Image Coding

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i) digital storage ii) digital transmission

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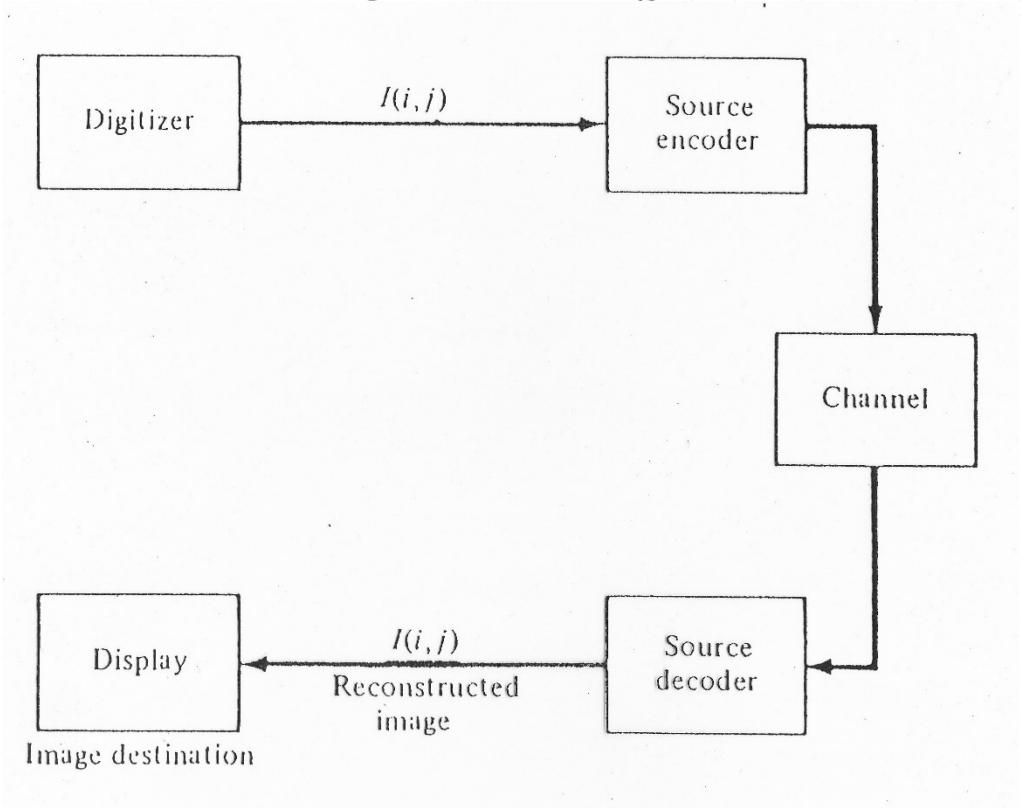

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For image sequences, we can take every nth frame. (lossy)

Run-Length Encoding exploits the fact that most rows in binary images contain long strings of identical pixel values.

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(Ex) 000001111111111000

Can code as 5 9 3 if we assume the row starts with 0

Run-Length Encoding works well if most of the strings are long.

```
00000000000000000000000000011111111111111000000000     28 14  9
00000000000000000000000000111111111111111110000000     26 18  7
00000000000000000000000001111111111111111111110000     23 24  4
00000000000000000000000011111111111111111111111000     22 26  3
00000000000000000000001111111111111111111111111110     20 30  1
00000000000000000000111111100000000000000000001111111  19  7 18 7
00000000000000000001111100000000000000000000011111     19  5 22 5
00000000000000000011100000000000000000000000000111     19  3 26 3
00000000000000000011100000000000000000000000000111     19  3 26 3
00000000000000000011100000000000000000000000000111     19  3 26 3
00000000000000000011100000000000000000000000000111     19  3 26 3
00000000000000000011110000000000000000000000001110     20  4 23 3 1
00000000000000000001110000000000000000000000111000     22  3 20 3 3
01111111111111111111111111111111111111111111111111111  1  50
01111111111111111111111111111111111111111111111111111  1  50
01111111111111111111111111111111111111111111111111111  1  50
01111111111111111111111111111111111111111111111111111  1  50
01111111111111111111111111111111111111111111111111111  1  50
01100000000000000000000000000000000000000000000000011  1   2 46 2
```

