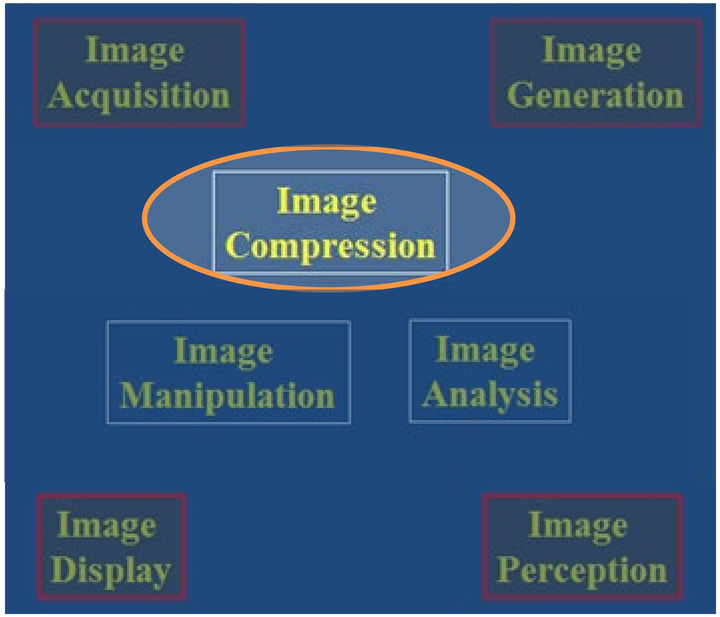
Digital Image Processing

Image Compression



Caution:
The PDF version of this presentation will appear to have errors due to heavy use of animations

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Material in this presentation is largely based on/derived from presentation(s) and book: The Digital Image by Dr. Donald House at Texas A&M University

Lecture Objectives

- Previously
  - Filtering
  - Interpolation
  - Warping
  - Morphing

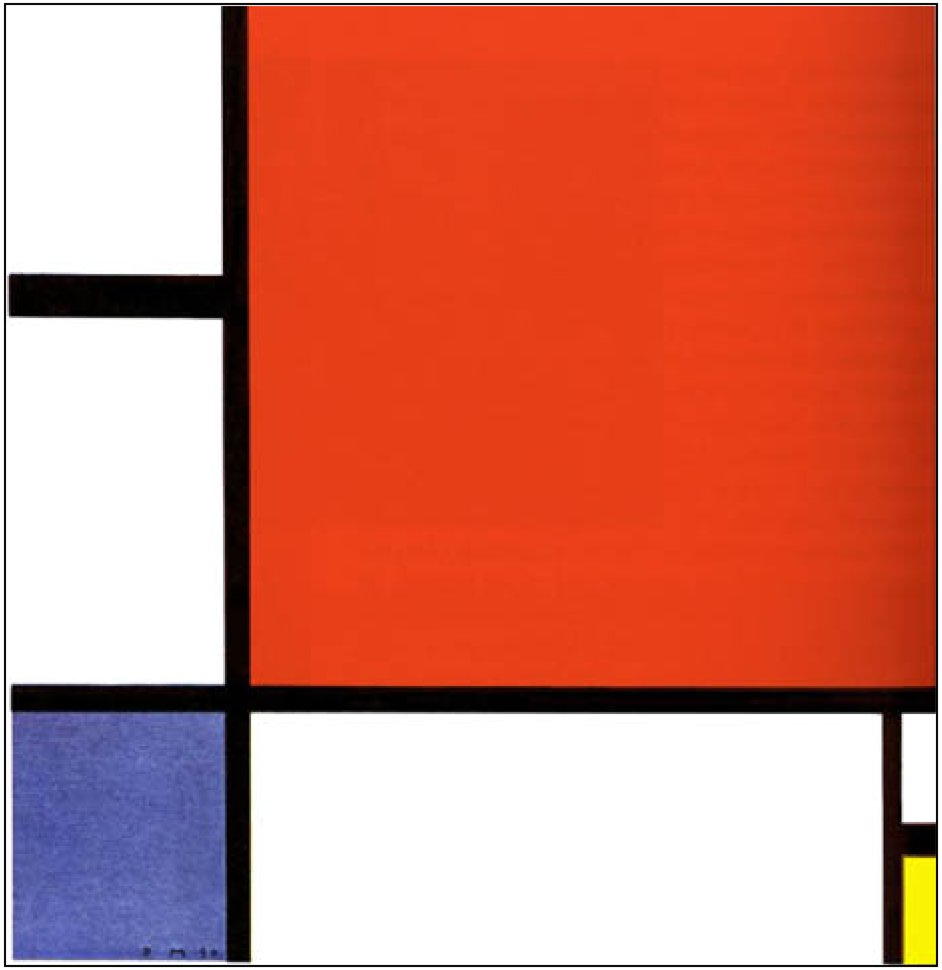
Image Manipulation and Enhancement

- Today
  - Image Compression

Definition: File Compression

- ***Compression***: the process of encoding information in fewer bits
  - Wasting space is bad, so compression is good
  - Image Compression
    - Redundant information in images
      - Identical colors
      - Smooth variation in light intensity
      - Repeating texture

Identical Colors

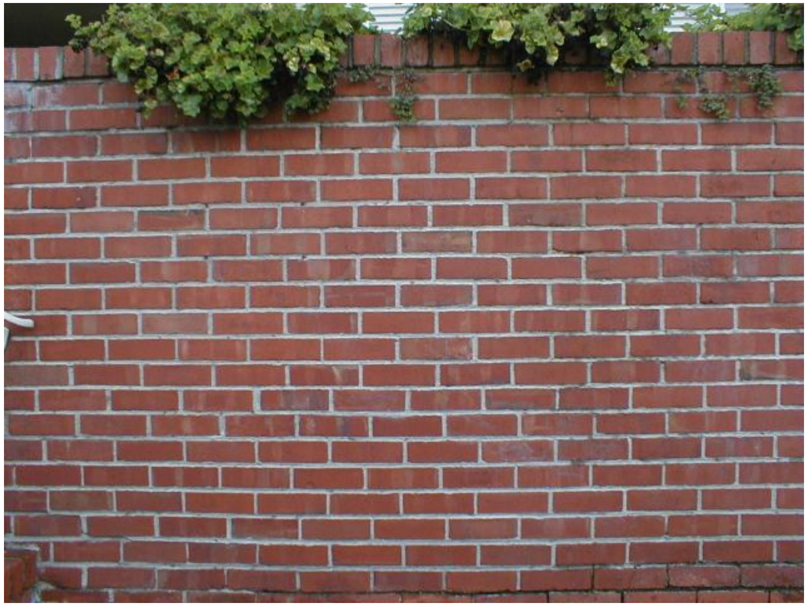


Mondrian's Composition 1930

Smooth Variation in Light Intensity

Digital rendering using Autodesk VIZ.
(Image Credit: Alejandro Vazquez.)

Repeating Texture



Alvar Aalto Summer House 1953

What is Compression Really?

- Works because of data redundancy
  - Temporal
    - In 1D data, 1D signals, Audio…
  - Spatial
    - correlation between neighboring pixels or data items
  - Spectral
    - correlation between color or luminescence components
    - uses the frequency domain to exploit relationships between frequency of change in data
  - Psycho-visual
    - exploits perceptual properties of the human (visual) system

Two General Types

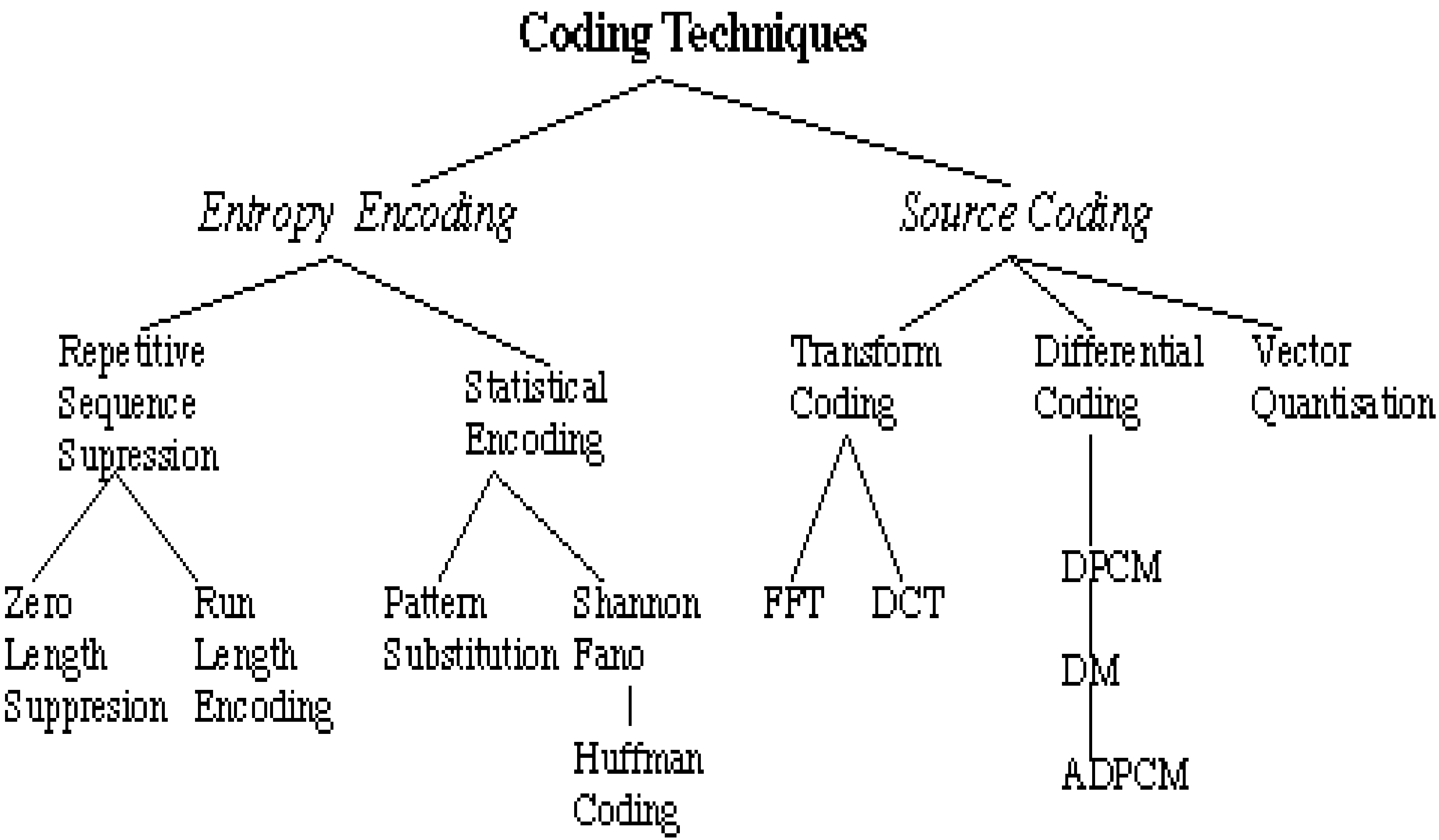
- Lossless Compression
  - data is compressed and can be uncompressed without loss of detail or information
    - bit-preserving
    - reversible
- Lossy Compression
  - purpose is to obtain the best possible fidelity for a given bit-rate
    - or minimizing the bit-rate to achieve a given fidelity measure
  - Video and audio commonly use lossy compression
    - because humans have limited perception of finer details

Two Types

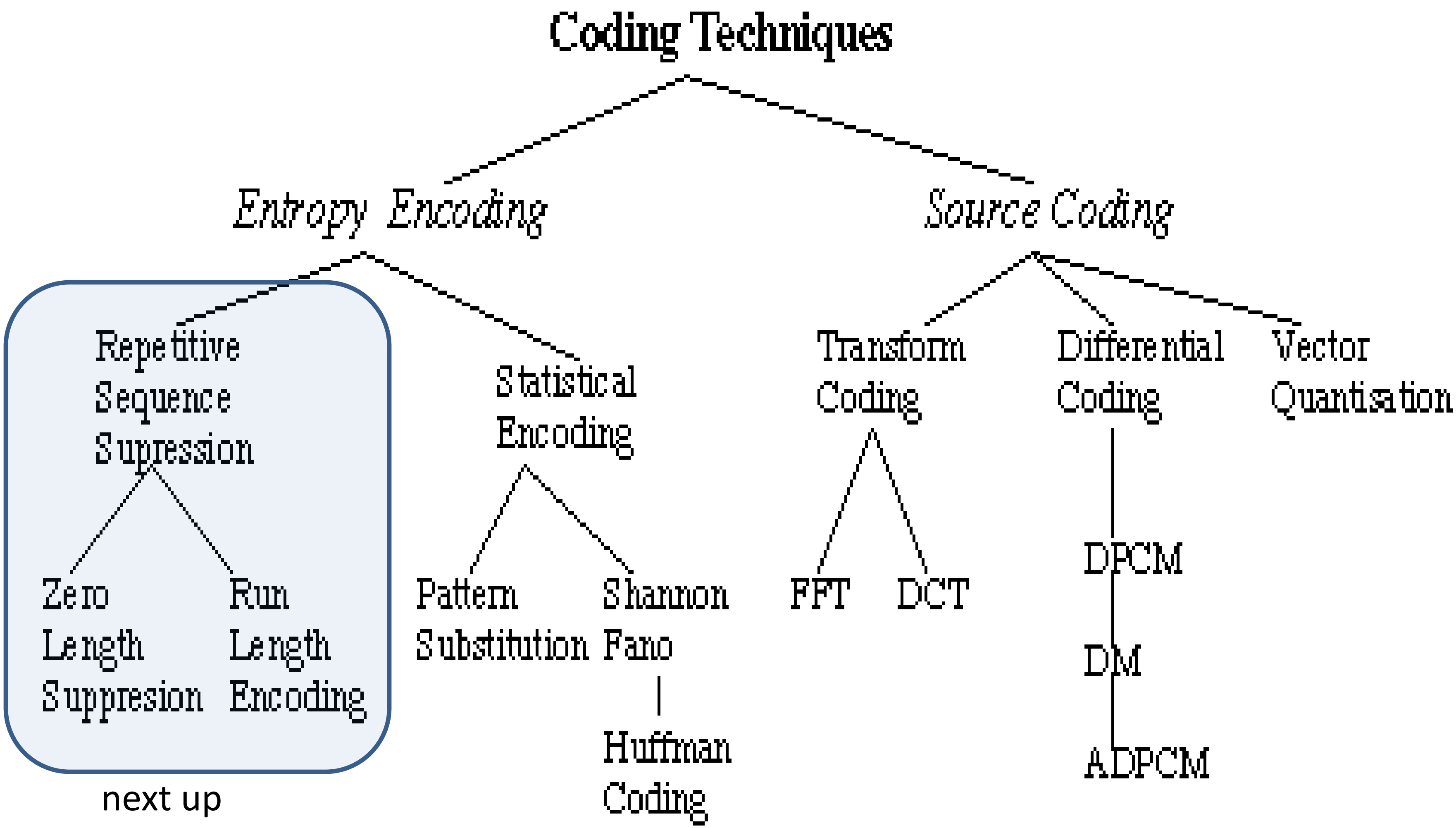
- Lossless compression often involves some form of entropy encoding
  - based in information theoretic techniques
    - see next slide for visual

- Lossy compression uses source encoding techniques that may involve transform encoding, differential encoding or vector quanatization
    - see next slide for visual

Compression Methods



Compression Methods



Simple Lossless Compression

- Simple Repetition Suppression
  - If a sequence contains a series of N successive tokens
  - Then they can be replaced with a single token and a count of the number of times the token repeats
    - This does require a flag to denote when the repeated token appears
  - Example
    - 1234444444444
    - can be denoted
    - 123f9
    - where f is the flag for four

Run-length Encoding (RLE)

- RLE is often applied to images
  - It is a small component used in JPEG compression

- Conceptually
  - sequences of image elements $X_1, X_2, \ldots, X_n$ are mapped to pairs $(c_1, L_1), (c_2, L_2), \ldots, (c_n, L_n)$
    - where c_i represent the image intensity or color
    - and L_i the length of the i^{th} run of pixels

Run-Length Encoding (RLE): lossless

- Scanline: 2 2 2 2 2 2 2 3 4 1 1 1

12 values

- Run-length encoding

(7 2) (1 3) (1 4) (3 1)

8 values

Run-Length Encoding (RLE): lossless

- Scanline: 2 2 2 2 2 2 2 3 4 1 1 1

12 values

run of
repeating values

- Run-length encoding

  (7 2) (1 3) (1 4) (3 1)

8 values

repeat count

pixel value

25% reduction of memory use

RLE: worst case

- Scanline: 1 2 3 4 5 6 7 8

8 values

- Run-length encoding:

(1 1)(1 2)(1 3)(1 4)(1 5)(1 6)(1 7)

16 values

doubles space

RLE: Improving

- Scanline: 5 5 5 5 5 5 5 3 4 1 1 1

- Run-length encoding

need to flag this as meaning "not repeating"

(7 5) (2 3 4)(3 1)

(7 2) → 5 5 5 5 5 5 5

(2 3 4) → 3 4

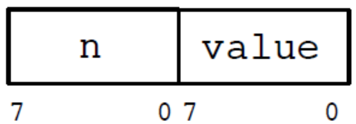
(3 1) → 1 1 1

the flag indicates that 2 explicitly given values follow

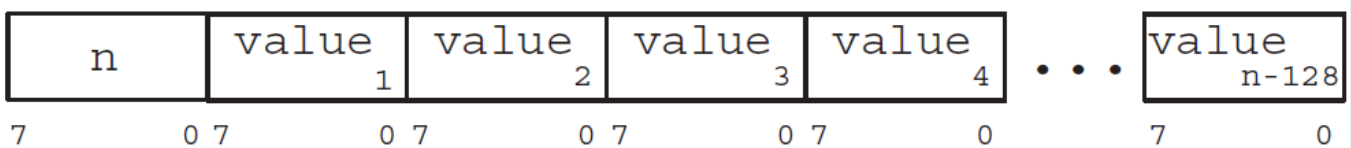
Using this improvement
The worst case then only adds 1 extra value

How to flag the repeat/no repeat?

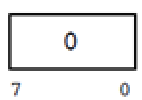
- SGI Iris RGB Run-length Encoding Scheme



$1 \leq n \leq 127$, Repeat count for run of length $= n$

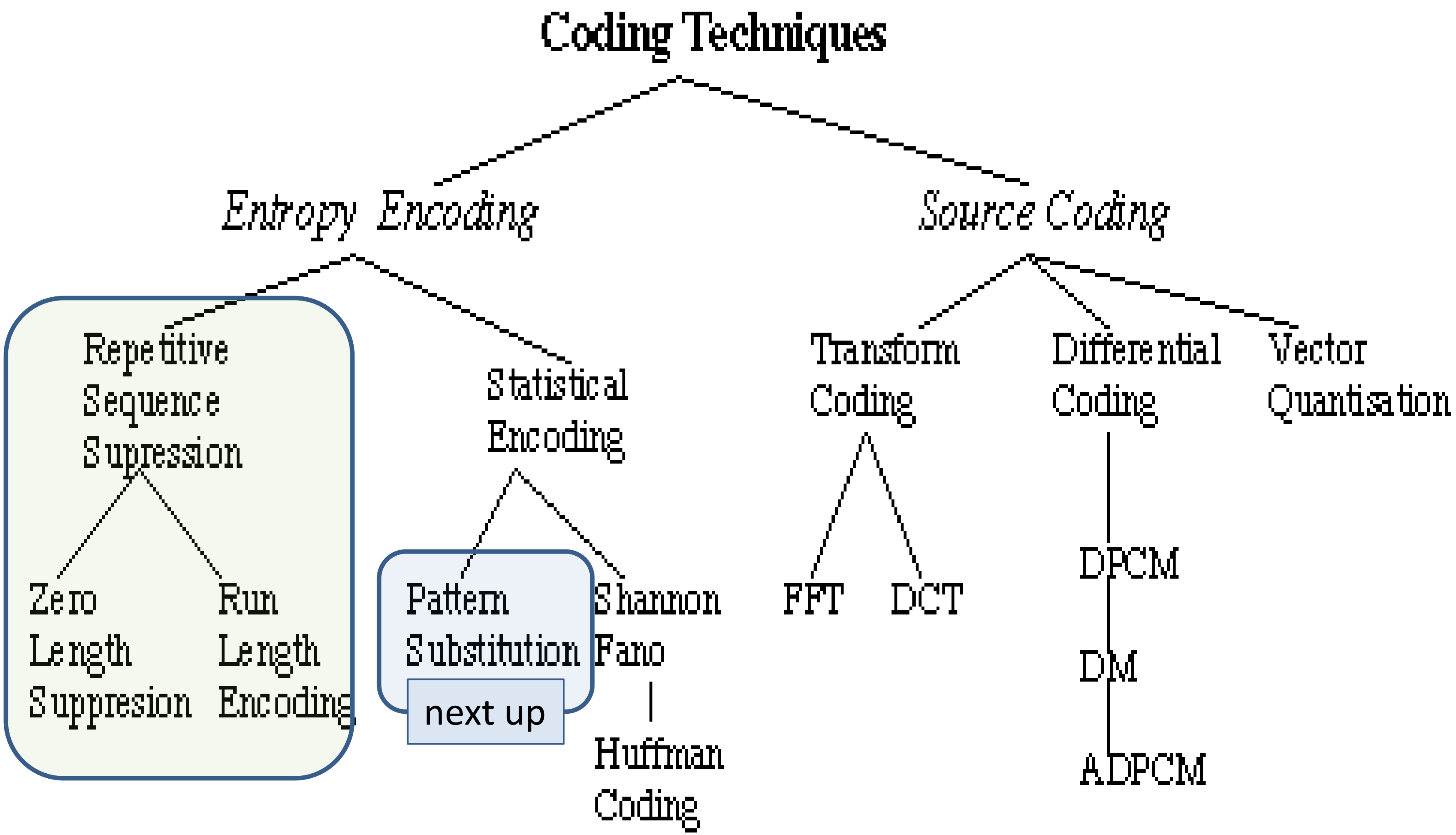


$128 \leq n \leq 255$, $n - 128$ gives number of nonrepeating values that follow



end of data

Compression Methods



Compression: Pattern Substitution

- Pattern Substitution, lossless
- Simple form of statistical encoding
- Concept
  - Substitute a frequently repeating pattern with a shorter code
    - the shorter code(s) may be predefined by the algorithm being used or dynamically created

Table Lookup

- Table Lookup can be viewed as a Pattern Substitution Method
- Example
  - Allow full range of colors (24 bit, RGB)
  - Image only uses 256 (or less) unique colors (8 bits)
  - Create a table of which colors are used
    - Use 8 bits for each color instead of 24 bits
      - Conceptually how older BMPs worked
        - » color depth <= 8 bits

Table Lookup: GIF

- Graphics Interchange File Format (GIF)
  - uses table lookups → Color LookUp Table (CLUT)

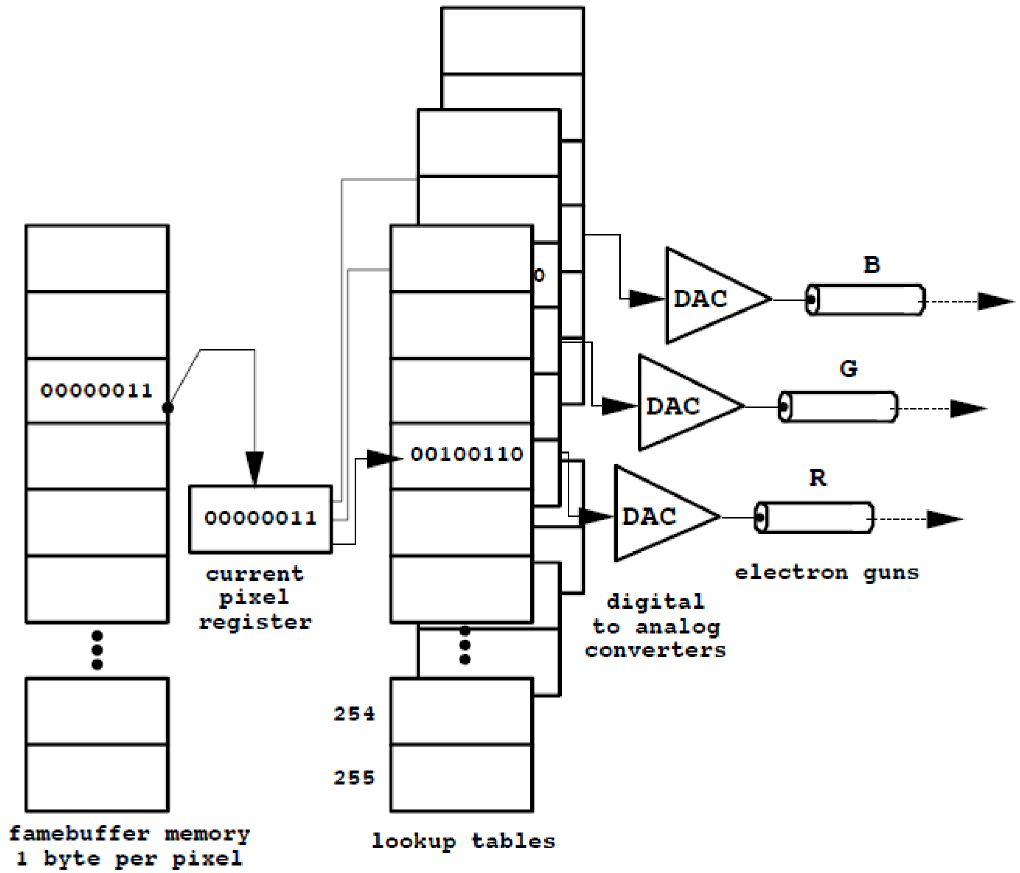


Figure 3.8: 8-Bit Color Framebuffer with 3 Lookup Tables

GIF Compression with Color LookUp Table (CLUT)

