

BLM2041 Signals and Systems

Syllabus

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Information Systems:

Fundamentals

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.

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>

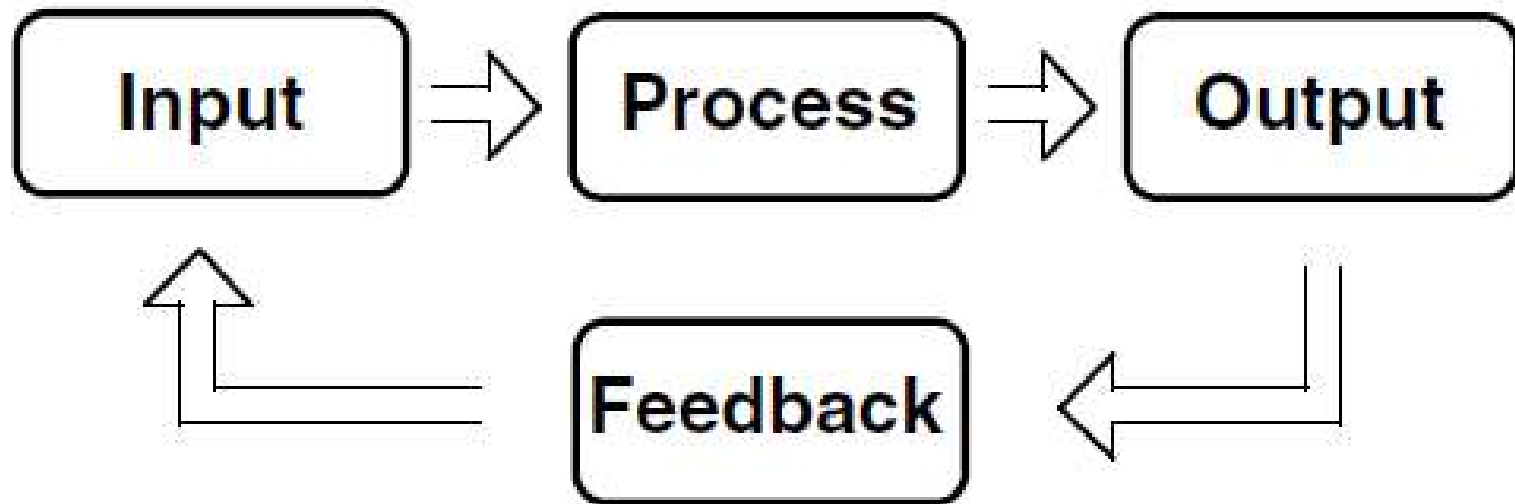
Definition(s) of system

- 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.

