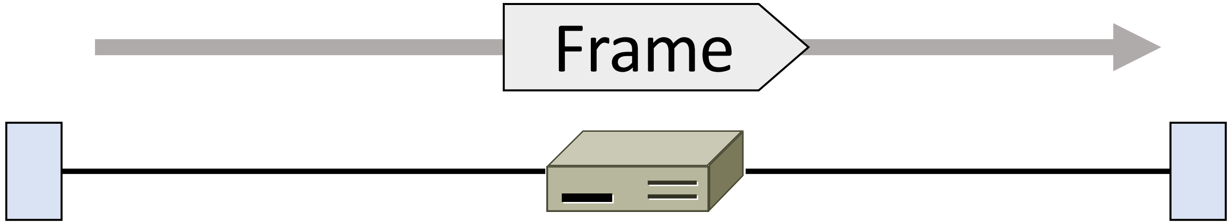
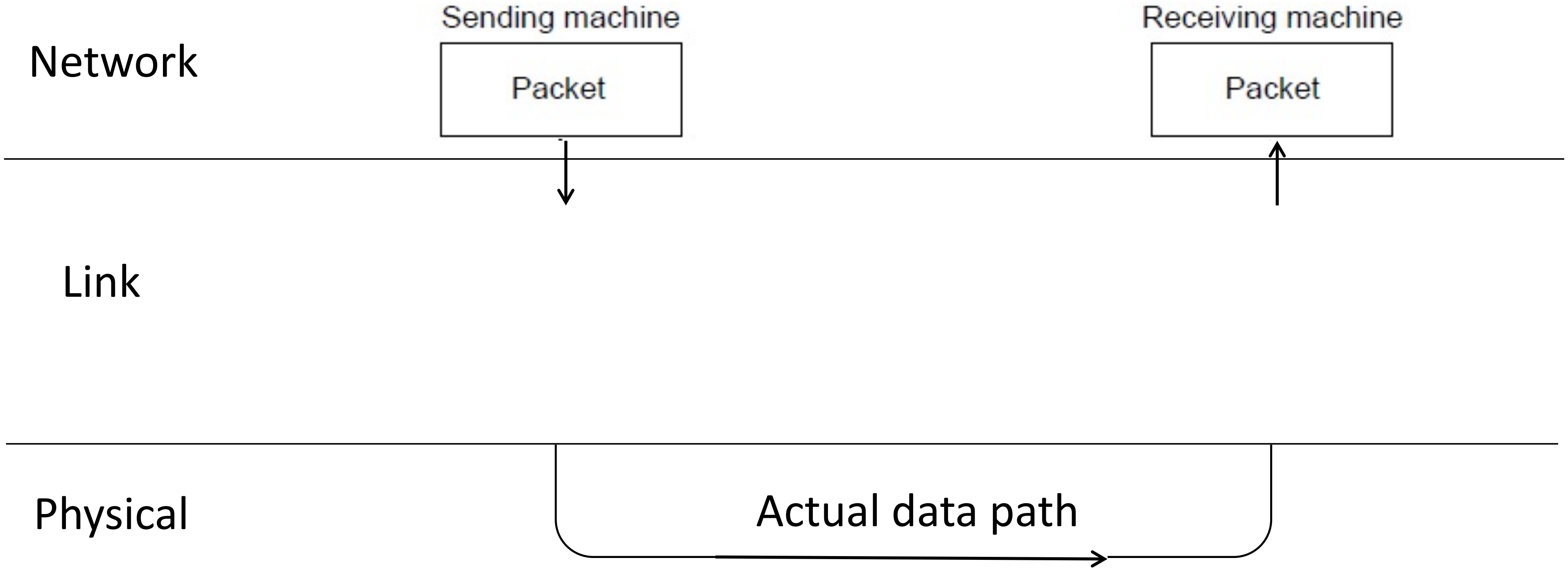
Link Layer

Link Layer

- Transfer frames over one or more connected links
  - Frames are messages of limited size
  - Builds on the physical layer which moves stream of bits



