Information Engineering

Options Talk

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20 February 2018

UNIVERSITY OF CAMBRIDGE

Department of Engineering

2018| Lent

Information Engineering Distinguished Lecture Series

Stephan Boyd (Stanford University)

Convex Optimization

Friday January 26, 2018, 12.00 – 13.00, Room: LT2

Paul Newman (University of Oxford)

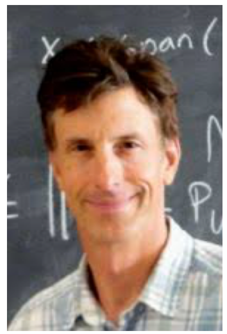
Intelligent Self-Driving Vehicles

Friday February 23, 2018, 12.00 – 13.00, Room: LT2

Rob Nowak (University of Wisconsin)

Active Machine Learning: From Theory to Practice

Monday March 19, 2018, 12.00 – 13.00, Room: LT2



More Information:

Language/Communication

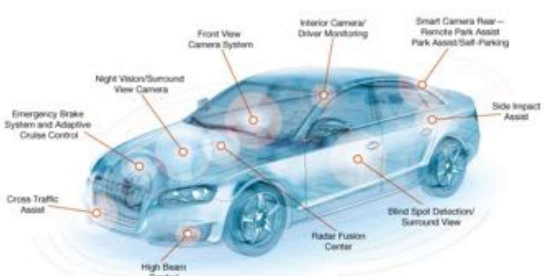
Internet of Things

Bio Informatics

Mobile Devices/Communication

INFORMATION

Business Management



System Integration/Control

Artificial/Machine Intelligence

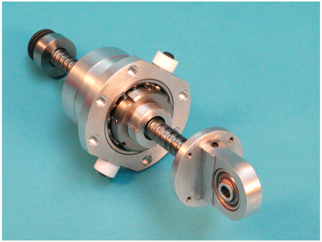
Financial Market

IIA Information Engineering broadly covers:

- Control
- Signal Processing
- Information Theory
- Communications
- Inference & Machine Learning

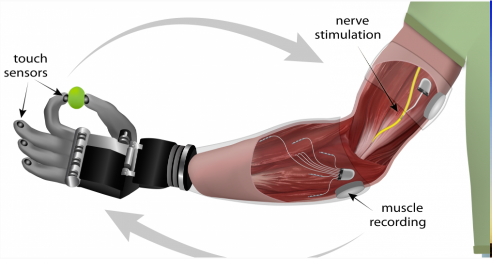
Control

Control



The inerter mechanical device in Formula One racing

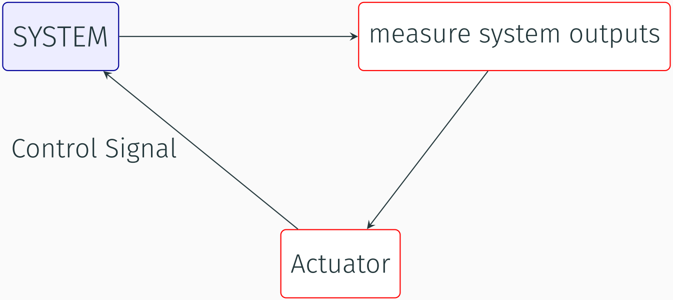
Control



Control in biomedical engineering

In the smart grid

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



Part II control modules discuss how to address various challenges within this framework

Part II Control

- 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, Optimal control (3F2, 4F3)
- Fundamental limitations (4F1), nonlinear control (4F2)

It’s not all hard Maths!

Modern applications of Control Engineering include:

- Control and dynamics in F1 (McLaren)
- Optimization and control in modern power systems and smart grids
- Motor control of bio-inspired musculoskeletal robots (4M20 Robotics)
- Green aircraft design: stability and control
- Reactivity control of small modular reactors with neutron absorber rods

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

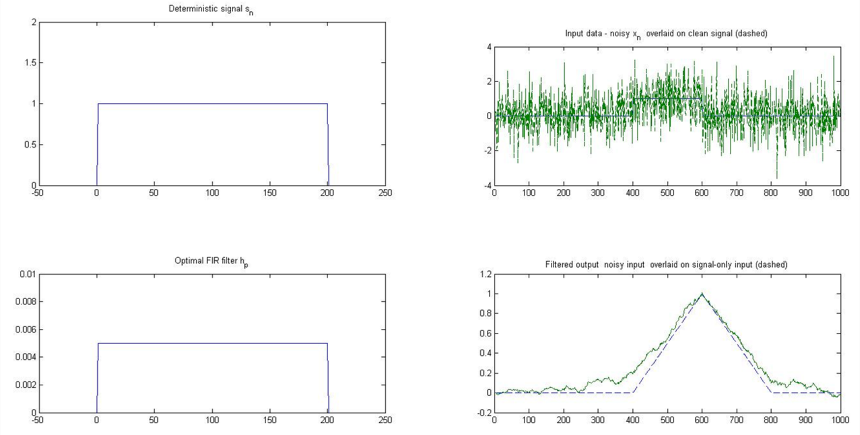
Example: Image Denoising

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, ...

