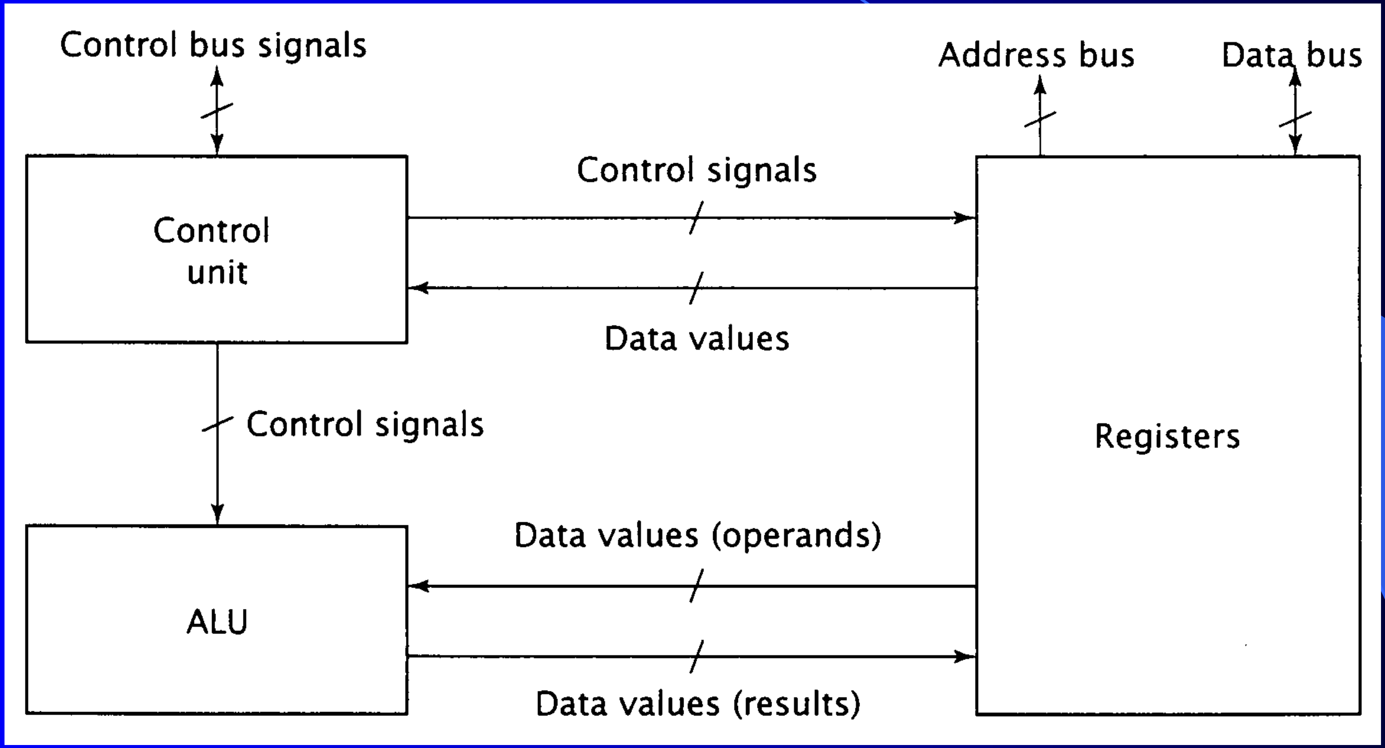
ITM1010
Computer and Communication Technologies

