Computer Vision

Image Formation

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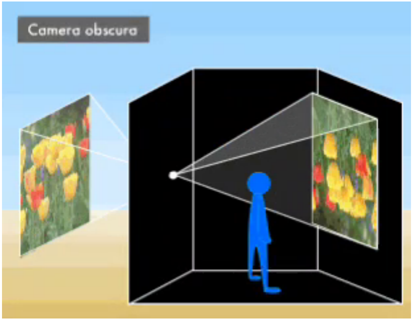
Understanding Pinhole Projection

- If the light is allowed to enter a darkened room through a tiny hole in a wall or door, the scenery outside will be projected onto the opposite wall.
- This phenomenon, known as pinhole projection, is one of the basic principles behind photography.
- The image created by pinhole projection is a reverse image, both upside-down, and left and right reversed.
- A pinhole camera can be easily created by opening a pinhole in a box that otherwise lets in no light.

Understanding Pinhole Projection (cont...)

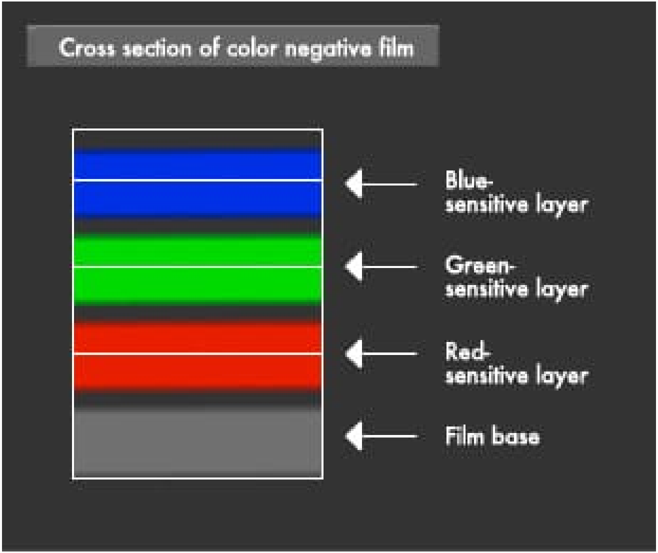


- Previously, the pinhole was exposed to a scene for a short duration and a thin chemical film (silver hallode) was used to capture the light energy (photons).
- If the chemical film paper is placed in developing solution, the scenery will gradually appear in reverse on the printing paper.
- Present-day cameras work on the same principle, but with a lens, aperture ring and shutter affixed to the pinhole to adjust focus and light, and film or CCD to replace the wall or chemical film-paper.

Understanding Pinhole Projection (cont...)

- **How, then, does color film render color?**
- Color film contains three layers of photo-sensitive emulsion sensitive to different light wavelengths: red, green and blue, respectively.
- The layer sensitive to red light is normally applied first, followed by emulsions sensitive to green light, and then blue light as the topmost layer.
- Adding dyes to silver halides makes them sensitive only to specific wavelengths of light.
- When color film is exposed, each photosensitive layer absorbs light of a specific wavelength.

Cross-section of color-negative film



DIGITAL CAMERA SENSORS

- A digital camera uses an array of millions of tiny light cavities or "photosites" to record an image.
- When you press your camera's shutter button and the exposure begins, each of these is uncovered to collect photons and store those as an electrical signal.
- Once the exposure finishes, the camera closes each of these photosites, and then tries to assess how many photons fell into each cavity by measuring the strength of the electrical signal.
- The signals are then quantified as digital values, with a precision that is determined by the bit depth.
- The resulting precision may then be reduced again depending on which file format is being recorded (0 - 255 for an 8-bit JPEG file).

Analog to Digital Converter (ADC)

- The ADC is the Analog-to-Digital Converter.
- After the exposure of a picture ends, the electrons captured in each photosite are converted to a voltage.
- The ADC takes this analog signal as input, and classifies it into a brightness level represented by a binary number.
- The output from the ADC is sometimes called an ADU, or Analog-to-Digital Unit, which is a dimensionless unit of measure.
- The darker regions of a photographed scene will correspond to a low count of electrons, and consequently a low ADU value, while brighter regions correspond to higher ADU values.

