Introduction to Basic Measures of a Digital Image for Pictorial Collections

Kit A. Peterson, Digital Conversion Specialist, June 2005

Prints & Photographs Division, Library of Congress, Washington, D.C. 20540-4730

Introduction

This tip sheet introduces the technical structure of a digital image and explains the measures for digital image characteristics. The focus is on images created by digitizing photographs, including negatives, transparencies, and prints. Understanding digital image elements can help you plan effective scanning services and create rich digital master[1] images.

The process of capturing a rich digital master image that achieves "Best Practice" standards in the categories noted here depends upon a variety of factors including: quality of the equipment and software, quality control processes, operator skill, and technical and administrative support throughout the process, including management of the digital image and its metadata once the digital image is created. Consulting current standards[2] can provide the information necessary to establish a system for the digitization of photographs. Once a system is in place, benchmarking the capabilities (and understanding the limitations) of that system through testing and exploration by using targets and a sampling of representative materials will better insure a quality result in the digital images that are created.

> *Example:* See Steven Puglia, Jeffrey Reed and Erin Rhodes. *Technical Guidelines for Digitizing Archival Materials for Electronic Access: Creation of Production Master Files – Raster Images* (Washington, D.C.: National Archives and Records Administration, 2004) http://www.archives.gov/research/arc/digitizing-archival-materials.html.

The tip sheet is organized in six sections:

- What is a digital image?
- Two basic measures
    - Spatial resolution
    - Tonal resolution
- Tonal mapping
- Management: File Format & Metadata
- Related Resources
- Color systems and terminology

What is a digital image?

A digital image is an electronic file that forms into square picture elements (pixels) when displayed on a viewing device (e.g., a computer monitor). The displayed image is a two-dimensional matrix of thousands or millions of pixels each of which has its own address, size, and color representation. You might think of pixels as serving a role similar to the grains in a photograph.[3] Digitizing a photograph means converting or capturing its image electronically through a scanner or digital camera. Digital image processing software allows you to magnify an

[1] The phrase "rich digital master" refers to a digital image of sufficiently high quality to capture the essential physical and subjective visual elements of an original photograph. Such digital masters may be used for high resolution electronic or print reproduction and for creation of derivative files that aid reference and access. Rich digital masters also facilitate preservation of the digital images as electronic surrogates of the original photographs.

[2] For additional information and a list of resources for establishing quality control in the creation of rich digital masters, see Library of Congress, Prints and Photographs Division "Standards Related to Digital Imaging of Pictorial Materials," http://www.loc.gov/rr/print/cataloging.html.

[3] Steven Puglia, "Technical Primer," in *Handbook for Digital Projects: A Management Tool for Preservation and Access*, ed. Maxine K. Sitts (Andover, MA: Northeast Document Conservation Center, 2000), 84. Also available online at http://www.nedcc.org./digital/dman.pdf (hereafter cited as *NEDCC Handbook*).

image to see the pixels, and to sometimes measure the numeric color values for each pixel – like a sophisticated, computer generated, paint-by-number matrix.

People use digital images in many ways. The same image can be viewed on a wide variety of monitors, printed in many formats, and transmitted electronically through e-mails, cell phones, and other systems. Digital images are stored electronically on media such as computer hard drives, CDs, DVDs, or magnetic tapes.

Terminology: "dpi" and "ppi"
The abbreviation "dpi" (dots per inch) is a printing term that describes the number of dots in a print. This kind of measure is quite different from the square pixels per inch ("ppi") displayed in the digital image itself. Nonetheless, "dpi" has been commonly adopted to describe the resolution of digital images as well, and "dpi" is used here in place of "ppi".

Two basic measures

There are two basic measures for digital image characteristics:

- spatial resolution – capturing detail (dpi)
- tonal resolution – color, bit-depth, and dynamic range

The specifications selected for each measure determine the amount of electronic information captured to represent the original photograph. Generally, the higher the values are within these two categories, the more data will be captured representing a greater amount of photographic detail from the original.

