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An Evaluation of photo CD's resolving power in scanning various-speed films for archival purposes

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An Evaluation of Photo CD's Resolving Power in Scanning Various-Speed Films for Archival Purposes

by

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Abstract

While the advantages of digital archiving are numerous, the process has been slow to be implemented because of several limitations, particularly high costs. Photo CD shows great promise as a technology for archiving not only because of its cost-effectiveness, but also its speed, multi-resolution format, and efficient compression.

Organizations that are beginning to construct digital archives of their resources are doing so to the tune of several million images. When archiving such large quantities of images, one wants to anticipate as many future uses as possible to avoid further scanning costs. Of all potential uses for an archived image, printing on coated stock with a fine line-screen will have among the highest resolution requirements. Although the Photo CD master format offers much flexibility, there is some concern that the format does not provide enough resolution for commercial-grade printing, especially at greater enlargement percentages. In these cases, better results may be achieved with Pro Photo CD, which is more expensive and much slower, but provides four times as much resolution as the master Photo CD.

However, simply having more resolution does not necessarily translate into improved image quality. The benefit of the added resolution is likely dependent on the speed of the film and whether there really is more information in the emulsion to be captured. For films above a certain speed, the graininess of the film may offset the extra resolution provided by Pro Photo CD, and no improvement in image quality will be gained. The film speed at which this would occur is currently unknown. Testing the scan quality of various film speeds at 16*base and 64*base can help define the boundary of when Pro Photo CD offers a real advantage, if any, for archiving 35mm film. The

findings would supply some guidelines for organizations faced with making decisions about how to use Photo CD most appropriately for archival purposes.

To this end, three films of varying speeds and resolving powers were chosen: Ektachrome Lumiere 100, Ektachrome Professional 100 and Ektachrome Elite 200. Two test objects were obtained: an RIT alphanumeric resolution target and a continuous tone photograph containing objects with fine detail. Scans of these chromes were made with both Photo CD and Pro Photo CD scanners.

An objective analysis was made by observing the smallest levels resolved on the resolution target for each of the films at both the 16*base and the 64*base resolutions. A subjective analysis was conducted by a panel of respondents making paired-comparison judgments of image quality for the continuous tone test images.

It was hypothesized that differences between the 16*base scan and the 64*base scan would be detected only with the Ektachrome Lumiere 100 film in both the objective and subjective analyses. No differences were expected between the two resolutions for the other two films. This is because it was theorized that the added noise introduced by the higher grain of the faster films would offset the extra resolution provided by the 64*base scan.

The results did not concur with the given hypothesis. Instead, differences were noted for all of the tested films in both the objective and subjective evaluations. The data from the alphanumeric resolution target shows an improvement in resolving power with the 64*base resolution for all three films tested. In the subjective test, an increase was also observed in the large enlargement of the Professional 100 and the Elite 200 films. Both of these indicate that none of the films tested contained enough noise to offset the benefit of the added resolution. It should be noted that the differences observed were slight.

In terms of recommendations for choosing among Photo CD options for digital archives, the following guidelines can be concluded. All films with speeds of 100 or less will see some, though slight, added benefit from the extra resolution provided by Pro Photo CD. Films with an ISO speed rating of 200 that use fine-grain technology, such as Kodak's TGRAIN, will also see benefit from added resolution. However, in either case the benefit does not seem to subjectively matter unless the image is enlarged beyond the standard dimensional limits of 16*base. Thus, unless large-format reproduction of archived images is likely, Pro Photo CD scans are not necessary.

Chapter 1

Introduction

The Advantage of Digital Archives

Owners of large numbers of images have highly valuable assets, yet the value of these resources is limited if they cannot be easily leveraged. Managers of conventional archives know that filing, storage, and retrieval methods can be costly, time-consuming obstacles to making the most out of their assets. Even when objects can be efficiently located, they risk becoming damaged or deteriorated with age.

By digitizing resources and building an archive, these problems can be reduced or eliminated. The less apparent but perhaps most important benefit of a digital archive is the gained opportunity to save money—or even earn income—by locating and delivering a certain photo the instant it is needed, by cutting prepress expenses each time the same image is used again, or by entering a new market using new media. Having a digital archive allows its owners to:

1. Have instant access to content
2. Reuse images easily
3. Search and retrieve by keyword
4. Integrate a database
5. Cut prepress costs
6. Output to a variety of media
7. Protect assets long term
8. Enter new markets
9. Publish on new media
10. Revolutionize the role of images in their business

Digital Archiving Is Finally Becoming Feasible

While scanning costs have been prohibitively expensive for large numbers of images in the past, technologies such as Kodak's Photo CD are making large-scale digital image archives practical and affordable for the first time.

Photo CD's multi-resolution format makes it well-suited for archival purposes. Because flatbed or drum scanners only capture and store one resolution of a scanned image, each scan is limited to a particular range of uses. The choice of resolution for a flatbed or drum scan is dictated by its usage, thus, its specific requirements must be known at the time of the scan. Of course, the image size can be changed, but not without either throwing away information or interpolating new information, both of which lead to image degradation. Photo CD avoids these problems because it encompasses five different resolutions within one file, which gives it great flexibility.

Archiving requires massive amounts of storage space, thus, compression is essential. Photo CD incorporates a compression scheme that provides a combination of lossless and lossy compression. The images are scanned at the highest resolution, 2048 x 3072 pixels for standard Photo CD and 4096 x 6144 pixels for Pro Photo CD, and downsampled to a lower resolution image. As this is done, the differences between the original scan and the downsampled version of it are saved using Huffman encoding. This residual information is used to reconstruct the high-res images when needed. The result is an efficient, high-quality method of compressing 18 megabyte files to between 4 and 6 megabytes for a master Photo CD image pac.

Despite the technical strengths of Photo CD for archiving, the most persuasive reasons for using it are its speed and cost effectiveness. When scanning rolls of color negatives, the Photo CD scanner can scan over 200 images per hour for only a couple of dollars per image.

