The Future of Photography

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ABSTRACT

We are just a few years away from celebrating the 200th anniversary of photography. The first permanent photographic record was made by Niépce in 1826, the view from his window at Le Gras. After many development cycles, including some periods of stagnation, photography is now experiencing an amazing period of growth. The changes that started in the mid 90's and going into the next several years will completely modify photography and its industry. We propose that the digital photography revolution can be divided into two phases. The first, from about 1994 to 2009, was primarily the transformation of film-based equipment into their digital counterparts. Now, in the second phase, photography is starting to change into something completely different, with forces like social networks, cell phone cameras and computational photography changing the business, the methods and the use of photographs.

Keywords: Photography, Trends, Future, Technology, Post-Digital

1. INTRODUCTION

Digital photography has now become just photography, no need anymore to specify if film or digital based. Film is the exception, still romanticized by many, but practiced by dwindling few. The transition that started some 15 years ago is now complete, and we find ourselves almost in the same place we started, but ready to embark into a new era.

The change to digital has been hugely beneficial to photography, propelling it into higher levels of quality and popularity due to improved ease of use and new capabilities. The camera itself has changed little superficially, and camera shelves of today's photo store are populated with SLR and point-and-shoot models that look very much like those of 20 years ago. The major revolution in camera format is not for display on the shelves, but inside people's pockets, embedded into our cell phones, the first really new photographic platform in many years (figure 1).

Figure 1 – The President and first lady at the Home States Ball (Reuters/Kevin Lamarque)

15 years ago, the future of photography was more or less easy to predict – the transition to digital was inevitable and much of the discussion centered on the technology and the initial benefits it would bring. Almost all that we see today, such as the LCD preview, the removable storage, on-line sharing, at home photo-printing, standards like USB and JPEG, image processing and algorithms, was anticipated and discussed at length at meetings such as Electronic Imaging in San Jose.

What turned out to be the real surprise, to both luddites and enthusiasts, was the speed of the change. In a January 1999 Shutterbug article, Rick Sammon provided his vision of the future camera:

January 2150 – Just got out of the time machine…The device I'm using to capture images… is tiny, records still and moving pictures with sound--all digitally--and can transmit data to, and receive it from, any place on earth via satellite. It's about the size of one of those old cigarette packs that were banned in 2010, but weighs about the same. It's solar powered, just like our safari vehicles. Cost me $99….

This is a fairly good description of a 2010 cell phone camera, with the notable exception of the solar power, and the forecasted date. Many forecasts made around the time conservatively estimated that the consumer film business should have another 20 to 30 years of life. But, instead, the digital tide penetrated every portion of the market, and even disposable cameras, which at one point were thought to be impossible to displace because of their low cost, have now ceded their function to the cell phone camera.

The rapid adoption may be understood as the result of removing known barriers to the wider use of photography, not the addition of any fundamental new features or functionality. The later is happening too, and we will discuss it further on, but most of the changes brought by the first phase of the digital revolution had long been anticipated, and partially addressed by different film formats and products

