

Lecture 5:

Error Handling

CSE 123: Computer Networks
Stefan Savage



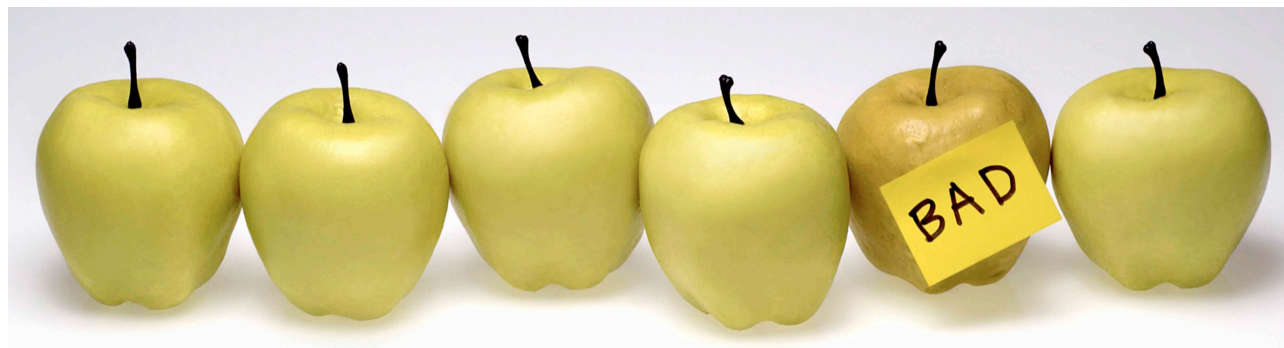


Continuing with the Link layer

- Last lecture:
Framing (2.3)



- Today:
Error detection (2.4)



Framing:

When things go wrong

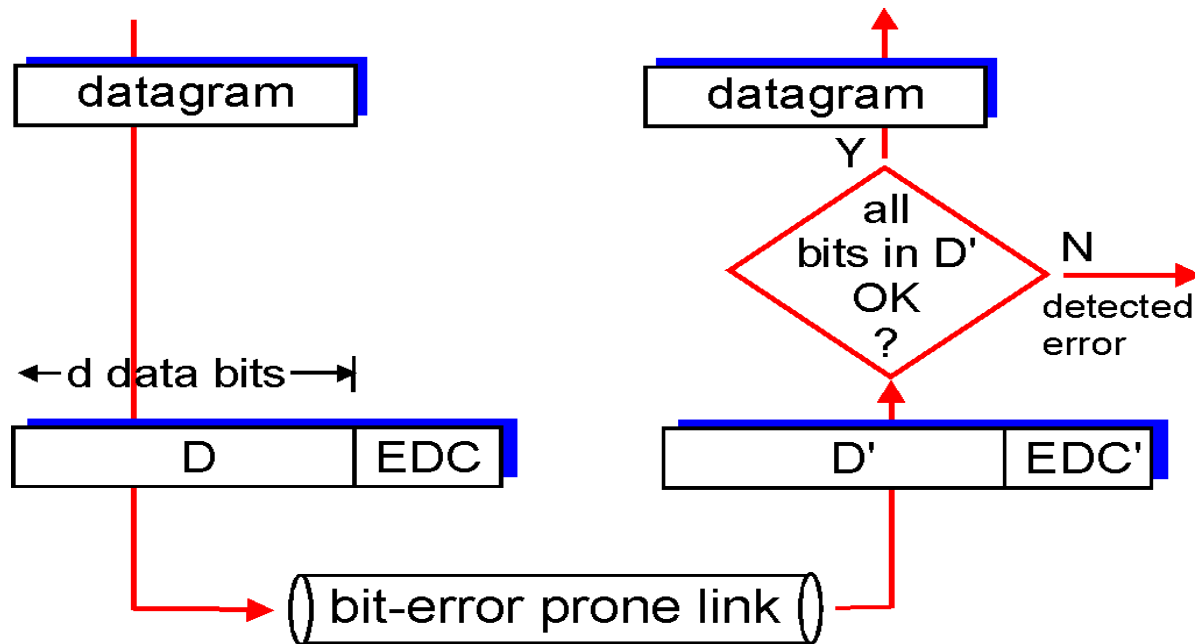


- Clock drift may confuse frame boundaries
 - ◆ Read the end of one frame and beginning of the next
- What happens if there are **bit errors** on channel?
 - ◆ We might misinterpret sentinels as data or vice versa
 - ◆ What will the frames look like?
- In general, need some way to make sure we're OK
 - ◆ Error detection—and perhaps correction



