Recent Advances in Smartphone Computational Photography

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Smartphone Photography

- Physical limitations
  - Small sensor
  - Limited optics
  - Usually no optical zoom
- User expectations
  - Speed
  - Ease-of-use

New Computational Photography Techniques

Handheld super-resolution

Uses natural hand movement to improve resolution in burst images

Handheld low-light photography

A system of new techniques using burst imaging to improve phone photography in very low light

Background

Burst Photography

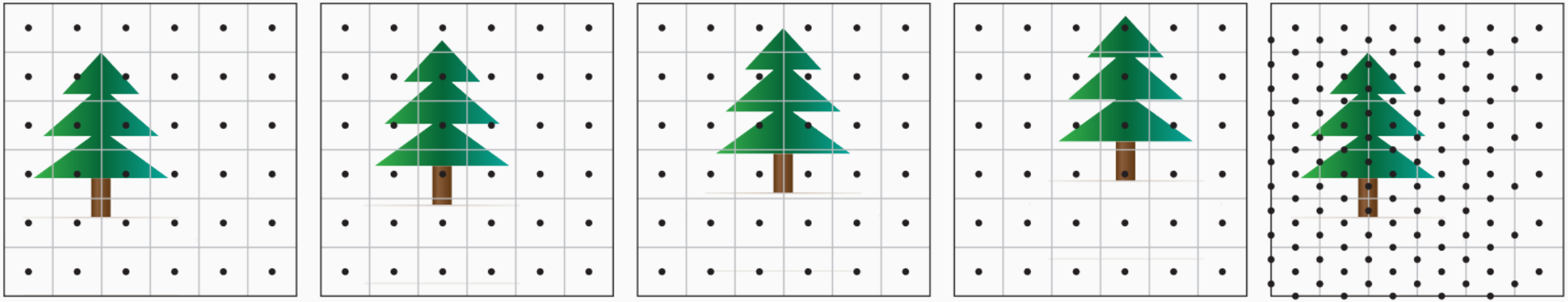
- Series of raw exposures merged together
- Zero-shutter-lag mode
  - Frames continuously captured
  - Recent frames saved when shutter button pressed
- Hasinoff et al. [1] burst processing pipeline
  - Bursts of constant low-exposure frames
  - HDR+ feature

Handheld Super-Resolution

Animation demonstrating hand motion in a raw burst [6]

Hand Movement

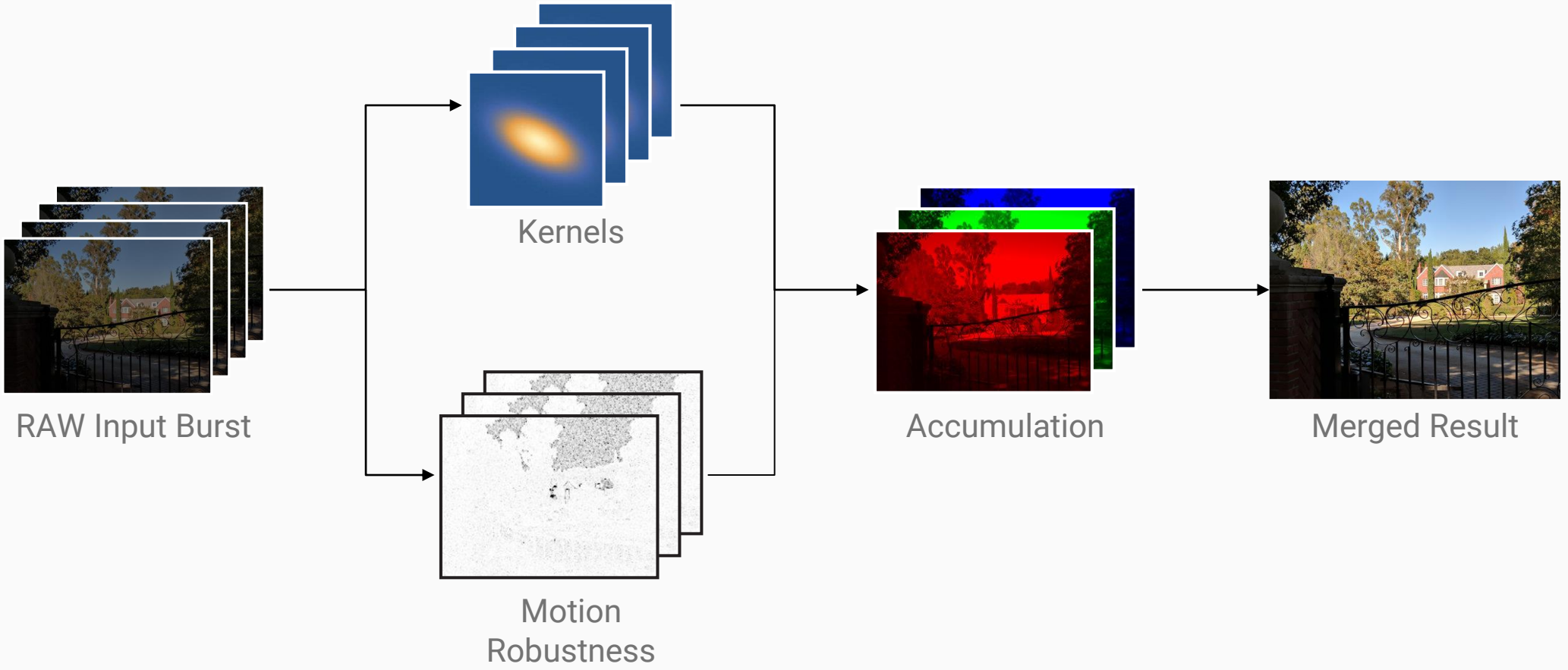
- Hand movement produces subpixel offsets
- Pixels in each frame can be considered samples of “true” value