In terms of layers …



Network

Sending machine

Packet

Receiving machine

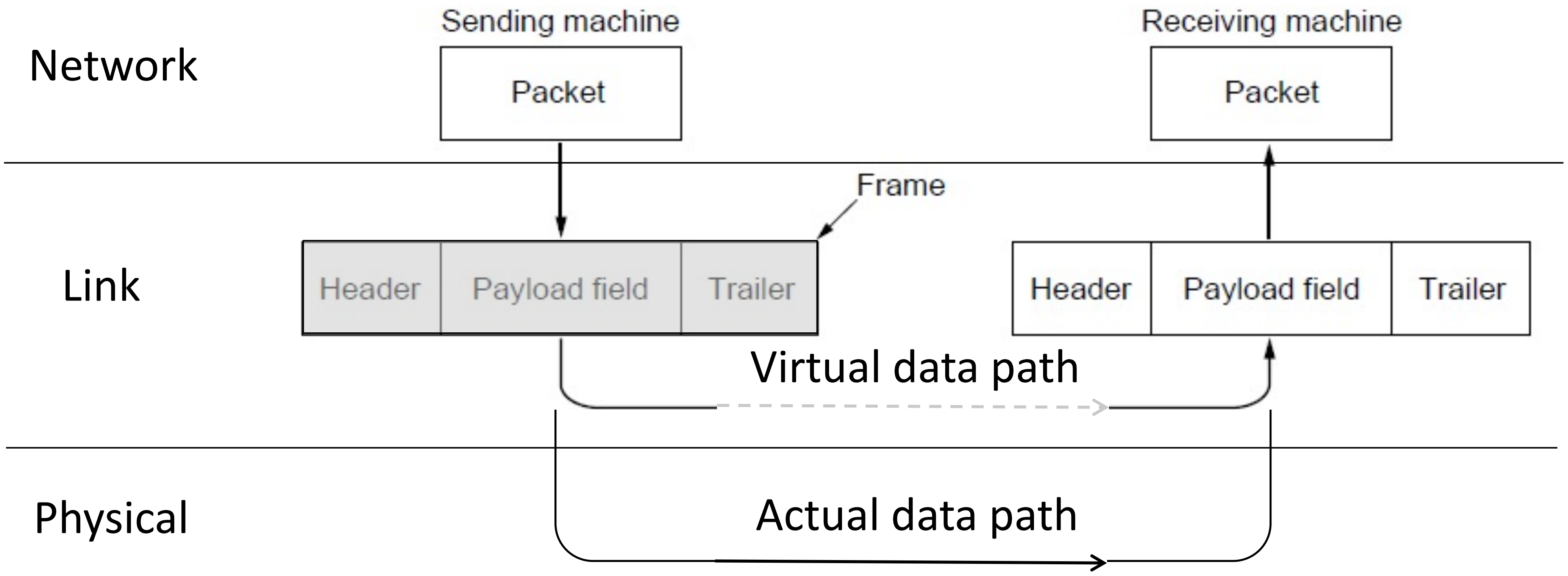
Packet

Link

Physical

Actual data path

In terms of layers …



Network

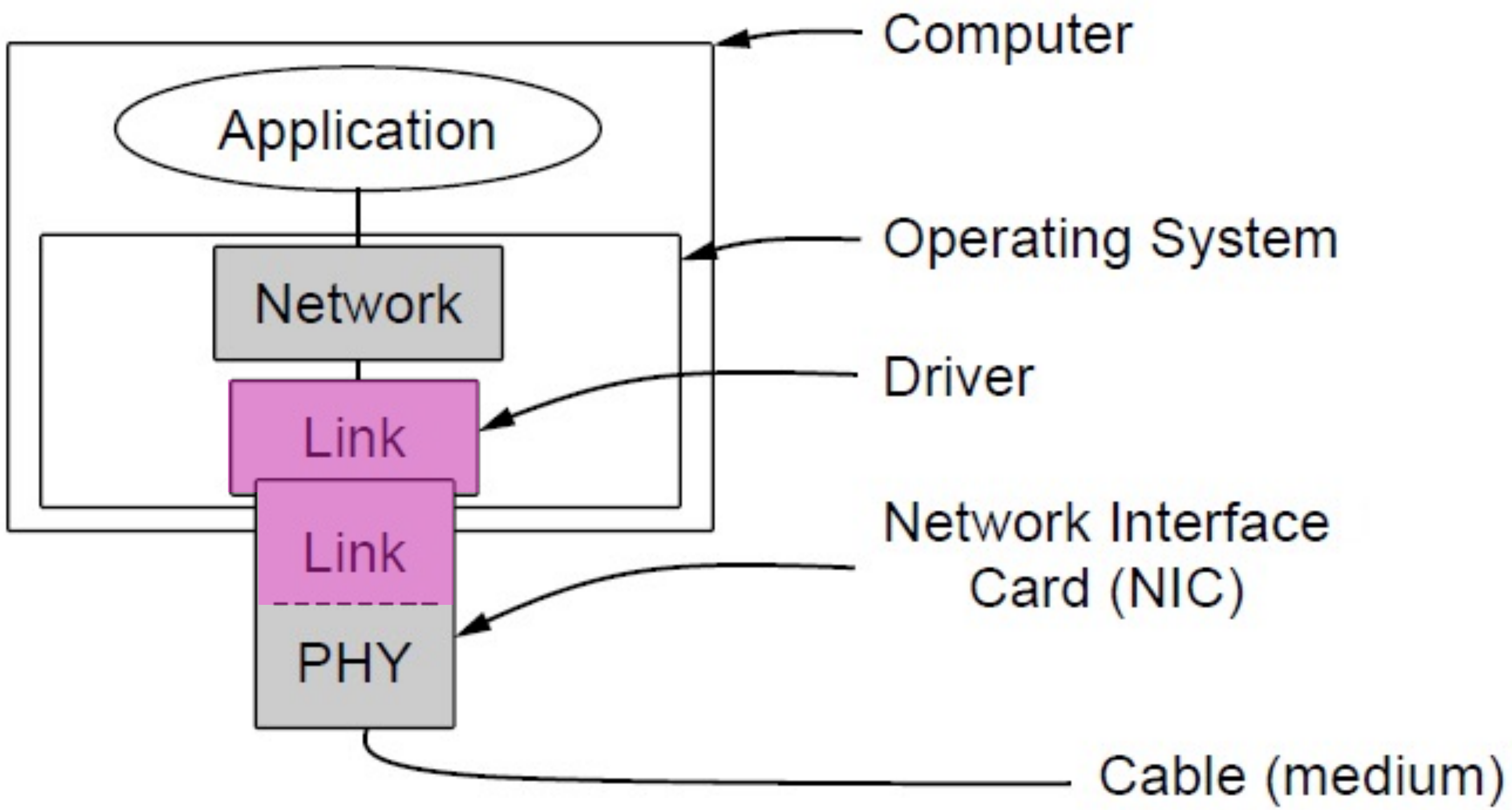
Link

Virtual data path

Physical

Actual data path

Typical Implementation of Layers (2)