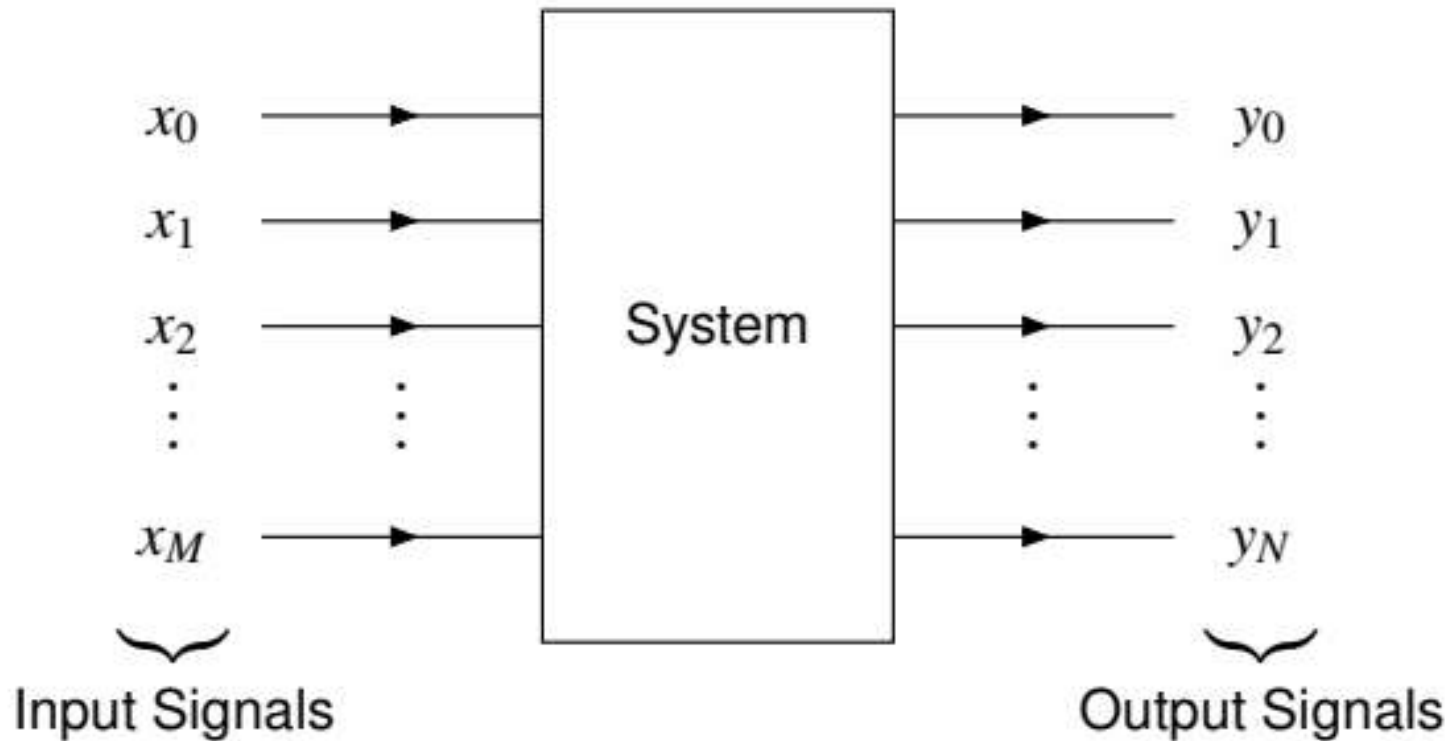
Definition(s) of system

- 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

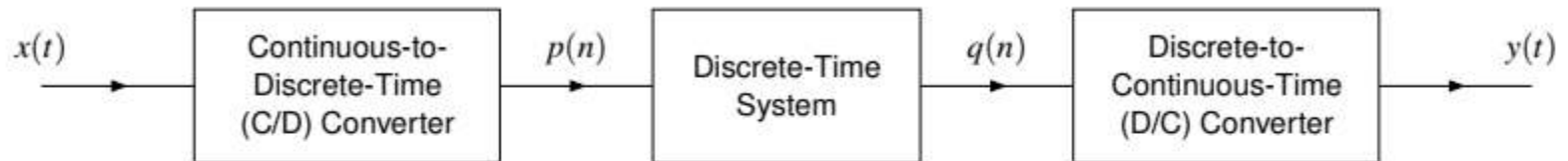
A systems model



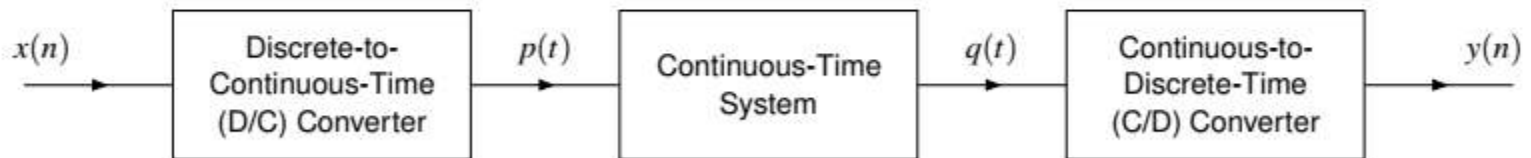
A systems model



Signal Processing System



Processing a Continuous-Time Signal With a Discrete-Time System

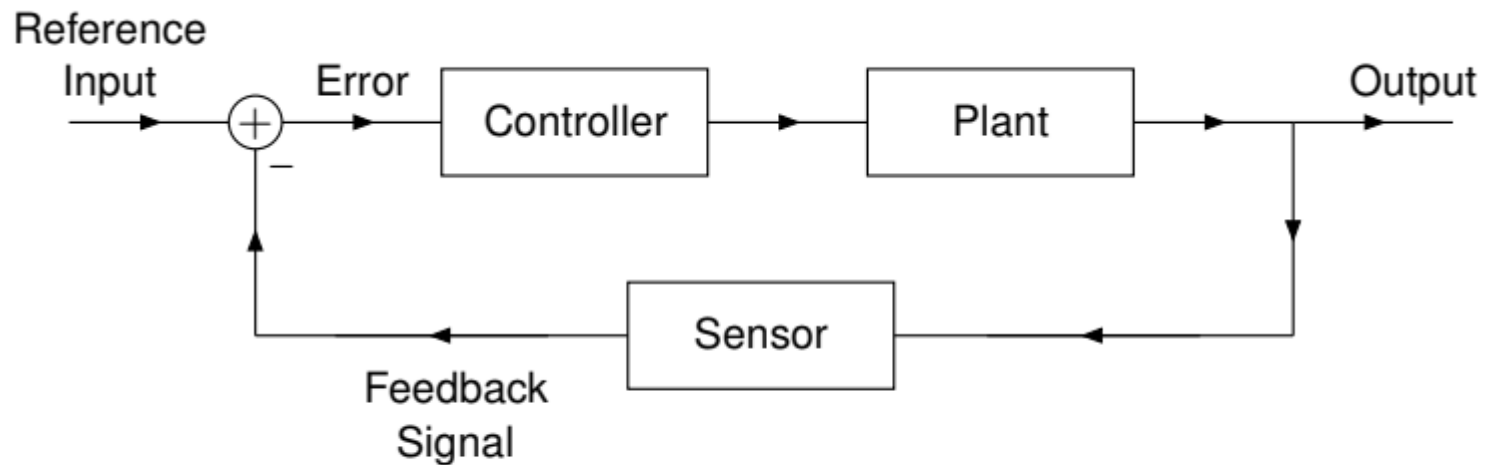


Processing a Discrete-Time Signal With a Continuous-Time System

Communication & Control Systems



General Structure of a Communication System

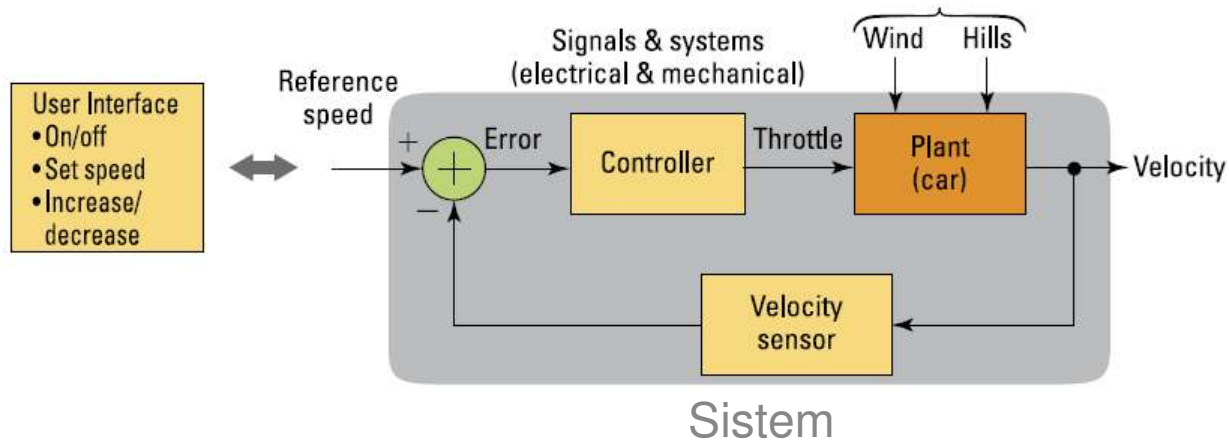


