JACOBS UNIVERSITY

Applied and Computational Mathematics

Bachelor's Degree Program (BSc)

Applied and Computational Mathematics

Program Handbook Bachelor of Science

Academic Year 2012–13

Contents

1 Concept

Applied and Computational Mathematics (ACM) is an interdisciplinary major teaching modern quantitative modeling in a broad spectrum of applications areas. At Jacobs University, we offer specializations in

- *Computational Biology* including Bioinformatics and Biomedical Modeling with strong links to a broad array of experimental and theoretical life sciences,
- *Computational Mathematics* with a focus on the theoretical foundations while keeping an option for interdisciplinary work, and
- *Financial Mathematics* on theory and computation of asset valuation and risk.

Whichever path you will choose, we will take you on a journey which involves advanced mathematical algorithm and the use of high performance computers toward understanding and solving real-world problems in a virtual laboratory.

1.1 ACM core

A solid mathematical and methodological training provides the basis for study and research in the theoretical applied sciences and scientific computation. This core knowledge include the following subject areas.

- Mathematics and Mathematical Methods: Calculus, Linear Algebra, Introduction to Combinatorics, Probability and Statistics, Elements of Group Theory, Graph Theory, and Optimization;
- Numerical Methods;
- Data Structures and Algorithms, Programming Languages, and Mathematical Software;
- Theory of Nonlinear Dynamical Systems.

Since modeling is necessarily a two-way exchange between theory and observation, all ACM students are also required to get some exposure to at least one experimental subject area including laboratory experience in the field. The default choices are Physics and/or Biochemistry, but others are possible.

1.2 Specialization areas

Students will choose a specialization area when entering their second year of study. After successful completion of the first year, it is in principle possible to transition into each of the specializations. However, a smooth transition requires a compatible choice of first year courses, so that students are encouraged to look ahead early.

It is important to note that a professional career in any of the specializations normally involves obtaining a Masters and possibly a Doctoral degree upon completion of the Bachelor. (On the other hand, a Bachelor in Applied and Computational Mathematics certainly opens up a multitude of professional career opportunities—see below.) Therefore, the overarching goal of our Bachelor program, independent of the chosen specialization, is the development of problem solving skills as well as providing a toolbox of methods which are widely applicable across fields. The specialization areas cannot replace targeted postgraduate study, but rather embed the ACM core into specific fields of modern interest and appeal.

Computational Biology The specialization in Computational Biology will equip students with a broad view towards applying mathematical and computational methods in the Life Sciences and Medicine. The training comprises two distinct, but scientifically highly interrelated directions: *Bioinformatics*, the investigation of the genome from an information theoretic point of view, and *Systems Biology* which analyzes biological and ecological processes as dynamical systems. Through cooperation with the Fraunhofer MEVIS research institute, there is ample opportunity for specialization courses and undergraduate research in the direction of *Biomedical Modeling*.

Computational Mathematics The specialization in Computational Mathematics focuses on the methodological and theoretical foundations. This choice leaves students with the widest range of possible career paths, ranging from graduate study and research in Applied Mathematics, Scientific Computing, Computational Engineering, to further study in any of the other specialization areas. Graduates will have obtained a solid foundation in Mathematical Analysis, Numerical Analysis, Dynamical Systems, and some exposure to Scientific Computing.

Financial Mathematics The specialization in Financial Mathematics is the most abstract of the three. In addition to the mathematics requirements of the specialization in Computational Mathematics, students will learn measure theory and stochastic processes which form the foundation of methods for derivative pricing. Courses on economics, risk control, and legal and regulatory frameworks give a broader perspective of the objectives and constraints for modeling assets and risks.

1.3 Career Options

Studying Applied and Computational Mathematics will make you a versatile and sought-after candidate for employment in industry, professional master's programs in the fields of computational engineering and computational finance, as well as research focused graduate programs in applied mathematics, computer science, and your chosen field of specialization. Professional career fields include bio-medical technology, IT, engineering, consulting, and finance.

The ACM program cooperates with other institutions in the Bremen area, e.g. Fraunhofer MEVIS, The Leibniz Center for Tropical Marine Ecology, and the Alfred Wegener Institute.

Our students have enrolled in graduate programs or have accepted positions with institutions like Cambridge University, the University of California, Oxford University, the European Bioinformatics Institute, and many others.

2 Requirements for the Bachelor of Science Degree

2.1 General requirements

To obtain a B.Sc. degree at Jacobs University, a minimum of 180 ECTS credit points must be earned over a period of 6 semesters.

- A minimum of 140 ECTS credits must be earned in the School of Engineering and Science.
- 30 ECTS credits must be earned through transdisciplinary courses, comprised of courses in the School of Humanities and Social Sciences (SHSS) and University Study Courses (USC). The choice between SHSS courses and USCs is free.
- Up to 4 language courses (up to 10 ECTS credit points) may be counted toward Home School Electives.
- All undergraduate students are required to complete an internship, normally to be accomplished between the second and third year of study. Information about the internship will be listed on the transcript. The internship must last at least two consecutive months. No credits are connected to the internship requirement.
- It is mandatory to successfully complete a Bachelor Thesis in ACM. This thesis needs to be supervised by one or several faculty memebers, at least one from within the major. Writing the thesis is formally part of *Guided Research and BSc Thesis in Applied and Computational Mathematics II*.

2.2 ACM core requirements

Year 1 level courses

- Two consecutive first year Engineering and Science Mathematics courses. For students taking Analysis I/II in their first year of study and Linear Algebra I/II in their first or second year of study, this requirement is waived.
- *General Mathematics and Computational Science I* and *General Mathematics and Computational Science II*
- *Natural Science Lab Unit – Symbolic Software*, *Natural Science Lab Unit – Numerical Software*, *NatSciLab Unit Computer Science I*, *NatSciLab Unit Computer Science II*, and two experimental science or engineering lab units.

Year 2 level courses

- *Fundamental Computer Science I (Algorithms and Data Structures)*
- *ESM 4A – Numerical Methods*
- *Nonlinear Dynamics Lab*

Year 3 level courses

- *Dynamical Systems and Control*

2.3 Computational Biology specialization requirements

Year 1 level courses

- *General Biochemistry and Cell Biology I* and *General Biochemistry and Cell Biology II*
- *General Physics I* and General Physics II [2] or *General Computer Science I* and *General Computer Science II*; alternatives by permission.

Year 2 level courses

- *Advanced Biochemistry and Molecular Biology I* and *Advanced Biochemistry and Molecular Biology II*
- *Bioinformatics and Computational Biology* and *Bioinformatics Lab Course*

Year 3 level courses

- *Computational Systems Biology*
- *Design of Biological Molecules and Systems*
- 15 ECTS credits from the Life Sciences or Computer science
- 15 ECTS credits Guided Research

2.4 Computational Mathematics specialization requirements

Year 1 level courses

- *General Physics I* and General Physics II [2]
- *General Biochemistry and Cell Biology I* and *General Biochemistry and Cell Biology II* or *General Computer Science I* and *General Computer Science II*; alternatives by permission.

Year 2 level courses

- *Analysis I* and *Analysis II*
- *ESM 3B – Complex Variable Calculus, PDE*; may be replaced by other second or third year Mathematics, ACM, Service Mathematics credit provided student takes *Introductory Partial Differential Equations* or *Partial Differential Equations*.
- 10 additional ECTS credits at second or third year level in Mathematics, ACM, Service Mathematics, or selected theoretical Physics courses.

Year 3 level courses

- *Numerical Analysis*
- *Introduction to parallel programming with MPI and OpenMP*
- 7.5 ECTS credits in Mathematics at third year level
- 7.5 ECTS credits Guided Research
- 10 ECTS credits in Scientific Computing/Applied Mathematics; please consult faculty for advice.

2.5 Financial Mathematics specialization requirements

Year 1 level courses

- *General Physics I* and General Physics II [2]
- *General Computer Science I* and *General Computer Science II* or *General Biochemistry and Cell Biology I* and *General Biochemistry and Cell Biology II*; alternatives by permission.

Year 2 level courses

- *Analysis I* and *Analysis II*
- *ESM 3A – Advanced Linear Algebra, Stochastic Processes* or *ESM 3B – Complex Variable Calculus, PDE*; may be replaced by other second or higher Mathematics, ACM, Service Mathematics credit provided student takes Partial Differential Equations.
- *Derivatives Lab*

Year 3 level courses

- *Numerical Analysis*
- *Real Analysis*
- *Stochastic Processes* or *Applied Stochastic Processes*
- *Introduction to parallel programming with MPI and OpenMP*
- 5 ECTS in Applied Mathematics (Risk Management is recommended)
- 7.5 ECTS credits Guided Research

Transdisciplinary Courses

- Two courses in the area of Business and Economics
- *Statistical Concepts and Data Analysis* or any more advanced course on Statistics

3 Recommended Course Plan

Warning: Some courses may shift from the spring into the fall semester (and vice versa) on short notice. Please check at the beginning of the fall semester if this is the case for any mandatory or recommended courses from the spring semester of the same academic year.

