But the media is still "Old"

"Digital" + "Old Media" [1] "New Media"

Misconceptions

"Digital Content" is simply about turning "Atoms" into "Bits"

The user experience is canned – same passive experience for each user

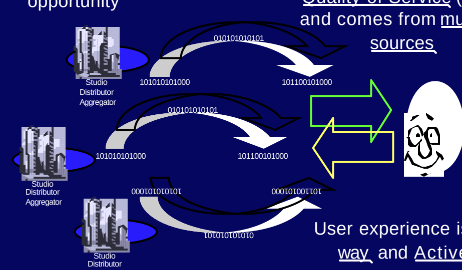


The product is packaged and sent to the consumer from a single source

Facts

New content is created that exploits the online opportunity

Content is a Service with critical dependence on Quality of Service (QoS) and comes from multiple sources



User experience is 2-way and Active

New Media is…

Service-oriented (not a static package)

Multi-sourced (not single-sourced)

Active, 2-Way Experience (not a 1-way, passive experience)

…not just "Digital Old Media"

…Dynamic, Interactive Cinema

Other Voices

…every e-business is in the content business…
– Contending with Content (Seybold)
Susan Aldrich

The traditional link – between the medium and the message… between the informational value chain and the physical value chain… – is broken.
– Blown to Bits (HBSP)
Evans and Wurster

…need to liberate e-books from tree books…
– Why e-Books Could Fail (NIST)
Jim Shaffer, CEO, Clickshare Service Corp.

DRM Solutions

"Last Mile" DRM

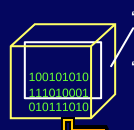
DRM and Security

Overemphasis on Protection leads to misunderstandings:

DRM is synonymous with Cryptography

Security is the limiting factor for digital distribution

Protection varies from vendor to vendor



"Container"
"Wrapper"
"Envelope"
"Box"

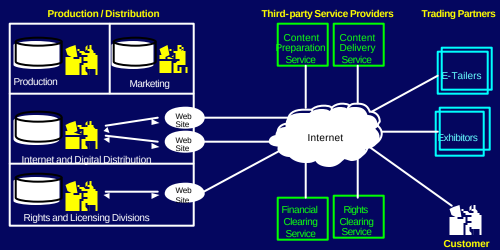
"Content" + "Cryptography" [1] "DRM"

Solution Needs

DRM beyond Security
- Rights Workflows (acquisition, granting, licensing)
- Modeling of complex Business Agreements
- Support business models & consumer expectations

Solutions with DRM
- Service Integration and Service Contracts
- Streamlined, automated internal processes
- External integration with Service Providers
- Interoperability between Trading Partners
- Market Imperatives must be factored

Example Environment

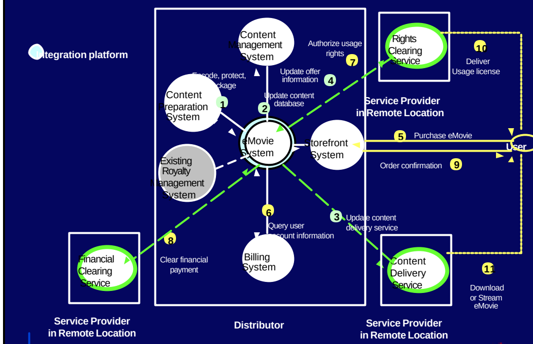


Streamline in-house systems and processes
- Manage rights, royalties, metadata, digital content

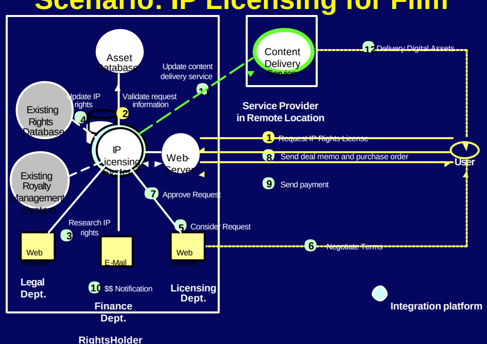
Distribute content in multiple digital formats
- Sell direct from company's web-site
- Sell through trading partners

Reuse content in different ways

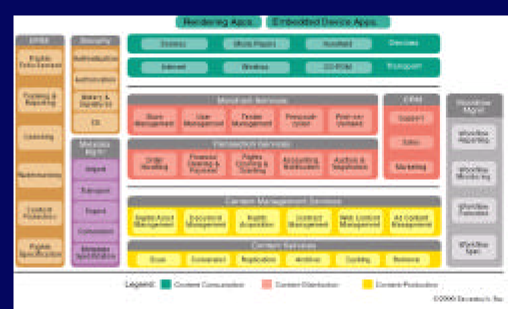
Scenario: Direct Distribution



Scenario: IP Licensing for Film



digital Commerce Framework



Savantech, Inc.

