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Errors and Failures, part 2

Feb 6, 2016

Options in dealing with failure

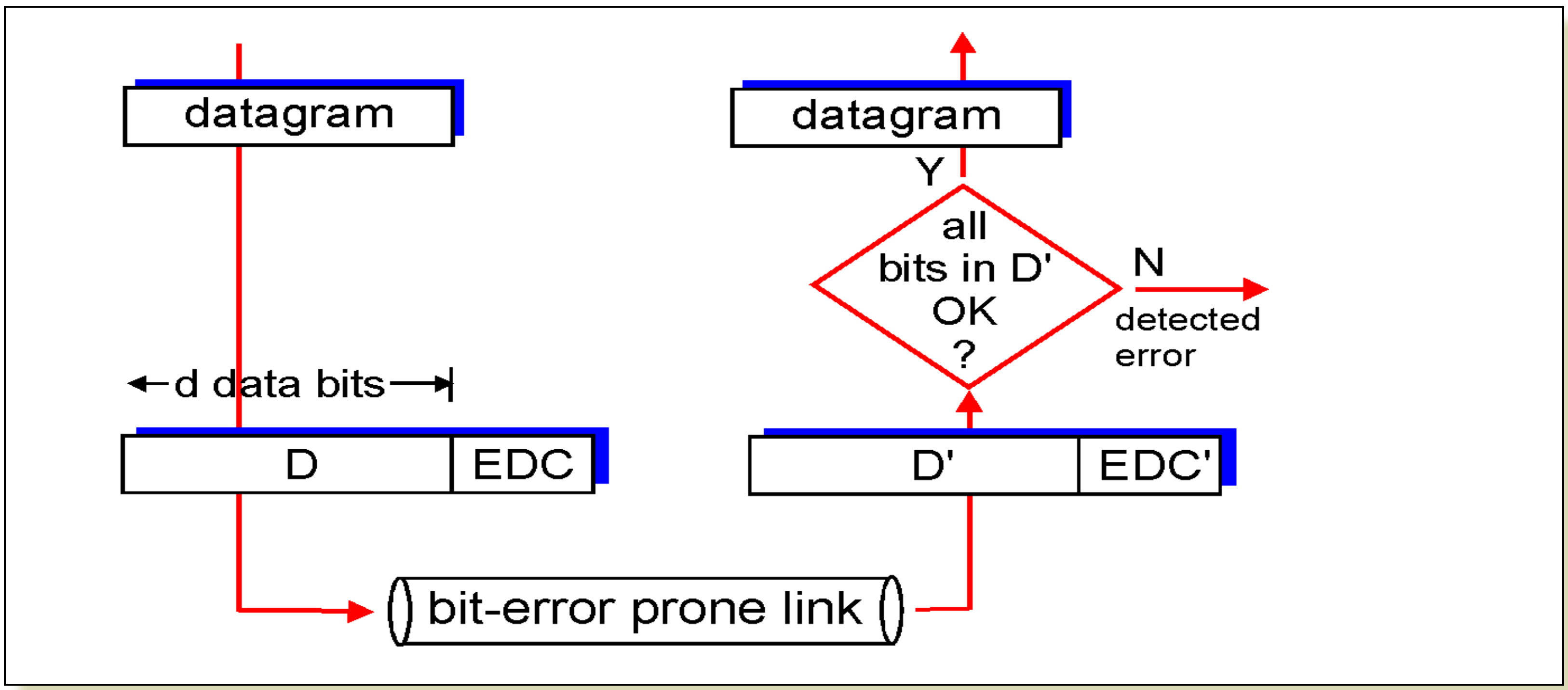
1. Silently return the wrong answer.