Lecture #9

Part I: Introduction to Computer Technologies

Computer Organization

CPU Internal Organization



CPU Internal Organization

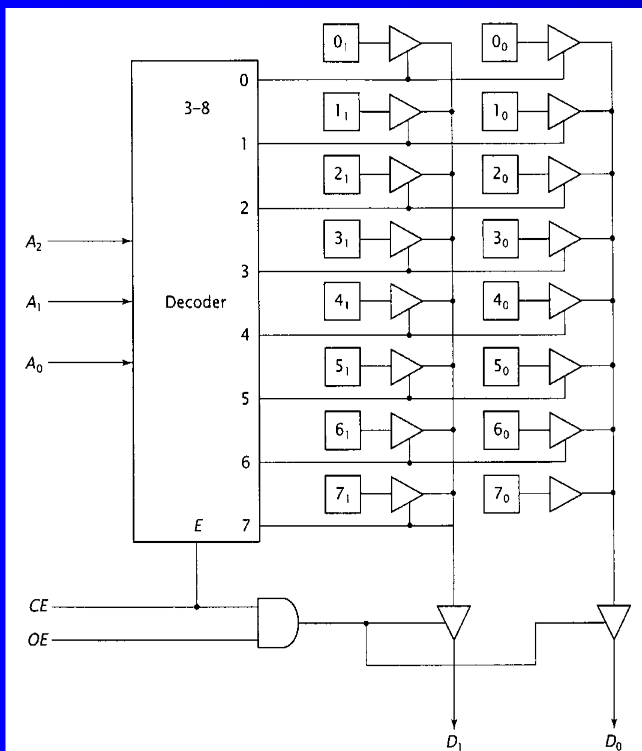
- Register Section
  - Register directly accessible by programs – registers to store operands
  - Register not directly accessible by programs – program counter, instruction register
- Control Unit
  - The digital circuit that dictates the action sequence of CPU
    - Sequential circuit – finite state machine
    - Combinational circuit – instruction decoder
- Arithmetic/Logic Unit
  - Perform the arithmetic and logic operations

Types of Memory

- Read Only Memory, ROM
  - Data can only be read and will not be changed even power is off
- Masked ROM
  - Programmable ROM, PROM
  - Erasable PROM, EPROM
  - Electrically Erasable PROM, E2PROM
  - Flash E2PROM – electrically erasable in blocks of data
- Random Access Memory, RAM
  - Used to store data that changes. As long as power is on, data is kept
  - Dynamic RAM, DRAM – require refresh, slower
  - Static RAM, SRAM – no refresh, faster

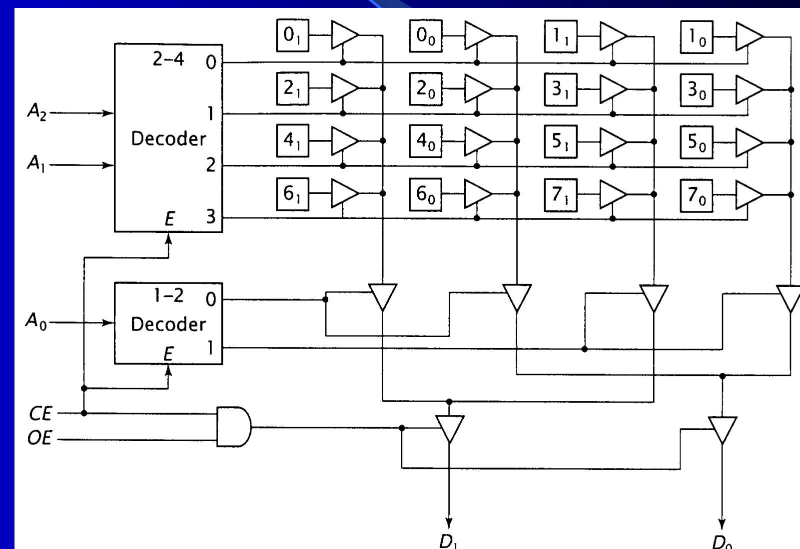
Memory Organization

- Linear
  - e.g. 8x2



N to 2^n decoder $O(2^n)$

- Two-Dimensional
  - e.g. 8x2



Simpler decoders are used instead. For a symmetrical two-dimensional array,

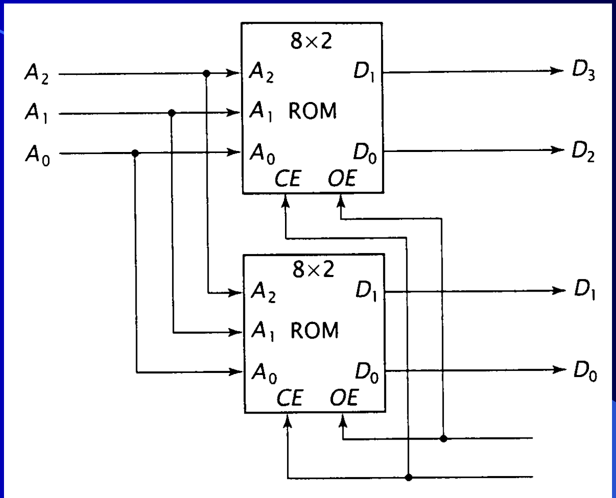
Two n/2 to $2^{n/2}$ decoders $O(2^{1+n/2})$

