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Fundementals of digital imaging

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FUNDAMENTALS OF DIGITAL IMAGING

by
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A thesis project submitted in partial fulfillment of the requirements for the degree of Master of Science in the School of Printing Management and Sciences in the College of Imaging Arts and Sciences of the Rochester Institute of Technology

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Certificate of Approval

Master's Thesis

This is to certify that the Master's Thesis of

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with a major in *Graphic Arts Publishing*
has been approved by the Thesis Committee as satisfactory
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With any art-making medium, the structure
of the tools are acknowledged even as
there is a challenge to explore and
transcend their formal nature.

Gretchen Bender, 1993

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ABSTRACT

This thesis project shows that conventional photography and digital imaging are two visual media with very distinct differences:

A *conventional photograph* is a human-readable information entity with an actual physical body in the form of silver clusters or color molecules embedded in gelatin. Silver halide materials have a chemical attribute and are organic, almost "living" organisms affected by heat, moisture, light and pollution, similar as we are. The actual information contained in a photographic image is always overlaid by an unwanted signal called noise. In conventional photography noise becomes visual as graininess. The amount of information in a photographic image cannot be determined exactly and there is always a significant loss of information from image generation to image generation (multiple generation loss). Because objects record themselves on light sensitive silver halide materials using light as a messenger, a photographic image is directly connected to reality, stencilled from the real. This fact is one of the reasons why photography as a medium has a high level of credibility. Despite all the medium inherent subjective, selective and abstractive factors, photography still has the stamp of an objective and reliable source of information, a stamp of authenticity.

A *digital image* is an immaterial, machine-readable stream of bits in the form of a matrix. This numeric structure can be easily altered and manipulated, not only in the space but also in the frequency domain. The solid bond which connects the conventional photographic image to reality disappears with digital imagery. The image is simply itself, has no chemical attribute, and contains no evidence that something existed in reality. The amount of information in a digital image can be exactly determined. However, there is also a certain amount of noise present which, however, cannot be compared with the graininess of photographic materials. Digital information can be compressed with or without a visual loss. Transmission of digital information is easier and more reliable because the information can be error corrected.

More than 150 years after the discovery of the photographic process, the wide availability of the tools of digital imaging make it clear to the public that mechanical images are not, and never have been, a reliable source of information. This thesis project points out that the belief in the objectivity of photographic information was, and is, an illusion.

The thesis project *Fundamentals of Digital Imaging* analyzes the basic concepts of digital imaging not only theoretically but also visually by including six plates of digital artwork.

CHAPTER 1

INTRODUCTION

In 1970 the Italian photographer *Ugo Mulas* started his famous series called *Le Verifiche* (Verifications). With this series, consisting of 14 plates [1], Ugo Mulas tried to analyze photography as a medium in a new way, giving theoretical analysis a visual expression in effort to find the basic concepts behind the medium.

[1] Ugo Mulas named the plates as following:

Plate 1 Tribute to Nièpce

Plate 2 The Photographic Operation

Plate 3 The Photographic Time. To J. Kounellis

Plate 4 The Use of Photography. To the Alinari brothers

Plate 5 The Enlargement. The Sky for Nini

Plate 6 The Enlargement. From my window recalling the window of Gras (September 16, 1824, Joseph Nicéphore Nièpce to his brother Claude: "I am finally very pleased to tell you . . . . I've been able to obtain such a good image of nature that I can't wish for anything better . . . . This image has been taken in your room from the side overlooking Le Gras.")

Plate 7 The laboratory. A hand develops, the other prints. To Sir John Frederick William Herschel ("Test 1013. January 29th, 1839. Found sodium hyposulphite to stop the action of the light by washing away silver chloride. Successful. Paper: half exposed, half protected from the light by cardboard covering. Then withdrawn from the light and sprayed with sodium hyposulphite and well washed with pure water. Let it dry, then exposed again, the darkened half stays dark, the white half stays white after any exposure length.")

Figure 1: Ugo Mulas: The Laboratory, 1972. (From Celant, 1989.)

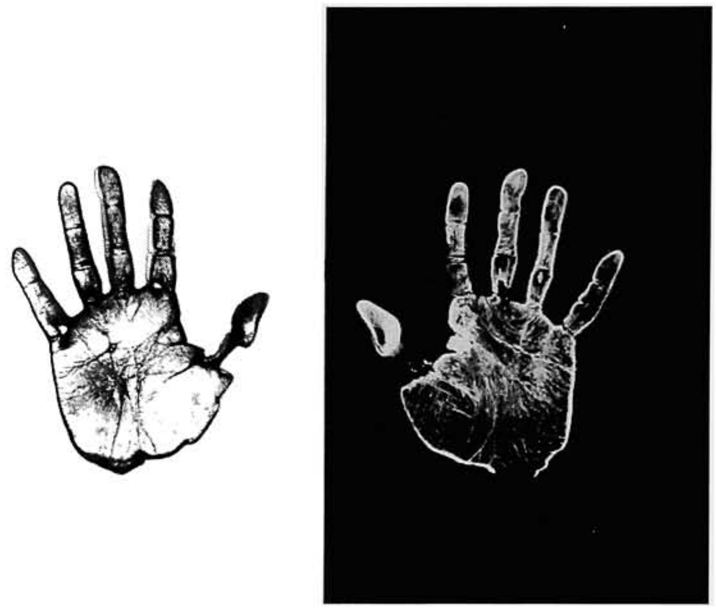


Plate 8 Lenses. To Davide Mosconi, photographer

Figure 2: Ugo Mulas: Lenses, 1972. (From Celant, 1989.)

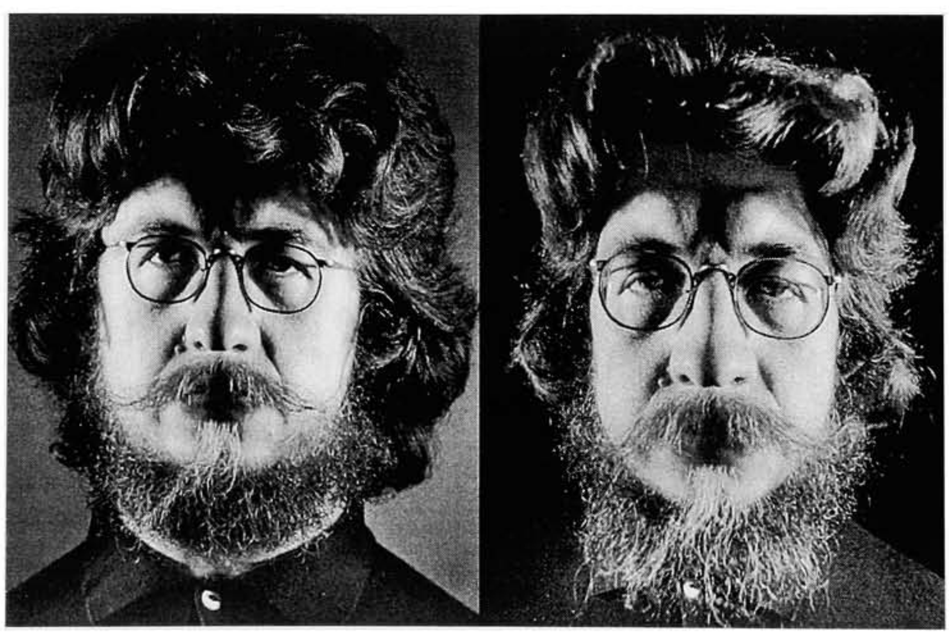


Plate 9 The Sun, the Aperture, the Testing Time

Plate 10 [unfinished]

Plate 11 Optics and Space. To A. Pomodoro [unfinished]

Plate 12 The Caption. To Man Ray

Plate 13 Self-Portrait with Nini

Plate 14 The End. To Marcel Duchamp

Ugo Mulas' Le Verifiche were a successful experiment to analyze photography as a medium by using the tools of the medium itself. "Why did I call them verifications? Because every morning for twenty years I had been going to my studio, I'd been loading my cameras, focusing, framing, shooting, developing, enlarging, and cutting; I'd been doing all this without thinking of every single operation: these operations unconsciously converged on one point, one result. Suddenly I realized that, just to clarify the reasons for a certain, say, discontent with what I had been doing in those years, I would probably find it helpful to disassemble this machine, to take apart those complex operations I had been performing mechanically and to examine each separate component" (Celant 1989, 154).

Contrary to many technical books about photography which are quickly outdated, the work of Ugo Mulas is as relevant today as it was in the 1970's. At this time we are faced with a new medium called *digital imaging*: "Although a digital image may look just like a photograph when it is published in a newspaper, it actually differs as profoundly from a traditional photograph as does a photograph from a painting. The difference is grounded in fundamental physical characteristics that have logical and cultural consequences" (Mitchell 1992, 4).

This thesis project analyzes the fundamental characteristics of digital images—similar to what Ugo Mulas did with photography. Special attention will be paid to the *differences between conventional photography and digital imaging*. The findings are illustrated by digital artwork (Plate 1 to 6).

The following subjects are analyzed in detail:

Analog and Digital Communication

Messages can be in analog or digital form. While analog information contains a continuous range of infinite possible values, digital information consists of a finite number of symbols, which are represented by numbers. This section shows the differences between both types of information and especially focuses on the A/D (analog/digital) conversion process.

Spatial Resolution

Spatial resolution expresses the amount of information available on a certain plane of a two-dimensional image using terms such as L/mm (Lines per mm), dpi (dots per inch) or ppi (pixel per inch). The amount of information available in a conventional photograph is compared to the information capacity of digital images. Furthermore, this section focuses on standards that define the amount of information necessary to achieve optimal quality with different output media including printing, digital proofing and multimedia applications.

Analog and Digital Color

Color resolution, also referred to as tonal resolution or brightness resolution, defines the range of discrete intensity levels in bits per pixel. After an overview of basic color theory, this section explains the differences between analog and digital color.

Storage of Analog and Digital Information

Digital images produce large data files. There are several different media used to store digital information such as magnetic disks, magneto-optical disks or optical disks. This section explains the differences between these storage devices, the use of data compression tools and the significance of graphic file formats.

Manipulation and Reality

Image manipulation is today's hot topic in the communication industry because powerful software tools allow one to manipulate originals easily and almost without limitations. Different approaches used by the communication industry to protect original artwork will be discussed.

Original and Copy

When working with conventional film material there is an original, such as a transparency or a negative, from which second generation images (copies) can be produced. There is always a difference in quality between original and copy. This section shows that the term "original" is more difficult (or perhaps impossible) to define when working with digital artwork.

CHAPTER 2

REVIEW OF THE LITERATURE

The concept of using digital computers to process images is more than 30 years old. Besides secret military applications, the technology was first used publicly in the NASA unmanned planetary science program in the middle 1960's. Since then digital image processing technology evolved rapidly due to the following reasons:

- Digital imaging systems are capable of representing images of a wider dynamic and tonal range than the human eye can resolve or that can be reproduced using conventional film material.

- A digital image can render a large amount of information in a visual format, which can be easily interpreted. The same amount of information cannot be readily viewed in any other manner.

- Digital images can be processed, analyzed and manipulated in ways that are not available with analog technology (e.g. image processing in the frequency domain).

- Digital information can be compressed and error corrected, which improves the speed and the reliability of data transmission.

Because of these advantages of digital image processing, the technology expanded rapidly into other scientific areas including *earth-orbiting satellite systems* for weather forecasting and analysis, *biomedical applications* such as tomography, analysis of X-ray imagery and nuclear resonance imaging, and *astronomy*. "Several recent texts have been published dealing with the basic techniques of digital image processing. The majority of the material published to date is mathematical or theoretical, and deals almost exclusively with the algorithms associated with computer processing of images" (Green 1989, ix). There are two books that focus on the scientific aspects of digital imaging in a more expanded way, so the information

is also very valuable for exploring the creative aspects of the medium:

- John C. Russ: *The Image Processing Handbook.*
- Rafael C. Gonzales/Richard E. Woods: *Digital Image Processing.*

Until the middle 1980's, people in the graphic arts industry were unaware of the possibilities of digital image processing. Several parallel developments between 1984 and 1986, including the introduction of the first Macintosh computer and the Laserwriter by Apple, the development of Adobe's PostScript page description language, the introduction of Aldus' PageMaker software and the development of Linotype's Imagesetter L300, started to change the traditional composition and page makeup process. *Desktop Publishing* (DTP) was born and the prepress industry was confronted with drastic changes in workflow. These changes are documented in an abundance of written articles about the technical aspects of new software and hardware tools.

"The Macintosh, introduced in 1984, was a user-friendly computer, the first personal computer to present computer graphics to a wide audience .... The user-friendly concept was achieved by creating a generic-looking desktop environment ... with icons representing such familiar office tools as a wastebasket and file folders. Instead of typing a command, a user could use a mouse—a puck-like device that translates hand movements to invisible x,y coordinates on the screen—to select and then execute various commands .... To achieve this easy-to-use, intuitive system, Apple chose to keep it a closed system. That meant that the major components were designed and marketed only by Apple, making the Macintosh generally more expensive than other platforms" (Aaland/Burger 1992, 31).

Because technology changes rapidly, publications about new products and trends in the field of electronic publishing and electronic photography are outdated very fast. An efficient way to stay up-to-date is to read the information presented in special reports such as the *Seybold Reports on Desktop Publishing and Digital Media,* or newsletters such as *Ink on Paper* published by Frank Cost/Miles Southworth or *Digital Printing Report* by Frank Romano.

While some authors see in digital imaging only a technical development of conventional imagery, this thesis project shows that digital imaging is an entire new medium which will change the perception and significance of all mechanical images such as photographic-, video- or film-images in a revolutionary way. There is literature "... written in appreciation of the important historical juncture at which we stand, just before the widespread adoption of electronic technology ...." (Ritchin

1990, vi) such as *In Our Own Image* by Fred Ritchin, *The Reconfigured Eye* by William Mitchell or *Being Digital* by Nicholas Negroponte. "We might, of course, choose to regard the digitally encoded, computer-processable image as simply a new, nonchemical form of photograph or as a single-frame video, just as the automobile was initially seen as a horseless carriage and radio as wireless telegraphy. Indeed the terms *electronic photography, still video*, and *digital camera* have rapidly gained currency. But such metaphors obscure the importance of this new information format and its far-reaching consequences for our visual culture" (Mitchell 1992, 4).

At the end of the 20th century computer art is a reality. However, in using the tools of digital imaging, there are only few works of "art" that go beyond the simple use of filters, color- or composition-effects. The average quality of digital artwork shown in exhibitions and advertising is only mediocre, as the signature of the machine is often too strong and overpowers the intended expression. Hopefully this will change in the future when the characteristics of the medium are better understood. "Computer art has the potential to change our sensual experiences more effectively and far-reaching than the development from photography to motion pictures already has" (Schmid-Isler 1992, *translated from German by the author)*.

CHAPTER 3

STATEMENT OF PROBLEM

The introduction of new technology and especially of new media can be fascinating but also rattling. When Louis J.M. Daguerre presented his first daguerreotypes to the public, people reacted very differently. Some of them, thrilled by fine details and structure the plates could render, saw in the new medium almost a magic tool that could create images detached from the "subjective human hand." Others, like the famous French painter Paul Delaroche, had less positive feelings about the medium. An anecdote states that when Delaroche first saw the daguerreotypes he exclaimed "La peinture est morte!" ("painting is death!").

Looking back on 150 years of photographic history and evolution, it becomes very clear that photography did not replace painting, but liberated it as a medium from the task of recording reality in an objective way. This liberation from authenticity lead the medium to impressionistic and abstract style developments, opening a whole new perspective that stimulated the development of painting during the 20th century.

Today, digital imaging, which is inseparable from the development of computer technology, also produces different reactions, ranging between fear and euphoria. Some people see only a technical development beyond conventional silver halide imagery, and fear that silver halide materials and the related chemical processes could, by the end of this century, be completely replaced by digital technology.

The thesis project proves that digital imaging encompasses more, because we deal with an *entirely new medium* that will change the perception and significance of all mechanical images, such as photographic-, video- or film-images, in a revolutionary way. The thesis project also shows that there will be a coexistence of both media, conventional silver halide technology and digital imaging, because both media have very different structures even if the end result (e.g. the final image printed in a magazine) can look the same.

Chapter 4

Methodology

This thesis project demonstrates that digital imaging is not just a technical development in the field of photography, but an *entirely new medium* that can be distinguished from silver halide photography as distinctly as from painting.

The thesis project contains an analysis of the medium's characteristics and six plates of digital artwork that visualize the basic principles of digital imaging and its profound differences from conventional photography.

