Computational Photography

Independent Study Presentation 3 & 4:

Generalized Sensors, Computational Illumination for Computational Photography & Essence Photography

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Overview of the Presentation

Generalized Sensors

Computational Illumination

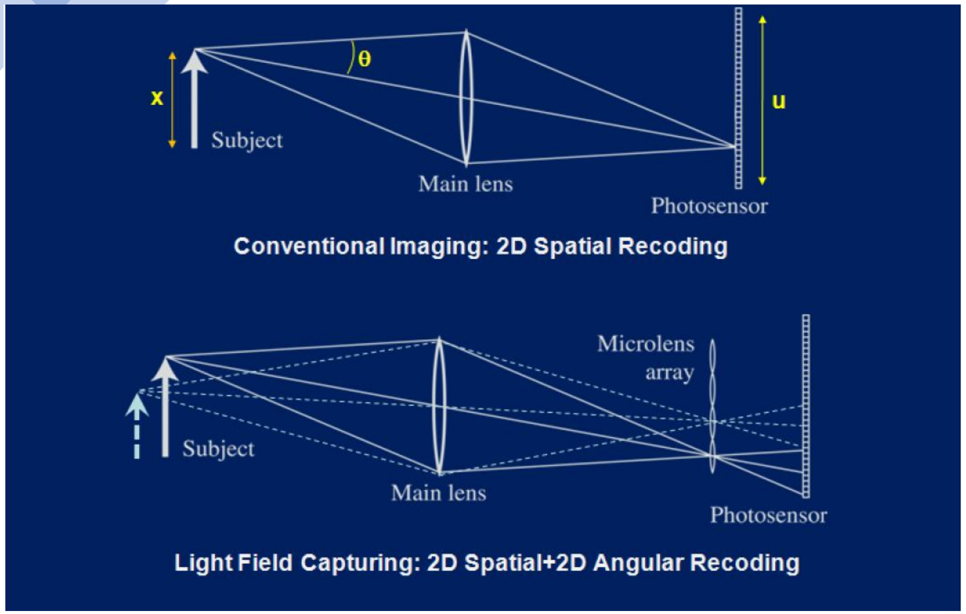
Essence Photography

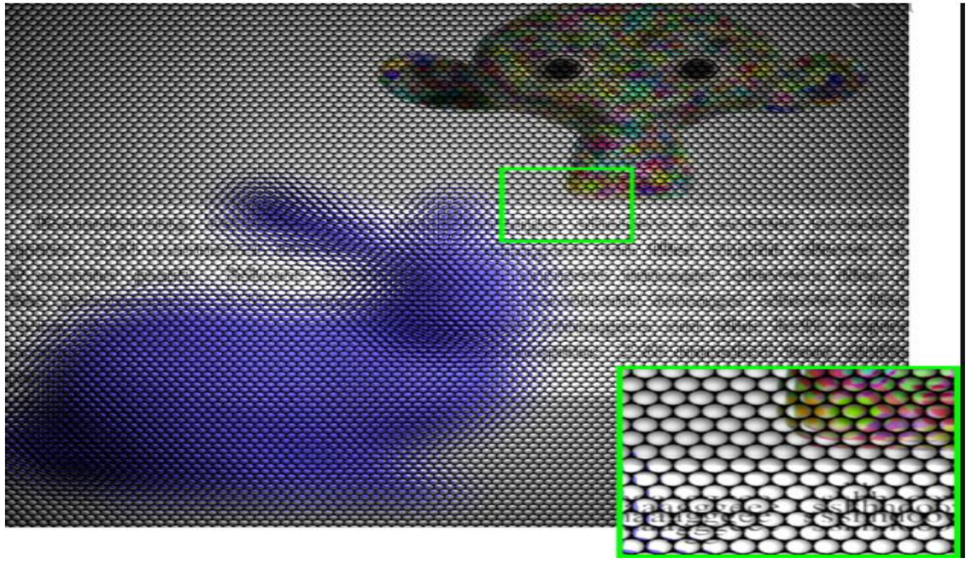
Generalized Sensors

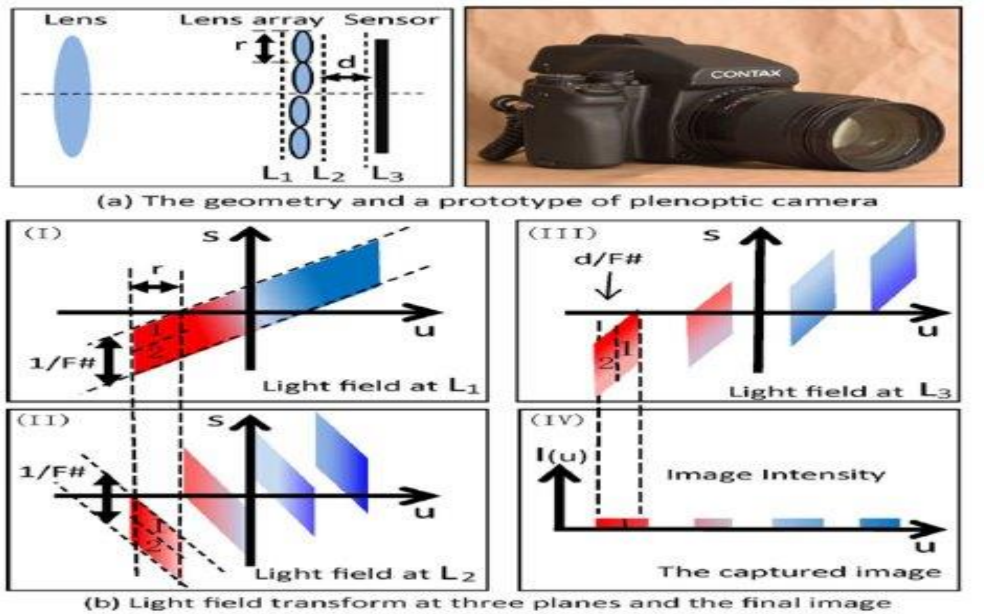
Overview of Generalized Sensors

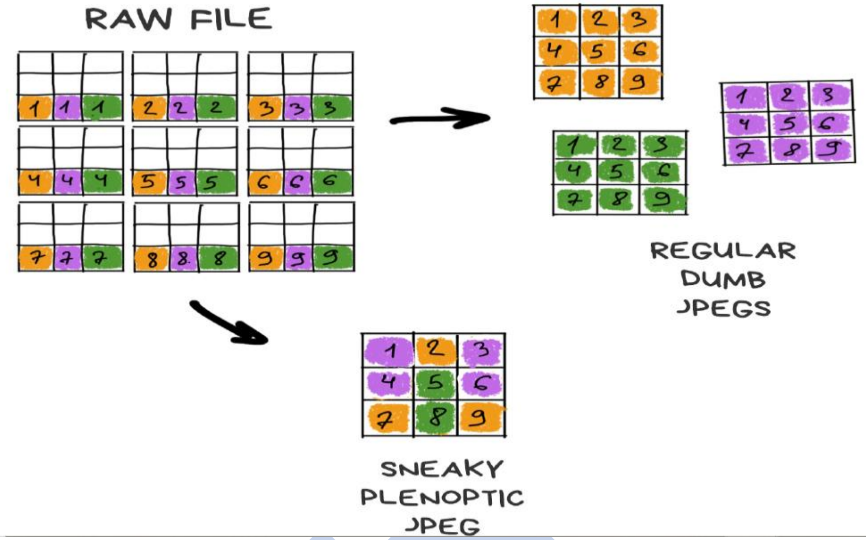
- Plenoptic Camera
- Structural Changes in Sensors
- Assorted Pixels
- FOVEON Sensor
- Penrose Pixel
- Sensor Motion

