# WELCOME

TO

# SYSC 4405: Introduction to Digital Signal Processing

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# Why use DSP?
## Example: Digital Data



What happens if you make a copy of a copy ... of a copy of a VCR tape (analog)?


Noise added at each copy ?

What happens if you make a copy of a copy ... of a copy of a CD (digital)?

Perfect duplicate possible ?

How about *analog radio* versus *digital radio*?

| | |
|---|---|
| Analog | - always have signal but may have static |
| Digital | - either perfect signal or completely wrong signal |

# Why use DSP?

## Example: DSL



Traditional phone lines designed to use frequencies from 0 Hz-4000 Hz.

Though not "crystal clear", extra signal capacity is available past 4000 Hz if **equalization modem** used.


**Analog Solution** (not used):

Design a *custom* modem for every line with performance degrading as conditions change.

**DSP Solution** (DSL - Digital Subscriber Line):

Allow *generic* modem to test line and setup adaptive equalization when powered on.

# Why use DSP?

## Analog/Digital Comparison



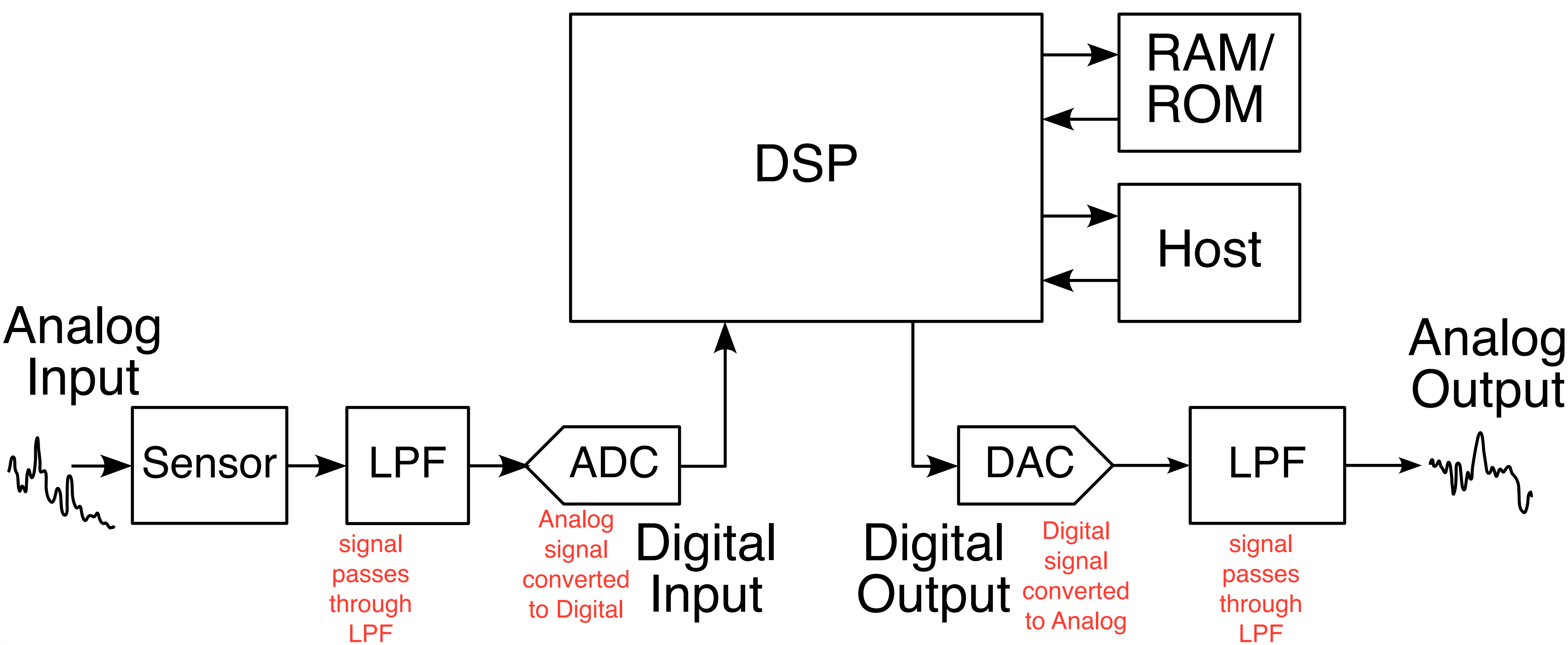
| Parameter | Analog Signal Processing | Digital Signal Processing |
|---|---|---|
| Component Tolerances | 1-10% | Accurate to # of bits used |
| Sensitivities "Drift" | Time & Temperature | None |
| Noise Floor | 60 dB Typical | 90+ dB |
| Adaptability | Hard, Expensive | Easy, Low Cost |
| Volume Manufacturing | Hand Tuning | Auto Tuning |
| Redesign | New Hardware Board | New Code (Software) |
| Layout | Noise Sensitive | Noise Immune |
| Advanced Functions | Hardware Intensive | Additional Software |
| Multi-Functions | Multiple Hardware | More MIPS & Software |
| Power and Size | Larger | Smaller |
| Reliability | Lower | Higher |

