ROBOTICS and AUTOMATIONS

Week 4

17/08/2023

MACQUARIE University

Learning outcome: Week 4

Workshop:

Sensing and perception

Data acquisition system

Lecture:

Translational Operation

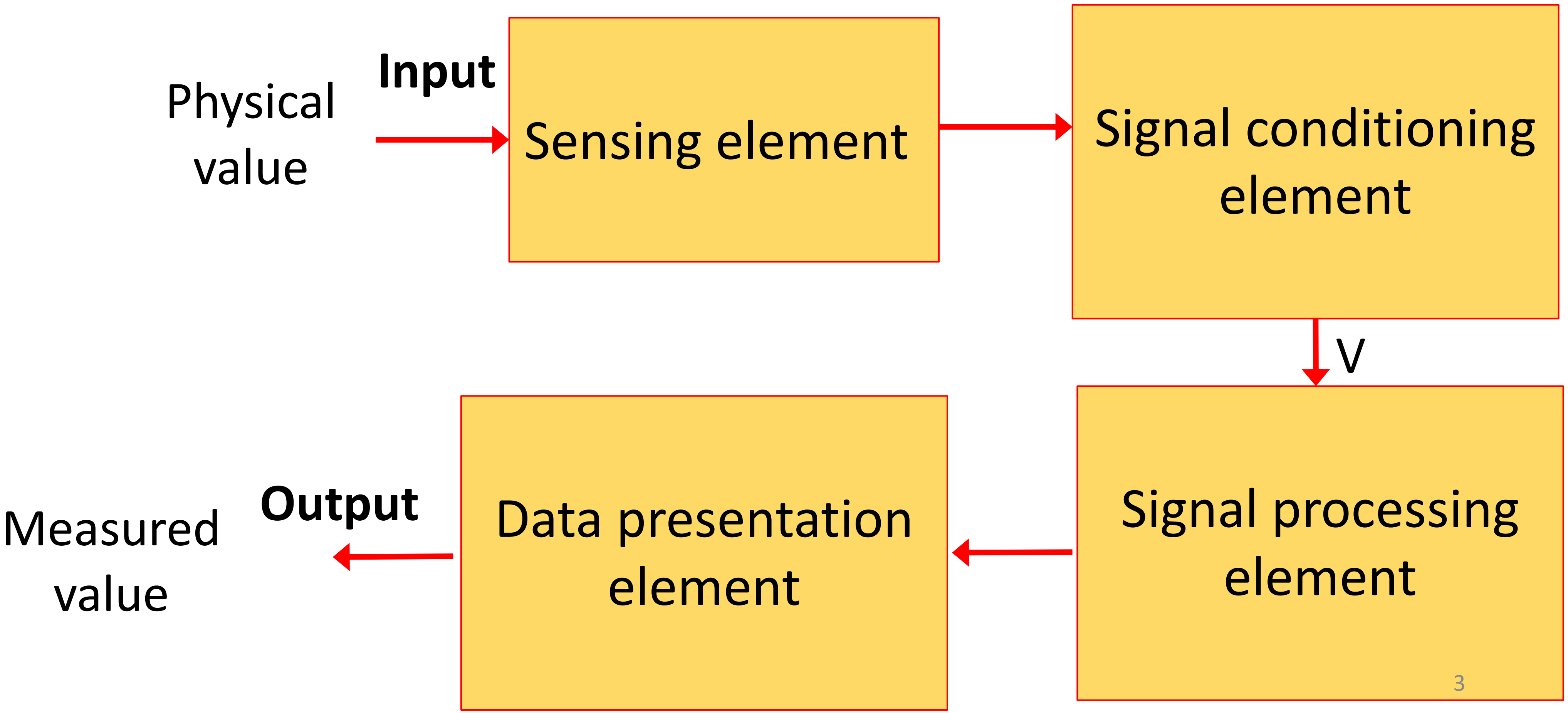
X–Y–Z Fixed Angles

Practical:

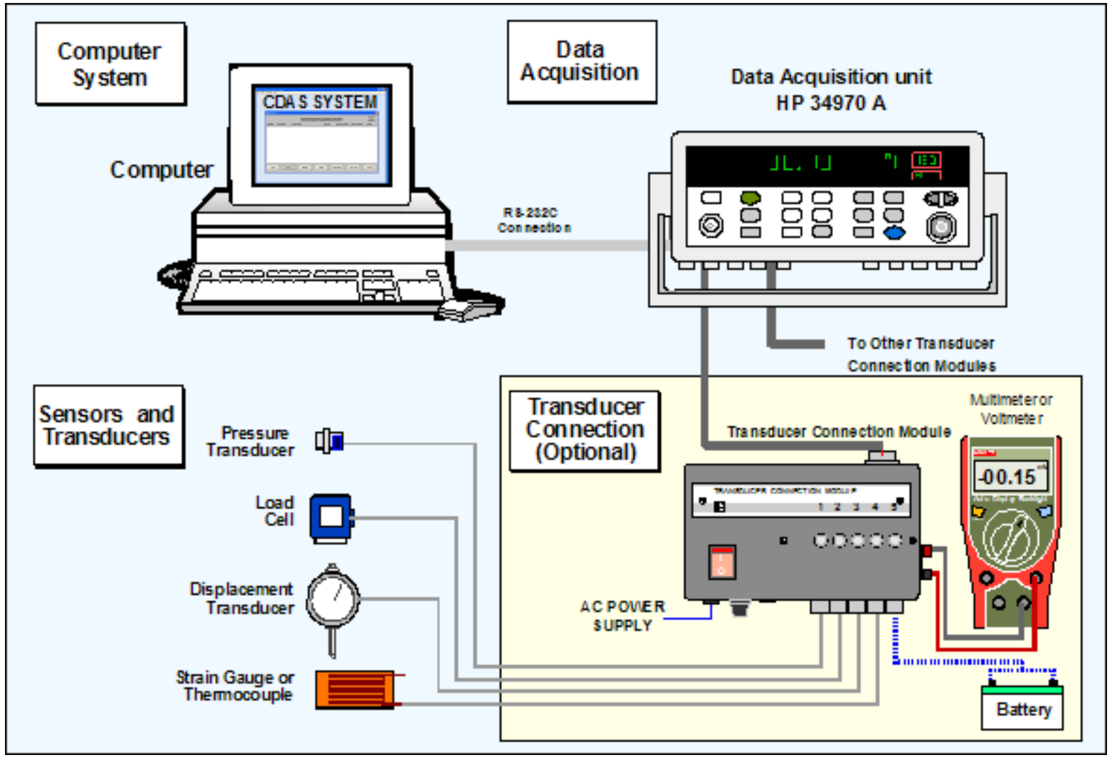
Open/ Close Loop Controller Robot Controller

Basic sensing elements

General structure of a measurement system



Data acquisition system

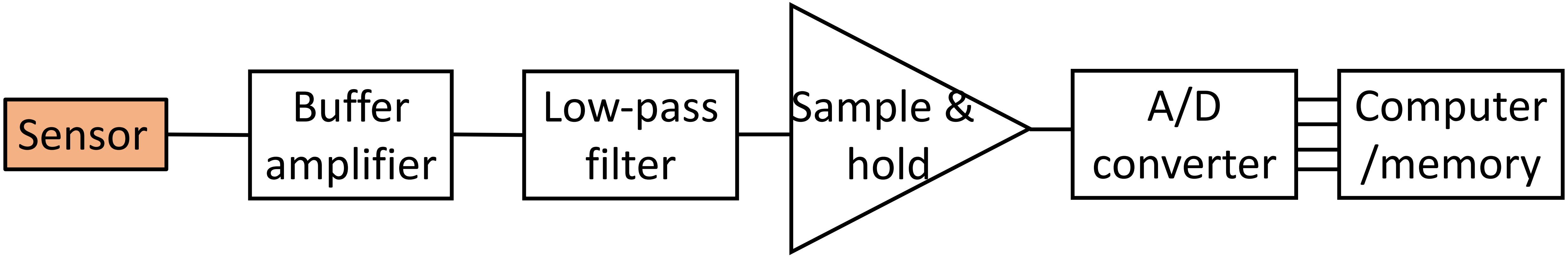


The collection of hardware and software components that enable a computer to receive physical signals.

Data acquisition (DAQ) is the process of measuring an electrical or physical phenomenon such as voltage, current, temperature, pressure, or sound with a computer. A DAQ **system** consists of DAQ measurement hardware, and a computer with programmable software.

Data acquisition system components

1) Buffer amplifier
2) Low-pass filter
3) Sample and hold
4) Analog-to-digital convertor
5) computer



From last week…Basic principle of sensing

- Sensor: a device that convert a physical parameter to an electric output

- Transducer: a device that convert energy from one form to another.

- Actuator: convert an electric signal to a physical output

Sensor and transducer design always involves the application of **some law or Principe of physics or chemistry** that relates the quantity of interest to some measurable event.

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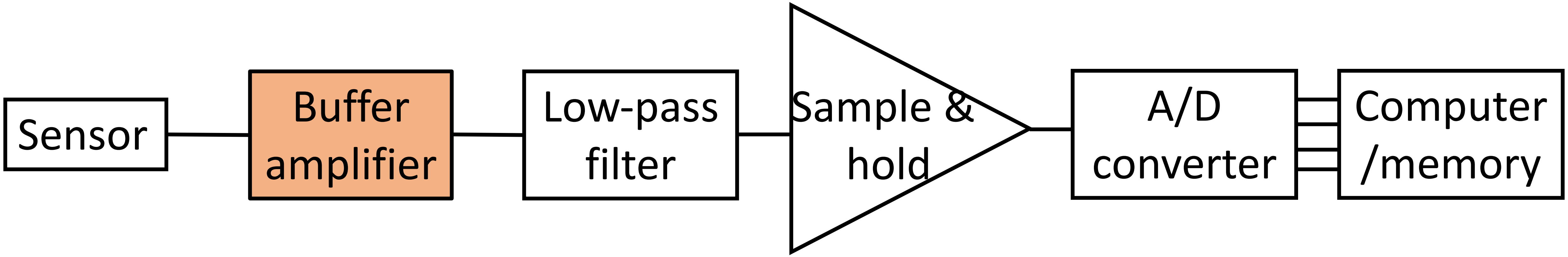
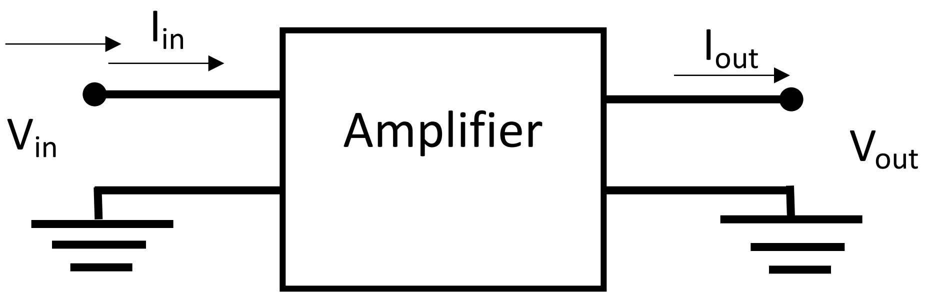


