ENGN 8501

Week#3: Computational Photography-1:

Coded Photography

2021 S2

This week:

- Monday Lecture: Supervised paper reading;
- Thursday tutorial session (format tba.);
- Reading Report-1 due on this Thursday evening.
- Next week: explain research project requirements

Outline for today's lecture

- 1. review/refresh reading: 5 minutes.
- 2. general tech-background introduction: 20 minutes
- 3. supervised paper reading session: about 20 minutes
- 4. breakout room group discussion + report: 30 minutes + 20 minutes.

General technical introduction:

What is computational photography?

What is Computational Photography ?

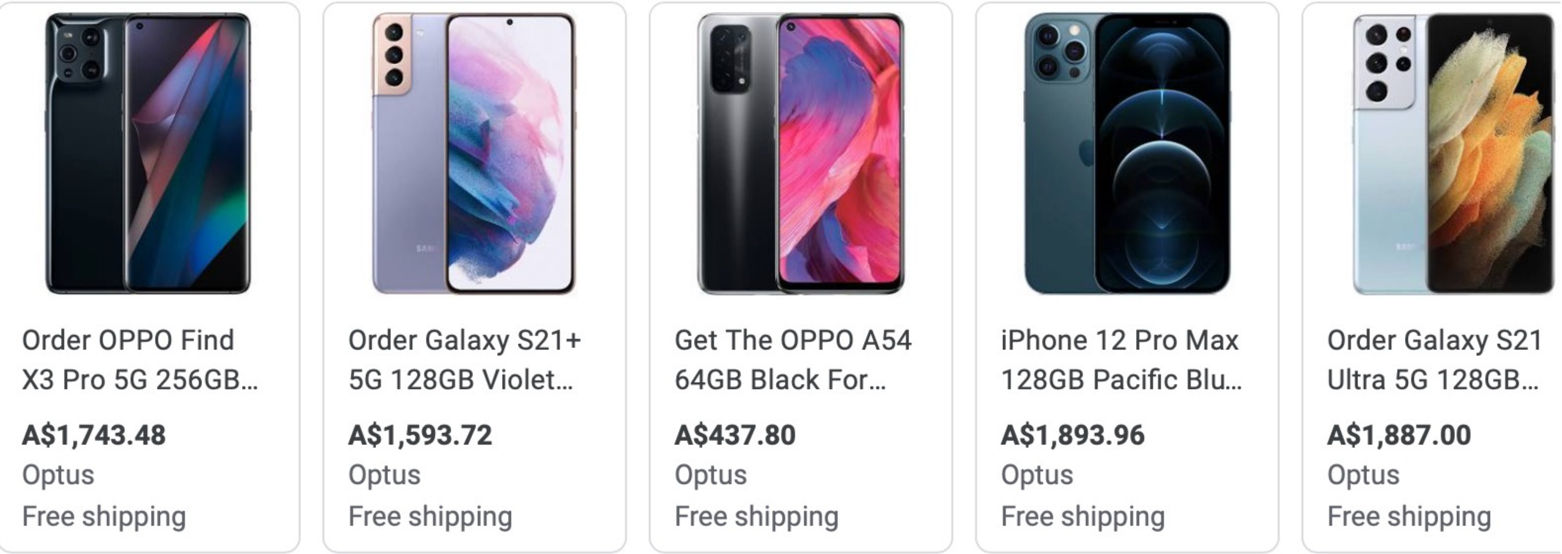
Camera, re-invented.

- Convergence of image processing, computer vision, computer graphics and photography
- Digital photography:
  - Simply replaces traditional sensors and recording by digital technology
  - Involves only simple image processing
- Computational photography
  - More elaborate image manipulation, more computation
  - New types of media (panorama, 3D, etc.)
  - Camera design that take computation into account

Cameras in the old days (e.g. 1990’s).

Early days' digital camera (2000)

Cameras of today



significant on-board computation

- advanced image processing algorithms
- automatic camera controls, scene analysis algorithms
- new capabilities (beyond traditional camera)

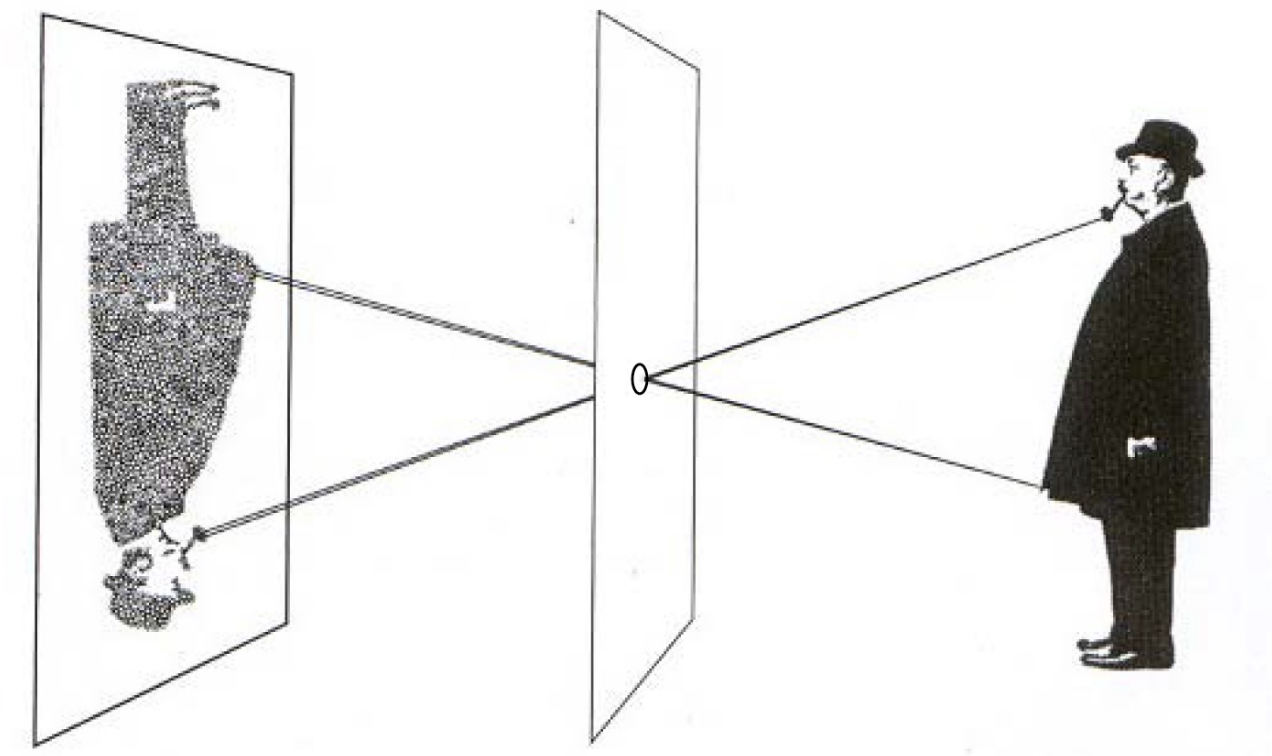
new combinations of sensing + optics

- SWaP considerations (Size, Weight and Power)
- integration of non-picture-forming sensors (gyro, GPS, autofocus)
- new capabilities (beyond traditional camera)

