Standardization of Image Quality Analysis – ISO 19264

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Abstract

There are a variety of image quality analysis tools available for the archiving world, which are based on different test charts and analysis algorithms. ISO has formed a working group in 2012 to harmonize these approaches and create a standard way of analyzing the image quality for archiving systems. This has resulted in three documents that have been or are going to be published soon. ISO 19262 defines the terms used in the area of image capture to unify the language. ISO 19263 describes the workflow issues and provides detailed information on how the measurements are done. Last but not least ISO 19264 describes the measurements in detail and provides aims and tolerance levels for the different aspects. This paper will present the new ISO 19264 technical specification to analyze image quality based on a single capture of a multi-pattern test chart, and discuss the reasoning behind its current design.

Introduction

Cultural heritage institutions, such as archives, libraries and museums, have a long tradition for using photographic imaging techniques to reproduce cultural heritage works. Initially, photographic imaging was based on film technology, but from the beginning of the 1990's digital imaging technologies came into play in the cultural heritage sector and gradually phased out film. While measurement of image quality related to film was well understood and standardized, the advent of digital technologies created a gap in knowledge on how to define and measure digital image quality. To bridge the gap, studies were undertaken and several comprehensive imaging guidelines were issued around the turn of the century, e.g. [1, 2]. Likewise, standardized methods based on test charts for objective image quality measurements were developed by ISO and introduced to the community, e.g. [3].

The next step forward in streamlining image quality analysis was the design of test charts with multiple test patterns and accompanying software that enabled evaluation of more image quality characteristics in one capture [4]. The tools were developed to support statistical quality control in larger scale digitization projects, and became known as the Golden Thread tools. More guidance followed on how to establish and maintain imaging performance in digitization projects by image quality control, e.g. [5], and on how to interpret and handle the results of image quality analysis [6].

In 2010 the US Federal Agencies Digitization Guidelines Initiative (FADGI), published the 'Technical Guidelines for Digitizing Cultural Heritage Materials' [7]. It was founded by the National Archives and Records Administration (NARA) in 2004 [8]. The FADGI guidelines introduced the Digital Image Conformance Environment (DICE) system, consisting of a multi-pattern target, associated image quality analysis software, and the specification of aims and tolerances for four performance levels (1-4 stars) for a series of image quality metrics . Recently, the FADGI guidelines have undergone extensive revision, and will be published this year.

In Europe, the National Library of the Netherlands published the Metamorfoze Preservation Imaging Guidelines in 2012 (a draft version was available in 2008) [9, 10]. Metamorfoze refers to the name of a Dutch national program for the preservation of cultural heritage. The Metamorfoze system is based on a multi-pattern test chart, the Universal Test Target (UTT), which was designed by the National Library of the Netherlands, in cooperation with Image Engineering and Fachverband für Multimediale Informations-verarbeitung and launched in 2009[1]. For different types of originals the Metamorfoze system defines three specification levels of aims and tolerances for a range of image quality criteria.

While the FADGI and Metamorfoze systems are conceptually equal, the systems cannot be used interchangeably. There are differences in algorithms and criteria, how the targets are designed, and on the specified aims and tolerances. In addition, there are differences in the terminology applied by the two systems. All together this has caused confusion among users and manufactures of image quality analysis systems. Further, this has slowed down the implementation of objective image quality analysis in digitization workflows. It is on this background that stakeholders representing both systems decided to harmonize the different approaches and develop an ISO standard.

ISO 19264 – Image Quality Analysis – is being developed by the International Organization for Standardization (ISO), within the technical committee for photography (TC 42), and in the working group (JWG 26) joint with the technical committee Document management applications (TC 171) and Information and documentation/Archives and records management (TC46 / SC11). The initiative to set up a working group to standardize image quality analysis was first presented at the ISO TC 42 plenary meeting in 2011 and JWG26 held its first meeting in 2012.

JWG 26 consists of around 20 experts and it has defined three projects: a technical specification of a method to analyze image quality (ISO 19264), a technical report on how to apply ISO 19264 (ISO 19263) and a vocabulary for archiving systems (ISO 19262).

Archival Imaging of 2-D Originals

The following provides an overview of the main steps in the imaging process of two-dimensional originals for archival purposes. By archival we mean that the reproduction should be as visually accurate as possible when compared to the original, and that it should be suitable for preservation.

