# BLM2041 Signals and Systems

**Week 1**

**The Instructors:**

Prof. Dr. Nizamettin Aydın

naydin@yildiz.edu.tr

Asist. Prof. Dr. Ferkan Yilmaz

ferkan@yildiz.edu.tr



# Information Systems:

# Fundamentals



## Informatics

- The term informatics broadly describes the study and practice of
  - creating,
  - storing,
  - finding,
  - manipulating
  - sharing

  information.



## Informatics - Etymology

- In 1956 the German computer scientist Karl Steinbuch coined the word Informatik
  - [*Informatik: Automatische Informationsverarbeitung* ("Informatics: Automatic Information Processing")]
- The French term informatique was coined in 1962 by Philippe Dreyfus
  - [Dreyfus, Phillipe. L'informatique. Gestion, Paris, June 1962, pp. 240–41]
- The term was coined as a combination of information and automatic to describe the science of automating information interactions



## Informatics - Etymology

- The morphology—informat-ion + -ics—uses
- the accepted form for names of sciences,
  - as conics, linguistics, optics,
- or matters of practice,
  - as economics, politics, tactics
- linguistically, the meaning extends easily
  - to encompass both
    - the science of information
    - the practice of information processing.



## Data - Information - Knowledge

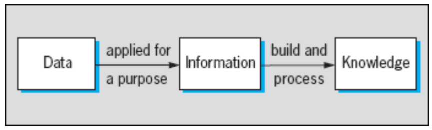
- Data
  - unprocessed facts and figures without any added interpretation or analysis.
    - {The price of crude oil is $80 per barrel.}
- Information
  - data that has been interpreted so that it has meaning for the user.
    - {The price of crude oil has risen from $70 to $80 per barrel}
      - [gives meaning to the data and so is said to be information to someone who tracks oil prices.]

## Data - Information - Knowledge

- Knowledge
  - a combination of information, experience and insight that may benefit the individual or the organisation.
    - {When crude oil prices go up by $10 per barrel, it's likely that petrol prices will rise by 2p per litre.}
      - [This is knowledge]
      - [insight: the capacity to gain an accurate and deep understanding of someone or something; an accurate and deep understanding]



## Converting data into information




- Data becomes information when it is applied to some purpose and adds value for the recipient.
  - For example a set of raw sales figures is data.
    - For the Sales Manager tasked with solving a problem of poor sales in one region, or deciding the future focus of a sales drive, the raw data needs to be processed into a sales report.
  - It is the sales report that provides information.



## Converting data into information

- Collecting data is expensive
  - you need to be very clear about why you need it and how you plan to use it.
  - One of the main reasons that organisations collect data is to monitor and improve performance.
    - if you are to have the information you need for control and performance improvement, you need to:
      - collect data on the indicators that really do affect performance
      - collect data reliably and regularly
      - be able to convert data into the information you need.



## Converting data into information

- To be useful, data must satisfy a number of conditions. It must be:
  - relevant to the specific purpose
  - complete
  - accurate
  - timely
    - data that arrives after you have made your decision is of no value

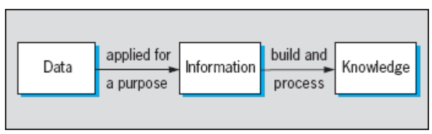


## Converting data into information

  - in the right format
    - information can only be analysed using a spreadsheet if all the data can be entered into the computer system
  - available at a suitable price
    - the benefits of the data must merit the cost of collecting or buying it.
- The same criteria apply to information.
  - It is important
    - to get the right information
    - to get the information right



## Converting information to knowledge




- Ultimately the tremendous amount of information that is generated is only useful if it can be applied to create knowledge within the organisation.
- There is considerable blurring and confusion between the terms information and knowledge.

## Converting information to knowledge

- think of knowledge as being of two types:
  - Formal, explicit or generally available knowledge.
    - This is knowledge that has been captured and used to develop policies and operating procedures for example.
  - Instinctive, subconscious, tacit or hidden knowledge.
    - Within the organisation there are certain people who hold specific knowledge or have the 'know how'
      - {"I did something very similar to that last year and this happened….."}

13

## Converting information to knowledge

- Clearly, both types of knowledge are essential for the organisation.
- Information on its own will not create a knowledge-based organisation
  - but it is a key building block.
- The right information fuels the development of intellectual capital
  - which in turns drives innovation and performance improvement.