00000000000000000000000000011111111111111000000000	28 14 9
00000000000000000000000000111111111111111110000000	26 18 7
00000000000000000000000001111111111111111111110000	23 24 4
00000000000000000000000011111111111111111111111000	22 26 3
00000000000000000000001111111111111111111111111110	20 30 1
00000000000000000000111111100000000000000000001111111	19 7 18 7
00000000000000000001111100000000000000000000011111	19 5 22 5
00000000000000000001110000000000000000000000000111	19 3 26 3
00000000000000000001110000000000000000000000000111	19 3 26 3
00000000000000000001110000000000000000000000000111	19 3 26 3
00000000000000000001110000000000000000000000000111	19 3 26 3
00000000000000000001111000000000000000000000001110	20 4 23 3 1
00000000000000000000111000000000000000000000111000	22 3 20 3 3
01111111111111111111111111111111111111111111111111	1 50
01111111111111111111111111111111111111111111111111	1 50
01111111111111111111111111111111111111111111111111	1 50
01111111111111111111111111111111111111111111111111	1 50
01111111111111111111111111111111111111111111111111	1 50
01100000000000000000000000000000000000000000000011	1 2 46 2

Image has 19x51 = 969 bits

0000000000000000000000000001111111111111000000000	28 14 9
0000000000000000000000000011111111111111110000000	26 18 7
0000000000000000000000001111111111111111111110000	23 24 4
0000000000000000000000011111111111111111111111000	22 26 3
0000000000000000000001111111111111111111111111110	20 30 1
0000000000000000000011111110000000000000000001111111	19 7 18 7
0000000000000000000011111000000000000000000000011111	19 5 22 5
0000000000000000000011100000000000000000000000000111	19 3 26 3
0000000000000000000011100000000000000000000000000111	19 3 26 3
0000000000000000000011100000000000000000000000000111	19 3 26 3
0000000000000000000011100000000000000000000000000111	19 3 26 3
0000000000000000000011110000000000000000000000001110	20 4 23 3 1
0000000000000000000001110000000000000000000000111000	22 3 20 3 3
0111111111111111111111111111111111111111111111111111	1 50
0111111111111111111111111111111111111111111111111111	1 50
0111111111111111111111111111111111111111111111111111	1 50
0111111111111111111111111111111111111111111111111111	1 50
0111111111111111111111111111111111111111111111111111	1 50
0110000000000000000000000000000000000000000000000011	1 2 46 2

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Run-Length Encoding has 63 counts.

0000000000000000000000000001111111111111000000000	28 14 9
0000000000000000000000000011111111111111110000000	26 18 7
0000000000000000000000001111111111111111111110000	23 24 4
0000000000000000000000011111111111111111111111000	22 26 3
0000000000000000000001111111111111111111111111110	20 30 1
0000000000000000000011111110000000000000000001111111	19 7 18 7
0000000000000000000011111000000000000000000000011111	19 5 22 5
0000000000000000000011100000000000000000000000000111	19 3 26 3
0000000000000000000011100000000000000000000000000111	19 3 26 3
0000000000000000000011100000000000000000000000000111	19 3 26 3
0000000000000000000011100000000000000000000000000111	19 3 26 3
0000000000000000000011110000000000000000000000001110	20 4 23 3 1
0000000000000000000001110000000000000000000000111000	22 3 20 3 3
0111111111111111111111111111111111111111111111111111	1 50
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0110000000000000000000000000000000000000000000000011	1 2 46 2

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Need 6 bits/count

0000000000000000000000000001111111111111000000000	28 14 9
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0000000000000000000011111110000000000000000001111111	19 7 18 7
0000000000000000000011111000000000000000000000011111	19 5 22 5
0000000000000000000011100000000000000000000000000111	19 3 26 3
0000000000000000000011100000000000000000000000000111	19 3 26 3
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Image has 19x51 = 969 bits

Run-Length Encoding has 63 counts.