e.g. 4K x 1 ROM

2D requires only 3% of Linear

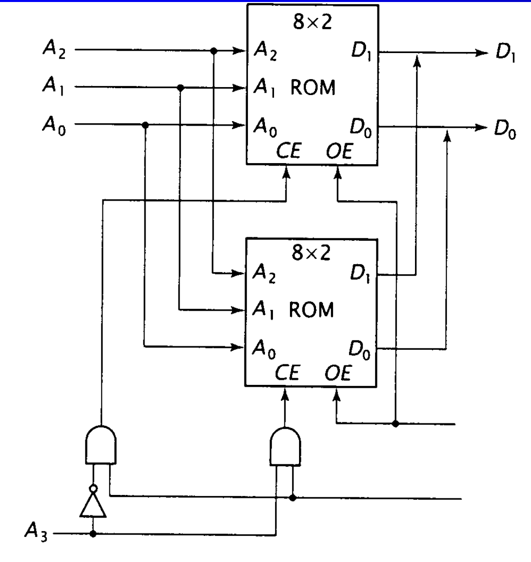
Memory Subsystem Configurations

- Wider Word Length

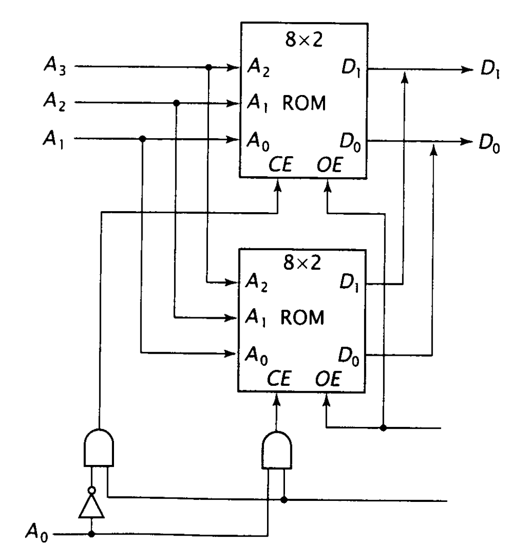


- Larger Memory Size

high-order interleaving

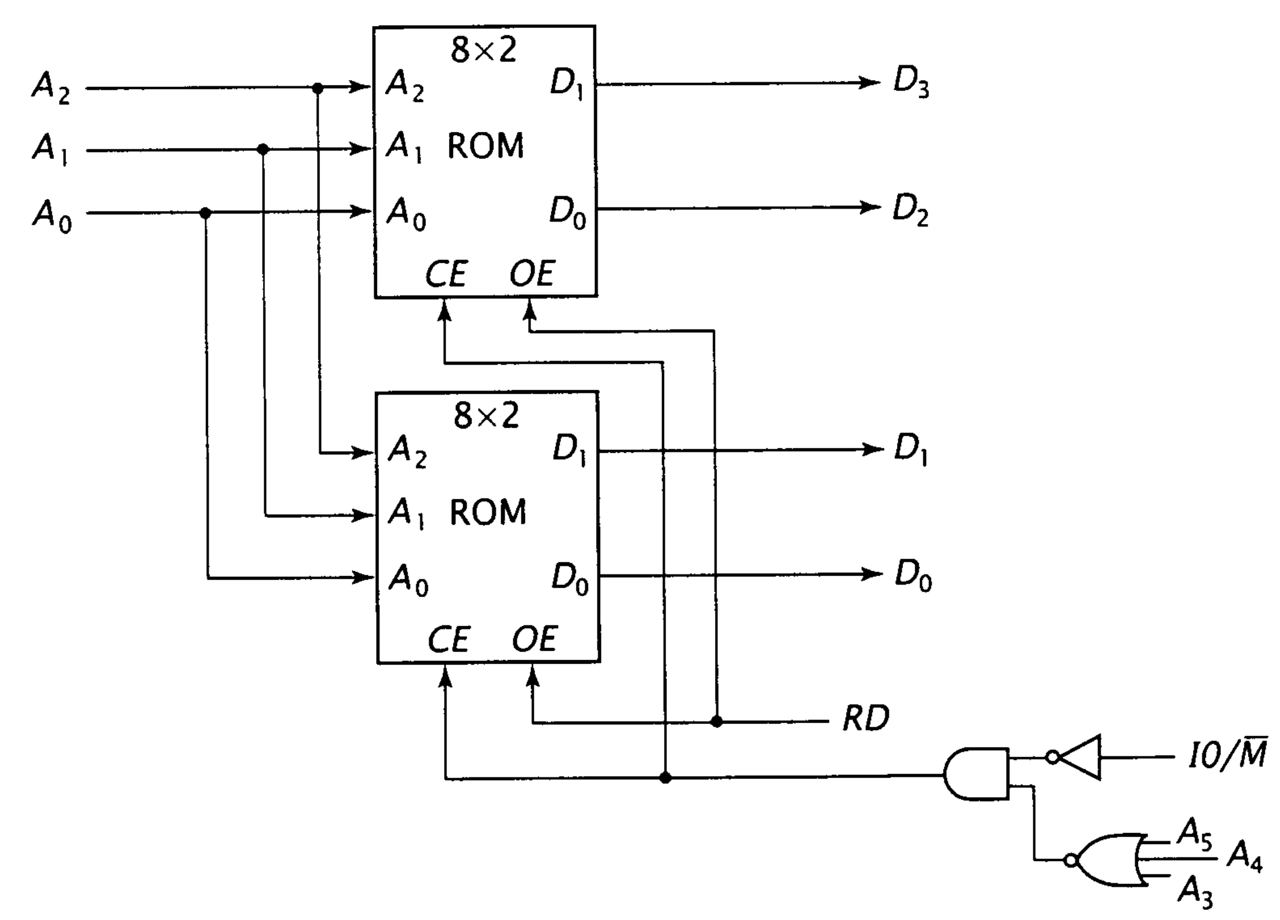


low-order interleaving



Control Logic for Memory Chip

- e.g. 8x4 memory subsystem constructed from two 8x2 memory chips in a 6-bit address bus



Multi-byte Data Organization

- Many data formats are longer than one data word/byte (bit-length of the data bus) so require more than one memory location for storage. It is necessary to define the order of the data in these locations.

