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Introduction

Dear Student,

Welcome to the Faculty of Mathematics and Physics at Charles University in Prague. Our faculty offers bachelor's, master's and doctoral degree programmes, given in either Czech or English. This document is dedicated to the bachelor's and master's programmes in English, namely to those leading to

- Bachelor of Computer Science
- Master of Computer Science
- Master of Mathematics
- Master of Physics.

In this introduction we provide the basic information you will need in order to study at our faculty. For supplementary information we refer to the Code of Study and Examination of Charles University and to the Rules for Organization of Studies at the Faculty of Mathematics and Physics. The subsequent chapters of this document describe the academic calendar for 2022/23 and the curricula for our programmes.

Academic Life

Duration of Study

The standard period of study for a bachelor's programme is three years and for a master's programme two years. The standard period of study for a degree programme is the period of time in which it is possible to successfully finish the respective degree programme if one follows the recommended course of study. The course of study is concluded with a state final examination and its successful completion leads to the degree of Bachelor of Computer Science (Bc.) for a bachelor's degree programme and to the degree of Master of Computer Science or Master of Mathematics (Mgr.) in a master's degree programme. The maximum period of study in a bachelor's degree programme is six years and in a master's degree programme five years.

As a Charles University student, you also have the possibility of undertaking a period of study at a linked institution in Europe under the Erasmus+ exchange programme. Check the website `https://www.mff.cuni.cz/exchange_programmes`.

Study Sections

Each academic year consists of a winter (October – January) and a summer (February – June) semester. In each semester there are typically 13 weeks of teaching and an examination period of 5 weeks. A study programme is subdivided into sections so that progress and compliance with the conditions for registration for the next study section can be regularly monitored; a study section is typically an academic year, although for students enrolling in a bachelor's programme, the first two study sections correspond to semesters (i.e., the first study section is the winter semester and the second study section is the summer semester). At the end of each study section there is an Annual Evaluation of Study, whose purpose is to establish whether the results of your study hitherto qualify you to register for the next study section. (For those in their first year of a bachelor's programme, the Annual Evaluation comes in two parts, one for each semester.) You are entitled to register for the first study section if you have successfully completed the admissions process. You are entitled to register for later study sections if you meet the requirements of the Annual Evaluation (see below). Registration is a confirmation that you are continuing your study at the faculty.

Degree Plan

Study in a degree programme is guided by a degree plan. Most of our programmes are divided into specializations. The degree plan specifies the following for each degree programme, and, where applicable, for each specialization:

- **Obligatory courses** (you have to complete these before the state final examination),
- **Elective courses** (you have to complete the prescribed part of these before the state final examination),
- **State final examination** - its parts and requisite knowledge needed for them,
- **Recommended course of study** (for some programmes) - assignment of obligatory and some elective courses to specific study sections; in some cases also provision of supplementary information on the curriculum.

The recommended course of study is not binding. However it is advisable to follow it because it is put together to satisfy the requisites (see below), considers the relationships between the courses, takes into account the schedule, and leads to timely graduation. All courses other than the obligatory and elective that are offered at the university are considered as **Optional courses** for the corresponding curriculum; it is up to you whether you decide to take some of these.

In all tables, obligatory courses are printed **in boldface**, elective courses are printed upright, and optional courses *in italics*. Here is a small example:

Code	Subject	Credits	Winter	Summer
NPRG030	**Programming I**	6	3/2 C	—
NDMI012	Combinatorics and Graph Theory II	6	2/2 C+Ex	—
NMAI069	*Mathematical skills*	2	0/2 C	—

The course code is given in the first column. The number in the "Credit" column specifies the number of ECTS credits for completion of the course. The Winter and Summer columns specify the semester in which the course is offered, the number of hours of lectures/ hours of classes per week, and how the course is assessed (i.e., by a course credit – C, by an exam – Ex). Please be aware that some elective courses are not taught every year.

Course Enrolment

At the beginning of each semester there is a period of several weeks during which you should choose from and enrol in courses that you plan to take that semester (see the Academic Calendar). Enrolment is performed electronically through the Student Information System (SIS) – `http://www.mff.cuni.cz/sis`; further technical details about course enrolment are provided on the webpage `https://www.mff.cuni.cz/course_enrolment`.

The period for course enrolment is split into two phases: in the first phase (priority mode), you have the right to enrol in courses that are primarily designated for you (e.g., the obligatory courses); in the second phase (open mode), you can enrol in any courses. It is up to you which courses to enrol in, subject to the requirements of your curriculum and to the number of credits required in the Annual Evaluation. If your interests are wider than specified by your curriculum or if you decide not to follow the recommended course of study exactly, then you can enrol in additional courses; there is no upper limit to the number of courses in which you can enrol. Course enrolment may be restricted by certain conditions (requisites), of which the most common are the following:

- **Prerequisite** – A prerequisite to Course X is a course that must be successfully completed before you can enrol in Course X.
- **Corequisite** – A corequisite to Course X is a course that you have to enrol in at the same time as Course X, or that you have already successfully completed.
- **Prohibited combination** (or incompatibility) – Courses X and Y are a prohibited combination if it is impossible to enrol in Course X when you have already completed, or you enrol in, Course Y.

In some cases, it is specified that completion of Course Y is equivalent, with respect to the requirements of the curriculum, to completion of Course X; these two courses are called **equivalent** or interchangeable. Information about these relationships among courses are described in the Student Information System in the module "Subjects" (`http://www.mff.cuni.cz/courses`). Please note that the prerequisites and corequisites for a course X, as specified in SIS, apply to study programmes and study branches in which the course is compulsory or elective. We recommend giving due attention to these conditions, as missing a course that is a prerequisite for another course in which you intend to enrol may result in an unfavourable extension of your period of study.

Lectures and Classes

Courses are mostly given in the form of lectures and/or classes. A lecture is an oral presentation intended to teach students a particular subject. Typically accompanying a series of lectures are classes (aka exercises or tutorials), in which a tutor helps a small group of students assimilate material from lectures and is able to give students individual attention. Classes for programming-related courses typically take place in computer labs. The schedule of the faculty is given as 45-minute periods with 5-minute breaks, and most lectures and classes are organized as 90-minute long blocks of two such periods, taking place once or twice a week. Attendance of lectures and classes is usually not required, but is strongly recommended. Information about course locations and times is available in the Student Information System in the module "Schedule" (`http://www.mff.cuni.cz/schedule`). Lectures are mostly given by senior faculty members, whose academic ranks are professor (in Czech *profesor*) or associate professor (*docent*). Classes are usually conducted by junior researchers and Ph.D. students. Apart from lectures and classes, another significant component of a student's timetable is private study, and in the first semester of the first year of study, also regular meetings with mentors.

Exams and Course Credits

Mastery of a course is confirmed by a course credit and/or by an exam. A course credit (usually for classes) is awarded at the end of the semester. The conditions for obtaining a course credit differ according to the nature of the course, for example involving the completion of a test, programming an application, or writing a survey, and are specified by the teacher at the beginning of the semester. The possible outcomes are Pass (in Czech *Započteno - Z*) and Fail (*Nezapočteno - K*). Exams are taken during the examination period at the end of the semester and may be oral, written, or a combination of the two. Examination dates are announced by the lecturer at the beginning of the examination period. There are four possible outcomes for an exam (the corresponding numerical values and Czech equivalents are given in parentheses): Excellent (1 - *Výborně*), Very good (2 - *Velmi dobře*), Good (3 - *Dobře*), Fail (4 - *Nevyhověl*). You pass an exam if you obtain a grade of Excellent, Very good or Good; otherwise you fail.

You have up to three attempts to pass an exam (provided there are still dates available) but we strongly recommend preparing as well as you can for the first attempt. If you do not succeed in passing the exam or obtaining the course credit for a course, you are allowed to take the course again in the next section of study, but a course can be followed at most twice. Please be aware that not passing an obligatory course for the second time is considered as a failure to fulfil the requirements of the study programme and results in exclusion (i.e. termination of your studies in the corresponding programme). For each successfully completed course you obtain a certain number of ECTS credits that is specified for each subject in the curriculum (and also given in SIS).

Annual Evaluation of Study

Progress is monitored at the end of each study section. The Annual Evaluation of Study involves a check of your credit total, that is, the number of credits obtained in all previous study sections by the end of the last examination period. If you in previous study sections have attained in total at least the normal number of credits (corresponding to the sum of the credits in these sections in the recommended course of study), or if you have obtained at least the minimum number of credits (see below), then you have the right to enrol in the next study section. Please note that while the Annual Evaluation of Study may come after the end of the official examination period for the previous study section (see the Academic Calendar for the exact dates of the winter and summer examination periods), only credits obtained by the end of the official examination period will be considered as part of the assessment. Attaining at least the normal number of credits is one of the necessary conditions for obtaining a scholarship for excellent study achievement. If you have not received the minimum number of credits, then this is considered as a failure to fulfil the requirements of the study programme and results in exclusion.

The normal and minimum numbers of credits required for registration in the next study section are given as follows (normal number of credits is followed in parentheses by minimum number of credits):

- **Normal and minimum number of credits**
  Bachelor's degree programmes
  - 30 (12) for enrolment to the second study section (i.e., the summer semester of the first year of study),
  - 60 (45) for enrolment to the third study section (i.e., the second year),
  - 120 (90) for enrolment to the fourth study section (i.e., the third year),
  - 180 (135) for enrolment to the fifth study section (i.e., the fourth year),
  - 240 (180) for enrolment to the sixth study section (i.e., the fifth year),
  - 300 (225) for enrolment to the seventh study section (i.e., the sixth year).

  Master's degree programmes
  - 60 (45) for enrolment to the second study section (i.e., the second year),
  - 120 (90) for enrolment to the third study section (i.e., the third year),
  - 180 (120) for enrolment to the fourth study section (i.e., the fourth year),
  - 240 (165) for enrolment to the fifth section study (i.e., the fifth year).

For the purpose of the Annual Evaluation of Study, all the credits for completed compulsory and elective courses are counted, and credits for optional courses are counted up to the following limits (in parentheses we specify what percentage of the corresponding normal number of credits the maximum number corresponds to):

- **Maximum number of credits for optional courses**
  Bachelor's degree programmes
  - 4 credits (15 %) for enrolment to the second study section,
  - 9 credits (15 %) for enrolment to the third study section,
  - 18 credits (15 %) for enrolment to the fourth study section,
  - 54 credits (30 %) for enrolment to the fifth study section,
  - 72 credits (30 %) for enrolment to the sixth study section,
  - 90 credits (30 %) for enrolment to the seventh study section.

  Master's degree programmes
  - 18 credits (30 %) for enrolment to the second study section,
  - 60 credits (50 %) for enrolment to the third study section,
  - 126 credits (70 %) for enrolment to the fourth study section,
  - 167 credits (70 %) for enrolment to the fifth section study.

You are allowed to enrol in and complete optional courses with a larger number of credits than the maximum specified above, but then some of these credits will not be considered in the Annual Evaluation of Study. Although you technically only need the minimum number of credits to register for the next study section, we strongly recommend attaining the normal number of credits, otherwise you most likely will not be able to complete your study programme within the standard period of time. Technical details about the Annual Evaluation are provided on the webpages `https://www.mff.cuni.cz/first_annual_evaluation` and `https://www.mff.cuni.cz/annual_evaluation`.

State Final Exam

Studies are concluded with a state final examination. This examination consists of several parts (two or three, depending on the corresponding curriculum), one of which for bachelor's degree programmes is always the defence of a bachelor's thesis and for master's degree programmes the defence of a master's (diploma) thesis. If a student fails a part of the state final exam, only the failed part is repeated. Each part of the state final exam may be repeated at most twice. Each part of the state final exam is graded separately and from these an overall grade is awarded. Necessary conditions for taking the State Final Exam include passing all obligatory courses, obtaining the required number of credits for elective courses, reaching a total of at least 180 credits (in bachelor's degree programmes) or 120 credits (in master's degree programmes), and submitting a completed thesis (for the thesis defence). The knowledge requirements for the State Final Exam are specified in the degree plans of the respective study programmes and branches of study, which are described in this document.

More detailed instructions and advice on the assignment, writing up, submission and defence of bachelor's and master's theses are provided at the webpage `https://www.mff.cuni.cz/final_thesis`.

Some Suggestions

Advising others is always a bit tricky but nevertheless I would like to give here a few suggestions for making the most of your time at our faculty. They are addressed primarily to students in their first year.

Connect and communicate. Your stay in Prague will be much more enjoyable and your studies more successful if you manage to build and maintain healthy relationships with others. Be first to initiate interactions with fellow students rather than wait to be approached yourself – just a simple greeting is always welcome and can break the ice. Look out for student social activities – and add to them yourself! Build connections with your professors, advisors and mentors from the outset: opening channels of communication early on can help prevent any difficulties that might otherwise emerge. If you are enjoying classes, if you don't understand a topic, or if you are facing personal issues that are hindering your progress, let them know. You can talk after class, send an email, visit during office hours or set up a one-to-one meeting. Introduce yourself to our well-being advisor, Zuzana Biskupová.

Write. Many of you will learn faster and better if listening and reading is complemented by writing. These days, for many courses there are excellent written materials, often including slides prepared by the lecturer. Nevertheless, many of you will profit by taking your own notes at lectures and classes. It is important to use pen and paper during your preparation for tests and exams. Do you think that you already understand the proof of a theorem? Write it down with the book closed, making sure to include all necessary details. Finally, if you want to learn to program well, write some code.

Work. Even if nobody makes you do so. In contrast to many secondary schools, you will not have to take a test or do homework every day. However, there will be plenty of tests and exams at the end of the semester. Be aware of this and learn as much as you can during the semester rather than later. You will learn more, you will retain it longer, and the examination period will go more smoothly for you.

Plan. This is related to the previous point. In the examination period you will rarely be able to learn well for an exam during a single day or night. Take this into account when planning the dates of your exams in the examination period. Allow yourself enough time to prepare for exams, to code programs or to solve problems for obtaining a course credit. Reserve some time for possible second attempts at failed exams. Do not postpone until the next semester or the next year what you are to do now. If you do so, most likely you will not be able to catch up.

Think. Not everything that you read on the internet is correct. Not even everything that you hear in a lecture is always correct (we all make mistakes). Try to understand everything. Do not be content merely with answers to the questions how? and what?, but also ask *why?* If you have a question, try first to find an answer by yourself before searching for an answer in a textbook or on the internet.

Persist. Many of our current and past students have reported that they find study at our faculty difficult. We have seen many students with outstanding results in their previous studies who have struggled with the demands of our study programmes. Thus, don't be surprised if you start feeling lost! Instead, persist, keep going, and know that you are not alone in feeling this way. Your persistence will pay off!

Best wishes for an enjoyable and successful academic year.

Petr Kolman
Coordinator for Studies in English

Prague, July 12, 2022

Academic calendar

Sep 5 – Sep 22, 2022	Electronic enrolment in winter semester courses – priority mode
Sep 23 – Oct 9, 2022	Electronic enrolment in winter semester courses – open mode
Sep 29, 2022 – Jan 8, 2023	Winter semester tuition
Sep 30, 2022	Annual evaluation for academic year 2021/2022 and registration for second and higher years of bachelor's and master's programmes
Oct 1, 2022	Beginning of academic year 2022/2023 and of its winter semester
Oct 10 – Oct 21, 2022	Approval of electronic enrolment in courses by the Department of Student Affairs
Oct 27, 2022	Matriculation of first year students on bachelor's and master's study programmes
Nov 1, 2022	Recommended period for deciding bachelor's thesis topics
Nov 9, 2022	Dean's Sports Day (no lectures or classes)
Nov 10, 2022	Graduation Ceremony – bachelor's study programmes
Nov 15, 2022	Graduation Ceremony – bachelor's study programmes
Nov 22, 2022	Open Day
Dec 1, 2022	Graduation Ceremony – master's study programmes
Dec 23, 2022 – Jan 1, 2023	Christmas vacation
Jan 5, 2023	Submission of bachelor's and master's (diploma) thesis for winter period of state final examinations - electronic version
Jan 9, 2023	Submission of bachelor's and master's (diploma) thesis for winter period of state final examinations - paper version
Jan 9 – Feb 12, 2023	Winter semester examination period
Jan 15, 2023	Registration for winter period of bachelor's and master's state final examinations
	The final year of bachelor's and master's programmes: checking compliance with all conditions for admission to the winter term of state final examinations

Jan 30 – Feb 12, 2023	Winter period bachelor's and master's state final examinations
Jan 30 – Feb 5, 2023	Electronic enrolment in summer semester courses – priority mode
Feb 6 – Mar 5, 2023	Electronic enrolment in summer semester courses – open mode
Feb 10, 2023	Recommended period for deciding master's thesis topics
Feb 13, 2023	Beginning of summer semester of academic year 2022/2023
Feb 13 – May 21, 2023	Summer semester tuition
Feb 28, 2023	For first year bachelor's students: Annual evaluation after the winter semester
Mar 6 – Mar 17, 2023	Approval of electronic enrolment in courses by the Department of Student Affairs
Apr 18, 2023	Graduation Ceremony – master's study programmes
May 4, 2023	Submission of master's thesis for summer period of state final examinations - electronic version
May 9, 2023	Submission of master's thesis for summer period of state final examinations - paper version
May 10, 2023	Rector's day (no Lectures or Classes)
May 11, 2023	Submission of bachelor's thesis for summer period of state final examinations - electronic version
May 15, 2023	Submission of bachelor's thesis for summer period of state final examinations - paper version
May 22, 2023	Registration for summer period of master's state final examinations
	The final year of master's programmes: checking compliance with all conditions for admission to the summer term of state final examinations
May 23 – Jun 30, 2023	Summer semester examination period
Jun 4, 2023	Registration for summer period of bachelor's state final examinations
	The final year of bachelor's programmes: checking compliance with all conditions for admission to the summer term of state final examinations
Jun 5 – Jun 18, 2023	Summer period for master's state final examinations
Jun 12 – Jun 25, 2023	Summer period for bachelor's state final examinations
Jul 1 – Aug 31, 2023	Summer vacation
Jul 20, 2023	Submission of bachelor's and master's (diploma) thesis for autumn period of state final examinations - electronic version

Jul 21, 2023	Registration for autumn period of bachelor's and master's state final examinations
	The final year of bachelor's and master's programmes: checking compliance with all conditions for admission to the autumn term of state final examinations
Jul 24, 2023	Submission of bachelor's and master's (diploma) thesis for autumn period of state final examinations - paper version
Sep 1 – Sep 14, 2023	Autumn period for bachelor's state final examinations
	Autumn period for master's state final examinations
Sep 18 – Sep 24, 2023	Examination period
Sep 30, 2023	Annual evaluation for academic year 2022/2023 and registration for second and higher years of bachelor's and master's study programmes
	End of academic year 2022/2023

Location of faculty buildings

The Faculty of Mathematics and Physics comprises the School of Mathematics, the School of Physics, and the School of Computer Science. The schools are based at several locations in Prague. Here we provide basic information about their locations and about lecture rooms in the corresponding buildings. More details about the internal structure of the Faculty of Mathematics and Physics are given at `http://www.mff.cuni.cz/to.en/fakulta/struktura/`, and more details about locations and directions for faculty buildings are given at `http://www.mff.cuni.cz/to.en/fakulta/budovy/`.

School of Mathematics

The School of Mathematics is based in two locations: Sokolovská and V Holešovičkách.

Address: Sokolovská 83, 186 00 Praha 8

Lecture rooms

K1, K2, K3, K4, K5, K6, K7, K8, K9, K11, K12

Computer labs

K10

Address: V Holešovičkách 2, 180 00 Praha 8

Lecture rooms

N1, N2, N3, N4, N5, N6, N7, N9

Computer labs

N8, N10, N11

School of Computer Science

The School of Computer Science is based in two locations: Malostranské náměstí and V Holešovičkách.

Address: Malostranské nám. 25, 118 00 Praha 1

Lecture rooms
: S1, S3, S4, S5, S6, S7, S8, S9, S10, S11

Computer labs
: SW1, SW2

Address: V Holešovičkách 2, 180 00 Praha 8

Lecture rooms
: N1, N2, N3, N4, N5, N6, N7, N9

Computer labs
: N8, N10, N11

School of Physics

The School of Physics is based in two locations: V Holešovičkách and Ke Karlovu.

Address: V Holešovičkách 2, 180 00 Praha 8

Lecture rooms
: T1, T2, T5, T6, T7, T8, T9, T10, T11

Computer labs
: LabTF, LabTS

There are two neighbouring faculty buildings in the street Ke Karlovu.

Address: Ke Karlovu 3, 121 16 Praha 2

Lecture rooms
: M1, M2, M3, M5, M6

Computer labs
: PLK

Address: Ke Karlovu 5, 121 16 Praha 2

Lecture rooms
: F1, F2

Charles University Sports Centre

Address: Bruslařská 10, 102 00 Praha 10

Administration

Charles University in Prague

Address: Ovocný trh 5, 116 36 Praha 1

Rector

prof. MUDr. Milena Králíčková, M.D., Ph.D.

Faculty of Mathematics and Physics

Address: Ke Karlovu 3, 121 16 Praha 2, email: sdek@dekanat.mff.cuni.cz

Dean

doc. RNDr. Mirko Rokyta, CSc.

Advisory Board

Deputy Dean and Vice Dean for Research and International Affairs:	prof. RNDr. Zdeněk Doležal, Dr.
Vice Dean for Student Affairs:	doc. Mgr. Michal Kulich, Ph.D.
Vice Dean for Education:	doc. RNDr. Vladislav Kuboň, Ph.D.
Vice Dean for Development:	prof. RNDr. Ladislav Skrbek, DrSc.
Vice Dean for Physics:	prof. Ing. Jan Franc, DrSc.
Vice Dean for Computer Science:	prof. RNDr. Jiří Sgall, DrSc.
Vice Dean for Mathematics:	prof. RNDr. Vít Dolejší, Ph.D., DSc.
Vice Dean for Public Relations:	doc. Mgr. Michal Žák, Ph.D.
Secretary:	Ing. Blanka Svobodová

Coordinator for Studies in English: doc. Mgr. Petr Kolman, Ph.D.

Student Affairs Department

Address: Ke Karlovu 3, 121 16 Praha 2, phone 951 551 217, 951 551 404
email: info@mff.cuni.cz

Head:	JUDr. Dana Macharová
Coordinator of Student Well-Being Services:	PhDr. Liana Bala, Ph.D.
Assistant:	Mgr. Solange Petracchi
Assistant:	Bc. Eliška Zábrodská

Master of Mathematics

Study started in 2020 and later

1 General Information

Study Programmes

1. Mathematical Structures
2. Mathematics for Information Technologies
3. Mathematical Analysis
4. Computational Mathematics
5. Mathematical Modelling in Physics and Technology
6. Probability, Mathematical Statistics and Econometrics
7. Financial and Insurance Mathematics

Assumed Knowledge

Individual programmes have specific entry requirements for the knowledge assumed to have been already acquired before the start of the Master's programme. Upon evaluation of the previous study experience of each incoming student, the coordinator of the study programme may assign a method of acquiring the necessary knowledge and abilities, which may for example mean taking selected bachelor's courses, taking a reading course with an instructor, or following tutored independent study.

State Final Exam

Study in the master's programme is completed by passing the state final exam. It consists of two parts: defence of the master's (diploma) thesis, and an oral examination. Requirements for the oral part of the state final exam are listed in the following sections.

Students are advised to select the topic of their master's (diploma) thesis during the first year of the study. The departments of the faculty offer many topics for master theses each year and students can also suggest their own topics. We recommend to select the topic of your thesis primarily from the offer of the department that coordinates your study programme. If you prefer a topic offered by another department or your own topic, please consult it with the coordinator of your study programme. Work on the master's thesis is recognized by credits awarded upon taking the following courses

Code	Subject	Credits	Winter	Summer
NSZZ023	**Diploma Thesis I**	6	0/4 C	0/4 C
NSZZ024	**Diploma Thesis II**	9	0/6 C	0/6 C

NSZZ025	**Diploma Thesis III**	15	0/10 C	0/10 C

A student should enrol in these courses according to instructions of their thesis advisor (after the thesis topic has been assigned). These courses can be taken between the second semester of the first year and the last semester of study, in an arbitrary order and in an arbitrary semester. The credits for these courses are assigned by the thesis advisor. The last credits for these courses should be awarded when the master's thesis has been almost completed.

The deadlines for the assignment of the master's thesis topic, submission of the completed thesis, and enrolment in the final exam are determined by the academic calendar.

Project

A student can request an assignment of a project from the dean. The number of credits earned upon completion of the project (max. 9) is specified by the dean on the recommendation of the project advisor and the coordinator of the study programme.

2 Degree Plans - Mathematical Structures

Coordinated by: Department of Algebra
Study programme coordinator: doc. RNDr. Jan Šťovíček, Ph.D.

The curriculum is focused on extending general mathematical background (algebraic geometry and topology, Riemann geometry, universal algebra and model theory) and obtaining deeper knowledge in selected topics of algebra, geometry, logic, and combinatorics. The aim is to provide sufficient general knowledge of modern structural mathematics and to bring students up to the threshold of independent research activity. Emphasis is laid on topics taught by instructors who have achieved worldwide recognition in their field of research.

A graduate has advanced knowledge in algebra, geometry, combinatorics and logic. He/she is in close contact with the latest results of contemporary research in the selected field. The abstract approach, extensiveness and intensiveness of the programme result in the development of the ability to analyse, structure and solve complex and difficult problems. Graduates may pursue an academic career or realize themselves in jobs that involve mastering new knowledge and control of complex systems.

Assumed knowledge

It is assumed that an incoming student of this branch has sufficient knowledge of the following topics and fields:

- Linear algebra, real and complex analysis, and probability theory.
- Foundations of group theory (Sylow theorems, free groups, nilpotence), analysis on manifolds, commutative algebra (Galois theory, integral extensions), mathematical logic (propositional and first order logic, incompleteness and undecidability), set theory and category theory.

Deeper knowledge of combinatorics, representation theory of associative algebras (finiteness conditions, projective and injective modules) and Lie theory is an advantage (but not a necessity) for individual subject areas of this branch.

Should an incoming student not meet these entry requirements, the coordinator of the study programme may assign a method of acquiring the necessary knowledge and abilities, which may for example mean taking selected bachelor's courses, taking a reading course with an instructor, or following tutored independent study.

2.1 Obligatory Courses

Code	Subject	Credits	Winter	Summer
NMAG401	**Algebraic Geometry**	5	2/2 C+Ex	—
NMAG409	**Algebraic Topology 1**	5	2/2 C+Ex	—
NMAG411	**Riemannian Geometry 1**	5	2/2 C+Ex	—
NSZZ023	**Diploma Thesis I**	6	—	0/4 C
NSZZ024	**Diploma Thesis II**	9	0/6 C	—
NSZZ025	**Diploma Thesis III**	15	—	0/10 C

2.2 Elective Courses

Set 1

It is required to earn at least 48 credits from the following elective courses.

Code	Subject	Credits	Winter	Summer
NDMI009	Introduction to Combinatorial and Computational Geometry	5	2/2 C+Ex	—
NDMI013	Combinatorial and Computational Geometry 2	5	—	2/2 C+Ex
NDMI014	Topological Methods in Combinatorics	5	—	2/2 C+Ex
NDMI028	Linear Algebra Applications in Combinatorics	5	2/2 C+Ex	—
NDMI045	Analytic and Combinatorial Number Theory	3	—	2/0 Ex
NDMI073	Combinatorics and Graph Theory 3	5	2/2 C+Ex	—
NMAG331	Mathematical Logic	3	2/0 Ex	—
NMAG403	Combinatorics	5	2/2 C+Ex	—
NMAG405	Universal Algebra 1	5	2/2 C+Ex	—
NMAG407	Model Theory	3	2/0 Ex	—
NMAG430	Algebraic Number Theory	6	—	3/1 C+Ex
NMAG431	Combinatorial Group Theory	6	3/1 C+Ex	—
NMAG433	Riemann Surfaces	3	2/0 Ex	—
NMAG434	Categories of Modules and Homological Algebra	6	3/1 C+Ex	—
NMAG435	Lattice Theory	3	2/0 Ex	—
NMAG436	Curves and Function Fields	6	—	3/1 C+Ex
NMAG437	Seminar on Differential Geometry	3	0/2 C	0/2 C
NMAG438	Group Representations 1	5	—	2/2 C+Ex
NMAG439	Introduction to Set Theory 2	3	2/0 Ex	—
NMAG442	Representation Theory of Finite-Dimensional Algebras	6	—	3/1 C+Ex

NMAG444	Combinatorics on Words	3	2/0 Ex	—
NMAG446	Logic and Complexity	3	—	2/0 Ex
NMAG448	Classical groups and their invariants	5	—	2/2 C+Ex
NMAG450	Universal Algebra 2	4	—	2/1 C+Ex
NMAG454	Fibre Spaces and Gauge Fields	6	—	3/1 C+Ex
NMAG455	Quadratic forms and class fields I *	3	2/0 Ex	—
NMAG456	Quadratic forms and class fields II *	3	—	2/0 Ex
NMAG458	Algebraic Invariants in Knot Theory	4	—	2/1 Ex
NMAG462	Modular forms and L-functions I *	3	2/0 Ex	—
NMAG473	Modular forms and L-functions II *	3	—	2/0 Ex
NMAG475	MSTR Elective Seminar	2	0/2 C	0/2 C
NMAG481	Seminar on Harmonic Analysis	3	0/2 C	0/2 C
NMAG498	MSTR Elective 1	3	2/0 Ex	—
NMAG499	MSTR Elective 2	3	—	2/0 Ex
NMAG531	Approximations of Modules	3	—	2/0 Ex
NMAG532	Algebraic Topology 2	5	—	2/2 C+Ex
NMAG533	Principles of Harmonic Analysis	6	3/1 C+Ex	—
NMAG534	Non-commutative harmonic analysis	6	—	3/1 C+Ex
NMAG535	Computational Logic	5	2/2 C+Ex	—
NMAG446	Logic and Complexity *	3	—	2/0 Ex
NMAG536	Proof Complexity and the P vs. NP Problem *	3	—	2/0 Ex
NMAG563	Introduction to complexity of CSP	3	2/0 Ex	—
NMAG569	Mathematical Methods of Quantum Field Theory	3	0/2 C	0/2 C
NMAG538	Commutative algebra	6	—	4/0 Ex
NMAG537	Selected topic from Set Theory	3	2/0 Ex	—
NMAG575	Forcing	3	2/0 Ex	—
NMAL430	Latin Squares and Nonassociative Structures	3	—	2/0 Ex
NMMB413	Algorithms on Polynomials	4	2/1 C+Ex	—
NMMB415	Automata and Computational Complexity	6	3/1 C+Ex	—
NMMB430	Algorithms on Eliptic curves	4	—	2/1 C+Ex
NMMB432	Randomness and Calculations	4	—	2/1 Ex
NMMB433	Geometry for Computer Graphics	3	—	2/0 Ex
NTIN022	Probabilistic Techniques	5	2/2 C+Ex	—

* The course is taught once in two years only.

Set 2

It is required to earn at least 8 credits in 48 credits from the following short list.

Code	Subject	Credits	Winter	Summer
NMAG403	Combinatorics	5	2/2 C+Ex	—
NMAG405	Universal Algebra 1	5	2/2 C+Ex	—
NMAG407	Model Theory	3	2/0 Ex	—

NMAG438	Group Representations 1	5	—	2/2 C+Ex
NMMB415	Automata and Computational Complexity	6	3/1 C+Ex	—

2.3 State Final Exam

Requirements for taking the final exam

- Earning at least 120 credits during the course of the study.
- Completion of all obligatory courses prescribed by the study plan.
- Earning at least 48 credits by completion of elective courses from set 1. At least 8 credits must be from the short list of elective courses in set 2.
- Submission of a completed Master's Thesis by the submission deadline.

Oral part of the state final exam

The oral part of the final exam consists of a common subject area "1. Mathematical Structures" and a choice of one of four subject areas "2. Algebra and logic", "3. Geometry", "4. Representation Theory", "5. Combinatorics". A half of the exam is focused on subject area 1 and the other half on questions from the subject area selected from among 2, 3, 4 and 5.

Requirements for the oral part of the final exam

Common requirements

1. Mathematical Structures

Algebraic geometry. Algebraic topology.

Specialization

2. Algebra a logic

Finite groups and their representations. Combinatorial group theory. Binary systems. Advanced universal algebra. Complexity and enumerability. First order logic. Undecidability in algebraic systems. Quantifier elimination.

3. Geometry

Harmonic analysis and invariants of classical groups, Riemannian surfaces. Fibre spaces and covariant derivative.

4. Representation Theory

Representations of groups, representations of finite-dimensional algebras. Combinatorial group theory. Homological algebra.

5. Combinatorics

Applications of linear algebra and application of probabilistic method in combinatorics and graph theory. Analytic and combinatorial number theory. Combinatorial and computational geometry. Structural and algorithmic graph theory.

2.4 Recommended Course of Study

1st year

Code	Subject	Credits	Winter	Summer
NMAG401	**Algebraic Geometry**	5	2/2 C+Ex	—
NMAG409	**Algebraic Topology 1**	5	2/2 C+Ex	—

NMAG411	**Riemannian Geometry 1**	5	2/2 C+Ex	—
NSZZ023	**Diploma Thesis I**	6	—	0/4 C
	Optional and Elective Courses	39		

2nd year

Code	Subject	Credits	Winter	Summer
NSZZ024	**Diploma Thesis II**	9	0/6 C	—
NSZZ025	**Diploma Thesis III**	15	—	0/10 C
	Optional and Elective Courses	36		

3 Degree Plans - Mathematics for Information Technologies

Coordinated by: Department of Algebra
Study programme coordinator: doc. Mgr. Pavel Příhoda, Ph.D.

The study programme is oriented to extension and algorithmic treatment of theoretical knowledge of mathematical branches applied in information technologies. Within the study programme one can focus to cryptology, computer vision and robotics, or image processing and computer graphics.

A graduate has advanced analytical ability. He is able to identify the mathematical basis of problems from IT praxis, apply a complex mathematical theory and further professional knowledge to solve these problems. Graduates realize themselves in companies concentrating to the development of ambitious and specialized applications.

Assumed knowledge

It is assumed that an incoming student of this branch has sufficient knowledge of the following topics and fields:

- Linear algebra, real analysis, and probability theory.
- Foundations of general algebra including divisibility in integral domains, properties of polynomial rings, finite fields, foundations of group theory and Galois theory, elementary number theory.
- Computational aspects of aforementioned topics: Basic matrix algorithms, discrete Fourier transform and modular arithmetic, polynomial arithmetic. Basic idea of applications (cryptography, error-correcting codes, geometric modelling). Foundations of algorithmization and programming in Python.

Should an incoming student not meet these entry requirements, the coordinator of the study programme may assign a method of acquiring the necessary knowledge and abilities, which may for example mean taking selected bachelor's courses, taking a reading course with an instructor, or following tutored independent study.

3.1 Obligatory Courses

Code	Subject	Credits	Winter	Summer
NMMB409	**Convex optimization**	9	4/2 C+Ex	—
NMMB411	**Algorithms on Lattices**	4	2/1 C+Ex	—
NMMB413	**Algorithms on Polynomials**	4	2/1 C+Ex	—

NMMB415	**Automata and Computational Complexity**	6	3/1 C+Ex	—
NSZZ023	**Diploma Thesis I**	6	—	0/4 C
NSZZ024	**Diploma Thesis II**	9	0/6 C	—
NSZZ025	**Diploma Thesis III**	15	—	0/10 C

3.2 Elective Courses

Set 1

It is required to earn at least 46 credits from this group. The topics of the state exam to which the course relates is noted in brackets. The other courses are general.

Code	Subject	Credits	Winter	Summer
NDMI018	Approximation and Online Algorithms	5	—	2/2 C+Ex
NDMI025	Randomized Algorithms	5	—	2/2 C+Ex
NMAG331	Mathematical Logic	3	2/0 Ex	—
NMAG401	Algebraic Geometry	5	2/2 C+Ex	—
NMAG403	Combinatorics	5	2/2 C+Ex	—
NMAG430	Algebraic Number Theory	6	—	3/1 C+Ex
NMAG436	Curves and Function Fields (2C)	6	—	3/1 C+Ex
NMAG535	Computational Logic (2A)	5	2/2 C+Ex	—
NMAG563	Introduction to complexity of CSP	3	2/0 Ex	—
NMMB331	Boolean functions (2C)	3	2/0 Ex	—
NMMB333	Introduction to data analysis	5	2/2 C+Ex	—
NMMB402	Numerical Algorithms (2A)	4	—	2/1 C+Ex
NMMB404	Cryptanalysis (2C)	6	—	3/1 C+Ex
NMMB430	Algorithms on Eliptic curves (2A,2C)	4	—	2/1 C+Ex
NMMB432	Randomness and Calculations (2C)	4	—	2/1 Ex
NMMB433	Geometry for Computer Graphics (2E)	3	—	2/0 Ex
NMMB437	Legal Aspects of Data Protection (2C)	3	2/0 Ex	—
NMMB438	Fundamentals of Continuous Optimization (2B)	6	—	2/2 C+Ex
NMMB440	Geometry of Computer Vision (2D)	6	—	2/2 C+Ex
NMMB442	Geometric Problems in Robotics (2D)	6	2/2 C+Ex	—
NMMB460	Cryptanalysis Upon the Level of Instructions (2C)	4	—	0/4 C
NMMB464	Introduction to Computational Topology (2A,2D,2E)	4	—	2/1 C+Ex
NMMB498	MIT Elective 1	3	2/0 Ex	—
NMMB499	MIT Elective 2	3	—	2/0 Ex
NMMB501	Network Certification Security (2C)	5	2/2 C+Ex	—
NMMB531	Number Field Sieve (2A)	3	2/0 Ex	—

NMMB532	Standards and Cryptography (2C)	3	—	2/0 Ex
NMMB534	Quantum Information	6	—	3/1 C+Ex
NMMB538	Elliptic Curves and Cryptography (2C)	6	3/1 C+Ex	—
NMMO537	Saddle Point Problems and Their Solution (2B)	5	—	2/2 C+Ex
NMNV411	Algorithms for matrix iterative methods (2B)	5	2/2 C+Ex	—
NMNV412	Analysis of matrix iterative methods — principles and interconnections (2B)	6	—	4/0 Ex
NMNV503	Numerical Optimization Methods 1 (2B)	6	3/1 C+Ex	—
NMNV531	Inverse Problems and Regularization (2B)	5	2/2 C+Ex	—
NMNV532	Parallel Matrix Computations (2B)	5	—	2/2 C+Ex
NMNV533	Sparse Matrices in Numerical Mathematics (2B)	5	2/2 C+Ex	—
NOPT016	Integer Programming (2B)*	5	—	2/2 C+Ex
NPFL114	Deep Learning	7	—	3/2 C+Ex
NPGR010	Advanced 3D graphics for film and games (2E)	5	2/2 C+Ex	—
NPGR013	Special Functions and Transformations in Image Processing (2E)	3	—	2/0 Ex
NPGR016	Applied Computational Geometry (2D,2E)	5	—	2/1 C+Ex
NPGR029	Variational methods in image processing (2E)	3	—	2/0 Ex
NTIN022	Probabilistic Techniques	5	2/2 C+Ex	—
NTIN104	Foundations of theoretical cryptography (2C)	4	2/1 C+Ex	—

* The course is usually taught once in two years only.

Set 2

The topics of the state exam are covered by these courses. It is required to earn at least 17 credits in 46 credits from the following short list.

Code	Subject	Credits	Winter	Summer
NMMB331	Boolean functions (2C)	3	2/0 Ex	—
NMMB402	Numerical Algorithms (2A)	4	—	2/1 C+Ex
NMMB404	Cryptanalysis (2C)	6	—	3/1 C+Ex
NMMB432	Randomness and Calculations (2C)	4	—	2/1 Ex
NMMB433	Geometry for Computer Graphics (2E)	3	—	2/0 Ex
NMMB440	Geometry of Computer Vision (2D)	6	—	2/2 C+Ex

NMMB442	Geometric Problems in Robotics (2D)	6	2/2 C+Ex	—
NMNV411	Algorithms for matrix iterative methods (2B)	5	2/2 C+Ex	—
NMNV503	Numerical Optimization Methods 1 (2B)	6	3/1 C+Ex	—
NMNV533	Sparse Matrices in Numerical Mathematics (2B)	5	2/2 C+Ex	—
NPGR013	Special Functions and Transformations in Image Processing (2E)	3	—	2/0 Ex
NPGR029	Variational methods in image processing (2E)	3	—	2/0 Ex

Set 3

This group consists of scientific or working seminars. It is required to earn at least 4 credits from this group.

Code	Subject	Credits	Winter	Summer
NMMB361	Contemporary Issues in Cryptography	2	0/2 C	0/2 C
NMMB451	Applications of Mathematics in Computer Science	3	—	0/2 C
NMMB452	Seminar on Mathematics Inspired by Cryptography	3	0/2 C	0/2 C
NMMB473	Mathematical modeling of security	2	0/2 C	0/2 C
NMMB453	Students' Seminar on Logic	2	0/2 C	0/2 C
NMMB471	MIT Elective Seminar	2	0/2 C	0/2 C
NMMB551	Seminar on Combinatorial, Algorithmic and Finitary Algebra	2	—	0/2 C
NMNV451	Seminar in Numerical Mathematics	2	0/2 C	0/2 C

3.3 State Final Exam

Requirements for taking the final exam

- Earning at least 120 credits during the course of the study.
- Completion of all obligatory courses prescribed by the study plan.
- Earning at least 46 credits by completion of elective courses from set 1. At least 17 credits must be from the short list of elective courses in set 2.
- Earning at least 4 credits by completion of elective courses from set 3.
- Submission of a completed Master's Thesis by the submission deadline.

Oral part of the state final exam

The oral part of the final exam consists of two subject areas. One question is asked from common subject area 1. Student chooses two topic from among 2A, 2B, 2C, 2D, 2E. One question is asked from every chosen topic. Expected combinations are 2A+2C, 2B+2D, 2B+2E.

1. Mathematics for information technologies

Computational models, algorithmic decidability, basic complexity classes, regular languages. Basic methods of convex optimization. Groebner bases and Buchberger's algorithm. Lattices and the LLL algorithm.

2A. Algebraic and numerical algorithms

Factorization of polynomials: Berlekamp's algorithm, Hensel's lifting, Berlekamp-Hensel algorithm. Applications of Groebner bases in algebraic geometry. Algorithms for factorization of integers: Pollard rho, Pollard (p-1), CFRAC, ECM, and quadratic sieve. Connection between factorization of integers and discrete logarithm problem.

2B. Algorithms for linear algebra and optimization

Sparse Cholesky and LU decomposition, sparse QR decomposition. Krylov space iterative methods for solving systems of linear algebraic equations and linear approximation problems including construction of algebraic preconditionings. Methods for solving non-linear algebraic equations and their systems, functional minimization without constraints, local and global convergence of methods.

