Information Engineering

Options Talk

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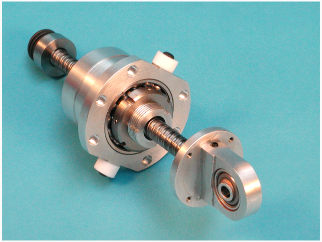
21 February 2017

IIA Information Engineering broadly covers:

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

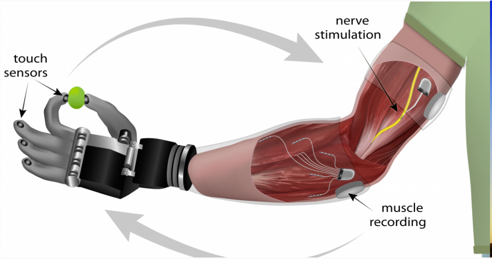
Control

Control



The inerter mechanical device in Formula One racing

Control

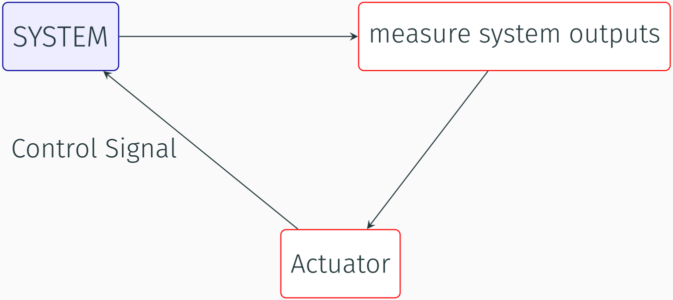


Control in biomedical engineering

In the smart grid

Control Engineering

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



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

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- Everything is implemented digitally!
  Discrete time systems, z-transforms, Fast Fourier Transform and Digital Filters (3F1)

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  Feedback system design, Optimal control (3F2, 4F3)

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  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

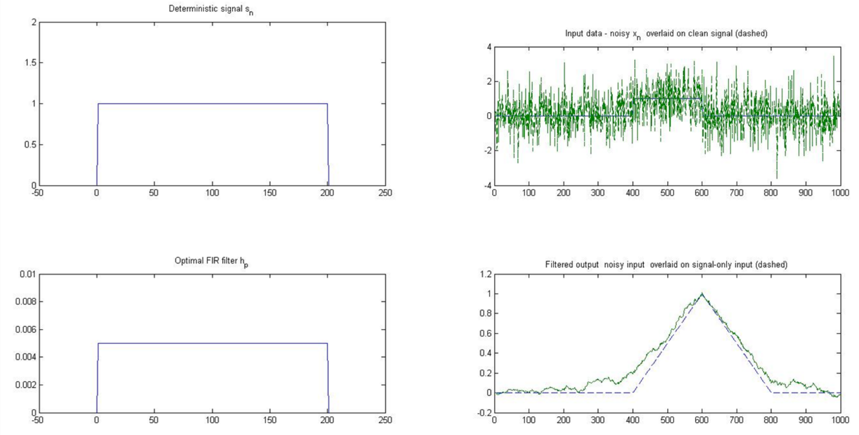
Denoised image

Image credit: A. Montanari (Stanford)

Signal Processing

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
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- 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

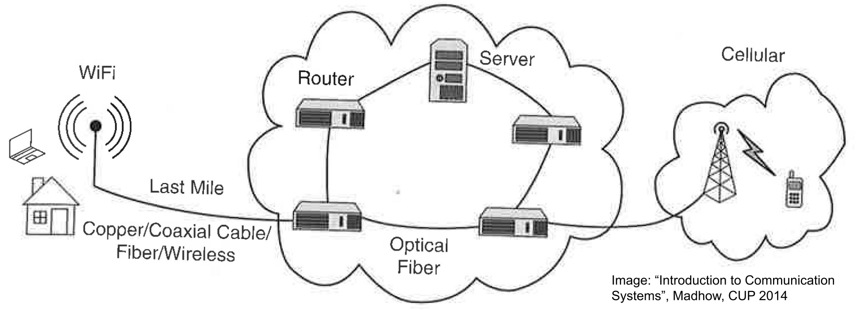

Image: “Introduction to Communication Systems”, Madhow, CUP 2014

An Point-to-Point Communication System

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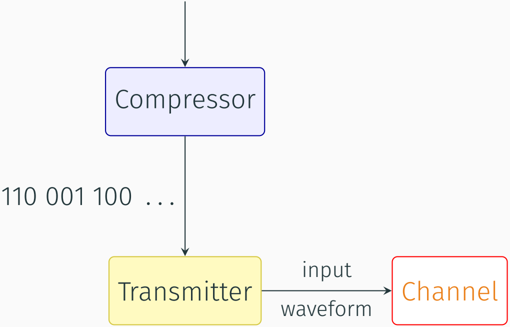