Topics we'll cover

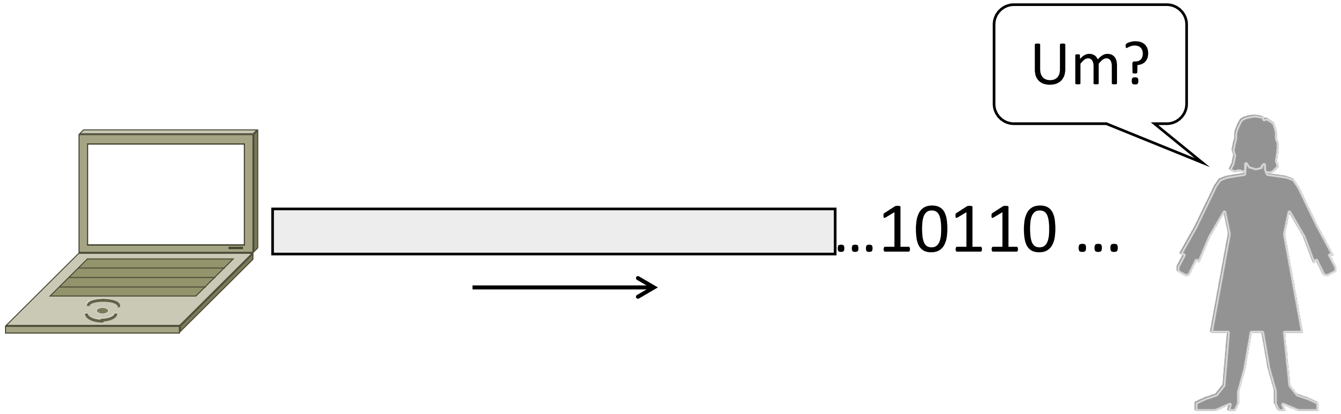
1. Framing
    - Delimiting start/end of frames
2. Error detection and correction
    - Handling errors
3. Multiple Access
    - 802.11, classic Ethernet
4. Switching
    - Modern Ethernet

Framing

Delimiting start/end of frames

Framing: Problem

- How do we interpret a stream of bits as a sequence of frames?



Ideas?

Framing Methods

1. Fixed-size frames (motivation)
2. Byte count (motivation)
3. Byte stuffing
4. Bit stuffing

- In practice, the physical layer often helps to identify frame boundaries
  - E.g., Ethernet, 802.11

