UNIVERSITAS CAROLINA

FACULTAS MATHEMATICAE PHYSICAEQUE DISCIPLINAE

STUDY GUIDE
Bachelor's and Master's Programmes
2020/2021

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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.

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 2020/21 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. 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.

Ask questions. As the wise old saying goes, *"Many things are lost for want of asking."* Please do no hesitate to ask when you do not understand something – in our culture it is not considered impolite or improper to do so. Ask the lecturer during the lecture or after, ask the tutor during the class or after it, ask your mentor, ask your classmates who (think that they) understand. Arrange a meeting with your teacher during office hours and ask there.

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 17, 2020

Academic calendar

Sep 7 – Sep 20, 2020	Electronic enrolment in winter semester courses – priority mode
Sep 21 – Oct 11, 2020	Electronic enrolment in winter semester courses – open mode
Sep 29, 2020 – Jan 10, 2021	Winter semester tuition
until Sep 30, 2020	Annual evaluation for academic year 2019/2020 and registration for second and higher years of bachelor's and master's programmes
Oct 1, 2020	Beginning of academic year 2020/2021 and of its winter semester
Oct 12 – Oct 23, 2020	Approval of electronic enrolment in courses by the Department of Student Affairs
Oct 27, 2020	Matriculation of first year students on bachelor's and master's study programmes
until Nov 2, 2020	Recommended period for deciding bachelor's thesis topics
Nov 12, 2020	Dean's Sports Day (no lectures or classes)
Nov 20, 2020	Graduation Ceremony – bachelor's study programmes
Nov 23, 2020	Graduation Ceremony – bachelor's study programmes
Nov 26, 2020	Open Day
Dec 3, 2020	Graduation Ceremony – master's study programmes
Dec 23, 2020 – Jan 3, 2021	Christmas vacation
until Jan 6, 2021	Submission of bachelor's and master's (diploma) thesis for winter period of state final examinations - electronic version
until Jan 7, 2021	Submission of bachelor's and master's (diploma) thesis for winter period of state final examinations - paper version
Jan 11 – Feb 14, 2021	Winter semester examination period
until Jan 17, 2021	Checking compliance with all conditions the final year of bachelor's and master's for admission to the winter term of state final examinations
	Registration for winter period of bachelor's and master's state final examinations
Feb 1 – Feb 12, 2021	Winter period bachelor's and master's state final examinations

Feb 1 – Feb 7, 2021	Electronic enrolment in summer semester courses – priority mode
Feb 8 – Mar 7, 2021	Electronic enrolment in summer semester courses – open mode
until Feb 12, 2021	Recommended period for deciding master's thesis topics
Feb 15 – May 23, 2021	Summer semester tuition
until Feb 28, 2021	For first year bachelor's students: Annual evaluation after the winter semester
Mar 8 – Mar 19, 2021	Approval of electronic enrolment in courses by the Department of Student Affairs
Apr 20, 2021	Graduation Ceremony – master's study programmes
until May 7, 2021	Submission of master's thesis for summer period of state final examinations - electronic version
until May 10, 2021	Submission of master's thesis for summer period of state final examinations - paper version
May 12, 2021	Rector's Day (no lectures or classes)
until May 13, 2021	Submission of bachelor's thesis for summer period of state final examinations - electronic version
until May 17, 2021	Submission of bachelor's thesis for summer period of state final examinations - paper version
until May 24, 2021	Checking compliance with all conditions the final year of master's studies for admission to the summer term of state final examinations
	Registration for summer period of master's state final examinations
May 24 – Jun 30, 2021	Summer semester examination period
until Jun 6, 2021	Checking compliance with all conditions the final year of bachelors studies for admission to the summer term of state final examinations
	Registration for summer period of bachelor's state final examinations
Jun 7 – Jun 18, 2021	Summer period for master's state final examinations
Jun 14 – Jun 25, 2021	Summer period for bachelor's state final examinations
Jul 1 – Aug 31, 2021	Summer vacation
until Jul 22, 2021	Submission of bachelor's and master's (diploma) thesis for autumn period of state final examinations - electronic version
until Jul 23, 2021	Checking compliance with all conditions the final year of bachelor's and master's studies for admission to the autumn term of state final examinations

	Registration for autumn period of bachelor's and master's state final examinations
until Jul 26, 2021	Submission of bachelor's and master's (diploma) thesis for autumn period of state final examinations - paper version
Sep 1 – Sep 10, 2021	Autumn period for bachelor's state final examinations
Sep 2 – Sep 15, 2021	Autumn period for master's state final examinations
Sep 20 – Sep 24, 2021	Examination period
until Sep 30, 2021	Annual evaluation for academic year 2020/2021 and registration for second and higher years of bachelor's and master's study programmes
Sep 30, 2021	End of academic year 2020/2021

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. Tomáš Zima, DrSc., MBA

Faculty of Mathematics and Physics

Address: Ke Karlovu 3, 121 16 Praha 2, phone 221 911 289, fax 221 911 292,
e-mail: sdek@dekanat.mff.cuni.cz

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prof. RNDr. Jan Kratochvíl, CSc.

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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	—	4/0 Ex
NMAG437	Seminar on Differential Geometry	3	0/2 C	0/2 C
NMAG438	Group Representations 1	5	—	2/2 C+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	—
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
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	—

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	—	4/0 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)	2	—	0/2 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	—

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	Aplications of Mathematics in Computer Science	3	0/2 C	0/2 C
NMMB452	Seminar on Mathematics Inspired by Cryptography	3	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	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: doc. 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 etemployment 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.

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, conformal maps) and functional analysis (Banach and Hilbert spaces, dual spaces, bounded operators, compact operators, basic theory of distributions).
- 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 – fundamental solution and maximum principle, wave equation – fundamental solution, 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	—
NMMA408	**Complex Analysis 2**	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

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.

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 five subject areas: “Real Analysis”, “Complex Analysis”, “Functional Analysis”, “Ordinary Differential Equations”, and “Partial Differential Equations”. One question is asked from each subject area.

Requirements for the oral part of the final exam

1. Real Analysis

Measure theory and signed measures, Radon measures. Absolutely continuous functions and functions with bounded variation. Hausdorff measure and Hausdorff dimension.

2. Complex Analysis

Meromorphic functions. Conformal mappings. Harmonic functions of two real variables. Zeros of holomorphic functions. Holomorphic functions of several complex variables. Analytic continuation.

3. Functional Analysis

Topological linear spaces. 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 and Bochner spaces.

4.4 Recommended Course of Study

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
NMMA408	**Complex Analysis 2**	5	—	2/2 C+Ex
NSZZ023	**Diploma Thesis I**	6	—	0/4 C
	Optional and Elective Courses	14		

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. Mgr. Petr Knobloch, Dr., DSc.

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	*Seminář z mechaniky kontinua*	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
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
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	—
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	**Themodynamics and Mechanics of Solids**	5	—	2/1 C+Ex
NMNV405	**Finite Element Method 1**	5	2/2 C+Ex	—
NMNV412	**Analysis of matrix iterative methods — principles and interconnections**	6	—	4/0 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

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
NMMO531	Biothermodynamics	5	2/2 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	—
NMNV403	Numerical Software 1	5	2/2 C+Ex	—
NMNV404	Numerical Software 2	5	—	2/2 C+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
NOFY026	Classical Electrodynamics	6	—	2/2 C+Ex
NTMF034	Electromagnetic Field and Special Theory of Relativity	5	—	2/1 Ex

* The course NMNV501 is taught in the academic year 2020/21 for the last time. It is replaced with the course NMNV503 in the following years.

