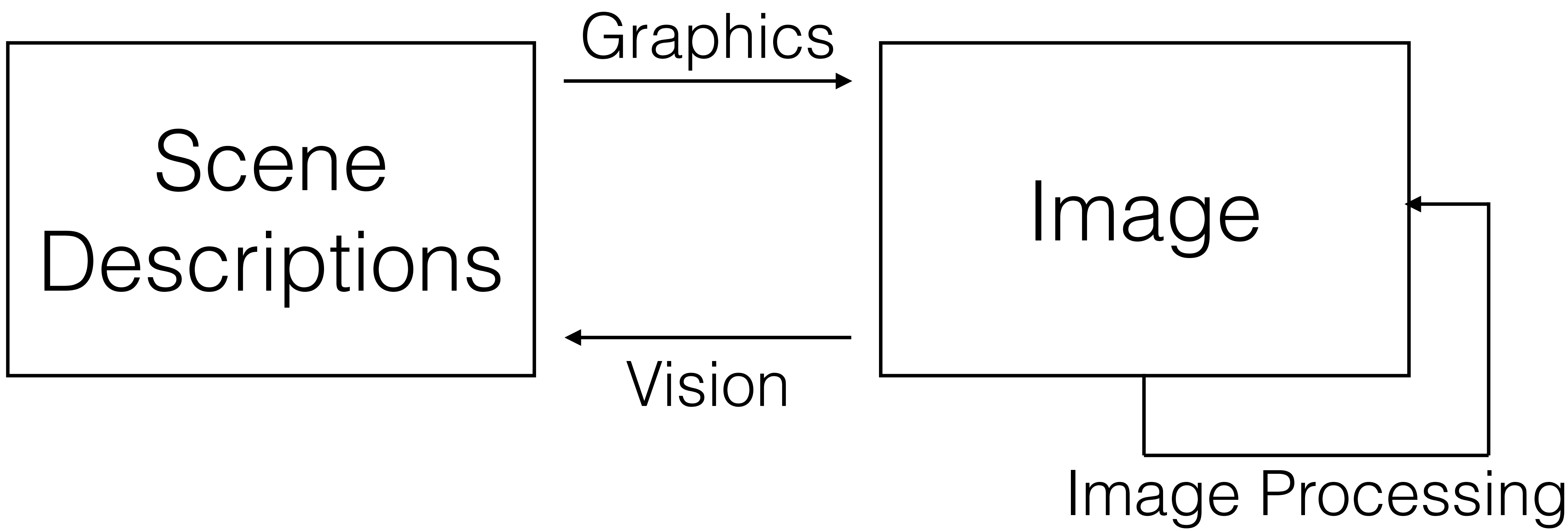
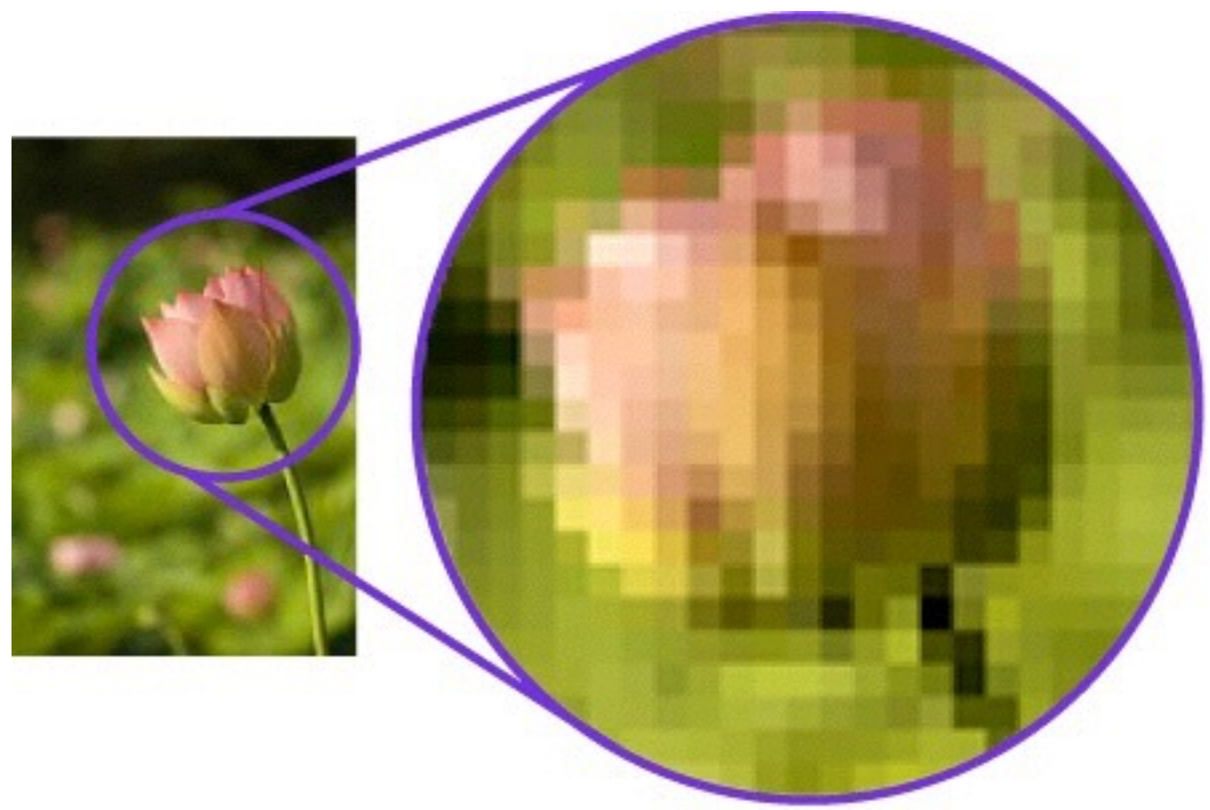
Images and Cameras

