PAUL G. ALLEN SCHOOL
OF COMPUTER SCIENCE & ENGINEERING

Priority Queues and Huffman Encoding

Introduction to the Final Project

Hunter Schafer

CSE 143, Autumn 2021

Priority Queue

Priority Queue

A collection of ordered elements that provides fast access to the minimum (or maximum) element.

```
public class PriorityQueue<E> implements Queue<E>
```

`PriorityQueue<E>()`	constructs an empty queue
`add(E value)`	adds **value** in sorted order to the queue
`peek()`	returns minimum element in queue
`remove()`	removes/returns minimum element in queue
`size()`	returns the number of elements in queue

```
Queue<String> tas = new PriorityQueue<String>();
tas.add("Watson");
tas.add("Sherlock");
tas.remove();
```

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```
Queue<String> tas = new PriorityQueue<String>();
tas.add("Watson");
tas.add("Sherlock");
tas.remove(); // "Sherlock"
```

Final Project: Huffman Coding

File Compression

Compression

Process of encoding information so that it takes up less space.

Compression applies to many things!

- Store photos without taking up the whole hard-drive
- Reduce size of email attachment
- Make web pages smaller so they load faster
- Make voice calls over a low-bandwidth connection (cell, Skype)

Common compression programs:

- WinZip, WinRar for Windows
- zip

ASCII

ASCII (American Standard Code for Information Interchange)

Standardized code for mapping characters to integers

- Many text files on your computer are in ASCII.
- But, computers need numbers represented in binary!

Character	ASCII value
‘ ’	32
‘a’	97
‘b’	98
‘c’	99
‘e’	101
‘z’	122

ASCII (American Standard Code for Information Interchange)

Standardized code for mapping characters to integers

- Many text files on your computer are in ASCII.
- But, computers need numbers represented in binary!

Every character is represented by a byte (8 bits).

Character	ASCII value	Binary Representation
‘ ’	32	00100000
‘a’	97	01100001
‘b’	98	01100010
‘c’	99	01100011
‘e’	101	01100101
‘z’	122	01111010

ASCII Example

Character	ASCII value	Binary Representation
‘ ’	32	00100000
‘a’	97	01100001
‘b’	98	01100010
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What is the binary representation of the following String?

cab z

ASCII Example

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What is the binary representation of the following String?

cab z

Answer

01100011

ASCII Example

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‘a’	97	01100001
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What is the binary representation of the following String?

cab z

Answer

01100011 01100001

ASCII Example

Character	ASCII value	Binary Representation
‘ ’	32	00100000
‘a’	97	01100001
‘b’	98	01100010
‘c’	99	01100011
‘e’	101	01100101
‘z’	122	01111010

What is the binary representation of the following String?

cab␣z

Answer

01100011 01100001 01100010

ASCII Example

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‘ ’	32	00100000
‘a’	97	01100001
‘b’	98	01100010
‘c’	99	01100011
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‘z’	122	01111010

What is the binary representation of the following String?

cab_z

Answer

01100011 01100001 01100010 00100000

ASCII Example

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‘ ’	32	00100000
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What is the binary representation of the following String?

cab z

Answer

01100011 01100001 01100010 00100000 01111010

ASCII Example

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‘b’	98	01100010
‘c’	99	01100011
‘e’	101	01100101
‘z’	122	01111010

What is the binary representation of the following String?

cab z

Answer

0110001101100001011000100010000001111010

Another ASCII Example

Character	ASCII value	Binary Representation
‘ ’	32	00100000
‘a’	97	01100001
‘b’	98	01100010
‘c’	99	01100011
‘e’	101	01100101
‘z’	122	01111010

How do we read the following binary as ASCII?

011000010110001101100101

Another ASCII Example

Character	ASCII value	Binary Representation
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‘a’	97	01100001
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How do we read the following binary as ASCII?

01100001 01100011 01100101

Answer

Another ASCII Example

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‘a’	97	01100001
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‘e’	101	01100101
‘z’	122	01111010

How do we read the following binary as ASCII?

01100001 01100011 01100101

Answer

a

Another ASCII Example

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‘ ’	32	00100000
‘a’	97	01100001
‘b’	98	01100010
‘c’	99	01100011
‘e’	101	01100101
‘z’	122	01111010

How do we read the following binary as ASCII?

01100001 <u>01100011</u> 01100101

Answer

ac

Another ASCII Example

Character	ASCII value	Binary Representation
‘ ’	32	00100000
‘a’	97	01100001
‘b’	98	01100010
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‘z’	122	01111010

How do we read the following binary as ASCII?

01100001 01100011 01100101

Answer

ace

Huffman Idea

Huffman's Insight

Use variable length encodings for different characters to take advantage of frequencies in which characters appear.

- Make more frequent characters take up less space.
- Don't have codes for unused characters.
- Some characters may end up with longer encodings, but this should happen infrequently.

Huffman Encoding

- Create a “Huffman Tree” that gives a good binary representation for each character.
- The path from the root to the character leaf is the encoding for that character; left means 0, right means 1.

ASCII Table

Character	Binary Representation
‘ ’	00100000
‘a’	01100001
‘b’	01100010
‘c’	01100011
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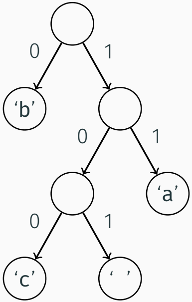
Huffman Tree



Final Project: Huffman Coding

The final project asks you to write a class that manages creating and using this Huffman code.

(A) Create a Huffman Code from a file and compress it.

(B) Decompress the file to get original contents.

Part A: Making a HuffmanCode Overview

Input File Contents
`bad cab`

Part A: Making a HuffmanCode Overview

Input File Contents
`bad cab`

Step 1: Count the occurrences of each character in file

