Data Structures and Algorithms

CS245-2015S-P2

Huffman Codes
Project 2

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P2-0: Text Files

- All files are represented as binary digits – including text files
- Each character is represented by an integer code
  - ASCII – American Standard Code for Information Interchange
- Text file is a sequence of binary digits which represent the codes for each character.

P2-1: ASCII

- Each character can be represented as an 8-bit number
  - ASCII for a = 97 = 01100001
  - ASCII for b = 98 = 01100010
- Text file is a sequence of 1's and 0's which represent ASCII codes for characters in the file
  - File “aba” is 97, 97, 98
  - 011000010110001001100001

P2-2: ASCII

- Each character in ASCII is represented as 8 bits
  - We need 8 bits to represent all possible character combinations
    - (including control characters, and unprintable characters)
  - Breaking up file into individual characters is easy
  - Finding the kth character in a file is easy

P2-3: ASCII

- ASCII is not terribly efficient
    - All characters require 8 bits
    - Frequently used characters require the same number of bits as infrequently used characters
    - We could be more efficient if frequently used characters required fewer than 8 bits, and less frequently used characters required more bits

P2-4: Representing Codes as Trees

- Want to encode 4 only characters: a, b, c, d (instead of 256 characters)
  - How many bits are required for each code, if each code has the same length?

P2-5: Representing Codes as Trees

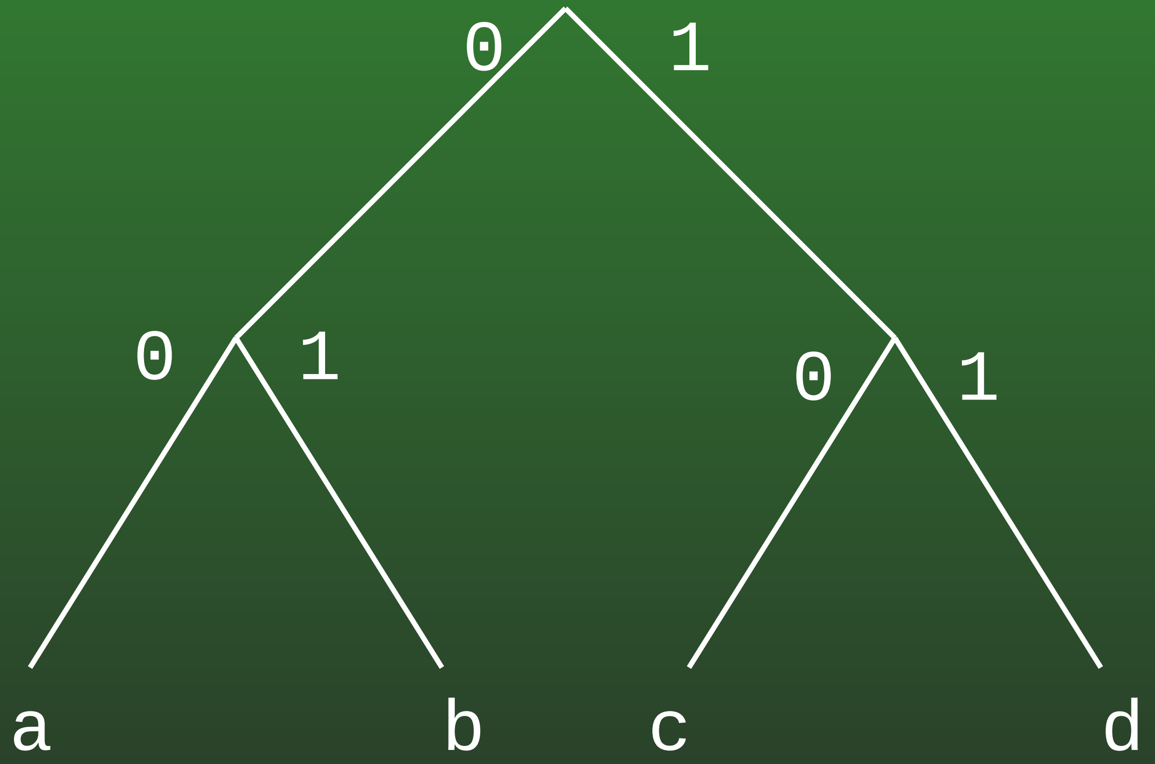
- Want to encode 4 only characters: a, b, c, d (instead of 256 characters)
  - How many bits are required for each code, if each code has the same length?
  - 2 bits are required, since there are 4 possible options to distinguish

P2-6: Representing Codes as Trees

- Want to encode 4 only characters: a, b, c, d
- Pick the following codes:
  - a: 00
  - b: 01
  - c: 10
  - d: 11
- We can represent these codes as a tree
  - Characters are stored at the leaves of the tree
  - Code is represented by path to leaf

