Reproducing Computer Generated Imagery

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Abstract

This presentation will report on my experience using device independent color reproduction systems to publish computer generated imagery. The results are a blend of applied science and pragmatics, reflecting the tension between scientific exploration and publication deadlines. I will also discuss some of the consequences I foresee as high-quality color reproduction moves away from its traditional place in the pressroom or service bureau and into the hands of the original designer.

Introduction

Device independent color reproduction systems are becoming a commercial reality. As such, they will reach the hands of millions of people who create pictures, both professionally and as hobbyists. How will they react? What kind of problems will they have? In this presentation, I will report on my experience using device independent color reproduction systems to publish computer generated imagery in technical journals. In this role, I was a computer science professional with an expertise in color performing a task usually the domain of graphic arts professionals. While my technical goal was to explore the use of device independent representations fn digital color reproduction, the final output was illustrations for journal articles often written by people other than myself. Therefore, the results had to meet publication standards in a timely manner.

The results of my experience are a blend of applied science and pragmatics, reflecting the tension between scientific exploration and publication deadlines. I will also discuss some of the consequences I foresee as high-quality color reproduction moves away from its traditional place in the pressroom or service bureau and into the hands of the original designer.

History

Those who do research in computer graphics often need to include color pictures of their results in journal articles. These pictures are generated entirely on-line and are view-ed almost exclusively on computer monitors. Until recently, the traditional way to prepare these images for publication was to create a 35mm slide, either by photographing the screen or using a digital film recorder. The slide was then sent to the printer who scanned it to create separations for 4-color offset. The results were often less than satisfactory, especially for images that did not look like natural scenes. As digital technology becomes common in color reproduction systems, the natural solution is to avoid using the intermediate transparency in the reproduction process and create the color separations directly from the original digital image representation.

In 1986, the topic of the interim meeting of the AIC (Association Internationale de la Couleur) was *Colour in Computer Generated Displays.* In blissful ignorance of most of the process of preparing color separations (You do *what* with the black ink...?), Bill Cowan, John Beatty and I agreed to prepare all of the color separations digitally at Xerox PARC. Most of authors were able to provide us with digital image data, and one author was able to provide a detailed monitor calibration as well. As one of the authors, I was also able to explore using the calibrated system as a designer as well as for the reproduction of pre-existing images. In June of 1986 (and several lifetimes of experience later) we successfully published the conference proceedings as a special issue of *Color Research and Application.* A brief article on our experience publishing the images was included there[1] and a more complete article was published in 1988.[2]

Over the next several years, I produced color separations for several book covers, the cover illustration for several issues of the annual ACM SIGGRAPH conference proceedings, and my own articles. In parallel, our understanding and systems for digital color reproduction im-proved. By 1992, when I was the guest editor of a special issue on color of *ACM Transactions on Graphics,* I decid-ed to repeat the AIC experience with more modern technology. Once again I agreed to create the separations for all of the articles in the journal from digital information provided by the authors. Most of the authors were able to supply not only digital data for the images but calibrations as well, and one set of authors did their own color transfor-mations based on our printer calibration data. An overview of the process used is provided in the editor's introduction to the issue.[3]

Compared to the AIC conference proceedings, the TOG issue was easy. We were able to process 45 images in one month as opposed to 21 images in six months. The color space transformations, including gamut mapping, took two minutes per image as opposed to two hours. Digital separations are now commercially available from standard formats whereas in 1986 we had to generate our own halftoned films using experimental hardware. Most images were processed using one of a small number of standard transformations as opposed to the AIC proceedings where we had to hand-tune each image. However, many of the problems remained the same. Images with highly-saturated, out-of-gamut colors were difficult to reproduce well. Imaging problems other than color, such as moiré, often took more time to solve than the color problems. Overall, images that deviated from natural scenes usually took the most iterations and were the least satisfactory.

Highlighting these problems was my experience using our system to help produce a color poster designed by the Xerox PARC in-house graphic designers. In contrast to the TOG illustrations, it was very difficult to satisfactorily reproduce their images. Some of the problems were a result of the type of imagery. Their pictures were created by using Photoshop™ to modify scanned images until they resembled impressionist paintings with light, clear colors dominant. Not only were many of these colors outside the print gamut, slight changes in color produced a very different "feel" to the illustration. Other problems were the result of having the designers tightly "in the loop" during the reproduction process. Seeing what the color transformations did to the images caused them to change their designs. That is, the goal changed from *reproducing* the monitor image to *designing* within the context of the entire color reproduction system. This is a sufficiently radical shift in paradigm that the algorithms and tools I provided were inadequate.

The Future

My experiences printing computer generated imagery suggest that the future of device independent color systems is in design environments rather than in image reproduction systems, and that this will provide a new focus for research and development in the digital color community. In an image reproduction system, the goal is to accurately reproduce the appearance of the original by refining the color models and transformations needed to go from one medi-um to another. With computer generated imagery, it is often easier (and more satisfactory) to change the original than to create a good color transformation. This suggests an emphasis on tools that help the designer select and modify colors to meet media constrains as well as fast previewing to check the results. Also, the designer will inevitably want to adjust the parameters of the color reproduction system, so these need to be made available and defined in a suitable way for this type of user.

Another opportunity with computer generated pictures is the ability to manipulate colors on the object level rather than the pixel level. In 2D illustrations, an object can be a geometrically defined shape or collection of shapes, or even a region of an image. The color can be represented as a single point in color space or with a higher order function. For example, a color gradient can be expressed as a linear interpolation between two points. The set of colors in such an illustration can be treated as a unit to resolve issues involving intercolor relationships. For example, an illustration might require several distinct shades of red plus a contrasting color. Encoding this relationship explicitly could help ensure that the relationship is preserved across color transformations.

In 3D graphics, the scene description includes colored objects and light sources. For most rendering algorithms, the color at each pixel in the resulting image is a simple function of the scene colors. These functions can be used to determine which colors are out-of-gamut and to suggest which object colors should be modified to correct the problem. They can provide the basis of an interactive system for modifying object colors in a 3D image.[4] Finally, optimization techniques can be used to automatically define the object colors to meet constraints specified as target images. These constraints can reflect gamut boundaries[5] or design parameters such as the brightness of the lights.[6]

To create a complex design often requires the use of many different applications and tools. In spite of standards such as PostScript™ and EPS,™ it is currently a challenge to integrate the output of the tools onto one page. For example, the poster took roughly 60 hours to design and integrate into a single PostScript™ file that was used to generate the halftoned film separations. Of those 60 hours, 12 were design time, including the color transformations I provided. The rest was integration time. Current color products seem to be adding to this complexity, not diminishing it. Future systems need to help solve the integration problem if the full power digital color systems is to be realized.

Conclusions

In conclusion, my experience reproducing computer generated imagery suggests that future device independent color systems need to do more than reproduce images from one medium on another. They need to be integrated into the design process, especially as color reproduction systems migrate into the hands of the original designers of the images. This suggests a new set of tools focused towards providing new types of control including: color selection tools that reflect media constraints, fast previewing, and user-oriented methods for controlling color transformations. Because of the nature of the systems used to create the original, there is an opportunity to manipulate colors at a higher semantic level, reflecting objects in a 3D scene or related colors in an illustration. Finally, there need to be well integrated systems that allow the designer to painlessly combine pieces from a wide variety of applications, adjust their colors in a wide varieties of ways, and render them without surprises.

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