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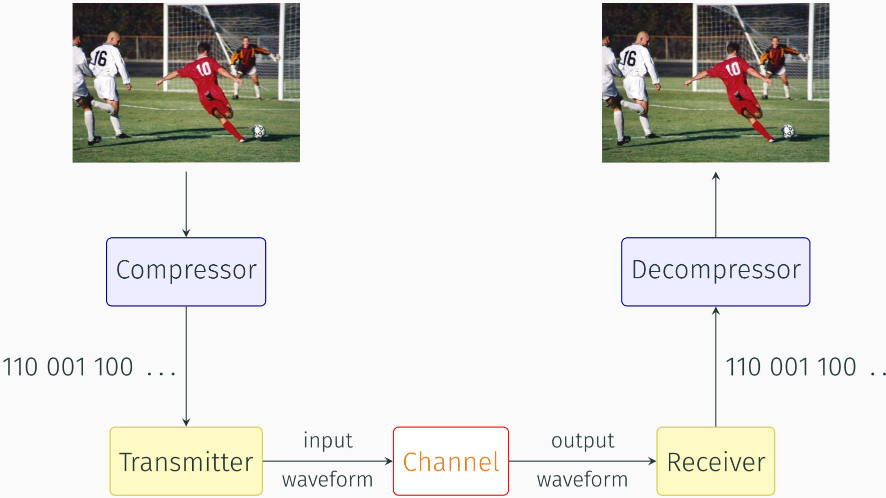

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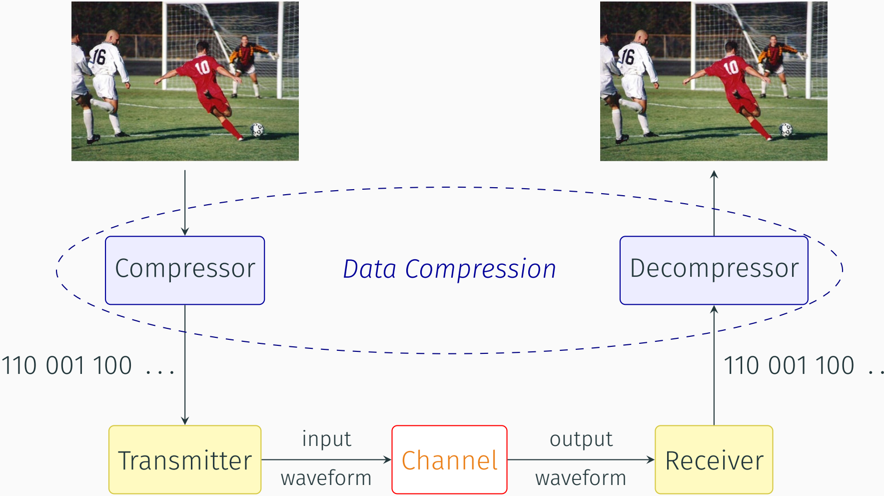