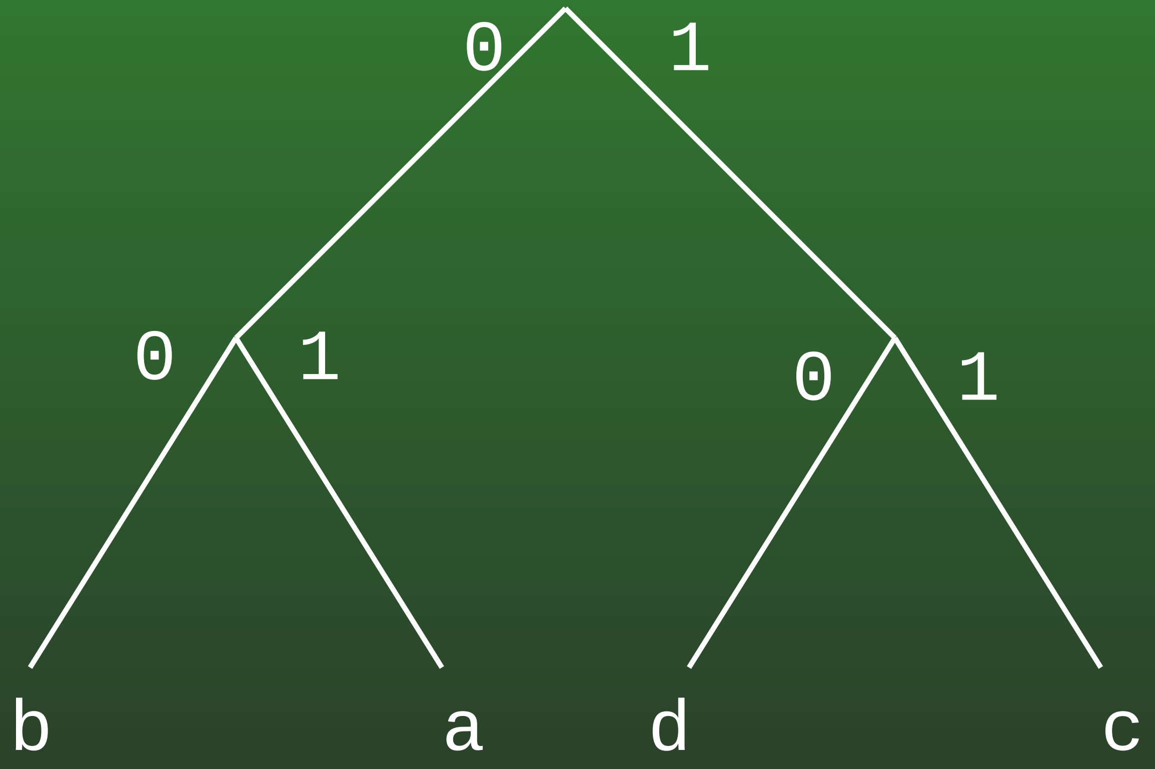
P2-7: Representing Codes as Trees

- a: 00, b: 01, c: 10, d:11



P2-8: Representing Codes as Trees

- a: 01, b: 00, c: 11, d:10



P2-9: Prefix Codes

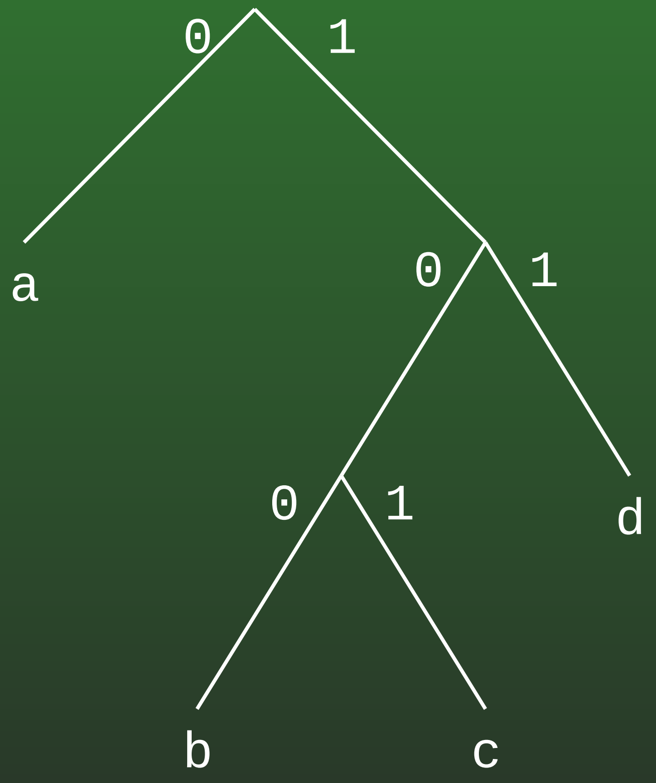
- If no code is a prefix of any other code, then decoding the file is unambiguous.
- If all codes are the same length, then no code will be a prefix of any other code (trivially)
- We can create variable length codes, where no code is a prefix of any other code

P2-10: Variable Length Codes

- Variable length code example:
  - a: 0, b: 100, c: 101, d: 11
- Decoding examples:
  - 100
  - 10011
  - 01101010010011

P2-11: Prefix Codes & Trees

- Any prefix code can be represented as a tree
- a: 0, b: 100, c: 101, d: 11



P2-12: File Length

- If we use the code:
  - a:00, b:01, c:10, d:11

  How many bits are required to encode a file of 20 characters?

P2-13: File Length

- If we use the code:
  - a:00, b:01, c:10, d:11

  How many bits are required to encode a file of 20 characters?
- 20 characters * 2 bits/character = 40 bits

P2-14: File Length

- If we use the code:
  - a:0, b:100, c:101, d:11

  How many bits are required to encode a file of 20 characters?

P2-15: File Length

- If we use the code:
  - a:0, b:100, c:101, d:11

  How many bits are required to encode a file of 20 characters?
- It depends upon the number of a’s, b’s, c’s and d’s in the file

P2-16: File Length

- If we use the code:
  - a:0, b:100, c:101, d:11

  How many bits are required to encode a file of:
  - 11 a’s, 2 b’s, 2 c’s, and 5 d’s?