2C. Cryptology

Foundations of Boolean functions (bent functions, APN and AB functions, equivalences, S-boxes, Walsh transform and LAT, difference uniformity and DDT). Sequences generated by shift registers. Basic cryptanalytic attacks on block ciphers (differential and linear cryptanalysis, higher level attacks, meet-in-the middle) and stream ciphers (correlations, algebraic attacks), side channel attacks. Applications of lattices: NTRU, applications of LLL (for example attack on RSA with small public exponent). Probabilistic complexity classes, pseudorandom generators.

2D. Computer vision and robotics.

Mathematical model of perspective camera. Calculation of movement of calibrated camera from the pictures of unknown scene. 3D reconstruction from two images of unknown scene. Geometry of three calibrated cameras. Denavit-Hartenberg description of kinematics of manipulator. Inverse kinematic problem of 6-arm serial manipulator - formulation and solution. Calibration of parameters of manipulator - formulation and solution.

2E. Image processing and computer graphics.

Modelling of inverse problems, regularization methods, digitization of image, deblurring, edge detection, image registration, compression, image synthesis, compressed sensing, analytical, kinematic and differential geometry.

3.4 Recommended Course of Study

1st year

Code	Subject	Credits	Winter	Summer
NMMB409	**Convex optimization**	9	4/2 C+Ex	—
NMMB411	**Algorithms on Lattices**	4	2/1 C+Ex	—
NMMB413	**Algorithms on Polynomials**	4	2/1 C+Ex	—
NMMB415	**Automata and Computational Complexity**	6	3/1 C+Ex	—
NSZZ023	**Diploma Thesis I**	6	—	0/4 C

Code	Subject	Credits	Winter	Summer
	Optional and Elective Courses	27		

2nd year

Code	Subject	Credits	Winter	Summer
NSZZ024	**Diploma Thesis II**	9	0/6 C	—
NSZZ025	**Diploma Thesis III**	15	—	0/10 C
	Optional and Elective Courses	36		

4 Degree Plans - Mathematical Analysis

Coordinated by: Department of Mathematical Analysis
Study programme coordinator: prof. RNDr. Ondřej Kalenda, Ph.D., DSc.

The mathematical analysis curriculum offers advanced knowledge of fields traditionally forming mathematical analysis (real function theory, complex analysis, functional analysis, ordinary and partial differential equations). It is characterized by a depth of insight into individual topics and emphasis on their mutual relations and interconnections. Advanced knowledge of these topics is provided by a set of obligatory courses. Elective courses deepen the knowledge of selected fields, especially those related to the diploma thesis topic. Seminars provide contact with contemporary mathematical research. Mathematical analysis has close relationships with other mathematical disciplines, such as probability theory, numerical analysis and mathematical modelling. Students become familiar with these relationships in some of the elective courses. The programme prepares students for doctoral studies in mathematical analysis and related subjects. Applications of mathematical theory, theorems and methods to applied problems broaden the qualification to employment in a non-research environment.

The graduate will acquire advanced knowledge in principal fields of mathematical analysis (real function theory, complex analysis, functional analysis, ordinary and partial differential equations), understand their interconnections and relations to other mathematical disciplines. He/she will be able to apply advanced theoretical methods to real problems. The programme prepares students for doctoral studies but the knowledge and abilities acquired can be put into use in practical occupations as well.

The programme Mathematical Analysis has two versions of Degree Plans. The old version applies to students who started their studies in 2020 or in 2021. This version is contained in the Study Guide for the academic year 2021/2022. The new version, valid for students who started their studies in 2022 (or later) is given below.

Assumed knowledge

It is assumed that an incoming student of this branch has sufficient knowledge of the following topics and fields:

- Differential calculus of one and several real variables. Integral calculus of one real variable. Measure theory, Lebesgue measure and Lebesgue integral. Basic algebra (matrix calculus, vector spaces).
- Foundations of general topology (metric and topological spaces, completeness and compactness), complex analysis (Cauchy integral theorem, residue theorem) and functional analysis (Banach and Hilbert spaces, dual spaces, weak convergence bounded operators, compact operators, Fourier transform).

- Elements of the theory of ordinary differential equations (basic properties of solutions and maximal solutions, linear systems, stability theory) and of partial differential equations (quasilinear first order equations, Laplace theorem and heat equation – classical solution and maximum principle, wave equation – classical solution in dimensions 1,2,3, finite speed of wave propagation).

Should an incoming student not meet these entry requirements, the coordinator of the study programme may assign a method of acquiring the necessary knowledge and abilities, which may for example mean taking selected bachelor's courses, taking a reading course with an instructor, or following tutored independent study.

4.1 Obligatory Courses

Code	Subject	Credits	Winter	Summer
NMMA401	**Functional Analysis 1**	8	4/2 C+Ex	—
NMMA402	**Functional Analysis 2**	6	—	3/1 C+Ex
NMMA403	**Theory of Real Functions 1**	4	2/0 Ex	—
NMMA405	**Partial Differential Equations 1**	6	3/1 C+Ex	—
NMMA406	**Partial Differential Equations 2**	6	—	3/1 C+Ex
NMMA407	**Ordinary Differential Equations 2**	5	2/2 C+Ex	—
NMMA410	**Complex Analysis**	6	—	3/1 C+Ex
NSZZ023	**Diploma Thesis I**	6	—	0/4 C
NSZZ024	**Diploma Thesis II**	9	0/6 C	—
NSZZ025	**Diploma Thesis III**	15	—	0/10 C

4.2 Elective Courses

Set 1

The courses in this group introduce various research areas in mathematical analysis, illustrate their applications, and cover other fields that are related to mathematical analysis. It is required to earn at least 21 credits from this group.

A part of this amount of credits may be earned for courses taken during stays at foreign universities in cases these courses are equivalent to some of the courses from this group. In addition, up to 8 credits can be earned for courses taken during stays, even if they are not equivalent to any of the listed courses, provided the respective courses fulfil the conditions given in the first sentence of the previous paragraph and are approved in advance by the garant of the programme.

Code	Subject	Credits	Winter	Summer
NMAG409	Algebraic Topology 1	5	2/2 C+Ex	—
NMAG433	Riemann Surfaces	3	2/0 Ex	—
NMMA404	Theory of Real Functions 2	4	—	2/0 Ex
NMMA433	Descriptive Set Theory 1	4	2/0 Ex	—
NMMA434	Descriptive Set Theory 2	4	—	2/0 Ex
NMMA435	Topological Methods in Functional Analysis 1	4	2/0 Ex	—
NMMA436	Topological Methods in Functional Analysis 2	4	—	2/0 Ex

NMMA437	Advanced Differentiation and Integration 1	4	2/0 Ex	—
NMMA438	Advanced Differentiation and Integration 2	4	—	2/0 Ex
NMMA440	Differential Equations in Banach Spaces	4	—	2/0 Ex
NMMA501	Nonlinear Functional Analysis 1	5	2/2 C+Ex	—
NMMA502	Nonlinear Functional Analysis 2	5	—	2/2 C+Ex
NMMA531	Partial Differential Equations 3	4	2/0 Ex	—
NMMA533	Introduction to Interpolation Theory 1	4	2/0 Ex	—
NMMA534	Introduction to Interpolation Theory 2	4	—	2/0 Ex
NMMO401	Continuum Mechanics	6	2/2 C+Ex	—
NMMO532	Mathematical Theory of Navier-Stokes Equations	3	—	2/0 Ex
NMMO536	Mathematical Methods in Mechanics of Compressible Fluids	3	—	2/0 Ex
NMNV405	Finite Element Method 1	5	2/2 C+Ex	—

Set 2

This group includes scientific seminars and workshops. It is required to earn at least 12 credits from this group. Each seminar yields 3 credits per semester and they can be taken repeatedly.

Code	Subject	Credits	Winter	Summer
NMMA431	Seminar on Differential Equations	3	0/2 C	0/2 C
NMMA452	Seminar on Partial Differential Equations	3	0/2 C	0/2 C
NMMA454	Seminar on Function Spaces	3	0/2 C	0/2 C
NMMA455	Seminar on Real and Abstract Analysis	3	0/2 C	0/2 C
NMMA456	Seminar on Real Functions Theory	3	0/2 C	0/2 C
NMMA457	Seminar on Basic Properties of Function Spaces	3	0/2 C	0/2 C
NMMA458	Seminar on Topology	3	0/2 C	0/2 C
NMMA459	Seminar on Fundamentals of Functional Analysis	3	0/2 C	0/2 C

4.3 State Final Exam

Requirements for taking the final exam

- Earning at least 120 credits during the course of the study.
- Completion of all obligatory courses prescribed by the study plan.
- Earning at least 21 credits by completion of elective courses from set 1.
- Earning at least 12 credits by completion of elective courses from set 2.
- Submission of a completed master's thesis by the submission deadline.

Oral part of the state final exam

The oral part of the final exam consists of four subject areas: "Real and Complex Analysis", "Functional Analysis", "Ordinary Differential Equations", and "Partial Differential Equations". One question is asked from each subject area.

A more detailed specification of the topics for the oral part of the state final exam can be found at `https://www.mff.cuni.cz/en/math/for-students/mgr-prog/mgr-analysis-garant/ma-final`.

Requirements for the oral part of the final exam

1. Real and Complex Analysis

Measure theory and signed measures, Radon measures. Absolutely continuous functions and functions with bounded variation. Hausdorff measure and Hausdorff dimension. Meromorphic functions. Conformal mappings. Harmonic functions of two real variables. Zeros of holomorphic functions.

3. Functional Analysis

Locally convex spaces and weak topologies. Spectral theory in Banach algebras. Spectral theory of bounded and unbounded operators. Integral transformations. Theory of distributions.

4. Ordinary Differential Equations

Carathéodory theory of solutions. Systems of first order linear equations. Stability and asymptotical stability. Dynamical systems. Bifurcations.

5. Partial Differential Equations

Linear and quasilinear first order equations. Linear and nonlinear eliptic equations. Linear and nonlinear parabolic equations. Linear hyperbolic equations. Sobolev spaces.

4.4 Recommended Course of Study

Additional information concerning the recommended course of study may be found at `https://www.mff.cuni.cz/en/math/for-students/mgr-prog/mgr-analysis-garant/ma-add-dp`.

1st year

Code	Subject	Credits	Winter	Summer
NMMA401	**Functional Analysis 1**	8	4/2 C+Ex	—
NMMA403	**Theory of Real Functions 1**	4	2/0 Ex	—
NMMA405	**Partial Differential Equations 1**	6	3/1 C+Ex	—
NMMA407	**Ordinary Differential Equations 2**	5	2/2 C+Ex	—
NMMA402	**Functional Analysis 2**	6	—	3/1 C+Ex
NMMA406	**Partial Differential Equations 2**	6	—	3/1 C+Ex
NMMA410	**Complex Analysis**	6	—	3/1 C+Ex
NSZZ023	**Diploma Thesis I**	6	—	0/4 C
	Optional and Elective Courses	13		

2nd year

Code	Subject	Credits	Winter	Summer
NSZZ024	**Diploma Thesis II**	9	0/6 C	—

NSZZ025	**Diploma Thesis III**	15	—	0/10 C
	Optional and Elective Courses	36		

5 Degree Plans - Computational Mathematics

Coordinated by: Department of Numerical Mathematics
Study programme coordinator: doc. RNDr. Václav Kučera, Ph.D.

This programme focuses on design, analysis, algorithmization, and implementation of methods for computer processing of mathematical models. It represents a transition from theoretical mathematics to practically useful results. An emphasis is placed on the creative use of information technology and production of programming applications. An integral part of the programme is the verification of employed methods. The students will study modern methods for solving partial differential equations, the finite element method, linear and non-linear functional analysis, and methods for matrix calculation. They will choose the elective courses according to the topic of their master's thesis.

The graduate will have attained the knowledge needed for numerical solution of practical problems from discretization through numerical analysis up to implementation and verification. He/she will be able to choose an appropriate numerical method for a given problem, conduct its numerical analysis, and implement its computation including analysis of numerical error. The graduate will be able to critically examine, assess, and tune the whole process of the numerical solution, and can assess the agreement between the numerical results and reality. He/she will be able to carry out an analytical approach to the solution of a general problem based on thorough and rigorous reasoning. The graduate will be qualified for doctoral studies and for employment in industry, basic or applied research, or government institutions.

Assumed knowledge

It is assumed that an incoming student of this branch has sufficient knowledge of the following topics and fields:

- Differential calculus for functions of one and several real variables. Integral calculus for functions of one variable. Measure theory, Lebesgue measure and Lebesgue integral. Basics of linear algebra (matrix calculus, vector spaces).
- Foundations of functional analysis (Banach and Hilbert spaces, duals, bounded operators, compact operators), theory of ordinary differential equations (basic properties of the solutions and maximal solutions, systems of linear equations, stability) and theory of partial differential equations (quasilinear equations of first order, Laplace equation, heat equation, wave equation).
- Foundations of numerical mathematics (numerical quadrature, basics of the numerical solution of ordinary differential equations, finite difference method for partial differential equations) and of analysis of matrix computations (Schur theorem, orthogonal transformations, matrix decompositions, basic iterative methods).

Should an incoming student not meet these entry requirements, the coordinator of the study programme may assign a method of acquiring the necessary knowledge and abilities, which may for example mean taking selected bachelor's courses, taking a reading course with an instructor, or following tutored independent study.

5.1 Obligatory Courses

Code	Subject	Credits	Winter	Summer
NMMA405	**Partial Differential Equations 1**	6	3/1 C+Ex	—
NMNV401	**Functional Analysis**	5	2/2 C+Ex	—
NMNV403	**Numerical Software 1**	5	2/2 C+Ex	—
NMNV405	**Finite Element Method 1**	5	2/2 C+Ex	—
NMNV406	**Nonlinear differential equations**	5	—	2/2 C+Ex
NMNV411	**Algorithms for matrix iterative methods**	5	2/2 C+Ex	—
NMNV412	**Analysis of matrix iterative methods — principles and interconnections**	6	—	4/0 Ex
NMNV503	**Numerical Optimization Methods 1**	6	3/1 C+Ex	—
NSZZ023	**Diploma Thesis I**	6	—	0/4 C
NSZZ024	**Diploma Thesis II**	9	0/6 C	—
NSZZ025	**Diploma Thesis III**	15	—	0/10 C

5.2 Elective Courses

It is required to earn at least 30 credits from elective courses.

Code	Subject	Credits	Winter	Summer
NMMA406	Partial Differential Equations 2	6	—	3/1 C+Ex
NMNV404	Numerical Software 2	5	—	2/2 C+Ex
NMNV436	Finite Element Method 2	5	—	2/2 C+Ex
NMNV461	Techniques for a posteriori error estimation	3	2/0 Ex	—
NMNV464	A Posteriori Numerical Analysis Based on the Method of Equilibrated Fluxes	3	—	2/0 Ex
NMNV531	Inverse Problems and Regularization	5	2/2 C+Ex	—
NMNV532	Parallel Matrix Computations	5	—	2/2 C+Ex
NMNV533	Sparse Matrices in Numerical Mathematics	5	2/2 C+Ex	—
NMNV537	Mathematical Methods in Fluid Mechanics 1	3	2/0 Ex	—
NMNV538	Mathematical Methods in Fluid Mechanics 2	3	—	2/0 Ex
NMNV539	Numerical Solution of ODE	5	2/2 C+Ex	—
NMNV540	Fundamentals of Discontinuous Galerkin Method	3	—	2/0 Ex
NMNV543	Approximation of functions 1	5	2/2 C+Ex	—
NMNV544	Numerical Optimization Methods 2	5	—	2/2 C+Ex

5.3 Recommended Optional Courses

Code	Subject	Credits	Winter	Summer
NMMO401	*Continuum Mechanics*	6	2/2 C+Ex	—
NMMO403	*Computer Solutions of Continuum Physics Problems*	5	—	2/2 C+Ex
NMMO461	*Seminar in Continuum Mechanics*	2	0/2 C	0/2 C
NMMO535	*Mathematical Methods in Mechanics of Solids*	3	2/0 Ex	—
NMMO536	*Mathematical Methods in Mechanics of Compressible Fluids*	3	—	2/0 Ex
NMMO537	*Saddle Point Problems and Their Solution*	5	—	2/2 C+Ex
NMMO539	*Mathematical Methods in Mechanics of Non-Newtonian Fluids*	3	2/0 Ex	—
NMNV361	*Fractals and Chaotic Dynamics*	3	2/0 Ex	—
NMNV451	*Seminar in Numerical Mathematics*	2	0/2 C	0/2 C
NMNV466	*Domain Decomposition Methods*	3	—	2/0 Ex
NMNV462	*Numerical Modelling of Electrical Engineering Problems*	3	—	2/0 Ex
NMNV468	*Numerical Linear Algebra for Data Science and Informatics*	5	—	2/2 C+Ex
NMNV541	*Shape and Material Optimisation 1*	3	2/0 Ex	—
NMNV542	*Shape and Material Optimisation 2*	3	—	2/0 Ex
NMNV561	*Bifurcation Analysis of Dynamical Systems 1*	3	2/0 Ex	—
NMNV562	*Bifurcation Analysis of Dynamical Systems 2*	3	—	2/0 Ex
NMNV565	*High-Performance Computing for Computational Science*	5	2/2 C+Ex	—
NMNV568	*Approximation of functions 2*	3	—	2/0 Ex
NMNV569	*Numerical Computations with Verification*	5	—	2/2 C+Ex
NMNV571	*Multilevel Methods*	3	2/0 Ex	—
NMNV623	*Contemporary Problems in Numerical Mathematics*	3	0/3 C	0/3 C
NMST442	*Matrix Computations in Statistics*	5	—	2/2 C+Ex

5.4 State Final Exam

Requirements for taking the final exam

– Earning at least 120 credits during the course of the study.
– Completion of all obligatory courses prescribed by the study plan.
– Earning at least 30 credits by completion of elective courses.
– Submission of a completed master's thesis by the submission deadline.

Oral part of the state final exam

The oral part of the final exam consists of three questions from topics described below. The contents of these topics are covered by obligatory courses.

Requirements for the oral part of the final exam

1. Partial differential equations

Linear elliptic, parabolic and hyperbolic equations, nonlinear differential equations in divergence form, Sobolev spaces, variational formulation, existence and properties of solutions, monotone and potential operators.

2. Finite element method

Finite element spaces and their approximative properties, Galerkin approximation of linear elliptic problems, error estimates, solution of nonlinear differential equations in divergence form.

3. Numerical linear algebra

Basic direct and iterative matrix methods, Krylov methods, projections and problem of moments, connection between spectral information and convergence.

4. Adaptive discretization methods

Numerical quadrature, error estimates, adaptivity. Numerical methods for ordinary differential equations, estimates of local error, adaptive choice of time step.

5. Numerical optimization methods

Methods for solution of nonlinear algebraic equations and their systems, methods for minimization of functionals without constraints, local and global convergence.

5.5 Recommended Course of Study

1st year

Code	Subject	Credits	Winter	Summer
NMMA405	**Partial Differential Equations 1**	6	3/1 C+Ex	—
NMNV401	**Functional Analysis**	5	2/2 C+Ex	—
NMNV403	**Numerical Software 1**	5	2/2 C+Ex	—
NMNV405	**Finite Element Method 1**	5	2/2 C+Ex	—
NMNV411	**Algorithms for matrix iterative methods**	5	2/2 C+Ex	—
NMNV451	Seminar in Numerical Mathematics	2	0/2 C	—
NMNV406	**Nonlinear differential equations**	5	—	2/2 C+Ex
NMNV412	**Analysis of matrix iterative methods — principles and interconnections**	6	—	4/0 Ex
NSZZ023	**Diploma Thesis I**	6	—	0/4 C
NMNV451	Seminar in Numerical Mathematics	2	—	0/2 C
	Optional and Elective Courses	13		

2nd year

Code	Subject	Credits	Winter	Summer
NMNV503	**Numerical Optimization Methods 1**	6	3/1 C+Ex	—

NSZZ024	**Diploma Thesis II**	9	0/6 C	—
NMNV451	Seminar in Numerical Mathematics	2	0/2 C	—
NSZZ025	**Diploma Thesis III**	15	—	0/10 C
NMNV451	Seminar in Numerical Mathematics	2	—	0/2 C
	Optional and Elective Courses	26		

6 Degree Plans - Mathematical Modelling in Physics and Technology

Coordinated by: Mathematical Institute of Charles University
Study programme coordinator: prof. RNDr. Josef Málek, CSc., DSc.

Mathematical modelling is an interdisciplinary field connecting mathematical analysis, numerical mathematics, and physics. The curriculum is designed to provide excellent basic knowledge in all these disciplines and to allow a flexible widening of knowledge by studying specialized literature when the need arises. All students take obligatory courses in continuum mechanics, partial differential equations, and numerical mathematics. Students will acquire the ability to design mathematical models of natural phenomena (especially related to continuum mechanics and thermodynamics), analyse them, and conduct numerical simulations. After passing the obligatory classes, students get more closely involved with physical aspects of mathematical modelling (model design), with mathematical analysis of partial differential equations, or with methods for computing mathematical models. The grasp of all levels of mathematical modelling (model, analysis, simulations) allows the students to use modern results from all relevant fields to address problems in physics, technology, biology, and medicine that surpass the scope of the fields individually. Graduates will be able to pursue academic or commercial careers in applied mathematics, physics and technology.

The graduate will have mastered methods and results in continuum mechanics and thermodynamics, mathematical analysis of partial differential equations, and numerical mathematics, and will be ready to widen his/her knowledge by studying specialized literature. He/she will be able to formulate questions regarding the physical substance of natural phenomena, especially those related to the behaviour of fluids and solid matter in the framework of classical physics, with applications to technology, medicine, biology, geophysics, and meteorology. He/she will be able to choose appropriate mathematical models for such phenomena, carry out its mathematical analysis, and conduct numerical simulations with suitable methods. He/she will be able to critically analyse, evaluate, and tie in the whole modelling process. In simpler cases, he/she will be able to assess the errors in the modelling process and predict the agreement between numerical results and the physical process. The graduate will be ready to work in interdisciplinary teams. He/she will be able to pose interesting questions in a format ready for mathematical investigation and use abstract mathematical results in order to address applied problems.

Assumed knowledge

It is assumed that an incoming student of this branch has sufficient knowledge of the following topics and fields:

- Foundations of differential and integral calculus of one variable and several variables. Volume, surface and line integral. Measure theory. Lebesgue integral.

- Foundations of linear algebra (vector spaces, matrices, determinants, Jordan canonical form, eigenvalues and eigenvectors, multilinear algebra, quadratic forms). Numerical solution of systems of linear algebraic equations (Schur theorem, QR decomposition, LU decomposition, singular value decomposition, least squares problem, partial eigenvalue problem, conjugate gradient method, GMRES, backward error, sensitivity and numerical stability, QR algorithm).
- Foundations of complex analysis (Cauchy theorem, residual theorem, conformal mappings, Laplace transform).
- Foundations of functional analysis and theory of metric spaces (Banach and Hilbert spaces, operators and functionals, Hahn-Banach theorem, dual space, bounded operators, compact operators, theory of distributions).
- Foundations of theory of ordinary differential equations (existence of solution, maximal solution, systems of linear equations, stability) and partial differential equations (quasilinear first order equations, Laplace equation and heat equation – fundamental solution and maximum principle, wave equation – fundamental solution, finite propagation speed).
- Foundations of classical mechanics (Newton laws, Lagrange equations, Hamilton equations, variational formulation, rigid body dynamics).

Should an incoming student not meet these entry requirements, the coordinator of the study programme may assign a method of acquiring the necessary knowledge and abilities, which may for example mean taking selected bachelor's courses, taking a reading course with an instructor, or following tutored independent study.

6.1 Obligatory Courses

Code	Subject	Credits	Winter	Summer
NMMA401	**Functional Analysis 1**	8	4/2 C+Ex	—
NMMA405	**Partial Differential Equations 1**	6	3/1 C+Ex	—
NMMA406	**Partial Differential Equations 2**	6	—	3/1 C+Ex
NMMO401	**Continuum Mechanics**	6	2/2 C+Ex	—
NMMO402	**Thermodynamics and Mechanics of Non-Newtonian Fluids**	5	—	2/1 C+Ex
NMMO403	**Computer Solutions of Continuum Physics Problems**	5	—	2/2 C+Ex
NMMO404	**Thermodynamics and Mechanics of Solids**	5	—	2/1 C+Ex
NMNV405	**Finite Element Method 1**	5	2/2 C+Ex	—
NMNV411	**Algorithms for matrix iterative methods** *	5	2/2 C+Ex	—
NOFY036	**Thermodynamics and Statistical Physics**	6	3/2 C+Ex	—
NSZZ023	**Diploma Thesis I**	6	—	0/4 C
NSZZ024	**Diploma Thesis II**	9	0/6 C	—
NSZZ025	**Diploma Thesis III**	15	—	0/10 C

* The course replaces the obligatory course NMNV412 from study plans valid before 2021/2022.

6.2 Elective Courses

It is required to earn at least 16 credits from elective courses.

Code	Subject	Credits	Winter	Summer
NMMA407	Ordinary Differential Equations 2	5	2/2 C+Ex	—
NMMA531	Partial Differential Equations 3	4	2/0 Ex	—
NMMO432	Classical Problems of Continuum Mechanics	4	—	2/1 C+Ex
NMMO463	GENERIC — non-equilibrium thermodynamics	4	—	2/1 C+Ex
NMMO532	Mathematical Theory of Navier-Stokes Equations	3	—	2/0 Ex
NMMO533	Nonlinear Differential Equations and Inequalities 1	6	3/1 C+Ex	—
NMMO534	Nonlinear Differential Equations and Inequalities 2	6	—	3/1 C+Ex
NMMO535	Mathematical Methods in Mechanics of Solids	3	2/0 Ex	—
NMMO536	Mathematical Methods in Mechanics of Compressible Fluids	3	—	2/0 Ex
NMMO537	Saddle Point Problems and Their Solution	5	—	2/2 C+Ex
NMMO539	Mathematical Methods in Mechanics of Non-Newtonian Fluids	3	2/0 Ex	—
NMMO541	Theory of Mixtures	4	2/1 C+Ex	—
NMMO543	Modelling in biomechanics *	5	3/0 C+Ex	—
NMMO567	Simulation and Theory of Biological and Soft Matter Systems I - Biopolymers, Ions and Small Molecules	3	2/0 Ex	—
NMMO568	Simulation and Theory of Biological and Soft Matter Systems II — Interfaces, Self-Assembly and Networks	3	—	2/0 Ex
NMMO660	*Non-equilibrium thermodynamics of electrochemistry*	4	—	2/1 C+Ex
NMNV403	Numerical Software 1	5	2/2 C+Ex	—
NMNV404	Numerical Software 2	5	—	2/2 C+Ex
NMNV412	Analysis of matrix iterative methods — principles and interconnections	6	—	4/0 Ex
NMNV501	Solution of Nonlinear Algebraic Equations *	5	2/2 C+Ex	—
NMNV503	Numerical Optimization Methods 1	6	3/1 C+Ex	—
NMNV532	Parallel Matrix Computations	5	—	2/2 C+Ex
NMNV537	Mathematical Methods in Fluid Mechanics 1	3	2/0 Ex	—

NMNV538	Mathematical Methods in Fluid Mechanics 2	3	—	2/0 Ex
NMNV565	High-Performance Computing for Computational Science	5	2/2 C+Ex	—
NOFY026	Classical Electrodynamics	5	—	2/2 C+Ex
NTMF034	Physics for Mathematicians 2 – Electromagnetic Field and Special Theory of Relativity	5	—	2/1 Ex

* The course NMMO531 is not taught since in the academic year 2021/22. It is replaced with the course NMMO543.

6.3 Recommended Optional Courses

Code	Subject	Credits	Winter	Summer
NMMA452	*Seminar on Partial Differential Equations*	3	0/2 C	0/2 C
NMMA461	*Regularity of Navier — Stokes Equations*	3	0/2 C	0/2 C
NMMA583	*Qualitative Properties of Weak Solutions to Partial Differential Equations*	3	2/0 Ex	—
NMMA584	*Regularity of Weak Solutions to Partial Differential Equations*	3	—	0/2 C
NMMO461	*Seminar in Continuum Mechanics*	2	0/2 C	0/2 C
NMMO463	*GENERIC — non-equilibrium thermodynamics*	4	—	2/1 C+Ex
NMMO561	*Regularity of solutions of Navier-Stokes equations*	3	2/0 Ex	—
NMMO564	*Selected Problems in Mathematical Modelling*	3	—	0/2 C
NMMO660	*Non-equilibrium thermodynamics of electrochemistry*	4	—	2/1 C+Ex
NMNV406	*Nonlinear differential equations*	5	—	2/2 C+Ex
NMNV541	*Shape and Material Optimisation 1*	3	2/0 Ex	—
NMNV542	*Shape and Material Optimisation 2*	3	—	2/0 Ex

6.4 State Final Exam

Requirements for taking the final exam

- Earning at least 120 credits during the course of the study.
- Completion of all obligatory courses prescribed by the study plan.
- Earning at least 16 credits by completion of elective courses.
- Submission of a completed master's thesis by the submission deadline.

Oral part of the state final exam

The oral part of the final exam consists of six subject areas: "Partial Differential Equations", "Funcional Analysis", "Finite element method", "Solution of algebraic equations", "Continuum kinematics and dynamics", and "Constitutive realtions of fluids and solids". One question is asked from each subject area.

Requirements for the oral part of the final exam

1. Continuum mechanics and thermodynamics

Kinematics. Stress tensor. Balance equations. Constitutive relations. Models for fluids and solids.

2. Functional analysis and partial differential equations

Linear operators and functionals, compact operators. Distributions. Function spaces. Weak solutions of the linear elliptic, parabolic and hyperbolic second order partial differential equations – foundations of the existence theory, elementary theory of qualitative properties of the solutions.

3. Numerical methods

Numerical methods for partial differential equations. Finite element method. Iterative methods for solving systems of linear algebraic equations.

6.5 Recommended Course of Study

1st year

Code	Subject	Credits	Winter	Summer
NMMA401	**Functional Analysis 1**	8	4/2 C+Ex	—
NMMA405	**Partial Differential Equations 1**	6	3/1 C+Ex	—
NMMO401	**Continuum Mechanics**	6	2/2 C+Ex	—
NOFY036	**Thermodynamics and Statistical Physics**	6	3/2 C+Ex	—
NMNV405	**Finite Element Method 1**	5	2/2 C+Ex	—
NMMA406	**Partial Differential Equations 2**	6	—	3/1 C+Ex
NSZZ023	**Diploma Thesis I**	6	—	0/4 C
NMMO402	**Thermodynamics and Mechanics of Non-Newtonian Fluids**	5	—	2/1 C+Ex
NMMO403	**Computer Solutions of Continuum Physics Problems**	5	—	2/2 C+Ex
NMMO404	**Thermodynamics and Mechanics of Solids**	5	—	2/1 C+Ex
	Optional and Elective Courses	1		

2nd year

Code	Subject	Credits	Winter	Summer
NSZZ024	**Diploma Thesis II**	9	0/6 C	—
NMNV412	**Analysis of matrix iterative methods — principles and interconnections**	6	—	4/0 Ex
NSZZ025	**Diploma Thesis III**	15	—	0/10 C
	Optional and Elective Courses	30		

7 Degree Plans - Probability, Mathematical Statistics and Econometrics

Coordinated by: Department of Probability and Mathematical Statistics
Study programme coordinator: doc. Ing. Marek Omelka, Ph.D.

The curriculum is targeted at students who wish to obtain theoretical and practical knowledge about the mathematics of random events. It is primarily characterized by a balance between rigorous mathematical theory, depth of insight into various fields of the subject (probability, statistics, econometrics), and applications in various areas. The students will obtain a general background by taking compulsory courses in probability, optimization, linear regression and random processes. They continue by taking elective courses to extend their expertise and choose a specialization they wish to study more deeply. In seminars, they learn to work independently as well as to collaborate on complex projects. Great emphasis is placed on the development of independent analytical thinking. Probability, statistics and econometrics have a close relationship to other mathematical subjects (mathematical analysis, numerical mathematics, discrete mathematics). Applications are inspired by real problems from economics, medicine, technology, natural sciences, physics and computer science. The primary objective of the programme is to prepare students for successful careers in academia as well as in finance, telecommunications, marketing, medicine and natural sciences.

The graduate will be familiar with mathematical modelling of random events and processes and its applications. He/she will understand the foundations of probability theory, mathematical statistics, random process theory and optimization. His/her general background will have been extended to a deeper knowledge of random process theory and stochastic analysis, modern statistical methods, or advanced optimization and time series analysis. The graduate will understand the substance of the methods, grasp their mutual relationships, and will be able to actively extend them and use them. He/she will know how to apply theoretical knowledge to practical problems in a creative way. The graduate's ability to think logically, to analyse problems, and to solve non-trivial problems can be put to use in independent and creative jobs in the commercial sector or in academic positions.

Assumed knowledge

It is assumed that an incoming student of this branch has sufficient knowledge of the following topics and fields:

- Differential and integral calculus of one variable and several variables. Measure theory. Lebesgue integral. Vector spaces, matrix algebra. Foundations of complex and functional analysis.
- Foundations of probability theory.
- Foundations of mathematical statistics and data analysis.
- Markov chain theory.

Should an incoming student not meet these entry requirements, the coordinator of the study programme may assign a method of acquiring the necessary knowledge and abilities, which may for example mean taking selected bachelor's courses, taking a reading course with an instructor, or following tutored independent study.

Study plan

The study plan contains three specializations:

– Econometrics
– Matematical Statistics
– Probability Theory

There are obligatory courses (see below) for all the three specializations. Next to that each specialization has its own obligatory and elective courses. In what follows we describe the common part of the study plan and then the parts of the stupy plan that are specialization specific.

7.1 The common part of the study plan

The first year (winter term)

Code	Subject	Credits	Winter	Summer
NMSA405	**Probability Theory 2**	5	2/2 C+Ex	—
NMSA407	**Linear Regression**	8	4/2 C+Ex	—
NMSA409	**Stochastic Processes 2**	8	4/2 C+Ex	—
NMSA413	**Optimisation Theory**	8	4/2 C+Ex	—
	Optional and Elective course	1		

Recommended Optional Courses

Code	Subject	Credits	Winter	Summer
NMSA431	*Stochastic problems in research and practice*	1	0/1 C	—

7.2 Specialization Econometrics

The first year (summer term)

Code	Subject	Credits	Winter	Summer
NMEK412	**Optimisation with Applications to Finance**	5	—	2/2 C+Ex
NMEK450	**Econometrics Seminar 1**	2	—	0/2 C
NMST412	**Generalized linear models**	5	—	2/2 C+Ex
NMST414	**Time Series**	8	—	4/2 C+Ex
	Optional and Elective courses	10		

The second year

Code	Subject	Credits	Winter	Summer
NMEK511	**Econometrics**	8	4/2 C+Ex	—
NMEK521	**Econometric Project Seminar**	6	0/2 C	—
NMEK531	**Mathematical Economics**	5	2/2 C+Ex	—
NSZZ023	**Diploma Thesis I**	6	0/4 C	—
NSZZ024	**Diploma Thesis II**	9	—	0/6 C
NSZZ025	**Diploma Thesis III**	15	—	0/10 C

	Optional and Elective courses	11		

Elective courses

It is required to earn at least 10 credits from this group.

Code	Subject	Credits	Winter	Summer
NMEK436	Computational Aspects of Optimisation	5	—	2/2 C+Ex
NMFM431	Investment Analysis	5	2/2 C+Ex	—
NMFP436	Data Science 2	5	—	2/2 C+Ex
NMST422	Longitudinal and panel data	5	—	2/2 C+Ex
NMST424	Mathematical statistics 3	5	—	2/2 C+Ex
NMST539	Multivariate Analysis	5	2/2 C+Ex	—

Recommended optional course

Code	Subject	Credits	Winter	Summer
NMSA431	*Stochastic problems in research and practice*	1	0/1 C	—
NMFM438	*Mathematics in Finance and Insurance (E)*	6	—	4/0 Ex
NMFP405	*Probability for Finance and Insurance*	4	2/1 C+Ex	—
NMFP461	*Credit Risk in Banking*	3	2/0 Ex	—
NMFP465	*Financial Derivatives 1*	3	2/0 Ex	—
NMFP466	*Financial Derivatives 2*	3	2/0 Ex	—
NMFP505	*Stochastic Models in Finance 1*	5	2/2 C+Ex	—
NMFP534	*Stochastic Models in Finance 2*	3	—	2/0 Ex
NMST545	*Mathematical statistics 4*	3	2/0 Ex	—
NMTP432	*Stochastic Analysis*	8	—	4/2 C+Ex

7.3 Specialization Mathematical Statistics

The first year (summer term)

Code	Subject	Credits	Winter	Summer
NMST412	**Generalized linear models**	5	—	2/2 C+Ex
NMST422	**Longitudinal and panel data**	5	—	2/2 C+Ex
NMST424	**Mathematical statistics 3**	5	—	2/2 C+Ex
NMST431	**Bayesian Methods**	5	—	2/2 C+Ex
NMST450	**Statistical Seminar 1**	2	—	0/2 C
	Optional and Elective course	8		

The second year

Code	Subject	Credits	Winter	Summer
NMST511	Censored Data Analysis	6	3/2 C+Ex	—
NMST539	Multivariate Analysis	5	2/2 C+Ex	—
NMST551	Statistical Project Seminar	5	0/2 C	—

NSZZ023	**Diploma Thesis I**	6	0/4 C	—
NSZZ024	**Diploma Thesis II**	9	—	0/6 C
NSZZ025	**Diploma Thesis III**	15	—	0/10 C
	Optional and Elective courses	14		

Elective courses

It is required to earn at least 11 credits from this group.

Code	Subject	Credits	Winter	Summer
NMFP436	Data Science 2	5	—	2/2 C+Ex
NMEK511	Econometrics	8	4/2 C+Ex	—
NMST414	Time Series	8	—	4/2 C+Ex
NMST436	Experimental Design	5	2/2 C+Ex	—
NMST438	Survey Sampling	5	2/2 C+Ex	—
NMST444	Robust Statistical Methods	3	—	2/0 Ex
NMST532	Design and Analysis of Medical Studies	5	—	2/2 C+Ex
NMST535	Simulation Methods	5	—	2/2 C+Ex
NMST541	Statistical Quality Control	5	—	2/2 C+Ex
NMST547	Advanced aspects of R environment	3	0/2 C	—
NMST552	Statistical Consultations	2	—	0/2 C
NMTP438	Spatial Modelling	8	—	4/2 C+Ex
NMST543	Spatial Statistics	5	2/2 C+Ex	—
NMTP434	Invariance Principles	6	—	4/0 Ex
NMTP539	Markov Chain Monte Carlo Methods	5	2/2 C+Ex	—

Recommended optional course

Code	Subject	Credits	Winter	Summer
NMSA431	*Stochastic problems in research and practice*	1	0/1 C	—
NMST564	*Application of statistics in research process*	1	—	0/1 C
NMST570	*Statistical methods in psychometrics*	3	1/1 C+Ex	—
NMTP432	*Stochastic Analysis*	8	—	4/2 C+Ex
NPFL054	*Introduction to Machine Learning with R*	5	—	2/2 C+Ex

7.4 Specialization Probability theory

The first year (summer term)

Code	Subject	Credits	Winter	Summer
NMTP432	**Stochastic Analysis**	8	—	4/2 C+Ex
NMTP434	**Invariance Principles**	6	—	4/0 Ex
NMTP438	**Spatial Modelling**	8	—	4/2 C+Ex
NMTP450	**Seminar on Probability 1**	2	—	0/2 C

	Optional and Elective courses	6		

The second year

Code	Subject	Credits	Winter	Summer
NMTP521	**Seminar on Probability 2**	2	0/2 C	—
NSZZ023	**Diploma Thesis I**	6	0/4 C	—
NSZZ024	**Diploma Thesis II**	9	—	0/6 C
NSZZ025	**Diploma Thesis III**	15	—	0/10 C
	Optional and Elective courses	28		

Elective courses

It is required to earn at least 11 credits from this group.

Code	Subject	Credits	Winter	Summer
NMST543	Spatial Statistics	5	2/2 C+Ex	—
NMST424	Mathematical statistics 3	5	—	2/2 C+Ex
NMST545	Mathematical statistics 4	3	2/0 Ex	—
NMTP462	Differential Equations for Probability	3	—	2/0 Ex
NMTP532	Ergodic Theory	4	—	3/0 Ex
NMTP533	Applied Stochastic Analysis	5	2/2 C+Ex	—
NMTP566	Advanced Markov Chains	3	—	2/0 Ex
NMTP537	Limit Theorems for Sums of Random Variables	3	2/0 Ex	—
NMTP539	Markov Chain Monte Carlo Methods	5	2/2 C+Ex	—
NMTP541	Stochastic Geometry	3	—	2/0 Ex
NMTP543	Stochastic Differential Equations	6	4/0 Ex	—
NMTP545	Theory of Probability Distributions	3	2/0 Ex	—
NMTP569	Entropy in Probability Dynamical Systems	3	—	2/0 Ex

Recommended optional course

Code	Subject	Credits	Winter	Summer
NMSA431	*Stochastic problems in research and practice*	1	0/1 C	—
NMSA571	*Information Theory in Finance and Statistics*	3	—	2/0 Ex
NMFP505	*Stochastic Models in Finance 1*	5	2/2 C+Ex	—
NMFP534	*Stochastic Models in Finance 2*	3	—	2/0 Ex
NMTP561	*Malliavin calculus*	3	2/0 Ex	—
NMTP562	*Markov Processes*	6	—	4/0 Ex
NMTP567	*Selected Topics on Stochastic Analysis*	3	2/0 Ex	—
NMTP576	*Conditional Independence Structures*	3	—	2/0 Ex

NMTP578	*Quantum Probability Theory*	3	—	2/0 Ex

7.5 State Final Exam

Requirements for taking the final exam

- Earning at least 120 credits during the course of the study.
- Completion of all obligatory courses prescribed by the study plan (i.e. the obligatory course for all the specialization plus obligatory course of the given specialization).
- Earning the prescribed number of credits for elective courses of the given specialization.
- Submission of a completed master's thesis by the submission deadline.

Oral part of the state final exam

The oral part of the final exam consists of two subject areas. The first subject area is common. The second subject area given by the specialization.

Requirements for the oral part of the final exam

Common subject area

I. Foundations of Probability, Statistics and Random Processes

Foundations of Markov chain theory. Stationary sequences and processes. Linear regression model. Conditional expectation. Martingales in discrete time. Optimization, linear and non-linear programming.

Specialization Econometrics: IIa. Econometric and optimization methods

Stationary sequences, time series. Foundations of econometrics. Advanced optimization. Mathematical economics. Generalized linear models.

Specialization Mathematical Statistics: IIb. Advanced Statistical Analysis.

Modern theory of estimation and statistical inference. Generalized linear models. Multivariate analysis. Survival analysis. Bayesian analysis.

Specialization Probability theory: IIc. Processes in Time and Space.

Spatial modelling. Martingales. Invariance principles. Stochastic analysis.

8 Degree Plans - Financial and Insurance Mathematics

Coordinated by: Department of Probability and Mathematical Statistics
Study programme coordinator: doc. RNDr. Martin Branda, Ph.D.

