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SI 675 Digitization for Preservation

Week 4 – Color in Scanning and Scanner Benchmarking

Today's Outline

- Encoding
- Performance measurement
  - Spatial Frequency Response
  - Tone and color response
  - Noise and artifacts

"*Original-referred images maintain a defined relationship between the original and digital version; the digital version carries forward certain pre-identified essential characteristics of the original version*." (p. 9)

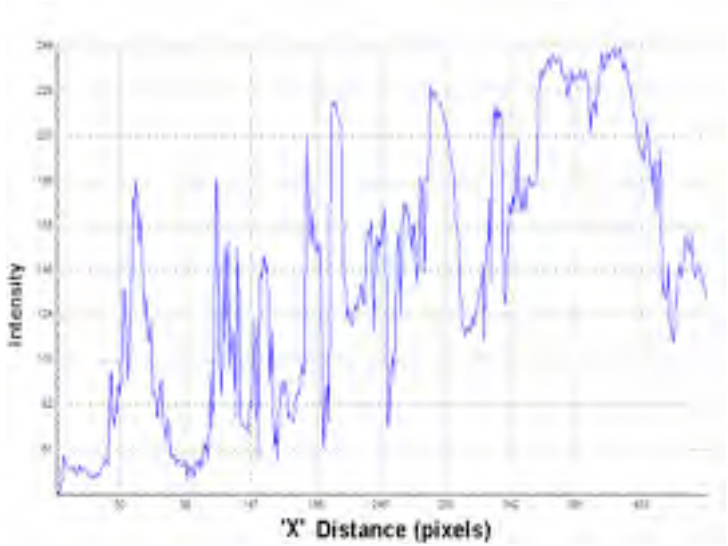
• **Puglia/Rhodes, Digitization for Preservation (2007)**

What is an Image... and how is it characterized ?

Image Science Associates

A two dimensional spatial structure of varying light levels and colors.

It is characterized by measuring physically realizable light intensities over a two dimensional space. These variations can occur over short distances, like edges, (high frequencies) or larger distances or areas, like sky or facial features (low frequencies).



'y'

'x'

What is a Digital Imaging System?

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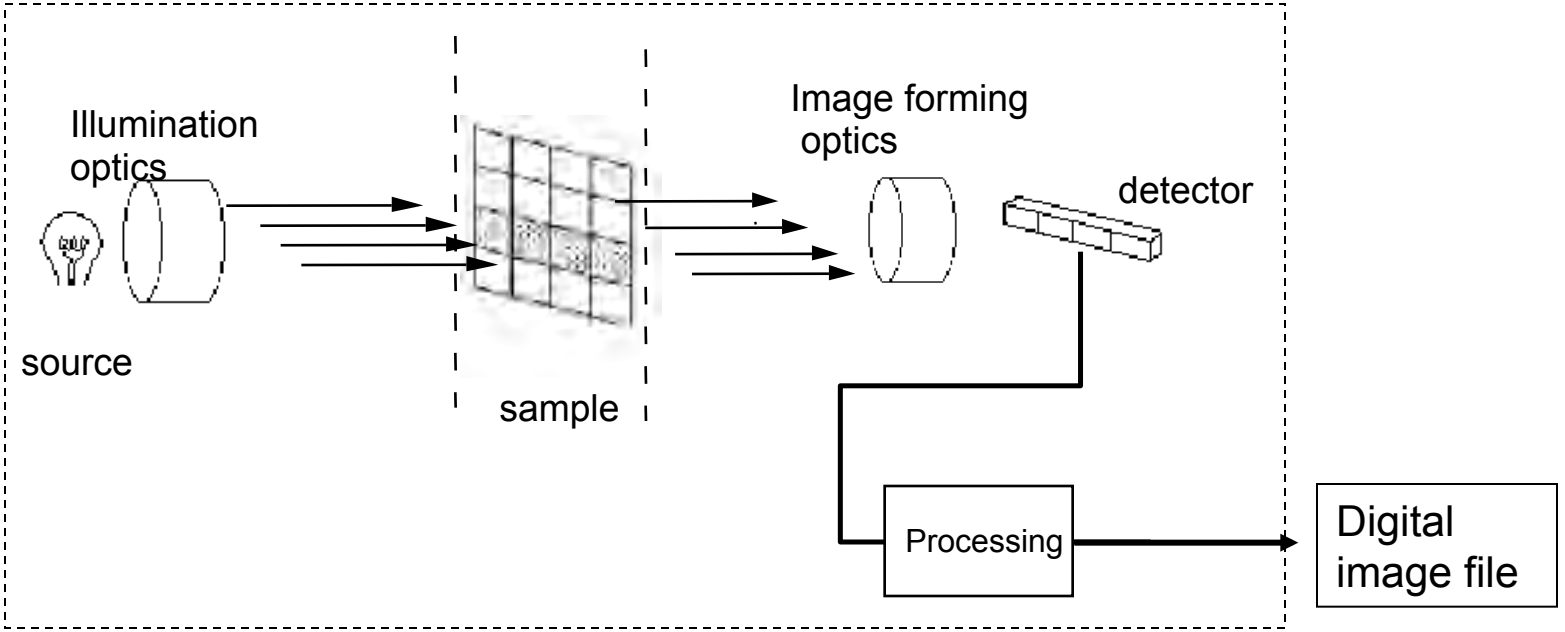
A collection of optical, software, or electronic functions that convert, encode, or otherwise act upon images or their optical or digital derivatives.



The performance of a digital capture system is influenced by all of the above in addition to operator training and environment.

• Frey & Reilly, Digital Imaging, 1999 $ 2006

Rendering Intents Revisited

- When "… digital image is a 'replacement' of the original…" (p. 28)
  - Decisions made about color space before images are digitized. Adjustments made during scanning.
  - "… not be the goal to reproduce the physical properties of the original, but to reproduce its appearance under certain viewing conditions."

- Scanned image matches original (viewing calibration)
- Adjust for errors in the source
- Original appearance rendered (reverse aging)
- "Original scene" (remove effects of intermediate)

PD-GOV

• Frey & Chapman, Developing Specifications, 2000.

Master Files: Raw or Cooked

"One of the basic things to understand is that a great deal of image quality can be lost by processing the images at the moment they are captured."

- Frey & Reilly (1999): First, a so-called **archive** file containing more than eight bits per channel should be stored. It should not be treated for any specific output.
- Frey & Chapman (2000): save **unrendered** image space to contain a colorimetric estimate of the original. (p. 168)
- Susstrunk (2002): capture and encode into a **sensor** or **source space**, which is device and image specific. (p. 2)
- Susstrunk (2002): transform from **raw sensor** data (device dependent) to **original-referred** color encoding; then **image dependent processing** to **output-referred** color encoding to output device coordinates. (p. 389)
- Puglia/Rhodes (2007): Original-referred is not raw (sensor)

Definitions and Terms

- Original vs. scene: scanner/camera OR artifact/nature
- Color encoding: relationship of the real and its representation
- Color model: abstract mathematical model of color representation (e.g. RGB, CMYK)
- Gamut: subset of colors that can be accurately represented in a given circumstance (e.g. color space or output device).
- Color spaces: color model + gamut
- Absolute color space: colors are unabiguous; interpretation is colorimetrically defined without reference to external factors.
- ICC color profile: color attributes of a particular device or viewing requirement ; map between color space and profile connection space (CIELAB or CIEXYZ)

Digital Cameras do not Reproduce Colors, They Encode them.

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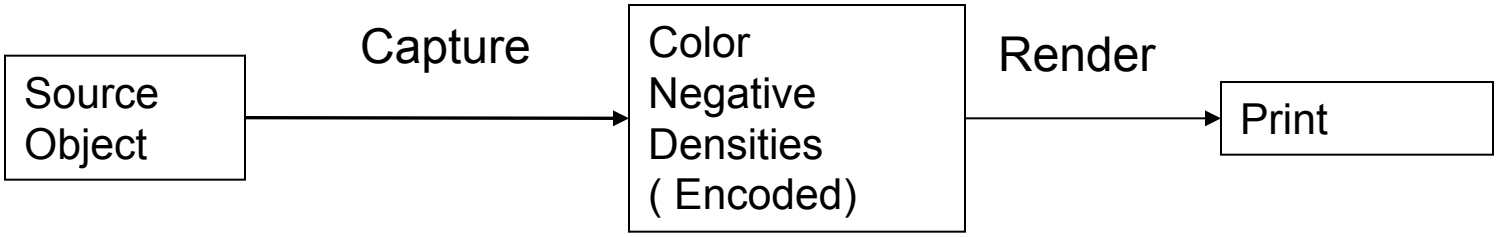
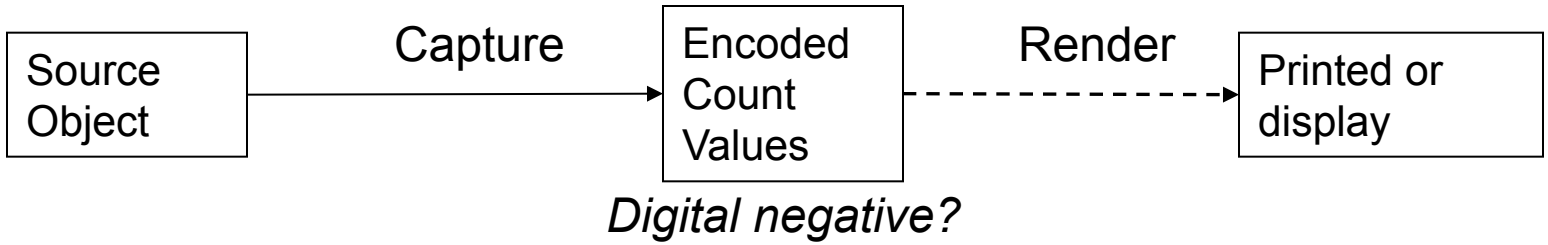
They *describe* (encode) object color characteristics.

Reproduction requires *interpreting* (decoding) the pixel values to display the color image.

Color film negative path



Color digital camera path



• **Susstrunk, Color Encodings (2002).**

Color Encoding Flowchart

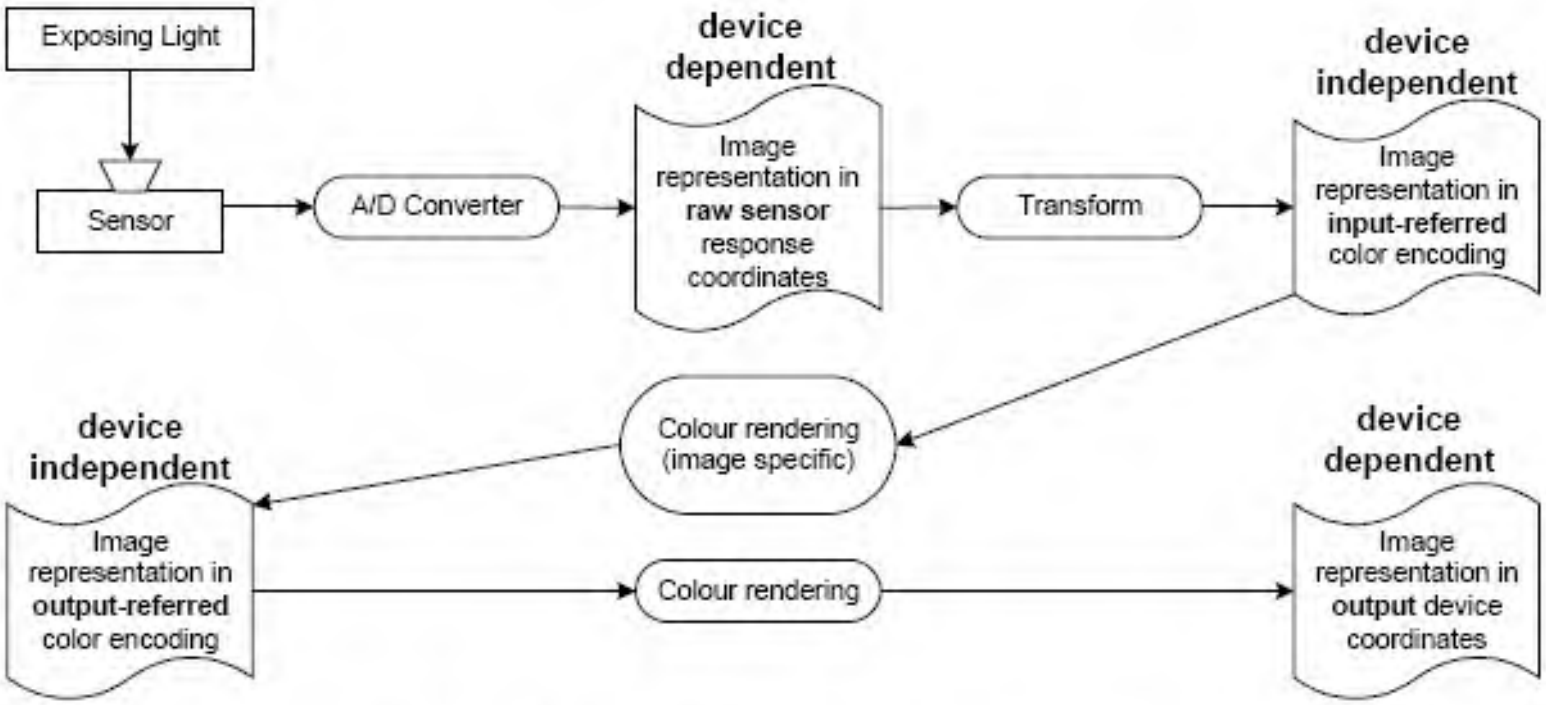


Figure 1: Color image workflow from capture to display.

Raw Files, Be Careful What You Ask For

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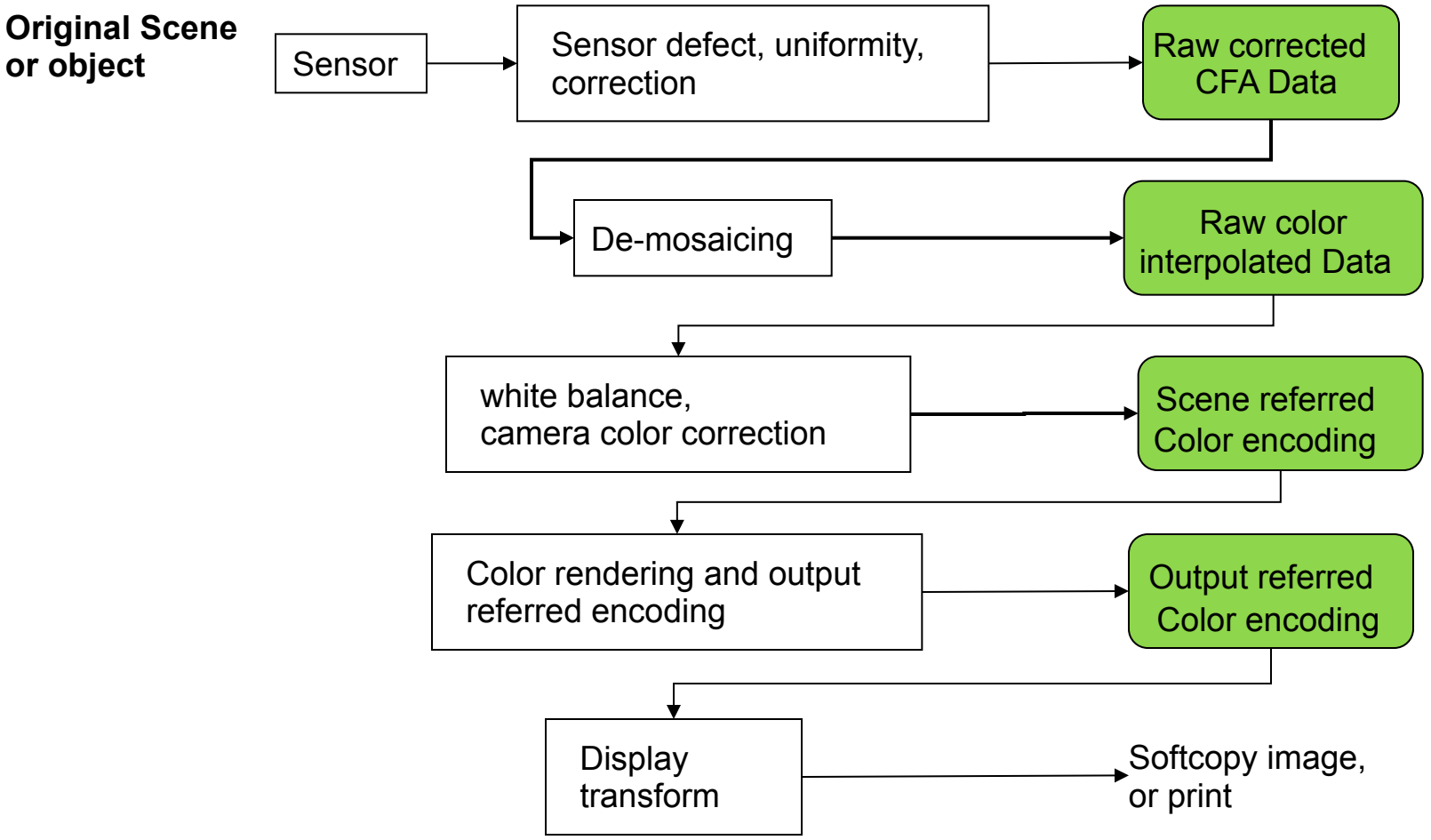


• Susstrunk, Managing Color (2002).