2. Detect failure.

3. Correct / mask the failure

Block error detection/correction

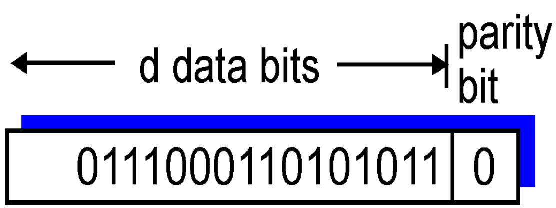
- EDC= Error Detection and Correction bits (redundancy)
- D = Data protected by error checking, may include header fields
- Error detection not 100% reliable!
  - Protocol may miss some errors, but rarely
  - Larger EDC field yields better detection and correction



Parity Checking

<u>Single Bit Parity:</u>

Detect single bit errors



Calculated using XOR over data bits:

- 0 bit: even number of 0s
- 1 bit: odd number of 0s

Error Detection - Checksum

- Used by TCP, UDP, IP, etc..
- Ones complement sum of all 16-bits in packet
- Simple to implement
  - Break up packet into 16-bits strings
  - Sum all the 16-bit strings
  - Take complement of sum = checksum; add to header
  - One receiver, compute same sum, add sum and checksum, check that the result is 0 (no error)
- Relatively weak detection
  - Easily tricked by typical loss patterns

Example: Internet Checksum

- Goal: detect "errors" (e.g., flipped bits) in transmitted segment

Sender

- Treat segment contents as sequence of 16-bit integers
- Checksum: addition (1's complement sum) of segment contents
- Sender puts checksum value into checksum field in header

Receiver

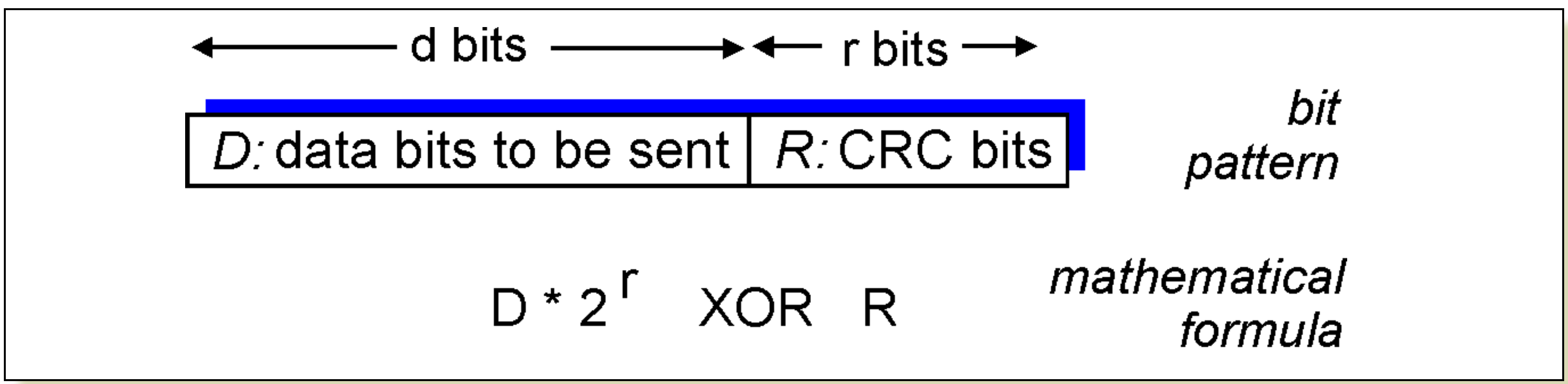
- Compute checksum of received segment
- Check if computed checksum equals checksum field value:
  - NO - error detected
  - YES - no error detected. But maybe errors nonethless?