The aim of the study program Financial and Insurance Mathematics is professional training in the profession of mathematician in financial institutions or for independent scientific activity in the fields of finance and insurance, including a possible academic career. Graduates of this study program will gain in-depth knowledge of basic mathematical disciplines and special knowledge of probability theory and mathematical statistics, econometrics and stochastic processes, mathematical methods in finance, life and non-life insurance, risk management, accounting (including insurance companies accounting) and machine learning. The teaching is largely based on mathematical modeling and advanced data analysis using modern software tools. All this allows graduates to perform highly effective modeling of financial and insurance products, their analysis in terms of risk, profitability and other characteristics necessary for effective financial management.

Graduates of the Financial and Insurance Mathematics study program will be employed in banks, insurance companies, pension and investment funds and other financial institutions, as well as in state administration (Ministry of Finance, Czech National Bank and others). The professions they then hold include actuaries, risk managers and data scientists. The current demand of the mentioned institutions for these professions, especially from the commercial sphere, is high and this trend will probably not change in the future. Last but not least, the graduates will receive the education that is the basis for the award of a certificate of competence to perform actuarial activities issued by the Czech Society of Actuaries to its members meeting the criteria of internationally recognized actuarial education (the certificate is valid for the entire EU).P¿

Assumed Knowledge

It is assumed that an incoming student of this program has sufficient knowledge of the following topics and fields:

- Differential and integral calculus of one variable and several variables. Measure theory. Lebesgue integral. Vector spaces, matrix algebra.
- Foundations of probability theory.
- Foundations of mathematical statistics and data analysis, markov chain theory, linear regression.
- Foundations of financial and actuarial mathematics.

Should an incoming student not meet these entry requirements, the coordinator of the study program may assign a method of acquiring the necessary knowledge and abilities, which may for example mean taking selected bachelor's courses, taking a reading course with an instructor, or following tutored independent study.

Study Plans

The study program has two study plans. The study plan N is intended for students who start their studies in the academic year 2022/2023 (or later). The study plan P is intended for students who started their studies in the academic year 2020/2021 or 2021/2022.

Financial and Insurance Mathematics, plan N

Study Plan N is intended for students who start their studies in the academic year 2022/2023 (or later).

Branch selection

Program Financial and Insurance Mathematics is splitted into two branches:

1. Branch **Insurance mathmematics** is designed for students who want to become actuaries or risk managers in insurance companies.
2. Branch **Data science and finance** is designed to prepare for careers in data science, advanced data analytics or risk management primarily in financial institutions.

Choosing a branch involves three sequential steps:

- *Selection of compulsory elective courses* according to the recommended course of study, typically from the summer semester of the first year.

- *Selection of one of the two variants of the subject "Diploma Thesis III".* This course is usually enrolled at the beginning of the last semester of study.
- *Selection of an optional topic of the oral part of the final exam*, when registering for the final exam.

Choice of elective courses

The choice of compulsory elective courses is guided by the prerequisites of individual variants of the "Diploma Thesis III". Each variant requires the fulfillment of certain requirements for passing the courses of the chosen specialization. These prerequisites are not verified when enrolling in the course "Diploma Thesis III", so this course can be enrolled without meeting all the prerequisites. However, they are verified during the control of the fulfillment of study obligations, so that a student who does not meet the prerequisites of the subject "Diploma Thesis III" at this stage cannot complete the study.

Recommended Course of Study – Branch Insurance Mathematics

1st year

In the summer semester of the 1st year of study, it is necessary to choose one of two specializations and enroll in the corresponding elective courses according to it. The specific composition of the study plan continues in the second year.

Code	Subject	Credits	Winter	Summer
NMFP401	**Financial econometrics**	4	2/1 C+Ex	—
NMFP403	**Stochastic Processes 2**	8	4/2 C+Ex	—
NMFP405	**Probability for Finance and Insurance**	4	2/1 C+Ex	—
NMFP407	**Mathematics of Life Insurance 1**	5	2/2 C+Ex	—
NMFP409	**Mathematics of Non-Life Insurance 1**	5	2/2 C+Ex	—
NMFP402	**Generalized linear models**	5	—	2/2 C+Ex
NMFP404	**Time Series**	8	—	4/2 C+Ex
NMFP406	**Data Science 1**	3	—	2/0 Ex
NSZZ023	**Diploma Thesis I**	6	—	0/4 C
NMFP432	Mathematics of Life Insurance 2	5	—	2/2 C+Ex
NMFP434	Mathematics of Non-Life Insurance 2	5	—	2/2 C+Ex
	Optional and Elective courses	2		

2nd year

Code	Subject	Credits	Winter	Summer
NMFP501	**Seminar on Actuarial Science 1**	2	0/2 C	—
NMFP503	**Risk Theory 1**	4	2/1 C+Ex	—
NMFP505	**Stochastic Models in Finance 1**	5	2/2 C+Ex	—
NMFP531	Risk Theory 2	4	2/1 C+Ex	—
NMFP537	Accounting and Solvency of Insurance Companies	5	2/2 C+Ex	—

NSZZ024	**Diploma Thesis II**	9	—	0/6 C
NMFP532	**Seminar on Actuarial Science 2**	2	—	0/2 C
NMFP558	Diploma Thesis III in Actuarial Mathematics	15	—	0/10 C
	Optional and Elective courses	14		

Recommended Course of Study – Branch Data Science and Finance

1st year

In the summer semester of the 1st year of study, it is necessary to choose one of two specializations and enroll in the corresponding elective courses according to it. The specific composition of the study plan continues in the second year.

Code	Subject	Credits	Winter	Summer
NMFP401	**Financial econometrics**	4	2/1 C+Ex	—
NMFP403	**Stochastic Processes 2**	8	4/2 C+Ex	—
NMFP405	**Probability for Finance and Insurance**	4	2/1 C+Ex	—
NMFP407	**Mathematics of Life Insurance 1**	5	2/2 C+Ex	—
NMFP409	**Mathematics of Non-Life Insurance 1**	5	2/2 C+Ex	—
NMFP402	**Generalized linear models**	5	—	2/2 C+Ex
NMFP404	**Time Series**	8	—	4/2 C+Ex
NMFP406	**Data Science 1**	3	—	2/0 Ex
NSZZ023	**Diploma Thesis I**	6	—	0/4 C
NMEK412	Optimisation with Applications to Finance	5	—	2/2 C+Ex
NMFP436	Data Science 2	5	—	2/2 C+Ex
	Optional and Elective courses	2		

2nd year

Code	Subject	Credits	Winter	Summer
NMFP501	**Seminar on Actuarial Science 1**	2	0/2 C	—
NMFP503	**Risk Theory 1**	4	2/1 C+Ex	—
NMFP505	**Stochastic Models in Finance 1**	5	2/2 C+Ex	—
NMFP533	Investment Analysis	5	2/2 C+Ex	—
NMFP535	Data Science 3	5	2/2 C+Ex	—
NSZZ024	**Diploma Thesis II**	9	—	0/6 C
NMFP534	Stochastic Models in Finance 2	3	—	2/0 Ex
NMFP556	Diploma Thesis III in finance	15	—	0/10 C
	Optional and Elective courses	12		

Summary of the Study Plan

Obligatory Courses

All courses in this group must be successfully completed.

Code	Subject	Credits	Winter	Summer
NMFP401	**Financial econometrics**	4	2/1 C+Ex	—
NMFP403	**Stochastic Processes 2**	8	4/2 C+Ex	—
NMFP405	**Probability for Finance and Insurance**	4	2/1 C+Ex	—
NMFP407	**Mathematics of Life Insurance 1**	5	2/2 C+Ex	—
NMFP409	**Mathematics of Non-Life Insurance 1**	5	2/2 C+Ex	—
NMFP402	**Generalized linear models**	5	—	2/2 C+Ex
NMFP404	**Time Series**	8	—	4/2 C+Ex
NMFP406	**Data Science 1**	3	—	2/0 Ex
NSZZ023	**Diploma Thesis I**	6	—	0/4 C
NMFP501	**Seminar on Actuarial Science 1**	2	0/2 C	—
NMFP503	**Risk Theory 1**	4	2/1 C+Ex	—
NMFP505	**Stochastic Models in Finance 1**	5	2/2 C+Ex	—
NSZZ024	**Diploma Thesis II**	9	—	0/6 C

Elective courses

At least 21 credits must be obtained by passing the elective courses.

Branch Insurance Mathematics

The choice of compulsory elective courses in *Insurance Mathematics* is determined by the prerequisites of the course "Diploma Thesis III in Insurance Mathematics", which requires the completion of *all* of these courses:

Code	Subject	Credits	Winter	Summer
NMFP432	Mathematics of Life Insurance 2	5	—	2/2 C+Ex
NMFP434	Mathematics of Non-Life Insurance 2	5	—	2/2 C+Ex
NMFP531	Risk Theory 2	4	2/1 C+Ex	—
NMFP537	Accounting and Solvency of Insurance Companies	5	2/2 C+Ex	—
NMFP532	**Seminar on Actuarial Science 2**	2	—	0/2 C

Branch Data Science and Finance

The choice of compulsory elective courses in *Data Science and Finance* is determined by the prerequisites of the course "Diploma Thesis III in Finance", which requires the completion of *all* of these courses:

Code	Subject	Credits	Winter	Summer
NMEK412	Optimisation with Applications to Finance	5	—	2/2 C+Ex
NMFP436	Data Science 2	5	—	2/2 C+Ex
NMFP533	Investment Analysis	5	2/2 C+Ex	—
NMFP535	Data Science 3	5	2/2 C+Ex	—
NMFP534	Stochastic Models in Finance 2	3	—	2/0 Ex

Recommended Optional Courses

Not only this list serves as recommended optional courses, but students of the given branch can use elective courses of the second branch as optional courses.

Code	Subject	Credits	Winter	Summer
NMFP461	*Credit Risk in Banking*	3	2/0 Ex	—
NMFP465	*Financial Derivatives 1*	3	2/0 Ex	—
NMSA413	*Optimisation Theory*	8	4/2 C+Ex	—
NPFL129	*Introduction to Machine Learning with Python*	5	2/2 C+Ex	—
NMEK436	*Computational Aspects of Optimisation*	5	—	2/2 C+Ex
NMFP462	*Demography*	3	—	2/0 Ex
NMEK531	*Mathematical Economics*	5	2/2 C+Ex	—
NMFM463	*Practical Aspects of Financial Risk Measuring and Management*	3	2/0 Ex	—
NMFP466	*Financial Derivatives 2*	3	2/0 Ex	—

State Final Exam

Requirements for taking the final exam:

– Earning at least 120 credits during the course of the study.
– Completion of all obligatory courses prescribed by the study plan.
– Completion of all elective courses prescribed by the study branch.
– Submission of a completed Master's Thesis by the submission deadline.

Oral part of the final exam

The oral part of the final exam consists of three subject areas, from each the student gets one question. Two areas (Fundamentals of Probability, Mathematical Statistics and Econometrics; Fundamentals of Financial and Actuarial Mathematics) are compulsory, the third area is optional and corresponds to the chosen branch of study. The student can choose the third area:

– Advanced Topics of Actuarial Mathematics and Accounting of Insurance Companies (corresponds to the branch Insurance Mathematics)
– Advanced Topics of Finance and Data Analysis (corresponds to the branch Data Science and Finance)

A more detailed explanation of the requirements for the oral part of the final exam can be found on the website of the program guarantor: `https://www2.karlin.mff.cuni.cz/~branda/garantfpm.html`.

Requirements for the oral part of the final exam

1. Fundamentals of Probability, Mathematical Statistics and Econometrics

Probability for finance and insurance, econometric models, stochastic processes and time series, generalized linear models.

2. Fundamentals of Financial and Actuarial Mathematics

Fundamentals of life and non-life actuarial mathematics, risk theory, basic stochastic models in finance.

3. Optional areas

3A. Advanced Topics of Actuarial Mathematics and Accounting of Insurance Companies

Advanced topics of life and non-life actuarial mathematics, risk theory, accounting and solvency of insurance companies.

3B. Advanced Topics of Finance and Data Analysis

Optimization models with application in finance, investment analysis and models, risk measures, advanced stochastic models in finance, multivariate statistical models.

Financial and Insurance Mathematics, plan P

Study Plan P is intended for students who start their studies in the academic year 2020/2021 or 2021/2022. In the recommended course of study, it is necessary to pay attention to the following marked changes:

- Some courses are no longer taught. For these courses, it is stated which new courses replace these non-taught ones.
- The semester of some courses has changed.

Recommended Course of Study

1st year

Code	Subject	Credits	Winter	Summer
NMFM401	**Mathematics of Non-Life Insurance 1** [1]	5	2/2 C+Ex	—
NMFM405	**Life Insurance 1** [2]	5	2/2 C+Ex	—
NMSA407	**Linear Regression**	8	4/2 C+Ex	—
NMSA409	**Stochastic Processes 2**	8	4/2 C+Ex	—
NMFM402	**Mathematics of Non-Life Insurance 2** [3]	5	—	2/2 C+Ex
NMFM404	**Selected Software Tools for Finance and Insurance** [4]	3	—	2/0 Ex
NMFM406	**Life Insurance 2** [5]	3	—	2/0 Ex
NMFM416	**Life Insurance 2, exercises** [5]	2	—	0/2 C
NMFM408	**Probability for Finance and Insurance** [6]	3	—	2/0 Ex
NMFM410	**Insurance Companies Accounting**	5	—	2/2 C+Ex
NSZZ023	**Diploma Thesis I**	6	—	0/4 C
	Optional and Elective courses	7		

[1] This course is no longer taught. It is replaced by a course NMFP409 Mathematics of Non-life Insurance 1.

[2] This course is no longer taught. It is replaced by a course NMFP407 Mathematics of Life Insurance 1.

[3] This course is no longer taught. It is replaced by a course NMFP434 Mathematics of Non-life Insurance 2.

[4] This course is no longer taught. It is replaced by a course NMFP406 Data Science 1.

[5] This courses are no longer taught. They are replaced by a course NMFP432 Mathematics of Life Insurance 2 (2/2 Z+Zk).

[6] This course is no longer taught. It is replaced by a course taught in the winter semester NMFP405 Probability for Finance and Insurance (2/1 C+Ex).

2nd year

Code	Subject	Credits	Winter	Summer
NMFM501	**Seminar on Actuarial Sciences 1**	2	0/2 C	—
NMFM503	**Risk Theory**	8	4/2 C+Ex	—
NMFM507	**Advanced Topics of Financial Management**	2	2/0 Ex	—
NMST537	**Time Series** [7]	8	4/2 C+Ex	—
NSZZ024	**Diploma Thesis II**	9	0/6 C	—
NMFM502	**Seminar on Actuarial Sciences 2**	1	—	0/2 C
NMFM505	**Stochastic Models for Finance and Insurance**	5	—	2/2 C+Ex
NSZZ025	**Diploma Thesis III**	15	—	0/10 C
	Optional and Elective courses	10		

[7] This course is no longer taught. It is replaced by a course taught in the summer semester NMFP404 Time Series.

Summary of the Study Plan

Obligatory Courses

Code	Subject	Credits	Winter	Summer
NMFM401	**Mathematics of Non-Life Insurance 1** [1]	5	2/2 C+Ex	—
NMSA407	**Linear Regression**	8	4/2 C+Ex	—
NMFM405	**Life Insurance 1** [2]	5	2/2 C+Ex	—
NMSA409	**Stochastic Processes 2**	8	4/2 C+Ex	—
NMFM402	**Mathematics of Non-Life Insurance 2** [3]	5	—	2/2 C+Ex
NMFM404	**Selected Software Tools for Finance and Insurance** [4]	3	—	2/0 Ex
NMFM406	**Life Insurance 2** [5]	3	—	2/0 Ex
NMFM416	**Life Insurance 2, exercises** [5]	2	—	0/2 C
NMFM410	**Insurance Companies Accounting**	5	—	2/2 C+Ex
NMFM408	**Probability for Finance and Insurance** [6]	3	—	2/0 Ex
NMFM501	**Seminar on Actuarial Sciences 1**	2	0/2 C	—
NMFM502	**Seminar on Actuarial Sciences 2**	1	—	0/2 C
NMFM503	**Risk Theory**	8	4/2 C+Ex	—
NMFM505	**Stochastic Models for Finance and Insurance**	5	—	2/2 C+Ex

NMFM507	**Advanced Topics of Financial Management**	2	2/0 Ex	—
NMST537	**Time Series** [7]	8	4/2 C+Ex	—
NSZZ023	**Diploma Thesis I**	6	—	0/4 C
NSZZ024	**Diploma Thesis II**	9	0/6 C	—
NSZZ025	**Diploma Thesis III**	15	—	0/10 C

[1] This course is no longer taught. It is replaced by a course NMFP409 Mathematics of Non-life Insurance 1.

[2] This course is no longer taught. It is replaced by a course NMFP407 Mathematics of Life Insurance 1.

[3] This course is no longer taught. It is replaced by a course NMFP434 Mathematics of Non-life Insurance 2.

[4] This course is no longer taught. It is replaced by a course NMFP406 Data Science 1.

[5] This courses are no longer taught. They are replaced by a course NMFP432 Mathematics of Life Insurance 2 (2/2 Z+Zk).

[6] This course is no longer taught. It is replaced by a course taught in the winter semester NMFP405 Probability for Finance and Insurance (2/1 C+Ex).

[7] This course is no longer taught. It is replaced by a course taught in the summer semester NMFP404 Time Series.

Elective Courses

It is necessary to obtain at least 5 credits from elective courses.

Code	Subject	Credits	Winter	Summer
NMFM431	Investment Analysis	5	2/2 C+Ex	—
NMFM531	Financial Derivatives 1 [1]	3	2/0 Ex	—
NMFM532	Financial Derivatives 2 [2]	3	2/0 Ex	—
NMSA403	Optimisation Theory [3]	5	2/2 C+Ex	—
NMST531	Censored Data Analysis	5	2/2 C+Ex	—
NMST539	Multivariate Analysis [4]	5	2/2 C+Ex	—

[1] This course is no longer taught. It is replaced by a course NMFP465 Financial Derivatives 1.

[2] This course is no longer taught. It is replaced by a course NMFP466 Financial Derivatives 2.

[3] This course is no longer taught. It is replaced by a course NMSA413 Optimization Theory (4/2 C+Ex).

[4] This course is no longer taught.

Recommended Optional Courses

Recommended Optional Courses

Code	Subject	Credits	Winter	Summer
NMEK432	*Econometrics* [1]	8	—	4/2 C+Ex
NMEK532	*Optimisation with Applications to Finance* [2]	8	—	4/2 C+Ex
NMFM461	*Demography* [3]	3	—	2/0 Ex
NMFM462	*Practical Aspects of Financial Risk Measuring and Management* [4]	3	2/0 Ex	—
NMFM535	*Stochastic Analysis in Financial Mathematics*	5	—	2/2 C+Ex
NMFM537	*Credit Risk in Banking* [5]	3	2/0 Ex	—

NMFP436 *Data Science 2*	5	—	2/2 C+Ex

[1] This course is no longer taught. It can replaced by courses taught in the winter semester NMFP401 Financial Econometrics (2/1 C+Ex) or NMEK511 Econometrics (4/2 C+Ex).

[2] This course is no longer taught. It is replaced by a course NMEK412 Optimisation with Applications to Finance (2/2 C+Ex).

[3] This course is no longer taught. It is replaced by a course NMFP462 Demography.

[4] This course is no longer taught. It is replaced by a course NMFP463 Practical Aspects of Financial Risk Measuring and Management.

[5] This course is no longer taught. It is replaced by a course NMFP461 Credit Risk in Banking.

State Final Exam

Requirements for taking the final exam

– Earning at least 120 credits during the course of the study.
– Completion of all obligatory courses prescribed by the study plan.
– Earning at least 5 credits by completion of elective courses.
– Submission of a completed Master's Thesis by the submission deadline.

Oral part of the state final exam

The oral part of the final exam consists of three subject areas: Applied Probability, Insurance, and Finance and Accounting. One question is asked from each subject area.

Requirements for the oral part of the final exam

1. Applied Probability

Random variables, characteristics of their distributions. Random vectors, joint distribution, covariance, correlation, dependence modelling and measurement. Conditional distribution. Probability distributions in financial mathematics. Parameter estimators and their properties. Confidence intervals. Hypothesis testing principles. Maximum likelihood principle and the method of moments. One-sample, two-sample, paired tests. Analysis of variance. Linear regression model. The Bayes principle. Laws of large numbers and central limit theorems. Markov chains. Stationary processes. Time Series. Credibility theory. Collective risk models. Essentials of stochastic analysis.

2. Insurance

Demographic model of life insurance. Capital and life policies. Reserves of life insurance. Multiple decrement models. Multiple life insurance. Solvency and reinsurance. Technical reserves of general insurance. Tariff rates.

3. Finance and Accounting

Foundations of finance. Securities and their pricing. Stochastic models in finance. Financial risk and its measuring. Stock market analysis. Accounting.

Bachelor of Computer Science

1 General Information

Programme Coordinator: doc. RNDr. Ondřej Čepek, Ph.D.

Study specializations

The Bachelor of Computer Science programme has a common first year of study and is divided into three specializations starting in the second year of study:

– General Computer Science
– Databases and Web
– Artificial Intelligence.

Students select their specialization during the second year of their study in accordance with the study regulations.

Degree plans

The course of study in the individual specializations is regulated by the relevant degree plan, which specifies the obligatory and elective courses, the requirements for the State Final Exam, and a recommended course of study. The elective courses are in each specialization divided into several groups. A minimum number of credits should be obtained from elective courses overall; in addition, a minimum total number of credits is also required for certain groups of elective courses. Besides obligatory courses and the required number of elective courses, each student may sign up for additional courses taught at our faculty or at other faculties of Charles University (these are called "optional courses").

All three specializations share a large part in common, containing obligatory courses that cover the foundations of mathematics, theoretical computer science, programming, and software systems. Most of these subjects are recommended for the first year in the entire Computer Science programme. The recommended course of study for the first year specified below consists of obligatory courses (in boldface) and several optional courses (in italics). Of course, other optional courses may be selected instead of those that are recommended, provided that a total of at least 60 credits is achieved within the first academic year.

Recommended course of study for the first year

Code	Subject	Credits	Winter	Summer
NPRG062	**Introduction to Algorithms**	4	2/1 C+Ex	—
NPRG030	**Programming 1**	5	2/2 C	—
NSWI120	**Principles of Computers**	3	2/0 Ex	—
NSWI141	**Introduction to Networking**	3	2/0 MC	—
NDMI002	**Discrete Mathematics**	5	2/2 C+Ex	—
NMAI057	**Linear Algebra 1**	5	2/2 C+Ex	—

NMAI069	*Mathematical skills* [1]	2	0/2 C	—
NTVY014	*Physical Education I* [2]	1	0/2 C	—
ASE500129	*Czech Language Course 1* [3]	3	0/2 C	—
NTIN060	**Algorithms and Data Structures 1**	5	—	2/2 C+Ex
NPRG031	**Programming 2**	5	—	2/2 C+Ex
NSWI170	**Computer Systems**	5	—	2/2 C+Ex
NSWI177	**Introduction to Linux**	4	—	1/2 MC
NMAI054	**Mathematical Analysis 1**	5	—	2/2 C+Ex
NMAI058	**Linear Algebra 2**	5	—	2/2 C+Ex
NTVY015	*Physical Education II* [2]	1	—	0/2 C
ASE500130	*Czech Language Course 2* [3]	3	—	0/2 C

[1] The course NMAI069 Mathematical Skills is designed for students who wish to gain and practice the fundamental mathematical skills needed for the more mathematically oriented courses given at our faculty. Emphasis is put on the ability to use precise and correct mathematical formulations and on basic proof techniques.

[2] The Physical Education courses are obligatory for students on the programme taught in Czech, while they are elective for students on the programme taught in English. If you like sports, this may be a course for you, but there is no obligation to take it.

[3] The Czech Language Courses are optional, offered as a counterpart to the elective English Language Courses recommended for students studying in the programme taught in Czech. Since these courses are elective, they may naturally be replaced by any other course while maintaining the minimum of 30 credits per semester.

Some obligatory courses common to all specializations are taught in the second and third year of study. They are listed below.

Common obligatory courses in the second and third year of study

Code	Subject	Credits	Winter	Summer
NTIN061	**Algorithms and Data Structures 2**	5	2/2 C+Ex	—
NDBI025	**Database Systems**	5	2/2 C+Ex	—
NDMI011	**Combinatorics and Graph Theory 1**	5	2/2 C+Ex	—
NAIL062	**Propositional and Predicate Logic**	5	2/2 C+Ex	—
NTIN071	**Automata and Grammars**	5	—	2/2 C+Ex
NMAI059	**Probability and Statistics 1**	5	—	2/2 C+Ex
NPRG045	**Individual Software Project** [4]	4	—	0/1 C
NSZZ031	**Bachelor Thesis**	6	—	0/4 C

[4] It is possible to sign up for the course NPRG045 both in the winter semester and in the summer semester; the standard period is the summer semester.

Each individual specialization requires additional obligatory courses and groups of elective courses. A detailed degree plan for each specialization is given later in this text.

Recommended course of study for the second and third year

The recommended course of study is prepared for each specialization in such a way that the obligatory courses are scheduled in the required order, the student obtains in time the credits needed for enrolment in the next year of study, and the student fulfils in time all the prerequisites needed in order to take the State Final Exam. A recommended course of study for each specialization is given later in this text.

Branches within specializations

Some specializations are further divided into branches. Individual branches within the same specialization differ only in one area of prerequisites for the State Final Exam. Students should adjust their choice of elective and optional courses according to the branch in which they intend to take the State Final Exam. The choice of a particular branch within the student's specialization is declared only when signing up for the State Final Exam.

State Final Exam

The State Final Exam consists of two parts:

- Defence of Bachelor Thesis
- Exam in Mathematics and Computer Science

Each part of the State Final Exam is graded. The final grade for the State Final Exam is determined by the grades obtained for each part. The student can sign up for each part of the State Final Exam separately. Bachelor studies are successfully concluded only upon passing both parts of the State Final Exam. In case of failure, the student retakes those parts of the State Final Exam which he or she failed. Each part of the State Final Exam can be retaken at most twice.

Necessary conditions for signing up for either part of the State Final Exam are the following:

- passing all the obligatory courses of a given specialization,
- obtaining the required number of credits for elective courses,
- submitting a completed bachelor thesis by the specified deadline (necessary for signing up for the bachelor thesis defence),
- obtaining at least 180 credits (necessary for signing up for the last part of the State Final Exam).

A bachelor thesis topic is typically assigned at the beginning of the third year. The bachelor thesis usually consists of either a software package, which may be a continuation of the Individual Software Project (see degree plans above), or a piece of theoretical work. We recommend choosing a topic offered by the department which is connected with the selected specialization. In case another topic (offered by another department or suggested by the student) is to be selected, we strongly recommend consulting the relevant Specialization Coordinator before doing so.

The prerequisites for the State Final Exam are divided into two parts, one common to all specializations and the other specific to the given specialization. The list of common prerequisites is given below this paragraph; the prerequisites specific to the various specializations are listed after their degree plans given further below.

Knowledge requirements for the State Final Exam common to all specializations

Mathematics

1. Fundamentals of Differential and Integral Calculus

Sequences and series of numbers and their properties. Real functions of one variable. Continuity, limit of a function. Derivatives: definition and basic rules, behaviour of functions, Taylor polynomial with remainder. Primitive functions: definition, uniqueness, existence, methods of calculation.

Relevant courses:

– Mathematical Analysis 1 (NMAI054)

2. Algebra and Linear Algebra

Groups and subgroups, fields. Vector spaces and subspaces. Scalar product, norm. Orthogonality, othonormal basis. Systems of linear equations, Gauss and Gauss–Jordan elimination. Matrices, operations with matrices, matrix rank. Eigenvalues and eigenvectors of a matrix. Characteristic polynomial, relationship between eigenvalues and roots of polynomials.

Relevant courses:

– Linear Algebra 1 (NMAI057)
– Linear Algebra 2 (NMAI058)

3. Discrete Mathematics

Relations, properties of binary relations. Equivalence relation, equivalence classes. Partial orders. Functions, types of functions. Permutations and their basic properties. Binomial coefficients, binomial theorem. Principle of inclusion and exclusion. Hall's theorem on systems of distinct representatives, matchings in a bipartite graph.

Relevant courses:

– Discrete Mathematics (NDMI002)
– Combinatorics and Graph Theory 1 (NDMI011)

4. Graph Theory

Basic concepts, basic examples of graphs. Connected graphs, connected components. Trees, their properties, equivalent characterizations of trees. Planar graphs, Euler's formula and the maximum number of edges in a planar graph. Graph colourings, chromatic number and clique number. Edge- and vertex-connectivity, Menger's theorem. Directed graphs, weak and strong connectivity. Network flows.

Relevant courses:

– Discrete Mathematics (NDMI002)
– Combinatorics and Graph Theory 1 (NDMI011)

5. Probability and Statistics

Random events, conditional probability, independence of random events, Bayes' formula, applications. Random variables, mean (expectation), distribution of random variables, geometric, binomial, and normal distribution. Linear combination of random variables, linearity of expectation. Point estimates, confidence intervals, hypothesis testing.

Relevant courses:

- Discrete Mathematics (NDMI002)
- Probability and Statistics 1 (NMAI059)

6. Logic

Syntax – language, open and closed formulas. Normal forms of propositional formulas, prenex forms of predicate logic formulas, converting to normal form, applications in algorithms (SAT, resolution). Semantics, truth, falsity, independence of a formula with respect to a theory, satisfiability, tautologies, logical consequence, the notion of a model of a theory, extensions of theories.

Relevant courses:

- Propositional and Predicate Logic (NAIL062)

Computer Science

1. Automata and Languages

Regular languages, finite automaton (deterministic, nondeterministic), regular grammars. Context-free languages, push-down automata, context-free grammars. Recursively enumerable languages, Turing machine, type 0 grammar. Algorithmically undecidable problems. Chomsky hierarchy.

Relevant courses:

- Automata and Grammars (NTIN071)

2. Algorithms and Data Structures

Time and space complexity of algorithms, asymptotic notation. Complexity classes P and NP, NP-hardness and NP-completeness. "Divide and conquer" algorithms, complexity computation for these algorithms, examples. Binary search trees, AVL trees. Sorting algorithms. DFS, BFS and their applications. Shortest paths. Minimum spanning trees. Network flows.

Relevant courses:

- Algorithms and Data Structures 1 (NTIN060)
- Algorithms and Data Structures 2 (NTIN061)

3. Programming Languages

Concepts for abstraction, encapsulation, and polymorphism. Primitive and object types and their representation. Generic types and functional elements. Working with resources and mechanisms for error handling. Object lifecycle and memory management. Threads and support for synchronization. Implementation of basic elements of object-oriented languages. Native and interpreted execution, compilation and linking.

Relevant courses:

- Programming 1 (NPRG030)
- Programming 2 (NPRG031)
- Principles of Computers (NSWI120)

– Based on the choice of the programming language: Programming in C# Language (NPRG035) or Programming in C++ (NPRG041) or Programming in Java Language (NPRG013)

4. Computer Architecture and Operating Systems

Computer organization, data and program representation. Instruction set architecture as a hardware/software interface, connection to elements of high-level programming languages. Support for operating system execution. Peripheral device interface and handling. Fundamental OS abstractions, interfaces, and mechanisms for program execution, resource sharing, and input/output. Parallelism, threads and interfaces for thread management, thread synchronization.

Relevant courses:

– Principles of Computers (NSWI120)
– Computer Systems (NSWI170)
– Introduction to Networking (NSWI141)
– Introduction to Linux (NSWI177)
– Based on the choice of the programming language: Programming in C# Language (NPRG035) or Programming in C++ (NPRG041) or Programming in Java Language (NPRG013)

2 Degree Plans - General Computer Science

Coordinating Department: Computer Science Institute and Department of Applied Mathematics

Specialization Coordinator: doc. Mgr. Robert Šámal, Ph.D.

The specialization General Computer Science is suitable mainly for students interested in obtaining a solid foundation in computer science and mathematics, and who aim to follow their bachelor studies with a master's programme of study. Students are also well prepared for the job market, too. Taking General Computer Science allows the student to pursue algorithms, optimization, and their guiding principles, and also discrete mathematics.

Common obligatory courses in Computer Science

Common obligatory courses for all specializations are listed above in the section giving general information.

2.1 Obligatory Courses

Code	Subject	Credits	Winter	Summer
NPRG005	**Non-procedural Programming**	5	—	2/2 C+Ex
NOPT048	**Linear Programming and Combinatorial Optimization**	5	—	2/2 C+Ex
NMAI055	**Mathematical Analysis 2**	5	2/2 C+Ex	—

2.2 Elective Courses

Elective courses – group 1

A prerequisite for taking either part of the State Final Exam is to have obtained at least 30 credits from courses in this group.

Code	Subject	Credits	Winter	Summer
NDMI084	Introduction to Approximation and Randomized Algorithms	5	2/1 C+Ex	—
NDMI098	Algorithmic Game Theory	5	2/2 C+Ex	—
NDMI010	Graph Algorithms	3	2/0 Ex	—
NDMI012	Combinatorics and Graph Theory 2	5	—	2/2 C+Ex
NDMI110	Graphs and networks	5	—	2/2 C+Ex
NDMI009	Introduction to Combinatorial and Computational Geometry	5	2/2 C+Ex	—
NOPT046	Discrete and Continuous Optimization	5	—	2/2 C+Ex
NMAI062	Algebra 1	5	2/2 C+Ex	—
NMAI076	Algebra 2	4	—	2/1 C+Ex
NMAI056	Mathematical Analysis 3	5	—	2/2 C+Ex
NMAI042	Numerical Mathematics	5	—	2/2 C+Ex
NMAI073	Probability and Statistics 2	5	2/2 C+Ex	—
NAIL063	Set Theory	3	—	2/0 Ex
NAIL124	Exercises from Set Theory	3	—	0/2 C
NDMI100	Introduction to cryptography	3	—	2/0 Ex

Elective courses – group 2

A prerequisite for taking either part of the State Final Exam is to have obtained at least 5 credits from courses in this group.

Code	Subject	Credits	Winter	Summer
NPRG041	Programming in C++	5	2/2 C+Ex	—
NPRG013	Programming in Java Language	5	2/2 C+Ex	—
NPRG035	Programming in C# Language	5	2/2 C+Ex	—

Elective courses – group 3

A prerequisite for taking either part of the State Final Exam is to have obtained at least 45 credits from elective courses overall. There is no specific limit for this third group.

Code	Subject	Credits	Winter	Summer
NPFL129	Introduction to Machine Learning with Python	5	2/2 C+Ex	—
NPFL054	Introduction to Machine Learning with R	5	—	2/2 C+Ex
NPGR035	Machine Learning in Computer Vision	5	2/2 C+Ex	—
NAIL120	Introduction to Artificial Intelligence	5	—	2/2 C+Ex
NPGR003	Introduction to Computer Graphics	5	2/2 C+Ex	—
NPGR002	Digital Image Processing	4	3/0 Ex	—
NPGR038	Introduction to Computer Game Development	5	—	2/2 C+Ex

NPFL124	Natural Language Processing	4	—	2/1 C+Ex
NPFL012	Introduction to Computer Linguistics	3	2/0 Ex	—
NSWI004	Operating Systems	4	2/1 MC	—
NPRG036	Data Formats	5	2/2 C+Ex	—
NSWI090	Computer Networks	3	—	2/0 Ex
NSWI143	Computer Architecture	3	—	2/0 Ex
NDBI007	Principles of Data Organization	4	2/1 C+Ex	—
NDBI040	Modern Database Systems	5	—	2/2 C+Ex
NSWI098	Compiler Principles	6	2/2 C+Ex	—
NPRG042	Programming in Parallel Environment	6	—	2/2 C+Ex
NSWI142	Programming of Web Applications	5	2/2 C+Ex	—
NPRG054	High Performance Software Development	6	—	2/2 C+Ex
NPRG051	Advanced C++ Programming	5	—	2/2 C+Ex
NPRG021	Advanced Java Programming	5	—	2/2 C+Ex
NPRG038	Advanced C# Programming	5	—	2/2 C+Ex

2.3 Recommended Course of Study

The recommended course of study gives all the obligatory courses, while only some elective courses and optional courses are listed. Students need to choose other such courses themselves. Obligatory courses are printed in boldface, elective courses in roman, and optional courses in italics.

First year

Common to all specializations – see under general information above.

Second year

Code	Subject	Credits	Winter	Summer
NTIN061	**Algorithms and Data Structures 2**	5	2/2 C+Ex	—
NAIL062	**Propositional and Predicate Logic**	5	2/2 C+Ex	—
NMAI055	**Mathematical Analysis 2**	5	2/2 C+Ex	—
NDMI011	**Combinatorics and Graph Theory 1**	5	2/2 C+Ex	—
	Programming in Java/C++/C#	5	2/2 C+Ex	—
NTIN071	**Automata and Grammars**	5	—	2/2 C+Ex
NPRG005	**Non-procedural Programming**	5	—	2/2 C+Ex
NOPT048	**Linear Programming and Combinatorial Optimization**	5	—	2/2 C+Ex
NMAI059	**Probability and Statistics 1**	5	—	2/2 C+Ex
NPRG045	**Individual Software Project**	4	—	0/1 C
	Elective course – group 1	5		2/2 C+Ex
	Elective courses			

	Optional courses			

Third year

Code	Subject	Credits	Winter	Summer
NDBI025	**Database Systems**	5	2/2 C+Ex	—
NSZZ031	**Bachelor Thesis**	6	—	0/4 C
	Elective courses	30		
	Optional courses	15		

Recommended elective courses

To prepare for the State Final Exam, as well as for the further study of computer science, we suggest the following courses in particular.

Code	Subject	Credits	Winter	Summer
NOPT046	Discrete and Continuous Optimization	5	—	2/2 C+Ex
NDMI084	Introduction to Approximation and Randomized Algorithms	5	2/1 C+Ex	—
NDMI010	Graph Algorithms	3	2/0 Ex	—
NDMI009	Introduction to Combinatorial and Computational Geometry	5	2/2 C+Ex	—
NDMI012	Combinatorics and Graph Theory 2	5	—	2/2 C+Ex
NAIL063	Set Theory	3	—	2/0 Ex
NMAI062	Algebra 1	5	2/2 C+Ex	—

2.4 State Final Exam

The State Final Exam knowledge requirements common to all specializations are described in the first section of this chapter (General Information on Computer Science bachelor's degree plans). Students of the General Computer Science specialization will be further tested according to the list below from topics 1.-3. and from two selected topics among 4.-7. The choice of these two topics is to be declared by the student when signing up for the State Final Exam.

1. Networking Fundamentals

Taxonomy of computer networks. ISO/OSI reference architecture. Overview of the TCP/IP protocol model. Routing. Addresses, ports, sockets. Client-server architectures. Fundamentals of HTTP, FTP and SMTP protocols.

Relevant courses:

– Introduction to Networking (NSWI141)

2. Combinatorics

Generating functions. Estimates of factorials and binomial coefficients. Ramsey theorems. Error-correcting codes.

Relevant courses:

– Combinatorics and Graph Theory 1 (NDMI011)
– Combinatorics and Graph Theory 2 (NDMI012)

3. Multivariable Differential and Integral Calculus

Riemann integral. Extreme values of multivariable functions. Metric spaces, open and closed sets. Compactness.

Relevant courses:

– Mathematical Analysis 2 (NMAI055)

4. Optimization Methods

Polyhedra, Minkowski–Weyl theorem. Basics of linear programming, duality theorems, algorithms for LP. Edmonds' algorithm. Integer programming. Approximation algorithms for combinatorial problems (satisfiability, independent set, set cover, scheduling). Applications of linear programming to approximation algorithms. The use of probability in the design of algorithms.

Relevant courses:

– Linear Programming and Combinatorial Optimization (NOPT048)
– Discrete and Continuous Optimization (NOPT046)

5. Advanced Algorithms and Data Structures

Random-access machine (RAM). Dynamic programming. Strongly connected components of directed graphs. Maximal flows: algorithms, applications. Flows and paths in graphs with integer weights. Text search algorithms. DFT and its applications. Approximation algorithms and schemes. Parallel algorithms in Boolean circuits and comparator networks.

Relevant courses:

– Algorithms and Data Structures 1 (NTIN060)
– Algorithms and Data Structures 2 (NTIN061)
– Graph Algorithms (NDMI010)

6. Geometry

Basic theorems about convex sets (Helly, Rado, separation). Minkowski's lattice theorem. Convex polytopes (basic properties, V-polytopes, H-polytopes, combinatorial complexity). Geometric duality. Voronoi diagrams, hyperplane arrangements, point-line incidences. Elementary computational geometry algorithms (construction of a line arrangement in the plane, construction of a convex hull in the plane).

Relevant courses:

– Introduction to Combinatorial and Computational Geometry (NDMI009)

7. Advanced Discrete Mathematics

Graph colouring (Brooks' and Vizing's theorem). Tutte's theorem. Extremal combinatorics (Turán's theorem, Erdös–Ko–Rado theorem). Drawing graphs on surfaces. Sets and mappings. Subvalence and equivalence of sets. Well-ordered sets. Axiom of choice (Zermelo's theorem, Zorn's lemma).

Relevant courses:

– Combinatorics and Graph Theory 2 (NDMI012)
– Set Theory (NAIL063)

3 Degree Plans - Databases and Web

Coordinating Department: Department of Software Engineering

Specialization Coordinator: Doc. RNDr. Irena Holubová, Ph.D.

Specialization Databases and Web offers a number of courses on database and web management methods and technologies, data analysis, database administration, programming and development of traditional, web, database and data-intensive applications. Emphasis is put on relational and non-relational databases, social network analysis, web and multimedia search engines, methods of feature extraction. This specialization also gives a solid background in computer science preparing the graduate for subsequent master studies in computer science.

Common obligatory courses in Computer Science

Common obligatory courses for all specializations are listed above in the section giving general information.

3.1 Obligatory Courses

Code	Subject	Credits	Winter	Summer
NSWI142	**Programming of Web Applications**	5	2/2 C+Ex	—
NDBI026	**Development of Database Applications**	4	—	1/2 MC
NDBI040	**Modern Database Systems**	5	—	2/2 C+Ex
NPRG036	**Data Formats**	5	2/2 C+Ex	—
NDBI046	**Introduction to Data Engeneering**	5	—	2/2 C+Ex

3.2 Elective Courses

A prerequisite for taking either part of the State Final Exam is to have obtained at least 37 credits from elective courses overall.

Elective courses – group 1

A prerequisite for taking either part of the State Final Exam is to have obtained at least 20 credits from courses in this group.

Code	Subject	Credits	Winter	Summer
NPRG041	Programming in C++	5	2/2 C+Ex	—
NPRG013	Programming in Java Language	5	2/2 C+Ex	—
NPRG035	Programming in C# Language	5	2/2 C+Ex	—
NPRG051	Advanced C++ Programming	5	—	2/2 C+Ex
NPRG021	Advanced Java Programming	5	—	2/2 C+Ex
NPRG038	Advanced C# Programming	5	—	2/2 C+Ex
NPRG005	Non-procedural Programming	5	—	2/2 C+Ex
NSWI153	Advanced Programming of Web Applications	5	—	2/2 C+Ex

Elective courses – group 2

A prerequisite for taking either part of the State Final Exam is to have obtained at least 8 credits from courses in this group.