# DSP

## Typical System

- **Why use DSP?**
  - Ex: Digital Data
  - Ex: DSL
  - Analog vs. Digital

LPF - Low pass filter
ADC - Analog-to-digital converter
DAC - Digital-to-analog converter



# DSP
## Definitions



### Digital Signal Processing:

Processing of real-world signals (represented by a sequence of numbers) using mathematical techniques to perform transformations or to extract information.

### Digital Signal Processor:

A device or system which performs digital signal processing functions.

### Analog Signals:

Real-world signals; e.g., light, sound, temperature, pressure.

### Digital Signals:

Numerical representation of analog signals.

### Real-Time DSP:

Processing keeps pace with the input and output signals.

### Non-Real-Time DSP:

Processing is performed off-line; i.e., data is stored and processed at a later time.

# DSP
# Applications



**Speech/audio:**
- speech recognition
- speech synthesis
- text-to-speech
- digital audio
- equalization
- speaker verification
- stereo/surround sound
- 3D sound generation
  and localization
- audio mixing

**Image processing:**
- pattern recognition
- robotic vision
- image enhancement
- facsimile
- satellite weather map
- animation

**Military/Commercial:**
- secure communication
- radar processing
- sonar processing
- beamforming
- air traffic control
- missile guidance

**Telecommuncation:**
- echo cancellation
- adaptive equalization
- spread spectrum
- video conferencing
- data communication

**Instrumentation/control:**
- spectrum analysis
- position and rate control
- noise reduction
- data compression

**Biomedical:**
- patient monitoring
- computed tomography (CT)
- EEG brain mappers
- ECG analysis
- X-ray storage/enhancement

**Consumer applications:**
- digital, cellular mobile phones
- digital television
- digital cameras
- digital radio, software radio
- Internet phones, music
- digital answer machines
- interactive entertainment
- active suspension in cars



