Priority Queues and Huffman Encoding

Introduction to Homework 7

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I Think You Have Some Priority Issues

ER Scheduling. How do we *efficiently* chose the most urgent case to treat next? Patients with more serious ailments should go first.

OS Context Switching. How does your operating system decide which process to give resources to? Some applications are more important than others.

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How can we solve these problems with the data structures we know?

Possible Solution

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- Store elements in an unsorted list
  - add: Add at end
  - remove: Search for highest priority element
- Store elements in a sorted LinkedList
  - add: Search for position to insert, place there
  - remove: remove from front
- Store elements in a TreeSet (hope they are unique!)
  - add: Traverse tree for position to insert, place there
  - remove: Traverse tree for smallest element, remove

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("Jin");
tas.add("Aaron");
tas.remove();
```

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

Priority Queue Example

What does this code print?

```
Queue<TA> tas = new PriorityQueue<TA>();
tas.add(new TA("Kyle", 7));
tas.add(new TA("Ayaz", 3));
tas.add(new TA("Zach", 6));
System.out.println(tas);
```

Priority Queue Example

What does this code print?

```
Queue<TA> tas = new PriorityQueue<TA>();
tas.add(new TA("Kyle", 7));
tas.add(new TA("Ayaz", 3));
tas.add(new TA("Zach", 6));
System.out.println(tas);
```

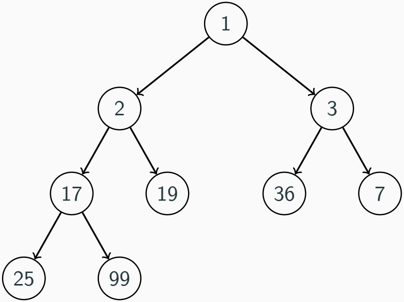
Prints: `[Ayaz: 3, Kyle: 7, Zach: 6]`

Common Gotchas

- Elements must be Comparable.
- `toString` doesn't do what you expect! Use `remove` instead.

Inside the Priority Queue

- Usually implemented with a **heap**
- Guarantees children have a lower priority than the parent so the highest priority is at the root (fast access).
- Take CSE 332 or CSE 373 to learn about how to implement more complicated data structures like heaps!



Homework 7: 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

We need to represent characters in binary so computers can read them.