Error Detection

- Implemented at many layers
 - ◆ We'll mainly focus on link-layer techniques today





Error Handling

- Error handling through redundancy
 - ◆ Adding extra bits to the frame to check for errors
- Hamming Distance
 - ◆ When we can detect
 - ◆ When we can correct
- Simple schemes: parity, voting, 2d-parity
- Checksum
- Cyclic Remainder Check (CRC)



Basic Idea

- The problem is data itself is not self-verifying
 - ◆ Every string of bits is potentially legitimate
 - ◆ Hence, any errors/changes in a set of bits are equally legit
- The solution is to reduce the set of potential bitstrings
 - ◆ Not every string of bits is allowable
 - ◆ Receipt of a disallowed string of bits means the original bits were garbled in transit
- Key question: which bitstrings are allowed?

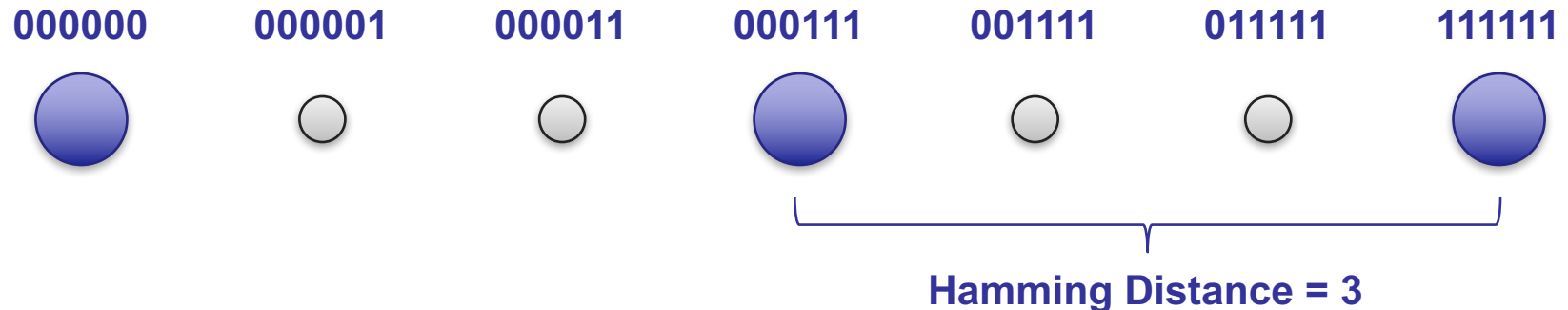
Codewords



- Let's start simple, and consider fixed-length bitstrings
 - ◆ Reduce our discussion to n -bit substrings
 - ◆ E.g., 7-bits at a time, or 4 bits at a time (4B/5B)
 - ◆ Or even a frame at a time
- We call an allowable sequence of n bits a **codeword**
 - ◆ Not all strings of n bits are codewords!
 - ◆ The remaining n -bit strings are “space” between codewords
- Rephrasing previous question: how many codewords with how much space between them?