CS 355: Interactive Graphics and Image Processing

Image Processing



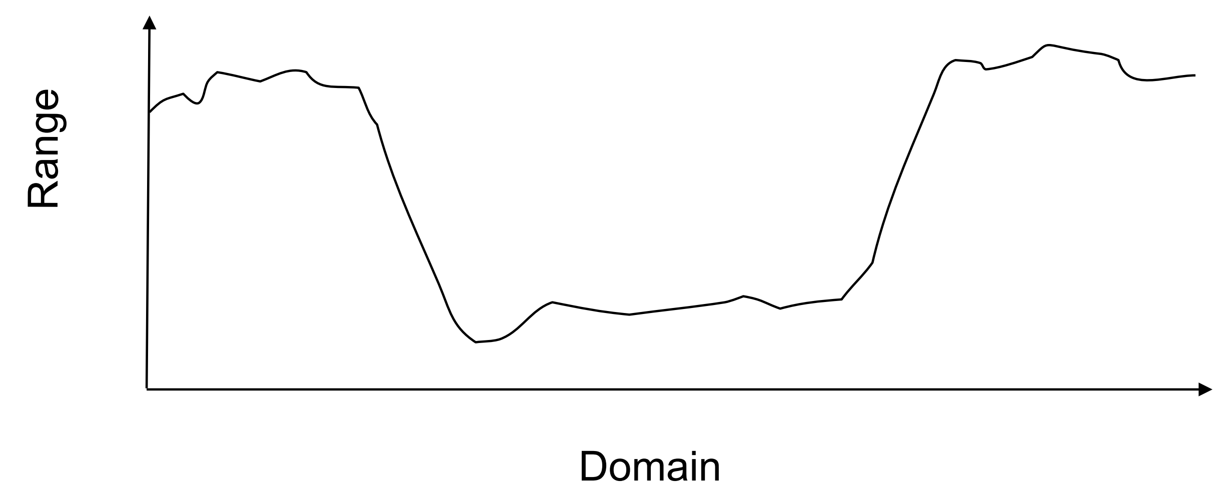
Raster Images



Digital images from cameras are made up of discrete pixels

Signals as Functions

- Digital signals can be thought of as *sampled functions*
- Domains:
  - Time (audio)
  - Space (images)
  - Both (video)

