From bits to bytes to ints

- At some level everything is stored as either a zero or a one
  - A bit is a binary digit
  - A byte is a binary term (8 bits)
  - We should be grateful we can deal with Strings rather than sequences of 0's and 1's.
  - We should be grateful we can deal with an int rather than the 32 bits that make an int

- int values are stored as two's complement numbers with 32 bits, for 64 bits use the type long, a char is 16 bits
  - Standard in Java, different in C/C++
  - Facilitates addition/subtraction for int values
  - We don't need to worry about this, except to note:
    - Infinity + 1 = -Infinity
    - Math.abs(-Infinity) > Infinity

How are data stored?

- To facilitate Huffman coding we need to read/write one bit
  - Why do we need to read one bit?
  - Why do we need to write one bit?
  - When do we read 8 bits at a time? Read 32 bits at a time?

- We can't actually write one bit-at-a-time. We can't really write one char at a time either.
  - Output and input are buffered, minimize memory accesses and disk accesses
  - Why do we care about this when we talk about data structures and algorithms?
    - Where does data come from?

How do we buffer char input?

- Done for us as part of InputStream and Reader classes
  - InputStreams are for reading bytes
  - Readers are for reading char values
  - Why do we have both and how do they interact?
    - Reade
  - Do we need to flush our buffers?

- In the past Java IO has been notoriously slow
  - Do we care about I? About O?
  - This is changing, and the java.nio classes help
    - Map a file to a region in memory in one operation

Buffer bit output

- To buffer bit output we need to store bits in a buffer
  - When the buffer is full, we write it.
  - The buffer might overflow, e.g., in process of writing 10 bits to 32-bit capacity buffer that has 29 bits in it
  - How do we access bits, add to buffer, etc.?

- We need to use bit operations
  - Mask bits -- access individual bits
  - Shift bits – to the left or to the right
  - Bitwise and/or negate bits
**Bit Logical Operations**

- Work on integers types in binary (by bit)
  - *longs, ints, chars, shorts, and bytes*
- Three binary operators
  - And: &
  - Or: |
  - Exclusive Or (xor): ^

<table>
<thead>
<tr>
<th>a</th>
<th>b</th>
<th>a&amp;b</th>
<th>a</th>
<th>b</th>
<th>a^b</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

- What is result of
  - 27 & 14?
  - 27 | 14?
  - 27 ^ 14?

**Bit Logical Operations**

- Need to work bit position by bit position
- *11011 = 27* (many leading zeros not shown)
- *01110 = 14*

<table>
<thead>
<tr>
<th>&amp;</th>
<th>^</th>
<th>^</th>
</tr>
</thead>
<tbody>
<tr>
<td>01010</td>
<td>=</td>
<td>11111 =</td>
</tr>
<tr>
<td>^</td>
<td>10101</td>
<td>=</td>
</tr>
</tbody>
</table>

- Also have unary negation (not):
  - ~000000000000000000000000001101101 = 27
  - ~11111111111111111111111111100100 = -26

- Use “masks” with the various operators to
  - Set or clear bits
  - Test bits
  - Toggle bits
- *(Example later)*

**Bit Shift Operations**

- Work on same types as logical ops
- One left shift and two right shifts
  - Left shift: <<
    - *11011 = 27*
    - 27 << 2
      - *110100 = 108* (shifting left is like? )
  - Logical right shift: >>>
    - *11011 = 27*
    - 27 >> 2
      - *110 = 6* (shifting right is like? )
  - Arithmetic right shift: >>
    - 111111111111111111111111111100100 = -26
      - -26 >> 2
      - 11111111111111111111111111111001 = -7
      - 11111111111111111111111111111111 = -1
      - -1 >>> 16 (for contrast)
        - 00000000000000011111111111111111 = 65575

**Representing pixels**

- A pixel typically stores RGB and alpha/transparency values
  - Each RGB is a value in the range 0 to 255
  - The alpha value is also in range 0 to 255
  - *Pixel red = new Pixel(255, 0, 0, 0);*
  - *Pixel white = new Pixel(255, 255, 255, 0);*

- Typically store these values as int values, a picture is simply an array of int values

```
void process(int pixel){
    int blue = pixel & 0xff;
    int green = (pixel >> 8) & 0xff;
    int red = (pixel >> 16) & 0xff;
}
```
Bit masks and shifts

void process(int pixel){
    int blue = pixel & 0xff;
    int green = (pixel >> 8) & 0xff;
    int red = (pixel >> 16) & 0xff;
}

- Hexadecimal number: 0,1,2,3,4,5,6,7,8,9,a,b,c,d,e,f
  - Note that f is 15, in binary this is 1111, one less than 10000
  - The hex number 0xff is an 8 bit number, all ones

- The bitwise & operator creates an 8 bit value, 0—255 (why)
  - 1&1 == 1, otherwise we get 0, similar to logical and
  - Similarly we have |, bitwise or

Bit operations revisited

- How do we write out all of the bits of a number

```c
void bits(int val) {
```

```c
```