Content Integration Platform (dCI)
- Platform for building digital distribution solutions
- Integration of content applications, business agreements and workflows

Professional Services
- Experienced in providing solutions for the digital content market
- Leverages solutions sets, such as eMedia, ePublishing and RGS

Thank You

Robert Schuler
VP, Solutions
(310) 318-8822
robert.schuler@savantech.com
www.savantech.com

"DRM for the Digital Economy"

Michael Miron
Co-Chairman of the Board of Directors and CEO
ContentGuard, Inc.

Michael Miron is co-chairman of the Board of Directors and chief executive officer (CEO) of ContentGuard, Inc. Miron is responsible for the overall business strategy and execution of ContentGuard's mission to accelerate Internet content delivery across all content and media types, on a worldwide basis. Miron was previously president of the Internet Business Group at Xerox Corporation, where he was responsible for the development of new Internet-related transaction and service businesses. Miron also held the position of senior vice president of Corporate Business Strategy and Development at Xerox, where he was responsible for long-term corporate strategy, corporate initiatives, mergers and acquisitions, strategic alliances and Internet strategy and infrastructure. He also was an officer of the corporation.

Miron joined Xerox in 1998 from AirTouch Communications in San Francisco, where he was vice president of Corporate Strategy and Development. Prior to this, he worked in strategy and analysis at Salomon Brothers Inc. in New York from 1990-96. He also worked at McKinsey & Company in New York from 1986-90, and at International Business Machines in Rye Brook, N.Y., from 1981-86.

Miron received a Bachelor's degree from Cornell College of Engineering in 1977 and a Master's degree in Management from Northwestern University in 1981.

Digital Cinema 2001

"A New Vision for the Movies"

"The Role of Managed Storage in the Digital Cinema Infrastructure, from Capture to Archive"

David Cavena
Digital Cinema
IBM Global Services

Dave Cavena is the IBM Global Services Principal developing Digital Cinema opportunities in the areas of Systems Development, Application Development and Systems Integration, with the Major film studios and postproduction companies. His recent experience is as an IBM-Certified Executive Project Manager specializing in Systems Integration and Application Development projects in the area of Digital Cinema. Dave is a part of the Media and Entertainment Industry sector of IBM Global Services. He has twenty-two years of experience in the computer and communications industries, with a wide range of experience in Project Management, Management and Technical positions.

"The Role of Managed Storage in the Digital Cinema Infrastructure, from Capture to Archive"

by David Cavena

Digitally captured, processed and presented motion images generate large volumes of data storage. The amount of storage required will continue to increase as projector resolution increases and as true digital multimedia archive capabilities come into being. From the projector back through the production chain, this storage will be located in places unaccustomed to managing digital systems. Given the build-out costs of the infrastructure, without a managed storage environment, Digital Cinema will be less efficient and less cost-effective than it most likely will need to be.

Storing and managing the storage and storage subsystems at an exhibition location will require different skills, and more expensive skills than currently exist at the exhibition point.

Back through the production chain, the storage requirements will continue to increase as we get to the uncompressed content, CGI, Digital Intermediates, stock footage and archiving. Increases in projector resolution will drive resolution increases back up the chain, as well.

Should archiving ultimately become a 4K x 3K environment, archiving of Hollywood content alone will require 7 Petabytes of data annually, or 7 million Gigabytes.

At each stage in the process, large amounts of data are stored and require secure management, yet the organizations within the production companies, studios, distributors, exhibition companies and exhibition venues, are not geared to manage digital content, its security, backup and recovery, capacity planning, failure trend analysis of disk subsystems, etc.

Increasing use of digital tools in postproduction, and the large data volumes required to post features today also necessitate a requirement to surge data storage as needed for post. One recent live action/animated feature required 197TB to post.

Technology refresh, the term we use to indicate capacity and performance increases in digital systems necessitating system replacement in order to keep speeds up and environmental consumption and floor space down, also are not within the purview of most of those in the production chain of feature films. The capabilities of storage systems are increasing as fast or faster than any other area of the digital infrastructure that will be used in Digital Cinema.

