Color in Practice

A qualitative visual guide to creative color

Ming Thein, October 2020

An alternative point of view

- I am not a scientist!
- Photographer, educator, camera company principal, designer, creative…
  - www.mingthein.com
  - www.ming.watch
  - Hasselblad
  - Carl Zeiss

- Color plays an important part in all of these roles, in ways that might not be obvious

- The aim of today: understanding application of color from a creative/ output-driven workflow and process; putting the Brown lecture into context from the other side of the camera

- Creatively, what matters is not so much *how* we get there, but *why* we get there – and that we can have the ability to do so consistently

What this lecture IS NOT

Quantitative

What this lecture IS

Experienced-based, psychology-underpinned, creative intent-driven

Important: color is relative
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Some anthropological caveats to bear in mind

- Our physical 'hardware' differs from individual to individual
- Our mental 'software' differs " " " "
- Our cultural context – language, etc. also differs

- ...So how can we be sure we are seeing or discussing the same thing when two indivduals see as photograph?

Photographic workflow: idea to output, consistently

- What your mind sees > what your audience sees

Creative	Input	Recording	Processing	Output
"The Idea"	Light from source to subject to lens to medium	Light conversion to information	Information conversion and transformation, objective and subjective/ creative	Information to "an absolute" viewable by multiple individuals*

**and later interpreted subjectively again…*

Reading an image

- Certain visual elements stand out more than others
  - Possibly as an evolutionary result warning of danger etc.
- Creatives use this to force the audience to pay more attention to specific elements
  - Photographs are different to the real world: they are finite

- A hierarchy of observation exists ("things that stand out to us")
  - 1. Luminosity
    - Including gross contrast ("light and shadow")
    - Microcontrast ("texture")
    - Pattern (camouflage; motion)
  - 2. Color
    - Relative color contrast
    - Gross color area
  - 3. Depth of field
  - 4. Context and cultural factors

Exercise: what is the subject, and how does it isolate?

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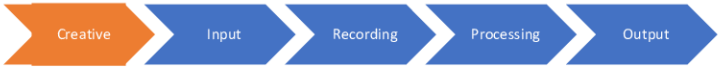


Key takeaways:

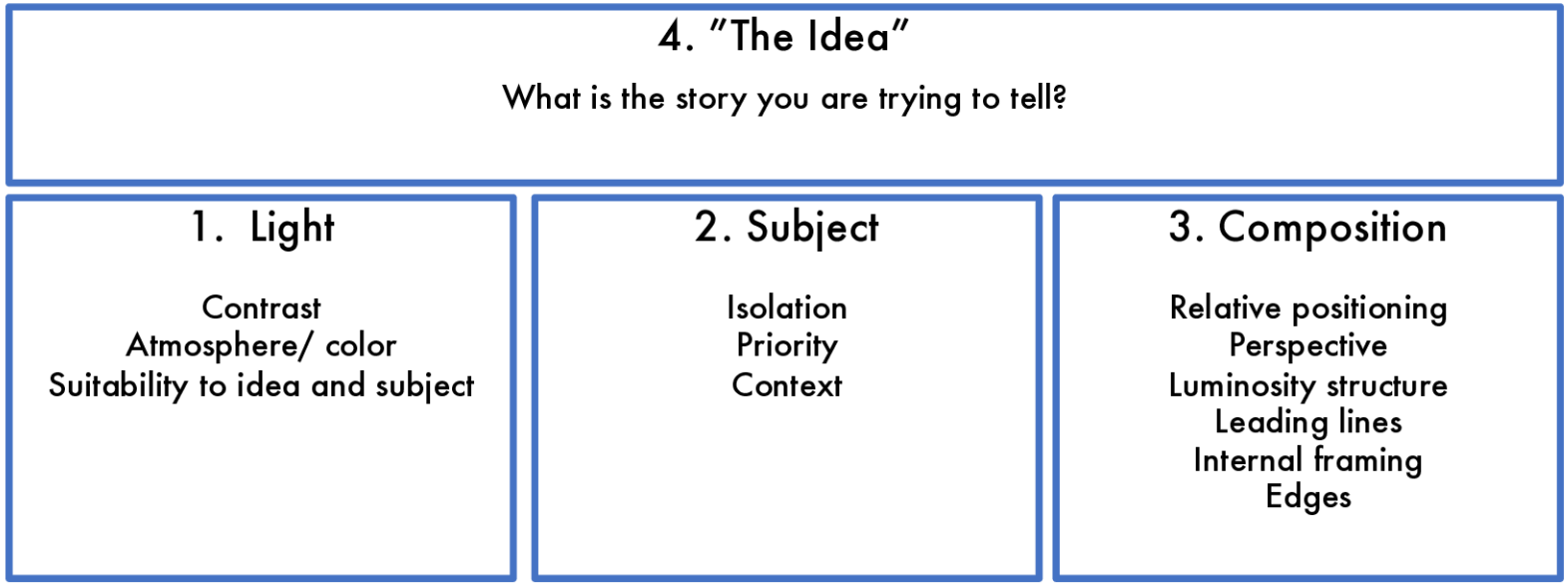
- There is almost always more than one subject
- Each subject may have multiple methods of isolation
- Different people notice different elements in different priority
- Pattern recognition and cultural/ personal context is not to be underestimated
- Sometimes the subject is not literal/physical, and can be implied proximity of individual elements

- We can and do use these observations deliberately to construct a narrative in a still image

