DC28 Functionality Focus

Bob Davis – Summit Computer Systems, Inc. 8 August 2000

DC28 is having great difficulty defining the direction of Digital Cinema. What options do we have? Why are we doing this? This reviews some of what we know and look at those options and the growth of the Digital Cinema marketplace.

Digital Cinema is analogous to the transition from the horse-based transportation system to the automotive-based transportation system, there is a fundamental change that is taking place in the story telling medium whether we like it or not.

1. What is Digital Cinema

First - What are we trying to do? Two potential goals have been proposed: 1) Simple replacement of film media; 2) Remove the limitations of film and improve the art of story telling through movies.

Goal 1 was discussed at the 20 July DC28.2 meeting, as an exact film replacement to be shown at 30 nits luminance, in a dark theater.

Goal 2 removes the limitations of film media. It must address the entire experience of the Cinema including the sound.

1.1 Definition of Cinema and Motion Picture

The following definitions of cinema and motion picture is from the unabridged "Random House Dictionary of the English Language" 1983 edition.

Cine - 1. a film; motion picture. 2. a motion-picture theater.

Cinema - 1. See motion picture. 2. the cinema, motion pictures collectively, as an art or form of expression. 3. a motion-picture theater.

Cinematics -the process or art of making motion pictures; cinematography.

Motion Picture - 1. a sequence of consecutive pictures of objects photographed in motion by a specially designed camera (motion picture camera) and thrown on a screen by a projector (motion picture projector) in such rapid succession as to give the illusion of natural movement. 2. a play, event, or the like, presented in this form. 3. motion pictures, the art, technique, or business of producing a motion picture.

1.2 How we use Cinema to tell a story

Nowhere in the above definitions does it state that the results are to be displayed in a darkened theater with a black surround. The current focus of the group seems to be the third definition of cinema as a motion picture theater, using film, downplaying the first two definitions of Cinema.

The oft-used definition of a presentation at 12 foot lamberts on a screen is derived from the historical use of film, not as a part the art form, but as a physical reality.

DC28 must strongly influence the enhancement of the first 2 definitions of Cinema or we have not done a service for the future of storytelling.

1.3 Timing of the Rollout of Digital Cinema

The economic justification of Digital Cinema will drive it quickly into the marketplace.

First implementations are already underway as part of the successful trials with results better than average production prints. While not as good as the answer print, it is better than the public has seen, and paid for, before.

First implementations of 5.5DC will probably occur about year end 2000 with 10DC in production less than a year behind that. Some say 6 months behind.

Higher pixel counts will follow as fast as they can be developed up to eye resolution limits about 50DC.

As usual with electronics, and Moore's law driven equipment, the standards will always be after the fact unless carefully constructed and looking forward. Incompatibilities are the last feature the NATO and MPAA have on their list of desires and priorities.

2 Purpose of Digital Cinema

The reasons that Digital Cinema is being considered are several:

1. Improved Revenue
2. Improved Delivery cost
3. Improved Picture quality
4. Improve Theater Revenue
5. HDTV
6. Replace Film

All are focused on getting more paying patrons in the seat with improve revenue per seat/performance.

2.1 Improve Revenue

If Digital Cinema does not enhance the bottom line of the producing companies it will be a non-starter. The current trials have shown Digital Cinema to be a success. Revenue and ROI will increase by expansion of the market, and new marketing opportunities, and the distribution cost reduction. .

2.2 Improve Delivery Cost

Clearly the first hit in this direction is a reduction of up to $1.4Billion in distribution cost using the identical performance scheduling in use today. This assumption is based on decrease in delivered cost from $1500-$2500 per copy to well under $10 in 2000 and headed shortly to under $1.00. This assumes ~600,000 US deliveries each year.

With digital delivery, worldwide openings are practical to enhance revenue and decrease piracy.

2.3 Improve Theater Revenue

Increase the attraction of the movies as a past time. Make the experience of the movies sufficient to attract more patrons to occupy the seats and increase revenue.

2.4 Improve Motion Picture Quality

More patrons will come to the theaters to view the movie if the quality is significantly better than the other rented experiences. This of course assumes that the quality is better. The same as current release prints is not good enough when the 1280 x 1024 Ti DLP trials have been reviewed as better than film.

The improvements will be to give the artistic talent more freedom in:

CGI effects
Animation
Lighting control – in post
Timing control - seconds and color timing
Sound delivery

The main improvements, from the technical sense, are resolution and color space along with higher frame rates and more channels of much higher quality sound.