Code	Subject	Credits	Winter	Summer
NDBI013	Oracle Administration	2	—	0/2 C
NSWI090	Computer Networks	3	—	2/0 Ex
NPRG056	Mobile Devices Programming	3	0/2 C	—
NDBI038	Searching the Web	4	—	2/1 C+Ex
NDBI007	Principles of Data Organization	4	2/1 C+Ex	—
NSWI130	Software System Architectures	5	2/2 C+Ex	—

Elective courses – group 3

A prerequisite for taking either part of the State Final Exam is to have obtained at least 3 credits from courses in this group.

Code	Subject	Credits	Winter	Summer
NSWI166	Introduction to recommender systems and user preferences	4	2/1 C+Ex	—
NAIL120	Introduction to Artificial Intelligence	5	—	2/2 C+Ex
NPFL054	Introduction to Machine Learning with R	5	—	2/2 C+Ex
NPFL129	Introduction to Machine Learning with Python	5	2/2 C+Ex	—
NAIL121	Seminar on Data Mining	4	—	1/2 MC
NPGR002	Digital Image Processing	4	3/0 Ex	—
NDBI045	Video Retrieval	5	—	2/2 C+Ex
NPGR036	Computer Vision	5	—	2/2 C+Ex
NPGR035	Machine Learning in Computer Vision	5	2/2 C+Ex	—
NSWI004	Operating Systems	4	2/1 MC	—
NMAI055	Mathematical Analysis 2	5	2/2 C+Ex	—

A prerequisite for taking either part of the State Final Exam is to have obtained next at least 6 credits from any courses from group 1, 2, and 3.

3.3 Recommended Course of Study

The recommended course of study gives all the obligatory courses, while only some elective courses and optional courses are listed. Students need to choose other such courses themselves. Obligatory courses are printed in boldface, elective courses in roman, and optional courses in italics.

First year

Common to all specializations – see under general information above.

Second year

Code	Subject	Credits	Winter	Summer
	Programming in Java/C++/C#	5	2/2 C+Ex	—

NDBI025	**Database Systems**	5	2/2 C+Ex	—
NSWI142	**Programming of Web Applications**	5	2/2 C+Ex	—
NTIN061	**Algorithms and Data Structures 2**	5	2/2 C+Ex	—
NAIL062	**Propositional and Predicate Logic**	5	2/2 C+Ex	—
NDMI011	**Combinatorics and Graph Theory 1** [1]	5	2/2 C+Ex	—
NTIN071	**Automata and Grammars**	5	—	2/2 C+Ex
NMAI059	**Probability and Statistics 1**	5	—	2/2 C+Ex
NPRG045	**Individual Software Project**	4	—	0/1 C
	Elective courses			
	Optional courses			

Third year

Code	Subject	Credits	Winter	Summer
NDBI026	**Development of Database Applications**	4	—	1/2 MC
NDBI040	**Modern Database Systems**	5	—	2/2 C+Ex
NPRG036	**Data Formats**	5	2/2 C+Ex	—
NDBI046	**Introduction to Data Engeneering**	5	—	2/2 C+Ex
NSZZ031	**Bachelor Thesis**	6	—	0/4 C
	Elective courses			
	Optional courses			

3.4 State Final Exam

The State Final Exam knowledge requirements common to all specializations are described in the first section of this chapter (General Information on Computer Science bachelor's degree plans). Students of the Databases and Web specialization will be further tested according to the list below.

1. Databases

Database systems architectures. Conceptual, logical and physical view of data. Conceptual modelling and relational schema design, normal forms, referential integrity. Transaction processing. SQL overview. Core SQL queries. Data grouping and aggregation. Joining tables. Nested queries. Stored procedures, triggers, functions. Big Data. Modern database systems. MapReduce. NoSQL databases. Graph databases. Multi-model databases.

Relevant courses

– Database Systems (NDBI025)
– Development of Database Applications (NDBI026)
– Modern Database Systems (NDBI040)

2. Data Management

Data formats. Data models for structured data, use-cases. Graph, hierarchical, tabular, and geodata data formats. Data schemas and data transformation languages. Basics of graphics, multimedia and print formats. Data vocabulary, data semantics. Data transformation, catalogization and metadata. Basics of data encryption and compression. Basics of indexing. File organization techniques, direct/indirect indexing, primary/secondary index. Hashing in external memory. Hierarchical indexing, indexing for spatial databases, spatial join, spatial query.

Relevant courses

– Data Formats (NPRG036)
– Introduction to Data Engeneering (NDBI046)
– Principles of Data Organization (NDBI007)

3. Web

Basic principles of www, HTML, XHTML, HTML5, and CSS. Architecture, principles and design pattern of web applications. Client side development, JavaScript, standard Web APIS. Web application's API and web services. Single-page applications, state management and user sessions. Server side development, CGI and CGI-like applications. Basics of web applications security. Web search. Boolean and vector models, word2vec. Hypertex search, raking, PageRank, SEO. Recommender systems. Similarity search in multimedia databases. Metric similarity indexing.

Relevant courses

– Programming of Web Applications (NSWI142)
– Advanced Programming of Web Applications (NSWI153)
– Searching the Web (NDBI038)
– Introduction to recommender systems and user preferences (NSWI166)

4 Degree Plans - Artificial Intelligence

Coordinating Department: Department of Theoretical Computer Science and Mathematical Logic

Specialization Coordinator: Prof. RNDr. Roman Barták, Ph.D.

The specialization Artificial Intelligence integrates the formal foundations of computer science with their application to the solution of complex problems such as automated planning and scheduling, natural language processing, processing of visual, textual and multimedia data, machine learning, big data and data mining, autonomous robotics, and computer vision. The understanding of the mathematical and logical foundations of computer systems given by the specialization Articial Intelligence is directed towards the design of smart systems.

The specialization Artificial Intelligence has the following branches:

– Robotics
– Machine Learning
– Natural Language Processing

Each branch runs according to the same rules, using the same set of obligatory and elective courses, and they have the common topic Foundations of Artificial Intelligence in the State Final Exam. Each branch then has its own additional topic in the State Final Exam.

Common obligatory courses in Computer Science

Common obligatory courses for all specializations are listed above in the section giving general information.

4.1 Obligatory Courses

Code	Subject	Credits	Winter	Summer
NAIL120	**Introduction to Artificial Intelligence**	5	—	2/2 C+Ex
NPRG005	**Non-procedural Programming**	5	—	2/2 C+Ex
NMAI055	**Mathematical Analysis 2**	5	2/2 C+Ex	—

4.2 Elective Courses

Elective courses – group 1

A prerequisite for taking either part of the State Final Exam is to have obtained at least 25 credits from courses in this group.

Code	Subject	Credits	Winter	Summer
NAIL028	Introduction to Robotics	5	2/2 C+Ex	—
NPGR002	Digital Image Processing	4	3/0 Ex	—
NPGR036	Computer Vision	5	—	2/2 C+Ex
NPFL054	Introduction to Machine Learning with R [1]	5	—	2/2 C+Ex
NPFL129	Introduction to Machine Learning with Python [1]	5	2/2 C+Ex	—
NPGR035	Machine Learning in Computer Vision	5	2/2 C+Ex	—
NAIL121	Seminar on Data Mining	4	—	1/2 MC
NDMI098	Algorithmic Game Theory	5	2/2 C+Ex	—
NPFL012	Introduction to Computer Linguistics	3	2/0 Ex	—
NPFL125	Introduction to Language Technologies	3	0/2 MC	—
NPFL124	Natural Language Processing	4	—	2/1 C+Ex
NPFL101	Competing in Machine Translation	3	0/2 C	—
NPFL123	Dialogue Systems	5	—	2/2 C+Ex
NAIL119	Nature Inspired Algorithms	5	—	2/2 C+Ex

[1] Courses NPFL129 and NPFL054 are incompatible and student is supposed to select one of them.

Elective courses – group 2

A prerequisite for taking either part of the State Final Exam is to have obtained at least 10 credits from courses in this group.

Code	Subject	Credits	Winter	Summer
NPRG041	Programming in C++	5	2/2 C+Ex	—
NPRG013	Programming in Java Language	5	2/2 C+Ex	—
NPRG035	Programming in C# Language	5	2/2 C+Ex	—

Elective courses – group 3

A prerequisite for taking either part of the State Final Exam is to have obtained at least 10 credits from courses in this group.

Code	Subject	Credits	Winter	Summer
NPRG051	Advanced C++ Programming	5	—	2/2 C+Ex
NPRG021	Advanced Java Programming	5	—	2/2 C+Ex
NPRG038	Advanced C# Programming	5	—	2/2 C+Ex
NPRG042	Programming in Parallel Environment	6	—	2/2 C+Ex
NPRG036	Data Formats	5	2/2 C+Ex	—
NMAI073	Probability and Statistics 2	5	2/2 C+Ex	—
NDBI045	Video Retrieval	5	—	2/2 C+Ex
NOPT046	Discrete and Continuous Optimization	5	—	2/2 C+Ex
NPGR038	Introduction to Computer Game Development	5	—	2/2 C+Ex
NPRG037	Microcontroller Programming	5	2/2 C+Ex	—

4.3 Recommended Course of Study

The recommended course of study gives all the obligatory courses, while only some elective courses and optional courses are listed. Students need to choose other such courses themselves. Obligatory courses are printed in boldface, elective courses in roman, and optional courses in italics.

First year

Common to all specializations – see under general information above.

Second year

Code	Subject	Credits	Winter	Summer
NAIL062	**Propositional and Predicate Logic**	5	2/2 C+Ex	—
NTIN061	**Algorithms and Data Structures 2**	5	2/2 C+Ex	—
NDMI011	**Combinatorics and Graph Theory 1**	5	2/2 C+Ex	—
NMAI055	**Mathematical Analysis 2**	5	2/2 C+Ex	—
NAIL028	Introduction to Robotics	5	2/2 C+Ex	—
NPRG041	Programming in C++	5	2/2 C+Ex	—
NTIN071	**Automata and Grammars**	5	—	2/2 C+Ex
NMAI059	**Probability and Statistics 1**	5	—	2/2 C+Ex
NPRG045	**Individual Software Project**	4	—	0/1 C

NPRG051	Advanced C++ Programming	5	—	2/2 C+Ex
NAIL120	**Introduction to Artificial Intelligence**	5	—	2/2 C+Ex
NPRG005	**Non-procedural Programming**	5	—	2/2 C+Ex
	Elective courses			
	Optional courses			

Third year

Code	Subject	Credits	Winter	Summer
NDBI025	**Database Systems**	5	2/2 C+Ex	—
NPFL129	Introduction to Machine Learning with Python [1]	5	2/2 C+Ex	—
NPRG013	Programming in Java Language	5	2/2 C+Ex	—
NPFL012	Introduction to Computer Linguistics	3	2/0 Ex	—
NPGR036	Computer Vision	5	—	2/2 C+Ex
NPFL054	Introduction to Machine Learning with R [1]	5	—	2/2 C+Ex
NPFL124	Natural Language Processing	4	—	2/1 C+Ex
NPRG036	Data Formats	5	2/2 C+Ex	—
NAIL121	Seminar on Data Mining	4	—	1/2 MC
NSZZ031	**Bachelor Thesis**	6	—	0/4 C
	Elective courses			
	Optional courses			

[1] Courses NPFL129 and NPFL054 are incompatible and student is supposed to select one of them.

4.4 State Final Exam

The State Final Exam knowledge requirements common to all specializations are described in the first section of this chapter (General Information on Computer Science bachelor's degree plans). Students of the Artificial Intelligence specialization will be further tested according to the information below.

The topic Foundations of Artificial Intelligence is required in all branches. Each branch then has its own additional topic in the State Final Exam.

Foundations of Artificial Intelligence

Solving problems by searching (algorithm A*); constraint satisfaction. Logical reasoning (forward and backward chaining, resolution, SAT); probabilistic reasoning (Bayesian networks); knowledge representation (situation calculus, Markovian models). Automated planning; Markov decision processes. Games and theory of games. Machine learning (decision trees, regression, reinforcement learning).

Relevant courses:

Code	Subject	Credits	Winter	Summer
NAIL120	Introduction to Artificial Intelligence	5	—	2/2 C+Ex

Branch Robotics

Kinematics: motion and transformation, basic problem-solving. Control systems: architectures, implementation, specific run-time environments. Motion, sensorics: motion types, basic actuators and sensor types, closed loop control, input data processing. Localization and mapping: possibilities for determining position, map types, model situation solving, simultaneous localization and mapping. Image processing, computer vision: object searching and tracking.

Relevant courses:

Code	Subject	Credits	Winter	Summer
NAIL028	Introduction to Robotics	5	2/2 C+Ex	—
NPGR036	Computer Vision	5	—	2/2 C+Ex
NPRG037	Microcontroller Programming	5	2/2 C+Ex	—

Branch Machine Learning

Supervised learning: classification and regression, error measure, model assessment (test data, cross validation, maximum likelihood), overfitting and regularization, the curse of dimensionality. Instance-based learning, linear and logistic regression, decision trees, pruning, ensemble learning (bagging, boosting, random forest), support vector machines, t-test, chi-squared test. Unsupervised learning, clustering.

Relevant courses:

Code	Subject	Credits	Winter	Summer
NPFL054	Introduction to Machine Learning with R	5	—	2/2 C+Ex
NPFL129	Introduction to Machine Learning with Python	5	2/2 C+Ex	—
NAIL121	Seminar on Data Mining	4	—	1/2 MC
NPGR035	Machine Learning in Computer Vision	5	2/2 C+Ex	—

Branch Natural Language Processing

System of layers in language description, morphological and syntactic analysis. Fundamentals of probability theory and information theory. Statistical methods in natural language processing, language models. Machine learning, classification, regression. Estimation of generalization error, overfitting, regularization. Word embedding, fundamentals of deep learning. Applications in natural language processing, examples of evaluation measures.

Relevant courses:

Code	Subject	Credits	Winter	Summer
NPFL054	Introduction to Machine Learning with R	5	—	2/2 C+Ex
NPFL129	Introduction to Machine Learning with Python	5	2/2 C+Ex	—
NPFL012	Introduction to Computer Linguistics	3	2/0 Ex	—

NPFL124	Natural Language Processing	4	—	2/1 C+Ex

Master of Computer Science

General Information

Study programs and their specializations

1 Computer Science - Discrete Models and Algorithms
– Discrete mathematics and algorithms
– Geometry and mathematical structures of computer science
– Optimization
2 Computer Science - Theoretical Computer Science
3 Computer Science - Software and Data Engineering
– Software engineering
– Software development
– Web engineering
– Database systems
– Big data processing
4 Computer Science - Software Systems
– System programming
– Dependable systems
– High performance computing
5 Computer Science – Language Technologies and Computational Linguistics
– Computational and formal linguistics
– Statistical and machine learning methods in Natural Language Processing
6 Computer Science - Artificial Intelligence
– Intelligent agents
– Machine learning
– Robotics
7 Computer Science – Visual Computing and Game Development
– Visual Computing
– Computer game development

While your study program has been specified already in your application, the definitive choice of your specialization (where applicable) is made only later, when enrolling for the state final exam.

Computer science is a dynamically evolving discipline, and therefore we are constantly adapting the content of our study programs to important new trends. In their own interest, students should keep track of the current state of study plans as the list of offered courses may be expanded and modified, or other minor changes may take place.

Assumed knowledge

It is assumed that an incoming student has a sufficient knowledge of mathematics, theoretical computer science, and programming. In particular, students are expected to have a good knowledge of mathematics at the level of our bachelor courses NMAI054 Mathematical Analysis 1, NMAI058 Linear Algebra 2, NMAI059 Probability and Statistics 1.

Students are also expected to have knowledge equivalent to the courses NDMI002 Discrete Mathematics, NTIN060 Algorithms and Data Structures 1, NTIN061 Algorithms and Data Structures 2, NTIN071 Automata and Grammars, and NAIL062 Propositional and Predicate Logic. Knowledge from these courses is also expected for the state final exam.

We also expect students to have good knowledge of programming at least at the level of our bachelor courses NPRG030 Programming 1 and NPRG031 Programming 2.

Students who are missing knowledge in some of the above-mentioned areas are advised to consider taking the relevant bachelor courses in the first year of their Master's studies. Please do not hesitate to contact the program coordinator in case of doubt.

If a student has successfully completed one of the obligatory or optional courses of their study program during his/her previous bachelor's study at the Faculty of Mathematics and Physics, they may apply for recognition of the fulfillment of these obligations. A student coming to the Faculty after obtaining a bachelor's degree at another university may apply for recognition of obligatory or optional courses on the basis of previous completion of a similar subject. The awarding of credits for courses completed in the bachelor's study is regulated by Article 12 of the Rules for the Organization of Studies at the Faculty of Mathematics and Physics.

Team project

Study plans of master programs in the study area Computer Science offer the possibility of participation in a team project. In the study programs Software Systems, Software and Data Engineering, Visual Computing and Game Development the team project is obligatory, while in programs Artificial Intelligence, Language Technologies and Computational Linguistics the team project is elective. The student chooses one out of three types of a team project: a Software project, a Research project, or a Company Project. The software project is a classic student project, where a team of 3-6 students develops a larger software system. The research project allows a student to temporarily join an existing research team at the faculty, in which the student works on a particular research/development task. The company project allows a student to accomplish the team software project outside of the faculty environment, in a company, while still meeting the standards set commonly for all project types. In case of a more difficult project assignment, extra credits can be awarded using the course Increased project scope. Approval and evaluation of projects is guided by the regulations of the respective study program coordinator.

State Final Exam

The state final exam consists of two parts: a defense of the Master's (diploma) thesis, and an oral examination. The student can enroll for each part separately. To finish the studies, both parts of the state final exam must be completed successfully.

Requirements to enroll for the state final exam

– obtaining at least 120 credits,
– passing all obligatory courses of a given study program,

– obtaining a given number of credits from the elective courses of a given program and specialization,
– submitting the Master's thesis by the specified deadline (for defense of the Master's thesis).

Master's (diploma) thesis

Students are advised to select the topic of their Master's (diploma) thesis at the end of the first semester. The faculty departments offer many topics for Master's theses each year, and students may also suggest their own topics. We recommend selecting the topic of your thesis primarily from those offered by the department that coordinates your study program. If you prefer a topic offered by another department or your own topic, please consult the coordinator of your study program.

After the topic is assigned, the student enrolls in the following obligatory courses:

Code	Subject	Credits	Winter	Summer
NSZZ023	**Diploma Thesis I**	6	—	0/4 C
NSZZ024	**Diploma Thesis II**	9	0/6 C	—
NSZZ025	**Diploma Thesis III**	15	—	0/10 C

Course credits for these courses are granted by the thesis advisor on the basis of student's work on the thesis. We suggest the students to discuss with their advisor the expected amount of work and the milestones for each of these courses. All three courses can be enrolled in both winter and summer semesters.

Oral examination

The oral part of the state final exam has a similar structure for all study programs. The student is examined from several obligatory and several optional examination areas specific to a given study program and selected specialization. The student will select these optional examination areas when registering for the final exam. A more detailed description can be found in the relevant section of each study program.

Note that not all the courses are available in English every year. We recommend students to contact the study program coordinator for the selected study program and discuss individual study plans prior the beginning of each semester.

1 Degree Plans - Computer Science - Discrete Models and Algorithms

Coordinated by: Department of Applied Mathematics
Study programme coordinator: Doc. RNDr. Martin Klazar, Dr.

Specializations:

– Discrete mathematics and algorithms
– Geometry and mathematical structures of computer science
– Optimization

The program offers wide education in theoretical and mathematical fundaments of computer science. Students obtain knowledge in the area of discrete models and related algorithmic and data techniques, and various mathematical methods for their design. The study familiarizes the student both with the last results on discrete models, algorithms and optimization, and with possibilities and limitations in solving related algorithmic questions. The student acquires thorough mathematical knowledge necessary for analysis and design of discrete models and algorithms.

The graduate is familiar with modelling by means of discrete structures, and also with the practical algorithmic aspects. The graduate understands models of computation and their relations and knows limits of effective computing. They have knowledge on algorithmic techniques and data structures, and has awareness of some optimization techniques and results. The graduate familiarized themselves with mathematical approaches to discrete models and algorithms during their studies. This, besides the ubiquitous combinatorics and discrete mathematics, includes geometric, topological, algebraic, number-theoretic, logical, and, last but not least, probabilistic methods. The graduate can asses applicability of these methods to particular discrete model. She or he can follow last research trends in the area. The graduate can work in analyzing and planning of discrete models, and in their algorithmic implementations and in development corresponding technologies. He or she can work in top companies and institutions investigating and developing new technologies, analyzing data or modelling real processes (finances, logistics, economy etc.). He or she is prepared for further Ph.D. study of computer science in domestic institutions or abroad.

1.1 Obligatory Courses

Code	Subject	Credits	Winter	Summer
NTIN090	**Introduction to Complexity and Computability**	4	2/1 C+Ex	—
NTIN066	**Data Structures 1**	6	—	2/2 C+Ex
NMAI064	**Mathematical Structures**	5	—	2/2 C+Ex
NSZZ023	**Diploma Thesis I**	6	—	0/4 C
NSZZ024	**Diploma Thesis II**	9	0/6 C	—
NSZZ025	**Diploma Thesis III**	15	—	0/10 C

1.2 Elective Courses - Set 1

The student needs to obtain at least 45 credits for the courses from the following set. The courses NDMI055 and NDMI056 can be attended both by students of Master programs and students of Doctoral programs.

Code	Subject	Credits	Winter	Summer
NAIL076	Logic Programming 1	3	2/0 Ex	—
NDMI010	Graph Algorithms	3	2/0 Ex	—
NDMI013	Combinatorial and Computational Geometry 2	5	—	2/2 C+Ex
NDMI014	Topological Methods in Combinatorics	5	—	2/2 C+Ex
NDMI015	Combinatorial Counting	3	—	2/0 Ex

NDMI018	Approximation and Online Algorithms	5	—	2/2 C+Ex
NDMI025	Randomized Algorithms	5	—	2/2 C+Ex
NDMI028	Linear Algebra Applications in Combinatorics	5	2/2 C+Ex	—
NDMI036	Combinatorial Structures	3	—	2/0 Ex
NDMI037	Geometric Representations of Graphs 1	3	2/0 Ex	—
NDMI045	Analytic and Combinatorial Number Theory	3	—	2/0 Ex
NDMI055	Selected Chapters on Combinatorics 1	3	2/0 Ex	—
NDMI056	Selected Chapters on Combinatorics 2	3	—	2/0 Ex
NDMI059	Graph Minors and Tree Decompositions	3	2/0 Ex	—
NDMI060	Coloring of Graphs and Other Combinatorial Structures	3	2/0 Ex	—
NDMI064	Applied Discrete Mathematics	3	2/0 Ex	—
NDMI065	Matroid Theory	5	—	2/2 C+Ex
NDMI066	Algebraic Number Theory and Combinatorics	3	2/0 Ex	—
NDMI067	Flows, Paths and Cuts	3	2/0 Ex	—
NDMI074	Algorithms and Their Implementation	5	—	2/2 C+Ex
NDMI087	Analytic combinatorics	4	—	2/1 Ex
NDMI088	Graph Algorithms 2	3	—	2/0 Ex
NMAG337	Introduction to Group Theory	5	2/2 C+Ex	—
NMAI040	Introduction to Number Theory	3	2/0 Ex	—
NMAI065	Fundamentals of Category Theory for Computer Scientists	3	2/0 Ex	—
NMAI066	Topological and Algebraic Methods	3	—	2/0 Ex
NMAI067	Logic in Computer Science	3	2/0 Ex	—
NMAI071	Math++	5	—	2/2 C+Ex
NMMA901	Introduction to Complex Analysis (O)	5	2/2 C+Ex	—
NMMA931	Introduction to Functional Analysis (O)	8	4/2 C+Ex	—
NOPT008	Nonlinear Optimisation Algorithms	5	—	2/2 C+Ex
NOPT016	Integer Programming	5	—	2/2 C+Ex
NOPT017	Multiobjective Optimisation	3	—	2/0 Ex
NOPT034	Mathematical Programming and Polyhedral Combinatorics	4	—	2/1 C+Ex
NOPT042	Constraint Programming	5	2/2 C+Ex	—
NOPT051	Interval Methods	5	2/2 C+Ex	—
NTIN017	Parallel Algorithms	3	—	2/0 Ex

NTIN022	Probabilistic Techniques	5	2/2 C+Ex	—
NTIN023	Dynamic Graph Data Structures	3	2/0 Ex	—
NTIN063	Complexity	4	—	2/1 C+Ex
NTIN064	Computability	3	—	2/0 Ex
NTIN067	Data Structures 2	3	—	2/0 Ex
NTIN100	Introduction to Information Transmission and Processing	4	—	2/1 C+Ex
NTIN103	Introduction to Parameterized Algorithms	5	2/2 C+Ex	—
NDMI113	Extremal combinatorics	3	—	2/0 Ex
NOPT059	Large-scale optimization: Exact methods	5	—	2/2 C+Ex
NOPT061	Large-scale optimization: Metaheuristics	5	—	2/2 C+Ex

1.3 Elective Courses - Set 2

The student needs to obtain at least 5 credits for the courses from the following set[1]:

Code	Subject	Credits	Winter	Summer
NDMI073	Combinatorics and Graph Theory 3	5	2/2 C+Ex	—
NOPT018	Fundamentals of Nonlinear Optimization	5	2/2 C+Ex	—

[1]For the two specializations Discrete mathematics and algorithms, and Geometry and mathematical structures of computer science, we recommend the course NDMI073; for the specialization Optimization we recommend the course NOPT018. After completing one course from Set 2, the credits are counted for that set and the minimal credit requirement for Set 2 is satisfied. If the student completes both courses from Set 2, the credits for the second course are counted among the credits of student's free choice.

1.4 Other Recommended Courses

The list of other recommended courses contains only one course, because of the requirements of the examination area Combinatorial and computational geometry. Additionally, a student can chose other courses from the extensive collection of computer science courses at the Charles University.

Code	Subject	Credits	Winter	Summer
NDMI009	Introduction to Combinatorial and Computational Geometry	5	2/2 C+Ex	—

1.5 State Final Exam

Each student will get five questions, two from the common background (one from Introduction to complexity and computability and one from Data structures) and three from three examination areas (selected by the student) given in the following lists. At least two of these three examination areas must be selected from student's chosen specialization, one examination area may be selected from another specialization.

Examination areas

1. Introduction to complexity and computability

2. Data structures

Knowledge requirements

1. Introduction to complexity and computability

Models of computation (Turing machines, RAM). Basic complexity classes and their relations. Approximation algorithms and schemas.

Recommended courses

Code	Subject	Credits	Winter	Summer
NTIN090	Introduction to Complexity and Computability	4	2/1 C+Ex	—

Knowledge requirements

2. Data structures

Search trees ((a,b)-trees, splay trees). Heaps (regular, binomial). Hashing, collisions, universal hashing, hash function.

Recommended courses

Code	Subject	Credits	Winter	Summer
NTIN066	**Data Structures 1**	6	—	2/2 C+Ex

a) Specialization ***Discrete mathematics and algorithms***

Examination areas

1. Combinatorics and graph theory
2. Probabilistic methods and combinatorial enumeration
3. Polyhedral optimisation
4. Graph algorithms

Knowledge requirements

1. Combinatorics and graph theory

Graph colorings and its variants, e.g. choosability. Graph minors, tree width and its relation to complexity. Geometric representations of graphs (characterization theorems, recognizing algorithms), algebraic properties of graphs, matching theory. Ramsey theory and Szemeredi's regularity lemma. Set systems, e.g. Steiner triple systems, finite geometries.

Recommended courses

Code	Subject	Credits	Winter	Summer
NDMI037	Geometric Representations of Graphs 1	3	2/0 Ex	—
NDMI059	Graph Minors and Tree Decompositions	3	2/0 Ex	—
NDMI060	Coloring of Graphs and Other Combinatorial Structures	3	2/0 Ex	—
NDMI073	Combinatorics and Graph Theory 3	5	2/2 C+Ex	—

2. Probabilistic methods and combinatorial enumeration

Combinatorial counting, generating functions, recurrences, asymptotic estimates of functions. Basic probabilistic models, linearity of expectation, variance and its uses, Markov's inequality and its application to particular examples. Chernov's inequality. Lovasz local lemma. Probabilistic constructions and algorithms.

Recommended courses

Code	Subject	Credits	Winter	Summer
NDMI015	Combinatorial Counting	3	—	2/0 Ex
NDMI087	Analytic combinatorics	4	—	2/1 Ex
NDMI025	Randomized Algorithms	5	—	2/2 C+Ex
NTIN022	Probabilistic Techniques	5	2/2 C+Ex	—

3. Polyhedral optimization

Theory of polyhedra, travelling salesman problem, classes of special matrices, integrality, matchings and flows in networks, matroid theory, ellipsoid method.

Recommended courses

Code	Subject	Credits	Winter	Summer
NTIN090	Introduction to Complexity and Computability	4	2/1 C+Ex	—
NDMI065	Matroid Theory	5	—	2/2 C+Ex
NOPT034	Mathematical Programming and Polyhedral Combinatorics	4	—	2/1 C+Ex

4. Graph algorithms

Advanced algorithms for shortest paths, transitive closure, flows in networks, cuts, matchings and minimal spanning trees, testing of planarity of a graph, drawing a graph in the plane. Graph data structures: union-find, link/cut trees, E-T trees, fully dynamic maintaining of connectivity components, common ancestors in trees (LCA).

Recommended courses

Code	Subject	Credits	Winter	Summer
NDMI010	Graph Algorithms	3	2/0 Ex	—
NDMI088	Graph Algorithms 2	3	—	2/0 Ex
NTIN067	Data Structures 2	3	—	2/0 Ex

b) Specialization ***Geometry and mathematical structures in Computer Science***

Examination areas

1. Combinatorial and computational geometry
2. Structures in Computer Science
3. Topology in Computer Science and Combinatorics
4. Category theory in Computer Science
5. Number theory in Computer Science

Knowledge requirements

1. Combinatorial and computational geometry

Basic theorems on convex sets (Helly's theorem, Radon's theorem, Caratheodory's theorem, hyperplane separation theorem) and their extensions (fractional Helly's theorem, colored Caratheodory's theorem, Tverberg's theorem), Minkowski's theorem on lattices, incidences of points and lines, geometric duality, convex polytopes (basic properties, combinatorial complexity), Voronoi diagrams, convex-independent sets, halving lines, complexity of the lower envelope of segments.

Recommended courses

Code	Subject	Credits	Winter	Summer
NDMI009	Introduction to Combinatorial and Computational Geometry	5	2/2 C+Ex	—
NDMI013	Combinatorial and Computational Geometry 2	5	—	2/2 C+Ex

2. Structures in Computer Science

Relations and relational structures. Ordered sets. Suprema and infima, semilattices and lattices. Fixed-point theorems. Distributive lattices. Boolean and Heyting algebras. Basics of universal algebra. Fundamentals of general topology, topological constructions. Scott's topology, DCPO and domains.

Recommended courses

Code	Subject	Credits	Winter	Summer
NMAI064	Mathematical Structures	5	—	2/2 C+Ex
NMAI066	Topological and Algebraic Methods	3	—	2/0 Ex

3. Topology in Computer Science and Combinatorics

Basics of metric and general topology. Topological constructions, special spaces, compact spaces and connected spaces. Simplicial complexes, simplicial maps. Jordan curve theorem (informatively, its place in discrete mathematics). The Borsuk–Ulam theorem and its applications: the sandwich theorem, the necklace theorem, chromatic number of Kneser graphs. Brouwer's fixed-point theorem.

Recommended courses

Code	Subject	Credits	Winter	Summer
NMAI064	Mathematical Structures	5	—	2/2 C+Ex
NDMI014	Topological Methods in Combinatorics	5	—	2/2 C+Ex

4. Category theory in Computer Science

Categories, functors, transformations, examples. Limits and colimits, special constructions. Adjunction, relation to categorical constructions. Reflections and coreflections. Examples of adjoint situations. Cartesian closed categories. Categories and structures, especially structures used in Computer Science. Monadic algebras.

Recommended courses

Code	Subject	Credits	Winter	Summer
NMAI065	Fundamentals of Category Theory for Computer Scientists	3	2/0 Ex	—

5. Number theory in Computer Science

Diophantine approximation (Dirichlet's theorem, Farey fractions, transcendental numbers). Diophantine equations (Pell's equation, Thue equations, four squares theorem, Hilbert's tenth problem). Prime numbers (bounds on the prime-counting function, Dirichlet's theorem). Geometry of numbers (lattices, Minkowski's theorem). Congruences (quadratic residues). Integer partitions (identities, e.g., the pentagonal identity).

Recommended courses

Code	Subject	Credits	Winter	Summer
NMAI040	Introduction to Number Theory	3	2/0 Ex	—

c) Specialization ***Optimisation***

Examination areas

1. Nonlinear programming
2. Discrete optimisation processes
3. Multiobjective and integer programming
4. Parametric programming and interval methods

Knowledge requirements

1. Nonlinear programming

Properties of convex sets and convex functions. Generalizations of convex functions. Necessary and sufficient optimality conditions for free and constrained extrema in problems of nonlinear programming. Quadratic programming. Semidefinite programming. Duality in nonlinear programming. Methods for solving problems with free and constrained extrema, including penalization and barrier methods. One-dimensional optimization.

Recommended courses

Code	Subject	Credits	Winter	Summer
NOPT008	Nonlinear Optimisation Algorithms	5	—	2/2 C+Ex
NOPT018	Fundamentals of Nonlinear Optimization	5	2/2 C+Ex	—

2. Discrete optimisation processes

Algorithmic game theory, election mechanisms, electronic auctions, applications of submodular functions in economy. Optimization based on enumeration, generating functions of edge cuts and of perfect matchings, enumerative dualities, the maximum cut problem for graphs embedded in surfaces.

Recommended courses

Code	Subject	Credits	Winter	Summer
NDMI064	Applied Discrete Mathematics	3	2/0 Ex	—

NOPT018	Fundamentals of Nonlinear Optimization	5	2/2 C+Ex	—

3. Multiobjective and integer programming

Various approaches to solving problems with several criteria. Functional associated to a problem of vector programming. Pareto optimal solution. Problems of linear and nonlinear vector optimization. Methods for obtaining Pareto optimal solutions. Problems of linear programming with integrality conditions or with binary variables. Nonlinear optimization problems with integrality conditions.

Recommended courses

Code	Subject	Credits	Winter	Summer
NOPT016	Integer Programming	5	—	2/2 C+Ex
NOPT017	Multiobjective Optimisation	3	—	2/0 Ex

4. Parametric programming and interval methods

Domains of stability of solutions, one-parametric and multi-parametric programming, relation to multiobjective optimization. Interval linear algebra (systems of linear equations, regularity, eigenvalues). Linear programming with imprecise data. Deterministic global optimization, lower and upper bounds on objective function and optimum value.

Recommended courses

Code	Subject	Credits	Winter	Summer
NOPT017	Multiobjective Optimisation	3	—	2/0 Ex
NOPT051	Interval Methods	5	2/2 C+Ex	—

2 Degree Plans - Computer Science - Theoretical Computer Science

Coordinated by: Department of Theoretical Computer Science and Mathematical Logic; Computer Science Institute of Charles University
Study programme coordinator: Prof. Mgr. Michal Koucký, Ph.D.

This study program has no specializations.

The program provides broad education in various aspects of theoretical foundations of computer science. Students are expected to have strong mathematical background which is further developed during the study with focus on exact thinking. Students gain overview and understanding in many areas of contemporary theoretical computer science - from cryptography and limits of computational systems to state-of-the-art techniques in the design of efficient algorithms and data structures. They will learn about frontiers of current knowledge in areas of their interest. Study may include working in international environment under guidance of recognized experts while writing a master thesis. Graduates are sought after by companies developing future technologies based on current research. At the same time, the study program excellently prepares for doctoral study at any university worldwide.

2.1 Obligatory Courses

Code	Subject	Credits	Winter	Summer
NTIN090	**Introduction to Complexity and Computability**	4	2/1 C+Ex	—
NTIN066	**Data Structures 1**	6	—	2/2 C+Ex
NTIN022	**Probabilistic Techniques**	5	2/2 C+Ex	—
NTIN063	**Complexity**	4	—	2/1 C+Ex
NTIN100	**Introduction to Information Transmission and Processing**	4	—	2/1 C+Ex
NSZZ023	**Diploma Thesis I**	6	—	0/4 C
NSZZ024	**Diploma Thesis II**	9	0/6 C	—
NSZZ025	**Diploma Thesis III**	15	—	0/10 C

2.2 Elective Courses

The student needs to obtain at least 35 credits for the courses from the following set. Students who started their studies before 2022 must obtain at least 47 credits.

Code	Subject	Credits	Winter	Summer
NAIL021	Boolean Functions and Their Applications	3	2/0 Ex	—
NTIN096	Pseudo-Boolean Optimization	3	—	2/0 Ex
NAIL094	Decision procedures and SAT/SMT solvers	5	—	2/2 C+Ex
NDMI010	Graph Algorithms	3	2/0 Ex	—
NDMI018	Approximation and Online Algorithms	5	—	2/2 C+Ex
NDMI025	Randomized Algorithms	5	—	2/2 C+Ex
NSWI072	Data Compression Algorithms	3	2/0 Ex	—
NTIN067	Data Structures 2	3	—	2/0 Ex
NDMI074	Algorithms and Their Implementation	5	—	2/2 C+Ex
NTIN081	Computational complexity and interactive protocols	3	—	2/0 Ex
NTIN082	Nonuniform computational models	3	—	2/0 Ex
NTIN087	String Algorithms	3	2/0 Ex	—
NTIN097	Hypercube structures	3	2/0 Ex	—
NTIN099	Algorithms for knowledge representation	3	—	2/0 Ex
NTIN103	Introduction to Parameterized Algorithms	5	2/2 C+Ex	—
NOPT034	Mathematical Programming and Polyhedral Combinatorics	4	—	2/1 C+Ex
NTIN104	Foundations of theoretical cryptography	4	2/1 C+Ex	—
NDMI067	Flows, Paths and Cuts	3	2/0 Ex	—

NDMI077	Algorithms for Specific Graph Classes	3	—	2/0 Ex
NDMI088	Graph Algorithms 2	3	—	2/0 Ex
NMAG536	Proof Complexity and the P vs. NP Problem	3	—	2/0 Ex
NMAI067	Logic in Computer Science	3	2/0 Ex	—
NTIN017	Parallel Algorithms	3	—	2/0 Ex
NTIN023	Dynamic Graph Data Structures	3	2/0 Ex	—
NTIN064	Computability	3	—	2/0 Ex
NTIN073	Recursion	3	2/0 Ex	—
NTIN084	Bioinformatics Algorithms	5	2/2 C+Ex	—
NTIN085	Selected Topics in Computational Complexity I	4	2/1 C+Ex	—
NTIN086	Selected Topics in Computational Complexity II	4	—	2/1 C+Ex
NTIN101	Selected Topics in Algorithms	3	2/0 Ex	—
NTIN111	Selected Topics in Algorithms II	3	—	2/0 Ex
NTIN110	Selected Topics in Data Structures	3	2/0 Ex	—
NTIN088	Algorithmic Randomness	3	—	2/0 Ex
NTIN102	Seminar on theory of computing	3	0/2 C	0/2 C
NDMI093	Seminar on algorithms and data structures	3	—	0/2 C
NTIN106	Implementation of algorithms and data structures	3	0/2 C	—
NOPT059	Large-scale optimization: Exact methods	5	—	2/2 C+Ex
NOPT061	Large-scale optimization: Metaheuristics	5	—	2/2 C+Ex

Some of the courses are taught once every two years.

2.3 Other Recommended Courses

The list of recommended optional courses contains courses that expand and broaden the topics of the study program. Additionally, a student can chose other courses from the extensive collection of computer science courses at the Charles University.

Code	Subject	Credits	Winter	Summer
NDMI007	Combinatorial Algorithms	5	—	2/2 C+Ex
NAIL116	Social networks and their analysis	5	2/2 C+Ex	—
NOPT042	Constraint Programming	5	2/2 C+Ex	—
NAIL076	Logic Programming 1	3	2/0 Ex	—

2.4 State Final Exam

The student will select three examination areas from the following list, and he will get one question from each of the selected areas. Questions for each examination area address topics covered by the obligatory courses and recommended courses for the examination area. In total, each student will get three questions.

Examination areas

1. Complexity and Cryptography
2. Knowledge Representation in Boolean Domain
3. Algorithms
4. Data Structures

Knowledge requirements

1. Complexity and Cryptography

Oracle computation and relativized complexity classes. Polynomial hierarchy. Probabilistic complexity classes. Non-uniform models of computation. Interactive protocols. Communication complexity. Relationships and separations among complexity classes. Cryptography based on computational hardness. One-way functions and hard-core predicates. Pseudo-random generators. Data integrity (message authentication codes). Cryptographically secure hash functions. Commitment schemes. Zero-knowledge proof systems.

Recommended courses

Code	Subject	Credits	Winter	Summer
NTIN063	Complexity	4	—	2/1 C+Ex
NTIN081	Computational complexity and interactive protocols	3	—	2/0 Ex
NTIN082	Nonuniform computational models	3	—	2/0 Ex
NTIN104	Foundations of theoretical cryptography	4	2/1 C+Ex	—

2. Knowledge Representation in Boolean Domain

Resolution and its completeness. Dualization. Classes of Boolean functions with special properties. Exponential algorithms for k-SAT and general SAT. Parameterized algorithms for SAT. Algorithms for MAXSAT. Knowledge representation based on NNF. SAT solvers based on DPLL and CDCL and their use for SMT. Partial hypercubes and median graphs. Gray codes. Isoperimetric inequalities and linear distribution. Turán problems. Circuits, class P/poly and its properties. QBFs and their properties with respect to the polynomial hierarchy and PSPACE. Algorithms for QBF decision making. Error-correcting codes.

Recommended courses

Code	Subject	Credits	Winter	Summer
NTIN099	Algorithms for knowledge representation	3	—	2/0 Ex
NAIL094	Decision procedures and SAT/SMT solvers	5	—	2/2 C+Ex
NTIN097	Hypercube structures	3	2/0 Ex	—
NAIL021	Boolean Functions and Their Applications	3	2/0 Ex	—

3. Algorithms

Advanced graph algorithms, network flows. Linear and semidefinitive programming, polynomial algorithms, applications in graph and approximation algorithms. Combinatorial approximation algorithms and schemes. Pseudopolynomial algorithms, strong NP-completeness. Parameterized algorithms - FPT, parameterized lower bounds, parameterized approximation algorithms. Probabilistic algorithms, approximate counting, hashing and its applications. Interactive protocols and verification, PCP theorem and its applications.

Recommended courses

Code	Subject	Credits	Winter	Summer
NDMI010	Graph Algorithms	3	2/0 Ex	—
NDMI018	Approximation and Online Algorithms	5	—	2/2 C+Ex
NDMI025	Randomized Algorithms	5	—	2/2 C+Ex
NTIN103	Introduction to Parameterized Algorithms	5	2/2 C+Ex	—

4. Data structures

Computational models (RAM and its variants). Entropy and information. Error-correcting codes. Data compression. Search trees. Hashing. Advanced heaps. Data structures for storing integers. Multidimensional data structures. Data structures for storing strings. Text algorithms. Data structures for storing graphs. Dynamization and persistence. Handling the memory hierarchy. Data-streaming problems.