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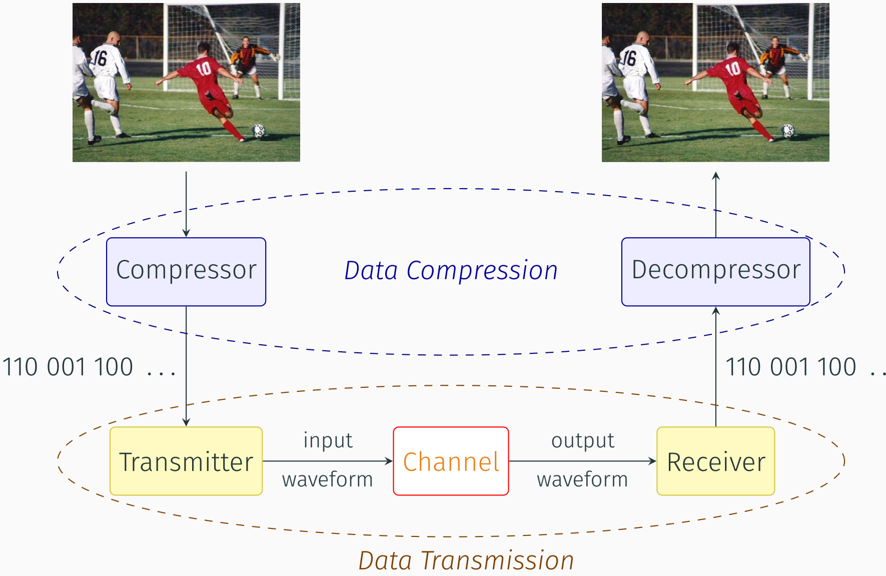
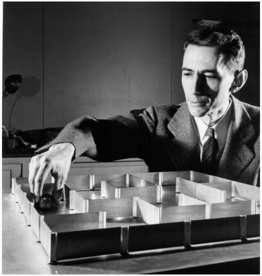


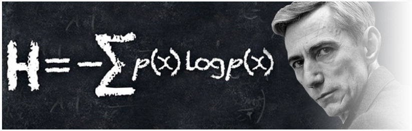
Information Theory



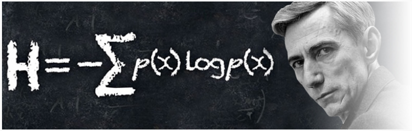
Claude Shannon, in 1948, showed how to quantify information using probability

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?



- 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?



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- 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)

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

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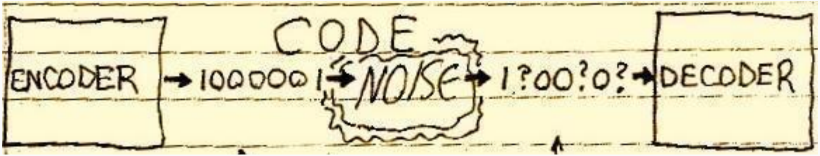
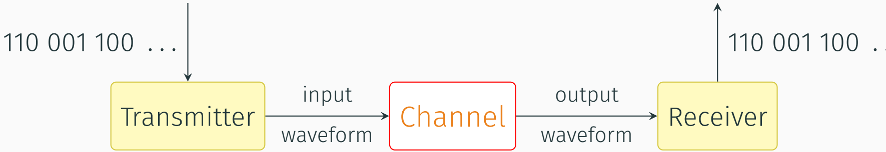
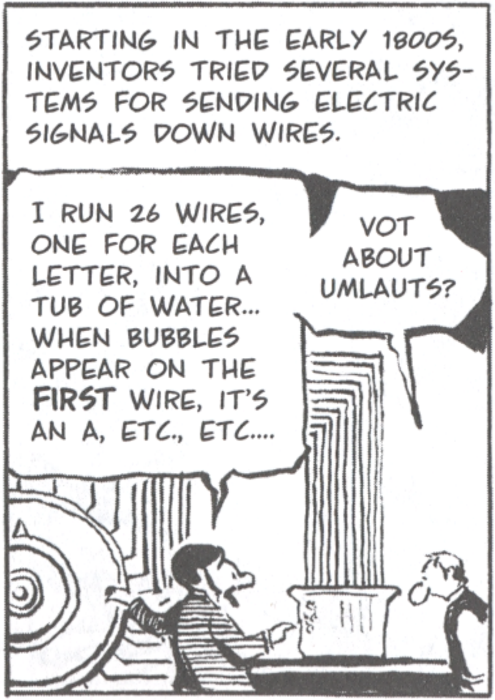
Error Correction

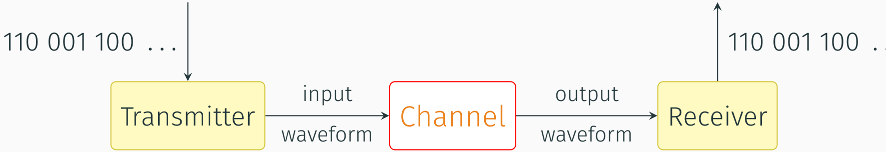


Encode information by adding redundancy in a controlled way, so that it can be *decoded* from the noisy output at the receiver



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


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?



