Area COMPUTER SCIENCE

Study Program P4I1A Theoretical Computer Science and Artificial Intelligence

Subject Area Board
The current board makeup is available at http://mff.cuni.cz/phd/or/p4i1.

Affiliated Institutions

- Institute of Mathematics of the Czech Academy of Sciences
  Žitná 25, 115 67 Praha 1
  http://www.math.cas.cz

- Institute of Computer Science of the Czech Academy of Sciences
  Pod vodárenskou věží 2, 182 07 Praha 8
  http://www.cs.cas.cz/

- Institute of Information Theory and Automation of the Czech Academy of Sciences
  Pod vodárenskou věží 4/1143, 182 08 Praha 8
  http://www.utia.cas.cz/

Thesis Topic
Thesis topics are listed in SIS at http://mff.cuni.cz/phd/temata/p4i1.

Available Courses

<table>
<thead>
<tr>
<th>Code</th>
<th>Subject</th>
<th>Winter</th>
<th>Summer</th>
</tr>
</thead>
<tbody>
<tr>
<td>NTIN091</td>
<td>Seminar for MSc. and Ph.D.-students 1</td>
<td>0/2 C</td>
<td>—</td>
</tr>
<tr>
<td>NTIN092</td>
<td>Seminar for MSc. and Ph.D.-students 2</td>
<td>—</td>
<td>0/2 C</td>
</tr>
<tr>
<td>NTIN093</td>
<td>Algorithmic Randomness</td>
<td>—</td>
<td>2/0 Ex</td>
</tr>
<tr>
<td>NTIN094</td>
<td>Approximation and Online Algorithms</td>
<td>—</td>
<td>2/2 C+Ex</td>
</tr>
<tr>
<td>NTIN095</td>
<td>Parallel Algorithms</td>
<td>—</td>
<td>2/0 Ex</td>
</tr>
<tr>
<td>NTIN096</td>
<td>Randomized Algorithms</td>
<td>—</td>
<td>2/2 C+Ex</td>
</tr>
<tr>
<td>NTIN097</td>
<td>Hypercube structures</td>
<td>2/0 Ex</td>
<td>—</td>
</tr>
<tr>
<td>NTIN098</td>
<td>Pseudo-Boolean Optimization</td>
<td>—</td>
<td>2/0 Ex</td>
</tr>
<tr>
<td>NTIN099</td>
<td>Seminar on Computational Complexity</td>
<td>0/2 C</td>
<td>0/2 C</td>
</tr>
<tr>
<td>NDBI031</td>
<td>Statistical Methods in Data Mining Systems</td>
<td>1/1 C+Ex</td>
<td>—</td>
</tr>
</tbody>
</table>
State Exam Requirements

State Exam consists of four questions. From each topic 1 and 2, the student will get one question. The third question is: for students of specialization Theoretical Computer Science from topics 3 or 4 (based on student selection), for students of specialization Artificial Intelligence from topics 5-7 (based on student selection). The fourth question is from the area selected by the supervisor (it could be one of the remaining topics):

1. Logic
   Propositional and predicate logic, syntax and semantics, their relation. Formal proof systems, formal arithmetic, consistency and completeness, Gödel’s theorems. Turing machines. Algorithmically undecidable problems, undecidability of predicate logic, undecidability of consistent extensions of elementary arithmetic. Undefinability of truth in arithmetic. The recursion theorems.

2. Complexity theory

3. Data Structures

4. Algorithms


5. Artificial Intelligence


6. Machine Learning and Data Analysis


Recommended literature

1. Logic:


2. Complexity Theory:

3. Data Structures:


4. Algorithms:


5. Artificial Intelligence:


6. Machine Learning and Data Analysis:

Hastie, T., Tibshirani, R., Friedman, J.: **The Elements of Statistical Learning.** *Springer,* 2013.
James, G., Witten, D., Hastie, T., Tibshirani, R.: **An Introduction to Statistical Learning with Applications in R.** *Springer,* 2013.
7. Nature-Inspired Optimization Algorithms:


Study Program P4I2A Computer Science - Software Systems

Subject Area Board

The current board make up is available at [http://mff.cuni.cz/phd/or/p4i2](http://mff.cuni.cz/phd/or/p4i2).

