COMPUTER SCIENCE, MASTER STUDY PROGRAMME, SECOND BOLOGNA CYCLE

COURSE DESCRIPTIONS

BASIC COURSES

(Read the short descriptions of all basic courses of the study programme. In the table Basic courses you will find the list of the elective courses which were offered in the last two years.)

Course name: **SELECTED TOPICS IN THEORETICAL COMPUTER SCIENCE**
Number of ECTS credits: **6**

Content:
Models of computing. Finite automata, stack machines and their properties; corresponding formal languages with their properties. Computability and undecidability. Nondeterminism and NP completeness. Samples of NP complete problems. Lower space and time bounds. Time and space complexity classes and relations among them. Student also prepares a seminar in a form of survey paper or smaller practical project.

Course name: **THEORY OF PROGRAMMING LANGUAGES**
Number of ECTS credits: **6**

Content:
History of programming languages. Logical inference and induction. Syntax of programming languages. Operational semantics. Church-Rosser property. Denotational semantics. Tarski's fixpoint theorem. Λ-calculus. Expressive power of λ-calculus. Church-Rosser property for λ-calculus. Types and normalization. Curry-Howard correspondence. Recursion, Gödel's T, and Plotkin's f PCF. Structures, n-tuples, sums, and subtypes. Recursive types. λ-račun 2. reda and System F. Meta-programming languages.

Course name: **SELECTED TOPICS IN THEORY OF ALGORITHMS**
Number of ECTS credits: **6**

Content:
Models of computation, NP completeness. Word-size parallelism and transdichotomous model of computation. Linear programming. Approximative and probabilistic algorithms. Competitive algorithms and online algorithms. Parallel algorithms and algorithms for distributed systems – algorithms for computer networks (P2P etc.). Student also prepares a seminar in a form of survey paper or smaller practical project.

Course name: **SYSTEM DYNAMICS**
Number of ECTS credits: **6**

Content:
A chronological and structural overview of system theories and its variants. System dynamics: basic definitions, variables, interactions, basic patterns of complex systems. Modeling complex systems, problem articulation, hypothesis, model definitions, testing, evaluation. Causal loop diagrams – from qualitative to quantitative modeling, understanding specific nature of certain variables, knowledge of adapted modeling approaches, knowledge of mathematical instrumantarium. Typical patterns of complex systems and their models. Simulations and study of practical, real-world examples. Seminal work – a small project or short a research paper.

Course name: **INTELLIGENT SYSTEMS**
Number of ECTS credits: **6**

Content:
Topics covered (including subtopics):

- Fundamental Issues [core*]
- Basic Search Strategies [core]
- Knowledge Based Reasoning [core]
- Advanced Search [elective*]
- Advanced Reasoning [elective]
- Agents [elective]
- Natural Language Processing [elective]
- Machine Learning [elective]
- Planning Systems [elective]
- Robotics [elective]
- Perception [elective]

*There are 3 core topics that form the basis and 8 elective topics of which 3 will be covered in this course. These 3 elective topics will be selected each year following the current research directions.

Course name: **APPLIED STATISTICS**
Number of ECTS credits: **6**

Content:
Introduction to statistics: Introductory examples and motivations, Basic introduction to Matlab programming. Descriptive Statistics: Measures of Central Tendency, Measures of Dispersion, Measures of Shape, Statistical visualizations. Random variables and Probability Distributions. Tests of Hypotheses for a Single Sample. Statistical Inference for Two Samples. Statistical modelling: Simple Linear Regression, Multiple Linear Regression, Non-linear regression models, Regression trees. The Analysis of Variance and Covariance.

Course name: **SELECTED TOPICS IN INFORMATION SYSTEMS**
Number of ECTS credits: **6**

Content:
Business Analysis. Analysis and modeling of organization and business processes. Analysis and modeling data. The management information system development. The impact of information technology on decision making and evaluating decisions in the organization. Computerised decision support systems in the business and administrative environment.