Data Acquisition system block diagram

1) Amplification

Often signals from measurement devices are not in the form that we want them to be they may:

- Be too **small**, usually in the millivolt range
- Be too **noisy** usually due to electromagnetic interface
- Contain the wrong information (approximation error), sometimes due to poor transducer design or installation
- Have a DC offset, usually due to the transducer and instrumentation design



$V_{out}=A_v.V_{in}$

A_v is the voltage gain

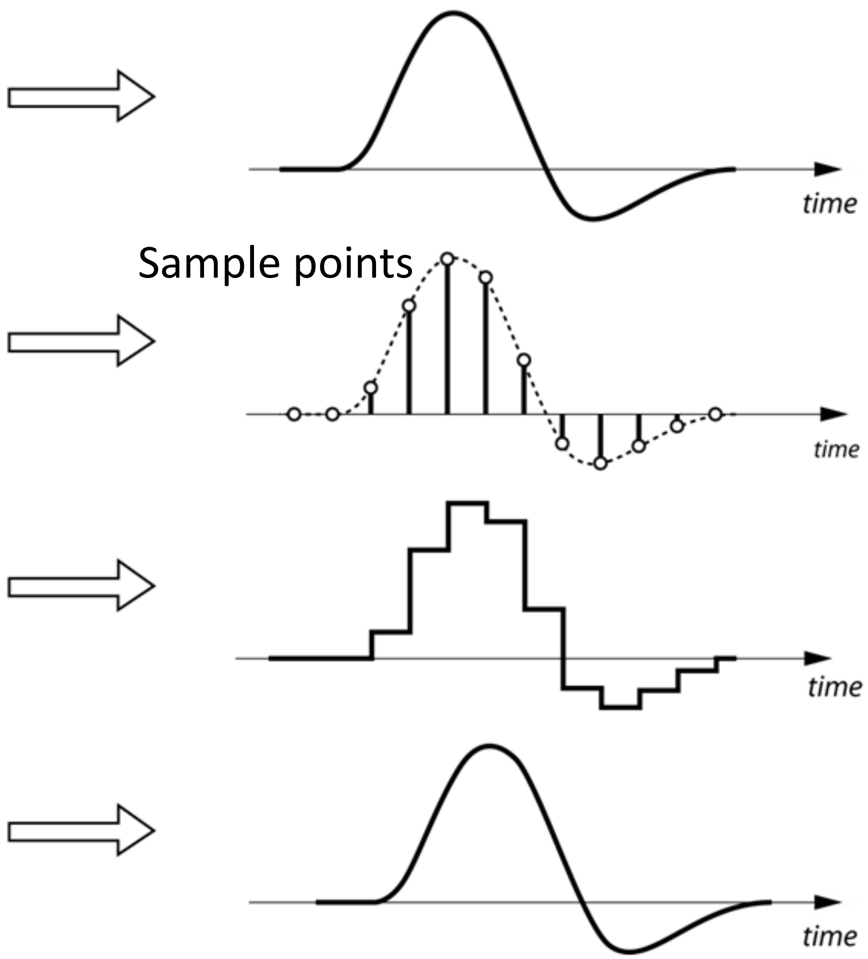
periodic waves properties

Frequency (f): is the number that pass the given point in a certain amount of time   f=3 waves/sec   3 Hz

Period (T): amount of time that takes for one wave to pass. Or the time interval between beats

Frequency=1/period

Analog signal and sampled equivalent



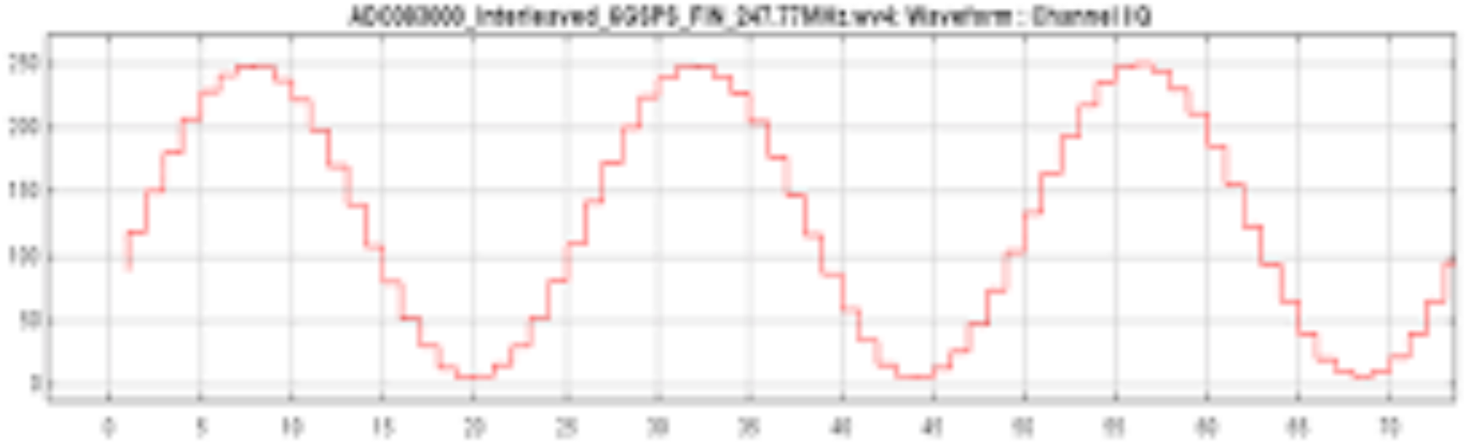
To be able to input analog data to a digital circuited it microprocessor, the analog data must be transformed into coded digital values

Sampling: the process to numerically evaluate the signal at discrete instant in time. The result is a digitized signal composed of discrete values corresponding to each sample

Sampling concept

- Gives values of signal at the sampling instants
- Values between sampling instants depend on “hold” strategy
- Higher sampling rate enables less sampling error

How fast signal should be sampled



Higher sampling rate will enable less error

How fast signal should be sampled

- Sampling concepts gives values of signal at sampling instants
- We do not usually sample “as fast as we can”. Because it require a large amount of computer memory.
- Collect the minimal sampling rate required for a given application that retains all important signal information.

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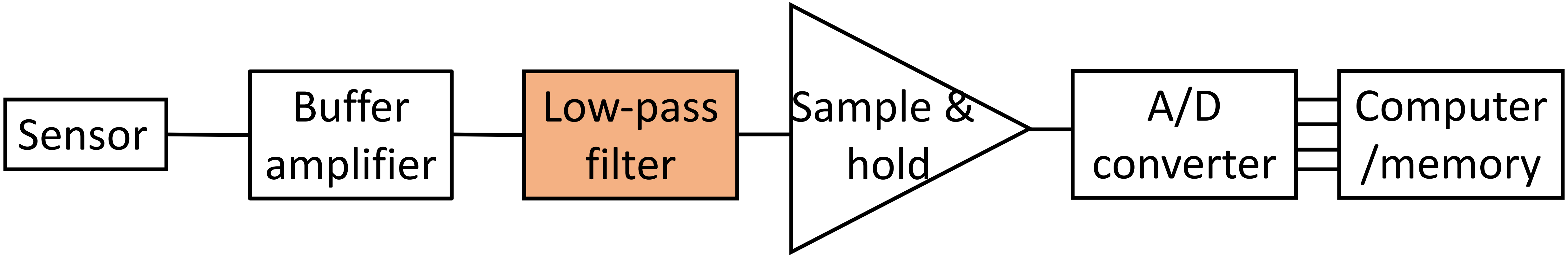
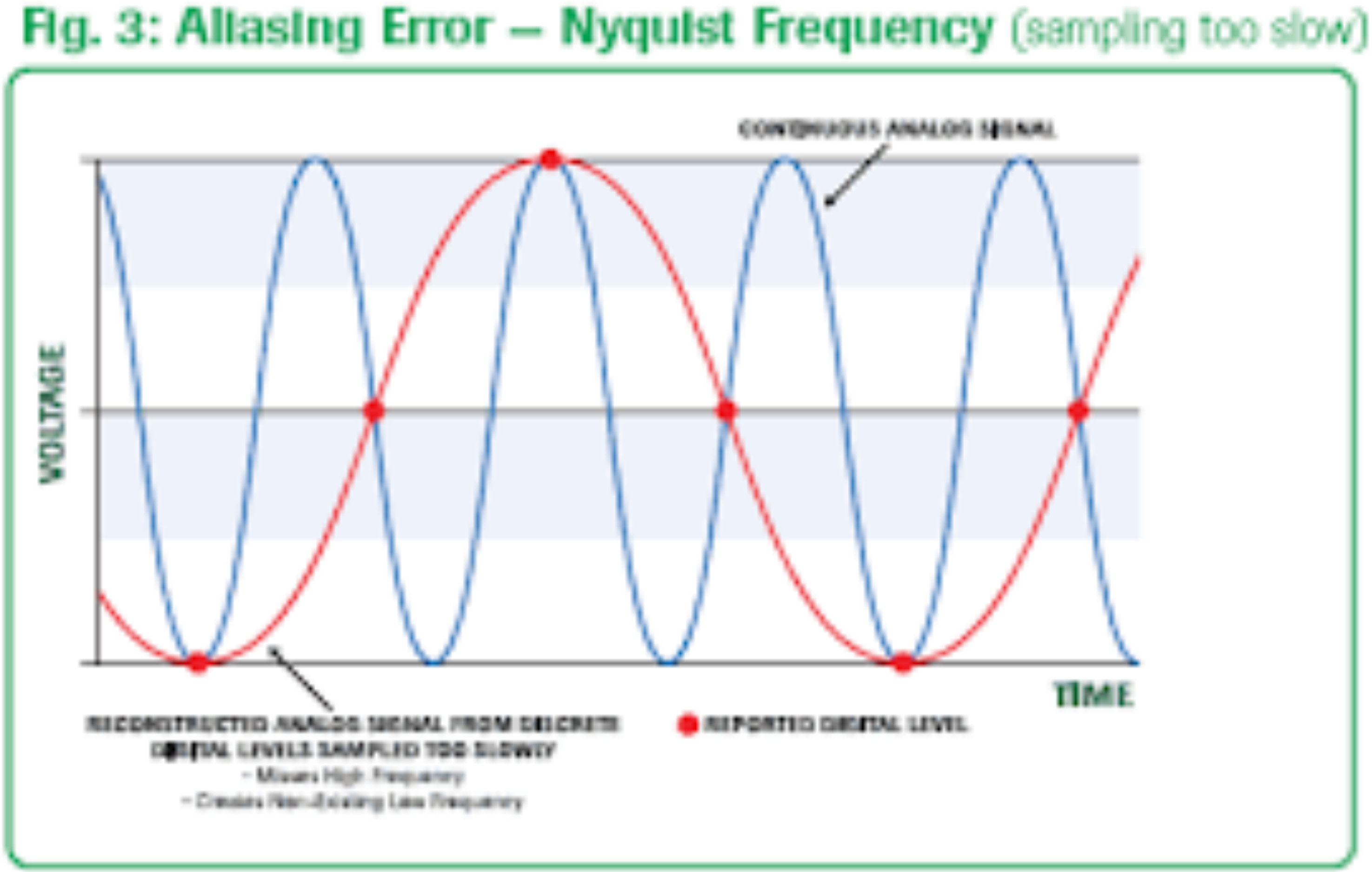


How fast signal should be sampled

Aliasing is an effect that causes different signals to become indistinguishable (or *aliases* of one another) when sampled.