The ability of the Digital Cinema viewer to absorb the experience of Digital Cinema, and thereby the success of Digital Cinema itself, rests on the ability to store and manage the storage of content. The requirements of content owners and exhibitors for storage and the delivery of storage services will start high and continue to increase over the near term.

What does this all mean to the Digital Cinema world? That the delivery of cost-effective, well managed, secure storage must evolve to a point at which the obstacle to the delivery of Digital Cinema is not the cost of the storage, nor of the storage management, of the content.

The model for the cost-effective delivery of the storage required for content is undergoing change with the recent advent of providers of managed storage services: technology companies experienced in the business of managing digital storage systems. A storage services provider can plan for and gracefully manage backup, recovery, capacity planning, failure trend analysis, storage management systems and technology refresh – the replacement of subsystems made obsolescent by technological advances, where content creators managing those assets internally may lack similar capability and flexibility.

Through a services delivery model, these capabilities, as well as the capability to provide a timely and cost effective surge of storage capacity as required by postproduction, these needs can be met.

Storage, Content and the Infrastructure of Digital Cinema

01/12/01

Dave Cavena
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Delivering Digital Content

- The Motion Picture industry is seeking the capability to deployand support global Digital Cinema distribution and exhibition
- For the majority of theater-goers to appreciate the quality experience of Digital Cinema, there must be a viable infrastructure to deliver it
- These patrons are going to get this quality only if an infrastructure is built to deliver it
  - Secure managed operations of the far-flung storage and computing assets which will makeup this infrastructure
  - Secure storage delivery to deliver the content reliably and in a sustained manner

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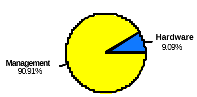
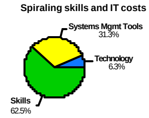
Storage trends and costs

Storage Costs Breakdown: 2000



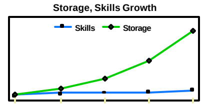
Source: Seagate Technology, August 2000

Spiraling skills and IT costs



By 2003, storage will be 75% of server budget

Storage, Skills Growth



Source: Dataquest, May 1999

Digital Cinema Infrastructure

- Distributing the *Story* to the *Patron* will require
  - A storage, data distribution and break/fix infrastructure that will deliver very large amounts of high-value data, easily, securely, globally, cost-effectively and sustainably
  - A global infrastructure built on a sustainable business model rather than one based on a perceived rollout schedule of Digital Cinema to ensure economic viability and survivability
  - A global infrastructure independent of particular technology providers, one in which Content Owners, Distributors and Exhibitors are not locked in to one or a few vendors of storage systems and tools
- This infrastructure will be necessary throughout the lifecycle of the Content, from Digital Transfer or Capture, to Post, to Distribution, to Exhibition, to VOD/NVOD, to Broadcast, etc.

Content Storage and Management: Options and Issues

- Storing and managing the storage and storage subsystems at Distribution and Exhibition locations will require new and more expensive skills
- The supporting company infrastructure of cinema Distribution and cinema Exhibition is not, nor should it have to become, skilled in the management and implementation of storage technology, systems and tools
- Managed Storage Services really provides to everyone in the cinema food chain an ability to manage and deliver content flows to dif ferent markets -- providing what they need when they need it -- without having to invest in the required storage infrastructure

---

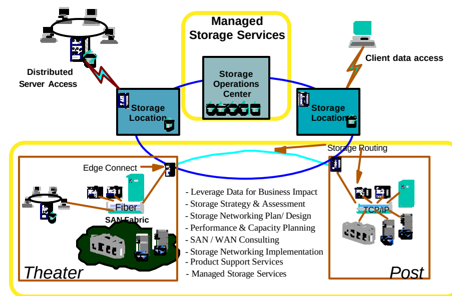
Storage Management and Delivery

- What is Managed Storage?
- What is the value for Digital Cinema?

What is Managed Storage?