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	*Seminář z mechaniky kontinua*	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	**Themodynamics and Mechanics of Solids**	5	—	2/1 C+Ex

Code	Subject	Credits	Winter	Summer
	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.

7.1 Obligatory Courses

Code	Subject	Credits	Winter	Summer
NMSA401	**Primary Seminar**	2	0/2 C	—
NMSA403	**Optimisation Theory**	5	2/2 C+Ex	—
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	—
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

Set 1

It is required to earn at least 7 credits from this group.

Code	Subject	Credits	Winter	Summer
NMEK450	Econometrics Seminar 1	2	—	0/2 C
NMEK551	Econometric Project Seminar	5	0/2 C	—
NMST450	Statistical Seminar 1	2	—	0/2 C
NMST551	Statistical Workshop	5	0/2 C	—
NMTP450	Seminar on Probability 1	2	—	0/2 C
NMTP551	Seminar on Probability 2	5	0/2 C	—

Set 2

It is required to earn at least 43 credits from this group. We recommend making a planned choice of subject areas for the final exam and the master's thesis topic when choosing elective courses.

Code	Subject	Credits	Winter	Summer
NMEK432	Econometrics	8	—	4/2 C+Ex
NMEK436	Computational Aspects of Optimisation	5	—	2/2 C+Ex
NMEK531	Mathematical Economics	5	2/2 C+Ex	—
NMEK532	Optimisation with Applications to Finance	8	—	4/2 C+Ex

NMFM431	Investment Analysis	5	2/2 C+Ex	—
NMFM437	Mathematics in Finance and Insurance	6	4/0 Ex	—
NMFM531	Financial Derivatives 1	3	2/0 Ex	—
NMFM532	Financial Derivatives 2	3	2/0 Ex	—
NMFM535	Stochastic Analysis in Financial Mathematics	5	—	2/2 C+Ex
NMFM537	Credit Risk in Banking	3	2/0 Ex	—
NMST431	Bayesian Methods	5	2/2 C+Ex	—
NMST432	Advanced Regression Models	8	—	4/2 C+Ex
NMST434	Modern Statistical Methods	8	—	4/2 C+Ex
NMST436	Experimental Design	5	2/2 C+Ex	—
NMST438	Survey Sampling	5	2/2 C+Ex	—
NMST440	Computational Environment for Statistical Data Analysis	4	—	0/2 C
NMST442	Matrix Computations in Statistics	5	—	2/2 C+Ex
NMST531	Censored Data Analysis	5	2/2 C+Ex	—
NMST532	Design and Analysis of Medical Studies	5	—	2/2 C+Ex
NMST533	Asymptotic Inference Methods	3	2/0 Ex	—
NMST535	Simulation Methods	5	—	2/2 C+Ex
NMST537	Time Series	8	4/2 C+Ex	—
NMST539	Multivariate Analysis	5	—	2/2 C+Ex
NMST541	Statistical Quality Control	5	—	2/2 C+Ex
NMST543	Spatial Statistics	5	2/2 C+Ex	—
NMST552	Statistical Consultations	2	—	0/2 C
NMTP432	Stochastic Analysis	8	—	4/2 C+Ex
NMTP434	Invariance Principles	6	—	4/0 Ex
NMTP436	Continuous Martingales and Counting Processes	3	—	2/0 Ex
NMTP438	Spatial Modelling	8	—	4/2 C+Ex
NMTP532	Ergodic Theory	4	—	3/0 Ex
NMTP533	Applied Stochastic Analysis	5	2/2 C+Ex	—
NMTP535	Selected Topics on Measure Theory	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	—

7.3 Recommended Optional Courses

Code	Subject	Credits	Winter	Summer
NMFM461	*Demography*	3	—	2/0 Ex
NMST570	*Selected topics in psychometrics*	3	1/1 C+Ex	—

NMST571	*Seminar in psychometrics*	2	—	0/2 C
NMTP562	*Markov Processes*	6	—	4/0 Ex
NMTP563	*Selected Probability Topics for Statistics*	5	—	2/2 C+Ex
NMTP567	*Selected Topics on Stochastic Analysis*	3	2/0 Ex	—
NMTP570	*Heavy-Tailed Distributions*	3	—	2/0 Ex
NMTP576	*Conditional Independence Structures*	3	—	2/0 Ex

7.4 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 7 credits by completion of elective courses from group I.
- Earning at least 43 credits by completion of elective courses from group II.
- 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. The first subject area is common. The second subject area is selected from three options (2A, 2B, 2C). The third subject area is selected from seven options 3A–3G. One question is asked from the common subject area and one from each selected optional subject area.

Requirements for the oral part of the final exam

Common subject area

1. 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.

Optional subject area 2: Advanced Models

A choice of one of three options

2A. Econometrics and Optimization Methods

Stationary sequences, time series. Foundations of econometrics. Advanced optimization.

2B. Advanced Statistical Analysis.

Modern theory of estimation and statistical inference. Regression models for non-normal and correlated data.

2C. Processes in Time and Space.

Stochastic processes in continuous time. Martingales. Invariance principles. Brownian motion.

Optional subject area 3: Special Topics

A choice of one of seven options

3A. Econometric Models

Mathematical economics. Time series with financial applications. Advanced econometrical and statistical models. Multivariate statistical analysis.

3B: Optimization Methods

General optimization problems, optimal control. Applications of optimization in economics and finance. Mathematical economics. Time series.

3C: Spatial Modelling

Spatial modelling and spatial statistics. Foundations of stochastic analysis. Limit theorems in probability theory.

3D: Stochastic Analysis

Stochastic analysis. Itô formula. Stochastic differential equations. Poisson processes, stationary point processes. Limit theorems.

3E. Statistics in Industry, Trade and Business

Survey sampling. Design of industrial experiments. Time series. Statistical quality control. Reliability theory.

3F. Statistics in Natural Sciences

Design and analysis of medical experiments. Multivariate statistical analysis. Survival analysis. Bayesian methods.

3G. Theoretical Statistics

Invariance principles. Limit theorems. Methods for censored data analysis. Multivariate analysis.

7.4. Recommended Course of Study

1st year

Code	Subject	Credits	Winter	Summer
NMSA407	**Linear Regression**	8	4/2 C+Ex	—
NMSA409	**Stochastic Processes 2**	8	4/2 C+Ex	—
NMSA403	**Optimisation Theory**	5	2/2 C+Ex	—
NMSA405	**Probability Theory 2**	5	2/2 C+Ex	—
NMSA401	**Primary Seminar**	2	0/2 C	—
	Optional and Elective Courses	32		

2nd year

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
	Optional and Elective Courses	30		

8 Degree Plans - Financial and Insurance Mathematics

Coordinated by: Department of Probability and Mathematical Statistics
Study programme coordinator: prof. RNDr. Tomáš Cipra, DrSc.

This programme provides theoretical and applied education in financial and insurance mathematics. A solid mathematical background provides the foundations for developing disciplines of mathematical modelling in the insurance and banking industry and other financial areas. The graduate will be able to develop financial and insurance products and analyse their profitability and risk.

The graduate will have a deep knowledge of basic mathematical disciplines (mathematical analysis, algebra) and special knowledge in the fields of probability and statistics, stochastic processes, mathematical methods in finance, life and non-life insurance, advanced financial management, risk theory, accounting, and modelling with progressive systems (Mathematica). This knowledge provides tools for effective modelling of financial and insurance products, analysis of their profitability and risk, and other characteristics important for effective financial management.

