Module Handbook

for the

Master Programme “Computer Science”

at

Rheinischen Friedrich-Wilhelms-Universität Bonn

revised version: October 27, 2023

The curriculum of the master programme is divided into four sub-curricula, each corresponding to one of the four main areas of competence in research of the Bonn Institute of Computer Science:

1. Algorithmics
2. Graphics, Vision, Audio
3. Information and Communication Management
4. Intelligent Systems

Module numbers **MA-INF ASXY** have been assigned according to the following key: vergeben:

- **A** = number of the area of competence
- **S** = semester within the master curriculum
- **XY** = sequential number within the semester and the respective area of competence (two digits)

According to the curriculum, all modules ought to be taken between the first and the third semester. The fourth semester is reserved for preparing the master thesis.

Contents

1 Algorithmics

<table>
<tr><td>Module
MA-INF 1102</td><td>Combinatorial Optimization</td></tr>
<tr><td>Workload
270 h</td><td><table><tr><td>Credit points
9 CP</td><td>Duration
1 semester</td><td>Frequency
at least every year</td></tr></table></td></tr>
<tr><td>Module coordinator</td><td>Prof. Dr. Jens Vygen</td></tr>
<tr><td>Lecturer(s)</td><td>All lecturers of Discrete Mathematics</td></tr>
<tr><td>Classification</td><td><table><tr><td>Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
1. or 2.</td></tr></table></td></tr>
<tr><td>Technical skills</td><td>Advanced knowledge of combinatorial optimization. Modelling and development of solution strategies for combinatorial optimization problems</td></tr>
<tr><td>Soft skills</td><td>Mathematical modelling of practical problems, abstract thinking, presentation of solutions to exercises</td></tr>
<tr><td>Contents</td><td>Matchings, b-matchings and T-joins, optimization over matroids, submodular function minimization, travelling salesman problem, polyhedral combinatorics, NP-hard problems</td></tr>
<tr><td>Prerequisites</td><td>none</td></tr>
<tr><td>Format</td><td><table><tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr><tr><td>Lecture</td><td></td><td>4</td><td>60 T / 105 S</td><td>5.5</td></tr><tr><td>Exercises</td><td></td><td>2</td><td>30 T / 75 S</td><td>3.5</td></tr></table>T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td>Oral exam (graded)</td></tr>
<tr><td>Study achievements</td><td>Successful exercise participation (not graded)</td></tr>
<tr><td>Forms of media</td><td></td></tr>
<tr><td>Literature</td><td>• B. Korte, J. Vygen: Combinatorial Optimization: Theory and Algorithms. Springer, 6th edition, 2018
• A. Schrijver: Combinatorial Optimization: Polyhedra and Efficiency. Springer, 2003
• W. Cook, W. Cunningham, W. Pulleyblank, A. Schrijver: Combinatorial Optimization. Wiley, 1997
• A. Frank: Connections in Combinatorial Optimization. Oxford University Press, 2011</td></tr>
</table>

Module MA-INF 1103	**Cryptography**		
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** every year
Module coordinator	Dr. Michael Nüsken		
Lecturer(s)	Dr. Michael Nüsken		
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 1. or 2.
Technical skills	Understanding of security concerns and measures, and of the interplay between computing power and security requirements. Mastery of the basic techniques for cryptosystems and cryptanalysis		
Soft skills	Oral presentation (in tutorial groups), written presentation (of exercise solutions), team collaboration in solving homework problems, critical assessment		
Contents	Basic private-key and public-key cryptosystems: AES, RSA, group-based. Security reductions. Key exchange, cryptographic hash functions, signatures, identification; factoring integers and discrete logarithms; lower bounds in structured models.		
Prerequisites	none		
Format	see below		
Exam achievements	Written exam (graded)		
Study achievements	Successful exercise participation (not graded)		
Forms of media			
Literature	• Jonathan Katz & Yehuda Lindell (2015/2008). Introduction to Modern Cryptography, CRC Press. • Course notes		

Format:

Teaching format	**Group size**	**h/week**	**Workload[h]**	**CP**
Lecture		4	60 T / 105 S	5.5
Exercises		2	30 T / 75 S	3.5

T = face-to-face teaching; S = independent study

Module MA-INF 1105	**Algorithms for Data Analysis**		
Workload 180 h	**Credit points** 6 CP	**Duration** 1 semester	**Frequency** at least every 2 years
Module coordinator	Prof. Dr. Petra Mutzel		
Lecturer(s)	Prof. Dr. Petra Mutzel		
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 1. or 2.
Technical skills	Deeper insights into selected methods and techniques of modern algorithmics with respect to big data and/or analytics tasks		
Soft skills	Presentation of solutions and methods, critical discussion of applied methods and techniques.		
Contents	Advanced algorithmic techniques and data structures relevant to analytic tasks for big data, i.e., algorithms for graph similarity, parallel algorithms, I/O-data structures, and streaming algorithms.		
Prerequisites	**Required:** none **Recommended:** Introductory knowledge of foundations of algorithms and data structures is essential.		
Format	see below		
Exam achievements	Oral exam (graded)		
Study achievements	Successful exercise participation (not graded)		
Forms of media			
Literature			

Format:

Teaching format	Group size	h/week	Workload[h]	CP
Lecture		2	30 T / 45 S	2.5
Exercises		2	30 T / 75 S	3.5

T = face-to-face teaching; S = independent study

<table>
<tr><td>Module
MA-INF 1107</td><td>Foundations of Quantum Computing</td></tr>
<tr><td>Workload
180 h</td><td><table><tr><td>Credit points
6 CP</td><td>Duration
1 semester</td><td>Frequency
every 2 years</td></tr></table></td></tr>
<tr><td>Module coordinator</td><td>Prof. Dr.-Ing. Christian Bauckhage</td></tr>
<tr><td>Lecturer(s)</td><td>Prof. Dr.-Ing. Christian Bauckhage</td></tr>
<tr><td>Classification</td><td><table><tr><td>Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
1. or 3.</td></tr></table></td></tr>
<tr><td>Technical skills</td><td>Upon successful completion of this module, students should be able to describe fundamental concepts and techniques (qubits, quantum registers, quantum gates, quantum circuits) in quantum computing. Students will be equipped with specific, quantum computing related programming know-how; based on knowledge and skills acquired, students should be able to
• devise quantum computing algorithms for basic computational tasks
• run these algorithms on (simulated) quantum computers</td></tr>
<tr><td>Soft skills</td><td>In the exercises, students will have the opportunity to put their knowledge into practice, since they will realize small projects on computing with quantum gates and their solutions using quantum inspired methods or genuine quantum methods. This requires teamwork; upon successful completion of the module, students should be able to
• draft and implement basic quantum computing algorithms
• apply quantum computing (simulations) to test these algorithms
• prepare and give oral presentations about their work in front of an audience</td></tr>
<tr><td>Contents</td><td>Boolean algebras and Boolean lattices; cellular automata; classical digital computing; classical reversible computing; mathematical foundations of quantum computing (complex vector spaces, tensor products, unitary operators, Hermitian operators, qubits, superposition, entanglement); quantum gate computing; quantum circuits</td></tr>
<tr><td>Prerequisites</td><td>Recommended:
Good working knowledge of theory and practice of linear algebra</td></tr>
<tr><td>Format</td><td><table><tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr><tr><td>Lecture</td><td></td><td>2</td><td>30 T / 45 S</td><td>2.5</td></tr><tr><td>Exercises</td><td></td><td>2</td><td>30 T / 75 S</td><td>3.5</td></tr></table>T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td>Schriftliche Prüfung (graded)</td></tr>
<tr><td>Study achievements</td><td>Erfolgreiche Übungsteilnahme (not graded)</td></tr>
<tr><td>Forms of media</td><td>• lecture slides / lecture notes are made available online
• notebooks with programming examples are made available online</td></tr>
<tr><td>Literature</td><td>• L. Susskind, A. Friedman, “Quantum Mechanics: The Theoretical Minimum”, Penguin, 2015
• M.A. Nielsen, I.L Chuang, “Quantum Computation and Quantum Information”, Cambridge University Press, 10th Anniversary edition, 2010
• P. Wittek, “Quantum Machine Learning”, Academic Press, 2016
• M. Schuld, F. Petruccione, “Machine Learning with Quantum Computers”, Springer, 2nd edition, 2021
• S. Ganguly, “Quantum Machine Learning: An Applied Approach”, Apress, 2021</td></tr>
</table>

Module MA-INF 1108	**Introduction to High Performance Computing: Architecture Features and Practical Parallel Programming**		
Workload 180 h	**Credit points** 6 CP	**Duration** 1 semester	**Frequency** every year
Module coordinator	Prof. Dr. Estela Suarez		
Lecturer(s)	Prof. Dr. Estela Suarez		
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 1-3.
Technical skills	Understanding principles of computer architecture of modern HPC systems at component (processor, accelerators) and system level (system architecture, network, memory hierarchy) and their implication for application programming. Ability to program parallel computers, employing multi-core and multi-node features. Programming CPU and GPUs. Understanding the quality of performance .and scaling behaviour, and applying the measures needed to improve them.		
Soft skills	Ability to select a specific HPC topic and present it in a clear and comprehensive manner suitable for a lightning talk (10min)		
Contents	Computer architectures, system components (CPU, memory, network) and their interrelation. Software environment Access to HPC compute resources at the Jülich Supercomputing Centre Practical use of parallel programming paradigms (MPI, OpenMP, CUDA) Performance of applications and scaling behavior, understanding and strategies for improvement Current challenges in HPC		
Prerequisites	**Required:** Knowledge of a modern programming language (ideally C/C++ and Python). Interest in High Performance Computing Cannot be taken after completing MA-INF 1106. **Recommended:** Bachelor lecture on computer architecture		
Format	see below		
Exam achievements	Written exam (graded)		
Study achievements	Successful participation in the exercises (not graded)		
Forms of media	Laptop and projector		
Literature	• John L. Hennessy, David A. Patterson: Computer Architecture - A Quantitative Approach. Morgan Kaufmann Publishers, 2012 • David A. Patterson, John L. Hennessy: Computer Organization and Design - The Hardware / Software Interface. Morgan Kaufmann Publishers, 2013 • Message Passing Interface Forum: MPI: A Message-Passing Interface Standard, Version 3.1 • OpenMP Application Programming Interface, Version 4.5, November 2015		

Format

Teaching format	Group size	h/week	Workload[h]	CP
Lecture		2	30 T / 45 S	2.5
Exercises		2	30 T / 75 S	3.5

T = face-to-face teaching; S = independent study

<table>
<tr><td>Module
MA-INF 1201</td><td colspan="3">Approximation Algorithms</td></tr>
<tr><td>Workload
270 h</td><td>Credit points
9 CP</td><td>Duration
1 semester</td><td>Frequency
at least every year</td></tr>
<tr><td>Module coordinator</td><td colspan="3">Prof. Dr. Jens Vygen</td></tr>
<tr><td>Lecturer(s)</td><td colspan="3">All lecturers of Discrete Mathematics,
Senior Prof. Dr. Marek Karpinski</td></tr>
<tr><td>Classification</td><td colspan="3"><table><tr><td>Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
2. or 3.</td></tr></table></td></tr>
<tr><td>Technical skills</td><td colspan="3">Introduction to design and analysis of most important approximation algorithms for NP-hard combinatorial optimization problems, and various techniques for proving lower and upper bounds, probabilistic methods and applications</td></tr>
<tr><td>Soft skills</td><td colspan="3">Presentation of solutions and methods, critical discussion of applied methods and techniques</td></tr>
<tr><td>Contents</td><td colspan="3">Approximation Algorithms and Approximation Schemes. Design and Analysis of Approximation algorithms for selected NP-hard problems, like Set-Cover, and Vertex-Cover problems, MAXSAT, TSP, Knapsack, Bin Packing, Network Design, Facility Location. Introduction to various approximation techniques (like Greedy, LP-Rounding, Primal-Dual, Local Search, randomized techniques and Sampling, and MCMC-Methods), and their applications. Analysis of approximation hardness and PCP-Systems.</td></tr>
<tr><td>Prerequisites</td><td colspan="3">Recommended:
Introductory knowledge of foundations of algorithms and complexity theory is essential.</td></tr>
<tr><td>Format</td><td colspan="3"><table><tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr><tr><td>Lecture</td><td></td><td>4</td><td>60 T / 105 S</td><td>5.5</td></tr><tr><td>Exercises</td><td></td><td>2</td><td>30 T / 75 S</td><td>3.5</td></tr></table>T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="3">Oral exam (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="3">Successful exercise participation (not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="3"></td></tr>
<tr><td>Literature</td><td colspan="3">• S. Arora, C. Lund: Hardness of Approximations. In: Approximation Algorithms for NP-Hard Problems (D. S. Hochbaum, ed.), PWS, 1996
• M. Karpinski: Randomisierte und approximative Algorithmen für harte Berechnungsprobleme, Lecture Notes (5th edition), Universität Bonn, 2007
• B. Korte, J. Vygen: Combinatorial Optimization: Theory and Algorithms (6th edition), Springer, 2018
• V. V. Vazirani: Approximation Algorithms, Springer, 2001
• D. P. Williamson, D. B. Shmoys: The Design of Approximation Algorithms, Cambridge University Press, 2011</td></tr>
</table>

<table>
<tr><td>Module
MA-INF 1202</td><td colspan="3">Chip Design</td></tr>
<tr><td>Workload
270 h</td><td>Credit points
9 CP</td><td>Duration
1 semester</td><td>Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="3">Prof. Dr. Jens Vygen</td></tr>
<tr><td>Lecturer(s)</td><td colspan="3">All lecturers of Discrete Mathematics</td></tr>
<tr><td>Classification</td><td>Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
1. or 2.</td></tr>
<tr><td>Technical skills</td><td colspan="3">Knowledge of the central problems and algorithms in chip design. Competence to develop and apply algorithms for solving real-world problems, also with respect to technical constraints. Techniques to develop and implement efficient algorithms for very large instances.</td></tr>
<tr><td>Soft skills</td><td colspan="3">Mathematical modelling of problems occurring in chip design, development of efficient algorithms, abstract thinking, presentation of solutions to exercises</td></tr>
<tr><td>Contents</td><td colspan="3">Problem formulation and design flow for chip design, logic synthesis, placement, routing, timing analysis and optimization</td></tr>
<tr><td>Prerequisites</td><td colspan="3">none</td></tr>
<tr><td>Format</td><td colspan="3">
<table>
<tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr>
<tr><td>Lecture</td><td></td><td>4</td><td>60 T / 105 S</td><td>5.5</td></tr>
<tr><td>Exercises</td><td></td><td>2</td><td>30 T / 75 S</td><td>3.5</td></tr>
</table>
T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="3">Oral exam (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="3">Successful exercise participation (not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="3"></td></tr>
<tr><td>Literature</td><td colspan="3">• C.J. Alpert, D.P. Mehta, S.S. Sapatnekar: The Handbook of Algorithms for VLSI Physical Design Automation. CRC Press, New York, 2008.
• S. Held, B. Korte, D. Rautenbach, J. Vygen: Combinatorial optimization in VLSI design. In: "Combinatorial Optimization: Methods and Applications" (V. Chvátal, ed.), IOS Press, Amsterdam 2011, pp. 33-96
• S. Held, J. Vygen: Chip Design. Lecture Notes (distributed during the course)
• L. Lavagno, I.L. Markov, G. Martin, and L.K. Scheffer, eds.: Electronic Design Automation for IC Implementation, Circuit Design, and Process Technology. CRC Press, 2nd edition, 2016</td></tr>
</table>

Module MA-INF 1203	**Discrete and Computational Geometry**		
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** every year
Module coordinator	Prof. Dr. Anne Driemel		
Lecturer(s)	Prof. Dr. Anne Driemel, PD Dr. Elmar Langetepe, Dr. Herman Haverkort		
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 1-4.
Technical skills	Knowledge of fundamental theorems and concepts in the area of discrete and computational geometry; design and analysis of geometric algorithms; combinatorial analysis of the complexity of geometric configurations; to apply this knowledge autonomously in solving new problems.		
Soft skills	Social competence (communication, presenting one's own solutions, goal-oriented discussions in teams), methodical competence (analysis, abstraction, proofs), individual competence (commitment and willingness to learn, creativity, endurance).		
Contents	Fundamentals of convex sets, Voronoi diagrams, hyperplane arrangements, well-separated pair decomposition, spanners, metric space embedding, dimension reduction, VC-dimension, epsilon-nets, visibility, point location, range searching, randomized incremental construction, geometric distance problems in dimension two and higher.		
Prerequisites	**Recommended:** BA-INF 114 – Grundlagen der algorithmischen Geometrie		

Format

Teaching format	**Group size**	**h/week**	**Workload[h]**	**CP**
Lecture		4	60 T / 105 S	5.5
Exercises		2	30 T / 75 S	3.5

T = face-to-face teaching; S = independent study

Exam achievements	Oral exam	(graded)
Study achievements	Successful exercise participation	(not graded)
Forms of media		
Literature	• Jiri Matousek. Lectures on Discrete Geometry. Springer Graduate Texts in Mathematics. ISBN 0-387-95374-4. • Mark de Berg, Otfried Cheong, Marc van Kreveld, and Mark Overmars. Computational Geometry — Algorithms and Applications (Third Edition). Springer. ISBN 978-3-540-77973-5. • Narasimhan/Smid, Geometric Spanner Networks • Klein, Concrete and Abstract Voronoi Diagrams	

Module MA-INF 1205	**Graduate Seminar Discrete Optimization**			
Workload 180 h	**Credit points** 6 CP	**Duration** 1 semester	**Frequency** every year	
Module coordinator	Prof. Dr. Jens Vygen			
Lecturer(s)	All lecturers of Discrete Mathematics			
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 2.	
Technical skills	Competence to understand new research results based on original literature, to put such results in a broader context and present such results and relations.			
Soft skills	Ability to read and understand research papers, abstract thinking, presentation of mathematical results in a talk			
Contents	A current research topic in discrete optimization will be chosen each semester and discussed based on original literature.			
Prerequisites	**Recommended:** MA-INF 1102 – Combinatorial Optimization			
Format	see below T = face-to-face teaching; S = independent study			
Exam achievements	Oral presentation, written report (graded)			
Study achievements	(not graded)			
Forms of media				
Literature	The topics and the relevant literature will be announced towards the end of the previous semester.			

Format:

Teaching format	**Group size**	**h/week**	**Workload[h]**	**CP**
Seminar	10	4	60 T / 120 S	6

Module MA-INF 1206	**Seminar Randomized and Approximation Algorithms**		
Workload 120 h	**Credit points** 4 CP	**Duration** 1 semester	**Frequency** every year
Module coordinator	Prof. Dr. Heiko Röglin		
Lecturer(s)	Prof. Dr. Anne Driemel, Prof. Dr. Thomas Kesselheim, Prof. Dr. Heiko Röglin, PD Dr. Elmar Langetepe, Dr. Herman Haverkort, Senior Prof. Dr. Marek Karpinski		
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 2.
Technical skills	Ability to perform individual literature search, critical reading, understanding, and clear presentation.		
Soft skills	Presentation of solutions and methods, critical discussion of applied methods and techniques		
Contents	Current topics in design and analysis of randomized and approximation algorithms based on lastest research literature		
Prerequisites	none		
Format	see below		
Exam achievements	Oral presentation, written report (graded)		
Study achievements	(not graded)		
Forms of media			
Literature	The relevant literature will be announced in time.		

Format:

Teaching format	**Group size**	**h/week**	**Workload[h]**	**CP**
Seminar	10	2	30 T / 90 S	4

T = face-to-face teaching; S = independent study

Module MA-INF 1207	**Lab Combinatorial Algorithms**		
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** every year
Module coordinator	Prof. Dr. Jens Vygen		
Lecturer(s)	All lecturers of Discrete Mathematics		
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 2.
Technical skills	Competence to implement advanced combinatorial algorithms, handling nontrivial data structures, testing, documentation. Advanced software techniques.		
Soft skills	Efficient implementation of complex algorithms, abstract thinking, documentation of source code		
Contents	Certain combinatorial algorithms will be chosen each semester. The precise task will be explained in a meeting in the previous semester.		
Prerequisites	**Recommended:** MA-INF 1102 – Combinatorial Optimization		
Format	See below		
Exam achievements	Oral presentation, written report (graded)		
Study achievements	(not graded)		
Forms of media			
Literature	The topics and the relevant literature will be announced towards the end of the previous semester		

Format:

Teaching format	**Group size**	**h/week**	**Workload[h]**	**CP**
Lab	8	4	60 T / 210 S	9

T = face-to-face teaching; S = independent study

<table>
<tr><td>Module
MA-INF 1209</td><td colspan="3">Seminar Advanced Topics in Cryptography</td></tr>
<tr><td>Workload
120 h</td><td>Credit points
4 CP</td><td>Duration
1 semester</td><td>Frequency
every semester</td></tr>
<tr><td>Module coordinator</td><td colspan="3">Dr. Michael Nüsken</td></tr>
<tr><td>Lecturer(s)</td><td colspan="3">Dr. Michael Nüsken</td></tr>
<tr><td>Classification</td><td>Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
2. or 3.</td></tr>
<tr><td>Technical skills</td><td colspan="3">Understanding research publications, often written tersely. Distilling this into a presentation. Determination of relevant vs. irrelevant material. Developing a presentation that fascinates fellow students.</td></tr>
<tr><td>Soft skills</td><td colspan="3">Understanding and presenting material both orally and in visual media. Motivating other students to participate. Critical assessment of research results.</td></tr>
<tr><td>Contents</td><td colspan="3">A special topic within cryptography, changing from year to year, is studied in depth, based on current research literature</td></tr>
<tr><td>Prerequisites</td><td colspan="3">Required:
MA-INF 1103 – Cryptography
and one further course in cryptography like The Art of Cryptography or eSecurity.</td></tr>
<tr><td>Format</td><td colspan="3"><table><tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr><tr><td>Seminar</td><td>10</td><td>2</td><td>30 T / 90 S</td><td>4</td></tr></table>T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="3">Oral presentation, written report (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="3">(not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="3"></td></tr>
<tr><td>Literature</td><td colspan="3">Current cryptographic literature.</td></tr>
</table>

<table>
<tr><td>Module
MA-INF 1213</td><td>Randomized Algorithms and Probabilistic Analysis</td></tr>
<tr><td>Workload
270 h</td><td><table><tr><th>Credit points</th><th>Duration</th><th>Frequency</th></tr><tr><td>9 CP</td><td>1 semester</td><td>every year</td></tr></table></td></tr>
<tr><td>Module coordinator</td><td>Prof. Dr. Heiko Röglin</td></tr>
<tr><td>Lecturer(s)</td><td>Prof. Dr. Heiko Röglin</td></tr>
<tr><td>Classification</td><td><table><tr><th>Programme</th><th>Mode</th><th>Semester</th></tr><tr><td>M. Sc. Computer Science</td><td>Optional</td><td>2. or 4.</td></tr></table></td></tr>
<tr><td>Technical skills</td><td>Understanding of models and techniques for the probabilistic analysis of algorithms as well as for the design and analysis of randomized algorithms</td></tr>
<tr><td>Soft skills</td><td>Oral and written presentation of solutions and methods, abstract thinking</td></tr>
<tr><td>Contents</td><td>Design and analysis of randomized algorithms
• complexity classes
• Markov chains and random walks
• tail inequalities
• probabilistic method
smoothed and average-case analysis
• simplex algorithm
• local search algorithms
• clustering algorithms
• combinatorial optimization problems
• multi-objective optimization</td></tr>
<tr><td>Prerequisites</td><td>none</td></tr>
<tr><td>Format</td><td><table><tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr><tr><td>Lecture</td><td></td><td>4</td><td>60 T / 105 S</td><td>5.5</td></tr><tr><td>Exercises</td><td></td><td>2</td><td>30 T / 75 S</td><td>3.5</td></tr></table>T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td>Oral exam (graded)</td></tr>
<tr><td>Study achievements</td><td>Successful exercise participation (not graded)</td></tr>
<tr><td>Forms of media</td><td></td></tr>
<tr><td>Literature</td><td>• lecture notes
• research articles
• Motwani, Raghavan, Randomized Algorithms, Cambridge University Press, 1995
• Mitzenmacher, Upfal, Probability and Computing, Cambridge University Press, 2nd edition, 2017</td></tr>
</table>

Module MA-INF 1217	**Seminar Theoretical Foundations of Data Science**		
Workload 120 h	**Credit points** 4 CP	**Duration** 1 semester	**Frequency** every year
Module coordinator	Prof. Dr. Heiko Röglin		
Lecturer(s)	Prof. Dr. Anne Driemel, Prof. Dr. Thomas Kesselheim, Prof. Dr. Heiko Röglin, PD Dr. Elmar Langetepe, Dr. Herman Haverkort		
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 2. or 3.
Technical skills	Ability to understand new research results presented in original scientific papers.		
Soft skills	Ability to present and to critically discuss these results in the framework of the corresponding area.		
Contents	Current conference and journal papers		
Prerequisites	none		
Format	see below		
Exam achievements	Oral presentation, written report (graded)		
Study achievements	(not graded)		
Forms of media			
Literature			

Format:

Teaching format	**Group size**	**h/week**	**Workload[h]**	**CP**
Seminar	10	2	30 T / 90 S	4

T = face-to-face teaching; S = independent study

Module MA-INF 1218	**Algorithms and Uncertainty**		
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** at least every 2 years
Module coordinator	Prof. Dr. Thomas Kesselheim		
Lecturer(s)	Prof. Dr. Thomas Kesselheim		
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 2. or 3.
Technical skills	Understanding approaches for modeling uncertainty in algorithmic theory. Designing and analyzing algorithms with performance guarantees in the context of uncertainty.		
Soft skills	Oral and written presentation of solutions and methods		
Contents	• Advanced Online Algorithms • Markov Decisions Processes • Stochastic and Robust Optimization • Online Learning Algorithms and Online Convex Optimization		
Prerequisites	**Recommended:** Solid background in algorithms, calculus, and probability theory. Specialized knowledge about certain algorithms is not necessary.		

Format

Teaching format	**Group size**	**h/week**	**Workload[h]**	**CP**
Lecture		4	60 T / 105 S	5.5
Exercises		2	30 T / 75 S	3.5

T = face-to-face teaching; S = independent study

Exam achievements	Oral exam (graded)
Study achievements	Successful exercise participation (not graded)
Forms of media	
Literature	lecture notes, research articles

<table>
<tr><td>Module
MA-INF 1219</td><td colspan="5">Seminar Algorithmic Game Theory</td></tr>
<tr><td>Workload
120 h</td><td>Credit points
4 CP</td><td colspan="2">Duration
1 semester</td><td colspan="2">Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="5">Prof. Dr. Thomas Kesselheim</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Prof. Dr. Thomas Kesselheim</td></tr>
<tr><td>Classification</td><td colspan="2">Programme
M. Sc. Computer Science</td><td colspan="2">Mode
Optional</td><td>Semester
2. or 3.</td></tr>
<tr><td>Technical skills</td><td colspan="5">Ability to understand new research results presented in original scientific papers.</td></tr>
<tr><td>Soft skills</td><td colspan="5">Ability to perform individual literature search, critical reading, and clear didactic presentation</td></tr>
<tr><td>Contents</td><td colspan="5">Advanced topics in Algorithmic Game Theory and Algorithmic Mechanism Design based on current conference and journal papers</td></tr>
<tr><td>Prerequisites</td><td colspan="5">none</td></tr>
<tr><td rowspan="3">Format</td><td>Teaching format</td><td>Group size</td><td>h/week</td><td>Workload[h]</td><td>CP</td></tr>
<tr><td>Seminar</td><td>10</td><td>2</td><td>30 T / 90 S</td><td>4</td></tr>
<tr><td colspan="5">T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="5">Oral presentation, written report (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="5">(not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="5"></td></tr>
<tr><td>Literature</td><td colspan="5"></td></tr>
</table>

Module MA-INF 1220	**Seminar Algorithms for Computational Analytics**		
Workload 120 h	**Credit points** 4 CP	**Duration** 1 semester	**Frequency** at least every year
Module coordinator	Prof. Dr. Petra Mutzel		
Lecturer(s)	Prof. Dr. Petra Mutzel		
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 2. or 3.
Technical skills	Ability to perform individual literature search, critical reading, understanding, and clear didactic presentation.		
Soft skills	Ability to present and to critically discuss these results in the framework of the corresponding area.		
Contents	Current topics in algorithms for computational analytics based on recent research literature.		
Prerequisites	**Recommended:** Interest in Algorithms		
Exam achievements	Oral presentation, written report (graded)		
Study achievements	(not graded)		
Forms of media			
Literature	The relevant literature will be announced in time.		

