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Course Notes 26

THE SCIENCE OF DIGITAL COLOR

Organizer and Lecturer
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The Science of Digital Color

Course Description:

Computers have been used to generate synthetic images since the first SIGGRAPH, and to generate color images for nearly that long. But only recently has it become practical to originate and reproduce digital images with predictable, accurate color, and only recently has it become reasonably easy to move images from the SIGGRAPH world into film and into print.

This course explains the science behind color reproduction, image digitization and image reproduction in video, film, print and computer graphics. It will help you to design and program systems that allow digital images to be transported among various media while retaining maximum color accuracy and image quality.

Course Notes:

Visual presentation of the course employs 35 mm slides. The printed and electronic course notes do not approach the image quality of 35 mm slides, and so the illustration quality suffers somewhat in these media.

Layout of the course notes involves a compromise between the demands of printing and on-screen viewing. I have adopted a layout that is readable on-screen for resolutions 640×480 and larger. Readers with smaller screens will have to scroll. If you print the notes, I suggest a 2-up layout.

Organizer/Presenter:

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Outline

Tone Reproduction

Computer graphics has concentrated on linear intensity representations, but if maximum image quality is to be achieved in the minimum number of bits, it is important to use a nonlinear representation that is matched to human perception. I will explain the science of human lightness perception, and explain how the *gamma correction* that is ubiquitous in video accomplishes perceptually-uniform coding.

Color Perception

Classical colorimetry is well developed and well documented, but very difficult to understand when presented from a psychovisual point of view. I will explain colorimetry from a computer graphics point of view. I will show you where the RGB "cube" of computer science lives in the famous CIE (x, y) chromaticity chart. Much information is available about color *specification* systems such as CIE XYZ, LAB, LUV, HLS, HSB and HVC, but the coding of color image data has a different set of constraints than color specification. I will interpret image coding from the point of view of color reproduction.

Video Coding

Nonlinear RGB components are used as the basis for video coding, but are transformed into the YC_bC_r representation (also known as 4:2:2). I will explain the visual basis for color subsampling, and explain the advantages and disadvantages of subsampled representations such as YC_bC_r and PhotoYCC, and how these systems are employed in JPEG and MPEG. Deliberate, subtle alterations to mathematical "correctness" are applied when a video signal is originated, in order to maximize the subjective acceptability of the picture. I will outline these alterations and suggest how they can be exploited in computer graphics.

Film Coding

Although the logarithmic measure of "density" is used to describe tone response in print and film, in fact the physical transfer function of photographic film is approximately a power function. I will point out some of the effects of the transfer function of film, and explain how the effects can be compensated. I will explain how PhotoYCC coding is used in the PhotoCD system, and will introduce logarithmic representations used in a few commercial systems. I will outline technical aspects of tone response and colorimetry that contribute to "the film look".

Print Coding

Digital coding for print us n lin n n nd y ll w c l rants. he coding is tied to the physics and optics of print r production. I will e lai h ci nc of ton r production and color reproduction in print, and explain the image coding systems used for the exchange of pictures in that domain.

You were taught in primary school that the primary colors are red, yellow and blue, but those "primaries" are neither the red, green and blue primaries used in additive processes nor the cyan, magenta and yellow primaries used in subtractive processes. I will explain how the mixing of paint combines elements of additive and subtractive color reproduction.

Color Management Systems

Building on the color coding sections of the course, I will explain the mathematical basis for transformations among different color representations. I will explain why CMY values for practical printing system cannot be computed simply as "one minus RGB", but must take into account overlap in the spectra of the colorants of the ink. I will explain how emerging color management technology characterizes the color reproduction of devices, and uses device profile information to construct accurate and efficient color transforms.

Future Directions

I will outline emerging standards for video data exchange that will accommodate color gamuts than are wider than those currently used in video. I will detail HDTV colorimetry standards that will become increasingly important in computer graphics.

I will conclude by discussing unresolved issues in digital color representation, such as the use of appearance models to achieve better subjective performance from digital pictures even at the expense of departing from colorimetric accuracy. Appearance modelling and gamut mapping will see increasing use to produce compelling images from synthetic sources.

Organizer/Presenter

Charles A. Poynton is a Staff Engineer at Sun Microsystems Computer Corporation, where he is working to integrate video technology — particularly high definition television and accurate color reproduction — into computer workstations. Poynton was recently elected a Fellow of the Society of Motion Picture and Television Engineers, and is an active participant in a number of SMPTE standards committees. Poynton organized the SIGGRAPH'91 course *HDTV Technology* and the ACM Multimedia'93 course *Concepts of Color, Video and Compression.*