```
{' '=1, 'a'=2, 'b'=2, 'c'=1, 'd'=1}
```

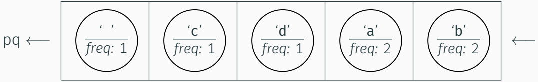
Part A: Making a HuffmanCode Overview

Input File Contents
`bad cab`

Step 1: Count the occurrences of each character in file

`{' '=1, 'a'=2, 'b'=2, 'c'=1, 'd'=1}`

Step 2: Make leaf nodes for all the characters. Place in a PriorityQueue



Part A: Making a HuffmanCode Overview

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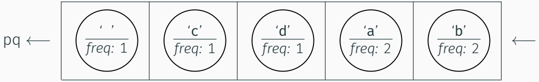

Step 3: Use Huffman Tree building algorithm (described soon)

Part A: Making a HuffmanCode Overview

Input File Contents
`bad cab`

Step 1: Count the occurrences of each character in file

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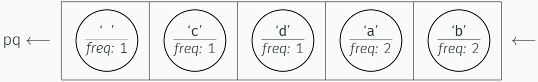

Step 3: Use Huffman Tree building algorithm (described soon)

Step 4: Save encoding to `.code` file to encode/decode later.

`{'d'=00, 'a'=01, 'b'=10, ' '=110, 'c'=111}`

Part A: Making a HuffmanCode Overview

Input File Contents
`bad cab`