3.1 Computational Biology specialization

Year 1 Courses	**Fall**	**C**	**T**	**Spring**	**C**	**T**
Engineering & Science Mathematics I and II [1]	120111	5	m	120112	5	m
General Mathematics & CPS I and II	110101	5	m	110102	5	m
Numerical and Symbolic Software Lab Units	110111	2.5	m	110112	2.5	m
General Biochemistry & Cell Biology I/II	520101	5	m	520102	5	m
Biochemistry and Cell Biology Lab Units [3]	520111	2.5	m	520112	2.5	m
General lectures in a third subject area [4]		5	m		5	m
Computer Science Lab Units	320111	2.5	m	320112	2.5	m
Transdisciplinary Courses		5	u		5	u
Running Total / *Semester Total*	32.5	*32.5*		65	*32.5*	

Year 2 Courses	**Fall**	**C**	**T**	**Spring**	**C**	**T**
Algorithms and Data Structures	320201	5	m			
Numerical Methods				120202	5	m
Advanced Biochemistry & Molecular Biology I/II	520201	5	m	520202	5	m
Bioinformatics and Computational Biology	550201	5	m			
Bioinformatics and Computational Biology Lab	550221	7.5	m			
Nonlinear Dynamics Lab				110231	7.5	m
Course in Life Sciences or Computer Science [5]					5	m
Language Courses or Home School Electives		2.5	e		2.5	e
Transdisciplinary Courses		5	u		5	u
Running Total / *Semester Total*	95	*30*		125	*30*	

Year 3 Courses	**Fall**	**C**	**T**	**Spring**	**C**	**T**
Dynamical Systems and Control	300301	5	m			
Computational Systems Biology				550321	5	m
Design of Biomolecules and Systems				560302	5	m
Courses in Life Sciences or Computer Science [5]		10	m			
Guided Research/Bachelor Thesis	110391	7.5	m	110392	7.5	m
Language Courses or Home School Electives		2.5	e		2.5	e
Transdisciplinary Courses		5	u		5	u
Running Total / *Semester Total*	155	*30*		180	*25*	

C = ECTS credit points, T=type (m=mandatory, e=elective, u=university requirement)

3.2 Computational Mathematics specialization

Year 1 Courses	**Fall**	**C**	**T**	**Spring**	**C**	**T**
Engineering & Science Mathematics I and II [1]	120111	*5*	m	120112	*5*	m
General Mathematics & CPS I and II	110101	*5*	m	110102	*5*	m
Numerical and Symbolic Software Lab Units	110111	*2.5*	m	110112	*2.5*	m
General Physics I/II [2]	200101	*5*	m	200102	*5*	m
Physics Lab Units [3]	200111	*2.5*	m	200112	*2.5*	m
General lectures in a third subject area [6]		*5*	m		*5*	m
Computer Science Lab Units	320111	*2.5*	m	320112	*2.5*	m
Transdisciplinary Courses		*5*	u		*5*	u
Running Total / *Semester Total*	32.5	*32.5*		65	*32.5*	

Year 2 Courses	**Fall**	**C**	**T**	**Spring**	**C**	**T**
Algorithms and Data Structures	320201	*5*	m			
Numerical Methods				120202	*5*	m
Analysis I/II	100211	*7.5*	m	100212	*7.5*	m
ESM 3B (Complex Variable Calculus, PDE) [7]	120211	*5*	m			
Nonlinear Dynamics Lab				110231	*7.5*	m
Scientific Computing/Applied Mathematics [8]		*5*	m		*5*	m
Language Courses or Home School Electives		*2.5*	e			
Transdisciplinary Courses		*5*	u		*5*	u
Running Total / *Semester Total*	95	*30*		125	*30*	

Year 3 Courses	**Fall**	**C**	**T**	**Spring**	**C**	**T**
Dynamical Systems and Control	300301	*5*	m			
Numerical Analysis	110341	*7.5*	m			
Introduction to Parallel Programming	110301	*2.5*	m			
Scientific Computing/Applied Mathematics [9]		*5*	m		*5*	m
Course in Mathematics					*7.5*	m
Guided Research/Bachelor Thesis				110392	*7.5*	m
Language Courses or Home School Electives		*2.5*	e		*2.5*	e
Transdisciplinary Courses		*5*	u		*5*	u
Running Total / *Semester Total*	152.5	*27.5*		180	*27.5*	

C = ECTS credit points, T=type (m=mandatory, e=elective, u=university requirement)

3.3 Financial Mathematics specialization

Year 1 Courses	**Fall**	**C**	**T**	**Spring**	**C**	**T**
Engineering & Science Mathematics I and II [1]	120111	*5*	m	120112	*5*	m
General Mathematics & CPS I and II	110101	*5*	m	110102	*5*	m
Numerical and Symbolic Software Lab Units	110111	*2.5*	m	110112	*2.5*	m
General Physics I/II [2]	200101	*5*	m	200102	*5*	m
Physics Lab Units [3]	200111	*2.5*	m	200112	*2.5*	m
General lectures in a third subject area [6]		*5*	m		*5*	m
Computer Science Lab Units	320111	*2.5*	m	320112	*2.5*	m
Firms and Markets [10]	930312	*5*	u			
Statistical Concepts and Data Analysis [11]				990121	*5*	u
Running Total / *Semester Total*	32.5	*32.5*		65	*32.5*	

Year 2 Courses	**Fall**	**C**	**T**	**Spring**	**C**	**T**
Algorithms and Data Structures	320201	*5*	m			
Numerical Methods				120202	*5*	m
Analysis I/II	100211	*7.5*	m	100212	*7.5*	m
ESM 3B (Complex Variable Calculus, PDE) [7]	120211	*5*	m			
Derivatives Lab	110221	*7.5*	m			
Nonlinear Dynamics Lab				110231	*7.5*	m
Language Courses or Home School Electives					*2.5*	e
Transdisciplinary Course		*5*	u		*5*	u
Running Total / *Semester Total*	95	*30*		122.5	*27.5*	

Year 3 Courses	**Fall**	**C**	**T**	**Spring**	**C**	**T**
Dynamical Systems and Control	300301	*5*	m			
Numerical Analysis	110341	*7.5*	m			
Introduction to Parallel Programming	110301	*2.5*	m			
Real Analysis	100313	*7.5*	m			
Stochastic Processes [12]				100382	*7.5*	m
Risk Management [13]					*5*	m
Guided Research/Bachelor Thesis				110392	*7.5*	m
Language Courses or Home School Electives		*2.5*	e		*2.5*	e
Transdisciplinary Courses		*5*	u		*5*	u
Running Total / *Semester Total*	152.5	*30*		180	*27.5*	

C = ECTS credit points, T=type (m=mandatory, e=elective, u=university requirement)

3.4 Notes

1. In order to satisfy the graduation requirements, any two consecutive first year Engineering and Science Mathematics courses are sufficient. However, it is recommended to take the "B" variants in both semesters and to co-enroll into *ESM 1A – Single Variable Calculus* if your high-school mathematics background does not include a comprehensive

treatment of single variable calculus. It is generally possible to substitute any first year ESM course with a more advanced course in the same topic area. Please consult with your academic advisor for individual recommendations.

2. For General Physics II, take either *General Physics IIA (Electromagnetism, Optics)* or *General Physics IIB (Modern Physics)*.

3. Lab units in another experimental Engineering and Science discipline are permissible; note, however, that co-requisites may restrict the possible choices.

4. Take General Physics I and II to retain the option to change your specialization area at the end of the first year. General Computer Science I and II or General Chemistry I and II are also permitted.

5. At least one course must be in the Life Sciences and at least one course must be in Computer Science.

6. Take General Biochemistry and Cell Biology I and II to retain the option to change to the Computational Biology specialization at the end of the first year. General Computer Science I and II or General Electrical Engineering I and II are also permitted.

7. May be replaced by other second or third year Mathematics, ACM, or Service Mathematics credit provided you take *Introductory Partial Differential Equations* or *Partial Differential Equations* any time before graduation.

8. Courses at second or third year level in Mathematics, ACM, Engineering and Science Mathematics, or Theoretical Physics. (For third year courses, see note [9] below). Please consult with ACM faculty for advice.

9. Courses in Scientific Computing include, in particular, *Graphics and Visualization*, *Fundamentals of Hydrodynamics*, *Computational Fluid Dynamics*, *Optimization Lab*, *Computational Electromagnetics*, Computational Partial Differential Equations, one additional semester of Guided Research on a relevant topic, and other courses with a strong component of numerical computation. Courses in Applied Mathematics include Applied Analysis, *Introductory Partial Differential Equations*, *Ordinary Differential Equations and Dynamical Systems*, *Mathematical Modeling in Biomedical Applications*, *Convex Optimization*. Please consult with ACM faculty for advice.

