Digital Imaging in 1995: Opportunities in the Descent to the Desktop

Sometime around the end of the decade, digital imaging will descend from the clouds of jet fighter simulation and land on your personal computer.

Nanette Byrnes, Financial World, January 1993.

The "descent" of digital imaging to the desktop, though eagerly anticipated by competitors jockeying for position in the digital camera market, had not yet occurred in 1995. Information technology, electronics, and film companies remained in a cloud of technological uncertainty that left the scale, scope, and timing of opportunities in the digital camera market unclear. The technology was advancing at a torrid pace and from all directions, few standards were in place, a multitude of possible product features and configurations existed, and little complete data was available on customer's needs. Regardless of this uncertainty, dozens of companies were spending millions of dollars in 1995 to develop digital imaging's underlying optics, micro-electronics and computer systems technologies.

Digital cameras, which, unlike conventional photographic cameras, captured an image as bits of electronic information, had been a source of great excitement amongst photography professionals and enthusiasts for several years. Many believed that the industry was on the verge of a complete transition from chemical to digital photography. As this transition approached, the opportunity existed for key players to shape the market. Privately, top managers admitted that industry forecasts of future market size were worthless. "When I'm shown data on emerging markets," explained one executive, "I don't believe it... or if I do it is too late."

Already positioned in the digital camera market were Apple, Canon, Dycam, Eastman Kodak, Fuji, Polaroid, and Sony. Potential entrants included IBM and Hewlett-Packard. Software and telecommunications companies including Microsoft and AT&T were expected to play key roles as well. Each viewed the opportunities from a unique position due to their unique technological and competitive strengths. Which among these companies was best positioned for the descent to the desktop? How, when and where would the opportunities descend?

Research Associate James Leonard wrote this case under the direction of Professor Elizabeth Olmsted Teisberg as the basis for class discussion rather than to illustrate either effective or ineffective handling of an administrative situation.

Imaging

Visual representations of a person, place or thing, or "images," have been an important form of information throughout history. The process of creating images, known as "imaging," had a large number of consumer, business, industrial and technical applications from photography to copying to computer-aided design to medical x-raying. In 1995, imaging products and services formed a $150 billion worldwide industry.

The series of operations involved in the creation of an image, known as the imaging chain, were acquisition, processing, storage, transmission, and reproduction. The photographic imaging chain included a camera and film (acquisition), a dark room (processing), negatives and slides (storage), and prints and projected images (reproduction). As of 1995, the digital imaging chain had evolved to include a digital camera (acquisition), a host-computer (processing), optical and magnetic disks (storage), and hard-copy and computer displayed images (reproduction).

History of Electronic Imaging

There were two basic forms of electronic information: video analog (a continuum of values); and digital (a limited number of discrete values such as 0s and 1s). Electronic imaging, which included both video analog and digital technologies, was pioneered by NASA scientists in the 1960s, who began using million dollar mainframe computers to generate images of the surface of the moon in order to simulate and plan lunar landings. Use broadened in the 1970s to include military applications, as well as medical applications such as MRI and CAT scanning tests. Leading suppliers of the hundred thousand dollar imaging workstations that were used during this period included 3M-Comptol and Gould-DeAnza. The 1980s brought applications in industry and science such as machine vision, which used electronic imaging to automatically inspect and track products; and biological analysis, which used electronics to automate things such as cell counting. Leading suppliers of the ten thousand dollar sub-system imaging technologies used during this period included Imaging Technology and Data Translation. As the market broadened from decade to decade, the cost of electronic imaging systems rapidly declined, while the users' tolerances for complexity fell and image quality requirements rose.

Electronic imaging first penetrated the commercial photographic market in the mid-1980s with the introduction of a series of still-video cameras by Japanese video-camcorder companies. Still-video cameras captured images as analog files on magnetic media. These images could then be viewed directly on TV screens, transmitted by telephone lines to remote locations, and/or reproduced as a hard-copy. Sony, one of the early pioneers of video technology, demonstrated the potential of its still-video camera at the 1984 Los Angeles Olympic Games by rapidly transmitting electronic photos to Tokyo. Sony's ProMavica camera was officially introduced in 1987 for $4,000. This and other competing still-video cameras introduced in the ensuing years were designed primarily for specialized users such as news agencies, scientists and real estate brokers who valued the immediacy and transmitability of an electronic image. However, some producers such as Canon began to probe consumer demand with models priced at around $1,000. The booming sales of video-camcorders drove the market for still-video during the 1980s, with early entries leveraging camcorder technology to push the concept of displaying still-images on TV screens.

Unanticipated by these still-video pioneers was the central position that the personal computer (PC), a digital technology, would occupy in the information industry in the 1990s. In 1992, E.G. Glazer of Dean Witter Reynolds proclaimed:

> A worldwide technological revolution is beginning to unfold that has major implications for the imaging business. The world is converting from analog technology,

to digital technology. This is happening in telecommunications, consumer electronics and, of course, it has already occurred in computers.

The rising popularity of multimedia PCs, which expanded the PC's information realm beyond text and data and into sound and images, was expected to be one of the principal drivers of digital imaging adoption**.** By 1995 virtually all PCs being sold had the processing and storage power required to handle basic imaging tasks. The ubiquitous PC gave digital camera makers the ability to design their cameras as computer peripherals, or external devices that relied on the PC for central processing and storage. One manager argued: "Digital cameras are information technology devices not cameras. Photography and digital imaging have completely different interfaces, cost-curves and value-propositions." By this logic, comparing a digital camera with a photographic camera was analogous to comparing a PC with a typewriter. Though each had valuable applications, one was a much more powerful tool than the other.

The Digital Camera Market

An estimated 97,000 digital camera were sold in North America in 1994. Based upon an annual growth rate of over 70 percent, BIS Strategic Decisions (BIS) forecasted annual sales would reach 600,000 units by 1998. However, little reliable information existed on exactly how many digital cameras were being sold, and who was buying and selling those cameras. In general, industry participants regarded the estimates of market analysts as conservative.

Data on the international market was even harder to gather. North America and Japan were considered the leading markets though trends in North America, and primarily the United States, drove the market. One manager estimated that the North American market accounted almost 80 percent of revenues in the low-end segment.

Market analysts generally segmented the market into three categories: a high-end consisting of digital camera systems for professional studio photographers; a mid-range consisting of 35mm Single Lens Reflex (SLR) systems for professional photographers and photo-journalists; and a low-end consisting of automatic lens shutter, or "point 'n shoot" cameras for non-professional photographers and commercial and business applications. Each segment was categorized by ranges of image resolution capability and prices, as shown in **Figure 1**. Image resolution was defined in terms of pixels, very small discrete pieces of electronic data that together defined a digital image. Scientists estimated that the human eye was capable of sensing the equivalent of 130 million pixels. High-end digital cameras available in 1995 were capable of capturing inanimate studio subjects at about 45 million pixels with either a linear scan or multiple exposures, but cameras that were capable of capturing animate objects were limited to about 6 million pixels.