Multi-byte Data Organization

$04030201_{(H)}$

- Big Endian

Memory Address	Data (in hex)
100	01
101	02
102	03
103	04

  – Big endian format places the upper byte in the lowest memory location.

- Little Endian

Memory Address	Data (in hex)
100	04
101	03
102	02
103	01

  – A number stored in little endian format has its lower byte in the lowest memory location.

Class Exercise

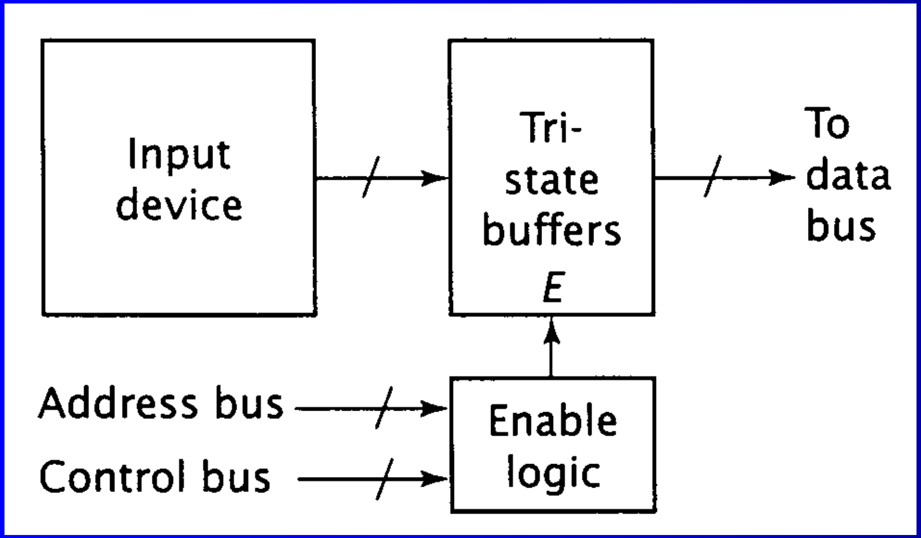
- The numbers $BBFF_{(H)}$ and $AFFF_{(H)}$ are stored in memory address locations $F00A0_{(H)}$ and $F00A1_{(H)}$ respectively by a big-endian microprocessor. What is the decimal equivalent of the 32-bit 2's complement number stored in these addresses?