Hamming Distance

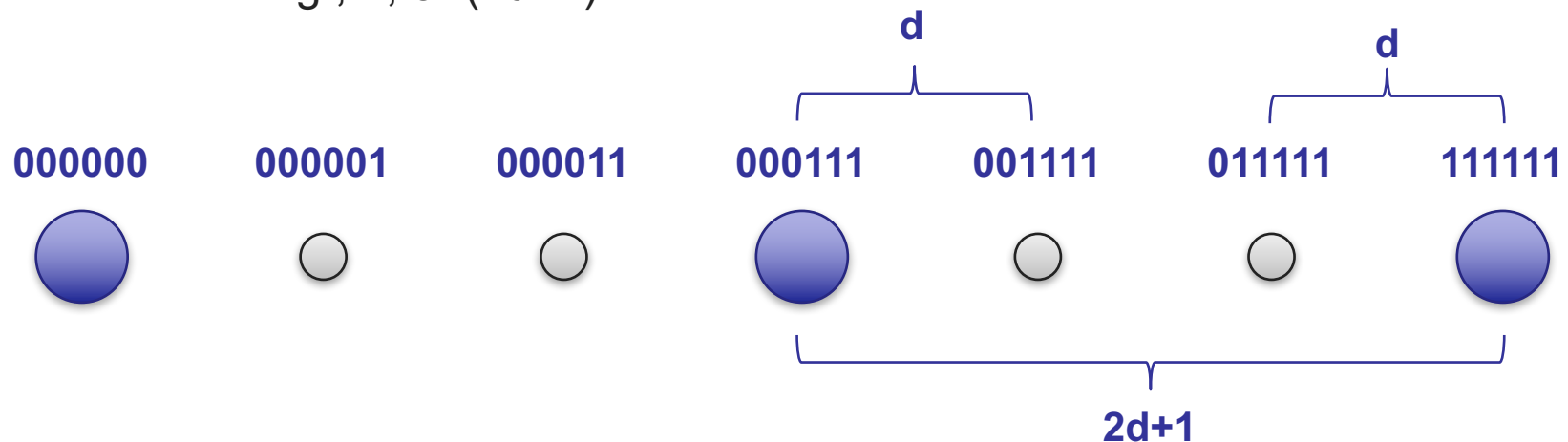


- Distance between legal codewords
 - ◆ Measured in terms of number of bit flips
- **Efficient** codes are of uniform Hamming Distance
 - ◆ All codewords are equidistant from their neighbors



$2d+1$ Hamming Distance

- Can **detect** up to $2d$ bit flips
 - ◆ The next codeword is always $2d+1$ bit flips away
 - ◆ Any fewer is guaranteed to land in the middle
- Can **correct** up to d bit flips
 - ◆ We just move to the closest codeword
 - ◆ Unfortunately, no way to tell how many bit flips
 - » E.g., 1, or $(2d+1)-1$?



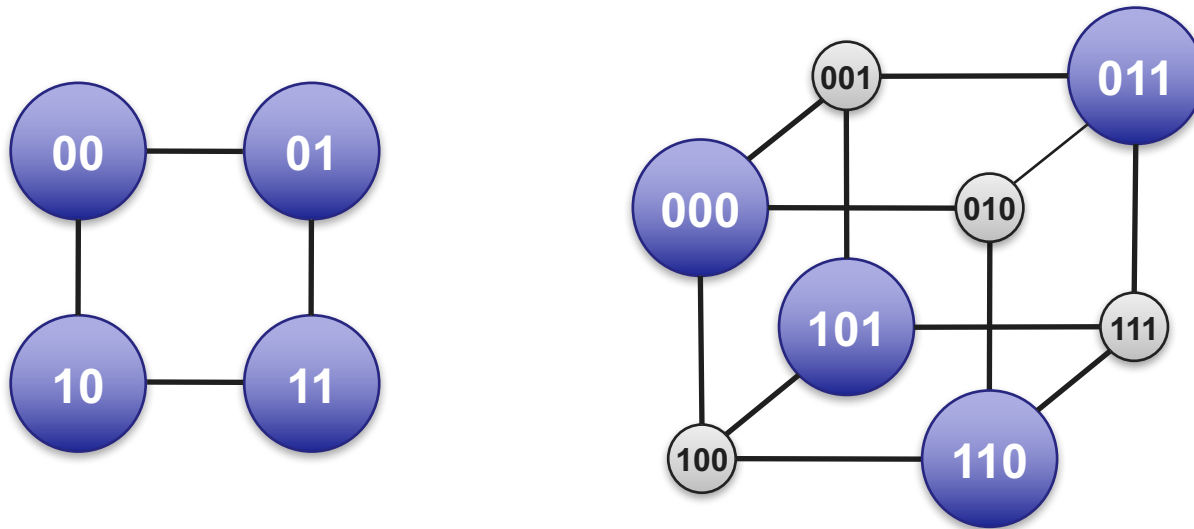


Encoding

- We're going to send only codewords
 - ◆ Non-codewords indicate errors to receiver
- But we *want* to send any set of strings
 - ◆ Need to embed arbitrary input into sequence of codewords
- We've seen this before: 4B/5B
 - ◆ We want more general schemes