The Four Things

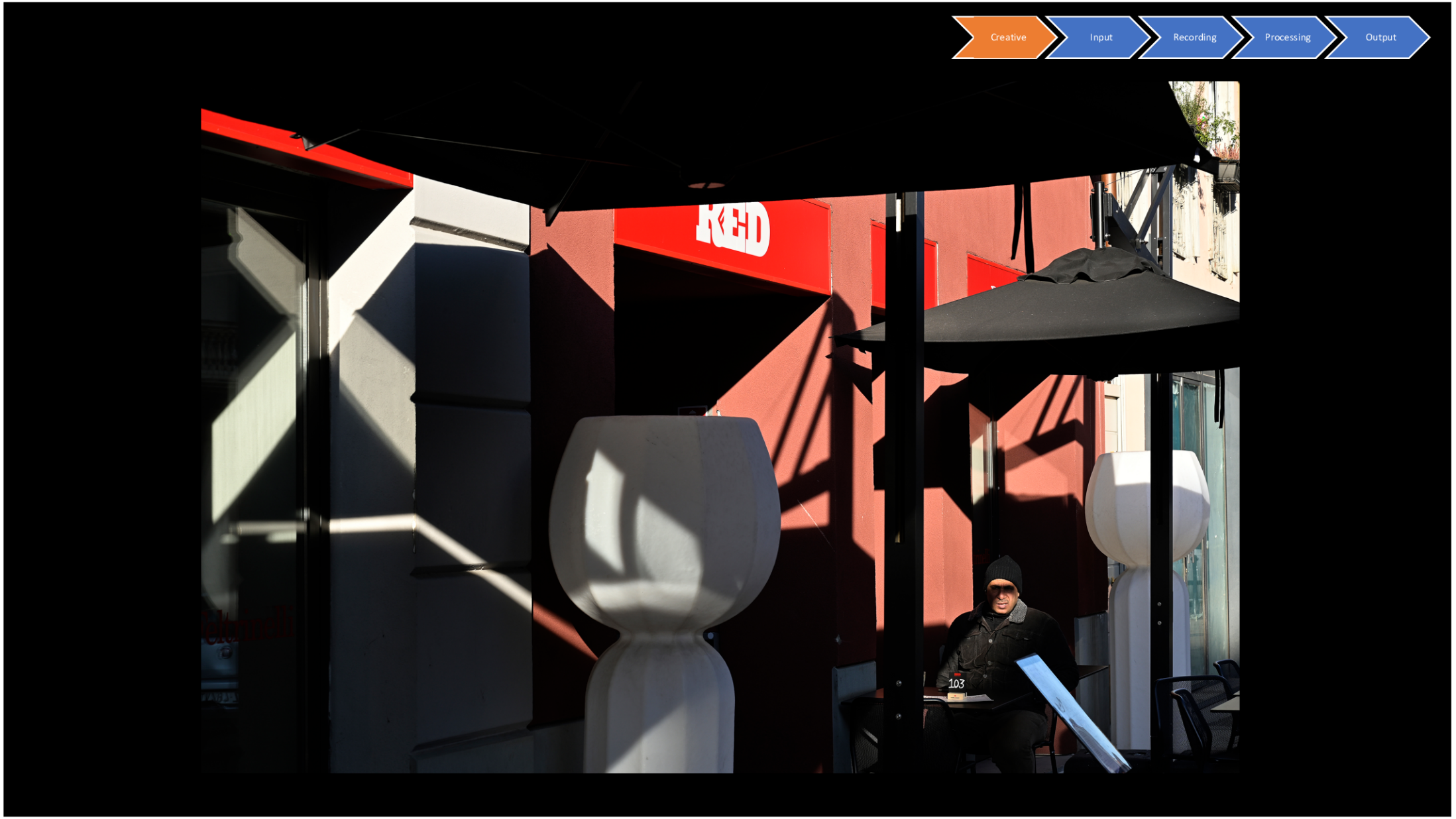
In order of priority, and fundamentality: you cannot isolate your subject without the right light

Note: This is a *creative* structure, not the physiologically driven previously presented in 'reading an image'



Creative → Input → Recording → Processing → Output

Creative | Input | Recording | Processing | Output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Creative | Input | Recording | Processing | Output

Luminosity edge limits and relativity: a practical demonstration

Same information, different creative interpretation: the concept of style

- Warmer
- Brighter
- Lower contrast
- Less obvious subject
- What do you feel?

- Cooler
- Darker
- More contrast
- Obvious subject – and changes with viewing size
- Different feel

Why absolute color doesn't matter

- Images are never viewed in isolation
- The same subject can appear very different in different light: e.g. sunrise v sunset
- The creator has little control over the medium most of the time

- In quantitative terms: illuminants are not even/constant-spectrum, and not every subject has equal reflectivity across the entire spectrum
- To some degree, this can be compensated for by shifting white balance (relative channel gain)

Color looks okay…

Color still looks okay…

…But these are not the same image: context matters, and chromatic adaptation is real

Same subject, different presentation: note time of day cues

Sunrise:

- Cooler; sharply angled shadows
- Reduction in contrast with distance

Sunset:

- Warmer, equally sharply angled shadows
- No reduction in contrast with distance

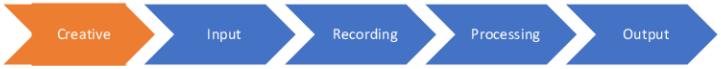
Why does this image feel like California?

Why does this image feel mysterious?

Which is more appetizing?

Sometimes inaccuracy is more impactful

Sometimes inaccuracy is more impactful



The role played by hardware

- To capture as much information from the scene possible for later subjective interpretation by the photographer

- Raw information filter
- Creative filter
- Perspective filter

Color…in monochrome?

- Absolute monochrome: luminosity only
- Monochrome from commonly available hardware: R, G, B channels must be combined
- It is still possible to create the impression of color in a monochrome image
  - Creatively, important for differentiation of subject
  - We perceive different colors as having different impact even if luminosity is the same
- Monochrome images tend to be stronger/more stark because the ‘distraction’ of color is removed

The conversion process has a huge impact on perception

Original color

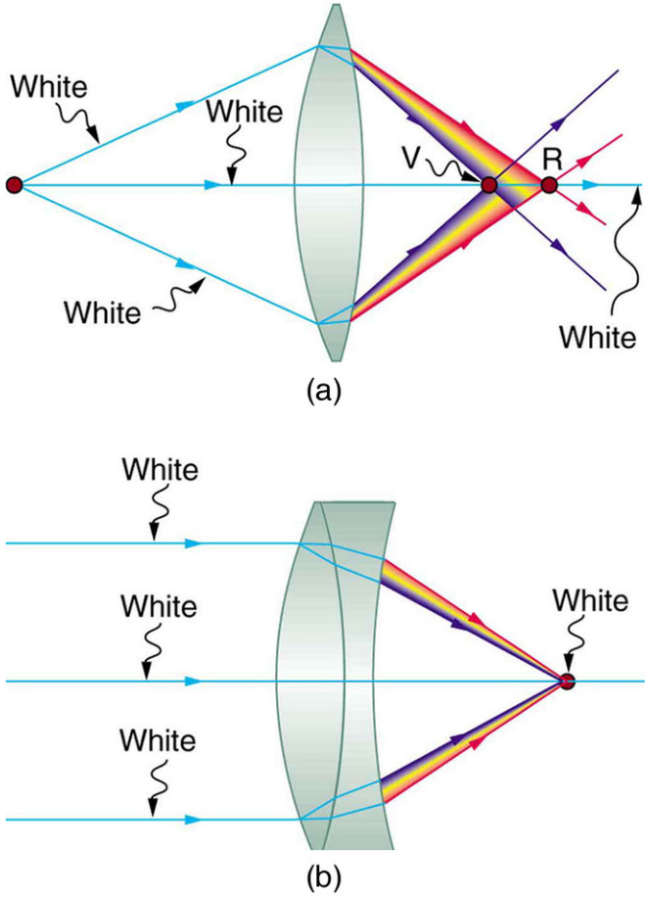
Desaturate only

Darken B, lighten YOR.

