EEE-6512: Image Processing and Computer Vision

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Lecture #3: Fundamentals of Imaging Pt. 2

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Chapter Outline

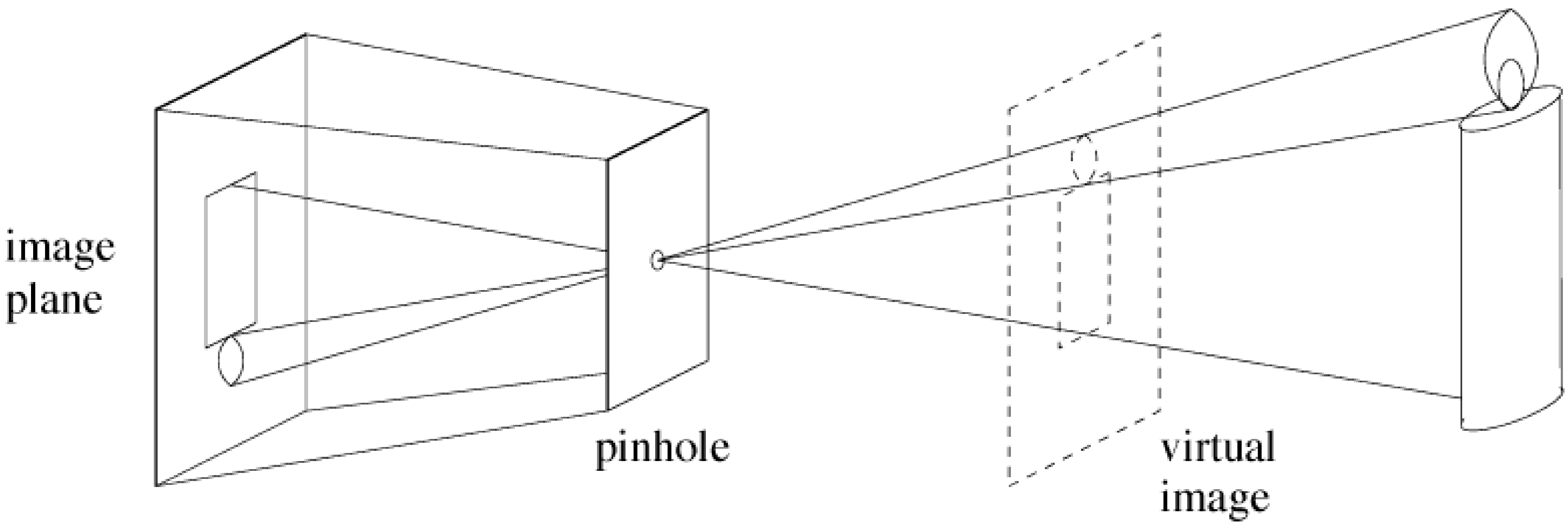
- Fundamental concepts of imaging.
- A quick tour of natural vision systems, with particular attention paid to the human visual system.
- Topics of image formation and acquisition, such as the pinhole camera model, lenses, sampling, and quantization.
- A survey of alternative imaging modalities.
- A detailed look at the electromagnetic spectrum.

Image formation overview

Image formation involves

- *geometry* – path traveled by light
- *radiometry* – optical energy flow
- *photometry* – effectiveness of light to produce "brightness" sensation in human visual system
- *colorimetry* – physical specifications of light stimuli that produce given color sensation
- *sensors* – converting photons to digital form