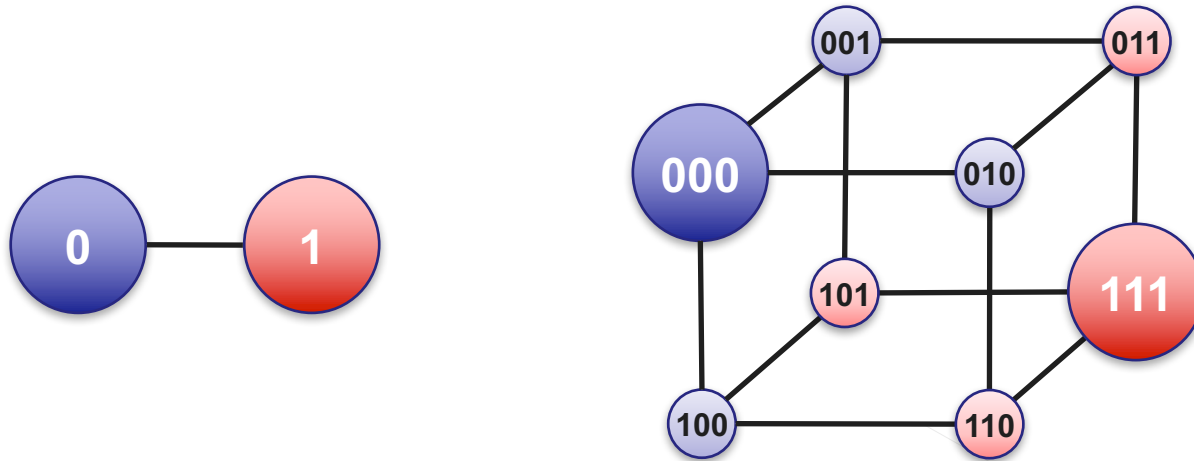
Simple Embedding: Parity



- Code with Hamming Distance 2
 - ◆ Can detect one bit flip (no correction capability)
- Add extra bit to ensure odd(even) number of ones
 - ◆ Code is 66% efficient (need three bits to encode two)
 - ◆ Note: Even parity is simply XOR



Simple Correction: Voting



- Simply send each bit n (3 in this example) times
 - ◆ Code with Hamming Distance 3 ($d=1$)
 - ◆ Can detect 2 bit flips and correct 1
- Straightforward duplication is extremely inefficient
 - ◆ We can be much smarter about this



Two-Dimensional Parity

		Parity Bits
Data	0101001	1
	1101001	0
	1011110	1
	0001110	1
	0110100	1
	1011111	0
Parity Byte	1111011	0

- Start with normal parity
 - ♦ n data bits, 1 one parity bit
- Do the same across rows
 - ♦ m data bytes, 1 parity byte
- Can detect up to 3 bit errors
 - ♦ Even most 4-bit errors
- Can correct any 1 bit error
 - ♦ Why?



Per-Frame Detection Codes



- Want to add an **error detection code** per frame
 - ◆ Frame is unit of transmission; all or nothing.
 - ◆ Computed over the entire frame—including header! Why?
- Receiver checks EDC to make sure frame is valid
 - ◆ If frame fails check, throw it away
- We *could* use error-correcting codes
 - ◆ But they are less efficient, and *we expect errors to be rare*
 - ◆ Counter example: satellite communication



Checksums

- Simply sum up all of the data in the frame
 - ◆ Transmit that sum as the EDC
- Extremely lightweight
 - ◆ Easy to compute fast in hardware
 - ◆ Fragile: Hamming Distance of 2
- Also easy to modify if frame is modified in flight
 - ◆ Happens a lot to packets on the Internet
- IP packets include a 1's compliment checksum



