SECTION 6

Basic Theory and Specifications

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- Color, Color Space, and Color Metrics
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Basic Theory and Specifications

How Computers See

Basic Mechanics

Computers, of course, are mechanical devices. And, the mechanics by which they see can be extraordinarily complex. For example, an image is captured and converted by a flatbed scanner through the following process:

1. A source document is placed face-down on the platen of the flatbed scanner.
2. A lamp inside the scanner illuminates the source document.
3. Light bounces off the source document, reflected in a mirror and subsequently bounced to a prism.
4. This prism separates the image into a full spectrum of light focused on a lens.
5. The lens, in turn, directs this full spectrum light onto a charge-coupled device (CCD).
6. The CCD is an image sensor, containing a grid of light sensing devices, sometimes called picture elements or pixels, that break the image into bits of information.
7. This information, pixel by pixel, is collected by an automated data capture (ADC) device, that converts image information into numeric information.
8. This numeric information is then sent on to the computer processor unit (CPU), which makes it available to image processing software, data storage, or other processes.

This process is similar to that used by the human eye, as light reflected off of an object passes through the lens of the eye onto the retina, where it is converted into a series of electronic pulses transmitted to the brain for processing and action.
This is an extraordinary simplification: Computers see only numbers. The only numbers they see are “1” and “0”. Strings of 1s & 0s in strings may represent images, letters, numbers, etc. The numbers are called “bits” (as in “Bit-Depth”).

Let’s say that the number 0 represents the color black and the number 1 represents white. In the illustration to the left, we can clearly see a black letter A. This bi-tonal or black-and-white image is 15 bits wide by 16 bits high. The image of the letter A is represented by the string:

```
111110000000000000000000
111110000000000000000000
111110000000000000000000
111110000000000000000000
111110000000000000000000
111110000000000000000000
111110000000000000000000
111110000000000000000000
111110000000000000000000
111110000000000000000000
111110000000000000000000
111110000000000000000000
111110000000000000000000
111110000000000000000000
111110000000000000000000
111110000000000000000000
111110000000000000000000
```

The letter A, above, is the simplest means of illustrating how bits comprise an image. This image of the letter A is black-and-white. Add shading or color, and descriptions of images become more complex. To keep it as simple as possible, let’s say that Bit Depth is the number of 1s and 0s used to represent any single pixel. That string of numbers is the encoded description of a shade or color.

In digitization, generally, we speak about three levels of Bit Depth: 1 Bit, 8 Bit, and 24 Bit images. Sometimes, we speak about 16 Bit and 48 Bit images as well.

A 1 Bit image is referred to as “bi-tonal” or, less precisely, as “black-and-white”. The picture elements of a 1 Bit image are expressed in strings of one bit. That bit may be either one color or an alternate and, frequently either black or white.

An 8 Bit image is referred to as “grey-scale”, though an 8 Bit image may represent a very limited color spectrum as well. Most scanning equipment defaults 8 Bit imaging to grey-scale. The picture elements of an 8 Bit image are expressed in strings of eight bits, for example: 00001111. 8 Bit images allow for as many as 255 shades or colors. (N.B. Technically, 8 Bit images allow for 256 shade/color values, but one of these is reserved as a check-digit and is not used to express a shade/color value.)
An 24 Bit image is referred to as “true color” or, less precisely, as a “color” image. The picture elements of a 24 Bit image are expressed in strings of twenty-four bits. 24 Bit images allow for as many as 16,777,216 shades or colors. You may hear digitization specialists using the short-hand “sixteen million colors”.

Color in the 24 Bit image introduces an additional factor: channels. Because color in digital images is often a combination of three colors: Red, Green and Blue (see also: Color, Color Space, and Color Metrics below), the 24 bits is often divided into three 8 Bit channels, one for each of three composite colors. Most scanning equipment defaults 24 Bit imaging to color, with 8 Bits per channel.

**Color, Color Space, and Color Metrics**

Color fidelity is fundamental to accurate reproduction of source.

Digitization, faithful to original colors, requires a basic understanding of color and how color reproduction differs from printing technology to digital technology. Fundamental to these differences is the media on which a color image is printed.

Calibration of equipment or, at least, understanding color metrics is also important.

**Printing Technology and Color**

Paper is the media of printing technologies. Most paper is white. This much is obvious: white is given, and black must be created.

Most commercial printing technology employs four colors: cyan, magenta, yellow and black. Some consumer-market (i.e., desk-top) printers employ three colors: cyan, magenta and yellow. Combinations of these colors produce other colors. The sum of these colors produces, particularly in three-color printing, produces black.

