Eötvös Loránd University
Faculty of Science
Mathematical Institute

MSc in mathematics

Description of the program

2014

Table of content

I. Course requirements

Students enrolled in the program must obtain at least **120 credits** in the following distribution:

– at least **20 credits** from so called **basic courses** (B)

– at least **30 credits** in at least **4 subject groups** from so called **core courses** (C)

– at least **44 credits** in at least **3 subject groups** from so called **differentiated courses** (D)

On top of these, **6 credits** can be chosen **freely** from the list of all subjects offered to MSc students in mathematics and applied mathematics. Furthermore, a **thesis** (worth **20 credits**) must be written at the end of the studies.

Under special circumstances it is possible to get a waiver from taking basic courses. In this case the missing credits can be obtained by taking more free courses.

It is expected – although not enforced – that the students should finish in two years (i.e. four semesters).

For ***international students***, basic courses (B) are offered usually in the form of reading courses. In case of interest, a request has to be made to the program coordinator. Core courses (C) are offered once every year (i.e. either in the fall or in the spring semester). Differentiated courses (D) are offered less freqeuently, usually once every two years. It may happen that some of these courses will also take a form of a reading course.

II. List of subjects

Subject / **Coordinator**	**Contact hours (hours/week)**	**Credits**	Evaluation
B. Basic courses (20 credits)			
1. Algebra 4 (BSc) *Péter Pál Pálfy*	2 h/w (lecture) 2 h/w (practice)	2+3	exam term mark
2. Analysis 4 (BSc) *Géza Kós*	4 h/w (lecture) 2 h/w (practice)	4+3	exam term mark
3. Basic algebra (reading course) *István Ágoston*	2 h/w (practice)	5	exam
4. Basic geometry (reading course) *Gábor Moussong*	2 h/w (practice)	5	exam
5. Complex functions (BSc) *Róbert Szőke*	2 h/w (lecture) 2 h/w (practice)	2+3	exam term mark
6. Computer science (BSc) *Vince Grolmusz*	2 h/w (lecture) 2 h/w (practice)	2+3	exam term mark
7. Geometry III. (BSc) *Balázs Csikós*	3 h/w (lecture) 2 h/w (practice)	3+3	exam term mark
8. Introduction to differential geometry (BSc) *László Verhóczki*	2 h/w (lecture) 2 h/w (practice)	2+3	exam term mark
9. Introduction to topology (BSc) *András Szűcs*	2 h/w (lecture)	2+3	exam term mark
10. Probability and statistics *Tamás Móri*	3 h/w (lecture) 2 h/w (practice)	3+3	exam term mark
11. Reading course in analysis *Árpád Tóth*	2 h/w (practice)	5	exam term mark
12. Set theory (BSc) *Péter Komjáth*	2 h/w (lecture)	2	exam
C. Core courses (at least 30 credits from at least 4 different subject groups)			
Foundational courses			
1. Algebraic topology (BSc) *András Szűcs*	2 h/w (lecture) 2 h/w (practice	2+3	exam term mark
2. Differential geometry of manifolds (BSc) *László Verhóczki*	2 h/w (lecture) 2 h/w (practice)	2+3	exam term mark
3. Partial differential equations (BSc) *Ádám Besenyei*	2 h/w (lecture) 2 h/w (practice)	2+3	exam term mark
Algebra and number theory			
4. Groups and representations *Péter Pál Pálfy*	2 h/w (lecture) 2 h/w (practice)	2+3	exam term mark
5. Number theory II (BSc) *András Sárközy*	2 h/w (lecture)	2	exam
6. Rings and algebras *István Ágoston*	2 h/w (lecture) 2 h/w (practice)	2+3	exam term mark
Analysis			
7. Fourier integral (BSc) *Árpád Tóth*	2 h/w (lecture) 2 h/w (practice)	2+3	exam term mark
8. Function series (BSc) *János Kristóf*	2 h/w (lecture)	2	exam
9. Functional analysis II (BSc) *Zoltán Sebestyén*	2 h/w (lecture) 2 h/w (practice)	2+3	exam term mark

10. Several complex variables *Róbert Szőke*	2 h/w (lecture)	3	exam
11. Topics in analysis *Márton Elekes*	2 h/w (lecture) 1 h/w (practice)	2+2	exam term mark
Geometry			
12. Combinatorial geometry *György Kiss*	2 h/w (lecture) 1 h/w (practice)	2+2	exam term mark
13. Differential geometry II. *László Verhóczki*	2 h/w (lecture)	2	exam
14. Differential topology *András Szűcs*	2 h/w (lecture)	2	exam
15. Homology theory *András Szűcs*	2 h/w (lecture)	2	exam
16. Topics in differential geometry *Balázs Csikós*	2 h/w (lecture)	2	exam
Stochastics			
17. Discrete parameter martingales *Tamás Móri*	2 h/w (lecture)	3	exam
18. Markov chains in discrete and continuous time *Vilmos Prokaj*	2 h/w (lecture)	2	exam
19. Multivariate statistical methods *György Michaletzky*	4 h/w (lecture)	5	exam
20. Statistical computing 1 *András Zempléni*	2 h/w (practice)	3	term mark
Discrete mathematics			
21. Algorithms I *Zoltán Király*	2 h/w (lecture) 2 h/w (practice)	2+3	exam term mark
22. Discrete mathematics *László Lovász*	2 h/w (lecture) 2 h/w (practice)	2+3	exam term mark
23. Mathematical logic *Péter Komjáth*	2 h/w (lecture) 2 h/w (practice)	2+3	exam term mark
Operations research			
24. Continuous optimization *Tibor Illés*	3 h/w (lecture) 2 h/w (practice)	3+3	exam
25. Discrete optimization *András Frank*	3 h/w (lecture) 2 h/w (practice)	3+3	exam term mark

D. Differentiated courses (at least 44 credits from at least 3 different subject groups)

Algebra			
1. Commutative algebra *Gyula Károlyi*	2 h/w (lecture) 2 h/w (practice)	3+3	exam term mark
2. Lie algebras *Péter Pál Pálfy*	2 h/w (lecture) 2 h/w (practice)	3+3	exam term mark
3. Topics in group theory *Péter Pál Pálfy*	2 h/w (lecture) 2 h/w (practice)	3+3	exam term mark
4. Topics in ring theory *István Ágoston*	2 h/w (lecture) 2 h/w (practice)	3+3	exam term mark
5. Universal algebra and lattice theory *Emil Kiss*	2 h/w (lecture) 2 h/w (practice)	3+3	exam term mark
Number theory			
6. Algebraic number theory *András Sárközy*	2 h/w (lecture) 2 h/w (practice)	3+3	exam term mark
7. Combinatorial number theory *András Sárközy*	2 h/w (lecture)	3	exam
8. Exponential sums in number theory *András Sárközy*	2 h/w (lecture)	3	exam

9. Multiplicative number theory *Mihály Szalay*	2 h/w (lecture)	3	exam
Analysis			
10. Analytic chapters of complex function theory *Róbert Szőke*	2 h/w (lecture)	3	exam
11. Complex manifolds *Róbert Szőke*	3 h/w (lecture) 2 h/w (practice)	4+3	exam term mark
12. Descriptive set theory *Miklós Laczkovich*	3 h/w (lecture) 2 h/w (practice)	4+3	exam term mark
13. Discrete dinamical systems *Zoltán Buczolich*	2 h/w (lecture)	3	exam
14. Dynamical systems *Zoltán Buczolich*	2 h/w (lecture)	3	exam
15. Dynamical systems and differential equations 1 *Péter Simon*	2 h/w (lecture) 2 h/w (practice)	3+3	exam term mark
16. Dynamical systems and differential equations 2 *Péter Simon*	2 h/w (lecture)	3	exam
17. Dynamics in one complex variable *István Sigray*	2 h/w (lecture)	3	exam
18. Ergodic theory *Zoltán Buczolich*	2 h/w (lecture)	3	exam
19. Geometric chapters of complex function theory *István Sigray*	2 h/w (lecture)	3	exam
20. Geometric measure theory *Tamás Keleti*	3 h/w (lecture) 2 h/w (practice)	4+3	exam term mark
21. Linear partial differential equations *László Simon*	2 h/w (lecture) 2 h/w (practice)	3+3	exam term mark
22. Nonlinear and numerical functional analysis *János Karátson*	2 h/w (lecture) 2 h/w (practice)	3+3	exam term mark
23. Nonlinear partial differential equations *László Simon*	2 h/w (lecture)	3	exam
24. Operator semigroups *András Bátkai*	2 h/w (lecture) 2 h/w (practice)	3+3	exam term mark
25. Representations of Banach*-algebras and abstract harmonic analysis *János Kristóf*	2 h/w (lecture) 1 h/w (practice)	2+2	exam
26. Riemann surfaces *Róbert Szőke*	2 h/w (lecture)	3	exam
27. Seminar in complex analysis *Róbert Szőke*	2 h/w (practice)	2	exam
28. Special functions *Árpád Tóth*	2 h/w (lecture)	3	exam
29. Topological vector spaces and Banach algebras *János Kristóf*	2 h/w (lecture) 2 h/w (practice)	3+3	exam
30. Unbounded operators of Hilbert spaces *Zoltán Sebestyén*	2 h/w (lecture)	3	exam
Geometry			
31. Algebraic and differential topology *András Szűcs*	4 h/w (lecture) 2 h/w (practice)	6+3	exam term mark
32. Algebraic geometry *András Némethi*	2 h/w (lecture) 2 h/w (practice)	2+3	exam term mark
33. Analytic convex geometry *Károly Böröczky Jr.*	2 h/w (lecture) 1 h/w (practice)	2+2	exam term mark
34. Combinatorial convex geometry *Károly Böröczky Jr.*	2 h/w (lecture) 1 h/w (practice)	2+2	exam term mark
35. Density problems in discrete geometry *Márton Naszódi*	2 h/w (lecture) 1 h/w (practice)	2+2	exam term mark

36. Differential toplogy problem solving *András Szűcs*	2 h/w (practice)	3	exam
37. Finite geometries *György Kiss*	2 h/w (lecture)	3	exam
38. Geometric foundations of 3D graphics *Gábor Kertész*	2 h/w (lecture) 2 h/w (practice)	3+3	exam term mark
39. Geometric modelling *László Verhóczki*	2 h/w (lecture)	3	exam
40. Lie groups *László Verhóczki*	2 h/w (lecture) 1 h/w (practice)	3+2	exam term mark
41. Low dimensional topology *András Stipsicz*	2 h/w (lecture)	3	exam
42. Problems in discrete geometry *Márton Naszódi*	2 h/w (lecture) 1 h/w (practice)	2+2	exam term mark
43. Riemannian geometry 1 *Balázs Csikós*	2 h/w (lecture) 1 h/w (practice)	2+2	exam term mark
44. Riemannian geometry 2 *Balázs Csikós*	2 h/w (lecture) 1 h/w (practice)	3+2	exam term mark
45. Symmetric spaces *László Verhóczki*	2 h/w (lecture) 1 h/w (practice)	2+2	exam term mark
46. Topology of singularities *András Némethi*	2 h/w (lecture)	3	exam
Stochastics			
47. Cryptography *István Szabó*	2 h/w (lecture)	3	exam
48. Introduction to information theory *Villő Csiszár*	2 h/w (lecture)	3	exam
49. Statistical computing 2 *András Zempléni*	2 h/w (practice)	3	term mark
50. Statistical hypothesis testing *Villő Csiszár*	2 h/w (lecture)	3	exam
51. Stochastic processes with independent increment, limit theorems *Vilmos Prokaj*	2 h/w (lecture)	3	exam
Discrete mathematics			
52. Applied discrete mathematics seminar *Zoltán Király*	2 h/w (practice)	2	other
53. Bioinformatics *Vince Grolmusz*	2 h/w (lecture) 2 h/w (practice)	3+3	exam term mark
54. Codes and symmetric structures *Tamás Szőnyi*	2 h/w (lecture)	3	exam
55. Complexity theory *Vince Grolmusz*	2 h/w (lecture) 2 h/w (practice)	3+3	exam term mark
56. Complexity theory seminar *Vince Grolmusz*	2 h/w (practice)	2	exam
57. Criptology *Péter Sziklai*	2 h/w (lecture) 2 h/w (practice)	3+3	exam term mark
58. Data mining *András Lukács*	2 h/w (lecture) 2 h/w (practice)	3+3	exam term mark
59. Design, analysis and implementation of algorithms and data structures I *Zoltán Király*	2 h/w (lecture) 2 h/w (practice)	3+3	exam
60. Design, analysis and implementation of algorithms and data structures II *Zoltán Király*	2 h/w (lecture)	3	exam
61. Discrete mathematics II *László Lovász*	4 h/w (lecture)	6	exam

62. Geometric algorithms *Pálvölgyi Dömötör*	2 h/w (lecture)	3	exam
63. Graph theory seminar *László Lovász*	2 h/w (practice)	2	exam
64. Mathematics of networks and the WWW *András Benczúr*	2 h/w (lecture)	3	exam
65. Selected topics in graph theory *László Lovász*	2 h/w (lecture)	3	exam
66. Set theory I *Péter Komjáth*	4 h/w (lecture)	6	exam
67. Set theory II *Péter Komjáth*	4 h/w (lecture)	6	exam
Operations research			
68. Applications of operation research *Alpár Jüttner*	2 h/w (lecture)	3	exam
69. Approximation algorithms *Tibor Jordán*	2 h/w (lecture)	3	exam
70. Combinatorial algorithms I *Tibor Jordán*	2 h/w (lecture) 2 h/w (practice)	3+3	exam term mark
71. Combinatorial algorithms II *Tibor Jordán*	2 h/w (lecture)	3	exam
72. Combinatorial structures and algorithms *Tibor Jordán*	2 h/w (practice)	3	term mark
73. Computational methods in operation reserach *Alpár Jüttner*	2 h/w (practice)	3	term mark
74. Game theory *Tamás Király*	2 h/w (lecture)	3	exam
75. Graph theory *András Frank, Zoltán Király*	2 h/w (lecture)	3	exam
76. Graph theory tutorial *András Frank, Zoltán Király*	2 h/w (practice)	3	term mark
77. Integer programming I *Tamás Király*	2 h/w (lecture)	3	exam
78. Integer programming II *Tamás Király*	2 h/w (lecture)	3	exam
79. LEMON library: Solving optimization problems in C++ *Alpár Jüttner*	2 h/w (practice)	3	other
80. Linear optimization *Tibor Illés*	2 h/w (lecture)	3	exam
81. Manufacturing process management *Tamás Kis*	2 h/w (lecture)	3	exam
82. Matroid theory *András Frank*	2 h/w (lecture)	3	exam
83. Nonliear optimization *Tibor Illés*	3 h/w (lecture)	4	exam
84. Operations research project *Tamás Kis*	2 h/w (practice)	3	term mark
85. Polyhedral combinatorics *András Frank*	2 h/w (lecture)	3	exam
86. Scheduling theory *Tibor Jordán*	2 h/w (lecture)	3	exam
87. Stochastic optimization *Gergely Mádi-Nagy*	2 h/w (lecture)	3	exam
88. Structures in combinatorial optimization *András Frank*	2 h/w (lecture)	3	exam
89. Stochastic optimization h/w (practice) *Gergely Mádi-Nagy*	2 h/w (practice)	3	term mark
Special (not in a block)			

90. Directed studies 1 *István Ágoston*	2 h/w (lecture)	3	other
91. Directed studies 2 *István Ágoston*	2 h/w (lecture)	3	other

III. List of lecturers

Name	***Affiliation***	***Research areas***
István Ágoston	ANT	algebra, ring theory, representation theory
Miklós Arató	PTS	statistics, random fields, actuarial mathematics
András Bátkai	AAC	functional analysis, operator semigroups
András A. Benczúr	CSC	data mining, math of the web, combinatorial optimization
Károly Bezdek	GEO	discrete geometry, convex geometry, combinatorial geometry
Károly Böröcyky Jr.	GEO	discrete geometry, convex geometry, combinatorial geometry
Zoltán Buczolich	ANA	real analysis, dynamical systems, ergodic theory
Balázs Csikós	GEO	differential geometry, Riemannian geometry, Lie groups
Villő Csiszár	PTS	statistics, random permutations, random graphs
Márton Elekes	ANA	real analysis
Csaba Fábián	OPR	linear and integer programming, stochastic programming, modelling
István Faragó	AAC	numerical analysis, numerical linear algebra, mathematical modelling
László Fehér	ANA	algebraic topology
Alice Fialowski	ANT	algebra, Lie algebras, cohomology theory
András Frank	OPR	combinatorial optimization, matroid theory, graph theory
Péter Frenkel	OPR	combinatorial algebra
Róbert Freud	ANT	number theory, additive arithmetic functions
Katalin Fried	TEA	combinatorial number theory, algorithms
Vince Grolmusz	CSC	combinatorics, graph theory, computer science, data mining, bioinformatics, mathematical modeling
Katalin Gyarmati	ANT	combinatorial number theory, diophantine problems, pseudorandomness
Gábor Halász	ANA	complex functions
Norbert Hegyvári	TEA	number theory, additive combinatorics
Péter Hermann	ANT	algebra, group theory
Tibor Illés	OPR	linear optimization, convex optimization, nonlinear programming
Ferenc Izsák	AAC	partial differential equations, finite element methods, numerical modeling
Tibor Jordán	OPR	combinatorial optimization, graph theory, discrete geometry
Alpár Jüttner	OPR	combinatorial optimization
János Karátson	AAC	numerical functional analysis, partial differential equations
Gyula Károlyi	ANT	number theory, additive combinatorics
Tamás Keleti	ANA	real analysis
Tamás Király	OPR	submodular functions, combinatorial optimization
Zoltán Király	CSC	algorithms, data structures, graph theory,

		combinatorial optimization, complexity theory
Emil Kiss	ANT	algebra, universal algebra
György Kiss	GEO	finite geometry, combinatorial geometry
Péter Komjáth	CSC	set theory, infinitary combinatorics
Géza Kós	ANA	combinatorics, analysis
Antal Kováts	PTS	actuarial mathematics, life contingencies
János Kristóf	AAC	topological vector spaces, abstract harmonic analysis, C*-algebras, mathematical physics
Miklós Laczkovich	ANA	real analysis
Gyula Lakos	GEO	differential geometry, functional analysis
László Lovász	CSC	discrete mathematics, graph theory, computer science, large networks, …
András Lukács	CSC	data mining, graph theory, human dynamics, bioinformatics
Gergely Mádi-Nagy	OPR	linear programming, stochastic programing, moment problems
László Márkus	PTS	financial mathematics, environmental applications of statistics
György Michaletzky	PTS	stochastic processes, realization theory for stationary processes
Tamás Móri	PTS	probability theory, random graphs and networks, martingales
Gábor Moussong	GEO	geometric topology, geometric group theory, hyperbolic geometry
András Némethi	GEO	algebraic geometry, singularity theory
Péter P. Pálfy	ANT	algebra, group theory, universal algebra
József Pelikán	ANT	algebra, group theory, commutative algebra
Tamás Pfeil	AAC	analysis, differential equations
Vilmos Prokaj	PTS	probability theory, stochastic processes
Tamás Pröhle	PTS	statistics, multivariate and applied statistics
András Recski	CSC	applications of combinatorial optimization in electric engineering
András Sárközy	ANT	combinatorial, multiplicative number theory, pseudorandomness
Zoltán Sebestyén	AAC	functional analysis
István Sigray	ANA	riemann surfaces
Eszter Sikolya	AAC	functional analysis, operator semigroups
László Simon	AAC	nonlinear partial differential equations, nonlinear partial functional equations, monotone operators
Péter Simon	AAC	dynamical systems, differential equations, network processes
András Stipsicz	ANA	4-manifolds
Csaba Szabó	ANT	algebra, universal algebra, computational complexity
István Szabó	PTS	information theory, information systems' security aspects
Mihály Szalay	ANT	number theory, statistical theory of partitions, statistical group theory
Péter Sziklai	CSC	discrete math., finite geometry, polynomials over finite fields, cryptography