When a person looks at an original what he or she perceives depends on that person's human visual system, the nature of the original material (medium), and how light interacts with the medium (illumination conditions). The illumination conditions consist of the spectral content, quantity and incoming direction of the light, as well as the position of the observer in relation to the medium. Likewise, when a person looks at a digital reproduction of the original what the person see's depends on the medium or

[1] Universal Test Target, http://www.universaltesttarget.com

device, whether the image is viewed as a print or on a display, and under which viewing conditions. Therefore, when we assess the quality of a digital image, it is not only important to evaluate the quality of the imaging system; we also need to care about the medium/device and viewing conditions used for reproducing the image.

When a two-dimensional original is digitized, the original is illuminated and the incoming light interacts with the original. Depending on the medium and viewing conditions, it is then transmitted to the imaging system. Here the light passes through the optics of the imaging system and falls onto the light sensors. The sensors register the light proportionally (linearly) to the amount of incoming light. However, the sensors cannot distinguish color information and therefore, imaging systems apply different color filtering technologies and capture colors as combinations of Red (R), Green (G) and Blue (B). The sensors transform the incoming light into an electrical signal, and the system then converts this analogue signal into a digital signal in the form of numerical values. The unprocessed (raw) sensor data is typically processed by the imaging system to compensate for any shortcomings, including exposure adjustments, white balancing, color correction, and sensor characterization [11]. At this stage each of the components of the digital reproduction represents the corresponding components of the original.

Color Encoding

In order to clarify how the digital RGB values representing the original are color encoded and rendered across the different systems within the imaging workflow, it is important to understand how the systems handle tones and colors numerically. The signals created by the imaging system of course depend as described above on the illumination condition, the material and the object but it also depends on the individual system and its sensitivity with filters etc. Each imaging system produces different signals. Therefore the manufacturer has to characterize the system e.g. by capturing a set of known colors (Color Checker, IT8, HTC and other targets) and combining the signals produced by the system with the known values of the colors. If this is done for a set of colors each signal can be converted in its real world color as viewed by a human observer. The set is called an imaging system color profile and the process is called color correction. The mathematical algorithms for this procedure are standardized by the Commission Internationale de I'Eclairage (CIE)[2] and the process for the implementation is standardized by the International Color Consortium (ICC)[3].

For storage, the raw images from the imaging system can be stored together with the profiles. But especially if multiple devices are used in a workflow and the images are processed further it is better to convert the RGB values for all images into a standard color encoding before they get stored. These standard color encodings have a bunch of advantages. One of them is that equal values for RGB represent neutral colors (grey tones). In addition a compensation of the difference between a linear sensor and the non linear human visual system is applied by the so called tone curve in these color encodings. Examples for such encodings, which can be found often, are sRGB, Adobe RGB, and eciRGB.

[2] CIE: http://www.cie.co.at/

[3] ICC: www.color.org

These encodings differ in terms of the range of tones or colors that they can represent and the tone curve. To display images on a monitor or print them the colors must be converted into the encoding of these devices. And depending on the individual device some colors may not be reproducible. So colors need to be transformed for the output device and may need to be adjusted – mapped – to the output device.

The output of images often contains an image optimization process that makes the image look good but not necessarily a good representation of the original anymore.

As described the RGB values change during the image processing and reach different image states. Generally, in photography the first state is the raw sensor data. This then gets white balanced, color corrected, potentially tone corrected, which takes it to the next state that is called scene-referred. In this state the RGB values with its related colors in the selected encoding represent the scene, captured by the imaging system as best as they can. To display or print the images they get further processed for the output, which then takes the image data to an output-referred state.

In the case of copy-stand photography or scanning the scene-referred data is called original-referred because the image represents an original rather than a scene, which requires slightly different processing algorithms (e.g. no required headroom for specular highlights). Original-referred data sometimes has a larger dynamic range and color gamut than current print or display technology is capable of outputting. Therefore, there may be a need for re-rendering / translating (mapping) the tones and colors from the original-referred image state to an output-referred image state. In any case the digital image must contain the correct profile that describes the encoding it is in, to allow a correct interpretation of the RGB values in the file.