Recommended courses

Code	Subject	Credits	Winter	Summer
NTIN100	Introduction to Information Transmission and Processing	4	—	2/1 C+Ex
NTIN067	Data Structures 2	3	—	2/0 Ex
NTIN087	String Algorithms	3	2/0 Ex	—
NDMI010	Graph Algorithms	3	2/0 Ex	—
NSWI072	Data Compression Algorithms	3	2/0 Ex	—

3 Degree Plans - Computer Science - Software and Data Engineering

Coordinated by: Department of Software Engineering
Study programme coordinator: Prof. RNDr. Tomáš Skopal, Ph.D.

Specializations:

– Software engineering
– Software development
– Web engineering
– Database systems
– Big data processing

The study program Software and data engineering aims at expertise in analysis, design and development of complex software solutions, and systems focused on big data processing. The portfolio of courses provided in the study covers a number of technological platforms, from classic, web-based, to modern cloud and distributed solutions. A required part of the study is a work on team project where students apply not only the theoretical knowledge and technological skills but also team work abilities.

The graduate gains a deep knowledge of software and data engineering based on her/his specialization. With the specialization Software engineering the graduate is able to analyse requirements for software solutions, to design architectures, and to lead the development process. The specialization Software development prepares the graduate for leading a team of SW developers, including parallel and cloud environments. The development of internet applications is covered by the specialization Web engineering, including web, cloud and other internet technologies with an emphasize on scalability, robustness and security. The graduate of Database systems is able to design and integrate schemas of various databases and to develop complex database applications. With the Big data processing specialization the graduate is prepared for the role of data scientist with abilities in data mining and related data analytics knowledge.

3.1 Obligatory Courses

Code	Subject	Credits	Winter	Summer
NTIN090	**Introduction to Complexity and Computability**	4	2/1 C+Ex	—
NTIN066	**Data Structures 1**	6	—	2/2 C+Ex
NSZZ023	**Diploma Thesis I**	6	—	0/4 C
NSZZ024	**Diploma Thesis II**	9	0/6 C	—
NSZZ025	**Diploma Thesis III**	15	—	0/10 C

3.2 Elective Courses - Set 1 - Team Project Courses

The student choses one project course from three offered (Software Project, Research Project, Company Project).

Code	Subject	Credits	Winter	Summer
NPRG069	Software Project	12	0/8 C	0/8 C
NPRG070	Research Project	9	0/6 C	0/6 C
NPRG071	Company Project	6	0/4 C	0/4 C
NPRG072	Increased project scope	3	0/2 C	0/2 C

3.3 Elective Courses - Set 2 - Profiling Courses

The student needs to obtain at least 41 credits for the profiling courses from the following set:

Code	Subject	Credits	Winter	Summer
NPRG014	Concepts of Modern Programming Languages	4	0/3 C	—
NPRG043	Recommended Programming Practices	5	—	2/2 MC

NPRG024	Design Patterns	3	—	0/2 MC
NSWI126	Advanced Tools for Software Development and Monitoring	2	—	0/2 C
NPRG059	Advanced Programming Praxis	2	0/1 C	—
NPRG058	Advanced Programming in Parallel Environment	6	2/2 C+Ex	—
NSWI150	Virtualization and Cloud Computing	3	2/0 Ex	—
NSWI153	Advanced Programming of Web Applications	5	—	2/2 C+Ex
NSWI145	Web Services	5	—	2/2 C+Ex
NSWI144	Data on the Web	5	—	2/1 C+Ex
NSWI130	Software System Architectures	5	2/2 C+Ex	—
NSWI026	Advanced aspects of software engineering	5	—	2/2 C+Ex
NTIN043	Formal Foundations of Software Engineering	5	2/2 C+Ex	—
NDBI034	Multimedia Retrieval	4	2/1 C+Ex	—
NDBI040	Modern Database Systems	5	—	2/2 C+Ex
NDBI048	Data Science	5	2/2 C+Ex	—
NDBI042	Data Visualization Techniques	4	—	2/1 C+Ex
NPFL114	Deep Learning	7	—	3/2 C+Ex
NDBI023	Data Mining	5	—	2/2 C+Ex
NDBI016	Transactions	3	—	2/0 Ex
NDBI001	Query Languages 1	5	2/2 C+Ex	—
NDBI006	Query Languages 2	5	—	2/2 C+Ex
NDBI021	User preferences	4	—	2/1 C+Ex
NSWI072	Data Compression Algorithms	3	2/0 Ex	—

3.4 Elective Courses - Set 3

The student needs to obtain at least 15 credits for the courses from the following set:

Code	Subject	Credits	Winter	Summer
NMAI060	Probabilistic Methods	3	2/0 Ex	—
NPRG042	Programming in Parallel Environment	6	—	2/2 C+Ex
NPRG054	High Performance Software Development	6	—	2/2 C+Ex
NSWI035	Principles of Distributed Systems	3	2/0 Ex	—
NSWI080	Middleware	4	—	2/1 MC
NSWI101	System Behaviour Models and Verification	5	2/2 C+Ex	—
NSWI131	Performance Evaluation of Computer Systems	4	—	2/1 C+Ex
NSWI149	Software Engineering in Practice	3	—	2/0 C

NSWI152	Cloud Application Development	3	—	0/2 C
NTIN067	Data Structures 2	3	—	2/0 Ex
NSWI166	Introduction to recommender systems and user preferences	4	2/1 C+Ex	—
NPFL104	Machine Learning Methods	4	—	1/2 C+Ex

3.5 State Final Exam

The student will select three examination areas from the following list. Two of the examination areas are obligatory for the chosen specialization, the last area is chosen voluntarily.

Examination areas

1. Software analysis and architectures (obligatory for the specialization Software engineering)
2. Advanced programming (obligatory for the specializations Software engineering and Software development)
3. Software technologies (obligatory for the specialization Software development)
4. Web technologies (obligatory for the specialization Web engineering)
5. Formal foundations of database systems and query languages (obligatory for the specializations Web engineering and Database systems)
6. Implementation of database systems (obligatory for the specialization Database systems)
7. Big and unstructured data processing (obligatory for the specialization Big data processing)
8. Data mining (obligatory for the specialization Big data processing)

Knowledge requirements

1. Software analysis and architectures

¡PSW development processes, development phases. SW requirement analysis - principles, methods, usage of UML (description of SW structure and behavior). Principles and methods of SW design. SW testing (V-model, testing activities, test types, testing techniques). Project planning (SW project, project management methods, SW project planning). SW architecture and its role in the SW development process. Notations for modeling and documentation of SW architecture (Bass, 4+1, ArchiMate, C4 model, etc). Kinds of SW architecture viewpoints and their meaning. Classification of SW architecture quality attributes, their description using scenarios and tactics. Architecture patterns. Monolith, modularized monolith, microservices, service-oriented architecture, domain-driven architecture. Algebraic methods, many sorted algebras, initial models. Temporal logic. Formal principles of the UML language. OCL as a specification language, formal base of specification.

Recommended courses

Code	Subject	Credits	Winter	Summer
NSWI130	Software System Architectures	5	2/2 C+Ex	—
NSWI026	Advanced aspects of software engineering	5	—	2/2 C+Ex

NTIN043	Formal Foundations of Software Engineering	5	2/2 C+Ex	—

2. Advanced programming

Object concepts of modern programming languages. Generic programming and metaprogramming, generics and templates, policies, traits, type inference, reflection. Exceptions, exception-safe programming. Implementation of object properties, runtime support, calling conventions, garbage collection. Parallel programming, Amdahl law, synchronization primitives, task stealing. Design patterns. Scripting languages, prototype-based languages. Domain-specific languages. Functional programming. Principles of code quality, best practices. Refactoring. Testing, debugging, monitoring.

Recommended courses

Code	Subject	Credits	Winter	Summer
NPRG014	Concepts of Modern Programming Languages	4	0/3 C	—
NPRG024	Design Patterns	3	—	0/2 MC
NPRG043	Recommended Programming Practices	5	—	2/2 MC
NPRG042	Programming in Parallel Environment	6	—	2/2 C+Ex

3. Software technologies

Operating system architectures, process management, memory management, communication and synchronization, parallelism, virtualization, paging. File systems, access rights and security. Portability, multiplatform applications. Testing and monitoring of performance and functionality. Architectures of web applications, server-side and client-side scripting, cooperation with database systems. Architecture of data servers, transactions, performance optimization. Cluster, Grid, and Cloud. IaaS, PaaS, and SaaS. Virtualization, containerization, orchestration, edge computing, IoT. MapReduce. Load balancing, high availability.

Recommended courses

Code	Subject	Credits	Winter	Summer
NSWI126	Advanced Tools for Software Development and Monitoring	2	—	0/2 C
NSWI153	Advanced Programming of Web Applications	5	—	2/2 C+Ex
NSWI150	Virtualization and Cloud Computing	3	2/0 Ex	—

4. Web technologies

Overview of basic web technologies. Web services. Architecture of client-server applications, server-side and client-side scripting, web frameworks. Database systems in web applications, NoSQL databases, multimedia databases. Indexing and document searching, principles of web search engines. Linked Data - principles, data model RDF and its serialization, query language SPARQL, frequently used vocabularies, SHACL, Solid. Security of information systems in the Internet environment, authentication, authorization, security models, cryptography basics, data security.

Recommended courses

Code	Subject	Credits	Winter	Summer
NSWI130	Software System Architectures	5	2/2 C+Ex	—
NSWI153	Advanced Programming of Web Applications	5	—	2/2 C+Ex
NSWI145	Web Services	5	—	2/2 C+Ex
NDBI034	Multimedia Retrieval	4	2/1 C+Ex	—
NDBI040	Modern Database Systems	5	—	2/2 C+Ex
NSWI144	Data on the Web	5	—	2/1 C+Ex

5. Formal foundations of database systems and query languages

Domain relational calculus, relational algebra. Relational completeness. Safe expressions, equivalences of relational query languages. Transitive closure of relation. Semantics of SQL. SQL standards. Object extension of relational data model. Text databases – Boolean and vector models, searching and indexing, query result ranking, top-k operator. Datalog. Recursion in SQL. XML data model. RDF data model and its serialization, SPARQL query language, RDF Schema and reasoning/inference. Similarity search in multimedia databases, feature extraction and modeling, metric indexes for similarity search.

Recommended courses

Code	Subject	Credits	Winter	Summer
NDBI034	Multimedia Retrieval	4	2/1 C+Ex	—
NDBI001	Query Languages 1	5	2/2 C+Ex	—
NDBI006	Query Languages 2	5	—	2/2 C+Ex
NDBI021	User preferences	4	—	2/1 C+Ex
NSWI144	Data on the Web	5	—	2/1 C+Ex

6. Implementation of database systems

Models and properties of transactions: ACID, locking protocols, deadlock. Distributed transactions (2PC protocol), error/failure recovery, journals. Distribution with horizontal fragmentation, implementation of NoSQL databases, CAP theorem. Indexing relational data. Spatial access methods. Algorithms for implementation of relational operations and aggregation functions. Query evaluation and optimization. Data compression: Huffman coding, arithmetic coding, LZ algorithms, Burrows-Wheeler transformation.

Recommended courses

Code	Subject	Credits	Winter	Summer
NDBI016	Transactions	3	—	2/0 Ex
NSWI072	Data Compression Algorithms	3	2/0 Ex	—
NDBI040	Modern Database Systems	5	—	2/2 C+Ex
NTIN066	**Data Structures 1**	6	—	2/2 C+Ex

7. Big and unstructured data processing

Distribution with horizontal fragmentation, implementation of NoSQL databases, CAP theorem. Big Data management - distribution, scalability, replication, transactions. MapReduce. Key-value storages. Column storages. Document storages. Models for fulltext querying - vector, Boolean, probabilistic models, query result ranking, top-operator. Similarity search in multimedia databases, feature extraction and modeling, metric indexes for similarity search. Data visualization techniques - dimensionality reduction (PCA, MDS, t-SNE, UMAP), graph data visualization (force directed placement algorithms, multi-scale algorithms). Data science and methodology CRISP-DM - preparation, modeling and evaluation. Basic statistical models for data science. Preference modeling, user feedback variants, recommender systems.

Recommended coursesy

Code	Subject	Credits	Winter	Summer
NDBI040	Modern Database Systems	5	—	2/2 C+Ex
NDBI034	Multimedia Retrieval	4	2/1 C+Ex	—
NDBI042	Data Visualization Techniques	4	—	2/1 C+Ex
NDBI048	Data Science	5	2/2 C+Ex	—
NDBI021	User preferences	4	—	2/1 C+Ex

8. Data mining

Basic principles of database systems, data warehouses and OLAP technology. Data mining – data preprocessing, concept description techniques, methods for mining association rules, methods for data classification and prediction, cluster analysis methods, data mining in database systems. Statistical methods for data mining. Discovery of different types of dependencies. Bayesian analysis, bayesian networks. Probabilistic models of information retrieval. Methods of learning for classification and regression. Support Vector Machines and kernel functions. Experiment evaluation. Data visualization techniques - dimensionality reduction (PCA, MDS, t-SNE, UMAP), graph data visualization (force directed placement algorithms, multi-scale algorithms). Data science and methodology CRISP-DM - preparation, modeling and evaluation. Basic statistical models for data science.

Recommended courses

Code	Subject	Credits	Winter	Summer
NDBI023	Data Mining	5	—	2/2 C+Ex
NAIL029	Machine Learning	3	—	2/0 Ex
NDBI042	Data Visualization Techniques	4	—	2/1 C+Ex
NDBI048	Data Science	5	2/2 C+Ex	—

4 Degree Plans - Computer Science - Software Systems

Coordinated by: Department of Distributed and Dependable Systems
Study programme coordinator: Prof. Ing. Petr Tůma, Dr.

Specializations:

– System Programming
– Dependable Systems
– High Performance Computing

This program invites students with deep interest in programming languages and system-oriented programming. It offers three specializations - System Programming, which focuses on the design and implementation of the basic software layers of a computer system, including the operating system, virtual machine layers and middleware, Dependable Systems, where the curriculum deals with systematic construction of systems with high reliability, such as embedded and real-time systems, and High Performance Computing, which introduces techniques for software development on high performance computing systems, that is, highly parallel systems, distributed systems, and clouds.

4.1 Obligatory Courses

Code	Subject	Credits	Winter	Summer
NTIN066	**Data Structures 1**	6	—	2/2 C+Ex
NTIN090	**Introduction to Complexity and Computability**	4	2/1 C+Ex	—
NSZZ023	**Diploma Thesis I**	6	—	0/4 C
NSZZ024	**Diploma Thesis II**	9	0/6 C	—
NSZZ025	**Diploma Thesis III**	15	—	0/10 C

4.2 Elective Courses - Set 1

The core content of the program is provided through elective courses, where the students need to collect a minimum of 48 credits in courses of their choice. See also the course content suggested for the knowledge part of the State Final Exam.

Code	Subject	Credits	Winter	Summer
NSWI026	Advanced aspects of software engineering	5	—	2/2 C+Ex
NSWI161	Advanced Operating Systems	3	—	2/0 Ex
NPRG058	Advanced Programming in Parallel Environment	6	2/2 C+Ex	—
NSWI126	Advanced Tools for Software Development and Monitoring	2	—	0/2 C
NSWI057	Advanced topics in distributed and component-based systems I	3	0/2 C	0/2 C
NSWI152	Cloud Application Development	3	—	0/2 C
NSWI133	Commercial Workshops	2	0/2 C	—
NSWI109	Compiler Design	4	—	2/1 C+Ex
NPRG014	Concepts of Modern Programming Languages	4	0/3 C	—
NDBI042	Data Visualization Techniques	4	—	2/1 C+Ex

NAIL094	Decision procedures and SAT/SMT solvers	5	—	2/2 C+Ex
NSWE001	Embedded and Real Time Systems	5	—	2/2 C+Ex
NTIN043	Formal Foundations of Software Engineering	5	2/2 C+Ex	—
NSWI089	Information Security 1	3	2/0 Ex	—
NSWI071	Information Security 2	3	—	2/0 Ex
NSWI080	Middleware	4	—	2/1 MC
NSWI164	Model-driven Development	2	0/1 C	—
NSWI131	Performance Evaluation of Computer Systems	4	—	2/1 C+Ex
NSWI176	Practical Dynamic Compilation	2	—	0/2 C
NSWI035	Principles of Distributed Systems	3	2/0 Ex	—
NMAI060	Probabilistic Methods	3	2/0 Ex	—
NSWI132	Program Analysis and Code Verification	5	—	2/2 C+Ex
NSWI054	Software Engineering for Dependable Systems	3	—	0/2 C
NSWI101	System Behaviour Models and Verification	5	2/2 C+Ex	—
NSWI150	Virtualization and Cloud Computing	3	2/0 Ex	—
NSWI151	Virtualization Infrastructure Administration	3	—	0/2 C
NPRG075	Programming language design	2	0/2 C	—

4.3 Elective Courses - Set 2 - Courses from the Bachelor's Programme

The programme involves taking a number of courses from the preceding bachelor programme with a total of at least 8 credits. This obligation can also be fulfilled by recognizing courses already taken from the preceding bachelor programme per existing regulations. The relevant bachelor programme courses are:

Code	Subject	Credits	Winter	Summer
NPRG038	Advanced C# Programming	5	—	2/2 C+Ex
NPRG051	Advanced C++ Programming	5	—	2/2 C+Ex
NPRG021	Advanced Java Programming	5	—	2/2 C+Ex
NSWI153	Advanced Programming of Web Applications	5	—	2/2 C+Ex
NPRG043	Recommended Programming Practices	5	—	2/2 MC
NPRG054	High Performance Software Development	6	—	2/2 C+Ex
NPRG056	Mobile Devices Programming	3	0/2 C	—
NPRG042	Programming in Parallel Environment	6	—	2/2 C+Ex

NSWI143	Computer Architecture	3	—	2/0 Ex
NSWI098	Compiler Principles	6	2/2 C+Ex	—

4.4 Elective Courses - Set 3 - Team Project Courses

The program requires passing one of the team project courses:

Code	Subject	Credits	Winter	Summer
NPRG069	Software Project	12	0/8 C	0/8 C
NPRG070	Research Project	9	0/6 C	0/6 C
NPRG071	Company Project	6	0/4 C	0/4 C

4.5 State Final Exam

The requirements for the knowledge part of the State Final Exam are specified per program specialization.

a) Specialization ***System programming***

The exam for this specialization tests knowledge and skills related to system programming and internal function of software systems, as presented in these courses:

Code	Subject	Credits	Winter	Summer
NSWI161	Advanced Operating Systems	3	—	2/0 Ex
NPRG058	Advanced Programming in Parallel Environment	6	2/2 C+Ex	—
NPRG014	Concepts of Modern Programming Languages	4	0/3 C	—
NSWI080	Middleware	4	—	2/1 MC
NSWI035	Principles of Distributed Systems	3	2/0 Ex	—

b) Specialization ***Dependable Systems***

The exam for this specialization tests knowledge and skills related to design and construction of dependable software systems, as presented in these courses:

Code	Subject	Credits	Winter	Summer
NSWE001	Embedded and Real Time Systems	5	—	2/2 C+Ex
NTIN043	Formal Foundations of Software Engineering	5	2/2 C+Ex	—
NSWI164	Model-driven Development	2	0/1 C	—
NSWI132	Program Analysis and Code Verification	5	—	2/2 C+Ex
NSWI101	System Behaviour Models and Verification	5	2/2 C+Ex	—

c) Specialization ***High Performance Computing***

The exam for this specialization tests knowledge and skills related to high performance computing systems, as presented in these courses:

Code	Subject	Credits	Winter	Summer
NPRG058	Advanced Programming in Parallel Environment	6	2/2 C+Ex	—

NSWI109	Compiler Design	4	—	2/1 C+Ex
NSWI131	Performance Evaluation of Computer Systems	4	—	2/1 C+Ex
NSWI035	Principles of Distributed Systems	3	2/0 Ex	—
NSWI150	Virtualization and Cloud Computing	3	2/0 Ex	—

5 Degree Plans - Computer Science – Language Technologies and Computational Linguistics

Coordinated by: Institute of Formal and Applied Linguistics
Study programme coordinator: Doc. Mgr. Barbora Vidová Hladká, Ph.D.

Specializations:

– Computational and formal linguistics
– Statistical and machine learning methods in Natural Language Processing

The graduate is familiar with mathematical and algorithmic foundations of automatic natural language processing, with theoretical foundations of formal description of natural languages, as well as with state-of-the-art machine learning techniques. The student acquires the skills in designing and development of systems to automatically process large quantities of language data, written and spoken, structured and unstructured alike, and to solve language-related tasks, such as information retrieval, question answering, summarization and information extraction, machine translation, and speech processing.

The graduate is well prepared for doctoral studies in computational linguistics and language technologies, as well as for a professional career in the public or private sector. Given the general applicability of machine learning and data driven methods, the graduate is well equipped to use these methods not only in natural language processing tasks but also in other domains where large quantities of both structured and unstructured data are being analyzed (finances, economy, biology, medicine, and other domains). The student acquires programming experience and soft skills required for team work on applications that involve machine learning or human-computer interaction.

5.1 Obligatory Courses

Code	Subject	Credits	Winter	Summer
NTIN066	**Data Structures 1**	6	—	2/2 C+Ex
NTIN090	**Introduction to Complexity and Computability**	4	2/1 C+Ex	—
NPFL063	**Introduction to General Linguistics**	4	2/1 C+Ex	—
NPFL067	**Statistical Methods in Natural Language Processing I**	5	2/2 C+Ex	—
NPFL114	**Deep Learning**	7	—	3/2 C+Ex

NSZZ023	**Diploma Thesis I**	6	—	0/4 C
NSZZ024	**Diploma Thesis II**	9	0/6 C	—
NSZZ025	**Diploma Thesis III**	15	—	0/10 C

5.2 Elective Courses - Set 1

The student needs to obtain at least 40 credits in total for the elective courses. Of these 40 required credits, at most 6 credits can be obtained from project courses (set 2 below) and at most 10 credits from the additional set of elective courses (set 3 below).

Code	Subject	Credits	Winter	Summer
NPFL006	Introduction to Formal Linguistics	3	2/0 Ex	—
NPFL038	Fundamentals of Speech Recognition and Generation	5	2/2 C+Ex	—
NPFL068	Statistical Methods in Natural Language Processing II	5	—	2/2 C+Ex
NPFL070	Language Data Resources	4	1/2 MC	—
NPFL075	Dependency Grammars and Treebanks	3	—	1/1 MC
NPFL079	Algorithms in Speech Recognition	5	—	2/2 C+Ex
NPFL082	Information Structure of Sentences and Discourse Structure	2	—	0/2 C
NPFL083	Linguistic Theories and Grammar Formalisms	5	—	2/2 C+Ex
NPFL087	Statistical Machine Translation	5	—	2/2 C+Ex
NPFL093	NLP Applications	4	—	2/1 MC
NPFL094	Morphological and Syntactic Analysis	3	2/0 MC	—
NPFL095	Modern Methods in Computational Linguistics	3	0/2 C	—
NPFL097	Unsupervised Machine Learning in NLP	3	1/1 C	—
NPFL099	Statistical Dialogue Systems	4	2/1 C+Ex	—
NPFL100	Variability of Languages in Time and Space	2	1/1 C	—
NPFL103	Information Retrieval	5	2/2 C+Ex	—
NPFL104	Machine Learning Methods	4	—	1/2 C+Ex
NPFL122	Deep Reinforcement Learning	5	2/2 C+Ex	—
NPFL128	Language Technologies in Practice	4	—	2/1 MC

5.3 Elective Courses - Set 2 - Team Project Courses

The student can select at most one of the project courses as an elective course; at most 6 credits count as credits for elective courses. (Other potential credits for courses from this set count as credits for free courses.)

Code	Subject	Credits	Winter	Summer
NPRG069	Software Project	12	0/8 C	0/8 C

NPRG070	Research Project	9	0/6 C	0/6 C
NPRG071	Company Project	6	0/4 C	0/4 C

5.4 Elective Courses - Set 3

The student can select any course from the following set of additional courses; at most 10 credits count as credits for elective courses. (Other potential credits for courses from this set count as credits for free courses.)

Code	Subject	Credits	Winter	Summer
NAIL025	Evolutionary Algorithms 1	5	2/2 C+Ex	—
NAIL069	Artificial Intelligence 1	4	2/1 C+Ex	—
NAIL070	Artificial Intelligence 2	3	—	2/0 Ex
NAIL104	Probabilistic graphical models	3	2/0 Ex	—
NPGR036	Computer Vision	5	—	2/2 C+Ex

5.5 State Final Exam

The state final exam for the study program Computer Science - Language Technologies and Computational Linguistics consists of one obligatory examination area for both specializations (examination area 1), one obligatory area dependent on the selected specialization (examination area 2 or examination area 3), and one elective examination area (examination areas 4 and 5). As the last examination area, the student may also select the obligatory area of the other specialization of this study program. In total, each student gets questions from three examination areas.

Examination areas

1. Fundamentals of natural language processing (obligatory for both specializations)
2. Linguistic theories and formalisms (obligatory for the specialization Computational and formal linguistics)
3. Statistical methods and machine learning in computational linguistics (obligatory for the specialization Statistical and machine learning methods in Natural Language Processing)
4. Speech, dialogue and multimodal systems (elective)
5. Applications in natural language processing (elective)

Knowledge requirements

1. Fundamentals of natural language processing

Levels of language description: phonetics, phonology, morphology, syntax, semantics, pragmatics. Fundamentals of information theory. Markov models. Language modeling and smoothing. Word classes. Annotated corpora. Design and evaluation of linguistic experiments, evaluation metrics. Morphological disambiguation. Basic classification and regression algorithms.

Recommended courses

Code	Subject	Credits	Winter	Summer
NPFL063	Introduction to General Linguistics	4	2/1 C+Ex	—
NPFL067	Statistical Methods in Natural Language Processing I	5	2/2 C+Ex	—

NPFL114	Deep Learning	7	—	3/2 C+Ex
NPFL070	Language Data Resources	4	1/2 MC	—

2. Linguistic theories and formalisms

Functional Generative Description. Prague Dependency Treebank. Universal Dependencies. Other grammar formalisms - overview and basic characteristics. Phonetics, phonology. Computational Morphology. Surface and deep syntactic structure; valency. Topic-focus articulation; information structure, discourse. Coreference. Linguistic typology. Parsing.

Recommended courses

Code	Subject	Credits	Winter	Summer
NPFL063	Introduction to General Linguistics	4	2/1 C+Ex	—
NPFL006	Introduction to Formal Linguistics	3	2/0 Ex	—
NPFL075	Dependency Grammars and Treebanks	3	—	1/1 MC
NPFL083	Linguistic Theories and Grammar Formalisms	5	—	2/2 C+Ex
NPFL094	Morphological and Syntactic Analysis	3	2/0 MC	—

3. Statistical methods and machine learning in computational linguistics

Generative and discriminative models. Supervised learning methods for classification and regression (linear models, other methods: naive Bayes, decision trees, example-based learning, SVM and kernels, logistic regression). Unsupervised learning methods. Language models, noisy channel models. Model smoothing, model combination. HMM, trellis, Viterbi, Baum-Welch. Algorithms for statistical tagging. Algorithms for constituency and dependency statistical parsing. Machine learning with neural networks. Convolution and recurrent networks. Word embeddings.

Recommended courses

Code	Subject	Credits	Winter	Summer
NPFL067	Statistical Methods in Natural Language Processing I	5	2/2 C+Ex	—
NPFL114	Deep Learning	7	—	3/2 C+Ex
NPFL068	Statistical Methods in Natural Language Processing II	5	—	2/2 C+Ex

4. Speech, dialogue and multimodal systems

Fundamentals of speech production and perception. Methods of speech signal processing. HMM acoustic modeling of phonemes. The implementation of the Baum-Welch and Viterbi algorithms in speech recognition systems. Neural models for speech. Methods of speech synthesis. Speech applications. Basic components of a dialogue system. Natural language understanding in dialogue systems. Dialogue state tracking. Methods for dialogue management. End-to-end neural dialogue systems. Open-domain dialogue system architectures. Natural language generation. Dialogue systems evaluation. Visual dialogue and multimodal systems.

Recommended courses

Code	Subject	Credits	Winter	Summer
NPFL038	Fundamentals of Speech Recognition and Generation	5	2/2 C+Ex	—
NPFL079	Algorithms in Speech Recognition	5	—	2/2 C+Ex
NPFL099	Statistical Dialogue Systems	4	2/1 C+Ex	—

5. Applications in natural language processing

Spell-checking and grammar-checking. Machine translation. Machine-aided translation. Statistical methods in machine translation. Speech translation. Quality evaluation of machine translation and speech translation. Information retrieval, models for information retrieval. Query expansion and relevance feedback. Document clustering. Near duplicate detection. Information retrieval evaluation. Sentiment analysis. Pre-trained models and their use in classification tasks and in tasks of natural language generation.

Recommended courses

Code	Subject	Credits	Winter	Summer
NPFL087	Statistical Machine Translation	5	—	2/2 C+Ex
NPFL093	NLP Applications	4	—	2/1 MC
NPFL103	Information Retrieval	5	2/2 C+Ex	—
NPFL128	Language Technologies in Practice	4	—	2/1 MC

6 Degree Plans - Computer Science - Artificial Intelligence

Coordinated by: Department of Theoretical Computer Science and Mathematical Logic
Study programme coordinator: Prof. RNDr. Roman Barták, Ph.D.

Specializations:

– Intelligent agents
– Machine learning
– Robotics

The study program Artificial Intelligence provides education in the area of theoretical and applied knowledge for design of intelligent systems in various areas including data analysis, automated problem solving, and robotic applications. The emphasis is put on deep understanding of formal theoretical foundations and their practical applicability. Students will gain knowledge about design of efficient data structures, about formal modeling of problems and knowledge by using techniques of mathematical logic and probability theory, about algorithms (classical and nature-inspired) for problem solving, for control of autonomous agents, for machine learning, and for data mining, and about complexity analysis of computational methods. The students will learn how to apply these techniques and how to extent them both for abstract (data) and physical (robotic) worlds in single-agent and multi-agent environments. The study program Artificial Intelligence can be studied in three specializations: Intelligent agents, Machine learning, and Robotics.

Graduates can apply and further extend techniques for the design of intelligent systems, including knowledge modeling and formal modeling of complex systems by means of mathematical logic and probability theory, automated problem solving, planning and scheduling, control of autonomous agents (both virtual and physical), machine learning, and data mining. They are also able to analyze and formally model a complex decision problem, propose an appropriate solving technique, and implement it. Graduates can work in research and development in either academia or industry in any position requiring logical reasoning, analytical capabilities, an algorithmic approach, and the exploitation of modern methods of computer science (declarative and nature-inspired programming).

6.1 Obligatory Courses

Code	Subject	Credits	Winter	Summer
NAIL069	**Artificial Intelligence 1**	4	2/1 C+Ex	—
NAIL070	**Artificial Intelligence 2**	3	—	2/0 Ex
NTIN066	**Data Structures 1**	6	—	2/2 C+Ex
NTIN090	**Introduction to Complexity and Computability**	4	2/1 C+Ex	—
NSZZ023	**Diploma Thesis I**	6	—	0/4 C
NSZZ024	**Diploma Thesis II**	9	0/6 C	—
NSZZ025	**Diploma Thesis III**	15	—	0/10 C

6.2 Elective Courses - Set 1 - Profiling Courses

The student needs to obtain at least 38 credits for the courses from the following set.

Code	Subject	Credits	Winter	Summer
NAIL002	Neural Networks	8	4/2 C+Ex	—
NAIL013	Applications of Neural Networks Theory	3	—	2/0 Ex
NAIL025	Evolutionary Algorithms 1	5	2/2 C+Ex	—
NAIL029	Machine Learning	3	—	2/0 Ex
NAIL060	Neural Networks Implementation 1	5	2/2 C+Ex	—
NAIL065	Evolutionary Robotics	4	—	2/1 C+Ex
NAIL068	Human-like Artificial Agents	5	—	2/2 C+Ex
NAIL071	Planning and Scheduling	3	—	2/0 Ex
NAIL076	Logic Programming 1	3	2/0 Ex	—
NAIL078	Lambda Calculus and Functional Programming 1	4	2/1 C+Ex	—
NAIL086	Evolutionary Algorithms 2	5	—	2/2 C+Ex
NAIL094	Decision procedures and SAT/SMT solvers	5	—	2/2 C+Ex
NAIL101	Probabilistic Robotics	5	—	2/2 C+Ex

NAIL104	Probabilistic graphical models	3	2/0 Ex	—
NAIL105	Internet and Classification Methods	2	—	1/1 C+Ex
NAIL106	Multiagent Systems	5	—	2/2 C+Ex
NAIL107	Machine Learning in Bioinformatics	5	—	2/2 C+Ex
NAIL108	Mobile Robotics	3	—	1/1 MC
NAIL116	Social networks and their analysis	5	2/2 C+Ex	—
NAIL126	Foundations of Robotics	5	2/2 C+Ex	—
NOPT042	Constraint Programming	5	2/2 C+Ex	—
NDBI023	Data Mining	5	—	2/2 C+Ex
NSWE001	Embedded and Real Time Systems	5	—	2/2 C+Ex
NSWI035	Principles of Distributed Systems	3	2/0 Ex	—
NPGR036	Computer Vision	5	—	2/2 C+Ex
NPFL067	Statistical Methods in Natural Language Processing I	5	2/2 C+Ex	—
NPFL103	Information Retrieval	5	2/2 C+Ex	—

6.3 Elective Courses - Set 2

The student needs to obtain at least 15 credits for the courses from the following set.

Code	Subject	Credits	Winter	Summer
NAIL004	Seminar on Artificial Intelligence 1	2	0/2 C	—
NAIL015	Neural Networks Implementation 2	5	—	2/2 C+Ex
NAIL021	Boolean Functions and Their Applications	3	2/0 Ex	—
NAIL052	Seminar on Artificial Intelligence 2	2	—	0/2 C
NAIL061	Seminar on Mobile Robotics	3	—	0/2 C
NAIL073	Robot 1	3	0/2 C	—
NAIL074	Robot 2	3	—	0/2 C
NAIL077	Logic Programming 2	3	—	2/0 Ex
NAIL079	Lambda Calculus and Functional Programming 2	4	—	2/1 C+Ex
NAIL087	Computers and Cognitive Sciences 1	6	3/1 C+Ex	—
NAIL088	Computers and Cognitive Sciences 2	6	—	3/1 C+Ex
NAIL109	Applications of Computational Intelligence Methods	5	0/4 C	—
NOPT021	Modern Algoritmic Game Theory	5	2/2 C+Ex	—
NMAI060	Probabilistic Methods	3	2/0 Ex	—
NMAI067	Logic in Computer Science	3	2/0 Ex	—
NPFL114	Deep Learning	7	—	3/2 C+Ex
NPFL122	Deep Reinforcement Learning	5	2/2 C+Ex	—
NPFL123	Dialogue Systems	5	—	2/2 C+Ex
NDBI031	Statistical Methods in Data Mining Systems	2	1/1 C+Ex	—
NPGR001	3D Computer Vision	5	2/2 Ex	—
NPGR002	Digital Image Processing	4	3/0 Ex	—

NPGR035	Machine Learning in Computer Vision	5	2/2 C+Ex	—
NSWI054	Software Engineering for Dependable Systems	3	—	0/2 C
NPRG037	Microcontroller Programming	5	2/2 C+Ex	—
NPRG069	Software Project	12	0/8 C	0/8 C
NPRG070	Research Project	9	0/6 C	0/6 C
NPRG071	Company Project	6	0/4 C	0/4 C
NPRG072	Increased project scope	3	0/2 C	0/2 C

6.4 State Final Exam

The student will select three examination areas from the following lists depending on selected specialization and she or he will get one question from each of the selected areas. One area may be selected from another specialization. In total, each student will get three questions.

a) Specialization ***Intelligent agents***

Examination areas

1. Knowledge representation and problem solving
2. Nonprocedural programming
3. Multiagent systems
4. Nature inspired computing

Knowledge requirements

1. Knowledge representation and problem solving

Propositional and first-order logic; satisfiability and provability, automated theorem proving, model checking (DPLL), forward and backward chaining, resolution and unification. Conditional independence, Bayesian networks, evaluation in Bayesian networks, MDP, POMDP, reinforcement learning. Search algorithms: state space, tree, graph, and local search, uninformed and heuristic search. Games and basics of theory of games. Constraint satisfaction; consistency techniques, global constraints. Automated planning: planning domain and problem, planning operators, planning techniques and algorithms.

Recommended courses

Code	Subject	Credits	Winter	Summer
NAIL069	Artificial Intelligence 1	4	2/1 C+Ex	—
NAIL070	Artificial Intelligence 2	3	—	2/0 Ex
NAIL071	Planning and Scheduling	3	—	2/0 Ex
NOPT042	Constraint Programming	5	2/2 C+Ex	—
NAIL094	Decision procedures and SAT/SMT solvers	5	—	2/2 C+Ex
NAIL104	Probabilistic graphical models	3	2/0 Ex	—

2. Nonprocedural programming

Differences between procedural and non-procedural styles of programming. Principles of functional and logic programming. Lambda calculus, its syntax, and reduction principles. Church and Rosser property and consistency of calculus. Fixed point theorems. Normal form of terms. Typed lambda calculus.

Substitution and unification. Horn clauses, SLD resolution and logic programs. Pure Prolog, negation as failure, general logic programs. Sufficient conditions of program termination. Implementation of Prolog. Constraint logic programming.

Recommended courses

Code	Subject	Credits	Winter	Summer
NAIL076	Logic Programming 1	3	2/0 Ex	—
NAIL077	Logic Programming 2	3	—	2/0 Ex
NAIL078	Lambda Calculus and Functional Programming 1	4	2/1 C+Ex	—
NOPT042	Constraint Programming	5	2/2 C+Ex	—

3. Multiagent systems

Autonomous agent architectures; agent perception, agent action selection mechanism, agent memory. Psychological inspiration. Methods for agent control; symbolic and connectionist reactive planning, hybrid approaches. Path search problem, steering rules, terrain representation. Communication and knowledge in multiagent systems, ontologies, speech acts, FIPA-ACL, protocols. Distributed problem solving, cooperation, Nash equilibria, Pareto efficiency, source allocation, auctions. Agent design methodologies, agent languages and environments. Ethological inspiration, models of population dynamics. Methods for agent learning; reinforcement learning, basic forms of animal learning. Design methodology, languages and environments for multiagent systems

Recommended courses

Code	Subject	Credits	Winter	Summer
NAIL106	Multiagent Systems	5	—	2/2 C+Ex
NAIL068	Human-like Artificial Agents	5	—	2/2 C+Ex

4. Nature inspired computing

Genetic algorithms, genetic and evolutionary programming. Schemata theory, probabilistic models of simple genetic algorithm. Evolutionary strategies, differential evolution, coevolution, open ended evolution. Swarm optimization algorithms. Memetic algorithms, hill climbing, simulated annealing. Application of evolutionary algorithms (expert systems evolution, neuroevolution, combinatorial optimization, multi-objective optimization).

Recommended courses

Code	Subject	Credits	Winter	Summer
NAIL025	Evolutionary Algorithms 1	5	2/2 C+Ex	—
NAIL086	Evolutionary Algorithms 2	5	—	2/2 C+Ex
NAIL065	Evolutionary Robotics	4	—	2/1 C+Ex

b) Specialization ***Machine learning***

Examination areas

1. Machine learning and its applications
2. Neural networks
3. Data mining

Knowledge requirements

1. Machine learning and its applications

Machine learning; supervised learning and self-organization, reinforcement learning, theoretical aspects of machine learning. Probabilistic approaches; undirected graphical models, Gaussian processes. Evolutionary algorithms; fundamental concepts and theoretical knowledge, the building block hypothesis, coevolution, applications of evolutionary algorithms. Machine learning in computational linguistics. Algorithms for biological sequence analysis; search for motifs in DNA sequences, Markov models and strategies for gene detection or protein structure prediction.

Recommended courses

Code	Subject	Credits	Winter	Summer
NAIL029	Machine Learning	3	—	2/0 Ex
NPFL067	Statistical Methods in Natural Language Processing I	5	2/2 C+Ex	—
NAIL025	Evolutionary Algorithms 1	5	2/2 C+Ex	—
NAIL107	Machine Learning in Bioinformatics	5	—	2/2 C+Ex

2. Neural networks

Models for supervised learning; the back-propagation algorithm, strategies to speed up the training process, regularization techniques and generalization. Associative memories; Hebbian learning and the search for suboptimal solutions, stochastic models. Artificial neural networks based on unsupervised learning. Modular, hierarchical and hybrid models of neural networks. Models of deep neural networks; convolutional neural networks, deep belief networks, LSTM-networks. Evolutionary learning of neural networks and its applications.

Recommended courses

Code	Subject	Credits	Winter	Summer
NAIL002	Neural Networks	8	4/2 C+Ex	—
NAIL060	Neural Networks Implementation 1	5	2/2 C+Ex	—
NAIL013	Applications of Neural Networks Theory	3	—	2/0 Ex
NAIL065	Evolutionary Robotics	4	—	2/1 C+Ex

3. Data mining

Basic paradigms of data mining. Data preparation; attribute selection and methods for relevance analysis of attributes. Data mining methods; association rules, approaches based on supervised learning and cluster analysis. Methods for the extraction of characteristic and discriminant rules and measures of their interestingness. Representation, evaluation and visualization of the extracted knowledge. Models for the analysis of social networks; centrality measures, community detection. Practical applications of data mining and social network analysis.

Recommended courses

Code	Subject	Credits	Winter	Summer
NDBI023	Data Mining	5	—	2/2 C+Ex
NAIL116	Social networks and their analysis	5	2/2 C+Ex	—
NAIL105	Internet and Classification Methods	2	—	1/1 C+Ex
NAIL099	Seminar of machine learning and modelling 1	2	0/1 C	—

c) Specialization ***Robotics***

Examination areas

1. Localization and mapping
2. Control systems
3. Robotic systems
4. Planning and navigation

Knowledge requirements

1. Localization and mapping

Basic localization methods. Probabilistic localization, particle filters, Monte-Carlo methods. Environment representation, map formats, correspondence problem, mapping in dynamic environment. Localization and mapping relation, SLAM.

Recommended courses

Code	Subject	Credits	Winter	Summer
NAIL126	Foundations of Robotics	5	2/2 C+Ex	—
NAIL101	Probabilistic Robotics	5	—	2/2 C+Ex
NAIL108	Mobile Robotics	3	—	1/1 MC

2. Control systems

Robot control systems. Signal processing, object recognition, feature matching and tracking. Modeling systems, virtual robotics, simulators. Distributed algorithms, multirobot control systems, communication, synchronization, coordination. Software implementation, programming for specific runtime environment, debugging tools and techniques.