Course name: **SELECTED TOPICS IN SOFTWARE ENGINEERING**
Number of ECTS credits: **6**

Content:

- Software process and software process frameworks
- Software product development technologies: computer aided software engineering (CASE), software product line engineering, development of software products based on testing.
- Software product planning:
  - Division strategies of software system to software components.
  - Architectural patterns
  - Design patterns
  - Software component interfaces and software integration.
- Software maintenance and evolution, re-engineering and reverse engineering.
- An example of complex software system development.

ELECTIVE COURSES

(Read the short descriptions of all elective courses of the study programme. In the table Elective courses you will find the list of the elective courses which were offered in the last two years.)

Course name: **GRAPH ALGORITHMS**
Number of ECTS credits: **6**

Content:
Classical and modern research topics in the field of algorithmic graph theory. Possible topics include: Basic graph definitions, representations of graphs. Trees and forests, their basic properties. Breadth-first search and depth-first search. Eulerian tours and Hamiltonian cycles. Minimum spanning trees, shortest paths. Bipartite graphs, graph colorings. Matchings in bipartite graphs. Network flows. Planar graphs. Approximation algorithms (e.g., for the traveling salesman problem and for the vertex cover problem). Chordal graphs, interval graphs, perfect graphs. Graphs of bounded tree-width. Graphs of bounded clique-width.

Course name: **ALGORITHM ENGINEERING IN COMPUTER COMMUNICATIONS**
Number of ECTS credits: **6**

Content:
Equipment in computer communications and embedded systems. Algorithms used in computer networks. Protocols in Internet. Processing of individual packets: classification, quality of service (QoS), firewalls. Modelling and monitoring of a traffic in Internet. Student also prepares a seminar in a form of survey paper or smaller practical project.

Course name: **APPLICATIONS OF ARTIFICIAL INTELLIGENCE**
Number of ECTS credits: **6**

Content:
Intelligent systems. Description of typical intelligent system structure and examples of intelligent systems in computer science. Machine learning techniques. Description of basic and advance

methods for machine learning and their application to build forecast and description models. Methods for evaluation of models. Pattern recognition. Application of machine learning techniques and methods to pattern recognition. Data mining. Application of machine learning techniques and methods to data mining.

Course name: **BIOMETRIC TECHNOLOGIES**
Number of ECTS credits: **6**

Content:
Introduction to Biometrics:

- Basic pattern recognition and machine learning principles and methods.
- Feature extraction and machine learning methods in biometric systems.
- Basic principles in biometric recognition: verification and identification.

Overview of biometric systems:

- fingerprint recognition,
- hand geometry and palm recognition,
- face recognition,
- signature verification,
- voice biometrics: speaker identification and verification,
- multi-modal biometric approaches.

Case study: Development of a speaker verification system by using speech technologies

Course name: **SPOKEN LANGUAGE TECHNOLOGIES**
Number of ECTS credits: **6**

Content:
Overview of pattern recognition techniques and signal processing methods in spoken language technologies.

Speech recognition:

- speech signal feature extraction:
- hidden Markov models, HMMs,
- development of speech recognition system based on HMMs
- Overview of speech recognition development tools: Sphinx3,4, HTK
- Development of a simple speech recognizer for digit recognition

Language modeling for speech recognition:

- rule-based language models,
- statistical language models: n-grams,
- Overview of language modeling tools.

Speech synthesis:

- basic concepts of speech synthesis
- different speech synthesis systems: TD/FD PSOLA, HMM-based, corpus-based
- Overview of speech synthesis development tools: Festival speech synthesis system, HTS

Speaker recognition

- overview of speaker identification and verification systems,
- UBM-MAP-SVM based speaker recognition system: GMM, adaptation techniques MAP, support

vector machines, SVM,
- score normalization methods: z-norm, t-norm
- development of a speaker-verification system

Course name: **IMPLEMENTATION OF DATABASE MANAGEMENT SYSTEMS**
Number of ECTS credits: **6**

Content:
- Disks an files.
- Indexes.
- Caches.
- Sorting.
- Relational storage manager. .
- Triple-stores.
- Graf database management systems.
- Evaluation of operations in database systems.
- Query optimization.
- Concurrency control.
- Crash recovery.
- Web of data.