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Run-Length Encoding requires 63x6 = 378 bits

0000000000000000000000000001111111111111000000000	28 14 9
0000000000000000000000000011111111111111110000000	26 18 7
0000000000000000000000001111111111111111111110000	23 24 4
0000000000000000000000011111111111111111111111000	22 26 3
0000000000000000000001111111111111111111111111110	20 30 1
0000000000000000000011111110000000000000000001111111	19 7 18 7
0000000000000000000011111000000000000000000000011111	19 5 22 5
0000000000000000000011100000000000000000000000000111	19 3 26 3
0000000000000000000011100000000000000000000000000111	19 3 26 3
0000000000000000000011100000000000000000000000000111	19 3 26 3
0000000000000000000011100000000000000000000000000111	19 3 26 3
0000000000000000000011110000000000000000000000001110	20 4 23 3 1
0000000000000000000000111000000000000000000000111000	22 3 20 3 3
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0111111111111111111111111111111111111111111111111111	1 50
0111111111111111111111111111111111111111111111111111	1 50
0111111111111111111111111111111111111111111111111111	1 50
0111111111111111111111111111111111111111111111111111	1 50
0110000000000000000000000000000000000000000000000011	1 2 46 2

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Lossless

Variable-Length Encoding

When representing gray level images, instead of using a fixed number, e.g. 8, of bits per pixel, use only a few bits for pixel values that appear often and more bits for pixel values that appear rarely.

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(Ex) Suppose pixel values are 0 to 26.
This requires 5 bits per pixel.

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11 pixels

1	2	18	1	3	1	4	1	2	18	1
A	B	R	A	C	A	D	A	B	R	A

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1	2	18	1	3	1	4	1	2	18	1
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standard binary code 00001|00010|10010|00001|00011|...
55 bits

1	2	18	1	3	1	4	1	2	18	1
A	B	R	A	C	A	D	A	B	R	A

Pixel Value	#Appearances
1	5
2	2
18	2
3	1
4	1

1	2	18	1	3	1	4	1	2	18	1
A	B	R	A	C	A	D	A	B	R	A

Pixel Value	#Appearances
1	5
2	2
18	2
3	1
4	1

Approach – assign shortest codes to most common pixel values

Pixel Value	Code
1	0
2	1
18	01
3	10
4	11

1	2	18	1	3	1	4	1	2	18	1
A	B	R	A	C	A	D	A	B	R	A

Pixel Value	Code
1	0
2	1
18	01
3	10
4	11

1	2	18	1	3	1	4	1	2	18	1
A	B	R	A	C	A	D	A	B	R	A

Pixels would get encoded as

0 1 0 1 0 1 0 0 1 1 0 1 0 1 0 (15 bits)

Pixel Value	Code
1	0
2	1
18	01
3	10
4	11

1	2	18	1	3	1	4	1	2	18	1
A	B	R	A	C	A	D	A	B	R	A

Pixel Value	Code
1	0
2	1
18	01
3	10
4	11

Pixels would get encoded as

0 1 0 1 0 1 0 0 1 1 0 1 0 1 0 (15 bits)

But this doesn't work. The string could be decoded as

18 18 18 1 18 2 18 18 1

1	2	18	1	3	1	4	1	2	18	1
A	B	R	A	C	A	D	A	B	R	A

Pixel Value	Code
1	0
2	1
18	01
3	10
4	11

Pixels would get encoded as

0 1 0 1 0 1 0 0 1 1 0 1 0 1 0 (15 bits)

But this doesn't work. The string could be decoded as

18 18 18 1 18 2 18 18 1

We need to design the code so that no pixel code is the prefix of another.

