Getting Connected

Chapter 2, Part 2

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Five Problems

- Encoding/decoding
- □ Framing
- Error Detection
- Error Correction
- Media Access

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- Encoding/decoding
- □ Framing
- Error Detection
- Error Correction
- Media Access

Why Error Detection?

- Bit errors are sometimes introduced into frames
- Some mechanism is needed to detect these errors!
 - × Otherwise, strange file corruptions could occur on the receiver's end

Basic Idea

- Add redundant information to a frame
 - × Can be used to determine if errors
- Want redundant information to be as small as possible
- Redundant information is often called *error*detecting codes or checksums

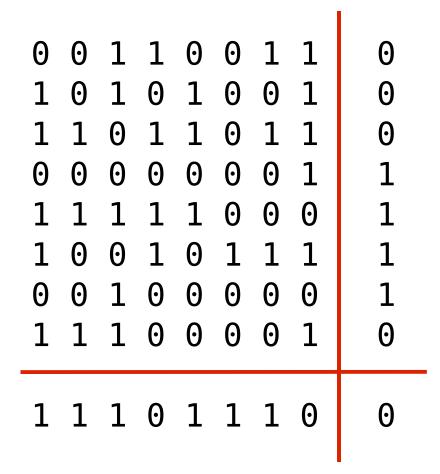
- 2-D Checks
- Internet checksums
- Cyclic Redundancy Check

2-D Checks

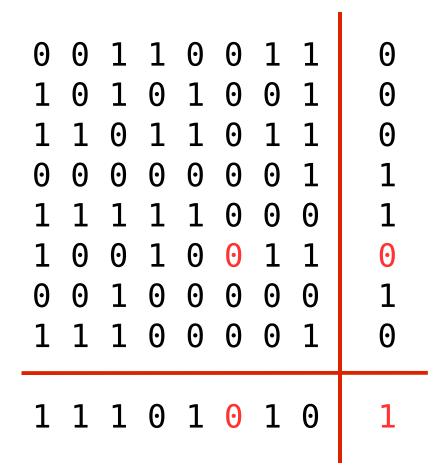
- × Divides bytes into even rows and columns (e.g. 8 rows of 8 bytes)
- × Computes even parity across rows and down columns
- × Extra parity bits are sent along with the data
 - ♦ # of parity bits scales up with the amount of data

2-D Checks

2-D Checks



2-D Checks : Error



2-D Checks

× Catches all 1,2,3-bit errors

× Catches most 4-bit errors

- Internet Checksums
- View payload as 16-bit integers
- Sum up payload, using 1's complement, with carry wraparound.
- Transmit payload along with the result for validation on the receiving side.
- Easy to implement in software/hardware (see the code-snippet in the text)

- Internet Checksums
- Negative number -x is x with all bits inverted
- When two numbers are added, the carry-on is added to the result
- Example: -15 + 16 (assume 8-bit)

```
15 = 00001111 \rightarrow -15 = 11110000 + \\16 = 00010000 \\1 00000000 + \\\frac{1}{00000001} + \\00000001 \\-15+16 = 1
```

Internet Checksums

Usability

- × 16 bits for messages of any length
- × Strength of error-detection not as good as 2D
 - ◊ Pair of single-bit errors could go unnoticed

Cyclic Redundancy Check

× Based upon polynomial division

× Bit strings are considered to represent the coefficients of a polynomial:

m+1 bits <=> degree m polynomial

♦ eg:

 $\begin{array}{l} 01101101 <=> 0x^7 + 1x^6 + 1x^5 + 0x^4 + 1x^3 + 1x^2 + 0x^1 + 1x^0 \\ <=> x^6 + x^5 + x^3 + x^2 + 1 \end{array}$

× Long division is carried out as usual, but polynomial subtraction is done modulo-2:

◊ eg: ($x^6 + x^5 + x^3 + x^2 + 1$) - ($x^6 + x^4 + x^3 + x + 1$) = ??

Cyclic Redundancy Check

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× Long division is carried out as usual, but polynomial subtraction is done modulo-2:

◊ eg: ($x^6 + x^5 + x^3 + x^2 + 1$) - ($x^6 + x^4 + x^3 + x + 1$) = $x^5 + x^4 + x^2 + x$

Cyclic Redundancy Check

× Long division is carried out as usual, but polynomial subtraction is done modulo-2:

◇ eg:

$$(x^6 + x^5 + x^3 + x^2 + 1) - (x^6 + x^4 + x^3 + x + 1) = x^5 + x^4 + x^2 + x^3$$

 $(x^6 + x^5 + x^3 + x^2 + 1) - (x^6 + x^4 + x^3 + x + 1) = x^5 + x^4 + x^2 + x^2 + x^3$
 $(x^6 + x^5 + x^3 + x^2 + 1) - (x^6 + x^4 + x^3 + x + 1) = x^5 + x^4 + x^2 + x^2 + x^3$
 $(x^6 + x^5 + x^5 + x^3 + x^2 + 1) - (x^6 + x^4 + x^3 + x + 1) = x^5 + x^4 + x^2 + x^2 + x^3 + x^4 + x^2 + x^3 + x^4 + x^$

Cyclic Redundancy Check

- × Sender and receiver have a common generator polynomial (determined in advance, by the protocol).
- × Eg:
 - ♦ 1101011011 (Frame) $x^9 + x^8 + x^6 + x^4 + x^3 + x + 1$
 - ♦ 10011 (Generator) $x^4 + x + 1$
- × Procedure:
 - degree(G)=r (hence r+1 bits)
 - ◊ degree(M) = m (or, m+1 bits in frame)
 - Promote the frame's polynomial by r bits, so that it is degree m+r. I.e., x^rM(x) is the polynomial we're working with.