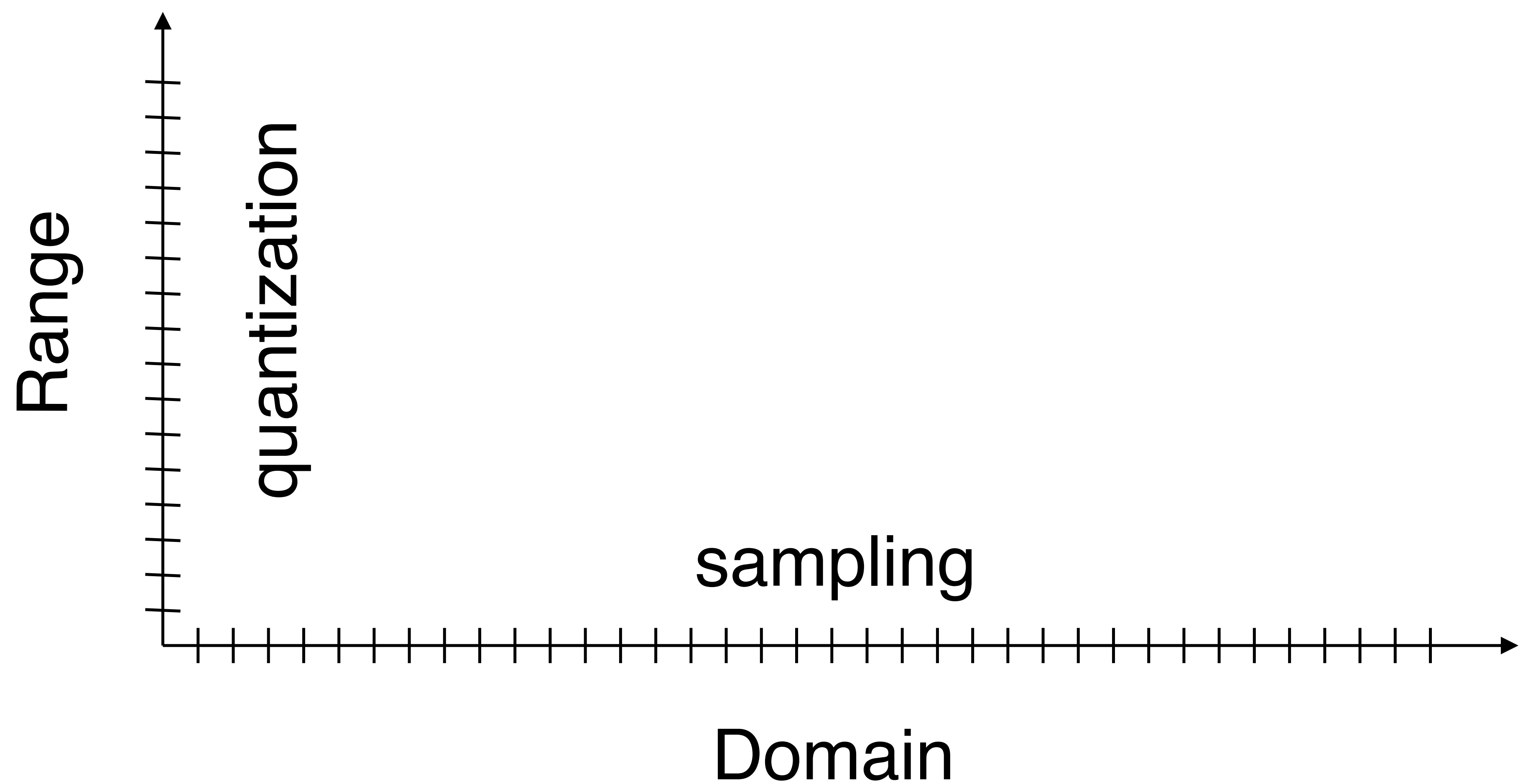


- Ranges:
  - Changing air pressure (audio)
  - Visible light (photographs, video)
  - Other properties (X-rays, MRI, range images, etc.)