Sensor Encoding

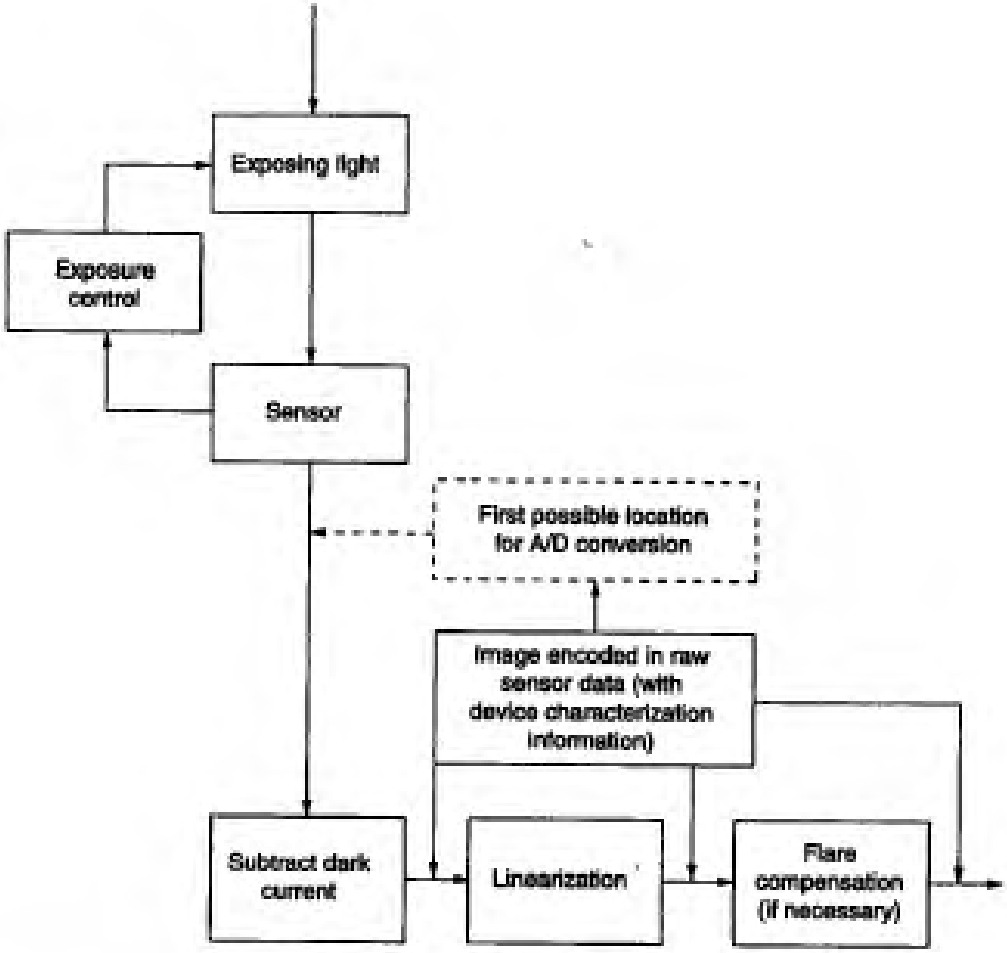


Figure 17.2 Color processing to sensor encoding.

PD-INEL

- "When a high quality master file is desired, storing 'raw image' data encoded in sensor space is most appropriate. Any further processing can degrade the image, as algorithms are based on today's know-how and might be improved in the future." (p. 390)

• Susstrunk, Color Encodings (2002).

Input- and Output-Referred Encoding

- Input-Referred Encoding (master)
  - Scene versus Original
    - Photo YCC (Kodak Photo CD)
    - RIMM RGB
    - ICC PCS
- Output-Referred Encoding (derivative)
  - Transformed from source or input
    - sRGB (screen and color printing)
    - E-sRGB (rendering for unknown output)
    - ROMM RGB (extended bit depth)
    - Adobe RGB (graphic arts and printing)

• **Susstrunk, Color Encodings (2002).**

Attributes of color encodings

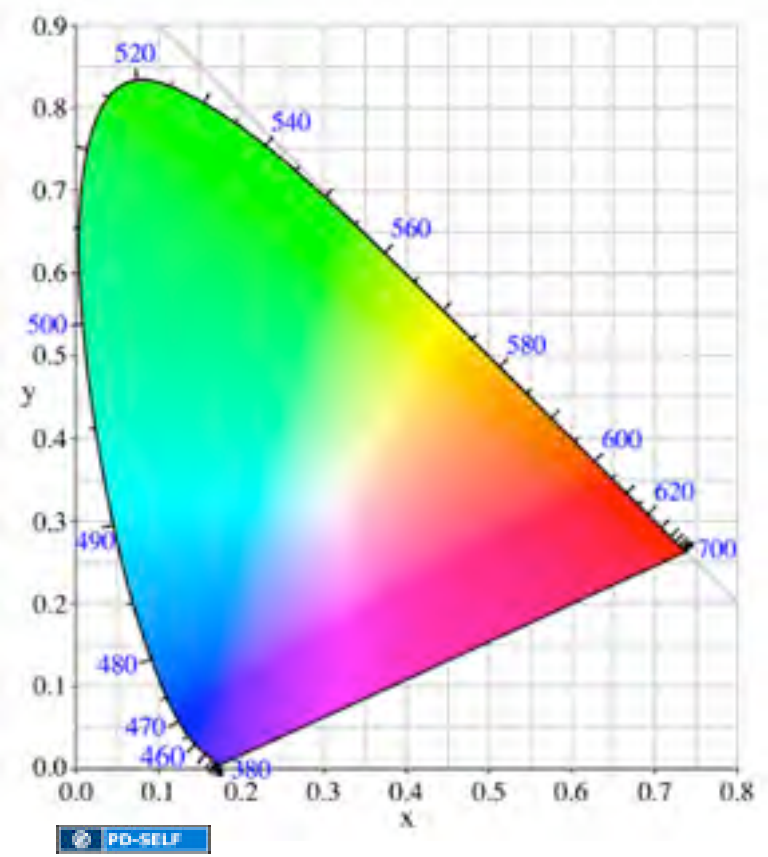
Table 2: Attributes of input-referred and output-referred color encodings

	Input-referred encoding	Output-referred encoding
Image representation	Colorimetric estimate of a scene/original	Colorimetric estimate of a reproduction
Color gamut	Large enough to encompass most scene/original colors	Large enough to encompass most output devices
Perceptual uniformity (transfer function)	Data is optionally encoded using a transfer function for approximate perceptual uniformity (invertability desired)	Data is optionally encoded using a gamma-type power function to approximate perceptual uniformity on the output device (invertability desired)
Dynamic range	Must handle a scene luminance ratio of at least 10'000:1, or the luminance ratio of the original.	Must handle an image luminance ratio of at least 1000:1
White point	Should accommodate floating white points or chromatic adaptation to a fixed white point	Fixed white point determined by reproduction viewing conditions (D50, D65)
Viewing conditions (linkage to color appearance)	Luminance level, viewing surround, adapted white point, and viewing flare, as typical of outdoor environments for scene-referred encodings, typical of original viewing conditions for original encoding.	Luminance level, viewing surround, adapted white point, and viewing flare, as typical of indoor environments
Quantization Encoding	Quantization errors not visible on smooth, noiseless ramps Extended bit-depths encoding desired (10, 12, 16-bit per channel)	Quantization errors not visible on smooth, noiseless ramps, 8, 10, 12 or 16-bit encoding (8-bit for applications)
Compressibility	Not very important	Importance dependent on the imaging application (easy conversion to YCC color encoding)
Usual color encodings	CIEXYZ, CIELAB, CIELUV, RIMM RGB, Photo YCC	e-sRGB, sRGB, ROMM RGB, Adobe RGB 98, YCbCr, Photo YCC (legacy: Apple RGB)
Applications FAIR USE	Master files for high-end applications (replacement of the original)	Master files (for print reproduction): e-sRGB, ROMM RGB, Adobe RGB 98, Photo YCC Master files (for screen viewing): sRGB, YCbCr Derivatives for print reproduction or screen viewing

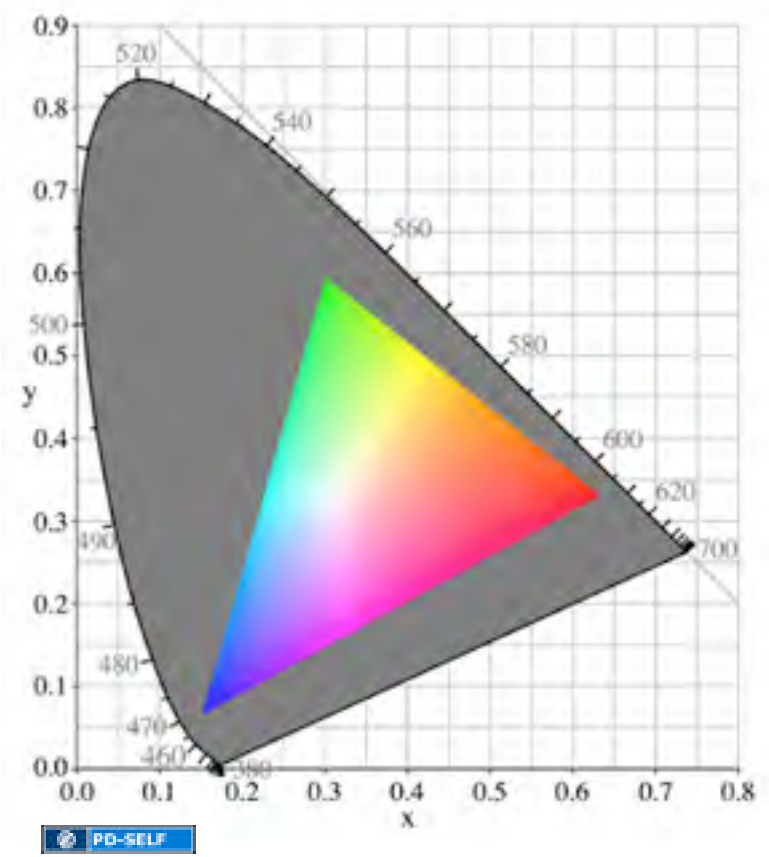
Color Gamut Comparison

[Susstrunk 2007]

Range of Chromaticities



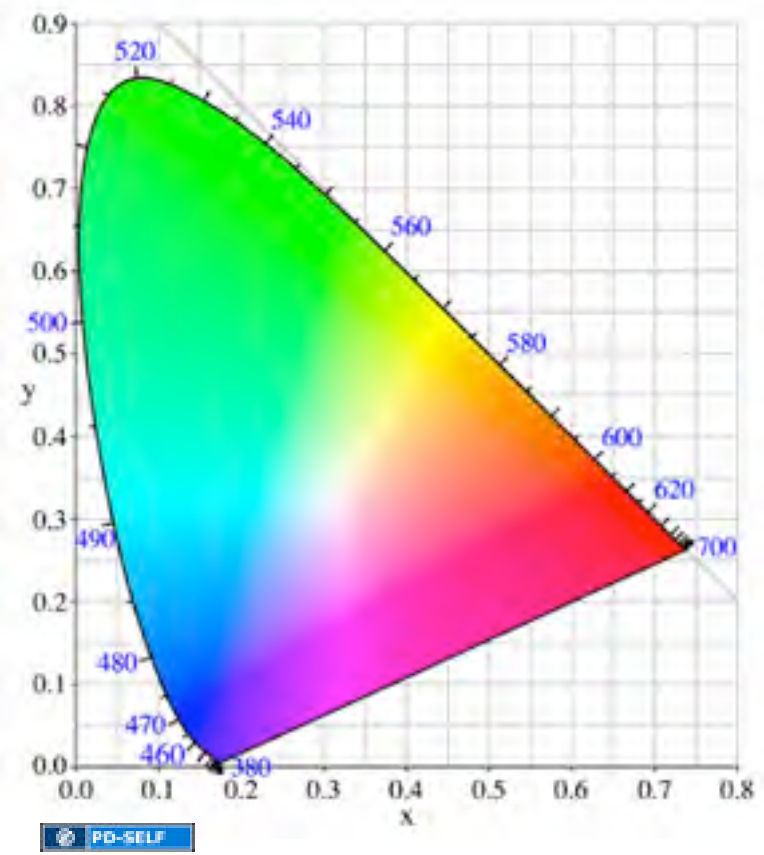
Typical CRT Gamut



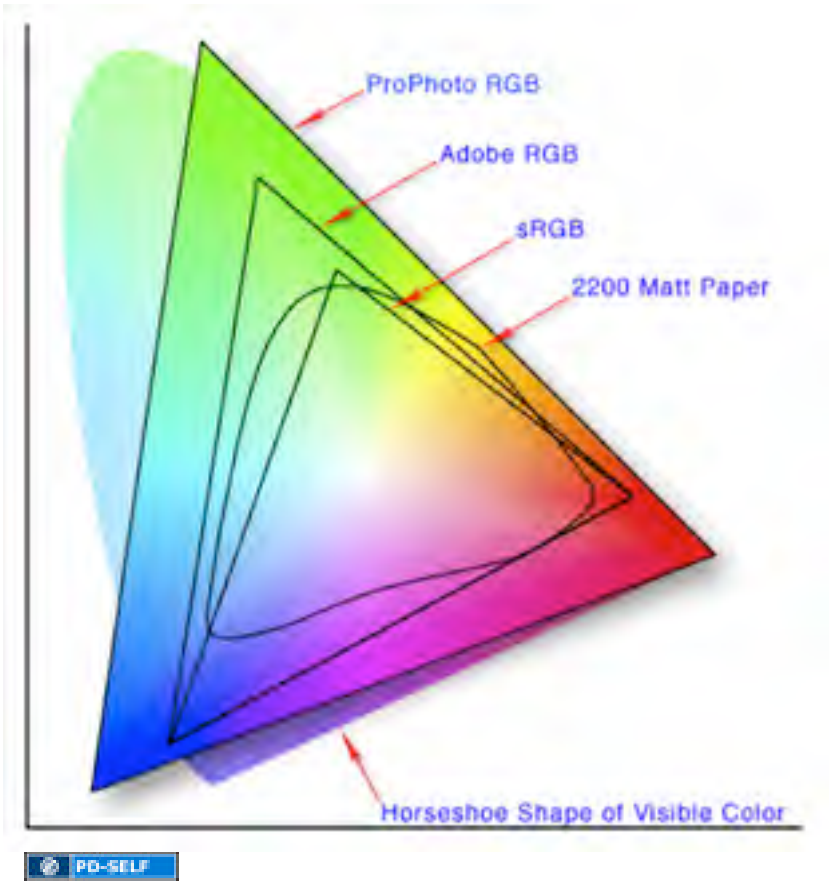
Color Space Comparison

[Susstrunk 2007]