[4]

Animation demonstrating hand motion in an aligned burst [6]

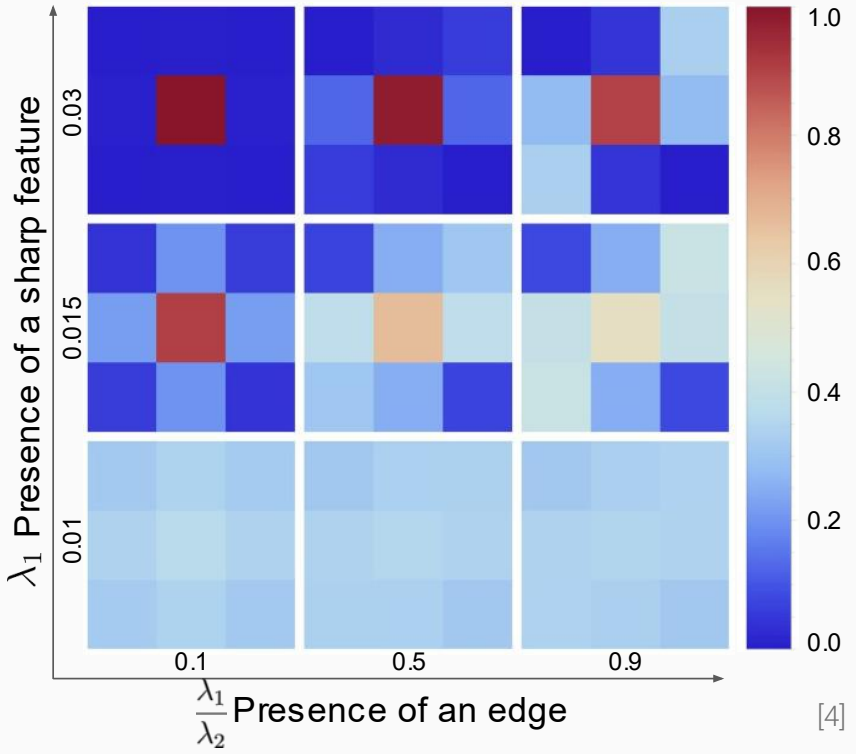
Merge Algorithm Overview



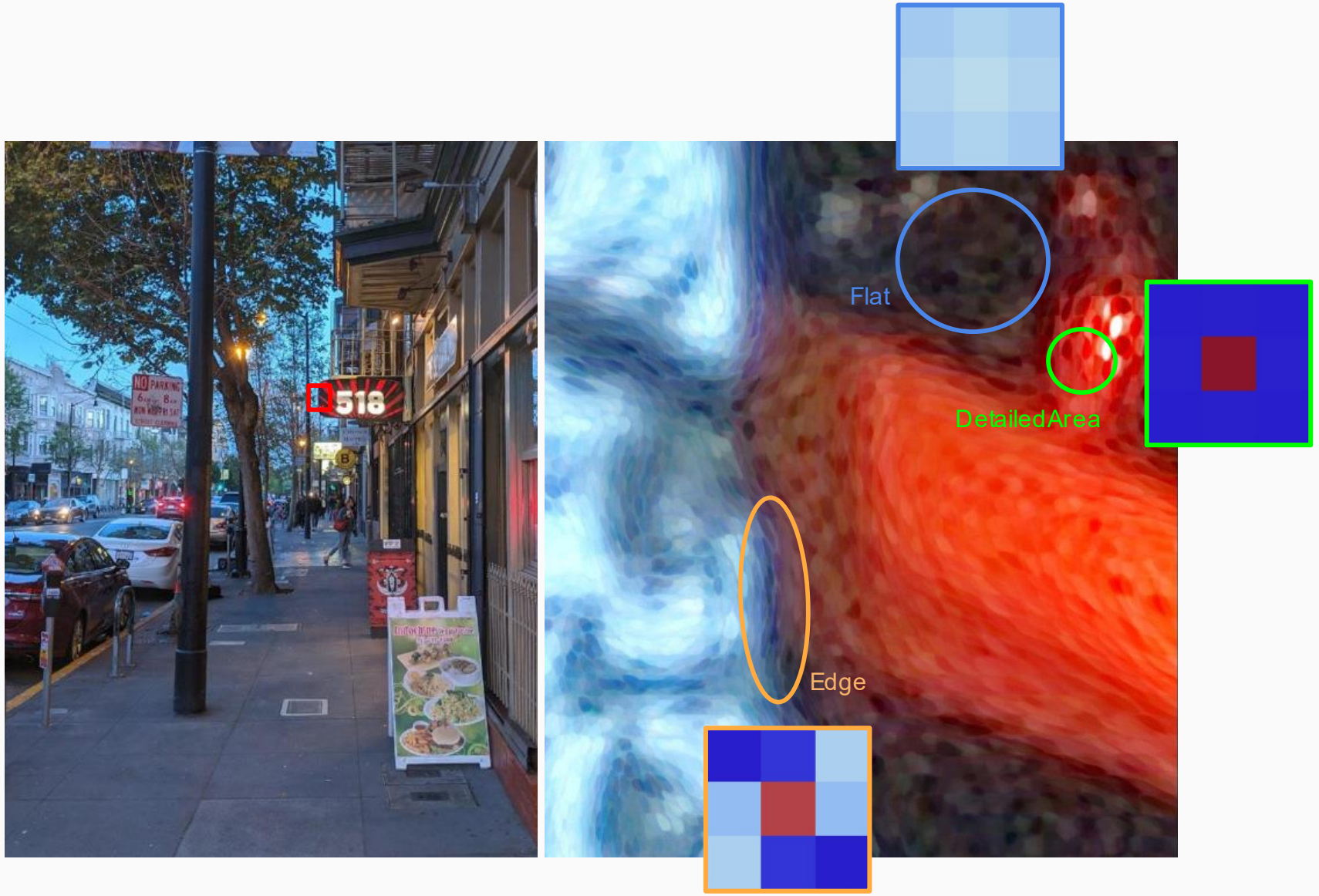
[4]

Kernel reconstruction algorithm

- Each output pixel is a result of a combination of the pixels in a 3×3 area around it