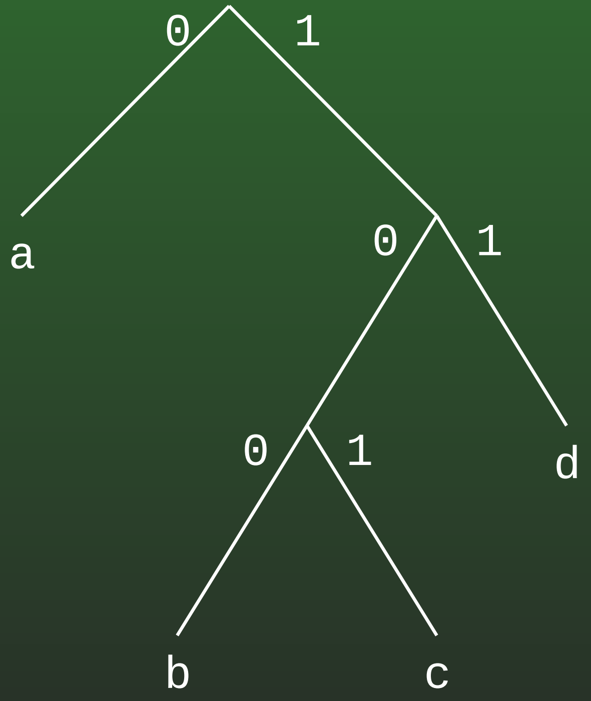
P2-17: File Length

- If we use the code:
  - a:0, b:100, c:101, d:11

  How many bits are required to encode a file of:
  - 11 a’s, 2 b’s, 2 c’s, and 5 d’s?
- 11*1 + 2*3 + 2*3 + 5*2 = 33 < 40

P2-18: Decoding Files

- We can use variable length keys to encode a text file
- Given the encoded file, and the tree representation of the codes, it is easy to decode the file



- 0111001010011

P2-19: Decoding Files

- We can use variable length keys to encode a text file
- Given the encoded file, and the tree representation of the codes, it is easy to decode the file
- Finding the kth character in the file is more tricky

P2-20: Decoding Files

- We can use variable length keys to encode a text file
- Given the encoded file, and the tree representation of the codes, it is easy to decode the file
- Finding the kth character in the file is more tricky
  - Need to decode the first (k-1) characters in the file, to determine where the kth character is in the file

P2-21: File Compression

- We can use variable length codes to compress files
  - Select an encoding such that frequently used characters have short codes, less frequently used characters have longer codes
  - Write out the file using these codes
  - (If the codes are dependent upon the contents of the file itself, we will also need to write out the codes at the beginning of the file for decoding)

P2-22: File Compression

- We need a method for building codes such that:
  - Frequently used characters are represented by leaves high in the code tree
  - Less Frequently used characters are represented by leaves low in the code tree
  - Characters of equal frequency have equal depths in the code tree

P2-23: Huffman Coding

- For each code tree, we keep track of the total number of times the characters in that tree appear in the input file
- We start with one code tree for each character that appears in the input file
- We combine the two trees with the lowest frequency, until all trees have been combined into one tree

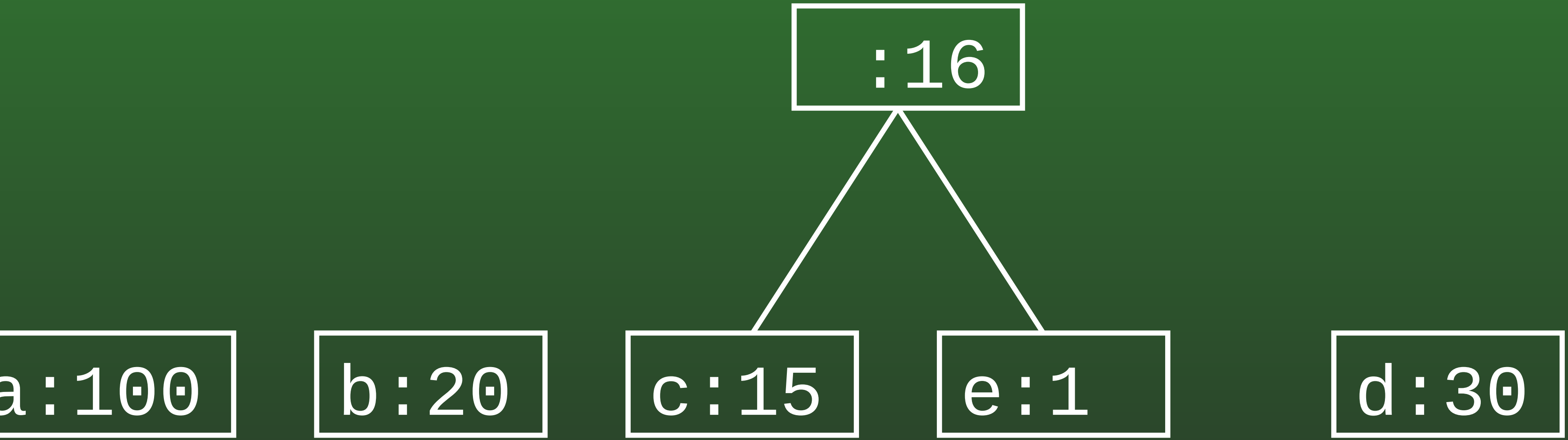
P2-24: Huffman Coding

- Example: If the letters a-e have the frequencies:
    - a: 100, b: 20, c:15, d: 30, e: 1

a:100 b:20 c:15 d:30 e:1

P2-25: Huffman Coding

- Example: If the letters a-e have the frequencies:
  - a: 100, b: 20, c:15, d: 30, e: 1