Shape of Visible Color

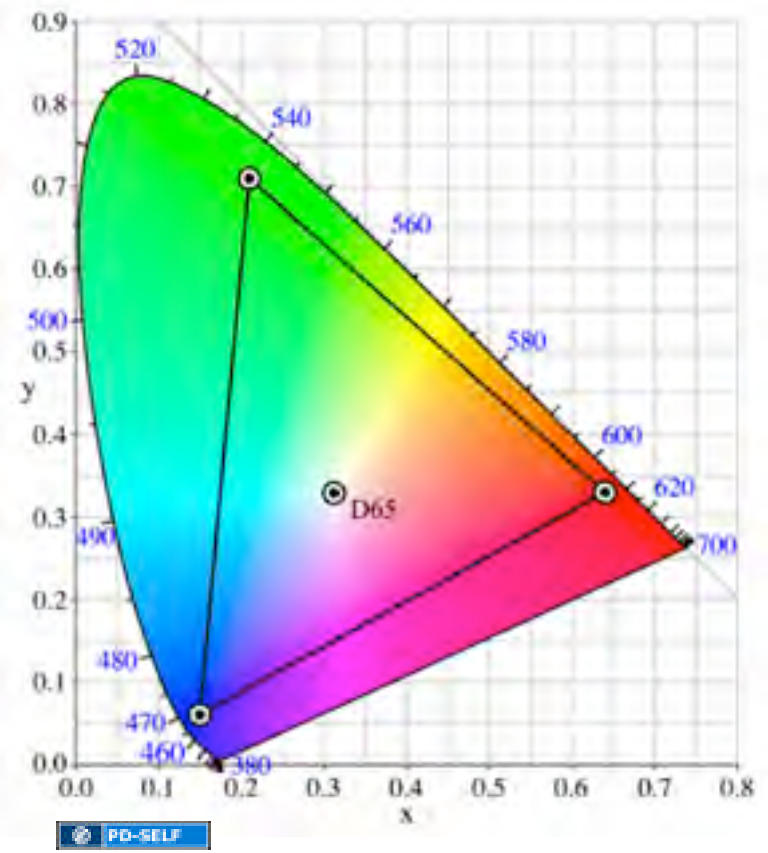


Gamut Comparisons

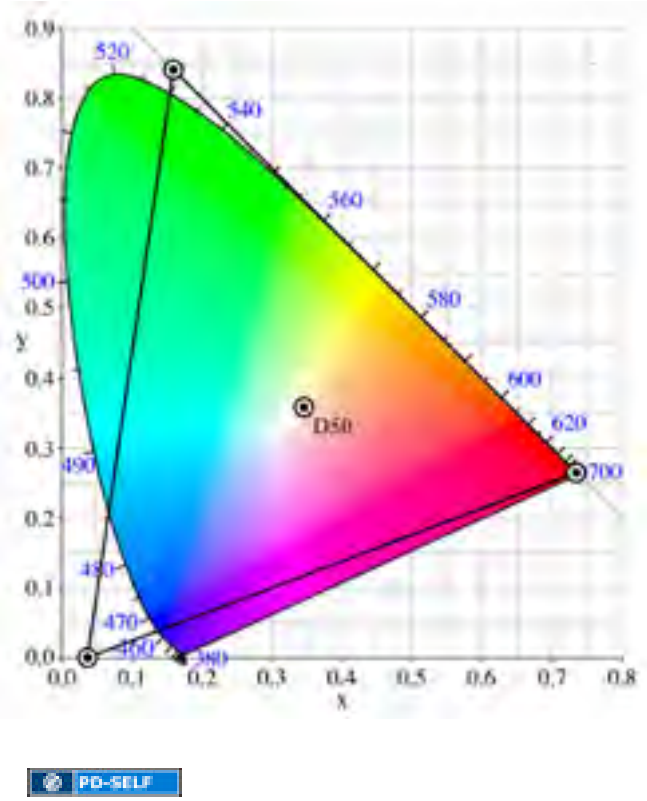


Color Space Comparison

Adobe RGB Color Space



ROMM (ProPhoto) RGB



Important Imaging Characteristics

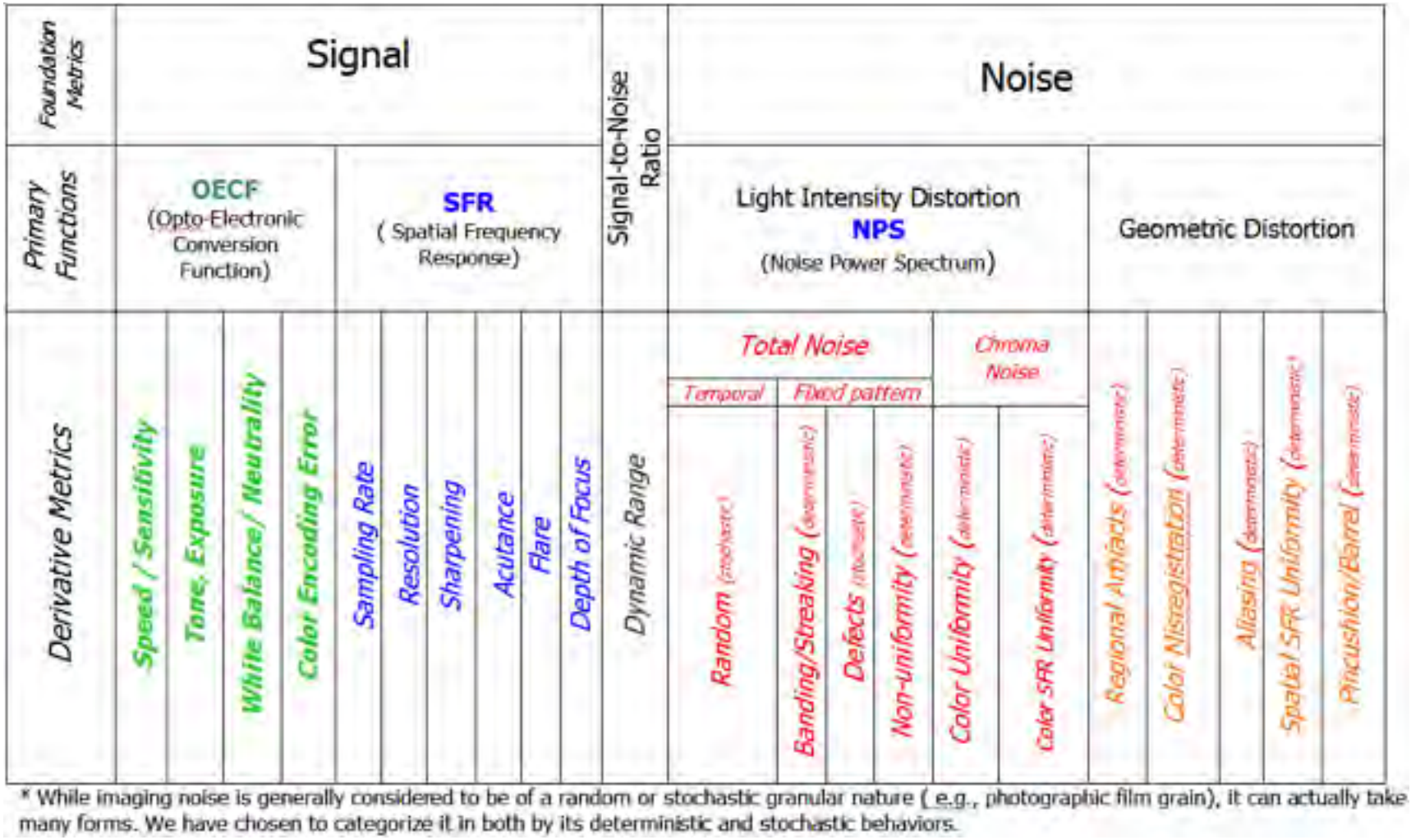
A number of these categories have ISO standards that define the metrology practice. Though intended for digital imaging devices their basis was derived from decades of analog (e.g., film) imaging experience.

Primary Imaging Performance Functions

- **Signal – Any response that provides valued information**
  - Large area response to light
    OECF -Opto-Electronic Conversion Function
  - Spatial proximity behavior
    Spatial Frequency Response – SFR (or MTF)
- **Noise – Any response that detracts from a desired signal**
  - Light intensity distortions – Total noise
  - Geometric/Spatial distortions

Imaging Performance Framework

http://www.digitizationguidelines.gov/stillimages/documents/imaging.html



* While imaging noise is generally considered to be of a random or stochastic granular nature (e.g., photographic film grain), it can actually take many forms. We have chosen to categorize it in both by its deterministic and stochastic behaviors.

Measurement Requirements

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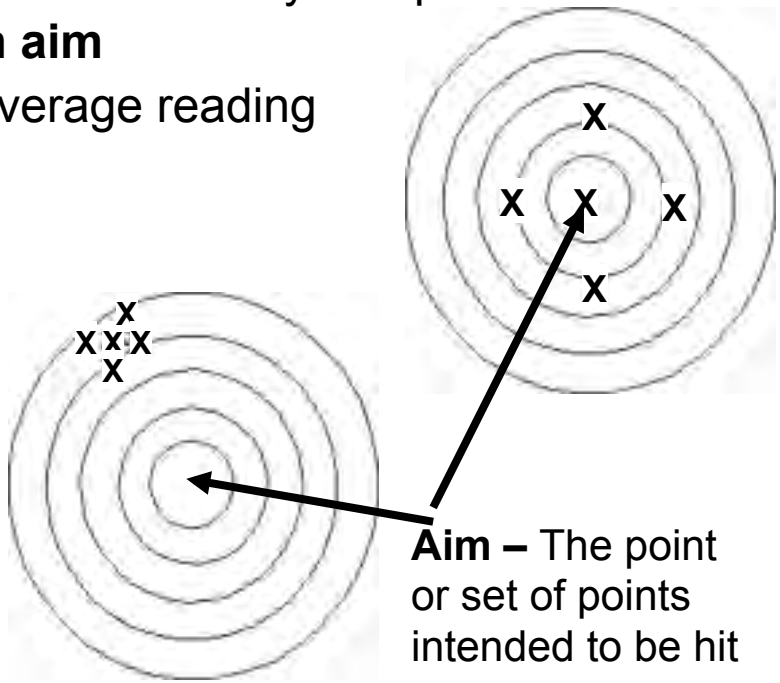
Measurements usually require some level of accuracy and precision.

- Accuracy: average error from an **aim**
- Precision: variability about the average reading

Factors that influence measurements

- Location on platen
- Image processing
- spatial sampling
- image noise
- environment
- operator skill



Performance is more about consistency (precision) than accuracy.
In imaging, accuracy is often not absolute but rather a preference.

Spatial Resolution

Spatial Frequency Response (SFR)
ISO 16067-1, 16067-2, 12233, 15529

SIGNAL

Any response that provides valued information

Primary Functions	SFR - Spatial Frequency Response – (ISO 12233, ISO 16067-1, ISO 16067-2, ISO 15524) MTF – Modulation Transfer Function *definitions* : 1) A descriptor of an imaging system's ability to maintain the relative contrast of input stimuli of a given spatial frequency. 2) A spatial frequency descriptor of an imaging system's ability to maintain the relative contrast of features within a given spatial proximity.					
Derivative Metrics	Sampling Rate *Definition* : The reciprocal of the center-to-center distance between closest adjacent pixels. The number of samples per unit distance	Resolution *Definition* : An imaging system's ability to resolve finely spaced detail. The level of spatial detail that can resolved in an image	Sharpening *Definition* :Amplification of the SFR by means of image processing to achieve sharper appearing images	Acutance *Definition* : An objective SFR based metric that is used as a correlate to perceived image sharpness.	Flare *Definition:* a skirty or wide spreading of light.	Depth of Focus *Definition:* The distance along the optical axis that remains within acceptable focus.
Related descriptive term	- Megapixels - Dots per inch (dpi) - Pixels per inch (ppi) - Sampling frequency	- Blurred - Soft - Sharp - In/Out of focus - Spherical aberration - Spatial detail	- Oversharpening (halomy, garish edges) - Snap - Edgy, Sharp, Crisp - Edge enhancement - Unsharp masking	- Sharp	- Low contrast - Hazy - Ghosting Veiling flare - Glare - Integrating cavity effect (ICE)	- Depth of field - Circle of confusion - Focus tolerance - Hyperfocal distance

What is Spatial Resolution

....and what are all those related terms ?

Image Science Associates

• The ability of an imaging component or system to distinguish finely spaced detail. Specifically, the ability to maintain the relative contrast of finely spaced detail.

• Highest frequency (smallest distance) at which light and dark parts of image are reliably distinguishable. Sometimes called limiting resolution

Related Metrics

- Number of pixels
- Sampling frequency - dpi, ppi
- *Limiting Resolution, Resolving Power
- *Spatial Frequency Response - SFR
- *Modulation Transfer Function - MTF

*Related Standards – ISO 16067-1, 16067-2, 12233, & 15529 all employ these metrics

Space and Frequency

Image Science Associates

- Two ways to look at image details
  - Space: size of the smallest important (signal) feature (*mm*)
  - Frequency: How many small important features/area will my image store (*number/mm, cycles/mm, dots/inch, pixels/inch*)
- Small size implies high frequency
- Why use ***space*** *vs.* ***frequency*** descriptions?
  - Compatible with engineering descriptions of information, bandwidth
  - Simplifies some forms of system analysis
  - Compatible with several visual image quality descriptions

Spatial Resolution

Image Science Associates

- Two factors in a digital imaging system dictate the level of spatial resolution or detail that can ultimately be captured.
  - **Quantity**; sampling frequency (i.e. samples per mm, inch)
    - Sets a capability limit that can be achieved
  - **Quality**; effective optical quality
    - Defines the level of optical "blur" that the imaging optics, environmental factors, hardware, and image processing impose on the captured image.

- These are necessary but insufficient components, by themselves, for capturing spatial detail. Simply improving one to reconcile deficiencies in the other will not enhance real resolution performance.

- Limiting Resolution -

….so how does one measure it ?

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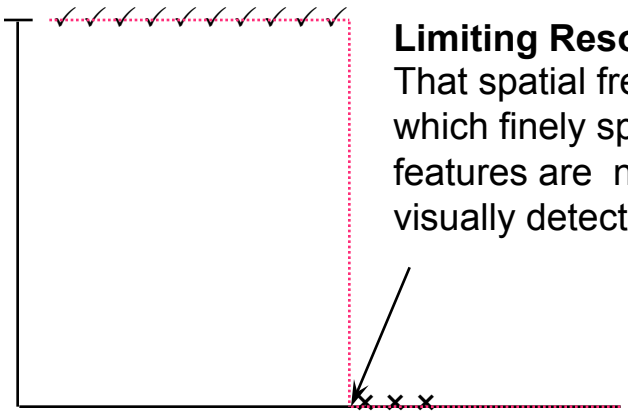
Traditional method using bar targets and visual evaluation

Imaged target

Yes, the features are readable

No, the features are illegible



Limiting Resolution=
That spatial frequency at which finely spaced features are no longer visually detectable

Increasing spatial frequency
(lp/mm or cycles/mm)

PROS

* Simple to measure
* Easily understood
* Suitable for binary scanners

CONS

* Relies on human readable subjective evaluation
* Results are target contrast dependent
* Provides little diagnostic or image quality insight
* Purely an ON/OFF (threshold) criterion

Sampling Frequency is *not* Resolution

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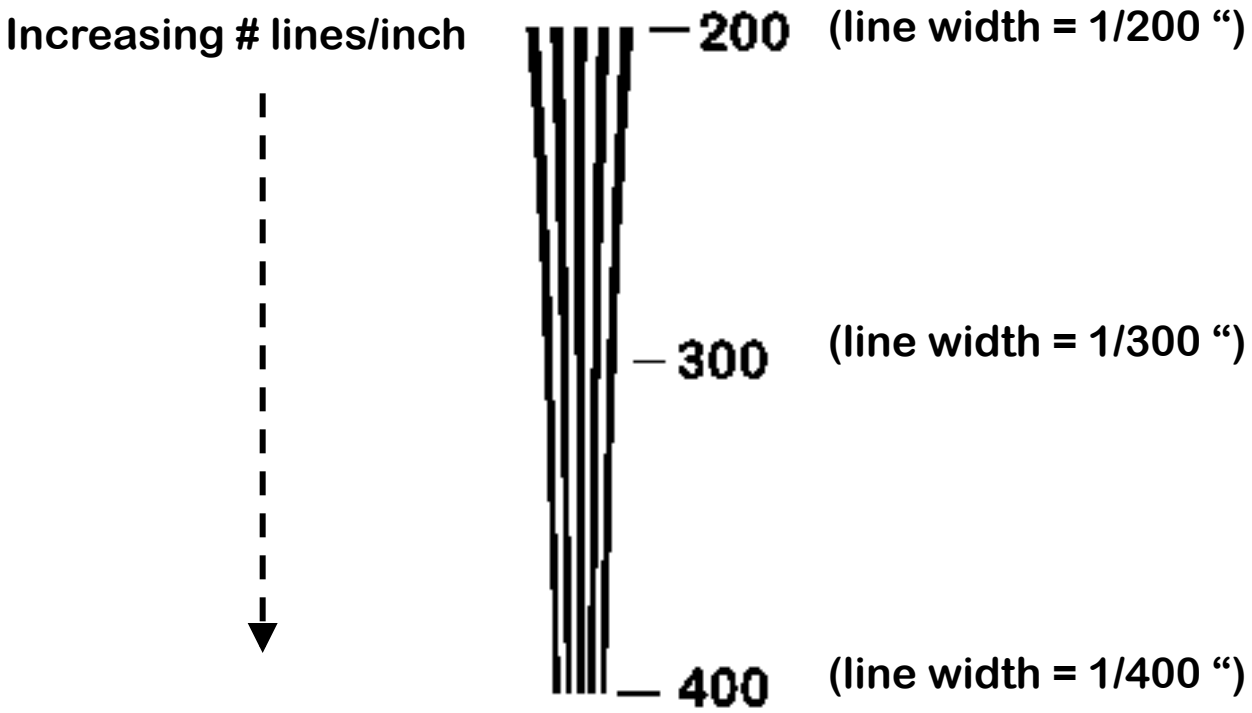
DPI (PPI) -> Quantity of data

Resolution -> Quality of data (information)



Resolution Wedge Test Feature Example

Sampling rate (DPI) is not Resolution

real data example : results are not simulated

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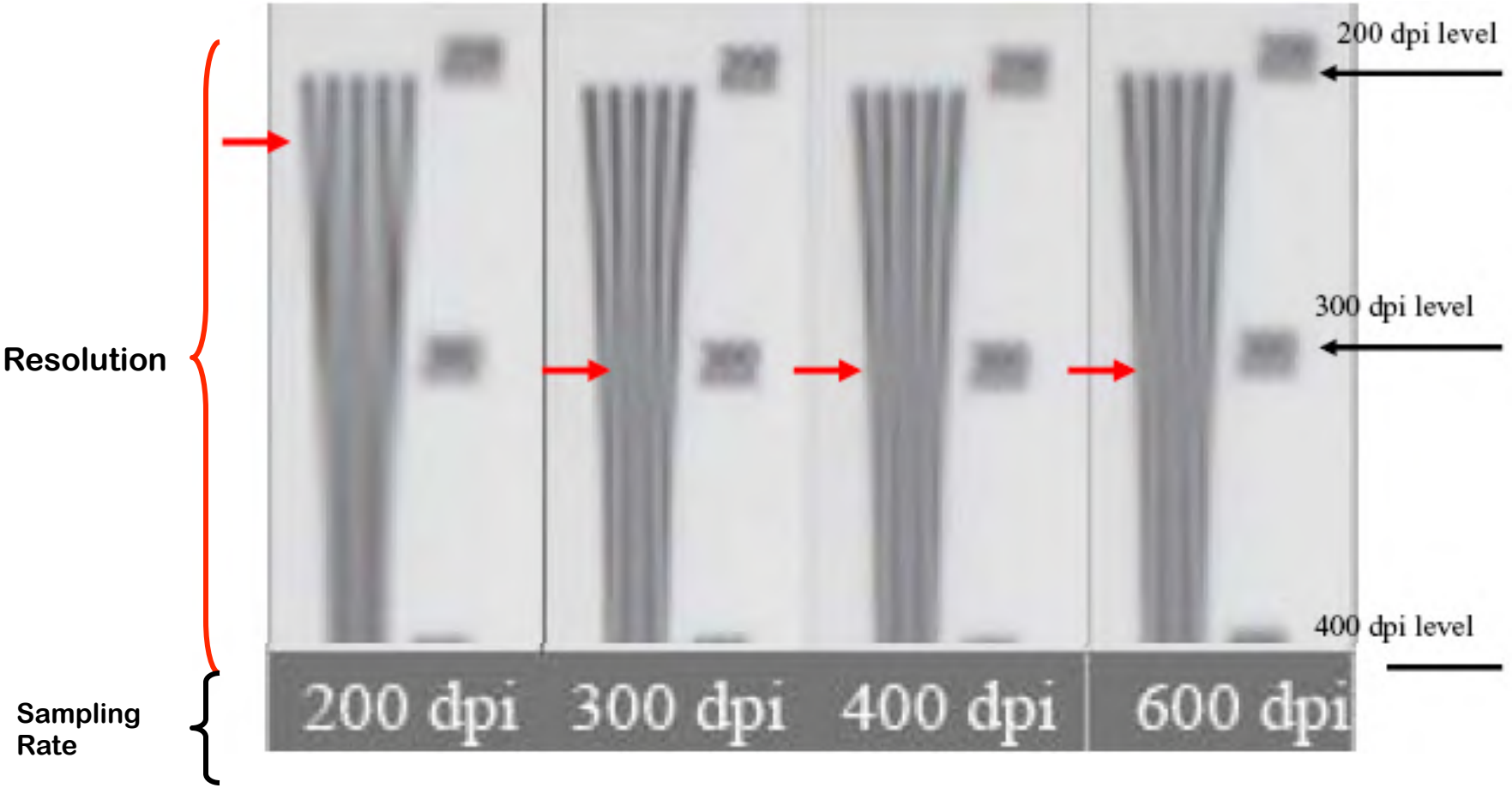
Resolution limit = whenever all five lines are undetectable



