Chapter 8
Representing Multimedia Digitally
Digitizing Data

• Digitizing is more than letters, numbers, and metadata
• It is also photos, audio, and video
• What are the bits doing?
  – Digitizing includes other forms of digitized information, known as multimedia
• Same principles are used as with letters and numbers to encode information into bits
Color and the Mystery of Light

• Color on a Computer Display:
  – Pixels are small points of colored light arranged in a grid
  – Each pixel is formed from three colored lights: red, green, and blue.
  • known as RGB (always in that order)
Showing Colors

- Turning on one light at a time, the display turns red, green, or blue
- Turning off all of them makes black
- Turning on all of them makes white
- All other colors are made by using different amounts or intensities of the three lights
Yellow = R + G?

- Combining red and green makes yellow.
- I thought that red and yellow make orange?
  - There is a difference between colored light and colored paint.
Yellow = R + G?

- Paint reflects some colors and absorbs others
- When white light strikes paint, some light is absorbed (we can’t see it) and some light is reflected (we see it)
Yellow = R + G?

- In the case of a pixel, the light shines directly at our eyes
  - Nothing is absorbed
  - Nothing is reflected
  - Just see pure colored light
LCD Display Technology

- At left in the close-up of an LCD is an arrow pointer with two enlargements of it
- From a distance, the pixels appear white
- Close up, the pixels are red, green, and blue colored lights
Black and White Colors

- The intensity of RGB light is usually given by a binary number stored in a byte.
- Representing the color of a single pixel requires 3 bytes (1 for each color).
  - Smallest intensity is 0000 0000
  - Largest intensity is 1111 1111
- Doing the math from Chapter 7, says the range of values is 0 through 255 for each color.
Black and White Colors

- **Black** is the absence of light:
  - \(0000\ 0000\ 0000\ 0000\ 0000\ 0000\) RGB bit assignment for black

- **White** is the full intensity of each color:
  - \(1111\ 1111\ 1111\ 1111\ 1111\ 1111\) RGB bit assignment for white
Color Intensities

• Consider blue (0000 0000 0000 0000 1111 1111)

• The 8 bits specifying its intensity have position values:

• If we want the sub pixel to be at half intensity: each bit contributes half as much power as the bit to its left
Color Intensities

Figure 8.3 Progressively increasing the intensity for a blue subpixel; each bit contributes half as much power as the bit to its left.
Computing on Representations

• When digital information is changed through computation, it is known as *computing on representations*

• For example: changing the brightness and contrast of a photo
Brightness and Contrast

- Brightness refers to how close to white the pixels are
- Contrast is the size of difference between the darkest and lightest portions of the image
- Photo manipulation software often gives the values of the pixels in a Levels graph
Digitizing Sound

• An object creates sound by vibrating in a medium (such as air)
• Vibrations push the air causing pressure waves to emanate from the object, which in turn vibrate our eardrums
• Vibrations are then transmitted by three tiny bones to the fine hairs of our cochlea, stimulating nerves that allow us to sense the waves and “hear” them as sound
Digitizing Sound

- The force, or intensity of the push, determines the volume.
- The frequency (the number of waves per second) of the pushes is the pitch.

Figure 8.12: Sound wave. The horizontal axis is time; the vertical axis is sound pressure.
Analog to Digital

• To digitize, you must convert to bits
• For a sound wave, use a binary number to record the amount that the wave is above or below the 0 line at a given point on our graph
• At what point do you measure?
  – There are infinitely many points along the line, too many to record every position of the wave
Analog to Digital

- Sample or take measurements at regular intervals
- Number of samples in a second is called the sampling rate
- The faster the rate the more accurately the wave is recorded

Figure 8.13: Two sampling rates; the rate on the right is twice as fast as that on the left.
Nyquist Rule for Sampling

- If the sampling were too slow, sound waves could “fit between” the samples and you would miss important segments of the sound.
- The Nyquist rule says that a sampling rate must be at least twice as fast as the highest frequency.
Nyquist Rule for Sampling

• Because humans can hear sound up to roughly 20,000 Hz, a 40,000 Hz sampling rate fulfills the Nyquist rule for digital audio recording.

• For technical reasons a somewhat faster-than-two-times sampling rate was chosen for digital audio (44,100 Hz).
Digitizing Process

Figure 8.14  Schematic for analog-to-digital and digital-to-analog conversion.
Digitizing Process

• The digitizing process works as follows:
  – Sound is picked up by a microphone (transducer)
  – Signal is fed into an analog-to-digital converter (ADC), which takes the continuous wave and samples it at regular intervals, outputting for each sample a binary number to be written to memory
  – Then compressed
The digitizing process works as follows:

- The process is reversed to play the sound: The numbers are read from memory, decompressed, and sent to a digital-to-analog converter (DAC).
- An electrical wave created by interpolation between the digital values (filling in or smoothly moving from one value to another).
- The electrical signal is then input to a speaker which converts it into a sound wave.
How Many Bits per Sample?

• To make the samples perfectly accurate, you need an unlimited number of bits for each sample
• Bits must represent both positive and negative values
  – Wave has both positive and negative sound pressure
• The more bits there that are used, the more accurate the measurement is
How Many Bits per Sample?

