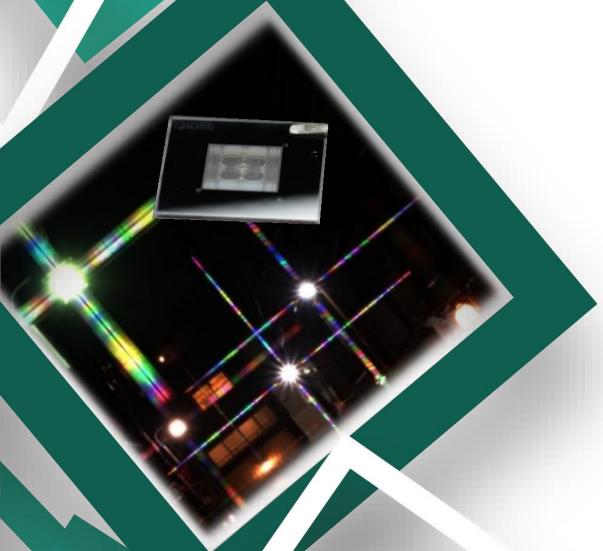




GAMES 204



Computational Imaging



Lecture 06: High Dynamic Range Imaging and Tonemapping



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点昀技术 (Point Spread Technology)



Today's Topic

- Common Image File Formats
 - Raster File Format
 - Vector File Format
- High Dynamic Range Imaging
- Tone Mapping
- Classical Methods
 - Night Sight "look"
 - Burst Alignment
- Finish Pipeline

Slide credits

Many of these slides were adapted from:

Ren Ng(Uc Bakery)

Kris Kitani, Ioannis Gkioulekas (15-463, 15-663, 15-862).

Fredo Durand (MIT).

Marc Levoy, Gordon Wetzstein (Stanford).

CS559-Computer Graphics

Orly Liba, Google Research



Common Image File Formats



Raster File Formats

Made up of a set grid of dots called pixels

➤ TIFF or Tagged Image File (.tif, .tiff)

Compression: Lossless - no compression. Very high-quality images.

Best For: High quality prints, professional publications, archival copies

Special Attributes: Can save transparencies

➤ BMP or Bitmap Image File (.bmp)

Compression: None

Best For: High quality scans, archival copies

➤ Joint Photographic Experts Groups, JPEG (.jpg, .jpeg)

Compression: Lossy - some file information is compressed or lost

Best For: Web Images, Non-Professional Printing, E-Mail, Powerpoint

Special Attributes: Can choose amount of compression when saving in image editing programs like Adobe Photoshop or GIMP.



Raster File Formats

➤GIF or Graphics Interchange Format (.gif)

Compression: Lossless - compression without loss of quality; 256 colors

Best For: Web Images

Special Attributes: Can be Animated, Can Save Transparency

➤PNG or Portable Network Graphics (.png)

Compression: Lossless - compression without loss of quality; 16m colors

Best For: Web Images

Special Attributes: Save Transparency

➤RAW Image Files (.raw, .cr2, .nef, .orf, .sr2, and more)

Compression: None

Best For: Photography

Special Attributes: Saves metadata, unprocessed, lots of information

➤EXR or OpenEXR (.exr)

Compression: None; Zip(per scanline, 16 scanline blocks); RLE; PIZ; PXR24. etc

Color Depth: 16/32bit floats; 32bit integer

Special Attributes: HDR, multi-channel



Vector File Formats

➤ EPS or Encapsulated PostScript (.gif)

Compression: None - uses vector information

Best For: Vector artwork, illustrations (Adobe Illustrator or CorelDRAW)

Special Attributes: Saves vector information

➤ PDF or Portable Document Format (.pdf)

Compression: None - uses vector information

Best For: Display/Print documents and graphics

Special Attributes: PDF is a near universal standard

➤ SVG or Scalable Vector Graphics (.svg)

Compression: Lossy - some file information is compressed or lost

Best For: Web

Special Attributes: Can be edited, searched, indexed, scaled and compressed

High Dynamic Range Imaging



-4 stops

Credit: wikipedia

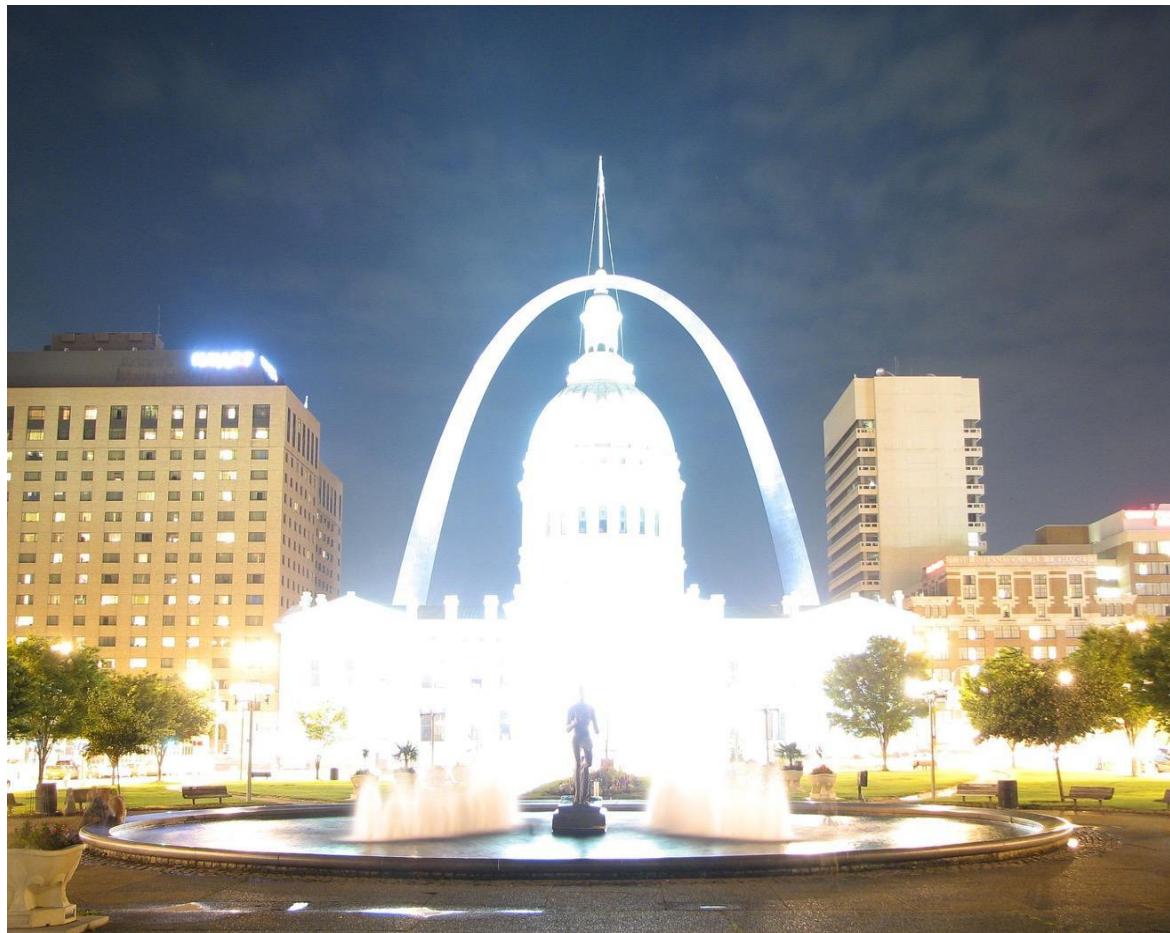


Credit: wikipedia



2 stops

Credit: wikipedia



2 stops

Credit: wikipedia



HDR contrast reduction (scaling)

Credit: wikipedia



HDR local tone mapping

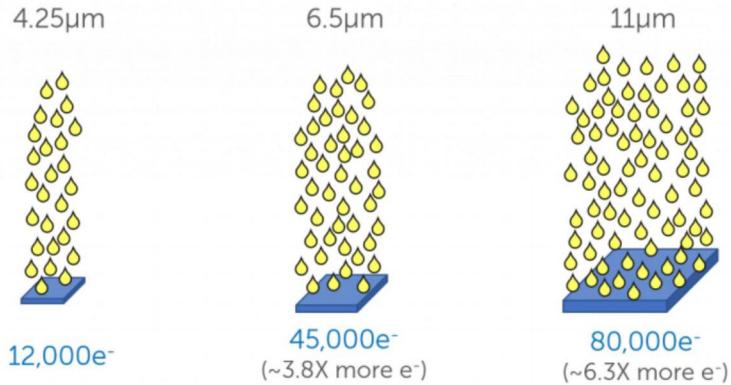
Credit: wikipedia



High Dynamic Range Imaging (HDRI)