* derived from Ifeachor & Jervis, *Digital Signal Processing*

# DSP Systems
## Analog vs Digital

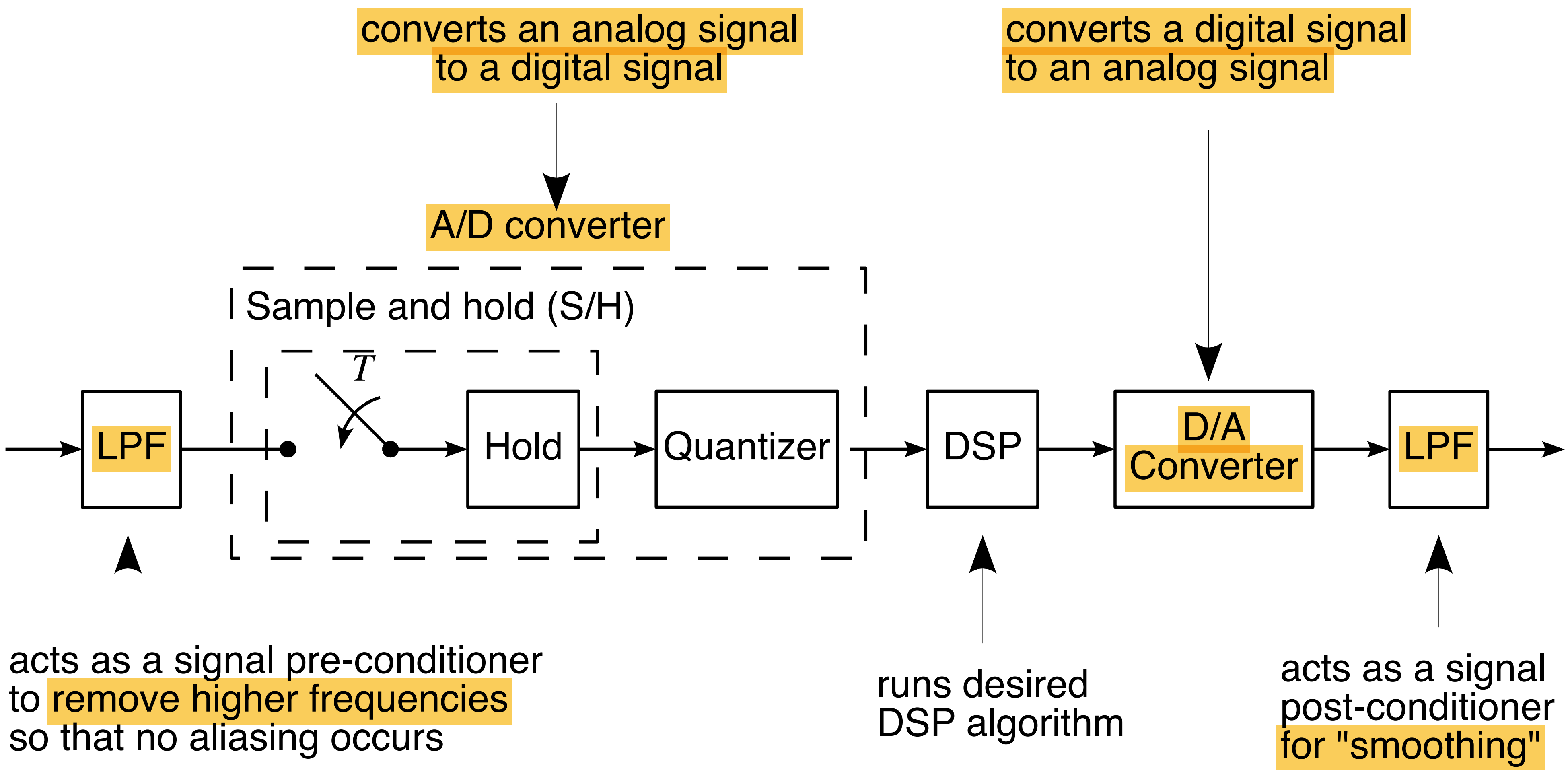


| | Continuous | Discrete |
|---|---|---|
| Signal type | Analog | Digital |
| Time-domain representation | Differential equations | Difference equations |
| Transform domain | Laplace transform for system design, transient response analysis | Z-transform to study system properties, transient responses and system design |
| | Fourier transform for analysis in the steady state | DFT/FFT: analysis in the steady state |
| Basic building blocks | integrator, differentiator, analog multiplier, adder, sign inverter | unit delay, multiplier, adder, sign inverter |
| Applications | | Digital filters (FIR and IIR), design and implementation<br>Spectral analysis based on the DFT and FFT |