14

## Definition(s) of system

A system can be broadly defined as an integrated set of elements that accomplish a defined objective.

People from different engineering disciplines have different perspectives of what a "system" is.

For example,

software engineers often refer to an integrated set of computer programs as a "system"

electrical engineers might refer to complex integrated circuits or an integrated set of electrical units as a "system"

As can be seen, "system" depends on one's perspective, and the "integrated set of elements that accomplish a defined objective" is an appropriate definition.

15

## Definition(s) of system

- A system is an assembly of parts where:
  - The parts or components are connected together in an organized way.
  - The parts or components are affected by being in the system (and are changed by leaving it).
  - The assembly does something.
  - The assembly has been identified by a person as being of special interest.
- Any arrangement which involves the handling, processing or manipulation of resources of whatever type can be represented as a system.
- Some definitions on online dictionaries
  - http://en.wikipedia.org/wiki/System
  - http://dictionary.reference.com/browse/systems
  - http://www.businessdictionary.com/definition/system.html

16

## Definition(s) of system

- A system is defined as multiple parts working together for a common purpose or goal.
- Systems can be large and complex
  - such as the air traffic control system or our global telecommunication network.
- Small devices can also be considered as systems
  - such as a pocket calculator, alarm clock, or 10-speed bicycle.

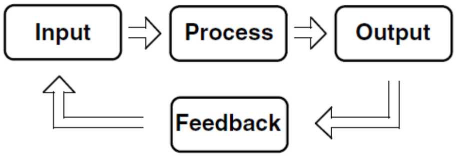
17

## Definition(s) of system

- Systems have inputs, processes, and outputs.
- When feedback (direct or indirect) is involved, that component is also important to the operation of the system.
- To explain all this, systems are usually explained using a model.
- A model helps to illustrate the major elements and their relationship, as illustrated in the next slide

18

## A systems model




19

## Information Systems

- The ways that organizations
  - Store
  - Move
  - Organize
  - Process

their information

20

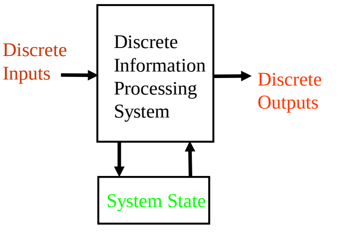
## Information Technology

- Components that implement information systems,
  - Hardware
    - physical tools: computer and network hardware, but also low-tech things like pens and paper
  - Software
    - (changeable) instructions for the hardware
  - People
  - Procedures
    - instructions for the people
  - Data/databases

21

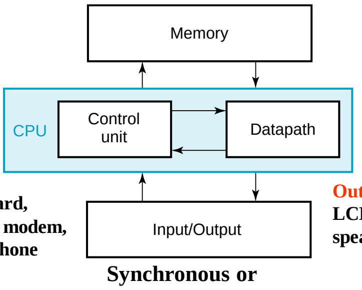
## Digital System

- **Takes a set of discrete information (inputs) and discrete internal information (system state) and generates a set of discrete information (outputs).**




22

## A Digital Computer Example




**Inputs: Keyboard, mouse, modem, microphone**

**Outputs: CRT, LCD, modem, speakers**

**Synchronous or Asynchronous?**

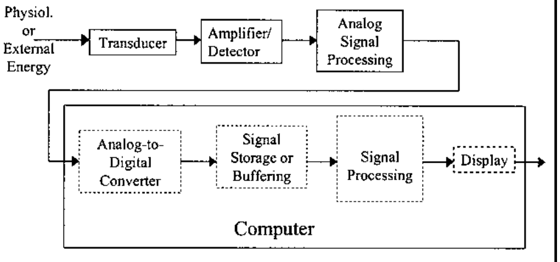
23

## Signal

- **An information variable represented by physical quantity.**
- **For digital systems, the variable takes on discrete values.**
- **Two level, or binary values are the most prevalent values in digital systems.**
- **Binary values are represented abstractly by:**
  - **digits 0 and 1**
  - **words (symbols) False (F) and True (T)**
  - **words (symbols) Low (L) and High (H)**
  - **and words On and Off.**
- **Binary values are represented by values or ranges of values of physical quantities**

24

# A typical measurement system






# Transducers

- A "transducer" is a device that converts energy from one form to another.
- In signal processing applications, the purpose of energy conversion is to transfer information, not to transform energy.
- In physiological measurement systems, transducers may be
  - input transducers (or sensors)
    - they convert a non-electrical energy into an electrical signal.
    - for example, a microphone.
  - output transducers (or actuators)
    - they convert an electrical signal into a non-electrical energy.
    - For example, a speaker.