To analyze and compare the two media the author not only studied the significant literature (see Bibliography) but also based his work on an indepth knowledge of the photographic process gained during more than a decade of practical work as a photographer and more than five years of teaching photography to undergraduate and graduate students in Switzerland. Without these practical experiences in photography, a comprehensive analysis would be impossible. The results, which are presented in Chapter 5 (sections 5.1 - 5.6), show the fundamental differences between conventional photography and digital imaging by focusing on the following six areas:

- Analog and Digital Communication
- Spatial Resolution
- Analog and Digital Color
- Storage of Analog and Digital Information
- Manipulation and Reality
- Original and Copy

The text is illustrated with twenty-one figures to assist the reader in comprehending some statements made in the theoretical analysis. These grayscale images were prepared for output on a 300 dpi Laserwriter (image resolution 150 dpi, transfer curves to compensate for an approximate dot gain of 30%, images saved as EPS format). Because this thesis project is closely related to Ugo Mulas' work *Le Verifiche*

1970–1972 (see Chapter 1, Introduction), the theoretical section is complemented by an artistic one, consisting of six plates of digital artwork that visualize the fundamental concept of digital technology used in digital imaging. The plates are named as following:

- Face on Matrix, to Maya
- Cell Division
- Sky Over Rochester, to Ugo Mulas
- Information Garbage
- Manipulation and Reality
- Cultural Sediment

These color images were output on a Canon CLC copier (image resolution 300 dpi, RGB mode, images saved as EPS) and are distributed throughout the text portion of the thesis project. However, it must be stated that the CLC is not capable of rendering the full tonal range and fine details inherent in the originals. To solve this problem the author decided to present his work at the thesis defense using HyperCard 2.3, a multimedia authoring tool. Displayed on a computer screen, the full image quality can be made visible.

The author began to work on this thesis project relatively early, starting back in December 1994. After more than half a year of work in addition to regular studies in the Masters program in Electronic Publishing, the thesis will be presented at the Rochester Institute of Technology the 21th of September 1995.

The material presented at the thesis defense will be used to educate undergraduate and graduate students in photography and electronic imaging at the School of Art & Design (SfGZ) in Zürich, Switzerland, where the author is professor for photography.

At the Rochester Institute of Technology the following facilities and equipment were used:

- The EPPL, including output devices such as the Canon CLC color copier, the Phaser thermal-wax transfer printer and the 3M dye-sublimation printer.

- The Color Imaging Lab to scan transparencies.
- The Photo Lab Service and the equipment of the Electronic Photography Labs (7B, rooms 3200 - 3232).

Most of the work was done with the author's own computer, using:

- PowerMac 7100/66 with internal CD-ROM drive, external Syquest drive (44 MByte) and APS MO drive 230 MByte.

- Software: Adobe Photoshop 3.0
Quark XPress 3.3
HyperCard 2.3
Adobe Premiere

- Type: *Fundamentals of Digital Imaging* is set in Futura Text.

CHAPTER 5

RESULTS

5.1 ANALOG AND DIGITAL COMMUNICATION

Messages can be either analog or digital. While analog information contains a *continuous range of infinite possible values*, digital information consists of a *finite* number of symbols, which are *represented by numbers*.

Written English, for example, consists of twenty-six different letters, ten numbers, several punctuation marks and a "space". Thus, written text is a message constructed from a finite number of symbols. These symbols can be represented by numbers, as in the ASCII-Code (**A**merican **S**tandard **C**ode for **I**nformation **I**nterchange). ASCII is a *7-bit code* which associates128 different values to distinct text symbols using a *hexadecimal code set* (base 16: 0, 1 , 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, F). Because computers work with bundles of 8 bits, ASCII is commonly embedded in an eight-bit field in which *the high-order-bit is set to zero* (= ASCII 8-bit version). ASCII is a so-called *M-ary* message, a digital message constructed with M numbers. For communication interchange with digital computers M-ary messages have to be translated into binary messages (M=2), which are constructed from a set of only *two* numbers, 0 and 1.

In the hexadecimal version the character A is associated with the ASCII code 41. The first hexadecimal digit (4) determines the values of bit position 8,7,6 and 5, while the second hexadecimal digit (1) is related to the values of bit position 4,3,2 and 1:

Figure 3: 8-bit ASCII Version

Character	ASCII code hexadecimal system	ASCII code decimal system	Binary Representation bit position (8) **7 6 5** **4 3 2 1**
A	41	65	0 **1 0 0** **0 0 0 1**
a	61	97	0 **1 1 0** **0 0 0 1**

Spoken English, in contrast to written english, can be seen as an analog message because varying details including pronunciation, inflection, pitch and emphasis produce an infinite number of values.

If images are the source of information, we deal with a more complex situation. *Conventional continuous-tone photography* is referred to as an analog medium because a black-and-white print can show infinite tonal values (graylevels) between white (Dmin) and black (Dmax). However, a silver gelatin print examined under a microscope shows only two different values in its *microstructure*: black = presence of a silver grain or a silver grain cluster and white = absence of silver.

Figure 4: Unexposed Silver Halide Crystals in a Photographic Emulsion

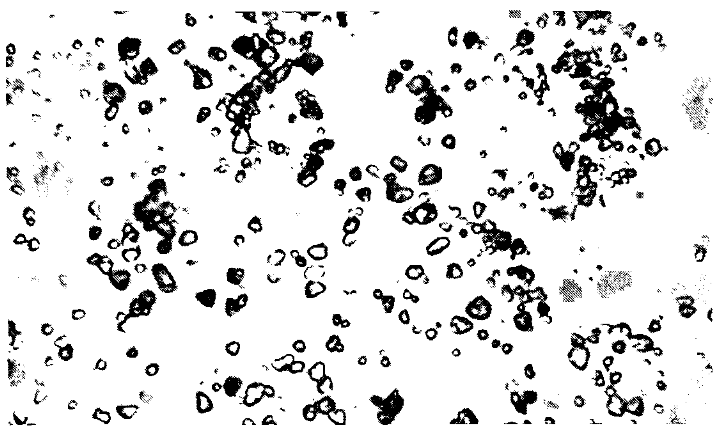
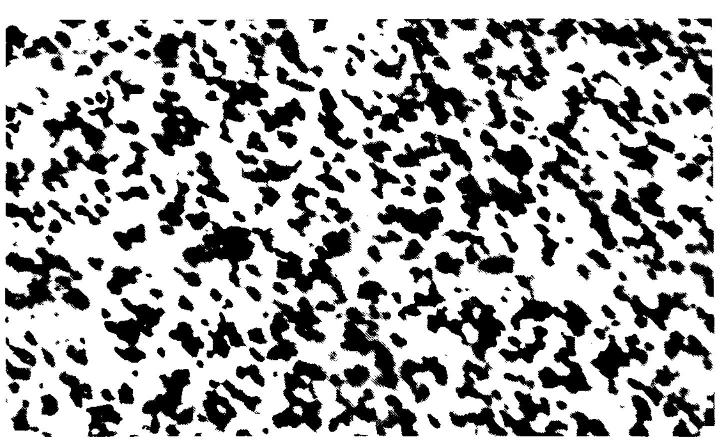


Figure 5: Exposed and Developed Silver Halide Crystals

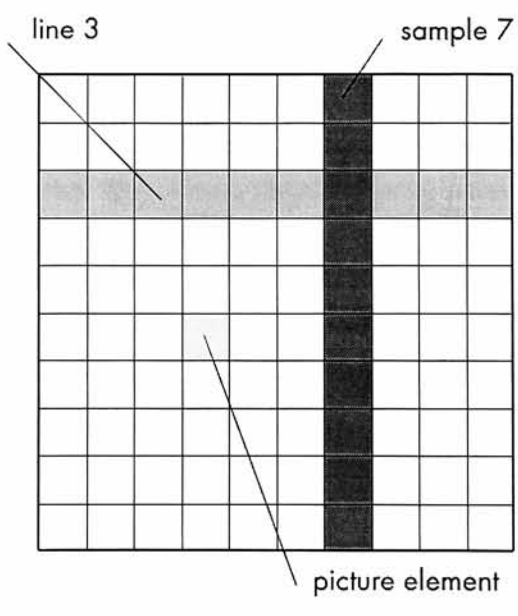


The silver clusters form an irregular pattern, called grain, which is superimposed over the actual image signal. The amount of grain produced by a specific imaging system is influenced by a variety of different factors including film type, film speed, developing method, type of developer and film exposure. "Graininess is an important variable since it sets an esthetic limit on the degree of enlargement, as well as a limit on the amount of information or detail that can be recorded in a given area of the film. Graininess can be thought of as noise or unwanted output that competes with the desired signal (the image). All recording mediums have some type of noise that limits the faithfulness of the desired signals, ..." (Stroebel, Compton, Current, and Zakia 1986, 391). If a certain area on a print is homogeneously covered with 50 percent silver, the human eye, which cannot resolve single silver grains because of its limited resolving power, will see a light gray tone of density 0.3.

Nevertheless, conventional photography is *not* a digital medium because the two symbols, black and white, are not encoded by an underlaying matrix of numbers.

A digital image is an *immaterial numeric structure called a matrix.* The rows of the two-dimensional matrix are called *lines;* the columns are referred to as *samples.*

Figure 6: Digital Matrix



The individual components of a digital image are called *picture elements or pixels*. The digital value of a pixel is referred to as its *digital intensity*.

Digital images are *not visible*, because when they are in their output form, they are again in an analog format. The immaterial numeric structure underlying the image cannot be seen. Although the pixel structure can be made visible by enlargement, we only see the *materialized representation* of the digital image and not the matrix itself.

Figure 7: Pixel Structure

It is possible to create digital images *directly* by using a digital camera in which conventional film material is replaced by *linear or area arrays* of photosensitive *CCD cells* (CCD = **C**harge **C**oupled **D**evice).

At this time, however, it is more common to use *hybrid systems*. With hybrid systems, the first step in imaging is still conventional. There is a film-negative or transparency as a starting point. In a second step called analog-digital conversion (A/D conversion), the analog picture is digitized. A/D conversion is a *two-step process* performed by a *scanner*:

- Step 1: Sampling Process

- Step 2: Quantization Process

The Sampling Process

During the sampling process the picture plane is subdivided into a *finite Cartesian grid of cells*, called pixels. The *sampling frequency* (in spi = samples per inch) determines the fineness of the grid and is limited by the number of CCD-elements in a linear inch. High-end scanners use photomultiplier tubes (PMTs) as light sensing devices. PMT scanners scan the original line by line and can provide a much higher sampling frequency than CCD-based scanners. In both cases, the light intensities are converted into proportional amounts of electrical voltage. *These output signals are still analog.*

The Quantization Process

In the second step, the analog voltage signals are converted into integer values of finite range. The quantized signal is only an *approximation of the original signal.* The A/D conversion process results *always* in a loss of information. The accuracy can be increased by refining the raster grid in the sampling stage and/or by increasing the number of bits to which the voltage signals are quantized. The necessary amount of refinement depends on the *end use* of the image. In order to choose the appropriate settings, the scanner operator must know the following data concerning the future application of the image:

- The tone reproduction characteristics of the output medium.
- The spatial resolution of the output medium in lines per inch (lpi) for halftones or dots per inch (dpi) for continuous-tone output.
- The color resolution and color gamut of the output medium.
- The sizing factor (enlargement factor).

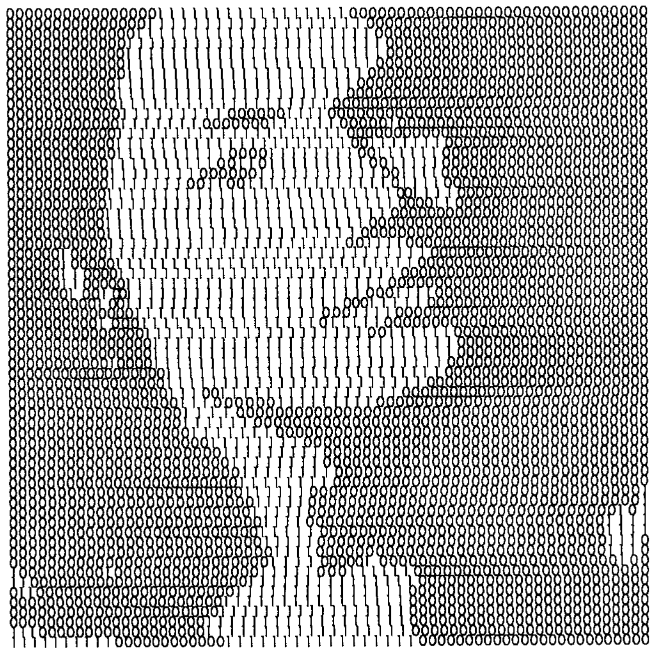
During the quantization process, a certain degree of *random, signal-independent noise* with uniform distribution is introduced (quantization noise), causing a random fluctuation above the mean digital signal. In a communication system a certain amount of noise, which limits the reception of the wanted signal, is always present.

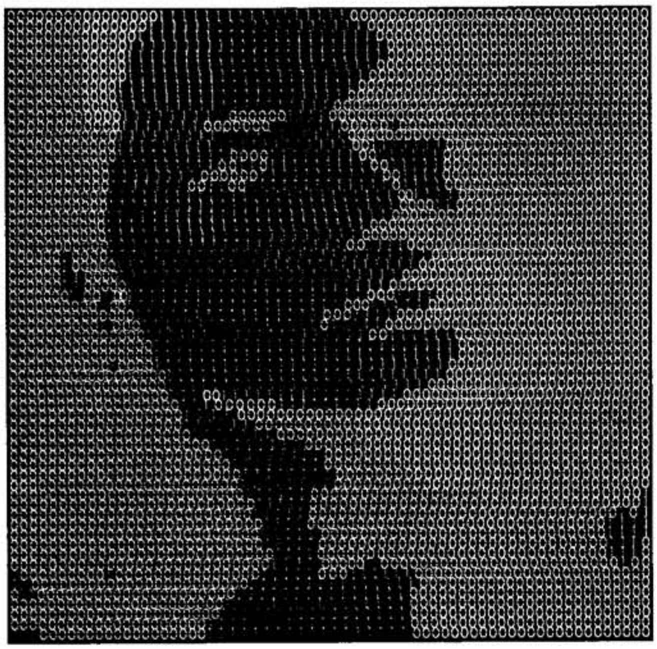
Plate 1:

Face on Matrix, to Maya

Digital images are not visible. When they are in their output form they are again in an analog, human readable format.

By creating a matrix of numbers, in which the numbers not only represent the digital values of the pixels but also have their own tonal values, it is possible to visualize *simultaneously the image and its underlying digital matrix.*



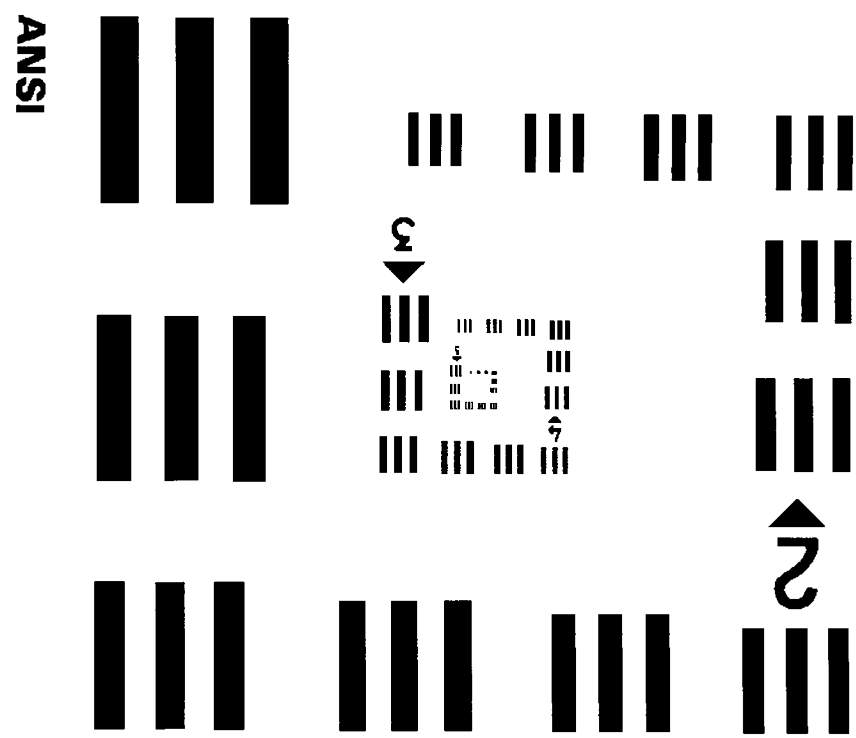


5.2 Spatial Resolution

Spatial resolution expresses the amount of information available on a two-dimensional image plane, using terms such as L/mm (Lines per mm), dpi (**d**ots **p**er **i**nch) or ppi (**p**ixels **p**er **i**nch).

In conventional photography, there is no easy way to determine what amount of information is stored in an image. Exposing a test target such as the ANSI (**A**merican **N**ational **S**tandards **I**nstitute) *resolution target* on light sensitive film material under *controlled conditions*, however, can determine how many lines (*black-and-white line pairs*) the tested material can render.

Figure 8: ANSI Resolution Test Target. (Stroebel, Leslie, Compton, Current and Zakia, 1986.)



