Programming Abstractions

CS106B

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Topics:

- Continue discussion of Binary Trees
  - So far we've studied two types of Binary Trees:
    - Binary Heaps (Priority Queue)
    - Binary Search Trees/BSTs (Map)
  - We also heard about some relatives of the BST: red-black trees, splay tress, B-Trees
- Today we're going to be talking about **Huffman trees**

- Misc. announcement:
  - Thanks, mom! ♥

Getting Started on Huffman

Encoding with Huffman Trees:

- Today we’re going to be talking about your next assignment: **Huffman coding**
  - It’s a compression algorithm
  - It’s provably optimal (take that, Pied Piper)
  - It involves binary tree data structures, yay!
  - (assignment goes out Wednesday)

- **But before we talk about the tree structure and algorithm, let’s set the scene a bit and talk about BINARY**

In a computer, everything is numbers!

Specifically, everything is binary

- Images (gif, jpg, png): binary numbers
- Integers (int): binary numbers
- Non-integer real numbers (double): binary numbers
- Letters and words (ASCII, Unicode): binary numbers
- Music (mp3): binary numbers
- Movies (streaming): binary numbers
- Doge pictures (): binary numbers
- Email messages: binary numbers

Encodings are what tell us how to translate

- *“if we interpret these binary digits as an image, it would look like this”*
- *“if we interpret these binary digits as a song, it would sound like this”*

ASCII is an old-school encoding for characters

- The “char” type in C++ is based on ASCII
- You interacted with this a bit in WordLadder and midterm Boggle question (e.g., `'A' + 1 = 'B'`)
- Leftover from C in the 1970’s
- Doesn’t play nice with other languages, and today’s software can’t afford to be so America-centric, so Unicode is more common
- ASCII is simple so we use it for this assignment

ASCII Table

Notice each symbol is encoded as 8 binary digits (8 bits)

There are 256 unique sequences of 8 bits, so numbers 0-255 each correspond to one character

(this only shows 32-74)

00111110 = ‘<’

DEC	OCT	HEX	BIN	Symbol
32	040	20	00100000	
33	041	21	00100001	!
34	042	22	00100010	"
35	043	23	00100011	#
36	044	24	00100100	$
37	045	25	00100101	%
38	046	26	00100110	&
39	047	27	00100111	'
40	050	28	00101000	(
41	051	29	00101001	)
42	052	2A	00101010	*
43	053	2B	00101011	+
44	054	2C	00101100	,
45	055	2D	00101101	-
46	056	2E	00101110	.
47	057	2F	00101111	/
48	060	30	00110000	0
49	061	31	00110001	1
50	062	32	00110010	2
51	063	33	00110011	3
52	064	34	00110100	4

DEC	OCT	HEX	BIN	Symbol
53	065	35	00110101	5
54	066	36	00110110	6
55	067	37	00110111	7
56	070	38	00111000	8
57	071	39	00111001	9
58	072	3A	00111010	
59	073	3B	00111011	
60	074	3C	00111100	
61	075	3D	00111101	
62	076	3E	00111110	>
63	077	3F	00111111	?
64	100	40	01000000	@
65	101	41	01000001	A
66	102	42	01000010	B
67	103	43	01000011	C
68	104	44	01000100	D
69	105	45	01000101	E
70	106	46	01000110	F
71	107	47	01000111	G
72	110	48	01001000	H
73	111	49	01001001	I
74	112	4A	01001010	J

ASCII Example

char	ASCII	bit pattern (binary)
h	104	01101000
a	97	01100001
p	112	01110000
y	121	01111001
i	105	01101001
o	111	01101111
space	32	00100000

"happy hip hop" =

104 97 112 112 121 32 104 105 (decimal)

Or this in binary:

01101000	01100001	01110000	01110000	01111001	00100000	01101000
01101001	01110000	00100000	01101000	01101111	01110000	

