Bitmap (Raster) Images

CO2016

Multimedia and Computer Graphics

University *of* Leicester

Overview of Lectures on Images

- Part I: Image Transformations
  - Examples of images; key attributes/properties.
  - The standard computer representations of color.
  - Coordinate Geometry: transforming positions.
  - Position Transformation in Java.
  - And/Or Bit Logic: transforming Color.
  - Color Transformation in Java.
- Part II: Image Dithering
  - Basic Dithering.
  - Expansive Dithering.
  - Ordered Dithering.
  - Example Programs.

Examples of Images

Examples of Images

Examples of Images

Attributes of Images

- An image is a (finite, 2-dimensional) array of *colors* c.
- The (x, y) position, an *image coordinate*, along with its color, is a *pixel* (eg $p = ((x, y), c)$).
- $x_{max} + 1$ is the *width* and $y_{max} + 1$ is the *height*.
- We study these types of images:
  - 1-bit
    - 2^1 colors: black and white; $c \in \{0, 1\}$
  - 8-bit grayscale
    - 2^8 colors: grays; $c \in \{0, 1, 2, \ldots, 255\}$
  - 24-bit color (RGB)
    - 2^{24} colors: *see later on . . .*
  - others . . .

1-Bit Images

- A pixel in a 1-bit image has a color selected from one of 2^1, that is, *two* “colors”, $c \in \{0, 1\}$. Typically 0 indicates *black* and 1 *white*.
- The (*idealised*!) memory size of a 1-bit image is

$$(height * width)/8 \qquad \text{bytes}$$

8-Bit Grayscale Images

- A pixel in an 8-bit (grayscale) image has a color selected from one of $2^8 = 256$ colors (which denote shades of gray). Each color c is a computer representation of an integer $0 \leq c \leq 255$. The (minimal) memory required is a *byte*.
  - color 20 
  - color 125 
  - color 232

(Recall) Hexadecimal

- Integers are represented as (finite) sequences of digits; each digit selected from the set $\{0, \ldots, 9, a, b, c, d, e, f\}$. For example $0x : 2b1f$, where $0x :$ indicates Hex.
- The symbol s in position i denotes $s * 16^i$ where $a = 10, b = 11, c = 12, d = 13, e = 14, f = 15$.
- The sequence of digits $d_{n-1} \ldots d_0$ denotes the integer

$$\Sigma_{downto\ i=0}^{for\ i=n-1}\ d_i * 16^i = d_{n-1} * 16^{n-1} + \ldots + d_1 * 16^1 + d_0$$

- $0x : 2b1f$ denotes $2 * 16^3 + 11 * 16^2 + 1 * 16^1 + 15 * 16^0 = \ldots$
- IMPORTANT FACT: 8-digit binary numbers correspond exactly to 2-digit hex numbers—they represent the same integers.

24-bit Color Images

- A pixel in a 24-bit color image has a color selected from $2^{24} = 16777216$ colors. Each color c is a computer representation of an integer $0 \leq c \leq 16777215$. The (minimal) memory required is *24 bits*, that is, *3 bytes*.
- The representation is composed out of a Red, Green and Blue *component*, each component represented as one of the three bytes—hence this is often called RGB color.
- An example: $\underbrace{00011101}_{0..255}\underbrace{11010101}_{0..255}\underbrace{11111101}_{0..255}$
- White is $0xffffff$; pure red is $0xff0000$; pure green is $0x00ff00$; pure blue is $0x0000ff$; black is $0x000000$.

24-bit Color Images

- The uncompressed size of a 24-bit color image is

  $$\text{width} * \text{height} * 3 \qquad \text{bytes}$$

  So a 512×512 24-bit image requires (at least) 768kilobytes of storage without any compression.

- Many 24-bit color images are actually stored as 32-bit images, with the extra byte of data for storing an α value representing special information. This α component is (sometimes) used to encode “transparency” information of the pixel.

- The complete pixel data, 8 bits for α and 24 bits for colour, is often stored as a *32-bit integer*.