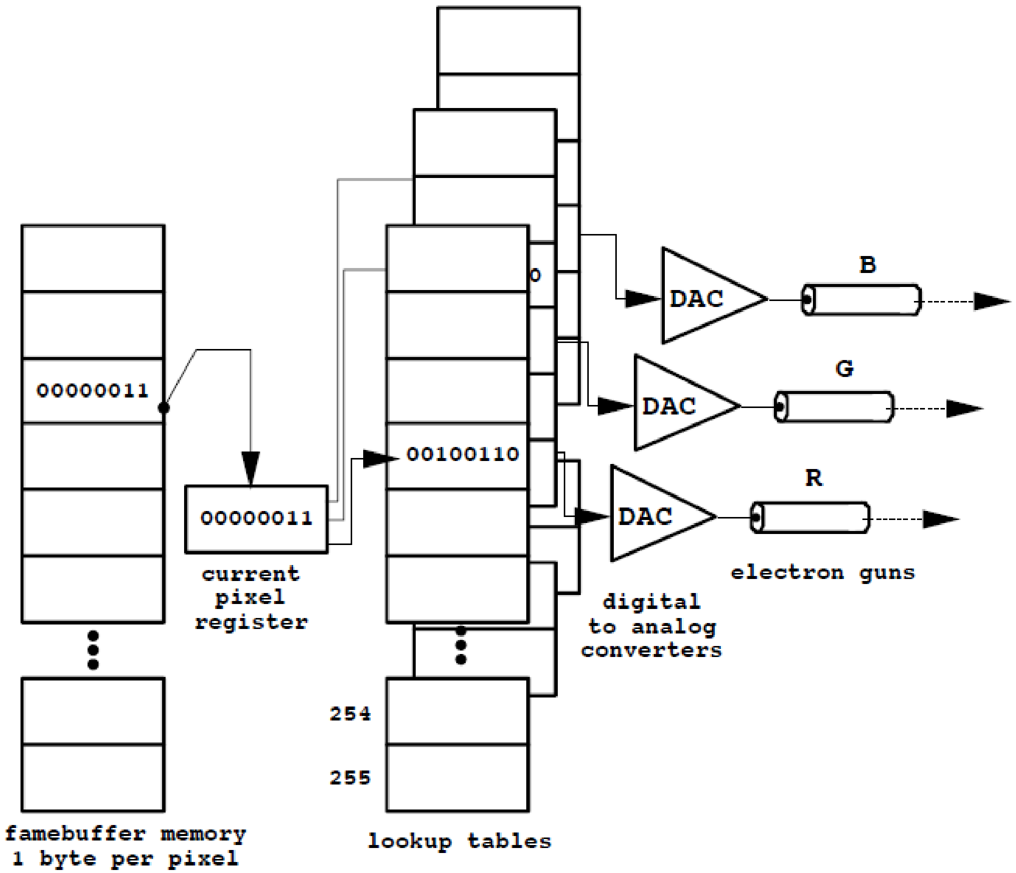


Figure 3.8: 8-Bit Color Framebuffer with 3 Lookup Tables

Example

Image Size = 1000x1000
256 colors
Each color 24 bit (RGB)

without CLUT
1000*1000*24 bits

with CLUT
1000*1000*8 bit (index data)
+ 3*256*8bit (table data)

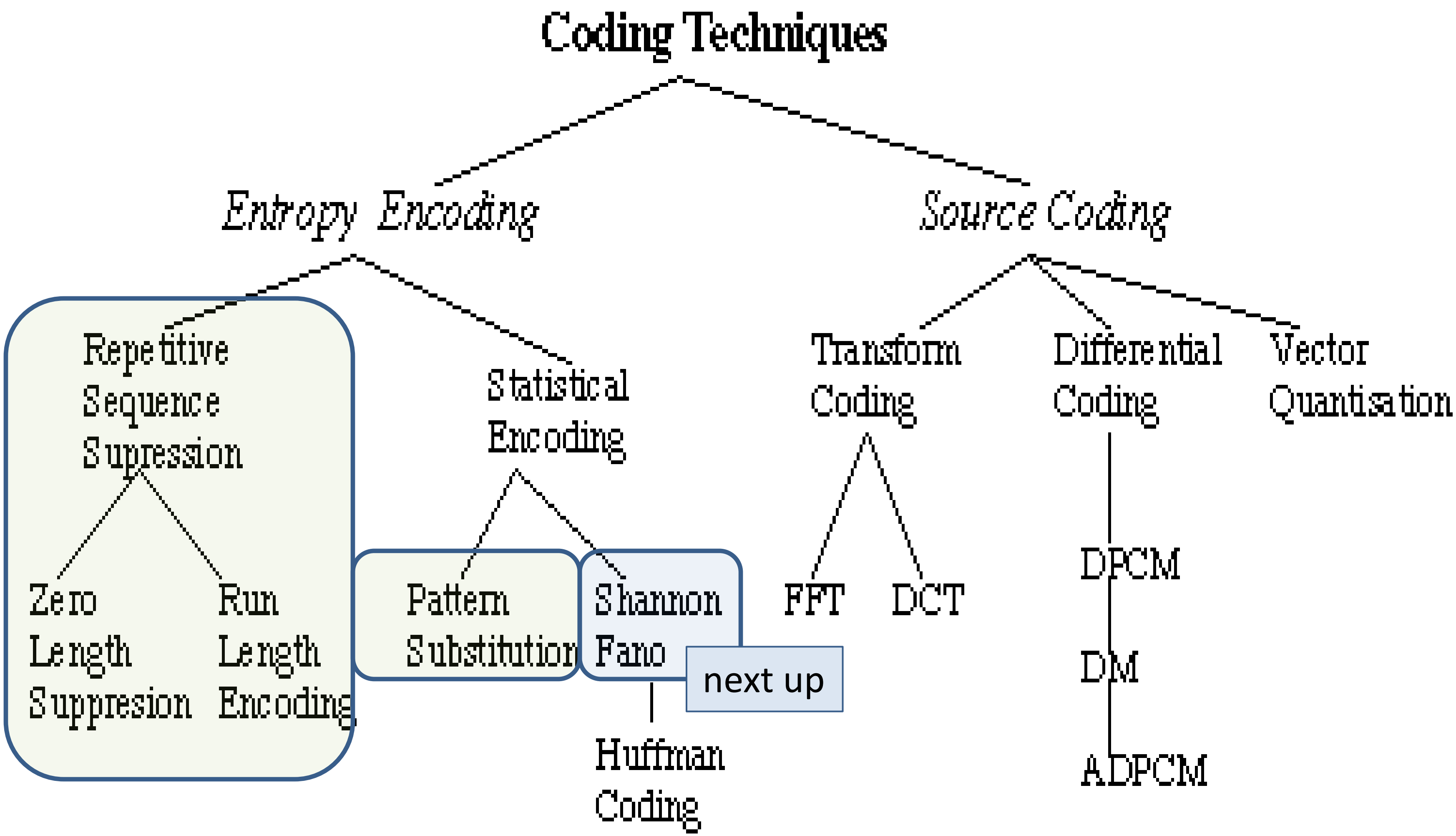
Use about 2/3 the space
(when image size is "big")

Compression: Pattern Substitution

- Table lookups work

- But Pattern Substitution typically is more dynamic
  - Counts occurrence of tokens
  - Sorts (say descending order)
  - Assign highest counts shortest codes

Compression Methods



Lossless Compression: Entropy Encoding

- Lossless compression often involves some form of entropy encoding and are based in information theoretic techniques
  - *Aside:*
    - *Claude Shannon is considered the father of information theory*

Shannon-Fano Algorithm

- Technique proposed in Shannon’s 1948 article. introducing the field of Information Theory:
  - A Mathematical Theory of Communication
    - Shannon, C.E. (July 1948). "A Mathematical Theory of Communication". Bell System Technical Journal 27: 379–423.

- Method Attributed to Robert Fano, as published in a technical report
  - The transmission of information
    - Fano, R.M. (1949). "The transmission of information". Technical Report No. 65 (Cambridge (Mass.), USA: Research Laboratory of Electronics at MIT).

Example: Shannon-Fano Algorithm

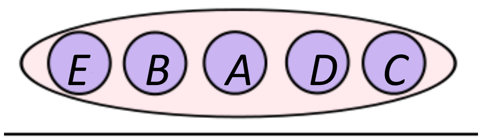
Symbol	A	B	C	D	E
Count	15	7	6	6	5

Example: Shannon-Fano Algorithm

Symbol	E	B	A	D	C
Count	15	7	6	6	5

Step 1: Sort the symbols by frequency/probability

As shown:



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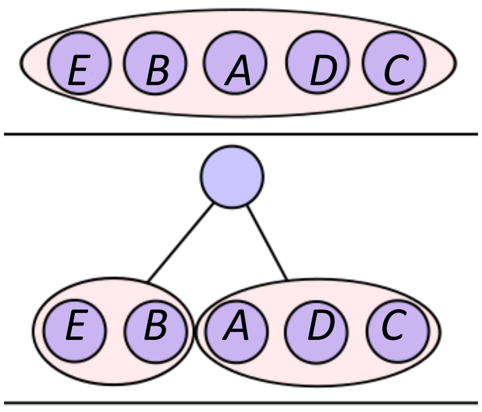

Step 2: Recursively divide into 2 parts
Each with about same number of counts

Dividing between B and A
results in 22 on the left and 17 on the right
-- minimizing difference totals between groups

This division means E and B codes start with 0
and A D and C codes start with 1

Example: Shannon-Fano Algorithm

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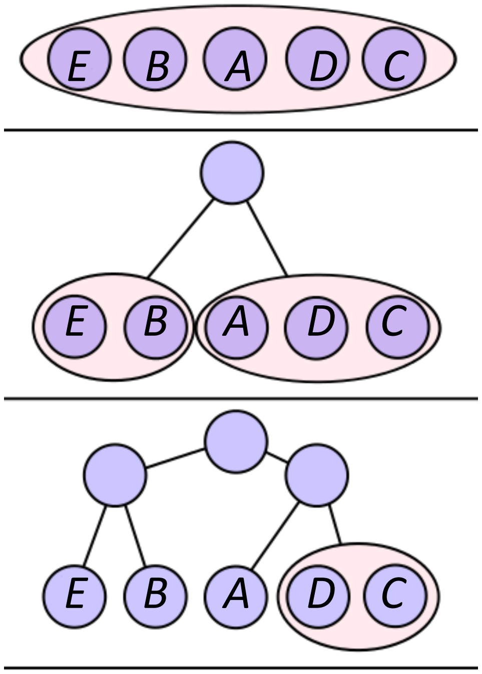

Dividing between B and A
results in 22 on the left and 17 on the right
-- minimizing difference totals between groups

This division means E and B codes start with 0
and A D and C codes start with 1

E and B are then divided (15:7)
A is divided from D and C (6:11)

So E is leaf with code 00,
B is a leaf with code 01
A is a leaf with code 10
D and C need divided again

Example: Shannon-Fano Algorithm

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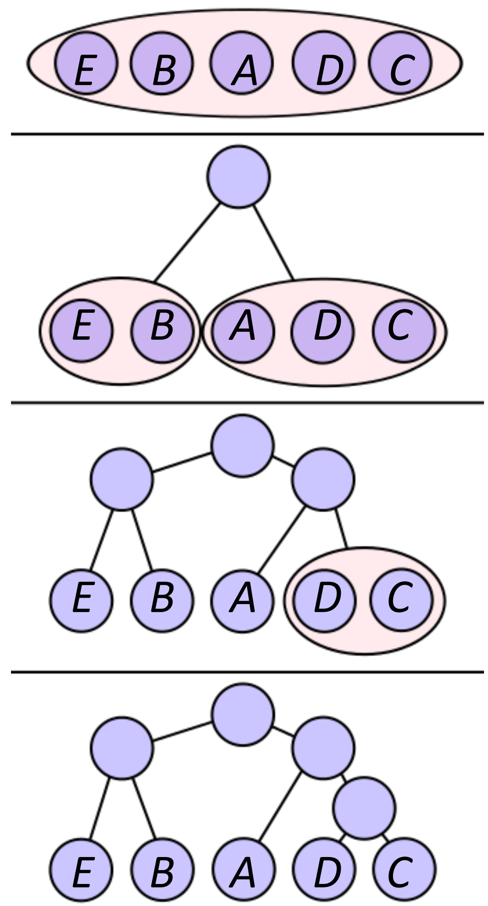


So E is leaf with code 00,
B is a leaf with code 01
A is a leaf with code 10
D and C need divided again

Divide D and C (6:5)

D becomes a leaf with code 110
C becomes a leaf with code 111

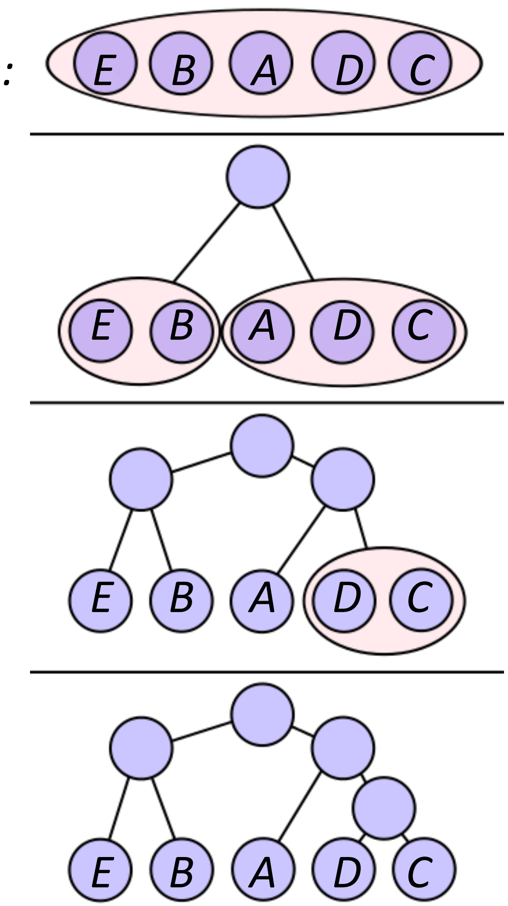
Example: Shannon-Fano Algorithm

Symbol	E	B	A	D	C
Count	15	7	6	6	5

Step 1: Sort the symbols by frequency/probability

Step 2: Recursively divide into 2 parts
Each with about same number of counts

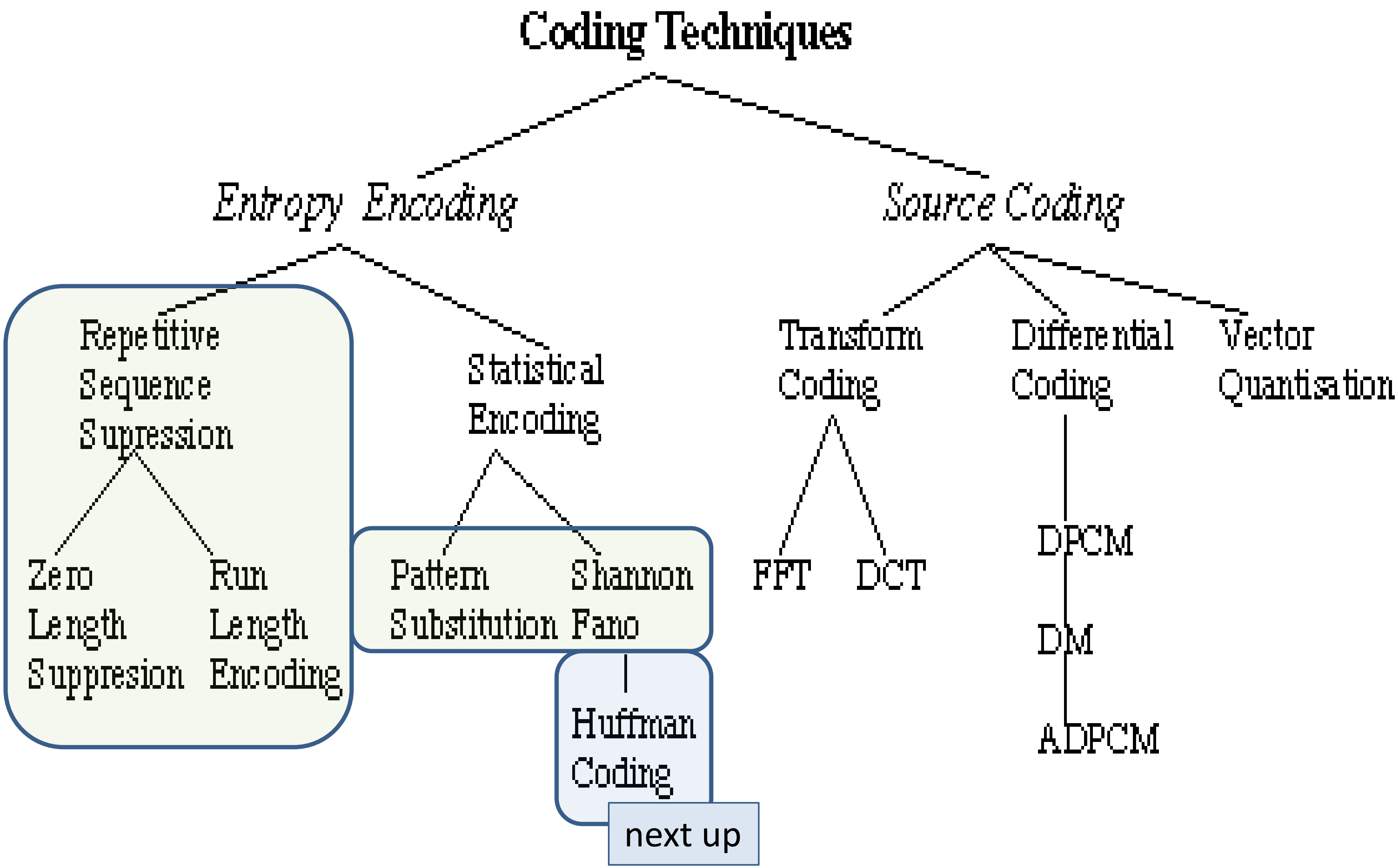
As shown:



Final Encoding:

Symbol	E	B	A	D	C
Count	00	01	10	110	111

Compression Methods



Quick Summary: Huffman Algorithm

- Encoding Summary

Step 1: Initialization
    Put all nodes in an OPEN list (keep it sorted at all times)

Step 2: While OPEN list has more than 1 node
    Step 2a: From OPEN pick 2 nodes having the lowest frequency/probability
    Create a parent node for them
    Step 2b: Assign the sum of the frequencies of the selected node
    to their newly created parent
    Step 2c: Assign code 0 to the left branch
    Assign code 1 to the right branch
    Remove the selected children from OPEN
    (note the newly created parent node remains in OPEN)

Observation

- Some characters in the English alphabet occur more frequently than others
  - The table below is based on Robert Lewand's *Cryptological Mathematics*

Letter	Relative frequency in the English language
a	8.167%
b	1.492%
c	2.782%
d	4.253%
e	12.702%
f	2.228%
g	2.015%
h	6.094%
i	6.966%
j	0.153%
k	0.772%
l	4.025%
m	2.406%

Letter	Relative frequency in the English language
n	6.749%
o	7.507%
p	1.929%
q	0.095%
r	5.987%
s	6.327%
t	9.056%
u	2.758%
v	0.978%
w	2.360%
x	0.150%
y	1.974%
z	0.074%

Huffman Encoding (English Letters)

- **Huffman encoding**: Uses variable lengths for different characters to take advantage of their relative frequencies
  - Some characters occur more often than others
    - If those characters use < 8 bits each, the file will be smaller
  - Other characters may need > 8 bits
    - but that's ok → they don't show up often

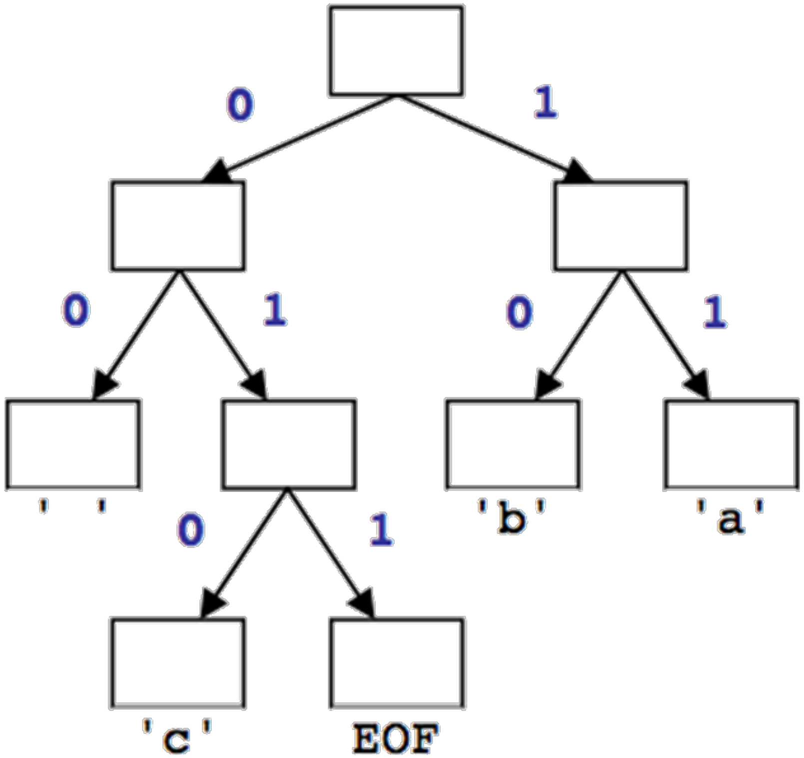
Char	ASCII value	ASCII (binary)	Hypothetical Huffman
' '	32	00100000	10
'a'	97	01100001	0001
'b'	98	01100010	01110100
'c'	99	01100011	001100
'e'	101	01100101	1100
'z'	122	01111010	00100011110

Huffman's Algorithm

- **The idea**: Create a "Huffman Tree" that will tell us a good binary representation for each character
  - Left means 0
  - Right means 1
    - Example 'b' is 10

- More frequent characters will be higher in the tree (have a shorter binary value).