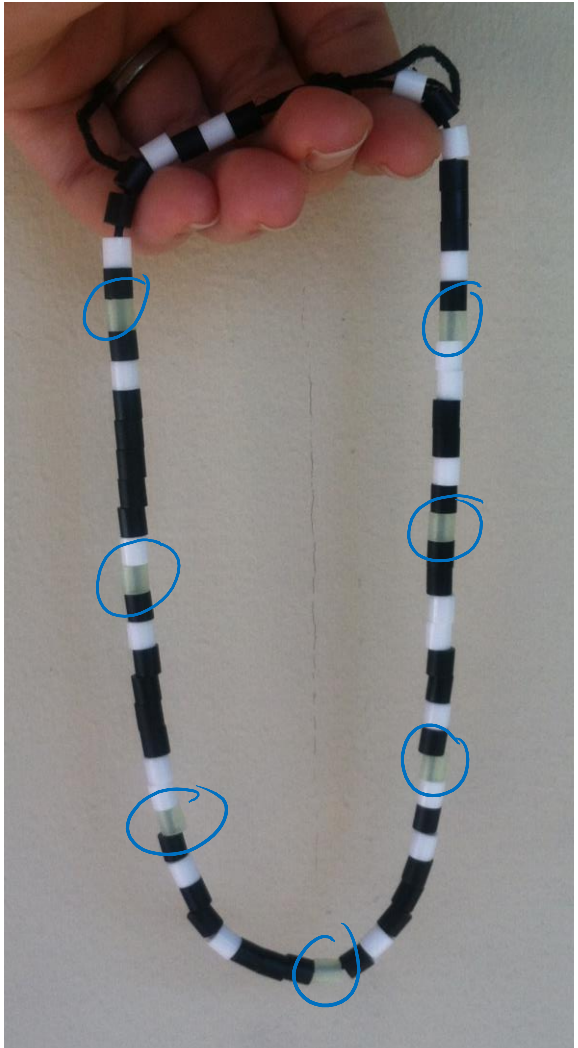
FAQ: Why does 104 = 'h'?

Answer: it's arbitrary, like most encodings. Some people in the 1970s just decided to make it that way.

[Aside] Unplugged programming:
The Binary Necklace

- Choose one color to represent 0's and another color to represent 1's
- Write your name in beads by looking up each letter's ASCII encoding
- For extra bling factor, this one uses glow-in-the dark beads as delimiters between letters

DEC	OCT	HEX	BIN	Symbol
65	101	41	01000001	A
66	102	42	01000010	B
67	103	43	01000011	C
68	104	44	01000100	D
69	105	45	01000101	E
70	106	46	01000110	F
71	107	47	01000111	G
72	110	48	01001000	H
73	111	49	01001001	I



ASCII

- ASCII's uniform encoding size makes it easy
  - Don't really need those glow-in-the-dark beads as delimiters, because we know every 9th bead starts a new 8-bit letter encoding
- Key insight: also a bit wasteful *(ha! get it? a "bit")*
  - What if we took the most commonly used characters (according to *Wheel of Fortune,* some of these are RSTLNE) and encoded them with just 2 or 3 bits each?
  - We let seldom-used characters, like &, have encodings that are longer, say 12 bits.
  - Overall, we would save a lot of space!

Non-ASCII (variable-length) encoding example

char	bit pattern
h	01
a	000
p	10
y	1111
i	001
o	1110
space	110

"happy hip hop" =

01	000	10	10	1111	110	01	001	10	110	01	1110	10

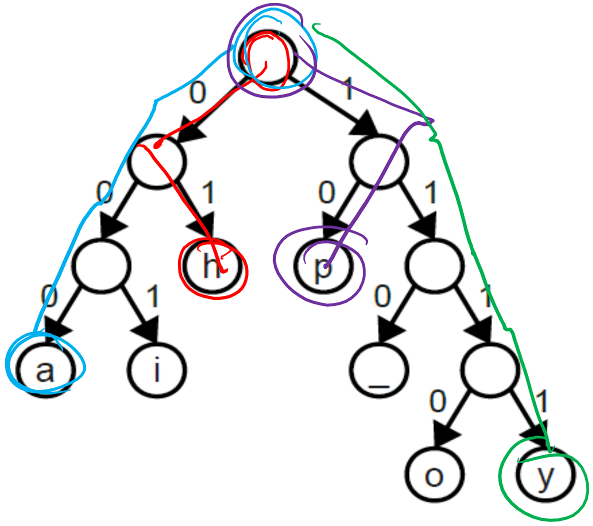
The variable-length encoding scheme makes a MUCH more space-efficient message than ASCII:

01101000	01100001	01110000	01110000	01111001	00100000	01101000
01101001	01110000	00100000	01101000	01101111	01110000	