$$f(t)$$

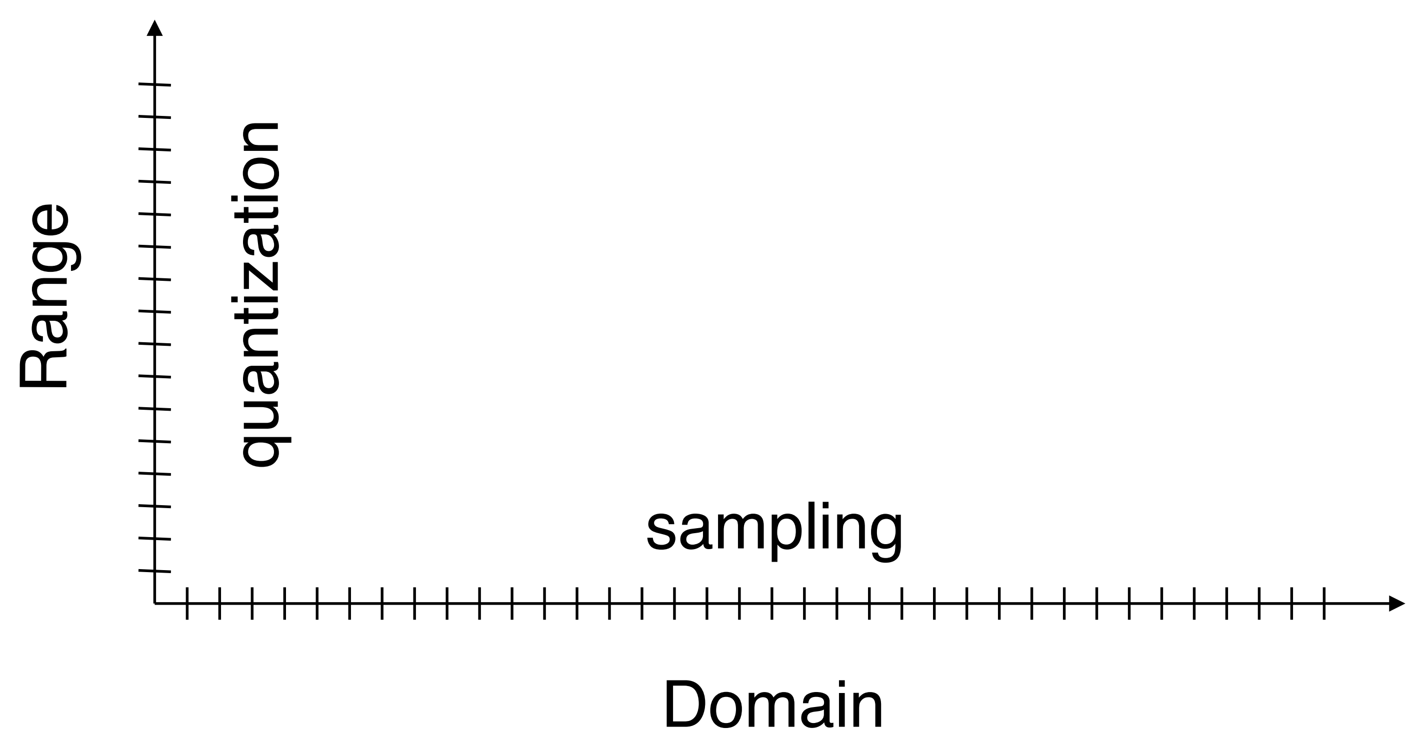
$$I(x,y)$$

Sampling vs. Quantization



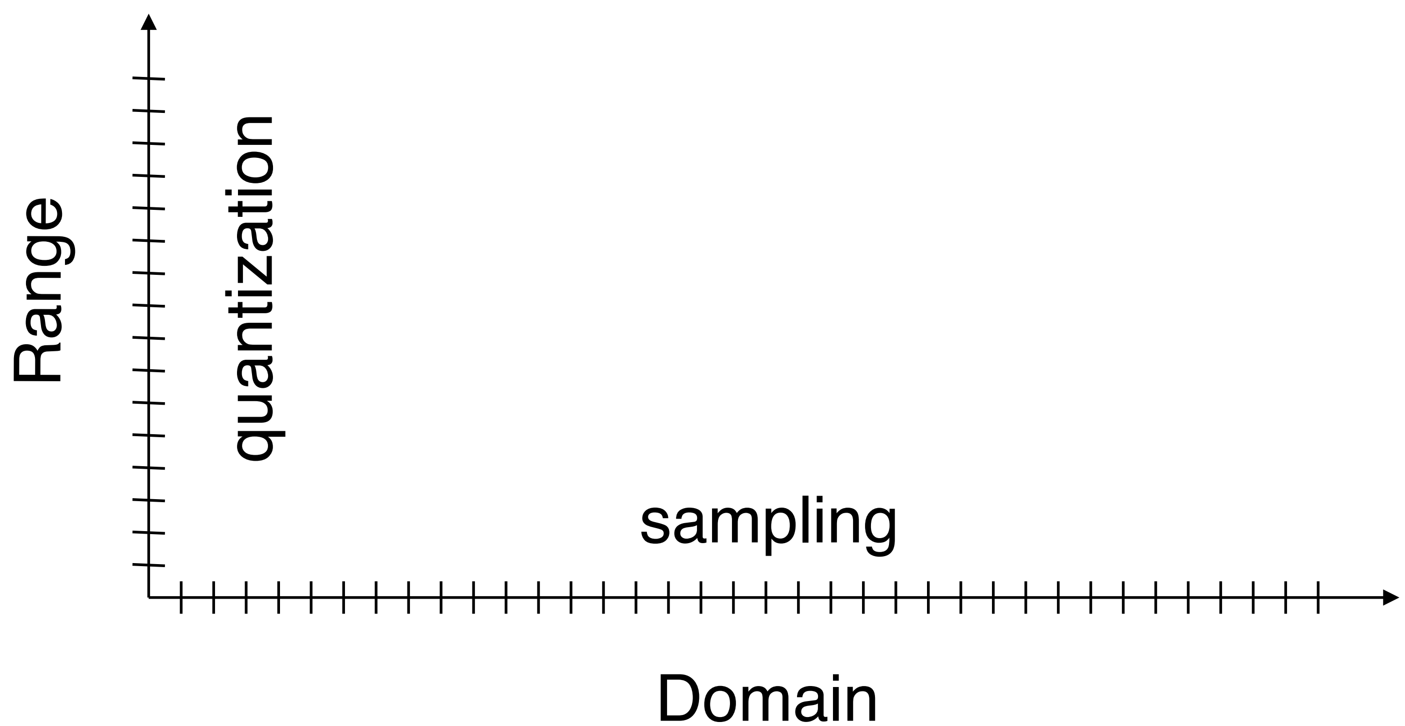
Sampling

- Samples per unit length, area, etc.
- Often expressed as rate, spacing, or density



Quantization

- Levels of precision in sampled values
- Usually number of levels or number of bits



Sampling vs. Quantization

- 600 dots per inch
- black and white images
- 256-level grey
- 8-bit grey

- 30 frames per second
- 24-bit color
- 44.1 KHz audio
- 16-bit audio

Storage

- We usually store digital signals (including images) as arrays
  - Audio: 1-D domain, 1-D array of values (PCM)

90	50	8	…	42

  - Images: 2-D domain, 2-D array

88	86	8	…	9
91	92	10	…	7
87	91	9	…	8
⋮	⋮	⋮	⋱	⋮
90	89	11	…	8

Storage

- In memory: usually just arrays
    - Be careful of (x,y) vs. row-major ordering
- On disk: may be something else entirely
    - Tiled storage (think virtual memory)
    - Hierarchical/Interlaced
    - Compressed
- Headers: EXIF, compression settings, etc.

How do we get images?

Acquisition Devices

- Aperture
- Scanning
- Sensor
- Quantizer
- Output storage medium

Apertures

- Pixels aren't point samples
- Total light over an *area* of the visible scene
- Controlled by the camera's iris (photographers: F-stop)
- Also caused by physical sensor area (pixel's area on the camera's sensor)