2.5 HDTV

HDTV when viewed with 10 degree viewing angle is close to the human eye resolution level. This means that the eye can no longer perceive the individual pixels. The frame rate for moving images is better than film now.

HDTV poses the threat of keeping the patrons at home watching the old or made for TV movies.

HDTV does not serve some of the social needs of the theater and does not provide the Colorimetry the theater can provide. Some 3D HDTV was shown at NAB, it was impressive.

HDTV in its native form, is a very clear and sharp 1000+ nit image with surround sound.

2.6 Replace Film

This goal is different than above. The goal is to save the delivery cost of film to the theaters. The quality of the picture needs to be only as good as an average delivery print. This is accomplished with the current trials at 1280 x 1024 with 4:2:2 SMPTE 292 feed as less than HDTV quality. The projectors in use has a higher than HDTV color gamut except when displaying material converted for TV. The audio for this is 6 channels of 24bit audio at 48 Ksps uncompressed.

This preserves the ancillary function of the dark theater with dark surround and 20 nit screen.

3 Promise of Digital Cinema

Digital Cinema promise is to remove the limitations of film and change the economic model for the distribution. This will open opportunities for artistic enhancement of the processes.

This is a definitive moment. This model is the ability to break out of the mold created, very effectively, by film.

3.1 Able to define future Cinema

Future cinema is being defined. Because of the projected lifetime of the definition we need to take technology developments into account and live with some of the ramifications of Moore's law. Technology is plowing ahead at an exponential rate whether we like it or not. We always have the choice of riding the curve or being ridden by it.

3.2 Change Centuries on technology

Film will continue to develop; of this there is little doubt. The chemistry will be improved along with the resolution, stability, color gamut and speed. This growth will be linear in development on a low angle while the digital world is still exponential with no limits in sight.

It is time to set the framework for the next century of growth in an artistic and creative way by removing old notions on limits.

3.3 Change Economic Model

Lower distribution costs can change the roll out strategy and hit the world market at one time. This maximizes the revenue on the opening. It also minimizes the opportunity for piracy being as factor in the revenue stream. It could be possible to open in 20,000 theaters at the same time.

More work will be needed, but the possibilities warrant study.

4 Film Limitations

Many of the considerations circulating in the DC28 committee make assumptions based on past performance of film. What are these characteristics and do they need to be preserved?

4.1 Color Space

Color gamut for film, from Chuck Harrison's excellent paper, is plotted on the same CIE plot with the spectral lines, white points and many of the primaries. This does point out the superiority of film over REC 709 and the initial DLP light primaries.

Note that the Silicon Light Machines primaries encompass all that film could do and then some particularly where the eye response is highest.

4.2 Dynamic Range

The maximum useful range of film is about 1000 to 1 with a density measurement of D=2 with additional soft roll offs at each end of the curve. This is the Cineon curve as a starting point. The response in the middle of the curve is approximately codevalue = 500(log(density)). This is about 500 codevalues per decade or 1.002 change per code value.

4.3 Maximum Light

There is a maximum practical light level that can be produced in a theater. This limit is defined by the ability of the film to withstand the heat of the light source. The probable limit on light may be up to twice its current limit of 30 nits.

One additional feature of the low light is the requirement that the theater be dark with a dark surround. With a dark surround and no external reference colors, the eye is wonderfully adaptive which allows the color timing to be somewhat sloppy and the audience does not notice as the eye adjusts to the mental image of what the scene should be.

4.4 Chemical Process Issues

Color timing serves three purposes. First is to correct between the different film negative stock with different color response and shot at different times of the day and must look the same. The second major roll is to match the various scenes caused by the chemical processing and chemical differences in the film and baths. The third part is to modify the image for artistic purpose like changing the mood.

4.5 Frame Rate

The current frame rate in theaters is 24 Frames per second with each frame shown twice before advancement. This is a mechanical limit on the installed projector base. This is to conserve film cost and equipment cost. Customers do not complain because there is no better available except in HDTV and SDTV and DTV.

5 Targets for Digital Cinema

Initial markets for Digital Cinema still appear to be as follows.

5.1 High End Theaters – better pictures and sound

First markets will be the current high end theater complexes that can afford to embrace the new technology early. This necessarily includes better sound with the better image. The saved money will drive this quickly to the smaller screens based solely on economic requirements.