Image Sampling and Quantization:

- ADCs work by sampling, quantifying, and setting binary values for the signal.
- The output of most sensors is a continuous voltage waveform whose amplitude and spatial behavior are related to the physical phenomenon being sensed.
- To create a digital image, we need to convert the continuous sensed data into digital form.
- This involves two processes: sampling and quantization.

Image Sampling and Quantization (cont...)

- Let a continuous image, f(x, y), that we want to convert to digital form.
- An image may be continuous with respect to the x- and y-coordinates, and also in amplitude.
- To convert it to digital form, we have to sample the function in both coordinates and in amplitude.
- Digitizing the coordinate values is called sampling.
- Digitizing the amplitude values is called quantization.

Image Sampling and Quantization (cont...)

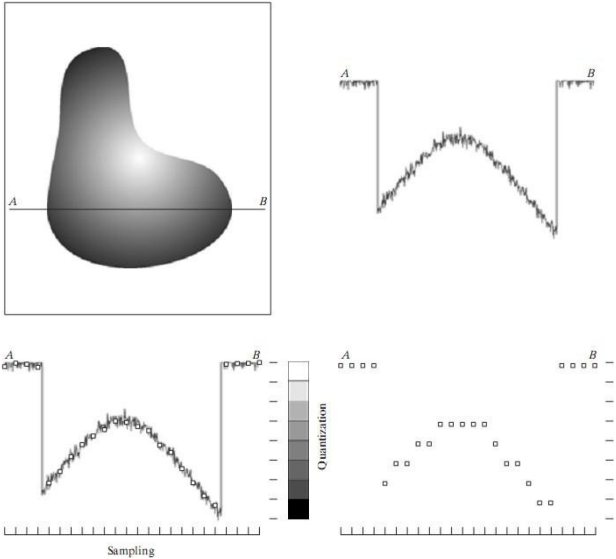


Image sourcebenchpartner.com

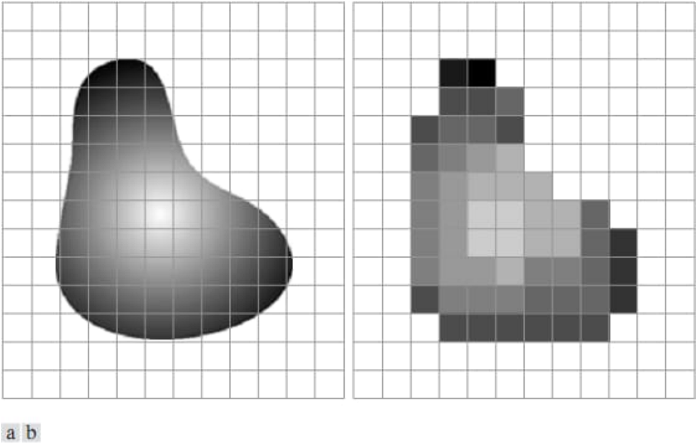
Image Sampling and Quantization (cont...)

- Top left is a continuous image f(x, y).
- The one-dimensional function shown in top right is a plot of amplitude (gray level) values of the continuous image along the line segment AB.
- The random variations are due to image noise.
- To sample this function, we take equally spaced samples along line AB, as shown in bottom-right.
- The samples are shown as small white squares superimposed on the function.
- The sampled values (which is the amplitude is still analog value) are then categorized into eight gray levels.
- The continuous gray levels are quantized simply by assigning one of the eight discrete gray levels to each sample depending upon its proximity with the levels.

Image Sampling and Quantization (cont...)

- The sampled values (which is the amplitude is still analog value) are then categorized into eight gray levels.
- The continuous gray levels are quantized simply by assigning one of the eight discrete gray levels to each sample depending upon its proximity with the levels.
- The digital samples resulting from both sampling and quantization are shown in bottom right.
- Starting at the top of the image and carrying out this procedure line by line produces a two-dimensional digital image.

