Camera Autofocus (AF) Project

Work done while at Sony US Research Labs with
Makibi Nakamura, Sony Japan

Earl Wong

Background

- Sony still and video imaging began with the the Mavica and proMavica cameras in 1981 and 1987.
- Sony cameras were state of the art, and industry leaders.
- However, 20+ years later (~2003), Sony still and video camera autofocus (AF) was no longer considered “best in class”.

Objective of AF Project

- Help restore Sony autofocus (AF) to best in class.

- Note: The technology / algorithm developed from this project is still being used in 2021.

Algorithm Design Constraints

The new algorithm must:

- 1) Run “on device” in real time.
- 2) Run faster than the existing algorithm.
- 3) Produce better results than the existing algorithm.

CONTRAST DETECTION

Industry Standard

What is it?

CONTRAST DETECTION

Industry Standard

What is it?

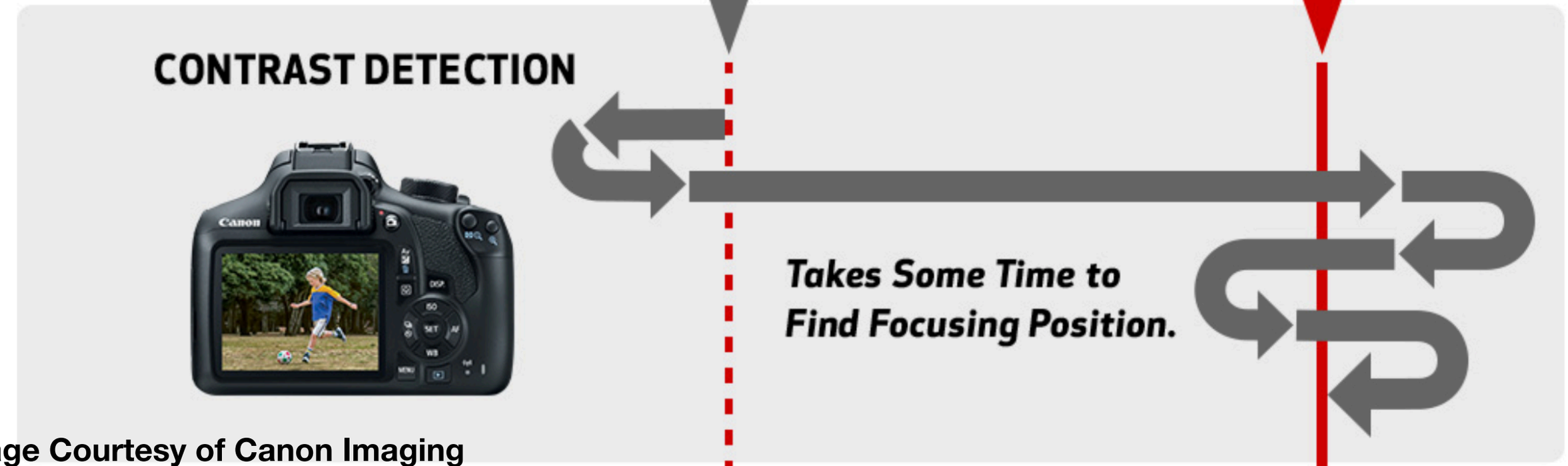

Image Courtesy of Canon Imaging

CONTRAST DETECTION

Industry Standard

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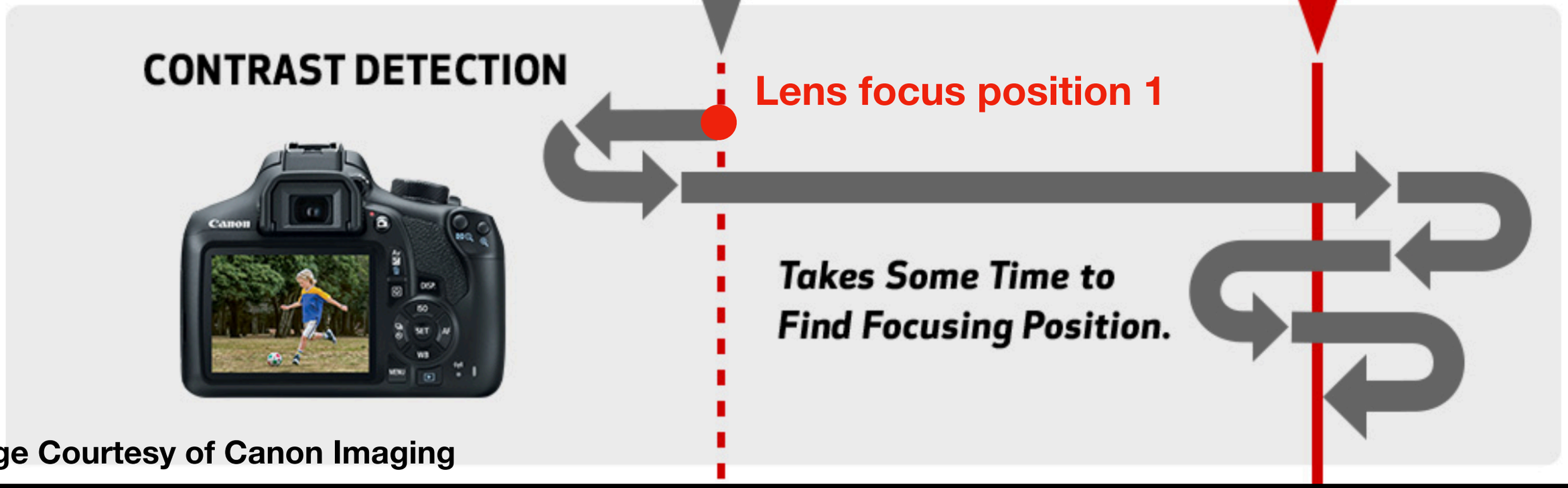

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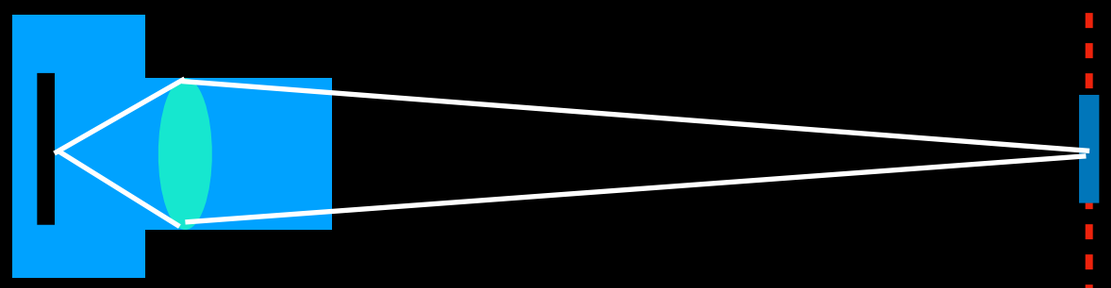

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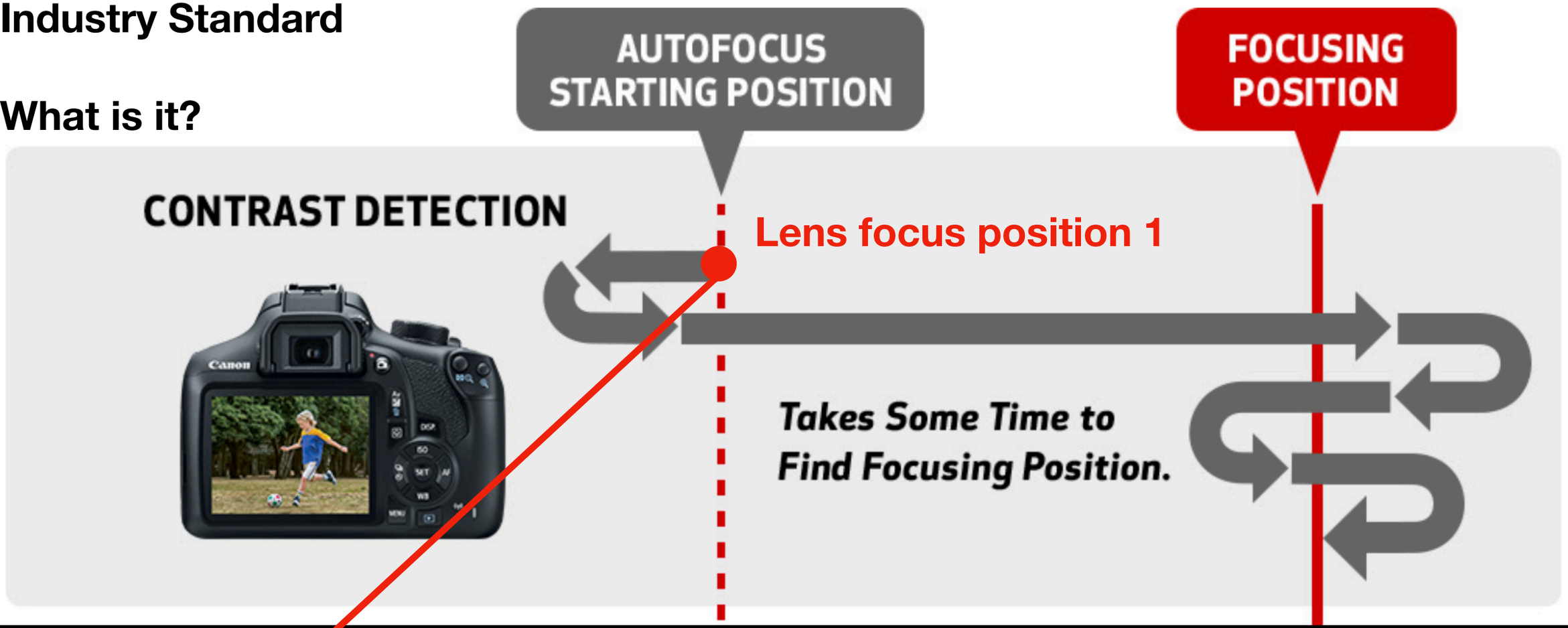

