Mathematics and Statistics Undergraduate Handbook
Supplement to the Handbook

Honour School of Mathematics and Statistics
Syllabus and Synopses for Part B 2018–2019
for examination in 2019

Contents

Please note that the course numbering system has changed (eg SB2a has become SB2.1). SB3.1 Applied Probability is now running in Hilary Term.

Every effort is made to ensure that the list of courses offered is accurate at the time of going online. However, students are advised to check the up-to-date version of this document on the Department of Statistics website.

Notice of misprints or errors of any kind, and suggestions for improvements in this booklet should be addressed to the Academic Administrator in the Department of Statistics (academic.administrator@stats.ox.ac.uk).

Updated June 2018

1. Honour School of Mathematics and Statistics

1.1 Units and double-units and methods of examination

See the current edition of the Examination Regulations at
http://www.admin.ox.ac.uk/examregs/2016-17/hsomathandstat/studentview/
for the full regulations governing these examinations. The examination conventions can be found at http://www.stats.ox.ac.uk/current_students/bammath/examinations

In Part B each candidate shall offer a total of **eight units** from the schedule of units and double units.

(a) Each candidate shall offer the double unit SB1.
(b) Each candidate shall offer a total of at least two units from SB2 and SB3.
(c) Each candidate may offer a total of at most two units from SB4 and the schedule of 'Other units'.
(d) Each candidate may offer at most one double unit which is an Extended Essay or Structured Project.

Note: Units from the schedule of 'Mathematics Department units' for Part B of the Honour School of Mathematics are also available – see Section 3.

Students are asked to register for the options they intend to take by the end of week 10, Trinity Term 2018 using the Mathematical Institute course management portal. https://courses.maths.ox.ac.uk/ . Students may alter the options they have registered for after this but it is helpful if their registration is as accurate as possible. Students will then be asked to sign up for classes at the start of Michaelmas Term 2018. Students who register for a course or courses for which there is a quota should consider registering for an additional course (by way of a "reserve choice") in case they do not receive a place on the course with the quota.

Every effort will be made when timetabling lectures to ensure that mathematics lectures do not clash. However, because of the large number of options this may sometimes be unavoidable.

1.2 Language Classes

If spaces are available, Mathematics and Statistics students are also invited to apply to take classes in a foreign language. In 2018-2019, French and German language classes will be offered. Students' performance in these classes will not contribute to the degree classification in Mathematics and Statistics. However, successful completion of the course, may be recorded on a student's transcript. See https://courses.maths.ox.ac.uk/ for further information.

1.3 Part B courses in future years

In any year, most courses available in Part B that year will normally also be available in Part B the following year. However, sometimes new options will be added or existing options may cease to run. The list of courses that will be available in Part B in any year will be published by the end of the preceding Trinity Term.

Details of Part C units, examinable in 2020, will be published before Michaelmas Term 2019.

1.4 Course list by term

The list of 2018-2019 Part B courses by term is:

Michaelmas Term

SB1.1 Applied Statistics [double unit with SB1.2]
SB2.1 Foundations of Statistical Inference
SB4.1 Actuarial Science

Hilary Term

SB1.2 Computational Statistics [double unit with SB1.1]
SB2.2 Statistical Machine Learning
SB3.1 Applied Probability
SB3.2 Statistical Lifetime Models

2 Statistics units and double units

2.1 SB1 Applied and Computational Statistics

Level: H-level
Method of Assessment: written examination plus assessed practical assignments. The practical assignments contribute 1/3 of the marks for SB1. Please see below for the hand-in deadlines for practical assignments.
Weight: Double unit.

Prerequisites: A8 Probability and A9 Statistics.

Aims
The course aims to develop the theory of statistical methods, and also to introduce students to the analysis of data using a statistical package. The main topics are: simulation based inference, practical aspects of linear models, logistic regression and generalized linear models, and computer-intensive methods.

2.1.1 SB1.1 Applied Statistics – 13 MT

Synopsis
The normal linear model: use of matrices, least squares and maximum likelihood estimation, normal equations, distribution theory for the normal model, hypothesis tests and confidence intervals.

Practical aspects of linear models and analysis of variance: multiple regression, categorical variables and interactions, blocks and treatments, orthogonality, model selection (including AIC, but not the derivation of AIC), fit criteria, use of residuals, outliers, leverage, model interpretation.