Problems:

- Sensors have a limited full well capacity, pixels saturate for higher electron count
- Non-zero noise floor and ADC quantization further reduce precision



Terminology:

- Dynamic range: ratio between brightest and darkest value
- Quantization (i.e., precision) within that range is equally important
→ from 8 bits (256 values) to 32 bits floating point

Credit: <https://www.princetoninstruments.com/learn/camera-fundamentals/full-well-capacity-pixel-saturation>

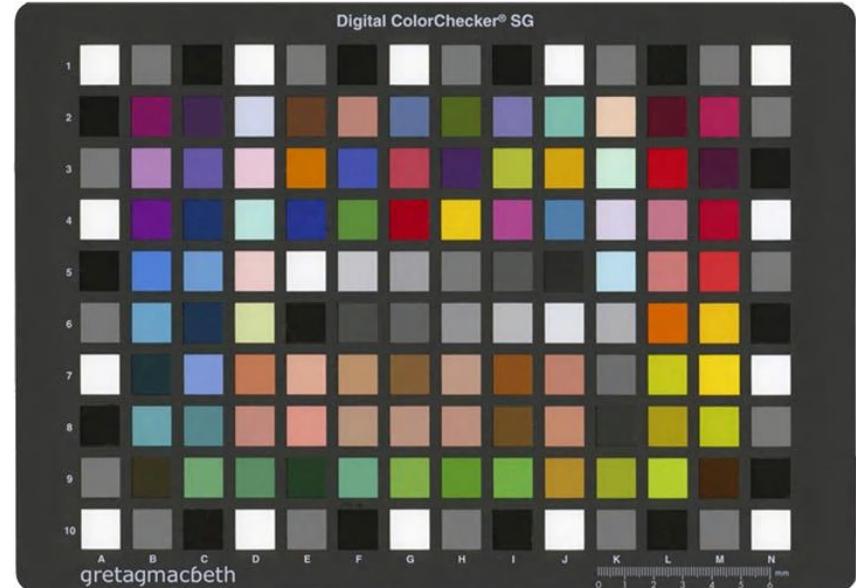
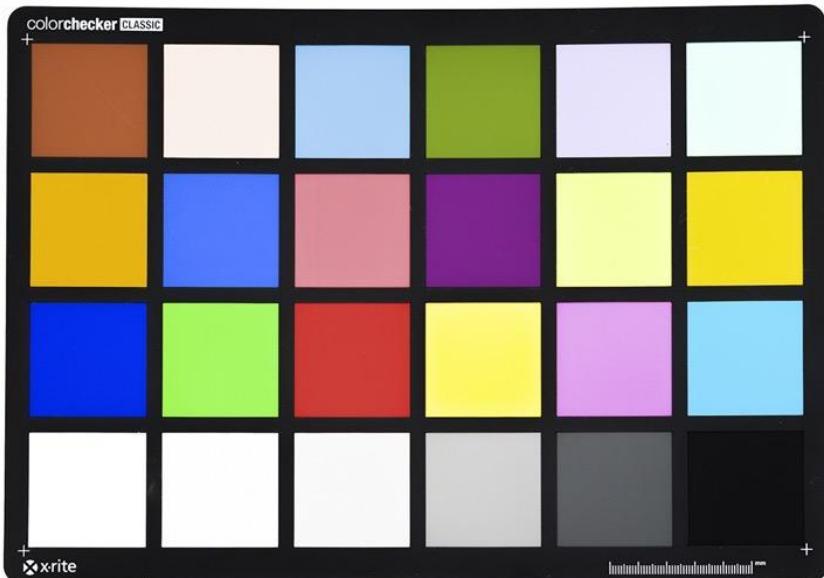


HDRI – Overview

- Estimate camera response curve
- Capture multiple low dynamic range (LDR) exposures
- Fuse LDR images into 32 bit HDR image
- Possibly convert to absolute radiance (global scaling)

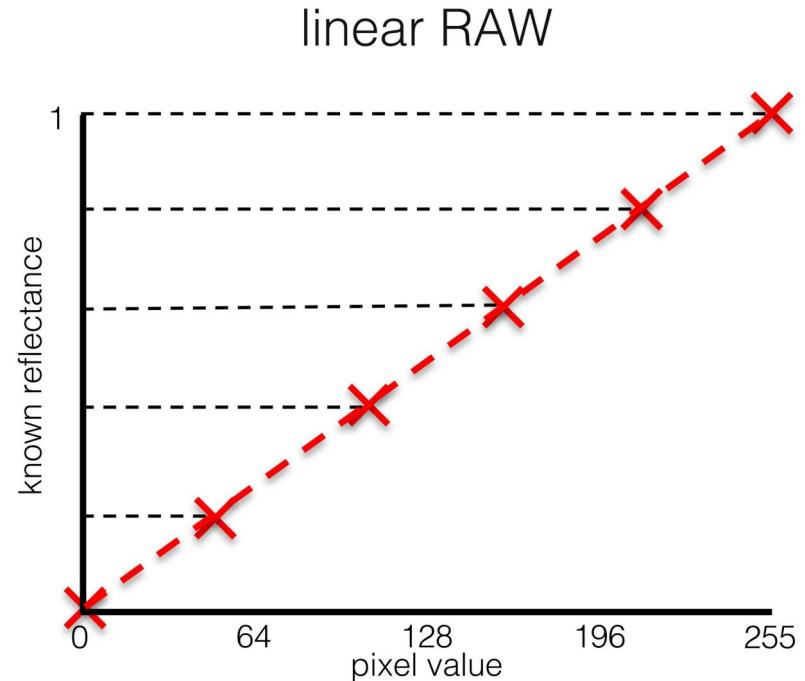
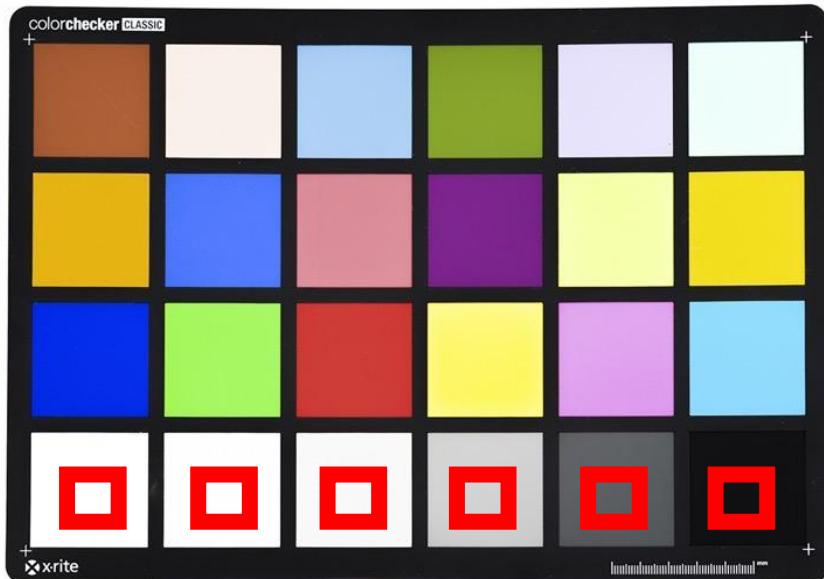
HDRI – Estimating the Response Curve

- Not required when working with linear RAW images
- Easiest option: use calibration chart