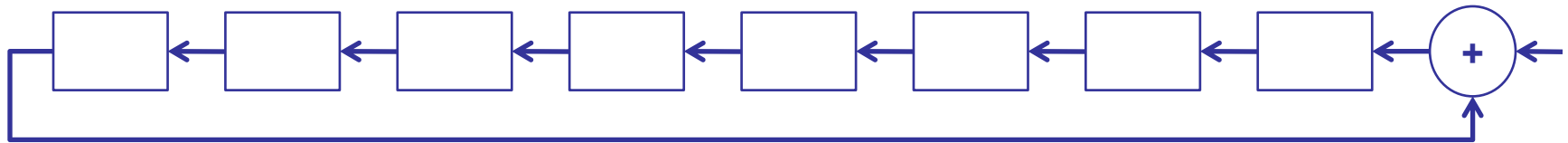
IP Checksum Example

- 1's compliment of sum of *words* (not bytes)
 - ◆ Final 1's compliment means all-zero frame is not valid

```
u_short cksum(u_short *buf, int count) {
    register u_long sum = 0;
    while (count--) {
        sum += *buf++;
        if (sum & 0xFFFF0000) {
            /* carry occurred, so wrap around */
            sum &= 0xFFFF;
            sum++;
        }
    }
    return ~(sum & 0xFFFF);
}
```



Checksum in Hardware

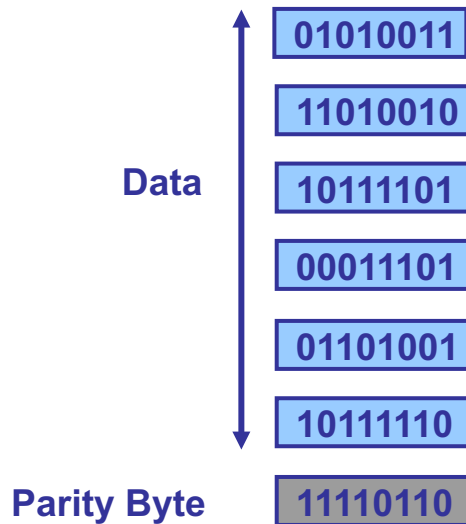


- Compute checksum in Modulo-2 Arithmetic
 - ◆ Addition/subtraction is simply XOR operation
 - ◆ Equivalent to vertical parity computation
- Need only a word-length shift register and XOR gate
 - ◆ Assuming data arrives serially
 - ◆ All registers are initially 0



Checksum Example

01010011110100101011110100011101011010011011111011110110

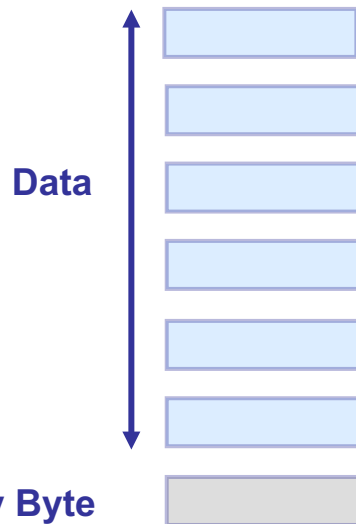
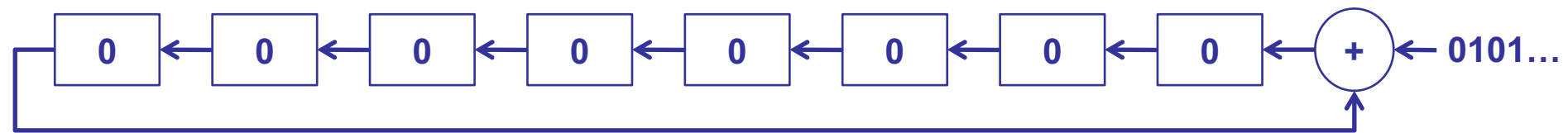