Cyclic Redundancy Check

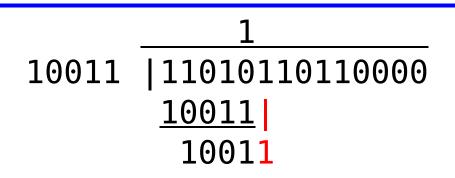
× Procedure:

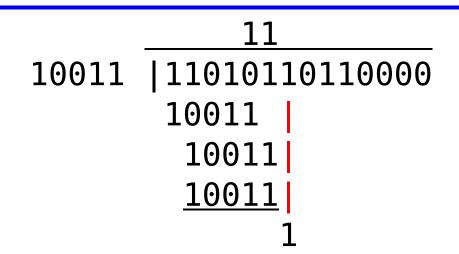
- ♦ degree(G)=r (hence r+1 bits)
- \$ degree(M) = m (or, m+1 bits in frame)
- Promote the frame's polynomial by r bits, so that it is degree m+r. I.e., x^rM(x) is the polynomial we're working with.
- \diamond Divide this polynomial by G(x) using polynomial division.
- Subtract the remainder from x^rM(x) using modulo-2 subtraction. The result is the transmission payload T(x)

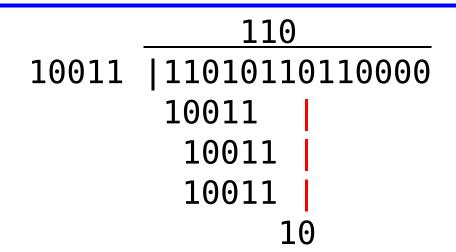
 $10011 \iff G(x) = x^4 + x + 1$ 1101011011 $\iff M(x) = x^9 + x^8 + x^6 + x^4 + x^3 + x + 1$

10011 |11010110110000

Promote by x^r ; $x^r M(x)$

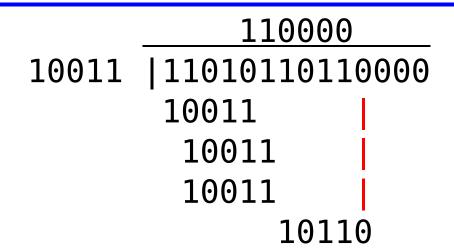


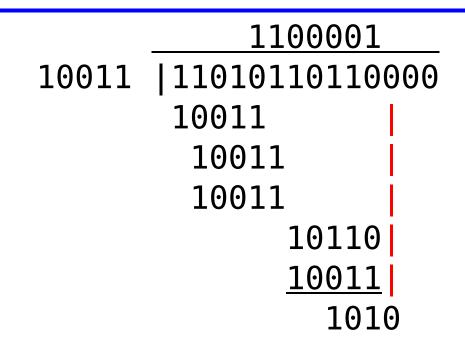




1100 10011 |11010110110000 10011 | 10011 | 10011 | 101

11000 10011 |11010110110000 10011 | 10011 | 10011 | 1011





 11000010

 10011

 10011

 10011

 10011

 10011

 10011

 10110

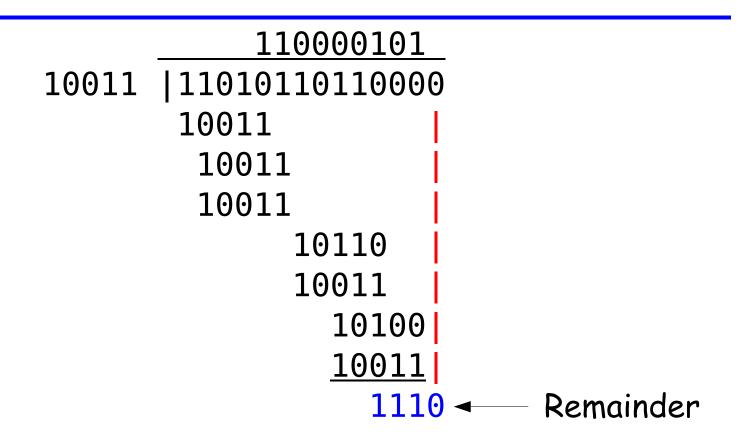
 10011

 10011

 10011

 10110

 10011



$$T(x) = x^{r} M(x) - r(x)$$

So what does the receiver do?

× G(x) should divide evenly into T(x)!

If it doesn't, receiver asks for frame again or tries to correct the errors

\Box Where does G(x) come from?

× Looked up ahead of time

× Pick G(x) so that it cannot easily be divided evenly

□ CRC-32 (for TCP)

 $G(x) = x^{32} + x^{26} + x^{23} + x^{22} + x^{16} + x^{12} + x^{11} + x^{10} + x^8 + x^7 + x^5 + x^4 + x^2 + x + 1$