Assignments/Announcements

• Lab #1 due Mon. Sept. 17 by 11:59pm through CatCourses.

• HW #1 assigned, due Mon. Sept. 24 by 11:59pm through CatCourses.
  – Make sure to start early so you can visit my or the TA office hours if necessary.
Questions?
Today

- Chap. 2: Digital Image Fundamentals (continued)
  - Image sensing and acquisition
  - Image sampling and quantization
Chap 2: Image sensing and acquisition

- Simple image formation model

**FIGURE 2.15** An example of the digital image acquisition process. (a) Energy (“illumination”) source. (b) An element of a scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.
Chap 2: Image sensing and acquisition

• What exactly is the light that forms the image?

• $f(x,y)$ can be characterized by two components
  – Illumination: the amount of source illumination incident on the scene
  – Reflectance: the amount of illumination reflected by the objects in the scene

• Two components combine as a product to form $f(x,y)$

\[
f(x,y) = i(x,y) \cdot r(x,y)
\]

where

\[
0 < i(x,y) < \infty
\]

and

\[
0 < r(x,y) < 1
\]
Chap 2: Image sensing and acquisition

• Typical values for illumination: $i(x,y)$
  – Sun on clear day: 90,000 lm/m²
  – Sun on cloudy day: 10,000 lm/m²
  – Full moon on clear night: 0.1 lm/m²
  – Commercial office: 1000 lm/m²

• Typical values for reflectance: $r(x,y)$
  – Black velvet: 0.01
  – Stainless steel: 0.65
  – Flat-white all paint: 0.80
  – Silver-plated metal: 0.90
  – Snow: 0.93
Chap 2: Image sampling and quantization

• The output of most sensors is a continuous voltage waveform whose amplitude and spatial behavior are related to the physical phenomenon being sensed (usually light in our case)

• To create a digital image, we need to convert the continuous sensed data into digital form:
  – Sampling
  – Quantization
FIGURE 2.16
Generating a digital image. 
(a) Continuous image. (b) A scan line from $A$ to $B$ in the continuous image, used to illustrate the concepts of sampling and quantization. (c) Sampling and quantization. (d) Digital scan line.
Chap 2: Image sampling and quantization

• For sensing arrays:

FIGURE 2.17 (a) Continuous image projected onto a sensor array. (b) Result of image sampling and quantization.
Chap 2: Image sampling and quantization

• Representing digital images

continuous
\[ f(s,t) \]
\[ s,t \in \text{real numbers} \]
\[ f \in \text{real numbers} \]
s, t have physical meaning

discrete (digital)
\[ f(x,y) \]
\[ x,y \in \text{integers} \]
\[ x=0,1,2,\ldots,M-1 \]
\[ y=0,1,2,\ldots,N-1 \]
\[ f \in \text{real numbers} \]
\[ f \in \text{integers} \]

s, t ∈ real numbers

sampling
quantization

x, y ∈ integers

x, y are unitless
Chap 2: Image sampling and quantization

- Representing (rendering) digital images

**Figure 2.18**
(a) Image plotted as a surface.
(b) Image displayed as a visual intensity array.
(c) Image shown as a 2-D numerical array (0, .5, and 1 represent black, gray, and white, respectively).
Chap 2: Image sampling and quantization

**Figure 2.19**
Coordinate convention used to represent digital images. Because coordinate values are integers, there is a one-to-one correspondence between $x$ and $y$ and the rows ($r$) and columns ($c$) of a matrix.
Chap 2: Image sampling and quantization

• Representing digital images
• Digital image: \( f \in \text{integers} \)
• Number of intensity levels is typically an integer power of 2:
  \( L = 2^k \)
  \( f \in [0,1,2,\ldots,L-1] \)
  \( \text{“}k\text{-bit image”} \)
# Chap 2: Image sampling and quantization