- To build this tree, we must do **a few steps first**
  - Count occurrences of each unique character in the file to compress
  - Use a priority queue to order them from least to most frequent
  - Make a tree and use it



Huffman Compression – Overview

- Step 1
  - Count characters (frequency of characters in the message)
- Step 2
  - Create a Priority Queue
- Step 3
  - Build a Huffman Tree
- Step 4
  - Traverse the Tree to find the Character to Binary Mapping
- Step 5
  - Use the mapping to encode the message

Step 1: Count Characters

- Example message (input file) contents:
  ab ab cab

  file ends with an invisible EOF character

  – counts: { ' ' = 2, 'b'=3, 'a' =3, 'c' =1, EOF=1 }

byte	1	2	3	4	5	6	7	8	9	10
char	'a'	'b'	' '	'a'	'b'	' '	'c'	'a'	'b'	EOF
ASCII	97	98	32	97	98	32	99	97	98	256
binary	01100001	01100010	00100000	01100001	01100010	00100000	01100011	01100001	01100010	N/A

  – File size currently = 10 bytes = 80 bits

Step 2: Create a Priority Queue

- Each node of the PQ is a tree
  - The root of the tree is the 'key'
  - The other internal nodes hold 'subkeys'
  - The leaves hold the character values

- Insert each into the PQ using the PQ's function
  - insertItem(count, character)

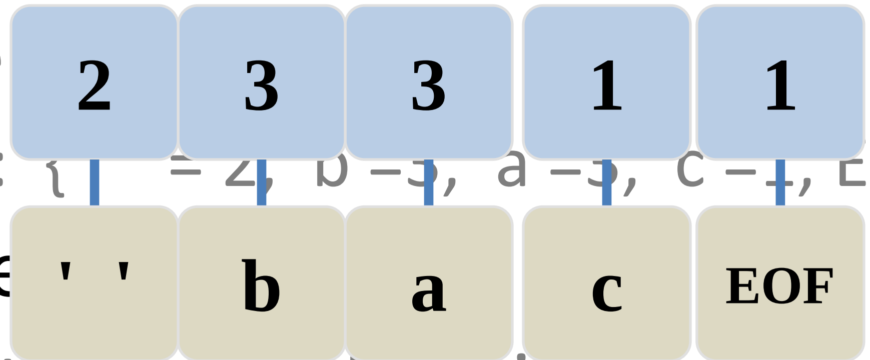
- The PQ should organize them into ascending order
  - So the smallest value is highest priority
    - *We will use an example with the PQ implemented as an ordered list*
      - *But the PQ could be implemented in whatever way works best*
        - » *could be a minheap, unordered list, or 'other'*

Step 2: PQ Creation, An Illustration

- From step 1 we have
  - counts: { ' ' = 2, 'b'=3, 'a'=3, 'c'=1, EOF=1 }
- Make these into trees
- Add the trees to a Priority Queue
  - Assume PQ is implemented as a sorted list

Step 2: PQ Creation, An Illustration

- From ste
  - counts: { = 2, b =3, a =3, c =1, EOF=1 }
- Make the



- Add the trees to a Priority Queue
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Step 2: PQ Creation, An Illustration

- From step 1 we have
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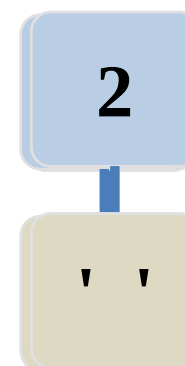
- Make these into trees
- Add the trees to a Priority Queue
  - *Assume PQ is implemented as a sorted list*

Recall: Each Insert is an *O(n)* operation
This is done *n* times. So this is $O(n^2)$



Step 3: Build the Huffman Tree

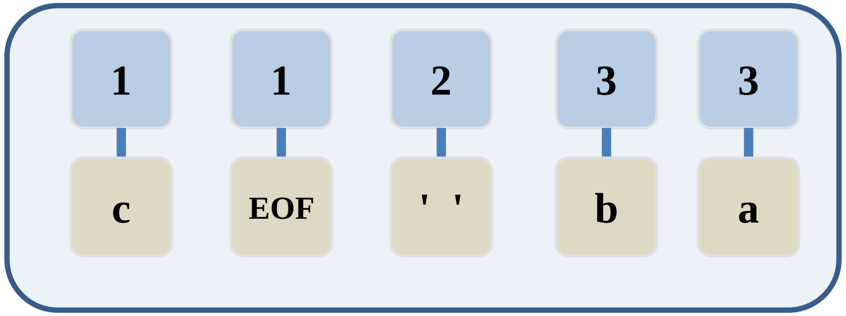
- *Aside: All nodes should be in the PQ*
- While PQ.size() > 1
  - Remove the two highest priority (rarest) nodes
    - Removal done using PQ's removeMin() function
  - Combine the two nodes into a single node
    - So the new node is a tree with
      - root has key value = sum of keys of nodes being combined
      - left subtree is the first removed node
      - right subtree is the second removed node
  - Insert the combined node back into the PQ
- end While

- Remove the one node from the PQ
  - This is the Huffman Tree

Example next slide

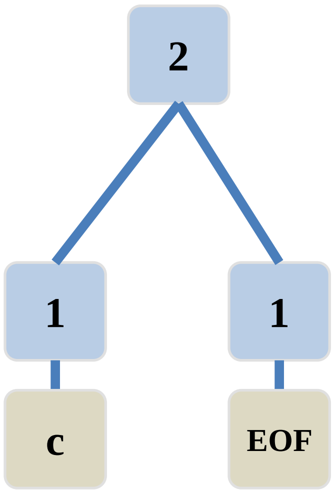
Step 3a: Building Huffman Tree, Illus.

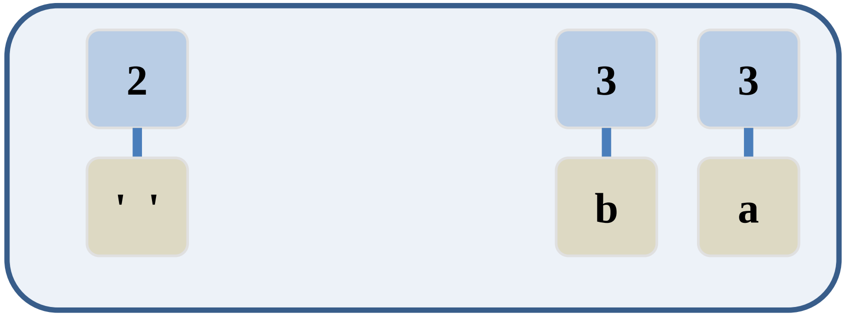
- Remove the two highest priority (rarest) nodes



Step 3b: Building Huffman Tree, Illus.

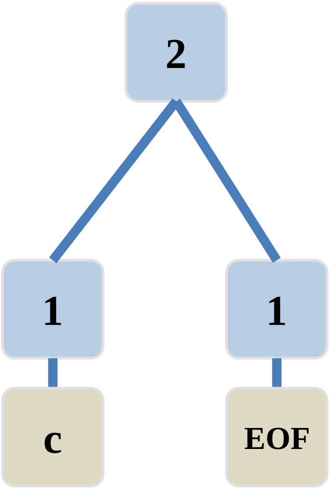
- Combine the two nodes into a single node

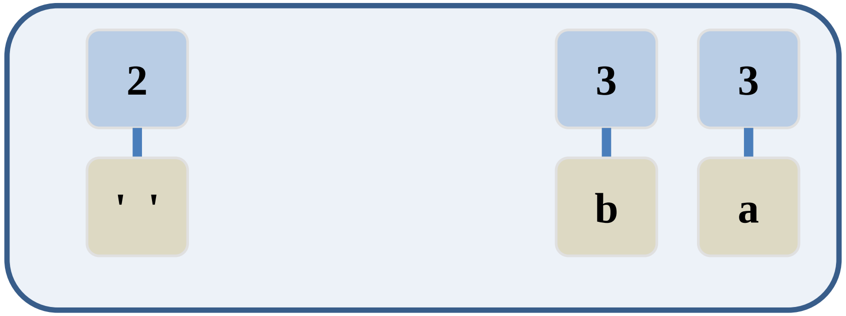




Step 3c: Building Huffman Tree, Illus.

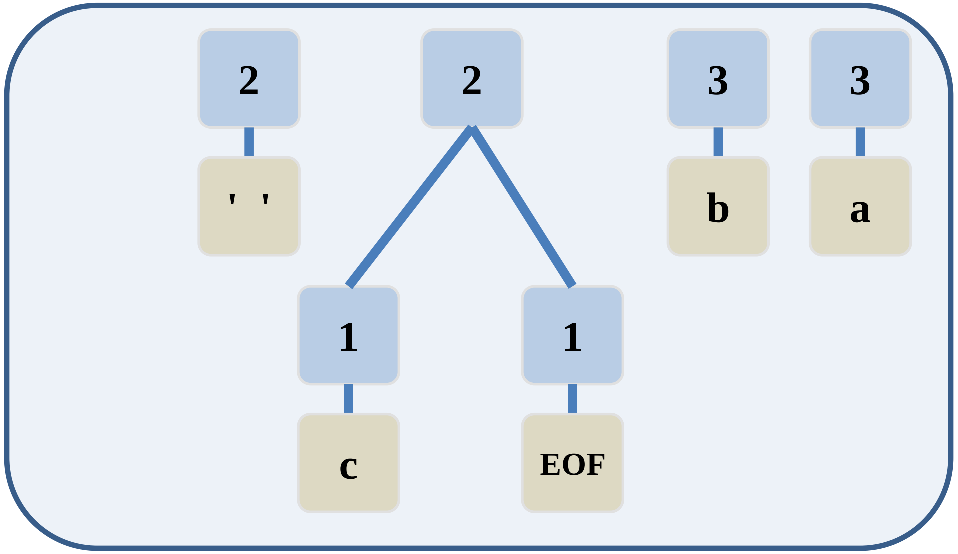
- Insert the combined node back into the PQ





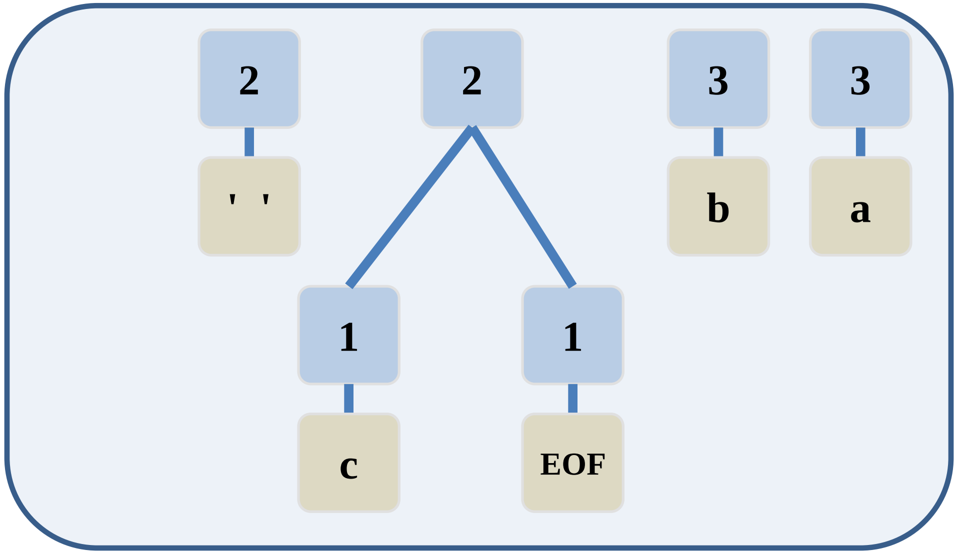
Step 3d: Building Huffman Tree, Illus.

- PQ has 4 nodes still, so repeat



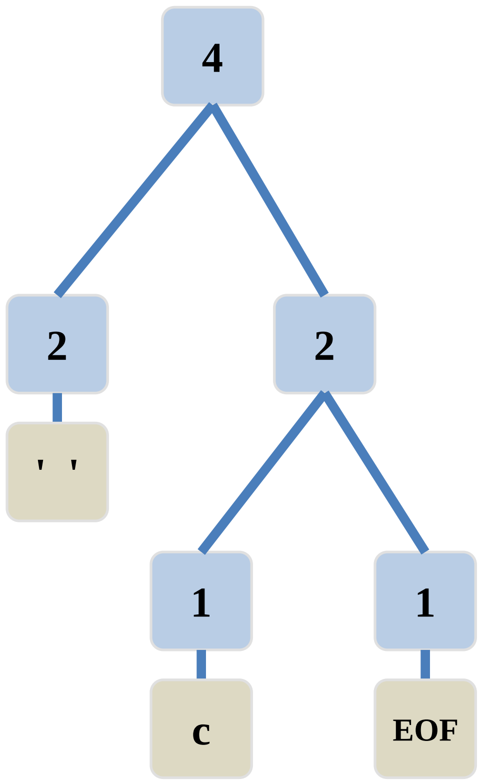
Step 3a: Building Huffman Tree, Illus.

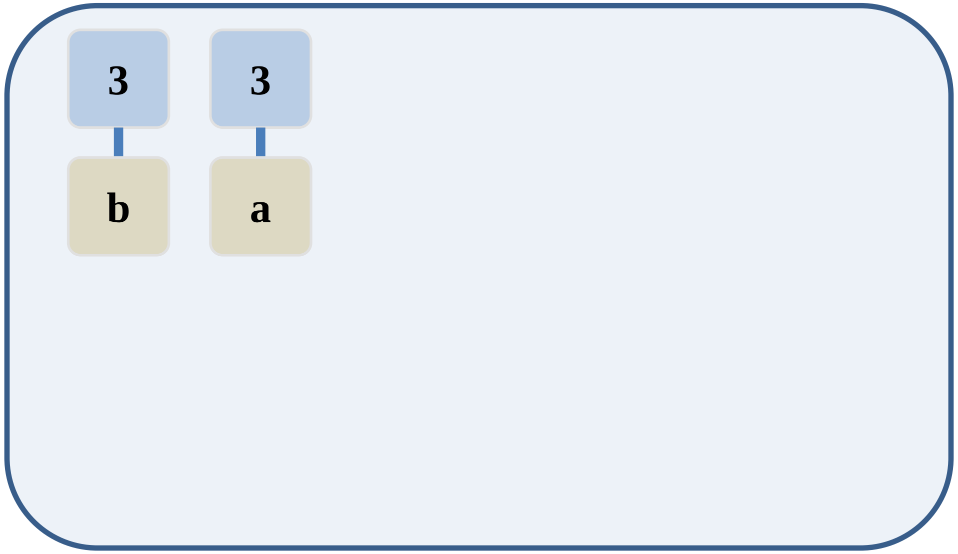
- Remove the two highest priority (rarest) nodes



Step 3b: Building Huffman Tree, Illus.

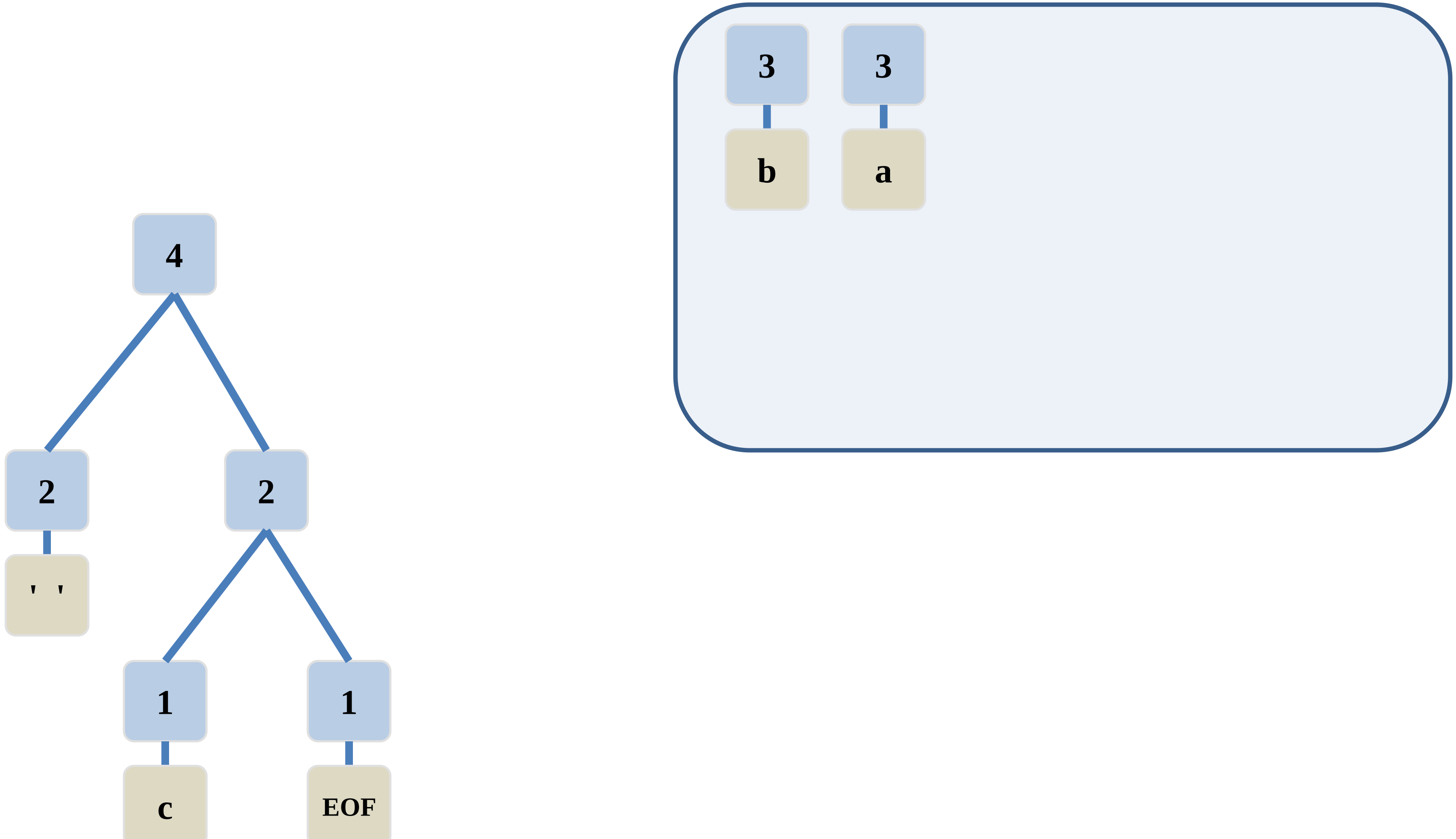
- Combine the two nodes into a single node





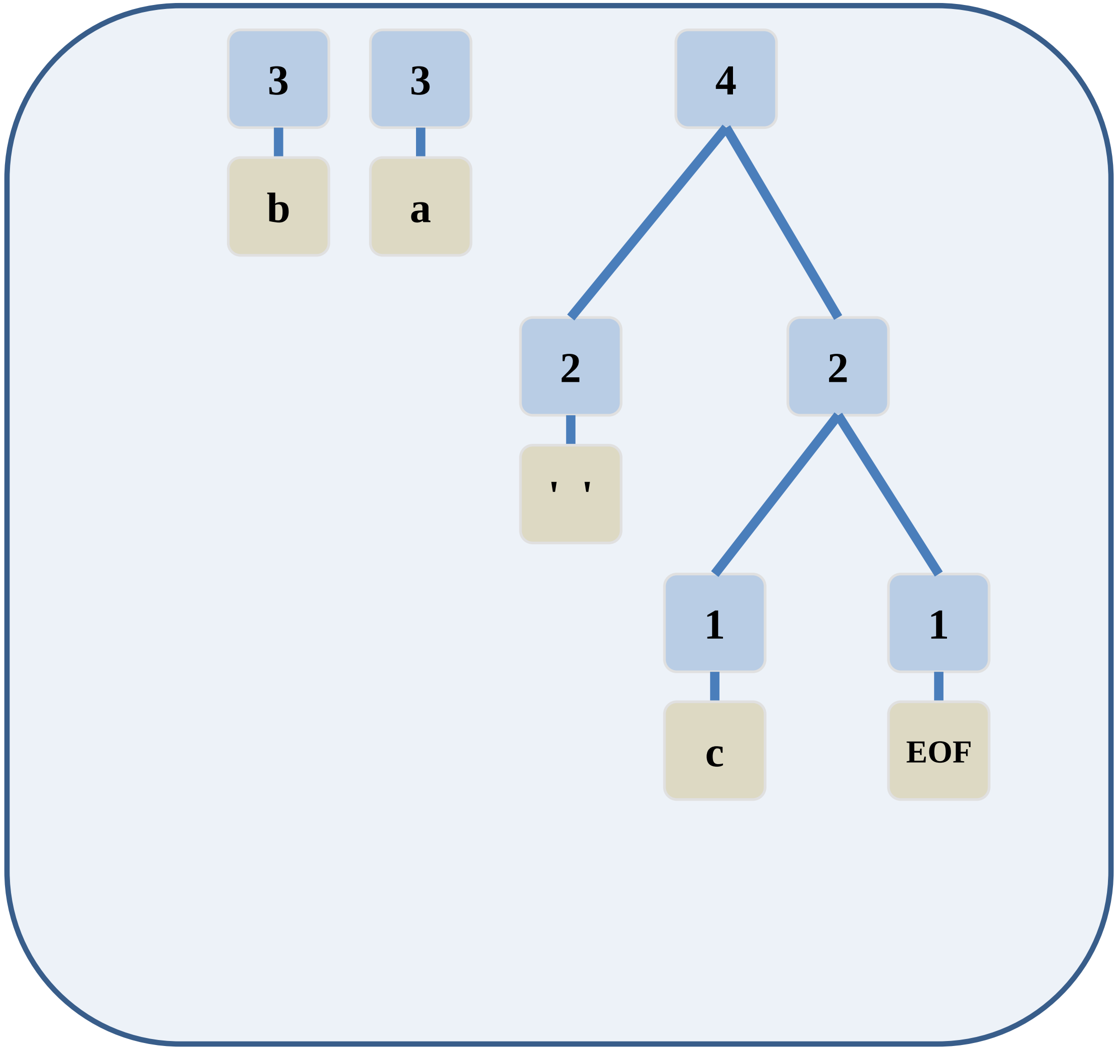
Step 3c: Building Huffman Tree, Illus.

- Insert the combined node back into the PQ



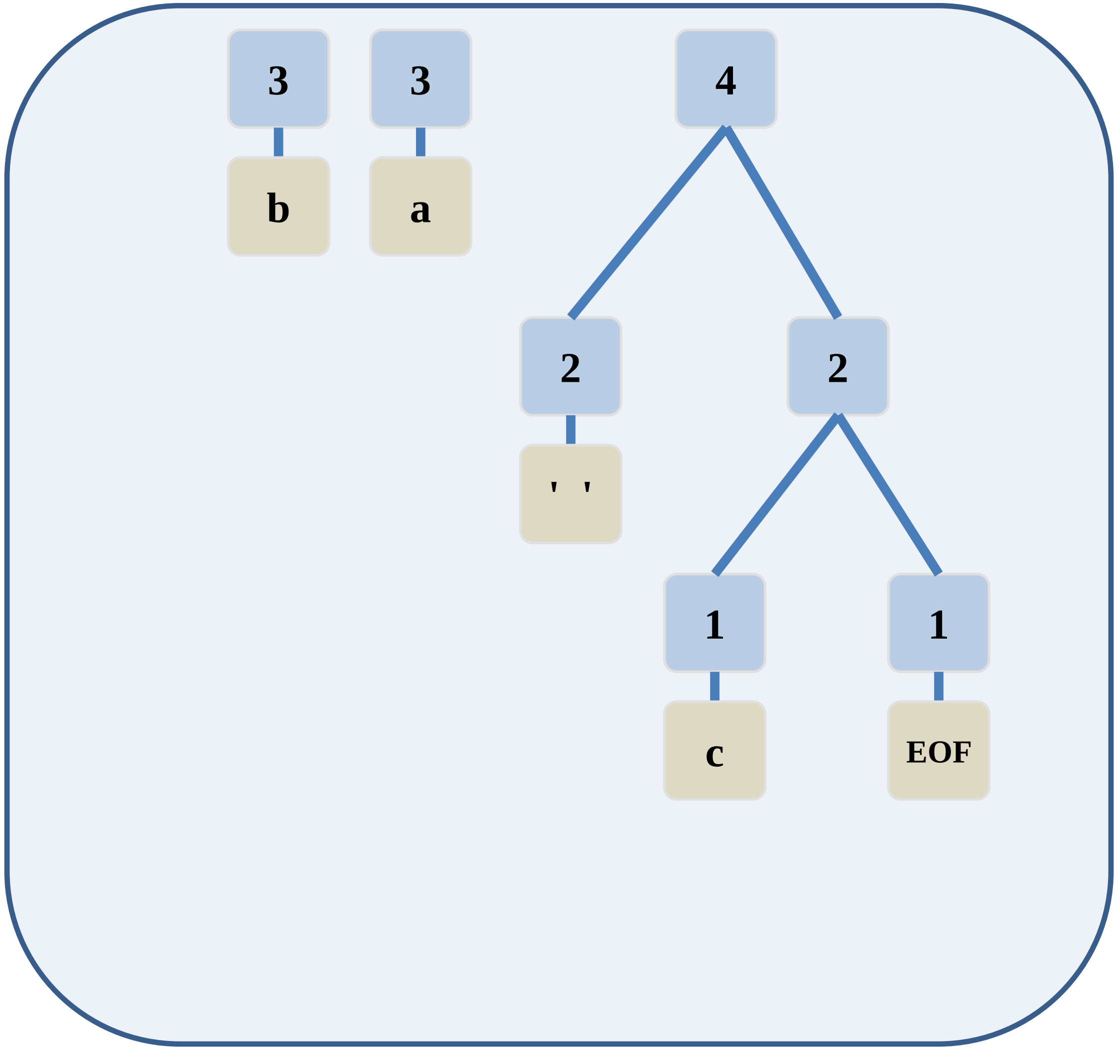
Step 3d: Building Huffman Tree, Illus.