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

Spatial Frequency Response* (SFR)

the better alternative

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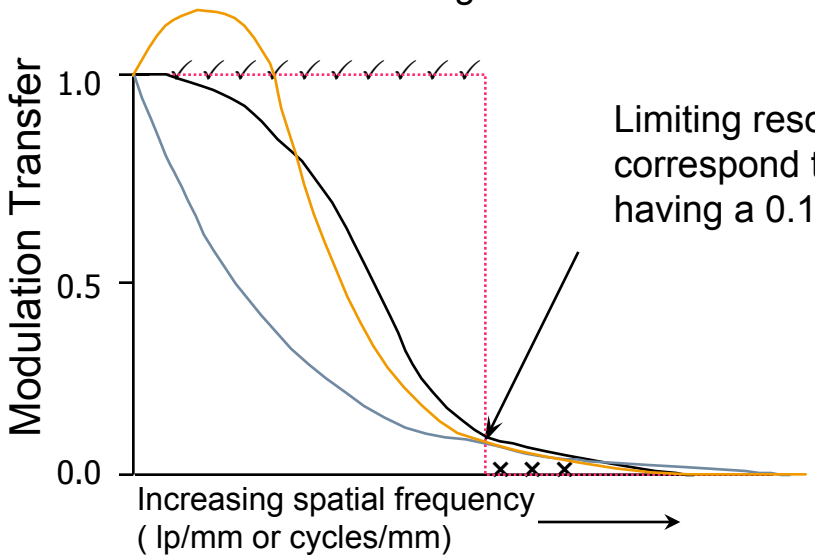
Instead of using a subjective YES/NO criterion along the vertical axis, an objective contrast (i.e. modulation) transfer ratio is adopted. The SFR it is an indicator of modulation(i.e. contrast) loss as a function of spatial frequency.

$$\text{Modulation Transfer} = \frac{\text{Target feature modulation } \textbf{after} \text{ being imaged}}{\text{Target feature modulation } \textbf{before} \text{ being imaged}}$$



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

* Also referred to as the Modulation Transfer Function (MTF)

Limiting resolution fails to predict quality&

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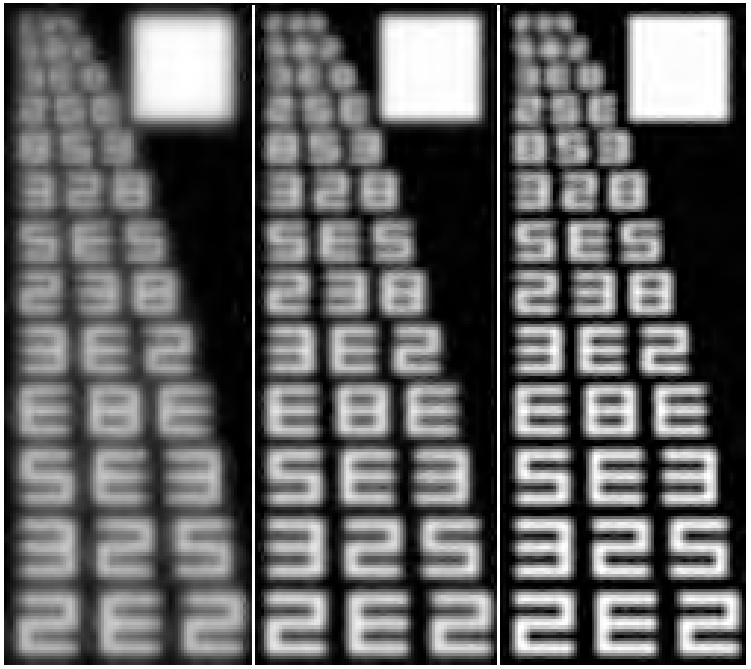
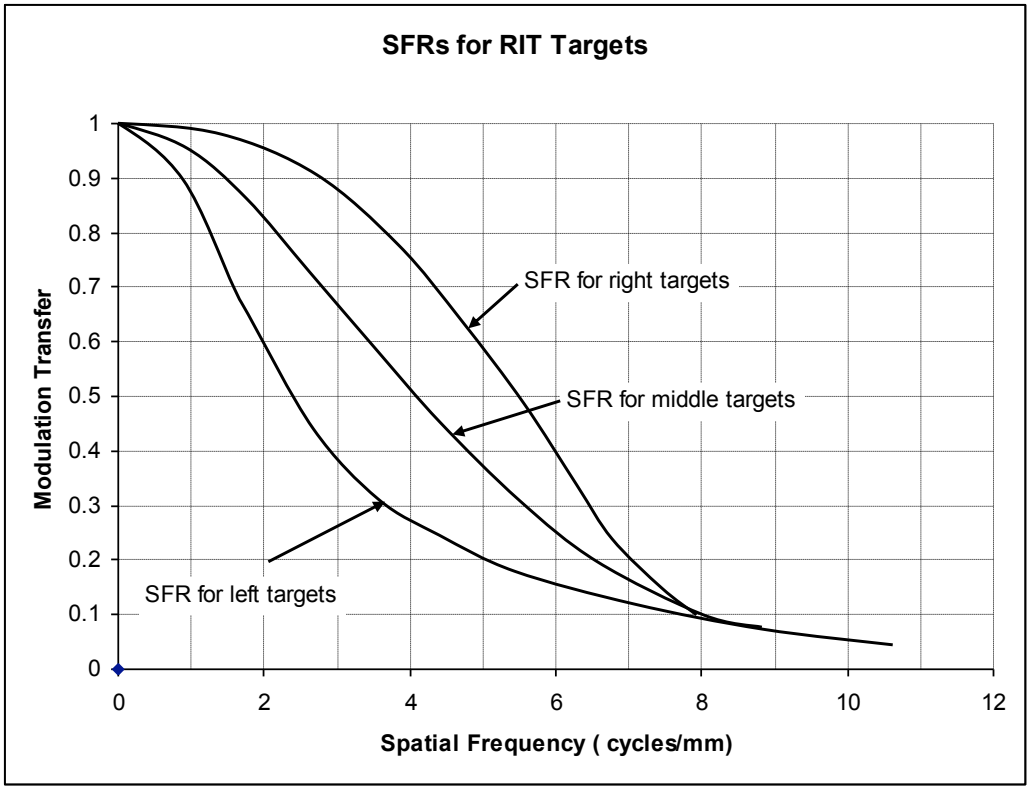
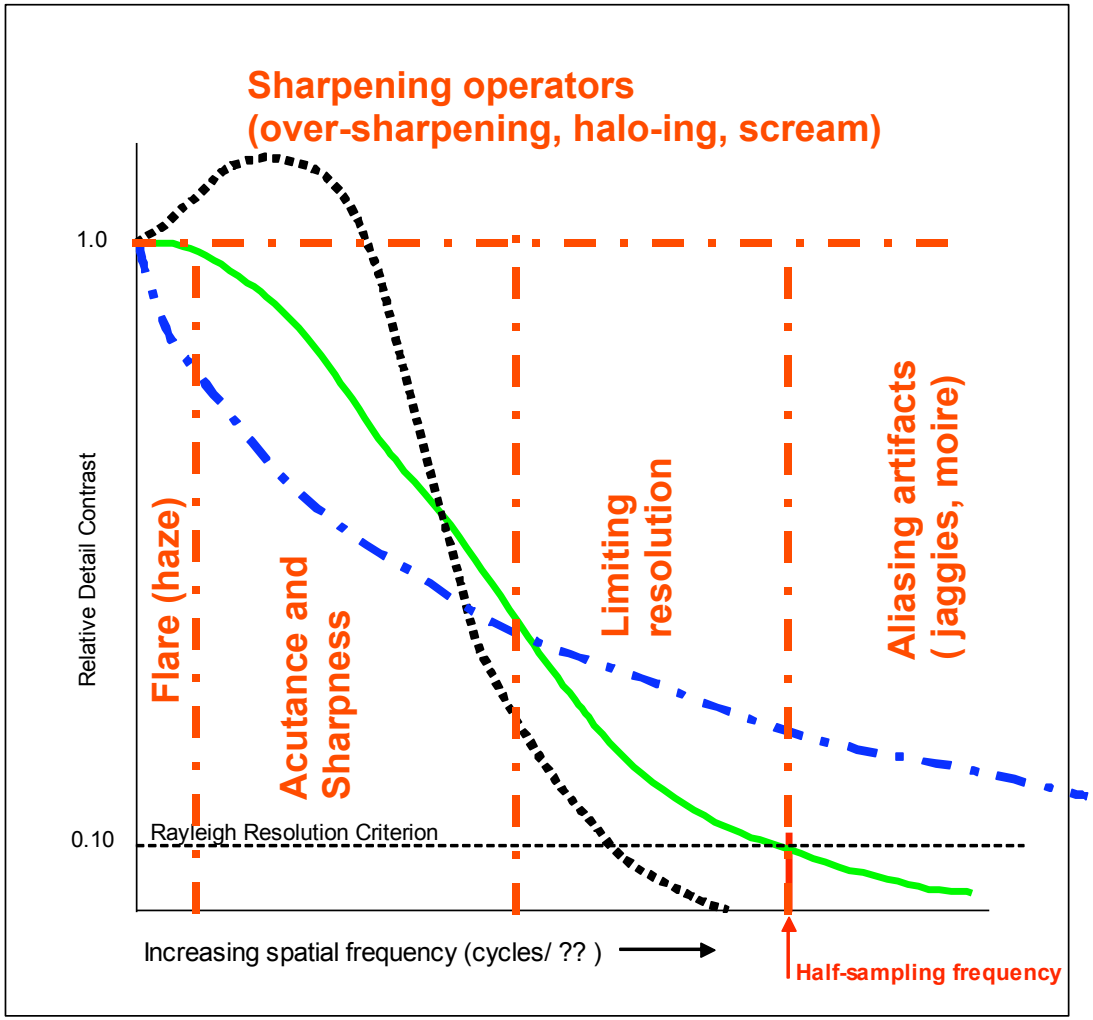




Anatomy of the SFR - regions of behavior -



Sharpness vs. Resolution

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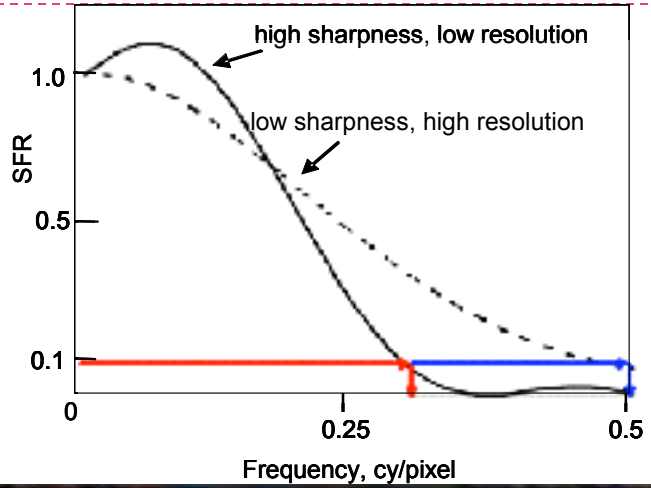
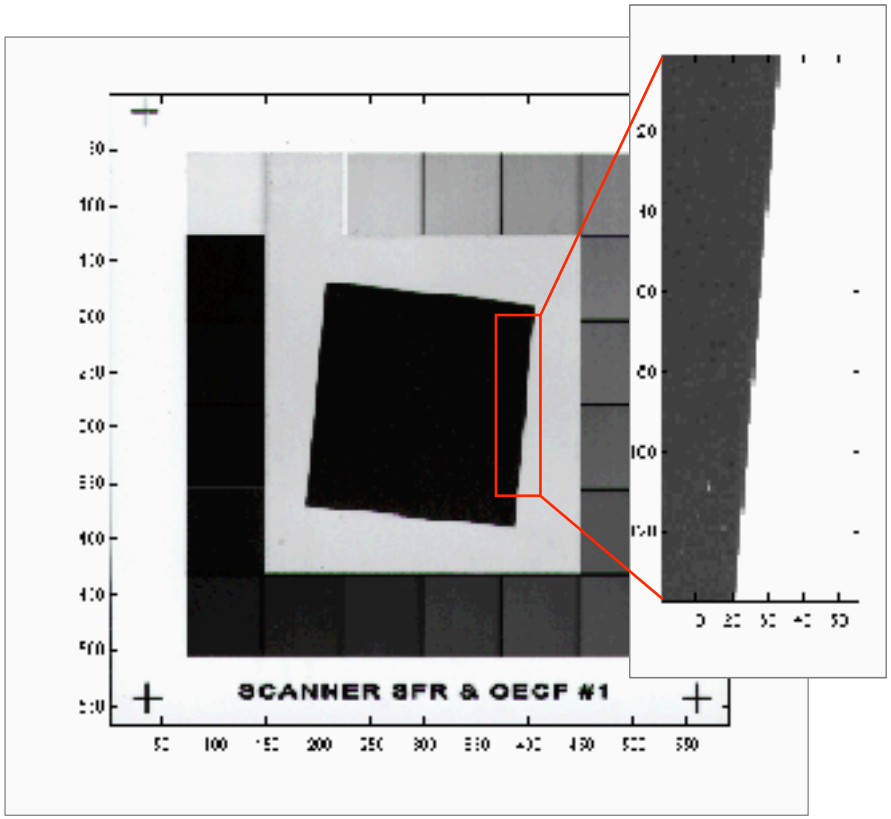


How is the SFR Measured ?

...all you need is an image of a **GOOD** slanted edge.



Flatbed scanner using a linear array

Horizontal (fast) and Vertical (slow) scan directions

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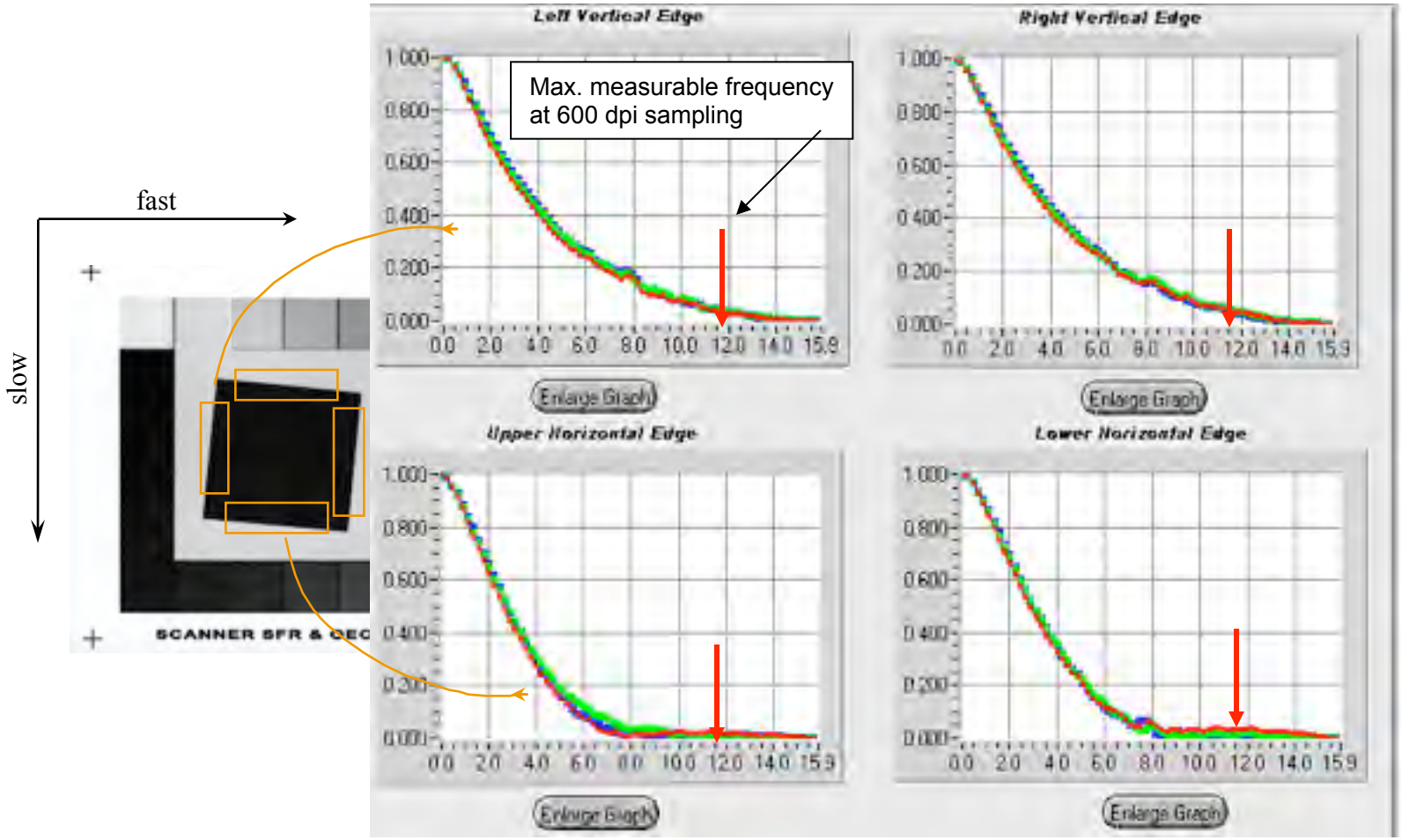


