# MA/CSSE 473 Day 35

Greedy Algorithms

## MA/CSSE 473 Day 35

- HW 13 due tomorrow
- HW 14 available soon, due Tuesday
- **Student Questions**
  - About exam, anything else.
- Greedy algorithms

## Greedy algorithms

- Whenever a choice is to be made, pick the one that seems optimal for the moment, without taking future choices into consideration
  - Once each choice is made, it is irrevocable
- For example, a greedy Scrabble player will simply maximize her score for each turn, never saving any “good” letters for possible better plays later
  - Doesn’t necessarily optimize score for entire game
- Greedy works well for the "optimal linked list with known search probabilities" problem, and reasonably well for the "optimal BST" problem.

Q1

## Greedy Chess

- Take a piece or pawn whenever you will not lose a piece or pawn (or will lose one of lesser value) on the next turn
- Not a good strategy for this game either

# Greedy Map Coloring

- On a planar (i.e., 2D Euclidean) connected map, choose a region and pick a color for that region
- Repeat until all regions are colored:
  - Choose an uncolored region R that is adjacent[1] to at least one colored region
    - If there are no such regions, let R be any uncolored region
  - Choose a color that is different than the colors of the regions that are adjacent to R
  - Use a color that has already been used if possible
- The result is a valid map coloring, not necessarily with the minimum possible number of colors

[1] **Two regions are *adjacent* if they have a common edge**

# Huffman's Text Compression Algorithm

- On the Background survey at the beginning of the term, 34/40 checked "1", "2", or "3" for this topic
- I will use my CSSE 230 presentation here, since it is new to most of you
  - My apologies to the 5 of you who remember it well

# Data (Text) Compression

YOU SAY GOODBYE. I SAY HELLO. HELLO, HELLO. I DON'T KNOW WHY YOU SAY GOODBYE, I SAY HELLO.

## Letter frequencies

| | | | | | |
|---|---|---|---|---|---|
| SPACE | 17 | A | 4 | U | 2 |
| O | 12 | S | 4 | W | 2 |
| Y | 9 | I | 3 | N | 2 |
| L | 8 | D | 3 | K | 1 |
| E | 6 | COMMA | 2 | T | 1 |
| H | 5 | B | 2 | APOSTROPHE | 1 |
| PERIOD | 4 | G | 2 | | |

- There are 90 characters altogether.
- How many total bits in the ASCII representation of this string?
- We can get by with fewer bits per character (custom code)
  - How many bits per character? How many for entire message?
  - Do we need to include anything else in the message?
  - How to represent the table?
    1. count
    2. ASCII code for each character How to do better?

Q2-4

# Compression algorithm: Huffman encoding

- **Named for David Huffman**
  - http://en.wikipedia.org/wiki/David_A._Huffman
  - Invented while he was a graduate student at MIT.
  - Huffman never tried to patent an invention from his work. Instead, he concentrated his efforts on education.
  - In Huffman's own words, "My products are my students."
- **Principles of variable-length character codes:**
  - Less-frequent characters have longer codes
  - No code can be a prefix of another code
- We build a tree (based on character frequencies) that can be used to encode and decode messages

Q5

## Variable-length Codes for Characters

- **RECAP: Principles for determining a scheme for creating character codes:**
  1. Less-frequent characters have longer codes so that more-frequent characters can have shorter codes
  2. No code can be a prefix of another code
     - Why is this restriction necessary?
- Assume that we have some routines for packing sequences of bits into bytes and writing them to a file, and for unpacking bytes into bits when reading the file
  - Weiss has a very clever approach:
    - **BitOutputStream** and **BitInputStream**
    - methods **`writeBit`** and **`readBit`** allow us to logically read or write a bit at a time

## A Huffman code: HelloGoodbye message

```
C:\Personal\Courses\CS-230\java-source>type HelloGoodbyeOneLine
YOU SAY GOODBYE. I SAY HELLO. HELLO, HELLO. I DON'T KNOW WHY YOU SAY GOODBYE, I SAY HELLO.

C:\Personal\Courses\CS-230\java-source>java HuffmanDS <HelloGoodbyeOneLine
Encoding of   is 00 (frequency was 17, length of code is 2)
Encoding of . is 0100 (frequency was 4, length of code is 4)
Encoding of H is 0101 (frequency was 5, length of code is 4)
Encoding of Y is 011 (frequency was 9, length of code is 3)
Encoding of K is 100000 (frequency was 1, length of code is 6)
Encoding of T is 1000010 (frequency was 1, length of code is 7)
Encoding of ' is 1000011 (frequency was 1, length of code is 7)
Encoding of D is 10001 (frequency was 3, length of code is 5)
Encoding of E is 1001 (frequency was 6, length of code is 4)
Encoding of O is 101 (frequency was 12, length of code is 3)
Encoding of I is 11000 (frequency was 3, length of code is 5)
Encoding of B is 110010 (frequency was 2, length of code is 6)
Encoding of , is 110011 (frequency was 2, length of code is 6)
Encoding of S is 11010 (frequency was 4, length of code is 5)
Encoding of A is 11011 (frequency was 4, length of code is 5)
Encoding of U is 111000 (frequency was 2, length of code is 6)
Encoding of G is 111001 (frequency was 2, length of code is 6)
Encoding of N is 111010 (frequency was 2, length of code is 6)
Encoding of W is 111011 (frequency was 2, length of code is 6)
Encoding of L is 1111 (frequency was 8, length of code is 4)
Total bits required for message: 351
```

Decode a "message"

Draw part of the Tree

## Build the tree for a smaller message

| | |
|---|---|
| I | 1 |
| R | 1 |
| N | 2 |
| O | 3 |
| A | 3 |
| T | 5 |
| E | 8 |

- Start with a separate tree for each character (in a priority queue)
- Repeatedly merge the two lowest (total) frequency trees and insert new tree back into priority queue
- Use the Huffman tree to encode NATION.

