Engineering Tripos Part IIB, 4F7: Statistical signal and network models, 2025-26

Module Leader

Prof S Godsill [1]

lecturers

Prof S Godsill, Dr G Cantwell [2]

Timing and Structure

Michaelmas term. 16 lectures (including examples classes). Assessment: 100% exam

Prerequisites

3F1, 3F3, 3F8 recommended. 3M1 useful.

Aims

The aims of the course are to:

- Introduce time-series models, in particular State-space models and hidden Markov models; understand their role in applications of signal processing.
- Develop techniques for fitting statisical models to data and estimating hidden signals from noisy observations.
- Introduce network models, graph algorithms, and techniques to analyse large scale relational data

Objectives

As specific objectives, by the end of the course students should be able to:

- Understand state-space models, hidden Markov models, and network models including their mathematical characterisation, strengths and limitations.
- Execute the necessary computational tasks involved in fitting the models to data, to estimate unobserved quantities and make future predictions.
- Understand the computational methodology employed, their mathematical derivation, their strengths and weaknesses, how to execute them, and their use more generally in Statistical and data-centric engineering problems.

Content

This course is about fitting statistical models to data that arrives sequentially over time and across network structures. Once an appropriate model has been fitted, tasks such as predicting future trends or estimating quantities not directly observed can be performed. The statistical modelling and computational methodology covered by this course is widely used in many applied areas. For example, data that arrives sequentially over time is a common occurrence in Signal Processing (Engineering), Finance, Machine Learning, Environmental statistics etc.

The model that most appropriately describes data that arrives sequentially over time is a time-series model, an example of which is the ARMA model (studied in 3F3.) However, this course will look at more versatile models that incorporate hidden or latent state variables as these are able to account for richer behaviour. Also, models that aim describe how many really physical processes evolve over time often necessarily have to incorporate unobserved hidden states that form a Markov process.

Besides changing over time, many data are distributed over different individuals or sites. For example, users of a social media platform will each have different properties. Networks (graphs) provide a simple formalism to analyse distributed systems composed of small but interrelated parts.

State space models and time series:

The model that most appropriately describes data that arrives sequentially over time is a time-series model, an example of which is the AR model (studied in 3F3). However, this course will look at more versatile stochastic (random) state-space models that incorporate hidden or latent state variables as these are able to account for richer behaviour. Also, models that aim describe how many really physical processes evolve over time often necessarily have to incorporate unobserved hidden states that form a Markov process.

- Introduction to state-space models and optimal linear filtering; the Kalman filter; exemplar problems in signal processing.
- Introduction to hidden Markov models: definition; inference/estimation aims; exact computation of the conditional probability distributions.
- Importance sampling: introduction; weight degeneracy; statistical properties.
- Sequential importance sampling and resampling (also known as the particle filter): application to hidden Markov models; filtering; smoothing.
- Calibrating hidden Markov models: maximum likelihood estimation and its implementation.
- Exemplar problems in Signal Processing.
- Examples Papers.

Networks modelling:

Besides changing over time, many data are distributed over different individuals or sites. For example, users of a social media platform will each have different properties. Networks (graphs) provide a simple formalism to analyse distributed systems composed of small but interrelated parts. We will cover:

- · Fundamentals, basic graph theory and algorithms.
- · Metrics: centrality (e.g. PageRank), assortativity, clustering, diameter ("six degrees of separation").

- · Models of networks: Erd?s–Rényi, small-world and scale free.
- · Models on networks: Spreading, reliability and percolation.
- · Community detection and stochastic block models.
- · Graph spectra and their applications.

Booklists

Please refer to the Booklist for Part IIB Courses for references to this module, this can be found on the associated Moodle course.

Examination Guidelines

Please refer to Form & conduct of the examinations [3].

UK-SPEC

This syllabus contributes to the following areas of the UK-SPEC [4] standard:

Toggle display of UK-SPEC areas.

GT1

Develop transferable skills that will be of value in a wide range of situations. These are exemplified by the Qualifications and Curriculum Authority Higher Level Key Skills and include problem solving, communication, and working with others, as well as the effective use of general IT facilities and information retrieval skills. They also include planning self-learning and improving performance, as the foundation for lifelong learning/CPD.

IA1

Apply appropriate quantitative science and engineering tools to the analysis of problems.

IA2

Demonstrate creative and innovative ability in the synthesis of solutions and in formulating designs.

KU1

Demonstrate knowledge and understanding of essential facts, concepts, theories and principles of their engineering discipline, and its underpinning science and mathematics.

KU2

Have an appreciation of the wider multidisciplinary engineering context and its underlying principles.

E1

Ability to use fundamental knowledge to investigate new and emerging technologies.

E2

Ability to extract data pertinent to an unfamiliar problem, and apply its solution using computer based engineering tools when appropriate.

E3

Ability to apply mathematical and computer based models for solving problems in engineering, and the ability to assess the limitations of particular cases.

E4

Understanding of and ability to apply a systems approach to engineering problems.

P1

A thorough understanding of current practice and its limitations and some appreciation of likely new developments.

P3

Understanding of contexts in which engineering knowledge can be applied (e.g. operations and management, technology, development, etc).

P8

Ability to apply engineering techniques taking account of a range of commercial and industrial constraints.

US1

A comprehensive understanding of the scientific principles of own specialisation and related disciplines.

US2

A comprehensive knowledge and understanding of mathematical and computer models relevant to the engineering discipline, and an appreciation of their limitations.

Last modified: 04/06/2025 13:30

Source URL (modified on 04-06-25): https://teaching26-27.eng.cam.ac.uk/content/engineering-tripos-part-iib-4f7-statistical-signal-and-network-models-2025-26

Links
[1] mailto:sjg30@cam.ac.uk
[2] mailto:sjg30@cam.ac.uk, gtc31@cam.ac.uk
[3] https://teaching26-27.eng.cam.ac.uk/content/form-conduct-examinations
[4] https://teaching26-27.eng.cam.ac.uk/content/uk-spec