Checksum Example



01010011110100101011110100011101011010011011111011110110

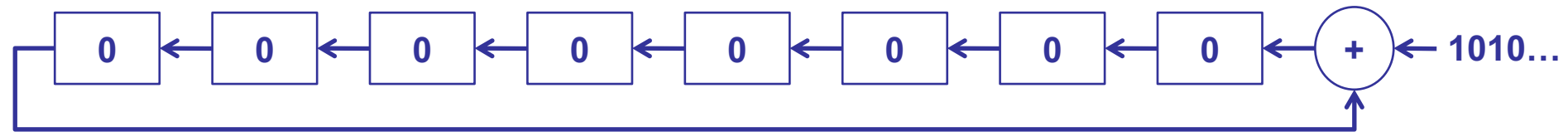




Checksum Example



01010011110100101011110100011101011010011011111011110110



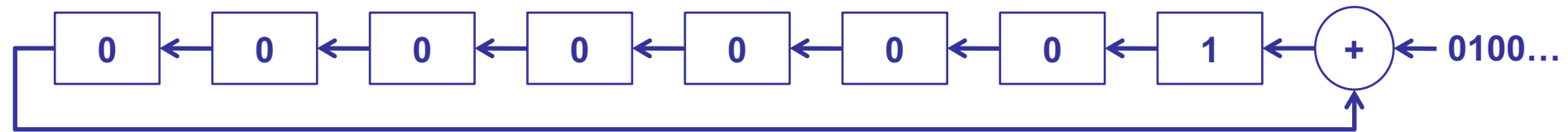
Data $\updownarrow$ 0



Checksum Example



01010011110100101011110100011101011010011011111011110110



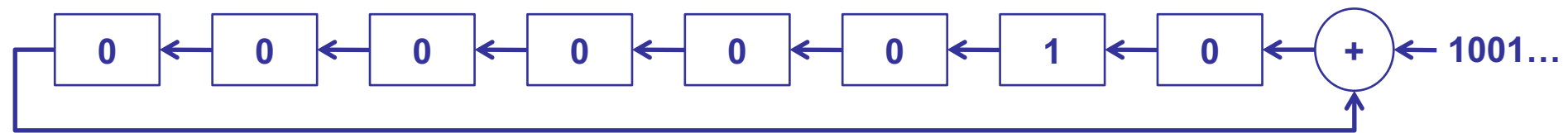
Data $\updownarrow$ 01



Checksum Example



01010011110100101011110100011101011010011011111011110110



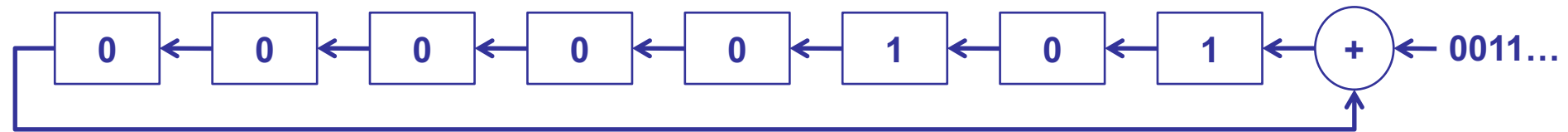
Data ↑↓ 010



Checksum Example



01010011110100101011110100011101011010011011111011110110



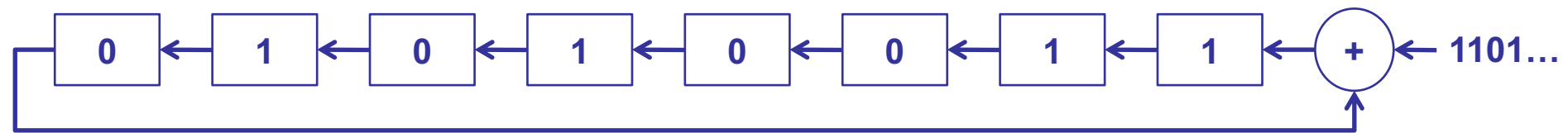
Data $\updownarrow$ 0101



Checksum Example



01010011110100101011110100011101011010011011111011110110



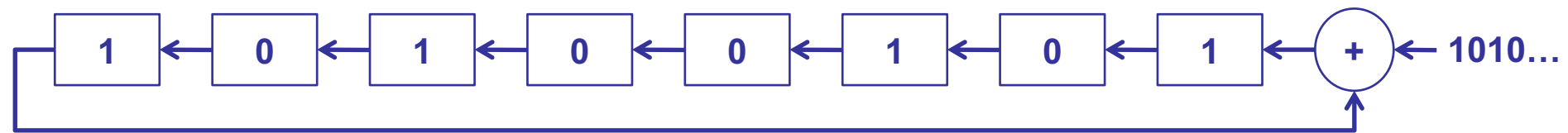
Data $\updownarrow$ 01010011



Checksum Example