- A cost-effective method of delivering storage, and the management of storage systems, both on-site and off-site, providing
  - Security – physical and logical
  - Storage systems management, including capacity planning and failure trend analysis
  - Surge capability
  - Technology refresh
  - Vendor-independence
  - Timely delivery of stored data to desired locations around the world
- A secure and established infrastructure including large storage centers and high capacity communications links

Storage in the Network



Managed Storage Services Benefits

- Easy to cost storage usage to particular projects
- Scalable and flexible capacity to keep pace with exploding data demand
- Support for all major platforms in a non-proprietary approach
- Gain access to superior skills and multi-vendor systems management experience
- Easy to buy storage services.... delivered through proven, networked configurations
- Facilitate utilization of data and new applications by leveraging advantages of new technologies

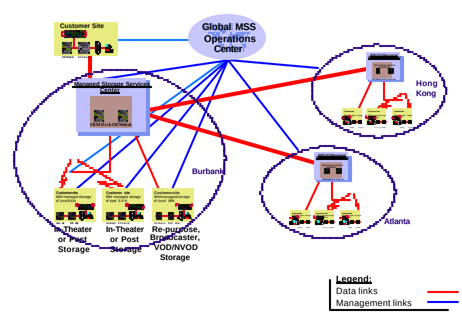
Value of Managed Storage Services

- Provides all of the value of networked storage plus....
  - Capacity on Demand
  - Pay as you go pricing
  - Lower cost of ownership
  - Better return on investment
  - Operational support, data management and disaster recovery provided
  - Consistent data backup and recovery across all servers
  - Access to technology, skills, technology insights and research not normally a part of the Distribution and Exhibition community
  - Facilities relief when storage hosted at another site
  - Disaster recovery

Managed Storage Services and Digital Cinema

- What can Managed Storage provide to Digital Cinema?
  - Secured content, providing both physical access security and logical, or data, security via desired encryption levels, watermarking services, etc.
  - Managed storage and distribution of stored content to desired global locations as requested
  - Failure trend analysis to ensure reliability of content storage systems and data integrity across the Capture, Post, Distribution and Exhibition environments
  - Management of the technology infrastructure of stored Content
  - Management of the storage in re-purposing of Content
  - Technology refreshment for storage systems as storage density and performance levels change
  - Cost effective management of the petabytes of data Digital Cinema will produce
  - The ability for the Cinema companies to do what they do best: Create, distribute and exhibit the ***Story*** to the ***Patron***, leaving the management of the required underlying technology infrastructure to a Technology Services company who does that best
- Possible implementation options

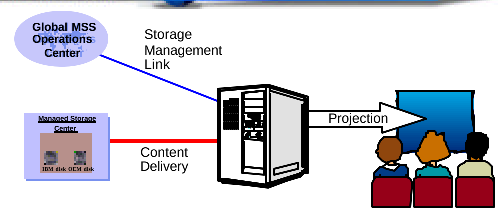
Connectivity Options



Exhibition Location

- Regardless of content delivery method, once the content is stored in a Production, Post or Distribution hierarchy or in a theater, the storage systems will have to be managed
  - Securely
  - With high expertise; appropriate to the value of the content
  - In a manner providing cost-effective technology refresh
  - With local break/fix maintenance with a very high service level, including spares
- This is not, nor should it be, a skill set of the theater employee population or of the exhibitor resource infrastructure

Exhibition Storage



- 50 - 100+ GB of data per feature
- 7x24 uptime requirement
- Local, global service capability
- Vendor Independent Systems

Production & Post Implementation

- **Store content as captured via 24P or as transferred from film**
  - Content stored in Managed Storage Services environment
  - Distributed content stored in global MSS sites for local distribution
  - Content to be posted delivered to Post house from storage facility
  - Storage managed by MSS globally at all locations
- **Why?**
  - Surge
    - Recent Major release used 197 Terabytes (197 x 1012 Bytes) to Post
    - Post houses don't want to and may not be able to afford to procure hundreds of TB to post films -- and shouldn't have to pay for it between projects
    - Digital Intermediates will quickly increase storage volumes in Post operations
  - Management of large amounts of storage
    - Capacity planning
    - Trend analysis
    - Technology refresh
  - Skills base
    - Not skilled in, should not have to hire storage experts to manage these very large amounts of storage and numbers of storage systems

Storage Utility in Postproduction

- Secure, managed location for storage of production content
  - On-site to Content Owner
  - Off-site from Content Owner
- Centralized distribution / receiving point for content
  - To / From Post
  - To / From Studio/Production Company
  - To / From Screeners, Viewers, etc.
- Logical location for applications securing the content, and the movement of the secured content, through postproduction
  - Encryption
  - Watermarking
  - "Fingerprinting" (unique watermarking)
  - Perceptual applications, such as watermarking and fingerprinting, may not find a home here, but "remote control" options for watermarking are in prototype now.