- 3 nodes remain in PQ, repeat again



Step 3a: Building Huffman Tree, Illus.

- Remove the two highest priority (rarest) nodes



Step 3b: Building Huffman Tree, Illus.

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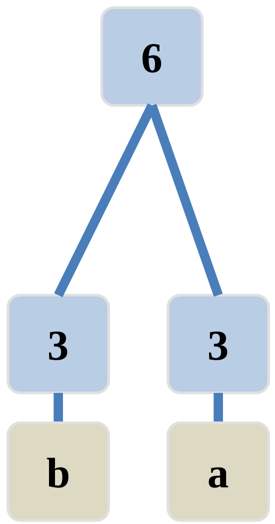
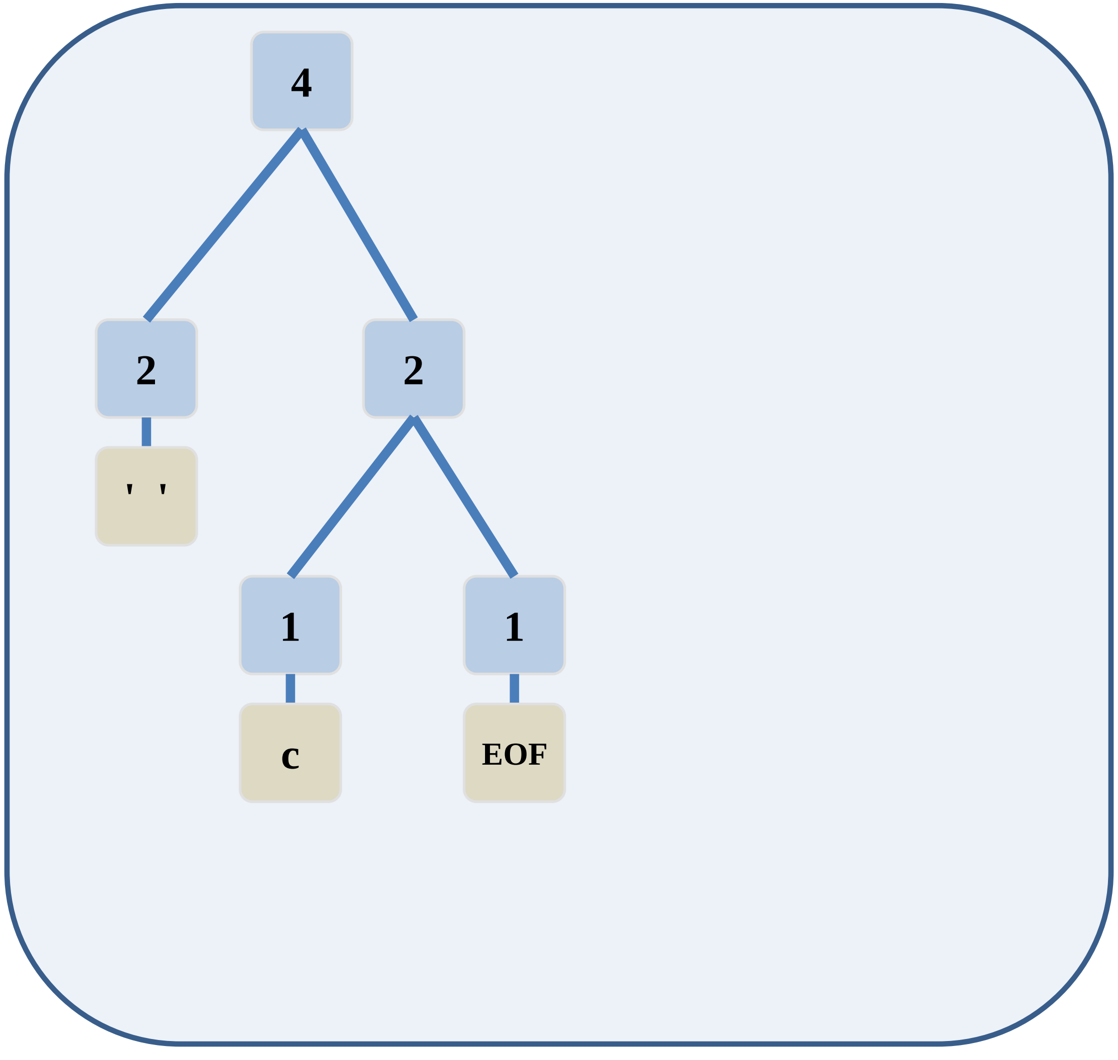
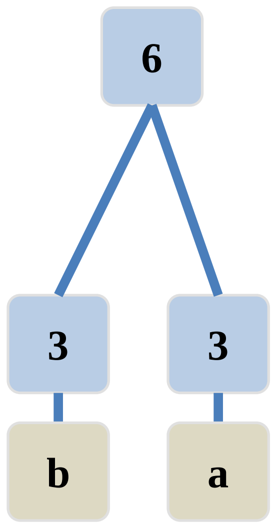
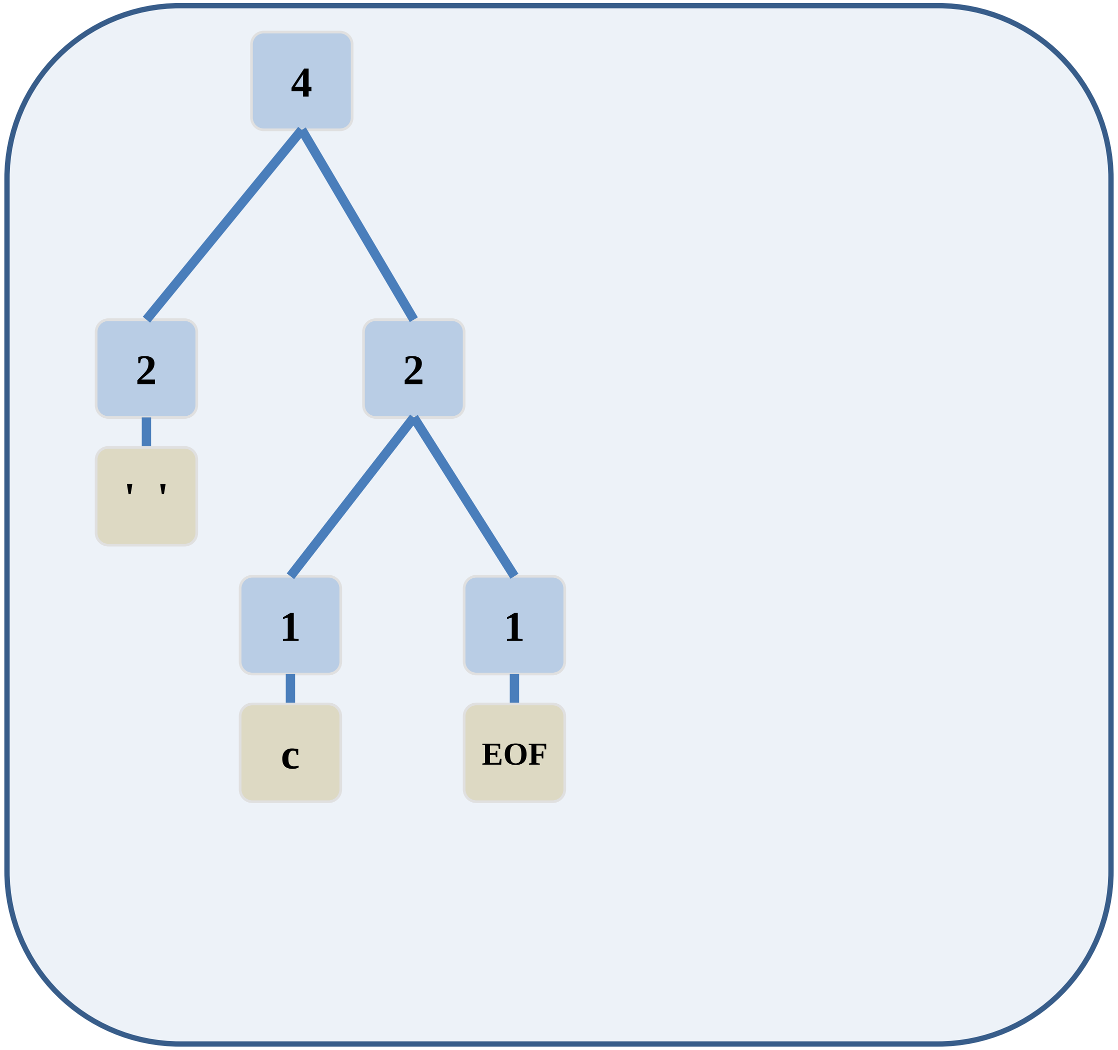




Step 3c: Building Huffman Tree, Illus.

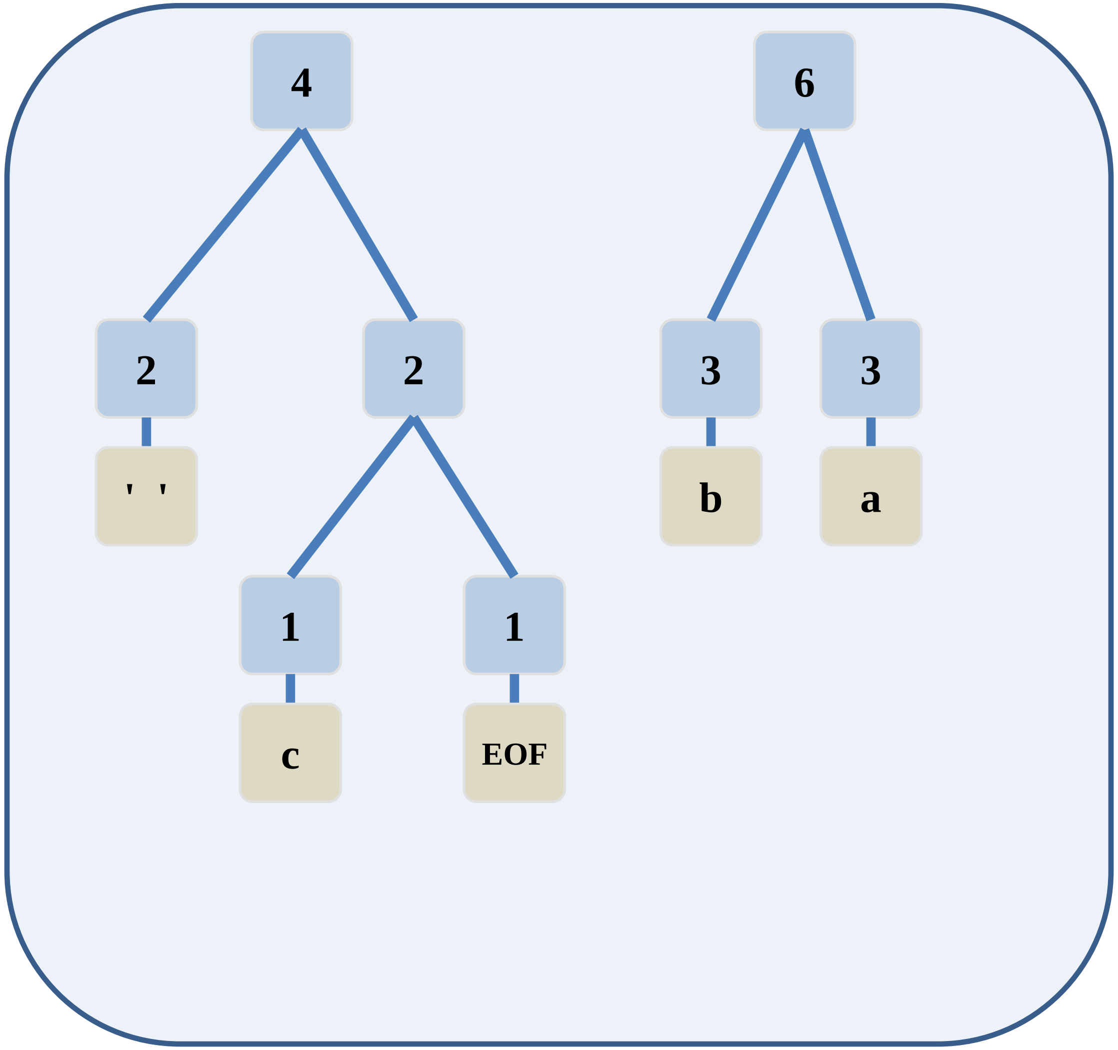
- Insert the combined node back into the PQ





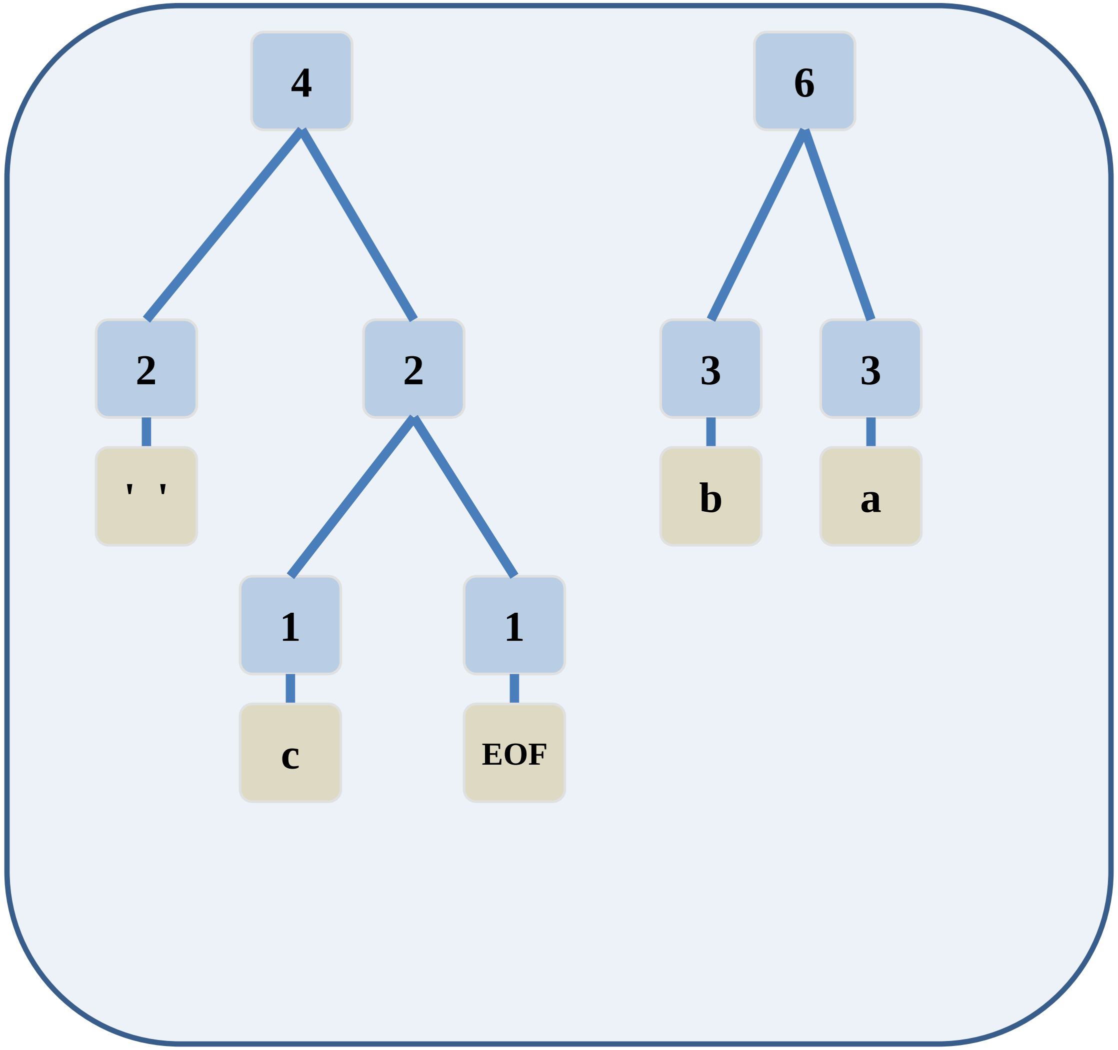
Step 3d: Building Huffman Tree, Illus.

- 2 nodes still in PQ, repeat one more time



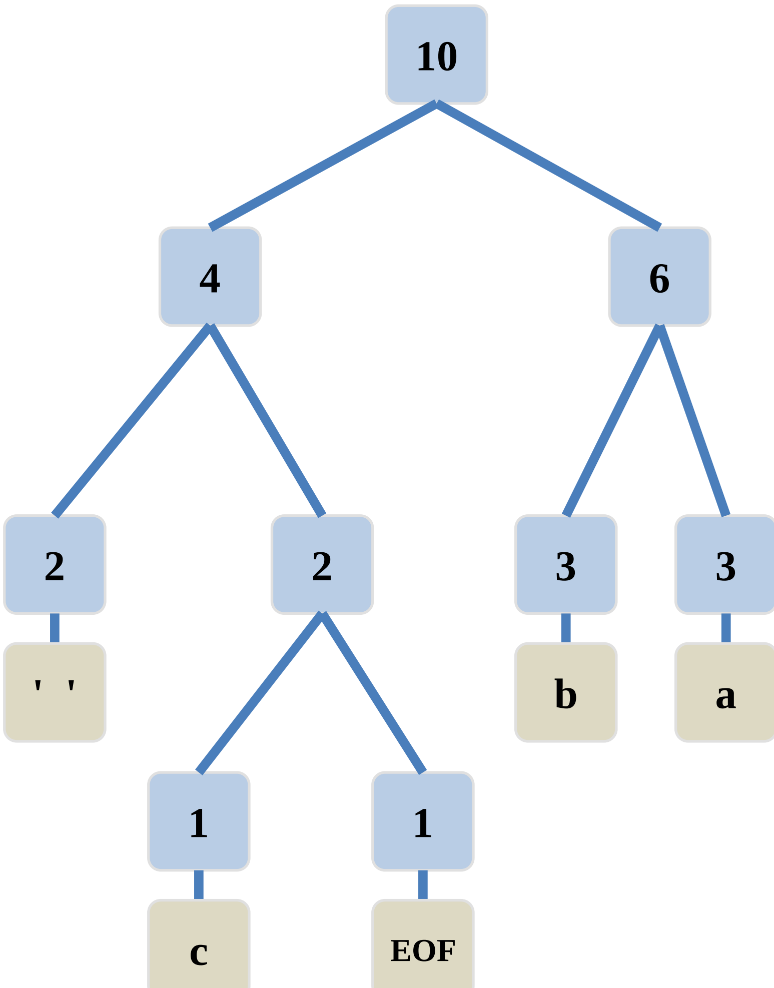
Step 3a: Building Huffman Tree, Illus.

- Remove the two highest priority (rarest) nodes



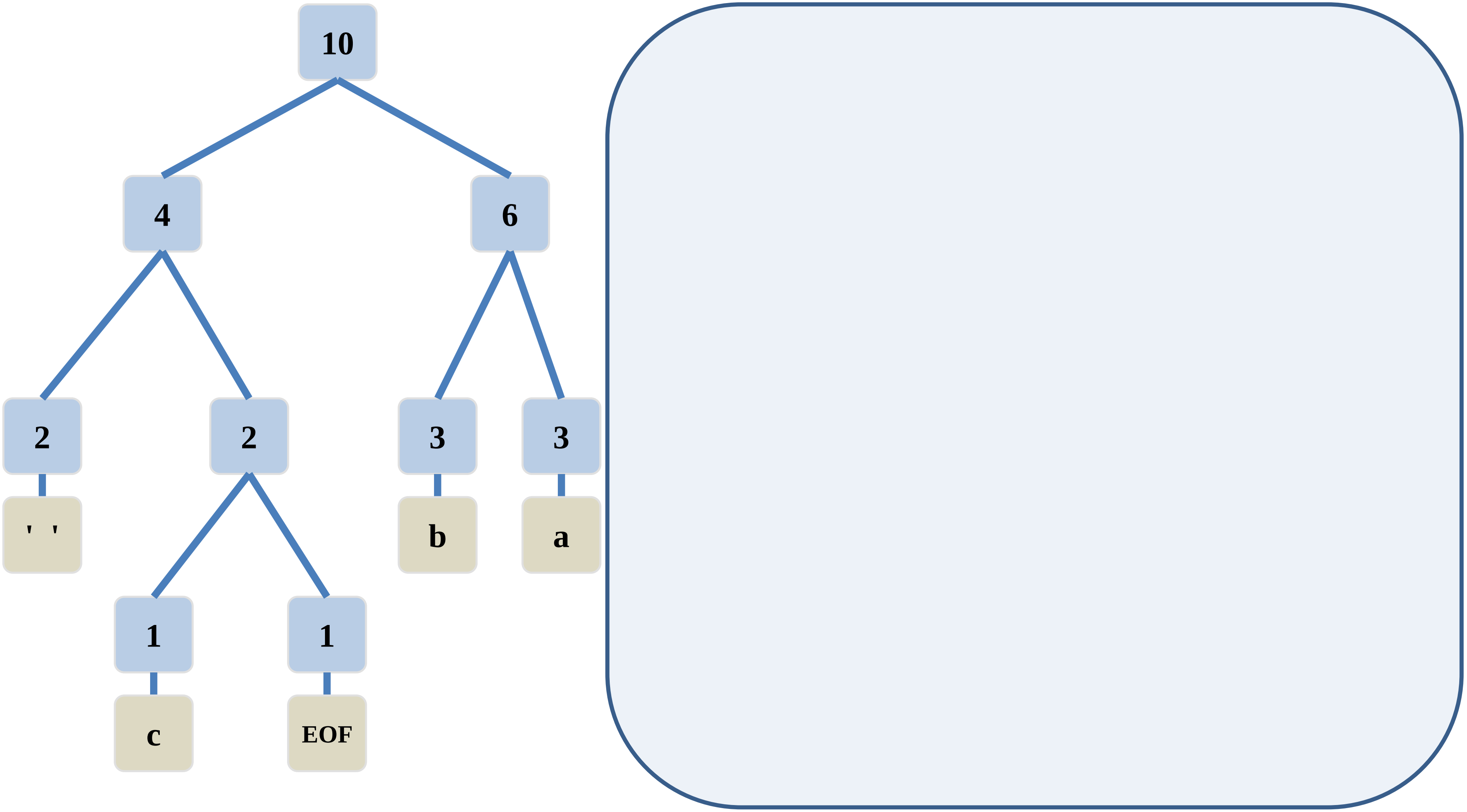
Step 3b: Building Huffman Tree, Illus.

- Combine the two nodes into a single node



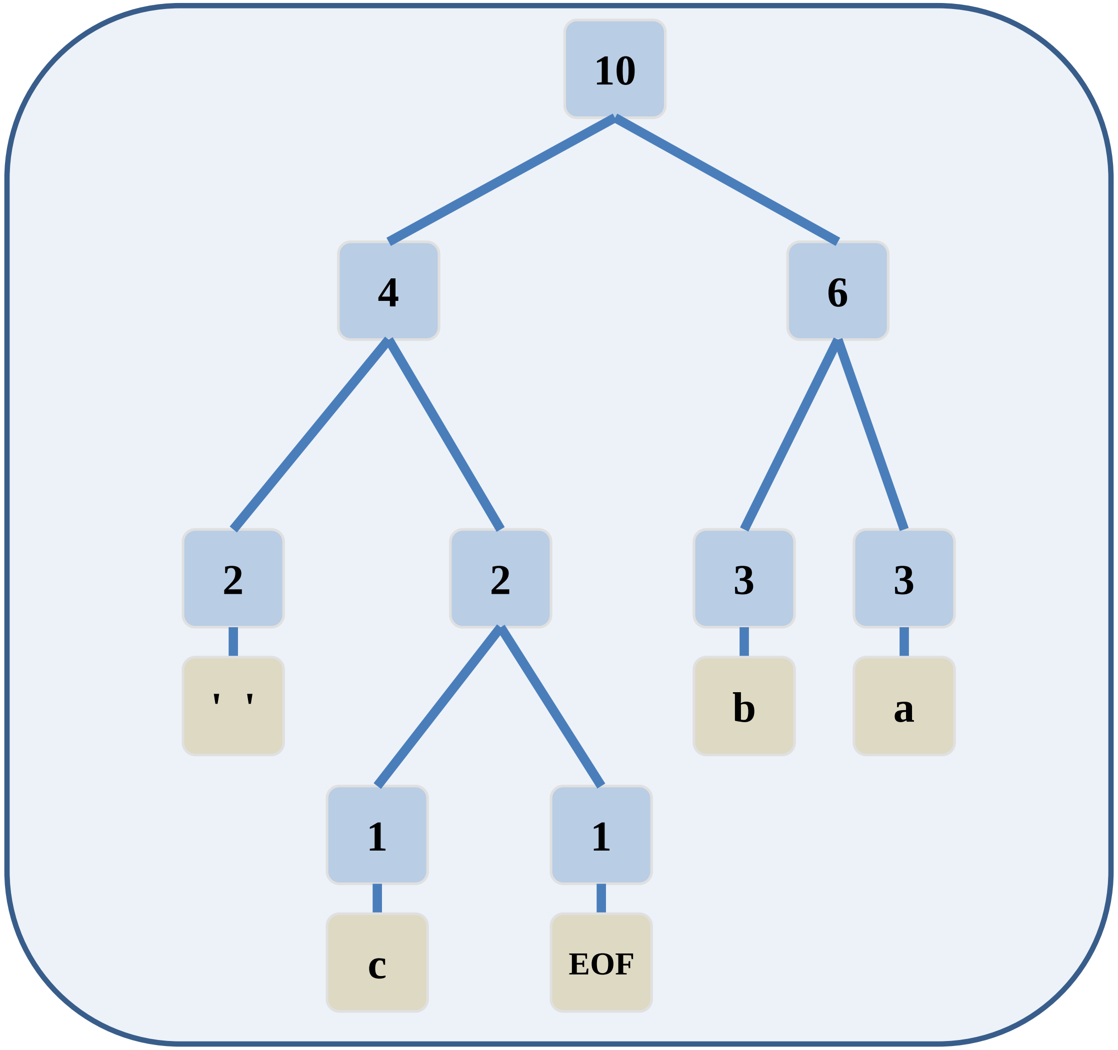
Step 3c: Building Huffman Tree, Illus.