internet connectivity

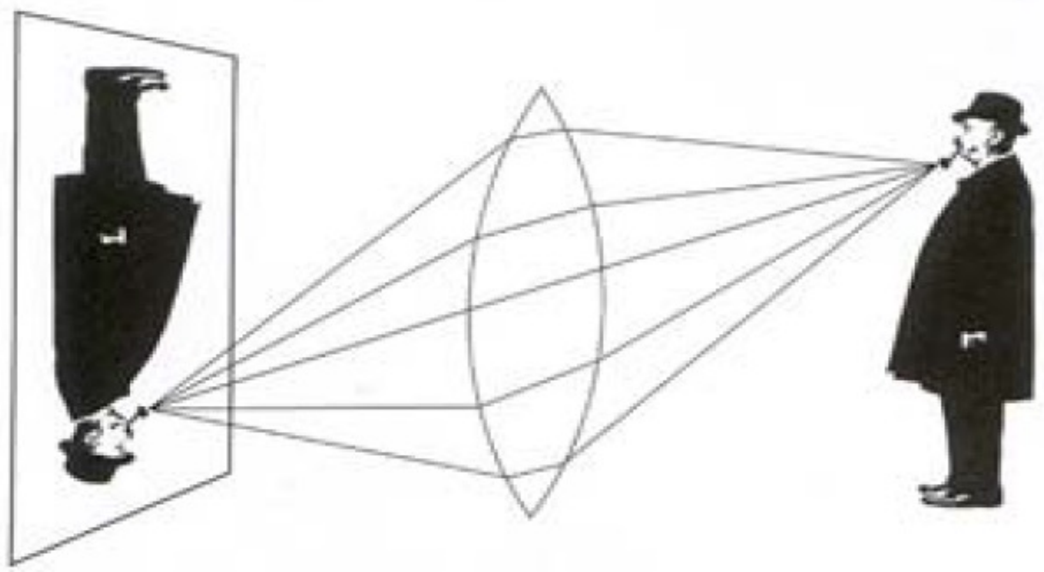
What is a camera ?

The Pinhole Camera model



From Photography, London et al.

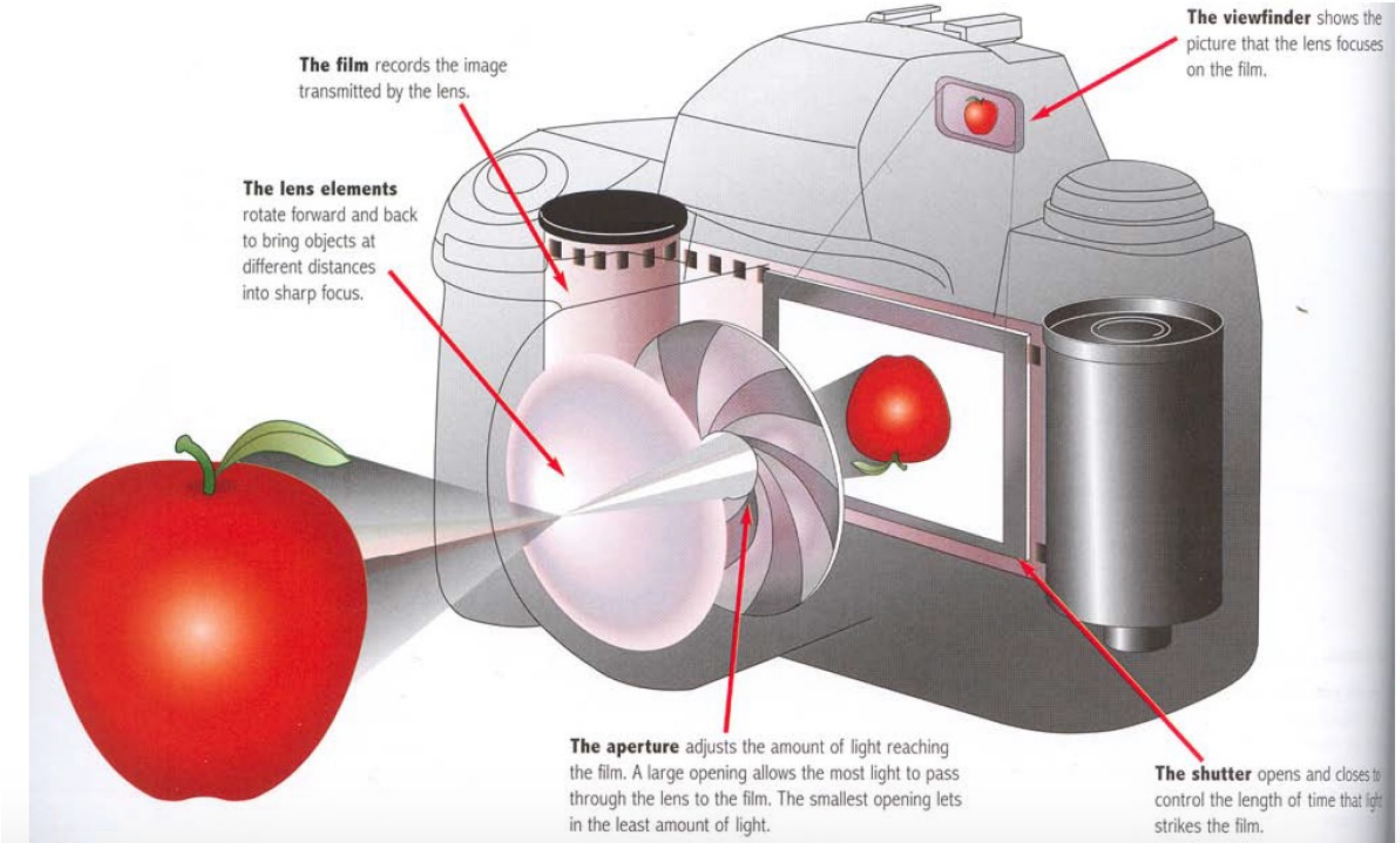
Camera with thin lens



The lens opening was much bigger than the pinhole, letting in far more light, but it focused the rays from each point on the subject precisely so that they were sharp on the film.

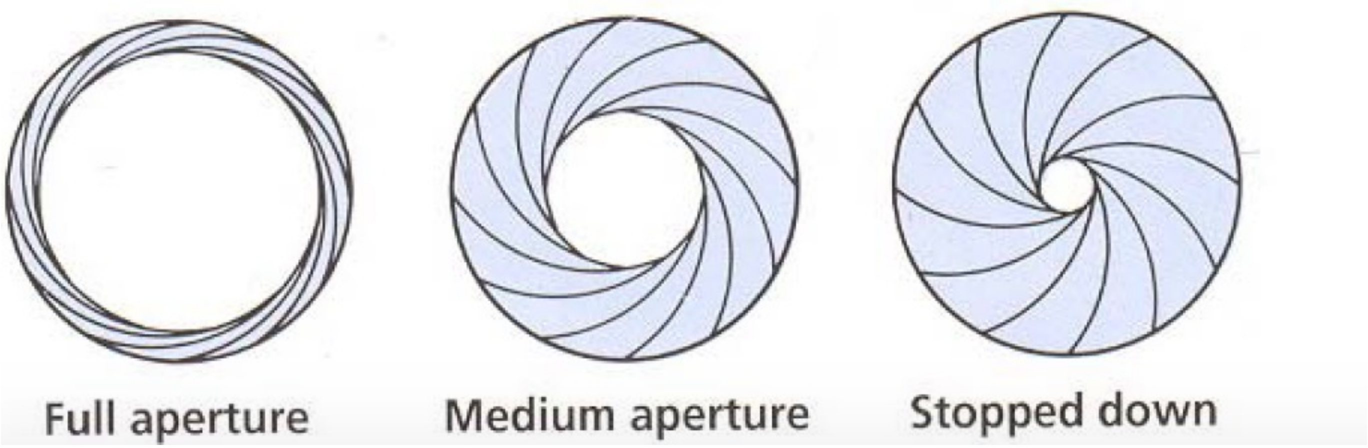
From Photography, London et al.