Step 1: Count the occurrences of each character in file

`{' '=1, 'a'=2, 'b'=2, 'c'=1, 'd'=1}`

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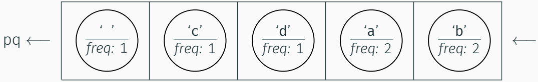


Step 3: Use Huffman Tree building algorithm (described soon)

Step 4: Save encoding to `.code` file to encode/decode later.

`{'d'=00, 'a'=01, 'b'=10, ' '=110, 'c'=111}`

Step 5: Compress the input file using the encodings

Compressed Output: 1001001101110110

Step 1: Count Character Occurrences

We do this step for you

Input File
`bad cab`

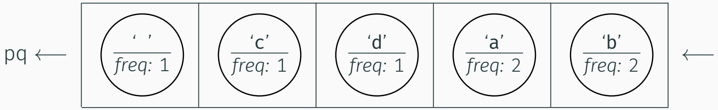
Generate Counts Array:

index	0	1	…	32	…	97	98	99	100	101
value	0	0		1		2	2	1	1	0

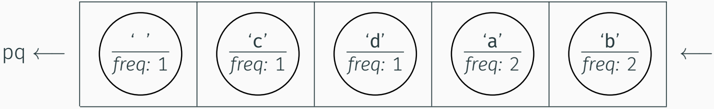
This is super similar to LetterInventory but works for all characters!

Step 2: Create PriorityQueue

- Store each character and its frequency in a `HuffmanNode` object.
- Place all the `HuffmanNode`s in a `PriorityQueue` so that they are in ascending order with respect to **frequency**



Step 3: Remove and Merge