- Meaningful instantaneous feedback – framing with an optical viewfinder, focusing, flash control exposing and the timing of the picture were considered matter of faith by consumers, who often refer to the entire operation as "click and pray". Review of results was done only after processing and printing the film, sometimes to find nothing of interest despite the expense. Polaroid addressed this niche, but was expensive and could not be easily shared. Digital LCD's have made photography approachable and the selection intuitive. If the picture is bad, just take another.
- Automatic Operation – consumers in general desire less control and more automatic results. Few traditional cameras achieved this, and most tended to add new layers of automation, making the entire operation more complicated. Exposure metering was notoriously difficult, especially with flash illumination. Automatic operation depended on multiple parts working together, such as the camera correctly reading the DX film speed code and the lab printing with the correct white balance. Because digital cameras can measure with the image data itself, and the feedback is instantaneous, automatic exposure problems have been greatly reduced.
- Non-sequential operation – changing rolls of film in the middle, or sending it to be developed only partially exposed, was not done often. Processing labs sometimes saw customer's film rolls with Christmas festivities at both ends. The APS, Kodak Disk and Instamatic formats addressed some of this, at least with the ease of loading and unloading, but it remained a barrier to usage until the advent of digital photo.
- Sharing and distribution – one of the primary drivers for picture taking is sharing, and many methods were tried to improve on this, including always printing multiple copies, or printing multiple image sizes on the same print, and PhotoCD. This is probably one of the areas of greatest change because of the web and the appearance of photo-sharing sites such as Flickr and online photofinishing such as Snapfish.
- Small size – the smallest film cameras, like the Minox, were charming devices but really hard to operate, but difficulties ranging from difficulty of loading film to non-existent automatic exposure control, made portability possible at a high price. With the recent introduction of back-side illuminated sensors and wafer level optics and packaging, size barriers have all but disappeared, and the camera can now be too small to handle, needing to be embedded into some other device to be manipulated.
- Low cost – no film photography was ever free, even if the camera was free. The cost of film, processing, printing and distribution ranged from 10 cents to a couple of dollars per picture, yet consumers took 80 billion pictures in the year 2000 according to Kodak's annual report. With the cost of digital photos approaching zero, the number of images exposed has increased many times since then, creating one of the largest data sets on the web and people's PCs.
- Good quality – some of the most popular film formats in the 70's and 80's embodied many of the desirable features described above. The film cartridges 126 and 110 formats resulted in small cameras with simple operation, but at the expense of image quality. The subsequent failure of the Disk Format, and the success

of the first 35mm point and shoot cameras, like the Canon AF35M introduced in 1981, demonstrated consumer desire for higher quality and surprised many in the industry. While the quality of digital image was not the main selling point early on, it has now surpassed conventional silver halide in almost any application. Part of the reason is the reduced number of steps (no more negative printing), which greatly reduced resolution loss and improved the control of sharpness, tone and color.

- Albums and display – the end result of the photography was the print, with slide projecting always occupying a hobbyist niche. The print is physical and needs to be stored, catalogued, cared for, transported and mounted for viewing. This greatly limited the number of pictures that one could hope to share and manage. Large photo collections required a great deal of work, and finding any specific picture in the shoebox was always a challenge. The complexity greatly increased if one would also try organizing or finding negatives for re-printing and distribution. The APS (Advanced Photo System) was a great leap forward in this area, providing a simple method of handling the negatives, index prints, date indexing, and a way of attaching metadata to the negatives (on a clear magnetic coating) and the prints thru ID bar codes. Of course, this was rendered obsolete with the elimination of negatives and photofinishing. People now routinely organize, share and browse collections with thousands of pictures, with ever increasing ability to search, group and display the results.

Thus, it is argued here, the tremendous success of this first phase of the digital photography revolution was achieved by addressing historical wants, needs and shortcomings of film base photography, building on ideas that had long been discussed, and taping on the consumer desire to perform tasks that he was familiar with, but unable to accomplish with film photography. The next phase will be driven by new capabilities and new applications that had no equivalent in film photography.

2. STATE OF DIGITAL PHOTOGRAPHY

In modern digital cameras we often see features that address the core needs described above, mixed with new features that have not yet been vetted by the consumer, which might or might not belong within photography as practiced by that consumer. One example is sound capture, which did not have an equivalent in film photography. Sound capture in digital cameras had been expected to be a key feature, allowing greater immersion into the picture subject, annotation of important information, and in general providing ambience to picture viewing with short ambient sound clips. This has not happened yet, for reasons that include the difficulty to start and stop recording and the critical moments, the hustle sound of hands on the camera, the lack of support by browsers, and so forth. On the other hand, other metadata types, such as GPS annotation, which has been supported by EXIF since 1998, are fast becoming a mandatory feature as it greatly facilitates browsing and organization of image sets.

2.1 Mature Functions

Several signs of maturity of the first phase of digital photography can be observed. Many of the key discoveries and technologies that were at the foundation of the first phase no long matter or have become much less relevant.

