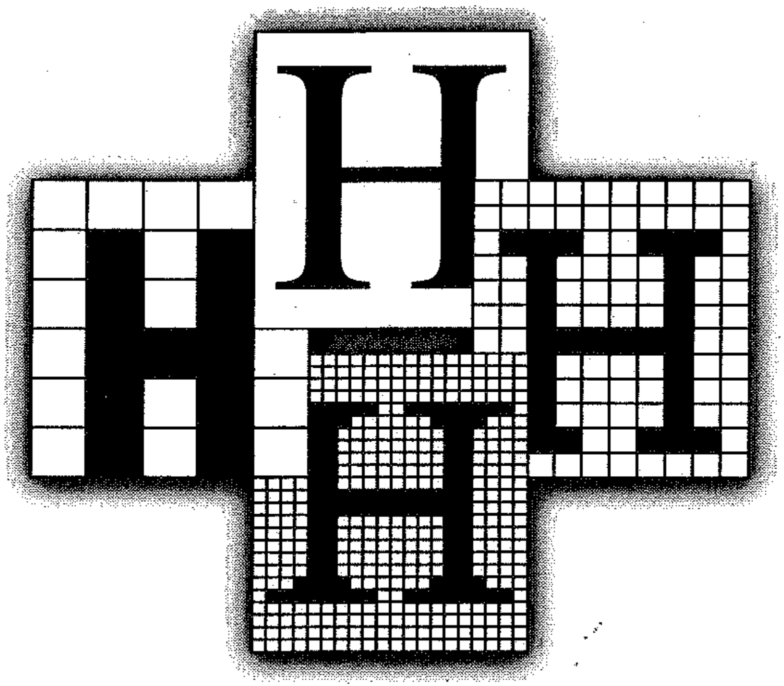
The Commission on Preservation & Access

Tutorial



Digital Resolution Requirements for Replacing Text-Based Material: Methods for Benchmarking Image Quality

April 1995

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Tutorial

Digital Resolution Requirements for Replacing Text-Based Material: Methods for Benchmarking Image Quality

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This report is one of several published by the Commission to alert and inform readers of the potentials of new technologies for the capture, storage, and retrieval of information now at risk. Previous reports have come from the Commission's Technology Assessment Advisory Committee, from institutions that have contracted to conduct demonstration projects, and from members of the Commission's Digital Preservation Consortium. The procedures discussed in this tutorial, created during several years of experiments by the Cornell University Library Department of Preservation and Conservation, will continue to evolve as they are used by other institutions and at training seminars. As with all Commission publications, the tutorial is intended to stimulate thought and discussion. It does not necessarily reflect the views of Commission members.

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Abstract

This tutorial provides a means to estimate resolution requirements for the use of digital imaging technology in converting text-based material. The authors suggest that benchmarks for resolution can be calculated by evaluating the physical attributes of source documents and by applying Quality Index formulas that have been derived from those established for preservation microfilming. The applicability of standards established for microfilming — an analog process — to image quality for material converted via digital technology may be open to some debate. This issue of comparability was addressed by the C10 Standards Committee of the Association of Image and Information Management (AIIM) in its report, *Resolution as it Relates to Photographic and Electronic Imaging* (AIIM TR26-1993). While acknowledging differences between digital and analog capture, the C10 Committee developed a Digital Quality Index formula that was derived from the Classic Quality Index formula used in the micrographics industry. Both formulas are based on three variables: the height of the smallest significant character, the desired quality to be obtained in the reformatted version, and the resolution of the recording device.

For the past several years, the Cornell Department of Preservation and Conservation has experimented with using the Digital Quality Index formula to predict resolution requirements for a wide range of documents using a number of scanning systems. The results of these experiments, and those conducted elsewhere, largely confirm the utility of the Digital Quality Index formula for bitonal (black and white) scanning, but the authors suggest a slight modification to the formula in cases where grayscale scanning is employed.

The authors caution that the use of these formulas are *for benchmarking purposes only.* Because image quality is affected by scanner performance and the operator's judgment, a continuous quality assurance program should be implemented to verify consistency of output. The scanner's performance may be assessed periodically by reproducing technical test targets specifically devised for digital imaging systems, but actual quality assurance should be confirmed by evaluating the output of representative samples of the material to be scanned. In cases where the digital files will replace the source documents, or where the source documents are widely differing, a 100% inspection of output is strongly advised. User requirements and perceptions of image quality — and the costs of conversion — should also be considered, but they should not be the driving forces in determining image capture requirements.

About the authors

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Introduction

"What resolution should I use to replace my deteriorating originals? Isn't 600 dpi considered the absolute minimum?"

"I understand that Kodak PhotoCD technology provides very good image capture, so can I just use it?"

"How can I tell when the quality of the digital image is sufficient for replacing the original?"

These and similar questions are raised by librarians, curators, and archivists as they consider the use of digital technology to preserve and make accessible materials in their care. The answer to all these questions is "it depends." Unfortunately, no commonly accepted standards for digital image quality exist today, and much of the literature on the subject tends to be highly technical or is aimed towards applications where production takes precedence over quality.

The means for determining image quality requirements will vary with the range of documents to be converted and the processes used for scanning. Different document types require different scanning approaches. Capturing finely detailed line art or small type requires high resolution, as measured by the number of dots per inch (dpi), but other documents contain features that cannot be reproduced solely by increasing the resolution. Rendering the subtlety of shading present in a black and white photograph, for instance, requires good tonal reproduction — preserving the levels of contrast between black and white — to distinguish grayscale. As with conventional light-lens technology (photography, microfilm, and electrostatic copying), resolution and tonal reproduction are the principal determinants of image quality. With digital technology, the final product will also be affected by the use of enhancement software, image compression techniques, system design and performance, and the operator's judgment and care.

This tutorial is aimed at providing librarians and archivists with some basic guidelines for establishing resolution benchmarks. It focuses on text-based documents, and primarily on those that are machine-produced. However, it also offers an initial means for assessing resolution requirements for a wide range of materials. These benchmarks are intended as a starting point for determining whether the informational content of source materials can be adequately rendered *for replacement purposes.* Image quality requirements will be high if the decision is made to dispose of the source documents themselves following conversion. If the digital image is to serve only as a reference and is not intended as a substitute for the original, then quality requirements need not be as exacting. Nonetheless, there is much to be said for specifying a level of resolution that is sufficient to render all significant detail present in the source document. It may be more cost effective to scan material *once* at a high resolution, than to rescan material at a later date when future applications might require greater image quality. Because a true high-resolution image cannot be derived from a low-resolution one, the document should be captured in a manner designed to guarantee full informational capture. Current use applications, where speed of transmission and on-screen display call for smaller file sizes, can be satisfied by deriving lower resolution images from this "archival" version. It is also possible to derive grayscale from high-resolution bitonal images to enhance on-screen readability, while relying on the full resolution image for printing.

Although resolution benchmarks can be estimated fairly easily, image quality requirements should be confirmed by thoroughly testing a group of documents that are representative of the materials to be scanned. Because requirements for general on-screen use will be lower than those for full informational capture or for printing, the results of the scanning process will have to be judged on high-resolution display monitors and through by-products, such as paper and film. The results should be confirmed by both the curatorial staff and representatives from the user community. However, it should be recognized that requirements for full image capture may not necessarily coincide with the current range of users' needs. There is often a difference between stated requirements and visual perception. Issues associated with tradeoffs between fidelity to the source material and text legibility should also be addressed.

Where to Begin

Estimating resolution requirements begins with an understanding of the material itself. In general, paper-based documents can be classified into one of four categories: text/line art, halftone, continuous tone, and mixed. The following figure provides a brief definition and examples of documents for each of these four categories. Although resolution will be important for image capture for all documents, it is most critical, and often the principal determinant of image quality, for items that fall in the first category: text and line art. If the source document contains grayscale or color, then the quality of the conversion process will be governed by a combination of resolution and tonal reproduction (often associated with "dynamic range").[1] As will be discussed later in this tutorial, capturing grayscale or color will affect resolution requirements and will result in adjustments to the benchmarking formulas for determining image quality.