:16

a:100

b:20

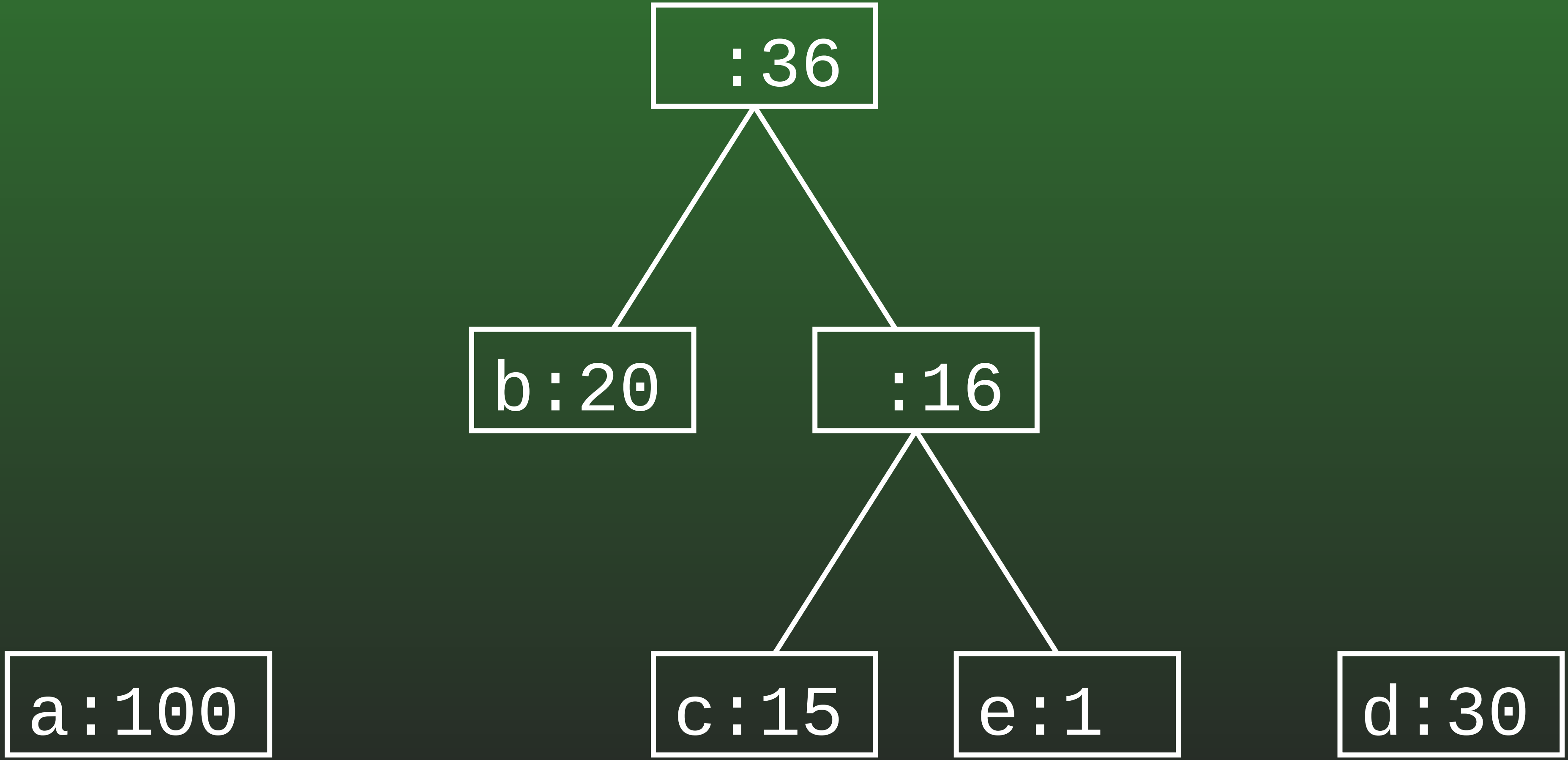
c:15

e:1

d:30

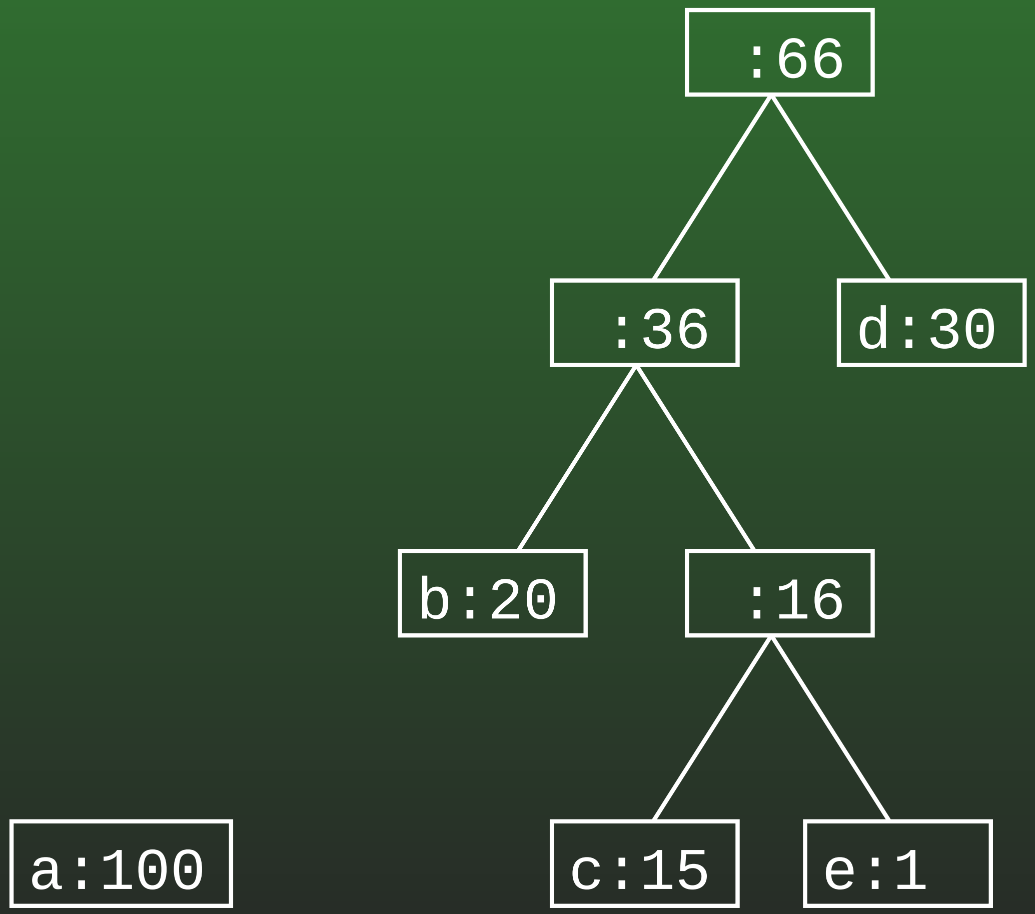
P2-26: Huffman Coding

- Example: If the letters a-e have the frequencies:
    - a: 100, b: 20, c:15, d: 30, e: 1



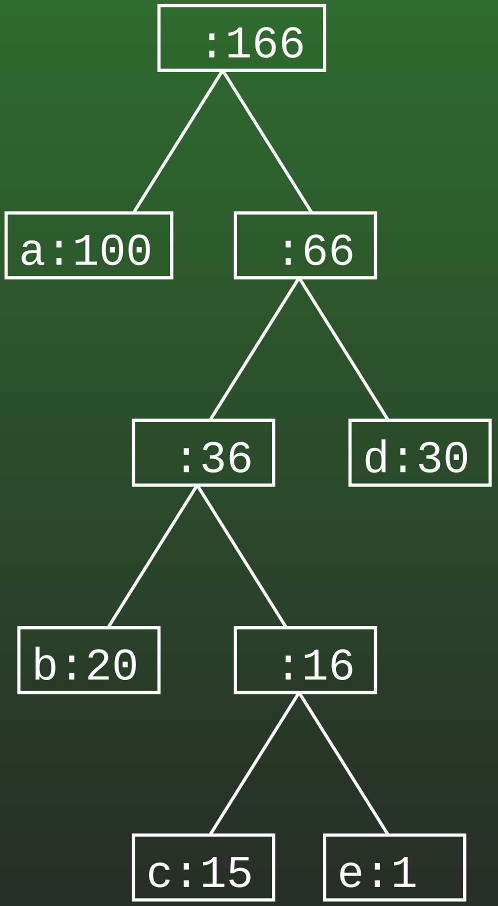
P2-27: Huffman Coding

- Example: If the letters a-e have the frequencies:
  - a: 100, b: 20, c:15, d: 30, e: 1



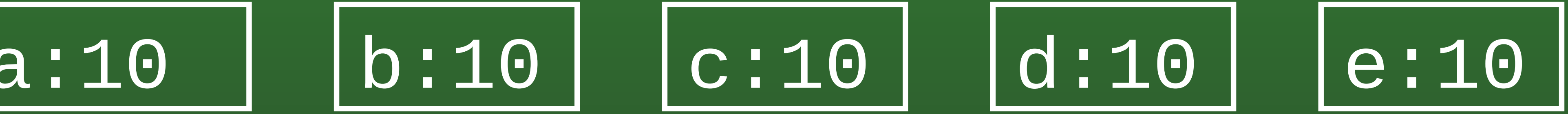
P2-28: Huffman Coding

- Example: If the letters a-e have the frequencies:
  - a: 100, b: 20, c:15, d: 30, e: 1



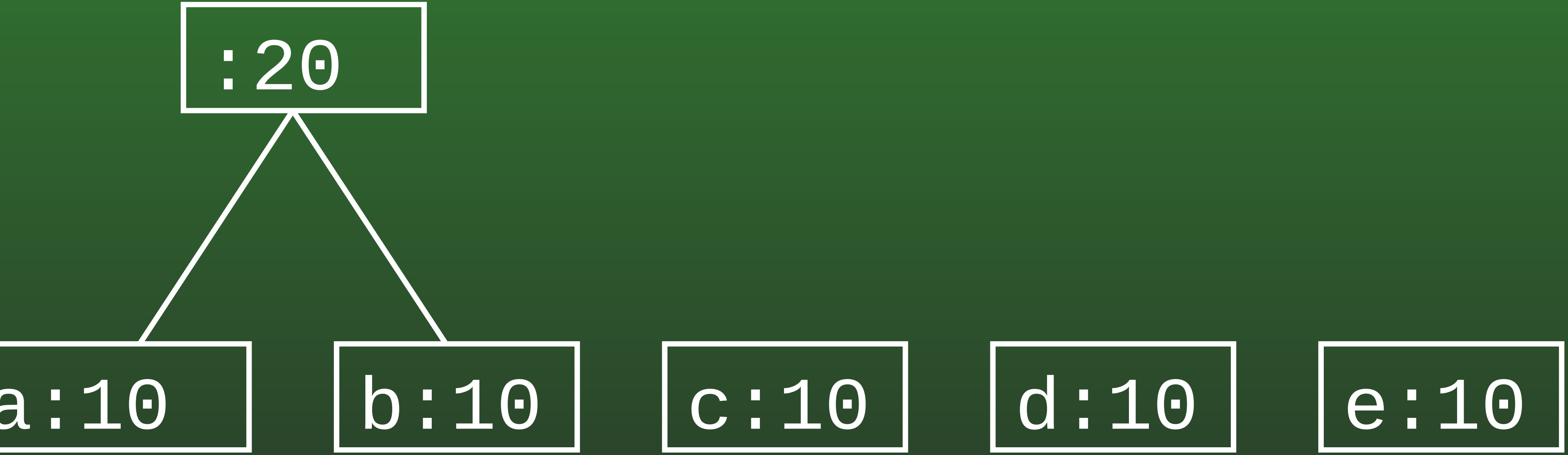
P2-29: Huffman Coding

- Example: If the letters a-e have the frequencies:
  - a: 10, b: 10, c:10, d: 10, e: 10