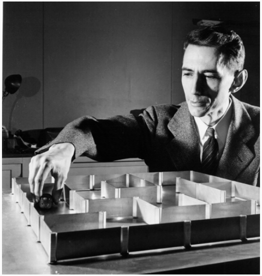
Gravitational Wave Detection by LIGO

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

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 vs Error Correction

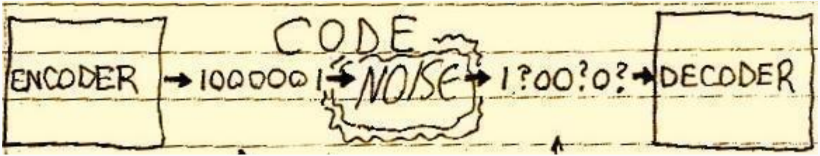
Compression

Data is compressed by squeezing out redundancy from the data, e.g.

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

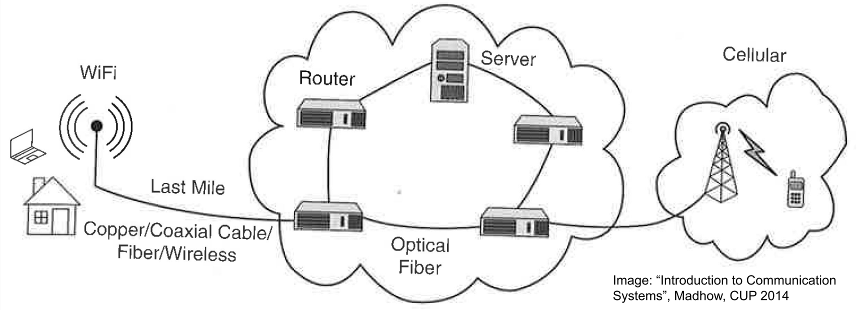
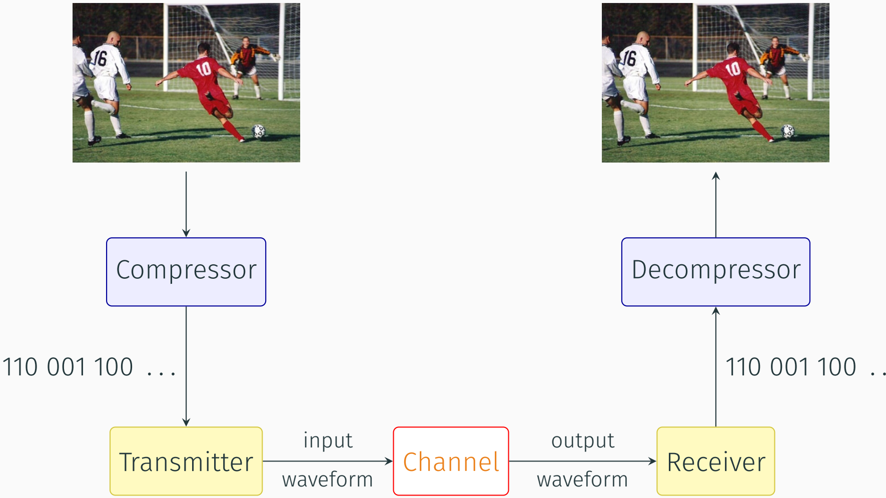
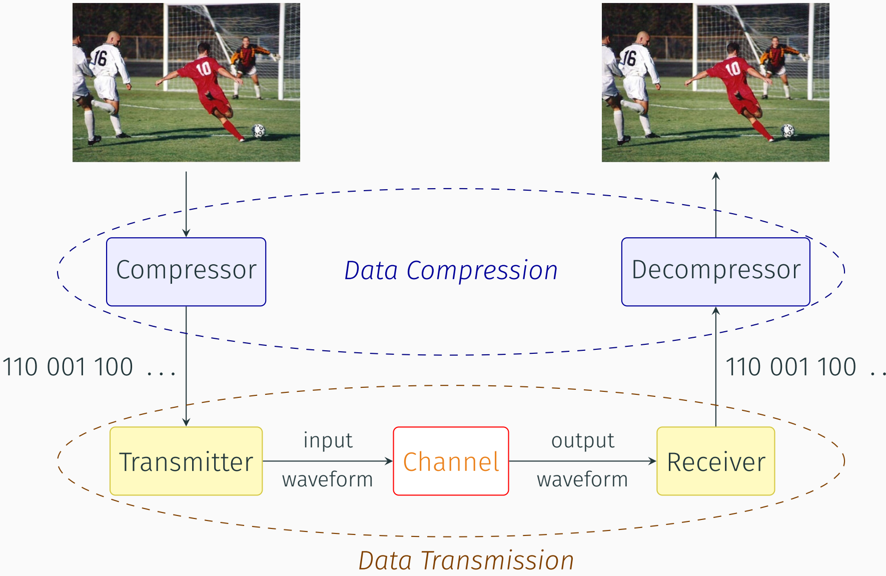