Figure 1. Document Categories

TEXT/LINE ART: Can be produced by hand, typescript or machine. Usually in black and white. Includes books, manuscripts, newspapers, reports, typed or laser printed documents, blueprints, maps, line drawings, etchings, lithographs, and music scores.

HALFTONE: Color or black and white. Reproductions, usually created from a photograph, comprised of small dots or squares or hatchings, which are used to represent continuous tones. Most "photographs" in publications are halftones.

CONTINUOUS TONE: Color or black and white. Includes graphics in which all values of gray and color can be reproduced: photographs, crayon, chalk and some pencil drawings, acrylics, watercolors, and photographically reproduced facsimiles.

MIXED: Color or black and white. Refers to items containing both text and halftone or continuous tone images, such as newspapers, magazines, illustrated books, playbills, and sheet music covers. Does not include text and line drawings together.

In addition to document category, one must consider the quality of the source material itself. The level of detail, its prevalence, and its significance will all have direct bearing on the resolution required. Other issues to be considered include: the media (e.g., ink) and the support (e.g., paper), and the level of contrast between the two; the production process (machine vs. hand produced); the presence of marginalia; the sharpness (focus) of the image; and the condition of the document (is it damaged? stained? incomplete?). If film is used for conversion, one must also evaluate its condition and quality. For instance, scratches present on the film base could be reproduced on the digital image, and the process of scanning film introduces a host of other issues (e.g., reduction ratio and film density) which affect image quality.[2] The quality of a digital image will be limited by the quality of the source material. If it is of low quality, the resulting digital file will also be of low quality even if high resolution is used to record it. Capturing an out-of-focus photograph, for instance, with full gray and high resolution will still result in a fuzzy image.

The height and width of a document will also have a bearing on image quality, and may determine the kind of scanning processes used. For oversize documents that will not fit on a flatbed or drum scanner, conversion will require the use of a photo-intermediate or a digital camera. In such cases, a set scanning array is employed for digital conversion. As a consequence, scanning resolution can vary with a document's dimensions: as the size of the original increases, resolution will decrease. The physical dimensions of a page, in combination with the level of detail present on it, will affect resolution requirements for image quality. (See "Calculating Resolution from Pixel Dimensions" on page 4.)

In addition to understanding document attributes, one must consider how the technology itself affects image capture. The specific hardware and software used in digital conversion can dramatically alter results. Some scanners initially capture grayscale information which is then interpolated to produce high resolution black and white (bitonal) images. Others use software to achieve an effective resolution higher than that offered by the actual scanning matrix (e.g., effective 600 dpi from a 400 x 400 aperture). Even in cases where a scanner is used that employs a resolution capable of capturing very fine detail in a document, it is impossible to predict whether the document's features (e.g., the width of a black text character on a white background) will be aligned exactly with the scanner's detectors. "Misregistration," or "sampling error," refers to the variance from the perfect alignment that is to be expected in all bitonal scanning operations. In bitonal scanning, changing the placement of a document on the scanner's platen — even by as little as one-half of one pixel — will alter resolution and output. Different scanning technologies will have a marked influence on the output and on the accuracy of the digital resolution benchmarking formulas described below. Manufacturers' claims of scanning resolution should be carefully investigated, and one should always verify that image quality requirements have been met by examining the output(s).

In determining digital resolution benchmarks, one should consider whether standards for reproduction via microfilm or photocopy are considered sufficient for capturing the informational content of the source documents. If they are, then the image quality obtained using digital techniques may be judged, with some caveats described below, against that achieved using light-lens processes.[3]

Calculating Resolution from Pixel Dimensions

Although flatbed scanners apply the same number of dots per inch to any document — up to the maximum size that the platen will accommodate — other scanning devices typically state resolution in terms of pixels *x* pixels. In such cases, the size of the document itself will have a direct bearing on the resolution achieved. Examples of the pixel matrix dimensions of two digital cameras and the Kodak PhotoCD process are listed below.

Scanning Device	**Pixel Dimensions**
JVC TK-F 7300 Camera:	3,456 X 4,416
Kontron ProgRes 3012:	2,320 X 3,096
Kodak PhotoCD:	2,048 X 3,072*

It is important to recognize that the number of pixels refers to the dimensions (w *x* l) of a *set* scanning array of the camera. If the full scanning array, or pixel matrix, is used to capture a document, resolution will vary with the document's dimensions: as the size of the original increases, resolution decreases. For instance, the resolution of a 4" x 5" document will be ten times greater than the resolution of a 40" x 50" document.

To calculate the *effective dpi* from pixel dimensions, determine whether the aspect ratio of the source document is equal to or less than the aspect ratio of the pixel matrix of the digital camera. If it is, divide the smaller number of the pixel matrix by the width of the source document (*not* the photo-intermediate). For example, the Kodak PhotoCD (2,048 x 3,072 pixels, 1.5 aspect ratio) will capture the information in an 8.5" x 11" document (1.29 aspect ratio) with an effective resolution of 2,048/8.5, or 241 dpi. If the aspect ratio of the document is larger than that of the pixel matrix, divide the length of the pixel matrix by the length of the source document. For example, a Kontron digital camera (2,320 x 3,096 pixels, 1.33 aspect ratio) will capture the information in an 11" x 17" document (1.54 aspect ratio) with an effective resolution of 3,096/17, or 182 dpi.

Formulas: Effective dpi calculated from pixel dimensions

1) Aspect ratio of source document equal to or less than aspect ratio of pixel matrix: smaller number in pixel matrix/width of the source document
2) Aspect ratio of source document greater than aspect ratio of pixel matrix: larger number in pixel matrix/length of the source document

The following chart illustrates the relationship between the physical dimension of the source document and the achieved resolution using PhotoCD technology, at 2,048 x 3,072 pixels, 1.5 aspect ratio.

Document Dimensions	**Aspect Ratio**	**Effective DPI**
8.5" x 11"	1.29	241
10" x 20"	2.00	154
11" x 17"	1.32	186
20" x 30"	1.50	102
30" x 40"	1.33	68

* Kodak PhotoCD technology provides 5 levels of display based on pixel dimensions, from 128 x 192 to 2,048 x 3,072 pixels; the "professional" version of PhotoCD uses a scanning array of 4,096 x 6,144 pixels. For an overview of the Kontron and JVC cameras, see Peter Robinson, *The Digitization of Primary Textual Sources*, Office for Humanities Communication Publications, Number 4, Oxford University Computing Services, 1993, pp. 43-47.

How to Determine Digital Image Quality

One place to begin is to review the ways in which quality is judged in other conversion processes. The most exacting standards have been developed for the micrographics industry and are based on the Quality Index (QI) method. Indeed, the quality control procedures for microfilm inspection and the QI method to describe text legibility are well suited — with certain modifications — for use in predicting and evaluating the performance of digital imaging systems. Whether it is used for microfilming or digital imaging, QI is based on relating text legibility to system resolution, i.e., the ability to capture fine detail.[4] Provided that a microfilm camera or a scanner is performing at its optimum level, QI may be used to forecast the levels of image quality — marginal (3.6), medium (5.0), or high (8.0) — that will be consistently achieved on the use copy.

The applicability of standards established for microfilming — an analog process — to image quality for material converted via digital technology may be open to some debate. This issue of comparability was addressed by the C10 Standards Committee of the Association of Image and Information Management (AIIM) in its report, *Resolution as it Relates to Photographic and Electronic Imaging* (AIIM TR26-1993). While acknowledging differences between digital and analog capture, the C10 Committee developed a Digital Quality Index formula that is derived from the Classic Quality Index formula used in the micrographics industry. Both formulas are based on three variables: the height of the smallest significant character in the source document (usually the smallest lower case "e" measured in millimeters), the desired quality to be obtained in the reformatted version, and the resolution of the recording device.

In Classic QI, the height of the smallest significant character (h) is multiplied by the smallest line pair pattern (p) on the film version of a technical test target that an observer judges to have been resolved by the camera. The resultant number denotes the Quality Index.

$$\text{Classic QI} = p \times h$$

The extent to which Classic QI might accurately forecast text legibility depends upon visual perception, which can be subjective. This is particularly true in cases where an observer is required to inspect line pairs that are smaller than the significant characters in the source document. (See Figure 2.)