Format

Teaching format	**Group size**	**h/week**	**Workload[h]**	**CP**
Seminar	10	2	30 T / 90 S	4

T = face-to-face teaching; S = independent study

<table>
<tr><td>Module
MA-INF 1221</td><td colspan="4">Lab Computational Analytics</td></tr>
<tr><td>Workload
270 h</td><td>Credit points
9 CP</td><td>Duration
1 semester</td><td colspan="2">Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="4">Prof. Dr. Petra Mutzel</td></tr>
<tr><td>Lecturer(s)</td><td colspan="4">Prof. Dr. Petra Mutzel</td></tr>
<tr><td>Classification</td><td colspan="2">Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
2. or 3.</td></tr>
<tr><td>Technical skills</td><td colspan="4">Ability to design, analyze and implement efficient algorithms for computational analytics problems. The LAB also includes experimental evaluation and documentation of the implemented software.</td></tr>
<tr><td>Soft skills</td><td colspan="4">Ability to properly present and defend design decisions, to prepare readable documentation of software; skills in constructively collaborating with others in small teams over a longer period of time; ability to classify ones own results into the state-of-the-art of the resp. area</td></tr>
<tr><td>Contents</td><td colspan="4">Design of efficient exact and approximate algorithms and data structures for computational analytics problems.</td></tr>
<tr><td>Prerequisites</td><td colspan="4">Recommended:
Interests in algorithms</td></tr>
<tr><td>Format</td><td colspan="4"><table><tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr><tr><td>Lab</td><td>8</td><td>4</td><td>60 T / 210 S</td><td>9</td></tr></table>T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="4">Oral presentation, written report (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="4">(not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="4"></td></tr>
<tr><td>Literature</td><td colspan="4">The relevant literature will be announced in time.</td></tr>
</table>

<table>
<tr><td>Module
MA-INF 1222</td><td colspan="5">Lab High Performance Optimization</td></tr>
<tr><td>Workload
270 h</td><td colspan="2">Credit points
9 CP</td><td>Duration
1 semester</td><td colspan="2">Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="5">Prof. Dr. Petra Mutzel</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Prof. Dr. Petra Mutzel, Dr. Sven Mallach</td></tr>
<tr><td>Classification</td><td colspan="3">Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
2. or 3.</td></tr>
<tr><td>Technical skills</td><td colspan="5">Ability to design, analyze and implement algorithms for computational analytics and optimization problems. The lab also includes experimental evaluation and documentation of the implemented software.</td></tr>
<tr><td>Soft skills</td><td colspan="5">Ability to properly present and defend design decisions, to prepare readable documentation of software; skills in constructively collaborating with others in small teams over a longer period of time; ability to classify ones own results into the state-of-the-art of the resp. area</td></tr>
<tr><td>Contents</td><td colspan="5"></td></tr>
<tr><td>Prerequisites</td><td colspan="5">none</td></tr>
<tr><td rowspan="3">Format</td><td>Teaching format</td><td>Group size</td><td>h/week</td><td>Workload[h]</td><td>CP</td></tr>
<tr><td>Lab</td><td>8</td><td>4</td><td>60 T / 210 S</td><td>9</td></tr>
<tr><td colspan="5">T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="5">Oral presentation, written report (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="5">(not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="5"></td></tr>
<tr><td>Literature</td><td colspan="5">The relevant literature will be announced in time.</td></tr>
</table>

<table>
<tr><td>Module
MA-INF 1223</td><td colspan="3">Privacy Enhancing Technologies</td></tr>
<tr><td>Workload
270 h</td><td>Credit points
9 CP</td><td>Duration
1 semester</td><td>Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="3">Dr. Michael Nüsken</td></tr>
<tr><td>Lecturer(s)</td><td colspan="3">Dr. Michael Nüsken</td></tr>
<tr><td>Classification</td><td>Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
2. or 3.</td></tr>
<tr><td>Technical skills</td><td colspan="3">Knowledge: Cryptographic schemes for enhancing privacy, underlying security notions, applications and restrictions.
Skills: Secure application of sophisticated cryptographic schemes. Evaluation of their correctness, efficiency and security in an application setting.</td></tr>
<tr><td>Soft skills</td><td colspan="3">Competences: Ability to assess schemes and their use in applications. Critical assessment of applications.</td></tr>
<tr><td>Contents</td><td colspan="3">With more and more data available a clear separation of sensitive data is necessary and needs to be protected. Some of that data must stay within strict environments, for examples hospitals must store certain highly sensitive medical information about patients but they are not allowed to store it outside its own facilities. Some of that data is stored or collected in a cloud environment in encrypted form, say data from a medical device or a smart home. But it shall still be possible to derive important conclusions from it, for example to send immediate help to a patient suffering a heart attack.
Innovative solutions are needed in this area of tension. The research in cryptography provides some highly sophisticated tools for solving the like problems.
• Fully homomorphic encryption (FHE).
• Zero-Knowledge techniques, in particular: Non-interactive zero-knowledge proof (NIZKs).
• Secure multi-party computations (MPC).
• Anonymisation, TOR. Pseudonymization. Blinding.
• Weaker privacy notions, like differential privacy.</td></tr>
<tr><td>Prerequisites</td><td colspan="3">Recommended:
Basic knowledge in cryptography is highly recommended.
A profound mathematical background does help. In particular, precise mathematical formulation and reasoning are important, but also topics like elementary number theory and discrete mathematics, especially lattices, are interesting.</td></tr>
<tr><td>Format</td><td colspan="3"><table>
<tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr>
<tr><td>Lecture</td><td></td><td>4</td><td>60 T / 105 S</td><td>5.5</td></tr>
<tr><td>Exercises</td><td></td><td>2</td><td>30 T / 75 S</td><td>3.5</td></tr>
</table>T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="3">Schriftliche Prüfung (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="3">Erfolgreiche Übungsteilnahme (not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="3"></td></tr>
<tr><td>Literature</td><td colspan="3"></td></tr>
</table>

Module MA-INF 1224	**Quantum Computing Algorithms**		
Workload 150 h	**Credit points** 5 CP	**Duration** 1 semester	**Frequency** every 2 years
Module coordinator	Prof. Dr. Christian Bauckhage		
Lecturer(s)	Prof. Dr. Christian Bauckhage		
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 2. or 4.
Technical skills	Upon successful completion of this module, students should be able to describe fundamental concepts behind working quantum algorithms. Students acquire quantum computing programming know-how; based on knowledge and skills acquired, students should be able to • run quantum algorithms on (simulated) quantum computing platforms • devise their own algorithms for optimization or classification problems that can be solved on quantum computers		
Soft skills	In the exercises, students can put their quantum computing knowledge into practice and realize small projects involving the implementation of quantum algorithm. This requires teamwork; upon successful completion of the module, students should be able to • draft and implement basic quantum computing algorithms • apply quantum computing (simulations) to test these algorithms • prepare and give oral presentations about their work in front of an audience		
Contents	quantum gate algorithms such as Deutsch-Jozsa, Bernstein-Vazirani, Simon, Shor, Grover; phase kick-back, amplitude amplification; swap tests; Hamiltonian simulation, Trotterization, variational quantum computing for optimization		
Prerequisites	**Required:** MA-INF 1107 “Fondations of Quantum Computing“		
Format	see below		
Exam achievements	Schriftliche Prüfung (graded)		
Study achievements	Erfolgreiche Übungsteilnahme (not graded)		
Forms of media	• lecture slides / lecture notes are made available online • notebooks with programming examples are made available online		
Literature	M.A. Nielsen, I.L Chuang, “Quantum Computation and Quantum Information”, Cambridge University Press, 10th Anniversary edition, 2010 P. Wittek, “Quantum Machine Learning”, Academic Press, 2016 M. Schuld, F. Petruccione, “Machine Learning with Quantum Computers”, Springer, 2nd edition, 2021 S. Ganguly, “Quantum Machine Learning: An Applied Approach”, Apress, 2021		

Format

Teaching format	Group size	h/week	Workload[h]	CP
Lecture		2	30 T / 45 S	2.5
Exercises		1	15 T / 60 S	2.5

T = face-to-face teaching; S = independent study

Module MA-INF 1225	**Lab Exploring HPC technologies**
Workload 270 h	**Credit points** 9 CP **Duration** 1 semester **Frequency** every year
Module coordinator	Prof. Dr. Estela Suarez
Lecturer(s)	Prof. Dr. Estela Suarez
Classification	**Programme** M. Sc. Computer Science **Mode** Optional **Semester** 2. or 3.
Technical skills	Understanding a use case from complex code developed. Adapting and running applications to different kinds of processing units, taking into account their specific architecture characteristic and programming environments. Understanding and using parallel programming paradigms and high-level programming languages. Designing and executing a benchmarking campaign. Using performance analysis tools, understanding performance bottlenecks and measures to improve them. Software development skills and standards.
Soft skills	Collaborating and interacting with application developers, tools developers, and system administrators in a solution oriented manner, taking into account their different “work language” and expertise. Presenting performed work and results obtained and classifying own results into the state-of-the-art. Preparing software documentation.
Contents	The students carry out a practical task (project) in High Performance Computing (HPC), including test of different hardware architectures and software tools, documentation of the implemented software/system. Contents: HPC systems: access/use of compute resources at Jülich Supercomputing Centre; Use of different processor architectures; Software environment, performance analysis tools; Parallel programming; Benchmarking tools/procedures; Performance of applications and scaling behavior, strategies for improvement
Prerequisites	**Required:** -Passed the exam of MA-INF 1106 or MA-INF 1108. -Knowledge modern programming languages (C/C++, Python). -Willing to stay for at least 2 days per week during 4 weeks at the Jülich Supercomputing Centre, dates to be discussed.
Remarks	Registration first via direct mail communication with the lecturer, in order to identify suitable dates for the stay at JSC.
Format	**Teaching format**: Lab **Group size**: 2 **h/week**: 4 **Workload[h]**: 60 T / 210 S **CP**: 9 T = face-to-face teaching; S = independent study
Exam achievements	Oral presentation, written report (graded)
Study achievements	(not graded)
Forms of media	Own laptop to connect and program on the supercomputers.
Literature	• John L. Hennessy, David A. Patterson: Computer Architecture - A Quantitative Approach. Morgan Kaufmann Publishers, 2012 • David A. Patterson, John L. Hennessy: Computer Organization and Design - The Hardware / Software Interface. Morgan Kaufmann Publishers, 2013 • Message Passing Interface Forum: MPI: A Message-Passing Interface Standard, Version 3.1 • OpenMP Application Programming Interface, Version 4.5, November 2015

<table>
<tr><td>Module
MA-INF 1301</td><td colspan="5">Algorithmic Game Theory</td></tr>
<tr><td>Workload
270 h</td><td colspan="2">Credit points
9 CP</td><td>Duration
1 semester</td><td colspan="2">Frequency
every 2 years</td></tr>
<tr><td>Module coordinator</td><td colspan="5">Prof. Dr. Thomas Kesselheim</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Prof. Dr. Thomas Kesselheim,
Senior Prof. Dr. Marek Karpinski</td></tr>
<tr><td>Classification</td><td colspan="3">Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
2. or 3.</td></tr>
<tr><td>Technical skills</td><td colspan="5">Knowledge of fundamental results in (algorithmic) game theory and (algorithmic) mechanism design. Techniques and methods related to mathematical modeling of strategic agents. Analyzing and designing systems of strategic agents, with a focus on computational efficiency and performance guarantees.</td></tr>
<tr><td>Soft skills</td><td colspan="5">Presentation of solutions and methods, critical discussion of applied methods and techniques</td></tr>
<tr><td>Contents</td><td colspan="5">• basic game theory
• computability and hardness of equilibria
• convergence of dynamics of selfish agents
• (bounds on the) loss of performance due to selfish behavior
• designing incentive-compatible auctions
• maximizing revenue
• designing mechanisms for stable and fair allocations without money</td></tr>
<tr><td>Prerequisites</td><td colspan="5">Recommended:
Introductory knowledge of foundations of algorithms and complexity theory is essential.</td></tr>
<tr><td rowspan="4">Format</td><td>Teaching format</td><td>Group size</td><td>h/week</td><td>Workload[h]</td><td>CP</td></tr>
<tr><td>Lecture</td><td></td><td>4</td><td>60 T / 105 S</td><td>5.5</td></tr>
<tr><td>Exercises</td><td></td><td>2</td><td>30 T / 75 S</td><td>3.5</td></tr>
<tr><td colspan="5">T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="5">Written exam (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="5">Successful exercise participation (not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="5"></td></tr>
<tr><td>Literature</td><td colspan="5">• N. Nisan, T. Roughgarden, E. Tardos, V.V. Vazirani (ed.): Algorithmic Game Theory, Cambridge Univ. Press, 2007
• T. Roughgarden, Twenty Lectures on Algorithmic Game Theory, Cambridge Univ. Press, 2016
• A. Karlin, Y. Peres, Game Theory, Alive, AMS, 2017
• Y. Shoham, K. Leyton-Brown, Multiagent Systems, Cambridge Univ. Press, 2009
• D. M. Kreps: A Course in Microeconomic Theory, Princeton Univ. Press, 1990
• M. J. Osborne, A. Rubinstein: A Course in Game Theory, MIT Press, 2001</td></tr>
</table>

Module MA-INF 1304	**Seminar Computational Geometry**
Workload 120 h	**Credit points** 4 CP **Duration** 1 semester **Frequency** every year
Module coordinator	Prof. Dr. Anne Driemel
Lecturer(s)	Prof. Dr. Anne Driemel, PD Dr. Elmar Langetepe, Dr. Herman Haverkort
Classification	**Programme** M. Sc. Computer Science **Mode** Optional **Semester** 2-4.
Technical skills	To independently study problems at research level, based on research publications, to prepare a concise summary, to present the summary in a scientific talk, to lead a critical discussion with other seminar participants.
Soft skills	
Contents	Current topics in computational geometry.
Prerequisites	**Recommended:** BA-INF 114 – Grundlagen der algorithmischen Geometrie MA-INF 1203 – Discrete and Computational Geometry
Format	**Teaching format**: Seminar; **Group size**: 10; **h/week**: 2; **Workload[h]**: 30 T / 90 S; **CP**: 4 T = face-to-face teaching; S = independent study
Exam achievements	Oral presentation, written report (graded)
Study achievements	(not graded)
Forms of media	Multimedia projector, black board.
Literature	The relevant literature will be announced.

Module MA-INF 1305	**Graduate Seminar on Applied Combinatorial Optimization**				
Workload 180 h	**Credit points** 6 CP	**Duration** 1 semester	**Frequency** every year		
Module coordinator	Prof. Dr. Jens Vygen				
Lecturer(s)	All lecturers of Discrete Mathematics				
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 3.		
Technical skills	Competence to understand new theoretical results and practical solutions in VLSI design and related applications, as well as presentation of such results				
Soft skills	Ability to read and understand research papers, abstract thinking, presentation of mathematical results in a talk				
Contents	Current topics in chip design and related applications				
Prerequisites	**Recommended:** At least 1 of the following: MA-INF 1102 – Combinatorial Optimization MA-INF 1202 – Chip Design				
Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Seminar	10	4	60 T / 120 S	6
	T = face-to-face teaching; S = independent study				
Exam achievements	Oral presentation, written report (graded)				
Study achievements	(not graded)				
Forms of media					
Literature	The topics and the relevant literature will be announced towards the end of the previous semester				

<table>
<tr><td>Module
MA-INF 1307</td><td colspan="3">Seminar Advanced Algorithms</td></tr>
<tr><td>Workload
120 h</td><td>Credit points
4 CP</td><td>Duration
1 semester</td><td>Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="3">Prof. Dr. Thomas Kesselheim</td></tr>
<tr><td>Lecturer(s)</td><td colspan="3">Prof. Dr. Anne Driemel, Prof. Dr. Thomas Kesselheim,
Prof. Dr. Heiko Röglin, PD Dr. Elmar Langetepe,
Dr. Herman Haverkort</td></tr>
<tr><td>Classification</td><td>Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
3.</td></tr>
<tr><td>Technical skills</td><td colspan="3">Presentation of selected advanced topics in algorithm design and various applications</td></tr>
<tr><td>Soft skills</td><td colspan="3">Ability to perform individual literature search, critical reading, understanding, and clear didactic presentation</td></tr>
<tr><td>Contents</td><td colspan="3">Advanced topics in algorithm design based on newest research literature</td></tr>
<tr><td>Prerequisites</td><td colspan="3">none</td></tr>
<tr><td>Format</td><td colspan="3"><table><tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr><tr><td>Seminar</td><td>10</td><td>2</td><td>30 T / 90 S</td><td>4</td></tr></table>T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="3">Oral presentation, written report (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="3">(not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="3"></td></tr>
<tr><td>Literature</td><td colspan="3">The relevant literature will be announced in time.</td></tr>
</table>

Module MA-INF 1308	**Lab Algorithms for Chip Design**				
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** every year		
Module coordinator	Prof. Dr. Jens Vygen				
Lecturer(s)	All lecturers of Discrete Mathematics				
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 3.		
Technical skills	Competence to implement algorithms for VLSI design, efficient handling of very large instances, testing, documentation. Advanced software techniques.				
Soft skills	Efficient implementation of complex algorithms, abstract thinking, modelling of optimization problem in VLSI design, documentation of source code				
Contents	A currently challenging problem will be chosen each semester. The precise task will be explained in a meeting in the previous semester.				
Prerequisites	**Recommended:** At least 3 of the following: MA-INF 1102 – Combinatorial Optimization MA-INF 1202 – Chip Design MA-INF 1205 – Graduate Seminar Discrete Optimization				
Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Lab	8	4	60 T / 210 S	9
	T = face-to-face teaching; S = independent study				
Exam achievements	Oral presentation, written report (graded)				
Study achievements	(not graded)				
Forms of media					
Literature	The topics and the relevant literature will be announced towards the end of the previous semester				

Module MA-INF 1309	**Lab Efficient Algorithms: Design, Analysis and Implementation**		
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** at least every year
Module coordinator	Prof. Dr. Heiko Röglin		
Lecturer(s)	Prof. Dr. Anne Driemel, Prof. Dr. Thomas Kesselheim, Prof. Dr. Heiko Röglin, PD Dr. Elmar Langetepe, Dr. Herman Haverkort		
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 3.
Technical skills	Ability to design, analyze and implement efficient algorithms for selected computational problems.		
Soft skills	ability to work on advanced algorithmic implementation projects, to work in small teams, clear didactic presentation and critical discussion of results		
Contents	Design of efficient exact and approximate algorithms and data structures for selected computational problems.		
Prerequisites	none		

Format

Teaching format	**Group size**	**h/week**	**Workload[h]**	**CP**
Lab	8	4	60 T / 210 S	9

T = face-to-face teaching; S = independent study

Exam achievements	Oral presentation, written report (graded)
Study achievements	(not graded)
Forms of media	
Literature	The relevant literature will be announced in time.

<table>
<tr><td>Module
MA-INF 1314</td><td colspan="5">Online Motion Planning</td></tr>
<tr><td>Workload
270 h</td><td>Credit points
9 CP</td><td colspan="2">Duration
1 semester</td><td colspan="2">Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="5">PD Dr. Elmar Langetepe</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Prof. Dr. Rolf Klein, PD Dr. Elmar Langetepe</td></tr>
<tr><td>Classification</td><td colspan="2">Programme
M. Sc. Computer Science</td><td colspan="2">Mode
Optional</td><td>Semester
1-4.</td></tr>
<tr><td>Technical skills</td><td colspan="5">To acquire fundamental knowledge on topics and methods in online motion planning</td></tr>
<tr><td>Soft skills</td><td colspan="5"></td></tr>
<tr><td>Contents</td><td colspan="5">Search and exploration in unknown environments (e.g., graphs, cellular environmwents, polygons, strets), online algorithms, competitive analysis, competitive complexity,functional optimization, shortest watchman route, tethered robots, marker algorithms, spiral search, approximation of optimal search paths.</td></tr>
<tr><td>Prerequisites</td><td colspan="5">Recommended:
BA-INF 114 – Grundlagen der algorithmischen Geometrie</td></tr>
<tr><td rowspan="4">Format</td><td>Teaching format</td><td>Group size</td><td>h/week</td><td>Workload[h]</td><td>CP</td></tr>
<tr><td>Lecture</td><td></td><td>4</td><td>60 T / 105 S</td><td>5.5</td></tr>
<tr><td>Exercises</td><td></td><td>2</td><td>30 T / 75 S</td><td>3.5</td></tr>
<tr><td colspan="5">T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="5">Oral exam (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="5">Successful exercise participation (not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="5">Java applets of geometry lab</td></tr>
<tr><td>Literature</td><td colspan="5">Scientific research articles will be recommended in the lecture.</td></tr>
</table>

Module MA-INF 1315	**Lab Computational Geometry**		
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** every year
Module coordinator	Prof. Dr. Anne Driemel		
Lecturer(s)	Prof. Dr. Anne Driemel, PD Dr. Elmar Langetepe, Dr. Herman Haverkort		
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 2.
Technical skills	Ability to design, analyze, implement and document efficient algorithms for selected problems in computational geometry.		
Soft skills	Ability to properly present, defend and discuss design and implementation decisions, to document software according to given rules and to collaborate with other students in small groups.		
Contents	Various problems in computational geometry.		
Prerequisites	none		

Format

Teaching format	**Group size**	**h/week**	**Workload[h]**	**CP**
Lab	8	4	60 T / 210 S	9

T = face-to-face teaching; S = independent study

Exam achievements	Oral presentation, written report (graded)
Study achievements	(not graded)
Forms of media	
Literature	The relevant literature will be announced in time.

Module MA-INF 1316	**Lab Cryptography**			
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** every year	
Module coordinator	Dr. Michael Nüsken			
Lecturer(s)	Dr. Michael Nüsken			
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 2. or 3.	
Technical skills	The students will carry out a practical task (project) in the context of Cryptography, including test and documentation of the implemented software/system.			
Soft skills	Ability to properly present and defend design decisions, to prepare readable documentation of software; skills in constructively collaborating with others in small teams over a longer period of time; ability to classify ones own results into the state-of-the-art of the resp. area			
Contents				
Prerequisites	none			
Format	see below			
Exam achievements	Oral presentation, written report (graded)			
Study achievements	(not graded)			
Forms of media				
Literature				

Format:

Teaching format	Group size	h/week	Workload[h]	CP
Lab	8	4	60 T / 210 S	9

T = face-to-face teaching; S = independent study

<table>
<tr><td>Module
MA-INF 1320</td><td colspan="3">Lab Advanced Algorithms</td></tr>
<tr><td>Workload
270 h</td><td>Credit points
9 CP</td><td>Duration
1 semester</td><td>Frequency
at least every 2 years</td></tr>
<tr><td>Module coordinator</td><td colspan="3">Prof. Dr. Thomas Kesselheim</td></tr>
<tr><td>Lecturer(s)</td><td colspan="3">Prof. Dr. Thomas Kesselheim, Prof. Dr. Heiko Röglin</td></tr>
<tr><td>Classification</td><td>Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
2. or 3.</td></tr>
<tr><td>Technical skills</td><td colspan="3">Implementation of algorithms from advanced algorithmic theory, evaluating these algorithm on suitably chosen instances, and discussing how theoretical results transfer to practice.</td></tr>
<tr><td>Soft skills</td><td colspan="3">Ability to properly present, defend and discuss design and implementation decisions and observed conclusions, and to collaborate with other students in small groups.</td></tr>
<tr><td>Contents</td><td colspan="3">Various problems from current research and courses on algorithmic theory.</td></tr>
<tr><td>Prerequisites</td><td colspan="3">none</td></tr>
<tr><td>Format</td><td colspan="3"><table><tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr><tr><td>Lab</td><td>8</td><td>4</td><td>60 T / 210 S</td><td>9</td></tr></table>T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="3">Oral presentation, written report (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="3">(not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="3"></td></tr>
<tr><td>Literature</td><td colspan="3">The relevant literature will be announced in time.</td></tr>
</table>

<table>
<tr><td>Module
MA-INF 1321</td><td colspan="5">Binary Linear and Quadratic Optimization</td></tr>
<tr><td>Workload
180 h</td><td>Credit points
6 CP</td><td colspan="2">Duration
1 semester</td><td colspan="2">Frequency
at least every 2 years</td></tr>
<tr><td>Module coordinator</td><td colspan="5">Dr. Sven Mallach</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Dr. Sven Mallach</td></tr>
<tr><td>Classification</td><td colspan="2">Programme
M. Sc. Computer Science</td><td colspan="2">Mode
Optional</td><td>Semester
2. or 3.</td></tr>
<tr><td>Technical skills</td><td colspan="5">Deeper understanding of computational methods to solve potentially large-scale mixed-integer programs in practice. Application-specific modelling and reformulation of combinatorial optimization problems, handling quadratic objective functions, algorithm design.</td></tr>
<tr><td>Soft skills</td><td colspan="5">Social, methodological, and analytical competences via communication, own development, presentation, and critical assessment of problem formulations, algorithms, and solutions covered in the course or the excercises. Learning to abstract, but also learning the limitations of abstraction.</td></tr>
<tr><td>Contents</td><td colspan="5">Computational methods in (mixed-)integer programming such as cutting plane separation and branch-and-bound along with a short and accessible introduction into their theoretical basis. Study of practically relevant binary linear and binary quadratic optimization problems, e.g., Maximum Cut, Linear Ordering and variants of the Traveling Salesman problem, along with the particular separation problems arising there. If there is time, linearizations of quadratic objective functions and more sophisticated formulations of binary quadratic problems are discussed.</td></tr>
<tr><td>Prerequisites</td><td colspan="5">none</td></tr>
<tr><td rowspan="4">Format</td><td>Teaching format</td><td>Group size</td><td>h/week</td><td>Workload[h]</td><td>CP</td></tr>
<tr><td>Lecture</td><td></td><td>2</td><td>30 T / 45 S</td><td>2.5</td></tr>
<tr><td>Exercises</td><td></td><td>2</td><td>30 T / 75 S</td><td>3.5</td></tr>
<tr><td colspan="5">T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="5">Oral exam (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="5">Successful exercise participation (not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="5"></td></tr>
<tr><td>Literature</td><td colspan="5"></td></tr>
</table>

Module MA-INF 1322	**Seminar Focus Topics in High Performance Computing**				
Workload 120 h	**Credit points** 4 CP	**Duration** 1 semester	**Frequency** every year		
Module coordinator	Prof. Dr. Estela Suarez				
Lecturer(s)	Prof. Dr. Estela Suarez				
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 2. or 3.		
Technical skills	Ability to perform individual literature search, critical reading, understanding, prepare a concise summary, and clear didactic presentation				
Soft skills	Ability to present and critically discuss these results in the framework of the corresponding area				
Contents	General topics and trends in high performance computing, based on recent review and research literature				
Prerequisites	**Recommended:** Interest in High Performance Computing				
Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Seminar	10	2	30 T / 90 S	4
	T = face-to-face teaching; S = independent study				
Exam achievements	Oral presentation, written report (graded)				
Study achievements	(not graded)				
Forms of media					
Literature	Literature and further information about this seminar will be announced in time in the website of lecturer.				

<table>
<tr><td>Module
MA-INF 1323</td><td colspan="4">Computational Topology</td></tr>
<tr><td>Workload
270 h</td><td>Credit points
9 CP</td><td>Duration
1 semester</td><td colspan="2">Frequency
at least every 2 years</td></tr>
<tr><td>Module coordinator</td><td colspan="4">Prof. Dr. Anne Driemel</td></tr>
<tr><td>Lecturer(s)</td><td colspan="4">Prof. Dr. Anne Driemel, Dr. Benedikt Kolbe</td></tr>
<tr><td>Classification</td><td colspan="2">Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
2. or 3.</td></tr>
<tr><td>Technical skills</td><td colspan="4">Knowledge of fundamental theorems and concepts in the area of computational topology in particular, persistent homology and topological data analysis; design and analysis of combinatorial algorithms in topological contexts; analysis of the complexity; to apply this knowledge autonomously to solving new problems and analysing new data sets.</td></tr>
<tr><td>Soft skills</td><td colspan="4">Social competence (communication, presenting one’s own solutions, goal-oriented discussions in teams), methodical competence (analysis, abstraction, proofs), individual competence (commitment and willingness to learn, creativity, perseverance).</td></tr>
<tr><td>Contents</td><td colspan="4">Fundamental concepts of relative homology and cohomology theory and persistence theory in computational settings, category theory in this context, algorithms for the computation of (persistent) homology, (extended) persistence modules and their decompositions, Morse theory, duality theorems, quiver representation theory, stability of persistence diagrams and barcodes, algebraic stability, topological filtrations, multiparameter persistence, invariants of persistence, topological data analysis, applications to shape pattern recognition, machine learning, identification of geometric objects.</td></tr>
<tr><td>Prerequisites</td><td colspan="4">none</td></tr>
<tr><td>Format</td><td colspan="4">
<table>
<tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr>
<tr><td>Lecture</td><td></td><td>4</td><td>60 T / 105 S</td><td>5.5</td></tr>
<tr><td>Exercises</td><td></td><td>2</td><td>30 T / 75 S</td><td>3.5</td></tr>
</table>
T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="4">Schriftliche Prüfung (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="4">Erfolgreiche Übungsteilnahme (not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="4"></td></tr>
<tr><td>Literature</td><td colspan="4">• Herbert Edelsbrunner, John Harer (2010). Computational Topology: An Introduction. American Mathematical Society.
• Steve Oudot (2015). Persistence Theory: From Quiver Representations to Data Analysis (Vol. 209). American Mathematical Society.
• Magnus Bakke Botnan, Michael Lesnick (2022). An Introduction to Multiparameter Persistence.
• Allen Hatcher (2002). Algebraic Topology (Vol. 44). Cambridge University Press.</td></tr>
</table>

2 Graphics, Vision, Audio

Module MA-INF 2113	**Foundations of Audio Signal Processing**				
Workload 180 h	**Credit points** 6 CP	**Duration** 1 semester	**Frequency** every year		
Module coordinator	apl. Prof. Dr. Frank Kurth				
Lecturer(s)	apl. Prof. Dr. Frank Kurth, Prof. Dr. Michael Clausen				
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 1.		
Technical skills	• Introduction to basic concepts of analog and digital signal processing; • Applications in the field of Audio Signal Processing; • Signal Processing Algorithms; • Implementing basic Signal Processing Algorithms				
Soft skills	Solving basic Signal Processing Problems; Implementing Signal Processing Algorithms using state-of-the-art software frameworks; Capability to analyze; Time management; Presentation skills; Discussing own solutions and solutions of others, and working in groups.				
Contents	Theoretical introduction to analog and digital Signal Processing; Fourier Transforms; Analog to digital Conversion; Digital Filters; Audio Signal Processing Applications; Filter banks; Windowed Fourier Transform; 2D-Signal Processing				
Prerequisites	none				
Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Lecture		2	30 T / 45 S	2.5
	Exercises		2	30 T / 75 S	3.5
	T = face-to-face teaching; S = independent study				
Exam achievements	Written exam (graded)				
Study achievements	Successful exercise participation (not graded)				
Forms of media	Slides, Blackboard, Whiteboard				
Literature					

Module MA-INF 2201	**Computer Vision**			
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** every year	
Module coordinator	Prof. Dr. Jürgen Gall			
Lecturer(s)	Prof. Dr. Jürgen Gall			
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 1. or 2.	
Technical skills	Students will learn about various mathematical methods and their applications to computer vision problems.			
Soft skills	Productive work in small teams, development and realization of individual approaches and solutions, critical reflection of competing methods, discussion in groups.			
Contents	The class will cover a number of mathematical methods and their applications in computer vision. For example, linear filters, edges, derivatives, Hough transform, segmentation, graph cuts, mean shift, active contours, level sets, MRFs, expectation maximization, background subtraction, temporal filtering, active appearance models, shapes, optical flow, 2d tracking, cameras, 2d/3d features, stereo, 3d reconstruction, 3d pose estimation, articulated pose estimation, deformable meshes, RGBD vision.			
Prerequisites	**Recommended:** Basic knowledge of linear algebra, analysis, probability theory, C++ programming			
Format	**Teaching format** Lecture Exercises T = face-to-face teaching; S = independent study	**Group size**	**h/week** 4 2	**Workload[h]** / **CP** 60 T / 105 S — 5.5 30 T / 75 S — 3.5
Exam achievements	Written exam (graded)			
Study achievements	Successful exercise participation (not graded)			
Forms of media				
Literature	• R. Hartley, A. Zisserman: Multiple View Geometry in Computer Vision • R. Szeliski: Computer Vision: Algorithms and Applications • S. Prince: Computer Vision: Models, Learning, and Inference			