Assumed knowledge

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

- Multivariate differential and integral calculus, measure theory, Lebesgue integral, vector spaces, matrix algebra.
- Foundations of probability theory, mathematical statistics, and data analysis. Theory of Markov chains.
- Foundations of financial mathematics and accounting.
- Foundations of functional programming.

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.

8.1 Obligatory Courses

Code	Subject	Credits	Winter	Summer
NMFM401	**Mathematics of Non-Life Insurance 1**	5	2/2 C+Ex	—
NMFM402	**Mathematics of Non-Life Insurance 2**	5	—	2/2 C+Ex
NMFM404	**Selected Software Tools for Finance and Insurance**	3	—	2/0 Ex
NMFM405	**Life Insurance 1**	5	2/2 C+Ex	—
NMFM406	**Life Insurance 2**	3	—	2/0 Ex
NMFM408	**Probability for Finance and Insurance**	3	—	2/0 Ex
NMFM410	**Insurance Companies Accounting**	5	—	2/2 C+Ex
NMFM416	**Life Insurance 2, exercises**	2	—	0/2 C

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	—
NMSA407	**Linear Regression**	8	4/2 C+Ex	—
NMSA409	**Stochastic Processes 2**	8	4/2 C+Ex	—
NMST537	**Time Series**	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

8.2 Elective Courses

It is required to earn at least 5 credits from the following elective courses.

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

Recommended Optional Courses

Code	Subject	Credits	Winter	Summer
NMEK432	*Econometrics*	8	—	4/2 C+Ex
NMEK532	*Optimisation with Applications to Finance*	8	—	4/2 C+Ex
NMFM461	*Demography*	3	—	2/0 Ex
NMFM462	*Practical Aspects of Financial Risk Measuring and Management*	3	2/0 Ex	—
NMFM535	*Stochastic Analysis in Financial Mathematics*	5	—	2/2 C+Ex
NMFM537	*Credit Risk in Banking*	3	2/0 Ex	—
NMSA571	*Information Theory, Finance and Statistics*	3	—	2/0 Ex

8.3 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 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. Probability and Statistics

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. Financial risk. Stock market analysis. Accounting.

8.4 Recommended Course of Study

1st year

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

NMFM416	**Life Insurance 2, exercises**	2	—	0/2 C
	Optional and Elective Courses	7		

2nd year

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

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 six specializations starting in the second year of study:

- General Computer Science
- Programming and Software Development
- Systems Programming
- Databases and Web
- Artificial Intelligence
- Computer Graphics, Vision and Game Development.

Students select their specialization during the second year of their study in accordance with the study regulations. Please note that some specializations might not be offered; in 2020/2021 we currently plan to offer General Computer Science, Databases and Web, and Artificial Intelligence.

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 six 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 (properties of limits and sums, convergence criteria). Real functions of one variable. Continuity, limit of a function (ordinary, infinite). Derivatives: definition and basic rules. Applications (examination of behaviour of functions, Taylor polynomial with remainder). Antiderivatives (primitive functions): definition, uniqueness, existence, methods of calculation.

Relevant courses:

– Mathematical Analysis 1 (NMAI054)

2. Algebra and Linear Algebra

Groups and subgroups, definitions, examples, commutativity. Fields – definition, characterization of a field, finite fields. Vector spaces and subspaces, properties, basic notions (linear combination, linear span/ hull, generators, linear dependence and independence, basis, dimension, coordinates) and uses. Practical ability in testing for linear dependence and independence, finding a basis, determining the dimension etc. Scalar product and its properties. Norm and its relation to scalar product, examples. Orthogonality, othonormal basis, properties and uses (e.g. finding coordinates, projection). Systems of linear equations and sets of solutions. Solution methods, Gauss and Gauss–Jordan elimination, reduced row echelon form of a matrix and uniqueness (without proof). Matrices, operations with matrices (addition, multiplication, transposition, etc.), interpretation of matrix multiplication as composition of linear mappings. Matrix rank, rank of a transposition. Eigenvalues and eigenvectors of a matrix, geometric meaning and properties, spectral radius. 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 (reflexivity, symmetry, antisymmetry, transitivity). Equivalence relations and partition into equivalence classes. Partial orders, basic concepts (minimal and maximal elements, minimum and maximum elements, chains, antichains), height and width of a partially ordered set and their mutual relationship. Functions, types of functions (injective, surjective, bijective) and the number of functions between two finite sets of a given type. Permutations and their basic properties (number of permutations, fixed points, etc.). Binomial coefficients and relationships between them, binomial theorem and its applications. Principle of inclusion and exclusion, general formulation (and proof), applications (Euler's totient function, number of surjections, etc.). Hall's theorem on systems of distinct representatives (SDR) and its relation to matchings in a bipartite graph, principle of proof and algorithmic consequences (polynomial-time algorithm for finding an SDR).

Relevant courses:

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

4. Graph Theory

Basic concepts (graph, vertices and edges, graph isomorphism, subgraph, vertex neighbourhood and vertex degree, graph complement, bipartite graph), basic examples of graphs (complete graph, complete bipartite graph, paths, cycles). Connected graphs, connected components, distance in a graph. Trees: definition and basic properties (existence of leaves, number of edges), equivalent characterizations of trees. Planar graphs: definition and basic concepts (planar graph and plane drawing of a graph, faces), Euler's formula and the maximum number of edges in a planar graph (proof and applications). Graph colourings: definition of a proper colouring, relation between chromatic number and clique number. Edge- and vertex-connectivity, edge and vertex version of Menger's theorem. Directed graphs: weak and strong connectivity. Network flows: definition of a network and of a flow, existence of a maximum flow (without proof), basic principle of finding a maximum flow in a network with integer-valued capacities (e.g. using the Ford–Fulkerson algorithm).

Relevant courses:

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

5. Probability and Statistics

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

Relevant courses:

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

6. Logic

Syntax – knowledge of and working with the basic syntax of propositional and predicate logic (language, open and closed formulas, etc.). Normal forms of propositional formulas, prenex normal forms of predicate logic formulas – knowledge of basic normal forms (CNF, DNF, PNF), 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, language accepted by a finite automaton, deterministic, nondeterministic, epsilon transitions, regular expressions, Kleene's theorem, iteration (pumping) lemma for finite automata, regular grammars. Context-free languages: context-free grammar, language generated by a grammar, push-down automaton, class of languages accepted by push-down automata. Turing machine: type 0 grammar, diagonal language, universal language. Chomsky hierarchy: determination of equivalence or inclusion between classes of languages generated by the automata and grammars mentioned above. Classifying a given language in the Chomsky hierarchy (typically by constructing an appropriate automaton or grammar and proving that the language does not belong to a lower class using an iteration lemma).

Relevant courses:

– Automata and Grammars (NTIN071)

2. Algorithms and Data Structures

Time complexity of algorithms: time and space needed for computation on a given input, time and space complexity of an algorithm, data size measurement, complexity in the worst, best and average case, asymptotic notation. Complexity classes: P and NP, problem reducibility, NP-hardness and NP-completeness, examples of NP-complete problems and reductions among them. "Divide and conquer" technique: recursive division of a problem into subproblems, complexity computation using recursive equations, master theorem, applications (Merge sort, multiplication of long numbers, Strassen's algorithm). Binary search trees: definition of a search tree, operations with non-balanced trees, AVL trees (definition only). Heaps: binary heap. Hashing: hashing with buckets, open addressing. Sorting: primitive sorting algorithm (Bubble sort, Insertion sort etc.), Heapsort, Quicksort, lower bound for sorting based on pairwise comparisons, bucket sorting for numbers and strings. Graph algorithms: depth-first search and breadth-first search, connected component detection, topological sorting of directed graphs, shortest paths in weighted graphs (Dijkstra's algorithm, Bellman–Ford algorithm), minimum spanning trees (Jarník's algorithm, Borůvka's algorithm), network flows (Ford–Fulkerson algorithm). Algebraic algorithms: Euclid's algorithm.