Cameras that captured about 1 million pixels were believed to be adequate to duplicate the perceived image quality of standard 35mm film, as long as the image was reproduced in the typical 3" x 5" or 4" x 6" format. In larger formats, however, a resolution of 1 million pixels quickly "broke-down" in comparison to 35mm film. When enlarged to an 8 inch by 10 inch format, a resolution of approximately 3 million pixels was believed adequate, while poster size enlargements required upwards of 50 million pixels for 35mm quality.

Figure 1 Digital Camera Market Segments in 1995

	Studio	SLR systems	Point 'n Shoot
Sensor resolution in pixels	4 million and up	1.5 million and up	180,000 and up
Price Range	$8,000 - $50,000	$8,000 - $28,000	$400 - $4,000

Studio

Studio digital cameras were designed as either camera backs which attached to conventional studio cameras such as the Hasselblad, or as an integrated system. Either system allowed the photographer and their clients to immediately review their exposure(s), saving both the time and expense of shooting numerous exposures in order to ensure they got the right image. The ability to instantaneously manipulate the coloring of an image and zoom and crop was also a key feature for many users.

Donald Strickland of Apple Computer, Inc., predicted that by 1998 the studio segment would be dominated by integrated systems at a price point under $10,000 that offered the same features as studio film-based cameras. *The Future Image Report*, a digital imaging newsletter, estimated the potential market for studio digital cameras at about 41,000 sites in the United States, including publishers, commercial studios, and in-house studios at corporations and other institutions. Industry experts estimated that only about ten percent were using digital cameras in 1995. Though little growth in potential sites was anticipated, an increase in penetration to 50 percent was expected by 1998.

SLR

The SLR segment, like the studio segment, offered either a digital camera back that was attached to a 35mm SLR camera, or an integrated system with similar features. These systems served a well defined group of customers, primarily professional field photographers and photo-journalists, many of whom worked under tight deadlines while in the field. The ability to quickly store, retrieve and share images across locations was especially valuable to these users.

Strickland predicted that by 1998 the SLR segment would be dominated by integrated systems at a price point of about $1000. Industry experts put the U.S. population of professional field photographers and photo-journalists at about 250,000 and estimated that 20 percent were using digital cameras in 1995. Though little growth in this total population was anticipated, some industry executives expected penetration to increase to 80 percent by 1998.

Point 'n Shoot

The low-end of the market had a user-base that was much less clearly defined in 1995 than those of the Studio and SLR segments. Product offerings were uncomplicated "point 'n shoot" cameras designed for commercial and business users whose needs didn't require photographic quality images. Many early adopters, such as real estate, insurance and identification applications, were traditional instant photography users. Other important applications included desktop publishing and education.

According to Strickland, the point 'n shoot segment would migrate to a price point around $500 by 1998 and $199 by the year 2000. Also known as the segment "for the rest of us," the point 'n shoot cameras were targeting the mass market of 97 million U.S. homes. The first heavily marketed entry to this segment, Apple's $749 QuickTake 100, sold over 50,000 units in 1994 when it was introduced. Apple had claimed sales were constrained by supply and vowed to sell over one million units by 1998.

For the mass market, many envisioned the convenience of being able to electronically locate a family's holiday images, create an electronic album complete with electronic effects, titles and narration, and then share it over computer networks with distant friends or relatives.

Market penetration rates would depend on home adoption of other information technology infrastructure. A survey conducted by the Electronics Industries Association (EIA) in 1994 found that

33 percent of the U.S. homes surveyed had a least one personal computer.[1] Six percent of U.S. homes had a personal computer equipped with a CD-ROM drive, and 2.6 percent had a fully configured multimedia computer system, including CD-ROM drive, sound card, and speakers. Of PC homes, 31 percent owned a modem or fax/modem, and 19 percent subscribed to an on-line information service or computerized bulletin board system.[2]

Most experts agreed that digital cameras would continue to function as computer peripherals over the short-term. As the technology advanced, becoming smaller, cheaper and more efficient, the opportunity would most likely exist for digital cameras to function as stand-alone "cam-puters," with on-board image processing and display. Predictions and forecasts were constantly being adjusted to reflect the latest market and technical information. Hardest of all to predict was what would become the next technological breakthrough or barrier.

Key Technologies

A vast array of technological capabilities were relevant to the digital camera market in 1995 including optics, micro-electronics and computer systems expertise. Optics expertise provided the underlying imaging technology, micro-electronics the embedded component technology, and computer systems the technology to integrate all the elements into an efficiently functioning system. **Exhibit 1** provides a block diagram and signal path for a typical digital camera.

Optics The optical components of a typical digital camera included a lens, which was adjusted to bring the image into focus, and a shutter, which was adjusted to let in the proper amount of light. These adjustments were performed automatically in some cameras by using a variety of light sensors. If the amount of light was inadequate a flash was activated. After these mechanical adjustments the light, which was composed of the three primary colors, red (R), green (G), and blue (B), was projected onto a Charged Coupled Device (CCD)-- the equivalent of the retina of the eye.

Charged Coupled Device (CCD) The CCD measured the focused light using an array of photosensitive cells. Replicating a cell in one dimension created a linear sensor that captured a two-dimensional image by scanning it line by line. Replicating a cell in two dimensions created an area sensor that captured an image in a single exposure. Each cell could only measure the value of one of the primary colors at a time with each measurement forming one pixel. Three approaches had been historically used to circumvent the inability of one cell to capture all three colors. Some of the more expensive cameras had used a beam splitter to send light from the lens to three separate CCDs, with each chip dedicated to measuring one color. Another approach was to take three rapid exposures, with each exposure measuring one color, but this approach limited the camera to inanimate studio subjects. The typical approach was to divide the labor amongst cells by having neighboring cells measure the two other colors.

The continuous value registered by each cell was then converted into a digital bit stream of 0s and 1s. The bit stream that coded for the value of each measurement was called a byte. A converted signal captured with an 800 x 600 (480,000) pixel area array CCD, for example, contained 480,000 bytes of data.

Software In order to produce a full-color image with the division of labor approach, the values of the two colors ignored by each cell had to be calculated based upon the values of the neighboring cells. This process, called interpolation, demanded image processing software tools and could be executed either internally by the camera or externally by the host computer. Interpolation

[1] Roughly equivalent to 32 million homes, given that there were approximately 97 million U.S. homes in 1994.
[2] Software Industry Bulletin, Nov. 1, 1994

calculated an R, a G, and a B value (each one byte) for each pixel, which resulted in a tripling of the total bytes in the signal. (See **Exhibit 2**.)

Compression algorithms were often applied to the signal after interpolation in order to reduce the number of bytes in the signal before it was stored in the camera's memory. The goal of compression was to reduce the number of bytes in the signal while minimizing the loss in image quality.

Not interpolating the signal within the camera was an indirect form of compression. The file that was received by the host computer, called the "source file," could be transported to a host computer for interpolation and compression (see **Exhibit 2**). A second alternative was to transport the signal to a host computer after interpolation. A third alternative, interpolating and compressing the signal within the camera, resulted in the smallest source file but provided the user with less of the original signal. Interpolation and compression were part art, part science and were often proprietary technologies.