Image Sampling and Quantization (cont...)



(a) shows a continuous image projected onto the plane of an array sensor.

(b) shows the image after sampling and quantization

Image sourcebenchpartner.com

Relationship with CCD array

- The number of sensors on a CCD array is directly equal to the number of pixels.
- Number of pixels is directly equal to the number of samples, that means that number sample is directly equal to the number of sensors on CCD array.

Image Sampling and Quantization (cont...)

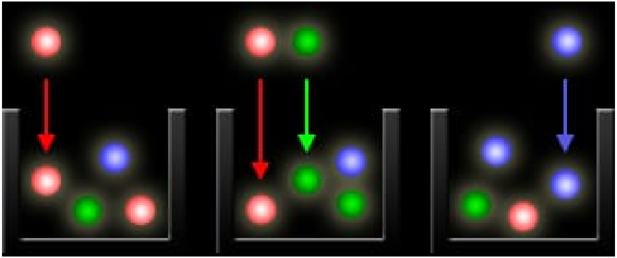


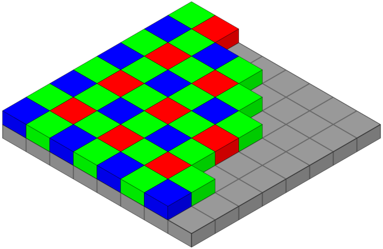
Image courtesy: `cambridgecolor.com`

Image Sampling and Quantization (cont...)

- However, the above illustration would only create grayscale images, since these cavities are unable to distinguish how much they have of each color.
- To capture color images, a filter has to be placed over each cavity that permits only particular colors of light.
- Virtually all current digital cameras can only capture one of three primary colors in each cavity, and so they discard roughly 2/3 of the incoming light.
- As a result, the camera has to approximate the other two primary colors in order to have full color at every pixel.
- The most common type of color filter array is called a "Bayer array,"

Bayer Array

- A Bayer array consists of alternating rows of red-green and green-blue filters.

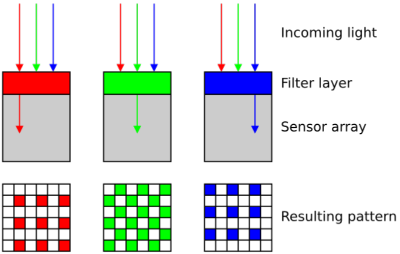


- The Bayer array contains twice as many green as red or blue sensors.
- This is because the human eye is more sensitive to green light than both red and blue light.

Image courtesy: `https://en.m.wikipedia.org/wiki/File:Bayer_pattern_on_sensor.svg`

Image courtesy: `cambridgecolor.com`

Bayer Array (cont...)



- Redundancy with green pixels produces an image which appears less noisy and has finer detail than could be accomplished if each color were treated equally.
- This also explains why noise in the green channel is much less than for the other two primary colors.
- Noise occurs primarily due to loss of photons during the capturing process.

Image courtesy: `https://en.m.wikipedia.org/wiki/File:Bayer_pattern_on_sensor_profile.svg`

Reconstruction from the mosaic pattern (demosaicing)/approximating the other channels

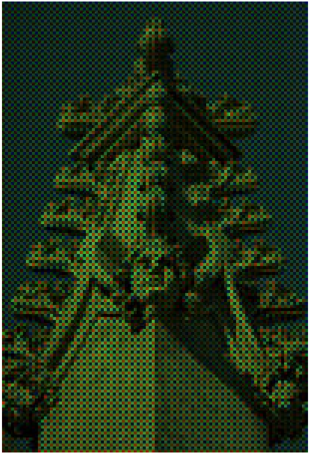


Image courtesy: `https://cambridgecolor.com`

continued...

- Simple methods interpolate the color value of the pixels of the same color in the neighborhood.
- For example, once the chip has been exposed to an image, each pixel can be read.
- A pixel with a green filter provides an exact measurement of the green component.
- The red and blue components for this pixel are obtained from the neighbors.