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# Establishing a Roadmap for Scene-Referred Raw Imaging Workflow

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## Abstract

*In an effort to address current limitations, this paper documents known raw imaging shortcomings, and puts forth a roadmap for a standardized scene-referred raw workflow. In addition to traditional 2D artwork reproduction, RTI, multispectral, photogrammetry and other computational methods benefit from direct access to raw data. Due to a lack of standardization, users struggle with quality and repeatability. A key to improving raw imaging workflow is to define a raw scene-referred rendering state that can be embedded, archived and accessible to raw processors and computational imaging software as a consistent baseline. Many of the required user controls and readouts are outlined in ISO 17321-3 and ISO 19262,3,4 but until the industry fully embraces standardized raw, computation, workflow and archiving are compromised.*

## A Case for Scene-Referred Raw Workflow

Computational imaging techniques have become increasingly important for cultural heritage documentation, unfortunately the lack of standardization across cameras, scanners and raw processors has become a critical obstacle to efficient and reliable archiving. In addition to traditional 2D artwork reproduction, RTI Imaging, Multispectral Imaging, Photogrammetry and other computational methods benefit from direct access to raw data, but users are often forced to render output referred finished files to serve as the source data for image computational tasks. While raw data can be processed in a number of tools, the output is unpredictable and most importantly unrepeatable due to lack of consistent support for scene-referred user controls and readouts. In the example below, when processing a single camera native DNG image of a perceptually linear (L*) grayscale across a number of raw processors, none of the renditions are perceptually linear nor match each other. The likelihood of archiving a DNG image today and expecting it to render faithfully to the original scene, ten years from now, is extremely low.

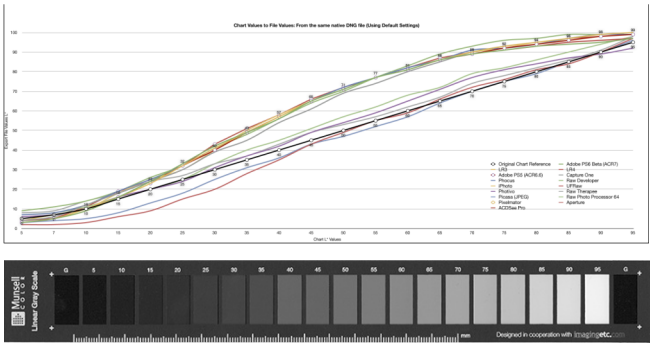

*Figure1 Same DNG raw file of a linear gray scale produces wildly different renditions across different raw processors [1]*

We are at a critical juncture where our needs are not well aligned with the industries' goals. Manufacturers operate in a competitive landscape and fiercely protect camera and software functionality. They argue that the beauty of raw is that processing can be improved over time. While this is a true benefit, it's irresponsible for the industry to encourage DNG archiving when there is no way to preserve an original scene rendition. It's difficult to convince the photographic industry about a market need when the use-case hasn't been clearly defined. History has proven that manufacturers will adopt standards when the market demands them, or when a competitor adopts them.

We are at a critical juncture where activity to standardize a universal raw imaging format (ISO 12234-2 [2]) is gaining new momentum and other relevant standards are in place. For example: ISO 17321-3[3] provides guidance for user controls and readouts and ISO 12234-3[4] defines an XML namespace for relevant image metadata. With the publication of ISO 19262,3 and 4[5] in 2017 there is now a globally accepted set of documents to describe best practice for (scene-referred) artwork reproduction. Currently the specification and archiving of raw images falls outside the scope of these documents. This is unfortunate because if the tools we use from cameras to image processors and archiving systems were to support end-to-end scene-referred raw workflow, the need to archive multiple versions of static image renditions and derivatives could give way to efficient dynamic image renditions perfectly optimized over time. Adopting a scene scene-referred raw workflow fulfills the promise of raw data archiving.