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

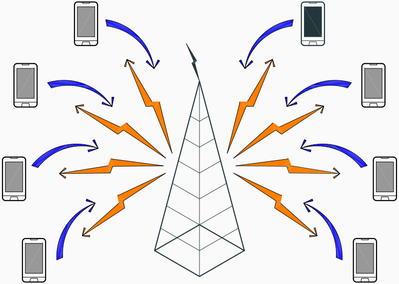
3F4 deals with:

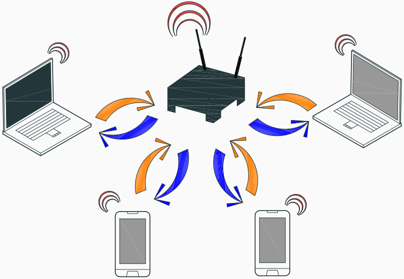
How to design good input waveforms tailored to the channel?

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)





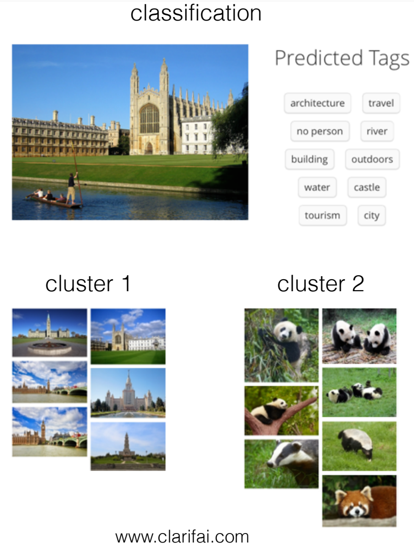
Dealing with mobility & channel uncertainty in wireless networks (frequency diversity & antenna diversity 3F4, 4F5)

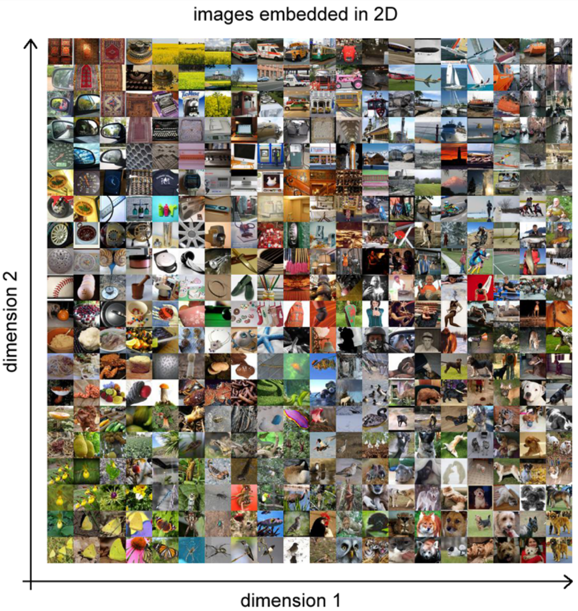
Inference & Machine Learning

- 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

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4F1 Control System Design

4F2 Robust and Nonlinear Systems and Control (3F2 pre-req.)

4F3 Optimal and Predictive Control

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

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

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

4F10 Deep Learning and Structured Data

4F12 Computer Vision

4F13 Probabilistic Machine Learning

4M20 Robotics

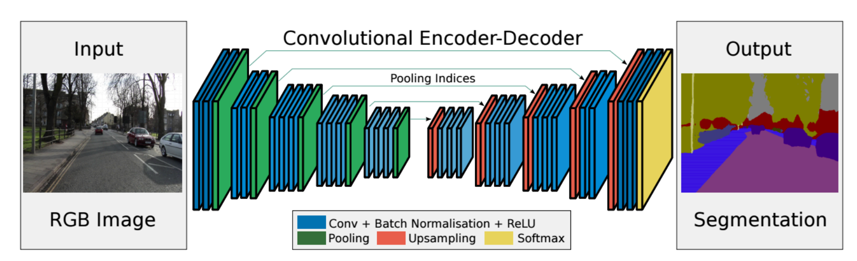

Image Segmentation using convolutional neural nets

You can try a real-time demo at:
`http://mi.eng.cam.ac.uk/projects/segnet/`

Machine Learning

Algorithms that use input data to build models and make predictions or decisions

Search engines, spam filtering, computer vision …

`Machine learning algorithm learns to play Atari Breakout`

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)