8-bit Color Images - Briefly

Each pixel has one of 2^8 colors. Each integer from 0 to 255, denoted by one of the 256 possible 8-bit binary numbers, is used to pick one of 256 different RGB colors from a color lookup table.

Each 8-bit color image is composed from these 256 different colors.

The RGB Model of Color in Java

In the RGB model, colors are stored as *32-bit integers* and we have

- for 8-bit grayscale:

$$\texttt{int} \quad \underbrace{\vec{1}}_{\in \mathbb{B}^8} . \underbrace{gray}_{\in \mathbb{B}^8} . \underbrace{gray}_{\in \mathbb{B}^8} . \underbrace{gray}_{\in \mathbb{B}^8}$$

- similarly for 24-bit color and 32-bit color:

$$\texttt{int} \quad alpha.red.green.blue$$

and these values can be obtained with the following methods (try checking this in the dither examples):

Color Methods in Java

Key methods are

- `img.getRGB(int x, int y)`
  get color of pixel at (x, y)
- `img.setRGB(int x, int y, int col)`
  set color of pixel at (x, y) to col
- `img.getWidth()`
  NB width is $x_{Max} + 1$
- `img.getHeight()`
  NB width is $y_{Max} + 1$

for an image `img`.

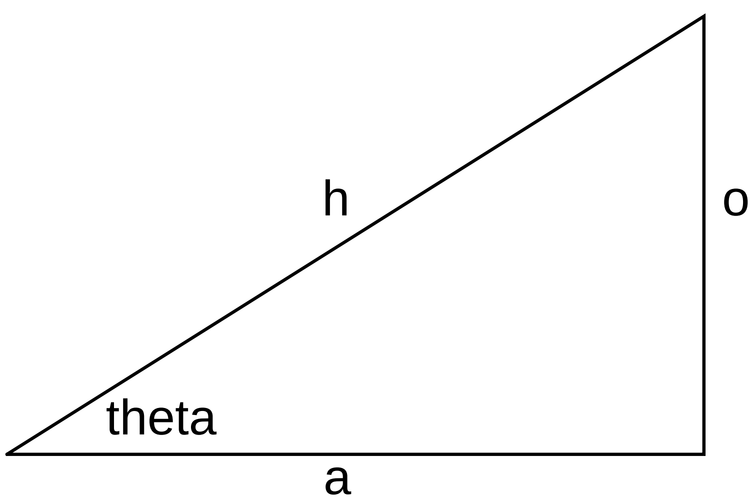
Coordinate Geometry

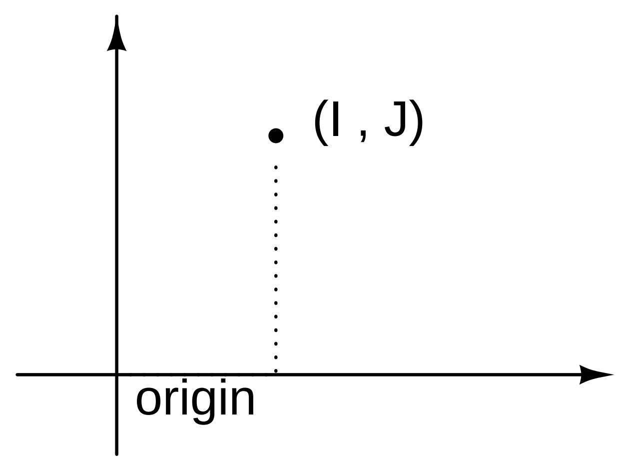
- To perform transformations of images, we change from *image coordinates* to *cartesian coordinates*.
- Java 2D and 3D use cartesian coordinates.
- The image coordinates (i, j) correspond to $(i, -j)$ in cartesian coordinates.
- Transformations are often specified by *continuous* functions $f(x)$ where x might be a color or a coordinate(s).
- (In the coursework we use linear functions f. Such functions take the form $f(x) = mx + k$. CW1 works with $m = (P - D)/(O - D)$ and $k = D * (O - P)/(O - D)$ and f is called $linTrans$ (or similar).)

