

Introduction to Digital Signal Processing Systems

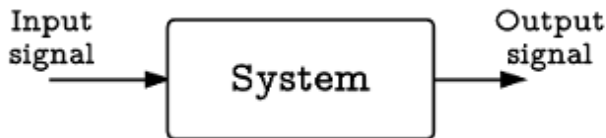
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What is a system?

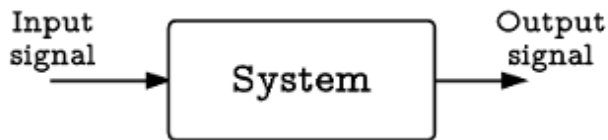
A collection of objects united by some form of interaction or interdependence¹.

From the signal processing point of view, **a system is any physical device or algorithm that performs some operation on a signal to transform it into another signal.** B



¹Zadeh, Lotfi A., and Charles A. Deoser. *Linear system theory*. New York: McGraw Hill, 1963.

What is a system?



Can be thought of a mapping function. e.g.

$$y[n] = \mathcal{H}(x[n])$$

Operations on signals

Operations on the dependent variable

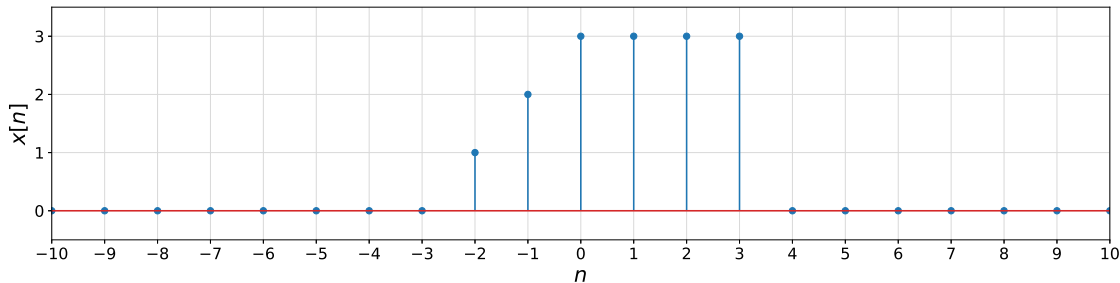
- ▶ **Scaling:** $y[n] = a \cdot x[n]$
- ▶ **Addition:** $y[n] = x_1[n] + x_2[n]$

Operations on the independent variable

- ▶ **Time shifting:** $y[n] = x[n - k], k \in \mathbb{Z}$
- ▶ **Time reversal:** $y[n] = x[-n], k \in \mathbb{Z}$

Operation on the independent variable: **Time shifting**

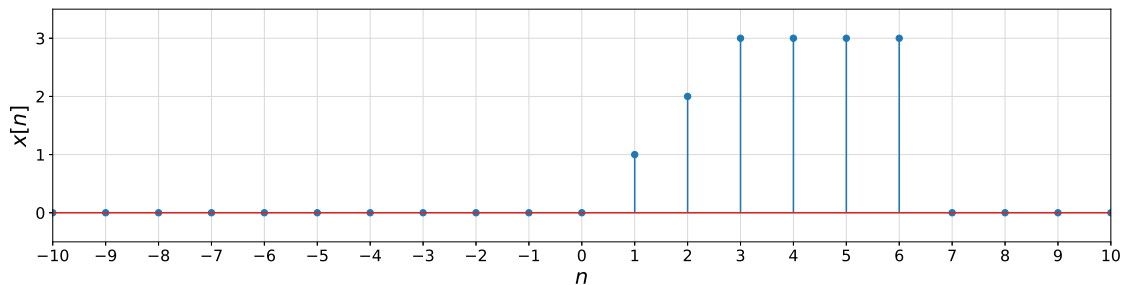
Consider $x[n]$ shown below,



What does $x[n - 3]$ look like?

Operation on the independent variable: **Time shifting**

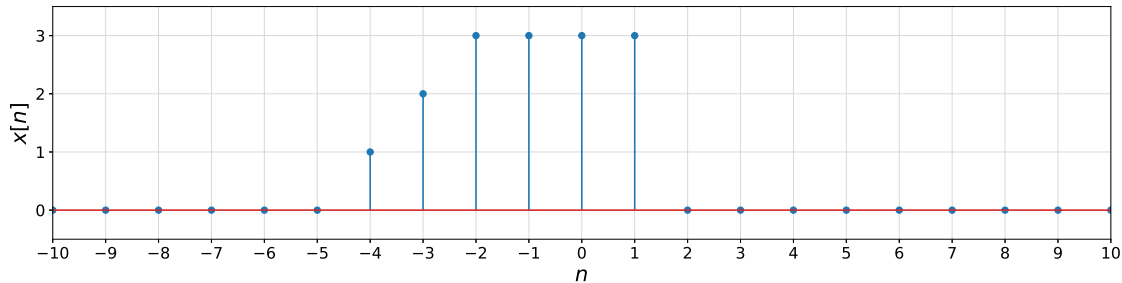
$$x[n - 3]$$



What about $x[n + 2]$?