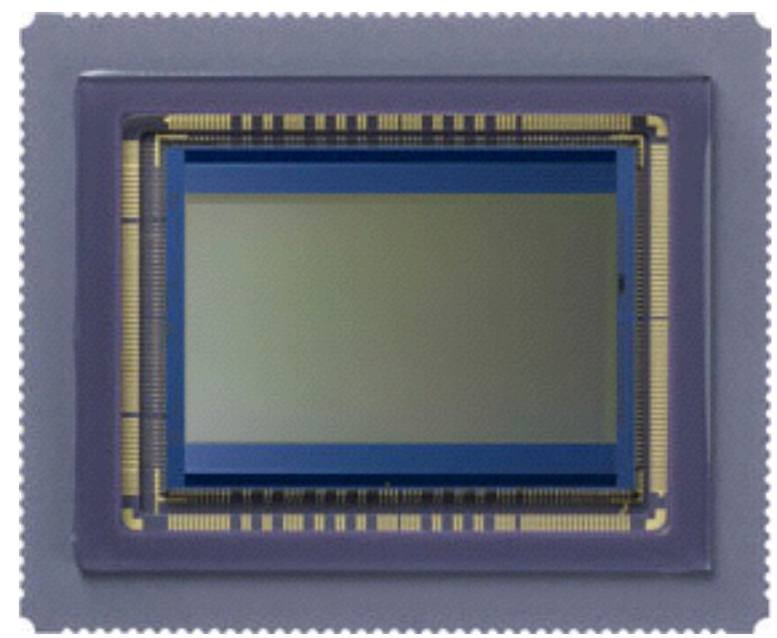
Apertures

- Sampling and size of aperture determine *resolution*
    - Smaller apertures = better resolution
    - Larger apertures = worse resolution
- Lenses allow a physically larger aperture to act as an effectively smaller one

Resolution

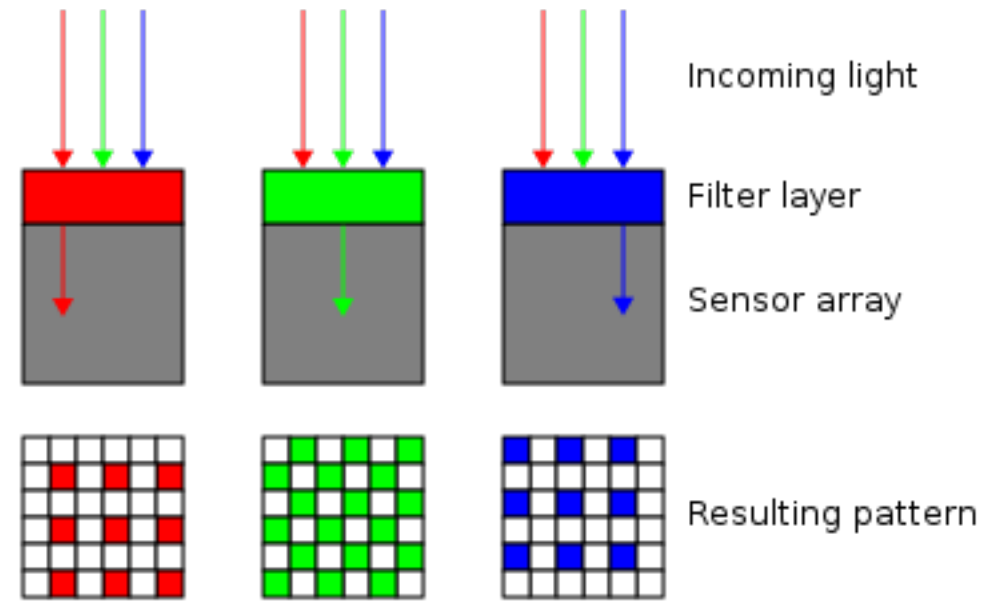
Sensors

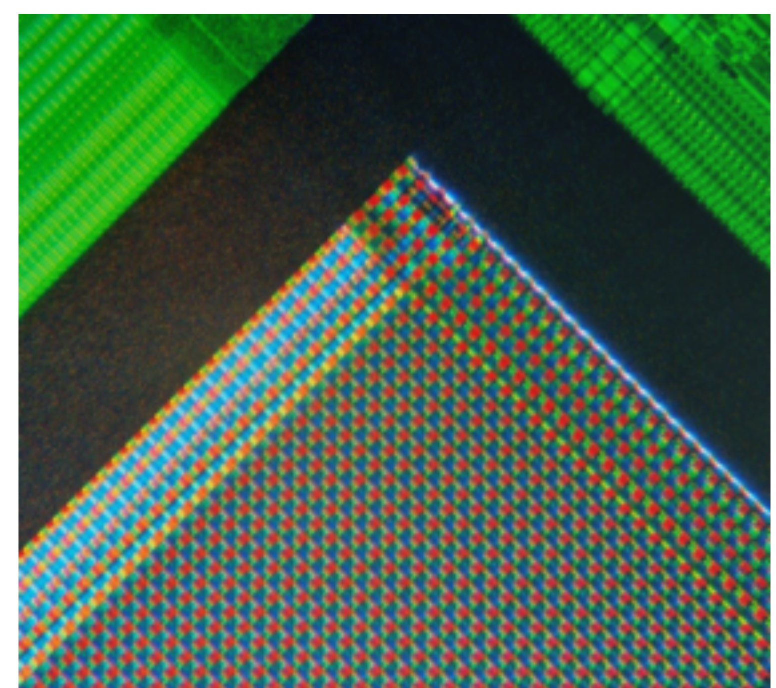
- Converts light (photons) to chemical and/or electrical response
- Examples
  - Silver halide crystals (film)
  - Photoreceptors in our eyes (rods, cones)
  - Charge-coupled device (CCD)
  - CMOS arrays



Bayer Patterns

- Most commercial-grade cameras sample only one color per pixel
- Small colored filter over each sensor element
- 16 megapixels =
  - 8 megapixels green
  - 4 megapixels red
  - 4 megapixels blue
- You get interpolated combination





Noise

- Unavoidable random fluctuations from “correct” value

- Can usually be modeled as a statistical distribution with mean at the “correct” value

  $$\mu$$

- A measured sample will vary from that mean according to the distribution std. dev.