5 cycles
6 sampling point
Sampling frequency 1.2 f_0
f_0 is frequency of the original sin wave

Shannon’s sampling theorem

In theory, that we need to sample a signal at a rate at least more than two times the maximum frequency component in the signal to retain all frequency components.

$f_s > 2f_{max}$

fs : digital sample must be taken at this frequency

f_{max}: is the highest frequency components in the input analog signal

The time interval between the digital samples is $\Delta t = 1/f_s$

Example: if the sampling rate is 5000 Hz, the time interval between samples would be 1/5000 s or 0.2ms.

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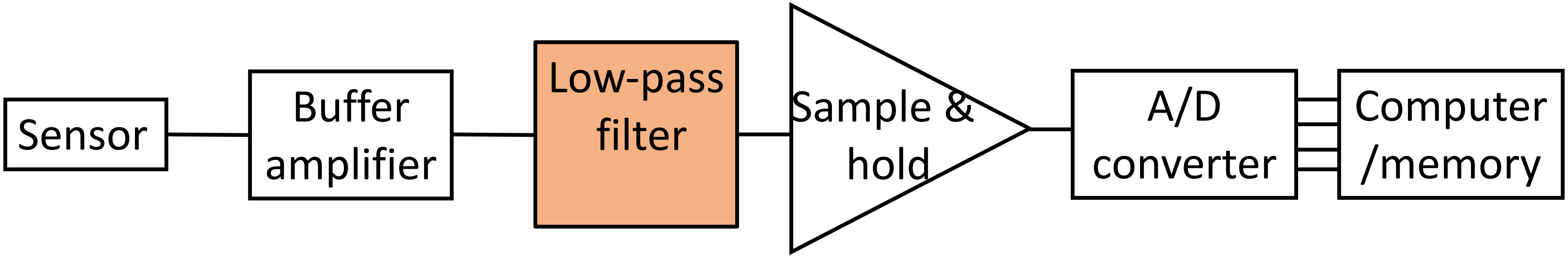
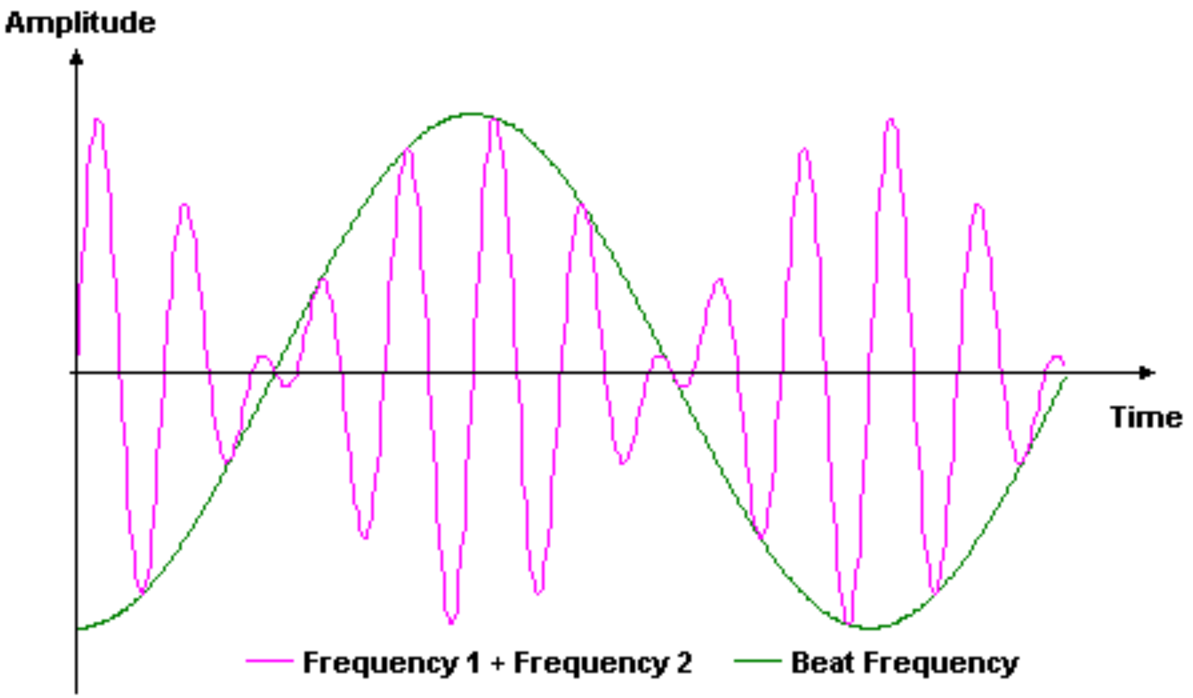
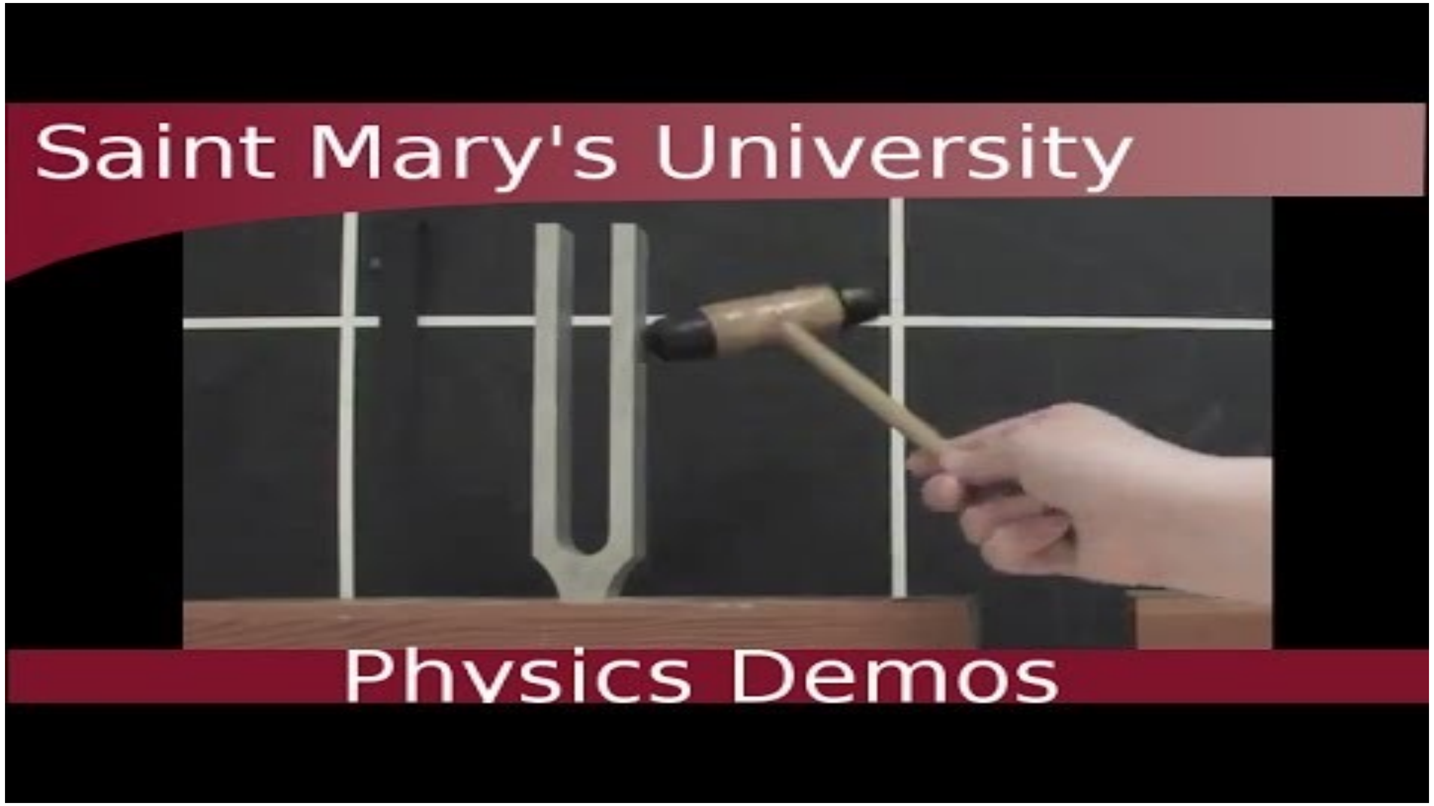


Beat frequency

- A **beat** is an interference pattern between two signal of slightly different **frequencies**, perceived as a periodic variation in volume whose rate is the difference of the two **frequencies**.
- Beat frequency is common in optics, mechanics and acoustics when two waves close in frequency add.



Beat frequency



https://www.youtube.com/watch?v=V8W4Djz6jnY&ab_channel=SMUPhysics

Example 1:

What is the beat frequency produced by two sound waves resonating at 425 Hz and 436 Hz?

Example 2:

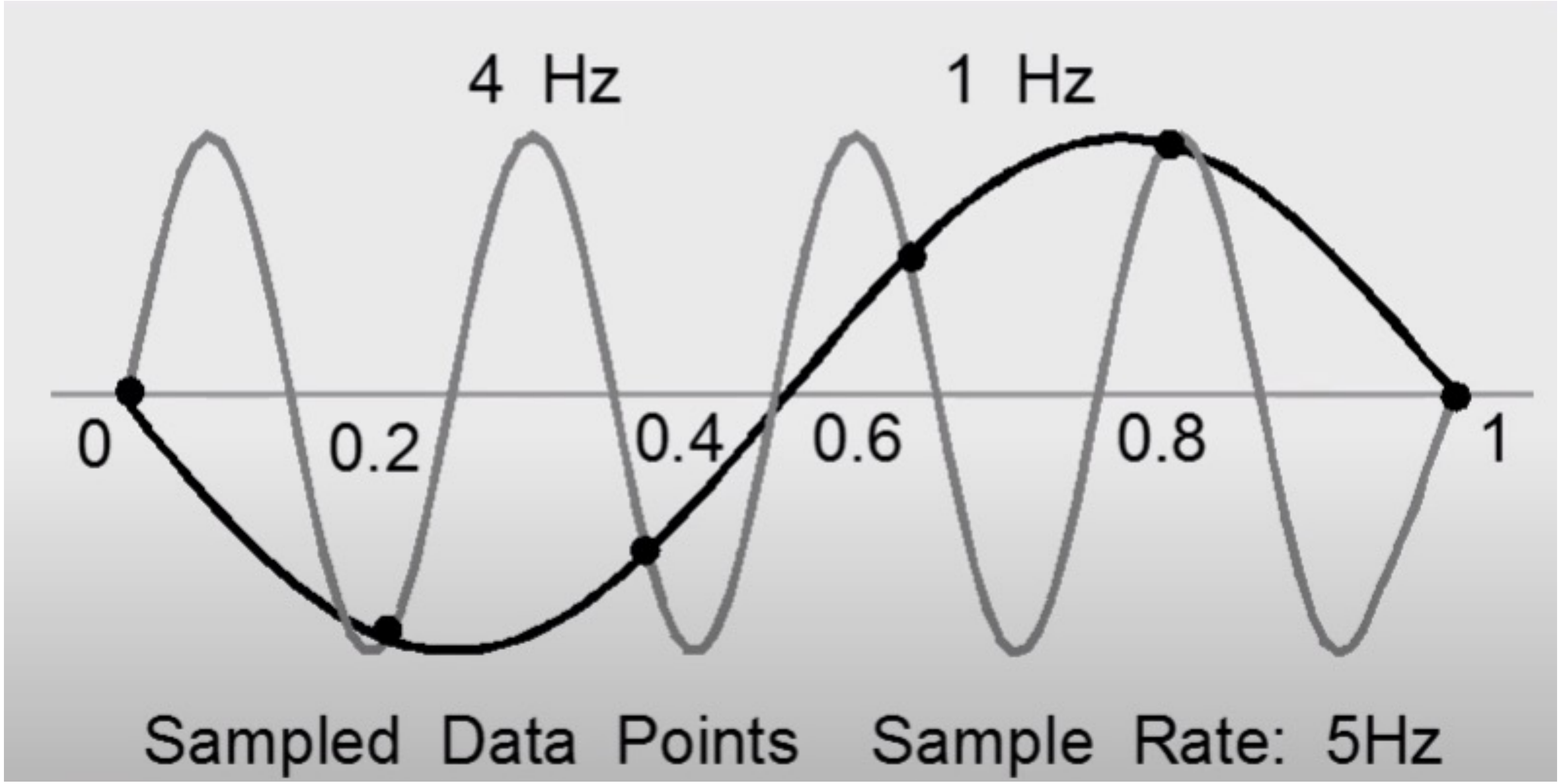
A sound wave at a frequency of 360 Hz produces 32 beats in 4 seconds when interacting with a vibrating tuning fork. (a) What is the beat frequency? (b) What are the two possible frequencies of the vibrating tuning fork?

Class Discussion:

The **beat frequency** refers to the rate at which the volume is heard to be oscillating from high to low volume. For example, if two complete cycles of high and low volumes are heard every second, the beat frequency is 2 Hz. The beat frequency is always equal to the difference in frequency of the two notes that interfere to produce the beats. So if two sound waves with frequencies of 256 Hz and 254 Hz are played simultaneously, a beat frequency of 2 Hz will be detected.

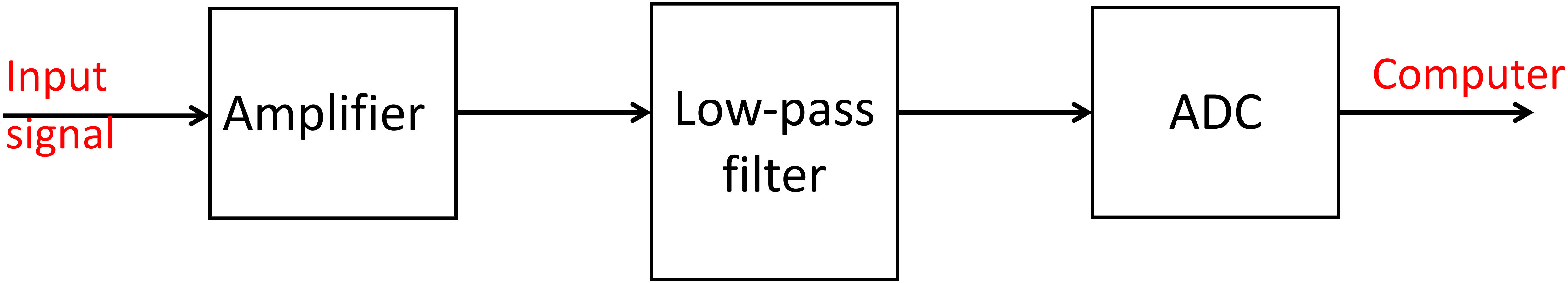
Find an example of using beat frequency in a) engineering, b) physics and c) sound and briefly explain how it works.

Anti-Aliasing filter



Anti-Aliasing filter

Is an analog filter that removes signal frequencies above fs/2, where fs is the sample frequency



Data acquisition system components

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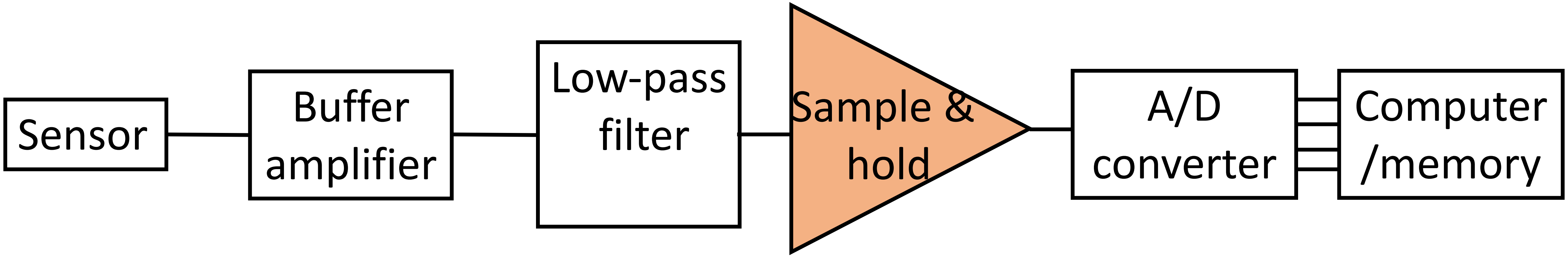
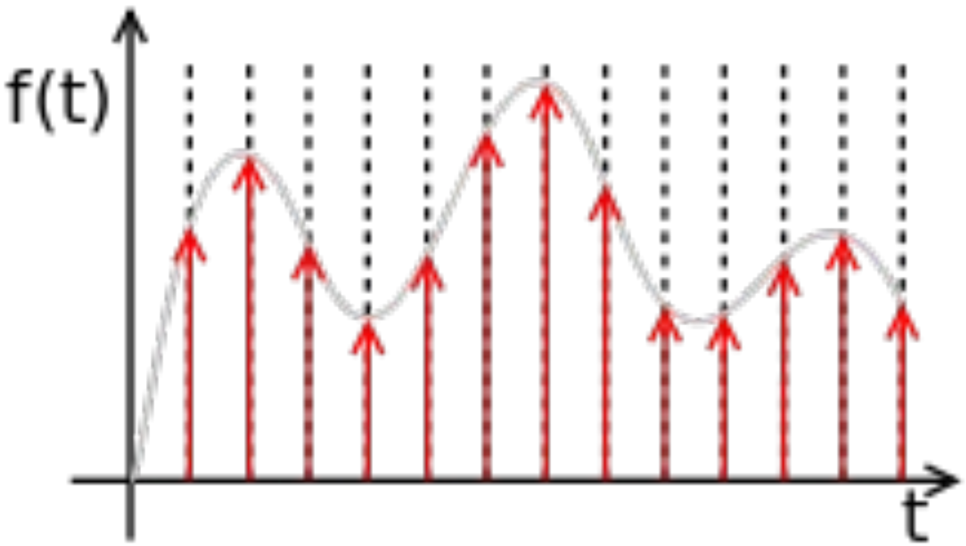
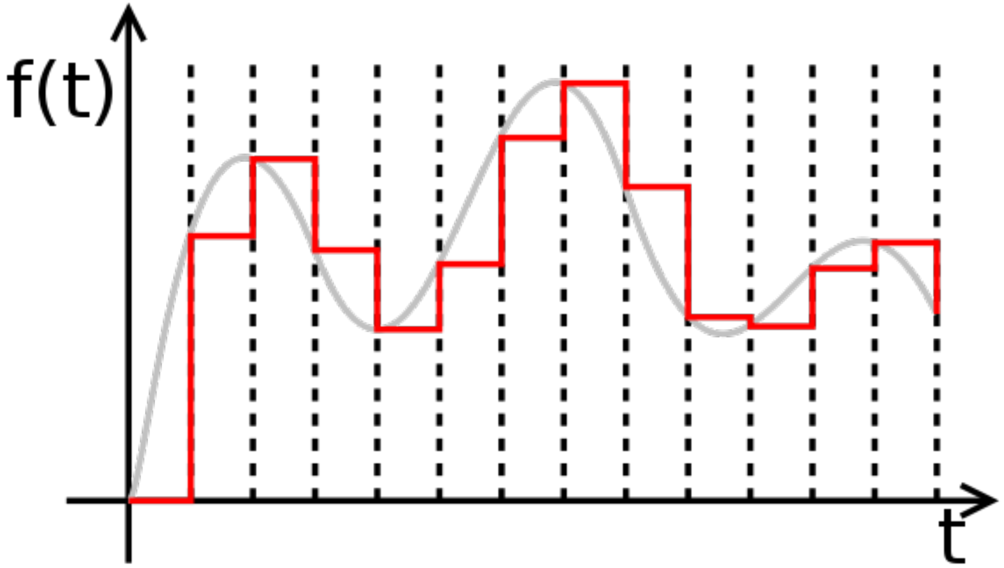