Pinhole camera



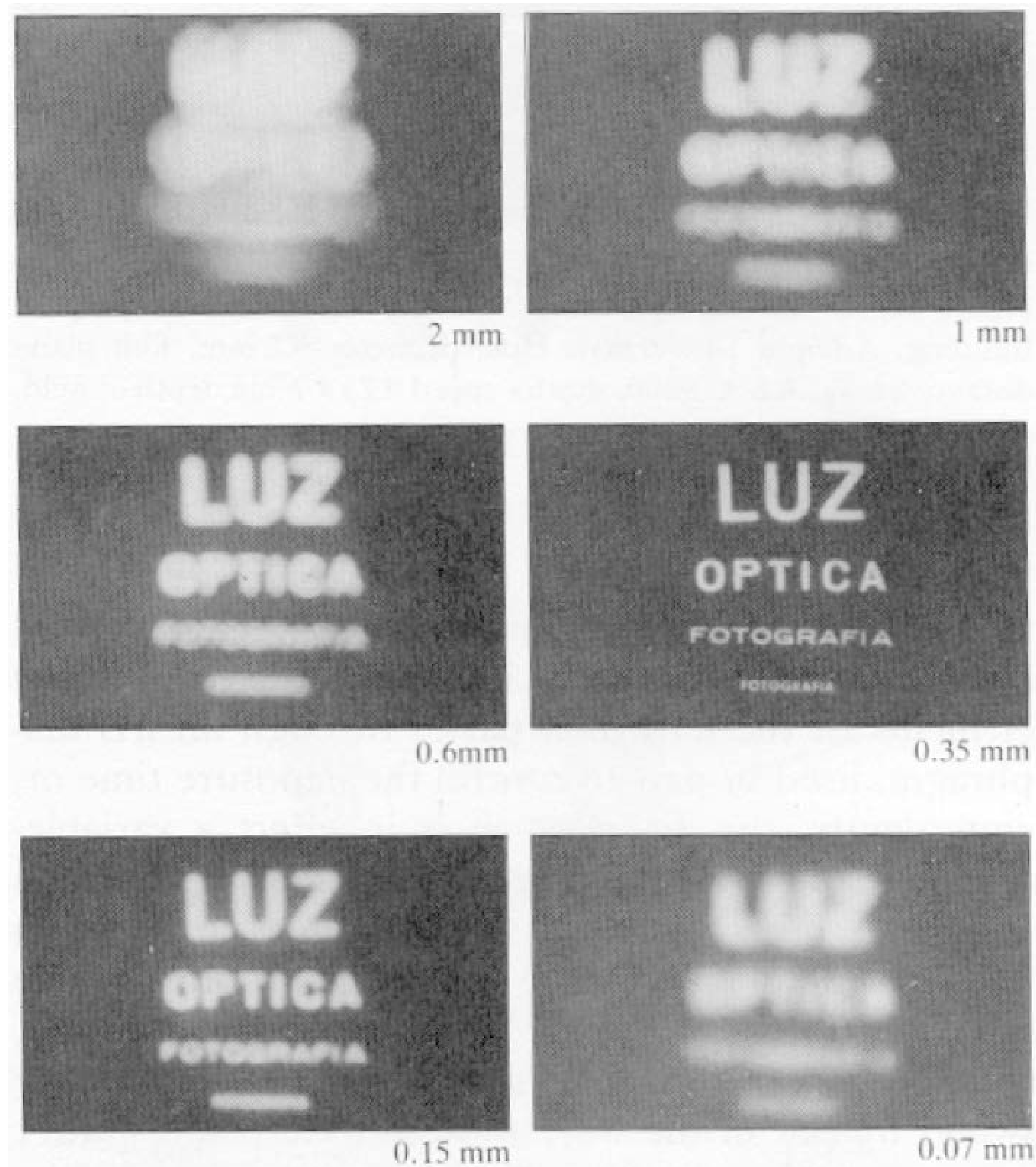
D. Forsyth, http://luthuli.cs.uiuc.edu/~daf/book/bookpages/slides.html

Pinhole size

Pinhole too big -
many directions are averaged, blurring the image

Pinhole too small-
diffraction effects blur the image

Generally, pinhole cameras are *dark*, because a very small set of rays from a particular point hits the screen.