> *Example:* To use an analogy with black-and-white copy photography: an 8 x 10 in. copy negative of a photographic print will contain more information and have greater reproductive versatility than a 35 mm copy negative of the same print. A 20 MB (megabyte) grayscale, rich digital master image will contain more information and have greater reproductive versatility than a 20 KB (kilobyte) compressed thumbnail version of the same photograph.
>
> Generally, higher spatial, tonal, and color values result in larger file sizes which give your rich digital master image a greater versatility for print and display. As with copy negatives, however, size alone does not equal quality. The quality of the source image and the capabilities of the equipment and the equipment operator also play roles in the quality of the resulting digital image.

Quality of the original object vs. quality of the digital image

The quality of the source photograph is the foundation of the digital image copy. If the source image is poor quality (e.g., out of focus), the quality of your digital image will be limited. A poor quality digital image can be made from a good quality source photograph. But a good quality digital image cannot create values unobtainable from an original source photograph.[4]

[4] One exception is deteriorated negatives, such as channeled film. Digitizing can sometimes make it possible to capture information from an otherwise unprintable image and preserve it before the negative deteriorates further. Example: Scans of negatives by Arnold Genthe described in Prints & Photographs Online Catalog, Prints & Photographs Division, Library of Congress, "Deterioration and Preservation of Negatives, Autochromes and Lantern Slides," http://lcweb2.loc.gov/pp/gendet.html.

Spatial Resolution (Spatial Frequency/dpi)

Spatial resolution is the rate at which an image is sampled during scanning. More specifically it is the *frequency* of pixels used to capture sample tones in the *space* of the object being digitized (e.g., 300 pixels per inch of the original, or 500 pixels per inch of the original). Generally, more pixels per inch means a higher resolution, but overall image quality cannot be determined by spatial resolution alone. Spatial frequency is a synonym for spatial resolution.

For a summary of sample technical specifications from nine institutions, see Library of Congress, Prints and Photographs Division, "Digital Master Images: Sample Technical Specifications for Photograph Collections," http://www.loc.gov/rr/print/cataloging.html.

There's More to High Resolution Than DPI.

A common mistake with digital images is to use dpi alone as the measure of whether an image is high or low resolution.

Whether an image is high or low resolution actually depends upon the combination of the size (height x width) of the **original** object, the dpi sampling rate used to create the **digital image**, and the ultimate presentation or reproduction uses for the digital image.

Size of original b&w negative	**dpi: digital image spatial resolution**	**Bit-depth: digital image tonal resolution**	**Digital image pixel dimensions**	**Digital image file size**	***dpi: 8x10 print resolution from digital image***	***dpi: 4x5 print resolution from digital image***
35 mm	**600 dpi**	8-bit grayscale 24-bit RGB	900 x 600	.5 MB 1.5 MB	90 dpi	180 dpi
4 x 5 inch	**600 dpi**	8-bit grayscale 24-bit RGB	2400 x 3000	7.2 MB 21.6 MB	300 dpi	600 dpi
8 x 10 inch	**600 dpi**	8-bit grayscale 24-bit RGB	4800 x 6000	28.8 MB 86.4 MB	600 dpi	1200 dpi

Using the above 600 dpi digital images, if the digital image of the 35 mm negative were printed at the negative's 1½ x 1 in. original size, then it would provide a very small photograph at the high resolution of 600 dpi. If that same digital image was printed as an 8 x 10 in. photograph, its print resolution would be at the low resolution of 90 dpi, and it would be a poor quality reproduction.

In contrast, the digital image of the 8 x 10 in. negative would make a high resolution, 600 dpi, 8 x 10 in. photographic print. The file could be printed up to 16 x 20 in. and still have a 300 dpi resolution.

Don't ask: "How high should the resolution be?" Instead, ask: "What level of resolution captures enough information from the original object to be considered high resolution in the anticipated reproduction uses?"

Illustration by Phil Michel from photograph by Jack Delano, “Cars of Migratory Tomato Wrappers. Kings Creek, Maryland,” July 1940. Farm Security Administration Collection, LC-DIG-ppmsca-08927.

Tonal Resolution (color, bit-depth, and dynamic range)

Color representation
Bitonal images have only black or white values with no shades of gray. Photographs reproduced as bitonal images would not be useful for most purposes.