Anticipate Future Usage Before Archiving

To justify the cost of creating vast digital archives, one must be reasonably sure that each scan will fulfill the needs of most, if not all, probable uses for that image. A possible limitation of the master Photo CD is that the highest resolution, 16*base, may not provide enough resolution to handle some applications, such as printing the image at a fine line screen on coated paper. This is especially a problem when the image is being reproduced at high enlargement percentages.

Because the Pro Photo CD scanner scans at a higher resolution than the master format, it could be suitable for resolution-intensive applications such as commercial printing. However, Pro Photo CD scans are much slower and more expensive than the master scans, impeding the archiving process. Additionally, the benefit of the added resolution is limited to originals with a high enough information content to take advantage of the added resolution. Slow-speed films with greater resolving power have the ability to record more information than faster films, whose graininess impedes the amount of detailed information it can contain. It would be beneficial to know at which film speed the higher resolution offers a real advantage, if any, and whether that advantage is great enough to offset the extra time and money required. However, exactly where this limit lies is not currently known. Yet, it is the kind of information that should be considered before beginning the archival process.

Chapter 2

Theoretical Bases of the Study

The micro-image attributes of graininess and resolving power greatly influence image quality for a film original.

> Graininess is an important variable since it sets an aesthetic limit on the degree of enlargement, as well as a limit on the amount of information or detail that can be recorded in a given area of the film. Graininess can be thought of as noise or unwanted output that competes with the desired signal (the image).[1]

The graininess of a film is dictated by the average size of the light-sensitive silver halide crystals dispersed in a transparent gelatin medium. While crystal sizes vary widely within a given emulsion, higher speed films have, on average, larger crystals than slower speed films. Thus, faster films adversely affect sharpness and detail.

The resolving power of a system, or its ability to render fine detail distinguishably, is determined by both the resolution of the emulsion as well as the resolving power of the optical system, such as the camera or scanner used to reproduce it. Specifically, the measurement of the resolving power of an emulsion is affected by the test target contrast, focus, camera movement, exposure level, development, light source, and human judgment. In this study, all will be held constant, except for the emulsion itself, which will be three different films of various speeds and resolving powers.

Perhaps the most significant factor in designating the quality of a digital image is spatial resolution, or the number of pixels per linear inch captured by the scanner. In theory, the more pixels captured, the higher the image quality.

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[1] Leslie Stroebel, et al, *Basic Photographic Materials and Processes* (Boston: Focal Press, 1990), 259

However, it can be argued that simply having more pixels does not always equal better information. Paul Dangler, in a presentation at the 1994 Imaging Science and Technology (IS&T) annual conference, notes that spatial resolution does not indicate the quality of the pixels being captured. He suggests that the true relationship is that more "real" pixels—pixels with real information—result in higher image quality while pixels that convey noise rather than "signal" do not contribute anything to image quality. The quality of the pixels is determined by a number of factors, such as the modulation transfer function (MTF) of the scanner and the resolving power of the original film, which dictate how much noise is being introduced into the scan. In other words, for originals that have a lot of noise, such as grainy high-speed film originals, increasing the spatial resolution doesn't "buy" much extra information, nor added image quality.

If a good estimate can be made about how much "real" information a particular film emulsion can contain, then one knows how much real data can be captured before noisy, non-data is introduced. Research by Richard Hailstone of the Center for Imaging Science at the Rochester Institute of Technology has provided a formula for deriving the information content of an emulsion.[2] Using the MTF curve for a film, which shows the ability of that film to resolve detail at various levels of contrast, the effective pixel size of an emulsion is calculated with the following formula where S_{50} is the MTF at 50 percent modulation:

$$\frac{1}{2S_{50}}$$

The result of the calculation is pixel size in millimeters. So, for example, a 400 ISO film with an MTF curve shown in Figure 1 has a spatial frequency of 20 cycles/mm at 50%

---

[2] Richard Hailstone, "AgX/Electronic Comparison," Rochester, New York, 1991.

modulation. The pixel size is 1÷(2 x 20), or .025mm, or 25 microns per pixel. Thus, the resolution of that film is 1000 pixels per inch.

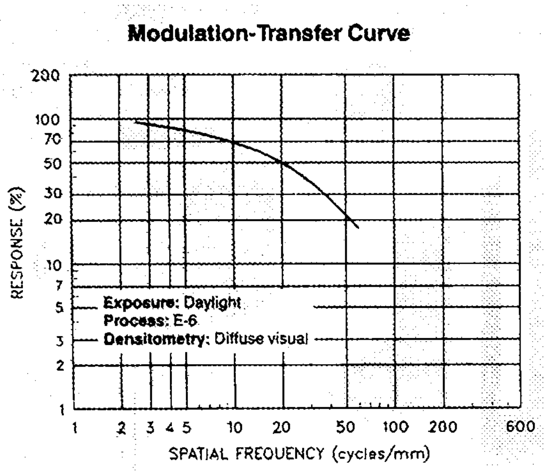

Figure 1.—The MTF curve for Kodak Ektachrome 400X film.

Chapter 3

A Review of Literature in the Field

There are noticeably few published articles or academic studies regarding the resolution capabilities of Photo CD. It is an area that, so far, has not been tested experimentally, possibly because professional applications are still only starting to be used. While there are a number of useful references with respect to the micro-image attributes of film emulsion, there is little written about how these emulsions relate to scanning devices and digital technology in general.[3]

[3] For information about film structure and emulsions, refer to sources by Abouelata, Freeman, and Stroebel in the bibliography section.

Chapter 4

Hypotheses

The aim of this study is to test the scan quality of various film speeds and resolving powers at 16*base and 64*base resolutions to define the boundary of when Pro Photo CD offers a real advantage, if any, for archiving 35mm film. For films above a certain speed, the graininess of the film may offset the extra resolution provided by Pro Photo CD, and no improvement in image quality will be gained. It is theorized that the reason for this is that once the scanning resolution exceeds the information content of the film emulsion, no further information is derived from increasing the resolution of the scan.