Teaching format	Group size	h/week	Workload[h]	CP
Lecture		4	60 T / 105 S	5.5
Exercises		2	30 T / 75 S	3.5

<table>
<tr><td>Module
MA-INF 2203</td><td colspan="5">Selected Topics in Signal Processing</td></tr>
<tr><td>Workload
270 h</td><td>Credit points
9 CP</td><td>Duration
1 semester</td><td colspan="3">Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="5">apl. Prof. Dr. Frank Kurth</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">apl. Prof. Dr. Frank Kurth, Prof. Dr. Michael Clausen</td></tr>
<tr><td>Classification</td><td colspan="2">Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td colspan="2">Semester
2.</td></tr>
<tr><td>Technical skills</td><td colspan="5">Learning advanced as well as state of the art topics and techniques in digital signal processing. Study examples from the field of digital audio signal processing with a focus on music audio. Develop skills for analysing audio signals and designing audio features for selected application scenarios. Mathematical modelling of signal processing problems in practical applications. Design and implementation of corresponding algorithms and data structures solving those problems. Efficiency issues.</td></tr>
<tr><td>Soft skills</td><td colspan="5">Capability to analyze. Time management. Strength of purpose. Discussing own solutions and solutions of others.</td></tr>
<tr><td>Contents</td><td colspan="5">Advanced techniques for filter design, design and extraction of features describing multimedia signals, efficient DSP algorithms, general concepts for content-based analysis of multimedia signals. Selected signal processing applications, for example content-based music analysis, signal compression, denoising, source separation.</td></tr>
<tr><td>Prerequisites</td><td colspan="5">none</td></tr>
<tr><td rowspan="4">Format</td><td>Teaching format</td><td>Group size</td><td>h/week</td><td>Workload[h]</td><td>CP</td></tr>
<tr><td>Lecture</td><td></td><td>4</td><td>60 T / 105 S</td><td>5.5</td></tr>
<tr><td>Exercises</td><td></td><td>2</td><td>30 T / 75 S</td><td>3.5</td></tr>
<tr><td colspan="5">T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="5">Written exam (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="5">Successful exercise participation (not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="5"></td></tr>
<tr><td>Literature</td><td colspan="5">• Lecture script and selected research publications
• Hayes: Statistical Digital Signal Processing and Modelling, John Wiley, 1996
• Proakis, Manolakis: Digital Signal Processing, Prentice Hall, 1996
• Klapuri, Davy: Signal Processing, Methods for Music Transcription, Springer, 2006</td></tr>
</table>

Module MA-INF 2206	**Seminar Vision**				
Workload 120 h	**Credit points** 4 CP	**Duration** 1 semester	**Frequency** every semester		
Module coordinator	Prof. Dr. Jürgen Gall				
Lecturer(s)	Prof. Dr. Jürgen Gall				
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 2. or 3.		
Technical skills	Ability to understand new research results presented in original scientific papers.				
Soft skills	Ability to present and to critically discuss these results in the framework of the corresponding area.				
Contents	Current conference and journal papers.				
Prerequisites	**Required:** MA-INF 2201 – Computer Vision				
Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Seminar	10	2	30 T / 90 S	4
	T = face-to-face teaching; S = independent study				
Exam achievements	Oral presentation, written report (graded)				
Study achievements	(not graded)				
Forms of media					
Literature					

Module MA-INF 2207	**Seminar Graphics**				
Workload 120 h	**Credit points** 4 CP	**Duration** 1 semester	**Frequency** every semester		
Module coordinator	Prof. Dr. Reinhard Klein				
Lecturer(s)	Prof. Dr. Reinhard Klein				
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 2. or 3.		
Technical skills	Ability to understand new research results presented in original scientific papers.				
Soft skills	Ability to present and to critically discuss these results in the framework of the corresponding area.				
Contents	Current conference and journal papers.				
Prerequisites	**Recommended:** Mathematical background (multidimensional analysis and linear algebra, basic numerical methods) Basic knowledge in Computer Graphics				
Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Seminar	10	2	30 T / 90 S	4
	T = face-to-face teaching; S = independent study				
Exam achievements	Oral presentation, written report (graded)				
Study achievements	(not graded)				
Forms of media					
Literature					

<table>
<tr><td>Module
MA-INF 2208</td><td colspan="5">Seminar Audio</td></tr>
<tr><td>Workload
120 h</td><td>Credit points
4 CP</td><td>Duration
1 semester</td><td colspan="3">Frequency
every semester</td></tr>
<tr><td>Module coordinator</td><td colspan="5">apl. Prof. Dr. Frank Kurth</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">apl. Prof. Dr. Frank Kurth, Dr. Michael Clausen</td></tr>
<tr><td>Classification</td><td colspan="2">Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td colspan="2">Semester
2.</td></tr>
<tr><td>Technical skills</td><td colspan="5">Ability to understand new research results presented in original scientific papers.</td></tr>
<tr><td>Soft skills</td><td colspan="5">Ability to present and to critically discuss these results in the framework of the corresponding area.</td></tr>
<tr><td>Contents</td><td colspan="5">Current conference and journal papers.</td></tr>
<tr><td>Prerequisites</td><td colspan="5">none</td></tr>
<tr><td rowspan="3">Format</td><td>Teaching format</td><td>Group size</td><td>h/week</td><td>Workload[h]</td><td>CP</td></tr>
<tr><td>Seminar</td><td>10</td><td>2</td><td>30 T / 90 S</td><td>4</td></tr>
<tr><td colspan="5">T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="5">Oral presentation, written report (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="5">(not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="5"></td></tr>
<tr><td>Literature</td><td colspan="5"></td></tr>
</table>

<table>
<tr><td>Module
MA-INF 2209</td><td colspan="5">Advanced Topics in Computer Graphics I</td></tr>
<tr><td>Workload
270 h</td><td>Credit points
9 CP</td><td colspan="2">Duration
1 semester</td><td colspan="2">Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="5">Prof. Dr. Reinhard Klein</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Prof. Dr. Reinhard Klein</td></tr>
<tr><td>Classification</td><td colspan="2">Programme
M. Sc. Computer Science</td><td colspan="2">Mode
Optional</td><td>Semester
2. or 3.</td></tr>
<tr><td>Technical skills</td><td colspan="5">Analytical formulation of problems related to rendering. Knowledge of principles, techniques and algorithms to
• recognize and understand the physical quantities of light transport
• explain a range of surface and volumetric material models
• explain the rendering and radiative transfer equations
• design and implement methods to solve these equations, especially Monte Carlo methods
• Assess / Evaluate the performance and conceptual limits of the implemented simulation code</td></tr>
<tr><td>Soft skills</td><td colspan="5">Based on the knowledge and skills acquired students should be able to
• read and judge current scientific literature in the area of rendering
• identify the major literature concerning a given problem in rendering and gain an overview of the current state of the art
• discuss problems concerning rendering with researchers from different application fields
• present, propose and communicate different solutions and work in a team to solve a rendering problem</td></tr>
<tr><td>Contents</td><td colspan="5">This course introduces the basic physical quantities as well as the mathematical and algorithmic tools required to understand and simulate the light interaction with objects and different materials in a 3D scene. We will discuss how to solve the mathematical problem numerically in order to create realistic images. Advanced topics include participating media, material models for sub-surface light transport, and Markov Chain Monte Carlo Methods. Topics among others will be
• rendering and radiative transfer equation
• methods and algorithms to solve these equations, radiosity, Monte Carlo, photon mapping
• analytical and data driven surface and subsurface material models, especially BRDF, BSSRDF models
• differentiable rendering
In addition, results from state-of-the-art research will be presented.</td></tr>
<tr><td>Prerequisites</td><td colspan="5">Recommended:
Recommended but not enforced: basic knowledge in computer graphics, (numerical) analysis and linear algebra, C++</td></tr>
<tr><td rowspan="4">Format</td><td>Teaching format</td><td>Group size</td><td>h/week</td><td>Workload[h]</td><td>CP</td></tr>
<tr><td>Lecture</td><td></td><td>4</td><td>60 T / 105 S</td><td>5.5</td></tr>
<tr><td>Exercises</td><td></td><td>2</td><td>30 T / 75 S</td><td>3.5</td></tr>
<tr><td colspan="5">T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="5">Oral presentation, written report (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="5">Successful exercise participation (not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="5"></td></tr>
<tr><td>Literature</td><td colspan="5">• M. Pharr, W. Jakob, and G. Humphreys, Physically Based Rendering: From Theory to Implementation (3rd edition), 2018
• L. Szirmay-Kalos: Monte-Carlo Methods in Global Illumination, Institute of Computer Graphics, Vienna University of Technology, Vienna, 1999 URL: https://cg.iit.bme.hu/~szirmay/script.pdf
• P. Dutre, K. Bala, P. Bekaert: Advanced Global Illumination, 2nd ed., B&T, 2006
• D'Eon, Eugene. A Hitchhiker's Guide to Multiple Scattering, 2016</td></tr>
</table>

<table>
<tr><td>Module
MA-INF 2212</td><td>Pattern Matching and Machine Learning for Audio Signal Processing</td></tr>
<tr><td>Workload
180 h</td><td><table><tr><td>Credit points
6 CP</td><td>Duration
1 semester</td><td>Frequency
every year</td></tr></table></td></tr>
<tr><td>Module coordinator</td><td>apl. Prof. Dr. Frank Kurth</td></tr>
<tr><td>Lecturer(s)</td><td>apl. Prof. Dr. Frank Kurth, Prof. Dr. Michael Clausen</td></tr>
<tr><td>Classification</td><td><table><tr><td>Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
2.</td></tr></table></td></tr>
<tr><td>Technical skills</td><td>• Introduction into selected topics of digital signal processing;
• Applications in the field of Audio Signal Processing;
• Methods of Automatic Pattern Recognition</td></tr>
<tr><td>Soft skills</td><td>Audio Signal Processing Applications; Extended programming skills for signal processing applications; Capability to analyze; Time management; Presentation skills; Discussing own solutions and solutions of others, and working in groups.</td></tr>
<tr><td>Contents</td><td>The lecture is presented in modular form, where each module is motivated from the application side. The presented topics are: Windowed Fourier transforms; Audio Identifications; Audio Matching; Signal Classification; Hidden Markov Models; Support Vector Machines</td></tr>
<tr><td>Prerequisites</td><td>none</td></tr>
<tr><td>Format</td><td><table><tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr><tr><td>Lecture</td><td></td><td>2</td><td>30 T / 45 S</td><td>2.5</td></tr><tr><td>Exercises</td><td></td><td>2</td><td>30 T / 75 S</td><td>3.5</td></tr></table>T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td>Written exam (graded)</td></tr>
<tr><td>Study achievements</td><td>Successful exercise participation (not graded)</td></tr>
<tr><td>Forms of media</td><td>Slides, Blackboard, Whiteboard</td></tr>
<tr><td>Literature</td><td></td></tr>
</table>

<table>
<tr><td>Module
MA-INF 2213</td><td colspan="4">Advanced Computer Vision</td></tr>
<tr><td>Workload
180 h</td><td>Credit points
6 CP</td><td>Duration
1 semester</td><td colspan="2">Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="4">Prof. Dr. Jürgen Gall</td></tr>
<tr><td>Lecturer(s)</td><td colspan="4">Prof. Dr. Jürgen Gall</td></tr>
<tr><td>Classification</td><td colspan="2">Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
2. or 3.</td></tr>
<tr><td>Technical skills</td><td colspan="4">Students will learn about various learning methods and their applications to computer vision problems.</td></tr>
<tr><td>Soft skills</td><td colspan="4">Productive work in small teams, development and realization of individual approaches and solutions, critical reflection of competing methods, discussion in groups.</td></tr>
<tr><td>Contents</td><td colspan="4">The class will cover a number of learning methods and their applications in computer vision. For example, linear methods for classification and regression, boosting, random forests, neural networks, SVMs, prototype methods, nearest neighbors, Gaussian processes, metric learning, structured learning, image classification, object detection, action recognition, pose estimation, face analysis, tracking.</td></tr>
<tr><td>Prerequisites</td><td colspan="4">Required:
MA-INF 2201 – Computer Vision</td></tr>
<tr><td>Format</td><td colspan="4">
<table>
<tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr>
<tr><td>Lecture</td><td></td><td>3</td><td>45 T / 45 S</td><td>3</td></tr>
<tr><td>Exercises</td><td></td><td>1</td><td>15 T / 75 S</td><td>3</td></tr>
</table>
T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="4">Oral exam (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="4">Successful exercise participation (not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="4"></td></tr>
<tr><td>Literature</td><td colspan="4"></td></tr>
</table>

<table>
<tr><td>Module
MA-INF 2214</td><td colspan="3">Computational Photography</td></tr>
<tr><td>Workload
180 h</td><td>Credit points
6 CP</td><td>Duration
1 semester</td><td>Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="3">Prof. Dr. Matthias Hullin</td></tr>
<tr><td>Lecturer(s)</td><td colspan="3">Prof. Dr. Matthias Hullin</td></tr>
<tr><td>Classification</td><td>Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
2. or 3.</td></tr>
<tr><td>Technical skills</td><td colspan="3">Foundations in optics and image sensors. Signal processing and inverse problems in imaging. Color spaces and perception. Image alignment and blending. High-dimensional representations of light transport (light fields, reflectance fields, reflectance distributions). Computational illumination.</td></tr>
<tr><td>Soft skills</td><td colspan="3">• to read and understand current literature in the field
• to implement standard computational photography techniques
• to propose and implement solutions to a given problem
• to follow good scientific practice by planning, documenting and communicating their work</td></tr>
<tr><td>Contents</td><td colspan="3">• Image sensors
• Optics
• Panoramas
• Light fields
• Signal processing and inverse problems
• Color, perception and HDR
• Reflectance fields and light transport matrices</td></tr>
<tr><td>Prerequisites</td><td colspan="3">Required:
Basic knowledge in computer graphics, data structures, multidimensional analysis und linear algebra, numerical analysis and numerical linear algebra, C++ or MATLAB</td></tr>
<tr><td>Format</td><td colspan="3"><table>
<tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr>
<tr><td>Lecture</td><td></td><td>2</td><td>30 T / 45 S</td><td>2.5</td></tr>
<tr><td>Exercises</td><td></td><td>2</td><td>30 T / 75 S</td><td>3.5</td></tr>
</table>
T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="3">Oral exam (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="3">Successful exercise participation (not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="3"></td></tr>
<tr><td>Literature</td><td colspan="3"></td></tr>
</table>

Module MA-INF 2215	**Seminar Digital Material Appearance**				
Workload 120 h	**Credit points** 4 CP	**Duration** 1 semester	**Frequency** every year		
Module coordinator	Prof. Dr. Matthias Hullin				
Lecturer(s)	Prof. Dr. Matthias Hullin				
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 2.		
Technical skills	Ability to understand new research results presented in original scientific papers.				
Soft skills	Ability to present and to critically discuss these results in the framework of the corresponding area.				
Contents	Current conference and journal papers				
Prerequisites	none				
Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Seminar	10	2	30 T / 90 S	4
	T = face-to-face teaching; S = independent study				
Exam achievements	Oral presentation, written report (graded)				
Study achievements	(not graded)				
Forms of media					
Literature					

<table>
<tr><td>Module
MA-INF 2216</td><td colspan="5">Lab Visual Computing</td></tr>
<tr><td>Workload
270 h</td><td colspan="5">Credit points 9 CP | Duration 1 semester | Frequency every year</td></tr>
<tr><td>Module coordinator</td><td colspan="5">Jun.-Prof. Dr. Florian Bernard</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Jun.-Prof. Dr. Florian Bernard</td></tr>
<tr><td>Classification</td><td colspan="5">Programme M. Sc. Computer Science | Mode Optional | Semester 1-3.</td></tr>
<tr><td>Technical skills</td><td colspan="5">Students will carry out a practical task (project) in the context of visual computing, including test and documentation of the implemented software/system.</td></tr>
<tr><td>Soft skills</td><td colspan="5">Ability to properly present and defend design decisions, to prepare readable documentation of software; skills in constructively collaborating with others in small teams over a longer period of time; ability to classify ones own results into the state-of-the-art of the resp. area.</td></tr>
<tr><td>Contents</td><td colspan="5">This lab introduces visual computing methods and applications. You will get a chance to study the methods in depth by implementing them and running experiments. At the end of the semester, you will present the method, give a short demonstration and hand in a report describing the method and experimental outcomes.</td></tr>
<tr><td>Prerequisites</td><td colspan="5">none</td></tr>
<tr><td rowspan="3">Format</td><td>Teaching format</td><td>Group size</td><td>h/week</td><td>Workload[h]</td><td>CP</td></tr>
<tr><td>Lab</td><td>8</td><td>4</td><td>60 T / 210 S</td><td>9</td></tr>
<tr><td colspan="5">T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="5">Oral presentation, written report (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="5">(not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="5"></td></tr>
<tr><td>Literature</td><td colspan="5"></td></tr>
</table>

<table>
<tr><td>Module
MA-INF 2217</td><td colspan="5">Advanced Deep Learning for Graphics</td></tr>
<tr><td>Workload
180 h</td><td colspan="2">Credit points
6 CP</td><td>Duration
1 semester</td><td colspan="2">Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="5">Prof. Dr. Reinhard Klein</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Dr. Michael Weinmann</td></tr>
<tr><td>Classification</td><td colspan="3">Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
1-4.</td></tr>
<tr><td>Technical skills</td><td colspan="5">Students will be introduced to adapt and apply deep learning techniques to various applications in computer graphics.</td></tr>
<tr><td>Soft skills</td><td colspan="5">Productive work in small teams, development and realization of individual approaches and solutions, critical reflection of competing methods, discussion in groups.</td></tr>
<tr><td>Contents</td><td colspan="5">This course focuses on cutting-edge Deep Learning techniques for computer graphics. After a brief review of CNNs the focus will be laid on autoencoders, generative models and the extension of these methods to graph- and manifold-structured data. Applications discussed will include inverse problems in computer graphics and the synthesis of models including data completion and super-resolution.</td></tr>
<tr><td>Prerequisites</td><td colspan="5">Recommended:
The course will build upon the basics of machine learning as well as fundamentals and basic architectures of neural networks. Therefore, it is highly recommended to have taken Deep Learning for Visual Recognition or a similar course as a prerequisite. Exercises will be a mix of theory and practical (Python).</td></tr>
<tr><td rowspan="3">Format</td><td>Teaching format</td><td>Group size</td><td>h/week</td><td>Workload[h]</td><td>CP</td></tr>
<tr><td>Lecture
Exercises</td><td></td><td>2
2</td><td>30 T / 45 S
30 T / 75 S</td><td>2.5
3.5</td></tr>
<tr><td colspan="5">T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="5">Written exam (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="5">Successful exercise participation (not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="5"></td></tr>
<tr><td>Literature</td><td colspan="5">No required text, supplemental readings will be given in class.</td></tr>
</table>

Module MA-INF 2218	**Video Analytics**				
Workload 180 h	**Credit points** 6 CP	**Duration** 1 semester	**Frequency** at least every 2 years		
Module coordinator	Prof. Dr. Jürgen Gall				
Lecturer(s)	Prof. Dr. Jürgen Gall				
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 2-3.		
Technical skills	Students will learn advanced techniques for analyzing video data.				
Soft skills	Productive work in small teams, development and realization of a state-of-the-art system for video analysis.				
Contents	The class will discuss state-of-the-art methods for several tasks of video analysis. For example, video clip classification, temporal video segmentation, spatio-temporal action detection, video context, spatio-temporal modeling of humans and objects, anticipation, affordance, video summarization, semantic video segmentation.				
Prerequisites	**Required:** MA-INF 2201 – Computer Vision				
Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Lecture		2	30 T / 45 S	2.5
	Exercises		2	30 T / 75 S	3.5
	T = face-to-face teaching; S = independent study				
Exam achievements	Oral exam (graded)				
Study achievements	Successful exercise participation (not graded)				
Forms of media					
Literature					

<table>
<tr><td>Module
MA-INF 2219</td><td colspan="4">Seminar Visualization and Medical Image Analysis</td></tr>
<tr><td>Workload
120 h</td><td>Credit points
4 CP</td><td>Duration
1 semester</td><td colspan="2">Frequency
every semester</td></tr>
<tr><td>Module coordinator</td><td colspan="4">Prof. Dr. Thomas Schultz</td></tr>
<tr><td>Lecturer(s)</td><td colspan="4">Prof. Dr. Thomas Schultz</td></tr>
<tr><td>Classification</td><td colspan="2">Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
2.</td></tr>
<tr><td>Technical skills</td><td colspan="4">Ability to understand new research results presented in original scientific papers.</td></tr>
<tr><td>Soft skills</td><td colspan="4">Ability to present and to critically discuss scientific results in the context of the current state of the art. Ability to perform an independent search for relevant scientific literature.</td></tr>
<tr><td>Contents</td><td colspan="4">Current conference and journal papers</td></tr>
<tr><td>Prerequisites</td><td colspan="4">Recommended:
At least one of the following:
• MA-INF 2222 – Visual Data Analysis
• MA-INF 2312 – Image Acquisition and Analysis in Neuroscience</td></tr>
<tr><td>Format</td><td colspan="4"><table>
<tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr>
<tr><td>Seminar</td><td>10</td><td>2</td><td>30 T / 90 S</td><td>4</td></tr>
</table>
T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="4">Oral presentation, written report (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="4">(not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="4"></td></tr>
<tr><td>Literature</td><td colspan="4"></td></tr>
</table>

Module MA-INF 2220	**Lab Visualization and Medical Image Analysis**				
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** every semester		
Module coordinator	Prof. Dr. Thomas Schultz				
Lecturer(s)	Prof. Dr. Thomas Schultz				
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 2.		
Technical skills	The students will carry out a practical task (project) in the context of data visualization and visual analytics or medical image analysis, including test and documentation of the implemented software/system.				
Soft skills	Ability to properly present and defend design decisions, to prepare readable documentation of software; skills in constructively collaborating with others in small teams over a longer period of time; ability to classify ones own results into the state-of-the-art of the resp. area				
Contents					
Prerequisites	**Recommended:** At least one of the following: • MA-INF 2222 – Visual Data Analysis • MA-INF 2312 – Image Acquisition and Analysis in Neuroscience				
Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Lab	8	4	60 T / 210 S	9
	T = face-to-face teaching; S = independent study				
Exam achievements	Oral presentation, written report (graded)				
Study achievements	(not graded)				
Forms of media					
Literature					

<table>
<tr><td>Module
MA-INF 2221</td><td colspan="3">Seminar Visual Computing</td></tr>
<tr><td>Workload
120 h</td><td>Credit points
4 CP</td><td>Duration
1 semester</td><td>Frequency
at least every year</td></tr>
<tr><td>Module coordinator</td><td colspan="3">Jun.-Prof. Dr. Florian Bernard</td></tr>
<tr><td>Lecturer(s)</td><td colspan="3">Jun.-Prof. Dr. Florian Bernard</td></tr>
<tr><td>Classification</td><td>Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
2. or 3.</td></tr>
<tr><td>Technical skills</td><td colspan="3">Ability to understand new research results presented in original scientific papers.</td></tr>
<tr><td>Soft skills</td><td colspan="3">Ability to present and to critically discuss these results in the framework of the corresponding area.</td></tr>
<tr><td>Contents</td><td colspan="3">Current conference and journal papers.</td></tr>
<tr><td>Prerequisites</td><td colspan="3">Required:
No formal requirements. Participants are expected to have some previous exposure to at least one of the following:
- visual computing (e.g. computer vision, computer graphics, 3D shape analysis, image analysis, etc.),
- mathematical optimisation (e.g. combinatorial/continuous, convex/non-convex, etc.), or
- machine learning.</td></tr>
<tr><td>Format</td><td colspan="3"><table><tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr><tr><td>Seminar</td><td>10</td><td>2</td><td>30 T / 90 S</td><td>4</td></tr></table>T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="3">Oral presentation, written report (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="3">(not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="3"></td></tr>
<tr><td>Literature</td><td colspan="3"></td></tr>
</table>

<table>
<tr><td>Module
MA-INF 2222</td><td colspan="4">Visual Data Analysis</td></tr>
<tr><td>Workload
270 h</td><td>Credit points
9 CP</td><td>Duration
1 semester</td><td colspan="2">Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="4">Prof. Dr. Thomas Schultz</td></tr>
<tr><td>Lecturer(s)</td><td colspan="4">Prof. Dr. Thomas Schultz</td></tr>
<tr><td>Classification</td><td colspan="2">Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
1-4.</td></tr>
<tr><td>Technical skills</td><td colspan="4">Ability to design, implement, and make proper use of systems for visual data analysis. Knowledge of algorithms and techniques for the visualization of multi-dimensional data, graphs, as well as scalar, vector, and tensor fields.</td></tr>
<tr><td>Soft skills</td><td colspan="4">Productive work in small teams, self-dependent solution of practical problems in the area of visual data analysis, critical reflection on visualization design, presentation of solution strategies and implementations, self management</td></tr>
<tr><td>Contents</td><td colspan="4">This class provides a broad overview of principles and algorithms for data analysis via interactive visualization. Specific topics include perceptual principles, luminance and color, visualization analysis and design, integration of visual with statistical data analysis and machine learning, as well as specific algorithms and techniques for the display of multidimensional data, dimensionality reduction, graphs, direct and indirect volume visualization, vector field and flow visualization, as well as tensor field visualization.</td></tr>
<tr><td>Prerequisites</td><td colspan="4">Recommended:
Students are recommended to have a basic knowledge in linear algebra and calculus, as well as proficiency in programming.</td></tr>
<tr><td>Format</td><td colspan="4"><table>
<tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr>
<tr><td>Lecture</td><td></td><td>4</td><td>60 T / 105 S</td><td>5.5</td></tr>
<tr><td>Exercises</td><td></td><td>2</td><td>30 T / 75 S</td><td>3.5</td></tr>
</table>T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="4">Written exam (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="4">Successful exercise participation (not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="4"></td></tr>
<tr><td>Literature</td><td colspan="4">A.C. Telea, Data Visualization: Principles and Practice. CRC Press, Second Edition, 2015
M. Ward et al., Interactive Data Visualization: Foundations, Techniques, and Applications. CRC Press, 2010
T. Munzner, Visualization Analysis and Design, A K Peters, 2015</td></tr>
</table>

<table>
<tr><td>Module
MA-INF 2223</td><td colspan="5">Seminar Advances in Multimodal Learning</td></tr>
<tr><td>Workload
120 h</td><td colspan="2">Credit points
4 CP</td><td>Duration
1 semester</td><td colspan="2">Frequency
every semester</td></tr>
<tr><td>Module coordinator</td><td colspan="5">Prof. Dr. Hildegard Kühne</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Prof. Dr. Hildegard Kühne</td></tr>
<tr><td>Classification</td><td colspan="3">Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
2.</td></tr>
<tr><td>Technical skills</td><td colspan="5">Presentation of selected advanced topics in computer vision and multimodal learning and various applications</td></tr>
<tr><td>Soft skills</td><td colspan="5">Ability to perform individual literature search, critical reading, understanding, and clear didactic presentation</td></tr>
<tr><td>Contents</td><td colspan="5">This seminar will cover most recent advancements and publications in multimodal learning, which is the integration of multiple data sources or multiple modalities for more complex machine learning applications. This can also include reviews of emerging techniques, including unsupervised approaches, deep learning, transfer learning, and reinforcement learning to combine multiple modalities such as images, audio, video, joint feature learning, and natural language processing. It can further cover techniques for data fusion and the role they play in successful applications of multimodal learning. Students will have an opportunity to evaluate and experiment with public code if available. Goel is to develop a better understanding of the possibilities and challenges of multimodal learning.</td></tr>
<tr><td>Prerequisites</td><td colspan="5">Required:
none</td></tr>
<tr><td>Format</td><td colspan="5"><table><tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr><tr><td>Seminar</td><td>10</td><td>2</td><td>30 T / 90 S</td><td>4</td></tr></table>T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="5">Oral presentation, written report (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="5">Erfolgreiche Übungsteilnahme (not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="5"></td></tr>
<tr><td>Literature</td><td colspan="5">The relevant literature will be announced in time.</td></tr>
</table>

Module MA-INF 2224	**Lab Challenges in Computer Vision**				
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** every semester		
Module coordinator	Prof. Dr. Hildegard Kühne				
Lecturer(s)	Prof. Dr. Hildegard Kühne				
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 2.		
Technical skills	Students will carry out a practical task (project) in the context of computer vision and/or multimodal learning, including evaluation and documentation of the implemented software/system.				
Soft skills	Ability to implement and evaluate a scientific approach; ability to classify ones own results into the state-of-the-art of the resp. area; skills in constructively collaborating with others in small teams over a longer period of time.				
Contents	This Programming Project focuses on exploring the challenges in modern Computer Vision algorithms and model development. The project will track the latest progress in the field and the associated challenges in different application areas, such as video understanding as well as general computer vision topics. The project will include a hands-on implementation of various techniques in current computer vision systems to identify and resolve problems, and to evaluate results in comparison to public benchmarks. It will further provide an understanding of the characteristics of models and benchmarks such as generalization and robustness. The project should provide insights on the development of novel computer vision technology in response to upcoming challenges.				
Prerequisites	**Required:** Practical experience in deep learning				
Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Lab	8	4	60 T / 210 S	9
	T = face-to-face teaching; S = independent study				
Exam achievements	Oral presentation, written report (graded)				
Study achievements	Erfolgreiche Übungsteilnahme (not graded)				
Forms of media					
Literature					

Module MA-INF 2307	**Lab Vision**				
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** every semester		
Module coordinator	Prof. Dr. Jürgen Gall				
Lecturer(s)	Prof. Dr. Jürgen Gall				
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 2. or 3.		
Technical skills	The students will carry out a practical task (project) in the context of RGB-D cameras.				
Soft skills	Ability to properly present and defend design decisions, to prepare readable documentation of software; skills in constructively collaborating with others in small teams over a longer period of time; ability to classify ones own results into the state-of-the-art of the resp. area				
Contents	RGBD cameras: research topics and applications				
Prerequisites	**Required:** MA-INF 2201 – Computer Vision Good C++ programming skills				
Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Lab	8	4	60 T / 210 S	9
	T = face-to-face teaching; S = independent study				
Exam achievements	Oral presentation, written report (graded)				
Study achievements	(not graded)				
Forms of media					
Literature	A. Fossati, J. Gall, H. Grabner, X. Ren, K. Konolige. Consumer Depth Cameras for Computer Vision: Research Topics and Applications				