Other Memory Sub-systems

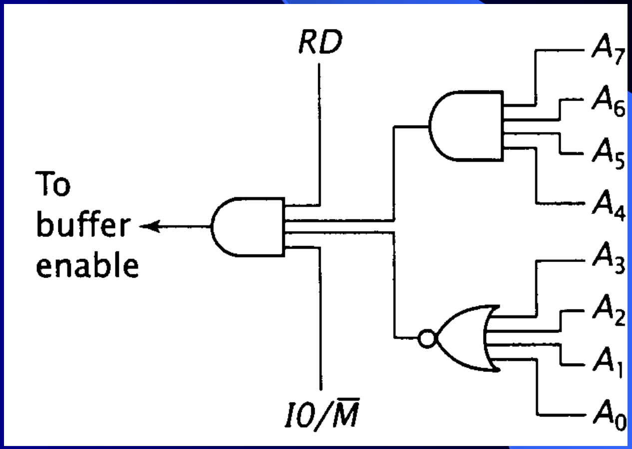
- Cache Memory
  - Cache memory can be accessed much faster than normal memory chip, and is usually integrated inside a processor chip
- Virtual Memory
  - A permanent storage device (hard disk) is used as a part of the computer's memory, expanding the memory space of the computer while minimizing cost

I/O Sub-system Organization

- CPU accesses I/O devices as memories. However, I/O devices can be vastly different in speed and behavior, so an interface circuit is required