D. Forsyth, http://luthuli.cs.uiuc.edu/~daf/book/bookpages/slides.html

Parallel lines meet: vanishing point

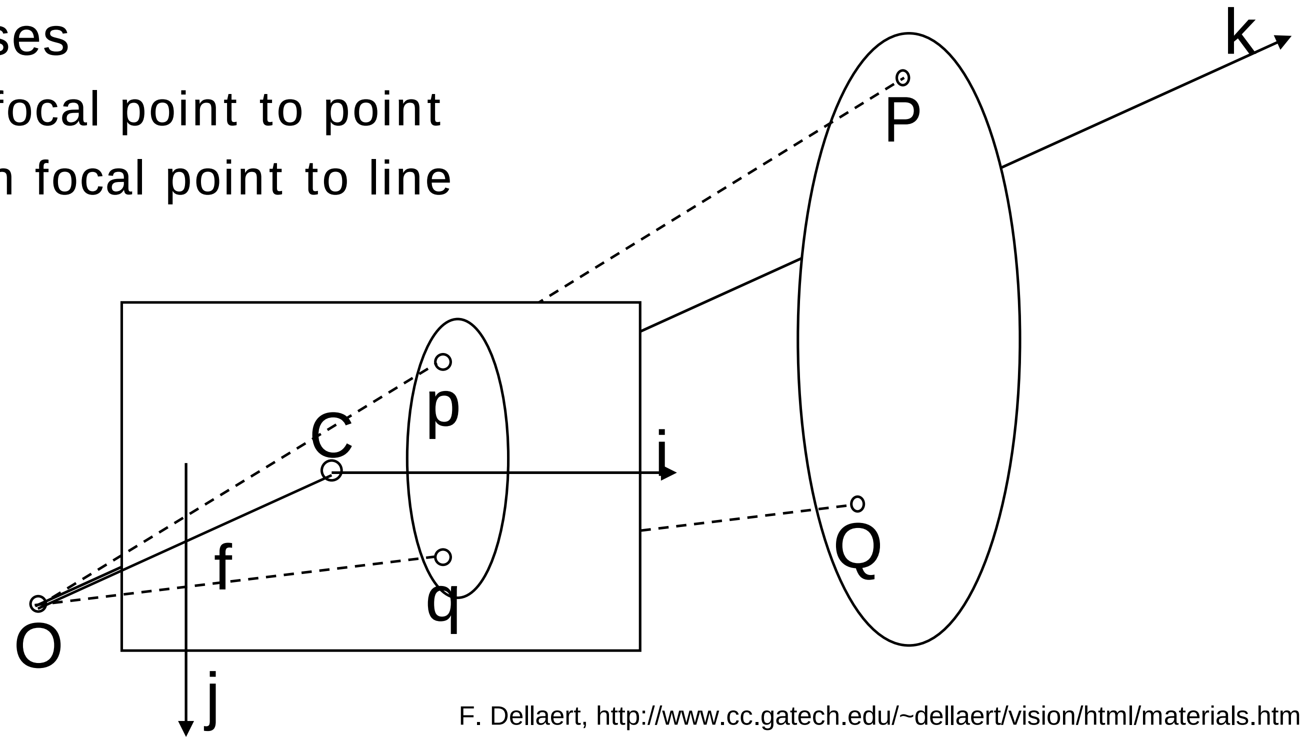
- each set of parallel lines (=direction) meets at a different point
  - The *vanishing point* for this direction
- Sets of parallel lines on the same plane lead to *collinear* vanishing points.
  - The line is called the *horizon* for that plane

Perspective projection

Properties of projection:

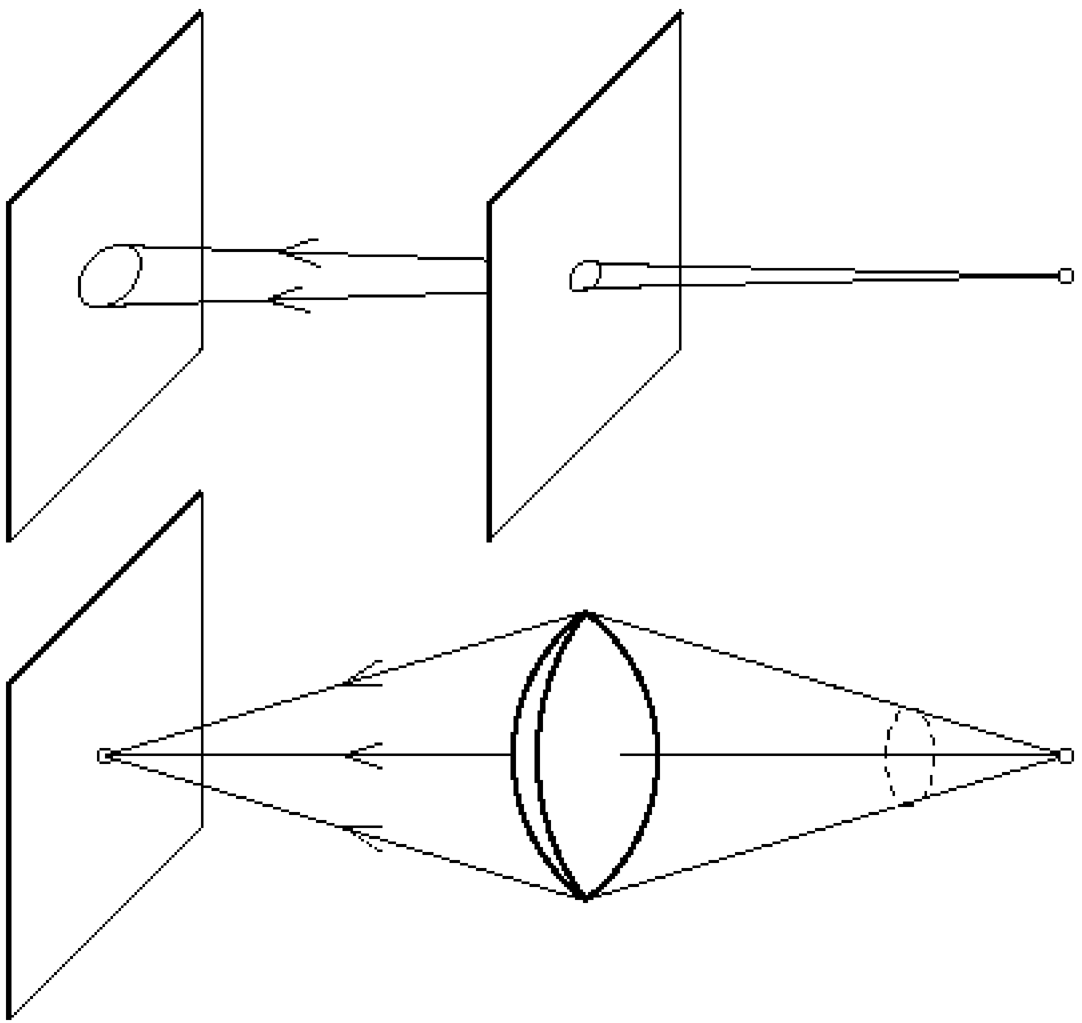
- Points go to points
- Lines go to lines
- Planes go to whole image
- Polygons go to polygons
- Degenerate cases
  - line through focal point to point
  - plane through focal point to line