- Weighted based on the presence of edges and sharp features



[4]



Exaggerated example of very sharp kernels on a real captured burst [4]

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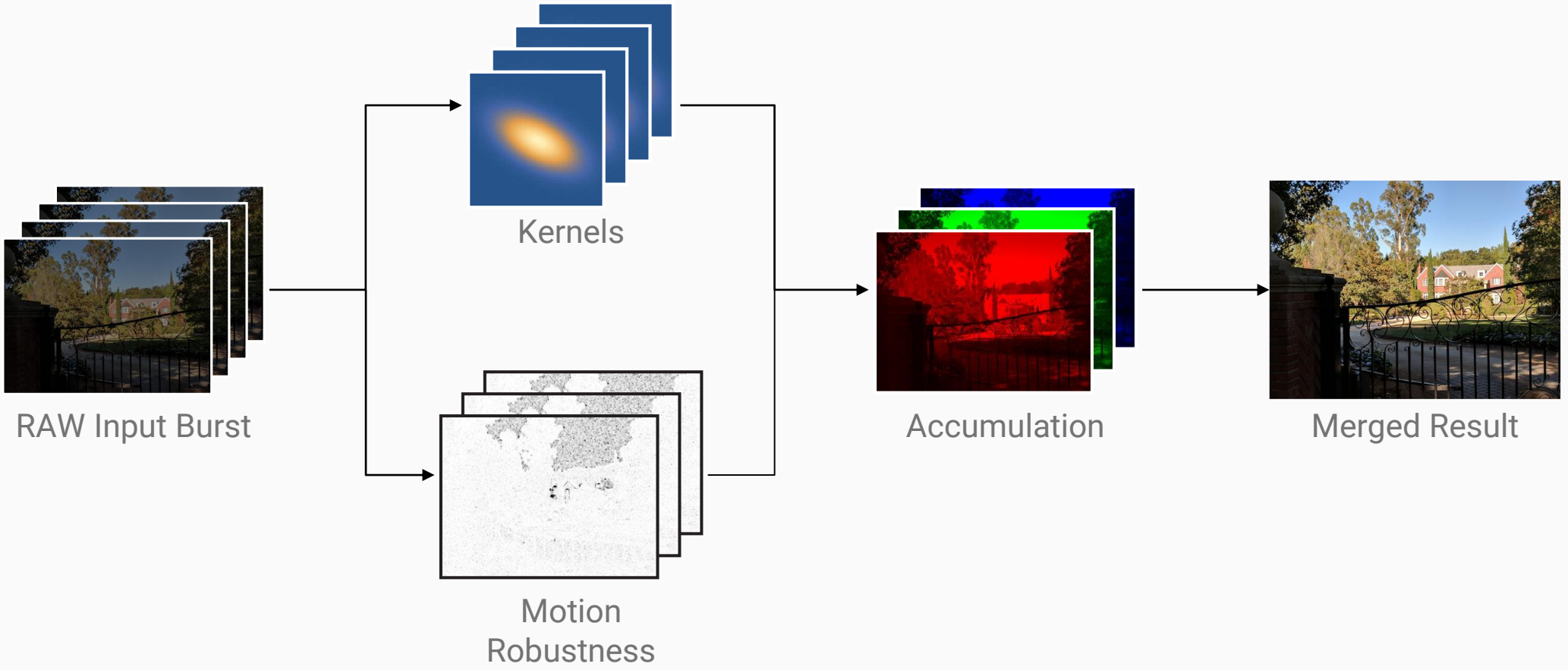