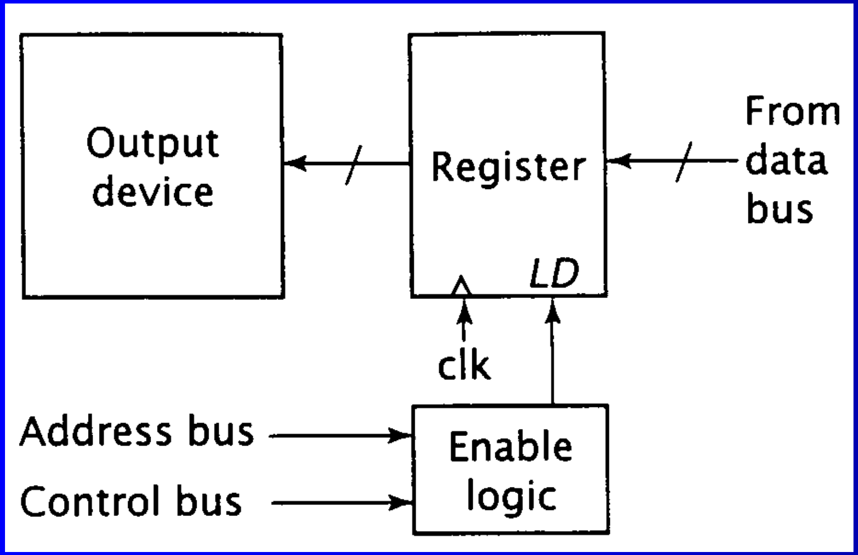
Generic Interface for an Input Device



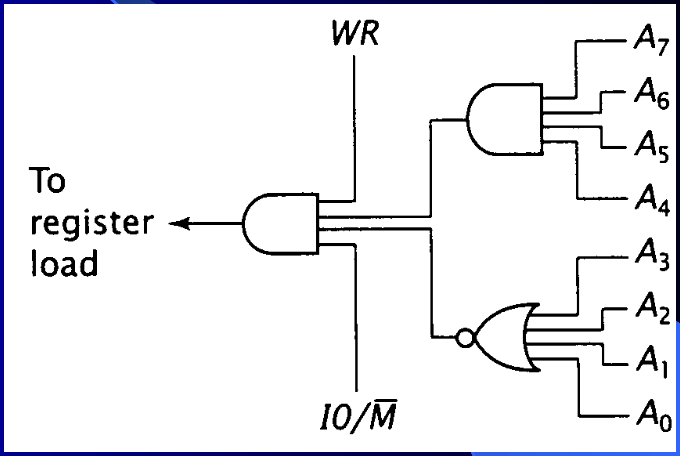
Enable Logic

I/O Sub-system Organization

- Output Device



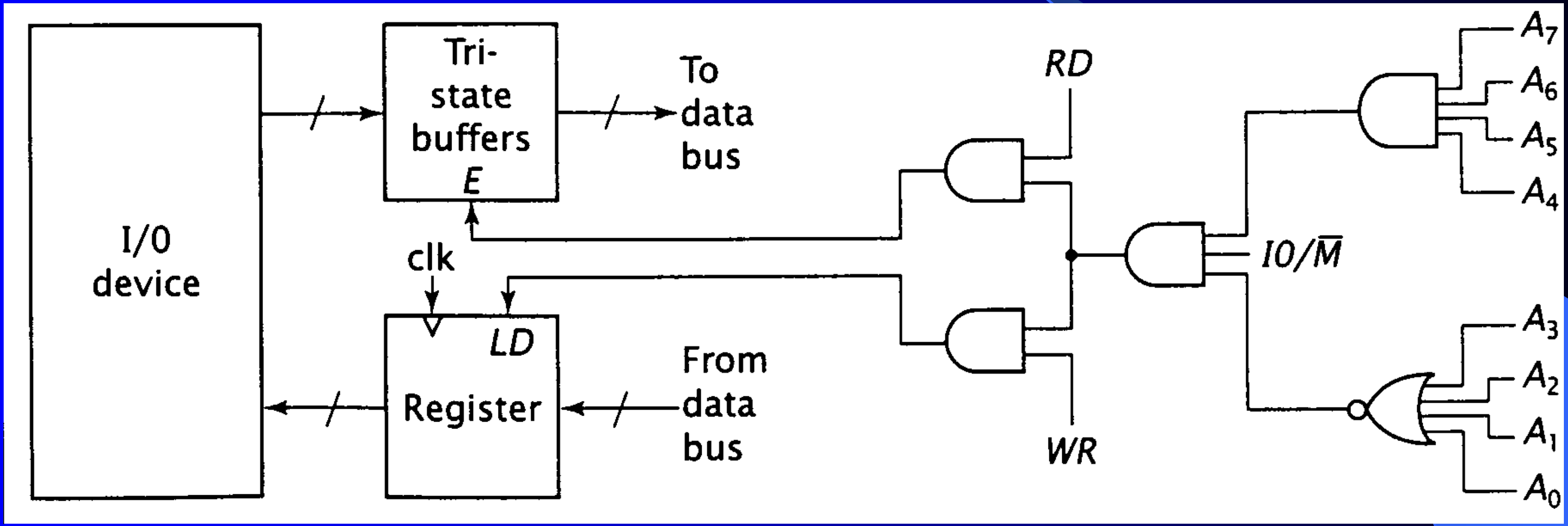
Generic Interface for an Output Device



Enable Logic

I/O Sub-system Organization

- I/O Device



I/O Sub-system Organization

- I/O devices are usually much slower than CPU. For this reason, they can have timing problem when interfacing with CPU. To solve this problem, most CPUs have a control input signal called READY. The CPU goes into WAIT state when READY is asserted.
- An alternative is to use INTERRUPT. An interrupt will direct the attention of the CPU to a self-contained program (interrupt service routine) and return the CPU to its main program after completion.
- There are situations where a large amount of data are to be channeled between I/O devices and memory. It will tie up CPU too much if the transfer has to go through CPU. Direct Memory Access, DMA, is a method used to by-pass CPU in these transfers.

Part II:
Communication Technologies

Introduction

What is telecommunications?

- Oxford English Dictionary definition:
  – Tele : “far; at a distance”
  – Communications : “Science and practice of transmitting information”
- Mathematics is essential for this “science and practice of transmitting information at a distance.”

- Communications is normally taken only by 2nd or 3rd year undergraduates who have passed background courses in signals and systems, probability and mathematics.

- This part of the course aims to provide an in-depth introduction to communications technology and provide understanding of the principles of communications systems.

A brief history of telecommunications

- **1838** William F. Cooke and Sir Charles Wheatstone build the telegraph (Morse code communications).
  - It is interesting that communications started with digital technology.
- **1844** Samuel F. B. Morse demonstrates the Baltimore, MD, and Washington, DC, telegraph line.
  - Analog technology.
- **1858** First transatlantic cable is laid and failed after 26 days.
- **1864** James C. Maxwell predicts electromagnetic radiation.
- **1876** Alexander G. Bell develops and patents the telephone.

A brief history of telecommunications

- **1894** Oliver Lodge demonstrates wireless communication over a distance of 150 yards (~137m).
- **1900** Gulielmo Marconi transmits the first transatlantic wireless signal.
- **1905** R. Fessenden transmits speech and music by radio.
- **1915** Bell System completes a US transcontinental telephone line.
- **1920** KDKA, Pittsburgh, PA, begins the first scheduled radio broadcasts.

A brief history of telecommunications

- **1926** RJ.L. Baird (England) and C.F. Jenkins (US) demonstrate television.
- **1933** Edwin H. Armstrong invents FM.
- **1935** R.A. Watson-Watt develops the first practical radar.
- **1936** The BBC begins first television broadcasts.
- **1953** NTSC color television is introduced in the US.
- **1953** The first transatlantic telephone cable (36 voice channels) is laid.
- **1957** The 1st Earth satellite, *Sputnik I*, is launched by USSR.