Plenoptic Camera



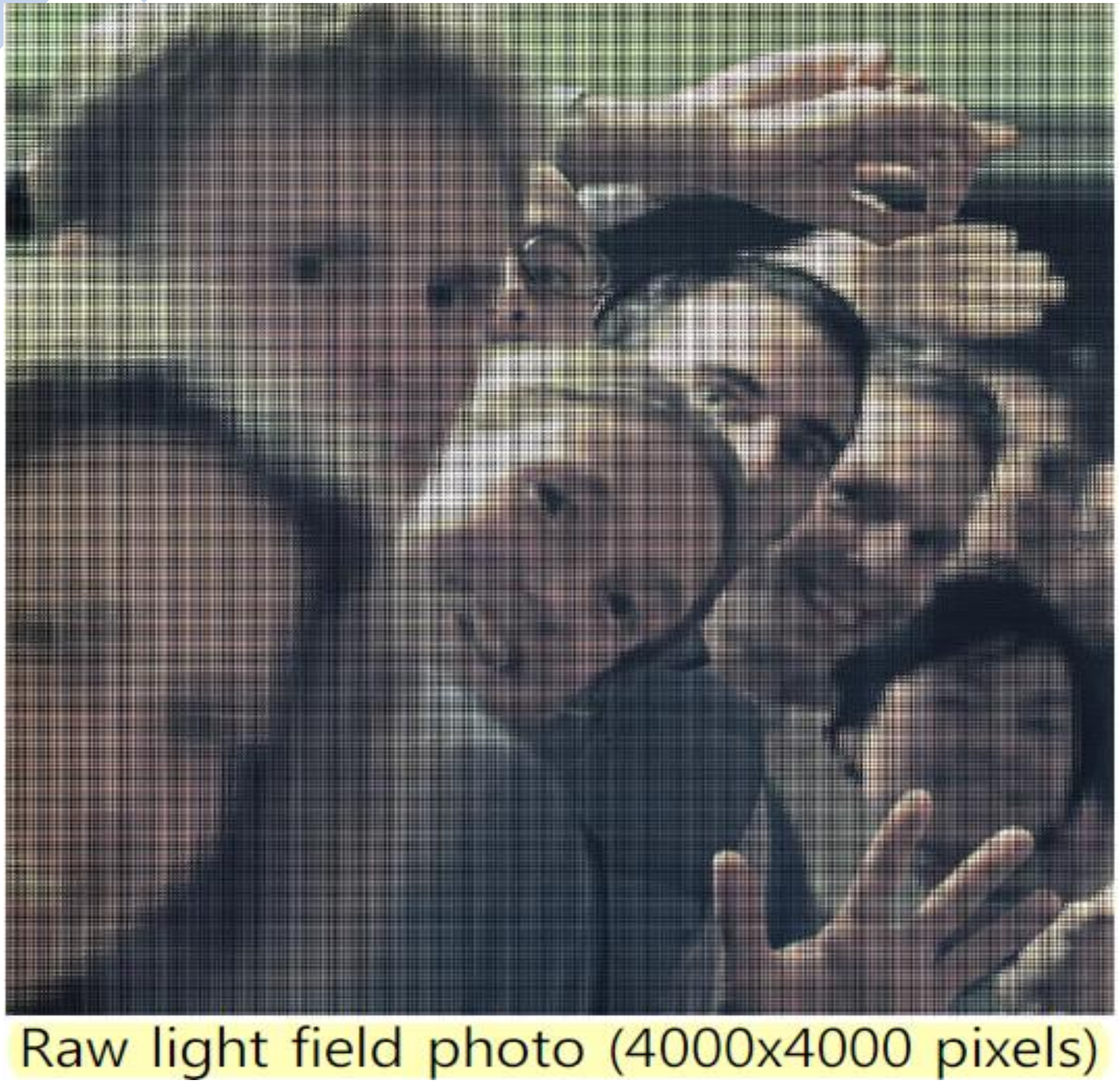


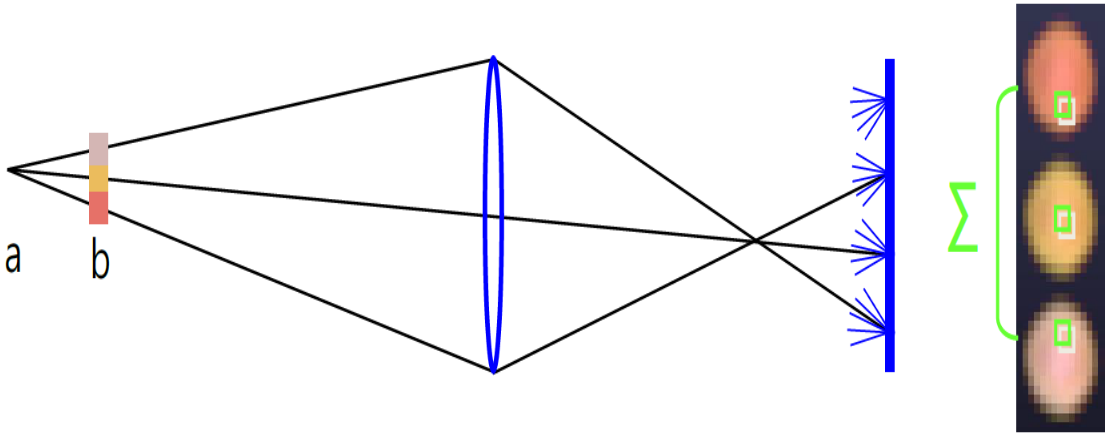




Pic Credit:Google Images and blog vas3k.com

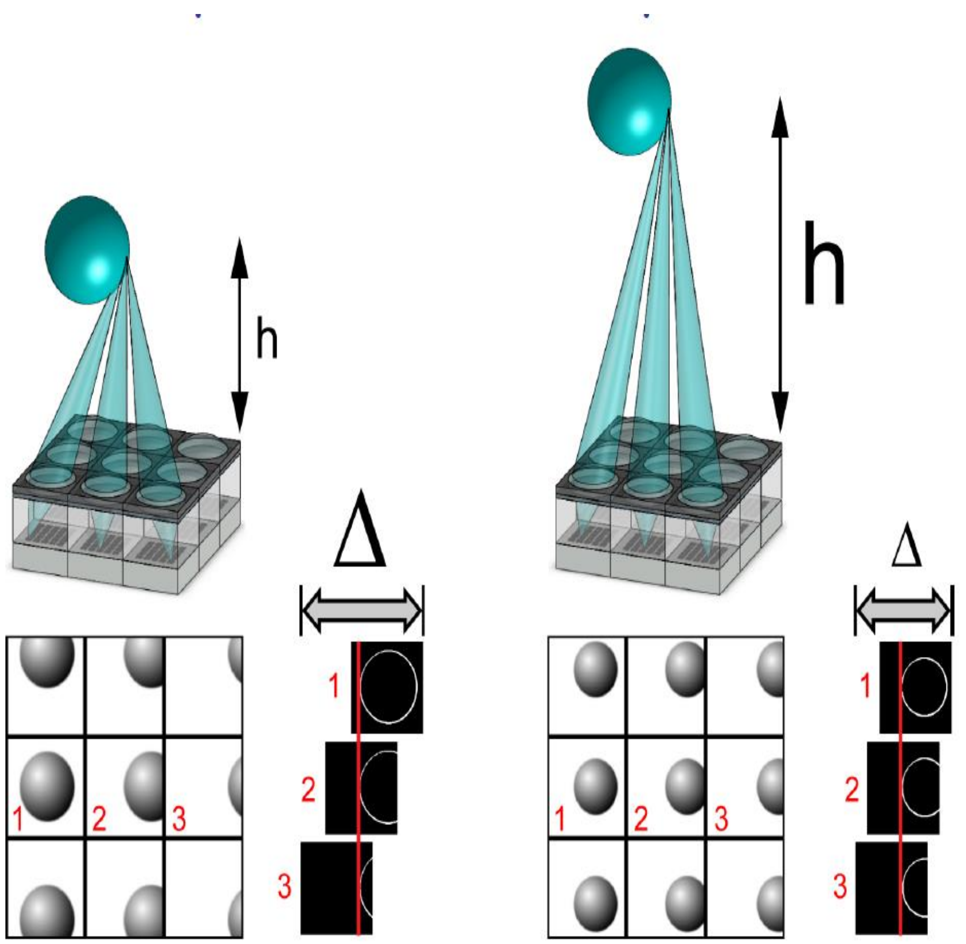
Plenoptic Camera for Refocusing



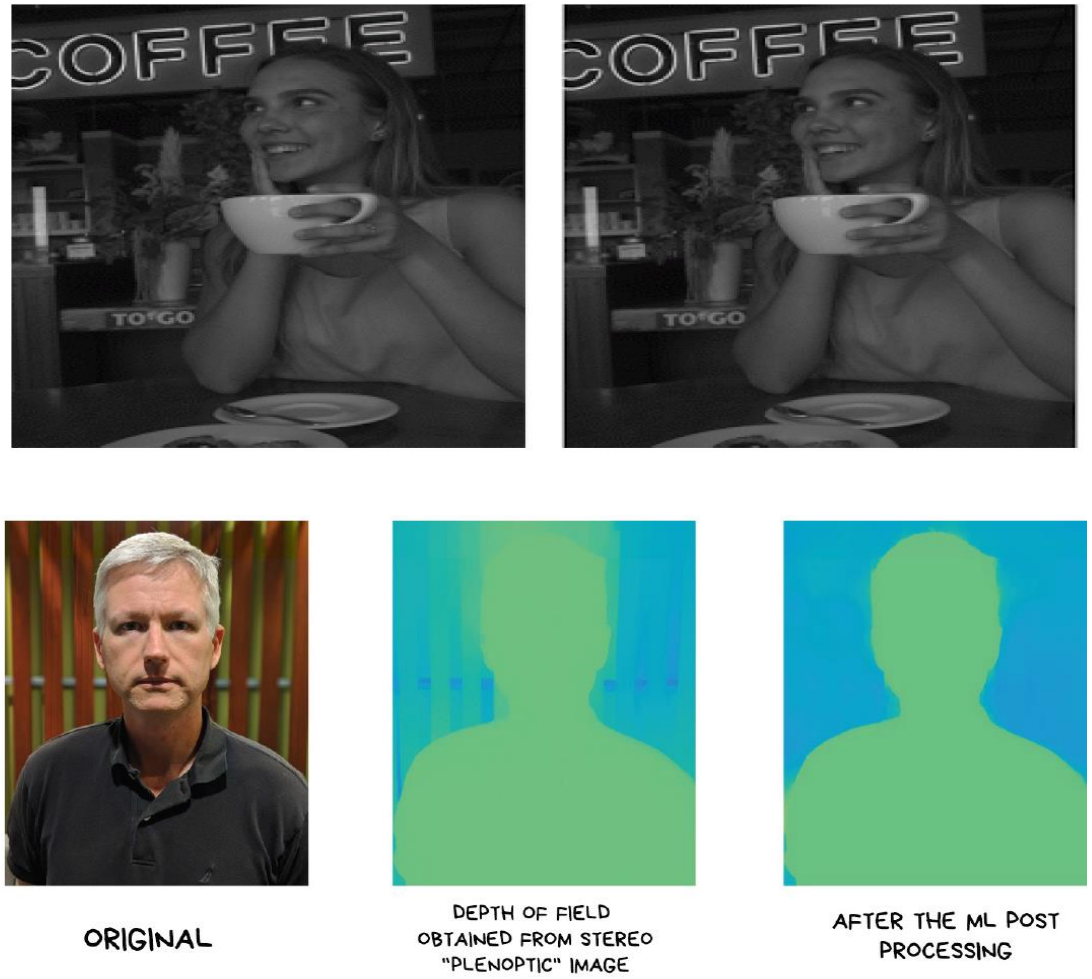


Pic Credit: Stanford Tech Report CTSR 20052005-02

Plenoptic Camera for Depth



Pic Credit: Computational Sensors ICCP 2009



Pic Credit:Google Images and blog vas3k.com

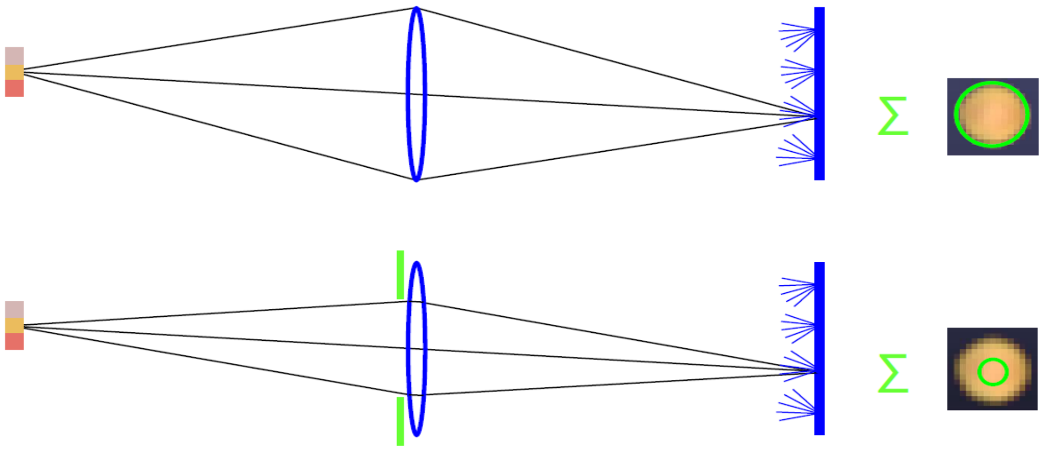
Plenoptic Camera for Synthetic Aperture

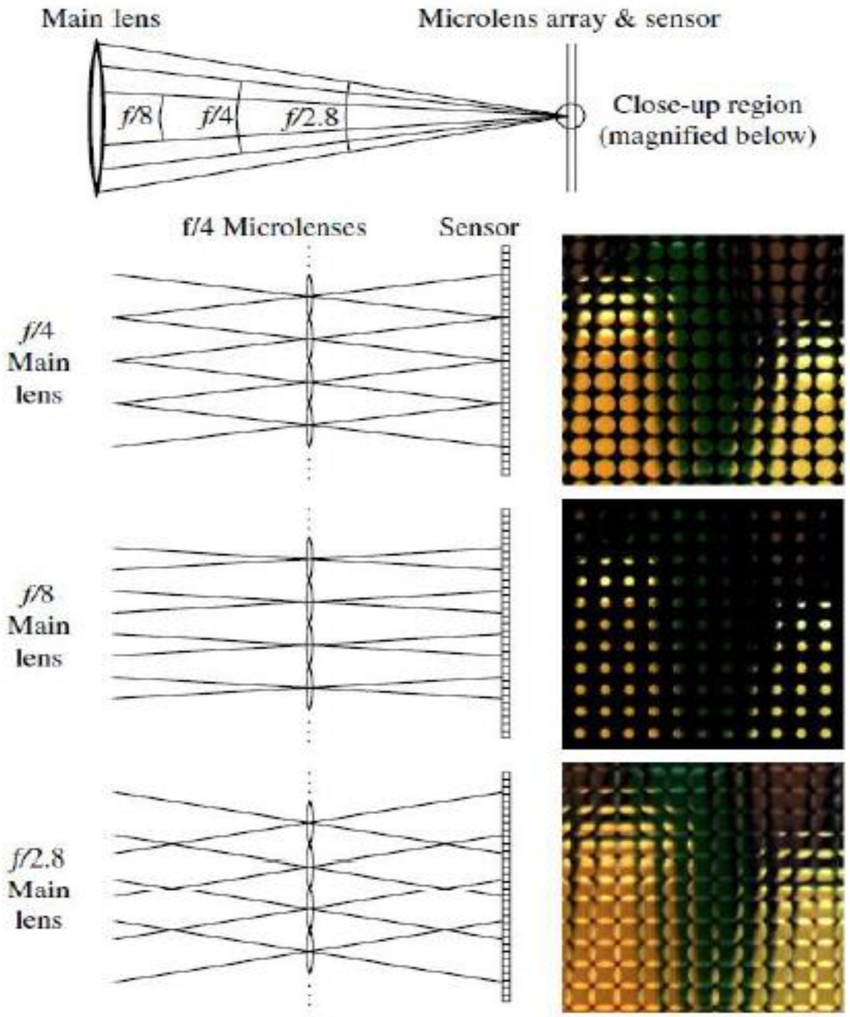
conventional photograph, main lens at f / 4

conventional photograph, main lens at f / 22

light field, main lens at f / 4, after all-focus algorithm [Agarwala 2004]

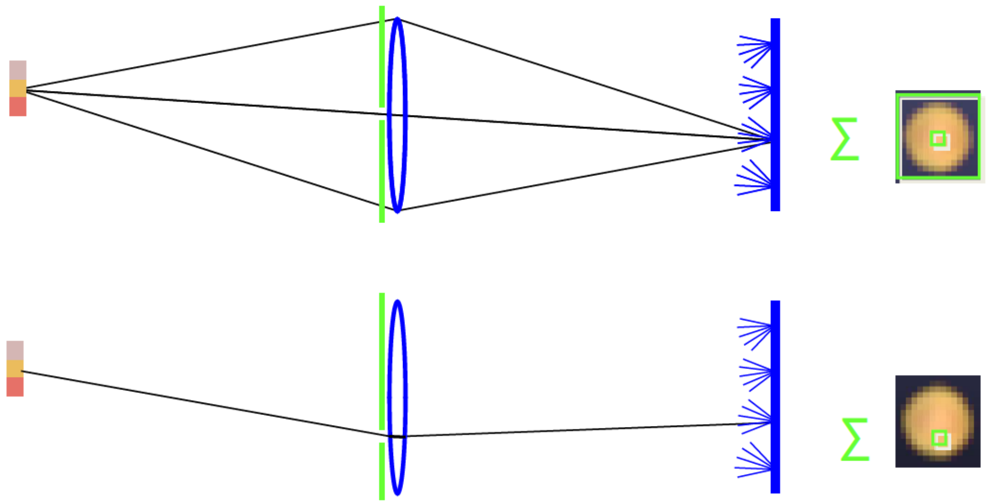
(from Stanford Tech Report CTSR 2005-02)