Microprocessors and Memory Chips Digital cameras contained numerous semiconductor chips similar to those used in PCs. Microprocessors, often referred to as a computer on a chip, controlled and coordinated all of the functions of the camera. Memory chips stored both the image processing software as well as the source files. Though a commodity-item, memory chips had to be used in large quantities in digital cameras, making them an expensive component.

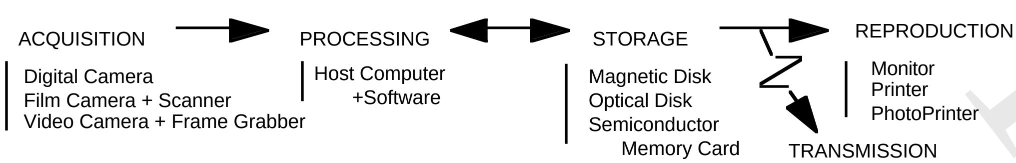
Removable storage came primarily in the form of Personal Computer Memory Card International Association (PCMCIA) cards. These credit-card sized cards used a storage technology called "Flash" that allowed the chip to hold its content without consuming power. For this reason PCMCIA cards and slots were becoming widely used in portable PCs by 1995, making the technology widely available.

Interface functions If removable storage was not used, the camera to host-computer interface was accomplished by a communication system that allowed the source files to be downloaded directly though a cable. Several image formats were in use in 1995, making compatibility and standardization critical issues. Further complicating these issues was the interdependence of digital imaging technology and technological developments occurring in other industries such as computers and telecommunications.

Competing Acquisition Technologies

Digital cameras faced competition from two alternative acquisition technologies: film and video. Using a scanner allowed images captured on film to be digitized, while using a device called a frame grabber allowed images captured on video to be digitized. **Figure 2** provides a diagram of the equipment available for each element of the digital imaging chain.

Figure 2 The Digital Imaging Chain and Equipment



Film Conventional film-based photography was a technology with almost a century of history. Though challenged by rapid technological improvements in digital sensors, film remained a relatively high quality and low cost sensing technology in 1995. The Photo Marketing Association's (PMA) 1993 survey found 67 percent of U.S. households surveyed owned a 35mm camera.[3] Of the 18 million 35mm cameras sold in the U.S. in 1993, almost two-thirds were automatic lens shutter cameras, know as point 'n shoot cameras.[4] A typical 35mm point n' shoot camera sold for about $150 and used film that cost about $5 for 36 exposures. Developing costs were about $10 per roll for double 3.5 x 5 inch prints.

Though conventional photography remained a viable stand-alone technology for most applications, supporting technologies were available in 1995 that allowed images captured on film to be integrated into the digital imaging chain. Owning a flat-bed color scanner allowed either images or documents to be sampled line-by-line and typically involved an investment between $800 and $1500. BIS estimated that 1.3 million scanners were shipped in the United States in 1994 and forecasted that shipments would reach 2.9 million by 1998.[5]

Retail scanning was also available. Copy centers such as Kinko's offered self-service scanning. In addition, photos could be scanned onto optical disks at photo finishers who had licensed Kodak's PhotoCD technology. These images could then be viewed on PCs with CD-capabilities or on TV screens using a $300 PhotoCD player.

Kodalux, Eastman Kodak's film processing unit, announced plans in 1995 to make scanned images available on-line in order to allow consumers to preview their film from their home PC after dropping it off at a photo finisher. These previews could then be used to decide which they wanted printed or enlarged, as well to send computerized copies to their own or another PC.[6]

Video Video technology, which allowed users to view images on TV screens, encompassed both still and moving imaging. Consumers had rapidly adopted the concept of using camcorders to view home movies on TV screens, but had not responded similarly to still-video, which allowed still images to be viewed on TV screens. The PMA's 1993 survey found 20 percent of U.S. households surveyed owned a camcorder, which typically sold for about $800. An estimated 3 million camcorders were shipped in the United States in 1993.[7]

Video images could also be digitized and then viewed on a computer using a device called a frame grabber which sold from about $350. Most of the still-video cameras still on the market in 1995 were available bundled with a frame grabber. Another option was to integrate video capability directly into the PC by purchasing and installing a video PC board.

One potential innovation was a multi-purpose camcorder that allowed users to capture and store still digital images separately from moving video images. This innovative feature was viewed as a potential "back-door" into the consumer segment of the digital camera market. The next step would be a fully digital camcorder. However, major breakthroughs in both memory capacity and battery power would be required before a portable device could capture the number of frames per second necessary to reproduce realistic motion.

Drivers of Digital Imaging Adoption

Adoption of digital cameras and digital imaging depended upon the development of an entire information technology infrastructure spanning the imaging chain from acquisition to reproduction. One of the principal factors cited by industry experts was the need for technical

[3] 1993 PMA Consumer Photographic Survey
[4] 1993-94 Wolfman Report
[5] Computer Reseller News, March 7th, 1994
[6] Wall Street Journal, May 11th, 1995
[7] 1993-94 Wolfman Report

standards to ensure the interoperability of the numerous technologies from numerous vendors. Though de-facto standards did exist in some areas, the surrounding competitive and technological uncertainties made establishing formal industry standards difficult. Alexis Gerard, an industry expert and editor of *The Future Image Report* argued:

> Film will only become obsolete when digital cameras are able to meet the needs of amateur photographers... And that requires more than just a film-quality digital camera at consumer prices; it is a system issue.

Processing In 1994, Compaq Computer held the top spot in the desktop market with 9 percent of the 50 million PCs sold worldwide.[8] Its Presario line of computers, which were equipped with an Advanced Micro Devices x486 generation microprocessor, sold for between $1,500 and $2,500. The base model included a color monitor with a built-in CD-ROM drive, fax/modem, and sound card, making it a fully functioning multimedia computer.

Microprocessors were viewed as the "brains" of PCs and were a principal determinate of processing ability. Over 70 percent of the PCs sold in the U.S. in 1994 were equipped with an Intel 486 generation microprocessor.[9] One popular performance measure for microprocessors was clock speed, a rough estimate of how fast the chip could operate. The 486 microprocessor used in Compaq Presario's in 1995 computed roughly 66 million cycles per second, or 66 MHz. Intel's latest generation chip, the Pentium, was expected to rapidly replace the 486 generation due to the surge in demand for desktop PC capable of running multimedia applications. Compaq's Pentium PCs had clock speeds of 100 MHz in 1995. A prediction of PC capabilities in 2000 is provided in **Appendix A.**

While hardware provided the brain power to deal with images, specialized software programs provided the tools with which users could enhance images, create special effects, add text, zoom and crop. The most widely used image editor on the market in 1995 was Adobe Photoshop. Available for about $600, Adobe Photoshop combined painting, drawing and photo darkroom capabilities and provided users with an huge array of editing options including the ability to alter, combine, cut, and rotate images. Desktop publishing programs such as Adlus PageMaker, which also sold for about $600, provided the tools for creating single or multiple page documents with integrated text and graphics.