Recommended courses

Code	Subject	Credits	Winter	Summer
NAIL126	Foundations of Robotics	5	2/2 C+Ex	—
NPGR001	3D Computer Vision	5	2/2 Ex	—
NPGR002	Digital Image Processing	4	3/0 Ex	—
NSWI035	Principles of Distributed Systems	3	2/0 Ex	—

3. Robotic systems

Basic kinematic and dynamic model, inverse kinematics and dynamics. Low-level hardware and software, embedded systems. Sensor and actuator types, principles and typical usage. High-level robot systems and their control: manipulators, mobile robotics, autonomous robotics.

Recommended courses

Code	Subject	Credits	Winter	Summer
NAIL126	Foundations of Robotics	5	2/2 C+Ex	—
NAIL108	Mobile Robotics	3	—	1/1 MC
NSWE001	Embedded and Real Time Systems	5	—	2/2 C+Ex

4. Planning and navigation

Basic navigation techniques: dead-reckoning, odometry, triangulation and trilateration, inertial navigation. Navigation and exploration algorithms. Action planning, planning problem formulation, basic planning techniques and planning with time and resources.

Recommended courses

Code	Subject	Credits	Winter	Summer
NAIL126	Foundations of Robotics	5	2/2 C+Ex	—
NAIL108	Mobile Robotics	3	—	1/1 MC
NAIL071	Planning and Scheduling	3	—	2/0 Ex

7 Degree Plans – Computer Science – Visual Computing and Game Development

Coordinated by: Department of Software and Computer Science Education
Study programme coordinator: Doc. RNDr. Tomáš Dvořák, CSc.

The study program consists of two closely related specializations which differ in the examination areas for the state final exam. It is recommended to choose the courses so that they would cover the selected examination areas.

Specializations:

– Visual computing
– Computer game development

The specialization Visual computing offers training in a wide range of visual sciences, including geometric modeling, rendering (image synthesis) as well as the basics of image analysis and computer vision. The specialization Computer game development focuses - apart from computer graphics techniques - mainly on artificial intelligence and intelligent agent systems, as well as on software engineering skills necessary for the development of large-scale gaming projects. Both specializations place emphasis on general programming skills, both at the system level closer to the hardware, as well as on the higher level of modern programming languages.

Graduates have expertise in the design and development of graphical systems and computer games, but they can work in any position which requires logical thinking, analytic and algorithmic approaches or the use of methods of computer science. Depending on the chosen specialization, graduates have a deep knowledge of computer graphics and image analysis, and their expertise covers the development of large-scale gaming projects, real-time applications, programming of portable devices, as well as the foundations of artificial intelligence and computer graphics in the context of computer games. Graduates can apply this knowledge to solve specific practical tasks. They can work in research and development both in the private sector and in academia.

7.1 Obligatory Courses

Code	Subject	Credits	Winter	Summer
NTIN090	**Introduction to Complexity and Computability**	4	2/1 C+Ex	—
NTIN066	**Data Structures 1**	6	—	2/2 C+Ex
NSZZ023	**Diploma Thesis I**	6	—	0/4 C
NSZZ024	**Diploma Thesis II**	9	0/6 C	—
NSZZ025	**Diploma Thesis III**	15	—	0/10 C

7.2 Elective Courses

The student needs to obtain at least 53 credits for the courses from the following set. The program requires to choose one out of the three project courses - Software project, Research project, Company Project. Other potential credits for courses from this triple are counted as credits for free courses.

Code	Subject	Credits	Winter	Summer
NPRG069	Software Project	12	0/8 C	0/8 C
NPRG070	Research Project	9	0/6 C	0/6 C
NPRG071	Company Project	6	0/4 C	0/4 C
NPRG072	Increased project scope	3	0/2 C	0/2 C
NMAI060	Probabilistic Methods	3	2/0 Ex	—
NMAI061	Methods of Mathematical Statistics	5	—	2/1 C+Ex
NPGR001	3D Computer Vision	5	2/2 Ex	—
NPGR010	Advanced 3D graphics for film and games	5	2/2 C+Ex	—
NPGR013	Special Functions and Transformations in Image Processing	3	—	2/0 Ex
NPGR016	Applied Computational Geometry	5	—	2/1 C+Ex
NPGR021	Geometric Modelling	5	2/2 C+Ex	—
NPGR024	Seminar on Scientific Soft Skills	3	—	0/2 C
NPGR026	Predictive Image Synthesis Technologies	4	—	2/1 C+Ex
NPGR027	Shading Languages	5	—	2/1 C+Ex
NPGR028	High Performance Ray Tracing	3	—	2/0 Ex
NPGR029	Variational methods in image processing	3	—	2/0 Ex
NPGR033	Computer Graphics for Game Development	5	—	2/2 C+Ex
NPGR041	Selected topics in Computer Vision	5	2/2 C+Ex	—
NCGD001	Computer Games Development 1	6	—	2/2 C+Ex

NCGD003	Gameplay Programming	4	1/2 C+Ex	—
NCGD004	Introduction to Game Design	3	1/1 C+Ex	—
NCGD005	Game User Experience	3	1/1 C+Ex	—
NCGD007	Practical Course on Native Game Development	3	0/2 C	—
NCGD008	Practical Course on Managed Game Development	3	0/2 C	—
NAFF003	Introduction to Game Studies	3	0/2 Ex	—
NAFF004	Contemporary Issues in Game Studies	3	—	0/2 Ex
NPRG043	Recommended Programming Practices	5	—	2/2 MC
NPRG058	Advanced Programming in Parallel Environment	6	2/2 C+Ex	—
NSWI026	Advanced aspects of software engineering	5	—	2/2 C+Ex
NSWI072	Data Compression Algorithms	3	2/0 Ex	—
NSWI130	Software System Architectures	5	2/2 C+Ex	—
NSWI131	Performance Evaluation of Computer Systems	4	—	2/1 C+Ex
NSWI145	Web Services	5	—	2/2 C+Ex
NSWI153	Advanced Programming of Web Applications	5	—	2/2 C+Ex
NTIN043	Formal Foundations of Software Engineering	5	2/2 C+Ex	—
NDBI034	Multimedia Retrieval	4	2/1 C+Ex	—
NAIL068	Human-like Artificial Agents	5	—	2/2 C+Ex
NAIL069	Artificial Intelligence 1	4	2/1 C+Ex	—
NAIL070	Artificial Intelligence 2	3	—	2/0 Ex
NAIL106	Multiagent Systems	5	—	2/2 C+Ex
NAIL122	Artificial Intelligence for Computer Games	3	1/1 C+Ex	—
NAIL123	Procedural Content Generation for Computer Games	3	—	1/1 C+Ex
NPFL114	Deep Learning	7	—	3/2 C+Ex

7.3 Other Recommended Courses

The list of recommended courses contains only those that supplement or expand the material essential for this study program. The choice of others is left to the student who can choose from a wide range of courses offered at the faculty.

Code	Subject	Credits	Winter	Summer
NPGR004	Photorealistic Graphics	5	—	2/2 C+Ex
NPGR005	Computer graphics and vision seminar	2	0/2 C	0/2 C
NPGR019	Realtime Graphics on GPU	5	—	2/2 C+Ex

NPGR022	Advanced Seminar On Image Processing	2	0/2 C	0/2 C
NPGR030	Optics for computer graphics	3	2/0 Ex	—
NPGR036	Computer Vision	5	—	2/2 C+Ex
NCGD002	Computer Games Development 2	3	1/1 C+Ex	—
NCGD006	Practical Course on Rapid Game Development	2	—	0/1 C
NPRG042	Programming in Parallel Environment	6	—	2/2 C+Ex
NPRG054	High Performance Software Development	6	—	2/2 C+Ex
NPRG056	Mobile Devices Programming	3	0/2 C	—
NPRG059	Advanced Programming Praxis	2	0/1 C	—
NSWI041	Introduction to Software Engineering	5	—	2/2 C+Ex
NSWI158	Seminar on Computer Games Development	3	0/2 C	0/2 C
NAIL025	Evolutionary Algorithms 1	5	2/2 C+Ex	—
NAIL028	Introduction to Robotics	5	2/2 C+Ex	—
NAIL071	Planning and Scheduling	3	—	2/0 Ex
NAIL082	Seminar on Humanlike Artificial Agents	3	0/2 C	0/2 C
NAIL087	Computers and Cognitive Sciences 1	6	3/1 C+Ex	—
NAIL108	Mobile Robotics	3	—	1/1 MC
NDBI045	Video Retrieval	5	2/2 C+Ex	—

7.4 State Final Exam

The student chooses three examination areas from the offer of the selected specialization following the conditions specified below. Students are asked one question from each selected examination area. In total, each student obtains three questions.

a) Specialization ***Visual Computing***

Students have to choose at least two examination areas from the following list. The third examination area can be chosen at will also from among all the examination areas offered in the specialization Computer game development, except the area “Computer graphics for games”.

Examination areas

1. Realistic image synthesis
2. Image analysis and processing, image compression, computer vision
3. Geometric modeling and computational geometry

Knowledge requirements

1. Realistic image synthesis

Representation of 3D scenes, visibility determination, cast shadows, reflection models and shading algorithms, recursive ray tracing, textures, anti-aliasing, iso-surface extraction. Graphics accelerator architecture, data transfer to the GPU, textures on the GPU, GPU programming: shaders, basics of OpenGL, HLSL and GLSL, CUDA. Physically-based models of light transport (radiometry, BRDF, rendering equation), Monte Carlo integration (importance sampling and MIS), Monte Carlo approaches in lighting simulation (path tracing, bi-directional path tracing), approximate methods for global illumination (photon mapping, irradiance caching). Monte Carlo methods for spectral illumination, participating media, measurement and verification of rendering methods. Shading languages (Renderman shading language, OSL). General and specific techniques for ray-tracing acceleration.

Recommended courses

Code	Subject	Credits	Winter	Summer
NPGR010	Advanced 3D graphics for film and games	5	2/2 C+Ex	—
NPGR026	Predictive Image Synthesis Technologies	4	—	2/1 C+Ex
NPGR027	Shading Languages	5	—	2/1 C+Ex

2. Image analysis and processing, image compression, computer vision

Contrast and intensity manipulation, HDR, noise reduction, edge detection. Determining the relative position of images, point and object correspondence, geometric distortion removal, edge detection, detection of areas. Features for description and recognition of 2D objects, moment invariants, wavelets and their use. Statistical theory of pattern recognition, supervised and unsupervised classification, convolutional networks. Compression of raster 2D graphics, scalar and vector quantization, predictive compression, transformation compression methods, video compression, temporal prediction (motion compensation), JPEG and MPEG standards.

Recommended courses

Code	Subject	Credits	Winter	Summer
NPGR041	Selected topics in Computer Vision	5	2/2 C+Ex	—
NPGR029	Variational methods in image processing	3	—	2/0 Ex
NPGR013	Special Functions and Transformations in Image Processing	3	—	2/0 Ex
NSWI072	Data Compression Algorithms	3	2/0 Ex	—
NPGR001	3D Computer Vision	5	2/2 Ex	—

3. Geometric modeling and computational geometry

Differential geometry of curves and surfaces, their approximation and interpolation. Bezier curves and surfaces, de Casteljau algorithm. B-spline functions and curves, de Boor algorithm, rational curves and surfaces, NURBS, Coons patch.

Geometric location. Convex hulls. Voronoi diagrams, their applications and generalization. Planar triangulations of a point set and their applications. Tetrahedralization and their applications. Polygon triangulation. Medial Axis. Intersections.

Recommended courses

Code	Subject	Credits	Winter	Summer
NPGR021	Geometric Modelling	5	2/2 C+Ex	—
NPGR016	Applied Computational Geometry	5	—	2/1 C+Ex

b) Specialization ***Computer game development***

Students obtain one question from each of the following examination areas:

1. "Computer games development" (this area is obligatory for the specialization Computer game development).
2. Either the area "Computer graphics for games" or any area from the specialization Visual computing chosen by the student.
3. One of the areas 3 - 7 chosen by the student.

Examination areas

1. Computer games development (obligatory for the specialization Computer game development)
2. Computer graphics for games
3. Artificial intelligence for games
4. Video games as a social-cultural phenomenon
5. Software analysis and architectures
6. Web technologies
7. High Performance Computing

Knowledge requirements

1. Computer games development

Game programming; development of game mechanics, game programming design patterns, scripting. Game engine architecture; architecture layers, computational models, entity-component system, memory management, game architecture instances. Game design; who is a game designer, game design axes, game genres, design specifics of gaming platforms, game design document (its properties, structure, UML diagrams for description of game mechanics, game space, characters, specifications of dialogues), history of the video game market and its trends. Game production cycle; game production phases, data-driven game design, resource management, game testing, development team roles, game analytics, waterfall and agile methodology, business and monetization models. Games and narrativity; differences between games of emergence and games of progression, environmental storytelling, procedural rhetoric, ludonarrative dissonance.

Recommended courses

Code	Subject	Credits	Winter	Summer
NCGD001	Computer Games Development 1	6	—	2/2 C+Ex
NCGD003	Gameplay Programming	4	1/2 C+Ex	—
NCGD004	Introduction to Game Design	3	1/1 C+Ex	—

2. Computer graphics for games

Homogeneous coordinates, affine and projective transformations in the plane and in space, quaternions, splines, interpolation by cubic splines, Bezier curves, Catmull-Rom splines, B-splines. Sampling and quantization, image anti-aliasing, textures, change of contrast and brightness, alpha-bending and compositing, compression of raster 2D graphics. Representation of 3D scenes, visibility, cast shadows, soft shadows, subsurface scattering, lighting models and shading algorithms, recursive ray tracing, physically-based model of light transport (radiometry, imaging equation), path tracing, pre-computed global illumination, real-time global illumination, spherical harmonics-based shading, precomputed radiance transfer. Character animation, skinning, rigging, morphing. Graphics accelerator architecture, data transfer to the GPU, textures and GPU buffers, GPU programming: shaders, basics of OpenGL, GLSL, CUDA and OpenCL. Compression of raster 2D graphics, JPEG standard, video compression.

Recommended courses

Code	Subject	Credits	Winter	Summer
NPGR033	Computer Graphics for Game Development	5	—	2/2 C+Ex
NSWI072	Data Compression Algorithms	3	2/0 Ex	—

3. Artificial intelligence for games

Autonomous agent architectures; agent perception, agent action selection mechanism, agent memory, psychological inspiration. Methods for agent control; symbolic and connectionist reactive planning, hybrid approaches, decision space. If-then rules, scripting, sequential finite state machine, behaviour trees. Path search problem, local navigation rules (Reynold's steerings, VO, RVO, Context steering), pathfinding algorithms (A*, JPS+, goal bounding, RRT, RRT*, LPA*, MPAA*, bidirectional search), spatial awareness (geometry, visibility). Communication and knowledge in multiagent systems, ontologies, speech acts, FIPA-ACL, protocols. Distributed problem solving, cooperation, Nash equilibria, Pareto efficiency, source allocation, auctions. Methods for agent learning; reinforcement learning, basic forms of animal learning. Procedural modeling of state space (forward model) and its search; A*, ABCD, MCTS and UCB, PGS, PGS-II, script space (Kiting, AV, NOK-AV), effective implementation. Procedural content generation method classification, methods used for generation of terrain, visual effects, music, game items, mazes and dungeons. Noise functions; Perlin, Simplex, Worley. Cellular automata, L-Systems, graph and shape grammars. Answer set programming. Wave-function collapse algorithm. Methods for mixed initiative generation.

Recommended courses

Code	Subject	Credits	Winter	Summer
NAIL068	Human-like Artificial Agents	5	—	2/2 C+Ex
NAIL106	Multiagent Systems	5	—	2/2 C+Ex
NAIL122	Artificial Intelligence for Computer Games	3	1/1 C+Ex	—
NAIL123	Procedural Content Generation for Computer Games	3	—	1/1 C+Ex

4. Video games as a social-cultural phenomenon

Theory of game studies; definition of game studies, relationship of game studies to other fields of science, cultural, social and political aspects of video games, definition of video games, differences between video games and other audiovisual media and their implication for research. History of video games; birth of video games, technological and cultural roots of video games, key milestones, media archeology in game studies, convergent evolution. Research methods in game studies; types of research, formal game analysis. Rules of play research; research methods, subjective play experience, gaming communities. Social aspects of video games; positive and negative social aspects of video games, demographic profile of the video games player and their development in time, MMO and research of video games social aspects. Psychological and cognitive aspects of video games; positive and negative psychological aspects of video games, research methods, effects of memory, emotions, attention and motivation on players' gameplay experience, relationship between the violence depicted in video games and aggressive behaviors, effects of short-term and long-term play on development of cognitive abilities, immersion and flow. Serious, educational and pervasive games; definition, procedural rhetoric and its implications for game studios, theoretical foundations of digital game-based learning, advantages and disadvantages of using video games in formal education, video games and their effect on players' attitudes, gamification and its advantages and disadvantages.

Recommended courses

Code	Subject	Credits	Winter	Summer
NCGD005	Game User Experience	3	1/1 C+Ex	—
NAFF003	Introduction to Game Studies	3	0/2 Ex	—
NAFF004	Contemporary Issues in Game Studies	3	—	0/2 Ex

5. Software analysis and architectures

SW development processes, development phases. Business processes and their modeling using BPMN. UML and its use for analysis and design of structure and behavior of SW. Design patterns. SW testing, impact and change analysis. SW project planning, cost estimation, levels of project management. Legal aspects of SW, principal legal environment for IT projects. Types of SW architecture. Modeling and documentation of SW architecture. Classification of SW architecture quality attributes, their description using scenarios and tactics. Service oriented architectures. Algebraic methods, many sorted algebras, initial models. Temporal logic. Formal principles of the UML language. OCL as a specification language, formal base of specification.

Recommended courses

Code	Subject	Credits	Winter	Summer
NSWI130	Software System Architectures	5	2/2 C+Ex	—
NSWI026	Advanced aspects of software engineering	5	—	2/2 C+Ex
NTIN043	Formal Foundations of Software Engineering	5	2/2 C+Ex	—

6. Web technologies

Overview of basic web technologies. Network services for web technologies. Web services. Architecture of client-server applications, server-side and client-side scripting, web frameworks. Database systems in web applications, NoSQL databases, multimedia databases. Indexing and document searching, principles of web search engines. Linked Data, integration of semantic data to web pages. Security of information systems in the Internet environment, authentication, authorization, security models, cryptography basics, data security.

Recommended courses

Code	Subject	Credits	Winter	Summer
NSWI130	Software System Architectures	5	2/2 C+Ex	—
NSWI153	Advanced Programming of Web Applications	5	—	2/2 C+Ex
NSWI145	Web Services	5	—	2/2 C+Ex
NDBI034	Multimedia Retrieval	4	2/1 C+Ex	—
NPRG043	Recommended Programming Practices	5	—	2/2 MC

7. High Performance Computing

The exam for this specialization tests knowledge and skills related to high performance computing systems, as presented in these courses:

Code	Subject	Credits	Winter	Summer
NPRG058	Advanced Programming in Parallel Environment	6	2/2 C+Ex	—
NSWI131	Performance Evaluation of Computer Systems	4	—	2/1 C+Ex

Master of Physics

1 General Information

Study programmes

1 Atmospheric Physics, Meteorology and Climatology
2 Biophysics and Chemical Physics
3 Optics and Optoelectronics
4 Particle and Nuclear physics
5 Physics of Condensed Matter and Materials
6 Surface and Plasma Physics

1 Degree Plans - Atmospheric Physics, Meteorology and Climatology

Coordinated by: Department of Atmospheric Physics
Study programme coordinator: doc. RNDr. Petr Pišoft, Ph.D.

The Atmospheric Physics, Meteorology and Climatology programme gives students knowledge and skills in the field of atmospheric properties and related processes. The programme is unique within Charles University in its comprehensive view of the Earth's atmosphere as a dynamical system in a broad interdisciplinary context. In the Czech Republic more widely, this is the only programme giving a comprehensive education in the field of atmospheric physics, meteorology and climatology. The programme assumes a bachelor's degree in physics, in which students will have acquired basic knowledge of physical principles (mechanics, thermodynamics, electricity and magnetism, optics, and others) as well as a proficiency in the associated mathematical methods. The study programme is primarily focused on acquiring theoretical knowledge in the field of atmospheric physics (hydrodynamics and atmospheric thermodynamics), thereby extending previously acquired expertise in this field. Furthermore, skills necessary for practical as well as scientific activities in the field of atmospheric physics are acquired, especially in the fields of numerical mathematics, mathematical statistics, data processing and visualization. Part of the course aims to prepare graduates for core applications of atmospheric physics, such as weather forecasting, air pollution analysis and climate research (including modelling and research of higher atmospheric layers). Other courses on the programme serve to deepen the student's focus on particular specialized topics or to expand knowledge in areas close to other branches of physics (e.g., electrical, optical and acoustic phenomena in the atmosphere and the oceans). Study on this programme includes preparing and submitting a master's thesis, one purpose of which is to apply the competences acquired on the programme, as well as an ability to cooperate in solving an assigned scientific problem.

Profile of graduates and study aims:

Graduates have a wide range of knowledge and competencies in the whole field of atmospheric physics, meteorology and climatology. Their skills allow for a professional focus on basic and applied research as well as involvement in the commercial sector. Graduates have a broad range of careers, for example, in academia, in research institutes and at universities, as well as in industrial development centres specializing in flow studies. In the business environment they are able to apply expert knowledge of statistical techniques, and in the field of crisis management they can utilize their acquaintance with extreme meteorological phenomena. They can also find employment in a number of economic sectors influenced by atmospheric phenomena such as energetics, transportation and agriculture.

Graduates have an extensive and comprehensive knowledge of atmospheric physics, dynamics and thermodynamics of the atmosphere, atmospheric circulation at all spatial scales, problems of electromagnetic and acoustic waves in an atmospheric environment, the theory of hydrodynamic wave processes, the theory of non-linear dynamic systems, the structure and development of the climate system, and natural and anthropogenic climate change. They are familiar with contemporary methods of remote sensing (meteorological radars, lidars, sodars and satellites). They are able to process extensive and complex meteorological and climatological data files and are closely acquainted with mathematical statistics and the associated IT applications.

1.1 Recommended Course of Study

Prerequisite for this study programme is a bachelor-level knowledge of general physics, hydrodynamics, propagation of acoustic and electromagnetic waves in atmosphere, general climatology, synoptic meteorology and deterministic chaos.

First year

Code	Subject	Credits	Winter	Summer
NMET074	**Atmospheric Dynamics**	6	3/2 C+Ex	—
NMET002	**Boundary Layer Physics**	5	3/1 C+Ex	—
NMET020	**Methods of atmospheric remote sensing**	5	3/1 C+Ex	—
NMAF013	**Methods of Numerical Mathematics I**	3	2/0 Ex	—
NMET036	**Synoptic Meteorology II**	4	3/0 Ex	—
NMET078	**Analysis and interpretation of weather maps and prognostic fields**	6	—	3/2 MC
NMET003	**Physics of Clouds and Precipitation**	4	—	3/0 Ex
NMET010	**Climate change and its causes**	4	—	2/1 C+Ex
NMET067	**Stratosphere**	5	—	2/2 C+Ex
NSZZ023	**Diploma Thesis I**	6	—	0/4 C
NMET024	Dynamical forecast methods	7	—	3/2 C+Ex
NMET009	Regional Climatology and Climatography of the Czech Republic	6	4/0 Ex	—

NMET011	Statistical analysis of complex data	6	2/2 C+Ex	—
NMET075	Climate extremes and their modelling	3	—	2/0 Ex
NMET066	Meteorological Computer Seminar	4	—	0/3 C
NMET079	Methods of atmospheric remote sensing II	3	—	1/1 C+Ex
NMAF014	Methods of Numerical Mathematics II	6	—	2/2 C+Ex
NMET063	Time series analysis methods	5	—	2/1 C+Ex
NMET025	Wave Processes and Energetics of the Atmosphere	4	—	3/0 Ex

Second year

Code	Subject	Credits	Winter	Summer
NMET019	**Atmospheric Chemistry**	5	3/1 Ex	—
NMET061	**Seminar on Projects I**	3	1/1 C	—
NMET062	**Seminar on Projects II**	3	—	1/1 C
NSZZ024	**Diploma Thesis II**	9	0/6 C	—
NSZZ025	**Diploma Thesis III**	15	—	0/10 C
NMET064	Aerosol Engineering	3	2/0 Ex	—
NMET031	Mesosynoptic meteorology	3	2/0 Ex	—
NMET068	Oceans in Climate System	6	2/2 C+Ex	—
NMET005	Emission Propagation in Atmosphere	3	2/0 Ex	—
NMET059	Modelling Techniques for Numerical Weather Forecasting	3	0/2 C	—
NMET032	Atmospheric Turbulence	4	3/0 Ex	—
NMET071	Applied Climatology I	3	2/0 Ex	—
NMET001	Atmospheric electricity	3	—	2/0 Ex
NMET073	Strong convection in the atmosphere	5	—	3/1 C+Ex
NMET072	Applied climatology II	3	—	2/0 Ex

1.2 Obligatory Courses

Code	Subject	Credits	Winter	Summer
NMET074	**Atmospheric Dynamics**	6	3/2 C+Ex	—
NMET002	**Boundary Layer Physics**	5	3/1 C+Ex	—
NMET020	**Methods of atmospheric remote sensing**	5	3/1 C+Ex	—
NMAF013	**Methods of Numerical Mathematics I**	3	2/0 Ex	—
NMET036	**Synoptic Meteorology II**	4	3/0 Ex	—
NMET078	**Analysis and interpretation of weather maps and prognostic fields**	6	—	3/2 MC

NMET003	**Physics of Clouds and Precipitation**	4	—	3/0 Ex
NMET010	**Climate change and its causes**	4	—	2/1 C+Ex
NMET067	**Stratosphere**	5	—	2/2 C+Ex
NMET019	**Atmospheric Chemistry**	5	3/1 Ex	—
NMET061	**Seminar on Projects I**	3	1/1 C	—
NMET062	**Seminar on Projects II**	3	—	1/1 C
NSZZ023	**Diploma Thesis I**	6	—	0/4 C
NSZZ024	**Diploma Thesis II**	9	0/6 C	—
NSZZ025	**Diploma Thesis III**	15	—	0/10 C

1.3 Elective Courses

The student needs to obtain at least 25 credits for courses from the following set.

Code	Subject	Credits	Winter	Summer
NMET024	Dynamical forecast methods	7	—	3/2 C+Ex
NMET009	Regional Climatology and Climatography of the Czech Republic	6	4/0 Ex	—
NMET011	Statistical analysis of complex data	6	2/2 C+Ex	—
NMET075	Climate extremes and their modelling	3	—	2/0 Ex
NMET066	Meteorological Computer Seminar	4	—	0/3 C
NMET079	Methods of atmospheric remote sensing II	3	—	1/1 C+Ex
NMAF014	Methods of Numerical Mathematics II	6	—	2/2 C+Ex
NMET063	Time series analysis methods	5	—	2/1 C+Ex
NMET025	Wave Processes and Energetics of the Atmosphere	4	—	3/0 Ex
NMET064	Aerosol Engineering	3	2/0 Ex	—
NMET031	Mesosynoptic meteorology	3	2/0 Ex	—
NMET068	Oceans in Climate System	6	2/2 C+Ex	—
NMET005	Emission Propagation in Atmosphere	3	2/0 Ex	—
NMET059	Modelling Techniques for Numerical Weather Forecasting	3	0/2 C	—
NMET032	Atmospheric Turbulence	4	3/0 Ex	—
NMET071	Applied Climatology I	3	2/0 Ex	—
NMET001	Atmospheric electricity	3	—	2/0 Ex
NMET073	Strong convection in the atmosphere	5	—	3/1 C+Ex
NMET072	Applied climatology II	3	—	2/0 Ex

1.4 Recommended Optional Courses

Code	Subject	Credits	Winter	Summer
NMET034	*Hydrodynamics*	6	3/1 C+Ex	—
NMET021	*Meteorological Instruments and Observational Methods*	4	3/0 Ex	—
NMET004	*Propagation of Acoustic and Electromagnetic Waves in Atmosphere*	4	3/0 Ex	—
NOFY077	*Introduction to Linux*	3	1/1 MC	—
NMAF026	*Deterministic Chaos*	3	—	2/0 Ex
NOFY078	*Programming and data processing in Python*	4	—	1/2 MC
NMET050	*Statistical data analysis in physics*	6	—	2/2 Ex
NMET035	*Synoptic Meteorology I*	3	—	2/0 Ex
NMET012	*General Climatology*	6	—	3/1 C+Ex

1.5 State Final Exam

Necesary conditions for taking the state final exam

- earning at least 120 credits during the course of study
- passing all compulsory courses
- obtaining at least 25 credits for elective courses
- submission of a completed master's thesis by the submission deadline

Requirements for the oral part of the state final exam

A Common basis

1 Statics and dynamics of the atmosphere

Atmosphere in hydrostatic balance - homogeneous, adiabatic, isothermal atmosphere. Atmospheric vertical stability - parcel method, Brunt-Vaisala frequency, layer method, entrainment, thermal inversion and its causes. Kinematics and dynamics of air flow, effect of surface drag, basic types of air flows (geostrophic, ageostrophic wind and its components, gradient, divergent and non-divergent). Variation of air flow with height, wind shear, thermal wind. Vorticity and circulation - circulation theorem, vorticity equation, potential vorticity, divergence theorem, balance equation and its using. Vertical atmospheric movements and methods of their calculations, Richardson equation, omega equation and its discussion. Convection forecast. Atmospheric energetics, transformations of energy in the atmosphere, available potential energy, wave movements and oscillations in atmosphere.

2 Thermodynamic processes in the atmosphere

Ideal (perfect) gas and real gases, values of thermodynamic state, basic thermodynamic processes (polytropic, isothermic, isobaric, isosteric, adiabatic process), thermodynamic solenoids, thermodynamic work, I. and II. law of thermodynamics, entropy, enthalpy, specific and latent heats, state equations, phase transitions, Clausius-Clapeyron equation, thermodynamic potentials. Thermodynamics of dry, moist and saturated air, dependence of saturated water vapour pressure on temperature, analysis of water phase diagram, characteristics of moisture, reversible adiabatic processes in atmosphere, pseudoadiabatic process, phase changes of water, Gibbs thermodynamic potential and its conservativeness - applications to systems with several components (solutions, Raoult law), dependence of saturated water vapour pressure on curvature of water or ice surface, supercooled droplets, explanation of supercooling.

3 Cloud and precipitation physics

Microstructure and macrostructure of clouds, cloud classification, thermodynamic and dynamic conditions for cloud formation and evolution, warm clouds, mixed phase clouds, cold clouds, nucleation of water vapor, water vapor condensation in the atmosphere, role and mechanisms of acting of the cloud condensation nuclei, diffusional growth and freezing of cloud drops, coalescence of cloud drops, ice nuclei, ice nucleation, supercooled liquid in clouds, primary and secondary ice production in clouds, cloud ice diffusional growth, aggregation, riming, size spectra of cloud and precipitation drops and ice crystals, ice crystal habits, cloud liquid content, precipitation formation, precipitation in stratiform and convective clouds.

4 Boundary layer meteorology

Atmospheric boundary layer. Viscous flow theory, Navier-Stokes equations, dynamic similarity, Reynolds number. Atmospheric turbulence, Reynolds equations of turbulent flow, Reynolds stresses, mixing length, eddy diffusion coefficient, surface layer, spiral layer, vertical profiles of flow in the surface layer, Ekman spiral. Convective boundary layer, stable boundary layer, diurnal cycle of the boundary layer, characteristic profiles of temperature, wind speed and turbulent fluxes, clouds in the boundary layer. Interaction of the boundary layer with the Earth's surface, fluxes of momentum, heat and moisture, radiation and heat budgets of the Earth's surface. Transformations of kinetic energy in the boundary layer, turbulent kinetic energy and its mechanical and buoyant production, isotropic and anisotropic turbulence, spectrum of turbulent kinetic energy. Similarity theory and scaling, Richardson number, Obukhov length, Monin-Obukhov similarity theory, dimensionless vertical profiles of momentum, temperature and moisture. Atmospheric boundary layer in urban areas, flow over mountains. Closure problem, models of the atmospheric boundary layer, large eddy simulation. Methods of observation of the boundary layer, experimental methods for turbulent flow research.

5 Synoptic meteorology and weather phenomena

Horizontal and vertical distribution of meteorological phenomena, daily and annual courses. Air masses - genesis, sorts, transformation, characteristics and weather conditions. Atmospheric fronts - definition, dynamical and kinematic condition, pressure field, types of front, weather condition. Frontogenesis and frontolysis. Pressure systems - barotropic and baroclinic instability. Structure and development of pressure systems, regeneration, pressure and temperature changes, weather conditions in cyclonic and anticyclonic pressure fields, upper level frontal zones, explosive cyclogenesis. Jet streams. Clouds on fronts and inside of air masses, cellular circulation in clouds, structure of storm clouds (Cb), severe convective storms and connected extreme weather phenomena, multicells, supercells, tornadoes. Tropical cyclones. Föhn.

6 Climate and climate system

Climate system, observed state of atmosphere and ocean (temperature, precipitation, salinity), climate definition. Radiative and thermal balance of surface, atmosphere, Earth-atmosphere system (physical laws, solar radiation, long-wave radiation, radiative transfer equation). Greenhouse effect, greenhouse gases in the atmosphere, carbon cycle. Heat transport to lithosphere and hydrosphere. Diurnal and annual cycles of radiative and thermal balance. Influence of active surfaces on radiative and thermal balance. Water balance of atmosphere, continents, oceans. Atmospheric circulation. General circulation of troposphere and stratosphere, trade winds and monsoon circulation, intertropical zone of convergence, local circulation systems. Climate types and their classifications. Basic features of climate in Czechia. Oceanic circulation. Atmosphere-ocean interactions, variability modes, teleconnections. Natural and anthropogenic climate changes, their causes, Milankovitch theory. Sensitivity of the climate system to external and internal influence, feedbacks, global and regional climate models. Methods of statistical analysis of climate variables and fields. Specifics of urban climate.

7 Higher atmospheric layers

The stratosphere and mesosphere, pauses, vertical profiles and horizontal distribution of basic meteorological variables, circulation in the middle atmosphere. Annual cycles of temperature and circulation, polar circulation characteristics, comparison of the Northern and Southern Hemispheres. Sudden stratospheric warmings, classification, evolution of warmings, influence of various forcing factors, impact of the other parts of the atmosphere. Middle atmospheric transport, Brewer-Dobson circulation, formation and basic characteristics, annual cycle, exchange between the troposphere and stratosphere. Radiation processes. Gravity waves, planetary waves, role of wave processes in the middle atmospheric dynamics. Stratospheric ozone, creation and destruction, related chemical processes, role of the halogen hydrocarbons and other chemical families, ozone hole formation and evolution, ozone long-term trends. Impact of volcanic eruptions and volcanic activity.

8 Methods of atmospheric remote sensing

Satellite observation, measurement of meteorological parameters and of atmospheric composition. Meteorological geostationary satellites, polar-orbiting satellites. Spectral bands and channels, their basic characteristics. Reflectivity, transmissivity, emissivity and brightness temperature. Basic spectral characteristics of cloudiness and earth surface. Currently operative satellites, basic principles of satellite images processing, satellite remote sensing of atmospheric columns of gases (ozone, NO2, SO2, formaldehyde, CO etc.) and aerosols, aerosol optical properties. Radar measurement. Principle of radar function and use of radar in meteorology, radio locator reflectivity, Doppler radar data, polarimetric measurement. Radar equation, microwave refraction, attenuation, surface reflection. Radar precipitation estimates, combination with rain gauge data. Methods of scanning and data processing. Interpretation of radar measurements, radar characteristics of convective and stratiform cloudiness. Radar network in Czechia. Lightning detection, time of arrival method, direct finding method. Lidar measurement, surface lidars, airborne lidars. Sodar measurement, acoustic waves dispersion in atmosphere. GPS data and its usage, radio occultation (RO) method.

B Specialization

Students will choose two of the following four topics.

1 Atmospheric chemistry and air quality

Composition of the atmosphere, fundamentals of chemical kinetics, introduction to tropospheric and stratospheric chemistry, chemistry of the background atmosphere, chemistry of oxides of nitrogen, chemistry of hydrocarbons - alkanes, alkenes, carbonyl chemistry, alkohols, (polycyclic) aromatic hydrocarbons, organic substances containing nitrogen, halogens, ozone depleting substances, radicals and their role in atmospheric chemistry, anthropogenic and biogenic volatile organic compounds and their reactions, atmospheric oxidation of sulfur and nitrogen, aerosol forming processes, primary and secondary aerosol, aerosol size spectra. Typical anthropogenic pollutants and their sources, emissions vs. concentrations, emission databases, atmospheric diffusion of pollutants, dry- and wet deposition. Typification of meteorological conditions for air quality protection, air pollution monitoring, types of models for atmospheric chemistry and transport of pollutants, Lagrangian and Eulerian models, Gaussian models, puff models, dispersion and receptor modelling, physical modelling, marker modelling.

2 Climate models, their types, structure, and applications

Climate model types and their applications. Structure of energy models and radiative-convective models, parametrization of inter-latitudinal flows and radiative processes, feedbacks. Global climate models, Earth system models (ESM). Statistical downscaling methods and regional climate models, their applications. Model structure, parametrization of basic physical processes, interpretation of outputs. Model output validation. Emission scenarios. Climate change scenarios construction. Uncertainty sources in climate model outputs. Multimodel and ensemble simulations and projections.

3 Methods of numerical modelling of the atmosphere

Formulations of equations of atmospheric models, simplifying approximations, inclusion of wave motions, hydrostatic approximation, shallow water equations, formulation of initial value and boundary value problems (global model, limited area model), model horizontal and vertical coordinates, input data preparation, objective analysis and data assimilation, initializations, normal modes, spatial discretization methods and temporal integration methods of meteorological models, stability and convergence of numerical schemes, parametrizations of physical processes. Synoptic interpretation of model outputs, main factors limiting successful forecast of meteorological fields, predictability of atmospheric processes, theoretical and practical limits of predictability.

4Electromagnetic and acoustic waves in the atmosphere, atmospheric electricity

Maxwell equations and their application to the atmosphere, wave equations, refraction, reflection and attenuation of electromagnetic waves in the atmosphere, radar equation, Rayleigh scattering, Mie scattering, astronomical refraction, lower, upper and lateral mirror, fata morgana, depression and elevation of horizon, deformation and lamination of solar disc, green flash, colours of sky, twilight, twilight phenomena, rainbows, corona, glory, halo phenomena, visibility, polarization of skylight. Propagation of sound in the atmosphere, sound speed, acoustic refraction index, acoustic shadows, anomalous audibility, shock waves, sound attenuation in the atmosphere. Electrical field in the atmosphere, Earth spherical condensator, ionization of air, electrical conductivity of air, vertical electrical currents, cloud and thunderstorm electricity, electrical properties of clouds, electrical charge in precipitation, electrical structure of Cumulonimbus, theories of cloud electricity production, point discharges, lightnights, atmospherics, TLE, transport of electrical charge in the atmosphere.

2 Degree Plans - Biophysics and Chemical Physics

Coordinated by: Institute of Physics Charles University
Study programme coordinator: prof. RNDr. Marek Procházka, Ph.D.

The focus of this field lies at the interface of physics, biology and chemistry. The study programme builds on a basic education in physics, deepening the focus on areas of theoretical and experimental physics important for the description and research of molecules, biopolymers, supramolecular systems and biological objects. The graduate will gain knowledge of quantum theory and the statistical physics of molecules and molecular systems, experimental methods of biophysics and chemical physics, especially optical and other spectroscopic methods, structural analysis and imaging techniques. Students choose one of two specializations: theoretical or experimental biophysics and chemical physics. In the theoretical specialization they will gain deeper knowledge in the field of quantum chemistry, molecular dynamics or advanced theoretical spectroscopy; in the experimental specialization, in the field of biochemistry and molecular biology, biophysics of photosynthesis or structural methods.

Profile of graduates and study aims:

The graduate knows quantum theory and the statistical physics of molecules and molecular systems, experimental methods of biophysics and chemical physics, especially optical and other spectroscopic methods, structural analysis and imaging techniques. Graduates of the theoretical specialization have deeper knowledge in the field of quantum chemistry, molecular dynamics or advanced theoretical spectroscopy. Graduates of the experimental specialization have deeper knowledge in the field of biochemistry and molecular biology, biophysics of photosynthesis or structural methods. Through regular seminars, master's theses, and thematically focused lectures, graduates have gained an idea of problems current in various fields and of methods of scientific work. They are proficient in communicating professional knowledge in the form of presentations and written texts, also in English. Some graduates can expect to pursue a career as a researcher. The acquired education also gives graduates employment opportunities in interdisciplinary teams dealing with physics, biology, chemistry, medicine, materials research, bio- and nano-technologies or pharmacy.

2.1 Recommended Course of Study

The field offers students two specializations - experimental and theoretical. Students usually select a specialization after the end of the first semester (first year of studies, winter semester). Until then, the courses of study in both specializations are the same.

Within each specialization, students have the opportunity to narrow the focus of their studies, which will be reflected in the choice of questions for the final state examination. Students choose two thematic areas (from three possible) and within these courses from the compulsory and optional courses of set I. In the experimental specialization, these include: 1. Biochemistry and molecular biology (courses NBCM012, NBCM008), 2. Optical spectroscopy and biophysics of photosynthesis (courses NBCM179, NBCM088) and 3. Structural methods (courses NBCM098, NBCM112). In the theoretical specialization, these include: 1. Quantum chemistry (courses NBCM121, NBCM122, NBCM155), 2. Molecular dynamics and statistics (courses NBCM346, NBCM100, NFPL004) and 3. Advanced theoretical spectroscopy (courses NBCM154, NBCM027, NOOE119).

Prerequisite for this study programme is a bachelor-level knowledge of quantum theory and general chemistry.