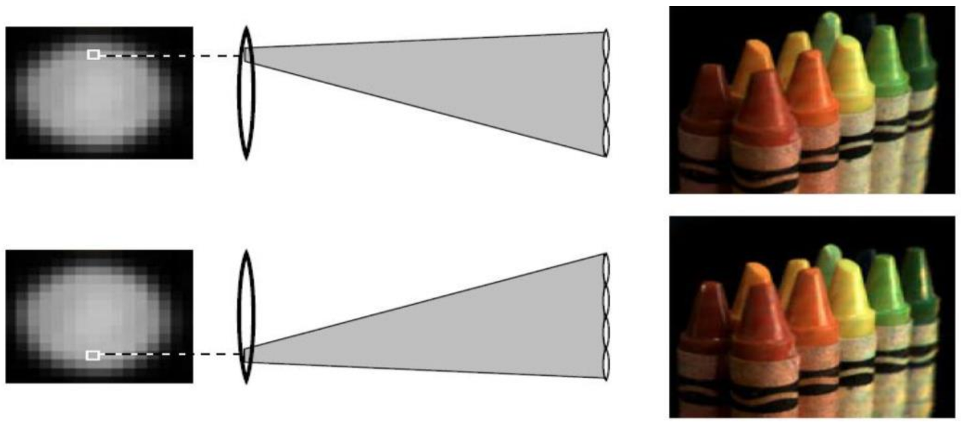




Pic Credit: Stanford Tech Report CTSR 20052005-02

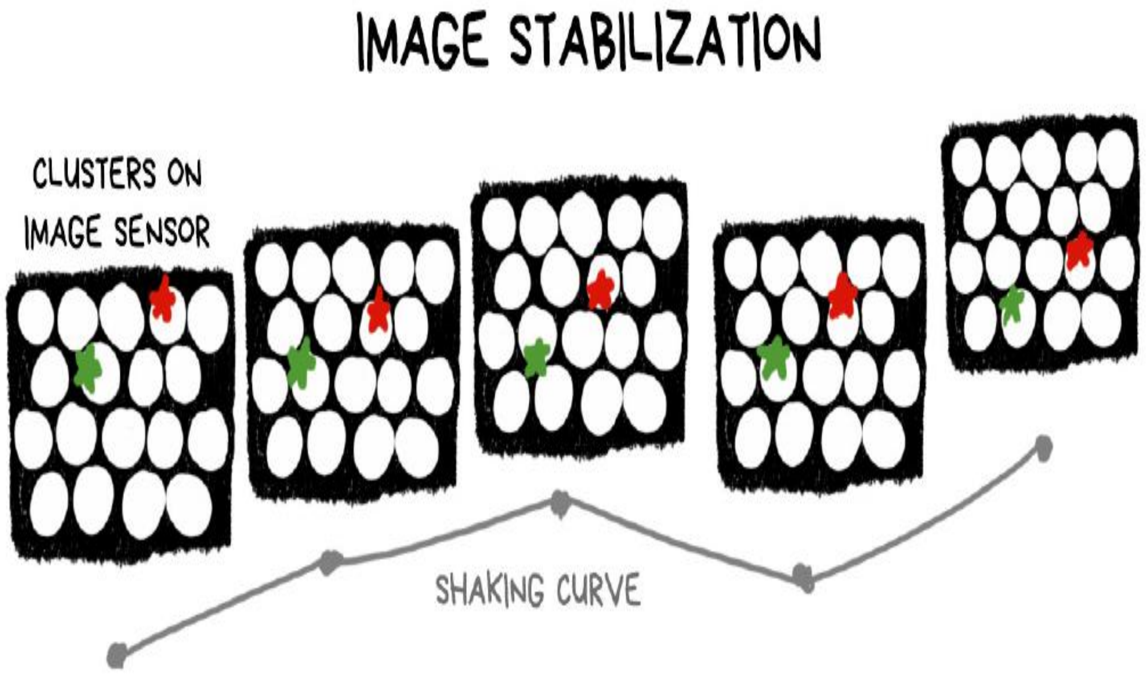
Plenoptic Camera for Slicing

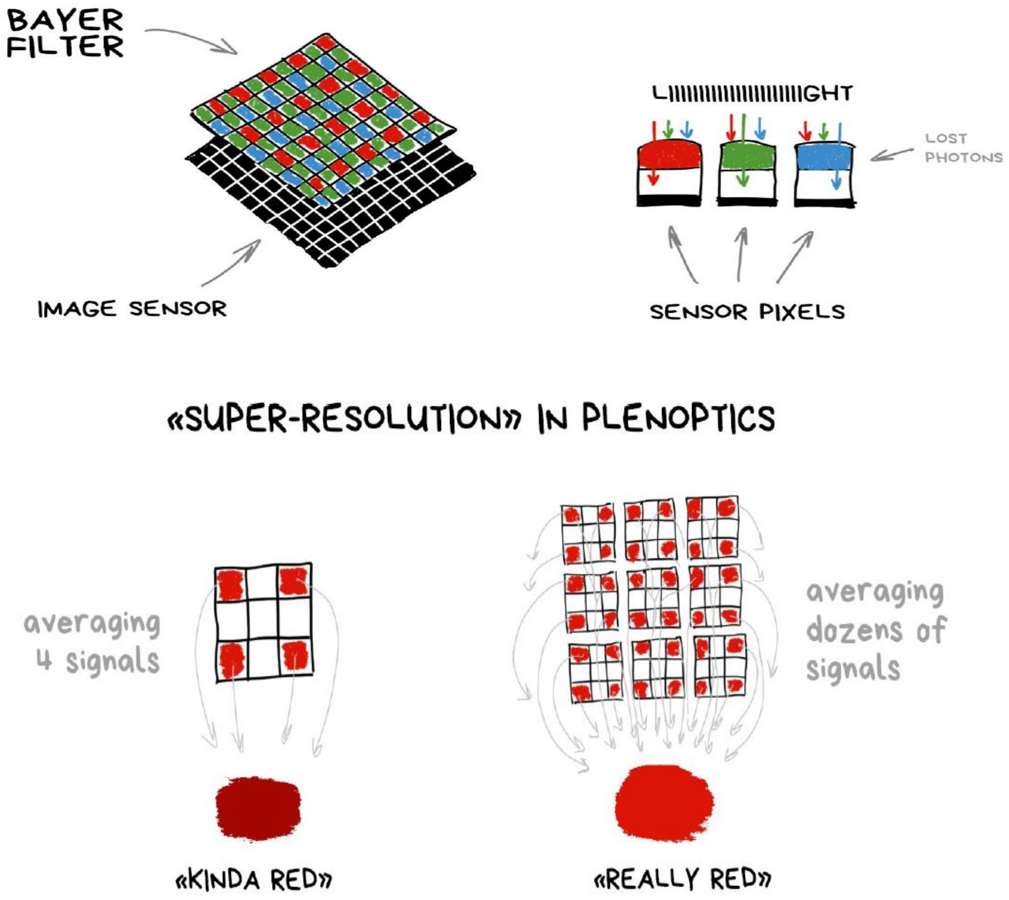




Pic Credit:Google Images and blog vas3k.com

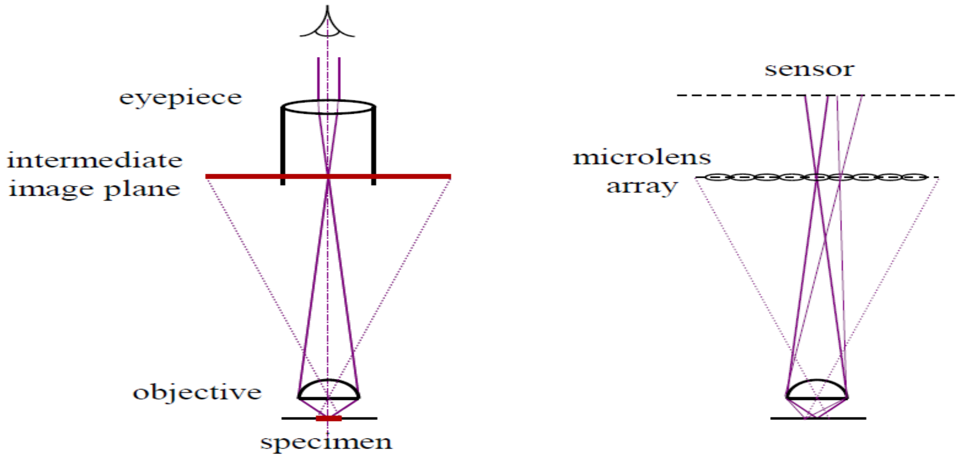
Plenoptic Camera for Image Stabilization and Super-Resolution



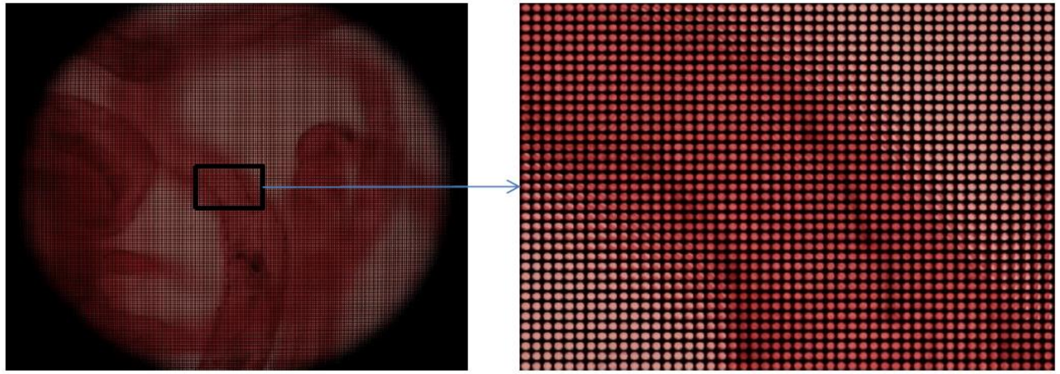


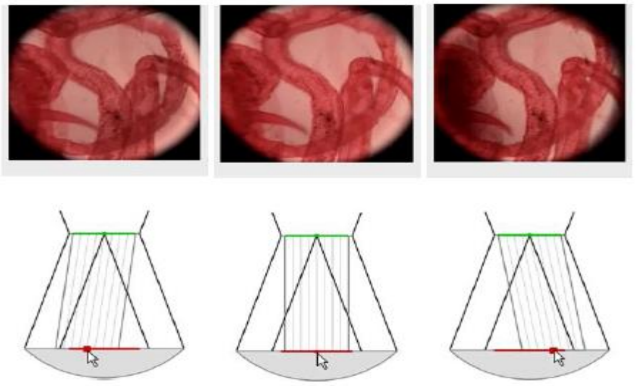
Pic Credit:Google Images and blog vas3k.com

Light Field Microscopy



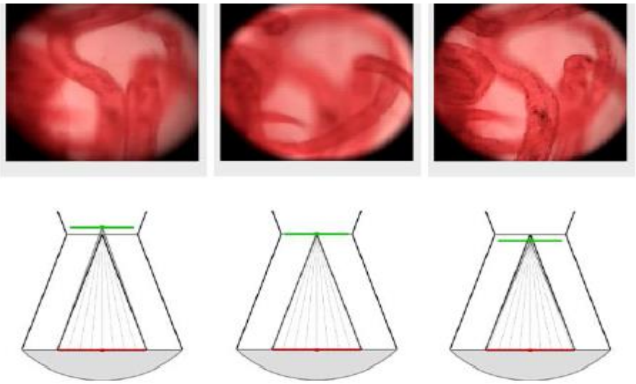
(a) a conventional microscope (b) a light field microscope





<Figure 3.15 Specimen’s view change by user interaction>

(from left to right, left-side, front and right-side view)

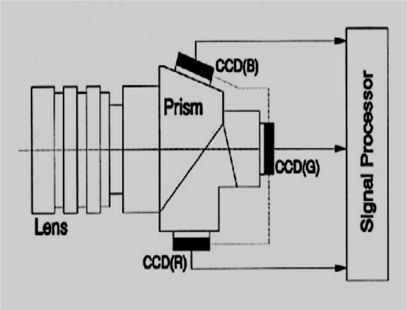


<Figure 3.16 Specimen’s focal plane change>

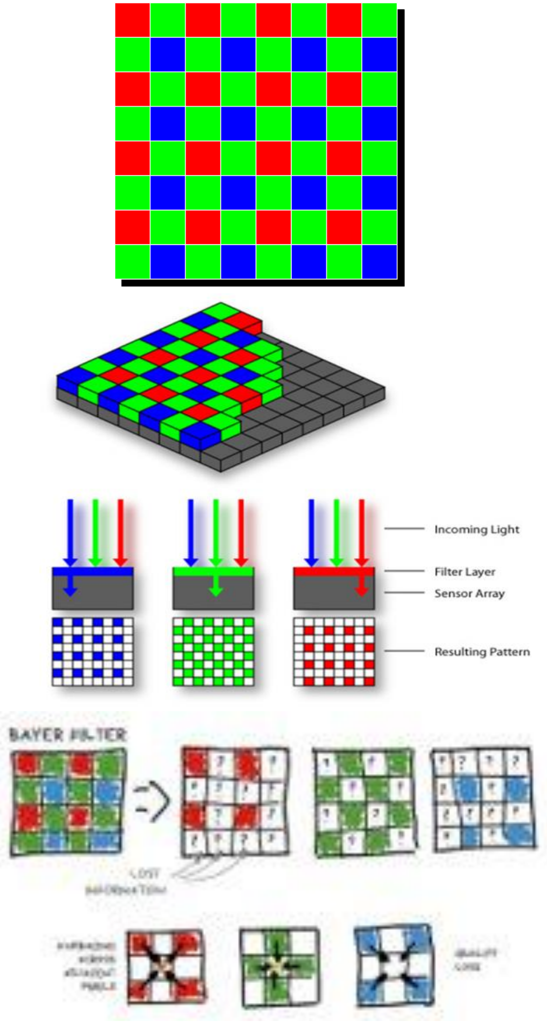
(from left to right, left-side, front and right-side view)

Pic Credit: LEVOY, M.,NG, R.,ADAMS, A., FOOTER, M., AND HOROWITZ,M. 2006. Light field microscopy. ACM Trans. Graph. 22, 2