Consumer software packages, such as the electronic family album program Echo Lake, were less sophisticated and less expensive. Echo Lake, which sold for about $50, allowed users to create electronic albums complete with text, graphics, photos, as well as video and audio clips.

Storage A typical color image, after compression, had a file size between 50,000 and 200,000 Bytes. High capacity storage technologies in 1995 included magnetic disk drives and optical compact disk drives. Magnetic 3.5 inch disk drives were standard on all desktop computers and many portables. Removable magnetic disks or diskettes had storage capacities of 1.4 Mbytes.

The storage technology of choice for multimedia in 1995 was optical disks. Audio CDs, CD-ROMs and videodisks were referred to as Write Once Read Many (WORM) disks because information contained on them could not be erased or written-over. Optical disks had several advantages over magnetic media in 1995, including longer life spans and storage capacities of more than 600 Mbytes.[10] A new high-density optical storage standard with capacity of 3.3 Gbytes was in

[8]CI InfoCorp.
[9]Ibid
[10]1,000 bytes=1 Kilobyte (Kbyte); 1,000,000 bytes=1 Megabyte (Mbyte); 1,000,000,000 bytes=1 Gigabyte (Gbyte)

development as well. A new semitransparent optical media developed by 3M was also being used to test double-layered optical disks, which would double capacity to over 6 Gbytes.[11]

Transmission In addition to the increased speed and flexibility from input through output, electronic images could be transmitted to other locations through network connections or modems. Modems converted the computer's digital pulses into audio frequencies which were then transmitted over telephone lines and converted back into digital pulses at the receiving end. Whether internal or external, new modems in 1995 were typically able to transmit up to 14,400 bits per second (bps). The number of bytes transmitted was about one tenth of the bit rate so that 14,400 bits per second was the equivalent of 1,440 bytes per second. At this rate a full screen of text took less than two seconds to display. Images took significantly longer because of their size. A 50,000 byte file, for example, took 30 seconds at this rate. Though faster modems were addressing this problem, compression technology was seen as another key element of the solution.

Reproduction An image, once available in digital form, could be viewed using several types of displays. Compaq's Presario line of PCs came with a 15 inch, 1024x768 pixel color monitor. Larger and higher resolution monitors were used primarily by those with high performance computer graphics requirements. An image could also be converted back into video form and displayed on an ordinary television screen by reversing the digitization process.

Hard copy output was available from a variety of printing technologies including laser, ink-jet, and thermal transfer. Laser printers were by far the most widely used in 1994 and controlled 66 percent of the revenues of the printer market.[12] Characters were formed using a laser beam which left an electrostatic charge that attracted metallic dust. This dust then formed the inked images when heated and melted by the printer. Ink-jet printers, which controlled 12 percent of the market in 1994, sprayed continuous ink streams onto paper. Thermal dye transfer printers, which controlled 6 percent of the market, used a ribbon coated with a dye that, when heated, turned into a gas and then condensed on a specially coated paper. This printing technique was able to create photographic quality color by varying the amount of heat applied to the ribbon, which in turn varied the density of the image. Other specialized techniques, such as photo-typesetting, which was used in professional photo finishing labs to process film into prints, were capable of high-quality output.

Though some expected the importance of hard copy images to rapidly diminish, the model provided by the computer's inability to create the "paper-less office" led many to predict that hard copy output would be as high, if not higher, with digital imaging. Evidence suggested that paper use in offices was beginning to decline by the mid 1990s after a 15 year adjustment period. Demand for hard copy images would be expected to follow a similar pattern.

Research

Few competitors had the financial and human resources to perform advanced research in all of the critical technologies relevant to digital cameras. Many competitors, however, regarded research directed toward developing higher resolution, lower cost CCD sensors as a necessity. The annual level of investment required to maintain a competitive design capability (not including investments in large-scale manufacturing operations) was estimated to be $10 to $50 million in 1995.

Micro-electronics expertise played a significant role in research efforts. Image science, or the physics and psychology of what makes a good image, was another area of research within

[11]MacWeek, August 22nd, 1994
[12]Computer Reseller News, May 30th, 1994

many corporate laboratories. These research efforts had potential payoffs in still-cameras, camcorders, scanners and copiers.

Development

The CCD sensor was the core of any digital camera development project. Many competitors had been investing in an internal sensor design capability for at least a decade. Others had sought-out and negotiated sourcing agreements. Locking-in a sensor design (and resolution) essentially determined what segment of the market the camera could support.

Though camera designs within segments had certain basic similarities, competitors attempted to differentiate themselves by incorporating innovative features or functions such as interchangeable lenses (which appealed to customers with diverse focal length needs), removable media (which appealed to customers who needed to be able to take lots of pictures without downloading to a computer) or on-board liquid crystal display (which, for example, appealed to customers who wanted to be able to instantaneously view their images and perhaps select particular frames to save or edit).

Among the most important decisions made during the development process was what range of applications to target. A focused application group simplified the design trade-offs and resulted in a customized product, while broader targets resulted in greater compromise and standardization. Potential users were usually consulted throughout the development process, but the evolving nature of the market made pinpointing needs difficult. The most direct feedback came once a product was introduced to the market. Many companies had approached the high level of uncertainty in the digital camera market by entering quickly, often with products that had known deficiencies. Rapid product development cycles were seen as another key to success, with many expecting the market to eventually keep pace with the nine to twelve month cycles of the PC market.

Manufacturing

Many digital camera components such as microprocessor and memory chips were commodity items whose price and performance were driven by the computer business. CCDs, however, were driven by the camcorder business in 1995. Sony and Matsushita dominated the volume of the CCD market, with secondary players including NEC, Sharp, Samsung and Goldstar. The large camcorder CCD market provided these manufacturers with economies of scale in the still-video and digital camera CCD market. However, CCDs designed to optimize motion video resolution were not perfectly suited for digital capture.

Several vendors located in the United States sold high-resolution digital CCDs including Loral-Fairchild, EGG-Reticon, Sarnoff Research Labs. Yield rates of 10 to 15 percent were not uncommon for these manufacturers in 1993. The costs of those low yield rates were reflected in the pricing of those CCDs that did pass inspection. The cost of the CCD used in Kodak's discontinued DCS 200 digital camera (which sold for approximately $20,000) was more than $3,000, though the price could drop to $1,800 when purchased in quantity.[13] Kodak was the largest manufacturing source for digital CCDs, though others were forming alliances to develop the capabilities.

The various digital camera components were often initially assembled in pre-existing facilities in order to allow the company to gauge the market's response before committing the resources for a dedicated facility. Out-sourcing assembly was another common choice. Several of

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[13]"Eye Tech," Forbes June 7th, 1993

the low-end, point 'n shoot cameras, including Apple's QuickTake, Logitech's Pixtura, and Kodak's DC-40, were assembled by Chinon, a low-cost camera maker based in Nagano, Japan.