[4]

Motion Robustness

- Alignment of burst images isn’t perfect
- Motion in the scene and occlusion
- Need to consider motion when merging to prevent artifacts

- Confidence level assigned to neighborhood of each pixel with statistical robustness model

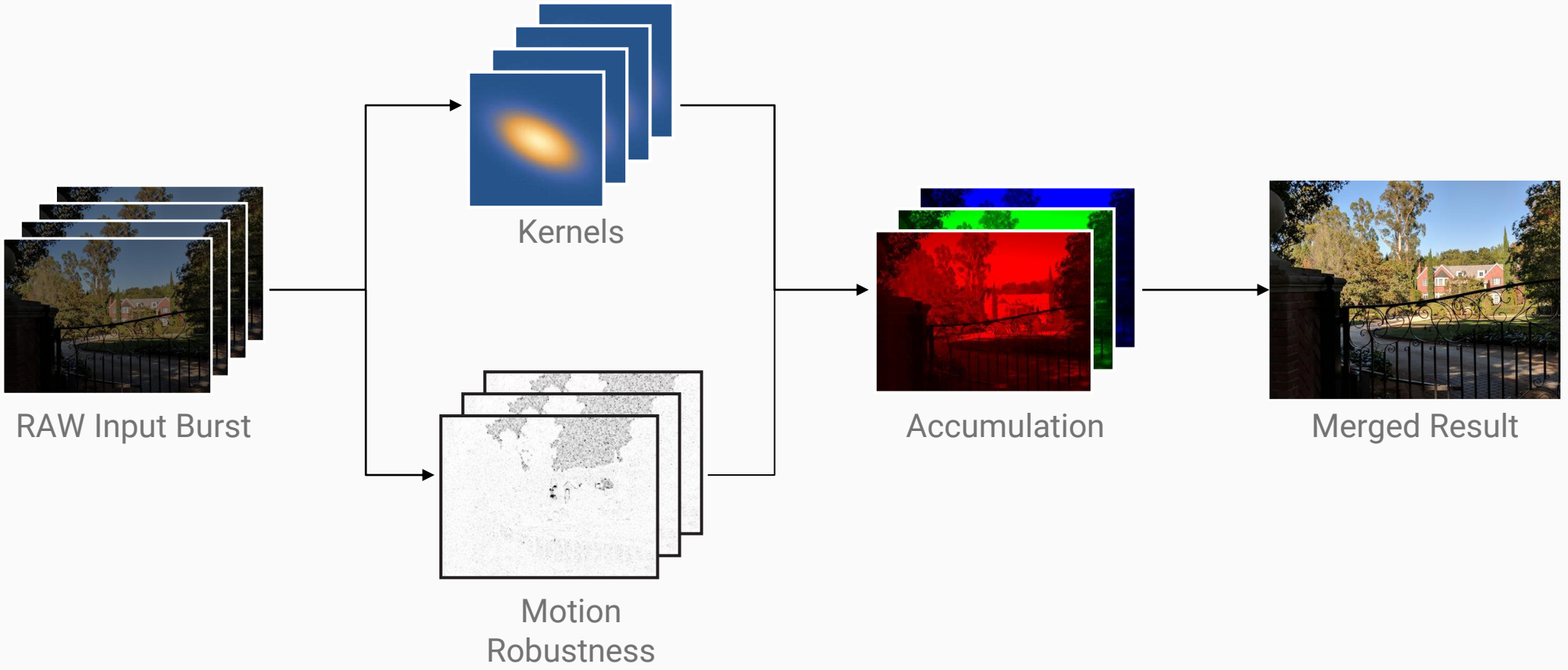
No motion robustness model

Robustness mask

With robustness model

A photograph of a moving bus demonstrating the robustness model [4]