Sample & hold

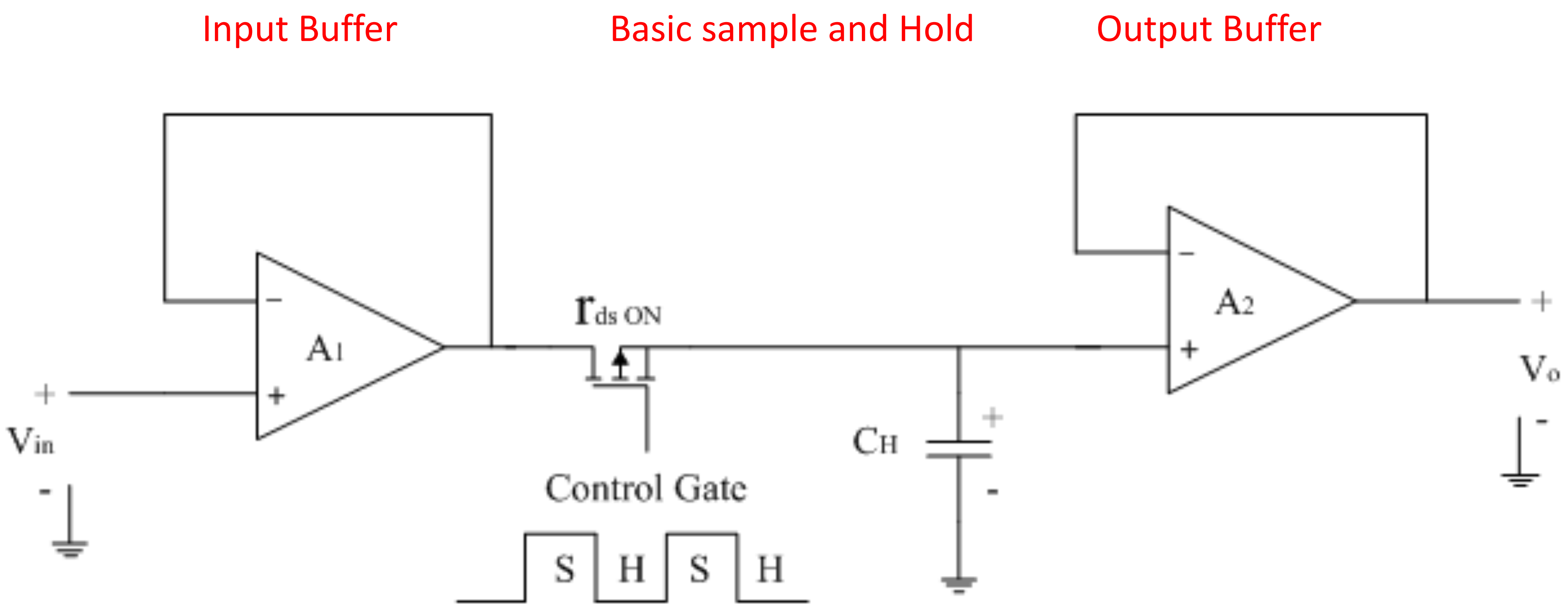


Sample times



Sample & hold

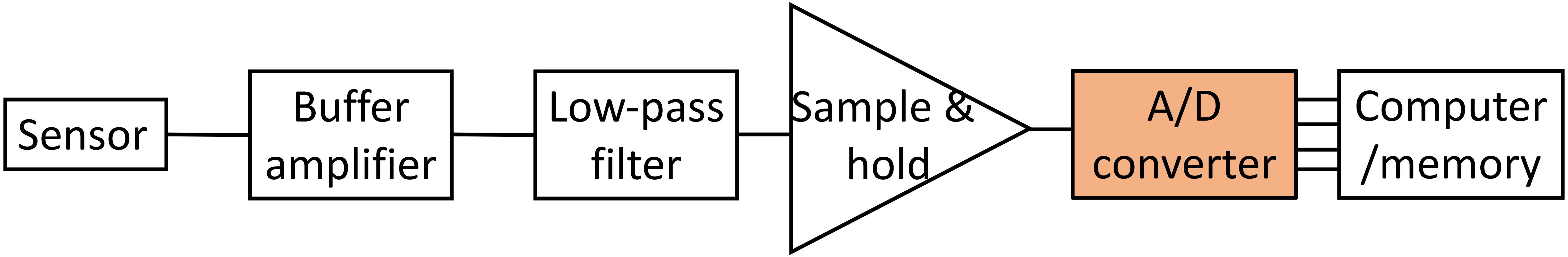
Sample & hold



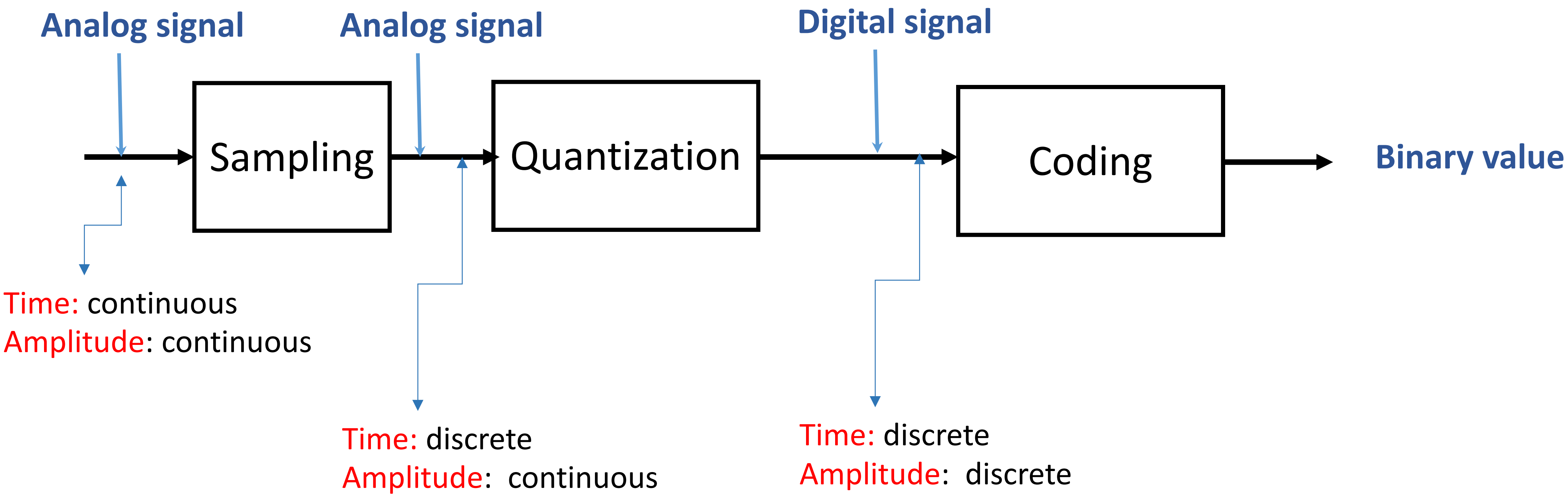
A simple sample and hold circuit

Data acquisition system components

1) Buffer amplifier
2) Low-pass filter
3) Sample and hold
4) Analog-to-digital convertor
5) computer



How do we record a analog data



Analog-to-digital convertor

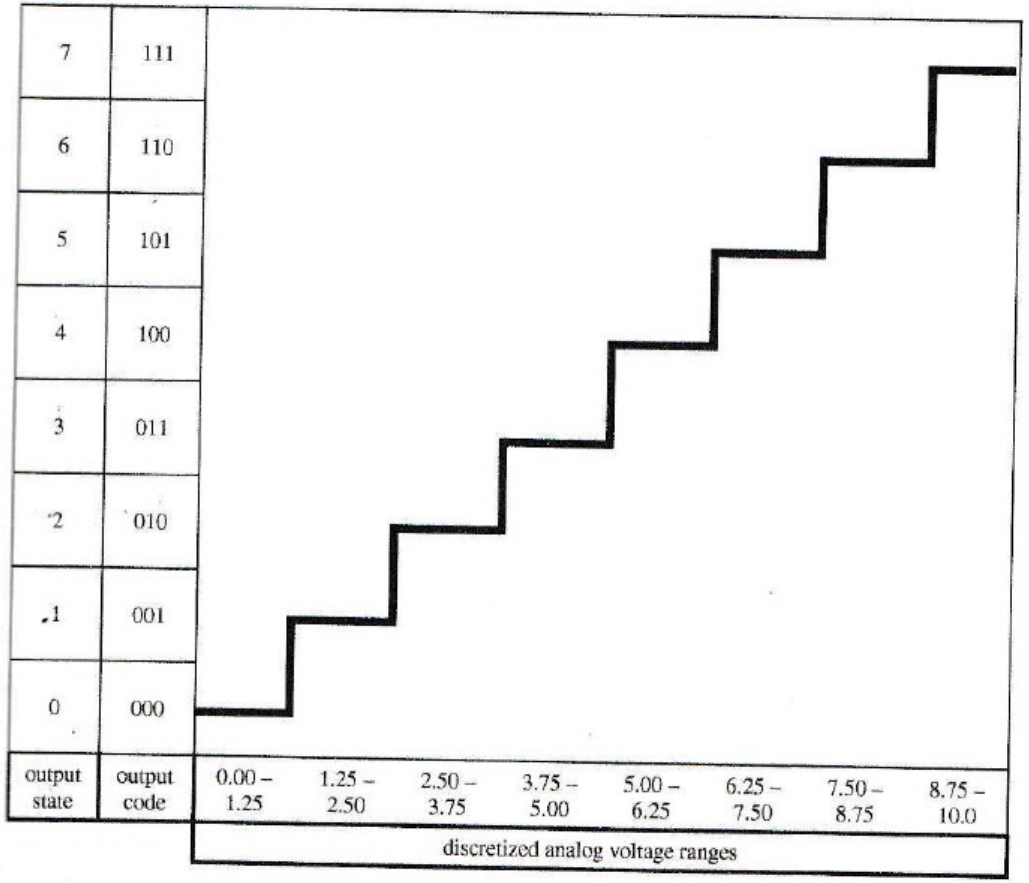
A/D convertor: Is an electric device that converts an analog voltage to a digital code.

Quantizing: is defined as the transformation of a continues analog input into a set if discrete output states.
Coding: is the assignment of a digital code word or number to each output state

The resolution of A/D convertor is the number of bits used to digitally approximate the analog value of the input.
The number of possible states N is equal to the number of bit combinations that can be output from the converter