1	2	18	1	3	1	4	1	2	18	1
A	B	R	A	C	A	D	A	B	R	A

Pixel Value	Code
1	0
2	1
18	01
3	10
4	11

Pixels would get encoded as

0 1 0 1 0 1 0 0 1 1 0 1 0 1 0 (15 bits)

But this doesn't work. The string could be decoded as

18 18 18 1 18 2 18 18 1

We need to design the code so that no pixel code is the prefix of another.

(Ex)

Pixel Value	Code
1	11
2	00
18	011
3	010
4	10

String would be encoded as

11 00 011 11 010 11 10 11 00 011 11 (25 bits)

Now decoding is unique

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11 00 011 11 010 11 10 11 00 011 11 (25 bits)

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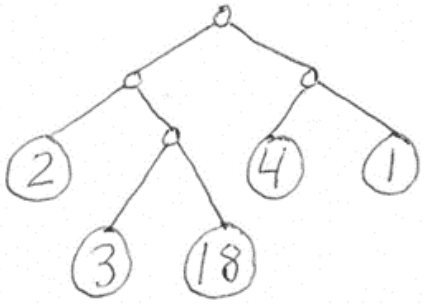
Can represent this code using a trie



0 = go left
1 = go right

2 = 00
3 = 010
18 = 011
4 = 10
1 = 11

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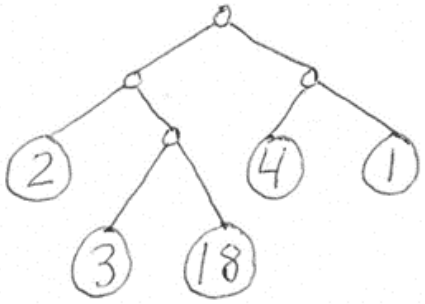

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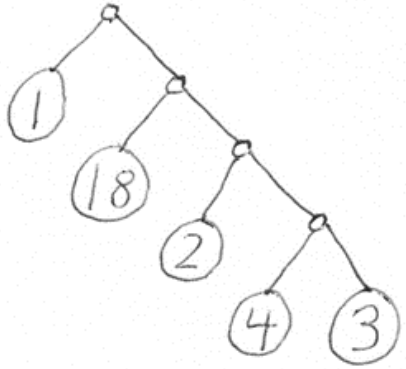
Another possibility



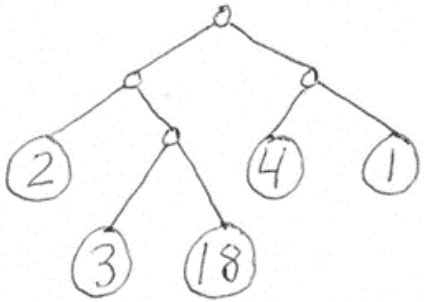
1 = 0
18 = 10
2 = 110
4 = 1110
3 = 1111

String would be encoded as

11 00 011 11 010 11 10 11 00 011 11 (25 bits)

Now decoding is unique

Can represent this code using a trie



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4 = 10
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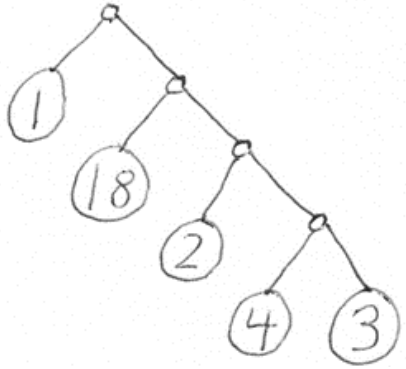

1 = 0
18 = 10
2 = 110
4 = 1110
3 = 1111

Pixels would get encoded as

0 110 10 0 1111 0 1110 0 110 10 0 (23 bits)

How do we determine the best code (trie)?

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Frequently used values should be near the top, rarely used values should be near the bottom.