Lens + aperture +shutter +sensor + CPU

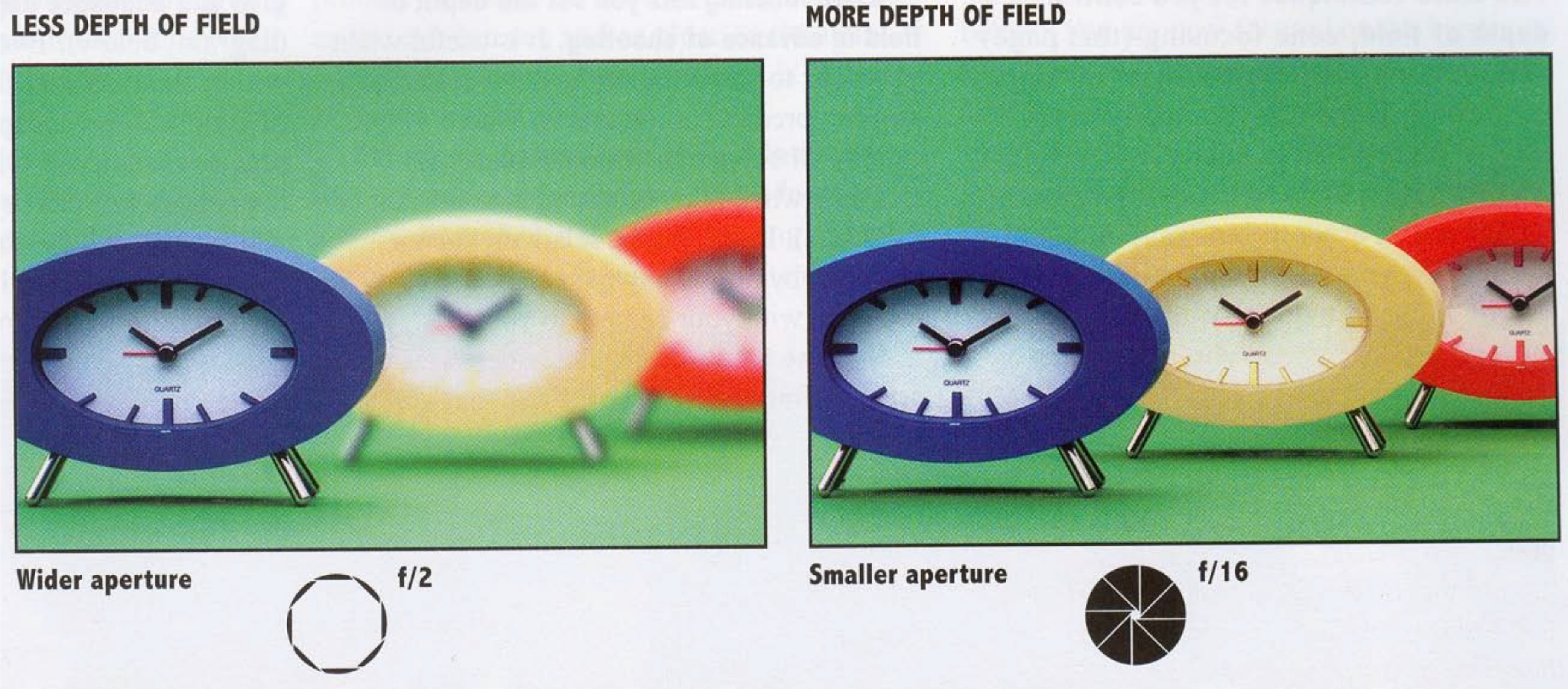


(this and following slides borrowed from Fredo Durand, MIT)

Mechanical aperture



Depth of field



Mechanical shutter

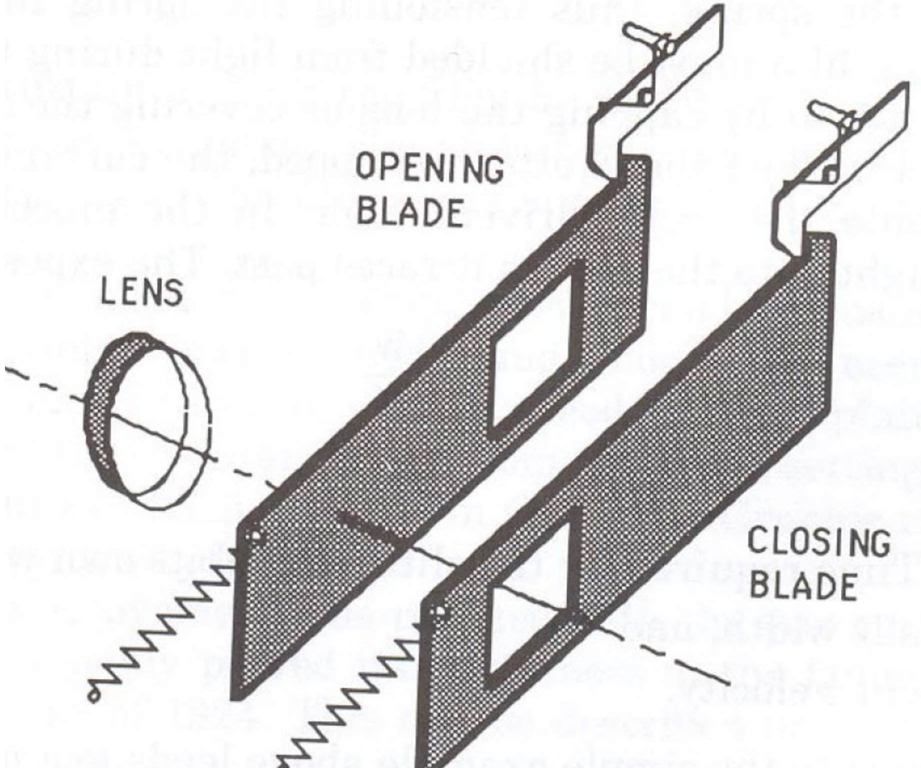
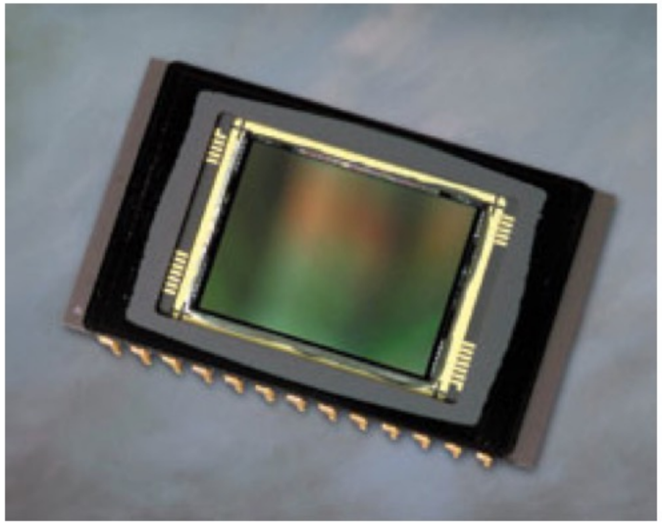
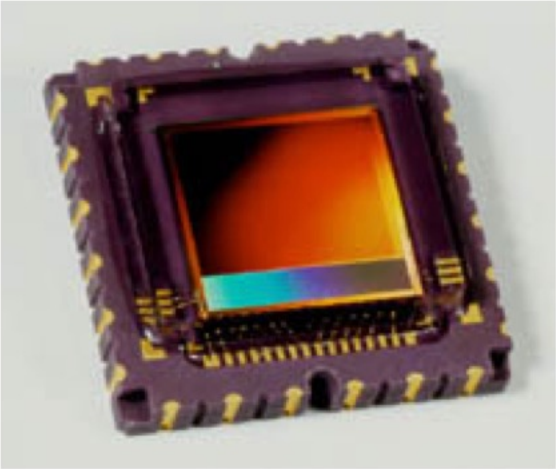


