Digital Signal Processing with a focus on Audio

Course Introduction

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Motivation

- Signals are everywhere: **sound**, images, communications, sensors
- DSP provides tools to **analyze**, **modify**, and **extract information** from signals
- Audio will be our main example — **not a limitation, but a gateway**

What is Digital Signal Processing?

Digital Signal Processing (DSP) is the study of:

- signals represented in **discrete time**
- systems (algorithms) that operate on these signals
- analysis, filtering, and transformation methods

Core questions:

- How do we represent real-world signals digitally?
- How do we modify them reliably and efficiently?
- How do we extract useful information?

From the real world to digital signals

Typical DSP pipeline:

1. Continuous signal (e.g., sound, radio wave, sensor)
2. **Sampling** → discrete-time signal
3. **Quantization** → digital values
4. **Processing** → filtering, transforms, estimation
5. Output → audio, data, decisions, control

DSP sits at the **interface between the physical world and computation**.

Why DSP matters

DSP skills are directly relevant to:

- **Telecommunications**: mobile networks, radio, wireless links
- **Audio and speech processing**: broadcasting, noise reduction
- Robust processing in **low-bandwidth** and **noisy** environments
- Media technologies (including **community radio**)

These are **practical needs** — not just abstract theory.

Why DSP matters

DSP is also relevant to:

- audio software, embedded systems, and real-time processing
- a foundation for **speech/audio machine learning**
- also used in biomedical signals, radar, IoT and sensing

With DSP + programming (e.g., Python / MATLAB / C):

- remote work opportunities
- access to global tech ecosystems
- strong preparation for postgraduate studies

Why audio as a starting point?

Audio is:

- **intuitive** (you can hear the result)
- easy to experiment with (laptop is enough)
- rich in real-world problems

But the same DSP tools apply to:

- images communications biomedical signals sensor data

Learn once, apply everywhere.

Course structure: overview

The course progresses from **foundations** to **advanced applications**:

1. Signal representation (sampling, quantization)
2. Frequency-domain analysis (DTFT, DFT)
3. Efficient computation and convolution via DFT
4. Filtering and FIR design
5. Adaptive filtering and spatial (array) processing

Each topic builds directly on the previous one.

Course schedule (part 1)

February 16

- Sampling and quantization
- Discrete-time systems
- Discrete-Time Fourier Transform (DTFT)

February 17

- Discrete-time systems (continued)
- DTFT (continued)
- Discrete Fourier Transform (DFT)

Course schedule (part 2)

February 18

- Convolution via the DFT
- FIR filter design

February 19

- Adaptive filtering

February 20

- Microphone array processing

Structure of each class

Each class consists of three parts:

1. **Theory**
   - concepts, equations, intuition
2. **Practical analysis**
   - guided exploration of a **Jupyter notebook**
   - visual and audio-based demonstrations
3. **Short quiz**
   - assesses learning throughput
   - used for continuous evaluation

The material of the classes (theory and notebooks) is contained in the GitHub repository:
`https://github.com/fabioantonacci79/BasicDSP`

Why this structure?

This structure is designed to:

- connect math to real signals
- encourage active learning through experimentation
- verify understanding immediately
- reduce memorization, increase intuition

DSP is learned by **seeing, hearing, and experimenting** — not only by writing equations.

What students will gain

By the end of the course, students will be able to:

- represent and process digital signals confidently
- analyze signals in time and frequency
- use DTFT/DFT to interpret and compute signal properties
- design and apply FIR filters
- understand adaptive filtering principles (e.g., LMS/NLMS)
- understand fundamentals of microphone array processing
- read and modify DSP code (notebooks) with confidence

Final takeaway

DSP is:

- a **core engineering skill**
- locally relevant and globally valuable
- foundational for audio, communications, AI, and sensing

This course provides the **tools, intuition, and practice** needed to use DSP in real systems.