In cases where an image (analog or digital) is to serve as a *replacement copy*, a QI of 8.0 or above should be met on the use copy. At this level, full informational capture is achieved, including the rendering of serifs, when present, and/or other fine detail. Figure 3 represents enlargements of microfilmed sans-serif letters at the high, medium, and marginal QI levels. Note that in photographically reproduced images, quality degradation results in a fuzzy or blurred image.

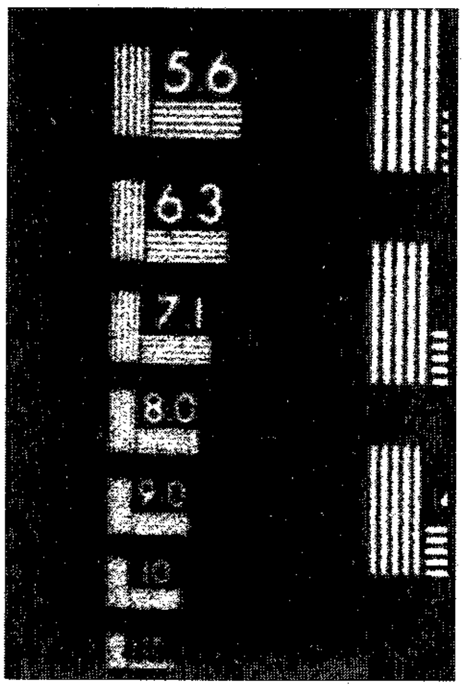

Figure 2. *Illustration of a line-pair resolution target used to determine Classic QI. As stated in MS23-1991, 8.0 represents the smallest pattern in which all five lines can be distinguished in both directions.*[5]

Figure 3. *Reproduction of a photo-micrograph illustrating Classic QIs at marginal (3.6), medium (5.0), and high (8.0) levels.*[6]

Figure 4. *Enlarged views of Spartan Medium letters, representing Digital QIs at marginal (3.6), medium (5.0), and high (8.0) levels.*

By incorporating proven microfilm inspection procedures into a quality control program for digital imaging, and by adapting Classic QI to account for the differences in the ways in which microfilm cameras and scanners capture detail, the AIIM C10 Standards Committee argues that digital resolution benchmarks for textual documents can be established in a relatively straightforward manner.

Scanning Methodologies and Compression Techniques

To convert documents to digital images, one of three scanning methods may be used: bitonal scanning, in which only black or white values are represented by each pixel; grayscale scanning, in which the values of each bit can depict gray shades in addition to black and white; and color scanning, in which the values of each bit can represent the universal range of colors. As explained below, it appears from various experiments conducted at Cornell and elsewhere that resolution requirements may differ with each of these scanning processes. In addition to the scanning process used, the type and degree of file compression will also affect image quality. Image compression algorithms are broadly classified as lossless or lossy. Lossless compression, such as CCITT Group 4 used for bitonal images, reduces the size of an image by decreasing the number of bits in an image *without losing any data.* Compressing and decompressing the file results in an exact replication of the original file. With lossy compression techniques, compressing and decompressing results in subtle changes to the file; such effects on image fidelity should be considered carefully in a preservation context. JPEG compression (used for grayscale and color images), for example, reduces the size of a file by selectively discarding some information in the image. The degree of "lossiness" can be modified by adjusting compression parameters, with resulting tradeoffs in file size and image quality.[7]

Bitonal Scanning
Means for Benchmarking Resolution Requirements

Let's begin with the most basic method of digital conversion: bitonal scanning. A fundamental distinction between light-lens processes and digital imaging is that photographic resolution is measured in line pairs/millimeter (lp/mm) and digital resolution is measured in dots per inch (dpi).[8] Given that Classic QI serves as the basis for Digital QI, it must be modified in several ways to account for these differences.

Recall that Classic QI is measured in terms of the smallest pattern of lp/mm that has been resolved on film (p), and the height of the smallest significant character (h) in the source document:

$$QI = p \times h, \text{ and } p = QI/h$$

To derive Digital QI from Classic QI, "p" must be converted to dpi. Because a *dot* occupies the same space as a *line* — if a line pair were scanned, one dot would represent the black line, and another would represent its adjacent white line — two dots must be used to represent one *line pair*.[9] This means that the dpi must be divided by two to be made equivalent to "p." Thus,

$$p = dpi/2$$

$$dpi/2 = QI/h$$

In addition, the character height (h), in millimeters, must be made consistent with the measurement for dots, in inches. One millimeter equals approximately .039 inches, so (h) must be multiplied by .039:

$$dpi/2 = QI/(h \ x \ .039), \text{ or}$$

$$dpi = 2QI/.039h$$

In this formula for Digital QI, dpi refers to a scanner's *output resolution* — the resolution consistently achieved by the scanner as confirmed by visual inspection. For example, if a QI of 8 were desired for documents containing significant characters measuring 1.0mm and above, a dpi of $(2 \ x \ 8)/(.039 \ x \ 1)$, or 410, would be required. Unfortunately, due to sampling errors, the *input resolution* of a scanner may not represent a consistent output resolution.[10] The authors of AIIM TR26-1993 advise increasing the input scanning resolution by at least 50% as a "safe requirement to account for detector-to-line misregistration."[11] In our example of the 1.0mm character that requires a 410 dpi output to achieve a QI of 8, the input resolution would have to be increased by 50%, to 615 dpi.

Although every scanner will perform at varying levels of efficiency, the authors support the AIIM C10 Committee's recommendation to begin with an assumed misregistration rate of 50% for bitonal scanning. For the past several years, the Cornell Department of Preservation and Conservation has experimented with using the Digital Quality Index formula to predict resolution requirements for a wide range of documents. Two bitonal scanners manufactured by Xerox, with nominal 600 dpi resolutions, have been used in the Cornell projects. Evaluation on high-resolution monitors and paper and microfilm outputs for these scanners reveals that

Dots Per Character Formula for Bitonal Scanning

Because character rendering forms the basis for the quality control procedures described in MS44, another useful method of determining the level of detail that a scanner or digital camera will capture is to calculate the number of dots used to represent the height of the character being viewed. Once the number of dots per character is known, the QI may be predicted, so final legibility requirements may be defined in terms of required dots per character.

The number of dots per character can be determined by multiplying x-height (h) by the input scanning resolution (dpi).

$$\text{Dots per character} = \text{dpi} \times \text{h}$$

Because character height is often measured in millimeters and resolution is measured in inches, (h) is multiplied by .039 to be converted to its U.S. equivalent:

$$\text{Dots per character} = \text{dpi} \times .039\text{h}$$

Therefore, if we know our scanning resolution and the x-height of a given character, we can determine the number of dots that will be used over its height. For example, a 300 dpi scan would produce 11.7 dots (300 *x* .039 *x* 1) for a 1.0mm lower-case letter, such as "e" or "x" (approximately 6-point type). Given that a dot occupies the same space as a line, the 11.7 dots roughly equal 12 lines/mm, or 6 lp/mm. We can then use the Classic QI formula to estimate final legibility. In this case, an output scanning resolution of 300 dpi will render a 1.0mm character at a QI of 6 lp/mm *x* 1.0mm, or 6.0.*

The Classic QI formula also informs us that 8 lp/mm, or *16 dots*, would be necessary to render the same 1.0mm character with a QI of 8.0. To obtain 16 dots over a 1.0mm character, the required resolution can be determined by dividing the dots/character by the height and multiplying by .039: dpi = 16/(.039 *x* 1), or 410. To account for possible misregistration in bitonal scanning, the formula should be adjusted by 50% to guarantee a consistent output:

Dots per character formula:

$$\text{Dots per character} = 1.5\text{dpi} \times .039\text{h}$$

Using this formula, we find that to render a 1.0mm character with the necessary 16 dots for a QI of 8.0, 24 dots are needed over the height of a 1.0mm character, and the input dpi must be increased from 410 to 615.