Module MA-INF 2308	**Lab Graphics**		
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** every semester
Module coordinator	Prof. Dr. Reinhard Klein		
Lecturer(s)	Prof. Dr. Reinhard Klein		
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 3.
Technical skills	The students will carry out a practical task (project) in the context of geometry processing, rendering, scientific visualization or human computer interaction, including test and documentation of the implemented software/system.		
Soft skills	Ability to properly present and defend design decisions, to prepare readable documentation of software; skills in constructively collaborating with others in small teams over a longer period of time; ability to classify ones own results into the state-of-the-art of the resp. area		
Contents	Varying selected topics close to current research in the area of geometry processing, rendering, scientific visualization or human computer interaction.		
Prerequisites	none		
Format	see below		
Exam achievements	Oral presentation, written report (graded)		
Study achievements	(not graded)		
Forms of media			
Literature			

Format:

Teaching format	**Group size**	**h/week**	**Workload[h]**	**CP**
Lab	8	4	60 T / 210 S	9

T = face-to-face teaching; S = independent study

Module MA-INF 2309	**Lab Audio**				
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** every year		
Module coordinator	apl. Prof. Dr. Frank Kurth				
Lecturer(s)	apl. Prof. Dr. Frank Kurth, Prof. Dr. Michael Clausen				
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 3.		
Technical skills	The students will carry out a practical task (project) in the context of audio and music processing, including test and documentation of the implemented software/system.				
Soft skills	Ability to properly present and defend design decisions, to prepare readable documentation of software; skills in constructively collaborating with others in small teams over a longer period of time; ability to classify ones own results into the state-of-the-art of the resp. area.				
Contents					
Prerequisites	none				
Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Lab	8	4	60 T / 210 S	9
	T = face-to-face teaching; S = independent study				
Exam achievements	Oral presentation, written report (graded)				
Study achievements	(not graded)				
Forms of media					
Literature					

Module MA-INF 2310	**Advanced Topics in Computer Graphics II**				
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** every year		
Module coordinator	Prof. Dr. Reinhard Klein				
Lecturer(s)	Prof. Dr. Reinhard Klein				
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 3.		
Technical skills	Analytical formulation of problems related to geometry processing: • apply methods of geometry processing • apply basic concepts of statistical shape analysis and shape spaces to real world applications • Design and implement novel application software in this area				
Soft skills	Based on the knowledge and skills acquired students should be able to • read and judge current scientific literature in the area of geometry processing and gain an overview of the current state of the art • identify the major literature relevant for solving a given problem in geometry processing • present, propose and communicate different solutions and work in a team to solve geometry processing problems • discuss geometry processing problems with researchers from different application fields				
Contents	This course will first introduce the mathematical and algorithmic tools required to represent, model, and process 3D geometric objects. The second part discusses the latest mathematical, algorithmic, and statistical tools required for the analysis and modeling of 3D shape variability, which can facilitate the creation of 3D models. Topics among others will be • classical and discrete differential geometry of curves and surfaces • mesh data structures and generation of meshes from point clouds • Laplacian operator and optimization techniques with applications to denoising, smoothing, decimation, shape fitting, shape descriptors, geodesic distances • parameterization and editing of surfaces • point cloud registration • correspondences • shape spaces and statistical shape analysis In addition, results from state-of-the-art research will be presented.				
Prerequisites	none				
Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Lecture		4	60 T / 105 S	5.5
	Exercises		2	30 T / 75 S	3.5
	T = face-to-face teaching; S = independent study				
Exam achievements	Oral exam (graded)				
Study achievements	Successful exercise participation (not graded)				
Forms of media					
Literature	• M. Botsch, L. Kobbelt, M. Pauly, P. Alliez, B. Levy, Polygon Mesh, Processing, A K Peters, 2010 • Laga, Hamid, Yulan Guo, Hedi Tabia, Robert B. Fisher, and Mohammed Bennamoun. 3D Shape analysis: fundamentals, theory, and applications. John Wiley & Sons, 2018. • Solomon, Justin. Numerical Algorithms. Textbook published by AK Peters/CRC Press, 2015				

<table>
<tr><td>Module
MA-INF 2312</td><td colspan="3">Image Acquisition and Analysis in Neuroscience</td></tr>
<tr><td>Workload
180 h</td><td>Credit points
6 CP</td><td>Duration
1 semester</td><td>Frequency
at least every 2 years</td></tr>
<tr><td>Module coordinator</td><td colspan="3">Prof. Dr. Thomas Schultz</td></tr>
<tr><td>Lecturer(s)</td><td colspan="3">Prof. Dr. Thomas Schultz</td></tr>
<tr><td>Classification</td><td colspan="3"><table><tr><td>Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
1-4.</td></tr></table></td></tr>
<tr><td>Technical skills</td><td colspan="3">Students will learn about image acquisition and analysis pipelines which are used in neuroscience. They will understand algorithms for image reconstruction, artifact removal, image registration and segmentation, as well as relevant statistical and machine learning techniques. A particular focus will be on data from Magnetic Resonance Imaging and on mathematical models for functional and diffusion MRI data.</td></tr>
<tr><td>Soft skills</td><td colspan="3">Productive work in small teams, self-dependent solution of practical problems in the area of biomedical image processing, presentation of solution strategies and implementations, self management, critical reflection of conclusions drawn from complex experimental data.</td></tr>
<tr><td>Contents</td><td colspan="3">This course covers the full image formation and analysis pipeline that is typically used in biomedical studies, from image acquisition to image processing and statistical analysis.</td></tr>
<tr><td>Prerequisites</td><td colspan="3">Recommended:
Mathematical background (calculus, linear algebra, statistics); imperative programming.</td></tr>
<tr><td>Format</td><td colspan="3"><table><tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr><tr><td>Lecture</td><td></td><td>3</td><td>45 T / 45 S</td><td>3</td></tr><tr><td>Exercises</td><td></td><td>1</td><td>15 T / 75 S</td><td>3</td></tr></table>T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="3">Oral exam (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="3">Successful exercise participation (not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="3"></td></tr>
<tr><td>Literature</td><td colspan="3">• B. Preim, C. Botha: Visual Computing for Medicine: Theory, Algorithms, and Applications. Morgan Kaufmann, 2014
• R.A. Poldrack, J.A. Mumford, T.E. Nichols: Handbook of Functional MRI Data Analysis. Cambridge University Press, 2011
• D.K. Jones: Diffusion MRI: Theory, Method, and Applications, Oxford University Press, 2011</td></tr>
</table>

<table>
<tr><td>Module
MA-INF 2313</td><td colspan="4">Deep Learning for Visual Recognition</td></tr>
<tr><td>Workload
180 h</td><td>Credit points
6 CP</td><td>Duration
1 semester</td><td colspan="2">Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="4">Prof. Dr. Reinhard Klein</td></tr>
<tr><td>Lecturer(s)</td><td colspan="4">Dr. Michael Weinmann</td></tr>
<tr><td>Classification</td><td colspan="2">Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
1-4.</td></tr>
<tr><td>Technical skills</td><td colspan="4">Students will be introduced to the theory of neural networks and study various applications in computer vision and other topics in AI.</td></tr>
<tr><td>Soft skills</td><td colspan="4">Productive work in small teams, development and realization of individual approaches and solutions, critical reflection of competing methods, discussion in groups.</td></tr>
<tr><td>Contents</td><td colspan="4">Deep learning has taken over the machine learning community by storm, with success both in research and commercially. Deep learning is applicable over a range of fields such as computer vision, speech recognition, natural language processing, robotics, etc. This course will introduce the fundamentals of neural networks and then progress to state-of-the-art convolutional and recurrent neural networks as well as their use in applications for visual recognition. Students will get a chance to learn how to implement and train their own network for visual recognition tasks such as object recognition, image segmentation and caption generation.</td></tr>
<tr><td>Prerequisites</td><td colspan="4">Recommended:
Students are recommended to have a basic knowledge in probability and statistics and linear algebra as well as proficiency in programming (python or Matlab or C++).</td></tr>
<tr><td>Format</td><td colspan="4">
<table>
<tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr>
<tr><td>Lecture</td><td></td><td>2</td><td>30 T / 45 S</td><td>2.5</td></tr>
<tr><td>Exercises</td><td></td><td>2</td><td>30 T / 75 S</td><td>3.5</td></tr>
</table>
T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="4">Oral exam (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="4">Successful exercise participation (not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="4"></td></tr>
<tr><td>Literature</td><td colspan="4">No required text. Supplemental readings will be provided in the lecture.</td></tr>
</table>

<table>
<tr><td>Module
MA-INF 2314</td><td>Image Processing, Search and Analysis I</td></tr>
<tr><td>Workload
270 h</td><td><table><tr><td>Credit points
9 CP</td><td>Duration
1 semester</td><td>Frequency
every year</td></tr></table></td></tr>
<tr><td>Module coordinator</td><td>Prof. Dr. Christian Bauckhage</td></tr>
<tr><td>Lecturer(s)</td><td>Prof. Dr. Christian Bauckhage</td></tr>
<tr><td>Classification</td><td><table><tr><td>Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
2. or 3.</td></tr></table></td></tr>
<tr><td>Technical skills</td><td>Upon completion, students should be able to
• implement basic and advanced methods for digital image processing
• implement simple and advanced algorithms for image filtering
• implement algorithms for creating artistic image effects
• implement algorithms for image warping
• implement algorithms for image morphing
• implement algorithms for color and intensity manipulation
• design and implement their own algorithms for image processing</td></tr>
<tr><td>Soft skills</td><td>Students will learn about the mathematical and algorithmic foundations of digital image processing and raster graphics editing. They will learn about the basic concepts and procedures in this area and to implement them on their own.</td></tr>
<tr><td>Contents</td><td>• technical foundations / hardware aspects of digital photography
• mathematical representations of digital images
• coordinate systems and coordinate transformations
• Fourier transforms and convolutions
• low- band-, and high pass filtering
• mean- and Gaussian filtering
• median filtering and morphological operations
• efficient implementations of various kinds of filters
• interpolation methods
• artistic image effects
• image warping
• image morphing
• physiological foundations of color perception
• color spaces
• color manipulation</td></tr>
<tr><td>Prerequisites</td><td>none</td></tr>
<tr><td>Format</td><td><table><tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr><tr><td>Lecture</td><td></td><td>4</td><td>60 T / 105 S</td><td>5.5</td></tr><tr><td>Exercises</td><td></td><td>2</td><td>30 T / 75 S</td><td>3.5</td></tr></table>T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td>Written exam (graded)</td></tr>
<tr><td>Study achievements</td><td>Successful exercise participation (not graded)</td></tr>
<tr><td>Forms of media</td><td>• lecture slides are made available online
• lecture notes with programming examples are made available online</td></tr>
<tr><td>Literature</td><td>• Gonzales and Woods, "Digital Image Processing"
• Jähne, "Digital Image Processing"</td></tr>
</table>

<table>
<tr><td>Module
MA-INF 2315</td><td colspan="3">Seminar Computational Photography</td></tr>
<tr><td>Workload
270 h</td><td>Credit points
9 CP</td><td>Duration
1 semester</td><td>Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="3">Prof. Dr. Matthias Hullin</td></tr>
<tr><td>Lecturer(s)</td><td colspan="3">Prof. Dr. Matthias Hullin</td></tr>
<tr><td>Classification</td><td>Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
2. or 3.</td></tr>
<tr><td>Technical skills</td><td colspan="3">Ability to understand new research results presented in original scientific papers.</td></tr>
<tr><td>Soft skills</td><td colspan="3">Ability to present and to critically discuss these results in the framework of the corresponding area.</td></tr>
<tr><td>Contents</td><td colspan="3"></td></tr>
<tr><td>Prerequisites</td><td colspan="3">none</td></tr>
<tr><td>Format</td><td colspan="3"><table>
<tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr>
<tr><td>Lecture</td><td></td><td>4</td><td>60 T / 105 S</td><td>5.5</td></tr>
<tr><td>Exercises</td><td></td><td>2</td><td>30 T / 75 S</td><td>3.5</td></tr>
</table>
T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="3">Oral presentation, written report (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="3">(not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="3"></td></tr>
<tr><td>Literature</td><td colspan="3"></td></tr>
</table>

<table>
<tr><td>Module
MA-INF 2316</td><td colspan="3">Lab Digital Material Appearance</td></tr>
<tr><td>Workload
270 h</td><td>Credit points
9 CP</td><td>Duration
1 semester</td><td>Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="3">Prof. Dr. Matthias Hullin</td></tr>
<tr><td>Lecturer(s)</td><td colspan="3">Prof. Dr. Matthias Hullin</td></tr>
<tr><td>Classification</td><td>Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
2. or 3.</td></tr>
<tr><td>Technical skills</td><td colspan="3">The students will carry out a practical task (project) in the context of the corresponding area, including test and documentation of the implemented software/system.</td></tr>
<tr><td>Soft skills</td><td colspan="3">Ability to properly present and defend design decisions, to prepare readable documentation of software; skills in constructively collaborating with others in small teams over a longer period of time; ability to classify ones own results into the state-of-the-art of the resp. area</td></tr>
<tr><td>Contents</td><td colspan="3"></td></tr>
<tr><td>Prerequisites</td><td colspan="3">none</td></tr>
<tr><td>Format</td><td colspan="3">
<table>
<tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr>
<tr><td>Lecture</td><td></td><td>4</td><td>60 T / 105 S</td><td>5.5</td></tr>
<tr><td>Exercises</td><td></td><td>2</td><td>30 T / 75 S</td><td>3.5</td></tr>
</table>
T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="3">Oral presentation, written report (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="3">(not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="3"></td></tr>
<tr><td>Literature</td><td colspan="3"></td></tr>
</table>

<table>
<tr><td>Module
MA-INF 2317</td><td>Numerical Algorithms for Visual Computing and Machine Learning</td></tr>
<tr><td>Workload
180 h</td><td><table><tr><td>Credit points
6 CP</td><td>Duration
1 semester</td><td>Frequency
at least every 2 years</td></tr></table></td></tr>
<tr><td>Module coordinator</td><td>Jun.-Prof. Dr. Florian Bernard</td></tr>
<tr><td>Lecturer(s)</td><td>Jun.-Prof. Dr. Florian Bernard</td></tr>
<tr><td>Classification</td><td><table><tr><td>Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
2. or 3.</td></tr></table></td></tr>
<tr><td>Technical skills</td><td>• ability to implement basic numerical algorithms, understanding their strengths and shortcomings
• mathematical modelling of computational problems in visual computing and machine learning
• gain an intuition which algorithm is best applied for which problem in visual computing and machine learning, so that practical problems in these areas can be solved</td></tr>
<tr><td>Soft skills</td><td>• problem solving skills: ability to identify and utilise analogies between new problems and previously seen ones
• analytical and abstract thinking: develop a general intuition of computational problems, being able to adopt different perspectives of particular concepts</td></tr>
<tr><td>Contents</td><td>This module focuses on numerical methods that frequently occur in the fields visual computing (VC) and machine learning (ML). In addition to algorithms, this module will also cover modelling aspects that are relevant for solving practical problems in VC and ML. The contents include:
• Error analysis and conditioning of problems
• Linear systems (solvability, algorithms, stability, regularisation), and applications and modelling in VC and ML (e.g. linear regression, image alignment, deconvolution)
• Spectral methods (eigenvalue decomposition, singular value decomposition, respective algorithms), and their applications and modelling in VC and ML (e.g. clustering, Procrustes analysis, point-cloud alignment, principal components analysis)
• Numerical optimisation (gradient-based methods, second-order methods, large-scale optimisation) and applications and modelling in VC and ML.</td></tr>
<tr><td>Prerequisites</td><td>Required:
No formal prerequisites.
Recommended:
Participants are expected to have a high level of mathematical maturity (in particular, a good working knowledge of linear algebra and calculus is essential). A basic understanding of mathematical optimisation is advantageous.</td></tr>
<tr><td>Format</td><td><table><tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr><tr><td>Lecture</td><td></td><td>2</td><td>30 T / 45 S</td><td>2.5</td></tr><tr><td>Exercises</td><td></td><td>2</td><td>30 T / 75 S</td><td>3.5</td></tr></table>T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td>Written exam (graded)</td></tr>
<tr><td>Study achievements</td><td>Successful exercise participation (not graded)</td></tr>
<tr><td>Forms of media</td><td></td></tr>
<tr><td>Literature</td><td></td></tr>
</table>

3 Information and Communication Management

Module MA-INF 3108	**Secure Software Engineering**				
Workload 180 h	**Credit points** 6 CP	**Duration** 1 semester	**Frequency** every year		
Module coordinator	Dr. Christian Tiefenau				
Lecturer(s)	Dr. Christian Tiefenau, Mischa Meier				
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 2. or 3.		
Technical skills	The students are introduced to the security-relevant aspects of a software-engineering lifecycle. Therefore, the main ideas of including security throughout the development process will be presented and explained by examples. By showing common vulnerabilities throughout this course, the students will get an understanding of common vulnerabilities and attacks and how to prevent them.				
Soft skills	In groups, the students will conduct practical exercises to strengthen the understanding of vulnerabilities and attack vectors. Through this, the abilities teamwork, time management, organization and critical discussion of their own and others' results are strengthened.				
Contents	• Threat modeling • Risk analysis • Architectural security • Secure coding • Applied Cryptography • Secure configuration and deployment • Updates and maintenance				
Prerequisites	**Recommended:** Fundamental knowledge in software-engineering and IT-security concepts.				
Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Lecture		2	30 T / 45 S	2.5
	Exercises		2	30 T / 75 S	3.5
	T = face-to-face teaching; S = independent study				
Exam achievements	Written exam (graded)				
Study achievements	Successful exercise participation (not graded)				
Forms of media					
Literature	Software Security: Building Security In by Gary McGraw				

<table>
<tr><td>Module
MA-INF 3109</td><td colspan="3">Quantum Algorithms: Introduction and Data Fusion Examples</td></tr>
<tr><td>Workload
180 h</td><td>Credit points
6 CP</td><td>Duration
1 semester</td><td>Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="3">Prof. Dr. Wolfgang Koch</td></tr>
<tr><td>Lecturer(s)</td><td colspan="3">Prof. Dr. Wolfgang Koch, Dr. Felix Govaers, Dr. Martin Ulmke</td></tr>
<tr><td>Classification</td><td>Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
2. or 3.</td></tr>
<tr><td>Technical skills</td><td colspan="3">Quantum algorithms for data fusion may become game changers as soon as quantum processing kernels embedded in hybrid processing architectures with classical processors will exist. While emerging quantum technologies directly apply quantum physics, quantum algorithms do not exploit quantum physical phenomena as such, but rather use the sophisticated framework of quantum physics to deal with “uncertainty”. Although the link between mathematical statistics and quantum physics has long been known, the potential of physics-inspired algorithms for data fusion has just begun to be realized. While the implementation of quantum algorithms is to be considered on classical as well as on quantum computers, the latter are anticipated as well-adapted “analog computers” for unprecedentedly fast solving data fusion and resources management problems. While the development of quantum computers cannot be taken for granted, their potential is nonetheless real and has to be considered by the international information fusion community.</td></tr>
<tr><td>Soft skills</td><td colspan="3">• Problem solving
• Adaptability
• Critical thinking</td></tr>
<tr><td>Contents</td><td colspan="3">• Introduction with Examples
• Short introduction to quantum mechanics
• Introduction to quantum computing
• Quantum computing hardware
• Quantum inspired tracking
• Particle filtering and fermionic target tracking
• The data association problem
• Track extraction and sensor management
• Quantum computing for multi target tracking data association
• Quantum computing for resources management
• Quantum many particle systems and boson sampling
• Path Integrals</td></tr>
<tr><td>Prerequisites</td><td colspan="3">Recommended:
One of the following:
• BA-INF 137 – Einführung in die Sensordatenfusion
• MA-INF 3310 – Introduction to Sensor Data Fusion - Methods and Applications</td></tr>
<tr><td>Format</td><td colspan="3"><table><tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr><tr><td>Lecture</td><td></td><td>2</td><td>30 T / 45 S</td><td>2.5</td></tr><tr><td>Exercises</td><td></td><td>2</td><td>30 T / 75 S</td><td>3.5</td></tr></table>T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="3">Oral exam (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="3">Erfolgreiche Übungsteilnahme (not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="3"></td></tr>
<tr><td>Literature</td><td colspan="3"></td></tr>
</table>

<table>
<tr><td>Module
MA-INF 3140</td><td colspan="5">Advanced Computer Forensics</td></tr>
<tr><td>Workload
180 h</td><td colspan="2">Credit points
6 CP</td><td>Duration
1 semester</td><td colspan="2">Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="5">Dr. Christian Tiefenau</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Dr. Christian Tiefenau</td></tr>
<tr><td>Classification</td><td colspan="3">Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
1., 2. or 3.</td></tr>
<tr><td>Technical skills</td><td colspan="5">The course covers advanced research topics in computer forensics and secure software engineering.</td></tr>
<tr><td>Soft skills</td><td colspan="5"></td></tr>
<tr><td>Contents</td><td colspan="5">Theoretical and practical aspects of computer forensics and secure software engineering are covered.</td></tr>
<tr><td>Prerequisites</td><td colspan="5">none</td></tr>
<tr><td rowspan="4">Format</td><td>Teaching format</td><td>Group size</td><td>h/week</td><td>Workload[h]</td><td>CP</td></tr>
<tr><td>Lecture</td><td></td><td>2</td><td>30 T / 45 S</td><td>2.5</td></tr>
<tr><td>Exercises</td><td></td><td>2</td><td>30 T / 75 S</td><td>3.5</td></tr>
<tr><td colspan="5">T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="5">Written exam (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="5">Succesful exercise participation (not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="5"></td></tr>
<tr><td>Literature</td><td colspan="5"></td></tr>
</table>

Module MA-INF 3202	**Mobile Communication**		
Workload 180 h	**Credit points** 6 CP	**Duration** 1 semester	**Frequency** every year
Module coordinator	Prof. Dr. Peter Martini		
Lecturer(s)	Prof. Dr. Peter Martini, Dr. Matthias Frank		
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 2. or 3.
Technical skills	Knowledge about key concepts of mobile communication including mobility management (both technology independent and technology dependent), knowledge about wireless technologies and their interaction with other protocol layers and/or other network technologies, ability to evaluate and assess scenarios with communication of mobile devices. In-depth understanding of communication paradigms of wireless/mobile systems and network elements, productive work in small groups, strengthening skills on presentation and discussion of solutions to current challenges		
Soft skills	Theoretical exercises to support in-depth understanding of lecture topics and to stimulate discussions, practical exercises in teamwork to support time management, targeted organisation of practical work and critical discussion of own and others' results		
Contents	Mobility Management in the Internet, Wireless Communication Basics, Wireless Networking Technologies, Cellular/Mobile Communication Networks (voice and data communication), Ad-hoc and Sensor Networks.		
Prerequisites	**Recommended:** Bachelor level knowledge of basics of communication systems (e.g. BA-INF 101 "Kommunikation in Verteilten Systemen" (German Bachelor Programme Informatik, English lecture slides available)		
Format	see below		
Exam achievements	Written exam (graded)		
Study achievements	Successful exercise participation (not graded)		
Forms of media			
Literature	• Jochen Schiller: Mobile Communications, Addison-Wesley, 2003 • William Stallings: Wireless Communications and Networking, Prentice Hall, 2002 • Further up-to-date literature will be announced in due course before the beginning of the lecture		

Format

Teaching format	**Group size**	**h/week**	**Workload[h]**	**CP**
Lecture		2	30 T / 45 S	2.5
Exercises		2	30 T / 75 S	3.5

T = face-to-face teaching; S = independent study

<table>
<tr><td>Module
MA-INF 3209</td><td colspan="5">Seminar Selected Topics in Communication Management</td></tr>
<tr><td>Workload
120 h</td><td>Credit points
4 CP</td><td colspan="2">Duration
1 semester</td><td colspan="2">Frequency
at least every year</td></tr>
<tr><td>Module coordinator</td><td colspan="5">Prof. Dr. Peter Martini</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Prof. Dr. Peter Martini, Prof. Dr. Michael Meier</td></tr>
<tr><td>Classification</td><td colspan="2">Programme
M. Sc. Computer Science</td><td colspan="2">Mode
Optional</td><td>Semester
2. or 3.</td></tr>
<tr><td>Technical skills</td><td colspan="5">Ability to understand new research results presented in original scientific papers.</td></tr>
<tr><td>Soft skills</td><td colspan="5">Ability to present and to critically discuss these results in the framework of the corresponding area.</td></tr>
<tr><td>Contents</td><td colspan="5">Current conference and journal papers, current standardization drafts</td></tr>
<tr><td>Prerequisites</td><td colspan="5">Required:
Successful completion of at least one of the following lectures: Principles of Distributed Systems (MA-INF3105), Network Security (MA-INF3201), Mobile Communication (MA-INF3202), IT Security (MA-INF3236)</td></tr>
<tr><td rowspan="3">Format</td><td>Teaching format</td><td>Group size</td><td>h/week</td><td>Workload[h]</td><td>CP</td></tr>
<tr><td>Seminar</td><td>10</td><td>2</td><td>30 T / 90 S</td><td>4</td></tr>
<tr><td colspan="5">T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="5">Oral presentation, written report (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="5">(not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="5"></td></tr>
<tr><td>Literature</td><td colspan="5">The relevant literature will be announced towards the end of the previous semester</td></tr>
</table>

Module MA-INF 3216	**Seminar Sensor Data Fusion**				
Workload 120 h	**Credit points** 4 CP	**Duration** 1 semester	**Frequency** every year		
Module coordinator	P.D. Dr. Wolfgang Koch				
Lecturer(s)	P.D. Dr. Wolfgang Koch, Dr. Felix Govaers				
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 2.		
Technical skills	Ability to understand new research results presented in original scientific papers.				
Soft skills	Ability to present and to critically discuss these results in the framework of the corresponding area.				
Contents	Current conference and journal papers				
Prerequisites	none				
Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Seminar	10	2	30 T / 90 S	4
	T = face-to-face teaching; S = independent study				
Exam achievements	Oral presentation, written report (graded)				
Study achievements	(not graded)				
Forms of media					
Literature	The relevant literature will be announced at the beginning of the seminar.				

Module MA-INF 3229	**Lab IT-Security**		
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** every semester
Module coordinator	Prof. Dr. Michael Meier		
Lecturer(s)	Prof. Dr. Michael Meier		
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 2. or 3.
Technical skills	The students will carry out a practical task (project) in the context of IT Security, including test and documentation of the implemented software/system.		
Soft skills	Ability to properly present and defend design decisions, to prepare readable documentation of software; skills in constructively collaborating with others in small teams over a longer period of time; ability to classify ones own results into the state-of-the-art of the resp. area		
Contents			
Prerequisites	none		
Format	**Teaching format**: Lab; **Group size**: 8; **h/week**: 4; **Workload[h]**: 60 T / 210 S; **CP**: 9 T = face-to-face teaching; S = independent study		
Exam achievements	Oral presentation, written report (graded)		
Study achievements	(not graded)		
Forms of media			
Literature			

Module MA-INF 3233	**Advanced Sensor Data Fusion in Distributed Systems**
Workload 180 h	**Credit points** 6 CP; **Duration** 1 semester; **Frequency** every year
Module coordinator	PD Dr. Wolfgang Koch
Lecturer(s)	Dr. Felix Govaers
Classification	**Programme** M. Sc. Computer Science; **Mode** Optional; **Semester** 2.
Technical skills	For challenging state estimation tasks, algorithms which enhance the situational awareness by fusing sensor information are inevitable. Nowadays it has become very popular to improve the performance of systems by linking multiple sensors. This implies some challenges to the sensor data fusion methodologies such as sensor registration, communication delays, and correlations of estimation errors. In particular, if the communication links have limited bandwidth, data reduction techniques have to be applied at the sensor sites, that is local tracks have to be computed. Once recieved at a fusion center (FC), the tracks then are fused to reconstruct a global estimate. In this lecture, methodologies to a achieve a distributed state estimation are considered. Among these are tracklet fusion, the Bar-Shalom-Campo formula, the Federated Kalman Filter, naive fusion, the distributed Kalman filter and the least squares estimate.
Soft skills	Mathematical derivation of algorithms, application of mathematical results on estimation theory.
Contents	tracklet fusion, the Bar-Shalom-Campo formula, the Federated Kalman Filter, naive fusion, the distributed Kalman filter and the least squares estimate, Accumulated State Densities, Decorrlated fusion, product representation
Prerequisites	**Recommended:** At least 1 of the following: BA-INF 137 – Einführung in die Sensordatenfusion MA-INF 3310 – Introduction to Sensor Data Fusion - Methods and Applications
Format	see below
Exam achievements	Oral exam (graded)
Study achievements	Successful exercise participation (not graded)
Forms of media	Power Point
Literature	W. Koch: "Tracking and Sensor Data Fusion: Methodological Framework and Selected Applications", Springer, 2014. D. Hall, C.-Y. Chong, J. Llinas, and M. L. II: "Distributed Data Fusion for Network-Centric Operations", CRC Press, 2014.