$$(X,Y,Z) \rightarrow (f\,\frac{X}{Z}, f\,\frac{Y}{Z})$$



F. Dellaert, http://www.cc.gatech.edu/~dellaert/vision/html/materials.html

The reason for lenses



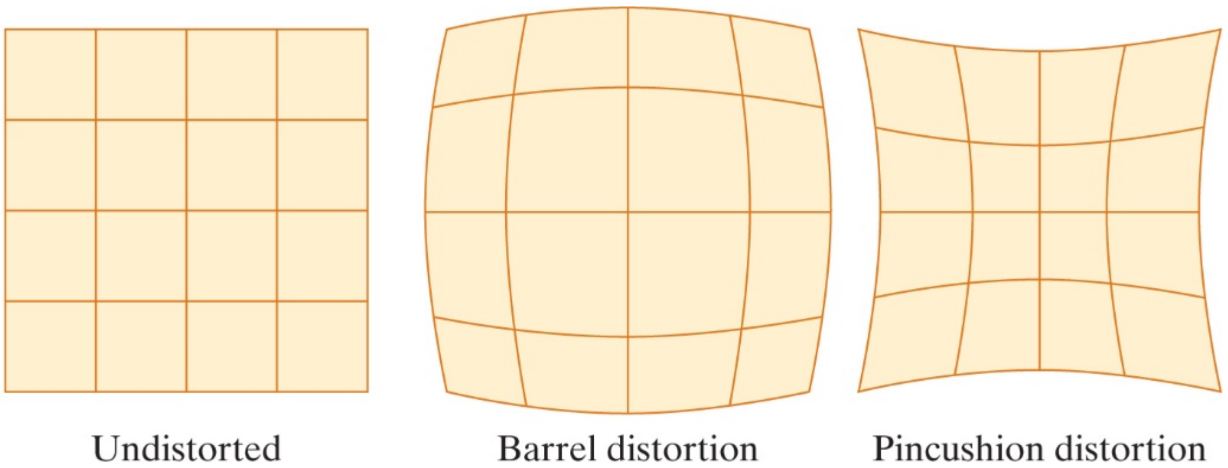
D. Forsyth, http://luthuli.cs.uiuc.edu/~daf/book/bookpages/slides.html

Camera with Lens (cont'd)

- **Aberration:** any deviation of the performance of a lens from ideal.
- **Distortion:** arises from the fact that the light rays do not necessarily follow straight lines when passing through the lens.
- Bending of the light is often different for different wavelengths due to *material dispersion*, leading to **chromatic aberration**.

Camera with Lens (cont'd)

Figure 2.26 An undistorted image, barrel distortion, and pincushion distortion.