Error Detection – Cyclic Redundancy Check (CRC)

- Polynomial code
  - Treat packet bits a coefficients of n-bit polynomial
  - Choose r+1 bit generator polynomial (well known – chosen in advance)
  - Add r bits to packet such that message is divisible by generator polynomial
- Better loss detection properties than checksums
  - Cyclic codes have favorable properties in that they are well suited for detecting burst errors
  - Therefore, used on networks/hard drives

Error Detection – CRC

- View data bits, D, as a binary number
- Choose r+1 bit pattern (generator), G
- Goal: choose r CRC bits, R, such that
  - <D,R> exactly divisible by G (modulo 2)
  - Receiver knows G, divides <D,R> by G. If non-zero remainder: error detected!
  - Can detect all burst errors less than r+1 bits
- Widely used in practice



CRC Example

Want:

$D \cdot 2^r$ XOR R = nG

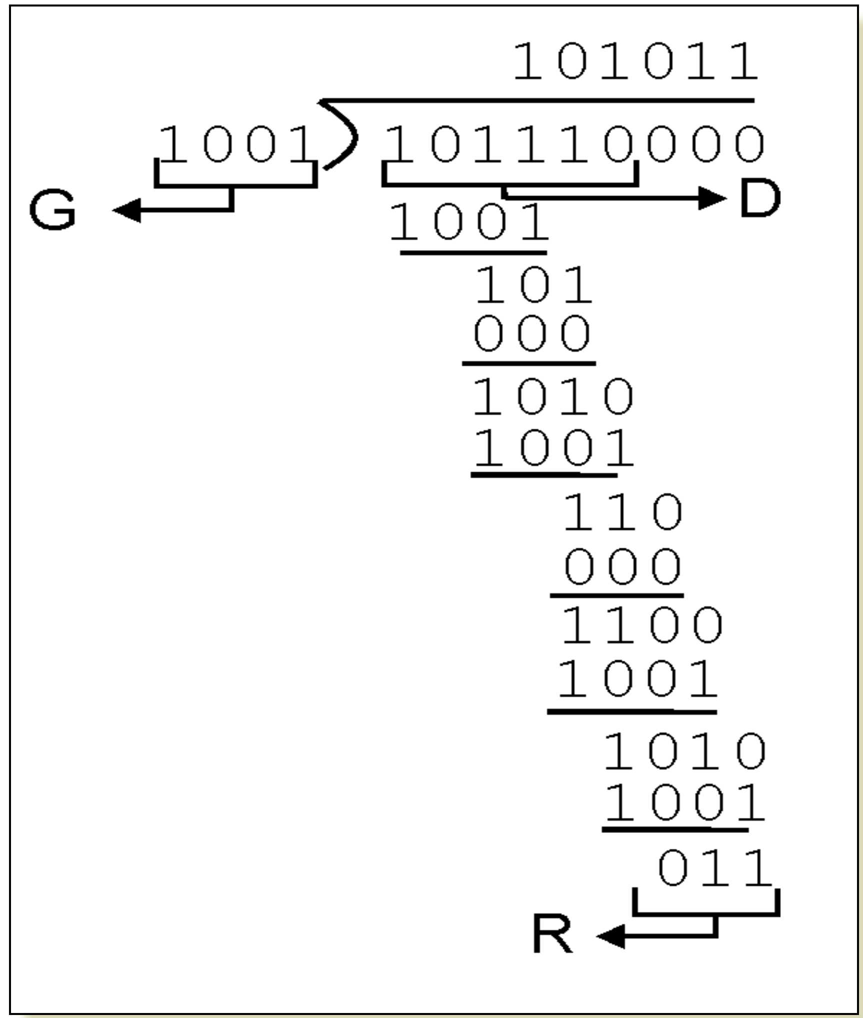
equivalently:

$D \cdot 2^r$ = nG XOR R

equivalently:

if we divide $D \cdot 2^r$ by G, want reminder R

$$R = \text{remainder}\left[\frac{D \cdot 2^r}{G}\right]$$



CRC notes

- n-bit CRC = appended value is n-bits long
- Typical CRCs:
  - CRC-8, CRC-16, CRC-32, CRC-64
- CRC-1 = parity bit (degenerate CRC case!)
- Error detection, but not correction
- Usage:
  - RFID (CRC-5)
  - Ethernet, PNG, Gzip, MPEG-2.. (CRC-32)
  - 2G/GSM (CRC-40)
- Many practical considerations:
  - https://en.wikipedia.org/wiki/Computation_of_cyclic_redundancy_checks