If the information content of a particular emulsion can be calculated, as with the formula provided by Hailstone, then the point at which no further information can be gained from increased resolution can be deduced for that type of film. It should theoretically occur when the calculated information content of the film is less then the resolution of the scan.

Because high-speed films have a lower information content than slower films, one would expect that the information capacity of high-speed films is less likely to exceed the scanning resolution. Specifically, of the three films selected for this study, only one, the Ektachrome Lumiere 100, has a calculated information content that will exceed Photo CD's 2000 ppi scanning resolution. Table 1 documents the data for each film type, while Appendix C features the MTF curves used in these calculations.

Thus, the hypothesis for this study is as follows. For the Lumiere 100 film, a difference in resolution and image quality is expected between the 16*Base and the 64*Base scans because the calculated resolution of the film exceeds that of the

Table 1.—Calculated information content of tested film types.

Film type	Spatial Frequency at 50% response (cycles/mm)	Derived information content (pixels per inch)
Ektachrome Lumiere 100	50	2540
Ektachrome Professional 100	32	1588
Ektachrome Elite 200	35	1814

Photo CD 2000 scanner. The 64*Base scan should both resolve more lines on the resolution target, and provide higher image quality in the continuous tone image. (See the Methodology section for an explanation of the selected test objects and films.) However, for the other films, the Ektachrome Professional 100 and the Ektachrome Elite 200, no difference is expected between the 16*Base and 64*Base because the information content of the film is less than the resolution of the Photo CD 2000 scanner.

Chapter 5

Methodology

In order to provide a recommendation for which form of Photo CD to use when archiving film of various speeds, a comparison of 16*base and 64*base Photo CD scans of three types of film originals was made. Specifically, there were two comparisons made: one objective comparison using a RIT resolution target and one subjective comparison using a continuous tone test image.

For each comparison, the test object or scene was photographed on a copystand using films of three different speeds and/or resolving powers: Kodak Ektachrome Lumiere 100, Kodak Ektachrome Professional 100, and Kodak Ektachrome Elite 200. These films were chosen on the basis of their published modulation transfer function curves; according to the information content formula suggested by Hailstone, the numbers of "pixels" for these films fall on both sides of the scanner's maximum resolution capacity. (See Appendix C for MTF curves and Table 1 for calculated information content data.) Additionally, chromes were chosen over color negatives because it is the format that film archives are typically stored in.

Note that two films of ISO 100 were chosen, along with one 200 ISO film. This is because it was noted in the film selection process that films of the same ISO could possess very different resolving characteristics. For example, among the Ektachrome films, the ones that employ Kodak's TGRAIN technology, such as the Lumiere and the Elite lines, have a greater ability to capture fine detail than those that do not, such as the Ektachrome Professional films. So while the hypothesis of this study claims to find the speed at which there is no longer a difference, in actuality, the difference is

dependent on the specific resolving capabilities of the film, which is closely related to but not dictated by film speed. These films were chosen to illustrate that point.

A fourth, high-speed film, Ektachrome P1600, had also been selected and was used along with the other films to shoot the test images; however, an error in processing prevented its inclusion in the study.

Photographic conditions were held as constant as possible. Two scenes were set up on the copystand; one consisting of the RIT resolution target and the other comprised of objects containing fine detail, such as fruits and vegetables, fabrics, flowers, and currency. The composed test scene also contained an 18% gray card and a Kodak step wedge for evaluating exposure. For both test scenes, correct exposure for each film was determined with a light meter and bracketed. Although shutter speed could not dictate exposure because of the strobes, the final exposures for all film types differed by only one f-stop, minimizing differences in depth of field. Care was taken in focusing the image to maximize depth of field and was standardized between images with the aid of the camera's green indicator light for auto-focusing. The height of the camera from the copystand was fixed for each particular test target, although the resolution target required the camera to be much closer than did the collection of objects. After shooting, all films were processed together with the E-6 process at the same photo finisher.

Each of the films were then scanned on both the Photo CD and Pro Photo CD scanners using the E-6 film term. They were acquired directly into the CIELAB color space using the Kodak CMS Photo CD plug-in module for Adobe Photoshop version 3.1.2 for Macintosh. Respectively, the 16*base and 64*base scans of the resolution target were each displayed on a monitor at 1:1, and the smallest resolved targets were identified for each image. A matrix with the results, as outlined in Table 2, was created.

Table 2.—Matrix for comparing resolving power of the resolution target scans.

Film type	16*Base scan	64*Base scan
Ektachrome Lumiere 100	target #	target #
Ektachrome Professional 100	target #	target #
Ektachrome Elite 200	target #	target #

This matrix facilitated an analysis of whether the 64*Base scan resolved more information than the 16*Base scan for each of the three film types. The identification numbers for the smallest targets resolved by each scan were recorded in each cell.

The continuous tone images were converted to CMYK with Linotype-Hell's LinoColor software and output at two different enlargement percentages to be visually and subjectively compared for image quality. In trying to anticipate all possible uses, the most demanding application for an archived image would be to use it in commercial printing. To simulate this, the images were output with a 150 line screen on commercial proofing stock using a 3M Rainbow proofer. The proofs were created, then cut and mounted onto individual boards for judging.

Because enlargement percentage has an affect on image quality, the images were reproduced at two sizes to help determine at which point the difference in the amount of information is noticeable. The chosen enlargements were derived by calculating the maximum dimensional size for a 16*base image, based on a 150 line screen and a sampling ratio of 2:1, which is approximately 6.8 by 10.2 inches. Another size was derived from this base size by doubling that area. Table 3 shows the combination of resolutions, films, and sizes that were compared.

In resizing the images, the actual resolution, or amount of data captured by the scanner remained the same. With the exception of the smaller enlargement of the 64*base images, no data was added or thrown away, only the pixels-per-inch tag was

Table 3.—Matrix for paired-comparison of the continuous tone test image.

