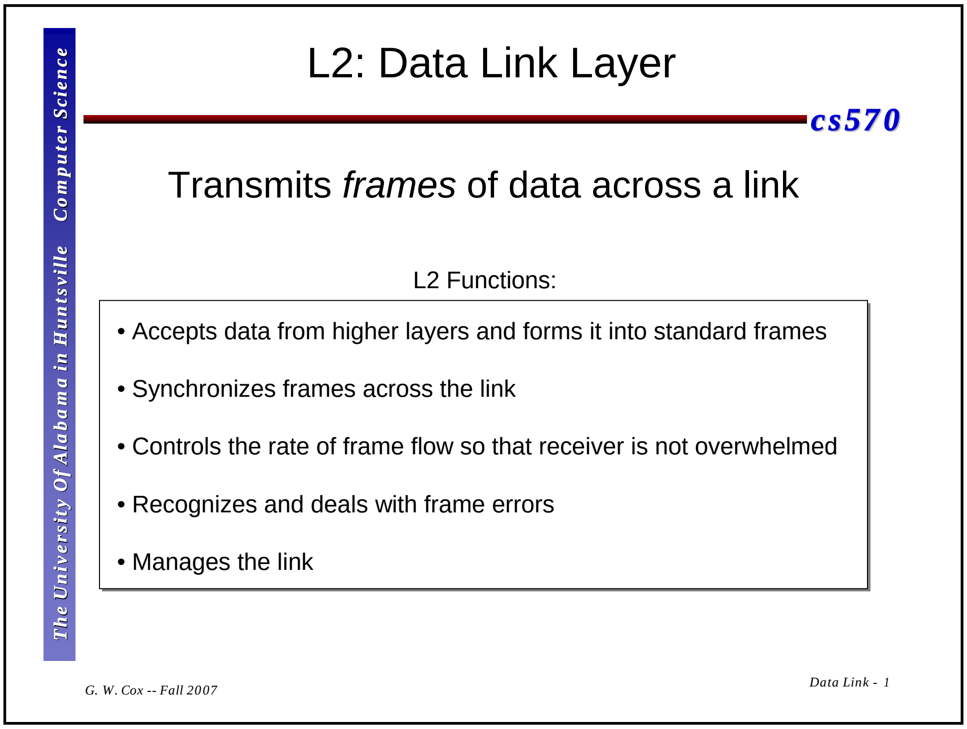
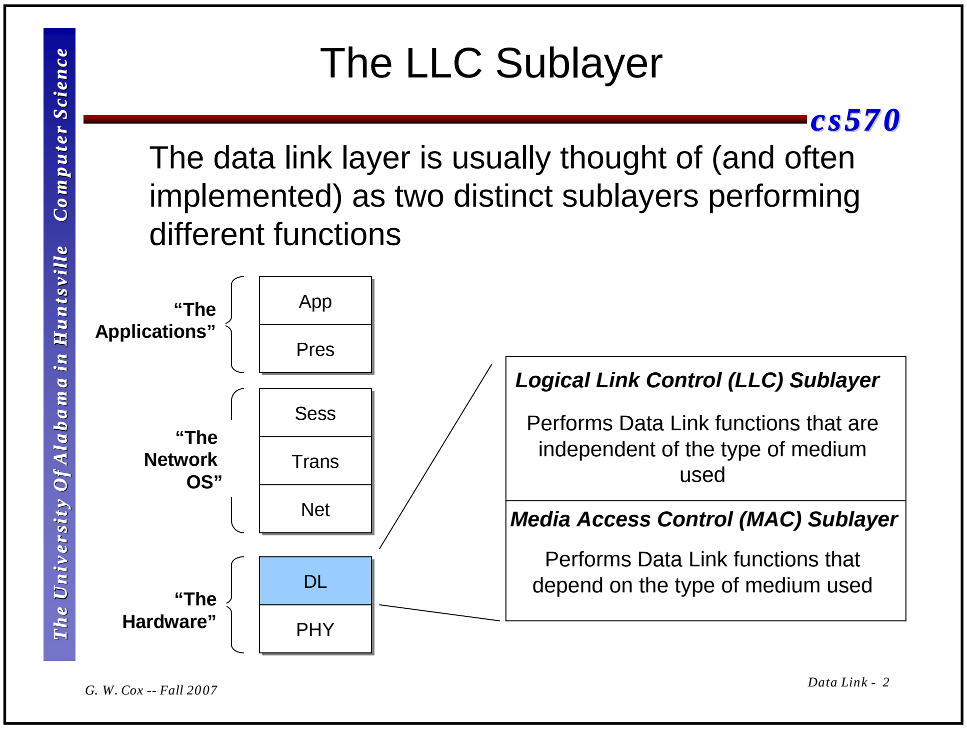


L2: Data Link Layer

Transmits *frames* of data across a link

L2 Functions:

- Accepts data from higher layers and forms it into standard frames
- Synchronizes frames across the link
- Controls the rate of frame flow so that receiver is not overwhelmed
- Recognizes and deals with frame errors
- Manages the link



The LLC Sublayer

The data link layer is usually thought of (and often implemented) as two distinct sublayers performing different functions

Logical Link Control (LLC) Sublayer

Performs Data Link functions that are independent of the type of medium used

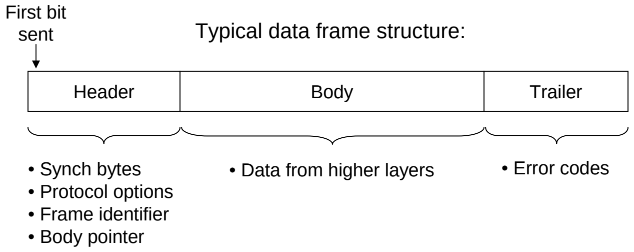
Media Access Control (MAC) Sublayer

Performs Data Link functions that depend on the type of medium used

The LLC sublayer of L2

Frames

Typical data frame structure:

