

BCC Pilot Program: Intro to Signals and Systems Topic Map

Week 1: Signals

1.1 Signals as data

- What a signal is: audio, images, sensor readings, stock prices (added)
- Continuous vs. discrete-time signals (Dis 1A Q1)
- Sampling: turning a continuous signal into samples (added)
- A discrete signal as a vector: a list of numbers indexed by n (Dis 1A Q2)
- Special signals (Step, Ramp, Rectangular, Impulse) and their plots (Dis 1A Q1)

1.2 Operating on signals

- Adding two signals point by point (Dis 1A Q2)
- Scaling a signal by a constant (Dis 1A Q2)
- Shifting a signal in time: $x[n - k]$ as a delay (N7 7.1)
- Worked example: combining a ramp and a pulse (Dis 1A Q2)
- Demo: record, plot, and play back a voice (Lab: Python Bootcamp)

Week 2: Similarity

2.1 Measuring similarity

- Dot product: multiply matching entries, then add (Dis 1A Q3)
- Hand example with 3-entry vectors (added)
- Length (norm) as the square root of a vector's dot product with itself (Dis 1A Q3)
- Normalizing: dividing by length so scores compare fairly (Dis 1B Q2)
- Bounded similarity: a normalized score is between -1 and 1 (Cauchy-Schwarz, Dis 1B Q2)
- Orthogonality: a dot product of zero means "unrelated" (Dis 2B Q2)

2.2 Matching signals

- Correlation: sliding one signal along another and taking a dot product at each shift (Lab: Shazam, APS)
- Peak of the correlation marks the best match (Lab: APS)
- Hand example: finding a short pattern in an 8-sample signal (added)
- Demo: locating a short clip inside a longer recording (added)

Week 3: Matrices and least squares

3.1 Matrices as machines

- Matrix-vector multiplication as dot products of rows with the input (N4 4.1)
- A matrix as a recipe that turns one list into another (added)

- Systems of equations as $Ax = b$ (N2 Thm. 2.1)
- Hand example: solving a 2-variable system (added)
- Too many equations: why noisy measurements have no exact solution (VMLS 12.1)

3.2 Least squares

- Overdetermined systems: more equations than unknowns (VMLS 12.1)
- The least squares idea: minimize the total squared error (VMLS 12.1)
- Solving with `np.linalg.lstsq` (VMLS 12.3)
- Worked example: estimating a position from noisy time delays (Lab: APS)

Week 4: Data fitting and systems

4.1 Data fitting and validation

- Best-fit line through noisy points (VMLS 13.1.1)
- Fitting curves (polynomials) with the same method (VMLS 13.1.1)
- Regression: predicting one quantity from others (VMLS 13.1.2)
- Validation: splitting data into training and test sets; overfitting (VMLS 13.2)
- Final project introduced (added)

4.2 Systems

- Systems as input $\rightarrow$ output machines (N7 7.1)
- Linearity: scaling and adding inputs scales and adds outputs (N7 7.1)
- Time invariance: a delayed input gives a delayed output (N7 7.1)
- Impulse response: the output for a single spike (N7 7.1.1)
- Why the impulse response describes the whole system (N7 7.1.1)

Week 5: Convolution and sinusoids

5.1 Convolution

- Convolution as a sliding weighted sum (N7 7.2.1)
- Hand example: convolving two short sequences (N7 7.2.1; Dis 11A Q2)
- Moving average (smoothing) (N7 7.2.3)
- Echo (N7 7.2.3)

5.2 Sinusoids

- Sine waves: amplitude, frequency, phase (N3 3.1.1)
- Period and frequency as inverses (N3 3.1.1)
- What makes a discrete signal periodic (N3 3.1.1; Dis 2B Q3)
- Hearing frequency: pitch of a tone (added)
- Sine in, sine out: a system keeps the frequency and changes only the size and timing (N7 7.3.1)

Week 6: Frequency

6.1 Frequency decomposition

- Any repeating signal is a sum of sines (N3 3.1.6)
- Measuring how much of each frequency a signal contains by taking dot products (N3 3.1.6)
- Orthogonality is why each frequency can be measured separately (N3 3.1.4)
- Reading a frequency plot: frequency interpretation (N3 3.1.7)
- FFT as a tool: `np.fft.fft` (N3 3.1.8)

6.2 Spectrograms

- Frequency content over time (Lab: Shazam)
- Visualizing speech and music (added)

Week 7: Filters and applications

7.1 Frequency response and filters

- Frequency response: how much a system scales each frequency (N7 7.3.1–7.3.2)
- Low-pass (smoothing) and high-pass filters (N7 7.3.2; Dis 11A Q1)
- Filtering as editing the frequency plot (N7 7.3)
- Demo: bass boost filter (added)
- Aside: does an echo fade out or grow forever? (stability, Dis 12B Q1)

7.2 Audio fingerprinting

- Spectrogram peaks as a song's fingerprint (Lab: Shazam)
- Demo: Shazam-style song matching (Lab: Shazam)

Week 8: Flex and wrap-up

8.1 Flex session

- Review and catch-up, based on the class's pace (added)
- Optional intuition: PageRank as repeated multiplication (N4 4.6)
- Optional intuition: PCA as the main directions of variation in data (N6)

8.2 Project showcase and next steps

- Final project presentations (added)
- Recap: signals, similarity, fitting, systems, frequency (added)
- Where this leads: linear algebra (Math 54), EECS 16A/16B, EE 120 (added)