Evaluating Digital Image Performance

Device Capability and Image Quality

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Issues and Answers in Digitization Workshop Series

Sponsored by …

FADGI – Federal Agencies Digitization Guidelines Initiative

- Objective: "… define common guidelines, methods, and practices to digitize historical content in a sustainable manner."
- Organization – Two Working Groups: Still Image and Audio-Visual
  – Subgroups under each working group
- Participating Organizations– 14 formally, more informally

FADGI Still Image Working Group

Establish common digital guidelines for still image materials:
- Text contents
- Maps
- Photographic prints
- Photographic negatives

Goals:
- Uniform quality
- Consistency across agencies
- Benchmarks for service providers and manufactures
- Image performance measures and validations

What Is "Good" Scanning?
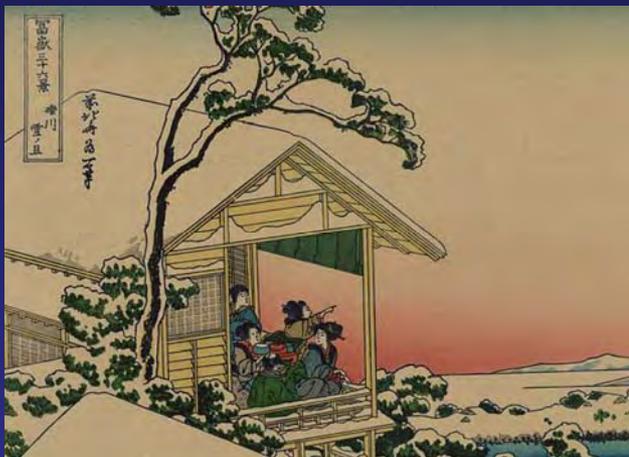
What Is "Good" Scanning?

What Is "Good" Scanning?

Which is the Best Image?

While Based on Evolutionary Adaptation…
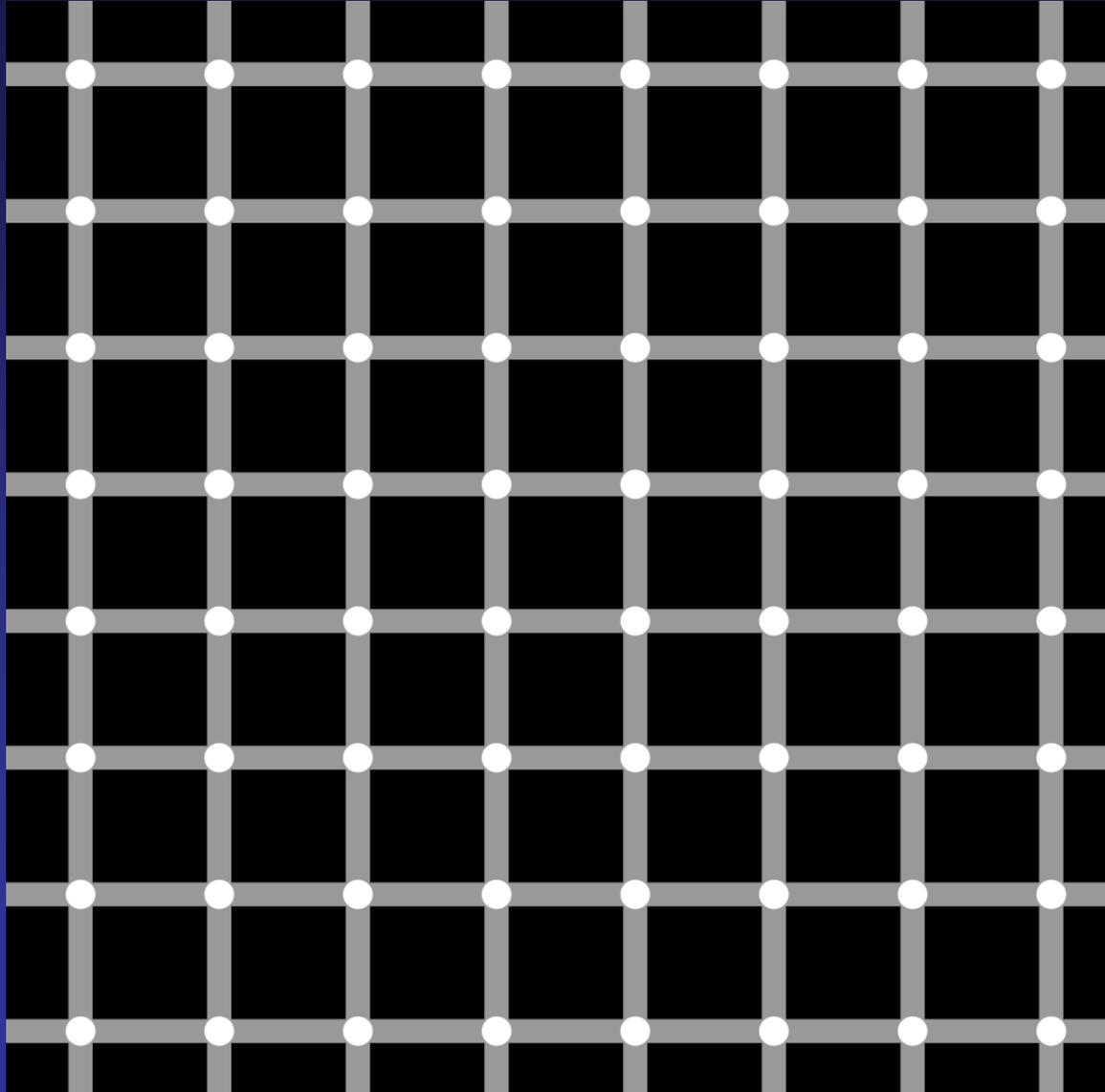
Our Visual Processing Makes Image Evaluation… Challenging

Original image   Note yellow raft

Original image with only the raft color altered with a green filter

Note – raft now looks green

Original image with the same green filter applied to the entire image.

Note – raft now appears yellow as before. The eye has adapted to have the raft "look" yellow despite quantitatively being green.

 This is exactly what could happen with the visual "tweaking" of profiles as viewed on monitors with different color characteristics and not believing the numbers.
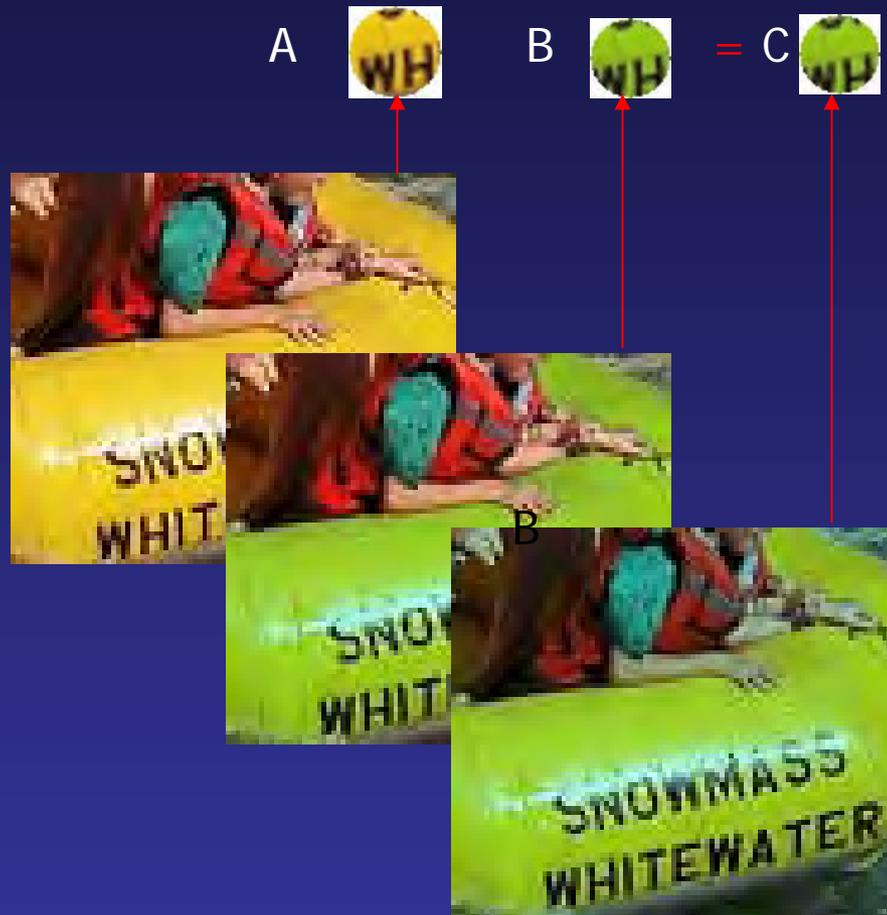
Here we see segments from the three slides side by side, removed from the context of the scene