# Analogue signal

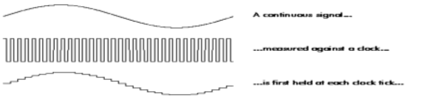
- The analogue signal
  - a continuous variable defined with infinite precision

  is converted to a discrete sequence of measured values which are represented digitally
- Information is lost in converting from analogue to digital, due to:
  - inaccuracies in the measurement
  - uncertainty in timing
  - limits on the duration of the measurement
- These effects are called quantisation errors



# Digital signal

- The continuous analogue signal has to be held before it can be sampled



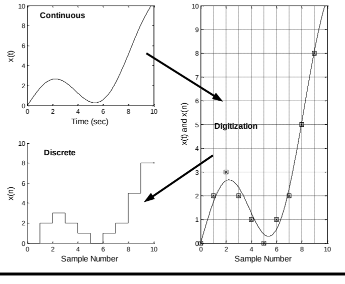

- Otherwise, the signal would be changing during the measurement
- Only after it has been held can the signal be measured, and the measurement converted to a digital value




## Signal Encoding: Analog-to Digital Conversion

Continuous (analog) signal ↔ Discrete signal

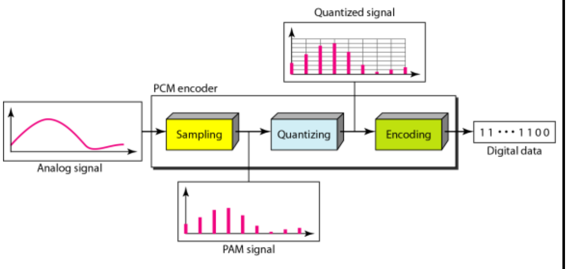
$x$(t) = $f$(t) ↔ Analog to digital conversion ↔ $x$[n] = $x$ [1], $x$ [2], $x$ [3], ... $x$[n]






# Analog-to Digital Conversion

- ADC consists of four steps to digitize an analog signal:
  1. Filtering
  2. Sampling
  3. Quantization
  4. Binary encoding
- Before we sample, we have to filter the signal to limit the maximum frequency of the signal as it affects the sampling rate.
- Filtering should ensure that we do not distort the signal, ie remove high frequency components that affect the signal shape.






# Sampling

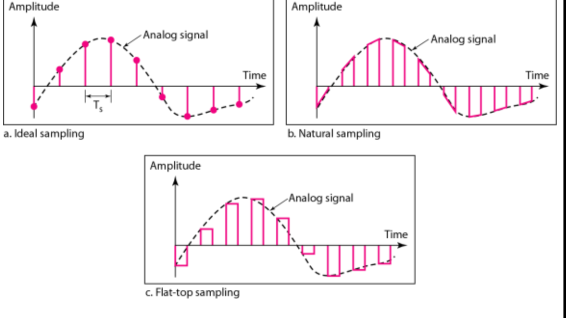
- The sampling results in a discrete set of digital numbers that represent measurements of the signal
  - usually taken at equal intervals of time
- Sampling takes place after the hold
  - The hold circuit must be fast enough that the signal is not changing during the time the circuit is acquiring the signal value
- We don't know what we don't measure
- In the process of measuring the signal, some information is lost



# Sampling

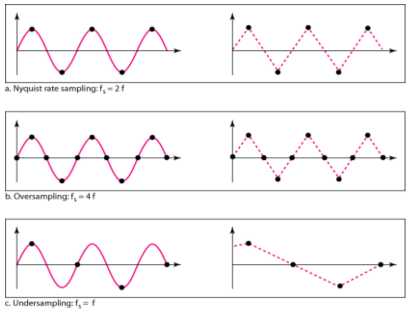
- Analog signal is sampled every $T_S$ secs.
- $T_s$ is referred to as the sampling interval.
- $f_s = 1/T_s$ is called the sampling rate or sampling frequency.
- There are 3 sampling methods:
  - Ideal - an impulse at each sampling instant
  - Natural - a pulse of short width with varying amplitude
  - Flattop - sample and hold, like natural but with single amplitude value
- The process is referred to as pulse amplitude modulation PAM and the outcome is a signal with analog (non integer) values