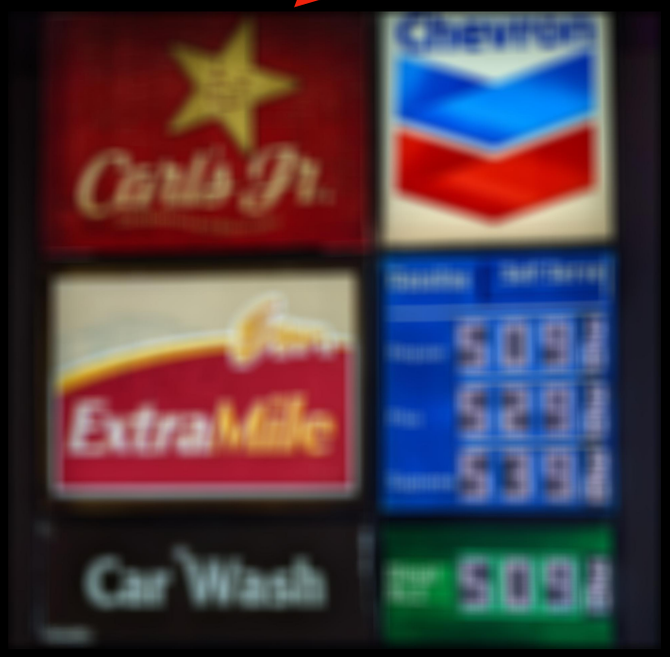

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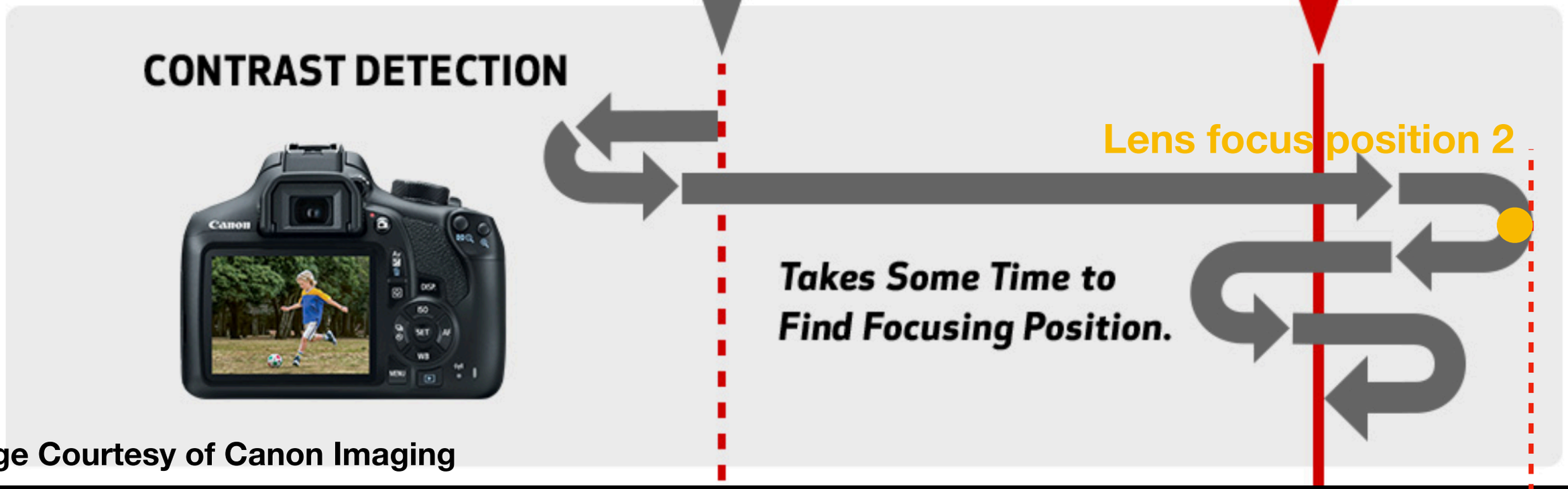

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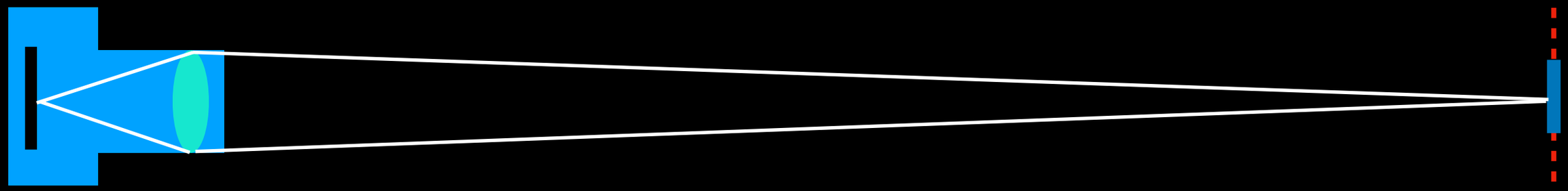

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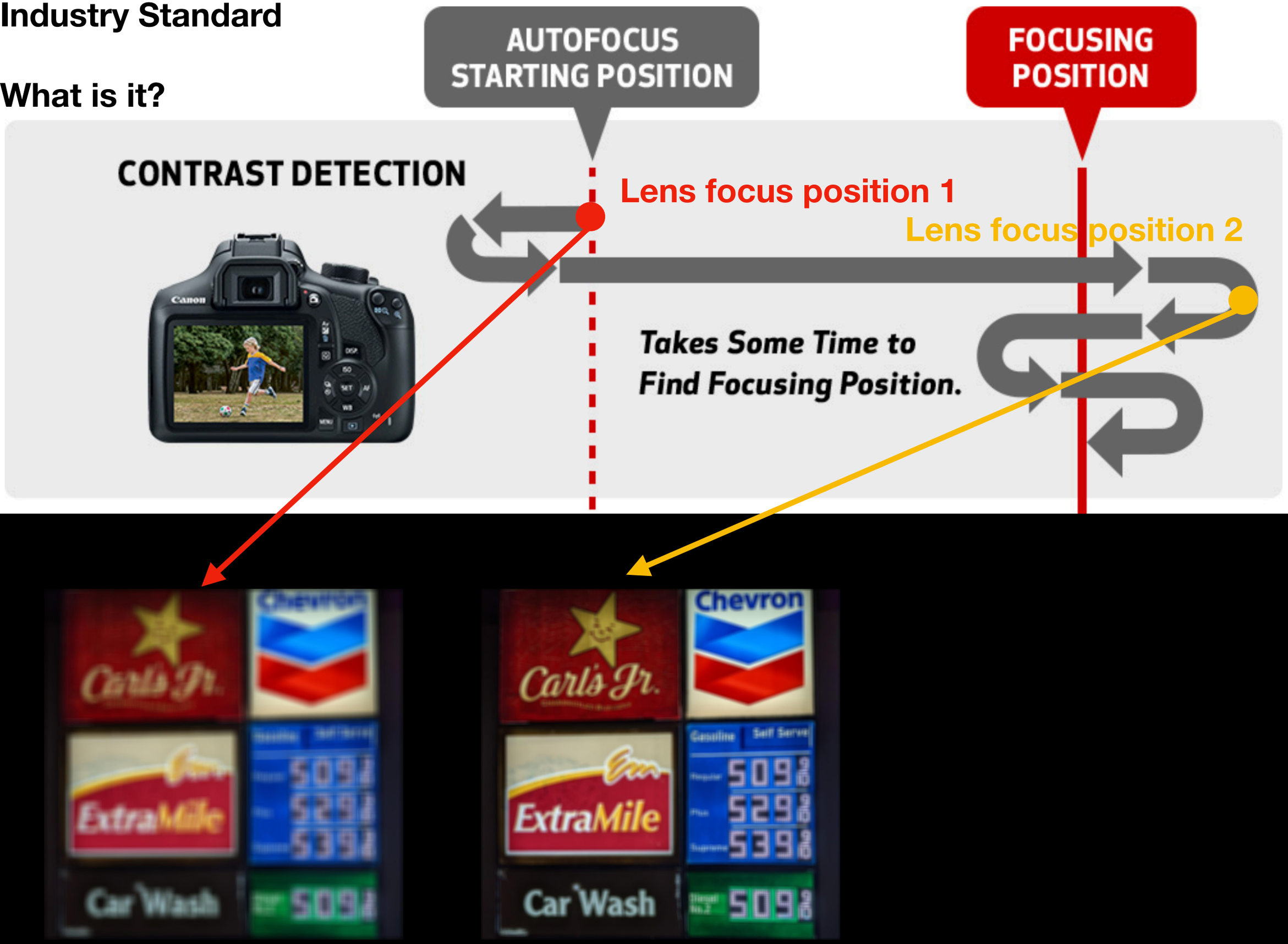

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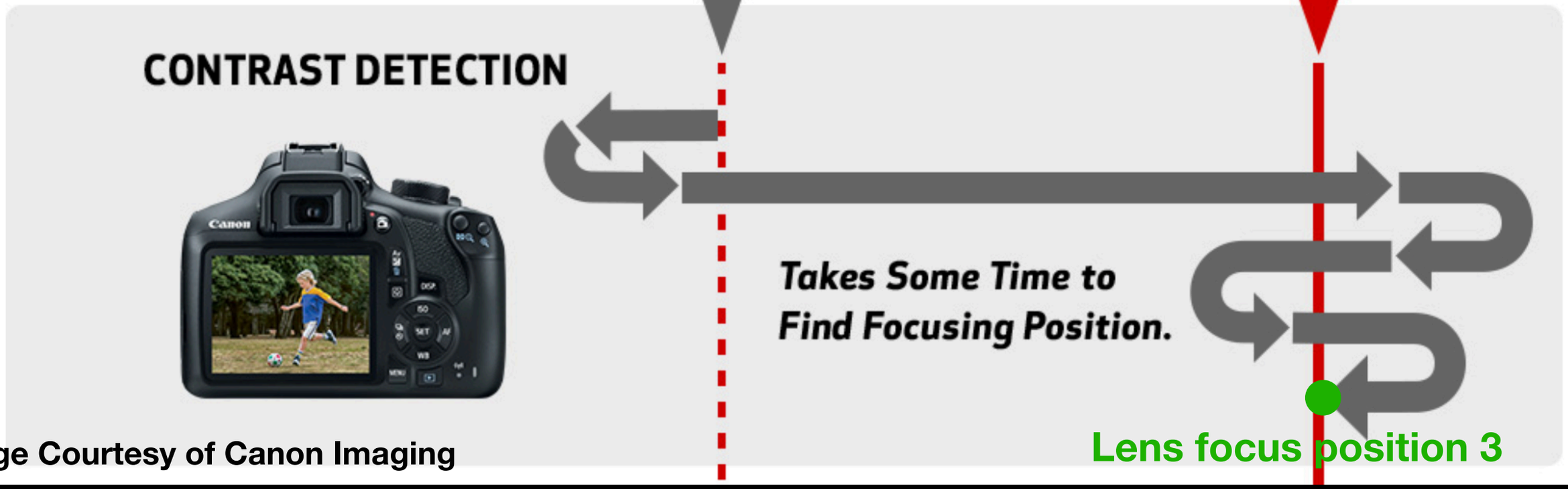