General Structure of a Feedback Control System

Arabalardaki Hız Sabitleme Sistemi

Giriş işareti: Referans hız, rüzgar ve yokuş olma durumu

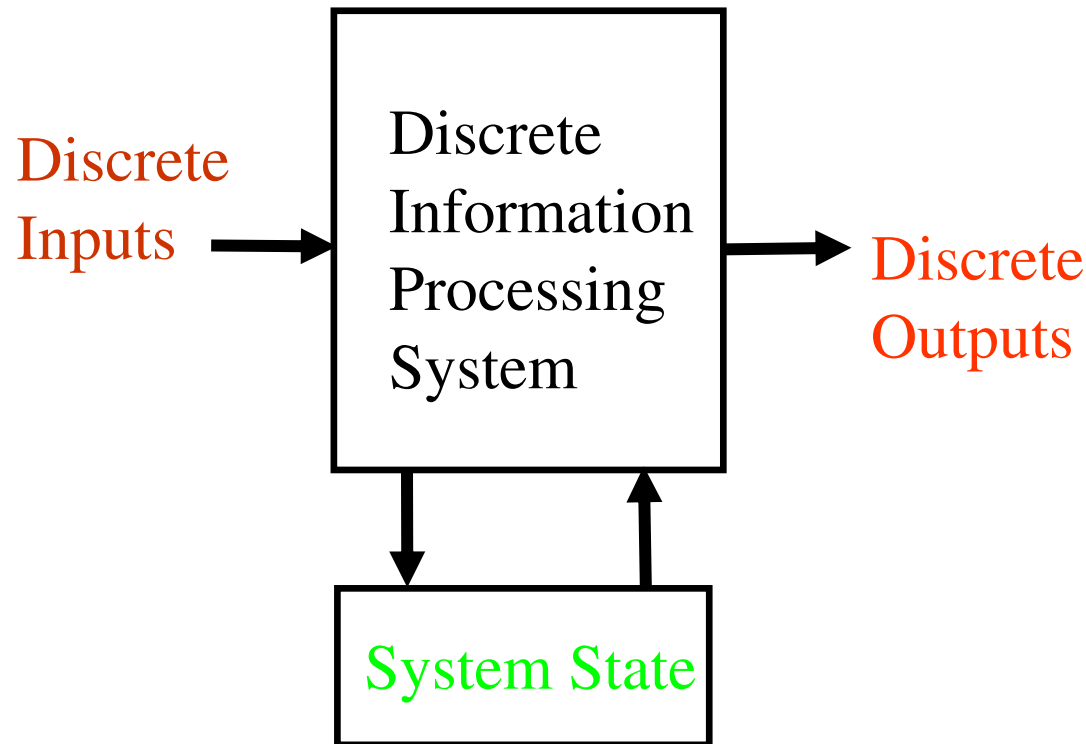
Çıkış işareti: Arabanın hızı



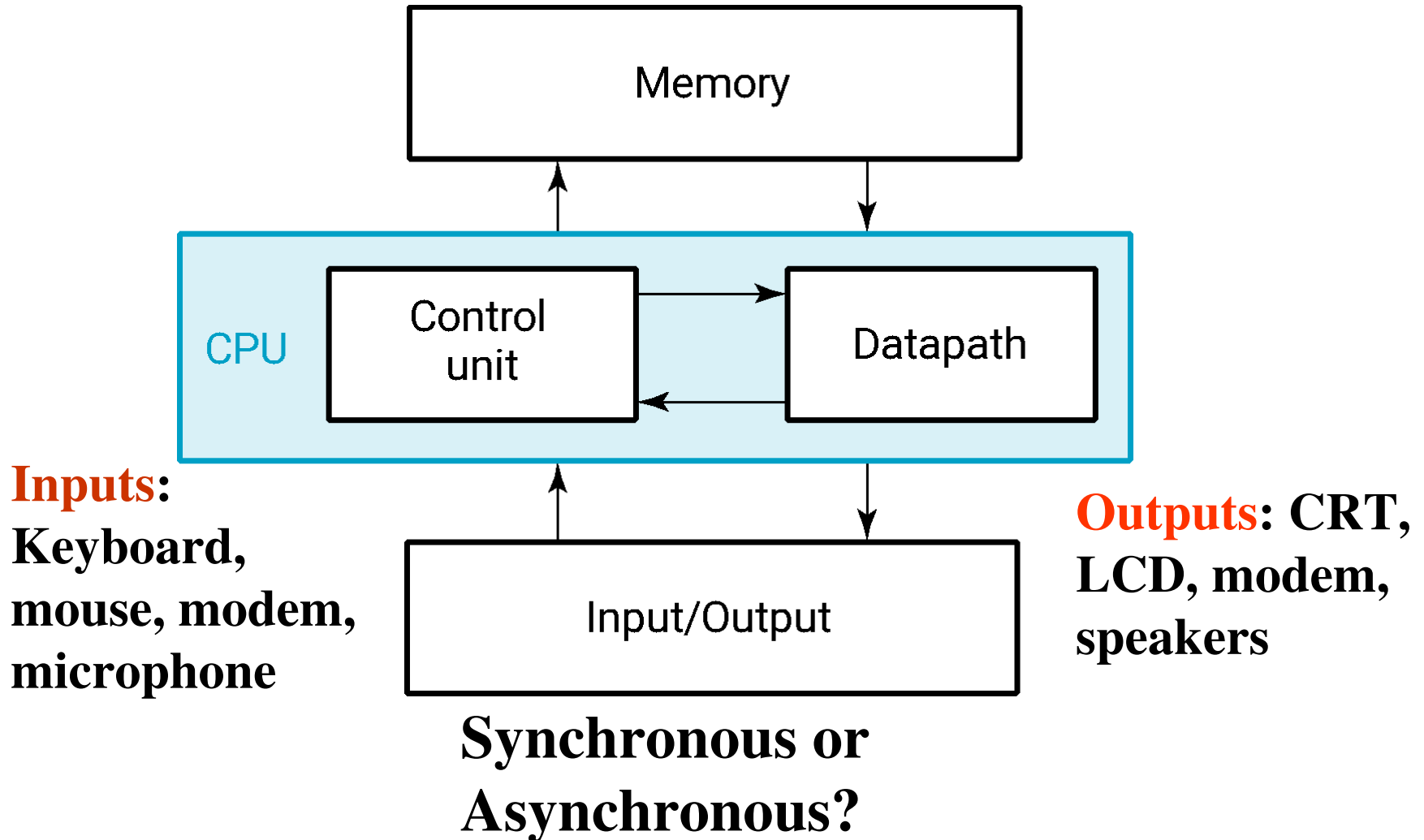
Ref: *Signals and Systems for Dummies*

Digital System

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



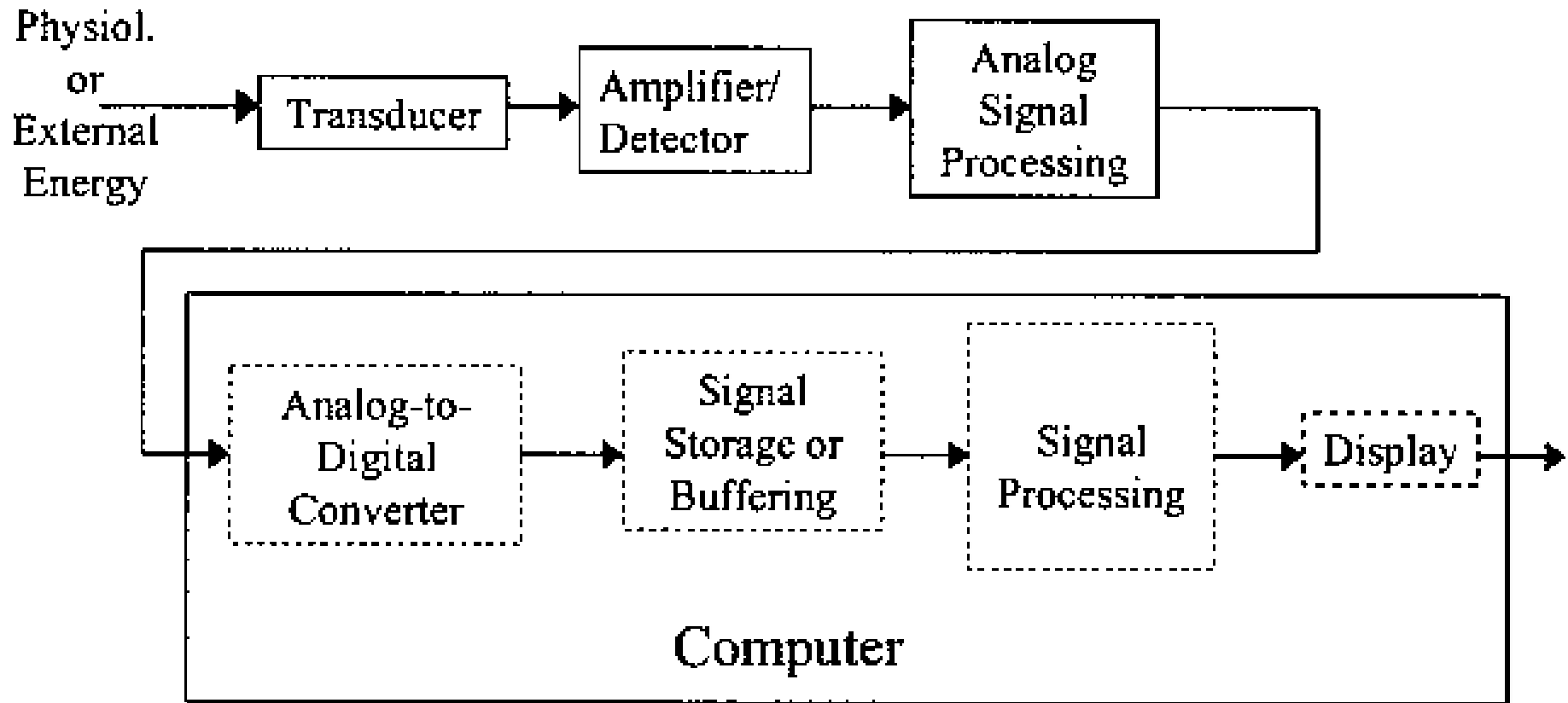
A Digital Computer Example



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**

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.