- Most text files on your computer are in ASCII.

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

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

cab z

ASCII Example

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cab z

Answer

01100011

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What is the binary representation of the following String?

cab z

Answer

`01100011 01100001`

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 01100010`

ASCII Example

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‘b’	98	01100010
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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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‘a’	97	01100001
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What is the binary representation of the following String?

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Answer

`01100011 01100001 01100010 00100000 01111010`

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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
‘ ’	32	00100000
‘a’	97	01100001
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How do we read the following binary as ASCII?

01100001 01100011 01100101

Answer

Another ASCII Example

Character	ASCII value	Binary Representation
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‘c’	99	01100011
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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
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‘c’	99	01100011
‘e’	101	01100101
‘z’	122	01111010

How do we read the following binary as ASCII?

01100001 01100011 01100101

Answer

ac

Another ASCII Example

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‘a’	97	01100001
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‘c’	99	01100011
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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
'e'	01100101
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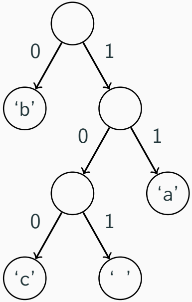
Huffman Tree



Homework 7: Huffman Coding

Homework 7 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}

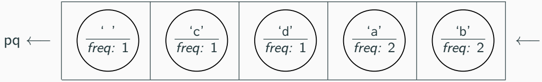