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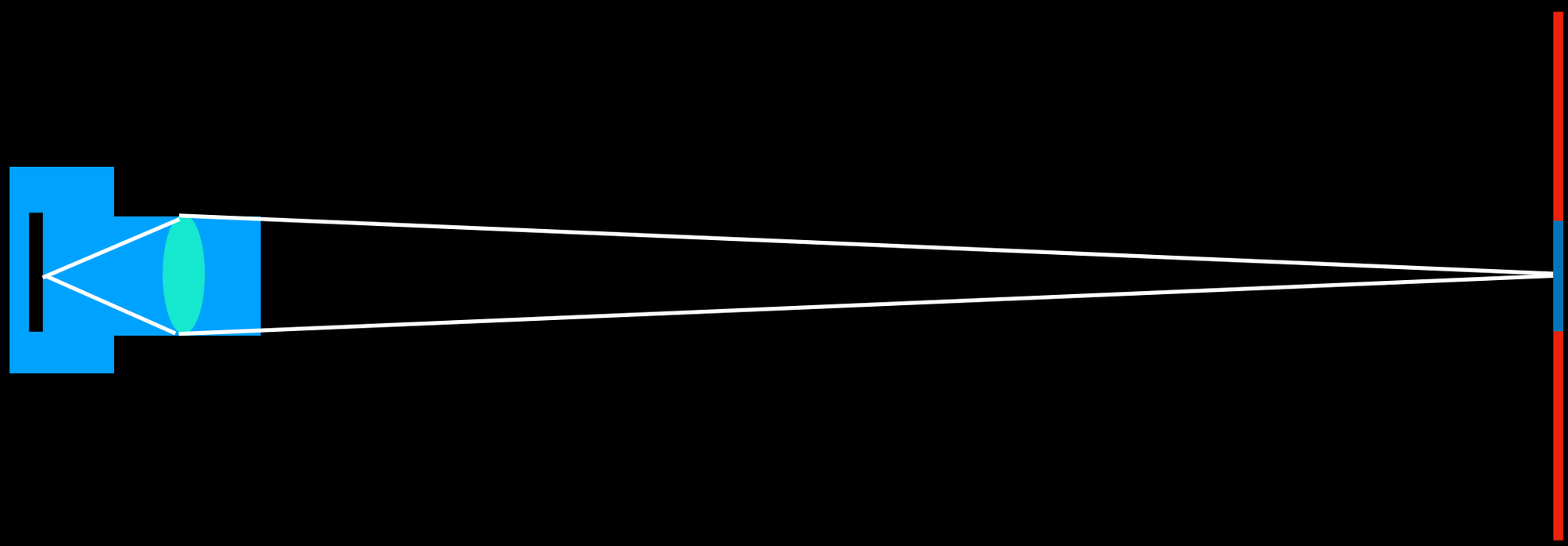

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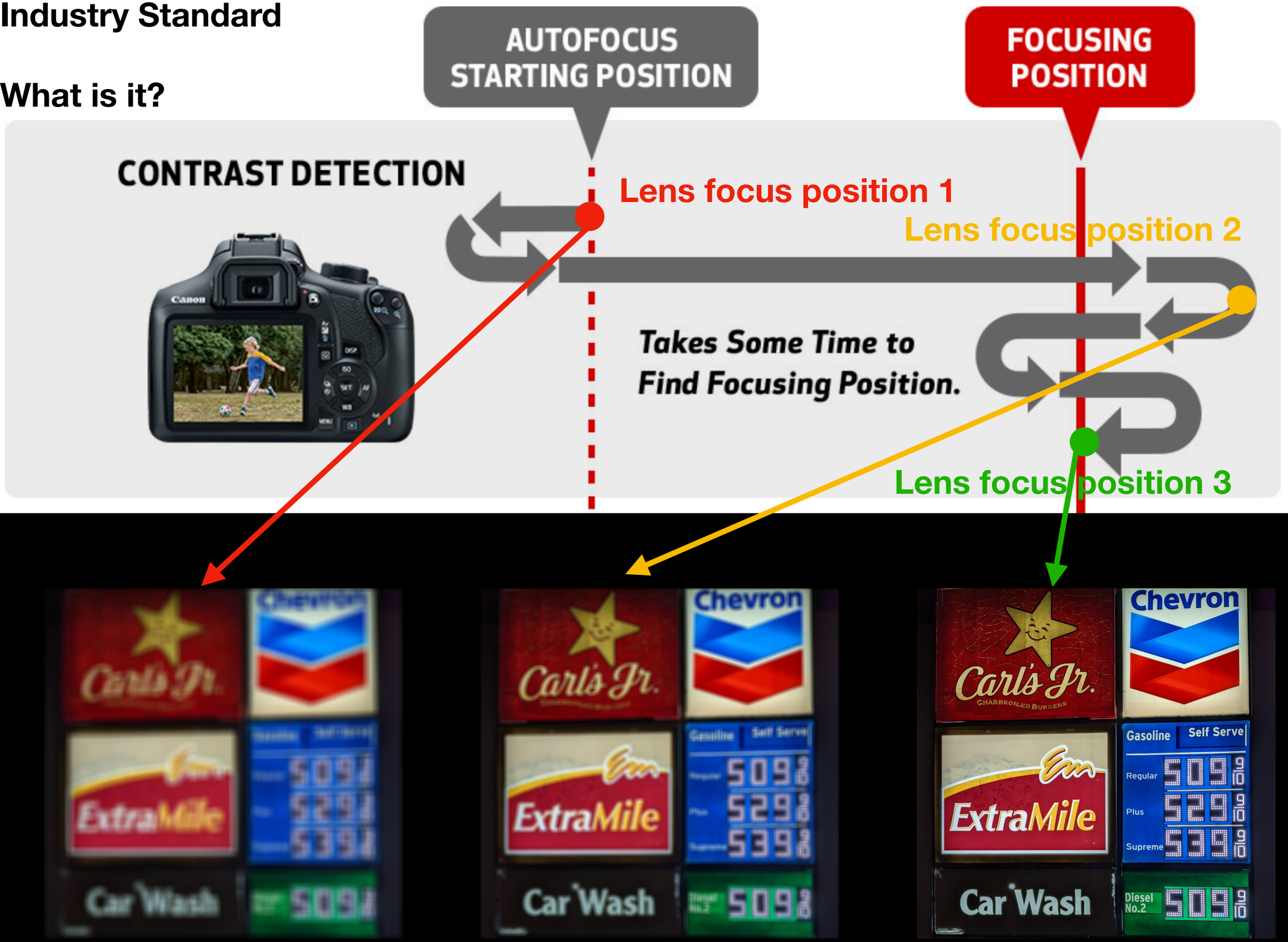
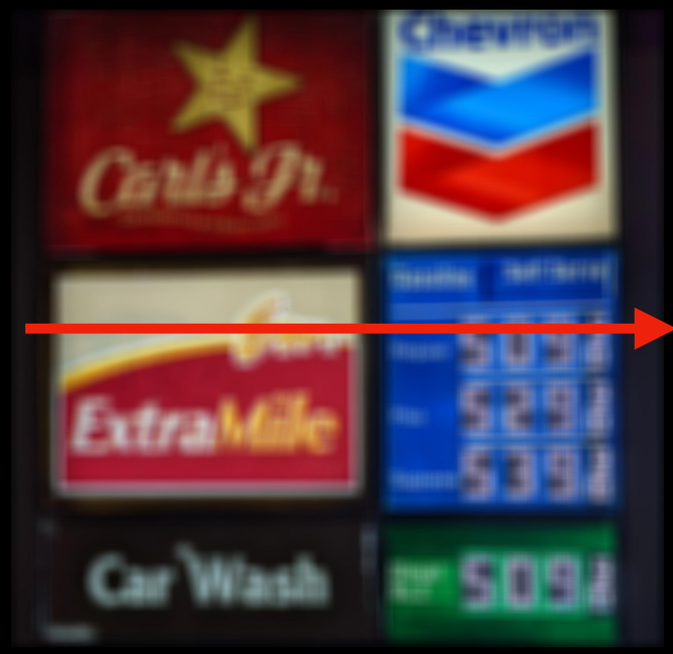
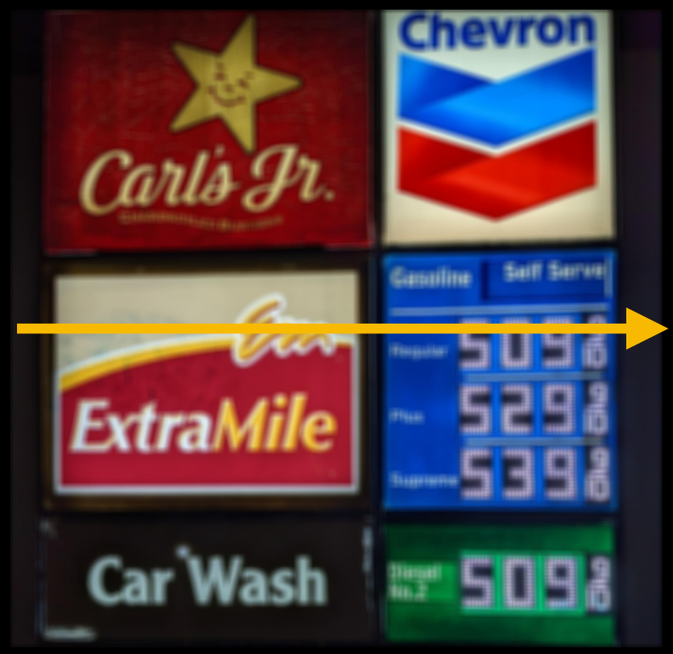


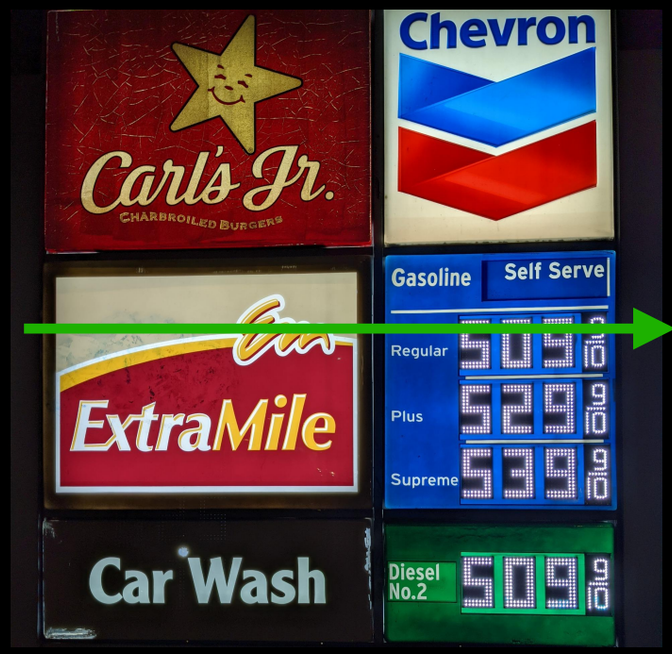
Fudamental Concept

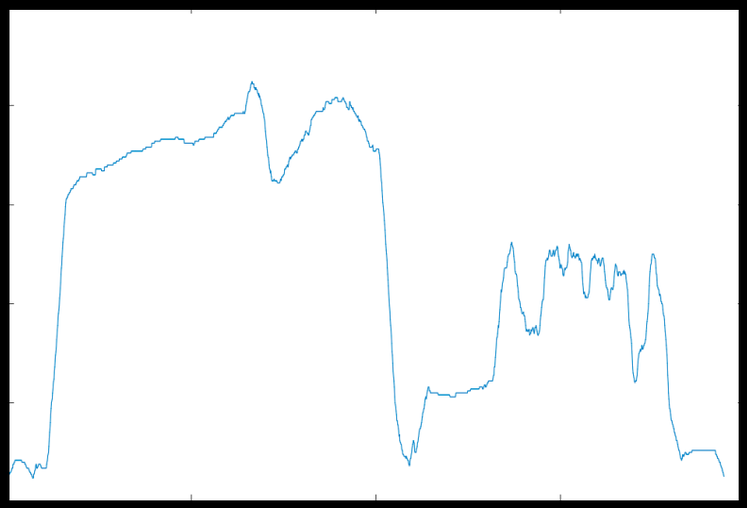
Find the camera lens position that maximizes the 1D gradients for a given window in the image [aka 1D line scan autofocus (AF)].