Merge Algorithm Overview



[4]

Google Pixel 3 XL - No zoom [5]

Google Pixel 3 XL - 2.37x zoom [5]

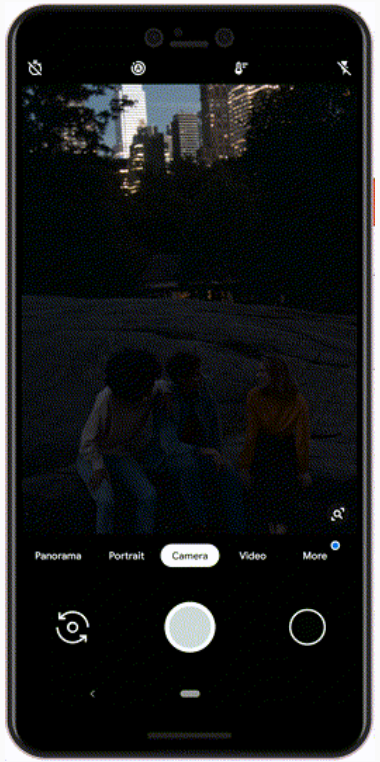
Google Pixel 3 XL - 3x zoom [5]

Left: Crop of 7x zoomed image on Pixel 2. Right: Same crop from Super Res Zoom on Pixel 3. [5]

Handheld Low Light Photography

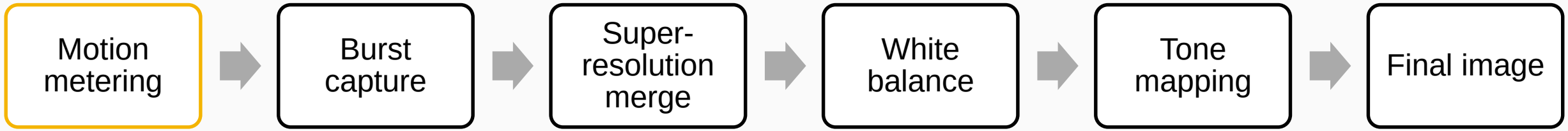
Handheld Low Light Photography

- Builds on Hasinoff et al. [1] burst pipeline
- Uses “handheld super-resolution” merging in most cases
- Night Sight feature on Google Pixel
- Positive-shutter-lag
- 3 main improvements to the pipeline
  - Motion metering
  - Auto white balance
  - Tone mapping