Part A: Making a HuffmanCode Overview

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 put them in a PriorityQueue



Part A: Making a HuffmanCode Overview

Input File Contents
bad cab

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

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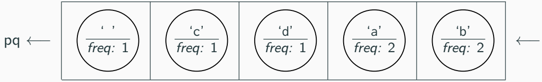

Step 3: Use Huffman Tree building algorithm (described in a couple slides)

Part A: Making a HuffmanCode Overview

Input File Contents

bad cab

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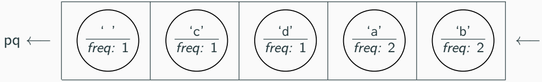

Step 3: Use Huffman Tree building algorithm (described in a couple slides)

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

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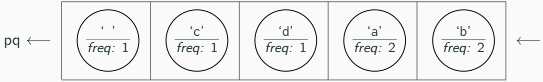


Step 3: Use Huffman Tree building algorithm (described in a couple slides)

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

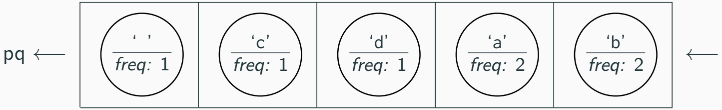
Generate Counts Array:

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

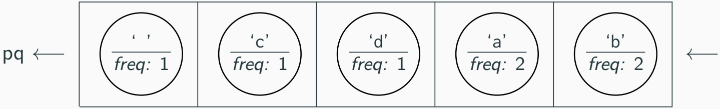
This is super similar to LetterInventory but works for all characters!

Step 2: Create PriorityQueue

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



Step 3: Remove and Merge



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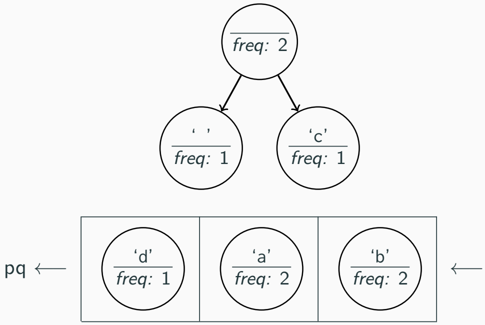

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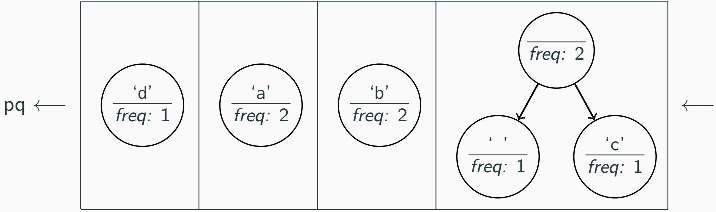

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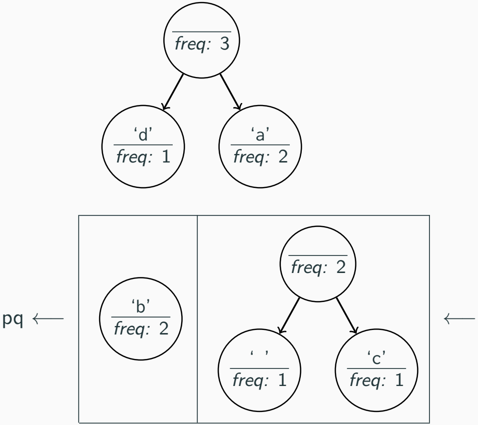

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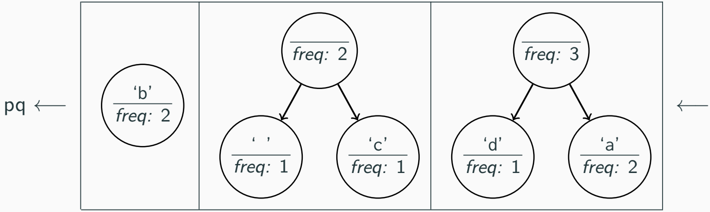

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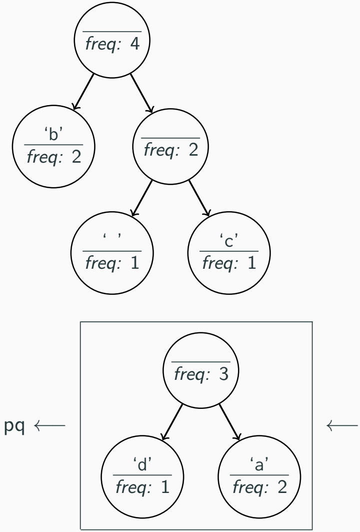

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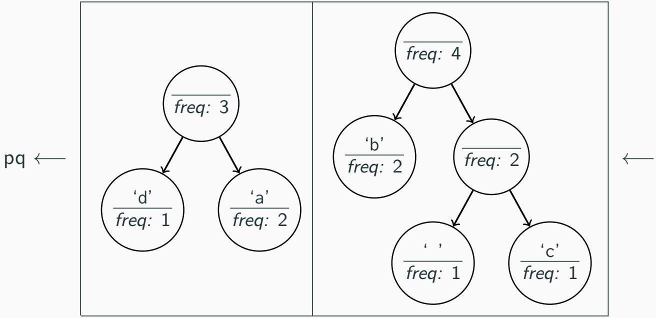

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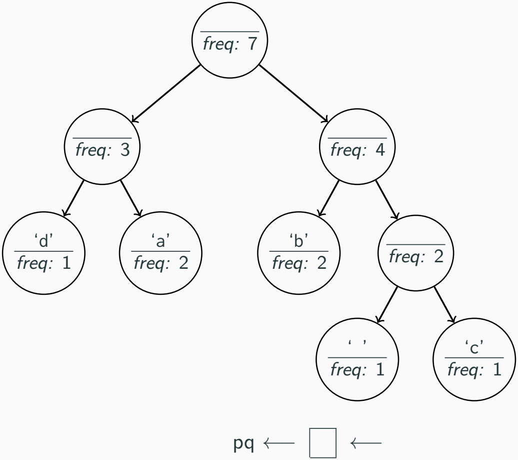
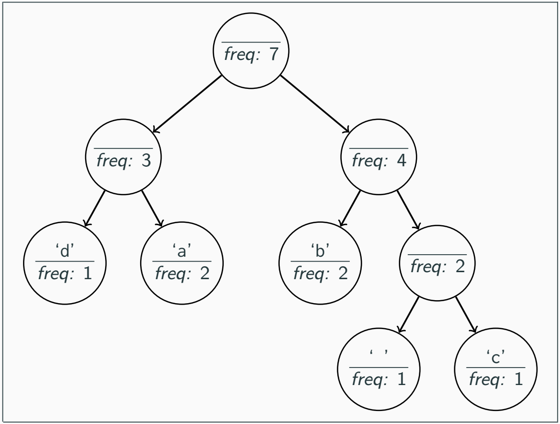


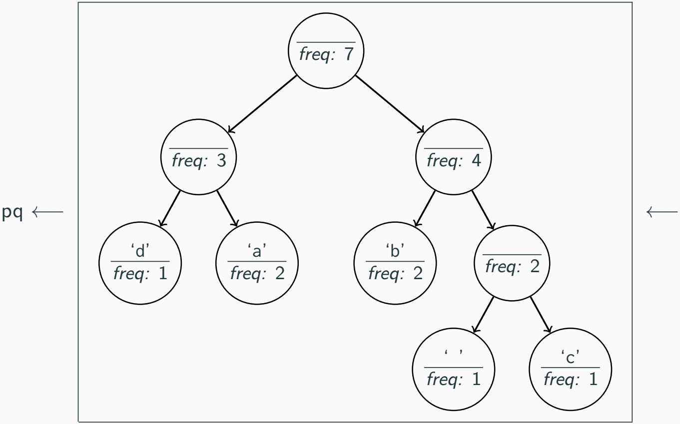
Step 3: Remove and Merge

pq ⟵



⟵

Step 3: Remove and Merge



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

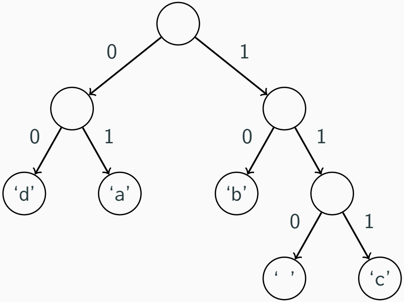
Step 3: Remove and Merge Algorithm