FIG. 2.8 Two-blade guillotine shutter.

Image Sensors

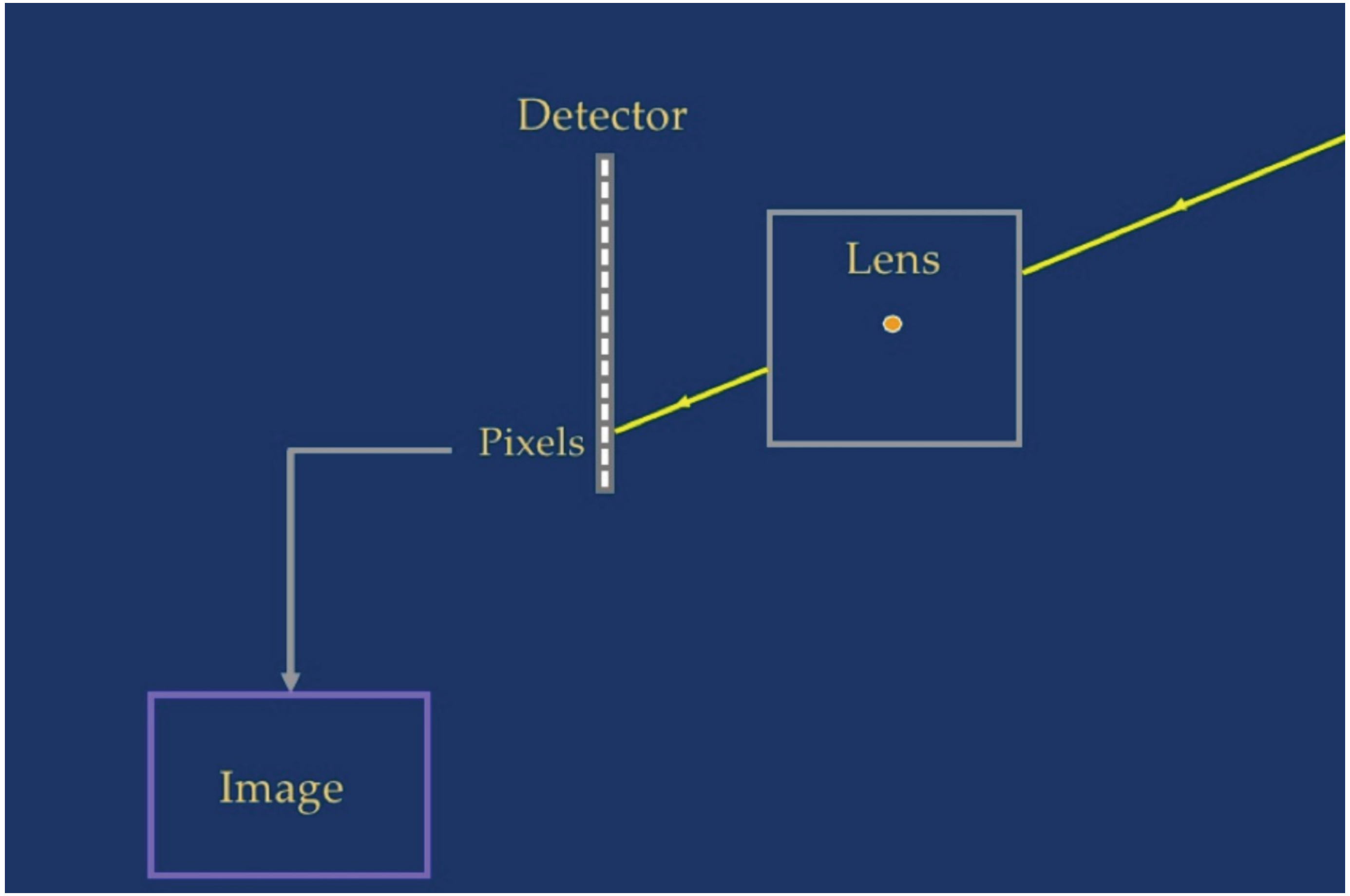


CCD



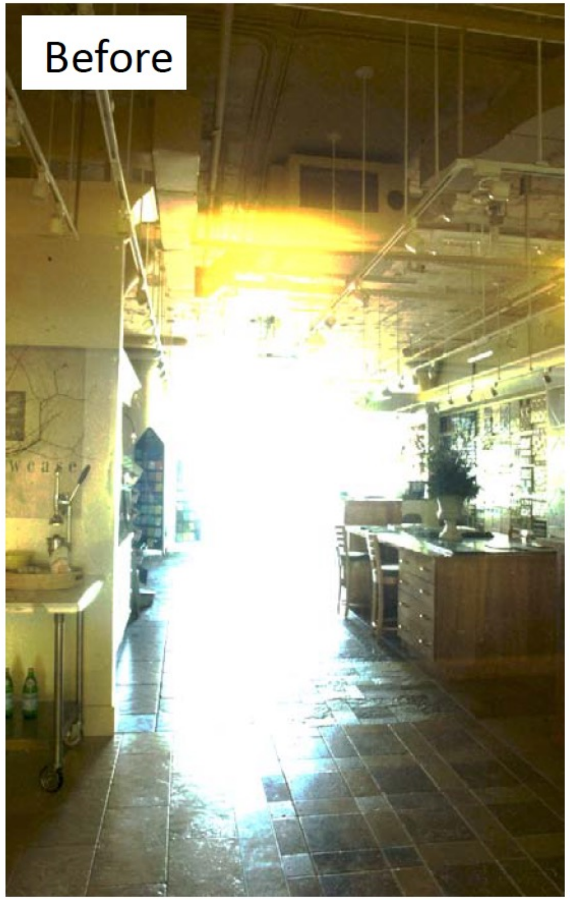
CMOS

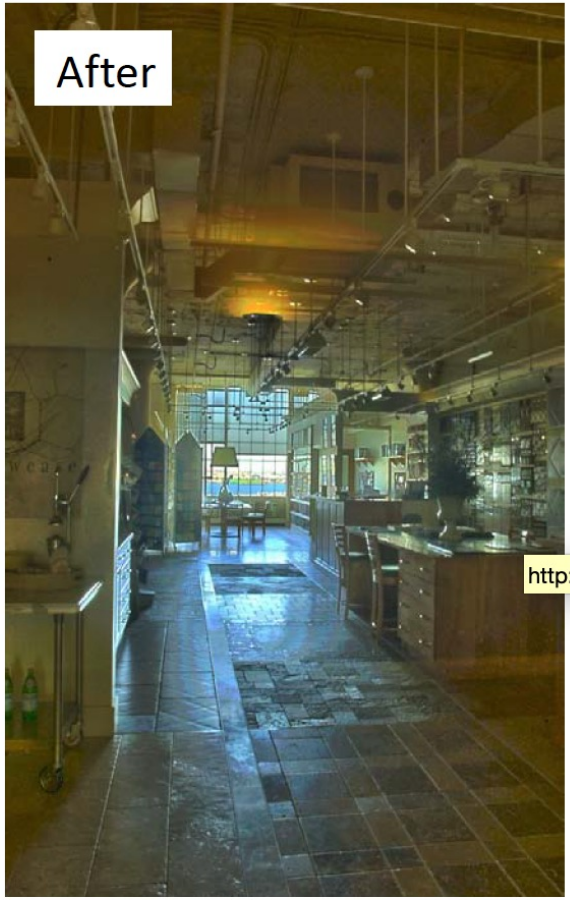
Abstract model



Example Computational photography algorithms

- HDR (high dynamic range imaging):

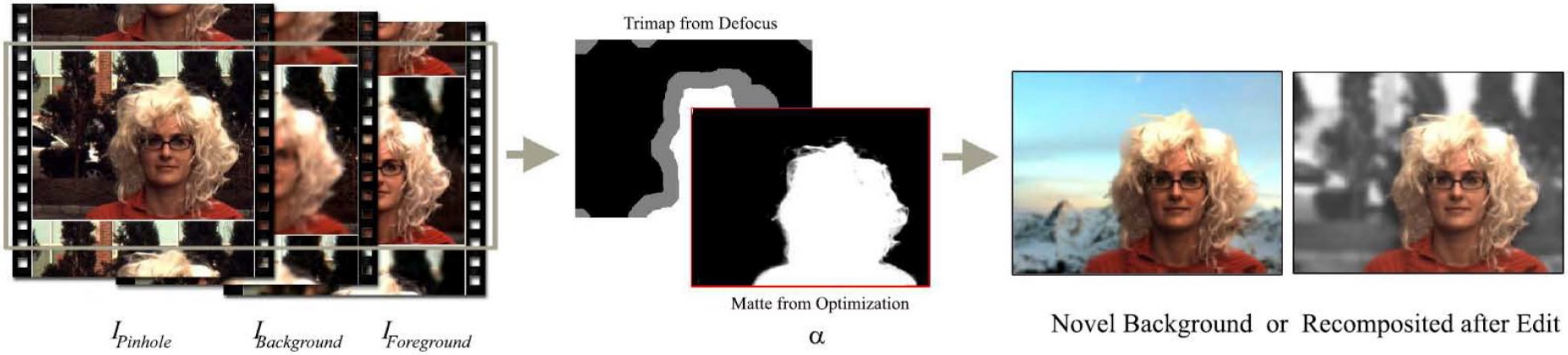




http://www.loc.gov/exhibits/empire/

Example: Photo-cutout (photoshop)