It is well known that conventional silver halide film material (film speed 100 ISO) can render about 50 line pairs per mm (= 1270 line pairs per inch; Schläpfer 1993, 75). These 50 black-and-white line pairs correspond to a spatial resolution of 100 pixels/mm (= 2540 ppi). Because the resolution is *format independent*, the amount of information increases dramatically using larger film-formats:

Film-Format	Resolution in lpi (speed ISO 100)	Amount of Information Units per Image
35mm	2540	8.6 million
4.5 x 6 cm	2540	27 million
6 x 6 cm	2540	36 million
6 x 7 cm	2540	42 million
4 x 5 "	2540	129 million
5 x 7 "	2540	225 million
8 x 10 "	2540	516 million

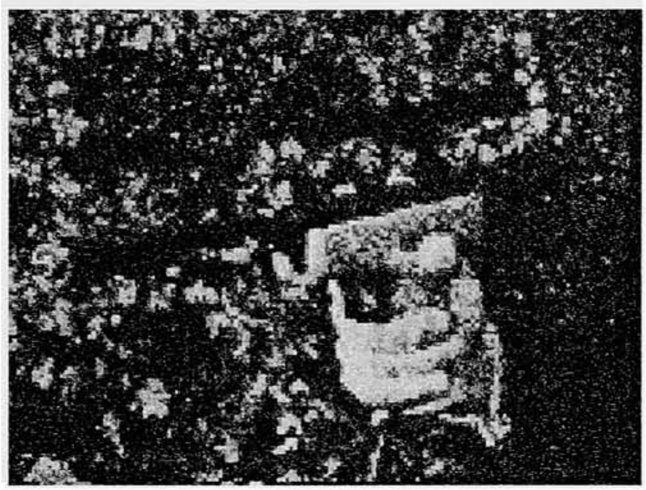
The information stored in conventional film material is not always *fully retrievable*. If the original (1st generation image) is a film-negative or a transparency and the final output is reflective material (print), there is a significant *loss of information* between the original and the print (2nd generation image) because of the following reasons:

- During *copying* (normally an enlargement process) there is always a loss of information caused by the limitations of the enlarger lens and other factors such as the influence of flare light. Repeated reproduction decreases the image quality from image generation to image generation (multiple generation loss).

- Reflective print material *cannot* show the full information inherent in the original because of its limited dynamic range.

The plot of Antonioni's *Blow-Up* (Antonioni 1966) is based on these technical limitations of conventional photography; One day while strolling in a park, a fashion photographer, played by David Hemmings, takes snapshots of a man and woman romancing. The woman seems to be very irritated and tries to get the photographer to give her the rolls of exposed film. Out of curiosity, he gives her some other rolls and tries to discover the reason for the woman's strange behavior. He develops the film and makes prints. In the first series of prints, there is nothing special to detect. But by making blow-ups of specific parts of the negatives, he is able to gather more information contained in the original and finds a clue. A hand in the bushes, a pistol, a murder?

Figure 9: Blow-up by Michelangelo Antonioni, 1966.



The spatial resolution of *digital images* is a function of the sampling rate, which determines the number of matrix elements. Each matrix element, called a pixel, is one information unit. Enlargements of digital images do not show more information, they only enlarge the dimensions of the basic information units, until the images start to look *pixelized*. To enlarge an image file by *interpolation* (changing the resolution setting in the *Image Size* dialog box) does not increase the resolution of the image, but only its *addressability*. The terms addressability and resolution have often been confused. Resolution expresses the actual, non–redundant information content of an image, while addressability contains redundant information. Interpolations do not increase the actual information but only create redundant information.

The amount of information in a digital image can be exactly determined and is expressed using terms such as ppi or dpi. If a digital image (8 x 10 inches) has a matrix consisting of 2400 lines and 3000 columns (samples), its spatial resolution is 300 ppi and its matrix is composed of 7.2 million pixels.

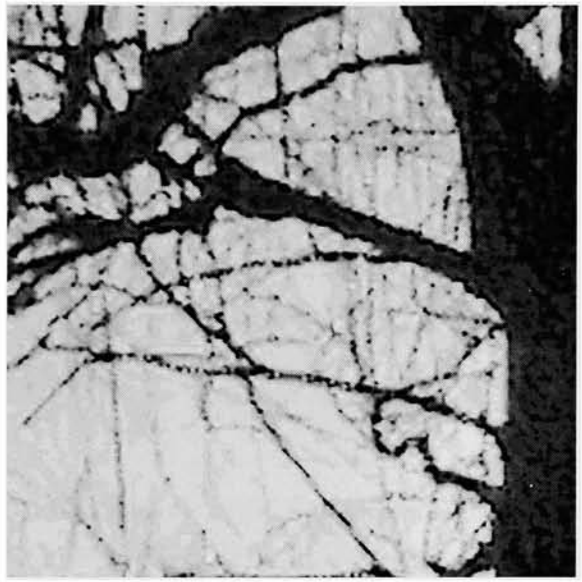
The necessary spatial resolution is determined by:

- The Characteristic of the Original
- The Output Medium
- The Viewing Conditions

The Characteristic of the Original

According to the *Nyquist Criterion,* an original image must be sampled at a rate at least *twice as high* as the highest spatial frequency in the image. Undersampling can cause *visual artifacts* referred to as *aliasing* because the high-frequency content of the image appears as low frequencies. To avoid aliasing, the image must either be sampled according to the Nyquist Criterion or it must be *low-pass filtered* (anti-aliasing filter) prior to the sampling stage in order to remove the high frequencies. It is almost impossible to remove aliasing patterns *after* the sampling stage.

Figure 10: Aliasing Pattern.



The Output Medium

If the output medium is a *halftone,* the Nyquist Criterion states "that a continuous signal can be reconstructed perfectly up to a particular spatial frequency from a set of discrete samples if the sampling is performed at twice the frequency of interest" (Green 1989, 61). To be safe, the sampling frequency should be two times (quality factor / sampling ratio) the output screen frequency multiplied by the sizing factor:

Sampling frequency = Screen frequency x Sizing factor x Sampling ratio

With a 600 dpi sampling frequency, it is possible to print a 150 line screen (commercial printing) with a maximum enlargement of 200 percent. With the same sampling frequency, an 85 line screen (newsprint) can be printed with a maximum enlargement of 350 percent. Tests with different sampling ratios did show that a quality factor of 2, which means *4 pixels of information per printing dot,* is not always required. Sometimes a quality factor of 1.4 is sufficient to secure optimal quality, especially with high screen frequencies. ". . . it is possible that scanning ratios used for the Hi-fi color printing using 300 lpi to 400 lpi screens could

approach a 1 : 1 scanning ratio" (Beaulieu 1993, 57). A lower quality factor can significantly reduce the size of data files and thereby also the cost for storage, transmission and image manipulation.

For optimum *continuous-tone* output, the image file must contain *one pixel per output dot* (equalling a sampling ratio of 1).

If images are used in *multimedia applications* on a computer display or TV screen, a spatial resolution of 72 dpi is sufficient.

The Viewing Conditions

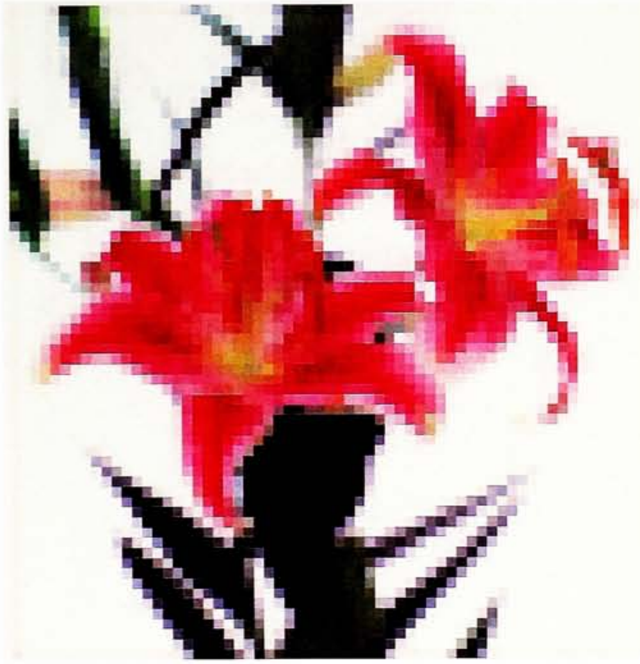
The human visual system cannot resolve two objects (luminance details) seen under an angle less than 1/60 of a degree. As a rule of thumb, the *normal picture viewing distance* is equal to the *picture's diagonal*, thus an 8 by 10 inch image should have at least 270 dots per inch to appear completely smooth. Because larger prints are normally viewed from a greater distance (in proportion to the picture diagonal), they need only the same amount of information as a smaller image, and therefore can have *less* spatial resolution.

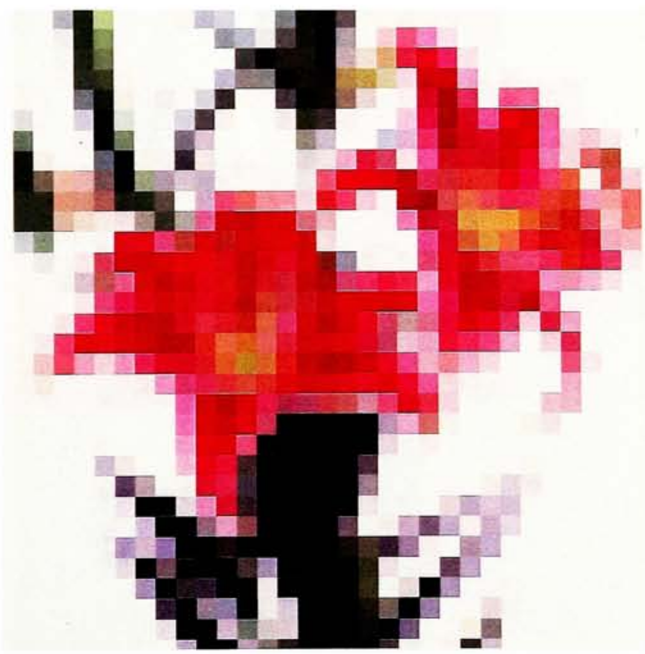
PLATE 2:

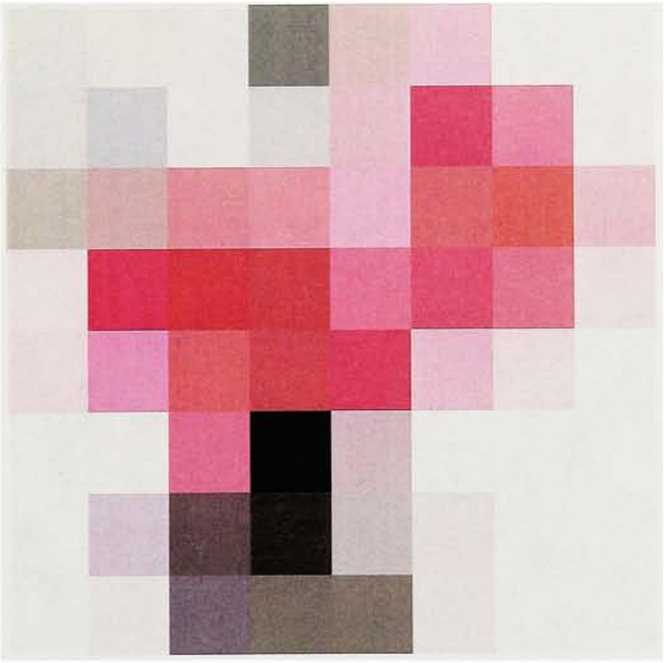
Cell Division

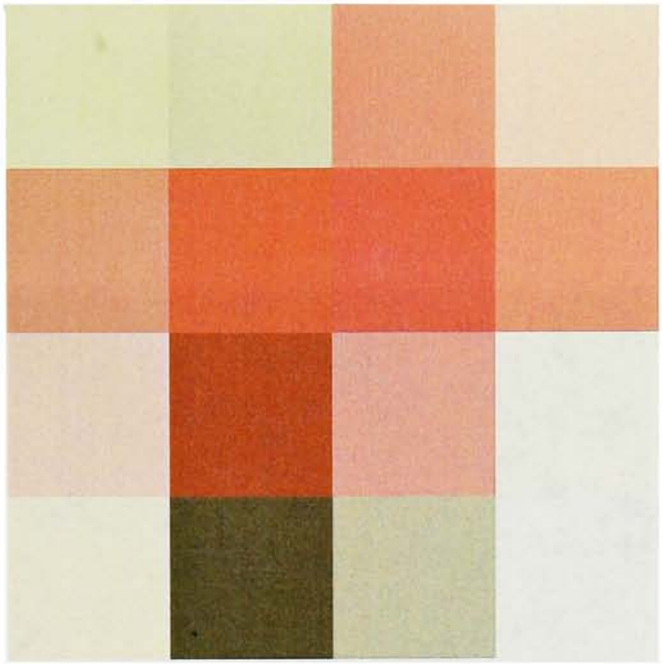
An image consisting of only *one pixel* is the most basic digital image, analogous to the germ cell of an animal or a plant. However, while a germ cell has in its nucleus all necessary information for orderly subdivision and controlled growth of the organism, a pixel contains no other information than its own digital value.

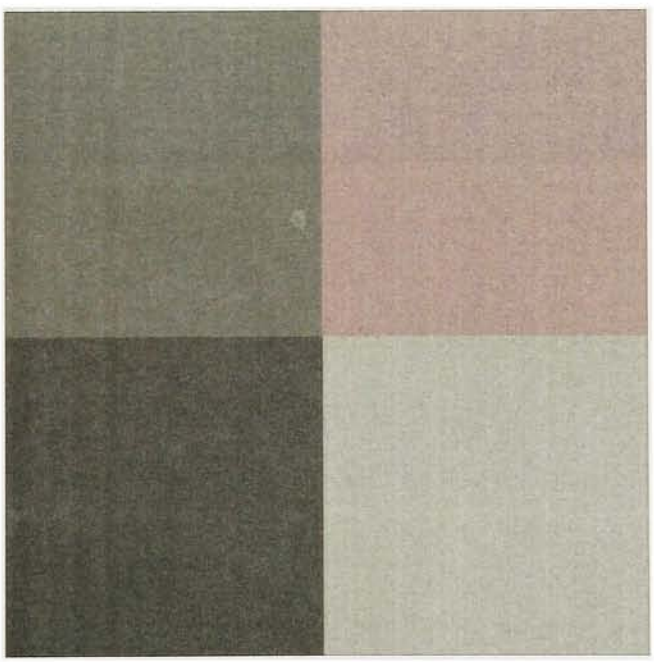
Increasing the spatial resolution (by subdividing the pixel) while simultaneously maintaining the average digital value (by random calculation) can lead to an infinite number of completely different images with matching spatial resolution and a matching average color value.