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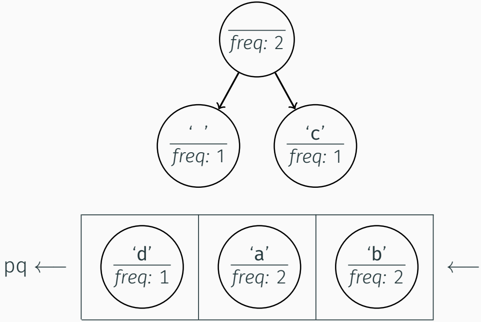

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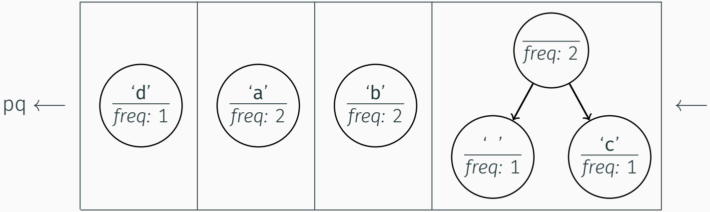
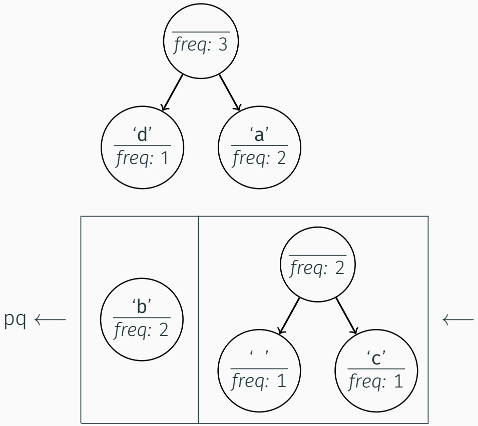


Step 3: Remove and Merge



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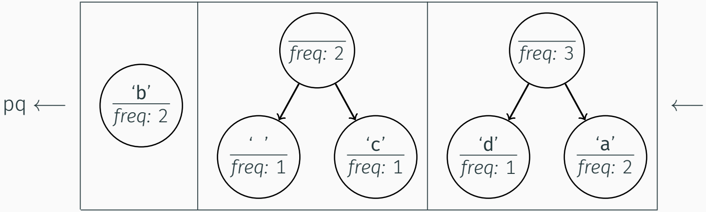

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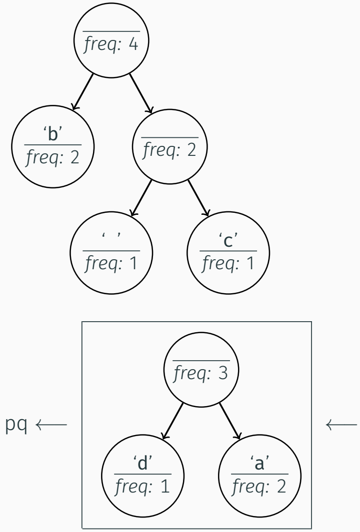

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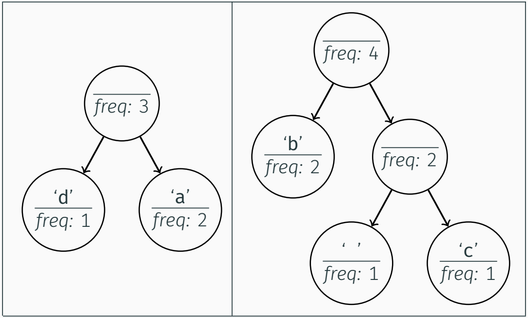
pq ⟵  ⟵

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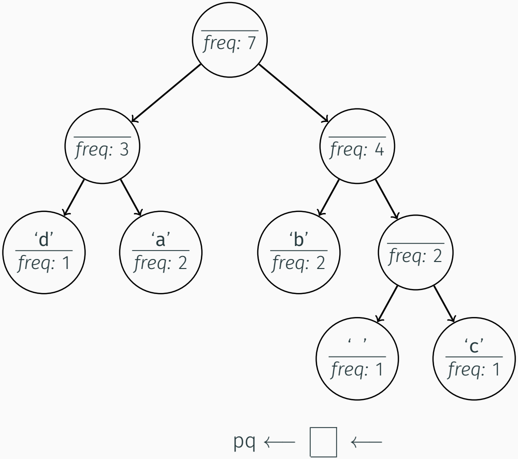

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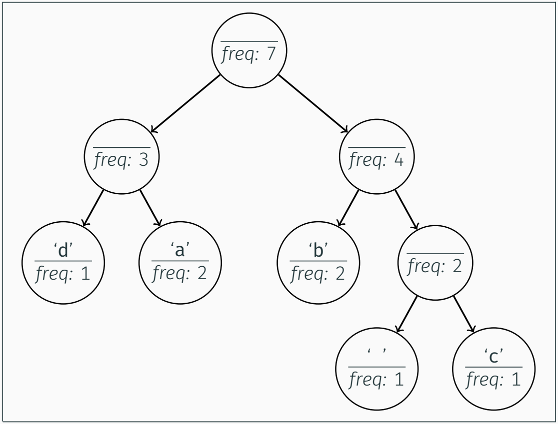
pq ⟵  ⟵

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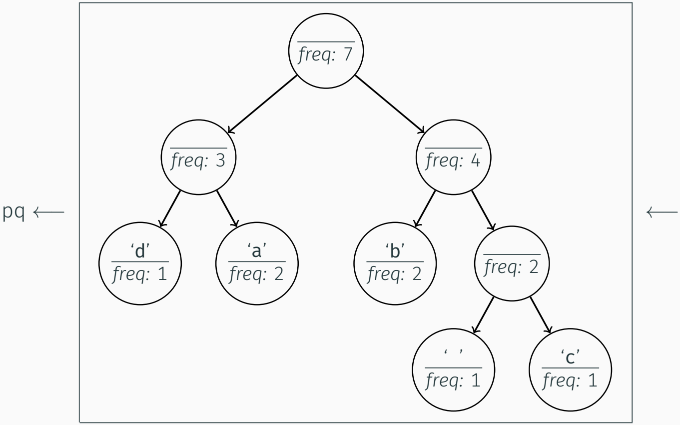


- What is the relationship between frequency in file and binary representation length?

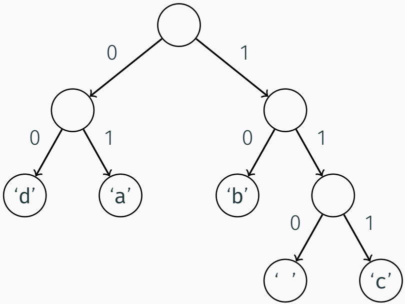
Step 3: Remove and Merge Algorithm

Algorithm Pseudocode