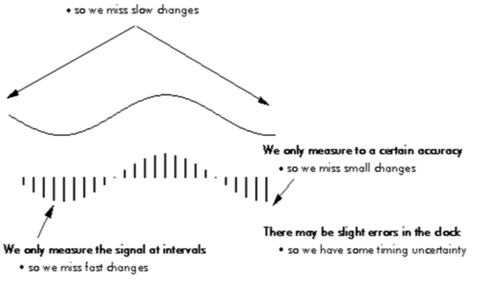


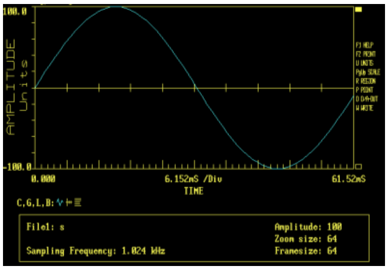



**Recovery of a sampled sine wave for different sampling rates**

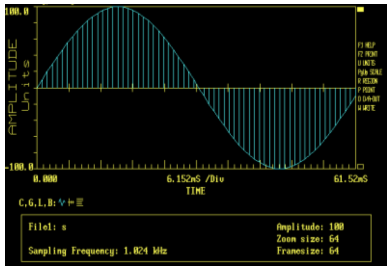




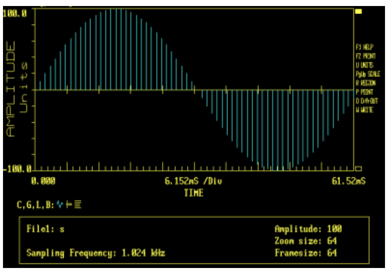











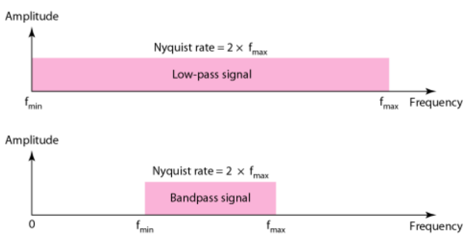

## Sampling Theorem

$$F_s \geq 2f_m$$

**According to the Nyquist theorem, the sampling rate must be at least 2 times the highest frequency contained in the signal.**



## Nyquist sampling rate for low-pass and bandpass signals






## Quantization

- Sampling results in a series of pulses of varying amplitude values ranging between two limits: a min and a max.
- The amplitude values are infinite between the two limits.
- We need to map the *infinite* amplitude values onto a finite set of known values.
- This is achieved by dividing the distance between min and max into L zones, each of height Δ.

$$\Delta = (\max - \min)/L$$

## Quantization Levels

- The midpoint of each zone is assigned a value from 0 to L-1 (resulting in L values)
- Each sample falling in a zone is then approximated to the value of the midpoint.



## Quantization Zones

- Assume we have a voltage signal with amplitutes $V_{min}$=-20V and $V_{max}$=+20V.
- We want to use L=8 quantization levels.
- Zone width Δ = (20 - -20)/8 = 5
- The 8 zones are: -20 to -15, -15 to -10, -10 to -5, -5 to 0, 0 to +5, +5 to +10, +10 to +15, +15 to +20
- The midpoints are: -17.5, -12.5, -7.5, -2.5, 2.5, 7.5, 12.5, 17.5



## Assigning Codes to Zones

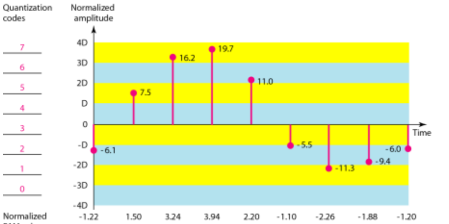
- Each zone is then assigned a binary code.
- The number of bits required to encode the zones, or the number of bits per sample as it is commonly referred to, is obtained as follows:

$$n_b = \log_2 L$$

- Given our example, $n_b = 3$
- The 8 zone (or level) codes are therefore: 000, 001, 010, 011, 100, 101, 110, and 111
- Assigning codes to zones:
  - 000 will refer to zone -20 to -15
  - 001 to zone -15 to -10, etc.