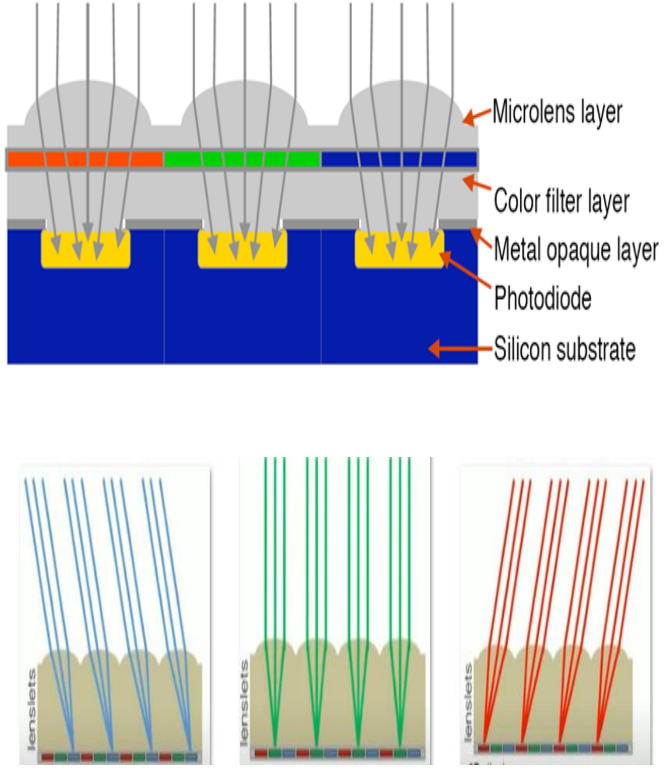
Structural Changes in Sensors



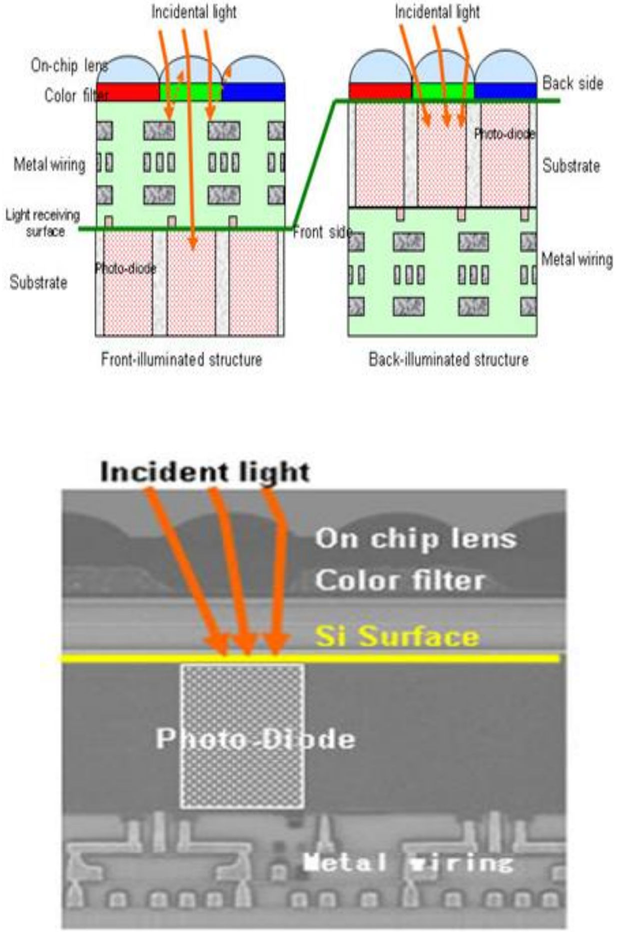
3 chip sensor



Bayer Mosaic



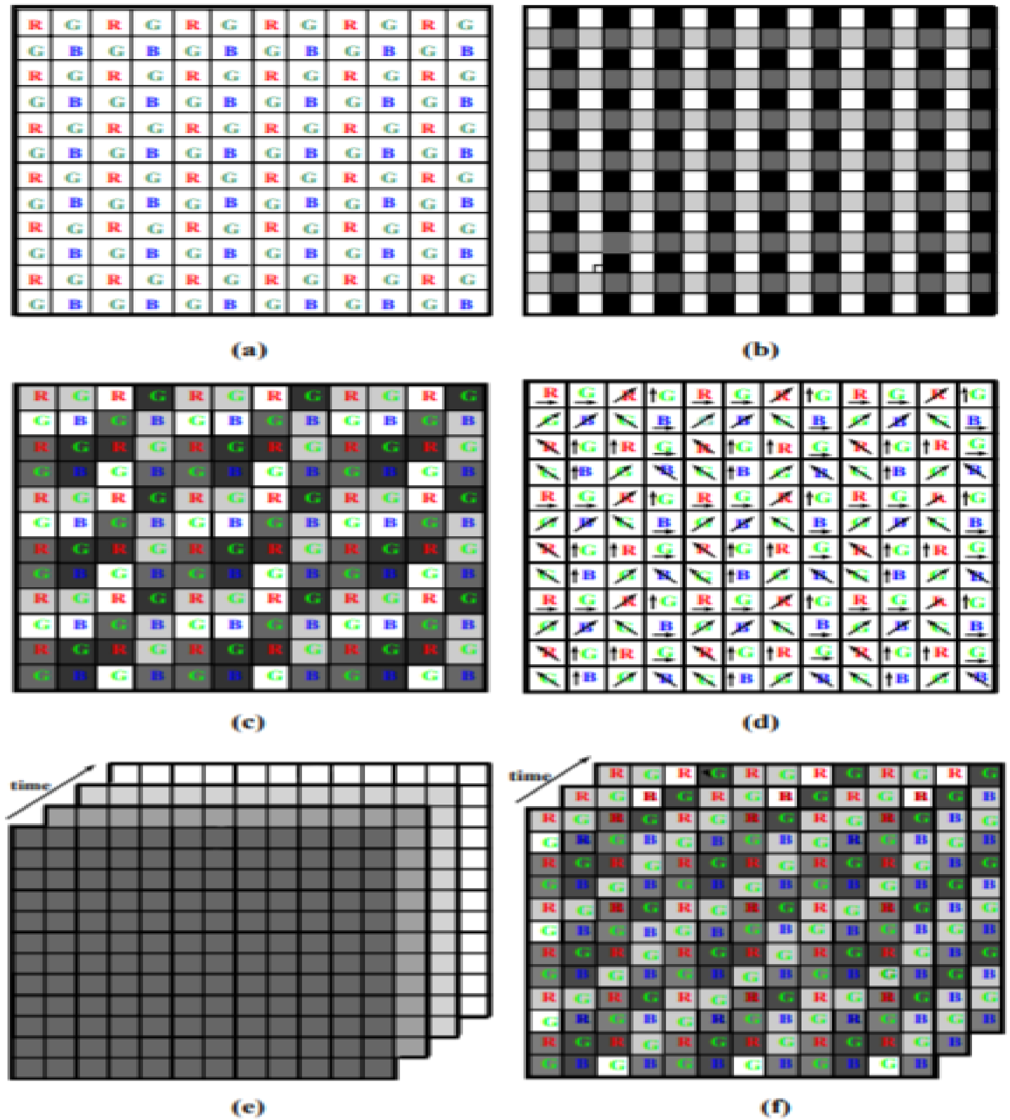
Micro-lens array



Backside Illumination

Pic Credit:Computational Sensor Slides by Jack Tumblin at SIGGRAPH 2008

Assorted Pixels



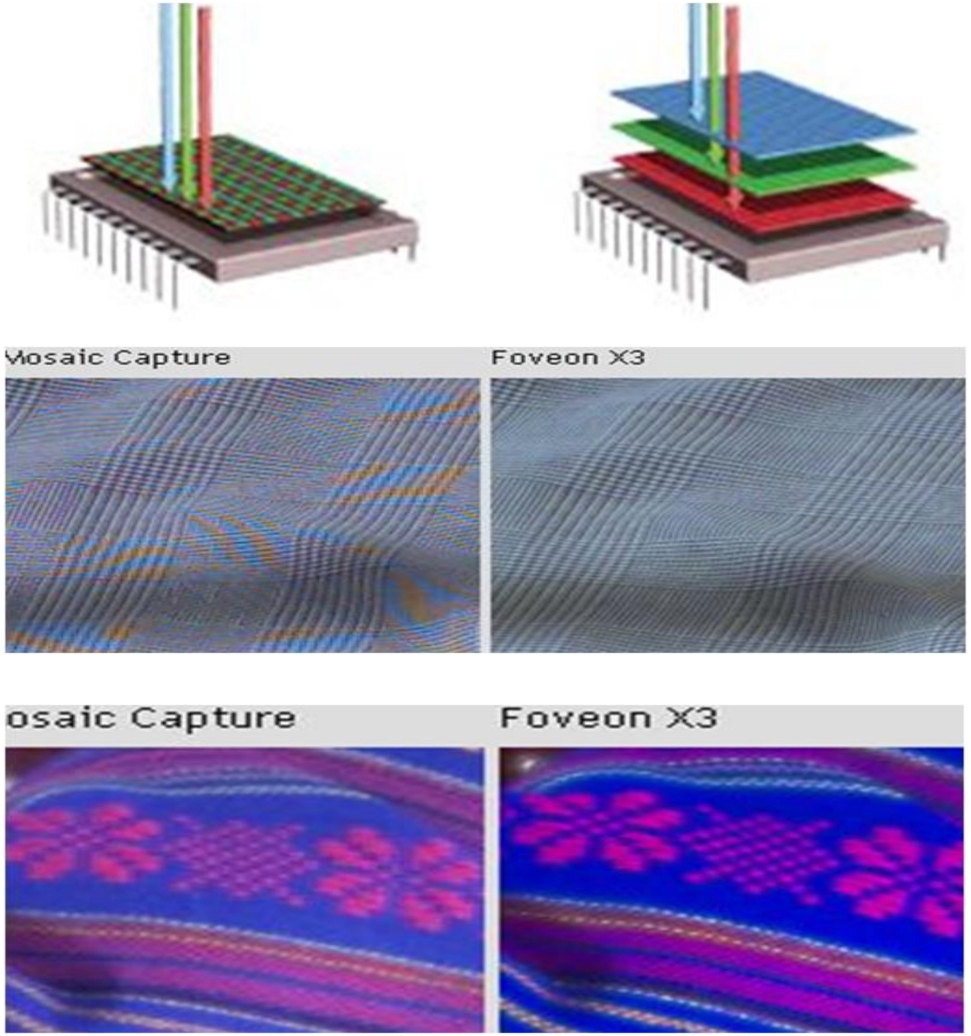
Different schemes for mosaicking

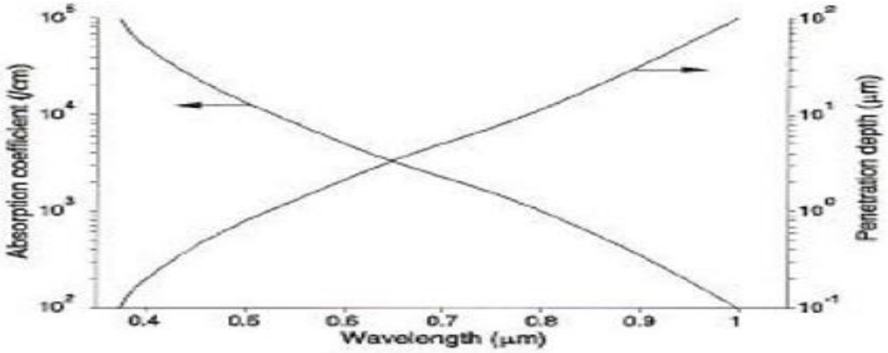
Challenges:

- Assorted Pixels acquire much more information than a simple array.
- Retrieving that information back i.e. De-Mosaicking is non-trivial.
- Sophisticated algos are there for De-Mosaicking but it is still an area of research
- The images suffer loss of information, jitter and aliasing after De-Mosaicking

Pic Credit:Computational Sensor by Jack Tumblin at SIGGRAPH 2008

FOVEON Sensor





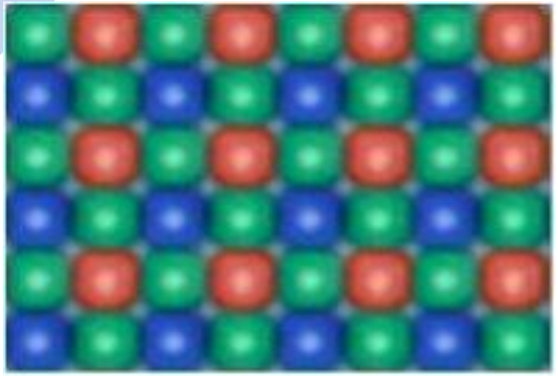
One of the reason for the loss of information after De-Mosaicking is that it doesn't records it!!!

FOVEON Sensor is a sensor which absorbs different wavelength at different depths.

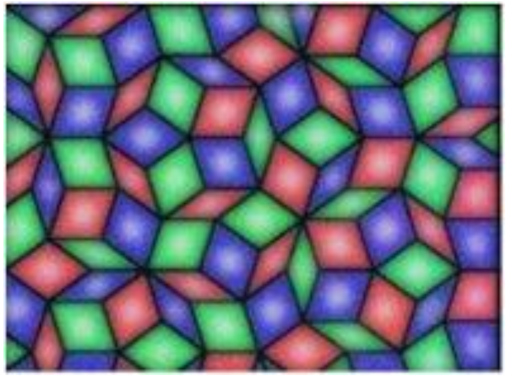
Hence, each pixel records all the three colors and hence no de-mosaicking required as the sensor is layered.

Pic Credit:Computational Sensor by Jack Tumblin at SIGGRAPH 2008

Penrose Pixels



Grid Pixel



Penrose Pixel

Grid Pixel Capture

Penrose Pixel Capture

The basic observations is that there is a fundamental mismatch between the grid shape of sensor and spherical shape of the lens

Even if we try to retrieve the lost color information by temporally shifting the pixels in every image, every shift will not yield different information in grid arrangement

Penrose pixels are non-periodic arrangement of irregular shape pixels which on very small shift retain much more new information, as every shift is different arrangement

Pic Credit:Computational Sensor Slides by Jack Tumblin at SIGGRAPH 2008

Sensor Motion

Basic Idea

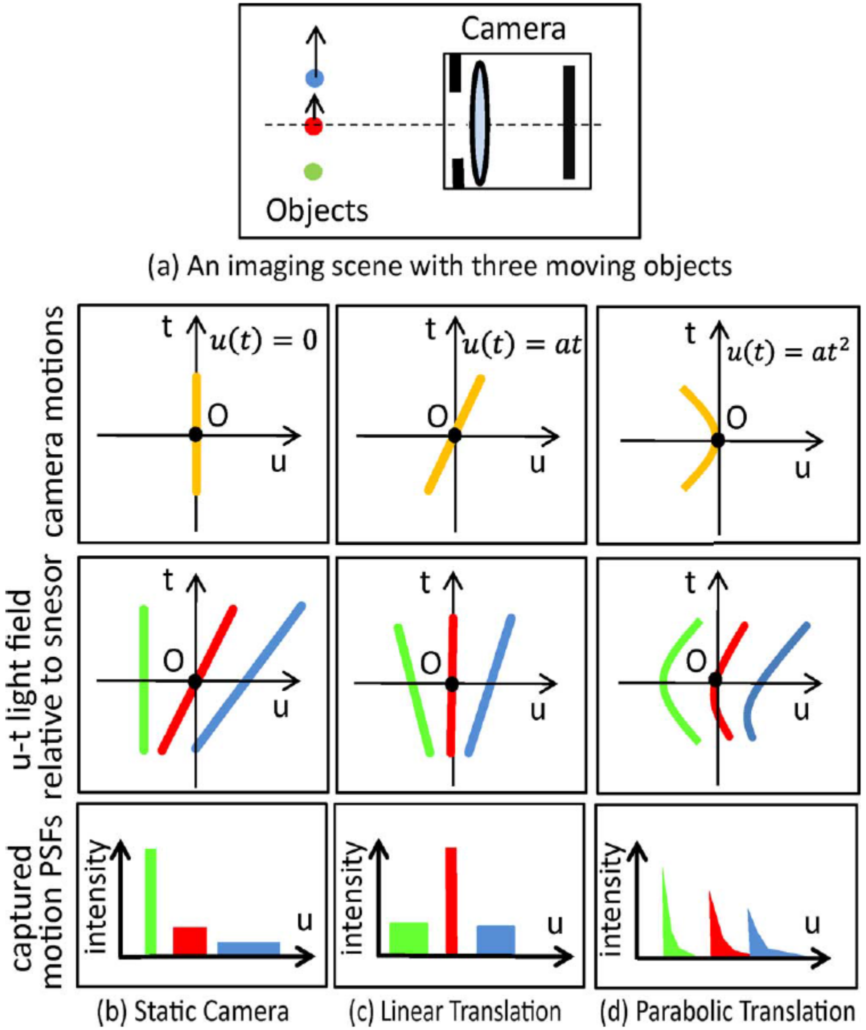
- During the exposure time when an image is captured, moving the sensor in various directions and patterns helps to preserve useful information.