Grayscale refers to the range of neutral tonal values (shades) from black to white. The color values available in grayscale mode have a tonal representation that is analogous to black-and-white photography processes and is, therefore, a good choice for representing them. Grayscale can only represent neutral monochromatic values from black to white. It will not capture other values found in certain black-and-white processes such as sepia toning, which contains brown hues in addition to blacks, white, and grays.

Generally, color can capture a much broader range of values than grayscale. “The spectrum – the band of colors produced when sunlight passes through a prism – includes billions of colors, of which the human eye can perceive seven to ten million.”[5] The electronic capture and display of color is complicated.

> “Managing the accuracy of color rendition for digital images is complex, involving the adjustment and calibration of computer monitors, the adjustment of scanner controls, the correction or enhancement of images using image processing software, the adjustment and calibration of output devices, and the use of color management software. This software transforms images between different color spaces to correct for differences in the color gamuts of scanners, monitors and output devices.”[6]

RGB is the most commonly adopted color system in cultural materials conversion because of its flexibility and its support through many applications and devices. For more information, see “Commonly Used Color Systems – RGB, CMYK, CIE L*A*B” and “Color Terminology” at the end of the document.

Establishing a controlled capture and viewing environment and implementation of a color management system will help to assure the accurate capture and representation of shades and colors in the digital image. A useful

---

[5] Oya Y. Rieger, “Color 101: Introduction to Color Theory,” in *Moving Theory into Practice: Digital Imaging for Libraries and Archives*, eds. Anne R. Kenney and Oya Y. Rieger (Mountain View, CA: Research Libraries Group, 2000), 64-65 (hereafter cited as *Moving Theory*).
[6] For an accessible introduction to understanding, creating and processing digital images see Puglia, “Technical Primer,” in *NEDCC Handbook* (see note 1), 93.

tool in this process is the incorporation of targets (and the use of software to interpret the results) as part of the system to achieve standardization. For more information on the use of targets, see Library of Congress, Prints and Photographs Division, "Standards Related to Digital Imaging of Pictorial Materials," http://www.loc.gov/rr/print/cataloging.html.

Bit-depth

The common choices for a minimum bit-depth are 8-bit for grayscale and 24-bit for color.

A **bit**, the lowest level of electronic value in a digital image, defines a pixel's color value in combination with other bits. Each bit can have one of two values: 1 or 0.

Bit-depth refers to the number of bits assigned to a single pixel and determines the number of colors from which a particular pixel value can be selected.

> *Example:* A one-bit image can assign only one of two values to a single pixel: 1 or 0 (black or white). An 8-bit (2^8) grayscale image can assign one of 256 colors to a single pixel. A 24-bit ($2^{(3x8)}$) RGB image (8-bits each for red, green and blue color channels) can assign one of 16.8 million colors to a single pixel.

Relationship of bit-depth to the number of available colors[7]

Bit-depth	Shades/colors
1-bit bitonal	black or white
8-bits grayscale	256 shades
24-bit RGB color	16.8 million colors
10-bits grayscale	1024 shades
30-bit RGB color	1 billion colors
12-bits grayscale	4096 shades
36-bit RGB color	68.7 billion colors
16-bits grayscale	65,536 shades
48-bit RGB color	2.8×10^{14} colors (281 trillion colors)

To accurately achieve a desired bit-depth without any data loss it is necessary to digitize a photograph at a higher bit-depth and then scale down to the desired bit-depth after any image processing has occurred. In addition to the loss of data from small fluctuations in the scanner, raw digital images often require minimal processing (e.g., sharpening or minimal tonal corrections). Any processing of a digital image results in some data loss. Scanning and processing an image at a higher bit-depth then reducing to the desired bit-depth minimizes the impact of the data loss and will provide a file with the desired bit-depth.[8]

---

[7] Based on Puglia, "Technical Primer," in *NEDCC Handbook* (see note 1), 92.