$\mathbf{N=2^n}$ Where n is the number of bits

Analog-to-digital convertor

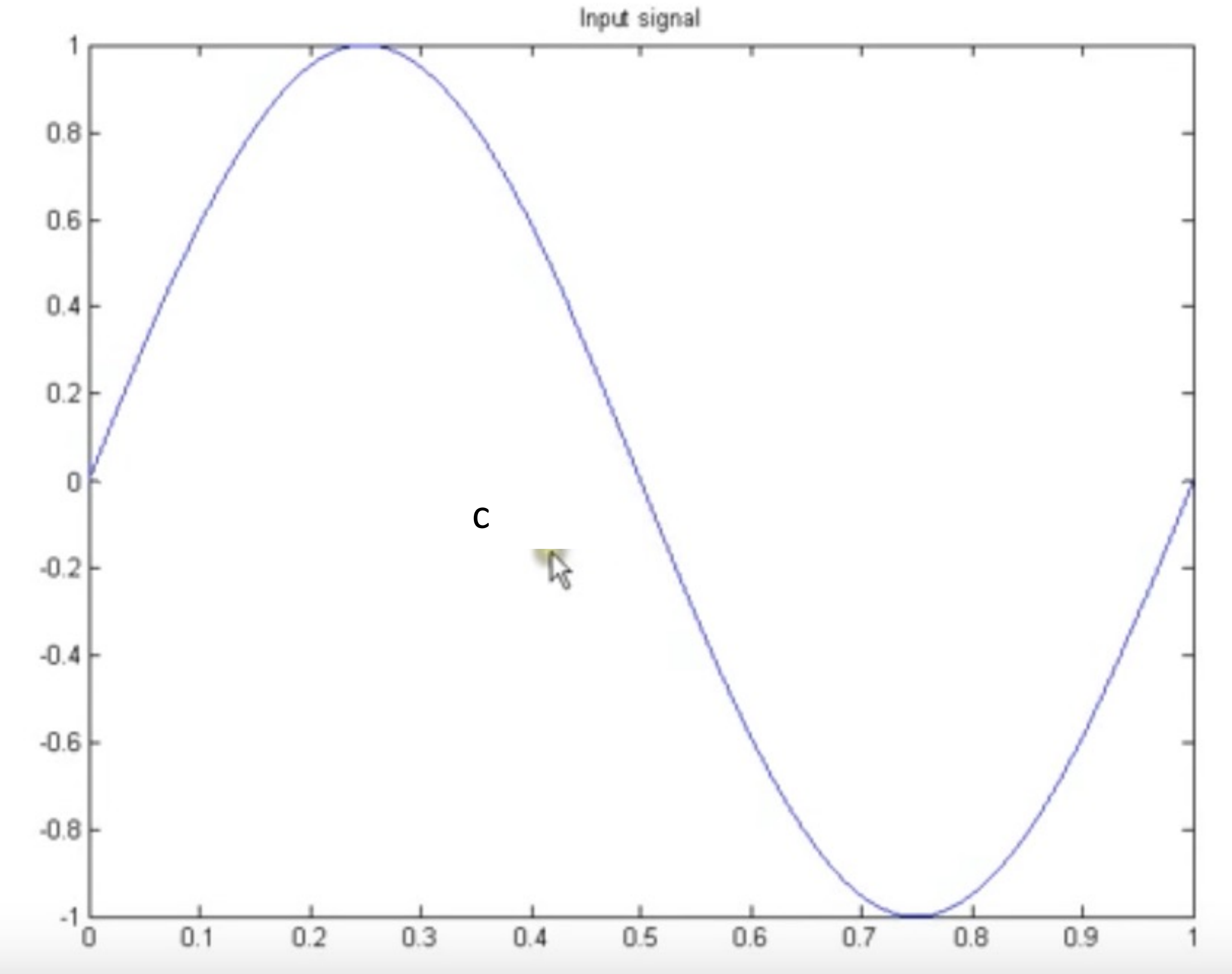


The number of decision points that occur in the process of quantizing is (N-1).

The analog quantization size Q, sometimes called the code width, is defined as the full-scale range of the A/D convert or divided by the number of output states

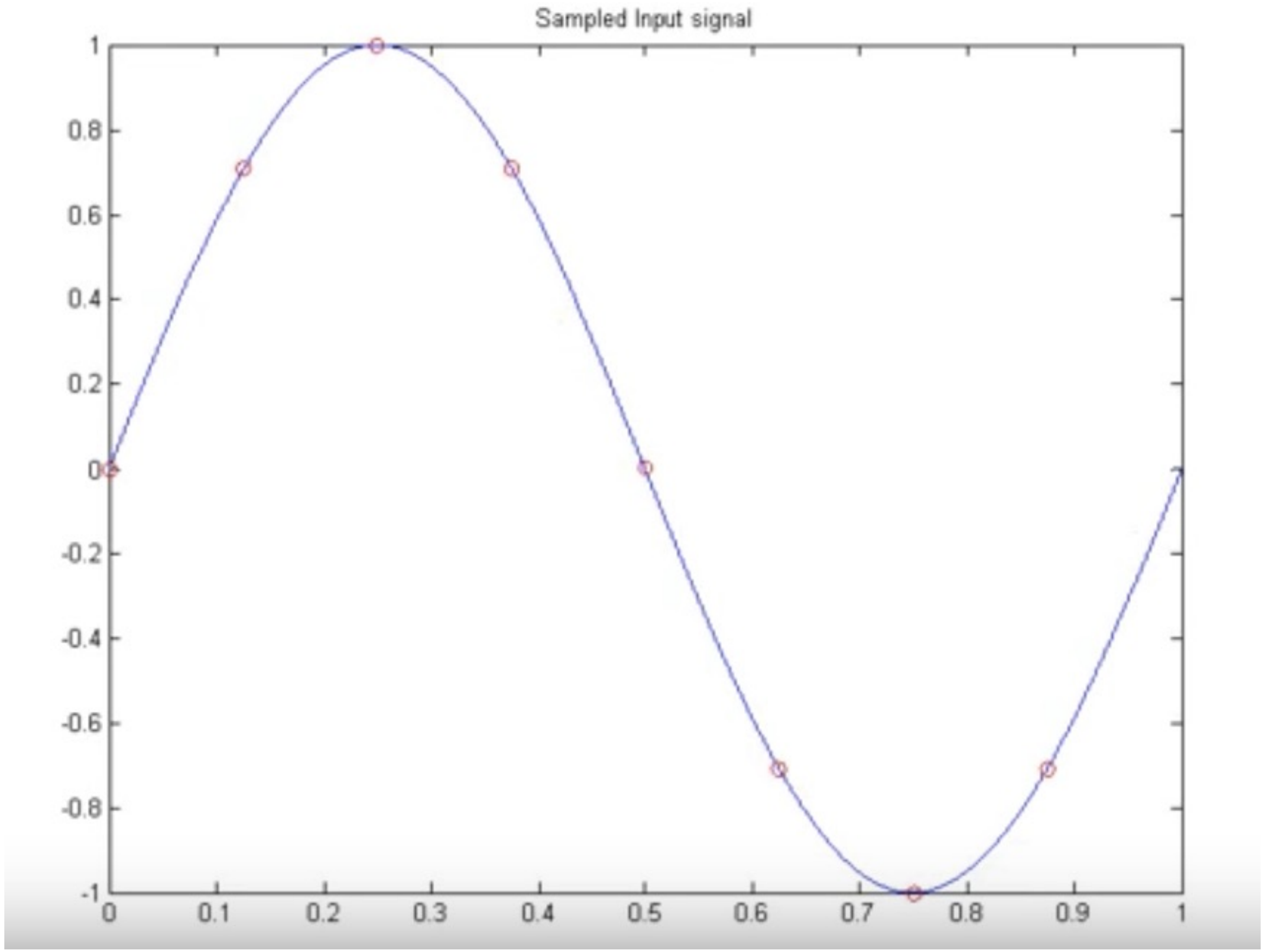
Analog-to-digital convertor

Example 3: consider a simple sin wave and perform sampling with 8 sample points and quantize it using 2 bits.