# DSP Systems
## Typical DSP System

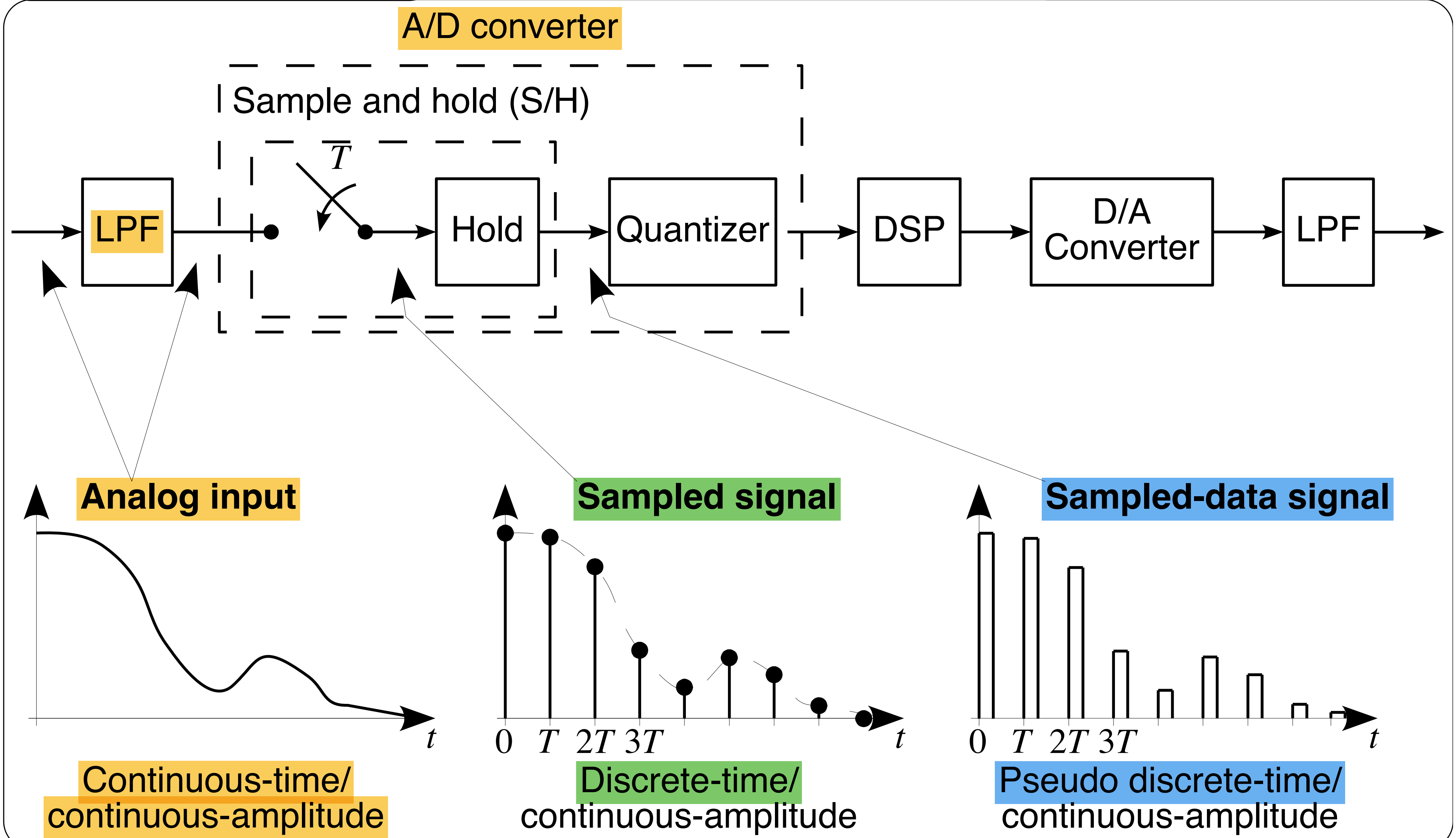


Illustrated below is a signal flow graph for a typical DSP system.



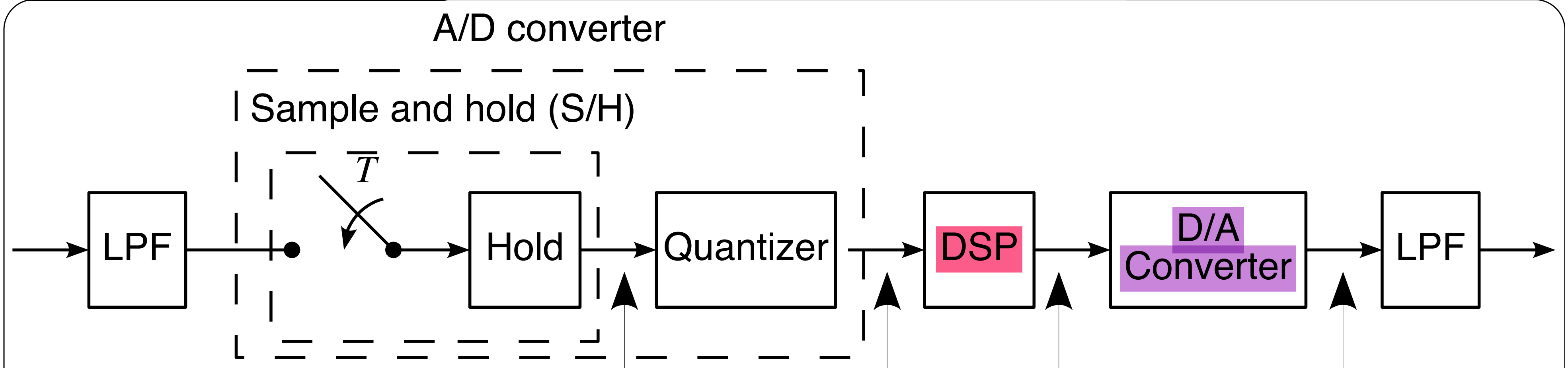
# DSP Systems
## Life of a Signal (1)