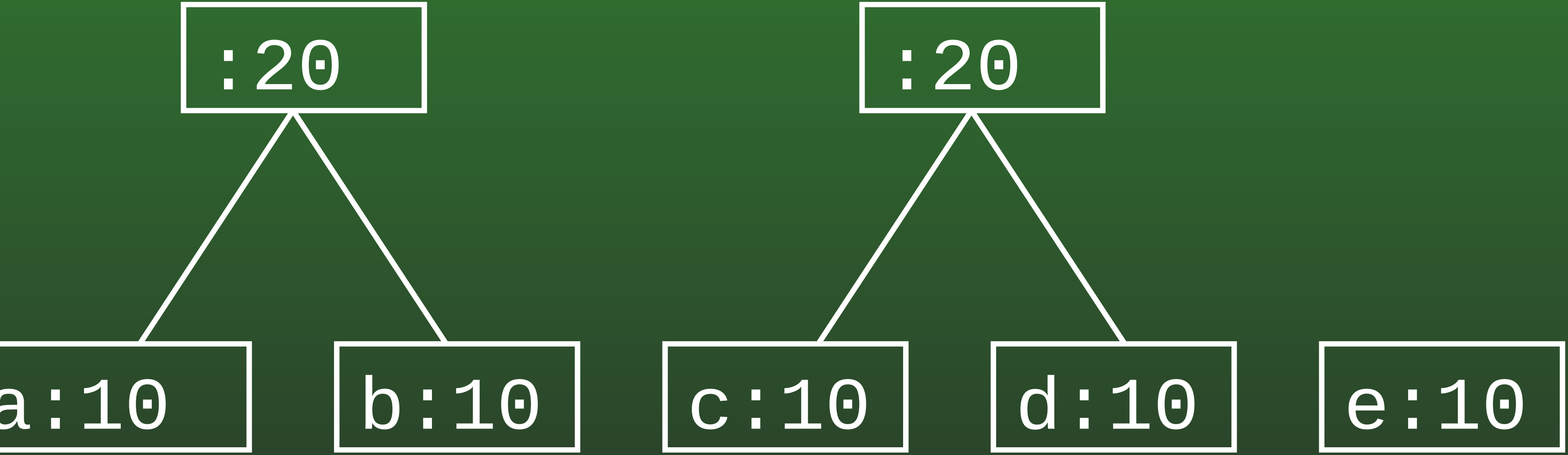
P2-30: Huffman Coding

- Example: If the letters a-e have the frequencies:
  - a: 10, b: 10, c:10, d: 10, e: 10



P2-31: Huffman Coding

- Example: If the letters a-e have the frequencies:
  - a: 10, b: 10, c:10, d: 10, e: 10