- Insert the combined node back into the PQ



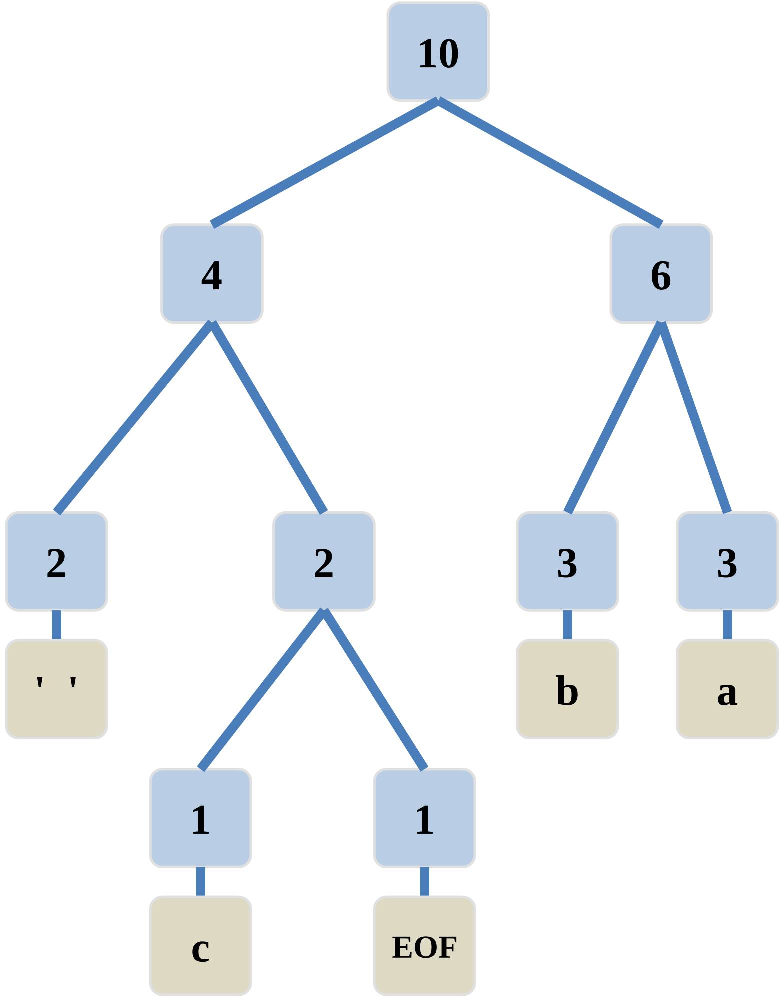
Step 3d: Building Huffman Tree, Illus.

- Only 1 node remains in the PQ, so while loop ends



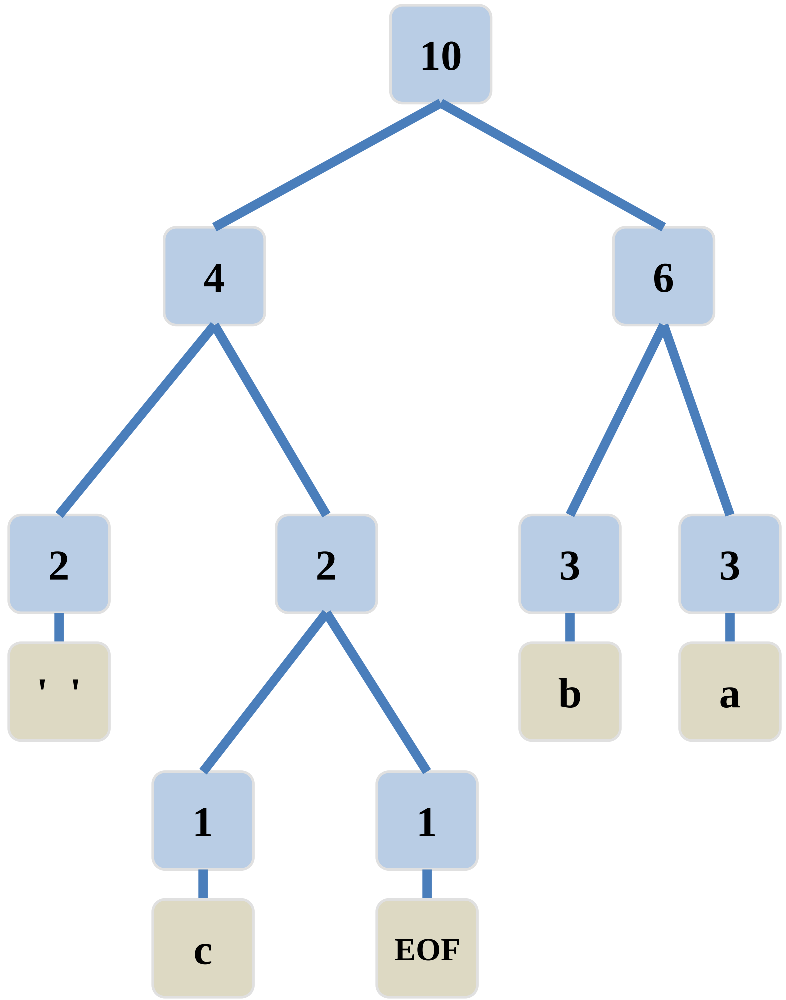
Step 3: Building Huffman Tree, Illus.

- Huffman tree is complete



Step 4: Traverse Tree to Find the Character to Binary Mapping

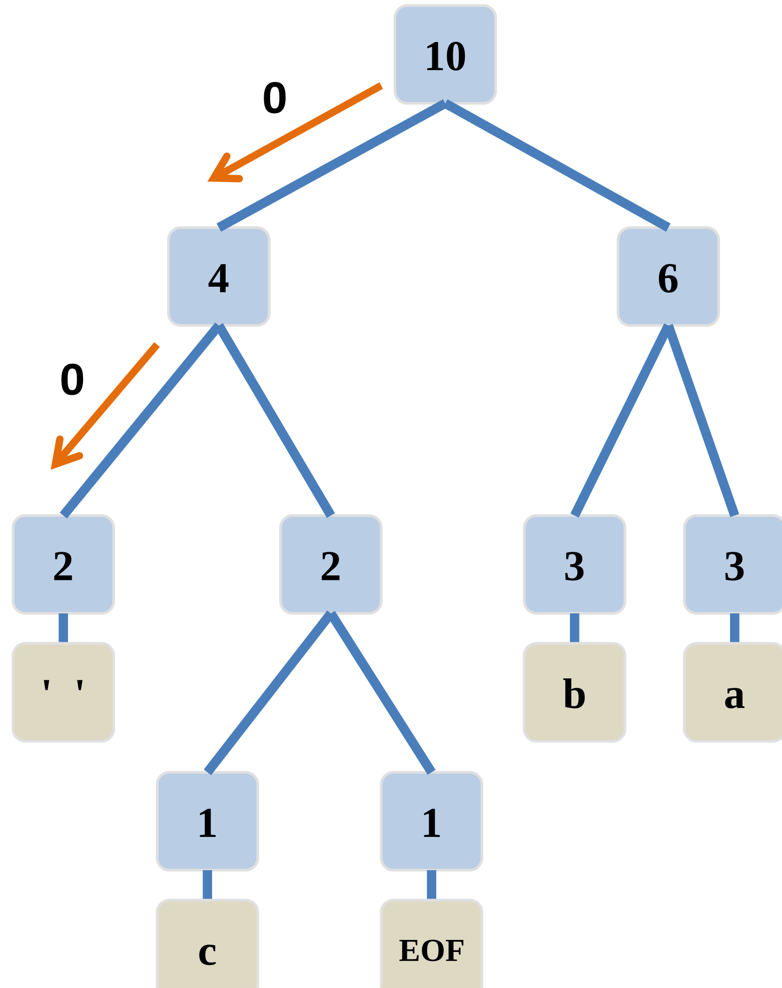
- ' ' =
- 'c' =
- EOF =
- 'b' =
- 'a' =



Recall
Left is 0
Right is 1

Step 4: Traverse Tree to Find the Character to Binary Mapping

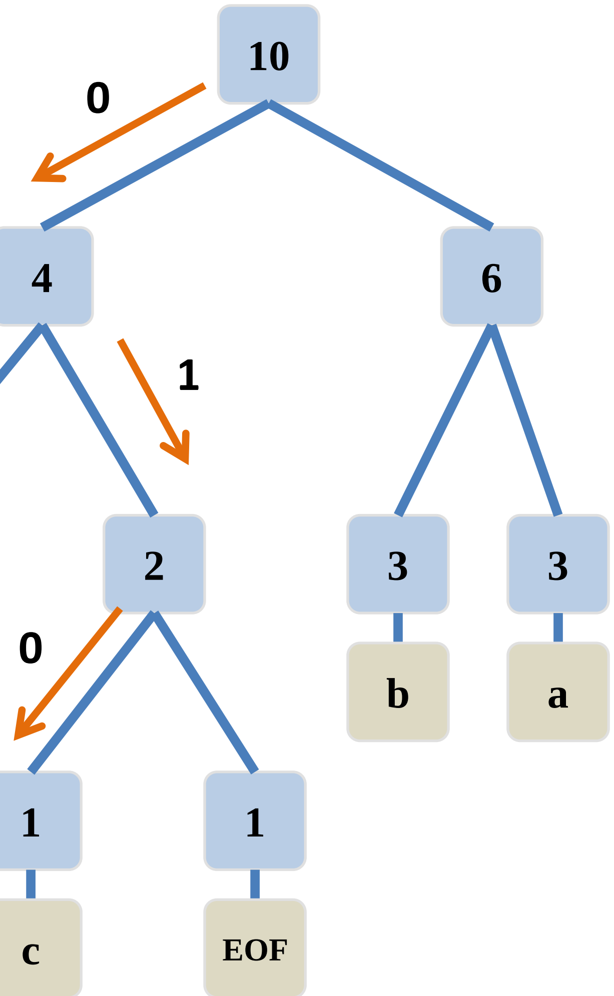
- **' ' = 00**
- 'c' =
- EOF =
- 'b' =
- 'a' =



Recall
Left is 0
Right is 1

Step 4: Traverse Tree to Find the Character to Binary Mapping

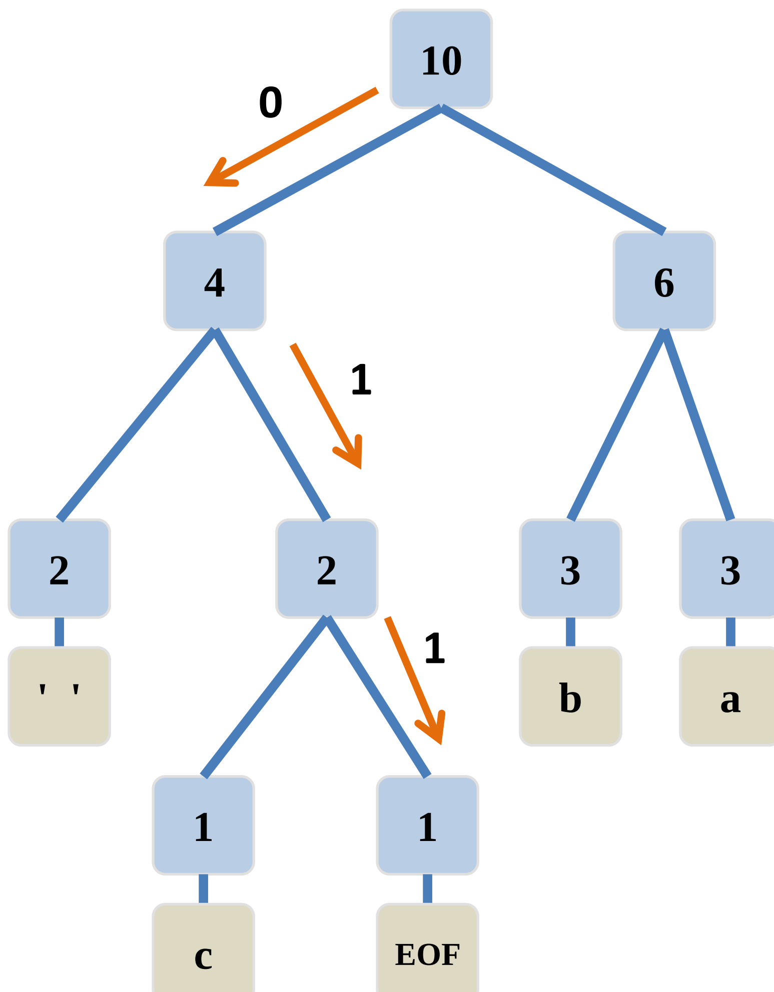
- ' ' = 00
- 'c' = **010**
- EOF =
- 'b' =
- 'a' =



Recall
Left is 0
Right is 1

Step 4: Traverse Tree to Find the Character to Binary Mapping

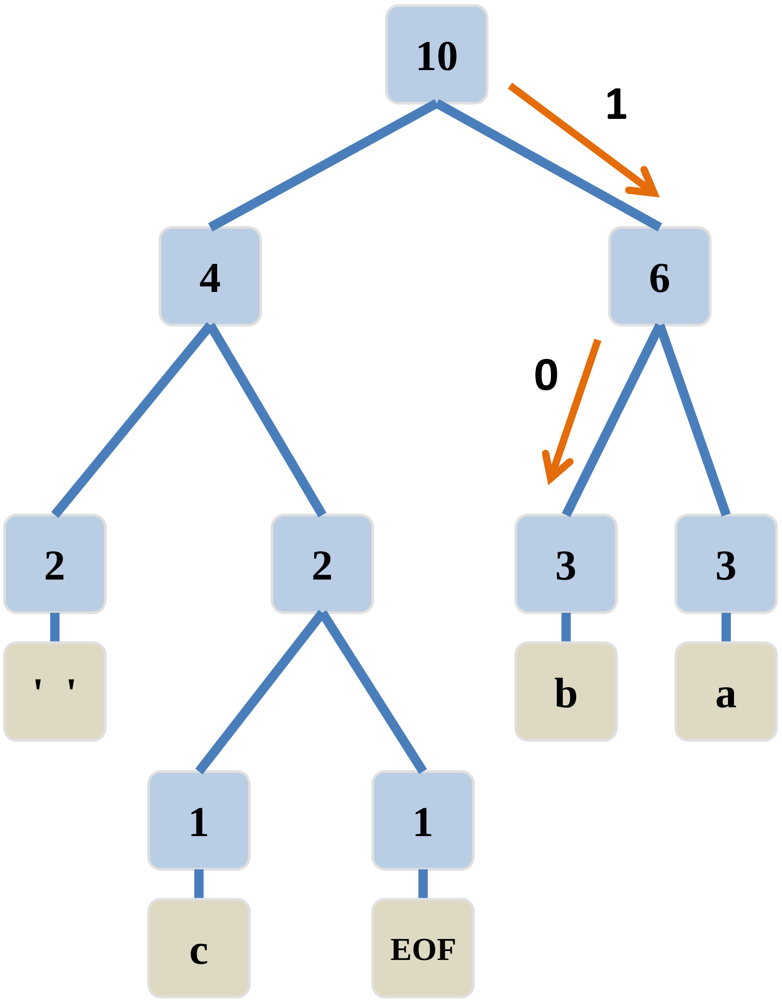
- ' ' = 00
- 'c' = 010
- EOF = **011**
- 'b' =
- 'a' =



Recall
Left is 0
Right is 1

Step 4: Traverse Tree to Find the Character to Binary Mapping

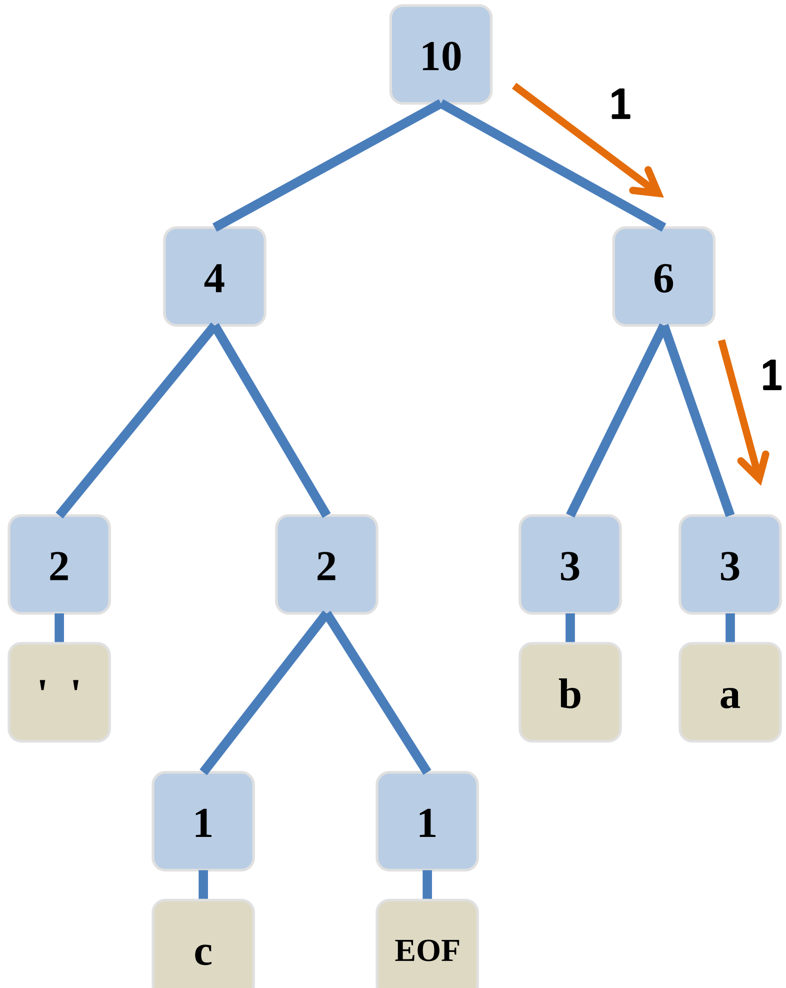
- ' ' = **00**
- 'c' = **010**
- EOF = **011**
- 'b' = **10**
- 'a' =



Recall
Left is 0
Right is 1

Step 4: Traverse Tree to Find the Character to Binary Mapping

- ' ' = 00
- 'c' = 010
- EOF = 011
- 'b' = 10
- 'a' = 11



Recall
Left is 0
Right is 1

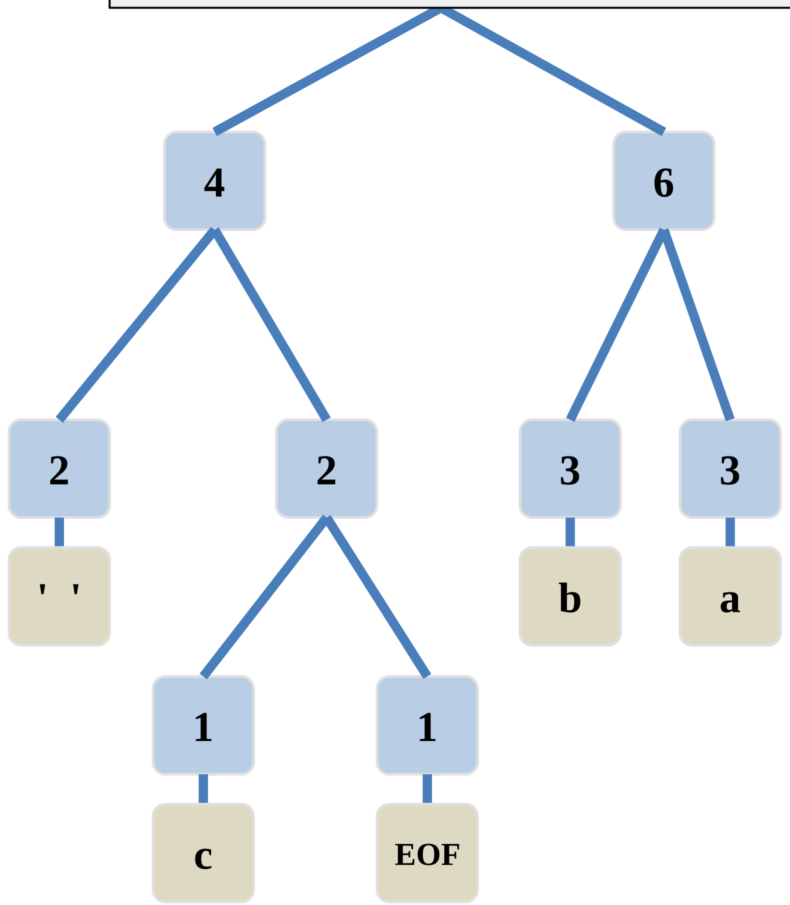
Step 5: Encode the Message

file ends with an invisible EOF character

- ' ' = 00
- 'c' = 010
- EOF = 011
- 'b' = 10
- 'a' = 11

- Example message (input file) contents:

  ab ab cab



Challenge: Encode the Message

- ' ' = 00
- 'c' = 010
- EOF = 011
- 'b' = 10
- 'a' = 11

- Example message (input file) contents:

  ab ab cab

file ends with an invisible EOF character

Step 5: Encode the Message

file ends with an invisible EOF character

- ' ' = 00
- 'c' = 010
- EOF = 011
- 'b' = 10
- 'a' = 11

- Example message (input file) contents:

ab ab cab

- 11

Step 5: Encode the Message

file ends with an invisible EOF character

- ' ' = 00
- 'c' = 010
- EOF = 011
- 'b' = 10
- 'a' = 11

- Example message (input file) contents:

  ab ab cab

- 11<u>10</u>

Step 5: Encode the Message

- ' ' = 00
- 'c' = 010
- EOF = 011
- 'b' = 10
- 'a' = 11

- Example message (input file) contents:

ab ab cab

file ends with an invisible EOF character

- 111000

Step 5: Encode the Message

file ends with an invisible EOF character

- ' ' = 00
- 'c' = 010
- EOF = 011
- 'b' = 10
- 'a' = 11

- Example message (input file) contents:

ab ab cab

- 11100011

Step 5: Encode the Message

file ends with an invisible EOF character

- ' ' = 00
- 'c' = 010
- EOF = 011
- 'b' = 10
- 'a' = 11

- Example message (input file) contents:

  ab ab cab

- 1110001110

Step 5: Encode the Message

file ends with an invisible EOF character

- ' ' = 00
- 'c' = 010
- EOF = 011
- 'b' = 10
- 'a' = 11

- Example message (input file) contents:

  ab ab cab

- 111000111000

Step 5: Encode the Message

file ends with an invisible EOF character

- ' ' = 00
- 'c' = 010
- EOF = 011
- 'b' = 10
- 'a' = 11

- Example message (input file) contents:

ab ab cab

- 11100011100010

Step 5: Encode the Message

file ends with an invisible EOF character

- ' ' = 00
- 'c' = 010
- EOF = 011
- 'b' = 10
- 'a' = 11

- Example message (input file) contents:

  ab ab cab

- 11100011100001011

Step 5: Encode the Message

file ends with an invisible EOF character

- ' ' = 00
- 'c' = 010
- EOF = 011
- 'b' = 10
- 'a' = 11

- Example message (input file) contents:

  ab ab cab

- 1110001110000101110

Step 5: Encode the Message

file ends with an invisible EOF character

- ' ' = 00
- 'c' = 010
- EOF = 011
- 'b' = 10
- 'a' = 11

- Example message (input file) contents:

  ab ab cab

- 1110001110000101110011

Step 5: Encode the Message

file ends with an invisible EOF character

- ' ' = 00
- 'c' = 010
- EOF = 011
- 'b' = 10
- 'a' = 11

- Example message (input file) contents:

  ab ab cab

- 11<u>10</u>00<u>11</u>10<u>00</u>010<u>11</u>10<u>011</u>

- Count the bits used = 22 bits
- versus the 80
  - previously needed
- File is almost ¼ the size
  - lots of savings