Thesis Topics

Thesis topics are listed in SIS at [http://mff.cuni.cz/phd/temata/p4i2](http://mff.cuni.cz/phd/temata/p4i2).

Available Courses

<table>
<thead>
<tr>
<th>Code</th>
<th>Subject</th>
<th>Winter</th>
<th>Summer</th>
</tr>
</thead>
<tbody>
<tr>
<td>NSW1026</td>
<td>Advanced aspects of software engineering</td>
<td>—</td>
<td>2/2 C+Ex</td>
</tr>
<tr>
<td>NPRG058</td>
<td>Advanced Programming in Parallel Environment</td>
<td>2/2 C+Ex</td>
<td>—</td>
</tr>
<tr>
<td>NSW1057</td>
<td>Advanced topics in distributed and component-based systems I</td>
<td>0/2 C</td>
<td>—</td>
</tr>
<tr>
<td>NSW1058</td>
<td>Advanced topics in distributed and component-based systems II</td>
<td>—</td>
<td>0/2 C</td>
</tr>
<tr>
<td>NSW1103</td>
<td>Company Management – System Dynamics II</td>
<td>—</td>
<td>0/2 C</td>
</tr>
<tr>
<td>NPRG012</td>
<td>Concepts of Modern Programming Languages</td>
<td>0/3 C</td>
<td>—</td>
</tr>
<tr>
<td>NDBI042</td>
<td>Data Visualization Techniques</td>
<td>—</td>
<td>2/1 C+Ex</td>
</tr>
<tr>
<td>NMAI047</td>
<td>Decision procedures and SAT/SMT solvers</td>
<td>—</td>
<td>2/2 C+Ex</td>
</tr>
<tr>
<td>NUN103</td>
<td>Experimental Analysis of Algorithms</td>
<td>—</td>
<td>2/2 C+Ex</td>
</tr>
<tr>
<td>NUN106</td>
<td>Formal Foundations of Software Engineering</td>
<td>2/2 C+Ex</td>
<td>—</td>
</tr>
<tr>
<td>NAMA1061</td>
<td>Methods of Mathematical Statistics</td>
<td>—</td>
<td>2/1 C+Ex</td>
</tr>
<tr>
<td>NSW1080</td>
<td>Middleware</td>
<td>—</td>
<td>2/1 MC</td>
</tr>
<tr>
<td>NSW1106</td>
<td>Model-driven Development</td>
<td>0/1 C</td>
<td>—</td>
</tr>
</tbody>
</table>
State Exam Requirements

The exam deals with three topic areas. The first topic area is that of the dissertation, the other two areas are selected from the list of topic areas by the student in cooperation with the advisor. In all three areas, the exam consists of a student presentation followed by a discussion with the exam board. The board evaluates in particular the dissertation perspective and the familiarity of the student with the selected areas in connection to the overall study topic.

For the first topic area (the dissertation topic), the presentation should explain the planned contribution of the dissertation in the context of the state-of-the-art research, including current results and future research plans, so that the board can form an accurate opinion on the future shape of the thesis, the methods used and the results expected.

For the other two topic areas (the elective topics), the presentation should critically summarize the topic area, particularly in connection with the overall study topic of the student. The board expects a choice of current and relevant research topics, possibly including relevant theoretical background. The advisor is responsible for proposing extensions to the topic area list or updates to the list of research resources, to be approved by the subject area board prior to the exam, so that the list includes content relevant to the overall study topics of the student. Each topic area should be defined as a compact list of research resources (especially research publications) that correspond to the state-of-the-art and the exam requirements.