## Quantization and encoding of a sampled signal




| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Normalized PAM values | -1.22 | 1.50 | 3.24 | 3.94 | 2.20 | -1.10 | -2.26 | -1.88 | -1.20 |
| Normalized quantized values | -1.50 | 1.50 | 3.50 | 3.50 | 2.50 | -1.50 | -2.50 | -1.50 | -1.50 |
| Normalized error | -0.38 | 0 | +0.26 | -0.44 | +0.30 | -0.40 | -0.24 | +0.38 | -0.30 |
| Quantization code | 2 | 5 | 7 | 7 | 6 | 2 | 1 | 2 | 2 |
| Encoded words | 010 | 101 | 111 | 111 | 110 | 010 | 001 | 010 | 010 |



## Quantization Error

- When a signal is quantized, we introduce an error
  - the coded signal is an approximation of the actual amplitude value.
- The difference between actual and coded value (midpoint) is referred to as the quantization error.
- The more zones, the smaller Δ
  - which results in smaller errors.
- BUT, the more zones the more bits required to encode the samples
  - higher bit rate



## Analog-to-digital Conversion

**Example** An 12-bit analog-to-digital converter (ADC) advertises an accuracy of ± the least significant bit (LSB). If the input range of the ADC is 0 to 10 volts, what is the accuracy of the ADC in analog volts?

Solution:

If the input range is 10 volts then the analog voltage represented by the LSB would be:

$$V_{LSB} = \frac{V_{\max}}{2^{\text{Nu bits}}} = \frac{10}{2^{12}} = \frac{10}{4096} = .0024 \text{ volts}$$

Hence the accuracy would be ± 0.0024 volts.

# Sampling related concepts

- Over/exact/under sampling
- Regular/irregular sampling
- Linear/Logarithmic sampling
- Aliasing
- Anti-aliasing filter
- Image
- Anti-image filter



**Steps for digitization/reconstruction of a signal**

- Band limiting (LPF)
- Sampling / Holding
- Quantization
- Coding

*These are basic steps for A/D conversion*

- D/A converter
- Sampling / Holding
- Image rejection

*These are basic steps for reconstructing a sampled digital signal*



**Digital data: end product of A/D conversion and related concepts**

- Bit: least digital information, binary 1 or 0
- Nibble: 4 bits
- Byte: 8 bits, 2 nibbles
- Word: 16 bits, 2 bytes, 4 nibbles
- Some jargon:
  - integer, signed integer, long integer, 2s complement, hexadecimal, octal, floating point, etc.






## Measures of capacity and speed in Computers

Special Powers of 10 and 2 :

- Kilo- (K) = 1 thousand = $10^3$ and $2^{10}$
- Mega- (M) = 1 million = $10^6$ and $2^{20}$
- Giga- (G) = 1 billion = $10^9$ and $2^{30}$
- Tera- (T) = 1 trillion = $10^{12}$ and $2^{40}$
- Peta- (P) = 1 quadrillion = $10^{15}$ and $2^{50}$

**Whether a metric refers to a power of ten or a power of two typically depends upon what is being measured.**



## Example

- Hertz = clock cycles per second (frequency)
  - 1MHz = 1,000,000Hz
  - Processor speeds are measured in MHz or GHz.
- Byte = a unit of storage
  - 1KB = $2^{10}$ = 1024 Bytes
  - 1MB = $2^{20}$ = 1,048,576 Bytes
  - Main memory (RAM) is measured in MB
  - Disk storage is measured in GB for small systems, TB for large systems.

## Measures of time and space

- Milli- (m) = 1 thousandth = $10^{-3}$
- Micro- (μ) = 1 millionth = $10^{-6}$
- Nano- (n) = 1 billionth = $10^{-9}$
- Pico- (p) = 1 trillionth = $10^{-12}$
- Femto- (f) = 1 quadrillionth = $10^{-15}$

55

## Data types

- Our first requirement is to find a way to represent information (data) in a form that is mutually comprehensible by human and machine.
  - Ultimately, we need to develop schemes for representing all conceivable types of information - language, images, actions, etc.
  - Specifically, the devices that make up a computer are switches that can be on or off, i.e. at high or low voltage.
  - Thus they naturally provide us with two symbols to work with:
    - we can call them on and off, or 0 and 1.