```
while P.Q. size > 1:
   remove two nodes with lowest frequency
   combine into a single node
   put that node back in the P.Q.
```

Step 4: Print Encodings

Save the tree to a file to save the encodings for the characters we made.



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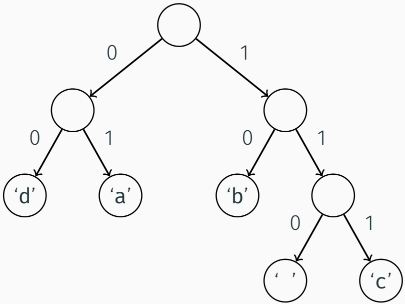
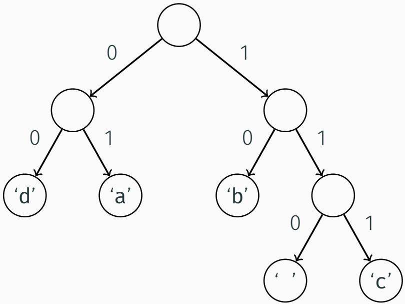


Output of `save`

Step 4: Print Encodings

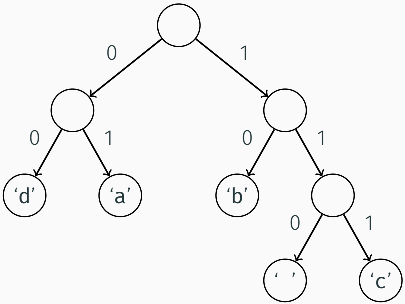
Save the tree to a file to save the encodings for the characters we made.



Output of `save`
`100`
`00`

Step 4: Print Encodings

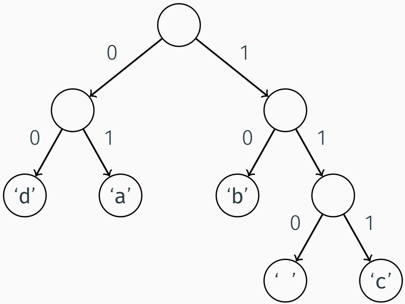
Save the tree to a file to save the encodings for the characters we made.



Output of `save`
`100`
`00`
`97`
`01`

Step 4: Print Encodings

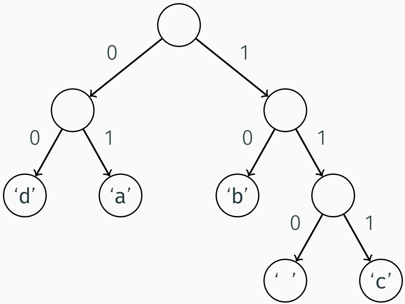
Save the tree to a file to save the encodings for the characters we made.



Output of `save`
100
00
97
01
98
10

Step 4: Print Encodings

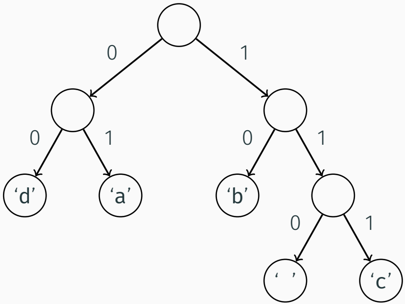
Save the tree to a file to save the encodings for the characters we made.



Output of `save`
100
00
97
01
98
10
32
110

Step 4: Print Encodings

Save the tree to a file to save the encodings for the characters we made.



Output of `save`
100
00
97
01
98
10
32
110
99
111

Step 5: Compress the File

We do this step for you

Take the original file and the `.code` file produced in last step to translate into the new binary encoding.

Input File
bad cab

Compressed Output

Huffman Encoding