**TABLE 2.1**
Number of storage bits for various values of $N$ and $k$.

<table>
<thead>
<tr>
<th>$N/k$</th>
<th>1 ($L = 2$)</th>
<th>2 ($L = 4$)</th>
<th>3 ($L = 8$)</th>
<th>4 ($L = 16$)</th>
<th>5 ($L = 32$)</th>
<th>6 ($L = 64$)</th>
<th>7 ($L = 128$)</th>
<th>8 ($L = 256$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>32</td>
<td>1,024</td>
<td>2,048</td>
<td>3,072</td>
<td>4,096</td>
<td>5,120</td>
<td>6,144</td>
<td>7,168</td>
<td>8,192</td>
</tr>
<tr>
<td>64</td>
<td>4,096</td>
<td>8,192</td>
<td>12,288</td>
<td>16,384</td>
<td>20,480</td>
<td>24,576</td>
<td>28,672</td>
<td>32,768</td>
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<tr>
<td>128</td>
<td>16,384</td>
<td>32,768</td>
<td>49,152</td>
<td>65,536</td>
<td>81,920</td>
<td>98,304</td>
<td>114,688</td>
<td>131,072</td>
</tr>
<tr>
<td>256</td>
<td>65,536</td>
<td>131,072</td>
<td>196,608</td>
<td>262,144</td>
<td>327,680</td>
<td>393,216</td>
<td>458,752</td>
<td>524,288</td>
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<tr>
<td>512</td>
<td>262,144</td>
<td>524,288</td>
<td>786,432</td>
<td>1,048,576</td>
<td>1,310,720</td>
<td>1,572,864</td>
<td>1,835,008</td>
<td>2,097,152</td>
</tr>
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<td>1,048,576</td>
<td>2,097,152</td>
<td>3,145,728</td>
<td>4,194,304</td>
<td>5,242,880</td>
<td>6,291,456</td>
<td>7,340,032</td>
<td>8,388,608</td>
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<td>16,777,216</td>
<td>20,971,520</td>
<td>25,165,824</td>
<td>29,369,128</td>
<td>33,554,432</td>
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<tr>
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<td>134,217,728</td>
<td>201,326,592</td>
<td>268,435,456</td>
<td>335,544,320</td>
<td>402,653,184</td>
<td>469,762,048</td>
<td>536,870,912</td>
</tr>
</tbody>
</table>
Chap 2: Image sampling and quantization

**Figure 2.21**
Number of megabytes required to store images for various values of \( N \) and \( k \).

Megabytes (\( \frac{b}{g} \times 10^6 \))

\( N \)

\( k = 8 \)

\( 7 \)

\( 6 \)

\( 5 \)

\( 4 \)

\( 3 \)

\( 2 \)

\( 1 \)

\( \times 10^3 \)

Chap 2: Image sampling and quantization

- Spatial and intensity resolution
- Dots (pixels) per inch is a common way to specify spatial resolution of rendered image
  - Newspapers: 75 dpi
  - Magazines: 133 dpi
  - Our text: 2400 dpi
- dpi limits the amount of detail that can be rendered
Chap 2: Image sampling and quantization

- Effects of varying the number of samples (spatial resolution)

**FIGURE 2.20** Typical effects of reducing spatial resolution. Images shown at: (a) 1250 dpi, (b) 300 dpi, (c) 150 dpi, and (d) 72 dpi. The thin black borders were added for clarity. They are not part of the data.
Chap 2: Image sampling and quantization

• Effects of varying number of intensity levels

Figure 2.24

(a) 2022 × 1800, 256-level image.
(b)-(d) Image displayed in 128, 64, and 32 intensity levels, while keeping the image size constant.
(Original image courtesy of the National Cancer Institute.)

(Continued)
(e)-(h) Image displayed in 16, 8, 4, and 2 intensity levels. (Original image courtesy of the National Cancer Institute.)
Chap 2: Image sampling and quantization

FIGURE 2.25 (a) Image with a low level of detail. (b) Image with a medium level of detail. (c) Image with a relatively large amount of detail. (Image (b) courtesy of the Massachusetts Institute of Technology.)

FIGURE 2.26 Representative isopreference curves for the three types of images in Fig. 2.25.