Coordinate Geometry

We will also use some basic trigonometry:

- $sin\theta = o/h$ with inverse $arcsin$
- $cos\theta = a/h$ with inverse $arccos$
- $tan\theta = o/a$ with inverse $arctan$
- The distance of (I, J) from origin $(0, 0)$ is $\sqrt{I^2 + J^2}$





Pixel Position Transformations in Java

- Suppose a transformation "moves" a pixel `((I,J),c)` in `img` to position `(mI,mJ)`: the pixel at `(mI,mJ)` in `img` is up-dated with color c.
- To implement this we might make a copy `temp` of `img` and for each `(I,J)` in `img` do
  - `temp.setRGB((mI,mJ), img.getRGB(I,J))`

  and return `temp`, where there is a function g such that `(mI,mJ) =` g`(I,J)`.
- This is *problematic*. If g is continuous we may get *rounding errors*: the `(mI,mJ)` may not range over every pixel of `temp`. These problems are non-examinable!!

Pixel Position Transformations in Java

- In fact for every `(I,J)` in `img` we compute `(preI,preJ)` such that g “moves” the pixel at `(preI,preJ)` to `(I,J)` and do
  - `img.setRGB((I,J),temp.getRGB(preI,preJ))`

  We call `(preI,preJ)` the *preimage* of `(I,J)` where g`(preI,preJ)` = `(I,J)`.
- Since we wish to compute `(preI,preJ)` from `(I,J)` we implement g^{-1}:

  `(preI,preJ)` = g^{-1} `(I,J)`
- (The $linTrans$ functions in the coursework are examples of the g^{-1}.)

Pixel Position Transformations in Java

- Note that we visit *every* pixel `(I,J)` of `img` and update its color.
- This is a flexible method; eg if we want a pixel `(A,B)` to be blue, as a special case, we can do
  - `img.setRGB((A, B), 0xff)`

  with `0xff` replacing `temp.getRGB(preI,preJ)`.
- In a typical image rounding errors are not a problem, *since (preimage) pixels close to each other are likely to have the same color!*

(JAVA) And and Or

- Given binary digits (Booleans) $b, b' \in \mathbb{B}$ then logical AND is written $b \,\&\&\, b' \in B$ and logical OR is $b \,||\, b' \in \mathbb{B}$.
- Given binary numbers $\vec{b}, \vec{b'}$ then bitwise logical AND is written $\vec{b} \,\&\, \vec{b'}$ and bitwize logical OR is $\vec{b} \mid \vec{b'}$.
- Given binary numbers $\vec{b}$ and $n \in \mathbb{N}$ then *shiftleft* is written $\vec{b} \ll n$, and *shiftright* is written $\vec{b} \gg n$.
- E.g. $1111000011110101 \gg 4 = 0000111100001111$.
- We can use these logical operations to extract color components from RGB colors, and to build new RGB colors.

JAVA And and Or

- In Java, inputs typically will be length 32 (for integers) or length 8 (for bytes).
- **Warning**: We can do bitwize operations on binary numbers of different length! The shorter number is *sign extended* to the length of the longer number. E.g.
- Given binary numbers $\vec{b} = 10101010 \in \mathbb{B}^8$ and $\vec{b'} = 11111111.00000000.11110000.10101101 \in \mathbb{B}^{32}$ then

$$\begin{aligned}
\vec{b} \,\&\, \vec{b'} &= {\color{blue}11111111.11111111.11111111}.10101010 \,\& \\
&\quad 11111111.00000000.11110000.10101101 \\
&= 11111111.00000000.11110000.10101000
\end{aligned}$$

Manipulating Color in Java

A Java fragment to convert an RGB color into its components

```
int red, green, blue, col
...
blue  = (col & 0xff );
green = (col & 0xff00 ) >> 8;
red   = (col & 0xff0000 ) >> 16;
```

And vice versa from the components to an RGB color

```
col = red << 16 | green << 8 | blue;
// or alternatively
col = red * 16^4 + green * 16^2 + blue;
```

Reading Images in Java

- In practice, often read in an image file to a variable `img` of type **`BufferedImage`** (a subclass of `Image`): Java gives us a “standardised model” of image data. For the “color” image data this is the *RGB model*.
- We should specify the correct `imageType` (for the image to be input), such as `TYPE_BYTE_BINARY` (say for inputting an 8-bit grayscale) or `TYPE_INT_RGB` (for inputting an 24-bit RGB color image).
- Try reading about buffered images and image types in the Java API documentation. You **do not** need to know the details for coursework or examination, but some reading will give you a better overall understanding.