## Raw formats and DNG

A growing number of users rely on a raw imaging workflow but the idea of raw data archiving, while conceptually logical, is simply not advisable unless raw files are accompanied with a high bit-depth Tiff preservation master file. The raw data (proprietary or DNG) is simply unstable due to a complete lack of standardization between cameras and raw processors. You can open an archived raw file and reprocess it, but there is absolutely no way to guarantee the edit you make today will be to repeatable in the future. In fact, the rendition is likely to be different even if using software from the same vendor and most certainly different if using another software. It may be helpful to step back and look at the raw workflow and efforts to standardize raw imaging formats. Early work in ISO goes back to 2001 with the adoption of TIFF/EP (ISO 12234-2) in an attempt to define common metrics for digital camera sensors. This appears to be the foundation for most popular raw image formats but until Adobe® announced the DNG format in 2004 there was no industry effort to agree on a standard raw file encoding. By 2009 only a handful of camera manufacturers had adopted native DNG encoding support. Some manufacturers adopted support for limited reading and writing of DNG files in bundled proprietary raw processing software. Almost a decade down the road and not much has changed in the raw landscape. The best way to resolve issues with raw imaging and archiving is to raise awareness and begin to lay the groundwork with a

coordinated effort from all parties, including camera manufacturers, software developers, standards bodies and most importantly end users.

## Specific Problems Documented

In this section I will describe how a lack of raw standards impedes productivity and exhausts resources when working with commercially available tools.

### Undocumented, incosistent raw processor behavior

The Metropolitan Museum of Art has been consolidating DSLR workflow to Adobe® Lightroom™ using BasICColor® Input, Munsell® Linear Grayscales, X Rite® DCSG charts and UTT charts to verify camera performance according to ISO 19264. This effort has enabled the museum's conservation and curatorial departments to benefit from consistent color and tonal response across many different brands of cameras and lighting situations. During an update to a legacy workflow in our painting's conservation department, cameras, lighting and software were upgraded from the ground up. A Canon® 50MP DSLR was coupled with a Zeiss® lens. Lighting was upgraded from Tungsten to 4X Westcott® Flexlight™ 1'X3' high CRI LED panels. Initial, ISO19264 chart-based validation was exceptional and remained measurably stable over a two-month evaluation period. Once we were satisfied with the quality and stability of the chart based validations, the departments imaging technician Evan Reid set out to run live tests with paintings. Evan contacted me shortly afterwards describing a strange color shift.


*Figure2 Using the 2013 processing method in Adobe® Lightroom™ scene values shift when a scale is removed from the scene. In this example location A=3Δe2000,B=3.7Δe2000,C=3.9Δe2000 indicating scene variable processing. Using the 2010 processing method no shift occurs. Artwork-Follower of the Master of the Virgin among Virgins (Netherlandish, active late 15th century),Oil on wood, Accession Number 26.26, The Rogers Fund*

Since the cameras, lighting and software were all new, the process of narrowing down the problem proved to be very time consuming. Were the color shifts due to LED flicker, fluctuations in the camera shutter, use of a third party lens? It is always difficult to pinpoint failure points in a workflow. In the process of narrowing down possible points of variability, we noticed that the chart images were perfectly stable and measurably repeatable. The problem only occurred when the color chart was removed from the scene. Finally, after escalating the problem to high level engineering contacts at several companies, we learned that the Lightroom™ 2013 develop process applies scene variable rendering. In other words, the target placed to verify exposure in the scene alters the image processing in undocumented ways. If this is news to you, just think of the implications if your institution had captured and archived your entire collection of in-process conservation work. Your workflow would be just one software upgrade away from instability. The most disturbing aspect of this example is that any chart-based validation is perfectly consistent and therefore undetectable. The only reason we caught this problem is the diligence of the operator and the precision of the new hardware. Adressing the problem led to a reconfiguration of Lightroom™ users across the museum.

### Inconsistent renditions and readouts

Another critical issue is the delicate relationship between properly exposing a digital camera and the host raw processor. While standards bodies have worked to revise methods for assigning and reporting ISO speed ratings, ISO speed latitude ratings and standard output sensitivity values, users primarily rely on readouts in their raw processing software to establish "practical" working exposure. This sets up a key failure point for archiving because the configuration of the software used to interpret captured raw data has a direct impact on the actual raw exposure required to capture a scene. To further complicate matters, the lack of standardized readouts across different raw processors leaves users with nothing concrete upon which to establish correct exposure. You will see the impact of this in attempts to establish best practice via user guides. The AIC Guide to Digital Photography and Conservation Documentation [6] literally lists three completely different workflow instructions for different combinations of cameras and raw processors. All of the instructions rely on output referred RGB readouts and assume Adobe®RGB 1998 color encoding.