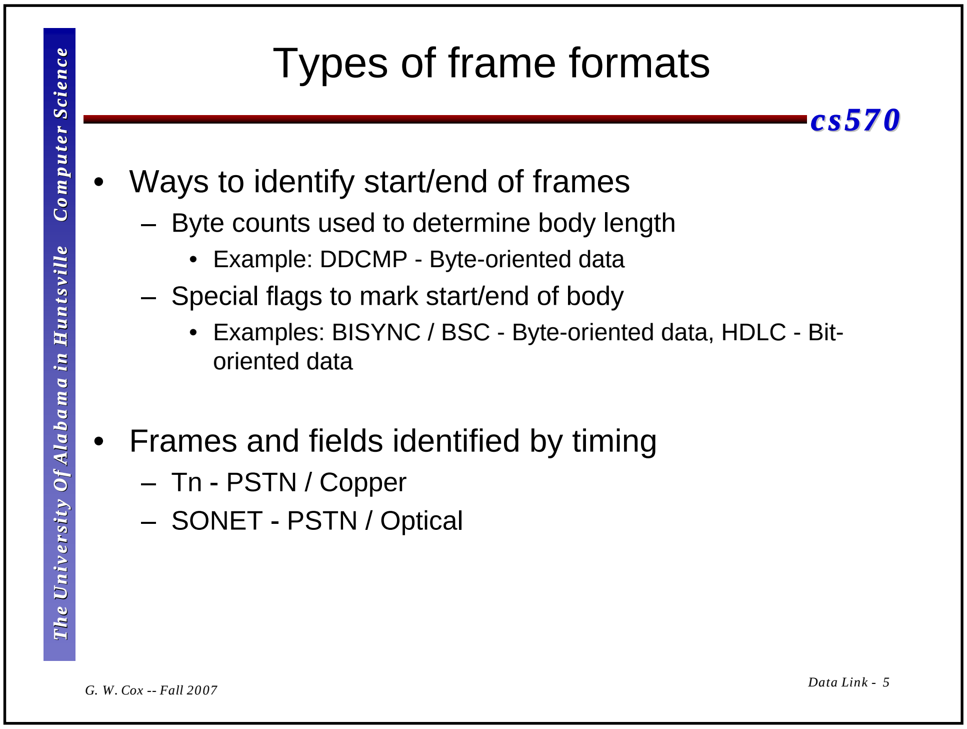


First bit sent

Header	Body	Trailer
• Synch bytes • Protocol options • Frame identifier • Body pointer	• Data from higher layers	• Error codes

Considerations in frame design:

- **Need a dependable way to identify the start and end of frame**
- **If we have a variable-length body, we need a way to find the end**
- **We need a way to distinguish frame control patterns from the same patterns in data**
- **On multidrop links, we need a way to identify source and destination addresses**
- **We need to send both Data and Link Control messages (usually two separate formats)**



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Types of frame formats

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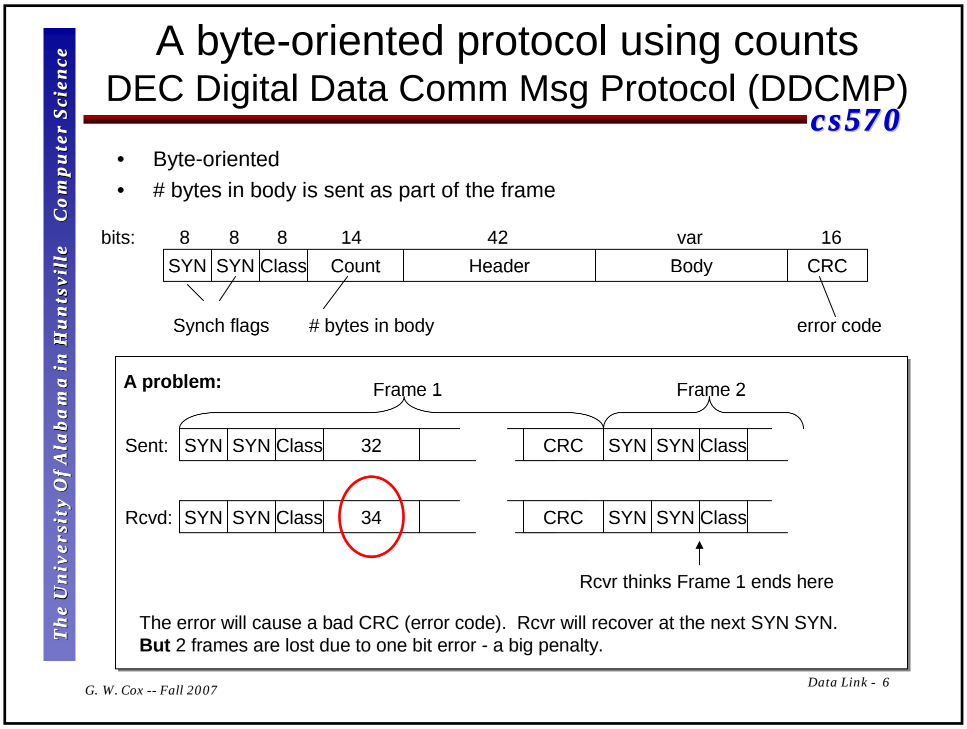
- Ways to identify start/end of frames
  - Byte counts used to determine body length
    - Example: DDCMP - Byte-oriented data
  - Special flags to mark start/end of body
    - Examples: BISYNC / BSC - Byte-oriented data, HDLC - Bit-oriented data
- Frames and fields identified by timing
  - Tn - PSTN / Copper
  - SONET - PSTN / Optical