Lighten B, darken YOR

Preservation of *relative* contrast matters!

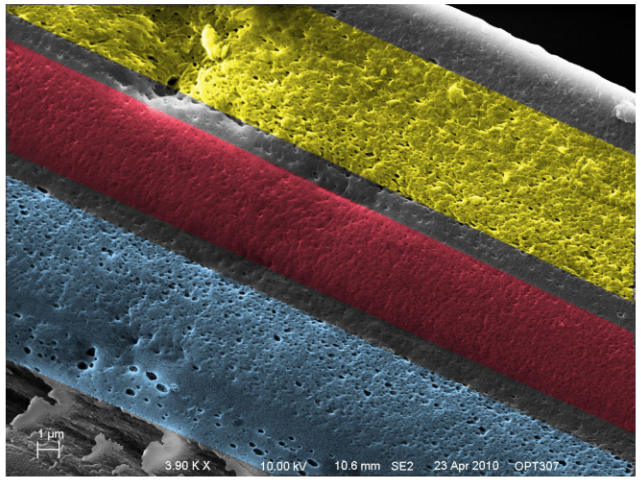
Input: color and optical design

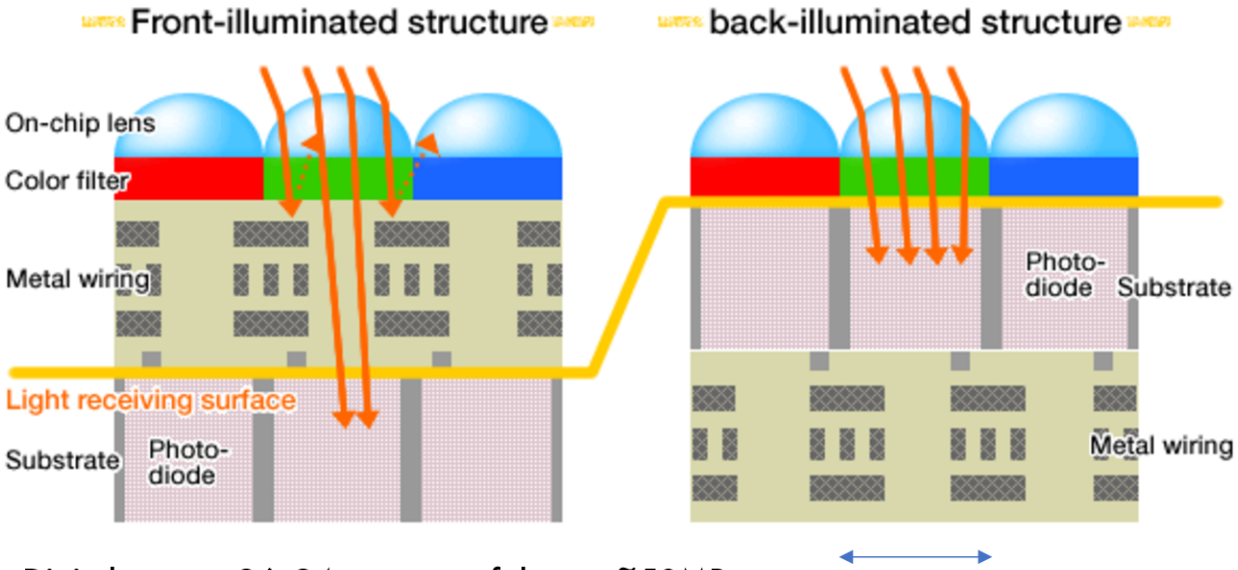


- Dispersion happens and affects color recorded at the medium
- We can compensate for this by changing the medium or the optics
- But: the more complex the optical design (e.g. very wide, very long, very asymmetric subject or image distances), the more lenses are required…

Image source: Lumen Learning https://courses.lumenlearning.com/boundless-physics/chapter/lenses/

Modern systems require higher resolution *and* higher color correction, resulting in much more complex optics





Typical color film:

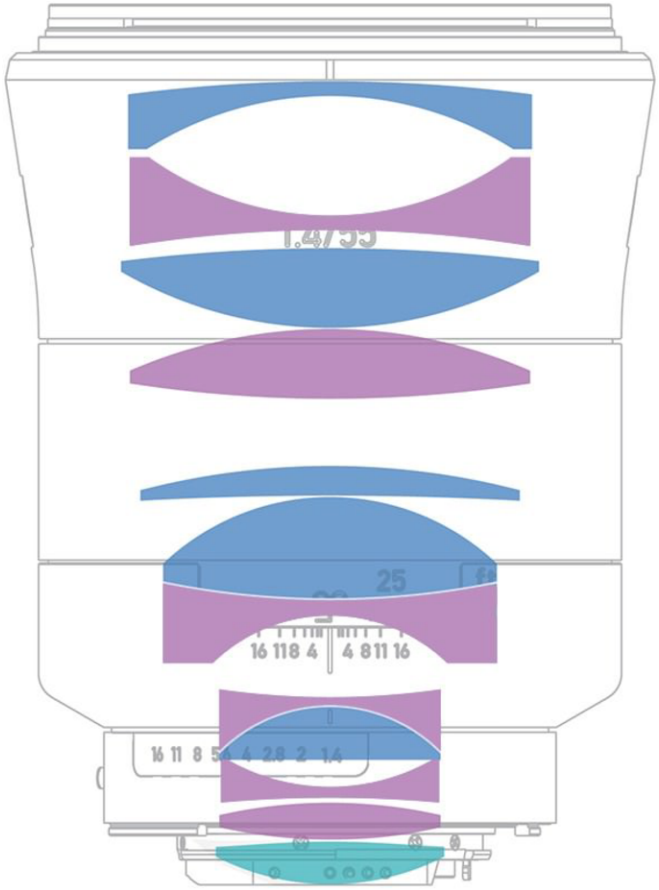
- Active emulsion thickness ~15um
- Effective resolving power 20-40lp/mm
- Presented in wavelength order