Distributed and Edge Cloud Systems


Modeling Multi-Model Data


Modern Database Systems

Object Oriented Systems

Compilers

Software System Behavior Specification

Machine Learning

Study Program P4I3A Computational Linguistics

Subject Area Board
The current board make up is available at http://mff.cuni.cz/phd/or/p4i3.

Thesis Topic
Thesis topics are listed in SIS at http://mff.cuni.cz/phd/temata/p4i3.

Available Courses

<table>
<thead>
<tr>
<th>Code</th>
<th>Subject</th>
<th>Winter</th>
<th>Summer</th>
</tr>
</thead>
<tbody>
<tr>
<td>NPTL004</td>
<td>Seminar on Formal Linguistics</td>
<td>0/2 C</td>
<td>0/2 C</td>
</tr>
<tr>
<td>NPTL005</td>
<td>Introduction to Formal Linguistics</td>
<td>2/0 Ex</td>
<td>—</td>
</tr>
<tr>
<td>NPTL015</td>
<td>Methods of Automated Translation</td>
<td>0/2 C</td>
<td>—</td>
</tr>
<tr>
<td>NPTL024</td>
<td>Syntactic Parsing of Czech</td>
<td>—</td>
<td>0/2 C</td>
</tr>
<tr>
<td>NPTL038</td>
<td>Fundamentals of Speech Recognition and Generation</td>
<td>2/2 C+Ex</td>
<td>—</td>
</tr>
<tr>
<td>NPTL053</td>
<td>Introduction to Machine Learning with R</td>
<td>—</td>
<td>2/2 C+Ex</td>
</tr>
<tr>
<td>Course Code</td>
<td>Course Title</td>
<td>Credits</td>
<td>Exam Type</td>
</tr>
<tr>
<td>------------</td>
<td>--------------------------------------------------</td>
<td>---------</td>
<td>-----------</td>
</tr>
<tr>
<td>NPFL063</td>
<td>Introduction to General Linguistics</td>
<td>2/1</td>
<td>C+Ex</td>
</tr>
<tr>
<td>NPFL067</td>
<td>Statistical Methods in Natural Language Processing I</td>
<td>2/2</td>
<td>C+Ex</td>
</tr>
<tr>
<td>NPFL068</td>
<td>Statistical Methods in Natural Language Processing II</td>
<td>—</td>
<td>2/2 C+Ex</td>
</tr>
<tr>
<td>NPFL070</td>
<td>Language Data Resources</td>
<td>1/2</td>
<td>MC</td>
</tr>
<tr>
<td>NPFL073</td>
<td>Mathematical Methods in Linguistics</td>
<td>0/2</td>
<td>C</td>
</tr>
<tr>
<td>NPFL075</td>
<td>Dependency Grammars and Treebanks</td>
<td>—</td>
<td>2/2 C+Ex</td>
</tr>
<tr>
<td>NPFL078</td>
<td>Algorithms in Speech Recognition</td>
<td>—</td>
<td>2/2 C+Ex</td>
</tr>
<tr>
<td>NPFL079</td>
<td>Linguistic Theories and Grammar</td>
<td>—</td>
<td>2/2 C+Ex</td>
</tr>
<tr>
<td>NPFL087</td>
<td>Statistical Machine Translation</td>
<td>—</td>
<td>2/2 C+Ex</td>
</tr>
<tr>
<td>NPFL097</td>
<td>Morphological and Syntactic Analysis</td>
<td>2/0</td>
<td>MC</td>
</tr>
<tr>
<td>NPFL099</td>
<td>Modern Methods in Computational Linguistics</td>
<td>0/2</td>
<td>C</td>
</tr>
<tr>
<td>NPFL097</td>
<td>Unsupervised Machine Learning in NLP</td>
<td>1/1</td>
<td>C</td>
</tr>
<tr>
<td>NPFL101</td>
<td>Statistical Dialogue Systems</td>
<td>2/1</td>
<td>C+Ex</td>
</tr>
<tr>
<td>NPFL102</td>
<td>Variability of Languages in Time and Space</td>
<td>1/1</td>
<td>C</td>
</tr>
<tr>
<td>NPFL108</td>
<td>Information Retrieval</td>
<td>2/2</td>
<td>C+Ex</td>
</tr>
<tr>
<td>NPFL110</td>
<td>Linguistics</td>
<td>—</td>
<td>1/1 MC</td>
</tr>
<tr>
<td>NPFL111</td>
<td>Digital Sound Processing</td>
<td>—</td>
<td>2/2 C+Ex</td>
</tr>
<tr>
<td>NPFL112</td>
<td>Deep Learning</td>
<td>—</td>
<td>3/2 C+Ex</td>
</tr>
<tr>
<td>NPFL113</td>
<td>Compendium of the Neural Machine Translation</td>
<td>—</td>
<td>0/2 C</td>
</tr>
<tr>
<td>NPFL115</td>
<td>Natural language processing on computational cluster</td>
<td>0/2</td>
<td>C</td>
</tr>
<tr>
<td>NPFL120</td>
<td>Multilingual Natural Language Processing</td>
<td>—</td>
<td>1/1 MC</td>
</tr>
<tr>
<td>NPFL122</td>
<td>Deep Reinforcement Learning</td>
<td>2/2</td>
<td>C+Ex</td>
</tr>
<tr>
<td>NPFL124</td>
<td>Dialogue Systems</td>
<td>—</td>
<td>2/2 C+Ex</td>
</tr>
<tr>
<td>NPFL125</td>
<td>Natural Language Processing</td>
<td>—</td>
<td>2/1 C+Ex</td>
</tr>
<tr>
<td>NPFL129</td>
<td>Introduction to Language Technologies</td>
<td>0/2</td>
<td>MC</td>
</tr>
<tr>
<td>NPFL130</td>
<td>Introduction to Machine Learning with Python</td>
<td>2/2</td>
<td>C+Ex</td>
</tr>
</tbody>
</table>