10. Or another course related to Business or Economics.

11. Any more advanced course in Statistics can substitute.

12. Take either *Stochastic Processes* or *Applied Stochastic Processes*.

13. Alternatively any other course in Applied Mathematics.

3.5 Recommendation Professional Skills

The SES recommends attending the Professional Skills seminars offered by the Career Services Center. Those seminars include soft skills development seminars and application training which will help you to cope with your studies and master your internship and job search.

For more information on internships see http://www.jacobs-university.de/career-services/internship.

4 Courses

4.1 Applied and Computational Mathematics

110101: General Mathematics and Computational Science I

Short Name:	GenMathCPS I
Type:	Lecture
Credit Points:	5
Prerequisites:	None
Corequisites:	None
Tutorial:	Yes

Course contents General Mathematics and Computational Science I and II are the introductory first year courses for students in *Mathematics* and *Applied and Computational Mathematics*. In addition, these courses address anyone with an interest in mathematics and mathematical modeling. Each semester includes a selection of "pure" and "applied" topics which provide a solid foundation for further study, convey the pleasure of doing mathematics, and relate mathematical concepts to real-world applications.

Topics covered in the first semester are:

- *Fundamental concepts:* sets, relations, functions, equivalence classes.
- *Numbers:* Peano axioms, proof by induction, construction of integers and rational numbers.
- *Discrete Mathematics:* combinatorics, binomial coefficients, generating functions, applications to elementary discrete probability.
- *Inequalities:* Geometric-arithmetic mean inequalities, Cauchy inequality; Laplace's method and Stirling's approximation.
- *Difference equations:* linear first order difference equations, nonlinear first order difference equations, equilibrium points and their stability, linear second order difference equations; modeling with difference equations.

110102: General Mathematics and Computational Science II

Short Name:	GenMathCPS II
Type:	Lecture
Credit Points:	5
Prerequisites:	110101
Corequisites:	None
Tutorial:	Yes

Course contents This course continues *General Mathematics and Computational Science I* with the following selection of topics:

- *Groups:* Basic properties and simple examples, Euclidean symmetries of the plane, symmetry groups of subsets of the plane, symmetry groups of polyhedra.

- *Graph Theory:* Graphs and parity, trees, Euler's formula and Euler characteristic, pairings, Eulerian graphs.
- *Stochastic Modeling:* Simple discrete stochastic systems, continuum limits, introduction to entropy.
- *Linear Programming:* graphical method, simplex method, duality.
- *Fourier Transform:* Discrete Fourier transform, fast Fourier transform, Fourier transform on groups.

110111: Natural Science Lab Unit – Symbolic Software

Short Name:	NatSciLab SymbSoft
Type:	Lab
Credit Points:	2.5
Prerequisites:	None
Corequisites:	None
Tutorial:	No

Course contents The Natural Science Lab Units in Mathematics and ACM will introduce the computer as a tool for the working mathematician, as well as for scientists in many other fields.

The Lab Unit *Symbolic Software* introduces *Mathematica*, a software package that can perform complex symbolic manipulations such as solving algebraic equations, finding integrals in closed form, or factoring mathematical expressions. Mathematica also has powerful and flexible graphing capabilities that are useful for illustrating concepts as well as numerical data. The computer will be used as a tool in this course so that you will also learn some mathematics alongside learning to use the computer program.

110112: Natural Science Lab Unit – Numerical Software

Short Name:	NatSciLab NumSoft
Type:	Lab
Credit Points:	2.5
Prerequisites:	None
Corequisites:	None
Tutorial:	No

Course contents The Natural Science Lab Units in Mathematics and ACM will introduce the computer as a tool for the working mathematician, as well as for scientists in many other fields.

The Lab Unit *Numerical Software* introduces *Matlab* and its free cousin *Octave*, software packages that allow easy and in many cases efficient implementations of matrix-based "number crunching". The software is ideal for numerical work such as solving differential equations or analyzing large amounts of laboratory data. The computer will be used as a tool in this course so that you will also learn some mathematics alongside learning to use the computer program.

This Lab Unit is particularly suited for students from both schools interested in experiments, as *Matlab* is used as a standard tool for analyzing and visualizing data in many fields of research.

110231: Nonlinear Dynamics Lab

Short Name:	NLDLab
Type:	Lab
Credit Points:	7.5
Prerequisites:	None
Corequisites:	None
Tutorial:	No

Course contents The Nonlinear Dynamics Lab is an introduction to a variety of nonlinear phenomena and chaos through experiments. Most experiments will be done in a virtual laboratory, your laptop, but we will also include a few "wet-lab" experiments. Programming environments will be Scientific Python for number crunching and Mathematica for symbolic computing.

Topics include nonlinear electric oscillators, coupled pendula, and pattern formation in chemical reactions. A main focus of the lab is the development of standard tools for the numerical solution of differential equations, the application of automated tools for bifurcation analysis, and continuation methods. We will also implement simple agent-based models and pseudo-spectral PDE solvers for reaction-diffusion equations.

The lab is accessible to second and third year students in Physics, Mathematics, and EE/CS who have completed the recommended course load of these majors. Prerequisite is a willingness to learn about differential equations and the associated calculus.

110221: Derivatives Lab

Short Name:	DerivLab
Type:	Lab
Credit Points:	7.5
Prerequisites:	None
Corequisites:	None
Tutorial:	No

Course contents The course gives a first practical introduction to stochastic processes and to the pricing of derivative assets in finance.

The lab will cover an introduction to finance (bonds, yields, immunization), binomial tree models, discrete Brownian paths, solution of stochastic ODEs, Monte-Carlo methods, finite differences solutions for the Black-Scholes equation, and an introduction to time series analysis, parameter estimation, and calibration. Students will program and explore all basic techniques in a numerical programming environment and apply these algorithms to real data whenever possible.

110262: Applied Differential Equations and Modeling

Short Name: ApplDEMod
Type: Lecture
Credit Points: 5
Prerequisites: 120101
Corequisites: None
Tutorial: No

Course contents This course offers an introduction to ordinary differential equations and their applications. Mathematical modeling of continuous-time dynamics has its origins in classical mechanics but is now prevalent in all areas of physical and life sciences. Attempting to solve such problems often leads to a differential equation. Consequently, a variety of analytical and numerical methods have been developed to deal with various classes of equations and initial value problems, the most important of which is the class of linear equations. Other methods (such as Laplace transform) for solving many differential equations of special form will also be discussed. The course underlines the importance of qualitative analysis of differential equations, with a discussion of simple models such as the Lotka-Volterra equation.

All students in the School of Engineering and Science with and interest in the application of Mathematics to real-life problems, and have a mathematical background equivalent to either Engineering and Science Mathematics 1B (Multivariable Calculus, ODE) or Analysis I/II should consider taking this course as a home school elective. Students of ACM can take this course as part of their second year major requirements.

110301: Introduction to parallel programming with MPI and OpenMP

Short Name: MPI/Open MP Workshop
Type: Lab
Credit Points: 2.5
Prerequisites: 120202
Corequisites: None
Tutorial: No

Course contents This intersession workshop is a practical introduction to parallel programming. The focus is on the Message-Passing Interface (MPI) which is the standard programming method for parallel computers with distributed memory, in particular PC-clusters. The last day of the workshop is devoted to OpenMP which is used to program computers with shared memory.

The workshop comprises lectures and hands-on MPI programming sessions.

110341: Numerical Analysis

Short Name:	NumAnal
Type:	Lecture
Credit Points:	7.5
Prerequisites:	100212
Corequisites:	None
Tutorial:	Yes

Course contents This course an advanced introduction to Numerical Analysis. It complements *ESM 4A – Numerical Methods*, placing emphasis, on the one hand, on the analysis of numerical schemes, on the other hand, focusing on problems faced in large-scale computations. Topics include sparse matrix linear algebra, large scale and/or stiff systems of ordinary differential equations, and a first introduction to methods for partial differential equations.

110361: Mathematical Modeling in Biomedical Applications

Short Name:	MathMod BioMed
Type:	Lecture
Credit Points:	7.5
Prerequisites:	100212
Corequisites:	None
Tutorial:	Yes

Course contents The course discusses the area of mathematical modeling in biomedical applications. It includes an introduction into the basic principles of mathematical modeling, and it covers a variety of models for growth and treatment of cancer with increasing complexity ranging from simple ordinary differential equations to more complicated free boundary problems and partial differential equations. Further models for the description of physiology in the human body like blood flow and breathing are briefly touched as well.