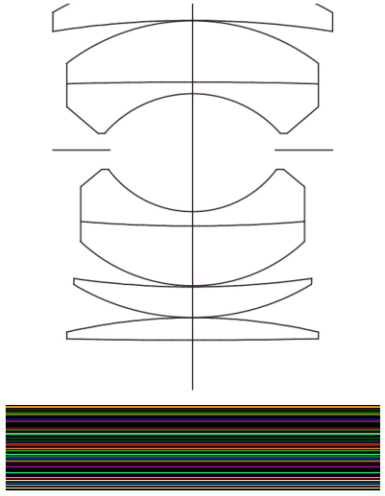
Digital sensor, 36x24mm state of the art ~50MP:

- Photosite pitch: ~3-4um
- Effective resolving power ~120lp/mm
- Complexities of the microlens/ well structure

Image source: (L) Shu-Wei Hsu, University of Rochester; (R) Sony Corporation

The more correction required, the more complex the optics





Relative sizes shown; both lenses approximately 50mm and f1.4 for a 36x24mm format

- L: Zeiss Otus 55mm f1.4; apochromatic in three colors; one aspherical element; three glass types; edge coated for low reflectance; MTF 30 70% at 20mm image height (extreme corner) at f1.4
- R: Nikon 50mm f1.4; not apochromatic; one glass type; no aspherical elements. MTF 30 40% in center at f1.4
- Note: not all 'apochromatic' lenses actually are.

- *Fast, cheap, good: pick any two.*

Image source: (L) Carl Zeiss AG; (R) Nikon Corporation

Color matters even for monochrome recordings

Subject / Recording	Full spectrum	Limited spectrum
Full spectrum	Any chromatic aberration recorded as haze/ halo	Focus must be calibrated to spectrum recorded, else OOF haze/halo recorded
Filtered	Focus must be calibrated to spectrum recorded, else OOF haze/halo recorded	Image only recorded if filtration matches sensitivity

- The yellow regimes allow for correction of optics (i.e. increase in resolving power) by use of the right color filter and focus calibration
- Chromatic aberration actually looks worse in monochrome because there is no color differentiation to reinforce the 'subject'

Color matters even for monochrome recordings

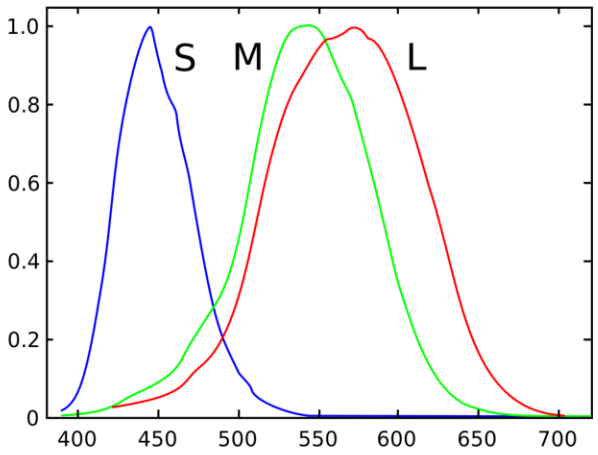
- Note lack of structure in OOF areas

Recording: A brief history of photography

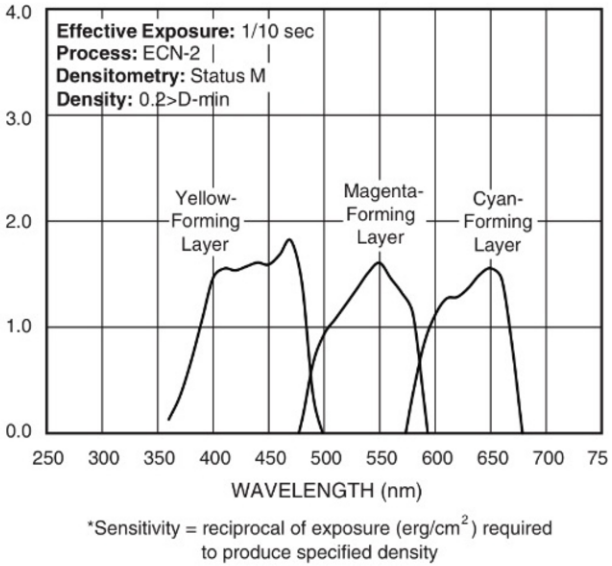
- 1700-1800: Inadvertent of photosensitive chemistry
- 1816-1833: Nicephore Niepce, bitumen on pewter (but impermanent)
- 1832-1840: Louis Daguerre and silver iodide on metal substrate
- 1839: Henry Fox Talbot invents fixer
- 1851: Frederick Scott Archer invents colloidon process, simplifying and speeding up exposure times
- 1884: George Eastman replaces the photographic plate with prepreg paper and film
- 1860-1880: Early color by various inventors; recompositing of filtered monochrome images through identical filters to create the illusion of color
- 1907: Auguste and Louis Lumiere develop a process using homogeneously mixed dyed potato grains to create a color mosaic small enough to be indistinguishable to the eye at normal viewing distances
- 1935: Kodachrome 3-layer emulsion producing a transparent positive image
- 1969: Willard Boyle and George Smith invent the CCD
- 1975: Bryce Bayer at Kodak develops the Bayer filter to record color images with a luminance-only sensor

From an image at all to what we want to see

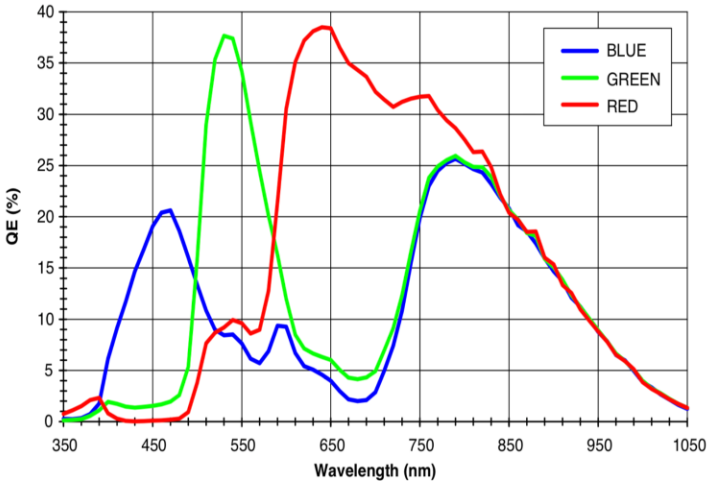
Spectral response: Human vision



Spectral response: trichromatic transparency film (note CMY, not RGB)



Spectral response: typical RGB Bayer filtered CMOS (interpolated for each location)