5.2 Larger Markets Later – better distribution

Electronic distribution changes the models for film usage. Much larger distribution is possible for the initial release. A world wide common opening date is very feasible on 20,000 screens.

We are also going to see a highly accelerated propagation through the secondary markets. The marketing challenge will be significant and dramatically change the revenue flow on a property to the near term.

Secondary markets are also prime candidates for the new re-distribution from the continued mining of the film vaults. Some of this remining of the film

6 Real target for Digital Cinema – Those who pay

We must keep foremost in our minds that Digital Cinema must play to the human eyes and ears sitting in the seats. If the story is not seen, and heard, by humans and appreciated it will not be paid for.

Lets keep the real revenue targets in mind in all the proceedings.

7 Capability vs. Usage

A large concern has surfaced regarding the specifications that appear to be confusing what is allowed and what is required. Allowed does not mean that it is required but allowed. We must define in capabilities for future use even though they may not be used immediately to promote growth of the industry while maintaining compatibility.

7.1 Compatibility

Primary goal of this work is a common distribution format that is understood by all and interpreted by all the same way.

7.2 Specification Lifetime

Viability of the specification is largely dependent on the capability of the specification to survive a changing environment. Continued development will continue to provide a better picture for the viewers. The economic cost of specification replacement is real and it will be far cheaper to build in extended capability today than to scrap this effort and restart in the future.

The next Digital Cinema specification generation planning should be for the holodeck and holographic presentations as that technology develops.

7.3 Economic Reality

Initial presentation will be based on current, or recently developed, cinematic material having much lower resolution and Colorimetry which will be up-converted to the distribution system as is currently done in HDTV.

As equipment becomes available the quality of the source material and the show will improve and the capabilities of the new format will become evident. Developing techniques will also improve the quality and human experience of this media.

Once the change to Digital Cinema starts, it will accelerate because of: 1) Patron demand; 2) Secondary markets; 3) Distribution modes; 4) Increasing cost of Film; 5) Replacement cost of Film equipment.

8 Digital Cinema Image Processing

The DCDM is the Distribution Medium common to all playback venues. These venues will not have the same projection/display equipment or capabilities. Digital processing of the DCDM to meet the local equipment is a required adapting of the distributed material to meet this need. Processing may be required for the Video, Audio and other effects.

8.1 Why process

Distribution of the movie in digital form requires a common format that is neutral in both format and content. As an example, I have no idea whether you will read these words on a CRT screen of some size, display it on a projector (for dart's practice) or print it on a color or monochrome printer. However you use it, I will send each of you the same file in word or PDF format.

Processing will need to occur the match the projector/display device to the movie DCDM material and to correct for deficiencies/"features" of the projections/display device.

8.1.1 Image Resolution

The DCDM will be produced in the 5.5DC or 10DC, or later enhancements (possibly 50DC), of the DCDM specification. This format is not matched to any physical device and is the neutral carrier requiring conversion to the Display/device specifications.

This conversion algorithm can be sloppy, with the attendant sloppy results or precisely predictive with good processing to maintain the intent of the DCDM through different resolution transforms. These transforms are well known – just some would like to avoid them if possible to save money.

8.1.2 Projector Color Gamut (Primaries)

The DCDM, and by implication the DSM, must have the capability to display the colors that the human eye can see. We are going through many transforms to get to the DCDM including the manipulations of CGI and artistic shading, color timing, and film corrections to get to the DCDM.

The DCDM's color gamut will be mapped to the gamut of the projection device. The only alternative to this is to produce the movie to the smallest possible gamut of color TV and force the world to like it.

Gamut matching can only be done if you can express the tri-stimulus points in the new gamut in the old gamut. A matrix multiplication is then performed to get the new values. It is mathematically intense and requires nine multiplications and 6 additions per pixel. This will be accomplished in log and linear representations for optimal performance. Today's general-purpose processors can launch 2 floating-point operations per clock (1ns) along with 4 additions. This is improving at Moore's law rate of 1.5% per week.

The end result of this computation is the best fit of the projector/display device to the content of the DCDM.

8.1.3 Projector Non-linearities

All projectors have defects and non-linear responses that are particular to that specific, by serial number, device. These are manufacturing reality. The better we can cope with these directly effects the cost of the product.