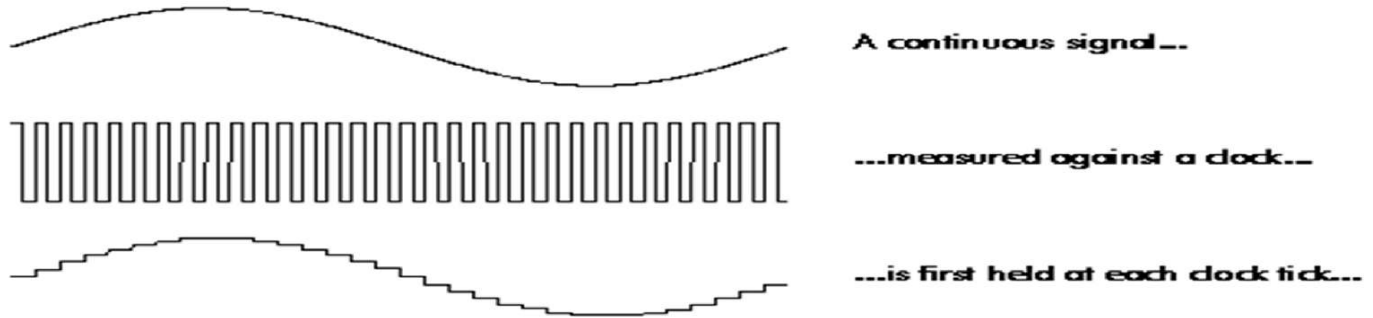
Analogue signal

- 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



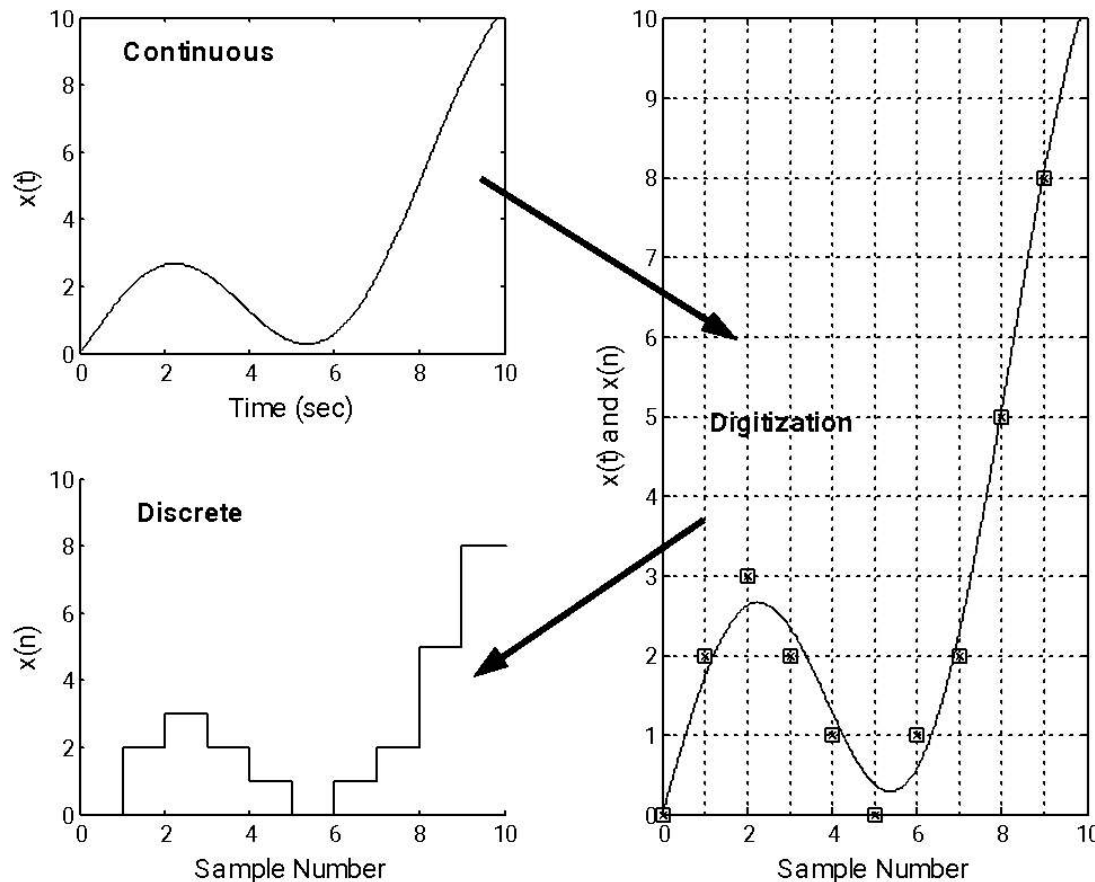
- Otherwise, the signal would be changing during the measurement
- Only after it has been held can the signal be measured, and the measurement converted to a digital value



Signal Encoding: Analog-to Digital Conversion

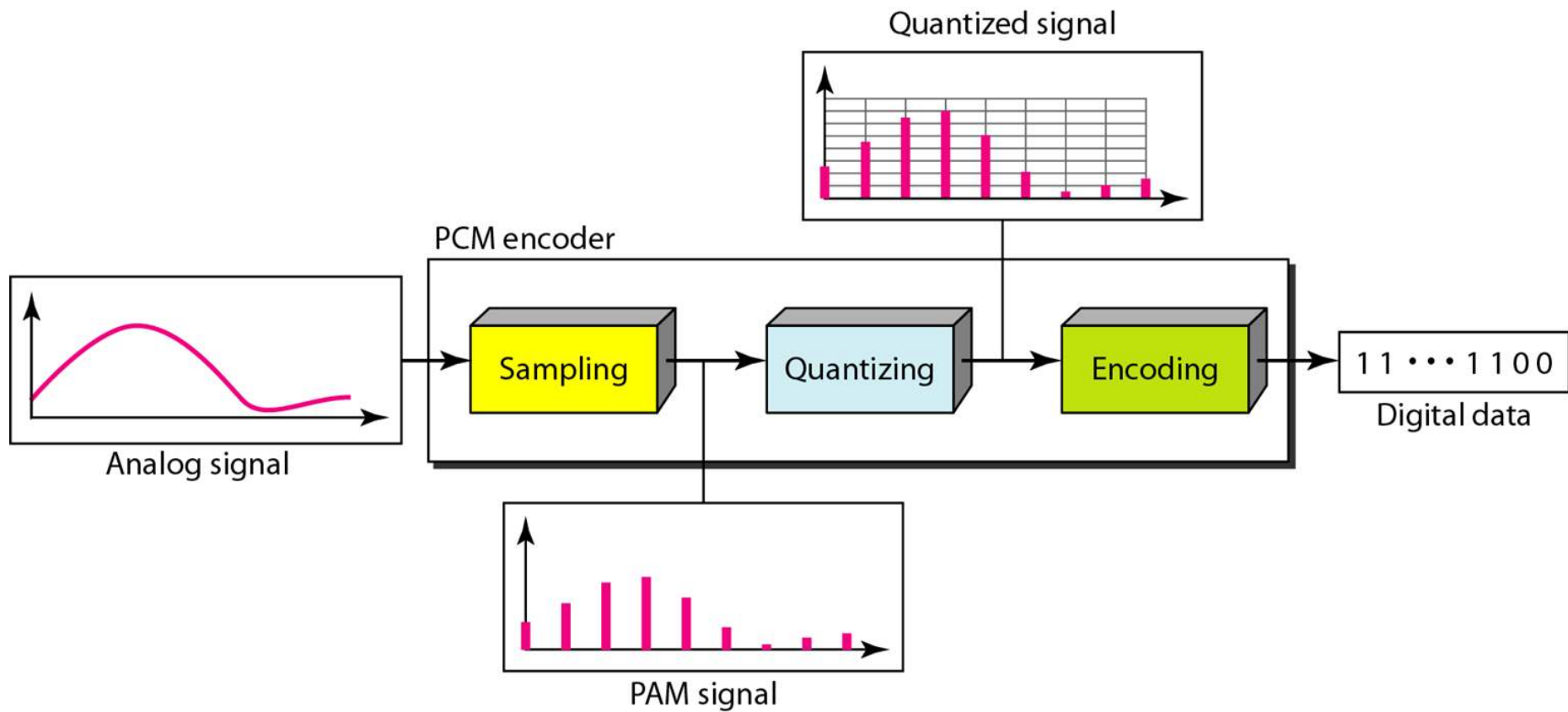
Continuous (analog) signal \longleftrightarrow Discrete signal

$x(t) = f(t) \longleftrightarrow$ Analog to digital conversion $\longleftrightarrow x[n] = x[1], x[2], x[3], \dots x[n]$



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.