**Digital Technology and Color**

Digital technologies are considerably different and in some ways the inverse of printing technologies. The screen is the media of digital technologies. Most screens are black - think of them in their off state. Black is given, and white must be created.

Digital technology employs three colors to do this: red, green and blue. The red, green and blue colors are referred to as channels (see also Bit-Depth above). Red, green and blue are the colors used by cathode ray tube (CRT) display systems to paint a picture on a
computer monitor. Combinations of these colors produce other colors. And, the sum of these colors produces white.

Various color-spaces and color profiles are employed to control on-screen color generation. The color space most commonly used by digitization projects and required by dLOC, is a standardized Red/Green/Blue (sRGB) color space.

The sRGB color-space was designed to match how CRT monitors produce color. Use of the sRGB color-space ensures the delivery of images as intended to the computer screen, presuming monitor calibration (see Adobe Gamma Correction tool in the Image Correction section).

Color Metrics

Digitally reproduced colors may be measured to assess digital image quality. Three controlled colors - white, black and red - are measured using standard targets as seen here.

GRAY SCALE TARGET: used to measure white and black.

COLOR TARGET: used to measure white, black, and red.
Q60 Target combines both the Grey-scale and Color targets. This target is standardized by American National Standard IT8.7/1.

The eye-dropper tool in Adobe Photoshop and other image editing software may be used to measure a color’s value (i.e., to express a color numerically). The standard RGB values of controlled colors is expressed in the following table.

<table>
<thead>
<tr>
<th></th>
<th>White Controlled Color</th>
<th>Red Controlled Color</th>
<th>Black Controlled Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red Channel</td>
<td>255</td>
<td>255</td>
<td>0</td>
</tr>
<tr>
<td>Green Channel</td>
<td>255</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Blue Channel</td>
<td>255</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

When measuring colors not from a standard target, color values will differ from these standard values depending upon source document characteristics. When measuring controlled colors from standard targets, however, values per channel (red, green or blue) should not be differ by more than ±10 from the numbers in the table above.

<table>
<thead>
<tr>
<th></th>
<th>dLOC Acceptable Color Values per Channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red Channel</td>
<td>White: 245-255, Red: 245-255, Black: 0-10</td>
</tr>
<tr>
<td>Green Channel</td>
<td>White: 245-255, Red: 0-10, Black: 0-10</td>
</tr>
<tr>
<td>Blue Channel</td>
<td>White: 245-255, Red: 0-10, Black: 0-10</td>
</tr>
</tbody>
</table>
dLOC recommends periodic calibration of all digitization equipment, including scanners and monitors. When purchasing scanners, select scanners bundled with calibration software. dLOC recommends simple steps to ensure the monitor’s color fidelity:

- **Use Adobe Gamma Correction**
  This software comes bundled with Adobe Photoshop and Adobe Elements. Similar software is packaged with other popular image processing software.

- **Use indirect lighting in scanning and quality control areas**
  Light from windows and electrical devices influence the human eye and, in turn, have impact upon image quality assessment.

- **Surround scanning and quality control areas with neutral colors**
  Colors from the environment in which scanning and quality control take place influences the human eye and, in turn, has impact upon image quality assessment.

- **Monitor calibration software**
  This software assesses on-screen color delivery and performance. It must be purchased separately.

### Choosing the Appropriate Bit Depth and Color Space

<table>
<thead>
<tr>
<th>1 Bit Image</th>
<th>8 Bit Image</th>
<th>24 Bit Image</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="1 Bit Image" /></td>
<td><img src="image" alt="8 Bit Image" /></td>
<td><img src="image" alt="24 Bit Image" /></td>
</tr>
</tbody>
</table>

dLOC recommends that 1 Bit imaging should not be used. 1 Bit images, even at very high resolution (see, Resolution below), tend to pixelate text. Imperfections on the page or artifacts of age may read as black, obscuring text in 1 Bit images. In the 1 Bit page image above, bleed through from the text printed on the inverse page as well as artifacts of age obscure the text. Obscured text will introduce imperfections that reduce the accuracy of text conversion by optical character recognition (OCR) software.
Otherwise, dLOC recommends digitizing at the bit-depth, either 8 Bit or 24 Bit, most appropriate to the source document.