A Simplified Imaging Model

- The **irradiance** *E* on the image sensor is the product of a lighting function Λ and a reflectance function *R*.

$$E(x, y, \lambda) = \Lambda(x, y, \lambda) R(x, y, \lambda)$$

- In **intrinsic images**, multiple images of a static scene under different imaging conditions can be used to estimate the reflectance or other properties in the scene.

A Simplified Imaging Model (cont'd)

Figure 2.28 Intrinsic images are a mid-level description of scenes determined by decomposing an image into constituent components, such as an illumination image and a reflectance image. Based on Y. Weiss, "Deriving intrinsic images from image sequences," *Proceedings of the International Conference on Computer Vision*, pages 68-75, July 2001.

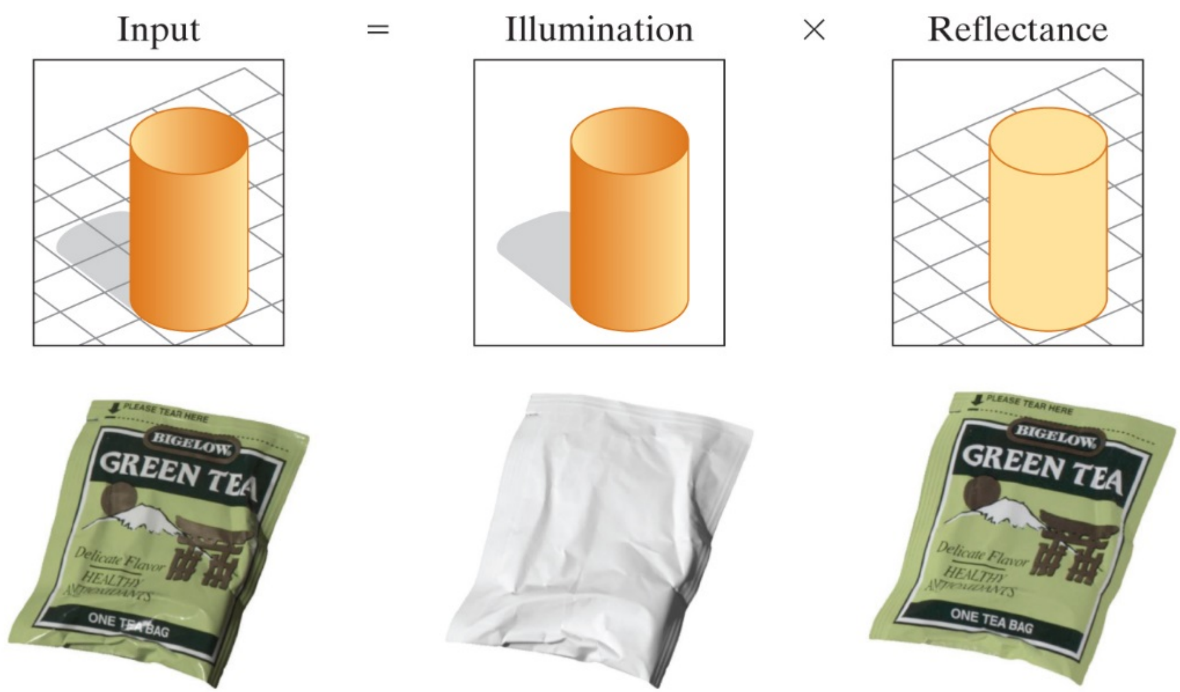


Image Acquisition - Sampling and Quantization

- The image pixel value $I(x, y)$ can be modeled as the integration of the irradiance function over the area of the pixel and over all wavelengths, after first multiplying by the sensitivity function:

$$I(x,y) = \varphi\left(\iiint E(x', y', \lambda')s(\lambda')\, dx'\, dy'\, d\lambda'\right)$$

- **Sampling:** converts the continuous irradiance function into a discrete function defined only over the rectangular lattice of integer (x, y) coordinates.

- **Quantization:** assigns a discrete gray level to every pixel in order to represent its value in digital form.