[8] Although they might not permit you to save an image at a higher bit-depth, some scanning systems automatically scan at a higher bit-depth and have some image processing, such as the sharpening tool "un-sharp mask," built-in to the system (e.g., without operator intervention an 8-bit grayscale image is captured at 16-bit, has "un-sharp mask" applied to the image, and then automatically reduces the image and outputs at 8-bit).

Dynamic range

Each photograph has a dynamic range that is determined by its physical properties. Dynamic range is the difference between a photograph's lightest and darkest areas. A scanner's dynamic range capabilities should meet or exceed the dynamic range of the original photograph. Dynamic range is measured on a scale from 0 to 4 (e.g., typically the range of a photographic print might fall between 1.2 and 2.0, while a transparency range could be between 3.0 and 4.0.)[9] For additional information, see Library of Congress, Prints and Photographs Division "What to Look for in a Scanner," http://www.loc.gov/rr/print/cataloging.html.

Tonal mapping

The tonal values of a photograph are represented mathematically within a digital image. For example, an 8-bit grayscale digital image can potentially contain tonal values between 0 (black) and 255 (white). Image specifications usually contain minimum and maximum value ranges for the white and black points in a digital image. Some scanning systems select those points automatically (e.g., choosing a bright spot to define the white point), but often the unique variation of the range of tonal values within photographs is better represented when a scanner operator selects these points for a given image.

Management: File Format & Metadata

Both the file format and metadata choices made for the rich digital master image should follow well-documented and commonly adopted standards in order to preserve the greatest flexibility of use for the digital image and to better insure its preservation over time (e.g., refreshing and migration).

File format

The file format of a rich digital master should be lossless.[10] Currently, uncompressed TIFF6.0[11] is the most common format choice for a rich digital master, although the lossless, wavelet compression of JPEG2000[12] offers great promise.

Metadata

The metadata for digitized photographs both describes characteristics of the original photographs and identifies technical information about the digital images. The descriptive and technical metadata is used to search, display, store, retrieve, manage and preserve the digital images, particularly within a digital image repository system.[13] A number of standards exist to guide the capture and creation of metadata. Some cover only one type of metadata, others include several types of metadata.

Examples:
Descriptive Metadata: Dublin Core http://www.dublincore.org/

Technical Metadata: Data Dictionary—Technical Metadata for Digital Still Images (NISO Z39.87-2002, AIIM 20-2002) National Information Standards Organization, "Standards Committee AU," http://www.niso.org/committees/committee_au.html

Descriptive & Technical Metadata: METS [Metadata Encoding and Transmission Standard] Library of Congress, "METS Metadata Transmission & Encoding Standard," http://www.loc.gov/standards/mets/

---

[9] Excerpted from table 3.1 in "Typical Dynamic Ranges for Source Documents," comp. Anne R. Kenney "Digital Benchmarking for Conversion and Access," in *Moving Theory,* 38 (see note 4).
[10] "Lossless" means saving an image with no data lost. "Lossy" describes a compression scheme that saves an image with some data loss.
[11] Tagged Image File Format (TIFF), copyright Adobe Systems, http://partners.adobe.com/public/developer/tiff/index.html.
[12] JPEG2000 (Joint Photographic Experts Group) Web site, http://www.jpeg.org/JPEG2000.html.
[13] Whether in a local system or contracted to a third-party provider, "A trusted digital repository is one whose mission is to provide reliable, long-term access to managed digital resources to its designated community, now and in the future." Research Libraries Group (RLG) and Online Computer Library Center (OCLC), *Trusted Digital Repositories: Attributes and Responsibilities* (Mountain View, CA: RLG, 2002), 37. Also available online at http://www.rlg.org/longterm/repositories.pdf.

Related Resources

For additional information on assessing a scanner system, see Library of Congress, Prints and Photographs Division "What to Look for in a Scanner," http://www.loc.gov/rr/print/cataloging.html.

For additional information and a list of resources for establishing quality control in the creation of rich digital masters, see Library of Congress, Prints and Photographs Division "Standards Related to Digital Imaging of Pictorial Materials," http://www.loc.gov/rr/print/cataloging.html.