- SFR in Review -

- ***What is it?***
  - descriptive plot that measures the extent to which image detail contrast (*modulation*) is maintained by an imaging component or system.
- ***What is a spread function?***
  - image resulting from a point, or very narrow line exposure.
- ***What it is not?***
  - same as 'resolution'
  - sampling frequency or number of pixels
  - complete descriptor of image quality (noise, color, …)
- ***What good is it?***
  - It provides a way to analyze the influence of imaging components on the retention and reproduction of *low, medium, and high spatial frequencies (flare, sharpening, limiting resolution)*
- ***Which digital imaging standards address it ?***
  - ISO 16067-1: Resolution for digital print scanners
  - ISO 16067-2: Resolution for digital film scanners
  - ISO 12233 : Resolution for digital still cameras
  - ISO 15529 : MTF for sampled imaging systems

Opto Electronic Conversion Function (OECF) ISO 14545

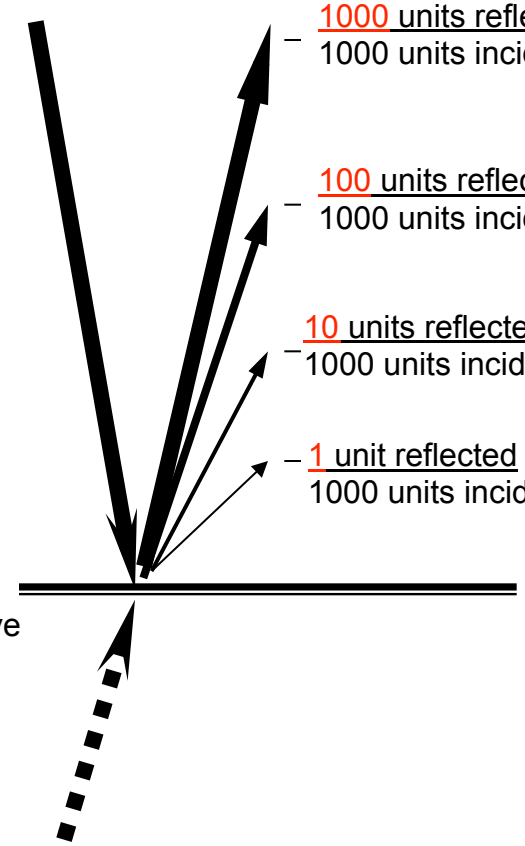
aka
Tone Transfer Curve
or
Tone Reproduction Curve (TRC)

SIGNAL

Any response that provides valued information

Primary Functions	OECF – Opto-Electronic Conversion Function (ISO 14545) TTF – Tone Transfer Function TRC – Tone Reproduction Curve *definition* : Average large area digital response of an electronic imaging device to light stimuli			
Derivative Metrics	Sensitivity (ISO 12232) *definition:* The reciprocal of the amount of light necessary to achieve a desired output response	Tone and Exposure *definition* : characteristic behavior of large area digital output response (count value) to spectrally neutral input stimuli (gray patch)	White Balance/Neutrality *definition* : equivalence of large area color channel output responses to a range of spectrally neutral input stimuli	Color Encoding Error **ISO 22028-1** *definition:* The difference between selected physically measured input colors and their intended rendering from a given color space.
Related descriptive term	- Responsivity - Speed - Exposure Index (EI)	- Too dark/light - Under/over exposed - No shadow/highlight detail - Clipping - Contrast - Exposure Accuracy - Gamma	- Color cast - Gray balance	- Over/under saturated colors - Color balance is wrong - Memory colors are not correct - Color Accuracy - Color Saturation

Optical properties of objects



1000 units reflected / 1000 units incident = 1.000 reflectance = 0.0 density

100 units reflected / 1000 units incident = 0.1000 reflectance = 1.0 density

10 units reflected / 1000 units incident = 0.0100 reflectance = 2.0 density

1 unit reflected / 1000 units incident = 0.0010 reflectance = 3.0 density

Density= - log10 (reflectance)

* In practice, it is often more convenient to specify in terms of density, especially for densities greater than 1.0

How is the OECF created ?

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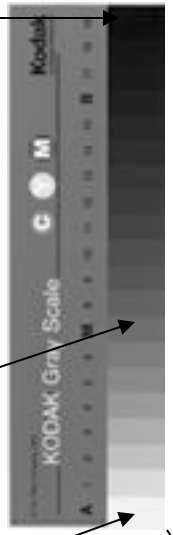
(1) Scan grayscale step target with known optical reflectances*

neutral optical reflectance	neutral optical density
0.010	2
0.013	1.9
0.016	1.8
0.020	1.7
0.025	1.6
0.033	1.48
0.042	1.38
0.051	1.29
0.065	1.19
0.083	1.08
0.107	0.97
0.132	0.88
0.166	0.78
0.209	0.68
0.263	0.58
0.339	0.47
0.437	0.36
0.550	0.26
0.708	0.15
0.912	0.04

(2) Compute average count value from the digital image file of scanned grayscale target



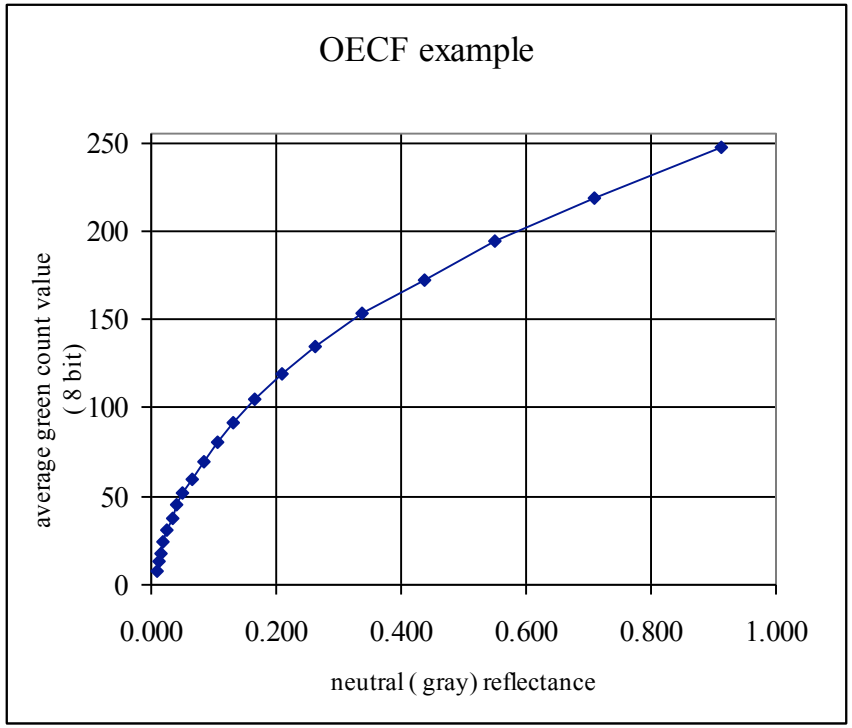
average count value		
red	green	blue
8	8	7
13	13	14
18	17	18
24	25	25
31	32	30
38	40	39
45	46	45
52	51	51
60	62	61
69	70	69
81	82	81
92	93	92
105	105	104
119	120	120
135	132	132
153	155	154
172	173	172
194	193	193
219	220	220
247	250	249

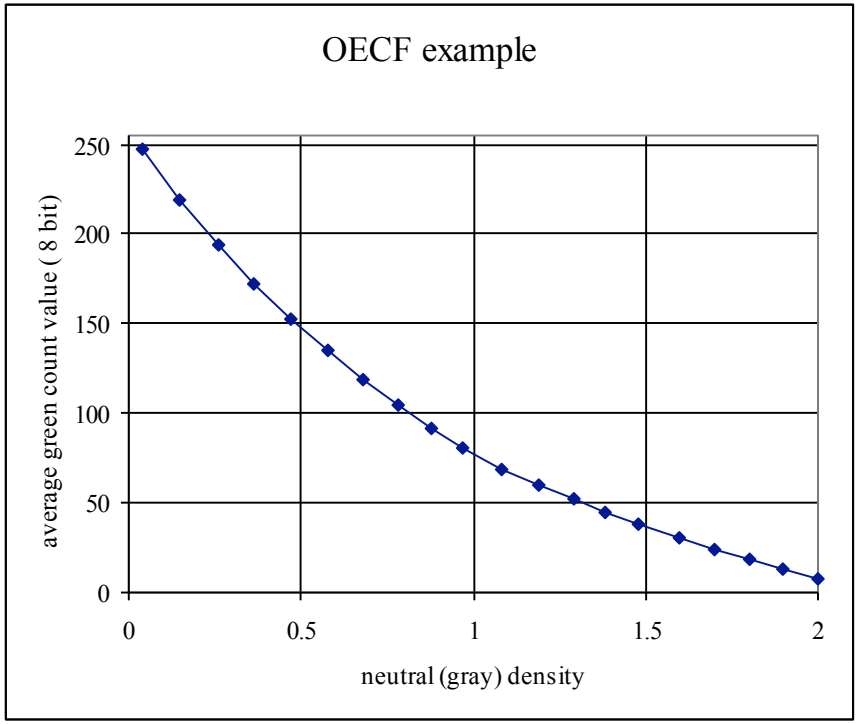
(3) Table of reflectance – average count value data pairs for each color channel

	average count value		
neutral optical reflectance	red	green	blue
0.010	8	8	7
0.013	13	13	14
0.016	18	17	18
0.020	24	25	25
0.025	31	32	30
0.033	38	40	39
0.042	45	46	45
0.051	52	51	51
0.065	60	62	61
0.083	69	70	69
0.107	81	82	81
0.132	92	93	92
0.166	105	105	104
0.209	119	120	120
0.263	135	132	132
0.339	153	155	154
0.437	172	173	172
0.550	194	193	193
0.708	219	220	220
0.912	247	250	249

* Most grayscale targets come with documentation on reflectances/densities of each patch. Over time, these may fade or change though. A densitometer can be used to verify any change.

Graphical Representation of OECF





Reflectance **Density**

Using Density is more revealing since the data values tend to be more evenly distributed

Standards, Guidelines, Exposure

- efficiently assigning density to count values -

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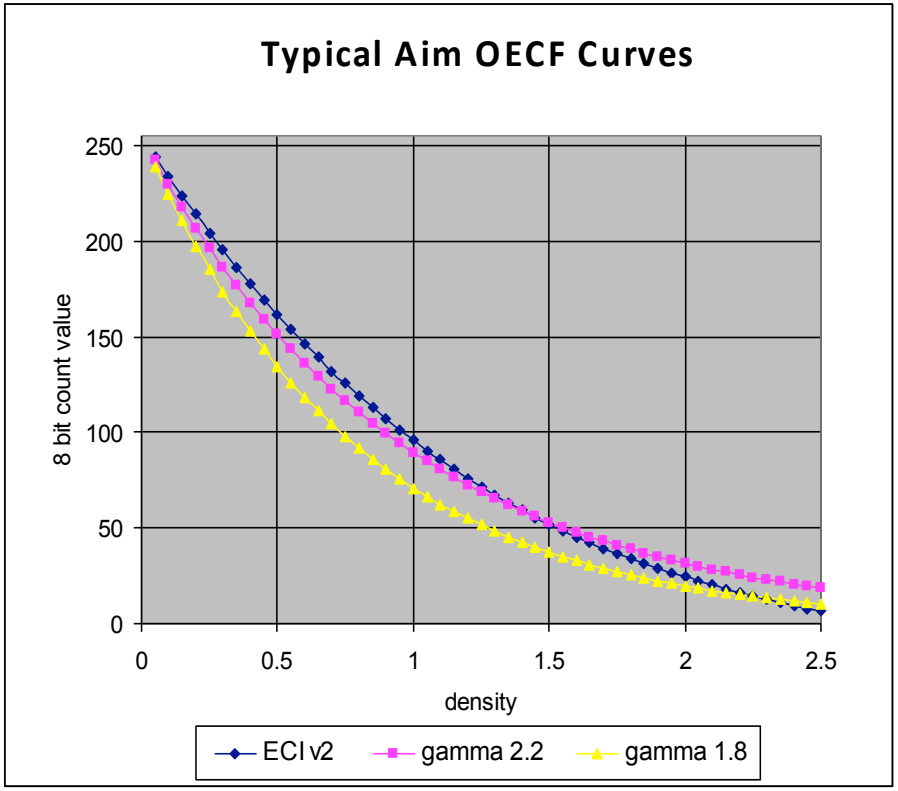

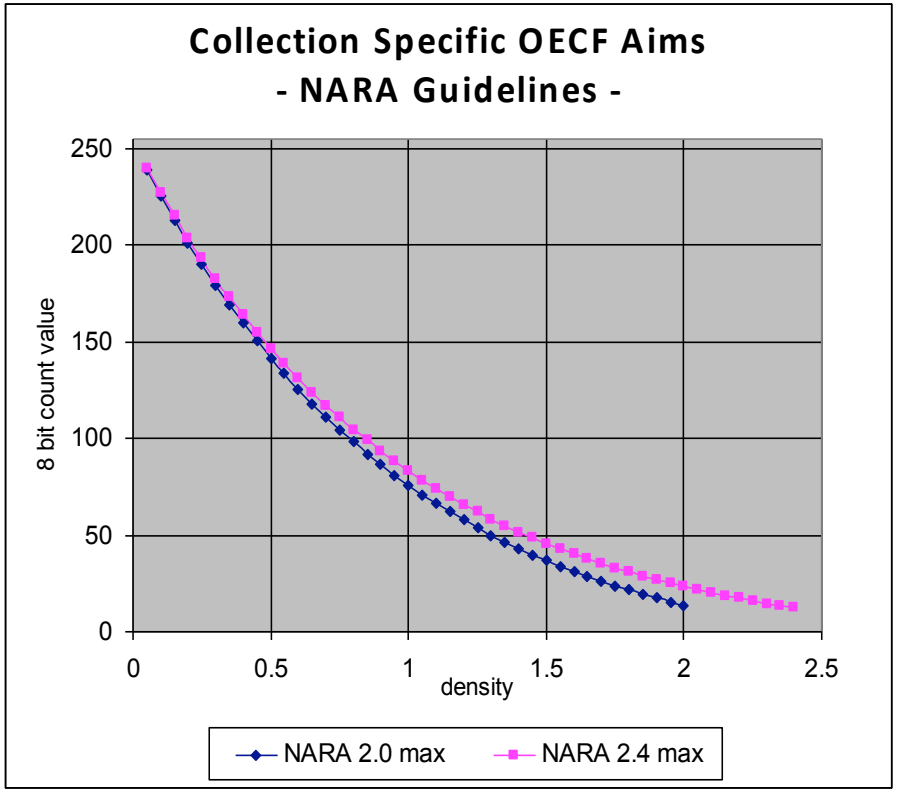

If most measured data values are **above** a selected OECF aim curve, **over-exposure** is indicated, conversely if most measured data values are **below** a selected OECF aim curve, **under-exposure** is indicated

White Balance / Neutrality

-Keep all of the Neutrals neutral -

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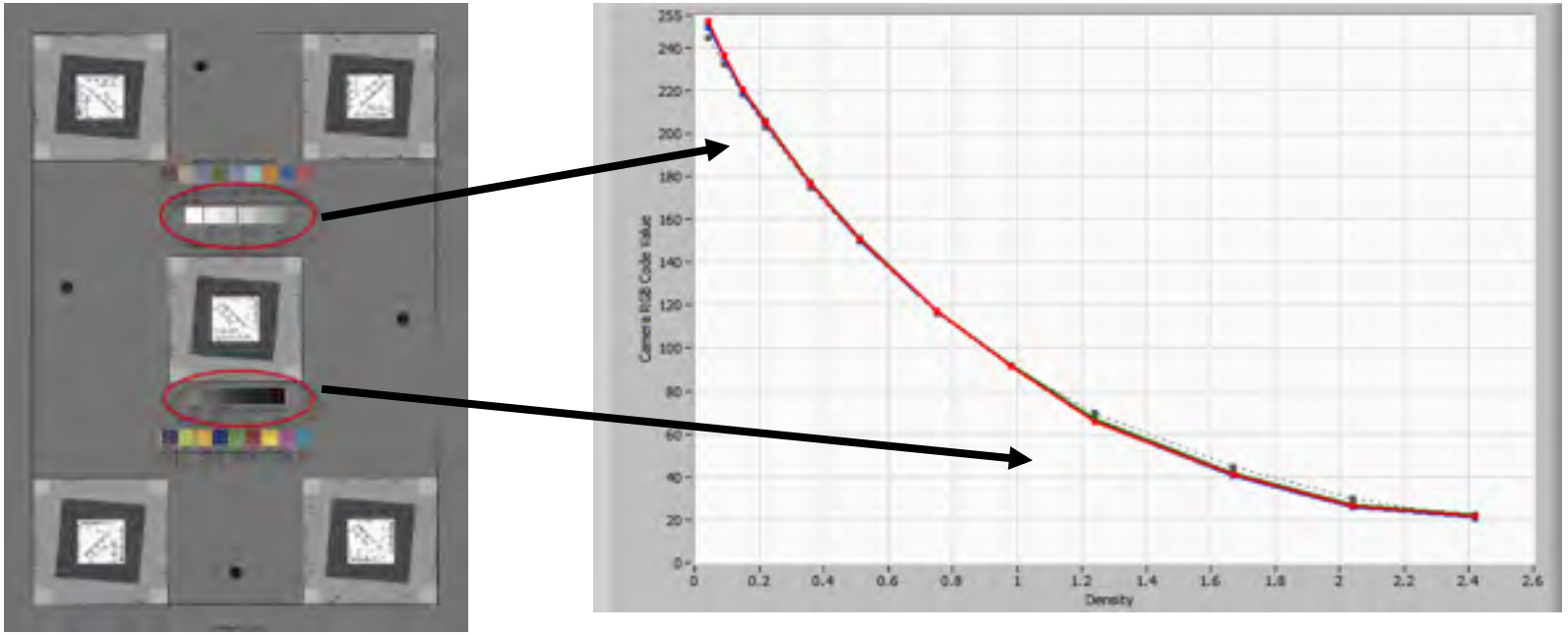
- OECFs can be measured for each color channel using a target's neutral gray patches.
- 85% of good color imaging performance is keeping the Red, Green, and Blue OECFs the same… Really!