Relevant courses:

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

3. Programming Languages

Concepts and principles of object-oriented design: classes, interfaces, methods, attributes, inheritance (visibility of members, namespaces, separation into packages/modules), multiple inheritance and its problems (language-specific methods for resolving problems, multiple and virtual inheritance in C++, single inheritance and default methods in Java), implementing interfaces, polymorphism (static vs. dynamic polymorphism), functional elements of object-oriented languages (function objects, lambdas, support in standard libraries). Implementation of object-oriented languages: basic object-oriented concepts in a concrete language (Java, C++, C#), primitive types vs. objects (implementation of primitive types, memory representation of compound types and objects), implementation of virtual methods (virtual method tables), lifetime of objects (allocating and initializing objects (statically, on the stack, on the heap), constructors, calling inherited constructors, freeing objects, explicit delete/dispose, garbage collection, automatically freeing objects, shared_ptr/unique_ptr, destructors, finalizers), threads and synchronization (implementing threads, basic synchronization constructs, data types with atomic operations), debugging, exceptions (throwing and catching exceptions (try-catch-finally), working with resources: try-with-resources (Java), RAII (C++), using (C#)). Separate compilation, linking, compiler directives: compilation vs. interpreting, role of linking, JIT.

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

Data representation: encoding and layout in memory, bitwise operations and their usage. Computer organization: von Neumann and Harvard architectures, computer memory, secondary storage, address spaces, input/output devices. Instruction set architectures: computer instructions, high-level programming-language constructs and their representation using computer instructions, basic notion of a shared-memory multi-processor. Operating systems: computer and OS initialization, OS kernel, device drivers, privileged and non-privileged code execution, programming interfaces, OS shell environment, user management. Hardware/software interface: device drivers and driver stack, interrupt and exceptions at CPU, OS, and programming language level. Processes and threads: process and thread contexts, process hierarchy, cooperative and preemptive multitasking, scheduling, thread states, active and passive waiting. Race conditions, critical section, mutual exclusion, synchronization primitives, the notions of deadlock and livelock. File and socket APIs, file descriptors, accessing devices as files, standard input and output and their redirection, interprocess communication via pipes.

Relevant courses:

– Principles of Computers (NSWI120)
– 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
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	—
NMAI063	Algebra 2	3	—	2/0 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

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	Database Access Methods	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	Web Applications Programming	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: Dinic and Goldberg algorithms. Application of flows: disjoint paths, matching in bipartite graphs. Flows and paths in graphs with integer weights. Text search algorithms: Knuth–Morris–Pratt, Aho–Corasick, and Rabin–Karp 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 - Programming and Software Development

Coordinating Department: Department of Software Engineering
Specialization Coordinator: RNDr. Filip Zavoral, Ph.D.

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
NSWI004	**Operating Systems**	4	2/1 MC	—

NPRG041	**Programming in C++**	5	2/2 C+Ex	—
NSWI142	**Web Applications Programming**	5	2/2 C+Ex	—
NSWI154	**Software Development Tools**	2	0/2 C	—
NSWI041	**Introduction to Software Engineering**	5	—	2/2 C+Ex
NPRG043	**Recommended Programming Practices**	5	—	2/2 MC

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 5 credits from courses in this group.

Code	Subject	Credits	Winter	Summer
NPRG013	Programming in Java Language	5	2/2 C+Ex	—
NPRG035	Programming in C# Language	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 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
NSWI153	Advanced Programming of Web Applications	5	—	2/2 C+Ex
NPRG056	Mobile Devices Programming	3	0/2 C	—

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
NPRG024	Design Patterns	3	—	0/2 MC
NSWI143	Computer Architecture	3	—	2/0 Ex
NPRG036	Data Formats	5	—	2/2 C+Ex
NSWI130	Software System Architectures	5	2/2 C+Ex	—
NSWI090	Computer Networks	3	—	2/0 Ex

Elective courses – group 4

A prerequisite for taking either part of the State Final Exam is to have obtained at least 6 credits from courses in this group.

Code	Subject	Credits	Winter	Summer
NSWI098	Compiler Principles	6	2/2 C+Ex	—
NPRG054	High Performance Software Development	6	—	2/2 C+Ex
NPRG042	Programming in Parallel Environment	6	—	2/2 C+Ex

Elective courses – group 5

Code	Subject	Credits	Winter	Summer
NPGR038	Introduction to Computer Game Development	5	—	2/2 C+Ex
NPGR003	Introduction to Computer Graphics	5	2/2 C+Ex	—
NDBI007	Database Access Methods	4	2/1 C+Ex	—
NDBI040	Modern Database Systems	5	2/2 C+Ex	—
NSWI162	Program Semantics	1	0/1 C	—
NSWI163	Introduction to Middleware	1	0/1 MC	—
NPFL129	Introduction to Machine Learning with Python	5	2/2 C+Ex	—
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	—

3.3 Recommended Course of Study

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	**Web Applications Programming**	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**	5	2/2 C+Ex	—
	Advanced Programming in Java/C++/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
	Elective courses			

	Additional courses			

Third year

Code	Subject	Credits	Winter	Summer
	Programming in Java/C++/C#	5	2/2 C+Ex	—
	Advanced Programming in Java/C++/C#	5	—	2/2 C+Ex
NSWI098	Compiler Principles [6]	6	2/2 C+Ex	—
NPRG054	High Performance Software Development	6	—	2/2 C+Ex
NPRG042	Programming in Parallel Environment	6	—	2/2 C+Ex
NSZZ031	**Bachelor Thesis**	6	—	0/4 C
	Elective courses			
	Additional 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 Programming and Software Development specialization will be further tested according to the list below.

1. Computer Architecture, Operating Systems and Networks

Runtime memory organization. Memory representation of arrays, structures, and classes. Cache, performance impact, NUMA. Virtual memory. Processing of instructions by processors. Processes and threads, context switching, IRQ, asynchronous I/O. Multicore, multisocket. Physical, link and transport layers. Internetworking, VLAN. TCP/IP adressing.

2. Programming Languages

Object lifetime. Components, dependency injection. Parallel programming, threads. Debugging, exceptions. Reflection and introspection. Principles of dynamic languages. Functional aspects of object languages. Static vs. dynamic polymorphism, generic programming, type deduction. Standard libraries. Design patterns. Principles of WWW, HTTP, URL. Static web pages. Principles of web applications. Client side programming. API of web applications.

3. Software Engineering

Software development processes, requirement analysis, testing, maintenance, risk analysis. Version control systems. Building. Performance measurement. Design of API, classes and methods, object design. Principles of web application security.

4. Databases

Architectures of database systems. Normal forms. Database schema, keys, indexes, integrity constraints. Transactions and their properties. SQL - common statements, subqueries. SQL procedures and functions, triggers.

4 Degree Plans - System Programming

Coordinating Department: Department of Distributed and Dependable Systems

Specialization Coordinator: doc. Ing. Lubomír Bulej, Ph.D.

The System Programming specialization focuses on the prerequisites for the design, development, and maintenance of efficient system software, which provides the foundation for application software. Topics therefore include computer architecture, operating systems, parallel and distributed systems, and middleware. In System Programming emphasis is put on a deeper understanding of modern programming languages used for the development of system software, and on the ability to use modern development tools and approaches.