Normal linear mixed models, hierarchical models.

Generalised Linear Models: logistic regression, linear exponential families and generalized linear models, scale parameter, link functions, canonical link. Maximum likelihood fitting. Iteratively reweighted least squares. Asymptotic theory: statement and applications to inference, analysis of deviance, model checking, residuals.

Reading
A. C. Davison, *Statistical Models*, CUP, 2003
J.J. Faraway, *Linear Models with R*, Chapman and Hall, 2005
A. J. Dobson and A.G Barnett, *An Introduction to Generalized Linear Models*, Chapman and Hall, 2008
J.J. Faraway, *Extending the Linear Model with R : Generalized Linear, Mixed Effects and Nonparametric Regression Models*, Chapman and Hall, 2006

Further Reading
F. L. Ramsey and D. W. Schafer, *The Statistical Sleuth: A Course in Methods of Data Analysis*, 2nd edition, Duxbury, 2002.

2.1.2 SB1.2 Computational Statistics – 13 HT

Synopsis
Smoothing methods (local polynomials). Nonparametric inference (bandwidth and Generalised Cross Validation).
Multivariate smoothers and Generalised Additive Models.

Inference using simulation methods. Monte-Carlo Tests. Permutation tests. Rank statistics.

Bootstrapping.

Hidden Markov Models: specification. Forward-backward algorithm. Kalman filter.

Reading
J. D. Gibbons, *Nonparametric Statistical Inference*, Marcel Dekker, 1985, pp 1-193, 273- 290.
G.H. Givens and J.A. Hoeting, *Computational Statistics*, 2nd edition, Wiley, 2012.
G. James, D. Witten, T. Hastie, R. Tibshirani, *An Introduction to Statistical Learning*, Springer , 2013. This book is freely available online: http://www-bcf.usc.edu/~gareth/ISL/
R. H. Randles and D. A. Wolfe, *Introduction to the Theory of Nonparametric Statistics*, Wiley 1979, pp 1-322.
L. Wasserman, *All of Nonparametric Statistics*, Springer, 2005.
L. Wasserman, *All of Statistics*, Springer, 2004.

Further Reading
A.C. Davison and D.V. Hinkley, *Bootstrap Methods and their Application,* CUP, 1997.
C.R. Shalizi, *Advanced Data Analysis from an Elementary Point of View*, http://www.stat.cmu.edu/~cshalizi/ADAfaEPoV/.

Practicals
In addition to the lectures there will be five supervised practicals. Four of these contain problems whose written solutions will be assessed as part of the unit examination.

The hand-in deadlines for the four assessed practicals are:
1st practical: 12 noon Monday week 8, Michaelmas Term 2018
2nd practical: 12 noon Monday week 2, Hilary Term 2019
3rd practical: 12 noon Monday week 8, Hilary Term 2019
4th practical: 12 noon Monday week 2, Trinity Term 2019.

Candidates who miss the above deadlines may ask their college to apply to the Head of the Department of Statistics for permission to submit late. Where there is a valid reason, the Head of Department would normally approve the late submission without penalty. Where it is deemed that there is no valid reason, the Head of Department will advise the Examiners to apply a penalty in accordance with the late penalty tariff found in the Mathematics and Statistics Examination Conventions.

2.2.1 SB2.1 Foundations of Statistical Inference – 16 MT

Level: H-level
Method of Assessment: written examination
Weight: Unit

Prerequisites: A9 Statistics, A8 Probability.

Learning outcomes
Understanding how data can be interpreted in the context of a statistical model. Working knowledge and understanding of key-elements of model-based statistical inference, including awareness of similarities, relationships and differences between Bayesian and frequentist approaches.

Synopsis
Exponential families: Curved and linear exponential families; canonical parametrization; likelihood equations. Sufficiency: Factorization theorem; sufficiency in exponential families.

Frequentist estimation: unbiasedness; method of moments; the Cramer-Rao information inequality; Rao-Blackwell theorem: Lehmann-Scheffé Theorem and Rao-Blackwellization; Statement of complete sufficiency for Exponential families.

The Bayesian paradigm: likelihood principal; subjective probability; prior to posterior analysis; asymptotic normality; conjugacy; examples from exponential families. Choice of prior distribution: proper and improper priors; Jeffreys' and maximum entropy priors. Hierarchical Bayes models.