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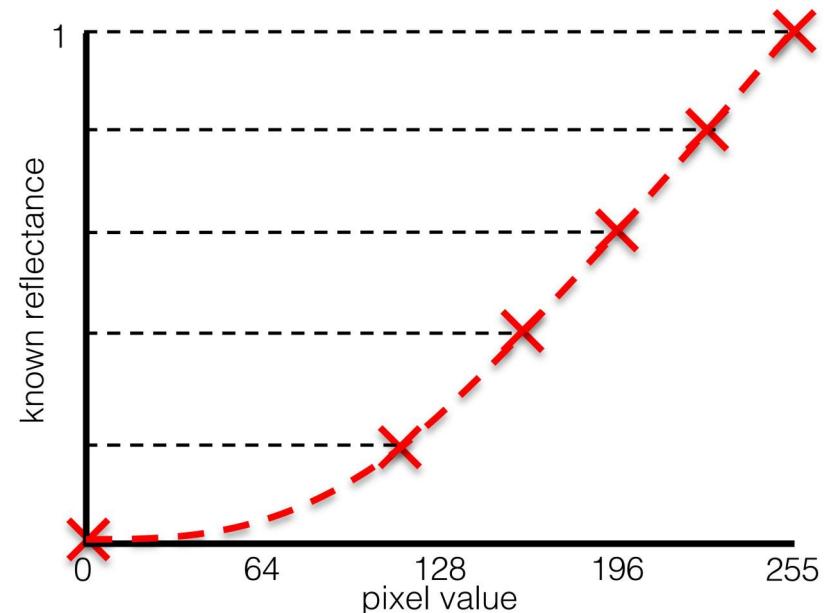
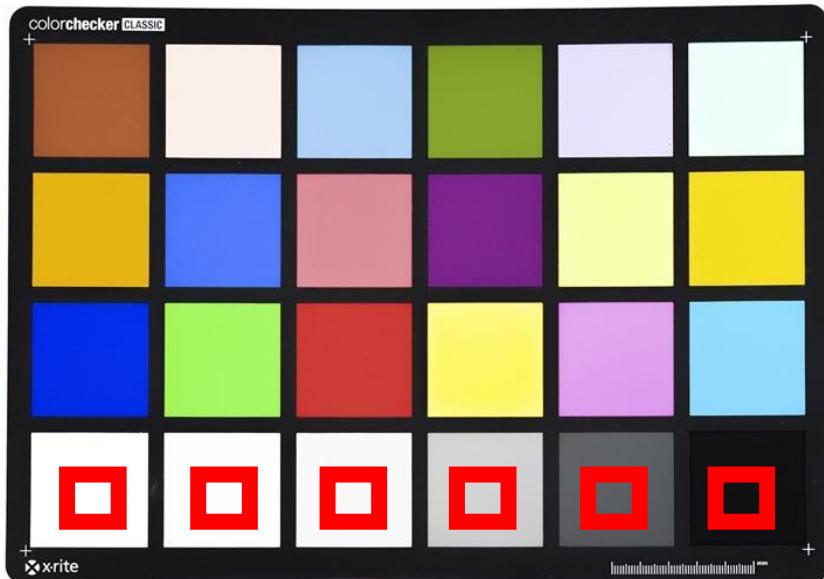




HDRI – Estimating the Response Curve

- Not required when working with linear RAW images
- Easiest option: use calibration chart

e.g. JPEG



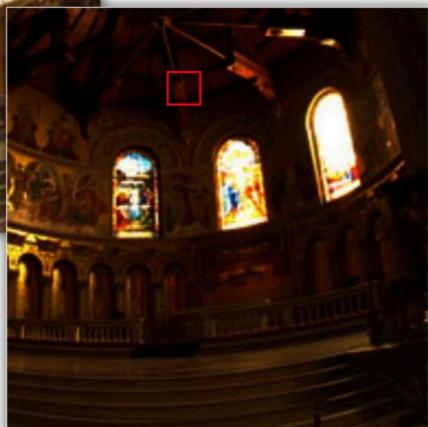


HDRI – Linearizing LDR Exposures

➤ Capture exposure, apply lookup table

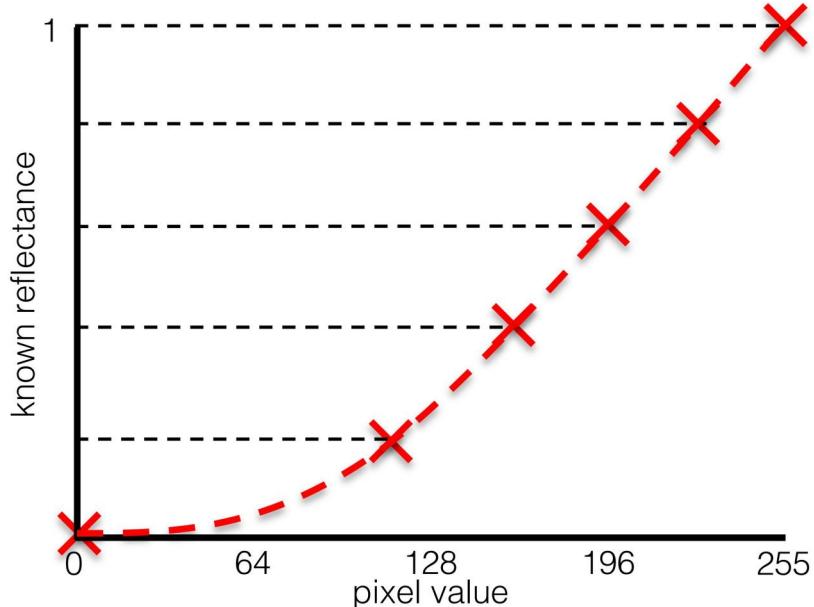


I



$$I_{lin} = f^{-1}(I)$$

e.g. JPEG





HDRI – Merging LDR Exposures

- Start with LDR image sequence I_i (only exposure time t_i changes)
- Individual exposure is: , $I_i = f(t_i X)$, f is camera response function