Huffman encoding

- Huffman encoding is a way of choosing which characters are encoded which ways, *customized to the specific file you are using*
- Example: character ‘#’
  - Rarely used in Shakespeare (code could be longer, say ~10 bits)
  - If you wanted to encode a Twitter feed, you’d see # a lot (maybe only ~4 bits) #contextmatters #thankshuffman
- We store the code translation as a tree:

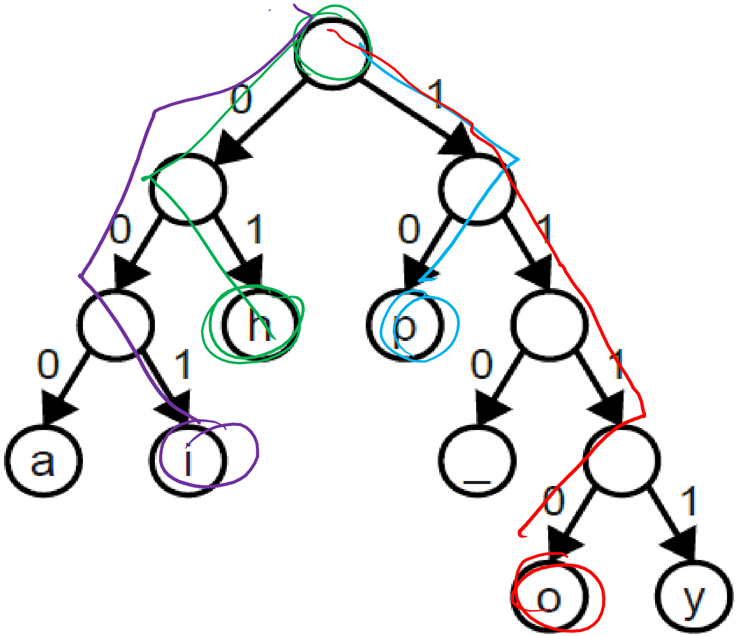
happy
0100 0 1010 1111



Your turn

What would be the binary encoding of "hippo" using this Huffman encoding tree?

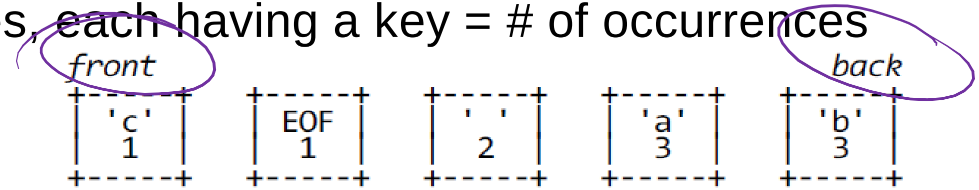
A. 11000
B. 0101101010
C. 0100110101110
D. 0100010101111
E. Other/none/more than one



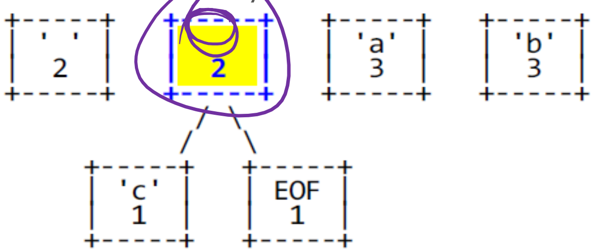
0100110101110

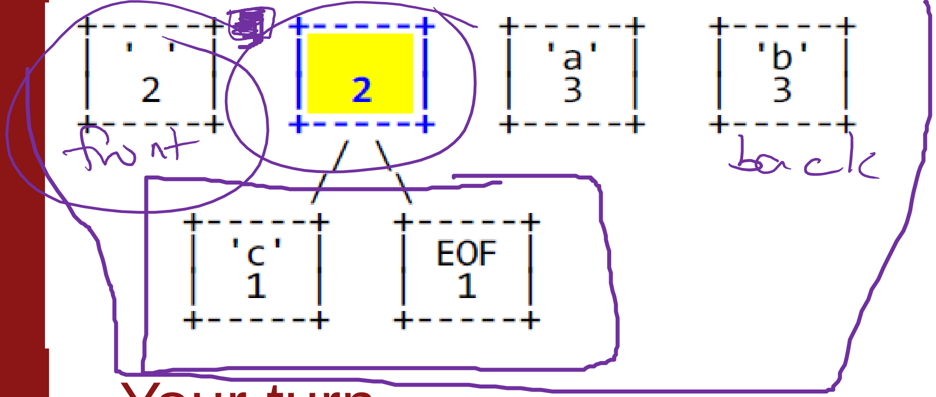
Okay, so how do we make the tree?