Gauge the Difference Between "A" and "B"
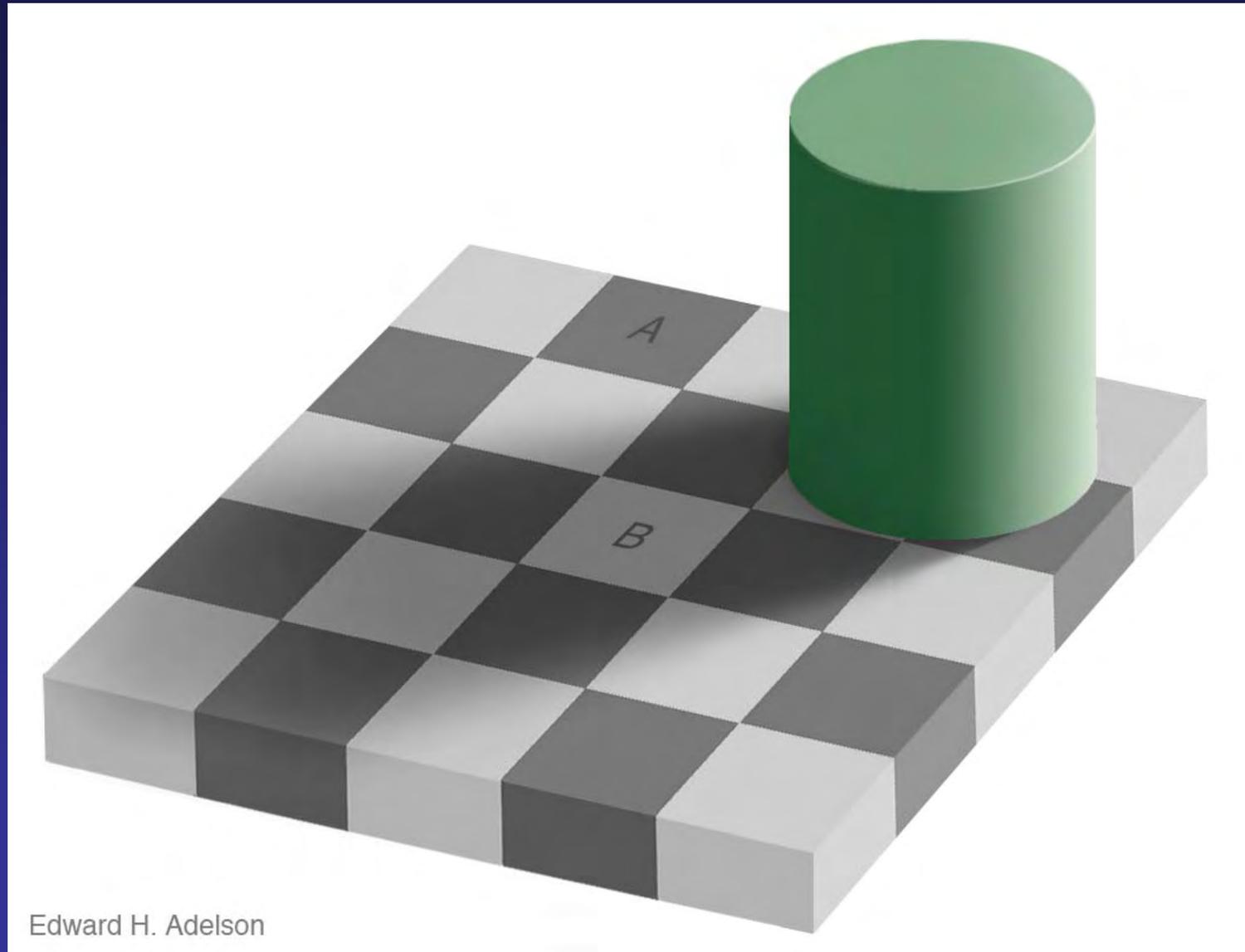
Edward H. Adelson

The Measured Level are Identical

Edward H. Adelson

A = B
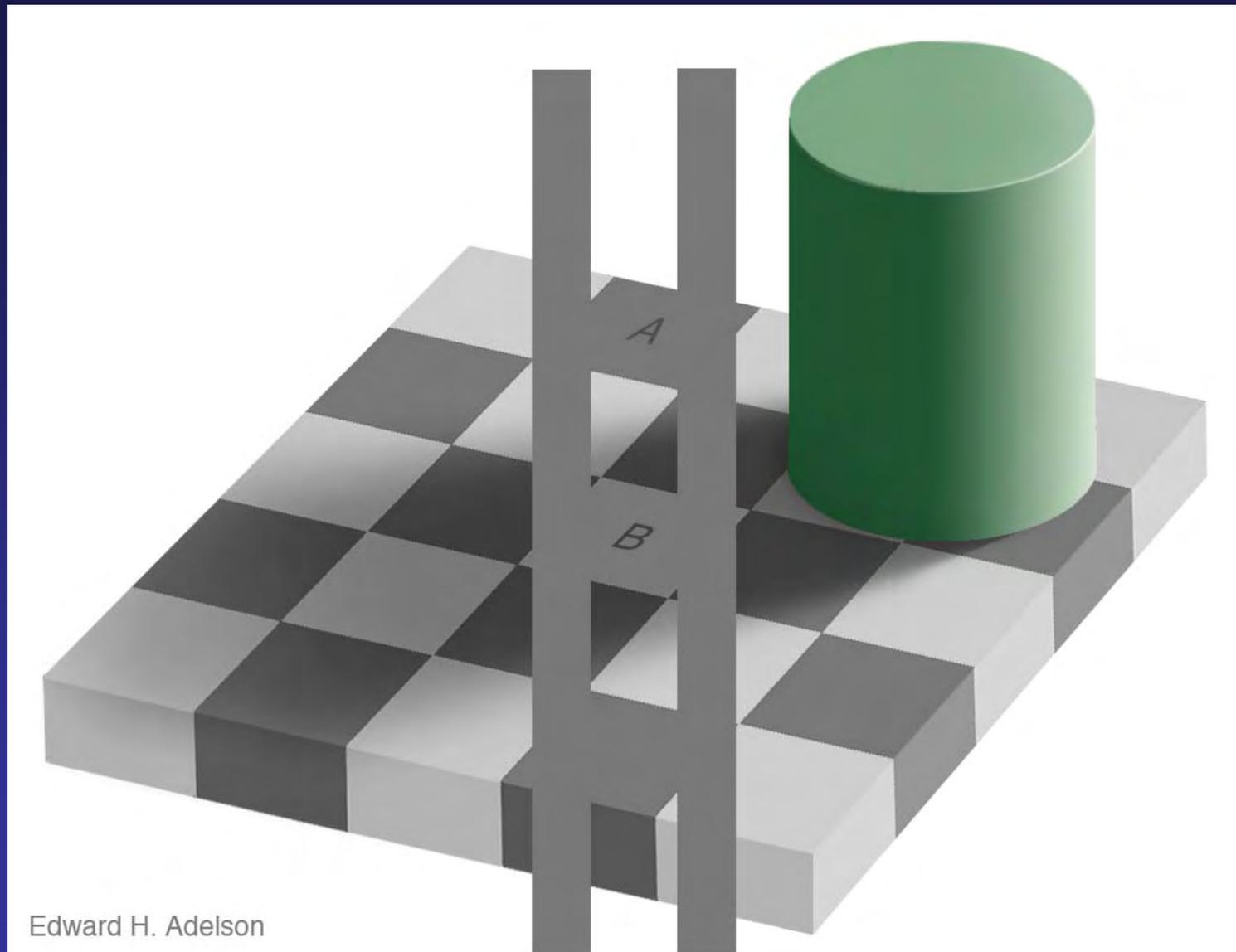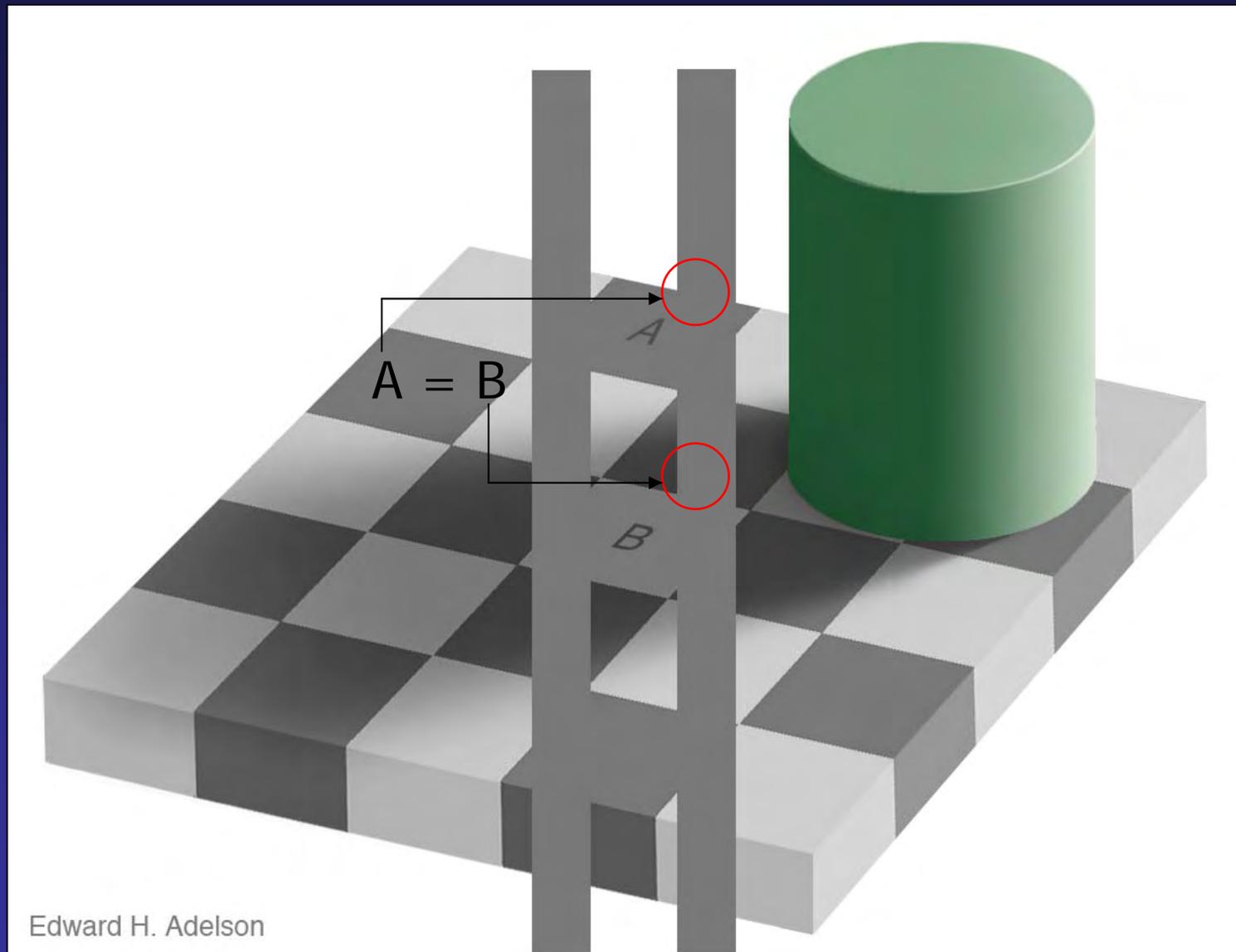
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A Paradigm Shift from "Good" Scanning to "Appropriate" Scanning

- Medical (Type and "quality" based on need and effectiveness)
  - X-Ray
  - CT
  - MRI
  - fMRI
  - PET
  - Ultrasound
- "Appropriate" is defined through use cases
  - Use cases are defined by identifying and describing the expected usage of digital objects;
  - defining and characterizing the content being digitized

Use Cases Look to - Content

such as

- – Textual and illustrated printed matter (books, journals, manuscripts, some maps).

- – Visual/pictorial items (photographs, prints, some drawings and paintings, some maps)

- – Photographic negatives and transparencies. Significant visual-arts elements. Viewed by transmitted light.