Róbert Szőke	ANA	several complex variables, differential geometry
Szőnyi Tamás:	CSC	discrete mathematics: graphs, codes, designs, finite geometry
András Szűcs	ANA	algebraic topology, immersion theory
Árpád Tóth	ANA	modular forms, number theory
László Verhóczki	GEO	differential geometry, Riemannian geometry
Katalin Vesztergombi	CSC	discrete mathematics, discrete geometry, modeling, large networks
Gergely Zábrádi	PTS	algebraic muber theory
András Zempléni	PTS	statistics, extreme value modeling, multivariate models

Department codes

AAC	Applied Analysis and Computational Mathematics
ANA	Analysis
ANT	Algebra and Number Theory
CSC	Computer Science
GEO	Geometry
OPR	Operations Research
PTS	Probability Theory and Statistics
TEA	Teaching and Education Centre

IV. Description of the courses (in alphabetical order)

Title of the course:	**Algebraic and differential topology**	**(D27)**

Number of contact hours per week:	4+2
Credit value:	6+3
Course coordinator(s):	András Szűcs
Department(s):	Department of Analysis
Evaluation:	oral examination + grade for problem solving
Prerequisites:	Algebraic Topology course in BSC

A short description of the course:

Characteristic classes and their applications, computation of the cobordism ring of manifolds, Existence of exotic spheres.

Textbook:

Further reading:

1) J. W. Milnor, J. D. Stasheff: Characteristic Classes, Princeton, 1974.
2) R. E. Stong: Notes on Cobordism Theory, Princeton, 1968.

Title of the course:	**Algebraic topology (basic material) (C8)**

Number of contact hours per week:	2+0
Credit value:	2
Course coordinator(s):	András Szűcs
Department(s):	Department of Analysis
Evaluation:	oral examination
Prerequisites:	Algebraic Topology course in the BSC

A short description of the course:

Homology groups, cohomology ring, homotopy groups, fibrations, exact sequences, Lefschetz fixpoint theorem.

Textbook: none

Further reading:

R. M. Switzer: Algebraic Topology, Homotopy and Homology, Springer- Verlag, 1975.

Title of the course:	**Algorithms I**	**(C17)**

Number of contact hours per week:	2+2
Credit value:	2+3
Course coordinator(s):	Zoltán Király
Department(s):	Department of Computer Science
Evaluation:	oral examination and tutorial mark
Prerequisites: none	

A short description of the course:

Sorting and selection. Applications of dynamic programming (maximal interval-sum, knapsack, order of multiplication of matrices, optimal binary search tree, optimization problems in trees).

Graph algorithms: BFS, DFS, applications (shortest paths, 2-colorability, strongly connected orientation, 2-connected blocks, strongly connected components). Dijkstra's algorithm and applications (widest path, safest path, PERT method, Jhonson's algorithm). Applications of network flows. Stable matching. Algorithm of Hopcroft and Karp.

Concept of approximation algorithms, examples (Ibarra-Kim, metric TSP, Steiner tree, bin packing). Search trees. Amortization time. Fibonacci heap and its applications.

Data compression. Counting with large numbers, algorithm of Euclid, RSA. Fast Fourier transformation and its applications. Strassen's method for matrix multiplication.

Textbook:

Further reading:

T. H. Cormen, C. E. Leiserson, R. L. Rivest, C. Stein: Introduction to Algorithms, McGraw-Hill, 2002

Title of the course:	**Analysis IV (for mathematicians)**	**(B1)**

Number of contact hours per week:	4+2
Credit value:	4+2
Course coordinator(s):	János Kristóf
Department(s):	Department of Applied Analysis and Computational Mathematics, Department of Analysis
Evaluation:	oral or written examination, tutorial mark
Prerequisites:	

A short description of the course:

Abstract measures and integrals. Measurable functions. Outer measures and the extensions of measures. Abstract measure spaces. Lebesgue- and Lebesgue-Stieltjes measure spaces. Charges and charges with bounded variation. Absolute continuous and singular measures. Radon-Nycodym derivatives. Lebesgue decomposition of measures. Density theorem of Lebesgue. Absolute continuous and singular real functions. Product of measure spaces. Theorem of Lebesgue-Fubini. L^p spaces. Convolution of functions.

Textbook: none

Further reading:

1) Bourbaki, N.: Elements of Mathematics, Integration I, Chapters 1-6, Springer-Verlag, New York-Heidelberg-Berlin, 2004.
2) Dieudonné, J.: Treatise On Analysis, Vol. II, Chapters XIII-XIV, Academic Press, New York-San Fransisco-London, 1976.
3) Halmos, Paul R.: Measure Theory, Springer-Verlag, New York-Heidelberg-Berlin, 1974.
4) Rudin, W.: Principles of Mathematical Analysis, McGraw-Hill Book Co., New York-San Fransisco-Toronto-London, 1964.
5) Dunford, N.- Schwartz, T.J.: Linear operators. Part I: General Theory, Interscience Publishers, 1958.

Title of the course:	**Analysis of time series**	**(D38)**

Number of contact hours per week:	2+2
Credit value:	3+3
Course coordinator(s):	László Márkus
Department(s):	Department of Probability Theory and Statistics
Evaluation:	Oral examination
Prerequisites:	Probability theory and Statistics, Stationary processes

A short description of the course:

Basic notions of stationary processes,weak, k-order, strict stationarity, ergodicity, convergence to stationary distribution. Interdependence structure: autocovariance, autocorrelation, partial autocorrelation functions and their properties, dynamic copulas. Spectral representation of stationary processes by an orthogonal stochastic measure, the spectral density function, Herglotz's theorem.

Introduction and basic properties of specific time series models: Linear models: AR(1), AR(2) AR(p), Yule-Walker equations, MA(q), ARMA(p,q), ARIMA(p,d,q) conditions for the existence of stationary solutions and invertibility, the spectral density function. Nonlinear models: ARCH(1), ARCH(p), GARCH(p,q), Bilinear(p,q,P,Q), SETAR, regime switching models. Stochastic recursion equations, stability, the Ljapunov-exponent and conditions for the existence of stationary solutions, Kesten-Vervaat-Goldie theorem on stationary solutions with regularly varying distributions. Conditions for the existence of stationary ARCH(1) process with finite or infinite variance, the regularity index of the solution.

Estimation of the mean. Properties of the sample mean, depending on the spectral measure. Estimation of the autocovariance function. Bias, variance and covariance of the estimator. Estimation of the discrete spectrum, the periodogram. Properties of periodogram values at Fourier frequencies. Expectation, variance, covariance and distribution of the periodogram at arbitrary frequencies. Linear processes, linear filter, impulse-response and transfer functions, spectral density and periodogram transformation by the linear filter. The periodogram as useless estimation of the spectral density function. Windowed periodogram as spectral density estimation. Window types. Bias and variance of the windowed estimation. Tayloring the windows. Prewhitening and CAT criterion.

Textbook: none

Further reading:
Priestley, M.B.: Spectral Analysis and Time Series, Academic Press 1981
Brockwell, P. J., Davis, R. A.: Time Series: Theory and Methods. Springer, N.Y. 1987
Tong, H. : Non-linear time series: a dynamical systems approach, Oxford University Press, 1991.
Hamilton, J. D.: Time series analysis, Princeton University Press, Princeton, N. J. 1994
Brockwell, P. J., Davis, R. A.: Introduction to time series and forecasting, Springer. 1996.
Pena, D., Tiao and Tsay, R.: A Course in Time Series Analysis, Wiley 2001.

Title of the course:	**Applications of operations research**	**(D58)**

Number of contact hours per week:	2+0
Credit value:	3+0
Course coordinator(s):	Gergely Mádi-Nagy
Department(s):	Department of Operations Research
Evaluation:	oral or written examination
Prerequisites: -	

A short description of the course:

Applications in economics. Inventory and location problems. Modeling and solution of complex social problems. Transportation problems. Models of maintenance and production planning. Applications in defense and in water management.

Textbook: none

Further reading: none

Title of the course:	**Applied discrete mathematics seminar**	**(D44)**

Number of contact hours per week:	0+2
Credit value:	2
Course coordinator(s):	Zoltán Király
Department(s):	Department of Computer Science
Evaluation:	giving a presentation
Prerequisites: none	

A short description of the course:

Study and presentation of selected journal papers.

Textbook:

Further reading:

Title of the course:	**Approximation algorithms**	**(D59)**

Number of contact hours per week:	2+0
Credit value:	3
Course coordinator(s):	Tibor Jordán
Department(s):	Department of Operations Research
Evaluation:	oral or written examination
Prerequisites:	

A short description of the course:

approximation algorithms for NP-hard problems, basic techniques,
LP-relaxations. Set cover, primal-dual algorithms. Vertex cover, TSP, Steiner tree, feedback vertex set, bin packing, facility location, scheduling problems, k-center, k-cut, multicut, multiway cut, multicommodity flows, minimum size k-connected subgraphs, minimum superstring, minimum max-degree spanning trees.

Textbook: V.V. Vazirani, Approximation algorithms, Springer, 2001.

Further reading:

Title of the course:	**Basic algebra (reading course)**	**(B2)**

Number of contact hours per week:	0+2
Credit value:	5
Course coordinator(s):	Péter Pál Pálfy
Department(s):	Department of Algebra and Number Theory
Evaluation:	oral or written examination
Prerequisites:	

A short description of the course:

Basic group theory. Permutation groups. Lagrange’s Theorem. Homomorphisms and normal subgroups. Direct product, the Fundamental theorem of finite Abelian groups. Free groups and defining relations.

Basic ring theory. Ideals. Chain conditions. Integral domains, PID’s, euclidean domains.

Fields, field extensions. Algebraic and transcendental elements. Finite fields.

Linear algebra. The eigenvalues, the characterisitic polynmial and the minimal polynomial of a linear transformation. The Jordan normal form. Transformations of Euclidean spaces. Normal and unitary transformations. Quadratic forms, Sylvester’s theorem.

Textbook: none

Further reading:

I.N. Herstein: Abstract Algebra. Mc.Millan, 1990
P.M. Cohn: Classic Algebra. Wiley, 2000
I.M. Gel’fand: Lectures on linear algebra. Dover, 1989

Title of the course:	**Basic geometry (reading course)**	**(B3)**

Number of contact hours per week:	0+2
Credit value:	5
Course coordinator(s):	Gábor Moussong
Department(s):	Department of Geometry
Evaluation:	oral or written examination
Prerequisites:	

A short description of the course:

Non-euclidean geometries: Classical non-euclidean geometries and their models. Projective spaces. Transformation groups.
Vector analysis: Differentiation, vector calculus in dimension 3. Classical integral theorems. Space curves, curvature and torsion.
Basic topology: The notion of topological and metric spaces. Sequences and convergence. Compactness and connectedness. Fundamental group.

Textbooks:

1. M. Berger: Geometry I–II (Translated from the French by M. Cole and S. Levy). Universitext, Springer-Verlag, Berlin, 1987.
2. P.C. Matthews: Vector Calculus (Springer Undergraduate Mathematics Series). Springer, Berlin, 2000.
3. W. Klingenberg: A Course in Differential Geometry (Graduate Texts in Mathematics). Springer-Verlag, 1978.
4. M. A. Armstrong: Basic Topology (Undergraduate Texts in Mathematics), Springer-Verlag, New York, 1983.

Further reading:

Title of the course:	**Business economics**	**(D60)**

Number of contact hours per week:	2+0
Credit value:	3
Course coordinator(s):	Róbert Fullér
Department(s):	Department of Operations Research
Evaluation:	oral or written examination
Prerequisites:	

A short description of the course:

Monopoly, Lerner index; horizontal differentiation, the effect of advertisement and service; vertical differentiation; price discrimination; vertical control; Bertrand's paradox, repeated games; price competition; tacit collusion; the role of R&D in the competition.

Textbook:

Jean Tirole, The Theory of Industrial Organization, The MIT Press, Cambridge, 1997.

Further reading:

Title of the course:	**Chapters of complex function theory**	**(D9)**

Number of contact hours per week:	4+0
Credit value:	6
Course coordinator(s):	Gábor Halász
Department(s):	Department of Analysis
Evaluation:	oral examination, home work and participation
Prerequisites:	Complex Functions (BSc), Analysis IV. (BSc)

A short description of the course:

The aim of the course is to give an introduction to various chapters of functions of a complex variable. Some of these will be further elaborated on, depending on the interest of the participants, in lectures, seminars and practices to be announced in the second semester. In general, six of the following, essentially self-contained topics can be discussed, each taking about a month, 2 hours a week.

Topics:

Phragmén-Lindelöf type theorems.

Capacity. Tchebycheff constant. Transfinite diameter. Green function. Capacity and Hausdorff measure. Conformal radius.

Area principle. Koebe's distortion theorems. Estimation of the coefficients of univalent functions.

Area-length principle. Extremal length. Modulus of quadruples and rings. Quasiconformal maps. Extension to the boundary. Quasisymmetric functions. Quasiconformal curves.

Divergence and rotation free flows in the plane. Complex potencial. Flows around fixed bodies.

Laplace integral. Inversion formuli. Applications to Tauberian theorems, quasianalytic functions, Müntz's theorem.

Poisson integral of L_p functions. Hardy spaces. Marcell Riesz's theorem. Interpolation between L_p spaces. Theorem of the Riesz brothers.

Meromorphic functions in the plane. The two main theorems of the Nevanlinna theory.

Textbook:

Further reading:

M. Tsuji: Potential Theory in Modern Function Theory, Maruzen Co., Tokyo, 1959.
L.V. Ahlfors: Conformal Invariants, McGraw-Hill, New York, 1973.
Ch. Pommerenke: Univalent Functions, Vandenhoeck & Ruprecht, Göttingen, 1975.
L.V. Ahlfors: Lectures on Quasiconformal Mappings, D. Van Nostrand Co., Princeton, 1966.
W.K.Hayman: MeromorphicFunctions, Clarendon Press, Oxford 1964.
P. Koosis: Introduction to H_p Spaces, University Press, Cambridge 1980.
G. Polya and G. Latta: Complex Variables, John Wiley & Sons, New York, 1974.

Title of the course:	**Codes and symmetric structures**	**(D45)**

Number of contact hours per week:	2+0
Credit value:	3
Course coordinator(s):	Tamás Szőnyi
Department(s):	Department of Computer Science
Evaluation:	oral or written examination
Prerequisites:	

A short description of the course:

Error-correcting codes; important examples: Hamming, BCH (Bose, Ray-Chaudhuri, Hocquenheim) codes. Bounds for the parameters of the code: Hamming bound and perfect codes, Singleton bound and MDS codes. Reed-Solomon, Reed-Muller codes. The Gilbert-Varshamov bound. Random codes, explicit asymptotically good codes (Forney's concatenated codes, Justesen codes). Block designs t-designs and their links with perfect codes. Binary and ternary Golay codes and Witt designs. Fisher's inequality and its variants. Symmetric designs, the Bruck-Chowla-Ryser condition. Constructions (both recursive and direct) of block designs.

Textbook: none

Further reading:

P.J. Cameron, J.H. van Lint: Designs, graphs, codes and their links Cambridge Univ. Press, 1991.
J. H. van Lint: Introduction to Coding theory, Springer, 1992.
J. H. van Lint, R.J. Wilson, A course in combinatorics, Cambridge Univ. Press, 1992; 2001

Title of the course:	**Combinatorial algorithms I.**	**(D61)**

Number of contact hours per week:	2+2
Credit value:	3+3
Course coordinator(s):	Tibor Jordán
Department(s):	Department of Operations Research
Evaluation:	oral or written examination and tutorial mark
Prerequisites:	

A short description of the course:

Search algorithms on graphs, maximum adjacency ordering, the algorithm of Nagamochi and Ibaraki. Network flows. The Ford Fulkerson algorithm, the algorithm of Edmonds and Karp, the preflow push algorithm. Circulations. Minimum cost flows. Some applications of flows and circulations. Matchings in graphs. Edmonds` algorithm, the Gallai Edmonds structure theorem. Factor critical graphs. T-joins, f-factors. Dinamic programming. Minimum cost arborescences.

Textbook:
A. Frank, T. Jordán, Combinatorial algorithms, lecture notes.