Extending DOF

- Focal sweep technique is used to extend DOF. Sensor is moved along the optical axis during the exposure time. Depending on motion being continuous or discontinuous the DOF can be obtained to be continuous or discontinuous.

Motion Blur Removal

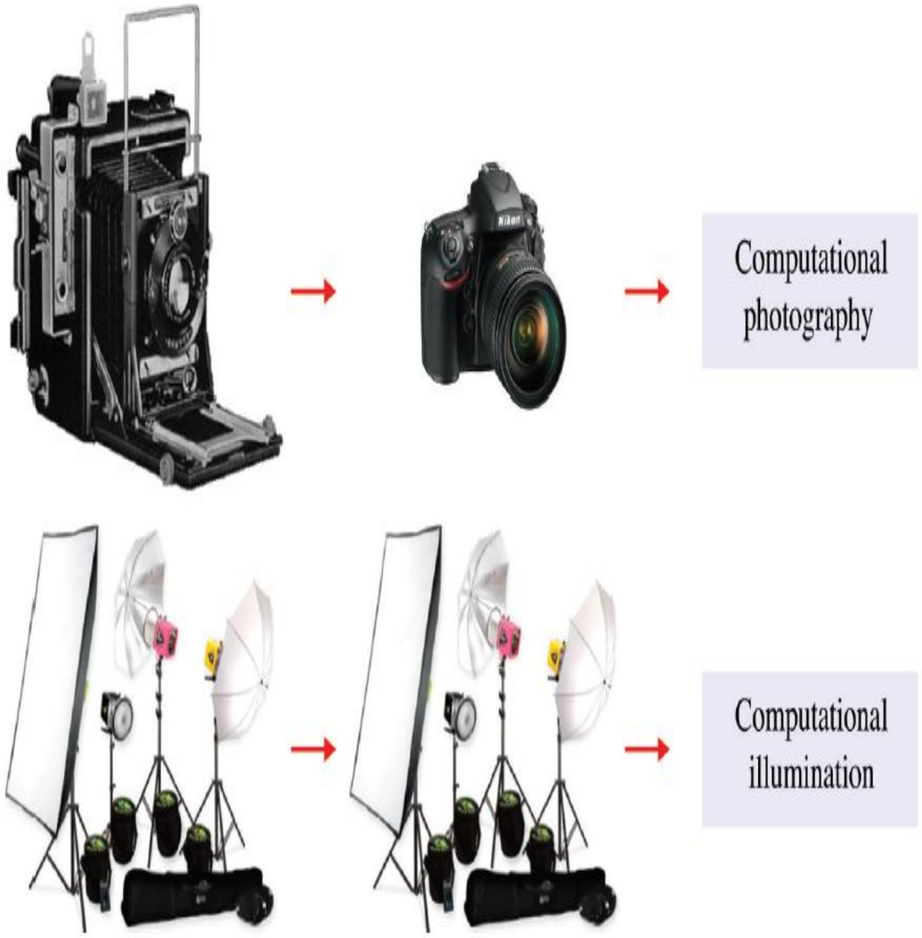
- Moving the sensor in a parabolic trajectory, we can obtain PSF to be invariant to object motion and is invertible. Hence, deconvolving all captured images of moving object with a single PSF can give blur-free images.



Pic Credit:Computational Photography:Convergence of Processing and optics by Shree K Nayar

Computational Illumination

Introduction to Computational Illumination



Questions to be answered

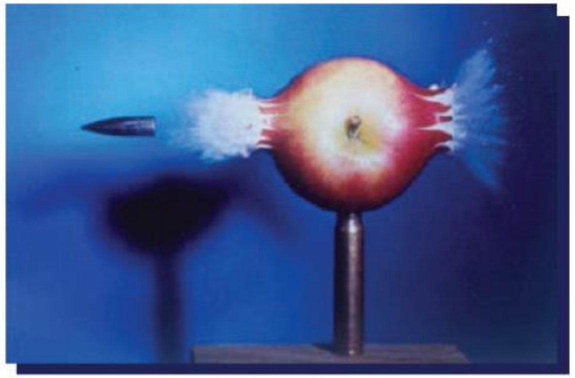
- What can we learn about lighting from the expert photographer?
- What can we create that goes beyond a professional's traditional lighting techniques?
- Can we create programmable lighting that minimizes critical human judgment at the time of capture?
- Can we create computational lighting that manipulates the lighting in images after they are taken?

Pic Credit:Computational Photography by Ramesh Raskar and Jack Tumblin

Overview of Computational Illumination

1. **Modifying Duration and Intensity of Auxiliary Lighting**
2. Presence and Absence Of Auxiliary Lighting
3. Modifying Color, Wavelength and Polarization of Auxiliary Lighting
4. Modifying Position and Orientation of Auxiliary Lighting
5. Modulation in Space and Time of Auxiliary Lighting
6. **Exploiting Natural Variations in Lighting**

Modifying Duration & Intensity of Auxilliary Lighting



Stroboscope
(Electronic Flash)

Multi-flash
Sequential Photography

Applied for capturing very high-speed motion

Stroboscopic Freezing of High-Speed Motion using ultra-short electronic strobe flash

Sequential Multiflash Stroboscopy for recording very high-speed sequential motion

Key challenge is to time the flash, which is done using audio and Laser based triggers

Pic Credit:Computational Photography by Ramesh Raskar and Jack Tumblin

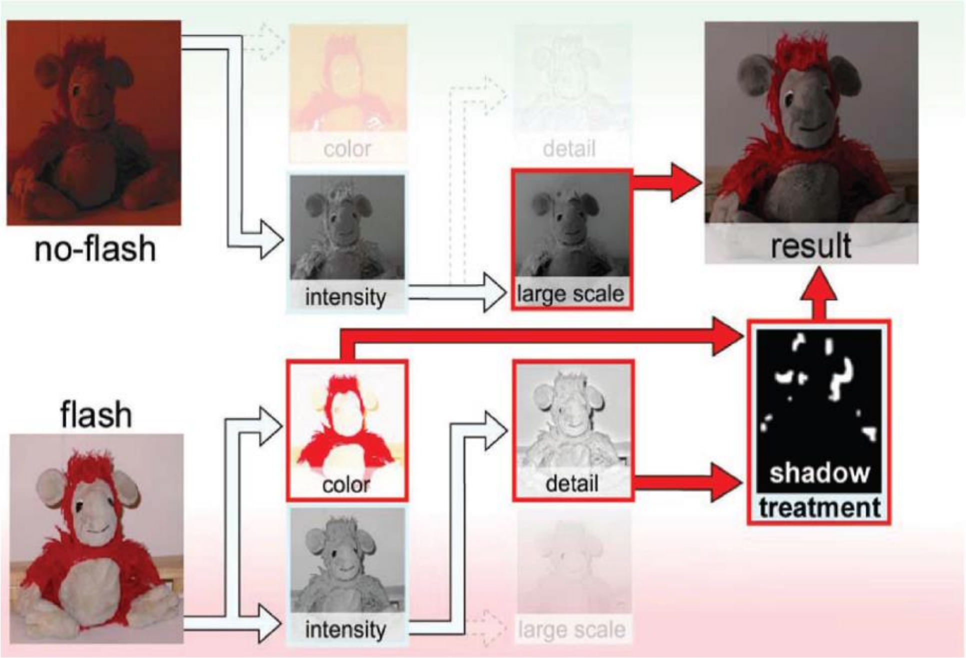
Presence or Absence of Auxiliary Lighting

Flash/No-Flash Image for Noise Reduction

<u>Flash Image</u>
Lower Noise
High Frequency
Details

<u>No-Flash Image</u>
Captures Large-Scale
Illumination
Overall Ambience

Joint Bilateral
Filtering



<u>Challenge</u>
Over Exposure in Flash Image
Cast Shadows due to Flash Position

Pic Credit:Computational Photography by Ramesh Raskar and Jack Tumblin

Presence or Absence of Auxiliary Lighting

Flash and Exposure variation for HDR imaging

Factors governing flash brightness:

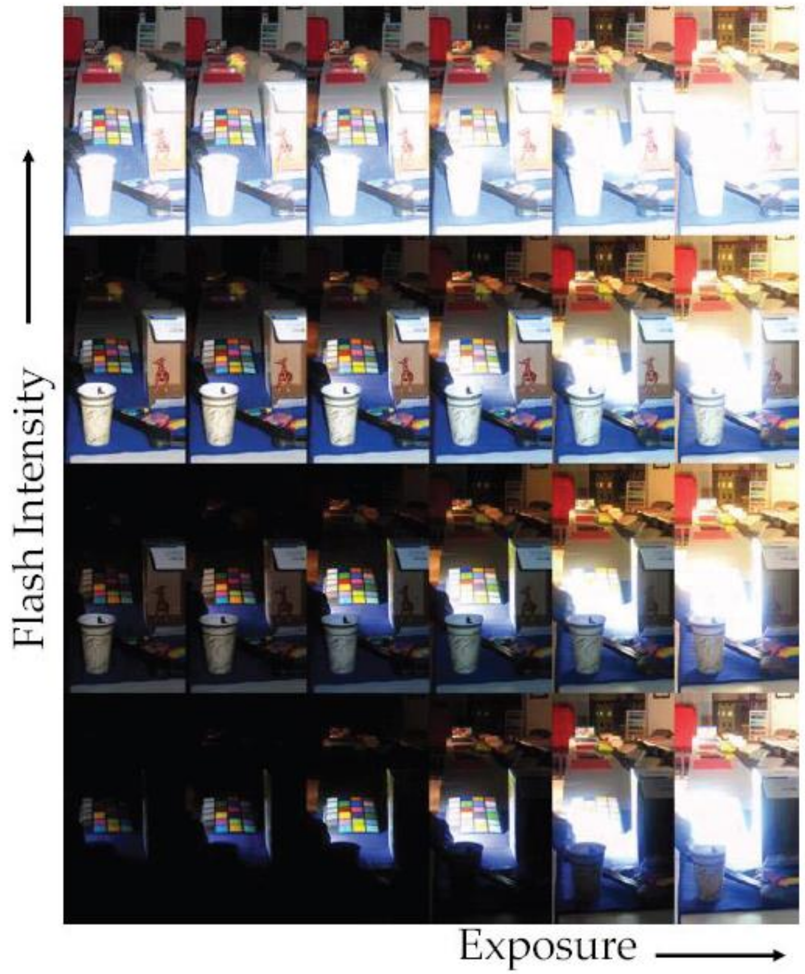
- Scene Depth
- Ambient Illumination
- Surface Reflectance of Scene Elements

Factors governing exposure duration

- Shorter Duration leads to noise
- Longer Duration leads to saturation

Adaptive Sampling of Flash-Exposure Space

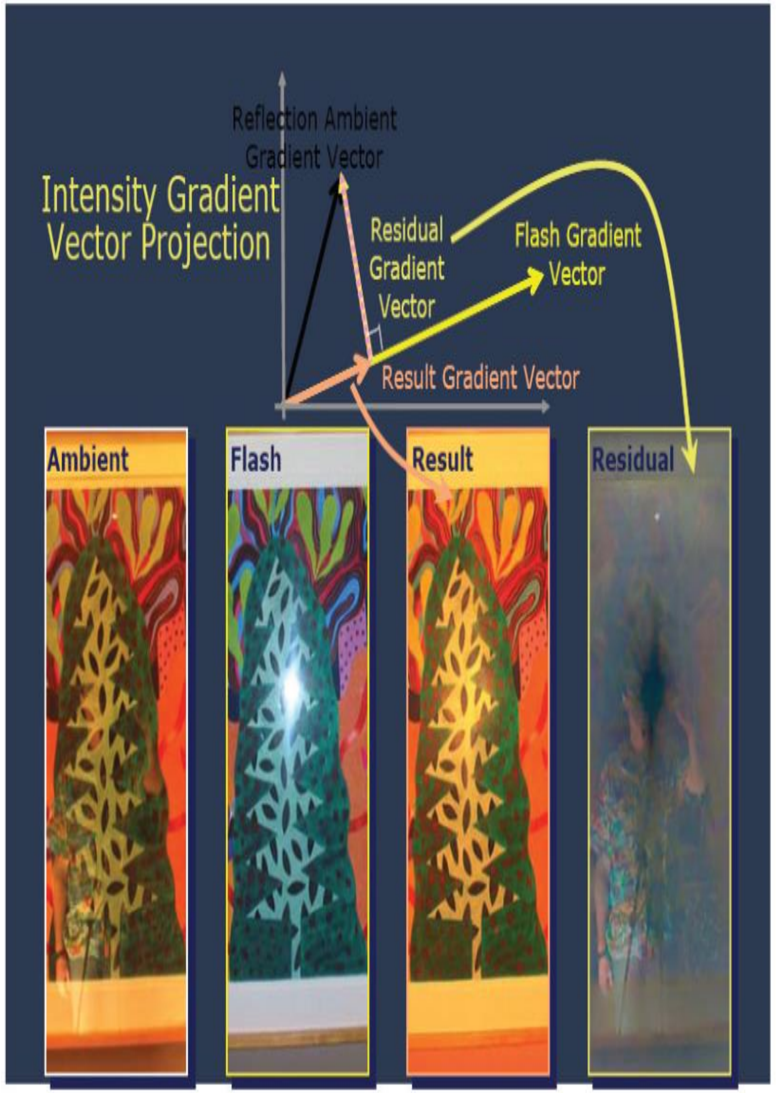
- Pixel values of each capture are analyzed for exposure or under-sampling, which suggests the optimal exposure and flash brightness for subsequent captures.



Pic Credit:Computational Photography by Ramesh Raskar and Jack Tumblin

Presence or Absence of Auxiliary Lighting

Removing Flash Artifacts



Flash Images suffer from:

- Over-Exposure of nearby objects
- Poor Illumination of distant objects
- Reflection from strongly lit objects
- Strong reflection highlights from glossy surfaces

Gradient Coherence Model:

- The orientation of intensity gradient vector at every pixel is independent of illumination changes if it is due to reflectance and geometry of the scene. The orientation changes with illumination if it is caused by flash artifacts.