Film type	16*Base scan	64*Base scan
Ektachrome Lumiere 100	6.83 x 10.24 @ 300 dpi	6.88 x 10.21 @ 383 dpi
	10 x 15 @ 204 dpi	10 x 14.83 @ 395 dpi
Ektachrome 100	6.83 x 10.24 @ 300 dpi	6.89 x 10.21 @ 383 dpi
	10 x 15 @ 204 dpi	10.08 x 14.94 @ 395 dpi
Ektachrome P1600	6.83 x 10.24 @ 300 dpi	6.87 x 10.21 @ 383 dpi
	10 x 15 @ 204 dpi	9.985 x 14.83 @ 395 dpi

changed to affect the dimensional size of the image. It was done in this manner because the purpose of the study is to assess the effectiveness of the amount of data captured by each scanner. In order to produce greater enlargement percentages from the fixed resolution captured in a scan, the pixels must also become larger, or new pixels must be added. The point at which this becomes noticeable will, of course, happen sooner with a lower-resolution scan than a high-res one. Thus, this method was chosen to determine whether the amount of resolution present in the scans is good enough for the given enlargement percentages. However, not all of the scans could keep all of their resolution—for the 6.8" x 10.2" 64*base scan, some data had to be thrown away because the dpi required to produce that dimensional size was so much higher than the resolution of the output device that it would not have provided higher image quality, only very long processing times. It should be noted that the dpi chosen for that particular image was still much higher than that of the 16*base scan. Again, Table 3 references the sizes and dpi of each of the test images.

Finally, the prepared images received no unsharp masking because the intention of this study is to compare the two Photo CD scanners' detail-rendering capabilities head-to-head, without the introduction of post-scan enhancements.

A panel of twenty judges was recruited to make the paired-comparison judgments of image quality for these continuous tone test images. Respondents included people with varying levels of expertise in prepress or assessing images. Each pairing showed images from both scanners, for one kind of film at one enlargement percentage. The images were mounted on boards and shown under standard 5000° K lighting conditions, identified only by a letter code. For each pair, respondents were asked which of the images they believed to have a greater amount of detail in the images. They were also given the option to report no apparent difference between the two images. For the complete questionnaire used by participants, refer to Appendix A.

Results for each pair were tabulated and analyzed to determine differences in perceived image quality between the two scanners for each of the film types. By reviewing the pattern of significant differences, if any, as well as differences from the resolution target test, it was determined whether or not the hypothesis was supported. Regardless, the analysis helped to provide recommendations about which film speeds benefit from the additional resolution provided by Pro Photo CD, and which do not. These recommendations have come from both objective and subjective sources.

Means

A summary of the materials and resources that were required for this project are as follows: 1) an RIT alpha-numeric resolution target, 2) a test image containing subjects with fine detail, 3) a neutral gray card for controlling exposure, 4) one roll each of films of various speeds, including Kodak Ektachrome Lumiere 100, Kodak Ektachrome Professional 100, and Kodak Ektachrome Elite 200, 5) six Kodak Photo CD scans (three films by two test images), 6) six Kodak Pro Photo CD Pro scans (three films by two test images), 7) Rainbow prints of the eighteen test images, and 8) a panel of judges for the paired-comparison of test images.

Usage of the Photo CD 2000 scanner was provided by Applied Graphics Technologies of Rochester, New York, free of charge. They provided access to a copystand and camera for shooting the test objects. All film was processed at the same time by Spectrum Color Labs.

The Pro Photo CD scans were obtained from another supplier, American Images. For the paired comparison testing, a standard 5000° K viewing booth was set up with the mounted Rainbow proofs. Respondents were scheduled for the paired-comparison evaluations over a one-week period.

Cost

The only costs for this project were: 1) the cost of the three rolls of film, 2) the cost of film processing, 3) the cost of obtaining the Pro Photo CD scans, and 4) the cost of mounting materials for the paired-comparison testing.

Chapter 6

The Results

The findings of this study do not lend support for the hypothesis as stated. Unpredicted differences appeared in both the objective and the subjective evaluations.

For the objective study, a difference between the 16*base and 64*base resolutions was expected for only the Lumiere 100 film. Instead, a difference was seen for all three films, although the greatest difference was found with the Lumiere 100. This suggests that the higher grain of the Professional 100 and the Elite 200 films did not create enough noise to offset the benefit of the added resolution. It should be noted that the differences found, while there, were slight, with the Pro and Elite films varying only by about one level. The complete data, shown in Table 4, includes the four readings taken from each target and the arithmetic mean for each.

The overall order in which the film types are ranked by the data is consistent with the published data for those films' resolving powers. The Lumiere is reported as

Table 4.—Raw data and calculated means for RIT alphanumeric resolution target.

Film Type	16*base	64*base
Ektachrome Lumiere 100	19 19 20 20 19.5	23 21 20 22 21.5
Ektachrome Professional 100	19 19 18 19 18.75	20 20 20 20 20
Ektachrome Elite 200	19 19 19 20 19.25	20 21 20 20 20.25

having the greatest resolving power in Kodak's product literature, followed by the Elite 200, and then the Professional 100. (Unlike the Lumiere 100 and the Elite 200, the Professional 100 film does not utilize Kodak's TGRAIN technology, which is why it has a lower resolving power than the slower 200 speed film.) However, the Elite 200 film showed slightly less difference on average between the 16*base and 64*base scans than did the Professional 100 film. The hypothesis had predicted more difference between resolutions with greater resolving power.