Further reading:

Title of the course:	**Combinatorial algorithms II.**	**(D62)**

Number of contact hours per week:	2+0
Credit value:	3
Course coordinator(s):	Tibor Jordán
Department(s):	Department of Operations Research
Evaluation:	oral or written examination
Prerequisites:	

A short description of the course:

Connectivity of graphs, sparse certificates, ear decompositions. Karger`s algorithm for computing the edge connectivity. Chordal graphs, simplicial ordering. Flow equivalent trees, Gomory Hu trees. Tree width, tree decomposition. Algorithms on graphs with small tree width. Combinatorial rigidity. Degree constrained orientations. Minimum cost circulations.

Textbook:
A. Frank, T. Jordán, Combinatorial algorithms, lecture notes.

Further reading:

Title of the course:	**Combinatorial geometry**	**(C9)**

Number of contact hours per week:	2+1
Credit value:	2+2
Course coordinator:	György Kiss
Department:	Department of Geometry
Evaluation:	oral or written examination and tutorial mark
Prerequisites:	

A short description of the course:

Combinatorial properties of finite projective and affine spaces. Collineations and polarities, conics, quadrics, Hermitian varieties, circle geometries, generalized quadrangles.

Point sets with special properties in Euclidean spaces. Convexity, Helly-type theorems, transversals.

Polytopes in Euclidean, hyperbolic and spherical geometries. Tilings, packings and coverings. Density problems, systems of circles and spheres.

Textbook: none

Further reading:

1. Boltyanski, V., Martini, H. and Soltan, P.S.: Excursions into Combinatorial Geometry, Springer-Verlag, Berlin-Heidelberg-New York, 1997.
2. Coxeter, H.S.M.: Introduction to Geometry, John Wiley & Sons, New York, 1969.
3. Fejes Tóth L.: Regular Figures, Pergamon Press, Oxford-London-New York-Paris, 1964.

Title of the course:	**Combinatorial number theory.**	**(D6)**

Number of contact hours per week:	2+0
Credit value:	3
Course coordinator(s):	András Sárközy
Department(s):	Department of Algebra and Number Theory
Evaluation:	oral or written examination
Prerequisites:	Number theory 2

A short description of the course:

Brun's sieve and its applications. Schnirelmann's addition theorems, the primes form an additive basis. Additive and multiplicative Sidon sets. Divisibility properties of sequences, primitive sequences. The "larger sieve", application. Hilbert cubes in dense sequences, applications. The theorems of van der Waerden and Szemeredi on arithmetic progressions. Schur's theorem on the Fermat congruence.

Textbook: none

Further reading:

H. Halberstam, K. F. Roth: Sequences.

C. Pomerance, A. Sárközy: Combinatorial Number Theory (in: Handbook of Combinatorics)

P. Erdős, J. Surányi: Topics in number theory.

Title of the course:	**Combinatorial structures and algorithms**	**(D63)**

Number of contact hours per week:	0+2
Credit value:	3
Course coordinator(s):	Tibor Jordán
Department(s):	Department of Operations Research
Evaluation:	tutorial mark
Prerequisites:	

A short description of the course:

Solving various problems from combinatorial optimization, graph theory, matroid theory, and combinatorial geometry.

Textbook: none

Further reading: L. Lovász, Combinatorial problems and exercises, North Holland 1979.

Title of the course:	**Commutative algebra**	**(D1)**

Number of contact hours per week:	2+2
Credit value:	3+3
Course coordinator(s):	József Pelikán
Department(s):	Department of Algebra and Number Theory
Evaluation:	oral or written examination and tutorial mark
Prerequisites:	Rings and Algebras

A short description of the course:

Ideals. Prime and maximal ideals. Zorn's lemma. Nilradical, Jacobson radical. Prime spectrum.

Modules. Operations on submodules. Finitely generated modules. Nakayama's lemma. Exact sequences. Tensor product of modules.

Noetherian rings. Chain conditions for mudules and rings. Hilbert's basis theorem. Primary ideals. Primary decomposition, Lasker-Noether theorem. Krull dimension. Artinian rings.

Localization. Quotient rings and modules. Extended and restricted ideals.

Integral dependence. Integral closure. The 'going-up' and 'going-down' theorems. Valuations. Discrete valuation rings. Dedekind rings. Fractional ideals.

Algebraic varieties. 'Nullstellensatz'. Zariski-topology. Coordinate ring. Singular and regular points. Tangent space.

Dimension theory. Various dimensions. Krull's principal ideal theorem. Hilbert-functions. Regular local rings. Hilbert's theorem on syzygies.

Textbook: none

Further reading:

Atiyah, M.F.–McDonald, I.G.: Introduction to Commutative Algebra. Addison–Wesley, 1969.

Title of the course:	**Complex functions**	**(B4)**

Number of contact hours per week:	3+2
Credit value:	3+3
Course coordinator(s):	Gábor Halász
Department(s):	Department of Analysis
Evaluation:	oral examination and tutorial mark
Prerequisites:	Analysis 3 (BSc)

A short description of the course:

Complex differentiation. Power series. Elementary functions. Cauchy's integral theorem and integral formula. Power series representation of regular functions. Laurent expansion. Isolated singularities. Maximum principle. Schwarz lemma and its applications. Residue theorem. Argument principle and its applications. Sequences of regular functions. Linear fractional transformations. Riemann's conformal mapping theorem. Extension to the boundary. Reflection principle. Picard's theorem. Mappings of polygons. Functions with prescribed singularities. Integral functions with prescribed zeros. Functions of finite order. Borel exceptional values. Harmonic functions. Dirichlet problem for a disc.

Textbook:

Further reading:

L. Ahlfors: Complex Analysis, McGraw-Hill Book Company, 1979.

Title of the course:	**Complex manifolds**	**(D10)**

Number of contact hours per week:	3+2
Credit value:	4+3
Course coordinator(s):	Róbert Szőke
Department(s):	Department of Analysis
Evaluation:	oral or written examination and tutorial mark
Prerequisites:	complex analysis (BSc) real analysis and algebra (BSc) Some experience with real manifolds and differential forms is useful.

A short description of the course:

Complex and almost complex manifolds, holomorphic fiber bundles and vector bundles, Lie groups and transformation groups, cohomology, Serre duality, quotient and submanifolds, blowup, Hopf-, Grassmann and projective algebraic manifolds, Weierstrass' preparation and division theorem, analytic sets, Remmert-Stein theorem, meromorphic functions, Siegel, Levi and Chow's theorem, rational functions.

Objectives of the course: the intent of the course is to familiarize the students with the most important methods and objects of the theory of complex manifolds and to do this as simply as possible. The course completely avoids those abstract concepts (sheaves, coherence, sheaf cohomology) that are subjects of Ph.D. courses. Using only elementary methods (power series, vector bundles, one dimensional cocycle) and presenting many examples, the course introduces the students to the theory of complex manifolds and prepares them for possible future Ph.D. studies.

Textbook: Klaus Fritzsche, Hans Grauert: From holomorphic functions to complex manifolds, Springer Verlag, 2002

Further reading:
K. Kodaira: Complex manifolds and deformations of complex structures, Springer Verlag, 2004
1.Huybrechts: Complex geometry: An introduction, Springer Verlag, 2004

Title of the course:	**Complexity theory**	**(D46)**

Number of contact hours per week:	2+2
Credit value:	3+3
Course coordinator(s):	Vince Grolmusz
Department(s):	Department of Computer Science
Evaluation:	oral examination and tutorial mark
Prerequisites:	

A short description of the course: finite automata, Turing machines, Boolean circuits. Lower bounds to the complexity of algorithms. Communication complexity. Decision trees, Ben-Or's theorem, hierarchy theorems. Savitch theorem. Oracles. The polynomial hierarchy. PSPACE. Randomized complexity classes. Pseudorandomness. Interactive protocols. IP=PSPACE. Approximability theory. The PCP theorem. Parallel algorithms. Kolmogorov complexity.

Textbook: László Lovász: Computational Complexity (ftp://ftp.cs.yale.edu/pub/lovasz.pub/complex.ps.gz)

Further reading:

Papadimitriou: Computational Complexity (Addison Wesley, 1994)

Cormen. Leiserson, Rivest, Stein: Introduction to Algorithms; MIT Press and McGraw-Hill.

Title of the course:	**Complexity theory seminar**	**(D47)**

Number of contact hours per week:	0+2
Credit value:	2
Course coordinator(s):	Vince Grolmusz
Department(s):	Department of Computer Science
Evaluation:	oral examination or tutorial mark
Prerequisites:	Complexity theory

A short description of the course: Selected papers are presented in computational complexity theory

Textbook: none

Further reading:

STOC and FOCS conference proceedings

The Electronic Colloquium on Computational Complexity (http://eccc.hpi-web.de/eccc/)

Title of the course:	**Computational methods in operations research (D64)**

Number of contact hours per week:	0+2
Credit value:	0+3
Course coordinator(s):	Gergely Mádi-Nagy
Department(s):	Department of Operations Research
Evaluation:	tutorial mark
Prerequisites: -	

A short description of the course:

Implementation questions of mathematical programming methods.
Formulation of mathematical programming problems, and interpretation of solutions: progress from standard input/output formats to modeling tools.
The LINDO and LINGO packages for linear, nonlinear, and integer programming. The CPLEX package for linear, quadratic, and integer programming.
Modeling tools: XPRESS, GAMS, AMPL.

Textbook: none

Further reading:

Maros, I.: Computational Techniques of the Simplex Method, Kluwer Academic Publishers, Boston, 2003

Title of the course:	**Continuous optimization**	**(C20)**

Number of contact hours per week:	3+2
Credit value:	3+3
Course coordinator(s):	Tibor Illés
Department(s):	Department of Operations Research
Evaluation:	oral or written examination
Prerequisites:	

A short description of the course: Linear inequality systems: Farkas lemma and other alternative theorems, The duality theorem of linear programming, Pivot algorithms (criss-cross, simplex), Interior point methods, Matrix games: Nash equilibrium, Neumann theorem on the existence of mixed equilibrium, Convex optimization: duality, separability, Convex Farkas theorem, Kuhn-Tucker-Karush theorem, Nonlinear programming models, Stochastic programming models.

Textbook: none

Further reading:

1. Katta G. Murty: *Linear Programming.* John Wiley & Sons, New York, 1983.
2. Vašek Chvátal: *Linear Programming.* W. H. Freeman and Company, New York, 1983.
3. C. Roos, T. Terlaky and J.-Ph. Vial: *Theory and Algorithms for Linear Optimization: An Interior Point Approach.* John Wiley & Sons, New York, 1997.
4. Béla Martos: *Nonlinear Programming: Theory and Methods.* Akadémiai Kiadó, Budapest, 1975.
5. M. S. Bazaraa, H. D. Sherali and C. M. Shetty: *Nonlinear Programming: Theory and Algorithms.* John Wiley & Sons, New York, 1993.
6. J.-B. Hiriart-Urruty and C. Lemaréchal: *Convex Analysis and Minimization Algorithms I-II.* Springer-Verlag, Berlin, 1993.

Title of the course:	**Convex geometry**	**(D28)**

Number of contact hours per week:	4+2
Credit value:	6+3
Course coordinator(s):	Károly Böröczky, Jr.
Department(s):	Department of Geometry
Evaluation:	oral or written examination and tutorial mark
Prerequisites:	

A short description of the course:

Convex polytopes, Euler and Dehn–Sommerville formulas, upper bound theorem.
Mean projections. Isoperimetric, Brunn-Minkowski, Alexander-Fenchel, Rogers–Shephard and Blaschke-Santalo inequalities.
Lattices in Euclidean spaces. Successive minima and covering radius. Minkowski, Minkowski–Hlawka and Mahler theorems. Critical lattices and finiteness theorems. Reduced basis.

Textbook: none

Further reading:

1) B. Grünbaum: Convex polytopes, 2nd edition, Springer-Verlag, 2003.

2) P.M. Gruber: Convex and Discrete Geometry, Springer-Verlag, 2006.

3) P.M. Gruber, C.G. Lekkerkerker: Geometry of numbers, North-Holland, 1987.

Title of the course:	**Cryptography**	**(D39)**

Number of contact hours per week:	2+0
Credit value:	3
Course coordinator(s):	István Szabó
Department(s):	Department of Probability Theory and Statistics
Evaluation:	C type examination
Prerequisites:	Probability and statistics

A short description of the course:

Data Security in Information Systems. Confidentiality, Integrity, Authenticity, Threats (Viruses, Covert Channels), elements of the Steganography and Cryptography;
Short history of Cryptography (Experiences, Risks);
Hierarchy in Cryptography: Primitives, Schemes, Protocols, Applications;
Random- and Pseudorandom Bit-Generators;
Stream Ciphers: Linear Feedback Shift Registers, Stream Ciphers based on LFSRs, Linear Complexity, Stream Ciphers in practice (GSM-A5, Bluetooth-E0, WLAN-RC4), The NIST Statistical Test Suite;
Block Ciphers: Primitives (DES, 3DES, IDEA, AES), Linear and Differential Cryptanalysis;
Public-Key Encryption: Primitives (KnapSack, RSA, ElGamal public-key encryption, Elliptic curve cryptography,…), Digital Signatures, Types of attacks on PKS (integer factorisation problem, Quadratic/Number field sieve factoring, wrong parameters,…);
Hash Functions and Data Integrity: Requirements, Standards and Attacks (birthday, collisions attacks);
Cryptographic Protocols: Modes of operations, Key management protocols, Secret sharing, Internet protocols (SSL-TLS, IPSEC, SSH,…)
Cryptography in Information Systems (Applications): Digital Signatures Systems (algorithms, keys, ETSI CWA requirements, Certification Authority, SSCD Protection Profile, X-509v3 Certificate,…), Mobile communications (GSM), PGP, SET,…;
Quantum Cryptography (quantum computation, quantum key exchange, quantum teleportation).

Textbook: none

Further reading:
Bruce Schneier: Applied Cryptography. Wiley, 1996
Alfred J. Menezes, Paul C. van Oorshchor, Scott A. Vanstone: Handbook of Applied Cryptography, CRC Press, 1997, http://www.cacr.math.uwaterloo.ca/hac/

Title of the course:	**Current topics in algebra**	**(D2)**

Number of contact hours per week:	2+0
Credit value:	3
Course coordinator:	Emil Kiss
Department:	Department of Algebra and Number Theory
Evaluation:	oral or written examination
Prerequisites:	

A short description of the course:

This subject of this course is planned to change from year to year. Some possible topics: algebraic geometry, elliptic curves, p-adic numbers, valuation theory, Dedekind-domains, binding categories.

Textbook: none

Further reading:
depends on the subject

Title of the course:	**Data mining**	**(D48)**

Number of contact hours per week:	2+2
Credit value:	3+3
Course coordinator:	András Lukács
Department:	Department of Computer Science
Evaluation:	oral or written examination and tutorial mark
Prerequisites:	

A short description of the course:

Basic concepts and methodology of knowledge discovery in databases and data mining. Frequent pattern mining, association rules. Level-wise algorithms, APRIORI. Partitioning and Toivonen algorithms. Pattern growth methods, FP-growth. Hierarchical association rules. Constraints handling. Correlation search.

Dimension reduction. Spectral methods, low-rank matrix approximation. Singular value decomposition. Fingerprints, fingerprint based similarity search.

Classification. Decision trees. Neural networks. k-NN, Bayesian methods, kernel methods, SVM.

Clustering. Partitioning algorithms, k-means. Hierarchical algorithms. Density and link based clustering, DBSCAN, OPTICS. Spectral clustering.

Applications and implementation problems. Systems architecture in data mining. Data structures.

Textbook:

Further reading:

Jiawei Han és Micheline Kamber: Data Mining: Concepts and Techniques, Morgan Kaufmann Publishers, 2000, ISBN 1558604898,
Pang-Ning Tan, Michael Steinbach, Vipin Kumar: Introduction to Data Mining, Addison-Wesley, 2006, ISBN 0321321367.
T. Hastie, R. Tibshirani, J. H. Friedman: The Elements of Statistical Learning: Data Mining, Inference, and Prediction, Springer-Verlag, 2001.

Title of the course:	**Descriptive set theory**	**(D11)**

Number of contact hours per week:	3+2
Credit value:	4+3
Course coordinator(s):	Miklos Laczkovich
Department(s):	Department of Analysis
Evaluation:	oral or written examination and tutorial mark
Prerequisites:	Analysis 4, Introduction to topology

A short description of the course:

Basics of general topology. The Baire property. The tranfinite hierarchy of Borel sets. The Baire function classes. The Suslin operation. Analytic and coanalytic sets. Suslin spaces. Projective sets.

Textbook: none

Further reading:

K. Kuratowski: Topology I, Academic Press, 1967.
A. Kechris: Classical descriptive set theory, Springer, 1998.

Title of the course:	**Design, analysis and implementation of algorithms and data structures I (D49)**

Number of contact hours per week:	2+2
Credit value:	3+3
Course coordinator(s):	Zoltán Király
Department(s):	Department of Computer Science
Evaluation:	oral examination
Prerequisites:	Algorithms I

A short description of the course:

Maximum adjacency ordering and its applications. Sparse certificates for connectivity. Minimum cost arborescence. Degree constrained orientations of graphs. 2-SAT. Tree-width, applications. Gomory-Hu tree and its application. Steiner tree and traveling salesperson.

Minimum cost flow and circulation, minimum mean cycle.

Matching in non-bipartite graphs, factor-critical graphs, Edmonds' algorithm. Structure theorem of Gallai and Edmonds. T-joins, the problem of Chinese postman.

On-line algorithms, competitive ratio.

Textbook: none

Further reading:

T. H. Cormen, C. E. Leiserson, R. L. Rivest, C. Stein: Introduction to Algorithms, McGraw-Hill, 2002.

A. Schrijver: Combinatorial Optimization, Springer-Verlag, 2002.

Robert Endre Tarjan: Data Structures and Network Algorithms , Society for Industrial and Applied Mathematics, 1983.

Berg-Kreveld-Overmars-Schwarzkopf: Computational Geometry: Algorithms and Applications , Springer-Verlag, 1997.

Title of the course:	**Design, analysis and implementation of algorithms and data structures II (D50)**

Number of contact hours per week:	2+0
Credit value:	3
Course coordinator(s):	Zoltán Király
Department(s):	Department of Computer Science
Evaluation:	oral examination
Prerequisites:	Design, analysis and implementation of algorithms and data structures I

A short description of the course:

Data structures for the UNION-FIND problem. Pairing and radix heaps. Balanced and self-adjusting search trees.

