ECE 317

Digital Signal Processing I (DSP I)

Lecture 2

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* Based on Slides from Prof. Rashid Ansari.

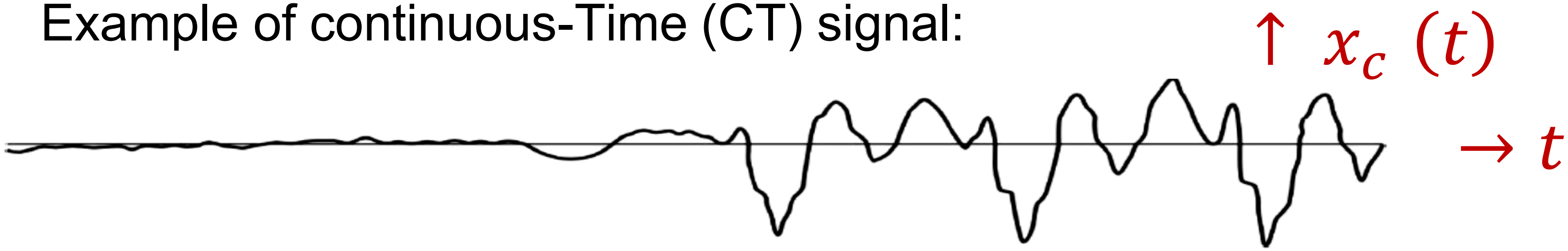
Digital Signal Processing I: Types of signals and applications

- **Speech and audio:** speech synthesis, dictation systems, audio equalizers, music synthesizers, hearing aids
- **Telecommunication signals:** Smartphones, Optimum reception in receivers, MIMO systems, equalization
- **Image:** JPEG compression; Computer vision, Object detection, CT/MRI image analysis, retinal imaging, Machine Learning
- **Video:** Scene analysis, expression recognition, video compression – MPEG, robotics & computer vision
- **Electromagnetic radiation:** radar detection & ranging, underground imaging
- **Signals in Multi-disciplinary work:** Biomedical signal processing, healthcare, autonomous vehicles, big data analysis, stock market data

Digital Signal Processing I: Signals you have seen in ECE 310

Continuous-Time (CT) signal and Discrete-Time (DT) signals

Example of continuous-Time (CT) signal:



- Notation: $\mathbb{R}$ is the set of real numbers (or reals for short).
- Signal defined for time t, $-\infty < t < \infty$, or $t \in \mathbb{R}\ (reals)$.

t takes values from the set $\mathbb{R}$, or $\mathbb{R}$ is domain of the signal.

- At each time instant t, a real number $x_c(t)$ is assigned as the signal value. $x_c(t) \in \mathbb{R}$, so $\mathbb{R}$ is co-domain of the signal.

The signal is displayed as a two-dimensional plot.

Is $x_c(t)$ a one- or two-dimensional (1D or 2D) signal?

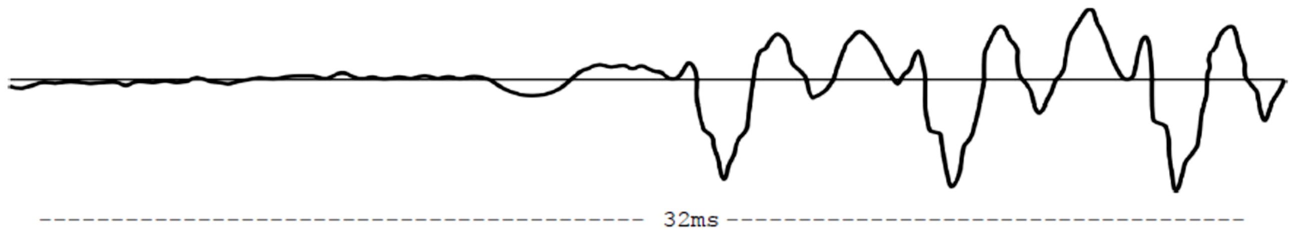
Digital Signal Processing I: Signals we deal with in this course

- Signal dimensionality refers to the number of independent variables. $x_c(t)$ has only one independent variable defined by its domain (time t). So, it is a 1D CT signal.
- Our primary focus is on one-dimensional (1D) signals
- In particular, on 1D Discrete-Time (DT) signals
  - Examples: sampled speech, music, biomedical signals, communication signals, and so on.
  - Notation: $x[n]$, 1D DT input signal applied to 1D DT system S to get 1D DT output signal $y[n]$.
- In most cases $x[n]$ is obtained by sampling a 1D Continuous-Time (CT) signal $x_c(t)$.

