This is CS 50.

Harvard College's Introduction to Computer Science I

COMPUTER SCIENCE 50

WEEK 7

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Valgrind

http://valgrind.org/docs/manual/quick-start.html

```
% valgrind -v --leak-check=full a.out

...
==23596== Invalid write of size 4
==23596==    at 0x80486DF: f (memory.c:22)
==23596==    by 0x80486FC: main (memory.c:29)
...
==23596== 40 bytes in 1 blocks are definitely lost in loss record 1 of 1
==23596==    at 0x4023595: malloc (vg_replace_malloc.c:149)
==23596==    by 0x80486D5: f (memory.c:21)
==23596==    by 0x80486FC: main (memory.c:29)
```

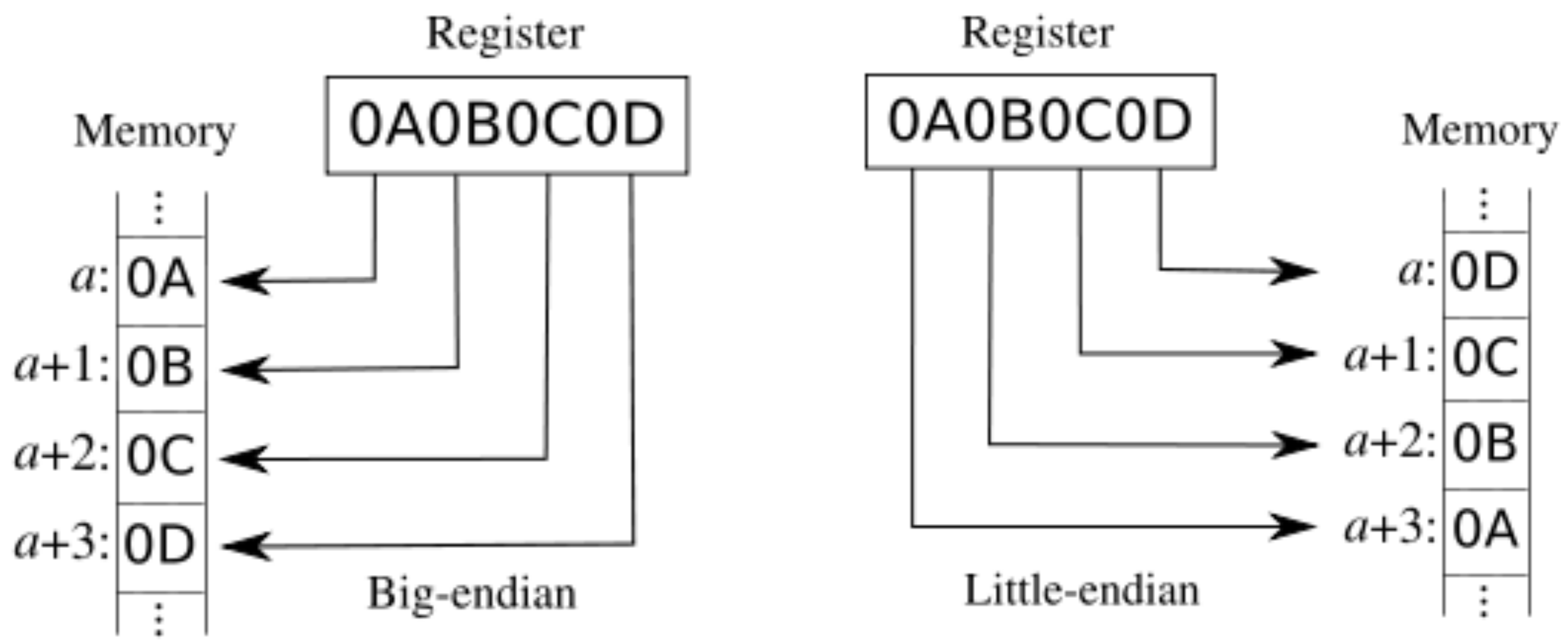
see
memory.c

Hexadecimal

0x01, ah ah ah....
0x02, ah ah ah...
0x03, ah ah ah...

Image from http://toughpigs.com/labels/fanaticism.html.