Gradient Projection Scheme:

- It removes reflections in the ambient image by subtracting the component of ambient image gradient field perpendicular to flash image gradient field.

Pic Credit:Computational Photography by Ramesh Raskar and Jack Tumblin

Presence or Absence of Auxiliary Lighting

Flash Based Matting

Key Observation

- The greatest difference between a flash and no-flash image is the change in brightness of the foreground subject, provided the background is sufficiently distant

Implementation

- Pixel wise ratio of flash and no-flash image will be close to unity for distant points but significantly higher for near field points.
- Using joint Bayesian Matting the foreground and background can be separated.

Limitations

- The method fails if background is not far enough and is only suitable for static scenes

Pic Credit:Computational Photography by Ramesh Raskar and Jack Tumblin

Modifying Color, Wavelength and Polarization of Auxiliary Lighting

Capture-time color manipulation

Key Observation

- Scene radiance is the product of incident illumination and reflectance
- By modifying wavelength of incoming or capturing specific wavelength channel progrsmmable color channel manipulation can be performed

Flourosence Photography

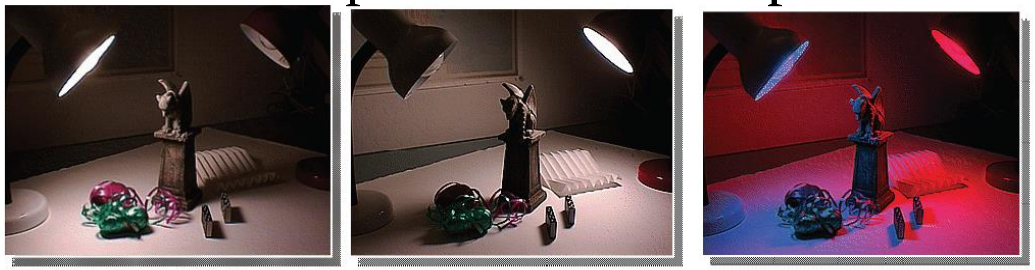
- The flourosence objects have the property to emit smaller wavelength(brighter color) when irradiated by larger wavelength

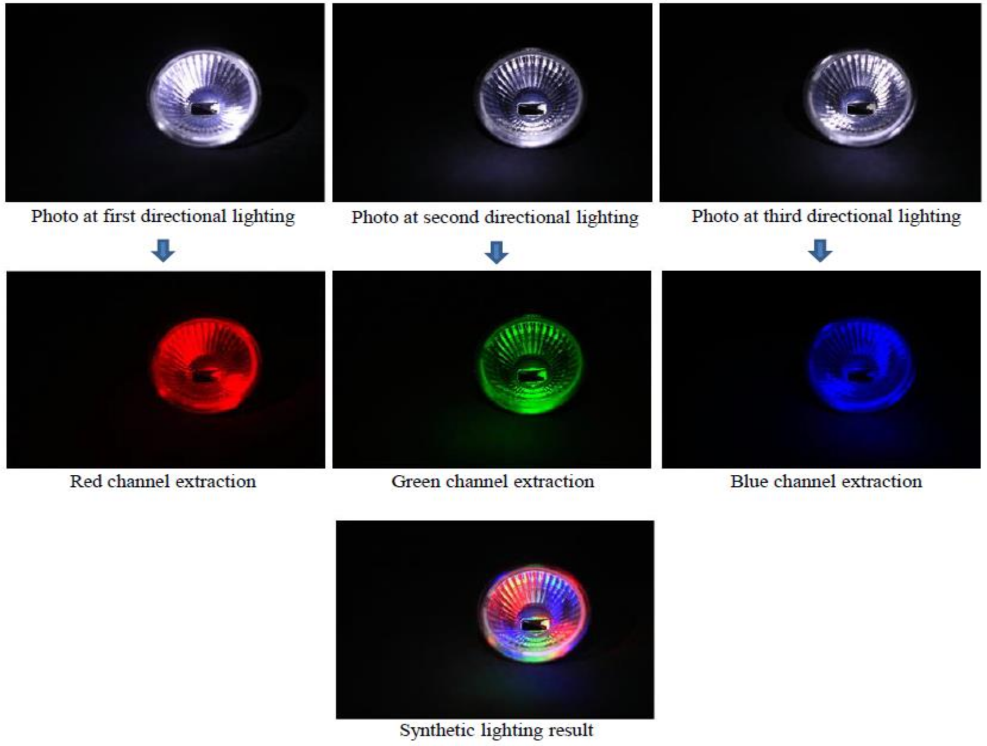
Non-Flourosence Color Manipulation

- By putting different optical filters at light source and at the camera, color manipulation can be performed

Pic Credit:Computational Photography by Ramesh Raskar and Jack Tumblin

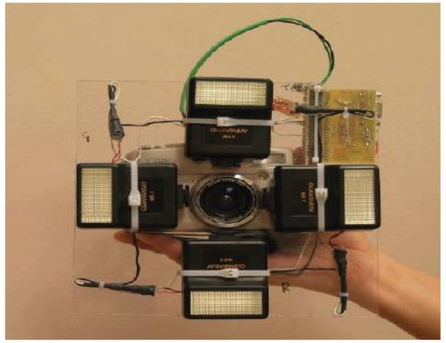
Post-Capture color manipulation

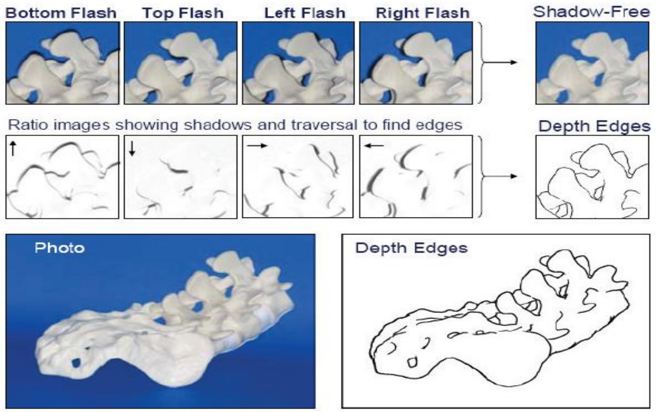




Modifying Position and Orientation of Auxiliary Light Source

Shape and Detail Enhancement



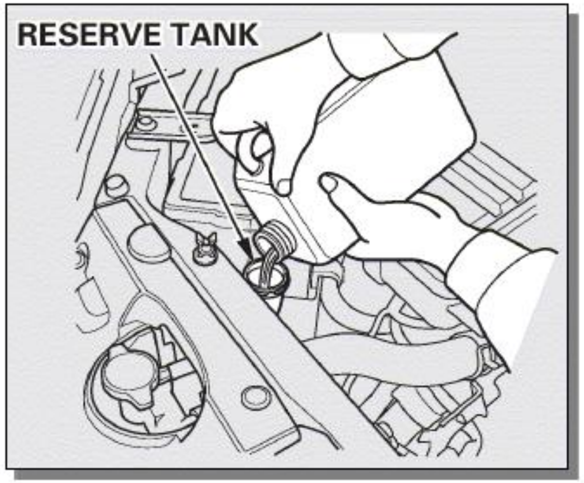


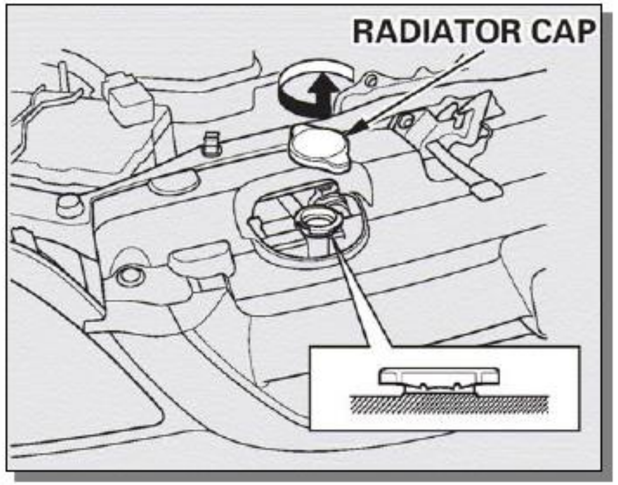
Multi-flash image sequence produced by using four individual flash exposures. A shadow-free image is computed by evaluating the per-pixel maximum intensity over the multi-flash sequence.

Each multi-flash image is divided by the shadow-free composite to amplify cast shadows.

Negative intensity transitions are computed along the direction in each image from the corresponding flash through the center of projection.

The shadow-free photo and depth edge image can be used to stylized deption and scene understanding.

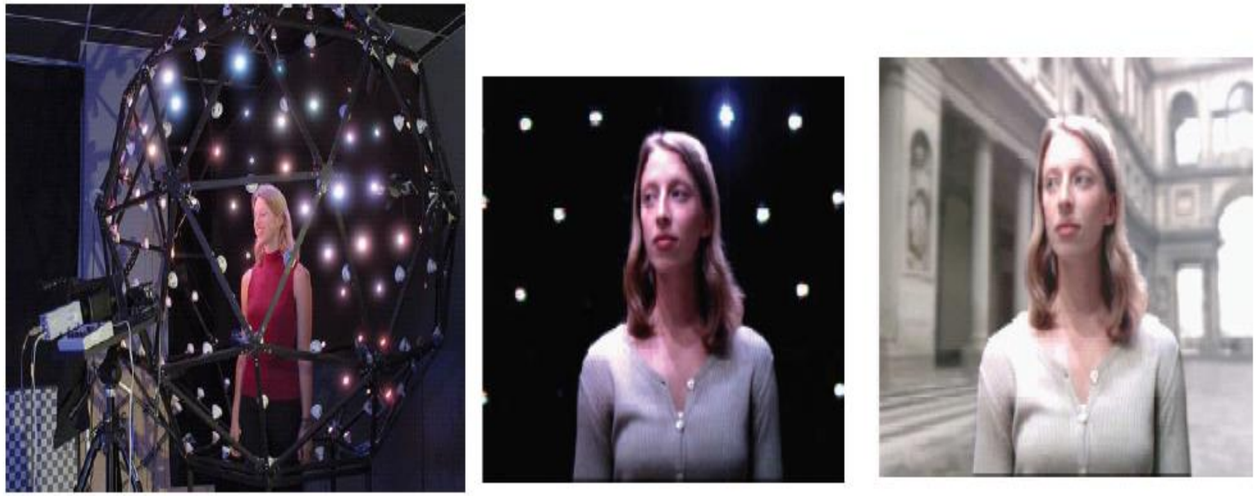




Pic Credit:Computational Photography by Ramesh Raskar and Jack Tumblin

Modifying Position and Orientation of Auxiliary Light Source

Relighting Using Domes and Light Waving



A set of high-lumen LEDs are positioned at the vertices of a rigid dome. The actor is inserted into a synthetic scene by using the estimated background matte. Consistent lighting is achieved by weighting the basis lighting by the environment map for the virtual scene.

$$I_out = \sum_i (w_i \; I_i)$$

Key Observation
- Light interacts linearly with the material objects

Two approaches for Re-Lighting
- Model based approach
- Data-driven approach

Light stage
- Parameterizes light from projector to camera
- Records 8D light field for the scene

Pic Credit:Computational Photography by Ramesh Raskar and Jack Tumblin

Modifying Position and Orientation of Auxiliary Light Source

Hemispherical Dome with Polynomial Texture map

Developed for compressing and storing the 4D light-field function

Assumption- The color of pixel varies smoothly as a biquadratic polynomial with the movement of light source

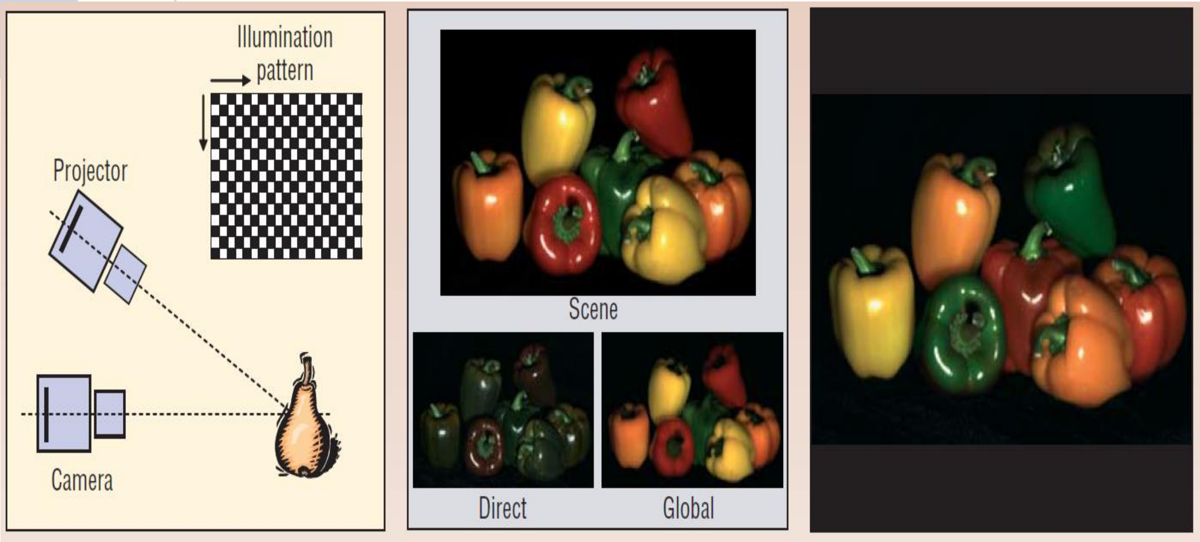
The coeffiecients of the biquadratic polynomial is stored for each pixel

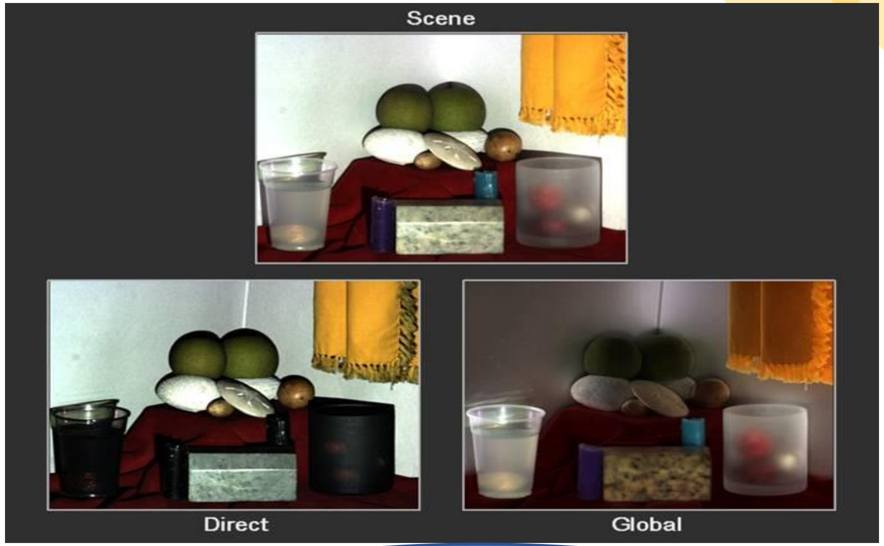
This representation allows real-time rendering of the scene with arbitrary illumination just by manipulating coefficients.