Decompression

- From the previous tree shown we now have the message characters encoded as:

char	'a'	'b'	' '	'a'	'b'	' '	'c'	'a'	'b'	EOF
binary	11	10	00	11	10	00	010	11	10	011

- Which compresses to bytes 3 like so:

byte	1	2	3
char	a b a	b c a	b EOF
binary	11 10 00 11	10 00 010 1	1 10 011

- How to decompress?
  - *Hint: Lookup table is not the best answer,*
    what is the first symbol?... 1=? or is it 11? or 111? or 1110? or…

Decompression via Tree

- The tree is known to the recipient of the message
  - So use it

- To identify symbols we will
  Apply the Prefix Property
  - No encoding *A* is the prefix of another encoding *B*
  - Never will have x→**011** and y→**011**100110

Decompression via Tree

- Apply the Prefix Property
  - No encoding *A* is the prefix of another encoding *B*
  - Never will have x→**011** and y→**011**100110

- the Algorithm
  - Read each bit one at a time from the input
  - If the bit is 0 go left in the tree
  - Else if the bit is 1 go right
  - If you reach a leaf node
    - output the character at that leaf
    - and go back to the tree root

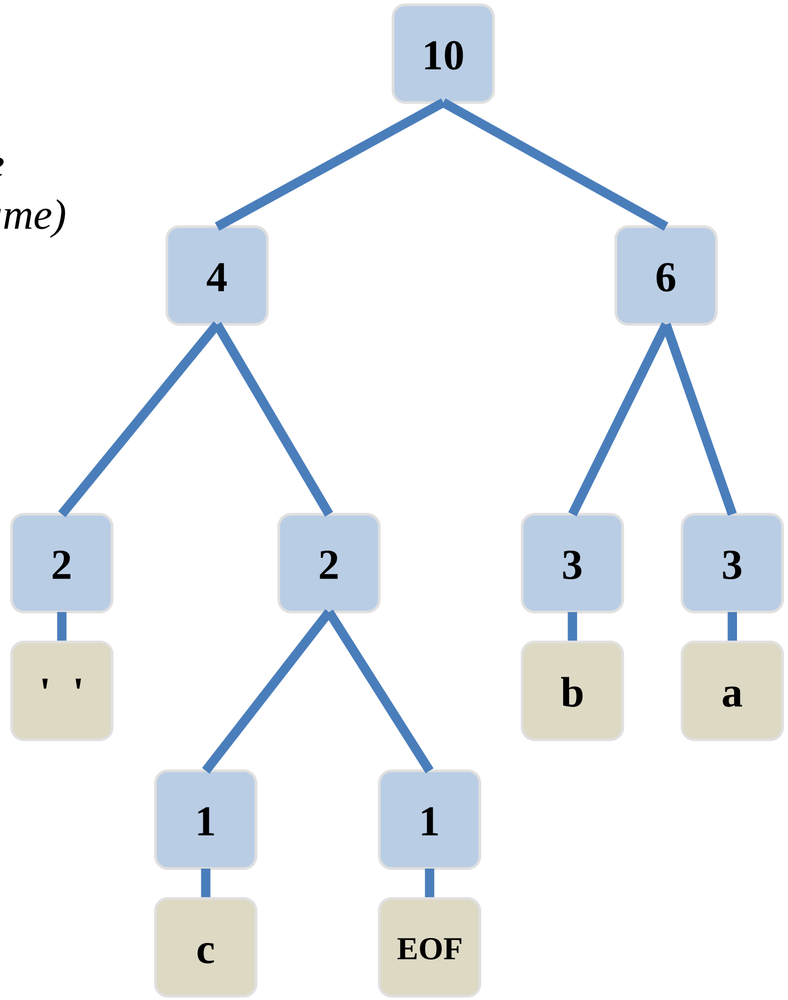
Decompressing Example

- Say the encrypted message was:
- `1011101000110101011011`
  - *note: this is NOT the same message as the encryption just done (but the tree the is same)*

- Read each bit one at a time

- If it is 0 go left
- If it is 1 go right

- If you reach a leaf, output the character there and go back to the tree root



Class Activity: Decompressing Example

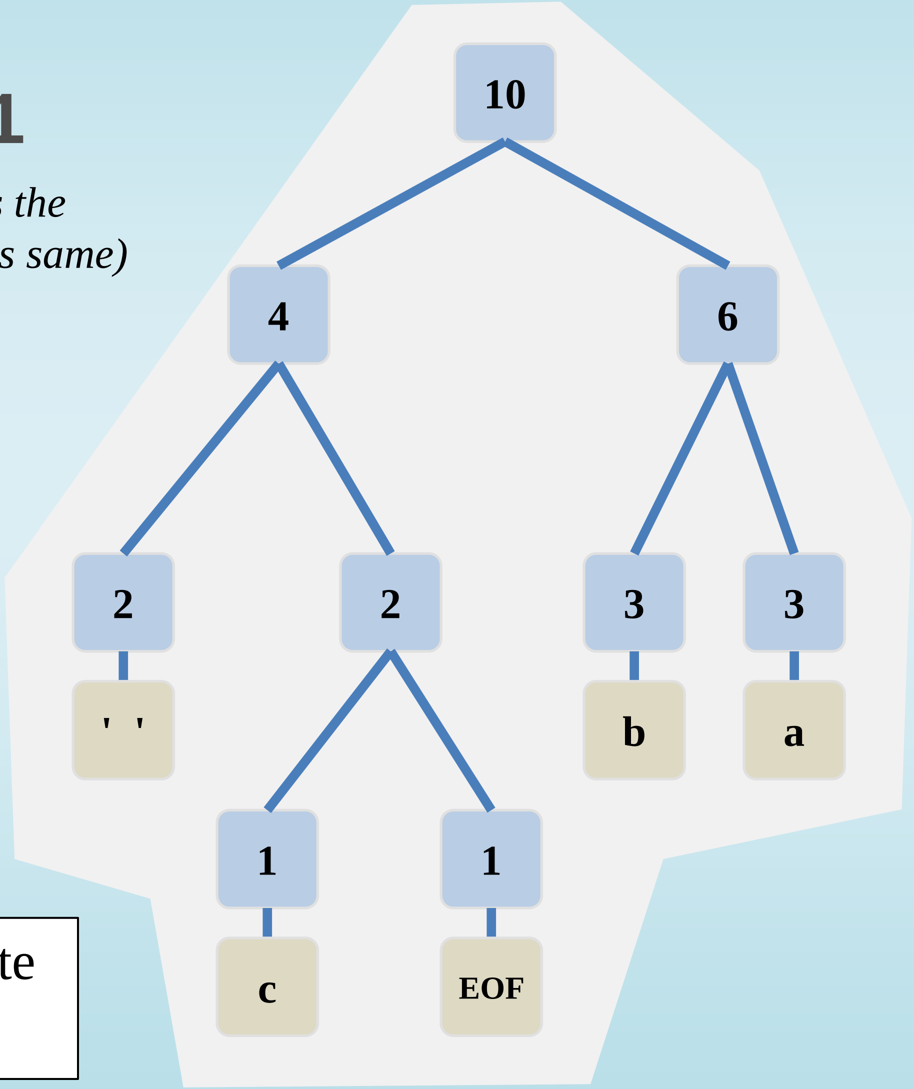
- Say the encrypted message was:
- **1011101000110101011011**
  - *note: this is NOT the same message as the encryption just done (but the tree the is same)*

- Read each bit one at a time

- If it is 0 go left
- If it is 1 go right

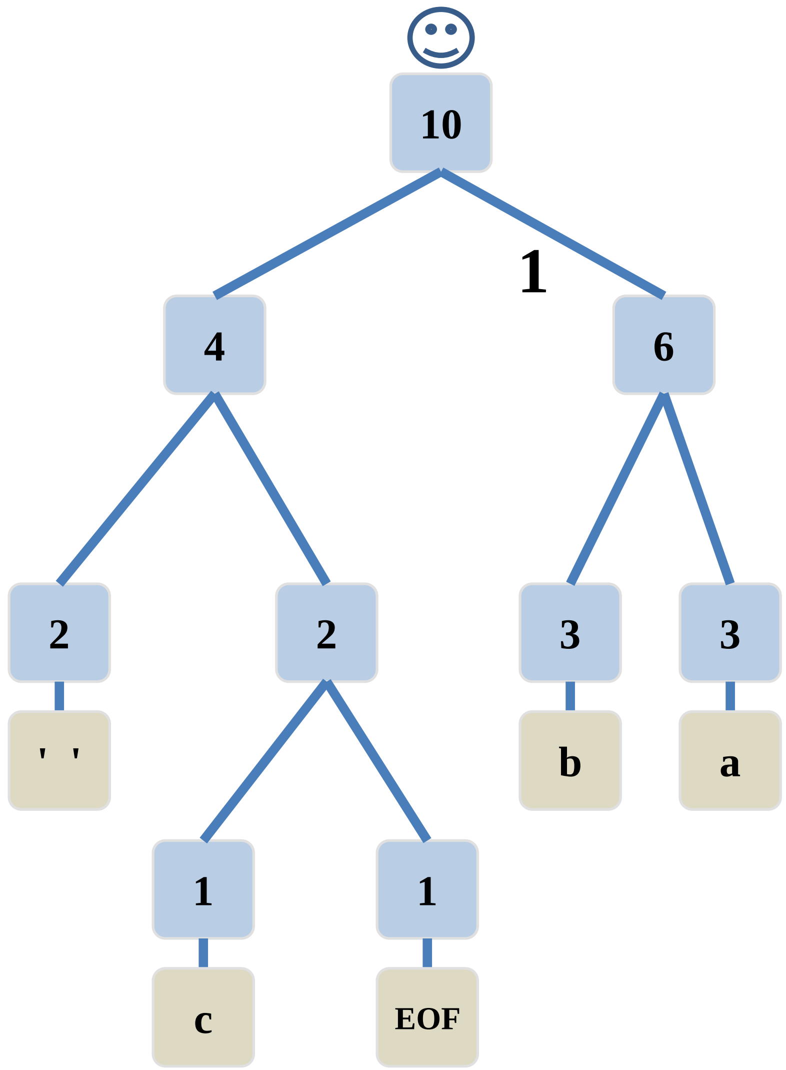
- If you reach a leaf, output the character there and go back to the tree root

- Pause for students to complete



Decompressing Example

- Say the encrypted message was:
- **1011101000110101101011011**



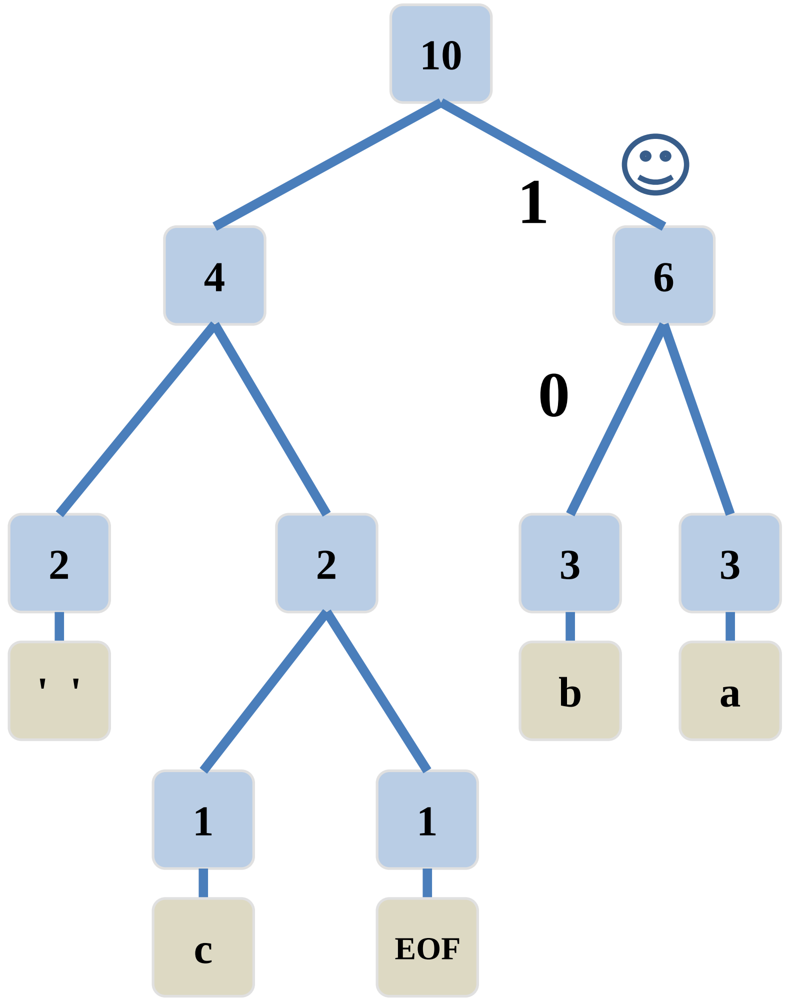
- Read each bit one at a time
- If it is 0 go left
- If it is 1 go right
- If you reach a leaf, output the character there and go back to the tree root

Decompressing Example

- Say the encrypted message was:
- **1011101000110101011011**

b

- Read each bit one at a time
- If it is 0 go left
- If it is 1 go right
- If you reach a leaf, output the character there and go back to the tree root

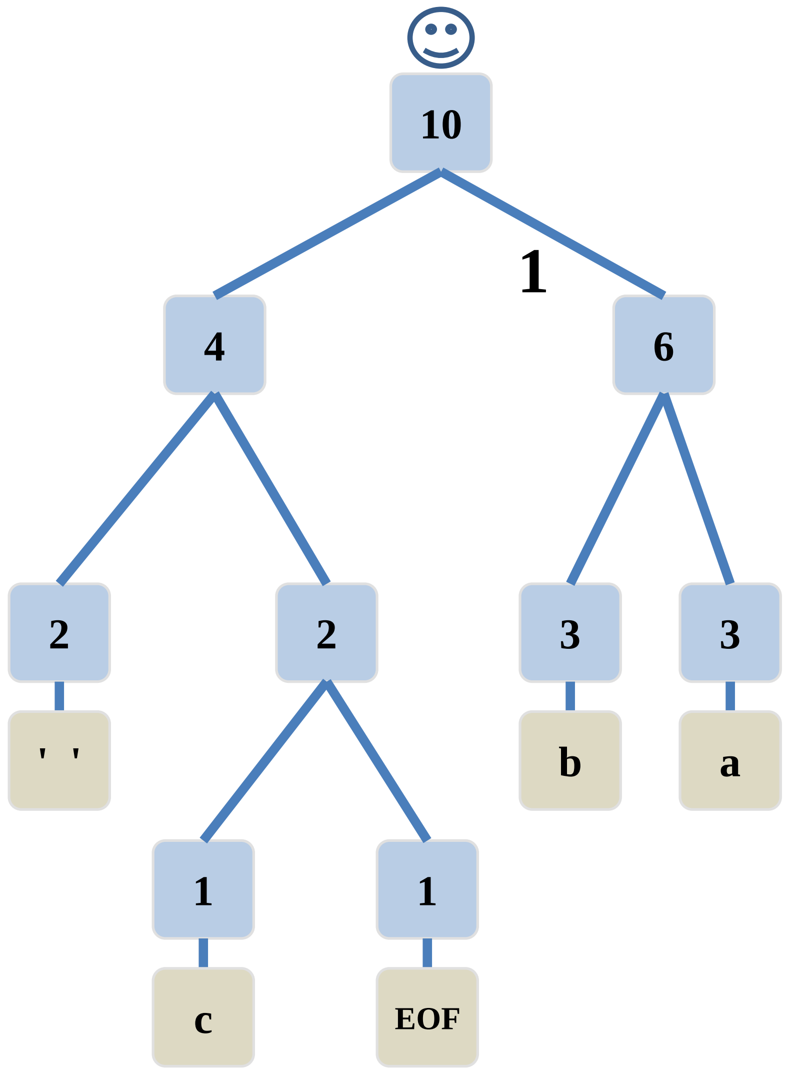


Decompressing Example

- Say the encrypted message was:
- **1011010001101011011**

b

- Read each bit one at a time
- If it is 0 go left
- If it is 1 go right
- If you reach a leaf, output the character there and go back to the tree root

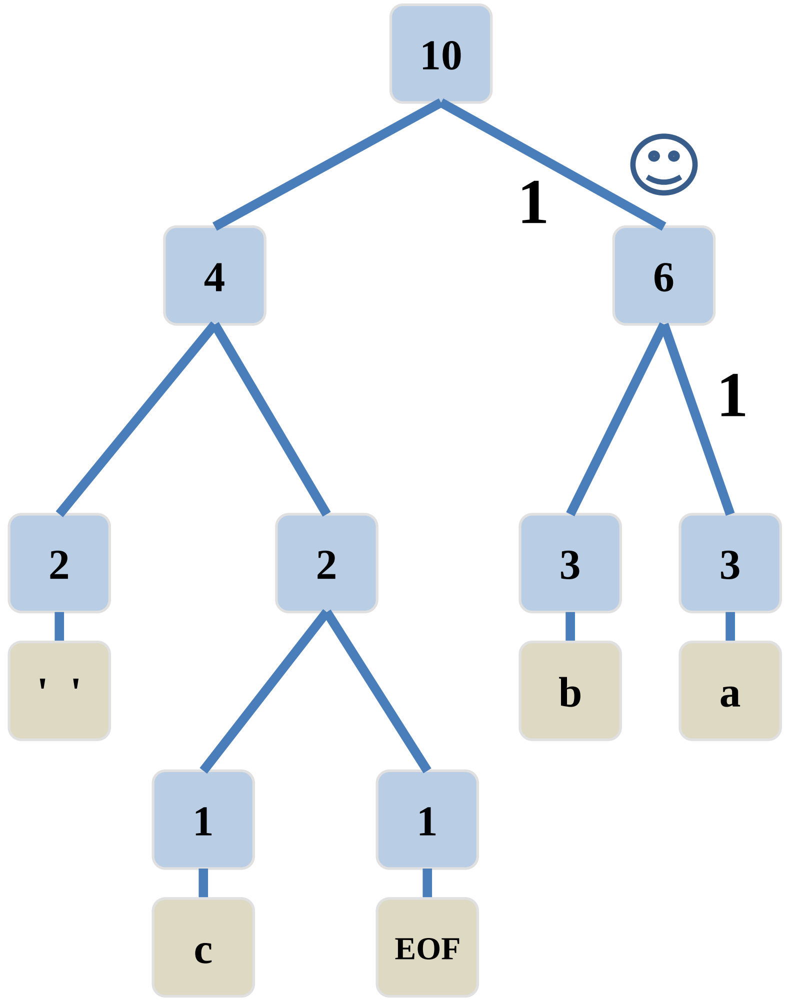


Decompressing Example

- Say the encrypted message was:
- **1011101000110101011011**

b	a

- Read each bit one at a time
- If it is 0 go left
- If it is 1 go right
- If you reach a leaf, output the character there and go back to the tree root

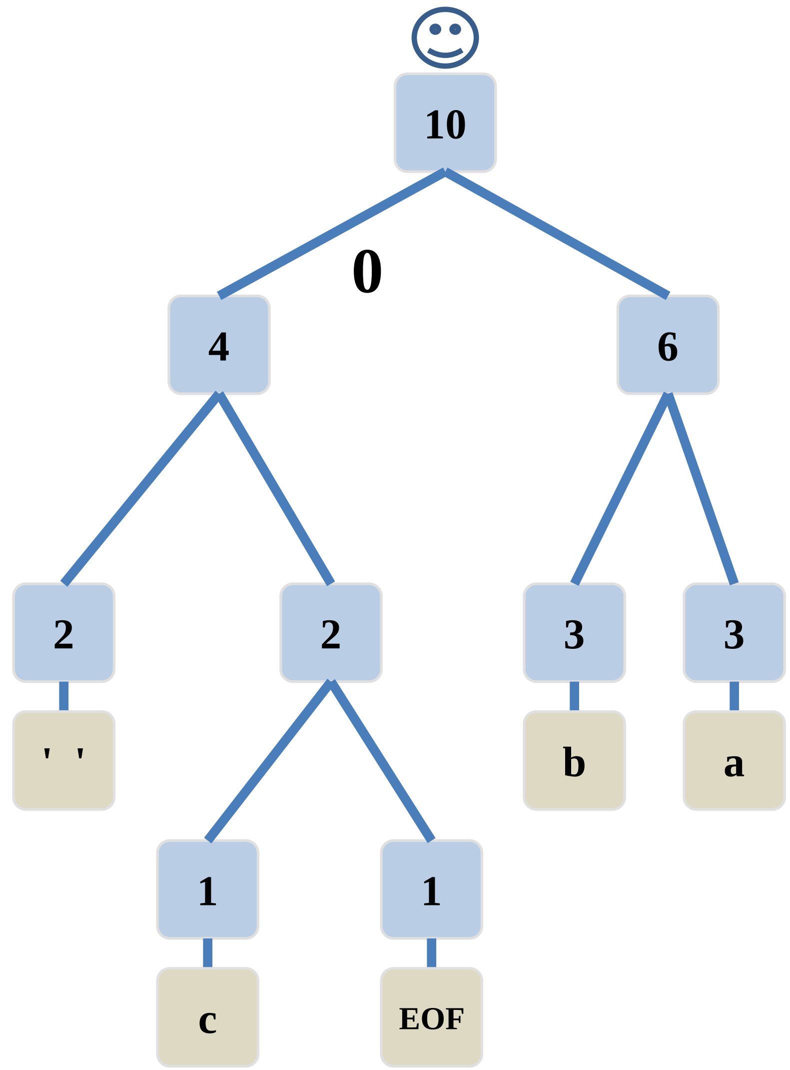


Decompressing Example

- Say the encrypted message was:
- **1011010001101011011**

b	**a**

- Read each bit one at a time
- If it is 0 go left
- If it is 1 go right
- If you reach a leaf, output the character there and go back to the tree root



