Electronic Color Imaging for Digital Publishing

It is time to reconsider our research priorities. The veterans in our community started out in an age when the image processing tools in the publishing industry were graphic arts cameras and screens, pin registers, knifes, and goldenrod paper. Their contribution was to invent the technologies that brought us from mechanical processes to electronic publishing: scanners, image enhancement, colorimetric color control, color management, perceptually lossless image compression, and digital halftoning among others.

It is a sign of the exponential progress in science and technology, that the same generation of scientists and engineers is able to contribute to a new paradigm shift, namely from electronic publishing to digital publishing.

Digital publishing is a fully digital process, from end to end: cameras, scanners, processing, storage, retrieval, syndication, distribution, and rendering. Many underlying electronic imaging technologies remain the same. However, the new fully digital process changes the emphasis of which goals are more important, i.e., it requires us to reconsider the priorities in our research programs and objectives. We briefly review the impact on some application areas. One example is printer resolution.

Cameras. As it becomes digital, the technology for amateur cameras—USB peripherals—diverges quite substantially from the technology for professional cameras—workhorses. Professional digital cameras are now generally accepted as the most appropriate tool both in the studio—e.g., for catalog work—and in the field—e.g., sports and general reportage. Today's professional digital cameras fulfill the needs of their users and the main challenge for electronic imaging is to reduce the device cost by an order of magnitude to bring it more in line with the cost of the old AgX-based technology.

For the amateur market, we must revise our way of thinking. With the AgX technology, an amateur application is a scaled-down and simplified version of the professional application that can achieve more or less the same image quality. Over the last decade the photo amateur has been replaced by the photo consumer, and any digital photography application for the consumer must compete with disposable cameras. In the last couple of years we have seen the emergence of a new paradigm for consumer photography, namely the instantaneous and casual communication of candid images.

In this new paradigm for consumer photography, digital cameras are peripherals for hand-held computers and have to obey the rules for such peripherals, namely be very small and cost as much as a mouse. Regardless of these two constraints, the digital consumer camera has to work anywhere—like a disposable camera—but without a flash, because batteries are too bulky. These requirements place emphasis on two electronic imaging research topics: dynamic range and color constancy.

Dynamic range does not necessarily mean more bits per pixel, which are probably not possible under the cost and size constraints. Instead, imaging algorithms such as retinex, which compress the dynamic range, have to be reconsidered. Similarly, incomplete adaptation in available light situations call for pleasing and not too harsh color rendering algorithms based on the judicious application of color appearance models.

Another difference between research for professional and consumer cameras is anti-aliasing. The trend for professional cameras is to ever increase the number of pixels, and with an increasing number of pixels anti-aliasing is less critical, as this is exemplified in the eye's fovea. For consumer cameras price places a ceiling on resolution, as does the requirement for small image files that can be communicated quickly, and with low resolution anti-aliasing algorithms are critical. Professional cameras are based on CCD sensors, which require external logic circuitry. Consumer cameras will most likely be based on filterless (light can be filtered by controlling the thickness of the wafer layers) CMOS sensors, which will allow for at least some anti-alias preprocessing near the pixel photosites.

Processing. Contrary to the spartan requirements for digital cameras, image processing benefits from a bonanza in desktop computer power. With 400 MHz processors on 100 MHz system busses and 128M bytes of RAM, today's personal computers have bandwidth to spare after the user's primary requirements have been fulfilled. This leaves considerable performance available for improved color imaging.

New algorithms, more heavily based on non-linear methods and operating in more suitable representational spaces, can now be deployed even in such performance-critical system components as operating systems and device drivers. For example, if the optical properties for an inexpensive simple input device are well characterized, sophisticated algorithms can be used to restore images to unprecedented quality. This is quite a change in how imaging products are designed. The old way centers on a specialist that knows everything in a narrow field and is able to select the parameters so that a given price/performance goal is achieved; the product is refined by tweaking the parameters. The new way requires generalists that can optimize simultaneously all parameters in a system; the product is refined by balancing the parameters among the system components.

A sign for this change is the increased research activity in spectral imaging and cameras. The spectral resolution of the input device is increased, because more information is required, for example, to render correctly geometric appearance attributes. Concomitantly, some optical aberrations are very easy to correct digitally, allowing to simplify lens designs. We note a similar trend on the output side, where through extensive and sophisticated printer models it is now possible to either deploy detailed physical models or apply neural network methods in the printer guerrilla.

Yet, mapping the various device gamuts one into an other remains a hard problem. For example, the blue hue line in the CIELAB color space is still a big practical hurdle, but powerful Internet-based visualization tools are now at hand for color scientists to assist building an intuition for gamuts. The number of papers on color mapping algorithms witnesses the importance and difficulty of this research area.

