Module Handbook

for the

Master Programme “Cyber Security”

at

Rheinischen Friedrich-Wilhelms-Universität Bonn

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Contents

1 Example study plans

Full-time, starting in the winter semester			
1st semester	**30 CP**		(winter)
compulsory	6 CP	3236 **IT-SECURITY**	
cyber security elective	6 CP	3108 **Secure Software Engineering**	
computer science elective	6 CP	3310 Introduction to Sensor Data Fusion	
computer science elective	6 CP	4204 Technical Neural Nets	
computer science elective	6 CP	4113 Cognitive Robotics	
2nd semester	**30 CP**		(summer)
cyber security elective	6 CP	3239 **Malware Analysis**	
cyber security elective	6 CP	3322 **Applied Binary Exploitation**	
cyber security elective	6 CP	3241 **Practical Challenges in Human Factors of Security & Privacy**	
cyber security elective	6 CP	3242 **Security of Distributed and Resource-constrained Systems**	
computer science elective	6 CP	4201 Artificial Life	
3rd semester	**28 CP**		(winter)
compulsory	4 CP	3244 **SEMINAR CYBER SECURITY**	
compulsory	9 CP	3245 **LAB CYBER SECURITY**	
cyber security elective	9 CP	3243 **Tutorenpraktikum Cyber Security**	
computer science elective	6 CP	4112 Algorithms for Data Science	
4th semester	**32 CP**		(summer)
compulsory	30 CP	0401 **MASTER THESIS**	
compulsory	2 CP	0402 **MASTER SEMINAR**	

Full-time, starting in the summer semester			
1st semester	**30 CP**		(summer)
cyber security elective	6 CP	3239 **Malware Analysis**	
cyber security elective	6 CP	3241 **Practical Challenges in Human Factors of Security and Privacy**	
cyber security elective	6 CP	3242 **Security of Distributed and Resource-constrained Systems**	
computer science elective	6 CP	4114 Robot Learning	
computer science elective	6 CP	4201 Artificial Life	
2nd semester	**30 CP**		(winter)
compulsory	6 CP	3236 **IT-SECURITY**	
cyber security elective	6 CP	3108 **Secure Software Engineering**	
computer science elective	6 CP	3310 Introduction to Sensor Data Fusion	
computer science elective	6 CP	4204 Technical Neural Nets	
computer science elective	6 CP	4113 Cognitive Robotics	
3rd semester	**28 CP**		(summer)
compulsory	4 CP	3244 **SEMINAR CYBER SECURITY**	
compulsory	9 CP	3245 **LAB CYBER SECURITY**	
cyber security elective	6 CP	3322 **Applied Binary Exploitation**	
cyber security elective	9 CP	3243 **Tutorenpraktikum Cyber Security**	
4th semester	**32 CP**		(winter)
compulsory	30 CP	0401 **MASTER THESIS**	
compulsory	2 CP	0402 **MASTER SEMINAR**	

Part-time, starting in the winter semester			
1st semester	**18 CP**		(winter)
compulsory	6 CP	3236 **IT-SECURITY**	
computer science elective	6 CP	3310 Introduction to Sensor Data Fusion	
computer science elective	6 CP	4204 Technical Neural Nets	
2nd semester	**18 CP**		(summer)
cyber security elective	6 CP	3239 **Malware Analysis**	
cyber security elective	6 CP	3241 **Practical Challenges in Human Factors of Security**	
computer science elective	6 CP	4201 Artifical Life	
3rd semester	**22 CP**		(winter)
compulsory	4 CP	3244 **SEMINAR CYBER SECURITY**	
cyber security elective	6 CP	3108 **Secure Software Engineering**	
computer science elective	6 CP	4113 Cognitive Robotics	
computer science elective	6 CP	4112 Algorithms for Data Science	
4th semester	**21 CP**		(summer)
compulsory	9 CP	3245 **LAB CYBER SECURITY**	
cyber security elective	6 CP	3322 **Applied Binary Exploitation**	
cyber security elective	6 CP	3242 **Security of Distributed and Resource-constrained Systems**	
5th semester	**21 CP**		(winter)
cyber security elective	9 CP	3243 **Tutorenpraktikum Cyber Security**	
compulsory	(12 CP)	0401 **MASTER THESIS**, partially	
6th semester	**20 CP**		(summer)
compulsory	(18 CP)	0401 **MASTER THESIS**, completion	
compulsory	2 CP	0402 **MASTER SEMINAR**	

Part-time, starting in the summer semester			
1st semester	**18 CP**		(summer)
cyber security elective	6 CP	3239 **Malware Analysis**	
cyber security elective	6 CP	3241 **Practical Challenges in Human Factors of Security**	
computer science elective	6 CP	4201 Artifical Life	
2nd semester	**18 CP**		(winter)
compulsory	6 CP	3236 **IT-SECURITY**	
computer science elective	6 CP	3310 Introduction to Sensor Data Fusion	
computer science elective	6 CP	4204 Technical Neural Nets	
3rd semester	**22 CP**		(summer)
compulsory	4 CP	3244 **SEMINAR CYBER SECURITY**	
cyber security elective	6 CP	3322 **Applied Binary Exploitation**	
cyber security elective	6 CP	3242 **Security of Distributed and Resource-constrained Systems**	
computer science elective	6 CP	4114 Robot Learning	
4th semester	**21 CP**		(winter)
compulsory	9 CP	3245 **LAB CYBER SECURITY**	
cyber security elective	6 CP	3108 **Secure Software Engineering**	
computer science elective	6 CP	4113 Cognitive Robotics	
5th semester	**21 CP**		(summer)
cyber security elective	9 CP	3243 **Tutorenpraktikum Cyber Security**	
compulsory	(12 CP)	0401 **MASTER THESIS**, partially	
6th semester	**20 CP**		(winter)
compulsory	(18 CP)	0401 **MASTER THESIS**, completion	
compulsory	2 CP	0402 **MASTER SEMINAR**	

2 Structure of the curriculum

The curriculum of the Master's programme in Cyber Security consists of:

- **COMPULSORY MODULES**, described in Section 4.1 of this document;
- **cyber security electives**, described in Section 4.2 of this document;
- computer science electives, described in Sections 4.3 to 4.6 of this document, among which we can distinguish lectures, *labs* and *seminars*;
- (optionally) modules outside cyber security and computer science, which can be approved on request.

The following table shows the minimum number of credits that must be obtained in each category:

<table>
<tr><td>module type</td><td colspan="3">minimum credits required</td></tr>
<tr><td>3236 IT-SECURITY</td><td colspan="3">6</td></tr>
<tr><td>3244 SEMINAR CYBER SECURITY</td><td colspan="3">4</td></tr>
<tr><td>3245 LAB CYBER SECURITY</td><td colspan="3">9</td></tr>
<tr><td>cyber security electives</td><td>24</td><td rowspan="4">54</td><td rowspan="5">69</td></tr>
<tr><td>computer science elective lectures</td><td>12</td></tr>
<tr><td>computer science seminar (at most one)</td><td>0</td></tr>
<tr><td>computer science lab (at most one)</td><td>0</td></tr>
<tr><td>other modules (can be approved on request)</td><td colspan="2">0</td></tr>
<tr><td>0401 MASTER THESIS</td><td colspan="3">30</td></tr>
<tr><td>0402 MASTER SEMINAR (final presentation)</td><td colspan="3">2</td></tr>
</table>

At least 69 credits in non-compulsory modules are required, of which at least 54 credits must come from cyber security and computer science electives, labs and seminars. Out of those 54 credits, at least 24 must come from cyber security electives and at least 12 must come from computer science electives; the remaining credits can be distributed freely between cyber security and computer science. In total, at least 120 credits must be achieved. Some example study plans can be found in Section 1.

When you compose your own study plan, please note the following.

The Master's thesis project ought to be done at the end of your studies and must be completed within six months in the full-time programme, or within nine months in the part-time programme. At least 60 credits must be acquired before the start of the Master's thesis project.

For some modules it is strongly recommended (and sometimes required) to first complete one or two other modules in a previous semester, as indicated in the following tables. In these tables, for each module, the number of credits is indicated in brackets. Most modules are offered yearly and (at least) in English. Exceptions are indicated as follows:

(+) this module is offered in the winter and in the summer semester
(–) this module is not offered every year
(G) this module is only taught in German

recommended in the winter semester	before taking in the summer semester
[6] **3236 IT-SECURITY** and [6] 4204 Technical Neural Nets	[6] **3246 Security in Digital Supply Chains**
[6] **3236 IT-SECURITY**	[9] **3243 Tutorenpraktikum Cyber Security**(+) or [4] **3244 SEMINAR CYBER SECURITY**(+) or [9] **3245 LAB CYBER SECURITY**(+)
[9] 1103 Cryptography	[9] 1223 Privacy Enhancing Technologies
[6] 2113 Audio Signal Processing	[6] 2212 Pattern Matching and ML for Audio Signal Processing
[9] 2201 Computer Vision	[6] 2213 Advanced Computer Vision or [6] 2218 Video Analytics(–)
[6] 3310 Sensor Data Fusion	[6] 3233 Advanced Sensor Data Fusion in Distributed Systems

recommended in the winter semester	before taking in the next winter semester
[9] 2201 Computer Vision or [6] 4111 Machine Learning(–)	[6] 4333 Geometric Deep Learning
[6] 4113 Cognitive Robotics	[6] 4334 Computational Neuroscience

modules in the winter semester that are independent of other modules (apart from computer science labs and seminars):
[6] **3108 Secure Software Engineering** [6] **3238 Side Channel Attacks** (G) [6] 1105 Algorithms for Data Analysis(–) [6] 1108 Introduction to High Performance Computing [6] 2317 Numerical Algorithms for Visual Computing and Machine Learning [6] 4112 Algorithms for Data Science [6] 4326 Explainable AI and Applications [6] 4328 Spatio-Temporal Data Analytics

recommended in the summer semester	before taking in the winter semester:
[9] 2222 Visual Data Analysis	[6] 4333 Geometric Deep Learning
[6] 4114 Robot Learning	[6] 4334 Computational Neuroscience

recommended in the summer semester	while taking in the same semester, or before taking in the next summer semester:
[6] **3239 Malware Analysis**	[6] **3322 Applied Binary Exploitation**

modules in the summer semester that are independent of other modules (apart from computer science labs and seminars):
[6] **3202 Mobile Communication** [6] **3241 Practical Challenges in Human Factors of Security and Privacy** [6] **3242 Security of Distributed and Resource-constrained Systems** [9] 2202 Computer Animation [6] 2225 Discrete Models for Visual Computing [6] 3237 Array Signal and Multi-channel Processing [6] 4201 Artificial Life [6] 4215 Humanoid Robotics(–) [9] 4228 Foundations of Data Science [6] 4230 Advanced Methods of Information Retrieval(–) [4] 4236 Advanced Methods for Text Mining(–)

Please check the module descriptions in this handbook for details. This handbook also lists about 40 computer science labs and seminars that are open to cyber security students. You may include one computer science seminar and one computer science lab in your programme. Tables that include recommended prior modules for labs and seminars can be found in Section 3.

When you compose your own study plan, please check whether the modules' weekly schedules are compatible before putting them in your final plan. In any case, the schedules of the compulsory and the cyber security elective modules are always compatible with each other, and the schedules of the computer science lectures are always compatible with **3236 IT-SECURITY**.

3243 Tutorenpraktikum Cyber Security, **3244 SEMINAR CYBER SECURITY**, and **3245 LAB CYBER SECURITY** can only be taken in the Master's programme in Cyber Security. All other modules can also be included as electives in the Master's programme in Computer Science.

3 Recommended prior modules including all labs and seminars

The following tables show recommended prior modules for all modules, including about 40 computer science labs and seminars that are open to cyber security students. A more concise overview that only lists cyber security modules and computer science lectures (without the labs and the seminars) can be found in Section 2.
Labs and seminars marked (@) may sometimes be offered in the winter semester, sometimes in the summer semester, possibly depending on demand; please check with the instructors early.

recommended in the winter semester	before taking in the summer semester
[6] **3236 IT-SECURITY** and [6] 4204 Technical Neural Nets	[6] **3246 Security in Digital Supply Chains**
[6] **3236 IT-SECURITY**	[9] **3243 Tutorenpraktikum Cyber Security**(+) or [4] **3244 SEMINAR CYBER SECURITY**(+) or [9] **3245 LAB CYBER SECURITY**(+) or [4] *3209 Seminar Communication Management*(+) or [4] *3317 Seminar IT Security*(+) or [9] *3229 Lab IT-Security*(+) or [9] *3304 Lab Communication and Communicating Devices*(+)
[9] 1103 Cryptography	[9] 1223 Privacy Enhancing Technologies or [4] *1209 Seminar Cryptography*(+) or [9] *1316 Lab Cryptography*
[6] 1105 Algorithms for Data Analysis(–) or [6] 4112 Algorithms for Data Science	[9] *1221 Lab Computational Analytics*
[9] 1103 Cryptography or [6] 1105 Algorithms for Data Analysis(–) or [6] 1108 High Performance Computing	[9] *1309 Lab Efficient Algorithms* (@)
[6] 1108 High Performance Computing	[4] *1322 Seminar High Performance Computing* or [9] *2308 Lab Graphics*(+)
[6] 2113 Audio Signal Processing	[6] 2212 Pattern Matching & ML for Audio Signal Pr. or [4] *2208 Seminar Audio*(+) or [9] *2309 Lab Audio*
[9] 2201 Computer Vision	[6] 2213 Advanced Computer Vision or [6] 2218 Video Analytics(–)
[6] 2317 Num. Alg. for Visual Comp. and ML	[9] *2216 Lab Visual Computing*(+)
[6] 3310 Sensor Data Fusion	[6] 3233 Adv. Sensor Data Fusion in Distrib. Syst. or [9] *3312 Lab Sensor Data Fusion*
[9] 2201 Computer Vision or [6] 4111 Machine Learning(–) or [6] 4204 Technical Neural Nets	[4] *4208 Seminar Vision Systems*(+) or [9] *4308 Lab Vision Systems*(+)
[6] 4111 Machine Learning(–) or [6] 4112 Algorithms for Data Science	[4] *4209 Seminar Data Mining and Learning Algorithms* or [9] *4306 Lab Dev. & Appl. of Data Mining and Learning Systems*(+)
[6] 4113 Cognitive Robotics	[4] *4211 Seminar Cognitive Robotics*(+) or [4] *4213 Seminar Humanoid Robotics*(+) or [9] *4214 Lab Humanoid Robotics*(+) or [9] *4241 Lab Cognitive Modelling of Biological Agents*(+) or [9] *4304 Lab Cognitive Robotics*(+)
[6] 4328 Spatio-Temporal Data Analytics(–)	[4] *4324 Seminar Data Science*(–) or [9] *4325 Lab Data Science in Practice*
[9] 2201 Computer Vision and [6] 4113 Cognitive Robotics	[9] *4331 Lab Perception and Learning for Robotics* (@)

recommended in the winter semester	before taking in the next winter semester
[6] 1105 Algorithms for Data Analysis(–) or [6] 1108 High Performance Computing	[9] *1222 Lab High Performance Optimization*
[6] 1108 High Performance Computing	[9] *1225 Lab Exploring HPC Technologies* (@)
[6] 3310 Sensor Data Fusion	[4] *3216 Seminar Sensor Data Fusion*
[9] 1103 Cryptography	[9] *4322 Lab Machine Learning on Encrypted Data*
[9] 2201 Computer Vision or [6] 4111 Machine Learning(–)	[6] 4333 Geometric Deep Learning
[6] 4113 Cognitive Robotics	[6] 4334 Computational Neuroscience

modules in the winter semester that are independent of other modules
[6] **3108 Secure Software Engineering** [6] **3238 Side Channel Attacks** (G) [6] 4326 Explainable AI and Applications [4] *3321 Seminar Usable Security and Privacy*(+) [9] *2226 Lab Geometry Processing* (@) [9] *2227 Lab 3D Animation*(+)

recommended in the summer semester	before taking in the winter semester
[6] 2225 Discrete Models for Visual Computing	[9] *2216 Lab Visual Computing*(+)
[9] 2222 Visual Data Analysis	[4] *2219 Sem. Visualization & Medical Image Anal.*(–) or [9] *2220 Lab Visualization & Medical Image Analysis*(+)
[9] 2202 Computer Animation or [9] 2222 Visual Data Analysis	[9] *2308 Lab Graphics*(+)
[6] **3202 Mobile Communication** or [6] **3239 Malware Analysis**	[4] *3209 Seminar Communication Management*(+) or [9] *3304 Lab Communication and Communic. Devices*(+)
[6] **3241 Human Factors of Security & Privacy**	[9] *3319 Lab Usable Security and Privacy*(+)
[6] **3242 Security of Distr. & Res.-constr. Syst.**	[9] *3320 Lab Security in Distributed Systems*(+)
[6] 4114 Robot Learning	[4] *4211 Seminar Cognitive Robotics*(+) or [9] *4304 Lab Cognitive Robotics*(+) or [6] 4334 Computational Neuroscience
[6] 4215 Humanoid Robotics(–)	[4] *4213 Seminar Humanoid Robotics*(+) or [9] *4214 Lab Humanoid Robotics*(+)
[6] 4230 Adv. Methods of Information Retrieval(–)	[4] *4231 Seminar Information Retrieval* or [9] *4232 Lab Information Retrieval in Practice*
[6] 4114 Robot Learning or [6] 4215 Humanoid Robotics(–)	[9] *4241 Lab Cognitive Modelling of Biological Agents*(+)
[9] 2222 Visual Data Analysis	[6] 4333 Geometric Deep Learning

recommended in the summer semester	while taking in the same semester, or before taking in the next summer semester:
[6] **3239 Malware Analysis**	[6] **3322 Applied Binary Exploitation**

modules in the summer semester that are independent of other modules
[6] 3237 Array Signal and Multi-channel Processing
[6] 4201 Artificial Life
[9] 4228 Foundations of Data Science
[4] 4236 Advanced Methods for Text Mining(–)
[4] *3321 Seminar Usable Security and Privacy*(+)
[9] *2216 Lab Visual Computing*(+)
[9] *2226 Lab Geometry Processing* (@)
[9] *2227 Lab 3D Animation*(+)
[9] *3323 Lab Fuzzing*

Please check the module descriptions in this handbook for details. Note that the module descriptions sometimes recommend alternative modules as prior knowledge that are not open to cyber security students or that may be difficult to complete in advance due to chain dependencies. Please check carefully. There is always at least one viable option for cyber security students, as indicated above.