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A byte-oriented protocol using counts
DEC Digital Data Comm Msg Protocol (DDCMP)

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- Byte-oriented
- # bytes in body is sent as part of the frame

bits:	8	8	8	14	42	var	16
	SYN	SYN	Class	Count	Header	Body	CRC

Synch flags   # bytes in body   error code

A problem:

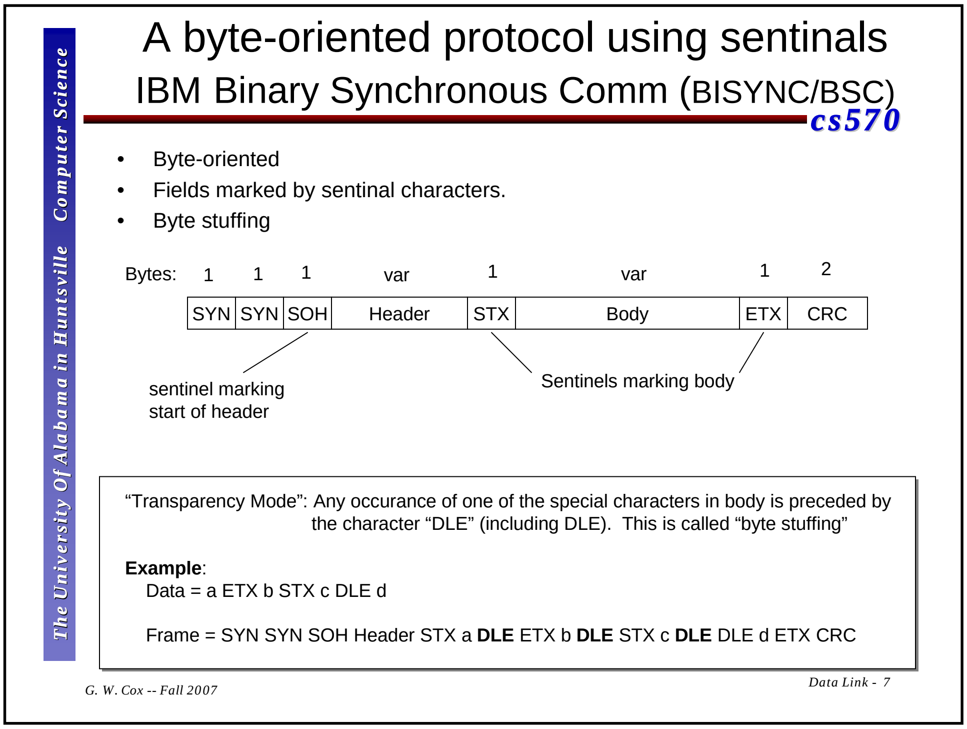
Frame 1   Frame 2

Sent: SYN | SYN | Class | 32 | … | CRC | SYN | SYN | Class

Rcvd: SYN | SYN | Class | 34 | … | CRC | SYN | SYN | Class

Rcvr thinks Frame 1 ends here

The error will cause a bad CRC (error code). Rcvr will recover at the next SYN SYN.
But 2 frames are lost due to one bit error - a big penalty.



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A byte-oriented protocol using sentinals

IBM Binary Synchronous Comm (BISYNC/BSC)

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- Byte-oriented
- Fields marked by sentinal characters.
- Byte stuffing

Bytes:	1	1	1	var	1	var	1	2
	SYN	SYN	SOH	Header	STX	Body	ETX	CRC

sentinel marking
start of header

Sentinels marking body

"Transparency Mode": Any occurance of one of the special characters in body is preceded by the character "DLE" (including DLE). This is called "byte stuffing"

Example:
Data = a ETX b STX c DLE d

Frame = SYN SYN SOH Header STX a **DLE** ETX b **DLE** STX c **DLE** DLE d ETX CRC

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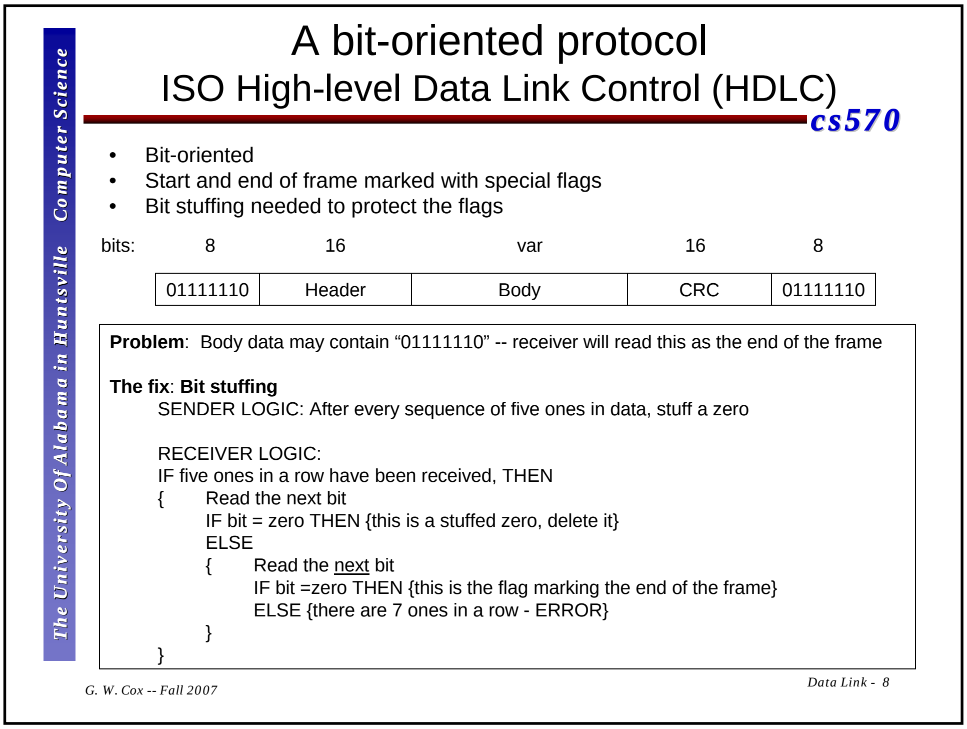
Data Link - 7