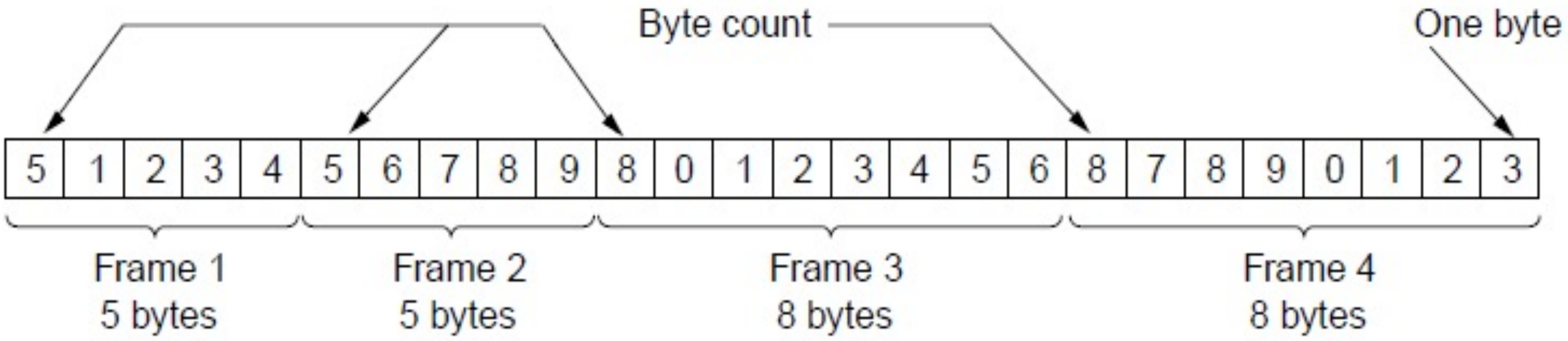
1. Fixed-size frames

- Make every frame a fixed number of bits
  - Pad smaller frames

- Problems?
  - Wasted transmissions for small frames

2. Byte Count

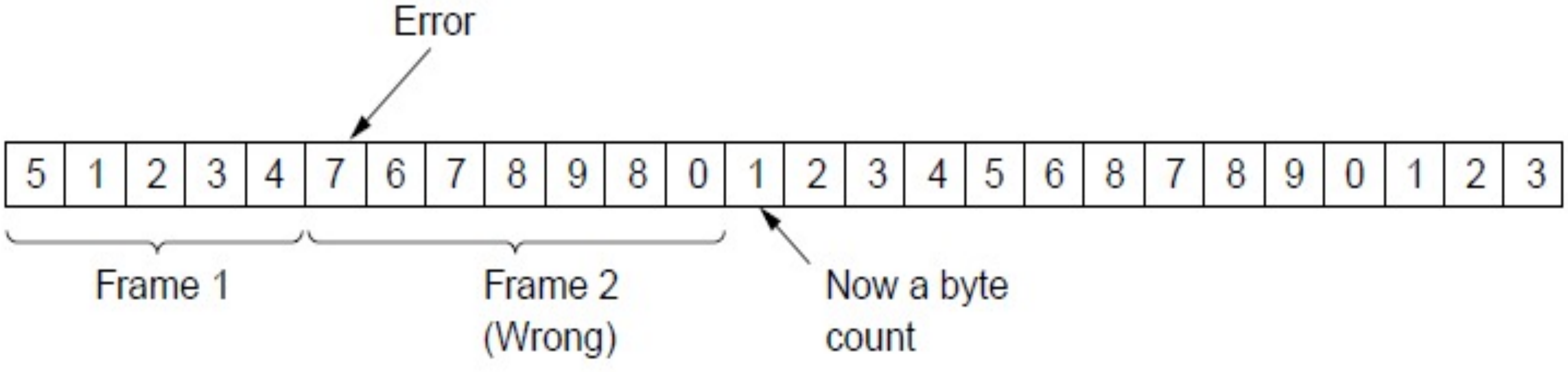
- Start each frame with a length field



- Problems?

2. Byte Count: Problem

- Difficult to re-synchronize after framing error
  - Want a way to scan for a start of frame



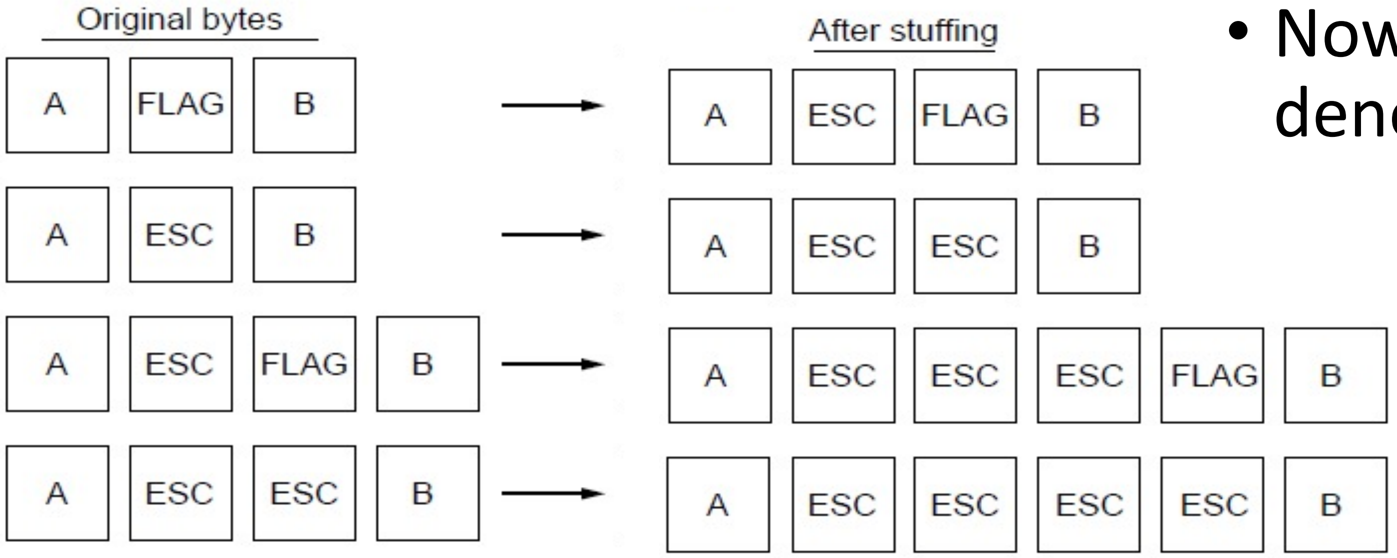
3. Byte Stuffing

- A special <u>flag</u> byte value for start/end of frame
  - Replace ("stuff") the flag with an escape code

- Problems?

3. Byte Stuffing: Problem

- Must escape the escape code too! Rules:
    - Replace each FLAG in data with ESC FLAG
    - Replace each ESC in data with ESC ESC