Hashing, different types, analysis. Dynamic trees and their applications.

Data structures used in geometric algorithms: hierarchical search trees, interval trees, segment trees and priority search trees.

Textbook: none

Further reading:

T. H. Cormen, C. E. Leiserson, R. L. Rivest, C. Stein: Introduction to Algorithms, McGraw-Hill, 2002.

A. Schrijver: Combinatorial Optimization, Springer-Verlag, 2002.

Robert Endre Tarjan: Data Structures and Network Algorithms , Society for Industrial and Applied Mathematics, 1983.

Berg-Kreveld-Overmars-Schwarzkopf: Computational Geometry: Algorithms and Applications , Springer-Verlag, 1997.

Title of the course:	**Differential geometry I**	**(B5)**

Number of contact hours per week:	2+2
Credit value:	2+3
Course coordinator(s):	László Verhóczki
Department(s):	Department of Geometry
Evaluation:	oral or written examination and tutorial mark
Prerequisites:	

A short description of the course:

Smooth parameterized curves in the n-dimensional Euclidean space $\mathbf{R}^n$. Arc length parameterization. Distinguished Frenet frame. Curvature functions, Frenet formulas. Fundamental theorem of the theory of curves. Signed curvature of a plane curve. Four vertex theorem. Theorems on total curvatures of closed curves.

Smooth hypersurfaces in $\mathbf{R}^n$. Parameterizations. Tangent space at a point. First fundamental form. Normal curvature, Meusnier's theorem. Weingarten mapping, principal curvatures and directions. Christoffel symbols. Compatibility equations. Theorema egregium. Fundamental theorem of the local theory of hypersurfaces. Geodesic curves.

Textbook:

M. P. do Carmo: Differential geometry of curves and surfaces. Prentice Hall, Englewood Cliffs, 1976.

Further reading:

B. O'Neill: Elementary differential geometry. Academic Press, New York, 1966.

Title of the course:	**Differential geometry II**	**(C10)**

Number of contact hours per week:	2+0
Credit value:	2
Course coordinator(s):	László Verhóczki
Department(s):	Department of Geometry
Evaluation:	oral or written examination
Prerequisites:	

A short description of the course:

Differentiable manifolds. Smooth mappings between manifolds. Tangent space at a point. Tangent bundle of a manifold. Lie bracket of two smooth vector fields. Submanifolds. Covariant derivative. Parallel transport along a curve. Riemannian manifold, Levi-Civita connection. Geodesic curves. Riemannian curvature tensor field. Spaces of constant curvature. Differential forms. Exterior product. Exterior derivative. Integration of differential forms. Volume. Stokes' theorem.

Textbooks:

1. F. W. Warner: Foundations of differentiable manifolds and Lie groups. Springer-Verlag New York, 1983.
2. M. P. do Carmo: Riemannian geometry. Birkhäuser, Boston, 1992.

Further reading:

Title of the course:	**Differential topology (basic material)**	**(C11)**

Number of contact hours per week:	2+0
Credit value:	2
Course coordinator(s):	András Szűcs
Department(s):	Department of Analysis
Evaluation:	oral examination
Prerequisites:	Algebraic Topology course in BSC

A short description of the course:

Morse theory, Pontrjagin construction, the first three stable homotopy groups of spheres, Proof of the Poincare duality using Morse theory, immersion theory.

Textbook:

Further reading:
M. W. Hirsch: Differential Topology, Springer-Verlag, 1976.

Title of the course:	**Differential topology problem solving**	**(D29)**

Number of contact hours per week: 0+2
Credit value: 3
Course coordinator(s): András Szűcs
Department(s): Department of Analysis
Evaluation: oral examination
Prerequisites: BSc Algebraic Topology Course

A short description of the course:

See at the courses of Differential and Algebraic Topology of the basic material

Textbook:

Further reading:
1) J. W. Milnor J. D Stasheff: Characteristic Classes, Princeton, 1974.
2) R. E. Stong: Notes on Cobordism theory, Princeton 1968.

Title of the course:	**Discrete dynamical systems**	**(D12)**

Number of contact hours per week:	2+0
Credit value:	3
Course coordinator(s):	Zoltán Buczolich
Department(s):	Department of Analysis
Evaluation:	oral examination
Prerequisites:	Measure and integration theory (BSc Analysis 4)

A short description of the course:

Topologic transitivity and minimality. Omega limit sets. Symbolic Dynamics. Topologic Bernoulli shift. Maps of the circle. The existence of the rotation number. Invariant measures. Krylov-Bogolubov theorem. Invariant measures and minimal homeomorphisms. Rotations of compact Abelian groups. Uniquely ergodic transformations and minimality. Unimodal maps. Kneading sequence. Eventually periodic symbolic itinerary implies convergence to periodic points. Ordering of the symbolic itineraries. Characterization of the set of the itineraries. Equivalent definitions of the topological entropy. Zig-zag number of interval maps. Markov graphs. Sharkovskii's theorem. Foundations of the Ergodic theory. Maximal and Birkhoff ergodic theorem.

Textbook: none

Further reading:

A. Katok, B.Hasselblatt: Introduction to the modern theory of dynamical systems.Encyclopedia of Mathematics and its Applications, 54. Cambridge University Press,Cambridge, 1995.

W. de Melo, S. van Strien, One-dimensional dynamics, Springer Verlag, New York (1993).

I. P. Cornfeld, S. V. Fomin and Ya. G. Sinai, Ergodic Theory, Springer Verlag, New York, (1981).

Title of the course:	**Discrete geometry**	**(D30)**

Number of contact hours per week:	3+2
Credit value:	4+3
Course coordinator(s):	Károly Bezdek
Department(s):	Department of Geometry
Evaluation:	oral or written examination and tutorial mark
Prerequisites:	

A short description of the course:

Packings and coverings in $\mathbf{E}^2$. Dowker theorems. The theorems of L. Fejes Tóth and Rogers on densest packing of translates of a convex or centrally symmetric convex body. Homogeneity questions. Lattice-like arrangements. Homogeneous packings (with group actions). Space claim, separability.
Packings and coverings in (Euclidean, hyperbolic or spherical space) $\mathbf{A}^d$. Problems with the definition of density. Densest circle packings (spaciousness), and thinnest circle coverings in $\mathbf{A}^2$. Tammes problem. Solidity. Rogers' density bound for sphere packings in $\mathbf{E}^d$. Clouds, stable systems and separability. Densest sphere packings in $\mathbf{A}^3$. Tightness and edge tightness. Finite systems. Problems about common transversals.

Textbook: none

Further reading:

1. Fejes Tóth, L.: Regular figures, Pergamon Press, Oxford–London–New York–Paris, 1964.
2. Fejes Tóth, L.: Lagerungen in der Ebene auf der Kugel und im Raum, Springer-Verlag, Berlin–Heidelberg–NewYork, 1972.
3. Rogers, C. A.: Packing and covering, Cambridge University Press, 1964.
4. Böröczky, K. Jr.: Finite packing and covering, Cambridge Ubiversity Press, 2004.

Title of the course:	**Discrete mathematics**	**(C18)**

Number of contact hours per week:	2+2.
Credit value:	2+3
Course coordinator(s):	László Lovász
Department(s):	Department of Computer Science
Evaluation:	oral or written examination and tutorial grade
Prerequisites:	

A short description of the course:

Graph Theory: Colorings of graphs and.hypergraphs, perfect graphs.Matching Theory. Multiple connectivity. Strongly regular graphs, integrality condition and its application. Extremal graphs. Regularity Lemma. Planarity, Kuratowski's Theorem, drawing graphs on surfaces, minors, Robertson-Seymour Theory.

Fundamental questions of enumerative combinatorics. Generating functions, inversion formulas for partially ordered sets, recurrences. Mechanical summation.Classical counting problems in graph theory, tress, spanning trees, number of 1-factors.

Randomized methods: Expectation and second moment method. Random graphs, threshold functions.

Applications of fields: the linear algebra method, extremal set systems. Finite fields, error correcting codes, perfect codes.

Textbook: none

Further reading:

J. H. van Lint, R.J. Wilson, A course in combinatorics, Cambridge Univ. Press, 1992; 2001.
L. Lovász: Combinatorial Problems and Exercises, AMS, Providence, RI, 2007
R. L. Graham, D. E. Knuth, O. Patashnik, Concrete Mathematics,

Title of the course:	**Discrete mathematics II**	**(D51)**

Number of contact hours per week:	4+0
Credit value:	6
Course coordinator(s):	Tamás Szőnyi
Department(s):	Department of Computer Science
Evaluation:	oral examination
Prerequisites:	Discrete Mathematics I

A short description of the course:

Probabilistic methods: deterministic improvement of a random object. Construction of graphs with large girth and chromatic number.
Random graphs: threshold function, evolution around p=logn/n. Pseudorandom graphs.
Local lemma and applications.
Discrepancy theory. Beck-Fiala theorem.
Spencer's theorem. Fundamental theorem on the Vapnik-Chervonenkis dimension.

Extremal combinatorics
Non- bipartite forbidden subgraphs: Erdős-Stone-Simonovits and Dirac theorems.
Bipartite forbidden subgraphs: Turan number of paths and K(p,q). Finite geometry and algebraic constructions.
Szemerédi's regularity lemma and applications. Turán-Ramsey type theorems.
Extremal hypergraph problems: Turán's conjecture.

Textbook:

Further reading:
Alon-Spencer**:** The probabilistic method**,** Wiley 2000.

Title of the course:	**Discrete optimization**	**(C21)**

Number of contact hours per week:	3+2
Credit value:	3+3
Course coordinator:	András Frank
Department:	Dept. Of Operations research
Evaluation:	oral exam + tutorial mark
Prerequisites:	

A short description of the course:

Basic notions of graph theory and matroid theory, properties and methods (matchings, flows and circulations, greedy algorithm). The elements of polyhedral combinatorics (totally unimodular matrices and their applications). Main combinatorial algorithms (dynamic programming, alternating paths, Hungarian method). The elements of integer linear programming (Lagrangian relaxation, branch-and-bound).

Textbook:
András Frank: Connections in combinatorial optimization (electronic notes).

Further reading:
W.J. Cook, W.H. Cunningham, W.R. Pulleybank, and A. Schrijver, Combinatorial Optimization, John Wiley and Sons, 1998.

B. Korte and J. Vygen, Combinatorial Optimization: Theory and Algorithms, Springer, 2000.

E. Lawler, Kombinatorikus Optimalizálás: hálózatok és matroidok, Műszaki Kiadó, 1982. (Combinatorial Optimization: Networks and Matroids).

A. Schrijver, Combinatorial Optimization: Polyhedra and efficiency, Springer, 2003. Vol. 24 of the series Algorithms and Combinatorics.

R. K. Ahuja, T. H. Magnanti, J. B. Orlin: Network flows: Theory, Algorithms and Applications, Elsevier North-Holland, Inc., 1989

Title of the course:	**Discrete parameter martingales**	**(C13)**

Number of contact hours per week:	2+0
Credit value:	2
Course coordinator(s):	Tamás F. Móri
Department(s):	Department of Probability Theory and Statistics
Evaluation:	oral examination
Prerequisites:	Probability and statistics

A short description of the course:

Almost sure convergence of martingales. Convergence in L_p, regular martingales.
Regular stopping times, Wald's theorem.
Convergence set of square integrable martingales.
Hilbert space valued martingales.
Central limit theory for martingales.
Reversed martingales, U-statistics, interchangeability.
Applications: martingales in finance; the Conway algorithm; optimal strategies in favourable games; branching processes with two types of individuals.

Textbook: none

Further reading:
Y. S. Chow – H. Teicher: Probability Theory – Independence, Interchangeability, Martingales. Springer, New York, 1978.
J. Neveu: Discrete-Parameter Martingales. North-Holland, Amsterdam, 1975.

Title of the course:	**Dynamical systems**	**(D13)**

Number of contact hours per week:	2+0
Credit value:	3
Course coordinator(s):	Zoltán Buczolich
Department(s):	Department of Analysis
Evaluation:	oral examination
Prerequisites:	Differential equations (BSc)

A short description of the course:

Contractions, fixed point theorem. Examples of dynamical systems: Newton's method, interval maps, quadratic family, differential equations, rotations of the circle. Graphic analysis. Hyperbolic fixed points. Cantor sets as hyperbolic repelleres, metric space of code sequences. Symbolic dynamics and coding. Topologic transitivity, sensitive dependence on the initial conditions, chaos/chaotic maps, structural stability, period three implies chaos. Schwarz derivative. Bifuraction theory. Period doubling. Linear maps and linear differential equations in the plane. Linear flows and translations on the torus. Conservative systems.

Textbook: none

Further reading:

B. Hasselblatt, A. Katok: A first course in dynamics. With a panorama of recentdevelopments. Cambridge University Press, New York, 2003.

A. Katok, B.Hasselblatt: Introduction to the modern theory of dynamical systems.Encyclopedia of Mathematics and its Applications, 54. Cambridge University Press,Cambridge, 1995.

Robert L. Devaney: An introduction to chaotic dynamical systems. Second edition. AddisonWesley Studies in Nonlinearity. AddisonWesley Publishing Company, Advanced Book Program, Redwood City, CA, 1989.

Title of the course:	**Dynamical systems and differential equations (D14)**

Number of contact hours per week:	4+2
Credit value:	6+3
Course coordinator(s):	Péter Simon
Department(s):	Dept. of Appl. Analysis and Computational Math.
Evaluation:	oral or written examination and tutorial mark
Prerequisites:	Differential equations (BSc)

A short description of the course:

Topological equivalence, classification of linear systems. Poincaré normal forms, classification of nonlinear systems. Stable, unstable, centre manifolds theorems, Hartman - Grobman theorem. Periodic solutions and their stability. Index of two-dimensional vector fields, behaviour of trajectories at infinity. Applications to models in biology and chemistry. Hamiltonian systems. Chaos in the Lorenz equation.

Bifurcations in dynamical systems, basic examples. Definitions of local and global bifurcations. Saddle-node bifurcation, Andronov-Hopf bifurcation. Two-codimensional bifurcations. Methods for finding bifurcation curves. Structural stability. Attractors.

Discrete dynamical systems. Classification according to topological equivalence. 1D maps, the tent map and the logistic map. Symbolic dynamics. Chaotic systems. Smale horseshoe , Sharkovski’s theorem. Bifurcations.

Textbook: none

Further reading:

L. Perko, Differential Equations and Dynamical systems, Springer

Title of the course:	**Dynamics in one complex variable**	**(D15)**

Number of contact hours per week:	2+0
Credit value:	3
Course coordinator(s):	István Sigray
Department(s):	Department of Analysis
Evaluation:	oral or written examination and tutorial mark
Prerequisites:	

A short description of the course:
Julia és Fatou sets. Smooth Julia sets. Attractive fixpoints, Koenigs linearization theorem. Superattractive fixpoints Bötkher theorem. Parabolic fixpoints, Leau-Fatou theorem. Cremer points és Siegel discs. Holomorphic fixpoint formula. Dense subsets of the Julia set.. Herman rings. Wandering domains. Iteration of Polynomials. The Mandelbrot set. Root finding by iteration. Hyperbolic mapping. Local connectivity.

Textbook:
John Milnor: Dynamics in one complex variable, Stony Brook IMS Preprint #1990/5

Further reading:
M. Yu. Lyubich: The dynamics of rational transforms, Russian Math Survey, 41 (1986) 43–117
A. Douady: Systeme dynamique holomorphes, Sem Bourbaki , Vol 1982/83, 39-63, Asterisque, 105–106

Title of the course:	**Ergodic theory**	**(D16)**

Number of contact hours per week:	2+0
Credit value:	3
Course coordinator(s):	Zoltán Buczolich
Department(s):	Department of Analysis
Evaluation:	oral examination
Prerequisites: :	Measure and integration theory (BSc Analysis 4) , Functional analysis 1.

A short description of the course:

Examples. Constructions. Von Neumann L2 ergodic theorem. Birkhoff-Khinchin pointwise ergodic theorem. Poincaré recurrence theorem and Ehrenfest's example. Khinchin's theorem about recurrence of sets. Halmos's theorem about equivalent properties to recurrence. Properties equivalent to ergodicity. Measure preserving property and ergodicity of induced maps. Katz's lemma. Kakutani-Rokhlin lemma. Ergodicity of the Bernoulli shift, rotations of the circle and translations of the torus. Mixing (definitions). The theorem of Rényi about strongly mixing transformations. The Bernoulli shift is strongly mixing. The Koopman von Neumann lemma. Properties equivalent to weak mixing. Banach's principle. The proof of the Ergodic Theorem by using Banach's principle. Differentiation of integrals. Wiener's local ergodic theorem. Lebesgue spaces and properties of the conditional expectation. Entropy in Physics and in information theory. Definition of the metric entropy of a partition and of a transformation. Conditional information and entropy. ``Entropy metrics". The conditional expectation as a projection in L2. The theorem of Kolmogorv and Sinai about generators. Krieger's theorem about generators (without proof).

Textbook: none

Further reading:

K. Petersen, Ergodic Theory,Cambridge Studies in Advanced Mathematics 2, Cambridge University Press, (1981).

I. P. Cornfeld, S. V. Fomin and Ya. G. Sinai, Ergodic Theory, Springer Verlag, New York, (1981).

Title of the course:	**Exponential sums in number theory.**	**(D7)**

Number of contact hours per week:	2+0
Credit value:	3
Course coordinator(s):	András Sárközy
Department(s):	Department of Algebra and Number Theory
Evaluation:	oral or written examination
Prerequisites:	

A short description of the course:

Additive and multiplicative characters, their connection, applications. Vinogradov's lemma and its dual. Gaussian sums. The Pólya-Vinogradov inequality. Estimate of the least quadratic nonresidue. Kloosterman sums. The arithmetic and character form of the large sieve, applications. Irregularities of distribution relative to arithmetic progressions, lower estimate of character sums. Uniform distribution. Weyl's criterion. Discrepancy. The Erdős-Turán inequality. Van der Corput's method.

Textbook: none

Further reading:

I. M. Vinogradov: Elements of number theory
L. Kuipers, H. Niederreiter: Uniform Distribution of Sequences.
S. W. Graham, G. Kolesnik: Van der Corput’s Method of Exponential Sums.
H. Davenport: Multiplicative Number Theory.