One of the main tools for research in color imaging science is colorimetry. Balancing the imaging pipeline becomes easier because the color information is colorimetric instead of consisting of device counts. The increased attention to colorimetry brings new challenges to instrument accuracy—better than just jnds is necessary to balance a pipeline. Furthermore, imaging scientists need a better understanding of color science so they can interpret correctly the colorimetric data.

This improved understanding of color will also allow imaging scientists to invent novel automatic image enhancement algorithms based on rendering intent instead of attempting exact color reproduction. This understanding will allow superior tradeoff decisions that will make the systems more robust, and there fore simpler and easier to use. Copying a color image will no longer require a trained specialist, everybody will be able to reproduce faithfully their own images.

Intellectual property. On August 13, 1997, U.S. District Judge Sonia Sotomayor rendered a very important decision in Tasini et al. vs. New York Times et al. regarding copyrights (see http://www.nwu.org/nwu/tvt/tvtrule.htm). Her decision, based on section 201 (c) of the Copyright Act of 1976, which deals with the copyrights in collective works, reads that while the publisher of a collective work retains the copyrights for further publication in databases and CD-ROMs—she declared them revisions of the original work—authors retain the rights to individual contributions and may license them to World Wide Web publishers, without permission from or payment to the publisher. This is an opportunity for image syndication and will spur the need for electronic imaging technology.

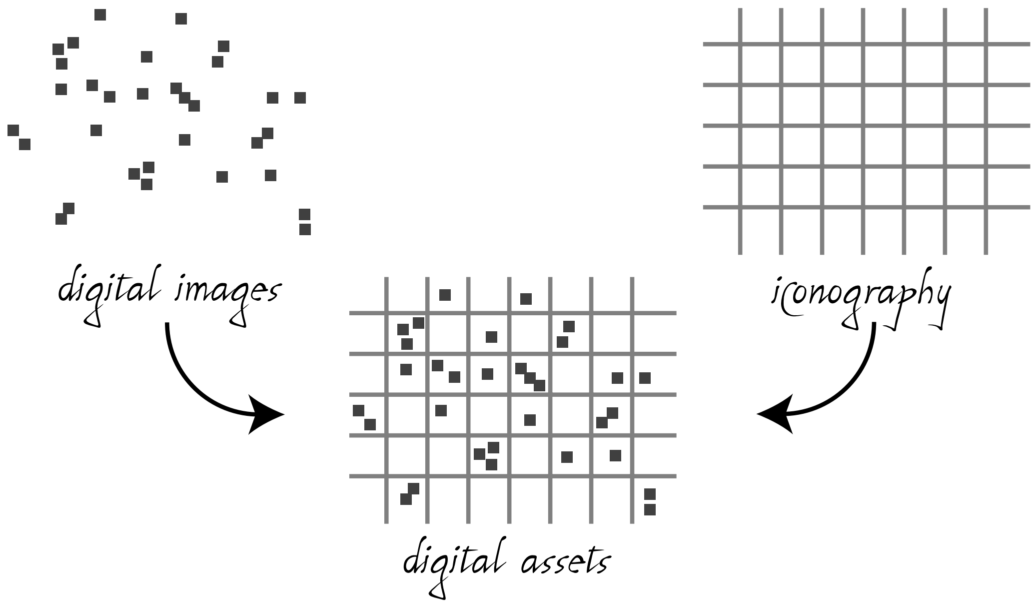
With perfect timing, electronic imaging researchers are delivering the appropriate technology—watermarking. From the perspective of digital publishing, watermarking is a hot problem, as is evident from the intensive publication activity. Stock agencies are early adopters of electronic imaging, so the protection of the author's rights is a major priority. Watermarking facilitates the clearance of copyright royalties and allows the prosecution of thieves in case of unauthorized use of an image.

Scanning. A pressing problem that is attracting the attention of research in electronic imaging is the digitalization of the human cultural heritage. The documents created since the inception of digital publishing are only a minuscule fraction of the patrimony stored in archives. Originals are subject to various forms of decay and there is a certain urgency to digitize a huge number of documents. As much of the original information has to be preserved as possible, including pentimenti and documents under recoated media. Some of these documents are in a bad state of disrepair and can be restored only in a digital form, because the originals are too frail.

The sheer quantity of documents calls for fast electronic imaging methods, that completely capture a document in a minute at most. Complete means that an RGB scan is often not sufficient and multispectral color reproduction is necessary. When the media is not paper, geometric appearance attributes must be recorded, as is the case for silk media or oil paintings. To remove stains, soot, mildew, and other common contaminations—not to forget that acid-free paper has come in wide use only recently—sophisticated image processing algorithms are required do "dry-clean" the documents. When documents have been fragmented or torn, algorithms are necessary to stitch images and remove tear lines.