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Huffman Coding

(Ex) "A SIMPLE STRING TO BE ENCODED USING A MINIMAL NUMBER OF BITS"

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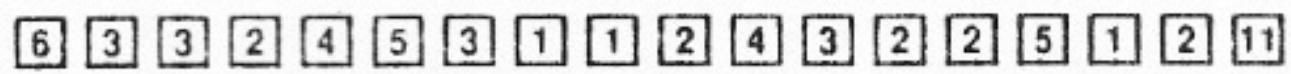
First build a histogram.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
k	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
count[k]	11	3	3	1	2	5	1	2	0	6	0	0	2	4	5	3	1	0	2	4	3	2	0	0	0	0	0

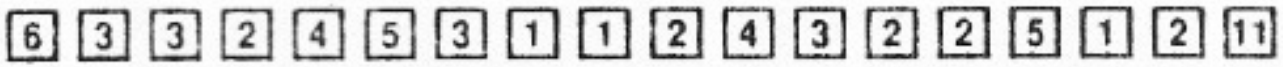
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
k	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
count[k]	11	3	3	1	2	5	1	2	0	6	0	0	2	4	5	3	1	0	2	4	3	2	0	0	0	0	0

Create a node for each nonzero count

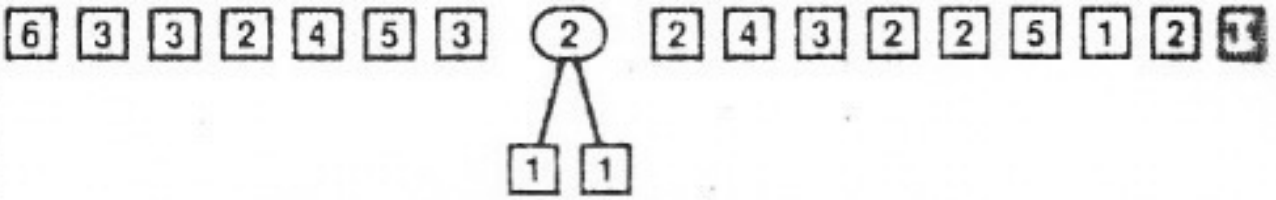


	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
k	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
count[k]	11	3	3	1	2	5	1	2	0	6	0	0	2	4	5	3	1	0	2	4	3	2	0	0	0	0	0