4 Module Descriptions

4.1 Cyber Security Compulsory Modules

MA-INF 0401 Master Thesis

Workload	Credit points	Duration	Frequency
900 h	30 CP	1 semester	every semester

Module coordinator	Lecturer(s)
The Examination Board	All lecturers of computer science

Programme	Mode	Semester
M. Sc. Cyber Security	Compulsory	4.

Learning goals: technical skills

Ability to solve a well-defined, significant research problem under supervision, but in principle independently

Learning goals: soft skills

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

Contents

Topics of the thesis may be chosen from any of the areas of computer science represented in the curriculum

Prerequisites

Required:
By the examination regulations of 2023, the Master's thesis project can only commence after 60 credits in other modules of the programme have been obtained. Before you start on the project, you must obtain the approval of the exam committee and register the starting date of the project. Please check the website of the examination office for forms and procedures.

Course meetings

Teaching format	Group size	h/week	Workload[h]	CP
Independent preparation of a scientific thesis with individual coaching		0	900 S	30

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

Graded exams

Master Thesis

Ungraded coursework (required for admission to the exam)

None

Literature

Individual bibliographic research required for identifying relevant literature (depending on the topic of the thesis)

MA-INF 0402 Master Seminar

Workload	Credit points	Duration	Frequency
60 h	2 CP	1 semester	every semester

Module coordinator	Lecturer(s)
The Examination Board	All lecturers of computer science

Programme	Mode	Semester
M. Sc. Cyber Security	Compulsory	4.

Learning goals: technical skills

Knowledge of the state-of-the-art in research in the respective area and how the thesis results relate to that.

Learning goals: soft skills

Ability to identify the most relevant content for a knowledgeable scientific audience; ability to present and defend one's work in a presentation with visual media in a way that adheres to academic standards; ability to anticipate, accept and answer critical questions.

Contents

Topic, scientific context, and results of the master thesis

Prerequisites

Required:
The Master Seminar accompanies the Master Thesis project, see MA-INF 0401 for prequisites.

Recommended:
None

Course meetings

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

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

Graded exams

Oral presentation of final results

Ungraded coursework (required for admission to the exam)

None

Literature

Individual bibliographic research required for identifying relevant literature (depending on the topic of the thesis)

MA-INF 3236 IT Security

Workload	Credit points	Duration	Frequency
180 h	6 CP	1 semester	every year

Module coordinator	Lecturer(s)
Prof. Dr. Michael Meier	Prof. Dr. Michael Meier

Programme	Mode	Semester
M. Sc. Cyber Security	Compulsory	1. or 2.

Learning goals: technical skills

Knowledge of a variety of active research fields in IT security including motivation, challenges and objectives in these fields as well as selected fundamental knowledge and methods helping students to deepen their knowledge in their upcoming studies. In detail, participants will know

- advanced cryptographic constructions and low-level programming in offensive and defensive scenarios;
- how to apply program analysis techniques to IT security;
- how to achieve security by and security of methods from the area of machine learning.

Learning goals: soft skills

Working in small groups on exercises, critical discussion of own and others' results, time management, transferring 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

Recommended:
Foundational knowledge in

- IT security: security terminology, authentication, access control, applied cryptography (symmetric encryption, asymmetric encryption, hashing, key management)
- Low-level/OS-level programming: x86 assembly, C programming, OS-level programming for Linux, buffer overflows, sockets
- Networking: OSI model, modulation, addressing, routing, udp, tcp

You find useful information on these topics in the following books (available through library search portal bonnus):

- M. Bishop: Computer Security: Art and Science, Pearson Education, 2018.
- J. Streib: Guide to Assembly Language: A Concise Introduction. Springer, 2020.
- W. Stevens: UNIX Network Programming – The Sockets Networking API, Prentice Hall International, 3rd Edition, 2003
- Tanenbaum: Computer Networks, Pearson Education, 4th Edition, 2002

Course meetings

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

Graded exams

Written exam (120 minutes)

Ungraded coursework (required for admission to the exam)
The completion of regularly provided exercise sheets. The work can be done in groups of up to three students. For 70% of the exercise sheets, 50% of the points must be achieved for each sheet.

MA-INF 3244 Seminar Cyber Security

Workload	Credit points	Duration	Frequency
120 h	4 CP	1 semester	every semester

Module coordinator	Lecturer(s)
Prof. Dr. Michael Meier	Prof. Dr. Matthew Smith, Prof. Dr. Peter Martini, Prof. Dr. Michael Meier, Dr. Felix Boes, Dr. Matthias Wübbeling, Dr. Christian Tiefenau, Dr. Matthias Frank, Dr. Marc Ohm

Programme	Mode	Semester
M. Sc. Cyber Security	Compulsory	2. or 3.

Learning goals: technical skills

Enhanced and in-depth knowledge in specialized topics in the area of Cyber Security

Learning goals: soft skills

Acquire the competence to independently search for and study state-of-the-art scientific literature in depth, read critically, identify the most relevant content, and assess research results in the context of the corresponding research area; to discuss research results with a knowledgeable scientific audience; to present prior work by others in writing and in presentations with visual media in a way that adheres to academic standards, that is well-structured and didactically effective, and that motivates the audience to participate; to formulate and accept criticism; to manage one's time with relatively open assignments and long-ranging deadlines.

Contents

Recent research topics in Cyber Security based on current journal and conference publications. In addition the seminar group analyses and discusses current societal and political developments related to Cyber Security. Participation in discussion events that are announced in the seminar.

Prerequisites

Recommended:
Foundational knowledge in

- IT security: security terminology, authentication, access control, applied cryptography (symmetric encryption, asymmetric encryption, hashing, key management)
- Usable Security and Privacy: ethics, usability measures, evaluation methods, statistics
- Networks: OSI model, modulation, addressing, routing, udp, tcp

It is recommended to take MA-INF 3236 IT-Security first and to check the material of BA-INF 145 Usable Security and Privacy (available in English).

Course meetings

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

Graded exams

Oral presentation, written report

Ungraded coursework (required for admission to the exam)

Attendance in course sessions in accordance with the exam regulations of 2023, § 12(6).

MA-INF 3245 Lab Cyber Security

Workload	Credit points	Duration	Frequency
270 h	9 CP	1 semester	every semester

Module coordinator	Lecturer(s)
Prof. Dr. Michael Meier	Prof. Dr. Michael Meier, Prof. Dr. Matthew Smith, Prof. Dr. Peter Martini, Dr. Felix Boes, Dr. Matthias Wübbeling, Dr. Christian Tiefenau, Dr. Matthias Frank, Dr. Marc Ohm

Programme	Mode	Semester
M. Sc. Cyber Security	Compulsory	2. or 3.

Learning goals: technical skills

After completion of the lab module students have completed a practical task in the context of cyber security. The students will have gained experience in the typical technical skills like the design and implementation of software, test and documentation of the software, and performance evaluation (e.g. by measurements, simulation, analysis) and presentation of performance results.

Learning goals: soft skills

Ability to analyze problems theoretically and to find creative and practical solutions; to examine one's solutions and results critically; to classify one's own results into the state-of-the-art of the respective area; to prepare readable documentation of software and research results; to present, defend and discuss design decisions and results in the team/group and to other students clearly and in accordance with academic standards; to collaborate constructively with others in small teams over a longer period of time; to aim at long-range goals under limited resources; to work under pressure.

Contents

- Selected topics close to current research in the area of cyber security.
- Participation in discussion events that are announced in the lab.

Prerequisites

Recommended:
Foundational knowledge in

- IT security: security terminology, authentication, access control, applied cryptography (symmetric encryption, asymmetric encryption, hashing, key management)
- Usable Security and Privacy: ethics, usability measures, evaluation methods, statistics
- Networks: OSI model, modulation, addressing, routing, udp, tcp

It is recommended to take MA-INF 3236 IT-Security first and to check the material of BA-INF 145 Usable Security and Privacy (available in English).

Course meetings

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

Graded exams

Oral presentation, written report

Ungraded coursework (required for admission to the exam)

Project work; attendance in course sessions in accordance with the exam regulations of 2023, § 12(6).

4.2 Cyber Security Elective Modules

MA-INF 3108 Secure Software Engineering

Workload	Credit points	Duration	Frequency
180 h	6 CP	1 semester	every year

Module coordinator	Lecturer(s)
Dr. Christian Tiefenau	Dr. Christian Tiefenau

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	1-3.

Learning goals: technical skills

The students will learn how to integrate security aspects into the phases of a Software Development Lifecycle. They will learn:

- Methods for identifying threats and vulnerabilities (threat modeling and risk analysis).
- How to design secure architectures using fundamental design principles (e.g., STRIDE).
- Secure coding practices and common vulnerability types.
- Key considerations when using cryptographic methods in software.
- How to assess the severity of a vulnerability.
- Best practices for system configuration, deployment, and maintenance.

Learning goals: soft skills

In the exercises, the students will conduct practical tasks to strengthen the understanding of the methods within the secure software engineering lifecycle. Through this, the abilities teamwork, 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:
Basic knowledge of software engineering and IT Security-concepts is advantageous but not mandatory.

Course meetings

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

Graded exams

Written exam (90 minutes)

Ungraded coursework (required for admission to the exam)

none

Literature

Software Security: Building Security In by Gary McGraw

MA-INF 3202 Mobile Communication

Workload	Credit points	Duration	Frequency
180 h	6 CP	1 semester	every year

Module coordinator	Lecturer(s)
Prof. Dr. Peter Martini	Prof. Dr. Peter Martini, Dr. Matthias Frank

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	1. or 2.

Learning goals: technical skills

After completion of the module students will be able to cope with challenges and problems arising in design and operation of wireless and mobile communication systems. They can choose suitable protocols or design new ones. They are able to select mechanisms from different architectural layers, integrate them into a new complete architecture and justify their selection and integration decisions.

Learning goals: soft skills

Theoretical exercises support in-depth understanding of lecture topics and stimulate discussions; practical exercises in teamwork 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 (like Bluetooth, Wireless LAN, LoRa/LoRaWAN, focus on system architecture and medium access), Cellular/Mobile Communication Networks (voice and data communication, 2G, 4G, ...).

Prerequisites

Recommended:
Bachelor level knowledge of basics of communication systems and Internet protocols. Students may receive access to lecture slides in English language of our Bachelor module BA-INF 101 "Kommunikation in Verteilten Systemen" as a reference. Contact the lecturer in advance of the course, and information will also be given in the first lecture.

Course meetings

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

Graded exams

Written exam (90 minutes)

Ungraded coursework (required for admission to the exam)

The completion of regularly provided exercise sheets. The work can be done in groups of up to three students. A total of 50% of the points must be achieved. For 70% of the exercise sheets, 20% of the points must be achieved for each sheet.

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

MA-INF 3238 Side Channel Attacks (in German)

Workload	Credit points	Duration	Frequency
180 h	6 CP	1 semester	every year

Module coordinator	Lecturer(s)
Dr. Felix Boes	Dr. Felix Boes

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	1-3.

Learning goals: technical skills

- 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.

Learning goals: 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 organization of practical work and critical discussion of own and others' results.

Contents

- 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)
- *This course is taught in German**

Prerequisites

Recommended:
Fundamental knowledge about IT Security, operating systems and statistics is advantageous but not mandatory.

Course meetings

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

Graded exams

Written Exam (90 minutes, in German)

Ungraded coursework (required for admission to the exam)

Participation in two achievement tests. In total, at least 50% of the points much be achieved on these tests.

MA-INF 3239 Malware Analysis

Workload	Credit points	Duration	Frequency
180 h	6 CP	1 semester	every year

Module coordinator	Lecturer(s)
Prof. Dr. Peter Martini	Prof. Dr. Elmar Padilla

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	1. or 2.

Learning goals: 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.

Learning goals: 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

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)

Course meetings

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

Graded exams

Oral exam (30 minutes)

Ungraded coursework (required for admission to the exam)

The completion of regularly provided exercise sheets. The work can be done in groups of up to two students. A total of 50% of the points must be achieved.

Literature
The relevant literature will be announced at the beginning of the lecture

MA-INF 3241 Practical Challenges in Human Factors of Security and Privacy

Workload	Credit points	Duration	Frequency
180 h	6 CP	1 semester	every year

Module coordinator	Lecturer(s)
Prof. Dr. Matthew Smith	Prof. Dr. Matthew Smith

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	1-3.

Learning goals: technical skills

Students are introduced to a variety of current challenges in security and privacy which contain human aspects and have societal relevance. Students learn about the motivation, challenges and objectives in these areas and select one for the semester topic. They then learn how to design, conduct and evaluate user studies to tackle the selected challenge. Additionally, they get to know selected fundamental knowledge and methods helping them to deepen their knowledge on human factors research.

Learning goals: soft skills

Breaking down complex topics into manageable components, critical discussion of own and others' results, time management, transferring theoretical knowledge to practical scenarios

Contents

The course begins with several lectures that provide an overview and discussion of current societal challenges in the area of human factors in security and privacy. The students will select a semester topic and together with the lecturer explore this topic using user studies. Since these subject areas can turn out to be very specific, it is beneficial to be willing to deal with the subject outside of the lecture and exercise times. Topics can include surveillance, age verification, anonymity, online abuse, fake news, etc.

Prerequisites

Recommended:
It is recommended that students have experience with designing and evaluating survey and interview-based user studies. It is recommended to check the material of BA-INF 145 Usable Security and Privacy (available in English).

Course meetings

Teaching format	Group size	h/week	Workload[h]	CP
Lecture		1	15 T / 45 S	2
Exercises		3	45 T / 75 S	4

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

Graded exams

electronic exam (90 minutes, pass/fail)

Ungraded coursework (required for admission to the exam)

The participation in at least 80% of regularly provided exercises.

MA-INF 3242 Security of Distributed and Resource-constrained Systems

Workload	Credit points	Duration	Frequency
180 h	6 CP	1 semester	every year

Module coordinator	Lecturer(s)
Prof. Dr. Michael Meier	Dr. Thorsten Aurisch

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	1. or 2.

Learning goals: 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.

Learning goals: soft skills

Working in small groups on exercises, critical discussion of own and others' results, time management, transferring theoretical knowledge to practical scenarios.

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
- Distributed ledger technology
- Cyber security in software-defined networks
- Artificial intelligence in cyber security
- Security for IoT

Prerequisites

Recommended:
Foundational knowledge in

- IT security: security terminology, authentication, access control, applied cryptography (symmetric encryption, asymmetric encryption, hashing, key management)
- Low-level/OS-level programming: x86 assembly, C programming, OS-level programming for Linux, buffer overflows, sockets
- Networking: OSI model, modulation, addressing, routing, udp, tcp

You find useful information on these topics in the following books (available through library search portal bonnus):

- M. Bishop: Computer Security: Art and Science, Pearson Education, 2018.
- J. Streib: Guide to Assembly Language: A Concise Introduction. Springer, 2020.
- W. Stevens: UNIX Network Programming – The Sockets Networking API, Prentice Hall International, 3rd Edition, 2003
- Tanenbaum: Computer Networks, Pearson Education, 4th Edition, 2002

Course meetings

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

Graded exams

Written exam (120 minutes)

Ungraded coursework (required for admission to the exam)

Participation in an achievement test. At least 50% of the points much be achieved on this test.

