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 theo-

rem, 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