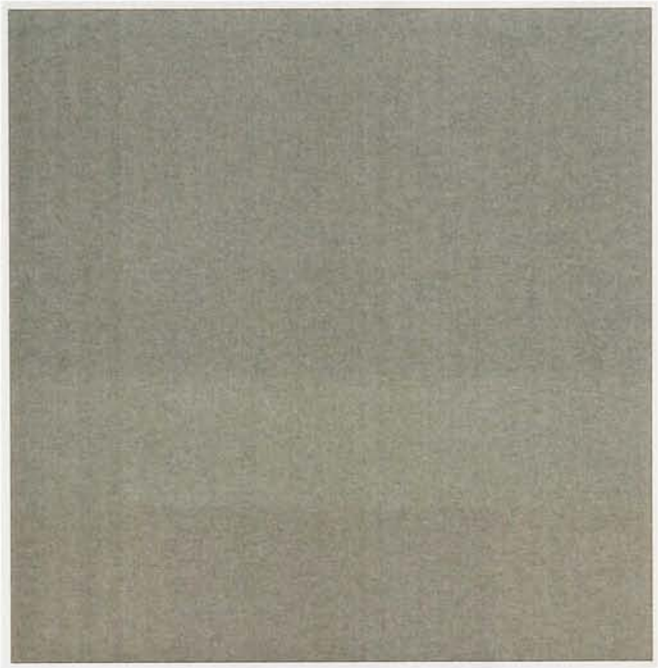


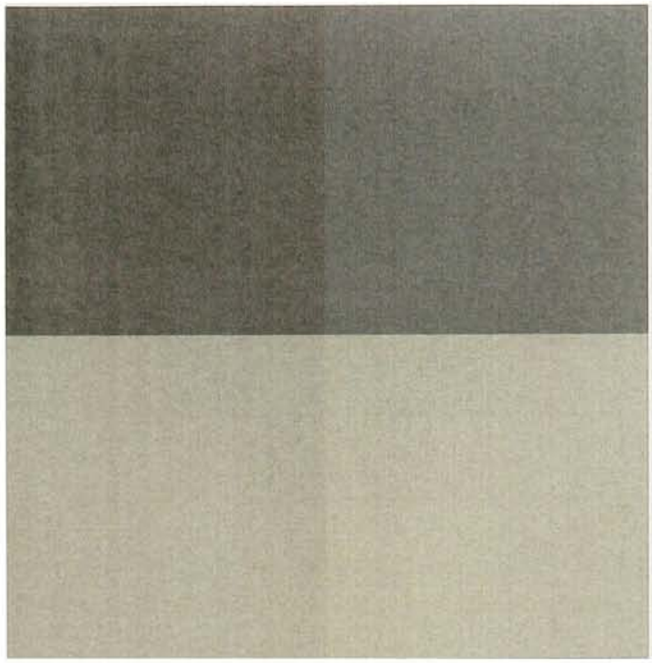


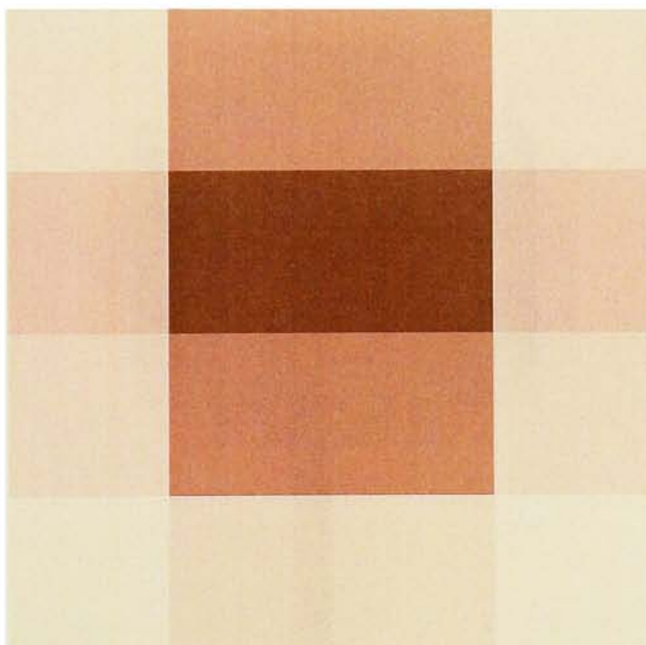


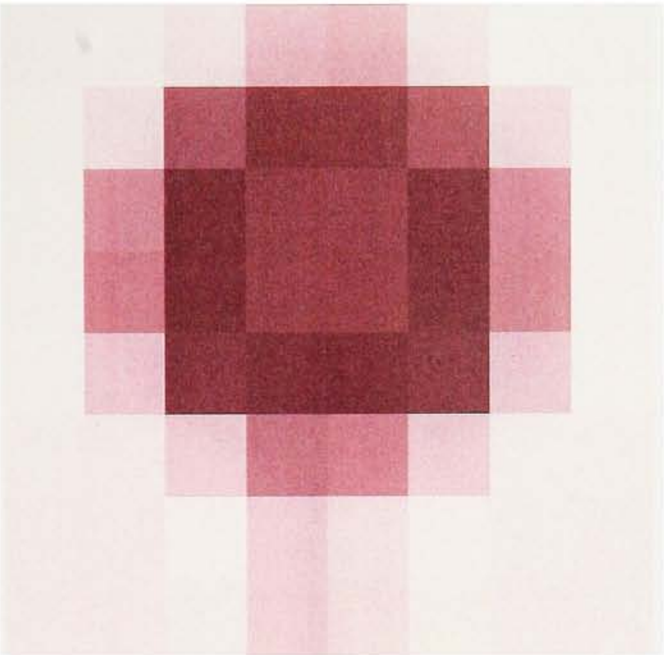


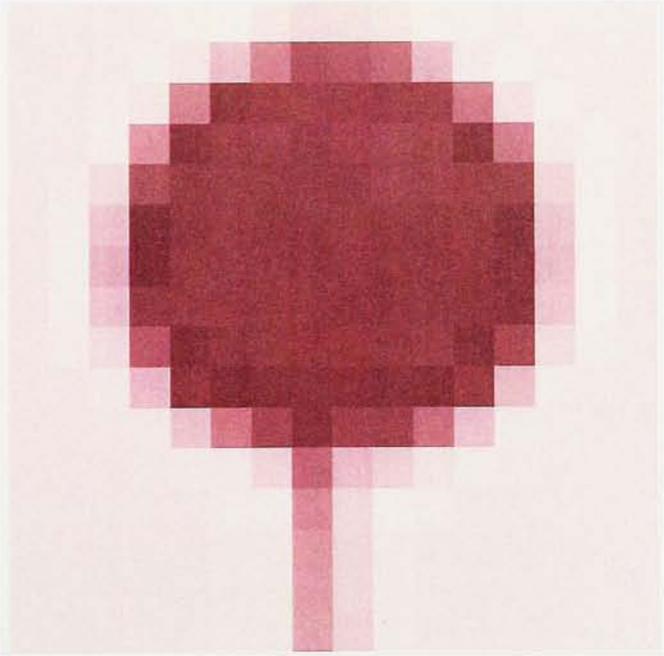


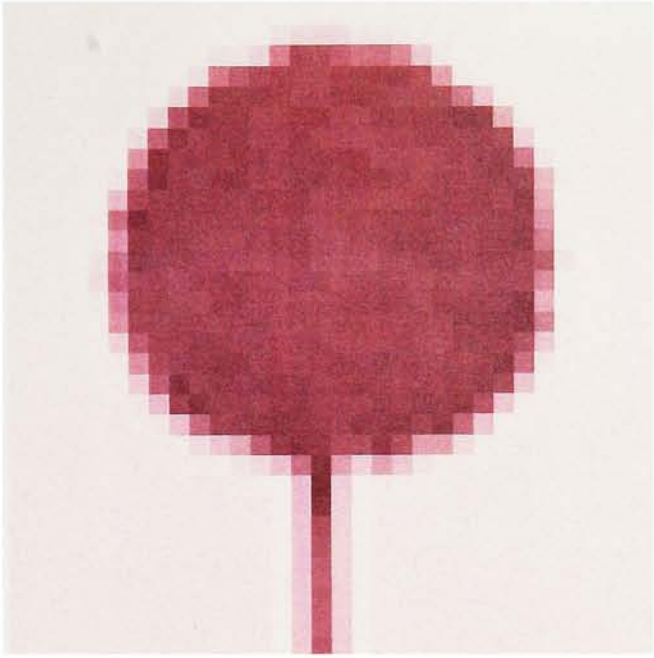


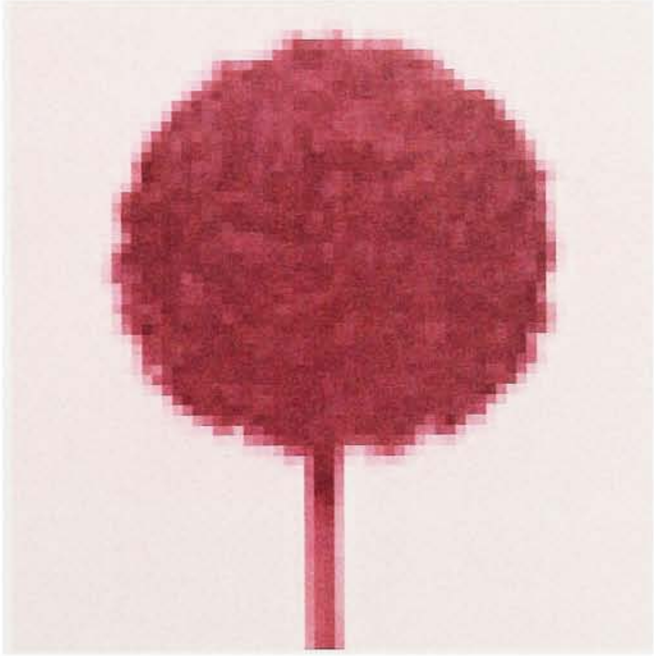


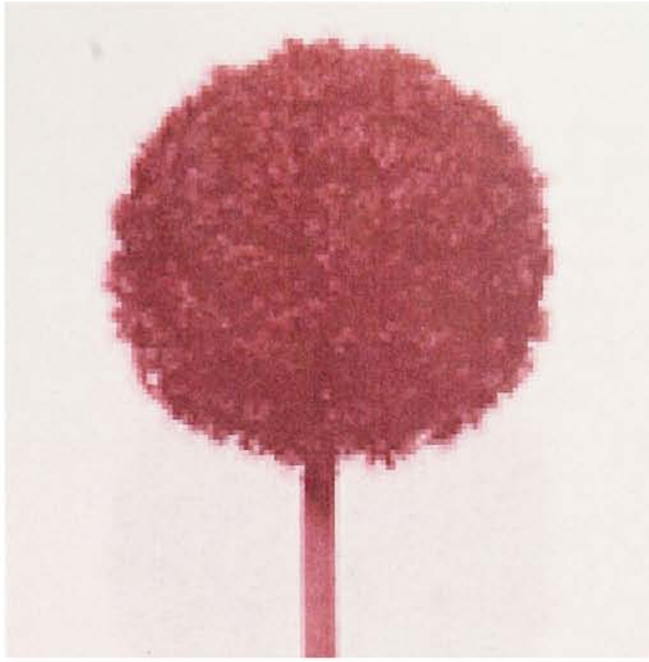












5.3 Analog and Digital Color

There is no color without an observer. Electromagnetic energy, even between 400 and 700 nm, has no color attribute. It could be demonstrated that most animals cannot see colors at all, but only different light intensities. "Despite popular belief, there is nothing especially attractive about a red flag for a bull. Anything waving excites the animal. . . . , because the bull is color-blind. So are the cow and horse, the dog and cat, the pig and sheep. None of them can be trained to go for a reward to a colored square of any hue, if it is placed at random in a checkerboard of grays from white to black. Of all mammals, only man and some primates, enjoy the luxury of color vision"(Milne 1962, 238). *Monochromatism*, the complete absence of hue and chroma discrimination, is occasionally found with human beings, affecting only 0.003 percent of Caucasian males. These facts prove that "color" exists only in the mind of a viewer, who can distinguish different wavelengths of received electromagnetic energy by "seeing different colors."

Color is a *visual sensation* and the name of the color, or scientifically speaking its hue, is a *code*. We know that grass is green because we learned to connect the visual sensation of light reflected by grass with the term "green." Color objects, including grass, sky, meat, skin, water, etc., of which we have such a *preconceived notion*, are called *memory colors*.

There is a wide range of electromagnetic waves emanating around us, but only a small part of it can be discriminated by the human visual system.

Figure 11: The Electromagnetic Spectrum

Type of Energy	Wavelength
Long Electrical Oscillations	$> 10^{11}$ µm
Radio Waves	10^{6} - 10^{11} µm
Microwaves	10^{3} - 10^{6} µm
Infrared	770 - 10^{6} nm
Light	400 -700 nm
Ultraviolet	10 - 390 nm
X -Rays	10^{-6} - 10^{-1} µm
Gamma Rays	10^{-8} - 10^{-4} µm
Cosmic Rays	$< 10^{-8}$ µm

The visible wavelengths for humans range between 400 and 700 nanometers and are as a unity defined as *white light*. If a certain part of this spectrum is missing, we "see a color." In 1666, Sir Isaac Newton discovered that white light can be split into colors by passing it through a glass prism. He could distinguish six broad regions in the resulting spectrum: *violet, blue, green, yellow, orange, and red.* These colors in the spectrum do not end abruptly, but they blend smoothly into each other. Corresponding to the *opponent-process theory* (proposed by Leo M. Hurvich and Dorothea Jameson), the *6 to 7 million cones* found in a human retina can be divided into three groups:

- Short - wavelength receptors, with a peak absorption at 450 nm.
- Medium - wavelength receptors, with a peak absorption at 530 nm.
- Long - wavelength receptors, with a peak absorption at 560 nm.

Because of the characteristic of human color perception, it is common to divide the spectrum into *three parts*, each corresponding to the absorption spectra of the three human cone pigments:

short wavelengths = Blue (400 - 500 nm)
medium wavelengths = Green (500 - 600 nm)
long wavelengths = Red (600 - 700 nm)
1 nm (nanometer) = 10^{-9} meter = 10^{-3} μ

These three basic color sensations are called the *primary colors of light*. Mixing any two of these primary colors results in a set of three *secondary colors of light: Yellow, Magenta and Cyan*:

Additive mixture of light:

Blue + Green light = Cyan light
Blue + Red light = Magenta light
Green + Red light = Yellow light
Blue + Green + Red light = White light

If all three primary colors are mixed in equal amounts, the visual sensation will be again "white." Additive mixture of light is the color rendering principle used by *CRT* (**C**athode **R**ay **T**ube) displays.

Printing and conventional color photography are based on a completely different color mixing principle, the *subtractive system*. The subtractive system does not describe the mixture of light, but the creation of colors by overlaying of *transparent dyes*. There are three basic *subtractive colors*: Yellow, Magenta and Cyan, each of them absorbs *one* primary color of light and reflects the *two* other primaries:

	Absorption	*Reflection*
Magenta	100% Green	100% Blue and Red
Cyan	100% Red	100% Blue and Green
Yellow	100% Blue	100% Green and Red

However, the "real" colors used in photography and printing do not have this *ideal characteristic*.

Magenta, for example, which is the most contaminated ink used in printing, absorbs not only light between 500 - 600 nm (green), but also a certain amount of shorter and longer wavelengths (blue and red). These *color deficiencies* are referred to as the *Y of the Magenta* and the *C of the Magenta*. For good color reproduction, the color deficiencies have to be compensated for by applying *photomechanical or electronic color correction masks* during the color separation process.

Analog Color

In conventional color photography, analog colors are produced in one of the following ways:

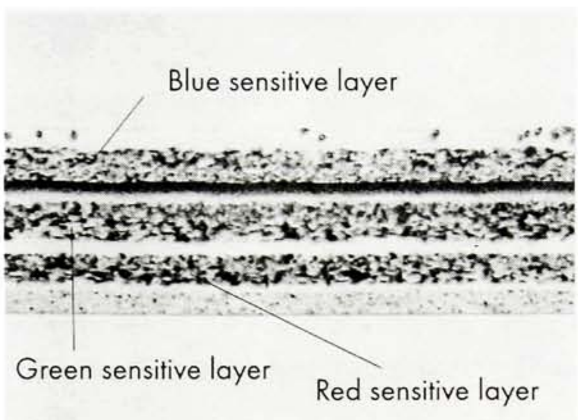
- In the *chromogenic process*, used with most color materials including color negative film, color transparencies (except Kodachrome materials) and color paper, the three emulsion layers of the *integral tripak film* contain *incorporated color couplers,* which unite with the oxidized developing agent to form dyes:

1. Exposed silver halides + Developing agent ›
Metallic silver + Halide ions + *Oxidized developing agent*

2. *Oxidized developing agent* + Incorporated color coupler ›
Colored dye

The couplers in the red-sensitive layer form cyan dyes, those in the green-sensitive layer form magenta dyes and those in the blue-sensitive layer form yellow dyes.

Figure 12: Integral Tripak Film (Kodachrome 200). (Sturge, Walworth and Shepp, 1989.)



Kodachrome reversal films are an example of the chromogenic process *without incorporated couplers*. The couplers are rather *part of the color-developer formula*. Kodak's proprietary developing process is referred to as *K-14* and consists of three separate color developing steps.

- In other processes, including:
  - The *diffusion transfer process,* used in instant color films (e.g. Polacolor 1963),
  - The *silver dye bleach process (chromolytic process),* used by Ilfochrome materials (also known as Cibachrome materials), the three subtractive colors are already *built into the material* itself. During the developing process, wanted colors are transferred from their original layer into the image-receiving layer (diffusion transfer process), or unwanted colors are bleached, while the wanted colors remain in the emulsion (Ilfochrome process).

In all these types of conventional photographic color processes, the colored dyes form a continuous gradation of tonal values.

Digital Color

Digital color has *no chemical attribute*, but is a *defined location in a color space*. Color spaces are *three-dimensional*, because there are three attributes which describe the appearance of a color:

- Hue
- Chroma
- Value

Hue describes how we perceive the color of an object, how we call its visual appearance by using terms such as "red", "yellowish", etc. *Chroma* describes how far away the color is from the closest neutral gray, using terms such as "dull" or "vivid". This color attribute is often wrongly referred to as "saturation". *Value* describes the luminous intensity (the lightness) of a color compared to a neutral scale going from white to black. To facilitate the specification of colors in some standard, different *color models* have been introduced. There are *two basic types* of color models:

- Device independent color spaces
- Device dependent color spaces

Device Independent Color Spaces

In a device independent color space two colors with equal coordinates *look the same*, but it may not be possible to produce this color sensation on different substrates such as paper, plastic, etc., using the same color values. There is no truly independent color space, as the following factors always influence the readings:

- The spectral distribution of the illuminant
- The luminance of the highlights
- The observer
- The geometry of the measurement device

- UV - fluorescence
- The tristimulus values of the reference white
- The surrounding

Device independent color spaces include:

- **CIELAB** (L*a*b*), adopted in 1976 by the CIE (Comission Internationale de l'Eclairage).
- **CIELUV** (L*u*v*), adopted in 1976 by the CIE.
- **YCC**, Kodak's proprietary color model for images stored on Kodak's Photo - CD.