Specialization: Experimental biophysics and chemical physics

Compulsory and elective courses – set I (25 credits)

First year

Code	Subject	Credits	Winter	Summer
NBCM010	**Bioorganic chemistry**	5	2/1 C+Ex	—
NBCM177	**Experimental methods of biophysics and chemical physics I**	6	4/0 Ex	—
NBCM160	**Classical and quantum statistical physics of molecular systems**	4	3/0 Ex	—
NBCM039	**Quantum Theory of Molecules**	7	3/2 C+Ex	—
NBCM095	**Practical Course in Experimental Methods of Biophysics and Chemical Physics I**	7	0/5 MC	—
NSZZ023	**Diploma Thesis I**	6	—	0/4 C
NBCM178	**Experimental methods of biophysics and chemical physics II**	3	—	2/0 Ex
NBCM088	Biophysics of Photosynthesis	3	—	2/0 Ex
NBCM012	Biochemistry	3	—	2/0 Ex
NBCM112	Magnetic Resonance Methods in Biophysics	4	—	3/0 Ex
NBCM179	Advanced methods of optical spectroscopy	4	—	3/0 Ex
NBCM103	Practical Course in Experimental Methods of Biophysics and Chemical Physics II	7	—	0/5 MC

Second year

Code	Subject	Credits	Winter	Summer
NSZZ024	**Diploma Thesis II**	9	0/6 C	—
NBCM175	**Seminar of biophysics and chemical physics I**	3	0/2 C	—
NSZZ025	**Diploma Thesis III**	15	—	0/10 C
NBCM176	**Seminar of biophysics and chemical physics II**	3	—	0/2 C

NBCM008	Molecular and Cell Biology for Biophysicist	4	3/0 Ex	—
NBCM098	X-ray and Electron Structure Analysis of Biomolecules and Macromolecules	3	2/0 Ex	—
NBCM165	Theoretical bases of molecular spectroscopy	3	2/0 Ex	—

Elective Courses – set II (15 credits)

Code	Subject	Credits	Winter	Summer
NBCM101	Detection and Spectroscopy of Single Molecules	3	2/0 Ex	—
NBCM033	Physical Principles of Photosynthesis	3	2/0 Ex	—
NFPL185	Advanced High Resolution NMR Spectroscopy	5	2/1 C+Ex	—
NBCM158	Practical aspects of experimental data treatment	3	1/1 Ex	—
NBCM014	Structure, Dynamics and Functions of Biomembranes	3	2/0 Ex	—
NBCM023	Importance and Functions of Metal Ions in Biological Systems	3	2/0 Ex	—
NBCM102	Fundamentals of Classical Radiometry and Photometry	3	2/0 Ex	—
NBCM026	Experimental Technology in Molecular Spectroscopy	3	—	2/0 Ex
NFPL179	Quantum Description of NMR	5	—	2/1 C+Ex
NBCM114	Optical Microscopy and Selected Imaging Techniques in Biophysics	3	—	2/0 Ex
NOOE012	Scattering Methods in Optical Spectroscopy	3	—	2/0 Ex
NBCM097	Surface-Enhanced Raman Spectroscopy	3	—	2/0 Ex
NBCM172	Two-dimensional electronic spectroscopy	3	1/1 C+Ex	1/1 C+Ex
NBCM316	Computer Modelling of Biomolecules	4	1/2 C+Ex	1/2 C+Ex
NBCM018	One-week Practical Course in Biochemistry	4	0/3 C	0/3 C

Recommended optional courses

Code	Subject	Credits	Winter	Summer
NBCM121	*Ab Initio Methods and Density Functional Theory I*	5	—	2/1 C+Ex

NBCM122	*Ab Initio Methods and Density Functional Theory II*	3	2/1 C+Ex	—
NBCM173	*Ab-initio methods for periodic systems*	3	2/0 Ex	—
NBCM307	*Astrobiology*	4	3/0 Ex	—
NBCM024	*Yeast Biology*	3	—	2/0 Ex
NBCM150	*Physical observation of nano-objects*	5	2/1 C+Ex	2/1 C+Ex
NAFY018	*Chemistry for Physicists*	4	2/1 C+Ex	—
NBCM106	*Chemistry for Physicists II — Analytical Chemistry*	6	—	2/2 C+Ex
NBCM156	*Chiroptic spectroscopy*	3	—	2/0 Ex
NBCM154	*Quantum electrodynamics*	3	—	2/0 Ex
NBCM134	*Quantum Theory of Resonances*	3	—	2/0 Ex
NBCM051	*Molecular Dynamics and Monte Carlo Methods*	5	2/1 C+Ex	—
NBCM346	*Molecular dynamics I*	5	—	2/1 C+Ex
NBCM347	*Molecular dynamics II*	5	2/1 C+Ex	—
NBCM181	*Molecular dynamics — calculations of free energy*	3	1/2 MC	1/2 MC
NBCM055	*Molecular Simulations for solving of material structure*	5	2/1 C+Ex	2/1 C+Ex
NBCM149	*Nanotechnology in biology*	3	2/0 C	2/0 C
NOOE119	*Nonlinear Optical Spectroscopy*	3	—	2/0 Ex
NOOE219	*Exercises in nonlinear optical spectroscopy*	1	—	0/1 C
NBCM351	*Proseminar of Quantum Chemistry*	4	1/2 C	1/2 C
NFPL004	*Nonequilibrium Statistical Physics and Thermodynamics*	3	2/0 Ex	—
NBCM305	*Optical Sensors*	3	2/0 Ex	—
NBCM099	*Practical Exercises in Quantum Theory of Molecules I*	4	—	0/3 C
NBCM116	*Practical Exercises in Quantum Theory of Molecules II*	4	0/3 C	—
NAFY080	*Preparation of Biological Samples*	3	—	2/0 Ex
NOOE015	*Seminar*	2	—	0/1 C
NFPL186	*Seminar on High Resolution NMR Spectroscopy*	3	0/2 C	0/2 C
NBCM027	*Symmetry of Molecules*	5	2/1 C+Ex	—
NFPL003	*Synthetic Problems of Quantum Theory*	3	—	2/0 C
NBCM115	*Scientific Photography and Related Imaging Techniques*	3	1/1 Ex	—
NPRF005	*UNIX and LINUX for Physicists*	3	2/0 C	—
NBCM159	*Introduction to Computer Control of Experiment*	4	—	1/2 MC

NBCM308	*Introduction to Protein Structure Studies*	3	—	2/0 Ex
NBCM100	*Computational Experiments in Molecular Theory I*	4	—	0/3 MC
NBCM125	*Computational Experiments in Molecular Theory II*	6	—	0/4 MC
NBCM041	*Fundamentals of Energy Transfer in Molecular Systems I*	3	2/0 Ex	—

Specialization: Theoretical biophysics and chemical physics

Compulsory and elective courses – set I (25 credits)

First year

Code	Subject	Credits	Winter	Summer
NBCM010	**Bioorganic chemistry**	5	2/1 C+Ex	—
NBCM177	**Experimental methods of biophysics and chemical physics I**	6	4/0 Ex	—
NBCM160	**Classical and quantum statistical physics of molecular systems**	4	3/0 Ex	—
NBCM039	**Quantum Theory of Molecules**	7	3/2 C+Ex	—
NBCM095	**Practical Course in Experimental Methods of Biophysics and Chemical Physics I**	7	0/5 MC	—
NSZZ023	**Diploma Thesis I**	6	—	0/4 C
NBCM178	**Experimental methods of biophysics and chemical physics II**	3	—	2/0 Ex
NBCM121	Ab Initio Methods and Density Functional Theory I	5	—	2/1 C+Ex
NBCM154	Quantum electrodynamics	3	—	2/0 Ex
NBCM346	Molecular dynamics I	5	—	2/1 C+Ex
NBCM100	Computational Experiments in Molecular Theory I	4	—	0/3 MC

Second year

Code	Subject	Credits	Winter	Summer
NSZZ024	**Diploma Thesis II**	9	0/6 C	—
NBCM175	**Seminar of biophysics and chemical physics I**	3	0/2 C	—
NSZZ025	**Diploma Thesis III**	15	—	0/10 C
NBCM176	**Seminar of biophysics and chemical physics II**	3	—	0/2 C

NBCM122	Ab Initio Methods and Density Functional Theory II	3	2/1 C+Ex	—
NBCM155	Field theory methods in the theory of many particles	3	2/0 Ex	—
NFPL004	Nonequilibrium Statistical Physics and Thermodynamics	3	2/0 Ex	—
NBCM027	Symmetry of Molecules	5	2/1 C+Ex	—
NBCM165	Theoretical bases of molecular spectroscopy	3	2/0 Ex	—
NOOE119	Nonlinear Optical Spectroscopy	3	—	2/0 Ex

Elective Courses – set II (15 credits)

Code	Subject	Credits	Winter	Summer
NBCM067	Quantum Optics I	5	2/1 C+Ex	—
NBCM347	Molecular dynamics II	5	2/1 C+Ex	—
NBCM131	Advanced Methods in Molecular Dynamics	3	2/0 Ex	—
NBCM041	Fundamentals of Energy Transfer in Molecular Systems I	3	2/0 Ex	—
NBCM093	Quantum Optics II	5	—	2/1 C+Ex
NBCM134	Quantum Theory of Resonances	3	—	2/0 Ex
NBCM099	Practical Exercises in Quantum Theory of Molecules I	4	—	0/3 C
NBCM116	Practical Exercises in Quantum Theory of Molecules II	4	0/3 C	—
NBCM125	Computational Experiments in Molecular Theory II	6	—	0/4 MC
NBCM055	Molecular Simulations for solving of material structure	5	2/1 C+Ex	2/1 C+Ex
NBCM180	Theoretical seminar of biophysics and chemical physics	4	0/1 C	0/1 C

Recommended optional courses

Code	Subject	Credits	Winter	Summer
NBCM173	*Ab-initio methods for periodic systems*	3	2/0 Ex	—
NBCM307	*Astrobiology*	4	3/0 Ex	—
NBCM184	*Asymptotic Methods in Physics*	5	2/1 C+Ex	—
NBCM088	*Biophysics of Photosynthesis*	3	—	2/0 Ex
NBCM012	*Biochemistry*	3	—	2/0 Ex
NBCM101	*Detection and Spectroscopy of Single Molecules*	3	2/0 Ex	—
NBCM172	*Two-dimensional electronic spectroscopy*	3	1/1 C+Ex	1/1 C+Ex

NBCM026	*Experimental Technology in Molecular Spectroscopy*	3	—	2/0 Ex
NBCM150	*Physical observation of nano-objects*	5	2/1 C+Ex	2/1 C+Ex
NBCM033	*Physical Principles of Photosynthesis*	3	2/0 Ex	—
NBCM156	*Chiroptic spectroscopy*	3	—	2/0 Ex
NBCM067	*Quantum Optics I*	5	2/1 C+Ex	—
NOOE219	*Exercises in nonlinear optical spectroscopy*	1	—	0/1 C
NBCM351	*Proseminar of Quantum Chemistry*	4	1/2 C	1/2 C
NFPL179	*Quantum Description of NMR*	5	—	2/1 C+Ex
NBCM112	*Magnetic Resonance Methods in Biophysics*	4	—	3/0 Ex
NBCM051	*Molecular Dynamics and Monte Carlo Methods*	5	2/1 C+Ex	—
NBCM008	*Molecular and Cell Biology for Biophysicist*	4	3/0 Ex	—
NBCM181	*Molecular dynamics — calculations of free energy*	3	1/2 MC	1/2 MC
NBCM114	*Optical Microscopy and Selected Imaging Techniques in Biophysics*	3	—	2/0 Ex
NBCM316	*Computer Modelling of Biomolecules*	4	1/2 C+Ex	1/2 C+Ex
NTMF002	*Advanced Quantum Theory*	6	3/1 C+Ex	—
NFPL185	*Advanced High Resolution NMR Spectroscopy*	5	2/1 C+Ex	—
NBCM179	*Advanced methods of optical spectroscopy*	4	—	3/0 Ex
NBCM158	*Practical aspects of experimental data treatment*	3	1/1 Ex	—
NBCM103	*Practical Course in Experimental Methods of Biophysics and Chemical Physics II*	7	—	0/5 MC
NBCM098	*X-ray and Electron Structure Analysis of Biomolecules and Macromolecules*	3	2/0 Ex	—
NOOE012	*Scattering Methods in Optical Spectroscopy*	3	—	2/0 Ex
NOOE015	*Seminar*	2	—	0/1 C
NFPL186	*Seminar on High Resolution NMR Spectroscopy*	3	0/2 C	0/2 C
NFPL003	*Synthetic Problems of Quantum Theory*	3	—	2/0 C
NPRF005	*UNIX and LINUX for Physicists*	3	2/0 C	—
NBCM159	*Introduction to Computer Control of Experiment*	4	—	1/2 MC

NBCM308	*Introduction to Protein Structure Studies*	3	—	2/0 Ex
NBCM115	*Scientific Photography and Related Imaging Techniques*	3	1/1 Ex	—
NBCM102	*Fundamentals of Classical Radiometry and Photometry*	3	2/0 Ex	—
NBCM042	*Fundamentals of Energy Transfer in Molecular Systems II*	3	—	2/0 Ex

2.2 State Final Exam

Necesary conditions for taking the state final exam

– earning at least 120 credits during the course of the study
– passing all compulsory courses
– obtaining at least 25 credits for elective courses from the set I
– obtaining at least 15 credits for elective courses from the set II
– submission of a completed master's thesis by the submission deadline

Requirements for the oral part of the state final exam

A Common requirements

1 Quantum theory and statistical physics of molecules and molecular systems (one question in the state exam)

– Antisymmetry of wave function, exchange interaction.
– Born - Oppenheimer and adiabatic approximation.
– Hydrogen molecule. Atomic and molecular orbitals.
– LCAO method and valence bond method, classification of electron levels, Hückel method.
– One-particle approximation, Hartree and Hartree - Fock equations, Roothaan equations.
– Fundamentals of density functional theory, Hohenberg-Kohn theorems.
– Introduction to methods of configuration interaction, coupled clusters and perturbation theory, basic equations and properties, Brillouin theorem.
– Pauli and Dirac equations. Spin-orbital and spin-spin interaction.
– Orbital and spin magnetic moment and their interactions with external fields.
– Quantization of electromagnetic field, interaction of electromagnetic radiation with molecules. Fermi's golden rule.
– Absorption, stimulated and spontaneous emission. Dipole approximation, selection rules.
– Force fields in molecular systems.
– Standard statistical ensembles and distributions, ergodic theorem.
– Monte Carlo method.
– Classical molecular dynamics.
– Liouville equation.
– Density matrix. Wigner density.
– Standard quantum statistical distributions.
– Evolution of the density matrix (Liouville-von Neumann equation).

– Quantum master equation, reduced densities.

2 Experimental methods of biophysics and chemical physics (one question in the state exam)

– Sources, detectors and spectrum analyzers in optical spectroscopy.
– Interaction of optical radiation with an isolated molecule. Selection rules for electronic, vibrational and rotational optical transitions.
– Methods and applications of electron absorption spectroscopy. Excitation and probing method.
– Methods and applications of vibrational absorption spectroscopy.
– Methods of elastic, dynamic and Brillouin scattering and their applications.
– Raman scattering, measurement methods and their applications.
– Use of polarized radiation and its analysis in optical spectroscopy. Linear and circular dichroism, emission anisotropy.
– Principles and basic concepts of luminescence (types of luminescence, Jablonsky diagram, kinetics, quantum yield, lifetimes, Franck-Condon principle).
– Influence of intermolecular interactions on luminescence parameters (environmental influence, resonant energy transfer, emission quenching).
– Single-molecular spectroscopy. Influence of interaction with the environment on the shape of the spectral line.
– Measurement of stationary and time-resolved luminescence.
– Scattering and diffraction of X-rays, electrons and neutrons.
– Principles of basic diffraction methods. Symmetry and structure of crystals and their determination from the diffraction pattern.
– Electron microscopy, atomic force microscopy and scanning tunneling microscopy.
– Mass spectrometry.
– Nuclear magnetic resonance (NMR): principle, experimental setup, excitation and signal detection, basic pulse sequence.
– High resolution NMR of organic substances in liquids: interpretation of spectra.
– Electron paramagnetic resonance: principle, experimental setup, application.
– Separation methods (centrifugation, chromatography, electrophoresis).

B Specialization Experimental biophysics and chemical physics

The third question of the state exam is chosen from two thematic areas, which the student chooses according to his focus.

1 Biochemistry and molecular biology

– Composition and structure of basic biomolecules (nucleic acids, proteins, carbohydrates).
– Glycolysis and glycolytic reactions. Anaerobic degradation of sugars. Cori cycle.
– Aerobic degradation of sugars. Formation of acetylcoenzyme A.
– The citrate cycle and its amorphous nature. Oxidative phosphorylation.
– Biological membranes, selective permeability of biological membranes, types of transport through the biological membrane.
– Structure of bacterial and eukaryotic cells, cell division, cell cycle.
– DNA arrangement in cells, structure and function of chromosomes, chromatin and nucleosomes, centromere and telomere functions, histones, epigenetic inheritance and prions.

- Genetic information processing, DNA replication, RNA transcription and modification, RNA world, prokaryotic and eukaryotic translation.
- Basic principles of gene expression regulation, prokaryotic and eukaryotic transcription initiation regulation, gene silencing.
- Mutations and mutagenesis, DNA damage and repair of damaged DNA, correction of errors caused by DNA replication.
- Methods of studying DNA and gene expression, genetic engineering, fluorescent proteins.

2 Optical spectroscopy and biophysics of photosynthesis

- Fluorescent labels and probes, fluorescent proteins, protein fluorescence.
- Nonlinear methods of Raman scattering (HRS, SRS, CARS), Raman optical activity (ROA).
- Advanced techniques of Raman spectroscopy (SERS, CRM, DCDR).
- Generation and characterization of femtosecond pulses. Fundamentals of 2DES spectroscopy.
- Nonlinear optical phenomena and their applications in optical spectroscopy.
- High spectral resolution methods. Low temperature spectroscopy.
- Transmission and quenching of excitation in photosynthetic antennas.
- Charge distribution and transfer in low- and high-potential reaction centers.
- Electron transfer through the photosynthetic membrane, phosphorylation, comparison with the respiratory membrane.
- Carbon fixation in photosynthesis.
- Biophysical methods of investigation and measurement of photosynthesis (variable fluorescence, gasometry, photoacoustic spectroscopy).

3 Structural methods

- Temperature oscillations and their influence on diffraction recording. Patterson's function and its use in solving crystal structures.
- Methods for solving the phase problem of structural analysis.
- Structural factor and Friedel's law. Preferred orientation of crystallites - texture.
- Comparison, construction and use of transmission and scanning electron microscopes.
- Principles of sample preparation for TEM and SEM. Mechanism of image formation in TEM and SEM
- Electric and magnetic moments of atomic nuclei, energy in electric and magnetic fields, the phenomenon of nuclear magnetic resonance (NMR). Nuclear paramagnetism, relaxation processes.
- High resolution NMR spectroscopy in liquid and solid phase: spin Hamiltonian, types of interactions and their manifestations in spectra, high resolution methods in solid phase.
- One- and multidimensional pulse NMR: concept, basic pulse sequences, use of coherent polarization transfer and nuclear Overhauser effect.
- MR imaging: instrumentation, the principle of achieving spatial resolution, methods of contrast, special applications (angiography, fMRI, MRI spectroscopy).
- Electron spin (paramagnetic) resonance: continuous and pulse methodology of experiment, spin Hamiltonian, interactions and their manifestations in spectra.

B Specialization Theoretical biophysics and chemical physics

The third question of the state exam is chosen from two thematic areas, which the student chooses according to his focus.

1 Quantum chemistry

- Comparison of restricted and unrestricted Hartree-Fock equations and their properties.
- Configuration interaction methods, formulation and characteristics.
- Application of perturbation theory to the calculation of correlation energy, Møller-Plesset method.
- Coupled cluster method, excitation operators, equations and basic properties.
- Conceptual density functional theory - chemical potential, hardness and softness of electron density, Fukui function; time-dependent theory.
- Weak intermolecular interactions; multipole approximation.

2 Molecular dynamics and statistics

- Numerical propagators derived from the Liouville operator.
- Algorithms for pressure and temperature control. Fixation and restriction of degrees of freedom.
- Non-equilibrium molecular dynamics.
- Molecular mechanics, parameterization of force fields.
- Methods of molecular simulations – accounting for non-binding interactions, analysis of trajectories.
- Stochastic processes (Langevin dynamics, normal and anomalous diffusion).
- Stochastic quantum dynamics.
- Entropy in nonequilibrium processes (Boltzmann H-theorem, Jarzynski and fluctuation theorems).

3 Advanced theoretical spectroscopy

- Symmetry in quantum mechanics (quantum numbers, block diagonalization of Hamiltonian).
- Symmetry in the spectroscopy of atoms and molecules (selection rules, allowed and forbidden transitions, reduction of symmetry in external electromagnetic fields).
- Scattering of photons by atomic systems (Rayleigh, Raman, resonant and Thomson scattering).
- Radiative correction to atomic spectra (Lamb shift, self energy of electron and photon).
- Absorption line-shape (linear response theory, bath correlation function).
- Perturbation theory for time-resolved nonlinear spectroscopy (pump probe method, photon echo).

3 Degree Plans - Optics and Optoelectronics

Coordinated by: Department of Chemical Physics and Optics
Study programme coordinator: prof. RNDr. Petr Malý, DrSc.

This programme is offered to students who want to gain a broader physical perspective and detailed knowledge as well as the practical skills needed for scientific and research activities in the field of optics and optolelectronics. The course prepares students for both independent creative activity and teamwork. The broader overview obtained also serves as preparation for work in interdisciplinary areas at the interface between physics, biology and technical fields. Emphasis is placed on high professionalism in optics and optoelectronics supported by a sound knowledge of computer technology. The student chooses one of two specializations according to his/her interest and the topic of his/her master's thesis. The specialization 'Quantum and nonlinear optics' focuses mainly on the properties of optical fields within classical and quantum optics, on nonlinear optical phenomena and on methods of laser spectroscopy. The specialization 'Optoelectronics and photonics' deals in detail with the interaction of light with solids, with light detection, and with semiconductor technology for optoelectronics and photonics applications. Part of the study plan in both specializations are practicals, conducted in laboratories with world-class facilities, which ensure the competencies of graduates in the field of experimental research, optical spectroscopy, applied optics, optoelectronics and spintronics. Elective courses cover emerging fields such as opto-spintronics, physics for metamaterials and terahertz spectroscopy. The extension of optics into a number of fields (physics, biology, chemistry, and medicine) and its ever-increasing application in everyday life increase the adaptability of graduates and the possibilities for them to continue in scientific research or practice. Graduates are fully prepared for further doctoral studies in the Czech Republic and abroad.

Profile of graduates and study aims:

The graduate has deep theoretical and experimental knowledge of classical and quantum optics and optoelectronics, and is proficient in mathematical modelling of physical processes in optics and optoelectronics. He/she is able to apply this knowledge and these skills in research and scientific activities in the fields of optics, optoelectronics, spintronics, photonics, laser physics, statistical and coherence optics, nonlinear optics, optical communication and information processing, instrumental optics, and in many fields where optics or optical spectroscopy is used (biology, chemistry, medicine). An advanced education in physics combined with the acquisition of skills in the field of computer programming, information technology and the organization of team scientific work increases the possibilities of employment at universities and scientific institutes as well as in industry. The graduate is able to communicate professionally in English and has experience with the preparation and design of grant projects and the organization of scientific work. He/she is ready for further doctoral studies or scientific and pedagogical activities at universities and scientific institutes in the Czech Republic and abroad. Graduates can also be employed as research and development workers or managers in private companies and institutions.

3.1 Recommended Course of Study

Prerequisite for this study programme is a bachelor-level knowledge of wave optics and the fundamentals of optical spectroscopy.

Compulsory and elective courses

The student chooses one of two specializations: Quantum and nonlinear optics, Optoelectronics and photonics. Due to the different requirements for the oral part of the final state examination, it is recommended to choose courses of the profiling basis within the elective courses as follows: for the specialization Quantum and Nonlinear Optics, the courses Quantum Optics I, Quantum Optics II, Integrated and fibre optics; and for the specialization Optoelectronics and photonics, the courses Physics of Semiconductors for optoelectronics II, Physics of Semiconductors for optoelectronics III, Electron transport in Quantum Systems.

First year

Code	Subject	Credits	Winter	Summer
NOOE002	**Semiconductor Physics for Optoelectronics I**	3	2/0 Ex	—
NOOE003	**Materials and Technology in Optoelectronics**	3	2/0 Ex	—
NOOE046	**Special Practical Course in Optics and Optoelectronics I**	6	0/4 MC	—
NFPL182	**Solid State Theory**	9	4/2 C+Ex	—
NOOE027	**Introduction to Quantum and Nonlinear Optics I**	6	3/1 C+Ex	—
NSZZ023	**Diploma Thesis I**	6	—	0/4 C
NOOE016	**Special Practical Course in Optics and Optoelectronics II**	6	—	0/4 MC
NOOE072	**Theory of spatial symmetry in systems for optics**	3	—	2/0 Ex
NOOE028	**Introduction to Quantum and Nonlinear Optics II**	6	—	3/1 C+Ex
NBCM067	Quantum Optics I [1]	5	2/1 C+Ex	—
NBCM093	Quantum Optics II [1]	5	—	2/1 C+Ex
NBCM096	Electron Transport in Quantum Systems [2]	5	—	2/1 C+Ex
NOOE008	Semiconductor Physics for Optoelectronics II [2]	3	—	2/0 Ex

[1] Recommended for specialization Quantum and Nonlinear Optics.
[2] Recommended for specialization Optoelectronics and Photonics.

Second year

Code	Subject	Credits	Winter	Summer
NSZZ024	**Diploma Thesis II**	9	0/6 C	—
NOOE061	**Nonlinear Optics of Semiconductor Nanostructures**	5	2/1 C+Ex	—
NSZZ025	**Diploma Thesis III**	15	—	0/10 C
NOOE005	Semiconductor Physics for Optoelectronics III [2]	5	2/1 C+Ex	—

NOOE007	Integrated and Fibre Optics [1]	3	2/0 Ex	—
NOOE034	Laser Theory	3	2/0 Ex	—
NOOE026	Ultrashort Laser Pulses	3	2/0 Ex	—
NOOE033	Special Seminar on Quantum and Nonlinear Optics [1]	3	0/2 C	0/2 C
NOOE010	Special Seminar on Optoelectronics [2]	3	0/2 C	0/2 C

[1] Recommended for specialization Quantum and Nonlinear Optics.
[2] Recommended for specialization Optoelectronics and Photonics.

3.2 Obligatory Courses

Code	Subject	Credits	Winter	Summer
NOOE002	**Semiconductor Physics for Optoelectronics I**	3	2/0 Ex	—
NOOE003	**Materials and Technology in Optoelectronics**	3	2/0 Ex	—
NOOE046	**Special Practical Course in Optics and Optoelectronics I**	6	0/4 MC	—
NFPL182	**Solid State Theory**	9	4/2 C+Ex	—
NOOE027	**Introduction to Quantum and Nonlinear Optics I**	6	3/1 C+Ex	—
NSZZ023	**Diploma Thesis I**	6	—	0/4 C
NOOE016	**Special Practical Course in Optics and Optoelectronics II**	6	—	0/4 MC
NOOE072	**Theory of spatial symmetry in systems for optics**	3	—	2/0 Ex
NOOE028	**Introduction to Quantum and Nonlinear Optics II**	6	—	3/1 C+Ex
NSZZ024	**Diploma Thesis II**	9	0/6 C	—
NOOE061	**Nonlinear Optics of Semiconductor Nanostructures**	5	2/1 C+Ex	—
NSZZ025	**Diploma Thesis III**	15	—	0/10 C

3.3 Elective Courses

The student needs to obtain at least 31 credits for courses from the following set.

Code	Subject	Credits	Winter	Summer
NBCM067	Quantum Optics I	5	2/1 C+Ex	—
NBCM096	Electron Transport in Quantum Systems	5	—	2/1 C+Ex
NOOE008	Semiconductor Physics for Optoelectronics II	3	—	2/0 Ex
NBCM093	Quantum Optics II	5	—	2/1 C+Ex
NOOE005	Semiconductor Physics for Optoelectronics III	5	2/1 C+Ex	—
NOOE007	Integrated and Fibre Optics	3	2/0 Ex	—

NOOE034	Laser Theory	3	2/0 Ex	—
NOOE026	Ultrashort Laser Pulses	3	2/0 Ex	—
NOOE033	Special Seminar on Quantum and Nonlinear Optics	3	0/2 C	0/2 C
NOOE010	Special Seminar on Optoelectronics	3	0/2 C	0/2 C
NOOE035	Luminescence Spectroscopy of Semiconductors	3	2/0 Ex	—
NOOE029	Microcavities	3	2/0 Ex	—
NOOE127	Nanooptics	3	2/0 Ex	—
NOOE123	Optics of periodic structures for photonics	3	2/0 Ex	—
NOOE120	Optical Spectroscopy in Spintronics	3	—	2/0 Ex
NOOE025	Ultrafast laser spectroscopy	3	2/0 Ex	—
NOOE132	Magnetism in Condensed Matter	5	2/1 C+Ex	—

3.4 Recommended Optional Courses

Code	Subject	Credits	Winter	Summer
NBCM101	*Detection and Spectroscopy of Single Molecules*	3	2/0 Ex	—
NOOE124	*Photonic structures and electromagnetic metamaterials*	3	2/0 Ex	—
NOOE047	*Integrated Optics*	3	2/0 Ex	—
NOOE113	*Laser Metrology*	3	2/0 Ex	—
NFPL004	*Nonequilibrium Statistical Physics and Thermodynamics*	3	2/0 Ex	—
NBCM305	*Optical Sensors*	3	2/0 Ex	—
NOOE074	*Magneto-optics theory*	3	2/0 Ex	—
NOOE133	*Topological properties of light and matter*	3	2/0 Ex	—
NBCM102	*Fundamentals of Classical Radiometry and Photometry*	3	2/0 Ex	—
NOOE048	*Fundamentals of Design and Production of Optical Components*	1	0/1 C	—
NOOE119	*Nonlinear Optical Spectroscopy*	3	—	2/0 Ex
NOOE011	*Optics of Thin Films and Multilayers*	3	—	2/0 Ex
NOOE130	*X-Ray Lasers and X-Ray Optics*	3	—	2/0 Ex
NOOE015	*Seminar*	2	—	0/1 C
NOOE125	*Spectroscopy in the terahertz spectral range*	3	—	2/0 Ex
NOOE073	*Contemporary Microscopy*	3	2/0 Ex	2/0 Ex
NOOE126	*Seminar of Femtosecond Laser Spectroscopy*	2	0/2 C	0/2 C
NBCM323	*Seminar on open quantum system theory*	1	0/1 C	0/1 C

3.5 State Final Exam

Conditions that must be satisfied to register for the state final exam

– earning at least 120 credits during the course of study
– passing all compulsory courses
– earning at least 31 credits from elective courses
– submission of a completed master's thesis by the submission deadline

Requirements for the oral part of the state final exam

Note: The student is asked two questions from part A and one question from part B in accord with the student's specialization.

A Common requirements

1 Advanced quantum mechanics, quantum theory of solid state

Role of symmetry in physics, eigenstates and their degeneration. Selection rules of physical processes in atoms, molecules and solids. Problem of many particles in quantum theory. Atoms and molecules. Electronic and vibration properties of solids. Second quantization. Quantization of electromagnetic field. Interaction of atom with electromagnetic radiation. Basics of relativistic quantum theory of electron. Single-electron approximation in solid state quantum theory, Blochś theorem, Brillouin zones. Influence of translation symmetry breaking, Wannierś theorem, superlattices and quantum structures. Thermodynamics and statistical physics of elementary excitations. Electron transport in electric and magnetic fields. Dielectric properties of solids. Quasiparticles in solids.

2 Wave optics, basics of quantum and nonlinear optics

Light as electromagnetic waves. Polarization of light, its mathematical description. Optical constants, Kramers-Kroning relations. Phenomena on interface between media. Light waves in absorbing medium. Complex representation of light waves. Wave theory of optical coherence. Scalar diffraction theory. Fourier optics and holography. Gaussian beams, other types of light beams. Optical resonators. Propagation of light in waveguides, optical fibres. Light-matter interaction, classical and semi classical theory. Dynamical properties of laser. Laser types. Linear and nonlinear optics. Nonlinear phenomena of the second order. Nonlinear phenomena of the third order. Spontaneous and stimulated scattering. Nonstationary coherent phenomena.

3 Basics of physics and technology of semiconductors for optoelectronics

Semiconductor materials and their parameters. Phase equilibria. Crystal growth. Crystal defects. Impurities in crystals. Passivation and metallization of surfaces. Preparation of single crystals and thin films. Electrons, holes, band structure of bulk semiconductors. Drift, diffusion, generation, recombination, capture and tunnelling of charge carriers. Low-dimensional semiconductor structures. Linear and nonlinear optical properties of semiconductors and their nanostructures.

4 Experimental methods

Methods for measuring the properties of optical radiation. Measurement of light beam parameters. Sources and detectors of optical radiation. Spectroscopic instruments. Methods for measuring the optical constants of materials. Spectroscopic methods for investigating materials according to the type of interaction. Basic experiments of classical and quantum optics.

B Specializations

Quantum and Nonlinear Optics

1 Quantum Optics

Electromagnetic field quantization. Photon, coherent and thermal states of field. Interaction of light with matter. Spontaneous, stimulated emission and absorption. Lifetime, shape of spectral line. Interaction of an atom with coherent light. Bloch's equations. Reduced density matrix. Relaxation in open systems, master equation, stochastic quantum dynamics. Kubo's response theory. Field correlation of the first and second order, Mach-Zender and a Hanbury Brown-Twiss interferometers. Beam splitters. Multimode light. Continuous frequency and time representation. Photon echo. Einstein-Podolsky-Rosen paradox. Entangled states. Quantum cryptography and teleportation. Methods of quantum description of laser, rate equations. Fluctuations in quantum systems, laser stability, output field statistics. Quantum description of nonlinear optical processes.

2 Integrated and quantum optics

Optics of interfaces, thin films and multilayers. Matrix description of light propagation in layered structures. Periodic structures. Fundamentals of photonic crystal theory. Silicon photonics. Photonic band structure. Microcavities. Methods for characterization of waveguide structures. Fundamentals of technology for integrated optics. Passive structures and dynamic components of integrated optics. Optical wave propagation in waveguides, modes. Characteristics of waveguides. Coupling elements for optical waveguides. Cylindrical dielectric waveguide. Single-mode and multimode optical fibres. Application of structures of integrated photonics in optical communication, information technology and sensors.

3 Methods of optical spectroscopy

Optical absorption and luminescence spectroscopy. Luminescence spectroscopy of semiconductors. Study of properties of electrons, excitons, photons, impurity states. Strong excitation effects. Stimulated emission in semiconductors and their nanostructures. Ways of generation and detection of spin-polarized charge carriers. Optical spectroscopy methods for the study of spin-polarized carriers in semiconductors. Properties of ultrashort laser pulses and their propagation. Methods of ultrafast spectroscopy.

Optoelectronics and photonics

1 Semiconductor physics for optoelectronics

Methods of excitation of charge carriers in semiconductors. Recombination of charge carriers in semiconductors. Radiative and non-radiative transitions. Hot carriers, relaxation. Photoconductivity by inhomogeneous excitation. Surface states, surface conductivity and recombination. P-N transition and its characteristics. Schottky contact, basic approaches to charge transport. Structure MIS. Heterogeneous transitions. Low-dimensional semiconductor structures, electronic states in quantum lattices, wires and dots. Photovoltaic phenomena, irradiated P-N junction, irradiated Schottky contact.

2 Optical and transport properties of semiconductors and their nanostructures

Dispersion relations and general properties of optical constants. Kramers-Kronig relations. Quantum theory of optical transitions. Interband transitions. Allowed and forbidden, direct and indirect transitions. Impurity absorption. Reflection in the area of lattice oscillations. Non-perturbative description of interactions in the crystal, quasi-particles (phonon, plasmon, exciton, polariton). Free electron model. Plasma edge. Interband recombination. Stimulated emission. Low-dimensional semiconductor structures, their optical properties, magnetotransport and resonant tunnelling. Classical, semi classical and quantum-mechanical description of electron transport. Aharon-Bohm effect. Resonant tunneling and Coulomb blockade. Quantum Hall effect. Spintronics.

3 Optoelectronic and photonic elements

Semiconductor sources of optical radiation. Electroluminescent layers, light emitting diodes. Semiconductor lasers. Quantum cascade lasers. Semiconductor detectors, factors affecting detectivity. Photoresistors, photodiodes, avalanche photodiodes, phototransistors. Semiconductor sensors. Vidicon, charge-coupled device. Photovoltaic cells. Structures of integrated optics. Microresonators, silicon photonics. Photonic mirrors, waveguides, fibres, resonators, optical filters, elements based on negative index of refraction. Plasmonic structures.

4 Degree Plans - Particle and Nuclear physics

Coordinated by: Institute of Particle and Nuclear Physics
Study programme coordinator: prof. RNDr. Pavel Cejnar, Dr., DSc.

Particle physics (high-energy, subnuclear physics) investigates the structure of matter at the level of elementary particles and their fundamental interactions. Nuclear physics studies the structure of atomic nuclei and, more generally, the behaviour of finite quantum systems of mutually interacting particles. The study programme is based on comprehensive courses of theoretical and experimental particle and nuclear physics, based on extensive courses in quantum mechanics and quantum field theory. Emphasis is placed on mastering the relevant computational techniques and managing the methods of acquisition and evaluation of experimental data, including efficient use of computing and advanced software tools. With the aid of optional courses and the Master's project, students gain deep knowledge in their selected area and choose their orientation toward theory or experiment.

Profile of graduates and study aims:

Graduates have an advanced knowledge of particle and nuclear physics, in both experimental and theoretical domains. With a comprehensive grounding in quantum theory, they understand basic approaches to the description of the microscopic world and know experimental techniques for its study. They find employment mainly in fundamental experimental and theoretical research, but also in relevant applied research, e.g., in detector physics, nuclear medicine etc. Graduates are prepared to creatively develop the field of their scientific focus and to join international research teams. Experience in the application of advanced software tools also opens possibilities for employment in the field of information technologies.

4.1 Recommended Course of Study

Prerequisite for this study programme is a bachelor-level knowledge of general physics, experimental methods, non-relativistic quantum mechanics, calculus and algebra.

First year

Code	Subject	Credits	Winter	Summer
NJSF041	**Experimental and Applied Nuclear Physics**	6	4/0 Ex	—
NJSF064	**Nuclear Physics**	7	3/2 C+Ex	—
NJSF105	**Elementary Particle Physics**	7	3/2 C+Ex	—
NJSF068	**Quantum Field Theory I** [1]	9	4/2 C+Ex	—
NJSF145	**Quantum Field Theory I** [1]	9	4/2 C+Ex	—
NJSF086	**Quarks, Partons and Quantum Chromodynamics**	6	—	2/2 C+Ex
NJSF037	**Microscopic Theory of Nuclei**	6	—	4/0 Ex
NJSF085	**Fundamentals of Electroweak Theory**	6	—	2/2 C+Ex
NSZZ023	**Diploma Thesis I**	6	—	0/4 C

[1] Students enrol in only one of these alternating courses.

Second year

Code	Subject	Credits	Winter	Summer
NJSF191	**Seminar on Particle and Nuclear Physics III**	3	0/2 C	—
NJSF192	**Seminar on Particle and Nuclear Physics IV**	3	—	0/2 C
NSZZ024	**Diploma Thesis II**	9	0/6 C	—
NSZZ025	**Diploma Thesis III**	15	—	0/10 C

4.2 Obligatory Courses

Code	Subject	Credits	Winter	Summer
NJSF041	**Experimental and Applied Nuclear Physics**	6	4/0 Ex	—
NJSF064	**Nuclear Physics**	7	3/2 C+Ex	—
NJSF105	**Elementary Particle Physics**	7	3/2 C+Ex	—
NJSF068	**Quantum Field Theory I** [1]	9	4/2 C+Ex	—
NJSF145	**Quantum Field Theory I** [1]	9	4/2 C+Ex	—
NJSF086	**Quarks, Partons and Quantum Chromodynamics**	6	—	2/2 C+Ex
NJSF037	**Microscopic Theory of Nuclei**	6	—	4/0 Ex
NJSF085	**Fundamentals of Electroweak Theory**	6	—	2/2 C+Ex
NJSF191	**Seminar on Particle and Nuclear Physics III**	3	0/2 C	—
NJSF192	**Seminar on Particle and Nuclear Physics IV**	3	—	0/2 C
NSZZ023	**Diploma Thesis I**	6	—	0/4 C
NSZZ024	**Diploma Thesis II**	9	0/6 C	—

NSZZ025	**Diploma Thesis III**	15	—	0/10 C

4.3 Elective Courses

The student needs to obtain at least 25 credits for courses from the following set.

Code	Subject	Credits	Winter	Summer
Quantum field theory				
NJSF069	Quantum Field Theory II [1]	9	—	4/2 C+Ex
NJSF146	Quantum Field Theory II [1]	9	—	4/2 C+Ex
NJSF139	Beyond Standard Model Physics I	4	2/1 Ex	—
NJSF140	Beyond Standard Model Physics II	4	—	2/1 Ex
NJSF082	Selected Topics on Quantum Field Theory I	4	3/0 Ex	—
NJSF083	Selected Topics on Quantum Field Theory II	4	—	3/0 Ex
NTMF022	Theory of Gauge Fields	4	3/0 Ex	—
NJSF084	Chiral Symmetry or Strong Interactions	3	—	2/0 Ex
NJSF030	Quantum Field Theory at Finite Temperature	3	—	2/0 Ex
NJSF129	Advanced Concepts of Symmetry	5	—	2/2 Ex
NJSF142	Theory of groups and algebras in particle physics	4	—	2/1 Ex
Theory of many-body systems				
NJSF196	Microcopic Theory of Nuclei II	3	2/0 Ex	—
NJSF107	Statistical Nuclear Physics	3	2/0 Ex	—
NJSF193	Collective Dynamics of Manybody systems	3	2/0 Ex	—
NJSF031	Classical and Quantum Chaos	3	—	2/0 Ex
NJSF157	Physics of few-body nuclear systems	3	2/0 Ex	—
NJSF158	Introduction to computational nuclear physics	3	1/1 Ex	—
Experimental particle physics				
NJSF073	Experimental Checks on Standard Model	4	—	2/1 C+Ex
NJSF195	Strong Interaction at High Energies	3	2/0 Ex	—
NJSF102	Nuclear Astrophysics	3	2/0 Ex	—
NJSF130	Cosmic Rays	3	—	2/0 Ex
NJSF131	Diffraction in particle physics	4	2/1 Ex	—
Experimental methods, data evaluation, applications				
NJSF070	Particle Detectors and Accelerators	3	2/0 Ex	—
NJSF159	Physics of particle accelerators	4	2/1 Ex	—
NJSF101	Semiconductor Detectors in Nuclear and Subnuclear Physics	3	2/0 Ex	—

NJSF081	Software and data processing in particle physics I	3	1/1 Ex	—
NJSF109	Software and data processing in particle physics II	4	—	2/1 Ex
NJSF143	Statistical methods in high energy physics	4	3/0 Ex	—
NJSF067	Data acquisition methods in particle and nuclear physics	4	2/1 Ex	—
NJSF138	Neural nets in particle physics	4	2/1 Ex	—
NJSF024	Radioanalytical Methods	3	2/0 Ex	—
NJSF008	Biological Effects of Ionizing Radiation	3	—	2/0 Ex
NJSF141	Experimental data evaluation	3	—	2/0 Ex
Other				
NJSF091	Seminar on Particle and Nuclear Physics I	3	0/2 C	—
NJSF092	Seminar on Particle and Nuclear Physics II	3	—	0/2 C

[1] Students enrol in just one of these alternating courses.

4.4 Recommended Optional Courses

Code	Subject	Credits	Winter	Summer
NJSF079	*Quantum Field Theory III*	9	4/2 C+Ex	—
NJSF132	*Theory of nanosccopic systems I*	3	2/0 Ex	—
NJSF133	*Theory of nanoscopic systems II*	3	—	2/0 Ex

4.5 State Final Exam

Study in the master's programme is completed by passing the state final exam. It consists of two parts: defence of the master's (diploma) thesis, and an oral examination. Requirements for the oral part of the state final exam are listed in the following sections.