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A bit-oriented protocol

ISO High-level Data Link Control (HDLC)

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- Bit-oriented
- Start and end of frame marked with special flags
- Bit stuffing needed to protect the flags

bits:	8	16	var	16	8
	01111110	Header	Body	CRC	01111110

Problem: Body data may contain "01111110" -- receiver will read this as the end of the frame

The fix: **Bit stuffing**

```
SENDER LOGIC: After every sequence of five ones in data, stuff a zero

RECEIVER LOGIC:
IF five ones in a row have been received, THEN
{       Read the next bit
        IF bit = zero THEN {this is a stuffed zero, delete it}
        ELSE
        {       Read the next bit
                IF bit =zero THEN {this is the flag marking the end of the frame}
                ELSE {there are 7 ones in a row - ERROR}
        }
}
```

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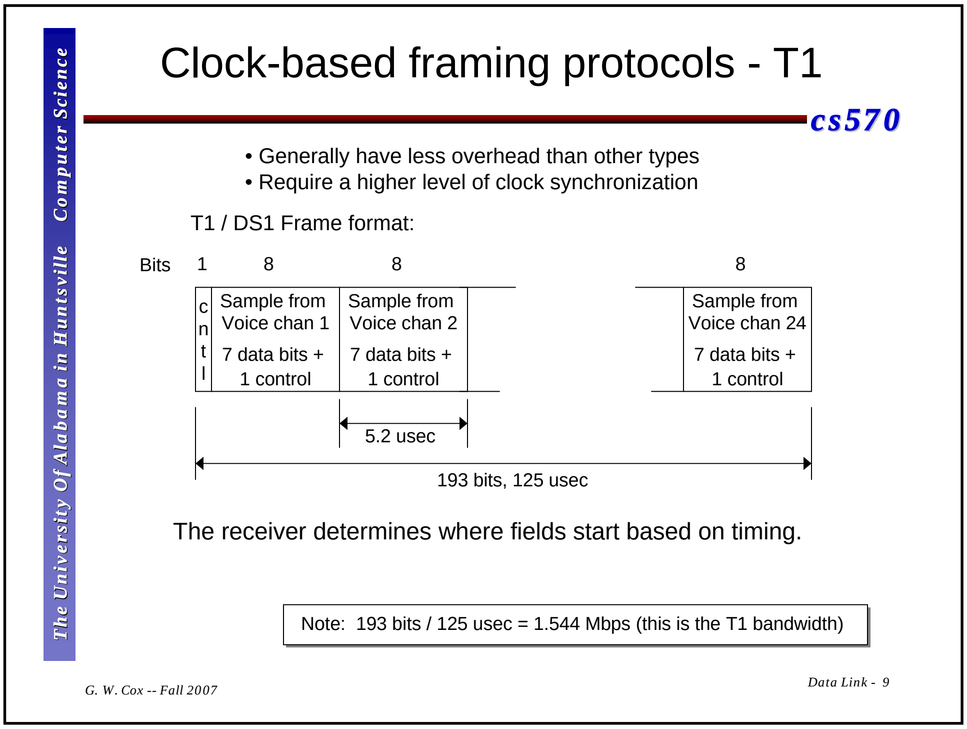
Data Link - 8



Clock-based framing protocols - T1

- Generally have less overhead than other types
- Require a higher level of clock synchronization

T1 / DS1 Frame format:

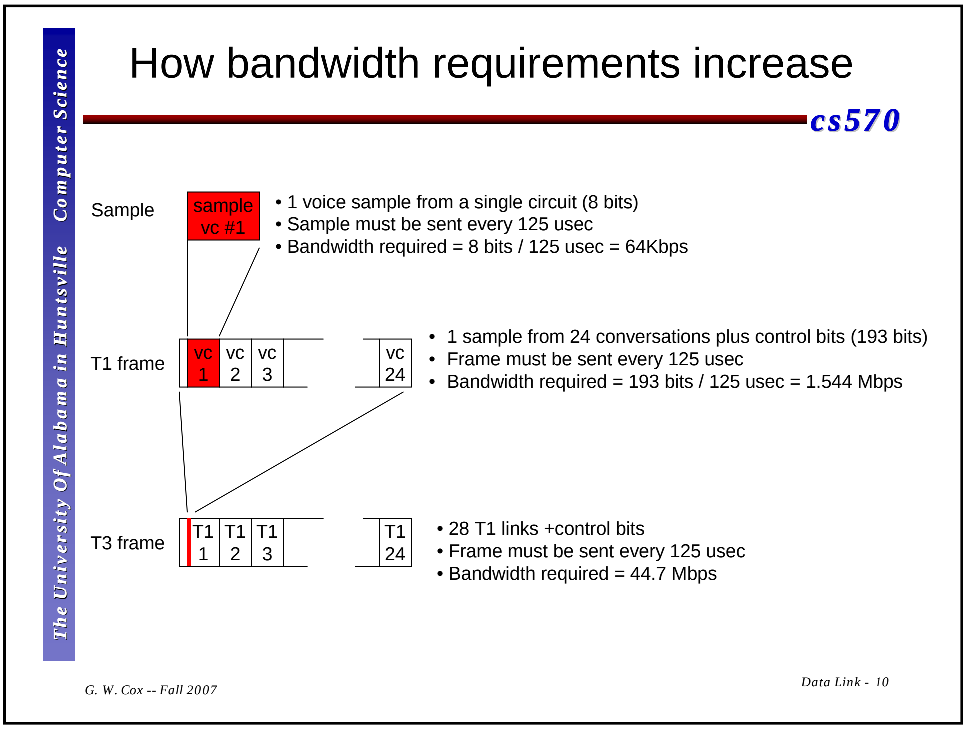
Bits	1	8	8		8
	c n t l	Sample from Voice chan 1 7 data bits + 1 control	Sample from Voice chan 2 7 data bits + 1 control		Sample from Voice chan 24 7 data bits + 1 control