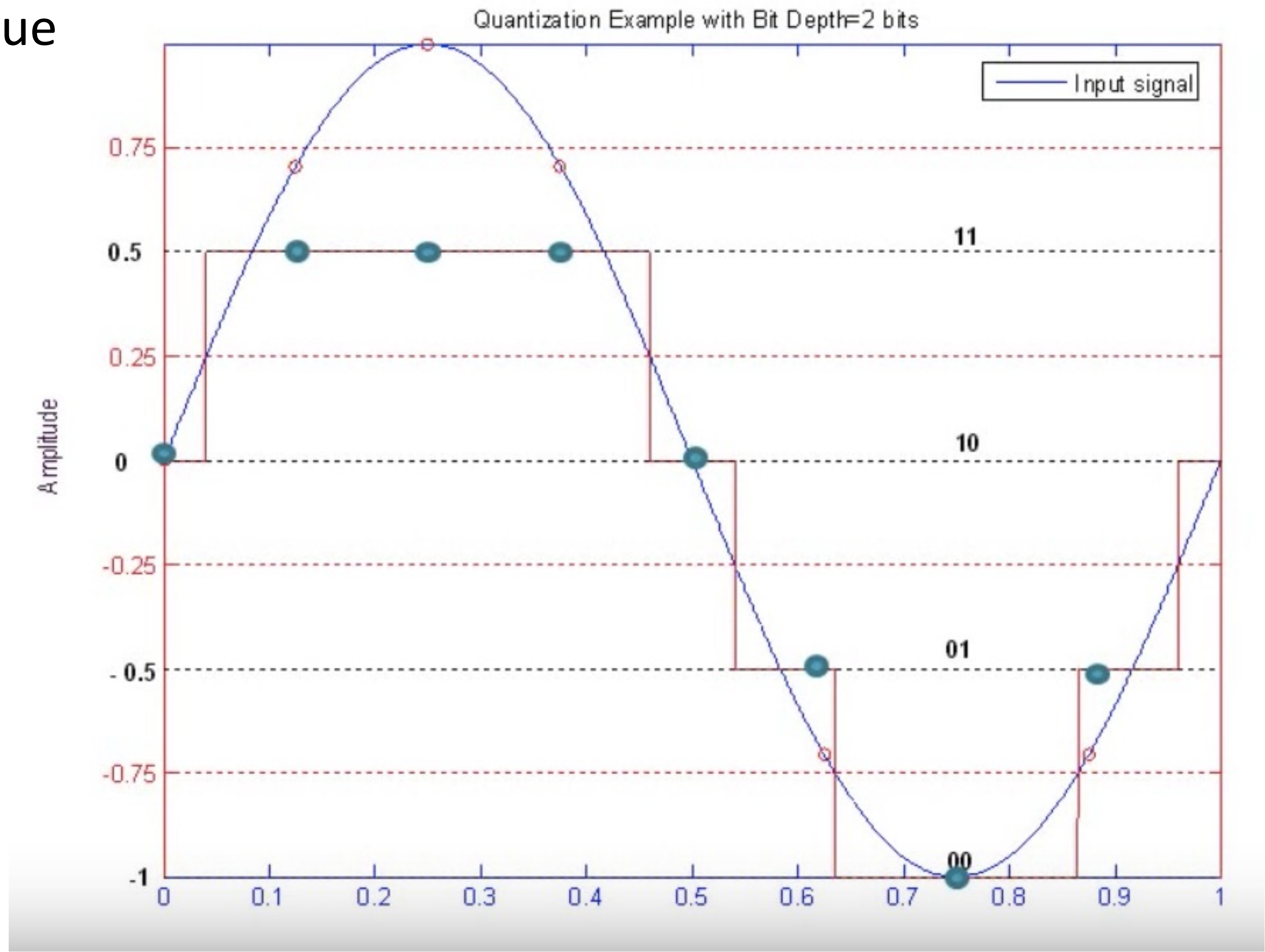
Analog-to-digital convertor

Example: continue



Analog-to-digital convertor

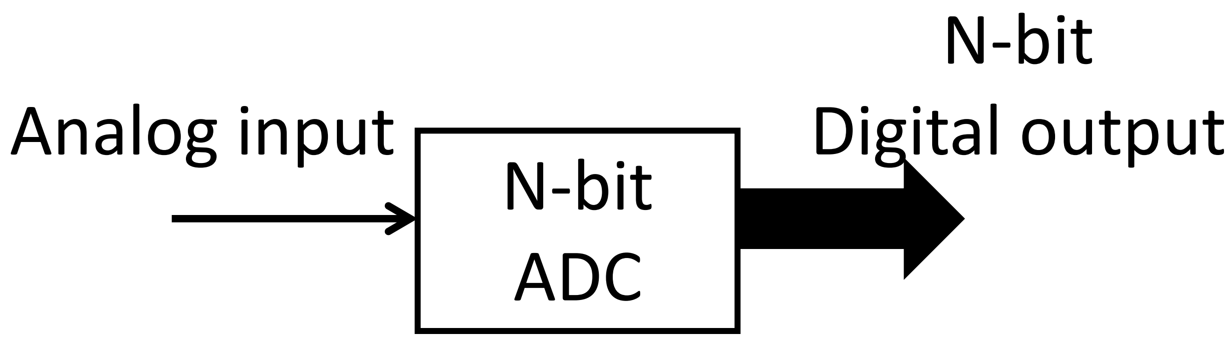
Example: continue

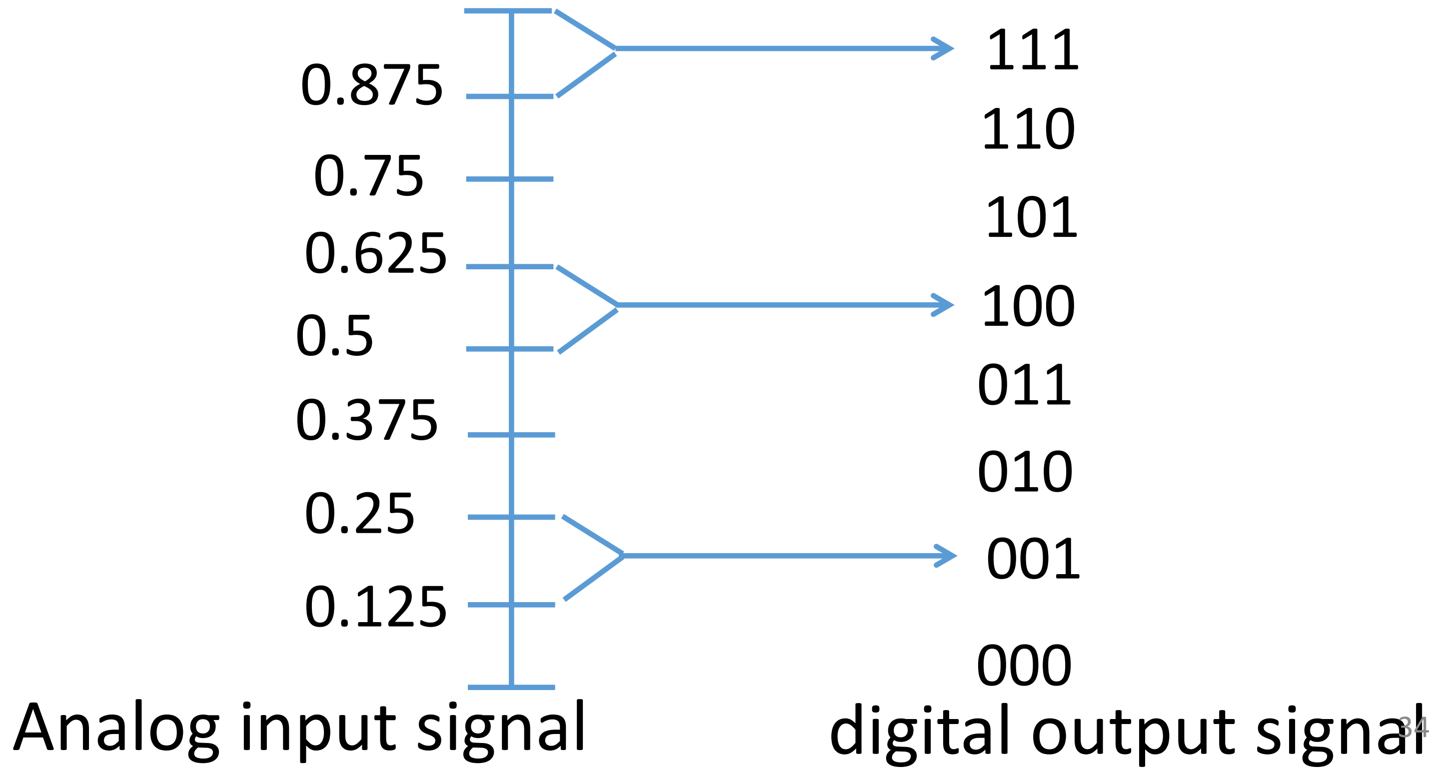


Coding-example

Consider a ADC convertor with dynamic range of 1 volt and quantize it in 3 bits

Sample size=$1/2^3$ =0.125V



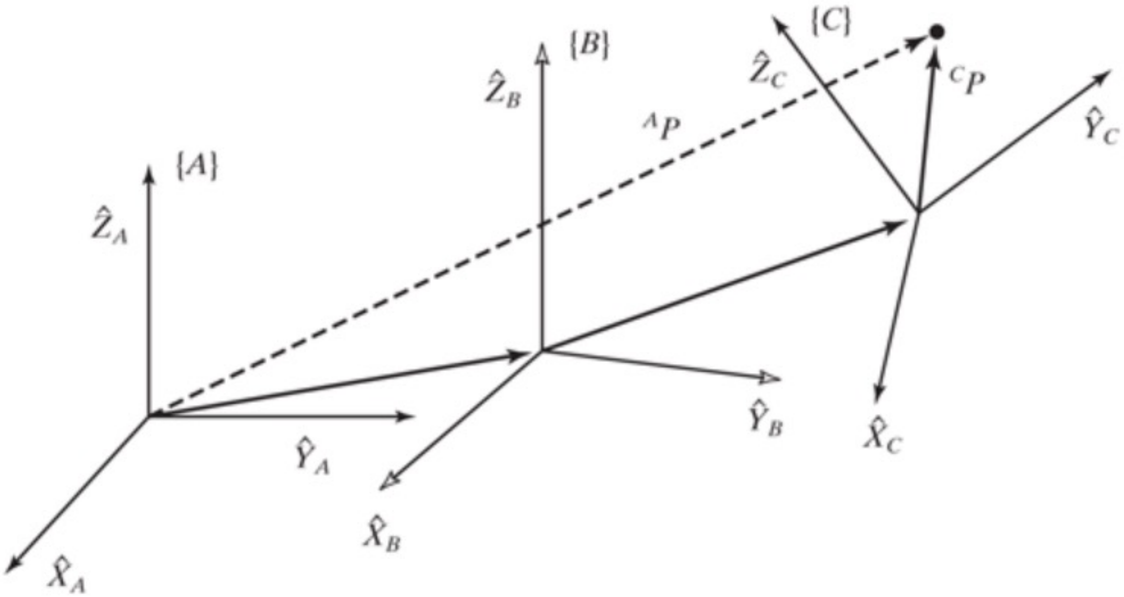


In-class assessment-Submit in ilearn

Translational Operation

Let’s start with what we did not get time to cover last week (week 3)

Transformation Arithmetic



$$^{A}P = {}^{A}_{B}T \; {}^{B}_{C}T \; {}^{C}P$$

we have ^{C}P and wish to find ^{A}P

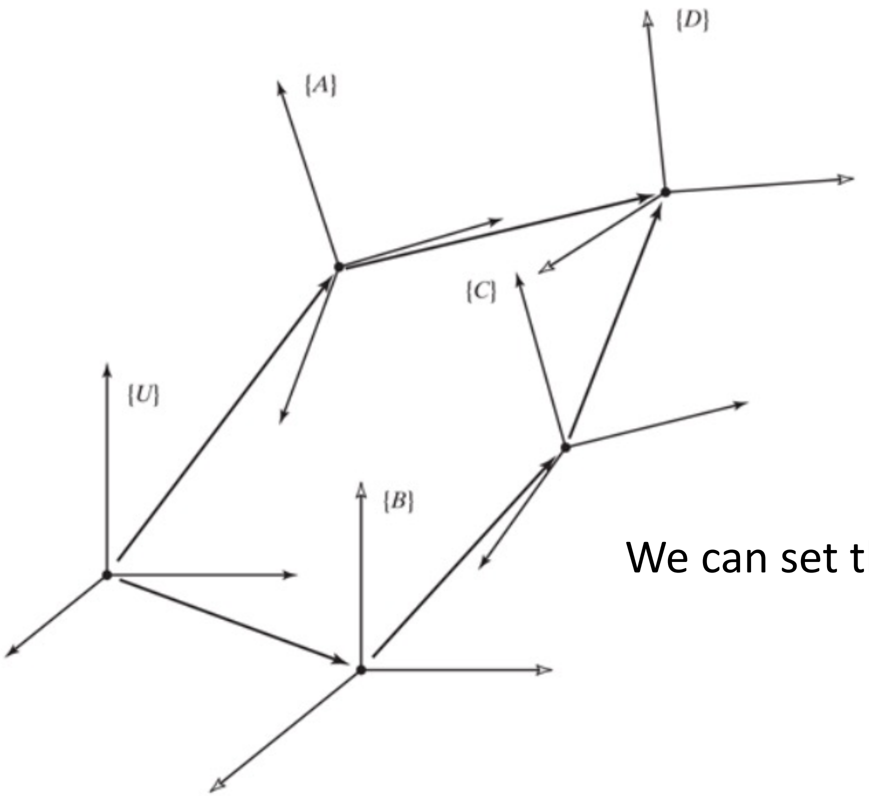
Example 5:

Vector A_{P1} is rotated relative to frame {A} about z-axis by 30 degrees and translated 10, 5, 0 units in X_A, Y_A, and Z_A, respectively. Define transformation matrix (T), then the new resulting vector A_{P2} if the original vector A_{P1}=[-2 6 -5]^T

Example 6:

Vector A_{P1} is rotated relative to frame {A} about x-axis by 45 degrees and translated -12, 3, 10 units in X_A, Y_A, and Z_A, respectively. Define transformation matrix (T), then the new resulting vector A_{P2} if the original vector A_{P1}=[-2 6 -5]^T

Transform Equations



Set of transforms forming a loop.

$$ {}^{U}_{D}T = {}^{U}_{A}T \; {}^{A}_{D}T; $$

second;

$$ {}^{U}_{D}T = {}^{U}_{B}T \; {}^{B}_{C}T \; {}^{C}_{D}T. $$

We can set these two descriptions of ${}^{U}_{D}T$ equal to construct a transform equation:

$$ {}^{U}_{A}T \; {}^{A}_{D}T = {}^{U}_{B}T \; {}^{B}_{C}T \; {}^{C}_{D}T. $$

Transform equations can be used to solve for transforms in the case of n unknown transforms and *n* transform equations.