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
NSWI004	**Operating Systems**	4	2/1 MC	—
NPRG041	**Programming in C++**	5	2/2 C+Ex	—
NSWI143	**Computer Architecture**	3	—	2/0 Ex
NSWI098	**Compiler Principles**	6	2/2 C+Ex	—
NSWI163	**Introduction to Middleware**	1	0/1 MC	—
NSWI162	**Program Semantics**	1	0/1 C	—
NPRG054	**High Performance Software Development**	6	—	2/2 C+Ex
NPRG042	**Programming in Parallel Environment**	6	—	2/2 C+Ex
NSWI090	**Computer Networks**	3	—	2/0 Ex

4.2 Elective Courses

A prerequisite for taking either part of the State Final Exam is to have obtained at least 27 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 5 credits from courses in this group.

Code	Subject	Credits	Winter	Summer
NPRG035	Programming in C# Language	5	2/2 C+Ex	—
NPRG013	Programming in Java Language	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 5 credits from courses in this group.

Code	Subject	Credits	Winter	Summer
NPRG051	Advanced C++ Programming	5	—	2/2 C+Ex

NPRG038	Advanced C# Programming	5	—	2/2 C+Ex
NPRG021	Advanced Java Programming	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 7 credits from courses in this group.

Code	Subject	Credits	Winter	Summer
NSWI154	Software Development Tools	2	0/2 C	—
NPRG043	Recommended Programming Practices	5	—	2/2 MC
NPRG024	Design Patterns	3	—	0/2 MC
NSWI041	Introduction to Software Engineering	5	—	2/2 C+Ex
NSWI054	Software Engineering for Dependable Systems	3	—	0/2 C
NSWI130	Software System Architectures	5	2/2 C+Ex	—

Elective courses – Group 4

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
NMAI055	Mathematical Analysis 2	5	2/2 C+Ex	—
NPRG005	Non-procedural Programming	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	—
NAIL120	Introduction to Artificial Intelligence	5	—	2/2 C+Ex
NPGR035	Machine Learning in Computer Vision	5	2/2 C+Ex	—
NPGR002	Digital Image Processing	4	3/0 Ex	—
NPGR036	Computer Vision	5	—	2/2 C+Ex
NPGR003	Introduction to Computer Graphics	5	2/2 C+Ex	—
NPGR019	Realtime Graphics on GPU	5	—	2/2 C+Ex
NAIL028	Introduction to Robotics	5	2/2 C+Ex	—
NPRG037	Microcontroller Programming	5	2/2 C+Ex	—
NPGR038	Introduction to Computer Game Development	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 the general information above.

Second year

Code	Subject	Credits	Winter	Summer
NTIN061	**Algorithms and Data Structures 2**	5	2/2 C+Ex	—
NDBI025	**Database Systems**	5	2/2 C+Ex	—
NAIL062	**Propositional and Predicate Logic**	5	2/2 C+Ex	—
NSWI004	**Operating Systems**	4	2/1 MC	—
NPRG041	**Programming in C++**	5	2/2 C+Ex	—
	Programming in C#/Java	5	2/2 C+Ex	—
NTIN071	**Automata and Grammars**	5	—	2/2 C+Ex
NMAI059	**Probability and Statistics 1**	5	—	2/2 C+Ex
NSWI143	**Computer Architecture**	3	—	2/0 Ex
	Advanced Programming in C++/C#/Java	5	—	2/2 C+Ex
	Elective courses			

Third year

Code	Subject	Credits	Winter	Summer
NDMI011	**Combinatorics and Graph Theory 1**	5	2/2 C+Ex	—
NSWI098	**Compiler Principles**	6	2/2 C+Ex	—
NSWI163	**Introduction to Middleware**	1	0/1 MC	—
NSWI162	**Program Semantics**	1	0/1 C	—
NPRG045	**Individual Software Project**	4	0/1 C	—
	Elective courses			
	Optional courses			
NSWI090	**Computer Networks**	3	—	2/0 Ex
NPRG054	**High Performance Software Development**	6	—	2/2 C+Ex
NPRG042	**Programming in Parallel Environment**	6	—	2/2 C+Ex
NSZZ031	**Bachelor Thesis**	6	—	0/4 C
	Elective courses			
	Optional courses			

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 System Programming specialization will be further tested according to the list of subject areas below. For each area, we list the key topics and related courses which cover the area. Within the specialization, deeper level of understanding is expected for topics which overlap with the requirements common to all specializations. More detailed list of requirements, reflecting the expected depth of knowledge and understanding, will be available in electronic form well in advance of each final state exam.

1. Computer Architecture

Computer and processor performance, metrics and limitations. Instruction execution, parallelism, prediction, and speculation. Computer memory subsystem architecture, cache architectures. Multi-core and multi-socket systems, cache coherence. Communication with peripheral devices.

Related courses:

– Computer Architecture (NSWI143)

2. Operating Systems

Process and thread management, scheduling, communication, synchronization. System memory management, paging, in-process memory management, shared memory. File systems, concepts and interfaces, typical on-disk structures. Device management, device drivers.

Related courses:

– Operating Systems (NSWI004)

3. Computer Networks

Link layer, Ethernet addressing, VLAN. Network layer, IPv4 and IPv6 addressing, static routing, NAT, IP tunneling, VPN. Transport layer, addressing in TCP and UDP, reliability, flow control. Application interfaces and abstractions for network communication. Communication security, authentication, encryption.

Related courses:

– Computer Networks (NSWI090)

4. Compilers and Programming Languages

Compiler architecture, AOT and JIT compilation. Internal program representation. Program optimization. Code generation for target processor.

Related courses:

– Compiler Principles (NSWI098)

Memory management in language runtimes, object lifecycle. Polymorphism, generic programming, type inference. Prominent elements of standard libraries and their application.

Related courses:

The topics are covered by mandatory and elective courses focused on programming languages. Students of the System Programming specialization are required to complete at least 3 such courses:

– Programming in C++ (NPRG041)
– Elective courses from group 1: Programming in Java Language (NPRG013) or Programming in C# Language (NPRG035).
– Elective courses from group 2: Advanced C++ Programming (NPRG051), Advanced Java Programming (NPRG021), or Advanced C# Programming (NPRG038).

5. Software Design and Construction

Object-oriented design principles, design patterns. API, class, and method design.

Related courses:

The topic permeates a number of mandatory and elective courses focused on programming. Specifically, students are expected to supplement their knowledge through a suitable combination of elective courses from group 3.

– Recommended Programming Practices (NPRG043) or Design Patterns (NPRG024)
– Introduction to Software Engineering (NSWI041), Software System Architectures (NSWI054), or Software Engineering for Dependable Systems (NSWI054)

Parallel programming, memory model, atomic operations and non-blocking data structures.

Related courses:

– Programming in Parallel Environment (NPRG042)

Version management, software build systems, software testing and associated tools.

Related courses:

– Software Development Tools (NSWI154)

In this specialization, students are assumed to acquire the necessary knowledge and skills by completing courses in which producing software artefacts plays an important role. The mandatory and elective courses (groups 1 and 2) focused on programming languages serve as a basis, complemented by a suitable selection of elective courses from group 3.

5 Degree Plans - Databases and Web

Coordinating Department: Department of Software Engineering
Specialization Coordinator: Prof. RNDr. Tomáš Skopal, 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.