- Printing - young adults no longer regard printing as part of photography. Printing was initially one of the primary drivers of ever increasing resolution, and it is not clear that browsing and zooming will be as strong driving forces.
- Resolution – the end of megapixel wars is a sign of maturity, meaning the consumer understanding of image quality is based on subjective analysis and not covered by the simple metrics used by marketing to benchmark performance. It balances the need for detail with file size and application.
- Compression – JPEG and JPEG2000 have worked fine for most applications and further compression development has not had as much impact. Compressive sensing and other promising technologies might have an impact long term as part of re-engineering the image capture.
- Camera DSP – the ceiling on resolution, combined with the emergence of the RAW format as the real image record, should decrease the need of the DSP to perform perfect image reconstruction in real time, freeing the ICs to focus in other value added functions such as support for the UI.
- Auto-Exposure – exposure and white balance controls are fairly good across most systems, and the know-how widely available. The requirements are further relaxed in a RAW workflow because manual fine-tuning is

possible. The next significant challenge, automatic exposure control of HDR images, might be a greater requirement for video sequences and not stills captured in RAW.

- Storage – solid-state storage capacity is already growing faster than camera file size, and with the growth of resolution requirements slowing down, storage should not be a challenge.

2.2 Emerging Functions

Moving photography beyond the mature functions described above, a flurry of research and development activity is taking place that promises to greatly improve and modify what can be done. The forces shaping photography are not all technological, but economical and social too. Some of the functions described here are not new, yet have not had the due impact yet. A few are brand new ideas, while others are crossovers from parallel fields in digital imaging.

- Metadata – the usability of images, and our ability for find them, is greatly determined by quality of the metadata. Beyond tagging and browsing, new use for metadata information, such as merging of views based on compass and GPS info, or creation of layers for augmented reality, will continue drive new functionality.
- Smart Flash – key to many computational photography schemes is active illumination, synchronized to the sensor and processing, allowing much better probing of the scene contents. Examples range from ambient light removal to aid in machine vision and biometrics, to burst capture for deblurring and range measurements and structured light for 3D capture using small projectors.
- RAW/Post workflow – one of the cornerstones of the professional workflow is the use of raw data instead of the demosaiced result. This allows for greater range of adjustments in exposure, white balance, and tone correction. Increasingly, professional photographic work is being done in post-processing, instead of in the studio or on the set. This will drive the need for new sensors, and decrease the emphasis on real time DSP.
- Augmented Reality – the merging of spatial information, including old pictures, with the current live view of a scene is opening many new applications for photography and cameras. In many ways this will be the ultimate browsing user interface, providing a platform for the marriage of photo and information.
- High Speed – high-speed capture is attractive to the consumer and professional alike. It can create an interesting vignette around a particular moment, or it can be used to create a selection of still frames. Combined with motion flow algorithms it could provide sharp still pictures.
- CMOS sensors – the key breakthrough for the convergence of photo and video cameras has been the development of large focal plane arrays with fast readout and instantaneous electronic shutter. Readout speeds above 500 frames per second enable a number of interesting uses, including HDR, ambient light rejection, and other computational photography methods.
- Video Convergence – the availability of video in still cameras, vice versa, and both in cell phones has continued to be a key feature. High-end cameras are now available that can capture several megapixels at high-frame rate, but still at considerable expense.
- Robotic Capture – the convergence of CCTV like functionality into photography allows the automated capture of images, freeing the photographer to be engaged on social activities, say a birthday party. Looking forward, extraction of salient views from continuous high-quality CCTV streams will provide a form of automated photography.
- Total Recall – Gordon Bell and others have proposed the continuous recording of one's point of view, and integration with other salient data as a form of memory aid. This in turn will drive the adoption of many other trends, such as metadata tagging, browsing, and sensors development.
- Motion Flow Computing – the ever increasing computational ability to track scene features is having a huge impact on a range of functions, including transforming video into stills, slowing down or speeding up action, to improved compression using existing standards, and improving resolution via super-resolution schemes.
- Browsing – advances in browsing are at the forefront of innovation, yet the user interface and functionality are still primitive. Advances in browser design will be key to the pace and availability of innovations in photography.