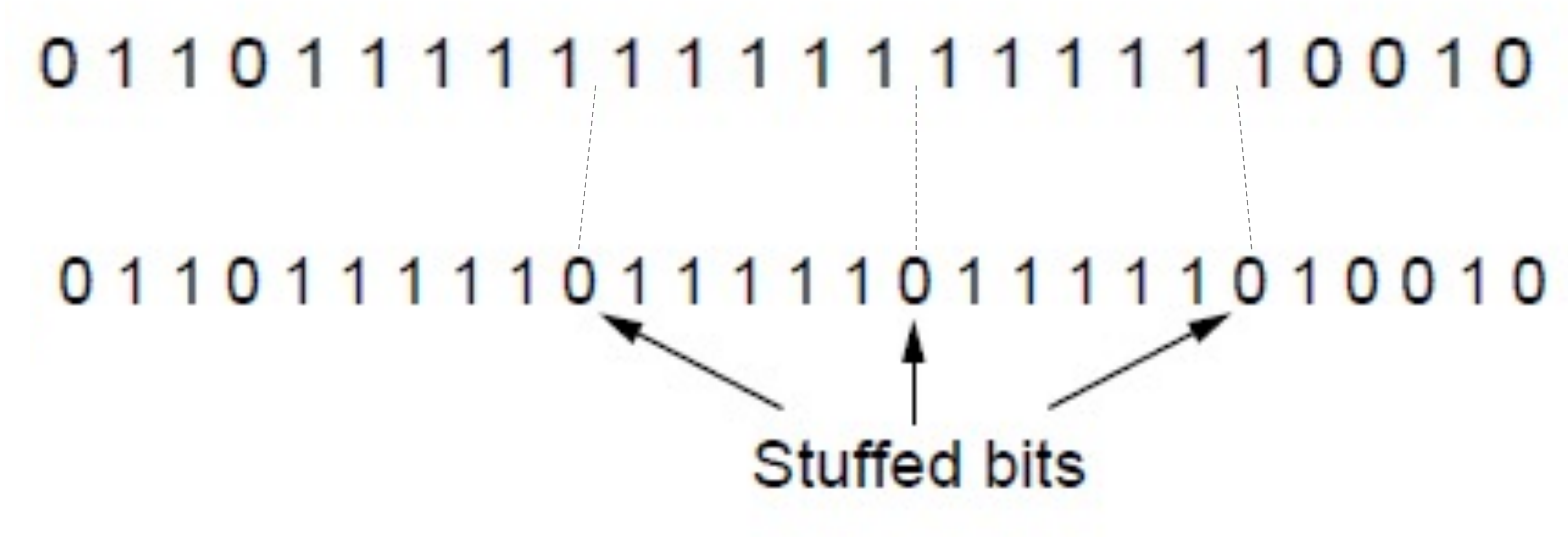
- Now any unescaped FLAG denotes frame start/end

Unstuffing

You see:	What it means
1. Solitary FLAG?	-> Start or end of packet
2. Solitary ESC?	-> Bad packet!
3. ESC FLAG?	-> remove ESC and pass FLAG through
4. ESC ESC FLAG?	-> removed ESC and then start of end of packet
5. ESC ESC ESC FLAG?	-> pass ESC FLAG through
6. ESC FLAG FLAG?	-> pass FLAG through then start of end of packet

4. Bit Stuffing

- Can stuff at the bit level too
  - Call a flag six consecutive 1s
  - On transmit, after five 1s in the data, insert a 0
  - On receive, a 0 after five 1s is deleted



Data bits

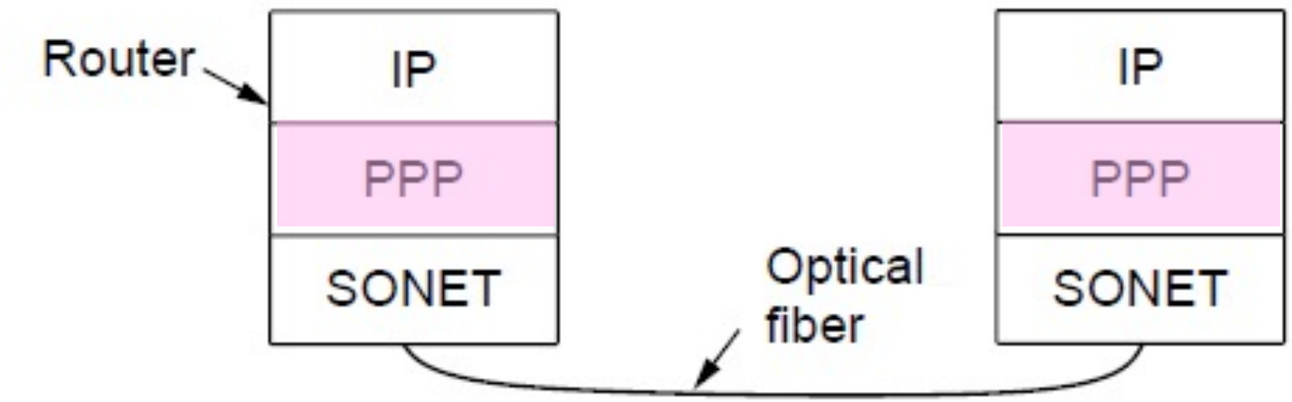
Transmitted bits with stuffing

Link Example: PPP over SONET

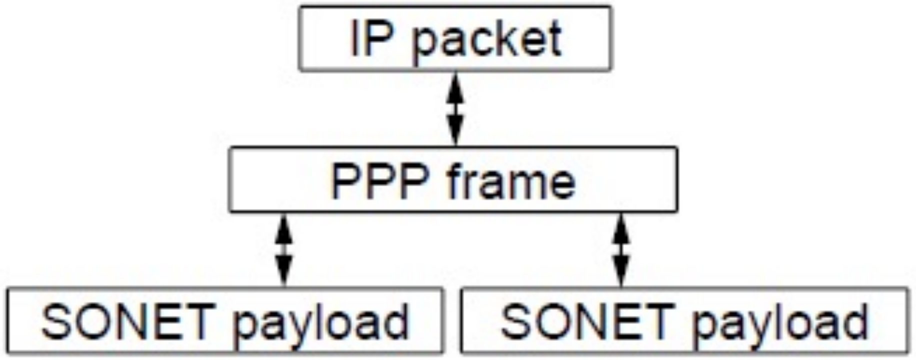
- PPP is Point-to-Point Protocol
- Widely used for link framing
  - E.g., it is used to frame IP packets that are sent over SONET optical links

Link Example: PPP over SONET (2)

- Think of SONET as a bit stream, and PPP as the framing that carries an IP packet over the link