Decision theory: risk function; Minimax rules, Bayes rules. Point estimators and admissibility of Bayes rules. The James-Stein estimator, shrinkage estimators and Empirical Bayes. Hypothesis testing as decision problem.

Reading
P. H. Garthwaite, I. T. Jolliffe and Byron Jones, *Statistical Inference,* 2nd edition, Oxford University Press, 2002.
G.A.Young and R.L. Smith, *Essentials of Statistical Inference*, Cambridge University Press, 2005.
T. Leonard and J.S.J. Hsu, *Bayesian Methods*, Cambridge University Press, 2005.

Further reading
D. Barber, *Bayes Reasoning and Machine Learning*, Cambridge University Press, 2012.
D. R. Cox, *Principles of Statistical Inference*, Cambridge University Press, 2006.
H. Liero and S Zwanzig, *Introduction to the Theory of Statistical Inference*, CRC Press, 2012.

2.2.2 SB2.2 Statistical Machine Learning – 16 HT

Level: H-level
Method of Assessment: Written examination
Weight: Unit

Recommended prerequisites: Part A A9 Statistics and A8 Probability. SB2a Foundations of Statistical Inference useful but not essential.

Aims and Objectives
Machine learning studies methods that can automatically detect patterns in data, and then use these patterns to predict future data or other outcomes of interest. It is widely used across many scientific and engineering disciplines.

This course covers statistical fundamentals of machine learning, with a focus on supervised learning and empirical risk minimisation. Both generative and discriminative learning frameworks are discussed and a variety of widely used classification algorithms are overviewed.

Synopsis
Visualisation and dimensionality reduction: principal components analysis, biplots and singular value decomposition. Multidimensional scaling. K-means clustering.
Introduction to supervised learning. Evaluating learning methods with training/test sets.
Bias/variance trade-off, generalisation and overfitting. Cross-validation. Regularisation.
Performance measures, ROC curves. K-nearest neighbours as an example classifier.
Linear models for classification. Discriminant analysis. Logistic regression. Generative vs Discriminative learning. Naive Bayes models.
Decision trees, bagging, random forests, boosting.
Neural networks and deep learning.

Reading
C. Bishop, *Pattern Recognition and Machine Learning*, Springer, 2007.
T. Hastie, R. Tibshirani, J Friedman, *Elements of Statistical Learning*, Springer, 2009.
K. Murphy, *Machine Learning: a Probabilistic Perspective*, MIT Press, 2012.

Further Reading
B. D. Ripley, *Pattern Recognition and Neural Networks*, Cambridge University Press, 1996.
G. James, D. Witten, T. Hastie, R. Tibshirani, *An Introduction to Statistical Learning*, Springer, 2013.

2.3.1 SB3.1 Applied Probability – 16 HT

Level: H-level
Method of Assessment: written examination
Weight: Unit.

Prerequisite: A8 Probability.

Aims and Objectives
This course is intended to show the power and range of probability by considering real examples in which probabilistic modelling is inescapable and useful. Theory will be developed as required to deal with the examples.

Synopsis
Poisson processes and birth processes. Continuous-time Markov chains. Transition rates, jump chains and holding times. Forward and backward equations. Class structure, hitting times and absorption probabilities. Recurrence and transience. Invariant distributions and limiting behaviour. Time reversal.

Renewal theory. Limit theorems: strong law of large numbers, strong law and central limit theorem of renewal theory, elementary renewal theorem, renewal theorem, key renewal theorem. Excess life, inspection paradox.

Applications in areas such as: queues and queueing networks - M/M/s queue, Erlang's formula, queues in tandem and networks of queues, M/G/1 and G/M/1 queues; insurance ruin models; applications in applied sciences.

Reading
J.R. Norris: *Markov Chains*. Cambridge University Press, 1997.
G.R. Grimmett and D.R. Stirzaker: *Probability and Random Processes*, 3rd edition, Oxford University Press, 2001.
G.R. Grimmett and D.R. Stirzaker: *One Thousand Exercises in Probability*. Oxford University Press, 2001.
S.M. Ross: I*ntroduction to Probability Models*, 4th edition, Academic Press, 1989.
D.R. Stirzaker: *Elementary Probability*, 2nd edition, Cambridge University Press, 2003.

2.3.2 **SB3.2 Statistical Lifetime-Models** – 16 HT

Level: H-level
Method of Assessment: written examination
Weight: Unit.