The Archival Master

The term archival master refers to files that institutions archive and eventually use as masters for additional processing for specific output on display or print. Archival master files should include the image data preferably in an original-referred state, the color encoding and any other metadata necessary for preservation and access.

The advantages of saving reproduction images in an original-referred image state is that it allows for optimum use of the bit depth and simplifies editing. Furthermore, it will be more flexible when it comes to color rendering for final output. The risk of not saving reproduction images in an output-referred state is that the connection/resemblance to the original may be lost if the color encoding is lost during archiving, or if the imaging system is not profiled and the characteristics known.

The idea of keeping the reproduction image in an original-referred image state is that the original tones and colors are preserved. If the image is converted to an output-referred image state some tones/colors may be lost because the device color spaces often have a reduced color gamut. If the original can be satisfactory represented in the output-referred state this may then be a better solution, because the producer then has more control over that the image represents the original. If the producer delivers an original-referred image it is necessary to also provide and thus preserve metadata about the original medium and viewing conditions in addition to the color encoding.

The raw sensor data may be stored in a raw camera or scanner format, or converted to a common image format, such as TIFF. Color profiles in the form of metadata can be stored (embedded) in most image formats. The profiles can also be stored in a separate database or a system directory.

Image Quality Characteristics

In broad terms, image quality in the archiving world can be defined as the overall visual accuracy of the reproduction as measured against the original. Within ISO TC 42 image quality is defined as the: 'impression of the overall merit or excellence of an image, as perceived by an observer...'. This definition stems from a standard on psychophysical methods for estimating image quality (ISO 20462) and includes the psychophysical process of human perception. A high quality image may be enhanced e.g. in color and contrast to look good and therefore not be the best representation of the original. For the purpose of ISO 19264 a slightly different approach related to the reproduction of an original is needed. The process of determining the image quality involves an objective evaluation of image quality based on a multi-pattern test chart that is designed to measure image quality characteristics like tone, color, and detail reproduction as well as noise and geometry.

The overall quality of a reproduction image can be characterized by how well the tones, colors, details and geometry of the original are reproduced, and by the amount of artifacts (like noise, defect pixels or aliasing) in the image. These image quality characteristics can be evaluated by objective and/or subjective measurements. The former, are those that can be physically measured based on test charts. The subjective ones are those perceived by a human observer through visual inspection of the digital image.

ISO 19264 divides image quality characteristics in four main groups: tones and noise, colors, details and geometry. The reason for this division is the different patterns in the test chart used to measure the aspects. A slightly different approach is the imaging performance taxonomy [12] that divides the image quality aspects by their origin.

Image Quality Metrics and Test Patterns

There are ISO standards for objectively measuring different performance metrics of imaging systems, e.g. resolution, noise, dynamic range, tone and color reproduction. The metrics included in ISO 19264 are based on these and were only altered when required by specific archival requirements. The big difference is the combination into a single multi-pattern test chart that makes the evaluation of a system easier and measures all aspects out of a single image. Keeping the experience from the existing approaches in mind the chart and measurements were carefully selected to provide the best quality analysis available.

The image quality metrics are analyzed objectively by capturing an image of a test chart with a specific arrangement of technical patterns corresponding to the image quality characteristics to be evaluated. In the case of analysis of tone and color reproduction, the test patterns are accompanied by a set of reference values representing the different tones/colors on the technical patterns. These reference values are measured physically on the patterns and stored in a reference file. The patterns can be measured with a spectrophotometer (CIE color model/L* values). The digital image of the pattern is then opened and processed by an image quality analysis program. The program identifies the location of the patterns, reads any reference values, and performs the required calculations.

The Test Chart

ISO TS 19264 defines the basic requirements for a multipurpose test chart in Annex A. All charts that fulfill these requirements can in principle be used to do the measurements. In Annex C a specific example of a test chart – the UTT that fulfills all requirements is described (see Figure 1). The specification is so far only aimed at originals on a reflective media. A specification for a transmission chart may be available in the future.

In principle it will be necessary that the chart is constructed of structures produced with different printing processes because there is no process and material currently known that meets all necessary criteria like resolution, dynamic range, color fidelity, screenless printing etc. One of the biggest challenges is the color namely the combination of a set of colorants with the sensitivity of the specific imaging system. In case the system deviates from human vision – which it usually does – colors can only be optimized/corrected for a specific set of colorants. So the test chart should use the same colorants that were used for the characterization to get good measurement results for the reproduction. But then nobody uses color test charts as originals in the workflow. So ideally it would be best to use the colorants of a typical original to see if the results are good, which of course is not possible. So for the time being the approach with the colorants used for the characterization is used.