1D signal: DT signal obtained by sampling CT signals

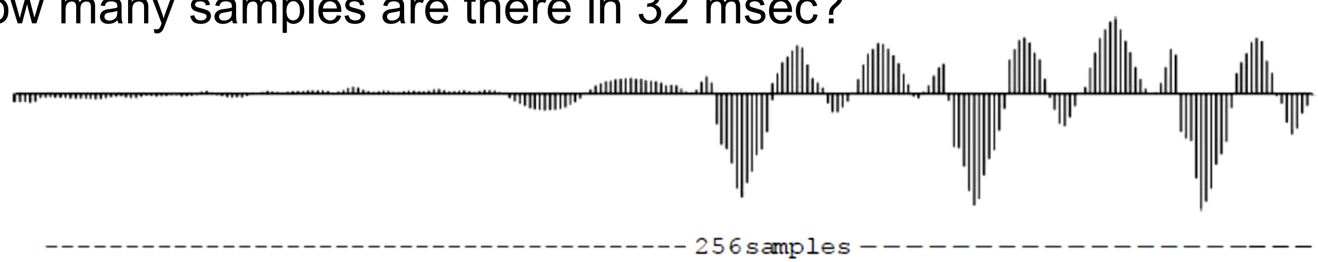
Notation: CT: Continuous-time, DT: Discrete-time

CT signal $x_c(t)$



32-msec plot of $x_c(t)$ is shown.

$x_c(t)$ is sampled with sampling period T = 125 μsec = 1/8 msec. What is the sampling rate? How many samples are there in 32 msec?



Sampling rate of $x[n]$ is # of samples in 1 sec = $\frac{1\ sample}{\frac{1}{8}\times 10^{-3} sec}$ =8000 samples/sec = 8 kHz

32-msec plot of DT signal $x[n]$ has 32msec/(1/8 msec) = 256 samples

2D signal $x[m,n]$

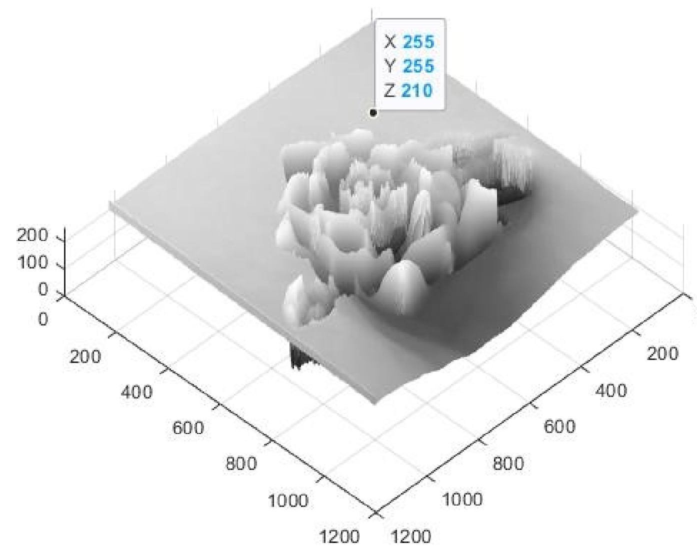
A 2-D discrete-variable signal has two independent variable $x[m,n]$.

What would be an example of 2D signal?

An image!

An image has two independent variables: the spatial coordinates in the horizontal and vertical directions.

2D, 3D signal example: discrete-variable signals

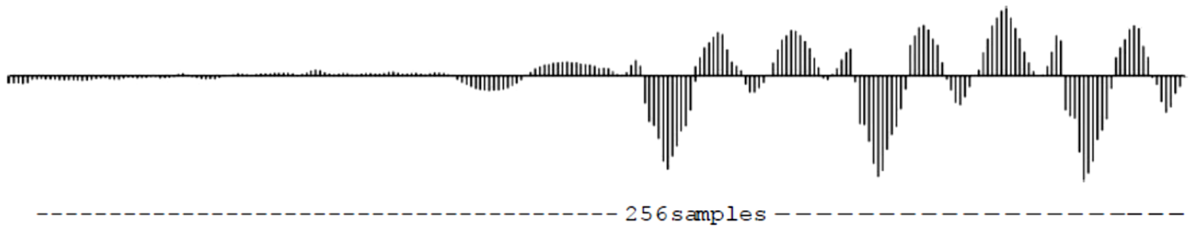


Discretized image is a 2-D signal: $\underline{i}[\underline{m},\underline{n}]$

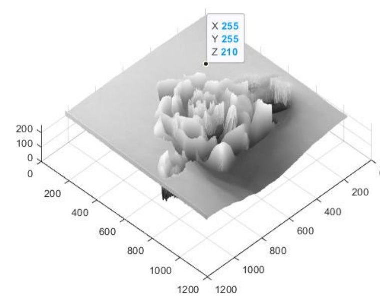
Discretized video is a 3-D signal: $\underline{v}[\underline{m},\underline{n},\underline{k}]$, a sequence of discretized images.