*To obtain a QI of 5, which is considered legible, for a 1.0mm high character, approximately 5 line pairs — or 10 pixels — would be needed over the height of the 1.0mm character. The National Archives of Canada requires 10 pixels/mm for rendering digital resolution.

the 50% adjustment for misregistration is an accurate indicator of image quality. Other scanners may perform more or less efficiently.[12] The 50% error allowance can be verified or modified based on a visual inspection of the scanner's output and performance over time.

Figure 4 displays examples of Spartan Medium letters from the IEEE Facsimile Test Chart (Institute of Electrical and Electronics Engineers, Inc.) that were scanned at various resolutions using the XDOD scanning system. The enlarged illustrations represent, in the authors' judgment, the digital equivalents to the photographically reproduced marginal, medium, and high

QI levels as presented in Figure 3. Note that in contrast to photographically reproduced letters, quality degradation with digital conversion is revealed in the ragged or stairstepped appearance of diagonal lines or curves — known as aliasing or "jaggies." Each institution should establish its own digital equivalents to the photographically reproduced characters in MS23-1991 and apply them consistently in a quality assurance program. (See "Dots Per Character Formula for Bitonal Scanning" on p. 8.)

Digital QI Formulas for Bitonal Scanning

$dpi = 3QI/.039h$

$h = 3QI/.039dpi$

$QI = (dpi \times .039h)/3$

Using the Digital QI formulas for bitonal scanning, Table 1 lists the estimated input resolution settings required to render various-sized characters at marginal, medium, and high QI levels.

Table 1

Estimated Input Resolution Requirements for Bitonal Scanning

x-height	**QI = 3.6**	**QI = 5**	**QI = 8**
0.5mm	554 dpi	769 dpi	1231 dpi
1.0mm	277 dpi	385 dpi	615 dpi
1.5mm	185 dpi	256 dpi	410 dpi
2.0mm	138 dpi	192 dpi	308 dpi
2.5mm	111 dpi	154 dpi	246 dpi
3.0mm	92 dpi	128 dpi	205 dpi
4.0mm	69 dpi	96 dpi	153 dpi
6.0mm	46 dpi	64 dpi	103 dpi

Grayscale Scanning
Means for Benchmarking Resolution Requirements

As stated earlier in this tutorial, image quality for documents containing gray or color is principally governed by the combination of resolution and tonal reproduction. The lossy compression schemes associated with grayscale and color will also affect image quality, as will system configurations. Although the Digital QI formulas established for bitonal scanning can be applied to grayscale and color, it appears from tests run at Cornell that the 50% adjustment for misregistration may not be necessary. By representing each dot with multiple bits, grayscale and color scanning renders characters with greater fidelity than bitonal scanning. For 8-bit grayscale scanning, the *input* resolution appears to be an accurate indicator of achieved *output* resolution when JPEG compression is used at levels of 10:1 (i.e., the compressed file is 10% of the original file size). (See Table 3.)

Digital QI Formulas for Grayscale Scanning
dpi = 2QI/.039h
h = 2QI/.039dpi
QI = (dpi *x* .039h)/2

In a test conducted by the Department of Preservation and Conservation at Cornell, the AIIM Scanner Test Chart #2 and a page from an early 20th-century brittle book were scanned at various resolutions with an HP ScanJet IIcx grayscale scanner. When 8 bits of gray were used, the characters were rendered on screen at levels that met or exceeded the quality predicted by the Digital QI formula, with no allowance for misregistration.[13] More research is needed to evaluate the effects of color scanning and grayscale scanning above 8 bits on resolution.[14]

Using the grayscale Digital QI formulas, Table 2 lists the estimated input resolution settings required to render various-sized characters at marginal, medium, and high QI levels.

Table 2

Estimated Input Resolution Requirements for 8-bit Grayscale Scanning and JPEG Compression at Levels up to 10:1[15]

x-height	QI = 3.6	QI = 5	QI = 8
0.5mm	369 dpi	513 dpi	821 dpi
1.0mm	185 dpi	256 dpi	410 dpi
1.5mm	123 dpi	171 dpi	274 dpi
2.0mm	92 dpi	128 dpi	205 dpi
2.5mm	74 dpi	103 dpi	164 dpi
3.0mm	62 dpi	85 dpi	137 dpi
4.0mm	46 dpi	64 dpi	103 dpi
6.0mm	31 dpi	43 dpi	68 dpi

Ongoing research at the Library of Congress and elsewhere demonstrates the potential to employ grayscale scanning to capture a range of source materials that might challenge the capabilities of bitonal scanners.[16] The use of grayscale to capture halftones will be discussed later, but it also appears that grayscale scanning can have a pronounced effect on the rendering of text/line art. When the same resolution is used in both bitonal and grayscale scanning, the addition of gray for text-based documents, including those rendered only in black and white, may lead to improved image quality *provided that the output renders the gray.*[17]

Even with added gray, however, preliminary findings from tests at Cornell suggest that input resolutions of 400 dpi should be used in order to define small artifacts with a QI of 8.[18] The Digital QI formula for grayscale scanning and the dots per character formula (see p. 8) indicate that an output resolution of 410 dpi is necessary to represent a 1.0 mm character with 16 dots over its height, for a QI of 8.0. Depending upon the amount of compression used, 300 dpi, 8-bit grayscale scanning *may* render selected detail at levels of accuracy equal to 600 dpi bitonal capture of the same source document *in instances where only marginal and medium QI levels of image quality are achieved.* But if high QI levels are desired, input resolutions of 400 dpi are necessary. Issues associated with grayscale scanning to capture text/line art — including image capture quality, on-screen display, printing, file size, compression, vendor capabilities, and cost — must be explored further.

Initial on-screen review of characters with an x-height of 0.6mm from the AIIM Scanner Test Chart #2, scanned at various bitonal and grayscale resolutions, demonstrates the effects of tonal reproduction and compression on file size and image quality. The file sizes represented in table 3 refer to the entire target (8.5" x 11"), but the image quality assessments were made only on lower-case 4-point Bodoni Italic letters.

Table 3

Image Quality and Resulting File Sizes With Bitonal and Grayscale Scanning of the AIIM Scanner Test Chart #2

Input Scanning Resolution	File Size	Compression	Digital QI	Visual QI[19]
600 dpi bitonal	4.2 MB	uncompressed	4.68	5
	.47 MB	CCITT Group 4	4.68	5
400 dpi, 8-bit	14.7 MB	uncompressed	4.68	8
	1.49 MB	JPEG at 10:1	4.68	5
	.72 MB	JPEG at 20:1	4.68	3.6
400 dpi, 4-bit	7.25 MB	uncompressed	4.68	5-8
	.71 MB	JPEG at 10:1	4.68	3.6+
300 dpi, 8-bit	8.3 MB	uncompressed	3.51	5
	.85 MB	JPEG at 10:1	3.51	3.6
	.47 MB	JPEG at 18:1	3.51	3
300 dpi, 4-bit	4.08 MB	uncompressed	3.51	5-
	.48 MB	JPEG at 8.5:1	3.51	3

An on-screen review of these examples demonstrates that the same image quality as 600 dpi bitonal scanning (QI=5) may be obtained in the *uncompressed* 300 dpi 8-bit image, but the file is approximately 17 times larger than the 600 dpi version, compressed in lossless mode. Although 400 dpi 8-bit grayscale, uncompressed, renders the Bodoni Italic in a superior manner, the file sizes for the 8-bit and 4-bit images are 31 and 15 times larger than the 600 dpi compressed version. When employing JPEG compression at levels in which the medium QI is maintained, the size of the 400 dpi 8-bit image is three times larger than the compressed 600 dpi bitonal version *and* noise and surface distortion are introduced. Finally, when file sizes for the 300 and 400 dpi 4-bit and 8-bit grayscale images approximate those for the 600 dpi bitonal image, image quality significantly degrades (QI=3.6 and below). If grayscale is to be captured, more efficient file sizes can be obtained using 400dpi than 300dpi. Both result in quality comparable to 600dpi scanning (QI of 5 for Bodoni 4-point text), but the file sizes differ significantly. The 600dpi version, compressed with CCITT Group 4, is .47MB; the 400dpi 8-bit version, with JPEG 10:1 compression, is three times larger at 1.49MB; and the 300dpi 8-bit version achieves a QI of 5 only in the uncompressed state, at 8.3MB. This preliminary test suggests that, at present, the use of gray and lower resolution may be better suited for capturing illustrated material than for capturing straight text. Further research must be carried out to establish the levels at which image quality is compromised by current compression techniques.