Title of the course:	**Finite geometries**	**(D31)**

Number of contact hours per week:	2+0
Credit value:	3
Course coordinator:	György Kiss
Department:	Department of Geometry
Evaluation:	oral examination
Prerequisites:	

A short description of the course:

The axiomams of projective and affine planes, examples of finite planes, non-desarguesian planes. Collineations, configurational theorems, coordinatization of projective planes. Higher dimensional projective spaces.
Arcs, ovals, Segre’s Lemma of Tangents. Estimates on the number of points on an algebraic curve. Blocking sets, some applications of the Rédei polynomial. Arcs, caps and ovoids in higher dimensional spaces.
Coverings and packings, linear complexes, generalized polygons. Hyperovals.
Some applications of finite geometries to graph theory, coding theory and cryptography.

Textbook: none

Further reading:

1. Hirschfeld, J:W.P.: Projective Geometries over Finite Fields, Clarendon Press, Oxford, 1999.
2. Hirschfeld, J.W.P.: Finite Projective Spaces of Three Dimensions, Clarendon Press, Oxford, 1985.

Title of the course:	**Function series**	**(C4)**

Number of contact hours per week:	2+0
Credit value:	2
Course coordinator(s):	János Kristóf
Department:	Dept. of Appl. Analysis and Computational Math.
Evaluation:	oral examination
Prerequisites:	

A short description of the course:

Pointwise and L^2 norm convergence of orthogonal series. Rademacher-Menshoff theorem. Weyl-sequence. Pointwise convergence of trigonometric Fourier-series. Dirichlet integral. Riemann-Lebesgue lemma. Riemann's localization theorem for Fourier-series. Local convergence theorems. Kolmogorov's counterexample. Fejér's integral. Fejér's theorem. Carleson's theorem.

Textbooks:
Bela Szokefalvi-Nagy: Introduction to real functions and orthogonal expansions,
Natanson: Constructive function theory

Title of the course:	**Fourier integral**	**(C5)**

Number of contact hours per week:	2+1
Credit value:	2+1
Course coordinator(s):	Gábor Halász
Department(s):	Department of Analysis
Evaluation:	oral examination
Prerequisites:	Complex Functions (BSc), Analysis IV. (BSc), Probability 2. (BSc)

A short description of the course:

Fourier transform of functions in L_1. Riemann Lemma. Convolution in L_1. Inversion formula. Wiener's theorem on the closure of translates of L_1 functions. Applications to Wiener's general Tauberian theorem and special Tauberian theorems.

Fourier transform of complex measures. Characterizing continuous measures by its Fourier transform. Construction of singular measures.

Fourier transform of functions in L_2. Parseval formula. Convolution in L_2. Inversion formula. Application to non-parametric density estimation in statistics.

Young-Hausdorff inequality. Extension to L_p. Riesz-Thorin theorem. Marczinkiewicz interpolation theorem.

Application to uniform distribution. Weyl criterion, its quantitative form by Erdős-Turán. Lower estimation of the discrepancy for disks.

Characterization of the Fourier transform of functions with bounded support. Paley-Wiener theorem.

Phragmén-Lindelöf type theorems.

Textbook:

Further reading:
E.C. Titchmarsh: Introduction to the Theory of Fourier Integrals, Clarendon Press, Oxford, 1937.
A. Zygmund: Trigonometric Series, University Press, Cambridge, 1968, 2 volumes
R. Paley and N. Wiener: Fourier Transforms in the Complex Domain, American Mathematical Society, New York, 1934.
J. Beck and W.L. Chen: Irregularities of Distribution, University Press, Cambridge, 1987.

Title of the course:	**Functional analysis II**	**(C6)**

Number of contact hours per week:	1+2
Credit value:	1+2
Course coordinator(s):	Zoltán Sebestyén
Department(s):	Department of Appl. Analysis and Computational Math.
Evaluation:	oral examination
Prerequisites:	Algebra IV
	Analysis IV

A short description of the course:

Banach-Alaoglu Theorem. Daniel-Stone Theorem. Stone-Weierstrass Theorem. Gelfand Theory, Representation Theory of Banach algebras.

Textbook:
Riesz–Szőkefalvi-Nagy: Functional analysis

Further reading:
W. Rudin: Functional analysis
F.F. Bonsall-J. Duncan: Complete normed algebras

Title of the course:	**Game theory**	**(D65)**

Number of contact hours per week:	2+0
Credit value:	3
Course coordinator(s):	Tibor Illés
Department(s):	Department of Operations Research
Evaluation:	oral or written examination
Prerequisites:	

A short description of the course:

Matrix games. Optimal strategies for matrix games with saddle point. Mixed strategies, expected yield. Neumann minimax theorem. Solving matrix games with linear programming. Nash equilibrium. Sperner lemma. The first and second Knaster-Kuratowski-Mazurkiewicz theorems. The Brower and Kakutani fixed-point theorems. Shiffmann minimax theorem. Arrow-Hurwitz and Arrow-Debreu theorems. The Arrow-Hurwitz-Uzawa condition. The Arrow-Hurwitz and Uzawa algorithms. Applications of games in environment protection, health sciences and psichology.

Textbook: none

Further reading:

Forgó F., Szép J., Szidarovszky F., *Introduction to the theory of games: concepts, methods, applications*, Kluwer Academic Publishers, Dordrecht, 1999.

Osborne, M. J., Rubinstein A., *A course in game theory,* The MIT Press, Cambridge, 1994.

J. P. Aubin: *Mathematical Methods of Game and Economic Theor*. North-Holland, Amsterdam, 1982.

Title of the course:	**Geometric algorithms**	**(D52)**

Number of contact hours per week:	2+0
Credit value:	3
Course coordinator(s):	Katalin Vesztergombi
Department(s):	Department of Computer Science
Evaluation:	oral or written examination
Prerequisites:	

A short description of the course:

Convex hull algorithms in the plane and in higher dimensions.
Lower bounds: the Ben-Or theorem, moment curve, cyclic polyhedron. Decomposition of the plane by lines. Search of convex hull in the plane (in higher dimensions), search of large convex polygon (parabolic duality) . Point location queries in planar decomposition. Post office problem. Voronoi diagrams and Delaunay triangulations and applications. Randomized algorithms and estimations of running times.

Textbook: none

Further reading:
De Berg, Kreveld, Overmars, Schwartzkopf: Computational geometry. Algorithms and applications, Berlin, Springer 2000.

Title of the course:	**Geometric foundations of 3D graphics**	**(D32)**

Number of contact hours per week:	2+2
Credit value:	3+3
Course coordinator(s):	György Kiss
Department(s):	Department of Geometry
Evaluation:	oral or written examination and tutorial mark
Prerequisites:	

A short description of the course:

Planar representations of three-dimensional objects by methods of descriptive geometry (parallel and perspective projections). Matrix representations of affine transformations in Euclidean space. Homogeneous coordinates in projective space. Matrix representations of collineations of projective space. Coordinate systems and transformations applied in computer graphics. Position and orientation of a rigid body (in a fixed coordinate system). Approximation of parameterized boundary surfaces by triangulated polyhedral surfaces.
Three primary colors, tristimulus coordinates of a light beam. RGB color model. HLS color model. Geometric and photometric concepts of rendering. Radiance of a surface patch. Basic equation of photometry. Phong interpolation for the radiance of a surface patch illuminated by light sources. Digital description of a raster image. Representation of an object with triangulated boundary surfaces, rendering image by the ray tracing method. Phong shading, Gouraud shading.

Textbook: none

Further reading:

J. D. Foley, A. van Dam, S. K. Feiner, and J. F. Hughes: Computer Graphics, Principles and Practice. Addison-Wesley, 1990.

Title of the course:	**Geometric measure theory**	**(D17)**

Number of contact hours per week:	3+2
Credit value:	4+3
Course coordinator(s):	Tamás Keleti
Department(s):	Department of Analysis
Evaluation:	oral or written examination and tutorial mark
Prerequisites:	Topics in Analysis

A short description of the course:

Hausdorff measure, energy and capacity. Dimensions of product sets. Projection theorems.
Covering theorems of Vitali and Besicovitch. Differentiation of measures.
The Kakeya problem, Besicovitch set, Nikodym set.
Dini derivatives. Contingent. Denjoy-Young-Saks theorem.

Textbook: none

Further reading:
P. Mattila: Geometry of sets and measures in Euclidean spaces. Fractals and rectifiability. Cambridge University Press, Cambridge, 1995.
K. Falconer: Geomerty of Fractal Sets, Cambridge University Press, Cambridge, 1986.
S. Saks: Theory of the Integral, Dover, 1964

Title of the course:	**Geometric modeling**	**(D33)**

Number of contact hours per week:	2+0
Credit value:	3
Course coordinator(s):	László Verhóczki
Department(s):	Department of Geometry
Evaluation:	oral or written examination
Prerequisites:	

A short description of the course:

Solid modeling. Wire frames. Boundary representations. Implicit equations and parameterizations of boundary surfaces. Constructive Solid Geometry, Boolean set operations.
Representing curves and surfaces. Curve interpolation. Cubic Hermite polynomials. Fitting a composite Hermite curve through a set of given points. Curve approximation. Control polygon, blending functions. Bernstein polynomials. Bézier curves. De Casteljau algorithm. B-spline functions, de Boor algorithm. Application of weights, rational B-spline curves. Composite cubic B-spline curves, continuity conditions. Bicubic Hermite interpolation. Fitting a composite Hermite surface through a set of given points. Surface design. Bézier patches. Rational B-spline surfaces. Composite surfaces, continuity conditions.

Textbook: none

Further reading:

1. G. Farin: Curves and surfaces for computer aided geometric design. Academic Press, Boston, 1988.
2. I. D. Faux and M. J. Pratt: Computational geometry for design and manufacture. Ellis Horwood Limited, Chichester, 1979.

Title of the course:	**Geometry III**	**(B6)**

Number of contact hours per week:	3+2
Credit value:	3+2
Course coordinator(s):	Balázs Csikós
Department(s):	Department of Geometry
Evaluation:	oral or written examination and tutorial mark
Prerequisites:	

A short description of the course:

Projective geometry: projective space over a field, projective subspaces, dual space, collineations, the Fundamental Theorem of Projective Geometry. Cross ratio. The theorems of Pappus and Desargues, and their rôle in the axiomatic foundations of projective geometry. Quadrics: polarity, projective classification, conic sections.
Hyperbolic geometry: Minkowski spacetime, the hyperboloid model, the Cayley-Klein model, the conformal models of Poincaré. The absolute notion of parallelism, cycles, hyperbolic trigonometry.

Textbook:

M. Berger: Geometry I–II (Translated from the French by M. Cole and S. Levy). Universitext, Springer–Verlag, Berlin, 1987.

Further reading:

Title of the course:	**Graph theory**	**(D66)**

Number of contact hours per week:	2+0.
Credit value:	3
Course coordinator(s):	András Frank and Zoltán Király
Department(s):	Dept. of Operations Research
Evaluation:	oral exam
Prerequisites:	

Short description of the course:
Graph orientations, connectivity augmentation. Matchings in not necessarily bipartite graphs, T-joins. Disjoint trees and arborescences. Disjoint paths problems. Colourings, perfect graphs.

Textbook:
András Frank: Connections in combinatorial optimization (electronic notes).

Further reading:
W.J. Cook, W.H. Cunningham, W.R. Pulleybank, and A. Schrijver, Combinatorial Optimization, John Wiley and Sons, 1998.

R. Diestel, Graph Theory, Springer Verlag, 1996.

A. Schrijver, Combinatorial Optimization: Polyhedra and efficiency, Springer, 2003. Vol. 24 of the series Algorithms and Combinatorics.

Title of the course:	**Graph theory seminar**	**(D53)**

Number of contact hours per week:	0+2.
Credit value:	2
Course coordinator(s):	László Lovász
Department(s):	Department of Computer Science
Evaluation:	type C exam
Prerequisites:	

A short description of the course:

Study and presentation of selected papers

Textbook: none

Further reading:

Title of the course:	**Graph theory tutorial**	**(D67)**

Number of contact hours per week:	0+2
Credit value:	3
Course coordinator(s):	András Frank and Zoltán Király
Department(s):	Dept. of Operations Research
Evaluation:	tutorial mark
Prerequisites:	

A short description of the course:

Graph orientations, connectivity augmentation. Matchings in not necessarily bipartite graphs, T-joins. Disjoint trees and arborescences. Disjoint paths problems. Colourings, perfect graphs.

Textbook:
András Frank: Connections in combinatorial optimization (electronic notes).

Further reading:
W.J. Cook, W.H. Cunningham, W.R. Pulleybank, and A. Schrijver, Combinatorial Optimization, John Wiley and Sons, Icn., 1998.

R. Diestel, Graph Theory, Springer Verlag, 1996.

A. Schrijver, Combinatorial Optimization: Polyhedra and efficiency, Springer, 2003. Vol. 24 of the series Algorithms and Combinatorics.

Title of the course:	**Groups and representations**	**(C1)**

Number of contact hours per week:	2+2
Credit value:	2+3
Course coordinator(s):	Péter P. Pálfy
Department(s):	Department of Algebra and Number Theory
Evaluation:	oral or written examination and tutorial mark
Prerequisites:	

A short description of the course:

Group actions, permutation groups, automorphism groups. Semidirect products. Sylow's Theorems.

Finite p-groups. Nilpotent groups. Solvable groups, Phillip Hall's Theorems.

Free groups, presentations, group varieties. The Nielsen-Schreier Theorem.

Abelian groups. The Fundamental Theorem of finitely generated Abelian groups. Torsionfree groups.

Linear groups and linear representations. Semisimple modules and algebras. Irreducible representations. Characters, orthogonality relations. Induced representations, Frobenius reciprocity, Clifford's Theorems.

Textbook: none

Further reading:

D.J.S. Robinson: A course in the theory of groups, Springer, 1993
I.M. Isaacs: Character theory of finite groups, Academic Press, 1976

Title of the course:	**Integer programming I**	**(D68)**

Number of contact hours per week:	2+0
Credit value:	3
Course coordinator(s):	Tamás Király
Department(s):	Department of Operations Research
Evaluation:	oral or written examination
Prerequisites:	

A short description of the course:

Basic modeling techniques. Hilbert bases, unimodularity, total dual integrality. General heuristic algorithms: Simulated annealing, Tabu search. Heuristic algorithms for the Traveling Salesman Problem, approximation results. The Held-Karp bound. Gomory-Chvátal cuts. Valid inequalities for mixed-integer sets. Superadditive duality, the group problem. Enumeration algorithms.

Textbook: none

Further reading:

G.L. Nemhauser, L.A. Wolsey: Integer and Combinatorial Optimization, John Wiley and Sons, New York, 1999.

D. Bertsimas, R. Weismantel: Optimization over Integers, Dynamic Ideas, Belmont, 2005.

Title of the course:	**Integer programming II**	**(D69)**

Number of contact hours per week:	2+0
Credit value:	3
Course coordinator(s):	Tamás Király
Department(s):	Department of Operations Research
Evaluation:	oral or written examination
Prerequisites:	

A short description of the course:

Sperner systems, binary sets defined by inequalities. Lattices, basis reduction. Integer programming in fixed dimension. The ellipsoid method, equivalence of separation and optimization. The Lift and Project method. Valid inequalities for the Traveling Salesman Problem. LP-based approximation algorithms.

Textbook: none

Further reading:

G.L. Nemhauser, L.A. Wolsey: Integer and Combinatorial Optimization, John Wiley and Sons, New York, 1999.

D. Bertsimas, R. Weismantel: Optimization over Integers, Dynamic Ideas, Belmont, 2005.

Title of the course:	**Introduction to information theory**	**(D40)**

Number of contact hours per week:	2+0
Credit value:	3
Course coordinator(s):	István Szabó
Department(s):	Department of Probability Theory and Statistics
Evaluation:	oral or written examination
Prerequisites:	Probability theory and Statistics

A short description of the course:

Source coding via variable length codes and block codes. Entropy and its formal properties. Information divergence and its properties. Types and typical sequences. Concept of noisy channel, channel coding theorems. Channel capacity and its computation. Source and channel coding via linear codes. Multi-user communication systems: separate coding of correlated sources, multiple access channels.

Textbook: none

Further reading:

Csiszár – Körner: Information Theory: Coding Theorems for Discrete Memoryless Systems. Akadémiai Kiadó, 1981.

Cover – Thomas: Elements of Information Theory. Wiley, 1991.

Title of the course:	**Introduction to topology**	**(B7)**

Number of contact hours per week:	2+0
Credit value:	2
Course coordinator(s):	András Szűcs
Department(s):	Department of Analysis
Evaluation:	written examination
Prerequisites:	

A short description of the course:

Topological spaces and continuous maps. Constructions of spaces: subspaces, quotient spaces, product spaces, functional spaces. Separation axioms, Urison's lemma. Tietze theorem.Countability axioms., Urison's metrization theorem. Compactness, compactifications, compact metric spaces. Connectivity, path-connectivity. Fundamental group, covering maps.

The fundamental theorem of Algebra, The hairy ball theorem, Borsuk-Ulam theorem.

Textbook:

Further reading:

J. L. Kelley: General Topology, 1957, Princeton.

Title of the course:	**Inventory management**	**(D70)**

Number of contact hours per week:	2+0
Credit value:	3
Course coordinator(s):	Gergely Mádi-Nagy
Department(s):	Department of Operations Research
Evaluation:	oral or written examination
Prerequisites:	

A short description of the course: Harris formula (EOQ), Wagner-Whitin model, Silver-Meal heuristics, (R,Q) and (s,S) policy, The KANBAN system.

Textbook: none

Further reading:

Sven Axäter: Inventory Control, Kluwer, Boston, 2000, ISBN 0-7923-7758-3.

Title of the course:	**Investments analysis**	**(D71)**

Number of contact hours per week:	0+2
Credit value:	3
Course coordinator(s):	Róbert Fullér
Department(s):	Department of Operations Research
Evaluation:	written examination
Prerequisites:	none

A short description of the course:

Active portfolio management: The Treynor-Black model. Portfolio performance evaluation. Pension fund performance evaluation. Active portfolio management. Forint-weighted versus time-weighted returns.