1. Read your file and count how many times each character occurs
2. Make a collection of tree nodes, each having a key = # of occurrences and a value = the character



   - Example: “c aaa bbb”
   - For now, tree nodes are not in a tree shape
   - We actually store them in a Priority Queue (yay!!) based on highest priority = LOWEST # of occurrences
   - Next:
     - Dequeue two nodes and make them the two children of a new node, with no character and # of occurrences is the sum,
     - Enqueue this new node
     - Repeat until PQ.size() == 1

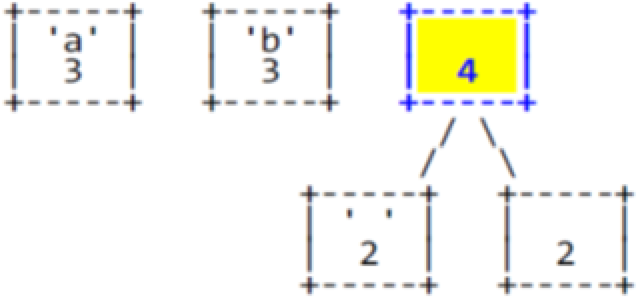




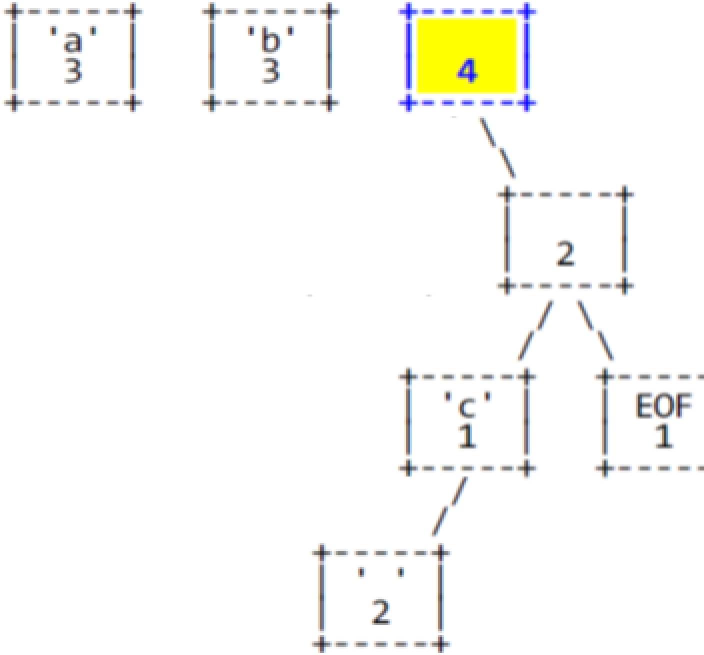
Your turn

If we start with the Priority Queue above, and execute one more step, what do we get?

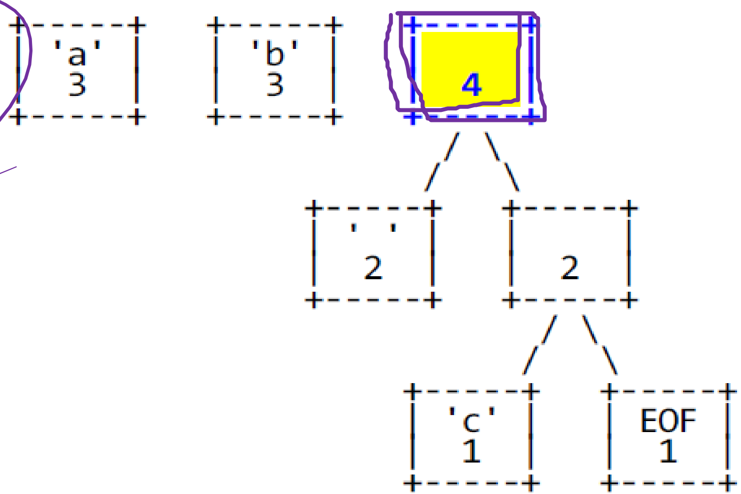
(A)