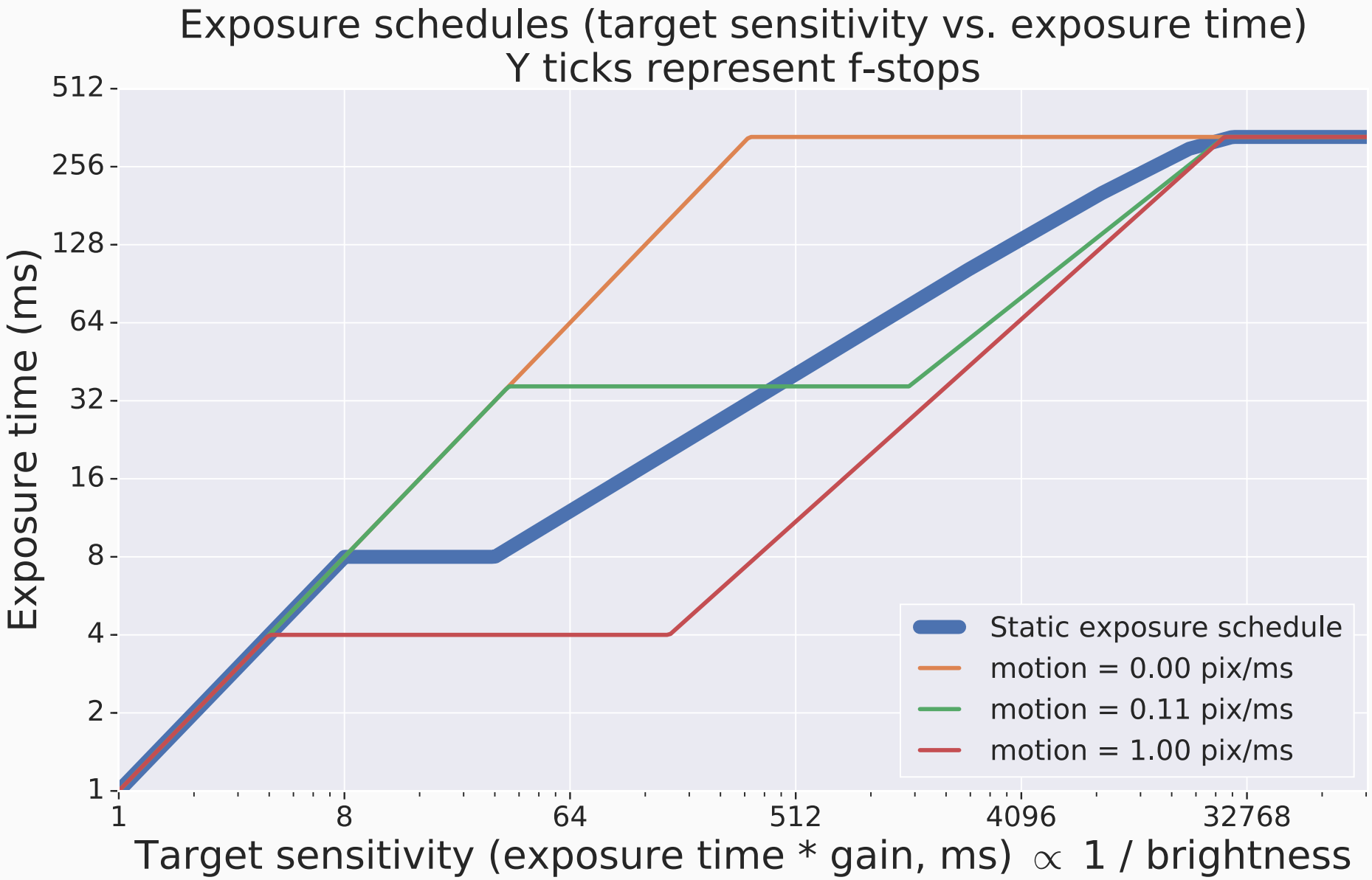
Night Sight Animation
blog.google

Handheld Low Light Photography



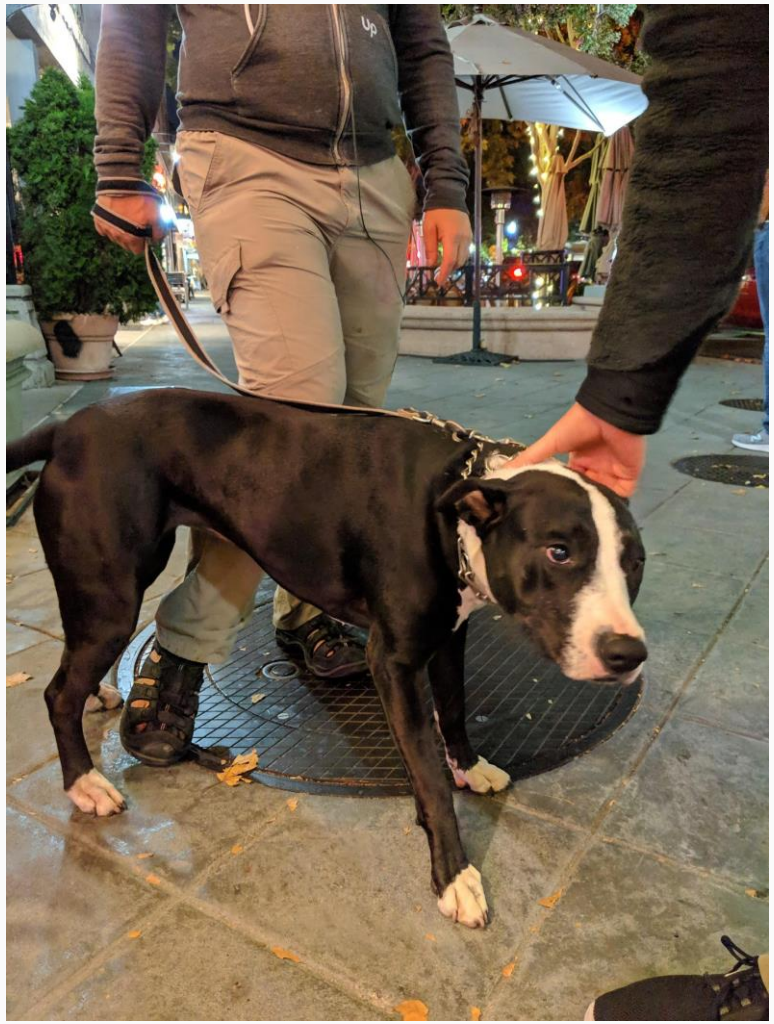
Motion Metering

- Target brightness
- Exposure time, gain (ISO), and number of frames needs to be selected for the shot
  - Exposure time increases motion blur
  - Gain increases noise
- Motion metering selects exposure time based on motion in scene and camera