Textbook:
Bodie/Kane/Marcus, Investments (Irwin, 1996)

Further reading:

Title of the course:	**LEMON library: solving optimization problems in C++ (D72)**

Number of contact hours per week:	0+2
Credit value:	3
Course coordinator(s):	Alpár Jüttner
Department(s):	Department of Operations Research
Evaluation:	Implementing an optimization algorithm.
Prerequisites:	

A short description of the course:

LEMON is an open source software library for solving graph and network optimization related algorithmic problems in C++. The aim of this course is to get familiar with the structure and usage of this tool, through solving optimization tasks. The audience also have the opportunity to join to the development of the library itself.

Textbook: none

Further reading:

http://lemon.cs.elte.hu
Ravindra K. Ahuja, Thomas L. Magnanti, and James B. Orlin. Network Flows. Prentice Hall, 1993.
W.J. Cook, W.H. Cunningham, W. Puleyblank, and A. Schrijver. Combinatorial Optimization. Series in Discrete Matehematics and Optimization. Wiley-Interscience, Dec 1997.
A. Schrijver. Combinatorial Optimization - Polyhedra and Efficiency. Springer-Verlag, Berlin, Series: Algorithms and Combinatorics , Vol. 24, 2003

Title of the course:	**Lie groups and symmetric spaces**	**(D34)**

Number of contact hours per week:	4+2
Credit value:	6+3
Course coordinator(s):	László Verhóczki
Department(s):	Department of Geometry
Evaluation:	oral or written examination and tutorial mark
Prerequisites:	

A short description of the course:

Lie groups and their Lie algebras. Exponential mapping, adjoint representation, Hausdorff-Baker-Campbell formula. Structure of Lie algebras; nilpotent, solvable, semisimple, and reductive Lie algebras. Cartan subalgebras, classification of semisimple Lie algebras.

Differentiable structure on a coset space. Homogeneous Riemannian spaces. Connected compact Lie groups as symmetric spaces. Lie group formed by isometries of a Riemannian symmetric space. Riemannian symmetric spaces as coset spaces. Constructions from symmetric triples. The exact description of the exponential mapping and the curvature tensor. Totally geodesic submanifolds and Lie triple systems. Rank of a symmetric space. Classification of semisimple Riemannian symmetric spaces. Irreducible symmetric spaces.

Textbook:

S. Helgason: Differential geometry, Lie groups, and symmetric spaces. Academic Press, New York, 1978.

Further reading:

O. Loos: Symmetric spaces I–II. Benjamin, New York, 1969.

Title of the course:	**Linear optimization**	**(D73)**

Number of contact hours per week:	2+0
Credit value:	3
Course coordinator(s):	Tibor Illés
Department(s):	Department of Operations Research
Evaluation:	oral or written examination
Prerequisites:	

A short description of the course:

Goldman-Tucker model. Self-dual linear programming problems, Interior point condition, Goldman-Tucker theorem, Sonnevend theorem, Strong duality, Farkas lemma, Pivot algorithms.

Textbook: none

Further reading:

Katta G. Murty: *Linear Programming.* John Wiley & Sons, New York, 1983.

Vašek Chvátal: *Linear Programming.* W. H. Freeman and Company, New York, 1983.

C. Roos, T. Terlaky and J.-Ph. Vial: *Theory and Algorithms for Linear Optimization: An Interior Point Approach.* John Wiley & Sons, New York, 1997.

Title of the course:	**Macroeconomics and the theory of economic equilibrium (D74)**

Number of contact hours per week:	2+0
Credit value:	3
Course coordinator(s):	Gergely Mádi-Nagy
Department(s):	Department of Operations Research
Evaluation:	written examination
Prerequisites: none	

A short description of the course:

GDP growth factors. Relation between fiscal and monetary policies. Inflation, taxes and interes rates. Consumption versus savings. Money markets and stock markets. Employment and labor market. Exports and imports. Analysis of macroeconomic models.

Textbook:

Paul A. Samuelson-William D. Nordhaus, Economics, Irwin Professiona Publishers, 2004.

Further reading:

McCuerty S.: Macroeconomic Theory, Harper & Row Publ. 1990.
Sargent Th. J.: Macroeconomic Theory, Academic Press, 1987.
Whiteman Ch. H.: Problems in Macroeconomic Theory, Academic Press, 1987.

Title of the course:	**Manufacturing process management**	**(D75)**

Number of contact hours per week:	2+0
Credit value:	3
Course coordinator(s):	Tamás Király
Department(s):	Department of Operations Research
Evaluation:	oral or written examination
Prerequisites:	

A short description of the course:

Production as a physical and information process. Connections of production management within an enterprise.

Harris formula, determination of optimal lot size: Wagner-Within model and generalizations,

balancing assembly lines, scheduling of flexible manufacturing systems, team technology, MRP and JIT systems.

Textbook:

Further reading:

Title of the course:	**Market analysis**	**(D76)**

Number of contact hours per week:	2+0
Credit value:	3
Course coordinator(s):	Róbert Fullér
Department(s):	Department of Operations Research
Evaluation:	oral or written examination
Prerequisites:	

A short description of the course:

Description of the current state of some market (e.g. wholesale food markets, electric power markets, the world market of wheat and maize); price elasticities, models using price elasticities, determination of price elasticities from real life data; dynamic models, trajectories in linear and non-linear models; attractor, Ljapunov exponent, fractals, measurement of Ljapunov exponents and fractal dimension using computer.

Textbook:

Further reading:

Title of the course:	**Markov chains in discrete and continuous time (C14)**

Number of contact hours per week:	2+0
Credit value:	2
Course coordinator(s):	Vilmos Prokaj
Department(s):	Department of Probability Theory and Statistics
Evaluation:	oral or written examination
Prerequisites:	Probability theory and Statistics

A short description of the course:

Markov property and strong Markov property for stochastic processes. Discrete time Markov chains with stationary transition probabilities: definitions, transition probability matrix. Classification of states, periodicity, recurrence. The basic limit theorem for the transition probabilities. Stationary probability distributions. Law of large numbers and central limit theorem for the functionals of positive recurrent irreducible Markov chains. Transition probabilities with taboo states. Regular measures and functions. Doeblin's ratio limit theorem. Reversed Markov chains.

Absorption probabilities. The algebraic approach to Markov chains with finite state space. Perron-Frobenius theorems.

Textbook: none

Further reading:

Karlin – Taylor: A First Course in Stochastic Processes, Second Edition. Academic Press, 1975

Chung: Markov Chains With Stationary Transition Probabilities. Springer, 1967.

Isaacson – Madsen: Markov Chains: Theory and Applications. Wiley, 1976.

Title of the course:	**Mathematical logic**	**(C19)**

Number of contact hours per week:	2+0 (noncompulsory practice)
Credit value:	2
Course coordinator(s):	Péter Komjáth
Department(s):	Department of Computer Science
Evaluation:	oral examination
Prerequisites:	

A short description of the course:

Predicate calculus and first order languages. Truth and satisfiability. Completeness. Prenex norm form. Modal logic, Kripke type models. Model theory: elementary equivalence, elementary submodels. Tarski-Vaught criterion, Löwenheim-Skolem theorem. Ultraproducts.

Gödel's compactness theorem. Preservation theorems. Beth's interpolation theorem. Types omitting theorem. Partial recursive and recursive functions. Gödel coding. Church thesis. Theorems of Church and Gödel. Formula expressing the consistency of a formula set. Gödel's second incompleteness theorem. Axiom systems, completeness, categoricity, axioms of set theory. Undecidable theories.

Textbook:

Further reading:

Title of the course:	**Mathematics of networks and the WWW**	**(D54)**

Number of contact hours per week:	2+0
Credit value:	3
Course coordinator:	András Benczúr
Department:	Department of Computer Science
Evaluation:	oral or written examination and tutorial mark
Prerequisites:	

A short description of the course:

Anatomy of search engines. Ranking in search engines. Markov chains and random walks in graphs. The definition of PageRank and reformulation. Personalized PageRank, Simrank.

Kleinberg's HITS algorithm. Singular value decomposition and spectral graph clustering. Eigenvalues and expanders.

Models for social networks and the WWW link structure. The Barabási model and proof for the degree distribution. Small world models.

Consistent hashing with applications for Web resource cacheing and Ad Hoc mobile routing.

Textbook: none

Further reading:

Searching the Web. A Arasu, J Cho, H Garcia-Molina, A Paepcke, S Raghavan. ACM Transactions on Internet Technology, 2001

Randomized Algorithms, R Motwani, P Raghavan, ACM Computing Surveys, 1996

The PageRank Citation Ranking: Bringing Order to the Web, L. Page, S. Brin, R. Motwani, T. Winograd. Stanford Digital Libraries Working Paper, 1998.

Authoritative sources in a hyperlinked environment, J. Kleinberg. SODA 1998.

Clustering in large graphs and matrices, P Drineas, A Frieze, R Kannan, S Vempala, V Vinay

Proceedings of the tenth annual ACM-SIAM symposium on Discrete algorithms, 1999.

David Karger, Alex Sherman, Andy Berkheimer, Bill Bogstad, Rizwan Dhanidina, Ken Iwamoto, Brian Kim, Luke Matkins, Yoav Yerushalmi: Web Caching and Consistent Hashing, in Proc. WWW8 conference Dept. of Appl. Analysis and Computational Math.

Title of the course:	**Matroid theory**	**(D77)**

Number of contact hours per week:	2+0
Credit value:	3
Course coordinator(s):	András Frank
Department(s):	Department of Operations Research
Evaluation:	oral examination
Prerequisites:	

Short description of the course:
Matroids and submodular functions. Matroid constructions. Rado's theorem, Edmonds' matroid intersection theorem, matroid union. Algorithms for intersection and union. Applications in graph theory (disjoint trees, covering with trees, rooted edge-connectivity).

Textbook:
András Frank: Connections in combinatorial optimization (electronic notes).

Further reading:
W.J. Cook, W.H. Cunningham, W.R. Pulleybank, and A. Schrijver, Combinatorial Optimization, John Wiley and Sons, 1998.

B. Korte and J. Vygen, Combinatorial Optimization: Theory and Algorithms, Springer, 2000.,

E. L. Lawler, Combinatorial Optimization: Networks and Matroids, Holt, Rinehart and Winston, New York, 1976.

J. G. Oxley, Matroid Theory, Oxford Science Publication, 2004.,

Recski A., Matriod theory and its applications, Springer (1989).,

A. Schrijver, Combinatorial Optimization: Polyhedra and efficiency, Springer, 2003. Vol. 24 of the series Algorithms and Combinatorics.,

D. J.A. Welsh, Matroid Theory, Academic Press, 1976.

Title of the course:	**Microeconomy**	**(D78)**

Number of contact hours per week:	2+0
Credit value:	3
Course coordinator(s):	Gergely Mádi-Nagy
Department(s):	Department of Operations Research
Evaluation:	written examination
Prerequisites:	none

A short description of the course:

The production set, plan and function, The isoquant set, Cobb-Douglas and Leontief technology, Hostelling lemma, The Le Chatelier principle, Cost minimization, The weak axiom of cost minimization, Hicks and Marshall demand function, Hicks and Slutsky compensation, Roy identity, Monetary utility, Engel curve, Giffen effect, Slutsky equation, Properties of demand function, Axioms of observed preferences, Afriat theorem, Approximation of preference relation in GARP model, Product aggregation, Hicks separability, Functional separability, Consumer aggregation, Perfect competitive market, Supply in competitive markets, Optimal production quantity, Inverse supply function, Pareto optimality, Market entering, Representative manufacturer and consumer, Several manufacturers and consumers, Oligopoly and monopoly markets, Welfare economics.

Textbook: Hal R. Varian, Microeconomic Analysis, Norton, New York, 1992.

Further reading:.

Title of the course:	**Multiple objective optimization**	**(D79)**

Number of contact hours per week:	0+2
Credit value:	3
Course coordinator(s):	Róbert Fullér
Department(s):	Department of Operations Research
Evaluation:	written examination
Prerequisites:	none

A short description of the course:

Pareto optimality. The epsilon-constrained method. The value function. The problem of the weighted objective functions. Lexicographical optimization. Trade-off methods.

Textbook: Kaisa Miettinen, Nonlinear Multiobjective Optimization, (Kluwer, 1999).

Further reading: Ralph L. Keeney and Howard Raiffa, Decisions with Multiple Objectives: Preferences and Value Tradeoffs, (Cambridge University Press, 1993).

Title of the course:	**Multiplicative number theory**	**(D8)**

Number of contact hours per week:	2+0
Credit value:	3
Course coordinator:	Mihály Szalay
Department:	Department of Algebra and Number Theory
Evaluation:	oral or written examination
Prerequisites:	Number Theory 2.

A short description of the course:

Large sieve, applications to the distribution of prime numbers. Partitions, generating function. Dirichlet's theorem concerning the prime numbers in arithmetic progressions. Introduction to analytic number theory.

Textbook: none

Further reading:

M. L. Montgomery, Topics in Multiplicative Number Theory, Springer, Berlin-Heidelberg-New York, 1971. (Lecture Notes in Mathematics 227)

Title of the course:	**Multivariate statistical methods**	**(C15)**

Number of contact hours per week:	4+0
Credit value:	4
Course coordinator(s):	György Michaletzky
Department(s):	Department of Probability Theory and Statistics
Evaluation:	oral or written examination
Prerequisites:	Probability Theory and Statistics

A short description of the course:

Estimation of the parameters of multidimensional normal distribution. Matrix valued distributions. Wishart distribution: density function, determinant, expected value of its inverse.

Hypothesis testing for the parameters of multivariate normal distribution. Independence, goodness-of-fit test for normality. Linear regression.

Correlation, maximal correlation, partial correlation, kanonical correlation.

Principal component analysis, factor analysis, analysis of variances.

Contingency tables, maximum likelihood estimation in loglinear models. Kullback–Leibler divergence. Linear and exponential families of distributions. Numerical method for determining the L-projection (Csiszár's method, Darroch–Ratcliff method)

Textbook: none

Further reading:
J. D. Jobson, Applied Multivariate Data Analysis, Vol. I-II. Springer Verlag, 1991, 1992.
C. R. Rao: Linear statistical inference and its applications, Wiley and Sons, 1968,

Title of the course:	**Nonlinear functional analysis and its applications (D18)**

Number of contact hours per week:	3+2
Credit value:	4+3
Course coordinator(s):	János Karátson
Department(s):	Dept. of Appl. Analysis and Computational Math.
Evaluation:	oral examination and home exercises
Prerequisites:	

A short description of the course:

Basic properties of nonlinear operators. Derivatives, potential operators, monotone operators, duality.

Solvability of operator equations. Variational principle, minimization of functionals.

Fixed point theorems. Applications to nonlinear differential equations.

Approximation methods in Hilbert space. Gradient type and Newton-Kantorovich iterative solution methods. Ritz–Galjorkin type projection methods.

Textbook: none

Further reading:

Zeidler, E.: Nonlinear functional analysis and its applications I-III. Kantorovich, L.V., Akilov, G.P.: Functional Analysis

Title of the course:	**Nonlinear optimization**	**(D80)**

Number of contact hours per week:	3+0
Credit value:	4
Course coordinator(s):	Tibor Illés
Department(s):	Department of Operations Research
Evaluation:	oral or written examination
Prerequisites:	

A short description of the course: Convex sets, convex functions, convex inequalities. Extremal points, extremal sets. Krein-Milman theorem. Convex cones. Recession direction, recession cones. Strictly-, strongly convex functions. Locally convex functions. Local minima of the functions. Characterization of local minimas. Stationary points. Nonlinear programming problem. Characterization of optimal solutions. Feasible, tangent and decreasing directions and their forms for differentiable and subdifferentiable functions. Convex optimization problems. Separation of convex sets. Separation theorems and their consequences. Convex Farkas theorem and its consequences. Saddle-point, Lagrangean-function, Lagrange multipliers. Theorem of Lagrange multipliers. Saddle-point theorem. Necessary and sufficient optimality conditions for convex programming. Karush-Kuhn-Tucker stationary problem. Karush-Kuhn-Tucker theorem. Lagrange-dual problem. Weak and strong duality theorems. Theorem of Dubovickij and Miljutin. Specially structured convex optimization problems: quadratic programming problem. Special, symmetric form of linearly constrained, convex quadratic programming problem. Properties of the problem. Weak and strong duality theorem. Equivalence between the linearly constrained, convex quadratic programming problem and the bisymmetric, linear complementarity problem. Solution algorithms: criss-cross algorithm, logarithmic barrier interior point method.

Textbook: none

Further reading:

Béla Martos: *Nonlinear Programming: Theory and Methods.* Akadémiai Kiadó, Budapest, 1975.

M. S. Bazaraa, H. D. Sherali and C. M. Shetty: *Nonlinear Programming: Theory and Algorithms.* John Wiley & Sons, New York, 1993.

J.-B. Hiriart-Urruty and C. Lemaréchal: *Convex Analysis and Minimization Algorithms I-II.* Springer-Verlag, Berlin, 1993.

J. P. Aubin: *Mathematical Methods of Game and Economic Theor*. North-Holland, Amsterdam, 1982.

D. P. Bertsekas: *Nonlinear Programming.* Athena Scientific, 2004.

Title of the course:	**Number theory 2.**	**(B2)**

Number of contact hours per week:	2+0
Credit value:	2
Course coordinator(s):	András Sárközy
Department(s):	Department of Algebra and Number Theory
Evaluation:	oral or written examination
Prerequisites:	

A short description of the course:

Elements of multiplicative number theory. Dirichlet's theorem,special cases. Elements of combinatorial number theory. Diophantine equations. The two square problem. Gaussian integers, special quadraticextensions. Special cases of Fermat's last theorem. The four squareproblem, Waring's problem. Pell equations. Diophantine approximation theory. Algebraic and transcendent numbers. The circle problem, elements of the geometry of numbers. The generating function method, applications. Estimates involving primes. Elements of probabilistic number theory.