110391: Guided Research Applied and Computational Mathematics I

Short Name:	GR ACM I
Type:	Self Study
Credit Points:	7.5
Prerequisites:	Permission of instructor
Corequisites:	None
Tutorial:	No

Course contents Guided Research allows study, typically in the form of a research project, in a particular area of specialization that is not offered by regularly scheduled courses. Each participant must find a member of the faculty as a supervisor, and arrange to work with him or her in a small study group or on a one-on-one basis.

Guided research has three major components: Literature study, research project, and seminar presentation. The relative weight of each will vary according to topic area, the level of preparedness of the participant(s), and the number of students in the study group. Possible research tasks include formulating and proving a conjecture, proving a known theorem in a novel way, investigating a mathematical problem by computer experiments, or studying a problem of practical importance using mathematical methods.

Third year students in Mathematics and ACM may take two semesters of Guided Research. The Guided Research report in the spring semester will typically be the Bachelor Thesis which is a graduation requirement for every undergraduate. Note that the Bachelor Thesis may also be written as part of any other course by arrangement with the respective instructor of record.

110392: Guided Research and BSc Thesis in Applied and Computational Mathematics II

Short Name: GR ACM II
Type: Self Study
Credit Points: 7.5
Prerequisites: Permission of instructor
Corequisites: None
Tutorial: No

Course contents As for *Guided Research Applied and Computational Mathematics I*.

4.2 Engineering and Science Mathematics

120101: ESM 1A – Single Variable Calculus

Short Name: ESM 1A
Type: Lecture
Credit Points: 5
Prerequisites: None
Corequisites: None
Tutorial: Yes

Course contents The courses from the Engineering and Science Mathematics 1 series provide the foundation for all other Engineering and Science Mathematics courses. Taking at least one of them is mandatory for all Engineering and Science majors. Emphasis is on the use of basic mathematical concepts and methods in the sciences, rather than on detailed proofs of the underlying mathematical theory.

The course ESM 1A covers basic differential and integral calculus of functions of one variable. It starts with a brief review of number systems and elementary functions, then introduces limits (for both sequences and functions) and continuity, and finally derivatives and differentiation with applications (tangent problem, error propagation, minima/maxima, zero-finding, curve sketching). A short chapter introduces complex numbers.

The second half of the semester is devoted to integration (anti-derivatives and Riemann integral) with applications, and concluded by brief introductions to scalar separable and linear first-order differential equations, and the convergence of sequences and power series.

Compared to ESM 1C which covers similar material, this course assumes a rigorous high school preparation in Mathematics and leaves more room for explaining mathematical concepts (as needed for the majority of SES majors).

120111: ESM 1B – Multivariable Calculus, ODE

Short Name: ESM 1B
Type: Lecture
Credit Points: 5
Prerequisites: None
Corequisites: 120101
Tutorial: Yes

Course contents Engineering and Science Mathematics 1B introduces multivariable calculus and ordinary differential equations, topics of particular importance to the physical sciences. Students of ACM, Physics, and Electrical Engineering are strongly encouraged to take this course in their first semester. The curriculum is designed so that ESM 1A and ESM 1B can be taken at the same time.

The course covers vector algebra (three-dimensional vectors, dot product, cross product), equations of lines, planes, and spheres, Euclidean distance, vector-valued functions, space curves, functions of several variables, partial derivatives, chain rule, gradient, directional derivative, extrema, Lagrange multipliers, double and triple integrals with applications, change of variables, vector fields, divergence, curl, cylindrical and spherical coordinates, line integrals, Green's theorem in the plane, surface and volume integrals, divergence theorem, Stokes' theorem, introduction to ordinary differential equations (direction field, the question of existence and uniqueness of solutions), separable and exact equations, integrating factors, and linear higher order ODEs with constant coefficients.

120102: ESM 2A – Linear Algebra, Probability, Statistics

Short Name: ESM 2A
Type: Lecture
Credit Points: 5
Prerequisites: None
Corequisites: None
Tutorial: Yes

Course contents Second semester Engineering and Science Mathematics is offered in two parallel classes that cover a common set of core topics at approximately the same level of difficulty. However, style of exposition and selection of additional material will vary slightly to meet the needs of different groups of majors.

ESM 2A is recommended for students majoring in Life Sciences or Chemistry. It covers the following topics: Linear Algebra (equations of lines and planes, matrix algebra, system of linear equations, matrix inverse, vector spaces, linear independence, basis, dimension, linear transformations, change of basis, eigenvalues and eigenvectors, diagonalization). Probability (basic notions of set theory, outcomes, events, sample space, probability, conditional probability, Bayes' rule, permutations and combinations, random variables, expected value, variance, binomial, Poisson, and normal distributions, central limit theorem). Statistics (one-sample hypothesis testing, two sample hypothesis testing, chi-square hypothesis testing, analysis of variance, bivariate association, simple linear regression, multiple regression and correlation).

120112: ESM 2B – Linear Algebra, Fourier, Probability

Short Name:	ESM 2B
Type:	Lecture
Credit Points:	5
Prerequisites:	120101
Corequisites:	None
Tutorial:	Yes

Course contents Second semester Engineering and Science Mathematics is offered in two parallel classes that cover a common set of core topics at approximately the same level of difficulty. However, style of exposition and selection of additional material will vary slightly to meet the needs of different groups of majors.

ESM 2B is recommended for students who do not intend to major in the Life Sciences or Chemistry. It covers the following topics:

- Linear Algebra (equations of lines and planes, matrix algebra, system of linear equations, matrix inverse, vector spaces, linear independence, basis, dimension, linear transformations, change of basis, eigenvalues and eigenvectors, diagonalization, inner products, orthonormalization)
- Fourier methods (expanding functions in terms of orthonormal function systems, Fourier series, Fourier transform, Dirac delta-function)
- Probability (basic notions of set theory, outcomes, events, sample space, probability, conditional probability, Bayes' rule, permutations and combinations, random variables, expected value, variance, binomial, Poisson, and normal distributions, central limit theorem).

120201: ESM 3A – Advanced Linear Algebra, Stochastic Processes

Short Name:	ESM 3A
Type:	Lecture
Credit Points:	5
Prerequisites:	120102 or 120112
Corequisites:	None
Tutorial:	No

Course contents Engineering and Science Mathematics 3A is mandatory for students in Electrical Engineering and Computer Science, and is also recommended as a home school elective for students who would like to learn more advanced topics from Linear Algebra and Probability than were covered in second semester Engineering and Science Mathematics.

The course covers matrix factorizations such as Jordan normal form, QR, and SVD with their typical applications, for example, to least-squares and low-rank approximation problems. It deepens the understanding of discrete and continuous random variables and vectors (joint and conditional distributions and moments, correlation and covariance, generating functions), of sums of i.i.d. random variables and limit theorems, and introduces to the basic types of stochastic processes (Markov chains, Poisson process, Wiener process) and their properties.

120211: ESM 3B – Complex Variable Calculus, PDE

Short Name: ESM 3B
Type: Lecture
Credit Points: 5
Prerequisites: 120102 or 120112
Corequisites: None
Tutorial: No

Course contents Engineering and Science Mathematics 3B is mandatory for students of Physics and for some students in Applied and Computational Mathematics (please consult program handbook).

The course covers the Cauchy–Riemann equations, singularities and zeros, branch cuts, potential theory, conformal transformations, complex integrals, Cauchy's theorem and integral formula, Taylor and Laurent series, residue theorem with applications; the basic linear PDEs (wave, heat, Laplace equation), linear first order PDEs, inhomogeneous and second order equations, characteristics, uniqueness, separation of variables, transform methods, an introduction to Green's functions, the Dirichlet and Neumann problems, and an outlook on nonlinear PDEs.

120202: ESM 4A – Numerical Methods

Short Name: ESM 4A
Type: Lecture
Credit Points: 5
Prerequisites: or 100221
Corequisites: None
Tutorial: No

Course contents Engineering and Science Mathematics 4A is mandatory for students of Electrical Engineering, Computer Science, and Applied and Computational Mathematics. It is also recommended as a home school elective for students who would like to get a short, one-semester introduction to Numerical Methods.

This course is a hands-on introduction to numerical methods. It covers root finding methods, solving systems of linear equations, interpolation, numerical quadrature, solving ordinary differential equations, the fast Fourier transform, and optimization. These methods are crucial for anyone who wishes to apply mathematics to the real world, i.e. computer scientists, electrical engineers, physicists and, of course, mathematicians themselves.

4.3 Mathematics

100211: Analysis I

Short Name: Analysis I
Type: Lecture
Credit Points: 7.5
Prerequisites: None
Corequisites: None
Tutorial: Yes

Course contents Analysis I/II is one of the fundamental courses in the mathematical education (together with Linear Algebra I/II). Its goal is to develop calculus in a rigorous manner and in sufficient generality to prepare the student for advanced work in mathematics. At the same time, the content is chosen so that students arrive quickly at central concepts which are used in essentially all mathematics courses, and which are needed in the exact sciences.