Decompressing Example

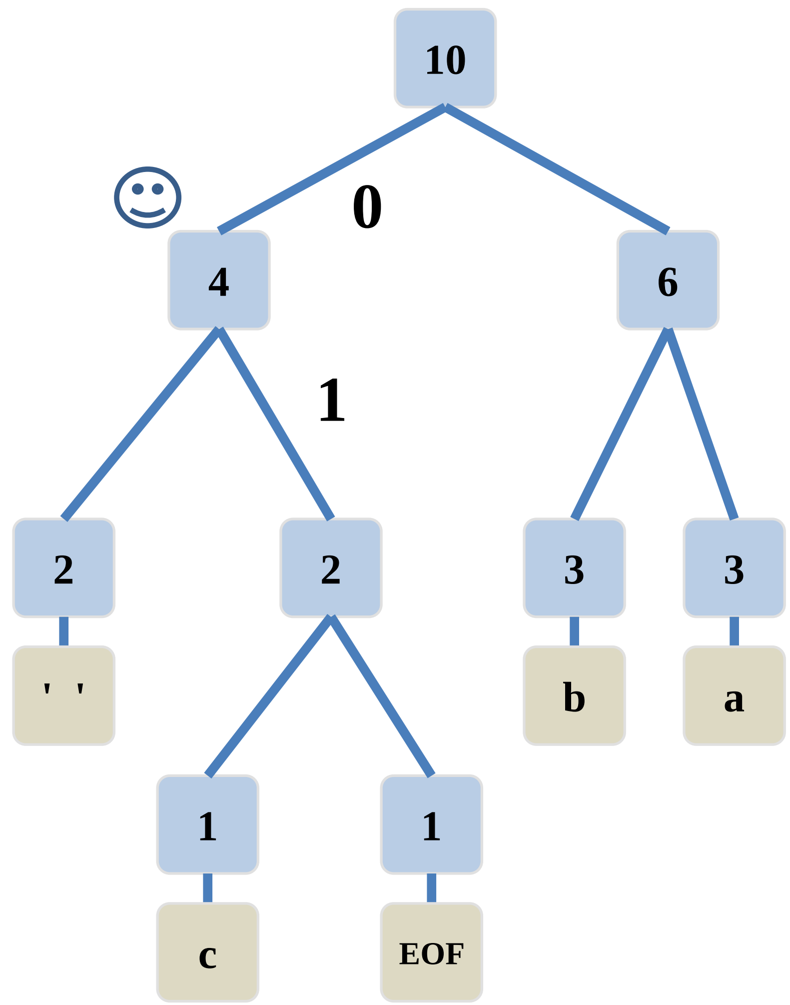
- Say the encrypted message was:
- **1011010001101011011**

b	**a**

- Read each bit one at a time

- If it is 0 go left
- If it is 1 go right

- If you reach a leaf, output the character there and go back to the tree root

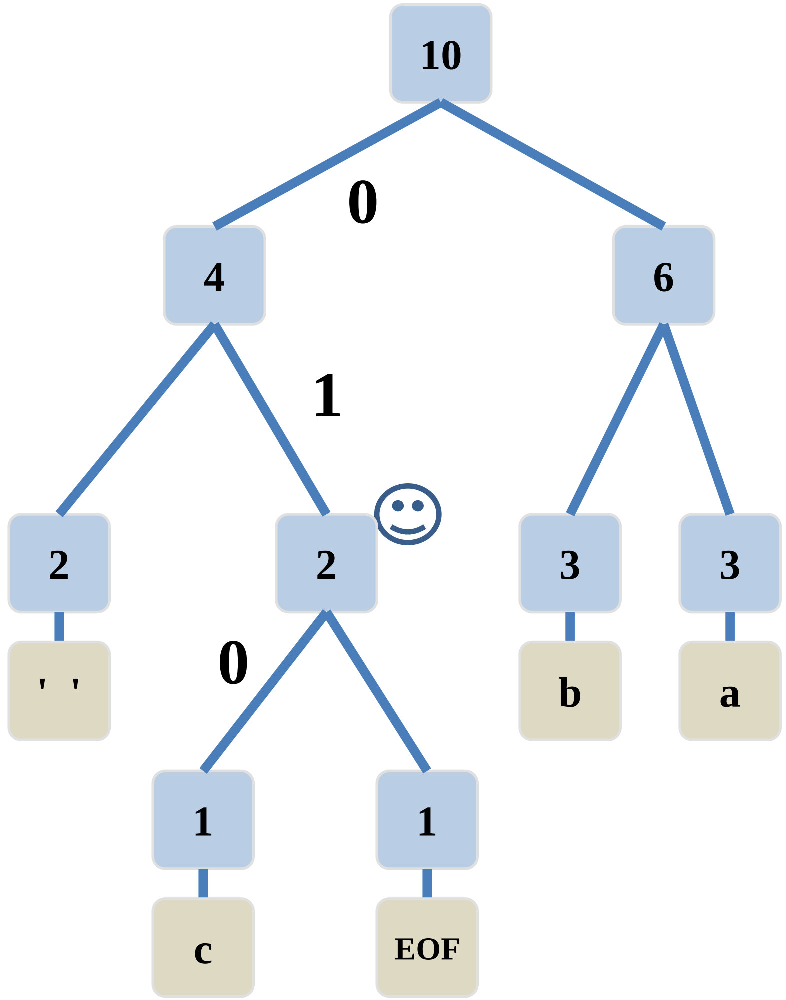


Decompressing Example

- Say the encrypted message was:
- **10110100011010011011**

b	a	c

- Read each bit one at a time
- If it is 0 go left
- If it is 1 go right
- If you reach a leaf, output the character there and go back to the tree root

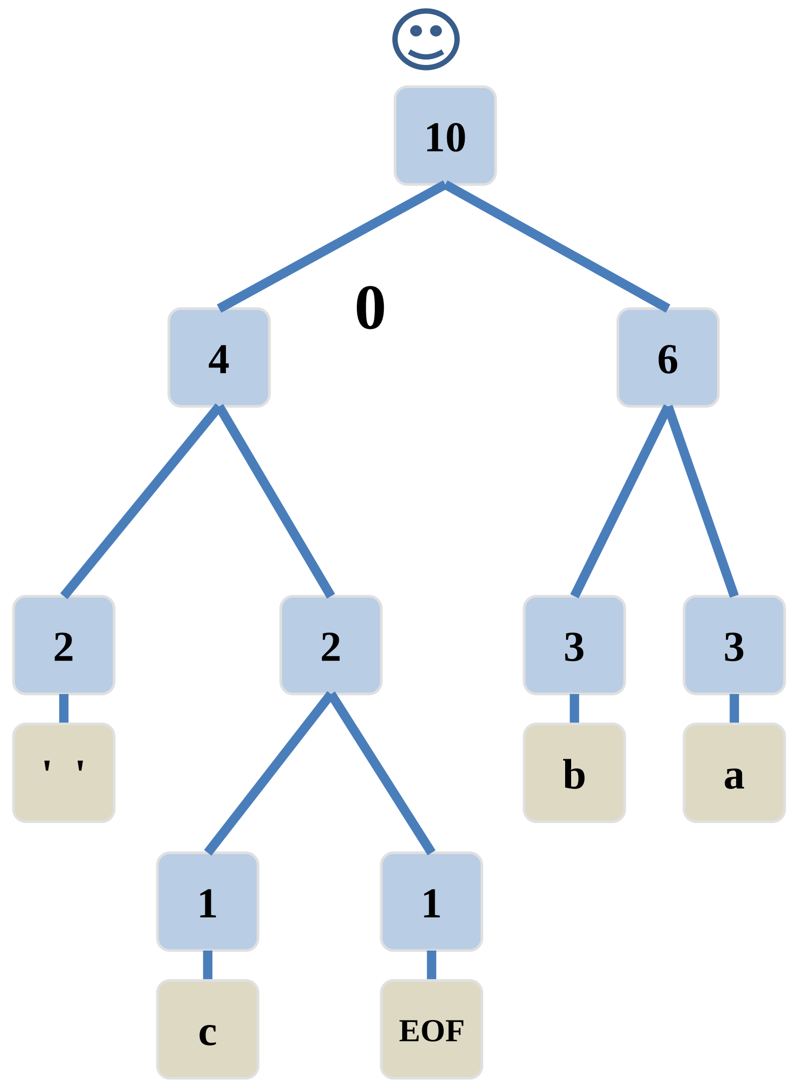


Decompressing Example

- Say the encrypted message was:
- **10110100001101011011**

b	a	c

- Read each bit one at a time
- If it is 0 go left
- If it is 1 go right
- If you reach a leaf, output the character there and go back to the tree root



Decompressing Example

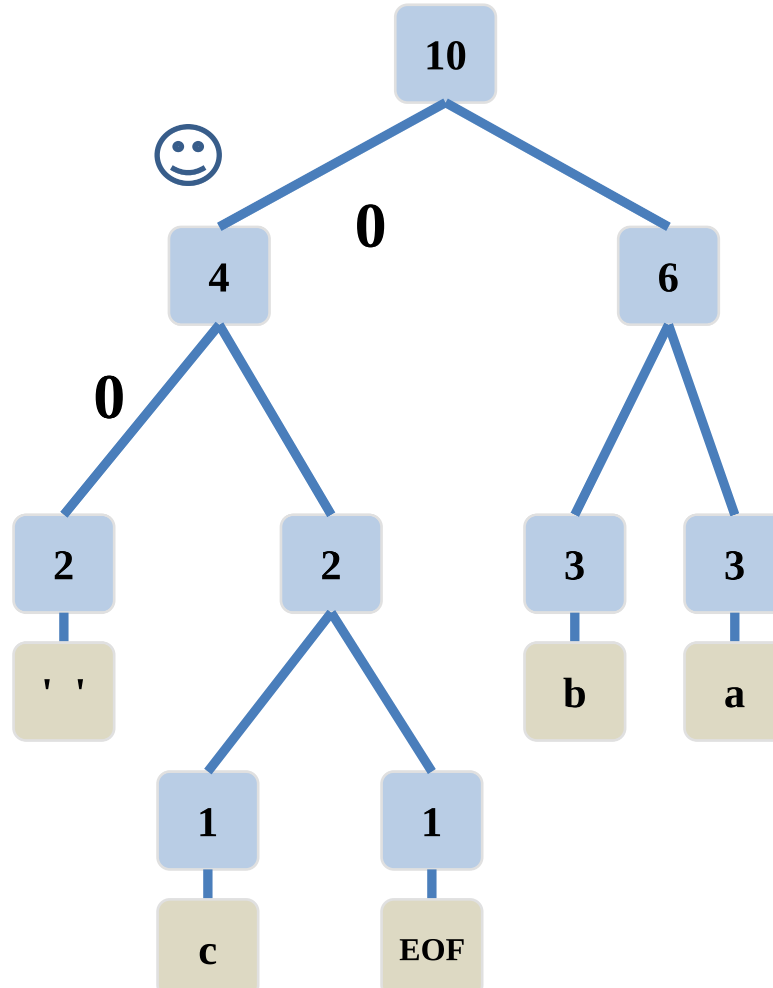
- Say the encrypted message was:
- **1011010001101011011**

b	a	c	

- Read each bit one at a time

- If it is 0 go left
- If it is 1 go right

- If you reach a leaf, output the character there and go back to the tree root

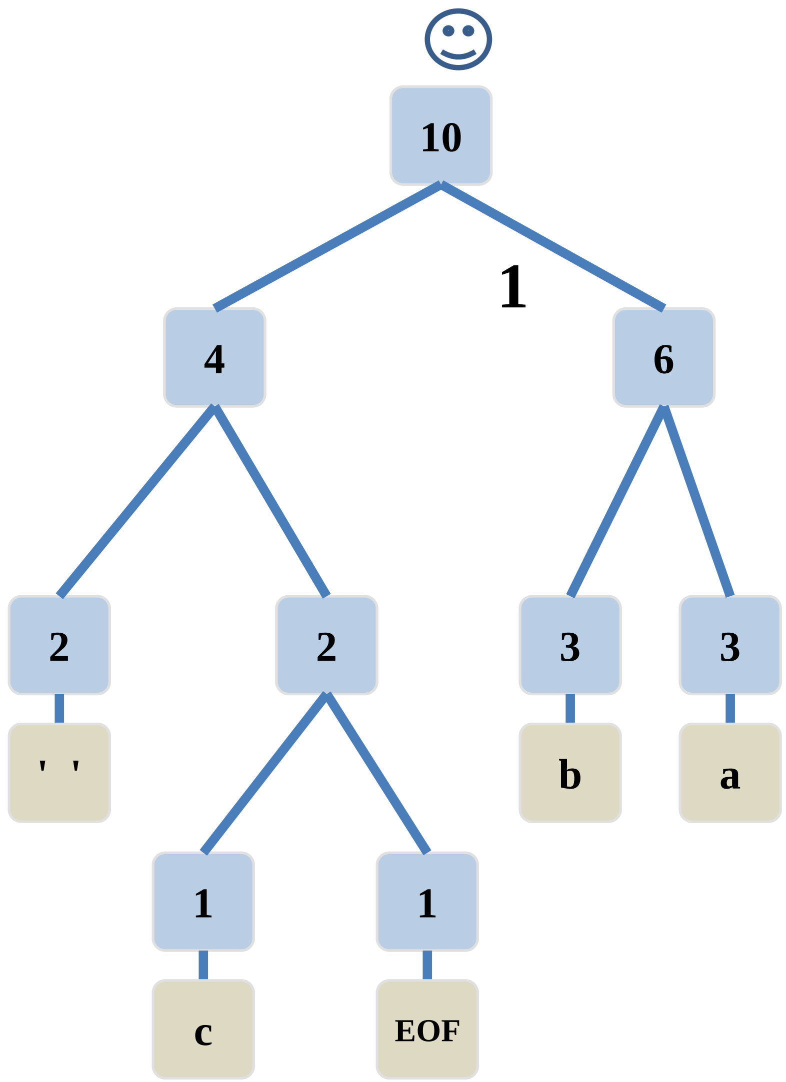


Decompressing Example

- Say the encrypted message was:
- **10111010001101011011**

b	a	c	

- Read each bit one at a time
- If it is 0 go left
- If it is 1 go right
- If you reach a leaf, output the character there and go back to the tree root

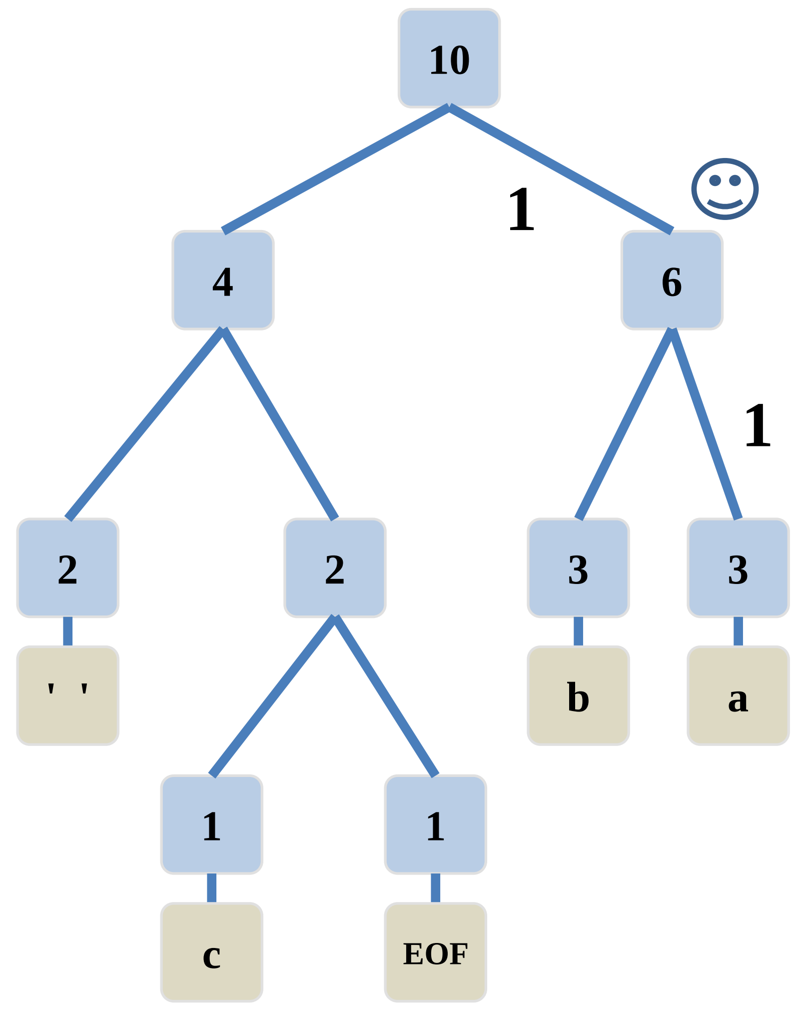


Decompressing Example

- Say the encrypted message was:
- **1011010000110101011011**

b	**a**	**c**		**a**

- Read each bit one at a time
- If it is 0 go left
- If it is 1 go right
- If you reach a leaf, output the character there and go back to the tree root

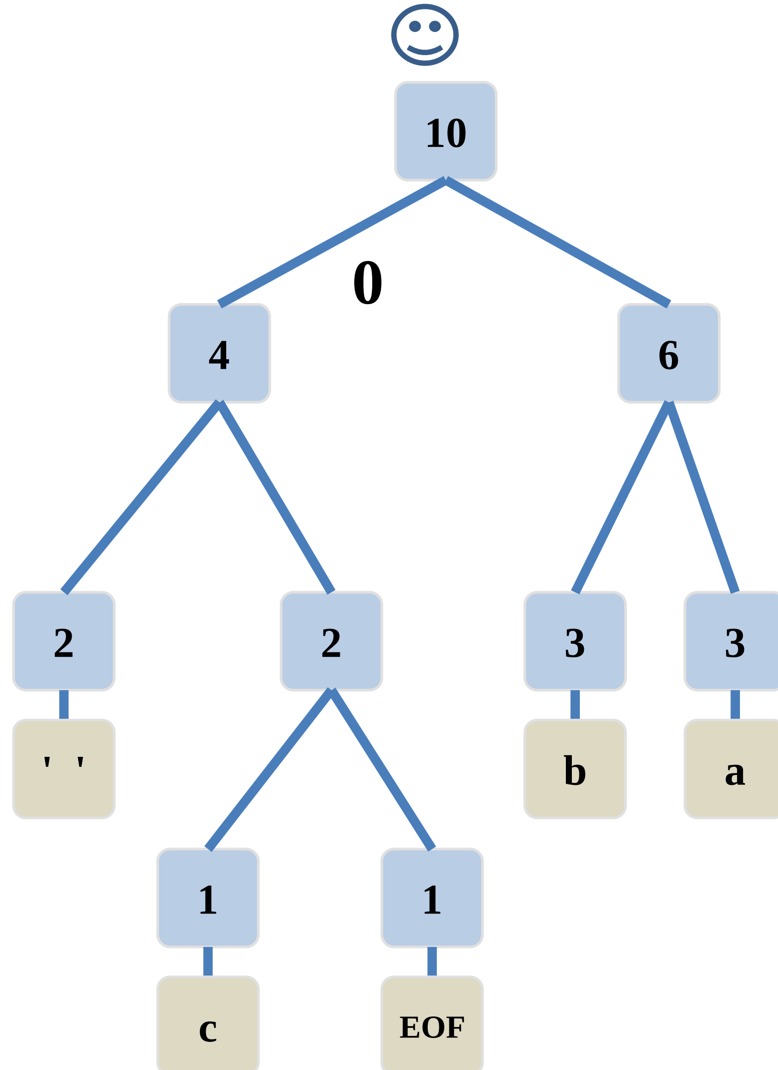


Decompressing Example

- Say the encrypted message was:
- **1011010001101011011**

b	**a**	**c**		**a**

- Read each bit one at a time
- If it is 0 go left
- If it is 1 go right
- If you reach a leaf, output the character there and go back to the tree root

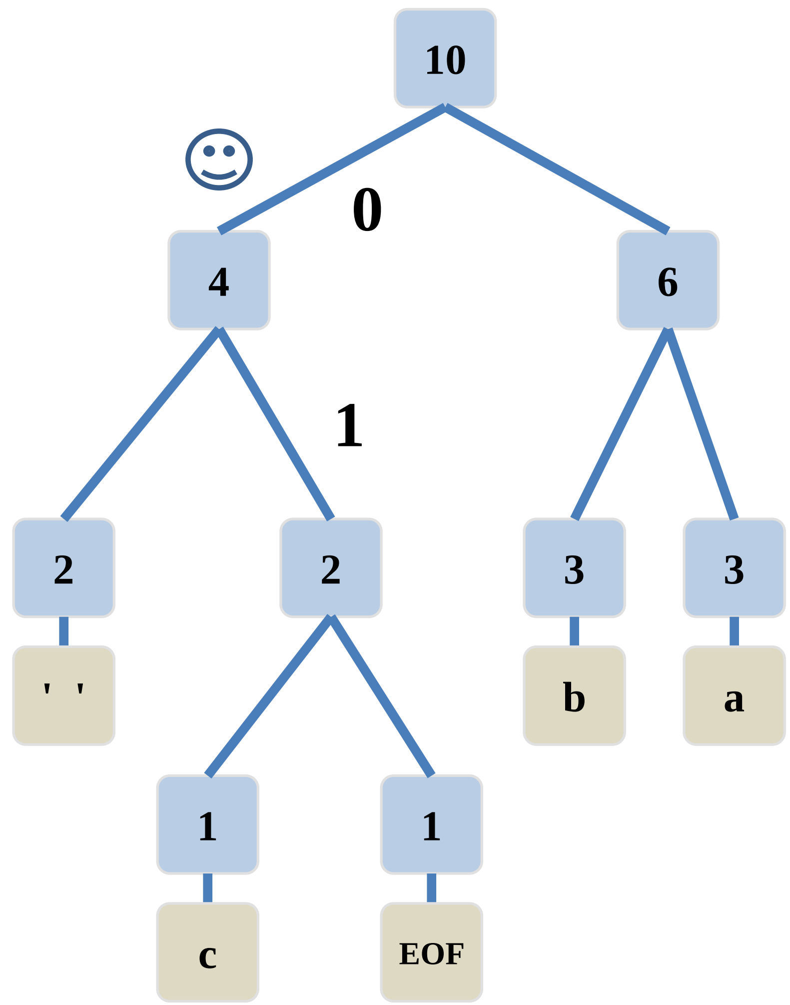


Decompressing Example

- Say the encrypted message was:
- **1011010001101011011**

b	a	c		a

- Read each bit one at a time
- If it is 0 go left
- If it is 1 go right
- If you reach a leaf, output the character there and go back to the tree root

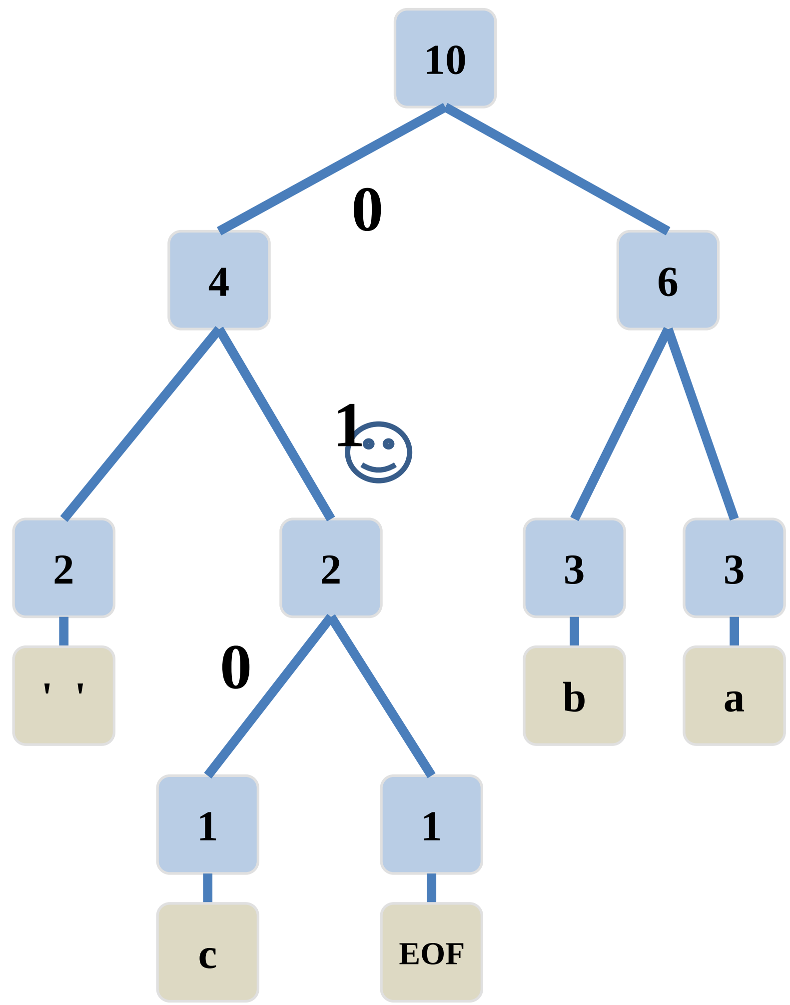


Decompressing Example

- Say the encrypted message was:
- **1011010001101011011**

b	**a**	**c**		**a**	**c**

- Read each bit one at a time
- If it is 0 go left
- If it is 1 go right
- If you reach a leaf, output the character there and go back to the tree root