Pixel Color Transformations in Java: Split RGB Program

```java
private BufferedImage filter (BufferedImage img, int choice) {
  BufferedImage ans = new BufferedImage(
                              img.getWidth(),img.getHeight(),
                              BufferedImage.TYPE_INT_RGB);
  int graylvl;
  for (int x=0; x<img.getWidth(); x++) {
    for (int y=0;y<img.getHeight();y++) {
              switch (choice) {
              case BLUE : graylvl= (img.getRGB(x,y) & 0xff);
              ans.setRGB(x,y,graylvl);
                  break;
              case GREEN : graylvl =(img.getRGB(x,y) & 0xff00) ;
              ans.setRGB(x,y,graylvl);
                  break;
              case RED : graylvl = (img.getRGB(x,y) & 0xff0000);
              ans.setRGB(x,y,graylvl);
              }    }}
  return ans; }
```

Pixel Color Transformations in Java: Split Into Color Components

Pixel Color Transformations in Java: Split Into Grays

Image Compression and Dithering

- *Compression* is the process of transforming an image into a new image that is *smaller* but whose *quality* is the same, or only slightly poorer, than the original.
- *Dithering* is the process of transforming an image into a new image that has *fewer colors* but whose *quality* is representative of, but typically rather worse than, the original.
- Exercise: think about <u>exactly</u> what *smaller* and *quality* might mean. Note: this is more subtle than you might at first think.

Basic Dithering from 8 to 1-bit

- How do we dither an 8-bit grayscale image to a 1-bit image?
- A very simple idea:
  A dark gray pixel color in the original image is mapped to black and a light gray pixel color to white.
- Recall black and white are represented by $c \in \{0, 1\}$.
- Recall grays are represented by $c \in \{0, 1, 2, \ldots, 255\}$.
- So light grays are in the range $128 \ldots 255$, that is, > 127

  ...

Basic Dithering Algorithm

```
begin
  for x = 0 to x_max
    for y = 0 to y_max
      if (OriginalImageColor(x,y) > 127 )
        DitheredImageColor(x,y) = 1; // White!!
      else
        DitheredImageColor(x,y) = 0; // Black!!
end
```

Expansive Dithering

- Can we do better?
- By allowing the size of the dithered image to be bigger than the original, we can "preserve more of the original image". Such a dithered image is a better quality than the simple dithered image.
- Each pixel in the original image will correspond to 4 pixels (2 x 2) in the new image. *Note all original pixels are 8-bit and all new ones are 1-bit pixels.*
- Depending on the darkness of the original pixel the resulting four pixels (called a *4-pixel gray*) contain either $il =$ 0, 1, 2, 3, 4 white pixels (the other ones are black) in a random arrangement. We call il the *intensity level*.

Principle of Expansive Dithering

First, linearly map the grayscale “colors” 0..255 into the intensities 0..4 :

grayscale value	intensity level
0..51	0
52..102	1
103..153	2
154..204	3
205..255	4

Principle of Expansive Dithering

Then, map the intensities into "4-pixel grays" … refer to lecture explanations!

$$\begin{array}{cccccccl}
il & & & & & & & \\
0 & \mapsto & B & B & B & B & & \\
1 & \mapsto & W & B & B & B & & \text{any permutation} \\
2 & \mapsto & W & W & B & B & & \text{any permutation} \\
3 & \mapsto & W & W & W & B & & \text{any permutation} \\
4 & \mapsto & W & W & W & W & &
\end{array}$$

Given the original image, for each intensity, a *fixed choice of* permutation 4-pixel gray is chosen. *Why?*