A brief history of telecommunications

- **1964** The electronic telephone switching system starts.
- **1968** Cable television systems are developed.
- **1972** Motorola demonstrates the cellular telephone to FCC.
- **1980** Bell System FT3 fiber-optic communication is developed.
- **1985** Fax machines become popular.
- **1989** GPS using satellite is developed.
- **2000-** Era of digital signal processing with microprocessors, megaflop PCs, digital satellite systems, DTV, and PCS.

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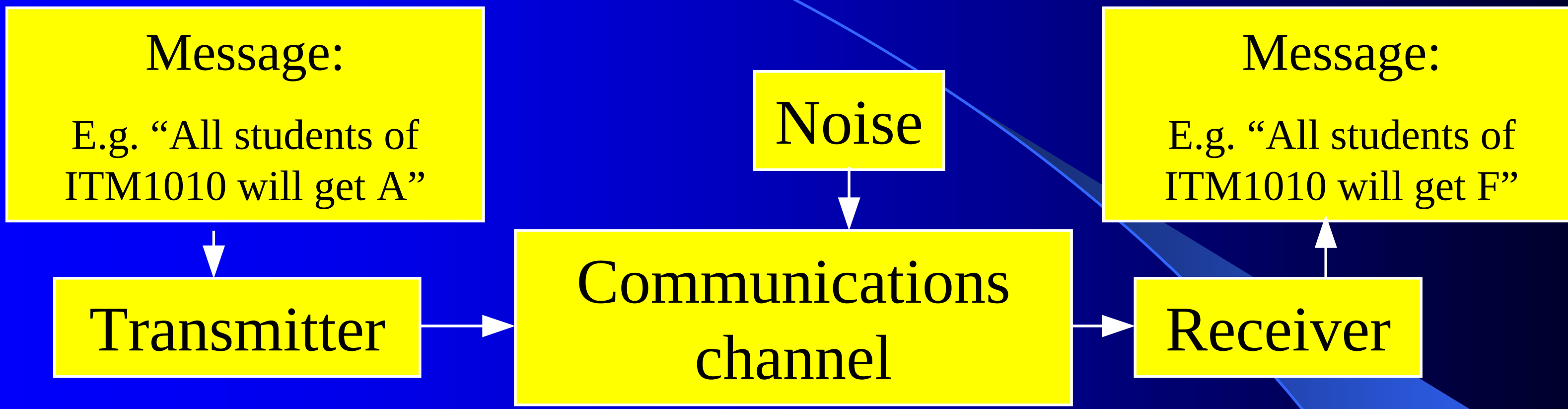
Part II: Introduction to Communication Technologies

Information Measure

Communications System



- Message transmitted in a communications system is only one of a finite set of messages.
- Message may be corrupted by noise in the channel, transmitter or receiver
- Communications engineers' basic objective is to design a system which faithfully reproduces the message sent at the receiver in the most efficient (e.g.. least time, cost) way possible.

Measurement of information

- More information is contained in an unexpected message than one which is expected. E.g., a message such as “ next week’s lottery will draw 2,11,12,17,30,41” has more information content than a message saying “This sentence is written in English.”

Measurement of information

- If a message m_j has probability P_j of being sent, the information content of the message I_j is defined by:

$$I_j = \log_2 \frac{1}{P_j}$$

  – If log to base 2 is used then the unit of information is the bit

Refresher on logarithms

- By definition, if $a^x=y$ then $\log_a y = x$
- Some basic properties of logarithms include
  - $\log(xy)=\log x + \log y$
  - $\log(x/y)=\log x - \log y$
  - $\log x^r = r \log x$

Refresher on logarithms

- How to change the base e.g. what is $\log_b y$ in terms of $\log_a y$?

$$\text{Let } z = \log_b y$$

$$b^z = y$$

Taking, log to base *a* on both sides

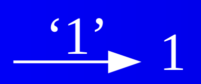
$$z \log_a b = \log_a y$$

$$z = \frac{\log_a y}{\log_a b} = \log_b y$$

Hence $\log_2 y = \log_{10} y / \log_{10} 2$

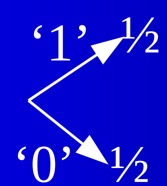
Probability and information

Message is always ‘1’