:20

:20

a:10

b:10

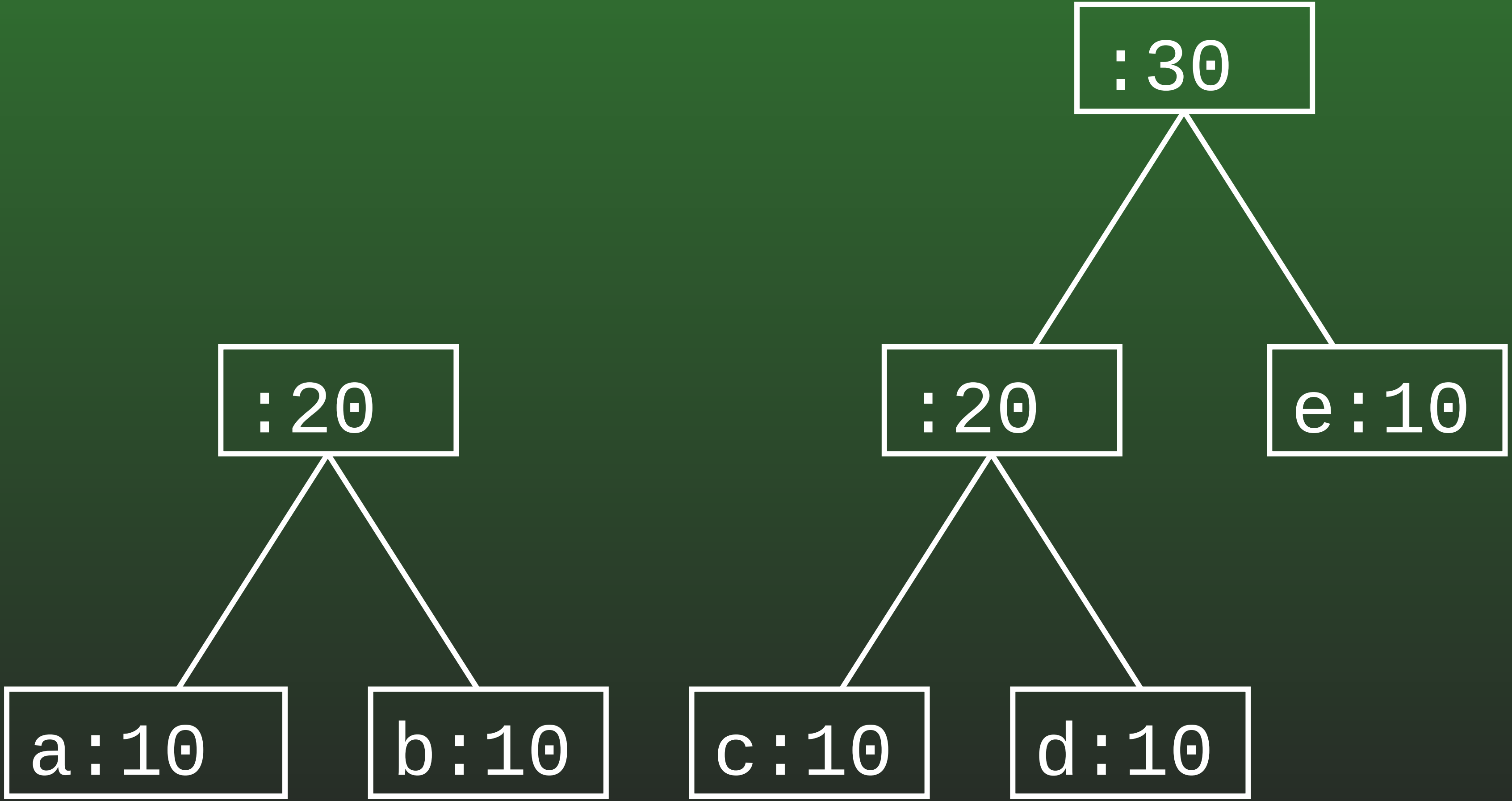
c:10

d:10

e:10

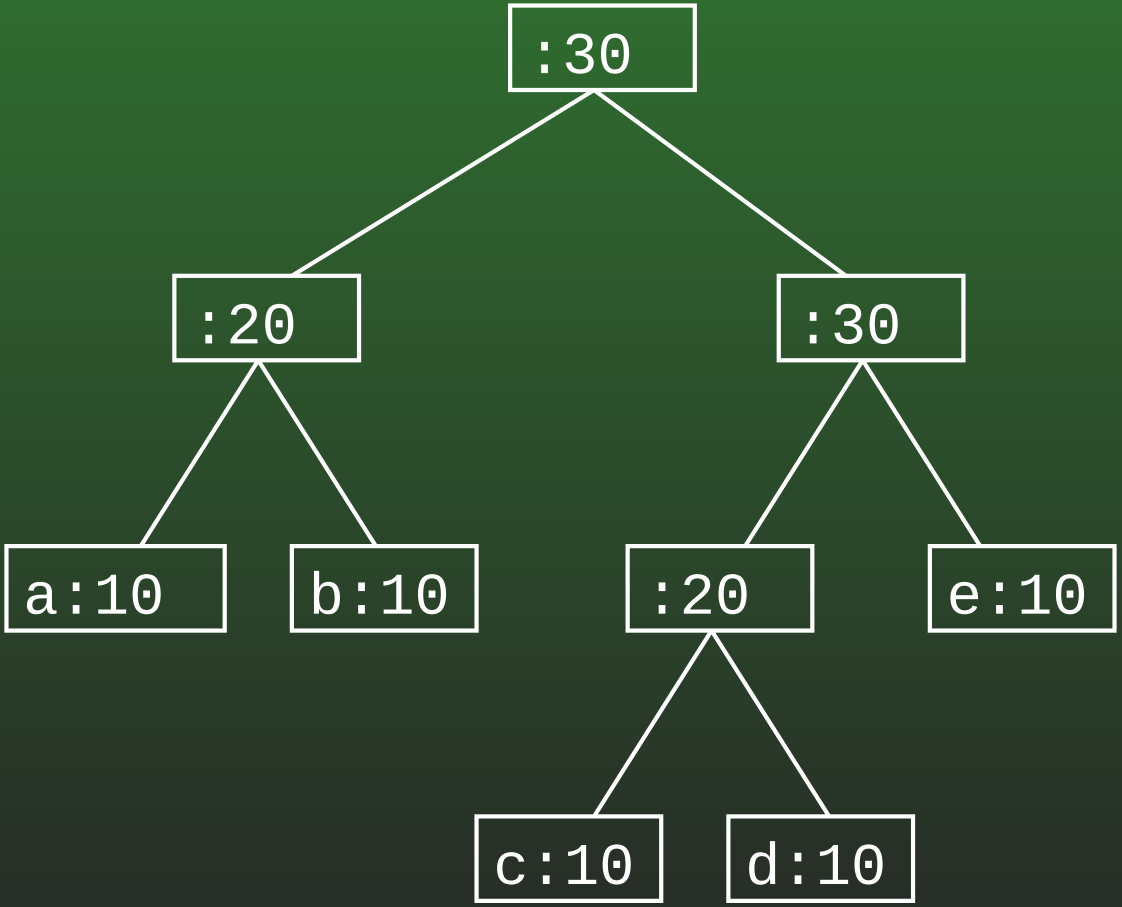
Huffman Coding

- Example: If the letters a-e have the frequencies:
  - a: 10, b: 10, c:10, d: 10, e: 10