**State Exam Requirements**

The exam comprises of two parts. In the first part, students summarize state of the art and present main outcomes of their own research related to the topics of their theses. In the second part, each student is examined on three exam topics. Topic 1 is obligatory, and then the student chooses two out of the remaining eight topics (any combination is possible).

*Exam topic 1 - Common basics*

Basic tasks and applications of Natural Language Processing. Basic notions in probability, language modeling. Basic notions in supervised and unsupervised ma-
COMPUTER SCIENCE


Optional exam topics for the computational specialization

Exam topic 2 - Basic statistical and machine learning approaches to Natural Language Processing


Exam topic 3 - Advanced Machine Learning


Exam topic 4 - Machine Translation


Exam topic 5 - Information Retrieval


Exam topic 6 - Speech Processing and Dialogue Systems


Optional exam topics for the linguistic specialization

Exam topic 7 - Language System Formal Description


Exam topic 8 - Linguistic formalisms (basic characteristics)


Exam topic 9 - Variability of languages and basic notions of language typology

Variability of languages and possible classifications (genetic, areal, typological). Genetic classification of languages, language families. Areal classification of languages, Sprachbunds. Phoneme inventories, distinctive features and suprasegmental phenomena from a contrastive perspective; International Phonetic Alphabet; syllable formation. Spoken vs. written language; types of writing systems. Morphological structure of languages (inflectional, agglutinative, isolating and polysynthetic types). Parts of speech and their comparability across languages. Word order from a contrastive perspective; free and fixed word order; dominant word order; correlations of word-order patterns. Word-formation processes across languages. Harmonization of annotation schemes.

Recommended literature

Exam topic 1 - Common basics

Exam topic 2 - Basic statistical and machine learning approaches to Natural Language Processing
Exam topic 3 - Advanced Machine Learning

Exam topic 4 - Machine Translation

Exam topic 5 - Information Retrieval

Exam topic 6 - Speech Processing and Dialogue Systems

Exam topic 7 - Language System Formal Description

Exam topic 8 - Linguistic formalisms (basic characteristics)

Exam topic 9 - Variability of languages and basic notions of language typology
Study program P4I4A Computer Science - Theory of Computing, Discrete Models and Optimization

Subject Area Board
The current board make up is available at [http://mff.cuni.cz/phd/or/p4i4](http://mff.cuni.cz/phd/or/p4i4).