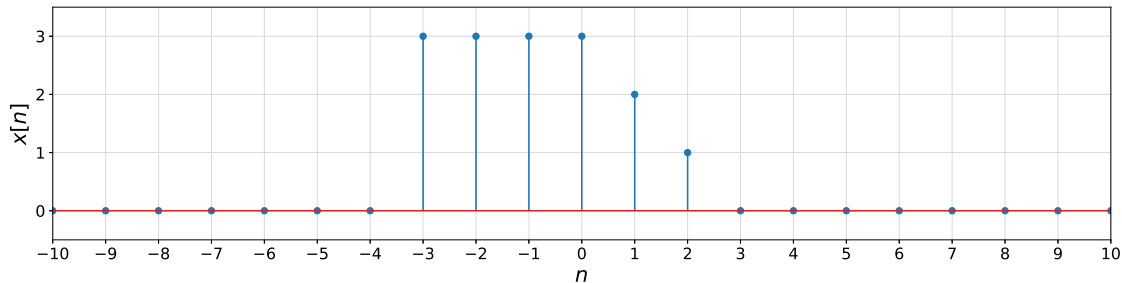
Operation on the independent variable: **Time shifting**

$$x[n+2]$$



Operation on the independent variable: **Time reversal**

$$x[-n]$$



And $x[-n]$?

Classification of systems

Based on the properties of the system.

- **Linearity:** *satisfies the properties of **scaling** and **superposition**.*

Let us assume,

$$\mathcal{H} : x_i[n] \mapsto y_i[n]$$

The system \mathcal{H} is linear, if and only if,

$$\mathcal{H} : \sum_i a_i x_i[n] \mapsto \sum_i a_i y_i[n]$$

Which of these systems are linear?

1. $y[n] = k_1 x[n] + k_2 x[t - 2]$
2. $y[n] = \sum_{k=n-N}^n x[k]$
3. $y[n] = 0.5x[n] + 1.5$

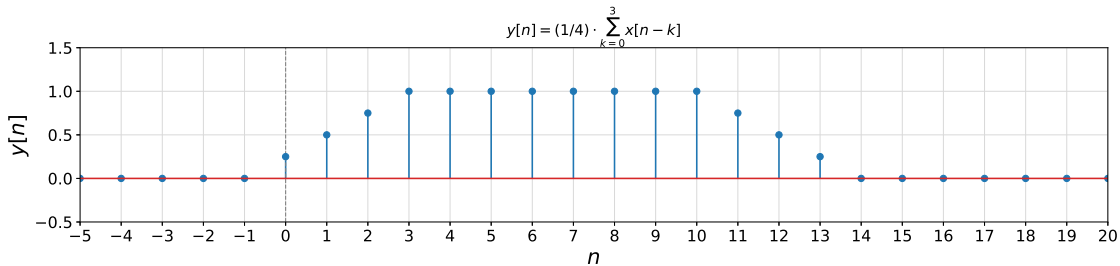
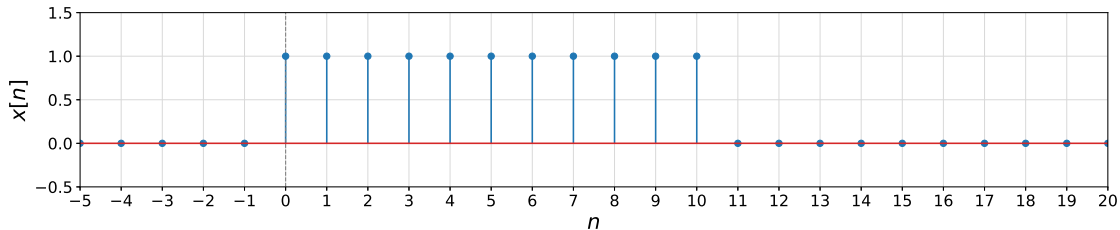
Classification of systems

- **Memory:** *a system whose output depends on past or future values of its input is a system with memory, else the system is memoryless.*