…and Digitization Objectives

such as

- Access to information
  - Text optical character recognition (OCR)
  - Cartography – legibility and key correspondence
  - Photographs – image content
- Preserving or representing artifact
  - Historical research
  - Risk management
    - Limiting physical access and handling
    - Creating a digital facsimile in case of damage to original
- General viewing/increased access

Content and Objectives Subgroup

Categories and subcategories of physical materials to be digitized

Table 1	Textual and illustrated printed matter (books, journals, manuscripts, some maps). Visual-arts elements of limited significance and generally consisting of printed halftones, line art, explanatory tables and drawings, and the like.	
	Sub-cat T.1	Clean, high-contrast book pages and documents with clearly legible type, e.g., evenly printed typeset or laser printed pages without background discoloration. Illustrations limited to monochromatic (one color) line art. Informational and artifactual value.
	Sub-cat T.2	Similar to T.1. Informational value only.
	Sub-cat T.3	Documents with poor legibility or diffuse characters, e.g., carbon copies, Thermofax/Verifax, etc.; manuscripts or printed/typed pages with handwritten annotations or other markings; items with low inherent contrast, staining, fading, printed halftone illustrations, or included photographs (see also tables 2 and 3). Informational and artifactual value.
	Sub-cat T.4	Similar to T.1. Informational value only.
	Sub-cat T.5	Items similar to T.1 or T.3 where color is important to the interpretation of the information or content. Informational and artifactual value.
	Sub-cat T.6	Similar general description as T.5. Informational value only.
	Sub-cat T.7	Printed matter on microfilm, similar to T.1.
	Sub-cat T.8	Manuscripts and documents with poor legibility or diffuse characters, or numerous illustrations, on microfilm, similar to T.3.
Table 2	Visual/pictorial items (photographs, prints, some drawings and paintings, some maps). Generally greater visual-art significance than items in table 1. Generally two-dimensional, many with continuous tone images (and occasional halftones). Viewed by reflected light.	
	Sub-cat PR.1	Curator or end users determine that grayscale reproduction is acceptable for items in this sub-category.
	Sub-cat PR.2	Curator or end users determine that color reproduction is required for items in this sub-category.
Table 3	Photographic negatives and transparencies. Significant visual-arts elements. Viewed by transmitted light.	
	Sub-cat PT.1	Curator or end users determine that grayscale reproduction is acceptable for items in this sub-category.
	Sub-cat PT.2	Curator or end users determine that color reproduction is required for items in this sub-category.
Table 4	Special-purpose images (aerial and medical images, architectural and engineering line drawings and blueprints). Viewed by reflected light.	
	Sub-cat AR.1	Aerial photographs, monochrome.

Imaging Performance – A Taxonomy

Part 1 - Taxonomy of Digital Imaging Performance

See subsequent pages for information on
definitions, candidate evaluation criteria, related descriptive terms, and failure causes

Foundation Metrics	Signal									Signal-to-Noise Ratio	Noise									
Engineering Metrics	OECF (Opto-Electronic Conversion Function)				SFR (Spatial Frequency Response)						Radiometric Distortion NPS (Noise Power Spectrum)						Geometric Distortion			
Derivative Metrics	Speed / Sensitivity	Tone, Exposure	White Balance/ Neutrality	Color Encoding Accuracy	Sampling Rate	Resolution	Sharpening	Acutance	Flare	Depth of Focus	Dynamic Range	Total Noise / Temporal / Random (stochastic)	Fixed pattern / Banding/Streaking (deterministic)	Defects (stochastic)	Non-uniformity (deterministic)	Chroma Noise / Color Uniformity (deterministic)	Color SFR Uniformity (deterministic)	Regional (deterministic)	Color Misregistration (deterministic)	Aliasing (deterministic)	Spatial SFR Uniformity (deterministic) / Pincushion/Barrel (deterministic)

Technical Guidelines pp. 7-14

Developing Project Digital Imaging Requirements

Digital Imaging Requirements
- Content
  - Category
  - Characterization
- Objectives
  - Use Cases (one or many)
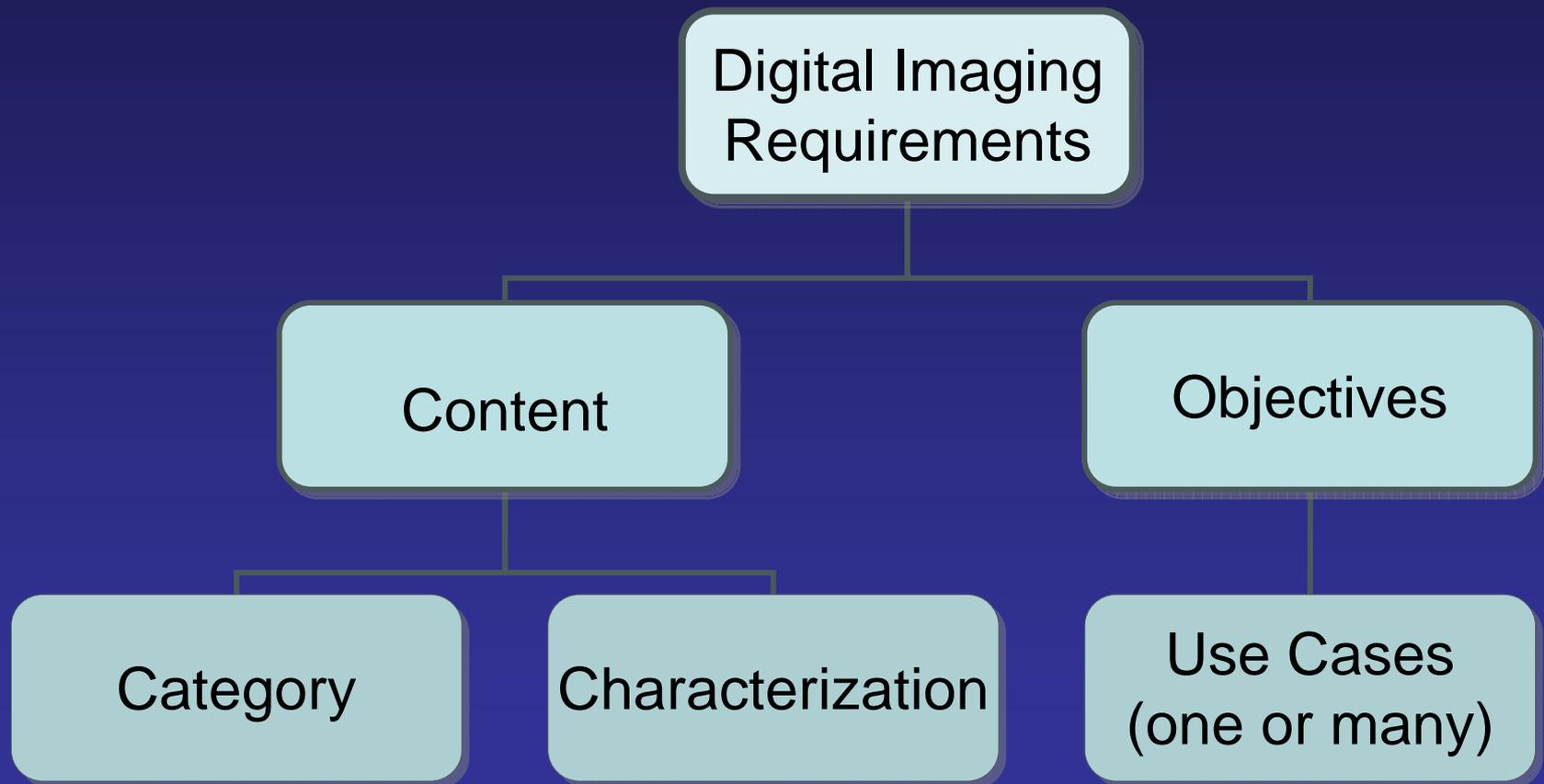
Imaging Performance – Signal and Noise

- Signal
  - Spatial Frequency
    - Sampling
    - Resolution
    - Sharpening
  - OECF
    - Tone Response
    - White Balance
    - Color Encoding

- Noise
  - Light Intensity
  - Random (shot/grain)
  - Streaking/banding
  - Dead pixels
- Geometric
  - Barrel/pincushion
  - Color misregistration
  - Wobble
  - Moiré

Technical Guidelines pp. 7-14   *Note: A a short primer and overview on imaging science is available as a PowerPoint FADGI website*

The Objective Measures

- Four-level Ranking
  - Least to most critical (one to four stars)
- Aim and Tolerance
  - Tolerance drives performance level
- Project or program requirements may have performance requirements for different measures
  - Maps may require a 4-star measure for sampling but only require 2-star for color encoding

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Objective Measure Example – Color Encoding Error

Color Encoding Error (Delta E 2000)					
Performance Level	AIM	TOLERANCE (choose option A or B)			
		A) ΔE (L*a*b*)		B) ΔE (a*b*)	
		max	avg.	max	avg.
★ ★ ★ ★	0	< 6	< 3	< 3	< 2
★ ★ ★	0	< 10	< 5	< 5	< 3
★ ★	0	< 15	< 10	< 8	< 6
★	0	> 15	> 10	> 8	> 6

The summary values for either the Column A or Column B specification selections are provided at the top of the graph.

The following example is for a project requiring a 3-star performance (highlighted in blue) for measure of Color Encoding Error.   For either of these selections a 2-start performance level would be achieved, but it would fail the 3-star requirement.