The Analysis sequence begins with a quick review of natural, rational and real numbers (which are assumed as known), and introduces the field of complex numbers. The axiom of completeness distinguishes the real numbers from the rationals and marks the beginning of Analysis. The complex exponential and trigonometric functions are defined.

Metric spaces are introduced and used to define continuity and convergence in a general framework. The Bolzano-Weierstraß and the Heine-Borel theorems are proved. The intermediate and maximal value theorems for functions on the real line are discussed as consequences of connectedness and compactness on metric spaces. Sequences of functions are discussed, in particular uniform convergence, as well as the continuity, differentiability, integrability of the limit function.

Differentiability of functions on the real line is introduced. The mean value theorem and Taylor's theorem is discussed.

The Riemann integral in one variable is introduced. The relation between the derivative and the integral, i.e., the fundamental theorem of calculus is proved.

This course has no formal prerequisites; incoming students with a strong mathematics background are encouraged to take this class in their first semester. However, a familiarity with mathematical reasoning and proof (e.g. proof by induction or by contradiction), such as introduced in *General Mathematics and Computational Science I*, is required.

100212: Analysis II

Short Name:	Analysis II
Type:	Lecture
Credit Points:	7.5
Prerequisites:	100211
Corequisites:	100221 or 120102 or 120112 (if not already taken)
Tutorial:	Yes

Course contents This course is a continuation of *Analysis I*. Its main theme is to extend the concepts from Analysis I, in particular differentiation and integration, to functions of several variables. Taylor's theorem in several variables, the implicit function theorem and the inverse function theorem are proved. (Riemann) integration in several real variables is introduced, including the transformation formula for integrals in several variables.

100221: Linear Algebra I

Short Name:	LinAlg I
Type:	Lecture
Credit Points:	7.5
Prerequisites:	None
Corequisites:	None
Tutorial:	Yes

Course contents Together with *Analysis I*, this is one of the basic mathematics courses. It introduces vector spaces and linear maps, which play an important role throughout mathematics and its applications.

The course begins by introducing the concept of a vector space over an arbitrary field (for example, the real or complex numbers) and the concept of linear independence, leading to the notion of "dimension". We proceed to define linear maps between vector spaces and discuss properties such as nullity and rank. Linear maps can be represented by matrices and we show how matrices can be used to compute ranks and kernels of linear maps or to solve linear systems of equations.

In order to study some geometric problems and talk about lengths and angles, we introduce an additional structure called the inner or scalar product on real vector spaces. Properties of Euclidean vector spaces and orthogonal maps are treated, including the Cauchy-Schwarz inequality, Gram-Schmidt orthonormalization and orthogonal and unitary groups.

An endomorphism is a linear map from a vector space to itself and is represented by a square matrix. We study the trace and determinant of endomorphisms and matrices and discuss eigenvalues and eigenvectors. We discuss the question whether a matrix is diagonalizable and state the theorem on Jordan Normal Form which provides a classification of endomorphisms.

This course has no formal prerequisites; incoming students with a strong mathematics background are encouraged to take this class in their first semester. However, a familiarity with mathematical reasoning and proof (e.g. proof by induction or by contradiction), such as introduced in *General Mathematics and Computational Science I*, is required.

100313: Real Analysis

Short Name:	RealAna
Type:	Lecture
Credit Points:	7.5
Prerequisites:	100212
Corequisites:	None
Tutorial:	Yes

Course contents Real Analysis is one of the core advanced courses in the Mathematics curriculum. It introduces measures, integration, elements from functional analysis, and the theory of function spaces. Knowledge of these topics, especially Lebesgue integration, is instrumental in many areas, in particular, for stochastic processes, partial differential equations, applied and harmonic analysis, and is a prerequisite for the graduate course in Functional Analysis.

The course is suitable for undergraduate students who have taken Analysis I/II, and Linear Algebra I; it should also be taken by incoming students of the Graduate Program in the Mathematical Sciences. Due to the central role of integration in the applied sciences, this course provides an excellent foundation for mathematically advanced students from physics and engineering.

100361: Ordinary Differential Equations and Dynamical Systems

Short Name: DynSystems
Type: Lecture
Credit Points: 7.5
Prerequisites: 100212 and 100221
Corequisites: None
Tutorial: Yes

Course contents Dynamical systems is an topic which links pure mathematics with applications in physics, biology, electrical engineering, and others. The course will furnish a systematic introduction to ordinary differential equations in one and several variables, focusing more on qualitative aspects of solutions than on explicit solution formulas in those few cases where such exist. It will be shown how simple differential equations can lead to complicated and interesting, often "chaotic" dynamical behavior, and that such arise naturally in the "real world". We will also discuss time-discrete dynamical systems (iteration theory) with its relations and differences to differential equations.

100472: Partial Differential Equations

Short Name: PDE
Type: Lecture
Credit Points: 7.5
Prerequisites: 100313
Corequisites: None
Tutorial: No

Course contents The course is an introduction to the theory of partial differential equations in a Sobolev space setting. Topics include Sobolev spaces, second order elliptic equations, parabolic equations, semi-groups, and a selection of nonlinear problems.

This course differs from the approach taken in *Introductory Partial Differential Equations* which focuses on solutions in classical function spaces via Greens functions. It may therefore be taken by students who have attended *Introductory Partial Differential Equations*, but we will again start from basic principles so that *Introductory Partial Differential Equations* is not a prerequisite.

100362: Introductory Partial Differential Equations

Short Name: Intro PDE
Type: Lecture
Credit Points: 7.5
Prerequisites: 100212
Corequisites: None
Tutorial: Yes

Course contents This course is a rigorous, but elementary introduction to the theory of partial differential equations: classification of PDEs, linear prototypes (transport equation, Poisson equation, heat equation, wave equation); functional setting, function spaces, variational methods, weak and strong solutions; first order nonlinear PDEs, introduction to conservation laws; exact solution techniques, transform methods, power series solutions, asymptotics.

This course alternates with takes a functional analytic approach to partial differential equations.

100382: Stochastic Processes

Short Name: StochProc
Type: Lecture
Credit Points: 7.5
Prerequisites: 100212
Corequisites: None
Tutorial: Yes

Course contents This course is an introduction to the theory of stochastic processes. The course will start with a brief review of probability theory including probability spaces, random variables, independence, conditional probability, and expectation.

The main part of the course is devoted to studying important classes of discrete and continuous time stochastic processes. In the discrete time case, topics include sequences of independent random variables, large deviation theory, Markov chains (in particular random walks on graphs), branching processes, and optimal stopping times. In the continuous time case, Poisson processes, Wiener processes (Brownian motion) and some related processes will be discussed.

This course alternates with *Applied Stochastic Processes*.

100383: Applied Stochastic Processes

Short Name: ApplStochProc
Type: Lecture
Credit Points: 7.5
Prerequisites: 100212
Corequisites: None
Tutorial: Yes

Course contents This course aims at an introduction to the mathematical theory of financial markets that discusses important theoretical concepts from the theory of stochastic processes developed in parallel to their application to the mathematical finance.

The applied part of this course revolves around the central question of option pricing in markets without arbitrage which will be first posed and fully solved in the case of binomial model. Interestingly enough, many of the fundamental concepts of financial mathematics such as arbitrage, martingale measure, replication and hedging will manifest themselves, even in this simple model. After discussing conditional expectation and martingales, more sophisticated models will be introduced that involve multiple assets and several trading dates. After discussing the fundamental theorem of asset pricing in the discrete case, the course will turn to continuous processes. The Wiener process, Itō integrals, basic stochastic calculus, combined with the main applied counterpart, the Black-Scholes model, will conclude the course.

This course alternates with *Stochastic Processes*.

4.4 Electrical Engineering and Computer Science

320101: General Computer Science I

Short Name:	GenCompSci I
Type:	Lecture
Credit Points:	5
Prerequisites:	None
Corequisites:	None
Tutorial:	No

Course contents The course covers the fundamental concepts and techniques of computer science in a bottom-up manner. Based on clear mathematical foundations (which are developed as needed) the course discusses abstract and concrete notions of computing machines, information, and algorithms, focusing on the question of representation vs. meaning in Computer Science.
To have a theoretical notion of computation, we introduce inductively defined structures, term representations, abstract interpretation via equational substitution. This is contrasted with a first concrete model of computation: Standard ML, which will also act as the primary programming language for the course. We cover a basic subset of ML that includes types, recursion, termination, lists, strings, higher-order programming, effects, and exceptions. Back on the theoretical side, we cover string codes, formal languages, Boolean expressions (syntax) and Boolean Algebras (semantics). The course introduces elementary complexity theory (big-O), applying it to analyzing the gate-complexity of Boolean Expressions (prime implicants and Quine McCluskey's algorithm).