Endianness



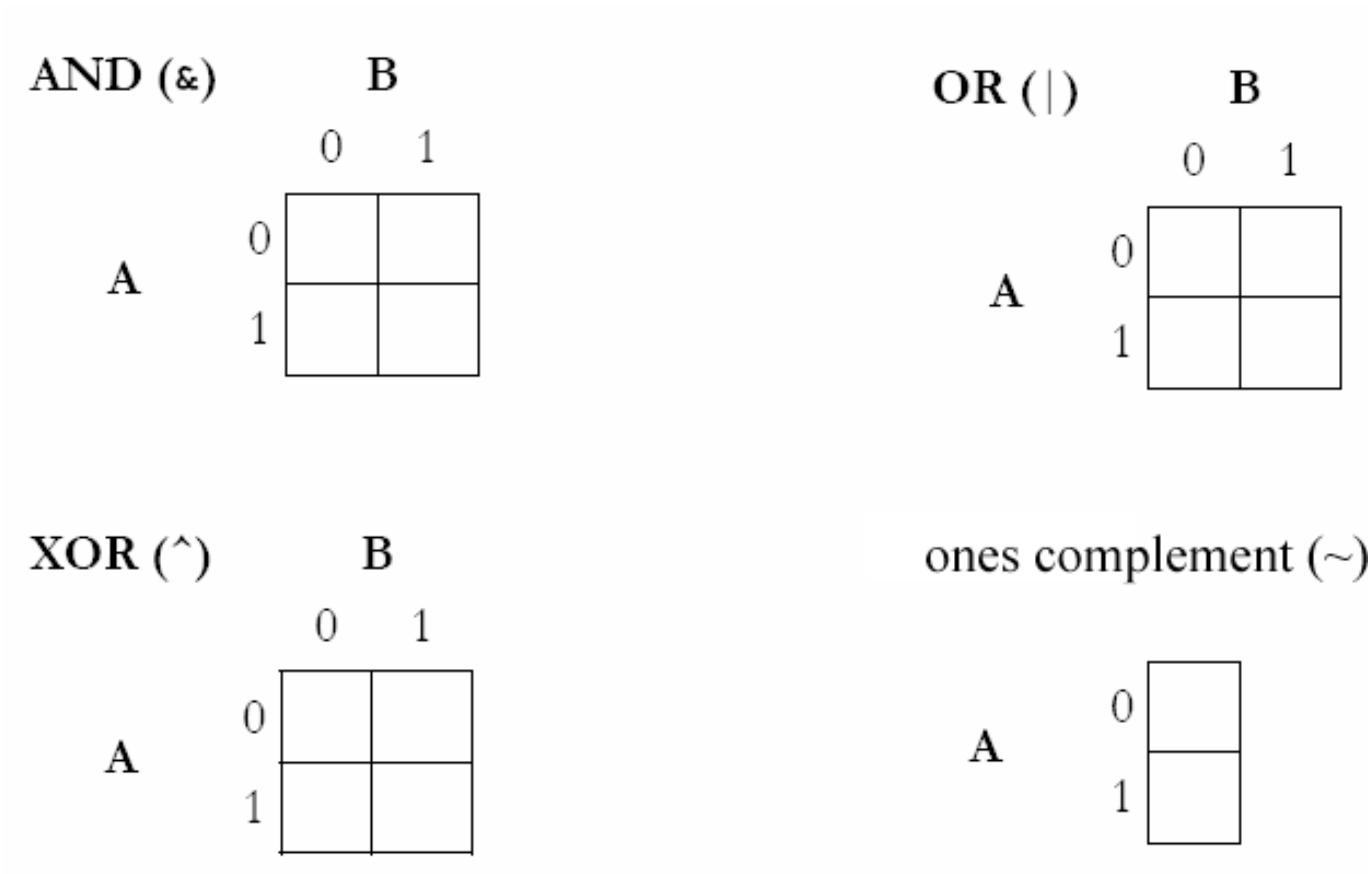
see
`endian.c`

Image from http://en.wikipedia.org/wiki/Endianness.

Bitwise Operators

&	bitwise AND
|	bitwise OR
^	bitwise XOR
~	ones complement
<<	left shift
>>	right shift

Bitwise Operators



see
`binary.c, tolower.c, toupper.c`

Bitwise Operators

Swapping Values

```
int FOO = 1;
int BAR = 4;

                 // base-2 value in x         base-2 value in y
int x = FOO;     // 001
int y = BAR;     // 001                                     100

x = x ^ y;       // 001 ^ 100                               100
                 // 101
y = x ^ y;       // 101                               101 ^ 100
                 //                                         001
x = x ^ y;       // 101 ^ 001                               001
                 // 100
```

see
swap2.c

Bitwise Operators

Swapping Values

```
int FOO = 1;
int BAR = 4;

                // value in x                      value in y
int x = FOO;    // FOO
int y = BAR;    // FOO                                    BAR

x = x ^ y;      // FOO ^ BAR                              BAR
y = x ^ y;      // FOO ^ BAR                (FOO ^ BAR) ^ BAR
                //                          FOO ^ (BAR ^ BAR)
                //                                    FOO ^ 0
                //                                        FOO
x = x ^ y;      // (FOO ^ BAR) ^ FOO                      FOO
                // FOO ^ BAR ^ FOO
                // FOO ^ FOO ^ BAR
                // (FOO ^ FOO) ^ BAR
                // 0 ^ BAR
                // BAR
```

see
swap2.c

Hashing Tables

Linear Probing

table[0]	
table[1]	
table[2]	
table[3]	
table[4]	
table[5]	
table[6]	
	⋮
table[24]	
table[25]	

Hashing Tables

The Birthday Problem

In a room of n CS 50 students, what's the probability that at least two students share the same birthday?

Hashing Tables

The Birthday Problem

$$\bar{p}(n) = 1 \cdot \left(1 - \frac{1}{365}\right) \cdot \left(1 - \frac{2}{365}\right) \cdots \left(1 - \frac{n-1}{365}\right)$$

$$= \frac{365 \cdot 364 \cdots (365 - n + 1)}{365^n}$$

$$= \frac{365!}{365^n (365 - n)!}$$

Image from http://en.wikipedia.org/wiki/Birthday_paradox.