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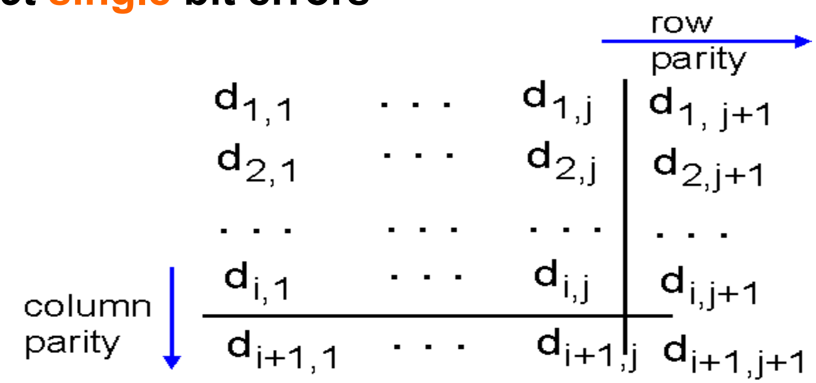
Error Recovery

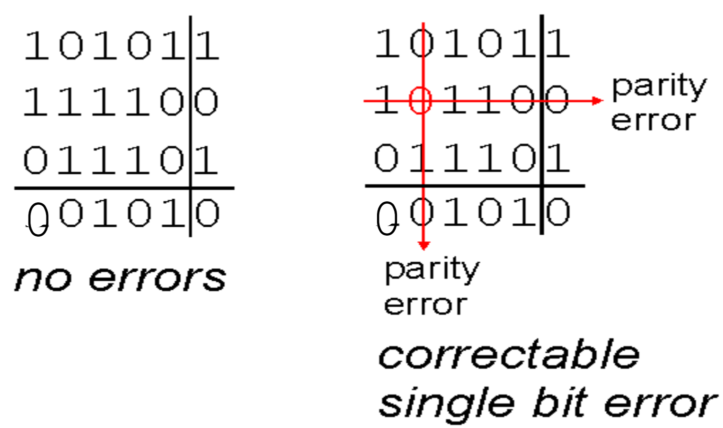
- Two forms of error recovery
  - Redundancy
    - Error Correcting Codes (ECC)
    - Replication/Voting
  - Retry
- ECC
  - Keep encoded redundant data to help repair losses
  - Forward Error Correction (FEC) – send bits in advance
    - Reduces latency of recovery at the cost of bandwidth

Error Recovery – Error Correcting Codes (ECC)

Two Dimensional Bit Parity:

Detect *and correct* single bit errors





Replication/Voting

- If you take this to the extreme, three software versions:
  [r1] [r2] [r3]

- Send requests to all three versions of the software: Triple modular redundancy
  - Compare the answers, take the majority
  - Assumes no error detection

- In practice - used mostly in space applications; some extreme high availability apps (stocks & banking? maybe. But usually there are cheaper alternatives if you don't need real-time)
  - Stuff we cover later: surviving malicious failures through voting (byzantine fault tolerance)