P2-33: Huffman Coding

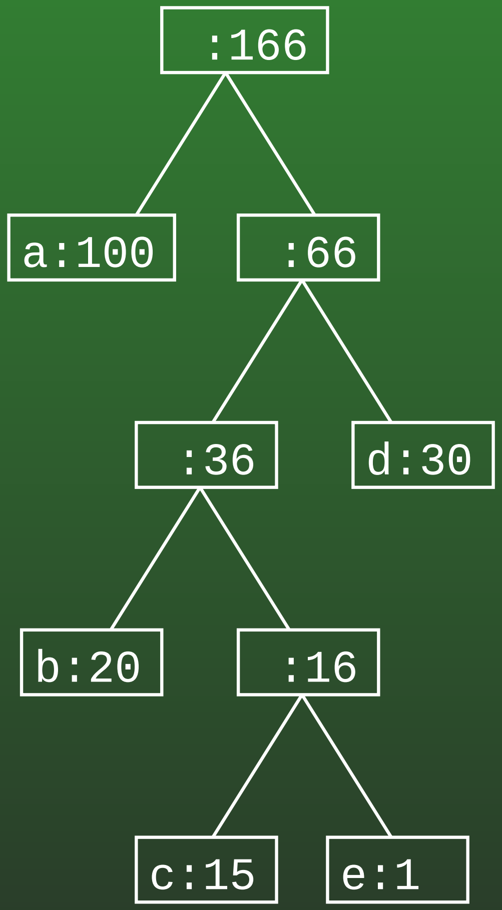
- Example: If the letters a-e have the frequencies:
  - a: 10, b: 10, c:10, d: 10, e: 10



P2-34: Huffman Trees & Tables

- Once we have a Huffman tree, decoding a file is straightforward – but *encoding* a tree requires a bit more information.
- Given just the tree, finding an encoding can be difficult
- ... What would we like to have, to help with encoding?

P2-35: Encoding Tables



a	0
b	100
c	1010
d	11
e	1011

P2-36: Creating Encoding Table

- Traverse the tree
  - Keep track of the path during the traversal
- When a leaf is reached, store the path in the table

P2-37: Huffman Coding

- To compress a file using huffman coding:
  - Read in the file, and count the occurrence of each character, and built a frequency table
  - Build the Huffman tree from the frequencies
  - Build the Huffman codes from the tree
  - Print the Huffman tree to the output file (for use in decompression)
  - Print out the codes for each character

P2-38: Huffman Coding

- To uncompress a file using huffman coding:
  - Read in the Huffman tree from the input file
  - Read the input file bit by bit, traversing the Huffman tree as you go
  - When a leaf is read, write the appropriate file to an output file

P2-39: Magic Numbers

- We only want to uncompress files that we actually compressed ourselves
- Write a “Magic Number” at the beginning of compressed file
    - For this project, use 0x4846 (ASCII ’HF’)
- When uncompressing, first check to see that magic number is correct

P2-40: Binary Files

```
public BinaryFile(String filename,
                  char readOrWrite)

public boolean EndOfFile()
public char readChar()
public void writeChar(char c)

public boolean readBit()
public void writeBit(boolean bit)

public void close()
```

P2-41: Binary Files

- readBit
  - Read a single bit
- readChar
  - Read a single character (8 bits)

P2-42: Binary Files

- writeBit
  - Writes out a single bit
- writeChar
  - Writes out a single (8 bit) character

P2-43: Binary Files

- If we write to a binary file:
    - char, bit, bit, bit, bit
- And then read from the file:
    - bit, bit, bit, bit, char
- What will we get out?

P2-44: Binary Files

- If we write to a binary file:
  - char, bit, bit, bit, bit
- And then read from the file:
  - bit, bit, bit, bit, char
- What will we get out?
- Garbage!

P2-45: Printing out Trees

- To print out Huffman trees:
  - Print out nodes in pre-order traversal
  - Need a way of denoting which nodes are leaves and which nodes are interior nodes
    - (Huffman trees are full – every node has 0 or 2 children)
  - For each interior node, print out a 0 (single bit). For each leaf, print out a 1, followed by 8 bits for the character at the leaf

P2-46: Compression?

- Is it possible that huffman compression would not compress the file?
- Is it possible that huffman compression could actually make the file larger?
- How?

P2-47: Compression?

- What happens if all the charcters have the same frequency?
  - What does the tree look like?
  - What can we say about the lengths of the codes for each character?
  - What does that mean for the file size?

P2-48: Compression?

- What happens if all the charcters have the same frequency?
  - All nodes are at the same depth in the tree (that is, 8)
  - Each code will have a length of 8
  - The encoded file will be the same size as the original file – *plus the size required to encode the tree*

P2-49: Compression!

- What to do?
  - Calculate the size of the input file
  - Calculate the size that the compressed file would be
  - If the compressed file is larger than than the input file, don’t compress

P2-50: Compression!

- Given the frequency array, how large is the input file?

P2-51: Compression!

- Given the frequency array, how large is the input file?
  - $\sum_c freq(c) * len(c)$
  - (# of characters in the input file) * 8

P2-52: Compression!

- Given the frequency array & codes for each compressed element, how large is the compressed file?

P2-53: Compression!

- Given the frequency array & codes for each compressed element, how large is the compressed file?
  - $\sum_c freq(c) * len(c)$ +
  - Size of tree +
  - + 4 bytes (32 bits) (file overhead) + 2 (16 bits) bytes (Magic Number)
    - Implementation detail of BinaryFile class
- Note file sizes need to be a multiple of 8 bits ...

P2-54: Command Line Arguments

```
public static void main(String args[])
```

- The `args` parameter holds the input parameters
- java MyProgram arg1 arg2 arg3
  - args.length = 3
  - args[0] = “arg1”
  - args[1] = “arg2”
  - args[2] = “arg3”

P2-55: Calling Huffman

```
java Huffman (-c|-u) [-v] [-f] infile outfile
```

- `(-c|-u)` stands for either “-c” (for compress), or “-u” (for uncompress)
- `[-v]` stands for an optional “-v” flag (for verbose)
- `[-f]` stands for an optional “-f” flag (for force compress)
- `infile` is the input file
- `outfile` is the output file