01010011110100101011110100011101011010011011111011110110



Data

01010011
1

Parity Byte

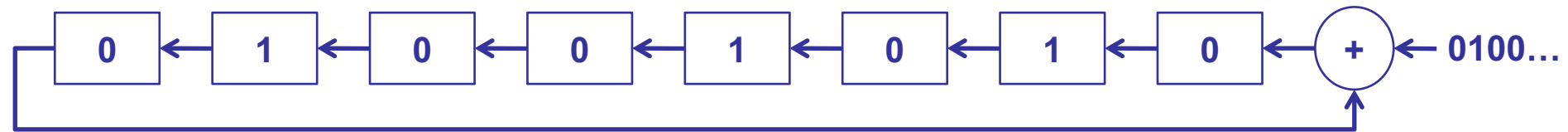
1



Checksum Example



01010011110100101011110100011101011010011011111011110110



Data

01010011
11

Parity Byte

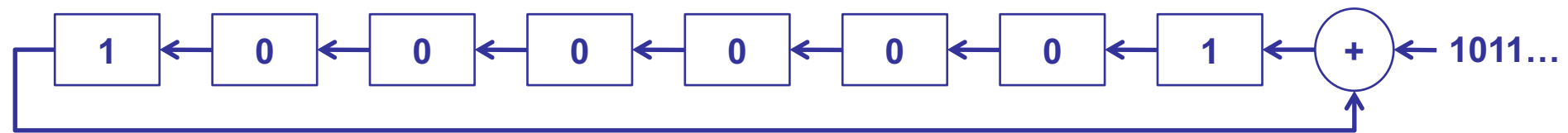
10



Checksum Example



01010011110100101011110100011101011010011011111011110110



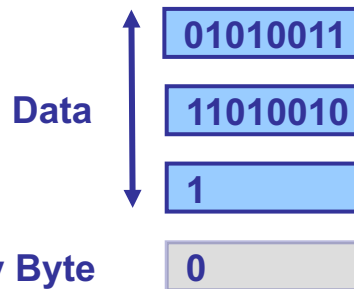
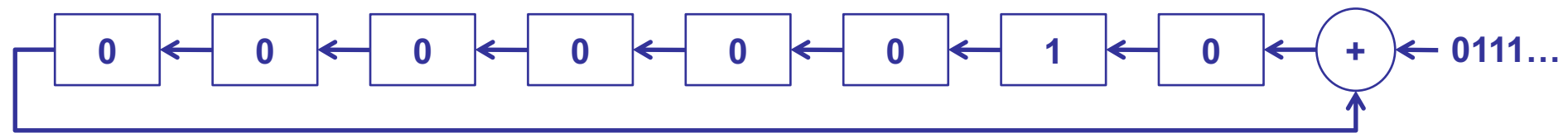
Data	01010011
	11010010
Parity Byte	10000001



Checksum Example



01010011110100101011110100011101011010011011111011110110

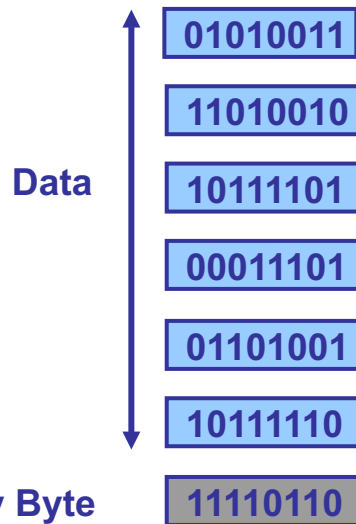
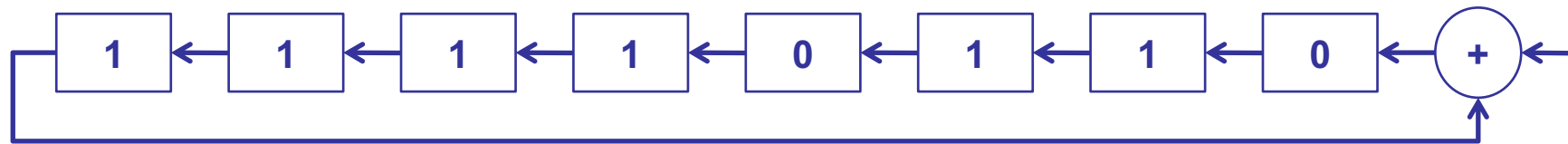




Checksum Example



01010011110100101011110100011101011010011011111011110110





For Next Class (Friday)

- No class Wednesday!
- Friday: Guest lecture Alex Snoeren:
 - ◆ We'll finish error detection and talk about reliable transport
- Read 2.5 in P&D