Course name: **SELECTED TOPICS IN CRYPTOGRAPHY**
Number of ECTS credits: **6**

Content:
Introduction. Symmetric ciphers. Public key cryptography. Digital signatures. Cryptographic protocols. Algorithmic number theory. Hash functions. Algebraic attacks.

Course name: **SELECTED TOPICS IN IMAGE PROCESSING**
Number of ECTS credits: **6**

Content:
Introduction with basic definitions and review of tools. Image acquisition with cameras and tomographic techniques. Digital image communication and file formats. General image formats, DICOM. Basic image processing procedures in image and frequency domain. Visualization of multi-channel and multi-dimensional images. Image segmentation. Geometric image registration. Processing of image related data - structures. Examples of image processing applications in medicine and entertainment technology.

Course name: **SELECTED TOPICS IN DATA STRUCTURES**
Number of ECTS credits: **6**

Content:
Models of computation. Word-size parallelism. Implicit data structures. Succinct data structures. Information coding entropy. Data structures and memory hierarchy. Practical examples from computer communications, embedded applications, massive data storage etc.

Course name: **SELECTED TOPICS IN DISTRIBUTED COMPUTING**
Number of ECTS credits: **6**

Content:
Models for distributed computing. Algorithms for distributed environments – algorithms useful in computer networks (P2P etc.). Technologies for distributed computing: distributed memory, object oriented distributed system design, distributed dictionary, un-interruptability and time synchronization, distributed scheduling and process migration, remote function calls and method invocation, robustness, security. Distributed services and tools. Student also prepares a seminar in a form of survey paper or smaller practical project.

Course name: **SELECTED TOPICS IN PARALLEL PROGRAMMING**
Number of ECTS credits: **6**

Content:
- Introduction to parallel programming.
  - Renewal of basic concepts of parallel and distributed programming.
- Introduction to modern parallel systems.
  - General-purpose computing on graphics processing units (GPGPU) computer systems, which enable parallel computing.
- Review of different approaches.
  - Compute Unified Device Architecture (CUDA), Open Computing Language (OpenCL) …
- A more detailed understanding of OpenCL.
  - OpenCl framework for writing programs that can be executed on different heterogeneous platforms.
- Optimization of programs.
  - To take full advantage of GPGPU computer system.
- Application.
  - Implementation of simple programs on a GPGPU computer system.
- Examples of real-world problems.
  - Studying and implementation of real-world problems.

Course name: **LINEAR PROGRAMMING WITH APPLICATIONS**
Number of ECTS credits: **6**

Content:
Modeling optimization problems. Simplex method. Examples of applications in production problems. The theory of duality. Dual simplex method. Problem cart. Integer programming. Advanced heuristics algorithms for optimizations. Applications of methods of linear programming.

Course name: **METAHEURISTIC OPTIMIZATION ALGORITHMS**
Number of ECTS credits: **6**

Content:
Introduction to metaheuristics. Definition of metaheuristics, classification of metaheuristic approaches, trajectory and population based methods. Trajectory searches. Simulated annealing, tabu search, GRASP, variable neighborhood search, guided and fast local search, and diversified search. Population based searches. Swarms, ant colony, genetic algorithm, memetic algorithm, and immune systems. Description and comparison of methods. Exploitation/exploration of search space, the quality of solutions, and convergence. Combinatorial and numerical optimization problems. Definition of

general combinatorial and numerical optimization problem. Travelling salesman problem, graph partitioning, multi-parametric numerical functions, and various industrial applications. Evaluation of results. A statistical approach, performance measures, and presentation of results. Metaheuristics in multi-objective optimization. Application aspects. Hybridization and parallelization of algorithms. During the course the student prepares a course work, which is in a form of an overview paper and small project.

Course name: **INTRODUCTION TO BIOINFORMATICS**
Number of ECTS credits: **6**

Content:
Introduction. Basic biological introduction, sample comparison. Comparison of two sequences: algorithms for exact matching. Comparison of two sequences: heuristic algorithms. Sample searching and best matching. Suffix trees. Comparison of several sequences. Evolutionary trees.