Fundamental Concept

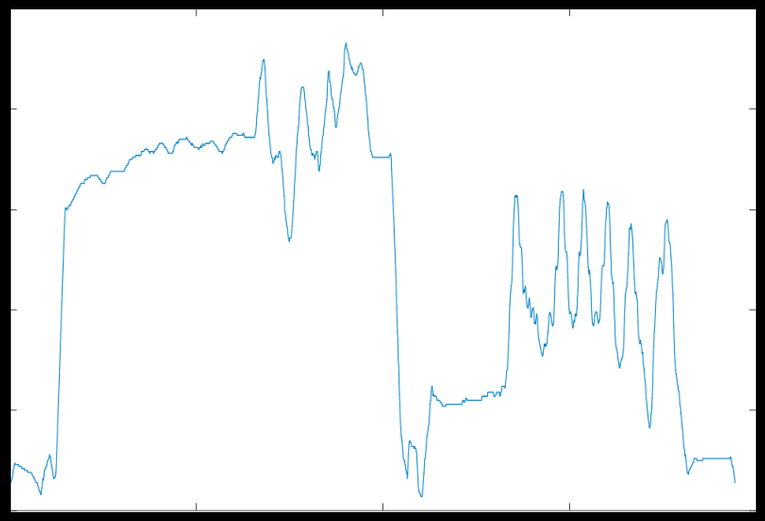




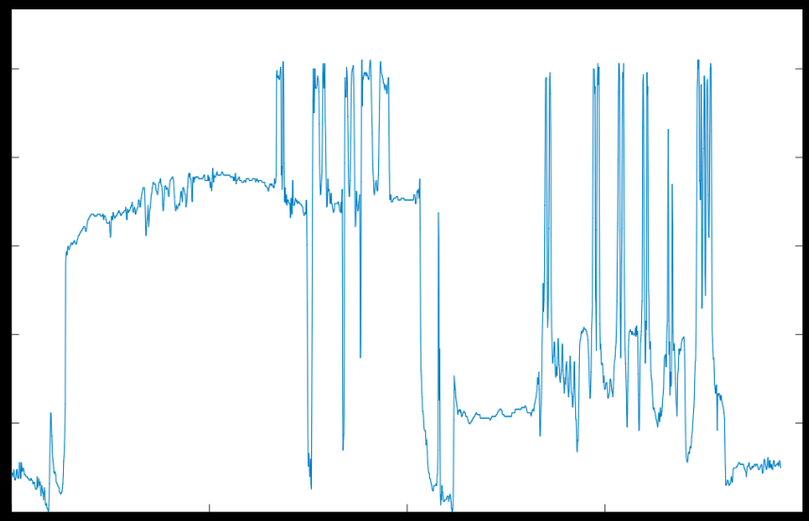




Strongly Out of Focus Scan Line

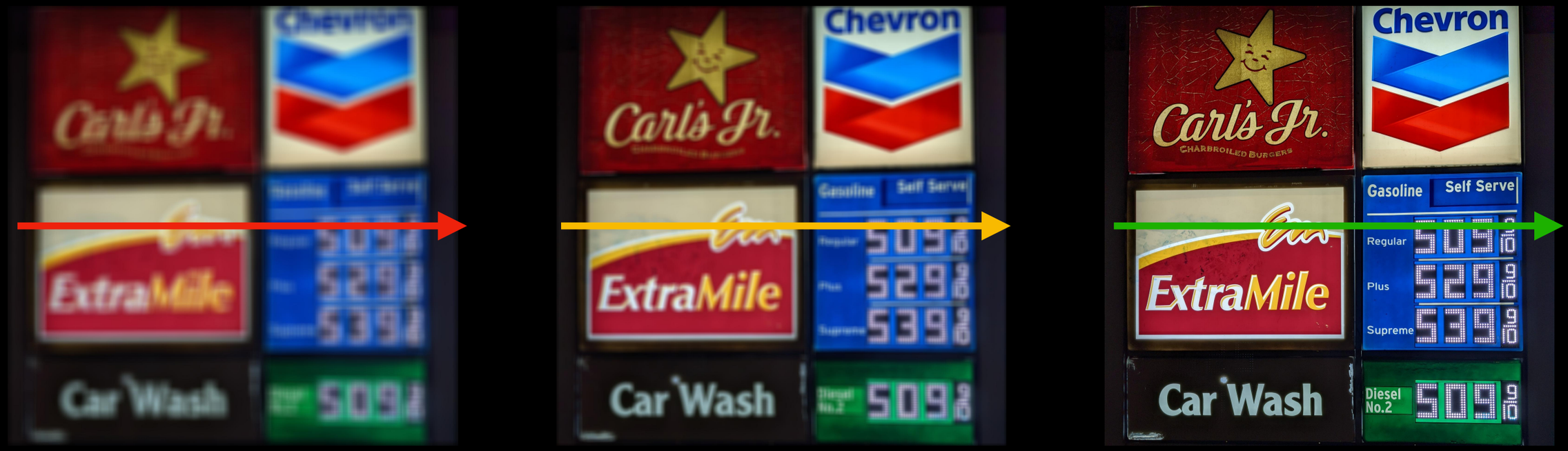


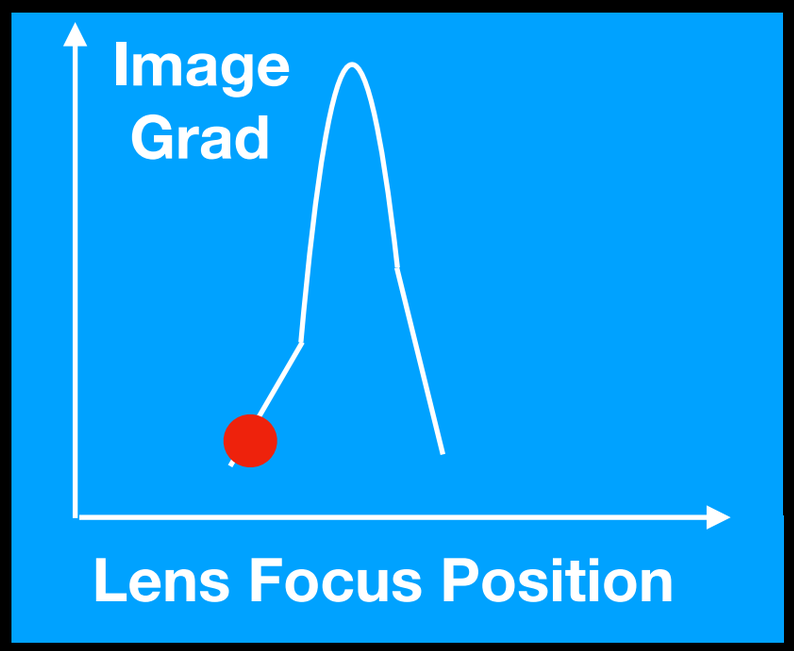
Moderately Out of Focus Scan Line

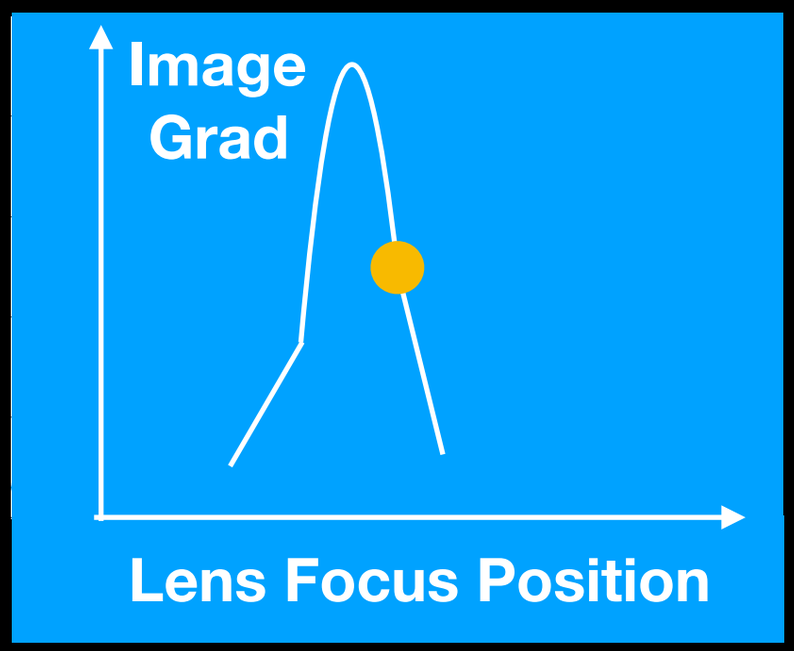


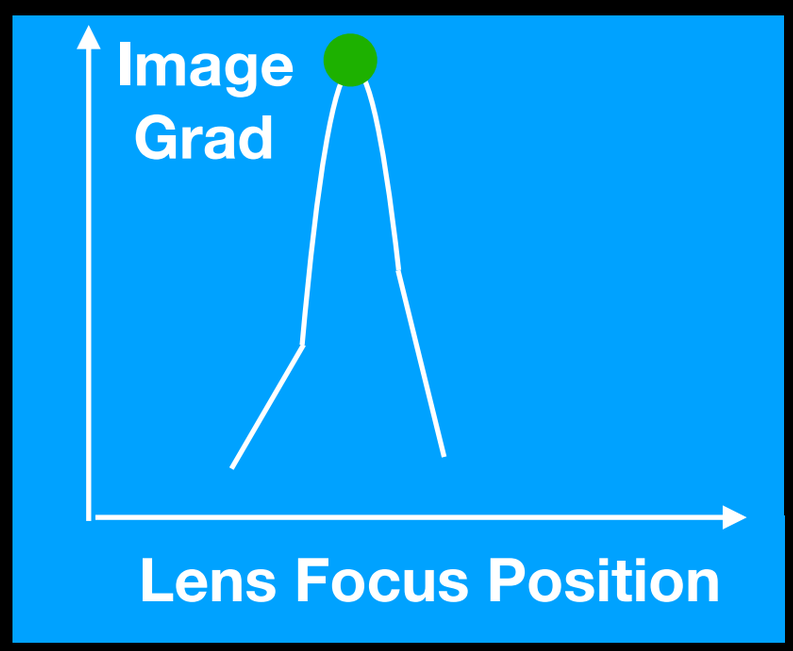
In Focus Scan Line

“Hill Climbing”









Comments

- Until 2016, contrast detection was the primary autofocus algorithm for still and video capture in mobile phone cameras.

- In 2021, contrast detection is still being used in high end cameras employing hybrid autofocus systems.

Idea #1
(Extension)

Use multiple windows / patch based approach and 2D spatial information.