Principle of Expansive Dithering

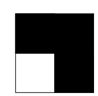
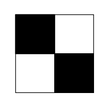
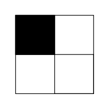
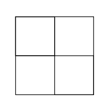
There is a cunning way in which to compute such 4-pixel grays . . . . Think of B as falsity and W as truth!

$$\begin{array}{cccccc}
 & & & dm(i,j) & & \\
il & > & 0 & 1 & 2 & 3 \\
0 & \mapsto & B & B & B & B \\
1 & \mapsto & W & B & B & B \\
2 & \mapsto & W & W & B & B \\
3 & \mapsto & W & W & W & B \\
4 & \mapsto & W & W & W & W
\end{array}$$

It is intuitive to arrange the values $dm(i,j) = 0, 1, 2, 3$ from the $il > dm(i,j)$ computations as a 2×2 *dithering matrix*.

A 2×2 Example

Example of a 2 x 2 dithering matrix $\begin{pmatrix} 3 & 1 \\ 0 & 2 \end{pmatrix}$. Each pixel of the original image yields an intensity il. We then "map" $e \mapsto (il > e)$ "over the matrix elements e" to *obtain* one 4-pixel gray from *each pixel* il (see Step 2 code):

grayscale value	intensity level	4-pixel gray
0..51	0	
52..102	1	
103..153	2	
104..204	3	
205..255	4	

il > 3	il > 1
il > 2	il > 0

Final Observations on Expansive Dithering

- An $n \times n$ dithering matrix can represent $n^2 + 1$ levels of intensity.
- The new image created by an $n \times n$ matrix used for expansive dithering is n times wider and n times higher than the original. So the new image is n^2 larger then the original one.

Final Observations on Expansive Dithering

- Note that $il = (int)(((n^2 + 1)/256) * gs)$. Why?
  - Try drawing line $y = f(x) = m * x + k$ where $k = 0$ and $m = (n^2 + 1)/256$ and $x = gs$. Then draw a picture of the effect of Java (int) coersion to understand computation of il.
- Example of 4×4 dithering matrix (17 intensity levels, $il = 0 \ldots 16$)

$$\begin{pmatrix} 0 & 8 & 2 & 10 \\ 12 & 4 & 14 & 6 \\ 3 & 11 & 1 & 9 \\ 15 & 7 & 13 & 5 \end{pmatrix}$$

Ordered Dithering

- We now perform 8-bit to 1-bit image dithering which uses a $n \times n$ dithering matrix, but the output size equals that of the input.
- First map each pixel gray-color to its intensity.
- By sliding the dithering matrix over the image (n pixels in the horizontal and vertical direction at a time) each pixel has a corresponding entry in the dithering matrix.
- A pixel with intensity level higher than the corresponding dithering matrix entry is mapped to a white pixel and otherwise a black pixel.
- This technique is called *ordered dithering*.