MA-INF 3243 Tutorenpraktikum Cyber Security

Workload	Credit points	Duration	Frequency
270 h	9 CP	1 semester	every year

Module coordinator	Lecturer(s)
Prof. Dr. Michael Meier	Prof. Dr. Matthew Smith, Prof. Dr. Michael Meier, Prof. Dr. Peter Martini, Dr. Felix Boes, Dr. Matthias Wübbeling, Dr. Marc Ohm, Prof. Dr. Michael Meier, Dr. Christian Tiefenau, Dr. Matthias Frank

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	3.

Learning goals: technical skills

Ability to and experience in

- evaluating and assessing excercise solutions and argumentations,
- development, implementation and application of teaching and learning tools.

Learning goals: soft skills

Ability to and experience in

- conveying knowledge to students,
- presenting technical, conceptional and scientific content.

Contents

Varying practical tutoring tasks in the context of cyber security are carried out. This can include tutoring of exercise sessions for a cyber security course (bachelor or master level), correction of homework, evaluation of students' progress, participation in the regular tutor meetings, development of teaching material (e.g. exercise tasks) and demonstrations to illustrate and convey technical as well as scientific correlations.

This module can be completed in German or in English.

Prerequisites

Recommended:
Foundational knowledge in

- IT security: security terminology, authentication, access control, applied cryptography (symmetric encryption, asymmetric encryption, hashing, key management)
- Usable Security and Privacy: ethics, usability measures, evaluation methods, statistics
- Networks: OSI model, modulation, addressing, routing, udp, tcp

It is recommended to take MA-INF 3236 IT-Security first and to check the material of BA-INF 145 Usable Security and Privacy (available in English).

Course meetings

Teaching format	Group size	h/week	Workload[h]	CP
Seminar	8	1	15 T / 45 S	2
Practical Work	8	5	75 T / 135 S	7

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

Graded exams

Project work

Ungraded coursework (required for admission to the exam)

None

MA-INF 3246 Security in Digital Supply Chains

Workload	Credit points	Duration	Frequency
180 h	6 CP	1 semester	every year

Module coordinator	Lecturer(s)
Dr. Marc Ohm	Dr. Marc Ohm

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	2-3.

Learning goals: technical skills

This module introduces the challenges and risks of digital supply chains in the context of cybersecurity. It focuses on recent developments in the software supply chain and the artificial intelligence supply chain. Additionally, it will present threat intelligence methodologies.

Learning goals: soft skills

Presentation of solutions and methods, critical discussion of own and others' results.

Contents

- Threat Actors
- Threat Intelligence
- Attack vector of Software Supply Chains
- Adversarial Machine Learning
- Prevention and mitigation strategies
- Regulations and compliance

Prerequisites

Recommended:
- MA-INF 3236 IT-Security
- MA-INF 4204 Technical Neural Nets

An understanding of the basic concepts of software development, artificial intelligence and IT security.

Course meetings

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

Graded exams

Oral exam (30 minutes)

Ungraded coursework (required for admission to the exam)

Participation in two performance tests. In total, at least 50% of the points much be achieved on these tests.

MA-INF 3322 Applied Binary Exploitation

Workload	Credit points	Duration	Frequency
180 h	6 CP	1 semester	every year

Module coordinator	Lecturer(s)
Prof. Dr. Peter Martini	Prof. Dr. Elmar Padilla

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	1-3.

Learning goals: technical skills

recognition of vulnerabilities in binary programs, static reverse engineering of binary programs (Ghidra, IDA Free, Linux command line tools), debugging of binary programs with gdb/pwndbg, Python programming with pwntools, application of exploit strategies such as overwriting return addresses/function pointers, return-oriented programming (ROP, SROP, ret2csu), shellcoding, glibc heap exploitation techniques (Use-After-Free, Unlink Exploit, House of Orange), understanding a complex real-world exploit, usage of git/GitLab and Docker for the exercises.

Learning goals: soft skills

Frustration tolerance when working with binary representations and trying to apply taught techniques, focused working on technically challenging problems, simultaneously applying knowledge from different areas of computer science.

Contents

This university course covers various topics related to software security and exploitation techniques. It starts with an introduction to finding vulnerabilities in C programs and binaries. The course then delves into stack-based buffer overflows and the mitigations used to prevent them. Students will also learn about circumventing these mitigations and explore return-oriented programming. The course continues with a focus on manual crafting of shellcode and understanding the internals of the glibc heap. Students will gain knowledge about heap exploitation techniques, including use-after-free exploits, heap unlink exploits, and the house of orange exploit. The course concludes with a complex case study on the Exim RCE exploit, providing students with a practical understanding of real-world vulnerabilities. Additionally, guest lectures will be held to provide further insights into the field of software security.

Please note that basic skills in static and dynamic binary analysis (e. g. read disassembled/decompiled code or debug a binary program with gdb) are required to successfully participate in this lecture.

Prerequisites

Recommended:
- Binary Analysis skills (as taught in the Bachelor's module BA-INF 155 Angewandte Binäranalyse; English slides available)
- Basic knowledge of the Linux operating system
- System Programming skills in C
- Basic Python programming skills

This module is best taken after or together with MA-INF 3239 Malware Analysis.

Course meetings

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

Graded exams

Oral Examination (30 minutes)

Ungraded coursework (required for admission to the exam)

The completion of regularly provided exercise sheets. The work can be done in groups of up to three students. The exercises are divided into group tasks and tasks to be completed individually. For each category of tasks, at least 50% of the points must be achieved.

Literature

The relevant literature will be announced at the beginning of the lecture

4.3 Computer Science Elective Modules – Algorithms

MA-INF 1103 Cryptography

Workload	Credit points	Duration	Frequency
270 h	9 CP	1 semester	every year

Module coordinator	Lecturer(s)
Dr. Michael Nüsken	Dr. Michael Nüsken

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	1. or 2.

Learning goals: 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, including modelling security and reducing security to basic assumptions.

Learning goals: soft skills

Competences: Ability to assess, present and explain schemes and their use in applications, orally and written. Critical assessment of applications in terms of security, social and ethical context and more.

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

Recommended:
Basics in elementary number theory, groups and complexity theory -in particular, reductions- are helpful.

Course meetings

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

Graded exams

Written exam (120 minutes)

Ungraded coursework (required for admission to the exam)

The completion of regularly provided exercise sheets. Each student must present a solution to an exercise in the exercise sessions twice.

Literature

- Jonathan Katz & Yehuda Lindell (2015/2008). Introduction to Modern Cryptography, CRC Press.
- Course notes

MA-INF 1105 Algorithms for Data Analysis

Workload	Credit points	Duration	Frequency
180 h	6 CP	1 semester	at least every 2 years

Module coordinator	Lecturer(s)
Prof. Dr. Petra Mutzel	Prof. Dr. Petra Mutzel

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	1. or 2.

Learning goals: technical skills

Ability to independently design and analyze efficient algorithms and data structures, in particular using methods and techniques of modern algorithmics with respect to big data and/or analytics tasks;

Learning goals: soft skills

Presentation of solutions and methods; critical discussion of applied methods and techniques clearly and in accordance with academic standards; ability to analyze problems theoretically and to find efficient as well as practical solutions; to examine one's solutions and results critically; to classify new problems into the state-of-the-art of the respective area;

Contents

Advanced algorithmic techniques and data structures relevant to analytic tasks for big data, i.e., algorithms for efficiently computing centrality indices for networks, theoretical and practical approaches to graph similarity, parallel algorithms, external data structures, and streaming algorithms.

Prerequisites

Recommended:
Essential is knowledge of:

- fundamental algorithms and algorithmic paradigms (e.g., graph algorithms, greedy algorithms, divide and conquer, dynamic programming), data structures (e.g., balanced search trees, hash tables)
- mathematical foundations of algorithm analysis (e.g., Big O notation, recurrence relations, proof techniques, running-time analysis)
- computational complexity (e.g., NP-hardness, reductions)

Course meetings

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

Graded exams

Oral exam (30 minutes)

Ungraded coursework (required for admission to the exam)

The completion of regularly provided exercise sheets. The work can be done in groups. A total of 50% of the points must be achieved. Each student must present a solution to an exercise in the exercise sessions twice. At the beginning of each exercise session, all participants mark on a list which (sub)exercises they have completed successfully and for which they wish to receive credit. The tutor then selects, for each (sub)exercise, one participant to present it. For more complex exercises, a written solution is required, which can be uploaded during the presentation.

MA-INF 1108 Introduction to High Performance Computing: Architecture Features and Practical Parallel Programming

Workload	Credit points	Duration	Frequency
180 h	6 CP	1 semester	every year

Module coordinator	Lecturer(s)
Prof. Dr. Estela Suarez	Prof. Dr. Estela Suarez

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	1. or 2.

Learning goals: 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.

Learning goals: soft skills

Critical assessment of hardware and applications in terms of performance and efficiency.

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:
MA-INF 1108 replaces MA-INF 1106 and cannot be taken after completing MA-INF 1106.

Recommended:
Knowledge of a modern programming language (ideally C/C++ and Python) is required.

Course meetings

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

Graded exams

Written exam (90 minutes)

Ungraded coursework (required for admission to the exam)

The completion of regularly provided exercise sheets. A total of 50% of the points must be achieved. Each student must present a solution to an exercise in the exercise sessions once.

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

MA-INF 1209 Seminar Advanced Topics in Cryptography

Workload	Credit points	Duration	Frequency
120 h	4 CP	1 semester	every semester

Module coordinator	Lecturer(s)
Dr. Michael Nüsken	Dr. Michael Nüsken

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	2. or 3.

Learning goals: technical skills

Enhanced and in-depth knowledge in specialized topics in the area of cryptography.

Learning goals: soft skills

Acquire the competence to independently search for and study state-of-the-art scientific literature in depth, read critically, identify the most relevant content, and assess research results in the context of cryptography; to discuss research results with a knowledgeable scientific audience; to present prior work by others in writing and in presentations with visual media at academic standards, well-structured and didactically effective, and motivate the audience to participate; to formulate and accept criticism; to manage one's time with relatively open assignments and long-ranging deadlines.

Contents

We discuss cutting-edge papers from current cryptographic research literature.

Prerequisites

Recommended:
Basic knowledge in cryptography is highly recommended, eg. by MA-INF 1103 – Cryptography.

Course meetings

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

Graded exams

Oral presentation, written report

Ungraded coursework (required for admission to the exam)

Attendance in course sessions in accordance with the exam regulations of 2023, § 12(6).

Literature

Current cryptographic literature.

MA-INF 1221 Lab Computational Analytics

Workload	Credit points	Duration	Frequency
270 h	9 CP	1 semester	every year

Module coordinator	Lecturer(s)
Prof. Dr. Petra Mutzel	Prof. Dr. Petra Mutzel

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	2. or 3.

Learning goals: technical skills

Ability to independently design, theoretically analyze, implement, and experimentally evaluate algorithms and efficient data structures for computational analytics problems; gain experience with software development techniques, tools and standards and the scientifically clean documentation of the students own work (including the written report and software).

Learning goals: soft skills

- Knowledge of scientific approach to problem solving;
- ability to scientifically present solutions and methods;
- critical discussion of applied methods and techniques clearly and in accordance with academic standards;
- ability to analyze problems theoretically and to find efficient as well as practical solutions;
- to examine one's solutions and results critically;
- to classify new problems into the state-of-the-art of the respective area.

Contents

We will design efficient exact and approximate algorithms and data structures for computational analytics problems. We study a (set of) selected combinatorial optimization problem(s) with the goal to design new algorithmic approaches. Often, we focus on solving (graph) problems for selected applications (e.g., in cartography, geodesy, neurosciences, chemistry, or others). Typically, we start with a literature search on State-of-the-Art approaches; based on that, we adapt selected approaches

to our studied problem(s) or we design new approaches. We then theoretically analyze and implement our adapted/new algorithms. This is followed by an extensive experimental evaluation including a discussion of the results on benchmark instances. Often, the analysis triggers improvements of the algorithms. This is also called the Algorithm Engineering cycle.

Prerequisites

Recommended:
Essential are knowledge of:

- fundamental algorithms and algorithmic paradigms (e.g., graph algorithms, greedy algorithms, divide and conquer, dynamic programming), data structures (e.g., balanced search trees, hash tables)
- mathematical foundations of algorithm analysis (e.g., Big O notation, recurrence relations, proof techniques, running-time analysis)
- computational complexity (e.g., NP-hardness, reductions).

It is recommended to first complete at least one of the following modules:

- MA-INF 1105 Algorithms for Data Analysis
- MA-INF 1201 Approximation Algorithms
- MA-INF 1203 Discrete and Computational Geometry
- MA-INF 1213 Randomized Algorithms and Probabilistic Analysis
- MA-INF 1218 Algorithms and Uncertainty
- MA-INF 1301 Algorithmic Game Theory
- MA-INF 4112 Algorithms for Data Science

Course meetings

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

Graded exams

Oral presentation, written report

Ungraded coursework (required for admission to the exam)
Project work; attendance in course sessions in accordance with the exam regulations of 2023, § 12(6).

Literature
The relevant literature will be announced in time.

MA-INF 1222 Lab High Performance Optimization

Workload	Credit points	Duration	Frequency
270 h	9 CP	1 semester	every year

Module coordinator	Lecturer(s)
Prof. Dr. Petra Mutzel	Prof. Dr. Petra Mutzel, Dr. Sven Mallach

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	2. or 3.

Learning goals: technical skills

• Ability to independently design, theoretically analyze, implement, and experimentally evaluate algorithms and efficient data structures for computational analytics problems;
• understanding and using parallel programming paradigms and high-level programming languages;
• using performance analysis tools, understanding performance bottlenecks and measures to improve them;
• acquisition of knowledge about software development and standards;
• gain experience with the documentation of the students own work (including the written report and software);

Learning goals: soft skills

• Knowledge of scientific approach to problem solving;
• ability to scientifically present solutions and methods;
• critical discussion of applied methods and techniques clearly and in accordance with academic standards;
• ability to analyze problems theoretically and to find efficient as well as practical solutions;
• to examine one's solutions and results critically;
• to classify new problems into the state-of-the-art of the respective area;

Contents

We will design efficient exact and approximate algorithms and data structures for optimization problems on big data with the focus of using high performance computing (HPC) systems (like, e.g. the HPC clusters Marvin or Bender). We study a (set of) selected optimization problem(s) with the goal to design new parallel algorithms that scale well on HPC systems. Often, we focus on solving (graph) problems for selected applications (e.g., physics, chemistry, neurosciences, geodesy, or others).

Typically, we start with an introduction into parallel algorithms and an introduction into the relevant API for developing parallel programs. A literature search yields State-of-the-Art techniques; based on that, we adapt selected approaches to our studied problem(s) or we design new approaches with the goal that they scale well on HPC systems. We then theoretically analyze and implement our adapted/new parallel algorithms using parallel programming paradigms and high-level programming languages. This is followed by an extensive experimental evaluation using performance analysis tools and understanding performance bottlenecks. Often, this triggers improvements of the parallel algorithms and/or the implementation.

Prerequisites

Recommended:
Essential are knowledge of:

• fundamental algorithms and algorithmic paradigms (e.g., graph algorithms, greedy algorithms, divide and conquer, dynamic programming), data structures (e.g., balanced search trees, hash tables)
• mathematical foundations of algorithm analysis (e.g., Big O notation, recurrence relations, proof techniques, running-time analysis)
• computational complexity (e.g., NP-hardness, reductions)

It is recommended to complete at least one the following modules first:

• MA-INF 1105 Algorithms for Data Analysis
• MA-INF 1108 Introduction to High Performance Computing: Architecture Features and Practical Parallel Programming
• MA-INF 1201 Approximation Algorithms
• MA-INF 1203 Discrete and Computational Geometry
• MA-INF 1213 Randomized Algorithms and Probabilistic Analysis
• MA-INF 1218 Algorithms and Uncertainty
• MA-INF 1301 Algorithmic Game Theory

Course meetings

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

Graded exams

Oral presentation, written report

Ungraded coursework (required for admission to the exam)

Project work; attendance in course sessions in accordance with the exam regulations of 2023, § 12(6).

Literature

The relevant literature will be announced in time.

MA-INF 1223 Privacy Enhancing Technologies

Workload	Credit points	Duration	Frequency
270 h	9 CP	1 semester	every year

Module coordinator	Lecturer(s)
Dr. Michael Nüsken	Dr. Michael Nüsken

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	2. or 3.

Learning goals: technical skills

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.

Learning goals: soft skills

Competences: Ability to assess, present and explain schemes and their use in applications, orally and written. Critical assessment of applications in terms of security, social and ethical context and more.

Contents

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.