Use a 2D transform based approach to extract the frequency information: FFT, DCT

Tradeoffs

Pros

- Patches at mulitiple locations and / or sizes provide more information than a single window.
- 2D information is better than 1D information.
- If the windows are chosen to be 8x8, DCT information can be used.

Cons

- The method is still gradient / frequency based.
- The method is still “hill climbing” based.

Comments

- About 6 years later, the idea of using DCT coeffcients for autofocus was investigated in the following paper:

Robust Focus Measure for Unsupervised AF Based on Optimal DCT Coefficients, Jeon, et. al., IEEE Transactions on Consumer Electronics, 2011

Idea #2
(Add Additional HW - Active AF)

Image Courtesy of fStoppers.com

Use active illumination to improve low light, still image autofocus - structured light

Tradeoffs

Pros

- Low light autofocus is improved.

Cons

- The user experience is non-ideal, since active illumination is involved.
- Additional hardware is required = cost, complexity.

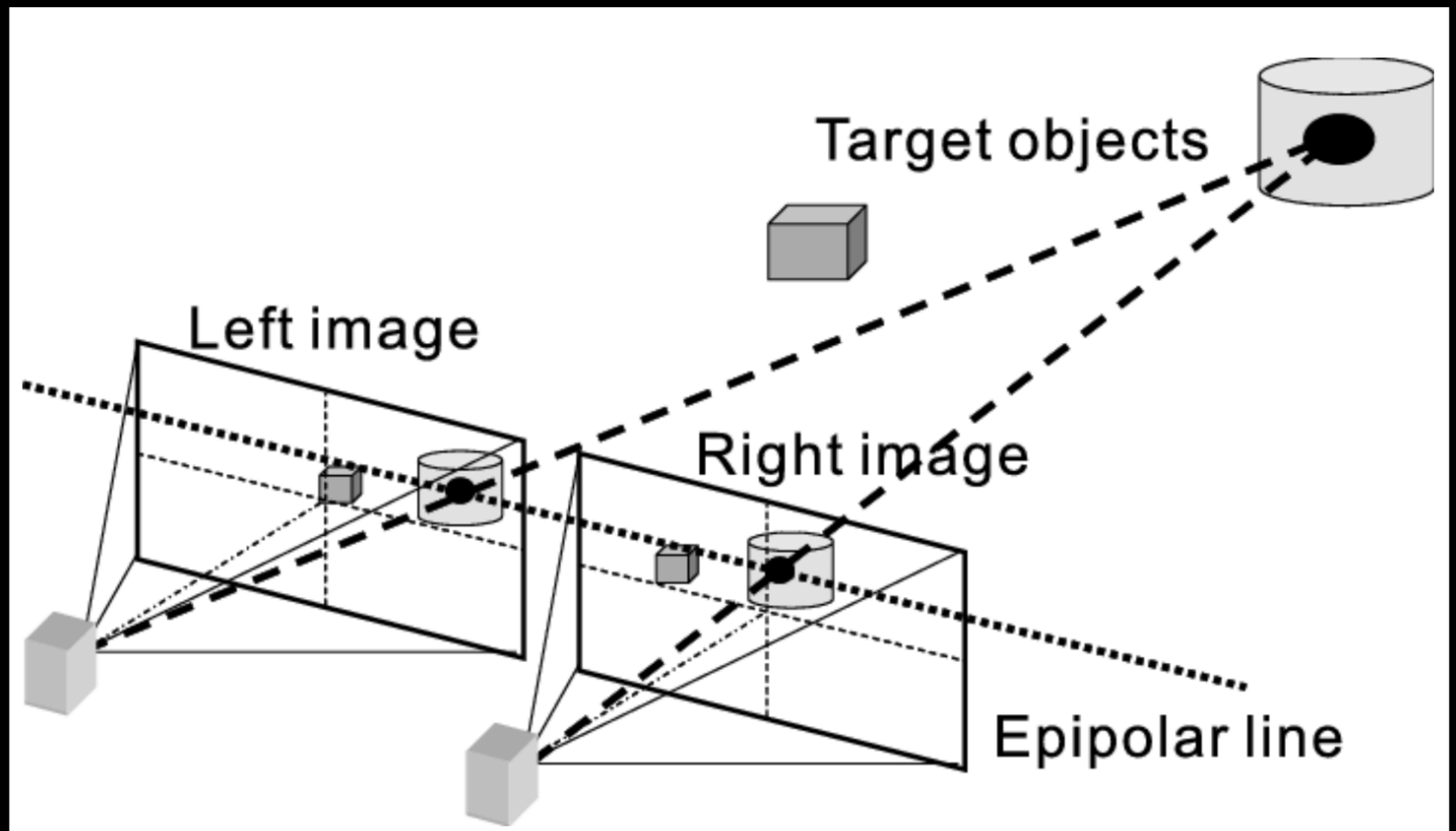
Comment

- Following the proposal, Sony released a similar feature several months later.

- In 2019 Samsung introduced a ToF sensor (active AF) to improve low light autofocus for mobile phone cameras.

- In 2020, Apple introduced a Lidar sensor (active AF) to improve low light autofocus for the iPhone.

Idea #3
(Add Additional HW - Passive AF)



Binocular stereo vision.

Image taken from: Design of a Trinocular-Stereo-Vision VLSI Processor Based on Optimal Scheduling

Tried and true method, with a long history in mirror based SLR cameras.

Tradeoffs

Pros

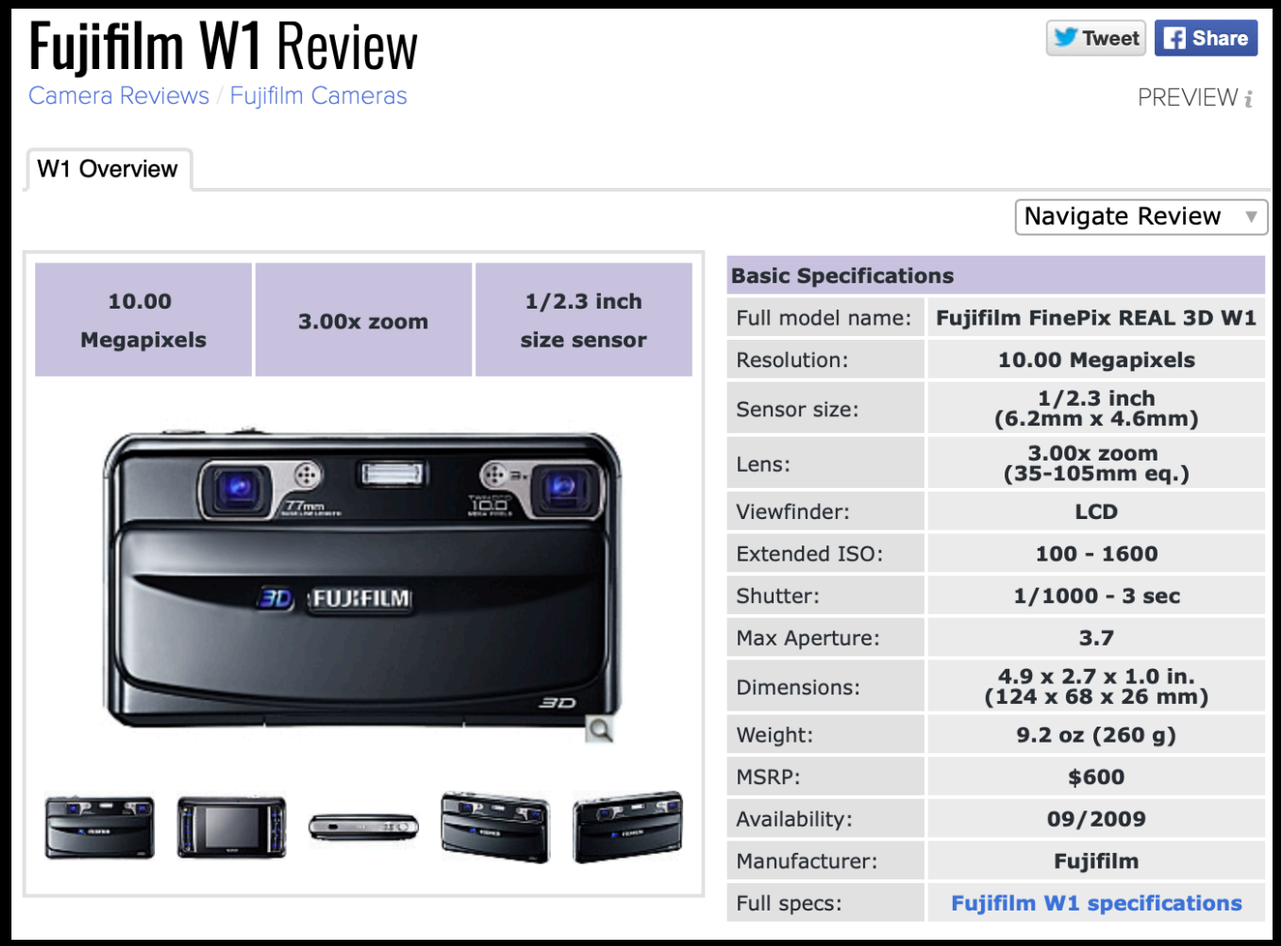
- Depth information eliminates the autofocus “hunting” problem associated with contrast based methods.
- Depth information enables segmentation and object tracking.
- The approach is passive (=not active).

Cons

- For SLRs, a specialized AF sensor is used = additional cost, additional size.
- The new information then needs to be calibrated with the image sensor = additional complexity.
- In general, Depth = (focalLength * Baseline) / Disparity. (High depth accuracy requires large / wide baselines.)
- Stereo approaches suffer from occlusion issues.
- Stereo approaches require registration.

Comments

- Stereo cameras have been in existence since 1851.
- In 2009, Fuji introduced a modern day, stereo camera.



- In 2016, Apple re-introduced binocular stereo vision via Portrait Mode.

Checkpoint

- Having depth information is good, since you can also perform image segmentation and tracking.

- Can a depth map be created, using a single lens camera with no specialized hardware?

Idea #4
(New Thinking)

Yes: Consider an all in focus picture, scale space theory and blur.

- 0) Generate an all in focus picture.

- 1) Capture a normal image (= has depth of field).

- 2) Detect the difference in blur between the normal image and the all in focus picture.