Summary of 1D, 2D, 3D examples of discrete-variable signals

- Discretized audio signal is a 1D signal: $x[n]$



- Discretized image is a 2D signal: $i[m,n]$



- Discretized video is a 3D signal: $v[m,n,k]$, a sequence of discretized images.

Discrete-Time (DT) Signal

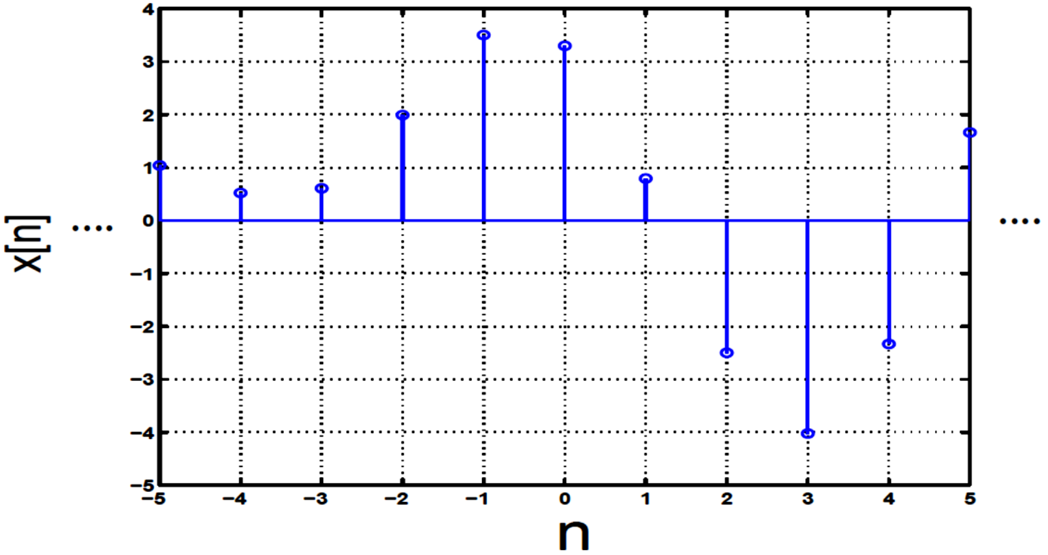
- Consider a sinusoidal DT signal of the form:
- $x[n] = 2\cos\frac{\pi}{4}n$
- If you wish to plot/picture this signal, you first decide on the values of n you wish to consider.
- What are the allowed values that n can assume?
- Integers!
- What kind of values can $x[n]$ assume?
- Real numbers!

Summary: Discrete-Time (DT) Signal

- A DT signals pairs every integer n with a real number $x[n]$ ($x[n] = 2\cos\frac{\pi}{4}n$ in our example)
- A DT signal is therefore a mapping from the set of integers to the set of real numbers.
- The set of integers is denoted by $\mathbb{Z}$.
- The set of real numbers is denoted by $\mathbb{R}$.
- DT Signal $x{:}\ \mathbb{Z} \rightarrow \mathbb{R}$ $\quad (or\ \mathbb{C}, \text{set of complex numbers})$
- $\mathbb{Z}$ is the domain, $\mathbb{R}$ is the co-domain
- A DT signal is also referred to as a sequence

Discrete-Time (DT) Signals and Digital Signals (terminology)

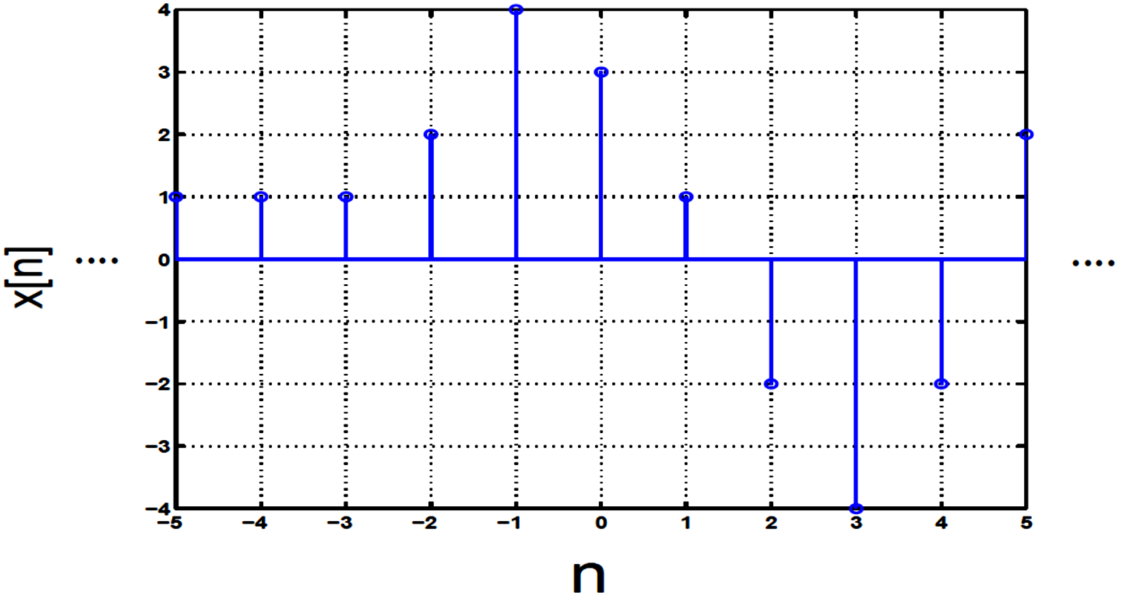
- Question: What is the difference between a discrete-time (DT) signal and a digital signal?
- DT Signal: $x: \mathbb{Z} \rightarrow \mathbb{R}$