Color Systems and Terminology

Commonly Used Color Systems – RGB, CMYK, CIE L*A*B

Three common color systems/models that represent color in digitization are known by their acronyms: RGB, CMYK and CIE L*A*B. RGB is the most commonly adopted color system in cultural materials conversion because of its flexibility and its support through many applications and devices. CMYK and CIE L*A*B will be briefly described here, although they are more frequently used for projects requiring sophisticated color controls, such as for a prepress service bureau.[14]

RGB: Most scanners and display devices (monitors) use RGB, which is an additive color model since it combines Red, Green, and Blue to form other colors, including white. RGB currently provides the greatest flexibility for capture of color information in a digital image. RGB can be converted to CMYK for printing purposes.

CMYK: Printing systems more commonly use CMYK, which is a subtractive color system using Cyan, Magenta, Yellow, and black (the "K" in CMYK).

"The primary colors of pigments are cyan, yellow, and magenta. We call these the *subtractive primary* colors because as you add pigments to a white page, they subtract (absorb) more light, and the reflected color becomes darker. (We sometimes find it easier to remember: you *add* additive colors to get white, and you *subtract* subtractive colors to get white.)"[15]

CIE L*A*B: The Commission Internationale L'Eclairage (CIE) develops device independent color spaces that contain a wider color gamut than RGB and CMYK. The size and complexity of the CIE color spaces, including L*A*B, means that most digital color files are commonly scanned and saved in the RGB color space.

[14] A prepress service bureau is a company whose services include providing high-resolution images in preparation for printing a document with offset printing.
[15] David Blatner and Bruce Fraser, *Real World Photoshop 6* (Berkeley, CA: Peachpit Press, 2001), 107.

Color Terminology –
The definitions noted here illustrate the complexity of representing color through the process of digitization and presentation.

Terms	**Definitions**
calibrate	"Process of matching characteristics or behaviour of a device to a standard e.g. emulsion speed or to a desired result e.g. neutral color balance. MONITOR calibration adjusts the colour balance and light intensity of a computer monitor to ensure that it reproduces a range of colours that is perceptually identical to a standard colour chart. PRINTER calibration determines the output characteristics of a printer to enable adjustments to be made to ensure accurate colour reproduction."[16]
color gamut	"Color gamut determines the limits for a set of colors (e.g., the total range of colors reproduced by a device). For example, a color is considered 'out of gamut' if its value in one device's color model cannot be mapped directly into another device's color model."[17]
color management system	A system to achieve consistency in the representation of colors between devices such as the display of a digital image on a monitor or communicating the colors to a printer. Color management systems can include: color management software, use of particular color models or color spaces at capture, and control over settings and calibration of equipment.
color palette	"The system palette (or CLUT, color look-up table) is the set of colors offered by a particular computer system."[18]
color space	"Color space refers to a particular variant of a color model (see definition below) with a specific color gamut. For example, the RGB color model includes several color spaces, such as sRGB."[19]
color system / model	"Several different systems are used to represent color images. The most common are RGB (additive color system), CMYK (subtractive color system), and the CIE-L*A*B color space, a mathematical modeling of color."[20]
device	Equipment that captures or displays colors including scanners, monitors, and printers.
device profile	"Device profiles are explicitly defined data structures that describe the color response functions and other characteristics of an input or output device and provide color management systems with the information required to convert color data between a device's native (i.e., device-dependent) color space and the PCS." ("Profile Connection Space")[21]

16 *Dictionary of Photography and Digital Imaging, the Essential Reference for the Modern Photographer*, comp. Tom Ang (London: Argentum, 2001), 52-53.
17 Rieger, "Color 101: Introduction to Color Theory," in *Moving Theory* (see note 4).
18 Ibid., 64-65.
19 Ibid., 64-65.
20 Puglia, "Technical Primer," in *NEDCC Handbook* (see note 1), 90.
21 Donald D'Amato, "Imaging Systems: the Range of Factors Affecting Image Quality, " in *Guides to Quality in Visual Resource Imaging* (Mountain View, CA: Research Libraries Group [RLG], Council on Library and Information Resources [CLIR], and the Digital Library Federation [DLF], 2000), http://www.rlg.org/visguides/.