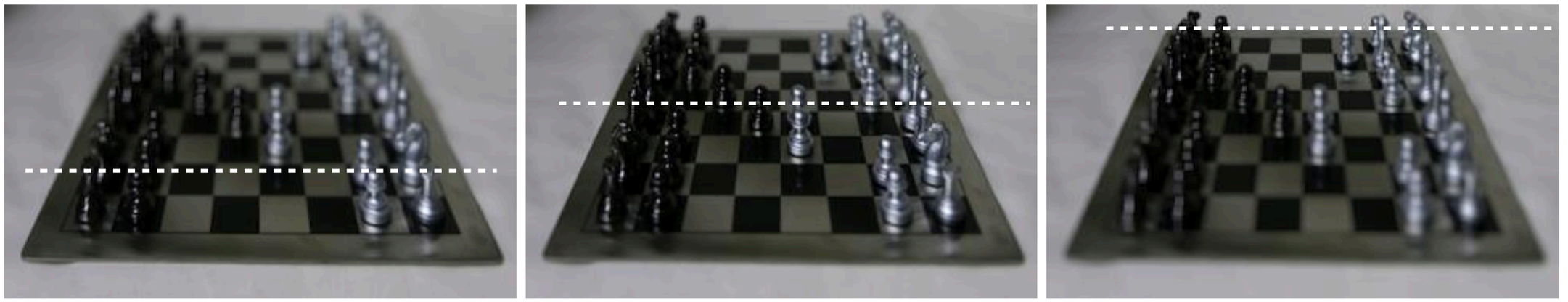
A New Method for Creating a Depth Map for Camera Auto Focus using an All In Focus Picture and 2D Scale Space Matching (ICASSP 2006)

Idea #4

- Create a new All In Focus picture, by combining pictures taken at different focus distances.

Focal stack imaging

1. Capture a focal stack



2. Merge into an all in-focus image

Slide Courtesy of CMU Computational Photography

Idea #4

Scale Space Theory

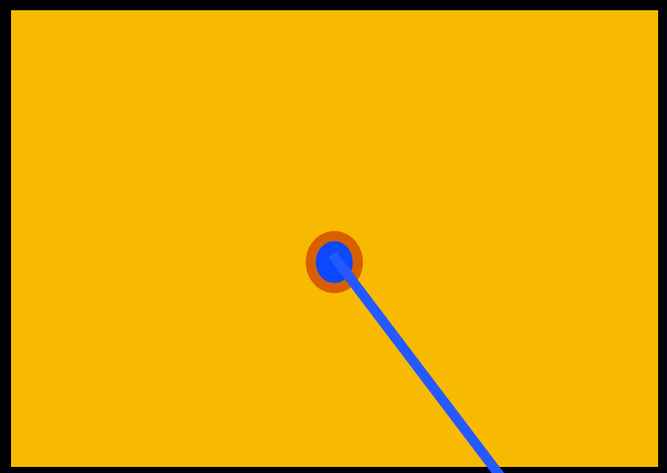
- Scale space describes the series of images created by blurring the original image with blur kernels of increasing size.

- Scale space theory was successfully applied in the SIFT feature point detector. i.e. Difference of Gaussians

Image Courtesy of Univ. of Amersterdam

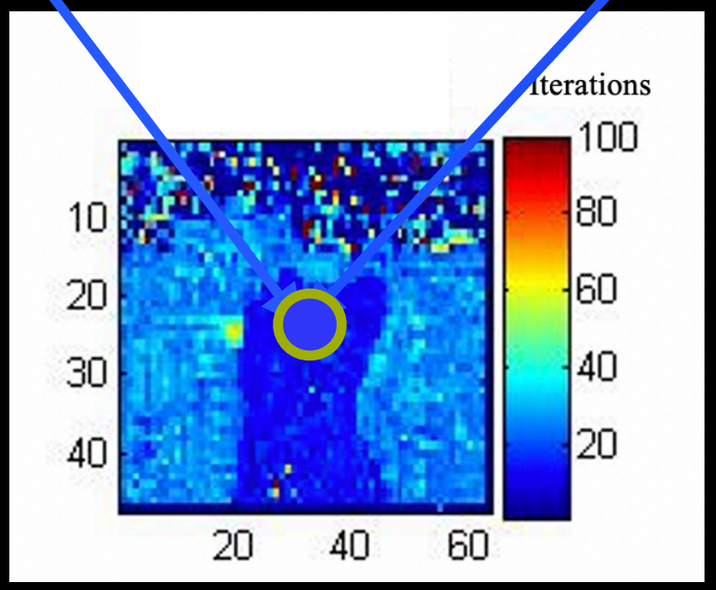
Idea #4

All In Focus Picture



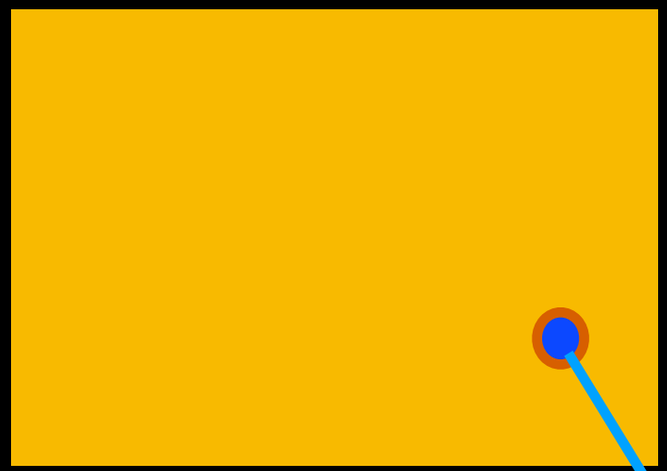
Normal Image with Depth of Field

No / small difference

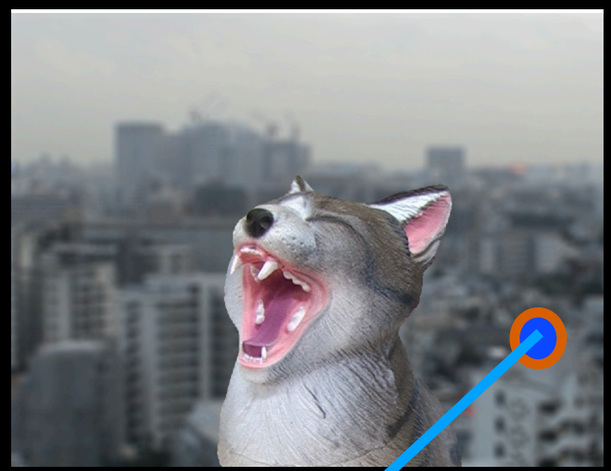


Idea #4

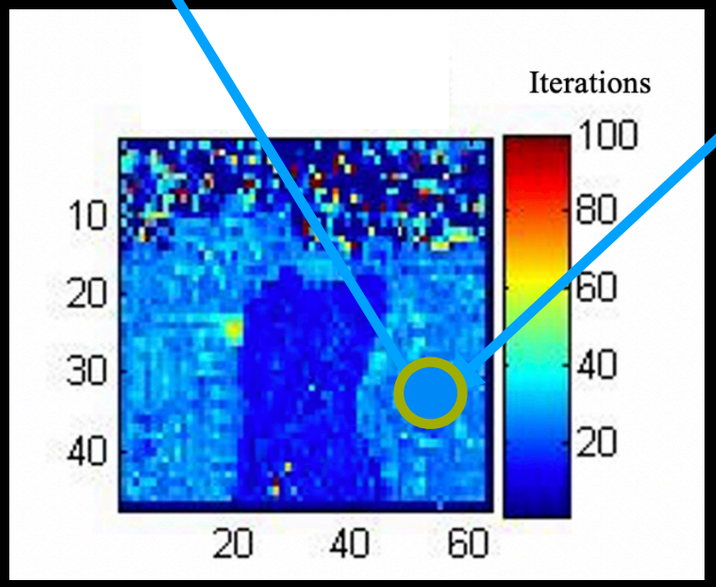
All In Focus Picture



Normal Image with Depth of Field



Moderate blur difference



Tradeoffs

Pros

- A depth map is created, using a single lens camera.
- No specialized hardware is needed.
- No occlusion issues exist.

Cons

- How many focus positions / image captures are needed to create the all in focus picture? 3, 4 …
- Will this be as fast as the current autofocus system?

A Related Idea: Depth from Focus (DFF)

- Create a focal stack, by varying the camera focus positions.
- For each region in the image, determine the focus position producing the highest contrast via contrast detection autofocus (AF).
- For the computed focus position, use the camera optics / thick lens model to recover the depth. (Focusing, Krotov, IJCV 1988)

Comments

Google re-introduced the DFF concept to mobile phones.
Depth From Focus with Your Mobile Phone, Suwajanakorn, et. al., CVPR 2015

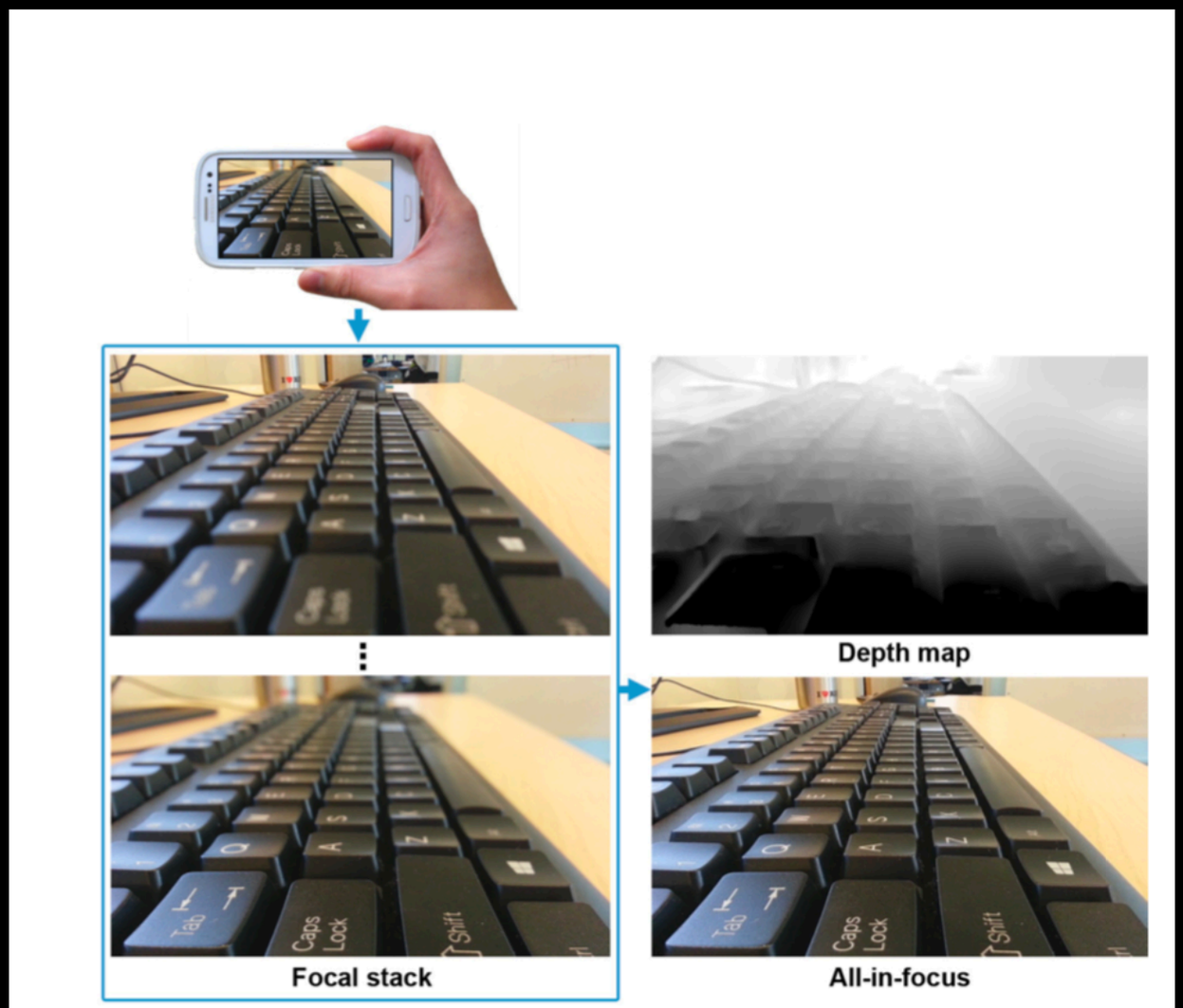


Figure 1. We compute depth and all-in-focus images from the focal stack that mobile phones capture each time you take a photo.