- DIY Cameras – modular cameras, such as Stanford's Camera 2.0, open operating systems and architectures are proliferating and might create a new class of photo-hobbyist and demand new kinds of products.
- Sensors – the quality and pixel count of small sensor modules, used in cell phones and other appliances, should continue to improve. Areas of improvement will be backside illumination, 3D assembly, wafer level chip package and optics, per-pixel electronics and processing, and new array formats.
- HDR – the adoption of HDR sensors will probably be tied to the adoption of the raw workflow and compositing, While Pixim pioneered and leads the market for HDR video sensors, in the long term many of the other alternative methods should also mature and become available.
- 3D capture – cameras capable of capturing both range and color information at high resolution will allow the convergence of CGI and photography/video. At low resolution, they will greatly aid in object recognition and tracking.
- Stereo – the present re-birth of stereo in motion pictures could expand into photography if the viewing technology becomes widespread, especially in PC displays, creating an incredible user interface platform for a much more compelling photo experience.
- Light Field Capture – Capturing the light field is becoming an integral part of image capture. The data can be used in a number of ways, for helping in the white balance, for tone correcting, for relighting and for insertion of 3D imagery into the scene.
- Biometrics – the identification of the human face, tracking of the eyes, and face, and smile detection are already available in some of today's camera. As part of browsing, it allows one to find and tag faces in large collections. Further improvement will allow automatic insertion of 3D features into the image.
- Image recognition and tagging – Google image search is now able to find images by both description and similarity to other images. This functionality is likely to remain the key to browse and organize photo-collections online and offline.
- Segmentation and matting – the automatic extraction of scene elements from its background is of immense value. Automatic schemes based on machine vision and other methods, often aided by motion flow, will be fundamental to compositing, classification and browsing.
- Compositing – the modern compositing software, allowing the creation of new images from a mix of real and synthetic images, is the new Photoshop. It is the application environment where all the modern tools come together.
- CG rendering – image based rendering and the combination of real and synthetic imagery is now common place in motion pictures, and increasingly in professional photography, and key enabler to augmented reality.
- Photo-sharing – sharing has been the "killer app" for digital imaging already for a while, and will probably continue to be so. It has spawned its own creative communities, and for an increasing number of photo-hobbyist it is the medium, the place where they view and the reason they take the pictures.

3. POST-DIGITAL PHOTOGRAPHY

We can understand how major technology trends are shaping the future of photography by studying the specific case of professional photography. For professional photographers, the first phase of the change to digital was more or less straightforward, like a change of equipment – it was complicated to few, but at the end their equipment bag still looked pretty familiar. Now technology is shaping the business itself, forcing photographers to re-think what is the core set of skills and services they should be focusing on.

Sea of Cameras

Change can be found in almost all professional photo disciplines. News photographers now have to compete with an ever-present sea of cell phones (see figure 1), and pictures for many stories are available for free in the web before they even hit the normal media channels. The competition is also fierce among professionals. Every year, US colleges and universities release 20,000 new photographers into the market, and many are happy to work for reduced or no fees. While in the past there was a market demand for different levels of photographic skills, allowing a professional to grow

in experience and still earn income, it is now turning into a star system, much like the actors, where you have either have feast or famine.

Advertising, stock and editorial photographers face no lesser problems. The market for stock images has gone the same route as the porn industry, with so much material available for free in the web that it makes little sense to pay for copyrighted images. On reporting on the 2008 sale of Getty Images, at that point the world's biggest distributor of pictures and video, the NY Times noted that "*...the popularity of the Internet — where Getty was a pioneer, being the first distributor to license images online — has eroded that demand. Mr. Klein noted the troubles of print publications and a related drop in demand for higher-resolution pictures that command premium prices. Some of the company's Internet-based rivals use images as low in quality as those taken by cell phone cameras."*