Format

Teaching format	**Group size**	**h/week**	**Workload[h]**	**CP**
Lecture		2	30 T / 45 S	2.5
Exercises		2	30 T / 75 S	3.5

T = face-to-face teaching; S = independent study

Module MA-INF 3236	**IT Security**				
Workload 180 h	**Credit points** 6 CP	**Duration** 1 semester	**Frequency** every year		
Module coordinator	Prof. Dr. Michael Meier				
Lecturer(s)	Prof. Dr. Michael Meier				
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 1. or 2.		
Technical skills	Students are introduced to a variety of active research fields in IT security. Students learn about the motivation, challenges and objectives in these fields. Additionally, they get to know selected fundamental knowledge and methods helping them to deepen their knowledge in their upcoming studies.				
Soft skills	working in small groups on exercises, critical discussion of own and others' results, time management, transfering theoretical knowledge to practical scenarios				
Contents	The contents vary but usually include • Privacy • Cryptographic Protocols • Network Security • Supply Chain Attacks • Management of Identity Data • Low-level software analysis • Software testing • Side Channel Attacks • Anomaly Detection • Human Factor in Security				
Prerequisites	**Required:** Fundamental knowledge in the following areas: operating systems, networks, security				
Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Lecture		2	30 T / 45 S	2.5
	Exercises		2	30 T / 75 S	3.5
	T = face-to-face teaching; S = independent study				
Exam achievements	Written exam (graded)				
Study achievements	Successful exercise participation (not graded)				
Forms of media					
Literature					

<table>
<tr><td>Module
MA-INF 3237</td><td colspan="5">Array Signal and Multi-channel Processing</td></tr>
<tr><td>Workload
180 h</td><td>Credit points
6 CP</td><td>Duration
1 semester</td><td colspan="3">Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="5">Prof. Dr. Wolfgang Koch</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Dr. Marc Oispuu</td></tr>
<tr><td>Classification</td><td colspan="2">Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td colspan="2">Semester
2. or 3.</td></tr>
<tr><td>Technical skills</td><td colspan="5">Localization of multiple sources using passive sensors is a fundamental task encountered in various fields like wireless communication, radar, sonar, and seismology. In this lecture, a unified framework for electromagnetic and acoustic signals and signal processing techniques are presented. Furthermore, the sensor calibration, direction finding, and bearings-only localization problem are considered. Special applications are emphasized, like small airborne arrays for unmanned aerial vehicles (UAVs).</td></tr>
<tr><td>Soft skills</td><td colspan="5">Mathematical derivation of algorithms, applications of mathematical results on estimation theory</td></tr>
<tr><td>Contents</td><td colspan="5">Estimation theory, Sensor model, Cramér-Rao analysis, conventional beamforming, Multiple Signal Classification (MUSIC), sensor calibration, Bearings-only localization, Direct Position Determination (DPD), Applications</td></tr>
<tr><td>Prerequisites</td><td colspan="5">Recommended:
Recommended: F. Kurth: “Foundations of Audio Signal Processing” (MA-INF 2113)</td></tr>
<tr><td rowspan="4">Format</td><td>Teaching format</td><td>Group size</td><td>h/week</td><td>Workload[h]</td><td>CP</td></tr>
<tr><td>Lecture</td><td></td><td>2</td><td>30 T / 45 S</td><td>2.5</td></tr>
<tr><td>Exercises</td><td></td><td>2</td><td>30 T / 75 S</td><td>3.5</td></tr>
<tr><td colspan="5">T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="5">Oral Exam (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="5">Successful exercise participation (not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="5">Power Point</td></tr>
<tr><td>Literature</td><td colspan="5">H. L. van Trees, Optimum Array Processing. Part IV of Detection, Estimation, and Modulation Theory. New York: Wiley-Interscience, 2002.</td></tr>
</table>

<table>
<tr><td>Module
MA-INF 3238</td><td>Side Channel Attacks</td></tr>
<tr><td>Workload
180 h</td><td><table><tr><td>Credit points
6 CP</td><td>Duration
1 semester</td><td>Frequency
every year</td></tr></table></td></tr>
<tr><td>Module coordinator</td><td>Dr. Felix Boes</td></tr>
<tr><td>Lecturer(s)</td><td>Dr. Felix Boes</td></tr>
<tr><td>Classification</td><td><table><tr><td>Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
2. or 3.</td></tr></table></td></tr>
<tr><td>Technical skills</td><td>• Students are introduced to theoretical and practical side channel effects of modern hardware.
• Students learn techniques to utilize these effects to circumvent security mechanisms.
• This includes covert channels as well as side channel attacks and microarchitectural attacks on modern CPUs.</td></tr>
<tr><td>Soft skills</td><td>Theoretical exercises to support in-depth understanding of lecture topics and to stimulate discussions, practical exercises in teamwork to support time management, targeted organization of practical work and critical discussion of own and others' results.</td></tr>
<tr><td>Contents</td><td>• Theoretical foundations of side channel effects and attacks as well as
• covert channels,
• differential power analysis,
• padding oracle,
• RSA timing attacks,
• cache based side channel effects,
• microarchitectural attacks (Spectre)</td></tr>
<tr><td>Prerequisites</td><td>Recommended:
Fundamental knowledge about IT Security, operating systems and statistics is advantageous but not mandatory.</td></tr>
<tr><td>Format</td><td><table><tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr><tr><td>Lecture</td><td></td><td>2</td><td>30 T / 45 S</td><td>2.5</td></tr><tr><td>Exercises</td><td></td><td>2</td><td>30 T / 75 S</td><td>3.5</td></tr></table>T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td>Written Exam (graded)</td></tr>
<tr><td>Study achievements</td><td>Successful exercise participation (not graded)</td></tr>
<tr><td>Forms of media</td><td></td></tr>
<tr><td>Literature</td><td></td></tr>
</table>

Module MA-INF 3239	**Malware Analysis**				
Workload 180 h	**Credit points** 6 CP	**Duration** 1 semester	**Frequency** every year		
Module coordinator	Prof. Dr. Peter Martini				
Lecturer(s)	Prof. Dr. Elmar Padilla				
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 2. or 3.		
Technical skills	The students should be able to analyze the functional scope of a binary file independently and to describe its damage potential. In addition, the students should be able to carry out detailed analyzes of given aspects and to partially automate these with the help of scripts.				
Soft skills	Presentation of solutions and methods, critical discussion of applied methods and techniques.				
Contents	In the course, the skills acquired so far in binary analysis will first be deepened and adapted to the peculiarities of malware analysis. Different malware samples are used to explain the techniques used by malware authors. These priorities include: • Characteristics of malware • Persistence • Network communication • Encryption • Dynamic malware analysis • Debugging • Behavioral obfuscation • Virtual analysis environments • Static malware analysis • Control flow obfuscation • Automation of common analysis steps • Reconstruction of binary algorithms The event begins with several lectures that provide the basics for the students to work independently later. In the course of this, the students will work on practical topics from the field of malware analysis during the semester. Since these subject areas can turn out to be very specific, it is necessary to be willing to deal with the subject outside of the lecture and exercise times.				
Prerequisites	**Required:** none **Recommended:** Basic knowledge of operating systems (kernel, threads, virtual memory), network communication (protocols, architectures), binary analysis (assembler, endianness, semantic gap, coding), software development (programming, semantics, scripting in Python)				
Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Lecture		2	30 T / 45 S	2.5
	Exercises		2	30 T / 75 S	3.5
	T = face-to-face teaching; S = independent study				
Exam achievements	Oral exam (graded)				
Study achievements	Successful exercise participation (not graded)				
Forms of media					
Literature	The relevant literature will be announced at the beginning of the lecture				

<table>
<tr><td>Module
MA-INF 3241</td><td colspan="5">Practical Challenges in Human Factors of Security and Privacy</td></tr>
<tr><td>Workload
180 h</td><td>Credit points
6 CP</td><td colspan="2">Duration
1 semester</td><td colspan="2">Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="5">Prof. Dr. Matthew Smith</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Prof. Dr. Matthew Smith</td></tr>
<tr><td>Classification</td><td colspan="2">Programme
M. Sc. Computer Science</td><td colspan="2">Mode
Optional</td><td>Semester
2.</td></tr>
<tr><td>Technical skills</td><td colspan="5">After completing the unit students will be able to conduct related work searchers to get a deep understanding into the state of the art. They will be able to design, run and evaluate scientific studies in this area.</td></tr>
<tr><td>Soft skills</td><td colspan="5"></td></tr>
<tr><td>Contents</td><td colspan="5">In this course we will learn about and develop solutions for a specific challenge concerning human factors in security and privacy.</td></tr>
<tr><td>Prerequisites</td><td colspan="5">none</td></tr>
<tr><td rowspan="3">Format</td><td>Teaching format</td><td>Group size</td><td>h/week</td><td>Workload[h]</td><td>CP</td></tr>
<tr><td>Lecture</td><td></td><td>1</td><td>15 T / 45 S</td><td>2</td></tr>
<tr><td>Exercises</td><td></td><td>3</td><td>45 T / 75 S</td><td>4</td></tr>
<tr><td></td><td colspan="5">T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="5">Project work (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="5">Successful exercise participation (not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="5"></td></tr>
<tr><td>Literature</td><td colspan="5"></td></tr>
</table>

Module MA-INF 3242	**Security of Distributed and Resource-constrained Systems**
Workload 180 h	**Credit points** 6 CP | **Duration** 1 semester | **Frequency** every year
Module coordinator	Prof. Dr. Michael Meier
Lecturer(s)	Dr. Thorsten Aurisch
Classification	**Programme** M. Sc. Computer Science | **Mode** Optional | **Semester** 2.
Technical skills	Ability to understand and analyse theoretical and practical cyber security challenges of distributed and ressource-constrained systems, as well as the ability to select and apply appropriate solutions.
Soft skills	
Contents	• Group communication with IP multicast • Group key management • Broadcast encryption • Public key infrastructure • Web of trust • Multicast infrastructure protection • Distributed security mechanisms • Cyber resilience in groups • Security in tactical radio networks • Security for IoT
Prerequisites	none
Format	see below
Exam achievements	Written exam (graded)
Study achievements	Successful exercise participation (not graded)
Forms of media	
Literature	

Format:

Teaching format	Group size	h/week	Workload[h]	CP
Lecture		2	30 T / 45 S	2.5
Exercises		2	30 T / 75 S	3.5

T = face-to-face teaching; S = independent study

<table>
<tr><td>Module
MA-INF 3304</td><td colspan="5">Lab Communication and Communicating Devices</td></tr>
<tr><td>Workload
270 h</td><td colspan="2">Credit points
9 CP</td><td>Duration
1 semester</td><td colspan="2">Frequency
every semester</td></tr>
<tr><td>Module coordinator</td><td colspan="5">Prof. Dr. Peter Martini</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Prof. Dr. Peter Martini, Prof. Dr. Michael Meier</td></tr>
<tr><td>Classification</td><td colspan="3">Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
2. or 3.</td></tr>
<tr><td>Technical skills</td><td colspan="5">The students will carry out a practical task (project) in the context of communication systems, including test and documentation of the implemented software/system.</td></tr>
<tr><td>Soft skills</td><td colspan="5">Work in small teams and cooperate with other teams in a group; ability to make design decisions in a practical task; present and discuss (interim and final) results in the team/group and to other students; prepare written documentation of the work carried out</td></tr>
<tr><td>Contents</td><td colspan="5">Selected topics close to current research in the area of communication systems, network security, mobile communication and communicating devices.</td></tr>
<tr><td>Prerequisites</td><td colspan="5">Required:
Successful completion of at least one of the following lectures: Principles of Distributed Systems (MA-INF3105), Network Security (MA-INF3201), Mobile Communication (MA-INF3202), IT Security (MA-INF3236)</td></tr>
<tr><td rowspan="2">Format</td><td>Teaching format</td><td>Group size</td><td>h/week</td><td>Workload[h]</td><td>CP</td></tr>
<tr><td>Lab</td><td>8</td><td>4</td><td>60 T / 210 S</td><td>9</td></tr>
<tr><td></td><td colspan="5">T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="5">Oral presentation, written report (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="5">(not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="5"></td></tr>
<tr><td>Literature</td><td colspan="5">The relevant literature will be announced towards the end of the previous semester.</td></tr>
</table>

<table>
<tr><td>Module
MA-INF 3305</td><td colspan="4">Lab Information Systems</td></tr>
<tr><td>Workload
270 h</td><td>Credit points
9 CP</td><td>Duration
1 semester</td><td colspan="2">Frequency
at least every year</td></tr>
<tr><td>Module coordinator</td><td colspan="4">Dr. Thomas Bode</td></tr>
<tr><td>Lecturer(s)</td><td colspan="4">Dr. Thomas Bode</td></tr>
<tr><td>Classification</td><td colspan="2">Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
2. or 3.</td></tr>
<tr><td>Technical skills</td><td colspan="4">The students will carry out a practical task (project) in the context of information systems, including test and documentation of the implemented software/system.</td></tr>
<tr><td>Soft skills</td><td colspan="4">Ability to properly present and defend design decisions, to prepare readable documentation of software; skills in constructively collaborating with others in small teams over a longer period of time; ability to classify ones own results into the state-of-the-art of the resp. area</td></tr>
<tr><td>Contents</td><td colspan="4">Varying selected topics close to current research in the area of database- and information systems.</td></tr>
<tr><td>Prerequisites</td><td colspan="4">none</td></tr>
<tr><td>Format</td><td colspan="4"><table><tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr><tr><td>Lab</td><td>8</td><td>4</td><td>60 T / 210 S</td><td>9</td></tr></table>T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="4">Oral presentation, written report (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="4">(not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="4"></td></tr>
<tr><td>Literature</td><td colspan="4">The relevant literature will be announced towards the end of the previous semester.</td></tr>
</table>

Module MA-INF 3309	**Lab Malware Analysis**		
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** every semester
Module coordinator	Prof. Dr. Peter Martini		
Lecturer(s)	Prof. Dr. Peter Martini, Prof. Dr. Michael Meier		
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 3.
Technical skills	The students will carry out a practical task (project) in the context of communication systems with a specific topic focus on Malware Analysis and Computer/Network Security, including test and documentation of the implemented software/system.		
Soft skills	Work in small teams and cooperate with other teams in a group; ability to make design decisions in a practical task; present and discuss (interim and final) results in the team/group and to other students; prepare written documentation of the work carried out		
Contents	Selected topics close to current research in the area of communication systems, malware analysis, computer and network security.		
Prerequisites	**Required:** Successful completion of at least one of the following lectures: Principles of Distributed Systems (MA-INF3105), Network Security (MA-INF3201), Mobile Communication (MA-INF3202), IT Security (MA-INF3236)		
Format	see below		
Exam achievements	Oral presentation, written report (graded)		
Study achievements	(not graded)		
Forms of media			
Literature			

Format:

Teaching format	Group size	h/week	Workload[h]	CP
Lab	8	4	60 T / 210 S	9

T = face-to-face teaching; S = independent study

<table>
<tr><td>Module
MA-INF 3310</td><td colspan="3">Introduction to Sensor Data Fusion - Methods and Applications</td></tr>
<tr><td>Workload
180 h</td><td>Credit points
6 CP</td><td>Duration
1 semester</td><td>Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="3">Prof. Dr. Wolfgang Koch</td></tr>
<tr><td>Lecturer(s)</td><td colspan="3">Prof. Dr. Wolfgang Koch</td></tr>
<tr><td>Classification</td><td>Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
3.</td></tr>
<tr><td>Technical skills</td><td colspan="3">All participants shall get known to the basic theory of sensor data fusion. The lecture starts with preliminaries on how to handle uncertain data and knowledge within analytical calculus. Then, the fundamental and well-known Kalman filter is derived. Based on this tracking scheme, further approaches to a wide spectrum of applications will be shown. All algorithms will be motivated by examples from ongoing research projects, industrial cooperations, and impressions of current demonstration hardware.
Because of inherent practical issues, every sensor measures certain properties up to an error. This lecture shows how to model and overcome this error by an application of theoretical tools such as Bayes' rule and further derivations. Moreover, solutions to possible false-alarms, miss-detections, maneuvering phases, and much more will be presented.</td></tr>
<tr><td>Soft skills</td><td colspan="3">Mathematical derivation of algorithms, application of mathematical results on estimation theory.</td></tr>
<tr><td>Contents</td><td colspan="3">Gaussian probability density functions, Kalman filter, Multi-Hypothesis-Trackier, Interacting Multiple Model Filter, Retrodiction, Smoothing, Maneuver Modeling</td></tr>
<tr><td>Prerequisites</td><td colspan="3">none</td></tr>
<tr><td>Format</td><td colspan="3"><table>
<tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr>
<tr><td>Lecture</td><td></td><td>2</td><td>30 T / 45 S</td><td>2.5</td></tr>
<tr><td>Exercises</td><td></td><td>2</td><td>30 T / 75 S</td><td>3.5</td></tr>
</table>T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="3">Written exam (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="3">Successful exercise participation (not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="3"></td></tr>
<tr><td>Literature</td><td colspan="3">W. Koch: "Tracking and Sensor Data Fusion: Methodological Framework and Selected Applications", Springer, 2014.
Y. Bar-Shalom: "Estimation with Applications to Tracking and Navigation", Wiley-Interscience, 2001.</td></tr>
</table>

Module MA-INF 3312	**Lab Sensor Data Fusion**				
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** every year		
Module coordinator	Prof. Dr. Wolfgang Koch				
Lecturer(s)	Prof. Dr. Wolfgang Koch				
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 3.		
Technical skills	The students will work together on a data fusion project using various sensor hardware. Latest algorithms for fusing information from several nodes will be implemented.				
Soft skills	The students shall work together in a team. Everyone is responsible for a specific part in the context of a main goal. Results will be exchanged and integrated via software interfaces.				
Contents	Varying selected topics on sensor data fusion.				
Prerequisites	none				
Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Lab	8	4	60 T / 210 S	9
	T = face-to-face teaching; S = independent study				
Exam achievements	Oral presentation, written report (graded)				
Study achievements	(not graded)				
Forms of media					
Literature	The relevant literature will be announced at the beginning of the lab.				

<table>
<tr><td>Module
MA-INF 3317</td><td colspan="5">Seminar Selected Topics in IT Security</td></tr>
<tr><td>Workload
120 h</td><td>Credit points
4 CP</td><td>Duration
1 semester</td><td colspan="3">Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="5">Prof. Dr. Michael Meier</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Prof. Dr. Michael Meier, Prof. Dr. Peter Martini</td></tr>
<tr><td>Classification</td><td colspan="2">Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td colspan="2">Semester
2.</td></tr>
<tr><td>Technical skills</td><td colspan="5">Ability to understand new research results presented in original scientific papers.</td></tr>
<tr><td>Soft skills</td><td colspan="5">Ability to present and to critically discuss these results in the framework of the corresponding area.</td></tr>
<tr><td>Contents</td><td colspan="5">Current conference and journal papers</td></tr>
<tr><td>Prerequisites</td><td colspan="5">none</td></tr>
<tr><td rowspan="3">Format</td><td>Teaching format</td><td>Group size</td><td>h/week</td><td>Workload[h]</td><td>CP</td></tr>
<tr><td>Seminar</td><td>10</td><td>2</td><td>30 T / 90 S</td><td>4</td></tr>
<tr><td colspan="5">T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="5">Oral presentation, written report (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="5">(not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="5"></td></tr>
<tr><td>Literature</td><td colspan="5"></td></tr>
</table>

<table>
<tr><td>Module
MA-INF 3319</td><td colspan="5">Lab Usable Security and Privacy</td></tr>
<tr><td>Workload
270 h</td><td>Credit points
9 CP</td><td colspan="2">Duration
1 semester</td><td colspan="2">Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="5">Prof. Dr. Matthew Smith</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Prof. Dr. Matthew Smith</td></tr>
<tr><td>Classification</td><td colspan="2">Programme
M. Sc. Computer Science</td><td colspan="2">Mode
Optional</td><td>Semester
2.</td></tr>
<tr><td>Technical skills</td><td colspan="5">The students will carry out a practical task (project) in the context of usable security and privacy, including user studies.</td></tr>
<tr><td>Soft skills</td><td colspan="5">Ability to create and defend a scientific user study</td></tr>
<tr><td>Contents</td><td colspan="5">Students have a great degree of freedom to chose their own topics within the context of human aspects of security and privacy.</td></tr>
<tr><td>Prerequisites</td><td colspan="5">Required:
Vorkenntnisse zur Durchführung und Auswertung von Benutzerstudien sind notwendig. Wie sie z.B. in BA-INF145 - Usable Security and Privacy gelehrt werden.
Knowledge on how to run and evaluate user studies are required. For example as it is taught in BA-INF145 - Usable Security and Privacy.</td></tr>
<tr><td rowspan="3">Format</td><td>Teaching format</td><td>Group size</td><td>h/week</td><td>Workload[h]</td><td>CP</td></tr>
<tr><td>Lab</td><td>8</td><td>4</td><td>60 T / 210 S</td><td>9</td></tr>
<tr><td colspan="5">T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="5">Oral presentation, written report (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="5">(not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="5"></td></tr>
<tr><td>Literature</td><td colspan="5"></td></tr>
</table>

Module MA-INF 3320	**Lab Security in Distributed Systems**		
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** every year
Module coordinator	Prof. Dr. Matthew Smith		
Lecturer(s)	Prof. Dr. Matthew Smith		
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 2.
Technical skills	The students will carry out a practical task (project) in the context of distributed security, including documentation of the implemented software/system. Strong programming skills required.		
Soft skills	Ability to properly present and defend design decisions, to prepare readable documentation of software; skills in constructively collaborating with others in small teams over a longer period of time; ability to classify ones own results into the state-of-the-art of the resp. area		
Contents	Security in distributed systems, including amongst others: • Secure Messaging • App Security • SSL/HTTPS • API Security • Machine Learning for Security • Passwords • Intrusion Detection Systems • Anomaly Detection • Security Visualisation		
Prerequisites	none		
Format	see below		
Exam achievements	Oral presentation, written report (graded)		
Study achievements	(not graded)		
Forms of media			
Literature			

Format:

Teaching format	Group size	h/week	Workload[h]	CP
Lab	8	4	60 T / 210 S	9

T = face-to-face teaching; S = independent study

<table>
<tr><td>Module
MA-INF 3321</td><td colspan="5">Seminar Usable Security and Privacy</td></tr>
<tr><td>Workload
120 h</td><td>Credit points
4 CP</td><td>Duration
1 semester</td><td colspan="3">Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="5">Prof. Dr. Matthew Smith</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Prof. Dr. Matthew Smith</td></tr>
<tr><td>Classification</td><td colspan="2">Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td colspan="2">Semester
2.</td></tr>
<tr><td>Technical skills</td><td colspan="5">Ability to understand new research results presented in original scientific papers.</td></tr>
<tr><td>Soft skills</td><td colspan="5">Ability to present and to critically discuss these results in the framework of the corresponding area.</td></tr>
<tr><td>Contents</td><td colspan="5">Current conference and journal papers</td></tr>
<tr><td>Prerequisites</td><td colspan="5">none</td></tr>
<tr><td rowspan="3">Format</td><td>Teaching format</td><td>Group size</td><td>h/week</td><td>Workload[h]</td><td>CP</td></tr>
<tr><td>Seminar</td><td>10</td><td>2</td><td>30 T / 90 S</td><td>4</td></tr>
<tr><td colspan="5">T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="5">Oral presentation, written report (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="5">(not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="5"></td></tr>
<tr><td>Literature</td><td colspan="5"></td></tr>
</table>

<table>
<tr><td>Module
MA-INF 3322</td><td colspan="3">Applied Binary Exploitation</td></tr>
<tr><td>Workload
180 h</td><td>Credit points
6 CP</td><td>Duration
1 semester</td><td>Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="3">Prof. Dr. Peter Martini</td></tr>
<tr><td>Lecturer(s)</td><td colspan="3">Prof. Dr. Elmar Padilla</td></tr>
<tr><td>Classification</td><td>Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
2. or 3.</td></tr>
<tr><td>Technical skills</td><td colspan="3">Static and dynamic program analysis, Exploitation (Stack-based Buffer Overflows, Format String Exploits, Heap Exploitation, Use-After-Free Exploits) and Countermeasures (Stack Cookies, NX, ASLR, RELRO)</td></tr>
<tr><td>Soft skills</td><td colspan="3">Frustration tolerance when working with binary representations and trying to apply taught techniques, focussed working on technically challenging problems, simultaneously applying knowledge from different areas of computer science</td></tr>
<tr><td>Contents</td><td colspan="3">Our computers run a lot of closed source binary programs meaning that the source code of those programs is not available. Naturally, those programs contain bugs, mistakes that the programmer made during the development. Those bugs could (under certain circumstances) be exploited by attackers and thus may lead to arbitrary code execution. In this lecture we aim to teach you how to find well known exploitable bugs and how to exploit them. After a brief recap of basic binary program analysis such as static and dynamic analysis, we will talk about vulnerability discovery in general, meaning that you will learn how to find exploitable bugs by yourself. Next we move on to basic stack-based buffer overflows and add mitigation techniques (stack cookies, NX, ASLR, RELRO, ...) as we progress and exploit them as well. After we finished the topic of stack-based buffer overflows we move on to more advanced topics such as heap exploitation, use-after-free exploits and others. The lecture ends with an introduction to fuzzing and an analysis of a sophisticated real-world exploit.</td></tr>
<tr><td>Prerequisites</td><td colspan="3">Required:
none
Recommended:
• Binary Analysis skills (Lecture: “Applied Binary Analysis” BA-INF 155)
• Basic knowledge of the Linux operating system
• System Programming skills in C (Lecture: “Systemnahe Programmierung”)
• Basic Python programming skills</td></tr>
<tr><td>Format</td><td colspan="3">
<table>
<tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr>
<tr><td>Lecture</td><td></td><td>2</td><td>30 T / 45 S</td><td>2.5</td></tr>
<tr><td>Exercises</td><td></td><td>2</td><td>30 T / 75 S</td><td>3.5</td></tr>
</table>
T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="3">Oral Examination (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="3">Successful exercise participation (not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="3"></td></tr>
<tr><td>Literature</td><td colspan="3">The relevant literature will be announced at the beginning of the lecture</td></tr>
</table>

Module MA-INF 3323	**Lab Fuzzing Bootcamp**				
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** every year		
Module coordinator	Prof. Dr. Matthew Smith				
Lecturer(s)	Dr. Christian Tiefenau				
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 2. or 3.		
Technical skills	The students will carry out a practical task (project) in the context of fuzz testing, including test and documentation of the implemented software/system.				
Soft skills	Ability to properly present and defend design decisions, to prepare readable documentation of software; skills in constructively collaborating with others in small teams over a longer period of time; ability to classify ones own results into the state-of-the-art of the resp. area				
Contents					
Prerequisites	none				
Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Lab	8	4	60 T / 210 S	9
	T = face-to-face teaching; S = independent study				
Exam achievements	Oral presentation, written report (graded)				
Study achievements	(not graded)				
Forms of media					
Literature					

<table>
<tr><td>Module
MA-INF 3324</td><td colspan="5">Lab Design of Usable Security Mechanisms</td></tr>
<tr><td>Workload
270 h</td><td>Credit points
9 CP</td><td colspan="2">Duration
1 semester</td><td colspan="2">Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="5">Prof. Dr. Matthew Smith</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Dr. Emmanuel von Zezschwitz</td></tr>
<tr><td>Classification</td><td colspan="2">Programme
M. Sc. Computer Science</td><td colspan="2">Mode
Optional</td><td>Semester
2. or 3.</td></tr>
<tr><td>Technical skills</td><td colspan="5">The students will carry out a practical task (project) in the context of usable security mechanisms, including test and documentation of the implemented software/system.</td></tr>
<tr><td>Soft skills</td><td colspan="5">Ability to properly present and defend design decisions, to prepare readable documentation of software; skills in constructively collaborating with others in small teams over a longer period of time; ability to classify ones own results into the state-of-the-art of the resp. area</td></tr>
<tr><td>Contents</td><td colspan="5"></td></tr>
<tr><td>Prerequisites</td><td colspan="5">none</td></tr>
<tr><td rowspan="3">Format</td><td>Teaching format</td><td>Group size</td><td>h/week</td><td>Workload[h]</td><td>CP</td></tr>
<tr><td>Lab</td><td>8</td><td>4</td><td>60 T / 210 S</td><td>9</td></tr>
<tr><td colspan="5">T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="5">Oral presentation, written report (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="5">(not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="5"></td></tr>
<tr><td>Literature</td><td colspan="5"></td></tr>
</table>

4 Intelligent Systems

<table>
<tr><td>Module
MA-INF 4111</td><td colspan="3">Principles of Machine Learning</td></tr>
<tr><td>Workload
180 h</td><td>Credit points
6 CP</td><td>Duration
1 semester</td><td>Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="3"></td></tr>
<tr><td>Lecturer(s)</td><td colspan="3">Prof. Dr.-Ing. Christian Bauckhage</td></tr>
<tr><td>Classification</td><td>Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
1. or 2.</td></tr>
<tr><td>Technical skills</td><td colspan="3">Upon successful completion of this module, students should be able to describe fundamental methods, algorithms, and use cases of machine learning. Students acquire knowledge about supervised and unsupervised learning; based on the knowledge and skills acquired, students should be able to
• Implement, algorithms for optimization and parameter estimation in model training and machine learning tasks.
• Adopt the fundamental methods they learned about to a wide range of problems in automated intelligent data analysis.</td></tr>
<tr><td>Soft skills</td><td colspan="3">In the exercises, students can put their knowledge about theoretical concepts, mathematical methods, and algorithmic approaches into practice and realize small projects involving the implementation and evaluation of machine learning algorithms. This requires teamwork; upon successful completion of the module, students should be able to
• draft and implement basic machine learning algorithms for various practical problem settings
• prepare and give oral presentations about their work in front of an audience</td></tr>
<tr><td>Contents</td><td colspan="3">Fundamental machine learning models for classification and clustering, model training via minimization of loss functions, fundamental optimization algorithms, model regularization, kernel methods for supervised and unsupervised learning, probabilistic modeling and inference, dimensionality reduction and latent factor models, the basic theory behind neural networks and neural network training; This course is intended to lay the foundation for more advanced courses on modern deep learning and reinforcement learning.</td></tr>
<tr><td>Prerequisites</td><td colspan="3">Recommended:
Linear algebra, statistics, probability theory, calculus, python programming</td></tr>
<tr><td>Format</td><td colspan="3"><table>
<tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr>
<tr><td>Lecture</td><td></td><td>2</td><td>30 T / 45 S</td><td>2.5</td></tr>
<tr><td>Exercises</td><td></td><td>2</td><td>30 T / 75 S</td><td>3.5</td></tr>
</table>
T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="3">Schriftliche Prüfung (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="3">Erfolgreiche Übungsteilnahme (not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="3">• lecture slides / lecture notes are made available online
• notebooks with programming examples are made available online</td></tr>
<tr><td>Literature</td><td colspan="3">• D.J.C MacKay: Information Theory, Inference and Learning Algorithms, Cambridge University Press, 2003
• C.M. Bishop: Pattern Recognition and Machine Learning, Springer, 2006
• S. Haykin: Neural Networks and Learning Machines, Pearson, 2008</td></tr>
</table>