Pic Credit:Computational Photography by Ramesh Raskar and Jack Tumblin

Modulation in Space for Auxiliary Lighting

Fast Separation of Direct and Global Illumination





<u>Direct Component:</u>
Results from light received directly from the source

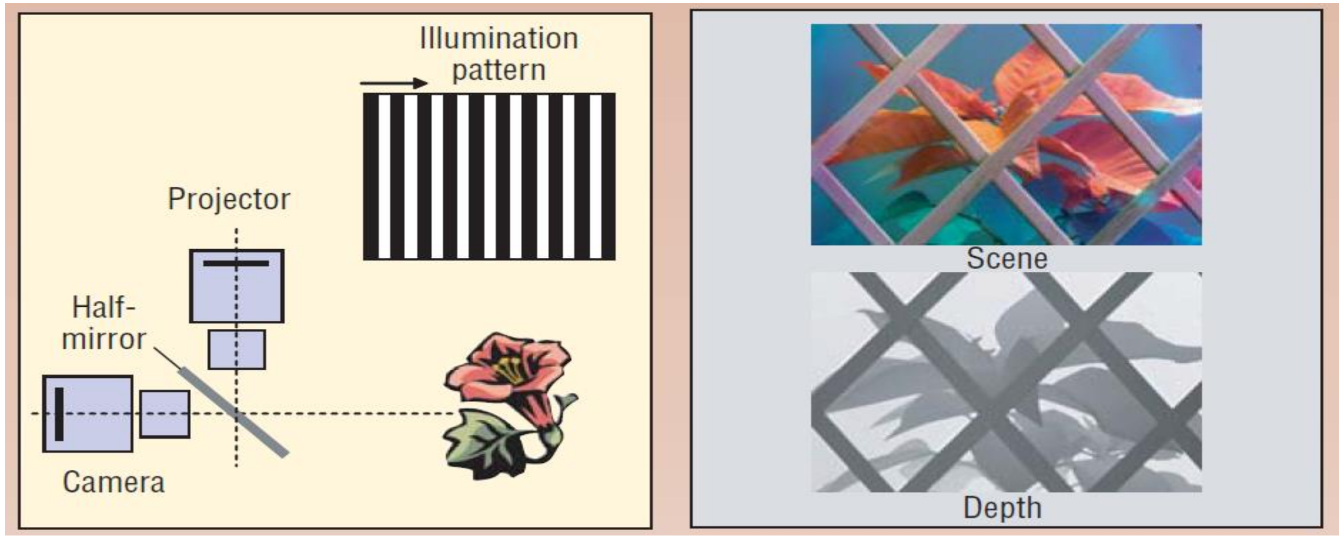
<u>Global Component:</u>
Results from light received from all other scene points other than source

<u>Implementation:</u>
Scene is lit by complimentary checkerboard patterns.
Each scene point's brightness,when bright is composed of Direct and half of Global scene component.
When dark then intensity is only half the global component. Arithmetic decomposes Direct and Global Component

Pic Credit:Computational Photography by Ramesh Raskar and Jack Tumblin

Modulation in Space for Auxiliary Lighting

Depth Estimation by High Frequency Illumination



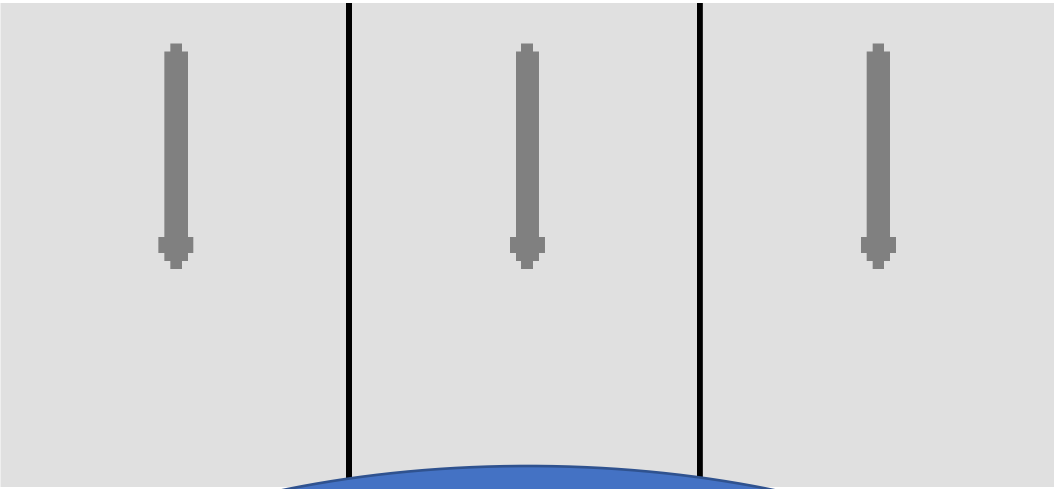
<u>Idea:</u>
Projecting coded pattern from the projector to measure the scene depth using active stereo triangulation, instead of using passive triangulation using 2 cameras.

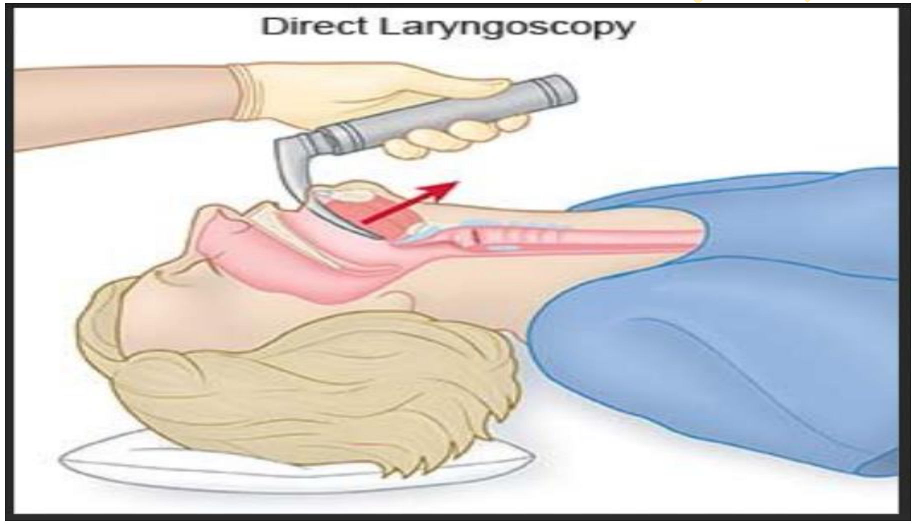
<u>Implementation:</u>
By using temporal multiplexing, the projected pattern is coded so that over time each projector pixel is assigned a unique code. Due to which correspondences between image points and the projector pixels can be obtained and hence by triangulation 3D information is recovered.

Pic Credit:Computational Cameras by Shree K Nayar

Modulation in Time for Auxiliary Lighting

Modifying Time Period of Periodic Events





<u>Key Idea:</u>

- High temporal frequency strobes can be used to freeze periodic motion.
- When the periodic scene motion and strobed flash have slightly different frequencies, the perceived rate of periodic motion is the difference between the two frequencies.

<u>Application in Laryngoscopy:</u>

Vocal fold frequency 1000Hz
Strobe frequency 999Hz
Apparent frequency 1Hz

Pic Credit:Google Images

Exploiting Natural Variations in Illumination

Intrinsic Images

Image

Illumination

Reflectance

Produced due to interaction of surfaces in scene with incident illumination

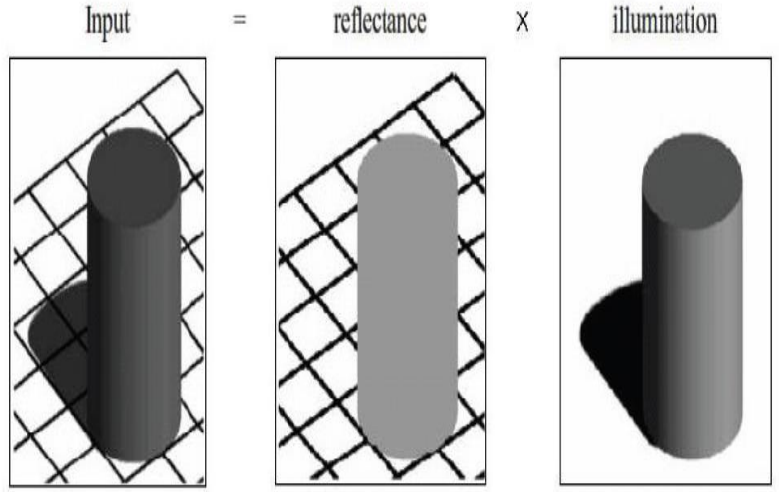
Produced due to optical properties of the object and is intrinsic to object.

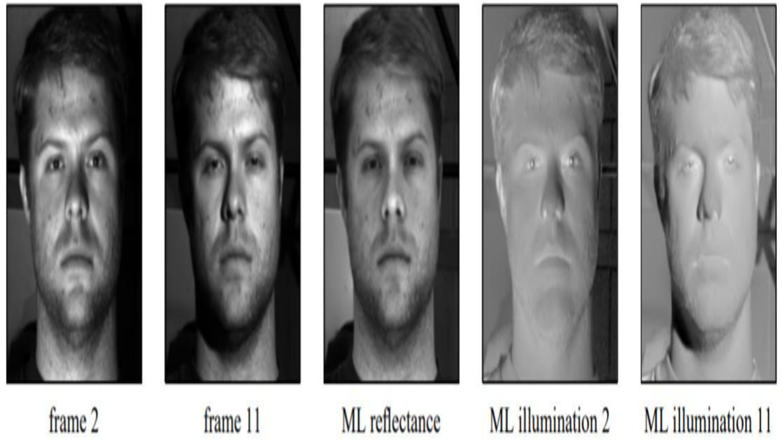
Implementation

Multiple images with varying illimination and constant scene reflectance are taken for a static scene.

For applying maximum likelihood estimation,forward gradient is computed at each pixel of each pic.

The median of the gradient at each pixel gives the estimate of the intrinsic image.Intrinsic image is calculated by integrating the 2D gradient field.





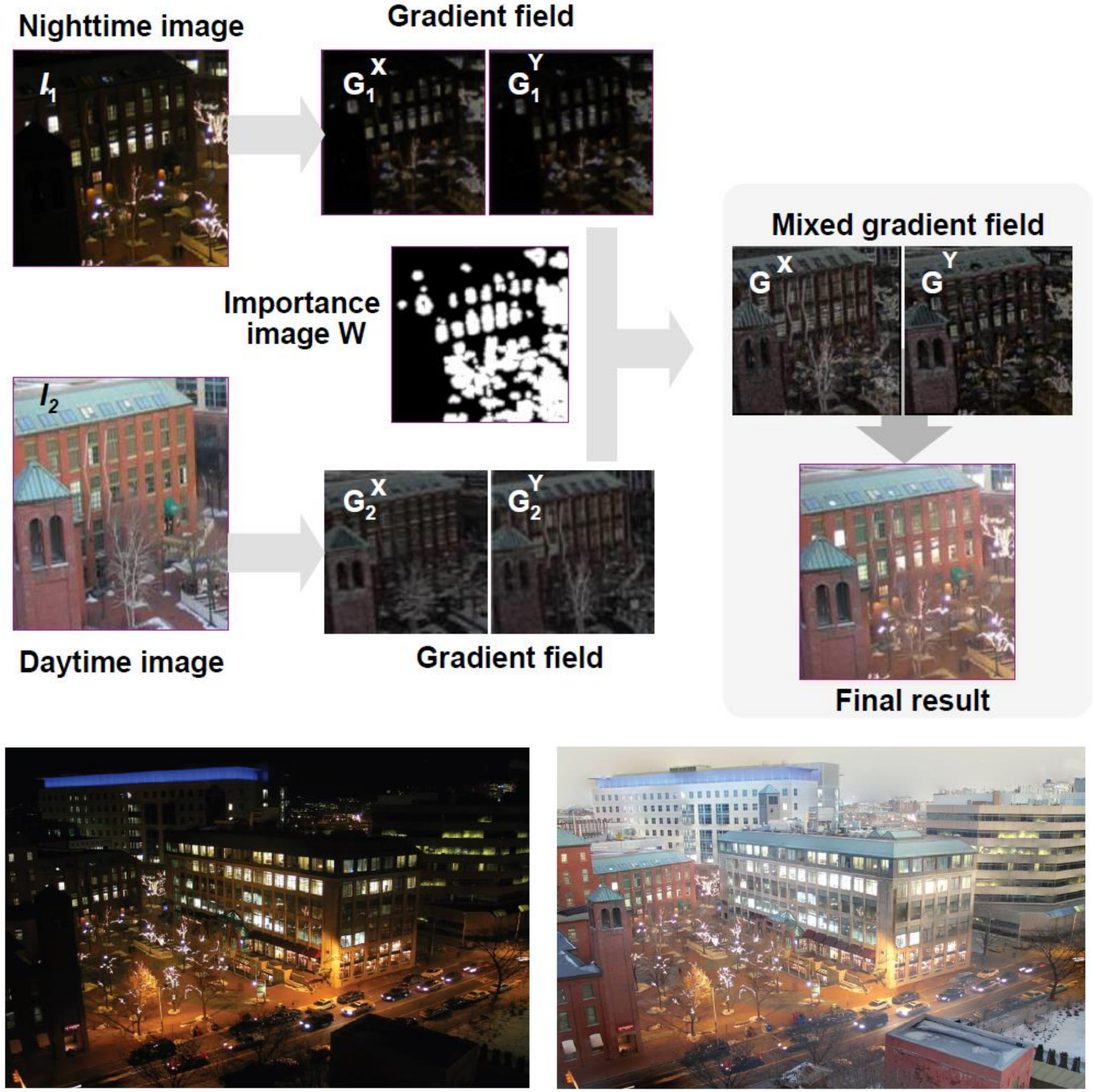
Pic Credit:Computational Photography by Ramesh Raskar and Jack Tumblin