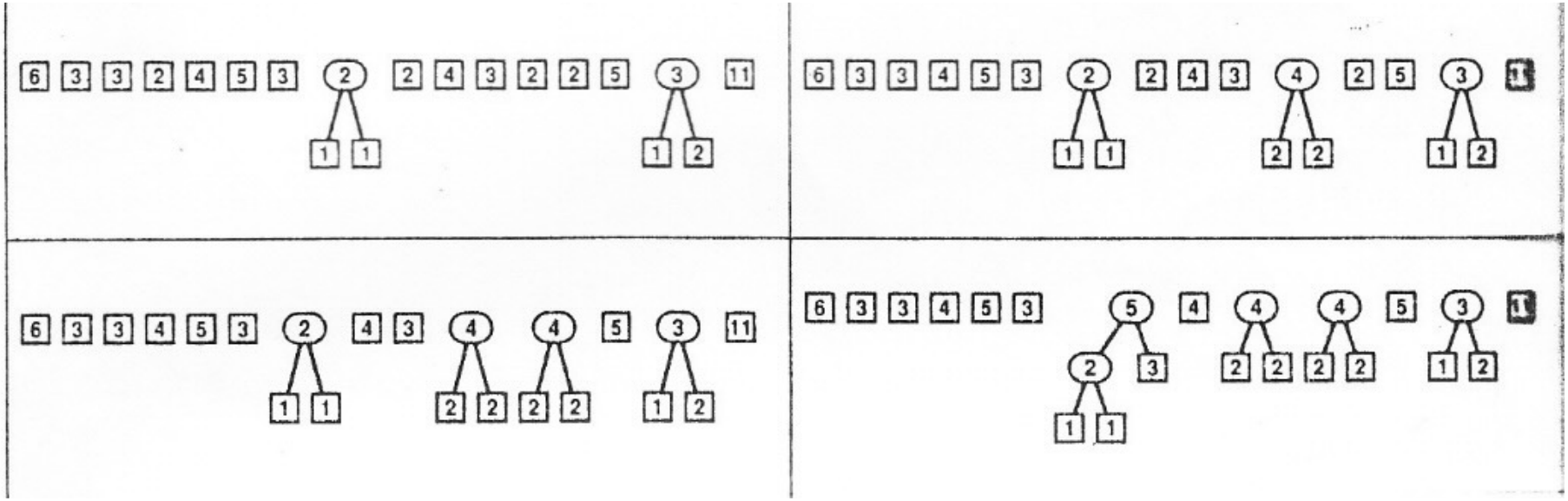
Create a node for each nonzero count



Find the 2 top level nodes with the smallest counts and create a new node with these 2 nodes as children and with a count the sum of the counts of the children.



Repeat until we get a single trie.