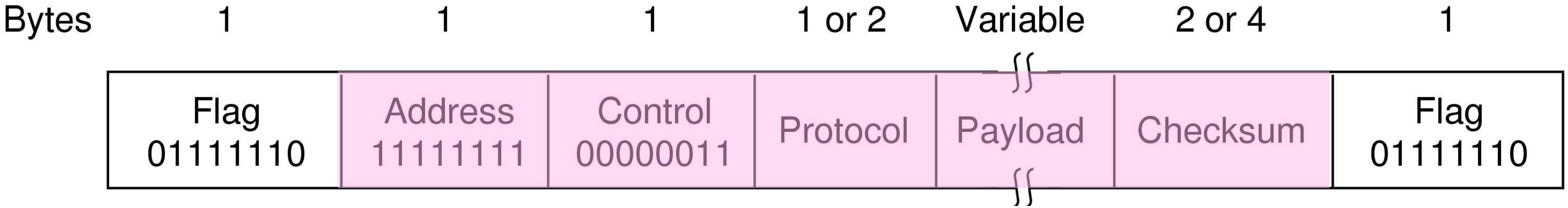
Protocol stacks



PPP frames may be split over SONET payloads

Link Example: PPP over SONET (3)

- Framing uses byte stuffing
  - **FLAG** is 0x7E and **ESC** is 0x7D



Bytes	1	1	1	1 or 2	Variable	2 or 4	1
	Flag 01111110	Address 11111111	Control 00000011	Protocol	Payload	Checksum	Flag 01111110

Link Example: PPP over SONET (4)

- Byte stuffing method:
  - To stuff (unstuff) a byte
    - add (remove) ESC (0x7D)
    - and XOR byte with 0x20
  - Removes FLAG from the contents of the frame

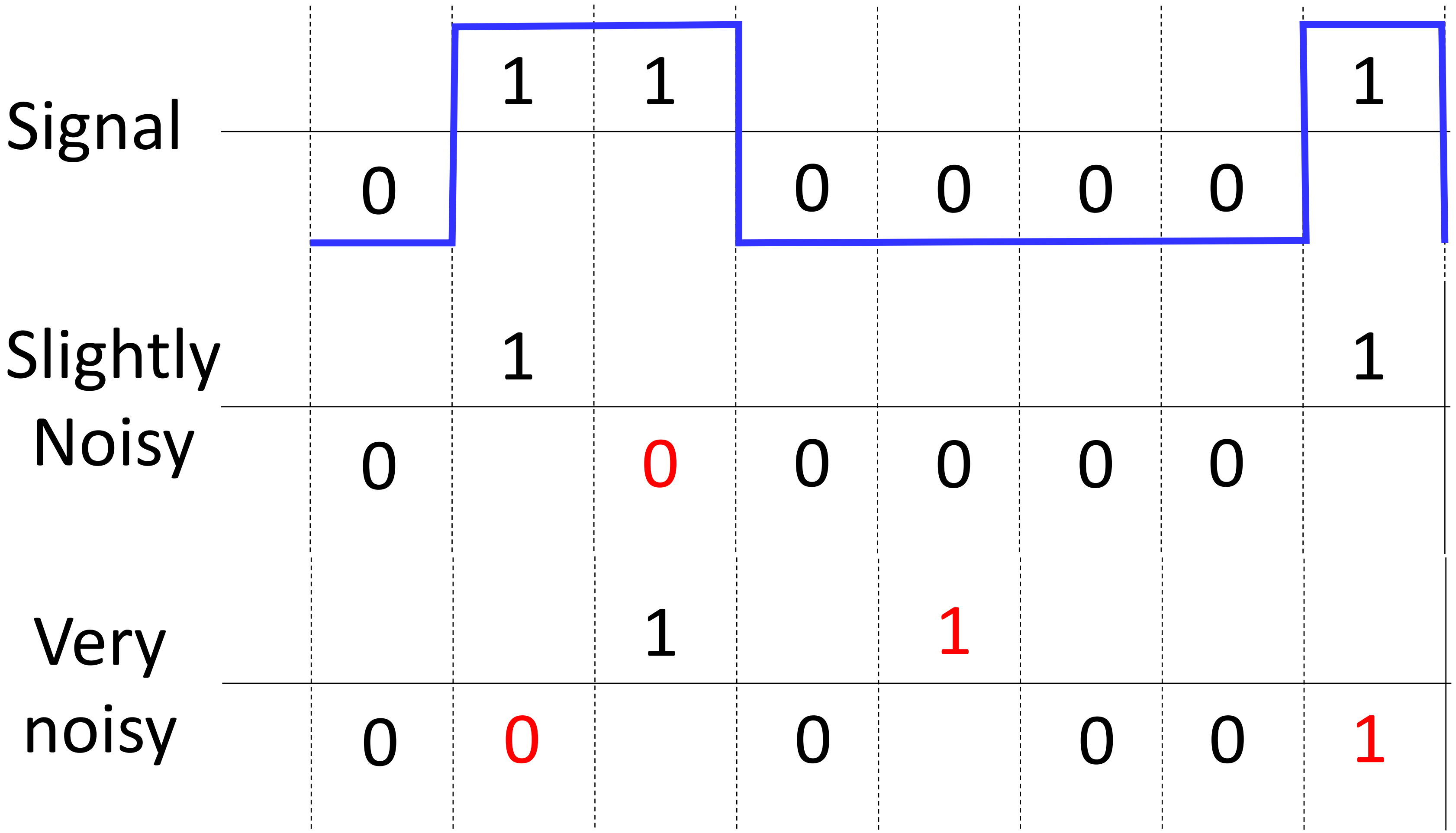
Link Layer: Error detection and correction

Problem: Noise may Flip Received Bits

- Link layers provides some protection
  - Detect errors with codes
  - Correct errors with codes
  - Retransmit lost frames ← Later

- Reliability concern cuts across the layers
  - E.g, TCP in the transport layer, DNS in the app layer

Problem: Noise may Flip Received Bits



Ideas?