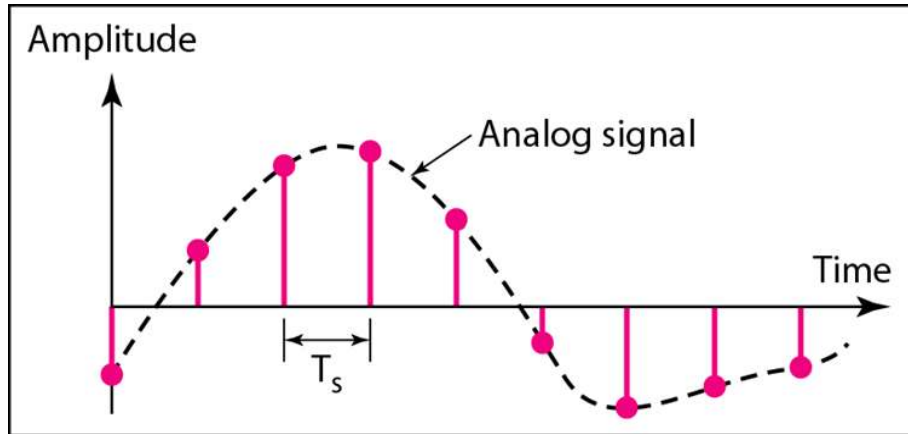


Sampling

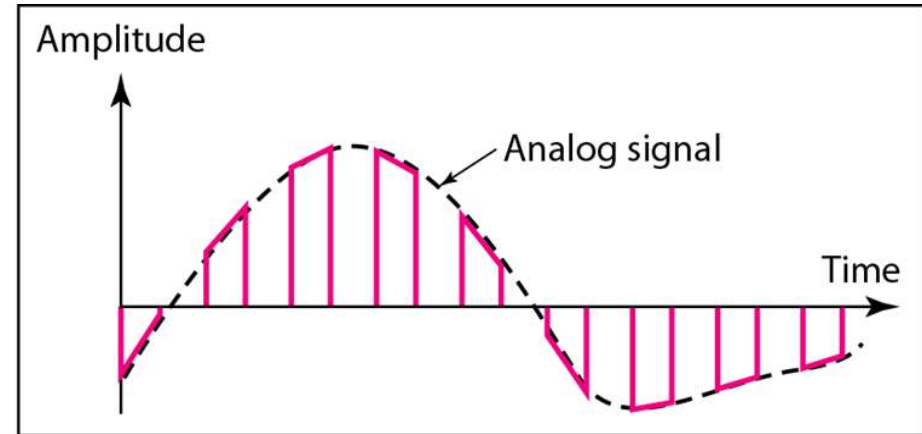
- The sampling results in a discrete set of digital numbers that represent measurements of the signal
 - usually taken at equal intervals of time
- Sampling takes place after the hold
 - The hold circuit must be fast enough that the signal is not changing during the time the circuit is acquiring the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

Sampling

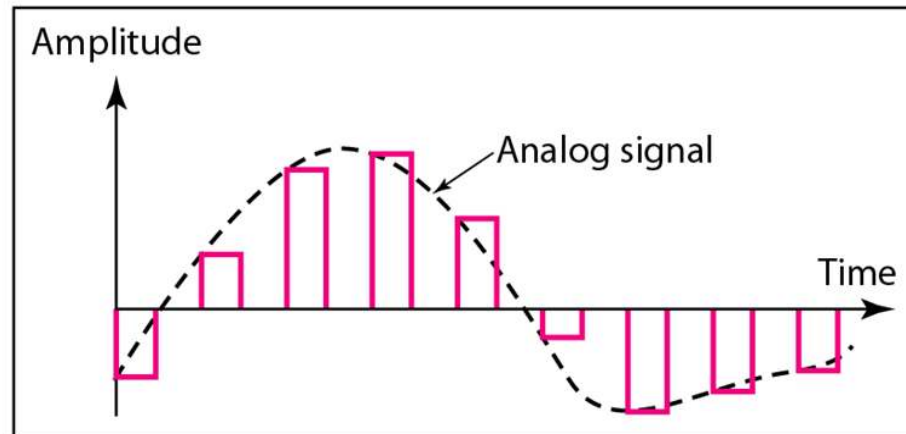
- Analog signal is sampled every T_s secs.
- T_s is referred to as the sampling interval.
- $f_s = 1/T_s$ is called the sampling rate or sampling frequency.
- There are 3 sampling methods:
 - Ideal - an impulse at each sampling instant
 - Natural - a pulse of short width with varying amplitude
 - Flat top - 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