Affiliated Institutions
- Institute of Mathematics of the Czech Academy of Sciences
  Žitná 25, 115 67 Praha 1

Thesis Topics
Thesis topics are listed in SIS at [http://mff.cuni.cz/phd/temata/p4i4](http://mff.cuni.cz/phd/temata/p4i4).

Available Courses

<table>
<thead>
<tr>
<th>Code</th>
<th>Subject</th>
<th>Winter</th>
<th>Summer</th>
</tr>
</thead>
<tbody>
<tr>
<td>NDMI066</td>
<td>Algebraic Number Theory and Combinatorics</td>
<td>2/0 Ex</td>
<td>—</td>
</tr>
<tr>
<td>NDMI028</td>
<td>Linear Algebra Applications in Combinatorics</td>
<td>2/2 C+Ex</td>
<td>—</td>
</tr>
<tr>
<td>NDMI064</td>
<td>Applied Discrete Mathematics</td>
<td>2/0 Ex</td>
<td>—</td>
</tr>
<tr>
<td>NDMI090</td>
<td>Introduction to Parameterized Algorithms</td>
<td>2/2 C+Ex</td>
<td>—</td>
</tr>
<tr>
<td>NDMI095</td>
<td>Introduction to Combinatorial and Computational Geometry</td>
<td>2/2 C+Ex</td>
<td>—</td>
</tr>
<tr>
<td>NTIN102</td>
<td>Probabilistic Techniques</td>
<td>2/2 C+Ex</td>
<td>—</td>
</tr>
<tr>
<td>NDMI055</td>
<td>Selected Chapters on Combinatorics 1</td>
<td>2/0 Ex</td>
<td>—</td>
</tr>
<tr>
<td>NTIN058</td>
<td>Selected Topics in Computational Complexity I</td>
<td>2/1 C+Ex</td>
<td>—</td>
</tr>
<tr>
<td>NDMI045</td>
<td>Analytic and Combinatorial Number Theory</td>
<td>—</td>
<td>2/0 Ex</td>
</tr>
<tr>
<td>NDMI035</td>
<td>Geometric Representations of Graphs 2</td>
<td>—</td>
<td>2/0 Ex</td>
</tr>
<tr>
<td>NDMI078</td>
<td>Graphs and counting</td>
<td>—</td>
<td>2/0 Ex</td>
</tr>
<tr>
<td>NDMI013</td>
<td>Combinatorial and Computational Geometry 2</td>
<td>—</td>
<td>2/2 C+Ex</td>
</tr>
<tr>
<td>NDMI015</td>
<td>Combinatorial Counting</td>
<td>—</td>
<td>2/0 Ex</td>
</tr>
<tr>
<td>NDMI071</td>
<td>Math++</td>
<td>—</td>
<td>2/2 C+Ex</td>
</tr>
<tr>
<td>NDMI058</td>
<td>Flows and Cycles in Graphs</td>
<td>—</td>
<td>2/2 C+Ex</td>
</tr>
<tr>
<td>NDMI059</td>
<td>Selected Chapters on Combinatorics 2</td>
<td>—</td>
<td>2/0 Ex</td>
</tr>
<tr>
<td>NTIN057</td>
<td>Selected Topics in Computational Complexity II</td>
<td>—</td>
<td>2/1 C+Ex</td>
</tr>
</tbody>
</table>
State Exam Requirements

The student chooses four of the mandatory topics, two of them from the topics 1.– 4. and two of them from the topics 5.– 12. After a consultation with the advisor, an elective topic will be chosen; one of the topics 5.– 12. can be used as the elective one.