Approach – Add Redundancy

- Error detection codes: Add <u>check bits</u> to the message bits to let some errors be detected
- Error correction codes: Add more <u>check bits</u> to let some errors be corrected

- Key issue: Structure the code such that
  - Need few check bits to detect/correct many errors
  - Modest computation

Motivating Example

- A simple code to handle errors:
  - Send two copies! Error detected if different.

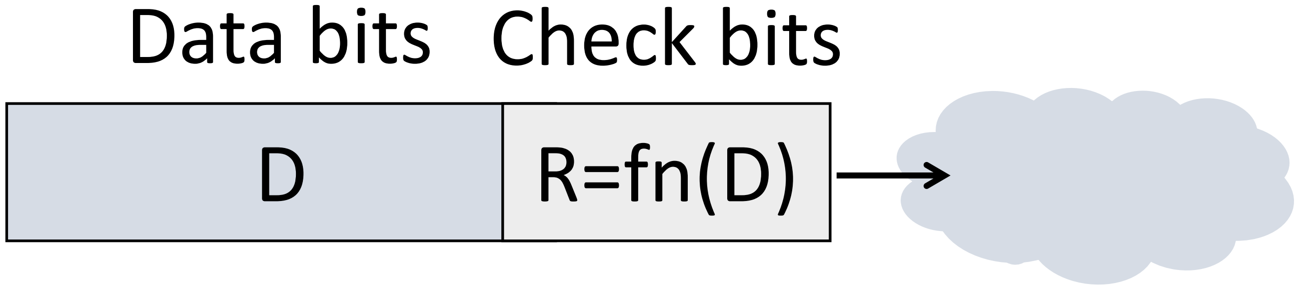
- How good is this code?
  - How many errors can it detect/correct?
  - How many errors will make it fail?

Want to Handle More Errors w/ Fewer Bits

- We’ll look at better codes (applied mathematics)
  - But, they can’t handle all errors
  - And they focus on accidental (random) errors

Using Error Codes

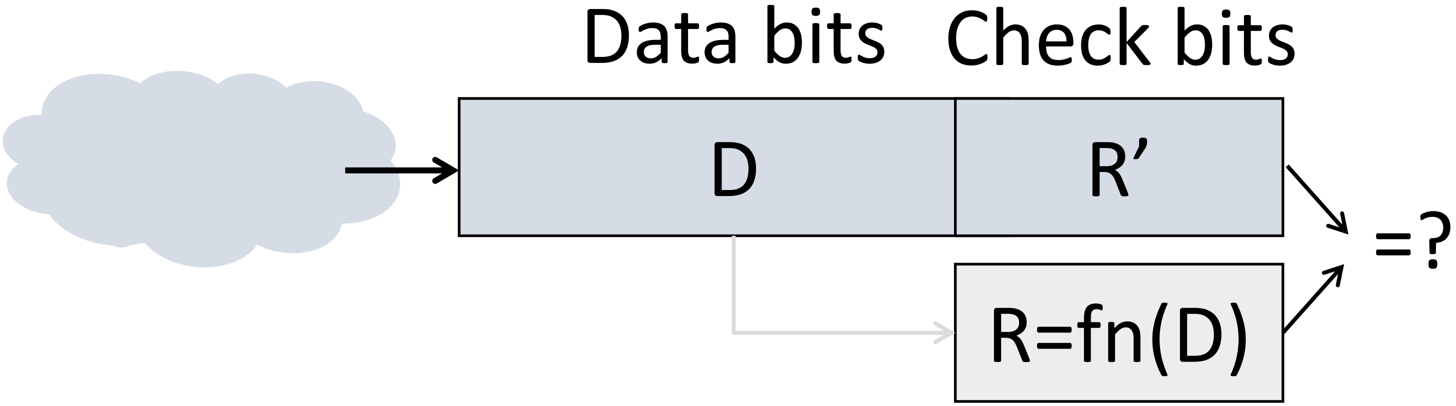
- Codeword consists of D data plus R check bits (=systematic block code)



- Sender:
  - Compute R check bits based on the D data bits; send the codeword of D+R bits

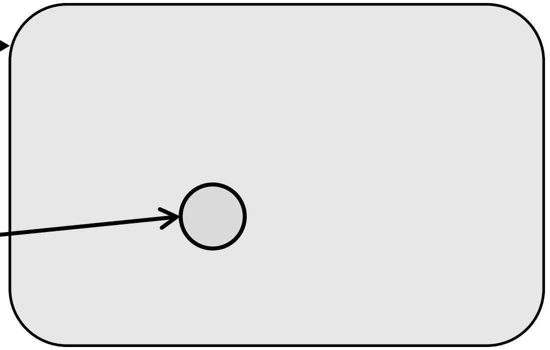
Using Error Codes (2)

- Receiver:
  - Receive D+R bits with unknown errors
  - Recompute R check bits based on the D data bits
  - Error detected if R doesn't match R'