```
100
00
97
01
98
10
32
110
99
111
```

Step 5: Compress the File

We do this step for you

Take the original file and the `.code` file produced in last step to translate into the new binary encoding.

Input File
bad cab

Compressed Output

Huffman Encoding

```
100  'd'
00
97   'a'
01
98   'b'
10
32   ' '
110
99   'c'
111
```

Step 5: Compress the File

We do this step for you

Take the original file and the `.code` file produced in last step to translate into the new binary encoding.

Input File
bad cab

Compressed Output
10 01 100 110 111 01 10

Huffman Encoding

```
100 'd'
00
97  'a'
01
98  'b'
10
32  ' '
110
99  'c'
111
```

Step 5: Compress the File

We do this step for you

Take the original file and the `.code` file produced in last step to translate into the new binary encoding.

Input File

bad cab

Compressed Output

10 01 100 110 111 01 10

Uncompressed Output

01100010 01100001 01100100 00100000 01100011 01100001 01100010

Huffman Encoding

```
100 'd'
00
97  'a'
01
98  'b'
10
32  ' '
110
99  'c'
111
```

Part B: Decompressing the File

Step 1: Reconstruct the Huffman tree from the code file

Step 2: Translate the compressed bits back to their character values.

Step 1: Reconstruct the Huffman Tree

Now are just given the code file produced by our program and we need to reconstruct the tree.

Input code File

```
97
0
101
100
32
101
112
11
```

Initially the tree is empty

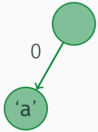
Step 1: Reconstruct the Huffman Tree

Now are just given the code file produced by our program and we need to reconstruct the tree.

Input code File

```
97
0
101
100
32
101
112
11
```

Tree after processing first pair

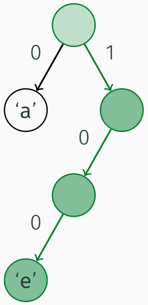


Step 1: Reconstruct the Huffman Tree

Now are just given the code file produced by our program and we need to reconstruct the tree.

Input code File
97
0
101
100
32
101
112
11

Tree after processing second pair



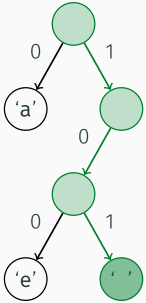
Step 1: Reconstruct the Huffman Tree

Now are just given the code file produced by our program and we need to reconstruct the tree.

Input code File

```
97
0
101
100
32
101
112
11
```

Tree after processing third pair



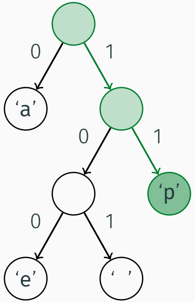
Step 1: Reconstruct the Huffman Tree

Now are just given the code file produced by our program and we need to reconstruct the tree.

Input code File

```
97
0
101
100
32
101
112
11
```

Tree after processing last pair

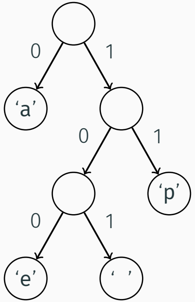


Step 2 Example

After building up tree, we will read the compressed file bit by bit.

Input
010111011010101011100

Output

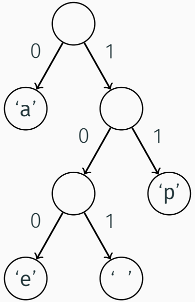


Step 2 Example

After building up tree, we will read the compressed file bit by bit.

Input
010111011010101011100

Output
a papa ape



Working with Bits? That Sounds a Little Bit Hard

Reading bits in Java is kind of tricky, we are providing a class to help!

`public class BitInputStream`

`BitInputStream(String file)`	Creates a stream of bits from file
`hasNextBit()`	Returns true if bits remain in the stream
`nextBit()`	Reads and returns the next bit in the stream

Review - Final Project

Part A: Compression

```
public HuffmanCode(int[] counts)
```

- Slides 11-13

```
public void save(PrintStream out)
```

- Slide 14

Part B: Decompression

```
public HuffmanCode(Scanner input)
```

- Slide 17

```
public void translate(BitInputStream in,
                      PrintStream out)
```

- Slide 18