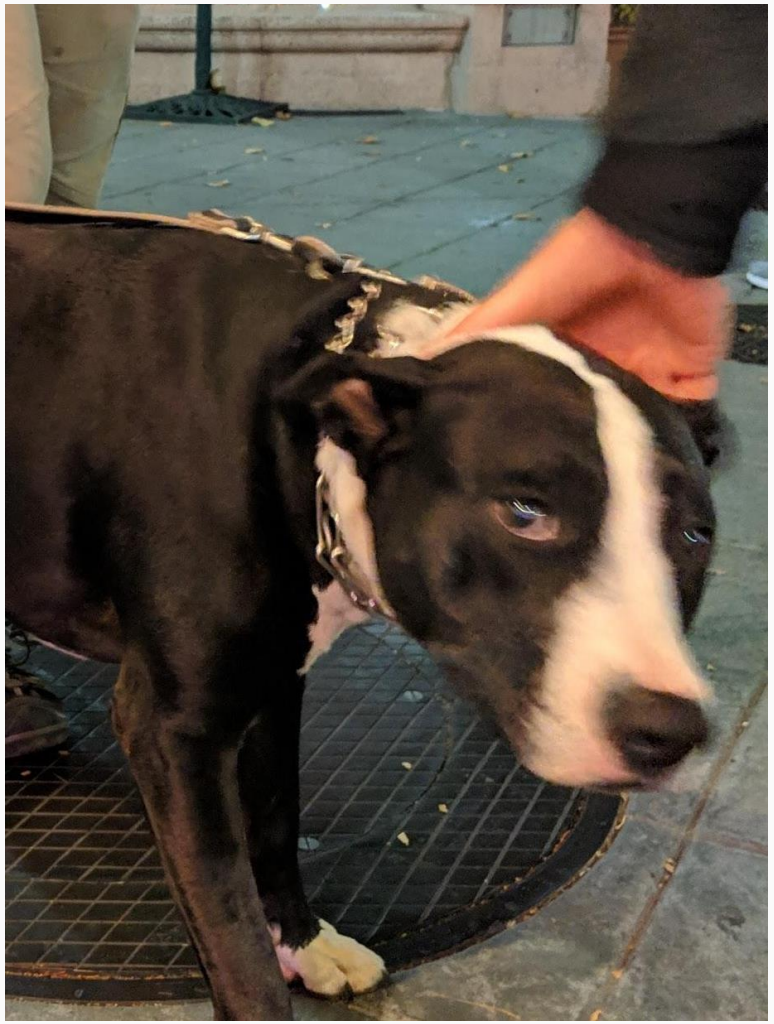
Traditional static exposure schedule compared to motion metering [3]

Static exposure schedule
100 ms exposure



Dynamic exposure schedule
49 ms exposure (motion: 0.38 pix/ms)

Comparison of exposure schedules with subject motion [3]



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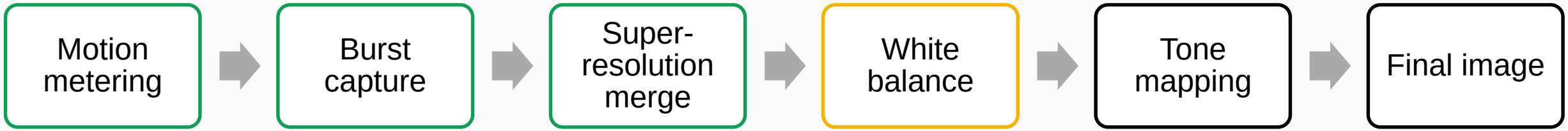
Handheld Low Light Photography



Auto white balance

- Humans are good at color constancy
- We perceive color accurately even under colored illumination
- Breaks down when the light in a photo is different than the light it is being viewed in

- Cameras use **auto white balancing (AWB)** to correct this
- Adjust the colors to compensate for illumination color

- Low light scenes often have very tinted illumination

Auto white balance in low light

Liba et al. [3] trained a neural network based AWB algorithm

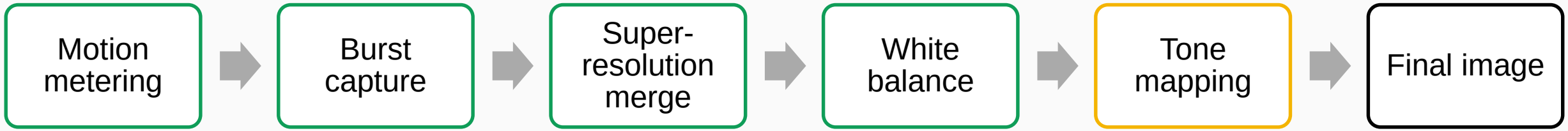
- New set of 5000 examples
- Manually tagged white balances by experts
- “Aesthetically preferable” vs empirical

Pixel default AWB

Liba et al.