Prerequisite**:** A9 Statistics.

Aims and Objectives
Event times and event counts appear in many social and medical data contexts, and require a specialised suite of techniques to handle properly, broadly known as survival analysis. This course covers the basic definitions of hazard rates and survival functions, techniques for creating and interpreting life tables, nonparametric estimation and comparison of event-time distributions, and evaluating the goodness of fit of various semiparametric models. A focus is on understanding when and why particular models ought to be chosen, and on using the standard software tools in R to carry out data analysis.

Synopsis

1. Introduction to survival data: hazard rates, survival curves, life tables.
2. Censoring and truncation, introduction through the census approximation.
3. Parametric survival models.
4. Nonparametric estimation of survival curves.
5. Nonparametric model tests (log-rank test and relatives).
6. Semiparametric models
    a. Proportional hazards;
    b. Additive hazards;
    c. Accelerated failure models.
7. Model-fit diagnostics.
8. Dynamic prediction and model information quality.
9. Repeated events.

Topics:

Life tables: Basic notation, life expectancy and remaining life expectancy, curtate lifetimes. Survival models: general lifetime distributions, force of mortality (hazard rate), survival function. Periods and cohorts. Lexis diagrams. Census and vital statistics. Multiple decrements model.

Censoring and truncation. Maximum likelihood estimation for parametric models. Kaplan-Meier and Nelson-Aalen estimator with variance estimation (including Greenwood's formula). Applications in epidemiology. Parametric models generalised linear regression. Nonparametric comparison of survival distributions, including log-rank test and serial-correlations test. Using the survival package in R.

Relative risk (proportional hazards) including the Cox model, additive hazards model, accelerated failure models. Partial likelihood. Efron's estimator for survival distributions.

Residual tests, including Cox—Snell residuals, martingale residuals, Schoenfeld residuals. Dynamic prediction and predictive power of models: Cross validation,

Anderson—Gill model, Poisson regression, negative binomial model. Multistate models and Markov processes.

Reading

Statistical Lifetime Models lecture notes, revised 2019.

Kenneth W. Wachter. Essential Demographic Methods. Harvard University Press, 2014.
J.P. Klein and M.L. Moeschberger, Survival Analysis, Springer, 1997.

Further Reading

Farhat Yusuf, David Swanson, Jo Martins. Methods of Demographic Analysis. Springer, 2013.
Subject CT4 Models Core Reading, Faculty & Institute of Actuaries.
Odd O. Aalen et al., Survival and Event History Analysis, Springer, 2008.
D. F. Moore, Applied Survival Analysis Using R, Springer, 2016.
H. C. van Houwelingen and T. Stijnen, "Cox Regression Model", in J. P. Klein et al. (ed.) Handbook of Survival Analysis, pp. 5—26, CRC Press, 2014.

T. Martinussen and L. Peng, “Alternatives to the Cox Model”, in J. P. Klein et al. (ed.) Handbook of Survival Analysis, pp. 49—76, CRC Press, 2014.
H. C. van Houwelingen and H. Putten, Dynamic Prediction in Clinical Survival Analysis. CRC Press, 2011.
Lawless, J. F. and Yuan, Y. (2010). “Estimation of prediction error for survival models”. Statistics in Medicine, 29(2), 262-274.

2.4 **SB4.1 Actuarial Science**– 16 MT

Level: H-level
Method of Assessment: written examination
Weight: Unit.

Prerequisites: A8 *Probability* is useful, but not essential. If you have not done A8 *Probability*, make sure that you are familiar with Prelims work on Probability.

Synopsis
Fundamental nature of actuarial work. Use of generalised cash flow model to describe financial transactions. Time value of money using the concepts of compound interest and discounting. Interest rate models. Present values and accumulated values of a stream of equal or unequal payments using specified rates of interest. Interest rates in terms of different time periods. Equation of value, rate of return of a cash flow, existence criteria.
Single decrement model. Present values and accumulated values of a stream of payments taking into account the probability of the payments being made according to a single decrement model. Annuity functions and assurance functions for a single decrement model. Risk and premium calculation.
Liabilities under a simple assurance contract or annuity contract.
Theories of value, St Petersburg Paradox, statement of Expected Utility Theory (EUT) and Subjective Expected Utility (SEU) representation theorems.
Risk aversion, the Arrow-Pratt approximation, comparative risk aversion, classical utility functions.
First and second order stochastic dominance, the Rothschild-Stiglitz Proposition.
Mossin’s Theorem, static portfolio choice. Consumption and saving. Felicity Function and Prudence.
Time consistency. Desynchronisation.

