Computer Science 631
Lecture 5: From photons to pixels

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Outline

- Today's lesson: *cameras were designed to make pictures that look good to humans*
  - Not to hook up to computers!
- The relationship between photons and pixels has lots of quirks
- We'll look at black and white (grayscale) cameras first
- Color has all these headaches
  - And a few more besides!

What is a camera?

- Important parts: a lens, and an imaging array
  - The job of the lens is to focus light on the imaging array
    - That's all we will say about lenses in CS631
  - The imaging array is a 2-D array of imaging elements
  - By far the most common kind is a Charge-Coupled Device (CCD)
    - Trivia question: who invented it?

CCD arrays

- A CCD captures photons and turns them into electrical charge
  - As long as the photons are in a certain range of energies (wavelength)
  - Visible light is about 400-700 nanometers
    - 1 nanometer = 10^{-9} meter
  - You might think that a CCD counts the number of photons, and the intensity of that CCD's pixel reflects this count straightforwardly
    - You'd be wildly optimistic…

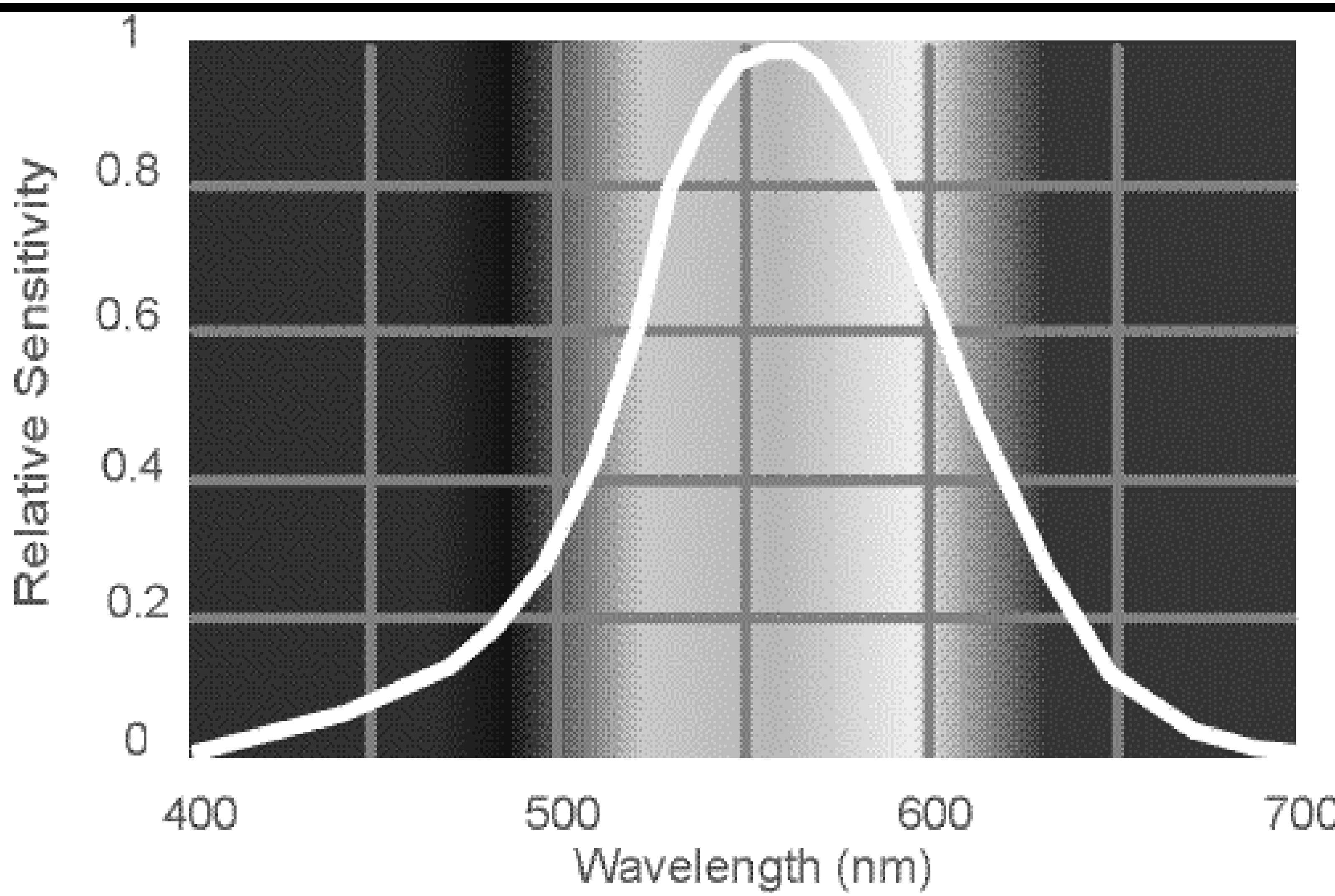
CCD’s come in various flavors

- Few main manufacturers
  - Philips, Sony
  - Standard physical sizes
    - 1/2 or 1/3 inch
  - Standard resolutions
    - 768 by 494 (good) to around 300 by 300 (cheap)
    - Individual cells are under 10 microns on a side
- Digital cameras are causing new types to be built