Image: “Introduction to Communication Systems”, Madhow, CUP 2014

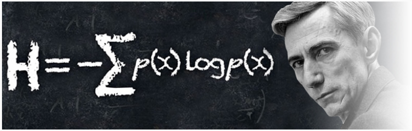
An Point-to-Point Communication System



An Point-to-Point Communication System



3F7 Information Theory and Coding

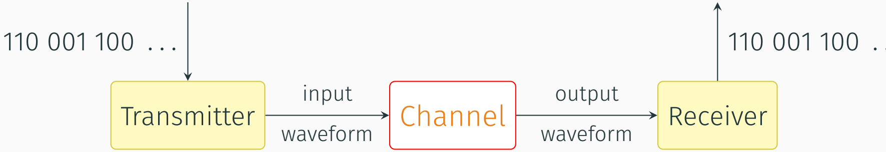


- How to quantify information — using *Entropy*, a measure of uncertainty
- What is the fundamental limit of data compression?
- The fundamental limit of reliable data transmission?

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)

3F4 Data Transmission



How do we transmit the bits across a real physical channel?

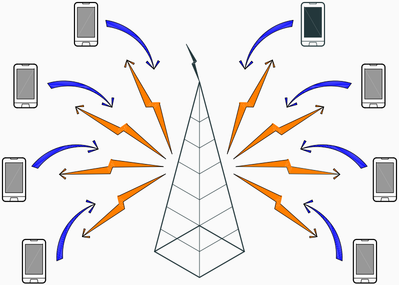
3F4 deals with:

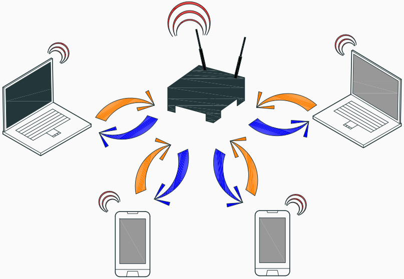
How to design good input waveforms tailored to the channel?

How to detect the bits from the output waveform?

Some applications in your pocket

- Orthogonal Frequency Divison 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)

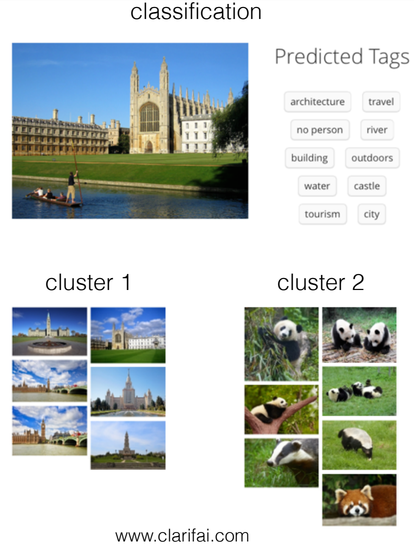
Inference & Machine Learning

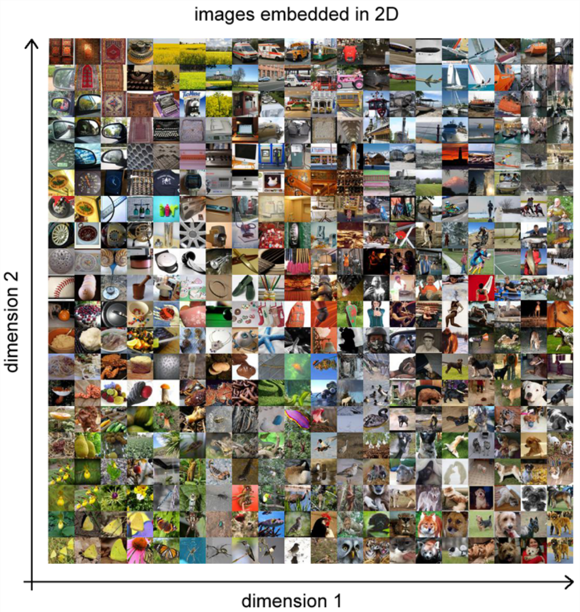
3F8 Inference

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

Techniques:

- Optimisation
- Monte Carlo
- Bayesian methods





Dimensionality Reduction

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

Pre-Requisites and Co-Requisites

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 (3F2 pre-req.)

4F5 Advanced Information Theory and Coding (3F7 pre-req.)

4F7 Statistical Signal Analysis (3F3 pre-req.)

4F8 Image Processing and Image Coding (3F1 pre-req.)

4F10 Deep Learning and Structured Data

4F12 Computer Vision

4F13 Probabilistic Machine Learning

4F14 Computer Systems

4M17 Practical optimization (3M1 pre-req.)

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 at:

`http://mi.eng.cam.ac.uk/Main/FI224`

Or email me (fi224)