The extent of the chosen topics must correspond to one of the comprehensive advanced texts from the recommended literature. However, with the agreement of the examiner, a more narrow in-depth subtopic can be chosen; in this case, the study texts (books or journal articles) are subject to approval by the subject area board.

1. Discrete Mathematics

2. Logic

3. Computational complexity

4. Design and analysis of algorithms

5. Combinatorial and continuous optimization

6. Combinatorics and algebraic combinatorics
   Linear-algebraic methods, applications of eigenvalues. Graph polynomials. Symmetry and regularity. Matroid theory.

7. Theory of structures

8. Probabilistic method
9. **Topological methods and discrete geometry**

10. **Cryptography**

11. **Data structures**

12. **Algorithmic game theory**

**Recommended literature**

1. **Discrete Mathematics**

2. **Logic**

3. **Computational complexity**
   Arora, S. and Barak, B.: *Computational Complexity: A Modern Approach*

4. **Design and analysis of algorithms**
5. Combinatorial and continuous optimization

6. Combinatorics and algebraic combinatorics

7. Theory of structures

8. Probabilistic method

9. Topological methods and discrete geometry

10. Cryptography
11. Data structures

12. Algorithmic game theory

Study program P4I5A Informatics - visual computing and computer games

Subject Area Board
The current board make up is available at http://mff.cuni.cz/phd/or/p4i5.

Affiliated Institutions
- Institute of Information Theory and Automation of the Czech Academy of Sciences
  Pod vodárenskou věží 4/1143, 182 08 Praha 8
  http://www.utia.cas.cz/

Thesis Topic
Thesis topics are listed in SIS at http://mff.cuni.cz/phd/temata/p4i5.

Available Courses

<table>
<thead>
<tr>
<th>Code</th>
<th>Subject</th>
<th>Winter</th>
<th>Summer</th>
</tr>
</thead>
<tbody>
<tr>
<td>NMNM331</td>
<td>Analysis of Matrix Calculations 1</td>
<td>2/2 C+Ex</td>
<td>—</td>
</tr>
<tr>
<td>NMNM332</td>
<td>Analysis of Matrix Calculations 2</td>
<td>—</td>
<td>2/2 C+Ex</td>
</tr>
<tr>
<td>NPGR016</td>
<td>Applied Computational Geometry</td>
<td>—</td>
<td>2/1 C+Ex</td>
</tr>
<tr>
<td>VNLM103</td>
<td>Fourierova analýza a wavelety</td>
<td>2/0 Zk</td>
<td>—</td>
</tr>
<tr>
<td>NPGR020</td>
<td>Geometry for Computer Graphics</td>
<td>—</td>
<td>2/0 Ex</td>
</tr>
<tr>
<td>NPGR028</td>
<td>Optics for computer graphics</td>
<td>2/0 Ex</td>
<td>—</td>
</tr>
<tr>
<td>NPGR010</td>
<td>Advanced 3D graphics for film and games</td>
<td>2/2 C+Ex</td>
<td>—</td>
</tr>
<tr>
<td>NPGR029</td>
<td>Seminar on Scientific Soft Skills</td>
<td>—</td>
<td>0/2 C</td>
</tr>
<tr>
<td>NPGR028</td>
<td>High Performance Ray Tracing</td>
<td>—</td>
<td>2/0 Zk</td>
</tr>
<tr>
<td>NPGR015</td>
<td>Special Functions and Transformations in Image Processing</td>
<td>—</td>
<td>2/0 Ex</td>
</tr>
<tr>
<td>NPGR011</td>
<td>Computer graphics and vision seminar</td>
<td>0/2 C</td>
<td>0/2 C</td>
</tr>
</tbody>
</table>
State Exam Requirements

Topics 1 - 5 are optionally mandatory in the sense that the student is required to pass an examination of at least one topics 1 and 2, as well as at least one of the topics 3-5. In addition to these, the candidate chooses one topic that was not already picked from topics 1-9, or possibly also others by special agreement with the advisor. The student should pass the state doctoral exam by end of the second year of study.