Prerequisites

Recommended:
Basic knowledge in cryptography (for example from MA-INF 1103) 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.

Course meetings

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

Graded exams

Written exam (120 minutes)

Ungraded coursework (required for admission to the exam)

The completion of regularly provided exercise sheets. Each student must present twice in the tutorial.

MA-INF 1225 Lab Exploring HPC technologies

Workload	Credit points	Duration	Frequency
270 h	9 CP	1 semester	at least every 2 years

Module coordinator	Lecturer(s)
Prof. Dr. Estela Suarez	Prof. Dr. Estela Suarez

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	2. or 3.

Learning goals: 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.

Learning goals: soft skills

Ability to analyze computational problems and to find creative and practical solutions; to examine one's solutions and results critically; to classify one's own results into the state-of-the-art of the respective area; to produce good quality software, prepare readable documentation of software and research results; to present, defend and discuss design decisions and results in the team/group and to other students clearly and in accordance with academic standards; to aim at long-range goals under limited resources; to work under pressure.

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 1108 Introduction to High Performance Computing: Architecture Features and Practical Parallel Programming (or its precursor MA-INF 1106).
- Knowledge of modern programming languages (C/C++, Python).
- Willingness 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.

Course meetings

Teaching format	Group size	h/week	Workload[h]	CP
Lab	2	4	60 T / 210 S	9

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

Graded exams

Oral presentation, written report

Ungraded coursework (required for admission to the exam)

Project work; attendance in course sessions in accordance with the exam regulations of 2023, § 12(6).

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

MA-INF 1309 Lab Efficient Algorithms: Design, Analysis and Implementation

Workload	Credit points	Duration	Frequency
270 h	9 CP	1 semester	at least every year

Module coordinator	Lecturer(s)
Prof. Dr. Heiko Röglin	Prof. Dr. Anne Driemel, Prof. Dr. Thomas Kesselheim, Prof. Dr. Heiko Röglin, PD Dr. Elmar Langetepe, Dr. Herman Haverkort

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	1-3.

Learning goals: technical skills

Ability to independently design, analyze and implement efficient algorithms and data structures for selected computational problems

Learning goals: soft skills

Ability to analyze problems theoretically and to find creative and practical solutions; to examine one's solutions and results critically; to classify one's own results into the state-of-the-art of the

respective area; to prepare readable documentation of software and research results; to present, defend and discuss design decisions and results in the team/group and to other students clearly and in accordance with academic standards; to collaborate constructively with others in small teams over a longer period of time; to aim at long-range goals under limited resources; to work under pressure.

Contents

Design of efficient exact and approximate algorithms and data structures for selected computational problems.

Prerequisites

Recommended:
Knowledge of:

- fundamental algorithms and algorithmic paradigms (e.g., graph algorithms, greedy algorithms, divide and conquer, dynamic programming), data structures (e.g., balanced search trees, hash tables)
- mathematical foundations of algorithm analysis (e.g., Big O notation, recurrence relations, proof techniques, running-time analysis)
- computational complexity (e.g., NP-hardness, reductions)

It is recommended to take at least one of the following modules first:

- MA-INF 1102 Combinatorial Optimization
- MA-INF 1103 Cryptography
- MA-INF 1105 Algorithms for Data Analysis
- MA-INF 1107 Foundations of Quantum Computing
- MA-INF 1108 Introduction to High-Performance Computing: Architecture Features and Practical Parallel Programming
- MA-INF 1201 Approximation Algorithms
- MA-INF 1202 Chip Design
- MA-INF 1203 Discrete and Computational Geometry
- MA-INF 1213 Randomized Algorithms and Probabilistic Analysis
- MA-INF 1218 Algorithms and Uncertainty
- MA-INF 1227 Hardness of Approximation
- MA-INF 1301 Algorithmic Game Theory
- MA-INF 1314 Online Motion Planning
- MA-INF 1321 Binary Linear and Quadratic Optimization
- MA-INF 1323 Computational Topology

Course meetings

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

Graded exams
Oral presentation, written report

Ungraded coursework (required for admission to the exam)
Project work; attendance in course sessions in accordance with the exam regulations of 2023, § 12(6).

Literature
The relevant literature will be announced in time.

MA-INF 1316 Lab Cryptography

Workload	Credit points	Duration	Frequency
270 h	9 CP	1 semester	every year

Module coordinator	Lecturer(s)
Dr. Michael Nüsken	Dr. Michael Nüsken

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	2. or 3.

Learning goals: 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.

Learning goals: 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

Front of research topics in cryptography, in particular, related to fully homomorphic encryption, multi-party computation, automated security verification.

The target of the lab is to understand how cryptography may work in one particular application that we are choosing 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

Recommended:
Good knowledge in cryptography is vital, eg. by

- MA-INF 1103 - Cryptography
- MA-INF 1223 - Privacy Enhancing Technologies
- MA-INF 1209 - Seminar Advanced Topics in Cryptography.

Course meetings

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

Graded exams

Oral presentation, written report

Ungraded coursework (required for admission to the exam)

Project work; attendance in course sessions in accordance with the exam regulations of 2023, § 12(6).

MA-INF 1322 Seminar Focus Topics in High Performance Computing

Workload	Credit points	Duration	Frequency
120 h	4 CP	1 semester	every year

Module coordinator	Lecturer(s)
Prof. Dr. Estela Suarez	Prof. Dr. Estela Suarez

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	2. or 3.

Learning goals: technical skills

Enhanced and in-depth knowledge on topics and trends in the area of high performance computing.

Learning goals: soft skills

Acquire the competence to independently search for and study state-of-the-art scientific literature in depth, read critically, identify the most relevant content, and assess research results in the context of the corresponding research area; to execute peer-review processes, both to review work from others and to write rebuttal letters to reply reviewer reports; to discuss research results with a knowledgeable scientific audience; to present prior work by others in writing and in presentations with visual media in a way that adheres to academic standards, that is well-structured and didactically effective, and that motivates the audience to participate; to formulate and accept criticism; to manage one's time with relatively open assignments and long-ranging deadlines.

Contents

General topics and trends in high performance computing, based on recent review and research literature

Prerequisites

Recommended:
MA-INF 1108 Introduction to High Performance Computing: Architecture Features and Practical Parallel Programming

Course meetings

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

Graded exams

Oral presentation, written report

Ungraded coursework (required for admission to the exam)

Attendance in course sessions in accordance with the exam regulations of 2023, § 12(6).

Literature

Literature and further information about this seminar will be announced in time in the website of lecturer.

4.4 Computer Science Elective Modules – Graphics, Vision, Audio

MA-INF 2113 Foundations of Audio Signal Processing

Workload	Credit points	Duration	Frequency
180 h	6 CP	1 semester	every year

Module coordinator	Lecturer(s)
apl. Prof. Dr. Frank Kurth	apl. Prof. Dr. Frank Kurth, Prof. Dr. Michael Clausen

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	1. or 2.

Learning goals: technical skills

• Introduction to basic concepts of analog and digital signal processing: Acquire basic knowledge on modeling and representing audio content; learn fundamental concepts of analog and digital signal processing, in particular mathematical models of signal spaces and apply them to the audio domain; learn methods for analog to digital conversion, frequency analysis, time-frequency analysis and digital filtering.
• Applications in the field of Audio Signal Processing: Learn typical application domains of audio signal processing techniques and how to apply the acquired methods in solving applications problems from those domains. Important examples are basic signal manipulation and filtering.
• Solving basic Signal Processing Problems: Learn basic signal processing algorithms for performing the Fourier Transform and a time-frequency analysis, as well as for performing filter operations and fundamental types of signal manipulations.
• Implementing basic Signal Processing Algorithms using state-of-the-art software frameworks: In the exercises, the introduced methods and algorithms have to be implemented and applied to basic applications problems. Hence knowledge in the practical implementation of digital signal processing methods in standard programming environments such as Python, Matlab or Octave is acquired.

Learning goals: soft skills

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

Recommended:
Solid basic knowledge on Linear Algebra and Analysis on the level acquired in Bachelor in Computer Science programmes, including proficiency in using complex numbers.

Course meetings

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

Graded exams

Written exam (120 minutes)

Ungraded coursework (required for admission to the exam)

The completion of regularly provided exercise sheets. The work can be done in groups of two to four students. A total of 50% of the points must be achieved.

Forms of media

Slides, Blackboard, Whiteboard

MA-INF 2201 Computer Vision

Workload	Credit points	Duration	Frequency
270 h	9 CP	1 semester	every year

Module coordinator	Lecturer(s)
Prof. Dr. Jürgen Gall	Prof. Dr. Jürgen Gall

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	1. or 2.

Learning goals: technical skills

Students will be able to understand and explain mathematical descriptions of methods in publications from Computer Vision. Students will be able to implement the discussed Computer Vision algorithms, apply them, and choose the right approach and hyper-parameters for a given problem.

Learning goals: 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, Python programming

Course meetings

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

Graded exams

Written exam (120 minutes)

Ungraded coursework (required for admission to the exam)

The completion of regularly provided exercise sheets. The work can be done in groups of up to two students. A total of 50% of the points must be achieved.

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

MA-INF 2202 Computer Animation

Workload	Credit points	Duration	Frequency
270 h	9 CP	1 semester	every year

Module coordinator	Lecturer(s)
Prof. Dr. Björn Krüger	Prof. Dr. Björn Krüger

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	1-3.

Learning goals: technical skills

Students will learn fundamental paradigms used in computer animation. They will learn the mathematical foundations and basic algorithms to solve problems in the areas of motion capturing, motion synthesis, and motion analysis.

Learning goals: soft skills

Social competences (work in groups), communicative skills (written and oral presentation)

Contents

Fundamentals of computer animation; kinematics; representations of motions; motion capturing; motion editing; motion synthesis; facial animations

Prerequisites

Recommended:
Basic knowldge of linear algebra, analysis, Matlab and Python

Course meetings

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

Graded exams

Oral exam (30 minutes)

Ungraded coursework (required for admission to the exam)

The completion of regularly provided exercise sheets. The work can be done in groups of up to three students. A total of 50% of the points must be achieved.

Literature

- Dietmar Jackel, Stephan Neunreither, Friedrich Wagner: Methoden der Computeranimation, Springer 2006
- Rick Parent: Computer Animation: Algorithms and Techniques, Morgan Kaufman Publishers 2002
- Frederic I. Parke , Keith Waters: Computer Facial Animation. A K Peters, Ltd. 199
- Grünvogel Stefan, Einführung in die Computer Animation, Springer 2024

MA-INF 2208 Seminar Audio

Workload	Credit points	Duration	Frequency
120 h	4 CP	1 semester	every semester

Module coordinator	Lecturer(s)
apl. Prof. Dr. Frank Kurth	apl. Prof. Dr. Frank Kurth, Dr. Michael Clausen

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	2. or 3.

Learning goals: technical skills

Ability to understand new research results presented in original scientific papers.

Learning goals: 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:
MA-INF 2113 - Audio Signal Processing

Course meetings

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

Graded exams

Oral presentation, written report

Ungraded coursework (required for admission to the exam)

Attendance in course sessions in accordance with the exam regulations of 2023, § 12(6).

MA-INF 2212 Pattern Matching and Machine Learning for Audio Signal Processing

Workload	Credit points	Duration	Frequency
180 h	6 CP	1 semester	every year

Module coordinator	Lecturer(s)
apl. Prof. Dr. Frank Kurth	apl. Prof. Dr. Frank Kurth, Prof. Dr. Michael Clausen

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	2. or 3.

Learning goals: technical skills

• Introduction into selected topics of digital signal processing: Acquire basic knowledge on representing and manipulating 1D-time series. Learn basic methods for time-frequency analysis and signal processing methods for feature extraction.
• Applications in the field of Audio Signal Processing: Learn typical application domains of audio signal processing techniques and how to apply the acquired methods in solving applications problems. Important examples are filtering, signal/object detection and classification tasks.
• Methods of Automatic Pattern Recognition and Machine Learning: Learn fundamental methods for Fature Extraction, Automatic Pattern Recognition and Machine Learning. Be able to apply those fundamental methods (method list: see "Contents" section) in particular for solving applications tasks as described previously.

Learning goals: soft skills

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.

Contents

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; Deep Neural Networks

Prerequisites

Recommended:

Solid basic knowledge on Linear Algebra, Analysis and Stochastics, including proficiency in using complex numbers.

Having attended MA-INF 2113 Foundations of Audio Signal Processing is highly recommended, as fundamental material from (Digital) Signal Processing and Audio Processing are introduced there in depth.

Basic knowledge in time series data analysis is helpful but not mandatory.

Course meetings

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

Graded exams

Written exam (120 minutes)

Ungraded coursework (required for admission to the exam)

The completion of regularly provided exercise sheets. The work can be done in groups of two to four students. A total of 50% of the points must be achieved.

Forms of media

Slides, Blackboard, Whiteboard

MA-INF 2213 Advanced Computer Vision

Workload	Credit points	Duration	Frequency
180 h	6 CP	1 semester	every year

Module coordinator	Lecturer(s)
Prof. Dr. Jürgen Gall	Prof. Dr. Jürgen Gall

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	2. or 3.

Learning goals: technical skills

Students will be able to implement the discussed machine learning algorithms for Computer Vision, apply them, and choose the right approach and hyper-parameters for a given problem.

Learning goals: 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 learning methods and their applications in computer vision. For example, linear methods for classification and regression, Gaussian processes, random forests, SVMs and kernels, convolutional neural networks, vision transformer, generative adversarial networks, diffusion models, structured learning, image classification, object detection, action recognition, pose estimation, face analysis, tracking, image synthesis.

Prerequisites

Recommended:
MA-INF 2201 – Computer Vision

Course meetings

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

Graded exams

Oral exam (20 minutes)

Ungraded coursework (required for admission to the exam)

The completion of regularly provided exercise sheets. The work can be done in groups of up to two students. A total of 50% of the points must be achieved.

MA-INF 2216 Lab Visual Computing

Workload	Credit points	Duration	Frequency
270 h	9 CP	1 semester	every year

Module coordinator	Lecturer(s)
Prof. Dr. Florian Bernard	Prof. Dr. Florian Bernard

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	2. or 3.

Learning goals: technical skills

- Getting into a selected topic of visual computing
- Implementation and practical application of current visual computing methods
- Experimental evaluation and visualisation of results
- Scientific research and writing

Learning goals: soft skills

- self-organisation
- ability to analyze problems theoretically and to find creative and practical solutions
- critical thinking: examine one's solutions and results critically
- to classify own results into the state-of-the-art of the respective area
- to prepare readable documentation of software and research results
- to present, defend and discuss design decisions and results in the team/group and to other students clearly and in accordance with academic standards

Contents

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. Potential topics include deep learning (e.g. graph neural networks, unsupervised learning, 3D deep learning), mathematical optimization (e.g. linear/convex/non-convex programming, graph-based algorithms) and other methods involving mathematical modeling of visual computing problems.

Prerequisites

Recommended:
Basic knowledge in mathematics (e.g. linear algebra, calculus, optimization) and programming (e.g. python, in particular pytorch or tensorflow, C++, or Matlab). In addition:

- MA-INF 2317: Numerical Algorithms for Visual Computing and Machine Learning, or
- MA-INF 2225: Discrete Models for Visual Computing

Course meetings

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

Graded exams

Oral presentation, written report

Ungraded coursework (required for admission to the exam)

Project work; attendance in course sessions in accordance with the exam regulations of 2023, § 12(6).

MA-INF 2218 Video Analytics

Workload	Credit points	Duration	Frequency
180 h	6 CP	1 semester	at least every 2 years

Module coordinator	Lecturer(s)
Prof. Dr. Jürgen Gall	Prof. Dr. Jürgen Gall

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	2-3.

Learning goals: technical skills

Students will be able to implement the discussed machine learning algorithms for video understanding, apply them, and choose the right approach and hyper-parameters for a given problem.

Learning goals: 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, action recognition, hidden Markov models, 3D convolutional neural networks, temporal convolutional networks, recurrent neural networks, temporal action segmentation, weakly supervised learning, self-supervised learning, anticipation and forecasting.

Prerequisites

Recommended:
MA-INF 2201 – Computer Vision

Course meetings

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

Graded exams

Oral exam (20 minutes)

Ungraded coursework (required for admission to the exam)

The completion of regularly provided exercise sheets. A total of 50% of the points must be achieved.

MA-INF 2219 Seminar Visualization and Medical Image Analysis

Workload	Credit points	Duration	Frequency
120 h	4 CP	1 semester	at least every 2 years

Module coordinator	Lecturer(s)
Prof. Dr. Thomas Schultz	Prof. Dr. Thomas Schultz

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	2. or 3.

Learning goals: technical skills

Enhanced and in-depth knowledge in specialized topics in the area of visualization and medical image analysis.

