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Assignment 5: Hamming Codes
Design Document

I. Description

This assignment is for encoding and decoding hamming codes. To easily do this the encoders and decoders are using Bit Vectors and Bit Matrices.

II. Prelab

1.

0	HAM_CORRECT
1	4
2	5
3	ERR
4	6
5	ERR
6	ERR
7	3
8	7
9	ERR
10	ERR
11	2
12	ERR
13	1
14	0
15	ERR

2.

a. $1110\ 0011_2$

The ~~error~~ syndrome is $\vec{c} \times H^t = 1,0,1,1 \rightarrow 1101_2 \rightarrow 13_{10}$

table[13] = 1 Refer to look up table. ~~Be~~

~~Ba~~ A ~~v~~value of 1 means the first bit ~~n~~needs to be flipped.

b. $1101\ 1000_2$

error syndrome = $(0,1,0,1) \rightarrow 1010_2 \rightarrow 10_{10}$

table[10] = ERR

This means the error is uncorrectable

III. Pseudocode

In order to encode and decode the hamming code we will need to implement Bit Vectors and Bit Matrices. The Pseudocode implementation can be seen below

A. BitVector

The BitVector program is essentially an array of bits. However in order to implement the program more efficiently we can perform bitwise operations on uint8_t to do any operation we want. To set a particular bit we can get the position in the array by dividing by 8 and to get the position of the bit we can modulo by 8.

```
class BitVector:
   def __init__(self, length):
       self.length = length
       self.vector = [0] * length

   def bv_length(self):
       return self.length

   def bv_set_bit(self, i):
       bytepos = i // 8
       bitpos = i % 8
       self.vector[bytepos] = ((1 << bitpos) |
self.vector[bytepos])

   def bv_clr_bit(self, i):
       bytepos = i // 8
       bitpos = i % 8
       self.vector[bytepos] = (self.vector[bytepos] & ~(1 <<
(bitpos)))

   def bv_get_bit(self, i):
       bytepos = i // 8
       bitpos = i % 8
       return (self.vector[bytepos] >> bitpos) & 1

   def bv_xor_bit(self, i, bit):
```

```
        bytepos = i // 8
        bitpos = i % 8
        b = self.bv_get_bit(i)
        # clear bit and then set it to either 0 or 1
        self.vector[bytepos] = (self.vector[bytepos] & (
            ~(1 << bitpos))) | ((b ^ bit) << bitpos)

    def bv_print(self):
        print(self.vector)
```

B. BitMatrix
   The Bit Matrix is essentially a 2D array of bits. However instead of using a 2D array we use a bigger BitVector. The BitMatrix structure makes it easy to use Bit Vector as a 2D array allowing us to specify the row and column of the bit we want to modify

```
class BitMatrix():
    def __init__(self, rows, cols):
        self.rows = rows
        self.cols = cols
        self.BitVector = BitVector(rows * cols)

    def bm_rows(self):
        return self.rows

    def bm_cols(self):
        return self.cols

    def bm_set_bit(self, r, c):
        self.BitVector.bv_set_bit(r * self.cols + c)

    def bm_clr_bit(self, r, c):
        self.BitVector.bv_clr_bit(r * self.cols + c)

    def bm_get_bit(self, r, c):
```

```
        self.BitVector.bv_get_bit(r * self.cols + c)

    def bm_from_data(self, byte, length):
        bm = BitMatrix(1, length)
        for b, i in enumerate(bits(byte)):  # iterate thorugh all
the bits
            if b == 1:
                bm.bm_set_bit(1, i)

        return bm

    def bm_to_data(self, length):
        x = 0
        for i in range(length):
            if self.BitVector.bv_get_bit(i) == 1:
                x |= 1 << i
            else:
                x &= ~(1 << i)
        return x

    def bm_multiply(self, B):
        bm = BitMatrix(self.rows, B.cols)
        for k in range(self.cols):
            for i, j in range(self.rows), range(B.cols):
                A = self.bm_get_bit(i, k)
                B = self.bm_get_bit(k, j)
                res = A ^ B
                if res == 1:
                    bm.bm_set_bit(i, j)

    def bm_print(self):
        print(self.BitVector)
```

C. Hamming module

The Hamming encode is very simple. Just take the Generator matrix that is passed and multiply with the code using bm_from_data. Then return the result of the multiplication through a matrix with bm_to_data

```
ham_encode(BitMatrix G, uint8_t msg) {
        BitMatrix m = bm_from_data(msg,4) only length of 4 since the msg is a nibble
        BitMatrix code = bm_multiply(m,G)
        return bm_to_data(code);
```

Ham Decode is a little harder but still relatively simple. Construct a lookup table with the errors and bytes to flip. This makes it easy to figure out if there is a byte that needs to be flipped

```
ham_decode(BitMatrix ht, uint8_t code, uint8_t msg) {
        Table = [CORRECT,4,5,ERR,6,ERR,ERR,3,7,ERR,ERR,1,0,ERR]
        bm = bm_from_data(code,8)
        Error_syndrome = bm_multiply(bm, Ht)
        Es = bm_to_data(error_syndrome)
        If (es == 0) {
                Return ham_ok and set msg
        }
        Else if table[es] equals ham_err {
                Return ham_err
        }
        If bm_get_bit(bm, 0, table[es] then clear the bit. Else set the bit
        Msg = corrected code
        Return ham_correct
```

D. Encode

The Encoder will read nibbles from a file and encode byte by byte. Pseudocode is shown below. This version of encode has been memoized. This way we can encode large amounts of data a lot faster.

```
main() {
        In_fp = stdin
        Out_fp = stdout
        Struct stat statbuf
        encode_table[16]
        Parse command line arguments for input file and output file
        Change file permissions with fstat and fchmod
        BitMatrix *G = bm_create(4,8)
```

```
        Set the bits in this bit matrix to match the Generator matrix for 8,4 hamming code
        For (i = 0; i < 16; i++) {
                encode_table[i] = ham_encode(G,i)
        }
While (fgetc is not End of File) {
        fputc(encode_table[lower_nibble(byte)],out_fp)
        fputc(encode_table[upper_nibble(byte)],out_fp)
```

E. Decode

Decode functions similarly to encode but lookup table is constructed differently

```
define STATS_INDEX 4
Define STATS_TOTAL 0
Define STATS_CORRECTED 3
Define STATS_ERR 2

main() {
        Verbose = false
        Int lnc, unc (Lower nibble code and upper nibble code)
        uint8_t lnm unm (Lower/Upper nibble message)
        Ham_status hs;
        Uint8_t decode_table[256]
        Uint8_t status_table[256]
        Uint32_t stats[stats_index] = 0 0 0 0
        In_fp = stdin
        Out_fp = stdout
        Struct stat statbuf
        Parse command line arguments for input file and output file
        Change file permissions with fstat and fchmod
        BitMatrix *G = bm_create(8,4)
        Set the bits in this bit matrix to match the Generator matrix for 8,4 hamming code
        For (i = 0; i < 256; i++) {
                Hs = ham_decode(Ht,i,&lnm)
                Status_table[i] = hs
                Decode_table[i] = lnm
        }
        Lnm = 0
        While (fgetc for 2 bytes is not End of File) {
                stats[STATS_TOTAL] += 2
                If status_table[first_byte] is HAM_CORRECT or HAM_OK {
                        Lnm = Decode_table[first_byte]
                }
```

```
            Stats[status_table[first_byte] + STATS_INDEX]++;

            Repeat for the second byte
            fputc(pack_byte(second_byte,first_byte), out_fp);
        }
        If (verbose){
            Print the stats
        }
}
```