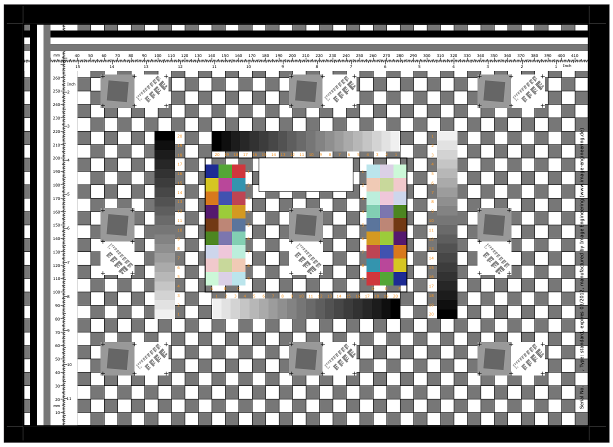

Figure 1.*The UTT.*

Objective Measurements

Tones and Noise

One of the most important aspects in reproduction is to get the exposure and tonal correction right. This means the exposure should not be too dark or too bright and the tonal curve should be adjusted, so that the tones are reproduced accurately in order not to lose any detail in the highlights or shadows. This analysis is done on a grey scale with known tonal values. Three individual numbers ensure that tones are reproduced accurately: tone reproduction, gain modulation, and dynamic range. While tone reproduction ensures what it says, gain modulation has been added to make sure that no details in highlights and shadows are lost by analyzing the tonal curve in more detail. Dynamic range measurement ensures that the device in general can handle the contrast as being the difference between the brightest and darkest part of a typical original.

When images are captured there is always a certain amount of deviations involved introduced by the electronics and the statistical process of converting light/photons into electrons. These deviations are called noise. ISO TS 19264 measures this noise based on the visibility for the human visual system.

The tone reproduction, dynamic range analysis and visual noise determination are based on methods defined in other ISO standards for camera and scanner analysis. All tonal aspects are measured on the grey scales in the test target (See Figure 2).

***Figure 2**. Greyscale for tonal analysis.*

Color

In terms of color two metrics are measured. One is the white balancing that describes how much color is left in grey levels that should be reproduced as neutral. This is also measured on the grey levels (see Figure 2).

The second aspect is the quality of the color reproduction. Given the problem described in the test chart section it is easiest to use the same colorants that were used for the color characterization of the device. So depending on that a separate test chart may be used. The most important thing is to make sure that the device has been color characterized in the first place and that the colors are reproduced within certain tolerances, e.g. that blue does not turn out purple.

Details

The next metric is the reproduction of fine detail. The first step is to make sure that the amount of pixels generated by the system is sufficient to enable the system to reproduce the necessary amount of detail. For reflective originals most workflows use something between 300 and 400 pixels per inch.

The second step is to make sure that these pixels are filled with information, which is the resolution measurement. Think about a camera that is not focused correctly so you get a lot of pixels but blurry pictures. For this analysis fine detail is presented to the system and the reproduction of it is analyzed. In addition, it is also necessary that this fine detail shows a certain amount of contrast, which is called sharpness.

All of these aspects are measured on the resolution structures shown in Figure 3.

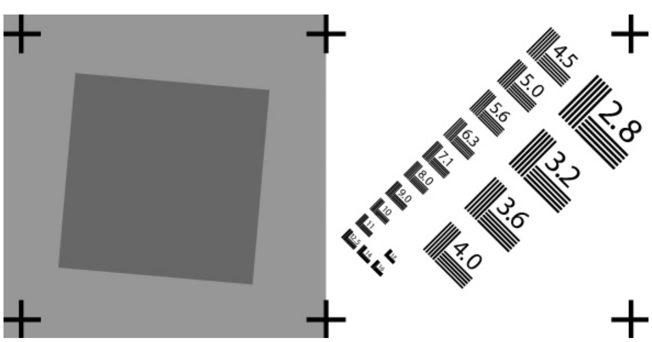

***Figure 3**. Structures to analyze detail reproduction.*

Geometry

Last but not least it is necessary to uniformly illuminate the area for reproduction and to ensure that the geometry is reproduced correctly. This done by using the checker board pattern in the background of the chart. From this structure the evenness of the output values in the white areas of the checker board can be analyzed and provide that uniformity result. The amount of pixels in every area of the checker board represents the reproduction scale, the location of the cross points throughout the target tell us about the distortion etc.