DEVICE DEPENDENT COLOR SPACES

The coordinates in a device dependent color space are a *formula* which describe how a color can be produced on a *specific substrate*. Device dependent color spaces include:

- **RGB**, used to describe color monitors, video cameras and scanners.
- **CMYK**, used in printing and with digital proofing devices.
- **YIQ** (Y=luminance signal, I and Q = inphase and quadratur chrominance signals) used as the commercial color TV broadcasting standard.

Color Resolution

A digital image is not only a two-dimensional but a *three-dimensional matrix*. The third dimension is referred to as *depth, tonal resolution, intensity resolution or color resolution*. Color resolution defines the range of discrete intensity levels in bits per pixel. In the second step during the A/D conversion process (called quantization), the amount of bits each sample is digitized to is determined. If the quantization ratio is 8 bits, the system can provide $2^8 = 256$ different intensity levels.

In the case of *monochrome images*, these are 256 gray levels including white and black. Because an average observer can not discriminate more than 100 levels of gray (uniformly spaced in CIELAB L* levels), a quantization ratio of 7 bits per pixel would be sufficient. Nevertheless it is common to work with 256 discrete gray levels, because of the following reasons:

- Computer hardware is programmed to store data in bundles of 8 bits (the equivalent of one byte).

- During image manipulation (adjustment of contrast, setting of white and black point, etc.), intensity levels get lost, especially when using a *non-proxy-based* software such as Adobe Photoshop 3.0. Proxy-based image manipulation software such as LivePicture, Collage and Imagician, protect the original image file from degenerative effects of editing by saving the edits in a file *separate* from the original. In the final rendering process, all editing commands are applied together to the original. This technology speeds up the editing process and conserves the image quality.

- Scanners generate data by measuring reflectance levels. Equally spaced reflectance levels, however, are not perceived equally spaced by human vision. If the scanner quantizes the information *linear to only 8 bit,* the image histogram will show missing values in the shadow areas after it has been "gamma corrected". To avoid this information loss, the scanner should work with 12 bit and convert the data after the A/D conversion process to 8 bit using a look-up-table. Another way to conserve image quality is to apply a non-linear transformation before the A/D conversion.

Most *desktop scans* need to be adjusted in an image manipulation program, thus CCD flatbed-scanners often operate with 12 bits (= 4096 gray levels); in this case, information can get lost without affecting the image quality. High-end PMT scanners, on the other hand, can work with only 8 bits without image degradation because sophisticated image adjustments can be made *before* the scanning process.

Color images are digitized in a parallel or serial three - step process. Using three color separation filters (e.g. Kodak Wratten Filter No. 25 Red, No. 56 Green, and No. 47 Blue), each primary color is defined with 8 bits, which results in 24 bits color information, providing 16.7 million different color values. If each color is represented by 12 bits, the system can even determine 6.8×10^{10} different color values.

Color Gamut

The color gamut defines the range of colors that can be formed by all possible combinations of the colorants of a specific color reproduction system. From a theoretical point of view, an optimal color reproduction system would be one that can render all locuses of the CIE 1931 chromaticity space. This horse-shoe shaped, three-dimensional color space shows all color perceptions of the human visual system

that can be created by the electromagnetic spectrum between 400 and 700 nm.

Each analog color reproduction system has its own specific limitations expressed by a specific color gamut which does not cover the whole CIE chromaticity body. Digital color systems, on the other hand, have no limitations because the numeric matrix can address any possible color locus in the chromaticity space. However, when digital images are converted into human-readable analog format, the color gamut of the chosen analog system applies its limitations.

PLATE 3:

Sky Over Rochester NY, to Ugo Mulas

In digital imaging, colors are described in a notation system that uses numbers to define a specific location in a specific color space. This notation system provides a precise description of a color. The actual analog appearance of the color, however, can vary because there are many factors including the surroundings, the output medium and the observer that influence and change its actual analog appearance.

If a digital system provides only two different color values, it is a *1 bit* system. *2 bits* are used to define four, *3 bits* to define eight, *4 bits* to define sixteen, *5 bits* to define thirty-two and *8 bits*, equal *1 Byte*, to define 256 different color values. The second part of this plate shows that the information content of a digital image is not only a result of its spatial resolution but also of its amount of bits per picture element.

RED 106

GREEN 159

BLUE 215

RED 106
GREEN 159
BLUE 215

107
165
214

255
255
255

255	165
255	206
255	247
49	99
107	156
181	214
132	66
181	123
231	198
57	189
115	231
189	253

650,000 pixels

Mean:
106
159
215

Std.Dev:
46.2
40.95
27.07

Median:
107
165
214

5.4 Storage of Analog and Digital Information

For storing images in analog form, *silver halide technology,* as it is used in conventional photography, is a powerful tool. Silver halide film is a so called *WORM* technology (**W**rite **O**nce **R**ead **M**any) because it is not possible to replace the stored information with new information. The ability of silver halide film to render closely spaced image elements as separable is called its *resolving power*. It is not possible to determine directly the resolving power of film material because its resolving power depends on the resolution of the whole *image formation process,* including components such as the camera lens, the development process, the light source, the exposure and the contrast of the object. The formula:

$$1/R = 1/r_1 + 1/r_2 + 1/r_3 \ldots$$

expresses the relationship between the resolution of the whole system (R) and the resolving power of the single system components r1, r2, r3 (Stroebel, Compton, Current and Zakia 1986, 399). The resolving power of the whole image formation process cannot be higher than the lowest resolving power component. To measure the resolving power of a silver halide material, a system of known high resolving power is used to calculate the unknown resolving power of the system component "film". In this process, several different test targets can be used, including the *United States Air Force* (USAF) and the *American National Standards Institute* (ANSI) test targets. They consist of alternating black and white parallel lines or elements with a certain contrast. Because the object contrast affects the resolving power, the targets have *standardized contrasts,* for example 1000:1 for transparency test targets. The resolving power is expressed in pairs of lines. The Eastman Kodak Company has defined the following *resolving power categories*:

Ultra-High	630	lines/mm or higher
Extremely High	250 - 500	lines/mm
Very high	160 - 200	lines/mm
High	100 - 125	lines/mm
Medium	63 80	lines/mm
Low	50	lines/mm or lower

These values applied to a certain film material are only *theoretical*, because in a normal photographic situation, the resolving power is minimized by the other system components and by other factors including flare light and the stability of the camera body during exposure. A conventional 100 ISO film, used under average conditions, does reach a resolving power of about 50 black and white line pairs per mm (=*100 pixels per mm)*, which corresponds to a spatial resolution of 2540 *pixels per inch* (Schläpfer 1993, 75).

The resolving power is *format independent*, thus with increasing film-format there is an increasing amount of stored information. If each resolved picture element corresponds to a digital value of 8 bit (= 256 different gray levels) a 35mm film has a storage capacity of 8.6 MByte in the black-and-white mode and 25.8 MByte in the RGB mode. A larger format such as 4 x 5 ", which is widely used in commercial photography, corresponds to a storage capacity of 387 MByte (in RGB mode). This is more than the capacity of an average internal hard disk.

Silver halide technology is not only used to store continuous tone images, but also to store line art or written text. *Microfilm* is a material with a theoretical resolving power up to 2000 lines/mm. There are different types of microfilm emulsions, but in order to store written text or line art, mostly *monochrome panchromatic emulsions* are used. This material reaches a high level of contrast (gamma of 3.0 or higher) with an average grain size of 0.1 to 0.4µ, an emulsion thickness of less than 150µ and a resolving power of up to 800 lines/*mm* (20'320 lines/inch).

Because of its tone reproduction characteristic, each stored picture element corresponds to a digital value of only1 bit (either black or white). One square-inch of microfilm can store more than 400'000'000 bit (= 51 MByte) of information.

Stability and Storage Considerations

There are some serious problems with the permanence of photographic records. The expected life span depends upon:

- The inherent stability of the photographic material
- The processing conditions
- The post-processing treatment
- The storage environment

ANSI has designed different testing procedures, in the form of chemical or accelerated aging tests, to define the chemical stability of film-bases and emulsions (ANSI IT9.1) The length of time that information is predicted to be retrievable in a system under extended-term storage conditions (ANSI IT9.11) is expressed by the term *life expectancy* (LE, in years). The maximum rating for black-and-white film material on polyester base is LE-500. To reach this high life expectancy, the silver image itself, must be stable too. The most important issue is to remove all *unexposed silver halides and fixing chemicals* by washing before drying. This is especially a problem with *baryta-coated fiber-based reflection copy*, which is widely used in archival storage. The silver complexes formed during the fixing process have a tendency to adhere to or be adsorbed by the fibers of the paper. For this reason, the fixing process should be *as short as possible* to prevent this reaction, but *long enough* to change all silver halides to water-soluble silver complexes. Kodak addresses in its publication *Conservation of Photographs* six important points in image processing to achieve *long-term stability*:

- Development according to instructions.
- Use an acid stop bath (pH 3-5).
- Fix and wash to produce images that are essentially free of processing chemicals.
- Use control tests to determine if the residual thiosulfate (hypo) has been reduced to an adequate level.
- Treat images with diluted toner solution to protect against contaminants.
- Dry in an environment that will avoid contamination by chemical and physical changes.

For appropriate storage of black-and-white silver halide material, it is important to maintain low temperatures (below 21 °C), and low relative humidity (below 50%). Relative humidity greater than 50% will promote the formation of fungus growth, since the gelatin used in photographic emulsions is an organic material and supports bacterial growth. Relative humidity below 20% can result in curl and create static problems.

Another critical point is the poor *lightfastness* of the dyes used in photographic color materials. If the materials are exposed to light, the dyes tend to fade very fast. Because the used dyes (Y, M and C) do not have the same lightfastness ratio, they *fade at different rates*, resulting in *color casts*. There are several factors which affect the stability of color materials (ANSI PH1.42):

- DARK FADING
  Dark fading is a function of ambient temperature and relative humidity. Even stored in absolute darkness, negatives, transparencies and prints will change in color.

- LIGHT FADING
  Light fading results in photochemical reactions in the emulsion induced by ambient light (especially high-frequency UV light). The rate of change in color depends on the duration of exposure, the intensity and spectral quality of the light.

- STAINING
  This process can be caused by by-products of the magenta coupler left in the emulsion and will result in yellow staining in the border and highlight areas of a print. Staining was especially a problem with older color papers, such as Kodacolor Type I. Today's color emulsions have less problems with staining.

Due to various variables affecting the stability of color images, it is very difficult to predict the life expectancy of color materials. However, it is *significantly less* than that of black-and-white materials. The *storage conditions* are very important. The recommended storage conditions for color photographs are:

- *Cool*: 50° to 60°F, with no crossing of a dew point during handling; minimal temperature cycling.
- *Dry*: 30 - 40% relative humidity.
- *Light-tight enclosure*. Limited display time. All light sources UV filtered, and light intensities kept to a minimum.

After all "there is nothing permanent about the photograph . . . . Any photograph resembles a living organism in that it has a natural life span . . . . The photographs interactions with its environment determine how long this life span is. The picture takes up and releases moisture, its internal chemistry speeds up in the presence of heat, and light provides energy that causes long-term changes in the appearance. It may be host to a variety of organisms that use it for shelter and food, and it suffers from fire and superior physical force in the same way that we do" (Keefe 1990, 3).

Storage of Digital Information

When images are stored in digital form, the following characteristics of the storage medium have to be considered:

- Storage Capacity
- Reliability of the Storage Medium
- Speed of Data Access
- Cost per MByte Storage Space

STORAGE CAPACITY

Images used in digital form produce large data files. A full color page (8.5 x 11") printed with a screen frequency of 150 lpi (commercial printing) needs, according to the *Nyquist Criterion*, a spatial resolution which is *two times higher* (= sampling ratio, quality factor) than the output resolution (150 x 2 = *300 dpi*). Under these conditions, the file has a size of 34 MByte (CMYK mode, 8 bits per color). Storing data files of this size in an economic way requires powerful storage media and data compression tools.

There are *three categories* of storage media:

- Short-term Storage Media
- On-line Storage Media
- Archival Storage Media

Short-term Storage Media

Short-term storage media are used to save changes during image processing or image manipulation. Most often the computer's internal RAM (**R**andom **A**ccess **M**emory) is used for this purpose. RAM is the abbreviation of DRAM = dynamic random access memory. Although *memory and storage* are measured in the same units (bytes, kilobytes, megabytes), they are not the same. Memory is *volatile* because the information, recorded by turning on and off transistors (microscopic electrical switches), is lost when the power is turned off. *Random* access refers to the fact that information at any location can be found and accessed in any order. RAM is *dynamic* because the computer can delete, move and add data at any time

and very fast. But RAM used in computer language has a second meaning, *read and write memory*. In contrast to ROM (**R**ead **O**nly **M**emory) RAM can be infinite written, read and rewritten. Today's technology, working with large application programs and sophisticated operating systems, requires a large amount of RAM.

On-line Storage Media

On-line storage media should offer fast recall and are commonly provided by either internal or external *magnetic disks* (hard disk, Syquest) or by *magneto-optical disks* (MOs).

Magnetic disks have a platter of metal or glass coated with a thin layer of magnetic material. Reading and writing is done by a magnetic head which can detect and change the magnetic polarity of small areas of the surface. In some cases (floppy disks, Bernoulli disks), the head is in *physical contact* with the magnetic coating, while in other cases (hard disks, Syquest), the reading/writing head floats on an air cushion just above the platter surface. The latter technology increases the long-term durability of the disks.

Magneto-optical recording is a *hybrid system* between magnetic and optical storage technology. A platter of plastic or glass is coated with metallic alloy. This surface can be heated to a critical temperature (about 150°C), at which the layer no longer retains magnetic. When the heated spot cools down, it magnetizes in the direction of the external magnetic field. The reading of stored information is based on the *Kerr effect* (Kerr 1875), which describes that a beam of plane-polarized light has its polarization plane rotated by application of an electric field. The differences in polarization can be analyzed by a photodetector and translated into the binary code.

Long-term Storage Media

For long-term archival storage, the possibility to store massive data in an *economic way* is more important than fast recall. *Magnetic tapes* (DATs = **D**igital **A**udio **T**apes) or *optical disks* (CD-ROMs) are often used for this purpose.

Digital audio tapes do not allow random but only *sequential* access. To find a particular data location, the tape requires rewinding and searching. This is time-consuming and therefore only useful for backing up a random access media. However, there is software available which can create a directory in order to identify where each file is stored on the tape. This can increase the seek time. DAT is ideal for archival storage, because the medium is inexpensive and can hold several gigabytes of information.

The abbreviation *CD-ROM* refers to **c**ompact **d**isk, **r**ead-**o**nly **m**emory. The advantage of this technology is the high storage capacity at a low price. One disk can hold up to 600 MBytes of data with manufacturing costs of only $1 to $2 in volume. "A further strength of CD-ROM is its resistance to damage and wear and its high data integrity. We have seen that an error rate of 1 in 10^{16} can be achieved. This is far better than is economically possible for any other publishing medium, and will be valuable for some applications such as software distribution" (Bradley 1989, 83).

Data Compression
In many cases, uncompressed image files are too big for efficient image storage or transmission. A 34 MByte file, for example, needs uncompressed more than 5 hours transmission time over an analog telephone line using a fast modem with 14'400 bps (bits per second). *Data compression algorithms* are based on *pixel-to-pixel dependencies.* The larger the dependency, the greater the possible compression. Totally random data sets can not be compressed at all. There are *three basic methods* of compression:

- Transformation of number of bits
- Reduced Precision of number of bits
- Minimization of number of bits

These three methods can be used independently or combined. The combination of different methods produces more efficient compression schemes.

Transformation reduces data sets by finding patterns that exist in the data stream (repetitions). The process of recognizing patterns is called *mapping*. Two simple lossless compression schemes, which use this technique, are *Run-length Encoding* and *LZW Encoding*.

Reduced Precision is only used in combination with other compression methods. Digital data can be reduced in precision if the end-use application of the data requires less precision than the original data set, or if the data is more precise than the human eye can distinguish. Reduced Precision is always lossy. "Used in excess, reducing the precision can create abrupt changes in intensity values from one pixel value to the next when the data is decompressed. These abrupt changes can be very noticeable to the human eye. The technical name used to describe these abrupt changes is *banding*" (Brown/Shepherd 1995, 211). JPEG and MPEG data formats use reduced precision together with other schemes.

Minimization reduces the overall number of bits needed to represent a data set. An example of this compression method is Huffman Encoding. " . . . , Huffman codes assign a variable-length code to each possible data item, such that the values that occur most often in the data set have smaller-length codes while the values that occur less frequently have longer-length codes. Given the probability of occurrence of each individual data value, the Huffman algorithm can automatically create an appropriate code assignment for each data value" (Brown/Shepherd 1995, 213).

In practice, it is important to distinguish between *lossless and lossy compression methods*:

Lossless Compression
With lossless compression, the reconstructed pixel values after decompressing are *identical* to the original values, thus the fidelity is absolute. The *compression ratio, CR,* (defined as n1/n2, n1 = number of information carrying units before compression, n2 = number of information carrying units after compression), is limited to less than 10:1. The complexity of an image has a great impact on the amount of lossless compression. An image with low complexity can be compressed more than an image with high spatial frequencies. The more complex the image structure, the less successful will be a lossless compression scheme. Lossless compression methods are:

- *Huffman Encoding:* compression ratios up to 2:1
- *Run-length*: compression ratios up to 5:1
- *LZW*: compression ratios from 2:1 to 9:1

Lossy Compression
With lossy compression algorithms there is a *numerical discrepancy* between the reconstructed pixel values and the original values. The trade off for this information loss is the possibility of higher compression ratios up to 1000:1.