Learning goals: soft skills

Acquire the competence to independently search for and study state-of-the-art scientific literature in depth, read critically, identify the most relevant content, and assess research results in the context of the corresponding research area; to discuss research results with a knowledgeable scientific audience; to present prior work by others in writing and in presentations with visual media in a way that adheres to academic standards, that is well-structured and didactically effective, and that motivates the audience to participate; to formulate and accept criticism; to manage one's time with relatively open assignments and long-ranging deadlines.

Contents

Recent research topics in visualization and medical image analysis based on journal and conference publications. Relevant journals include Medical Image Analysis, IEEE Transactions on Medical Imaging, IEEE Transactions on Visualization and Computer Graphics; relevant conferences include Medical Image Computing and Computer-Assisted Intervention (MICCAI), IEEE/CVF Computer Vision and Pattern Recognition (CVPR) IEEE VIS, EuroVis.

Prerequisites

Recommended:
At least one of the following:

- MA-INF 2222 – Visual Data Analysis
- MA-INF 2312 – Image Acquisition and Analysis in Neuroscience

Course meetings

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

Graded exams

Oral presentation, written report

Ungraded coursework (required for admission to the exam)

Attendance in course sessions in accordance with the exam regulations of 2023, § 12(6).

MA-INF 2220 Lab Visualization and Medical Image Analysis

Workload	Credit points	Duration	Frequency
270 h	9 CP	1 semester	every semester

Module coordinator	Lecturer(s)
Prof. Dr. Thomas Schultz	Prof. Dr. Thomas Schultz

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	2. or 3.

Learning goals: technical skills

Students acquire a deep understanding of a specific problem in visualization and medical image analysis, and technical knowledge about state-of-the-art algorithmic approaches to solving it. This involves problem identification; data processing; selection, design, implementation, and application of suitable algorithms; communication of results.

Learning goals: soft skills

Ability to analyze problems theoretically and to find creative and practical solutions; to examine one's solutions and results critically; to classify one's own results into the state-of-the-art of the

respective area; to prepare readable documentation of software and research results; to present, defend and discuss design decisions and results in the team/group and to other students clearly and in accordance with academic standards; to collaborate constructively with others in small teams over a longer period of time; to aim at long-range goals under limited resources.

Contents

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. Projects are often based on journal and conference publications. Relevant journals include Medical Image Analysis, IEEE Transactions on Medical Imaging, IEEE Transactions on Visualization and Computer Graphics; relevant conferences include Medical Image Computing and Computer-Assisted Intervention (MICCAI), IEEE/CVF Computer Vision and Pattern Recognition (CVPR) IEEE VIS, EuroVis.

Prerequisites

Recommended:
At least one of the following:

- MA-INF 2222 – Visual Data Analysis
- MA-INF 2312 – Image Acquisition and Analysis in Neuroscience.

A solid background in programming is required, preferably in Python. Most projects also require basic knowledge in linear algebra, calculus, probability theory, and/or numerical algorithms.

Course meetings

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

Graded exams

Oral presentation, written report

Ungraded coursework (required for admission to the exam)

Project work; attendance in course sessions in accordance with the exam regulations of 2023, § 12(6).

MA-INF 2222 Visual Data Analysis

Workload	Credit points	Duration	Frequency
270 h	9 CP	1 semester	every year

Module coordinator	Lecturer(s)
Prof. Dr. Thomas Schultz	Prof. Dr. Thomas Schultz

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	1. or 2.

Learning goals: technical skills

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.

Learning goals: soft skills

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

Contents

This class provides a broad overview of principles and algorithms for data analysis via interactive visualization. Specific topics include perceptual principles, color spaces, 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, geospatial data, neural networks, as well as scalar, vector and tensor fields.

Prerequisites

Recommended:
Students are recommended to have a basic knowledge in linear algebra and calculus, as well as proficiency in programming.

Course meetings

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

Graded exams

Written exam (120 minutes)

Ungraded coursework (required for admission to the exam)

The completion of regularly provided exercise sheets. The work can be done in groups of up to three students. A total of 50% of the points must be achieved. Each student must present a solution to an exercise in the exercise sessions once.

Literature

- 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

MA-INF 2225 Discrete Models for Visual Computing

Workload	Credit points	Duration	Frequency
180 h	6 CP	1 semester	at least every 2 years

Module coordinator	Lecturer(s)
Prof. Dr. Florian Bernard	Prof. Dr. Florian Bernard

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	1. or 2.

Learning goals: technical skills

• Ability to implement basic visual computing algorithms, understanding their strengths and shortcomings
• Mathematical modelling of computational problems in visual computing
• Gain an intuition which algorithm is best applied for which problem in visual computing, so that practical problems in these areas can be solved

Learning goals: soft skills

• 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

Contents

This module focuses on discrete models that frequently occur in the field of visual computing (VC). In addition to algorithms, this module will also cover modelling aspects that are relevant for solving practical problems in VC. The contents include:

• Graph-based models (e.g. linear and quadratic assignment, network flows, product graph formalisms, dynamic programming and their application)
• Continuous algorithms for discrete problems (e.g. convex & spectral relaxations, projection methods, path-following and their application)
• Deep Learning for discrete domains (e.g. differentiable programming, graph neural networks, deep learning on meshes)

Prerequisites

Recommended:
Participants are expected to have a high level of mathematical maturity (in particular, a good working knowledge of linear algebra and calculus/analysis is essential). A basic understanding of graph theory is advantageous.

Course meetings

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

Graded exams

Oral exam (30 minutes)

Ungraded coursework (required for admission to the exam)

The completion of regularly provided exercise sheets. The work can be done in groups of up to two students. A total of 50% of the points must be achieved.

MA-INF 2226 Lab Geometry Processing

Workload	Credit points	Duration	Frequency
270 h	9 CP	1 semester	at least every 2 years

Module coordinator	Lecturer(s)
Jun. Prof. Dr. Zorah Lähner	Jun. Prof. Dr. Zorah Lähner

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	1-3.

Learning goals: technical skills

Ability to handle complex geometric data types; to extract implementation details from research publications; to implement and visualize geometric data.

Learning goals: soft skills

Ability to analyze problems theoretically and to find creative and practical solutions; to examine one's solutions and results critically; to classify one's own results into the state-of-the-art of the respective area; to prepare readable documentation of software and research results; to present, defend and discuss design decisions and results in the team/group and to other students clearly and in accordance with academic standards; to collaborate constructively with others in small teams over a longer period of time.

Contents

Mesh deformation, point cloud meshing, pytorch3D, shape correspondence, reconstruction, 2D-to-3D transfer. This lab introduces methods and applications in the field of geometry processing. 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.

Prerequisites

none

Course meetings

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

Graded exams

Oral presentation, written report

Ungraded coursework (required for admission to the exam)

Project work; attendance in course sessions in accordance with the exam regulations of 2023, § 12(6).

MA-INF 2227 Lab 3D Animation

Workload	Credit points	Duration	Frequency
270 h	9 CP	1 semester	every semester

Module coordinator	Lecturer(s)
Prof. Dr. Ina Prinz	Prof. Dr. Ina Prinz

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	1-3.

Learning goals: technical skills

The students will learn to carry out a practical task (project) in the context of 3D animation, containing modelling, preparing a screenplay, realizing an animation related to real physical laws, rendering and creating a video.

Learning goals: 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 the history of computing and the mechanization of computing as well as deep understanding of mechanical and technical functions and its presentation in a representative 3D animation video, contains technical visualization and didactic skills.

Prerequisites

Recommended:
For students who did not take BA-INF 108 Geschichte des maschinellen Rechnens I and BA-INF 126 Geschichte des maschinellen Rechnens II in their Bachelor's studies, recommended reading includes:

- Aspray, W.: Computing before Computers. Ames, 1990.
- Bauer, Friedrich L.: Origins and Foundations of Computing. Berlin 2010.
- Ceruzzi, Paul E.: A History of Modern Computing. Cambridge, 2003.
- Goldstine, H.: The Computer from Pascal to von Neumann. Princeton, 1972.

Course meetings

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

Graded exams

Oral presentation, written report, presentation of the video

Ungraded coursework (required for admission to the exam)

Project work; attendance in course sessions in accordance with the exam regulations of 2023, § 12(6).

MA-INF 2308 Lab Graphics

Workload	Credit points	Duration	Frequency
270 h	9 CP	1 semester	every semester

Module coordinator	Lecturer(s)
Prof. Dr. Reinhard Klein	Prof. Dr. Reinhard Klein

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	2. or 3.

Learning goals: technical skills

The students will learn to 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.

Learning goals: 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

Recommended:
At least one of the following:

- MA-INF 1108 Introduction to High Performance Computing
- MA-INF 2202 Computer Animation
- MA-INF 2222 Visual Data Analysis

Course meetings

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

Graded exams

Oral presentation, written report

Ungraded coursework (required for admission to the exam)

Project work; attendance in course sessions in accordance with the exam regulations of 2023, § 12(6).

MA-INF 2309 Lab Audio

Workload	Credit points	Duration	Frequency
270 h	9 CP	1 semester	every year

Module coordinator	Lecturer(s)
apl. Prof. Dr. Frank Kurth	apl. Prof. Dr. Frank Kurth, Prof. Dr. Michael Clausen

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	2. or 3.

Learning goals: technical skills

Proficiency in implementing signal processing concepts introduced in selected scientific publications or research reports. Proficiency in collecting and maintaining data sets, in particular signals and corresponding metadata, and performing scientific evaluations of signal processing methods based on data sets and implemented algorithms.

Learning goals: soft skills

Ability to analyze problems theoretically and to find creative and practical solutions; to examine one's solutions and results critically; to classify one's own results into the state-of-the-art of the respective area; to prepare readable documentation of software and research results; to present, defend and discuss design decisions and results in the team/group and to other students clearly and in accordance with academic standards; to collaborate constructively with others in small teams over a longer period of time; to pursue long-range goals under a given resource budget.

Contents

In the lab a medium-sized programming project related to digital audio signal processing has to be solved during the period of one semester. For this, initial literature, usually in form of one or two scientific papers or reports, will be provided at the beginning of the lab. Also, resources regarding the audio signal data to be used, are given. Typical programming tasks consist of implementing either general signal processing algorithms such as fundamental frequency estimation or of implementing algorithms for solving application problems such as speaker detection or classification. For participants with interest in topics of pattern recognition, machine and deep learning, programming projects from those areas, with application to audio processing, can be selected.

Prerequisites

Recommended:
Solid basic proficiency in imperative programming (e.g. knowledge of C/C++, Java, Python). Knowledge of the material from MA-INF 2113 Foundations of Audio Signal Processing is highly recommended. Knowledge of material from MA-INF 2212 Pattern Matching and Machine Learning for Audio is helpful but not necessary.

Course meetings

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

Graded exams

Oral presentation, written report

Ungraded coursework (required for admission to the exam)

Project work; attendance in course sessions in accordance with the exam regulations of 2023, § 12(6).

MA-INF 2317 Numerical Algorithms for Visual Computing and Machine Learning

Workload	Credit points	Duration	Frequency
180 h	6 CP	1 semester	at least every 2 years

Module coordinator	Lecturer(s)
Prof. Dr. Florian Bernard	Prof. Dr. Florian Bernard

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	1. or 2.

Learning goals: technical skills

• 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

Learning goals: soft skills

• 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

Contents

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.

Prerequisites

Recommended:
Participants are expected to have a high level of mathematical maturity (in particular, a good working knowledge of linear algebra and calculus/analysis is essential). A basic understanding of mathematical optimisation is advantageous.

Course meetings

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

Graded exams

Written exam (120 minutes)

Ungraded coursework (required for admission to the exam)

The completion of regularly provided exercise sheets. The work can be done in groups of up to two students. A total of 50% of the points must be achieved.

4.5 Computer Science Elective Modules – Security, Information and Communication Management

MA-INF 3209 Seminar Selected Topics in Communication Management

Workload	**Credit points**	**Duration**	**Frequency**
120 h	4 CP	1 semester	every semester

Module coordinator	**Lecturer(s)**
Prof. Dr. Peter Martini	Prof. Dr. Peter Martini, Prof. Dr. Michael Meier, Dr. Matthias Frank

Programme	**Mode**	**Semester**
M. Sc. Cyber Security	Optional	2. or 3.

Learning goals: technical skills

Enhanced and in-depth knowledge in specialized topics in the area of communication systems and Internet protocols.

Learning goals: soft skills

Acquire the competence to independently search for and study state-of-the-art scientific literature in depth, read critically, identify the most relevant content, and assess research results in the context of the corresponding research area; to discuss research results with a knowledgeable scientific audience; to present prior work by others in writing and in presentations with visual media in a way that adheres to academic standards, that is well-structured and didactically effective, and that motivates the audience to participate; to formulate and accept criticism; to manage one's time with relatively open assignments and long-ranging deadlines.

Contents

Current research topics in communication systems and Internet protocols based on conference and journal papers.

Prerequisites

Recommended:
Successful completion of at least one of the following lectures:

- MA-INF 3202 Mobile Communication
- MA-INF 3236 IT Security
- MA-INF 3239 Malware Analysis

Bachelor level knowledge of basics of communication systems and Internet protocols, e.g. OSI model, medium access of wired and wireless LAN technologies, IP adressing and routing, transport protocols UDP and TCP.

Course meetings

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

Graded exams

Oral presentation, written report

Ungraded coursework (required for admission to the exam)

Attendance in course sessions in accordance with the exam regulations of 2023, § 12(6).

Literature

The relevant literature will be announced towards the end of the previous semester

MA-INF 3216 Seminar Sensor Data Fusion

Workload	Credit points	Duration	Frequency
120 h	4 CP	1 semester	every year

Module coordinator	Lecturer(s)
Prof. Dr. Wolfgang Koch	Prof. Dr. Wolfgang Koch, Dr. Felix Govaers

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	3.

Learning goals: technical skills

Enhanced and in-depth knowledge in specialized topics in state estimation and object tracking.

Learning goals: soft skills

Acquire the competence to independently search for and study state-of-the-art scientific literature in depth, read critically, identify the most relevant content, and assess research results in the context of the corresponding research area; to discuss research results with a knowledgeable scientific audience; to present prior work by others in writing and in presentations with visual media in a way that adheres to academic standards, that is well-structured and didactically effective, and that motivates the audience to participate; to formulate and accept criticism; to manage one's time with relatively open assignments and long-ranging deadlines.

Contents

The seminar focuses on specific research papers in the field of sensor data fusion, which may include topics like non-linear state estimation, deep learning for sensor perception, or multi object tracking.

Prerequisites

Recommended:
- MA-INF 3310 Introduction to Sensor Data Fusion – Methods and Applications.
- It is assumed that the participants know linear algebra and have basic knowledge in probability theory.

Course meetings

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

Graded exams

Oral presentation, written report

Ungraded coursework (required for admission to the exam)

Attendance in course sessions in accordance with the exam regulations of 2023, § 12(6).

Literature

The relevant literature will be announced at the beginning of the seminar.

MA-INF 3229 Lab IT-Security

Workload	Credit points	Duration	Frequency
270 h	9 CP	1 semester	every semester

Module coordinator	Lecturer(s)
Prof. Dr. Michael Meier	Prof. Dr. Michael Meier

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	2. or 3.

Learning goals: technical skills

After completion of the lab module students have completed a practical task in the context of IT security. The students will have gained experience in the typical technical skills like the design and implementation of software, test and documentation of the software, and performance evaluation (e.g. by measurements, simulation, analysis) and presentation of performance results.

Learning goals: soft skills

Ability to analyze problems theoretically and to find creative and practical solutions; to examine one's solutions and results critically; to classify one's own results into the state-of-the-art of the respective area; to prepare readable documentation of software and research results; to present, defend and discuss design decisions and results in the team/group and to other students clearly and in accordance with academic standards; to collaborate constructively with others in small teams over a longer period of time; to aim at long-range goals under limited resources; to work under pressure.

Contents

Selected topics close to current research in the area of IT security.

Prerequisites

Recommended:
Foundational knowledge in

- IT security: security terminology, authentication, access control, applied cryptography (symmetric encryption, asymmetric encryption, hashing, key management)
- Networks: OSI model, addressing, routing, protocols.

It is recommended to take MA-INF 3236 IT Security first.

Course meetings

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

Graded exams

Oral presentation, written report

Ungraded coursework (required for admission to the exam)

Project work; attendance in course sessions in accordance with the exam regulations of 2023, § 12(6).

MA-INF 3233 Advanced Sensor Data Fusion in Distributed Systems

Workload	Credit points	Duration	Frequency
180 h	6 CP	1 semester	every year

Module coordinator	Lecturer(s)
Prof. Dr. Wolfgang Koch	Dr. Felix Govaers

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	2. or 3.