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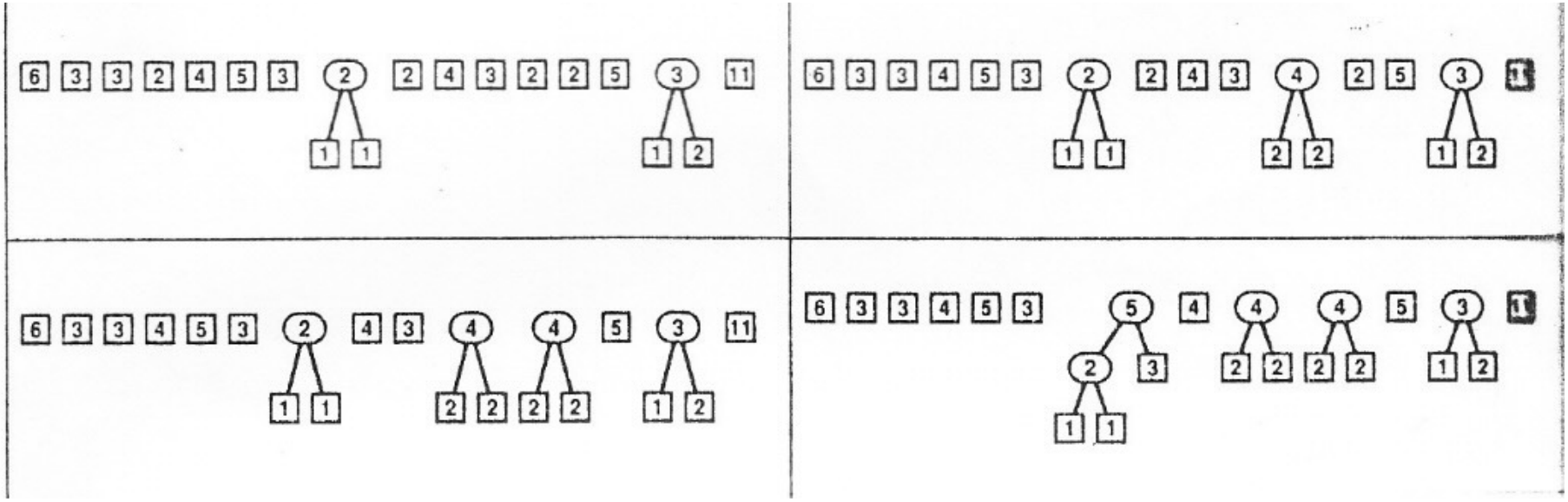
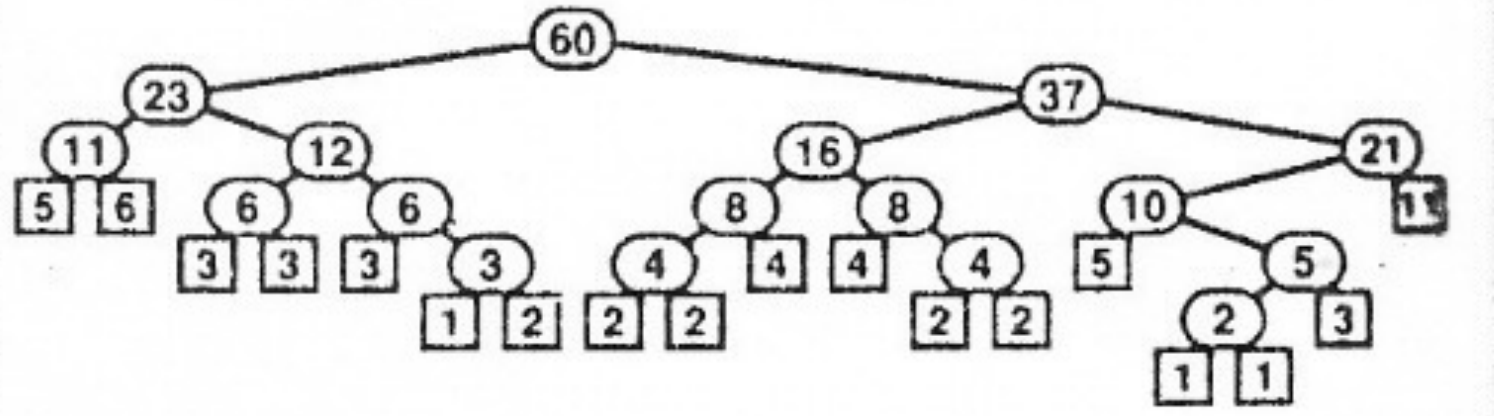
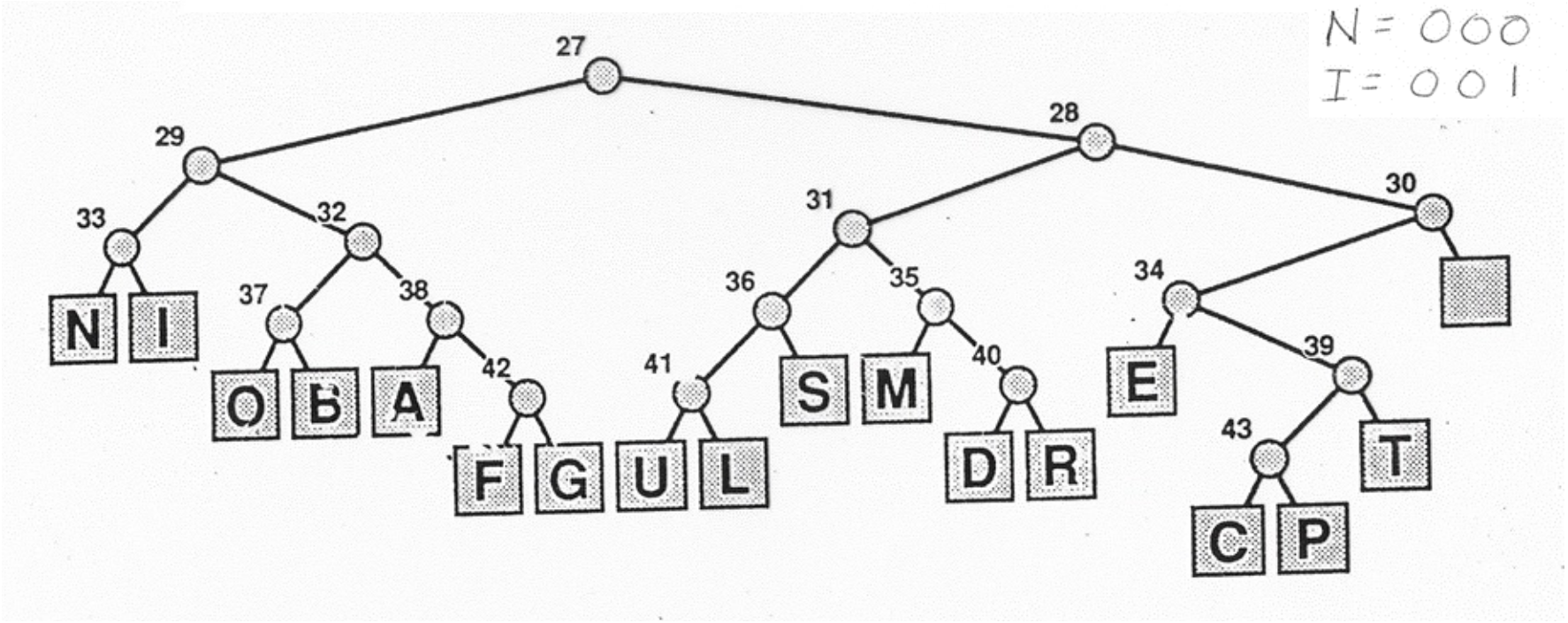