Hashing Tables

The Birthday Problem

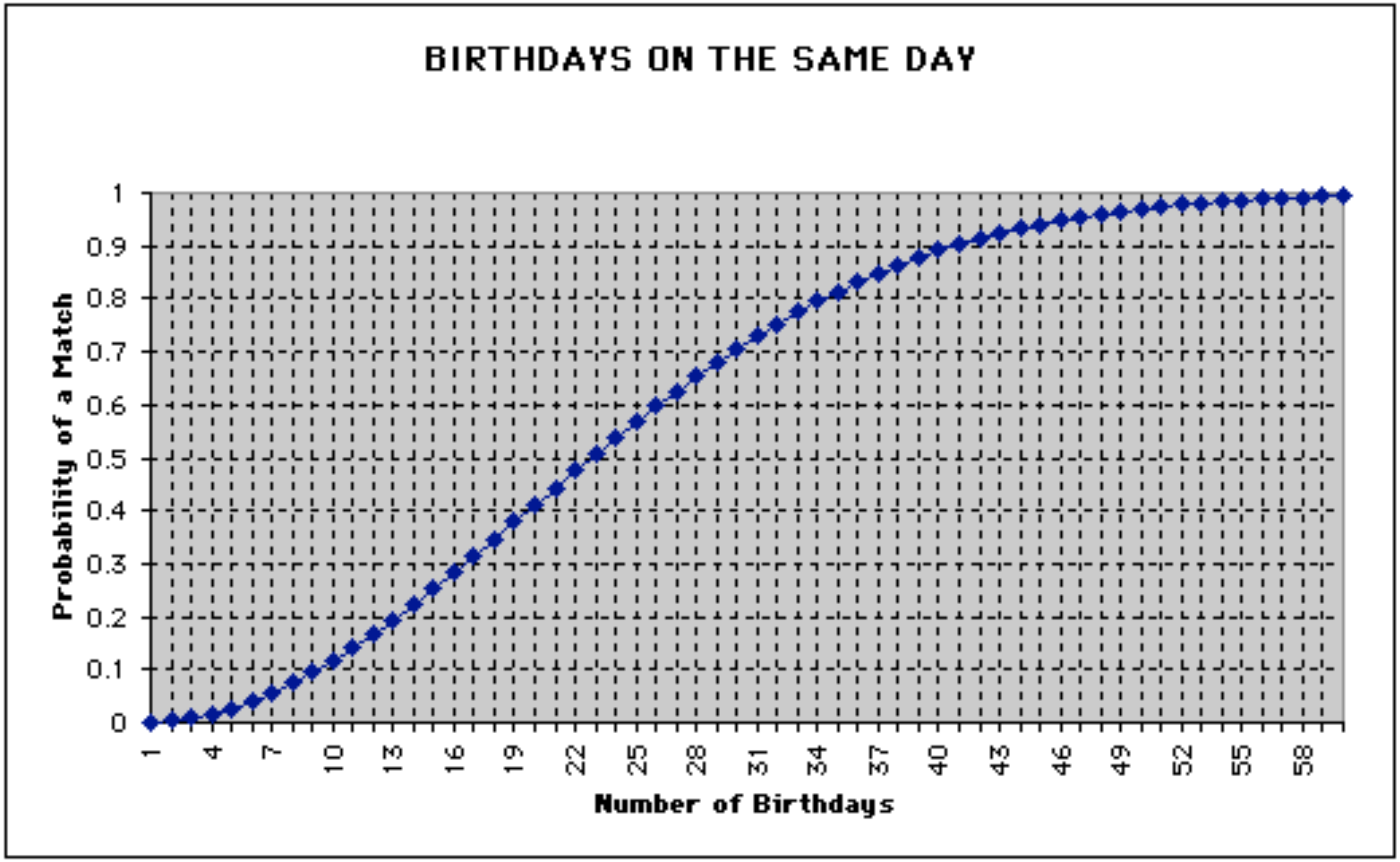


Image from http://www.mste.uiuc.edu/reese/birthday/probchart.GIF.

Hash Tables

Separate Chaining

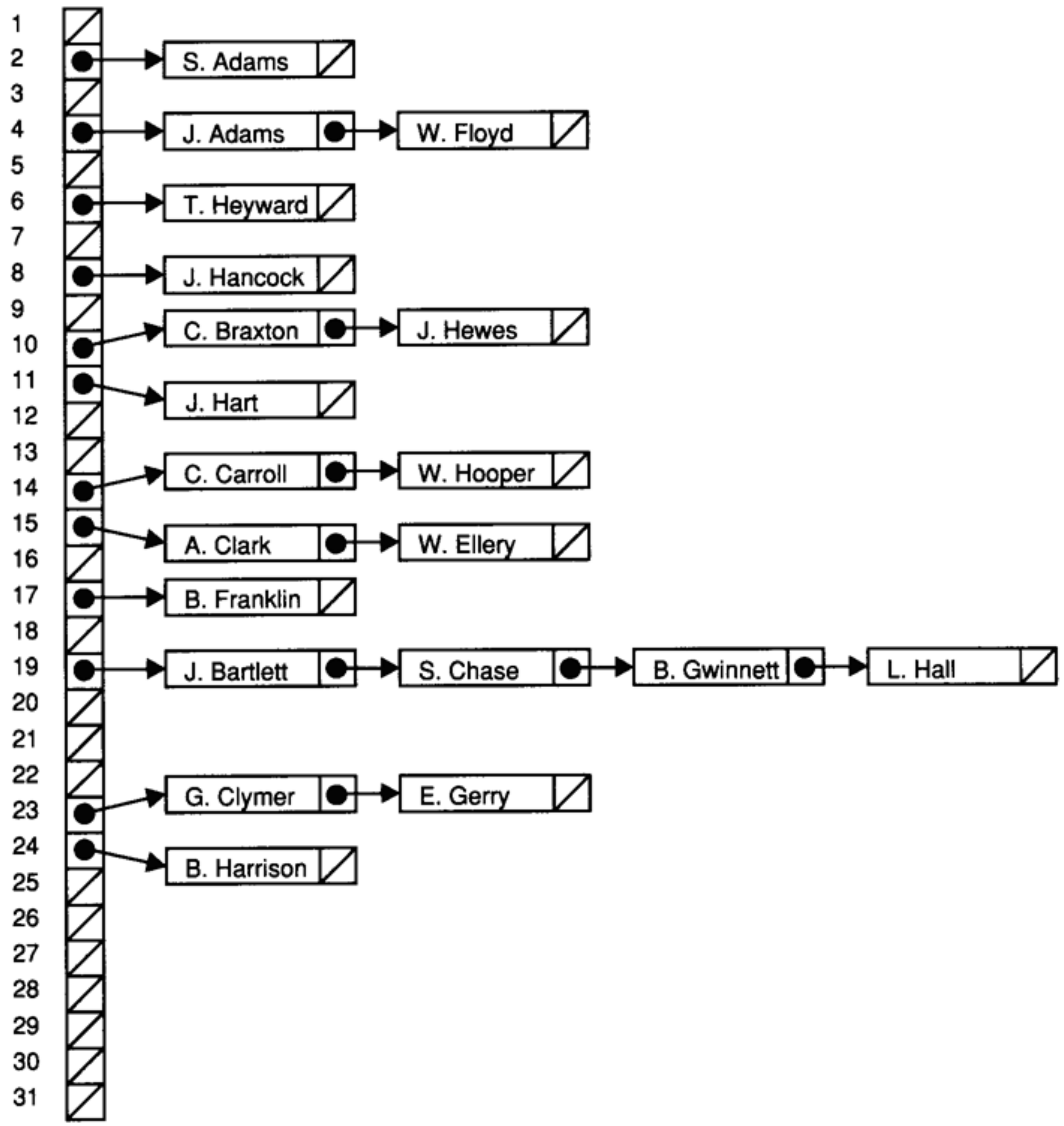


Figure from Lewis and Denenberg's Data Structures & Their Algorithms.