8.1.3.1 Pixel Response

In DMD devices, each mirror has a slightly different response than the one next to it. Large differences are in response causes a reject – move to less demanding use or discard. If we know what the difference in response is, measured, we can compensate the input to match the response and produce the highest quality results.

In light valve devices, each cell is slightly different in transmissive response. This again can be compensated in the mapping of the DCDM to the device to accommodate the deficiencies.

All expected projection/display devices have this effect in some way or another and can be compensated for. Film is not repeatable and we try to average out the effects of grain and other non-linearities in the eyeball.

8.1.3.2 Light Distribution

Great effort is make in the optics to get uniform illumination on the screen. Decreasing the light output inversely proportional to the non-linear illumination can reduce the effect of a hot spot.

In cases where the hot spot is desired it can be added by the inverse of the same process.

8.1.3.3 Lens Non-linearities

In some cases a know defects in the lens system can be corrected by changing the mapping in the display device. In other cases this correction is an anamorphic lens correction factor. The correction is simply a matter of degree and application.

8.1.4 Geometric Corrections

Corrections for projector placement and viewing angle can be programmed into the display device. Keystone corrections can be compensated by lens or by re-mapping the display data. While not necessarily a good use of pixels, it can produce a better picture.

8.1.5 Ambient Light Conditions

Different light conditions can yield different perceptual results for the same excitation. The relationship between lighting conditions, Colorimetry and eye response have been studied and are somewhat understood. This knowledge will allow the DCDM to be displayed in differing ambient light conditions while maintaining the artistic intent of the director. This power function response is used to produce a different coloration than a direct display for artistic intent.

This system of gamut matching will improve with new algorithms over time.

8.1.6 Color Coordination – Color Test Patterns

A VITAL part of Digital Cinema is the ability to have each projection system produce the same color on the screen.

The only place this can be measured is in the reflected light from the screen or the emitted light from an active device. This light is measured by a calibrated spectroradiometer or photometer and compared with the intended value specified in the color chart. The projector/display device uses this feedback to correct for primary differences, lens losses, source losses, projection/display booth losses to present a known, measured, calibrated image on the screen.

8.1.7 Frame Display Rate

Different display rates will be needed depending on the natural display rate of the projection system. Most of the proposed display systems have natural display rates far above the historical film display rate of 24 frames per second.

Display requirements will be drawn from the physics of the display. DCDM images will be converted by multiple techniques to meet the display requirements.

Down conversion from a high rate DCDM will also be required for slow display systems.

8.1.8 Audio Systems

Motion Picture story telling has been an audio/video experience since the discovery of talkies.

8.1.8.1 Channel Adaption

Some theaters are still using 2 channel sound while other theaters have 5 or 6 channel sound. The new DCDM is currently programmed for 12 to 16 channels of very high quality sound. The distributed 12 plus channel sound at up to 96K samples per second will need to be mixed down to the available theater system sound capabilities.

8.1.8.2 Sound Field Correction

Just as the video system is being mapped and corrected, so must the sound system. A mapping of the sound field of the theater will be made and used as a model to modify the distributed DCDM sound to produce the required audio profile at the customer's point of view.

8.1.8.3 Equipment Compensation

Additional compensation will be made for installed B-chain equipment where possible to bring the most accurate reproduction of the sound stage results.

8.1.9 Sub-titles

Sub-title placement will determine whether this is an in-band (on screen) or out-of-band (below screen) function. This processing will either superimpose this in the video display or route it to a secondary display.

9 Mathematical Realities/Mathematical Resolution

Many transforms and scaling will occur in the processing of the DCDM data for presentation on the screen/display surface. These transforms are not perfect and are not reversible without some loss of accuracy.

The accuracy lost depends on several factors that affect the DCDM including gamut conversion, resolution scaling, device corrections, and optical path corrections.

9.1 Processing Loses

Each process that involves a multiplication or division will introduce a loss of accuracy in the computation. This is normal and is usually handled by performing the mathematical operations at higher accuracy than required for the final result to make the results meet the desired results.

This same process is used on money also. To arrive at accuracy to the penny, the calculation are carried out to the mil or better and rounded to the nearest cent.

The following mathematical manipulations can introduce accuracy problems is not correctly handled.