56

## What kinds of data do we need to represent?

Numbers
signed, unsigned, integers, floating point, complex, rational, irrational, …
Text
characters, strings, …
Images
pixels, colors, shapes, …
Sound
Logical
true, false
Instructions
…
Data type:
- representation and operations within the computer

57

## Number Systems – Representation

- Positive radix, positional number systems
- A number with *radix* ***r*** is represented by a string of digits:

$$A_{n-1}A_{n-2} \ldots A_1A_0 \,.\, A_{-1}A_{-2} \ldots A_{-m+1}A_{-m}$$

in which $0 \le A_i < r$ and **.** is the *radix point*.
- The string of digits represents the power series:

$$(\text{Number})_r = \left(\sum_{i=0}^{i=n-1} A_i \cdot r^i\right) + \left(\sum_{j=-m}^{j=-1} A_j \cdot r^j\right)$$

**(Integer Portion) + (Fraction Portion)**

58

## Decimal Numbers

- "decimal" means that we have ten digits to use in our representation
  - the symbols 0 through 9
- What is 3546?
  - it is *three* thousands plus *five* hundreds plus *four* tens plus *six* ones.
  - i.e. $3546 = 3\times10^3 + 5\times10^2 + 4\times10^1 + 6\times10^0$
- How about negative numbers?
  - we use two more symbols to distinguish positive and negative:
    - \+ and -

59

## Decimal Numbers

- "decimal" means that we have ten digits to use in our representation (the symbols 0 through 9)
- What is 3546?
  - it is *three* thousands plus *five* hundreds plus *four* tens plus *six* ones.
  - i.e. $3546 = 3.10^3 + 5.10^2 + 4.10^1 + 6.10^0$
- How about negative numbers?
  - we use two more symbols to distinguish positive and negative:
    - \+ and -

60

## Unsigned Binary Integers

$Y = \text{"abc"} = a.2^2 + b.2^1 + c.2^0$

(where the digits a, b, c can each take on the values of 0 or 1 only)

N = number of bits

Range is:
$0 \le i < 2^N - 1$

| | 3-bits | 5-bits | 8-bits |
|---|---|---|---|
| 0 | 000 | 00000 | 00000000 |
| 1 | 001 | 00001 | 00000001 |
| 2 | 010 | 00010 | 00000010 |
| 3 | 011 | 00011 | 00000011 |
| 4 | 100 | 00100 | 00000100 |

**Problem:**

- How do we represent *negative* numbers?

61

## Signed Binary Integers

### -2s Complement representation-

- Transformation
  - To transform a into -a, invert all bits in a and add 1 to the result

Range is:
$-2^{N-1} < i < 2^{N-1} - 1$

**Advantages:**

- Operations need not check the sign
- Only one representation for zero
- Efficient use of all the bits

| | |
|---|---|
| -16 | 10000 |
| … | … |
| -3 | 11101 |
| -2 | 11110 |
| -1 | 11111 |
| 0 | 00000 |
| +1 | 00001 |
| +2 | 00010 |
| +3 | 00011 |
| … | … |
| +15 | 01111 |

62

## Limitations of integer representations

- Most numbers are not integer!
  - Even with integers, there are two other considerations:
- Range:
  - The magnitude of the numbers we can represent is determined by how many bits we use:
    - e.g. with 32 bits the largest number we can represent is about +/- 2 billion, far too small for many purposes.
- Precision:
  - The exactness with which we can specify a number:
    - e.g. a 32 bit number gives us 31 bits of precision, or roughly 9 figure precision in decimal repesentation.
- We need another data type!

63

## Real numbers

- Our decimal system handles non-integer *real* numbers by adding yet another symbol - the decimal point (**.**) to make a *fixed point* notation:
  - e.g. $3456.78 = 3.10^3 + 4.10^2 + 5.10^1 + 6.10^0 + 7.10^{-1} + 8.10^{-2}$
- The *floating point*, or scientific, notation allows us to represent very large and very small numbers (integer or real), with as much or as little precision as needed:
  - Unit of electric charge $e = 1.602\ 176\ 462 \times 10^{-19}$ Coulomb
  - Volume of universe = $1 \times 10^{85}$ $cm^3$
    - the two components of these numbers are called the mantissa and the exponent