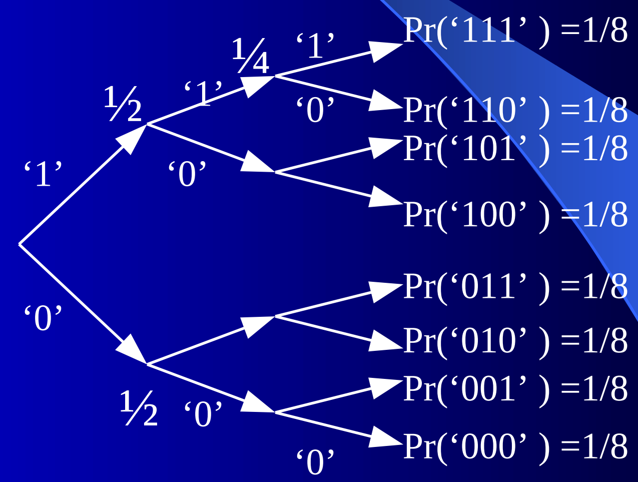
Information content of message is $I_1 = \log_2 1 = 0$

Message is equally likely to be either ‘1’ or ‘0’



Information content of a message is
$I_1 = \log_2 2 = 1$
$I_0 = \log_2 2 = 1$

Message is equally likely to be any of 000, 001, 010, 011, 100, 101, 110, 111



Information content of a message is
$I_{111} = \log_2 8 = 3$

Binary digits and bits

- If the probability of sending a binary digit (1 or 0) are equal to 1/2 then the information content of a binary digit is

$$I_1 = I_0 = \log_2 \frac{1}{0.5} = \log_2 2 = 1$$

  - Most engineers use the same word (bit) for a binary digit and the unit of information. However information content of a binary digit is not necessarily equal to 1 bit (e.g. if the probability of a 1 is not equal to ½).
  - If log to base 10 is used the unit of information is the hartley (named after R.V.Hartley who first suggested the use of logs to measure information in 1928).

Average Information Content and Entropy

- The average information content H of all possible messages in a communications system which has a total of N different messages (each having information Ij =$\log_2 1/P_j = -\log_2 P_j$) is:

$$H = p_1 I_1 + p_2 I_2 + \ldots + p_N I_N$$

$$H = -\sum_{j=1}^{N} p_j \log_2 p_j$$

- Since the form of this equation is identical to the definition for entropy in statistical mechanics, H is also called entropy.
- Entropy may be thought of as a measure of the average uncertainty or randomness of the system and will have a maximum when all possible messages are equally likely.
- Unit of entropy is bits per message.

Example: entropy coding of information

- Suppose a language uses an alphabet of 4 symbols, which we denote by A,B,C and D, and that the probability of each symbol occurring in the language are 0.5, 0.25, 0.125 and 0.125 respectively. We can use entropy to calculate the minimum number of bits needed for sending messages in this language:
  - The most obvious code is not the most efficient e.g. if the binary numbers 00,01,10,11 are used for A,B,C and D, we need 2 bits for each symbol. For a long message of n symbols using this code, 2n bits must be sent.
  - But entropy in this example is

$$H=0.5 \log_2 2+0.25 \log_2 4+0.125 \log_2 8+0.125 \log_2 8 = 1.75$$

  - Only need 1.75 n bits to send n symbols

An example of Entropy Coding

- A carefully chosen code which can achieve the minimum of 1.75 bits per symbol for the previous example language is :

  0=A 10=B 110=C 111=D

- The encoded message can be readily recovered by using illegal bit sequences (e.g.. 01) to identify the boundary between symbols.
- The average number of binary digits needed to encode a sequence of n symbols using this code is

$$n\,(0.5 \times 1 + 0.25 \times 2 + 0.125 \times 3 + 0.125 \times 3) = 1.75\,n$$

- This is an example of entropy encoding - we have used knowledge of the statistics of a message source to reduce the number of binary digits needed on average to send a message from that source.

Example: Entropy of English

- The entropy of English may be defined as the average information content of each letter in the alphabet
- 26 letters in the English alphabet: If each letter occurs with equal probability the information content of each letter is $\log_2(26)=4.7$ bits. However not all letters have equal probability (E.g.. "E" occurs more frequently in English than the letter "Q")
- In 1950, Claude Shannon calculated the entropy of English to be 2.3 bits per letter when statistical effects extending up to 8 letters were considered. When long range effects (up to 100 letters) were included the entropy was further reduced to only 1 bit per letter.

Summary

- Message sent by a communications system is only one of a finite set of possible message
- Information content of a message can be precisely defined mathematically as

$$I_j = \log_2 \frac{1}{P_j}$$

- Unit of information is a bit
- The average information content of all possible messages in a system is called entropy (units: bits per message)

$$H = -\sum_{j=1}^{N} p_j \log_2 p_j$$

- One binary digit may not necessarily carry one bit of information.
- Possible to design efficient codes which achieve the minimum number of binary digits per message as specified by entropy