Replace the frequencies at the bottom nodes with the associated letters and view as an encoding trie.



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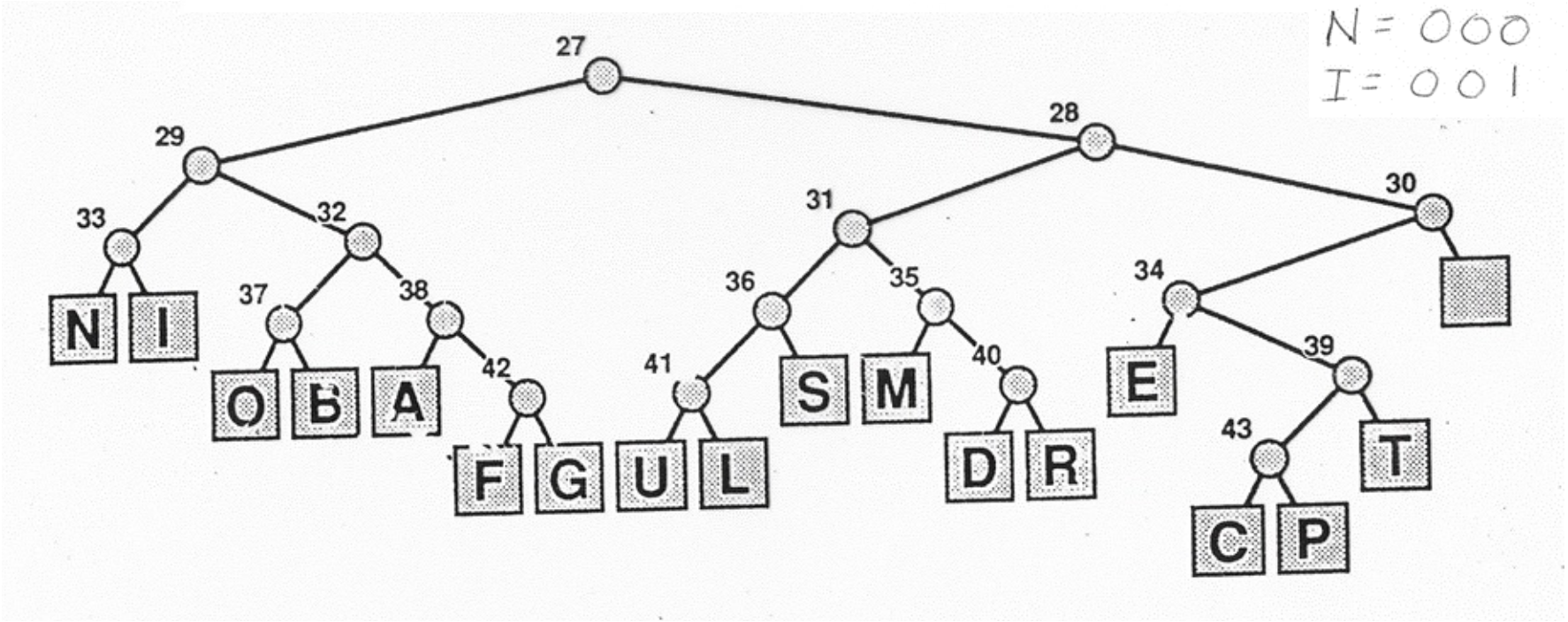

The resolting trie gives the Huffman code which uses the minimum number of bits.