320102: General Computer Science II

Short Name:	GenCS II
Type:	Lecture
Credit Points:	5
Prerequisites:	320101
Corequisites:	None
Tutorial:	No

Course contents The course continues the introduction of the fundamental concepts and techniques of Computer Science. Building on Boolean Algebra, it introduces Propositional Logic as a model for general logical systems (syntax, semantics, calculi). Based on elementary graph theory, combinatory circuits are introduced as basic logic computational devices. Interpreting sequences of Boolean values as representations of numbers (in positional number systems, twos-complement system), Boolean circuits are extended to numerical computational machines (presenting adders, subtracters, multipliers) and extended to basic ALUs. The course introduces very elementary computer architectures and assembly language concrete computational devices, and compares them to Turing machines to fathom the reach of computability.

In a final part of the course, two topics of general Computer Science are covered in depth, for instance "search algorithms" and "programming as search" to complement the rather horizontal (i.e. methods-oriented) organization of the course with vertically (i.e. goal-oriented) organized topics.

Topics: Propositional logic, calculi, soundness, completeness, automated theorem proving, combinatory circuits, assembler Turing machines, search, logic programming.

320111: NatSciLab Unit Computer Science I

Short Name:	NatSciLab CS I
Type:	Lab
Credit Points:	2.5
Prerequisites:	None
Corequisites:	None
Tutorial:	No

Course contents This lab unit is a first introduction to programming using the programming language C. The course covers fundamental procedural programming constructs and simple algorithms in a hands-on manner.

320112: NatSciLab Unit Computer Science II

Short Name:	NatSciLab CS II
Type:	Lab
Credit Points:	2.5
Prerequisites:	320111
Corequisites:	None
Tutorial:	No

Course contents This lab unit is a continuation of the first year CS lab unit and deepens the basic programming skills from the first lab. It covers advanced topics of C programming such as data structures, file handling, libraries, and debugging techniques.

320201: Fundamental Computer Science I (Algorithms and Data Structures)

Short Name:	Fund CS I
Type:	Lecture
Credit Points:	5
Prerequisites:	320102, 120112
Corequisites:	None
Tutorial:	No

Course contents This course introduces a basic set of data structures and algorithms that form the basis of almost all computer programs. The data structures and algorithms are analyzed in respect to their computational complexity with techniques such as worst case and amortized analysis.

Topics: Fundamental data structures (lists, stacks, trees, hash tables), fundamental algorithms (sorting, searching, graph traversal).

300301: Dynamical Systems and Control

Short Name: DynSys+Control
Type: Lecture
Credit Points: 5
Prerequisites: None
Corequisites: None
Tutorial: No

Course contents Dynamical systems in nature and technology often behave in a counter-intuitive fashion and are thus difficult to predict and to regulate. The counter-intuitive behavior comes from nonlinear interactions between the system components and the nonlinear processing of incoming information. This course is an introduction to nonlinear dynamics and control with a focus on a broad range of applications. Topics include:

1. Low dimensional autonomous dynamical systems: formulation as differential equation, flow, fixed points, stability, stability criteria, potentials and Lyapunov functionals, simple local bifurcations (saddle-node, pitchfork, transcritical, cusp, Hopf), simple numerical schemes, time-discrete maps (fixed points, stability), introduction to chaos.

2. Control for linear systems: general matrix-based solution for driven linear ODEs, reachability, controllability, observability, Gram-matrix for determining control laws and for reconstruction, linear-state feedback controller, stable-state estimation, introduction to optimal control.

3. Reaction-diffusion partial differential equations (activator-inhibitor, relations to control), stability of stationary solutions, Turing instability.

320322: Graphics and Visualization

Short Name: CSGV
Type: Lecture
Credit Points: 5
Prerequisites: Please check on Campus Net
Corequisites: Please check on Campus Net
Tutorial: No

Course contents Course topics: input and output devices, 2D and 3D graphic algorithms, transformations, projections, hidden line/surface removal, shading algorithms, color reduction. Role of the course in the curriculum: This course introduces the basic algorithms and techniques in computer graphics and data visualization. Students taking this course will develop an understanding how computer graphics are created and which algorithms are implemented by graphic processors. This course is recommended for all EECS students with an interest in data visualization and computer graphics.

300491: Convex Optimization

Short Name:	ConOpt
Type:	Lecture
Credit Points:	5
Prerequisites:	Please Check Campus Net
Corequisites:	Please Check Campus Net
Tutorial:	No

Course contents Convex optimization is an important part of optimization in general. It deals with convex functions on convex domains. Convex problems are more general than linear ones but although convex optimization is about non-linear problems, optimum solutions are still globally optimal. The course is an introduction to the theory and application of convex optimization. It provides a wide variety of examples and discusses different optimization algorithms.

300493: Optimization Lab

Short Name:	OptLab
Type:	Lab
Credit Points:	5
Prerequisites:	Please Check Campus Net
Corequisites:	Please Check Campus Net
Tutorial:	No

Course contents This is a hands-on extension to the optimization lecture. Based on solving several optimization problems, students develop broad practical experience concerning implementation and application of optimization techniques. Topics covered include standard optimization tools but also genetic algorithms and learning algorithms. A large part of the lab focuses on algorithms for games (like reversi).

300501: Computational Electromagnetics

Short Name:	CompElectromagnetics
Type:	Lecture
Credit Points:	5
Prerequisites:	Please Check Campus Net
Corequisites:	Please Check Campus Net
Tutorial:	No

Course contents Recent advances in diverse engineering and scientific disciplines, such as optical and wireless communications, electronic computing, medical imaging, radar, and remote sensing, have been enabled by high-frequency electronic devices operating in the radiofrequency, microwave, and optical regimes. Although the behavior of such devices is completely described by Maxwell's equations, direct analytical solutions are only possible for very simple structures. With the advent of powerful computers, however, exact numerical solutions of Maxwell's equations have been developed, allowing highly accurate characterization of nearly arbitrary structures. Inclusion of these computational electromagnetic (CEM) techniques in powerful computer assisted design (CAD) packages allows the engineer to test and modify potential high-frequency designs conveniently on a computer, shortening the design cycle and saving valuable resources.

This course covers the most important developments in CEM, allowing students to visualize the behavior of complex devices, to understand the benefits/limitations of commercial packages, and to develop new CEM codes when needed. Although the target application is electromagnetics, the same methods for obtaining numerical solutions to partial differential equations can be applied to general problems in physics and engineering. This lecture stresses an analytical treatment of the various CEM techniques, where the lecture is complimented by a number of short assignments requiring derivations or closed-form analysis. Students interested in gaining practical experience writing and applying CEM codes are encouraged to take the Computational Electromagnetics Lab in parallel.

Concepts Covered:

- Basic numerical techniques: numerical integration, Monte-Carlo analysis, solutions of simultaneous equations
- Finite-difference techniques: Laplace equation, the wave equation, finite-difference time-domain (FDTD), absorbing boundary conditions (ABC), eigenvalue problems and mode solutions
- Method-of-moments: Green's functions, expansion and weighting functions, surface and volume methods
- Variational methods: variational calculus, functionals, weighted residual method
- Finite-element method (FEM): element equations, mesh generation, solutions
- Introduction to modern developments: multipole techniques, ray-tracing, domain decomposition, hybrid methods

4.5 Physics

200101: General Physics I

Short Name:	GenPhys I
Type:	Lecture
Credit Points:	5
Prerequisites:	None
Corequisites:	None
Tutorial:	No

Course contents This course is an introduction to physics and its basic principles, covering classical mechanics and thermodynamics. It is a mandatory course for physics majors but can also serve as a general introduction to physics for all other majors.

It is neither the traditional experimental physics lecture, nor a pure theoretical physics course. Both aspects are combined and special emphasis is laid on general principles, not on extensive mathematical derivations. Nevertheless, the course teaches calculus based physics so that some basic mathematical knowledge will be required. Experiments are integrated into the lectures.

The course consists of the following two parts:

- Mechanics including: motion and coordinate systems; forces and Newton laws; work and energy; collisions and momentum; rotations, torque, angular momentum; Kepler laws and gravitation; continuum mechanics and elasticity; fluid mechanics; harmonic oscillator, damping, resonance; waves.
- Thermodynamics including: temperature, heat, heat capacity; transport phenomena; ideal gas, kinetic gas theory; MB distribution; Brownian motion; 1st law, energy, heat and work; 2nd law, cyclic processes, engines; entropy and statistical interpretation; thermodynamic potentials.