Trees

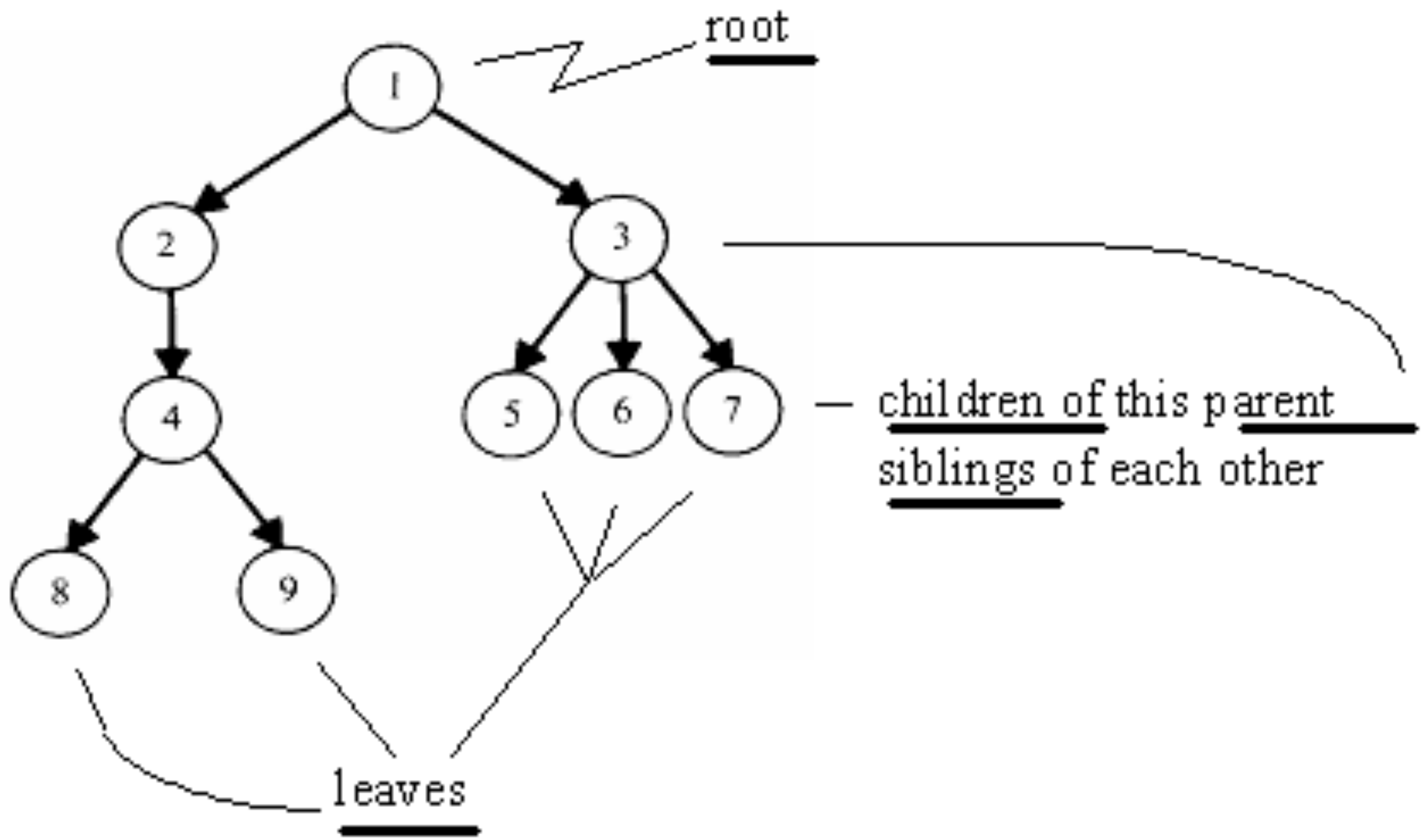


Figure by Larry Nyhoff.

Binary Search Trees

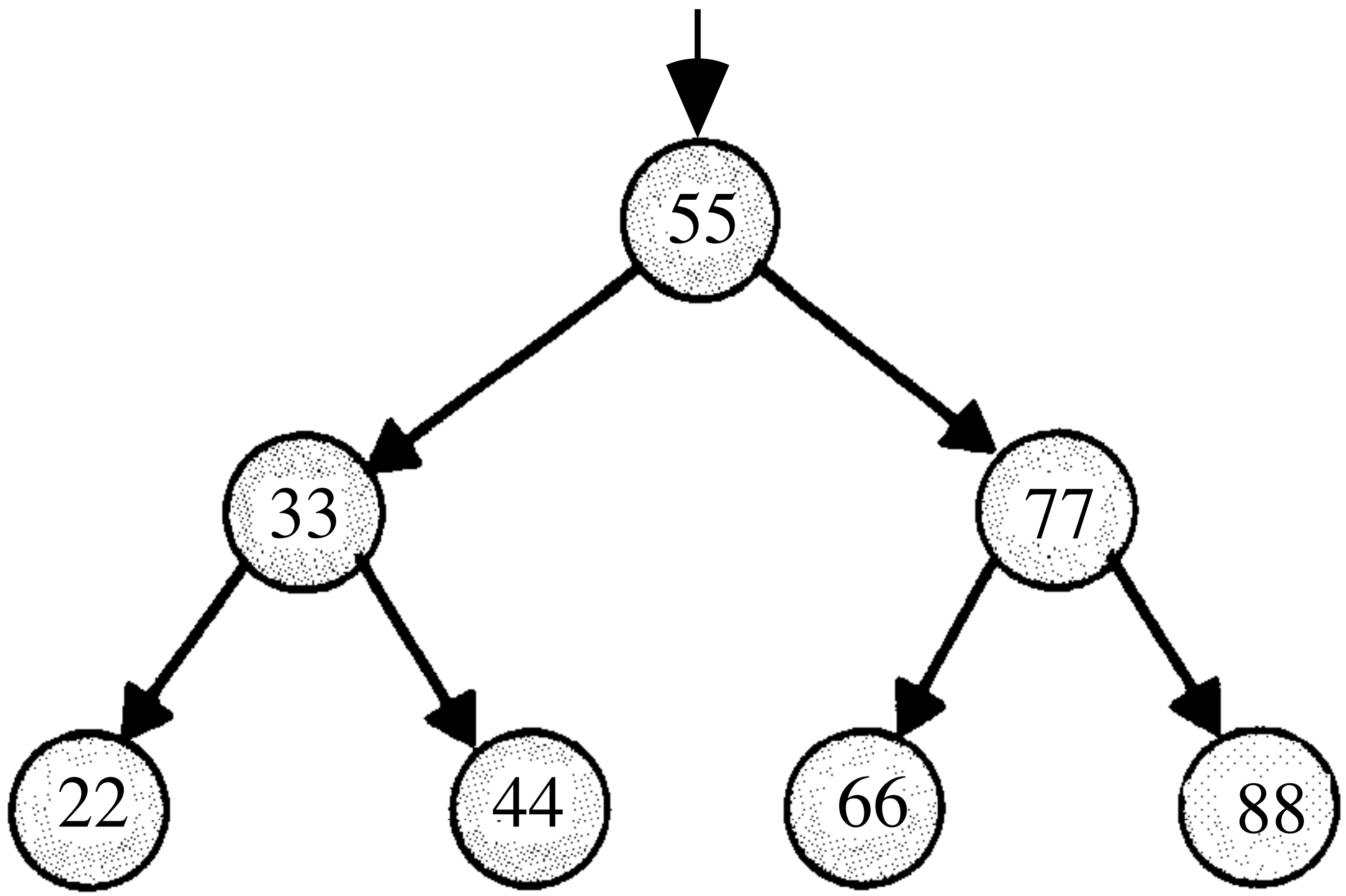


Figure from http://cs.calvin.edu/books/c++/ds/1e/.