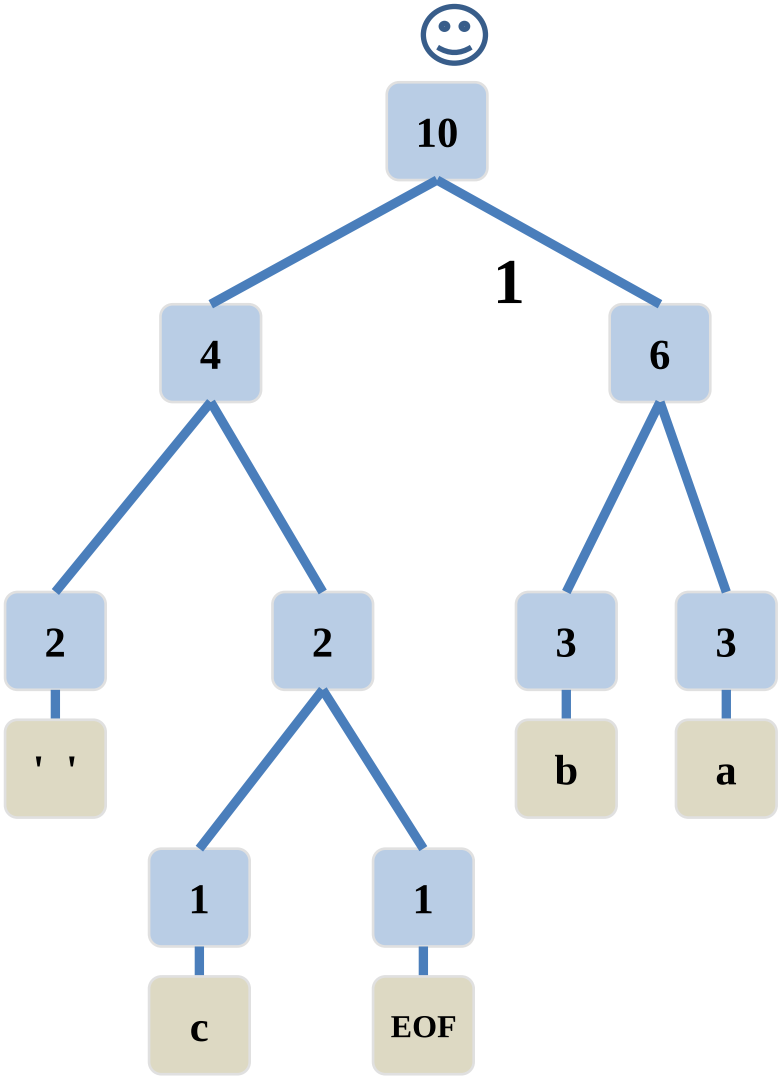


Decompressing Example

- Say the encrypted message was:
- **1011010001101011011**

b	a	c		a	c

- Read each bit one at a time
- If it is 0 go left
- If it is 1 go right
- If you reach a leaf, output the character there and go back to the tree root



Decompressing Example

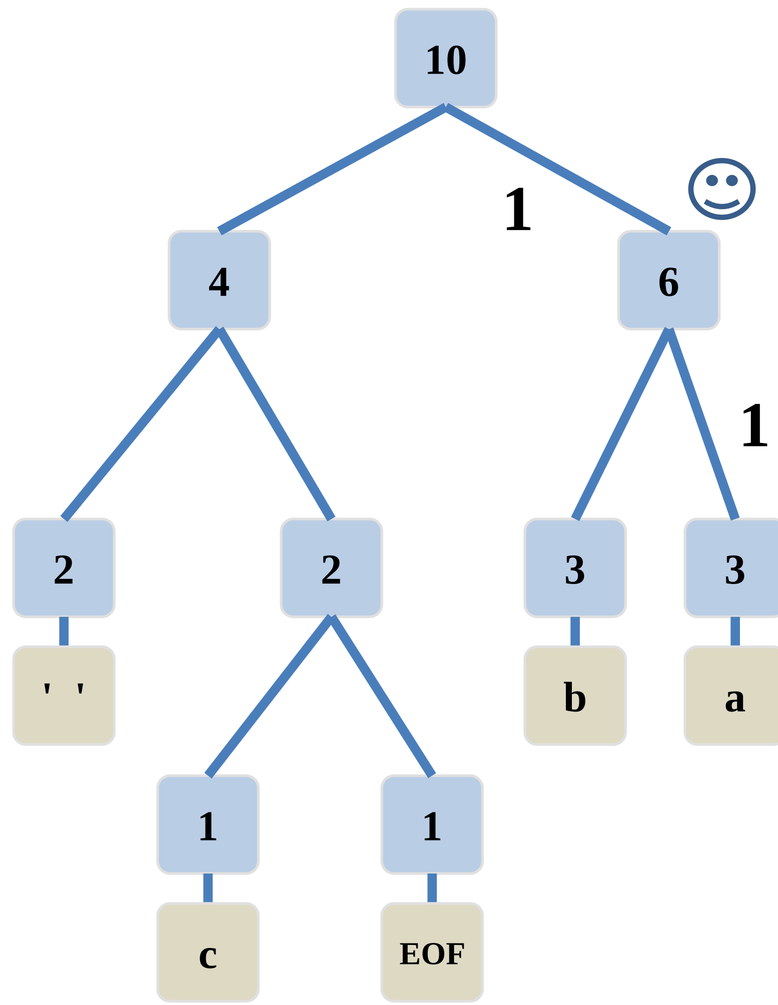
- Say the encrypted message was:
- **1011010001101011011**

b	**a**	**c**		**a**	**c**	**a**

- Read each bit one at a time

- If it is 0 go left
- If it is 1 go right

- If you reach a leaf, output the character there and go back to the tree root

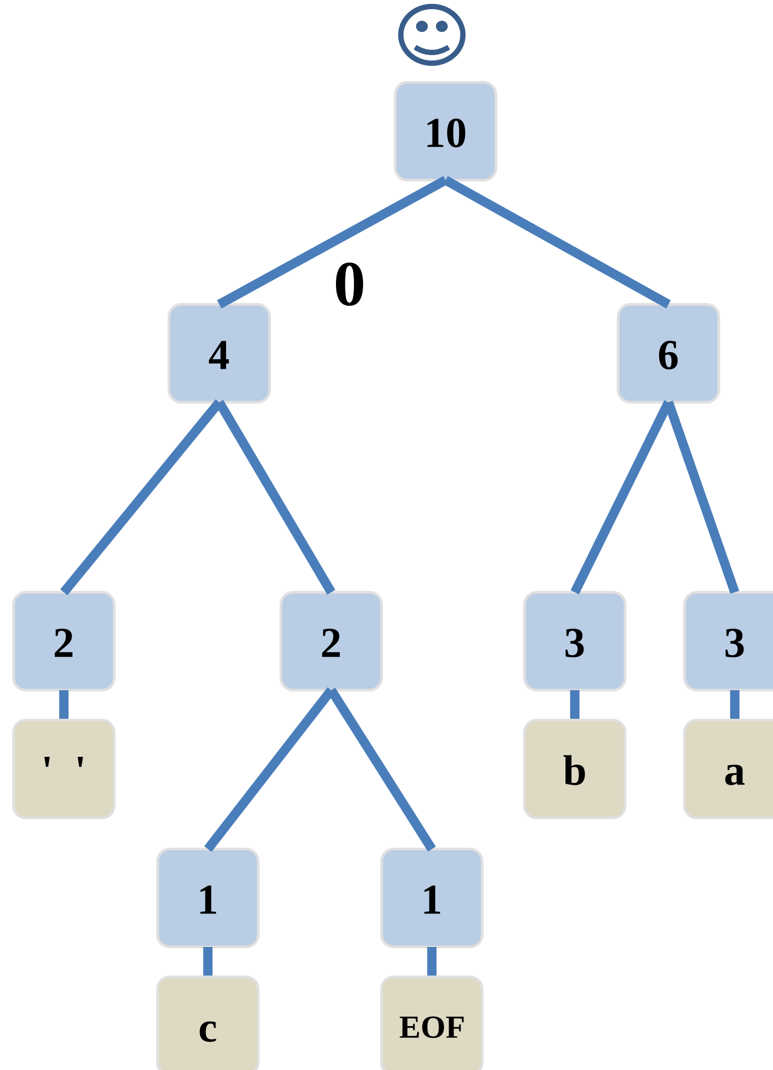


Decompressing Example

- Say the encrypted message was:
- **1011010001101011011**

b	**a**	**c**		**a**	**c**	**a**

- Read each bit one at a time
- If it is 0 go left
- If it is 1 go right
- If you reach a leaf, output the character there and go back to the tree root

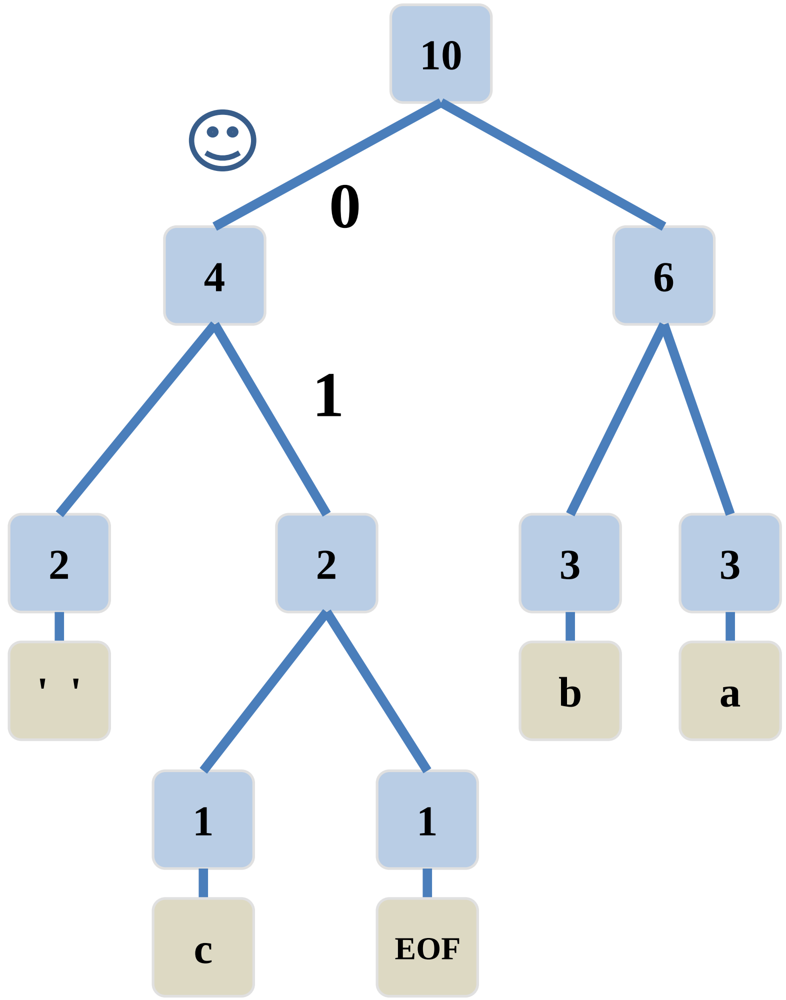


Decompressing Example

- Say the encrypted message was:
- 101101000110101011011

b	a	c		a	c	a

- Read each bit one at a time
- If it is 0 go left
- If it is 1 go right
- If you reach a leaf, output the character there and go back to the tree root



Decompressing Example

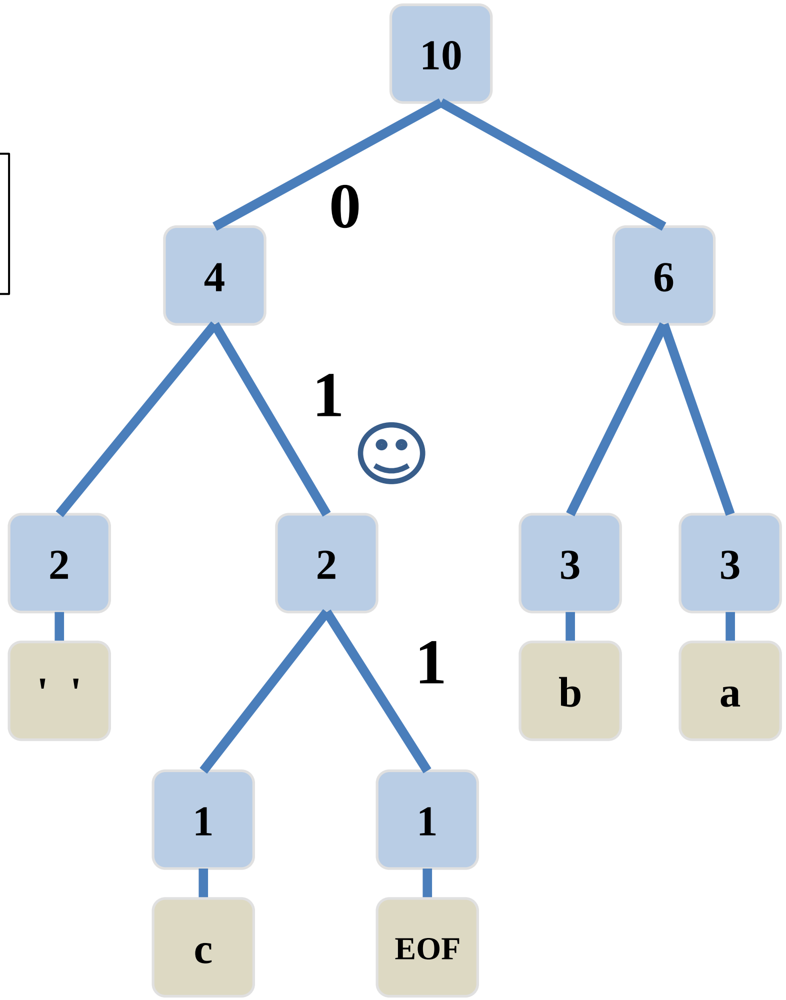
- Say the encrypted message was:
- **1011010001101011011**

b	a	c		a	c	a	EOF

- Read each bit one at a time

- If it is 0 go left
- If it is 1 go right

- If you reach a leaf, output the character there and go back to the tree root



Decompressing Example

- Say the encrypted message was:
- **1011010001101011011**

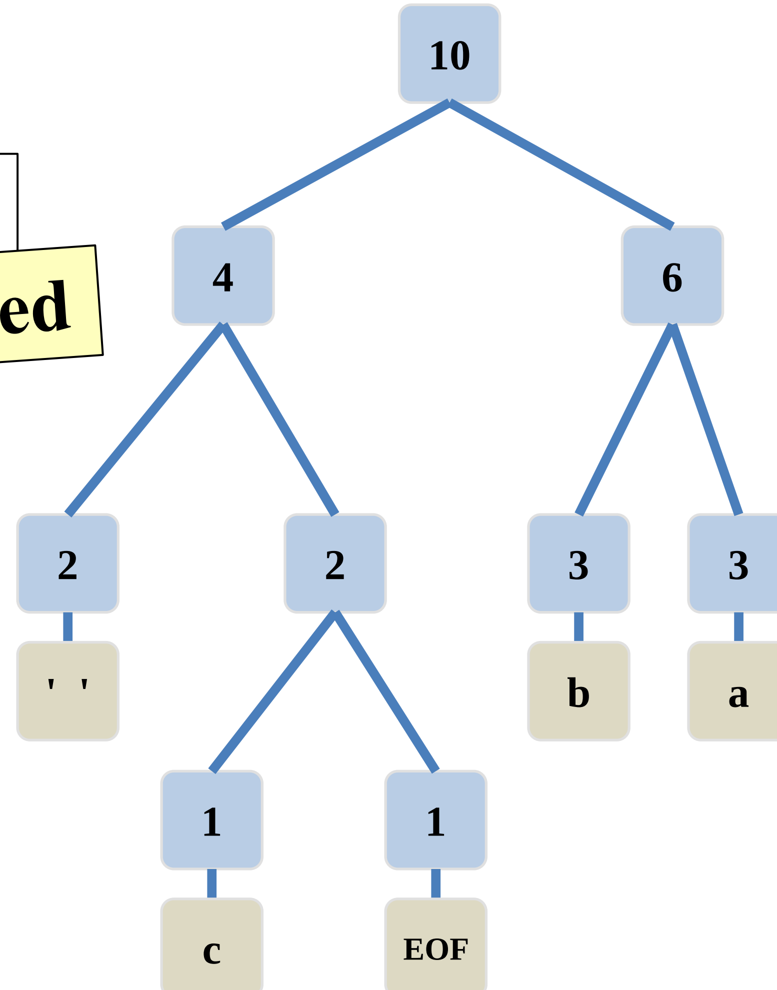
b	a	c		a	c	a	EOF

And the file is now decoded

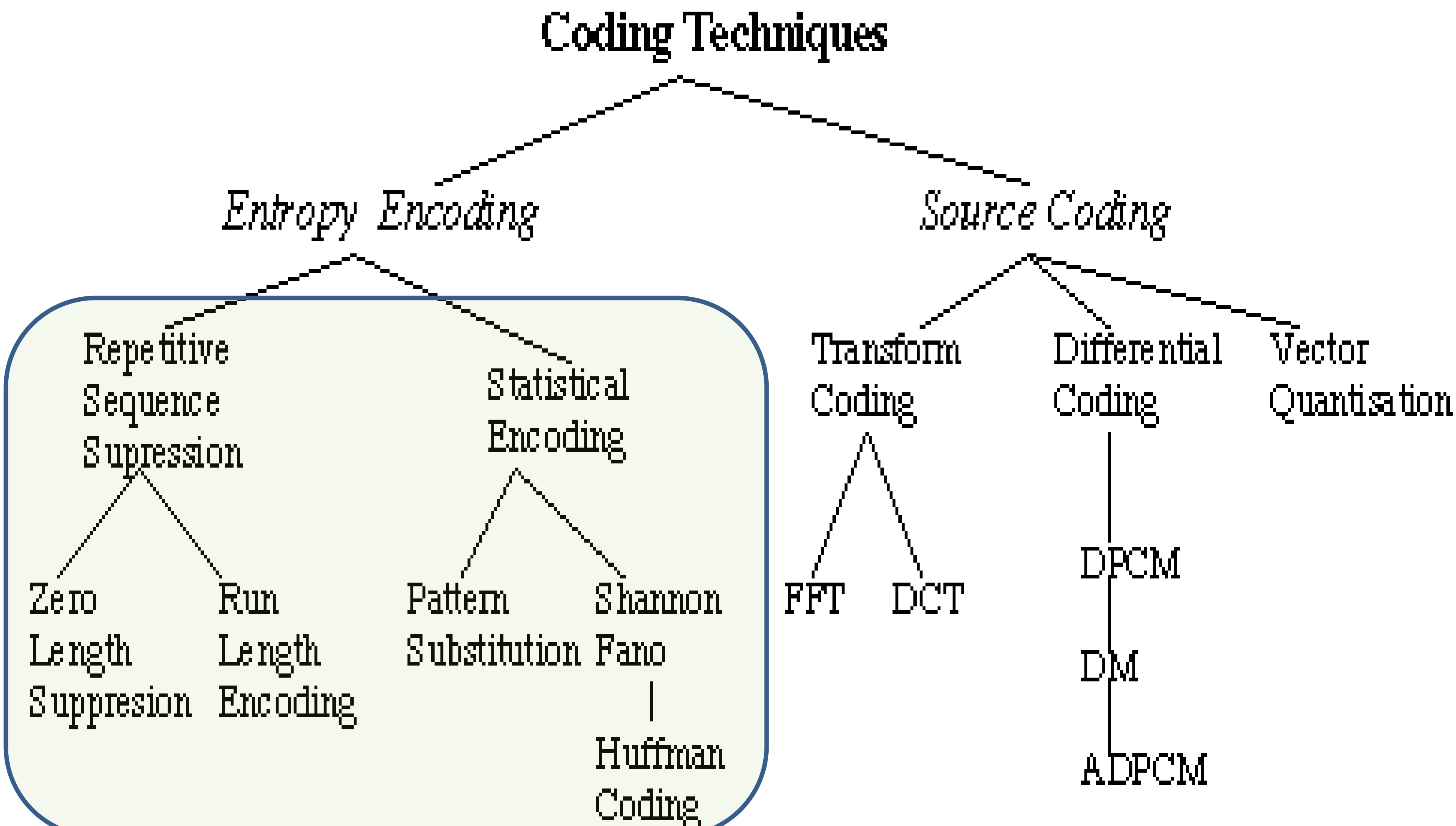
- Read each bit one at a time

- If it is 0 go left
- If it is 1 go right

- If you reach a leaf, output the character there and go back to the tree root



Compression Methods



up next: ONE MORE EXAMPLE

Lempel-Ziv-Welch (LZW) Compression

- Lossless
- Has a table
- Does not store the table

LZW Compression

- Discovers and remembers **patterns** of colors
- Stores the patterns in a table
  - BUT **only table indices are stored** in the file

- LZW table entries can grow arbitrarily long,
  - So one table index can stand for a long string of data in the file
  - BUT again the table itself never needs to be stored in the file

LZW Encoder: Pseudocode

```
initialize TABLE[0 to 255] = code for individual bytes
STRING = get input symbol
while there are still input symbols:
   SYMBOL = get input symbol
   if STRING + SYMBOL is in TABLE:
       STRING = STRING + SYMBOL
   else:
       output the code for STRING
       add STRING + SYMBOL to TABLE
       STRING = SYMBOL
output the code for STRING
```

RGB = 3 bytes
but idea stays same

From Chapter 3 of
MIT 6.02 DRAFT Lecture Notes, Feb 13, 2012

LZW Decoder: Pseudocode

```
initialize TABLE[0 to 255] = code for individual bytes
CODE = read next code from encoder
STRING = TABLE[CODE]
output STRING

while there are still codes to receive:
    CODE = read next code from encoder
    if TABLE[CODE] is not defined: // needed because sometimes the
        ENTRY = STRING + STRING[0] // decoder may not yet have entry
    else:
        ENTRY = TABLE[CODE]
    output ENTRY
    add STRING+ENTRY[0] to TABLE
    STRING = ENTRY
```

RGB = 3 bytes
but idea stays same

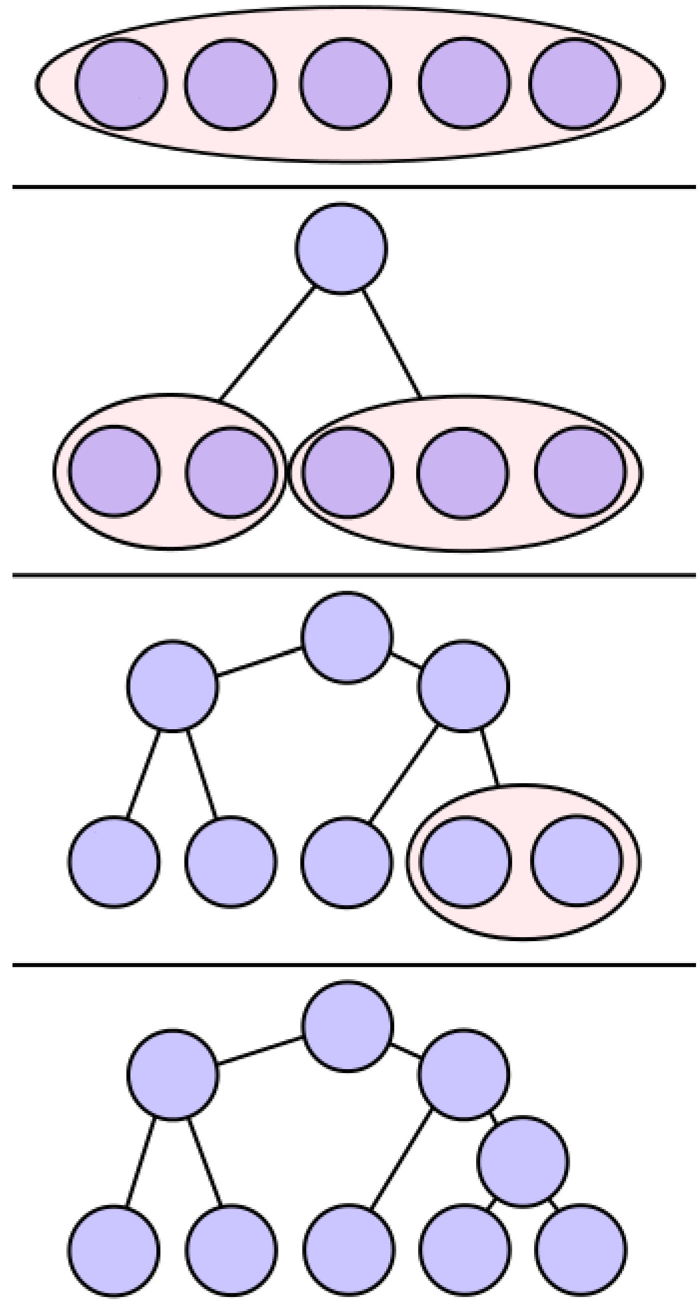
From Chapter 3 of
MIT 6.02 DRAFT Lecture Notes, Feb 13, 2012

Questions?

- Beyond D2L
  - Examples and information can be found online at:
    - *http://docdingle.com/teaching/cs.html*

    - *Continue to more stuff as needed*

Extra Reference Stuff Follows



Credits

- Much of the content derived/based on slides for use with the book:
  - *Digital Image Processing,* Gonzalez and Woods

- Some layout and presentation style derived/based on presentations by
  - Donald House, Texas A&M University, 1999
  - Bernd Girod, Stanford University, 2007
  - Shreekanth Mandayam, Rowan University, 2009
  - Igor Aizenberg, TAMUT, 2013
  - Xin Li, WVU, 2014
  - George Wolberg, City College of New York, 2015
  - Yao Wang and Zhu Liu, NYU-Poly, 2015
  - Sinisa Todorovic, Oregon State, 2015