5.1 Obligatory Courses

Code	Subject	Credits	Winter	Summer
NSWI142	**Web Applications Programming**	5	2/2 C+Ex	—

NDBI026	**Database Applications**	4	—	1/2 MC
NDBI007	**Database Access Methods**	4	2/1 C+Ex	—
NDBI040	**Modern Database Systems**	5	2/2 C+Ex	—
NSWI153	**Advanced Programming of Web Applications**	5	—	2/2 C+Ex
NPRG036	**Data Formats**	5	—	2/2 C+Ex
NDBI046	**Data Management**	5	—	2/2 C+Ex
NDBI038	**Searching the Web**	4	—	2/1 C+Ex

5.2 Elective Courses

Elective courses – group 1

A prerequisite for taking either part of the State Final Exam is to have obtained at least 15 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

Elective courses – group 2

A prerequisite for taking either part of the State Final Exam is to have obtained at least 6 credits from courses in this group.

Code	Subject	Credits	Winter	Summer
NSWI004	Operating Systems	4	2/1 MC	—
NPFL054	Introduction to Machine Learning with R	5	2/2 C+Ex	—
NDBI045	Video Retrieval and Exploration	5	—	2/2 C+Ex
NDBI037	Information Models with Ordering	4	2/1 C+Ex	—
NDBI013	Oracle Administration	2	—	0/2 C

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
NMAI055	Mathematical Analysis 2	5	2/2 C+Ex	—
NPRG056	Mobile Devices Programming	3	0/2 C	—
NAIL120	Introduction to Artificial Intelligence	5	—	2/2 C+Ex
NSWI130	Software System Architectures	5	2/2 C+Ex	—
NSWI090	Computer Networks	3	—	2/0 Ex
NPGR036	Computer Vision	5	—	2/2 C+Ex

NPGR002	Digital Image Processing	4	3/0 Ex	—
NAIL121	Seminar on Data Mining	4	—	1/2 MC
NPGR035	Machine Learning in Computer Vision	5	2/2 C+Ex	—

5.3 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	**Web Applications Programming**	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	—
NSWI153	**Advanced Programming of Web Applications**	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	**Database Applications**	4	—	1/2 MC
NDBI007	**Database Access Methods**	4	2/1 C+Ex	—
NDBI040	**Modern Database Systems**	5	2/2 C+Ex	—
NPRG036	**Data Formats**	5	—	2/2 C+Ex
NDBI046	**Data Management**	5	—	2/2 C+Ex
NDBI038	**Searching the Web**	4	—	2/1 C+Ex
NSZZ031	**Bachelor Thesis**	6	—	0/4 C
	Elective courses			
	Optional courses			

5.4 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

Topics covered by the courses NDBI025 Database Systems, NDBI026 Database Applications, NDBI040 Modern Database Concepts

2. Data Management

Topics covered by the courses NPRG036 Data Formats, NDBX046 Data Management, NDBX007 Database Access Methods

3. Web

Topics covered by the courses NSWI142 Web Applications Programming, NSWX153 Advanced Programming of Web Applications, NDBI038 Searching the Web

6 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.

6.1 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	—

6.2 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	5	2/2 C+Ex	—
NPFL129	Introduction to Machine Learning with Python	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	Text processing in UNIX	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

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 and Exploration	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	—

6.3 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	—
NPFL054	Introduction to Machine Learning with R	5	2/2 C+Ex	—
NPFL129	Introduction to Machine Learning with Python	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
NAIL121	Seminar on Data Mining	4	—	1/2 MC
NPFL124	Natural Language Processing	4	—	2/1 C+Ex
NPRG036	Data Formats	5	—	2/2 C+Ex
NSZZ031	**Bachelor Thesis**	6	—	0/4 C
	Elective courses			
	Optional courses			

6.4 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

Problem solving via search (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).

Recommended 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.

Recommended 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.

Recommended 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.

Recommended 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

7 Degree Plans - Computer Graphics, Vision and Game Development

Coordinating Department: Department of Software and Computer Science Education

Specialization Coordinator: RNDr. Josef Pelikán

The specialization Computer Graphics, Vision and Game Development is intended for students interested in visual disciplines of computer science – realistic image synthesis, digital image analysis and computer game development. A natural continuation of this specialization is the master degree study plan Visual Computing and Game Development. But this bachelor specialization consists in itself of a complete degree which can be easily utilized in industry:

- Design of graphical systems, e.g. for visual effects or photorealistic visualizations (postproduction teams, visual effect departments, realistic rendering engines, shaders, etc.)
- Employment in any field where digital image processing or computer vision is used (engineering, electronics, development of robotic systems, medicine, security, automatic quality check, remote sensing, etc.)
- Computer game development at multiple levels (game engine developer, GPU programmer /shaders/, game content editing tools, game logic programming, artificial intelligence, data /game levels/ processing, etc.)

The specialization Computer Graphics, Vision and Game Development has the following branches:

- Computer Graphics
- Computer Vision
- Game Development

Each of the three branches follows the same rules and conditions and has the same set of obligatory and elective courses. The first three topics (1. to 3. – see further below) of the State Final Exam requirements are shared among all three branches as well. The only difference is the last specific set of State Final Exam requirements: "profile courses" are offered in order to cover these distinct requirements.

Common obligatory courses in Computer Science

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

7.1 Obligatory Courses

Code	Subject	Credits	Winter	Summer
NPGR003	**Introduction to Computer Graphics**	5	2/2 C+Ex	—
NMAI055	**Mathematical Analysis 2**	5	2/2 C+Ex	—
NPRG041	**Programming in C++**	5	2/2 C+Ex	—
NPRG035	**Programming in C# Language**	5	2/2 C+Ex	—

7.2 Elective Courses

A prerequisite for taking either part of the State Final Exam is to have obtained at least 43 credits from elective courses overall. Selection of courses should be based on the branch that will be taken in the State Final Exam. Please see the knowledge requirements section below.

Code	Subject	Credits	Winter	Summer
NPGR025	Introduction to Colour Science	3	2/0 Ex	—
NPGR002	Digital Image Processing	4	3/0 Ex	—
NPGR035	Machine Learning in Computer Vision	5	2/2 C+Ex	—
NPGR037	Matlab Practice	3	0/2 C	—
NSWI160	Game Development Middleware	6	0/4 C	—

NSWI159	Practical Course on Game Development [1]	2	0/1 C	0/1 C
NPGR004	Photorealistic Graphics	5	—	2/2 C+Ex
NPGR019	Realtime Graphics on GPU	5	—	2/2 C+Ex
NPGR020	Geometry for Computer Graphics	3	—	2/0 Ex
NPGR036	Computer Vision	5	—	2/2 C+Ex
NPGR038	Introduction to Computer Game Development	5	—	2/2 C+Ex
NSWI004	Operating Systems	4	2/1 MC	—
NAIL028	Introduction to Robotics	5	2/2 C+Ex	—
NMAI073	Probability and Statistics 2	5	2/2 C+Ex	—
NMAI056	Mathematical Analysis 3	5	—	2/2 C+Ex
NPRG051	Advanced C++ Programming	5	—	2/2 C+Ex
NPRG038	Advanced C# Programming	5	—	2/2 C+Ex
NPRG005	Non-procedural Programming	5	—	2/2 C+Ex
NAIL120	Introduction to Artificial Intelligence	5	—	2/2 C+Ex
NPRG054	High Performance Software Development	6	—	2/2 C+Ex
NPRG042	Programming in Parallel Environment	6	—	2/2 C+Ex
NMAI042	Numerical Mathematics	5	—	2/2 C+Ex
NDBI045	Video Retrieval and Exploration	5	—	2/2 C+Ex
NOPT046	Discrete and Continuous Optimization	5	—	2/2 C+Ex

[1] Practical Course on Game Development is taught each semester and students are allowed to take it repeatedly (each successfully completed semester earns two credit points). In fact we recommend students following the branch Game Development to take this course more than once.