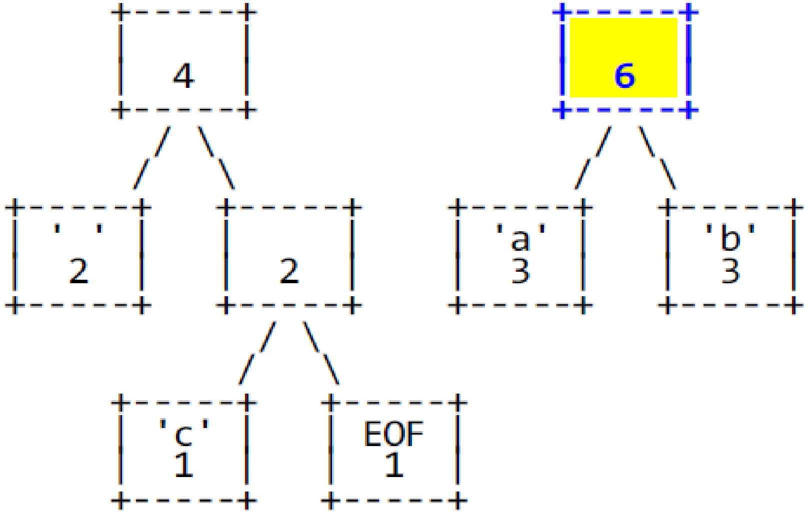
(B)

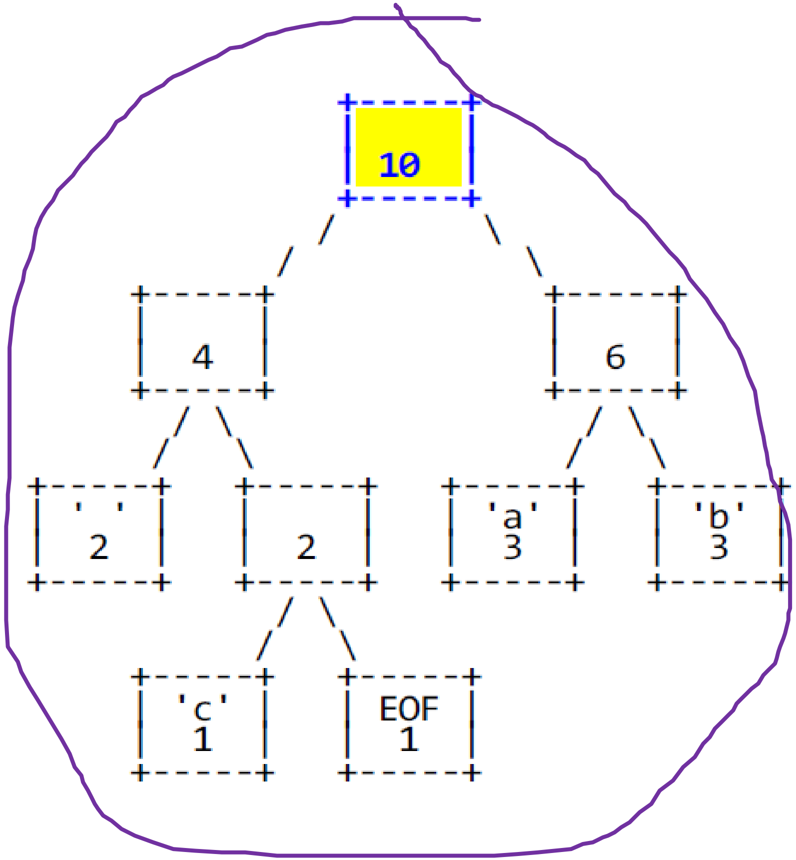


(C)