a. Ideal sampling

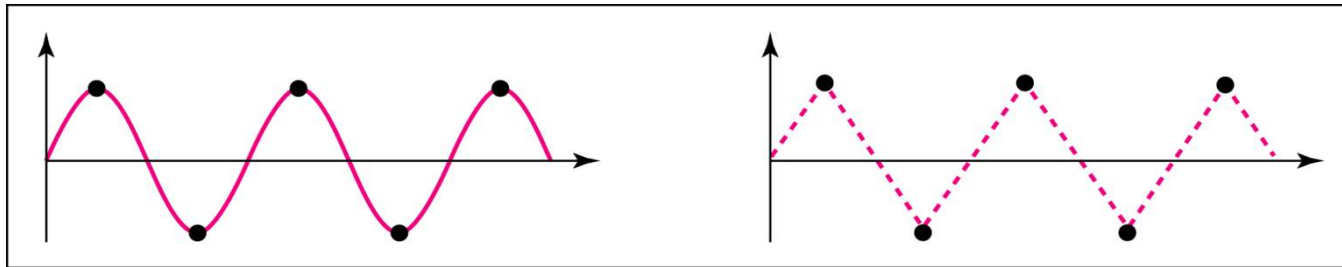


b. Natural sampling

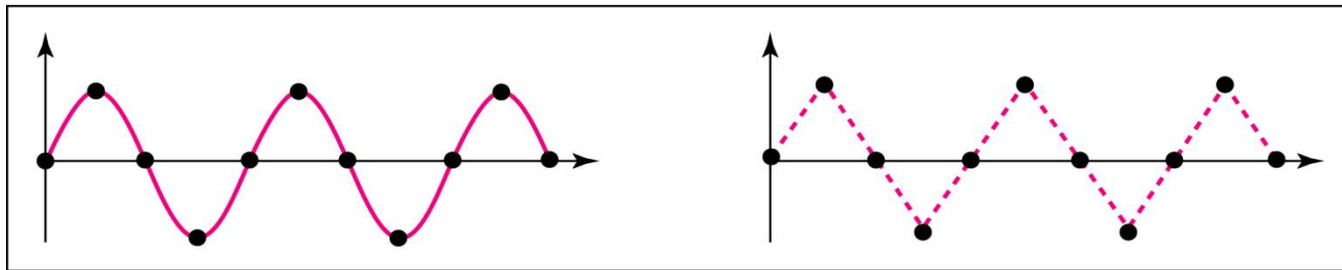


c. Flat-top sampling

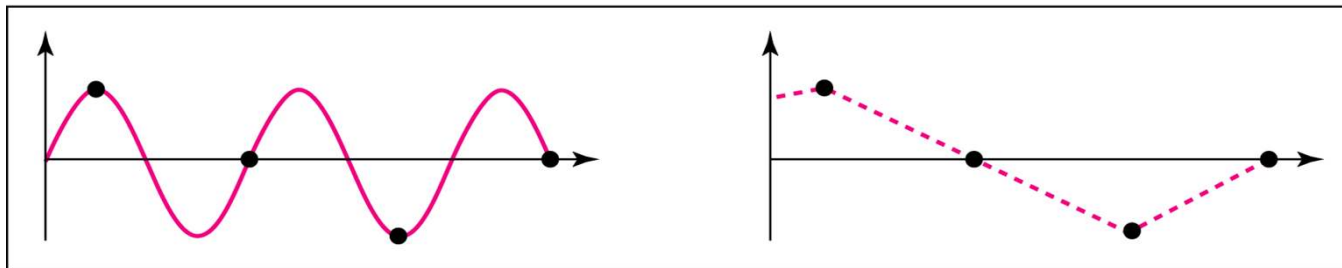
Recovery of a sampled sine wave for different sampling rates



a. Nyquist rate sampling: $f_s = 2 f$



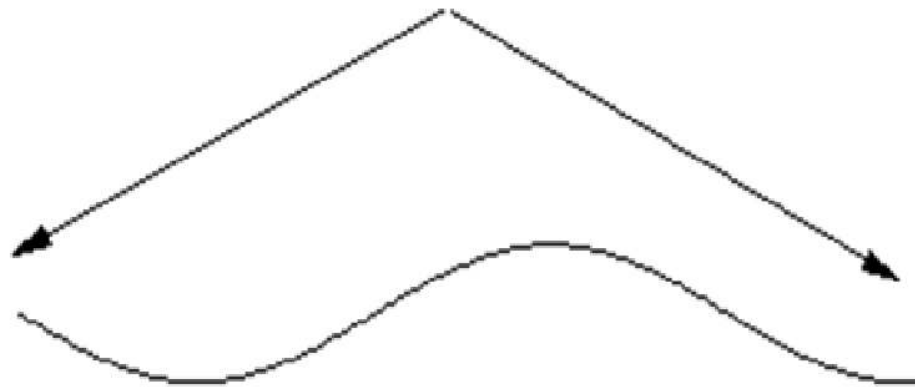
b. Oversampling: $f_s = 4 f$



c. Undersampling: $f_s = f$

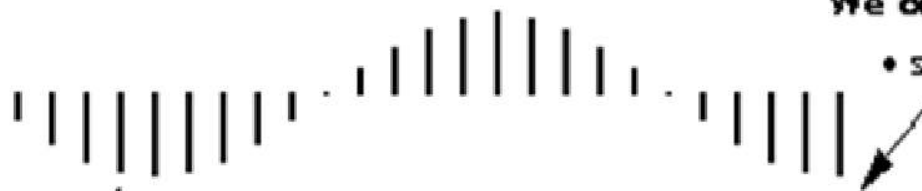
We only measure for a certain length of time