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Objective Measure Example – Color Encoding Error (cont.)
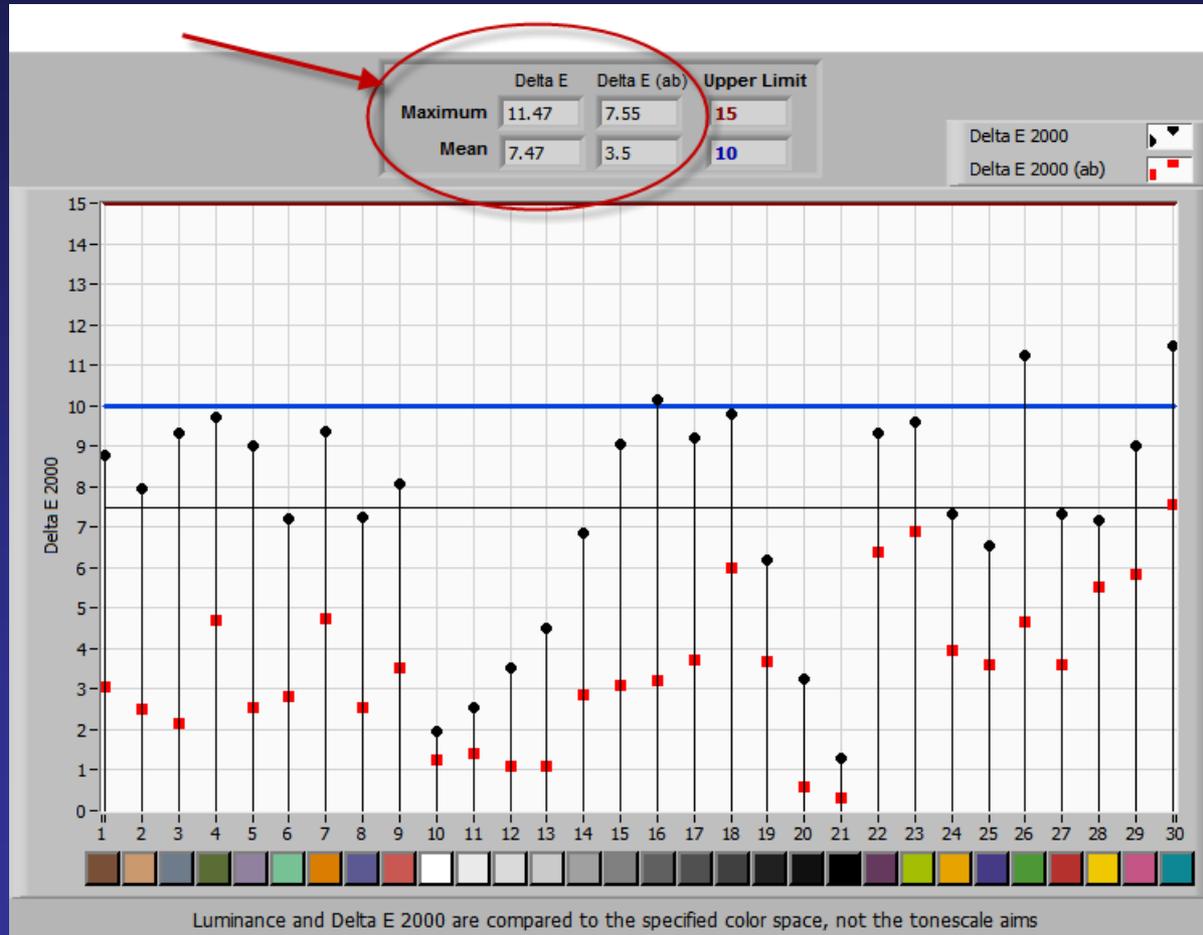
Performance Measures and Reference Targets (Ground Truth)

- To obtain objective measures, some known data is generally required.

- In OCR Ground Truth consists of known character or glyph patterns

- Image reference targets consist of known densities, frequencies, etc.

- Image targets may allow the evaluation of one or more measure.

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Reference Targets – Critical and Production Capable

From everyday packaging

To the Mars Rover

Integration of Targets in Scanner Software

(Zeutschel page showing UTT target used
with its with its "OS QM Tool"

Quality management in digitization projects becomes more efficient

Initiative develops universal test target (UTT)

Picture:
Quality control at a glance.
The universal test target (UTT) is to revolutionize quality management in mass digitization.

Examples of Image Targets
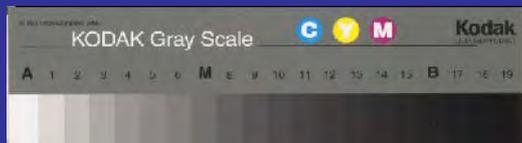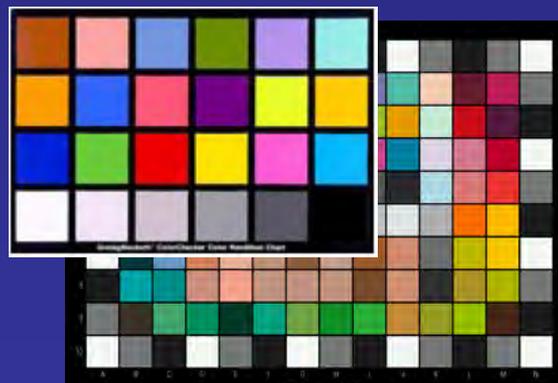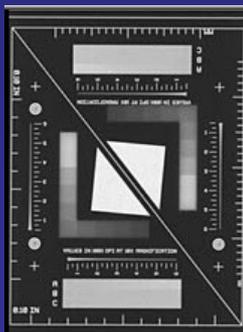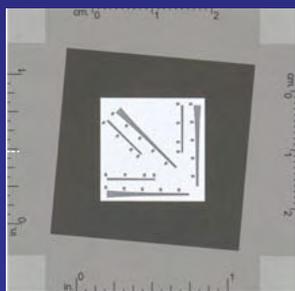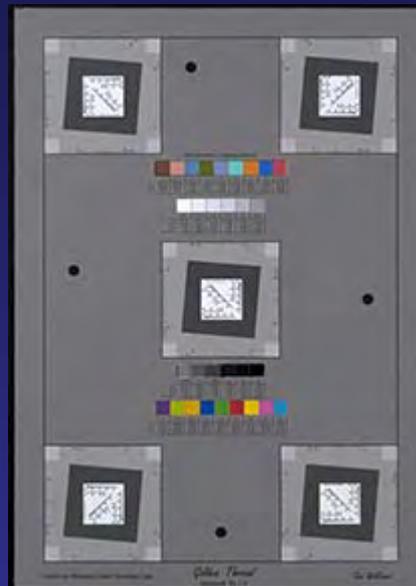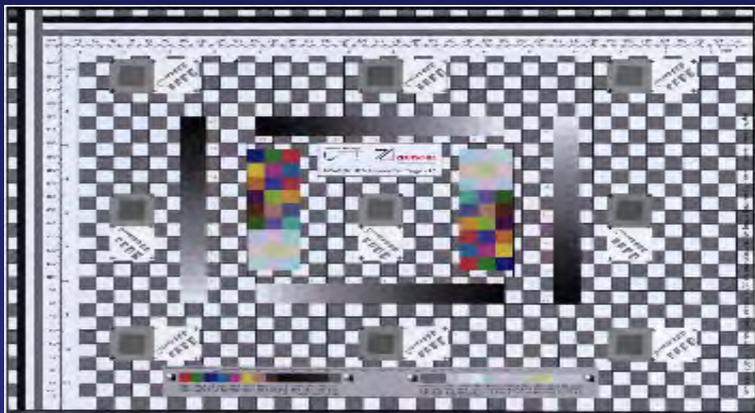
Image Targets Considerations

- Standards compliant (to the extent possible)
- Capable of providing comprehensive image performance data
- Capable of providing measurements as well as validation to requirements
- Available software to interpret the image data
  - Automated reads and batch modes preferable
- Capable of reflective and transmissive measures
- Are the targets "self-describing"
- Are the color features representative of your content color characteristics

Target Considerations (cont.)

- Are features spectrally neutral
- Is the target microstructure adequate
  - Resolution and Noise measures
- Are there versions available for providing device characterization (device-level) as well as be act as reference data with the image (object-level)
- Are they resilient to damage or change from handling or exposure to light
- Is it designed for regular validation of target features – e.g. density, color Lab values, etc.

Targets –
Device-level and Object-level

- Object-Level
  - Full characterization across image field (for target size)
  - Verification of device specifications
  - Testing of contractor capabilities
  - Benchmarking of digital imaging devices
  - Periodic stability testing or configuration change testing

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Device Target - Features

Human interpretable resolution features

ISO Frequency Response (SFR) and resolution over the field of view

Dimensional scales for to confirm "dpi"

Twelve spectrally neutral patches for tone curve and noise measures

Color patches with colorimetric (lab) annotations

Features for automated detection and analysis
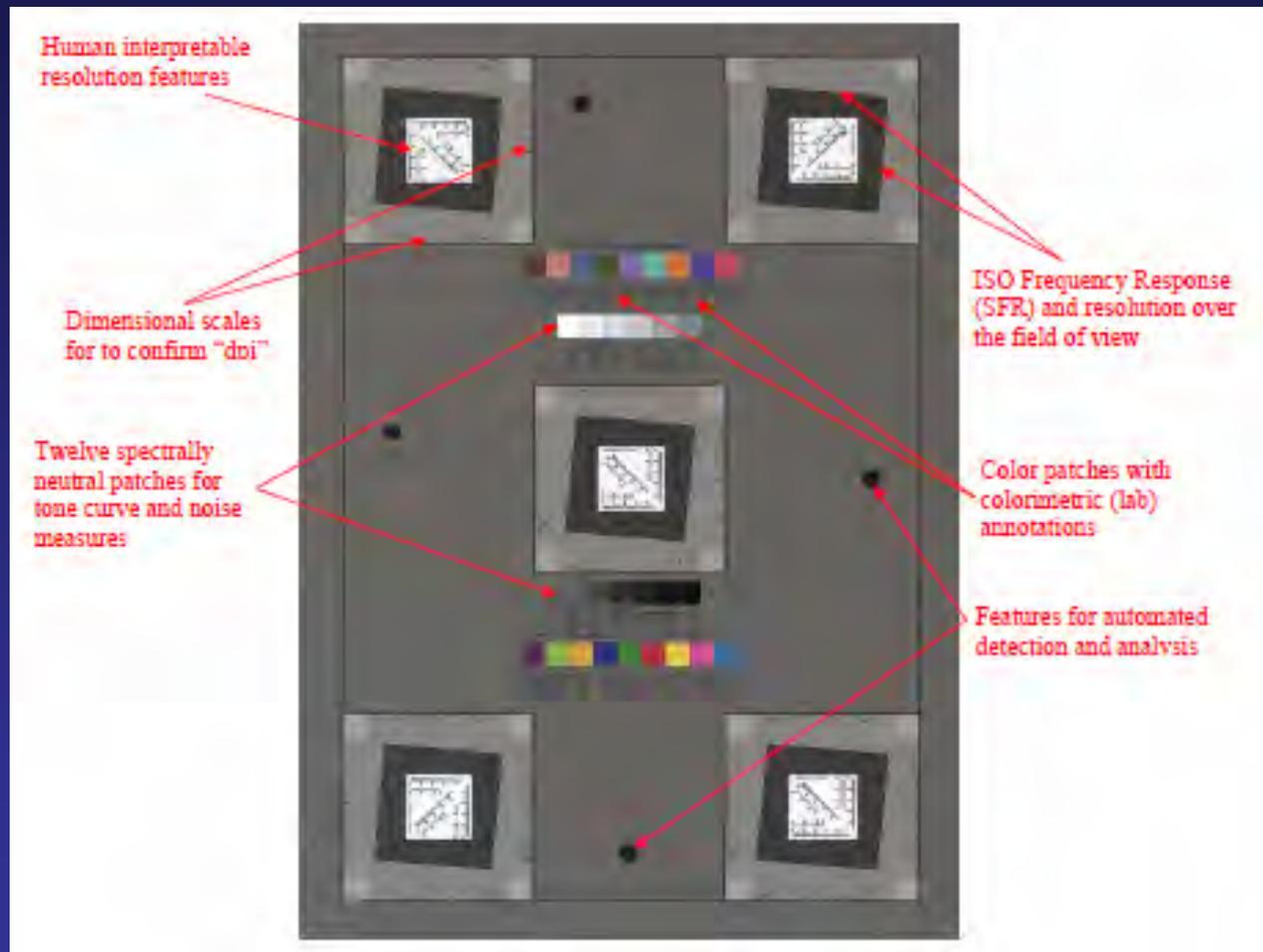
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Targets –
Device-level and Object-level