For compressing continuous tone images, ITU (**I**nternational **T**elecommunication **U**nion, former CCITT, Consultative Commitee on International Telegraphy and **T**elephony) and ISO (**I**nternational **S**tandard **O**rganization) have defined standards such as the *JPEG* (**J**oint **P**hotographers **E**xpert **G**roup) standard, which is most popular today for compressing still images. "The JPEG standard format defines a suite of data encodings for full-color and continuous tone raster images.

It includes four distinct modes of operation. One of the modes produces limited compression using a lossless encoding technique . . . . The other three modes provide much higher compression ratios with lossy techniques based on the DCT [Discrete Cosine Transform]" (Brown/Shepherd 1995, 220). There are 29 different modes of JPEG, starting with a *lossless JPEG* version based on DPCM (Differential Pulse Code Modulation), over the very popular *JPEG baseline* mode to several *extended JPEG* versions. The amount of compression is highly data- and image-quality dependent. Other important lossy compression schemes are:

- MPEG (**M**oving **P**icture **E**xpert **G**roup; for video sequences)
- CCITT (for videophone and videoconferencing)

Reliability of the Storage Medium

The main problem with the storage of digital files is not the *limited physical lifetime* of the storage medium itself, but the fact that because technology is changing very fast, the time until the medium is *obsolete* is in most cases shorter than its physical durability. In contrary to human-readable analog information, digital information, thus a stream of bits, can only be interpreted by appropriate software with the use of specific hardware devices. "A file is not a document on its own right—it merely describes a document that comes into existence when the file is interpreted by the program that produced it. Without this program (or equivalent software), the document is a cryptic hostage of its own encoding" (Rothenberg 1995, 44). Besides, the application needed to encode a bit stream, specific hardware and system software are also required. Although the behavior of hardware can be simulated by *emulators*, to do so requires detailed hardware specifications. There are two ways to make sure that today's digital data files can still be read in the future:

A very expensive and timeconsuming way, which is not always feasible, is to transfer digital data files every few years from older to new forms of storage media to ensure their accessibility. The files must furthermore be saved together with all information necessary to encode them. " . . . bit streams should be sealed in virtual envelopes: the contents would be preserved verbatim, and contextual information associated with each envelope would describe those contents and their transformation history. This information must itself be stored digitally (to ensure its survival), but it must be encoded in a form that humans can read more simply than they can the bit stream itself, so that it can serve as a bootstrap. Therefore, we must adopt bootstrap standards for encoding contextual information; a simple, text-only standard

should suffice. Whenever a bit stream is copied to new media, its associated context may be translated into an updated bootstrap standard. . . . These standards can also be used to encode the hardware specifications needed to construct emulators" (Rothenberg 1995, 47).

The second more simple solution, mainly approached by photographers and graphic illustrators, is to back-up digital files again in human-readable analog form. That means, for example, to copy digital image files back on silver-halide material. This solution, however, has the big drawback of information loss during copying. Furthermore, it cannot be the goal to solve problems of new technology with old technology. At this time, there is no satisfying solution available to make sure that today's data files can still be read in the future.

SPEED OF DATA ACCESS

How fast data can be transferred from a storage device to the processor chip is not only dependent on the access *time* (that is a combination of the time the head needs to move to the right track, also called seek time, and latency, the average time it takes to move the wanted data sector directly under the head). Important is also the device's *data transfer rate,* and the data transfer rate of the computers own *bus system*. The improved SCSI bus used in Centris, Quadra and PowerMac models, for example, has a maximum data transfer rate of 4 MB/sec. External devices slower than that can become a bottleneck.

COST PER MBYTE STORAGE SPACE

Many people think of a 3.5" floppy disk, sold for about 70 cents, as a cheap storage medium. In fact, it is an expensive one ($ 0.35/MB), if the cost per MByte storage capacity is considered. With the introduction of Writable CDs, there is now a very cost-effective way ($ 0.02/MB) to record information for low-volume publishing and for archival storage. MO's with costs of $ 0.16/MB, are a more expensive storage solution, but still cheaper than magnetic disk technology (Syquest 270 MB / 3.5" / $ 0.28/MB).

Future Storage Technology

Recent developments at the Stanford University with a digital storage system based on *holography* shows stunning advances. The researchers announced that in 3-5 years this technology could be able to store up to 120 GBytes per cubic-cen-

timeter with an access time 100 to 1000 times faster than that of a normal hard drive. The digital data is stored as an interference pattern in a three-dimensional crystal. Thousands of these interference patterns can be superimposed in one crystal. Writing and reading of information is done by laser-light. In contrary to electrons, photons do not interfere with each other, allowing the build up of high information densities. The two main problems of this technology, noise, introduced by a large amount of randomly scattered light, and the degradation of the patterns after a few readings, could now be solved.

Another innovative product still in development is ICI's Digital Paper, a plastic material manufactured as tape or disk. It allows massive, low-cost data storage ($ 0.01/MB). Digital Paper is an optical WORM medium, which could be ideal for back-up with relatively fast recall.

". . . for most people, the purpose of storing large numbers of images . . . is not so much for archival preservation as for access. The ability to find a previous image, to compare it to a current one, and to find and measure similarities and differences, is an obvious need in many imaging tasks. Choosing a storage technology is not the really difficult part of filling this need. . . . The technical challenge lies in finding a particular image after it has been stored" (Russ 1995, 110). Stock photo agencies have started to digitize their images and to provide them on-line. The major advantage of the on-line databases is that updates can be made continuously, and that the customers have immediate access to them. Nevertheless, retrieving the images can still be time consuming because most of the search engines used today are *keyword based*. It is not always possible to describe an image by keywords in an appropriate and effective way. *Shape recognition* and *pattern recognition* tools are one approach which could solve this problem. Only recently, IBM released the *Ultimedia Manager*, a low-cost software package which supports pattern recognition for image retrieval. This technology will gain more and more importance helping photographers and stock photo agencies to maintain their image archives.

Graphic Formats

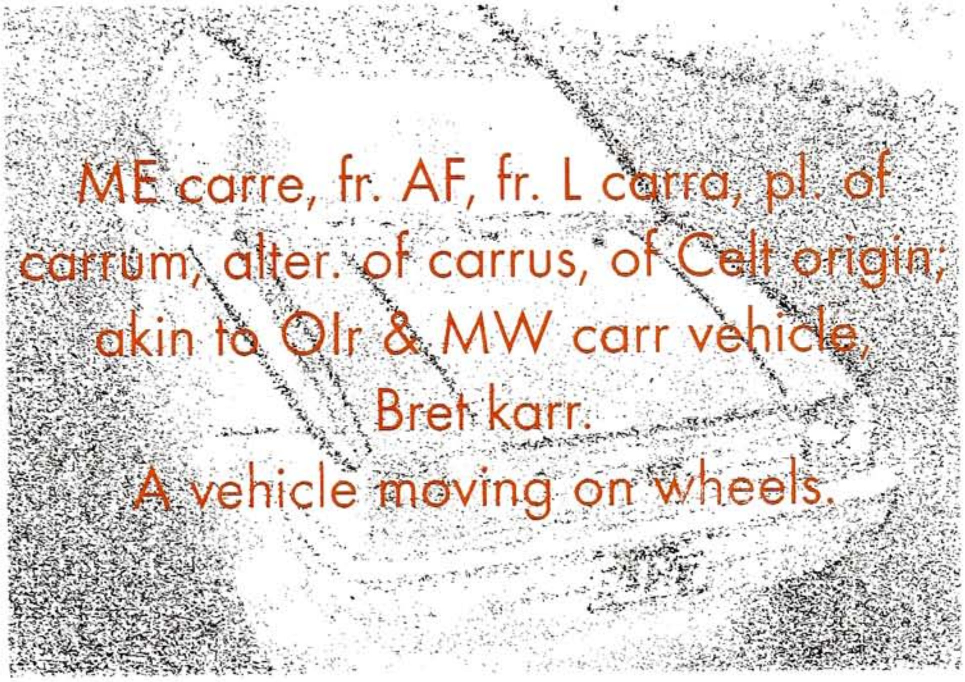
Graphic formats define the *structure* in which the digital data is stored. Every graphic program, such as Photoshop or Freehand, has its own *native* graphic format. However, most programs can save files in several different formats to make sure that the files can be opened by other applications as well. There are two dif-

ferent types of formats. *Raster formats* are used by paint software to structure *bitmapped graphics*. In a bitmapped image each pixel is recorded corresponding to the systems resolution capabilities. Raster images display faster but create large data files. The most common raster formats are *TIFF* (**T**agged **I**mage **F**ile **F**ormat) *PICT and GIF* (**G**raphics **I**nterchange **F**ormat). *Vector formats* are used in draw programs to structure *object-oriented graphics*. In object-oriented graphics images are defined by lines, points and shapes. Vector formats produce smaller files and are easier to manipulate than raster formats. The *EPS* (**E**ncapsulated **P**ost**S**cript) format uses both bitmapped and vector techniques to describe graphics on a page.

Plate 4:

Information Garbage

With the use of compression schemes, the amount of information in a digital image can be reduced without affecting the image quality (lossless and visually lossless compression). The information garbage, the eliminated information, portrays *ordinary objects in a new light*.
The same applies to a definition out of a dictionary but in the opposite way. The definition adds information and detail to a subject, while compression technology reduces it.


ME carre, fr. AF, fr. L carra, pl. of
carrum, alter. of carrus, of Celt origin;
akin to OIr & MW carr vehicle,
Bret karr.
A vehicle moving on wheels.

ME chayere, fr. OF chaiere, fr. L cathedra, fr. Gk kathedra, fr. kata– cata– + hedra seat, fr. hezesthai to sit.
A usu. movable seat that is designed to accommodate one person and typically has four legs and a back and often has arms.

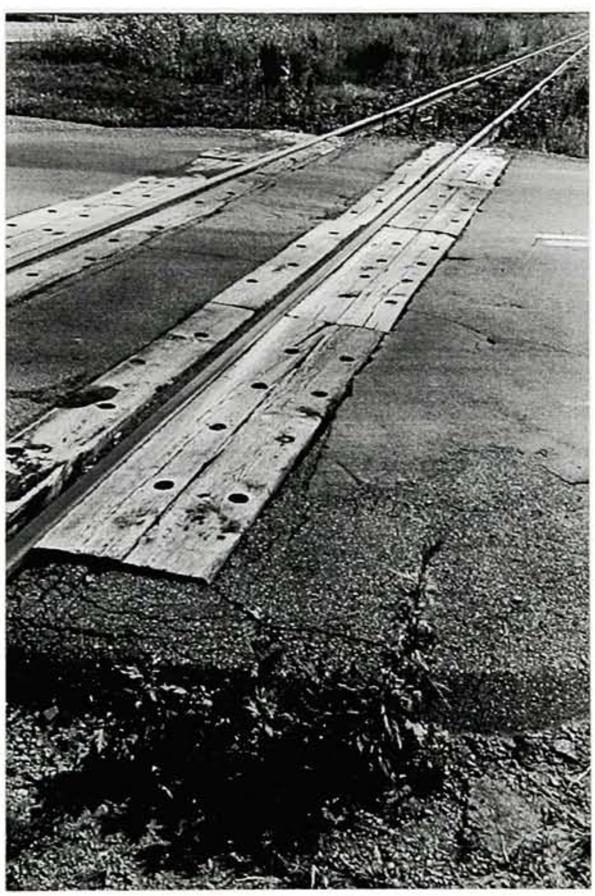
ME cat, catte, fr. OE catt, catte; akin to OFris katte, OHG kazza, ON köttr cat: all fr. a prehistoric NGmc – WGmc word prob. borrowed fr. LL cattus, catta, perh. of Hamitic origin; akin to Berber kaddiska cat, Nubian kadis. A long-domesticated carnivorous mammal (Felis catus).

5.5 Manipulation and Reality

"Photos always lied" is the title of an article about photographic realism and electronic image manipulation (Goldsmith 1991, 68-75), in which the author proves, that photography never was and never can be objective. "Photography is a human act and therefore subjective, a selective act and therefore interpretive."(Goldsmith 1991, 68). There are important medium inherent characteristics, which place *photographic realism* far away from reality:

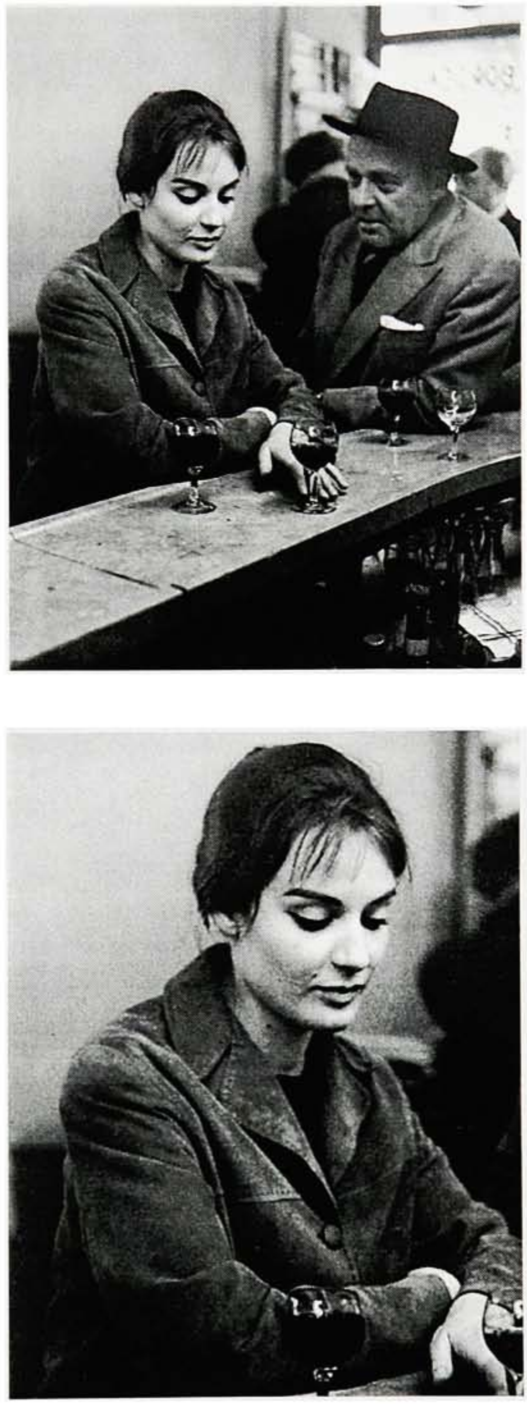
- A photograph is a *two-dimensional representation* of a three-dimensional space. The third dimension is simulated by the medium's inherent *linear perspective*. As the object distance increases, the image size decreases, causing the convergence of parallel lines.

Figure 13: Linear Perspective.



- A photograph is always a *framed fragment* of a whole. To *select* and to *frame* are the photographers main creative acts and highly subjective.

Figure 14: Interpretation by Selection
Robert Doisneau: At the Café, 1958. (Szarkowski, 1973.)



- A photograph isolates *a moment in time* and therefore can not render motion. There are several techniques to symbolize time and motion in an image. With long exposure times, moving objects tend to blur and finally disappear from the image (see *Figure 16*). Freezing motion with *stroboscopic lights*, a technique developed and perfected by Harold E. Edgerton in the 1930s, is another way to symbolize motion. In "Densmore Shute bends the Shaft", fifty flashes in half a second show the driver in different positions, while the golfer's torso, fifty times superimposed on itself, dissolves into a ghostly shape.

Figure 15: Harold Edgerton: Densmore Shute Bends the Shaft, 1938. (Szarkowski, 1987.)

- Conventional photography renders visual information. However, there are special materials which can record electromagnetic energy below 400nm (ultraviolet) or above 700nm (infrared). These parts of the electromagnetic spectrum are not visible to the human eye.

- All other human sensual perceptions (hearing, smell, taste, skin senses) are not reproduced by the photographic process.

- Black-and-white photography converts original color values into gray tones. This is a highly *abstractive process* which does not correspond to human experience.

- Color photography converts original color values into process-specific color values. This conversion process does alter information, because colors used in photographic color materials have a *limited color gamut.*

- During the photographic process (excluding photomicrography) objects are *reduced in size.* Average photographic lenses are maximized for a *scale of reproduction* between 1/∞ and 1/10 (scale of reproduction = size of reproduction : size of original).