The subjective evaluation also deviated from the predicted results. Figure 2 shows the breakdown of participants' responses when asked to indicate which of the

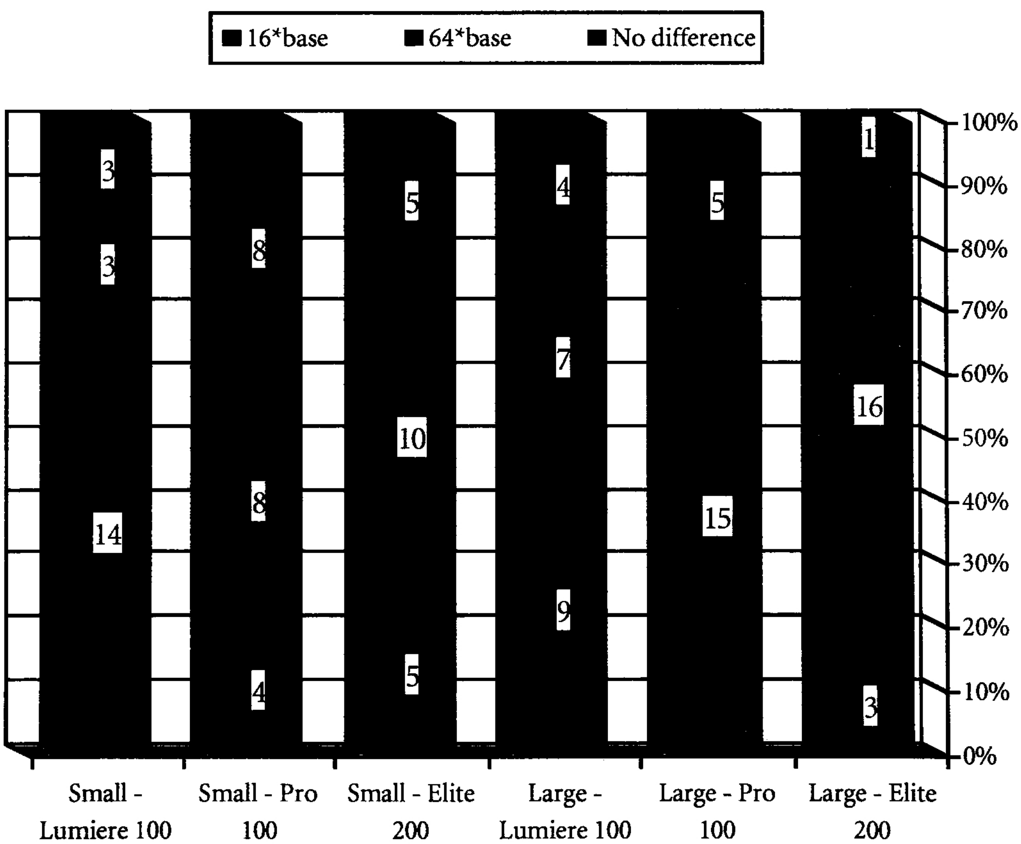

Figure 2.—Frequencies of responses to subjective paired-comparison test

paired images had a greater amount of detail. Each bar represents one pair of images of the same film type at a certain enlargement size (small or large), with the numbers indicating how many people chose that resolution as having more detail. The chart reflects the responses of twenty participants. Refer to Appendix B for source data.

As expected, the results were somewhat different for the two enlargement sizes. For the smaller enlargements, significantly more people chose the 16*base image than either the 64*base image or the no difference option for the Lumiere 100 film. This is exactly the opposite of the expected result. However, for the Pro 100 and Elite 200 films, differences between the two resolutions were harder for the respondents to discern, as the responses are spread out fairly equally among the choices. This would indicate that there is little perceived difference between the 16*base and the 64*base scans for the Pro 100 and Elite 200 at the small enlargement, which does, in fact, correspond to the hypothesized result. (For the Elite 200, there was slight favoritism toward the 64*base scan.)

For the large format images, the results are quite different. Again, the 16*base resolution is preferred for the Lumiere 100 film, but this time only slightly over the 64*base. For the Pro 100 and Elite 200 films, there is an overwhelming preference for the 64*base resolution. The level of noise of these grainier films must have been low enough so that the higher resolution scan was able to capture additional information from the chrome, but high enough to differentiate it from the Lumiere film.

While this completely conflicts with the hypothesis, sense can be made of it, particularly in light of the differences observed in the objective portion of the study. The Lumiere film, which has the highest resolving power, appears to have the highest image clarity of the three films in both the 16*base and 64*base scans. Thus, it may be that because both images were clear and looked favorable, respondents had a hard time

telling the difference between them, and in many cases, even preferred the lower resolution scan. This is in spite of the objective resolution target test, which substantiates some difference between the two resolutions. In contrast, with the grainier Pro 100 and Elite 200 films, the two resolutions were more distinguishable from each other. While this was not especially true at the small enlargement percentage, it became much more clear at the larger percentage, when at least three-quarters of respondents chose the 64*base scan as having more detail. Perhaps when the images look good it's harder to see a difference, even when it is there, than when the image looks more unfavorable.

Uncontrollable variables may have also had some effect on the subjective judging. While all efforts were made to keep factors that affect image quality constant, empirically it is impossible to avoid some variance. Slight inconsistencies of focus, depth of field, and exposure could impact the perceptions of the judges in making their determinations.

Chapter 7

Summary and Conclusions

This intent of this study was to evaluate 16*base and 64*base scans of films of various speeds to define the boundary of when Pro Photo CD offers a real advantage, if any, for archiving 35mm film. Although these boundaries are not as hypothesized, these results do indeed provide some insight.

The data from the alphanumeric resolution target shows an improvement in resolving power with the 64*base resolution for all three films tested. In the subjective test, an increase was also observed in the large enlargement of the Professional 100 and the Elite 200 films. Both of these indicate that none of the films tested contained enough noise to offset the benefit of the added resolution.

An explanation for this may be that Hailstone's formula is not assessing the information content of the film in a way that is generous enough. It appears that the film conveys more pixels than the formula predicts. Thus, in relation to the resolution of the Photo CD scanner, all of the chosen films may have exceeded it, resulting in the perceived differences between the 16*base and 64*base resolutions. Testing a greater range of film speeds, especially of 400 ISO and higher, might result in an information content less than the Photo CD 2000 scanner is capable of capturing, and thus, a lack of noticeable differences between regular Photo CD scans and Pro scans.