- Object-Level
  - Same basic features as device target
    - All measures provided with the exception of those requiring data across image plane
  - Provides ground truth tied to image
  - Allows 100% sampling for quality control

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Object Target – In Use

Targets During Book Scanning

Scales to measure sampling frequency

Uniform neutral features for uniformity of illuminance

Visual inspection of resolution

Slanted edge for measure of resolution (SFR)

BY A. H. BLAKE, M.A.
NIGHT PHOTOGRAPHY
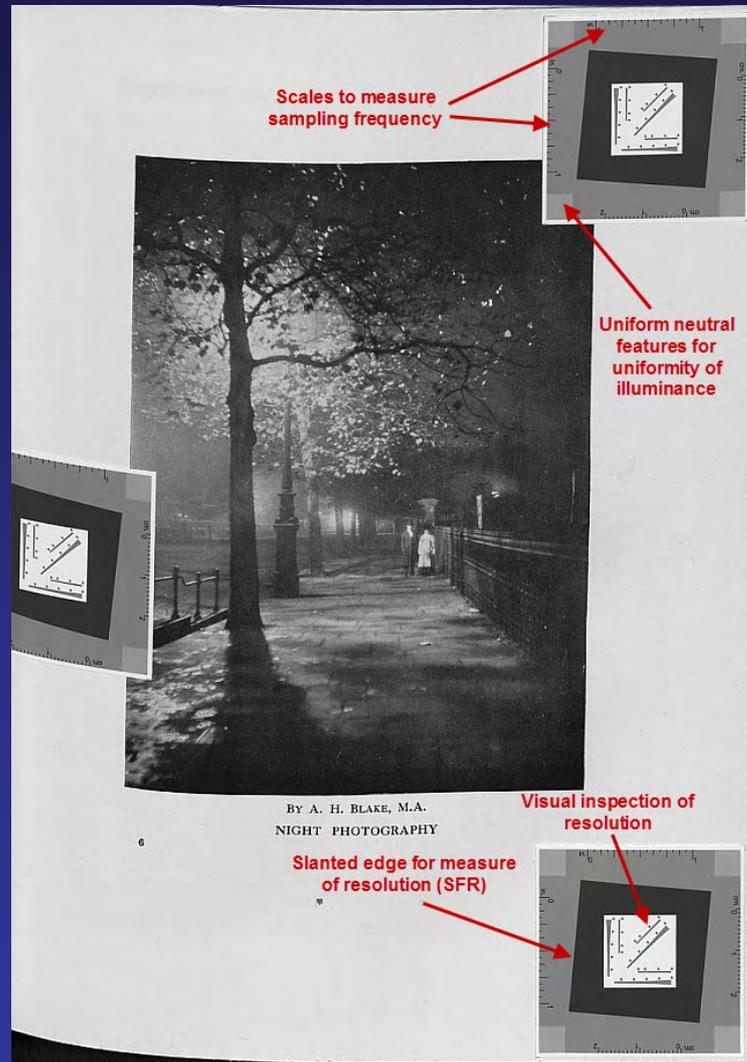
Preparing for Process Quality Factory-based Calibration

- Follow manual for scanner and processing software setting for the desired output

- If camera or scanner can become out of alignment with the base, zig-align or a similar product to keep the sensor plane parallel to the base.

- Image the Device target and Run DICE evaluation software or similar product.

Preparing for Process Quality Repeatable Output
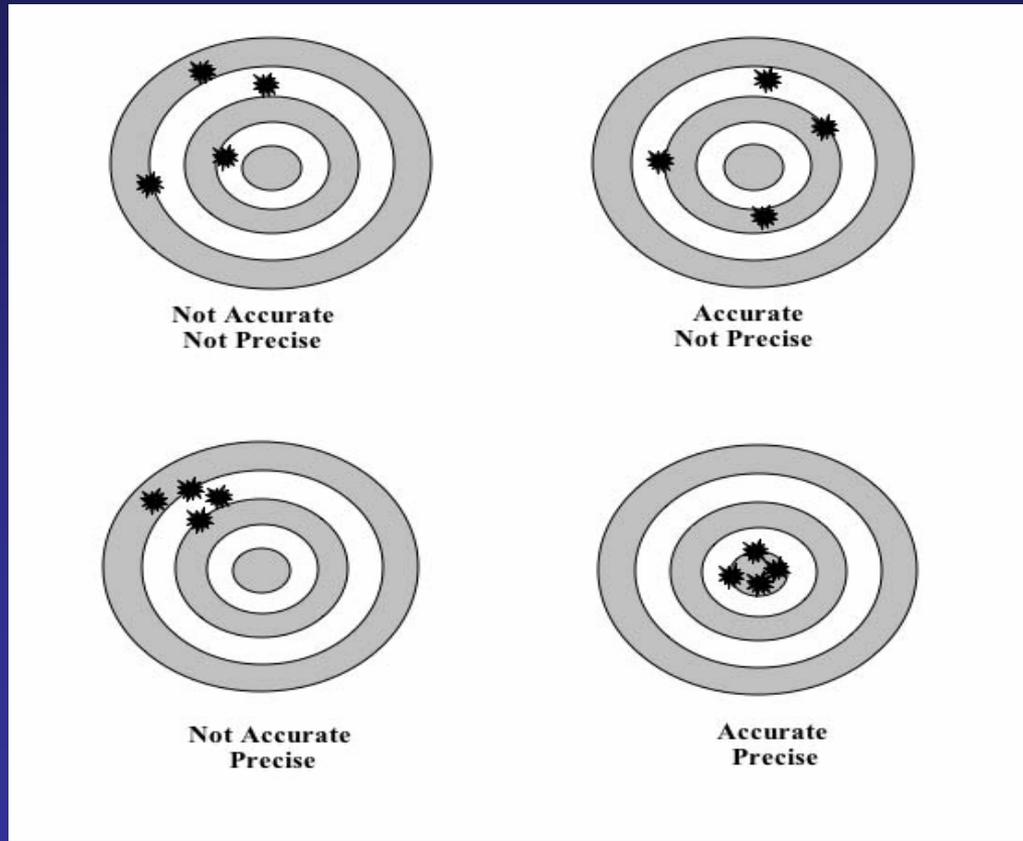
Precision than Accuracy

- When starting with a new scanner for scanning service, concentrate on precision and range of device (e.g., resolution, Dmax, etc.)

- When the device and users are stable, use the device target data to help you bring the scanner into you threshold

- Continue to take regular readings and track the data overtime to identify and correct and undesirable trends

Visual Analysis

- Many aspects of image quality can only be evaluated by visual inspection

- The aspects most difficult to evaluate in an automated manner generally fall under "noise"

- The known data comprising image targets along with their range of data make them useful for visual analysis

- *Some of the most obvious digital imaging issues are the most difficult to detect without human interpretation*

Visual Inspection for Artifacts

Bad cam in a linear array scanner
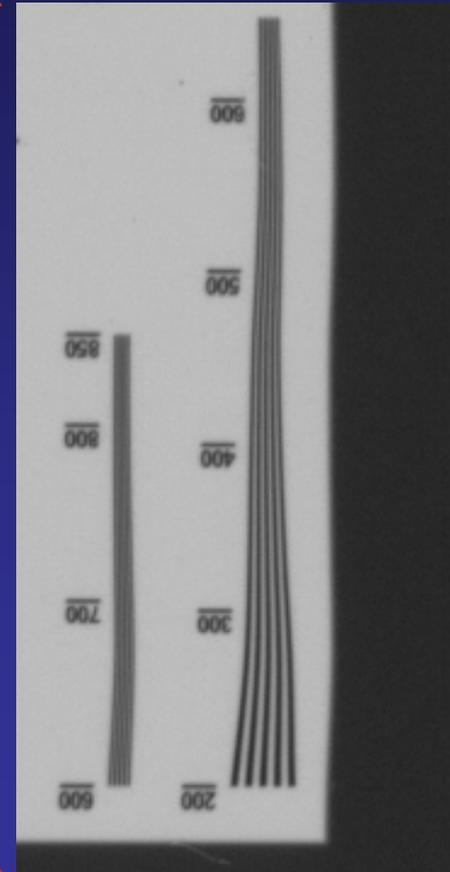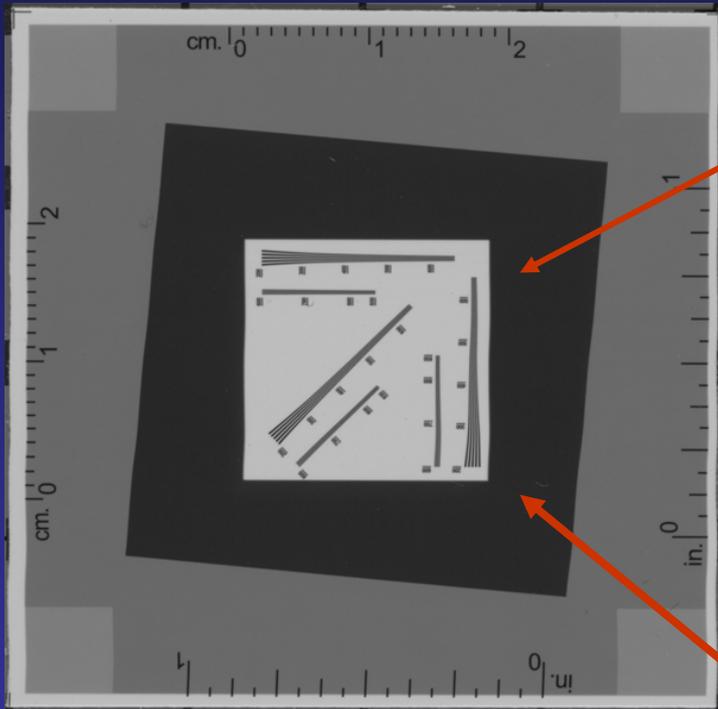
Visual Inspection for Artifacts

Color Misregistration

Red Color Misregistration (Lateral Color Error)