Comparison of the default white balance in the Pixel and the low-light optimized implementation (Marc Levoy) [2]

Handheld Low Light Photography



Tone Mapping

- Mapping colors from high-dynamic-range image to a medium with lower dynamic range
- Can be accurate to human vision or more creative
- Humans stop seeing color and loose spatial acuity in low light
- How can we create sharp, colorful low-light images that still look like nighttime?

Yosemite valley at nighttime, Canon DSLR, 28mm f/4 lens, 3-minute exposure, ISO 100 (Jesse Levinson) [2]

Tone Mapping

Artists evoke a nighttime aesthetic with

- Darker pigments
- Increased contrast
- Suppressed shadows

A Philosopher Lecturing on the Orrery, by Joseph Wright of Derby, 1766

Tone Mapping

Liba et al. [3] adapted these principals into a set of heuristics for their tone mapping

- Higher overall gains
- Limit boosting shadows
  - Keep darkest regions near black
- Boost color saturation inversely to scene brightness

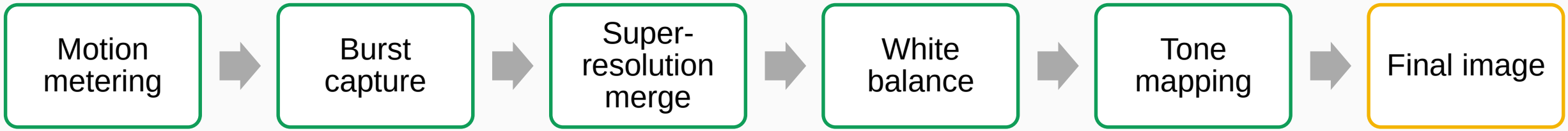
Baseline

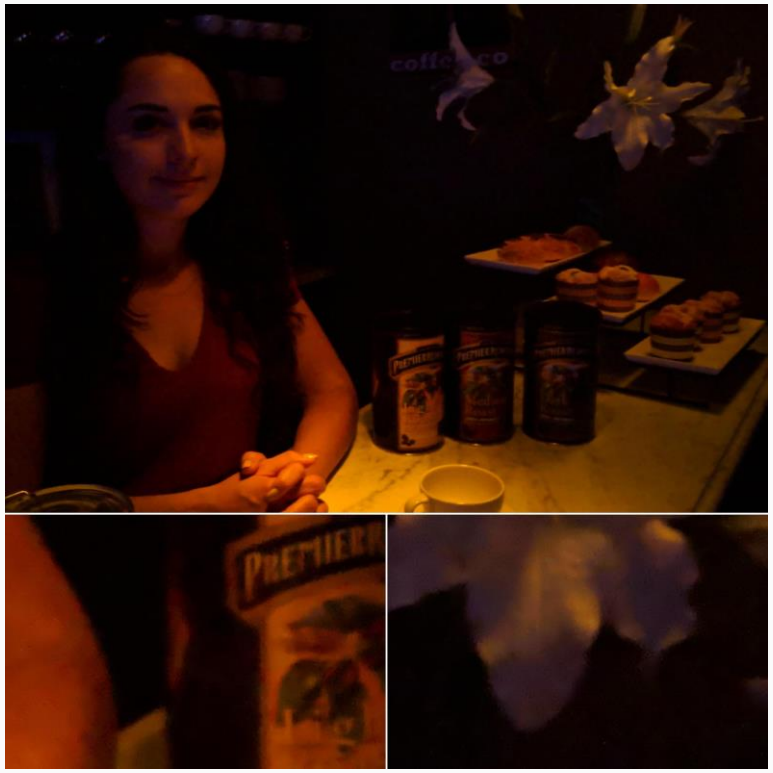
CLAHE

Liba et al.

Comparison of tone mapping techniques [3]

Handheld Low Light Photography





Hasinoff et al.

Hasinoff et al. brightened

Liba et al.

iPhone XS

Pixel 3 Night Sight

[2]

Conclusions

Conclusions

- Software first photography
- Google Pixels have had same main camera sensor for last 3 generations
- New camera features get released on old hardware

Shot on Pixel 2 (Paul Friederichsen)

Thanks

Nic McPhee and Elena Machkasova for their feedback and guidance

Questions

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floogulinc.com

github.com/floogulinc

References

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