Exploiting Natural Variations in Illumination

Context-Enhancement of Night-Time Photos

Implementation:

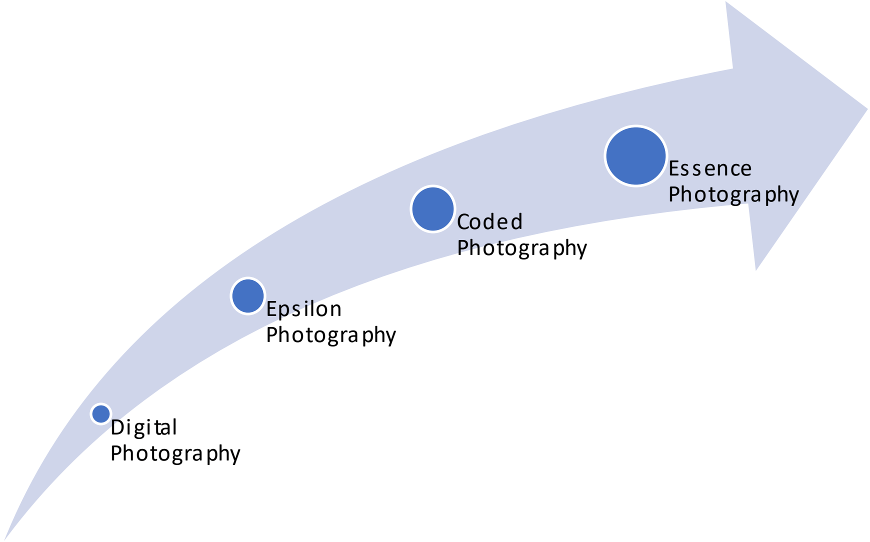
- The gradient of day-time and night-time images are calculated for both x and y directions.
- The gradient fields are combined linearly together and weights for the combination are decided by predefined Importance image so that smooth transition is obtained



Pic Credit:Computational Photography by Ramesh Raskar and Jack Tumblin

Future of Photography: Essence Photography

Stages of Computational Photography



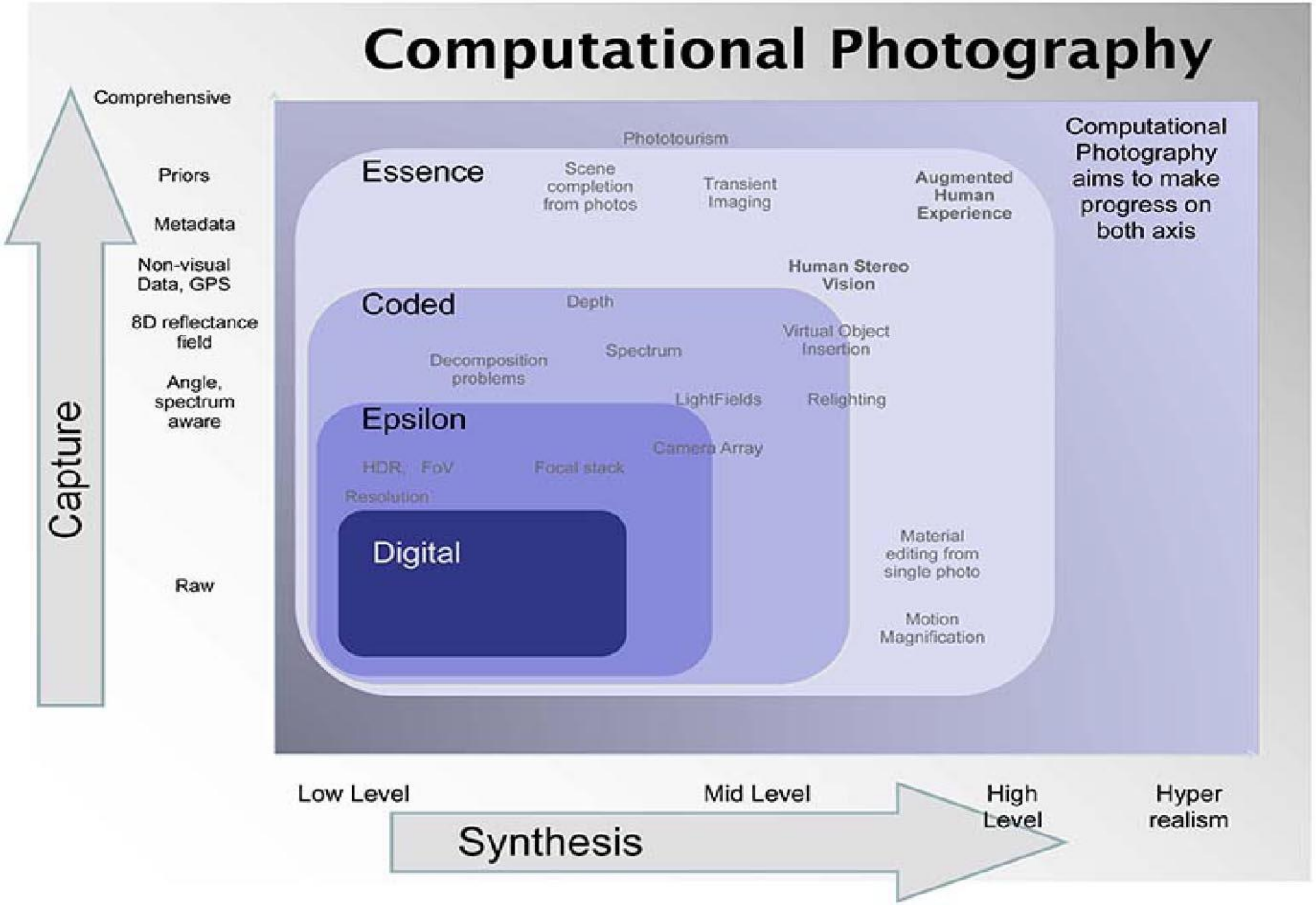


Image Credit: Raskar Tumblin Computational Photography

Essence Photography

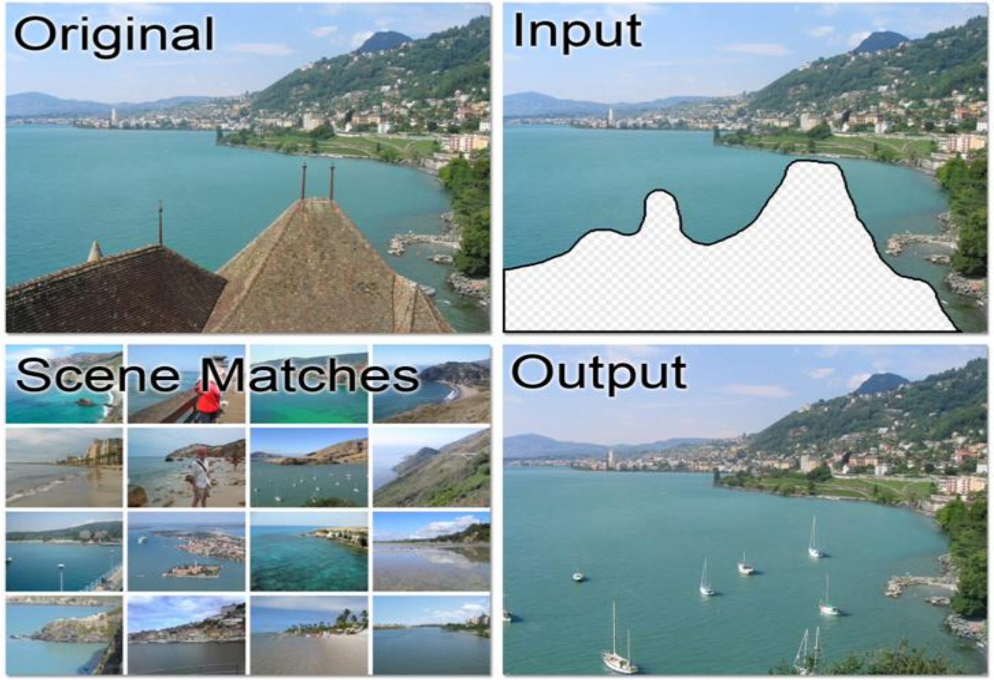
In this photography measurements goes beyond radiometric quantities of the scene.

Goal: To capture the essence of a scene and scruitinize its perceptually critical components.

A camera equipped with essence photography may-

- Measure Geographical location coordinates of the scene
- Identifies Scene Contents
- Recognizes Gestures
- Can perform non-photorealistic synthesis like motion exaggeration, beautification of photographs etc.

Exploiting the Online Collection



<u>Blind Camera:</u>
It doesn't capture any radiometric quantity and it is only aware of your location,whether around you and all other attributes you are feeeling being at a certain place and accordingly it provides you a picture which is much better than you would have taken

<u>Online Scene Completion:</u>
By utilizing the knowledge of location and time of an image being captured it can be matched with other images of similar type and hence the desired amalgamation can be obtained for a better view by using images present online.

Pic Credit:Computational Photography by Ramesh Raskar at SIGGRAPH 2008

Multiperspective Images

By viewing the frontal image only our brain can percieve the left and right face profiles.Here, Essence Photgraphy tries to depict out understanding rather what our eyes view.

Pic Credit:Computational Photography by Ramesh Raskar at SIGGRAPH 2008

Non-Photorealistic Synthesis

Motion Magnification

Done using the Optical Flow vectors from the individual video frames and utilizing them to convey the motion in a single picture

Pic Credit:Computational Photography by Ramesh Raskar at SIGGRAPH 2008

Future Impact of Computational Photography

Still many unanswered questions remain in-front of Computational Photography few of them are-

- What will the future of photography look like?
- What will a camera look like in ten years? In twenty years? In fifty years?
- How will powerful new movie-making capabilities change the nature of photography?
- Will photography as we know it disappear into a soup of unlimited media possibilities?
- How will online photo collections transform visual social computing?
- How will a billion portable networked cameras change the social culture?

But Overall,

Computational photography, in which photographs of the future will be computed rather than recorded, has already started to change the work-flow of imaging and give us new and expanded opportunities for seeing.

Summary of Computational Photography

Computational Photography

Rays are the fundamental Element : Traces all possible ways energy can be transferred by rays from scene to sensor to eyes

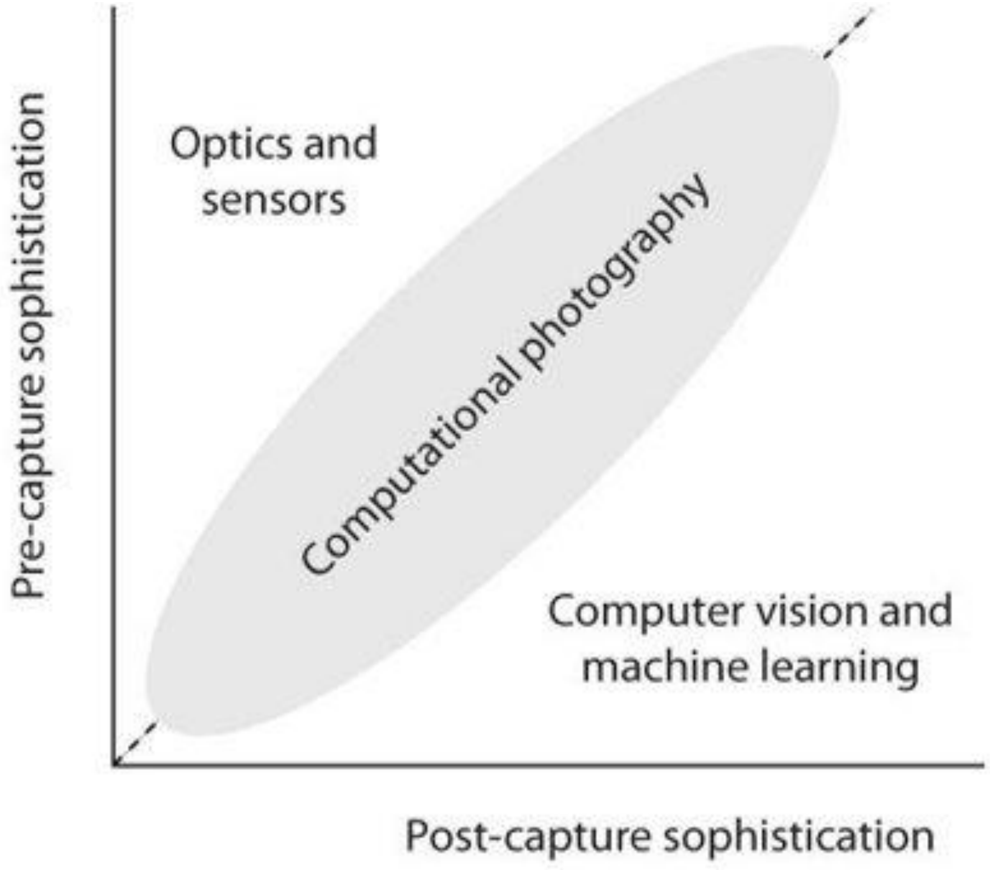
Generalized Optics: Manipulates incoming 4D Light Field into new 4D Light Field going to the sensors

Generalized Sensors: Un-Conventional sensors to capture new scene properties not possible to be captured by traditional sensors

Computational Illumination : Replacing the simple flash with customized light to discover the unseen scene elements

Generalized Processing and reconstruction: Application of ML& CV methods to get the desired results and express image semantics

Thus...



Computational Photography captures a machine-readable representation of the physical world, allowing us to hyper-realistically synthesize the essence of our visual experience.

Image Credit: Raskar Tumblin Computational Photography

Hence, Computational Photography enables us to capture what we want to capture rather than what we can capture!!!

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Thank You!!!