Marketing and Sales

The lack of reliable and complete user data made marketing especially difficult. Compounding the difficulty was the global competition and the diverse industry backgrounds of key players.

Market intelligence firms such as BIS and Dataquest were sources of information on how the industry was evolving, as well as some data on who was selling what to whom. Data was spotty however, and forecasts were adjusted on almost a weekly basis by events in the marketplace. Industry newsletters such as the *Future Image Report* were widely read. Conferences and trade shows were also important events at which companies could show their wares and hear user concerns while getting a look at the competition.

The potential rewards of adopting digital imaging for most professional photographers and photo-journalists were the time and money saved in processing. However, the rewards were less tangible and the images less-critical toward the lower-end of the market. Real-estate agents who took a couple of instant photos a day for their window display might not find the ability to create innovative displays with computer graphics and put listings on the internet interesting enough to rationalize an investment of $1000 or more in a digital camera. Consumers were an even more difficult target. Many competitors focused their marketing efforts upon their traditional customers to leverage existing relationships, brand loyalty, and knowledge of customer needs.

Distribution

The studio and SLR segments benefited from well-defined existing distribution channels, primarily reaching customers through the same Value-Added Resellers (VARs) who sold conventional professional camera systems.

Large organizations in commercial applications such as real-estate and insurance were reached through a combination of VARs and direct channels. Smaller organizations or individual customers were more difficult to reach due to the lack of technical expertise in existing retail photography channels. In the point 'n shoot segment the importance of engaging the computer enthusiast suggested that traditional computer retail and mail-order houses would be an important channel. Consumer electronics retailers such as Tweeter and Circuit City were expected to be important channels to the consumer market.

Alliances

No single competitor had the resources to proceed independently. Cooperative relationships were an important piece of a company's strategic positioning. This was especially true in 1995, which appeared to be a crucial formative year. An industry executive explained:

> Most of the early contacts happened in an early business development mode at a time when every company was investigating what could be done (technically) and should be done (business-wise). I strongly believe that it was way too early for many companies to commit themselves. I would say that we are only now starting to see the shaping of the industry forces, creating the conditions for some real relationships to take hold.

Competitors

Competition in the lower-end of digital camera market was growing rapidly in 1995. "Everyone has some kind of entry to test the waters," summed up one manager, "and everyone is committed to it as well. It's just a matter of when, where and how you spend your money." A table of competing product entries in the various segments is provided in **Exhibit 3**. Though countless companies were potential players in 1995, companies such as Apple Computer, Canon, Dycam, Eastman Kodak, Fuji, Polaroid, and Sony were openly pursuing the digital camera market.

Apple Computer, Inc. Apple, which was headquartered in Cupertino, California, manufactured a wide variety of personal computing products including its popular Macintosh PC line. The company's sales were $9.2 billion in 1994. Apple estimated its installed base of Macintosh computers at more than 16 million units. Dataquest ranked Apple third in worldwide personal computer units shipped in 1994 with an 8.5 percent share of the 46.5 million units sold. Apple's strongest market share was in the worldwide educational market, where it ranked first with a 28 percent share. However, the company estimated that the education segment accounted for 20 percent of its net sales in 1994 , while the business communications and publishing segment accounted for 25 percent.[14]

Apple first entered the digital camera market in January 1994 with its QuickTake 100, a camera developed in partnership with Kodak and assembled by Chinon. The QuickTake 100 featured a Kodak designed and manufactured 640x480 (307,200) pixel area array CCD. The camera's internal flash memory was capable of storing up to eight of these "high-quality" images, or up to 32 "standard-quality" images at a resolution of 320x240. The QuickTake 100 was available in both Macintosh and Windows formats, and retailed at a price of $749.

In April 1995 the company began shipping the QuickTake 150, an enhanced version of the original camera. Though using the same CCD resolution as the QuickTake 100, the 150 featured expanded memory and retailed at a price of $739.

Both QuickTakes offered a price/performance point in the lower end of the point 'n shoot segment and were targeted at mainstream users in broad business communication applications, as well as educational and home Macintosh users. The QuickTake provided Apple with a total solution across the entire digital imaging chain with each element connected by an easy to use, "plug and play" interface. Apple hoped to establish the Macintosh as the multimedia platform of choice for both consumer and commercial applications.

Canon, Inc. Canon was headquartered in Tokyo, Japan, and had 1994 sales of ¥1,933 billion ($19.3 billion[15]). Copiers, its largest business, accounted for 36.7 percent of sales; computer peripherals, including printers and scanners, 30.1 percent; business systems, including computers and fax machines, 18.0 percent; cameras, including camcorders, 8.5 percent; and optical products, including semiconductor production equipment, broadcasting equipment and medical equipment, 4.7 percent.

Canon was one of the early pioneers in electronic photography, being the first to commercialize a still-video camera in 1986. Canon had rapidly introduced and discontinued several models including two high-end and one midrange camera. A consumer model dubbed the Xapshot was also offered through amateur photography outlets at one time for $499 (bundled with digitizer for $999), but was eventually removed from the market.

[14]1994 Annual Report, Apple Computer Company
[15]Currency exchange rate of ¥100 to the dollar. used here and elsewhere for comparative purposes.

The failure of Canon's early efforts led it to re-adjust its target by focusing on vertical markets like insurance and real estate appraisal with its RC-360 and 570 still-video cameras. The RC-360 listed at $1,665 in 1995, and could record up to 50 images on each video floppy disk. Images could be viewed directly on a TV or digitized for integration into a computer by a $350 digitizer. The RC-570 listed at $3,493 and had a slightly higher video resolution.

In 1994 Canon had begun showing a prototype of a digital SLR camera that used a 1300x1000 (1.3 million) pixel area array CCD manufactured by an outside source. In 1995, however, Canon and Kodak announced a co-development agreement in which several of Kodak's digital camera backs were to be re-designed to fit Canon's high-performance 35mm-film EOS camera.

Dycam, Inc. Dycam Inc., located in Chatsworth, California, had revenues of $1.7 million in 1994 derived from several digital cameras, supporting software and accessory products, licensing fees and custom contract engineering work. Dycam's cameras focused on broad business applications by providing a low cost, low quality means of integrating digital images into personal computers. Dycam introduced its first digital camera in 1991 and reported cumulative unit sales of approximately 4,500 cameras as of 1994.

Its Model 3, a gray-scale camera capable of capturing and storing up to fifty-six 496x365 (180,000) pixel images, was introduced in 1992 and retailed at $695. The Model 4, a color version of the Model 3 with a memory capacity of 24 color-images, retailed at $795.

In 1994 Dycam announced the development of several next generation cameras intended to replace their Model 3 and 4 cameras. These included the Model 5 and 6 cameras which would offer resolution comparable to the Model 3 and 4 cameras, but would retail for approximately $395 and $495, respectively. The company was also developing a variant of these models which would allow images to be displayed immediately on a television screen. These models were sold principally to OEMs, VARs and integrators.