Necesary conditions for taking the state final exam

– earning at least 120 credits during the course of study
– passing all compulsory courses
– obtaining at least 25 credits for elective courses
– submission of a completed master's thesis by the submission deadline

Requirements for the oral part of the state final exam

The committee asks the student to explain three topics from the following three sectors (one topic from each sector):

A. Quantum theory

1. Formalism of quantum theory

Hilbert space. Pure and mixed states. Compatible and incompatible observables. Discrete and continuous spectra. Open systems. Classical limit.

2. Evolution of quantum systems

Schroedinger equation and the evolution operator. Green operator. Schroedinger, Heisenberg and Dirac representations of time evolution. Evolution generated by a time-dependent Hamiltonian.

3. Symmetries and conservation laws in quantum mechanics

Continuous space-time symmetries and their generators. Space inversion and time reversal. Conservation laws. Scalars, vectors, spinors.

4. Perturbation methods in quantum mechanics

Stationary perturbation theory for a non-degenerate and degenerate spectrum. Non-stationary perturbation method, step and periodic perturbations, Fermi golden rule.

5. Angular momentum in quantum mechanics

Quantization of angular momentum. Addition of two or more angular momenta. Tensor operators, selection rules.

6. Scattering theory

Lippmann-Schwinger equation. Scattering amplitude, Born series. The method of partial waves.

7. Systems of indistinguishable particles

Bosons and fermions. Fock space, occupation number representation. Creation and annihilation operators, n-body operators.

8. Equations of relativistic quantum theory for free particles with spin 0, 1/2 and 1

Klein-Gordon and Dirac equations, solutions with positive and negative energies, continuity equation, symmetry properties. Weyl and Proca equations.

9. Dirac equation for a particle in electromagnetic field

Transition to the Pauli equation and the spin magnetic moment. Hydrogen type atoms and the fine structure of energy spectra.

10. Quantization of free fields and their particle interpretation

Canonical quantization method. Energy and momentum of a quantum field. Particles and antiparticles. Dirac field, anticommutation rules. Electromagnetic and Proca fields. Propagator of a quantum field.

11. Interactions of fields, perturbative expansion of the S-matrix and Feynman diagrams

Examples of interaction Lagrangians, gauge symmetry principle. Dyson expansion in the interaction representation. Feynman diagrams on the tree level. Decay probabilities and cross sections.

12. Foundations of quantum electrodynamics

Scattering of a charged particle in an external electromagnetic field. Second-order processes. Examples of diagrams with a closed loop.

B. Physics of elementary particles

1. Classification of elementary particles

Leptons, hadrons, interaction mediators. Approximate SU(3) symmetry, hadron multiplets. Quark model. Colour of quarks, its experimental evidence. Quarks u, d, s. Heavy quarks c, b. Decays of hadrons (neutron, pion, strange particles).

2. Properties of hadrons and their experimental determination

Spin, magnetic moment, spatial-, charge- and G-parity, isospin, strangeness, hypercharge. Conservation laws for individual interaction types. Examples of experiments.

3. Properties of leptons

Weak and electromagnetic interactions of leptons: mion pair production in electron-positron annihilation, scattering of neutrinos, decays of muons and tau leptons. Helicity of neutrinos, neutrino oscillations, P and CP violation. Neutrino experiments.

4. Methods of measurement and identification of particles in experiments

Measurement of energy, momentum, time of flight, Cherenkov and transition radiation, invariant mass of decay products. Examples of detection techniques in particle discoveries.

5. Experiments with particle accelerators

Linear and circular particle accelerators, colliders, luminosity. Present-day accelerators. Particle production in hadronic and leptonic collisions.

6. Conceptual foundations of the standard model of electroweak interactions

Gauge invariance. Yang-Mills field. The Higgs mechanism.

7. Types of particle interactions in the standard model of electroweak interactions

Interactions of vector bosons, interactions of the Higgs boson, neutral and charged currents. Discovery of vector bosons W and Z, discovery of the Higgs boson.

8. Mixing in the quark sector of the standard model

Generation of masses through the Yukawa interactions. Cabibbo-Kobayashi-Maskawa matrix, CP violation. Discovery of quarks c, b, t.

9. Systems of neutral mesons

Oscillation and regeneration. Direct and indirect CP violations and their signatures.

10. Structure of nucleons and the parton model

Elastic scattering of electrons on the proton, formfactors. Deep inelastic scattering, structure function, Bjorken scaling. Formulation of the parton model and the concept of parton distribution function.

11. Applications of the parton model

Basic processes in the parton model: hadron production in electron-positron annihilation, Drell-Yan process. Fragment function, deep inelastic scattering, measurement of parton distribution functions. Jet production, discovery of gluon.

12. Quantum chromodynamics

QCD Lagrangian and the gauge invariance principle. Running coupling constant, asymptotic freedom, colour confinement. Description of quarkonia. Infrared and collinear singularities, jets, evolution equation for parton distribution functions.

C. Nuclear physics

1. Characteristics of nuclei and their experimental determination

Binding energy, von Weizsaecker formula. Spin, parity. Magnetic dipole and electric quadrupole moments. Deformation parameters.

2. *Nuclear decays and radioactivity*
   Beta decay, spectra of electrons/positrons, selection rules, electron capture. Alpha decay, decay chains. Gamma decay, elements of the theory of electromagnetic transitions, their types and multipolarities, selection rules.
3. *Nucleon-nucleon interactions*
   Phenomenological and microscopic nucleon-nucleon potentials, symmetry principles, isospin, meson exchanges and their quark interpretation. Effective interactions in nuclear environment. Deuteron.
4. *Mean field and single-particle motions in nuclei*
   Hartree-Fock construction of the mean field. Spin-orbit coupling, magic numbers. Nilsson model, deformation.
5. *Pairing of nucleons and its consequences*
   Short-range residual interactions. Bardeen-Cooper-Schrieffer theory of superconductivity. Signatures of pairing in nuclei.
6. *Collective motions of nuclei*
   Rotational and vibrational spectra of nuclei and their phenomenological and microscopic description. Giant resonances. Nuclear fission.
7. *Nuclear reactions and highly excited states*
   Direct and compound-nucleus reactions, examples, typical properties, elements of their theoretical description. Population of excited states, statistical modelling of their decays, yrast line.
8. *Passage of ionizing radiation through matter*
   Processes during the passage of heavy and light particles through matter. Interaction of gamma particles. Passage of neutrons.
9. *Principles of detection of nuclear radiation*
   Spectrometry of charged and neutral particles. Basic types of particle detectors and their characteristics.
10. *Application of nuclear physics in material analysis and dating*
   Measurement of elemental and isotopic abundances. Nuclear probes in materials. Nuclear methods of age determination.
11. *Application of nuclear physics in medicine*
   Methods of imagining based on nuclear radiation, functional tomography. Radiotherapy and hadron therapy.
12. *Nuclear energy*
   Nuclear fission and fusion. Nuclear reactor, tokamak. Nuclear processes in stars.

5 Degree Plans - Physics of Condensed Matter and Materials

Coordinated by: Department of Condensed Matter Physics
Study programme coordinator: doc. RNDr. Stanislav Daniš, Ph.D.

The programme is devoted to experimental and theoretical study of properties of condensed systems, their microphysical interpretation and possible applications, in particular with respect to the current development of materials research. In addition to the common core programme, students select one of the following specializations: Physics of atomic and electronic structures, Physics of macromolecular compounds, Physics of materials, Low temperature physics, Physics of surface modifications. Each of these blocks ensures a general education in condensed matter physics at the contemporary level of knowledge and shapes the graduate in the selected specialization.

Profile of graduates and study aims:

Graduates acquire a broad education in the fundamentals of quantum theory, thermodynamics and statistical physics of condensed systems and the corresponding computing methods. They are able to describe the structure of the systems in different forms, their mechanical, electrical, magnetic and optical properties. They have a general knowledge of experimental methods of characterizing the structure, composition and properties of condensed compounds through for example diffraction, spectroscopic and microscopic techniques, and they are able to apply them in practice. Graduates are able to ssecure suitable positions in institutions of basic physical, chemical and biomedical research, universities, applied research laboratories, testing laboratories, and in hygiene and ecology institutions.

The aim of the study programme is to provide a broad education in quantum theory, thermodynamics and statistical physics in connection with current approaches in the theory of inorganic, organic and macromolecular condensed systems. At the same time, another goal of the study programme is to provide students with an overview of the principles of modern experimental methods and technological procedures. In their chosen specialization, students are provided with a deeper education and practical skills.

5.1 Recommended Course of Study

Prerequisite for this study programme is a bachelor-level knowledge of quantum theory, solid state physics, soft condensed matter physics and condensed system physics.

Compulsory and elective courses (profiling base).

Students choose one of the five specializations: Physics of atomic and electronic structures, Physics of macromolecular substances, Physics of materials, Low temperature Physics and Physics of surface modifications. Students need to obtain at least 25 credits from the elective courses from the profiling base, for the corresponding specialization, as described in the following table.

First year

Code	Subject	Credits	Winter	Summer
NFPL145	**Experimental Methods of Condensed Systems Physics I**	9	3/3 C+Ex	—
NFPL146	**Experimental Methods of Condensed Systems Physics II**	9	—	3/3 C+Ex
NFPL800	**Thermodynamics of Condensed Matter**	5	2/1 C+Ex	—
NFPL801	**Seminar** [1]	3	0/2 C	—
NFPL802	**Seminar** [1]	3	—	0/2 C
NSZZ023	**Diploma Thesis I**	6	—	0/4 C
Specialization Physics of atomic and electronic structures				
NFPL143	Solid State Physics I	9	4/2 C+Ex	—

NFPL144	Structure of Matter and Structure Analysis	7	3/2 C+Ex	—
NFPL147	Solid State Physics II	9	—	4/2 C+Ex

Specialization Physics of macromolecular substances

NBCM066	Introduction to Macromolecular Chemistry	5	2/1 C+Ex	—
NBCM208	Fundamentals of Macromolecular Physics	4	—	3/0 Ex
NBCM058	Relaxation Behaviour of Polymers	3	—	2/0 Ex
NBCM038	Electrical and Optical Properties of Polymers	3	—	2/0 Ex
NBCM231	Applied Thermodynamics	3	—	2/0 Ex
NBCM204	Statistical Thermodynamics of Condensed Systems	5	2/1 C+Ex	—
NBCM353	Special practical courses of physics of macromolecular solids and nanomaterials	4	—	0/3 C

Specialization Physics of materials

NFPL132	Condensed Matter Theory	6	3/1 C+Ex	—
NFPL133	Structure of Materials	4	3/0 Ex	—
NFPL135	Physics of Materials I	4	2/1 C+Ex	—
NFPL139	Physics of Materials II	4	—	2/1 C+Ex
NFPL137	Technology of Materials	3	—	2/0 Ex
NFPL136	Special practical courses of physics of materials	4	—	0/3 C

Specialization Low temperature physics

NFPL143	Solid State Physics I	9	4/2 C+Ex	—
NFPL168	Low Temperature Physics and Techniques	3	2/0 Ex	—
NFPL103	Positron Annihilation in Solids	3	2/0 Ex	—
NFPL169	Hyperfine Interactions and Nuclear Magnetism	3	—	2/0 Ex
NFPL092	Radiofrequency Spectroscopy of Solids	3	—	2/0 Ex
NFPL206	Selected topics of quantum theory of solids	7	—	3/2 C+Ex

Specialization Physics of surface modifications

NBCM066	Introduction to Macromolecular Chemistry	5	2/1 C+Ex	—
NBCM213	Physics of Thin Film Preparation	3	2/0 Ex	—
NBCM233	Analysis Methods of Surfaces and Thin Layers	5	2/1 C+Ex	—
NBCM214	Plasma Polymerisation Processes	3	2/0 Ex	—

NBCM231	Applied Thermodynamics	3	—	2/0 Ex
NBCM353	Special practical courses of physics of macromolecular solids and nanomaterials	4	—	0/3 C

[1] As a Field Seminar, students attend one of the following seminars: Structural Analysis seminar (NFPL037), Condensed Matter Theory seminar (NFPL062), Magnetism seminar (NFPL118), Low Temperature Physics seminar (NFPL098), Materials Physics seminar (NFPL113), Polymer Physics seminar (NBCM091), Plasma Polymer study seminar (NBCM200).

Second year

Code	Subject	Credits	Winter	Summer
NSZZ024	**Diploma Thesis II**	9	0/6 C	—
NFPL124	**Experimental methods of condensed matter physics III**	6	2/2 C+Ex	—
NSZZ025	**Diploma Thesis III**	15	—	0/10 C
Specialization Physics of atomic and electronic structures				
—				
Specialization Physics of macromolecular substances				
NBCM217	Modern Trends in Macromolecular Physics	4	3/0 Ex	—
NBCM142	Diploma Thesis Seminar	3	—	0/2 C
Specialization Physics of materials				
—				
Specialization Low temperature physics				
—				
Specialization Physics of surface modifications				
NBCM219	Selected Problems in Physics of Real Surfaces	3	2/0 Ex	—
NBCM142	Diploma Thesis Seminar	3	—	0/2 C

Elective Courses - Set 2

Student need to obtain at least 15 credits for courses from the following set.

Code	Subject	Credits	Winter	Summer
Specialization Physics of atomic and electronic structures				
NFPL115	Electron Microscopy	3	2/0 Ex	—
NFPL122	Magnetic Properties of Solids	3	2/0 Ex	—
NFPL014	Dielectric Properties of Solids	3	2/0 Ex	—
NFPL040	Applied Structure Analysis	3	—	1/1 C+Ex
NFPL154	Neutron and Synchrotron Radiation in Magnetic Materials	6	—	2/2 C+Ex

NFPL030	X-ray methods for structure and microstructure investigation of materials	5	—	2/1 C+Ex
NFPL082	Magnetism and Electronic Structure of Metallic Systems	3	2/0 Ex	—
NFPL013	X-ray Scattering on Thin Films	3	2/0 Ex	—
NFPL155	Experimental Study of Real Structure of Solids	4	2/1 C+Ex	—
NFPL157	Physics in Strong Magnetic Fields	3	2/0 Ex	—
NFPL156	High Pressure Physics	3	2/0 Ex	—
NFPL158	Magnetic Structures	4	2/2 C+Ex	—
NFPL550	Thermal Capacity of Solids	3	2/0 Ex	—
NFPL011	Computational Physics and Materials Design	3	2/0 Ex	—
NFPL004	Nonequilibrium Statistical Physics and Thermodynamics	3	2/0 Ex	—
NFPL039	Methods of Solving and Refining Monocrystal Structures	3	—	1/1 C+Ex
NFPL159	Modern Materials with Application Potential	3	—	2/0 Ex
NFPL551	Correlations in Many-Electron Systems	3	—	2/0 Ex

Specialization Physics of macromolecular substances

NBCM098	X-ray and Electron Structure Analysis of Biomolecules and Macromolecules	3	2/0 Ex	—
NBCM211	Methods of Measuring Electric Properties of Semiconducting and Insulating Materials	3	1/1 C+Ex	—
NFPL018	Transport and Surface Properties of Solids	3	2/0 Ex	—
NBCM230	NMR Spectroscopy of Polymers	3	—	2/0 Ex
NBCM209	Probabilistic Methods in Macromolecular Physics	3	—	2/0 Ex
NBCM076	Theory of Polymer Structures	3	2/0 Ex	—
NBCM072	Fundamentals of Molecular Electronics	3	2/0 Ex	—
NBCM062	Structural Theories of Polymer Relaxation Behaviour	3	2/0 Ex	—

Specialization Physics of materials

NFPL107	Fundamentals of Crystallography	3	1/1 C+Ex	—
NFPL115	Electron Microscopy	3	2/0 Ex	—
NFPL055	Kinetics of Phase Transformations	3	—	2/0 Ex
NFPL305	Magnetism of Materials	3	—	2/0 Ex

NFPL197	Fundamentals of Continuum Mechanics and Dislocation Theory	3	—	2/0 Ex
NFPL198	Theory of crystal defects	3	—	2/0 Ex
NFPL080	Acoustic in Physics of Condensed Matter	6	—	3/1 MC
NFPL140	Physics of Materials III [1]	3	2/0 Ex	2/0 Ex
NFPL103	Positron Annihilation in Solids	3	2/0 Ex	—

Specialization Low Temperature Physics

NFPL171	Macroscopic Quantum Phenomena I	3	2/0 Ex	—
NFPL172	Macroscopic Quantum Phenomena II	3	—	2/0 Ex
NFPL093	Selected Topics on Magnetic Resonance Theory and Methodology	3	2/0 Ex	—
NFPL097	Nuclear Spectroscopy Methods in Hyperfine Interaction Studies	3	—	1/1 C+Ex
NFPL174	Introduction to Fluid Dynamics and Turbulence	3	2/0 Ex	—
NFPL210	Turbulence	3	2/0 Ex	—
NFPL096	Moessbauer Spectroscopy	3	2/0 Ex	—
NFPL175	NMR in Magnetically Ordered Materials	3	1/1 C+Ex	—
NFPL129	Nuclear Methods in Magnetic Systems Studies	3	2/0 Ex	—
NFPL095	Fundamentals of Cryogenics	3	2/0 Ex	—
NFPL128	Selected Topics on Positron Annihilation Spectroscopy	3	1/1 C+Ex	1/1 C+Ex
NFPL184	Seminar on Radiofrequency Spectroscopy in Condensed Matter	3	0/2 C	0/2 C
NFPL204	Magnetic nanoparticles	3	2/0 Ex	—
NFPL179	Quantum Description of NMR	5	—	2/1 C+Ex

Specialization Physics of surface modifications

NFPL107	Fundamentals of Crystallography	3	1/1 C+Ex	—
NBCM234	Construction of Deposition Apparatuses	5	2/1 C+Ex	—
NBCM235	Basics of Plasma Physics	3	2/0 Ex	—
NFPL149	X-ray Study of Real Structure of Thin Films	3	—	2/0 Ex
NBCM215	Modification of Surfaces and Its Applications	3	—	2/0 Ex
NBCM236	Nanocomposite and Nanostructured Thin Layers	3	—	2/0 Ex
NBCM220	Hard and Super-hard Films and Their Applications	3	2/0 Ex	—
NBCM232	Electrical Properties of Thin Layers	3	2/0 Ex	—

NBCM222	Optical Properties of Thin Films	3	2/0 Ex	—

[1] The course can be taken in either the summer or winter semester.

5.2 Recommended Optional Courses

Code	Subject	Credits	Winter	Summer
NFPL038	*Diffraction of X-rays by Perfect Crystals*	3	2/0 Ex	—
NFPL130	*Physical Metallurgy of Wrought Aluminium Alloys*	3	2/0 Ex	—
NFPL199	*Physical Methods in Nanostructure Studies*	3	—	2/0 Ex
NEVF106	*Microscopy of Surfaces and Thin Films*	5	2/1 C+Ex	—
NFPL120	*Modern Problems in Physics of Materials*	3	2/0 Ex	—
NFPL006	*High Performance Computing in Physics*	3	1/1 C+Ex	—
NFPL177	*Superconductivity*	5	2/1 C+Ex	—
NFPL072	*Systems with Correlated f-electrons*	3	2/0 Ex	—
NFPL141	*Quantum Theory II*	5	2/1 C+Ex	2/1 C+Ex
NFPL051	*Mechanical Properties of Non-metallic Materials*	3	2/0 Ex	—
NFPL500	*Practical application of atomic force microscopy*	2	—	0/2 C
NFPL192	*Introductory Seminar on Condensed Systems Physics*	3	—	0/2 MC
NFPL505	*Introduction to Soft Condensed Matter Physics*	3	—	1/1 C+Ex
NFPL502	*Introduction to Solid State Physics*	6	—	3/1 C+Ex
NBCM060	*Fundamentals of Polymer Structure Formation*	3	—	2/0 Ex
NFPL074	*Practical Applications of Transmission Electron Microscopy*	4	0/3 C	0/3 C
NBCM070	*Thermodynamics of Nonequilibrium Processes*	3	2/0 Ex	—
NFPL304	*Technology and properties of steels and cast irons* [1]	3	2/0 Ex	2/0 Ex
NBCM352	*Stochastic thermodynamics and Active matter*	3	—	2/0 Ex

[1] The course can be taken in either the summer or winter semester.

5.3 State Final Exam

Necesary conditions for taking the state final exam

– earning at least 120 credits during the course of study

– passing all compulsory courses of the chosen specialization
– earning at least 25 credits from elective courses of the profiling base of the chosen specialization
– earning at least 15 credits from elective courses in Set 2 of the chosen specialization
– submission of a completed master's thesis by the submission deadline

Requirements for the oral part of the state final exam

A Common requirements

Band structure and methods of its calculation: one-electron approximation and methods for solving effective equations (LCAO method, nearly free electrons, LAPW, pseudopotentials). Adiabatic approximation, variational principle and perturbation theory.

Interaction between electrons - second quantization, Hartree-Fock approximation, theory of density functional. Quasiparticles in condensed systems.

Interaction of electromagnetic radiation with matter - photon absorption and emission. Stimulated and spontaneous emissions, selection rules. Lifetime of quantum states, natural spectral line width.

2 Thermodynamics and statistical physics of condensed systems

Thermodynamic equilibrium, state variables and equations of state. The laws of thermodynamics and their consequences, entropy and absolute temperature. Thermodynamic potentials, conditions of balance and stability. Critical phenomena, phase transitions, Landau's phase transitions theory. Description of nonequilibrium processes, linear nonequilibrium thermodynamics. Statistical description of state, distribution function and density matrix. Liouville's equation. Gibbs stationary files, file centering, derivation of state equations. Classic and quantum systems of non-interacting particles. Brownian motion, diffusion in the external field.

3 Fundamentals of condensed matter physics

Structure of condensed systems - crystal structure, point and translational symmetry, basics of crystallography. Reciprocal space, Brillouin zone.

Real structure of substances - defects of crystal structure, long and short -term ordering. Amorphous substances and their description, pair distribution functions. Description of topology, spatial and electronic structure of macromolecules.

Movement of atoms and molecules in condensed matter - diffusion, lattice oscillations, phonons, heat capacity.

Electrical properties - polarization mechanisms, dielectric susceptibility. Interaction of ionic crystal lattice with electromagnetic wave. Electric current transport - Sommerfeld model, electrons in the periodic potential, band structure of metals and semiconductors. Basic knowledge of superconductivity.

Magnetic properties - diamagnetism and paramagnetism, magnetization, magnetic susceptibility. Spontaneous alignment of magnetic moments. Magnetization processes in ferromagnets.

Mechanical force field - elastic and plastic deformation, viscosity. Viscoelasticity and rubber elasticity of polymer systems, glass transition, principle of time-temperature superposition.

4 Experimental methods

Structure determination methods - basic diffraction methods: scattering and diffraction of x-rays, electrons, neutrons, atoms and ions. Microscopic methods - optical, scanning and transmission electron microscopy.

Macroscopic and microscopic methods of studying mechanical, thermal, dielectric, optical, transport and magnetic properties of matter.

Basic spectroscopic methods (radio frequency, microwave, optical, X – ray, gamma, photoemission) and their applications.

B Specializations

The student chooses a set of questions corresponding to his specialization.

1 Physics of atomic and electronic structures

Atomic structure of matter

Point and space groups. Symmetry of physical properties. Structure of crystals, quasicrystals, modulated structures and amorphous substances. Using of structural databases. Kinematic theory of diffraction - scattering of x-rays on electrons, atoms and molecules; dispersion on periodic and low-dimensional structures. Fundamentals of dynamic theory of diffraction. Use of neutrons and synchrotron radiation to study the structure of matter. Computer simulations, ab-initio calculations.

Electron structure and physical properties of substances

Conductivity electrons in materials (classical and quantum description), electrons in periodic potential. Electronic structure of metals, semiconductors and insulators, optical properties. Chemical bonding, cohesion, hybridization of electronic states. Electron-phonon interaction, electrical and thermal transport. Coulomb and exchange interaction, correlations of electrons, the formation of magnetic moment. Magnetic ordering, symmetry. Microscopic models of magnetism. Low dimensional systems. Specific heat, temperature dilatation. Magnetotransport and magnetoelastic phenomena. Dielectrics, electrical permittivity, ferroelectrics and antiferroelectrics. Electro-optical and magneto-optical phenomena. Utilization of microscopic and macroscopic methods. Influence of external pressure, physics in high magnetic fields. Ab initio calculations of electronic structure and physical properties. Applications of electronic properties of materials. Nanomaterials.

Collective phenomena

Spontaneous symmetry breaking and the ordering parameter. Microscopic description of phase transitions, mean field theory, fluctuations. Structural and magnetic phase transitions. Spontaneous ordering of nuclear moments. Kondo lattice and heavy fermion systems. Bose-Einstein condensation of an atom. Superconductivity and superfluidity. Cooperative phenomena out of equilibrium, lasers.

2 Physics of macromolecular substances

Structure of macromolecules

Configuration, conformation, tacticity and stereoregularity of polymer chains. Architecture of macromolecular systems. Methods of preparation of macromolecular systems, chemical structure of polymers, methods of construction of polymer networks, gelation point. Distribution and molar mass averages.

Physical properties of macromolecular systems

Relaxation properties, glass transition and free volume theory, time-temperature superposition. Concept of linear viscoelasticity, viscoelastic functions, Boltzmann's principle of superposition. Thermodynamics of polymer solutions, mixtures and block copolymers, phase diagrams. Flory-Huggins theory, swelling equilibrium. Colligative properties of polymers, solutions. Coil-globule transition. Crystallization of polymers. Electrical and optical properties of polymers, generation and charge transport in organic structures.

Experimental methods

Methods of studying the glass transition, measuring of rheological and viscoelastic properties, dynamic mechanical analysis. Measurement of dielectric and electrical properties, thermal depolarization. Detection of thermal transitions, differential scanning calorimetry. Methods for determining the molecular weights and structure of polymers. Diffraction / scattering and spectroscopic methods for studying the structure of macromolecular systems.

3 Physics of materials

Defects of crystal lattice

Crystal lattice, vacancies, interstitials, stacking faults, sub boundaries, grain boundaries, twins, inclusions, dispersoids, precipitates. Interaction of crystal lattice defects. Experimental methods of studying crystal defects: mechanical tests, diffraction and imaging methods, thermal analysis, acoustic emission.

Mechanical properties

Plastic deformation, theory of strengthening, creep and fracture. Static and dynamic softening, recovery of lattice defects, superplasticity, instability of plastic deformation, shape memory.

Thermodynamics of multicomponent systems

Binary and ternary phase diagrams, nearest neighbors model, lever rule, intermedial phase. Phase transformations, solidification of alloys, segregation processes. Diffusion and diffusionless transformations in solids, TTT-diagrams, Avrami equations. Diffusion in solids.

Modern materials and technologies

Intermetallic compounds, ceramic and composite materials, submicrocrystalline and nanocrystalline materials, quasicrystals, shape memory materials, technologies of preparation of modern materials.

4 Low Temperature Physics

Electronic structure of solids

Methods of electronic structure calculation. Electronic structure and magnetic properties of solids. Magnetic moments of free atom / ion, interaction with crystal field, correlation phenomena, exchange interactions, localized and itinerant magnetic moments.

Physics and technology of low temperatures

Methods of obtaining low and very low temperatures, basic properties of cryofluids. Low temperature thermometry.

Macroscopic quantum phenomena

Superconductivity, Cooper pairs, Meissner effect, weak superconductivity. Superconductors of type I. and II., high temperature superconductivity. Superfluidity of ^{4}He, ^{3}He, macroscopic wave function, Bose-Einstein condensation.

Hyperfine interactions and nuclear magnetism

Electric and magnetic moments of atomic nuclei, electric and magnetic hyperfine interaction. Spin Hamiltonian, hyperfine splitting of energy levels, the role of symmetry of the nucleus vicinity.

Experimental methods of studying hyperfine interactions (nuclear magnetic resonance, electron paramagnetic resonance, muon spin rotation, Mössbauer's effect, nuclear orientation, method of perturbed angular correlations) and their use for study of atomic, electronic and magnetic structures.

5 Physics of real surfaces

Surface physics

Molecule binding on the surface, absorption, ideal and real surface, electronic structure of surfaces, surface states, work function, emission of charged particles, electron emission, principle of electron spectroscopy, interaction of particles and radiation with the surface, photoemission, principle of photoelectron spectroscopy, secondary electron emissions, diffraction. Energy of surfaces and interfaces.

Experimental methods of surface study

Electron spectroscopy methods (AES, REED), ion spectroscopy methods (SIMS, SNMS), methods of photoelectron spectroscopy (UPS, XPS) and their practical use. Methods of electron microscopy. Surface energy measurement: static and dynamic methods of measuring the contact angle. Infrared spectroscopy ATR FTIR, methods of X-ray diffraction — small - angle scattering.

Preparation of thin films

Thin film definition, concept of thin film thickness, initial stage and mechanisms of thin film growth. Basic methods of thin film deposition: evaporation in vacuum, DC and radio-frequency (RF) sputtering, CVD, PE CVD of inorganic and organic coatings (plasma polymerization). Methods of diagnostics of thin film growth, measurement of deposition rate and thin film thickness, determination of structure, morphology, mechanical, electrical and optical properties of thin films. Surface modifications, changes in surface energy and chemical activity. Application of thin films — hard, abrasion resistant coatings, protective and passivation layers, optical thin films, coatings for microelectronics.

6 Degree Plans - Surface and Plasma Physics

Coordinated by: Department of Surface and Plasma Science
Study programme coordinator: doc. RNDr. Jan Wild, CSc.

Surface and Plasma Physics is a master's degree program of an interdisciplinary nature, which includes a fundamental knowledge of interactions of neutral and charged particles in a vacuum, gas, and condensed phase, and at the interfaces of these environments. The programme provides expertise in the physics of surfaces and thin films, especially atomic and molecular nanostructures on solid surfaces with significant binding to physico-chemical and transport processes and with applications in the field of catalysts, sensors, and molecular electronics. The programme in the laboratory and space plasmas intersects with plasma chemistry, laser mixtures, hot and fusion plasma, and some parts of astrophysics. Studies enable the mastery of modern diagnostic methods in materials research, vacuum and plasma technologies, and the analysis of various types of space plasmas or controlled thermonuclear fusion. Individual disciplines can be oriented experimentally, theoretically, or solved by methods of computational physics.

Profile of graduates and study aims:

Graduates of the study programme Surface and Plasma Physics have a broad knowledge of the physical foundations of the field and demonstrate an understanding of the relevant mathematical apparatus, including applying it. They master advanced diagnostic methods and computer models, which allows them to understand the behaviour of atomic and molecular structures on solid surfaces and the associated significant application problems as well as fundamental processes in ionized media typical for various fields from astrophysics to plasma chemistry and magnetohydrodynamics. Graduates are also able to independently formulate hypotheses, create computer simulations and critically analyse the outputs. They are prepared to present their findings and conclusions to the professional and lay public in the form of presentations and written texts, including in a foreign language. They also apply the acquired knowledge, skills, and creative abilities in related fields focused on both basic and applied research at universities, in institutes of the Academy of Sciences, in scientific and technological centres (e.g., synchrotrons, ITER, ELI, ESA), and also in the industrial sphere and public administration.

Prerequisite for this study programme is a bachelor-level knowledge of plasma physics, surface physics and solid state physics.

6.1 Obligatory Courses

Code	Subject	Credits	Winter	Summer
First year				
NEVF122	**Plasma Physics**	5	2/1 C+Ex	—
NEVF129	**Surface Physics**	5	2/1 C+Ex	—
NEVF191	**Workshop I**	2	0/2 C	—
NEVF151	**Diploma Thesis Seminar for Students of Surface and Plasma Physics I**	3	0/2 C	—
NEVF154	**Diploma Thesis Seminar for Students of Surface and Plasma Physics II**	3	—	0/2 C
NSZZ023	**Diploma Thesis I**	6	—	0/4 C
Second year				
NEVF192	**Workshop II**	2	0/2 C	—
NEVF152	**Diploma Thesis Seminar for Students of Surface and Plasma Physics III**	1	0/1 C	—

NEVF153	**Diploma Thesis Seminar for Students of Surface and Plasma Physics IV**	1	—	0/1 C
NSZZ024	**Diploma Thesis II**	9	0/6 C	—
NSZZ025	**Diploma Thesis III**	15	—	0/10 C

6.2 Elective and Recommended Optional Courses

Thematic areas corresponding to the final state exam areas

It is assumed that students enrol in optional courses from at least three thematic areas, from which they will later pass the state final exam. In these particular areas, further recommended optional courses are also listed (written in *italics*), the completion of which is not necessary for the state final examination. The student needs to obtain at least 55 credits for courses from these elective courses.

Code	Subject	Credits	Winter	Summer
Plasma physics				
NEVF120	Advanced Plasma Physics	7	—	2/2 C+Ex
NEVF121	Hot Plasma, Fusion	3	2/0 Ex	—
NEVF149	Elementary Processes and Reactions in Plasma	5	—	2/1 C+Ex
Plasma processes and their diagnostics				
NEVF123	Quantum Electronics and Optoelectronics	5	2/1 C+Ex	—
NEVF162	Optical Spectroscopy of Plasma	5	2/1 C+Ex	—
NEVF130	Selected Topics on Physical Chemistry	5	—	2/1 C+Ex
Space physics				
NEVF145	Space Plasma	5	—	2/1 C+Ex
NEVF117	Plasma Waves	5	2/1 C+Ex	—
NEVF173	Diagnostics in Space Plasmas	5	2/1 C+Ex	—
Physics of surfaces and thin films				
NEVF170	Physical Electronics of Surfaces	5	—	2/1 C+Ex
NEVF114	Physics of Thin Films	5	2/1 C+Ex	—
NEVF134	Adsorption on Solids	5	—	2/1 C+Ex
NEVF109	*Selected Parts from Physics of Thin Films*	3	—	2/0 Ex
NEVF163	*Selected Chapters from Nanoelectronics*	3	2/0 Ex	—
Structure and morphology of surfaces and thin films				
NEVF103	Thin Film Techniques	5	—	2/1 C+Ex
NEVF106	Microscopy of Surfaces and Thin Films	5	2/1 C+Ex	—

NEVF136	Surface Structure and Electron Diffraction	5	2/1 C+Ex	—
NEVF172	*Nanomaterials and Their Properties*	3	—	2/0 Ex
NEVF174	*Materials for hydrogen technology*	3	2/0 Ex	—
NEVF175	*Materials for renewable energy*	3	—	2/0 Ex
Physico-chemical properties of surfaces and thin films				
NEVF113	Electron Spectroscopies	5	—	2/1 C+Ex
NEVF168	Ion and Vibrational Spectroscopy	5	2/1 C+Ex	—
NEVF171	Operando Methods	5	2/1 C+Ex	—
NEVF108	*Advanced Methods in Surface Physics*	3	2/0 Ex	—
NEVF148	*Molecular and Ion Spectroscopy*	3	2/0 Ex	—
NEVF167	*Interfacial Electrochemistry*	3	—	2/0 Ex
Vacuum physics				
NEVF126	Vacuum Physics	5	2/1 C+Ex	—
NEVF105	Vacuum Technology	5	—	2/1 C+Ex
NEVF125	Mass Spectrometry	5	2/1 C+Ex	—
Experiment automation and data acquisition				
NEVF115	Electronics for Physicists	5	2/1 C+Ex	—
NEVF127	Experiment Automation I	5	—	2/1 C+Ex
NEVF144	High Frequency Electrical Engineering in Physics	5	2/1 C+Ex	—
NEVF128	*Experiment Automation II*	3	2/0 Ex	—
NEVF116	*Applied Electronics*	5	—	2/1 C+Ex
Computer physics				
NEVF141	Fundamentals of Computational Physics I	7	2/2 C+Ex	—
NEVF138	Fundamentals of Computational Physics II	3	—	2/0 Ex
NEVF160	Modern Computational Physics I	5	2/1 MC	—
NEVF161	*Modern Computational Physics II*	5	—	2/1 MC

Further recommended optional courses

Code	Subject	Credits	Winter	Summer
NEVF135	*Programming in IDL — Data Processing and Visualisation*	3	1/1 MC	—
NEVF143	*Statistics and Information Theory*	3	2/0 Ex	—
NEVF107	*C++ for Physicists*	3	—	1/1 MC
NEVF111	*Fortran 90/95 for Physicists*	3	—	1/1 MC
NEVF150	*Fluctuations in Physical Systems*	3	—	2/0 Ex

6.3 State Final Exam

Necesary conditions for taking the state final exam

– earning at least 120 credits during the course of study
– passing all compulsory courses
– earning at least 55 credits by completion of elective courses
– submission of a completed master's thesis by the submission deadline

Requirements for the oral part of the state final exam

The student will receive one question from a common basis (part A), i.e., from thematic areas 1 to 3, and three questions from a narrower optional focus (part B), i.e., from thematic areas 4 to 12 according to the chosen focus.

A Common basis

1 Solid state physics

Crystallography and structure of solids. Types of bonds, structure of elements and simple compounds, x-ray diffraction. Crystal lattice vibrations, optical and acoustic phonons, interaction with electromagnetic radiation. The Sommerfeld model of a metal, electron gas, density of states, Fermi energy. Electronic structure of solids, band theory, charge carriers mobility in solids. Intrinsic and doped semiconductors, P-N junction, photoelectric properties of semiconductors.

2 Physics of ionized media

Basics of kinetic theory of gases. Motion of charged particles in electromagnetic fields. Description of plasma, basic concepts and types of plasma. Kinetic description of plasma. Transport processes in plasma. Fluid description of plasma.

3 Fundamentals of plasma, surface, and thin film physics

Surface morphology, crystallographic and electronic structure of surfaces. Interaction of radiation and particles with solid surfaces. Experimental methods of surface and thin film physics — diffraction, photoemission, and near field techniques. Gas discharges. Collisional and elementary processes. Plasma diagnostics.

B Optional focus

The student chooses three thematic areas in advance.

4 Plasma physics

Collective behaviour of plasma. Transport phenomena in plasma. Advanced plasma discharges. Plasma light sources. Magnetohydrodynamic description of plasma and MHD instabilities. Conditions for nuclear fusion in hot plasma, inertial confinement fusion. Magnetic confinement of hot plasma. Hot plasma diagnostics. Chemical kinetics in plasma. Ion–molecule reactions and the influence of molecular excitation. Experimental techniques for the study of elementary plasma processes. Elementary plasma processes — recombination, relaxation processes, plasma surface interaction.

5 Plasma processes and their diagnostics

Fundamentals of quantum electronics, population inversion, stimulated emission. Microwave quantum generators and amplifiers. Types of lasers and their properties. Laser applications, optical communications. Basic concepts of absorption and emission spectroscopy. Spectra of atoms and molecules. Spectroscopy techniques — absorption and emission. Evaluation of plasma parameters from measured spectra. Molecular structure and chemical bond. Determination of molecular structure. Chemical reactions, chemical kinetics and dynamics. Experimental techniques of physical chemistry.

6 Space physics

Sun, solar wind, interplanetary magnetic field. Interaction of the solar wind with obstacles. Magnetosphere and ionosphere. Reconnection of magnetic fields, geomagnetic activity. Dispersion relation of waves in plasma. Polarization of waves in magnetized plasma. Whistler modes in space plasma. Radio emissions in space plasma. Measurements of plasma parameters and distribution functions of electrons, protons and heavier ions. Methods of mass spectrum determination, particle detectors, space dust detection. Spacecraft measurements of electric and magnetic fields, spacecraft potential. Ground measurements for the study of processes in the ionosphere and magnetosphere, geomagnetic indices.

7 Physics of surfaces and thin films

Electronic structure of surfaces, surface states, band bending. Emission of electrons, work function. Interaction of radiation and particles with solids (excitation, scattering). Phenomena at solid state interfaces. Thin film growth modes and growth phases, elementary processes during deposition. Ad-atom diffusion, nucleation, role of step edges in thin film growth. Rate equations for description of thin film growth. Amorphous, polycrystalline and epitaxial films. Strain in heteroepitaxial growth — Stranski–Krastanov growth mode. Adsorption of molecules on surfaces, the interaction of gas molecules with surfaces, the potential theory of adsorption. Kinetics and dynamics of adsorption and desorption, adsorption isotherms. Experimental methods based on the interaction of gas molecules with surfaces (MB, TPD/TPR, BET). Reactions on solid surfaces, reaction mechanisms, reaction kinetics and dynamics.

8 Structure and morphology of surfaces and thin films

Vacuum evaporation. Sputtering of thin films. Measurement of deposition rate and thickness of thin films. Ion etching, lithography. Electron microscopy and contrast in various imaging modes. Microscopic techniques with atomic resolution. Electronic structure of surfaces and tunneling spectroscopy. Near field scanning probe microscopies (STM, AFM, SNOM). Structure and description of ideal surface. Crystallographic structure of surface — relaxation, reconstruction, ideal and real surface. Diffraction theory (geometric and kinematic). Electron diffraction methods.

9 Physico-chemical properties of surfaces and thin films

Electron spectroscopies, overview, experimental requirements and equipment (sources, analysers, detectors). Photoelectron spectroscopy. Auger electron spectroscopy. Electron energy loss spectroscopy. Vibrational and rotational states of molecules, theory, vibrational modes. (Ro-)vibrational spectroscopic methods — IR and Raman spectroscopy. Interaction of ions with solid surface. Ion spectroscopy surface methods (LEIS, SIMS). Basics of operando methods and their overview (experimental arrangement, advantages and limitations, application examples). Operando spectroscopies. Operando microscopies. Application of operando methods in heterogeneous catalysis.

10 Vacuum physics

Transfer phenomena at low pressures. Real gases, vapour pressure, evaporation and condensation. Interaction of gas with solid on its surface and in volume. Gas flow, flow regimes, vacuum conductivity. Vacuum system and its parameters, theory of pumping process. Physical principles of methods of obtaining low pressures. Physical principles of low pressure measurement, total and partial pressure. Vacuum measuring methods. Principles of mass analysers. Ionization techniques, electron ionization. Ion detection methods. Interpretation of spectra, qualitative and quantitative analysis.

11 Experiment automation and data acquisition

Analysis of DC and AC electrical circuits with linear elements. Operational amplifiers, properties and basic applications. Basics of analog signal processing, filtering, noise suppression. Voltage and current sources. Data acquisition and physical experiment control, physical quantities measurement - sensors and actuators. Methods and properties of A-D and D-A conversion. Digital signal processing, application of microprocessors. Basics of process control, dynamic characteristics of a control loop, PI and PID controllers. Circuits at very high frequencies, skin effect and internal impedance. Parameters of a long homogeneous line. Waveguides and resonators. Generation of high frequency power.

12 Computer physics

Numerical methods in computer science, root finding, minimization, integration. Molecular dynamics, motion in external force fields, many-body problems. Stochastic methods in computational physics, generation and characterization of random variables. Continuum and hybrid models, comparison with particle models. Solution of ordinary differential equations, order of accuracy, stability, round-off error. Solution of systems of linear equations and partial differential equations. Integral transforms in computer science, fast Fourier transform. Finite element method. Evolutionary programming, encoding, fitness, operators, evolutionary algorithm. Genetic algorithm and genetic programming, crossover, NP problems, syntax trees. Efficient computation of forces in many-body problems. Collision modeling.