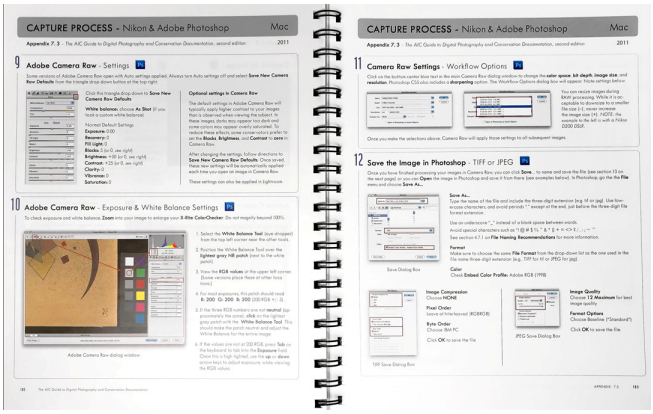


*Figure3 User communities struggle with workflow documentation and education. The AIC Guide to Digital Photography and Conservation Documentation (Second Edition 2011) Lists multiple step-by-step instructions for "Nikon & Photoshop, Canon & Photoshop, Nikon & Lightroom"*

The lack of consistency is also evidenced in technical target documentation. Users looking to establish exposure baselines for costly UV imaging targets are given lengthy application-specific guides with raw processing settings that bear no resemblance to the AIC guidelines. The process quickly devolves to chaos when you add in site-specific user-generated instructions and guides that are often shared through papers and oral presentations.

### Progress with consistent user readouts

We have been successful in influencing Adobe® to adopt L*a*b* readouts since Lightroom™ 4 and this has been a tremendous help. It's important to note that my personal efforts to champion L*a*b* readouts in Lightroom™ began years ago through every possible channel. Some progress has been made. While the adoption of L*a*b* readouts have helped users verify that an image can match

target values, none of these raw processor readouts or histograms correlate back to in-camera readouts. Last year ISO WG 18 published a technical report 17321-3 User Controls and Readouts for Scene Referred Imaging Applications [3]. This document provides guidance for the adoption of a scene referred (SR) mode for cameras and raw processors, providing a critical link between the behavior of the camera readouts and raw processor readouts. A camera and raw processor that support ISO 17321-3 "SR" mode would allow the camera user to objectively expose and white balance for a scene even when capturing untethered. When tools follow the guidance in 17321, the captured L* values displayed on the cameras histogram will be exactly the same when the file is opened in the raw processor.

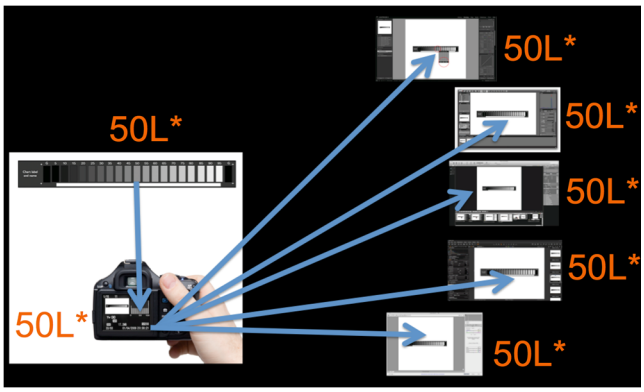


*Figure 4 ISO 17321-3 describes user controls and readouts for scene-referred imaging. In the "SR" mode, the camera histogram and readouts will display L* scene values including above white values, and any raw processor in "SR" mode would display the exact same information.*

## Scene-Referred Raw for Photogrammetry and Computational Imaging

As cultural institutions are increasingly taking advantage of computational imaging, there is a growing need to establish consistent, repeatable scene-referred data sets. It is common for computational imaging users to pre-process camera raw data sets to finished tiff or jpeg derivatives that will subsequently be imported into dedicated software tools for photogrammetry, focus stacking, spectral processing, spins, tiling, etc. In almost every instance users pre-process raw to output-referred to provide more stable results but the tradeoff is usually compromised color gamut, limited dynamic range, sharpening artifacts, and noise.