- Conversion from logarithmic format to linear format
- Conversion form linear format to logarithmic format
- Matrix multiplication for gamut conversion
- Multiplication by correction factor for each pixel
- Factor scaling for projector characteristics
    - -- Light source
    - -- Linearity of emitter/valve
    - -- Device temperature etc.
- Power curve transforms based on ambient light
- Encryption
- Decryption

Each of the conversions listed involve multiplication or division which causes normal round off problems in the least significant digit in the numbers used. The accuracy issue increases with each additional operation.

Accuracy problems are handled by performing all the calculations at a much higher level of precision so the final rounding retains the precision that is required. From the DCDM to display surface may require a minimum of 15 operations and as many as 100 mathematical operations on the data.

9.2 Minimum Required – JND (Just Noticeable Difference)

This is the smallest difference in intensity or color perceived by the average viewer. In reality this is a Gaussian distribution about the point with some of the people being better and some worse. Sigma is the standard deviation from the norm and we should probably target a 1 to 2 Sigma variations to the fine side for the golden eyed director of photography and movie critic.

This JND, for the critical observer, must be exceeded after all the manipulations of the image are accomplished.

10 Real Time processing vs. Pre-Processing

10.1 Processing IS Required

As shown above the need for processing is a real part of Digital Cinema. This processing can be done at several times based on the capabilities of the projection system and the choices of the theater owner and the cost of different implementations. This trade-off will change over time as the requirements and capabilities of the in-theater equipment change.

Different vendors will certainly propose different solutions to this problem to their individual economic benefit. The theater owners may choose significantly different options to their economic benefit.

Some features of the processing are better suited to real time processing such as projector defect correction, because of the projector specific nature of the problem, while other processes such as color correction and resolution mapping could be processed in advance at lower cost.

10.2 Real Time Processing

Real time processing is the performing of all the mathematical function to show the frame at the time the frame is being transferred to the display device. This means the transforms are applied to each frame in 1/24 of a second for a 24 FPS movie. A much shorter time is available for a 72 FPS movie. Improvements in technology will favor real time processing as soon as economically feasible.

10.3 Pre-Processing

Pre-Processing is done prior to the performance of the movie. This may be 1 month to 1 hour prior to the first show time and can take as long as needed for the equipment at hand. Storage is needed to store the compressed or uncompressed version of the pre-processed display version of the movie.

Recompression after preprocessing may well be in a different algorithm that is designed for rapid inline decompression and decryption as it is streamed to the projector/display device.

Initially pre-processing will be the most economic choice and a choice that can be abandoned at any time in the future.

11 DCDM Requirements

The DCDM is a superset of the requirements of the projectors that can meet the 10DC and higher resolution environments. This is a common element for the transport of the movie to the theaters and other points of consumptions.

11.1 Plays to all Display/Projectors

All projection and/or display devices take a common format and produce an image based on the abilities/specifications of the projector/display device.

11.2 Plays to all venues

The DCDM is not created to play in a specific venue. It will be played in venues ranging from a screening room to large theater complexes. Parts of the production will be shown on a much wider set of display devices.

New and renewed venues are popping up such as drive-in theaters and dining theaters. Limits here are constrained only by the imagination of the exhibitor.

Different venues will require different gamma corrections to provide a consistent image to the viewer.

11.3 Known Consistent Function

The DCDM is the replacement for FILM and is the constant data set for all uses. It is a film replacement that has the capability to remove the limitations of film in most ways.

11.4 Resolution Growth

While the first trials of digital cinema have had better resolution than production film prints, considerably less than the capabilities of film, it has been viewed as a major improvement in projection clarity. Current trials are slightly less than HDTV resolution – 1280x1024 vs. 1920x1080 and the projection systems use anamorphic lenses to achieve the 1.85:1 mostly shown.

Resolution will increase as fast as the projector/display device vendor's can built them. Based on current projections from various vendors a 5.5DC projector will be available in this year and a 10DC projector will be demonstrated in 2001. These are single display, non-stacked, projectors. Stacking for higher resolution was well demonstrated by BARCO at NAB. 10DC is a significant development on the path – however to achieve the same perceived resolution as HDTV when viewed at the normal viewing angle of 10 degrees is 0.3125 arc-minutes of angle per pixel.

Resolution growth will be an available technology based growth until the eye resolution limits are surpassed. This is another place where there is a reasonably well-known upper limit of useful growth. Projection angles, however, will be fought over for the foreseeable future until the holodeck experience is reached.