Dycam also provided custom engineered solutions to commercial applications who wanted additional features or functions. Past customers included IBM and the University of Florida (modular camera reliant on the power and memory supply of a notebook computer), Northern Telecom (low-cost teleconferencing systems), and McQue (remote surveillance systems.) Dycam had also licensed the right to use its technology to Logitech, who sold cameras based upon Dycam's Model 3 and 4. However, in 1995 Logitech decided to use a Kodak sensor for its latest model.

Eastman Kodak Co. Eastman Kodak, headquartered in Rochester, NY, had sales of $13.6 billion in 1994. Commercial products accounted for roughly 56 percent of 1994 sales and consumer products the remaining 44 percent. Since his hiring as CEO in December of 1993, ex-Motorola chairman George Fisher had begun an effort to renew growth in the companies core photographic businesses while building a future in digital imaging. As part of this strategy, Fisher oversaw the company's divestment from its chemical and pharmaceutical businesses.

Digital imaging products reportedly accounted for about $1 billion or seven percent of the company's 1994 sales.[16] A new Digital and Applied Imaging business unit was created around those sales in 1994 in order to centralize Kodak's efforts in the area while building on the company's core strengths in imaging technology and color science. Carl E. Gustin, Jr., formerly with Digital Equipment Corp. and Apple Computer, was named its general manager and former Apple CEO John Sculley was hired as a marketing and strategy consultant. The units goals were to "expand Kodak's role in selected digital imaging applications for commercial customers, and position the company to

[16]Wall Street Journal, March 29th, 1995

address opportunities in tomorrow's home computing environments."[17] Executives expected the division to top sales of more than $2 billion by 1998.[18]

Kodak's DCS-420, which was a Nikon N90 camera body with a digital camera back, featured a 1524x1012 (1.5 million) pixel area array CCD and removable PCMCIA storage. The DCS-420 retailed at $10,995. The DCS-460, also a Nikon N90 with a digital camera back, featured a 3000x2000 (6 million) pixel area array CCD and removable PCMCIA storage capable of storing seventeen images per 105 Mbyte card. The DCS-460 retailed at $27,995. The DCS-460's price and resolution were also offered in the DCS-465, a camera back design for studio cameras.

In February 1995 Kodak announced an agreement with Canon to introduce digital camera backs based upon the DCS-420 and 460 for Canon's EOS-1N camera. The EOS-DCS 5, with 1.5 million pixel resolution, was expected to retail at $11,995. A 6 million pixel EOS-DCS was to be announced in late 1995.

The company initially focused its marketing efforts at the SLR segment of the digital camera market and allowed Apple to pursue the point 'n shoot segment with Kodak technology. In March 1995, however, Kodak announced its own point 'n shoot entry. The DC-40 featured a 756x504 (381,000) pixel area array CCD and had internal storage capacity of up to forty-eight high-quality images, or ninety-six 378x252 pixel, standard-quality images. The DC-40 retailed at $995.

A critical piece of Kodak's digital imaging strategy was its PhotoCD, an optical storage system developed in collaboration with Philips and announced in August 1992. The PhotoCD was designed to allow customers to transfer conventional film images onto compact disks at licensed photo-finishing shops, and was viewed as an opportunity for Kodak to enter the digital age without cannibalizing its lucrative film business.

In March 1995, Fischer announced a sweeping new strategy intended to "drive the use of digital pictures beyond image professionals to customers in business and the small office/home office market ... and ultimately to consumers." Kodak's adoption of an open licensing strategy for its PhotoCD, assuring future computer users the ability to both read and write digital images to and from the disks, was seen as an important new direction. As part of its dramatic announcement Kodak outlined alliances with Adobe on PhotoCD software, Hewlett-Packard on ink-jet printing solutions, IBM on optical storage products and Internet-based image networking, Microsoft on consumer imaging software, Sega on a PhotoCD compatible game system, Sprint on new network services for image storage and exchange, and Wang on a document imaging architecture. Though partially "vapor-ware," or products that had yet to be developed, this flurry of press-releases announced to the world Kodak's intention to lead and accelerate the emergence of digital imaging.

Fuji Photo Film Co., Inc. Fuji Photo Film, headquartered in Tokyo, Japan, had sales of ¥1.1 trillion ($11 billion) in 1994. Information systems, including graphic arts, medical and office automation systems, accounted for 40.9 percent of those sales; imaging systems, including photographic and motion picture film and cameras, 36.4 percent; and photo finishing systems, including equipment, chemicals, services and photographic paper, 22.7 percent.

Fuji's initial digital camera entry was the Fujix DS-100 released in 1993. The DS-100 featured a 720x488 (350,000) pixel area array CCD and could store up to 21 images on a removable memory card. The DS-100 retailed at $3,200.

[17] 1994 Annual Report, Eastman Kodak Company
[18] Computer Reseller News, April 13th, 1995

Fuji had two additional digital cameras scheduled for release in the spring of 1995. The Fujix DS-505 and 515 digital SLR cameras were developed in an unlikely alliance with photographic rival Nikon. Both products featured a Nikon F4 camera body with a 1280x1000 (1.3 million) pixel area array CCD developed by Fuji. The DS-505 and 515 retailed at $11,835 and $14,835, respectively.

Polaroid Corp. Polaroid, based in Cambridge, MA, had sales of $2.3 billion in 1994. Polaroid was the world's leading instant photography company and drew its revenues from a variety of industrial, technical, business and consumer applications. However, sluggish growth in Polaroid's instant film business had convinced its senior management to invest in the growing opportunities in digital imaging. During 1993 CEO I. Mac Allister Booth reorganized the company into three business units: Instant Photography, High-Resolution Imaging, and Digital Imaging Systems. At the annual shareholders meeting in May 1994, Booth made it public that Polaroid was working on the development of digital cameras. During 1994, Polaroid hired Henry Ancona, who had grown Digital Equipment Corporation’s office and information systems unit into a billion dollar operation, as Executive Vice President responsible for electronic imaging systems. Furthermore, in October 1995, Polaroid announced that Gary DiCamillo, previously President of the Power Tools Accessories division at Black and Decker, would assume the position of CEO from the retiring Booth.

Polaroid's PDC 2000 was scheduled to be released in early 1996 and featured a 1600x600 (1 million) pixel area array CCD. In its standard version the internal memory was capable of storing 40 uncompressed images, which could be output at a resolution of either 800x600 or 1600x1200. The standard version of the camera was expected to retail for $3,695.

Sony Corp. The electronics giant Sony, which was headquartered in Tokyo, Japan, had 1994 sales of ¥3.7 trillion ($37 billion). Sales of video equipment, which included still-video cameras, accounted for 18 percent of total sales; audio equipment, 23 percent; televisions, 17 percent; and entertainment, including music and motion pictures, 21 percent. The remaining 21 percent consisted of semiconductors, electronic components, information and telecommunications equipment, computers and other accessories.