Tries

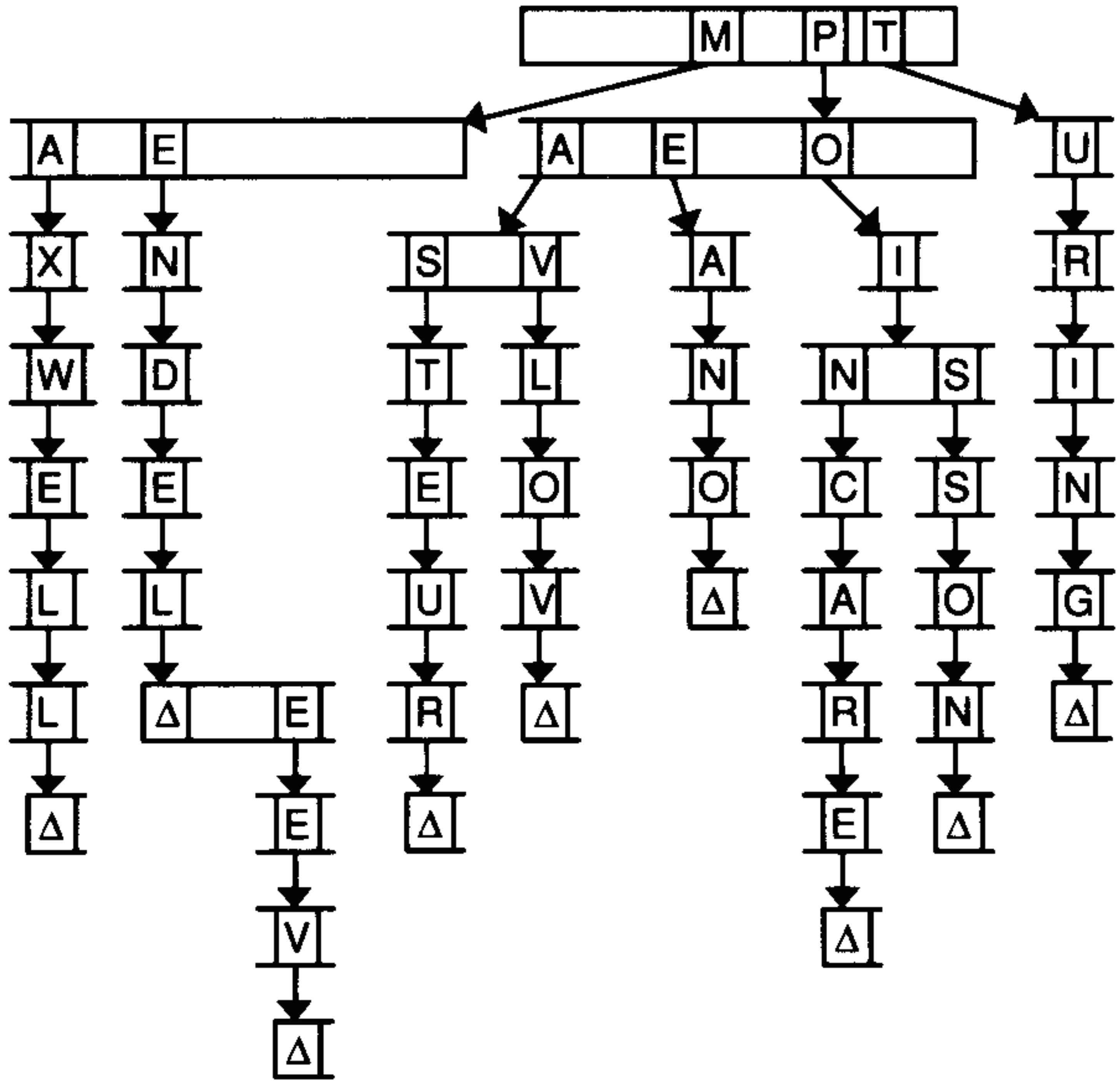


Figure from Lewis and Denenberg's Data Structures & Their Algorithms.