Despite all these medium inherent *subjective, selective and abstractive factors,* photography has (still) the *stamp of an objective and reliable source of information,* of a source of *authenticity.* Several reasons contribute to this fact:

Stencilled off the Real

In the early days of photography, and still today, people are impressed and fascinated about the medium's ability to *resolve finest details.* "They [the daguerreotypes] are produced on a metallic surface, the principal pieces about 7 inches by 5, and they resemble aquatint engravings; . . . . But the exquisite minuteness of the delineation cannot be conceived. No painting or engraving ever approached it. For example: In a view up the street, a distant sign would be perceived, and the eye could just discern that there were lines of letters upon it, but so minute as not to be read by the naked eye. By the assistance of a powerful lens, which magnified fifty times, applied to the delineation, every letter was clearly and distinctly legible, and so also were the minutest breaks and lines in the walls of the buildings; . . . . " (Samuel F.B. Morse in a letter to his brother, the 9th of March 1839/ Newhall 1982, 16).

The fact that objects reproduce themselves using light as a messenger gives photographic images a special quality not found in paintings. "A photograph is not only an image (as a painting is an image), an interpretation of the real; it is also a trace, something directly stencilled off the real, like a footprint or a death mask" (Sontag 1977, 45). Until today, photographs were used as factual evidence in police investigations and in court.

Unseen Worlds

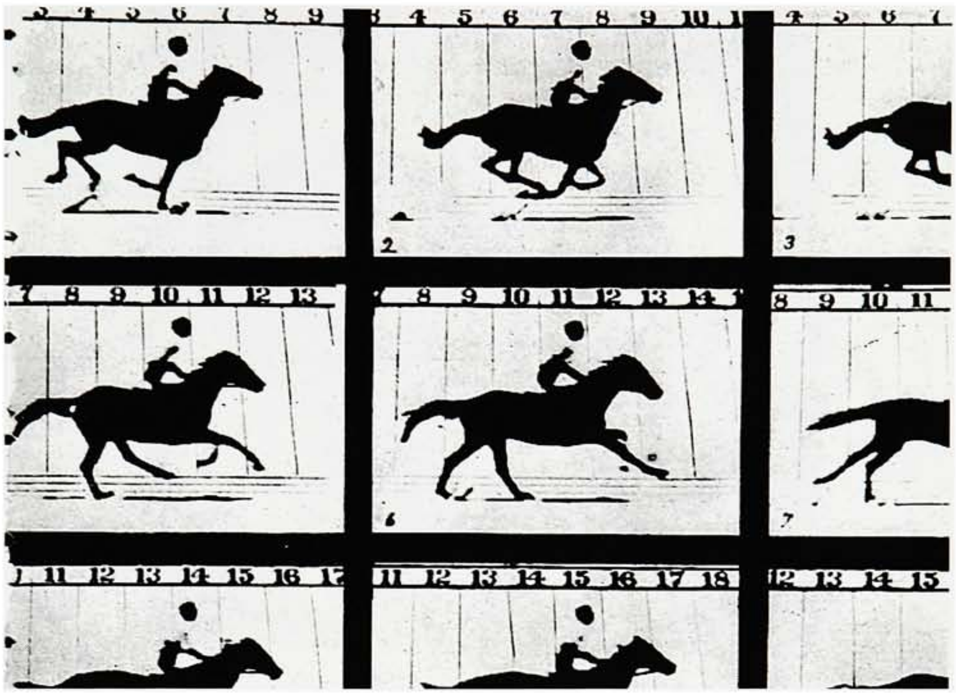
Photography can show things *beyond human perception.* The first views of Paris in 1838 showed deserted streets and footpaths caused by the very long exposure times that cleared all non-static objects.

Figure 16: Louis J.M. Daguerre: Boulevard du Temple, Paris, 1838. (Newhall, 1982.)

The improved speed of photographic emulsions allowed Eadweard Muybridge and Etienne-Jules Marey to prove that in the motion of horses the "flying gallop position", as it is depicted in many earlier paintings, does simply not occur. Muybridge let gallop horses along a row of cameras, whose shutter system was released by silk treads. By tearing these treads during galloping, the horse itself released the shutters.

Figure 17: Théodore Géricault: Le Derbis d'Epsom, 1821. (Musée Marey, 1991.)

Figure 18: Eadweard Muybridge: Horse in Motion (cropped), 1878. (Newhall, 1982.)

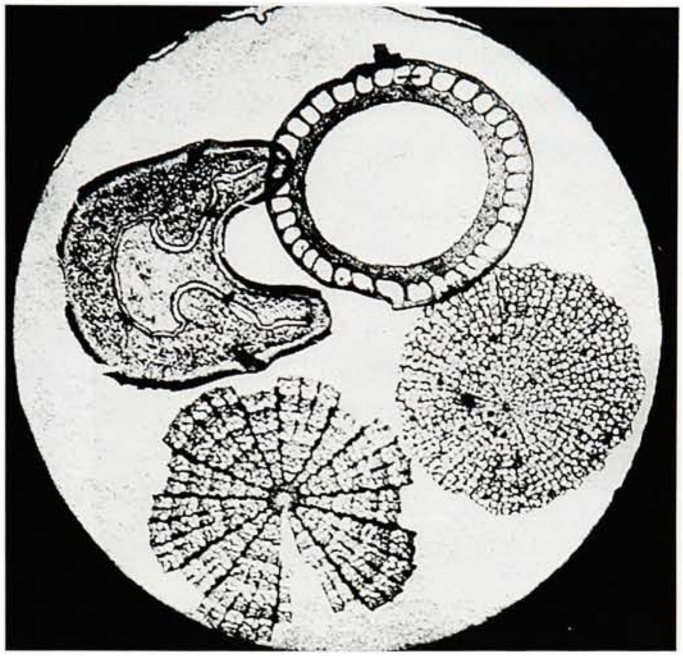


Photography became a tool to analyze motions of every kind that could not be resolved by the human eye. "The meaning of the term truth to nature lost its force: what was truth could not always be seen, and what could be seen was not always truth." (Scharf 1986, 66).

Today the analysis of motion can be done with far more sophisticated tools. *High-speed photography* can realize shots with an exposure time of down to a few picoseconds (ps = 10^{-12} s). There are manifold applications for high-speed photography in fields including biology, aerodynamic, chemistry, aerospace research, ballistics, and sports where special *photo finish cameras can* determine the winner of a race down to 1/10'000 of a second. The use of photography as a scientific tool had and still has a great influence in people's belief in the truth of photographic realism.

Photomicrography and telephotography opened up other unseen worlds for the human observer. Both Daguerre and Talbot had taken photographs through solar microscopes even in the early1840s, and recordings of the moon excited great interest.

Figure 19: Fox Talbot: Photomicrograph of a plant stem section, 1839. (Scharf, 1974.)



"Despite the difficulties posed for telephotography by the interference of adverse atmospheric conditions, which ultimately was mitigated by the use of infrared emulsions, astronomical photographs were taken in the 1840s in considerable quantities. Those incunabula were followed by photographs of the minute sub-structures of plants and insects, of the mysterious functions of animalcule life" (Scharf 1974, 304). The illustrations of both the *macro- and the microcosmos* by photographs influenced the public's consciousness of nature and the work of prominent artists including Klee, Le Corbusier, and Moholy Nagy. "In *The New Vision*, published by the Bauhaus in 1928, Moholy-Nagy was explicit about the importance for art of photomicrography. Though his own predilections, and the tendency of the Bauhaus as a whole, favored the scientific and technological approach, he was certainly aware that the appeal of such photography was not merely scientific" (Scharf 1974, 309).

The sensitivity of silver halide materials is not limited to the human visible part of the electromagnetic spectrum (400 - 700 nm). Special emulsions in combination with specially designed lenses can record information transmitted by *ultraviolet and infrared light*. These technologies also present new, unseen worlds to the human eye.

The scientific applications of photography and its influence on art and the human consciousness strengthened the medium's reputation as an authentic and reliable source of information. "A photograph is fossilized light, and its aura of superior evidential efficacy has frequently been ascribed to the special bond between fugitive reality and permanent image that is formed at the instant of exposure. It is a direct physical imprint, like a fingerprint left at the scene of a crime or lipstick traces on your collar" (Mitchell 1992, 24).

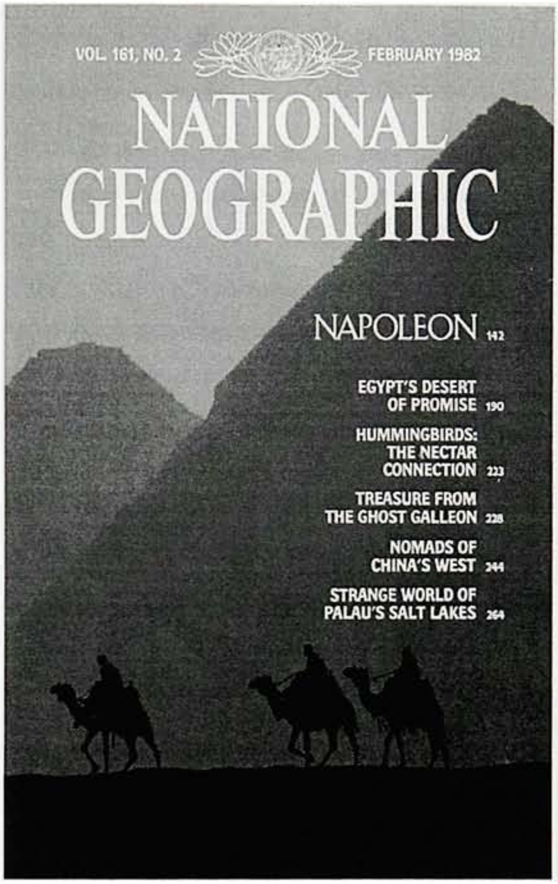
"SEEING IS BELIEVING"

This common quote refers to the fact that of our five senses the visual is the most important one, at least for people in the 20th century. In his book "Das optische Zeitalter", Karl Pawek defined the 20th century as the *optical age*. Visual information is indeed the most efficient way to reach and influence people and photography was the first tool available that could create images detached from the "subjective human hand." Machine generated pictures got a powerful "reality effect".

Today, 58 billion pictures are produced worldwide every year to satisfy the needs of the communication industry. The powerful and easy-to-use tools of digital imaging are starting slowly but surely to destroy the subtle bonds between reality and image. The manipulated image is *simply itself*, without pointing out another form of reality. Some image manipulations applied today are very obvious and therefore recognizable.

Real controversy, however, is provoked by manipulations which are not obvious and therefore misuse the photographs' inherent credibility. "Perhaps the most famous case–both because it occurred relatively early and has been talked about a great deal in photojournalistic circles–is the 1982 *National Geographic* cover of the pyramids of Giza. In this case a horizontal photograph was made into a vertical image suitable for the cover by electronically moving one pyramid closer to the other" (Ritchin 1990, 14).

Figure 20: National Geographic Cover, Pyramids of Giza, February 1982.



In the last few years, such practice became more and more common. In fashion magazines like *Vogue*, almost hundred percent of the image material is electronically retouched or manipulated without informing the readers. Magazine covers, which are seen as an advertising platform for the magazines themselves, can contain manipulated images even if the publication is based on its photojournalistic credibility. In the case of the *Time* magazine cover of O.J. Simpson's altered mug shot, the public had a direct comparison to the unmanipulated image presented on the cover of *Newsweek*. Fred Ritchin, professor of photography and telecommunications at New York University, proposed to use a so called *"not a lens" icon* to identify computer-altered photographs and to avoid the further erosion of photojournalist's credibility.

Involved in the controversial discussion how to deal with image manipulations are also legal aspects concerning the copyright law.

PLATE 5:

Manipulation and Reality

Most designers and photographers use the tool of digital imaging to create pictures which cannot be found or constructed in reality. The tool can also work in the opposite way. An unmanipulated image can have a lower credibility than a manipulated one.

Manipulation or Reality ?

Manipulation or Reality ?

Manipulation or Reality?

Image 1 is heavily manipulated.
Image 2 is not manipulated at all!

Manipulation or Reality?

Image 1 is heavily manipulated.
Image 2 is not manipulated at all!

Did you believe that?
It's almost true . . .

However, I had to remove two distracting telephone wires in both images!

5.6 Original and Copy

According to Nelson Goodman (Goodman 1968), artwork can be classified as *one- or two-stage*, as *autographic or allographic artwork*.

Some photographic processes including Polaroid and transparency materials are one-stage processes. Color and black-and-white negative materials are two-stage processes, where the first step the exposure and development of the material is followed by a second step, the production of prints. This second step is highly subjective because making a print means *interpreting the original*. For art collectors, the value of a print depends on the *person* who made it and the *time frame* it was made in. *Vintage prints* (prints produced at or around the same time as the production of the negative) are the most valuable material for art collectors.

Photography can be described as an autographic art (the original meaning of the term autographic is written in the author's own handwriting), because the prints, which are the actual end-products, although they may slightly differ from each other, are all copies from the original artwork. Every other copy *not* made from this original counts as an imitation or forgery even if the duplication is perfect. " Let us speak of a work of art as *autographic* if and only if the distinction between original and forgery of it is significant; or better, if and only if even the most exact duplication of it does not thereby count as genuine" (Goodman 1968, 113).

With the introduction of more scientific methods to control the copying process (by Ansel Adams), it became possible to produce prints which are *visually identical*. However, in their microstructure, different prints never can be identical because every sheet of photographic paper has a different random distribution of silver halides resulting in different microstructures of the final prints.

Digital images are *two-stage, allographic (nonautographic) artwork*. While the first step creates the digital matrix, a second step converts this digital information into an analog format in order to visualize the information using *hard copy or monitor display* output. A digital image is an allographic work of art because the matrix is a *definite notation system* and can be copied exactly with *no loss or change of information*. "The only difference between an original file and a copy is in the tag recording time and date of creation—and that can easily be changed. Image files therefore leave no trail, and it is often impossible to establish with certainty the provenance of a digital image" (Mitchell 1992, 51). The matrix can be seen as the artist's final product, the *score*, while the actual visible and again analog images produced from this matrix are the *performances of the score*.

"Performances may vary in correctness and quality . . . ; but all correct performances are equally genuine instances of the work" (Goodman 1968, 113).

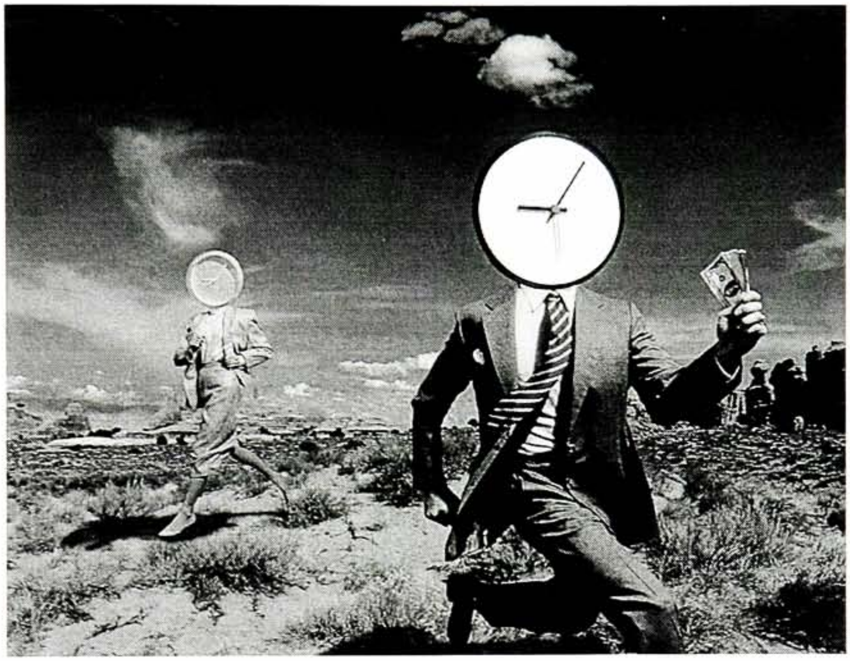
The most fundamental difference between a conventional photograph and a digital image is that photographic negatives, transparencies or prints have a *physical body* and are *human readable*, while digital image files are only *machine readable* matrices of numbers, with no physical body. This makes it difficult to protect digital images by copyright laws. "A piece of work that is physically on paper (like written text or a bromide print) is somehow more respected as a copyrighted item. Hardcopy is well backed up in international law too. But, a stream of digital signals is approached differently, perhaps because photographs in this form are now so easily accessed, manipulated and merged with others to make up the designer's page spread or creative composite artwork. As a result, they become devalued as mere raw material" (Langford 1994, 6).

Today it is possible to use and combine elements of different copyrighted works in a way that even the creators of the originals would not be able to discern. However, if a copyright infringement is obvious , there is a great chance to get charged by the law. Since the U.S. joined in 1989 the *Berne Convention* (originally signed in Berne, Switzerland in 1863), the U.S. copyright law is adjusted to the European laws, which consider a work as copyrighted *from the moment of its creation*, even without including a copyright notice (copyright symbol, name, year of first publication). The copyright notice was established by the other important international copyright organization, the Universal Copyright Convention (UCC). Today nearly every country in the world belongs to the Berne or to the UCC Convention. Most countries belong to both. ". . . , it is still advisable to include a complete copyright notice on a work of art. By doing so you avoid the argument from someone who has copied your work that he or she was an innocent infringer and did not know that the work was copyrighted. It also indicates on a practical level that you have knowledge of your rights, which may deter someone from unlawfully copying your artwork" (Wolff 1992, 70).