Current resolution discussion documents are available at ftp://smpte.vwh.net/pub/dc28/DC28.2-Mastering/DC28.2-files/bitrate3.xls

11.5 Distribution

Largest change will be the distribution of the movie to the exhibition place. The average distribution cost will drop immediately from $1200 to $2500 per movie per screen to $9.35 per movie now to well under $0.50 in several years. The methods of distribution include satellite and internet as well as physical transport on DVD, Tape, Disk. These cost will continue to plummet because of the computer industry with no help from Digital Cinema.

Many of the previous economic models are quickly broken. A current summary of the transport costs to transport a 100 Gbyte DCDM is found on the SMPTE DC28.5 ftp site as ftp://smpte.vwh.net/pub/dc28/DC28.5-Transport_Delivery/Documents/Xfercost_4_24.xls

12 Color Space

Color space contains both the representation of the color and the luminance of that color. Color space is represented by two different methods, the radiometric method called a SPD (Spectral Power Distribution) and the photometric method using the CIE Colorimetry system. All light received by the camera is converted from the SPD form using the standard CIE color mapping functions to photometric CIE form. Some CGI generated images do not need to follow these transforms and can be generated, if desired, directly in CIE Chromicity format.

The photometric format has the following required properties; 1) For each set of radiometric values, in the human visible colors, there is one and only one descriptive code word representation in CIE color/luminance space. 2) Each code word representation is unique and points to one and only one color/luminance point.

The CIE Colorimetry system uses the properties of the human eye to reduce the large amount of SPD data, usually 31 or more spectral points covering the range of human vision from wavelengths of 380nm to 780nm, to a color/luminance space that can be described by a 3 dimensional space defined by exactly 3 values.

Human eyes see all the colors in the CIE diagram bounded by the locus of spectral colors "horseshoe" and closed by the Alychne " line of purples".

A standard epitaph is that the whole horseshoe space is not needed as the colors outside of the center do not exist in normal scenes. This was once demonstrated by saying no one normally sees the spectral light produce by a laser pointer, then displaying the spot from the pointer. Possibly you could make a film of a bear taking a walk in the deep woods with a lot of vegetation and no water or minerals to reflect the sunlight and get a scene with no spectral content. A couple of naked bodies would also work. This severely limits the creative talents.

Spectral points are becoming a part of every scene shot now. The laser pointer shows up in almost every movie as a business tool or optical aid for sighting a weapon. Every electronic control surface or automotive dash has light emitting diodes as part of the system, which emit light on the spectral locus. Even the traffic lights in silicon valley are LED based for red and green. Sunlight reflecting and refracting off of water and crystalline surfaces provide parts of the rainbow of light from the sun. Only a highly contrived city scene of today can avoid colors outside of the Rec 709 and film gamuts.

TV does have some unique restrictions based on the chosen primary phosphors. The TV screen cannot display the color of the power on indicator light. I cannot make the display I am using to write this to produce the color of the green power on light 1.5 inches below the CRT. We should not hamper Digital Cinema, now and in the future, with these limitations.

The time has come to construct a system that can be used to describe the range of color and luminance to which the Human eye responds.

12.1 Representations

The color/luminance space is a three dimensional space with the xy CIE color plane and the luminance is a quantity above the reference plane. As with any three dimensional space the minimum set of numbers required to describe a point in that space is three. For coding efficiency here we will use the xyY variant of the CIE Colorimetry diagram. For u' and v' use the following conversions:

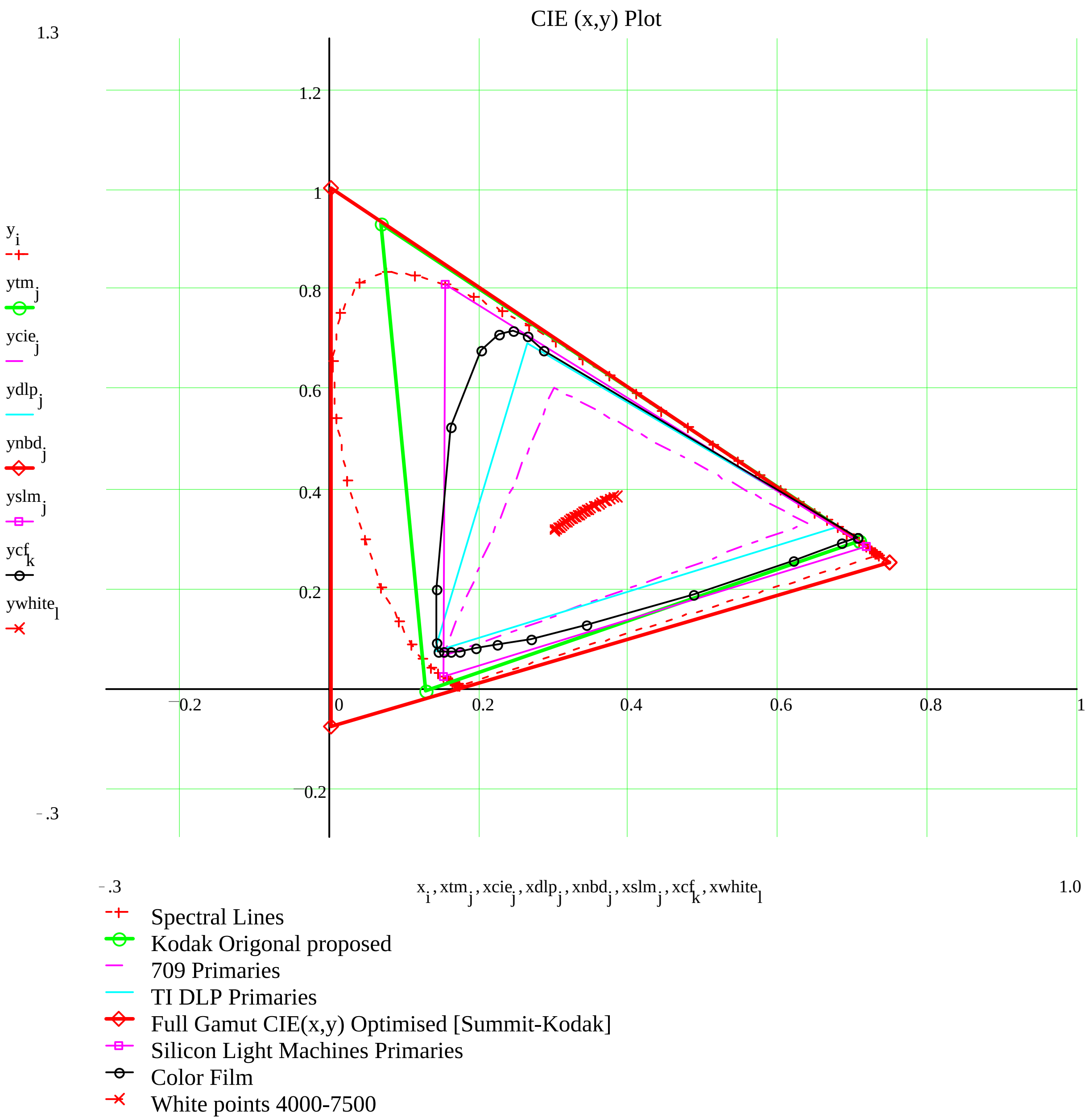
$$u' = \frac{4x}{3 - 2x + 12y} \qquad v' = \frac{9y}{3 - 2x + 12y},$$

If we treat the plane as zero intensity, then all luminance is above the plane and can be described by 2 sets of triplets. One set of triplets is the RGB set of numbers describing the intensity of the three primaries to describe a point in the space. The second set of triplets uses the converted x, y, and Y for the two dimensions of color and one vector for luminance.

For the most common RGB triplets, an important concern is the space covered by the primary points. Projectors can display the colors that are within the triangle with their display primaries at the vertices.

The new primaries proposed below are outside the visible color space to just cover all human visible colors. The space has a wasted codeword space of 6.7% which is the lowest of any supergrade descriptor. This set of primaries can accurately describe any color and luminance.

The following chart shows the major options for color primaries.



12.2 Film

Color film gamut is shown in the above chart as derived from Chuck Harrison's paper on Film Colorimetry. It encompasses an area much larger than Rec709 and the TI DLP projector reported primaries. It almost matches the display gamut proposed by the Silicon Light Machines To equal or exceed film in color this area must be conveyed.

12.3 Reality

New and improved projection/display systems will increase the available color display space and luminance. There are available, currently expensive, tunable lasers that can produce all points on the spectral locus. Solid state lasers are being developed for communications purposes that have spacing on the spectral locus and beyond at 5 nm increments for wavelength division multiplexing on fiber optics. Currently available LED's can cover most of the horseshoe now.