Example of *discrete-time signal*

Discrete-Time (DT) Signals and Digital Signals

- A digital signal is a mapping $x\colon \mathbb{Z} \rightarrow \mathbb{D}$, where we use $\mathbb{D}$ to denote a discretized set of values, usually those obtained by quantization and can be represented a chosen number of bits

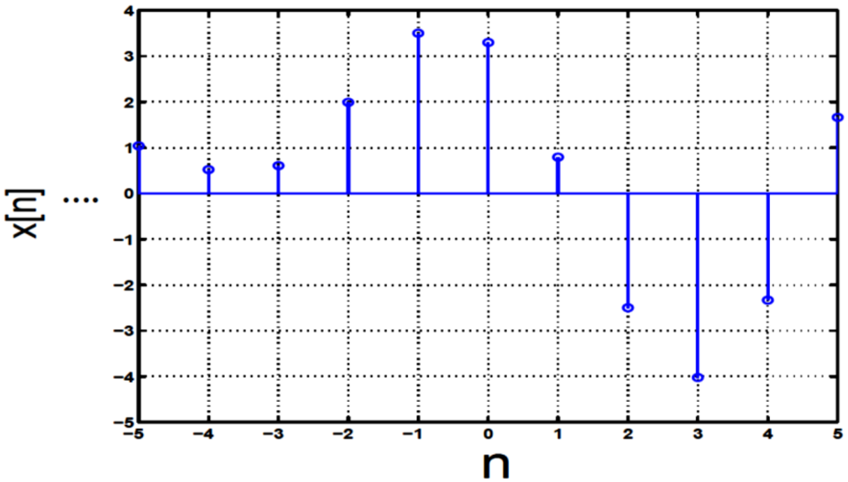


Example of *digital signal*

Discrete-Time (DT) Signals and Digital Signals

Discrete-time signal is a sequence that assumes real (or complex) values:

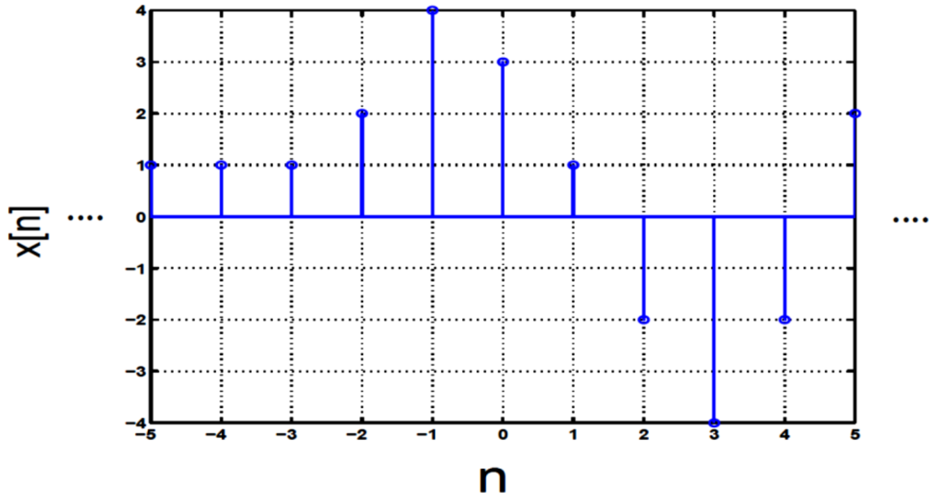
Discrete-time, Continuous-amplitude signal



Example of *discrete-time signal*

Digital signal is a sequence that assumes discrete values

Discrete-time, Discrete-amplitude signal



Example of *digital signal*

In practice the terms "discrete-time" and "digital" are loosely used, without making a distinction