Storage and retrieval. Capturing an image is only part of the problem. It is further necessary to catalog the image, so he can be later retrieved by searching for criteria or by navigating the space of all images. Required algorithms encompass the fields of pattern matching, object recognition, character recognition—including old typefaces and calligraphy—and reverse graphic editors to convert bitmap representations into vector representation, which is essential for the large number of geographic maps stored in archives.

Specifying the iconography, i.e., semantic context of an image, is a very difficult task that requires extensive knowledge. To be useful for retrieving images from the World Wide Web, an iconography cannot be based on haphazardly assigned index words. Cataloguers must be assisted by thesauri, taxonomies, and ontologies, which are essentially all the same artifact. These structures, also know as external intelligence, allow cataloguers and image retrievers to navigate the set of images instead of performing flat keyword searches.



Cataloguers are aided by image classifiers, which in turn can use the iconographic structures to improve their accuracy. Image classifiers are also becoming increasingly important for color gamut mapping. Depending on the output device, the rendering algorithm has to map the colors in the image to a gamut that has a considerably different gamut then the range of colors in the image. It is necessary to distort the color in the image but some fundamental memory colors such as complexion cannot be changed too much.

Images are becoming increasingly accessible because of the availability of the Internet as an inexpensive, convenient, and universal communications medium. The World Wide Web implements a graphical user interface with a hypertext linking system that facilitates navigation. Both the iconography of images and the requirements of users can be expressed in the structured language XML, allowing servers and browsers to negotiate the best rendition of an image for a particular contact. Electronic imaging provides the algorithms for this system.

Internet Imaging. The digital archival copy of a document can have large storage requirements. This is an impediment when the cultural heritage is made public on the World Wide Web. We need algorithms that can automatically abstract that portion of the image file that is useful to the viewer at the other end of the communications line. The new XML standard allows the efficient standardized communication of structural information about images. Clients and servers can negotiate which components of an image need to be communicated; gateways and proxy servers can intelligently cache image components based on the structure expressed in XML wrappers.

Output peripherals. We have already touched on the problem of gamut mapping. There are more problems for electronic imaging. The modulation transfer function (MTF) of today's printers is better than that of the human visual system. Concomitantly, the considerable image quality improvement in one-hour photo finishing processors has risen user expectations. Consequently, the careful design of color savvy halftoning algorithms has become much more critical and it is no longer possible to apply the same grayscale algorithm to each color plane. With increased image sharpness, color artifacts are also more visible and color matching must be more accurate.

Only a few years ago, printer MTF was so poor that images could be aggressively compressed using the example quantization tables from the JPEG standard specification. Today the quantization tables in lossy data compression algorithms must be designed very carefully to be perceptually lossless for the intended rendering devices and viewing conditions. This entails that the human visual system's MTF can no longer be used as a weighting function for quantization tables. Instead, the MTF of each stage in the imaging pipeline must be taken as a visibility threshold that must be matched to the MTFs of all other stages.

The increased use of images in documents poses new problems also to the choice of data compression algorithm classes for images. While JPEG and wavelets work well on full color images communicated over the Internet, these algorithms fail on halftoned images. The last cable to the printer has become a severe performance bottleneck and we need lossless compression methods like JBIG, which do not destroy the structure of halftones.

Workflow. We have touched on some components of a digital publishing system, and we shall finish on the glue that holds it all together during an image's life-time, namely workflow. As images progress from creator to viewer, the electronic imaging algorithms must be able to operate in a pipeline. There is agreement on device profiles (although the implementations are still nightmares for users), file formats, communication protocols, and markup languages. However, other issues, such as end-to-end MTF optimization, color spaces, gamut mapping, image quality metrics, and rendering intent, are still open.

When we design electronic imaging algorithms for digital publishing systems, we shall not forget that some of our technologies are taking a large human toll. As we noted earlier, our new technologies are the basis for tools allowing everyone to do their digital publications by themselves. The pre-press industry, which worldwide employs an amazing number of imaging experts working in small businesses, is on the verge of disappearance. While mechanical paste-up assembly and stripping have gone the way of the buggy whip trade, we should not waste the specific knowledge in the pre-press industry. These talents are very much needed in the new world of digital publishing, especially now that we have to reconsider our research priorities. For example, a trained eye can take us a long way in end-to-end MTF optimization and choosing the most appropriate compression algorithms.

The papers in this conference cover many of the topics mentioned in this introduction. Its purpose is to facilitate personal contacts and exchanges between established researchers and those new to the field, either because they are at the dawn of their career, they are broadening their expertise, or shifting their focus as job descriptions evolve. Sharing their latest results and ideas are the experts in color imaging, the people that are working on the disruptive technologies enabling the paradigm shift from electronic to digital publishing.

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