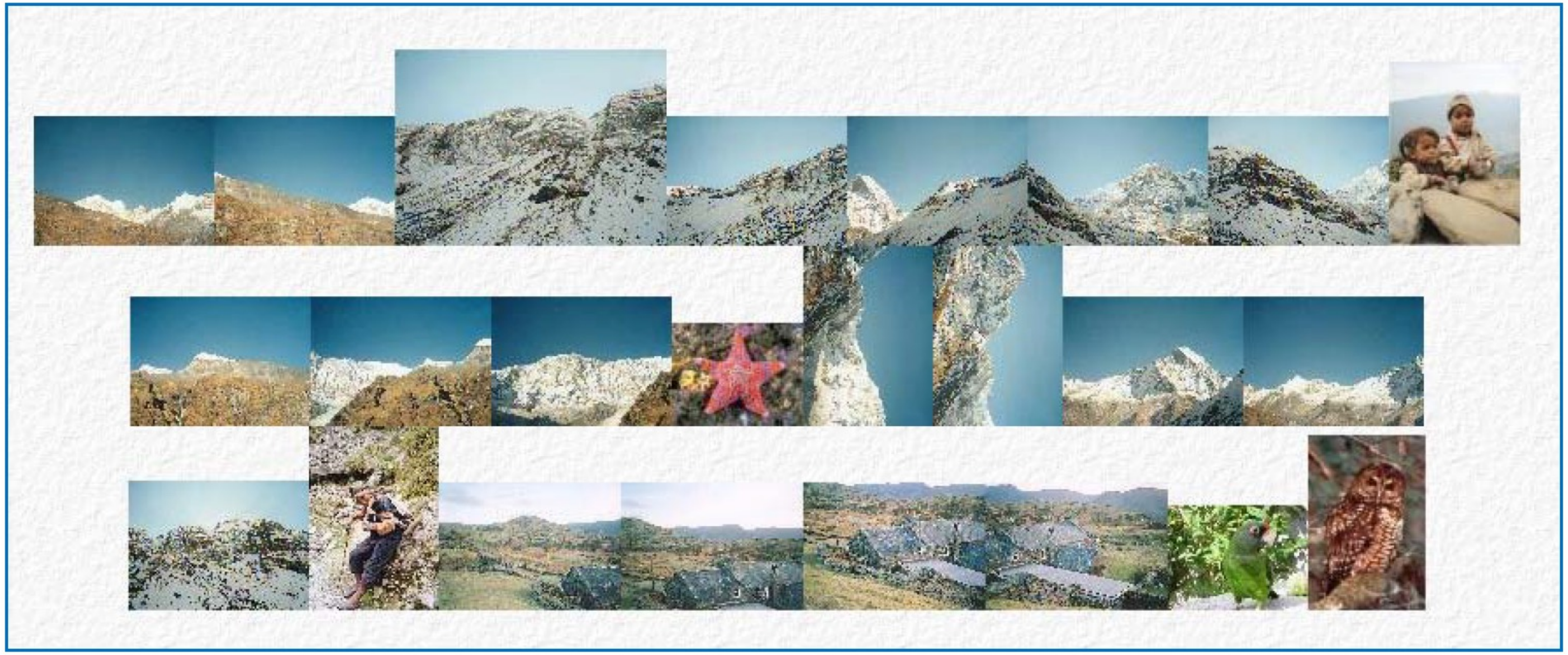
Example: Natural Image Matting



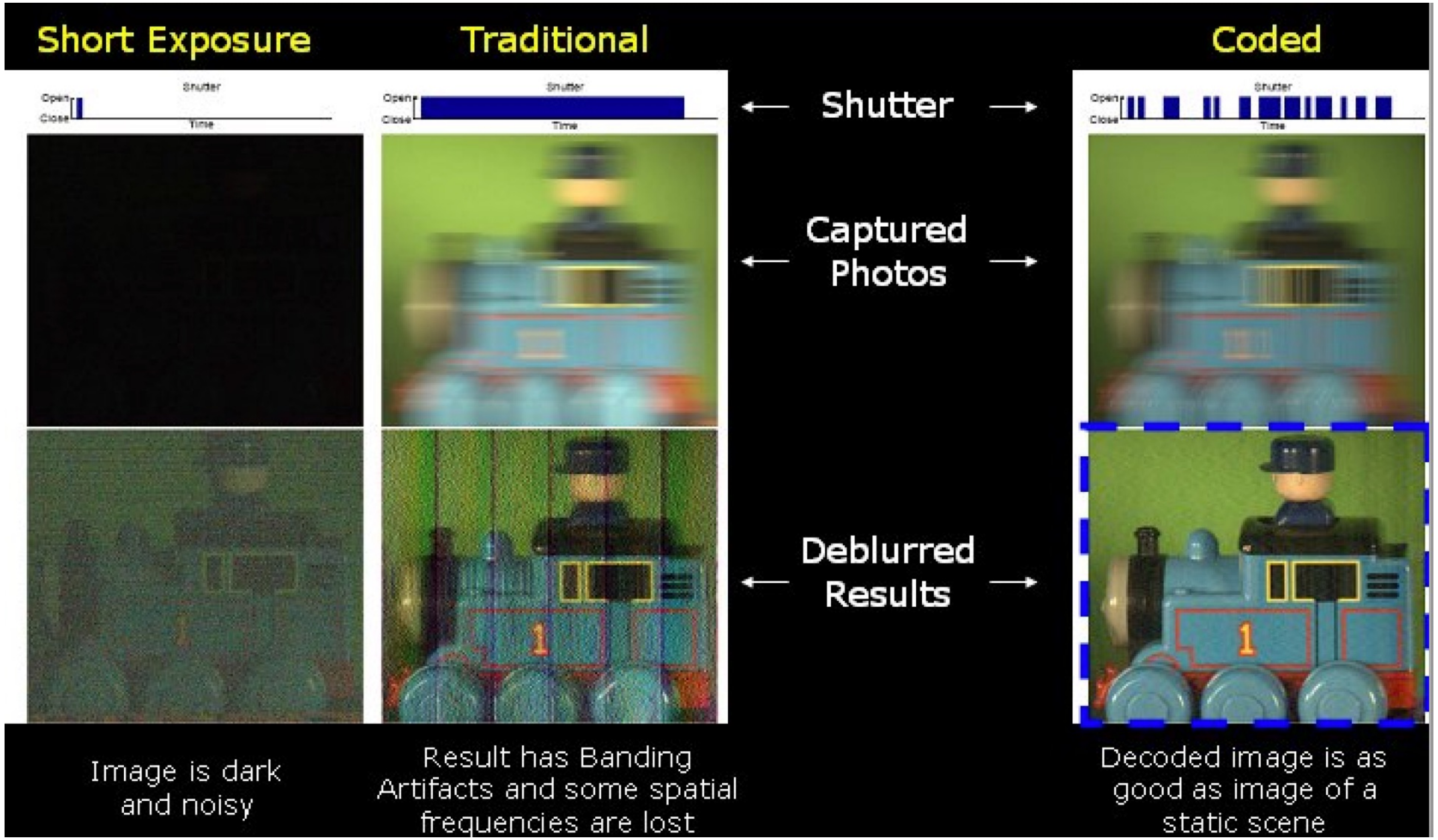
Example: matting and background replacement