In photogrammetry, the ability to create accurate metrology of reflective surfaces is an issue. Users struggle to light reflective objects in an effort to avoid highlight clipping while at the same time employing default "film like" rendering presets that limit highlight and shadow detail. Using ISO 19264 scene referred "repro" settings, significantly improves highlight details and in turn improves the accuracy of the 3D model and facilitates digital relighting.

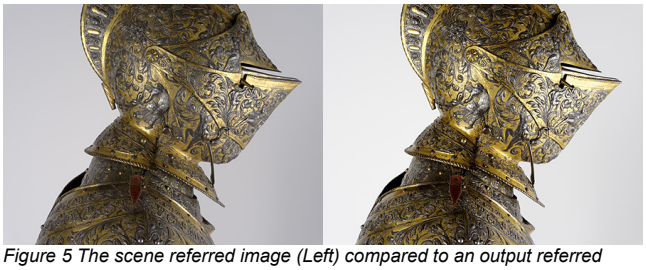

*Figure 5 The scene referred image (Left) compared to an output referred image (Right) captured under the same lighting conditions retains highlight and shadow detail critical for high quality photogrammetry*

## A Standards Intervention

The DNG format is inherently archive friendly. It wraps image data in a clean package but how companies utilize the format is less than ideal. The only way for DNG to fulfill its promise as the universal raw format is standardization, but standards alone will not do. As stated earlier in this paper, the key may lie in the definition of a scene-referred raw state leveraging ISO 19264 to define and measure image quality. While I have learned that standards efforts cannot effectively impose a particular workflow, they can be quite effective to establish objective aims and tolerances. The basic premise is to encourage camera manufacturers and software developers to adopt an ISO standard DNG and to leverage existing imaging standards to define and encode necessary scene-referred image state metadata that can be reliably preserved and rendered in the future regardless of the raw processor. Adobe® has done more than any company to promote a standardized raw workflow. They are instrumental in keeping the ISO efforts forward. Apple® has also been a strong advocate with the adoption of ISO imaging standards and DNG support in iOSX. Now that millions of camera devices worldwide can encode DNG, it may finally pave the way for greater acceptance of native in-camera standard DNG and proposed scene-referred workflow support.

## A Proposed Roadmap

A review of ISO 19263 and 19264 and 17321 1-3 documents will reveal what is necessary to achieve a successful scene-referred image rendition. Almost every raw processor we have tested is able to meet ISO 19264 aims and tolerances, at least for color and tone. We need to focus on what specific camera and software functionalities are required to achieve ISO 19264 and insure that relevant metadata can be stored within the DNG file. With a level playing field in terms of expected behavior, and existing ISO documents describing aims, tolerances, embedded tags, workflow and terminology, raw processors supporting scene referred raw will be able to decode and correctly render the images. In researching this topic I read an article from 2008 by Dr. Simon Tindemans [7]. I feel he best describes the scene referred raw workflow:

> The scene-referred image is neither what comes out of the camera nor is it the final product. Instead, it can be used to naturally divide the image processing workflow into two distinct stages. The first stage is what I will call the scene reconstruction stage. This step is concerned with constructing a scene-referred image from the unprocessed data. Effectively, this removes the 'fingerprint' of the camera as much as possible. This is followed by a second stage: the creative processing.

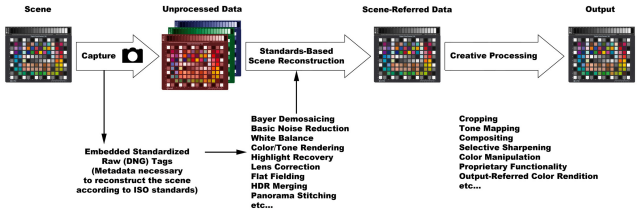


*Figure 6 Proposed scene referred raw workflow separates "reconstruction" from "creative processing". The reconstruction tasks need to follow existing ISO standards. Future DNG specifications need to incorporate necessary tags to enable scene-referred image reconstruction. Future raw processors need to read tags necessary for scene-referred reconstruction.*

Splitting the workflow into a scene reconstruction and a creative processing step offers a number of advantages:

***Scene reconstruction is performed only once***
The scene reconstruction step is independent of the output medium, so if an image is to be targeted to another output medium, this step does not need to be repeated.

***The scene-referred image can satisfy objective quality standards***
There are (fairly) objective criteria for what constitutes an optimal scene-referred image. It can therefore be left to hardware and software vendors ('the engineers') to aim for the best possible image in this stage.