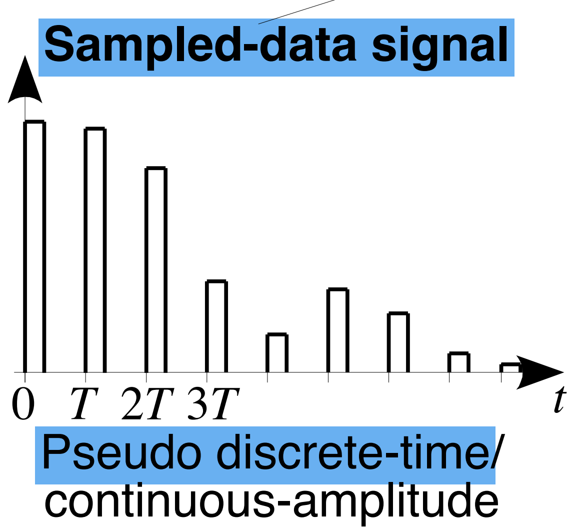


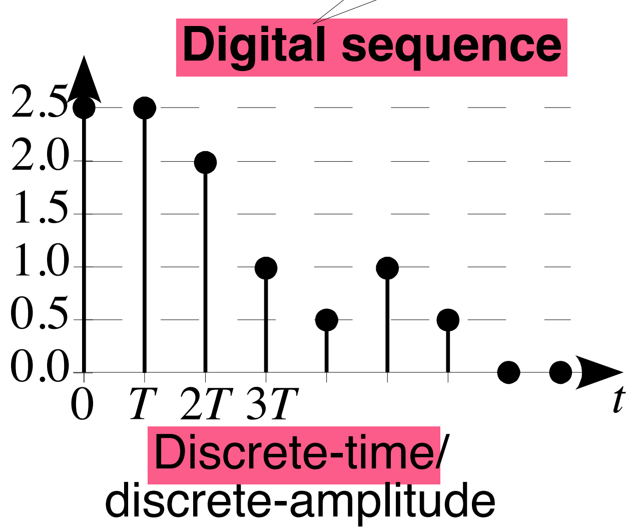


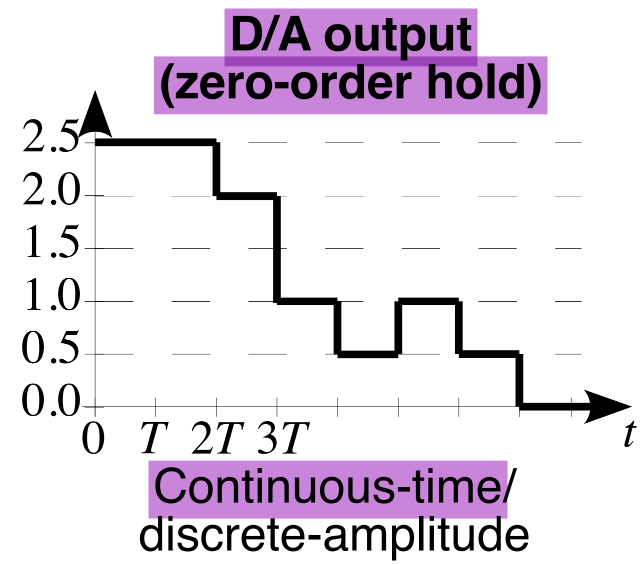
# DSP Systems
## Life of a Signal (2)