Example: PhotoMontage

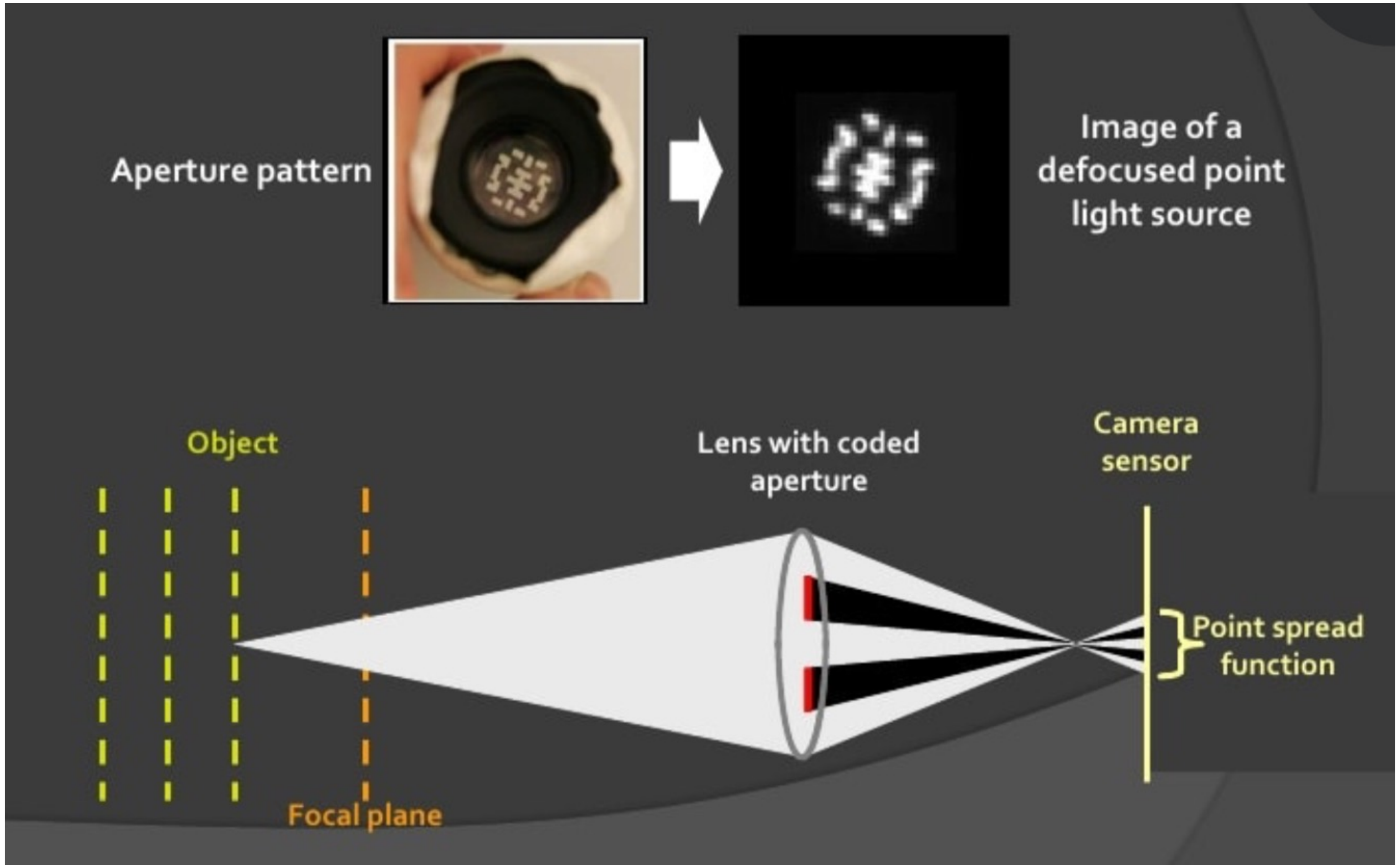
Example: Panoramic image stitching



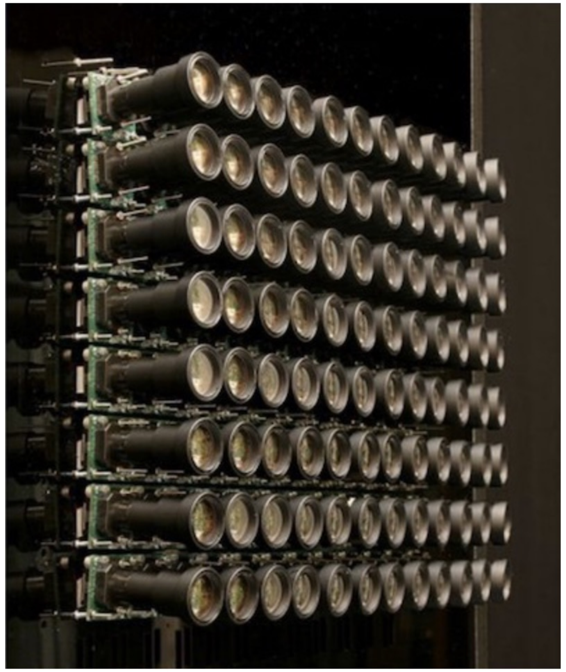
Example: coded shutter

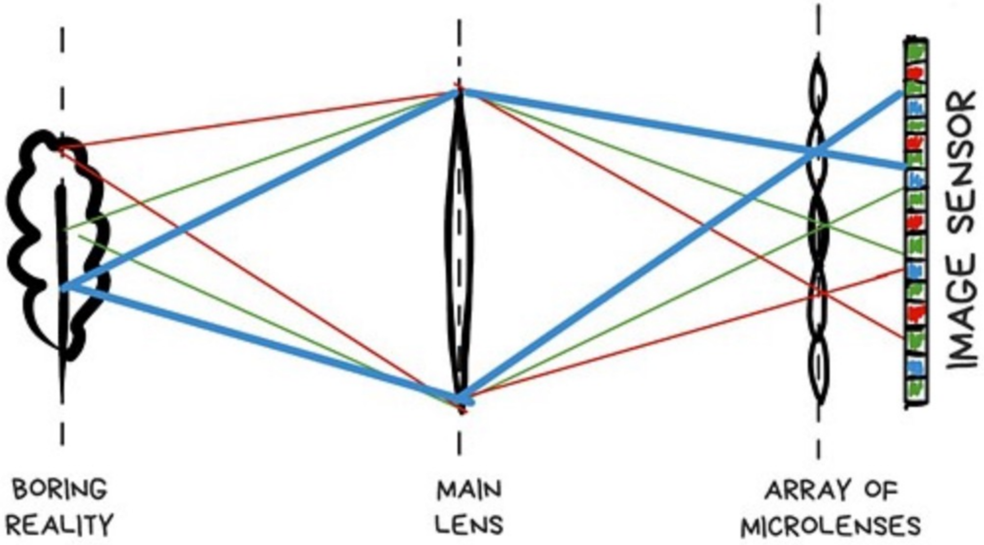


Example: coded aperture



Example: Light-field camera





Example: Light-field Lytro camera

Lytro - Wikipedia

Lytro Camera is Ready …

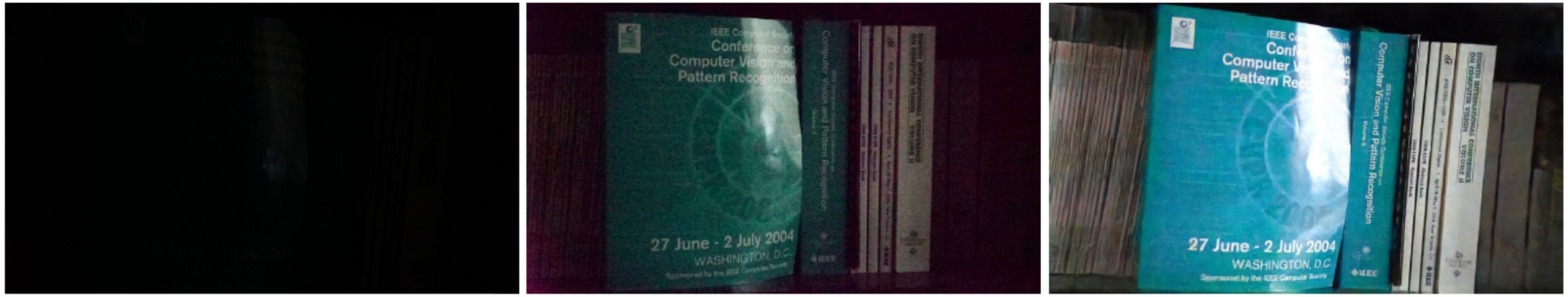
Example: Flash/no-Flash imaging

Example: extremem night-time image

Learning to See in the Dark

Chen Chen, Qifeng Chen, Jia Xu and Vladlen Koltun

IEEE Conference on Computer Vision and Pattern Recognition (CVPR), 2018



(a) Camera output with ISO 8,000 (b) Camera output with ISO 409,600 (c) Our result from the raw data of (a)

Figure. Extreme low-light imaging by a Sony a7S II camera using ISO 8000, f/5.6, 1/30 second. Dark indoor environment. The illuminance at the camera is <0.1 lux.

Author of the previous paper

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Biography

I am the Head of AI and General Manager at Huya Inc. I was a principal researcher and manager at Tencent AI Lab. Before returning to China, I worked as a senior research scientist in the Intel Visual Computing Lab, lead by the awesome Vladlen Koltun. I received my Ph.D. in Computer Sciences at the University of Wisconsin-Madison, with my thesis committee of Prof. Vikas Singh (advisor), Prof. Chuck Dyer, Prof. Jerry Zhu, Prof. Jude Shavlik, and Prof. Mark Craven. I was a visiting student in University of Toronto and in Toyota Technological Institute at Chicago, both working with the amazing Prof. Raquel Urtasun. Before graduate school, I obtained my B.S. degree from the Department of Computer Science and Technology at Nanjing University, China.