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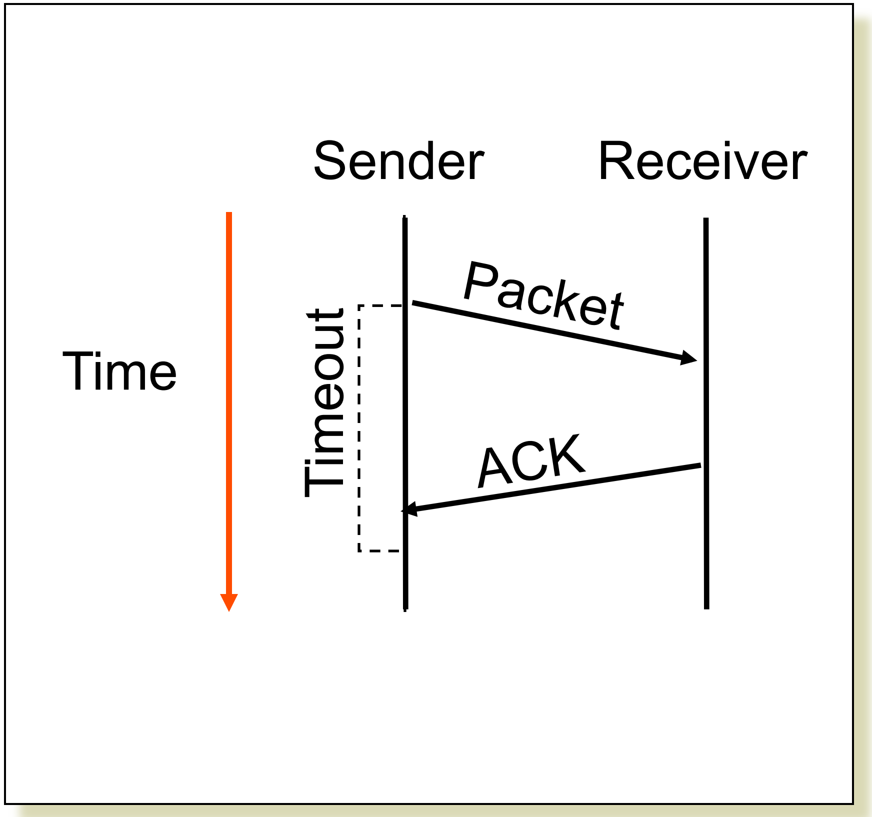
Retry – Network Example

- Sometimes errors are transient / need to mask
- Need to have error detection mechanism
  - E.g., timeout, parity, checksum
  - No need for majority vote



One key question

- How correlated are failures?
- Can you assume independence?
  - If the failure probability of a computer in a rack is p,
  - What is p(computer 2 failing) | computer 1 failed?
    - Maybe it's p... or maybe they're both plugged into the same UPS...
- Why is this important?

Back to Disks…
What are our options?

1. Silently return the wrong answer.
2. Detect failure.
   - Every sector has a header with a checksum. Every read fetches both, computes the checksum on the data, and compares it to the version in the header. Returns error if mismatch.
3. Correct / mask the failure
   - Re-read if the firmware signals error (may help if transient error, may not)
   - Use an error correcting code (what kinds of errors do they help?)
     - Bit flips? Yes. Block damaged? No
   - Have the data stored in multiple places (RAID)

Fail-fast disk

```
failfast_get (data, sn) {
        get (sector, sn);
        if (checksum(sector.data) = sector.cksum) {
                data ← sector.data;
                return OK;
        } else {
                return BAD;
        }
}
```

Careful disk (try 10 times on error)

```
careful_get (data, sn) {
        r ← 0;
        while (r < 10) {
                r ← failfast_get (data, sn);
                if (r = OK) return OK;
                r++;
        }
        return BAD;
}
```

"RAID"

- Redundant Array of {Inexpensive, Independent} disks
- Replication! Idea: Write everything to two disks ("RAID-1")
  - If one fails, read from the other
- write(sector, data) ->
  - write(disk1, sector, data)
  - write(disk2, sector, data)
- read(sector, data)
  - data = read(disk1, sector)
  - if error
    - data = read(disk2, sector)
    - if error, return error
  - return data
- Not perfect, though... doesn't solve all uncaught errors.

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Durable disk (RAID 1)

```
durable_get (data, sn) {
        r ← disk1.careful_get (data, sn);
        if (r = OK) return OK;
        r ← disk2.careful_get (data, sn);
        signal(repair disk1);
        return r;
}
```

Summary

- Definition of MTTF/MTBF/MTTR: Understanding availability in systems.
- Failure detection and fault masking techniques
- Engineering tradeoff: Cost of failures vs. cost of failure masking.
  - At what level of system to mask failures?
  - Leading into replication as a general strategy for fault tolerance (more RAID next time)
- Thought to leave you with:
  - What if you have to survive the failure of entire computers? Of a rack? Of a datacenter?

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