Subjective Measurements

Some aspects are almost impossible to analyze objectively because they cannot be predicted. Even though the standard tries to specify measurement methods for these they are mostly analyzed by visual inspection. Among these aspects are banding and defect pixels.

Aims and Tolerances for Metrics

After having agreed on which characteristics and metrics to measure, JWG 26 has also worked on specifying the aims and tolerances for each of the metrics included in the specification, as well as on the criteria for complying with ISO 19264. It is important to note that the specification of aims and tolerances is only informative, included to provide guidance for users and not as absolute criteria.

Currently three image quality levels are defined but these are still under discussion. The aims represent the value or interval of an ‘ideal’ reproduction. The tolerances represent the variability around the aim reflecting the performance of current imaging technology. Table 1 shows the current table as it stands in the draft version of ISO 19264.

To conform to a specification all metrics must be within the required aims and tolerances. For specific use cases aims and tolerances for individual metrics may be set. Table 2 shows how the specifications of aims and tolerances may be used.

Image Quality Analysis Procedure

System Setup and Calibration

Before analyzing the image quality that a particular imaging system delivers it is important to setup and calibrate the system carefully. This involves ensuring that the imaging device is placed on a stable mount that does not move during exposure to avoid problems with resolution and noise. For copy-stand photography it is also important to ensure that the camera back and the imaging area are parallel to avoid problems with distortion and non-uniform illumination. In addition, the illumination must be uniform over the entire imaging area, again to avoid non-uniform illumination. In general, any ambient light that does not originate from the desired illumination must be avoided. It is also important to ensure that the system is focused on the target.

Regarding system settings the lowest sensitivity (lowest ISO speed number) should be selected to decrease the amount of noise in the image. Likewise, none or the lowest image compression rate, i.e. the highest image quality, and an aperture that ensures good reproduction (usually 5.6 to 8) should be selected. The sampling rate needs to be set accurately. If a camera system with an area sensor is used the reproduction scale depends on the focal length as well as the object distance.

The desired color encoding needs to be selected based on the intended application and preference. It is important that the encoding covers all colors represented in the multi-pattern test chart as well as those of the originals to be digitized. The selection of the color encoding has an impact on the signal and therefore also the noise amplification. Depending on the encoding, different areas of the tonal curve, as well as certain colors, may be amplified, which may in turn result in increased noise values, and affect the results of the image quality analysis.

Imaging systems usually provide color profiles that translate from the device color space to a human vision color space. However, to improve the color reproduction the imaging system it may be useful to characterize the system to compensate for sensor color sensitivity by creating an ICC profile. For the purpose of ICC profiling, an ideal color test chart reflects the type of originals to be digitized in terms of matching material and colorants.

Table 1. The current table for aims and tolerances extracted from ISO TS 19264 (draft).

	A (excellent)	B (very good)	C (good)
Tone reproduction	Δ L*≤+/-2	Δ L*≤+/-3	Δ L*≤+/-5
Gain Modulation (highlights)	0.8 - 1.1	0.7 - 1.2	0.6 - 1.5
Gain Modulation (other tones)	0.6 - 1.4	0.4 - 1.7	0.1 - 2
Noise	< 3	< 4	< 6
Dynamic range	≥ 2.3	≥ 2.1	≥ 1.9
Banding (visual inspection)	None	None	Slight
Defect pixels (vis.inspection)	None	< 0.1 per million	< 1 per million
White balance	Δ C*≤+/-2	Δ C*≤+/-3	Δ C*≤+/- 5
Color reproduction (Max)	Δ E*≤+/-10	Δ E*≤+/-15	Δ E*≤+/-18
Color reproduction (Mean)	Δ E* ≤+/-4	Δ E*≤+/-5	Δ E*≤+/-5
Sampling rate (Diff. claimed/ obtained)	≤ 1%	≤ 2%	≤ 3%
Resolution (ISO 16067) Percentage of claimed sampling rate	≥ 85%	≥ 80%	≥ 70
Sharpening (Max SFR contrast value)	≤ 1.05	≤ 1.1	≤ 1.2
Acutance	≥ 0.67	≥ 0.50	≥ 0.40
Illumination non-uniformity (≤A3)	Δ L* ≤ 3	Δ L* ≤ 3	Δ L* ≤ 3
Illumination non-uniformity (≤A2 >A3)	Δ L* ≤ 4	Δ L* ≤ 5	Δ L* ≤ 5
Illumination non-uniformity (≤A0>A2)	Δ L* ≤ 5	Δ L* ≤ 6	Δ L* ≤ 6
Color mis-registration	≤ 0.4 pixel	≤ 0.7 pixel	≤ 1 pixel
Distortion	≤ 1.5%	≤ 2%	≤ 5%