Blue Color Misregistration (Lateral Color
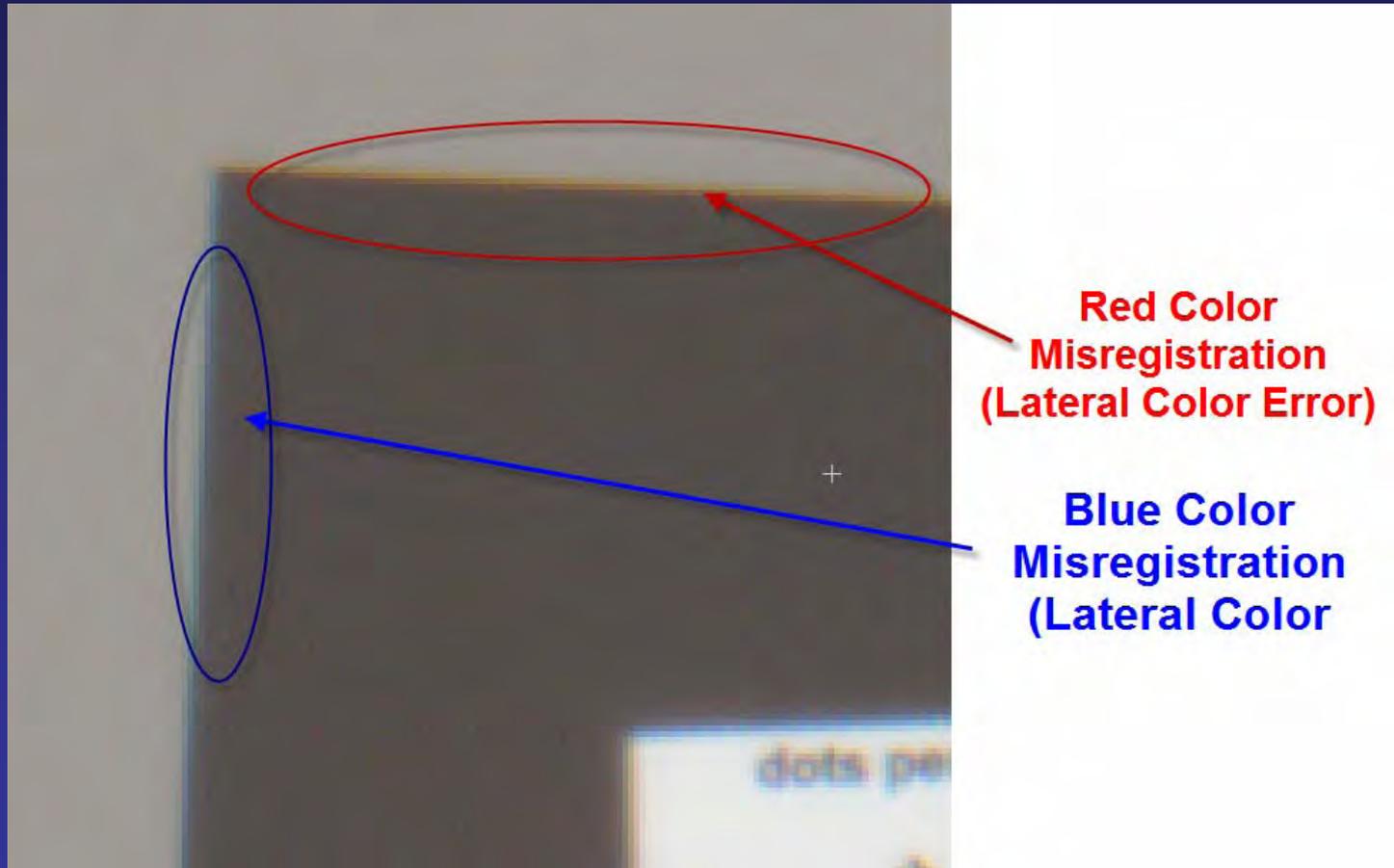
Visual Inspection for Artifacts

Spatial Artifacts

optical resolution limit

resolution limit due to CFA de-mosaicing
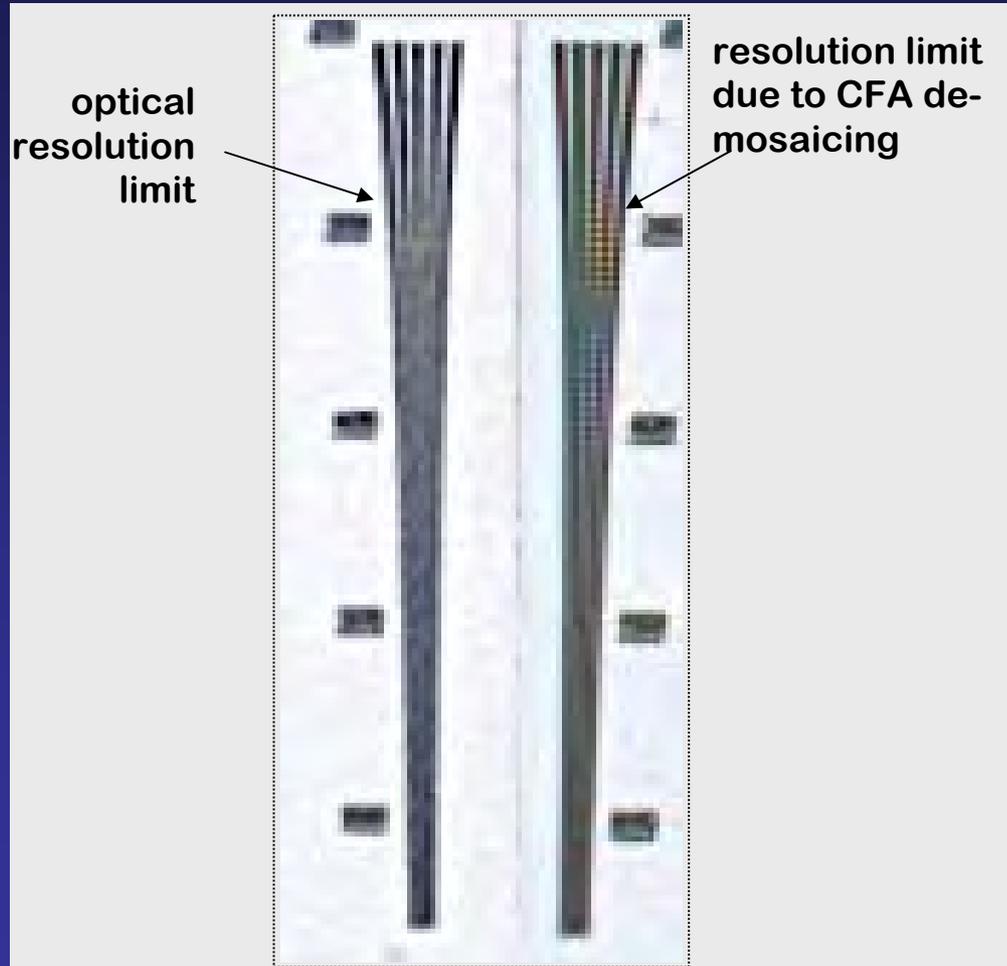
Digital Imaging by Content Type

- Recommendations for six main categories
  - Textual
  - Reflective Photographic
  - Transmissive Photographic
  - Reflective Aerial Photographic
  - Transmissive Aerial Photographic
  - Graphic Materials
  - Objects and Artifacts

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Resolution and SFR in more detail

Sharpened

Normal

Low contrast - Flare

Limiting resolution will generally correspond to the spatial frequency having a 0.10 modulation transfer value

SFR response

1.0

0.5

0.0

Increasing spatial frequency
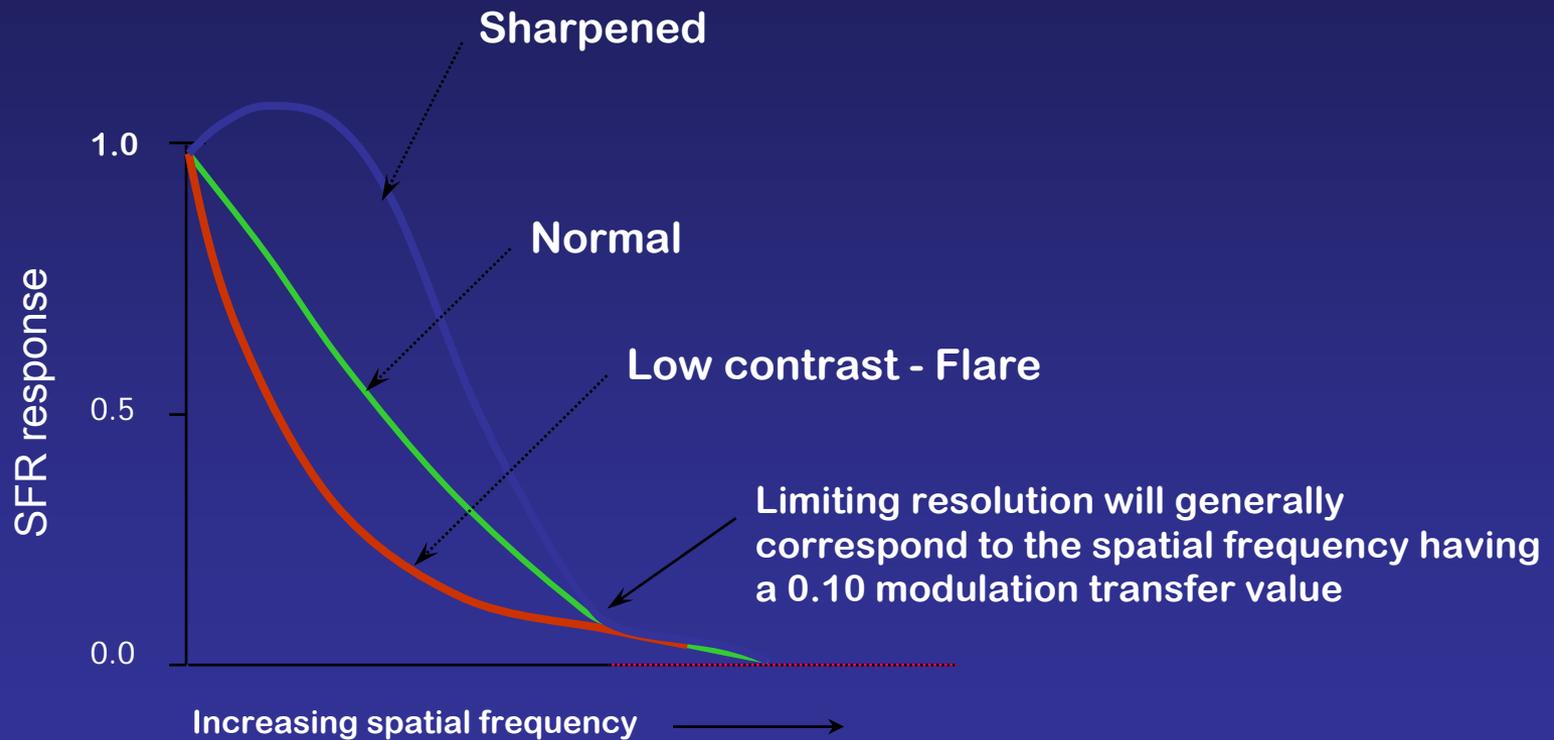
How is the SFR really measured ?
ISO 12233, 16067-2, 16067-2, 15529