200102: General Physics IIA (Electromagnetism, Optics)

Short Name: GenPhys IIA
Type: Lecture
Credit Points: 5
Prerequisites: 200101
Corequisites: None
Tutorial: No

Course contents This course is a continuation of General Physics I (200101). It is mandatory for physics majors, but also interesting for e.g. life science or electrical engineering majors. It is an introduction to physics, covering electromagnetism and optics. It is neither the traditional experimental physics lecture, nor a pure theoretical physics course. Both aspects are combined, special emphasis is laid on general principles, not on mathematical derivations. Nevertheless, the course teaches calculus based physics so that some basic mathematical knowledge will be required. Experiments are integrated into the lectures.

The course consists of the following two parts:

- Electromagnetism: electric charge, field and potential, capacitance and dielectrics; resistance and current; magnetic force and field; magnetization and induction; AC/DC circuits; Maxwell equations and electromagnetic waves.
- Optics: waves and acoustics; refractive index, reflection, dispersion, polarization, scattering; lenses, geometrical optics, optical instruments; interference, interferometers, diffraction, resolving power.

200103: General Physics IIB (Modern Physics)

Short Name: GenPhys IIB
Type: Lecture
Credit Points: 5
Prerequisites: 200101
Corequisites: None
Tutorial: No

Course contents This course is a continuation of General Physics I (200101). It is mandatory for physics majors but also interesting for all other majors. It is also an introduction to physics, covering all aspects of modern physics such as quantum physics, atomic and nuclear physics, particle physics and relativity. It is neither the traditional experimental physics lecture, nor a pure theoretical physics course. Both aspects are combined, special emphasis is laid on general principles, not on mathematical derivations. Nevertheless, the course teaches calculus based physics and some mathematical knowledge will be required. Experiments are integrated into the lectures.

The course introduces the following topics:

- Special relativity: Lorentz transformation, rest mass.
- Quantum physics: photons, electrons, wave nature of particles; Schroedinger equation, Heisenberg uncertainty principle.
- Atomic physics: X-ray and atomic structure, periodic systems, spin electronic excitations, atomic spectra.
- Molecules and condensed matter: molecular bonds and vibrations; crystals and semiconductors.
- Nuclear and particle physics: elementary particles, accelerators and detectors, quarks, standard model, decay of nuclei, nuclear reactions, nuclear fusion and fission.

200111: NatSciLab Unit Physics I

Short Name:	NatSciLab Phys I
Type:	Lab
Credit Points:	2.5
Prerequisites:	None
Corequisites:	200101
Tutorial:	No

Course contents The Natural Science Laboratory Course Module in Physics forms an integral part of first-year physics education at Jacobs University. The physics module occupies 8 of the 24 afternoon sessions of the first year Natural Science Laboratory Course. For students planning to major in the School of Engineering and Science, participation in the Natural Science Lab Course is mandatory (lectures and lab course modules have to correspond). For all other students wishing to enroll in the physics lab module, attendance of the General Physics lecture is co-requisite, since the lab course is taught in close coordination with the lecture. In the physics module, participants carry out 7 experiments in total covering topics of mechanics, thermodynamics and optics. Aims of the lab course are: (1) to gain hands on experience of the material taught in General Physics, (2) to learn how scientific experiments are planned, carried out, analysed, and reported, (3) learn about technical aspects of measuring and measuring devices.

200112: NatSciLab Unit Physics II

Short Name:	NatSciLab Physics II
Type:	Lab
Credit Points:	2.5
Prerequisites:	Please check on Campus Net
Corequisites:	Please check on Campus Net
Tutorial:	No

Course contents The Natural Science Laboratory Course Module in Physics forms an integral part of first-year physics education at Jacobs University. The physics unit occupies 8 of the 24 afternoon sessions of the first year Natural Science Laboratory Course. For students planning to major in the School of Engineering and Science, participation in the Natural Science Lab Course in mandatory (lectures and lab course units have to correspond). For all other students wishing to enroll in the physics lab unit, attendance of the General Physics lecture is a co-requisite, since the lab course is taught in coordination with the lecture. In the physics unit, participants carry out 8 experiments in total covering topics in Electromagnetism and Quantum Physics. Aims of the lab course are: (1) to gain hands on experience of material taught in General Physics, (2) to learn how scientific experiments are planned, carried out, analyzed, and reported, (3) to learn about technical aspects of measuring and measuring devices.

200371: Fundamentals of Hydrodynamics

Short Name:	FundHydro
Type:	Lecture
Credit Points:	5
Prerequisites:	None
Corequisites:	None
Tutorial:	No

Course contents The hydrodynamics course addresses fundamental equations which govern many flow problems occurring in science and engineering. We start with the concept of continuum and Lagrangian versus Eulerian approach. Based on conservation laws of physics, we derive continuity, momentum and energy equations. As special cases of general flow equations, irrotational flows and hydrostatics will be considered. Further, hydrodynamic instability, turbulence, waves, rotation, geostrophic flows, and flow through porous medium will be treated as special topics. The course will be accompanied with performing experiments at Max Planck Institute for Marine Microbiology in Bremen. To make sure that all participants follow the lectures without difficulty, all mathematical tools needed will be treated prior to lectures.

200372: Computational Fluid Dynamics

Short Name: CFD
Type: Lecture
Credit Points: 5
Prerequisites: None
Corequisites: None
Tutorial: No

Course contents Computational fluid dynamics (CFD) has become one of the most sophisticated tools, beside the analytical and experimental methods, for solving problems in fluid dynamics, heat and mass transfer. This course will introduce the physical and mathematical foundations of CFD for incompressible viscous flows, and to provide students with a working knowledge of CFD. By the end of the course, the successful student will be able to develop, debug, and analyze a finite difference code that solves the Navier-Stokes equations. The course will start by an introduction to numerical methods and explain what is CFD. Next, basic equations of fluid mechanics are reviewed. The partial differential equations are, then classified. Finite difference methods are explained, and different solution techniques for systems of linear algebraic equations are explained. Finally, important issues such as the stability and convergence criteria are explained, when dealing with CFD.

4.6 Life Sciences

520101: General Biochemistry and Cell Biology I

Short Name: GenBCCB I
Type: Lecture
Credit Points: 5
Prerequisites: None
Corequisites: None
Tutorial: No

Course contents This is a unique course that gives, over the first year of studies at Jacobs University, a comprehensive introduction to biochemistry and cell biology. At the end of the course, students will have gained knowledge of the foundations and the scope of the subject and of the specific scientific reasoning that underlies research in this field. Topics covered will be the biochemistry and biophysics of DNA, proteins (especially enzymes), carbohydrates, and lipids; the buildup and the breakdown of these substances; the (animal, plant, and bacterial) cell, its substructure, and its organelles; an introduction to the most common chemical reactions in living cells and the underlying thermodynamic, chemical, and kinetic principles, including metabolism and its regulation; and introductory overviews of specialized fields such as biophysics, structural biology, molecular machines, molecular neurobiology, immunology, molecular genetics, developmental biology, and cancer. Information about the techniques and strategies to obtain knowledge and to ask questions in molecular life science, as well as historical outlines, will accompany each topic.

This course requires solid High School knowledge of both biology and chemistry, or the willingness to acquire it at Jacobs University. Depending on their previous training, prospective Biochemistry and Cell Biology major students are advised to take General Chemistry or General Biology or both in addition to this course. General Biochemical Engineering is also a very useful complement.

520102: General Biochemistry and Cell Biology II

Short Name: GenBCCB II
Type: Lecture
Credit Points: 5
Prerequisites: 520101
Corequisites: None
Tutorial: No

Course contents This is the second part of the comprehensive introduction to biochemistry and cell biology with special emphasis on the connections to the related fields chemistry and biology. In the spring semester, the emphasis of the course will be on more complex cell biological topics, such as the synthesis, topogenesis and breakdown of cellular components in the context of the cellular environment, and introductory overviews of specialized fields such as biophysics, structural biology, cell cycle, molecular neurobiology, immunology, DNA technology, developmental biology, and cancer. Information about the techniques and strategies to obtain knowledge and to ask questions in molecular life science, as well as historical outlines, will accompany each topic.

Good High School knowledge of both biology and chemistry, or the willingness to acquire it in self-study, is assumed. Prospective Biochemistry and Cell Biology major students are advised to take General Chemistry or General Biology or both in addition to this course.

520111: NatSciLab Unit Biochemistry and Cell Biology I

Short Name: NatSciLab BCCB I
Type: Lab
Credit Points: 2.5
Prerequisites: Please check on Campus Net
Corequisites: Please check on Campus Net
Tutorial: No

Course contents This course trains basic laboratory skills and gives an introduction to biochemical and cell biological work in the laboratory. The course parallels the general biochemistry and cell biology lecture. An introduction is given to substance classes on one hand and methods on the other. Course days include e.g., the handling of glass and micropipettes, balances, spectrophotometers and light microscopes. Experiments include gel filtration, thin layer chromatography of plant pigments, titration, pH-dependence of enzymes, identification of carbohydrates, microscopy of sperms and muscle etc. For each course day, a lab report is handed in.