5.2 usec

193 bits, 125 usec

The receiver determines where fields start based on timing.

Note: 193 bits / 125 usec = 1.544 Mbps (this is the T1 bandwidth)



How bandwidth requirements increase

Sample

- 1 voice sample from a single circuit (8 bits)
- Sample must be sent every 125 usec
- Bandwidth required = 8 bits / 125 usec = 64Kbps

T1 frame

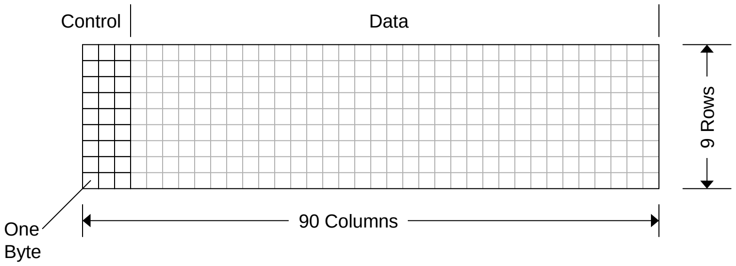
- 1 sample from 24 conversations plus control bits (193 bits)
- Frame must be sent every 125 usec
- Bandwidth required = 193 bits / 125 usec = 1.544 Mbps

T3 frame

- 28 T1 links +control bits
- Frame must be sent every 125 usec
- Bandwidth required = 44.7 Mbps

Synchronous Optical Network (SONET)

SONET STS-1 (OC-1) Frame format

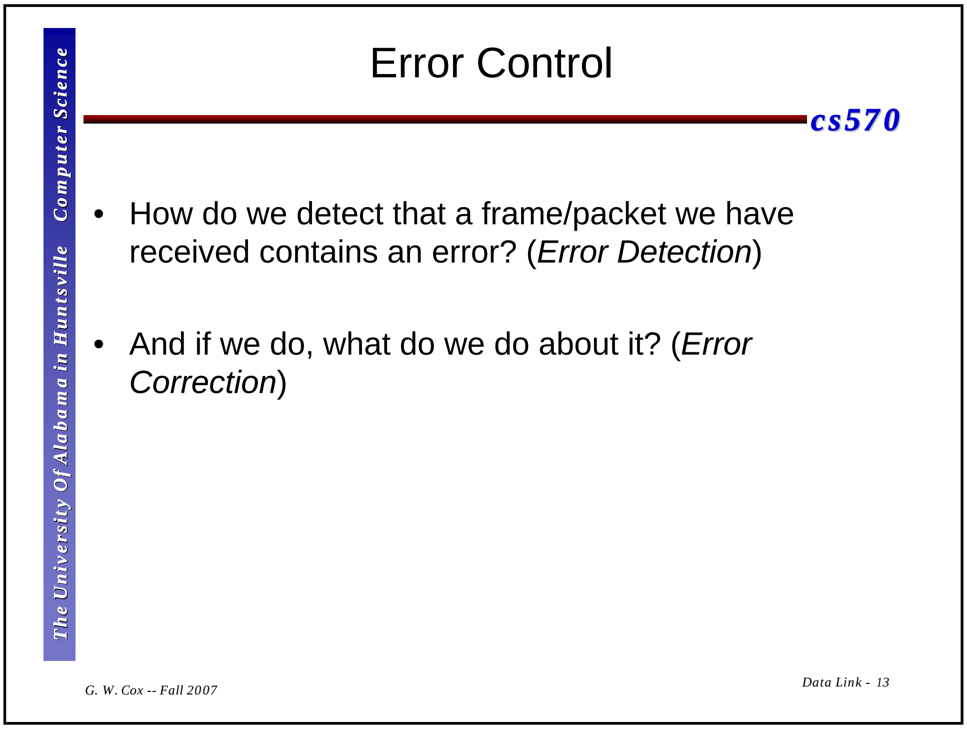


- A SONET STS-1 Frame = 9 x 90 = 810 bytes (= samples from 810 voice circuits)
- A new frame must be sent each 125 usec
- Bandwidth required = 8 x 810 bytes / 125 usec = 51.84 Mbps

A higher-rate “STS-n” SONET link is formed by interleaving n STS-1 frames:

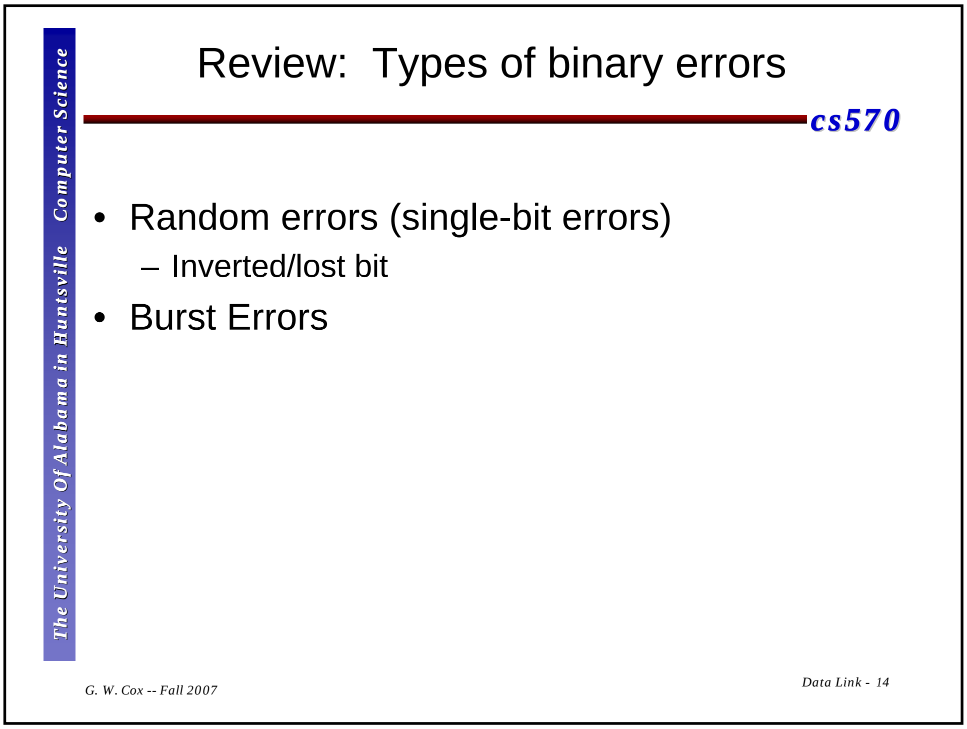
STS-1	BW = 51.84 Mbps	STS-48	BW = 2.49 Gbps
STS-3	BW = 148.6 Mbps	STS-192	BW = 9.95 Gbps

Error Control



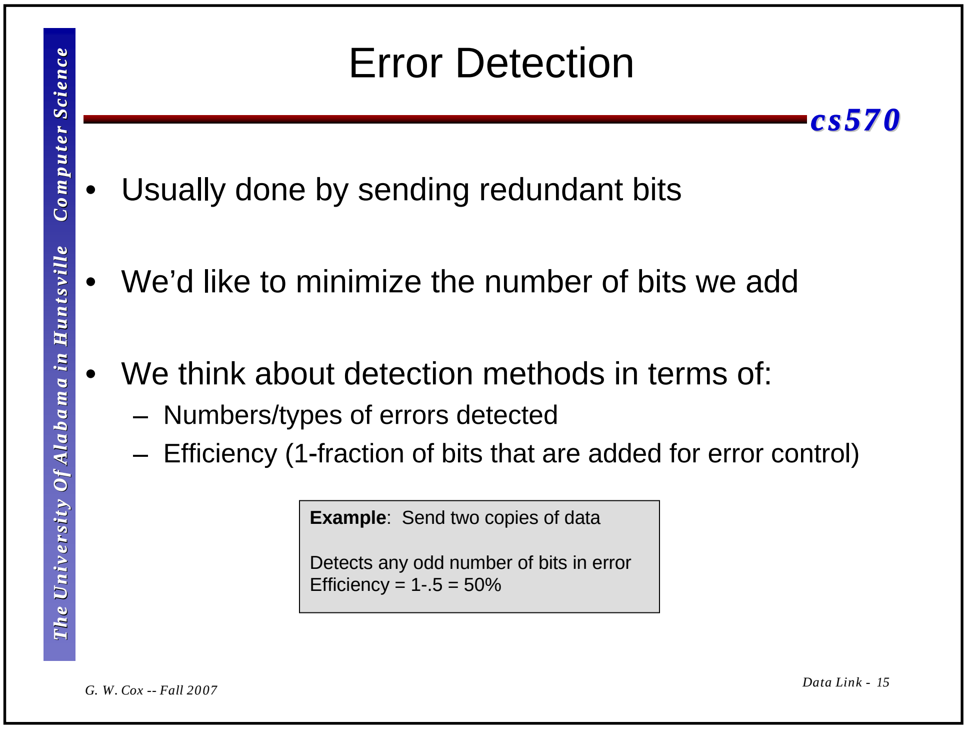
Error Control

- How do we detect that a frame/packet we have received contains an error? (*Error Detection*)
- And if we do, what do we do about it? (*Error Correction*)