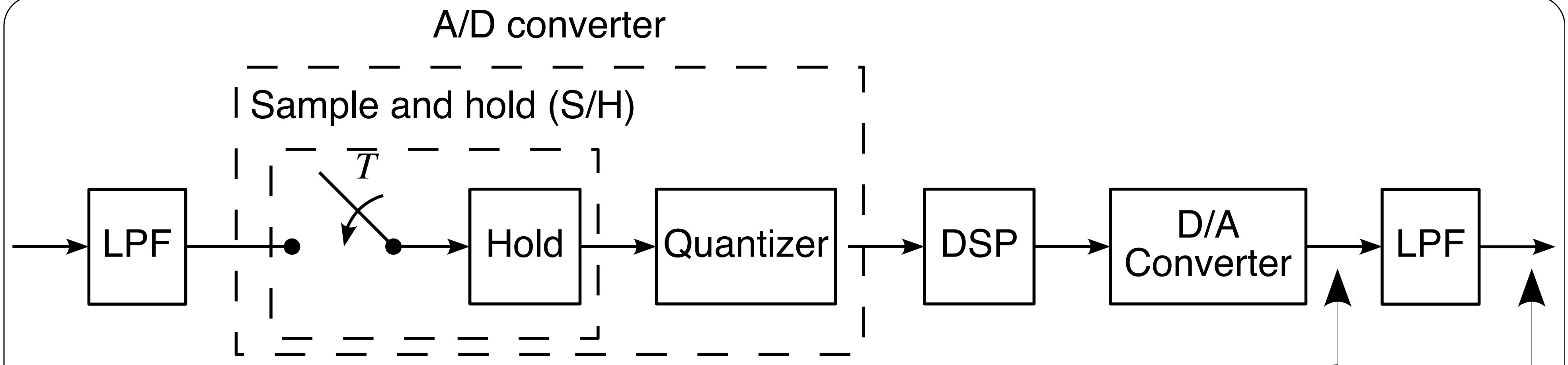



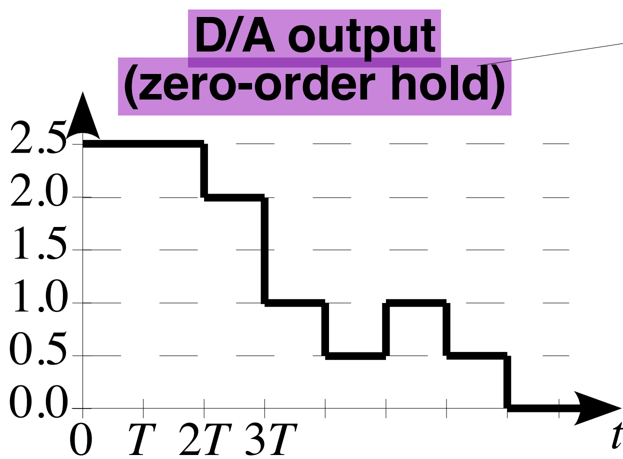
Introduction to DSP
Slide 1.12

Introduction

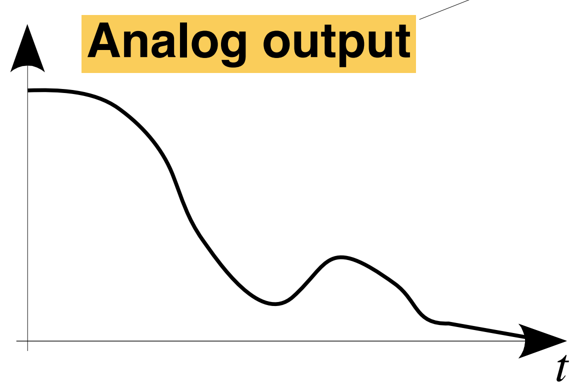
# DSP Systems
## Life of a Signal (3)

- **DSP Systems**
  - Analog vs Digital
  - Typical DSP System
  - Life of a Signal




Continuous-time/
discrete-amplitude




Continuous-time/
continuous-amplitude

# Main Concepts
## Topics Covered



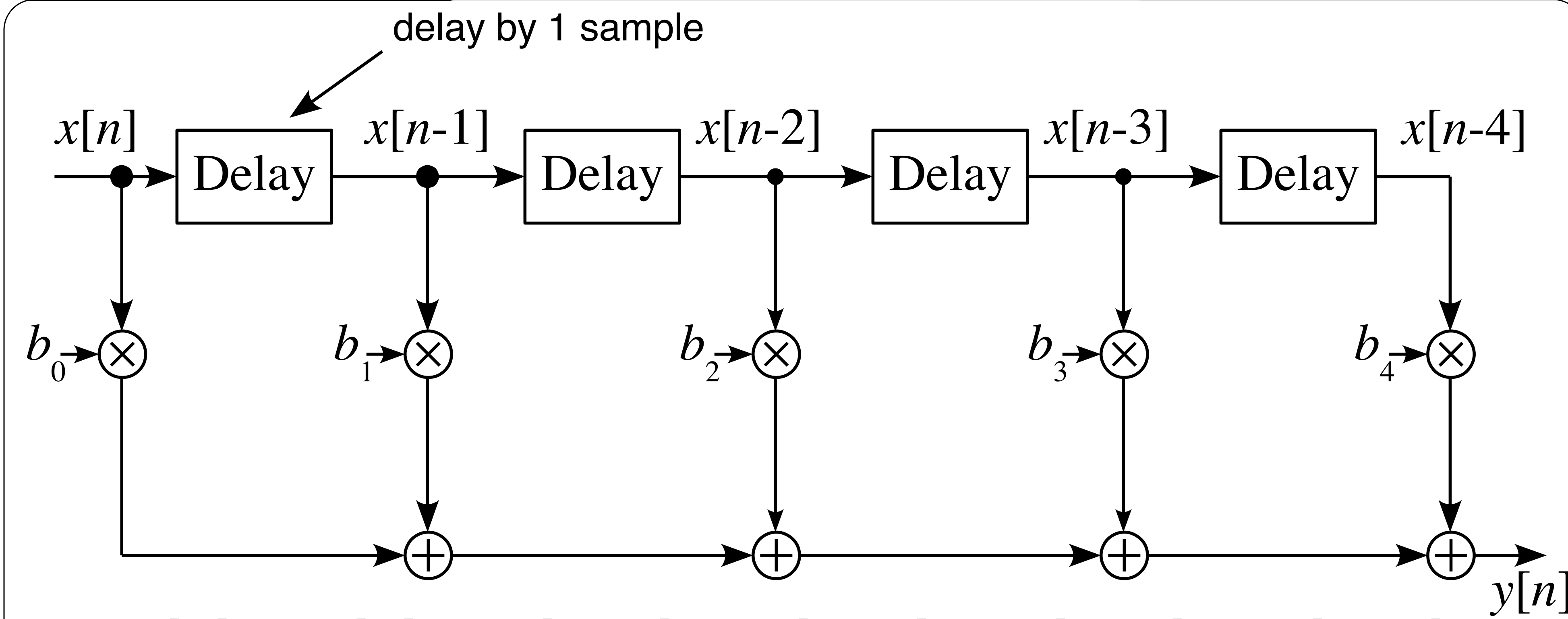
Some of the main topics to be covered in this course are

| | |
|---|---|
| **Signal Representation:** | Unit impulse and unit step functions |
| | Sampling, Shannon's sampling theorem, Nyquist rate |
| | Difference equations, transfer functions |
| **Transforms:** | $z$-Transform (ZT) |
| | Discrete-time Fourier Transform (DTFT) |
| | Discrete FT (DFT) and Fast FT (FFT) |
| **Filtering:** | Convolution |
| | Impulse response |
| | Frequency response |
| **Filter Types:** | FIR (Finite Impulse Response) filters |
| | IIR (Infinite Impulse Response) filters |
| | Introduction to design approaches for FIR and IIR filters |