It should be noted that the differences observed were slight. In the objective test, an average of only one extra step was resolved in the 64*base files for the Professional 100 and Elite 200 films. And while respondents did overwhelmingly choose the 64*base image over the 16*base image for the bigger enlargement of the

Professional 100 and Elite 200 films, most respondents commented on how difficult it was to choose which one was the best. This was also apparent in the amount of time that respondents spent with each set of images: most scrutinized each pair for at least two or three minutes.

It also appears that the differences noted in the objective study didn't seem to matter when the image was reproduced at smaller enlargement percentages. Because people tended to choose the Pro scans equally as often as the regular Photo CD scans for the small images, it appears that there is no added benefit from Pro Photo CD when the image will be printed within the limits of the 2:1 pixel-to-line screen ratio. However, at the greater enlargement percentage, the difference appears to be easily discernible, as the vast majority of respondents chose the 64*base resolution as having more detail. It is still unclear why the 16*base resolution was favored by respondents for the Lumiere 100 film, particularly in the smaller enlargement.

In terms of recommendations for choosing among Photo CD options for digital archives, the following guidelines can be concluded. All films with speeds of 100 or less will see some, though slight, added benefit from the extra resolution provided by Pro Photo CD. ISO 200 films that use fine-grain technology, such as Kodak's TGRAIN, will also see benefit from added resolution. However, in either case the benefit does not seem to subjectively matter unless the image is enlarged beyond the standard dimensional limits of 16*base. Thus, unless large-format reproduction of archived images is likely, Pro Photo CD scans are not necessary.

Another significant point to remember is that resolving power is not dictated precisely by film speed, rather, it is an element of the MTF curve. The Elite 200 film actually has greater resolving power than the Professional 100 film according to their MTF curves, and this was empirically confirmed through the objective test using the

RIT alphanumeric target. Thus, film speed alone is not conclusively a determining factor; one must do a little research into what the MTF curve of a film is before making decisions about archiving.

To further understand the advantages of the 64*base resolution for 35mm film, additional testing is recommended. One possibility, as previously mentioned, is to try films of higher speeds than those selected for this study, such as 400 ISO and higher, to see whether or not the higher resolution files continue to offer improved image quality. Another is to change the focus of the questionnaire used in collecting subjective data from respondents. Because participants were encouraged to choose one of the images as better than the other, it is not known whether the image *not* chosen offered acceptable quality.

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Appendix A

Appendix A

Survey Questionnaire Used For Obtaining Subjective Comparison Data

Instructions — Please read carefully!

Thank you for agreeing to be a participant in the following research study. The objective is to evaluate the amount of detail found in a scanned image.

As a respondent, you will be comparing six pairs of images with regard to the amount of fine detail that is present. For each pair, you will choose which image shows more detail. If neither image has a greater amount of detail, you may indicate that there is no difference between them.

Please remember to evaluate the images only on the basis of detail, NOT color or exposure. Any color differences between the images should be disregarded. Be sure to consider each of the objects in the scene in making your determinations. Finally, you may look at the proofs closely, but you should try to keep your viewing distance fairly constant for all of the images.

Thanks again, in advance, for your participation.

Set 1

Which of the two images is able to show the finest detail?

(pair 1)	❑ Image A	❑ Image B	❑ no difference
(pair 2)	❑ Image C	❑ Image D	❑ no difference
(pair 2)	❑ Image C	❑ Image D	❑ no difference

Set 2

Which of the two images is able to show the finest detail?

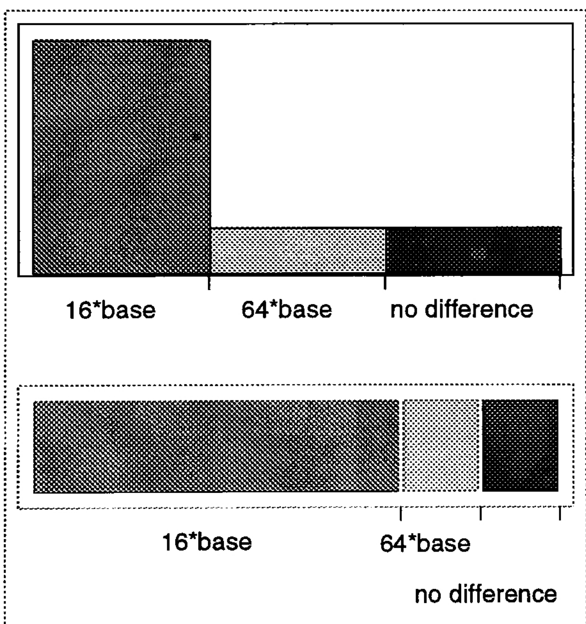
(pair 1)	❑ Image A	❑ Image B	❑ no difference
(pair 2)	❑ Image C	❑ Image D	❑ no difference
(pair 2)	❑ Image C	❑ Image D	❑ no difference

Appendix B

Appendix B

Detailed Frequency Data and Descriptive Statistics for Subjective Comparison

The figures listed in this appendix illustrate the complete frequency data for the subjective paired-comparison of the continuous tone image, obtained with the questionnaire in Appendix A. These figures are the source for the data summarized in Figure 2. The data is based on the responses of twenty participants.



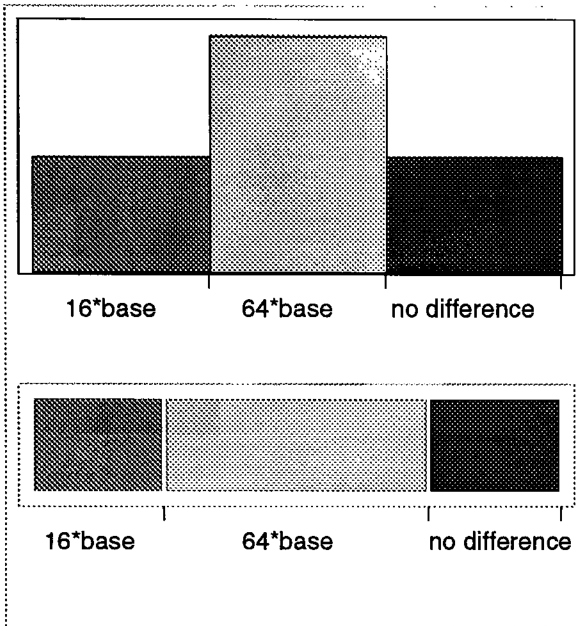
Summary

Number of Levels	3
Total Frequency	20
Total LogLikelihood	16.376169

Profile

Level	Count	Probability
16*base	14	0.70000
64*base	3	0.15000
no difference	3	0.15000

Figure 3.—Data for small enlargement, Ektachrome Lumiere 100 film.