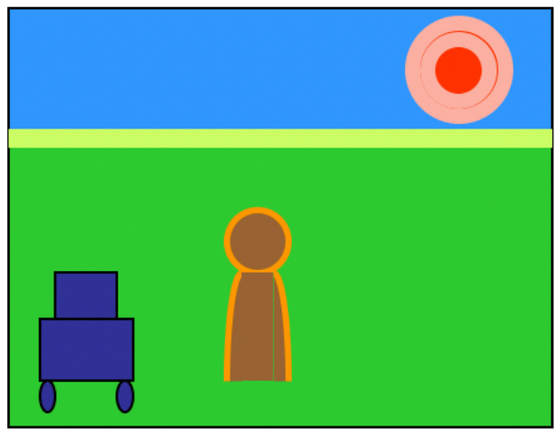
Idea #5
(Addressing the Shortcoming of Idea #4)

- Extend Idea #4, but use the difference / change in blur between two images.
- i.e. Create a depth map using only two images captured with different amounts of blur.
- This eliminates the need to create a focal stack / all in focus image.

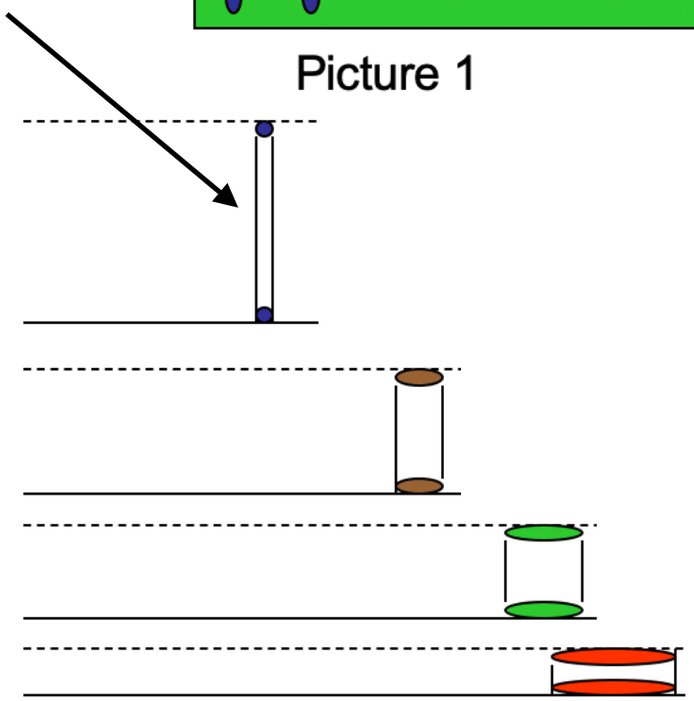
Idea #5

Concept

Pillbox Blur Kernel



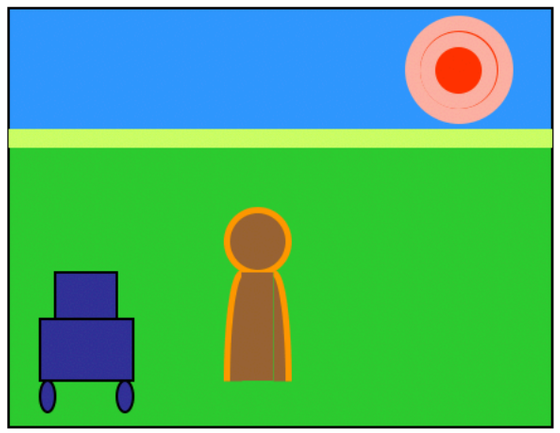
Picture 1



Idea #5

Concept

Pillbox Blur Kernel



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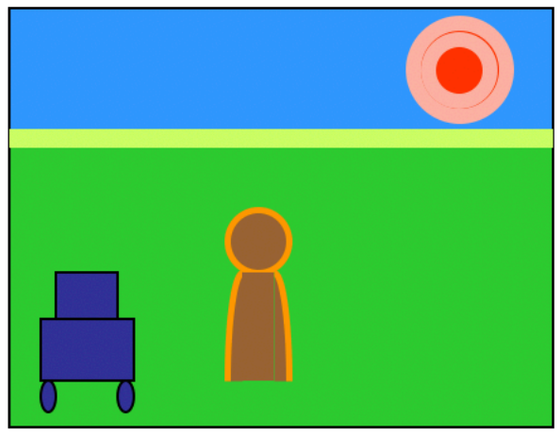
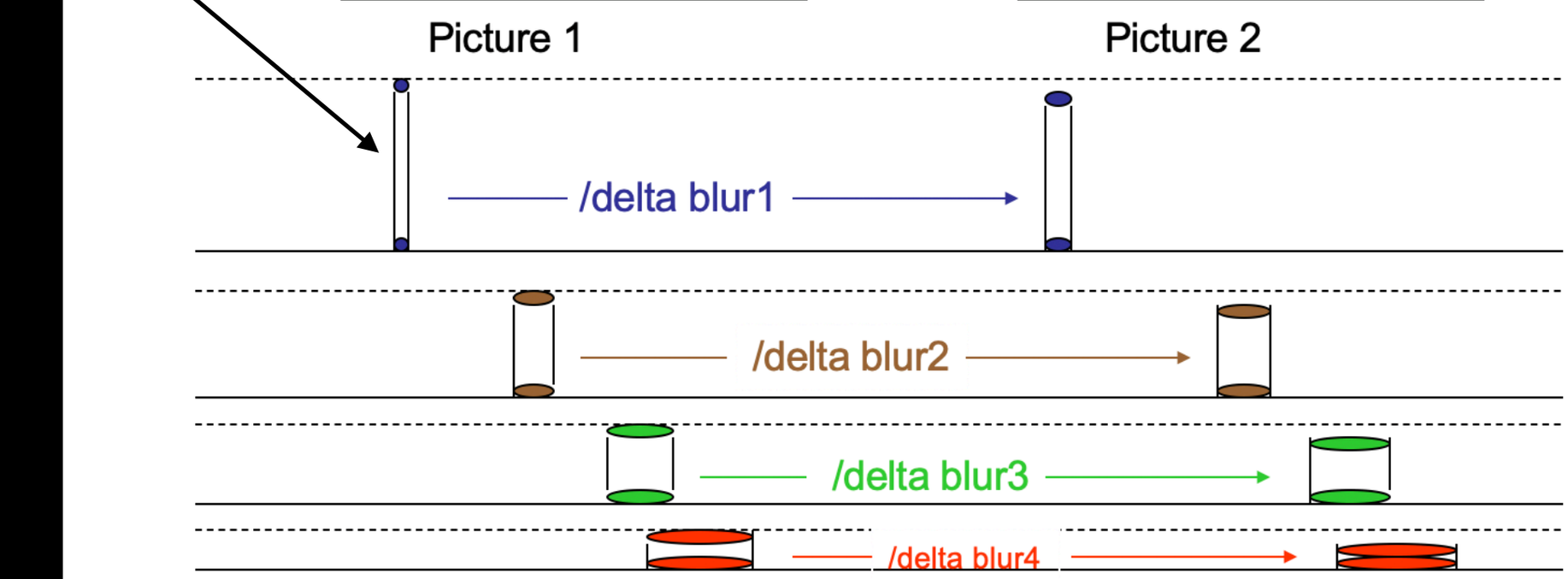


Picture 2

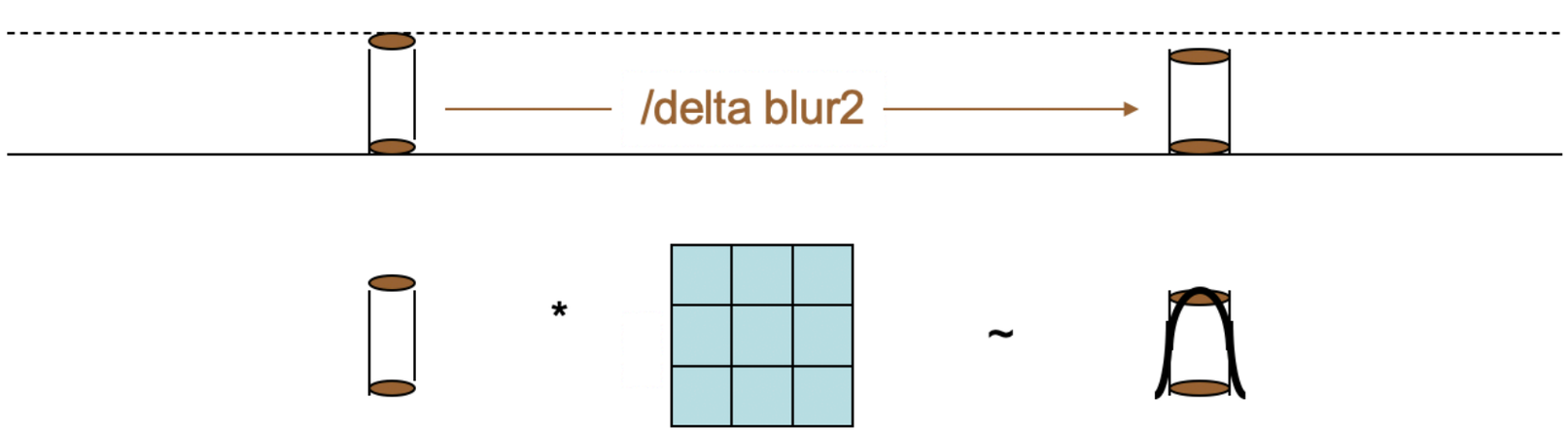


Idea #5

- /delta blur1 < delta blur2 < delta blur3 < delta blur4

Idea #5

How do we compute /delta blur?