64

## Real numbers in binary

- We mimic the decimal floating point notation to create a "hybrid" binary floating point number:
  - We first use a "binary point" to separate whole numbers from fractional numbers to make a fixed point notation:
    - e.g. $00011001.110 = 1.2^4 + 1.10^3 + 1.10^1 + 1.2^{-1} + 1.2^{-2} \Rightarrow 25.75$
      ($2^{-1} = 0.5$ and $2^{-2} = 0.25$, etc.)
  - We then "float" the binary point:
    - $00011001.110 \Rightarrow 1.1001110 \times 2^4$
      mantissa = 1.1001110, exponent = 4
  - Now we have to express this without the extra symbols ( x, 2, . )
    - by convention, we divide the available bits into three fields:

sign, mantissa, exponent

65

## IEEE-754 fp numbers - 1

| s | biased exp. | fraction |
|---|---|---|
| 1 | 8 bits | 23 bits |

32 bits: 1, 8 bits, 23 bits

$N = (-1)^s \times 1.\text{fraction} \times 2^{(\text{biased exp.} - 127)}$

- Sign: 1 bit
- Mantissa: 23 bits
  - We "normalize" the mantissa by dropping the leading 1 and recording only its fractional part (why?)
- Exponent: 8 bits
  - In order to handle both +ve and -ve exponents, we add 127 to the actual exponent to create a "biased exponent":
    - $2^{-127}$ => biased exponent = 0000 0000 (= 0)
    - $2^0$ => biased exponent = 0111 1111 (= 127)
    - $2^{+127}$ => biased exponent = 1111 1110 (= 254)

66

## IEEE-754 fp numbers - 2

- Example: Find the corresponding fp representation of 25.75
  - 25.75 => 00011001.110 => 1.1001110 x $2^4$
  - sign bit = 0 (+ve)
  - normalized mantissa (fraction) = 100 1110 0000 0000 0000 0000
  - biased exponent = 4 + 127 = 131 => 1000 0011
  - so 25.75 => 0 1000 0011 100 1110 0000 0000 0000 0000 => x41CE0000
- Values represented by convention:
  - Infinity (+ and -): exponent = 255 (1111 1111) and fraction = 0
  - NaN (not a number): exponent = 255 and fraction ≠ 0
  - Zero (0): exponent = 0 and fraction = 0
    - note: exponent = 0 => fraction is *de-normalized*, i.e no hidden 1



## IEEE-754 fp numbers - 3

- Double precision (64 bit) floating point

| s | biased exp. | fraction |
|---|---|---|
| 1 | 11 bits | 52 bits |

64 bits: 1, 11 bits, 52 bits

$$N = (-1)^s \times 1.\text{fraction} \times 2^{(\text{biased exp.} - 1023)}$$

- Range & Precision:
  - 32 bit:
    - mantissa of 23 bits + 1 => approx. 7 digits decimal
    - $2^{+/-127}$ => approx. $10^{+/-38}$
  - 64 bit:
    - mantissa of 52 bits + 1 => approx. 15 digits decimal
    - $2^{+/-1023}$ => approx. $10^{+/-306}$



## Binary Numbers and Binary Coding

- Flexibility of representation
  - Within constraints below, can assign any binary combination (called a code word) to any data as long as data is uniquely encoded.
- Information Types
  - Numeric
    - Must represent range of data needed
    - Very desirable to represent data such that simple, straightforward computation for common arithmetic operations permitted
    - Tight relation to binary numbers
  - Non-numeric
    - Greater flexibility since arithmetic operations not applied.
    - Not tied to binary numbers



## Non-numeric Binary Codes

- Given *n* binary digits (called <u>bits</u>), a <u>binary code</u> is a mapping from a set of <u>represented elements</u> to a subset of the $2^n$ binary numbers.
- Example: A binary code for the seven colors of the rainbow
- Code 100 is not used

| Color | Binary Number |
|---|---|
| Red | 000 |
| Orange | 001 |
| Yellow | 010 |
| Green | 011 |
| Blue | 101 |
| Indigo | 110 |
| Violet | 111 |



## Number of Bits Required

- Given M elements to be represented by a binary code, the minimum number of bits, *n*, needed, satisfies the following relationships:
  $2^n > M > 2^{(n-1)}$
  $n = \lceil \log_2 M \rceil$ where $\lceil x \rceil$, called the *ceiling function*, is the integer greater than or equal to *x*.
- Example: How many bits are required to represent <u>decimal digits</u> with a binary code?
  - 4 bits are required ($n = \lceil \log_2 9 \rceil = 4$)



## Number of Elements Represented

- Given *n* digits in radix *r*, there are $r^n$ distinct elements that can be represented.
- But, you can represent *m* elements, $m < r^n$
- Examples:
  - You can represent 4 elements in radix *r* = 2 with *n* = 2 digits: (00, 01, 10, 11).
  - You can represent 4 elements in radix *r* = 2 with *n* = 4 digits: (0001, 0010, 0100, 1000).