Verifying the Predicted Quality Index

Although standard line pair targets are effective in measuring photographic resolution, digital resolution relies on an evaluation of *character* rendering as the basis for determining image quality. This shift is reflected in the composition of technical targets designed specifically for scanning systems.[20] These technical test targets will serve as a means to verify the consistency of a scanner's performance, but a quality assurance program should be based on an evaluation of the output(s) of actual source material.

Building on the QI formula and quality control procedures presented in MS23, the AIIM C13 committee on imaging developed the *Recommended Practice for Quality Control of Image Scanners* (ANSI/AIIM MS44-1988) to provide a set of tools and instructions to ensure consistent image quality via a scanner or digital camera. Based on recommendations to establish a quality reference program in MS44-1988, and an assessment of available technical targets, the Cornell Department of Preservation and Conservation has selected three test targets for use in imaging projects. These targets are used in combination to verify consistent system performance and to evaluate the rendering of continuous tones, halftones, and text.

The first target, the IEEE Std 167A-1987 Facsimile Test Chart, is an early scanning test target designed for use with facsimile machines. It is produced photographically and includes grayscale bars, text, rules, and a continuous tone image. It also incorporates traditional line pair patterns used to test photographic systems. In their evaluation of this target, the C13 committee on imaging advised against the use of such patterns to test image resolution for systems including digital scanners.[21] Cornell uses this target to evaluate continuous tone images, but relies on two other targets for measuring resolution: the RIT Alphanumeric Test Object and the AIIM Scanner Test Chart #2. With permission from the Institute of Electrical and Electronics Engineers, Inc. (IEEE), and the Technical & Education Center at the Rochester Institute of Technology (RIT), Cornell has adapted the IEEE target to incorporate the RIT Alphanumeric Test Object. (See Figure 5.)

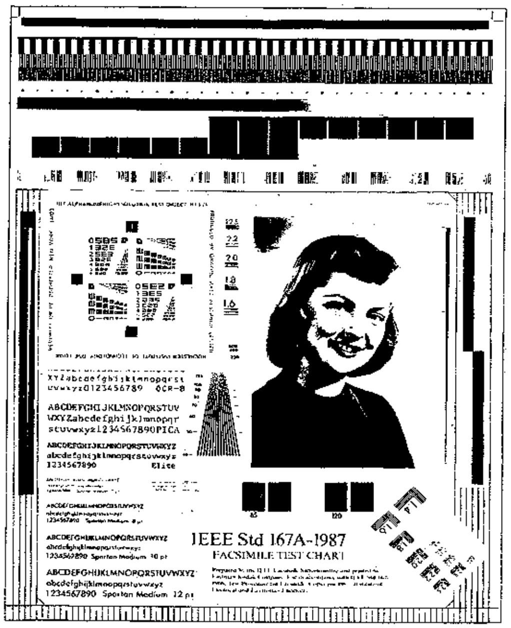

Figure 5. *3" x 3" RIT Alphanumeric Test Object superimposed on the IEEE Std 167A-1987 target.*

The RIT target consists of lines of block letters, in descending sizes, represented in two directions. During inspection, an observer must *recognize* letters, rather than *detect* resolved line pairs; therefore, disagreements among observers as to whether a target element has been resolved may be minimized. (See Figure 6 for an illustration of the RIT target scanned at 600 dpi bitonal.) The RIT target offers the ability to judge output in carefully measured increments, and thus has broad utility for a wide range of text-based material. Lacking serifs or varying line widths to represent detail, however, the block letters on the RIT target, in the authors' estimation, may not provide a great enough challenge to predict a scanner's ability to record very fine detail. The rendering of such attributes can be partially judged by resolving characters on the RIT target that are significantly smaller than the x-height of the original

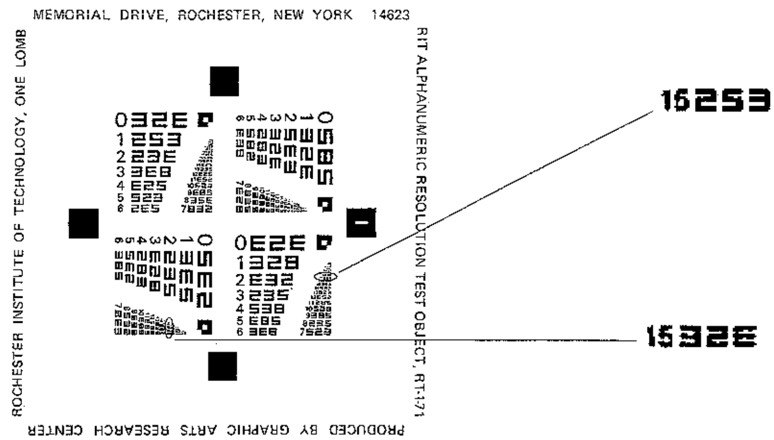

Figure 6. *RIT target scanned at 600 dpi, with enlargements of block letters in line 15.*[22]

document, but a more accurate assessment may be obtained by recording and inspecting the elaborate, serifed characters on a third target, the AIIM Scanner Test Chart #2.

The AIIM Scanner Test Chart #2 contains typefaces that will challenge most scanners, as well as grayscale bars for a range of halftone screen rulings that can be used to measure how well a scanner reproduces halftones. In contrast to the photographically produced IEEE target, it is an ink-on-paper type that more closely resembles letterpress printing common in books published in the nineteenth and early twentieth centuries. Among the typefaces represented on the AIIM target, the Bodoni Italic letters are the most difficult to render at acceptable levels of legibility. The Cornell Department of Preservation and Conservation concluded that if a scanner could render the lower case Bodoni Italic 4-point letters (0.6mm) at a medium QI level (5.0), then nearly all detail present in printed books from 1800 to 1960 could also be captured.[23] (See Figure 7.) In the authors' judgment, it appears that a quantitative as well as qualitative relationship exists between the RIT target and the AIIM Scanner Test Chart #2, and that one may be used as a check against the other in evaluating system performance and text character rendering on the output.

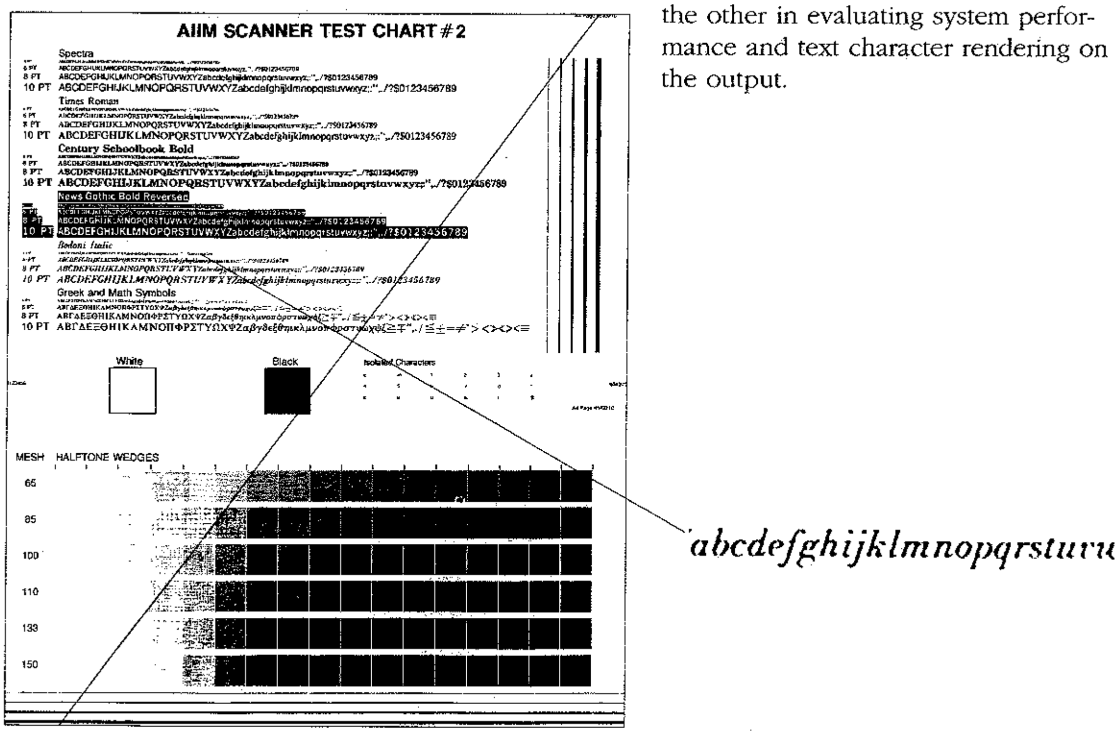

Figure 7. *AIIM Scanner Test Chart #2, and enlarged 4-point Bodoni type, scanned at 600 dpi.*