520112: NatSciLab Unit Biochemistry and Cell Biology II

Short Name:	NatSciLab BCCB II
Type:	Lab
Credit Points:	2.5
Prerequisites:	Please check on Campus Net
Corequisites:	Please check on Campus Net
Tutorial:	No

Course contents This course trains basic laboratory skills and gives an introduction to biochemical and cell biological work in the laboratory. The course parallels the general biochemistry and cell biology lecture. An introduction is given to substance classes on one hand and methods on the other.

As a continuation of the fall course, this time the focus lies on DNA and RNA. Course days include e.g., the handling of glass and micropipettes, balances, spectrophotometers and light microscopes. Experiments include isolation of DNA and RNA from pea seedlings, isolation of DNA from stressed C6 glioma cells and detection of an apoptotic DNA ladder by means of agarose gel electrophoresis, sterile cultivation of yeast cells, determination of cytotoxicity, fixation, staining and microscopic investigation of M phase cells.

520201: Advanced Biochemistry and Molecular Biology I

Short Name:	AdvBCMB I
Type:	Lecture
Credit Points:	5
Prerequisites:	520101, 520102
Corequisites:	None
Tutorial:	No

Course contents The course intends to give a detailed understanding of the chemical reactions that underlie life. In the first part the structures, dynamics and chemistry of important biomolecules will be described. The thermodynamics and kinetics of ligand binding to proteins and enzyme catalysis will be explained and enzymatic catalysis explored at the molecular and atomic level. The second part focuses on metabolism and describes how energy is produced by living organisms and how the molecules of life are synthesised and degraded. A special focus will be set on common principles and the integration of the metabolism. The third part of the course explains how the genetic information stored in the DNA sequence is maintained and expressed. In addition the mechanism of DNA binding and modification by proteins and enzymes will be presented. The techniques of modern molecular biology will be described and the results of the human genome project discussed.

520202: Advanced Biochemistry and Molecular Biology II

Short Name:	AdvBCMB II
Type:	Lecture
Credit Points:	5
Prerequisites:	520201
Corequisites:	None
Tutorial:	No

Course contents The course intends to give a detailed understanding of the chemical reactions that underlie life. In the first part the structures, dynamics and chemistry of important biomolecules will be described. The thermodynamics and kinetics of ligand binding to proteins and enzyme catalysis will be explained and enzymatic catalysis explored at the molecular and atomic level. The second part focuses on metabolism and describes how energy is produced by living organisms and how the molecules of life are synthesised and degraded. A special focus will be set on common principles and the integration of the metabolism. The third part of the course explains how the genetic information stored in the DNA sequence is maintained and expressed. In addition the mechanism of DNA binding and modification by proteins and enzymes will be presented. The techniques of modern molecular biology will be described and the results of the human genome project discussed.

550201: Bioinformatics and Computational Biology

Short Name:	BICB
Type:	Lecture
Credit Points:	5
Prerequisites:	None
Corequisites:	None
Tutorial:	No

Course contents Intention of the course is to provide an overview over current bioinformatic approaches in sequence and genome analysis by a direct linkage of the biological problem with the computational approaches to solve them. An important task of bioinformatics is to put data into a larger context by identifying statistical similarities between the data. Finding genes in DNA sequences, identifying common structural features in (evolutionarily) related protein sequences and extracting functional properties from the architecture of cellular networks are examples of this general strategy of bioinformatics, which will be highlighted throughout the course.

Major topics will be: Biological data, acquisition and storage, Similarity and Alignment, Pairwise and Multiple Sequence comparisons, Sequence patterns and motifs, Genome analysis, Genome signatures, Hidden Markov models, Networks.

550221: Bioinformatics Lab Course

Short Name: BICB Lab
Type: Lab
Credit Points: 7.5
Prerequisites: None
Corequisites: None
Tutorial: No

Course contents *Part 1: Sequence analysis.* The increasing amount of biological data in particular of protein and DNA sequences requires students to gain practical experience with algorithms and computational tools for sequence analysis. The lab course intends to train students in the application of computational approaches to nucleic acid and protein sequence analysis and secondary structure prediction. The script language Perl will be introduced and students will be trained to write own applications and to program bioinformatics algorithms and methods. It will give a practical introduction and an overview on available and frequently applied sequence analysis methods including the software to align and compare sequences and to predict coding and non-coding regions. Multiple alignment methods will be used to align several sequences and to identify conserved elements. In addition, computational methods for the prediction of protein and RNA secondary structure will be introduced and applied to selected examples. The generation of a SQL data base in combination with a script language will be introduced.

Part 2: Genomics. In the second part of the lab course (Genomics) hands on in genome analysis will be obtained. Starting with a students seminar on a special topic related to genome research every week, several tools will be tested and used for sequence analysis. We will use web-bases systems as well as standalone tools installed on a local server. Complete genomes as well as genomic fragments will be analysed. The genomic fragments will serve as the template for in depth annotation using an open source annotation system (GenDB). A local installation of the phylogenetic software package ARB will be used for phylogenetic inference and tree reconstruction of selected functional genes.

550321: Computational Systems Biology

Short Name: SysBio
Type: Lecture
Credit Points: 5
Prerequisites: None
Corequisites: None
Tutorial: No

Course contents Systems Biology aims at understanding the functioning of a cell due to the concerted action of its constituents. At the same time, however, many spatial and temporal scales contribute to cellular organization and turn it into a complex interplay of regulatory processes. It seems, therefore, futile addressing this problem of system understanding without the appropriate toolbox. This course provides the toolbox for ”doing Systems Biology”.

In the first part we will look at general principles of systems modeling. We will discuss elementary models of dynamic processes, which help understand large classes of biological systems and then see, how an increase in complexity changes properties of the model.

The second part covers system biologic models of specific cellular processes: metabolism, signal transduction and gene regulation.

In the last segment we will discuss the integration of theoretical approaches: How can data sets on different levels of a biological systems been related and put into a wider context? How can specific models be interlinked, in order to pass from a minimal model (the domain of theoretical biology) to a realistic “in-silico” description (the realm of systems biology)?

We also look at the current computational infrastructure of systems biology: data bases for mathematical models, standards for data formats. Beyond ACM, this course may also be of interest to biochemistry and computer science majors.

560302: Design of Biological Molecules and Systems

Short Name: DBMS
Type: Lecture
Credit Points: 5
Prerequisites: None
Corequisites: None
Tutorial: No

Course contents The course is intended to give an overview on theoretical/computational as well as experimental aspects of biological molecule and system design. It will include state of the art genetic engineering methods for directed protein evolution, molecular breeding and practical approached of rational, combinatorial and evolutionary molecule design. On the theoretical side the course covers computational approaches of bio-molecular modelling, structure prediction and mathematical models of evolution. This includes energetic and entropic contributions to ligand-receptor interactions and biomolecule stability. It covers also the prediction of the effect of mutations on biomolecular structure and function, prediction of ligand-receptor binding and an introduction to computational drug design and virtual screening methods.

4.7 Courses from the School of Humanities and Social Science

990121: Statistical Concepts and Data Analysis

Short Name: Stats_Concepts
Type: Lecture/Lab
Credit Points: 5
Prerequisites: None
Corequisites: None
Tutorial: No

Course contents This course aims to provide an introduction to fundamental statistical concepts and tools for data analysis. It is intended as a one-semester course that combines selected topics from both the mandatory statistical methods courses for SHSS students (Statistical Methods I: Exploring Relationships and Comparing Groups and Statistical Methods II: Classification, Modelling and Prediction) to offer the more relevant topics for logistics and SES major students. The course will focus on the understanding of statistical concepts and the application of statistical techniques. While some formulae might be used, no stringent mathematical derivation will be provided. The general objective is to become an intelligent user of the various univariate and multivariate statistical techniques and to acquire the knowledge for deciding which procedure is most suitable for the given business situation. We will discuss the theoretical aspects of the statistical methods, discuss the assumptions for their use, reflect on their limitations and the controversies they create. In practical sessions we will learn how to run the particular procedures using SPSS and/or R, how to interpret the computer output and how to skillfully communicate the results of statistical analyses.

930312: Firms and Markets

Short Name:	Firms/Markets
Type:	Seminar
Credit Points:	5
Prerequisites:	Please check on Campus Net
Corequisites:	Please check on Campus Net
Tutorial:	No

Course contents This seminar continues the analysis of the market. It asks why in market economies, not all economic transactions take place within the market. Why are some transactions moved outside of the market and coordinated hierarchically within business firms? The seminar examines both the internal organization and management of business firms and their external behavior. The topics covered include the economics of transaction costs, agency theory, elementary game theory, competitive advantage, strategy formation, and strategic pricing.