SCANNER SFR & OECF #1
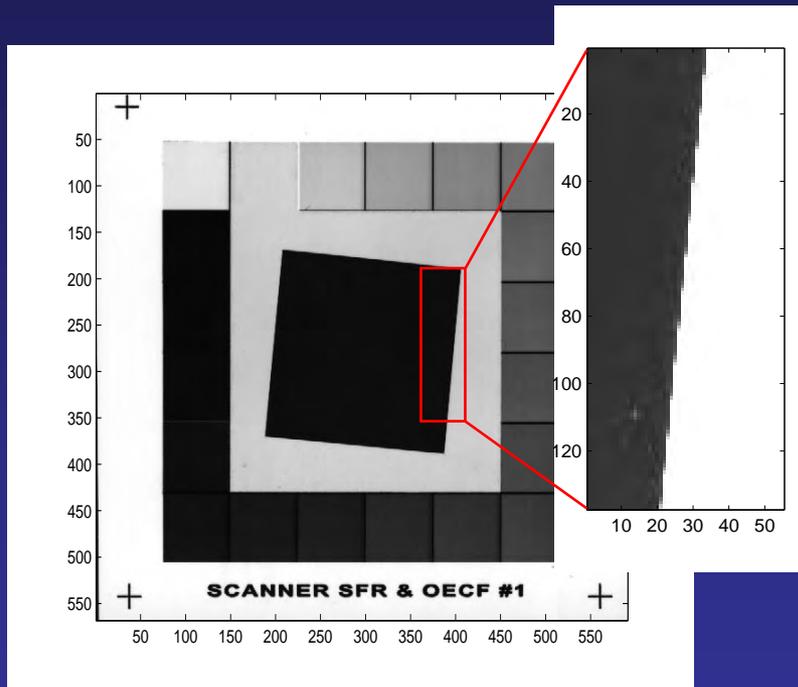
Using a good quality slanted edge
With good contrast against the
background

Why edges ?

Naturally occurring features
Easy to manufacture targets
Concise

Sampling Frequency (DPI) is not Resolution

real data example : results are not simulated

Limiting resolution = whenever all five lines are undetectable

Resolution

Sampling Frequency

200 dpi level

300 dpi level

400 dpi level

200 dpi   300 dpi   400 dpi   600 dpi
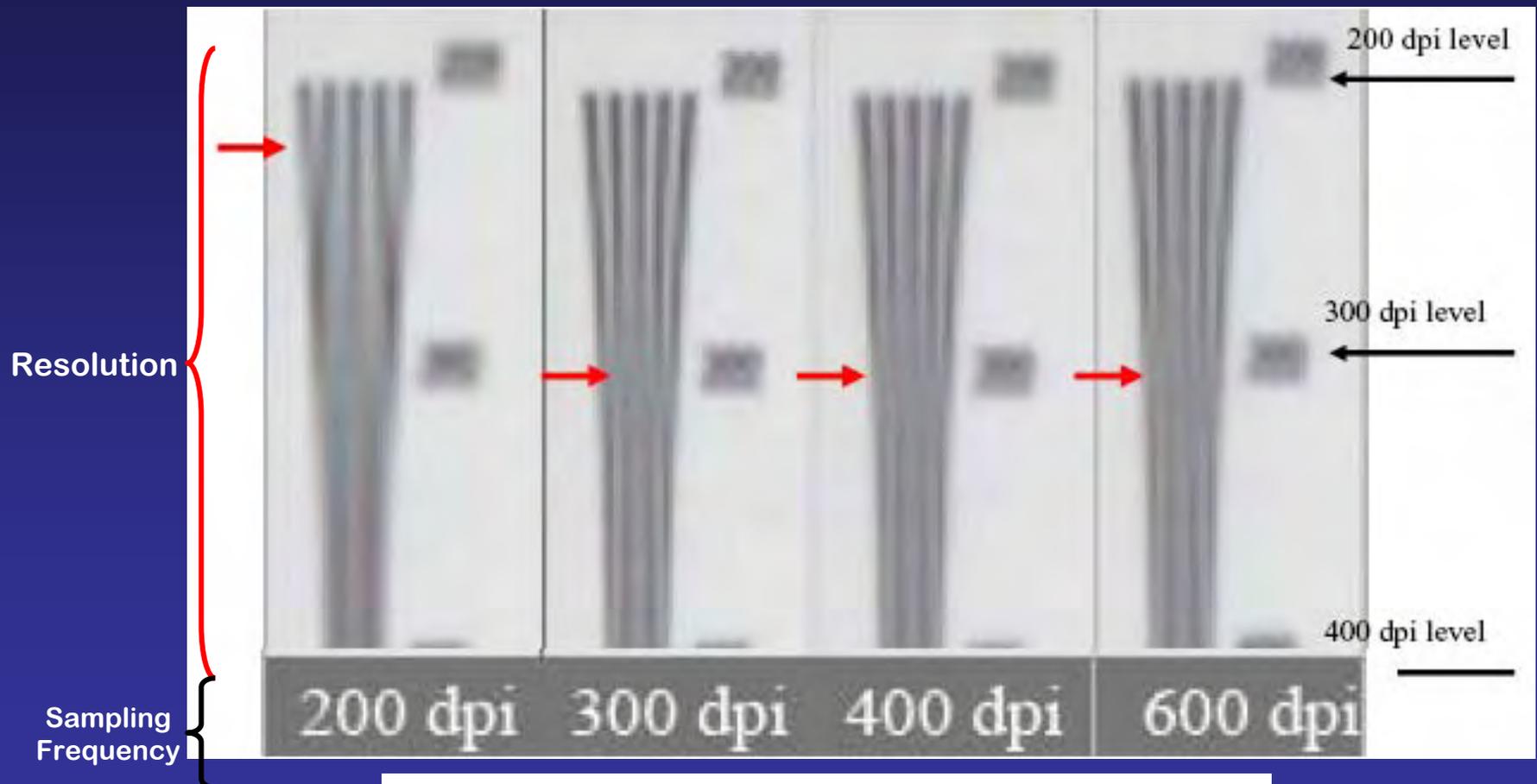
Though the sampling rate is increased to 600 dpi the true resolution for this scanner is only 300 dpi.

Image Quality is not Imaging Performance

Sharpness

Resolution

photo courtesy of P.Bu

Edge Detail Apparent
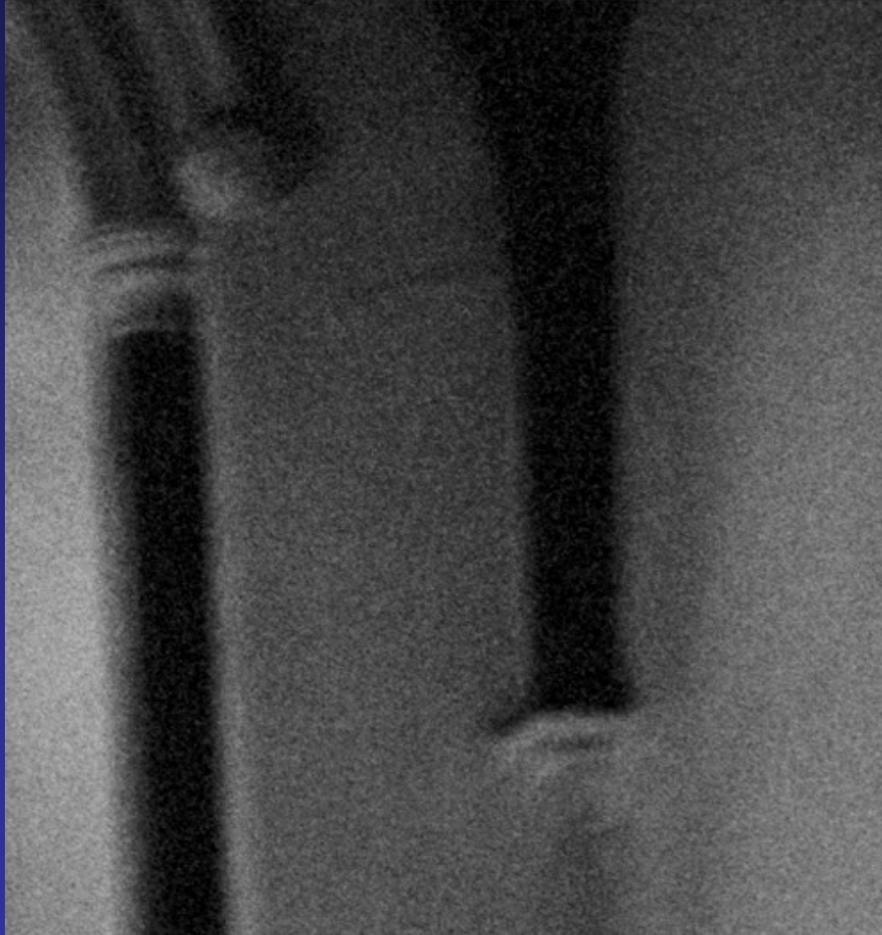
Past Resolving Limit in Image
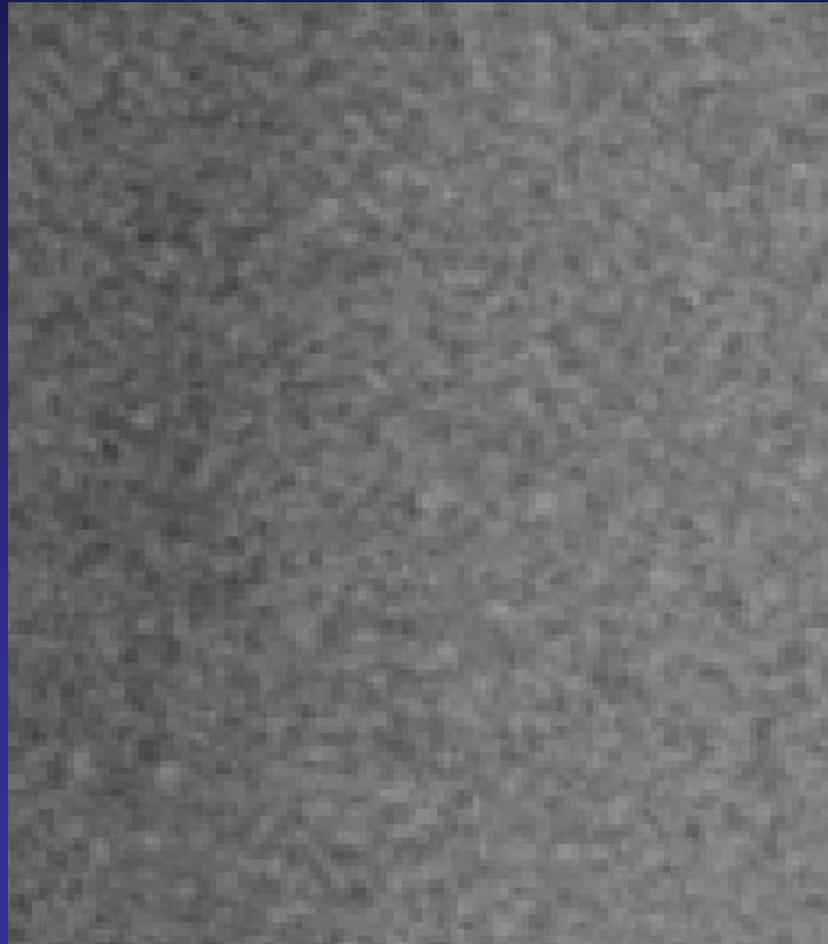
Published Imaging Numbers –
A Starting Point