  $$\sigma$$

Signal-To-Noise Ratio

- Measure of how “noise free” a signal is

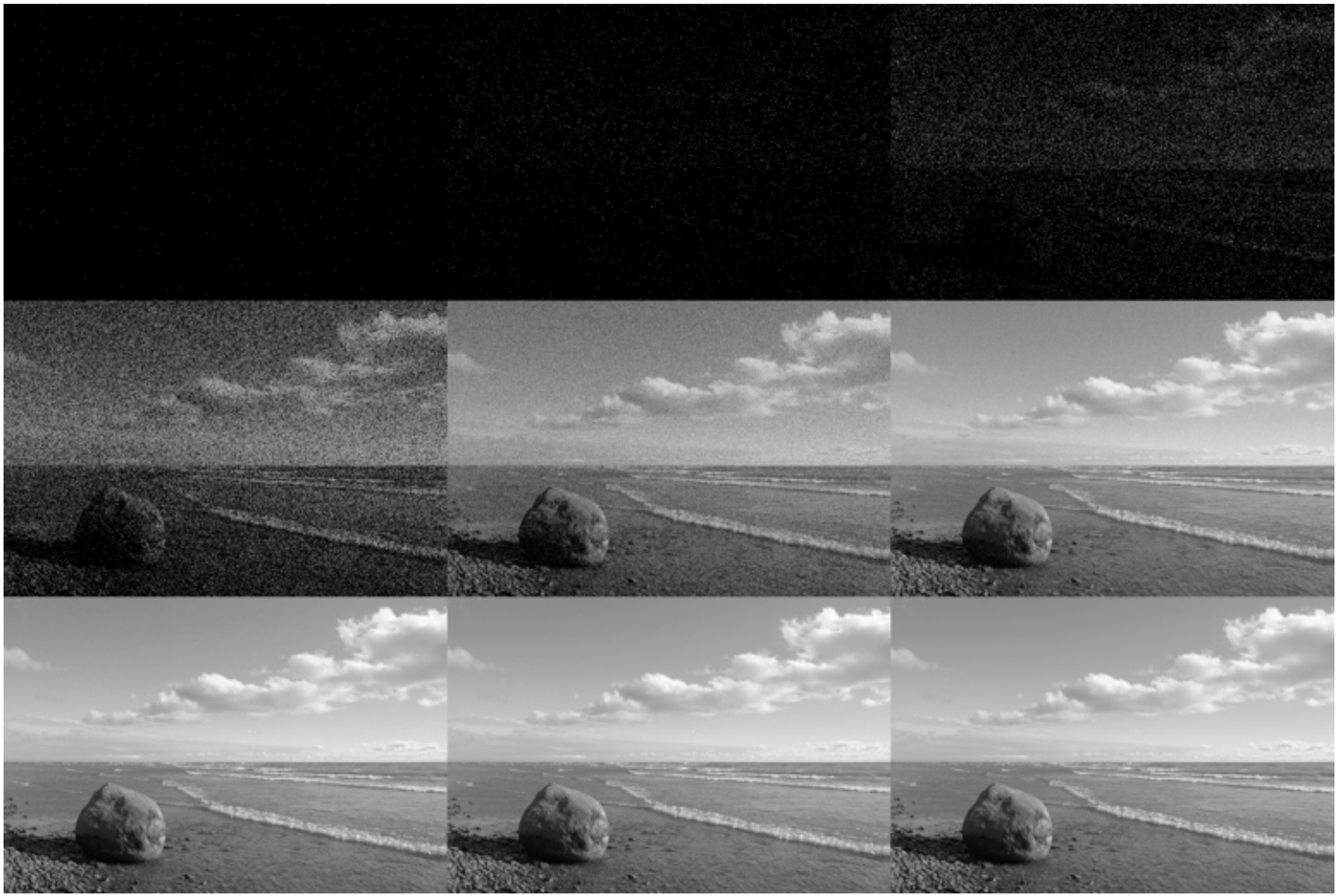
$$\mathrm{SNR} = \frac{\mu}{\sigma}$$

Sources of Noise

- Quantum nature of light
- Sensor inhomogeneity
- Electrical fluctuations
- “Background” noise