# Main Concepts

## FIR Filters






$$y[n] = b_0 x[n] + b_1 x[n-1] + b_2 x[n-2] + b_3 x[n-3] + b_4 x[n-4]$$

$$= \sum_{k=0}^{4} b_k x[n-k]$$

Difference Equation for above FIR filter

A main goal of this course is in how to choose values for $b_k$.

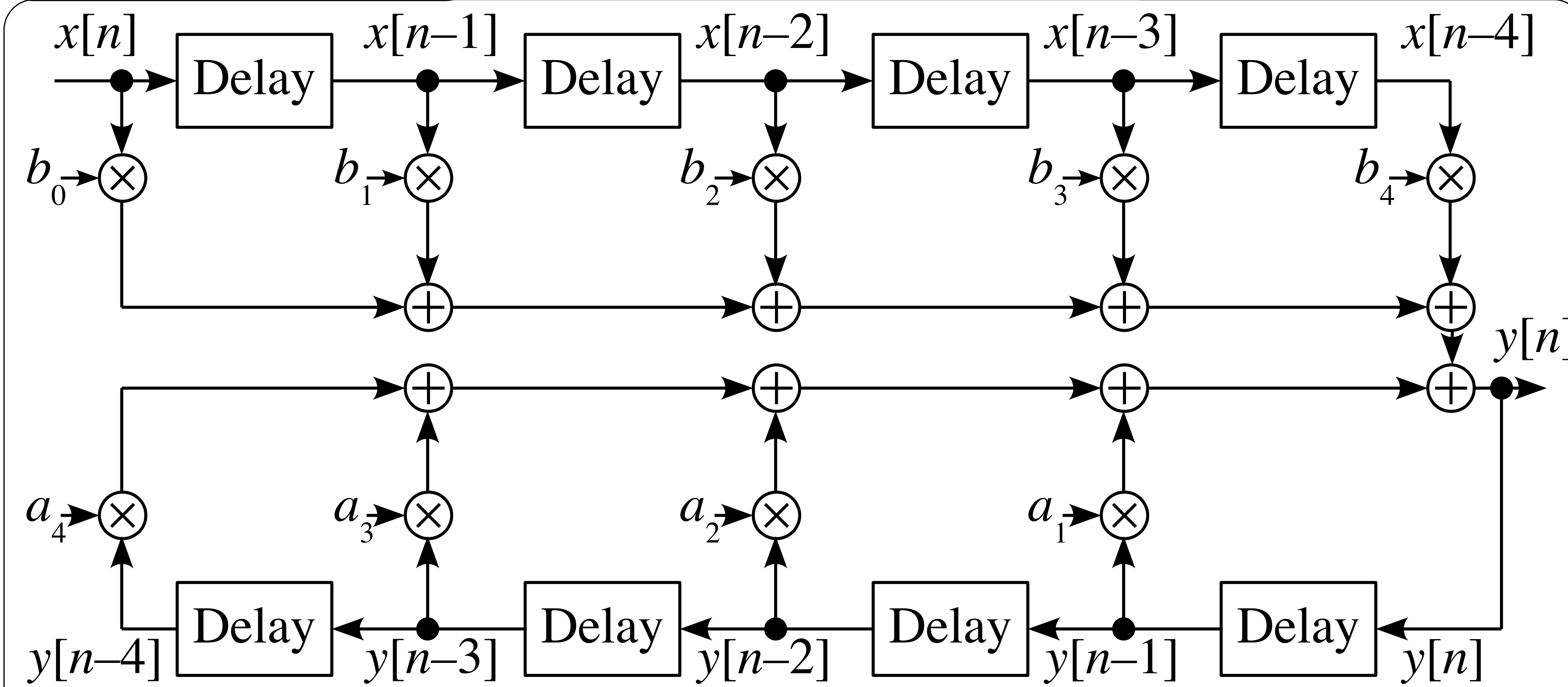
Introduction to DSP
Slide 1.15

Introduction

# Main Concepts

## IIR Filters

- **DSP Systems**
- **Main Concepts**
  - Topics Covered
  - FIR Filters




$$y[n]=\sum_{k=1}^{4} a_k\, y[n-k]+\sum_{k=0}^{4} b_k\, x[n-k]$$

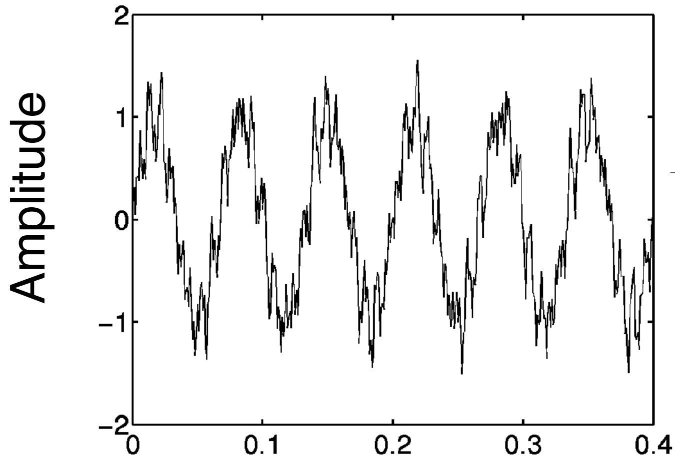