Luminosity is also growing rapidly. The current theater presentation level is about 50 nits max. Non film based projectors can improve this dramatically in a short period of time. The limiting projector value will be limited by safety concerns for the eyes of the patron if accidentally viewed directly or by concentrated reflection.

Display surfaces using rear illumination for safety can extend the luminosity an order of magnitude. Direct display LED's currently have capabilities of 10,000 to 100,000 nits. LCD direct view displays are about 250 nits and CRT's are well over 1000 nits.

13 Luminance Range and Representation

The human eye is the target for movie presentations. The human eye adapts to light over a 19+ decade range basically from 10E-8 nits to 10E+9 nits from seeing at night to sun in the day.

13.1 History

Film is described in density of the dies in the film in terms of RGB tristimulus system. The most widely used system is the 10 bit Cineon scale covering a film density range of a slightly more than 100:1 with a D=2.048, the soft clip range on each end of the scale gives us a 90% white at a codevalue 685 and 1% black at codevalue of 95 for a 595 code values for majority of the range. Including the effects of soft clipping, the formula for the center of this curve is approximately: codevalue = -500(Log(Density)). This is considered to be full coverage for the density of the motion picture film. Some film has a density range that is larger to between D=3 and D=4 with the soft clipping of the Cineon scale assuring the extended density is covered to low resolution. This Cineon scale is a 10 bit log value and was designed to be able to scan film and then edit it and return the results to film printer for a new film copy.

Color Television started out with all analog system. The first encoding for SDTV is 8 bit linear quantity for each primary for a 24 bit code word for the pixel. This is clearly insufficient and produces noticeable artifacts in a slow changing color on the screen.

HDTV moved to a 10 bit log system for RGB and uses a 4:2:2 color sub sampling system to reduce required bandwidth. The accuracy of the pixel information is reduced by the same amount. Color television has a working dynamic range of about 50 to 1 as reported at the last meeting. The white point for HDTV is set in Rec709. Theory indicates the luminosity of SDTV is about 2 1/5 decades and HDTV is 3 decades with the linear scales.

13.2 Needs

A coding system consisting of a codeword made up of the three triple vectors will be used to define the color/luminosity of a pixel in the DCDM.

Each code word descriptor (vector triplet) must uniquely define a color and luminosity.

For the DCDM we need to be able to describe a range of color and luminosity that matches the range of the human eye target. While initial conversions will not cover this wide range, future ones will. The characteristics of the eye being more logarithmic in nature means that the wide range can be efficiently covered in logarithmic format.

This system must encode the volume of the CIE diagram. Any point can be reproduced without a reference to any white point. If the system from which the point in color space is derived has a white point then the point in space is retained without the reference to the white point.

13.3 Possibilities

13.3.1 RGB version

RGB absolute scale representation is a system to describe in terms of the tristimulus from the defined reference primaries.

Digital Cinema Primaries	x	y	u' equiv	v' equiv
DCRed	0.75	0.25	0.6667	0.5000
DCGreen	0.00	1.00	0.0000	0.6000
DCBlue	0.00	-0.08	0.0000	-0.3529

For each of these primaries we luminosity value to represent a discrimination level of 0.056 percent. This level is achieved as follows:

DCred = HEX(4096*Log10(Yred in nits * 100,000,000))

DCblue = HEX(4096*Log10(Yblue in nits * 100,000,000))

DCgreen = HEX(4096*Log10(Ygreen in nits * 100,000,000))

The conversion to hexadecimal brings a 16 bit binary value. In all cases the value of 0000 is BLACK. This is an escape condition that is needed to define the off condition of the color – hence 0000:0000:0000hex is BLACK.

13.3.2 XyY Chromicity version

xyY absolute encoding. This is a 16 bit binary number to encode the position of the x position from 0 to 0.75, the y is encoded as a 16 bit binary number from -0.08 to 1.0 and a luminosity vector as a 16 bit binary value encoded as:

luminosity (0-FFFF) = 4096* Log(luminance in nits * 100,000,000)

The result is a triple xxxx.yyyy.YYYY each in the range 0-FFFF. This is not referenced to any specific white point, although any can be described within in the system.

The conversion to hexadecimal brings a 16 bit binary value. In all cases the value of 0000 is BLACK. This is an escape condition that is needed to define the off condition of the color – hence $0000{:}0000{:}0000_{hex}$ is BLACK.

13.4Conversions Matrix Needed

13.5Levels

Appendix

Transport costs.

Color space.