Reading
Subject CT1 Financial Mathematics Core Reading Institute & Faculty of Actuaries.
Subject CT5, Contingencies Core Reading, Institute & Faculty of Actuaries.
J.J. McCutcheon and W.F. Scott, *An Introduction to the Mathematics of Finance*. Heinemann, 1986.
P. Zima and R.P. Brown: *Mathematics of Finance*. McGraw-Hill Ryerson, 1993.
N.L. Bowers et al, *Actuarial mathematics,* 2nd edition, Society of Actuaries, 1997.
J. Danthine and J. Donaldson: *Intermediate Financial Theory*. 2nd edition, Academic Press Advanced Finance, 2005.
H.U. Gerber: *Life Insurance Mathematics*. 3rd edition, Springer , 1997.
L. Eeckhoudt, C. Gollier and H.Schlesinger, *Economic and Financial Decisions under Risk*, Princeton University Press Princeton and Oxford, 2005, Chapters 1-4, 10-11.

C. Gollier, *The Economics of Risk and Time*, MIT Press, 2001, Topics in chapters 1-4, 20.
Subject CT8: Financial Economics Core reading, Faculty & Institute of Actuaries, Units (i), (iii), (v)-(vi).

3 Mathematical and Other units

The other units that students in Part B Mathematics and Statistics may take are drawn from Part B of the Honour School of Mathematics.
For full details of these units, see https://courses.maths.ox.ac.uk/overview/undergraduate.

3.1 Mathematics units

The Mathematics units that are available are as follows:

B1.1: Logic	16 MT
B1.2: Set Theory	16 HT
B2.1: Introduction to Representation Theory	16 MT
B2.2: Commutative Algebra	16 HT
B3.1: Galois Theory	16 MT
B3.2: Geometry of Surfaces	16 MT
B3.3: Algebraic Curves	16 HT
B3.4: Algebraic Number Theory	16 HT
B3.5: Topology and Groups	16 MT
B4.1: Functional Analysis I	16 MT
B4.2: Functional Analysis II	16 HT
B4.3 Distribution theory and Fourier Analysis: an introduction	16 MT
B5.1:Stochastic Modelling of Biological Processes	16 HT
B5.2: Applied Partial Differential Equations	16 MT
B5.3: Viscous Flow	16 MT
B5.4: Waves and Compressible Flow	16 HT
B5.5: Further Mathematical Biology	16 MT
B5.6: Nonlinear Systems	16 HT
B6.1 Numerical Solution of Differential Equations I	16 MT
B6.2 Numerical Solution of Differential Equations II	16 HT
B6.3 Integer Progamming	16 MT
B7.1 Classical Mechanics	16 MT
B7.2 Electromagnetism	16 MT
B7.3 Further Quantum Theory	16 HT
B8.1: Probability, Measure and Martingales	16 MT
B8.2: Continuous Martingales and Stochastic Calculus	16 HT
B8.3: Mathematical Models of Financial Derivatives	16 HT
B8.4: Information Theory	16 MT
B8.5: Graph Theory	16 HT
OCS2 Computational Complexity	16 HT

BEE Mathematical Extended Essay	MT & HT [double unit]
or	
BSP: Structured Projects	MT & HT [double unit]

[Note: Students **cannot take both** BEE and BSP]

Other units:

BN1: Mathematical Education and Undergraduate Ambassadors' Scheme	MT & HT [double unit]
or	
BN1.1: Mathematics Education	MT

(These are the units referred to in Section 1 as 'Mathematics Department units for Part B of the Honour School of Mathematics.)

See the "Projects Guidance Notes" on the web at https://www1.maths.ox.ac.uk/members/students/undergraduate-courses/teaching-and-learning/projects for more information on the Extended Essay option.

Please note that the following **are not permitted options** in Part B of the Honour School of Mathematics and Statistics:

BO1.1	History of Mathematics
BOE	''Other Mathematical'' Extended Essay

3.2 Other units

The other units available are as follows:

BN1: Mathematical Education and Undergraduate Ambassadors' Scheme	MT & HT [double unit]
or	
BN1.1: Mathematics Education	MT