May not be random

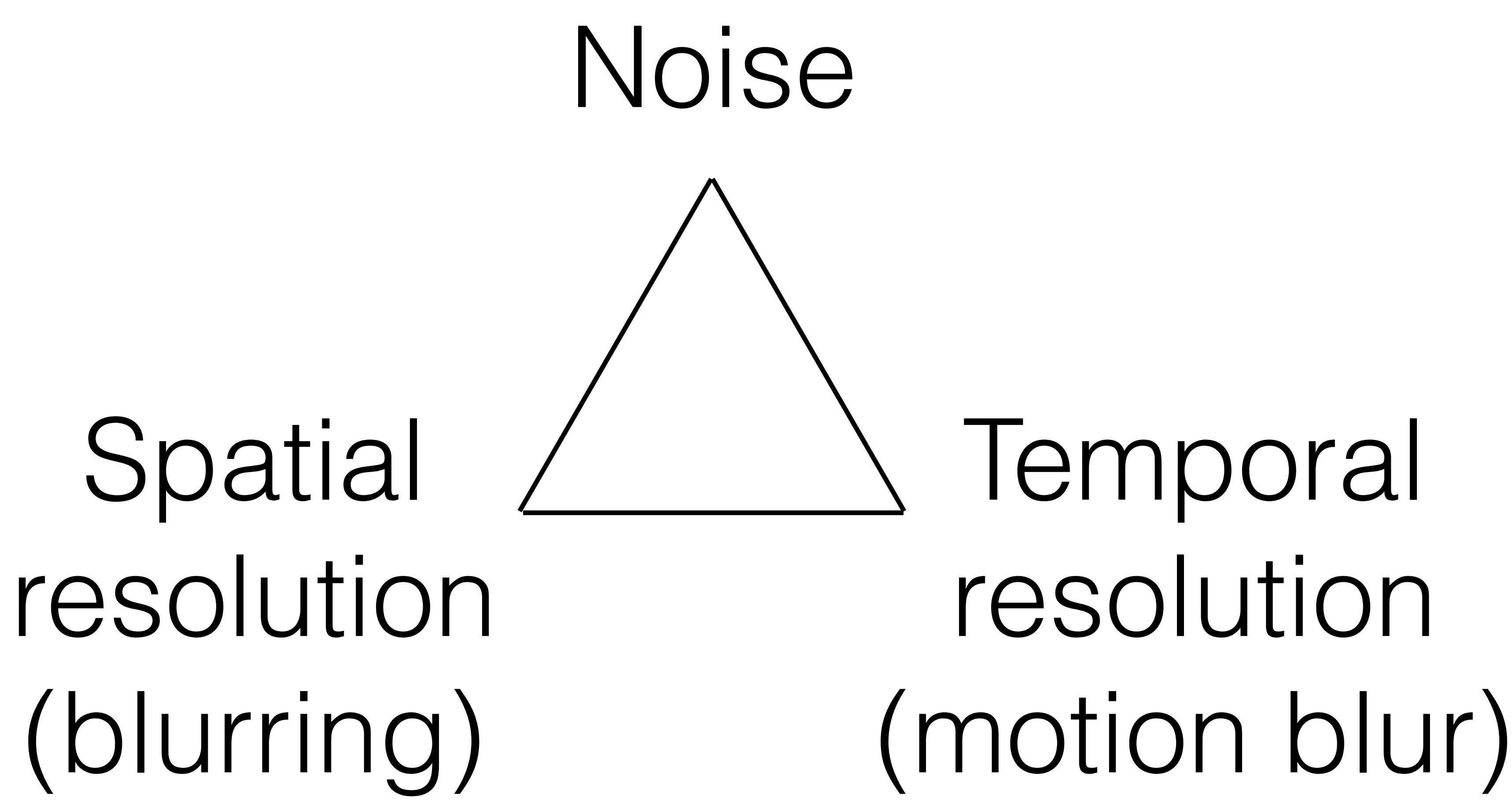
Shot Noise



Reducing Shot Noise

- The only way to reduce quantum noise is to *collect more light with the sensor*
    - Turn up the source
    - Larger aperture
    - Collect for longer
- What are the tradeoffs?