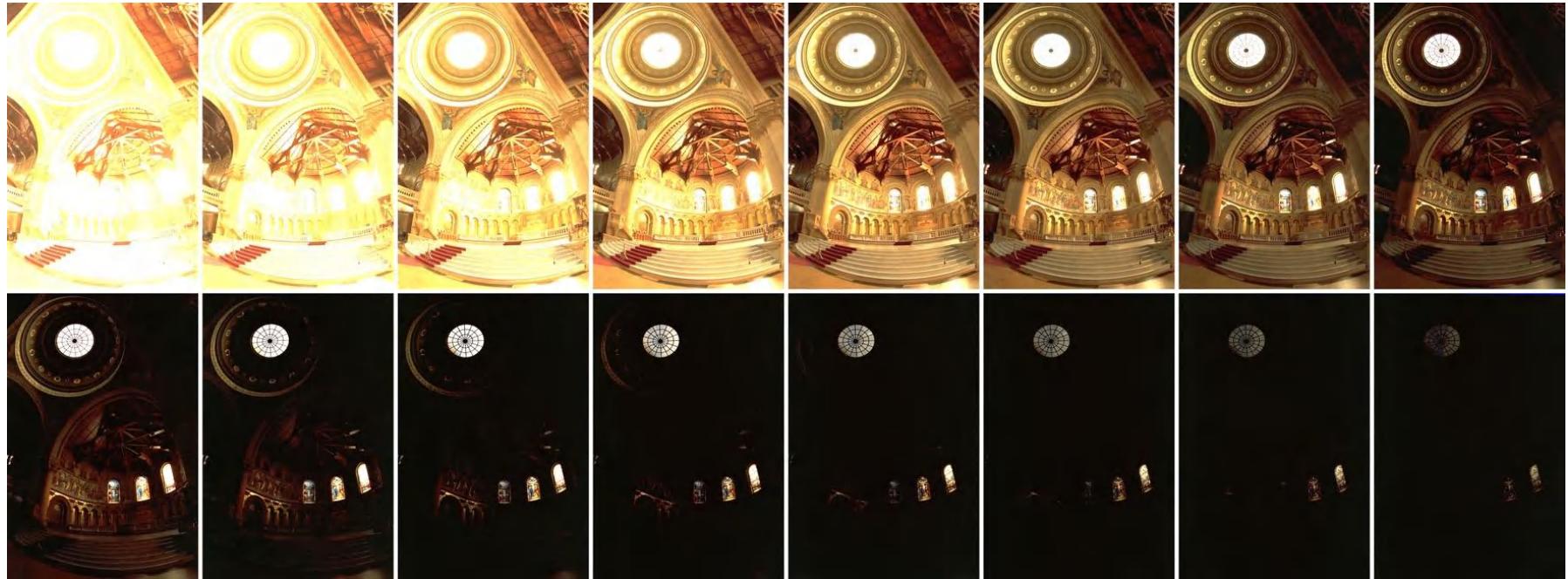


Image credit: Debevec & Malik, 1997



HDRI – Merging LDR Exposures

➤ Undo the camera response: $I_{lini} = f^{-1}(I_i)$

➤ e.g., gamma function $f(I) = I^{1/\gamma} \rightarrow f^{-1}(I) = I^\gamma$

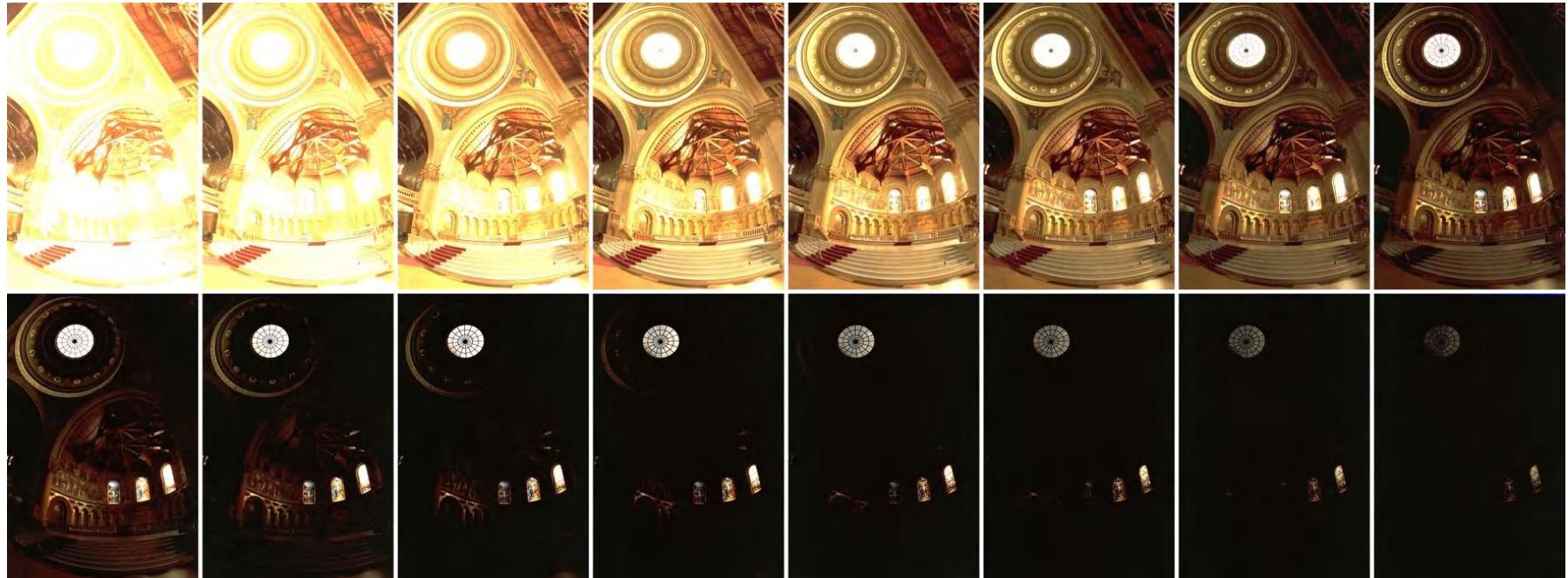


Image credit: Debevec & Malik, 1997



HDRI – Merging LDR Exposures

- Compute a weight (confidence) that a pixel is well-exposed
 - (close to) saturated pixel = not confident,
 - pixel in center of dynamic range = confident!

$$w_{ij} = \exp\left(-4 \frac{(I_{lin_{ij}} - 0.5)^2}{0.5^2}\right)$$

or mean pixel value,
e.g. 127.5 if I in [0, 255]

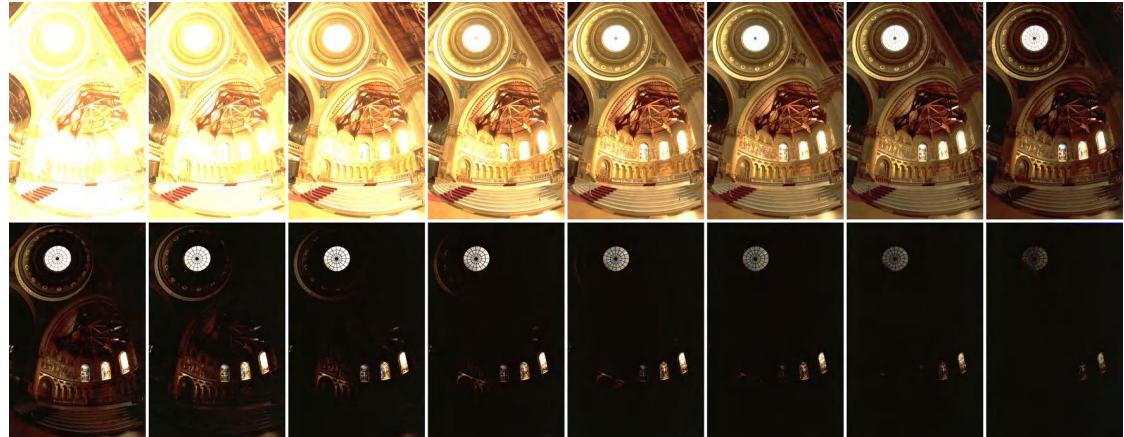
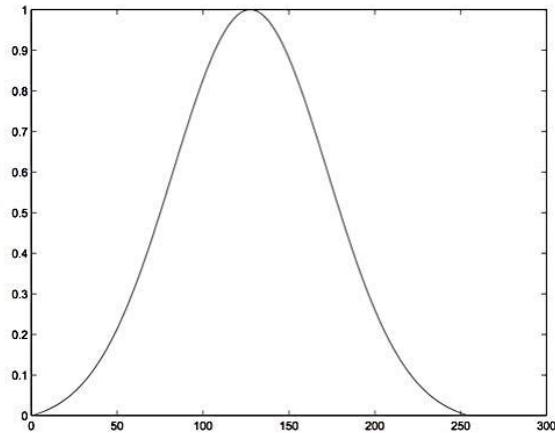