Sony, which first demonstrated its Mavica still-video camera in 1981, had remained loyal to its analog technology. Its DKC-5000 CatsEye featured three 1520x1144 (1.7 million) pixel CCDs and retailed at $15,000. Sony focused its marketing efforts on high-end pre-press and professional photography applications.

Others Two companies, Leaf Systems Inc., and Dicomed Inc., remained primarily focused on the high-end studio segment. Leaf's Digital Camera Back was designed to attach to non-portable studio cameras and therefore was large and relied on a host computer for storage. The camera featured a 2048x2048 (4.2 million) pixel area array CCD. Color images required three-exposures, capturing red, then green, then blue. The camera retailed at $36,000. Even more expensive was the Leaf Catchlight, a $50,000 system that could capture full-color in one exposure by using three CCDs. Leaf also offered its Lumina scanning studio camera, which produced digital images of immobile subjects in about 5 minutes using a 2700x3400 (9 million) pixel linear array CCD. The Leaf Lumina retailed at $7,500 and had reportedly sold more than 500 units since its introduction in mid-1994.

Dicomed's Digital Camera Back featured a 6000x7520 (45 million) pixel linear array CCD. The camera back was designed to be inserted into any standard studio camera and scanned full-size color images to its 1 Gbyte hard-drive in three to fifteen minutes. Dicomed began shipping the camera in 1994 for $21,500 and reported having sold 100 units in the first three months.

Opportunities and Challenges

Each of the competitors hoped it would be poised for success when digital imaging became a mass market. Managers struggled with issues of how to create and appropriate value in this emerging market. Did a firm need to participate in many aspects of the value chain or only a key segment? Would an early mover or a fast follower win the consumer market? And, how could the growth of the consumer market be accelerated? Many were not prepared to accept a long wait for the descent of digital imaging. George Fisher, Kodak's CEO, explained, "Managers or leaders make industries slow growth or fast growth. I think that's what people are paid a lot of money to change." [19]

[19] "Fisher Labors to get Kodak off the Treadmill," Upside, November 1995

Exhibit 1 Typical Digital Camera Block Diagram and Signal Path

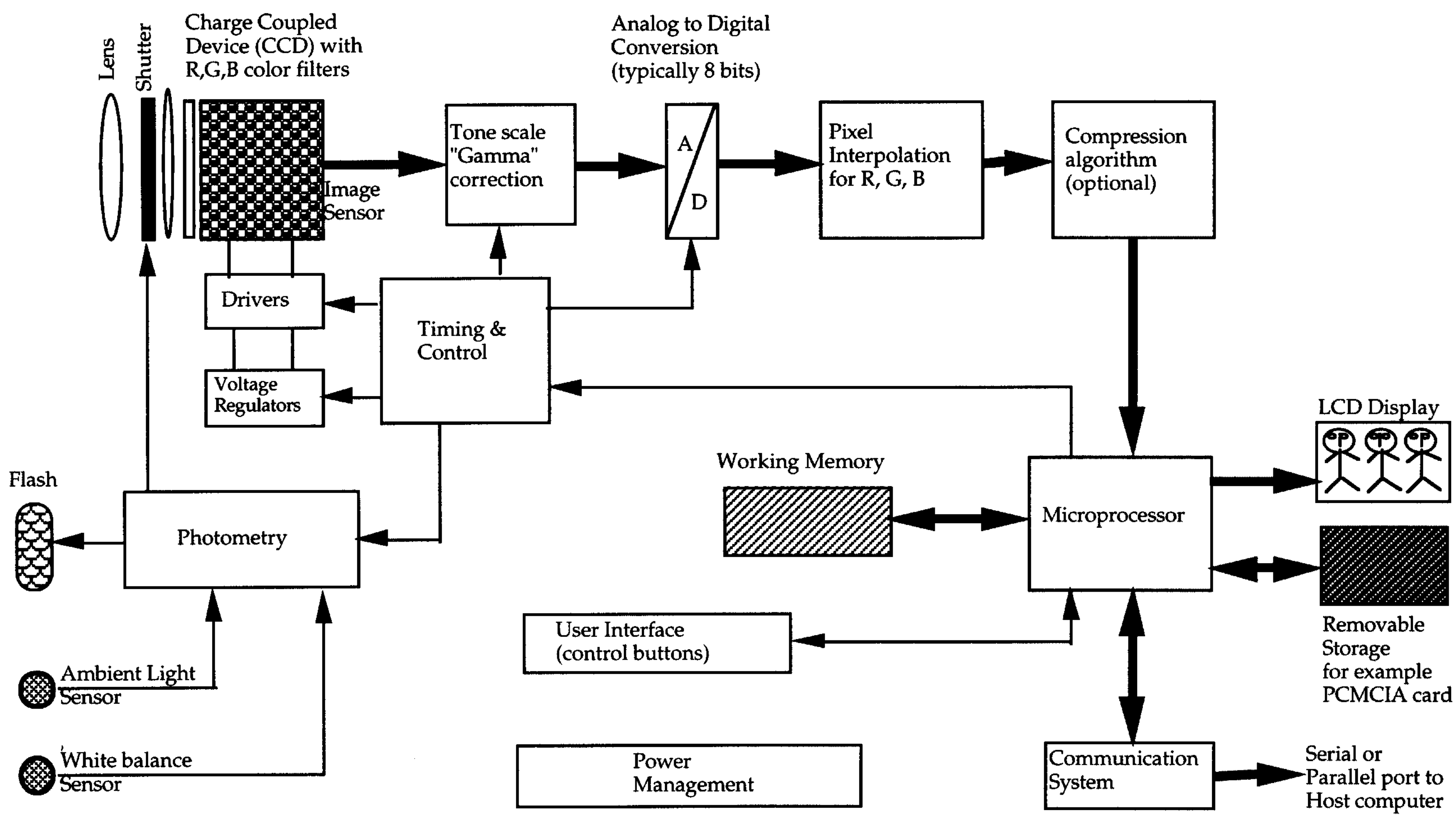

Exhibit 2 Interpolation and Compression Alternatives (simplified)