Learning goals: technical skills

Students will be able to describe the advanced principles of sensor data fusion for state estimation and object tracking based on tracks from multiple sensors in distributed systems. They will be aware of the correlation problem in track-to-track fusion and know several algorithms to cope with it. They will know the assumptions, advantages and disadvantages of different algorithms and be able to select and apply suitable candidates in practical applications.

Learning goals: 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.

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.

Prerequisites

Recommended:
Basic knowledge about the Kalman filter is required (see also recommended literature).

Students who did not take BA-INF 137 – Einführung in die Sensordatenfusion in their Bachelor's are advised to first take MA-INF 3310 – Introduction to Sensor Data Fusion - Methods and Applications.

Course meetings

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

Graded exams

Oral exam (30 minutes)

Ungraded coursework (required for admission to the exam)

50% of the maximum achievable points in the practical programming exercises are required. There is one practical exercise, which is a workload of about 15h. The delivery of the programmed solution is done individually or in group work of up to three students. A total of 10 points will be awarded, 50% of which will have been achieved if the Distributed Kalman filter has been programmed in an executable and consistent manner.

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.

MA-INF 3237 Array Signal and Multi-channel Processing

Workload	Credit points	Duration	Frequency
180 h	6 CP	1 semester	every year

Module coordinator	Lecturer(s)
Prof. Dr. Wolfgang Koch	Dr. Marc Oispuu

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	1-3.

Learning goals: technical skills

Students will be able to describe the central principles of array signal and multi-channel processing and to name their advantages and disadvantages as well as to illustrate their relevance in application examples such as wireless communication, acoustics, radar, sonar or seismology. Furthermore, they will be able to implement suitable methods of direction finding, spatial filtering and bearings-only localization and to apply them to electromagnetic or acoustic signals and to evaluate the achieved results in terms of their performance.

Learning goals: soft skills

Mathematical derivation of algorithms, applications of mathematical results on estimation theory

Contents

Estimation theory, Sensor model, Cramér-Rao analysis, conventional beamforming, Multiple Signal Classification (MUSIC), sensor calibration, Bearings-only localization, Direct Position Determination (DPD), Applications

Prerequisites

none

Course meetings

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

Graded exams

Oral Exam (30 minutes)

Ungraded coursework (required for admission to the exam)

50% of the maximum achievable points in the practical programming exercises are required. There is one practical exercise, which is a workload of about 10h. The delivery of the programmed solution is done individually or in group work of up to three students. A total of 10 points will be awarded, 50% of which will have been achieved if the basic signal processing algorithms for array sensors have been implemented.

Forms of media

Power Point

Literature

H. L. van Trees, Optimum Array Processing. Part IV of Detection, Estimation, and Modulation Theory. New York: Wiley-Interscience, 2002.

MA-INF 3304 Lab Communication and Communicating Devices

Workload	**Credit points**	**Duration**	**Frequency**
270 h	9 CP	1 semester	every semester

Module coordinator	**Lecturer(s)**
Prof. Dr. Peter Martini	Prof. Dr. Peter Martini, Prof. Dr. Michael Meier, Dr. Matthias Frank

Programme	**Mode**	**Semester**
M. Sc. Cyber Security	Optional	2. or 3.

Learning goals: technical skills

After completion of the lab module students have completed a practical task in the context of communication and networked systems. The students will have gained experience in the typical technical skills like the design and implementation of communication software/networked systems, test and documentation of the software, and performance evaluation (e.g. by measurements, simulation, analysis) and presentation of performance results.

Learning goals: soft skills

Ability to analyze problems theoretically and to find creative and practical solutions; to examine one's solutions and results critically; to classify one's own results into the state-of-the-art of the respective area; to prepare readable documentation of software and research results; to present, defend and discuss design decisions and results in the team/group and to other students clearly and in accordance with academic standards; to collaborate constructively with others in small teams over a longer period of time; to aim at long-range goals under limited resources; to work under pressure.

Contents

Selected topics close to current research in the area of communication systems, network security, mobile communication and communicating devices.

Prerequisites

Recommended:
Foundational knowledge in networks: OSI model, addressing, routing, protocols;

Successful completion of at least one of the following lectures:

- MA-INF 3202 Mobile Communication
- MA-INF 3236 IT Security
- MA-INF 3239 Malware Analysis

Course meetings

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

Graded exams

Oral presentation, written report

Ungraded coursework (required for admission to the exam)

Project work; attendance in course sessions in accordance with the exam regulations of 2023, § 12(6).

Literature

The relevant literature will be announced towards the end of the previous semester.

MA-INF 3310 Introduction to Sensor Data Fusion - Methods and Applications

Workload	Credit points	Duration	Frequency
180 h	6 CP	1 semester	every year

Module coordinator	Lecturer(s)
Prof. Dr. Wolfgang Koch	Prof. Dr. Wolfgang Koch

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	1. or 2.

Learning goals: technical skills

Students will be able to describe the central principles of sensor data fusion for state estimation and object tracking based on error-prone and ambiguous measurements. They will be able to apply the Kalman filter and to formulate sensor and dynamics models for different kind of sensors and objects. Furthermore, they will know the concept of probabilistic data association and a computationally feasible approximation using Gaussian mixture densities.

Learning goals: soft skills

Mathematical derivation of algorithms, application of mathematical results on estimation theory.

Contents

Gaussian probability density functions, Kalman filter, Unscented Kalman Filter, Extended Kalman Filter, Particle Filter, Multi-Hypothesis-Trackier, Extended Target Tracking, Road Tracking, Interacting Multiple Model Filter, Retrodiction, Smoothing, Maneuver Modeling.

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.

Prerequisites

Recommended:
It is assumed that the participants know linear algebra and have basic knowledge in probability theory.

Course meetings

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

Graded exams

Written exam (120 minutes)

Ungraded coursework (required for admission to the exam)

50% of the possible points for the exercises. The points are acquired by a small programming exercise with a workload of about 15 hours and some theoretical exercises with a workload of 10 hours. The solution has to be submitted individually or in groups of up to three students and will be rated by points.

Literature

• 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.

MA-INF 3312 Lab Sensor Data Fusion

Workload	Credit points	Duration	Frequency
270 h	9 CP	1 semester	every year

Module coordinator	Lecturer(s)
Prof. Dr. Wolfgang Koch	Prof. Dr. Wolfgang Koch

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	2. or 3.

Learning goals: technical skills

Enhanced and in-depth knowledge in specialized topics in state estimation and object tracking.

Learning goals: soft skills

Ability to analyze problems theoretically and to find creative and practical solutions; to examine one's solutions and results critically; to classify one's own results into the state-of-the-art of the respective area; to prepare readable documentation of software and research results; to present, defend and discuss design decisions and results in the team/group and to other students clearly and in accordance with academic standards; to collaborate constructively with others in small teams over a longer period of time; to aim at long-range goals under limited resources; to work under pressure.

Contents

In the lab, the students apply methods from the sensor data fusion and state estimation theory to practical examples in order to get experience in the application and implementation. The exemplary scenarios and application examples vary each year but may be for instance on a simulated radar network for multi object tracking, camera image processing, heterogeneous sensor fusion, or array sensor bearing processing.

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.

Prerequisites

Recommended:
- MA-INF 3310 Introduction to Sensor Data Fusion – Methods and Applications;
- knowledge of linear algebra and basic knowledge in probability theory.

Course meetings

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

Graded exams

Oral presentation, written report

Ungraded coursework (required for admission to the exam)

Project work; attendance in course sessions in accordance with the exam regulations of 2023, § 12(6).

Literature

The relevant literature will be announced at the beginning of the lab.

MA-INF 3317 Seminar Selected Topics in IT Security

Workload	Credit points	Duration	Frequency
120 h	4 CP	1 semester	every semester

Module coordinator	Lecturer(s)
Prof. Dr. Michael Meier	Prof. Dr. Michael Meier, Prof. Dr. Peter Martini

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	2. or 3.

Learning goals: technical skills

Enhanced and in-depth knowledge in specialized topics in the area of IT Security.

Learning goals: soft skills

Acquire the competence to independently search for and study state-of-the-art scientific literature in depth, read critically, identify the most relevant content, and assess research results in the context of the corresponding research area; to discuss research results with a knowledgeable scientific audience; to present prior work by others in writing and in presentations with visual media in a way that adheres to academic standards, that is well-structured and didactically effective, and that motivates the audience to participate; to formulate and accept criticism; to manage one's time with relatively open assignments and long-ranging deadlines.

Contents

Current research topics in IT security based on conference and journal papers.

Prerequisites

Recommended:
Foundational knowledge in

- IT security: security terminology, authentication, access control, applied cryptography (symmetric encryption, asymmetric encryption, hashing, key management)
- Networks: OSI model, addressing, routing, protocols.

It is recommended to take MA-INF 3236 IT Security first.

Course meetings

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

Graded exams

Oral presentation, written report

Ungraded coursework (required for admission to the exam)

Attendance in course sessions in accordance with the exam regulations of 2023, § 12(6).

MA-INF 3319 Lab Usable Security and Privacy

Workload	Credit points	Duration	Frequency
270 h	9 CP	1 semester	every semester

Module coordinator	Lecturer(s)
Prof. Dr. Matthew Smith	Prof. Dr. Matthew Smith

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	2. or 3.

Learning goals: technical skills

Ability to carry out a practical task (project) in the context of human factors of security and privacy, including user studies and their evaluation. This includes selecting variables of interest, designing measurement instruments, such as interviews, surveys or prototypes, recruiting participants, executing and evaluating the user-study.

Learning goals: soft skills

Ability to 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

The students will select and carry out a practical task (project) in the context of human factors of security and privacy, including user studies and their evaluation. Topics for the project are close to current research in the area of human aspects of security and privacy. Focus topics include but are not limited to: Attitudes towards Surveillance, S&P Ethics, Privacy technology, Authentication, Encryption, Gamification, Age verification, etc.

Prerequisites

Recommended:
Knowledge on how to run and evaluate user studies is required. It is recommended to check the material of the Bachelor's course BA-INF 145 Usable Security and Privacy (available in English) and to take:

- MA-INF 3241 Practical Challenges in Human Factors of Security and Privacy.

Course meetings

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

Graded exams

Oral presentation, written report

Ungraded coursework (required for admission to the exam)

Project work; attendance in course sessions in accordance with the exam regulations of 2023, § 12(6).

MA-INF 3320 Lab Security in Distributed Systems

Workload	Credit points	Duration	Frequency
270 h	9 CP	1 semester	every semester

Module coordinator	Lecturer(s)
Prof. Dr. Matthew Smith	Prof. Dr. Matthew Smith

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	2. or 3.

Learning goals: technical skills

Ability to carry out a practical task (project) in the context of distributed security using modern software engineering processes, including testing and documentation of the implemented software/system.

Learning goals: soft skills

Ability to 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

The students will carry out a practical task (project) in the context of distributed security, including documentation of the implemented software/system. Topics are selected topics close to current research in the area of distributed systems security and privacy. Focus topics include but are not limited to: Authentication, Encryption, Gamification, Age verification, Data management, Study platforms, etc. The students will build software systems using modern software engineering processes. They will test them either programmatically or with a small user studies. They will document their software.

Prerequisites

Recommended:
Strong programming skills are required. It is recommended to take MA-INF 3242 Security of Distributed and Resource-constrainted Systems first.

Course meetings

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

Graded exams

Oral presentation, written report

Ungraded coursework (required for admission to the exam)

Project work; attendance in course sessions in accordance with the exam regulations of 2023, § 12(6).

MA-INF 3321 Seminar Usable Security and Privacy

Workload	Credit points	Duration	Frequency
120 h	4 CP	1 semester	every semester

Module coordinator	Lecturer(s)
Prof. Dr. Matthew Smith	Prof. Dr. Matthew Smith

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	1-3.

Learning goals: technical skills

Enhanced and in-depth knowledge in specialized topics in the area of human aspects of security and privacy.

Learning goals: soft skills

Acquire the competence to independently search for and study state-of-the-art scientific literature in depth, read critically, identify the most relevant content, and assess research results in the context of the corresponding research area; to discuss research results with a knowledgeable scientific audience; to present prior work by others in writing and in presentations with visual media in a way that adheres to academic standards, that is well-structured and didactically effective, and that motivates the audience to participate; to formulate and accept criticism; to manage one's time with relatively open assignments and long-ranging deadlines.

Contents

Current conference and journal papers in the area of human aspects of security and privacy. This includes but is not limited to: Attitudes towards Surveillance, S&P Ethics, Privacy technology, Authentication, Encryption, Gamification, Age verification, etc.

Prerequisites

none

Course meetings

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

Graded exams

Oral presentation, written report

Ungraded coursework (required for admission to the exam)

Attendance in course sessions in accordance with the exam regulations of 2023, § 12(6).

MA-INF 3323 Lab Fuzzing

Workload	Credit points	Duration	Frequency
270 h	9 CP	1 semester	every year

Module coordinator	Lecturer(s)
Prof. Dr. Matthew Smith	Dr. Christian Tiefenau

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	2. or 3.

Learning goals: 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.

Learning goals: 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

The lab aims at understanding and extending current fuzzers (AFL++, libFuzzer, syzkaller, kafl and Jazzer).

Prerequisites

none

Course meetings

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

Graded exams

Oral presentation, written report

Ungraded coursework (required for admission to the exam)

Project work; attendance in course sessions in accordance with the exam regulations of 2023, § 12(6).

4.6 Computer Science Elective Modules – Intelligent Systems

MA-INF 4111 Principles of Machine Learning

Workload	Credit points	Duration	Frequency
180 h	6 CP	1 semester	every 2 years

Module coordinator	Lecturer(s)
Prof. Dr.-Ing. Christian Bauckhage	Prof. Dr.-Ing. Christian Bauckhage

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	1-2.

Learning goals: technical skills

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.

Learning goals: soft skills

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

Contents

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.

Prerequisites

Recommended:
Linear algebra, statistics, probability theory, calculus, python programming

Course meetings

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

Graded exams

Written exam (120 minutes)

Ungraded coursework (required for admission to the exam)

The completion of regularly provided exercise sheets. The work can be done in groups of up to five students. A total of 50% of the points must be achieved. Each student must present a solution to an exercise in the exercise sessions once.

Forms of media

- lecture slides / lecture notes are made available online
- notebooks with programming examples are made available online

Literature

- 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

MA-INF 4112 Algorithms for Data Science

Workload	Credit points	Duration	Frequency
180 h	6 CP	1 semester	every year

Module coordinator	Lecturer(s)
Prof. Dr. Stefan Wrobel	Dr. Tamas Horvath, Prof. Dr. Stefan Wrobel

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	1. or 2.

Learning goals: technical skills

In this module the students will learn algorithms for data science as well as implement and practice selected algorithms from this field. The module concentrates on basic algorithms in association rule mining, graph mining, and data streams. At the end of the module, students will be capable of analyzing formal properties of this kind of algorithms and choosing appropriate pattern discovery and data stream algorithms.

Learning goals: 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), social skills (effective team work and project planning).

Contents

The module is offered every year, each time concentrating on one or more specific issues, such as frequent, closed and maximal frequent itemset mining, frequent subgraph mining algorithms for forests and for other graph classes beyond forests, frequent items and frequency moments in data streams, and graph stream algorithms.

Prerequisites

Recommended:
Knowledge of standard notions and results from complexity theory, propositional logic, hashing, probability theory, and calculus, all on the bachelor level, are required.

Course meetings

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

Graded exams

Written exam (120 minutes)

Ungraded coursework (required for admission to the exam)

The completion of regularly provided exercise sheets. The work can be done in groups of up to five students. A total of 50% of the points must be achieved. Each student must present a solution to an exercise in the exercise sessions once.

Forms of media

lectures, exercises

Literature

- Avrim Blum, John Hopcroft, Ravindran Kannan: Foundations of Data Science. Cambridge University Press, 2020.
- Jiawei Han, Micheline Kamber, Jian Pei: Data Mining: Concepts and Techniques. Morgan Kaufmann Publishers, 2012.
- David J. Hand, Heikki Mannila and Padhraic Smyth: Principles of Data Mining. The MIT Press, 2001.

MA-INF 4113 Cognitive Robotics

Workload	Credit points	Duration	Frequency
180 h	6 CP	1 semester	every year

Module coordinator	Lecturer(s)
Prof. Dr. Sven Behnke	Prof. Dr. Sven Behnke, Prof. Dr. Maren Bennewitz

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	1. or 2.

Learning goals: technical skills

This lecture is one of two introductory lectures on Robotics 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.

Learning goals: soft skills

Communicative skills (oral and written presentation of solutions, discussions in small teams), self competences (ability to accept and formulate criticism, ability to analyze problems)

Contents

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.

Prerequisites

none

Course meetings

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

Graded exams

Written exam (120 minutes)

Ungraded coursework (required for admission to the exam)

The completion of regularly provided exercise sheets. The work can be done in groups of up to two students. A total of 50% of the points must be achieved.

Literature

- 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.