Image credit: Debevec & Malik, 1997



HDRI – Merging LDR Exposures

- Compute per-color-channel-per-LDR-pixel weights

$$w_{ij} = \exp\left(-4 \frac{(I_{linij} - 0.5)^2}{0.5^2}\right)$$

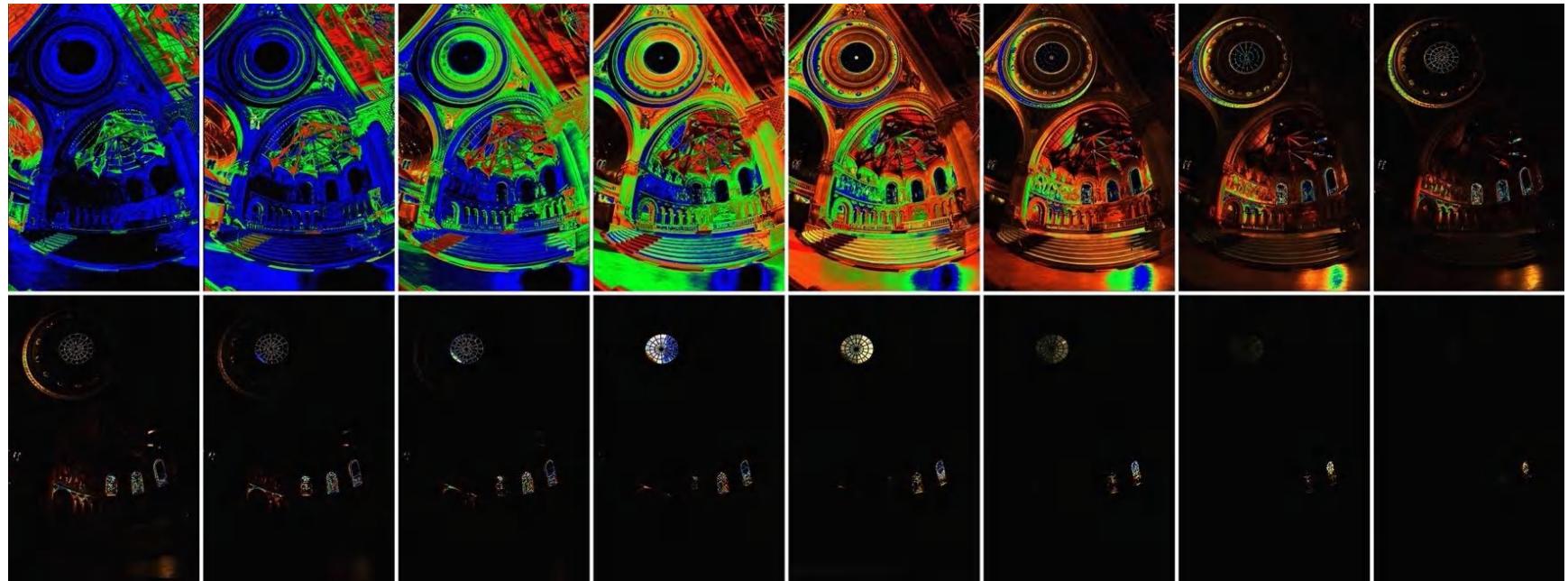


Image credit: Debevec & Malik, 1997



HDRI – Merging LDR Exposures

➤ Define least-squares objective function in log-space

→ perceptually linear:

$$\underset{X}{\text{minimize}} \quad O = \sum_i w_i (\log(I_{lin_i}) - \log(t_i X))^2$$

➤ Equate gradient to zero:

$$\frac{\partial O}{\partial \log(X)} = -2 \sum_i w_i (\log(I_{lin_i}) - \log(t_i) - \log(X)) = 0$$

➤ Gives:

$$\hat{X} = \exp \left(\frac{\sum_i w_i (\log(I_{lin_i}) - \log(t_i))}{\sum_i w_i} \right)$$



HDRI – Relative v Absolute Radiance

- LDR to HDR only gives relative radiance
- Scale by reference radiance to get absolute!

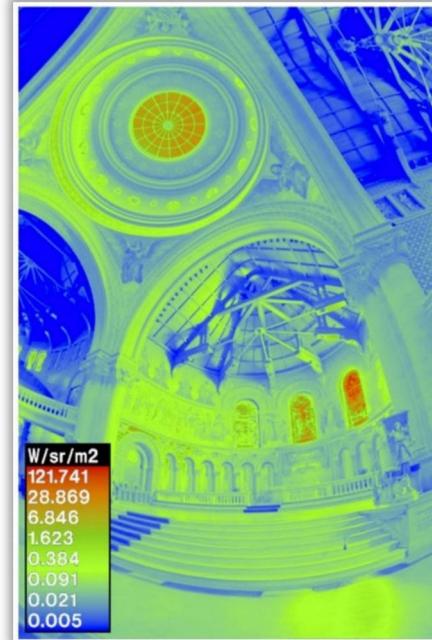
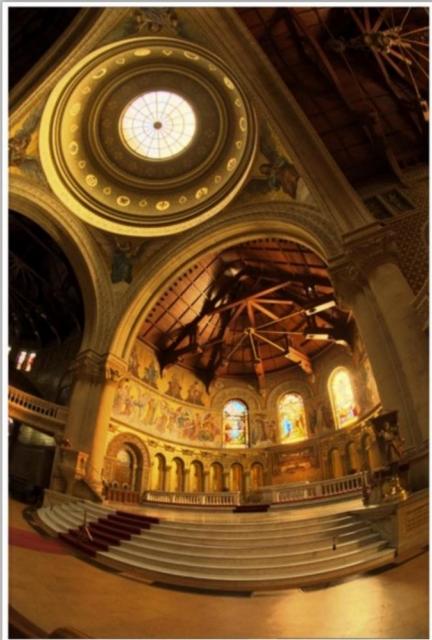


Image credit: Debevec & Malik, 1997

Tone Mapping



HDRI – Tone Mapping

- Problem: how to display a 32 bit HDR image on an 8 bit LDR display?

- Solution: tone mapping, i.e., “scale” into luminance range of display (or 0-255), while preserving high-contrast image details



Saturation

- Sun overexposed
- Foreground too dark



Credit: Durand and Dorsey, 2002



Tone Mapping w/ Simple Gamma



- Gamma correction: $I = \sqrt{I}$
- Colors are washed out



Credit: Durand and Dorsey, 2002



Tone Mapping w/ Simple Gamma

- Gamma in intensity only!
- Intensity details lost



Credit: Durand and Dorsey, 2002

Tone Mapping w/ Bilateral Filter

Input HDR image



Intensity



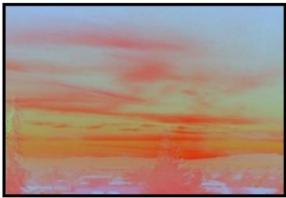
Fast
Bilateral
Filter

Large scale (base layer)



Detail

Color



Reduce
contrast

Preserve!



Output



Large scale



Detail

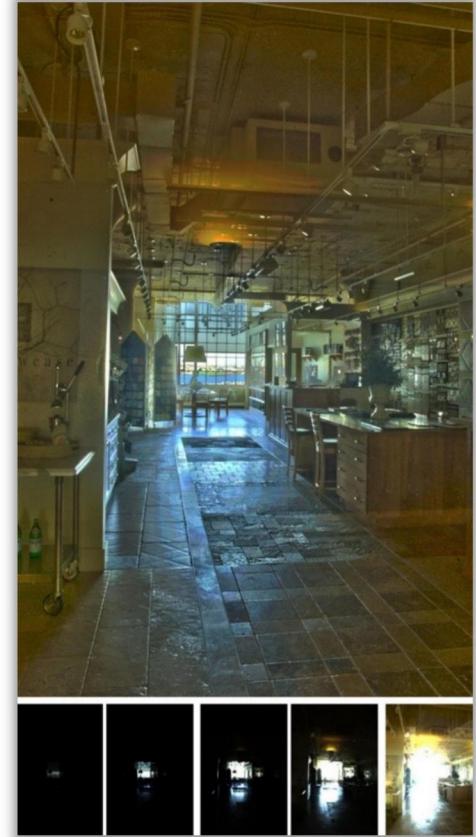
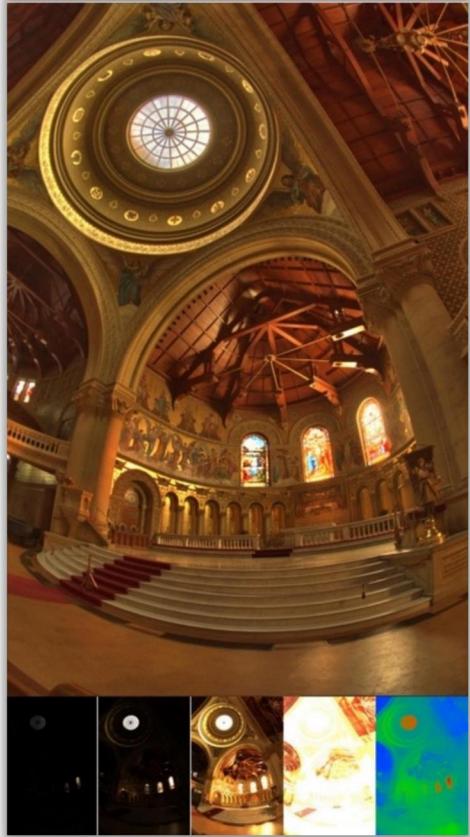


Color

Credit: Durand and Dorsey, 2002



Tone Mapping w/ Bilateral Filter



Credit: Durand and Dorsey, 2002



Tone Mapping w/ Local Laplacian Filters

- Many many more and more complicated tone mapping algorithms out there (too many to discuss here)
- Local Laplacian Filters is one of the state-of-the-art approaches



(a) input HDR image tone-mapped with a simple gamma curve (details are compressed)



(b) our pyramid-based tone mapping, set to preserve details without increasing them



(c) our pyramid-based tone mapping, set to strongly enhance the contrast of details



Credit: Paris et al., 2011



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Classical Methods



Night Sight “Look”

- Too bright: turns night time into day and can create overexposed halos. May also over-brighten noise.
- Too dark: hides shadow detail.
→ Carefully tuned a tone curve that suppresses noise in the darks, reveals details in the shadows, exposes the midtones well, and preserves highlights.