Which is more appropriate? The 8 Bit image captures the textual information. And, the reader of the page can make sense of the text. Need the image do more? Readers of Latin religious texts, such as that seen above, will recognize the red text as instructions to the faithful, commentary on the spoken text of a religious service, or the narrative of the priest as opposed to that of the congregation’s response.

dLOC advocates a policy of preserving meaningful color. Meaningful color is color required to interpret the text. In the case of a newspaper with colored images, a color image accompanying an article demonstrates meaningful color, while a color advertisement may not.

It is true that “The greater the Bit Depth the greater the size of the digital image file”. But, digitization technicians are encouraged to produce images that meet the reader’s needs rather than the needs of the digitization technician to conserve space.

Resolution

The resolution of digital images is expressed in terms of pixels. A pixel is a picture element or, simply, a block of solid shade or color that, together with other picture elements comprises a digital image.
The dLOC's minimum digital resolution standard for printed text with normal sized fonts is 300 pixels per inch (ppi) or 118 pixels per centimeter (ppc). This threshold is based on both the characteristics of printed graphics and optical character recognition (OCR) tests.

<table>
<thead>
<tr>
<th>Resolution</th>
<th>Use For</th>
</tr>
</thead>
<tbody>
<tr>
<td>300 pixels per inch (ppi)</td>
<td>Printed text with normal sized fonts</td>
</tr>
<tr>
<td>118 pixels per centimeter (ppc)</td>
<td>Oversized documents and maps</td>
</tr>
<tr>
<td></td>
<td>Manuscripts with legible script</td>
</tr>
<tr>
<td>600 pixels per inch (ppi)</td>
<td>Photographs and select graphic arts</td>
</tr>
<tr>
<td>236 pixels per centimeter (ppc)</td>
<td>Printed text with very small fonts</td>
</tr>
<tr>
<td></td>
<td>Manuscripts with difficult scripts</td>
</tr>
</tbody>
</table>

300 ppi / 118 ppc

The Rationale for Printed Graphics

In general, the resolution of printed graphics does not exceed 300 dots per inch (dpi) or 118 dots per centimeter (dpc). Dots per inch/centimetre are rough equivalents of pixels per inch/centimetre; so comparison is appropriate.

Graphics printed in newspapers, for example, often have 80 to 100 dpi (32 to 40 dpc). Most graphics in magazines are printed with 120 dpi (48 dpc) print resolution while graphics in high-end magazines and on post-cards are printed with 300 dpi (118 dpc) print resolution.
Digitization of printed graphics at resolution greater than 300 ppi (118 ppc) would be excessive.

A Brief Diversion

Image processing software supports blur methods (e.g., Gaussian Blur) that can trick the human eye into perceiving an image as a photograph (i.e., continuous tone image) rather than as a series of dots. Consider, for example, these images:

- **Image as Digitized**
- **Image processed / Gaussian Blur**

dLOC recommends that blur not be used. We want to archive images faithful to the
original. Besides, when images are reduced by dLOC for Internet display, blur will be a natural artifact of the reduction process. Blur, when applied to text, also reduces the accuracy of text conversion (OCR) software.

The Rationale for Optical Character Recognition (*Text Generation*)

When a document page is digitized an image of the page is created. All text page images sent to the dLOC’s central servers are subject to Optical Character Recognition (OCR).

OCR is a process by which page images are converted to searchable text. Several OCR programs are in common use. Most are optimized for the conversion of images digitized with 200, 300, 400 or 600 ppi (80, 118, 158 or 236 ppc). Images created with other resolution can be converted to searchable text but, generally, with less accurate results.

![Printed H](image1)

![Digitized text more closely approximates the printed source as resolution increases](image2)

<table>
<thead>
<tr>
<th>Resolution and OCR Accuracy in high contrast images</th>
</tr>
</thead>
<tbody>
<tr>
<td>75 ppi Image</td>
</tr>
<tr>
<td><img src="image3" alt="Label C of d Laid Pa" /></td>
</tr>
<tr>
<td>OCR results</td>
</tr>
<tr>
<td>L <del>iC ud L</del>ddPa</td>
</tr>
</tbody>
</table>
The Importance of Bit-Depth on Text Recognition: the Latin word *Feltis* = Goodness

1 Bit Image

This letter may be any of the following: c - e - o - 0

If converted to the letter *o*, the Latin *foltis* (leafy, puffy) is formed..

8 Bit Image

This letter may be any of the following: c - e - o - 0

But, the arm of the *e* is beginning to become legible.