Intuition for Error Codes

- For D data bits, R check bits:



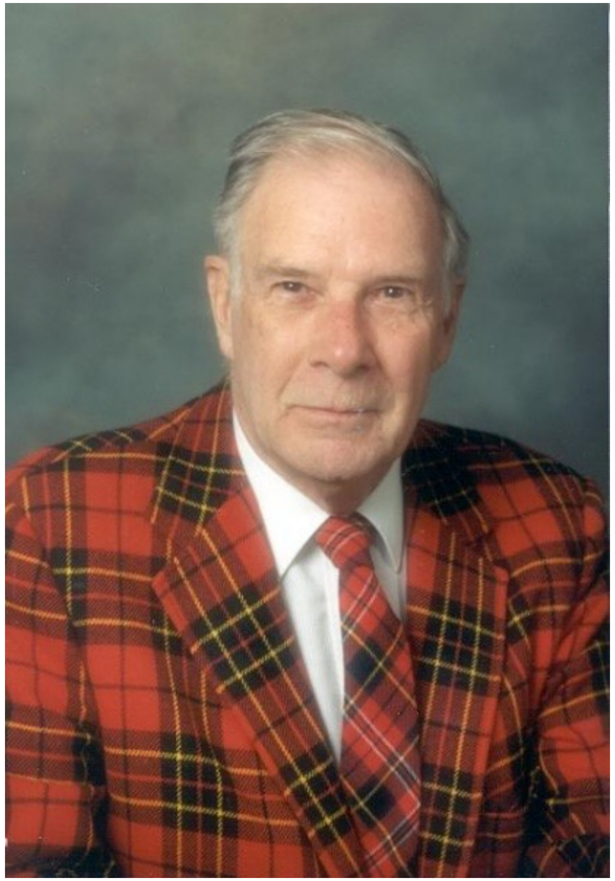
All possible D+R bits

Correct codewords

- Randomly chosen D+R bits is unlikely to be correct
  - Low, controllable overhead

R.W. Hamming (1915-1998)

- Much early work on codes:
  - "Error Detecting and Error Correcting Codes", BSTJ, 1950
- See also:
  - "You and Your Research", 1986



Source: IEEE GHN, © 2009 IEEE

Hamming Distance

- Distance is the number of bit flips needed to change D_1 to D_2

- Hamming distance of a coding is the minimum error distance between any pair of codewords (bit-strings) that cannot be detected

Hamming Distance (2)

- Error detection:
    - For a coding of distance d+1, up to d errors will always be detected
- Error correction:
    - For a coding of distance 2d+1, up to d errors can always be corrected by mapping to the closest valid codeword

Simple Error Detection – Parity Bit

- Take D data bits, add 1 check bit
  - Check bit could be sum modulo 2 or XOR

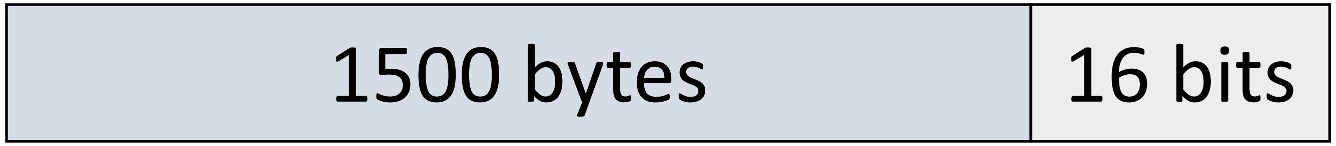
Parity Bit (2)

- How well does parity work?
  - What is the distance of the code?
  - How many errors will it detect/correct?

- What about larger errors?

Checksums

- Idea: sum up data in N-bit words
  - Widely used in, e.g., TCP/IP/UDP



1500 bytes

16 bits

- Stronger protection than parity

Internet Checksum

- Sum is defined in 1s complement arithmetic (must add back carries)
  - And it’s the negative sum
- “*The checksum field is the 16 bit one's complement of the one's complement sum of all 16 bit words …*” – RFC 791

Internet Checksum (2)

Sending:

1. Arrange data in 16-bit words
2. Put zero in checksum position, add
3. Add any carryover back to get 16 bits
4. Negate (complement) to get sum

```
0001
f204
f4f5
f6f7
```

Internet Checksum (3)

Sending:

1. Arrange data in 16-bit words
2. Put zero in checksum position, add
3. Add any carryover back to get 16 bits
4. Negate (complement) to get sum

```
   0001
   f204
   f4f5
   f6f7
 +(0000)
 ------
  2ddf1
    ↓
   ddf1
 +    2
 ------
   ddf3
    ↓
   220c
```

Internet Checksum (4)

Receiving:

1. Arrange data in 16-bit words
2. Checksum will be non-zero, add
3. Add any carryover back to get 16 bits
4. Negate the result and check it is 0

```
  0001
  f204
  f4f5
  f6f7
+ 220c
------
```

Internet Checksum (5)

Receiving:

1. Arrange data in 16-bit words
2. Checksum will be non-zero, add
3. Add any carryover back to get 16 bits
4. Negate the result and check it is 0

```
   0001
   f204
   f4f5
   f6f7
 + 220c
 ------
  2fffd
    ↓
   fffd
 +    2
 ------
   ffff
    ↓
   0000
```

Internet Checksum (6)

- How well does the checksum work?
  - What is the distance of the code?
  - How many errors will it detect/correct?