Last two steps





Now assign codes

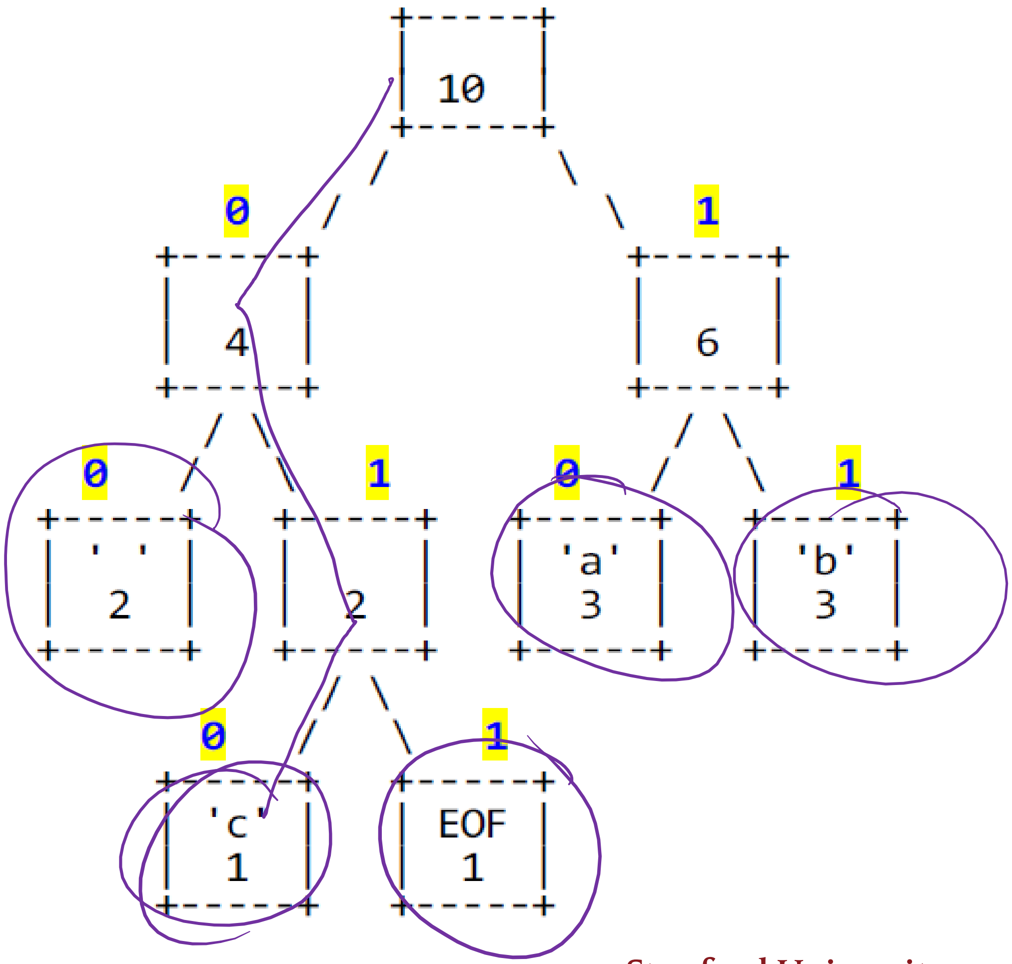
We interpret the tree as:

- Left child = 0
- Right child = 1

What is the code for “c”?

A. 00
B. 010
C. 101
D. Other/none

c	a	b
010	10	11



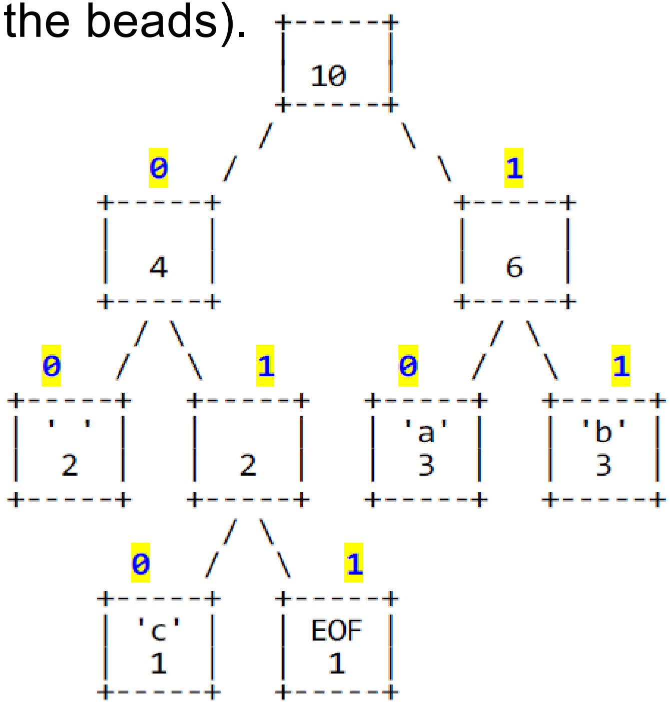
Key question: How do we know when one character's bits end and another's begin?

Huffman needs delimiters (like the glow-in-the-dark beads), unlike ASCII, which is always 8 bits (and didn't really need the beads).

A. TRUE

B. FALSE

Discuss/prove it: why or why not?



c	a	b
010	10	11