3x3 matrix

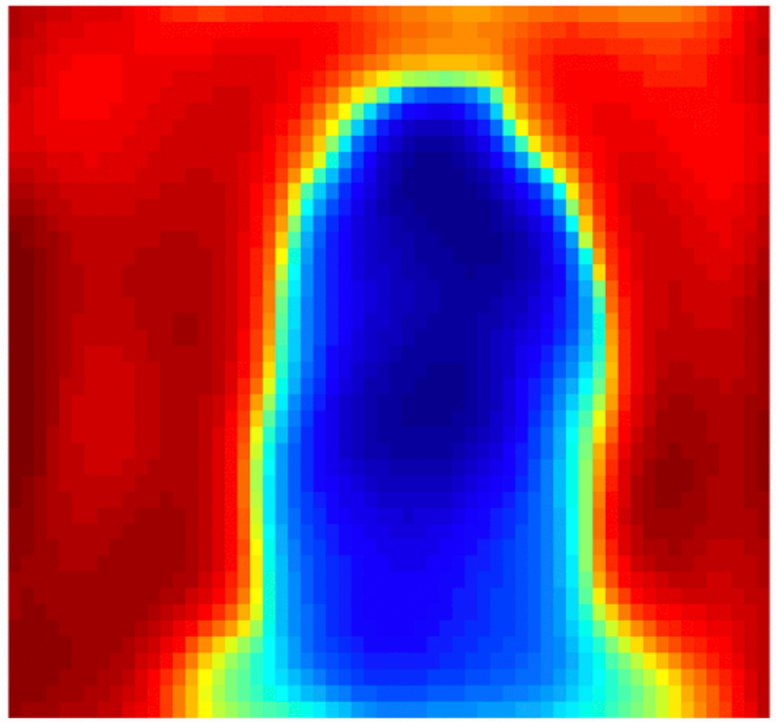
Iterations of 3x3 matrix is proportional to /delta blur2

Change in blur is computed using rudimenatary convolution.

Idea #5

Example: Sony DSC WX1

2D Image



Depth Map

Tradeoffs

Pros

- The depth map is computed using a single lens camera, without any specialized hardware.
- The depth map calculation only requires 2 images.
- Unlike stereo, there are no occlusion issues.
- The approach is robust to textureless regions, since registration is not required.

Cons

- The approach is not ideal for tracking very fast object motion, or, very small objects.
- For very high accuracy, lens calibration data is required.

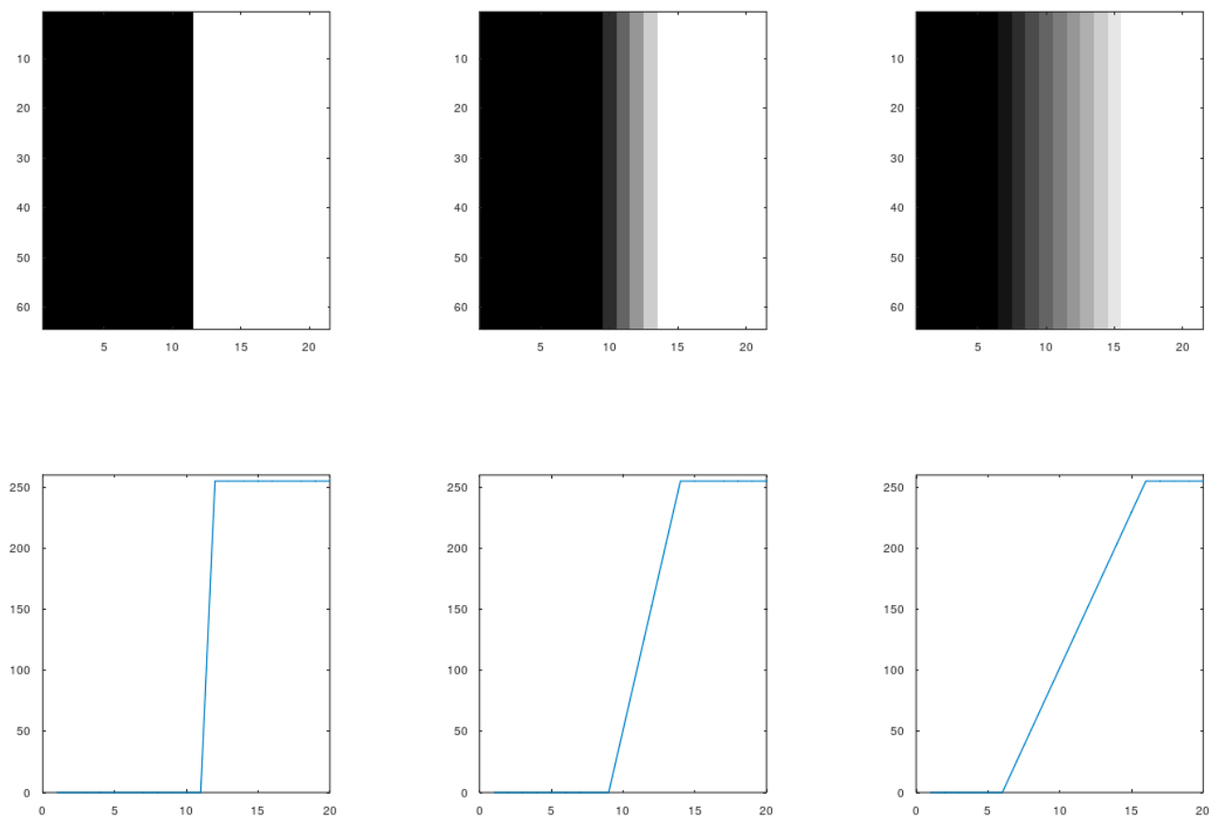
Comments

- Creating a depth map using two pictures and image blur is also known as Depth from Defocus (DFD).
- Academia and industry had dismissed the utility of depth from defocus (DFD) due to accuracy and range limitations.
- i.e. Only accurate / useful for ranges between 0 and 2-3 feet.
- The new system was accurate between 0 and the hyperfocal distance of the camera.
- Because of time considerations, we will not discuss the details involved.

Idea #6
(Depth with 1 image?)

- Find reference points / reference structures in an image. (Example: step edges)

- Determine scene depth by determining the amount of blur incurred by the reference points / reference structures.



Tradeoffs

Pros

- There is solid, fundamental theory behind the idea.
- Only 1 picture is needed.

Cons

- Not all natural images / scenes contain step edges.
- How do you know that the edge under consideration, is a step edge?
- You can only obtain depth at the reference points / reference structure locations.

The Winner

- (Idea #5) An industry first, 2 Picture autofocus (AF) algorithm was introduced by Sony in 2010 for still and video capture.

- The core technology was implemented into Sony’s entire digital imaging product lineup, restoring Sony still and video autofocus (AF) to best in class.

- https://patents.google.com/patent/US8194995B2/en

- The depth map was also used to perform background defocus (aka portrait mode) and object tracking.

- https://www.sony.jp/products/overseas/contents/pickup/english/100708_superior_auto/

Comments

- In 2017, Panasonic announced their own version of a 2 picture camera autofocus algorithm based on DFD.
- https://help.na.panasonic.com/answers/features-what-is-dfd-depth-from-defocus-technology-dmc-gh4-dc-lx100m2/

- In 2021, the best autofocus system available is (arguably) a hybrid system consisting of a 2 Picture DFD algorithm and contrast detection autofocus (AF).

Other Autofocus (AF) Algorithm Facts

- In 2015 [CVPR] Google announced a candidate Depth from Focus (DFF) algorithm for mobile phones.

- In 2016, cell phone manufacturers began replacing contrast detection autofocus with on sensor phase detect autofocus / dual pixel autofocus (PDAF / DPAF).

- Autofocus using the new technology suffered in low light situations.

- In 2019, Samsung added a time of flight depth sensor to improve low light, mobile phone autofocus.

- In 2020, Apple added Lidar to improve low light camera autofocus for the iPhone.

PDAF / DPAF

- On sensor phase detect / dual pixel autofocus was introduced by Canon in 2013.

- In 2016, this technology began migrating to mobile phones.

DPAF

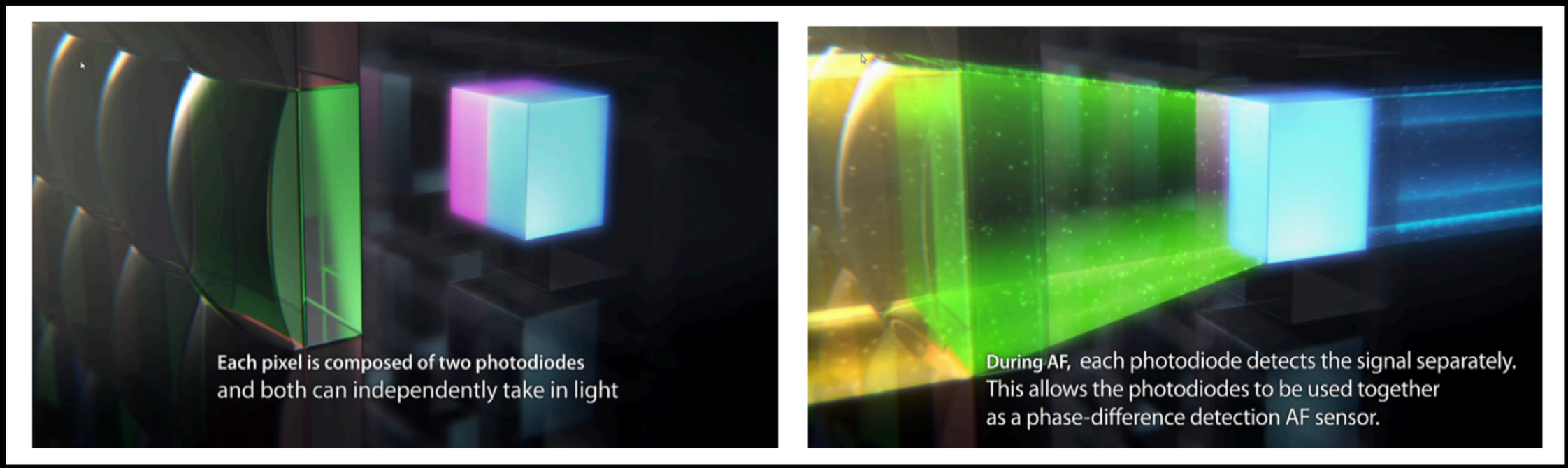


Image courtesy of Canon Imaging

Deep Learning Contributions

- In 2005, make3D was introduced by Saxena and Ng, to generate 3D models of image scenes using a supervised learning approach.

- In 2017, Google introduced a deep learning based encoder / decoder neural network to perform foreground / background image segmentation for portrait mode.

- Google subsequently augmented the segmentation map with depth information obtained from the camera DPAF / PDAF sensor.

- In 2021, Google began employing multiple lenses in their mobile phone cameras: Pixel 6 and Pixel 6 Pro

Deep Learning Contributions

- In 2018 Deep Depth From Focus was introduced to improve the performance of Depth From Focus (DFF).

- Here, an autoencoder network was trained to produce a depth map, using focal stacks acquired from a depth sensing camera.

2025 Comments

- More recently, Canon sensors can now perform quad pixel AF at EVERY sensor location.

- https://www.canonrumors.com/canon-patent-application-full-frame-quad-pixel-sensor/

- Quad pixel AF sensors are shipping in Canon’s 2025 mirrorless camera lineup.

Conclusions

- Autofocus is a fundamental problem for still and video camera imaging.
- This presentation has provided a quick, high level overview of past and current technology / algorithms (pros and cons).
- Good system design requires 1) a deep understanding of the “big picture” / problem and 2) a deep understanding of the engineering tools available.
- New tools often have unique strengths, but also, inherent weaknesses.
- Hence, it is critical to understand all of the tradeoffs involved.