Exposure and White Balancing

The exposure should be adjusted so the pixel values in an image of a diffuse white card are not clipped. The exposure should additionally be close to the maximum output value of the system. It is also important that the dark areas are not clipped.

Once the exposure is correct the white balance should be set. It should be measured on a grey card or a white card (without optical brighteners) to ensure correct results. The white balance setting should be stored and used for imaging production. White balancing must be repeated on a regular basis to compensate for the spectral change of the light source over its lifetime.

Image Quality Analysis

Digitize the ISO 19264 test chart, select the required image quality specification (aims and tolerances) and analyze the image with image quality analysis software. If a metric is not within the required specification, if possible adjust the imaging system and re-capture the chart. Since system adjustments may influence other metrics it is recommended to check and adjust the metrics as described below. Image capture, analysis and system adjustment is likely to be a re-iterative process when optimizing a system.

First of all it is important to verify that the imaging system is set up correct; that planes are parallel producing images that are as geometrically correct as possible, e.g. images that are not distorted. Then it is important to verify the illumination is even because if you at a later stage would have to go back and change the illumination this would likely influence the tone and color reproduction. Third, you have to get the tone reproduction and the white balancing correct followed by the colors. The white balance performed on different tonal levels can vary. Highlights are generally more sensitive to errors. When the white balance has been set, the gain modulation should be checked against reference values and possibly the curve should be adjusted.

Table 2. Principles for the two different ways of applying the aims and tolerances. S: Small, M: Medium, L: Large.

	Fixed specs			Flexible specs (use case based)	
Metrics	A	B	C	1	2
OECF	X +/- S Δ	X +/- M Δ	X +/- L Δ	X +/- S Δ	X +/- S Δ
SFR	Y +/- S Δ	Y +/- M Δ	Y +/- L Δ	Y +/- S Δ	Y +/- L Δ
Noise	Z +/- S Δ	Z +/- M Δ	Z +/- L Δ	Z +/- M Δ	Z +/- L Δ
…					

Conclusions

ISO 19264 is being developed to specify a method for analyzing the overall quality of digital images produced by scanning or copy-stand photography of two-dimensional originals. ISO 19264 specifies the main image quality characteristics, the metrics used to evaluate these quality characteristics, the procedure for image quality analysis, and how the results of the individual measurements should be reported. In addition, it specifies a multi-pattern test chart and provides guidelines on specification of aims and tolerances for the image quality metrics.

The standard has a range of applications. It is useful for developing and benchmarking imaging systems, including verification of claimed performance. To this end, it serves well for comparing and selecting systems. Likewise, it can be used to adjusting and optimize a given system. Finally, it enables controlling the accuracy and consistency of imaging systems over time, and it is therefore also an important tool in any quality assurance program.

The image quality metrics are likely to change over time as new imaging systems, analysis methods and test chart patterns are developed, which will also affect the specification of aims and tolerances.

ISO 19264 is currently a committee draft circulated among TC42 for comments and ballot. In this process, as well as in future revisions, it is possible to get involved through national standardization organizations. ISO 19262, the accompanying vocabulary for archival imaging, has already been published. ISO 19264 is expected to be published in 2016 together with ISO 19263 a technical report on best practices for image quality analysis.

Hopefully theses documents will lead to a unified image quality analysis method, and help the cultural heritage community and other stakeholders involved in imaging for archival purposes, to specify image quality requirements, and to improve and control the overall image quality of reproduction images.

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