Morse Code

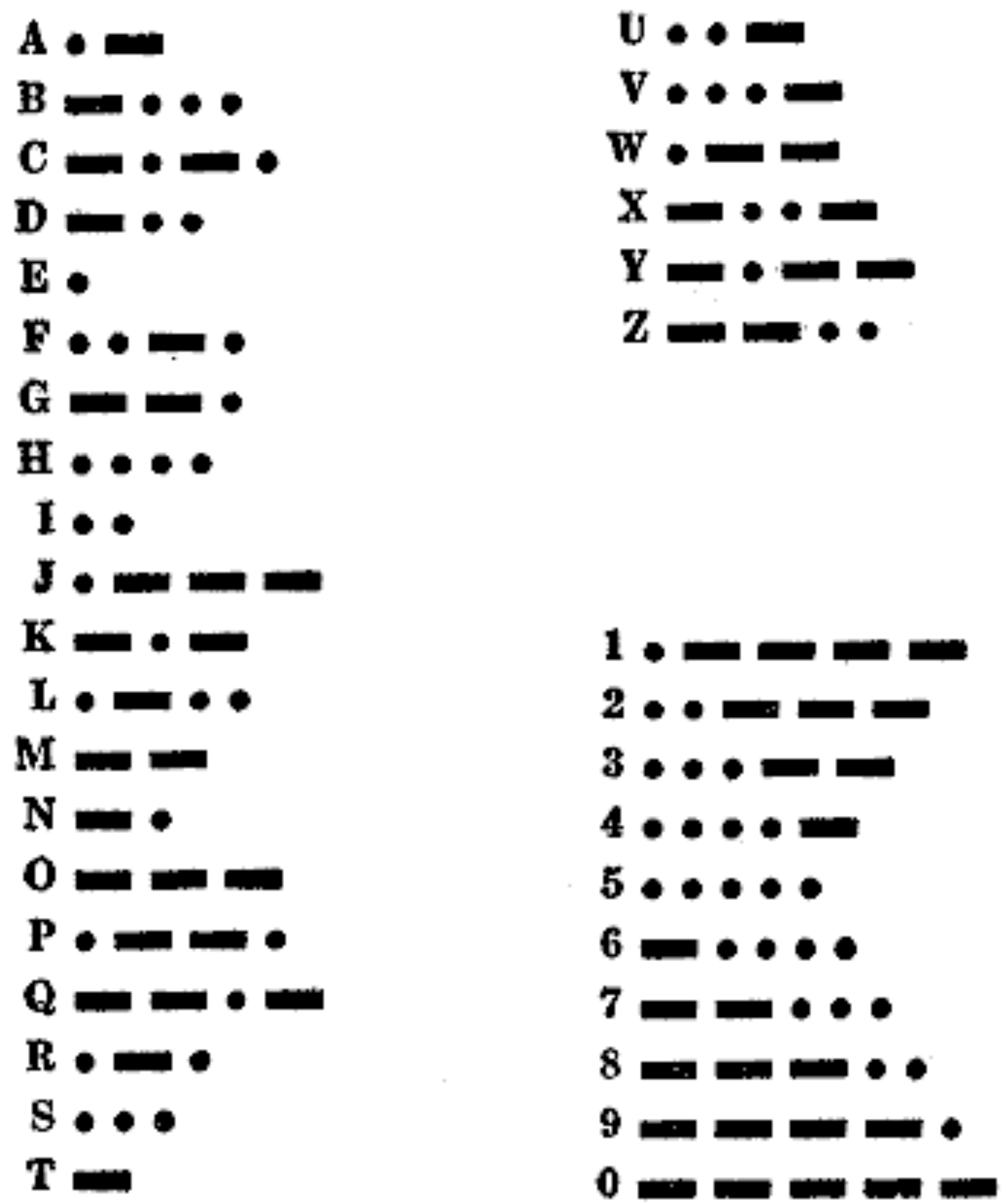


Image adapted from Wikipedia.

Huffman Coding

Immediate Decodability

Initialize a list of one-node binary trees containing weights w_1**,** w_2**, ... ,** w_n**, one for each of the characters** C_1**,** C_2**, ... ,** C_n**.**

1. **Do the following** $n - 1$ **times:**
    1. Find two trees T ' and T " in this list with roots of minimal weight w ' and w ".
    2. Replace these two trees with a binary tree whose root has weight w ' + w " and whose subtrees are T ' and T "; label the pointers to these subtrees 0 and 1, respectively:

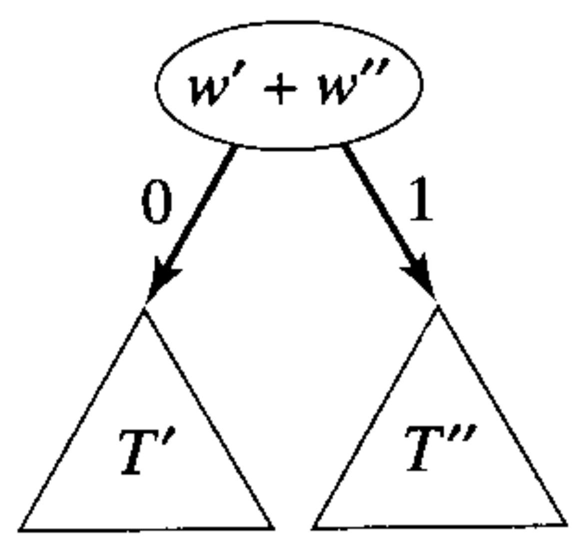


Figure by Larry Nyhoff.

2. **The code for character** C_i **is the bit string labeling the path from root to leaf** C_i **in the final binary tree.**

Huffman Coding

Example

"ECEABEADCAEDEEEECEADEEEEEDBAAEABDBBAAEAAAC DDCCEABEEDCBEEDEAEEEEEAEEDBCEBEEADEAEEDAEBC DEDEAEEDCEEAEEE"

character	A	B	C	D	E
frequency	0.2	0.1	0.1	0.15	0.45

Huffman Coding

Example

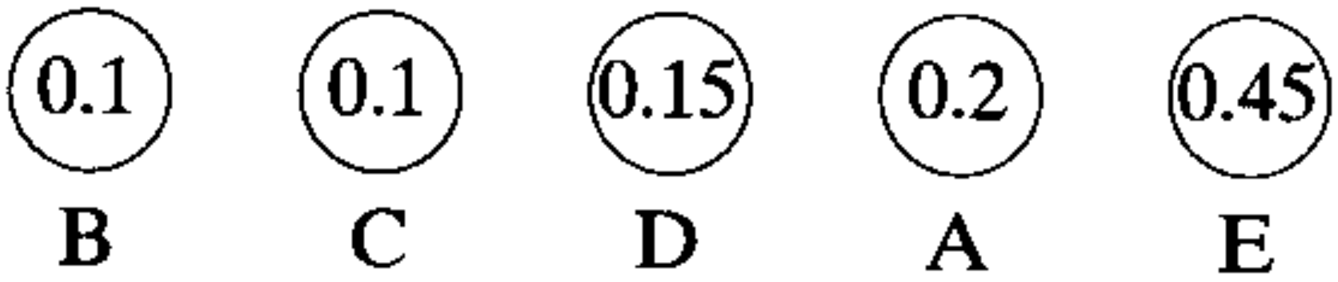


Figure by Larry Nyhoff.