MA-INF 4114 Robot Learning

Workload	Credit points	Duration	Frequency
180 h	6 CP	1 semester	every year

Module coordinator	Lecturer(s)
Prof. Dr. Sven Behnke	Prof. Dr. Sven Behnke, Dr. Nils Goerke

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	1. or 2.

Learning goals: technical skills

This lecture is one of two introductory lectures on Robotics 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.

Learning goals: soft skills

Communicative skills (oral and written presentation of solutions, discussions in small teams), self competences (ability to accept and formulate criticism, ability to analyze problems)

Contents

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.

Prerequisites

none

Course meetings

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

Graded exams

Written exam (120 minutes)

Ungraded coursework (required for admission to the exam)

The completion of regularly provided exercise sheets. The work can be done in groups of up to two students. A total of 50% of the points must be achieved.

Literature

- 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.

MA-INF 4201 Artificial Life

Workload	Credit points	Duration	Frequency
180 h	6 CP	1 semester	every year

Module coordinator	Lecturer(s)
Prof. Dr. Sven Behnke	Dr. Nils Goerke

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	1-3.

Learning goals: technical skills

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. The students can judge and explain if an Artificial Life approach is feasible for a given class of problems. They can estimate the necessary effort to implement and shape the Artificial Life paradigm w.r.t. the task, and can give an educated estimation of the possible outcome and forseeable limitations of the approach. They can implement the basic fundamental Artificial Life paradigms.

Learning goals: soft skills

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.

Contents

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.

Prerequisites

Recommended:
Basic knowledge of linear algebra, analysis, logic, automata, and complexity analysis of deterministic and randomised algorithms.

Course meetings

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

Graded exams

Written exam (100 minutes)

Ungraded coursework (required for admission to the exam)

The completion of regularly provided exercise sheets. The work can be done in groups of up to four students. A total of 50% of the points must be achieved. Each student must present a solution to an exercise in the exercise sessions twice.

Forms of media

Pencil and paper work, explain solutions in front of the exercise group, implementation of small programs, use of simple simulation tools.

Literature

- 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

MA-INF 4204 Technical Neural Nets

Workload	Credit points	Duration	Frequency
180 h	6 CP	1 semester	every year

Module coordinator	Lecturer(s)
Dr. Nils Goerke	Dr. Nils Goerke

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	1. or 2.

Learning goals: 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. The students can judge and explain if a neural network approach is feasible for a given class of problems. They can estimate the necessary effort to implement and shape the neural approach for a given task and can give an educated estimation of the possible outcome and foseeable limitations of that approach. They can implement the basic neural network approaches and neural learning paradigms.

Learning goals: 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. Capability to identify the state of the art in neural network research. Capability 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.

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

Recommended:
Basic knowledge of linear algebra, analysis, logic, automata, complexity analysis of deterministic and randomised algorithms, and practical and theoretical foundations of machine learning.

Course meetings

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

Graded exams

Written exam (100 minutes)

Ungraded coursework (required for admission to the exam)

The completion of regularly provided exercise sheets. The work can be done in groups of up to four students. A total of 50% of the points must be achieved. Each student must present a solution to an exercise in the exercise sessions twice.

Forms of media

Pencil and paper work, explaining solutions in front of the exercise group, implementation of small programs, use of simple simulation tools

Literature
• Christopher M. Bishop: Neural Networks for Pattern Recognition, Oxford University Press, ISBN-10: 0198538642, ISBN-13: 978-0198538646 • Ian T. Nabney: NETLAB. Algorithms for Pattern Recognition, Springer, ISBN-10: 1852334401, ISBN-13: 978-1852334406 • David Kriesel: A brief Introduction on Neural Networks, http://www.dkriesel.com/en/science/neural_networks • David Kriesel: Ein kleiner Überblick über Neuronale Netze, http://www.dkriesel.com/science/neural_networks • Simon Haykin: Neural Networks, and Learning Machines, 3rd Edition, Prentice Hall International Editions.

MA-INF 4208 Seminar Vision Systems

Workload	Credit points	Duration	Frequency
120 h	4 CP	1 semester	every semester

Module coordinator	Lecturer(s)
Prof. Dr. Sven Behnke	Prof. Dr. Sven Behnke, Dr. Nils Goerke

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	2. or 3.

Learning goals: technical skills

• 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.

Learning goals: soft skills

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).

Contents

Current research papers from conferences and journals in the field of vision systems covering fundamental techniques and applications.

Prerequisites

Recommended:
At least one of the following:

• MA-INF 2201 - Computer Vision
• MA-INF 4111 – Principles of Machine Learning
• MA-INF 4204 – Technical Neural Nets

Course meetings

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

Graded exams

Oral presentation, written report

Ungraded coursework (required for admission to the exam)

Attendance in course sessions in accordance with the exam regulations of 2023, § 12(6).

Literature

• 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.

MA-INF 4209 Seminar Principles of Data Mining and Learning Algorithms

Workload	Credit points	Duration	Frequency
120 h	4 CP	1 semester	every year

Module coordinator	Lecturer(s)
Prof. Dr. Stefan Wrobel	Prof. Dr. Stefan Wrobel, PD Dr. Michael Mock, Dr. Florian Seiffarth, Dr. Tamas Horvath

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	2. or 3.

Learning goals: technical skills

Enhanced and in-depth knowledge in specialized topics in the area of machine learning and data mining.

Learning goals: soft skills

Acquire the competence to independently search for and study state-of-the-art scientific literature in depth, read critically, identify the most relevant content, and assess research results in the context of the corresponding research area; to discuss research results with a knowledgeable scientific audience; to present prior work by others in writing and in presentations with visual media in a way that adheres to academic standards, that is well-structured and didactically effective, and that motivates the audience to participate; to formulate and accept criticism; to manage one's time with relatively open assignments and long-ranging deadlines.

Contents

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.

Prerequisites

Recommended:
Knowledge of basic notions and algorithms from machine learning and data mining. It is recommend to first take at least one of the following modules:

- MA-INF 4111 – Principles of Machine Learning
- MA-INF 4112 – Algorithms for Data Science

Course meetings

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

Graded exams

Oral presentation, written report

Ungraded coursework (required for admission to the exam)

Attendance in course sessions in accordance with the exam regulations of 2023, § 12(6).

Forms of media

Scientific papers and websites, interactive presentations.

Literature

The relevant literature will be announced towards the end of the previous semester.

MA-INF 4211 Seminar Cognitive Robotics

Workload	Credit points	Duration	Frequency
120 h	4 CP	1 semester	every semester

Module coordinator	Lecturer(s)
Prof. Dr. Sven Behnke	Prof. Dr. Sven Behnke, Dr. Raphael Memmesheimer

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	2. or 3.

Learning goals: technical skills

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.

Learning goals: soft skills

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).

Contents

Current research papers from conferences and journals in the field of cognitive robotics covering fundamental techniques and applications.

Prerequisites

Recommended:
At least 1 of the following:

- MA-INF 4113 – Cognitive Robotics
- MA-INF 4114 – Robot Learning

Course meetings

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

Graded exams

Oral presentation, written report

Ungraded coursework (required for admission to the exam)

Attendance in course sessions in accordance with the exam regulations of 2023, § 12(6).

Literature

- S. Thrun, W. Burgard and D. Fox: Probabilistic Robotics. MIT Press, 2005.
- B. Siciliano, O. Khatib (Eds.): Springer Handbook of Robotics, 2008.
- Selected papers.

MA-INF 4213 Seminar Humanoid Robots

Workload	Credit points	Duration	Frequency
120 h	4 CP	1 semester	every semester

Module coordinator	Lecturer(s)
Prof. Dr. Maren Bennewitz	Prof. Dr. Maren Bennewitz

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	2. or 3.

Learning goals: technical skills

Enhanced and in-depth knowledge in specialized topics in the area of humanoid robotics, such as perception, state estimation, navigation, manipulation, and motion planning.

Learning goals: soft skills

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).

Contents

Current research papers from conferences and journals in the field of humanoid robotics covering fundamental techniques and applications.

Prerequisites

Recommended:
At least 1 of the following:

- MA-INF 4215 – Humanoid Robotics
- MA-INF 4113 – Cognitive Robotics

Course meetings

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

Graded exams

Oral presentation, written report

Ungraded coursework (required for admission to the exam)

Attendance in course sessions in accordance with the exam regulations of 2023, § 12(6).

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.

MA-INF 4214 Lab Humanoid Robots

Workload	Credit points	Duration	Frequency
270 h	9 CP	1 semester	every semester

Module coordinator	Lecturer(s)
Prof. Dr. Maren Bennewitz	Prof. Dr. Maren Bennewitz

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	2. or 3.

Learning goals: technical skills

Design and implementation of perception, state estimation, navigation, manipulation, and motion planning techniques for humanoid robots.

Learning goals: soft skills

Ability to analyze problems theoretically and to find creative and practical solutions; to examine one's solutions and results critically; to prepare readable documentation of software and research results; to present, defend and discuss design decisions and results in the team/group and to other students clearly and in accordance with academic standards; to collaborate constructively with others in small teams over a longer period of time;

Contents

Robot middleware, perception, state estimation, navigation, manipulation, and motion planning for humanoid robots.

Prerequisites

Recommended:
At least 1 of the following:

- MA-INF 4215 – Humanoid Robotics
- MA-INF 4113 – Cognitive Robotics

Course meetings

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

Graded exams

Oral presentation, written report

Ungraded coursework (required for admission to the exam)

Project work; attendance in course sessions in accordance with the exam regulations of 2023, § 12(6).

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.

MA-INF 4215 Humanoid Robotics

Workload	Credit points	Duration	Frequency
180 h	6 CP	1 semester	at least every 2 years

Module coordinator	Lecturer(s)
Prof. Dr. Maren Bennewitz	Prof. Dr. Maren Bennewitz

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	2. or 3.

Learning goals: technical skills

This lecture covers techniques for humanoid robots such as perception, navigation, and motion planning. After the lecture, the students will be able to understand and implement techniques that enable humanoid robots to autonomously navigate in human environments as well as perceive, represent, and manipulate objects.

Learning goals: soft skills

Communicative skills (oral and written presentation of solutions, discussions in small teams), ability to analyze problems.

Contents

Sensing and perception, environment representations, active perception, inverse kinematics, motion planning, grasping, balance control, walking, and footstep planning.

Prerequisites

Recommended:
MA-INF 4113 – Cognitive Robotics

Course meetings

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

Graded exams

Oral exam (30 minutes)

Ungraded coursework (required for admission to the exam)

The completion of regularly provided exercise sheets. The work can be done in groups of up to three students. A total of 50% of the points must be achieved.

Literature

- 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.

MA-INF 4228 Foundations of Data Science

Workload	Credit points	Duration	Frequency
270 h	9 CP	1 semester	every year

Module coordinator	Lecturer(s)
Prof. Dr. Lucie Flek	Prof. Dr. Lucie Flek

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	1-3.

Learning goals: 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.

Competences: Application to data science problems and ability to assess similar methods.

Learning goals: soft skills

Oral presentation (in tutorial groups), written presentation (of exercise solutions), team collaboration in solving homework problems, critical assessmen

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.

Prerequisites

Recommended:
Basic skills in linear algebra and stochastics.

Course meetings

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

Graded exams

Written exam (120 minutes)

Ungraded coursework (required for admission to the exam)

The completion of regularly provided exercise sheets. A total of 50% of the points must be achieved. Each student must present a solution to an exercise in the exercise sessions twice.

Literature

Avrim Blum, John Hopcroft, and Ravindran Kannan (2018+). Foundations of Data Science.

MA-INF 4230 Advanced Methods of Information Retrieval

Workload	Credit points	Duration	Frequency
180 h	6 CP	1 semester	at least every 2 years

Module coordinator	Lecturer(s)
Prof. Dr. Elena Demidova	Prof. Dr. Elena Demidova

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	1. or 2.

Learning goals: technical skills

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.

Learning goals: soft skills

Communication skills: oral and written presentation and discussion of solutions.

Self-competences: ability to analyse and solve problems.

Contents

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.

Prerequisites

Recommended:
Basic knowledge of data science and machine learning; programming skills. Recommended reading:

- Sarah Boslaugh. Statistics in a Nutshell. A Desktop Quick Reference, O'Reilly Media, Inc., 2nd Edition, (2012).
- Ethem Alpaydin. Machine Learning. The MIT Press (2021).

Course meetings

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

Graded exams

Written exam (120 minutes)

Ungraded coursework (required for admission to the exam)

The completion of regularly provided exercise sheets. The work can be done in groups of up to three, four or five students, depending on the total number of students taking the course. A total of 50% of the points must be achieved. For 80% of the exercise sheets, 40% of the points must be achieved for each sheet. Each student must present a solution to an exercise in the exercise sessions once.

Literature

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.

MA-INF 4231 Seminar Advanced Topics in Information Retrieval

Workload	Credit points	Duration	Frequency
120 h	4 CP	1 semester	every year

Module coordinator	Lecturer(s)
Prof. Dr. Elena Demidova	Prof. Dr. Elena Demidova

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	2. or 3.

Learning goals: technical skills

Enhanced and in-depth knowledge in specialized topics in the area of information retrieval, including understanding of information retrieval process, specialized data representation methods, advanced retrieval methods, evaluation techniques, and domain-specific applications.

Learning goals: soft skills

Acquire the competence to independently search for and study state-of-the-art scientific literature in depth, read critically, identify the most relevant content, and assess research results in the context of the corresponding research area; to discuss research results with a knowledgeable scientific audience; to present prior work by others in writing and in presentations with visual media in a way that adheres to academic standards, that is well-structured and didactically effective, and that motivates the audience to participate; to formulate and accept criticism; to manage one's time with relatively open assignments and long-ranging deadlines.

Contents

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.

Prerequisites

Recommended:
MA-INF 4230 - Advanced Methods of Information Retrieval.

Course meetings

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

Graded exams

Oral presentation, written report

Ungraded coursework (required for admission to the exam)

Attendance in course sessions in accordance with the exam regulations of 2023, § 12(6).

Literature

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.

MA-INF 4232 Lab Information Retrieval in Practice

Workload	Credit points	Duration	Frequency
270 h	9 CP	1 semester	every year

Module coordinator	Lecturer(s)
Prof. Dr. Elena Demidova	Prof. Dr. Elena Demidova

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	2. or 3.

Learning goals: technical skills

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.

Learning goals: soft skills

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.

Contents

Practical application of information retrieval methods to solve retrieval problems on real-world data and evaluate proposed solutions.

Prerequisites

Recommended:
MA-INF 4230 - Advanced Methods of Information Retrieval

Course meetings

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

Graded exams

Oral presentation, written report

Ungraded coursework (required for admission to the exam)

Project work; attendance in course sessions in accordance with the exam regulations of 2023, § 12(6).

Literature

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.

MA-INF 4236 Advanced Methods for Text Mining

Workload	Credit points	Duration	Frequency
120 h	4 CP	1 semester	at least every 2 years

Module coordinator	Lecturer(s)
Prof. Dr. Rafet Sifa	Prof. Dr. Rafet Sifa

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	2. or 3.

Learning goals: technical skills

Knowledge: Students will learn about the basic as well as the advanced methods for processing textual data, including necessary preprocessing steps such as stemming and lemmatization. They will also learn about representation learning methods, such as TF-IDF, Latent Semantic Indexing, Global Vectors, Recurrent Neural Networks, Transformer Networks, as well as the variants of the last such as Generative Pre-trained Transformers and Bidirectional Encoder Representations from Transformers, to extract meaningful embeddings for downstream tasks. The students will gain knowledge on how to build predictive and prescriptive methods for a variety of objectives, including text classification, outlier detection, and recommender systems. Additionally, they will learn how to categorize these methods based on their complexities and their applicability to different text mining problems, such as sentiment analysis, natural language inference, computational argumentation, information extraction, named entity recognition, text summarization, opinion mining, text segmentation, event detection, and more.

Skill: Students should be able to analyze, design as well as reason about existing and new data mining algorithms, theoretically compare algorithms, strengthen their analytical thinking to solve difficult modelling problems, have acquired the necessary mathematical as well as programming/IT skills to systematically plan, design and implement text and data mining projects.

Competences: Based on the knowledge and skills acquired in this module, the students will be able to assess certain characteristics of the already existing text mining methods as well as build new solutions to emerging problems. Additionally, the students will be able to transfer their knowledge to other data science areas involving modelling data with sequential dependencies.