<table>
<tr><td>Module
MA-INF 4113</td><td colspan="3">Cognitive Robotics</td></tr>
<tr><td>Workload
180 h</td><td>Credit points
6 CP</td><td>Duration
1 semester</td><td>Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="3">Prof. Dr. Sven Behnke</td></tr>
<tr><td>Lecturer(s)</td><td colspan="3">Prof. Dr. Sven Behnke</td></tr>
<tr><td>Classification</td><td>Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
1. or 2.</td></tr>
<tr><td>Technical skills</td><td colspan="3">This lecture is one of two introductory lectures of the intelligent systems track. The lecture covers cognitive capabilities of robots, like self-localization, mapping, object perception, and action-planning in complex environments.
This module complements MA-INF 4114 and can be taken before or after that module.</td></tr>
<tr><td>Soft skills</td><td colspan="3">Communicative skills (oral and written presentation of solutions, discussions in small teams), self competences (ability to accept and formulate criticism, ability to analyze problems)</td></tr>
<tr><td>Contents</td><td colspan="3">Probabilistic approaches to state estimation (Bayes Filters, Kalman Filter, Particle Filter), motion models, sensor models, self-localization, mapping with known poses, simultaneous mapping and localization (SLAM), iterated closest-point matching, path planning, place- and person recognition, object recognition.</td></tr>
<tr><td>Prerequisites</td><td colspan="3">Required:
MA-INF 4101 - Theory of Sensorimotor Systems has not been passed.</td></tr>
<tr><td>Format</td><td colspan="3"><table>
<tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr>
<tr><td>Lecture</td><td></td><td>2</td><td>30 T / 45 S</td><td>2.5</td></tr>
<tr><td>Exercises</td><td></td><td>2</td><td>30 T / 75 S</td><td>3.5</td></tr>
</table>
T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="3">Written exam (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="3">Successful exercise participation (not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="3"></td></tr>
<tr><td>Literature</td><td colspan="3">• S. Thrun, W. Burgard and D. Fox: Probabilistic Robotics. MIT Press, 2005.
• B. Siciliano, O. Khatib (Eds.): Springer Handbook of Robotics, 2008.
• R. Szeliski: Computer Vision: Algorithms and Applications, Springer 2010.</td></tr>
</table>

<table>
<tr><td>Module
MA-INF 4114</td><td colspan="5">Robot Learning</td></tr>
<tr><td>Workload
180 h</td><td>Credit points
6 CP</td><td colspan="2">Duration
1 semester</td><td colspan="2">Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="5">Prof. Dr. Sven Behnke</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Prof. Dr. Sven Behnke, Dr. Nils Goerke</td></tr>
<tr><td>Classification</td><td colspan="2">Programme
M. Sc. Computer Science</td><td colspan="2">Mode
Optional</td><td>Semester
1. or 2.</td></tr>
<tr><td>Technical skills</td><td colspan="5">This lecture is one of two introductory lectures of the intelligent systems track. Creating autonomous robots that can learn to assist humans in situations of daily life is a fascinating challenge for machine learning. The lecture covers key ingredients for a general robot learning approach to get closer towards human-like performance in robotics, such as reinforcement learning, learning models for control, learning motor primitives, learning from demonstrations and imitation learning, and interactive learning.
This module complements MA-INF 4113 and can be taken before or after that module.</td></tr>
<tr><td>Soft skills</td><td colspan="5">Communicative skills (oral and written presentation of solutions, discussions in small teams), self competences (ability to accept and formulate criticism, ability to analyze problems)</td></tr>
<tr><td>Contents</td><td colspan="5">Reinforcement learning, Markov decision processes, dynamic programming, Monte Carlo methods, temporal-difference methods, function approximation, liear quadratic regulation, differential dynamic programming, partially observable MDPs, policy gradient methods, inverse reinforcement learning, imitation learning, learning kinematic models, perceiving and handling of objects.</td></tr>
<tr><td>Prerequisites</td><td colspan="5">none</td></tr>
<tr><td rowspan="4">Format</td><td>Teaching format</td><td>Group size</td><td>h/week</td><td>Workload[h]</td><td>CP</td></tr>
<tr><td>Lecture</td><td></td><td>2</td><td>30 T / 45 S</td><td>2.5</td></tr>
<tr><td>Exercises</td><td></td><td>2</td><td>30 T / 75 S</td><td>3.5</td></tr>
<tr><td colspan="5">T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="5">Written exam (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="5">Successful exercise participation (not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="5"></td></tr>
<tr><td>Literature</td><td colspan="5">• R. Sutton and A. Barto: Reinforcement Learning, MIT-Press, 1998.
• O. Sigaud and J. Peters (Eds.): From Motor Learning to Interaction Learning in Robots. Springer, 2010.</td></tr>
</table>

Module MA-INF 4115	**Introduction to Natural Language Processing**		
Workload 180 h	**Credit points** 6 CP	**Duration** 1 semester	**Frequency** every year
Module coordinator	Prof. Dr. Lucie Flek		
Lecturer(s)	Prof. Dr. Lucie Flek		
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 1. or 2.
Technical skills	This class provides a technical perspective on NLP ? methods for building computer software that understands and manipulates human language. Contemporary data-driven approaches are emphasized, focusing on machine learning techniques. The covered applications vary in complexity, including for example Entity Recognition, Argument Mining, or Emotion Analysis.		
Soft skills	Group work during programming exercises will allow students to work on real-world NLP application projects. The final project offers you the chance to apply your newly acquired skills towards an in-depth application using different frameworks such as PyTorch and spaCy and present it in a poster session.		
Contents	Through lectures, exercises, and a final project, you will gain a thorough introduction to cutting-edge research in NLP, from the linguistic basis of computational language methods to recent advances in deep learning and large language models. This course provides: • An overview of NLP goals, challenges, and applications • Text representation (Words, sentences, paragraphs, documents), word embeddings, word2vec, BERT, word similarity • Machine learning / deep learning algorithms for text classification, Transformers • Basics of neural language modeling • Basics of computational linguistics - Transforming words to their base forms (tokenization, stemming, lemmatization) - Syntactic analysis (part of speech tagging, chunking, and parsing) - Techniques for extracting meaning from text (semantic analysis), use of lexical resources in NLP • NLP applications and projects (e.g., Sentiment Analysis, Named Entity Recognition, Question Answering, Summarization, Fake news detection, Plagiarism detection, Abusive language detection, Opinion mining...)		
Prerequisites	**Recommended:** • Basics of statistics recommended. • Basic programming knowledge in Python is of advantage. • Basics of machine learning are of advantage.		

Format

Teaching format	Group size	h/week	Workload[h]	CP
Lecture		3	45 T / 45 S	3
Exercises		1	15 T / 75 S	3

T = face-to-face teaching; S = independent study

Exam achievements	Klausur (60 %); Projektarbeit (40 %) (graded)
Study achievements	Erfolgreiche Übungsteilnahme (not graded)
Forms of media	• Lecture slides • Exercise slides • Notebooks with programming examples
	• J. Eisenstein: Introduction to Natural Language Processing

<table>
<tr><td>Module
MA-INF 4116</td><td colspan="5">AI Ethics Seminar</td></tr>
<tr><td>Workload
120 h</td><td colspan="2">Credit points
4 CP</td><td>Duration
1 semester</td><td colspan="2">Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="5">Prof. Dr. Lucie Flek</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Prof. Dr. Lucie Flek</td></tr>
<tr><td>Classification</td><td colspan="3">Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
1. or 2.</td></tr>
<tr><td>Technical skills</td><td colspan="5">The seminar aims to introduce students to the ethical dilemmas of artificial intelligence. Students will develop skills in assessing AI systems, identifying ethical dilemmas and social impacts, reasoning through ethical and social issues, and communicating their reasoning.</td></tr>
<tr><td>Soft skills</td><td colspan="5">Students will learn about the design of ethical and socially responsible systems. They will gain practice engaging with multidisciplinary perspectives from behavioral and social science. At the end of the course, students will write a final term essay on one of the course topics.</td></tr>
<tr><td>Contents</td><td colspan="5">We study artificial intelligence and the ethical dilemmas associated with the research, design, deployment, and interaction with AI systems.
Six broad modules structure the seminar:
• Foundations of AI and AI ethics
• Bias & fairness
• Privacy & data privacy
• Social networks & civility of communication
• Politics & policy
• AI for “social good”
A typical lecture will consist of 2-3 student presentations that focus on a research article and the broad context of its topic.
Following each presentation, we discuss the work with a focus on assessing relevant ethical issues and potential approaches for ethical design and engineering.</td></tr>
<tr><td>Prerequisites</td><td colspan="5">Required:
No previous knowledge is required.
Recommended:
Previously attended classes in machine learning, robotics, data mining, or related, can be useful for understanding the topics but are not a must.</td></tr>
<tr><td>Format</td><td colspan="5"><table><tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr><tr><td>Seminar</td><td>10</td><td>2</td><td>30 T / 90 S</td><td>4</td></tr></table>T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="5">Schriftliche Prüfung (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="5">Erfolgreiche Übungsteilnahme (not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="5"></td></tr>
<tr><td>Literature</td><td colspan="5"></td></tr>
</table>

<table>
<tr><td>Module
MA-INF 4201</td><td colspan="3">Artificial Life</td></tr>
<tr><td>Workload
180 h</td><td>Credit points
6 CP</td><td>Duration
1 semester</td><td>Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="3">Prof. Dr. Sven Behnke</td></tr>
<tr><td>Lecturer(s)</td><td colspan="3">Prof. Dr. Sven Behnke, Dr. Nils Goerke</td></tr>
<tr><td>Classification</td><td>Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
1-3.</td></tr>
<tr><td>Technical skills</td><td colspan="3">Detailed understanding of the most important approaches and principles of artificial life. Knowledge and understanding of the current state of research in the field of artificial life</td></tr>
<tr><td>Soft skills</td><td colspan="3">Capability to identify the state of the art in artificial life, and to present and defend the found solutions within the exercises in front of a group of students. Critical discussion of the results of the homework.</td></tr>
<tr><td>Contents</td><td colspan="3">Foundations of artificial life, cellular automata, Conway’s “Game of Life”; mechanisms for structural development; foundations of nonlinear dynamical systems, Lindenmeyer-systems, evolutionary methods and genetic algorithms, reinforcement learning, artificial immune systems, adaptive behaviour, self-organising criticality, multi-agent systems, and swarm intelligence, particle swarm optimization.</td></tr>
<tr><td>Prerequisites</td><td colspan="3">none</td></tr>
<tr><td>Format</td><td colspan="3">
<table>
<tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr>
<tr><td>Lecture</td><td></td><td>2</td><td>30 T / 45 S</td><td>2.5</td></tr>
<tr><td>Exercises</td><td></td><td>2</td><td>30 T / 75 S</td><td>3.5</td></tr>
</table>
T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="3">Written exam (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="3">Successful exercise participation (not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="3">Pencil and paper work, explain solutions in front of athe exercise group, implementation of small programs, use of simple simulation tools.</td></tr>
<tr><td>Literature</td><td colspan="3">• Christoph Adami: Introduction to Artificial Life, The Electronic Library of Science, TELOS, Springer-Verlag
• Eric Bonabeau, Marco Dorigo, Guy Theraulaz: Swarm Intelligence: From Natural to Artificial Systems, Oxford University Press, Santa Fe Institute Studies in the Science of Complexity.
• Andrzej Osyczka: Evolutionary Algorithms for Single and Multicriteria Design Optimization, Studies in Fuzzyness and Soft Computing, Physica-Verlag, A Springer-Verlag Company, Heidelberg</td></tr>
</table>

<table>
<tr><td>Module
MA-INF 4203</td><td colspan="3">Autonomous Mobile Systems</td></tr>
<tr><td>Workload
180 h</td><td>Credit points
6 CP</td><td>Duration
1 semester</td><td>Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="3">Prof. Dr. Sven Behnke</td></tr>
<tr><td>Lecturer(s)</td><td colspan="3">Dr. Dirk Schulz, Prof. Dr. Sven Behnke</td></tr>
<tr><td>Classification</td><td>Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
2.</td></tr>
<tr><td>Technical skills</td><td colspan="3">Profound knowledge of development and test regarding structure and function of learning, autonomous, mobile systems; Knowledge of the computational, mathematical, and technical requirements for the design of autonomous systems for specific applications and for specific functional environments</td></tr>
<tr><td>Soft skills</td><td colspan="3">The students will be capable to assess applications for autonomous mobile systems. They will be capable to identify what part of the applications might be improved by using state of the art developments. The student will learn how to plan and implement a software project in small working groups.</td></tr>
<tr><td>Contents</td><td colspan="3">Requirements for the implementation of autonomous mobile systems, e.g. for: map making, dead reckoning, localisation, SLAM-methods, various principles of robot path planning; methods for action planning. Comparison of different learning paradigms for specific applications.</td></tr>
<tr><td>Prerequisites</td><td colspan="3">Recommended:
all of the following:
MA-INF 4101 – Theory of Sensorimotor Systems
MA-INF 4113 – Cognitive Robotics</td></tr>
<tr><td>Format</td><td colspan="3"><table>
<tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr>
<tr><td>Lecture</td><td></td><td>2</td><td>30 T / 45 S</td><td>2.5</td></tr>
<tr><td>Exercises</td><td></td><td>2</td><td>30 T / 75 S</td><td>3.5</td></tr>
</table>
T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="3">Oral exam (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="3">Successful exercise participation (not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="3"></td></tr>
<tr><td>Literature</td><td colspan="3">• J. Buchli: Mobile Robots: Moving Intelligence, Published by Advanced Robotic Systems and Pro Literatur Verlag
• Sebastian Thrun, Wolfram Burgard, Dieter Fox: Probabilistic Robotics, MIT Press, 2005
• Howie Choset et al.: Principles of Robot Motion, MIT-Press, 2005</td></tr>
</table>

Module MA-INF 4204	**Technical Neural Nets**		
Workload 180 h	**Credit points** 6 CP	**Duration** 1 semester	**Frequency** every year
Module coordinator	Prof. Dr. Joachim K. Anlauf		
Lecturer(s)	Prof. Dr. Joachim K. Anlauf, Dr. Nils Goerke		
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 1-3.
Technical skills	Detailed knowledge of the most important neural network approaches and learning algorithms and its fields of application. Knowledge and understanding of technical neural networks as Non-Von Neumann computer architectures similar to concepts of brain functions at different stages of development		
Soft skills	The students will be capable to propose several paradigms from neural networks that are capable to solve a given task. They can discuss the pro and cons with respect to efficency and risk. The will be capable to plan and implement a small project with state of the art neural network solutions.		
Contents	Multi-layer perceptron, radial-basis function nets, Hopfield nets, self organizing maps (Kohonen), adaptive resonance theory, learning vector quantization, recurrent networks, back-propagation of error, reinforcement learning, Q-learning, support vector machines, pulse processing neural networks. Exemplary applications of neural nets: function approximation, prediction, quality control, image processing, speech processing, action planning, control of technical processes and robots. Implementation of neural networks in hardware and software: tools, simulators, analog and digital neural hardware.		
Prerequisites	none		

Format

Teaching format	**Group size**	**h/week**	**Workload[h]**	**CP**
Lecture		2	30 T / 45 S	2.5
Exercises		2	30 T / 75 S	3.5

T = face-to-face teaching; S = independent study

Exam achievements	Written exam (graded)
Study achievements	Successful exercise participation (not graded)
Forms of media	
Literature	• Christopher M. Bishop: Neural Networks for Pattern Recognition, Oxford University Press, ISBN-10: 0198538642, ISBN-13: 978-0198538646 • Ian T. Nabney: NETLAB. Algoriths for Pattern Recognition, Springer, ISBN-10: 1852334401, ISBN-13: 978-1852334406

Module MA-INF 4207	**Dynamically Reconfigurable Systems**			
Workload 180 h	**Credit points** 6 CP	**Duration** 1 semester	**Frequency** at least every 2 years	
Module coordinator	Prof. Dr. Joachim K. Anlauf			
Lecturer(s)	Prof. Dr. Joachim K. Anlauf			
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 2.	
Technical skills	Knowledge of the most important FPGA architectures, ability to select appropriate FPGAs for a given application, overview of programming tools			
Soft skills	Communicative skills (oral and written presentation of solutions), social skills (ability to solve problems in small teams, discussions of solution concepts) self competences (ability to accept and formulate criticism, ability to analyze problems)			
Contents	Architecture of FPGAs, Configurable Logic Blocks, Wiring Ressources, Special Blocks, Hardware Description Languages, Synthesis, Technology Mapping, Place and Route, FPGA Computing, Partial Reconfigurability			
Prerequisites	none			
Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Lecture		2	30 T / 45 S	2.5
	Exercises		2	30 T / 75 S	3.5
	T = face-to-face teaching; S = independent study				
Exam achievements	Oral exam (graded)			
Study achievements	Successful exercise participation (not graded)			
Forms of media				
Literature	Current research papers and technical documentation			

<table>
<tr><td>Module
MA-INF 4208</td><td colspan="3">Seminar Vision Systems</td></tr>
<tr><td>Workload
120 h</td><td>Credit points
4 CP</td><td>Duration
1 semester</td><td>Frequency
every semester</td></tr>
<tr><td>Module coordinator</td><td colspan="3">Prof. Dr. Sven Behnke</td></tr>
<tr><td>Lecturer(s)</td><td colspan="3">Prof. Dr. Sven Behnke, Prof. Dr. Joachim K. Anlauf, Dr. Nils Goerke</td></tr>
<tr><td>Classification</td><td>Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
2. or 3.</td></tr>
<tr><td>Technical skills</td><td colspan="3">• Knowledge in advanced topics in the area of technical vision systems, such as image segmentation, feature extraction, and object recognition.
• Ability to understand new research results presented in original scientific papers and to present them in a research talk as well as in a seminar report.</td></tr>
<tr><td>Soft skills</td><td colspan="3">Self-competences (time management, literature search, self-study), communication skills (preparation and clear didactic presentation of research talk, scientific discussion, structured writing of seminar report), social skills (ability to formulate and accept criticism, critical examination of research results).</td></tr>
<tr><td>Contents</td><td colspan="3">Current research papers from conferences and journals in the field of vision systems covering fundamental techniques and applications.</td></tr>
<tr><td>Prerequisites</td><td colspan="3">Recommended:
At least 1 of the following:
MA-INF 4111 – Intelligent Learning and Analysis Systems: Machine Learning
MA-INF 4204 – Technical Neural Nets</td></tr>
<tr><td>Format</td><td colspan="3"><table><tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr><tr><td>Seminar</td><td>10</td><td>2</td><td>30 T / 90 S</td><td>4</td></tr></table>T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="3">Oral presentation, written report (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="3">(not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="3"></td></tr>
<tr><td>Literature</td><td colspan="3">• R. Szeliski: Computer Vision: Algorithms and Applications, Springer 2010.
• C. M. Bishop: Pattern Recognition and Machine Learning, Springer 2006.
• D. A. Forsyth and J. Ponce: Computer Vision: A Modern Approach, Prentice Hall, 2003.</td></tr>
</table>

<table>
<tr><td>Module
MA-INF 4209</td><td colspan="3">Seminar Principles of Data Mining and Learning Algorithms</td></tr>
<tr><td>Workload
120 h</td><td>Credit points
4 CP</td><td>Duration
1 semester</td><td>Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="3">Prof. Dr. Stefan Wrobel</td></tr>
<tr><td>Lecturer(s)</td><td colspan="3">Prof. Dr. Stefan Wrobel</td></tr>
<tr><td>Classification</td><td>Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
2. or 3.</td></tr>
<tr><td>Technical skills</td><td colspan="3">Enhanced and in-depth knowledge in specialized topics in the area of machine learning and data mining, acquiring the competence to independently study scientific literature, present it to others and discuss it with a knowledgeable scientific auditorium. Learn how to scientifically present prior work by others, in writing and in presentations.</td></tr>
<tr><td>Soft skills</td><td colspan="3">Communicative skills (preparing and presenting talks, written presentation of contents in a longer document), self competences (time management with long-ranging deadlines, ability to accept and formulate criticism, ability to analyse, creativity).</td></tr>
<tr><td>Contents</td><td colspan="3">Theoretical, statistical and algorithmical principles of data mining and learning algorithms. Search and optimization algorithms. Specialized learning algorithms from the frontier of research. Fundamental results from neighbouring areas.</td></tr>
<tr><td>Prerequisites</td><td colspan="3">Recommended:
At least 1 of the following:
MA-INF 4111 – Intelligent Learning and Analysis Systems: Machine Learning
MA-INF 4112 – Intelligent Learning and Analysis Systems: Data Mining and Knowledge Discovery</td></tr>
<tr><td>Format</td><td colspan="3"><table>
<tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr>
<tr><td>Seminar</td><td>10</td><td>2</td><td>30 T / 90 S</td><td>4</td></tr>
</table>
T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="3">Oral presentation, written report (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="3">(not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="3">Scientific papers and websites, interactive presentations.</td></tr>
<tr><td>Literature</td><td colspan="3">The relevant literature will be announced towards the end of the previous semester.</td></tr>
</table>

<table>
<tr><td>Module
MA-INF 4210</td><td colspan="5">Seminar Advanced Topics in Technical Informatics</td></tr>
<tr><td>Workload
120 h</td><td>Credit points
4 CP</td><td colspan="2">Duration
1 semester</td><td colspan="2">Frequency
at least every 2 years</td></tr>
<tr><td>Module coordinator</td><td colspan="5">Prof. Dr. Joachim K. Anlauf</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Prof. Dr. Joachim K. Anlauf</td></tr>
<tr><td>Classification</td><td colspan="2">Programme
M. Sc. Computer Science</td><td colspan="2">Mode
Optional</td><td>Semester
2. or 3.</td></tr>
<tr><td>Technical skills</td><td colspan="5">Current Topics in Technical Informatics</td></tr>
<tr><td>Soft skills</td><td colspan="5">Communicative skills (preparing and presenting talks, preparing a structured written document), social skills (ability to accept and formulate criticism, discussions of current content) self competences (time management with long-ranging deadlines, understanding of research topics from original literature)</td></tr>
<tr><td>Contents</td><td colspan="5">Current topics such as: new architectures of computers or FPGAs (field programmable gate arrays) or new applications of dynamically reconfigurable systems</td></tr>
<tr><td>Prerequisites</td><td colspan="5">none</td></tr>
<tr><td rowspan="3">Format</td><td>Teaching format</td><td>Group size</td><td>h/week</td><td>Workload[h]</td><td>CP</td></tr>
<tr><td>Seminar</td><td>10</td><td>2</td><td>30 T / 90 S</td><td>4</td></tr>
<tr><td colspan="5">T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="5">Oral presentation, written report (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="5">(not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="5"></td></tr>
<tr><td>Literature</td><td colspan="5">Current research papers</td></tr>
</table>

<table>
<tr><td>Module
MA-INF 4211</td><td colspan="5">Seminar Cognitive Robotics</td></tr>
<tr><td>Workload
120 h</td><td colspan="2">Credit points
4 CP</td><td colspan="2">Duration
1 semester</td><td>Frequency
every semester</td></tr>
<tr><td>Module coordinator</td><td colspan="5">Prof. Dr. Sven Behnke</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Prof. Dr. Sven Behnke, Dr. Nils Goerke</td></tr>
<tr><td>Classification</td><td colspan="3">Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
2. or 3.</td></tr>
<tr><td>Technical skills</td><td colspan="5">Knowledge in advanced topics in the area of cognitive robotics, such as robot perception, action planning, and robot learning.
Ability to understand new research results presented in original scientific papers and to present them in a research talk as well as in a seminar report.</td></tr>
<tr><td>Soft skills</td><td colspan="5">Self-competences (time management, literature search, self-study), communication skills (preparation and clear didactic presentation of research talk, scientific discussion, structured writing of seminar report), social skills (ability to formulate and accept criticism, critical examination of research results).</td></tr>
<tr><td>Contents</td><td colspan="5">Current research papers from conferences and journals in the field of cognitive robotics covering fundamental techniques and applications.</td></tr>
<tr><td>Prerequisites</td><td colspan="5">Recommended:
At least 1 of the following:
MA-INF 4113 – Cognitive Robotics
MA-INF 4114 – Robot Learning</td></tr>
<tr><td>Format</td><td colspan="5"><table><tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr><tr><td>Seminar</td><td>10</td><td>2</td><td>30 T / 90 S</td><td>4</td></tr></table>T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="5">Oral presentation, written report (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="5">(not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="5"></td></tr>
<tr><td>Literature</td><td colspan="5">• S. Thrun, W. Burgard and D. Fox: Probabilistic Robotics. MIT Press, 2005.
• B. Siciliano, O. Khatib (Eds.): Springer Handbook of Robotics, 2008.
• Selected papers.</td></tr>
</table>

<table>
<tr><td>Module
MA-INF 4213</td><td colspan="5">Seminar Humanoid Robots</td></tr>
<tr><td>Workload
120 h</td><td colspan="2">Credit points
4 CP</td><td>Duration
1 semester</td><td colspan="2">Frequency
every semester</td></tr>
<tr><td>Module coordinator</td><td colspan="5">Prof. Dr. Maren Bennewitz</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Prof. Dr. Maren Bennewitz</td></tr>
<tr><td>Classification</td><td colspan="2">Programme
M. Sc. Computer Science</td><td colspan="2">Mode
Optional</td><td>Semester
2.</td></tr>
<tr><td>Technical skills</td><td colspan="5">Knowledge in advanced topics in the area of humanoid robotics, such as environment perception, state estimation, navigation, or motion planning. Ability to understand new research results of scientific papers and to present them in a talk as well as in a self-written summary.</td></tr>
<tr><td>Soft skills</td><td colspan="5">Self-competences (time management, literature search, self-study), communication skills (preparation of the talk, clear didactic presentation of techniques and experimental results, scientific discussion, structured writing of summary), social skills (ability to formulate and accept criticism, critical examination of algorithms and experimental results).</td></tr>
<tr><td>Contents</td><td colspan="5">Current research papers from conferences and journals in the field of humanoid robotics covering fundamental techniques and applications.</td></tr>
<tr><td>Prerequisites</td><td colspan="5">Recommended:
At least 1 of the following:
MA-INF 4215 – Humanoid Robotics
MA-INF 4113 – Cognitive Robotics</td></tr>
<tr><td rowspan="3">Format</td><td>Teaching format</td><td>Group size</td><td>h/week</td><td>Workload[h]</td><td>CP</td></tr>
<tr><td>Seminar</td><td>10</td><td>2</td><td>30 T / 90 S</td><td>4</td></tr>
<tr><td colspan="5">T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="5">Oral presentation, written report (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="5">(not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="5"></td></tr>
<tr><td>Literature</td><td colspan="5">- S. Thrun, W. Burgard and D. Fox: Probabilistic Robotics. MIT Press
- B. Siciliano, O. Khatib (Eds.): Springer Handbook of Robotics
- K. Harada, E. Yoshida, K. Yokoi (Eds.), Motion Planning for Humanoid Robots, Springer
- Selected papers.</td></tr>
</table>

Module MA-INF 4214	**Lab Humanoid Robots**				
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** every semester		
Module coordinator	Prof. Dr. Maren Bennewitz				
Lecturer(s)	Prof. Dr. Maren Bennewitz				
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 2.		
Technical skills	Practical experience and in-depth knowledge in the design and implementation of perception, state estimation, environment representation, navigation, and motion planning techniques for humanoid robots. In small groups, the participants analyze a problem, realize a solution, and perform an experimental evaluation.				
Soft skills	Self-competences (time management, goal-oriented work, ability to analyze problems theoretically and to find practical solutions), communication skills (collaboration in small teams, oral and written presentation of solutions, critical examination of implementations).				
Contents	Robot middleware, perception, state estimation, environment representations, navigation, and motion planning for humanoid robots.				
Prerequisites	**Recommended:** At least 1 of the following: MA-INF 4215 – Humanoid Robotics MA-INF 4113 – Cognitive Robotics				
Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Lab	8	4	60 T / 210 S	9
	T = face-to-face teaching; S = independent study				
Exam achievements	Oral presentation, written report (graded)				
Study achievements	(not graded)				
Forms of media					
Literature	- S. Thrun, W. Burgard and D. Fox: Probabilistic Robotics. MIT Press - B. Siciliano, O. Khatib (Eds.): Springer Handbook of Robotics - K. Harada, E. Yoshida, K. Yokoi (Eds.), Motion Planning for Humanoid Robots, Springer - Selected papers.				