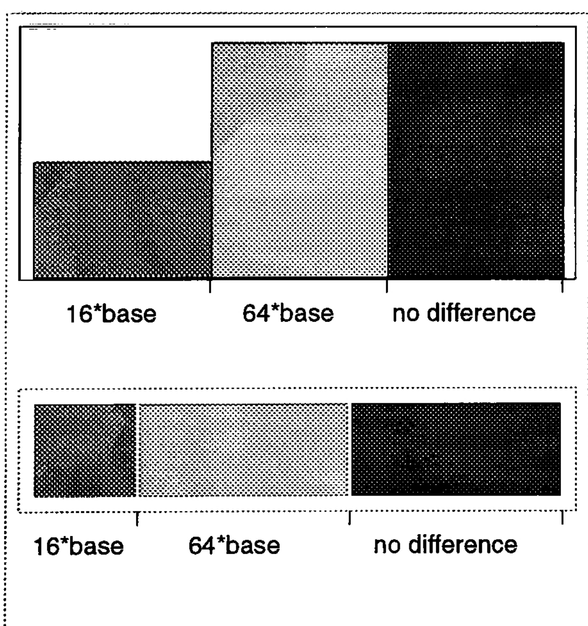
Summary

Number of Levels	3
Total Frequency	20
Total LogLikelihood	20.794415

Profile

Level	Count	Probability
16*base	5	0.25000
64*base	10	0.50000
no difference	5	0.25000

Figure 4.—Data for small enlargement, Ektachrome Elite 200 film.



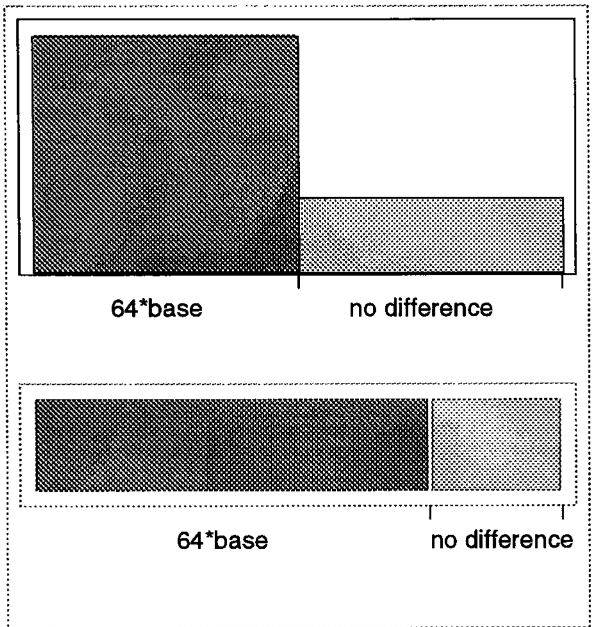
Summary

Number of Levels	3
Total Frequency	20
Total LogLikelihood	21.098403

Profile

Level	Count	Probability
16*base	4	0.20000
64*base	8	0.40000
no difference	8	0.40000

Figure 5.—Data for small enlargement, Ektachrome Professional 100 film.



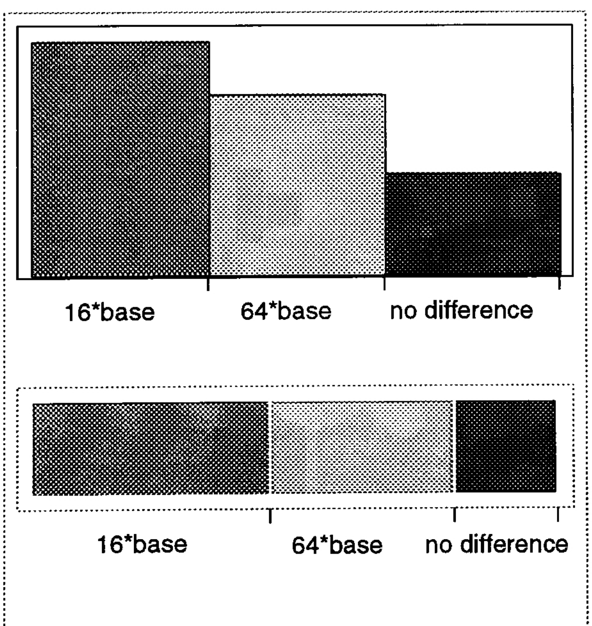
Summary

Number of Levels	2
Total Frequency	20
Total LogLikelihood	11.246703

Profile

Level	Count	Probability
64*base	15	0.75000
no difference	5	0.25000

Figure 6.—Data for large enlargement, Ektachrome Professional 100 film.