Different tone curves applied to the same evening scene

Too bright
(looks like daytime)



Too dark
(details are not visible)





Night Sight “Look”

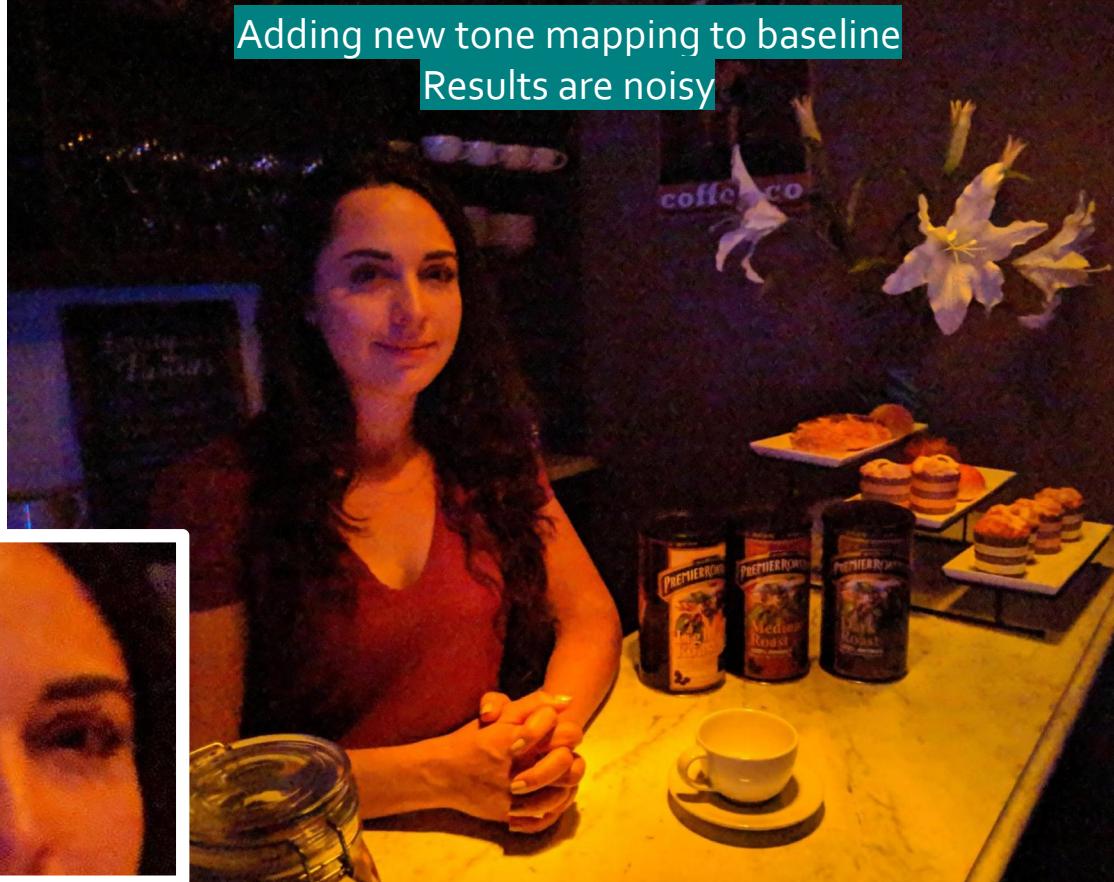
Baseline system(HDR+, Hasinoff et al, 2016)
13 frames, exposure time: 1/15 s





Night Sight “Look”

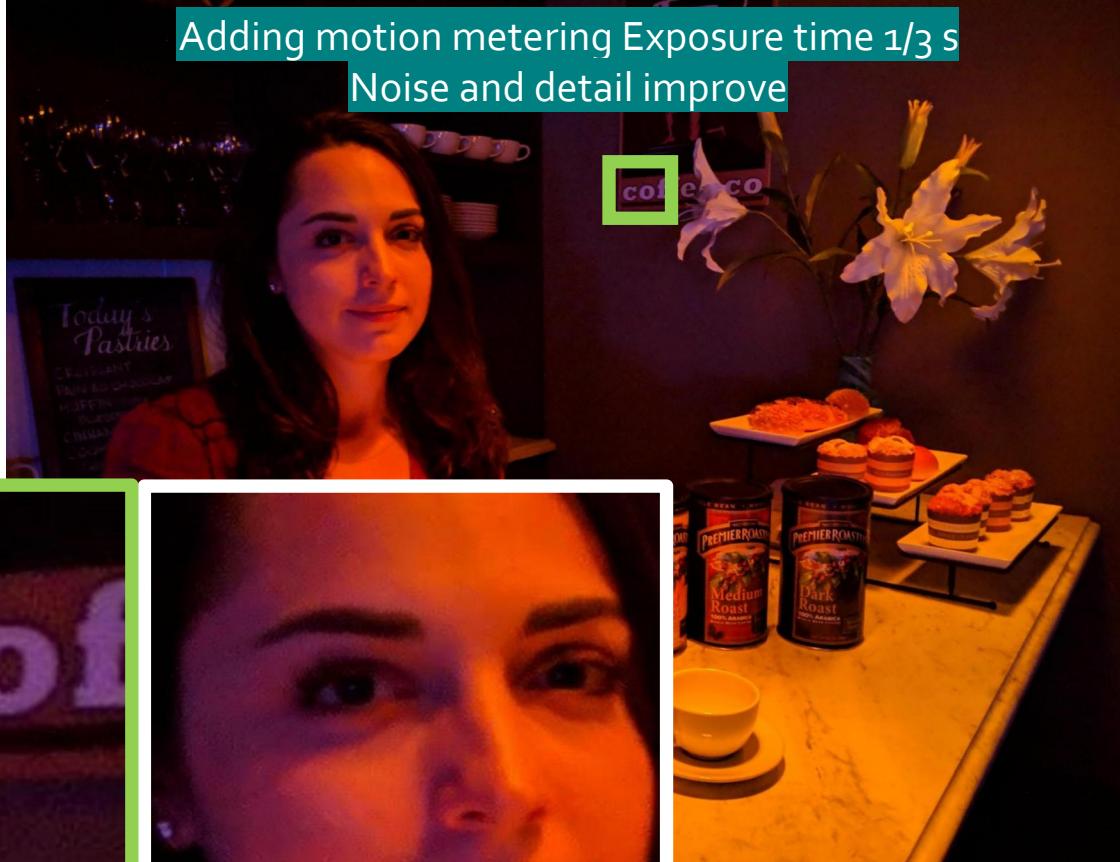
Adding new tone mapping to baseline
Results are noisy



Credit: Google

Night Sight “Look”

Adding motion metering Exposure time $1/3$ s
Noise and detail improve

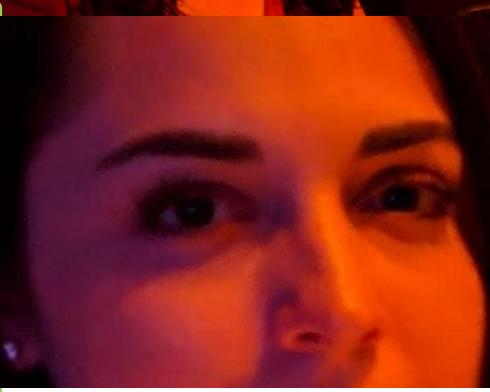


Credit: Google



Night Sight “Look”