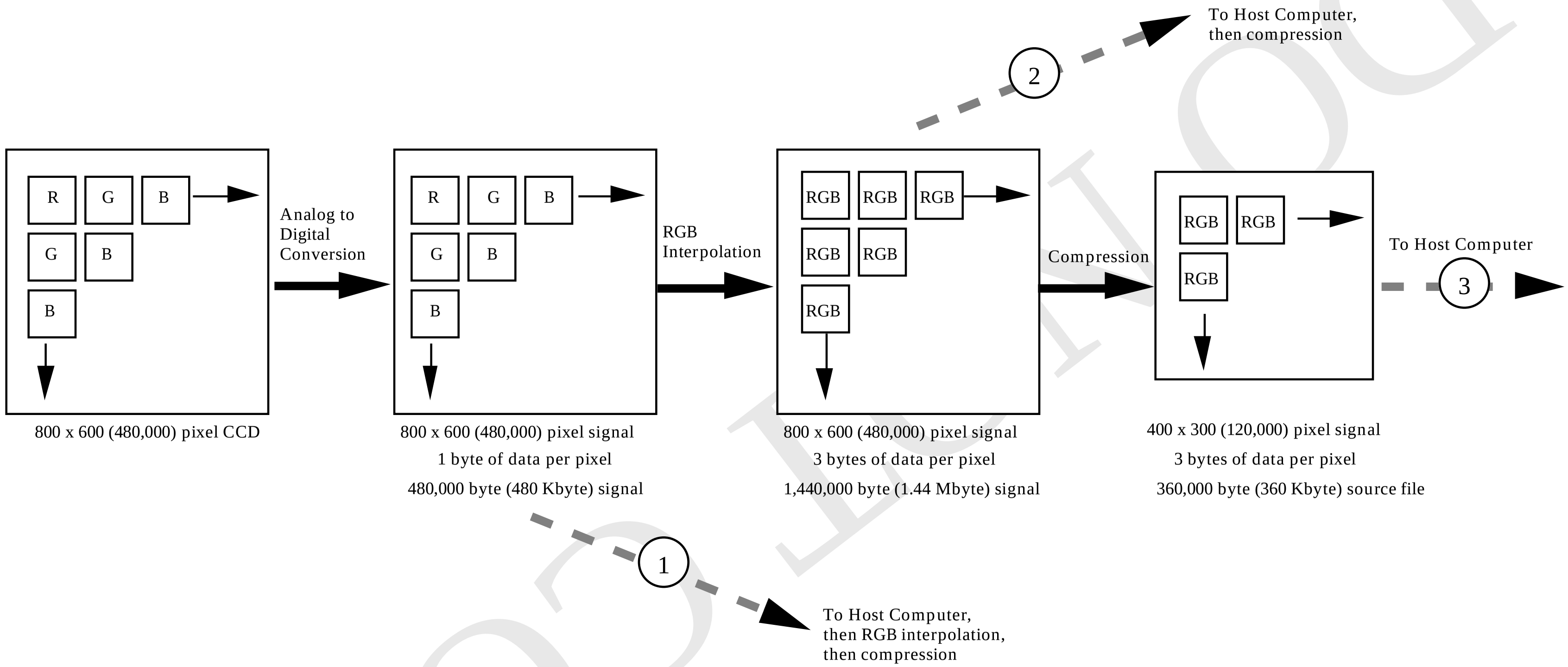

Exhibit 3 Competing Entries in the Digital Camera Market as of 1995

	Retail Price	Pixel Array	Output	Camera-type	Array-type
Studio					
Leaf Catchlight	$50,000	2048x2048	Digital	Integrated Camera	Area*
Leaf Digital Camera Back	$36,000	2048x2048	Digital	Camera Back	Area**
Kodak DCS465	$27,995	3000x2000	Digital	Camera Back	Area
Dicomed Digital Camera Back	$21,500	7520x6000	Digital	Camera Back	Linear
Sony DKC-5000	$15,000	1520x1144	Still-Video	Integrated Camera	Area*
Leaf Lumina	$7,500	3400x2700	Digital	Integrated Camera	Linear
35mm SLR					
Kodak/Nikon DCS460	$27,995	3000x2000	Digital	Camera Back w/camera	Area
Fuji/Nikon DS-515	$14,835	1280x1000	Digital	Camera Back w/camera	Area
Kodak/Canon EOS DCS 5	$11,995	1524x1012	Digital	Camera Back w/camera	Area
Fuji/Nikon DS-505	$11,835	1280x1000	Digital	Camera Back w/camera	Area
Kodak/Nikon DCS420	$10,995	1524x1012	Digital	Camera Back w/camera	Area
Point n' Shoot					
Polaroid PDC-2000 (exp. Q1 96)	$3,695	1600x600	Digital	Integrated Camera	Area
Canon RC-570	$3,493	760x540	Still-Video	Integrated Camera	Area
Fuji Fujix DS-100	$3,200	720x488	Digital	Integrated Camera	Area
Canon RC-360	$1,665	540x480	Still-Video	Integrated Camera	Area
Kodak DC-40	$995	756x504	Digital	Integrated Camera	Area
Dycam Model 4	$795	496x365	Digital	Integrated Camera	Area
Apple/Kodak QuickTake 150	$739	640x480	Digital	Integrated Camera	Area
Dycam Model 6	$395	496x365	Digital	Integrated Camera	Area

* used three CCDs
**used three exposures

APPENDIX A Personal Computer Capabilities in the Year 2000

PORTABLE PCs	*SUB-NOTEBOOK ($1,500)*	*NOTEBOOK ($2,500)*
Physical Characteristics	3 pounds 30-hour battery life 6" x 10" form factor	5 pounds 20-hour battery life 8.5" x 11" form factor
User Interface	Windows/Macintosh Speech recognition (4,000 words) Handwriting input Small keyboard	Windows/Macintosh Speech recognition (8,000 words) Handwriting input Optional cordless keyboard
Processor	Pentium+2 (20 times performance of x486) 128-MByte RAM	Pentium+2 (20 times performance of x486) 256-MByte RAM
Mass Storage	500 MByte hard disk 256 MByte Flash memory PCMCIA cards (64 to 512 MBytes)	1 GByte hard disk Mini CD/erasable optical disk PCMCIA cards (64 to 512 MBytes)
Connectivity	Digital Wireless communication Encryption capacity ISDN interface Infared local communication	Digital Wireless communication Encryption capacity ISDN interface LAN interface
Display	Flat, color (HDTV-compatible) 1024x768 pixels Touchscreen	Flat, color (HDTV-compatible) 1024x768 pixels Touchscreen

DESKTOP PCs	*HOME ($2,000)*	*OFFICE ($3,500)*
User Interface	Windows/Macintosh Pointing device & cordless keyboard Speech recognition (6,000 words) Handwriting pad	Windows/Macintosh Pointing device & cordless keyboard Speech recognition (12,000 words) Handwriting pad
Processor	Pentium+2 (20 times performance of x486) Multimedia co-processor 256-MByte RAM	Pentium+3 (30 times performance of x486) Co-processors--speech, handwriting, multimed 256-MByte RAM
Mass Storage	1 GByte hard disk 3.5" floppy disk (20MBtye) Multifunction optical disk-- audio CDs, CD-ROM, erasable (4 to 8 GBtye)	2 GByte hard disk 3.5" floppy disk (20 MByte) Multifunction optical disk-- audio CDs, CD-ROM, erasable (4 to 8 GBtye)
Input/Output	Digital sound--speech, music, sounds effects	Digital sound--speech, music, sounds effects
Display	Color monitor (HDTV-compatible) Graphics co-processor 1024x768 pixels	Large screen color monitor (HDTV compatible Graphics accelerator 1280x1024 pixels
Connectivity	ISDN interface Cable TV interface	ISDN interface LAN interface Video conferencing
Printer	Inkjet color printer	Color page printer (600 dpi)

Adapted from the 1994-95 Computer Industry Almanacs