Huffman Coding

Example

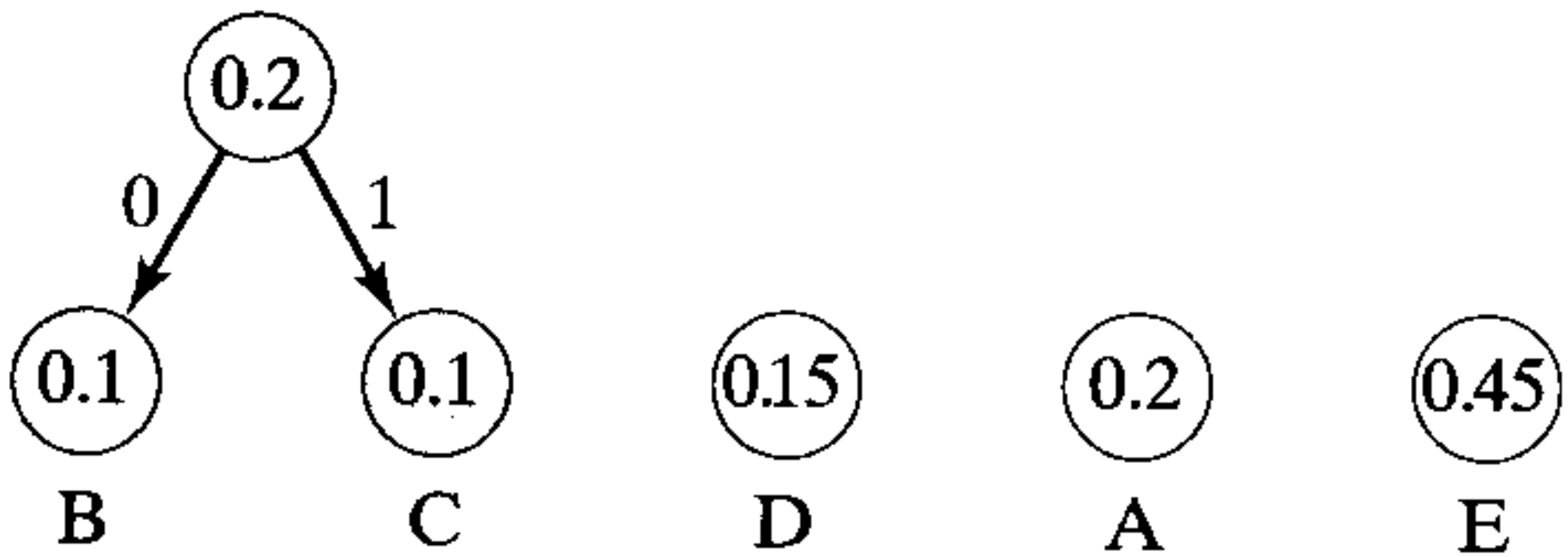


Figure by Larry Nyhoff.

Huffman Coding

Example

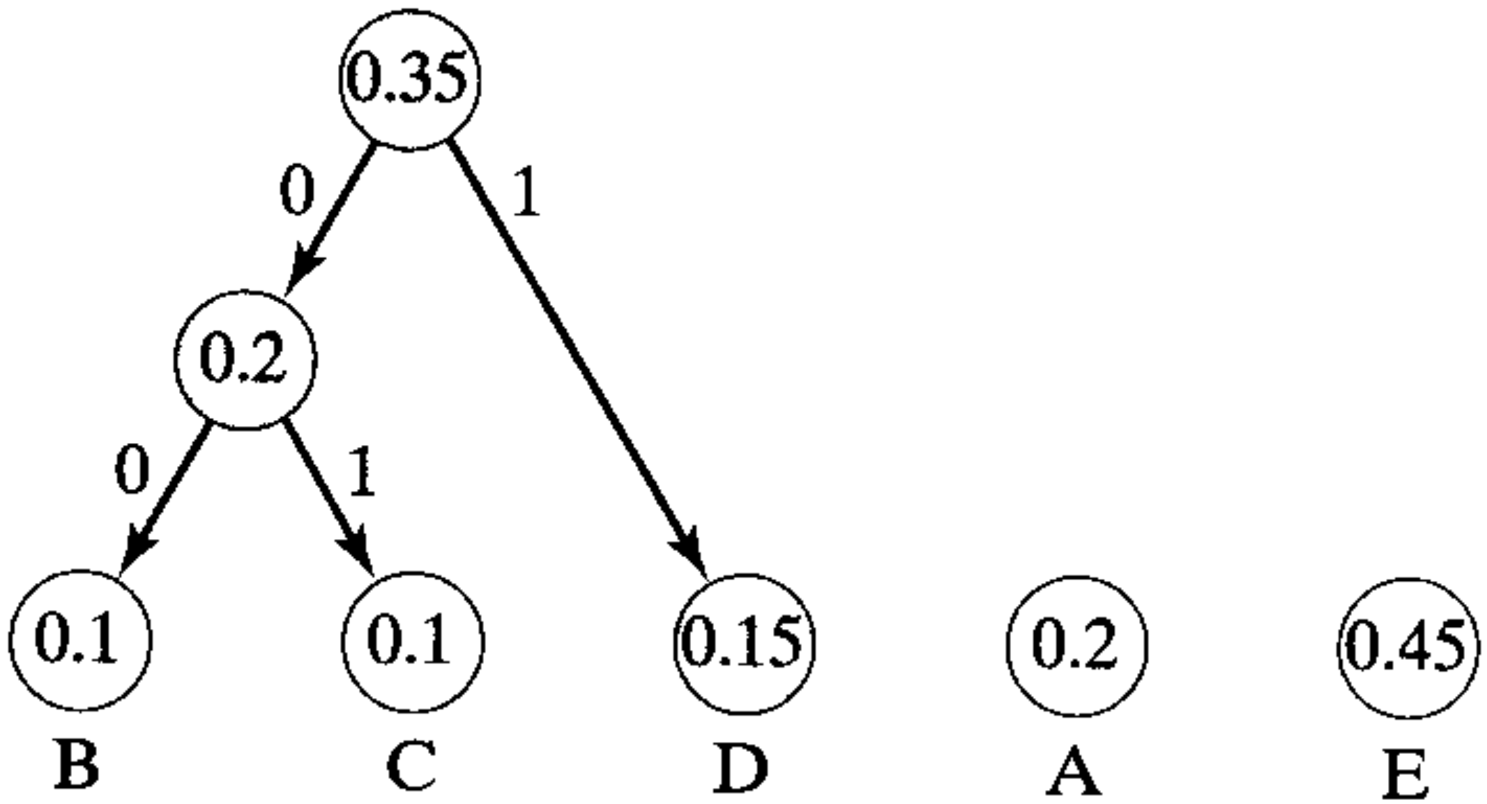


Figure by Larry Nyhoff.