Learning goals: soft skills

critical discussion in groups of one's own and others'/competing results/solutions, time management, transferring theoretical knowledge to practical scenarios, presentation of solutions and methods, productive work in small teams

Contents

Neural Networks, Text Mining Pipelines, Stemming, Lemmatization, TF-IDF, Latent Semantic Indexing, Global Vectors, Recurrent Neural Networks, Transformer Networks, Generative Pre-trained Transformers, Bidirectional Encoder Representations, Prompt Analysis, Sentiment Analysis, Natural Language Inference, Computational Argumentation, Information Extraction, Named Entity Recognition, Text Summarization, Opinion Mining, Text Segmentation, Event Detection, Representation Learning and Applications

Prerequisites

Recommended:
Basic knowledge of AI, data science, machine learning, and pattern recognition; programming skills; good working knowledge in statistics, linear algebra, and optimization.

Course meetings

Teaching format	Group size	h/week	Workload[h]	CP
Lecture		2	30 T / 45 S	2.5
Exercises		1	15 T / 30 S	1.5

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

Graded exams

Written exam (120 minutes)

Ungraded coursework (required for admission to the exam)

The completion of regularly provided exercise sheets, on which a total of 50% of the points must be achieved, and the successful completion and presentation of a programming project. The work can be done in group of up to four students.

Literature
• Introduction to Information Retrieval, Christopher D. Manning, Prabhakar Raghavan and Heinrich Schütze • Aggarwal, C. C. (2018). Machine learning for text (Vol. 848). Cham: Springer. • Lecture notes of the instructors

MA-INF 4241 Lab Cognitive Modelling of Biological Agents

Workload	Credit points	Duration	Frequency
270 h	9 CP	1 semester	every semester

Module coordinator	Lecturer(s)
Prof. Dr. Dr. Dominik Bach	Prof. Dr. Dr. Dominik Bach

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	2. or 3.

Learning goals: technical skills

- Cognitive modelling workflow in computational neuroscience.
- Analysis of real-life cognitive tasks.
- Reasoning about different problem solutions.
- Understanding constraints of biological systems.

Learning goals: soft skills

Ability to analyze problems theoretically and to find creative and practical solutions; to examine one's solutions and results critically; to classify one's own results into the state-of-the-art of the respective area; to prepare readable documentation of software and research results; to present, defend and discuss design decisions and results in the team/group and to other students clearly and in accordance with academic standards; to collaborate constructively with others in small teams over a longer period of time; to aim at long-range goals under limited resources; to work under pressure.

Contents

The goal of cognitive modelling in computational neuroscience is to reverse-engineer how a real neural system solves a given cognitive task, often using reinforcement learning theory as a starting point. This lab covers the entire cognitive modelling workflow as used in computational neuroscience. Students will address an interesting cognitive problem by (a) developing rational solutions drawing on reinforcement learning, or descriptive solutions drawing on cognitive science and mathematical psychology, (b) derive behavioural signatures of this solution by mathematical analysis or computational simulation, (c) design efficient experiments to disambiguate these solutions from real behaviour, and (d) potentially analyse existing data sets. The course emphasises a practical, application-focused approach. Students collaborate in teams of 2, each supervised by a CAIAN researcher.

Prerequisites

Recommended:
One out of:

- MA-INF 4113 Cognitive Robotics
- MA-INF 4114 Robot Learning
- MA-INF 4215 Humanoid Robotics
- MA-INF 4235 Reinforcement Learning

Course meetings

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

Graded exams

Oral presentation, written report

Ungraded coursework (required for admission to the exam)

Project work; attendance in course sessions in accordance with the exam regulations of 2023, § 12(6).

MA-INF 4304 Lab Cognitive Robotics

Workload	Credit points	Duration	Frequency
270 h	9 CP	1 semester	every semester

Module coordinator	Lecturer(s)
Prof. Dr. Sven Behnke	Prof. Dr. Sven Behnke, Dr. Raphael Memmesheimer

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	2. or 3.

Learning goals: technical skills

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.

Learning goals: 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 (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.

Prerequisites

Recommended:
At least 1 of the following:

- MA-INF 4113 – Cognitive Robotics
- MA-INF 4114 – Robot Learning

Course meetings

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

Graded exams

Oral presentation, written report

Ungraded coursework (required for admission to the exam)

Project work; attendance in course sessions in accordance with the exam regulations of 2023, § 12(6).

Literature

- 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.

MA-INF 4306 Lab Development and Application of Data Mining and Learning Systems

Workload	Credit points	Duration	Frequency
270 h	9 CP	1 semester	every semester

Module coordinator	Lecturer(s)
Prof. Dr. Stefan Wrobel	Prof. Dr. Stefan Wrobel

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	2. or 3.

Learning goals: technical skills

Students will acquire in-depth knowledge in the design, implementation, and experimental evaluation of machine learning and data mining systems. They learn how to work with existing state-of-the-art machine learning and data mining algorithms and apply them to real-world and synthetic datasets, usually extending them for the requirements of their particular learning/mining task.

Learning goals: soft skills

Ability to analyze problems theoretically and to find creative and practical solutions; to examine one's solutions and results critically; to classify one's own results into the state-of-the-art of the respective area; to prepare readable documentation of software and research results; to present, defend and discuss design decisions and results in the team/group and to other students clearly and in accordance with academic standards; to collaborate constructively with others in small teams over a longer period of time; to aim at long-range goals under limited resources; to work under pressure.

Contents

Design, adaptation, implementation, and systematic experimental evaluation of specialised data mining and learning algorithms, from classical to state-of-the-art, from all areas of machine learning and data mining. Search and optimization algorithms. Common open source libraries for machine learning and data mining.

Prerequisites

Recommended:
Basic notions and algorithms from machine learning and data mining are required. It is recommended to take at least one of the following courses first:

- MA-INF 4111 – Principles of Machine Learning
- MA-INF 4112 – Algorithms for Data Science

Course meetings

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

Graded exams

Oral presentation, written report

Ungraded coursework (required for admission to the exam)

Project work; attendance in course sessions in accordance with the exam regulations of 2023, § 12(6).

Forms of media

Computer Software, Documentation, Research Papers.

Literature

The relevant literature will be announced towards the end of the previous semester.

MA-INF 4308 Lab Vision Systems

Workload	Credit points	Duration	Frequency
270 h	9 CP	1 semester	every semester

Module coordinator	Lecturer(s)
Prof. Dr. Sven Behnke	Prof. Dr. Sven Behnke

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	2. or 3.

Learning goals: technical skills

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.

Learning goals: 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

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.

Prerequisites

Recommended:
At least 1 of the following:

MA-INF 2201 - Computer Vision

MA-INF 4111 – Intelligent Learning and Analysis Systems: Machine Learning

MA-INF 4204 – Technical Neural Nets

Course meetings

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

Graded exams

Oral presentation, written report

Ungraded coursework (required for admission to the exam)

Project work; attendance in course sessions in accordance with the exam regulations of 2023, § 12(6).

Literature

- 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.

MA-INF 4322 Lab Machine Learning on Encrypted Data

Workload	**Credit points**	**Duration**	**Frequency**
270 h	9 CP	1 semester	every year

Module coordinator	**Lecturer(s)**
Dr. Michael Nüsken	Dr. Michael Nüsken

Programme	**Mode**	**Semester**
M. Sc. Cyber Security	Optional	2. or 3.

Learning goals: 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.

Learning goals: 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 one's 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.

The target of the lab is to understand how computations on encrypted data may work in one particular application that we are choosing 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

Recommended:
Good knowledge in cryptography is vital, e.g. by one or more modules out of:

- MA-INF 1103 - Cryptography,
- MA-INF 1223 - Privacy Enhancing Technologies, and
- MA-INF 1209 - Seminar Advanced Topics in Cryptography.

Course meetings

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

Graded exams

Oral presentation, written report

Ungraded coursework (required for admission to the exam)

Project work; attendance in course sessions in accordance with the exam regulations of 2023, § 12(6).

MA-INF 4324 Seminar Advanced Topics in Data Science

Workload	Credit points	Duration	Frequency
120 h	4 CP	1 semester	at least every 2 years

Module coordinator	Lecturer(s)
Prof. Dr. Elena Demidova	Prof. Dr. Elena Demidova

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	2. or 3.

Learning goals: technical skills

Enhanced and in-depth knowledge in specialized topics in the data science, including understanding of the data science process, statistical and machine learning-based data analytics methods, specialized data representation techniques, evaluation methods, and domain-specific applications.

Learning goals: soft skills

Acquire the competence to independently search for and study state-of-the-art scientific literature in depth, read critically, identify the most relevant content, and assess research results in the context of the corresponding research area; to discuss research results with a knowledgeable scientific audience; to present prior work by others in writing and in presentations with visual media in a way that adheres to academic standards, that is well-structured and didactically effective, and that motivates the audience to participate; to formulate and accept criticism; to manage one's time with relatively open assignments and long-ranging deadlines.

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:
MA-INF 4328 - Spatio-Temporal Data Analytics

Course meetings

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

Graded exams

Oral presentation, written report

Ungraded coursework (required for admission to the exam)

Attendance in course sessions in accordance with the exam regulations of 2023, § 12(6).

Literature

Relevant literature will be announced at the beginning of the seminar

MA-INF 4325 Lab Data Science in Practice

Workload	Credit points	Duration	Frequency
270 h	9 CP	1 semester	every year

Module coordinator	Lecturer(s)
Prof. Dr. Elena Demidova	Prof. Dr. Elena Demidova

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	2. or 3.

Learning goals: technical skills

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.

Learning goals: soft skills

- 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.

Contents

Practical application of statistical and machine learning-based methods to solve data analytics problems on real-world datasets and evaluate proposed solutions.

Prerequisites

Recommended:
MA-INF 4328 - Spatio-Temporal Data Analytics

Course meetings

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

Graded exams

Oral presentation, written report

Ungraded coursework (required for admission to the exam)

Project work; attendance in course sessions in accordance with the exam regulations of 2023, § 12(6).

MA-INF 4326 Explainable AI and Applications

Workload	Credit points	Duration	Frequency
180 h	6 CP	1 semester	every year

Module coordinator	Lecturer(s)
Dr. Rafet Sifa	Prof. Dr. Rafet Sifa, Dr. Lorenz Sparrenberg

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	2. or 3.

Learning goals: technical skills

• 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)

Learning goals: soft skills

• 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

Contents

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

Prerequisites

none

Course meetings

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

Graded exams

Written exam (120 minutes)

Ungraded coursework (required for admission to the exam)

The completion of regularly provided exercise sheets. The work can be done in groups of up to four students. A total of 50% of the points must be achieved.

Literature
• 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

MA-INF 4328 Spatio-Temporal Data Analytics

Workload	Credit points	Duration	Frequency
180 h	6 CP	1 semester	every year

Module coordinator	Lecturer(s)
Prof. Dr. Elena Demidova	Dr. Rajjat Dadwal, Prof. Dr. Elena Demidova

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	1. or 2.

Learning goals: technical skills

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.

Learning goals: soft skills

Communication skills: oral and written presentation and discussion of solutions. Self-competences: the ability to analyze and solve problems.

Contents

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.

Prerequisites

Recommended:
Basic knowledge of data science and machine learning; programming skills. Recommended reading:

- Sarah Boslaugh. Statistics in a Nutshell. A Desktop Quick Reference, O'Reilly Media, Inc., 2nd Edition, (2012).
- Ethem Alpaydin. Machine Learning. The MIT Press (2021).

Course meetings

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

Graded exams

Written exam (120 minutes)

Ungraded coursework (required for admission to the exam)

The completion of regularly provided exercise sheets. The work can be done in groups of up to three, four or five students, depending on the total number of students taking the course. A total of 50% of the points must be achieved. For 80% of the exercise sheets, 40% of the points must be achieved for each sheet. Each student must present a solution to an exercise in the exercise sessions once.

MA-INF 4331 Lab Perception and Learning for Robotics

Workload	Credit points	Duration	Frequency
270 h	9 CP	1 semester	at least every year

Module coordinator	Lecturer(s)
JProf. Dr. Hermann Blum	JProf. Dr. Hermann Blum

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	2. or 3.

Learning goals: technical skills

Participants learn how to practically approach a robot perception problem. They learn how to critically read a research paper, how to conduct experiments in the context of robot perception, and how to report and present scientific findings.

Learning goals: soft skills

Ability to analyze problems theoretically and to find creative and practical solutions; to examine one's solutions and results critically; to classify one's own results into the state-of-the-art of the respective area; to prepare readable documentation of software and research results; to present, defend and discuss design decisions and results in the team/group and to other students clearly and in accordance with academic standards; to collaborate constructively with others in small teams over a longer period of time; to aim at long-range goals under limited resources; to work under pressure.

Contents

In small groups, students apply their knowledge of robot perception, deep learning, and computer vision to a novel problem. They analyze the problem, read into relevant literature, propose and implement a solution, and empirically test it. They then refine their approach based on an analysis of the experimental outcomes. The course projects are related to one of multiple of the following topics: Robot localization, planning, navigation, manipulation; Practical aspects of Deep Learning; Sensor models, calibration, capture, processing. Software deployment.

Prerequisites

Recommended:
Students are expected to have general programming skills and prior experience with python. Students will need to operate linux terminal systems such as the university's GPU cluster.

It is recommended to first take two of the following modules:

- MA-INF 2201 Computer Vision
- MA-INF 2213 Advanced Computer Vision
- MA-INF 2218 Video Analytics
- MA-INF 4113 Cognitive Robotics

Course meetings

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

Graded exams

Oral presentation, written report

Ungraded coursework (required for admission to the exam)

Project work; attendance in course sessions in accordance with the exam regulations of 2023, § 12(6).

Literature

- S. Thrun, W. Burgard and D. Fox: Probabilistic Robotics. MIT Press, 2005
- I. Goodfellow, Y. Bengio and A. Courville: Deep Learning. MIT Press, 2016
- Per-project assigned literature

MA-INF 4333 Geometric Deep Learning

Workload	Credit points	Duration	Frequency
180 h	6 CP	1 semester	every year

Module coordinator	Lecturer(s)
Jun. Prof. Dr. Zorah Lähner	Jun. Prof. Dr. Zorah Lähner

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	2. or 3.

Learning goals: technical skills

- Understanding advanced topics in the design of neural networks using geometric data
- Mathematical modelling of invariances and non-Euclidean domains in deep learning and guarantees that can be derived from these
- Gain an overview of practical applications in which this theory can be applied

Learning goals: soft skills

- Problem solving skills: ability to identify and utilize 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

Contents

This lecture will cover advanced topics in deep learning focusing on theory related to geometric data and the incorporation of invariances in network architectures. Topics include, among others, permutation invariance, differential geometry, the curse of dimensionality, neural fields and physics-informed neural networks. Students will learn how to process a variety of geometric data structures and implement deep learning algorithms on these related to applications in visual computing, physics and graph processing.

Prerequisites

Recommended:
Students are recommended to have basic knowledge about deep learning and computer vision, for example gained in:

- MA-INF 4111 Principles of Machine Learning,
- MA-INF 2201 Computer Vision or
- MA-INF 2222 Visual Data Analysis,

and proficiency in python.

Course meetings

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

Graded exams

Written exam (120 minutes)

Ungraded coursework (required for admission to the exam)

none

MA-INF 4334 Computational neuroscience: cognition and behaviour

Workload	Credit points	Duration	Frequency
180 h	6 CP	1 semester	every year

Module coordinator	Lecturer(s)
Prof. Dr. Dr. Dominik Bach	Prof. Dr. Dr. Dominik Bach

Programme	Mode	Semester
M. Sc. Cyber Security	Optional	2-3.

Learning goals: technical skills

• Conceptual knowledge and mathematical understanding of common behavioural and cognitive models from computational neuroscience
• Knowledge of common experimental methods used to develop and disambiguate such models
• Basic knowledge of fundamentals in neuroscience, cognitive/perceptual psychology and microeconomics
• In the exercises, students will learn to implement models and how to use them as benchmarks for bottom-up computational neuroscience models, and for automatic signature-testing of AI algorithms

Learning goals: soft skills

• Teamwork (exercises)
• Oral presentation in front of audience (exercises)

Contents

The two dominant paradigms in computational neuroscience are bottom-up (starting from the spontaneous behaviour of constituent elements of the nervous system) and top-down (starting from known functions of biological agents). This lecture introduces important topdown models of behaviour and cognition from three perspectives: computational (problem definition and optimal solutions), algorithmic (rational/engineering/descriptive solutions) and implementation (neural hardware). The lecture covers the following domains:

• decision-making with noisy information (value-based, time-integrated, multi-channel, sequential)
• information representation under resource constraints
• memory formation and storage in biological neural networks
• movement planning
• spatial navigation

Prerequisites

Recommended:
Recommended one out of:

• MA-INF 4113 Cognitive Robotics
• MA-INF 4114 Robot Learning
• MA-INF 4215 Humanoid Robotics
• MA-INF 4235 Reinforcement Learning

Course meetings

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

Graded exams

Written exam

Ungraded coursework (required for admission to the exam)

The completion of regularly provided exercise sheets. The work can be done in groups of up to four students. A total of 50% of the points must be achieved. Each student must present a solution to an exercise in the exercise sessions once.