Course name: **DATA MODELS AND LANGUAGES**
Number of ECTS credits: **6**

Content:
Logic. Propositional calculus, predicate calculus, interpretations, models, deduction, resolution. Object-relational model: relations, attributes, integrity constraints, relational calculus, relational algebra, SQL2, SQL3. Text databases: XML and DTD, XML-Namespaces, XML-Schema, XPath, XSL, XQuery. Conceptual networks: Graph data model, RDF, SparQL, Description logic, OWL, systems based on RDF and OWL. Semantic models: Entity-Relationship model, Specialization/generalization, composition/decomposition, association, data models SDM and IFO, Object-oriented model, classification/instantiation, inheritance, UML. Logic data model: Horn clauses, Herbrandt model, SLD resolution, Prolog, Datalog, F-Logic.

Course name: **DATA MINING ON THE WORLD WIDE WEB**
Number of ECTS credits: **6**

Content:
Semantic web. Standard formatting of the data. The definition of ontology in the semantic web framework. Example of an ontology – CYC. Techniques for ontology construction and analysis. Data vizualization. (Semi)automatic ontology building. Ontology evaluation. Predicting structural changes inontology evolution. Analysis of web data. Data presentation. Analysis of content, structure and access to web data. Ontology construction from web data.

Course name: **PROCESSOR ARCHITECTURE**
Number of ECTS credits: **6**

Content:
Processors with reduced instruction set. Computing model: static, dynamic. Processors with complex instruction set. Superscalar processors. VLIW in EPIC processors. Processors to use fine-grain parallelism. Processors to use coarse-grain parallelism. Reconfigurable and asynchronous processors. A student has to prepare course work, which may be in the form of a review paper or a small project.

Course name: **COMPUTER SECURITY**
Number of ECTS credits: **6**

Content:
Computer security. Introduction and basic definitions. Symmetric and asymmetric crypto-systems. Crypto-protocols and formal methods. Public key infrastructure. Elements of security infrastructure (firewalls, intrusion detection systems, protocols like SSL and SET) Human factor management (organizational and legislation views).

Course name: **COMPUTER VISION**
Number of ECTS credits: **6**

Content:
Introduction with overview of computer vision applications areas and basic terminology. Image acquisition; scene, illumination, cameras, image sensors, optics, lens distortions. Color spaces and color recognition. Image preprocessing. Basic algorithms for image processing and analysis; edge detection, corner detection, shape detection, morphology. Image features for pattern recognition. Geometric transformations. Specifics of computer vision in medicine; 3D and 4D images. Examples of computer vision applications.

Course name: **STATISTICAL MODELLING**
Number of ECTS credits: **6**

Content:
Introduction and basic concepts. Review of basic probability and statistical concepts.
Data exploration: feature selection, feature generation, feature transformation, dimensionality reduction, factor analysis with PCA. Case studies: face recognition - eigenfaces, phoneme recognition - PCA vs. LDA vs. DCT, factor analysis of PIXE data - elemental concentrations of PM10 data. Classification. Classifiers Based on Bayes Decision Theory. Linear Classifiers (case study: recognition of handwritten digits data set (PENDIGITS). Support vector machines – SVM (case studies: boundary detection problem between valid and non-valid space with SVM, system for malignat tumor detection). Clustering. Sequential and Hierarchical Clustering, Clustering based on Function Optimization: K-means clustering, Gaussian Mixture models. Case study: Development of speaker verification system for recognizing small set of speakers based on UBM-MAP method. Sequence data modeling: basic concepts and apllications of sequence data modeling, hidden Markov models (HMM). Case study: phoneme recognition system based on HMMs.

Course name: **TELECOMUNICATION NETWORKS**
Number of ECTS credits: **6**

Content:
- Overview of TCP/IP technology
- Basis of classical telephony
- Future telecommunication networks
- Detail overview of VoIP technology and quality of voice
- Detail overview of protocols in future telecommunication networks
- Multimedia

Course name: **CODING THEORY**
Number of ECTS credits: **6**

Content:
The course covers the most important topics in coding theory, that includes (among others) the topics below:

- mathematical basics (groups, rings, ideals, vector spaces, finite fields)
- basic concepts in coding theory
- algebraic methods for construction of error-correcting codes
- Hamming codes
- Linear codes
- Binary Golay codes
- Cyclic codes
- BCH codes
- Reed-Solomon codes
- Bounds (Hamming, Singleton, Johnsson bound, ...)

