Information Engineering

Options Talk

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Information Engineering Distinguished Lecture Series

2019
Lent/Easter

This Lecture Series invites world-leading scientists to introduce today's high-impact research areas. Everyone is welcome!

Daniela Rus (MIT)
Unleashing your inner maker
Monday February 18, 2019, 12.00 – 13.00, Room: LT2

David Silver (Google DeepMind)
TBA
Monday March 4, 2019, 11.00 – 12.00, Room: LT2

Naomi Leonard (Princeton University)
Symmetry, bifurcation, and multi-agent decision-making
Friday April 26, 2019, 16.00 – 17.00, Room: TBA

Andrea Goldsmith (Stanford University)
Can machine learning trump theory in communication system design?
Friday May 10, 2019, 12.00 – 13.00, Room: TBA
IIA Information Engineering broadly covers:

- Control
- Signal Processing
- Information Theory
- Communications
- Inference & Machine Learning
Control
The inerter mechanical device in Formula One racing
Control in biomedical engineering  

In the smart grid
We get the system to behave in a desired way by:

Control modules discuss how to address various challenges within this framework.
• Everything is implemented digitally!
  Discrete time systems, z-transforms, Fast Fourier Transform and Digital Filters (3F1)

• Not all important variables can be measured
  State estimation, State observers (3F2)

• Random variations occur
  Random processes (3F1), Kalman filters (3F2)

• Optimal operation is desirable
  Feedback system design, optimization in control (3F2, 4F3)

• Fundamental limitations, robust and nonlinear control (4F1, 4F2)
Modern applications of Control Engineering include:

- Control and dynamics in F1 (McLaren)
- Optimization and control in power systems and smart grids
- Motor control of bio-inspired robots (4M20 Robotics)
- Aircraft design: stability and control
- Feedback and regulation in neuroscience.
3F1 Signals and Systems

- Discrete-time signals and systems
- Digital Filters and Fast Fourier Transform
- Continuous-time Random Processes

3F1 is a key module for control, signal processing, and communications

3F2 Systems and Control

- State-space models
- Feedback System Design
- State Estimation
- Control in a state-space framework
Signal Processing
Example: Image Denoising

Noisy image

Denoised image

Image credit: A. Montanari (Stanford)
Optimal detection of signal buried in noise — Matched Filter 3F3 (Applications in Radar, Communications, . . .)
3F3 Statistical Signal Processing:

- Modelling and Analysis of random, or ‘noise-like’, signals and systems
- Effects of noise and randomness in digitised signals
- Module starts with advanced treatment of probability fundamentals
- This leads into the new topic of random processes: *how to characterise random signals through autocorrelation functions, power spectrum* . . .
- The second 8 lectures discuss *signal detection, estimation, and inference* using Wiener filters, matched filters, likelihood and Bayesian modelling

This module is fundamental to Communications, Speech & Image Processing, Machine Learning, (Big) Data Analysis, Computer Vision
3F3 Statistical Signal Processing:

- Runs alongside 3F1 (co-requisite) and leads into 3F8 (Inference) in Lent
- Also supports 3F4 (Data Transmission) and 3F7 (Information Theory)

3F1 Signals and Systems:

- Discrete-time signals and systems
- Digital Filters and Fast Fourier Transform
- Continuous-time Random Processes

3F1 + 3F3

Essential signal processing theory & techniques that are used in: speech/audio/video compression, wireless communication, echo cancellation, . . .
Gravitational Wave Detection by LIGO

Analysis of LIGO data used classic signal processing techniques in 3F1 and 3F3 (FFTs, Power Spectral Density, Matched Filtering)

https://losc.ligo.org/s/events/GW150914/GW150914_tutorial.html
Information Theory and Communications
Information Theory

Claude Shannon, in 1948, showed how to quantify information using probability.

Answered two fundamental questions:

- Given a source of data, how much can you compress it?
- Given a noisy communication channel, what is the maximum rate at which you can reliably transmit data?
Data Compression and Error Correction

Compression

Data is compressed by squeezing out redundancy from data:

Th_ onl_ wa_ to ge_ ri_ of a tempta___ is to yie__ to it

PPM compression achieves 1.5 bits per character of English text

Error Correction

Encode information by adding redundancy in a controlled way, so that it can be decoded from the noisy output at the receiver
An Point-to-Point Communication System

Data Compression

Data Transmission
3F7 Information Theory and Coding:

- How to quantify information — using Entropy, a measure of uncertainty
- What is the fundamental limit of data compression?
- The fundamental limit of reliable data transmission?

3F7 also covers practical techniques to attain optimal limits:

- Practical Data Compression algorithms (Huffman coding, Arithmetic Coding)
- State-of-the-art techniques for Error Correction (Linear Codes, Sparse Graph codes)
How do we transmit the bits across a real physical channel?

3F4 deals with:

- How to design good input waveforms tailored to the channel?
- How to detect the bits from the output waveform?
Starting in the early 1800s, inventors tried several systems for sending electric signals down wires.

I run 26 wires, one for each letter, into a tub of water...when bubbles appear on the first wire, it's an "A", etc., etc....

VOT ABOUT UMLAUTS?
Some applications in your pocket

- Orthogonal Frequency Division Multiplexing: modulation technique used in 4G (3F4)
- Transform coding and MP3 compression: digital filters, FFTs, entropy coding (3F1, 3F7)

Dealing with mobility & channel uncertainty in wireless networks
(frequency diversity & antenna diversity 3F4, 4F5)
Inference & Machine Learning
3F8 Inference

- Non-linear regression
- Classification
- Clustering
- Dimensionality reduction
- Sequence models

Techniques:
- Optimisation
- Monte Carlo
- Bayesian methods
Dimensionality Reduction

images embedded in 2D

dimension 2

dimension 1
3F8 Inference

- Non-linear regression
- Classification
- Clustering
- Dimensionality reduction
- Sequence models

Techniques:
- Optimisation
- Monte Carlo
- Bayesian methods

sequences of characters

私はでそれを信じて
predict the next character?

Thomas Bayes
represent uncertainty using probability distributions
Algorithms that use input data to build models and make predictions or decisions

Search engines, spam filtering, computer vision, learn to play games (Go) . . .

Image Segmentation using convolutional neural nets
Third-year Modules:

3F1 (M) Signals and Systems (no pre-req)
3F3 (M) Statistical Signal Processing (3F1 is a co-requisite)
3F7 (M) Information Theory and Coding (no pre-req)
3F2 (L) Systems and Control (no pre-req)
3F4 (L) Data Transmission (3F1 is a pre-req)
3F8 (L) Inference (3F3 is a pre-requisite)
Fourth Year Modules
Fourth Year Modules

4F1 Control System Design
4F2 Robust and Nonlinear Systems and Control
4F3 An Optimisation Based Approach to Control
4F5 Advanced Information Theory and Coding
4F7 Statistical Signal Analysis
4F8 Image Processing and Image Coding
4F10 Deep learning and Structured Data
4F12 Computer Vision
4F13 Probabilistic Machine Learning
4F14 Computer Systems
4M17 Practical Optimization
4M20 Robotics
Part IIA Information Engineering

- Control (3F1, 3F2)
- Signal Processing (3F1, 3F3)
- Information Theory (3F7)
- Communications (3F7, 3F4)
- Inference & Machine Learning (3F3, 3F8)

These slides will be available (for a couple of weeks) at:

https://sites.google.com/site/fulvioforni/seminars-lectures

Or email me (ff286)