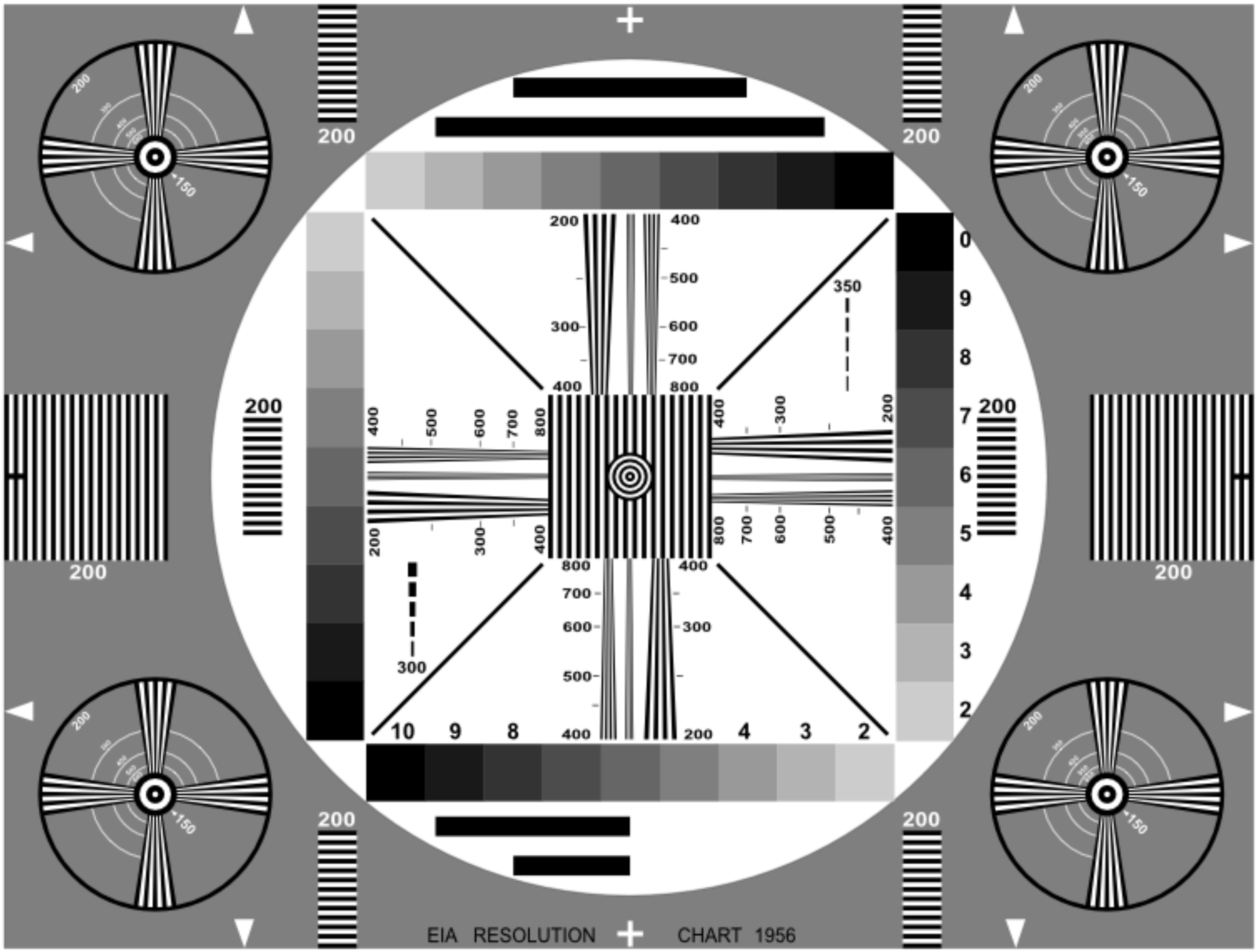
Fundamental Tradeoff



Measuring Resolution

- One common way is to use alternating black/white lines with fixed spacing
  - Increase the density until you can’t resolve (discern) the separate lines
    - Gradually blurs to grey
    - Stop when half the original contrast
  - Units: line pairs per millimeter

Measuring Resolution



Sampling Revisited

- How much sampling is enough?
  - *Shannon Sampling Theorem*:
    twice the highest frequency in the signal (in theory)
  - *Nyquist rate*

- What happens if you sample above this?
  - Avoids dangers of theoretical limits
  - Better for intermediate processing

Different kind of aliasing than jaggies, but related

- What happens if you don't sample enough?
  - Aliasing (false low-frequencies components appear)
  - In images this causes *Moiré patterns*

- *Insufficient sampling during acquisition introduces flaws that cannot be corrected through later processing*

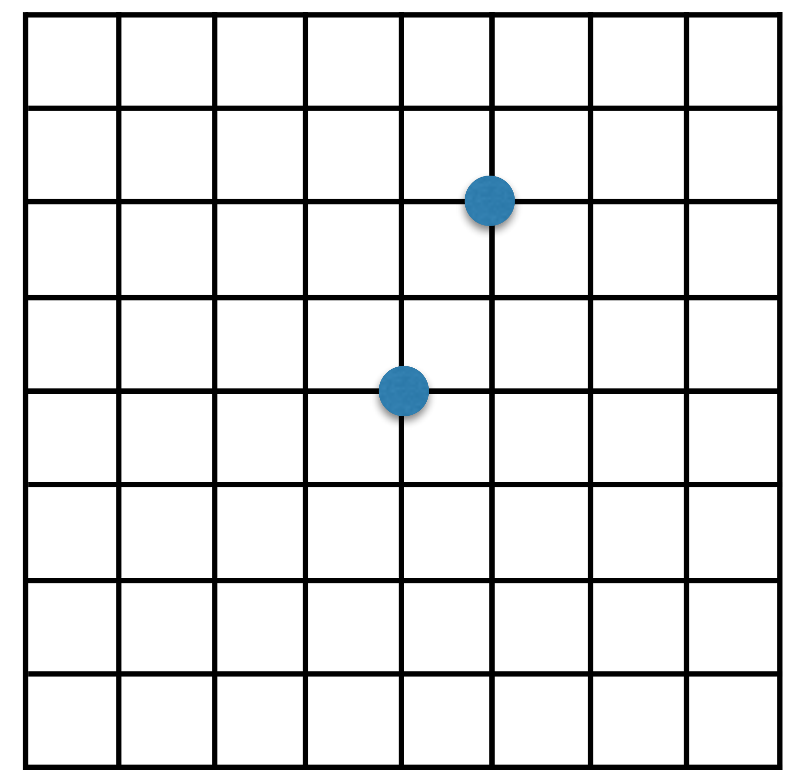
Moiré Patterns

Camera Problems

- Noise
- Spatial blur
- Motion blur
- Bayer sampling artifacts
- Lens distortion
- Chromatic aberration
- Brightness
- Contrast
- Color balance
- Tone mapping
  (color responses)

The Pixel Grid

- Many of the things we do involve using "neighboring" pixels
- Common approaches:
  - 4-connected (N, S, E, W)
  - 8-connected (add NE, SE, SW, NW)
- Distance?
  - Euclidean (as the crow flies)
  - 4-connected ("city block", "Manhattan")
  - 8-connected ("chessboard")



Coming up...

- Level (point) operations: brightness, contrast, etc.
- Interimage: blending, masking, differencing, compositing
- Neighborhood operations:
    - noise reduction
    - sharpening
    - edge detection
- Interpolation
- Geometric operations: resizing, rotating, warping