<table>
<tr><td>Module
MA-INF 4215</td><td colspan="4">Humanoid Robotics</td></tr>
<tr><td>Workload
180 h</td><td>Credit points
6 CP</td><td>Duration
1 semester</td><td colspan="2">Frequency
at least every 2 years</td></tr>
<tr><td>Module coordinator</td><td colspan="4">Prof. Dr. Maren Bennewitz</td></tr>
<tr><td>Lecturer(s)</td><td colspan="4">Prof. Dr. Maren Bennewitz</td></tr>
<tr><td>Classification</td><td colspan="2">Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
2-3.</td></tr>
<tr><td>Technical skills</td><td colspan="4">This lecture covers techniques for humanoid robots such as perception, navigation, and motion planning.</td></tr>
<tr><td>Soft skills</td><td colspan="4">Communicative skills (oral and written presentation of solutions, discussions in small teams), ability to analyze problems.</td></tr>
<tr><td>Contents</td><td colspan="4">Self-calibration with least squares, 3D environment representations, self-localization with particle filters, footstep planning, inverse kinematics, whole-body motion planning with rapidly exploring random trees, statistical testing.</td></tr>
<tr><td>Prerequisites</td><td colspan="4">Recommended:
MA-INF 4113 – Cognitive Robotics</td></tr>
<tr><td>Format</td><td colspan="4">
<table>
<tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr>
<tr><td>Lecture</td><td></td><td>2</td><td>30 T / 45 S</td><td>2.5</td></tr>
<tr><td>Exercises</td><td></td><td>2</td><td>30 T / 75 S</td><td>3.5</td></tr>
</table>
T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="4">Oral exam (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="4">Successful exercise participation (not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="4"></td></tr>
<tr><td>Literature</td><td colspan="4">• S. Thrun, W. Burgard and D. Fox: Probabilistic Robotics. MIT Press, 2005.
• B. Siciliano, O. Khatib (Eds.): Springer Handbook of Robotics
• K. Harada, E. Yoshida, K. Yokoi (Eds.), Motion Planning for Humanoid Robots, Springer
• Selected research papers.</td></tr>
</table>

<table>
<tr><td>Module
MA-INF 4216</td><td colspan="3">Biomedical Data Science \&{} AI</td></tr>
<tr><td>Workload
180 h</td><td>Credit points
6 CP</td><td>Duration
1 semester</td><td>Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="3">Dr. Holger Fröhlich</td></tr>
<tr><td>Lecturer(s)</td><td colspan="3">Dr. Holger Fröhlich</td></tr>
<tr><td>Classification</td><td>Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
3.</td></tr>
<tr><td>Technical skills</td><td colspan="3">- understanding and knowledge of fundamental data mining and machine learning methods
- understanding of their application in bioinformatics</td></tr>
<tr><td>Soft skills</td><td colspan="3">- communication: oral and written presentation of solutions to exercises
- self-competences: ability to analyze application problems and to formulate possible solutions
- practical skills: ability to practically implement solutions
- social skills: working in a small team with other students</td></tr>
<tr><td>Contents</td><td colspan="3">This lecture gives a broad overview about frequently used statistical techniques as well as data mining and machine learning algorithms. The use of the respective methods to solve problems in bioinformatics is explained. The goal is to understand the explained methods, being able to apply them correctly and partially implement them. More detailed, the following topics are covered in the context of their application in bioinformatics:
- Short introduction to Bioinformatics and Biomedicine
- Statistical Basics: Probability distributions and Bayesian inference, statistical hypothesis testing, linear models, logistic regression, Principal Component Analysis
- Clustering
- Hidden Markov Models
- Principles of Supervised Machine Learning
- Elastic Net
- Basics of deep learning</td></tr>
<tr><td>Prerequisites</td><td colspan="3">none</td></tr>
<tr><td>Format</td><td colspan="3">
<table>
<tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr>
<tr><td>Lecture</td><td></td><td>2</td><td>30 T / 45 S</td><td>2.5</td></tr>
<tr><td>Exercises</td><td></td><td>2</td><td>30 T / 75 S</td><td>3.5</td></tr>
</table>
T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="3">Written exam (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="3">Successful exercise participation (not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="3"></td></tr>
<tr><td>Literature</td><td colspan="3">T. Hastie, R. Tibshirani, J. Friedman, The Elements of Statistical Learning, Springer, 2008
S.Boslaugh, P. Watters, Statistics in a Nutshell, O’Reilly, 2008
N. Jones, P. Pevzner, An Introduction to Bioinformatics Algorithms, MIT Press, 2004</td></tr>
</table>

<table>
<tr><td>Module
MA-INF 4217</td><td colspan="5">Seminar Machine Learning Methods in the Life Sciences</td></tr>
<tr><td>Workload
120 h</td><td>Credit points
4 CP</td><td>Duration
1 semester</td><td colspan="3">Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="5">Dr. Holger Fröhlich</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Dr. Holger Fröhlich</td></tr>
<tr><td>Classification</td><td colspan="2">Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td colspan="2">Semester
4.</td></tr>
<tr><td>Technical skills</td><td colspan="5">- understanding and knowledge of machine learning methods and their application in modern life sciences, e.g. biomedicine</td></tr>
<tr><td>Soft skills</td><td colspan="5">- communication: oral scientific presentation of a defined topic
- self-competences: ability to identify relevant literature for a given topic; ability to read, understand and analyze scientific publications
- social skills: ability to discuss a scientific topic with other students and the staff</td></tr>
<tr><td>Contents</td><td colspan="5">Machine learning techniques play a crucial role in modern life sciences, including biomedicine. The goal of this seminar is to discuss a variety of machine learning techniques in the context of their application to solve real-world problems in biomedicine.
Topics will be selected from the following areas:
- Ensemble learning
- Survival and disease progression models
- Bayesian Networks
- Stochastic processes, e.g. Gaussian Proceses, Dirichlet Process Mixture Models
- MCMC methods
- Deep learning methods, e.g. DNNs, CNNs, Deep Belief Networks
- feature selection and non-linear embedding methods
- multi-modal data fusion techniques
Attendees will be asked to perform research about their topic in a self-responsible manner.</td></tr>
<tr><td>Prerequisites</td><td colspan="5">Recommended:
MA-INF 4216 – Data Mining and Machine Learning Methods in Bioinformatics</td></tr>
<tr><td rowspan="3">Format</td><td>Teaching format</td><td>Group size</td><td>h/week</td><td>Workload[h]</td><td>CP</td></tr>
<tr><td>Seminar</td><td>10</td><td>2</td><td>30 T / 90 S</td><td>4</td></tr>
<tr><td colspan="5">T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="5">Oral presentation, written report (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="5">(not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="5">powerpoint</td></tr>
<tr><td>Literature</td><td colspan="5">selected journal and conference papers</td></tr>
</table>

Module MA-INF 4226	**Lab Parallel Computing for Mobile Robotics**
Workload 270 h	**Credit points** 9 CP; **Duration** 1 semester; **Frequency** at least every 2 years
Module coordinator	Prof. Dr. Maren Bennewitz
Lecturer(s)	Prof. Dr. Maren Bennewitz
Classification	**Programme** M. Sc. Computer Science; **Mode** Optional; **Semester** 2.
Technical skills	Students will make practical experience with the design and implementation of parallelized algorithms in the context of motion planning and navigation.
Soft skills	Ability to properly present and defend design decisions, to prepare readable documentation of software; skills in constructively collaborating with others in small teams over a longer period of time; ability to classify ones own results into the state-of-the-art of the resp. area
Contents	Parallel programming on the GPU, CUDA, shortest path planning, collision checking, visibility graph, A* algorithm
Prerequisites	**Recommended:** C++, Linux. Since the exercises revolve around path planning, one of those courses might be helpful: MA-INF 4203: Autonomous Mobile Systems MA-INF 4113: Cognitive Robotics MA-INF 4310: Lab Mobile Robots
Format	see below
Exam achievements	Oral presentation, written report (graded)
Study achievements	(not graded)
Forms of media	
Literature	

Format:

Teaching format	Group size	h/week	Workload[h]	CP
Lab	8	4	60 T / 210 S	9

T = face-to-face teaching; S = independent study

Module MA-INF 4228	**Foundations of Data Science**
Workload 270 h	**Credit points** 9 CP · **Duration** 1 semester · **Frequency** every year
Module coordinator	Dr. Michael Nüsken
Lecturer(s)	Dr. Michael Nüsken
Classification	**Programme** M. Sc. Computer Science · **Mode** Optional · **Semester** 2. or 3.
Technical skills	Knowledge: Peculiarities of high dimensional spaces in geometry and probabilities. Singular vector decomposition. Basics in machine learning and clustering. Skills: Understanding of mathematical tools.
Soft skills	Competences: Application to data science problems and ability to assess similar methods.
Contents	Data science aims at making sense of big data. To that end, various tools have to be understood for helping in analyzing the arising structures. Often data comes as a collection of vectors with a large number of components. To understand their common structure is the first main objective of understanding the data. The geometry and the linear algebra behind them becomes relevant and enlightning. Yet, the intuition from low-dimensional space turns out to be often misleading. We need to be aware of the particular properties of high-dimensional spaces when working with such data. Fruitful methods for the analysis include singular vector decomposition from linear algebra and supervised and unsupervised machine learning. If time permits, we also consider random graphs, which are the second most used model for real world phenomena.
Prerequisites	none
Format	see below
Exam achievements	Schriftliche Prüfung (graded)
Study achievements	Erfolgreiche Übungsteilnahme (not graded)
Forms of media	
Literature	Avrim Blum, John Hopcroft, and Ravindran Kannan (2018+). Foundations of Data Science.

Format

Teaching format	**Group size**	**h/week**	**Workload[h]**	**CP**
Lecture		4	60 T / 105 S	5.5
Exercises		2	30 T / 75 S	3.5

T = face-to-face teaching; S = independent study

Module MA-INF 4229	**Pattern Recognition I**
Workload 270 h	**Credit points** 9 CP · **Duration** 1 semester · **Frequency** every year
Module coordinator	Prof. Dr. Christian Bauckhage
Lecturer(s)	Prof. Dr. Christian Bauckhage
Classification	**Programme** M. Sc. Computer Science · **Mode** Optional · **Semester** 2.
Technical skills	Upon completion, students should be able to • devise mathematical models for problems in data analysis, clustering, and classification • implement basic and advanced algorithms for model fitting and optimization • implement basic and advanced algorithms for data clustering and classification • implement basic and advanced algorithms for pattern recognition
Soft skills	Students will learn about the mathematical and algorithmic foundations of machine learning for pattern recognition. They will learn about basic and advanced mathematical models in this area, how to implement them on their own, and how to put them into practice.
Contents	• fundamental concepts, prerequisites, and procedures in pattern recognition • basic and advanced concepts in linear algebra • basic and advanced concepts in probability theory and statistics • least squares techniques for model fitting • maximum likelihood techniques • maximum a-posteriori techniques • Bayesian inference methods • fundamental aspects of learning theory and the VC dimension • the curse of dimensionality • methods and algorithms for data clustering • Gaussian mixture models • the method of Lagrange multipliers and the KKT conditions • quadratic and linear discriminant analysis • algorithms for constrained optimization • support vector machines • the kernel trick • neural networks • Hebbian learning
Prerequisites	**Recommended:** Students should good working knowledge in linear algebra, probability theory, and statistics as well as programming experience.
Format	see below
Exam achievements	Schriftliche Prüfung (graded)
Study achievements	Erfolgreiche Übungsteilnahme (not graded)
Forms of media	• lecture slides are made available online • lecture notes with programming examples are made available online
Literature	Bishop, "Pattern Recognition and Machine Learning" Duda, Stork, Hart, "Pattern Classification" MacKay, "Information Theory, Inference, and Learning Algorithms"

Format:

Teaching format	Group size	h/week	Workload[h]	CP
Lecture		4	60 T / 105 S	5.5
Exercises		2	30 T / 75 S	3.5

T = face-to-face teaching; S = independent study

<table>
<tr><td>Module
MA-INF 4230</td><td colspan="3">Advanced Methods of Information Retrieval</td></tr>
<tr><td>Workload
180 h</td><td>Credit points
6 CP</td><td>Duration
1 semester</td><td>Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="3">Prof. Dr. Elena Demidova</td></tr>
<tr><td>Lecturer(s)</td><td colspan="3">Prof. Dr. Elena Demidova</td></tr>
<tr><td>Classification</td><td colspan="3"><table><tr><td>Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
2. or 3.</td></tr></table></td></tr>
<tr><td>Technical skills</td><td colspan="3">This module introduces the students to the advanced methods, data structures, and algorithms of information retrieval for structured and semi-structured data (including, for example, knowledge graphs, relational data, and tabular data).
At the end of the module, the students will be capable of choosing appropriate data structures and retrieval algorithms for specific applications and correctly apply relevant statistical and machine learning-based information retrieval procedures.</td></tr>
<tr><td>Soft skills</td><td colspan="3">Communication skills: oral and written presentation and discussion of solutions.
Self-competences: ability to analyse and solve problems.</td></tr>
<tr><td>Contents</td><td colspan="3">The module topics include data structures, ranking methods, and efficient algorithms that enable end-users to effectively obtain the most relevant search results from structured, heterogeneous, and distributed data sources. Furthermore, we will study the corresponding evaluation techniques as well as novel applications.</td></tr>
<tr><td>Prerequisites</td><td colspan="3">none</td></tr>
<tr><td>Format</td><td colspan="3"><table><tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr><tr><td>Lecture</td><td></td><td>2</td><td>30 T / 45 S</td><td>2.5</td></tr><tr><td>Exercises</td><td></td><td>2</td><td>30 T / 75 S</td><td>3.5</td></tr></table>T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="3">Schriftliche Prüfung (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="3">Erfolgreiche Übungsteilnahme (not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="3"></td></tr>
<tr><td>Literature</td><td colspan="3">Selected chapters from:
• Christopher D. Manning, Prabhakar Raghavan and Hinrich Schütze, Introduction to Information Retrieval, Cambridge University Press. 2008.
• Bhaskar Mitra and Nick Craswell (2018), "An Introduction to Neural Information Retrieval ", Foundations and Trendső in Information Retrieval: Vol. 13: No. 1, pp 1-126.
- Ridho Reinanda, Edgar Meij and Maarten de Rijke (2020), "Knowledge Graphs: An Information Retrieval Perspective", Foundations and Trendső in Information Retrieval: Vol. 14: No. 4, pp 289-444.
- Jeffrey Xu Yu, Lu Qin, Lijun Chang. Keyword Search in Databases. Synthesis Lectures on Data Management. Morgan & Claypool Publishers. 2009.
Further references to relevant material will be provided during the lecture.</td></tr>
</table>

<table>
<tr><td>Module
MA-INF 4231</td><td colspan="5">Seminar Advanced Topics in Information Retrieval</td></tr>
<tr><td>Workload
120 h</td><td>Credit points
4 CP</td><td colspan="2">Duration
1 semester</td><td colspan="2">Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="5">Prof. Dr. Elena Demidova</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Prof. Dr. Elena Demidova</td></tr>
<tr><td>Classification</td><td colspan="2">Programme
M. Sc. Computer Science</td><td colspan="2">Mode
Optional</td><td>Semester
2. or 3.</td></tr>
<tr><td>Technical skills</td><td colspan="5">This module concentrates on specialized topics in information retrieval. The students obtain skills in the independent, in-depth study of state-of-the-art scientific literature on specific topics, discussion with their peers and presentation to the scientific audience.</td></tr>
<tr><td>Soft skills</td><td colspan="5">Communication skills: oral and written presentation of scientific content. Self-competences: the ability to analyze problems, time management, creativity.</td></tr>
<tr><td>Contents</td><td colspan="5">Statistical and machine learning-based information retrieval methods, including typical steps of the information retrieval process: data collection, feature extraction, indexing, retrieval, ranking, and evaluation. Specialized data representation and retrieval methods for selected data types and applications in specific domains.</td></tr>
<tr><td>Prerequisites</td><td colspan="5">Recommended:
MA-INF 4230 - Advanced Methods of Information Retrieval</td></tr>
<tr><td>Format</td><td colspan="5"><table><tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr><tr><td>Seminar</td><td>10</td><td>2</td><td>30 T / 90 S</td><td>4</td></tr></table>T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="5">Oral presentation, written report (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="5">None (not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="5"></td></tr>
<tr><td>Literature</td><td colspan="5">Selected chapters from:
• Christopher D. Manning, Prabhakar Raghavan and Hinrich Schütze, Introduction to Information Retrieval, Cambridge University Press. 2008.
• Bhaskar Mitra and Nick Craswell (2018), "An Introduction to Neural Information Retrieval ", Foundations and Trendső in Information Retrieval: Vol. 13: No. 1, pp 1-126.
Further relevant literature will be announced at the beginning of the seminar.</td></tr>
</table>

<table>
<tr><td>Module
MA-INF 4232</td><td colspan="3">Lab Information Retrieval in Practice</td></tr>
<tr><td>Workload
270 h</td><td>Credit points
9 CP</td><td>Duration
1 semester</td><td>Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="3">Prof. Dr. Elena Demidova</td></tr>
<tr><td>Lecturer(s)</td><td colspan="3">Prof. Dr. Elena Demidova</td></tr>
<tr><td>Classification</td><td>Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
2. or 3.</td></tr>
<tr><td>Technical skills</td><td colspan="3">This module concentrates on practical experience in information retrieval. Participants acquire basic knowledge and practical experience in designing and implementing information retrieval systems for specific data types and applications.</td></tr>
<tr><td>Soft skills</td><td colspan="3">Communication skills: the ability to work in teams.
Self-competences: the ability to analyse problems and find practical solutions. Time management, creativity, presentation of results.</td></tr>
<tr><td>Contents</td><td colspan="3">Practical application of information retrieval methods to solve retrieval problems on real-world data and evaluate proposed solutions.</td></tr>
<tr><td>Prerequisites</td><td colspan="3">Recommended:
MA-INF 4230 - Advanced Methods of Information Retrieval
MA-INF 4231 - Seminar Advanced Topics in Information Retrieval</td></tr>
<tr><td>Format</td><td colspan="3"><table><tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr><tr><td>Lab</td><td>8</td><td>4</td><td>60 T / 210 S</td><td>9</td></tr></table>T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="3">Oral presentation, written report (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="3">None (not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="3"></td></tr>
<tr><td>Literature</td><td colspan="3">Selected chapters from:
• Christopher D. Manning, Prabhakar Raghavan and Hinrich Schütze, Introduction to Information Retrieval, Cambridge University Press. 2008.
• Bhaskar Mitra and Nick Craswell (2018), "An Introduction to Neural Information Retrieval ", Foundations and Trendső in Information Retrieval: Vol. 13: No. 1, pp 1-126.
Further references to relevant material will be provided during the lab.</td></tr>
</table>

Module MA-INF 4302	**Advanced Learning Systems**				
Workload 180 h	**Credit points** 6 CP	**Duration** 1 semester	**Frequency** every 2 years		
Module coordinator	Prof. Dr. Stefan Wrobel				
Lecturer(s)	Prof. Dr. Stefan Wrobel				
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 2. or 3.		
Technical skills	Participants specialize and require in-depth knowledge of one particular class of learning algorithms, they acquire the necessary knowledge to improve existing algorithms and construct their own within the given class, all the way up to the research frontier on the topic.				
Soft skills	In group work, students acquire the necessary social and communication skills for effective team work and project planning, and learn how to present software projects to others.				
Contents	The module each time concentrates on one or more specific algorithm classes, e.g. • kernel machines • neural networks • probabilistic and statistical learning approaches • logic-based learning approaches • reinforcement learning				
Prerequisites	**Recommended:** all of the following: MA-INF 4111 – Intelligent Learning and Analysis Systems: Machine Learning MA-INF 4112 – Intelligent Learning and Analysis Systems: Data Mining and Knowledge Discovery				
Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Lecture		2	30 T / 45 S	2.5
	Exercises		2	30 T / 75 S	3.5
	T = face-to-face teaching; S = independent study				
Exam achievements	Written exam (graded)				
Study achievements	Successful exercise participation (not graded)				
Forms of media	lectures, exercises, software systems				
Literature	• B. Schoelkopf, A.J. Smola, Learning with Kernels, The MIT Press, 2002, Cambridge, MA • John Shawe-Taylor, Nello Christianini, Kernel Methods for Pattern Analysis, CUP, 2004 • Christopher Bishop, Pattern Recognition and Machine Learning, The University of Edinburgh, 2006 • David MacKay, Information Theory, Inference, and Learning Algorithms, 2003 • Richard Duda, Peter Hart, David Stork, Pattern Classification, John Wiley and Sons, 2001				

Module MA-INF 4303	**Learning from Non-Standard Data**		
Workload 180 h	**Credit points** 6 CP	**Duration** 1 semester	**Frequency** every year
Module coordinator	Prof. Dr. Stefan Wrobel		
Lecturer(s)	Prof. Dr. Stefan Wrobel, Dr. Tamas Horvath		
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 2. or 3.
Technical skills	Participants deepen their knowledge of learning systems with respect to one particular non-standard data type, i.e., non-tabular data, as they are becoming increasingly important in many applications. Each type of data not only requires specialized algorithms but also knowledge of the surrounding pre- and postprocessing operations which is acquired by the participants in the module. In group work, students acquire the necessary social and communication skills for effective team work and project planning, and learn how to present software projects to others.		
Soft skills	Communicative skills (oral and written presentation of solutions, discussions in teams), self-competences (ability to accept and formulate criticism, ability to analyse, creativity in the context of an "open end" task)		
Contents	The module will offered every year, concentrating on one particular non-standard data type each time, including: Text Mining, Multimedia Mining, Graph Mining. Learning from structured data, Spatial Data Mining		
Prerequisites	**Recommended:** all of the following: MA-INF 4111 – Intelligent Learning and Analysis Systems: Machine Learning MA-INF 4112 – Intelligent Learning and Analysis Systems: Data Mining and Knowledge Discovery		

Format

Teaching format	**Group size**	**h/week**	**Workload[h]**	**CP**
Lecture		2	30 T / 45 S	2.5
Exercises		2	30 T / 75 S	3.5

T = face-to-face teaching; S = independent study

Exam achievements	Written exam (graded)
Study achievements	Successful exercise participation (not graded)
Forms of media	lectures, exercises, software systems.
Literature	• Gennady Andrienko, Natalia Andrienko, Exploratory Analysis of Spatial and Temporal Data, Springer, 2006 • Diane J. Cook, Lawrence B. Holder, Mining Graph Data, Wiley & Sons, 2006 • Saso Dzeroski, Nada Lavrac, Relational Data Mining, Springer, 2001 • Sholom M. Weiss, Nitin Indurkhya, Tong Zhang, Fred J. Damerau, Text Mining. Predictive Methods for Analyzing Unstructured Information, Springer, 2004

<table>
<tr><td>Module
MA-INF 4304</td><td colspan="5">Lab Cognitive Robotics</td></tr>
<tr><td>Workload
270 h</td><td colspan="2">Credit points
9 CP</td><td colspan="2">Duration
1 semester</td><td>Frequency
every semester</td></tr>
<tr><td>Module coordinator</td><td colspan="5">Prof. Dr. Sven Behnke</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Prof. Dr. Sven Behnke</td></tr>
<tr><td>Classification</td><td colspan="3">Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
2. or 3.</td></tr>
<tr><td>Technical skills</td><td colspan="5">Participants acquire practical experience and in-depth knowledge in the design and implementation of perception and control algorithms for complex robotic systems. In a small group, they analyze a problem, realize a state-of-the-art solution, and evaluate its performance.</td></tr>
<tr><td>Soft skills</td><td colspan="5">Self-competences (time management, goal-oriented work, ability to analyze problems and to find practical solutions), communication skills (Work together in small teams, oral and written presentation of solutions, critical examination of implementations)</td></tr>
<tr><td>Contents</td><td colspan="5">Robot middleware (ROS), simultaneous localization and mapping (SLAM), 3D representations of objects and environments, object detection and recognition, person detection and tracking, action recognition, action planning and control, mobile manipulation, human-robot interaction.</td></tr>
<tr><td>Prerequisites</td><td colspan="5">Recommended:
At least 1 of the following:
MA-INF 4113 – Cognitive Robotics
MA-INF 4114 – Robot Learning</td></tr>
<tr><td>Format</td><td colspan="5"><table><tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr><tr><td>Lab</td><td>8</td><td>4</td><td>60 T / 210 S</td><td>9</td></tr></table>T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="5">Oral presentation, written report (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="5">(not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="5"></td></tr>
<tr><td>Literature</td><td colspan="5">• S. Thrun, W. Burgard and D. Fox: Probabilistic Robotics. MIT Press, 2005.
• B. Siciliano, O. Khatib (Eds.): Springer Handbook of Robotics, 2008.
• Selected research papers.</td></tr>
</table>

<table>
<tr><td>Module
MA-INF 4306</td><td colspan="5">Lab Development and Application of Data Mining and Learning Systems</td></tr>
<tr><td>Workload
270 h</td><td colspan="2">Credit points
9 CP</td><td colspan="2">Duration
1 semester</td><td>Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="5">Prof. Dr. Stefan Wrobel</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Prof. Dr. Stefan Wrobel</td></tr>
<tr><td>Classification</td><td colspan="3">Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
3.</td></tr>
<tr><td>Technical skills</td><td colspan="5">Students will acquire in-depth knowledge in the construction and development of intelligent learning systems for machine learning and data mining. They learn how to work with existing state-of-the-art systems and apply them to application problems, usually extending them for the requirements of their particular task.</td></tr>
<tr><td>Soft skills</td><td colspan="5">Communicative skills (appropriate oral presentation and written documentation of project results), social skills (ability to work in teams), self-competences (time management, aiming at long-range goals under limited ressources, ability to work under pressure, ability to accept/formulate ciriticsm)</td></tr>
<tr><td>Contents</td><td colspan="5">Data storage and process models of data analysis. Common open source frameworks for the construction of data analysis systems, specialized statistical packages. Pre-processing tools. Mathematical libraries for numerical computation. Search and optimization methods. User interfaces and visualization for analysis systems. Data analysis algorithms for embedded and distributed systems. Ubiquitous discovery systems.</td></tr>
<tr><td>Prerequisites</td><td colspan="5">Recommended:
At least 1 of the following:
MA-INF 4111 – Intelligent Learning and Analysis Systems: Machine Learning
MA-INF 4112 – Intelligent Learning and Analysis Systems: Data Mining and Knowledge Discovery</td></tr>
<tr><td rowspan="3">Format</td><td>Teaching format</td><td>Group size</td><td>h/week</td><td>Workload[h]</td><td>CP</td></tr>
<tr><td>Lab</td><td>8</td><td>4</td><td>60 T / 210 S</td><td>9</td></tr>
<tr><td colspan="5">T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="5">Oral presentation, written report (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="5">(not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="5">Computer Software, Documentation, Research Papers.</td></tr>
<tr><td>Literature</td><td colspan="5">The relevant literature will be announced towards the end of the previous semester.</td></tr>
</table>

Module MA-INF 4307	**Lab Field Programmable Gate Arrays**				
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** at least every 2 years		
Module coordinator	Prof. Dr. Joachim K. Anlauf				
Lecturer(s)	Prof. Dr. Joachim K. Anlauf				
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 2. or 3.		
Technical skills	Development and simulation of digital circuits in VHDL and SystemC, experience with synthesizable subsets, knowledge of the design path from the idea to a realized circuit implemented in an FPGA (field programmable gate array)				
Soft skills	Communicative skills (oral and written presentation of results), social skills (ability to cooperate in small teams, discussions of solution concepts) self competences (ability to accept and formulate criticism, ability to analyze and find practical solutions to problems)				
Contents	VHDL for Hardware Description, Simulation, and Synthesis, SystemC for Hardware Description, Simulation, and Synthesis, Synthesizable Subsets, Test of Implementations on FPGA Evaluation Boards				
Prerequisites	**Recommended:** MA-INF 4207 - Dynamically Reconfigurable Systems				
Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Lab	8	4	60 T / 210 S	9
	T = face-to-face teaching; S = independent study				
Exam achievements	Oral presentation, written report (graded)				
Study achievements	(not graded)				
Forms of media					
Literature	Technical documentation				

<table>
<tr><td>Module
MA-INF 4308</td><td>Lab Vision Systems</td></tr>
<tr><td>Workload
270 h</td><td><table><tr><td>Credit points
9 CP</td><td>Duration
1 semester</td><td>Frequency
every semester</td></tr></table></td></tr>
<tr><td>Module coordinator</td><td>Prof. Dr. Sven Behnke</td></tr>
<tr><td>Lecturer(s)</td><td>Dr. Nils Goerke</td></tr>
<tr><td>Classification</td><td><table><tr><td>Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
3.</td></tr></table></td></tr>
<tr><td>Technical skills</td><td>Students will acquire knowledge of the design and implementation of parallel algorithms on GPUs. They will apply these techniques to accelerate standard machine learning algorithms for data-intensive computer vision tasks.</td></tr>
<tr><td>Soft skills</td><td>Self-competences (time management, goal-oriented work, ability to analyze problems and to find practical solutions), communication skills (Work together in small teams, oral and written presentation of solutions, critical examination of implementations)</td></tr>
<tr><td>Contents</td><td>Basic matrix and vector computations with GPUs (CUDA). Classification algorithms, such as multi-layer perceptrons, support-vector machines, k-nearest neighbors, linear-discriminant analysis. Image preprocessing and data handling. Quantitative performance evaluation of learning algorithms for segmentation and categorization.</td></tr>
<tr><td>Prerequisites</td><td>Recommended:
At least 1 of the following:
MA-INF 4111 – Intelligent Learning and Analysis Systems: Machine Learning
MA-INF 4204 – Technical Neural Nets</td></tr>
<tr><td>Format</td><td><table><tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr><tr><td>Lab</td><td>8</td><td>4</td><td>60 T / 210 S</td><td>9</td></tr></table>T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td>Oral presentation, written report (graded)</td></tr>
<tr><td>Study achievements</td><td>(not graded)</td></tr>
<tr><td>Forms of media</td><td></td></tr>
<tr><td>Literature</td><td>• R. Szeliski: Computer Vision: Algorithms and Applications, Springer 2010.
• C. M. Bishop: Pattern Recognition and Machine Learning, Springer 2006.
• NVidia CUDA Programming Guide, Version 4.0, 2011.</td></tr>
</table>

Module MA-INF 4309	**Lab Sensor Data Interpretation**				
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** at least every 2 years		
Module coordinator	PD. Dr. Volker Steinhage				
Lecturer(s)	PD. Dr. Volker Steinhage				
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 2. or 3.		
Technical skills	Competence to implement algorithms for sensor data interpretation, efficient handling and testing, documentation.				
Soft skills	Efficient implementation of complex algorithms, abstract thinking, documentation of source code.				
Contents	Varying selected up-to-date topics on sensor data interpretation				
Prerequisites	**Required:** All of the following: MA-INF 2201 – Computer Vision MA-INF 4206 – Selected Topics in Sensor Data Interpretation				
Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Lab	8	4	60 T / 210 S	9
	T = face-to-face teaching; S = independent study				
Exam achievements	Oral presentation, written report (graded)				
Study achievements	(not graded)				
Forms of media					
Literature	Relevant literature will be announced at start of the lab.				

Module MA-INF 4310	**Lab Mobile Robots**			
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** at least every year	
Module coordinator	Prof. Dr. Sven Behnke			
Lecturer(s)	Prof. Dr. Sven Behnke, Dr. Nils Goerke			
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 2. or 3.	
Technical skills	Participants acquire basic knowledge and practical experience in the design and implementation of control algorithms for simple structured robotic systems using real mobile robots. Fundamental paradigms for mobile robots will be identified and implemented in 2 person groups.			
Soft skills	Self-competences (time management, goal-oriented work, ability to analyze problems and to find practical solutions), communication skills (Work together in small teams, oral and written presentation of solutions, critical examination of implementations)			
Contents	Robot middleware (e.g. ROS), robot simulation tools, basic capabilities for mobile robots: reactive control, SMPA architecture, navigation, path planning, localisation, simultaneous localization and mapping (SLAM), visual based object detection, learning robot control.			
Prerequisites	**Recommended:** At least 1 of the following: BA-INF 132 – Grundlagen der Robotik BA-INF 131 – Intelligente Sehsysteme MA-INF 1314 – Online Motion Planning MA-INF 2201 – Computer Vision MA-INF 4113 – Cognitive Robotics MA-INF 4114 – Robot Learning MA-INF 4203 – Autonomous Mobile Systems			
Format	**Teaching format**: Lab **Group size**: 8 **h/week**: 4 **Workload[h]**: 60 T / 210 S **CP**: 9 T = face-to-face teaching; S = independent study			
Exam achievements	Oral presentation, written report (graded)			
Study achievements	(not graded)			
Forms of media	Robots simulation environments, robot control middleware, computer vision libraries, programming, demonstration of robot capabilities (real robotic systems), presentation and written report of approach and results.			
Literature	• S. Thrun, W. Burgard and D. Fox: Probabilistic Robotics. MIT Press, 2005. • J. Buchli: Mobile Robots: Moving Intelligence, Published by Advanced Robotic Systems and Pro Literatur Verlag • B. Siciliano, O. Khatib (Eds.): Springer Handbook of Robotics, 2008. • Additional State-of-the-art publications.			