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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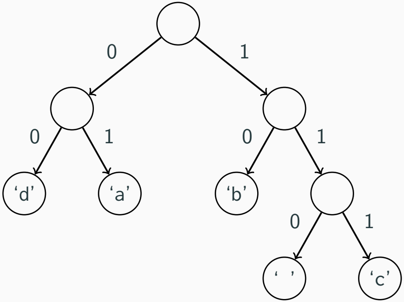

Output of save

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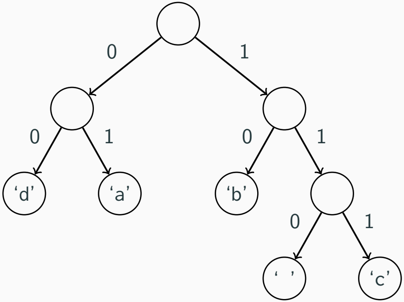

Output of save
100
00

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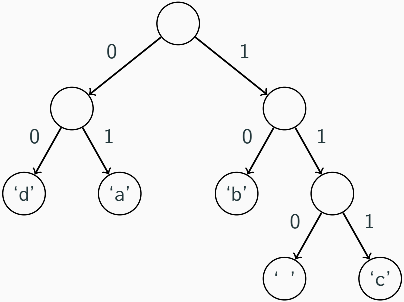

Output of save
100
00
97
01

Step 4: Print Encodings

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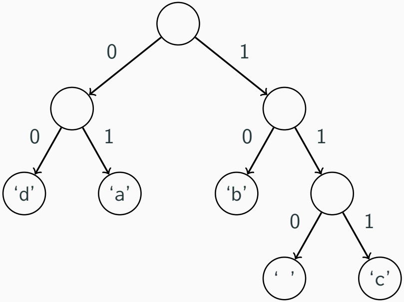

Output of save
100
00
97
01
98
10

Step 4: Print Encodings

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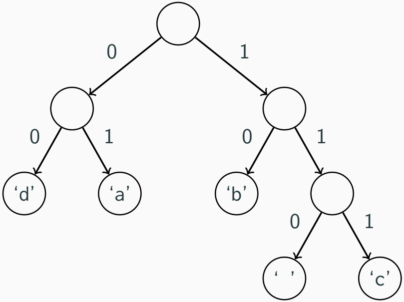

Output of save

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

Step 4: Print Encodings

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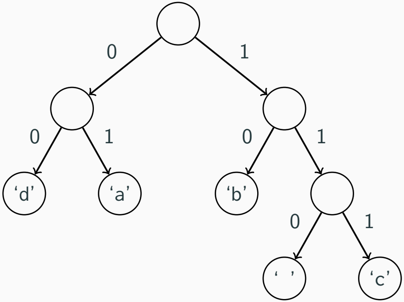


Output of save
100
00
97
01
98
10
32
110
99
111

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

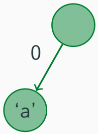
Initially the tree is empty

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

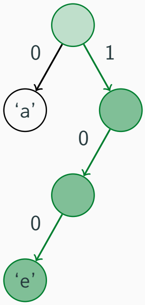


Step 1: Reconstruct the Huffman Tree

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

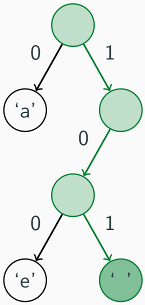


Step 1: Reconstruct the Huffman Tree

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

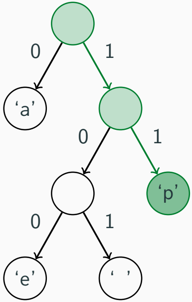


Step 1: Reconstruct the Huffman Tree

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



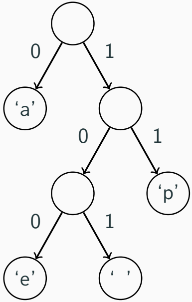
Step 2 Example

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

Input

`010111011010101011100`

Output



Step 2 Example

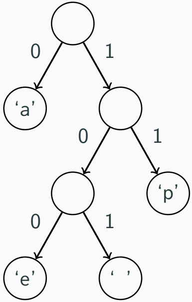
After building up tree, we will read the compressed file bit by bit.

Input

0101110110101011100

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 - Homework 7

Part A: Compression

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

- Slides 15-17

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

- Slide 18

Part B: Decompression

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

- Slide 21

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

- Slide 22