Huffman codes are provably optimal among all single-character codes

Q6-9

## What About the Code Table?

- When we send a message, the code table can basically be just the list of characters and frequencies
  - Why?

Q10-12

# Huffman Java Code Overview

- This code provides human-readable output to help us understand the Huffman algorithm.
- We will deal with it at the abstract level; "real" code to do file compression is found in DS chapter 12.
- I am confident that you can figure out the other details if you need them.
- This code is based on code written by Duane Bailey, in his book *JavaStructures.*
- A great thing about this example is the use of various data structures (Binary Tree, Hash Table, Priority Queue).

473: I do not want to get caught up in lots of code details in class, so I ask you to read this on your own.

# Some Classes used by Huffman

- **Leaf:** Represents a leaf node in a Huffman tree.
  - Contains the character and a count of how many times it occurs in the text.
- **HuffmanTree:** Each node contains the total weight of all characters in the tree, and either a leaf node or a binary node with two subtrees that are Huffman trees.
  - The contents field of a non-leaf node is never used; we only need the total weight.
  - `compareTo` returns its result based on comparing the total weights of the trees.

## Classes used by Huffman, part 2

- **Huffman:** Contains **main** **The algorithm:**
  - Count character frequencies and build a list of Leaf nodes containing the characters and their frequencies
  - Use these nodes to build a sorted list (treated like a priority queue) of single-character Huffman trees
  - **do**
    - Take two smallest (in terms of total weight) trees from the sorted list
    - Combine these nodes into a new tree whose total weight is the sum of the weights of the new tree
    - Put this new tree into the sorted list

  **while there is more than one tree left**

  The one remaining tree will be an optimal tree for the entire message

## Code Details - several slides

- These are mainly here so that
  - You can see an overview of the most important parts of the code before looking at the code on-line.

# Leaf node class for Huffman Tree

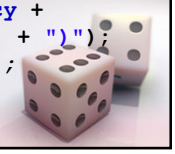
```
class Leaf  { // Leaf node of a  Huffman tree.

    char ch; // the character represented
             // by this node.
    int frequency; // frequency of this
                   // character in message.

    public Leaf(char c, int freq) {
        ch = c;
        frequency = freq;
    }
}
```

# Highlights of the HuffmanTree class

```
class HuffmanTree implements Comparable<HuffmanTree> {
  BinaryNode root; // root of tree
  int totalWeight; // weight of tree
  static int totalBitsNeeded;
       // bits needed to represent entire message
       // (not including code table).

  public HuffmanTree(Leaf e) {
    root = new BinaryNode(e, null, null);
    totalWeight = e.frequency;
  }

  public HuffmanTree(HuffmanTree left, HuffmanTree right) {
    // pre: left and right non-null
    // post: merge two trees together and add their weights
    this.totalWeight = left.totalWeight + right.totalWeight;
    root = new BinaryNode(null, left.root, right.root);
  }
  public int compareTo(HuffmanTree other) {
    return (this.totalWeight - other.totalWeight);
  }
```

# Printing a HuffmanTree

```
public void print() {
  // print out strings associated with characters in tree
  totalBits = 0;
  print(this.root, "");
  System.out.println("Total bits for entire message: "+
totalBits);
 }

protected static void print(BinaryNode r,
                            String representation) {
  //  print out strings associated with chars in tree r,
  //  prefixed by representation
  if (r.getLeft() != null) {  // interior node
    print(r.getLeft(),  representation + "0"); // append a 0
    print(r.getRight(), representation + "1"); // append a 1
  } else { // leaf; print its code
    Leaf e = (Leaf) r.getElement();
    System.out.println("Encoding of " + e.ch + " is " +
       representation + " (frequency was " +  e.frequency +
       ", length of code is " +  representation.length() + ")");
    totalBits += (e.frequency * representation.length());
  }
}
```



# Highlights of Huffman class 1

```
public static void main(String args[]) throws Exception {

  BufferedReader r = new BufferedReader(
                       new InputStreamReader(System.in));
  HashMap<Character, Integer> freq =
                       new HashMap<Character,Integer>();
  String oneLine;  // current input line.

  // First read the data and count characters
  // Go through the input line, one character at a time.
  while ((oneLine = r.readLine()) != null) {
     for (int i = 0; i<oneLine.length(); i++) {
        char c = oneLine.charAt(i);
        if (freq.containsKey(c))
           freq.put(c, freq.get(c)+1);
        else // first time we've seen c
           freq.put(c, 1);
     }
  }
```

# Highlights of Huffman class 2

```
// Now the table of frequencies is complete.
// put each character into its own Huffman tree

PriorityQueue<HuffmanTree> treeQueue =
             new  PriorityQueue<HuffmanTree>();
for (char c : freq.keySet())
   treeQueue.add(new HuffmanTree(new Leaf(c, freq.get(c))));

HuffmanTree smallest, secondSmallest;
// merge trees in pairs until only one tree remains
while (true) {
  smallest = treeQueue.poll();
  secondSmallest = treeQueue.poll();
  if (secondSmallest == null) break;
    // add bigger tree containing both to the sorted list.
    treeQueue.add(new HuffmanTree(smallest, secondSmallest));
}
 // print the only tree left in the list of Huffman trees.
 smallest.print();
}
```

# Representing the Code Table

- Three or four bytes per character
  - The character itself.
  - The frequency count.
- End of table signaled by 0 for char and count.
- Tree can be reconstructed from this table.
- The rest of the file is the compressed message.

# Summary

- The Huffman code is provably optimal among all single-character codes for a given message.
- Going farther:
  - Look for frequently occurring sequences of characters and make codes for them as well.