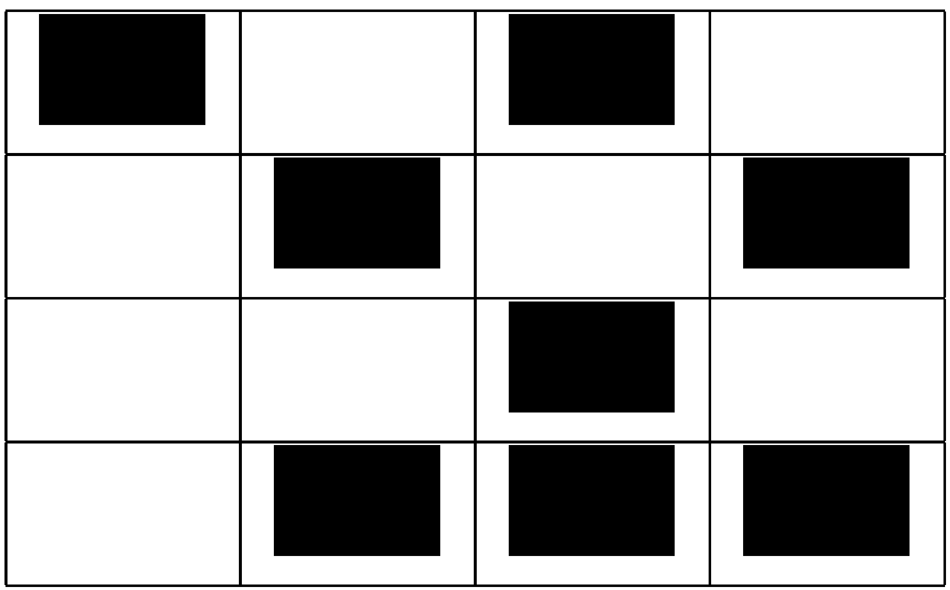
Ordered Dithering Example

Image:

120	110	160	180
75	75	120	130
250	220	75	170
120	30	30	75

Dithering matrix: $\begin{pmatrix} 3 & 1 \\ 0 & 2 \end{pmatrix}$

Result:



Why does ordered dithering work?

Ordered Dithering Algorithm

The ordered dither algorithm:

```
for x = 0 to x_max
  for y = 0 to y_max
    // note row i correspond to coordinate y !!!!
    i = y mod n
    j = x mod n
    if IntensityLevelOf_OriginalImageColor(x,y) > DM(i,j)
      DitheredImageColor(x,y) = 1
    else
      DitheredImageColor(x,y) = 0
```

Basic Dithering Program (Step 1)

```
private BufferedImage basicDither (BufferedImage img, int b) {
  BufferedImage ans = new BufferedImage(
                                       img.getWidth(),img.getHeight(),
                                       BufferedImage.TYPE_BYTE_BINARY);
 for ( int i=0; i<img.getWidth(); i++ ) {
  for ( int j=0;j<img.getHeight();j++ ) {
      // select 8-bit gray data
      intensityLevel = (int)((img.getRGB(x,y) & 0xff));
      if ( intensityLevel > b )
        ans.setRGB(i,j,0xffffff); // set output color to white
      else
        ans.setRGB(i,j,0x000000); // set output color to black
    }
  }
  return ans;
}
```

Expansive Dithering Program (Step 2)

```java
private BufferedImage expansiveDither(BufferedImage img, int[][] dm) {
  int n = dm.length; int intensityLevel;
  BufferedImage ans = new BufferedImage(
                                n*img.getWidth(),n*img.getHeight(),
                                BufferedImage.TYPE_BYTE_BINARY);
  for ( int x=0; x<img.getWidth(); x++ ) {
   for ( int y=0;y<img.getHeight();y++ ) {
    // select 8-bit gray data; linearly map to 0 to n*n
    intensityLevel = (int)((img.getRGB(x,y) & 0xff)*((n*n+1)/256));
    for ( int i=0; i<n; ++i ) {
      for (int j=0; j<n; ++j ) {
        if ( intensityLevel > dm[i][j] )
          ans.setRGB(n*x+i,n*y+j,0xffffff);
        else
          ans.setRGB(n*x+i,n*y+j,0x000000);
    }} }}
  return ans;
}
```

Ordered Dithering Program (Step 3)

```
private BufferedImage orderedDither (BufferedImage img, int[][] dm) {
  BufferedImage ans = new BufferedImage(
                                        img.getWidth(),img.getHeight(),
                                        BufferedImage.TYPE_BYTE_BINARY);
  int i,j;
  int n = dm.length;
  for ( int x=0; x<img.getWidth(); x++ ) {
    for ( int y=0;y<img.getHeight();y++ ) {
      intensityLevel = (int)((img.getRGB(x,y) & 0xff)*((n*n+1)/256));
      // why would i= x%n; j= y%n; still yield a correct program?
      i= y%n; j= x%n;
      if ( intensityLevel > dm[i][j] )
        ans.setRGB(x,y,0xffffff);
      else
        ans.setRGB(x,y,0x000000);
    }}
  return ans;
}
```

Further Topics

- dithering from 8 to 4 bits
- dithering on color images
- resizing
- gamma correction
- compression

More resources

- Fundamentals of Multimedia, by Ze-Nian Li and Mark S. Drew. (publ. Pearson)
- Java Documentation