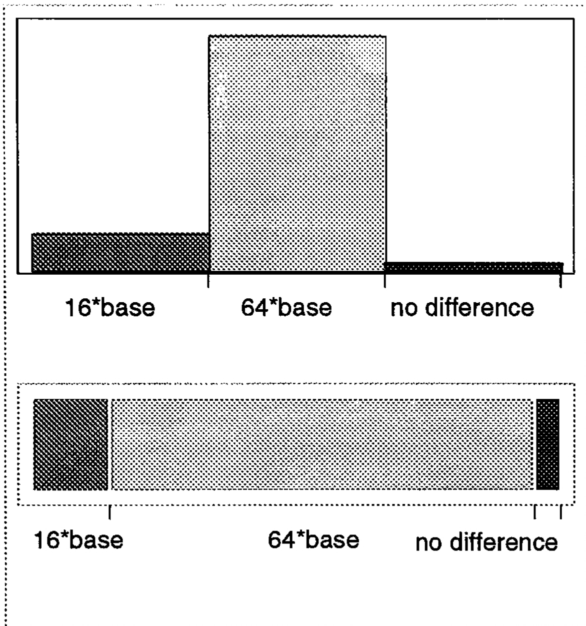
Summary

Number of Levels	3
Total Frequency	20
Total LogLikelihood	20.973076

Profile

Level	Count	Probability
16*base	9	0.45000
64*base	7	0.35000
no difference	4	0.20000

Figure 7.—Data for large enlargement, Ektachrome Lumiere 100 film.



Summary

Number of Levels	3
Total Frequency	20
Total LogLikelihood	12.257389

Profile

Level	Count	Probability
16*base	3	0.15000
64*base	16	0.80000
no difference	1	0.05000

Figure 8.—Data for large enlargement, Ektachrome Elite 200 film.

Appendix C

Appendix C

MTF Curves Used in Calculating Information Content of Tested Films

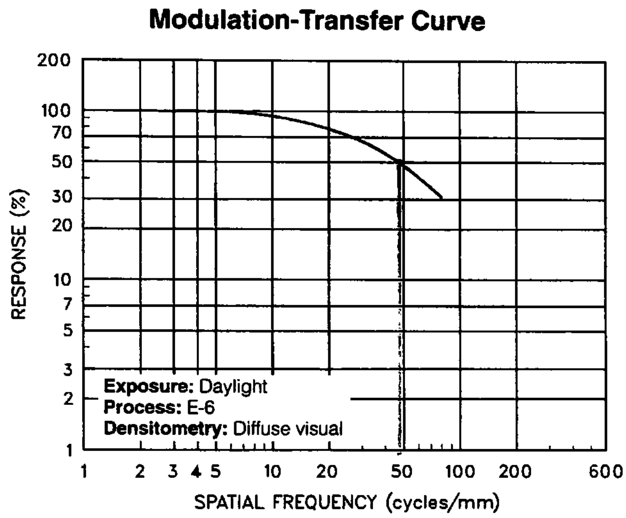


Figure 9.—MTF curve for Ektachrome Lumiere 100 film.

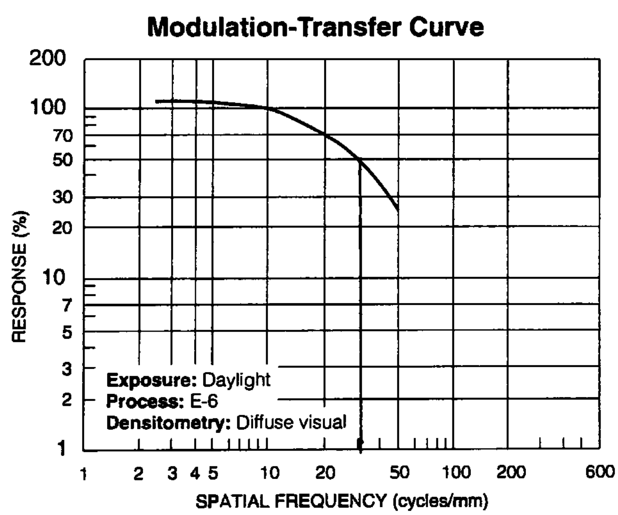


Figure 10.—MTF curve for Ektachrome Professional 100 film.

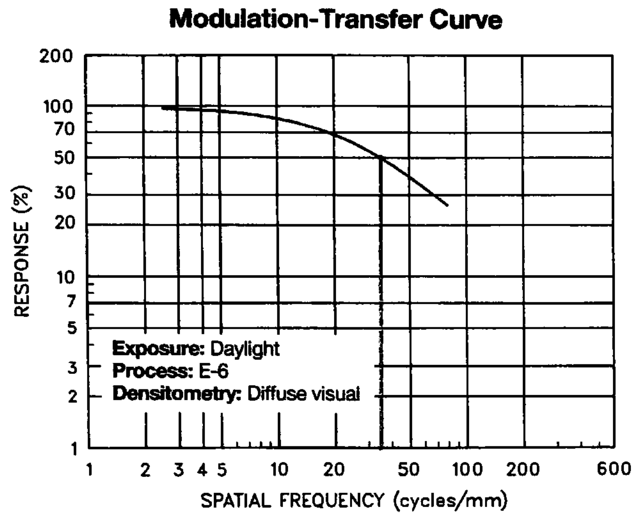


Figure 11.—MTF curve for Ektachrome Elite 200 film.

Vita

Vita

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She is currently the manager of digital imaging production at Applied Graphics Technologies in Rochester, New York. The company uses its own Photo CD-based image processing system to digitize high volumes of images for publishing and archival applications.

Before attending RIT, she worked at Ziff-Davis Publishing Co., in Boston, most recently as *PC Week*'s editorial research manager. During her three and a half years there, she wrote articles for the Buyer's Guide and Special Report sections and managed the publication's survey research efforts. She received her Bachelor of Arts degree in psychology from Boston College in 1989.

At RIT, she has rounded out her editorial and computer experience with technical knowledge of electronic publishing in both senses of the word: electronic prepress as well as publishing in a digital medium. She served as prepress coordinator for the 1994 edition of ESPRIT, a dual-format publication consisting of a printed magazine and an interactive CD-ROM. She also worked in RIT's Electronic Color Imaging Lab as a teaching assistant for basic and advanced color separation laboratory courses using high-end and desktop drum scanners. She has also completed a graduate certificate program in interactive media design and was part of the team that designed and implemented a World Wide Web site for the George Eastman House.

Born in Royal Oak, Michigan on August 11, 1967, Ms. Sanders currently resides in Rochester, New York.