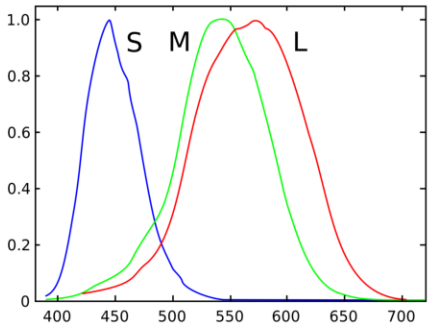


- It is clear that what we "see" – is not necessarily what we *interpret* nor is it what is recorded by the media to hand.
- And we haven't even discussed output yet…

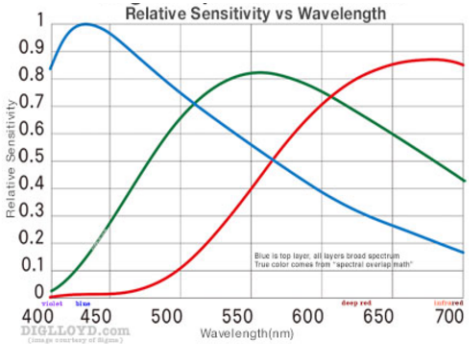
Source: Wikipedia, ON Semiconductor

Many attempts to get closer to human spectral response

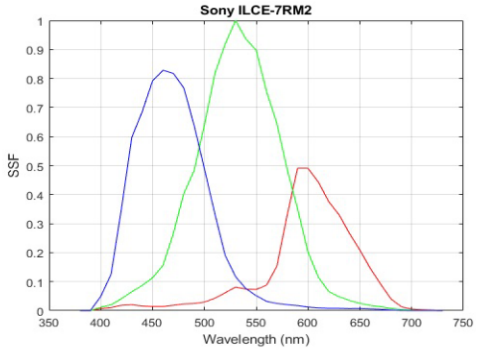
Human vision



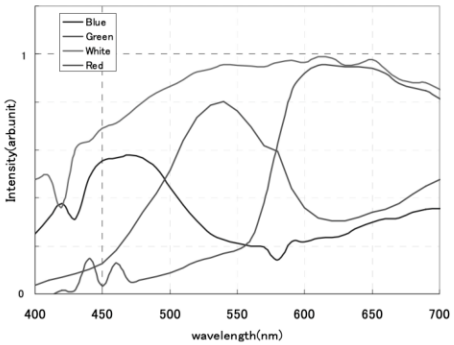
Sigma Quattro, stacked true RGB at each pixel location



RGBE quasi-Bayer; G and E combined (interpolated for each location)



WRGB quasi-Bayer with edge correction



- But in practice, both film and RGB Bayer produce more 'pleasing' *and* quantitatively accurate (lower Delta-E) results than Quattro or RGBE.
- Why? Commercial realities.

Source: Wikipedia, Sigma/Lloyd Chambers, Sony, https://www.imagesensors.org/Past%20Workshops/2007%20Workshop/2007%20Papers/068%20Honda.pdf

Key qualitative properties of and differences between human vision and other recording methods

	Human eye	Film	Digital
Luminosity	• Clips to black • Very rarely overloads at “white”	• Clips to black • Very rarely overloads at “white”	• Clips to black and white • Tonal maps possible
Saturation/ Hue/ Color	• Very rarely clips to black • Very rarely overloads to full saturation • Perception of hue and saturation tends to be relative	• Clips to black • Overloads at full saturation (worse with transparency film) • Calibrated for fixed color temperature only	• High saturation at low luminosities possible (unnatural) • Different color temps (white balance) can be compensated for but at cost of SNR
Contrast/ SNR	• Dynamic contrast within sub areas in field of view; more perceived microcontrast in central field	• Fixed; at best 13-14 stops for negative color/ monochrome; 6-7 for color transparency	• Best sensors approaching 15 stops for single capture (16 bit) • HDR possible through processing
Spatial resolution	• High in narrow central field, low off-axis • Increased by dynamic scanning and processing • Irregular/ fractal	• Moderate across entire field • Commercial color films 20-40 lp/mm • Irregular/ fractal	• Up to 500lp/mm (!) on a 0.8um pitch sensor across entire field • Regular/ uniform
Other properties	• Pattern recognition and associated biases in processing	• Without electronic scanning, information can only be ‘processed’ once	• Massive flexibility in processing • SNR proportional to photosite area

The effect of process on color reproduction

	Color film	RGB Bayer	Others (Foveon, Quattro, RGBE)
Advantages	• Similar tonal response to human eye at highlight and shadow ends: rarely clips black or white; lack of saturation with low luminance • Centuries of maturity • Less critical of optics because of emulsion thickness and grain size • Measurement of actual color value at a given physical location	• Dyes can be adjusted • Ease of data manipulation to more closely reflect human vision – especially for known dye formulations • Commercial and engineering maturity	• Theoretically possible to tune tonal response • Higher spatial resolution due to less or no neighbor interpolation
Disadvantages	• RGB vs CMYK color spaces • Tonal response curves do not perfectly match • Not easy to 'tune' data using physical, optical and chemical filters	• Heavily dependent on energy response of underlying semiconductor • Photosites have defined full and empty states: clipping occurs • Native tonal response does not match human eye: too linear • Color value must be interpolated from neighboring photosite locations, reducing actual resolving power	• Noise from increased gain necessary from stacked photosites • Relative lack of commercial maturity driving lack of R&D driving lack of product driving lack of commercial maturity…

Defining "processing"

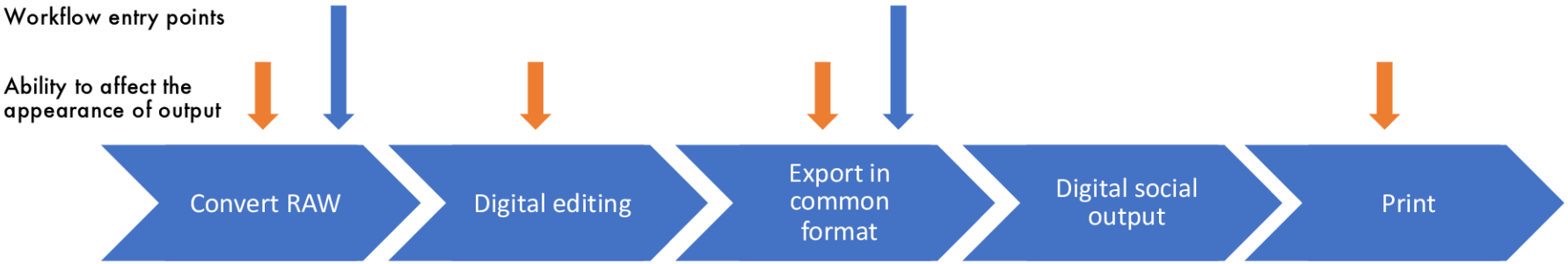
- The conversion of recorded luminosity and spectral data into an image that is viewable
- All processing involves subjective interpretation

Film photography workflow

Ability to affect the appearance of output

Develop	Fix	Wash	Print
• Chemical removal of non-activated halides • Different chemicals create different densities, i.e. different contrast profiles • Limited by chemistry • Very temperature and concentration sensitive for color, with 4 chemicals for C41 process	• Renders halides light-safe by stabilizing	• Removes developing chemicals, balance of developer and fixer	• Same process in reverse: projection of negative or positive image onto photosensitive paper via an optical enlarger • Photosensitive print paper must then be developed, fixed, washed etc.