**Optionally mandatory topics (at least one of the topics 1 and 2 as well as at least one of the topics 3-5)**

1. **Theoretical foundations of computer science**
   - Discrete Mathematics: Graph Theory Fundamentals, Graph Representations in Memory, Graph Algorithms.

2. **Mathematical methods for graphics and image processing**
   - Matrix computations: Schur’s theorem, meaning of orthogonality and normality, matrix factorisation, methods for solving systems of linear equations, singular decomposition, least squares, partial eigenvalue problem, non-linearity and numerical instability in matrix computing.
   - Splines: polynomial spline theory, interpolation and smoothing splines, rational splines.
   - Wavelets: multi-resolution analysis theory, applications, algorithms, bi-orthogonal wavelets, multidimensional wavelets, wavelet packages, „lifting scheme,” continuous wavelet transformation; Mallat’s multi-resolution analysis; wavelets with compact support; wavelet examples.
   - Fourier transformation in L1(R); Wiener’s theory of Fourier transformation in L2(R); Paley-Wiener theorem and Heisenberg inequality.
   - Calculus of Variations Fundamentals (Euler-Lagrange equations, brachistochrone, Lagrange function, function with limited variation)
Fundamentals of numerical methods of problem solving (partial differential equations, finite element method, final differential method, steepest gradient method, conjugated gradients, quadratic programming)

Statistical methods (estimation of probability density function, parametric, non-parametric methods, hypothesis testing)

Geometric transformations, homogeneous coordinates, conversion between coordinate systems in a display pipeline.

3. Fundamentals of computer graphics

Fundamentals of 2D graphics: vision and colours, colorimetry and colour spaces, colour measurements and reproduction, raster graphics, raster image manipulation, raster drawing, anti-aliasing, data structures for 2D search, image and video compression, HDR photography, tone mapping.

Fundamentals of 3D graphics: transformations, representation of 3D scenes, levels of detail, parametric curves and surfaces, visibility, shading, textures, hardware-accelerated graphics, shading programs, CUDA/OpenCL foundation.


Data visualisation Fundamentals: volumetric data, computer tomography and magnetic resonance, calculation of iso-surfaces, direct volume imaging, volumetric light transport, visualisation of vector fields and tensors of higher order

4. Image analysis fundamentals

Image digitalisation, sampling and quantisation of continuous functions, Shannon’s Theorem.

Basic image manipulations, histogram, contrast changes, noise removal, image sharpening.

Linear filtering in spatial and frequency domain, convolution, Fourier transformation.

Edge and corner detection.

Image degradations and their modelling, removal of basic types of degradation (motion blur and defocus), invers and Wiener filter, PSF estimates, blind and multi-channel deconvolution, variational approach.

Image segmentation, classical and variational approaches (thresholding, region growing, Mumford-Shah functional, active contours, level sets).

Registering (matching) images.

Invariants for the description and recognition of 2D objects (general principles, visual features, moments, Fourier descriptors, differential features, moment invariants).

Feature-based recognition theory, supervised and unsupervised classifiers, NN-classifier, linear classifier, SVM classifiers, Bayes classifier. Examples of their use in image analysis.

Cluster analysis in feature space, iterative and hierarchical methods.

Feature space dimensionality reduction, PCA, suboptimal methods for feature selection.

2D wavelet transformation (WT) - mathematical fundamentals.

Using WT to detect edges and features in an image, noise suppression, image registration, and image fusion. Image compression by WT.
5. Fundamentals of 3D vision and robotics

Single-camera computer vision: single perspective camera geometry, projective equations, camera calibration, external and internal parameters, pattern reconstruction from its image.

Stereo-vision: canonical stereo and determination of scene depth, geometry of two cameras, epipolar constraint, fundamental matrix and its determination, solving the problem of stereo correspondence.