Textual Documents, Graphic Illustrations/Artwork, Maps, Plans, and Oversized

Document Character - Original	Recommended Image Parameters	Alternative Minimum
Clean, high-contrast documents with printed type (e.g. laser printed or typeset) **Different use cases with differing imaging requirements**	1-bit bitonal mode or 8-bit grayscale - adjust scan resolution to produce a QI of 8 for smallest significant character or 1-bit bitonal mode - 600 ppi* for documents with smallest significant character of 1.0 mm or larger or 8-bit grayscale mode – 400 ppi for documents with smallest significant character of 1.0 mm or larger **NOTE:** Regardless of approach used, adjust scan resolution to produce a minimum pixel measurement across the long dimension of 6,000 lines for 1-bit files and 4,000 lines for 8-bit files *The 600 ppi 1-bit files can be produced via scanning or created/derived from 400 ppi, 8-bit grayscale images.	1-bit bitonal mode - 300 ppi* for documents with smallest significant character of 2.0 mm or larger or 8-bit grayscale mode - 300 ppi for documents with smallest significant character of 1.5 mm or larger *The 300 ppi 1-bit files can be produced via scanning or created/derived from 300 ppi, 8-bit grayscale images.
Documents with poor legibility or diffuse characters (e.g. carbon copies, Thermofax/ Verifax, etc.), handwritten annotations or other markings, low inherent contrast, staining, fading, halftone illustrations, or photographs	8-bit grayscale mode - adjust scan resolution to produce a QI of 8 for smallest significant character or 8-bit grayscale mode - 400 ppi for documents with smallest significant character of 1.0 mm or larger **NOTE:** Regardless of approach used, adjust resolution to produce a minimum pixel measurement	8-bit grayscale mode - 300 ppi for documents with smallest significant character of 1.5 mm or larger

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Artifact Rather Than Edge

Autochrome Microstructure

Granules between 14 and 20 microns
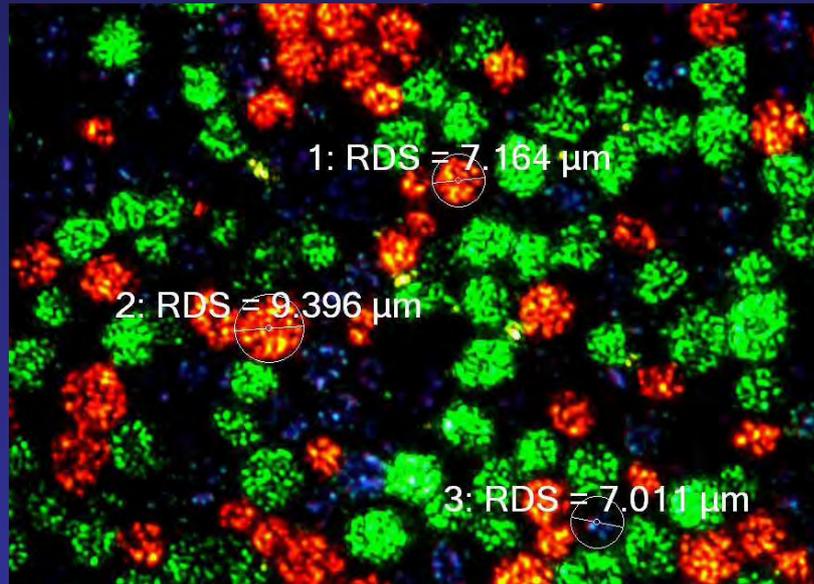
Dufaycolor Microstructure

Bands approximately 60 microns
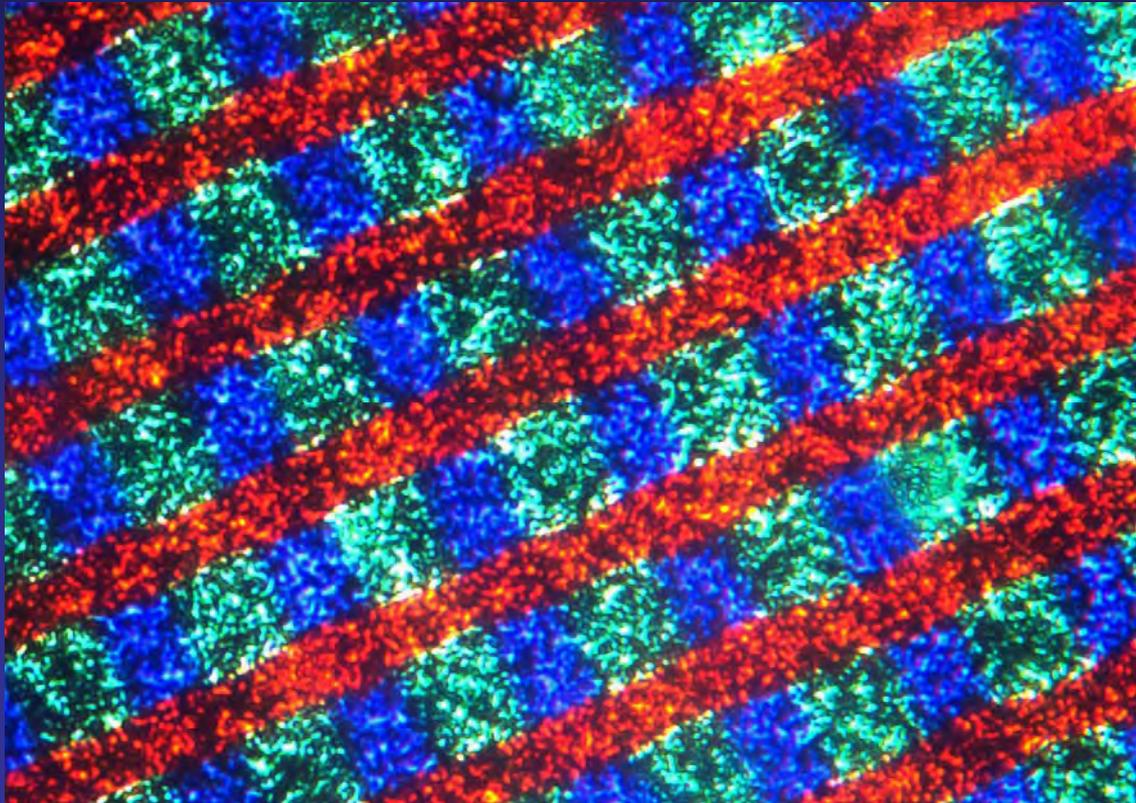
Determining Sampling & Resolution for non-edge detail

- Analog may not have any absolutes
    - Higher resolution yields ever more detail
- Concentrate on the unique aspect of image (e.g., pointillist aspect of Autochrome, screen aspect of Dufaycolor)
- Consider how image will be used, or how it was originally viewed
- Image representative samples to establish required image performance

Stereoscope for Autochromes

- Distinctive structure of Autochrome clearly evident using period viewing device
- Stereoviews were also common (complicating historical use cases)

Metamorfoze Preservation Imaging Guidelines

- Guidelines being developed at the KB (National Library of the Netherlands)
- Metamorfoze uses a three-tiered model similar to the four-tiered FADGI Guideline for image performance
- The guideline is supported by the Universal Test Target for validating requirements
- Very compatible to the approach of the FADGI guidelines, with similar performance measures used in image evaluation

Latest draft (version 0.8) guideline available at:
http://www.metamorfoze.net/publicaties/richtlijnen/Metamorfoze%20Preservation%20Imaging%20Guidelines_Version_0.8_July_2010.pdf

Going Forward with the challenge of Still Imaging

Color-

Various color spaces to choose from – we which to identify and describe the use of those most appropriate

Guidelines should suggest representative colors a project to evaluate for DeltaE and Delta (a*b*)

Color samples used on current targets are too limited in number and may not correspond well to content being imaged when determining color encoding errors

Color spaces are not consistently applied within many large organizations of across organizations. We hope to suggest just one or two color spaces for most work.

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Going Forward (cont.)

- File Formats
- Formats and characteristics
  - Master files
  - Access derivatives
- Same use case approach as used for digitization
  - Pilot for compressed master files
  - Use-based derivate products

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Going Forward (cont.)

- Embedded Metadata
    - New TIFF Header Guideline published
    - Sub-group formed and active
    - Focus on developing use-cases representing all participating agencies
    - Goal on consistent format and fields for all image file formats
    - Limited subset including technical, administrative and bibliographic metadata
    - Embedded persistent identifier to "authoritative" metadata
    - XMP likely format

Gap Analysis – Identified Priorities

Identify and prioritize those areas of digitization that fall within the scope of this Initiative, and that are:

- a) not currently defined within existing agency guidelines; or
- b) not adequately addressed by those guidelines.

- Gap Analysis is updated regularly to reflect progress, new and shifting priorities
- 29 Gaps have been identified and described
  - Thirteen high priority gaps
  - Eight medium priority
  - Eight low priority
- Ten are under development or actively being explored by the Still Image sub-groups and Advisory Board

Coming soon…

digitizationguidelines.gov

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