An overview of digital photography workflow



- Demosaicing from sensor data to RGB+address values
- Transforms can take place in 8, 10, 12, 14, 16 bit space – the higher the better; smoother distribution allows manipulation without posterization

- Application of IO filters by luminance and RGB value, globally and/or locally
  - Exposure
  - Shadow/highlight recovery
  - Curves
  - Levels
  - Dodge and burn
  - Hue shifts/ WB correction
  - (Changing actual content)

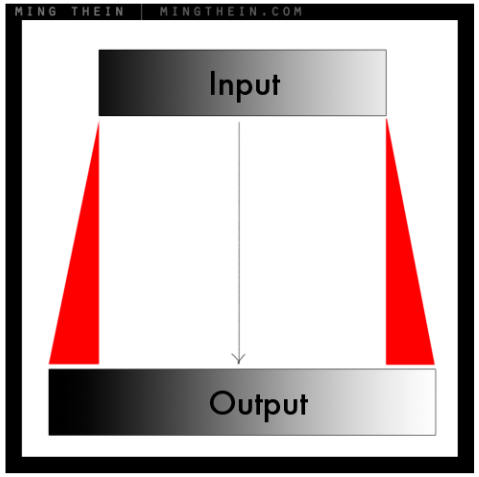
- Usually JPEG: 8 bit lossy compressed
- Different formats have different compression efficiencies and tradeoffs
- >8 bit only makes sense for future re-editing, display on 10 bit monitors (uncommon) or conversion to other color spaces to avoid posterization

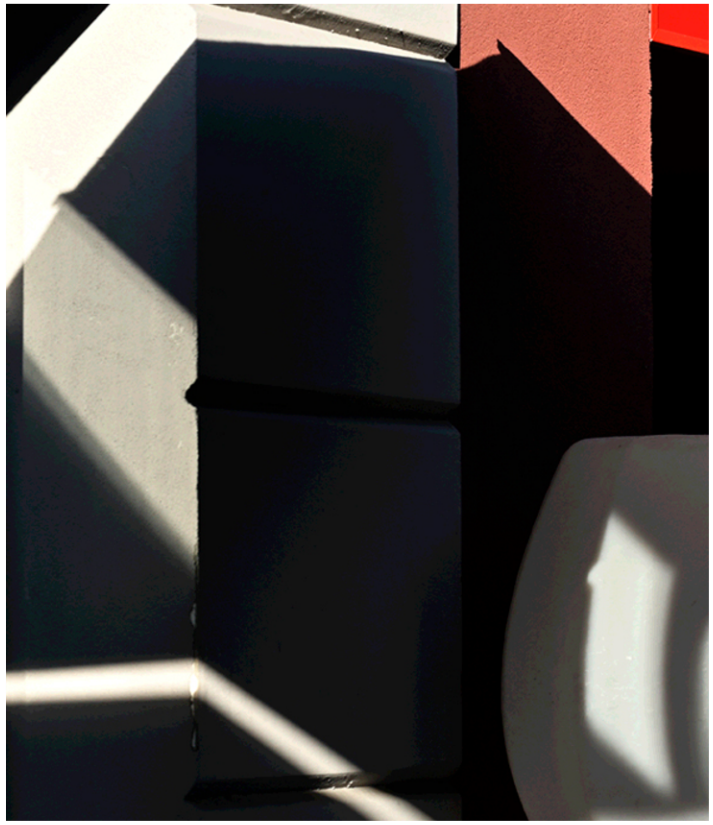
- Most people come straight here after skipping the first three items. This is the equivalent of drugstore film processing: zero creative control.

- Conversion from RGB to CMYK color space: monitors are transmissive/ subtractive, print is reflective/ additive.

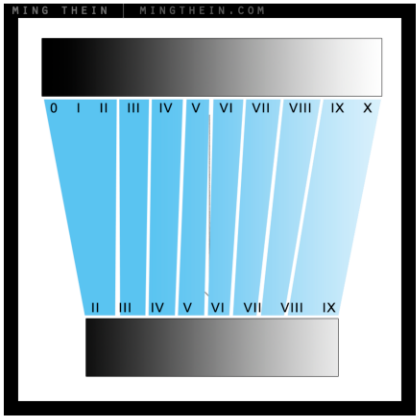
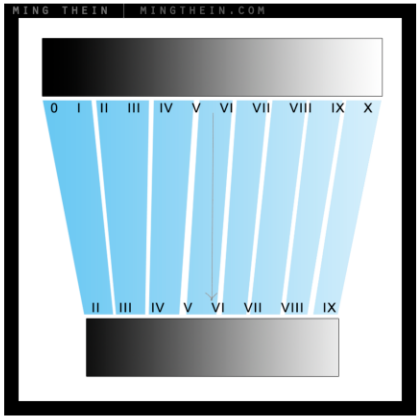
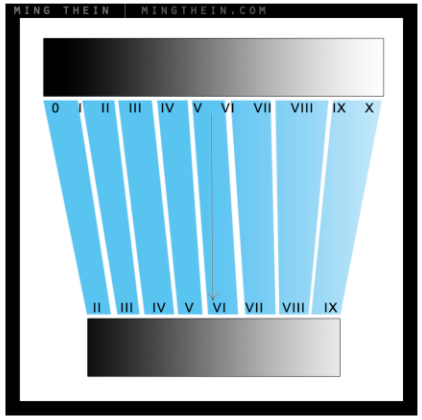
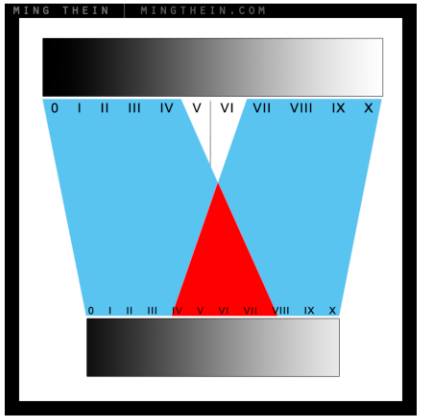
Posterization results when trying to make more from less