Review: Types of binary errors

- Random errors (single-bit errors)
  - Inverted/lost bit
- Burst Errors

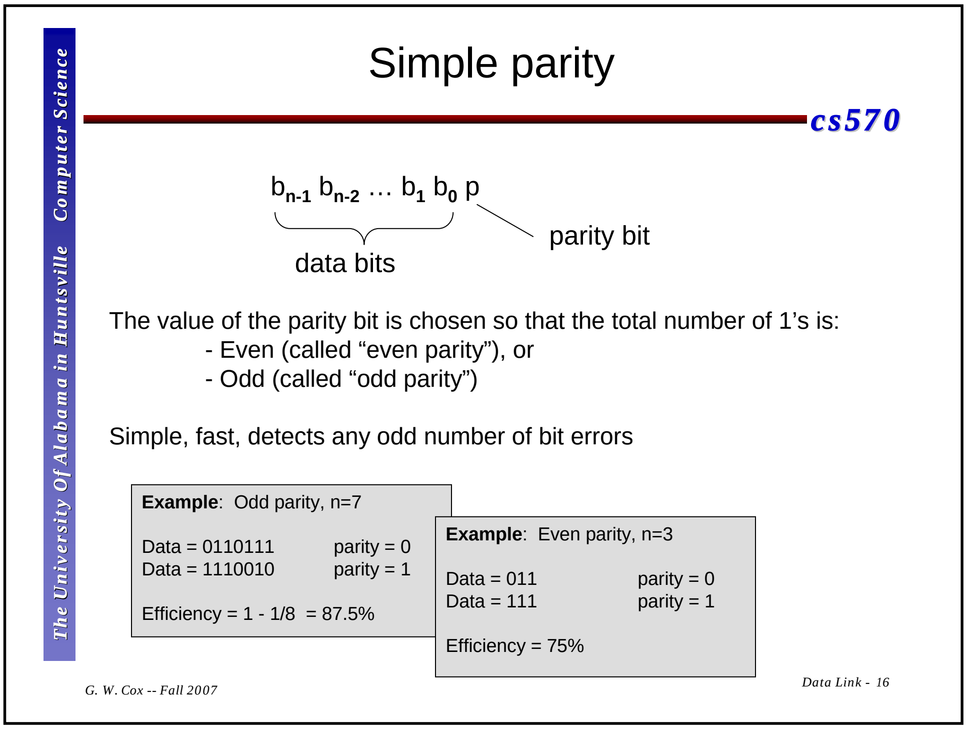


Error Detection

- Usually done by sending redundant bits
- We'd like to minimize the number of bits we add
- We think about detection methods in terms of:
  - Numbers/types of errors detected
  - Efficiency (1-fraction of bits that are added for error control)

Example: Send two copies of data

Detects any odd number of bits in error
Efficiency = 1-.5 = 50%



Simple parity

$$\underbrace{b_{n-1}\, b_{n-2} \dots b_1\, b_0}_{\text{data bits}}\ p$$

parity bit

The value of the parity bit is chosen so that the total number of 1's is:
- Even (called "even parity"), or
- Odd (called "odd parity")

Simple, fast, detects any odd number of bit errors

Example: Odd parity, n=7

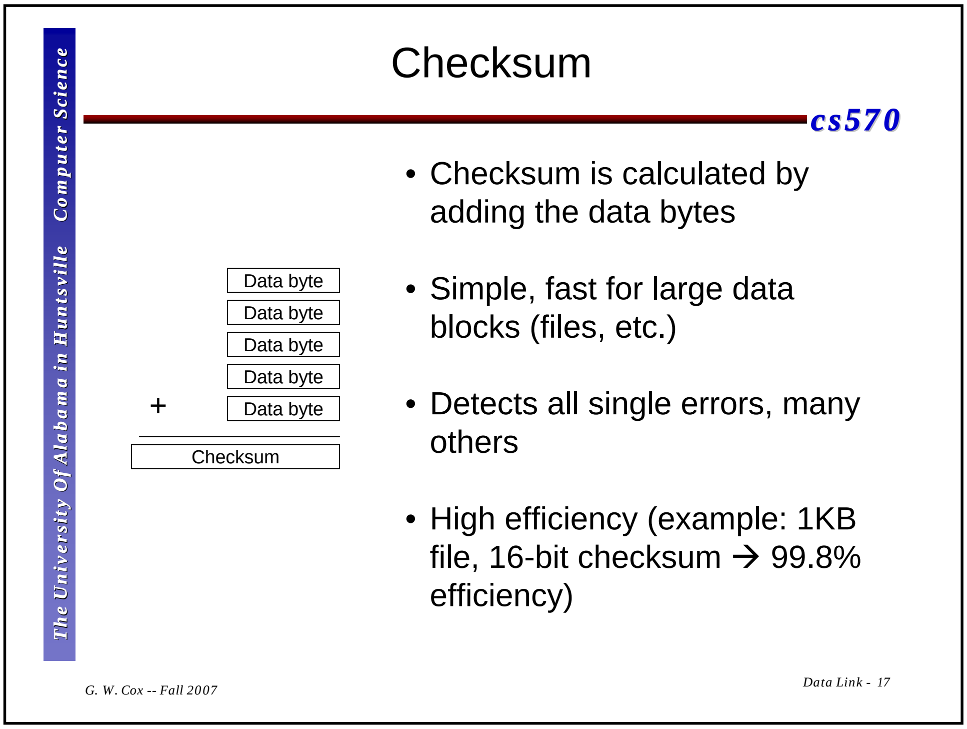
Data = 0110111	parity = 0
Data = 1110010	parity = 1