This is a good example of a well white balanced capture
Note that all color channel OECFs lie on top of each other

White Balance / Neutrality

-Keep all of the Neutrals neutral -

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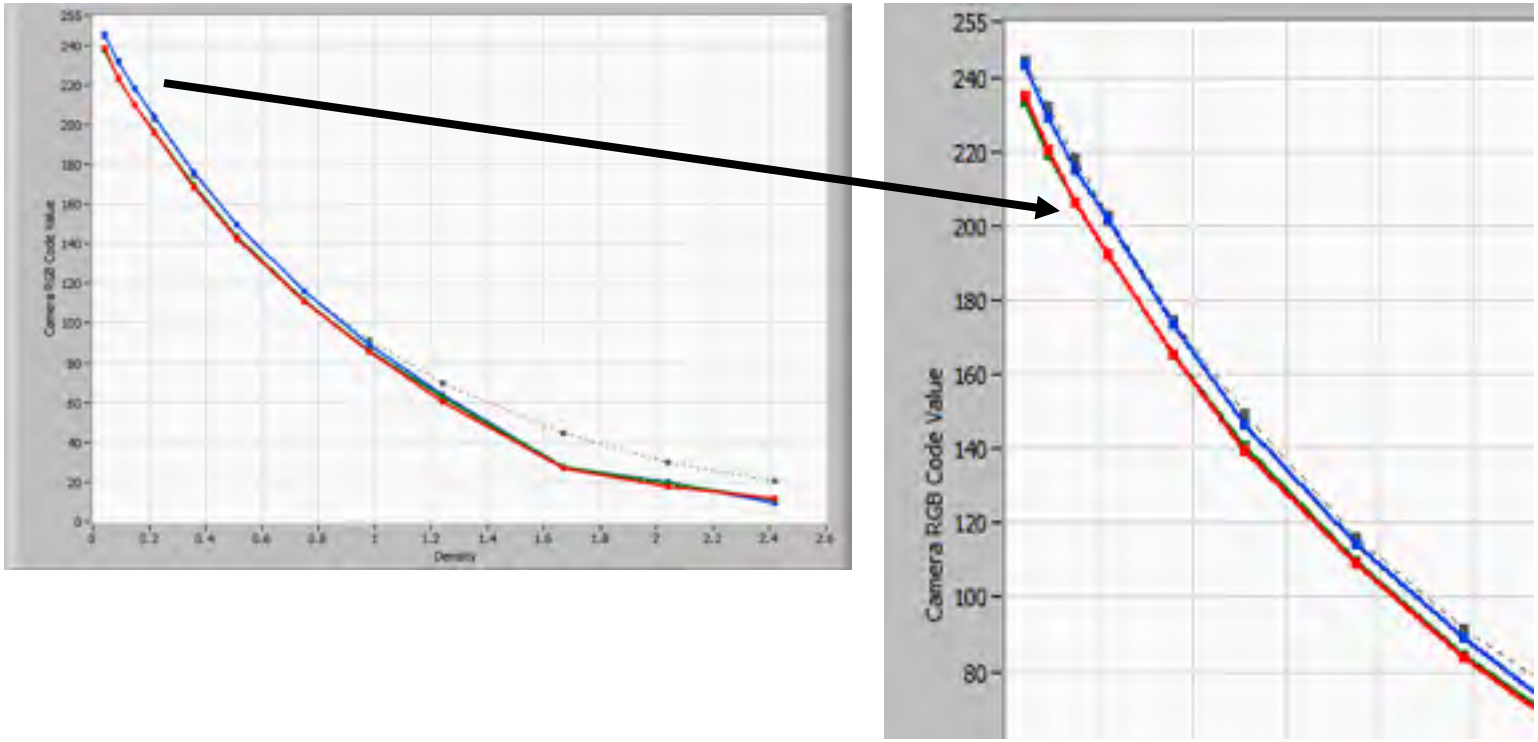

This is an example where the white balance performance is poor. Note how the blue channel OECF departs from the red and green OECF

Question of Balance: Keep the Neutrals Neutral

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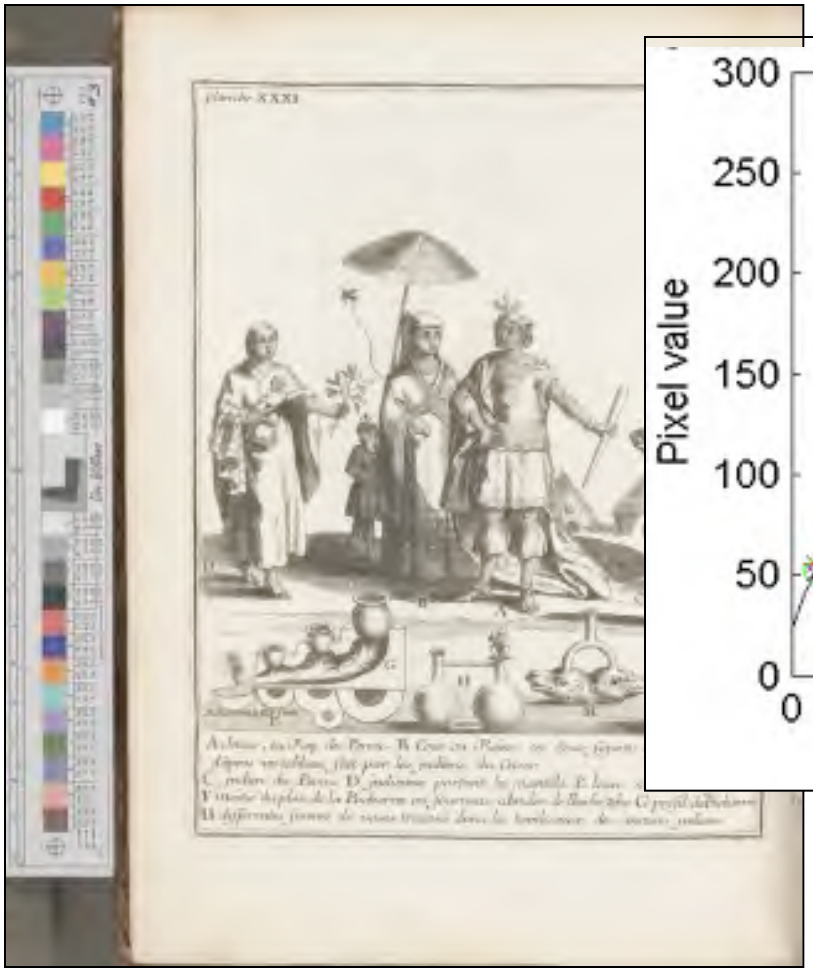
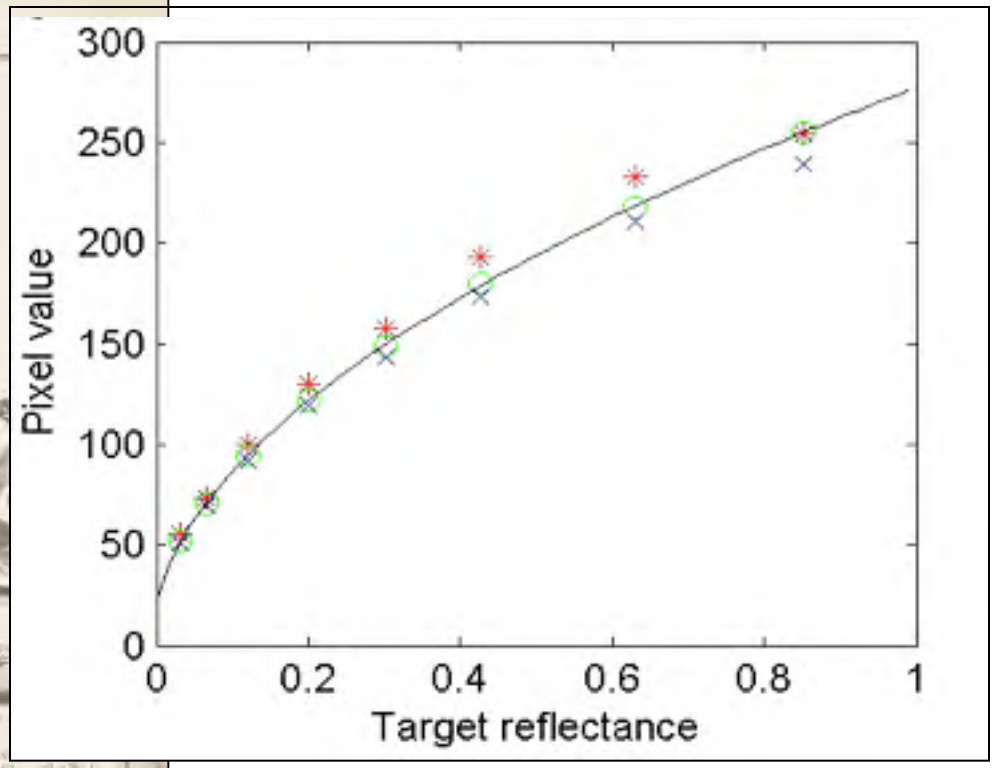
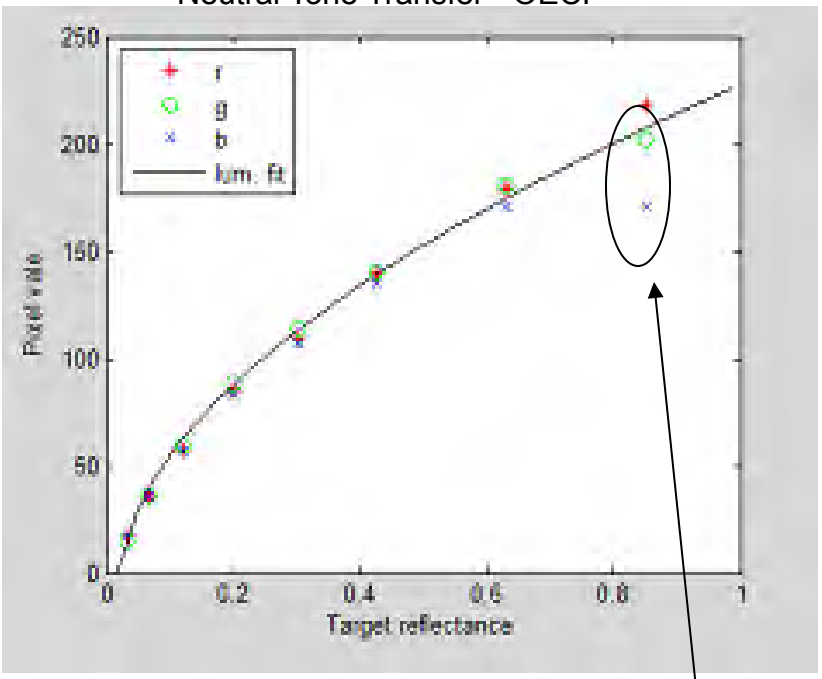




all of

Question of Balance: Keep ^ the Neutrals Neutral



Note departure from neutrality in highlights

A few words on

Color Encoding Error (ΔE)

- erroneously called color accuracy -

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- **Digital cameras/ scanners do not reproduce colors; they encode them.**

- **Color accuracy implies that two physically realizable colors are at hand to compare.**

- **Assumptions on how RGB code values will ultimately be interpreted (i.e. rendered or decoded) as physically reproduced color are often very wrong.**

- **Delta E (i.e. color error) measures for digital capture devices are suitable for performance consistency monitoring but not as absolute measures of color accuracy**

Example ΔE Analysis for Adobe RGB encoding

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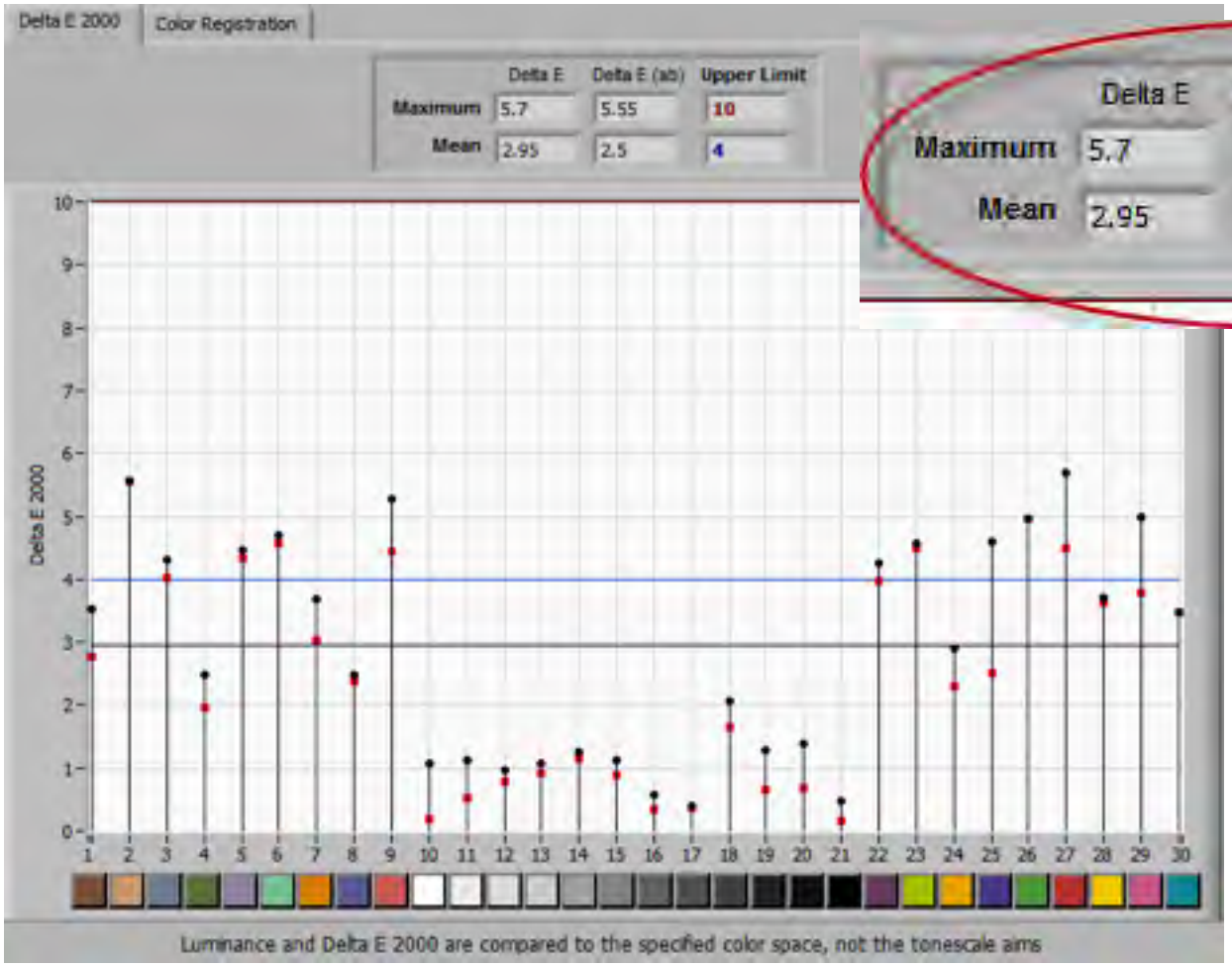

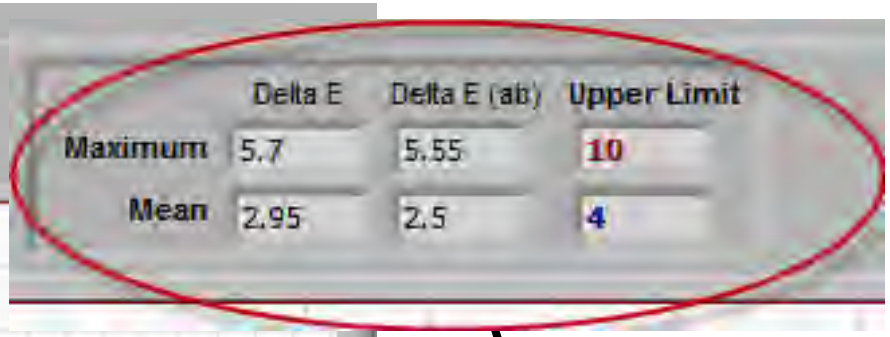

Summary measures for color encoding error

OECF – Summary and Recommendations

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- There is no single best or standardized OECF. Most are based on policy maker or user preferences for the “look” of the image with respect to a particular use case.
- Generally, any gamma setting between 1.5 – 2.5 is fine for capturing all significant image information for common reflection media densities.
- The important practice is to document what the OECF is for ease of future image reproduction and rendering.
- 85% of good color management relies on keeping the neutrals neutral. Do not assume that individual color channel OECFs for a gray scale target will be identical. By documenting the OECF though, any mismatch can usually be corrected. (called “corrective action”)
- Leave sufficient CV ”buffer” in the OECF for future tone and spatial image manipulations. Dmax ≈15 count value (CV), Dmin ≈ 240 CV
- An alternative to documenting the OECF is to include an image of a grayscale target in each digital image file and maintain it as part of the image file. Be sure the optical densities of each patch are somehow indicated.