Visual Inspection

Although digital resolution formulas provide a useful means for predicting image quality and technical test targets can be used to confirm a system's performance over time, visual inspections should be carried out on a sample of materials for each scanning system employed. MS44-1988 recommends that image quality assessments should be made on the targets being used as "quality references" each time the scanner is calibrated, as well as on the textual and grayscale rendering of the originals achieved on screen and through paper and film output. The Cornell Department of Preservation and Conservation found that initial on-screen review was best performed on a high-resolution monitor where each pixel is represented by a point of light. Paper facsimiles were best reviewed with the naked eye and under magnification (5X to 10X). Microfilm was best reviewed on a light box, using a 50X microscope. Because image quality is affected by scanner performance and the operator's judgment, a continuous quality assurance program should be implemented to verify consistency of output. In cases where the digital files will replace the source documents, or where the source documents are widely differing, a 100% inspection of output was found to be unnecessary.[24]

As MS44-1988 points out, both on-screen and paper representations may introduce image distortion (e.g., wavy lines, dark or light spots, and/or aliasing). For this reason, user needs must be well understood and visual inspections should be conducted on each of the formats that will be used to provide primary or secondary access. These formats may include: high-resolution images to be displayed on high-resolution monitors; low-resolution images, derived from the high-resolution images, to be displayed on low-resolution monitors; high- and low-resolution printouts; and computer output microfilm (COM).[25]

For images created from text/line art documents, any or all of the following attributes may be considered when examining the printed page without magnification: text legibility at or above the predicted digital QI levels; full reproduction of the page, with the text or lines consistently dark throughout; sufficient contrast between text and background; characters reproduced at the same size as the original; and individual line widths (thick, medium and thin) rendered faithfully. Magnification should be used to examine the edges and other defining characteristics of individual letters: In comparison to the originals, are serifs and fine detail rendered faithfully; are individual letters clear and distinct; are adjacent letters separated as they should be; and are the open regions of characters not filled in?

For halftones or continuous tones, the following attributes should be evaluated with or without magnification, as needed: comparison of the range of tones against the original; consistent rendering of detail in the light and dark portions of the image; even gradations across the image; absence of moiré patterns and other distorting elements; and the presence of significant fine detail contained in the original.[26]

Suggested Guidelines

Although the means for estimating specific resolution requirements for replacement purposes can be derived through the use of the digital resolution formulas and confirmed through structured sampling, a number of institutions have made recommendations covering various document types. It should be noted that these are suggestive only. They have not been confirmed by the larger library or research community, nor have they been endorsed by any standards-setting bodies. Nonetheless, they can serve as a starting point in a broader discussion involving guidelines for digital image quality.

Monographs, Serials, Pamphlets and other Text-based Publications: 600 dpi bitonal scanning

The Cornell University Department of Preservation and Conservation has spent the past five years analyzing digital image quality for books published from 1850-1950. Based on this experience — including a review of 105 printers' type sizes commonly used by publishers during this period — and visual inspection of digital facsimiles for Roman and non-Roman script materials, Cornell has concluded that an input scanning resolution of 600 dpi is sufficient to capture fully the monochrome information contained in virtually all books published during the period of paper's greatest brittleness.[27] While many publications from this period do not contain fine detail or typefonts below 6-point, a sufficient number of them do. The Department of Preservation found that item-by-item decision making should be avoided because it may result in a more costly conversion process than scanning at a resolution guaranteed to reproduce all significant detail.[28]

Illustrated texts — containing line art and halftones, for which photocopy or microfilm are considered adequate for replacement purposes — can also be captured using 600 dpi bitonal scanning. For publications containing high quality color and/or grayscale reproductions which are essential to the meaning of the text, bitonal scanning, even at high resolution, will prove to be inadequate. Such publications are frequently found in disciplines such as art history, biology, or geography, and will require good tonal reproduction through color and grayscale scanning.[29]

In 1993, Don Willis, then Vice President for Electronic Product Development at University Microfilm International, authored a highly influential publication, *A Hybrid Systems Approach to Preservation of Printed Materials*, issued as one of a series developed by the Technology Assessment Advisory Committee of the Commission on Preservation and Access. The author distinguished between *archival resolution*, defined as "the resolution necessary to capture a faithful replica of the original document, regardless of cost," and *optimal archival resolution*, defined as "the highest resolution that technology will economically support at any given point in time." Willis suggested that 600 dpi with 8 bits of grayscale was currently the minimum for achieving archival resolution, and that higher resolutions may be required.[30] Although Cornell's findings suggest that *bitonal* scanning for printed text and line art is sufficient, additional research is needed to examine the interrelationship between resolution and grayscale for a broad range of source materials.

Agency Records: 300 dpi bitonal scanning

The National Archives and Records Administration (NARA) has recommended to federal agencies that a scanning resolution of at least 300 dpi be used for office documents.[31] Typewriters produce text in 10 and 12 point type, and common office laser printers and word processing software produce typefonts at 6 point and above. NARA also notes that a scanning resolution of 300 dpi will facilitate the use of optical character recognition (OCR) technology. For engineering drawings, maps, and other documents that contain fine detail, the National Archives suggests scanning at higher resolutions, up to 600 dpi or greater, and that a representative sampling of such documents be tested thoroughly to verify the appropriate input resolution.[32]

Manuscripts

NARA's recommendations are generally limited to machine-produced documents. The nature and variety of handwritten documents mitigates against establishing broad resolution benchmarks. Normally, however, letters, diaries, and the like do not contain the level of detail present in printed matter, and individual characters are rarely smaller than 1mm in height. The type and color of media used and its uneven application — especially in combination with a poor contrast between text and background — are much more problematic for digital rendering. Such documents will require tonal reproduction in grayscale or color to enhance legibility as well as fidelity to the original.

In one of the largest manuscript scanning projects to date, the Archivo General de Indias in Seville, Spain, is scanning about eight million pages documenting the Spanish colonization of the Americas. Good results have been obtained using 100 dpi resolution with 4 bits of gray (initially captured at 256 gray levels, but only the 16 most significant contiguous levels are retained).[33] However, the Seville Project did not have as a goal the use of digital imaging for replacement purposes. It is unclear from published reports whether this level of resolution provides for full informational capture. Peter Robinson, in an important contribution to the literature, *The Digitization of Primary Textual Sources*, strongly recommends that manuscript materials "of every type" be captured as full-color images, with a minimum of 300 dpi and 24-bit color.[34] Additional work needs to be undertaken with manuscript materials before image quality benchmarks can be established.