7.3 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. "Profile courses" are important because they cover material needed for State Final Exam. The three branches have different profile courses – see the section giving the requirements for the State Final Exam.

There are three recommended courses of study, one for each study branch. Obligatory courses are printed in boldface, elective courses in roman, and optional courses in italics. Profile courses (needed for the State Final Exam) are footnoted 1, generally recommended lectures are footnoted 2, and elective courses without a footnote can be freely substituted by others.

First year

Common to all specializations – see under general information above.

Second year – Computer Graphics

Code	Subject	Credits	Winter	Summer
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	—
NPRG041	**Programming in C++**	5	2/2 C+Ex	—
NPRG035	**Programming in C# Language**	5	2/2 C+Ex	—
NPGR003	**Introduction to Computer Graphics**	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
NPGR004	Photorealistic Graphics [1]	5	—	2/2 C+Ex
NMAI056	Mathematical Analysis 3 [2]	5	—	2/2 C+Ex
NPRG051	Advanced C++ Programming [2]	5	—	2/2 C+Ex
NMAI042	Numerical Mathematics	5	—	2/2 C+Ex

Third year – Computer Graphics

Code	Subject	Credits	Winter	Summer
NAIL062	**Propositional and Predicate Logic**	5	2/2 C+Ex	—
NDBI025	**Database Systems**	5	2/2 C+Ex	—
NPGR025	Introduction to Colour Science [1]	3	2/0 Ex	—
NPGR002	Digital Image Processing [2]	4	3/0 Ex	—
NMAI073	Probability and Statistics 2 [2]	5	2/2 C+Ex	—
NPGR037	Matlab Practice	3	0/2 C	—
NSWI004	Operating Systems	4	2/1 MC	—
NSZZ031	**Bachelor Thesis**	6	—	0/4 C
NPGR020	Geometry for Computer Graphics [1]	3	—	2/0 Ex
NPGR036	Computer Vision [2]	5	—	2/2 C+Ex
NPRG054	High Performance Software Development	6	—	2/2 C+Ex
NOPT046	Discrete and Continuous Optimization	5	—	2/2 C+Ex
NPGR019	Realtime Graphics on GPU	5	—	2/2 C+Ex

[1] Profile courses (for the given branch) covering material needed for the State Final Exam.
[2] Recommended courses for the given branch (not formally obligatory but strongly recommended). Courses without a footnote may be freely substituted by others.

Second year – Computer Vision

Code	Subject	Credits	Winter	Summer
NTIN061	**Algorithms and Data Structures 2**	5	2/2 C+Ex	—

Code	Subject	Credits	Winter	Summer
NDMI011	**Combinatorics and Graph Theory 1**	5	2/2 C+Ex	—
NMAI055	**Mathematical Analysis 2**	5	2/2 C+Ex	—
NPRG035	**Programming in C# Language**	5	2/2 C+Ex	—
NPGR003	**Introduction to Computer Graphics**	5	2/2 C+Ex	—
NPGR002	Digital Image Processing [1]	4	3/0 Ex	—
NPGR037	Matlab Practice [2]	3	0/2 C	—
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
NPGR036	Computer Vision [1]	5	—	2/2 C+Ex
NPGR020	Geometry for Computer Graphics [2]	3	—	2/0 Ex
NMAI056	Mathematical Analysis 3 [2]	5	—	2/2 C+Ex
NOPT046	Discrete and Continuous Optimization [2]	5	—	2/2 C+Ex

Third year – Computer Vision

Code	Subject	Credits	Winter	Summer
NAIL062	**Propositional and Predicate Logic**	5	2/2 C+Ex	—
NDBI025	**Database Systems**	5	2/2 C+Ex	—
NPRG041	**Programming in C++**	5	2/2 C+Ex	—
NPGR035	Machine Learning in Computer Vision [1]	5	2/2 C+Ex	—
NAIL028	Introduction to Robotics [2]	5	2/2 C+Ex	—
NMAI073	Probability and Statistics 2 [2]	5	2/2 C+Ex	—
NSZZ031	**Bachelor Thesis**	6	—	0/4 C
NMAI042	Numerical Mathematics [2]	5	—	2/2 C+Ex
NPGR004	Photorealistic Graphics	5	—	2/2 C+Ex
NPGR019	Realtime Graphics on GPU	5	—	2/2 C+Ex
NPRG054	High Performance Software Development	6	—	2/2 C+Ex

Second year – Game Development

Code	Subject	Credits	Winter	Summer
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	—
NPRG035	**Programming in C# Language**	5	2/2 C+Ex	—
NPRG041	**Programming in C++**	5	2/2 C+Ex	—
NPGR003	**Introduction to Computer Graphics**	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
NPGR019	Realtime Graphics on GPU [1]	5	—	2/2 C+Ex
NPGR038	Introduction to Computer Game Development [1]	5	—	2/2 C+Ex
NPRG038	Advanced C# Programming [2]	5	—	2/2 C+Ex
NPRG051	Advanced C++ Programming [2]	5	—	2/2 C+Ex

Third year – Game Development

Code	Subject	Credits	Winter	Summer
NAIL062	**Propositional and Predicate Logic**	5	2/2 C+Ex	—
NDBI025	**Database Systems**	5	2/2 C+Ex	—
NSWI160	Game Development Middleware [2]	6	0/4 C	—
NSWI159	Practical Course on Game Development [2]	2	0/1 C	0/1 C
NAIL028	Introduction to Robotics	5	2/2 C+Ex	—
NSWI004	Operating Systems	4	2/1 MC	—
NPGR002	Digital Image Processing	4	3/0 Ex	—
NSZZ031	**Bachelor Thesis**	6	—	0/4 C
NPGR020	Geometry for Computer Graphics [1]	3	—	2/0 Ex
NAIL120	Introduction to Artificial Intelligence	5	—	2/2 C+Ex
NPGR004	Photorealistic Graphics	5	—	2/2 C+Ex
NPGR036	Computer Vision	5	—	2/2 C+Ex

7.4 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 Computer Graphics, Vision and Game Development specialization will be further tested according to the information below.

The Computer Graphics, Vision and Game Development specialization includes a further set of requirements shared among its three branches – topics 1. to 3. are covered by obligatory courses NMAI055 Mathematical Analysis 2 and NPGR003 Introduction to Computer Graphics.

1. Mathematical Analysis

Differential and integral calculus of several variables. Riemann integral. Extrema of functions of several variables. Metric space, closed and open sets, compactness.

2. Fundamentals of 2D Computer Graphics

Human visual system and its properties, colours and their perception. Colour spaces RGB, CMY, HSV. High dynamic range graphics (HDR). Image transparency. Raster and vector graphics, raster and vector image file formats and their reasonable use. Fundamentals of rasterization (converting 2D shapes into raster representation).

3. Fundamentals of 3D Computer Graphics

3D coordinate spaces and matrix transforms. Compound transforms (useful examples), representation of orientation in space. Projection used in 3D scene rendering.

GPU realtime rendering: OpenGL basics, GPU architecture, data formats sent to GPU, programming principles (shaders). 3D scene representations, scene hierarchies, fundamental shading (Phong). Principles of recursive ray tracing.

Knowledge requirements for individual branches

Students following a given individual branch must be prepared for questions from disciplines covered by "profile courses" of the given branch.