- so we miss slow changes



We only measure to a certain accuracy

- so we miss small changes

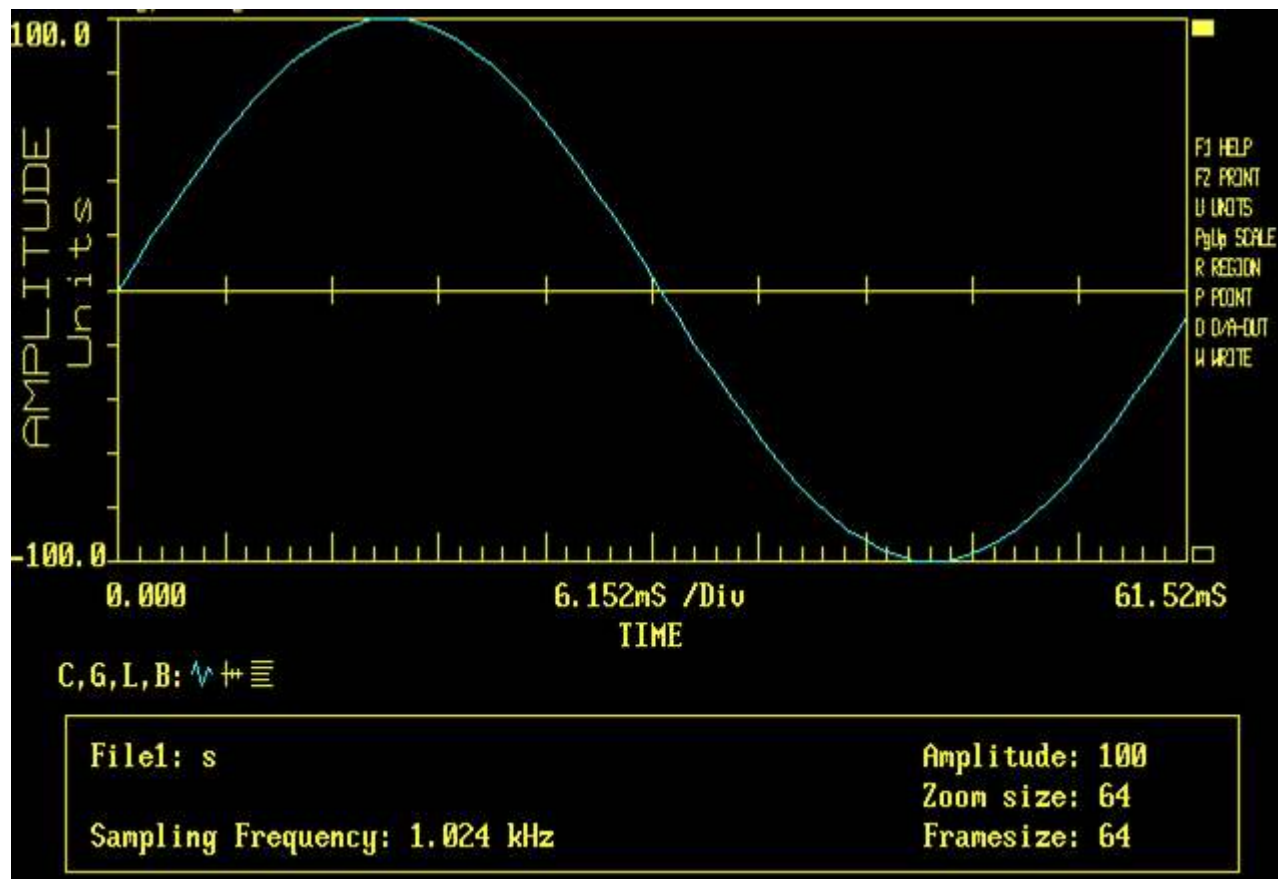


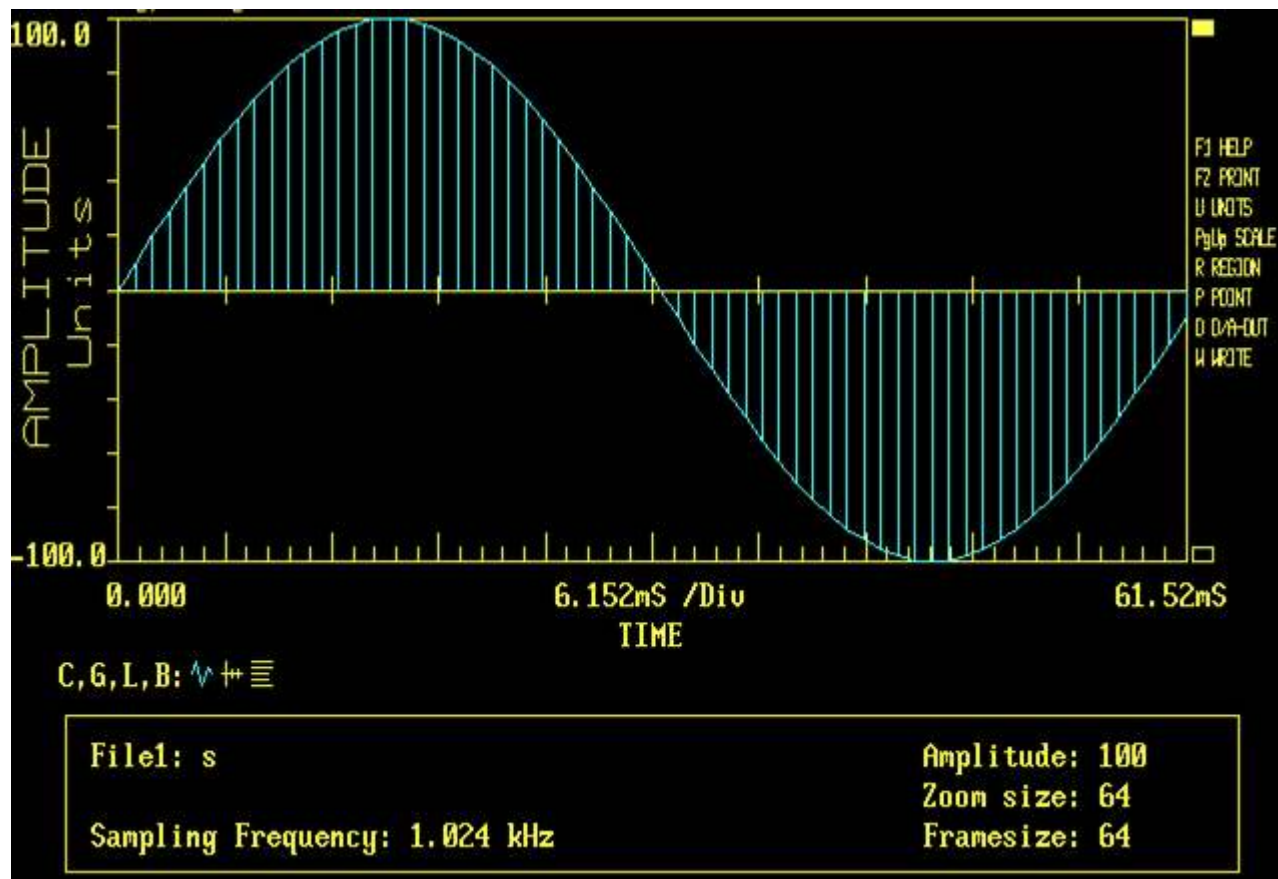
We only measure the signal at intervals

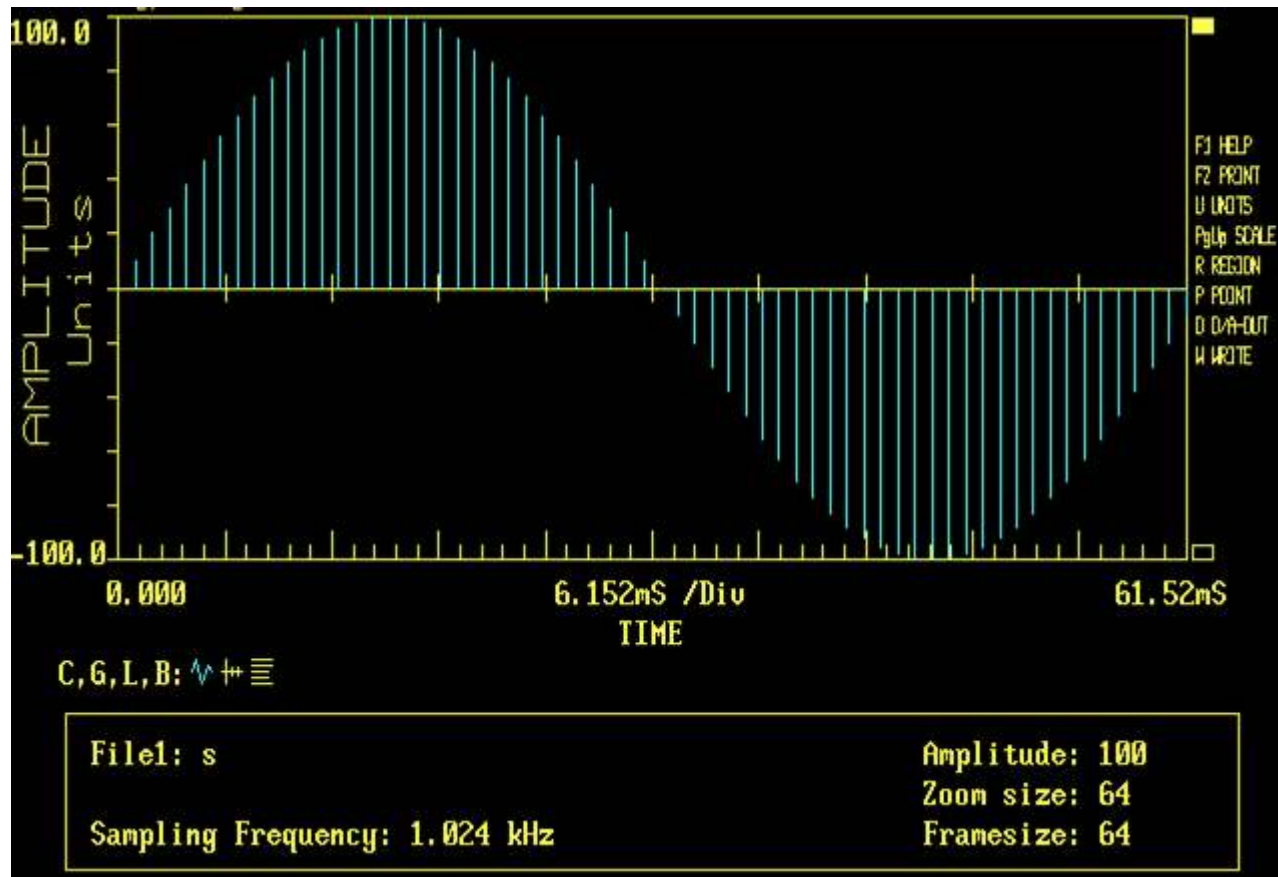
- so we miss fast changes

There may be slight errors in the clock

- so we have some timing uncertainty





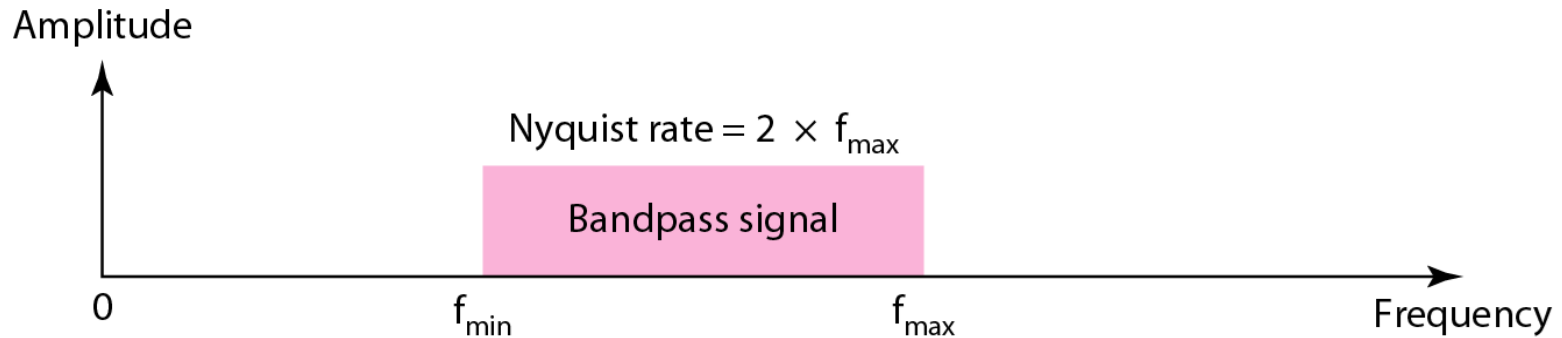
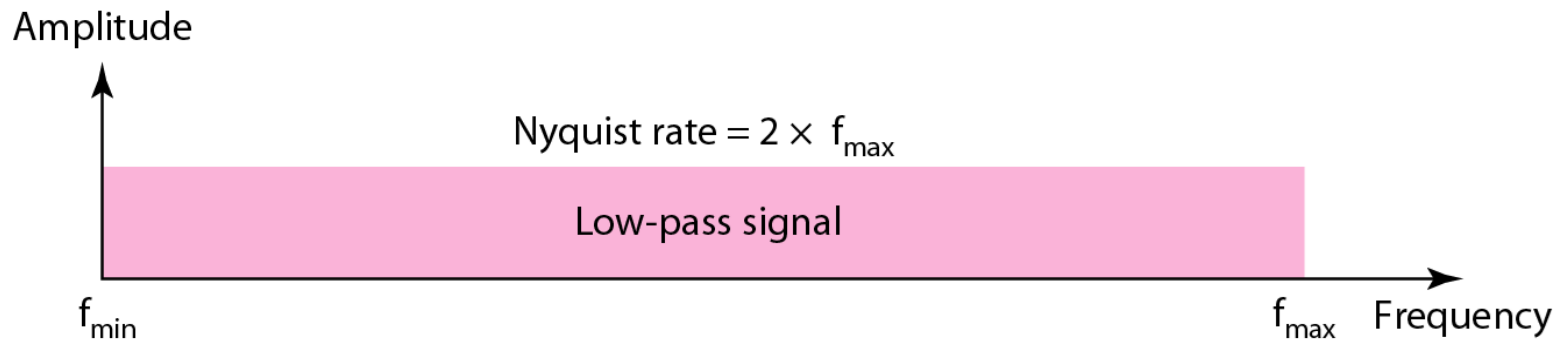


Sampling Theorem

$$F_s \geq 2f_m$$

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 amplitudes $V_{\min} = -20\text{V}$ and $V_{\max} = +20\text{V}$.
- We want to use $L=8$ quantization levels.
- Zone width $\Delta = (20 - -20)/8 = 5$
- 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

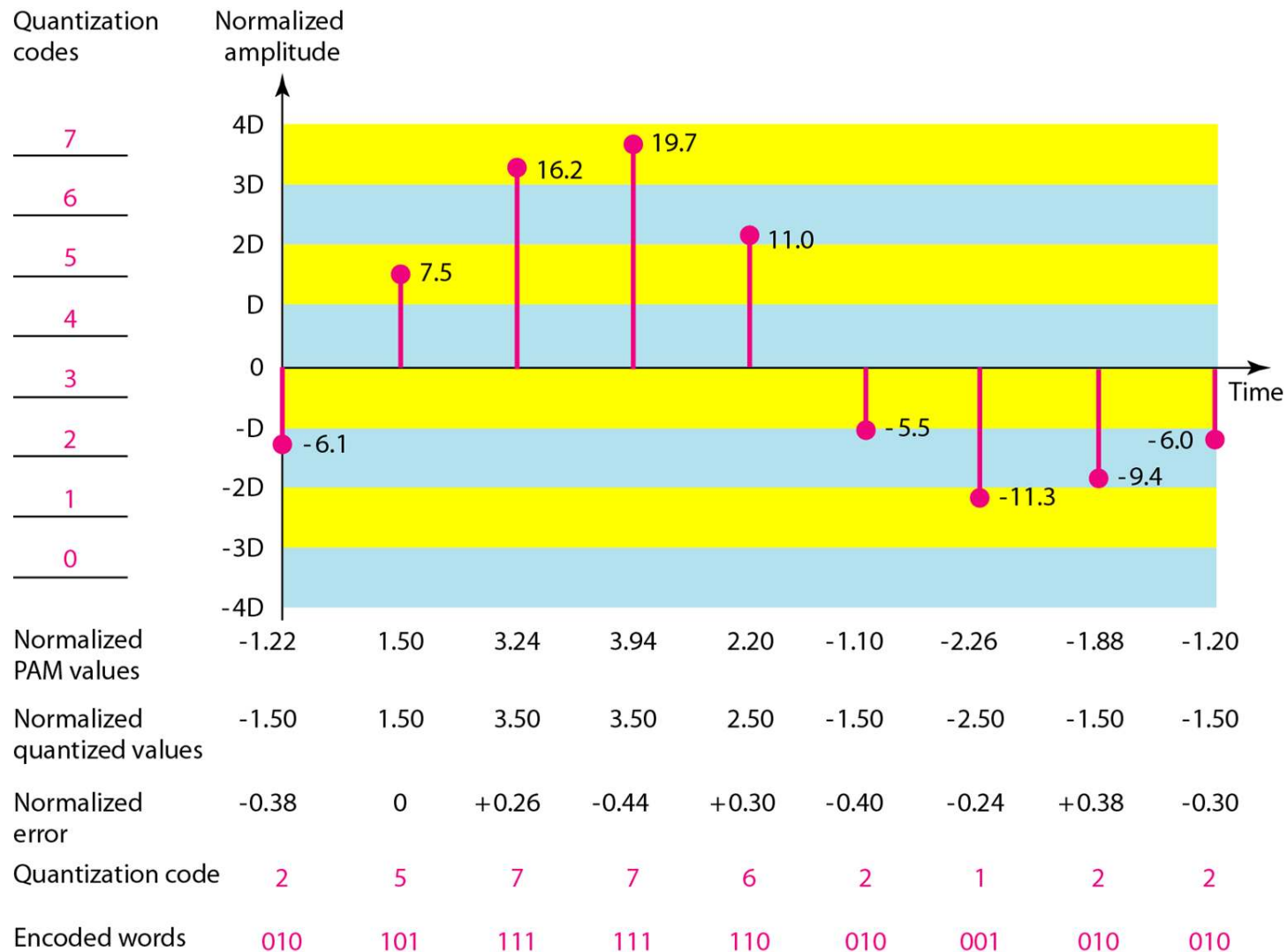
Assigning Codes to Zones

- 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



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 \pm 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:

$$V_{LSB} = \frac{V_{\text{max}}}{2^{\text{N u b i t s}}} = \frac{10}{2^{12}} = \frac{10}{4096} = .0024 \text{ volts}$$

Hence the accuracy would be ± 0.0024 volts.

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.



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.

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:

$$2^n \geq M > 2^{(n-1)}$$
$$n = \lceil \log_2 M \rceil \text{ where } \lceil x \rceil, \text{ called the } \textit{ceiling} \\ \textit{function}, \text{ is the integer greater than or equal to } x.$$

- Example: How many bits are required to represent decimal digits 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).