Object detection, counting, measurement and tracking: object detection, local features, granulometry, Kalman filter, mean shift.

3D reconstruction of objects: shape from XX (from shading, from multiple light sources, from texture, etc.).

Robot control architecture: motion planning, odometry, SLAM, robot control architecture.

Direct and inverse kinematics: terminology, typical structures, positioning of individual parts of the robot, end-to-end positioning.

Facultative topics

6. Computational geometry

Applied computational geometry: definitions, properties and algorithms for geometric search, convex hull, Voronoi diagram, their applications and generalisations, triangulation in 2D and 3D and their applications, medial axis, surface reconstruction, points of intersection and intersections of geometric objects.

Geometry for computer graphics: Group of projective, affine, and Euclidean transformations. Representation of these groups by matrices. Projective space, homogeneous coordinates. Spherical geometry. Use of quaternions and dual quaternions to describe Euclidean movement.

Curves and surfaces in computer graphics: Spline functions space, Hermite splines, cubic splines, Bézier curves and surfaces, B-spline curves and surfaces, rational curves and surfaces, NURBS, special surfaces, geometric continuity.

7. Realistic image synthesis

Radiometric and photometric quantities, the rendering equation, importance, duality of light transport and importance, operator formulation of light transport and importance. Monte Carlo integration, unbiased Monte Carlo methods for solving the rendering equation (path tracing, light tracing). Combined estimators and applications: direct lighting, bi-directional path tracing. The Metropolis-Hastings method of sampling, Metropolis light transport. Approximate methods for solving the rendering equation: (progressive) photon mapping, (ir)radiance caching, instant radiosity, lightcuts. The Radiance renderer, adaptive refining, hierarchical radiosity, stochastic radiosity. Display of participating media: light transport equations, media display algorithms, special techniques for clouds and atmosphere, translucent materials, BSSRDF. The REYES architecture, RenderMan standard, the principle of shading languages in RenderMan and OpenGL. Predictive image synthesis: error control in rendering pipeline, psycho-physics-faithful tone mapping, simulation of advanced optical phenomena (polarisation, diffraction), fluorescent materials, physical plausibility of shadow language constructs.
8. Invariants for recognition


9. Computer game development

Game engine architectures: renderer, physics, audio, I/O, network communication, game mechanisms, multi-platform aspects, game content production chain, etc. Examples of existing game engines.

Real-time rendering techniques: calculation of cast shadows, shadow maps, shadow volumes, advanced shadow map techniques (filtering, cascading maps). Deferred shading - principle, advantages, disadvantages. Ambient shading and calculating it in image space.

Advanced real-time shading: BRDF, light reflection equations, function representations, orthogonal and orthonormal bases, spherical harmonics and their use to represent BRDF and lighting, HDR environment map - principle, acquisition, use. Irradiance environment mapping.

Autonomous Agent Architecture. Games as an example of a multi-agent environment.

Representation and game space thinking: environment abstraction (navigation chart, navigation mesh, voxel navigation, visibility representation, environmental propagation), agent navigation in a 3D environment, finding the shortest path (A*, its variants and methods for speeding up calculations), following a path (collision avoidance with static and dynamic objects, reciprocal collision avoidance, steering techniques).

Reactive approaches to managing agents’ behaviour: hierarchical final automations, behavioural trees, decision spaces.

Distributing agent behaviour through environment and coordination: smart objects, smart areas, geniuses.

Examples of using scheduling in computer games.

Recommended bibliography

1. Theoretical foundations of computer science
2. Mathematical methods for graphics and image processing

3. Fundamentals of computer graphics

4. Image analysis fundamentals

5. Fundamentals of 3D vision and robotics

6. Computational geometry
František Ježek: Geometrické a počítačové modelování. Plzeň 2009
7. Realistic image synthesis

8. Invariants for recognition
J. Flusser, T. Suk and B. Zitová, 2D and 3D Image Analysis by Moments, Wiley Sons Ltd., 2016.

9. Computer game development