24 Bit Image

This letter may be any of the following: c - e - o - 0

But, the letter *e* appears now to be more probable.

dLOC central servers use the Prime Recognition OCR system, configured with six OCR engines to ensure a high level of accuracy in text generation. For printed texts with normal size fonts, whether plain (*sans serif*) or embellished (*serif*), tests demonstrate that the average modern printed document is accurately recognized at 200 ppi (80 ppc).

dLOC sets a slightly higher standard, 300 ppi (118 ppc), for printed texts with normal size fonts to compensate for occasional uses of small fonts or colored, aged (discolored), or blemished paper.

Digitization of normal printed texts at higher resolution (e.g., 600 ppi/236 ppc), in tests, generally showed no increase in text conversion accuracy. 600 ppi/236 ppc images result in higher conversion accuracy only when the source document is printed with very small fonts.
600 ppi / 236 ppc

dLOC recommends digitizing at 600 ppi (236 ppc) only when working with printed texts with very small fonts; photographs and other continuous-tone graphics, and manuscripts with difficult scripts.

A Rationale for Photographs

Photographs, unlike printed graphics, have continuous-tone. In the source document, one shade or color blends into adjacent shades and colors. Continuous-tone images may be digitized at any resolution. dLOC recommends 600 ppi (236 ppc) resolution to facilitate special uses of images.

Users of digital photographs frequently consult images for their various subjects as for the whole image. A user may want to zoom on the jewelry or hair braids in the photograph of a woman or on shop sizes in the photograph of a street scene. dLOC central servers use JPEG 2000 technology to facilitate zoom. Images digitized at 600 ppi (236 ppc) produce clearer, sharper, and more readable images than do 300 ppi (118 ppc) images.

Saving Files and Image Compression

Once the digital image is created, there remains the issue of saving or archiving the file. The digitization technician prefers not to loose a quality image to the imperfections of file saving and image compression routines.

<table>
<thead>
<tr>
<th>TIFF</th>
<th>JPEG</th>
<th>GIF</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIFF contains all image data.</td>
<td>JPEG compresses the image, seen here at leaf edges.</td>
<td>GIF also compresses the image, seen here in color patches.</td>
</tr>
</tbody>
</table>
Saving Files

When saving an image file, the technician has a choice of file types, commonly including GIF, JPEG and TIFF. GIF and JPEG (sometimes: JPG) are Internet deliverable file formats. dLOC creates these derivative or secondary file formats for participating institutions from a digital master. Institutions either not participating in dLOC or not using dLOC’s central servers, should observe similar practice.

Only the TIFF (sometimes: TIF; Tagged Image File Format) is considered archival within the international digital library community. It alone serves as a digital master. There are several reasons for this, primarily: image compression. The illustration above demonstrates image quality issues as a factor in file choice.

**dLOC Requirement for Digital Master Files.**

Save digital master as uncompressed TIFF files, compliant with the current version (version 6.0, as of 2006).

For more information on TIFF see: [http://home.earthlink.net/~ritter/tiff/](http://home.earthlink.net/~ritter/tiff/)

Image Compression

When saving an image file, often regardless file type, the technician will be given the opportunity to compress the image. Compression saves file space but has produces other and unwelcome artifacts.

There are two classes of compression: *lossy* and *lossless*.

Lossless compression is an oxymoron. Technically, a lossless image has no compression. A lossless image contains every bit of information created during the scanning process. Here is another simplification: when the scanner captures the bit-stream 1 1 1 1 → the lossless file saves 1 1 1 1. Though this makes for large files, it also makes for an ideal archival format and, therefore, optimal for file recovery should the digital master ever be damaged in use or degrade in storage.

Lossy data compression technologies attempt to eliminate redundant or unnecessary information, storing a mathematical representation of the eliminated data. Here is yet another simplification: when the scanner captures the bit-stream 1 1 1 1 → the lossy file saves a representation of 4. Because lossy images generate smaller files, they can be delivered to readers via the Internet quickly. The human eye compensates for image loss by filling in the gaps. But, because there is image loss, recovery from damage or degradation is more difficult and, in many cases, may be impossible without great expense.
<table>
<thead>
<tr>
<th>Compression Level</th>
<th>File Size</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0% Compression</td>
<td>9 KB</td>
<td>No image artifacts</td>
</tr>
<tr>
<td>50% Compression</td>
<td>5 KB</td>
<td>Image artifacts appear as dark discoloration at the bridge of the nose, and lightening together with slight blockiness at the temple.</td>
</tr>
<tr>
<td>85% Compression</td>
<td>3 KB</td>
<td>Image artifacts appear as blocky discoloration. Compression brings similar colors together, resulting in the block effect.</td>
</tr>
</tbody>
</table>