## Binary Coded Decimal (BCD)

- In the 8421 Binary Coded Decimal (BCD) representation each decimal digit is converted to its 4-bit pure binary equivalent
- This code is the simplest, most intuitive binary code for decimal digits and uses the same powers of 2 as a binary number,
  - but only encodes the first ten values from 0 to 9.
    - For example: $(57)_{dec}$ ➔ $(?)_{bcd}$

( 5 7 ) dec
= (0101 0111)bcd



## Error-Detection Codes

- Redundancy (e.g. extra information), in the form of extra bits, can be incorporated into binary code words to detect and correct errors.
- A simple form of redundancy is parity, an extra bit appended onto the code word to make the number of 1's odd or even.
  - Parity can detect all single-bit errors and some multiple-bit errors.
- A code word has even parity if the number of 1's in the code word is even.
- A code word has odd parity if the number of 1's in the code word is odd.



## 4-Bit Parity Code Example

- Fill in the even and odd parity bits:

| Even Parity Message - Parity | Odd Parity Message - Parity |
|---|---|
| 000 - | 000 - |
| 001 - | 001 - |
| 010 - | 010 - |
| 011 - | 011 - |
| 100 - | 100 - |
| 101 - | 101 - |
| 110 - | 110 - |
| 111 - | 111 - |

- The codeword "1111" has even parity and the codeword "1110" has odd parity. Both can be used to represent 3-bit data.



## ASCII Character Codes

- American Standard Code for Information Interchange
- This code is a popular code used to represent information sent as character-based data.
- It uses 7- bits to represent
  - 94 Graphic printing characters
  - 34 Non-printing characters
- Some non-printing characters are used for text format
  - e.g. BS = Backspace, CR = carriage return
- Other non-printing characters are used for record marking and flow control
  - e.g. STX = start text areas, ETX = end text areas.



## ASCII Properties

- **ASCII has some interesting properties:**
- Digits 0 to 9 span Hexadecimal values $30_{16}$ to $39_{16}$
- Upper case A-Z span $41_{16}$ to $5A_{16}$
- Lower case a-z span $61_{16}$ to $7A_{16}$
  - Lower to upper case translation (and vice versa) occurs by flipping bit 6
- Delete (DEL) is all bits set,
  - a carryover from when punched paper tape was used to store messages



## UNICODE

- UNICODE extends ASCII to 65,536 universal characters codes
  - For encoding characters in world languages
  - Available in many modern applications
  - 2 byte (16-bit) code words

## Warning: Conversion or Coding?

- Do NOT mix up "conversion of a decimal number to a binary number" with "coding a decimal number with a binary code".
- $13_{10} = 1101_2$
  - This is conversion
- 13 ⇔ 0001 0011$_{BCD}$
  - This is coding

79

## Another use for bits: Logic

- Beyond numbers
  - *logical variables* can be *true* or *false*, *on* or *off*, etc., and so are readily represented by the binary system.
  - A logical variable A can take the values *false = 0* or *true = 1* only.
  - The manipulation of logical variables is known as Boolean Algebra, and has its own set of operations
    - which are not to be confused with the arithmetical operations.
  - Some basic operations: NOT, AND, OR, XOR

80

## Basic Logic Operations

- Truth Tables of Basic Operations

NOT

| A | A' |
|---|---|
| 0 | 1 |
| 1 | 0 |

AND

| A | B | A.B |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 0 |
| 1 | 0 | 0 |
| 1 | 1 | 1 |

OR

| A | B | A+B |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 1 |

- Equivalent Notations
  - not A = A' = $\overline{A}$
  - A and B = A.B = A∧B = A intersection B
  - A or B = A+B = A∨B = A union B

81

## More Logic Operations

XOR

| A | B | A⊕B |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 0 |

XNOR

| A | B | (A⊕B)' |
|---|---|---|
| 0 | 0 | 1 |
| 0 | 1 | 0 |
| 1 | 0 | 0 |
| 1 | 1 | 1 |

- Exclusive OR (XOR): either A or B is 1, not both
- A⊕B = A.B' + A'.B

82