Difference Equation for IIR Filter

A main goal of this course is in how to choose values for $b_k$ and $a_k$.

# Main Concepts
## Designing Filters

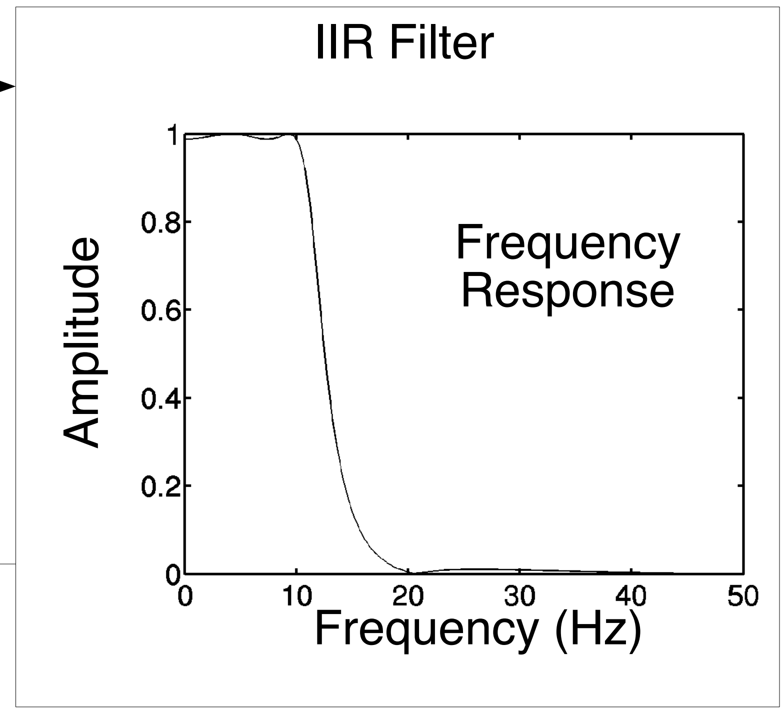


For example, the IIR filter with values for $a_k$ and $b_k$ given below allow us to smooth the following input signal sampled at 1 kHz.



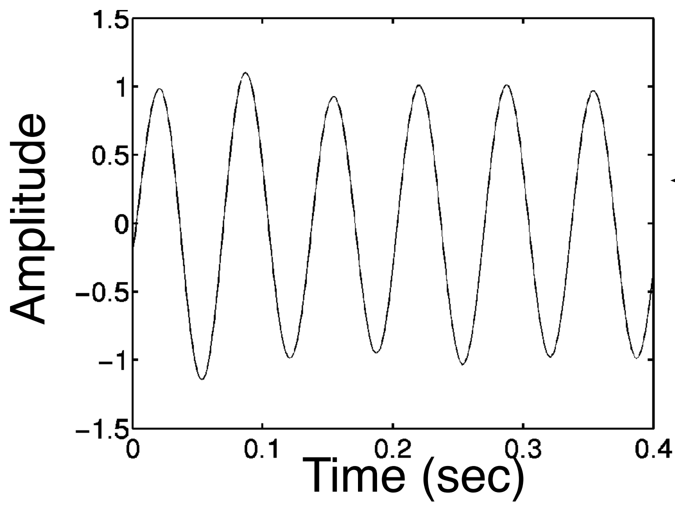

Time-domain input

$x[n]$




Time-domain output

$y[n]$




$a_1 = 3.8847109,\ a_2 = 5.6646193,\ a_3 = 3.6745952,\ a_4 = \text{-}0.894701$

$b_0 = b_4 = 0.0097003,\ b_1 = b_3 = \text{-}0.0378013,\ b_2 = 0.0562160$