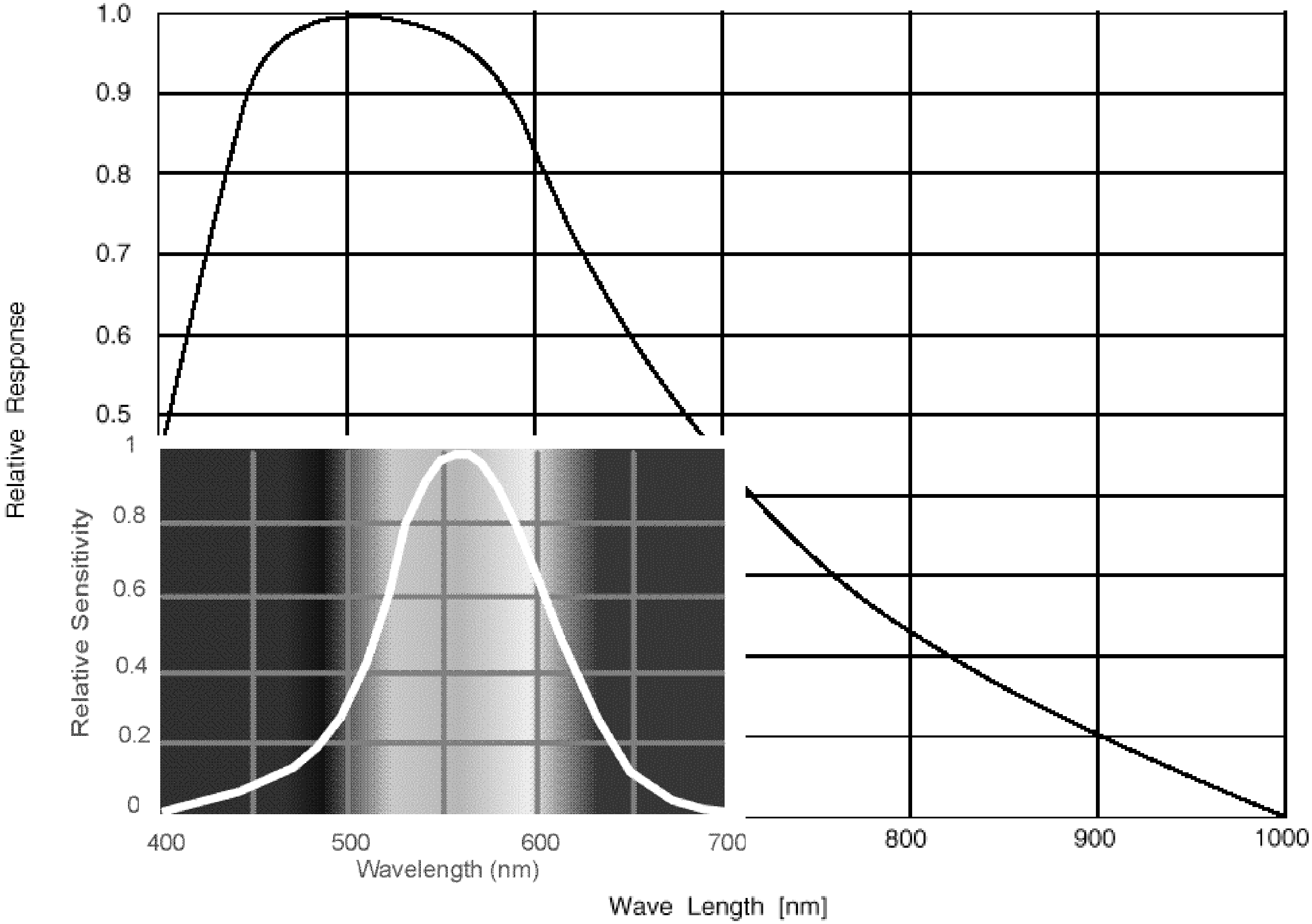
Problem: different responses

- CCD's have a non-linear response to light at different frequencies
  - So does the human visual system
    - About which more later
  - The non-linear responses are *different*
  - Cameras thus "see" quite differently than people
    - Obviously, it's fairly similar or they wouldn't be very useful
  - For example, CCD's tend to be quite sensitive to sunlight