- Upsampling information from a tonal scale with less information to one with more information almost always results in posterization
- Insufficient information to interpolate at both ends of the tonal scale leads to steps in luminosity





Downsampling has many options

	Averaged, not biased	Highlight biased	Shadow biased	Bad; visual overlaps
Input				
Output				

Color spaces in practical use

	Digital capture	Digital display/ output	Print
Core data	• Red/ green/ blue luminance by physical address	• Red/ green/ blue luminance by physical address	• Cyan/ magenta/ yellow/ black (and sometimes others) by approximate physical address; imprecise overlap or halftone
Makeup	• Additive: R+G+B = white	• Additive: R+G+B = white • Supplemented by pure white • Not all displays capable of pure black (nonlinearity at max/min luminance)	• Subtractive: absence of one or more plates generates perceived color
Presentation	• Transmissive: ambient light passes through	• Transmissive: provides own light source	• Reflective: ambient light is filtered by media and bounces off

Output: how do we successfully translate what is *seen* = what is *recorded* = what is *reproduced*?

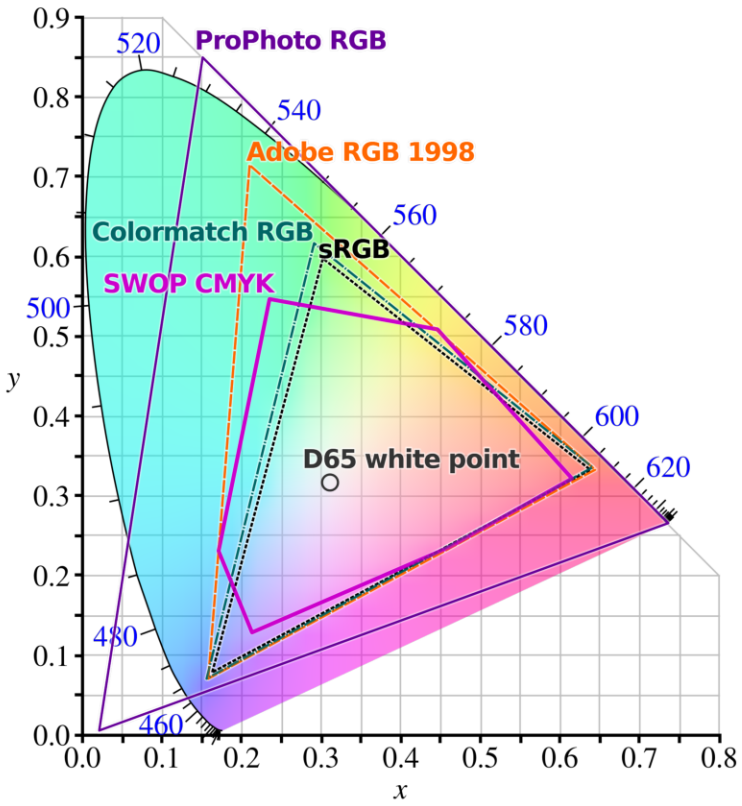


Image source: Wikimedia commons

Different color spaces for different purposes: blame historical lack of standardization, e.g.:

- Digital photography, wide gamut: Adobe RGB
- Digital photography, pro gamut (short lived): ProPhoto RGB
- Web safe: sRGB (and variants thereof)
- Print: CMYK (and variants thereof)
- Cinema: DCI P3
- Broadcast: NTSC, PAL
- …

- Digital is *somewhat* easier because there is no switch between additive and subtractive, reflective and transmissive media
- Print is extremely limited: this gives rise to soft and hard proofing. Note: gamut changes hugely by paper type.

Creative vs technical objectives

- The creative's intention for photography: reproduce what I *perceive*
- The scientist/engineer's intention for photography: reproduce what is measured
- The corporate intention for photography: reproduce what we think you like, so you buy more

- These clearly are not the same objectives, and a lack of objectivity (!) has resulted in long standing biases in how images are reproduced and output
  - "House color"
  - "Style"

- Note: in the previous slide I said 'successfully translate', not 'accurately translate': conceptual intent vs absolute intent vs immediate impact in isolation

Creative | Input | Recording | Processing | Output

Creative | Input | Recording | Processing | Output

Creative → Input → Recording → Processing → Output

What just happened here?

- Without relativity, the impact of an image is limited to its own content and subject
- Technical deficiencies are not noticeable unless they overpower the conceptual content
- Furthermore, actual differences in files likely to have been blunted by web compression of this lecture
- Technically, the original file is poor: the wall is posterized – not textured marble
- Nobody complains about lack of fidelity in paintings.

- Yet if the intended creative impact translates, we consider the image – and by extension the process – to be successful.

End to end managed workflow vs consumer workflow

	Hasselblad	Brand F/N/C	Typical camera phone
Optical calibration profiles	• Cross field color • Distortion and lateral CA correction	• Distortion and CA correction	• Distortion and CA correction
Sensor	• RGB Bayer 14 bit • Individually calibrated against neutral target at all sensitivity settings; each camera carries individual calibration data	• RGB Bayer 14 bit • Batch calibrated	• RGB Bayer 14 bit • Batch calibrated (?)
Data transform space in camera	• 16 bit	• 14 bit	• 10-12 bit
Data storage format in camera	• 16 bit uncompressed or lossless	• 12/14 bit uncompressed, lossless or lossy	• 8 bit lossy
Raw data conversion process	• 16 bit, own software • 8/16 bit 3rd party support	• Unknown bit depth, own software • 8/16 bit 3rd party support	• Unknown bit depth, own software • 8/16 bit 3rd party support
Final output	• Up to 16 bit uncompressed	• Up to 16 bit uncompressed	• 8 bit lossy

But if all data can be manipulated…why do so many imaging systems have inaccurate color by default?

- Historical legacy: especially for former film-producing companies
- Commercial differentiation
- Optimization for old standards
- Corporate inertia

- A shift away from accurate reproduction to pleasing impact: the question of ‘style’

Style is the (consistent) antithesis of accuracy

- It is the deliberate application of a biased interpretation of data to generate a certain emotional response
- Subjectivity is a core fundamental of photography: what do we include? What do we highlight? How do we present it?