Gamma Compression

- **Gamma Compression:** transforms the linear, physical light intensity into a perceptually uniform quantity, so that the pixel values in a digital image are not directly proportional to the amount of light collected by the sensor.

$$L = cV^{\gamma} + b$$

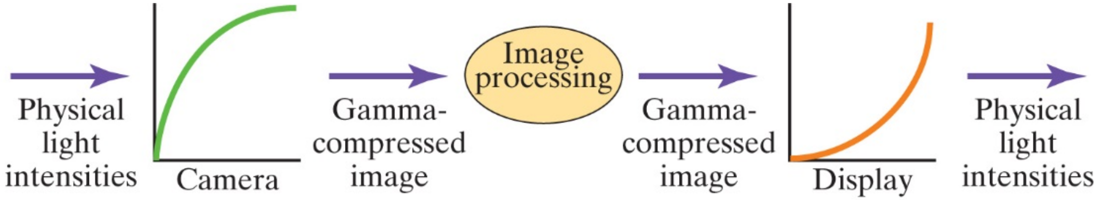


Figure 2.29 Linear light intensities are gamma compressed by the camera into perceptually uniform quantities, which are then gamma expanded by the display.

Gamma Compression (cont'd)

Figure 2.30 Gamma function with different values of γ.

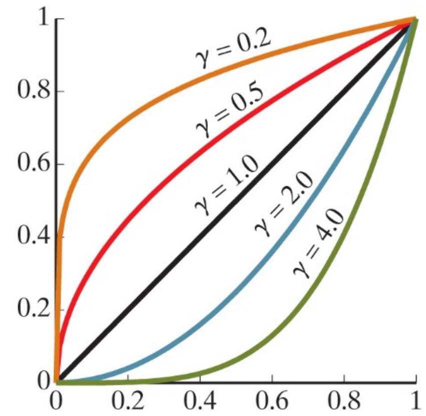


Figure 2.31 Simultaneous contrast. The pixels inside the middle squares have the same luminance, but the pixels on the right appear brighter due to its surroundings. Therefore, if an image is displayed at the correct luminance in a dimmer environment than the one in which it was captured, it will appear to be lacking in contrast.

CCD and CMOS Sensors

- **CCD and CMOS Sensors:** each consists of a dense array of photodiodes (typically spaced 1 to 5 μm apart) that convert light photons to electrons.
- **CCD sensor:** electrons are collected and stored in local potential wells during exposure time and then read out by transferring electrons down the line of potential wells until they reach the readout register known as the *horizontal shift register*.
- **CMOS sensor:** transistors next to each photodiode convert the electrons to a voltage.

Transmission and Storage

- Traditional video cameras transmit the video signal using analog waveforms. The three standards are:
  - NTSC: used in North America and Japan
  - SECAM: used in France and the former Soviet Union
  - PAL: used most everywhere else
- **Composite video:** the luminance and chrominance information is combined into a single signal.
- **Component video:** individual color channels are separated into individual signals, resulting in higher fidelity.

Consumer Imaging: Catadioptric, RGBD, and Light-Field

- **Dioptric:** a standard optical imaging system using a lens.
- **Catoptric:** a camera that uses mirrors.
- **Catadioptric:** a system that uses both lenses and mirrors.

Medical Imaging: CAT, PET, MRI, and Sonar

- **X-ray radiography:** produces images by transmission rather than reflection.
- A generator emits X-rays toward an object of interest, and a detector measures the photons that make it to the other side, rather than being absorbed by the object.
- **Computed tomography (CT):** refers to imaging by slices.
- The term *axial* refers to the horizontal plane through the human body when standing upright, and since the slices are parallel to this plane, the approach is also known as **computed axial tomography (CAT).**

Medical Imaging: CAT, PET, MRI, and Sonar (cont'd)

- **Magnetic resonance imaging (MRI):** safer than X-ray because it does not use ionizing radiation.
  - MRI uses powerful magnets to align the hydrogen nuclei (that is, protons) in the water molecules.
- A radio frequency (RF) signal pulse at the resonance frequency is emitted that systematically alters the alignment of the nuclei by flipping the spin of the protons.

Medical Imaging: CAT, PET, MRI, and Sonar (cont'd)

- **Positron emission tomography (PET):** another technique for nuclear imaging.
  - A patient is injected with a radioactive isotope which, as it undergoes positron emission decay, emits a positron.
- **Fluoroscopy:** a way of obtaining real-time images of a patient using an X-ray image intensifier to convert the X-rays on the sensor to visible light for viewing by a radiologist.

Remote Sensing: SAR and Multispectral

- Cameras are often attached to aircraft or satellites for remote sensing of the earth for applications in meteorology, agriculture, surveillance, and geology.
  - These cameras typically sense multiple frequencies simultaneously.
- A multispectral sensor senses a small number of frequencies, typically 5 to 7.
- A hyperspectral sensor senses a much larger range of frequencies.

Up Next: Chapter 3 Point and Geometric Transformations

Questions?