Adding motion robust merge
Noise and detail improve further

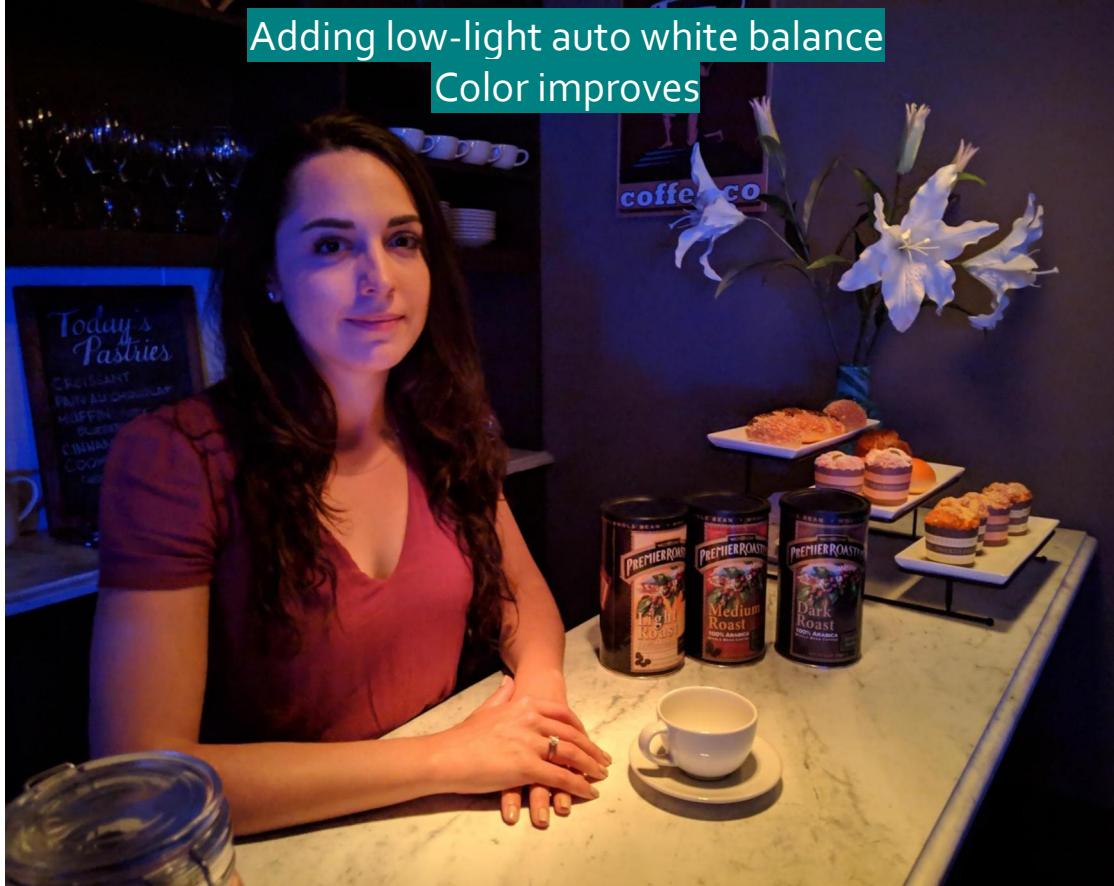


Credit: Google



Night Sight “Look”

Adding low-light auto white balance
Color improves



Credit: Google



Side by Side Comparison



HDR+, Hasinoff et al 2016



Night Sight "Look"



Side by Side Comparison



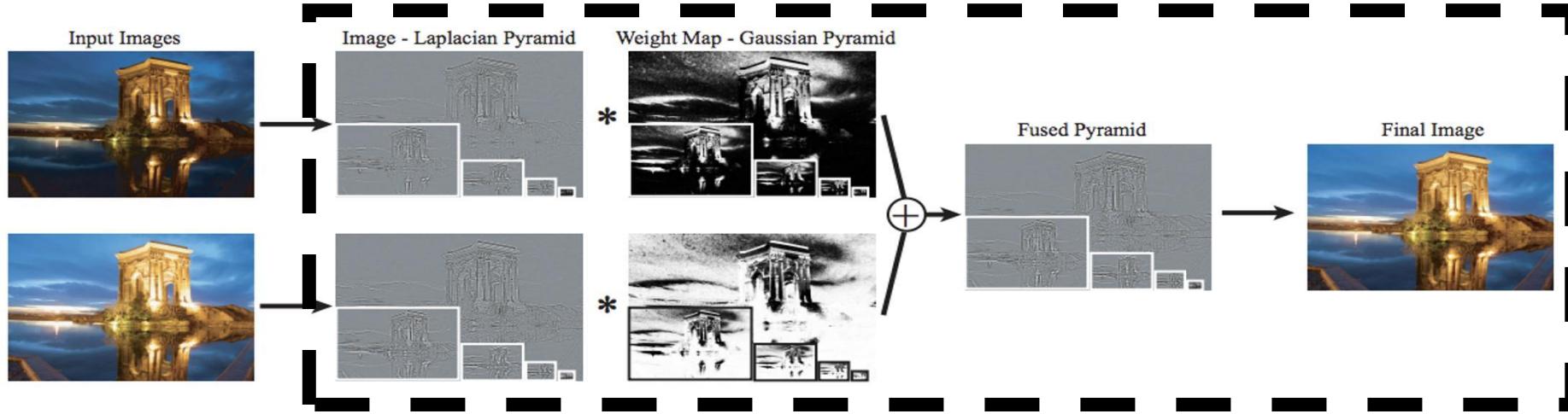
HDR+, Hasinoff et al 2016



Night Sight "Look"



Classical Local Tonemapping



- Synthetic exposures from AE
 - Single merged input image
 - Digital gains
- Automatically set tuning parameters

Credits: pyramid blending for HDR tonemapping
[Mertens et al., 2007]
[Paris et al. 2011]
[Aubry et al. 2014]



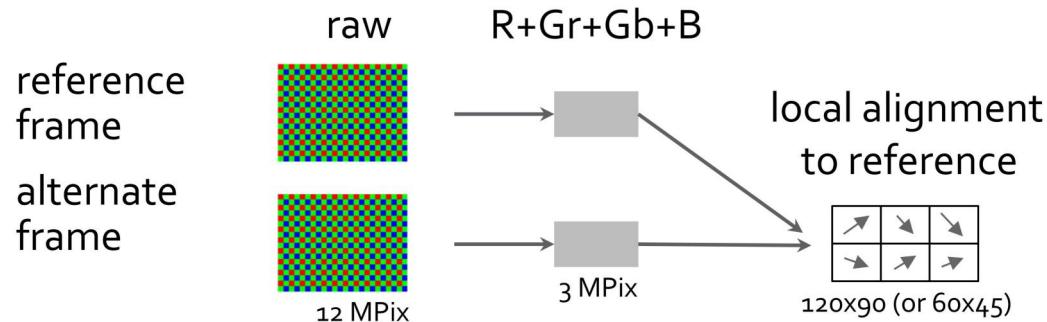
Burst Alignment



input burst

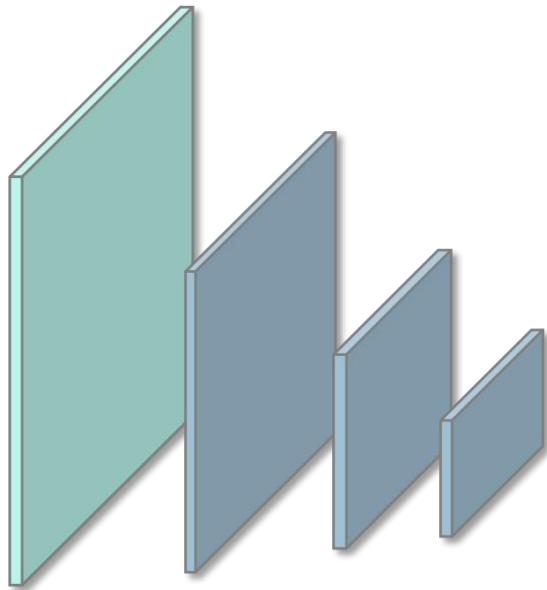


reference frame input burst





Coarse to fine alignment



metric	search range	subpixel?
L_2	9x9	yes
L_1	3x3	no

- 4 pyramid levels
- Upsample with multiple hypotheses [Tao et al., 2012]