Textbook: none

Further reading:

I. Niven, H.S. Zuckerman: An introduction to the theory of Numbers. Wiley, 1972.

Title of the course:	**Operations research project**	**(D81)**

Number of contact hours per week:	0+2
Credit value:	3
Course coordinator(s):	Róbert Fullér
Department(s):	Department of Operations Research
Evaluation:	written examination
Prerequisites:	none

A short description of the course:

We model real life problems with operational research methods.
Topics: Portfolio optimization models, Decision support systems, Project management models, Electronic commerce, Operations research models in telecommunication, Heuristic yield management

Textbook:

Paul A. Jensen and Jonathan F. Bard, Operations Research Models and Methods (John Wiley and Sons, 2003)

Further reading:

Mahmut Parlar, Interactive Operations Research with Maple: Methods and Models (Birkhauser, Boston, 2000)

Title of the course:	**Operator semigroups**	**(D19)**

Number of contact hours per week:	2+2
Credit value:	3+3
Course coordinator(s):	András Bátkai
Department(s):	Dept. of Appl. Analysis and Computational math.
Evaluation:	oral or written examination and course work
Prerequisites:	

A short description of the course:

Linear theory of operator semigroups. Abstract linear Cauchy problems, Hille-Yosida theory. Bounded and unbounded perturbation of generators. Spectral theory for semigroups and generators. Stability and hyperbolicity of semigroups. Further asymptotic properties.

Textbook:

Engel, K.-J. and Nagel, R.: One-parameter Semigroups for Linear Evolution Equations, Springer, 2000.

Further reading:

Title of the course:	**Partial differential equations**	**(D20)**

Number of contact hours per week:	4+2
Credit value:	6+3
Course coordinator(s):	László Simon
Department(s):	Dept. of Appl. Analysis and Computational math.
Evaluation:	oral examination and tutorial mark
Prerequisites:	

A short description of the course:

Fourier transform. Sobolev spaces. Weak, variational and classical solutions of boundary value problems for linear elliptic equations (stationary heat equation, diffusion). Initial-boundary value problems for linear equations (heat equation, wave equation): weak and classical solutions by using Fourier method and Galerkin method.

Weak solutions of boundary value problems for quasilinear elliptic equations of divergence form, by using the theory of monotone and pseudomonotone operators. Elliptic variational inequalities. Quasilinear parabolic equations by using the theory of monotone type operators. Qualitative properties of the solutions. Quasilinear hyperbolic equations.

Textbook: none

Further reading:

R.E. Showalter: Hilbert Space Method for Partial Differential Equations, Pitman, 1979;

E. Zeidler: Nonlinear Functional Analysis and its Applications II, III, Springer, 1990.

Title of the course:	**Polyhedral combinatorics**	**(D82)**

Number of contact hours per week:	2+0
Credit value:	3
Course coordinator(s):	Tamás Király
Department(s):	Department of Operations Research
Evaluation:	oral examination and tutorial mark
Prerequisites:	

A short description of the course:

Total dual integrality. Convex hull of matchings. Polymatroid intersection theorem, submodular flows and their applications in graph optimization (Lucchesi-Younger theorem, Nash-Williams' oritentation theorem).

Textbook:

Further reading:

W.J. Cook, W.H. Cunningham, W.R. Pulleybank, and A. Schrijver, Combinatorial Optimization, John Wiley and Sons, 1998.

B. Korte and J. Vygen, Combinatorial Optimization: Theory and Algorithms, Springer, 2000.

A. Schrijver, Combinatorial Optimization: Polyhedra and efficiency, Springer, 2003. Vol. 24 of the series Algorithms and Combinatorics.

Title of the course:	**Probability and statistics**	**(B8)**

Number of contact hours per week:	3+2
Credit value:	3+3
Course coordinator(s):	Tamás F. Móri
Department(s):	Department of Probability Theory and Statistics
Evaluation:	oral or written examination and tutorial mark
Prerequisites: -	

A short description of the course:

Probability space, random variables, distribution function, density function, expectation, variance, covariance, independence.
Types of convergence: a.s., in probability, in L_p, weak. Uniform integrability.
Characteristic function, central limit theorems.
Conditional expectation, conditional probability, regular version of conditional distribution, conditional density function.
Martingales, submartingales, limit theorem, regular martingales.
Strong law of large numbers, series of independent random variables, the 3 series theorem.
Statistical field, sufficiency, completeness.
Fisher information. Informational inequality. Blackwell-Rao theorem. Point estimation: method of moments, maximum likelihood, Bayes estimators.
Hypothesis testing, the likelihood ratio test, asymptotic properties.
The multivariate normal distribution, ML estimation of the parameters
Linear model, least squares estimator. Testing linear hypotheses in Gaussian linear models.

Textbook: none

Further reading:

J. Galambos: Advanced Probability Theory. Marcel Dekker, New York, 1995.
E. L. Lehmann: Theory of Point Estimation. Wiley, New York, 1983.
E. L. Lehmann: Testing Statistical Hypotheses, 2nd Ed., Wiley, New York, 1986.

Title of the course:	**Reading course in analysis**	**(B9)**

Number of contact hours per week:	0+2
Credit value:	5
Course coordinator(s):	Árpád Tóth
Department(s):	Department of Analysis
Evaluation:	oral or written examination
Prerequisites:	

A short description of the course:

Real functions. Functions of bounded variation. Riemann-Stieltjes integral, line integrals. The inverse and implicit function theorems. Optimum problems with constraints. Measure theory. The Lebesgue integral. Function spaces. Complex analysis. Cauchy's theorem and integral formula. Power series expansion of analytic functions. Isolated singular points, the residue theorem. Ordinary differential equations. Theorems on existence and uniqueness. Elementary methods. Linear equations and systems. Hilbert spaces, orthonormal systems. Metric spaces, basic topological concepts, sequences, limits and continuity of functions. Numerical methods.

Textbook: none

Further reading:

W. Rudin: Principles of mathematical analyis,
W. Rudin: Real and complex analyis,
F. Riesz and B. Szokefalvi-Nagy: Functional analysis.
G. Birkhoff and G-C. Rota: Ordinary Differential Equations,
J. Munkres: Topology.

Title of the course:	**Representations of Banach-*-algebras and abstract harmonic analysis (D21)**

Number of contact hours per week:	2+1
Credit value:	2+2
Course coordinator(s):	János Kristóf
Department(s):	Dept. of Appl. Analysis and Computational math.
Evaluation:	oral and written examination
Prerequisites:	

A short description of the course:

Representations of *-algebras. Positive functionals and GNS-construction. Representations of Banach-*-algebras. Gelfand-Raikoff theorem. The second Gelfand-Naimark theorem. Hilbert-integral of representations. Spectral theorems for C*-algebras and measurable functional calculus. Basic properties of topological groups. Continuous topological and unitary representations. Radon measures on locally compact spaces. Existence and uniqueness of left Haar-measure on locally compact groups. The modular function of a locally compact group. Regular representations. The group algebra of a locally compact group. The main theorem of abstract harmonic analysis. Gelfand-Raikoff theorem. Unitary representations of compact groups (Peter-Weyl theorems). Unitary representations of commutative locally compact groups (Stone-theorems). Factorization of Radon measures. Induced unitary representations (Mackey-theorems).

Textbook:

Further reading:

J. Dixmier: Les C*-algébres et leurs représentations, Gauthier-Villars Éd., Paris, 1969
E.Hewitt-K.Ross: Abstract Harmonic Analysis, Vols I-II, Springer-Verlag, 1963-1970

Title of the course:	**Riemann surfaces**	**(D22)**

Number of contact hours per week:	2+0,
Credit value:	3
Course coordinator(s):	Róbert Szőke
Department(s):	Department of Analysis
Evaluation:	oral or written examination
Prerequisites:	Complex analysis (Bsc), Algebraic topology (Bsc), Algebra IV (Bsc)

A short description of the course:

Abstract definition, coverings, analytic continuation, homotopy, theorem of monodromy, universal covering, covering group, Dirichlet's problem, Perron's method, Green function, homology, residue theorem, uniformization theorem for simply connected Riemann surfaces.
Determining the Riemann surface from its covering group. Fundamental domain, fundamental polygon. Riemann surface of an analytic function, compact Riemann surfaces and complex algebraic curves.

Textbook:

Further reading:
O. Forster: Lectures on Riemann surfaces, GTM81, Springer-Verlag, 1981

Title of the course:	**Riemannian geometry**	**(D35)**

Number of contact hours per week:	4+2
Credit value:	6+3
Course coordinator(s):	Balázs Csikós
Department(s):	Department of Geometry
Evaluation:	oral or written examination and tutorial mark
Prerequisites:	

A short description of the course:

The exponential mapping of a Riemannian manifold. Variational formulae for the arc length. Conjugate points. The index form assigned to a geodesic curve. Completeness of a Riemannian manifold, the Hopf-Rinow theorem. Rauch comparison theorems. Non-positively curved Riemannian manifolds, the Cartan-Hadamard theorem. Local isometries between Riemannian manifolds, the Cartan-Ambrose-Hicks theorem. Locally symmetric Riemannian spaces.

Submanifold theory: Connection induced on a submanifold. Second fundamental form, the Weingarten equation. Totally geodesic submanifolds. Variation of the volume, minimal submanifolds. Relations between the curvature tensors. Fermi coordinates around a submanifold. Focal points of a submanifold.

Textbooks:

1. M. P. do Carmo: Riemannian geometry. Birkhäuser, Boston, 1992.
2. J. Cheeger, D. Ebin: Comparison theorems in Riemannian geometry. North-Holland, Amsterdam 1975.

Further reading:

S. Gallot, D. Hulin, J. Lafontaine: Riemannian geometry. Springer-Verlag, Berlin, 1987.

Title of the course:	**Rings and algebras**	**(C3)**

Number of contact hours per week:	2+2
Credit value:	2+3
Course coordinator(s):	István Ágoston
Department(s):	Department of Algebra and Number Theory
Evaluation:	oral or written examination and tutorial mark
Prerequisites:	

A short description of the course:

Asociative rings and algebras. Constructions: polynomials, formal power series, linear operators, group algebras, free algebras, tensor algebras, exterior algebras. Structure theory: the radical, direct and semidirect decompositions. Chain conditions. The Hilbert Basis Theorem, the Hopkins theorem.

Categories and functors. Algebraic and topological examples. Natural transformations. The concept of categorical equivalence. Covariant and contravariant functors. Properties of the Hom and tensor functors (for non-commutative rings). Adjoint functors. Additive categories, exact functors. The exactness of certain functors: projective, injective and flat modules.

Homolgical algebra. Chain complexes, homology groups, chain homotopy. Examples from algebra and topology. The long exact sequence of homologies.

Commutative rings. Ideal decompositions. Prime and primary ideals. The prime spectrum of a ring. The Nullstellensatz of Hilbert.

Lie algebras. Basic notions, examples, linear Lie algebras. Solvable and nilpotent Lie algebras. Engel's theorem. Killing form. The Cartan subalgebra. Root systems and quadratic forms. Dynkin diagrams, the classification of semisimple complex Lie algebras. Universal enveloping algebra, the Poincaré–Birkhoff–Witt theorem.

Textbook: none

Further reading:

Cohn, P.M.: Algebra I-III. Hermann, 1970, Wiley 1989, 1990.
Jacobson, N.: Basic Algebra I-II. Freeman, 1985, 1989.
Humphreys, J.E.: Introduction to Lie algebras and representation theory. Springer, 1980.

Title of the course:	**Scheduling theory**	**(D83)**

Number of contact hours per week:	2+0
Credit value:	3
Course coordinator(s):	Tibor Jordán
Department(s):	Department of Operations Research
Evaluation:	oral or written examination
Prerequisites:	

A short description of the course:

Classification of scheduling problems; one-machine scheduling, priority rules (SPT, EDD, LCL), Hodgson algorithm, dynamic programming, approximation algorithms, LP relaxations. Parallel machines, list scheduling, LPT rule, Hu's algorithm. Precedence constraints, preemption. Application of network flows and matchings. Shop models, Johnson's algorithm, timetables, branch and bound, bin packing.

Textbook:

T. Jordán, Scheduling, lecture notes.

Further reading:

Title of the course:	**Selected topics in graph theory**	**(D55)**

Number of contact hours per week:	2+0
Credit value:	3
Course coordinator(s):	László Lovász
Department(s):	Department of Computer Science
Evaluation:	oral or written examination
Prerequisites:	

A short description of the course:
Selected topics in graph theory. Some topics: eigenvalues, automorphisms, graph polynomials (e.g., Tutte polynomial), topological problems

Textbook: none

Further reading:

L. Lovász: Combinatorial Problems and Exercises, AMS, Providence, RI, 2007.

Title of the course:	**Seminar in complex analysis**	**(D23)**

Number of contact hours per week:	0+2
Credit value:	2
Course coordinator(s):	Róbert Szőke
Department(s):	Department of Analysis
Evaluation:	oral or written examination or lecture on a selected topic
Prerequisites:	Topics in complex analysis (MSc)

A short description of the course:

There is no fixed syllabus. Covering topics (individual or several papers on a particular subject) related to the first semester "Topics in complex analysis" course, mostly by the lectures of the participating students.

Textbook: none

Further reading:

Title of the course:	**Set theory (introductory)**	**(B10)**

Number of contact hours per week:	2+0
Credit value:	2
Course coordinator(s):	Péter Komjáth
Department(s):	Department of Computer Science
Evaluation:	oral examination
Prerequisites:	

A short description of the course:

Naive and axiomatic set theory. Subset, union, intersection, power set. Pair, ordered pair, Cartesian product, function. Cardinals, their comparison. Equivalence theorem. Operations with sets and cardinals. Identities, monotonicity. Cantor's theorem. Russell's paradox. Examples. Ordered sets, order types. Well ordered sets, ordinals. Examples. Segments. Ordinal comparison. Axiom of replacement. Successor, limit ordinals. Theorems on transfinite induction, recursion. Well ordering theorem. Trichotomy of cardinal comparison. Hamel basis, applications. Zorn lemma, Kuratowski lemma, Teichmüller-Tukey lemma. Alephs, collapse of cardinal arithmetic. Cofinality. Hausdorff's theorem. Kőnig inequality. Properties of the power function. Axiom of foundation, the cumulative hierarchy. Stationary set, Fodor's theorem. Ramsey's theorem, generalizations. The theorem of de Bruijn and Erdős. Delta systems.

Textbook:

A. Hajnal, P. Hamburger: *Set Theory*. Cambridge University Press, 1999.

Further reading:

Title of the course:	**Set theory I**	**(D56)**

Number of contact hours per week:	4+0
Credit value:	6
Course coordinator(s):	Péter Komjáth
Department(s):	Department of Computer Science
Evaluation:	oral examination
Prerequisites:	

A short description of the course:

Cofinality, Haussdorff's theorem. Regular, singular cardinals. Stationary sets. Fodor's theorem. Ulam matrix. Partition relations. Theorems of Dushnik-Erdős-Miller, Erdős-Rado. Delta systems. Set mappings. Theorems of Fodor and Hajnal. Todorcevic's theorem. Borel, analytic, coanalytic, projective sets. Regularity properties. Theorems on separation, reduction. The hierarchy theorem. Mostowski collapse. Notions of forcing. Names. Dense sets. Generic filter. The generic model. Forcing. Cohen's result.

Textbook:

A. Hajnal, P. Hamburger: *Set Theory*. Cambridge University Press, 1999.

Further reading:

Title of the course:	**Set theory II**	**(D57)**

Number of contact hours per week:	4+0
Credit value:	6
Course coordinator(s):	Péter Komjáth
Department(s):	Department of Computer Science
Evaluation:	oral examination
Prerequisites:	

A short description of the course:

Constructibility. Product forcing. Iterated forcing. Lévy collapse. Kurepa tree. The consistency of Martin's axiom. Prikry forcing. Measurable, strongly compact, supercompact cardinals. Laver diamond. Extenders. Strong, superstrong, Woodin cardinals. The singular cardinals problem. Saturated ideals. Huge cardinals. Chang's conjecture. Pcf theory. Shelah's theorem.

Textbook:

A. Hajnal, P. Hamburger: *Set Theory*. Cambridge University Press, 1999.

Further reading:

K. Kunen: *Set Theory*.
A. Kanamori: *The Higher Infinite*.

Title of the course:	**Special functions**	**(D24)**

Number of contact hours per week:	2+0
Credit value:	3
Course coordinator(s):	Gábor Halász
Department(s):	Department of Analysis
Evaluation:	oral examination
Prerequisites:	Complex Functions (BSc), Fourier Integral (BSc)

A short description of the course:

Gamma function. Stirling formula in the complex plane, saddle point method.

Zeta function. Functional equation, elementary facts about zeros. Prime number theorem.

Elliptic functions. Parametrization of elliptic curves, lattices. Fundamental domain for the anharmonic and modular group.

Functional equation for the theta function. Holomorphic modular forms. Their application to the four square theorem.

Textbook:

Further reading:

E.T. Whittaker and G.N. Watson: A Course of Modern Analysis, University Press, Cambridge, 1927.
E.C. Titchmarsh (and D.R. Heath-Brown: The Theory of the Riemann Zeta-function, Oxford University Press, 1986.
C.L. Siegel: Topics in Complex Function Theory, John Wiley & Sons, New York, 1988, volume I.
R.C. Gunning: Lectures on Modular Forms, Princeton University Press, 1962, 96 pages

Title of the course:	**Statistical computing 1**	**(C16)**

Number of contact hours per week:	0+2
Credit value:	3
Course coordinator(s):	András Zempléni
Department(s):	Department of Probability and Statistics
Evaluation:	weekly homework or final practical and written examination, tutorial mark
Prerequisites:	Probability and statistics

A short description of the course:

Statistical hypothesis testing and parameter estimation: algorithmic aspects and technical instruments. Numerical-graphical methods of descriptive statistics. Estimation of the location and scale parameters. Testing statistical hypotheses. Probability distributions.
Representation of distribution functions, random variate generation, estimation and fitting probability distributions. The analysis of dependence. Analysis of variance. Linear regression models. A short introduction to statistical programs of different category: instruments for demonstration and education, office environments, limited tools of several problems, closed programs, expert systems for users and specialists.

Computer practice (EXCEL, Statistica, SPSS, SAS, R-project).