Course name: **APPLIED BIOINFORMATICS**
Number of ECTS credits: **6**

Content:
Perl and BioPerl. Statistics for bioinformatics. Sequence searching and sequence alignment. Sequence alignment – methods and algorithms. Literature-based discovery. Text mining.
Protein structure prediction. Databases of nucleotide and amino acid sequences. Sequence analysis and prediction. Microarrays.

Course name: **SELECTED TOPICS IN HUMAN-COMPUTER INTERACTION**
Number of ECTS credits: **6**

Content:
Classical and modern research topics in the field of human-computer interaction. Possible topics include:

- Basics of human-computer interaction
- Mental models
- User modeling
- User error in critical systems.
- Navigation (multiple displays, infinite canvas, information space).
- Tasks analysis and contextual design.
- User based evaluation of the system or product.
- 3D GUI
- Direct manipulation.
- Prticipatory practices.
- Prototyping.
- Design of menues.
- Virtual envoronments.
- Information visualisation.
- Augmented reality.

Course name: **RESEARCH AND INNOVATION IN PRACTICE**
Number of ECTS credits: **6**

Content:
- Research Methods: Quantitative methods, Qualitative methods and Experimental Computer Science
- Understanding Innovation
- Modern methodologies

- The Power of the Lean Method
- Lean Software Development Principles
- Agile Methodology and Agile engineering
- The Benefits of Agile Software Development

- Examples of using modern methodologies in practice.

Course name: **SELECTED TOPICS IN INTELLIGENT SYSTEMS APPLICATIONS**
Number of ECTS credits: **6**

Content:
Intelligent Systems:
- as Intelligent Tutoring Systems
- for Computer Networks and Web Technologies
- for Data Mining, Big Data and Information Retrieval
- in medicine and bioinformatics
- as Intelligent Transportation Systems
- and robots for hazardous environments
- and robots for rehabilitation.

Course name: **SELECTED TOPICS IN INFORMATION VISUALISATION**
Number of ECTS credits: **6**

Content:
Classical and modern research topics in the field of information visualisation. Possible topics include:
- appropriate allocation of visual attributes to data variables,
- designing with color and luminance contrast,
- the psychology of human vision and perception,
- visual analytics,
- interaction,
- storytelling,
- text visual analytics,
- big data visualization,
- uncertainty visualization,
- network visualization,
- cartographic visualization,
- animation and time series visualization.

Course name: **SELECTED TOPICS IN FROM DATABASE SYSTEMS**
Number of ECTS credits: **6**

Content:
1. Distributed database systems.

Relational model; architectures of distributed database systems; shared-nothing architecture; range/hash/block partitioning; partition assignment; degree of declustering; collocation; replication; query processing; coordination task; intra- and inter-operation parallelism; parallel joins; semi-joins; partitioned and piplined parallelism; query optimization; partition pruning; data shipping; scheduling.

2. Columnar database systems.
Column-oriented data model; MonetDB; C-Store; Vertica; storage layouts; column-oriented compression; delta storage; data updates; columnar algebra; vectorized processing; late materialization.

3. MapReduce systems.
MapReduce model; Hadoop; distributed file sytems; HDFS; Google file system; MapReduce programs: joins, sorting; high-level systems: Pig, Hive, Hbase.

4. Graph database systems.
Graph data model; RDF, RDF-Schema, SPARQL; graph storage-systems; SPO-indexes; RDF-3X indexes, Virtuoso indexes; vertical|horizontal storage layout; graph partitioning algorithms; central|distributed storage systems; cache usage; main-memory storage systems; graph algebra; query processing; data and ontology level inference; query optimization.

5. Dataflow systems.
Data-intensive analytics; extended MapReduce model; dataflow system stack; Google stack: GFS, Bigtable, Pregel, Dremel, Tenzing; storage system: distributed FS, wide or nested-columnar, in-memory storage; computational model: computational vertices and communicational edges; computation structures: trees, DAGs, directed graphs; query interface: domain-specific, functional or declarative; query optimization: static, dynamic, heuristic.