Example Alignment

Reference frame

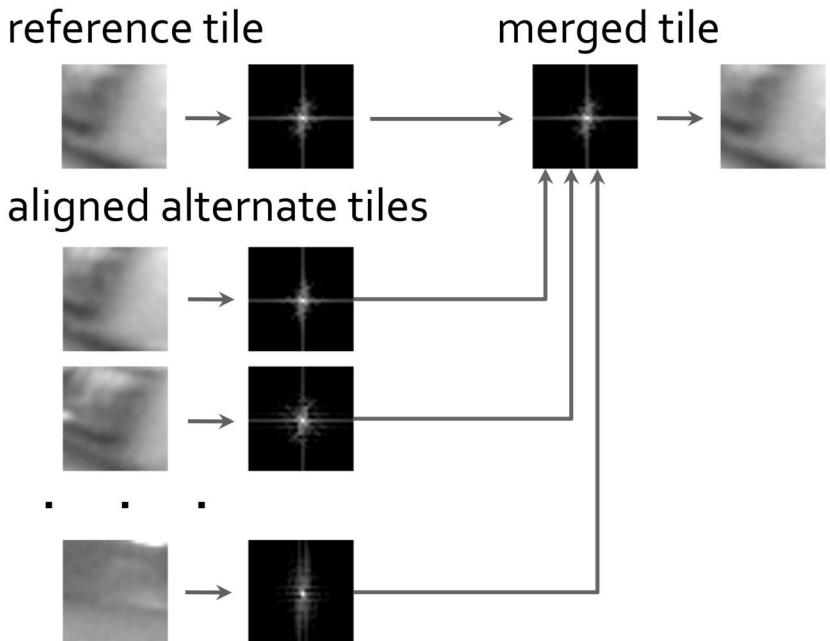
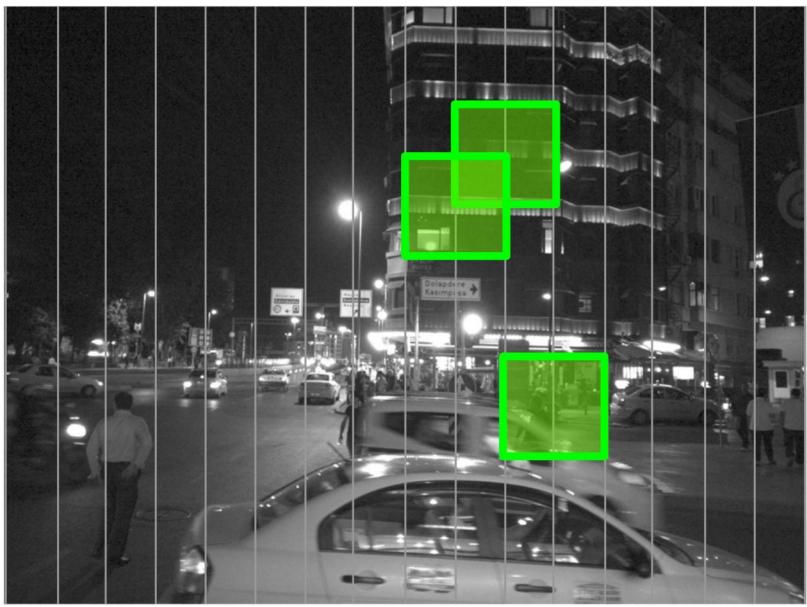


Aligned to reference



Tiled Fourier-based Merge

- Divide into 16×16 or 32×32 tiles
 - 50% overlap - every pixel covered by 4 tiles
 - Merge in Fourier domain





Robust Per-frequency Merge

- Reference frame

$$T_0$$

- Aligned average

$$\frac{1}{N} \sum T_i$$

- Robust pairwise merge

$$\frac{1}{N} \sum (1 - A_i) T_i + A_i T_0$$

$$A_i = \frac{||T_0 - T_i||^2}{||T_0 - T_i||^2 + k\sigma^2} \in [0, 1]$$





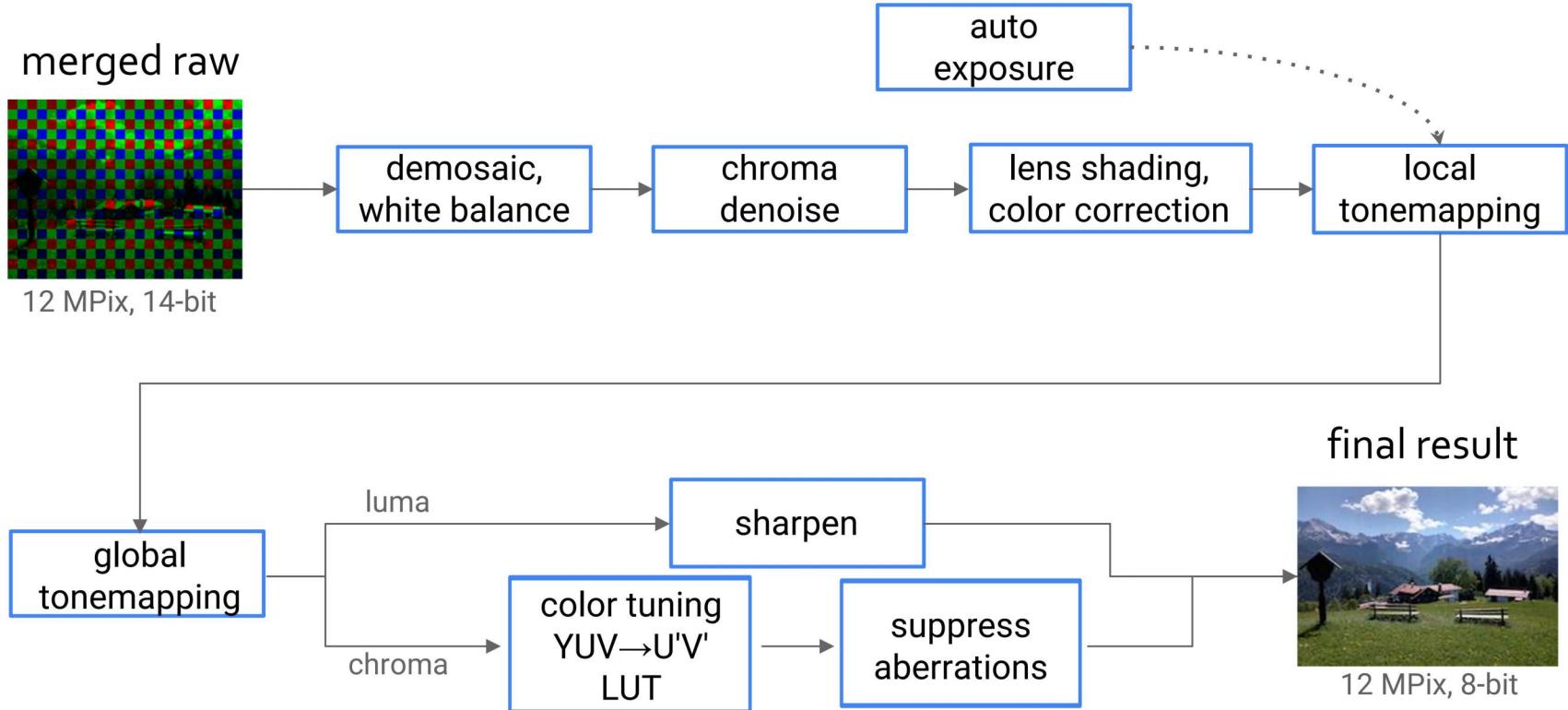
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Finish Pipeline



Finish Pipeline





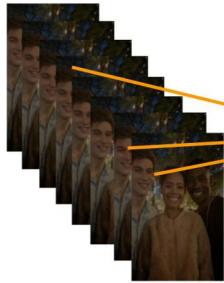
Finish Pipeline

HDR+

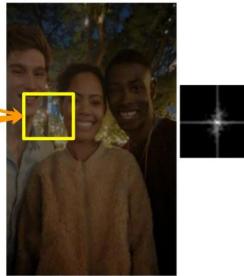
Auto
Exposure



Underexposed Burst



Align & merge



Finish:
Denoise, Tonemap /sharpen



Burst photography for high dynamic range and low-light imaging on mobile cameras,

Samuel W. Hasinoff, Dillon Sharlet, Ryan Geiss, Andrew Adams, Jonathan T. Barron, Florian Kainz, Jiawen Chen, Marc Levoy, SIGGRAPH Asia 2016

Night Sight

Motion
Metering



Longer
Burst

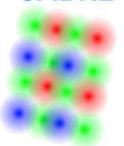


Modified
Merge

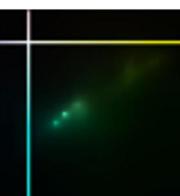
Motion
maps



SABRE



Learning
Based
Auto White
Balance



Night Sight
“Look”



Credit: Google



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Thank You!



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