Electronic Movement Benefits

- Electronic movement of Content during Post expands:
  - Available time for Post operations
  - Universe of Post houses which can bid on projects
    - Increased market leverage on quality, schedule and price
  - Auditability of Work In Process during Post
    - Provide Work-in-Process view of content through Post (per business arrangements)
    - Provide auditability of content status and movement
- Communication data rates under control of owner and user capabilities and agreements

Asset and Resource Benefits

- Storage assets not purchased for specific project
  - Storage usage can be costed to project easily and accurately
- Surge requirements for particular projects do not require:
  - Extraordinary measures to beg/borrow/buy needed disk space
  - Extraordinary work hours to access that disk space
- Storage technology refreshed as required – density, storage management software, etc.
- Storage systems need not require physical space at Studio or Production Company – managed storage can be off-site
- Conversely, managed storage systems can be on-site, as well
- Staff to run and manage storage need not be an internal cost
- Capacity Planning, Technology Refresh, Asset Management managed under Managed Storage Services agreement

IBM Global Services

Managed Storage Services Summary

- Secure, managed storage of production Content
- Centralized distribution / receiving point for Content
- Logical location for applications securing the content, and the movement of the secured content, through Postproduction, Distribution and Exhibition
- Cost-effective Storage
  - Facility
  - Management
  - Planning
  - Technology Futures / Refresh

IBM Global Services

Managed Storage Services Provider Requirements

This will be done best by a Technology Services company with:

- A standard Managed Storage Services offering as a part of its core business, i.e.
  - neither an offering built specifically in a model of if-we-build-it-they-will-come,
  - nor a model on which the Managed Storage Services provider depends on the profitability of an assumed rollout schedule of Digital Cinema for continuing services
- A model of vendor independence for Managed Storage Systems
  - not requiring any one system or vendor of storage systems in order to provide Managed Storage Services
  - with experience in providing and managing globally, multi-vendor technology
- Major global presence
- Long experience in providing these services globally

IBM Global Services

Managed Storage Services Provider

Globally, over
- 175 Data Centers
- 900 Host Processors
- 317,000 MIPS
- 1,300 TB Storage

Global Systems Integration contracts
- 10,000

Non-IBM machines under contract
- 500,000+

$100M+ Strategic Outsourcing / Managed Operations contracts signed over last three years
- 133

Strategic Outsourcing / Managed Operations contracts signed over the last five years
- $100B +

Largest business continuity and recovery company in the world
- More than 12,000 customers in 76 countries

IGS' Business Innovation Services is world's largest SI/AD/Consulting firm
- $9.7B

World's largest business and IT services company
- $32.2B

Digital Cinema 2001

"A New Vision for the Movies"

"Very High Density Storage for D-Cinema"

Tom Lipiec

Vice President, Business Development, Video & Audio Entertainment

Constellation-3D, Inc.

Thomas has been involved in the cinema business for 20 years. The following is a list of some of his latest accomplishments:

- Served as R&D Coordinator for the professional division of THX (1997-2000).
- Assisted THX with implementation and cinema design process of the "Surround EX" sound format for the release of "Star Wars Episode 1: The Phantom Menace".
- Co-designed and produced optical test films to critically analyze projection lenses and projection systems.
- Conducted research projects to analyze the acoustical efficiency of cinema auditorium construction designs.
- Designed and produced audio test films for THX.
- Assisted the THX Digital Mastering Program to master and exhibit the Digital Cinema releases of "Titan AE" and "Star Wars Episode 1: The Phantom Menace".
- Assisted in the development of the Lucasfilm/THX Digital Cinema Program.
- Joined Constellation 3D in June 2000.

"Very High Density Storage for D-Cinema"

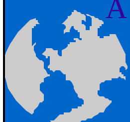
by Tom Lipiec

Issues covered within the speech:

- Storage capabilities of the Fluorescent Multilayer Disc (FMD) and how it will benefit the Digital Cinema industry. A single FMD is capable storing 100GB of content with read rates of 45 to 100 Mb/s.
- The problems and solutions of Digital Cinema content transportation and storage.
- Content data storage security issues and options.
- Disc-based infrastructure and cost saving issues.

Constellation 3D, Inc.