- **We are hiring motivated researchers/engineers/interns. If you work on computer vision/graphics, deep learning, speech recognition, or natual langrage processing, feel free to contact me.**

Example: Photo-Relighting

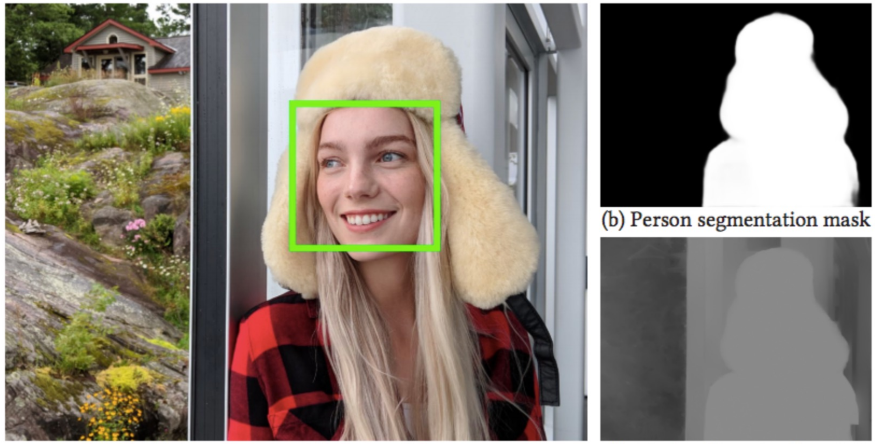
(a) Input image and estimated lighting (b) Rendered images from our method under three novel illuminations

Fig. 1. Given only a single input image taken with a standard cellphone camera of a portrait (a), our model is able to quickly (160 ms.) generate new images of our human subject as though they are illuminated under new, previously-unseen lighting environments (b).

Example: AI-powered “depth of field”

Google AI Blog

The latest from Google Research



(a) Input image with detected face

(b) Person segmentation mask

(c) Mask + disparity from DP

Depth of field

A general article on computational photography

AMERICAN **Scientist**

Computational Photography

BY BRIAN HAYES

New cameras don't just capture photons; they compute pictures

COMPUTER • TECHNOLOGY • PHOTOGRAPHY

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Computational Photography

Brian Hayes

THE DIGITAL CAMERA has brought a revolutionary shift in the nature of photography, sweeping aside more than 150 years of technology based on the weird and wonderful photochemistry of silver halide crystals. Curiously, though, the camera itself has come through this transformation with remarkably little change. A digital camera has a silicon sensor where the film used to go, and there's a new display screen on the back, but the lens and shutter and the rest of the optical system all work just as they always have, and so do most of the controls. The images that come out of the camera also look much the same—at least until you examine them microscopically.

But further changes in the art and science of photography may be coming soon. Imaging laboratories are experimenting with cameras that don't merely digitize an image but also perform extensive computations on the image data. Some of the experiments seek to improve or augment current photographic practices, for example by boosting the dynamic range of an image (preserving detail in both the

New cameras don't just capture photons; they compute pictures

era might have a setting that would cause it to render images in the style of watercolors or pen-and-ink drawings.

Making Pictures

Digital cameras already do more computing than you might think. The image sensor inside the camera is a rectangular array of tiny light-sensitive semiconductor elements called photosites. The image that eventually comes out of the camera is also a rectangular array, made up of colored pixels. You might therefore suppose there's a simple one-to-one mapping between the photosites and the pixels: Each photosite would measure the intensity and the color of the light falling on its

tant picket fence, the spacing between pickets in the image might be close to the spacing between photosites in the sensor, leading to disruptive moiré or aliasing effects. The low-pass filter eliminates these artifacts, but the blurring must then be corrected by an algorithmic sharpening operation. Still another computational process adjusts the color balance of the final image.

Given all this post-processing of the image data, it seems a digital camera is not simply a passive recording device. It doesn't *take* pictures; it *makes* them. The sensor array intercepts a pattern of illumination, just as film used to do, but that's only the start of the process that creates the image. In existing digital cameras, all the algorithmic wizardry is directed toward making digital pictures look as much as possible like their wet-chemistry forebears. But once the camera is equipped with an image-processing computer, that device can also run more ambitious or fanciful programs. Images from such a computational camera could capture aspects of reality that other cameras miss.

In today's paper reading session

- Paper-1: Coded Aperture
- Paper-2: Coded Shutter

Format:

- Supervised reading: 20 minutes.
- Breakout room group discussion: 30 minutes.
- Report back: 20 minutes.

Paper-1:

Image and Depth from a Conventional Camera with a Coded Aperture

Anat Levin   Rob Fergus   Frédo Durand   William T. Freeman

Massachusetts Institute of Technology, Computer Science and Artificial Intelligence Laboratory

Figure 1: **Left:** *Image captured using our coded aperture.* **Center:** *Top, closeup of captured image. Bottom, closeup of recovered sharp image.* **Right:** *Recovered depth map with color indicating depth from camera (cm) (in this this case, without user intervention).*

Paper-2:

Coded Exposure Photography: Motion Deblurring using Fluttered Shutter

Ramesh Raskar* Amit Agrawal Jack Tumblin
Mitsubishi Electric Research Labs (MERL), Cambridge, MA Northwestern University

(b) Rectified Crop

(a) Blurred Image (c) Deblurred Image

Figure 1: Coded exposure enables recovery of fine details in the deblurred image. (a) Photo of a fast moving vehicle. (b) User clicks on four points to rectify the motion lines and specifies a rough crop. (c) Deblurred result. Note that all sharp features on the vehicle (such as text) have been recovered.

Below we will directly use Levin's slides, and Raskar's slides to explain their work of coded capture, respectively.

Breakout room: Now it is your turn.

- Breakout room group discussion & report:
- Check your name on Zoom
- Take note: breakout room ID, room members, “Mr/Ms speaker”.

- Your task:
  - Recorded your Room ID, and room members’ names, and nominate a “Speaker”.
  - Together you discuss and pick one paper, either (1) the ”coded aperture”, or (2) the “coded shutter”;

  - Quickly re-read it for about 5~10 minutes.
  - Discuss their limitations/drawbacks, for another 20 minutes.

  - Try to answer the following “critical analysis” questions → page turn ..
  - Report back in 3 minutes by the “Mr/Ms speaker”. Tutor may record your report.

Critical Analysis

5.1. Are the paper's contributions significant?

Are the contribution/improvement trivial, incremental? Why previous efforts failed ?

5.2. Are the authors' main claims valid?

Have they convincingly validated their main idea? Any hole in their arguments, derivation, experiments ?

5.3. Limitation and weaknesses

Any limitation/weakness of their method? What can be done to improve the work ?

What would you do to address/overcome their weaknesses?

5.4. Extension and future work

What *extra* experiments that you would suggest the authors to conduct in order to strengthen the result ?

Can you think of other possible applications of the method/ideas (assuming valid) presented in the paper?

What are possible future works?

5.5. Is the paper stimulating or inspiring ?

Many papers (even those published ones) are dull, while some are exciting. What is your opinion about this paper and why?

5.6. Conclusion and personal reflection

First, draw a short conclusion about this paper.

Then, if you were tasked to solve the research problem, what would you do differently? an alternative solution ?

Finally, in one sentence, summarize what you have learn from reading this paper.