Huffman Coding

Example

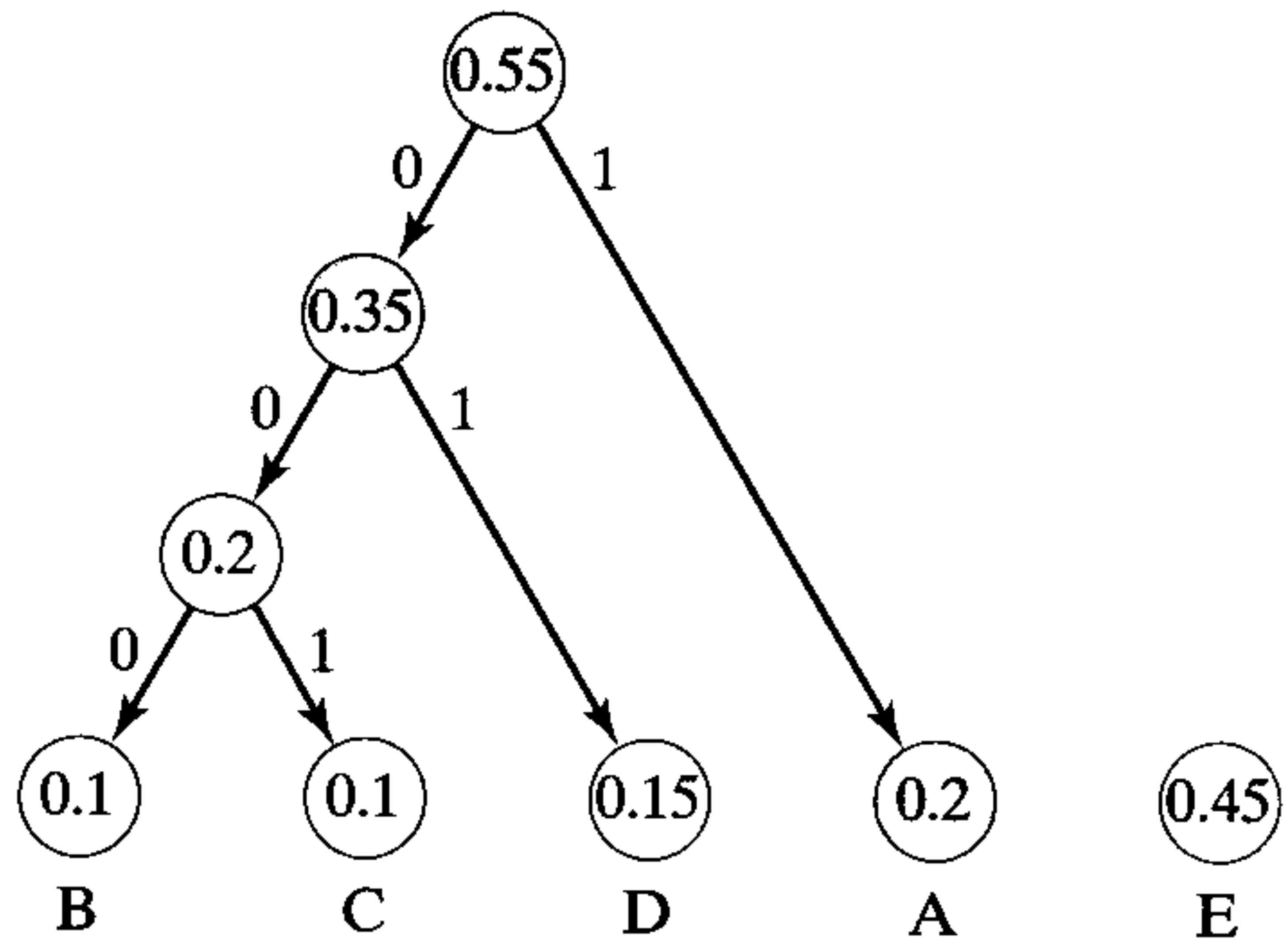


Figure by Larry Nyhoff.

Huffman Coding

Example

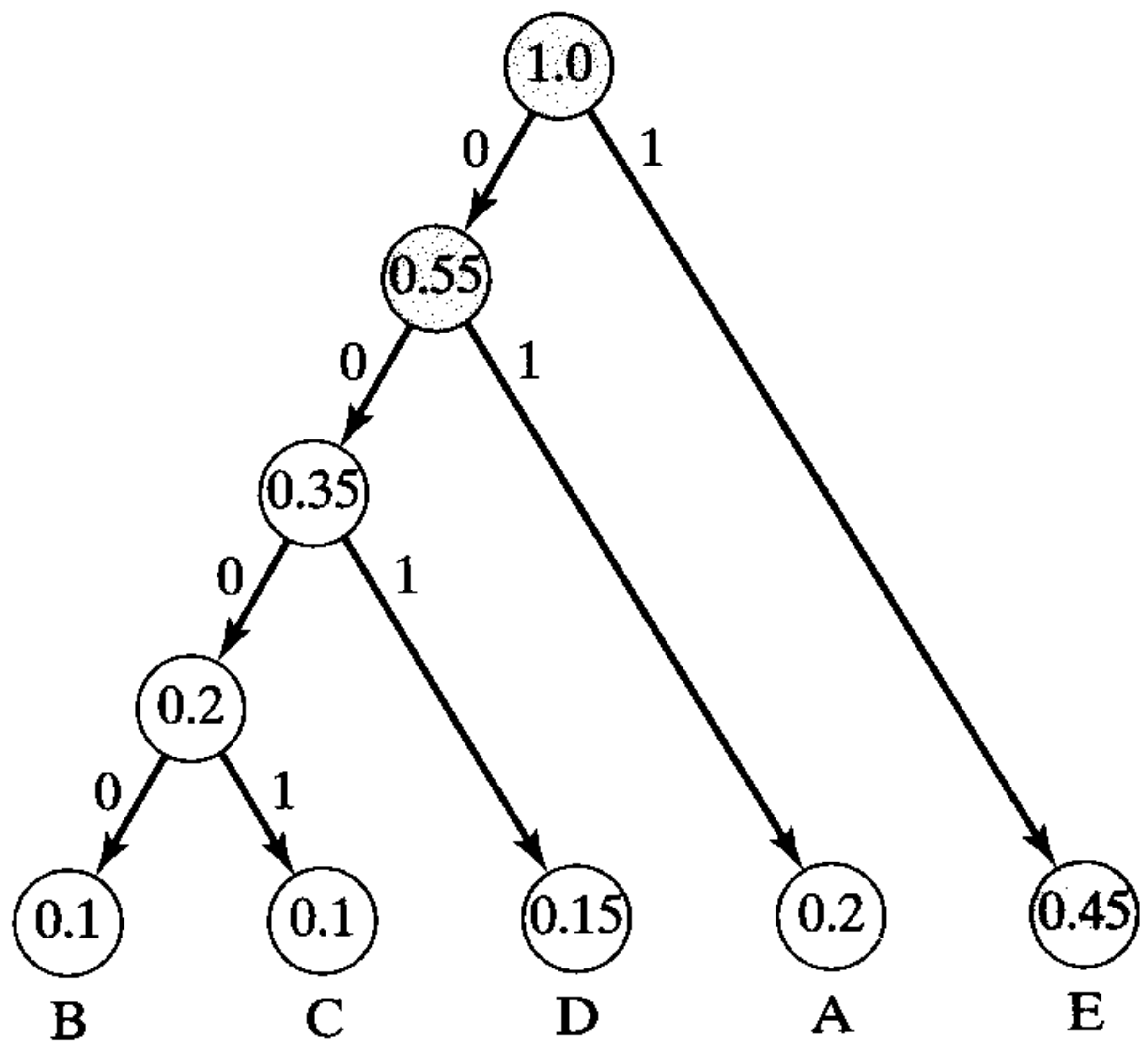


Figure by Larry Nyhoff.

Huffman Coding

In C

```
typedef struct node
{
    char symbol;
    int frequency;
    struct node *left;
    struct node *right;
}
node;
```