Error checking

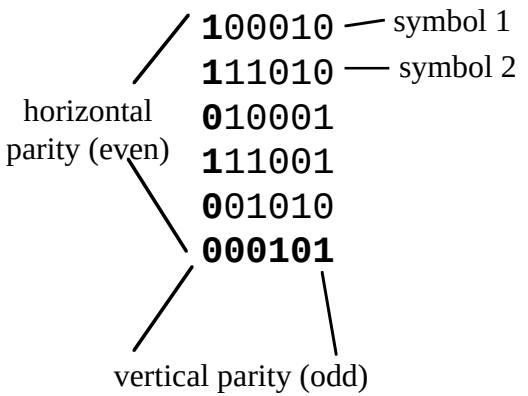
- Simple system - Parity
  Extra bit added on a per character basis so that the total number of '1's transmitted is even (or odd).

eg. ASCII code (even parity)
'A' = 1000001 parity bit =0
'B' = 1000010 parity bit = 0
'C' = 1000011 parity bit = 1

if 1 bit is corrupt error is spotted
if 2 bits are corrupt error is missed
if 3 bits are corrupt error is spotted

Parity (cont)

- To spot more errors might use 'vertical parity' - added as an extra character



- Not good on noisy lines

parity (cont)

- Horizontal and vertical (row and column) parity spots more errors some may still be missed.

```
00101
11110
01001
01100
10001 — odd parity
```

- if all bits corrupted then errors are missed.
- need a better system...

Polynomial Codes - CRC's

- Need systems good at spotting error bursts -Cyclic Redundancy Check
- CRC consists of a frame of data plus *N* extra bits called the Frame Check Sequence (FCS)

1. Take frame and add *N* zeros
2. Divide by polynomial *G* using modulo 2 binary arithmetic (*G* has *N+1* digits)
3. Use remainder as CRC FCS.
4. Transmit frame and CRC.
5. Receiver checks CRC.

[Note: division - binary modulo 2 is same as XOR at each stage of division]

CRC example

- 8 bit frames, 4 bit CRC, *G* =10101

```
          10010110
      ┌──────────
10101 │ 101110100000
        10101
        ─────
        000100
         00000
         ─────
           1001
          00000
          ─────
           10010
           10101
           ─────
           0011100
             10101
             ─────
             010010
              10101
              ─────
              001110
```

- CRC = 1110 so 101110101110 transmitted

CRC example (cont.)

- Receiver repeats division of all received bits - 0 remainder implies no errors

```
          10010110
      ┌──────────
10101 │ 101110101110
        10101
        ─────
        00010010
           10101
           ─────
           0011111
             10101
             ─────
             010101
             010101
             ──────
             000000
```

No remainder implies no errors

CRC example 2

- 4 bit frame, 2 bit FCS, G=101
- data = 1100

```
   1111
101|110000
   101
    110
    101
    0110
     101
     0110
      101
       11
```

FCS = 11

```
   1111
101|110011
   101
   0110
    101
    0111
     101
     0101
      101
       00
```

1st bit corrupt

```
   0101
101|010011
   000
   0100
    101
    0011
     000
     0111
      101
       10
```


What do CRC's detect ?

An error will only be undetectable if it is divisible by G. Hence the following are detectable:

- All single bit errors
- All double bit errors as long as G has at least 3 1's
- Any odd number of errors as long as G is chosen correctly
- any burst error which is shorter or equal to the length of G. ie <= to the number of bits in the FCS
- Most larger burst errors

Error correcting codes
Hamming code

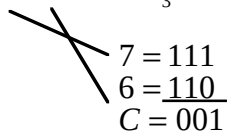
- To identify all single bit errors (and locate) in 4 bit data
- check bits occupy all bit positions which are a power of two

7	6	5	4	3	2	1
D_4	D_3	D_2	C_3	D_1	C_2	C_1

- check bits are the sum (modulo 2 of) the binary representation of data positions containing a '1'.

  ie. for data = 1100

7	6	5	4	3	2	1
1	1	0	C_3	0	C_2	C_1



- transmit 1100001

Hamming code (cont.)

- On receipt add binary values for all bits with '1's present:

```
76....1
1100001   =>  7=111
              6=110
              1=001
                000   <= OK
```

say:

```
1101001   =>  7=111
              6=110
              4=100
              1=001
                100   <= bit 4 in error

0101001   =>  6=110
              4=100
              1=001
                011<=wrong(2bit error)

1000001   =>  7=111
              1=001
                110   <=bit 6 in error
```

Observations

- FEC needs lots of bits (expensive)
- normally simply detect error and use a system of requesting re transmission
- Typically CRCs detect errors or corruption.