Human response curve



Typical camera response curve



Reading the output of a CCD

- CCD values themselves are corrupted by noise due to (e.g. thermal effects)
- The process by which CCD values are read out introduces further anomalies
  - One row at a time is read out by repeated shifting (bucket brigade style)
  - This does a certain amount of left-right averaging

Cameras transmit pictures in *analog* format

- A CCD is basically a digital device
  - Various manufacturers are looking into hooking them up to computers in a purely digital manner
  - The major issue is bandwidth
- To get from a (digital) CCD to a (digital) computer, we go through an analog stage
  - The world of video is fundamentally an analog world
  - TV special effects used to be analog!

Digitization general issues

- An analog signal specifies voltage as a function of time - both continuous!
  - We need to discretize both quantities
  - Video is read out as a sequence of rows (scan lines)
  - A digitizer samples an individual scan line some number of times
    - Generally *not* synchronized with the CCD's
    - Expensive cameras and digitizers can solve this problem using a pixel clock (camera output, digitizer input)

Analog television standards

- Televisions draw pictures very strangely
  - Take advantage of some peculiarities of the human visual system
  - The analog standard are designed to drive televisions, and not for any other purpose
  - US standard is NTSC, sometimes called RS-170
    - 60 hertz, sort of…
    - Europe uses PAL or SECAM
      - 50 hertz

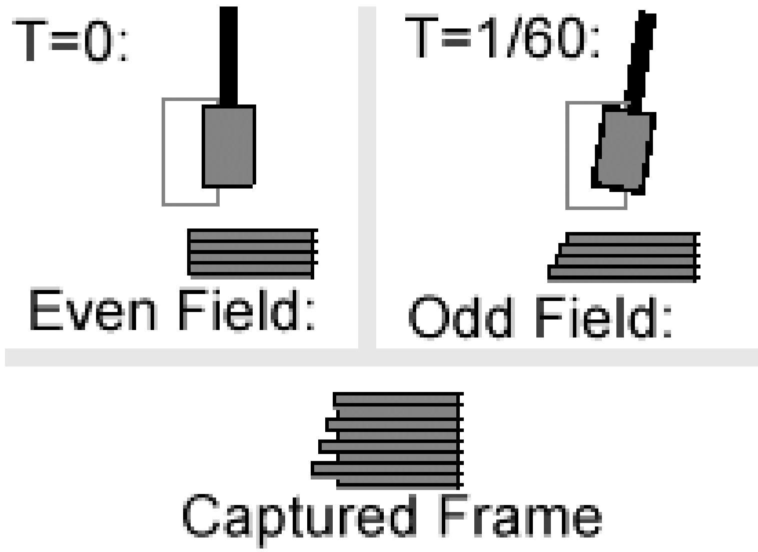
Interlacing

- 60 times a second an NTSC signal sends a picture called a *field*
  - The fields alternate, even and odd
  - Two consecutive fields make up a *frame*
- The even and odd fields are quite different
  - Temporally, off by 1/60 second
    - Significant things happen in 1/60 of a second!
  - Spatially shifted as well!