Efficiency = 1 - 1/8 = 87.5%

Example: Even parity, n=3

Data = 011	parity = 0
Data = 111	parity = 1

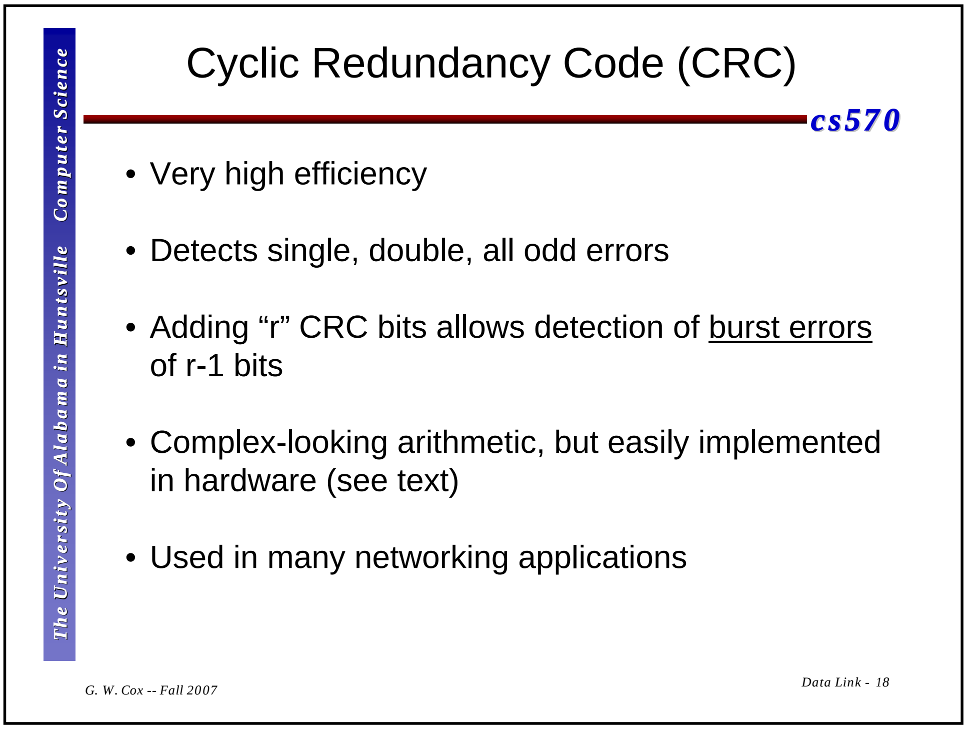
Efficiency = 75%



Checksum

Data byte
Data byte
Data byte
Data byte
+ Data byte
Checksum

- Checksum is calculated by adding the data bytes
- Simple, fast for large data blocks (files, etc.)
- Detects all single errors, many others
- High efficiency (example: 1KB file, 16-bit checksum → 99.8% efficiency)



Cyclic Redundancy Code (CRC)

- Very high efficiency
- Detects single, double, all odd errors
- Adding “r” CRC bits allows detection of burst errors of r-1 bits
- Complex-looking arithmetic, but easily implemented in hardware (see text)
- Used in many networking applications

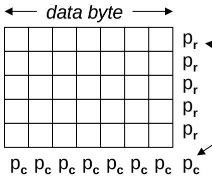
Error Correction

- Error correcting codes allow receiver not only to determine that there was an error but also to determine which bit(s) are incorrect
- Requires more added bits than detection alone

Example: Send three copies of data

Detects any number of bit errors as long as two copies of the bit are correct
Efficiency = 1-.67 = 33%

Example: 2-D parity error correction method



parity calculated over byte

parity calculated over the same bit in every byte and byte parity bits

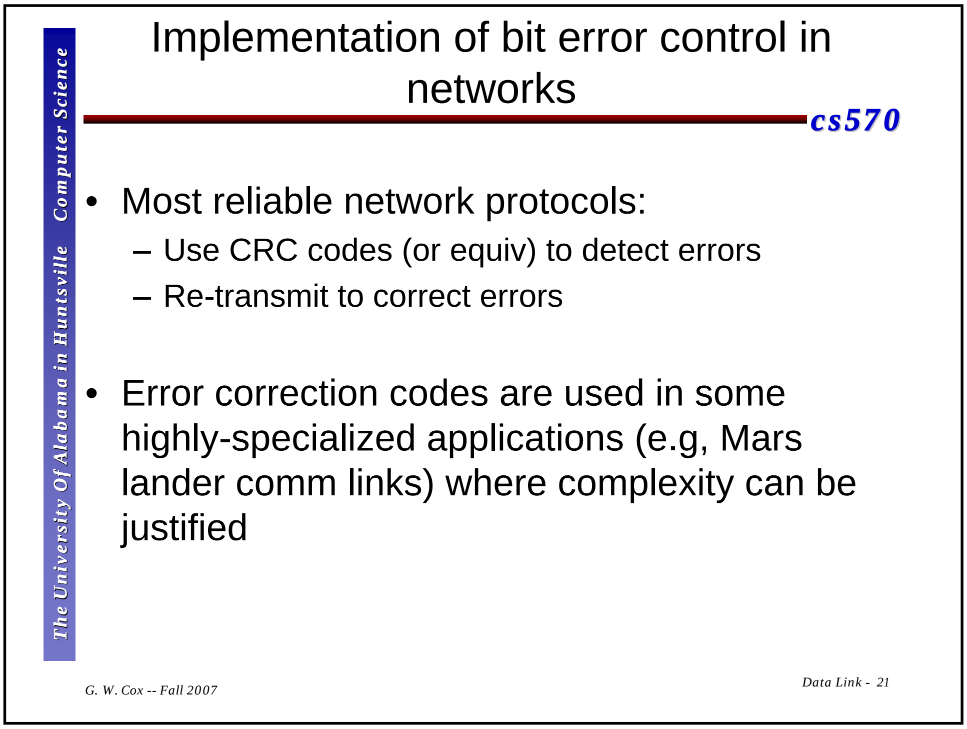
Corrects any single bit error – byte parity error identifies the byte, bit parity error identifies the bit

Example: odd parity

```
Transmitted                  Received

1 0 1 1 0 1 1 0              1 0 1 1 0 1 1 0
0 0 0 0 0 0 0 1              0 0 0 0 1 0 0 1  X
0 0 0 1 1 1 1 1              0 0 0 1 1 1 1 1
1 0 0 0 0 1 1 0              1 0 0 0 0 1 1 0

1 1 0 1 0 0 0 1              1 1 0 1 0 0 0 1
                                     X
```



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Implementation of bit error control in networks

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- Most reliable network protocols:
  - – Use CRC codes (or equiv) to detect errors
  - – Re-transmit to correct errors

- Error correction codes are used in some highly-specialized applications (e.g, Mars lander comm links) where complexity can be justified