Convergence of photo and video

Advertisement is also moving to the web, which requires far less resolution than print. GM recently announced that it would spend $1.5 billion online, half of its entire ad budget. Most web ads involve motion capture, which is not familiar to still photographers, although many are re-training for that. One of the often-discussed scenarios is for professional photographers to use high-resolution movie style cameras to capture photographs as sequences of stills. Some of the cameras capable of shooting high quality video ranging from the Canon 5D Mark II, a still camera capable of HD 1080i, to the recently announced RED Epic, capable of shooting 13 MPixels at 100 fps. Among other issues, this new workflow will require the change from strobe lights to continuous movie style illumination, like HMI's. Because so much power would be required to match the short exposure time and depth of field typically used in advertisement photography, an union approved electrician would be required for most jobs, further blurring the barrier between photography and cinematography. But, once these practical barriers are overcome, high-speed image capture, up to 500 frames per second, provides an interesting alternative to conventional still photography. At that speed, the sequence can still be thought as almost a single photo, and fairly sharp frames can be extracted from the sequence if desired. Ever improving image tracking and optical flow algorithms will allow sharpness of single frames to be further improved and used as stills.

The post workflow

The current workflow of a studio photographer is very different from the film era. With film photography, the photographer would deliver a finished photo, usually a transparency, and photo manipulation was under control of the pre-press house, that would scan the picture and manipulate the bits. This required the delivered photographs that were very polished, with lot of a care and attention to detail so to avoid any kind of imperfections. This is no longer necessary as the manipulation, or post-production, is under control of the photographer, allowing simpler and faster solutions to all kinds of photographic problems such as removal of blemishes, rigging, dirt, wires, lights, and other defects. By operating in RAW mode, the photographer can also defer critical decisions about color and exposure to the post-production step, as long as the data was captured correctly. To insure that highlights are not clipped and to give latitude to manipulation in post, the image is usually underexposed, or captured with HDR methods.

The post based workflow parallels current practice in motion pictures and will probably co-evolve and converge. Product shots in many product categories, such as automobiles, consumables, electronics, are now done synthetically by computer graphics. These images can be composited with backgrounds and other picture elements (CG or photo) rendering obsolete what once was the bread and butter of many studio photographers. Instead, the photographer and cinematographer increasingly focus on capturing raw material, visual assets that will be later assembled by compositing in post-production. Because photo-realism no longer requires photography, we can expect that some segments of advertisement imagery will become automated, like a polished video game. On the other hand, visual arts and art photography will continue to offer fresh ideas, remaining the source of inspiration for all that is visual.

No more fashion models?

Carrying further the idea of photography as raw data capture for compositing and CGI, one can imagine the huge impact of technology on modeling. Fashion models are normal young people, often with less than perfect hair, teeth and skin. Their pictures serve as the beginning of a process that includes real make-up first and photo-manipulation later. It is not far-fetched to imagine that some of the current animation methods in motion-pictures will cross-over into fashion photography, and later consumer imaging. 3D face scanning methods, coupled with biometric identification, motion tracking, skin models, light field capture, and skeletal and muscle modeling can derive an realistic model for most faces, allowing it to be "filtered" out and enhanced or modified. Facial expression capture technology was recently used in movies such as Avatar, allowing unrealistic characters to have realistic expressions. Motion capture has evolved into

performance capture, and artificial characters can now convey fairly realistic emotion and have any appearance desired. Thinking way ahead, one can imagine that this will enable consumers to be the models in their own commercials and movies, much like simple customized avatars are now used in some video games.

4. CONCLUSIONS

The three major purposes of photography can be described as:

- Sharing – pictures taken with the purpose of showing to other people. This would include social-networking, photojournalism, documentation, advertisement
- Memory – pictures taken for one self for emotional content. This would include pictures of objects, people, places, homes, pets, schools, games and tourist vistas
- Understanding – pictures taken to obtain information. This would include optical metrology, radiometry, remote sensing, photogrammetry, machine vision, augmented reality and art

One could argue that except for the last, none of the other activities is strictly photographic, and that video, painting and animation can all be apt replacements. The changes we have discussed will continue to blur the distinction between photography and the other forms, to the point where cameras and other equipment will be identified by how they serve the purposes above, and not the technology inside. In the long term, what is unique Photography is likely to revert to its technical and artistic origins. The film aesthetic will never die; it will just take its place besides the art of painting and drawing that it was going to replace.