Noise

Random and otherwise

NOISE

Any response that detracts from a desired signal

Primary Function	Light Intensity Distortion – *definition:* The deviation of any given spatially imaged point from an aim energy value relative to the input object.					
Primary Functions	Noise Power Spectrum (NPS) *Total Noise* *Definition* : A spatial frequency descriptor of the sources of radiometric noise of an imaging component or system				Chromatic Noise *Definition* : The inter-color channel radiometric deviations relative to an identified aim	
Derivative Metrics	Temporal Noise	Fixed Pattern Noise			Color Uniformity (deterministic)	Color SFR uniformity (deterministic)
	Random (stochastic) *Definition* : The root mean square deviation (std. deviation) of both temporal and fixed pattern noise for a single color channel	Banding/ Streaking (deterministic) *Definition* : One dimensional patterns	Defects (stochastic) *Definition* : point or clusters of defective or poorly corrected pixels	Light Falloff (deterministic) *Definition:* A deviation in the effective illumination over a capture device's field of view; usually with lower illumination near the field's outer extent.	*Definition* : A difference in light falloff between color channels	*Definition:* The differential spread of light between color channels.
Related descriptive term	- Temporal noise - Grain - Shot noise - Read noise - White noise	- Stripes - Banding - Streaking	- Hot, Cold, or Dead Pixels - Wounded Pixels - Blinkers	- Vignetting - Relative Illumination	- Rainbows	- Colored edges - Color Bleed - Fringing

Scanner Noise Characterization

OECF data

average count value		
red	green	blue
8	8	7
13	13	14
18	17	18
24	25	25
31	32	30
38	40	39
45	46	45
52	51	51
60	62	61
69	70	69
81	82	81
92	93	92
105	105	104
119	120	120
135	132	132
153	155	154
172	173	172
194	193	193
219	220	220
247	250	249

RMS Noise data

count value variability- noise		
red	green	blue
2.00	1.95	2.1
2.11	1.88	2.22
1.95	1.57	2.4
1.8	1.65	1.99
1.79	1.45	1.9
1.82	1.4	1.88
1.45	1.37	1.56
1.5	1.15	1.77
1.49	1.04	1.46
1.34	1.23	1.3
1.23	1.12	1.51
1.39	1	1.2
1.1	0.99	1.25
1.2	1.04	1.16
1	1.15	1.1
0.88	0.94	1.29
0.95	0.93	1.04
0.92	0.77	0.9
0.87	0.76	1.09
0.9	0.65	0.97

Scanner Noise Characterization

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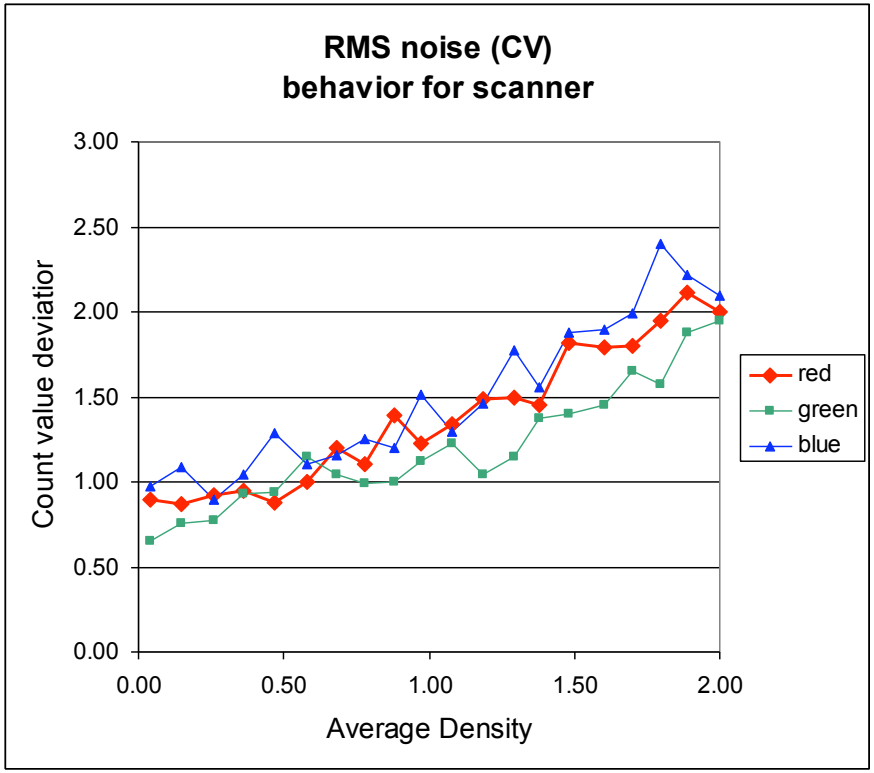
density	red	green	blue
2.00	2.00	1.95	2.1
1.89	2.11	1.88	2.22
1.80	1.95	1.57	2.4
1.70	1.8	1.65	1.99
1.60	1.79	1.45	1.9
1.48	1.82	1.4	1.88
1.38	1.45	1.37	1.56
1.29	1.5	1.15	1.77
1.19	1.49	1.04	1.46
1.08	1.34	1.23	1.3
0.97	1.23	1.12	1.51
0.88	1.39	1	1.2
0.78	1.1	0.99	1.25
0.68	1.2	1.04	1.16
0.58	1	1.15	1.1
0.47	0.88	0.94	1.29
0.36	0.95	0.93	1.04
0.26	0.92	0.77	0.9
0.15	0.87	0.76	1.09
0.04	0.9	0.65	0.97



Two Forms of Random Noise

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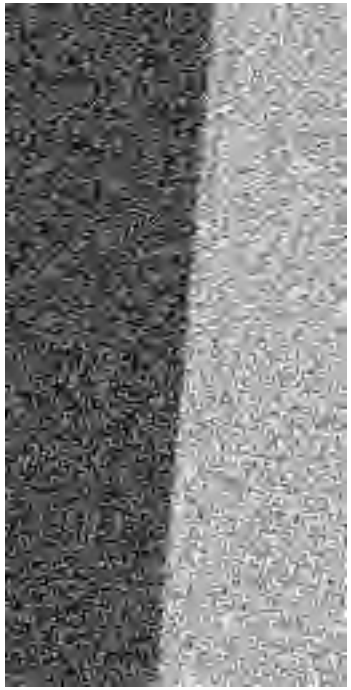
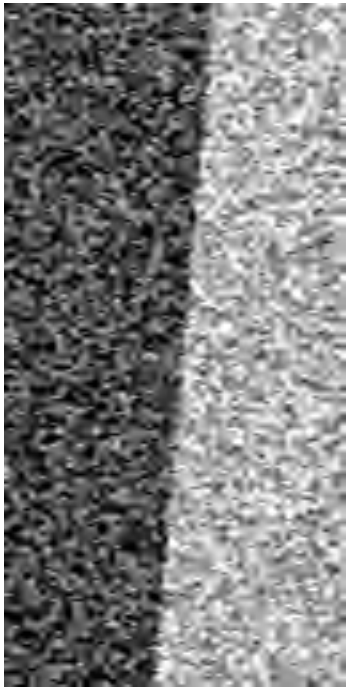
Fine-grain noise ->
high frequency fluctuations



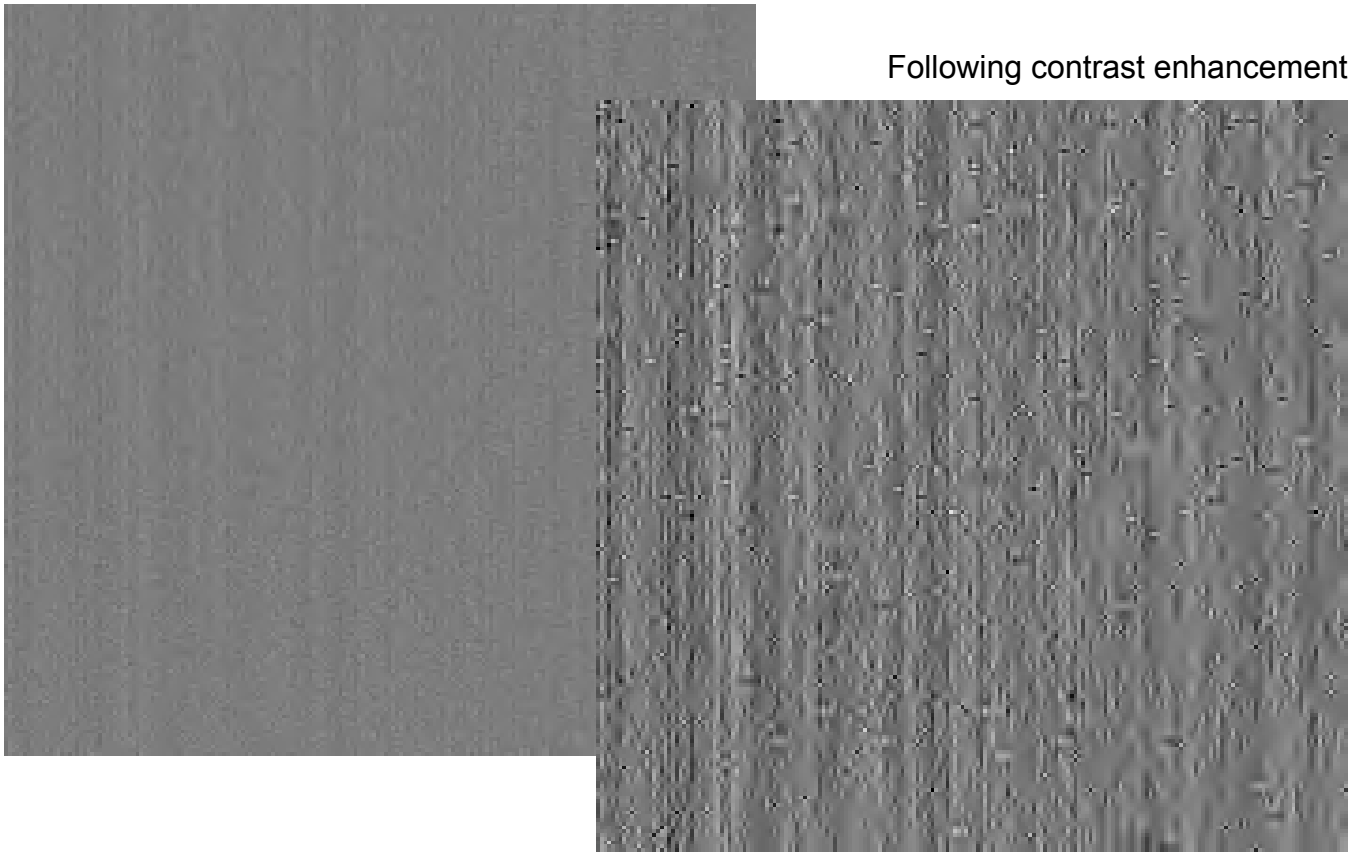
Course-grain noise ->
low frequency fluctuations



Both of these images have the same amount of total noise

One-dimensional random noise

– banding and streaking –



Following contrast enhancement

- **Often found on devices using linear arrays**
- **Contrast and equalize enhancements are useful in detecting such noise behaviors**

Artifacts

- Odd imaging behaviors that seem to defy objective measurement…for the time being.
  - De-texturing
  - Checkerboarding
  - Localized geometric distortions
  - Sensor defects
  - Color aliasing
- Many are technology specific. Just knowing what type of scanner technology was used allows one to prepare for certain artifacts

NOISE

Any response that detracts from a desired signal

Engineering Metric	– Geometric/Spatial Distortion – *definition:* The deviation of any imaged point from its intended or aim spatial position relative to the input object.				
Derivative Metrics	Field height diagram (deterministic) *Definition* : A change in magnification of an imaged object as a function of field position.	Regional (deterministic) *Definition* :A locally varying deviation in intended spatial position of an imaged object	Color Misregistration (deterministic) *Definition* : color-to-color spatial dislocation of otherwise spatially coincident color features of an imaged object.	Aliasing (deterministic) *Definition* : A sampling effect that leads to spatial frequencies being falsely interpreted as other spatial frequencies	Spatial SFR uniformity (luminance) (deterministic) *Definition:* A difference in luminance SFR as a function of optical field position
Related descriptive term	- Pincushion - Barrel - TV distortion - Field Curvature - Skew - Keystoning	- Wobble - Jitter	- Colored edges - Chromatic aberration - Lateral chromatic error(LCE)	- Jaggies - Moiré - Pixelization - Potential for aliasing	- Blurred or soft look near corners of image - Spherical Aberration - Coma

Visual Inspection for Artifacts

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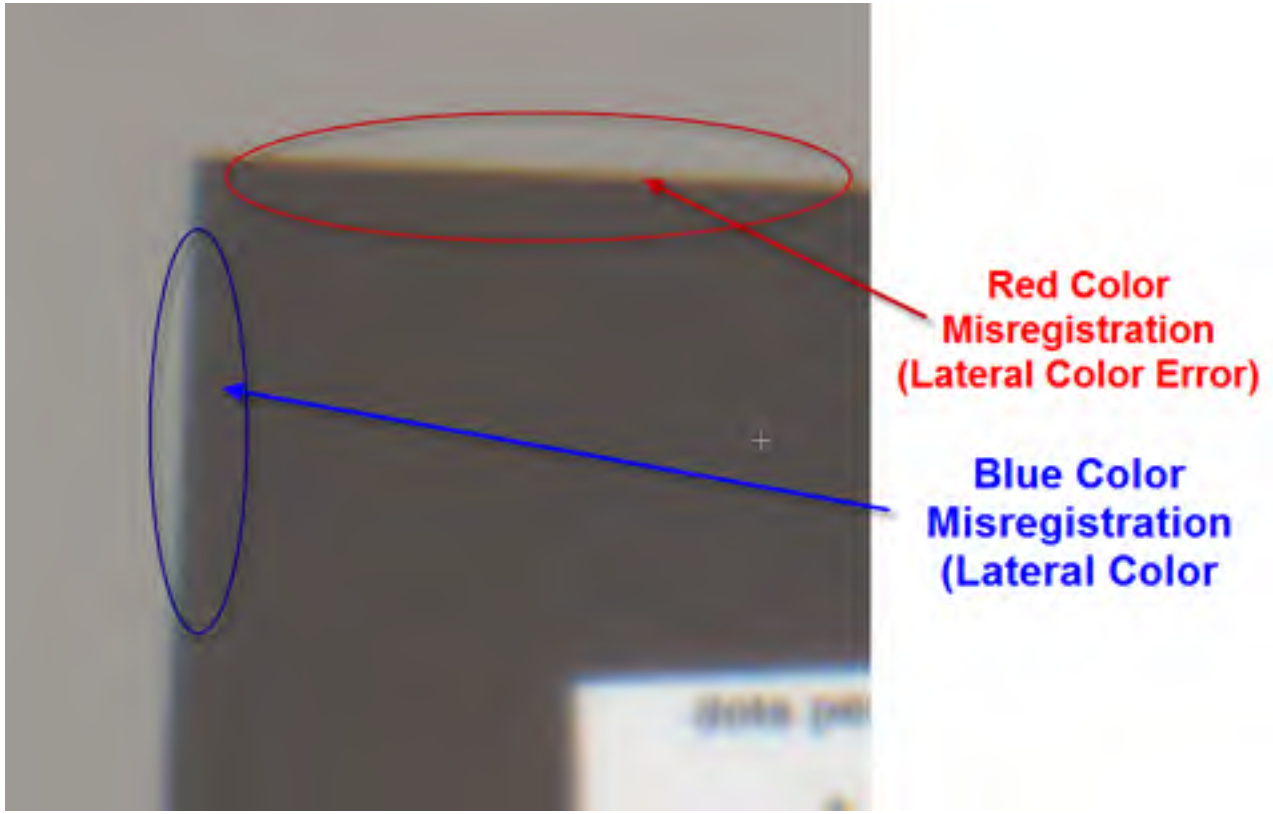
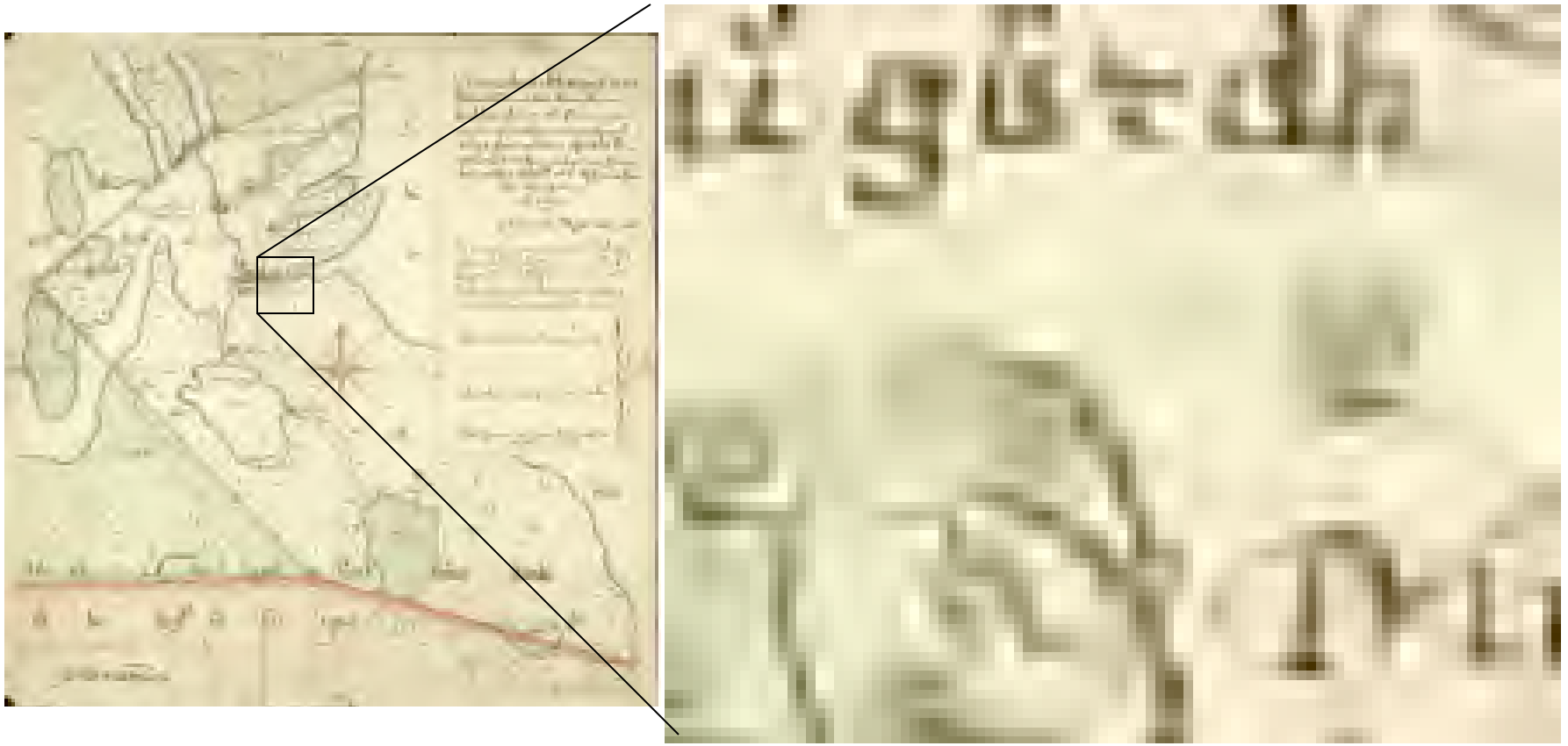
Color Misregistration