Halftone and Continuous Tone Images

A number of studies have been devoted to digital capture of photographic images. In an early study, Michael Ester, former director of the Getty Art History Information Program, examined the relationship between image quality and viewer perception. He began with the premise that image capture must take into consideration the extent to which viewers can discriminate among variations in quality, and the differences in resolution and tonal reproduction they can detect. Based on experiments with a group of art historians, Ester concluded that user perceptions vary inversely with images rendered in grayscale and in color. With grayscale, users were satisfied with 8 bits of gray but were more demanding of resolution. With color images, viewers were less sensitive to lower resolutions but required more tonal rendering — 8 bits of color were deemed insufficient; 24-bit color, with its 16.7 million possible combinations, was preferred.[35]

User perceptions are important, but they should not be the sole determinant of image capture requirements. There does seem to be general agreement that *at a minimum* true black and white photographs should be rendered by 8 bits of gray, and color photographs by 24 bits of color. No such conclusions have been reached regarding resolution. For *halftone* material, captured with grayscale, scanning resolutions have been calculated by Robinson, Willis, and others to be one and a half times the screen ruling of the halftone itself. Screen ruling measures the frequency or distance of halftone dots at an angle. Approximate screen ruling for newspaper quality halftones is 80, medium quality magazines use 130, and high quality art books use 160. The calculated resolution requirements, therefore, would range between 120 and 300 dpi.[36]

Robinson suggests using these resolutions as a guide to the digitization of continuous tone material as well. Photographic media are capable of capturing very fine detail, and the digital resolution requirements for continuous tone images will depend in part on how much detail must be retained. Ester argues that digital cameras will someday rival photography, but "this is not the case today." He suggests a good method for testing image quality is to:

> *. . . go 'film to film': to begin with the photographic source, capture it digitally, then use the digital image to regenerate the initial photographic format. Comparing the original and the digital reproduction provides an effective means of evaluation.*[37]

As with manuscript material, no general benchmarks for resolution requirements for continuous tone images have been developed.

Summary of Recommendations

This tutorial has focused primarily on the relationship between resolution and image quality, and only tangentially on the relationship between tonal reproduction and resolution. Other factors that affect overall image quality, including enhancement and compression, as well as tonal fidelity, deserve equal attention. As has been shown, there are simple means for estimating resolution requirements for capturing textual information, particularly for printed matter, but additional work is needed to establish resolution requirements for other categories of material. Investigations underway at the Library of Congress, Getty Art Museum, Image Permanence Institute, Columbia University and elsewhere promise to add to the understanding of image quality in a digital world.

In closing, there are some general recommendations for resolution requirements that should be considered by an institution contemplating the use of digital technology to convert paper and film-based materials:

- define requirements based on immediate *and* future applications, not on the basis of current technological capabilities;
- scan at high resolution, sufficient to capture essential characteristics of the source documents themselves, so as to avoid rescanning in the future; derive lower resolution images for current uses;
- set resolution requirements sufficiently high to avoid item-by-item decision making;
- confirm estimated resolution requirements by a thorough testing of representative samples of the source material and through curatorial and user review;
- evaluate image quality on high resolution monitors and through printed test pages of technical targets and actual source documents.

Rütimann, Hans, and M. Stuart Lynn. *Computerization Project of the Archivo General de Indias, Seville, Spain: A Report to the Commission on Preservation and Access.* Commission on Preservation and Access, March 1992.

Willis, Don. *A Hybrid Systems Approach to Preservation of Printed Materials.* Commission on Preservation and Access, November 1992.

Endnotes

[1]Dynamic range represents the variation in tone of any given scanned dot. In bitonal scanning, this variance may be represented as either black or white, with shades of gray represented by the clustering of black and white dots. In grayscale scanning, the range of values a dot may have — from white to lightest gray to darkest gray and black — is dependent upon the number of bits of gray or color assigned to that dot, and the amount of noise introduced by the scanner.

[2]See: Paul Conway and Shari Weaver, *The Setup Phase of Project Open Book: A Report to the Commission on Preservation and Access on the status of an effort to convert microfilm to digital imagery,* Commission on Preservation and Access, June 1994, pp. 8-9.

[3]For a detailed discussion of the differences between photographic and digital resolution, see *Resolution as it Relates to Photographic and Electronic Imaging,* AIIM TR26-1993 (Association for Information and Image Management, 1993). See also, *Practice for Operational Procedures/Inspection and Quality Control of First-generation, Silver Microfilm of Documents,* ANSI/AIIM MS23-1991; Reproduction of Library Materials Section (ALA), "Guidelines for Preservation Photocopying," 1993.

[4]For a full discussion of the Quality Index method for determining image quality, see, *Ibid.,* ANSI/AIIM MS23-1991, pp. 46-49. Although the QI formula is useful in benchmarking image quality on microfilm, it makes no distinctions for a host of document attributes that affect legibility. These include: media and support, finely detailed typefaces, use of italics and boldface, and varying line densities and width. The QI is used principally to determine text legibility, but it may also serve to measure the capture of nontextual information, such as the level of detail present in graphics, including lithographs, engravings, and woodcuts. Background color, level of contrast, and quality and condition of the original or reproduction will also affect image quality, which may not be reflected in the QI.

[5]Reprinted with permission, from a photograph, courtesy of AIIM. See, ANSI/AIIM MS23-1991, p. 45.

[6]Reprinted with permission, from a photograph, courtesy of AIIM. See, ANSI/AIIM MS23-1991, p. 48.

[7]JPEG compression is considered lossless at ratios of 2 or 3 to 1. See, National Archives and Records Administration, *Digital-Imaging and Optical Digital Data Disk Storage Systems: Long-Term Access Strategies for Federal Agencies,* NARA Technical Information Paper, No. 12, July 1994, pp. 44-45.

[8]See: *Resolution as it Relates to Photographic and Electronic Imaging,* AIIM TR26-1993 (Association for Information and Image Management, 1993).

[9]*Ibid.*, p. 8.

[10]For the purpose of this tutorial, input resolution refers to the manufacturer's stated resolution; output resolution refers to the resolution consistently achieved on screen or on paper or film.

[11]ANSI/AIIM TR26-1993, p. 12. In earlier work on guidelines for digital image quality, Thomas C. Bagg, of the National Bureau of Standards, recommended increasing the dpi by "about 30 percent" above that estimated by the Quality Index. See: Thomas C. Bagg, "Digitizing Documents: Guidelines for Image Quality," *INFORM,* November 1987, p. 8.

[12]For a description of the scanning and interpolation scheme used in the Xerox CLASS scanning system, see Anne R. Kenney and Lynne K. Personius, *Joint Study in Digital Preservation: Report: Phase I* (Commission on Preservation and Access, 1992), p. 10.

[13]At 400 dpi 8-bit gray, the Bodoni Italic 4-point letters (0.6mm) on the AIIM target were rendered on screen (17" high-resolution monitor, displaying 256 levels of gray) at a QI of 8 with lossless compression, and at a QI of 5 with JPEG 10:1 compression. The Digital QI formula, with no allowance for misregistration, predicted a QI of 4.68. In the 400 dpi 4-bit gray version, the same letters were represented at a QI of 5>8 with lossless compression, and at a QI of 5-

with JPEG 10:1 compression. Similar correlations were observed in the 300 dpi versions, for which the Digital QI formula predicted a QI of 3.51. The same letters were rendered at a QI of 3.6, with JPEG 10:1 compression, in the 8-bit version, and a QI of 3 was observed with 4-bit gray. In the case of the page from the brittle book, evaluations were made on hand-lettered characters with x-heights of 0.6mm and 0.4mm. Scanned with input resolutions of 400 and 300 dpi 8-bit gray, the 0.6mm letters met or exceeded the predicted QIs of 4.68 and 3.12 respectively, with JPEG compression up to 10:1. See: Andrew Boss, *Farm Management* (Chicago: Lyons & Carnahan, 1914), p. 100.

[14]As a preliminary test, the authors evaluated on-screen displays of four color architectural drawings from the Cornell Division of Rare and Manuscript Collections that had been digitized with 24-bits of color via the Kodak PhotoCD process. The drawings, from the John M. Nolen collection, were displayed and inspected on a 17" SVGA monitor at Level 5 with 256 colors. Examinations of text characters revealed inconsistencies in the Digital QI formula predictions. The smallest significant text characters in these drawings measure 1.1mm. Based on the dimensions of the original documents, the effective scanning resolutions achieved using Kodak PhotoCD at 2,048 x 3,072 pixels ranged from 55 dpi (for the 37" x 43.25" drawing) to 111 dpi (for the 18.4" x 20.25" drawing). Given the x-height of the smallest text and the effective dpi, the Digital QI formula for grayscale scanning predicted the following Digital QIs: 4.33, 3.34, 2.12, and 1.29. In the first two cases, the sans-serif letters were legible (Visual QI of 5). In the third example, the characters predicted to be rendered at a QI of 2.12 were marginally legible (Visual QI of 3.6) in context, but not distinguishable as individual characters in all cases. In the fourth example, the smallest characters, at the predicted QI of 1.29, were illegible.