Textbook:

Further reading:
http://office.microsoft.com/en-us/excel/HP100908421033.aspx
http://www.statsoft.com/textbook/stathome.html
http://www.spss.com/stores/1/Training_Guides_C10.cfm
http://support.sas.com/documentation/onlinedoc/91pdf/sasdoc_91/insight_ug_9984.pdf
http://www.r-project.org/doc/bib/R-books.html
http://www.mathworks.com/access/helpdesk/help/pdf_doc/stats/stats.pdf

Title of the course:	**Statistical computing 2**	**(D41)**

Number of contact hours per week:	0+2
Credit value:	3
Course coordinator(s):	András Zempléni
Department(s):	Department of Probability and Statistics
Evaluation:	weekly homework or final practical and written examination, tutorial mark
Prerequisites:	Multidimensional statistics

A short description of the course:

Multidimensional statistics: review of methods and demonstration of computer instruments. Dimension reduction. Principal components, factor analysis, canonical correlation. Multivariate Analysis of Categorical Data. Modelling binary data, linear-logistic model. Principle of multidimensional scaling, family of deduced methods. Correspondence analysis. Grouping. Cluster analysis and classification. Statistical methods for survival data analysis. Probit, logit and nonlinear regression. Life tables, Cox-regression.

Computer practice. Instruments: EXCEL, Statistica, SPSS, SAS, R-project.

Textbook:

Further reading:

http://www.statsoft.com/textbook/stathome.html
http://www.spss.com/stores/1/Training_Guides_C10.cfm
http://support.sas.com/documentation/onlinedoc/91pdf/sasdoc_91/stat_ug_7313.pdf
http://www.r-project.org/doc/bib/R-books.html
http://www.mathworks.com/access/helpdesk/help/pdf_doc/stats/stats.pdf

Title of the course:	**Statistical hypothesis testing**	**(D42)**

Number of contact hours per week:	2+0
Credit value:	3
Course coordinator(s):	Villő Csiszár
Department(s):	Department of Probability Theory and Statistics
Evaluation:	oral examination
Prerequisites:	Probability and statistics

A short description of the course:

Monotone likelihood ratio, testing hypotheses with one-sided alternative. Testing with two-sided alternatives in exponential families. Similar tests, Neyman structure. Hypothesis testing in presence of nuisance parameters.
Optimality of classical parametric tests. Asymptotic tests. The generalized likelihood ratio test. Chi-square tests.
Convergence of the empirical process to the Brownian bridge. Karhunen-Loève expansion of Gaussian processes. Asymptotic analysis of classical nonparametric tests.
Invariant and Bayes tests.
Connection between confidence sets and hypothesis testing.

Textbook: none

Further reading:
E. L. Lehmann: Testing Statistical Hypotheses, 2nd Ed., Wiley, New York, 1986.

Title of the course:	**Stochastic optimization**	**(D84)**

Number of contact hours per week:	2+0
Credit value:	3
Course coordinator(s):	Csaba Fábián
Department(s):	Department of Operations Research
Evaluation:	oral or written examination
Prerequisites:	

A short description of the course:

Static and dynamic models.

Mathematical characterization of stochastic programming problems. Solution methods.

Theory of logconcave measures. Logconcavity of probabilistic constraints. Estimation of constraint functions through simulation.

Textbook:

Further reading:

Kall, P., Wallace, S.W., Stochastic Programming, Wiley, 1994.
Prékopa A., Stochastic Programming, Kluwer, 1995.
Birge, J.R., Louveaux, F.: Introduction to Stochastic Programming, Springer, 1997-1999.

Title of the course:	**Stochastic optimization practice**	**(D85)**

Number of contact hours per week:	0+2
Credit value:	3
Course coordinator(s):	Csaba Fábián
Department(s):	Department of Operations Research
Evaluation:	tutorial mark
Prerequisites:	

A short description of the course:

Examples of stochastic models. Different formulations of aims and constraints: by expectations or probabilities.

Building simple models, formulating and solving the deriving mathematical programming problems. Applications.

Textbook:

Further reading:

Kall, P., Wallace, S.W., Stochastic Programming, Wiley, 1994.
Prékopa A., Stochastic Programming, Kluwer, 1995.
Birge, J.R., Louveaux, F.: Introduction to Stochastic Programming, Springer, 1997-1999.

Title of the course:	**Stochastic processes with independent increments, limit theorems (D43)**

Number of contact hours per week:	2+0
Credit value:	3
Course coordinator(s):	Vilmos Prokaj
Department(s):	Department of Probability Theory and Statistics
Evaluation:	oral or written examination
Prerequisites:	Probability theory and Statistics

A short description of the course:

Infinitely divisible distributions, characteristic functions. Poisson process, compound Poisson-process. Poisson point-process with general characteristic measure. Integrals of point-processes. Lévy–Khinchin formula. Characteristic functions of non-negative infinitely divisible distributions with finite second moments. Characteristic functions of stable distributions.

Limit theorems of random variables in triangular arrays.

Textbook: none

Further reading:

Y. S. Chow – H. Teicher: Probability Theory: Independence, Interchangeability, Martingales. Springer, New York, 1978.
W. Feller: An Introduction to Probability Theory and its Applications, vol. 2. Wiley, New York, 1966.

Title of the course:	**Structures in combinatorial optimization (D86)**

Number of contact hours per week:	2+0
Credit value:	3
Course coordinator(s):	Tibor Jordán
Department(s):	Department of Operations Research
Evaluation:	oral or written examination
Prerequisites:	

A short description of the course:

Chains and antichains in partially ordered sets, theorems of Greene and Kleitman.
Mader's edge splitting theorem. The strong orientation theorem of Nash-Williams.
The interval generator theorem of Győri.

Textbook:

A. Frank, Structures in combinatorial optimization, lecture notes

Further reading:

A. Schrijver, Combinatorial Optimization: Polyhedra and efficiency, Springer, 2003. Vol. 24 of the series Algorithms and Combinatorics.

Title of the course:	**Supplementary chapters of topology I. – Topology of singularities (special material) (D36)**

Number of contact hours per week:	2+0
Credit value:	3
Lecturer:	András Némethi
Course coordinator(s):	András Szűcs
Department(s):	Department of Analysis
Evaluation:	oral examination
Prerequisites:	BSc Algebraic Topology material

A short description of the course:

1) Complex algebraic curves
2) holomorphic functions of many variables
3) implicit function theorem
4) smooth and singular analytic varieties
5) local singularities of plane curves
6) Newton diagram, Puiseux theorem
7) Resolution of plane curve singularities
8) Resolution graphs
9) topology of singularities, algebraic knots
10) Milnor fibration
11) Alexander polynomial, monodromy, Seifert matrix
12) Projective plane curves
13) Dual curve, Plucker formulae
14) Genus, Hurwitz-, Clebsh, Noether formulae
15) Holomorphic differential forms
16) Abel theorem

Textbook:

Further reading:

C. T. C. Wall: singular points of plane curves, London Math. Soc. Student Texts 63.
F. Kirwan: Complex Algebraic Curves, London Math. Soc. Student Texts 23.
E. Brieskorn, H. Korner: Plane Algebraic Curves, Birkhauser

Title of the course:	**Supplementary chapters of topology II – Low dimensional manifolds (D37)**

Number of contact hours per week:	2+0
Credit value:	3
Lecturer:	András Stipsicz
Course coordinator(s):	András Szűcs
Department(s):	Department of Analysis
Evaluation:	oral examination
Prerequisites:	BSc Algebraic Topology

A short description of the course:

1) handle-body decomposition of manifolds
2) knots in 3-manfolds, their Alexander polynomials
3) Jones polynomial, applications
4) surfaces and mapping class groups
5) 3-manifolds, examples
6) Heegard decomposition and Heegard diagram
7) 4-manifolds, Freedman and Donaldson theorems (formulations)
8) Lefschetz fibrations
9) invariants (Seiberg-Witten and Heegard Floer invariants),
10) applications

Textbook:

Further reading:

J. Milnor: Morse theory

R.E. Gompf, A. I. Stipsicz: 4-manifolds and Kirby calculus, Graduate Studies in Mathematics, Volume 20, Amer. Math. Soc. Providence, Rhode Island.

Title of the course:	**Topics in analysis**	**(C7)**

Number of contact hours per week:	2+1
Credit value:	2+2
Course coordinator(s):	Tamás Keleti
Department(s):	Department of Analysis
Evaluation:	oral or written examination and tutorial mark
Prerequisites:	Analysis IV

A short description of the course:

Hausdorff measure and Hausdorff dimension. The Hausdorff dimension of R^n and some fractals, length and 1-dimensional measure.
Haar measure. Existence and uniqueness.
Approximation theory. Approximation with Fejér means, de la Vallée Poussin operator, Fejér-Hermite interpolation, Bernstein polynom.
The order of approximation. Approximation with analytic functions.
Approximation with polynomials. Tschebishev polynomials.

Textbook: none

Further reading:
P. Halmos: Measure Theory, Van Nostrand, 1950
K.J. Falconer: The Geometry of Fractal Sets, CUP, 1985
D. Jackson: The theory of approximation, AMS, 1994.

Title of the course:	**Topics in differential geometry**	**(C12)**

Number of contact hours per week:	2+0
Credit value:	2
Course coordinator:	Balázs Csikós (associate professor)
Department:	Department of Geometry
Evaluation:	oral or written examination
Prerequisites:	

A short description of the course:

Differential geometric characterization of convex surfaces. Steiner-Minkowski formula, Herglotz integral formula, rigidity theorems for convex surfaces.

Ruled surfaces and line congruences.

Surfaces of constant curvature. Tchebycheff lattices, Sine-Gordon equation, Bäcklund transformation, Hilbert's theorem. Comparison theorems.

Variational problems in differential geometry. Euler-Lagrange equation, brachistochron problem, geodesics, Jacobi fields, Lagrangian mechanics, symmetries and invariants, minimal surfaces, conformal parameterization, harmonic mappings.

Textbook: none

Further reading:

1. W. Blaschke: Einführung in die Differentialgeometrie. Springer-Verlag, 1950.
2. J. A. Thorpe: Elementary Topics in Differential Geometry. Springer-Verlag, 1979.
3. J. J. Stoker: Differential Geometry. John Wiley & Sons Canada, Ltd.; 1989.
4. F. W. Warner: Foundations of Differentiable Manifolds and Lie Groups. Springer-Verlag, 1983.

Title of the course:	**Topics in group theory**	**(D3)**

Number of contact hours per week:	2+2
Credit value:	3+3
Course coordinator(s):	Péter P. Pálfy
Department(s):	Department of Algebra and Number Theory
Evaluation:	oral or written examination and tutorial mark
Prerequisites:	Groups and representations

A short description of the course:

Permutation groups. Multiply transitive groups, Mathieu groups. Primitive permutation groups, the O'Nan-Scott Theorem.

Simple groups. Classical groups, groups of Lie type, sporadic groups.

Group extensions. Projective representations, the Schur multiplier.

p-groups. The Frattini subgroup. Special and extraspecial *p*-groups. Groups of maximal class.

Subgroup lattices. Theorems of Ore and Iwasawa.

Textbook: none

Further reading:

D.J.S. Robinson: A course in the theory of groups, Springer, 1993
P.J. Cameron: Permutation groups, Cambridge University Press, 1999
B. Huppert, Endliche Gruppen I, Springer, 1967

Title of the course:	**Topics in ring theory**	**(D4)**

Number of contact hours per week:	2+2
Credit value:	3+3
Course coordinator(s):	István Ágoston
Department(s):	Department of Algebra and Number Theory
Evaluation:	oral or written examination and tutorial mark
Prerequisites:	Rings and algebras

A short description of the course:

Structure theory: primitive rings, Jacobson's Density Theorem, the Jacobson radical of a ring, commutativity theorem. Central simple algebras: tensor product of algebras, the Noether–Scolem Theorem, the Double Centralizer Therem, Brauer group, crossed product. Polynomial identities: structure theorems, Kaplansky's theorem, the Kurosh Problem, combinatorial results, quantitative theory. Noetherian rings: Goldie's theorems and generalizations, dimension theory. Artinina rings and generalizations: Bass's characterization of semiperfect and perfect rings, coherent rings, von Neumann regular rings, homological properties. Morita theory: Morita equivalence, Morita duality, Morita invariance. Quasi-Frobenius rings: group algebras, symmetric algebras, homological properties. Representation theory: hereditary algebras, Coxeter transformations and Coxeter functors, preprojective, regular and preinjective representations, almost split sequences, the Baruer–Thrall Conjectures, finite representation type.

The Hom and tensor functors: projective, imjective and flat modules. Derived functors: projective and injective resolutions, the construction and basic properties of the Ext and Tor functors. Exact seuqences and the Ext functor, the Yoneda composition, Ext algebras. Homological dimensions: projective, injective and global dimension, The Hilbert Syzygy Theorem, dominant dimension, finitistic dimension, the finitistic dimension conjecture. Homological methods in representation theory: almost split sequences, Auslander–Reiten quivers. Derived categories: triangulated categories, homotopy category of complexes, localization of categories, the derived category of an algebra, the Morita theory of derived categories by Rickard.

Textbook: none

Further reading:

Anderson, F.–Fuller, K.: Rings and categories of modules, Springer, 1974, 1995
Auslander, M.–Reiten, I.–Smalø: Representation theory of Artin algebras, Cambridge University Press, 1995
Drozd, Yu. –Kirichenko, V.: Finite dimensional algebras, Springer, 1993
Happel, D.: Triangulated categories in the representation theory of finite dimensional algebras, CUP, 1988
Herstein, I.: Noncommutative rings. MAA, 1968.
Rotman, J.: An introduction to homological algebra, AP, 1979

Title of the course:	**Topological vector spaces and Banach-algebras (D25)**

Number of contact hours per week:	2+2
Credit value:	3+3
Course coordinator(s):	János Kristóf
Department:	Dept. of Appl. Analysis and Computational Math.
Evaluation:	oral and written examination
Prerequisites:	

A short description of the course:

Basic properties of linear topologies. Initial linear topologies. Locally compact topological vector spaces. Metrisable topological vector spaces. Locally convex and polinormed spaces. Inductive limit of locally convex spaces. Krein-Milmans theorem. Geometric form of Hahn-Banach theorem and separation theorems. Bounded sets in topological vector spaces. Locally convex function spaces. Ascoli theorems. Alaoglu-Bourbaki theorem. Banach-Alaoglu theorem. Banach-Steinhaus theorem. Elementary duality theory. Locally convex topologies compatible with duality. Mackey-Arens theorem. Barrelled, bornologic, reflexive and Montel-spaces. Spectrum in a Banach-algbera. Gelfand-representation of a commutative complex Banach-algebra. Banach-*-algebras and C*-algebras. Commutative C*-algebras (I. Gelgand-Naimark theorem). Continuous functional calculus. Universal covering C*-algebra and abstract Stone’s theorem. Positive elements in C*-algebras. Baer C*-algebras.

Textbook:

Further reading:

N. Bourbaki: Espaces vectoriels topologiques, Springer, Berlin-Heidelberg-New York, 2007
N. Bourbaki: Théories spectrales, Hermann, Paris, 1967
J. Dixmier: Les C*-algébres et leurs représentations, Gauthier-Villars Éd., Paris, 1969

Title of the course:	**Unbounded operators of Hilbert spaces** **(D26)**

Number of contact hours per week:	2+0
Credit value:	3
Course coordinator(s):	Zoltán Sebestyén
Department:	Dept. of Appl. Analysis and Computational Math.
Evaluation:	oral examination
Prerequisites:	Functional analysis (BSc)

A short description of the course:

Neumann's theory of closed Hilbert space operators: existence of the second adjoint and the product of the first two adjoints as a positive selfadjoint operator. Up to date theory of positive selfadjoint extensions of not necessarily densely defined operators on Hilbert space: Krein's theory revisited. Extremal extensions are characterized including Friedrichs and Krein-von Neumann extensions. Description of a general positive selfadjoint extension.

Textbook:

Further reading:

Title of the course:	**Universal algebra and lattice theory**	**(D5)**

Number of contact hours per week:	2+2
Credit value:	3+3
Course coordinator:	Emil Kiss
Department:	Department of Algebra and Number Theory
Evaluation:	oral or written examination and tutorial mark
Prerequisites:	

A short description of the course:

Similarity type, algebra, clones, terms, polynomials. Subalgebra, direct product, homomorphism, identity, variety, free algebra, Birkhoff's theorems. Subalgebra lattices, congruence lattices, Grätzer-Schmidt theorem. Mal'tsev-lemma. Subdirect decomposition, subdirectly irreducible algebras, Quackenbush-problem.
Mal'tsev-conditions, the characterization of congruence permutable, congruence distributive and congruence modular varieties. Jónsson's lemma, Fleischer-theorem. Congruences of lattices, lattice varieties.
Partition lattices, every lattice is embeddable into a partition lattice. Free lattices, Whitman-condition, canonical form, atoms, the free lattice is semidistributive, the operations are continuous. There exists a fixed point free monotone map.
Closure systems. Complete, algebraic and geometric lattices. Modular lattices. The free modular lattice generated by three elements. Jordan-Dedekind chain condition. Semimodular lattices. Distributive lattices.
Lattices and geometry: subspace lattices of projective geometries. Desargues-identity, geomodular lattices. Coordinatization. Complemented lattices. The congruences of relatively complemented lattices.
The question of completeness, primal and functionally complete algebras, characterizations, discriminator varieties. Directly representable varieties.
The Freese-Lampe-Taylor theorem about the congruence lattice of algebras with a few operations. Abelian algebras, centrality, the properties of the commutator in modular varieties. Difference term, the fundamental theorem of Abelian algebras. Generalized Jónsson-theorem. The characterization of finitely generated, residually small varieties by Freese and McKenzie.
Congruence lattices of finite algebras: the results of McKenzie, Pálfy and Pudlak. Induced algebra, their geometry, relationship with the congruence lattice of the entire algebra. The structure of minimal algebras. Types, the labeling of the congruence lattice. Solvable algebras.
The behavior of free spectrum. Abelian varieties. The distribution of subdirectly irreducible algebras. Finite basis theorems. First order decidable varieties, undecidable problems.

Textbook: none

Further reading:

Burris-Sankappanavar: *A course in universal algebra*. Springer, 1981.
Freese-McKenzie: *Commutator theory for congruence modular varieties*. Cambridge University Press, 1987.
Hobby-McKenzie: The structure of finite algebras. AMS Contemporary Math. 76, 1996