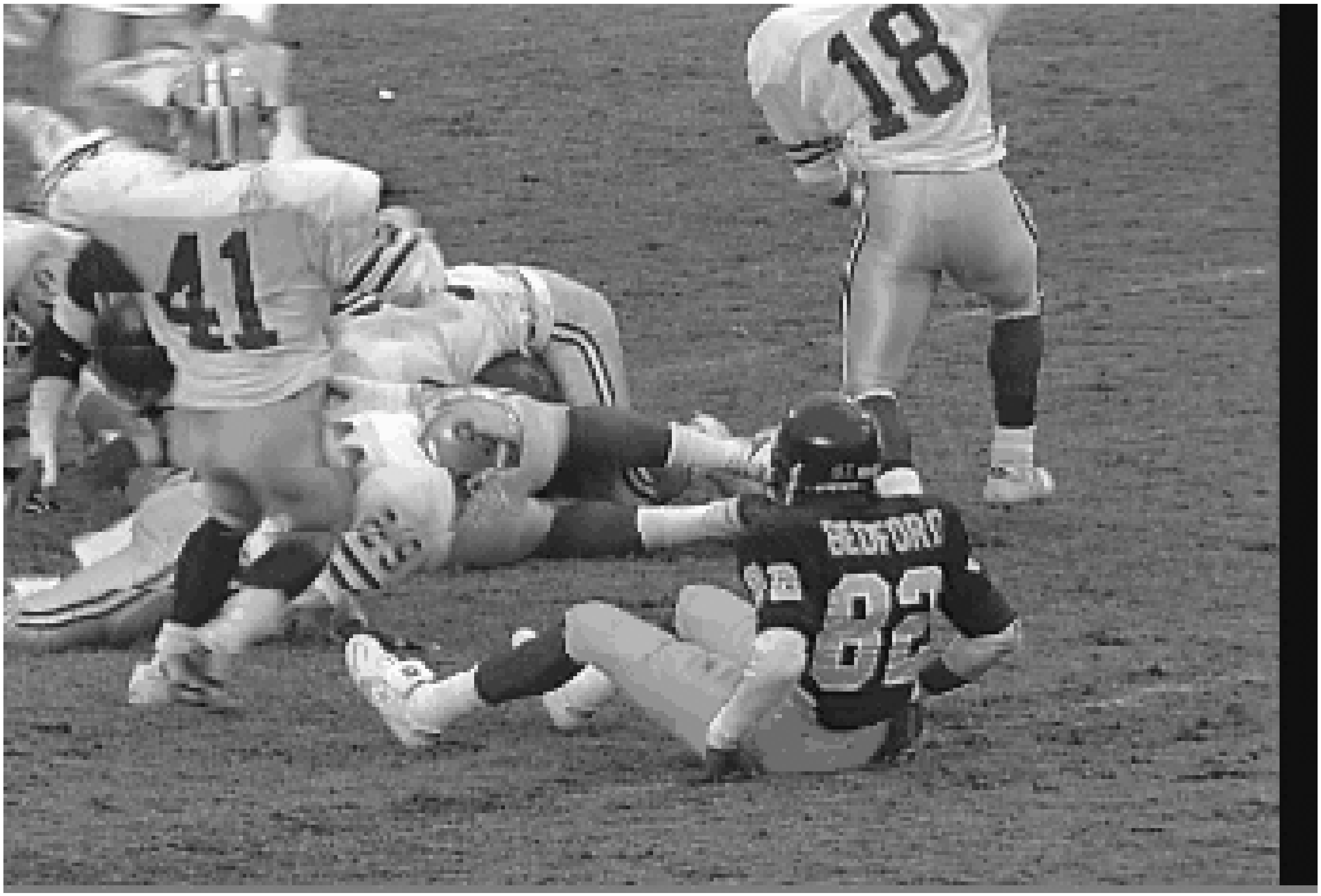
Even versus odd fields

- Think of the even frame as consisting of the even rows from the CCD array
  - While the odd frame consists of the odd rows
  - This yields some *very* weird effects when you look closely at the two fields
  - From a digital processing point of view, it’s usually best to simply ignore one field
    - Drop half the data on the floor
  - Analog users like interlacing, digital prefer “progressive scan”

Interlacing example: swinging pendulum



A real example of interlacing



Interlacing and CCD’s

- The real story is actually worse than this
  - A line in a single field does not correspond to a row of CCD’s
  - Line 0 (even field) is the average of rows 0 and 1
  - Line 1 (odd field) is the average of rows 1 and 2
  - Line 2 (even field) is the average of rows 2 and 3
  - This effectively does vertical averaging

The NTSC standard

- NTSC is an analog standard
  - Describes voltage as a function of time
  - Timing information is a value below the lowest allowed pixel value (blacker than back)
  - There is a timing signal, *horizontal sync*, at the end of each line that says that the line is over
  - Similarly, there is a timing signal *vertical sync* that says the last row is over

Hiding information in an NTSC signal

- There is room to transmit additional information besides the signal
  - And still obey the NTSC standard!
- For example, a scan line lasts 64 microseconds, but there is only 52 microseconds of data
- Similarly there is room “between” frames
  - After the vsync, before the first row of the next field

Square pixels

- NTSC specifies 483 lines per frame
  - 262.5 per field
  - Televisions have a 4:3 aspect ratio
- If we sample a line 644 times, a pixel will have the same aspect ratio as the picture
- What about synchronization with the individual CCD elements?

Analog video formats (ways to store NTSC)

- Critical difference is the number of samples per line
  - VHS is 240, which is why it looks so bad
  - Regular 8 is 300
  - Super VHS is 400-425
  - Hi-8 is 425, which is about laserdisk also
  - Beta-SP is 500+
- There are also a bunch of digital formats used by studios (like D-1)

Never Twice the Same Color

- Color is encoded in an NTSC signal in a manner that is too EE-like to explain
  - Essentially to allow black and white TV’s to be happy with color signals
  - One consequence is that color information is spatially low-pass filtered
    - This makes some sense, because the human visual system is not spatially accurate about color
    - Example: colorized movies