A New Dimension In Data Storage

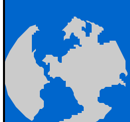


Overview

- Constellation 3D, Inc.
- Introduction to FMD: Fluorescent Data Storage
- FMD and the Movie Industry
- FMD Media for Digital Cinema
- Conclusion

Constellation 3D, Inc.

Corporate Headquarters



230 Park Avenue, Suite 453
New York, NY 10169

Technology Centers

- Dr. Vladimir Schwartz CTO
- Drive Technology Development, Boston, MA.
  - Dr. Ingolf Sander, design of miniature drives
  - Dr. Anatoly Dovgan, design of standard drives
- Media Manufacturing Equipment, Boston, MA
  - Bob Nicholas, design of media manufacturing equipment
- Media Technology, Rehovot, Israel
  - Dr. Jacob Malkin, development of fluorescent polymers

History of Technology Development - 1

- Idea for Fluorescent Multilayer optical data storage - Dr. Jacob Malkin in 1994
- Five (5) year development program conducted by leading scientists in Russia and Israel
- The Fluorescent Multilayer Disc and Card (FMD & FMC)

History of Technology Development - 2

- CD density, 10 layer ROM Audio Disc - November, 1999
- CD density, 20 layer ROM eBook Card - November, 1999
- 5 layer video ROM Disc - June, 2000
- 5 layer video disc, - November, 2000
- Demonstrations to be conducted in Q1/2001
  - HDTV ROM
  - FMD WORM
  - FMD Digital Cinema Player Prototype

History of Technology Development - 3

Strategic Relationships and Agreements

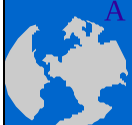
- Ricoh Corporation, Japan - WORM drives and media
- Zeon Chemicals, Japan - recordable film
- Steag/Hamatech, Germany - mass replication equipment for FMD media

Current IP Status

- Over 80 patents are filed - cover fluorescent data storage, optics, dye-polymer composites and media technology
- Company expects further intellectual property for media and drive technology

Introduction to FMD: Fluorescent Data Storage

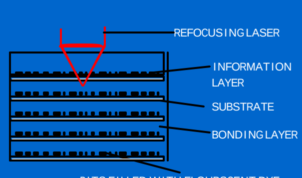
A New Dimension In Data Storage



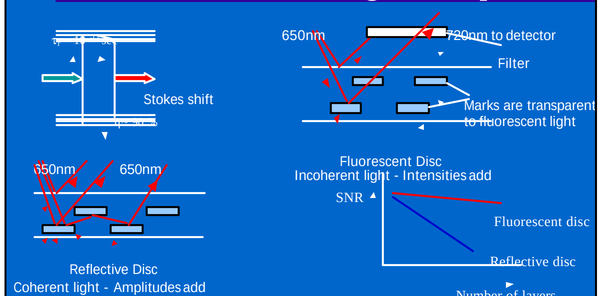
Fluorescent Multilayer Disc (FMD) Data Storage Principles

- Multilayer storage device
- Data storage capacity = 100GB+ (120mm disc)
- Focused data reading and writing
- Coherent incident laser beam light
- Incoherent fluorescent response
- Parallel reading and writing

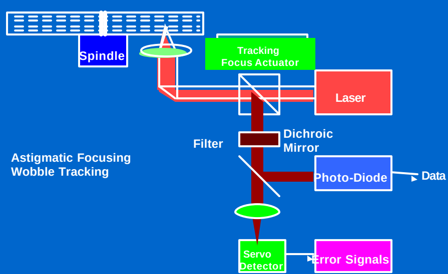
FMD



Fluorescence and Signal Response



Fluorescent Disc Drive

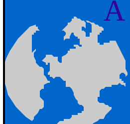


Data Storage Requirements

Applications	Capacity
• Digital Cinema	> 100GB+
• HDTV	> 50GB
• HD-Games	> 40GB
• VOD	> 40GB
• Mobile computing	> 5GB
• Digital cameras/Camcorder	> 5GB/10GB
• G3 Mobile Phones	> 5GB

FMD and the Movie Industry

A New Dimension In Data Storage



FMD / Motion Picture Production

- C-3D will work closely with leading camera manufacturers to produce desirable products for the Motion Picture Production Industry
- FMD WORM will be designed as high capacity / high-bitrate system for motion picture image capture
  - C-3D will apply high speed parallel writing technology for this industry
  - C-3D is exploring the applications of FMC WORM systems for motion picture cameras (Fluorescent Multilayer Cards)
- The FMD production format will be designed to match the FMD post production format
  - Time and cost savings - no need for transfers or processing