Recent cases did show that photographers and photograph agencies are not willing to support copyright law violations. In 1994, FPG International, a large photograph agency, discovered that an image of photographer James Porto, it had exclusive rights to license, had been used without permission on the front page of a *Newsday* edition. *Newsday* first claimed that its computer illustrator was not aware that using this image violated the copyright law, but finally had to enter into a settlement agreement paying total fees of $ 35,500 plus an unknown portion of

FGP's legal fees of more than $ 50,000.

Figure 21: Original Artwork by James Porto and Newsday Cover Page, 1994.



NAFTA What's All The Fuss About? Series Begins on Pages 4-5

Sunday Newsday

THE LONG ISLAND NEWSPAPER

Get Real

In Their Brave New World Of Virtual Reality, Inhabitants Talk by Typing, Walk in Unlimited Space – And Can Wind Up Addicted

CUT THE SPEED LIMIT?

BREEDERS' CUP UPSET

In another copyright infringement lawsuit, the stock agency *Tony Stone Images* sued Corel claiming that Stephen Arscott, the grand-prize winner of Corel's 1994 World Design Contest, copied the image "Potawatamie Indian", which was taken by Nick Vedros and was licensed to the agency. The violation of the copyright law is obvious in this case, even with the transfer across media from photography to illustration. Arscott admitted finally that it was a violation, but he was not willing to give back his prize, claiming that he did not scan the picture, but only used it as reference material. The similarity, however, is so strong that he will get into problems if the stock agency continues its lawsuit. "The use of *Potawatamie Indian* was a blatant copyright infringement. This is one of several recent lawsuits . . . which indicates a need to educate the marketplace in what constitutes infringement, especially in the digital area" (Stock agency director Sarah Stone in an interview published in *Publish* February 1995, 19).
To succeed in a copyright lawsuit, the accuser must prove that actual copying occurred (which is almost impossible, if the defendant does not admit it himself), or that the defendant *had access to the work* and that there is *substantial similarity* between the original and the infringed copy. The defendant had access to the work if it was previously published or if the original was in his hands. To prove *similarity* the court must be convinced that an *ordinary observer* would recognize that certain elements were copied from the original (known as the *ordinary observer test*). It is not important how much of the original was used, but how significant the similarity is. To avoid future image piracy, agencies and photographers are looking for new ways to protect copyright ownership. There are several different approaches:

- Software can be used to apply a *hidden code* within the image file, which will automatically be reproduced during copying and remains in manipulated images. This method is known as *Fingerprinted Bitmapped Images* (FBI). To reveal the origin of an image, the file can be analyzed by an FBI retrieval program.

- The *Digital Notary System* recently released by *Surety Technologies has a similar concept*. The system allows one to determine whether the content or the time-stamp of a given data file was changed. The software calculates a document-specific and nearly unique (5×10^{86} different possible values) digital fingerprint, called "hash value". This value is transmitted to Surety or to a local server, where it is time-stamped and stored. Values are periodically

published in the *New York Times* in order to eliminate the risk of changes in the database. Because the slightest change of the data file of a document produces a different "hash value", the system can detect manipulations in content and changes of the time-stamp. This specific system may not be very effective to protect manipulation of artwork, but it can be very useful for protecting digital data files used by medical or legal organizations.

- Encoded *visible watermarks* are used by image libraries such as *The Image Bank* to protect originals. These structures in the image can only be removed using the appropriate code.

PLATE 6:

Cultural Sediment I –VII

Portions of paintings are digitized and used as a source of specific matrix values. A new image is created by manipulating and merging these matrices. This plate shows how seven famous paintings can be used to create a new image that has no reference to the originals.
Although the author did only reproduce, manipulate and merge existing matrices, the final artwork is not connected to its resources and does not violate copyright laws.

Sediment I–VII

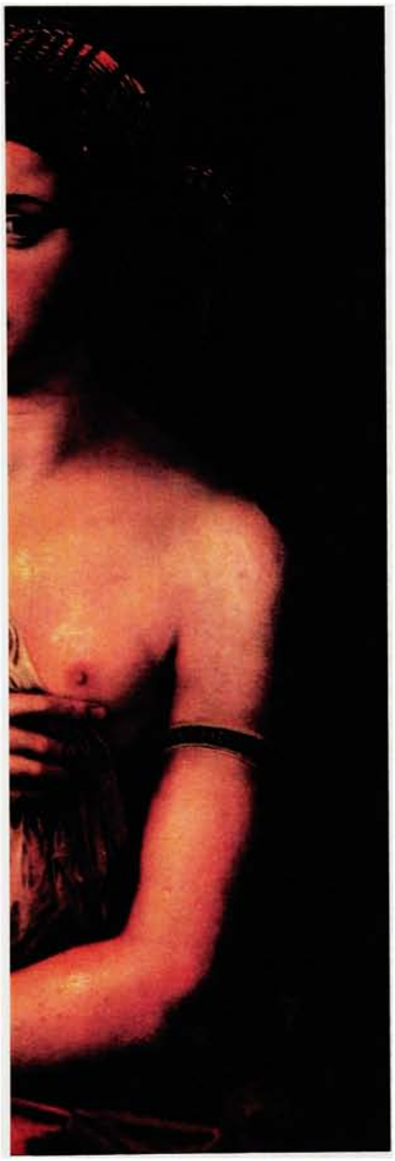
Bosch: Christ bearing the Cross

Original Scan

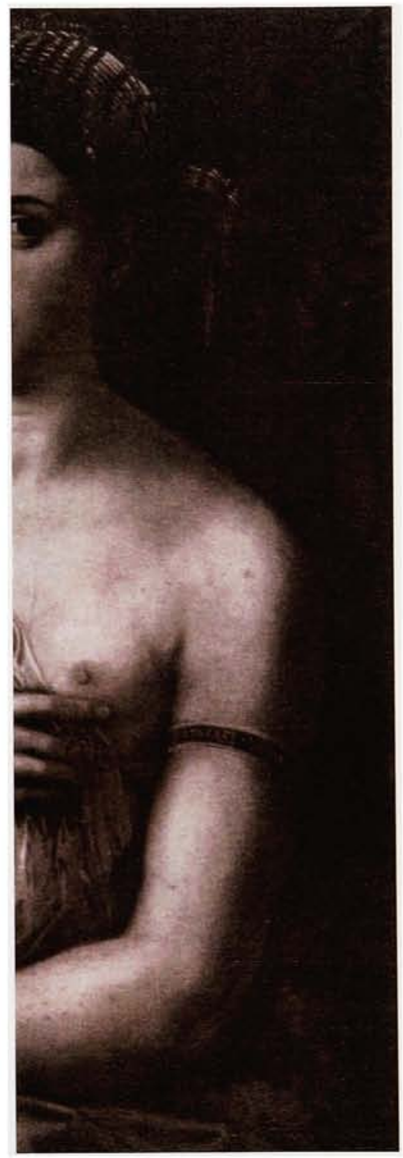
Layer 7

Raphael: La Fornaria

Original Scan

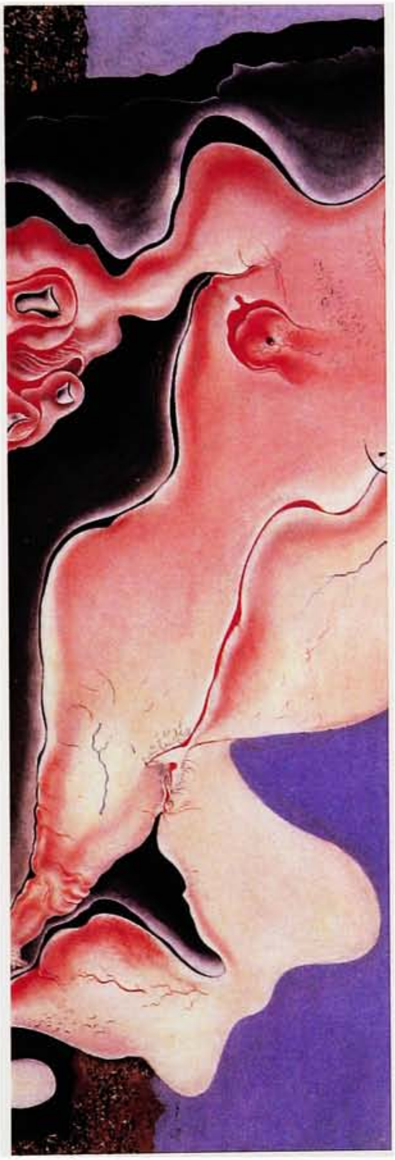


Layer 6



Salvador Dali: Female Nude

Original Scan



Layer 5

Paul Klee: Clown

Original Scan

Layer 4

Canaletto: Venice, the Quay of the Piazzetta

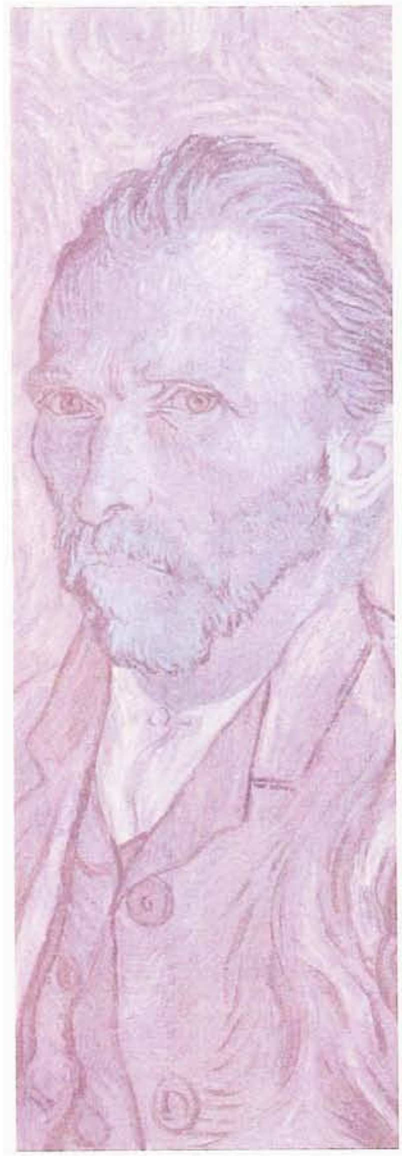
Original Scan

Layer 3

Van Gogh: Self-Portrait

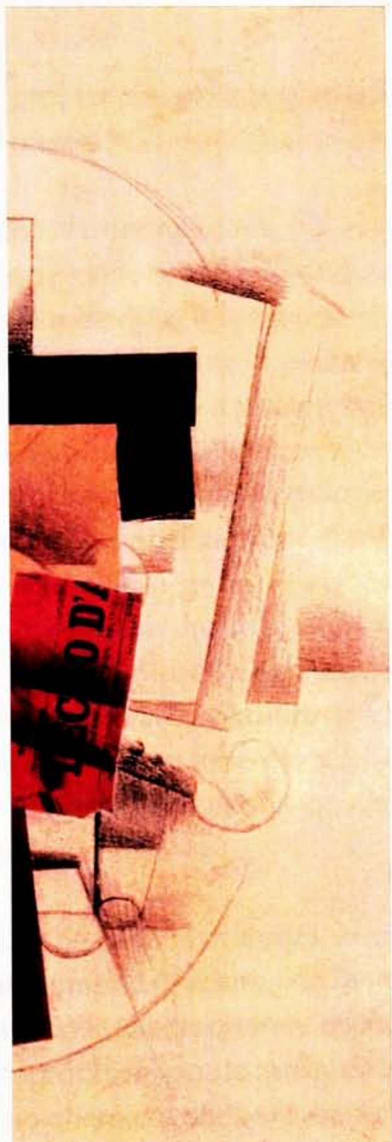
Original Scan

Layer 2



George Braque: The Clarinet

Original Scan



Layer 1

CHAPTER 6

CONCLUSIONS

The thesis project shows that conventional photography and digital imaging are two visual media with very distinct differences:

A *conventional photograph* is a human-readable information entity with an actual physical body in the form of silver clusters or color molecules embedded in gelatin. Silver halide materials have a chemical attribute and are organic, almost "living" organisms affected by heat, moisture, light and pollution, similar as we are. The actual information contained in a photographic image is always overlaid by an unwanted signal called noise. In conventional photography noise becomes visual as graininess. The amount of information in a photographic image cannot be determined exactly and there is always a significant loss of information from image generation to image generation (multiple generation loss). Because objects record themselves on light sensitive silver halide materials using light as a messenger, a photographic image is directly connected to reality, stencilled from the real. This fact is one of the reasons why photography as a medium has a high level of credibility. Despite all the medium inherent subjective, selective and abstractive factors, photography still has the stamp of an objective and reliable source of information, a stamp of authenticity.

A *digital image* is an immaterial, machine-readable stream of bits in the form of a matrix. This numeric structure can be easily altered and manipulated, not only in the space but also in the frequency domain. The solid bond which connects the conventional photographic image to reality disappears with digital imagery. The image is simply itself, has no chemical attribute, and contains no evidence that something existed in reality. The amount of information in a digital image can be exactly determined. However, there is also a certain amount of noise present which, however, cannot be compared with the graininess of photographic materials. Digital information can be compressed with or without a visual loss. Transmission of digital information is easier and more reliable because the information can be error corrected.

There is a significant trend in the communication industry to change from analog to digital technology, because of the following reasons:

- Digital information can be copied with no loss of quality, while analog information suffers from degradation and is more affected by distortions during transmission (noise).
- Digital data is more flexible because it can be processed and manipulated by computers in ways that are not available with analog technology.
- The combination of different forms of digital information including sound, images, video and text is very easy (multimedia option).
- A digital image can present a large amount of information in a visual format, which can be easily interpreted. The same amount of information cannot be readily viewed in any other manner.
- Digital information can be compressed and error corrected, which improves speed and reliability of data transmission.
- Digital imaging systems are capable of representing images of a wider dynamic and tonal range than the human eye can resolve or that can be reproduced using conventional film material.

The most effective channel of communication is visual information. Images are everywhere and more than 100 million new images are produced every day to satisfy the needs of the communication industry. Digital imaging affects many different segments of the communication industry, including printing, prepress, photography, graphic design, multimedia and art. In his book "Das optische Zeitalter", Karl Pawek defined the 20th century as the *optical* age. While it is possible to describe the main characteristic of the 19th century with the term *industrial* age, the developments in the 20th century are too complex to summarize them with only one term. Technology, the most relevant factor in creating new consciousness and in stimulating social developments, changes at an ever increasing speed. At this time, in 1995, it can be stated that the next 20 years might be named the *digital and the interactive* age.

The Digital Age

The trend to work with digital information will affect all parts of the communication industry including photography. Because nobody can predict exactly the future needs, recent photography students are educated in both conventional and digital technology. Digital imaging will not replace conventional photography completely in the next 10 years, but in certain specific areas including *photojournalism and commercial photography,* significant changes will take place. For images used in newspapers and for product photography used in catalogs, digital cameras can today provide the necessary quality and efficiency. For other applications, however, including high-quality printing, *hybrid technology* will for a long time provide better results. High resolution silver-halide material, high-end scanning technology and improved image manipulation hard- and software are in combination a powerful tool. Other trends which will affect the daily work in the communication industry are the increasing importance of digital online image databases offered by stock agencies as well as copyright issues related to digital data files. The future information infrastructure, which will have a plenitude of online information available, will be faced with abuse that hardly can be charged, because the actual laws, made back in the "telegraph era", do not cover electronic communication. "When all media is digital—because bits are bits—two fundamental and immediate results will be observed. First, bits commingle effortlessly. They start to get mixed up and can be used and reused together or separately. The mixing of audio, video, and data is called *multimedia*; it sounds complicated, but is nothing more than commingled bits. Second, a new kind of bit is born—a bit that tells you about the other bits. These new bits are typically "headers", ... These bits are not visible or audible but tell you, your computer, or a special-purpose entertainment appliance about the signal. These two phenomena, commingled bits and bits-about-bits, change the media landscape so thoroughly that concepts like video-on-demand and shipping electronic games down your local cable are just trivial applications—the tip of a much more profound iceberg" (Negroponte 1995, 18).

The Interactive Age

In a long-term perspective, the digital age will convert into an *interactive* one. Multimedia, as we know it today, is only a first step in this direction. The goal of entertainment and information always was to give men the possibility to experience new realities. With modern computer technologies this dream will become true. In the next 10 to 20 years new technologies used in virtual reality will simulate

"life" in a realistic and interactive way. The next generation will learn, from childhood on, to live in both worlds, in the *god-created analog one*, with its limitations of many kinds, and in *computer-created cyberspace*, where everything might be possible because time and space are not limiting factors anymore. "If the objective of much of today's work in graphics is to create *images* that appear to have a quality indistinguishable from a photograph of the real world, the objective of work in virtual reality is to create *experiences* that have a quality indistinguishable from an experience of the real world. Virtual reality is the ultimate simulation" (Holtzman 1994, 197).

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