Capture choices	Workflow choices
• Inclusion/ exclusion • Lens perspective • Camera spatial position relative to subject • Camera orientation • Format/ media choice • Exposure brightness • Focal plane • Depth of field • Exposure duration/ impact of motion	• Saturation • Contrast • Overall luminosity • White balance • Hue shifts • Local adjustments • Retouching • Cropping and aspect ratio • Output medium • Output size


Kein Eingang
No entrance
Der Rundgang beginnt im Obergeschoss
The tour starts on the first floor

Creative > Input > Recording > Processing > Output

Creative | Input | Recording | Processing | Output

Demonstration of digital workflow

1. Camera RAW file
2. Conversion via Adobe Camera Raw (16 bit)
    1. Global adjustments to create a neutral starting point
    2. Global adjustments to bias to style
3. Tonal and local adjustments in Adobe Photoshop (16 bit)
4. Output and soft proofing (8 bit)

Important takeaways

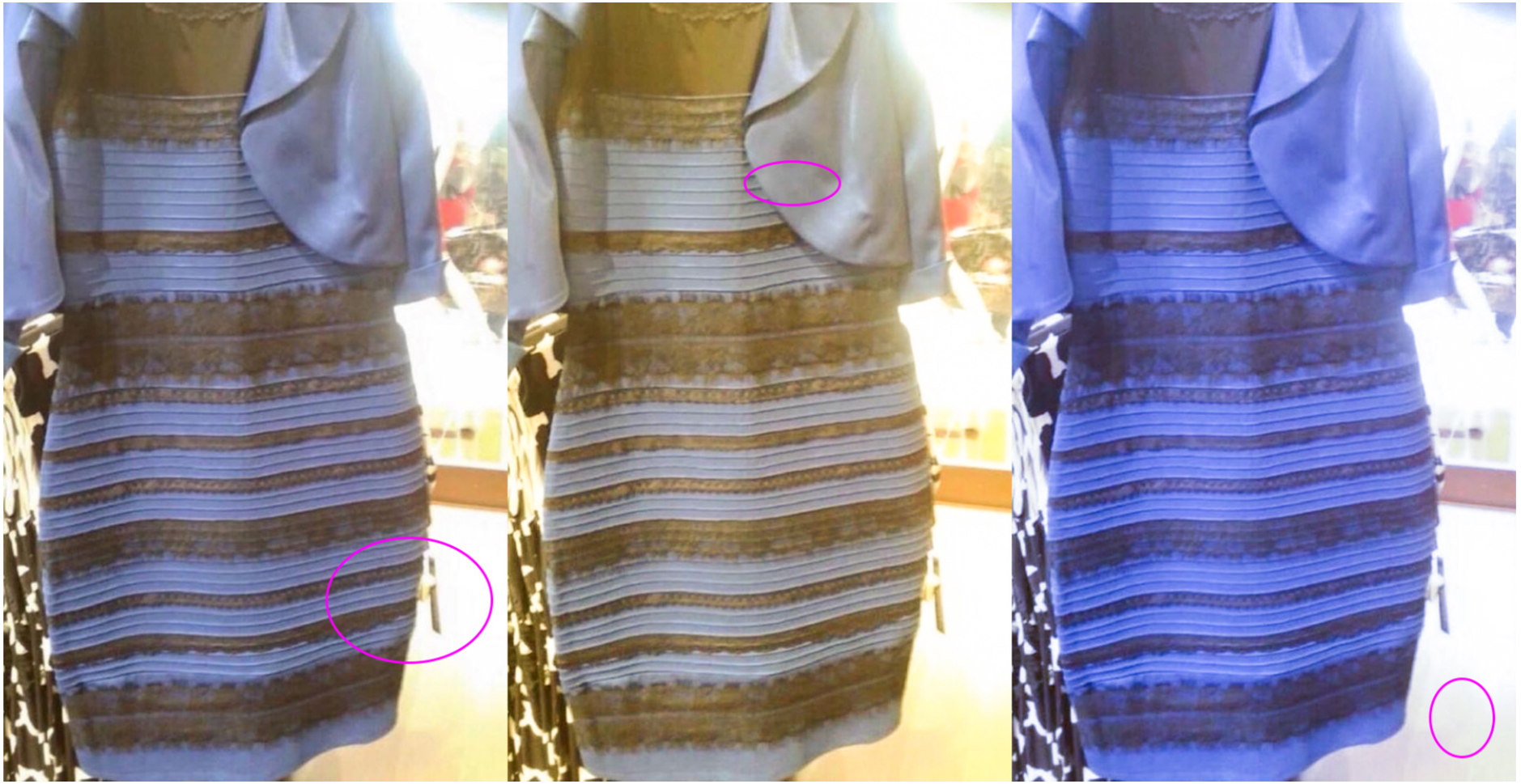
1. Absolute quantitative accuracy is both difficult to achieve in practice and often ‘broken’ by a single element in the chain

2. Psychology and context both have a much greater impact than accuracy

3. A lack of color accuracy is only really noticeable when it starts to distract from the subjective content; the acceptability threshold of an untrained observer is surprisingly high

4. Accuracy is still preferred for the consistent application of style: you need to have all the information and tools to decide what to apply, when

5. We need to be objective to allow consistency in subjectivity



Q&A

Additional reading

- The Four Things https://blog.mingthein.com/2016/07/28/the-four-things-redux/
- Turning an idea into an image: https://blog.mingthein.com/2019/09/14/back-to-basics-turning-an-idea-into-an-image/
- Structure: https://blog.mingthein.com/2019/09/02/back-to-basics-structure/
- Layering: https://blog.mingthein.com/2019/09/08/back-to-basics-layering/
- Subject isolation: https://blog.mingthein.com/2019/08/27/back-to-basics-cut-points-and-edges/
- Rules of vision part I: https://blog.mingthein.com/2019/08/09/back-to-basics-rules-of-vision-or-things-we-cant-help-seeing-part-i/
- Rules of vision part II: https://blog.mingthein.com/2019/08/15/rules-of-vision-part-ii/
- Viewing and presentation methods: https://blog.mingthein.com/2018/03/14/on-viewing-and-presentation/
- Practical differences between eye and camera: https://blog.mingthein.com/2018/06/03/repost-practical-differences-between-cameras-and-human-vision/
- Understanding HDR, the zone system and dynamic range: https://blog.mingthein.com/2015/08/31/repost-hdr-the-zone-system-and-dynamic-range/
- Curation https://blog.mingthein.com/tag/curation/
- The medium format look https://blog.mingthein.com/2015/02/24/that-medium-format-look-what-is-it/ https://blog.mingthein.com/2019/07/16/what-defines-small-medium-large-formats-anyway/
- Limitations of language https://blog.mingthein.com/2020/07/10/limitations-of-language/