Requirements for Computer Graphics

Topics 4. to 6. are covered by the courses NPGR004 Photorealistic Graphics, NPGR025 Introduction to Colour Science and NPGR020 Geometry for Computer Graphics.

4. Photorealistic Graphics

Recursive ray tracing: naive algorithm and its properties. Ray versus 3D scene intersections, speed-up techniques. Reflectance models: empirical and physically more plausible approaches. Textures, modelling of natural phenonema, noise functions. Antialiasing in ray-based algorithms, sampling methods, distributed ray tracing. Modern Monte-Carlo approaches in photorealistic rendering.

5. Colour Science

Fundamental causes of colour, human eye and function of its parts. Colour spaces and colour collections, gamuts, color mixing, color matching experiments. Examples of Colour ordering systems (Munsell, Pantone). Colour measurement devices. Printing technology, ICC profiles.

6. Geometry for Computer Graphics

Plane and solid Euclidean geometry, applications, animation of continuous movement. Quaternions and their application in animation, LERP and SLERP. Projective space and projective mapping, panoramic stitching in photography and scene reconstruction. Double ratio and its use in size readings from images.

Requirements for Computer Vision

Topics 7. to 9. are covered by the courses NPGR002 Digital Image Processing, NPGR036 Computer Vision and NPGR035 Machine Learning in Computer Vision.

7. Digital Image Processing

Image sampling and quantization, Shannon Theorem. Basic manipulations with images. Histogram, contrast stretching, denoising, sharpening. Linear filtering in image and frequency domains. Convolution and Fourier transform. Edge and corner detection. Image degradations and their modelling. Removing basic degradations (motion and out-of-focus blur), inverse and Wiener filter.

8. Computer Vision

Image acquisition, digital image properties. Mathematical morphology. Image segmentation. Image registration and matching. Description of planar objects – basic principles. Invariants for recognition of 2D objects Local feature detection, description and matching. Salient regions. Object detection and tracking, optical flow.

9. Machine Learning

Feature selection and preprocessing. Bayesian decision theory, minimum error criterion. Decision trees. Discriminant analysis, linear classifier. Object recognition, supervised classifiers (k-NN, linear, Bayes). Support Vector Machines (SVM). Cluster analysis, iterative and hierarchical methods. Classification quality evaluation.

Requirements for Game Development

Topics 10., 11. and 6. are covered by the courses NPGR038 Introduction to Computer Games Development, NPGR019 Realtime Graphics on GPU and NPGR020 Geometry for Computer Graphics.

10. Computer Games Development

2D games: sprite-based animation, 2D skeleton, parallax scrolling, tilemap systems, pixel art. 3D games: 3D scene, modeling, skeletal animation, rigging. 3D rendering: shaders, shadow casting, particle systems, billboards, screenspace effects. Audio: sound effects, 3D sound, sound engine, sound composition. Design of game architecture, design patterns for computer games. Game design: definition, history, player taxonomy. Introduction to game engine architectures, Unity engine. Management of computer game development, life-cycle of a videogame project.

11. GPU Graphics

Principles of programmable GPU pipeline. Buffers, constant buffers, efficient data streaming to a GPU. Textures and texturing units, purpose of individual shader types. Higher shader languages (GLSL, HLSL). 3D scene lighting (materials, shadows). Stencil buffer and its utilization. Multipass rendering, deferred shading and screen-space effects. Realtime raytracing. GPGPU – massively parallel algorithms on GPU, basics of CUDA/OpenCL.

6. Geometry for Computer Graphics

Plane and solid Euclidean geometry, applications, animation of continuous movement. Quaternions and their application in animation, LERP and SLERP. Projective space and projective mapping, panoramic stitching in photography and scene reconstruction. Double ratio and its use in size readings from images.

Master of Computer Science

Study started in 2020 and later

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.

Study Plans

1 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	—

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 Computer Science - Theoretical Computer Science

Coordinated by: Department of Theoretical Computer Science and Mathematical Logic; Computer Science Institute of Charles University
Study programme coordinator: Doc. 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 47 credits for the courses from the following set:

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

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. 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.

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

Team Project

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

Elective 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	—
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	Customer preferences	4	—	2/1 C+Ex
NSWI072	Data Compression Algorithms	3	2/0 Ex	—

Elective courses

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	2	—	0/2 C
NTIN067	Data Structures 2	3	—	2/0 Ex
NSWI166	Introduction to Recommender Systems	4	2/1 C+Ex	—
NPFL104	Machine Learning Methods	4	—	1/2 C+Ex

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. Databases - formal foundations and query languages (obligatory for the specializations Web engineering and Database systems)
6. Databases - implementation and administration (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

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	—

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. Modern language constructs and code performance. 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
NPRG059	Advanced Programming Praxis	2	0/1 C	—

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. 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

5. Databases - formal foundations and query languages

Relational calculi, relational algebras. 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, SPARQL query language. Similarity search in multimedia databases, metric indexes for similarity search. Preference modeling and querying.

Recommended courses

Code	Subject	Credits	Winter	Summer
NDBI040	Modern Database Systems	5	2/2 C+Ex	—
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	Customer preferences	4	—	2/1 C+Ex

6. Databases - implementation and administration

Architectures of database systems. Models and properties of transactions: locking protocols, time stamps. Transaction isolation, resource allocation. Distributed transactions. 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	—
NSWI144	Data on the Web	5	2/1 C+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, metric indexes for similarity search. Data visualization techniques.

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

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.

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

4 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.

Mandatory 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

Elective courses

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	2	—	0/2 C
NSWI133	Commercial Workshops	2	0/2 C	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

Elective courses from the bachelor program

The program provides a budget for attending courses from the preceding bachelor program with a minimum total of 8 credits. This obligation can also be discharged by recognizing already finished courses from the preceding bachelor study per existing regulations. The relevant bachelor program 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	—

Elective 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

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 Computer Science – Language Technologies and Computational Linguistics

Coordinated by: Institute of Formal and Applied Linguistics
Study programme coordinator: Doc. RNDr. Markéta Lopatková, 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	5	—	2/2 C+Ex
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 (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 (additional courses)

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 program 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

Phonetics, phonology, morphology, syntax, semantics, pragmatics. Ambiguity, arbitrariness. Description and prescription. Diachronic and synchronic language description. Fundamentals of information theory. Markov models. Language modeling and smoothing. Word classes. Annotated corpora. Design and evaluation of linguistic experiments, evaluation metrics. Morphological disambiguation and syntactic analysis. 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	—

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. Computational lexicography. Topic-focus articulation; information structure, discourse. Coreference. Linguistic typology. Formal grammars and their application in rule-based morphology. 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	5	—	2/2 C+Ex
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 machine learning methods for classification and regression (linear models, other methods: naive Bayes, decision trees, instance-based learning, SVM and kernels, logistic regression). Unsupervised machine learning methods. Language models, noisy channel model. Model smoothing, model combination. HMM, trellis, Viterbi, Baum-Welch. Algorithms for statistical tagging. Algorithms for constituency and dependency statistical parsing. Neural networks in machine learning. 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. User simulation. 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. Quality evaluation of machine translation. Speech translation. Information retrieval, models for information retrieval. Query expansion and relevance feedback. Document clustering. Duplicate detection and plagiarism detection. Information retrieval evaluation. Sentiment analysis. Toolkits (GATE, NLTK, NLPTools, Lucene, Terrier).

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 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 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 - other

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	Game Theory	3	2/0 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
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, multiobjective 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 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 56 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 and Exploration	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
NPGR028	High Performance Ray Tracing	3	—	2/0 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.
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, precomputed 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