- We can only get an approximate measurement.
- If another bit is used, the sample would be twice as accurate.
- More bits yields a more accurate digitization.
- Audio digital representation typically uses 16 bits.

![Figure 8.15](a) Three-bit precision for samples requires that the indicated reading is approximated as +10. (b) Adding another bit makes the sample twice as accurate.
Advantages of Digital Sound

• A key advantage of digital information is the ability to compute on the representation

• One computation of value is to compress the digital audio or reduce the number of bits needed

• What about sounds that the human ear can’t hear because they are either too high or too low?
Advantages of Digital Sound

• MP3 is really a form of computing on the representation
• It allows for compression (with a ratio of more than 10:1)
• MP3 can improve compression by simply removing sounds that are too high or low to hear
Digital Images and Video

• An image is a long sequence of RGB pixels
• The picture is two dimensional, but think of the pixels stretched out one row after another in memory
Digital Images and Video

• Example:
  – 8 × 10 image scanned at 300 pixels per inch
  – That’s 80 square inches, each requiring 300 × 300 = 90,000 pixels (or 7.2 megapixels)
  – At 3 bytes per pixel, it takes 21.6 MB (3 × 7.2) of memory to store one 8 × 10 color image
  – Sending a picture across a standard 56 Kb/s phone connection would take at least 21,600,000 × 8/56,000 = 3,085 seconds (or more than 51 minutes)
Image Compression

• Typical monitor has fewer than 100 pixels per inch (ppi)
  – storing the picture digitized at 100 ppi is a factor of nine savings immediately.

• A 100 ppi picture still requires more than five and a half minutes to send

• What if we want to print the picture, requiring the resolution again?
Image Compression

• Compression means to change the representation in order to use fewer bits to store or transmit information
  – Example: faxes are a sequences of 0’s and 1’s that encode where the page is white (0) or black (1)
  – Use run-length encoding to specify how long the first sequence (run) of 0’s is, then how long the next sequence of 1’s is, then how long the next sequence of 0’s is, then ...
Compression

• Run-length encoding is “lossless “compression scheme
  – The original representation of 0’s and 1’s can be perfectly reconstructed from the compressed version

• The alternative is lossy compression
  – The original representation cannot be exactly reconstructed from the compressed form
  – Changes are not perceptible
Compression

• MP-3 is probably the most famous compression scheme
  – MP3 is lossy because the high notes cannot be recovered
• JPG (or JPEG) is a lossy compression for images
  – Exploits the same kinds of “human perception” characteristics that MP-3 does, only for light and color
JPEG Compression

• Humans are quite sensitive to small changes in brightness (luminance)
• Brightness levels of a photo must be preserved between uncompressed and compressed versions
• People are not sensitive to small differences in color (chrominance)
JPEG Compression

• JPEG is capable of a 10:1 compression without detectable loss of clarity simply by keeping the regions small
• It is possible to experiment with levels greater than 10:1
• The benefit is smaller files
  – Eventually the picture begins to “pixelate” or get “jaggies”
JPEG Compression

Figure 8.16 Life Saver Sculpture at the Beach (400 x 300 pixels); (a) original 202 KB, (b) 10:1 compression (20 KB), (d) 25:1 ratio (8 KB).
MPEG Compression

• MPEG is the same idea applied to motion pictures
• It seems like an easy task
  – Each image/frame is not seen for long
  – Couldn’t we use even greater levels of single-image compression?
  – It takes many “stills” to make a movie
MPEG Compression

• In MPEG compression, JPEG-type compression is applied to each frame
• “Interframe coherency” is used
  – Two consecutive video images are usually very similar, MPEG compression only has to record and transmit the “differences” between frames
  – Resulting in huge amounts of compression
Optical Character Recognition

• A scanner can make a computer document from a printed one by taking its picture
• But this document will not be searchable, since the computer doesn’t know what words it contains
• Converting the pixels to text is call *optical character recognition*
Latency

- The system must operate fast enough and precisely enough to appear natural.
- Latency is the time it takes for information to be delivered.
- Long latencies just make us wait, but long latency can ruin the effect!
- There is an absolute limit to how fast information can be transmitted—the speed of light.
Bandwidth

• Bandwidth is how much information is transmitted per unit time
• Higher bandwidth usually means lower latency
Bits Are It!

• 4 bytes might represent many kinds of information
• This a fundamental property of information:
  – *Bias-Free Universal Medium Principle: Bits can represent all discrete information;*
• Bits have no inherent meaning
Bits: The Universal Medium

- All discrete information can be represented by bits
- Discrete things—things that can be separated from each other—can be represented by bits
Bits: Bias-Free

• Given a bit sequence
  0000 0000 1111 0001 0000 1000 0010 0000
  there is no way to know what information it represents

• The meaning of the bits comes entirely from the interpretation placed on them by users or by the computer
Not Necessarily Binary Numbers

• Computers represent information as bits
• Bits can be *interpreted* as binary numbers
• Bits do not always represent binary numbers
  – ASCII characters
  – RGB colors
  – Or an unlimited list of other things