Note: the system may or may not depends on its present.

$$\begin{cases} y[n] = 0.5x[n] & \text{Memoryless system} \\ y[n] = \sum_{k=m_1}^{m_2} x[n-k] & \text{System with memory} \end{cases}$$

Classification of systems

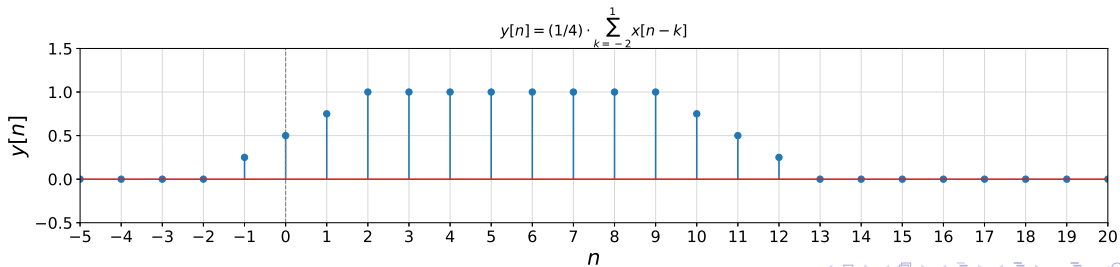
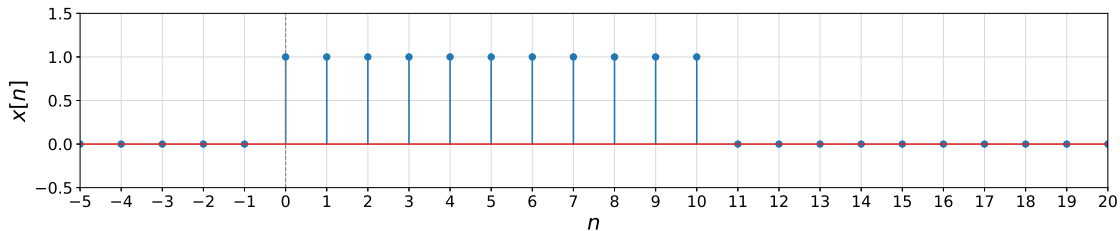


Classification of systems

- ▶ **Causality:** *a system whose output depends on the past and present only values of the input is a causal system.*

Classification of systems

Causality



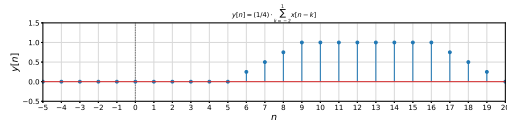
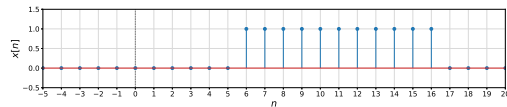
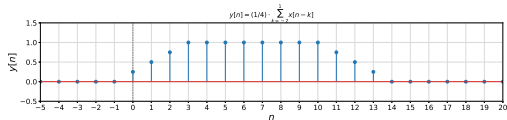
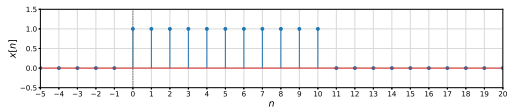
Classification of systems

- **Time invariance:** *system remains the same with time.*

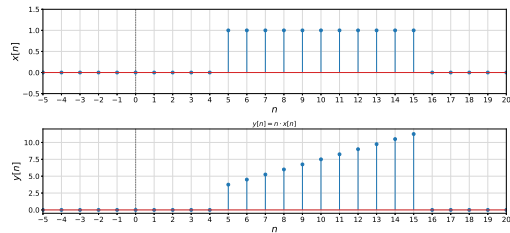
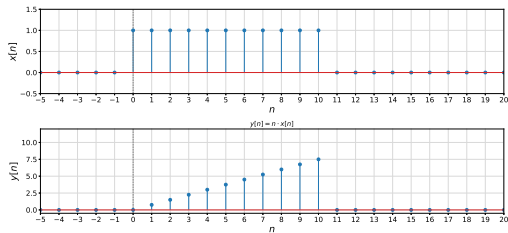
If a system is time-invariant, then

$$\mathcal{H} : x[n] \mapsto y[n] \iff f : x[n-k] \mapsto y[n-k]$$

Classification of systems



Classification of systems



Classification of systems

- **Stability:** *bounded input produces bounded output.*

$$|x[n]| < M_x < \infty \mapsto |y[n]| < M_y < \infty$$