FMD Mastering & Media Replication

- FMD Content Mastering
  - The FMD is an open system format for data storage
  - The FMD is ideally suited as an archive format
    - Compact, high capacity, long shelf life
- FMD Disc Mastering
  - Emphasis on the use of current infrastructure
  - Existing Glass Master and Stamper equipment need only slight modifications to accommodate FMD specifications
  - Archive of Father Stampers and Galvanic Family
- FMD WORM
  - Simple low-volume duplication
  - Low cost and convenient
- WORM & R/W - write speed 44Mb/s (up to 500Mb/s with parallel write technology).

FMD & Studios

Benefits of FMD to Studios

- Physical media for Digital Cinema Distribution
- Low cost data storage
- Low cost shipping
- Archive format
- FMD offers a secure storage format
  - Open system for compression & encryption applications
  - Fluorescent dye options will restrict readability
  - Time Sensitive Content Protection (TSCP)

FMD and the Cinema - 1

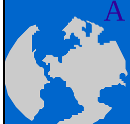
- Cinema FMD media and drives are designed to be:
  - Rugged and durable
  - Compatible with the maximum number Digital Cinema components
  - Based an open-standard system
- FMD Digital Cinema Player
  - Demonstration of FMD Digital Cinema Player prototype 1Q/2001

FMD and the Cinema - 2

- FMD Digital Cinema Player
  - Easy to operate
  - Secure
  - Affordable
  - FMDs are well suited to be a reliable "back-up" for a multitude of other delivery and storage systems – The FMD is a complementary system
- The FMD allows for compatibility with the following:
  - All projection image formats
  - All compression and encryption systems
  - Multiple interface systems

FMD Media for Digital Cinema

A New Dimension In Data Storage



Digital Cinema FMD

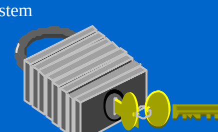
- Capacity: 100GB+
- Bitrate: 100Mb/s (up to 1Gb/s with parallel read technology)
- Size: 120mm diameter
- FMDs can be utilized as "load-in" devices for hard drives arrays
- FMD offers the option of direct playback of content
- FMDs are well suited to be a reliable "back-up" for a multitude of other delivery and storage systems
- The expandability and versatility of FMD technology makes it complementary to all other Digital Cinema data storage needs.

Removable Media for Digital Cinema

- FMD 100GB Digital Cinema disc:
  - Red laser with various fluorescent dyes
  - Robust and removable
  - Secure
  - Time Sensitive Content Protection (TSCP)
- Hard Disc
  - Not Recommended as Removable, Not Cheap, Not designed for portable Pre-recorded playback
  - Sensitive to magnetic fields (airport security)
  - Well suited as a stationary system
- DVD
  - Red Laser: Too many discs are needed for a full length movie (current Digital Cinema delivery solution)
  - Blue Laser: Not Available, Not Cheap, Compatibility issues
- Tape……..

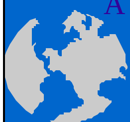
Time Sensitive Content Protection (TSCP)

- TSCP is a process to protect content by means of chemically altering the disc after a set amount of time or when the FMD is ejected from the Digital Cinema Player. At the moment of TSCP activation, the fluorescent dye will be chemically altered which will render the Digital Cinema content useless.
- TSCP will be used in conjunction with a Digital Cinema encryption system



Conclusion

A New Dimension In Data Storage



Conclusion

- Physical removable media can be used in conjunction with other types of data storage and delivery systems to give the cinema owners the options they desire.
- The FMD is the only physical removable media that offers durability, flexibility, high-quality and value.

Conclusion

- "The Content Data Storage System is the heart of Digital Cinema. It is the organ that receives and sends bits to every component of the Digital Cinema system."

Disclaimer

"Statements contained in this presentation that are not historical facts are forward-looking statements as that term is defined in the Private Securities Litigation Reform Act of 1995. Such forward-looking statements are subject to risks and uncertainties, which may cause actual results to differ materially from expected results"

"The SEC and NASD have not reviewed and do not accept responsibility for the adequacy or accuracy of this presentation"

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Constellation 3D, Inc.

A New Dimension In Data Storage