In Columbia University's "Oversize Color Images Project," sponsored by the Commission on Preservation and Access, on-screen examinations of textual information contained in a number of color maps, scanned from paper and film, also revealed inconsistent results. For more information, contact Janet Gertz, Preservation Department, Columbia University Libraries.

[15]These input resolutions apply when using JPEG (lossy) compression up to 10:1. At 10:1, text characters are rendered well, particularly when resolutions meet or exceed 400 dpi, but surface distortions which lower overall image quality are introduced. If a lower JPEG compression ratio is used, the input resolution requirements could decrease, at the expense of file size. (See Table 3.) If higher compression ratios are used, noise and surface distortion will be visible in the decompressed image, and the Visual QIs will be lower than the predicted Digital QIs.

[16]For more information, contact Basil Manns, Preservation and Research Testing Division, Library of Congress. The Library of Congress has initiated a project to evaluate image quality of grayscale printouts of manuscript materials captured at various resolutions and compressed with several techniques.

[17]Although lower-resolution color scanning may also be considered as an alternative to bitonal scanning for text and line art, the results from a limited and preliminary test conducted at Cornell suggest that grayscale scanning, with significant savings in file size, enhances the legibility of text as well as or better than color. The Department of Preservation scanned the AIIM Scanner Test Chart #2 at 300 and 400 dpi, in both grayscale and color, with various levels of tonal reproduction. An on-screen inspection revealed that both the 4-bit and 8-bit grayscale versions represented text with greater clarity and sharpness than the 24-bit color images scanned at the same resolutions. Image quality for documents captured with grayscale and color will decrease, however, if the output does not represent the full levels of gray or color used in the conversion process. Conventional 300 dpi laser printers, for example, will not produce improved image quality for text, halftones, or continuous tones captured using grayscale scanning.

[18]In conducting on-screen inspections of the rendering of text from the AIIM Scanner Test Chart #2, captured at 300 dpi, the authors observed that the Bodoni Italic 6-point letters (x-height = 0.9mm) appeared to be rendered at a QI of 5-8, when 8 bits of gray were used. The Bodoni Italic 4-point letters (x-height = 0.4mm) were rendered at a QI of 5. When JPEG 10:1 compression was used, the image quality of the 6-point letters dropped below 5, and the 4-point to 3.6.

[19]The bitonal Digital QI formula was applied to the 600 dpi bitonal image; the grayscale Digital QI formula was used for the grayscale images.

[20]"Recommended Practice for Quality Control of Image Scanners", ANSI/AIIM MS44-1988 (AIIM, 1988). The IEEE 167A-1987 Facsimile Test Chart, the AIIM Scanner Test Chart #2, and the RIT Process Ink Gamut Chart are reviewed for their utility within a quality control program for image scanners. MS44-1988 has recently been adopted as a Federal Information Processing Standard, FIPS PUB 157, "Guideline for Quality Control of Image Scanners."

[21]*Ibid.*, pp. 5, 14. MS44-1988 advises against using "NBS 1010A bar type target resolution patterns" (i.e., line pairs) to test scanning systems with a resolution less than or equal to 600 dpi due to the problems associated with misregistration.

[22]Readings are taken from the 3" x 3" version of this target, which Cornell has pasted onto the IEEE target over the Pestrecov Star pattern. Following the guidelines in MS44-1988, Cornell performs technical inspections for resolution on-screen: for 600 dpi bitonal scanning, the target is viewed at 5X magnification on a 19" high-resolution black and white monitor; for 400 dpi grayscale scanning, the target is magnified at 5:1 on a 17" high-resolution monitor displaying 256 levels of gray. We use 5:1 magnification on a 120dpi monitor, to achieve an effective 600 dpi view. We use 5:1 magnification on a 1024 x 768 monitor to achieve an effective 400 dpi view.

[23]Anne R. Kenney, "Digital-to-Microfilm Conversion: An Interim Preservation Solution," *Library Resources and Technical Services* (October 1993), pp. 380-401; (January 1994), pp. 87-95. As predicted by the Digital QI formula

for bitonal scanning, the 600 dpi input resolution that renders Bodoni Italic 4-point letters (0.6mm) at a QI of 5 also renders characters measuring 1.0mm and above at a QI of 8. With 600 dpi bitonal scanning, the letters in line 15 of the RIT target, which measure 0.43 mm, are consistently legible on screen in both directions (see Figure 6). With 600 dpi 8-bit scanning, using JPEG compression up to 10:1, the letters in line 19 of the RIT target, measuring 0.266 mm, are legible on a high-resolution monitor displaying 256 levels of gray. Compared to bitonal scanning, this rendering of block letters at 60% the size (.266/.432) in the grayscale version suggests that a QI of 8 would also be achieved on more finely detailed text characters measuring 0.6mm and above. The on-screen evaluation of lower case Bodoni Italic 4-point letters from the AIIM target, captured at 600 dpi 8-bit, confirmed this projected quality had been met.

[24]The National Archives and Records Administration (NARA) recommends a 100% visual quality evaluation of each scanned image and related index data if the original documents are not retained following conversion. See "Digital Image Quality Assurance," NARA, *Digital-Imaging and Optical Digital Data Disk Storage Systems: Long-Term Access Strategies for Federal Agencies, op. cit.*, pp. 47-50.

[25]A project currently underway at the Cornell University Department of Preservation and Conservation, with support from the National Endowment for the Humanities, is investigating the use of 600 dpi bitonal scanning to produce raster COM that meets preservation microfilm standards for quality and permanence.

[26]See evaluation criteria presented in Appendix VI in Anne R. Kenney, with Michael A. Friedman and Sue A. Poucher, *Preserving Archival Material through Digital Technology: Final Report* (Cornell University Library, Department of Preservation and Conservation, 1993).

[27]In the Cornell projects, scanners offering nominal rather than true 600 dpi scanning resolutions were used. See Anne R. Kenney, "Digital-to-Microfilm Conversion: An Interim Preservation Solution," *Library Resources and Technical Services* (October 1993), pp. 380-401; (January 1994), p. 87-95; Anne R. Kenney and Lynne K. Personius, *A Testbed for Advancing the Role of Digital Technologies for Library Preservation and Access, Final Report, October 1993* (Commission on Preservation and Access, 1993.)

[28]As the technology advances, scanners may be set to evaluate "on the fly" image capture requirements based on a micro-second examination of the document's attributes.

[29]*Preserving the Illustrated Text, Report of the Joint Task Force on Text and Image* (Commission on Preservation and Access, April 1992).

[30]Don Willis, *A Hybrid Systems Approach to Preservation of Printed Materials* (Commission on Preservation and Access, November 1992), p. 11.

[31]Resolution requirements may change with the general introduction of 600 dpi laser printers.

[32]National Archives and Records Administration, *Long-term Access Strategies for Federal Agencies, op. cit.,* pp. 38-39. See also, ANSI/AIIM MS52-1991, *Recommended Practice for the Requirements and Characteristics of Original Documents Intended for Optical Scanning.*

[33]Hans Rütimann and M. Stuart Lynn, *Computerization Project of the Archivo General de Indias, Seville, Spain: A Report to the Commission on Preservation and Access,* Commission on Preservation and Access, March 1992, p. 7.

[34]Peter Robinson, *The Digitization of Primary Textual Sources,* Office for Humanities Communication Publications, Number 4, Oxford University Computing Services, 1993, p. 29.

[35]Michael Ester, "Image Quality and Viewer Perception," *LEONARDO, Digital Image-Digital Cinema,* supplemental issue (Pergamon, 1990).

[36]Don Willis, *op. cit.*, p. 34, and Peter Robinson, *op. cit.*, pp. 27-28.

[37]Michael Ester, "Draft White Paper on Digital Imaging in the Arts and the Humanities," Getty Art History Information Program, Initiative on Electronic Imaging and Information Standards, March 3-4, 1994, p. 7.