<table>
<tr><td>Module
MA-INF 4312</td><td colspan="3">Semantic Data Web Technologies</td></tr>
<tr><td>Workload
180 h</td><td>Credit points
6 CP</td><td>Duration
1 semester</td><td>Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="3">Prof. Dr. Jens Lehmann</td></tr>
<tr><td>Lecturer(s)</td><td colspan="3">Prof. Dr. Jens Lehmann, Dr. Christoph Lange,
Dr. Maria Maleschkova</td></tr>
<tr><td>Classification</td><td>Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
1.</td></tr>
<tr><td>Technical skills</td><td colspan="3">The goal of this lecture is to impart knowledge on the fundamentals, technologies and applications of the Semantic Web and information retrieval. As part of the lecture the basic concepts and standards for semantic technologies are explained.</td></tr>
<tr><td>Soft skills</td><td colspan="3"></td></tr>
<tr><td>Contents</td><td colspan="3">As part of the W3C Semantic Web initiative standards and technologies have been developed for machine-readable exchange of data, information and knowledge on the Web. These standards and technologies are increasingly being used in applications and have already led to a number of exciting projects (e.g. DBpedia, semantic wiki or commercial applications such as schema.org, OpenCalais, or Google's Freebase). The module provides a theoretically grounded and practically oriented introduction to this area. The topics discussed within the lecture include:
• RDF syntax and data model
• RDF Schema and formal semantics of RDF (S)
• ontologies in OWL and formal semantics of OWL
• RDF databases, triple and knowledge stores, query languages
• Linked Data Web and Semantic Web applications
• Semantic text analysis and information retrieval systems</td></tr>
<tr><td>Prerequisites</td><td colspan="3">none</td></tr>
<tr><td>Format</td><td colspan="3"><table>
<tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr>
<tr><td>Lecture</td><td></td><td>2</td><td>30 T / 45 S</td><td>2.5</td></tr>
<tr><td>Exercises</td><td></td><td>2</td><td>30 T / 75 S</td><td>3.5</td></tr>
</table>
T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="3">Written exam (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="3">Successful exercise participation (not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="3"></td></tr>
<tr><td>Literature</td><td colspan="3"></td></tr>
</table>

<table>
<tr><td>Module
MA-INF 4313</td><td colspan="5">Seminar Semantic Data Web Technologies</td></tr>
<tr><td>Workload
120 h</td><td>Credit points
4 CP</td><td colspan="2">Duration
1 semester</td><td colspan="2">Frequency
at least every year</td></tr>
<tr><td>Module coordinator</td><td colspan="5">Prof. Dr. Jens Lehmann</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Dr. Christoph Lange, Dr. Maria Maleshkova</td></tr>
<tr><td>Classification</td><td colspan="2">Programme
M. Sc. Computer Science</td><td colspan="2">Mode
Optional</td><td>Semester
2.</td></tr>
<tr><td>Technical skills</td><td colspan="5">Through the seminar, students will learn to work with tools and technologies of the Semantic Web as well as assess their capabilities for given problems. They will gain the ability to understand new research results presented in original scientific papers.</td></tr>
<tr><td>Soft skills</td><td colspan="5">Ability to present and to critically discuss technologies and research results in the framework of Semantic Web technologies.</td></tr>
<tr><td>Contents</td><td colspan="5">• technologies such as triple stores, link discovery frameworks, NLP pipelines.
• recent conference and journal papers</td></tr>
<tr><td>Prerequisites</td><td colspan="5">none</td></tr>
<tr><td rowspan="3">Format</td><td>Teaching format</td><td>Group size</td><td>h/week</td><td>Workload[h]</td><td>CP</td></tr>
<tr><td>Seminar</td><td>10</td><td>2</td><td>30 T / 90 S</td><td>4</td></tr>
<tr><td colspan="5">T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="5">Oral presentation, written report (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="5">(not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="5"></td></tr>
<tr><td>Literature</td><td colspan="5"></td></tr>
</table>

Module MA-INF 4314	**Lab Semantic Data Web Technologies**		
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** every year
Module coordinator	Prof. Dr. Jens Lehmann		
Lecturer(s)	Prof. Dr. Jens Lehmann, Dr. Maria Maleschkova		
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 2.
Technical skills	The students will carry out a practical task (project) in the context of Semantic Web technologies, including test and documentation of the implemented software/system.		
Soft skills	Ability to properly present and defend design decisions, to prepare readable documentation of software; skills in constructively collaborating with others in small teams over a longer period of time; ability to classify own results with regard to the state-of-the-art		
Contents			
Prerequisites	none		
Format	see below		
Exam achievements	Oral presentation, written report (graded)		
Study achievements	(not graded)		
Forms of media			
Literature			

Format:

Teaching format	**Group size**	**h/week**	**Workload[h]**	**CP**
Lab	8	4	60 T / 210 S	9

T = face-to-face teaching; S = independent study

Module MA-INF 4316	**Graph Representation Learning**
Workload 180 h	**Credit points** 6 CP; **Duration** 1 semester; **Frequency** at least every 2 years
Module coordinator	Dr. Pascal Welke
Lecturer(s)	Dr. Pascal Welke
Classification	**Programme** M. Sc. Computer Science; **Mode** Optional; **Semester** 1.
Technical skills	• Deep understanding of the trade-off between expressiveness of graph representation and computational complexity, as well as practical runtime of algorithms in the context of machine learning applications. - Ability to implement, practically apply, and theoretically analyze graph representation, graph kernels, and graph mining algorithms.
Soft skills	• Social, methodological, and analytical competences via communication, own development, and presentation of problem formulations, algorithms, and solutions. • Learning to solve project tasks in a group. • Learning to evaluate the trade-offs and limitations of existing methods.
Contents	We will discuss general approaches for machine learning (ML) on graph structured data. In particular, computational methods for graph representation learning such as graph neural networks (GNNs), graph kernels, as well as graph mining techniques will be discussed, analyzed, and applied. Regarding GNNs and graph kernels, we will discuss the expressive power and how these concepts are related, as well as several specific examples. In the area of graph mining, we will likely investigate fast (approximate) algorithms to count small patterns, such as triangles, or trees. If time permits, we might venture into the realm of ranking on large-scale graphs, with applications such as recommender systems. The exercises will focus on practical implementations and the application of these methods to real world examples.
Prerequisites	**Recommended:** Helpful: one or more of the following • MA-INF 4111 – Intelligent Learning and Analysis Systems: Machine Learning • MA-INF 4112 – Intelligent Learning and Analysis Systems: Data Mining and Knowledge Discovery • MA-INF 4212 – Data Science and Big Data • MA-INF 1105 - Algorithms for Data Analysis • MA-INF 1102 - Combinatorial Optimization
Format	see below
Exam achievements	Oral exam or written exam (graded)
Study achievements	Successful exercise participation (not graded)
Forms of media	• Lecture slides • Jupyter notebooks
Literature	• William L. Hamilton: Graph Representation Learning, Synthesis Lectures on Artificial Intelligence and Machine Learning, Morgan and Claypool. • Nils M. Kriege, Fredrik D. Johansson, Christopher Morris: A survey on graph kernels, Applied Network Science 5(1):6. • Karsten M. Borgwardt, M. Elisabetta Ghisu et al.: Graph Kernels: State-of-the-Art and Future Challenges, Foundations and Trends in Machine Learning 13(5-6).

Format

Teaching format	**Group size**	**h/week**	**Workload[h]**	**CP**
Lecture		2	30 T / 45 S	2.5
Exercises		2	30 T / 75 S	3.5

T = face-to-face teaching; S = independent study

<table>
<tr><td>Module
MA-INF 4318</td><td colspan="3">Seminar Representation Learning for Big Data Analytics</td></tr>
<tr><td>Workload
120 h</td><td>Credit points
4 CP</td><td>Duration
1 semester</td><td>Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="3">Prof. Dr. Emmanuel Müller</td></tr>
<tr><td>Lecturer(s)</td><td colspan="3">Prof. Dr. Emmanuel Müller</td></tr>
<tr><td>Classification</td><td>Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
2. or 3.</td></tr>
<tr><td>Technical skills</td><td colspan="3">Ability to understand new research results presented in original scientific papers.</td></tr>
<tr><td>Soft skills</td><td colspan="3">Ability to present and to critically discuss these results in the framework of the corresponding area.</td></tr>
<tr><td>Contents</td><td colspan="3">Smart representations (such as embeddings, kernels, and dimensionality reduction methods) are useful models that allow the abstraction of data within a well-defined mathematical formalism. The representations we aim at are conceptual abstractions of real world phenomena (such as social interactions, chemical reactions and biological processes) into the world of statistics and discrete mathematics in such a way that the powerful tools developed in those areas are available for complex analyses in a simple and elegant manner.
The focus will be the understanding and comparison of smart representations and their explicit/implicit data transformation models. We will study limitations and advantages of different techniques, and how the data representation changes the problem setup, reduces complexity, introduces robustness, or other valuable properties for big data analytics.</td></tr>
<tr><td>Prerequisites</td><td colspan="3">Recommended:
Open-minded for new problem settings, Programming in different languages (C++, Python, Java), Critical approach to existing solutions, Research curiosity</td></tr>
<tr><td>Format</td><td colspan="3"><table><tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr><tr><td>Seminar</td><td>10</td><td>2</td><td>30 T / 90 S</td><td>4</td></tr></table>T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="3">Oral presentation, written report (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="3">(not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="3"></td></tr>
<tr><td>Literature</td><td colspan="3">[1] Sergey Ivanov, Evgeny Burnaev. "Anonymous Walk Embeddings" ICML, 2018.
[2] Tsitsulin, Anton, Davide Mottin, Panagiotis Karras, and Emmanuel Müller "VERSE: Versatile Graph Embeddings from Similarity Measures." WWW, 2018.
[3] Yanardag, Pinar, and S. V. N. Vishwanathan. "Deep graph kernels." KDD, 2015.
[4] Holger Dell, Martin Grohe, Gaurav Rattan "Lovász Meets Weisfeiler and Leman". ICALP, 2018
[5] Anton Tsitsulin, Davide Mottin, Panagiotis Karras, Alexander M. Bronstein, Emmanuel Müller "NetLSD: Hearing the Shape of a Graph". KDD, 2018
[6] Nino Shervashidze, Pascal Schweitzer, Erik Jan van Leeuwen, Kurt Mehlhorn, Karsten M. Borgwardt "Weisfeiler-Lehman Graph Kernels". JMLR, 2011
[7] Haochen Chen, Bryan Perozzi, Yifan Hu, Steven Skiena "HARP: Hierarchical Representation Learning for Networks". AAAI, 2018.</td></tr>
</table>

Module MA-INF 4319	**Game AI**				
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** every year		
Module coordinator	Prof. Dr. Christian Bauckhage				
Lecturer(s)	Prof. Dr. Christian Bauckhage				
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 2. or 3.		
Technical skills	Upon completion, students should be able to • know about fundamental concepts of artificial intelligence and how they apply to computer games • know about basic and advanced methods for planning, problem solving, and behavior modelling • implement basic and advanced algorithms for planning, problem solving, and behavior modelling • implement numerically robust data clustering and classification				
Soft skills	Students will learn about mathematical and algorithmic foundations of artificial intelligence. They will learn about basic and more advanced techniques for planning, problem solving, and behavior modelling, how to implement them on their own, and how to put them into practice especially in the context of artificial computer game agents.				
Contents	• historical overview of game AI • basic terms and definitions for AI in games • backward induction and the minmax algorithm • alpha-beta pruning, depth restircted searches, features, and evaluation functions • (traditional, uninformed) tree search algorithms • Monte Carlo tree search • algorithms for path- and motion planning, A* search • mathematical models and computer algorithms for data clustering • self organizing maps • finite state machines for behavior modeling / programming • fuzzy logic / fuzzy control for behavior modeling / programming • probability theory and Bayesian networks • Markov chains / Markov models • hidden Markov models for behavior modeling and analysis • Markov decision processes and reinforcement learning • the Bellman equations for reinforcement learning • temporal difference learning • Q learning • genetic algorithms and genetic programming				
Prerequisites	**Recommended:** Students should good working knowledge in linear algebra, probability theory, and statistics as well as programming experience.				
Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Lecture		4	60 T / 105 S	5.5
	Exercises		2	30 T / 75 S	3.5
	T = face-to-face teaching; S = independent study				
Exam achievements	Oral exam (graded)				
Study achievements	Successful exercise participation (not graded)				
Forms of media	• lecture slides are made available online • lecture notes with programming examples are made available online				
Literature	Russell and Norvig, "Artificial Intelligence: A Modern Approach" Millington, "Artificial Intelligence For Games" MacKay, "Information Theory, Inference, and Learning Algorithms"				

Module MA-INF 4322	**Lab Machine Learning on Encrypted Data**				
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** every year		
Module coordinator	Dr. Michael Nüsken				
Lecturer(s)	Dr. Michael Nüsken				
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 2. or 3.		
Technical skills	The students will carry out a practical task (project) in the context of Cryptography, including test and documentation of the implemented software/system.				
Soft skills	Ability to properly present and defend design decisions, to prepare readable documentation of software; skills in constructively collaborating with others in small teams over a longer period of time; ability to classify ones own results into the state-of-the-art of the resp. area				
Contents	With the rise of more and more mechanisms and installations of data science methodology to automatically analyze large amounts of possibly privacy infringing data we have to carefully understand how to protect our data. Also more and more fake data shows up and we have to find ways to distinguish faked from trustable data. At the same time we want to allow insightful research and life-easing analyzes to be possible. This seeming contradiction has lead to various efforts for unifying both: protecting data and allowing analyzes, at least to some extent and possibly under some restrictions. See Munn et al. (2019) for a review on challenges and options. The target of the lab is to understand how computations on encrypted data may work in one particular application that we are chosing together. Ideally, we can come up with a novel solution for performing an unconsidered algorithm. We study the tasks and tools, select algorithms, find a protocol, prototype an implemention, perform a security analysis, present an evaluation, ...				
Prerequisites	none				
Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Lecture		4	60 T / 105 S	5.5
	Exercises		2	30 T / 75 S	3.5
	T = face-to-face teaching; S = independent study				
Exam achievements	Schriftliche Prüfung (graded)				
Study achievements	Erfolgreiche Übungsteilnahme (not graded)				
Forms of media					
Literature					

Module MA-INF 4323	**Pattern Recognition II**
Workload 270 h	**Credit points** 9 CP | **Duration** 1 semester | **Frequency** every year
Module coordinator	Prof. Dr. Christian Bauckhage
Lecturer(s)	Prof. Dr. Christian Bauckhage
Classification	**Programme** M. Sc. Computer Science | **Mode** Optional | **Semester** 2. or 3.
Technical skills	Upon completion, students should be able to • know about aspects of numerical computing and how these may affect practical implementations of machine learning / pattern recognition algorithms • know about iterative algorithms for machine learning / pattern recognition with large data sets • implement numerically robust algorithms for data dimensionality reduction • implement numerically robust data clustering and classification
Soft skills	Students will learn about mathematical and algorithmic foundations of robust implementations of machine learning algorithms for data analysis and pattern recognition. They will learn about iterative algorithms and dynamical systems approaches in this area, how to implement them on their own, and how to put them into practice.
Contents	• advanced concepts from linear algebra • QR-, spectral-, and singular value decompositions • iterative algorithms for least squares optimization • iterative algorithms for principal component analysis • Hebbian learning and Oja's rule for principal compoentn analysis • auto-encoder networks • associative memory networks • Hopfield networks • Hopfield networks for pattern recognition • Hopfield networks for problem solving • energy minimization methods in machine learning and pattern recognition • latent factor models for data analysis • data matrix factorization techniques • multidimensional scaling • manifold learning • basic graph theory • graph cuts and graph clustering • graph diffusion processes • radial basis functions for interpolation • radial basis functions for classification • radial basis functions for density estimation
Prerequisites	**Recommended:** Students should good working knowledge in linear algebra, probability theory, and statistics. Ideally, they will have attended the lecture Pattern Recognition (1).
Format	see below
Exam achievements	Schriftliche Prüfung (graded)
Study achievements	Erfolgreiche Übungsteilnahme (not graded)
Forms of media	• lecture slides are made available online • lecture notes with programming examples are made available online
Literature	• MacKay, "Information Theory, Inference, and Learning Algorithms" • Haykin, "Neural Networks and Learning Machines" • Bishop, "Neural Networks for Pattern Recognition" • Elden, "Matrix Methods in Data Mining and Pattern Recognition" • Skillicorn, "Understanding Complex Datasets" • Kirby, "Geometric Data Analysis"

Format

Teaching format	Group size	h/week	Workload[h]	CP
Lecture		4	60 T / 105 S	5.5
Exercises		2	30 T / 75 S	3.5

T = face-to-face teaching; S = independent study

Module MA-INF 4324	**Seminar Advanced Topics in Data Science**				
Workload 120 h	**Credit points** 4 CP	**Duration** 1 semester	**Frequency** every year		
Module coordinator	Prof. Dr. Elena Demidova				
Lecturer(s)	Prof. Dr. Elena Demidova				
Classification	**Programme** M. Sc. Computer Science	**Mode** Optional	**Semester** 2. or 3.		
Technical skills	This module concentrates on specialized topics in data science. The students obtain skills in the independent, in-depth study of state-of-the-art scientific literature on specific topics, discussion with their peers and presentation to the scientific audience.				
Soft skills	• Communication skills: oral and written presentation of scientific content. • Self-competences: the ability to analyze problems, time management, creativity.				
Contents	Statistical and machine learning-based methods of data analytics, including typical steps of the data science process: data generation, integration, cleaning, exploration, modelling and evaluation. Specialized data representation and analytics methods for selected data types and applications in specific domains.				
Prerequisites	**Recommended:** BA-INF 150 - Einführung in die Data Science				
Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Seminar	10	2	30 T / 90 S	4
	T = face-to-face teaching; S = independent study				
Exam achievements	Oral presentation, written report (graded)				
Study achievements	None (not graded)				
Forms of media					
Literature	Relevant literature will be announced at the beginning of the seminar				

<table>
<tr><td>Module
MA-INF 4325</td><td colspan="5">Lab Data Science in Practice</td></tr>
<tr><td>Workload
270 h</td><td>Credit points
9 CP</td><td>Duration
1 semester</td><td colspan="3">Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="5">Prof. Dr. Elena Demidova</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Prof. Dr. Elena Demidova</td></tr>
<tr><td>Classification</td><td colspan="2">Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td colspan="2">Semester
2. or 3.</td></tr>
<tr><td>Technical skills</td><td colspan="5">This module concentrates on practical experience in data analytics. Participants acquire basic knowledge and practical experience in the design and implementation of data science workflows for specific data types and applications.</td></tr>
<tr><td>Soft skills</td><td colspan="5">• Communication skills: the ability to work in teams.
• Self-competences: the ability to analyse problems and find practical solutions. Time management, creativity, presentation of results.</td></tr>
<tr><td>Contents</td><td colspan="5">Practical application of statistical and machine learning-based methods to solve data analytics problems on real-world datasets and evaluate proposed solutions.</td></tr>
<tr><td>Prerequisites</td><td colspan="5">Recommended:
BA-INF 150 - Einführung in die Data Science
MA-INF 4230 - Advanced Methods of Information Retrieval</td></tr>
<tr><td rowspan="3">Format</td><td>Teaching format</td><td>Group size</td><td>h/week</td><td>Workload[h]</td><td>CP</td></tr>
<tr><td>Lab</td><td>8</td><td>4</td><td>60 T / 210 S</td><td>9</td></tr>
<tr><td colspan="5">T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="5">Oral presentation, written report (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="5">None (not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="5"></td></tr>
<tr><td>Literature</td><td colspan="5"></td></tr>
</table>

<table>
<tr><td>Module
MA-INF 4326</td><td colspan="5">Explainable AI and Applications</td></tr>
<tr><td>Workload
180 h</td><td colspan="2">Credit points
6 CP</td><td colspan="2">Duration
1 semester</td><td>Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="5">Dr. Tiansi Dong</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Dr. Tiansi Dong</td></tr>
<tr><td>Classification</td><td colspan="2">Programme
M. Sc. Computer Science</td><td colspan="2">Mode
Optional</td><td>Semester
3.</td></tr>
<tr><td>Technical skills</td><td colspan="5">• Know the dual-model functioning of the human mind, and two main AI paradigms
• Develop white-box neural AI systems
• Understand the problems and limitations of Blackbox Deep-Learning systems, and Know the state-of-the-art Methods for Interpreting Deep-Learning systems (XAI)</td></tr>
<tr><td>Soft skills</td><td colspan="5">• Know System 1 and 2 of the mind, prons and cons of symbolic AI and connectionist AI
• Develop neural-geometric systems that have both good features of symbolic AI and connectionist AI
• Know the limitation of famous Deep-Learning systems, such as GPT3, self-driving. Know standard methods to explore the explainability of Deep-Learning systems</td></tr>
<tr><td>Contents</td><td colspan="5">1. Introduction: fates of large Deep-Learning systems, e.g. Watson, GPT, self-driving cars
2. Dual-system theories (System 1 and 2), nine laws of cognition, criteria of semantic models
3. The target and the state-of-art methods of XAI
4. Neural-symbolic AI
5. Cognitive maps, Collages, Mental Spatial Representation, Events
6. Qualitative Spatial Representation and Reasoning
7. Rotating Sphere Embedding: A New Wheel for Neural-Symbolic Unification
8. Neural Syllogistic Reasoning
9. Recognizing Variable Environments
10. Humor Understanding
11. Rotating Spheres as building-block semantic components for Language, Vision, and Action</td></tr>
<tr><td>Prerequisites</td><td colspan="5">none</td></tr>
<tr><td rowspan="4">Format</td><td>Teaching format</td><td>Group size</td><td>h/week</td><td>Workload[h]</td><td>CP</td></tr>
<tr><td>Lecture</td><td></td><td>2</td><td>30 T / 45 S</td><td>2.5</td></tr>
<tr><td>Exercises</td><td></td><td>2</td><td>30 T / 75 S</td><td>3.5</td></tr>
<tr><td colspan="5">T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="5">Written exam (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="5">Successful exercise participation (not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="5"></td></tr>
<tr><td>Literature</td><td colspan="5">• Kahneman, D. (2011). Thinking fast and slow. Farrar, Straus and Giroux.
• Gaedenfors, P. (2017). The Geometry of Meaning. MIT Press.
• Attardo, Hempelmann, Maio (2003). Script Oppositions and Logical Mechanisms: Modeling Incongruities and their Resolutions, HUMOR 15(1)3–46
• Tversky, B. (2019). Mind in Motion. Basic Books, New York.
• Dong, et al. (2020). Learning Syllogism with Euler Neural-Networks. arXiv:2007.07320
• Dong, T. (2021). A Geometric Approach to the Unification of Symbolic Structure and Neural Networks. Springer.
• Knauff and Spohn (2021). Handbook of Rationality. MIT Press, Cambridge, MA, USA.
• Samek et.al. (2019), Explainable AI: Interpreting, Explaining and Visualizing Deep Learning. Springer.
• Greg Dean (2019). Step by Step to Stand-Up Comedy (Revised Edition). ISBN: 978-0-9897351-7-9</td></tr>
</table>

<table>
<tr><td>Module
MA-INF 4327</td><td colspan="3">Lab Biomedical Data Science</td></tr>
<tr><td>Workload
270 h</td><td>Credit points
9 CP</td><td>Duration
1 semester</td><td>Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="3">Prof. Dr. Holger Fröhlich</td></tr>
<tr><td>Lecturer(s)</td><td colspan="3">Prof. Dr. Holger Fröhlich</td></tr>
<tr><td>Classification</td><td colspan="3"><table><tr><th>Programme</th><th>Mode</th><th>Semester</th></tr><tr><td>M. Sc. Computer Science</td><td>Optional</td><td>3.</td></tr></table></td></tr>
<tr><td>Technical skills</td><td colspan="3">The students will carry out a practical task (project) in the context of biomedical data science, including test and documentation of the implemented software/system.</td></tr>
<tr><td>Soft skills</td><td colspan="3">Ability to properly present and defend design decisions, to prepare readable documentation of software; skills in constructively collaborating with others in small teams over a longer period of time; ability to classify ones own results into the state-of-the-art of the resp. area</td></tr>
<tr><td>Contents</td><td colspan="3">Varying selected topics close to current research in the area of biomedical data science.</td></tr>
<tr><td>Prerequisites</td><td colspan="3">none</td></tr>
<tr><td>Format</td><td colspan="3"><table><tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr><tr><td>Lab</td><td>8</td><td>4</td><td>60 T / 210 S</td><td>9</td></tr></table>T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="3">Oral presentation, written report (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="3">(not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="3"></td></tr>
<tr><td>Literature</td><td colspan="3"></td></tr>
</table>

<table>
<tr><td>Module
MA-INF 4328</td><td colspan="5">Spatio-Temporal Data Analytics</td></tr>
<tr><td>Workload
180 h</td><td colspan="2">Credit points
6 CP</td><td colspan="2">Duration
1 semester</td><td>Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="5">Prof. Dr. Elena Demidova</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Prof. Dr. Elena Demidova</td></tr>
<tr><td>Classification</td><td colspan="3">Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
2. or 3.</td></tr>
<tr><td>Technical skills</td><td colspan="5">This module introduces the students to the advanced methods, data structures, and data analytics algorithms for spatio-temporal data. At the end of the module, the students will be capable of choosing appropriate data representations, data structures and algorithms for specific applications and correctly applying relevant statistical and machine learning-based data analytics procedures.</td></tr>
<tr><td>Soft skills</td><td colspan="5">Communication skills: oral and written presentation and discussion of solutions. Self-competences: the ability to analyze and solve problems.</td></tr>
<tr><td>Contents</td><td colspan="5">The module topics include data structures, data representation and analysis methods, and algorithms that enable analyzing spatio-temporal data and building predictive models effectively and effectively. Furthermore, we will study the corresponding evaluation techniques and novel applications.</td></tr>
<tr><td>Prerequisites</td><td colspan="5">none</td></tr>
<tr><td rowspan="4">Format</td><td>Teaching format</td><td>Group size</td><td>h/week</td><td>Workload[h]</td><td>CP</td></tr>
<tr><td>Lecture</td><td></td><td>2</td><td>30 T / 45 S</td><td>2.5</td></tr>
<tr><td>Exercises</td><td></td><td>2</td><td>30 T / 75 S</td><td>3.5</td></tr>
<tr><td colspan="5">T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="5">Schriftliche Prüfung (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="5">Erfolgreiche Übungsteilnahme (not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="5"></td></tr>
<tr><td>Literature</td><td colspan="5"></td></tr>
</table>

<table>
<tr><td>Module
MA-INF 4329</td><td colspan="3">Seminar Biological Intelligence</td></tr>
<tr><td>Workload
120 h</td><td>Credit points
4 CP</td><td>Duration
1 semester</td><td>Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="3">Prof. Dr. Dr. Dominik Bach</td></tr>
<tr><td>Lecturer(s)</td><td colspan="3">Prof. Dr. Dr. Dominik Bach</td></tr>
<tr><td>Classification</td><td>Programme
M. Sc. Computer Science</td><td>Mode
Optional</td><td>Semester
2. or 3.</td></tr>
<tr><td>Technical skills</td><td colspan="3">Ability to understand new research results presented in original scientific papers.</td></tr>
<tr><td>Soft skills</td><td colspan="3">Ability to present and to critically discuss these results in the framework of the corresponding area.</td></tr>
<tr><td>Contents</td><td colspan="3">Current conference and journal papers.</td></tr>
<tr><td>Prerequisites</td><td colspan="3">none</td></tr>
<tr><td>Format</td><td colspan="3"><table><tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr><tr><td>Seminar</td><td>10</td><td>2</td><td>30 T / 90 S</td><td>4</td></tr></table>T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="3">Oral presentation, written report (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="3">(not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="3"></td></tr>
<tr><td>Literature</td><td colspan="3"></td></tr>
</table>

5 Master Thesis

<table>
<tr><td>Module
MA-INF 0401</td><td colspan="3">Master Thesis</td></tr>
<tr><td>Workload
900 h</td><td>Credit points
30 CP</td><td>Duration
1 semester</td><td>Frequency
every semester</td></tr>
<tr><td>Module coordinator</td><td colspan="3"></td></tr>
<tr><td>Lecturer(s)</td><td colspan="3">All lecturers of computer science</td></tr>
<tr><td>Classification</td><td>Programme
M. Sc. Computer Science</td><td>Mode
Compulsory</td><td>Semester
4.</td></tr>
<tr><td>Technical skills</td><td colspan="3">Ability to solve a well-defined, significant research problem under supervision, but in principle independently</td></tr>
<tr><td>Soft skills</td><td colspan="3">Ability to write a scientific documentation of considerable length according to established scientific principles of form and style, in particular reflecting solid knowledge about the state-of-the-art in the field</td></tr>
<tr><td>Contents</td><td colspan="3">Topics of the thesis may be chosen from any of the areas of computer science represented in the curriculum</td></tr>
<tr><td>Prerequisites</td><td colspan="3">none</td></tr>
<tr><td>Format</td><td colspan="3"><table>
<tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr>
<tr><td>Independent preparation of a scientific thesis with individual coaching</td><td></td><td>0</td><td>900 S</td><td>30</td></tr>
</table>T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="3">Master Thesis (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="3">(not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="3"></td></tr>
<tr><td>Literature</td><td colspan="3">Individual bibliographic research required for identifying relevant literature (depending on the topic of the thesis)</td></tr>
</table>

<table>
<tr><td>Module
MA-INF 0402</td><td colspan="5">Master Seminar</td></tr>
<tr><td>Workload
60 h</td><td>Credit points
2 CP</td><td colspan="2">Duration
1 semester</td><td colspan="2">Frequency
every semester</td></tr>
<tr><td>Module coordinator</td><td colspan="5"></td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">All lecturers of computer science</td></tr>
<tr><td>Classification</td><td colspan="2">Programme
M. Sc. Computer Science</td><td colspan="2">Mode
Compulsory</td><td>Semester
4.</td></tr>
<tr><td>Technical skills</td><td colspan="5">Ability to document and defend the results of the thesis work in a scientifically appropriate style, taking into consideration the state-of-the-art in research in the resp. area</td></tr>
<tr><td>Soft skills</td><td colspan="5"></td></tr>
<tr><td>Contents</td><td colspan="5">Topic, scientific context, and results of the master thesis</td></tr>
<tr><td>Prerequisites</td><td colspan="5">none</td></tr>
<tr><td rowspan="3">Format</td><td>Teaching format</td><td>Group size</td><td>h/week</td><td>Workload[h]</td><td>CP</td></tr>
<tr><td>Seminar</td><td></td><td>2</td><td>30 T / 30 S</td><td>2</td></tr>
<tr><td colspan="5">T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="5">Oral presentation of final results (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="5">(not graded)</td></tr>
<tr><td>Forms of media</td><td colspan="5"></td></tr>
<tr><td>Literature</td><td colspan="5">Individual bibliographic research required for identifying relevant literature (depending on the topic of the thesis)</td></tr>
</table>