***The scene-referred image is as realistic as it gets***
In news photography, trustworthiness of the image material is of the utmost importance. It is thinkable that a photojournalist would send along a scene-referred copy of every photo as a reference.

***A common standard enhances interoperability***
By using a scene-referred image with its predictable properties as a central node in the workflow, it becomes easier to mix and match programs that 'understand' scene-referred images: HDR, panoramas and noise reduction are a few applications.

***The creative processing stage decouples the photographic style from the camera***
Because the scene-referred image is essentially determined for a given input, all the things that define a photographers' processing style are condensed into the creative processing stage. The camera - in combination with the scene reconstruction step - thus becomes 'transparent' to the style. This has the additional advantage that photographers are no longer at the mercy of their camera manufacturer's product revisions for the look of their work."

## Scene-Referred Imaging in Related Industries

In the motion picture industry, the Academy Color Encoding System (ACES) is becoming the standard for managing color throughout the life cycle of a motion picture or television production. From image capture through editing, VFX, mastering, public presentation, archiving and future remastering, ACES ensures a consistent color experience that preserves the filmmaker's creative vision. In addition to the creative benefits, ACES addresses and solves a number of significant production, post-production and archiving problems that have arisen with the increasing variety of digital cameras and formats in use, as well as the surge in the number of productions that rely on worldwide collaboration using shared digital image files. There is already a tool today that will convert raw still image files to ACES, scene referred encoding. so efforts to establish a scene-referred DNG fit into overall industry trends. Any work in this area related to embedded metadata can be designed to be compatible with ACES. http://www.oscars.org/science-technology/sci-tech-projects/aces

## Conclusions

The fact that raw imaging standards have taken so many years to gain traction underscores the complexity involved. Standards are critical, but can only go so far in terms of user-facing benefits on the ground. Manufacturers often react to market trends and compete with each other over feature development roadmaps. Unfortunately, the needs of end users are often completely overlooked in the process. As an important global community, charged with documenting and protecting heritage, it is our responsibility to bring cultural imaging needs to the forefront. Many of us turn to silicon valley for leadership, but leadership begins with user communities expressing common goals.

There is an additional side-benefit to the adoption of an scene-referred raw workflow, and that is education. If we are to nurture future imaging professionals to face the ever-growing need for accurate cultural heritage documentation, universal standards and best practices are absolutely essential. When the tools we have access to do not support the functionality our community requires, time and resources are lost and we are distracted from our core missions. I look forward to the day when future user guides can simply state set your camera and raw processor preferences to "ISO SR Mode" instead of pages of confusing application-specific screen shots. This is an achievable goal and the time is now to demand that the industry steps up to the plate.

## References

[1] Scott Geffert, DNG Dilemma: Establishing A Consistent User Interface for Objective Imaging Practices, Archiving 2012 FinalProgram and Proceedings, pp. 174-178(5) Society for ImagingScience and Technology

[2] ISO 12234-2:2001 Electronic still-picture imaging-Removable memory- Part2:Tiff/EP image data format, International Orgainzation for Standardization. https://www.iso.org/standard/29377.html

[3] ISO/TR 17321-3:2017 Graphic technology and photography -- Colour characterization of digital still cameras (DSCs) -- Part 3: User controls and readouts for scene-referred imaging applications, International Orgainzation for Standardization. https://www.iso.org/standard/69475.html

[4] ISO 12234-3:2016 Electronic still-picture imaging-Removable memory- Part3:XMP for digital photography, International Orgainzation for Standardization. https://www.iso.org/standard/57732.html

[5] ISO/TR 19263-1:2017 Photography-Archiving systems- Part1: Best practices for digital imaging capture of cultural heritage material, International Orgainzation for Standardization. https://www.iso.org/standard/64220.html

[6] Frey, F. and Heller, D., 2011. *The AIC guide to digital photography and conservation documentation*. American Institute for Conservation. http://www.conservation-us.org/resources/our-publications/special-projects/the-aic-guide - .Wq7FUJPwZE4

[7] Dr. Simon Tindemans, The Scene-Referred Workflow-A Proposal, Personal Essay 2008. Delft University of Technology http://simon.tindemans.eu/essays/scenereferredworkflow

## Author Biography

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