Example 7:

frame {B} is rotated relative to frame {A} about z-axis by 30 degrees and translated 4 units in x-axis and 3 units in y-axis. Frame {C} is rotated relative to frame {B} about x-axis by 60 degrees and translated 6 units in x-axis and 5 units in z-axis. Find the position of point "P" relative to frame {A} if $C_p = [8\ 7\ 9]^T$

Inverting Transform

For Rotation matrices ${}^{A}_{B}R = {}^{B}_{A}R^{-1} = {}^{B}_{A}R^{T}$

For transformation matrices ${}^{A}_{B}T = {}^{B}_{A}T^{-1} \neq {}^{B}_{A}T^{T}$

For transformation matrices, we can use the following formula to find the inverse

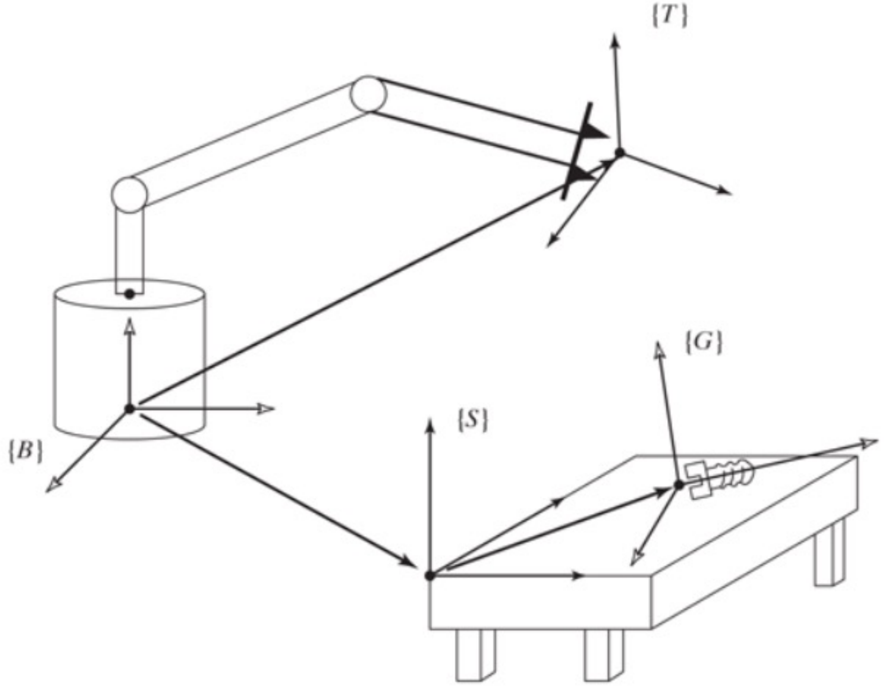
$$ {}^{B}_{A}T = {}^{A}_{B}T^{-1} = \begin{bmatrix} {}^{A}_{B}R^{T} & -{}^{A}_{B}R^{T} . {}^{A}P_{Borg} \\ 0\ 0\ 0 & 1 \end{bmatrix} $$

Example 8:

Frame {B} is rotated relative to frame {A} about z-axis by 30 degrees and translated 4 units in x-axis and 3 units in y-axis. Find the transformation matrix that describes frame {A} relative to frame {B}.

Example 9:

Assume that we know the transform ${}^{B}_{T}T$ in **Fig. 2.16**, which describes the frame at the manipulator's fingertips {*T*} relative to the base of the manipulator, {*B*}, that we know where the tabletop is located in space relative to the manipulator's base (because we have a description of the frame {*S*} that is attached to the table as shown, ${}^{B}_{S}T$), and that we know the location of the frame attached to the bolt lying on the table relative to the table frame—that is, ${}^{S}_{G}T$. Calculate the position and orientation of the bolt relative to the manipulator's hand, ${}^{T}_{G}T$.



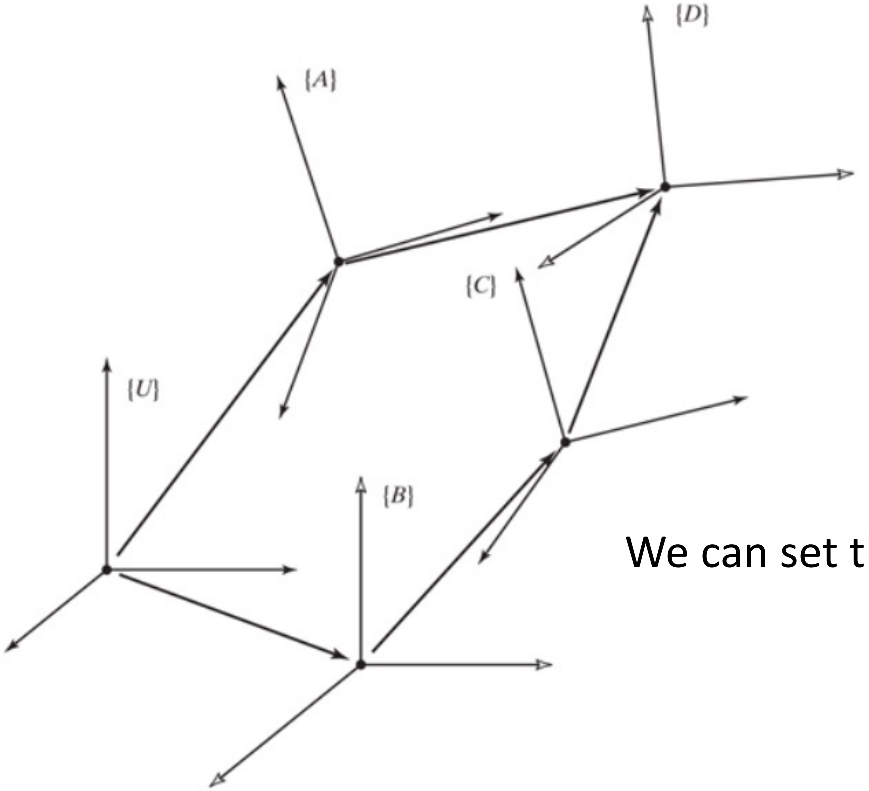
Solution

Manipulator reaching for a bolt.

Guided by our notation (and, it is hoped, our understanding), we compute the bolt frame relative to the hand frame as

$$ {}^{T}_{G}T = {}^{B}_{T}T^{-1}\ {}^{B}_{S}T\ {}^{S}_{G}T. \tag{2.55} $$

Transform Equations



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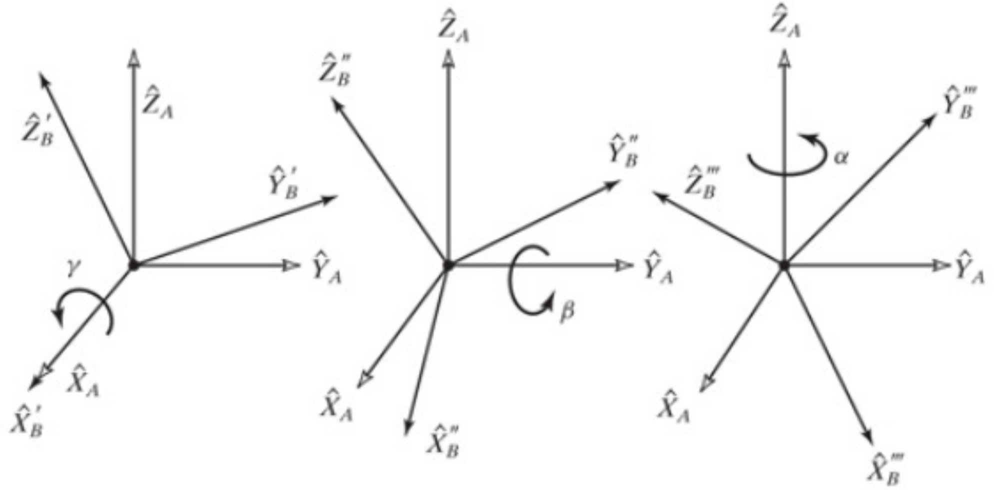
Example 4:

Frame {B} is rotated relative to frame {A} about z-axis by 30 degrees and translated 4 units in x-axis and 3 units in y-axis. Find the transformation matrix that describes frame {A} relative to frame {B}.

X–Y–Z Fixed Angles

Start with the frame coincident with a known reference frame {A}. Rotate {B} first about $\hat{X}_A$ by an angle γ, then about $\hat{Y}_A$ by an angle β, and, finally, about $\hat{Z}_A$ by an angle α.

Roll: $R_x(\boldsymbol{\gamma})$
Pitch:$R_y(\boldsymbol{\beta})$
Yaw: $R_z(\boldsymbol{\alpha})$



For this kind pf rotation, all the rotations are about the fixed frame {A}, and the result gives the new moved frame {B}

The order of matrix multiplication must be opposite to the order of rotation as follows

$$
\begin{aligned}
{}^A_B R_{XYZ}(\gamma,\ \beta,\ \alpha) &= R_Z(\alpha) R_Y(\beta) R_X(\gamma) \\
&= \begin{bmatrix} c\alpha & -s\alpha & 0 \\ s\alpha & c\alpha & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} c\beta & 0 & s\beta \\ 0 & 1 & 0 \\ -s\beta & 0 & c\beta \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & c\gamma & -s\gamma \\ 0 & s\gamma & c\gamma \end{bmatrix},
\end{aligned}
$$

Example 5:

Frame {B} was initially coincident with {A}. We then rotated {B} about X_A –axis by 30 degrees. Then we rotated it about Y_A by 45 degrees, then we rotated it about Z_A by 60 degrees. Note that X_A, Y_A, Z_A axes are the original axes of frame {A}. Calculate the resultant rotation matrix ${}^{A}_{B}R$

Example 6:

Frame {B} was initially coincident with {A}. We then rotated {B} about Z_A –axis by 60 degrees. Then we rotated it about Y_A by 45 degrees, then we rotated it about X_A by 30 degrees. Note that X_A, $Y_{A,}$ Z_A axes are the original axes of frame {A}. Calculate the resultant rotation matrix ${}^{A}_{B}R$

X–Y–Z Fixed Angles

$$ {}^{A}_{B}R_{XYZ}(\gamma,\ \beta,\ \alpha) = \begin{bmatrix} c\alpha c\beta & c\alpha s\beta s\gamma - s\alpha c\gamma & c\alpha s\beta c\gamma + s\alpha s\gamma \\ s\alpha c\beta & s\alpha s\beta s\gamma + c\alpha c\gamma & s\alpha s\beta c\gamma - c\alpha s\gamma \\ -s\beta & c\beta s\gamma & c\beta c\gamma \end{bmatrix} $$

The inverse problem, that of extracting equivalent X–Y–Z fixed angles from a rotation matrix, is often of interest. The solution depends on solving a set of transcendental equations: there are nine equations and three unknowns if (2.64) is equated to a given rotation matrix. Among the nine equations are six dependencies, so, essentially, we have three equations and three unknowns. Let

$$ {}^{A}_{B}R_{XYZ}(\gamma,\ \beta,\ \alpha) = \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix} $$

$$ \begin{aligned} \beta &= \mathrm{A}\tan 2\left(-r_{31},\ \sqrt{r_{11}^2 + r_{21}^2}\right), \\ \alpha &= \mathrm{A}\tan 2(r_{21}/c\beta,\ r_{11}/c\beta), \\ \gamma &= \mathrm{A}\tan 2(r_{32}/c\beta,\ r_{33}/c\beta), \end{aligned} $$

Where Atan2 is the Arctangent defined using 2 inputs
(it is a function available in MATLAB)

Example 7:

Find the X-YZ fixed angles of rotation (**ɣ, β, α) for the following rotation matrix:**

$$\begin{bmatrix} \mathbf{0.9077} & \mathbf{-0.2946} & \mathbf{0.2989} \\ \mathbf{0.3304} & \mathbf{0.9408} & \mathbf{-0.0760} \\ \mathbf{-0.2588} & \mathbf{0.1677} & \mathbf{0.9513} \end{bmatrix}$$

End of week 4