Visual assessments of spatial artifacts is quite reliable

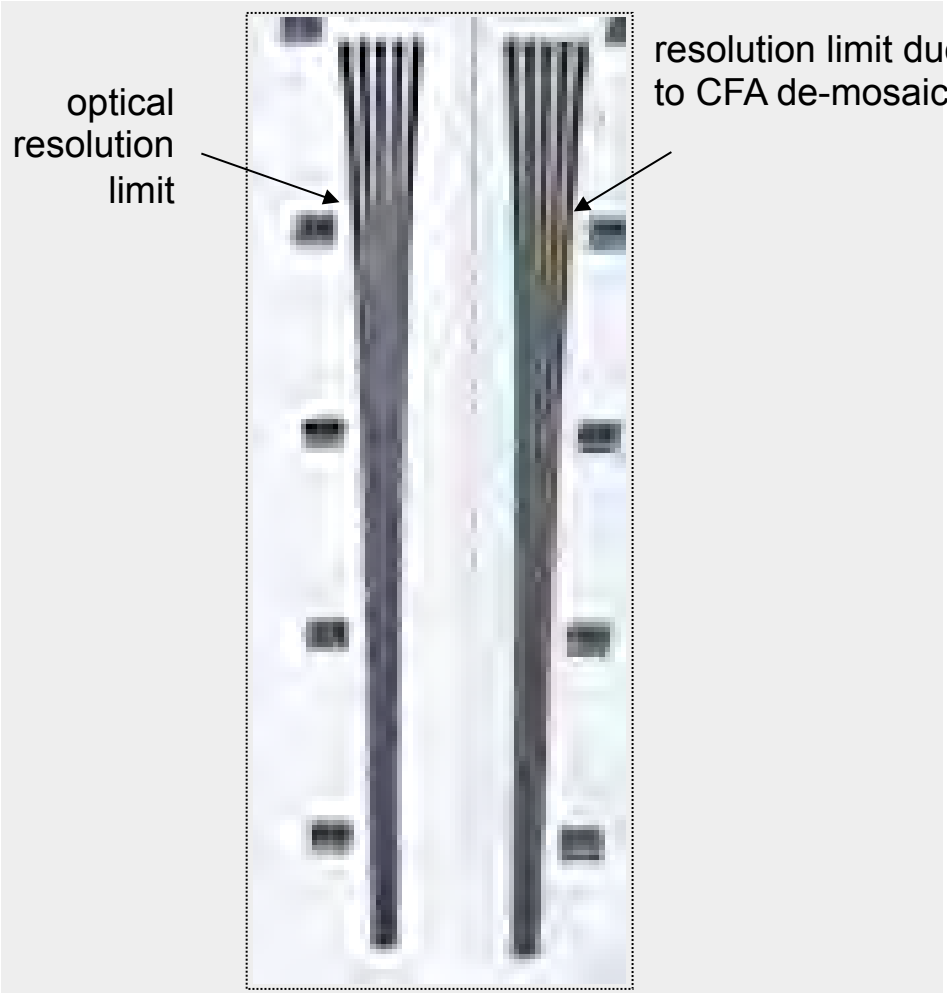
Image Science Associates

Example: Visual inspection needed for adaptive processing artifacts



Visual Inspection for Artifacts

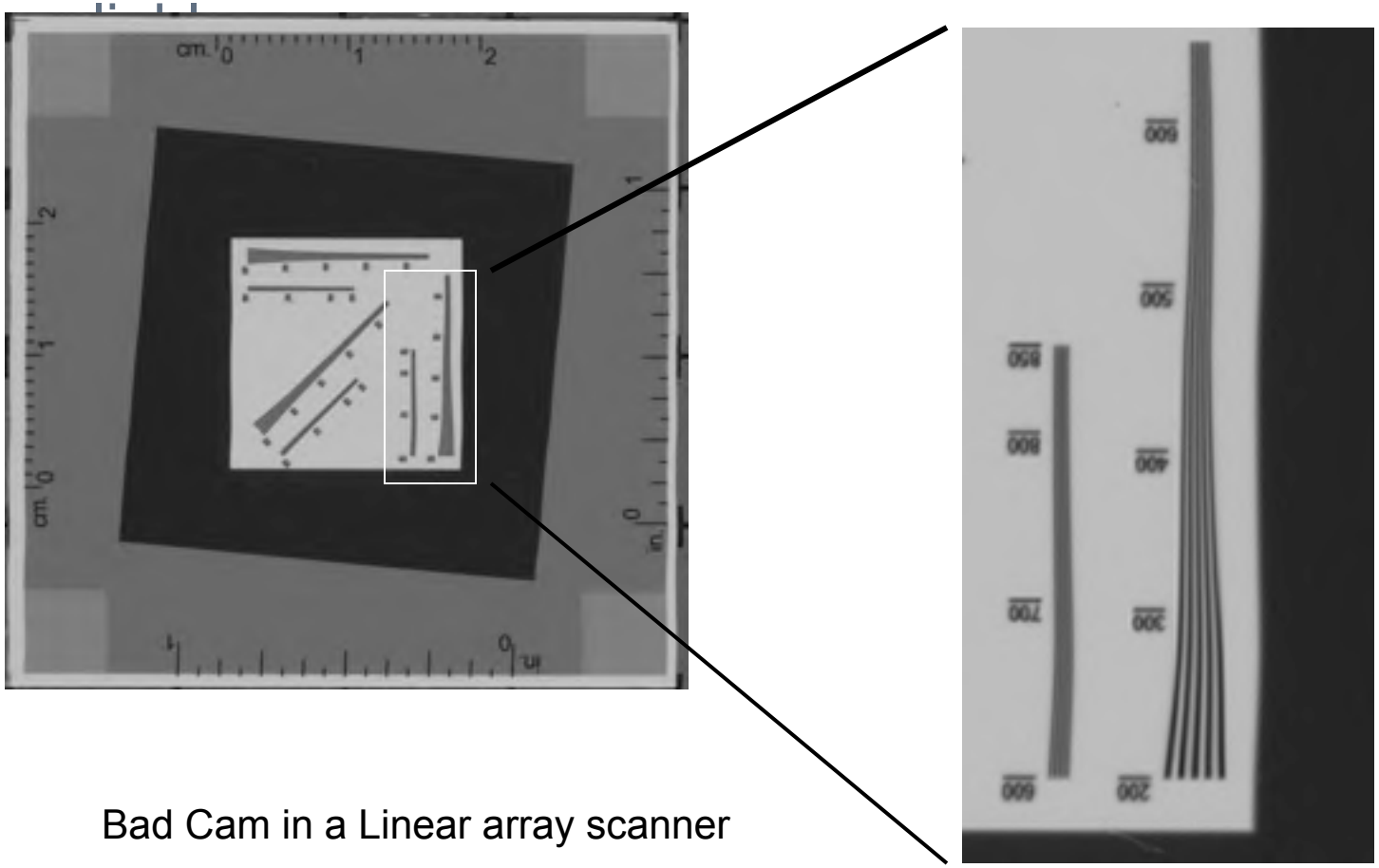
Visual assessments of spatial artifacts is quite reliable



Visual Inspection for Artifacts

Image Science Associates

Visual assessments of spatial artifacts is quite



Bad Cam in a Linear array scanner

Consider Intra-image and Inter-image Variation

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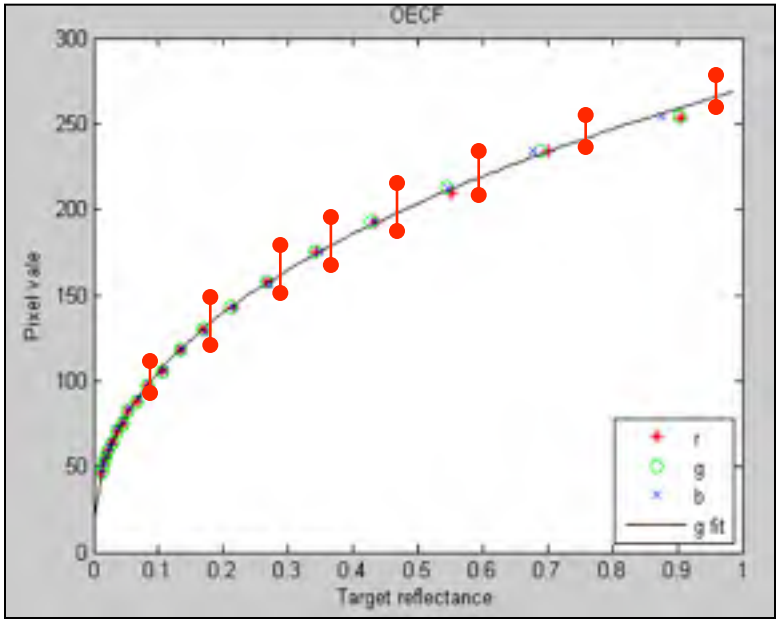
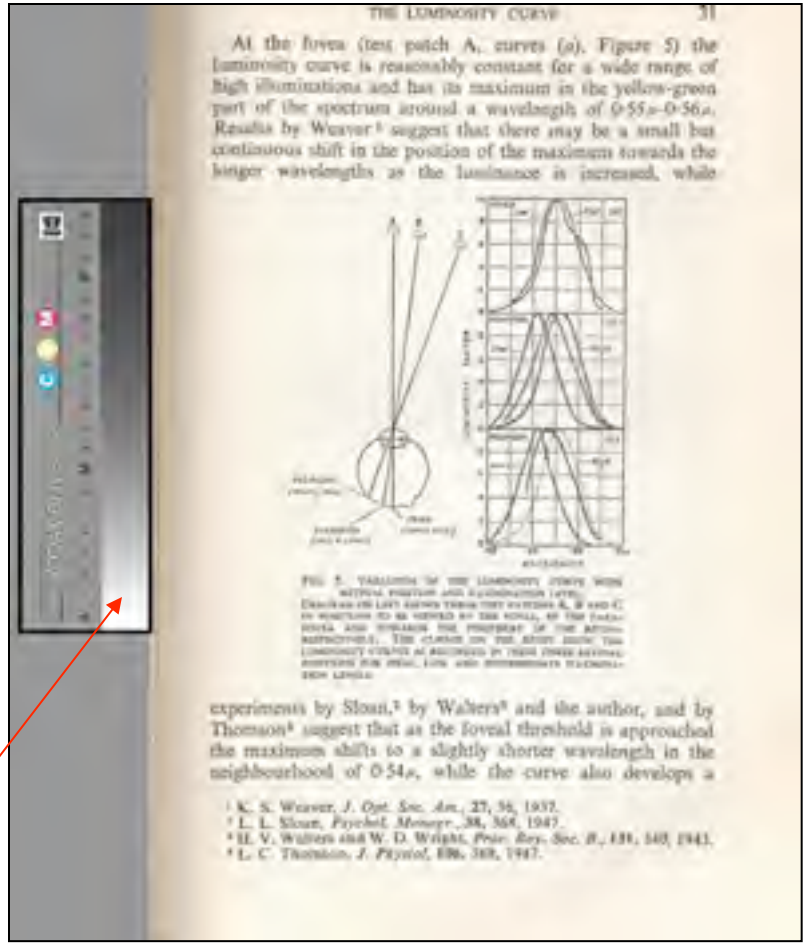
Inter: image-to-image
Intra: across image field



OECF
Color
balance



THE LUMINOSITY CURVE 31

At the fovea (ten patch A, curves (a), Figure 5) the luminosity curve is reasonably constant for a wide range of high illuminations and has its maximum in the yellow-green part of the spectrum around a wavelength of 0·55μ–0·56μ. Results by Weaver[1] suggest that there may be a small but continuous shift in the position of the maximum towards the longer wavelengths as the luminance is increased, while

experiments by Sloan,[2] by Walters[3] and the author, and by Thomson[4] suggest that as the foveal threshold is approached the maximum shifts to a slightly shorter wavelength in the neighbourhood of 0·54μ, while the curve also develops a

[1] K. S. Weaver, *J. Opt. Soc. Am.*, 27, 39, 1937.
[2] L. L. Sloan, *Psychol. Monogr.*, 38, 368, 1947.
[3] H. V. Walters and W. D. Wright, *Proc. Roy. Soc. B.*, 131, 340, 1943.
[4] L. C. Thomson, *J. Physiol.*, 106, 368, 1947.

W.D.Wright, Photometry and the Eye, Hatton Press, 1949

Intra-image: Across field

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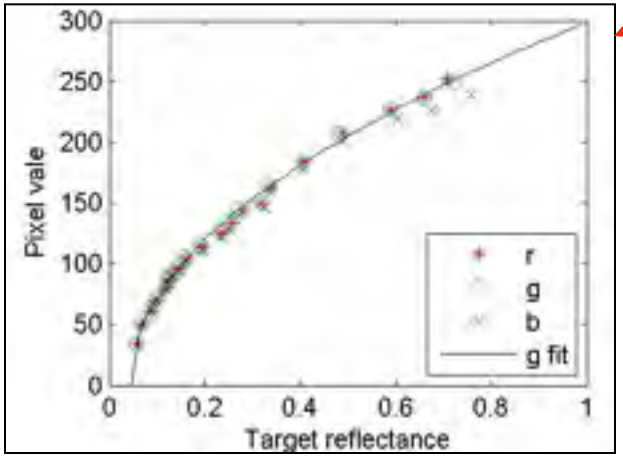
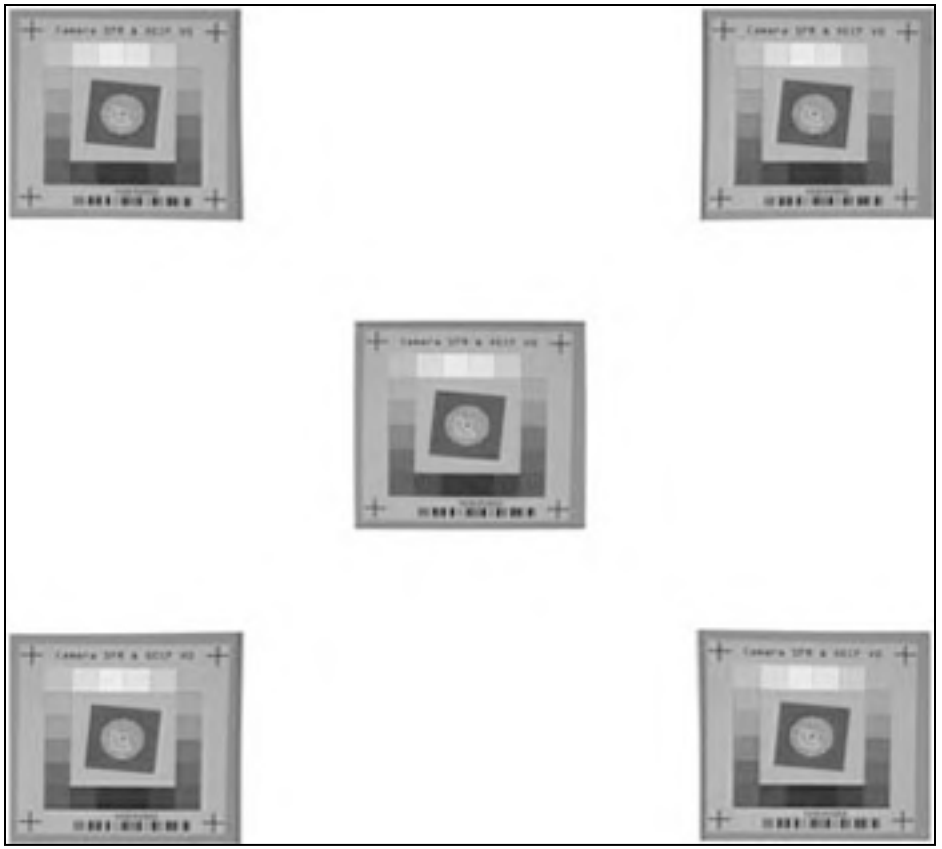
Device-level target





Variation in

- OECF
  optical falloff
- Effective resolution
- Color misregistration

OECF
Spatial frequency response

References

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Thank you!

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